Glossary of Physical Oceanography and Related Disciplines

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May 26, 2004

The Glossary

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AABW Abbreviation for Antarctic Bottom Water.

AACW Abbreviation for Antarctic Circumpolar Water.

AAIW Abbreviation for Antarctic Intermediate Water.

AASW Abbreviation for Antarctic Surface Water.

AATE Abbreviation for Arctic Acoustic Transmission Experiment, a project of the APL at the University of Washington School of Oceanography.

Abiki An instance of the meteorological tsunami phenomenon in Nagasaki Bay. See Hibaya and Kajiura [1982].

ABF Abbreviation for Angola-Benguela Front.

ABL 1. Abbreviation for atmospheric boundary layer. 2. Abbreviation for airborne backscatter lidar.

ABP Abbreviation for Acoustic Backscatter Probes.

absolute humidity The ratio of the mass of water vapor in a sample of moist air to a unit volume of the sample. It is expressed in grams per cubic meter and also called the vapor concentration.

absolute vorticity The sum of the relative vorticity (ζ) and the planetary vorticity, i.e. $\zeta + f$. More later.

absorptance In radiation transfer, the fraction of incoming radiation that is absorbed by a medium. The sum of this, the transmittance, and the reflectance must equal unity.

absorption A process by which incident radiation is taken into a body and retained without reflection or transmission. It increases either the internal or the kinetic energy of the molecules or atoms composing the absorbing medium.

absorption band In atmospheric radiative transfer, a collection of absorption lines in a particular frequency interval.

absorption line In atmospheric radiative transfer, a discrete frequency at which an energy transition of an atmospheric gas occurs due to the absorption of incident solar radiation. The line width depends on broadening processes, the most important of which are natural, pressure (also known as collision), and Doppler broadening.

ABW See Arctic Bottom Water.

abyssal hill Small hills found only in the deep sea which rise from the ocean basin floor with heights ranging from 10 to over 500 feet and widths from a few hundred feet to a few miles. They are found along the seaward margin of most abyssal plains and originate from the spreading of mid-ocean ridges. As such, they usually form two strips parallel to mid-ocean ridges. They generally decrease in height as one traverses away from the ridges as they gradually become covered with sediment and are replaced by abyssal plains. See Fairbridge [1966].

The official IHO definition for this undersea feature name is "a tract of small elevations on the deep seafloor."

abyssal plain Flat areas of the ocean basin floor which slope less than 1 part in 1000. These were formed by turbidity currents which covered the preexisting topography. Most abyssal plains are located between the base of the continental rise and the abyssal hills. The remainder are trench abyssal plains that lie in the bottom of deep-sea trenches. This latter type traps all sediment from turbidity currents and prevents abyssal plains from forming further seaward, e.g. much of the Pacific Ocean floor. See Fairbridge [1966].

The official IHO definition for this undersea feature name is "an extensive, flat, gently sloping or nearly level region at abyssal depths."

abyssal zone This originally meant (before the mid-1800s) the entire depth area beyond the reach of fisherman, but later investigations led to its use being restricted to the deepest regions with a uniform fauna and low temperatures. Thus it was distinguished from the overlying bathyal or archibenthal zone with more varied fauna and higher temperatures. Eventually an underlying hadal zone was defined for areas in trenches and deeps below 6000-7000 m depth. The upper boundary of the abyssal zone ranges between 1000-3000 m, with the position of the 4° C isotherm generally considered the demarcation line. It is the world's largest ecological unit, with depths exceeding 2000 m comprising over three-quarters of the world ocean. See Fairbridge [1966].

abyssopelagic zone One of five vertical ecological zones into which the deep sea is sometimes divided. There is a pronounced drop in the number of species and the quantity of animals as one passes into this zone. It is separated from the overlying bathypelagic zone by the 4° C isotherm and from the underlying hadopelagic zone at about 6000 meters. The distinction between pelagic and benthic species can be difficult to ascertain in this zone. See Bruun [1957].

a-c meter An instrument used to perform in-situ measurements of the amount of chlorophyll in water. It does this by pulling water into two tubes, one measuring light absorption and the other attenuation. A beam of light with a wavelength rotating among three values is projected into each tube. The attenuation tube determines light absorption and scattering by measuring how much of the original light beam remains after it passes through the water inside the blackened tube. The absorption tube determines only how much light is absorbed by particles by measuring how much light is left of the original beam including that which has bounded off particles. This tube is lined with a quartz mirror which, in contrast to the absorbing black surface in the attenuation tube, reflects scattered light toward the detector. Chlorophyll causes a large change in the attenuation of light with a wavelength of about 676 nanometers, so a measurement of attenuation at the appropriate wavelength is a proxy measurement of chlorophyll concentration to first order. A fluorometer can also be used to measure chlorophyll.

ACC 1. Abbreviation for the Antarctic Circumpolar Current. 2. Abbreviation for the Alaskan Coastal Current.

ACCE Abbreviation for Atlantic Climate Change Experiment, a joint program between WOCE and NOAA's ACCP designed to increase understanding of the meridional overturning circulation (MOC) of the Atlantic Ocean and the overlying atmosphere at interannual and longer time scales. The goals of ACCE were:

- to provide a quantitative 4–D observational description of the pathways and material property fluxes of the MOC within the North Atlantic Ocean that vary on time scales from interannual to at least decadal;
- to improve understanding and modeling of the relationships between the rates and natural variability of the MOC, internal ocean properties, SST, and the variability of the overlying atmosphere; and

- to identify and initiate measurements to be continued beyond the ACCE observational period to monitor the variability of important elements of the MOC and its relation to global climate variability.

See WOCE [1995].

[http://www.aoml.noaa.gov/phod/acce/]
[http://www-ocean.tamu.edu/WOCE97/Future/acce.html]

ACCIS Acronym for Austral Chilean Coast and Inland Sea project, a program to facilitate the development of an interdisciplinary and multi–institutional program focused on ecological and socio–econonomic–human health issues in the temperate waters of the Austral Chilean Coast and Inland Sea.

[http://www.ccpo.odu.edu/~atkinson/ACCIS/accis.html]

ACCLAIM Acronym for the Antarctic Circumpolar Current Levels by Altimetry and Island Measurements program in the South Atlantic and Southern Oceans. It consists of measurements from coastal tide gauges and bottom pressure stations, along with an ongoing research program in satellite altimetry. ACCLAIM was the Proudman Oceanographic Laboratory's main contribution to WOCE and now provides data for CLIVAR, GLOSS and PSMSL.

The coastal tide gauge portion of ACCLAIM took place in two phases. In Phase I from 1983, measurements at coastal tide gauge sites were sub–surface pressure (SSP) measurements rather than sea level (where SSP is defined as the total, measured pressure recorded by a sub–surface pressure transducer, a measurement including the atmospheric as well as the water column pressure). These data were acquired with different sensors and with different pressre integration periods. Phase II, which started in early 1993, involved replacing the gauges at several sites with 'B gauges' that recorded SSP, air pressure and sea level. These gauges have precise datum control and are used to provide long term sea level change data to the PSMSL. See Spencer et al. [1993].

[http://www.pol.ac.uk/psmsl/programmes/acclaim.info.html]

ACCP Abbreviation for the Atlantic Climate Change Program, a NOAA research initiative for understanding the decadal-scale interactions of deep circulation in the Atlantic and how it influences the overlying atmosphere. The goals of ACCP are:

- to determine the seasonal-to-decadal and multidecadal variability in the climate system due to interactions between the Atlantic Ocean, sea ice, and the global atmosphere using observed data, proxy data, and numerical models;
- to develop and utilize coupled ocean-atmosphere models to examine seasonal- to-decadal climate variability in and around the Atlantic basin, and to determine the predictability of the Atlantic climate system on seasonal-to- decadal timescales;
- to observe, describe, and model the space-time variability of the large- scale circulation of the Atlantic Ocean and determine its relation to the variability of the sea ice and sea surface temperature and salinity in the Atlantic on seasonal, decadal, and multidecadal timescales; and
- to provide the necessary scientific background to design an observing system of the large-scale Atlantic Ocean circulation pattern, and develop a suitable Atlantic Ocean model in which the appropriate data can be assimilated to help define the mechanisms responsible for the fluctuations in Atlantic Ocean circulation.

See Molinari et al. [1994].

[http://www.aoml.noaa.gov/phod/accp/]

accuracy The degree of freedom from error. The total error compared to a theoretically true value. Contrast with and see precision for an example.

ACE Abbreviation for Antarctic Current Experiment, a GARP project.

ACE Acronym for Australian Coastal Experiment, an investigation whose primary goal was to identify continental shelf waves (CSW). It was carried out off the coast of New South Wales (eastern Australia) between Cape Howe and Newcastle from September 1983 to March 1984. The experiment included an array of current meters with three main lines with five moorings each, repeated CTD and XBT surveys, meteorological measurements from moored buoys and coastal stations, sea level measurements at coastal tide gauges, and bottom pressure measurements at a few sites. Each of the three mooring lines was arranged perpendicular to the local coastline, were nominally identical, and consisted of 15 Aanderaa current meters on 5 moorings.

A free wave analysis of the data gathered demonstrated that waves passed through the experimental array and exhibited dispersion characteristics strongly indicative of coastal trapped waves. The measured pattern speed was between those predicted for free and forced waves. There was some predictive skill using a trapped wave model. Although the model predictions only accounted for a maximum of 40% of the observed variance, the best statistical predictor could only account for 50%. This led to the conclusion that not all of the energy in the weather forcing band was described by coastal trapped waves. See Freeland et al. [1986] and Church and Freeland [1987].

ACME Abbreviation for Advisory Committee on the Marine Environment, an ICES committee.

ACMP Abbreviation for Advisory Committee on Marine Pollution, an ICES committee.

ACMRR Abbreviation for Advisory Committee of Experts on Marine Resources Research, a FAO committee.

ACOMR Abbreviation for Advisory Committee on Oceanic Meteorological Research, an WMO committee.

ACOPS Abbreviation for Advisory Committee on Protection of the Sea.

ACOUS Acronym for Arctic Climate Observations using Underwater Sound, a joint U.S. and Russian program started in 1995. The main objective of ACOUS is to establish a long–term, real–time Arctic Ocean observing system using cabled moorings that integrate point measurements with acoustic remote sensing measurements. The remote sensing is used to monitor basin–scale changes in the ocean temperature and the thickness of the Arctic ice cover. See Mikhalevsky et al. [1999].

acoustic signature A set of characteristics used to describe a sound signal. This may include sound echos from targets, radiated and ambient noise, with salient echo characteristics including target strength, spectral reflectivity versus frequency, doppler shift, doppler spread and target range extent.

acoustic tomography The inference of the state of the ocean from precise measurements of the properties of sound waves passing through it. This technique takes advantage of the facts that the properties of sound in the ocean are functions of temperature, water velocity and other salient oceanographic properties and that the ocean is nearly transparent to low-frequency sound waves. These felicitous circumstances combine to allow signals transmitted over hundreds to thousands of kilometers to be processed with inverse methods to obtain estimates of large-scale fields of ocean properties. An especially advantageous feature of this method is that, given the 3000 knot speed of sound in the ocean, reasonably synoptic fields can be constructed. The chief problems presently encountered in this field are those related to engineering sufficiently accurate transmitters and receivers for the task. See Munk et al. [1995].

acoustical oceanography The study of sound propagation in the ocean and its underlying sediments. This ranges from the earliest use of depth soundings to chart the ocean floor to the use of SONAR to locate schools of fish, underwater vehicles and ocean drifters to the most recent applications of acoustic tomography to infer large-scale properties of the ocean and the ocean floor.

ACSYS Abbreviation for the Arctic Climate System Study, a WCRP program whose goal to to ascertain the role of the Arctic in global climate. The primary scientific objectives are:

- understanding the interactions between the Arctic Ocean circulation, ice cover and the hydrological cycle;
- initiating long–term climate research and monitoring programs for the Arctic; and
- providing a scientific basis for an accurate representation of Arctic processes in global climate models.

The components of ACSYS include:

- Arctic Ocean Circulation Program;
- Arctic Sea–Ice Program;
- Arctic Atmosphere Program;
- Hydrological Cycle in the Arctic Region;
- ACSYS Modeling Program; and
- Data Management and Information.

[http://acsys.npolar.no/]

adaptive mesh refinement A method for locally refining grids in finite difference ocean models. The basic idea behind the method is to attain a given accuracy for a minimum amount of work. This is done by computing estimates of the truncation error, and creating refined grids (or removing existing ones) where and when it is necessary. The approach is also recursive so that fine grids can contain even finer grids. See Blayo and Debreu [1999] for an initial application of this method to ocean circulation models.

ADCP Abbreviation for Acoustic Doppler Current Profiler, an instrument used to measure ocean currents. It transmits high frequency acoustic signals which are backscattered from plankton, suspended sediment, and bubbles, all of which are assumed to be traveling with the mean speed of the water. The ADCP estimates horizontal and vertical velocity as a function of depth by using the Doppler effect to measure the radial relative velocity between the instrument and scatterers in the ocean.

Three acoustic beams in different directions are the minimum number required for measuring the three velocity components, with a fourth adding redundancy and an error estimate. A ping is transmitted from each transducer about once per second, with the echo returning over an extended period. Echos from shallow depths return before those from greater depths. Profiles are produced by range–gating the echo signal, i.e. breaking the echo into successive segments called depth bins corresponding to successively deeper depth ranges. The noisy velocity estimates from each ping are vector–averaged into 1– to 10–minute ensembles, and the resulting relative velocities are rotated from the transducer's to the earth's reference frame using the ship's gyrocompass.

A navigation calculation is performed to obtain absolute currents, which are obtained by subtracting the average of the ship velocity relative to a reference layer (i.e. ADCP velocities) from the absolute ship velocity over the ground (from GPS navigation). The raw absolute current velocities relative to the reference layer are then smoothed to reduce the effect of noise in the position fixes, and combined with the navigation data to obtain the best estimates of ship positions and velocities. Thus, absolute currents at any depth can be determined from the ship navigation data and the relative ADCP measurements.

The ADCP measures the ocean current velocity continuously over the upper 300 m of the water column, usually in 8 m depth increments. It is also used to estimate the abundance and distribution of biological scatterers over the same depth range and in the same depth increments.

ADCP data collection requires that four instruments work together. These are the ADCP itself, the ship's gyrocompass, a GPS receiver, and a GPS Attitude Determination Unit (ADU).

[http://ilikai.soest.hawaii.edu/sadcp/]

adiabatic Involving or allowing neither gain nor loss of heat.

adiabatic compressibility A quantity arising from taking derivatives of the density in the (p, θ, S) representation of the equation of state. It is defined by

$$\kappa = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial p}\right)_{\theta,S}$$

where ρ is the fluid density, p the pressure, θ the potential temperature, and S the salinity. See Muller [1995], McDougall et al. [1987] and the related saline contraction coefficient and thermal expansion coefficient.

ADIOS Acronym for Asian Dust Input to the Oceanic System. See Betzer et al. [1988].

adjoint model See Errico [1997].

adjustment time A time scale characterizing the decay of an instantaneous input pulse into a reservoir. It is also used to characterize the adjustment of the mass of a reservoir following a change in the source strength.

Adriatic Bottom Water (ABW) A water mass – also known as Adriatic Deep Water – formed in the southern Adriatic Sea that exits into the Ionian Sea via Otranto Strait. The temperature and salinity of ABW are 13°C and 38.6 psu, respectively. There are a couple of competing conjectures as to the origin of the ABW:

- some postulate that North Adriatic Deep Water flowing into the canyon in the shelf of Bari mixes with Modified Levantine Intermediate Water (MLIW) to form ABW; and
- others think that contribution of NADW is minor and that the ABW is formed mainly by the mixing of the surface water in the center of the South Adriatic Pit with the underlying MLIW during periods of deep convection.

Either way, most studies confirm that ABW represents the most important component of the bottom water of the entire Eastern Mediterranean. See Artegiani et al. [1993].

Adriatic Deep Water (ADW) Another name for Adriatic Bottom Water (ABW).

Adriatic Sea A part of the eastern basin of the Mediterranean Sea located between Italy and the Balkan Peninsula. It is landlocked on the north, east and west, and is linked with the Mediterranean through the Otranto Strait to the south. The Adriatic is a rectangular basin oriented in a NW–SE direction with a length of about 800 km and a width of about 200 km. It can be divided into three sub–basins:

- a northernmost shallow basin with the bottom sloping gently to the south and reaching at most 100 m;
- three pits located along the transversal line off Pescara (one of which is known as the Jabuka Pit), with a maximum depth of 280 m; and
- a southern basin called the South Adriatic Pit (separated from the middle basin by the 170 m deep Palagruza Sill) characterized by approximately circular isobaths, with a maximum depth of about 1200 m in the center.

The bottom rises toward the Strait of Otranto past the southern basin, with the strait having a maximum depth of 780 m, and average depth of 325 m, and a width of about 75 km.

The meteorological forcing has been summarized by Artegiani et al. [1993] as:

> Mainly during the winter, the Adriatic Sea region is under a continuous influence of passing mid–latitude meteorological perturbations and of the wind systems associated with them. The two main wind systems are the bora and the scirocco. The bora is a dry and cold wind blowing in an offshore direction from the eastern coast. The scirocco blows from the southeast (i.e. along the longitudinal axis of the basin) bringing rather humid and relatively warm air into the region. In particular, the bora produces appreciable buoyancy fluxes through evaporative and sensible heat loss, induces both wind–driven and thermohaline circulation, and, most importantly, is responsible for deep water formation processes.

This is one of the two regions within the Mediterranean where freshwater input exceeds evaporation (the other being the Black Sea). This is due mostly to outflow from the Po River in the north, which accounts for 1700 m^3 s^{-1} of the 4000 m^3 s^{-1} total river discharge in the Adriatic.

The flow between the Adriatic and the greater Mediterranean through the Otranto Strait is that of a typical dilution basin wherein low salinity water exits near the surface and high salinity water enters at depth. The Mediterranean inflow is of surface Ionian water and, in a deeper layer from 200–300 m, of Modified Levantine Intermediate Water (MLIW). This inflow occurs over a wide area along the eastern shore of the strait, with near–surface outflow concentrated in a thin layer along the western coast. The latter consists of relatively fresh water originating mostly from the northern Adriatic. The remainder of the outflow consists of Adriatic Bottom Water (ABW), a water mass formed in the southern basin that flows over the sill of the Otranto Strait into the Ionian Sea.

The mean basin–wide circulation is generally a cyclonic pattern with several smaller, more or less permanent gyres embedded therein. A topographically controlled cyclonic gyre sitting over the South Adriatic Pit partially isolates the northern Adriatic from Mediterranean influence. This gyre causes a bifurcation of the incoming MLIW, with part of it entering the northern basins over the Palagruza Sill, while the rest is entrained into the South Adriatic cyclonic circulation cell. The circulation regime varies seasonally and interannually in response to changes in the heating and wind regimes. Seasonally, the winter circulation is characterized by a prevalence of warmer Mediterranean inflow reinforced by southerly winds. In summer, there is a stronger outflow of fresher and warmer Adriatic water along the western coast supported by the Etesian winds. See Buljan and Zore-Armanda [1976], Orlic et al. [1992], Artegiani et al. [1993], Tomczak and Godfrey [1994], Artegiani et al. [1997a], Artegiani et al. [1997b], Poulain [2001] and Vilibic and Orlic [2002].

ABW Abbreviation for Adriatic Bottom Water.

ADW Abbreviation for Adriatic Deep Water.

Aegean Deep Water See POEM Group [1992].

Aegean Sea A marginal sea in the eastern Mediterranean Sea centered at approximately 25° E and 38° N. It is located between the Greek coast to the west, the Turkish coast to the east, and the islands of Crete and Rhodes to the south. It contains more than 2000 islands forming small basins and narrow passages with very irregular coastline and topography. The northern part of the Aegean is also known as the Thracian Sea, and the southern part between the Cretan Arc and the Kiklades Plateau (defined as the 400 m isobath) as the Cretan Sea. It contains an extended plateau (Thermaikos, Samothraki, Limnos and Kyklades) as well as the deep basins the North Aegean Trough (1600 m maximum depth), the Chios Basin (1160 m) and the Cretan Sea (two depressions in the east 2561 m and 2295 m deep). It covers an area of 20,105 km^2, has a volume of 74,000 km^3, and a maximum depth of 2500 m.

It is connected to the Levantine Sea to the southeast via the Cassos or Kasos Strait (67 km wide, 1000 m deep) between Crete and Karpathos, the Karpathos strait (43 km wide, 850 m deep) between Karpathos and Rhodes, and the Rodos or Rhodos Strait (17 km wide, 350 m deep) between Rhodes and Turkey. It joins the Ionian Sea and Cretan Sea to the southwest through the Antikithira Strait between Crete and Antikithira (32 km wide, 700 m deep), the Kithira Strait between Antikithira and Kithira (33 km wide, 160 m deep), and the Elafonissos Strait between Kithira and Peloponnese (11 km wide and 180 m deep). There is considerable and complicated interchange of water with the eastern Mediterranean through these passages. The Strait of Dardanelles (55 m deep, 0.45–7.4 km wide) provides a northern link to the Black Sea from which the Aegean receives around 190 km^3 per year of water.

The climate in the Aegean Sea area is characterized by the presence of two distinct periods, summer and winter, with spring and autumn relatively short and transitional. The topography and continual alternation of land and sea make the climate highly variable. Annual river runoff averages about 18,800 $\times 10^6$ m^3, and evaporation exceeds precipitation and river runoff. The most prominent wind pattern is the Etesian winds, which are persistent, northerly, cold and dry winds that often reach gale force in July and August. When this wind approaches the southern Aegean is bifurcates, becoming northeasterly over the Kitherian Straits and northwesterly–westerly over the southeastern Aegean. The Etesians vanish in late autumn to be replaced by violent cyclonic storms and highly variable prevailing winds.

The surface circulation is most affected by the summer Etesian winds and the low salinity inflow from the Black Sea. The winds cause upwelling along the western coasts of the islands in the eastern Aegean, and a accompanying cold surface zone with temperatures 2–3°C lower than in the northern and western Aegean. During the summer, this colder water is present in the eastern Aegean from Rodos Island up to the Limnos Plateau. In winter, the warmer waters of Levantine origin are found in the same area, while the cold waters arriving from the Strait of Dardanelles spread over the Samothraki Plateau and follow the general cyclonic circulation of the north Aegean. In addition to the overall cyclonic circulation, there is also a Samothraki anticyclonic gyre located in the northeastern part of the North Aegean, a semi–permanent feature that can be detected through most of the year, and an anticyclone near Athos.

The surface flow in the south is into the Aegean between Kithira and Crete, Crete and Karpathos, Karpathos and Rhodes, and Rhodes and Turkey, and into the Mediterranean between Kithira and the Peloponnese coast. There is systematic wind–driven upwelling along the northern coasts of the Patraikos and Korinthiakos Gulfs.

The main water masses found in the Aegean are (from shallowest to deepest):

- Black Sea Water (BSW);
- Levantine Intermediate Water (LIW);
- modified Atlantic Water (AW); and
- Eastern Mediterranean Deep Water (EMDW).

The BSW enters from the Strait of Dardanelles, producing a pronounced halocline in the norther Aegean with a maximum depth from 20–80 m. It moves southward and westward, following the general cyclonic circulation, and can be detected by a surface salinity minimum as far south as the Kithira Straits. LIW is the saltiest water mass of the eastern Mediterranean. It is generated in the Levantine and southern Aegean Seas in February and March. It flows eastwards and westwards from the Aegean, and also flows into the Aegean via the eastern straits of the Cretan Arc. It predominates in the subsurface layers of the Cretan Sea as well as in the eastern parts of the Aegean as far north as the southern boundary of the Limnos Plateau, and is easily identified by its salinity maximum. The modified AW enters the Aegean through the straits of the Cretan Arc and is identifed in several regions as a subsurface (30–200 m) salinity maximum. The Aegean deep water mass extends from about 400–500 m to the bottom, with temperatures ranging from 12–14.5°C and salinities from 38.68–38.9. See POEM Group [1992], Stergiou et al. [1997] and Balopoulos et al. [1999].

AEROCE Acronym for Atmosphere/Ocean Chemistry Experiment, a multi–disciplinary and –institutional program focusing on a number of aspects of the atmospheric chemistry over the North Atlantic Ocean. The objectives of AEROCE are:

- to gauge the impact of anthropogenic sources on the chemical and physical properties of the atmosphere;
- to assess the consequences of the perturbuations on natural processes including climate; and
- to predict the longer term efforts via the use of models.

The program officially started in 1987 with coordinate measurements from four stations, i.e. Barbados, West Indies; Bermuda; Izaña, Tenerife, Canary Islands; and Mace Head Ireland. Five more stations were added in June 1995 to give greater geographical coverage of continuous measurements of bulk aerosol chemical composition and condensation nuclei.

`[http://web.mit.edu/igac/www/newsletter/highlights/old/AEROCE.html]`

AESOP Acronym for Alaska Environmental Satellite Oceanography Project, a collection of remote sensing experiments and projects being performed at the Institute of Marine Sciences at the University of Alaska Fairbanks. This seems to have been mothballed as of 2001. This is part of the larger SEA Project.

`[http://murre.ims.uaf.edu/]`

AESOP Acronym for Antarctic Environment and Southern Ocean Process Study, also known as the U.S. Southern Ocean Joint Global Ocean Flux Study (JGOFS). AESOP involved studies of two different and distinct regions. The first was the Ross Sea continental shelf, where a series of six cruises (on the R.V.I.B. Nathaniel B. Palmer) collected data from October 1996 through February 1998. The second was the southwest Pacific sector of the Southern Ocean spanning the Antarctic Circumpolar Current (ACC) at 170°W, where data were collected during five cruises (on the R.V. Roger Revelle) from September 1996 through March 1998, as well as during selected transits between New Zealand and the Ross Sea.

The objectives of the project were to:

- better constrain the fluxes of carbon in the Southern Ocean,
- identify the factors and processes regulating the magnitude and variability of primary productivity, and
- gain a sufficient understanding of the Southern Ocean to model past and present carbon fluxes with sufficient accuracy to predict its response to future global changes.

The findings of AESOPS include:

- the Ross Sea continental shelf is among the most productive of all Antarctic systems, with a significant seasonal cycle;
- a seasonal bloom occurs in the region of the Polar Front;
- the annual production of the Ross Sea can be quantified by measuring deficits of nutrients and dissolved carbon dioxide;
- the phytoplankton blooms in the Ross Sea have essentially no losses due to microzooplankton herbivores;
- while iron did not stimulate phytoplankton growth in low silica waters north of the silica gradient, it substantially stimulated diatom growth in waters south of the gradient;
- the Polar Front region exhibits extreme mesoscale variability; and
- dissolved organic carbon concentrations increase seasonally by less than a third as much as particulate organic carbon levels.

See Smith et al. [2000] and other papers therein.

[http://usjgofs.whoi.edu/research/aesops.html]

AFZ Abbreviation for Arctic Frontal Zone.

AGDW Abbreviation for Aegean Deep Water.

age of tide The delay, usually a day or two, between full and new moons (when the equilibrium semi–diurnal tide is maximum) and the following spring tides. This terminology was first used to refer to this phenomenon by Whewell in 1883, although Defant referred to it as "spring retardation" in 1961 and Wood later (in 1978) used the terms "age of the phase inequality" and "age of the diurnal equality" to refer to, respectively, the ages of the semi–diurnal and diurnal tides. This delay is caused by frictional energy dissipation in coastal seas, although a localized increase in the age of tide is also a good indication of resonances at that location. See Murty and El-Sabh [1985].

age of water The elapsed time since a given water mass was last at the sea surface. See Groves and Hunt [1980].

agger See double tide.

aggregation A process that significantly alters the sizes, characteristics and abundances of suspended particles in the ocean. There are two major mechanisms for aggregation:

- biologically mediated aggregation, which occurs when small particles are aggregated into fecal pellets through the feeding activities of animals; and
- aggregation via the largely physical processes of collision and sticking, i.e. coagulation.

The impacts of aggregation on marine ecosystems include:

- much of the particulate matter reaching the ocean interior and sea floor sinks as large, rapidly settling aggregates of detritus, mucous, algae and microorganisms in the visible size range, i.e. marine snow, so the export of carbon and nutrients from the surface ocean is directly linked to the mechanisms responsible for combining small particles into larger units capable of rapid settlement, i.e. aggregation;
- aggregation of small organisms and other organic particles affects the abilities of grazers to isolate their food from the aquatic environment and makes more food available to large–particle feeders;

- aggregation produces particles large enough to maintain unique internal chemical environments that can support unusual, microbial communities and potentially provide island–like refuges for protozoa and micorozooplankton; and
- aggregation affects the optical properties of seawater by altering the size distribution and abundance of particles available to absorb and scatter light.

See Alldredge and Jackson [1995].

aguaje A condition observed annually in the coast water off Peru in which the water is discolored red or yellow and there is a significant loss of marine life. It typically occurs from April through June and is probably caused by an increase in water temperatures via the importation of warmer waters by ocean currents. This causes the death of temperature sensitive marine organisms such as dinoflagellates, which may in turn kill other organisms via the release of toxins. The annual nature of this phenomenon makes it distinct from the El Nino phenomenon occurring in the same region. This is also known as salgaso or aqua enferma.

Agulas Basin An ocean basin located off the southern tip of Africa at about 43° S in the South Atlantic Ocean. It includes the Agulhas Abyssal Plain. See Fairbridge [1966].

Agulhas Current The western boundary current in the Indian Ocean south of 30° S. The southern Agulhas Current flows southwestward as a narrow jet along a steep continental slope, and is normally pinned to within 10–15 km of its mean position at latitudes 28.5–34°S. Large meanders – called the Natal pulse – can sometimes occur within this region. These extend an average of 170 km offshore with downstream propagation rates of about 21 cm s^{-1}, with the rates decreasing to 5 cm s^{-1} as the continental shelf broadens near 34°S. At this point the current separates from the coast and continues southwestward along the Agulhas Bank, where many meanders, plumes and eddies exist. The maximum transport of the Agulhas occurs in the vicinity of Agulhas Bank, where transport estimates range from 95 to 136 Sv. The core of the current has been defined as where surface velocities exceed 100 cm s^{-1}, with the core averaging about 34 km wide with a mean peak speed of 136 cm s^{-1} (with a greatest peak speed of 245 cm s^{-1}).

At around 36°S the Agulhas leaves the continental shelf and develops oscillations of increasing amplitude, eventually retroflecting back toward the Indian Ocean in the region of 16–20°E as the Agulhas Return Current. The retroflection loop usually encloses a pool of Indian Ocean surface water south of Africa whose temperature is more than 5° warmer than South Atlantic surface water at similar latitudes. The core of the Return Current infrequently passes over the Agulhas Plateau. See Lutjeharms and van Ballegooyen [1988] and Peterson and Stramma [1991].

Agulhas Front (AF) A strong subsurface to intermediate depth front beneath the upper 100–150 m that originates at around 20°–25° E below the southern tip of Africa. It extends to between 65°–90° E where it merges with the Southern Subtropical Front in the Indian Ocean sector of the ACC. The chief identification criterion is usually the depth range of the 10° isotherm, about 300–800 m south of Africa at 16°–27° E. This range shrinks to about 400–650 m to the east in the Kerguelan–Amsterdam passage, indicating the gradual weakening of the AF. A thermostad on the warm side of the AF in the 150–300 m layer is another useful identification criterion. This thermostad cools and freshens to east, ranging from 17°–18° C/35.5–35.6 at 20° E to 12°–14° C/35.2–35.4 at 70° E. See Belkin and Gordon [1996].

Agulhas Retroflection See Peterson and Stramma [1991] and Lutjeharms et al. [1992].

Agulhas Return Current The Agulhas Return Current (ARC) is the intense flow along the Subtropical Convergence south of Africa. It forms the connecting link between the generically similar South Atlantic Current and the South Indian Ocean Current, thus contributing to the water exchange between these two basins. It originates with the almost complete retroflection of the Agulhas Current (AC) south of Africa. As the ARC emerges from the retroflection, its velocity and volume transport (75 cm/s, 54×10^6 m^3/s) are decreased from those of the AC (110 cm/s, 70×10^6 m^3/s). The Indian Tropical Surface Water characteristics of the AC are also removed in the retroflection, and the central water masses are somewhat freshened via admixture with Atlantic waters. The nascent ARC almost immediately executes an equatorward meander of variable extent over the Agulhas Plateau, and then proceeds eastward.

On average the ARC lies at a latitude of 39°30'S south of Africa, increasing slowly downstream to a latitude of 44°30'S at 60°E, except where it crosses a number of meridional ridges where northward shifts of up to 2°30' are occasionally observed. Geostrophic speeds relative to 1500 m demonstrate a gradual eastward decrease in the velocity of the current from an average of 75 cm/s at the Agulhas retroflection to 13 cm/s at 76°E. Volume transports are similarly reduced from 54×10^6 m^3/s in the retroflection region to 15×10^6 m^3/s at 76°E, although the θ/S characteristics remain remarkably unchanged. The distinct ARC velocity core disappears between 66°E and 70°E, and its characteristic South Indian Subtropical Surface Water is not found east of 61°E. Given this evidence, Lutjeharms and Ansorge [2001] suggest that the ARC be called such from the Agulhas retroflection region to the Crozet Basin, with the flow to the east of the basin to be called the South Indian Ocean Current.

Lutjeharms and Ansorge [2001] comment on an interesting correspondence and provide fodder for future dissertations:

> It is remarkable that the extent and location of the Agulhas Return Current, typified in this way, corresponds almost exactly with one of the largest contiguous regions of high mesoscale variability in the world ocean. All these altimeter results show a tongue of very high mesoscale turbulence starting at the Agulhas retroflection and extending eastward along the path of the Agulhas Return Current, as described here, to terminate over the Crozet Basin. The dimensions and geographical location of this band of high current variability is seen in many other data sets as well, e.g. drifting buoys and sea surface temperatures. It is therefore a notably persistent characteristic of global ocean circulation. Since it is so well correlated with the course of the Agulhas Return Current, it is most probably due to enhanced levels of meandering and eddy shedding along the Subtropical Convergence, where the Agulhas Return Current's presence causes increased horizontal shear and instability. This needs further investigation.

See Peterson and Stramma [1991] and Lutjeharms and Ansorge [2001].

Agulhas Undercurrent A current flowing beneath the Agulhas Current. LADCP measurements indicate the core is centered around 1200 m, against the continental slope and directly below the surface core of the southwestward flowing Agulhas Current. Maximum velocities of 30 cm/s to the northeast are observed in the undercurrent, and its volume transport is 6 Sv, about a tenth that of the overlying Agulhas. See Beal and Bryden [1997].

AIDJEX Acronym for Arctic Ice Dynamics Joint Experiment, a collaborative program between the U.S., Canada and Japan that took place in two phases in 1975–1976. In summer 1975 four manned camps were maintained on ice floes in the Arctic Ocean to measure surface and geostrophic winds, ocean current velocities, and ice floe position. In April of 1976 the submarine USS Gurnard traversed 777 nautical miles along three tracklines in the Beaufort Sea, collecting ice thickness data from upward-looking acoustical soundings. See Trowbridge [1976].

air–sea interaction The processes that involve the transfer of energy, matter, and momentum between the atmosphere and the ocean. The is one of the least well understood areas of physical oceanography, with the theory inadequate and the data sparse. Specific areas with glaring gaps include the interaction of the wind and surface waves, the parameterization of subgrid scale processes in large–scale circulation models, and the transfer of gases across the air–sea interfaces. See Deacon and Webb [1962], Donelan [1990], Geernaert [1990], Kraus and Businger [1994], Rogers [1995], Smith et al. [1996] and Geernaert [1999].

[http://earth.agu.org/revgeophys/rogers01/rogers01.html]

AIRES Acronym for Automatic Recording Inverted Echo Sounder.

Airy wave A theory of waves of small amplitude in water of arbitrary depth that is also known as linear wave theory. The derivation of the theory, given the assumptions of small wave slope ($H/L \ll 1$) and a depth much greater than the wave height ($h/H \gg 1$), gives the expression for the water surface elevation

$$\eta(x,t) = \frac{H}{2}\cos(kx - \sigma t)$$

where H is the wave height, k the wave number, and σ the wave frequency. An expression for the wave length has also been developed, although it must be solved iteratively.

Simpler expressions are available for the limiting cases of deep and shallow water, with deep water being the case where $h/L_\infty > 1/4$ (where h is the depth and L_∞ the deep water wavelength) and shallow water the case where $h/L_\infty < 1/20$. The particles move generally in closed elliptical orbits that decrease in diameter with depth, reducing to limiting cases of circles and straight lines in, respectively, deep and shallow water. See Kinsman [1984], LeMehaute [1976] and Komar [1976].

AITMP Abbreviation for Arctic Ice Thickness Monitoring Project.

AIW Abbreviation for Arctic Intermediate Water.

AIWEX Acronym for Arctic Internal Wave Experiment, a project of the APL at the University of Washington that took place in 1985. See also LEADEX. See Levine [1990].

Ajax Expedition An oceanographic research expedition from 1983-1984.

ALACE Acronym for Autonomous Lagrangian Circulation Explorer float, an instrument that can be programmed to cycle up and down through the water column at predetermined intervals to provide vertical profiles of temperature and salinity. ALACE floats have been used to track currents down to 1.5 km. In operation, the float sinks to its neutral buoyancy depth, drifts with the current, and after a programmed time (5–30 days) increases its buoyancy by pumping oil into an external bladder to rise to the surface. It then transmits data to Service Argos satellites over a 24 hour period, returns the oil to the internal bladder, and sinks again to its neutral buoyancy depth. The cycling continues until the battery energy is depleted after around 100 cycles, or until the float fails for some other reason. See Davis et al. [1992].

Aland Sea A part of the Baltic Sea bordered by the Gulf of Bothnia to the north, the Gulf of Finland to the east, and the man part of the Baltic Sea to the south.

Alaska Coastal Current A narrow, high-speed, westward flow which extends for more than 1000 km along the coast of Alaska. This is a separate feature from the offshore, deepwater Alaskan Stream. It was not recognized as such up until the mid-1970s when a series of hydrocast surveys in the area was begun which led to its identification as a distinct circulation feature. The ACC is driven by freshwater discharge from the mountainous and coastal regions around the Gulf of Alaska and the consequent nearshore confinement of this low-salinity water by westward winds. It is typically narrow (< 50 km), shallow (< 150 m) and partially baroclinic. It flows most intensely between 145 and 155° W through the Shelikov Strait between the Alaskan Peninsula and Kodiak and Afognak Islands, but extends recognizably along the Peninsula as far as 165° W.

The baroclinic speeds and transports have been estimated as typically <30 cm s^{-1} and 0.4 Sv, respectively, in the winter, spring and summer. In the fall, when the freshwater influx leads to the spin-up of the ACC, the speeds and transports have been estimated as 89-133 cm s^{-1} and 1.0-1.2 Sv, respectively. Current mooring measurements have yielded estimates of six-month mean total transports ranging from 0.85 Sv at 151° W to 0.64 Sv at 155° in Shelikof Strait, with daily means as high as 2.5 Sv and marked variability from day to day. This variability is thought to be mainly due to variations in wind-forcing caused by the passage of large-scale storms along the coast. The mean baroclinic transport as estimated from the same measurements was found to be about 75% of the total. See Stabeno et al. [1995].

Alaska Current The eastern limb of the counterclockwise-flowing subpolar gyre in the North Pacific. This current is concentrated on the shelf region by the freshwater input from Alaskan rivers which enhances the pressure gradient across it. It is strongest in winter with current speeds around 0.3 m/s and weakest in July and August when prevailing winds tend to oppose its flow. This current may or may not be distinguished from a western boundary current flowing along the Aleutian Islands and called the Alaskan Stream. Both have previously gone by the name of Aleutian Current. Whether or not the nomenclature makes a distinction, the Alaskan Stream and Current do have distinguishing characteristics. The Current is shallow and highly variable while the Stream is steadier and reaches to the ocean floor. The more barotropic nature of the latter is evidence that it is indeed a product of western boundary current dynamics while the former is in an eastern boundary regime. See Thomson [1972]. Tomczak and Godfrey [1994].

Alaska Gyre A subpolar cyclonic circulation in the northeast Pacific associated with the Aleutian low. The primary currents consist of a broad eastern boundary current flowing north, condensing into a narrow western boundary flow in the apex of the gyre and proceeding west–southwest along the Aleutian Peninsula as the Alaskan Stream. See Lagerloef [1995].

Alaskan Stream See Alaska Current.

ALBATROSS Acronym for Antarctic Largescale Box Analysis and the Role Of the Scotia Sea, a cruise along the rim of the Scotia Sea that took place from March 15 to April 23, 1999 on the RRS *James Clark Ross*. The aim of the cruise was to study the influence of the Scotia Sea on global ocean circulation by undertaking a detailed hydrographic survey of a box surrounding the Scotia Sea, with CFCs, oxygen isotopes, tritium, helium and nutrients sampled as well as the traditional temperature, salinity and oxygen. The specific goals of ALBATROSS were:

- to determine the pathways of the Weddell Sea Deep Water (WSDW) as it enters and leaves the Scotia Sea;
- to quantify the cooling and freshening of Circumpolar Deep Water (CDW) as it crosses the Scotia Sea;
- to determine the pathway and transport of Southeast Pacific Deep Water (SEPDW) across the Falkland Plateau;
- to measure the transport of the Falkland Current and compare with the transport of the wind stress curl forced western boundary current;

- to compute heat, fresh water and other tracer budgets for the Scotia Sea, southwestern Atlantic and western Weddell Sea;
- the calculate the transport and characterize the fronts associated with the ACC as it enters and leaves the Scotia Sea;
- to determine the interannual variability of the transport and water mass properties of the ACC at Drake Passage; and
- to determine temporal changes to the water masses of the Scotia Sea and the extent to which recently ventilated deep waters may have been affected by climate change.

[http://www.mth.uea.ac.uk/ocean/ALBATROSS/]

albedo The proportion of incident radiation reflected by a surface. About 30% of the incoming solar energy is reflected back to space from the earth, of which 25% is reflected by clouds and 5% by the surface or by atmospheric molecules or suspended particles. The clouds and atmospheric gases and particles absorb 25% of the incident radiation with the remainder absorbed at the surface. See Peixoto and Oort [1992], Ch. 6.

Alboran Sea The westernmost basin of the Mediterranean Sea. The Alboran Sea extends from the Gibraltar Strait to the Alboran Islands, an area between about 35° and 38° N and 6° N and the Equator. It abuts the Balearic Sea to the east. According to Vargas-Yanez et al. [2002]:

> Its circulation and water masses are coupled to the exchange through the Strait of Gibraltar, originated by the excess of evaporation over precipitation and river runoff in the Mediterranean. This deficit produces a thermohaline circulation that can be summarised as Atlantic water flowing at the surface of the strait into the Alboran Sea, and saltier and denser Mediterranean water flowing at depth toward the Atlantic. As the Atlantic current progresses into the Mediterranean, it changes its properties due to sea-air fluxes and mixing with resident Mediterranean waters. These changes start in the Alboran Basin, so we can consider its upper layer as filled by surface Atlantic water, more or less modified, and with a variable thickness depending on its geographical location.
>
> The classical circulation pattern in the upper layer of the Alboran Sea is a swift Atlantic current surrounding and feeding two anticyclonic gyres: The Western Alboran Gyre and the Eastern Alboran Gyre (WAG, EAG).

The circulation exhibits considerable variability, characterized by the stability of the two–gyre system in the summer months, and by a coastal jet sometimes called the Algerian Current flowing close to the African shore in the winter. See Va [1984], Fairbridge [1966], Gascard and Richez [1985], Vazquez-Cuervo et al. [1996], Viúdez et al. [1998] and Vargas-Yanez et al. [2002].

Alboran gyre A gyre found in the Alboran Sea. See Speich et al. [1996] and Nof and Pichevin [1999].

ALE Acronym for Arbitrary Lagrangian Eulerian, a finite element solution technique for fluid flow problems with moving interfaces, e.g. moving walls, free surfaces, etc. In the ALE method, the newly updated free surface is determined purely via the Lagrangian method, i.e. by the velocities of the fluid particles at the free surface. The nodes in the interior of the domain are displaced in an arbitrarily prescribed way to obtain a mesh of proper shape and to avoid mesh crossing.

Aleutian Current See Alaska Current.

Aleutian low A center of action centered over the Aleutian Islands between the east coast of the Siberian Kamchatka Peninsula and the Gulf of Alaska at about 50° N. It is prominent in the winter and disappears in summer, with the average central pressure below 1000 mb in January. See Angell and Korshover [1974].

ALEX Acronym for AIDJEX Lead Experiment, which took place Feb. 23 through Apr. 10, 1974 and investigated small–scale meteorological and oceanographic processes associated with leads in pack ice near Barrow, Alaska. The experiment plan called for rapid deployment of five instrumental huts, measuring equipment and personnel by helicopeters and fixed–wing aircraft. The processes of primary interest were sensible, latent, and radiant heat loss to the atmosphere as well as the sinking of convective plumes of saline water formed by freezing and brine rejection at the surface. Logistical problems limited the success of the experiment, with the helicopter range limiting deployment to within 30 miles of Barrow and a dearth of suitable leads in that area. See SMith et al. [1990].

ALFOS Acronym for Long-life, multi-cycle, pop-up RAFOS floats, i.e. RAFOS floats that surface at regular intervals throughout their lifetime and transmit data via satellite.

Alfred Wegener Institute (AWI) The German national research center for polar and marine research. The Institute was founded in 1980 and named after the geophysicist and polar researcher Alfred Wegener. The mandate of the AWI includes fundamental scientific research in the polar regions, national coordination of polar research projects, and logistic support of polar expeditions from other German institutes. The Institute uses the RV Polarstern to perform research at sea. See the AWI Web site[1].

Algerian Current A current that flows eastward along the Algerian coast in the Mediterranean Sea. It flows as a narrow, easily distinguished current for around 300 km from about 0 to 4° E with a width of less than 30 km, average and maximum velocities of 0.4 and 0.8 m/s, respectively, and a tranport of about 0.5 Sv. This is a continuation of the current associated with the Almeria-Oran Front that is itself a continuation of the flow of Atlantic Ocean water entering through the Gibraltar Strait. See Arnone et al. [1990], Tomczak and Godfrey [1994] and Salas et al. [2001].

Algerian Eddies Eddies formed via the instability of the Algerian Current (AC). The generation and propagation of AEs is described by Puillat et al. [2002]:

> Basically, instead of flowing steadily alongslope, the AC meanders. Part of the Modified Atlantic Water (MAW) then recirculates inside the meander, so that a surface anticyclonic eddy is created, embedded between the crest of the meander and the continental slope. Transient (few days) surface cyclonic circulations (CC) are also frequently observed on satellite images upstream from the meander crest, and have been evidenced in situ by drifting buoys trajectories and hydrology. However, only anticyclonic eddies can develop [,i.e. Algerian Eddies (AE)]. The generation of AEs is observed from ∼0° to ∼8°E. AEs trajectories begin with an alongslope-downstream propagation at few kilometers per day, while within their embedding meander, the water typically flows at ∼50 km/day. AEs diameters vary during their course between 50 and 150 km up to ∼250 km. AEs lifetimes range from few weeks to several months. The maxima reported up to now are at least 6 months, with in situ observations, and at least 9 months, with satellite images. [The authors of this paper go on to conclude that AE maximum lifetimes can exceed 3 years.]
>
> The AEs alongslope-downstream propagation usually ends in the Channel of Sardinia, where AEs dramatically interact with the bathymetry. Most of them (the less energetic?) collapse

[1] http://www.awi-bremerhaven.de/

> and release MAW that continues to flow through the channel. A few AEs per year follow the deep isobaths northward across the channel and detach from the Algerian slope, which implies a deep structure. It is now confirmed that these AEs can be anticyclonic coherent structures down to the bottom (∼3000 m). Additional complexity arises, however, from recent observations showing that this vertical coherence down to the bottom is not permanent. AEs detached from the Algerian slope then drift northward along the Sardinian one. Before reaching ∼40°N, AEs detach from the Sardinian slope and propagate in the open basin. Some AEs come back eventually close to the Algerian slope, where they interact with their parent current.

See Puillat et al. [2002].

aliasing A phenomenon encountered when sampling a continuous function to produce values at discrete points. If the sampling frequency isn't high enough to resolve the highest frequency signal present in the continuous function, then the high frequency information above the sampling frequency will appear as a false enhancement of (or, equivalently, be aliased onto) a related lower frequency in the computed power spectrum.

ALIPOR Acronym for Autonomous Lander Instrumentation Packages for Oceanographic Research, a project funded by MAST III to create a European fleet of lander vehicles that can operate together in joint research projects. Lander vehicles will be built to carry out a variety of experiments ranging from sediment probes to fish tracking. Three facets of lander technology are to be addressed: (1) the development of techniques to launch a fleet of landers from a single ship; (2) the development of new sensors for examining processes in the water of the deep benthic boundary layer at depths ranging from 200 to 5000 meters; and (3) the design and construction of two new types of landers, i.e. one that can carry several sensing devices and another compact one that can be operated from a small vessel. See the ALIPOR Web site[2].

Alk Common abbreviation for alkalinity.

alkalinity A property of sea water operationally defined as the excess positive charge to be balanced by CO_3 and HCO_3 ions. The carbonate ion content of any unit of sea water is equal to its alkalinity (i.e. excess positive charge) minus its total dissolved carbon content. See Broecker and Peng [1982].

Almeria-Oran Front A front and an associated current that separate the fresher water flowing in from the Atlantic Ocean via the Gibraltar Strait from the saltier Mediterranean Sea water to the west. The incoming water flows eastward as a jet, breaks into one or two large eddies of around 150 km diameter, and then is deflected to the right (the south) by the Coriolis force where it encounters the African coast and continues flowing eastward as the Algerian Current. See Tomczak and Godfrey [1994].

ALT Acronym for the radar altimeter used on the TOPEX/POSEIDON mission. The ALT was the first spaceborne dual–frequency altimeter and is the primary instrument for the mission. Measurements are made at two frequencies (5.3 and 13.6 GHz) and combined to minimize the errors caused by the presence of ionospheric free electrons, the total content of which is obtained as a by–product of the measurement. This instrument was based on previous Seasat and Geosat altimeters with several improvements including the 5.3 GHz channel for the ionospheric measurement, more precise height measurement, and a longer lifetime. See Hayne et al. [1994].

ALVIN A deep submersible commissioned on June 5, 1964 at the Woods Hole Oceanographic Institution. It has been used for over a thousand research and rescue missions in the years since it was first launched,

[2] http://www.abdn.ac.uk/ nhi648/alipor.htm

most from aboard the tender ship Atlantis II, which was retired from that duty in 1996. See Kaharl [1990].

[http://www.marine.whoi.edu/ships/alvin/alvin.htm]
[http://www.whoi.edu/oceanus/OceanusS95Alvin.html]

AmasSeds Abbreviation for Amazone Shelf Sediment Study, an international field program designed to investigate the transport of fresh water and suspended sediment from the Amazon River into the Atlantic. See Nittrouer et al. [1991].

Amazon River More later.

Amazon shelf See Geyer et al. [1996].

AMO Abbreviation for Atlantic Multidecadal Oscillation.

AMOC Acronym for Acoustic Monitoring of the Ocean Climate in the Arctic Ocean, a 1994–1998 program whose overall objective was to develop and design an acoustic system for long–term monitoring of the ocean temperature and ice thickness in the Arctic Ocean, including the Fram Strait, for climate variability studies and global warming detection. The specific objectives included:

- compilation and analysis of existing ocean and ice data from the Arctic ocean for use in climate and acoustic models;
- simulation of present and future ocean temperature, salinity and speed of sound fields, ice thickness concentration and extent in the Arctic Ocean caused by natural variability and global warming scenarios, as input to acoustic modeling;
- simulation of present and future basin–wide acoustic propagation using natural variability and global warming scenarios to investigate the sensitivity of acoustic methods for global warming detection;
- simulation of present and future acoustic propagation in the Fram Strait to investigate the sensitivity of acoustic methods for monitoring heat and volume fluxes in an area of strong mesoscale eddy activity; and
- design of an optimum acoustic monitoring system for climate change detection in the Arctic Ocean.

[http://www.nrsc.no/~amoc/]

AMODE Acronym for Acoustic Mid–Ocean Dynamics Experiment, a 1991-1992 experiment involving a tomography array located between Puerto Rico and Bermuda. The width of the array was abouata 670 km and is consisted of six mooring acoustic sources and receivers. The array detected signals of the lowest internal wave modes at diurnal frequencies. See Dushaw and Worcester [1998].

AMODE-MST Abbreviation for Acoustic Mid-Ocean Dynamics Experiment–Moving Ship Tomography group. See AMODE-MST Group [1994].

amount effect A term applied to the relationship between isotopic composition and monthly rainfall where months with heavy rainfall show different isotopic concentrations than do months with low rainfall. In high rainfall months, rain frequency is higher which entails a higher relative humidity in sub-cloud air, hence less evaporation from raindrops. Since the rate of evaporation determines the isotopic concentrations (the greater the rate the higher the heavy stable isotope composition), low rainfall months should show a higher heavy stable isotopic composition than high rainfall months.

AMP Abbreviation for Advanced Microstructure Profiler, an instrument developed at the APL.

amphidrome A stationary point around which tides rotate in a counterclockwise (clockwise) sense in the northern (southern) hemisphere, i.e. the point about which the cotidal lines radiate. The vertical range of the tide increases with distance away from the amphidrome, with the amphidrome itself the spot where the tide vanishes to zero (or almost zero). This is also called an amphidromic point. See Fairbridge [1966].

amphridomic point See amphidrome.

AMT Acronym for Atlantic Meridional Transect.

AMTEX Acronym for the Air Mass Transformation Experiment, conducted near Japan in 1974 and 1975. See Geernaert [1990].

Amundsen Abyssal Plain One of the three plains that comprise the Pacific-Antarctic Basin (the others being the Bellingshausen and Mornington Abyssal Plains). It is located at around 150° W.

Amundsen Sea A marginal sea of Antarctica centered at about 112° W and 73° S. It sits between the Bellingshausen Sea to the east and the Ross Sea to the west, with the Antarctic Circle serving as the northern boundary. See Fairbridge [1966] and Grotov et al. [1998].

AMUSE Acronym for A Mediterranean Undercurrent Seeding Experiment, an experiment taking place from 1993–1995 whose overall objective was to observe directly the spreading pathways by which Mediterranean Water enters the North Atlantic, including the direct observation of Mediterranean eddies, i.e. meddies. The measurements included repeated high resolution XBT section and RAFOS float deployments across the Mediterranean Undercurrent south of Portugal near 8.5°W.

A total of 49 floats were deployed at the rate of about two floats per week on 23 cruises of the Portuguese vessel *Kialoa II* and one cruise of the R/V *Endeavor*. The floats were ballasted for 1100 or 1200 decibars to seed the lower salinity core of the Undercurrent. The objectives of the float study were:

- to identify where meddies form;
- to make the first direct estimate of meddy formation frequency;
- to estimate the fraction of time meddies are being formed; and
- to determine the pathways by which Mediterranean Water which is not trapped in meddies enters the North Atlantic.

[http://science.whoi.edu/users/abower/AMUSEdr/amdr.htm]

Anadyr Current A surface current that flows along the northwestern side of the Bering Sea and on through the Bering Strait. It is mostly seasonally invariant with a velocity of about 0.3 m/s. See Tomczak and Godfrey [1994].

analog In signal processing this refers to a continuous physical variable which bears a direct relationship to another variable so that one is proportional to the other. An example would be the mercury level in a thermometer and its relation to the temperature, both of which vary continuously on the macroscopic level. Contrast with digital.

Andaman Sea A body of water in the northeastern corner of the Indian Ocean that lies to the west of the Malay Peninsula, the north of Sumatra, the east of the Andaman Islands, and the south of the Irrawaddy Delta in Burma. It stretches about 650 km from west to east and 1200 km from north to south. The Andaman communicates with the westward lying Bay of Bengal through several channels between the chain of islands that stretches along 93° E., including the Preparis (200 m deep), Ten Degree (800 m deep) and Great (1800 m deep) Channels. It is connected with the Australasian Mediterranean Sea via the Malacca Strait between Thailand and Sumatra. It has been variously estimated to have an area of 600,000 to 800,000 km2 and an average and maximum depth of, respectively, 870-1100 m and 4200 m.

The temperature of the surface waters fluctuates mildly from a monthly average of about 30° C in the summer months to one of about 27.5 in the winter months. They drop off with depth to about 5° C and 2000 m. The surface salinities exhibit strong seasonal variations due to an extremely large freshwater influx from the Irrawaddy and Salween rivers during monsoon season. In the northern part the salinities range from about 20 during the monsoon months from June to November to about 32 from Demember to May. These grade to a fairly constant 33.5 in the southwest end and to a maximum of about 35 near 1500 m depth.

The steadiest current is the inflow through the Malacca Straits, averaging around 1/3-2 knots through the year. The monsoons controls the currents elswhere, driving inflow waters from the Bay of Bengal through the western channels from June to August during the southwest monsoon. This also pushes the Malaccan inflow against the Sumatran coast and forces some Andaman sea water through the Straits. When these winds die southwestward currents gradually form that are maintained and enhanced by the northeast monsoon from December through February. A more sudden shift is seen from March through May when the southwest monsoons begins anew. See Fairbridge [1966].

anelastic approximation A filtering approximation for the equations of motion that eliminates sound waves by assuming that the flow has velocities and phase speeds much smaller than the speed of sound. In its purest form, it requires that the reference state be isentropic as well as hydrostatic, although in practice the reference state is often taken to be nonisentropic which can have deleterious effects on the energy conservation properties of the full set of equations. The anelastic approximation is one of the set of approximations used for the somewhat similar Boussinesq approximation. See Ogura and Phillips [1962], Durran [1989], and Houze [1993], pp. 35-37.

Angola Basin An ocean basin located to the west of Africa at about 15° S in the south-central Atlantic Ocean. It is demarcated to the north by the Guinea Ridge, south of which lies the Angola Abyssal Plain which is fed by the Congo Canyon, the largest in the eastern Atlantic. This has also been known as the Buchanan Deep. See Fairbridge [1966].

Angola-Benguela Front A front, often abbreviated as ABF, caused by the confluence of the southward flowing Angola Current and the northward flowing Benguela Current near 16° S off the African coast. This can be identified in the temperature of the upper 50 m and in the salinity to at least 200 m. See Tomczak and Godfrey [1994] and Lass et al. [2000].

Angola Current The eastern part of a cyclonic gyre centered around 13° S and 4° E that is driven by the South Equatorial Countercurrent in the Atlantic Ocean. This subsurface circulation gyre extends from just below the surface to around 300 m depth with velocities of about 0.5 m/s in the section nearest the African coast. The confluence between this southward flowing current and the northward flowing Benguela Current near 16° S off the African coast is called the Angola-Benguela Front. See Tomczak and Godfrey [1994].

Angola Dome A small cyclonic gyre, centered near 10° S and 9° E, driven by the South Equatorial Undercurrent in the eastern Atlantic Ocean. It is called a dome due to the elevation or doming of the thermocline in the middle of the gyre. This is distinct from the larger gyre that incorporates the Angola Current. See Peterson and Stramma [1991] and Tomczak and Godfrey [1994].

angular frequency The repetition rate of a cyclic process measured in radians/sec. If the frequency in cycles/sec is f, then the angular frequency $\omega = 2\pi f$.

angular momentum The product of mass times the perpendicular distance from the axis of rotation times the rotation velocity. The angular momentum about the Earth's axis of rotation can be expressed as the sum of the angular momentum of the solid Earth's rotation plus the angular momentum of zonal air motion relative to the surface of the Earth. Were this quantity to be absolutely conserved, a parcel of air with the angular momentum of the Earth's surface at the Equator would have a westerly zonal wind speed of 134 m/s at 30° latitude. See Hartmann [1994].

anisotropic Descriptor for a physical property (e.g. density, etc.) that varies depending on the direction in which it is measured.

Annual El Niño Current (AENC) See Cucalón [1987] and Strub et al. [1998].

anomaly of specific volume Another name for the specific volume anomaly.

AnSlope Acronym for Antarctic Slope, a program to investigate cross–slope exchanges at the Antarctic Slope Front. The official site tells us:

> AnSlope seeks an answer to the question: What is the role of the Antarctic Slope Front and continental slope morphology in the exchanges of mass, heat, and freshwater between the shelf and oceanic regimes, in particular those leading to outflows of dense water into intermediate and deep layers of the adjacent deep basins and world ocean circulation?
>
> The importance to the global ocean circulation and climate of cold water masses originating in the Antarctic is now understood, but the processes by which these water masses enter the deep ocean circulation are not. We have developed a program called AnSlope* to address this problem. Our primary goal is to identify the principal physical processes that govern the transfer of shelf-modified dense water into intermediate and deep layers of the adjacent deep ocean. At the same time, we seek to understand the compensatory poleward flow of waters from the oceanic regime. We identify the upper continental slope as the critical gateway for the exchange of shelf and deep ocean waters. Here the topography, velocity and density fields associated with the nearly ubiquitous Antarctic Slope Front (ASF) must strongly influence the advective and turbulent transfer of water properties between the shelf and oceanic regimes.
>
> AnSlope has four specific objectives: [A] Determine the ASF mean structure and the principal scales of variability (spatial from 1 km to 100 km, and temporal from tidal to seasonal), and estimate the role of the Front on cross-slope exchanges and mixing of adjacent water masses; [B] Determine the influence of slope topography (canyons, proximity to a continental boundary, isobath divergence/convergence) on frontal location and outflow of dense Shelf Water; [C] Establish the role of frontal instabilities, benthic boundary layer transports, tides and other oscillatory processes on cross-slope advection and fluxes; and [D] Assess the effect of diapycnal mixing (shear-driven and double-diffusive), lateral mixing identified through intrusions, and nonlinearities in the equation of state (thermobaricity and cabbeling) on the rate of descent and fate of outflowing, near-freezing Shelf Water.
>
> AnSlope addresses these objectives with an integrated observational and modeling program structured as follows. A collaborative core program begins in 2002, containing the components considered central to meeting AnSlope objectives, primarily through acquisition of a set of measurements focused over the outer continental shelf and upper slope of the northwestern Ross Sea. This will allow us to assess the regional AABW production rate, and to identify the cross-front exchange processes that must be taken into account when

> assessing provision of dense water to the deep basins elsewhere around Antarctica. The core elements are: moorings; CTD/LADCP and CTD-based microstructure; tracers; and basic tidal modeling. "Enhancement" proposals, to be submitted separately, request support for the modeling studies that are necessary to fully exploit the measurements and develop the techniques for parameterizing cross-front exchanges in regional and global models. Three cruises are proposed, beginning in Austral summer 2003, over a period of 12 to 14 months. Moorings would be in place throughout this period. The Italian CLIMA program in the Ross Sea provides a valuable international enhancement for the AnSlope observational component. The German BRIOS-2 coupled ice-ocean GCM program is complementary to the US process-oriented modeling studies, and provides a test-bed for AnSlope-generated parameterizations of cross-front exchange.

AnSlope is the fourth project of iAnZone.

[http://www.ldeo.columbia.edu/physocean/anslope/]

Antarctic Bottom Water (AABW) A type of water in the seas surrounding Antarctica with temperatures ranging from 0 to -0.8° C, salinities from 34.6 to 34.7, and a density near 27.88. ABW is formed in the Weddell and Ross Seas. This is the densest water in the free ocean, with the only denser waters being found in regional sill basins such as the Norwegian Sea or the Mediterranean. It is overlain by Antarctic Circumpolar Water (AACW) at a depth of 1000 to 2000 m [3000 m (Tchernia)] and overlies Weddell Sea Bottom Water (WSBW) in some locations.

The flow of AABW in the tropical Atlantic is described by Rhein et al. [1998] as:

> About one-third of the northward flowing AABW at 10°S (4.8 Sv) and at 5°S (4.7 Sv) west of about 31°30'W enters the Guiana Basin, mainly through the southern half of the Equatorial Channel at 35°W (1.5–1.8 Sv). The other part recirculates and some of it flows through the Romanche Fracture Zone into the eastern Atlantic. In the Guiana Basin, west of 40°W, the sloping topography and the strong, eastward flowing deep western boundary current might prevent the AABW from flowing west: thus it has to turn north at the eastern slope of the Ceara Rise (2.2 Sv). At 44°W, north of the Ceara Rise, AABW flows west in the interior of the basin in a main core near 7°15'N (1.9 Sv). A net return flow of about 0.5 Sv was found north of 8°43'N. A large fraction of the AABW (1.1 Sv) enters the eastern Atlantic through the Vema Fracture Zone, leaving only 0.3 Sv of AABW for the western Atlantic basins.

See Jacobs et al. [1970], Tomczak and Godfrey [1994], Tchernia [1980] and Rhein et al. [1998].

Antarctic Circumpolar Current (ACC) A major eastward flowing current that circles the globe in the Southern Ocean. It is principally driven by surface wind stress, although there is a significant thermohaline component that is not yet well understood. In the way of vorticity dynamics a simple Sverdrup balance with dissipative mechanisms of form drag by bottom topography and lateral dissipation in western boundary layers has been found consistent with the data. The present best estimates of its transport through Drake Passage give a net mean transport of 125 Sv (with a standard deviation of 10 Sv) above 2500 m.

The transport of the ACC is concentrated in two current cores separated by a transition zone with surface water characteristics intermediate between those found to the south in the Antarctic Zone and to the north in the Subantarctic Zone, with the transition zone being known as the Polar Frontal Zone. The maximum geostrophic surface speeds in these cores have been calculated as 25-45 cm s^{-1} in Drake Passage.

There is also considerable mesoscale variability in the ACC region due to instabilities causing both cold and warm core rings to be shed. These eddies have been found to have spatial scales varying from 30 to 100 km, surface velocities typically 30 cm s^{-1} or greater, and are vertically coherent from surface to bottom. The regions of highest variability have been found to be correlated with prominent topographic features on the sea floor.

The ACC is a region of complicated and large meridional heat flux, with a mean ocean heat loss to the south estimated at about 0.45 petawatts due to ocean-atmosphere heat exchange and equatorward Ekman transport. This is thought to be balanced by the import of heat via eddy processes and deep boundary currents, although the proportions are known only vaguely as yet. See Nowlin, Jr. and Klinck [1986].

Antarctic Circumpolar Water (AACW) A type of water in the seas surrounding Antarctica with temperatures ranging from 0 to 0.8° C, salinities from 34.6 to 34.7 ppt, and a depth range from a few hundred meters to about 1000-2000 m [3000 m (Tchernia)] It is formed from a mixture of overlying North Atlantic Deep Water (NADW) and underlying (at 1000-2000 m) Antarctic Bottom Water (AABW). It has a temperature maximum around 500-600 m and a salinity maximum between 700-1300 m. This was originally called Warm Deep Water (WDW) by Deacon, but renamed AACW by Sverdrup. See Tomczak and Godfrey [1994], pp. 83, 287 and Tchernia [1980].

Antarctic Circumpolar Wave Interannual variations in the atmospheric pressure at sea level, wind stress, sea surface temperature and sea–ice extent that propagate eastwards around the Southern Ocean. These anomalies propagate with the circumpolar flow with a period of 4–5 years and taking 8–10 years to circle the pole. See White and Peterson [1996].

`[http://acw.ucsd.edu/]`

Antarctic Convergence See Polar Front.

Antarctic Divergence In physical oceanography, a region of rapid transition located in the Antarctic Zone of Southern Ocean between the Continental Water Boundary to the south and the Polar Front to the north. It can be distinguished hydrographically by a salinity maximum below about 150 m caused by the upwelling of water of high salinity, i.e. North Atlantic Deep Water. Above this the maximum is blurred by high precipitation and the melting of ice. Its position corresponds reasonably well to the demarcation between the east and west wind drifts which, in the light of Ekman dynamics, at least partially explains its divergent nature. See Tomczak and Godfrey [1994], pp. 76-79.

Antarctic Front In meterology, a front which develops and persists around the Antarctic continent at about 60-65° S, and divides Antarctic Air from the maritime Polar Air to the north.

Antarctic Intermediate Water (AAIW) In physical oceanography, a type of water mass in the Southern Ocean thought to originate mainly through convective overturning of surface waters during winter west of South America, after which it is injected into the subtropical gyre and fills the southern subtropics and tropics from the east.

In the Atlantic, the densest SAMW found in the Subantarctic Zone between the Subantarctic Front and the Subtropical Front is thought to be the primary precursor to AAIW, although some postulate substantial input across the Subantarctic Front. The AAIW in the South Atlantic originates from a surface region of the circumpolar layer, especially in the northern Drake Passage and the Falkland Current loop. AAIW from the Indian Ocean is added to the Atlantic AAIW via Agulhas Current leakage. The AAIW is recognized by a subsurface oxygen maximum and a salinity minimum north of about 50°S, although the oxygen maximum becomes weak north of 15°S. The oxygen maximum is found at a slightly lower density than the salinity minimum.

The salinity minimum is found at about 300 m near the Subantarctic Front at around 45°S, descends northward to 900 m at 30°S near the subtropical gyre center, and rises again to 700 m at the equator. The AAIW spreads to the North Atlantic, identified by a salinity minimum near the equator at a σ_θ value of about 27.3. This minimum has been found to 24°N, although traces of AAIW can be followed as far north as 60°N. AAIW is characterized by a temperature near 2.2° C and a salinity around 33.8 near its formation region, but erodes by the time it reaches the Subtropical Front to values closer to 3° C and 34.3. See Piola and Georgi [1981], Whitworth and Jr. [1987], Tsuchiya [1989], Tomczak and Godfrey [1994], Boebel et al. [1997] and Schmid et al. [2000].

Antarctic Polar Front See Polar Front.

Antarctic Polar Frontal Zone (APFZ) A concept originated in the 1960s following a detailed study of the Polar Front. This was later transformed into the concept of the Polar Frontal Zone. See Gordon [1971], Gordon [1977], and Belkin and Gordon [1996].

Antarctic Surface Water (AASW) In physical oceanography, a water mass in the Antarctic Zone of the Southern Ocean AASW is found in the upper 200 m south of the Polar Front (PF) and is cold, fresh, and high in oxygen and nutrients relative to the subantarctic surface waters, although it is high in nutrients compared to underyling waters. The most easily distinguishable characteristics of AASW in summer sections is a intense temperature minimum at about 200 m that marks the base of the winter mixed layer. The water around this minimum is also commonly known as Winter Water, and ranges from 50 m deep in the Weddell Gyre to nearly 1000 m just north of the PF. It is characterized by very low temperatures ranging down to the freezing point of -1.9° C and low salinities as the result of ice melting in the summer in the upper 100-250 m of the water column. See Tomczak and Godfrey [1994] and Whitworth and Jr. [1987].

Antarctic Zone A name given to the region in the Southern Ocean between the Polar Front to the north and the Southern ACC Front to the south. The AZ is one of four distinct surface water mass regimes in the Southern Ocean, the others being the Continental Zone (CZ) to the south and the Polar Frontal Zone (PFZ) and Subantarctic Zone (SAZ) to the north. See Orsi et al. [1995].

ANTARES A research program whose overall objective is to describe and model the biogeochemical processes controlling the dynamics of nutrients (C, N, S, P) and silica in the Southern Ocean. More detailed objectives include investigating the seasonal ice zone, deploying arrays of sediment traps, and studying benthic processes.

The first program cruise, ANTARES I, took place from March 29 to May 18, 1993 on board the R. V. Marion Dufresne. Stops were made at the Kerguelan and Crozet Islands on a ship track that traversed an area between 40° and 60° S and 50° and 75° E in the Southern Ocean. Hydrographic and nutrient data were acquired with rosette hydrocasts and CTD and oxygen profiles were obtained with a Neil Brown Mark III B probe. Various core samples were also taken at a total of 20 stations where 142 hydrological and coring sampling operations were performed. See Gaillard [1997].

anticyclone An atmospheric pressure distribution in which there is a high central pressure relative to the surroundings. This term was selected to imply the possession of characteristics opposite to those found in a cyclone or depression. As such, the circulation about the center of an anticyclone is clockwise (counter-clockwise) in the northern (southern) hemisphere, and the weather is generally quiet and settled.

anticyclonic The direction of rotation around a center of high pressure. This is clockwise in the northern hemisphere and counter-clockwise in the southern.

Antilles Current More later.

antitriptic wind A type of wind that occurs when the pressure gradient is balanced by the force of friction. These are the atmospheric analogs of Poisseuille flow. See Dutton [1986].

ANZFLUX Acronym for the Antarctic Zone Flux experiment, the objective of which was to measure the magnitude of heat flux through the air-sea-ice interface and to describe the mechanisms that drive and control the fluxes of heat, salt and momentum. It took place aboard the RV Nathaniel B. Palmer in the Eastern Weddell Sea from June 27 to August 24, 1994. See McPhee et al. [1996].

[http://www.ldeo.columbia.edu/physocean/proj_ANZ.html]
[http://www.oc.nps.navy.mil/~bird/ANZFLUX.html]

AODW Abbreviation for Arctic Ocean Deep Water.

AOGCM Abbreviation for atmosphere/ocean general circulation model, a numerical model that has fully dynamical atmosphere and ocean components that are somehow coupled.

AOIPS Abbreviation for Atmospheric and Oceanographic Information Processing System. See Hasler and desJardins [1987].

AOMIP Acronym for Arctic Ocean Model Intercomparison Project, an effort designed to identify systematic errors in Arctic Ocean models under realistic forcing. The main goals of the proposed research are to examine the ability of Arctic Ocean models to simulate variability on seasonal to interannual scales, and to qualitatively and quantatively understand the behaviour of different Arctic Ocean models. AOMIP's major objective is to use a suite of sophisticated models to simulate the Arctic Ocean circulation for the periods 1946-1998 and 1899-1998. Forcing will use the observed climatology and the daily atmospheric pressure and air temperature fields. Model results will be contrasted and compared to understand model strengths and weaknesses.

[http://fish.cims.nyu.edu/project_aomip/overview.html]

AOML Abbreviation for Atlantic Oceanographic and Meteorological Laboratory.

AOS Acronym for Arctic Ocean Section.

AOSB Abbreviation for Arctic Ocean Sciences Board, a non–governmental body including members and participants from research and governmental institutions from several nations. The long–term mission of the AOSB is to facilitate Arctic Ocean research by the support of multinational and multidisciplinary natural science and engineering programs. It was established in May 1984.

[http://www.aosb.org/]

AOSN Abbreviation for Autonomous Ocean Sampling Network, a project whose long–term goals are to create and demonstrate a reactive survey system capable of long–term unattended deployments in harsh environments. The scientific objectives include:

- to create small, high performance mobile platforms capable of deployments lasting for several months, with both propellor–driven, fast survey vehicles and buoyancy–driven glider vehicles being developed;
- to create an infrastructure that supports controlling, recovering data from, and managing the energy of remote deployed mobile platforms, with structure elements including moorings, docking stations, acoustic communications, two–way satellite communcations, and the Internet;
- to demonstrate these capabilities in science–driven field experiments; and

- to develop adaptive sampling strategies to most efficiently meet deployment objectives.

See Curtin et al. [1993].

[http://auvlab.mit.edu/MURI/index.html]

AOU Abbreviation for Apparent Oxygen Utilization, defined as the difference between the observed oxygen content and the saturation oxygen content of a sample of sea water. This is a method of estimating the amount of dissolved oxygen utilized by organisms via respiration, although it is called "apparent" for a reason. Surface waters may more than likely carry more than the saturation amount of oxygen due to the nonlinearity in the solubility of oxygen with temperature. The effects of this nonlinearity are small, though, and the AOU is usually quite close to TOU, the True Oxygen Utilization. See Broecker and Peng [1982].

APARE Acronym for East Asian/North Pacific Regional Experiment, an IGAC activity. The scientific goals of APARE are to quantify the oxidising efficiency, and atmospheric acidification by studying the emission, transport, chemical transformation, and deposition of primary and secondary chemical species over the East Asian Continental Rim Region and northwestern Pacific Ocean. The objectives are:

- to assess transport and chemical transformations of air pollutants over the East-Asian continent and the northwestern Pacific Ocean, with particular emphasis on distribution and photochemistry of reactive species to understand oxidizing efficiency and the 03 budget in the region; and
- to determine the deposition of primary and secondary pollutants in the East Asian region, with major emphasis on understanding the present status and future prospects of acidification of the atmosphere and deposition of acidic species in the region.

[http://web.mit.edu/afs/athena.mit.edu/org/i/igac/www/sub_pages/apare.html]

APE Abbreviation for available potential energy.

APEX Acronym for Arctic Polynya Experiment. See Pease et al. [1985].

APFZ Abbrevation for Antarctic Polar Frontal Zone.

aphotic zone The region below the euphotic zone where no light is available for photosynthesis.

APO Abbreviation for Association of Physical Oceanography, the name of what is now known as the IAPSO from 1929 to 1948.

apron The official IHO definition for this undersea feature name is "a gently dipping surface, underlain primarily by sediment, at the base of any steeper slope."

APROPOS Acronym for Advances and Primary Research Opportunities in Physical Oceanography Studies, a workshop for physical oceanographers held at Monterey, California from December 15–17, 1997. The goal was to evaluate the current status of research in physical oceanography and to identify future opportunities and infrastructure needs. Similar workshops were held at the time for biological oceanography (sf OEUVRE), ocean chemistry (FOCUS) and marine geology and geophysics (FUMAGES).

Future directions and problems mentioned in the final report included:

- the difficulties inherent in global climate prediction wherein the decadal timescale only allows scientists to observe a few realizations in their lifetimes, and the need to circumvent this by expanding the current database and framing hypotheses about past climate change and ocean circulation using paleoceanographic studies;

- better understanding the ocean's role in the hydrologic cycle;
- advancements on fundamental issues such as the causes of the temperature–salinity relationship, thermocline maintenance, and interhemispheric water mass exchanges;
- the increasing use of observational tools such as satellites and tomography to obtain large-scale, detailed and long-term measurements of the oceans;
- emerging issues concerning connections between large– and small–scale motions, e.g. between small–scale turbulent mixing and large–scale meridional overturning circulation;
- better understanding of the processes involved in cross–shelf transports;
- increased understanding of inland waters such as estuaries, wetlands, tide flats and lakes will probably lead to progress on the general circulation problem;
- unraveling the connections between the spatial and temporal distribution of turbulent mixing, the large–scale meridional overturning circulation, and climate variability;
- radical advances in knowledge of the structure of the ocean on scales between the mesoscale (50 km) and the microscale (less than 10 m) via the use of towed and autonomous vehicles; and
- general circulation model components greatly in need of improvement include deep convection, boundary currents and benthic boundary layers, the representation of the dynamics and thermohaline variability of the upper mixed layer, fluxes across the air–sea interface, diapycnal mixing and topographic effects.

[http://www.joss.ucar.edu/joss_psg/project/oce_workshop/apropos/]

ARABESQUE A U.K.–led, international program of upper–ocean biogeochemistry investigations in the Arabian Sea region. It was conducted during two contrasting seasons, i.e. the waning of the southwest monsoon in August/September, and the intermonsoon–northeast monsoon transition in November/December 1994. Biogeochemical studies were carried out along three transects in the Gulf of Oman and the Arabian Sea, with the main transcect, 1590 km in length, orthogonal to the southern Oman coast. See Burkill [1999].

Arabian Gulf See Persian Gulf.

Arabian Sea A regional sea, centered at approximately 65° E and 15° N, that is bounded by Pakistan and Iran to the north, Oman, Yemen and the Somali Republic to the west, India to the east, and the greater Indian Ocean to the south. The southern boundary, from an oceanographic point of view, runs from Goa on the Indian coast along the west side of the Laccadive Islands to the equator, and thence slightly to the south to near Mombasa on the Kenyan coast. It covers an area of about 7,456,000 km^2.

The flow pattern in the Arabian Sea is seasonal, changing with the monsoon winds. In the northeast monsoon season (from November until March) the winds are light and the surface circulation is dominated by a weak westward, counter-monsoon flow (as an extension of the North Equatorial Current) with velocities usually under 0.2 m/s. This pattern starts in November with water supplied by the East Indian Winter Jet flowing around the southern tip of Indian and heading northwestward along the western Indian shelf.

Westward flow dominates in the southern parts until late April with the north gradually shifting into a weak anticyclonic pattern. With the advent of the southwest monsoon in April, the Somali Current and its northward extension, the East Arabian Current, both develop into strong, northeastward flowing currents by mid-May. The anticyclonic pattern in the eastern Arabian Sea is simultaneously being gradually replaced by a moderate eastward flow composed of extensions of the Somali Current and the Southwest Monsoon Current. This pattern lasts for 4-5 months, peaking in June and July at about 0.3

m/s and weakening rapidly in October as the eastward flow around southern India once again pushes northwestward.

From May to September there is strong upwelling in the East Arabian Current along Oman, accompanied by a 5° C or more lowering of coastal temperatures due to the cold upwelling water. This upwelling isn't as conducive to primary production as elsewhere due to the rapidly moving current removing much of the upwelled additional biomass before it can be utilized. See Qasim [1982] and Schott and Fischer [2000]. See the Arabian Sea Study Web site[3].

Arabian Sea High Salinity Water (ASHSW) See Kumar and Prasad [1999]

Arabian Sea Process Study (ASPS) A 1995 JGOFS program. See Shi et al. [1999].

Arafura Sea Part of the southeastern Australasian Mediterranean Sea centered at about 10° S and 137° E. It is bounded by Irian Jaya and Papua/New Guinea to the north and northeast, the Timor Sea to the west, and Australia and the Gulf of Carpenteria to the south and the southeast. It is mostly a large shelf (covering about 650,000 km^2) ranging from 50 to 80 m deep, although it can get as deep as 3650 m to the northwest in the Aru Basin.

There is a steady westward flow along the southern side of the Sunda Islands that is part of the larger pattern of throughflow through the Australasian Mediterranean from the Pacific to the Indian Ocean. South of this the circulation varies with the monsoon and trade winds that drive it. The deep water is renewed from the northwest via the Timor Trough.

Sea surface temperatures range from a maximum of 28.4° in Dec.-Feb. to a minimum of 26.1° in Jun.-Aug., while salinities annually range from 34.2-34.8 in the deeper parts to the north to 34.2 to 35.0 on the Arafura Shelf. See Fairbridge [1966] and Tomczak and Godfrey [1994].

Aral Sea See Zenkevich [1957] and Zenkevitch [1963].

ARCANE A French research program to observe and model the movement of the Mediterranean Water (MW) in the eastern North Atlantic Ocean in the interior and along the eastern boundary. It is a joint civilian and military exercise taking place between 40 and 50° N with most of the work to be done east of 14° E up to the 200 meter isobath, although some float work will take place out to 25° W to link with the proposed U.S. RAFOS deployments in this region. The plans call for the release of 60 RAFOS and 40 MARVOR floats. Also deployed will be 7 acoustic sources for tomographic work, 40 drifting buoys drogued at 150 meters mostly on the continental slopes of the Iberian Peninsula, 6 current meter moorings (with a total of 27 current meters) on and near the continental slopes of the Iberian Peninsula for 3 years, and a bottom mounted ADCP to be moored for several 3 month periods. This program is scheduled to last until 1999 and is a companion program to EUROFLOAT.

`[http://www.ifremer.fr/lpo/arcane/]`

archipelagic plain The official IHO definition for this undersea feature name is "a gentle slope with a generally smooth surface of the sea floor, characteristically found around groups of islands or seamounts."

ARCSS Abbreviation for ARCtic System Science, an NSF global change program. The goals of ARCS are to understand the chemical, physical, biological and social processes of the arctic system that interacts with the total earth system and thus contributes to or is influenced by global change in order to advance the scientific basis for predicting environmental change on a decade to centuries time scale. See the ARCSS Web site[4].

[3] http://www.icess.ucsb.edu/opl/arabian.html
[4] http://arcss.colorado.edu

ARCTEMIZ See Richez [1998].

Arctic Atmosphere Program (AAP) A component of ACSYS whose goal is to better understand the Arctic atmosphere that provides the dynamic and thermodynamic forcing of the Arctic Ocean circulation and sea ice. The objectives of AAP include:

- to encourage intercomparisons of reanalysis efforts and the assembly of long–term datasets from these intercomparisons;
- to identify shortcomings and implement improvoed parameterizations in the atmospheric modeling systems used for future reanalysis efforts and in climate models;
- to promote intercomparisons of the high latitude performance of climate models;
- to promote the quality control, archiving, updating, publication on CD–ROM, and migration to relevant data centers of key atmospheric datasets;
- to promote strategies for rescue of at–risk atmospheric datasets; and
- provide a polar clouds and radiation program through the GEWEX Clouds and Radiation Panel and other programs.

[http://acsys.npolar.no/impplan/atmosphere.htm]

Arctic Bottom Water In physical oceanography, a water mass type which fills the deep basins in the Arctic Sea at depths less than 3000 m. Its formation process involves the interplay of two sources, GSDW and water from the Arctic shelf regions. The salinities of ABW are generally close to 34.95 but highest in the Canada Basin. The potential temperature in most basins is between -0.8° C and -0.9° C, although the Lomonossov Ridge prevents ABW colder than -0.4° C from entering the Canada Basin. Its main impact in the overall ocean circulation is its contribution to the formation of NADW in the depth range between 1000 m and 4000 m. See Tomczak and Godfrey [1994], pp. 99, 282.

Arctic Circumpolar Boundary Current (ACBC) The main water transformations in the Arctic Mediterranean take place in a boundary current of Atlantic Water, which enters the Arctic across the Greenland–Scotland Ridge. After entering, it flows around the Arctic Ocean before exiting as the East Greenland Current, primarily via the Denmark Strait. On route, it experiences many branchings and mergings. The details of its journey around the Arctic are summarized by Rudels et al. [1999]:

> The circulation is dominated by the movement of warm Atlantic Water entering across the eastern part of the Greenland–Scotland Ridge into the Norwegian Sea. It flows along the Norwegian coast as the Norwegian Atlantic Current. When it reaches the latitude of the Bear Island Channel, its first major bifurcation occurs. A substantial fraction flows eastward and enters the Barents Sea, while the main part continues northward as the West Spitsbergen Current. Several branches are deflected westward from the current: north of the Greenland Sea basin, north of the Boreas basin and in Fram Strait. Only a smaller part of the West Spitsbergen Current eventually enters the Arctic Ocean and flows eastward along the Eurasian continental slope. North of the Kara Sea the boundary current meets the branch that turned east and entered the Barents Sea north of Norway. This branch reaches the Arctic Ocean by crossing the Barents Sea and the northern part of the Kara Sea. The combined boundary current continues eastward a short distance before it again splits. Branches leave the continental slope along bathymetric features, particularly along the Nansen-Gakkel Ridge, the Lomonosov Ridge and the Mendeleyev Ridge. However, a part of the boundary current follows the continental slope around the entire Arctic Ocean. As this part recrosses the Lomonosov Ridge into the Eurasian Basin it meets and mixes with

> the other branches as they converge east of the Morris Jesup Plateau. The waters exit the Arctic Ocean through Fram Strait, where they combine with the recirculating waters of the West Spitsbergen Current to continue southward along the Greenland continental slope as the East Greenland Current. The boundary current again diverges at bathymetric features, in this case the Greenland Fracture Zone and the Jan Mayen Fracture Zone, and branches from the boundary current enter the interior of the Boreas Basin and the Greenland Sea Basin. Exchanges in both directions occur, and the East Greenland Current is resupplied with water masses formed in the subpolar seas. The main part of the boundary current exits the Arctic Mediterranean through the 600 m deep Denmark Strait, but its denser fractions are deflected eastward along the Jan Mayen Fracture Zone and along the Iceland shelf slope and eventually enter the Norwegian Sea. The upper part of these waters then returns to the North Atlantic through the 850 m deep Faeroe-Shetland Channel.

See Rudels et al. [1999].

arctic domain A hydrographic division sometimes used in the North Atlantic Ocean to distinguish it from the polar domain to the north and the Atlantic domain to the south. In this region upper layer waters are relatively cold (0 to 4° C) and saline (34.6 to 34.9). The most significant indication that this domain is not just a smooth transition zone between the polar and Atlantic domains is that the waters are markedly denser than either of the surface source water masses (i.e. σ_t ranges from 27.5 to greater than 28). See Swift [1986].

Arctic Frontal Zone (AFZ) A frontal zone that runs meridionally between about 5 and 8° E in the Greenland Sea. It separates warm, salty, northward-flowing Norwegian Atlantic Water (NwAtW) in the Norwegian Atlantic Current and the West Spitsbergen Current to the east from the cooler and fresher Arctic Surface Water (ASW) in the Greenland Sea gyre to the west.

The AFZ consists of two semipermanent frontal interfaces with warm, saline Norwegian Atlantic Water to the east and Arctic Water from the Greenland Sea gyre to the west. These two interfaces bound a band of shallow cyclonic cold eddies and anticyclonic warm eddies with horizontal scales on the order of 40–50 km, consistent with the local Rossby radius. Drifter trajectories show a mean surface velocity across the AFZ to the north, and the mean northward geostrophic transport (relative to 1000 dbar) connected with the zonal density gradient in the AFZ is about 3.8 Sv. The accompanying transports of heat and fresh water across the AFZ are thought to be of great importance for the control of deep convection processes in the Greenland Sea gyre. See van Aken et al. [1995].

Arctic Intermediate Water (AIW) A water mass found at intermediate depths in the arctic domain in the North Atlantic Ocean. It is identified by a temperature minimum at a depth of about 75 to 150 m as well as temperature and salinity maximums at depths ranging from about 250 to 400 m, with the extremes being the product of winter cooling and sinking in the arctic domain. It is useful to separate this water mass into lower and upper AIW.

The lower AIW contains the temperature and salinity maximums but generally not the temperature minimum, with temperatures ranging from 0 to 3° C and salinities greater than 34.9, with the maximums clear signs that this water mass is produced by the cooling and sinking of Atlantic Water (AW). The upper AIW is defined as including the denser portion of the water associated with the temperature minimum, including much of the water column from the minimum up to the temperature maximum. It is characterized by temperatures less than 2° C in the salinity range 34.7 to 34.9 (with a lower limit of 34.6 suggested by some).

The definitions for upper and lower AIW deliberately overlap in density, with upper AIW in the Iceland Sea having a temperature of 0° C, S = 34.88 and $\sigma_t = 28.03$ as opposed to a portion of the lower AIW in the northern Greenland Sea having T = 3° C, S = 35.05, and $\sigma_t = 27.95$. This is only true of the northeastern Greenland Sea, however. Elsewhere, upper AIW always overlies lower AIW. See Swift [1986].

Arctic Mediterranean Sea The area comprising the Greenland Sea, the Iceland Sea, the Norwegian Sea and the Arctic Ocean. The first three are sometimes referred to as the Nordic Seas.

The area has restricted communication with the rest of the world ocean, with the passages being:

- to the Pacific via the Bering Strait;
- to the North Atlantic via the Greenland–Scotland Ridge; and
- through the Canadian Arctic Archipelago and the Davis Strait west of Greenland.

Aagaard and Carmack [1985] summarize the thermohaline circulation.

Arctic Ocean The smallest and most poorly studied of the oceans on earth. It covers an area of 14 million square km that is divided by three submarine ridges, i.e. the Alpha Ridge, the Lomonosov Ridge, and an extension of the mid-Atlantic ridge. It is also nearly landlocked, covered year-round by pack ice, and one-third of its area is continental shelf containing marginal seas. The marginal seas of the Arctic are the Beaufort Sea, the Chukchi Sea, the East Siberian Sea, the Laptev Sea, the Kara Sea and the Barents Sea. An important climatic function of the Arctic and its adjacent seas is the production of the dense water than drives the global transports of heat and fresh water between the high latitude North Atlantic and the Pacific.

The physical processes that combine to produce the circulation in the Arctic and its marginal seas include:

- salt rejection from sea–ice growth forming dense water that continues surface buoyancy forcing after the freezing point is reached, preferentially where offshore winds maintain open waters for prolonged periods;
- advection of ice produced in marginal seas that exports fresh water from the basin, compensating for the freshening effect of precipitation and run–off from Arctic rivers; and
- drainage of dense shelf water from the Arctic shelves into the deep Eurasian basin, a process that affects the deep water properties in the convective gyres via exchanges through the Fram Strait.

See Coachman and Aagaard [1974], Carmack [1990], McPhee [1990], Muench [1990] and Padman [1995].

Arctic Ocean Circulation Program (AOCP) A component of ACSYS designed to investigate the feedback between changes in the upper Arctic Ocean and its ice cover and changes in the global heat balance. The AOCP consists of four components:

- **Arctic Ocean Hydrographic Survey -** A program to collect a high quality hydrographic database representative of the Arctic Ocean with the goal of determining the general circulation and its transit times, and the rate of transformation of the different water masses.
- **Arctic Ocean Shelf Studies -** A program aimed at understanding how the shelf processes partition salt and fresh water components, how the resulting buoyancy fluxes are coupled to the ocean interior, at defining the dynamics and thermodynamics of the shelf waters sufficiently to permit realistic modeling, and at determining the variability on the shelves and how that affects the interior ocean.

- **Arctic Ocean Variability Project** - A program designed to assess the variability of the circulation and density structure of the Arctic Ocean including exchanges with the surrounding seas, to find the rates and variability of the processes important in maintaining present ocean conditions, and to provide a basis for further monitoring of climate change in the Arctic.
- **Arctic Ocean Climate Database Project** - A project to establish a universally available digital hydrographic database for the Arctic Ocean for analysis of climate–related processes and variability, and to provide a dataset suitable for the initialization and verification of Arctic climate and circulation models.

[http://acsys.npolar.no/impplan/ocean.htm]

Arctic Ocean Deep Water (AODW)
See Swift [1986].

Arctic Ocean Section (AOS)
A 1994 expedition in which two icebreakers - the USCGC Polar Sea and the CCGS Louis S. St. Laurent - sailed from Nome, Alaska to the North Pole across the entire Arctic basin, covering over 2000 nautical miles. The purpose of AOS was the increase understanding about the role of the Arctic in climate change and gather baseline data on contaminants in the region. See Tucker and Cate [1996] and Wheeler et al. [1996].

The significant science findings of the expedition were:

- the Atlantic layer of the Arctic Ocean was found to be 0.5–1.0°C warmer than prior to 1993;
- a large eddy of cold fresh water was found centered at 1000 m on the periphery of the Makarov Basin;
- biological productivity was estimated to be ten times greater than previous estimates;
- an active microbial community was found; and
- mesozooplankton biomass was found to increase with latitude.

[http://www.crrel.usace.army.mil/news/news-archives/arctic-crossing/monthly.htm]
[http://www.crrel.usace.army.mil/library/pub97fyo.htm]

Arctic Sea Ice Program (ASIP)
A component of ACSYS whose objectives are:

- to assemble a climatological archive which documents the state of pack ice in both the Arctic and Antarctic seas; and
- to study the interaction of polar pack ice with other elements of the global climate system.

The elements of the implementation strategy include:

- assembling a climatology of Arctic and Antarctic sea ice based on available historical observations and new observing initiations within ACSYS;
- determining the southward flux of pack ice;
- studying the processes by which pack ice, the ocean and the atmosphere interact; and
- studying sea ice mechanics at spatial scales (> 1 km) relevant to its behavior in a geophysical context.

[http://acsys.npolar.no/impplan/seaice.htm]

Arctic Surface Water (ASW) A water mass found in the arctic domain in the North Atlantic Ocean. The ASW is the summer surface water mass above the seasonal thermocline and has temperatures greater than 0° C for the salinity range 34.4 to 34.7 and greater than 2° C for the range 34.7 to 34.9. See Swift [1986].

Argentine Basin An ocean basin located in the western South Atlantic Ocean off the coast of Argentina. It is separated from the Brazil Basin to the north by the Rio Grande Rise and includes the Argentine Abyssal Plain. See Fairbridge [1966].

Argo A global array of 3,000 free–drifting profiling floats that will measure the temperature and salinity of the upper 2000 m of the ocean. This will allow the continuous monitoring of the climate state of the ocean. Once the full network is in place in 2002 or thereabouts, Argo will provide 100,000 T/S profiles and reference velocity measurements per year from floats distributed over the oceans at about a 3 degree spacing. The floats will cycle to 2000 m depth every 10 days, with a planned 4–5 year lifetime for individual instruments. All data will be made publicly available in near real–time via the GTS, and in scientifically quality–controlled form within a few months.

[http://www-argo.ucsd.edu/]

Argon-39 An isotope of argon that is useful as a tracer in ocean studies. It is a radioactive inert gas with a half life of 269 years and is produced in the atmosphere by cosmic ray interactino with Argon-40. It is well-mixed through the troposphere and its variation in concentration over the last 1000 years has been estimated to be no more than about 7%. This means that its distribution in the atmosphere and ocean is in steady state.

It enters the ocean by gas exchange with the equilibrium time between the surface mixed layer and the atmosphere being about a month. The equilibrium concentration in surface water is calculated from the solubility of argon, a well known function of temperature and salinity, and the also well known concetration of Ar-39 in the atmosphere. The surface concentration in regions of deep water formation, where the surface water may not equilibrate with the atmosphere due to rapid convection processes, can be determined from measurements. Measurement is at present an onerous process requiring 1500 liters of water, and the concentration measured is reported in % modern, i.e. the Ar-39:Ar:40 ratio of the sample divided by the Ar-39:Ar:40 ratio of the troposphere. The minimum detectable limit is about 5% modern (with an error of 3-5% modern) which corresponds to an age of 1100 years with a resolution of about 50 years.

Argon-39 is an ideal tracer for investigating mixing and circulation in the deep ocean and in the mid to lower thermocline. Its distribution is in steady state and the boundary conditions are well known, i.e. there is no flux across the ocean bottom and the surface water concentration is known everywhere. Its distribution in the ocean interior is affected only by circulation, mixing and radioactive decay process, and since the decay rate is know it serves as a clock for circulation and mixing processes. See Loosli [1983], Sarmiento [1988] and Broecker and Peng [1982].

ARIES Acronym for Autosampling and Recording Insrumental Environmental Sampler, a multi–function sampling device providing high resolution concurrent sampling of physical, chemical and biological parameters throughout the water column from a moving ship. ARIES is modular, being composed of a water sampling unit, a plankton sampling unit and an oceanographic sensor unit. See Dunn et al. [1993].

Arlindo Project A joint oceanographic research endeavor of Indonesia and the United States whose primary goal is to study the circulation and water mass stratification within the Indonesian Seas, especially to determine sources, pathways, and mixing histories of the throughflow water masses for the monsoon extremes. "Arlindo" is an acronym for Arus Lintas Indonesia, meaning "throughflow" in the Bahasa Indonesian language.

The first stage of the project, Arlindo Mixing, consisted of a suite of CTD measurements extending to the seafloor or 3000 dbar, tracer chemistry, and biological productivity stations obtained from the Indonesian research vessel Baruna Jaya I during the southeast monsoon of 1993 (Aug. 6 to Sept. 12) and northwest monsoon of 1994 (Jan. 25 to Mar. 3). The results have been summarized as:

> The primary interocean throughflow path in the upper thermocline is that of North Pacific thermocline water flowing through the Makassar Strait into the Flores and southern Banda Seas before curling southward into the Timor Sea and Indian Ocean. This path tracks the mostxi persistent course of water masses core layer indicators along a potential throughflow pathway. Even in the southern Banda Sea the North Pacific core layer indicators are evident, albeit very attenuated; they are not observed in the northern Banda Sea, which attests to the Makassar/Flores origin. The sill at the southern end of Makassar Strait is about 550 m deep. No signs of deep water upwelling lifting over the sill is evident. An attenuated, fragmented thermocline salinity and CFC maximum layer in Makassar Strait during the NWM relative to the SEM, suggests that the throughflow slackens in that season, allowing accumulative effects of local mixing.
>
> East of Sulawesi there is little evidence of North Pacific water mass throughflow into the Banda Sea. The North Pacific thermocline water entering the northwest corner of the Maluku Sea, exits back to the north in the northeast corner of the Maluku Sea. The presence of relatively salty water of South Pacific origin is observed in the 10-14C interval in the Seram Sea. This water enters the Seram Sea directly from the South Pacific via the New Guinea Coastal Current and Halmahera Sea (sill depth near 500 m). Below the thermocline the main source of the throughflow is South Pacific water masses, though they are derived from a more indirect route, via the North Pacific's Mindanao Current, entering the Indonesian Seas at the Maluku Sea. It is this water that spills over the 1940 m deep Lifamatola Sill into the depths of the Banda Sea.

The second stage was called Arlindo Circulation, whose goal was to resolve the throughflow transport and velocity field across the central passages of the Indonesian Seas. It took place from Nov. 20–Dec. 15, 1996 and Feb. 17–Mar. 7, 1988. The third stage is called Arlindo Monitoring and is intended to provide a long term data set of the throughflow to enable study at timescales of ENSO events. It is scheduled from 1998 to 2007. See Ilahude and Gordon [1996].

[http://www.ldeo.columbia.edu/physocean/proj_AM.html]

Arons, Arnold (1916–2001) Co-creator of the Stommel–Arons theory of deep circulation.

[http://world.conk.com/world/phaskell/aa.html]

arrested salt wedge estuary One of four principal types of estuaries as distinguished by prevailing flow conditions. This is a type in which there is a relatively stationary interface between an underlying stable salt wedge of sea water and an overlying strong flow of fresh river water.

ASCAP Acronym for the Air–Sea interaction, Cloud And Precipitation experiment over the Baltic Sea, a component of BALTEX. ASCAP is a comprehensive campaign for an air–sea interaction field campaign in the Baltic Sea, with the central aim being to improve model parameterization schemes via a better understanding of the physical mechanisms and validation of remote sensing algorithms. The objectives are:

- measurements of parameters determining air–sea interaction processes, the sea state, and wave spectra;
- in–situ measurements and observations of clouds, water vapor and precipitation;
- parameterization of air–sea interaction processs in region models;
- validation of algorithms to estimate cloud parameters, water vapor and precipitation from radar and satellite data; and
- validation of numerical models against long–term measurements.

The measurement phase took place from 1995 until 1997.

[http://w3.gkss.de/english/Baltex/campaign2.html]

ASEAMS Acronym for Association of Southeast Asian Marine Scientists.

aseismic ridge An undersea ridge that is not seismically or volcanically active. Examples of aseismic ridges are the Walvis Ridge, the Rio Grande Plateau, the Kerguelen Plateau, the Seychelles Ridge and the Lomonosov Ridge. See Fairbridge [1966].

ASGAMAGE An acronym that is the contraction of ASGAS–EX (for Air Sea Gas Exchange project) and MAGE. The ASGAMAGE project started on March 1, 1996 and lasted until March 1, 1999. The scientific objectives were:

- to find relationships between the transport coefficients for the gas fluxes and any relevant geophysical parameters;
- to test new methods and new equipment for the measurement of air–sea fluxes of CO_2, DMS and other gases;
- to intercompare different methods and systems to measure the transfer velocity of trace gases over the sea; and
- to find out whether and, if at all, under what conditions there can be a significant vertical gradient in the CO_2 concentration in the upper meters of the water column.

ASGAMAGE consisted of two experimental periods, with the first taking place from May 6 to June 7, 1996. It involved taking measurements at and around the Meetpost Noordwijk (MPN), a research platform 9 km off the Dutch coast. The second period, taking place from Oct. 7 to Nov. 8, 1996, involved more measurements at MPN and a cruise of the RRS Challenger. The measurement activities were primarily aimed at a determination of air–sea gas transfer coefficients with the differential tracer method being made simultaneously with micrometeorological experiments.

[http://www.knmi.nl/onderzk/oceano/special/asgamage/]

ASHES Acronym for Axial Seamount Hydrothermal Emissions Study.

ASHSW Abbreviation for Arabian Sea High Salinity Water.

ASIAEx Acronym for Asian Sea International Acoustics Experiment, a scientific collaboration between the U.S., China, Korea, Japan, Taiwan, Russia and Singapore. The ASIAEx major field experiments began in 2000, one focusing on acoustic bottom reverberation and the other on acoustic cross–shelf progagation.

[http://www.arl.nus.edu.sg/asiaex/]

Asia Minor Current (AMC) A meandering current flowing westward and then northward along the Turkish coast and the southeastern coast of Rhodes. It borders the northwest part of the Rhodes gyre, and originates as part of the mid–Mediterranean jet branching to the north. There is a major branch in the AMC in the region of the Rhodes and Karpathos Straits. Both branches intrude into the south Aegean Sea and meander in the northeastern Cretan Sea as a continuation of the AMC. The branches carry warm and saline Levantine waters within the upper 300–400 dbar layer. See Theocharis et al. [1999].

ASLO Acronym for the American Society of Limnology and Oceanography, the purposes of which are to promote the interests of limnology, oceanography and related sciences, to foster the exchange of information across the range of aquatic science, and to further investigations dealing with these subjects. ASLO originated with the Limnological Society of America (LSA), which was established in 1936 to furhter interest and research in limnological science. In 1948 LSA merged with the Oceanographic Society of the Pacific to become ASLO, and currently has over 3800 memebers from 50 countries. See the ASLO Web site[5].

ASREX Acronym for Acoustic Surface Reverberation Experiment.

`[http://uop.whoi.edu/data/uopdata.html]`

ASTTEX From the web site:

> ASTTEX examines the fluxes of heat, salt and mass entering the South Atlantic ocean via the Agulhas Retroflection. The goal of the experiment is to provide a quantitative, multi-year Eulerian measurement of the strength and characteristic scales of Agulhas-South Atlantic mass and thermohaline fluxes, which contain a strong mesoscale component, resolving those fluxes on density horizons. While it has been estimated that up to half of the Agulhas-South Atlantic exchange is contained in mesoscale rings and eddies [Byrne, 2000] and the strength of the mesoscale fluxes could potentially vary a great deal in time, this has yet to be confirmed by a single, consistent set of observations – principally for want of a method with which to make the measurement. Ship-based surveys lack the temporal resolution required and the only prior mooring deployment that spanned the Cape Basin (conducted as part of the Benguela Sources and Transport experiment) was not at eddy-resolving resolution. An additional element of uncertainty is added by the extreme variability in size, strength and thermohaline signature of individual Agulhas eddies, which are dissimilar enough that some were at one time ascribed an origin in the Brazil Current.
>
> The core of the ASTTEX field component is a 24-month deployment of sixteen moorings that monitor the transports of Indian Ocean water into the South Atlantic via the Agulhas Current at eddy-resolving resolution (70 - 80 km). The moored array consists of twelve pressure sensor-equipped inverted echo sounders (PIES) three near-bottom current meters (CM), and one validation mooring with six recording conductivity-temperature (CT) sensors. All of the moorings are deployed along a Topex-Poseidon/Jason satellite altimeter groundtrack. The mooring deployment was completed on January 16, 2003.
>
> ASTTEX also includes the large-scale analysis of regional sea surface height (SSH) anomaly fields during the field portion of the experiment as well as a long-term (12-year) analysis of Agulhas eddies in the SSH record (1992-2004). This component, spearheaded by Dr. Witter, provides a large-scale, low-frequency context for the experiment. The SSH fields are be derived from Topex-Poseidon and Jason-1 altimeter data.

[5] http://aslo.org/

> ASTTEX uses a new technique which allows the mapping of fully depth-resolved salinity and temperature profiles from the combination of acoustic travel time and sea surface height. This method is called GEM-ETTA for Gravest Empirical Mode – 3D. GEM is a technique developed by Dr. Watts and some of his current and former students, and uses historic hydrography and acoustic travel time as proxies for vertically resolved in situ thermohaline profiles. A similar technique, ETTA (Enhanced Thermohaline Transport Analysis) was developed by Dr. Byrne in her doctoral thesis and uses historic hydrography and altimetric sea surface height in concert with acoustic travel time to distinguish thermohaline anomalies in the water column. ASTTEX has provided a context in which to integrate these two independently-developed methods as GEM-ETTA.

Acronym for Agulhas–South Atlantic Thermohaline Transport Experiment. See Boebel et al. [2003].

[http://gyre.umeoce.maine.edu/ASTTEX/]

ASW See Arctic Surface Water.

ATEX Acronym for Atlantic Trade Winds Experiment, an experiment designed to study the development of the boundary layer in the trade winds near the ITCZ. It was conducted in 1969 and based on a triangle of ships drifting with the NE trades. Spatial structures of the boundary layer were gathered. Air–sea fluxes were measured by the profile method and the eddy correlation technique was used on two separate buoys, i.e. a stable, wave–following buoy for profiles and a servo–stabilized buoy for eddy fluxes. Sea Dunckel et al. [1974] and Geernaert [1990].

Atlantic domain One of three regions into which the North Atlantic Ocean is sometimes divided for the purposes of describing water mass formation processes in the region, with the other two being the (northward lying) arctic domain and the polar domain. Surface source water masses from the Atlantic domain (called Atlantic Water (AW), are carried into the arctic domain by the Norwegian Atlantic Current and, to a much smaller extent, by the North Icelandic Irminger Current. See Swift [1986].

Atlantic Multidecadal Oscillation (AMO) A 65–80 year cycle with a 0.4°C range observed in North Atlantic sea surface temperature for 1856–1999. AMO warm phases occurred during 1860–1880 and 1940–1960, with cool phases during 190–1925 and 1970–1990. The signal is global in scope, with a positively correlated co–oscillation in parts of the North Pacific, although it is most intense in the North Atlantic and covers the entire basin.

During AMO warmings most of the U.S. experiences less than normal rainfall, including Midwest droughts in the 1930s and 1950s. Mississippi River outflow varies by 10% between warm and cool phases. The geographical pattern of variability is influenced mainly by changes in summer rain. Winter patterns of interannual rainfall variability associated with ENSO are significantly changed between AMO phases.

Atlantic Ocean Much more later.

The near–surface lateral circulation of the South Atlantic Ocean or, equivalently, the subtropical gyre circulation, has been summarized by Stramma and England [1999]. This is a slightly modified version of their summary.

> Beginning in the southwest Atlantic, the subtropical gyre of the South Atlantic consists of the southward western boundary current, the Brazil Current, which separates from the coast in the confluence zone with the Falkland Current. From there, the Brazil Current, with admixtures of Falk Current waters, leaves the shelf and flows eastward as the South Atlantic Current. At about 40°W, east of the Mid–Atlantic Ridge, part of this flow recirculates where

a frontal structure called the Brazil Current Front turns northward, while most of the water continues eastward. As it nears South Africa, part of the South Atlantic Current continues into the Indian Ocean while another part turns north to become the Benguela Current, and eventually the South Equatorial Current (SEC). The SEC in the near–surface layer reaches the Brazilian shelf near 16°S and separates into the southward flow of the Brazil Current and, at subsurface depth, into the northward flow of the North Brazil Undercurrent. The Benguela Current also receives water from the Indian Ocean from a leakage of the Agulhas Current (AC) at its retroflection south of South Africa.

See Iselin [1936], Worthington [1976], Peterson and Stramma [1991], Schmitz and McCartney [1993], Schmitz [1995], Stramma and England [1999], Stramma and Schott [1999] and Fratantoni [2001].

Atlantic-Indian Basin One of three major basins in the Southern Ocean. It extends from its western border with the Pacific-Antarctic Basin at the Scotia Ridge and Drake Passage (at about 70° W) to its eastern border with the Australian-Atlantic Basin at the Kerguelan Plateau (about 75° E). It consists of the Enderby and Weddell Abyssal Plains and is bounded to the north below 4000 m by the Mid-Atlantic and South-West Indian Ridges except for deeper connections into the Argentine Basin in the western Atlantic and into the deep basins of the western Indian Ocean.

Atlantic Meridional Transect An ongoing research program that exploits the twice–annual passage of the RRS James Clark Ross between the U.K. and the Falkland Islands - before and after its use in the Antarctic research program in the Austral Summer - to obtain spatially–intensive time and space series data over the 13,500 km transect. The transect starts at the U.K. and heads southwest to the first waypoint at a JGOFS time–series station at 47°N, 20°W. From there it follows the 20°W meridian to 13°N, after which it heads south and west to Montevideo (Uruguay) and Stanley (Falkland Islands).

The objectives of the AMT program include:

- gauging the effects of anthropogenically induced environmental change on the physical and biological systems along the transcent;
- improving knowledge of marine biogeochemical processes, ecosystem dynamics, food webs and fisheries, as well as characterize physical and biogeochemical provinces;
- developing a research strategy to integrate shipboard measurements with remote sensing, modeling, etc. to maximally exploit the time and space series obtained on the transect;
- providing calibration and validation of satellite sensors of ocean color, sea surface temperature, and solar radiation;
- quantifying ecosystem responses to changes in the abundance of radiatively and chemically active trace gases; and
- developing coupled physical–biological models of production and ecosystem dynamics.

The progress and limitations of AMT as of 2000 has been synthesized by Aiken et al. [2000] as:

> AMT cruises 1 to 7 (1995–1998) have seen the completion of phase 1 of the AMT programme, wherein many of the new, autonomous technologies and operational approaches have been pioneered and proven. There are obvious limitations in the programme, particularly one which has objectives related to issues of climate change. Notably, the physical oceanography is superficial, CTD casts have been limited to 200 m in most cases with no geostrophic reference and the spatial resolution of circa 400 km from typically 1 cast per day is too coarse. As a basin scale programme the AMT samples the temperate N. Atlantic poorly; there is no sampling north of 50°N. As a programme focused on climate change,

> a time series based on samples only twice a year has severe limitations, with no adequate resolution of the seasonal cycle in any province. Nevertheless, the fledgling four-year time series can already provide measurements of inter-annual variability, which is an essential pre-requisite for any study of decadal trends. With another 10 cruises planned over five years (1999–2003) during phase 2, the basis of a study of climate change will be well established. During this period there must be a focus on those measurements that are sensitive to climate forcing or are known indices of anthropogenic influences on climate. Collaboration with other European national research activities is planned to improve the coverage of the seasonal cycle in the north Atlantic and create a European Atlantic Time and Space Series (EATSS) project. Core to this are the twice yearly transects of the other Antarctic research vessels, the Polarstern (Germany), the Hesperides (Spain) and the Pelagia (Netherlands) with opportunistic research cruises in the area 20–63°N, 20°W, by UK, German, French, Dutch, Belgian and Spanish vessels. If this develops, it will be true to say, that the AMT programme has laid down the foundation for a study of decadal trends in the marine ecosystems of the Atlantic Ocean with which to understand and model their responses to climate change.

See Aiken and Bale [2000] and the other papers in a special AMT results issue.

Atlantic period A post-LGM European climate regime. This refers to the period from about 6000-3000 BC that spans most of the warmest postglacial times. It is also known as the Postglacial Climatic Optimum. It was preceded by the Boreal period and followed by the Sub-Boreal period. See Lamb [1985], p. 372.

Atlantic Water (AW) A water mass traditionally defined as any water with salinity greater than 35.0 entering the arctic domain from the Atlantic domain. AW first entering the Iceland and Norwegian Seas typically has temperatures of 6-8° C and a salinity range of about 35.1–35.3, although the property ranges of other waters obviously connected with AW have prompted some to expand the definition to include all waters warmer than 3° C and more saline than 34.9. Estimates of the total influx of AW range as high as 9 Sv. See Swift [1986].

ATLAS Acronym for Autonomous Temperature Line Acquisition System, a taut–line mooring with sensors measuring surface winds, air temperature, relative humidity, sea surface temperature, and ten subsurface temperatures to a depth of 500 m. Daily mean data are telemetered to shore in near real–time via NOAA's polar orbiting satellites and Service Argos. The standard ATLAS mooring has a design lifetime of one year, with over 500 having been deployed sine 1984.

`[http://www.pmel.noaa.gov/toga-tao/atlas.html]`

atmospheric tide Those oscillations in any atmospheric field whose periods are integral fractions of either a lunar or a solar day. These differ from ocean tides in several ways, one of which is that atmospheric tides are excited not only by the tidal gravitational potential of the sun and moon but also (and to the larger extent) by daily variations in solar heating. Another difference is that the atmosphere is a spherical shell and thus there are no coastal boundaries to worry about. Finally, the response of the atmosphere to tidal forcing is by means of internal gravity waves rather than the barotropic surface waves of the sea. See Lindzen [1971].

atmospheric turbulence See Wyngaard [1992].

ATOC Abbreviation for Acoustic Thermometry of Ocean Climate, a program composed of two complementary enviromental initiatives: (1) to gather information about temperatures in the ocean using acoustic tomography to verify the predictions of existing climate models; and (2) to assess the potential effects of low frequency sound transmissions on marine mammals and sea turtles through its MMRP component. See the ATOC Web site[6].

atoll One of three geomorphologically distinct types of coral reefs, the other two being fringing reefs and barrier reefs. An atoll is an annular reef formed around a subsiding volcanic island. See Barnes and Hughes [1988].

ATSR Abbreviation for Along-Track Scanning Radiometer microwave sounder, a satellite-borne instrument designed to measure land and ocean surface temperatures. The ATSR is a passive two-channel radiometer that scans the near-infrared and middle-infrared bands with a spatial resolution of 1 km x 1 km and a swath width of 500 km. It views the Earth from an orbit of about 800 km and can measure ocean temperature to within 0.3° C. The ATSR can be used to detect exceptional local incidents, large scale changes, and general trends in the Earth's climate. See the ATSR Web site[7].

ATTOM Acronym for Acoustic Travel Time Ocean Current Monitor.

austausch coefficient A German term for a quantity equivalent to the eddy viscosity coefficient.

Australasian Subantarctic Front See Subantarctic Front.

Australian-Antarctic Basin One of three major basins in the Southern Ocean. It extends from its eastern boundary with the Pacific-Antarctic Basin at the longitude of Tasmania (at about 145° E) to the Kerguelan Plateau (at about 75° E). The South-East Indian Ridge separates it from the Indian Ocean at depths greater than 4000 m except for a gap in the Ridge at 117° E.

Australasian Mediterranean Sea The region on either side of the equator between the islands of the Indonesian archipelago. This has the most complicated topography of any of the regional seas of the world, consisting of a series of deep basins with limited interconnections, each characterized by its own type of bottom water of great age. The basins comprising this include the Banda, Sulawesi (formerly Celebes), Molucca, Halmahera, Serman, Sulu, Flores, Java and Sawu Seas, with the Banda being the largest and deepest.

The net transport is believed to be westward at all times, from the Pacific to the Indian Ocean, with a maximum in August (estimated at 12-20 Sv) and a minimum in February (estimated at 2-5 Sv). It takes the form of a western boundary current that is strongest along Mindanao and and Kalimantan. The transport also occurs mainly in the upper layers with little transport below 500 m and about 75% above 150 m. Most of the high salinity input occurs across the sill between the Pacific and the Sulawesi Sea, while most of the low salinity output is through various narrow passages between the south Indonesian islands, with both input and output occurring over the entire water depth over the sills.

The freshening of the throughput occurs due to both high freshwater input from seasonal precipitation and to strong turbulent mixing that effects water mass conversion in the upper 1000 m of the water column, with the turbulence probably due to locally strong tidal currents. This mixing process imparts a unique character to the Australasian Mediterranean in that the salinity field in the upper 1000 m is nearly homogeneous while the temperature field is still stratified. This occurs because even though both temperature and salinity are strongly mixed the intense solar heating in the region serves to maintain the temperature stratification. See Tomczak and Godfrey [1994].

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[6] http://atoc.ucsd.edu/

[7] http://www.cis.rl.ac.uk/proj/ATSR/index.htm

authigenic One of three major components of deep sea sediments, the other two being detrital and biogenic. Authigenic minerals are those formed by spontaneous crystallization within the sediment or water column, and make up only a small fraction of the total sediment volume. The most important of this type of sediment is the iron-manganese oxide material formed by reduction of these metals deep in the sediment column. The resultant material migrates upwards and is deposited in the oxygenated upper layers of sediment. It can also be produced as a by-product of hydrothermal activity near ridge crests. See Broecker and Peng [1982].

Autonomous Ocean Sampling Network (AOSN) A network which uses man small, low–cost AUVs operating from a network of moorings to gather data in oceanographic field programs. A pilot system is currently under development led by the MIT Sea Grant program. See the AOSN Web site[8].

Autosub An autonomous underwater vehicle (AUV), i.e. a robotic vehicle designed to carry a varying scientific payload which is changed to suit each mission. See Collar and McPhail [1995].

`[http://www.soc.soton.ac.uk/PR/Autosub.html]`

autotrophic Self–nourishing organisms with the ability to synthesize organic molecules from CO_2 using either photosynthesis or chemosynthesis.

AUV Abbreviation for autonomomous underwater vehicle, a vehicle that can roam the ocean and collect data on its own. They can wait for episodic, short–lived events and change course immediately to concentrate on the most interesting areas during an experiment. The MIT/WHOI program built the first prototype AUV, called the Sea Squirt, in 1988 which was used to take various measurements in rivers, harbors, lakes and ponds. The second prototype, called the Odyssey I, was first launched from an oceanographic research vessel in early 1993 in the Antarctic. It was capable of operating at depths of 6000 m. The third prototype, the Odyssey II, was designed to operate at full ocean depths. It was designed to be mass produced and to be configurable in a number of ways depending on mission requirements. An on–board computer executes navigation and control programs, and an acoustic modem is used for two–way digital communication. The first full–scale test of the Odyssey II took place in February 1998 in midwinter in the Labrador Sea. The plan of the experiment was to have the AUVs gather data about bottom water formation for three months, recharging and dumping data at an underwater docking station at regular intervals. A mechanical problem limited the experiment to two weeks, although much useful data was gained for the improvement of future experiments.

`[http://auvlab.mit.edu/]`

available potential energy (APE) A quantity first derived in Lorenz [1955] in an investigation to discover what portion of total potential energy could be transformed into kinetic energy under the constraint of quasi–hydrostatic and adiabatic processes. Available potential energy (APE) was defined as the difference between a system's mass integrated total potential energy and the total potential energy of a hydrostatic reference state, i.e. the difference in potential energy between the actual physical state and the reference state, where the latter is defined as the state of minimum potential energy that can be reached through reversible adiabatic processes. In the reference state, all density surfaces are level. This was extended in Van Mieghem [1956] to deal with non–hydrostatic states. See Reid et al. [1981], Oort et al. [1989], Kucharski [1997] and Huang [1998].

AVHRR Abbreviation for Advanced Very High Resolution Radiometer, a five channel scanning radiometer with channels in the visible, visible near infrared, and infrared water vapor window. These were selected for production of quantitative sea surface temperature products and visible and IR imagery depicting clouds and thermal features, e.g. the Gulf Stream. The AVHRR produces 1 km resolution data.

[8] http://www.mit.edu:8001/research/seagrant/aosn.htm

AVP Abbreviation for Absolute Velocity Profiler, an instrument developed at the APL to measure velocity profiles in the ocean. This dropsonde references an electromagnetically inferred velocity profile to one measured near the sea floor. See Sanford et al. [1985].

AW Abbreviation for Atlantic Water.

AXBT Abbreviation for airborne expendable bathythermograph, an air–deployed, expendable, ocean temperature profiling probe. The AXBT consists of a temperature probe, 300–1000 meters of cable, a VHF transmitter and antenna, and a salt water activated battery. When the AXBT hits the ocean surface and stabilizes, the transmitter is activated and the temperature probe released. The surface transmitter telemeters the temperatures measured by the falling probe to a data gathering system on the aircraft that released it.

[http://aol11.wff.nasa.gov/axbt/]

AXCP Abbreviation for airborne expendable current profiler.

AXCTD Abbreviation for airborne expendable conductivity, temperature and depth profiler.

azoic zone Term used to describe the part of the deep sea thought lifeless in the mid-19th century. It was thought that the abyss was filled with a thick layer of 4° C (since sea water was thought to be densest at that temperature), motionless water which, combined with the tremendous pressures and absence of sunlight, virtually guaranteed an absence of life. The term was coined by the naturalist Edward Forbes in the 1840s who, after dredging for life forms in various regions, postulated eight bands or depth zones, each characterized by a particular assemblage of animals. These zones extended to a lower limit he set at about 300 fathoms below which the existence of life was highly unlikely. His results (and therefore perceptions) on this issue were skewed by an 1841 cruise in the eastern Mediterranean where he dredged for life forms at depths up to 230 fathoms in what is now known to be a relatively barren area. The contrast of this with the rich hauls he made in shallower waters around England led to his thinking the abyss devoid of life. See Schlee [1973].

Azores Current The northern branch of the subtropical gyre in the North Atlantic Ocean. This carries around 15 Sv of water along 35-40° N to the western part of the gyre, i.e. the Canary Current. From Alves et al. [2002]:

> To first order, the Azores Current (AzC) and its associated thermohaline front are in geostrophic balance. It separates fresher and colder waters of north and north-eastern origin from warm and saltier water masses at the south (mainly the 18C mode water). The AzC is the northern border of the subtropical gyre and acts as a continuous link to the south-eastern branch of Gulf Stream.
>
> The AzC feeds the Canary Current, that in turn connects with the westwards North Equatorial Current (or Cape Verde Current), which closes the gyre when it merges with the Gulf Stream. The AzC is a quasi-permanent feature throughout the year, centred between 33 and 35N, with a variable eastward transport, ranging from about 9 Sv in winter (1 Sv=106 m3/s), 12 Sv in summer, to about 19 Sv in spring.
>
> Many climatological studies suggest the AzC is a shallow baroclinic feature no deeper than 1000 m. Surface mean speeds reach 30–40 cm/s, decreasing to some 5 cm/s at about 700 m depth. Unstable wavelengths ranging from 200 up to 400 km or more may occur in the AzC system. Energetic time cycles between 20 and 120 days have been observed.

See Sy [1988], New et al. [2001] and Alves et al. [2002].

Azores Countercurrent (AzCC) A band of westward transport all across the North Atlantic at about the latitude of the Azores. The driving mechanism is an anomaly in the meridional change of the wind stress curl in the eastern North Atlantic. According to Alves et al. [2002]:

> [A]n Azores Counter Current (AzCC) is expected to form north of the AzC axis, as a result of a rectification process of the turbulent mesoscale features associated with the AzC jet. This appears as a westward–flowing mean stream transporting some 2–5 Sv. This is consistent with the meridional asymmetry observed across the AzC system, in which more turbulent features tend to spread and survive at the northern flank of AzC than to the south.

See Onken [1993] and Alves et al. [2002].

Azores Front See Rudnick and Luyten [1996].

Azores High A center of action centered near the Azores Islands (near 35° N and 25° W). It extends from near the western end of the Mediterranean Sea westward almost to Florida in the summer months, with the western section in summer sometimes referred to as the Bermuda High. See Angell and Korshover [1974].

Azov, Sea of A large gulf or lagoon, centered at about 46° N and 37° E, connected to the Black Sea by the narrow and shallow (around 5 m sill depth) Kerch Strait. The Sea of Azov covers around 38,000 sq. km which comprises 9% of the area of the Black Sea system but only 0.5% of the volume. See Zenkevitch [1963].

B

backing Said of the anti-clockwise change of direction of a wind, as opposed to veering.

backscattering cross–section The ratio of the acoustic power scattered at an angle of 180° from the incident acoustic wave to the acoustic intensity incident on a unit volume or area. This measure, typically referenced to a unit distance, e.g. 1 m, is the ratio of the reflected acoustic power to incident acoustic power per unit area. The units of this ratio are area, e.g. m^2.

backshore That part or zone of a beach profile that extends landward from the sloping foreshore to a point of either vegetation development or a change of physiography, e.g. a sea cliff or a dune field. See Komar [1976].

Baffin Bay A large sea located between the Canadian Archipelago and the Labrador Sea. It is about 1000 km and 400 km. Most of Baffin Bay is deeper than 1500 m, but deep water exchange with the Labrador Sea is restricted by a sill in Davis Strait with a depth of 670 m. A mobile ice cover forms during winter and moves southward under the prevailing winds. Icebergs calved from glaicers in southern and western Greenland drift across the bay and southward in the Baffin Current to southern latitudes. A significant oceanographic feature of Baffin Bay is the North Water, a partially open water area in the northern part where complete ice cover would be expected under prevailing climatological conditions.

The principal currents are a relatively warm northwards flowing current along the Greenland coast, and the cold southwards flowing Baffin Current. This cyclonic circulation is driven by surface inflows of low salinity Arctic water through the Canadian Archipelago in the north and by means of the West Greenland Current in the south. Current meter data from northern Baffin Bay show strong surface Arctic outflows to a depth of about 500 m, directed to the south and generally following the bathymetry. There is a strong annual cycle in the mean currents, with the currents stronger in summer and weaker in winter. This variability is probably driven by seasonal changes in buoyancy forcing, which enhances the coastal currents on the wide shelves. Tidal currents up to 0.4 m s^{-1} have been observed on the shelves and along the shelf slopes, and consist mainly of semidiurnal components, with a considerable diurnal component in some areas.

The surface layer, defined as the layer extending to the maximum depth influenced by wind stress, is a few tens of meters thick. The surface layer water has a density of 1026 kg/m^3 or less, with the deeper water weighing in at 1027 kg/m^3. Their salinities are 32.5 and 34.0, respectively. In the eastern part of the bay there is a layer between about 200 and 800 m characterized by relatively warm and saline water. This is considered the result of inflow of Atlantic water through the Davis Strait. Substantial tidal currents have been measured in the eastern part of the bay, e.g. up to about 20 cm/s at locations where the water depth is 500 m. See Ingram and Prinsenberg [1998].

[http://www.bmp.gl/E/EB3_petroleum/EB3_50ba_10na_baffin.html]

baguio The local name given to tropical cyclones in the Phillipines, especially those occurring from July to November.

balanced equations Approximations to the primitive equations that filter out the inertia–gravity waves but retain the geostrophic motions. Examples include:

- planetary geostrophic equations
- quasi–geostrophic equations
- semi–geostrophic equations

The primitive and planetary geostrophic equations can be seen as the limiting cases, with the former including all motions and the latter filtering a wide range of motions via its complete omission of inertia. The other equation sets are attempts to find a compromise between the former and latter. See McWilliams and Gent [1980], G. and Flierl [1981] (p. 508), Salmon [1985], Allen et al. [1990], Allen [1993], Allen and Newberger [1993], Muller [1995] and Mohebalhojeh and Dritschel [2001].

Balearic Channels The collective name give to the Ibiza Channel, the Mallorca Channel and the deep trough in the Gulf of Valencia, all features found within the Balearic Sea.

According to Pinot et al. [2002]:

> The Balearic Channels are important passages for the meridional exchange between the cooler, more saline waters of the northern basin and the warmer, fresher waters of the southern (Algerian) basin of the western Mediterranean. The Northern Current carries northern waters from the Gulf of Lions southward along the continental slope in the Balearic Sea. This current bifurcates as it reaches the northern end of the Ibiza Channel. The main branch proceeds southward and crosses the sill carrying cool and salty water into the Algerian Basin, while the minor one is retroflected cyclonically and returns to the north-east forming the Balearic Current that crosses the continental slope of the islands. This latter current is also fed by warmer, fresher southern waters from the Algerian Basin, which flow northward through both channels. This smooth pattern obtained from a climatological analysis was later found to be the average picture of a highly fluctuating circulation.

. See Pinot et al. [2002].

Balearic Sea One of the seas that comprise the western basin of the Mediterranean Sea which is sometimes called the Catalan Sea. It lies between the Iberian coast and the Balearic Islands (Ibiza, Mallorca, Menorca) in the northwestern Mediterranean. It is separated from the Tyrrhenian Sea to the east by Sardinia and Corsica and abuts the Alboran Sea to the west. The bathymetry is dominated by the Balearic Abyssal Plain, which covers over 30,000 square miles, covering the majority of the basin floor at depths ranging from 2700-2800 m. This is bordered to the northwest by the Rhone Fan, a large sedimentary cone.

The circulation can be seen to first order to be a single oblong cyclonic cell with a divergence zone aligned with the shape of the basin. More detailed studies have shown the surface circulation to be strong year–round and characterizied by two permanent density fronts. These are the Catalan Front on the continental shelf slope and the Balearic Front on the Balearic Islands shelf slope, with the former the more active. The northern area a plume of cold water frequently seen moving southward along the continental slope and shedding dipole eddies along its leading edge. Energetic filaments continuously spawned by the Catalan Front seem to be associated with this plume. See Fairbridge [1966], La Violette et al. [1990], Pinot and Ganachaud [1999] and Pinot et al. [2002].

Bali Sea A regional sea which is part of the Australasian Mediterranean Sea in the southwest Pacific Ocean. It is classified as a distinct sea for navigational purposes but is usually grouped with the Flores Sea for oceanographic purposes. It is centered at around 116° E and 8.5° S and is bordered by Bali and Sumbawa to the south and Madura to the west, and abuts the Java Sea to the north and the Flores Sea to the east. The Bali Sea covers an area of about 45,000 km^2 and has a greatest depth of 1590 m. It is mostly underlain by a small trough extending to the west of the Flores Trough and is bound by sills to the south (the 200 m Bali Strait and the 220 m Lombok Strait) and by a narrow, 600 m deep passage connecting it to the Makassar Stait to the north.

The circulation and water mass properties are continuous with the contiguous Flores and Java Seas to the east and north, repectively. Most of the oceanographic interest in the Bali Sea is concerned with its role in the Indonesian throughflow of Pacific Ocean waters into the Indian Ocean, with most if not all of this flow passing through the aforementioned Bali and Lombok Straits. See Fairbridge [1966].

BALTEX Acronym for the Baltic Sea Experiment, a GEWEX project to study coupled hydrological processes between complicated terrain, sea and ice and the atmospheric circulation to determine the energy and water budgets of the Baltic Sea and related river basins. The scientific objectives are:

- to explore and model the various mechanisms determining the space and time variability of energy and water budgets of the BALTEX area and its interactions with surrounding regions;
- to relate these mechanisms to the large–scale circulation systems in the atmosphere and oceans; and
- to develop transportable methodologies to contribute to research in other regions.

[http://w3.gkss.de/baltex/baltex_home.html]

Baltic Current See Kattegat.

Baltic Operational Oceanographic System (BOOS) A cooperative endeavor among national government agencies in the countries surrounding the Baltic Sea responsible for the collection of observations, model operations and production of forecasts, services and information for the marine industry, and public and other end users. BOOS is a regional Task Team under EuroGOOS.

BOOS will be implemented from 1999–2003 by the accomplishment of nine projects:

- optimizing the existing operational observing network;
- use of remote sensted radar and satellite data;
- an operational mesoscale analysis system called PRODAS;
- optimization of existing models and coupled models;
- ecological modeling;
- study of harmful algae blooms via HABWARN;
- development of an anthropogenic load model;
- an assessment of the current state of the Baltic environment; and
- development of Info–BOOS.

[http://www.boos.org/]

Baltic Sea A dilution basin type of mediterranean sea that is connected to and experiences limited, intermittent water exchange with the North Sea. It comprises several parts separately known as the Gulf of Bothnia, the Aland Sea, the Gulf of Finland, the Gulf of Riga, Kattegat and Skagerrak. It has a mean depth is about 57 m, an area of about 370,000 km^2, and a volume of about 20,000 km^3, and is one of the largest brackish water bodies in the world. About 17% of its area is shallower than 10 m. The Baltic Sea depression is essentially a long fjord in the north–south direction (1500 km) with an average width of 230 km. The topography divides it into a series of relatively deep basins, with maximum depths ranging from 105-459 m.

The Baltic has a positive freshwater balance with an annual river runoff of 440–480 km^3, or about 2.2% of the volume. The runoff is usually maximum in May and minimum in January or February. A permanent salinity stratification results in a transition layer at 65–75 m. The residence time is on the order of several decades. The difference between precipitation (640 mm) and evaporation (500 mm) adds another 60 km^3 per year.

The circulation in the Baltic Sea is mainly driven by three forces:

- wind stress;
- horizontal density differences due to freshwater inflow from rivers and saline water inflow via the Danish Straits; and
- sea level inclination from the Danish Straits towards the interior.

On average, sea level rises about 25 cm from the Danish Straits towards the Gulf of Bothnia due to the river runoff.

If not interrupted by wind–driven currents, a continuous inflow of saline water from the Skagerrak forms the deep water of the Baltic. It is estimated that 740 km^3 of saline water enters the Baltic per year. The inflow enters through the Great Belt (65%), the Sound (25%) and the Little Belt (10%). After passing through these, the saline water passes over the shallow Darss Sill (18 m), crosses the Arkona basin, flows through Bornholm Strait into the Bornholm Basin, and finally flows through Stolpe Channel into the Gotland Basin. The value of σ_t increases from less than 5.0 in the Gulf of Finland to more than 25.0 in the Skagerrak. See Segerstrale [1957], Zenkevitch [1963], Rodhe [1998] and Stigebrandt [1999].

Baltica A paleogeographic area during the late Precambrian and early Paleozoic that comprised northwestern Europe, including most of what are now the U.K., Scandinavia, European Russian and Central Europe. It formed the southeastern margin of the Iapetus Ocean and was moved by the subduction of that ocean (during the Caledonian orogenic event) such that it made contact with North America and Greenland during the Silurian and Early Devonian.

Banda Intermediate Water (BIW) See Rochford [1966].

Banda Sea A regional sea in the Australasian Archipelago covering approximately 470,000 square kilometers and centered at about 126° E and 5° S. It consists of several basins and troughs interconnected by sills whose depths are mostly greater than 3000 m. See Gordon et al. [1994] and Arief [1998].

bank The official IHO definition for this undersea feature name is “an elevation of the sea floor, over which the depth of water is relatively shallow, but sufficient for safe surface navigation.”

bar A unit of pressure equal to the pressure of 29.530 in. or 750.062 mm of mercury under the standard conditions of 0° C temperature and 9.80665 m/s^2 gravitational acceleration. Also, a popular locale during lengthty conferences.

barat The local name given to strong, northwesterly squalls on the north coast of the island of Celebes that occur most frequently from December to February.

Barents Sea One of the seas found on the Siberian shelf in the Arctic Mediterranean Sea. It is located between the White Sea to the west and the Kara Sea to the east and adjoins the Arctic Ocean proper to the north.

The Barents Sea is a key region for the modification of water masses in the Arctic, being one of several marginal seas in the Arctic wherein water flowing over shallow regions is transformed when heat loss and brine injection during the formation of sea ice increase density in the winter and sea ice meltwater and river runoff decrease surface water density in the summer. It differs from the other marginal seas in the region in that it has close connections with both the Norwegian Sea and the Arctic Ocean. See Zenkevitch [1963], Pfirman et al. [1994], Pfirman et al. [1995] and Harris et al. [1998].

baroclinic Descriptive of an an atmosphere or ocean in which surfaces of pressure and density intersect at some level or levels. The state of the real atmosphere and ocean, as opposed to barotropic. In a baroclinically stratified fluid total potential energy can be converted to kinetic energy. More later.

baroclinic flow In oceanography, the vertically varying circulation associated with horizontal imhomogeneities in the stratification of the oceans.

baroclinic instability To be completed.

baroclinicity vector A quantity that can be derived from the vorticity equation and expressed as:

$$\mathbf{B} = \frac{\nabla \rho \times \nabla p}{\rho^2} = -\nabla \left(\frac{1}{\rho}\right) \times \nabla p = -\nabla \times \left(\nabla \frac{p}{\rho}\right)$$

where ρ is the density and p the pressure. This indicates a tendency to generate vorticity whenever density surfaces are inclined to pressure surfaces. See Gill [1982].

baroclinic radius of deformation See Rossby radius of deformation.

barotropic Descriptive of a hypothetical atmosphere or ocean in which surfaces of pressure (isobaric surfaces) and density (isentropic surfaces) coincide at all levels, as compared to baroclinic. In a state of barotropic stratification, no potential energy is available for conversion to kinetic energy.

barotropic flow In oceanography, depth-independent circulation due to changes in surface elevation. More later.

barotropic instability To be completed.

barotropic radius of deformation See Rossby radius of deformation.

barrier reef One of three geomorophologically distinct types of coral reefs, the other two being fringing reefs and atolls. Barrier reefs are separated from land by a lagoon usually formed by coastal subsidence. See Barnes and Hughes [1988].

barrier layer In physical oceanography, the layer between the thermocline and the halocline. It is called this because of its effect on the mixed layer heat budget due to the temperature at the bottom of the barrier layer being zero, which excludes heat loss to the underlying water via mixing. It is defined as the difference between the thickness of the isothermal layer and the mixed layer (determined by a defined change in density), with the isothermal layer generally being greater than or equal to the mixed layer depth. In the Western Pacific, an area with a barrier layer, horizontal temperature gradients are also very small, leading to the conclusion that the net heat flux at the ocean surface must be close to zero. See Tomczak and Godfrey [1994].

BASFE Abbreviation for Baltic Sea Fluorescence Experiment, conducted between March 1 and 10, 1994 aboard the RV A.V. Humboldt as a collaborative project between the IRSA in Italy and the Institute for Baltic Sea Research–IOW in Germany. Water was collected along several transects and at anchor stations over the diel cycle from four or five depths using a rosette. A pulse amplitude modulated (PAM) fluorometer was used on sample concentrated by gentle filtration to measure phytoplankton photosynthesis.

`[http://me-www.jrc.it/other/data/balttext.html]`

basin The official IHO definition for this undersea feature name is "a depression, in the sea floor, more or less equidimensional in plan and of variable extent."

BASIS Acronym for Barents Sea Impact Study, a research project developed under the auspices of IASC for studying the impacts of global change in the Barents region, which includes the Barents Sea and the northernmost parts of Sweden, Finland, Norway and European Russia. The main emphasis is on the Barents Sea and fisheries, and on terrestrial ecosystems, forestry and reindeer herding.

[http://www.urova.fi/home/arktinen/basis.htm]
[http://basis.uni-muenster.de/]

BASIS Acronym for Baltic Air–Sea–Ice Study, a field experiment of BALTEX. The objective of BASIS is to create and analyze an experimental data set for optimization and verification of coupled atmosphere–ice–ocean models. The specific objectives are:

- investigation of water budget, momentum and thermal interaction at air–ice, air–sea and sea–ice boundaries;
- investigation of the atmospheric boundary layer (ABL);
- investigation of the ocean boundary layer (OBL); and
- validation of coupled atmosphere–ice–ocean models.

The intensive field phase of BASIS took place in the Gulf of Bothnia in the Baltic Sea in a boundary zone between the open sea and the ice–covered sea from February 16 to March 7, 1998. Ships used included the Swedish RV Argos and the Finnish RV Aranda.

[http://www2.fimr.fi/project/basis/index.htm]

BASS Acronym for Basic Air Sea Studies, a series of experiments carried out in Bass Strait, Australia during the period 1975–1985. The data sets gathered results in a clearer understanding of the relationships between wave state, wind stress, and surface layer turbulence. See Chambers and Antonia [1981].

BASYS Acronym for Baltic Sea System Studies, a project of the MAST and INCO program of the EU. The objectives of BASYS are to further the understanding of the susceptibility of the Baltic Sea to external forcing and to improve the quantification of past and present fluxes.

[http://www.io-warnemuende.de/Projects/Basys/]

Batchelor scale A length scale at which the steepening of scalar concentration gradients by the rate–of–strain is balanced by diffusive smoothing. It is defined as:

$$L_B = \left(\nu\kappa^2/\varepsilon\right)^{1/4}$$

where ν is the kinematic viscosity of seawater, κ is the molecular diffusivity, and ε is the rate at which turbulent kinetic energy is lost, i.e.

$$\varepsilon = 2\nu {e_{ij}}^2$$

where

$$e_{ij} = \frac{1}{2}(u_{ij} + u_{ji})$$

is the rate of strain tensor (with units of m^2s^{-3} or Wkg^{-1}). See McDougall et al. [1987].

bathyal zone The marine ecologic zone that lies deeper than the continental shelf but shallower than the deep ocean floor, i.e. those depths corresponding to the locations of the continental slope and rise. The depth range is from 100-300 m down to 1000-4000 m depending on such variables as the depth of the shelf break, the depth of light penetration, and local physical oceanographic conditions. See Fairbridge [1966].

bathymetry The measurement and charting of the spatial variation of the ocean depths. See Fairbridge [1966].

bathypelagic zone One of five vertical ecological zones into which the deep sea is sometimes divided. This is the zone starting from 100 to 700 m deep (coinciding with the upper limit of the psychrosphere) at the 10° C isotherm. The number of species and populations decreases greatly as one proceeds into the bathypelagic zone where there is no light source other than bioluminescence, temperature is uniformly low, and pressures are great. This overlies the abyssopelagic zone and is overlain by the mesopelagic zone. See Bruun [1957].

This is the lowest of the three vertical sections of the pelagic part of the ocean, the other two being the upper euphotic and the middle mesopelagic.

bathythermograph A device developed by Athelstan Spilhaus in 1938 to measure temperature/depth profiles in the ocean, the bathythermograph was basically a reworking of a mostly unworkable device called an oceanograph built in 1934 by Carl–Gustav Rossby for the same purpose. It consisted of an open, rectangular frame in which a compressible bellows with a pen arm and stylus was mounted at one end. The stylus rested on a smoked glass slide and moved across it to scratch a record of ocean temperatures. The stylus also moved vertically with changes in depth and thus created a temperature/depth profile.

The bathythermograph (or BT) was further improved by Maurice Ewing and Allyn Vine in 1940. Their version responded more quickly to temperature changes and was streamlined so it could be lowered and raised more quickly from a moving ship than could the previous more unwieldy version. In 1940 WHOI started doing military research for the government, a large part of which was concerned with sonar and the use of BTs with it. Knowledge of the vertical temperature structure of the ocean was extremely helpful to sonar operators since sound speed in sea water is a strong function of temperature, and various types of vertical temperature profiles would lead to sound traveling differently in the ocean. BT data was also useful for adjusting the buoyancy or trim of submarines since it could help provide an estimate of how much ballast would be needed to move a submarine from periscope depth to greater depths. A strong thermocline would require much more ballast for the submarine to descend.

The military research also led to further improvements in the BT including better aerodynamics for more stable operation at higher speeds as well as moving the glass slide and stylus from within the BT to inside the submarine. By early 1943 many submarines were outfitted with and used BTs. In an extremely helpful quid pro quo, the glass slides were given to WHOI and Scripps after missions in both oceans, allowing charts of the vertical temperature structure of the ocean to be constructed. Over 60,000 slides from the North Atlantic alone were thus made available to oceanographers. See Spilhaus [1938] and Schlee [1973].

BATS Acronym for Bermuda Atlantic Time-series Study, a JGOFS project to obtain and study long-term time-series of biogeochemical cycles in the Sargasso Sea near Bermuda. See Michaels and Knap [1996] and Steinberg et al. [2001].

More information can be found at the BATS Web site[9].

BAVAMEX Acronym for the Baltic Sea Vertical Mixing and Advection Experiment, a BALTEX program to investigate vertical mixing and advection in the major basins of the Baltic Sea.

`[http://w3.gkss.de/english/Baltex/campaign2.html]`

[9] http://www.bbsr.edu/bats/

Bay of Bengal The northeastern arm of the Indian Ocean, located between peninsular India and Burma. It covers about 2,200,000 sq. km and is bordered on the north by the Ganges and Brahmaputra River deltas, on the east by the Burmese peninsula and the Andaman and Nicobar Islands, on the west by India proper and Ceylon, and on the south by the Indian Ocean proper. The average depth is around 3000 m with maximum depths reaching over 400 m in the southern parts.

Major circulation features are the East Indian Current, a northward current flowing along the Indian shelf from January through October, and the East Indian Winter Jet, a southwestward flowing current that replaces during the remainder of the year. This current reversal is due to the seasonal change from the Northeast to the Southwest Monsoon and the concomitant wind forcing. General clockwise and conterclockwise circulation gyres are seen throughout the Bay accompanying, respectively, the Current and the Winter Jet, although the situation becomes a bit more complicated during the transition periods.

The monsoonal wind variations and the resulting circulations also serve to induce upwelling near the coasts during the spring (with the northward current) and the piling up of surface water along the coasts during the late fall and early winter (with the southward currents). Thus the isopycnals tilt upwards and downwards towards the shore during, respectively, the spring and late fall. The annual mean SST for the region is above 28.5° C., although upwelling can reduce this to 25-27° C during the spring. The salinities are kept lower than normal oceanic values (especially in the western parts) by extensive monsoonal river runoff. See Tomczak and Godfrey [1994], Fairbridge [1966] and Shetye et al. [1996].

Bay of Bengal Water A water mass that originates in the northern Bay of Bengal via monsoonal input from the Ganges and Brahmaputra Rivers. It is a low salinity water mass that spreads across the Bay in an approximately 100 m thick layer that produces a strong halocline beneath (above the overlying Indian Central Water) and keeps the surface salinity in the eastern parts of the Bay below 33.0 throughout the year. Although there are no variations in temperature through the BBW layer, there are salinity variations below 50 m (and therefore above the main halocline) due to the fact that weak wind mixing erases variations over only about half the depth of the layer. This causes the permanent existence of a barrier layer. The low salinity surface water to the west of India, sometimes called East Arabian Sea Water (EAW), is usually subsumed under the BBW rubric due to its nearly identical properties. See Tomczak and Godfrey [1994].

Bay of Biscay See Fairbridge [1966], pp. 637 and van Aken [2002].

Bay of Bothnia See Gulf of Bothnia.

Bay of Nice The Bay of Nice (5000 m long) is located in the north western Mediterranean basin, in the Côte d'Azur region, between 43°39' and 43°41'N and 7°12' and 7°18'E. The "Promenade des Anglais" hugs the coastline of the Bay. Its extension resulted in a general beach width reduction. Heavy swell arises mainly from east and south.

The Bay of Nice lacks a real continental shelf. There is a small shelf at the west side of the Bay in the Var prodelta area where the depth does not exceed 30 or 40 m. The Nice-Côte d'Azur airport, having undergone successive extensions from 1945 to 1985, covers 376 h of which two-thirds were obtained by filling the submerged Var prodelta area with Pliocene sediments. The extension obstructs the transport of sand and shingle from the Var embouchure to the East; it has also modified the previous near-shore current circulation. During the late 1960s and 1970s, the deficit of sand drifting to the east also resulted from the intensive extraction from the Var bed for the supply of building material. Today the Bay is fed almost entirely by the Paillon, a small river, 31 km long with a watershed of 236 km2. Its flow varies seasonally, usually between 1 and 40 m3/s, but it can exceptionally exceed 500 m3/s.

Since the Var sedimentary material no longer reaches the beaches of Nice, the Borough Council has adopted a coastal protection policy consisting of breakwaters in the western part of the Bay (in the late 1970s), and sediment replenishment on the beaches. The aim of these interventions is to broaden the beaches from 10 or 15 m to 20 or 25 m on average and stabilise them.' After Di Lauro et al. [2004].

BBL In oceanography, abbreviation for benthic (or bottom) boundary layer.

BBOP Abbreviation for Bermuda Bio-Optics Project.

BBTRE The Brazil Basin Tracer Release Experiment was a WHOI program in 1996 and 1997 who goal was to use two independent methods to quantify turbulent mixing in the eastern Brazil Basin. The methods employed were:

- injecting an SF6 tracer and tracking its dissipation over time; and
- making discrete, instantaneous estimates of the turbulence using the HRP instrument.

The experiment involved released approximately 110 kg of sulfur hexafluoride on an isopycnal near 4000 m depth near 21deg 40' S, 18deg 25' W. The location is over a system of ridge spurs and canyons that run zonally towards the crest of the Mid Atlantic Ridge. The spurs attain depths of nearly 4400 m in the vicinity of the tracer release and the canyon valleys about 5000 m, with both shoaling to the east towards the Ridge crest where individual bathymetric peaks extend to about 2000 m depth.

The tracer was surveyed in 1996 within two weeks of its release, with HRP measurements indicating weak turbulent dissipation at all depths (with a diapycnal diffusivity of about 0.1 $cm^2\ s^{-1}$) in the western half of the Brazil Basin where the bottom is smooth. Mixing rates were much greater over the rough topography, with measured diapycnal diffusivity values of about 0.5 $cm^2\ s^{-1}$ for the depth and region of the tracer cloud (and values greater than twice this near the bottom). A survey cruise in 1997 sampled the distribution of sulfur hexafluoride about 14 months after its release. The average diffusivity over the 14 months on the injection isopycnal was estimated to be at least 1.5 $cm^2\ s^{-1}$, with values of 10 $cm^2\ s^{-1}$ estimated near the bottom of the canyons. See Polzin et al. [1997] and Montgomery [1997].

[http://www.whoi.edu/science/AOPE/cofdl/tracerlab/bbtre.html]

beach berm The nearly horizontal portion of a beach formed by the deposition of sediment by receding waves. A beach may have more than one berm. See Komar [1976].

beach face The sloping section of a beach profile below the beach berm which is normally exposed to the action of the wave swash. See Komar [1976].

Beaufort Sea The marginal sea consisting of the waters off the northern coast of Alaska and Canada. This is bounded to the east by Banks Island of the Canadian Arctic Archipelago and on the west by the Chukchi Sea. The bathymetric characteristics include the narrowest continental shelf found anywhere in the Arctic Ocean. This shelf is dissected by three submarine valleys, the largest of which is 45 km wide, and drops off rapidly to the Beaufort Deep, whose maximum depth is 3940 m. Although it is geographically identified as a separate entity, the Beaufort Sea is oceanographically an integral part of the Arctic Ocean and as such can't be described in isolation.

Substantially different circulation regimes are found on the inner and outer shelf regions, with the demarcation line corresponding approximately to the 50 m isobath. The inner shelf is strongly wind driven in summer, with a westward water motion driven by the prevailing easterly winds. This circulation varies seasonally, responding rapidly to large changes (including even an occasional reversal in prevailiing wind direction), and is far less energetic in the winter (with wind effects persisting even under the fast ice close to the shore). The outer shelf circulation is energetic at subtidal frequencies throughout the year, with the dominant feature being the Beaufort Undercurrent, a bathymetrically steered mean eastward flow extending from around the 50 m isobath to at least the base of the continental slope. This relatively strong current apparently increases with depth (to around 10 cm s^{-1}) and is probably not locally driven but rather part of the large scale circulation in the Canadian Basin, although the portion of the Undercurrent overlying the shelf can be modified by local wind forcing. Frequent cross–shelf motions are found near the inshore edge of the Undercurrent, with daily means exceeding 5 cm s^{-1} and durations typically 3 days or more. These serve to transport materials between the inner and outer shelf regions.

The most prominent hydrographic feature on the shelf is a subsurface summer temperature maximum generally found seaward of around 40–50 m depth which disappears during the winter. This is associated with an eastward flow of water originating in the Bering Sea. The warm water enters via the eastern Bering Strait and follows the Alaskan coast around Point Barrow. It is composed of two water masses called Alaskan Coastal Water (ACW) and Bering Sea Water (BSW). The ACW has summer temperatures of 5°–10° C west of Barrow with salinities less than 31.5. It mixes rapidly with local surface water as it moves eastward and is not clearly identifiable east of around 147°–148° W. The BSW is more saline and has a density range from 25.5–26.0 σ_t, and can be traced as far east as Barter Island at 143° W. See Fairbridge [1966] and Aagaard [1984].

Beaufort Sea Mesoscale Project A NOAA ERL project undertaken to provide a quantitative understanding of the circulation over the Beaufort Sea Shelf and of its atmospheric and ocean forcing. Major emphasis was placed on providing extensive synoptic oceanographic and meteorological coverage of the Beaufort Sea during 1986–88. See Aagaard et al. [1989].

Beaufort Undercurrent See Beaufort Sea.

Beaufort wind scale More later.

BEDMAP A project to develop a new ice thickness and subglacial topographic model of the Antarctic region, including bathymetry to 60°S.

[http://www.antarctica.ac.uk/aedc/bedmap/]

BEL Abbreviation for Bottom Ekman Layer, the lowest of three layers into which the bottom 1000 m of the ocean are sometimes divided, with the other two being the BNL and the BML. The height of the turbulent BEL depends on the near–bottom current speed and varies in time. See Klein and Mittelstaedt [1992].

Belgian Antarctic Expedition A research expedition carried out in the Antarctic regions from 1897 to 1899 aboard the ship "Belgica." This was the first vessel to winter in the Antarctic regions. See Murray and Hjort [1912], p. 16.

Bellingshausen Abyssal Plain One of three plains that comprise the Pacific-Antarctic Basin (the others being the Amundsen and the Mornington Abyssal Plains. It is located at around 100-120° W.

Bellingshausen Sea A marginal sea located off Antarctica from approximately 70 to 100° W northwards to the Antarctic Circle. It is located between Thurston Island to the west and the Antarctic Peninsula to the east and was named for the Russian admiral Baron Fabian Gottlieb von Bellingshausen who led an expedition to Antarctic waters at the behest of Alexander I in 1819. He is considered the first to have actually discovered the continent of Antarctic, those preceding him not having seen it because of ice and low visibility. The geographic features include Ronne and Marguerite Bay as well as

Peter I, Charcot and Alexander I Islands. See Fairbridge [1966], Turner and Owens [1995] and Grotov et al. [1998].

Belt Sea More later.

BEMEX Acronym for Bering Sea Experiment, a US/USSR study of the Arctic ice cap.

BEMPEX Acronym for Barotropic Electromagnetic and Pressure Experiment, which took place in the North Pacific in 1986–87. See Luther et al. [1990].

BENGAL Acronym for BENthic biology and Geochemistry of a north-eastern Atlantic abyssal Locality. This is a high resolution temporal and spatial study whose objective is to understand how the properties of the abyssal boundary layer respond to and modify the incoming chemical signal from the surface layers and therefore affect the paleoceanographic record in the underlying sediment. BENGAL aims to quantify and characterize the incoming flux (with time–lapse sediment traps and midwater particle cameras), its resuspension (with transmissometers and current meters), and its ultimate deposition (with chemical analysis of core samples and time–lapse sea–bed photography). See Billett and Rice [2001].

[http://www.marine.ie/datacentre/projects/bengal/]

Bengal, Bay of See Bay of Bengal.

Benguela Current A current that flows northward along the west coast of southern Africa between about 15 and 35° S. This is the eastern limb of the subtropical gyre circulation system in the South Atlantic Ocean. See Fairbridge [1966], Peterson and Stramma [1991] and Garzoli and Gordon [1996].

Benguela Current Experiment See Garzoli et al. [1999].

[http://www.aoml.noaa.gov/phod/benguela/]

benthic Descriptive of organisms that are attached to or resting on bottom sediments, as opposed to pelagic.

benthos One of three major ecological groups into which marine organisms are divided, the other two being the nekton and the plankton. The benthos are organisms and communities found on or near the seabed. This includes those animals (zoobenthos) and plants (phytobenthos) living on (epifauna) or in (endofauna) marine substrata as well as those that swim in close proximity to the bottom without ever really leaving it. In terms of size, this is generally divided into three categories: meiobenthos, the organisms that pass through a 0.5 mm sieve; macrobenthos, those that are caught by grabs or dredges but retained on the 0.5 m sieve; and epibenthos, those organisms than live on rather than in the seabed. Those in the latter category are usually larger.

Benthic life is subject to vertical zonation depending chiefly on light, moisture and pressure. This has led to the division of benthonic animals into two systems and seven zones. Proceeding from shallow to deep water, the first system is the phytal or littoral system, composed of the supralittoral, mediolittoral, infralittoral and circalittoral zones. The second system, the aphytal or deep system, is composed of the bathyal, abyssal and hadal zones. See Fairbridge [1966].

Berghaus, Heinrich (1797–1884) See Peterson et al. [1996], p. 65.

Bering Sea A marginal sea located on the northern rim of the Pacific Ocean centered at approximately 58° N and 160° W. It is surrounded by Alaska to the east, Siberia to the west and northwest, and the Aleutian Island arc to the south. It has an area of about 2,300,000 km^2 and a volume of about 3,700,000 km^3. The bathymetry is about equally divided between a vast shelf to the northeast that is at most 200 m deep and the Aleutian Basin where depths range from 3800-3900 m over most of the region. The Shirshov Ridge (along 171° E between 500-1000 m depth) and the shallower Bowers Ridge (along 180° E then turning west along 55° N) effectively divide the Basin into three parts. It is connected to the Arctic Mediterranean Sea via the Bering Strait and to the Pacific via several sills between the various Aleutian Islands, although the main connection is thought to be between 168° E and 172° W where the sill depth is about 1590 m.

The main circulation features include a large part of the westward flowing Alaskan Stream entering the Bering Sea through the passage centered at 170° W, turning east, and driving a cyclonic (counterclockwise) gyre in the Aleutian Basin. This largely barotropic current sees the two main ridges as obstacles which sets up a system of two eddies, one on each side of the Shirshov Ridge. Eddies have been observed separating from the eastern limb (often called the Bering Slope Current) of the Bering Sea gyre, the larger of the two systems. There is a countercurrent further up the Bering Slope whose dynamics are those of an eastern boundary current in a subpolar gyre. A series of currents and related fronts largely driven by Alaska Stream inflow through a shallower passage at 175° W flow north-northwestward on the broad shelf region.

The main circulation feature of the northern Bering Sea is the Anadyr Current, a largely seasonally invariant current flowing northeastward and supplying most of the Bering Strait throughflow. This throughflow, driven by sea level differences across the strait, varies from about 0.1 m/s in the summer to 0.5 m/s in the winter, with flow through the Shpanberg Strait seasonally shifting from northward to southward to compensate for the differences. The shelf flows also make some mostly unknown contribution to this throughflow. The western limb of the smaller gyre to the west of the Shirshov Ridge contributes to and becomes part of the southwestward flowing Kamchatka Current.

The local water masses are derived from Pacific Ocean water masses transported in to the area and modified by processes on the shelf. This results in a temperature minimum at or below 100 m, low surface salinities rapidly rising to about 300 m, and overall low oxygen concentrations. The water overlying the temperature minimum is surface water imported from the Alaska Stream, and the water below that is Pacific Deep Water. See Zenkevitch [1963], Tomczak and Godfrey [1994], Fairbridge [1966], Coachman [1986], Cokelet and Stabeno [1997] and Schumacher and Stabeno [1998].

Bering Slope Current A current that flows from southeast to northwest along the northeast continental slope of the Aleutian Basin of the Bering Sea, parallel to the continental slope of the eastern Bering Sea shelf. According to Johnson et al. [2004]:

> Water property distributions, direct velocity measurements at the 1000-dbar float park pressure, and geostrophic transport estimates relative to near that park pressure all reveal robust signatures of the Bering Slope Current. The mean along-slope velocity estimates made at 1000 dbar from direct measurements within the current region yield an along-slope transport of 3.0 (+/-0.9) Sv when applied uniformly in the vertical to the upper 1900 dbar from the 1000-m isobath to 120 km offshore of that isobath. This value can be combined with the geostrophic transport estimates relative to 990 dbar, between the surface and 990 dbar and between 990 and 1900 dbar. The result is an absolute geostrophic estimate of the current transport, 5.8 (+/-1.7) Sv above 1900 dbar and offshore of the 1000-m isobath.

See Kinder et al. [1975] and Johnson et al. [2004].

Bering Strait A narrow ocean passage separating the North American and Asian continents. The transport of water through this passage, estimated at about 0.6 Sv of northward flowing low salinity water largely supplied by the Anadyr Current, contributes little to the global budgets of any ocean properties. Its principal role in large-scale circulation is apparently its contribution to the stratification of the Arctic Ocean. See Aagaard et al. [1985], Coachman and Aagaard [1988] and Cooper et al. [1997].

berm crest The seaward limit of a beach berm.

Bermuda Bio-Optics Project (BBOP) An ICESS project to explore the relationship between light and upper ocean geochemistry at the BATS site off the island of Bermuda. The goal is to evaluate the role that light plays in the cycling of carbon, nitrogen, silica, phosphorous and sulfur in the upper ocean and to assess the ability to study these processes using the SeaWiFS satellite sensors.

[http://www.crseo.ucsb.edu/bbop/bbop.html]

Bermuda High See Azores High.

Bermuda Testbed Mooring Program (BTM) A program run by the Ocean Physics Laboratory at ICESS. This mooring was deployed in June 1994 about 80 km southwest of Bermuda and has provided the oceanographic community with a deep–water platform for developing, testing, calibrating, and intercomparing instruments which can obtain long–term data sets.

[http://www.opl.ucsb.edu/btm.html]

Bernoulli function A function defined as:

$$B = gz + \alpha p + u^2$$

where g is gravitational acceleration, z is the vertical coordinate, α is something, p is the pressure and u is the horizontal velocity. The first two terms of this are called the Montgomery potential, and sometimes the Bernoulli function in the geostrophic approximation. The gradient of this drives the flow in models with z, isopycnal or sigma coordinates in the vertical. See Saunders [1995].

BERPAC A joint US/USSR Bering and Chukchi Seas research program whose goal is to examine the status of marine ecosystems of the Pacific Ocean, Bering Sea and Chukchi Sea, and to assess their role in determining global climate. The objectives of BERPAC consist of the study of the biogeochemical cycles of contaminants, related oceanographical processes, and food–web interactions in the North Pacific waters that flow through the Bering and Chukchi Seas, including the study of the behavior of organic pollutants at the water/sediiment interface since sediments are source of the secondary pollution of ecosystems. See Nagel [1992].

[http://pices.ios.bc.ca/wg/wg5/wg5_93.htm]

Beryllium–7 A radioactive nuclide with a half–life of 53.3 days produced by cosmic rays (i.e. electron capture decay to ^{7}Li) that can be used as a tracer of ventilation processes occurring on a seasonal timescale. It is deposited by rainfall on the ocean surface, and homogenized within the surface mixed layer, with a fraction found to penetrate into the upper thermocline. The extent of penetration before decay depends partly on the strength of vertical mixing and advective processes. The distribution below the mixed layer at any time depends largely on the depth history of the mixed layer, i.e. Beryllium–7 found in the thermocline can be remnant or previous mixed layers formed within several half–lives of the isotope (a seasonal timescale). Thus, if the depth history of the mixed layer is known, then the mixing and advection component affecting the Beryllium–7 distribution can be found. Conversely, given an understanding of these processes, it can be used to interpret mixed layer history on a seasonal timescale. See Kadko and Olson [1996].

BESIS Acronym for Bering Sea Impact Study.

BEST Acronym for Benguela Sources and Transport program, a field program from June 1992 to November 1993 consisting of moored instruments and three hydrographic surveys, designed to address questions about the Benguela Current:

- What is the transport, and what are the sources, of the Benguela Current and how do they vary with time?
- What is the dominant means of transfer of Agulhas water into the Atlantic?
- What is the interaction of the Agulhas eddy field with the large scale circulation?

The principal investigators were Arnold Gordon, Silvia Garzoli and Dale Pillsbury.

From WOCE Notes (Vol. 6, 1994, pp. 10–15):

> The BEST (Benguela Source and Transport) project was designed to investigate the form of the Benguela Current and ratio of the Agulhas Current and South Atlantic Current source waters masses. The transport of the Benguela Current and its variability is measured by a moored array of instruments as well as analysis of the TOPEX/POSEIDON satellite altimeter and CTD density field observations. The source of the water is determined by analysis of the water mass properties measured from CTD observations.
>
> To accomplish the BEST objectives, an extensive field program was carried out between June 1992 and November 1993. The field work consisted of three hydrographic surveys and a moored array of inverted echo sounders (IES), inverted echo sounders with pressure gauges (PIES) and current meter moorings (CMM). The BEST mooring array was deployed in June 1992 and, during October/November 1993, 4 PIES and 4 current meter moorings (CMM) along 30S, and 2 IES at the edges of the line Cape Town 37.5S, 12.3E were recovered.
>
> ...
>
> The BEST objectives contribute to the WOCE international plan. The 30S array will provide the transport information of the WOCE ACM-4 mooring , as called for in the WOCE science plan, 1988. Paired with ACM-3 in the Brazil Current (part of the German WOCE program) the BEST 30S mooring array will aid in accomplishing the WOCE South Atlantic heat flux line objectives. The IES deployed off Cape Town will help to relate the Algulhas Retroflection characteristics to the transport across 30S. The main hydrographic work in the Agulhas Retroflection region and in the intervening region will define the water mass characteristics of the Benguela Current and assess the relative contributions of South Atlantic and Indian Ocean water to the Benguela Current.

[http://www.ldeo.columbia.edu/physocean/proj_Best.html]

beta plane approximation In oceanography, a simplified coordinate system for the equations of motion where the variation of the Coriolis parameter f with latitude is approximated by

$$f = f_0 + \beta y$$

where f_0 is the value of f at the mid-latitude of the region and β the latitudinal gradient of f at that same latitude. This is used to investigate both equatorial and mid-latitude phenomena (for which there are slightly different beta plane approximations) where f varies significantly over a few tens of degrees latitude. The beta plane approximation allows considerable simplification of the governing equations and therefore the use of analytical investigation methods. See Gill [1982].

The beta plane equations are obtained by introducing a background stratification into the shallow water equations, expanding them around a reference latitude θ_0 with respect to $\varepsilon \sim \theta - \theta_0$, and keeping terms up to first order in ε. This approximation introduces the horizonal coordinates

$$\begin{aligned} x &= r_0 \cos\theta_0(\phi - \phi_0) \\ y &= r_0(\theta - \theta_0) \end{aligned}$$

and expands the Coriolis parameter as

$$f = f_0 + \beta_0 y + \cdots$$

where β_0 is the beta paramter at the reference latitude. The resulting equations (after Muller [1995]) are:

$$\begin{aligned}
\frac{\partial u}{\partial t} &+ u\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} \\
&- \frac{uv}{r_0}\tan\theta_0 - f_0 v - \beta_0 y v \\
&= -\frac{1}{\rho_*}\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial \delta p}{\partial x} \\
\frac{\partial v}{\partial t} &+ u\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} \\
&+ \frac{u^2}{r_0}\tan\theta_0 + f_0 u + \beta_0 y u = -\frac{1}{\rho_*}\frac{\partial \delta p}{\partial y} \\
0 &= g\delta\rho + \frac{\partial \delta p}{\partial z} \\
\frac{\partial w}{\partial z} &= -\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} + \frac{v}{\rho_0}\tan\theta_0 \\
\left[\frac{\partial}{\partial t}\right. &+ \left. u\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial t}\right]\delta\rho = wN^2\frac{g}{\rho_*}
\end{aligned} \tag{1}$$

where (u, v, w) are the velocity components in the (x, y, z) directions, r_0 is the mean radius of the Earth, θ_0 is the reference latitude, $f_0 = 2\Omega\sin\theta_0$ is the Coriolis parameter at the reference latitude,

$$\beta_0 = \frac{1}{r_0}\frac{\partial f}{\partial \theta} = \frac{2\Omega}{r_0}\cos\theta_0$$

is the beta parameter at the reference latitude, ρ_* is a constant reference density, δp and $\delta\rho$ are motionally induced deviations from prescribed background fields, and N is the buoyancy frequency.

beta plane equations See beta plane approximation.

beta refraction An effect that results from the latitudinal variation of Rossby wave phase speed which is, in turn, due to the beta effect. If a line of Rossby waves were started along a straight eastern ocean boundary, then those at low latitudes would arrive at the western boundary before those at high latitudes.

beta spiral method An inverse method for determining the oceanic velocity field where the motion is geostrophic and the potential vorticity locally balanced. This method provides a mechanism for determining the absolute geostrophic circulation field rather than just the relative field. More later. See Schott and Stommel [1978].

bias The amount by which the average of a set of values departs from a reference value. In statistics and signal processing, it is usually felicitous to remove this before proceeding to further and more complicated data manipulations.

bias correction A method of flux correction that guarantees no long-term climate drift and reduces the other problems of flux correction. Fluxes are modified at the ocean-atmosphere interface but the correction is carried out on mean annual rather than monthly mean values, thus resulting in smaller and spatially smoother corrections. An interactive computation is also applied to reduce consistencies in the bias correction. This method was developed by J. Oberhuber at the DKRZ.

bibliography The Scripps library contains a Cumulative Biography on the History of Oceanography, a Bibliography of Ocean Scientists, and a Handlist of Source Books on the History of Oceanography. All are available at the given URL.

[http://scilib.ucsd.edu/sio/archives/histoceanogr/]

Bigelow, Henry Bryant (1879-1967) A Harvard–trained zoologist who first went to see on an expedition to the Maldive Islands with Alexander Agassiz in 1901. He later participated in the Eastern Tropical Pacific Expedition also organized by Agassiz. He first led an expedition in 1908 when he took to Grampus to Gulf Stream waters to collect various faunal samples. After four years of writing and publishing the results from these expeditions, the desk-bound Bigelow embarked on a groundbreaking series of research cruises in the Gulf of Maine in 1912. He spent the next 15 years, interrupted briefly by service as a navigation officer on an army transport, doing repeated studies of the Gulf of Maine in the manner pioneered by the ICES in Europe twenty years before. He studied the fish, plankton and hydrography of the Gulf, repeatedly taking many measurements over the years including temperatures, water samples, water color and transparency, currents (using an Ekman current meter), salinity (using the ICES method of titration and their Standard Water), quantitative and regular plankton hauls, and dredging and trawling. In later years he would release drift bottles to deduce the overall Lagrangian circulation pattern in the Gulf.

Bigelow was an American pioneer in that he was the first to apply the ICES methods of repeated measurements over many years to American waters. The results of the Gulf of Maine studies were published in separate monographs for the fish (1915), plankton (1926), and physical oceanography (Bigelow [1927]). Bigelow also published an autobiography (Bigelow [1964]) and an economic overview of oceanography (Bigelow [1931]. See Graham [1968].

bioacoustical oceanography The application of underwater acoustics to investigations of biological patterns and processes in the sea. This has been traditionally divided into two distinct groups of investigators, those who study the sounds produced by marine organisms, and those who produce sounds and listen to the returning echoes to study the distributions of marine organisms. See Greene et al. [1998].

BIODAFF Acronym for Biodiversity and Fluxes in Glacial Arctic Fjords, a project to study the effects of seasonal fluctuations in salinity, turbidity and sedimentation rates in the glacial fjords on Svalvard on how the diversity of ice flora and fauna is structured by stress gradients and the physical ice habitat. Also studied will be the zonation of macrobenthic organisms on hard bottom substrates and how this zonation changes longitudinally in the fjord against the general stress gradients. The work will involve several diving transects from inner to outer fjord. This project is being performed by the Norwegian Polar Institute under the leadership of Haakon Hop during 1996.

biogenic One of three major components of deep sea sediments, the other two being authigenic and detrital. Biogenic sediment consists mainly of calcite and opal produced as the hard parts of organisms and eventually precipitated. Calcite is formed by coccoliths (plants) and foraminifera (animals) and opal by diatoms (plants) and radiolarians (animals). See Broecker and Peng [1982].

biogeochemical province See also oceanic province. See Longhurst [1995], Longhurst et al. [1995] and Hooker et al. [2000].

BIOGEST Acronym for Biogas Transfer in Estuaries, a research project funded by the European Union whose aim is to understand the distribution of biogases in the surface water of European estuaries and to quantify related atmospheric exchanges.

[http://www.ulg.ac.be/oceanbio/biogest/biogest.htm]

biological oceanography The study of life in the oceans and how the physical and chemical properties of the ocean are influenced by marine life. The basic goal is to examine the distribution, abundance, and production of marine species and to obtain a basic understanding of the processes controlling them. Compare to chemical, geological and physical oceanography. See Mann and Lazier [1996], Parsons et al. [1984], Barnes and Mann [1980], Day et al. [1989], Falkowski [1980], Falkowski and Woodhead [1992], Mann [1982], Morris [1980], Valiella [1984] and Mills [1989].

biological pump The transformation, via photosynthesis in the ocean surface layer by plant cells (primarily phytoplankton), of dissolved inorganic carbon (DIC) into biogenic carbon, including, for example, the $CaCO_3$ in shells of coccolithophorids. The photosynthetic organisms incorporating the inorganic carbon return much of it to CO_2 in the surface layer via respiration, but a significant fraction settles below the main thermocline. This is an oceanic sink for atmospheric CO_2 where a rain of small debris consisting of phytoplankton shells and zooplankton fecal pellets and molts sink out of the ocean surface waters. These sinking particles remove POC from surface mixed layers into stratified, relatively deep layers where, on a millenial time scale, it is no longer susceptible to exchange with the atmosphere. Particulate matter removed in this manner is called export flux.

It is estimated that 75% of the difference in DIC concentration between the surface and deep oceans is due to the biological pump. If this pump were eliminated, the carbon released from the deep ocean as it equilibrated with the atmosphere would more than double the CO2 concentration in the atmosphere. On a global scale, the downward transport of CO_2 by the physical (i.e. vertical transport of CO_2–laden water) and biological pumps amounts to around 102 Gt C yr^{-1}. The upward physical transport is about 100 Gt C yr^{-1}, leaving a net uptake of about 2 Gt C yr^{-1}. See Rowe and Baldauf [1995] and Chisolm [1995].

BIOMASS Acronym for Biological Investigations of Marine Antarctic Systems and Stocks, a program whose principle objective was to gain a deeper understanding of the structure and dynamic functioning of the Antarctic marine ecosystem as a basis for the future management of potential living resources. BIOMASS has two major field campaigns, the First (FIBEX) and Second (SIBEX) International BIOMASS Experiments.

The goal of FIBEX was to determine how much krill is in the Antarctic. It was composed of 16 research cruises carried out between November 1980 and April 1981, and produced a synoptic picture of the distribution of krill over a large area of the southern ocean. The goal of SIBEX was to improve the understanding of the dynamics of the krill–dominated part of the Antarctic marine ecosystem. It involved two field seasons, SIBEX–1 (8 cruises, Oct. 1983 to Apr. 1984) and SIBEX–2 (10 cruises, Nov. 1984 to Apr. 1985), and produced a temporal sequence of observations focused mainly on the Bransfield Strait and Prydz Bay regions.

[http://ioc.unesco.org/iochtm/w107/w107www3.htm]

Biot number A dimensionless number or parameter expressing a ratio of thermal internal resistance to surface film resistance. It is generally used in heat transfer calculations such as unsteady state flow. It is defined as:

$$B_i = \frac{h_T \Delta x}{k}$$

where h_T is a heat transfer coefficient, k the thermal conductivity, and Δx a mid–plane distance.

Biowatt A program to study bioluminescence and optical variability in the sea. See Marra and Hartwig [1984].

bioturbation The stirring of sediment by animal life.

Bismarck Sea A regional sea located in the northwest corner of the South Pacific Ocean. The Bismarck Sea is bounded to the southwest by New Guinea and to the north, east, and south by the Bismarck Archipelago. Its area and volume are about 40,000 km^2 and 60,000 km^3, respectively.

BITS Acronym for Biophysical Interdisciplinary Tropic Studies buoy, an instrumented and unmanned mooring designed to acoustically measure the size and abundance of marine life populations, collect the supporting data that characterizes the marine environment, and automatically transmit the data to shore stations for analysis. The BITS system was developed by Tracor and the University of Southern California. It employs a bi–frequency acoustic projector which operates at 165 kHz and 1.1 MHz, with backscattered acoustic signals received by the sensors transmitted via VHF packet telemetry to shore stations.

[http://www.aard.tracor.com/home/eco/MarEco.html]

BIW Abbreviation for Banda Intermediate Water.

Bjerknes, Jacob (1897-1975) One of the founders of modern meteorology, Bjerknes entered and revolutionized the field at the age of 20 with his discovery of the structure of extratropical cyclones. His father was the physicist and geophysicist Vilhelm Bjerknes.

[http://www.nap.edu/readingroom/books/biomems/jbjerknes.html]

Bjerknes, Vilhelm More later.

Bjerknes hypothesis The hypothesis that ENSO varies as a self-sustained cycle in which anomalies of SST in the Pacific cause the trade winds to strengthen or slacken, and that this in turn drives the changes in ocean circulation that produce anomalous SST. First advanced by Bjerknes [1969].

Bjerknes' theorem A generalization of Stokes' theorem that enables the calculation of the circulation on a rotating Earth. See Turner [1973], Hide [1978], and Dutton [1986].

Black Sea A mediterranean sea, centered at approximately 35° E and 44° N, that is the world's largest inland water basin. It has an area of about 461,000 km^2 and a volume of 537,000 km^3 with a mean depth of around 1200–1300 m, although depths greater than 2000 m are common in the central basin. The western part of the Black Sea is a wide shelf that gradually narrows to the south and breaks at around 100-150 m. In the rest of the basin the shelf doesn't exceed 10-15 km in width. It is connected to the Marmara Sea via the narrow (760 m wide) and shallow (27.5 m maximum depth) Bosporus Strait, and further connects to the Mediterranean Sea via the long and narrow Dardanelles. It is also connected to the Sea of Azov to the north.

The Black Sea is a dilution basin due to a large freshwater input from the Danube, Dniester, Dnieper, Severskiy Donets and Don rivers (350 km^3/yr). The flow through the Bosporus comprises a surface flow of low salinity water towards the Mediterranean (260 km^3/yr) and an underlying return flow of salty Mediterranean water (120 km^3/yr). Precipitation (140 km^3/yr) and evaporation (350 km^3/yr) close the freshwater budget. The volume averaged salinity is 22, with surface salinities in the central part ranging from 16-18 and increasing to 21-22.5 at depths greater than 150-200 m. The surface temperatures range from 25° C in the summer to 6-8° C in the open sea, with the northwestern part and the Sea of Azov covered with ice during the winter. The deep water is 8-9° C year round. The upper 50 m are saturated with oxygen, the content of which diminishes until, at a depth of 150-200 m, hydrogen sulfide appears and renders the lower regions uninhabitable.

The most remarkable circulation feature is the cyclonicically meandering Rim Current, the interior of which is formed either by one elongated cell covering the entire basin or by two separate cyclonic cells occupying the western and eastern halves of the basin. The interior of the Western and Eastern Gyres contains a number of recurring cyclonic mesocale eddies. These are in contact with each other by a recurrent anticyclonic eddy called the Central Basin Eddy, a recurrent feature observed to form via the merging of two anticyclonic eddies pinched off from the baroclinically unstable Rim Current southeast of Crimea and off Cape Sinop.

The upper layer flow field also consists of several mesoscale eddies distributed along the periphery of the basin. The two most pronounced and persistent of such are the anticylonic Batumi Eddy in the southeastern corner of the basin and the anticyclonic Sevastapol Eddy in the continental shelf topography of the Danube Fan, west of the Crimean Peninsula. The latter has also been reported in the literature as the Trabzon Eddy. Two other quasi–permanent anticyclonic eddies are found along the Anatolian (Turkish) coastal belt. They are situated off the Sakarya and Kizilirmak Rivers and given their names. Another quasi–permanent anticyclonic feature is the Bosphorous Eddy located northwest of the Bosphorous–Black Sea junction. Two other recurrent coastal anticyclonic eddies have been identified between Sakarya Canyon and Cape Sinop. Along the northern coast, the anticyclonic Crimean and Causasian Eddies are the most pronounced mesoscale features, with the Kali–Akra Eddy a recurrent feature to the north of the Bosphorous Eddy.

The intermediate depth circulation is characterized by the disappearance of the Rim Current, the shifting of eddy centers, coalescence of eddies, persistence of some features for the whole water column but changes with depth in the structure of others, and more organized and large sub–basin features. See Caspers [1957], Zenkevitch [1963], Fairbridge [1966], Stanev [1990], Murray [1991a], Oguz et al. [1993], Özsöy and Ünlüata [1997] and Özsoy and Ünlüata [1998].

Black Sea Oceanography Expedition

See Murray [1991b] and other papers therein.

Black Sea Water (BSW)

A water mass formed in the Black Sea that flows into the Aegean Sea through the Strait of Bosporus, the Marmara Sea and the Strait of Dardanelles. The flux into the Aegean varies from 180–200 km^3 yr^{-1} to a maximum of 700 km^3 yr^{-1} between April and October. BSW is of primary importance to processes in the Aegean, but plays a secondary role in the overall water balance of the Mediterranean.

BSW is recognized by a surface salinity minimum, with the salinity off the mouth of the Strait of Dardanelles varying from 24 to 26 psu during the warm months and from 30–35 psu during the cold months. A pronounced halocline develops in the North Aegean, with the maximum depth ranging from 20–80 m. As it travels westward and southward, BSW is modified following the general cyclonic circulation of the Aegean. During the winter, it spreads westwards and then northwards, entering the Samothraki Plateau. It flows westwards over the plateau and then southwards along the eastern coast of the mainland to Evvia Island. If the thermohaline front in the Andros Strait is well developed, the BSW flows eastwards along the northern boundaries of the Kyklades Plateau, following the general cyclonic circulation. If the thermohaline front disappears, the BSW bifurcates, with one branch moving eastwards along the northern boundary of the Kyklades Plateau and the other southwards into the Saronikos Gulf, causing the winter salinity minima seen there. During the summer, the general cyclonic circulation pattern still prevails, with the Etesian winds causing the BSW to flow southwestwards to Evvia Island and then southwards. The low salinity waters flow through Andros Strait and create the second salinity minimum observed in the South Evvoikos and Saronikos Gulfs. It has been detected (by the surface salinity minimum) as far south as the Kithira Straits. See Stergiou et al. [1997].

Black Stream See Kuroshio Current.

BLIPS Acronym for Benthic Layer Interactive Profiling System. See Adam Jr. et al. [1990].

blocking

BML Abbreviation for Bottom Mixed Layer, the middle of three layers into which the bottom 1000 m of the ocean are sometimes divided, with the other two being the BNL and the BEL. The thickness of the BML typically ranges from 20–80 m, although values between 10–150 m have been observed. The particle concentration within the BML is usually homogeneously mixed, although occasional episodes of local resuspension by strong bottom flows can change this. See Klein and Mittelstaedt [1992].

BNL Abbreviation for Benthic Nepheloid Layer, the thickest and upper of three layers into which the bottom 1000 m of the ocean are sometimes divided, with the other two being the BML and BEL. The BNL is characterized by an increasing concentration of suspended material towards the bottom, and it extends from the clear water minimum (CWM) (at around 1000 meters above the bottom) down to the deep–sea bottom. See Klein and Mittelstaedt [1992].

BOFS Abbreviation for Biogeochemical Ocean Flux Study, a U.K. contribution to JGOFS funded by the NERC. The goal of GOFS was to study differences in glacial-interglacial paleoenvironments of the eastern Atlantic Ocean, especially between the last glacial and the Holocene. The results are presented in a special issue of Paleoceanography (Vol. 10, No. 3, 1995). See especially the short review by Elderfield and Thomas [1995].

[http://www.bodc.ac.uk/projects/bofs.html]

Bohai Gulf See Bohai Sea

Bohai Sea See Guan [1994] and Lin et al. [2001].

Bohnecke mechanical recording current meter A mechanical current meter, first designed and used in the 1930s, in which the propellor and the compass both drive a set of horizontal dials with raised numbers on their vertical rims. A clockwork mechanism moves a strip of tin foil past the vertical rims of the dials and a hammer presses the the foil against the raised numbers on the rims every 5 or 10 minutes. The speed and direction can be obtained from the information on the foil. Wide use of this mechanism was forestalled by the difficulty in finding a material for the spring in the clockwork that could withstand the corrosive exposure to sea water. See Sverdrup et al. [1942].

Bohol Sea A small sea centered in the Philippines at about 124° E and 9° S. It is surrounded by the islands of Mindanao to the southeast and Negros, Bohol and Leyte to the northwest. It is connected to the Sulu Sea to the west via a passage between Negros and Mindanao, the Visayan Sea to the north via the Tanon Strait, the Camotes Sea to the north via the Bohol Strait and a passage between Bohol and Leyte, and to the Leyte Gulf to the northeast via the Surigao Strait. Prominent geographic features include the islands of Siquijor and Camiguin and Sogod (in Leyte), Gingoog, Macajalar and Iligan (in Mindanao) Bays. This has also been called the Mindanao Sea.

boiling water phenomena The name given to the intense surface signature of intense internal waves in the Strait of Gibraltar. According to Bruno et al. [2002]:

> Those surface signatures in the Gibraltar Strait are known by the local Spanish fishermen and sailors as "hervideros" (boiling waters) and "hileros de corriente" (streamers), in reference to the visible behaviour of the surface waters. They were reported in the literature, for the first time, in the Spanish Navy Sailing Directions by Tofiño (1832), being mentioned and documented as well in the English Sailing Directory by Purdy (1840) and later editions of the Spanish Sailing Directions. A free translation of part of their description is as follows: "They appear instantaneously without previous signs. Suddenly a roughness in the sea surface appears as when the water is boiling, and a surfing chaotic sea is established. If wind and wind-induced forces are considered, the streamers are dangerous not only for smaller ships but for bigger ships also. Sometimes the vessel acquires a vortex motion without steerage".

See Bruno et al. [2002].

Boltzman equation The Navier-Stokes equations can be derived from the Boltzmann equation by considering appropriate limits, i.e. Knudsen and Mach numbers tending to zero, and appropriate averaging procedures to define new coarse-grained variables (velocity and pressure) and associated transport coefficients (viscosity and density). See Farge et al. [1996].

bolus velocity See eddy-induced transport velocity.

BOMEX Acronym for Barbados Oceanography Meteorology EXperiment, a joint experiment between NOAA and the Government of Barbados conducted over the tropical Atlantic east of Barbados in the summer of 1969. See Holland [1970], Pond et al. [1971] and Geernaert [1990].

[http://rainbow.ldeo.columbia.edu/data/NASAentries/nasa611.html]

BOOS Acronym for Baltic Operational Oceanographic System.

BOP Abbreviation for Bayesian oscillation patterns, patterns found using BSA. See Ruiz de Elvira and Bevia [1994].

BOPS Acronym for Bio-Optical Profiling System, an instrument for measuring optical and physical parameters in the water column.

borderland The official IHO definition for this undersea feature name is "a region adjacent to a continent, normally occupied by or bordering a shelf and sometimes emerging as islands, that is irregular or blocky in plan or profile, with depths well in excess of those typical of a shelf."

Boreal period A post-LGM European climate regime. This refers to the period from about 7000-6000 BC when temperatures continued to rise, e.g. the colder seasons of the year gradually became milder (although probably with some dry and frosty winters) and the summers became generally warmer than today. It was preceded by the Pre-Boreal period and followed by the Atlantic period. See Lamb [1985], p. 372.

Bosphorus Straits The significance of these straits is summarized by Peneva et al. [2001]:

> The transport through the Bosphorus Straits is one of the major factors controlling the stratification in the Black Sea, the latter impacting a number of important processes, such as the ventilation of deep layers, intermediate water formation, synoptic variability. Mass balance estimates yield an average upper layer outflow of 600 km3 year-1 and a lower layer

> inflow of 300 km3 year-1, which gives 300 km3 year-1 for the vertically integrated transport through the strait. Long-term estimates of the components of fresh water balance (river runoff, precipitation and evaporation) in the 20th century show that the amplitude of extreme oscillations could exceed the long-term mean values. However, the temporal variability is largely unknown, particularly the low-frequency range.

The authors investigate the long-term variability using tide gauge and hydo-meteorological data over 1923-1997, and obtain the variability of basin volume and transport in the straits.

> It is found that the main signal in the transport is the seasonal one, with maximum values in March-April and minimum in August. The amplitude of this signal is $\sim 2/3$ of the amplitude of the net fresh water flux. In low frequency range, oscillations with periods 10 and 4 years have significant amplitudes. However, the ratio between the magnitude of oscillations in the forcing (fresh water flux) and the response (transport in the strait) tends to unity. This indicates that the resistance of strait to climatic variability with interannual and decadal time scales is negligible.

See Peneva et al. [2001].

Bothnian Sea See Gulf of Bothnia.

bottom boundary layer models Killworth and Edwards [1999] review the use of these in numerical ocean models and present another model.

Bottom Cold Water (BCW) See Isobe [1995].

Bourne, William (?1535–1582) A British innkeeper who wrote what some consider to be the first popularization of the extent ideas constituting that which we now consider to be the field of oceanography. In this book, entitled A booke called the Treasure for Traveilers, deuided into fiue Bookes and published in 1578, he invoked the primum mobilus concept as the driving force beyond the movement of the moon, but also ascribed to the moon itself some unknown power responsible for the observed tides and steady currents (whose complexity beyond the steady westward flow of the primum mobilus he also deemed partially due to the distrupting presence of land masses).

Bourne's picture of the flow in the Atlantic started with the general westward flow around the southern tip of Africa merging with that in the Atlantic, with the combined volume being too great to squeeze through the Straits of Magellan. Thus part of the flow was diverted northwards along the South American coast, into the Gulf of Mexico, and then out between Florida and Cuba and eastwards towards Europe. He also proposed a second type of steady, non–tidal current that flows against the wind during periods of strong winds, with the driving force being a hypothesized upward tilt of the sea surface downwind caused by waves piling up water there. See Peterson et al. [1996].

Boussinesq approximation A set of filtering approximations originally developed by Boussinesq. According to Sander [1998]:

> In his attempts to explain the motion of the light in the aether Boussinesq (in 1903) opened a wide perspective of mechanics and thermodynamics. With a theory of heat convection in fluids and of propagation of heat in deforming or vibrating solids he showed that density fluctuations are of minor importance in the conservation of mass. The motion of a fluid initiated by heat results mostly in an excess of buoyancy and is not due to internal waves excited by density variations. In other words, the continuity equation may be reduced to the vanishing of the divergence of the velocity field, and variations of the density can be

> neglected in the inertial accelerations but not in the buoyancy term. Although used before him, Boussinesq's theoretical approach established a cardinal simplification for a special class of fluids which fundamentally differ from gases and may eliminate acoustic effects.

They result in an equation set applied to almost all oceanic motions except sound waves. The four approximation steps are:

- subtracting a motionless hydrostatically balanced reference state from the equations of motion;
- making the anelastic approximation;
- assuming that the vertical scale of motion is small compared to the scale depth (or height); and
- ignoring the inertial but not the buoyancy effects of variations in the mean density.

The term "Boussinesq approximation" is not always used identically with the above series of approximation steps, e.g. it may or may not include the assumption of incompressibility.

Mahrt [1986] addresses the issue of which assumptions properly constitute the Boussinesq approximations:

> The derivation of conditions for the validity of the Boussinesq approximations is not as straightforward as many would assume. In the literature, a variety of sets of conditions have been assumed which, if satisfied, allow application of the Boussinesq approximations. The Boussinesq approximation can be divided into two parts. The first group of assumptions allows use of incompressible mass continuity and linearization of the ideal gas law, which are referred to as the shallow motion approximations. Additional restrictions allow neglect of the pressure influence on buoyancy. This more restrictive subclass of shallow motions is equivalent to the full Boussinesq approximations, also referred to as the shallow convection approximations.
>
> The different derivations of the shallow motion approximations share the following conditions:
>
> - the perturbations of variables of state must be small compared to basic state averaged values;
> - the motion must be shallow compared to the scale depth of the basic flow; and
> - restrictions on the time scale are required.

See Spiegel and Veronis [1960], Mihaljan [1962], Greenspan [1969], Phillips [1977] (pp. 15-20), Mahrt [1986], Zeytounian [1990] (pp. 142-176), Muller [1995], Thunis and Bornstein [1996] and Sander [1998].

Boussole Strait See Okhotsk Sea.

Bowen ratio The ratio of the amount of sensible to that of latent heat lost by a surface to the atmosphere by the processes of conduction and turbulence. See Hicks and Hess [1977] and Lewis [1995].

BPR Abbreviation for bottom pressure recorder.

Bransfield Strait A strait located between the northern tip of the Antarctica Peninsula and the South Shetland Islands. It is about 120 km wide and extends 460 km from Clarence Island in the northeast to Low Island in the southwest. It consists of three separate basins isolated from the surrounding ocean by relatively shallow sills, with local deep water formation processes resulting in different water characteristics in each of the basins. The basins deepen to the northeast, having a maximum axial depth in the west basin of 1100 m near Low Island and a maximum depth of 2700 m in the east basin south of Elephant Island. Sills shallower than 500 m almost entirely circle the strait, with the east basin having the deepest access to outside water with sills deeper than 500 m. There are no passages deeper than 500 m into either the central or west basins, and the central basin is isolated from the adjacent basins by sills of 1000 and 1100 m at its western and eastern boundaries. See Clowes [1934], Wilson et al. [1999], López et al. [1999] and Gordon et al. [2000].

brash ice A type of sea ice defined by the WMO as:

> Accumulations of floating ice made up of fragments not more than 2 meters across; the wreckage of other forms of ice.

See WMO [1970].

brave west winds See roaring forties.

Brazil Basin An ocean basin located off the eastern coast of Brazil in the west-central Atlantic Ocean. It is bounded to the north by the Belem (formerly Para) Rise, at which end there is also a broad depression called the Recife (formerly Pernambuco) Abyssal Plain. This has also been called the Tizard Deep. See Fairbridge [1966].

Brazil Current A western boundary current that forms the western limb of the subtropical gyre in the South Atlantic Ocean. This current is conspicuously weak as compared with other western boundary currents since only about 4 Sv of the water from the northern limb of the gyre, i.e. the South Equatorial Current (SEC), turns south, with the rest turning north to feed the North Brazil Current (NBC). The BC is not only comparatively weak but also much weaker than might be expected from observed wind fields, more about which later.

The portion of the SEC that feeds the BC turns south at about 10–15° S. The incipient BC is shallow and flows closely confined to the continental shelf, with direct current measurements at 23° S showing that nearly half of its transport of 11 Sv was inshore of the the 200 m isobath. There also seems to be a semi-permanent offshore meander near 22–23° S that may be related to local upwelling. South of 24° S the BC flow intensifies at a rate of about 5% per 100 km, with the intensification apparently linked to a recirculation cell south of about 30° S (although there is some evidence for an more extensive recirculation cell extending from 20 to 40° S).

Geostrophic transport estimates for the southern BC based on shallow or intermediate zero flow levels (1300-1600 m) have ranged from 18–22 Sv at 33–38° S. Evidence for much deeper flow (from the examination of water mass characteristics) has led to estimates ranging from 70–76 Sv at 37–38° S with a zero flow level at 3000 m. The latter estimates are at latitudes very close to where the BC separates from the coast and thus may be considered as estimates of the maximum BC flow.

The BC separates from the continental shelf between 33 and 38° S with the average being near 36° S. There is some evidence for a seasonal variation in the latitude of this point, with it being generally farther north in the (local) winter than in summer. After it separates from the boundary, it continues to flow in a general southward direction together with the return flow from the Falkland Current, with the southern limit to the warm water it bounds fluctuating between 38–46° S on time scales of about two months. After the flow reaches it maximal southern extent it turns back towards the north (as what is sometimes called the Brazil Current Front) and appears to close back on its source flow near 42° S. The north–south excursions of its southern limit result in eddies averaging about 150 km in diameter being shed at a rate of about one per week.

It was first proposed by Stommel that the reason the BC is weaker than expected from observed wind fields is because of an opposing effect of the thermohaline circulation. The formation of North Atlantic Deep Water requires a net transfer of thermocline water from the South Atlantic to the North as well as net northward fluxes of intermediate and bottom waters. This leads to the situation where the surface circulation of the South Atlantic subtropical gyre is not a closed system because the majority of the SEC flow turns north and crosses the equator due to the demands of the thermohaline circulation. See Peterson and Stramma [1991].

Brazil Current Front See Peterson and Stramma [1991].

Brazilian Coastal Current A relatively slow but highly energetic coastal current, flowing in the opposite direction to the Brazil Current. The BCC occurs over the Southern Brazilian Continental Shelf during from spring through winter, reaching its most northerly extreme at 25.2°S in August. After de Souza and Robinson [2004].

Brazil–Malvinas Confluence A region where the Brazil Current meets the Malvinas Current at around 38°S. This collision of subtropical and subantarctic waters produces one of the most spectacular of the oceanic fronts and complex SST fields seen in the world ocean. At the BMC, subantarctic surface waters meet subtropical thermocline water in a front that can have a gradient as strong as 8°C per km. It is frequently marked by a ribbon of warm, low salinity water of Rio de la Plata origin that has folded over the northern tip of the cyclonic trough formed by the Malvinas Current and its return to the south. A warm, low salinity cap tens of meters thick often covers the western segments of the warm subtropical water. It is derived from the continental shelf north of the Rio de la Plata.

The specific configuration of the BMC at any given time is thought to depend on the relative strengths of the baroclinic and barotropic fields of the Malvinas and Brazil Currents. Its variability occurs over time scales ranging from the intra–annual to the inter–annual, with the spatial characteristics including changes in the latitudes of separation of the western boundary currents from the continental margin, and changes in the geometry of their extensions in the offshore region. On intra–annual time scales, the variability is dominated by the periodic production of transient, cold–core eddies from the Malvinas Current and warm–core eddies from the Brazil Current. These have associated SST anomalies that can be as large as 10°C on space and time scales of 1000 km and two months, respectively.

On annual time scales the variability of the western south Atlantic is dominated by the seasonal displacements of the BMC. It is found farther north during austral winter (July–September) than during the summer. Besides the annual cycle, thought to be driven by variations in the strengths of the Malvinas and Brazil Currents, there is a semi–annual component of variability with near zero amplitude at 30°S increasing to nearly half the magnitude of the annual signal at 50°S. This is probably a response to the semi–annual cycle in zonal winds over the Southern Ocean. See Garzoli and Garraffo [1989] and Goni et al. [1996].

breaker zone The portion of the nearshore zone where waves arriving from offshore become unstable and break. See Komar [1976].

Brewer-Dobson circulation The meridional atmospheric circulation that transports air poleward and downward from the tropical middle atmosphere. Air is transferred between the equator and poles by this circulation on a time scale of months, indicative of the strong control by the Coriolis force that deflects the air stream zonally and inhibits meridional motions. See Salby [1992].

BROKE Acronym for Baseline Research on Oceanography, Krill and Environment, a study conducted off east Antarctica in the Austral summer of 1995–96. The primary focus was to describe the distribution and abundance of Antarctic krill and to determine possible sources of Antarctic bottom water in the region. See Nicol et al. [2000].

Brunt frequency See buoyancy frequency.

Brunt-Vaisala frequency See buoyancy frequency.

BSA Abbreviation for Bayesian signal analysis, a method designed to be optimal for analyzing short time series which can work with an SNR as low as 0.6. No hypotheses are made about the actual series belonging to any hypothetical ensemble or infinite series; only the given data are used to find the probability of some a priori signal being contained in the data. A measure of the accuracy of the estimate can also be obtained. See Ruiz de Elvira and Bevia [1994].

BSFOCI Abbreviation for Bering Sea Fisheries Oceanography Coordinated Investigations, a NOAA COP program whose overall goal is to reduce uncertainty in resource management decisions through ecological research on recruitment and stock structure of walleye pollock, presently the largest single–species fishery in the world. A combination of basin circulation studies, analysis of recent and historical data, and development of genetic testing methods has advanced the definition of the stock structure of Bering Sea pollock in this program. See the BSFOCI Web site[10].

BSPFTE Abbreviation for Barents Sea Polar Front Experiment. See the BSPFTE Web site[11].

BTM Abbreviation for Bermuda Testbed Mooring Program.

Buchanan Deep See Angola Basin.

Buchanan, John Young More later.

bucket temperature The surface temperature of the ocean as measured by a bucket thermometer. This can also be the temperature measured by immersing a surface thermometer into a freshly drawn bucket of water.

bucket thermometer A thermometer with an insulated container around the bulb. It is used to measure ocean temperatures by lowering it on a line, allowing it to equilibrate with the temperature of the surface water, withdrawing it along with the water surrounding it, and reading the temperature. The water serves both as insulation for the thermometer (after withdrawal) and as a sample for a salinity determination.

buffer factor Defined as the fractional change in atmospheric CO_2 divided by the fractional change in oceanic DIC after equilibrium has been reached. This factor characterizes the fraction of the CO_2 flux from the atmosphere to the mixed layer that will react to form carbonate and bicarbonate ions. This is also known as the Revelle factor. See Najjar [1991].

buffer sublayer That part of a boundary layer where the viscous stress and the Reynolds stress have the same order of magnitude and the linear velocity profile turns smoothly into the logarithmic profile. See Kagan [1995].

bulk parameterizations In studying air–sea interactions, it is difficult to obtain direct measurements of the surface fluxes, and those that are available are extremely limited in geographic scope. Therefore, extensive, global–scale estimates must be obtained via parameterizations of the surface fluxes that permit the use of more easily obtained quantities. The basic premise of the concept of bulk parameterizations is to relate the surface layer fluxes to logarithmic profiles of the mean quantities. The fluxes can then be determined from the mean wind, temperature and humidity at a single height by introducing bulk transfer coefficients of heat, moisture and momentum. This method is also used to quantify gas exchange processes. See Geernaert [1990] and Rogers [1995].

[10] http://hpcc.noaa.gov/cop/96fact.html#FOCI
[11] http://vaquero.who.edu/BSPFTE.html

buoyancy

buoyancy frequency The frequency with which a parcel or particle of fluid displaced a small vertical distance from its equilibrium position in a stable environment will oscillate. It will oscillate in simple harmonic motion with an angular frequency defined by:

$$N^2 = g\left(\alpha\frac{\partial\theta}{\partial z} - \beta\frac{\partial S}{\partial z}\right)$$

where g is the gravitational acceleration, $theta$ is the potential temperature, α is the thermal expansion coefficient, and β is the saline contraction coefficient. In practice, the equivalent formula:

$$N^2 = \left(-\frac{g}{\rho}\frac{\partial\rho}{\partial z}\right)^{\frac{1}{2}}$$

is often used, where c is the velocity of sound, although care must be taken to consistently evaluate ρ and c. See Turner [1973] and McDougall et al. [1987].

buoyancy scale An important length scale in stratified flow with internal waves. This is defined as:

$$L_B = \sqrt{\bar{w}^2}/N$$

where $\bar{w}$ is the ratio of the vertical turbulent and internal wave fluctuations and N the buoyancy frequency. This is used instead of the Ozmidov scale if the vertical velocity fluctuations due to internal waves are small compared to those due to turbulence.

Burger number A dimensionless number indicative of the importance of baroclinicity in a flow field. It is the square of the ratio of the Rossby radius of deformation to the horizontal scale of the flow, and is given by:

$$B_u = \frac{NH}{fL}$$

where N is the buoyancy frequency, H the vertical scale of the flow (i.e. the depth), f is the inertial frequency, and L the horizontal scale of the flow. A Burger number of zero indicates a rotation dominated flow, while large values indicate stratification dominated flows. This was named for the mathematician/meteorologist Alewyn Burger.

Burma Sea See Andaman Sea.

Buys Ballot's law A synoptic meteorology rule stating that if, in the northern hemisphere, an observer stands with his back to the wind, pressure is lower on his left hand than on his right, while in the southern hemisphere the converse is true. This was enunciated by Buys Ballot of Utrecht in 1857 and is basically a restatement of the fact that winds blow clockwise around a depression in the northern hemisphere and anticlockwise in the southern hemisphere.

0.1 C

caballing See cabbeling.

cabbeling In physical oceanography, a phenomenon that occurs when two water masses with identical densities but different temperatures and salinities mix to form a third water mass with a greater density than either of its constituents. This is hypothesized to be a major cause of sinking in high northern latitudes. See McDougall [1987b].

cabbeling coefficient A quantity given by

$$d = \frac{1}{\beta}\frac{\partial\beta}{\partial\theta} - \frac{1}{\alpha}\frac{\partial\alpha}{\partial\theta} + \frac{\alpha}{\beta^2}\frac{\partial\beta}{\partial S} - \frac{1}{\beta}\frac{\partial\alpha}{\partial S}$$

where *beta* is the saline contraction coefficient, α is the thermal expansion coefficient, θ is the potential temperature, and S is the salinity. This describes changes of the isopycnal slope along isopycnals. See Muller [1995].

CABEX Acronym for Cascadia Basin Experiments, an underwater acoustics experiment performed jointly by the APL at the University of Washington School of Oceanography and the Acoustical Oceanography Research Group at the IOS. In this experiment acoustic arrays are designed to record images of sea surface zone backscattering in order to distinguish between rough surface scattering and scattering from bubble distributions near and beneath the surface. The hypothesis being tested is whether the small void fraction bubble clouds are responsible for the observed increase over simple rough surface backscattering predictions at moderate to high wind speeds. See the CABEX Web site[12].

calcareous Of or containing calcium carbonate or another, usually insoluble, calcium salt.

calcareous ooze A fine-grained, deep-sea deposit of pelagic origin containing more than 30% calcium carbonate derived from the skeletal material of various plankton. It is the most extensive deposit on the ocean floor but restricted to depths less than about 3500 m due to the carbon compensation depth.

CALCOFI Acronym for California Co-operative Fisheries Investigations.

`[http://www-mlrg.ucsd.edu/calcofi/]`
`[http://www.sio.ucsd.edu/explorations/calcofi/]`

CalCOOS Acronym for the California Coastal Ocean Observation System, the mission of which is to provide an observation–based description of the resources of California's coastal ocean in support of science, coastal resource management and emergency response.

`[http://www.calcoos.org/]`

caldera The official IHO definition for this undersea feature name is "a collapsed or partially–collapse seamount, commonly of annular shape."

California Current The eastern limb of the clockwise flowing subtropical gyre in the North Pacific. The California Current flows equatorward throughout the year offshore from California from the shelf break to about 1000 km from the coast. The current is strongest at the surface and extends over the upper 500 m of the water column, with seasonal mean speeds of about 10 cm s^{-1}. It carries relatively colder fresher subarctic water equatorward. Within about 300 km of the coast, some of the fresher water in the upper 20 m is associated with the Columbia River plume. South of Point Conception a

[12] http://wavelet.apl.washington.edu/CABEX/top.html

portion of the Current turns southeastward and then shoreward and poleward. This is known as the Southern California Countercurrent (SCCC) during times when the flow successfully rounds the Point, and as the Southern California Eddy when the flow recirculates within the Bight.

From April until September northerly winds prevail which leads to upwelling and equatorward surface flow through the spring and summer months. This leads to an extremely large temperature gradient between a few kilometers offshore and the land surface with concomitant condensation and the sort of heavy fogs for which San Francisco is notorious. See Hickey [1979], Hickey [1993], Tomczak and Godfrey [1994] and Hickey [1998].

California Undercurrent One of the two narrow, poleward–flowing boundary currents in the California Current system (the other being the Inshore Countercurrent). The CU appears as a subsurface maximum of flow between 100 and 250 m deep over the continental slope and transports warm, saline equatorial waters. It flows within 150 km of the coast as opposed to the 850–900 km extent of the southward flowing CC. The flow seems to be continuous for distances of 400 km or more, and has been observed at locations ranging from Baja California to Vancouver Island. Current measurements off Central California indicate continuous, year–round flow over the upper slope at around 350 m with an average speed of 7.6 cm s^{-1}. See Collins et al. [2000].

CALK Acronym for Carbonate ALKalinity, a function of carbonate and bicarbonate ion concentration.

CAMBIOS A French program to monitor the Azores front and the flow of meddy across that region. This is to be done via acoustic tomography using three sound transceivers as well as with a series of CTD/ADCP stations and some XBT deployments. See the CAMBIOS Web site[13].

Camotes Sea A small sea within the Visayan Islands that comprise the middle portion of the Philippines. It is centered at about 124.5° E and 10.5° N and is connected to the Visayan Sea to the northwest (between the islands of Cebu and Leyte), and to the Bohol Sea to the south via the Tanon Strait and a passage between the islands of Bohol and Leyte. The Camotes Islands are prominently features in the midst of this sea.

Canadian Arctic Archipelago See Collin and Dunbar [1964].

Canadian Basin Deep Water (CBDW) A water mass ... See Hansen and Osterhus [2000].

CANALES An oceanographic experiment taking place in the Balearic Sea from 1996 to 1998 to investigate the interannual, seasonal and mesoscale variability of the circulation in the Balearic Channels. The experiment consisted of four parts:

- 13 hydrographic cruises from March 1996 to June 1998;
- 14 vector–averaging mechanical current meters deployed on four mooring lines from May to November, 1996;
- analysis of daily composite infrared SST images of the western Mediterranean; and
- the use of an inverse model to obtain transport estimates from the data collected.

See Pinot et al. [2002].

Canary Basin An ocean basin located to the west of the Canary Islands in the eastern North Atlantic Ocean. This is bound to the north by the Azores Rise and is mostly composed of the Madeira Abyssal Plain, although a smaller depression called the Seine Abyssal Plain is also found there. This has also been called the Monaco Deep. See Fairbridge [1966] and Barton et al. [1998].

[13]http://www.cms.udel.edu/woce/field/french_atlantic.html

Canary Current See Hill et al. [1997] and Barton et al. [1998].

CANIGO A European Union research project whose goal is to understand of the marine system in the Canary–Azores–Gibraltar region of the Northeast Atlantic Ocean and its links wit the Alboran Sea. The project objectives are to obtain improved knowledge about the physical processes controlling the subtropical gyre and related mesoscale circulations through observations and modeling; to study the carbon cycle in the pelagic system and estimate the carbon flow from this system to deeper waters; to quantify the influence of coastal upwelling and Saharan dust on particle fluxes in the Canary region and its change through the last glacial and interglacial periods; and to quantify, understand and model the exchange system thorugh the Strait of Gibraltar, the processes of formation, evolution and fate of the Mediterranean outflow, and to measure the biogeochemical fluxes accompanying the water exchanges.

The program, scheduled to start in August 1996 and to last for 38 months, consists of observations with ships, moored instrumentation, drifters, and acoustic tomography. Laboratory experiments, satellite data, and numerical models will also be used. The project is coordinated by the Instituto Espanol de Oceanografia in Spain and the participants include Portgual, the UK, France, Germany, Norway, Sweden, Italy, Austria, Switzerland, Ireland and Israel.

From Parrilla et al. [2002a]:

> Canary Islands Azores Gibraltar Observations (CANIGO) is an European research project that was carried out as a target study in the European Union's Marine Science and Technology (MAST) III program from 1996 to 1999. Its general objective was to gain a better understanding of the physics, biogeochemistry and paleoceanography of the eastern subtropical North Atlantic. The study region of CANIGO encompassed the subtropical frontal system of the Azores, the Gibraltar exchange, the northern Canary Islands region and the transition zone of the NW African upwelling margin. CANIGO included scientists of 45 institutions from 12 countries (Austria, France, Germany, Israel, Italy, Ireland, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom). More than 300 scientists, technicians and students dedicated about 4000 months of work to the project. The disciplines of physics, chemistry, biology and geology were included in a combined observational and modeling program.
>
> The specific goals of CANIGO were: (1) to obtain an improved knowledge of physical processes controlling the North Atlantic subtropical gyre and the related mesoscale circulation through observations and nested circulation models; (2) to study the carbon cycle in the pelagic system in nutrient limited (oligotrophic) and nutrient-rich (productive) waters and to estimate the carbon flow through and from the pelagic system to deep waters; (3) to determine, quantitatively, the influence of coastal upwelling and Saharan dust on the magnitude and composition of particle flux in the Canary region, and to investigate how this influence changed through the last glacial and interglacial period; and (4) to quantify, understand and model the water mass exchange system through the Strait of Gibraltar, the processes of formation, evolution and fate of the Mediterranean Outflow, including the associated submesoscale eddies, and to measure the biogeochemical fluxes (in terms of carbon, nitrogen, trace metals and metalloids) accompanying these water exchanges.
>
> The work program consisted of observations with ships, moored instrumentation, drifters, floats and acoustic tomography, laboratory experiments, the use of satellite data, numerical modeling and the processing and joint analysis of data. Cruises with research vessels were generally multidisciplinary and multinational. The ship time in CANIGO, including research vessels and ships of opportunity, added up to almost two years, distributed in 48 cruises of variable duration. Around 1700 time series records were obtained from 38 moorings.

See Parrilla et al. [2002a] and Parrilla et al. [2002b].

[http://www.cms.udel.edu/woce/field/spain_atlantic.html]

Cantabrian Sea See Gil et al. [2002].

canyon The official IHO definition for this undersea feature name is "a relatively narrow, deep depression with steep sides, the bottom of which generally deepends continuously, developed characteristically on some continental slopes."

capacitance matrix method An algorithm for imposing additional conditions on the solution of a boundary value elliptic problem at specified grid points in the interior of the computational domain. It effectively determines a modification to the right-hand side of the governing elliptic equation which will precisely satisfy the additional interior boundary conditions. Pragmatically it allows the inclusion of island and irregular coastal boundaries while retaining the use of fast and accurate elliptic solving routines at a modest additional computational expense. See Wilkin et al. [1995].

CAPE Abbreviation for convective available potential energy.

CAPE Acronym for Circumpolar Arctic PaleoEnvironments, an organization within IGBP–PAGES to provide the vehicle through which international and national Arctic paleo–programs can be linked. The primary emphasis of CAPE is to facilitate the scientific integration of paleoenvironmental research on terrestrial environments and adjacent margins covering the last 250,000 years of Earth history, particularly those tasks that cannot easily be achieved by individual investigators or even regionally focused research teams. See CAPE Project Members [2001].

[http://www.ngdc.noaa.gov/paleo/cape/cape.html]

Cape Basin An ocean basin located to the west of South Africa at about 35° S in the South Atlantic Ocean. This includes the Cape Abyssal Plain which is fed by the Orange River. This has also been called the Walvis Basin. See Fairbridge [1966].

Cape Horn Current (CHC) A current found south of approximately 42°S along the coast of Chile. The west wind drift of the subtropical gyre veers south and becomes the Cape Horn Current at this latitude. The lower salinity and higher oxygen values found in the upper part of the current as it moves south indicate interaction with the estuarine circulation in the complex fjords along the coast. These properties are limited to the region next to the coast at 42°S, but extend to around 100 km offshore at 51°S. See Strub et al. [1998].

Cape Verde Basin An ocean basin located at about 15° N off the west coast of Africa in the North Atlantic Ocean. It includes the Cape Verde Abyssal Plain, separated from the Madeira Abyssal Plain to the north by a belt of abyssal hills, and the Gambia Abyssal Plain. This has also been known as the North African Trough, the Chun Deep, and the Moseley Deep. See Fairbridge [1966].

Cape Verde Frontal Zone A major discontinuity in the warm water sphere in the eastern tropical Atlantic named as such by Zenk et al. [1991]. It marks the boundary between the North and South Atlantic Central Waters (NACW, SACW) that form a strong thermohaline front north of the Cape Verde Islands. See Zenk et al. [1991] and Klein and Siedler [1995].

capillary wave A wave on a fluid interface for which the restoring force is surface tension. See Dias and Kharif [1999] and Perlin and Schultz [2000].

carbon-14 dating A radioisotope dating method wherein a radioactive isotope of carbon, also called radiocarbon, is used to date materials containing carbon. Carbon-14 is produced in the atmosphere by a reaction between slow cosmic ray neutrons and stable nitrogen-14 and subsequently becomes incorporated into molecules of carbon dioxide by reactions with oxygen or by exchange reactions with stable carbon isotopes in molecules of carbon monoxide or carbon dioxide. These molecules are rapidly mixed through the atmosphere and hydrosphere to reach a constant level of concentration representing a steady-state equilibrium, maintained by the constant production of carbon-14 and its continuous decay to stable carbon-12.

The carbon-14 molecules enter plants tissues via photosynthesis or by absorption through roots and the concentration subsequently remains constant due to a balance between incorporation and decay. Animals feeding on such plants have a similar constant radiocarbon level. When the plants and animals die, the incorporation of carbon-14 stops while the decay into carbon-12 continues with a half-life period of 5570 years. Thus if the radiocarbon activity in a living plant or animal is known, its activity in the dead tissues of a similar plant or animal can be used to calculate the time elapsed since its death by measuring the ratio of carbon-14 to carbon-12. This is known as the carbon-14 date of the sample. See Bowen [1991] and the Radiocarbon Web site[14].

carbon compensation depth The level in the ocean below which the solution rate of calcium carbonate exceeds its deposition rate. This is also called the carbonate compensation depth.

carbon cycle Refers to the cycling of carbon in the form of carbon dioxide, carbonates, organic compounds, etc. between various reservoirs, e.g. the atmosphere, the oceans, land and marine biota and, on geological time scales, sediments and rocks. The largest natural exchange fluxes occur between the atmosphere and the terrestrial biota and between the atmosphere and the surface water of the oceans.

carbon dating See carbon-14 dating.

carbon dioxide This is the most important of the greenhouse gases with an atmospheric concentration of 353 ppm (in 1990), up from an estimated 260-290 in pre-industrial times (pre-1880). This gas plays a very large part in the natural carbon cycle, with the amount of carbon taken out of the atmosphere each year by plant photosynthesis being almost perfectly balanced by the amount put back into the atmosphere by the processes of animal respiration and plant decay.

The chief natural sources the burning of coal, oil and natural gas, the so-called fossil fuels, and the cutting down and burning of forests, with the latter contributing about a third as much as the former. See Revelle and Fairbridge [1957].

carbonate pump The name given to the cycling of CaCO3 in the ocean. Plants and animals living in the euphotic zone have CaCO3 skeletons (tests) which they precipitate from dissolved calcium and carbonate ions. The CaCO3 formed this way eventually sinks and is dissolved back to calcium and carbonate ions in the deeper parts of the water column and in the sediments. The ocean circulation closes the loop by transporting the ions back to the surface waters. This pump creates a surface depletion and a deep enrichment of both DIC and alkalinity. An increase in the strength of this pump will serve to increase atmospheric CO2 since the pump variations have twice as great an effect on alkalinity as on DIC. See Najjar [1991].

Cariaco Basin The Cariaco Basin is a 1400 m deep depression within the continental shelf of Venezuela, connected to the southeastern Caribbean Sea across a sill that reaches approximately 140 m at its deepest point. See Richards [1975] and Astor et al. [2003].

[14] http://www2.waikato.ac.nz/c14/webinfo/index.html

Caribbean Current One of two downstream branches into which the confluence of the Guiana Current and the North Equatorial Current split when encountering the Lesser Antilles. The Antilles Current flows northward along the eastward side of the Antillean Island Arc to eventually merge into the Florida Current, while the Caribbean Current flows west–northwesterly through the various passages between the Windward Islands of the Lesser Antilles.

The characteristics of the Carribean Current derived from the observed annual average density field show it to be a warm, persistent, and powerful current with a gentle increase in velocity as it flows from the Windward Islands to the Yucatan Channel. The axis of the main flow is about 20 km wide, extends from the surface to a few tens of meters below, and streams about 200–300 km off the coast of Venezuela. It then veers northwest across, over and beyond the various submarine channels of the Jamaica–Honduras Ridge and exits through the Yucatan Channel. The axis of the current has an annual average velocity of 0.50 m/s, with the spring–summer velocity (0.80 m/s) greater than that of autumn–winter (0.40 m/s). Maximum velocities greater than 2.0 m/s have been measured, and the velocities decrease with depth to speeds not greater than 0.05 m/s at 1000 m. The annual average volume transport is estimated at 30 Sv.

The trajectories of satellite–tracked drifters indicate that the trajectory of the Caribbean Current is most correctly referred to in a statistical sense, e.g. Gallegos [1996] refers to "the loops, cusps, meanders and reversals, the presence of eddies, filaments of currents and countercurrents, and other typical motions, including turbulence, within a wide range of time and space scales." See Gallegos [1996].

Caribbean Sea The largest marginal sea of the Atlantic Ocean, with a surface area of 2.52×10^6 km^2 and a volume of 6.48×10^6 km^3 (twice that of the Mediterranean Sea). The north and eastern boundaries are the Greater and Lesser Antilles, and the southern extent is bounded by the irregular coasts of Venezuela, Colombia and Panama. The western boundary is Central America. It is located between 8–22°N latitude and 60–89$\circ$W longitude, i.e. about 3000 km east to west and 1500 km south to north.

The average depth of the Caribbean is 4400 m, and it consists of five principal basins. They are, from east to west (with average depths):

- the Grenada Basin (3000 m);
- the Venezuela Basin (5000 m), the largest of the basins;
- the Columbia Basin (4000 m);
- the Cayman Trench (6000 m), with a maximum depth of 7100 m; and
- the Yucatan Basin (5000 m).

The major sills and ridges (with maximum depths) separating the basins from each other, the Atlantic, and the Gulf of Mexico are, from east to west:

- the Grenada (740 m), St. Vincent (890 m), St. Lucia (980 m), Martinique (950 m), Dominica (950 m) and Guadaloupe Passages connecting the Grenada Basin with the Atlantic;
- the Aves Ridge (1800 m) connecting the Grenada and Venezuela Basins;
- the Jungfern (1815 m), Anegada (1910 m) and Mona (475 m) sills connecting the Venezuela Basin to the Atlantic;
- the Beata Ridge (3600 m) separating the Venezuela and Colombian Basins;
- the Jamaica–Haiti Passage (1475 m) and various channels across the ridge between Jamaica and the Honduras–Nicaragua continental shelf (1600 m) separating Columbia Basin and the Cayman Trench;

- the Windward Passage (1690 m) connecting the Cayman Trench with the Atlantic;
- the Cayman Ridge (4000 m) separating the Cayman Trench from the Yucatan Basin; and
- the Yucatan Channel (2040 m) connecting the Yucatan Basin with the Gulf of Mexico.

The water masses and circulation of the Caribbean have been summarized by Mooers and Maul [1998]. Their summary is repeated here in slightly modified form:

> The IAS [Intra–Americas Sea, i.e. the coastal, estuarine, riverine, continental shelf and deep waters of the Gulf of Mexico, Caribbean Sea, Guianas and Bahamas (including the Straits of Florida)] contains the "roots" of the Gulf Stream system, and its circulation is consequently dominated by throughflow, with a volume transport estimated to be about 30 Sv. The inflow is derived from the tropical and subtropical North Atlantic Ocean. For example, the Guyana Current is a major source of inflow from the tropical Atlantic Ocean. The majority of the inflow enters the Caribbean Sea through several passages, of variable sill depth, between the Antilles Islands and, to a lesser estent, the Windward Passage. The remainder bypasses the Caribbean Sea via the Antilles Current, some of which flows through the Bahamas Islands and enters the Straits of Florida.
>
> Associated with the throughflow regime is the thermohaline–driven lower branch of the meridional overturning circulation known as the Deep Western Boundary Current (DWBC), which flows equatorward at a depth of about 3 km along the periphery of the IAS continental slope. This intense, deep flow is part of the Global Conveyer Belt in the Atlantic and has a volume transport of about 15 Sv. Although little DWBC water spills directly into the IAS through the major deep passages, it mixed with the ambient middepth Atlantic waters to form the remarkably uniform bottom water in the Caribbean Sea Basin. Dynamically, the role of the DWBC on IAS circulation is essentially unknown.
>
> Surface waters of the tropical Atlantic Ocean (T $\approx$ 28°C, S $\approx$ 36 ppt) flow into the IAS through the Antilles Passages, and except for extreme winters, flow out the Straits of Florida with almost the same general T–S properties. Below the surface, at typically 200 m, the subtropical underwater (SUW) dominates the shape of the T–S curve (T $\approx$ 22°C, S $\approx$ 36.7 ppt) in the main flows of the Gulf Stream system. Outside the current, the salinity is typically reduced to S $\approx$ 36.2 ppt, due to mixing with the ambient waters, usually of riverine origin but also due to excess of precipitation (P) over evaporation (E), particularly in the northern Gulf of Mexico. SUW is formed in the central tropical Atlantic where E $>$ P and sinks along an isopycnal surface before and during IAS passage.
>
> The next 500 m or so of the water column is dominated by Western North Atlantic Central Water (WNACW) with a typical temperature range of 20°C $>$ T $>$ 8°C and salinity range of 36.3 $>$ S $>$ 35.2 ppt. At about 700 m, the characteristic salinity minimum of Antarctic Intermediate Water (AAIW) near S $\approx$ 34.8 ppt and T $\approx$ 7°C can be traced from the northern Straits of Florida through the IAS, including the western Gulf of Mexico (where SUW is only found in Loop Current anticyclonic edies), through the Caribbean Sea and eventually of course to its (E $<$ P) source off Antarctica. Finally, in the deepest waters, $>$1000 m or so, the mid–depth waters of the Atlantic (slightly increased salinity) are generally recognized. The deep waters of the IAS are remarkably uniform (T $\approx$ 4°C, S $\approx$ 35 ppt) and created by overflows of the sills in the deeper passages (especially the Anegada and Windward Passages).
>
> The surface flow through the island passages organizes into the Caribbean Current that flows westward off the northern coast of South America and then northward along the eastern coast of Central America. Subsequently, it becomes known as the Yucatan Current as it flows through the Yucatan Channel and then becomes known as the Loop Current as it penetrates northward into the eastern Gulf of Mexico. It then turns anticyclonically southward to exit to

the east through the Straits of Florida, where it is known as the Florida Current and its volume transport is about 30 Sv. The persistent cyclonic Panama–Colombian Gyre (PCG), located in the southwestern Caribbean Sea, where it interacts with the plume of the Magdelena River, is the other major component of the surface general circulation.

The flow through the Antillean Passages is spatially complex (i.e. undercurrents and countercurrents; bottom trapping) and temporally variable on time scales of months and years wit no clear annual cycle.

The deep circulation is largely unexplored but there are dynamical reasons to anticipate a mean cyclonic flow along bottom topography in both the Caribbean Sea and the Gulf of Mexico. ... The Caribbean Sea is composed of several basins that divide the deep circulation. Geochemical data provide some estimates of deep–water age and residence times, but the physical processes involved (i.e. flow over the deep sills of the island passages) are onlly now being investigated theoretically and observationally.

The macroscale, seasonal wind forcing (which is regional as well as remote, i.e. from the North Atlantic, in nature) modulates the general circulation of the open basins by approximately 10% and may lead to flow reversals over shelves. For example, the summertime intensification of the trade winds leads to ecologically significant coastal upwelling and westward shelf flows along the northern coasts of South America, the Yucatan Peninsula and Cuba.

See Wust [1964], Gordon [1967], Kinder et al. [1985], Gallegos [1996] and Mooers and Maul [1998].

Caribbean Surface Water (CSW)
See Corredor and Morell [1999].

[http://cima.uprm.edu/cats/cats.htm]
[http://cima.uprm.edu/~morelock/mor2.htm]

Caroline Basin
See Siedler et al. [2004].

Carpenter, William (1813–1885)
See Peterson et al. [1996], p. 93.

Carruthers residual current meter
A current meter designed to measure and record the residual current over a longer period of time. In a manner similar to that of the Ekman current meter, a device drops small metal balls into a compass box after a certain number of turns of the propeller. The average velocity and direction are obtained by counting, after an extended period of time, the number and distribution of balls dropped (of over 22,000 available) into the slots of the compass box. See Sverdrup et al. [1942].

CARUSO
Acronym for CARbon dioxide Uptake by the Southern Ocean, an experiment undertaken from January 1988 to December 2000 to test the hypothesis that "the carbon dioxide uptake by the Southern Ocean is being dominated by synergistics of light and iron regulating the photosynthetic carbon dioxide fixation of large diatoms and carbon export into deeper Antarctic waters." The specific objectives of the program were:

- estimation of the biological and physical carbon dioxide pumps in the Southern Ocean via application of transient tracers such as chlorofluorocarbons, $^3He/^4He$ and tritium;
- investigation of the co–limitation of light and iron of bloom forming diatoms;
- quantification of iron sources to Antarctic surface waters via the use of natural isotopic tracers (^{228}Ra and $^{143}Nd/^{144}Nd$);
- field observations and an in situ iron fertilization experiment; and

- a modeling study of the biological, chemical and physical systems in the Antarctic.

[http://kellia.nioz.nl/projects/caruso/]

Caspian Sea See Zenkevich [1957] and Zenkevitch [1963].

Catalan Sea See Balearic Sea.

CATCH Acronym for the Couplage avec l'ATmosphère en Conditions Hivernales experiment, which took place in the North Sea in January and February 1997. See Eymard [1999].

CATO Expedition See Scripps Institution of Oceanography [1979a].

CCD Abbreviation for Calcite Compensation Depth, defined as the depth at which the CaCO3 content of sediments reaches 20%.

CDW Abbreviation for Circumpolar Deep Water.

CEAREX Acronym for Coordinated Eastern Arctic Experiment, a multi-national and multi-platform field program carried out in the Greenland and Norwegian Seas (north to Svalbard) from Sept. 1988 through May 1989. It was a collaboration between Canada, Denmark, France, Norway and the United States and consisted of four phases: the Polarbjorn Drift Phase, the Whaler's Bay/SIZEX Phase, the Oceanography Camp Phase, and the Acoustic Camp Phase. See Pritchard and et al. [1990].

[http://nsidc.org/NSIDC/CATALOG/ENTRIES/nsi-0020.html]

Celebes Sea Alternate name for the Sulawesi Sea.

Celtic Sea A shallow embayment of the eastern North Atlantic bounded by Southern Ireland, southwest Wales, Cornwall and Brittany. It is usually separated from the Irish Sea by a line drawn from Ramsey Island to Carnsore Point and from the English Channel by a line drawn from Ushant to Lands End. The seaward limit is usually set at the slope break at about 165–185 m. See Cooper [1967], Fairbridge [1966], Pingree [1980] and Simpson [1998].

Celtic Seas A term used for the European shelf seas to the west and south of the British Isles. These include the Hebrides and Malin shelves west of Scotland, the Irish Shelf, the English Channel, the Celtic Sea and the Irish Sea. See Simpson [1998].

Cenderawasih Bay A bay on the northern coast of Irian Jaya centered at approximately 135° E and 2.5 deg. S at the southwestern edge of the Pacific Ocean. It connects with the Pacific via the Woinui and Yapen Straits and is bordered immediately to the north by the New Guinea Trench.

belcentersofaction

centers of action Large semipermanent belts of high or low sea level pressure distributed around the Earth that largely control the general circulation of the atmosphere and the concomitant long-term weather patterns. The term was originally used by Teisserenc de Bort in 1881 to describe maxima and minima of pressure on daily charts, but has evolved to have the more global meaning. These centers include the Icelandic Low, the Aleutian Low, the Pacific High, the Azores High, the Siberian High, and the Asiatic Low. See Herman and Goldberg [1985].

Central South Equatorial Current One of three distinct branches into which the South Equatorial Current splits in the western South Atlantic. See Stramma [1991].

Central Water In physical oceanography, a term used to identify thermocline water masses in all three oceans. The water arrives at the thermocline via a process known as subduction. Central Water is characterized by T-S relationships that span a large range that is nonetheless well-defined by the method of formation. The term was originally introduced to differentiate between thermocline water of the central north Atlantic Ocean (now known as NACW) and water from the shelf area to west, but now has the abovementioned broader meaning. See Tomczak and Godfrey [1994].

CEPEX Acronym for Central Equatorial Pacific Experiment, conducted in March and April 1993 with the goal of establishing the respective roles of cirrus radiative effects and surface evaporation in limiting maximum surface temperatures in the equatorial Pacific. It examined the validity of a hypothesized thermostat effect which may limit greenhouse warming. Deep intensive convection is observed to occur when tropical SSTs exceed about 27° C. This produces cirrus (ice particle clouds) anvils that spread out over millions of square kilometers. It is hypothesized that while these clouds trap outgoing infrared radiation, they also reduce incoming solar radiation, the net effect being to stabilize SSTs, thereby acting in effect as a thermostat.

CEPEX employed surface, airborne, and space-borne platforms to measure radiation fluxes, cirrus radiative and microphysical properties, vertical water vapor distribution, evaporation from the sea surface, and precipitation. The specific objectives were:

- to measure the vertical structure of the water vapor greenhouse effect;
- to measure the effect of cirrus on radiation fluxes over the equatorial Pacific Ocean;
- to measure the east–west gradients of SSTs and the evaporative and sensible heat fluxes from the sea surface along the equatorial Pacific Ocean;
- to measure the east–west gradients of vertical distribution of water vapor along the equatorial Pacific Ocean; and
- to explore the microphysical factors contributing to high albedo of widespread cirrus layers.

See Ramanathan et al. [1995].

`[http://www-c4.ucsd.edu/~cids/cepex/]`
`[http://www.joss.ucar.edu/cgi-bin/codiac/projs?CEPEX]`

CEPTE Acronym for Central Equatorial Pacific Tomography Experiment, a long–term, 1000 km scale tomography experiment taking place from Dec. 1998 to Dec. 2000. The purpose is to measure the shallow overturning of a meridional circulation cell, i.e. a subtropical circulation cell (STC) that has been hypothesized as one mechanism by which El Nino/La Nina events in the tropics are connected to the subtropical ocean. CEPTE involved five JAMSTEC tomography moorings deployed in an array about 1000 km across just north of the equator at about 180°W.

Ceram Sea See Seram Sea.

CESNA Acronym for the Climate Expert System for the North Atlantic, part of a project to develop a practical system that can manipulate qualitative information in a way that facilitates insights into observed and anticipated climate changes. At present CESNA can be used to estimate changes in mean winter and annual climatic characteristics with a one year lead time in the region that includes eastern North America, the North Atlantic, the adjacent Arctic seas and much of Europe. See the CESNA Web site[15].

CFC See chlorofluorocarbon.

[15] http://www.cs.colorado.edu/ sergei/cesna.html

CFL Abbreviation for Courant, Friedrichs, and Levy, the discoverers of a time step limitation for numerical simulations of partial differential equations.

Chain Fracture Zone One of the pathways (along with the Romanche Fracture Zone) for AABW and lower NADW from the western to the eastern trough of the equatorial Atlantic Ocean across the Mid–Atlantic Ridge. To the west of the CFZ sill, the AABW and NADW cores are separated by a deep thermocline marking the vertical transition between them. This thermocline erodes eastward and vanishes in the eastern basin. See Mercier and Morin [1997] and Messias et al. [1999].

Challenger Expedition (1872-1876) A three and a half year voyage starting in 1872 that laid the scientific foundation for every major branch of oceanography. The ship, captained by George S. Nares and later Frank T. Thomson, took over 350 stations in all the oceans except the Arctic and logged 68,890 nautical miles. Perhaps the only ultimately unsatisfying aspect of the expedition was that the ship, a spar-decked vessel with auxiliary steam power, was slow and clumsy and had the habit of rolling about 50° to either side. The expedition was led by Sir Wyville Thompson, with his chief assistant John Murray and the expedition's chemist J. Y. Buchanan also playing major roles.

The observations and records obtained aboard the Challenger furnished data for charting the main bathymetric contours of the ocean basins, established the cold and relatively constant nature of temperatures at great depths, located the exact position of many islands and sea mounts, established that there was no zone in the sea in which life did not exist, and enabled the construction of accurate charts of the principle surface (and some subsurface) currents in the world ocean. The deep sea data were obtained with trawls lowered on hemp ropes. The ship dragged for samples in water as deep as 4,475 fathoms and trailed as much as eight miles of line in trawls that took 12 or 14 hours to complete.

The foundations of marine geology were laid by Murray with his study of the deep-sea sediments obtained in the trawls. The sediments discovered were newly classified as globigerina, radiolarian or diatom oozes or red clay, and their spatial distribution was mapped. The plankton nets, simple bags of muslin or silk attached to iron rings one foot in diameter captured many new planktonic forms, permanently changing that branch of marine biology. Many new and different forms of life were dredged from great depths, permanently dispelling the notion that these depths were lifeless and founding deep-sea biology. The expedition's chemist Buchanan took seventy-seven water samples throughout the oceans, deriving data from these that formed the foundation of chemical oceanography. He also dispelled the myth of Bathybius.

The scientific results of the expedition were published in fifty large volumes over fifteen years, edited first under the direction of Thompson and, after his death, by Murray. The best artists in England were hired to create the illustrations. The funding for this publishing endeavor was not included as part of the budget of the expedition and it was a constant struggle for Thompson and Murray to obtain financial resources to complete the endeavor, so it might also be said that the foundations for the difficulty of obtaining funds for oceanographic research were also laid by this expedition.

The Challenger Expedition probably contributed more to the science of oceanography than any single expedition before or after. It marked the beginning of oceanography as a disciplined science, with the scientists establishing a pattern of scrupulously precise observations and efficiency. While the quality of ships and of sampling and measuring devices have greatly improved since 1872, it is doubtful that the standards set by the Challenger Expedition will ever be exceeded. It was truly a landmark in oceanography. See Thomson and Murray [1884–1895].

Challenger Report A fifty volume set of reports on the results of the Challenger Expedition. The six main sections of the report were narrative, physics and chemistry, deep–sea deposits, botany, zoology and a summary. A more detailed breakdown is:

I. Narrative. Three bound volumes.

- Vol. 1 (1172 pp.)
  Narrative of the cruise of H.M.S. Challenger, with a general account of the scientific results of the expedition (in two volumes) – T. H. Tizard, H. N. Moseley, J. Y. Buchanan and John Murray

- Vol. 2 (823 pp.)
  - Magnetical results – Commander Maclear, Lieutenent Bromley, Staff–Commander Tizard, E. W. Creak (305 pp.)
  - Meteorological observations – Staff–Commander Tizard (
  - Pressure errors of the Challenger thermometer – P. G. Tait
  - Petrology of St. Paul's Rocks (Atlantic) – A. Renard

II. Physics and Chemistry. Two bound volumes.

- Vol. 1 (325 pp.)
  - Part I – Composition of ocean water – W. Dittmar
  - Part II – Specific gravity of samples of ocean water – J. Y. Buchanan
  - Part III — Deep–sea temperature observations – Officers of the Expedition
- Vol. 2 (633 pp.)
  - Part IV – On some of the physical properties of fresh–water and of sea–water – P. G. Tait
  - Part V – Atmospheric circulation, based on the observations made on board H.M.S. Challenger and other meteorological observations – A. Buchan
  - Part VI – Magnetical results - E. W. Creak
  - Part VII – Petrology of oceanic islands – A. Bernard

III. Deep–Sea Deposits. One bound volume. (583 pp.)

- Deep–sea deposits – John Murray and A. Renard
- Analytical examination of manganese nodules, with special reference to the presence or absence of the rarer elements – J. Gibson
- Chemical analyses of marine deposits, manganese nodules, phosphatic concretions, zeolitic crystals, volcanic lapillae, glauconite, bones of cetaceans, teeth of sharks, etc. – Brazier, Dittmar, Renard, Sipocz, Anderson et al.

IV. Botany. Two bound volumes.

- Vol. 1. (910 pp.)

  - Introduction. – Present state of knowledge of various insular floras, being an introduction to the botany of the Challenger Expedition – W. B. Hemsley

  - Part I. – Botany of the Bermudas and various other Islands of the Atlantic and Southern Oceans.–The Bermudas – W. B. Hemsley

  - Part II. – Botany of the Bermudas and various other Islands of the Atlantic and Southern Oceans.–St. Paul's Rocks, Fernando–Noronha and contiguous islets, Ascension, St. Helena, South Trinidad, the Tristan da Cunha Group, Prince Edward Group (Marion Island), the Crozets, Kerguelan Island, Macdonald Group (Heard Island), Amsterdam and St. Paul Islands – W. B. Hemsley
  - Part III. – Botany of Juan Fernandez, south–eastern Moluccas, and the Admiralty Islands – W. B. Hemsley

- Vol. 2 (214 pp.)
  - Part IV. – Diatomaceae - C. A. F. C. degli Antelminelli

V. Zoology. Forty bound volumes.

- Vol. 1 (553 pp.)
  - General introduction to the zoological series of reports – C. Wyville Thomson
  - Part I. – Brachiopoda. – T. Davidson
  - Part II. – Pennatulida. – A. v. Kölliker
  - Part III. – Ostracoda. – G. S. Brady
  - Part IV. – Cetacea. Bones of. – W. Turner
  - Part V. – Green turtle (Chelone viridis, Schneid.). Development of the. – W. K. Parker
  - Part VI. – Shore fishes. – A. Günther
- Vol. 2 (422 pp.)
  - Part VII. – Certain Hydroid, Alcyonarian, and Madreporarian corals. – H. N. Moseley
  - Part VIII. – Birds. – P. L. Selater
- Vol. 3 (496 pp.)
  - Part IX. – Echinoidea. – A. Agassiz
  - Part X. – Pycnogonida. – P. P. C. Hoek

- Vol. 4. (558 pp.)
  - Part XI. – Petrels. Anatomy of the. – W. A. Forbes
  - Part XII. – Deep–sea Medusae. – E. Haeckel
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- Vol. 7 (493 pp.)
  - Part XVIII. – Spheniscidae. Anatomy of the. – M. Watson
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  - Part XX. – Hydroida. First part.–Plumularidae. – G. J. Allman
  - Part XXI. – Orbitolites. Specimens of the genus. – W. B. Carpenter

VI. Summary. Two bound volumes.

- Summary of the scientific results obtained at the sounding, dredging, and trawling stations of H.M.S. Challenger. – J. Murray (1665 pp.)
  With appendices, viz.:–
- Spirula. – T. H. Huxley and P. Pelseneer (32 pp.)
- Oceanic circulation based on the observations made on board H.M.S. Challenger and other observations. – A. Buchan (38 pp.)

CHAMP Acronym for the Coral Health And Monitoring Program, a NOAA project to provide services to help improve and sustain coral reef health throughout the world. The goals include establishing an international network of coral reef researchers to share information about and monitor coral health, providing near real-time data products derived from satellite images and monitoring stations at coral reef areas, providing a data repository for historical data, and adding to the general fund of coral reef knowledge. See the CHAMP Web site[16].

chaos That which we should be mindful of.

Charlie Gibbs Fracture Zone See Saunders [1994].

Jule Charney (1917-1981) A dominant figure in atmospheric science and geophysical fluid dynamics in general in the three decades following WWII.

[http://www.nap.edu/readingroom/books/biomems/jcharney.html]

chemical oceanography The most thorough and complete series of reviews on the topic can be found in the *Chemical Oceanography* series. The chapters to date are:

1. Ocean and estuarine mixing processes - K. F. Bowden
2. Sea water as an electrolyte solution - M. Whitfield
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7. Minor elements in sea water - P. G. Brewer
8. Dissolves gases other than CO_2 - D. R. Kester
9. The dissolved gases–carbon dioxide - G. Skirrow
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11. The micronutrient elements - C. P. Spencer
12. Biological and chemical aspects of dissolved organic material in sea water - P. J. Le B. Williams
13. Particulate organic carbon in the sea - T. R. Parsons
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17. Marine pollution - E. D. Goldberg
18. Radioactive nuclides in the marine environment - J. D. Burton
19. Analytical chemistry of sea water - J. P. Riley et al.
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22. Seaweed in industry - E. Booth
23. Marine drugs: chemical and pharmacological aspects - H. W. Youngken, Jr. and Y. Shimizu
24. Oceanic sediments and sedimentary processes - T. A. Davies and D. S. Gorsline
25. Weathering of the Earth's crust - G. D. Nicholls
26. Lithogenous material in marine sediments - H. L. Windom

[16]http://coral.aoml.noaa.gov/

27. Hydrogenous material in marine sediments: excluding manganese nodules - H. Elderfield
28. Manganese nodules and other ferro–manganese oxide deposits - D. S. Cronan
29. Biogenous deep sea sediments: production, presentation and interpretation - W. H. Berger
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34. The geochemistry of deep–sea sediments - R. Chester and S. R. Aston
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45. Trace elements in sea–water - K. W. Bruland
46. The chemistry of interstitial waters of deep sea sediments: interpretation of deep sea drilling data - J. M. Gieskes
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50. Marine pollution - M. R. Preston
51. Electroanalytical chemistry of sea water - C. M. G. Van Den Berg

Compare to biological, geological and physical oceanography. See Holland [1978].

chemical tracers See England and Maier-Reimer [2001].

Chile Current Another name used for the Peru Current.

Chile–Peru Current Another name used for the Peru Current.

China Coastal Current A southward flowing current along the Chinese coast in the Yellow Sea. This current brings low salinity water from the northern parts of the Yellow Sea, particularly the Bohai Gulf, to the south and on into the East China Sea where part of it continues along the coast and another part joins and turns eastward with the northward flowing Taiwan Current.

chlorine titration The method developed by Knudsen and others in 1902 to determine the chlorinity and therefore salinity of a sea water sample. See Dietrich [1963].

chlorinity A concept originally defined (circa 1900) to circumvent the difficulties inherent in attempting to directly measure the salinity of sea water. It was determined by volumetric titration using silver nitrate and originally defined as "the weight in grams (in vacuo) of the chlorides contained in one gram of seawater (likewise measured in vacuo) when all the bromides and iodides have been replaced by chlorides." This was defined in terms of the atomic weights known in 1902 and as such was dependent on any changes in their determinations. The weights did change so the definition was kept in terms of the 1902 atomic weights until a new definition was determined in 1937. The new definition of chlorinity as "the mass of silver required to precipitate completely the halogens in 0.3285234 kg of sample seawater" was free of this limitation.

The chlorinity was later defined in terms of electrical conductivity when it was determined that density may be predicted from conductivity measurements with nearly an order of magnitude better precision than from a chlorinity titration. This change was also predicated on the development of precise and reliable electronic instruments in the 1950s to perform the measurements. This led to the present method of calculating the chlorinity (and thence salinity) by experimental determination of a relationship between chlorinity and the conductivity ratio of a sample at atmospheric pressure and 15° C to that of a standard seawater. See Lewis [1980] and Lewis and Perkin [1978].

chlorofluorocarbon (CFC) Any of a group of exceptionally stable compounds containing carbon, fluorine, and chlorine, which have been used especially as refrigerants and aerosol propellants. CFCs are climatically significant for their ability to break down ozone molecules in the atmosphere. There are several kinds of CFCs, the most common being CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115, having ODPs of, respectively, 1, 1, 0.8, 1 and 0.6. They are also significant as a greenhouse gas since, molecule for molecule, they are 10,000 times more efficient in trapping heat in the atmosphere than carbon dioxide. The GWPs of CFC-11 and CFC-12 are, respectively, 5000 and 8500.

chlorosity The number of grams of chloride and chloride equivalent to the bromide in one liter of sea water at 20° C. See Riley and Chester [1971].

Chukchi Sea One of the seas found on the Siberian shelf in the Arctic Mediterranean Sea. It is located to the east of the East Siberian Sea, to the north of the Bering Strait, and adjoins the Arctic Ocean proper to the north. This has also been called the Chukotsk Sea. See Zenkevitch [1963], Weingartner et al. [1998] and Münchow et al. [1999].

Chukotsk Sea See Chukchi Sea.

CICAR Acronym for Cooperative Investigation of the Caribbean and Adjacent Regions, an IOC Coordination Group.

CINCS A project to study pelagic–benthic coupling in the oligotrophic Cretan Sea. The primary aim of the study was to study biogeochemical exchanges between the Cretan continental shelf and the adjacent open marine ecosystem of the oligotrophic Cretan Sea. The CINCS program ran in parallel and was complementary to the PELAGOS program.

Tselepides and Polychronaki [2000] provide the details of the study:

> The scientific and administrative coordination of the project was undertaken by the Institute of Marine Biology of Crete and involved collaboration with 40 scientists from seven other laboratories (Netherlands Institute for Sea Research, National Centre of Marine Research in Athens, University of Genova, University of Tromso, Southampton Oceanography Centre, University of Crete and the Laboratory of Marine Microbiology in Marseille) representing six of the European Union countries. The study area was a 30 by 40nm area in the south Cretan

Sea contiguous to the northern coast of the island of Crete and cover a bathymetric depth range of 40 to 1570 m. Sampling was conducted at a grid of stations which were intensively sampled on eight bimonthly oceanographic cruises between May 1994 and September 1995. Two research vessels (the R/V *Aegaeo* and *Philia*) were used simultaneously to cope with the intensive sampling schedule and a number of technologically advanced sampling gears (including benthic landers, time lapse cameras and a submersible) were used for the first time in the Eastern Mediterranean.

See Tselepides and Polychronaki [2000].

[http://www.ncmr.ariadne-t.gr/frame/CINCS.html]
[http://bali.cetiis.fr/mtp/MTP1/Projets/cincs.html]

circalittoral zone This has also been called the outer sublittoral zone.

circle of mean temperature A concept advanced by Sir James Clark Ross in 1847 in which he posited that there is a latitude circle where the mean temperature of the sea is constant through its entire depth. North of this line, located at 56° S and having a temperature of 39.5° F, the sun warms the sea to temperatures above this mean temperature such that at 45° S the mean temperature line has descended to 600 fathoms. The limit of the sun's influence was ascertained to be 1200 fathoms, at which latitude the surface temperature was 78∘ F. Similarly, the mean temperature line descends to the south of the circle where it exists at a depth of 750 fathoms at 70° S, above which the temperature decreases to a surface minimum of 30° F. The latitude of the circle corresponds closely to the mean position of what is now known as the Antarctic Convergence, thus leading to Ross identifying an important oceanic feature for the wrong reasons. The figure of 39.5° F was used because Ross, throughout his 3 year voyage, consistently measured temperatures at depths as great as 1200 fathoms but never record a temperature lower than 39.5° F due to pressure distortion effects on his thermometers. See Deacon [1971].

Circumpolar Deep Water (CDW) The most extensive water mass found in the ACC, CDW is usually further split into Upper Circumpolar Deep Water (UCDW) and Lower Circumpolar Deep Water (LCDW). UCDW is characterized by an oxygen minimum and nutrient maxima (with sources in the Indian and Pacific Oceans) as well as by a relative minimum in temperature south of the Subantarctic Front (SAF) induced by the overlying Antarctic Intermediate Water (AAIW) and Winter Water. LCDW is characterized by a salinity maximum and nutrient minima derived from North Atlantic Deep Water (NADW).

The source region of the split (and LCDW) is in the southwest Atlantic where relatively warm, salty, oxygen rich and nutrient poor NADW meets the ACC just below the oxygen minimum therein, thus splitting the CDW into two parts. The upper branch of this split retains the oxygen minimum layer present before the split, with the lower branch also showing an oxygen minimum induced by high oxygen concentrations in both the overlying NADW and the underlying Antarctic Bottom Water. The latter minimum has been eroded via mixing by the time the LCDW reaches the Greenwich Meridian, to be replaced by a general increase in oxygen from the UCDW minimum to the bottom.

The oxygen minimum of the UCDW lies slightly below the phosphate and nitrate maxima. At the Drake Passage the concentrations in this minimum increase from 3.7 mL/L in the Subantarctic Zone (SAZ) to 4.1 mL/L in the Antarctic Zone (AZ). The NADW influx to the east of this reverses this trend such that concentrations decrease to the south at the Greenwich Meridian, e.g. from 4.2 mL/L near the SAF to less than 4.1 mL/L near the PF. The mean concentrations of the nutrient maxima at the Drake Passage or 2.42 μmol/L for phosphate and 35.4 μmol/L for nitrate. The phosphate maximum is eroded by NADW north of the PF such that it is reduced to 2.36 μmol/L at the Greenwich Meridian, although it is unchanged south of the PF. The nitrate concentration erodes slightly to 34.8 μmol/L north of the SAF at the Greenwich Meridian, while it increases to as high as 36.8 μmol/L near the PF.

The mean salinity at the LCDW salinity maximum at Drake Passage is 34.729, the lowest in the Southern Ocean since there it is most remote from the NADW source of the maximum. The phosphate minima concentration at Drake passage is about 2.25 μmol/L while the nitrate minima is 32.5 μmol/L. That are reduced to, respectively, 1.98 μmol/L and 29.9 μmol/L, north of the PF at the Greenwich Meridian, with the concentrations reduced even south of the PF, although to a lesser degree.

The paths of LCDW in the Atlantic are summarized by Onken [1995]:

> In the Atlantic, LCDW is found in all basins. From the Argentine Basin it flows north and invades the Brazil Basin via the Vema and Hunter Channels and the Lower Santos Plateau. At the northern end of the Brazil Basin, the flow splits into an eastward branch through the Romanche Fracture Zone and a northwestward one, which spills over the broad equatorial sill into the Guiana Basin and finally into the North American Basin, where it can be identified up to 40°N. The eastern North Atlantic, that is, the Cape Verde, Canary and Iberian Basins, are supplied via the Vema Fracture Zone at ≈11°N. Here LCDW influence has been traced northward up to ∼32°N. The Sierra Leone and Angola Basins get their LCDW contribution through the Romanche Fracture Zone from the Brazil Basin; however, the abyss of the southwesternmost corner of Angola Basin is also partly influenced by LCDW, which originates from the Cape–Agulhas Basin and spills over deep sills in the Walvis Ridge named the Walvis Passage.

See Reid et al. [1977], Whitworth and Jr. [1987] and Onken [1995].

CIRFZ The Circulation in the Romanche Fracture Zone experiment took place in November–December 1994. It was a cooperative effort between American and French scientists aboard the N/O Le Noroit to study the movement of Antarctic Bottom Water (AABW) through the Romanche Fracture Zone. During the 20 day experiment 55 HRP profiles and more than 30 CTD stations were completed, with most of the work concentrated in and around the Zone. Twelve more HRP dives comprising two equatorial sections were made after the work in the Zone to examine the structure of the deep equatorial jets. It was found that very strong eastward velocities in the deepest part of the Zone were responsible for high levels of turbulent mixing of the AABW. See Polzin et al. [1996] and Montgomery [1996].

CITHER Acronym for CIrculation THERmohaline, a French program to study the South Atlantic equatorial and meridional boundary regions. This was part of the French contribution to WOCE and was funded by CNRS, IFREMER and ORSTROM, and was carried out by scientists from CEN/Saclay, Université de Bretagne, Occidentale, IIM/Vigo (Spain), Univeristy of Bremen (Germany) and BNPL/Sequim (USA). According to the web site:

> CITHER is an experimental programme in physical and geochemical oceanography aiming at a better description and understanding of the general circulation of the South and Equatorial Atlantic, and the contribution of this oceanic region to the global thermohaline circulation. It rests on the realization of five large scale hydrographic lines of the WOCE Hydrographic Programme (WHP) and their analysis both in themselves for local studies, and in association with other hydrographic lines and Lagrangian measurements for more synthetic approaches of the whole South Atlantic region.

See Arhan et al. [1998].

[http://www.ifremer.fr/lpo/cither/]

C–LAB Acronym for Communication–Linked Automatic Buoy, a moored oceanographical and meteorological buoy system operating in Prince William Sound, Alaska since late 1991. This started out as part of the CFOS project but became part of the SEA project in 1994. The buoy is moored to the southeast of Naked Island, Alaska in water 190 m deep. It is usually deployed in late February or early March and recovered in late November. C–LAB consists of a suite of meteorological instruments to measure wind speed and direction, air temperature, and barometric pressure. Water temperature measurements are made at 11 different depths, and there is a fluorometer at 10 m depth to measure the fluorescence of microscopic phytoplankton. Data are collected 12–18 times per day via the ARGOS system. See the C–LAB Web site[17].

clapotis More later.

Clausius-Clapeyron equation An equation expressing rate of change of the saturation vapor pressure with temperature. It is given by

$$\frac{de_w}{dT} = \frac{L_v}{T(v_v - v_w)}$$

where e_w is the saturation vapor pressure, T the temperature, L_v the latent heat of vaporization, v_v the specific volume of the vapor phase, and v_w the specific volume of the water phase. This is given approximately by

$$L_v(T) \simeq 2.5008 \times 10^{-6} - 2.3 \times 10^3\, t\; J\,\mathrm{kg}^{-1}$$

where t is the temperature in degrees Celsius.

CLIMAP Acronym for Climate: Long-Range Investigation Mapping and Prediction, a project started in 1971 by a consortium of scientists from many institutions to study the history of global climate over the past million years, particularly the elements of that history recorded in deep-sea sediments. One goal of CLIMAP, the Last Glacial Maximum Project, was to reconstruct the boundary conditions for the climate 18,000 years ago to serve as boundary conditions for atmospheric GCM simulations. See Project [1976] and Project [1981].

climate Traditionally defined in terms of the mean atmospheric conditions at the earth's surface. Peixoto and Oort [1992] offer the more technical and broader "set of averaged quantities completed with higher moment statistics (such as variances, covariances, correlations, etc.) that characterize the structure and behavior of the atmosphere, hydrosphere, and cryosphere over a period of time." Any definition as least implicitly involves some sort of averaging procedure to distinguish the climate from that more instantaneous quantity we call the weather.

climate drift The divergence of a coupled atmosphere-ocean numerical model simulation from an initial or observed state due to imbalances between the components. See also systematic errors and flux correction. The origin of this drift is the mismatch between the externally-prescribed air-sea surface fluxes used to drive each model during the spin-up phase and the surface fluxes computed by the coupled model once the ocean and atmosphere components are joined. Sources for this difficulty involve shortcomings in the simulation of extensive layers of marine stratocumulus clouds in tropical and sub-tropical regions, errors in surface fluxes, insufficient model resolution, spin up and initialization difficulties, sea ice representation problems, and the treatment of the vertical penetration of heat into the ocean. This has also been called solution drift. See Sausen et al. [1988], Manabe and Stouffer [1988], and Meehl [1992].

[17] http://murre.ims.alaska.edu:8000/~eslinger/CLAB/clab.html

climate forcing agents Any of several factors which can change the balance between the energy (in the form of solar radiation) absorbed by the Earth and that emitted by it in the form of long-wave infrared radiation, i.e. the radiative forcing of climate. Examples include changes in the amount or seasonal distribution of solar radiation that reaches the Earth due to Milankovitch forcing, changes in the albedo due to desertification, deforestation, or changes in ice area, and the absorption of solar radiation by aerosols in the atmosphere.

Clyde Sea See Simpson and Rippeth [1993].

CME Abbreviation for Community Modeling Effort, a WOCE component to design and execute a series of baseline calculations of the wind- and thermohaline-driven, large-scale ocean circulation, to make comparisons of these simulations with observations, and to evaluate the performance of the models and identify needed improvements. See the CME Web site[18].

CMICE See Current Meter Intercomparison Experiment.

CMIP Abbreviation for Coupled Model Intercomparison Project, an analog of AMIP for global coupled ocean–atmosphere general circulation models. It began in 1995 under the auspices of CLIVAR and is supported (as is AMIP) by PCMDI. The purpose of CMIP is to examine climate variability and predictability as simulated by the models, and to compare the model output with observations where available. See the CMIP Web site[19].

CMO Abbreviation for Coastal Mixing and Optics program, a project to study the mixing of ocean water on the continental shelf, and the effect of the mixing on the transmission of light through the water.

`[http://wavelet.apl.washington.edu/CMO/]`
`[http://www.whoi.edu/science/AOPE/cofdl/cmo/]`

cnoidal wave A periodic wave that can have widely spaced sharp crests separated by wide troughs, not unlike the wave froms just outside the breaker zone near the shore. Limiting cases of cnoidal waves include solitary waves (when the wave period becomes infinite) and Airy waves, although the mathematical difficulties of the theory have kept it from such wide application. The cnoidal wave profile is given by

$$\eta = H\,\mathrm{cn}^2\left[2K(\kappa)\left(\frac{x}{L} - \frac{t}{T}\right), \kappa\right]$$

where L is the wavelength, T the period, H the wave height, $K(\kappa)$ the complete elliptic integral of the first kind of modulus κ, η the coordinate of the water surface above the trough level at the horizontal coordinate x, and $\mathrm{cn}(r)$ the Jacobian elliptic function of r (from whence comes "cnoidal" analogous to "sinusoidal"). See Komar [1976] and LeMehaute [1976].

COADS Acronym for Comprehensive Ocean Air Data Set, a CGCP program to update and enhance the most extensive and widely used set of surface marine data available for the global ocean over the past 150 years. See the COADS Web site[20].

COAMPS Acronym for Coupled Ocean Atmosphere Mesoscale Prediction System, a numerical weather prediction model of the NRL.

COARE Acronym for Coupled Ocean-Atmosphere Response Experiment, a TOGA experiment conducted in thr equatorial western Pacific from November 1992 through February 1993. The stated aims of COARE were to describe and understand:

[18] http://www.ucar.edu/oceanmodel.html
[19] http://www-pcmdi.llnl.gov/covey/cmip/cmiphome.html
[20] http://www.ncdc.noaa.gov/onlinedata/coads/coads.html

- the principal processes responsible for the coupling of the ocean and atmosphere in the western Pacific warm pool system;
- the principal atmospheric processes that organize convection in the warm pool region;
- the oceanic response to combined buoyancy and wind stress forcing in the western Pacific warm pool region; and
- the multiple scale interactions that extend the oceanic and atmospheric influence of the western Pacific warm pool system to other regions and vice–versa.

Additional information can be found at the TOGA COARE Web site[21]. See Webster and Lukas [1992] and Godfrey et al. [1998].

COAST A 5–year interdisciplinary research project on cross–shelf transport processes in a wind–driven system. This is sponsored by the NSF and part of the CoOP program. The program consists of field experiments off the Oregon coast along with coordinated ocean circulation, ecosystem and atmospheric modeling. COAST started in early 2000, with major field work taking place in summer 2001 and winter 2003. The major participants are Oregon State University, the University of North Carolina and LDEO.

[http://damp.oce.orst.edu/coast/]

COAST Acronym for Coastal Observation and Simulations with Topography, a PMEL program. COAST was conducted from Nov. 30 to Dec. 15, 1993 and the purpose was to collect the observations needed to document and ultimately anticipate the influence of orography on mesoscale weather phenomena in coastal environments. The objectives were:

- to identify conditions that contribute to the development of coastally trapped disturbances during periods of strong but relatively uniform onshore flow; and
- to observe the mesoscale structure of fronts and other features associated with baroclinic cyclones over the open sea, and describe their evolution as they come under the influence of orography.

See Bond et al. [1997].

[http://www.atmos.washington.edu/~gcg/MG/coastsum.html]

Coastal Mixing and Optics Project (CMO) A project funded by ONR and performed by the Ocean Physics Laboratory at ICESS. The objective is to determine how particles and optical properties respond to physical forcing under various oceanic conditions on a broad continental shelf off the east coast of the U.S. This will be done by collecting time series of optical and physical data from several depths using a variety of newly developed optical and physical instruments placed on a mooring at a mid–shelf location. See the CMO Web site[22].

coastal trapped wave To be completed.

COASTWATCH See Espedal et al. [1998].

COBSEA Acronym for Co-ordinating Body of the Seas of East Asia.

CODAR Acronym for Coastal Ocean Dynamics Applications Radar.

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[21] http://www.coare.ucar.edu/
[22] http://www.icess.ucsb.edu/opl/cmo.html

CODE Acronym for Coastal Ocean Dynamics Experiment, a program to study shelf processes that took place north of San Francisco during the summers of 1981–1982. The program employed drifters, hydrographic measurements, Doppler–acoustic surveys, wind measurements, and remote sensing to study a prominent, persistent filament near Point Arena. It was notable for the first integrated use of remote sensing for a study of this magnitude, the first coastal use of the ADCP, and the introduction of a new generation of high quality near–surface drifters. It led to a clear understanding of regional scale wind driving and provided a moored array data set still uses as the standard to test models. See Davis [1985], Winant et al. [1987] and Lentz and Beardsley [1991].

COHMAP The Cooperative Holocene Mapping Project (COHMAP) was an initiative to assemble a global array of well-dated paleoclimate data and use a GCM to identify and evaluate causes and mechanisms of climate change over the last 18,000 years. See Project [1988].

COLD Acronym for Coupled Ocean–Ice Linkages and Dynamics, a research program whose components include LTER, RACER and SANTA CLAuS. See the COLD Web site[23].

cold start problem In climate modeling, this is a problem that results from beginning a model simulation at a point in time when the climate response to natural and anthropogenic forcing that happened before the start of the simulation is already in progress. An example would be specifying 1950 initial conditions for a simulation of the effects of anthropogenic CO2 increases when the CO2 increases although the CO2 increases started in the latter half of the 19th century. This results in a simulation that is missing at least 50 years of the time evolution of the modeled system's response to increasing atmospheric CO2, which can be vital to the prediction of future states of a system with components that change on time scales greater than 50 years, e.g. the ocean.

Columbia Current (CC) According to Strub et al. [1998]:

> The Columbia Current flows to the north next to the coast off northern Ecuador and Columbia and is strongest in austral winter (August). It is confined to the top 100 m, reaches velocities of order 1.0 m s^{-1} and stays within 100–200 km of the coast. During most periods, it forms the eastern limb of a cyclonic gyre that fills the Panama Bight.

See Wooster [1959] and Strub et al. [1998].

Columbia River Estuary See Sherwood et al. [1990].

COMAR Acronym for Coastal Marine Program, a UNESCO project.

Comprehensive Ocean Air Data Set This is an extensive data set that was created by combining, editing and summarizing global in situ marine data from many sources. It covers the period 1854-1992. It is a cooperative project among ERL, NOAA, the NCDC, CIRES and NCAR. Extensive hypertext documentation[24] is available. There is also a further processed version of this data set called UWM/COADS. See Woodruff et al. [1987].

computational grid A mapping of discrete points onto a continuum (e.g. the ocean, the atmosphere, etc.) to comprise a grid-like structure. This is done to enable a numerical solution of the equations governing the specific continuum in cases where analytical solutions are impossible or infeasible due to irregular boundary conditions, nonlinearities in the governing equations, or some combination thereof. A discretized version of the equations is solved at each point in the grid, and the collection of these

[23] http://hahana.soest.hawaii.edu/hotcold.html
[24] http://www.ucar.edu/dss/pub/COADS.html

solutions is combined (usually graphically) to recover a continuum-like solution. It is hoped that this solution well approximates the hypothesized correct solution.

computational mode An artifact of numerical solution procedures that use a centered scheme for temporal advancement, i.e. one that requires information at three time levels. Starting such a scheme requires two independent initial conditions, one specified and the other calculated from this using a temporal scheme requiring only two time levels. This results in a solution that is actually the sum of two solutions, one related to the actual physics of the problem and the other purely an artifact of the numerical procedure. The numerical solution usually alternates at each time step, resembling a sawtooth wave over time, and can be damped by averaging the solution over two consecutive time steps at suitably chosen intervals. See Kowalik and Murty [1993].

concentration basin See mediterranean sea.

cone See fan.

CONFLUENCE A program to investigate the upwelling region and mixing of the Rio Plata into the southwest Atlantic Ocean.

conservation laws More later.

consistency In numerical modeling, a numerical computational scheme is said to be consistent if the discrete algebraic equations created by the process of discretization recover or reduce to the original continuum differential equations as the spacing in the computational grid is shrunk to zero. The scheme is said to be unconditionally consistent if the above is true no matter how (i.e. in what order, etc.) the grid is shrunk. Thus consistency deals with relations between equations in their continuum versus discrete forms, as opposed to convergence.

continental margin The official IHO definition for this undersea feature name is "the zone, generally consisting of shelf, slope and continental rise, separating the continent from the deep sea floor or abyssal plain; occasionally a trench may be present in place of a continental rise."

continental rise The official IHO definition for this undersea feature name is "a gentle slope rising from the oceanic depths towards the foot of a continental slope."

continental shelf See shelf.

continental slope The relatively steep slope usually found between the continental shelf and the abyssal plain. Continental slopes range from 3 to 6° in slope (with 4° being about average), range in depth from 100-300 m to 1400-3200 m, range in width from 20-100 km, and occupy about 8.5% of the ocean floor if the 2000 m contour is taken as the deeper border. The continental shelf and slope are said to comprise the continental margin.

Continental Slope Current A persistent poleward flow over the continental slope region off northwestern Europe. It is thought to originate as far south as the Armorican Slope region off the west coast of northern France, and flows north past the exit of the Faroe–Shetland Channel. This current supplies the saltiest and warmest water exchanged over the Greenland–Scotland Ridge, a water mass known as North Atlantic Water. See Hansen and Osterhus [2000] and the references therein.

continental shelf oceanography See Allen et al. [1983], Brink [1987], Walsh [1988], Brink [1991] and Huyer [1990].

continental shelf wave To be completed.

Continental Water Boundary (CWB) In physical oceanography, a frontal region in the Southern Ocean located at around 61-62° S that separates the Continental Zone to the south and its separate water mass of uniform temperature and low salinity in the upper 500 m from the Antarctic Zone to the north. The term was introduced to demarcate the northern limit of a cold water mass (colder than about 0°C) near the South Shetland Islands having a subsurface isothermal layer extending from about 150 m depth to more than 500 m. See Tomczak and Godfrey [1994], pp. 76. This is also known in the Weddell Sea region as the Weddell Gyre Boundary.

Continental Zone In physical oceanography, a region in the Southern Ocean between the Southern ACC Front and the continent of Antarctica. It is characterized hydrographically by a water mass of uniform temperature and low salinity in the upper 500 m. The CZ is one of four distinct surface water mass regimes in the Southern Ocean, the others being (to the north) the Antarctic Zone (AZ), the Polar Front Zone (PFZ) and the Subantarctic Zone (SAZ). See Orsi et al. [1995].

continuity equation See Sander [1998].

continuous plankton meter A device used by biological oceanographers to provide continuous qualitative and quantitative records of plankton distribution and patchiness when studying swarms over large areas. The meter is a square or round torpedo-shaped tube about 1 m long that is towed behind a ship underway at full speed. There is a small entrace hole in the front end which leads to a wider tunnel across which a band of silk gauze is stretched. This gauze is slowly wound from one spool to another via a propeller mechanism attached to the outside of the meter, thus being linked to the speed of the meter and therefore the distance it has traveled. Data gathered with the meter is considered supplementary to other types of net tow data gathered separately at individual stations. See Sverdrup et al. [1942].

contra solem A term introduced by V. W. Ekman in 1923 to describe motion turning to the left (right) in the northern (southern) hemisphere, i.e. cyclonic motion. This is the reverse of cum sole.

contrail cirrus A type of cloud hypothesized to form when water vapor within jet aircraft plumes undergoes homogeneous and/or heterogeneous nucleation processes upon which ice particles form and grow. They persist for only a short time if the ambient air is dry, but may last for minutes to hours and spread into linear formations a few kilometers in width and tens of kilometers in width if humid conditions prevail. They also tend to cluster in groups. Various investigations attempting to show a connection between them have at least showed a correlation between increased use of jet fuel in some regions and the average annual number of clear days. See Liou [1992].

convective adjustment In the numerical modeling of ocean circulation, this is a process wherein, after each time step, the vertical potential density gradient is calculated and, if denser water anywhere overlies lighter water, the densities are mixed such that a state of either a neutral or slightly positive stability is created. This process numerically mimics the convective overturning processes observed and inferred in the real ocean at locations such as the Weddell Sea, although the real process takes place at spatial scales on the order of a kilometer or less while the model resolution is such that the spacing between grid points is usually much greater than this.

convergence In numerical modeling, a numerical computational scheme is said to be convergent is the solutions to the discrete algebraic equations created by the process of discretization approach the solutions of the original continuum differential equations as the spacing in the computational grid is shrunk to zero. Thus convergence deals with relations between solutions of equations in their continuum versus discrete forms, as opposed to consistency.

CONVEX–91 Acronym for CONtrol Volume EXperiment, 1991, a survey designed to investigate the shape and strength of the Northeastern sector of the North Atlantic subpolar gyre, and to examine the exchanges between the upper and deep waters of the area. This was part of the Gyre Dynamics Experiment, itself part of WOCE core project 3. See Read [2001].

conveyor belt A simple model of a closed global thermohaline interbasin exchange circulation scheme introduced by Broecker [1987], Broecker [1991], and Gordon [1986]. Cold and salty deep water formed in the Norwegian/Greenland Sea (called NADW) flows southward as a deep current where around 30% is transported via the ACC to the Indian and Pacific Oceans. The flow travels northward along the western boundaries of these oceans and upwells in the northern portions. This drives a warm, shallow return flow that travels from the Northern Pacific through the Indonesian Archipelago and the Indian Ocean (gaining the water upwelled there) towards the South Atlantic via the southern tip of Africa. There it is joined by the remaining 70% that mixed with AAIW and returned to the South Atlantic via the Drake Passage. A general northward flow returns the water to the North Atlantic. The regions of deep water formation around Antarctica form AADW which flows under and mixes with the NADW, forming another component in the mixture. This is a simple (and to some an overly simplistic) view of the thermohaline circulation, but it is useful as a first order description. A more complete and accurate version of the interbasin exchange circulation pattern has been developed.

cooscillating tide The tide created in an estuary caused by the ocean tide at the entrance to the estuary acting as a driving force. See Officer [1976].

COPE Acronym for Coastal Ocean Probing Experiment, a NOAA ETL experiment which took place in 1995. The objectives were to determine how environmental conditions affect observations of internal waves with active and passive microwave sensors, to develop improved instrumentation and techniques for observation of the air–sea interface, and to evaluate new scattering theories. See Trokhimovski et al. [2000]. See the COPE Web site[25].

COPS Acronym for Coastal Ocean Prediction Systems Program.

coral bleaching A phenomena wherein coral reefs bleach as a result of high temperatures or other environmental stresses, e.g. pollution episodes. Observations indicate that since 1979 bleaching episodes have coincided with El Nino war events and suggest that the scale of bleaching since 1979 is unprecedented since 1870. See Goreau and Hayes [1994] and Glynn [1993].

coral reef A limestone structure found in relatively shallow water composed of corals, organisms that secrete limestone foundations to provide structural support and protection. There are three geomorphologically distinct types of coral reefs, fringing reefs, barrier reefs, and atolls, although there are gradations between these types. All these types have the same basic biological structure and result from the same processes of accretion. See Wells [1957] and Barnes and Hughes [1988].

Coral Sea A marginal sea located in the southwest Pacific centered at about 155° E and 14° S off of the northeast coast of Australia. It is also bordered by the Solomon Islands and Papua New Guinea to the north and west, New Caledonia and the New Hebrides Islands to the east, and abuts the Tasman Sea to the south. The bathymetry is essentially composed of the Solomon Basin to the northwest, the Coral Sea Basin in the center, and the New Hebrides basin to the east. It has a mean depth of about 2400 m with a maximum depth of 9140 m in the New Britain Trench. The shallowest parts are found on the continental shelf off of Queensland. See Rotschi and Lemasson [1967].

[25] http://www6.etl.noaa.gov/projects/cope.html

core layer method A systematic attempt to apply hydrography to describe the waters of the ocean as developed by Wust and his students in the 1930s. In this method he distinguished between different core layers characterized by maxima or minima in their oxygen, salinity or temperature fields. While of unquestioned descriptive value, this method has some significant limitations. The number of layers that can be identified using this techique is limited, e.g. Wust identified just seven such layers in the North Atlantic, a shortcoming ameliorated by the development of the isopycnal method. Also, these layers were too often uncritically assumed to be the main paths of ocean circulation, an assumption that has been proven to be incorrect on more than one occasion.

Coriolis acceleration An acceleration, the magnitude of which for a particle moving horizontally on the surface of the Earth is $2\Omega V \sin\phi$ where Ω is the angular velocity of the rotation of the Earth, V the vector velocity relative to the Earth's surface, and ϕ the latitude. This acceleration is directed perpendicular to the direction of V and to the right (left) in the northern (southern) hemisphere. There are other terms for three-dimensional motion in GFD, but they are generally negligible.

Coriolis effect The denotes the effect of the Coriolis force to deviate a moving body perpendicular to its velocity.

Coriolis force The force which, acting on a given mass, produces the Coriolis acceleration. It is a fictitious force introduced to facilitate the application of Newton's second law of motion to a rotating reference frame. See Persson [1998].

Coriolis parameter This is defined by

$$f = 2\Omega \sin\phi$$

where Ω is the angular velocity of the rotation of the Earth and ϕ the latitude. This gives the Coriolis acceleration on a moving particle when multiplied by that particle's velocity.

CORK Acronym for Circulation Obviation Retrofit Kit, a device that allows boreholes to be isolated from the ocean water above the seabed and conditions in the hole to be monitored for long periods of time. CORK's purpose is to provide a long–term seafloor observatory intended to allow a monitored and accessible borehole to return to its pre–drilling state.

The CORK data logger can record temperature and pressure data for five years, and store it in memory for an additional five years until it can be retrieved via either a manned submersible or a ROV. The data is obtained by a string of sensors hanging from CORK at the bottom of the borehole. It also has fittings for recovering samples from inside the hole and allows fluid to be injected into the hole for certain kinds of tests.

`[http://www-odp.tamu.edu/sciops/labs/downhole/cork.html]`
`[http://www-odp.tamu.edu/dsd/TOOLS/CORK.HTM]`

COROAS Acronym (in Portuguese) for Oceanic Circulation in the Western Region of the South Atlantic, a Brazilian research program whose objective was to determine the seasonal mean fields of velocity, heat and mass transport by the Brazil Current and the AAIW flowing into the coastal region of southeastern Brazil. The specific objectives included:

- estimating the baroclinic and barotropic components of the circulation along the Brazilian coast, including the continental shelf and shelf break regions, between Ubatuba and Cananéia;
- continuously monitoring the velocity field and heat and mass transports of the Brazil Current and AAIW along the southeastern Brazilian coast;
- determining the importance of mesoscale vortices to the heat and mass transport of the Brazil Current;

- determining the response of the continental shelf water to the forcing of intrusions by the Brazil Current and AAIW; and
- studying the deep circulation in the Brazil Basin, including its interaction with the Argentine Basin.

The experiment took place from November 1992 through February 1994.

[http://www.labmon.io.usp.br/projects/coroas/coroas.html]

CORSA Acronym for Cloud and Ocean Remote Sensing around Africa, a project which aims to provide a quality controlled data set of surface, atmospheric and cloud parameters over a time period and at a resolution not available from any other source. The data are derived from NASA AVHRR GAC level 1b data products, with over 13,000 of these products having been processed. See the CORSA Web site[26].

COSNA Acronym for Composite Observing System for the North Atlantic.

Costa Rica Coastal Current (CRCC) A current found entirely in the eastern tropical Pacific. It begins just offshore of the Panama Bight where the North Equatorial Countercurrent (NECC) ends to the east of the Galapagos, and turns to the north off the coast of Central America and Mexico. It meets the southward flowing California Current around the mouth of the Gulf of California. The position of this confluence varies seasonally, with the meeting occurring off Tehuantepec during March and April, and off Baja California during September and October. After this confluence, it turns west to become part of the North Equatorial Current (NEC). The presence of this current is inferred mostly from large–scale hydrographic measurements. The northern part of this is sometimes called the Mexican Current.

During the winter months, strong winds cross Central America through several isthmuses, e.g. Tehuantepec and Papagayo. These disturb the Costa Rica Coastal Current by spinning up a wind jet across the shelf, and intense cooling of the sea surface beneath the jet results from the upwelling and entrainment of subsurface water. Large anticyclonic warm core eddies develop to the right (north) of the wind jet, along with weaker, short–lived cyclonic counter–eddies to its left (south). An average of five of the anticyclonic eddies are spun off each year. See Badan-Dangon [1998].

Costa Rica Dome A region centered to the west of Central America around 8–10°N and 88–90°W and about 200 to 400 km wide. Open ocean upwelling causes a domelike configuration of the local well–defined thermocline, bringing nutrients to the photic zone and sustaining increased biological productivity. This cyclonic gyre is located between the North Equatorial Countercurrent (NECC) to the south, the Costa Rica Coastal Current (CRCC) to the east and north, and the extension of the California Current and beginnings of the North Equatorial Current (NEC) to the north and northwest. See Wyrtki [1964], Umutani and Yamagata [1991] and Badan-Dangon [1998].

cotidal line Lines joining the points where high water occurs at the same time. The lines show the lapse of time between the moon's transit over a reference meridian (usually the Greenwich meridian) and the occurrence of high water for any point lying on the line.

coupled model In climate modeling this refers to the combination of an atmospheric GCM with some sort of ocean model rather than the simple specification of SSTs as a lower boundary condition. From simple to complex, the ocean model hierarchy used proceeds from swamp ocean models to slab ocean or mixed-layer models to oceanic GCM models. See Meehl [1992] and Bye [1996].

Cox number See McDougall et al. [1987].

[26] http://me-www.jrc.it/CORSA/SST/corsa.html

CPOP Abbreviation for complex principal oscillation pattern, a generalization of the POP concept into the complex domain. Although this was introduced to extend the POP technique to the modeling of standing wave oscillations, it was also found the CPOPs evolve more regularly and with less noise than POPs. Also, prediction skills are significantly stronger than with the POP model. See Burger [1993].

CPR Abbreviation for continuous plankton recorder. See Reid et al. [2003].

CREAMS Acronym for Circulation Research of the East Asian Marginal Seas.

[http://hikari.riam.kyushu-u.ac.jp/creams.html]
[http://sam.ucsd.edu/onr_jes/onr_jes.html]

Cretan Arc Straits According to Kontoyiannis et al. [1999]:

> The Cretan Arc is the region that extends from the southern part of Peloponissos (at Elafonisos), through the islands of Kithira and Antikithira, along Crete to the islands of Kassos, Karpathos and Rhodes, and ends at the Asia Minor Coast to the north of Rhodes. It consists of a series of straits with complex bathymetry, which are gateways connecting the South Aegean Sea with the Ionian Sea to the west and the Levantine Sea to the east. On the eastern side, there are the Kassos Strait (∼65 km width, ∼900 m sill depth), the Karpathos Strait (∼40 km width, ∼850 m sill depth), and the Rhodes Strait (∼15 km width, ∼350 m sill depth). On the western side are the Antikithira Strait (∼30 km width, ∼700 m sill depth), the Kithira Strait (∼35 km width, ∼160 m sill depth) and the Elafonisos Strait (∼10 km width, ∼180 m sill depth).

The results of their flow measurement program in the straits contradict the traditional characterization of typical inflow/outflow at the surface/bottom, i.e.

- a deep, persistent outflow of Cretan Deep Water (CDW) ($\sigma_\theta > 29.2$), with a total annual mean of ∼0.6 Sv through the Antikithira and Kassos Straits at depths below 400 m and 500 m, respectively, with the highest outflowing transports (∼0.8 Sv) in April–June and the lowest (∼0.3 Sv) in October–December;
- a weakly varying (from 1.7 to 2.1 Sv) inflow in the upper 400–500 m of the Rhodes and Karpathos Straits, which is affected by the Asia Minor Current;
- a net outflow in the upper 400 m of the Antikithira and Kithira Straits, which is influenced by the Mirtoan/West Cretan Cyclone and varies seasonally from ∼2.5 Sv in early winter to ∼0.8 Sv in summer/early autumn.
- a complex and highly variable flow regime in the Kassos Strait, governed by interactions among the East Cretan Cyclone, the Ierapetra anticyclone, and the westward extension of the Rhodes Gyre, e.g. a net inflow of ∼0.7 Sv in autumn/early winter of one year and a net outflow of 0.5 Sv in the early spring/summer of the next year.

See Kontoyiannis et al. [1999].

Cretan Intermediate Water (CIW) A modified form of Levantine Intermediate Water (LIW) that enters the southern Aegean Sea as LIW via the eastern Cretan Straits and is ventilated and transformed by convective processes to become a slightly denser intermediate water mass. See Theocharis et al. [1999].

Cretan Sea According to Georgopoulos et al. [2000]:

> The Cretan Sea is the southernmost, largest in volume and deepest (2500m) basin of the Aegean Sea. It communicates with the Levantin Basin and the Ionian Sea through the eastern and western straits of the Cretan Arc respectively, through sills that are no deeper than 700m. To the north of the Cretan Basin is the shallow (<200 m) shelf of the Cyclades Plateau. The hydrology and the water mass dynamics of the south Aegean Sea have been known from the historic works of Lacombe et al. [1958] and Ovchinnikov [1966], and were reviewed by Malanotte-Rizzoli and Hecht [1988].

This is supplemented by Theocharis et al. [1999]:

> The Cretan Sea constitutes the larger and deepest basin of the south Aegean with an average depth of 1000 m and contains two depressions in the eastern part reaching 2500 m. To the northwest the Mirtoan basin reaches 1000 m. Between the Mirtoan and Cretan Sea depths are of the order of 600 m. The Cretan Sea is bounded to the north by the Kiklades Plateau at a depth of 400 m and to the south by the Cretan Arc islands. It communicates with the Ionian and the Levantine Seas through a series of six Straits, namely the Cretan Arc Straits. These are characterized by high relief and have sill depths ranging from 150 to 1000 m. Outside the Straits the sea bed plunges towards the deep basins of the Hellenic Trench (depth ∼3000-4000 m).

Theocharis et al. [1999] summarize the water mass pathways and dynamics in the Cretan Sea region:

> Modified Atlantic Water (MAW) comes from the western Ionian and is carried within the surface and/or sub-surface layers by the Mid–Mediterranean Jet (MMJ) and its branches; it enters the Cretan Sea mainly through the Antikithira Strait but occasionally through the Kassos Strait. Black Sea Water (BSW) flows in at the surface from the north and west Aegean and reaches the Mirtoan Sea. At times its influence can be traced as far as the Kitherian straits. The Asia Minor Current (AMC) carries the surface saline waters of Levantine origin towards the south Aegean that subsequently extend over large areas of the Cretan Sea. This input leads to the formation of highly saline Cretan Intermediate Water (CIW) within the Cretan Sea. Variability in the salinity of CIW can be attributed to the extent to which MAW participates in the formation process. However, we also detected less saline intermediate water being formed within the Cretan Basin, as well as intermediate waters with deeper characteristics most probably having their origin in the Mirtoan Basin.
>
> Thus, the intermediate water masses are represented at different areas in the θ-S diagram. Consequently, we clearly distinguish the typical LIW that enters the Aegean through the straits both from the Levantine and the Ionian Seas, as well as the more saline CIW and the colder and denser Mirtoan Intermediate Water (MIW). Interestingly, the latter flows southwards and, being dense enough, sinks in the deep troughs of the western Cretan Sea, thus probably contributing to the formation of the new very dense Cretan Deep Water (CDW) in the Cretan Sea. Moreover, a well-defined intermediate 'minimum temperature and salinity' Transition Mediterranean Water (TMW) layer in the south Aegean Sea is a new and important structural feature. Its appearance might be related to the CDW outflow towards the deep and bottom layers of the eastern Mediterranean. TMW enters the south Aegean through the Cretan Arc Straits, follows two opposite paths and fills the entire Basin. Recently, the CDW has been making a considerable contribution to the formation of the new, warmer, saltier and denser Deep Water observed in the Eastern Mediterranean, that has been displacing the Eastern Mediterranean Deep Water (EMDW) of Adriatic origin, not only in the adjacent open sea regions outside the Aegean Sea, but also more distantly in the Ionian and Levantine Seas. Thus the Cretan Sea is the unique source of the new type of EMDW.

> Finally, we have identifed the densest water mass of the south Aegean, Mirtoan Deep Water (MDW), that is almost totally isolated in the deep and bottom layers of the Mirtoan Basin. Both MIW and MDW possibly have their origins in the neighbouring Kiklades Plateau. The new hydrological vertical structure of the Cretan Sea is characterised by the superposition of three or four basic water masses, which develops significant thermohaline gradients between them. This new structure is limiting the depth to which convective mixing extends to $<\sim$250 dbar; in the past it was considered that homogenisation of the entire water column was possible. This also indicates that the 'new' CDW has its origin in the surrounding areas, as the Kiklades Plateau and/or the Mirtoan Basin. The persistence of the basic circulation elements and the vertical hydrological structure throughout the observation period indicate that a rather stable regime is reached. However, in the context of the drastic changes occurred during the last seven years in the deep thermohaline cell of the eastern Mediterranean, we would consider this regime transitional.

This body of water has also been (mostly historically) called the Sea of Crete and the Sea of Candia. See Theocharis et al. [1999], Balopoulos et al. [1999] and Georgopoulos et al. [2000].

Cretan Sea Overflow Water (CSOW) A designation proposed for a new deep water mass formed in the Cretan Sea. CSOW is warmer ($\theta > 13.6$°C) and more saline (S > 38.80) than Eastern Mediterranean Deep Water (EMDW). The formation of CSOW is an event of relatively recent origin, and is part of recent overall changes observed in the thermohaline circulation of the Eastern Mediterranean. The transition is mainly from a system with a single source of deep water in the Adriatic Sea (EMDW) to one with an additional source in the Aegean Sea (CSOW).

Other observed changes have been (according to Klein et al. [1999]):

> All major water masses of the Eastern Mediterranean, including the Levantine Intermediate Water (LIW), have been strongly affected by the change. The stronger inflow intoxi the bottom layer caused by the discharge of CSOW into the Ionian and Levantine Basins induced compensatory flows further up in thexi water column, affecting the circulation at intermediate depth. In the northeastern Ionian Sea the saline intermediate layer consisting ofxi Levantine Intermediate Water and Cretan Intermediate Water (CIW) is found to be less pronounced. The layer thickness has been reduced by factor of about two, concurrently with a reduction of the maximum salinity, reducing advection of saline waters into the Adriatic. As a consequence, a salinity decrease is observed in the Adriatic Deep Water. Outside the Aegean the upwelling of mid-depth waters reaches depths shallow enough so that these waters are advected into the Aegean and form a mid-depth salinity-minimum layer. Notable changes have been found in the nutrient distributions. On the basin-scale the nutrient levels in the upper water column have been elevated by the uplifting of nutrient-rich deeper waters. Nutrient-rich water is now found closer to the euphotic zone than previously, which might induce enhanced biological activity. The observed salinity redistribution, i.e. decreasing values in the upper 500–1400 m and increasing values in the bottom layer, suggests that at least part of the transition is due to an internal redistribution of salt. An initiation of the event by a local enhancement of salinity in the Aegean through a strong change in the fresh water flux is conceivable and is supported by observations.

See Klein et al. [1999].

Cromwell Current See Equatorial Undercurrent.

cryosphere That part of the climate system consisting of the ice fields of Antarctica and Greenland, other continental snow and ice fields, sea ice and permafrost. At present the Antarctic ice sheet holds 89.3%

of the total global ice mass, with the Greenland ice sheet holding 8.6% and mountain glaciers and permafrost holding 0.76% and 0.95%, respectively. The remaining 0.39% is distributed among seasonal snow and sea ice. See Untersteiner [1984], Hibler and Flato [1992], and Van der Veen [1992].

CRYSYS Acronym for CRYospheric SYStem, a Canadian interdisciplinary science investigation under the NASA EOS program. The goals of CRYSYS are to develop capabilities for monitoring and understanding regional and North American variations in cryospheric variables, to develop and validate local, regional and global models of climate/cryospheric processes and dynamics, and the assemble, maintain and analyze key historical, operational and research cryospheric data sets. See the CRYSYS Web site[27].

C–SALT Acronym for Caribbean–Sheets and Layers Transect, a combined mesocale, fine– and microstructure survey of the well–ordered thermohaline staircase in the tropical North Atlantic east of Barbados. Such staircases are thought to be the sites of enhanced vertical mixing by the salt finger form of double–diffusive convection. The C–SALT program was a coordinated attempt to measure the intensity of salt finger convection, monitor the finescale shear and density environment, establish the lateral extent of the layered structure, and collect velocity, hydrographic and tracer data needed to evaluate the role of the fingering processes in the regional evolution of water properties. The experiment was carried out in the spring and autumn of 1985 in an area centered at about 57°W, 12°N at the confluence of the high salinity Subtropical Underwater (SUW) at 150 m depth and the fresher Antarctic Intermediate Water (AAIW) at 750 m depth. The superposition of these two extrema gives rise to a strongly destabilizing vertical salinity gradient, i.e. the main determining factor for staircase formation.

The C–SALT program found a large, coherent, and long–lived thermohaline staircase in its study area. The occurrence of mixed layers at the minimum density ratio and the observed water mass transitions within layers indicate that salt fingers make a substantial contribution to both maintenance of the staircase and vertical mixing. See Schmitt et al. [1987].

CSCS Abbreviation for Chukchi Sea Circulation Study.

CSEC Abbreviation for Central South Equatorial Current.

CSR Abbreviation for Cruise Summary Report. See ROSCOP.

CSW Abbrevation for continental shelf wave.

CTD In oceanography, an abbreviation for Conductivity-Temperature-Depth, an instrument for performing oceanographic measurements. The CTD measures (either directly or indirectly) the three most important oceanographic parameters for describing the distribution of water in the ocean: temperature, salinity, and pressure.

CTDO Abbreviation for Conductivity-Temperature-Depth-Oxygen profiler.

CTW Abbreviation for coastal trapped wave.

CTZP Acronym for the Coastal Transition Zone Program, a research program that took place in 1987 and 1988 off the northern coast of California. The important questions this program attempted to address were the physical and biological nature and structure of cold filaments, what causes a filament to form, and the physical and biological characteristics of a filament. In order to address these questions the program included a modeling effort and divided the field effort into a pilot and a main program.

[27] http://www.dow.on.doe.ca/CRYSYS/

The pilot program took place in 1986–1987 and had the goals of gaining some three–dimensional information about biological, chemical, and turbulent processes in a filament as well as to gain further background information about the detailed physical structure. It included four large–scale, coarsely resolved surveys from San Francisco to northern California, taking place in both winter and summer. The goal was to see if filaments or related currents could be identified when upwelling was not present, thus confirming or denying the hypothesis that filaments are related to coastal upwelling.

The main program took place in summer 1988 and consisted primarily of a time series of repeated maps meant to chart out the time dependence of a single filament near Point Arena, California. It also allowed for well–sampled repeat sections of microstructure variability and detailed biological process measurements. The objective was to characterize the detailed temporal evolution of a filament and the processes that maintain its structure. See Brink and Cowles [1991].

CU Abbreviation for California Undercurrent.

CUE Acronym for Coastal Upwelling Experiment, an IDOE project.

CUEA Acronym for Coastal Upwelling Ecosystems Analysis, an IDOE project. See Smith [1981] and Barber and Smith [1981].

cum sole Descriptive of rotation in the same sense as a vector that points toward the sun, i.e. motion turning to the right (left) in the northern (southern) hemisphere, i.e. anticyclonic motion. This term, along with the opposite contra solem, was coined by V. W. Ekman in 1923.

curl The curl of a vector field is a measure of its rotational motion, i.e. when applied to the velocity vectors of air or water motion, the curl is nonzero if the parcel is spinning. In mathematical terms, the divergence of a vector function is defined by

$$\nabla \times A$$

where ∇ is the gradient operator that operates with a vector (or cross) product on the vector field A. See Dutton [1986].

current A flow of water within the sea which is coherent at least in a time–averaged sense. The currents identified as such in the world ocean include: Agulhas Current, Agulhas Return Current, Alaska Coastal Current, Alaska Current, Aleutian Current, Algerian Current, Anadyr Current, Angola Current, Antarctic Circumpolar Current (ACC), Antilles Current, Azores Current, Baltic Current, Benguela Current, Bering Slope Current, Brazil Current, California Current, Canary Current, Caribbean Current, Central South Equatorial Current, Chile Current, China Coastal Current, Cromwell Current, Davidson Current, Davidson Inshore Current, Delware Coastal Current, East Australian Current, East Arabian Current, East Africa Coast Current, East Auckland Current, East Cape Current, East Greenland Current, East Icelandic Current, East Indian Current, East Korea Current, East Spitsbergen Current, Equatorial Countercurrent, Equatorial Intermediate Current, Falkland Current, Florida Current, Gaspe Current, Guineau Current, Guyana Current, Haida Current, Hopen–Bjornoya Current, Humboldt Current,

current meter See Gould [2001] for a historical overview.

Current Meter Intercomparison Experiment (CMICE) See Beardsley et al. [1981].

CW Abbreviation for Central Water.

CWB Abbreviation for Continental Water Boundary.

cyclone An atmospheric pressure distribution in which there is a low central pressure relative to the surroundings. The circulation around the center is anticlockwise (clockwise) in the northern (southern) hemisphere.

cyclonic The direction of rotation around a center of low pressure. This is counter-clockwise in the northern hemisphere and clockwise in the southern. The term originates from the circulation observed around tropical cyclones.

cyclosonde A device that allows the profiling of the water column by alternately rising to the surface and sinking to a predetermined depth. It does so by adjusting its buoyancy. This device can be used as a platform for a variety of instruments. See Van Leer et al. [1974].

cyclostrophic wind A theoretically hypothesized wind that would exist, when blowing around circular isobars, as a balance between the pressure gradient and the centrifugal force. The Coriolis force is neglected, and as such this is a useful approximation only in low latitudes, e.g. in tropical cyclones.

CZCS Abbreviation for Coastal Zone Color Scanner, a scanning radiometer with six spectral channels centered at 0.443, 0.520, 0.550, 0.670, 0.750 and 11.5 micrometers and selected to allow measurement of ocean color and temperature, suspended sediment and chlorophyll concentrations, and ocean pollutants. It works by measuring the ratio of different colors of visible light, with the basic idea being that the higher the concentration of chlorophyll-a in the water column, the greater the proportion of light in the peaks of its absorption spectrum that will be missing. This measurement is used as a proxy for the amount of phytoplankton primary production going on in the water column.

The CZCS sensor operates in the visible portion of the spectrum so it can only collect data in clear sky conditions. This leads to the necessity of taking multi-year averages over some areas, e.g. the Indian Ocean, to get useful images. The device resolution is 800 m. This instrument flew aboard the NIMBUS-7 satellite and was active between November 1978 and June 1986. Other ocean color sensors are being launched between 1996-1998, including NASA's SeaWiFs, NASDA's OCTS, and DLR's MOS.

The CZCS data is classified into various product levels depending on the processing of the data and what type of ancillary data is include. Level 0 data is the raw binary sensor counts recorded for radiation at 6 wavelengths. A Level 1 data product is the raw binary sensor counts cut into 2 minute scenes and bundled with orbital and atmospheric data. A Level 2 data product is a processed product where a sensitivity loss correction, atmospheric correction, and chlorophyll derivation algorithm have bee applied to a level 1 product to calculate surface reflectances, land/cloud flags, subsurface reflectances, atmospheric signals, and chlorophyll concentration.

A Level 3 Primary product is generated by remapping a number of level 2 products from the same day to a fixed geographical area, with the areas known as basins. This uses the orbital and geo-referencing data from the Level 1 product and applies a coastline feature matching algorithm. The basins are calculated in Alber's equal area projection with a 1 km pixel size. A Level 3 composite product is generated by calculating the average cholorophyll value for each pixel over a number of Level 3 Primary products. See the CZCS Dataset Guide Document[28].

[28] http://daac.gsfc.nasa.gov/DATASET_DOCS/czcs_dataset.html

0.2 D

daily retardation In tidal studies, the amount of time by which a tidal phase lags the previous day's corresponding phase. These lags average about 50 minutes.

Dampier, William (1652–1715) See Peterson et al. [1996], p. 33.

Darwin, George H. More later.

data assimilation See Anderson et al. [1996].

Davidson Current See Inshore Countercurrent.

Davidson Inshore Current See Inshore Countercurrent.

D–BAD MOCNESS Acronym for Dual–Beam Acoustics Deployed on a Multiple Opening/Closing Net and Environmental Sensing System, an instrument designed to collect acoustic data and net samples simultaneously from the same portion of the water column. See Greene et al. [1998].

DBE Abbreviation for Deep Basin Experiment.

DCP Abbreviation for Data Collection Platform.

dead-water phenomenon A phenomenon caused by a thin layer of fresh meltwater overlaying an otherwise salty sea. It is exceptionally hard to propel a boat (by rowing or any other method) in such a situation since energy has to be expended to generate not only surface waves but also internal waves at the saltwater-freshwater interface. Ekman [1904] first performed systematic analytical and experimental studies of this phenomenon. See also Kraus and Businger [1994], p. 246.

Deacon Cell A name often given to the meridional circulation of the Southern Ocean wherein deep water upwells, is blown north by wind stress in an Ekman layer, and sinks at the Antarctic Convergence. According to Speer et al. [2000]:

> The conception of the Deacon cell was based on the idea of a transformation of water from cold, dense layers to warmer, lower density layers. A second, deeper, cell is associated with bottom-water formation, sinking, and entrainment next to the Antarctic continent, equatorward flow near the bottom, and the southward inflow of deep water. Thus, deep inflow must compensate both near-bottom and near-surface northward outflow; this deep inflow is thought to be accomplished geostrophically since ridges provide lateral boundaries that support east-west pressure gradients below their crests.

Similar, although much weaker, cells are seen in the northern subpolar gyres as well as cells flowing in the opposite sense in the tropics. See McWilliams [1996] and Speer et al. [2000].

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Dead Sea According to Gertman and Hecht [2002]:

The Dead Sea is a large and deep terminal lake, situated in the lowest section of the Jordan Rift Valley between Israel and Jordan. As a terminal lake, the level of the Dead Sea is determined by the balance between evaporation, rain and runoff (the last including the inflow of subsurface springs). Historical records indicate that throughout its existence, the water level of the Dead Sea oscillated significantly. However, since the early 1960s, the countries controlling the fresh watershed of the Dead Sea (i.e. Israel, Syria and Jordan) began to use these waters intensively. As a result, the inflow of fresh waters into the Dead Sea has diminished significantly and the evaporation from the lake exceeded rain and runoff into it. Moreover, Israel and Jordan are using the Dead Sea waters for the production of minerals, which also contributes to the depletion of these waters. Thus, from a level of -397 m (i.e. 397 m below mean sea level) in 1960, the surface of the Dead Sea has dropped almost continuously (Steinhorn and Anati) and at the beginning of 1978, it went below -399.6 m, the level of the sill of the Lynch Straits. Until that time, the morphology of the Dead Sea consisted of a large and deep northern basin and a smaller and much shallower southern basin, the two communicating via the Lynch Straits. Following the recession of the water level, the entire southern basin would have dried up. The erection of dikes transformed the area of the southern basin into evaporation ponds for the production of minerals. The water in those ponds is pumped in from the northern basin of the Dead Sea. Moreover, with the recession of the water level below the level of the Lynch Straits (in 1978), the length of the Dead Sea decreased from 80 to about 50 km, its maximum depth has diminished to 328 m, its surface area has diminished to 815 km2 and its volume has diminished to 146 km3. The sea surface level of the Dead Sea is still dropping and in 2001 has reached -414 m, while its maximum depth has been reduced to 316 m. Due to thermodynamic constrains, the Dead Sea evaporation will reach a balance, which will prevent the further reduction of its sea level. This is expected to occur in about 500 years when the Dead Sea level will drop to about -550 m below mean sea level.

See Niemi et al. [1997] and Gertman and Hecht [2002].

de Brahm, William (1718–1799) See Peterson et al. [1996].

decibar More later.

Deep Basin Experiment (DBE) A component of WOCE focused on increasing the knowledge and understanding of deep circulation processes. The primary objectives were:

- to observe and quantify the deep circulation within an abyssal basin,
- to distinguish between boundary and interior mixing processes,
- to understand how passages affect the water flowing through them, and
- to study the means by which deep water crosses the equator.

Specifically, the DBE examined the deep interior flow of the Brazil Basin with these objectives in mind. See Hogg et al. [1996].

`[http://www.whoi.edu/science/PO/people/mvanicek/DBE/]`

deep convection In physical oceanography, the sinking of surface waters to form deep water masses, a process of fundamental importance for ocean climate and the maintenance of a stably stratified world ocean. There are two main types of deep convection, the physics of which are very different. The first is convection near an open boundary, which involves the formation of a dense water mass which reaches the bottom of the ocean by descending a continental slope. The second type is open-ocean deep convection, where the sinking occurs far from land and is predominantly vertical.

There are five separate ingredients involved in the formation of deep water near ocean boundaries:

- a reservoir in which to form dense water, which takes the form of either a very wide shelf or one that slopes upward away from the coast to form a sill;
- a source of dense water within the reservoir which, in polar regions, is the brine release that occurs during wintertime ice formation;
- a reason for the dense water to leave the reservoir and descend the slope, which takes the form of an already existing circulation that drives at least part of the dense water off the shelf, e.g. the Ross Sea features a cyclonic circulation pattern, an onshore Ekman flux driven by prevailing easterlies, and katabatic wind forcing;
- a requirement that more than one water mass be involved in dense water formation, with this requirement not playing a dynamical role but apparently necessary from the lack of observations to the contrary;
- a requirement that the densities, geography, and dynamics involved actually permit the water to sink.

There is another list of ingredients involved in open-ocean deep convection:

- a background cyclonic circulation, needed to form an upward doming of isopycnals in the center of the gyre to reduce the stability of the water column;
- preconditioning which, operating over a period of week, creates a region of very weak static stability within the cyclonic dome which can then begin convection if the surface forcing is sufficiently intense;
- similar to the ocean boundary convection case, more than one water mass be involved, i.e. the existence of several water masses provides subsurface sources of heat and salt which can be exposed to the surface during convection, both of which can be destabilized by cooling;
- sufficiently strong surface forcing must be involved, which usually takes the form of heat loss by sensible and latent flux to cold winds. This forcing causes a violent mixing phase consisting of rapid vertical convection and mixing, which takes place in cellular structures with horizontal and vertical scales of similar size. The convection mode also seems to be nonpentrative, i.e. mixing occurs such that the density structure remains a continuous function of depth;
- a breakup or sinking and spreading phase, accomplished by some combination of the processses of baroclinic instability, vertical shear, topography and mixing by internal waves that is not yet well understood.

Jones and Marshall [1993] discuss the phases of open–ocean deep convection:

> There are three successive phases that characterize open–ocean deep convection: *preconditioning*, on the large scale (of order 100 km); *violent mixing* occurring in localized, intense plumes (on scales of order 1 km); and *sinking* and *spreading* of the convectively tainted water, on a scale of 5–10 km.
>
> During *preconditioning*, the gyre–scale circulation and buoyancy forcing combine to predispose a particular site to overturn. For example, in the Gulf of Lions the background cyclonic circulation is subject to persistent surface heat loss priming the center of the gyre, where isopycnals dome up toward the surface. With the onset of strong surface forcing the near–surface stratification, over an area up to 100 km across, can be readily erased exposing

> the very weakly stratified water mass beneath the surface. Subsequent cooling events can then initiate *violent mixing* in which the whole of the fluid column overturns, drawing buoyancy from depth, in numerous cells of horizontal scale of order 1 km; downward velocities of order 10 cm s^{-1} can devleop in only a few hours in this violent–mixing phase. The largest ascending and descending currents penetrate the whole depth of the mixed–water column. In concert the plumes are thought to rapidly mix properties over the preconditioned site, forming a "chimney" of homogeneous fluid. Chimneys ranging in scale from several to many tens of kilometers have been observed. At the density front between the homogeneous and stratified water, geostrophic eddies develop on a scale comparable with the local Rossby radius of deformation. With the cessation of strong forcing there is a sharp decline in convective overturning; the predominantly vertical heat transfer of the mixing phase gives way to horizontal advection associated with eddying on geostrohpic scales. The mixed fluid "slumps" under gravity and rotation, *spreading* out at middle depths and leading, on a time scale of days, to the disintegration of the chimney. As the dense fluid sinks, water from outside the chimney is drawn in, restratifying near–surface layers.

See Killworth [1983], Jones and Marshall [1993] and Marshall and Schott [1999].

deep scattering layer A layer of organisms found in most oceanic waters that scatters sound. These layers are usually found during the day at depths ranging from 600 to 2400 feet, are rarely less than 150 feet thick, and can be as thick as 600 feet. Several layers are often recorded simultaneously and can range horizontally for many kilometers. Most of these layers undergo diurnal vertical movements. There are also shallow (over continental shelves) and surface scattering layers.

deep water wave More later.

Defant, Albert More later.

deformation radius See Rossby radius of deformation.

degenerate amphidromic point An amphidromic point whose center or nodal point appears to be located over land rather than water.

Delaware Coastal Current See Sanders and Garvine [1996].

Demerara Eddy The name given to what was once thought to be a semipermanent anticyclone north of the North Brazil Current (NBC) retroflection. Better temporal and spatial sampling has shown this to be a series of eddies pinched off by the retroflection rather than a persistent feature.

denitrification In the ocean this is the process by which bacteria use nitrate instead of oxygen as an oxidant of organic matter. It may be considered as the biological reduction of nitrate or nitrite to nitrogen or nitrous oxide. This takes place under low oxygen conditions. See Riley and Chester [1971].

Denmark Strait See Greenland–Scotland Ridge.

Denmark Strait Overflow The flow through and over the 600 m sill depth in the Denmark Strait between Iceland and Greenland. This is thought to be around 3.0 Sv of which 2.5 Sv is Arctic Intermediate Water and 0.5 Sv is Upper Polar Deep Water. The mixture of these water masses after they pass the strait is called Northwest Atlantic Bottom Water (NWABW). This is the coldest and densest of the source waters for North Atlantic Deep Water and is characterizied by a salinity minimum. See Swift [1984] and Dickson and Brown [1994].

densimetric Froude number See Froude number.

density (of sea water) Much more later.

density current See turbidity current.

density ratio The ratio of the effect of a temperature change on density divided by the effect of a salinity change. This was found in the Spice Experiment to be roughly equal to one for horizontal scales ranging from 10 m to 1000 km. See Figueroa [1996].

dependent variable In numerical modeling and general mathematics, a variable whose value changes as a function of another variable, i.e. the latter is first specified and the latter then calculated. The specified variables are called independent variables. Examples of variables that are usually dependent in numerical modeling include velocities, temperatures, and densities, with the independent variables usually being the spatial positions and time, although some variables can be either depending on the situation. For example, when pressure coordinates are used the pressure is an independent variable and the height or depth a dependent one, but when level coordinates are used the positions are reversed.

depth of frictional resistance The depth at which the wind-induced current direction is 180 degrees from that of the wind in an Ekman spiral.

depth of no motion See level of no motion.

design wave More later.

detrital The most voluminous of three major components of deep sea sediments, the other two being authigenic and biogenic. Detrital material is derived from the mechanical and chemical fragmentation of continental materials, most of which is in the form of alumino-silicate minerals. It is transported chiefly by rivers into coastal waters and by the wind onto the sea surface. See Broecker and Peng [1982].

detritus A general collective term for loose mineral and rock that is broken or worn off by mechanical means, as by disintegration or abrasion.

diagenesis The chemical, physical, and biological changes sediment undergoes after it is initially deposited. This includes such processes as compaction, cementation, reworking, authigenesis, replacement, crystallization, leaching, hydration, bacterial action, and formation of concretions that normally occur at temperatures and pressures characteristic of surface conditions. Weathering and metamorphic processes are usually excluded from this category.

diagnostic In numerical modeling, an equation is diagnostic if the present value of a dependent variable is calculated from the present value(s) of one or more dependent variables.

dianeutral Across a neutral surface.

diapycnal Motion or transport directed across surfaces of constant density or isopycnals.

diapycnal mixing See Gregg [1987].

diatom ooze A soft, siliceous, deep-sea deposit of which more than 30% is composed of silica-rich diatom cell walls. This type of siliceous ooze (another of which is radiolarian ooze) predominates in high latitudes around the coast of Antarctica and in the North Pacific, but is overwhelmed by sediment of continental origin in the North Atlantic. This type of ooze covers about 9% of the sea floor. Compare to calcareous ooze. See Tchernia [1980].

DIC Abbreviation for Dissolved Inorganic Carbon, which includes the sum of dissolved CO_2 gas and the ions HCO_3 and CO_3. This is dominated by the bicarbonate (HCO_3) ion is sea water and occasionally referred to as total CO_2.

dicothermal layer A vertical ocean layer sometimes found in high northern latitudes. It is a cold (as low as -1.6° C) layer from 50 to 100 m sandwiched between warmer surface and deeper layers. The water column remains stable due to a salinity gradient that counters the unstabilizing effects of the temperature gradient.

DieCAST A numerical ocean circulation model derived from the Sandia Ocean Modeling System (SOMS). The general features, as described in the user manual:

> The models combine aspects of the Arakawa "a" and "c" grids. The models use fourth order interpolations to transfer data between the "a" and "c" grid locations in order to combine the best features of the two grids. This procedure eliminates the "a" grid "null space" problems noted by Dukowicz (1993) and reduces or eliminates the numerical dispersion caused by Coriolis term integration on the "c" grid. The modified "a" grid model includes a fourth order approximation for the baroclinic pressure gradient associated with the important quasi-geostrophic thermal wind (the models do not assume quasi-geostrophic flow, but appropriately yield quasi-geostrophic flow under prevailing open ocean conditions).
>
> The models are designed to treat all open lateral boundaries that fall on their logically rectangular grid boundaries. The open boundary coding is designed for efficient use of vector and massively parallel computers, as is the rest of the coding. However, because of the generally small number of inflow points involved, special river sources and sinks may sometimes be best treated specially ("hardwired") rather than using the general open boundary conditions.
>
> The models include spherical metrics. Future curvilinear versions may allow the grid lines to curve according to a grid generator. In certain special applications, salinity effects on density can be accounted for by appropriate modification of initial and boundary temperature, thus giving "pseudo-temperatures" such that the appropriate density results from thexi equation of state based on "pseudo temperature".

See Dietrich and Kuo [1994].

`[http://www.maths.unsw.edu.au/~bxs/DieCAST/MANUAL/]`

differential diffusion According to Gargett [2003]:

> There are ... small–scale processes that transport T and S differentially. The best–known of these are the double–diffusive processess (salt fingering and double–diffusive layering), which occur in ocean regions where mean T and S gradients have opposite influence on density. ... even when both T and S gradients are stabilizing, there is potential for differential transport of T and S in the ocean.
>
> Under certain conditions, it is possible for the larger molecular diffusivity of T to produce preferential turbulent transfer of T relative to S. The mechanism by which this occurs is similar to that underlying double diffusion. However, a major difference is that double diffusion is driven by the release of potential energy from the gravitationally unstable component of the mean fields, while in differential diffusion, kinetic energy comes from 'ordinary' turbulence. In this latter case, the conceptual picture is that of a locally overturning eddy that stirs an embedded scalar field.
>
> ...

> The differential diffusion of T and S occurs at very small spatial scales, nevertheless potentially it has importance to very large-scale ocean processes, such as the thermohaline circulation and the global re-supply of nutrients. In a coarse-resolution model of a 'North Atlantic' ocean basin, Gargett and Holloway (1992) implemented different vertical diffusivities for T and S in the sense expected of differential diffusion, and noted an increase of 50% in the meridional overturning circulation. Although the magnitude of such changes appears to be lessened in global domains, differential diffusion may yet prove important in situations such as diurnal and seasonal pycnoclines where vertical diffusion is associated with intermittent turbulence occurring in the presence of strongly stable stratification. If vertical diffusion of nutrients across such pycnoclines is the rate-limiting process for biological new production in some regions of the ocean, it would be essential to quantify potential differential transport of S (nutrients) relative to T.

See Gargett [2003].

differential heating The difference in how land and water surfaces absorb heat, with water having a higher heat capacity than land. The same amount of solar radiation will heat the same area of ground more than it will the ocean. The heat absorbed by the ocean will be distributed over a greater vertical extent than on land due to mixing in the water column. These factors lead to the difference between land and ocean temperatures being greatest in the summer when the amount of solar radiation is the highest, with the land being warmer than the ocean. In the winter the ocean surface is warmer than the land, although the differential isn't as great as in winter. Diurnal variations in differential heating lead to the phenomenon known as a sea breeze, while long term (i.e. over weeks to months) variations lead to prevailing winds often called monsoons.

dilution basin See mediterranean sea.

DIM Acronym for Dissolved Inorganic Matter.

dimensionless number See Biot number, Ekman number, Froude number, gradient Richardson number, Grashof number, overall Richardson number, Peclet number, Prandtl number, Rayleigh number, Rossby number, Strouhal number and Weber number.

direct tide A tide which is in phase with the apparent motion of the attracting body, whether it be the sun or the moon. It has its local maximums directly under the tide–producing body and on the opposite side of the earth. See also reversed tide. From Baker, Jr. et al. [1966].

DISCO Strained acronym for DImethyl Sulphide biogeochemistry within a COccolithophore bloom, an integrated, multidisciplinary Lagrangian process study of the routes, rates and controls on the biogeochemical cycling of dimethyl sulphide (DMS) within a growing bloom of the coccolithophorid alga, *Emiliania huxleyi*. See Burkill et al. [2002].

discretization In numerical modeling, the process of converting differential equations governing processes occurring in a continuum into equivalent algebraic equations governing processes occurring in a computational grid. This process is guided by considerations of consistency, convergence, and stability.

dispersion The dependence of wave velocity on the frequency of wave motion. The name comes from the fact that waves starting at the same place will, if they have different frequencies, move away at different speeds and thus disperse or spread out.

dispersion curve A graph showing the dependence of the frequency on the wavenumber for dispersive waves. This is usually created by first using a dispersion relation to obtain frequency/wavenumbers pairs, and then plotting them.

dispersion relation An equation with which one can determine the frequency (and thus phase speed) of waves of a given wavenumber, or occasionally vice versa.

diurnal 1. Generally, occurring once a day. 2. Descriptive of a tide that has only one high and one low water per day, as opposed to semidiurnal.

divergence The divergence of the flux of a quantity expresses the time rate of depletion of the quantity per unit volume. Negative divergence is called convergence and relates to the rate of accumulation. When applied to the velocity vectors of air or water motion, the divergence is positive when the parcels are expanding. In mathematical terms, the divergence of a vector function is defined by

$$\nabla \circ A = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_y}{\partial y}$$

where ∇ is the gradient operator that operates with a scalar product on the vector field A, and $A_n/\partial n$ are the scalar components of A in a Cartesian coordinate system. See Dutton [1986].

divergence theorem A theorem stating that no matter how the divergence of a vector field varies over a volume, its integral depends only on the integral of the components of that field normal to the surface of the boundary. It is mathematically stated in vector notation by

$$\int\int\int_V \nabla \cdot A \, dV = \int\int_S A \cdot \eta \, d\sigma$$

where A is the vector field, V the volume, S the surface, dV an differential volume element, and $d\sigma$ a differential surface element. See Dutton [1986].

DMS Abbreviation for dimethylsulphide, a gas emitted by phytoplankton in seawater where it escapes to the air and and reacts to form aerosols and presumably has a non-negligible climate effect. DMS often has a maximum at the surface or within the euphotic zone and decreases rapidly below this. It also has a strong seasonal cycle with a maximum in the summer and a minimum in the winter. See DMS-cloud-climate hypothesis for the exposition of one mechanism. See Charlson et al. [1987].

DMS-cloud-climate hypothesis The main source of sulfate particles and CCN over the oceans is the oxidation of DMS. As such the DMS may determine the concentrations and size spectra of cloud droplets and therefore the cloud albedo over large regions of the oceans. Marine stratiform clouds are of particular importance in this regard as they cover about one-quarter of the world's oceans and therefore play a major role in the Earth's radiative balance. This scenario is the basis for what is called the DMS-cloud-climate hypothesis. See Charlson et al. [1987] and Jaenicke [1993].

DMSP Abbreviation for DiMethyl Sulfonium Propionate, thought to be the dominant precursor to DMS in the oceans. DMS can be formed by the enzymatic cleavage of DMSP as well as by the oxidation of DMSP with OH-, oxygen or hydrogen peroxide. DMSP is present in both particulate and dissolved forms, with the latter thought to be the larger source of DMS. DMSP most likely originates in phytoplankton where it is believed to serve in maintaining osmotic pressure (i.e. an osmolyte). See Najjar [1991].

DOC Abbreviation for dissolved organic carbon, which consists of three pools:

- a refractory pool not readily usable by biological organisms with a turnover time on the order of ocean mixing cycles,
- a usable labile pool with turnover time from hours to a day, and;

- a semi-labile pool with a turnover time of months to season.

Analyses of the composition of DOC indicate bulk C:N ratios ranging from 16 to 38, and that 22–33% of the total DOC is > 1000 molecular weight and composed largely of carbohydrate material, with C:N ratios from 15–22. See Ducklow [1995].

Dole effect Defined as the difference between the $\delta^{18}O$ of atmospheric O_2 in air and the $\delta^{18}O$ of contemporaneous seawater. This effect mainly reflects the isotopic composition of O_2 produced by marine and terrestrial photosynthesis, as well as the extent to which the heavy isotope is discriminated against during respiration. Secondary factors include changes in terrestrial and marine fertility, varying isotope fractionation associated with the hydrologic cycle, and changes in respiratory isotope effects on either a species or community level. See Bender et al. [1994].

DOM Abbreviation for Dissolved Organic Matter. This includes colloidal as well as purely dissolved material and is operationally defined as all organic matter that will pass through a filter with a fine mesh size, typically between about 0.1 and 1 μm. See Najjar [1991].

DON Abbreviation for dissolved organic nitrogen.

Donde Va? An oceanographic experiment which took place in the Alboran Sea (in the western Mediterranean) during June–October 1982. It was conducted to study the large anticyclonic gyre formed by the inflowing jet of low salinity Atlantic Water. The objective was to better understand the kinematics and dynamics of the gyre using numerical modeling, remote sensing, and field measurements. See Va [1984].

Doodson filter A Doodson X0 filter is a simple filter designed to damp out the main tidal frequencies. It takes 19 values on either side of a central value and calculates a weighted average. If the initial values are at a higher frequency than hourly, then they are first averaged to give hourly values.

[http://www.pol.ac.uk/psmslh/gloup/doodson_X0.html]

DORIS Acronym for the Doppler orbitography and radiopositioning integrated by satellite instrument flown on the TOPEX/POSEIDON mission. This instrument provides, in addition to the LRA instrument, satellite tracking data, although DORIS uses microwave Doppler rather than laser techniques. The basic operational principle is based on the accurate measurement of the Doppler shift of radio frequency signals emitted by ground beacons and received by the satellite. It is composed of an on–board receiver and a network of ground transmitting stations, the latter of which are equipped with meteorological sensors the measure temperature, humidity, and atmospheric pressure for correcting for atmospheric effects on the transmitted signals. The DORIS signals are transmitted at two frequencies (401.25 and 2036.25 MHz), one for Doppler measurement and another to allow the removal of the effects of ionospheric free electrons on the tracking data. The DORIS system is also being installed in the SPOT mission series as well as on ENVISAT. See the DORIS Web site[29].

DOTREX Acronym for Deep Ocean Tracer Experiment.

double diffusion In physical oceanography, this refers to the difference in the molecular diffusion rates of heat and salt in sea water, the molecular diffusion rate of heat being about 100 times that of salt. If two water masses with the same density but different combinations of temperature and salinity are in contact, the double (or differential) diffusion can give rise to density changes that render the layers unstable. Two phenomena that are possible consequences of this are double diffusive instability and layering. This is also known as salt fingering.

[29] http://www-projet.cst.cnes.fr:8060/doris/Mission.html

A fascinating history is given by Ruddick and Gargett [2003]:

> In Sydney, Australia in the 19th century, W.S. Jevons (1857) performed the first known laboratory experiments on heat-sugar fingers. He described long, narrow convection cells that formed when warm, sugary water was introduced over cool, fresh water and correctly attributed the phenomenon to a difference in the diffusivities for heat and sugar. He suggested the instability might be responsible for the streamers sometimes observed in cirrus clouds, although they are now thought to arise from a difference in turbulent diffusivity of mass and momentum (McIntyre, 1970). Although Jevons' work motivated Rayleigh (1883) to derive the first expression for the frequency of internal waves in a stratified fluid, the fundamental notion that convective fluid motions can arise as a result of different molecular diffusivities was forgotten for nearly 100 years (Schmitt, 1995)!
>
> The rediscovery of double-diffusion was described by Schmitt (1995), and in a compressed form by Henry Stommel in his autobiography (Stommel, 1984). While trying to design a method of monitoring deep-sea pressure off Bermuda using submarine liquid-filled tubes to carry the pressure signal, Arnold Arons suggested that a pipe with heat-conducting walls would allow a self-sustaining flow, the 'perpetual salt fountain', to occur (Stommel et al., 1956). Stommel (1984) illustrated (Fig. 1) the sequence of interactions between himself, Melvin Stern, Arnold Arons, Alan Faller and Willem Malkus. Within a few years came a simple laboratory demonstration of the fountain, recognition of the possibility of some form of convection, including the setup for lateral interleaving, a simple laboratory experiment finding tall thin salt-fingers, and an analytic salt-finger solution (Stern, 1960). As noted by Schmitt (1995), both Arons and Faller credited Stern (1960) with the rediscovery of salt-fingers.
>
> Soon afterwards, Turner, 1965 and Turner, 1967 brought his understanding of turbulence, entrainment, and dimensional reasoning to the field of oceanography. He performed laboratory experiments inferring the fluxes of heat and salt across thin diffusive and salt-finger interfaces, and used dimensional reasoning to collapse the observations, establishing the so-called '4/3' flux laws. This may represent the single most important step towards quantifying double-diffusive fluxes to date, although its general applicability in oceanic situations is becoming increasingly questioned.
>
> The development and use of the continuously profiling salinity-temperature-depth (STD) recorder rapidly brought about the realization that salinity and temperature profiles were not smooth between the point observations afforded by bottles. Instead, profiles often exhibit a huge variety of fine structure, including salinity-compensated temperature inversions (Roden, 1964 and Stommel and Federov, 1967) and systems of interfaces or steps separated by apparently well-mixed, convecting layers (Tait and Howe, 1968) – the so-called 'thermohaline staircase'. These observations coincided with laboratory work showing how a staircase can be formed from smooth gradients by double-diffusive fluxes, both diffusive (Turner, 1968) and fingering (Stern and Turner, 1969). Stern (1967) used instability theory to show how salt-finger fluxes can drive lateral interleaving to produce salinity-compensated temperature inversions, and demonstrated that turbulent mixing with equal diffusivities for heat and salt cannot create such inversions.
>
> By 1969 the picture appeared to be complete: smooth oceanic gradients can be broken down into steps and layers by double-diffusion. The fluxes can be carried across the steps by double-diffusive processes, and then across the layers by convection. These fluxes were estimated by the 4/3 flux laws to be vastly greater than they would be in smooth gradients. Double-diffusion moved in the eyes of (some) oceanographers from being an 'oceanographic curiosity' to a potentially major player that could drive significant diapycnal mixing. The

diapycnal double-diffusive fluxes could drive lateral interleaving motions, and hence lateral fluxes of salt and heat. This early work, and much more, is described in a clear and physical manner in Turner (1973); it is highly recommended reading.

See Schmitt [1994] and Ruddick and Gargett [2003].

double diffusive convection See double diffusive instability.

double diffusive instability In physical oceanography, this is a consequence of the double diffusion phenomena. If a layer of warmer, saltier water overlies a layer of cooler, fresher water such that the density of the upper layer is equal to or less than the density of the lower layer, the saltier water at the interface will lose heat to the cooler water below faster than it will lose salt because of the differences in molecular diffusivities. This may cause the water immediately above/below the interface to become denser/lighter which will cause it to sink/rise to the lower/upper layer. These fallings and risings occur in thin columns and the process is referred to as salt fingering, and the process of the water actually moving as double diffusive convection (also thermohaline or thermosolutal convection). See Kunze [2003].

double high water See double tide.

double Kelvin wave To be completed.

double tide Either a high water consisting of two maximums of about the same height separated by a relatively small depression or a low water consisting of two minimums separated by a relatively small elevation. This has also been called a double high water, an agger, and a gulder.

DOVETAIL Acronym for Deep Ocean VEntilation Through Antarctic Intermediate Layers, a research program whose main goal is to understand the physical processes in the Weddell–Scotia Confluence (WSC) region sufficiently to quantify the ventilation of the world ocean achieved by the Weddell Sea water masses. The program objectives are:

- to assess the quantity, physical and chemical characteristics of Weddell Sea source waters for the WSC;
- to describe the dominant physical processes associated with spreading and sinking of dense Antarctic waters within the WSC region;
- to estimate the ventilation rate of the world ocean from the Weddell Sea; and
- to estimate seasonal fluctuations in region ocean transport and hydrographic structure, and assess the likely influence of interannual variability on rates of ventilation by Weddell Sea waters.

DOVETAIL is a component of iAnZone.

According to the LDEO DOVETAIL site:

> The US observation program began in late July 1997 with a 40 day cruise on board the RVIB Nathaniel B Palmer, during which CTD/tracer transects were carried out, and current meter moorings and drifting ice buoys were deployed. ... The moorings deployed on this cruise will join several moorings put out earlier by investigators of the Alfred Wegener Institute in 1996.
>
> DOVETAIL priorities parallel, and the results will contribute to, ongoing global change research. The processes responsible for vertical and horizontal fluxes within the ocean and associated interaction with the sea ice and atmosphere in polar regions must be properly represented in global circulation and climate models. The DOVETAIL study region, off the

> tip of the Antarctic Peninsula serves as the primary gateway between the southern polar waters and the global ocean. This region can therefore be considered as a "vital" location for long term monitoring of the discharge of cold Antarctic Water into the global ocean. Results from the DOVETAIL experiment will aid in establishing long-range monitoring of this critical region. Both the Global Ocean Observing System (GOOS) and the ocean component of the Global Climate Observation System (GCOS) have been established by a number of international bodies to provide such monitoring data.

See Muench and Hellmer [2002].

[http://www.ldeo.columbia.edu/physocean/proj_Dove.html]
[http://www.esr.org/dovetail/dovetail.html]
[http://www.awi-bremerhaven.de/Modelling/BRIOS/dovetail.html]

DRAKE Acronym for Dynamic Response And Kinematics Experiment, an ISOS program consisting of a series of experiments to obtain measurements of various quantities in the Drake Passage. One took place in 1977 (DRAKE 77) and another in 1979 (DRAKE 79).

DRAKE 79 was a year long (1979–1980) measurement program spanning the entire Drake Passage. The current meter array consisted of two major parts. The main line (ML) array was designed to measure the total transport through the passage, and a cluster of moorings in the central passage was a mapping and statistics (MS) array for sampling the flow variability in the Polar Frontal Zone (PFZ). The current meters were positioned at nominal depths of 500 m and 2500 m on all moorings, and at 1400 m on the MS moorings. See Nowlin, Jr. and Klinck [1986] and Klinck [1985].

Drake Passage A narrow constriction between South America and Antarctica between 56 and 63° S through which the Antarctic Circumpolar Current (ACC) must accelerate and squeeze in its trip around the globe. It is about 780 km wide at a depth of 500 m. Direct current and bottom pressure measurements in the Passage have led to estimates of ACC flow of around 110-130 Sv through it.

DSL Abbreviation for deep scattering layer.

DSRT Abbreviation for Deep-Sea Reversing Thermometer.

DWBC 1. Abbreviation for Deep Western Boundary Current. 2. Abbreviation for Deep Water Brazil Current.

dynamic depth See dynamic height.

dynamic distance See dynamic height.

dynamic height In oceanography, this refers to the pressure associated with a column of water. Horizontal variations of this (due to horizontal variations in temperature and salinity) are mapped to determine what is called the dynamic topography and its corresponding geostrophic flow field in the ocean. The dynamic height is measured in dynamic meters and is defined by

$$D(p_1, p_2) = \int_{p_1}^{p_2} \delta(T, S, p)\, dp$$

where p_1 and p_2 are two reference pressure levels, δ the specific volume anomaly, T the temperate, S the salinity, and p the pressure. This is analogous to a meteorologist's use of a pressure chart, with the direction of flow aligned with the contours and the intensity of flow inversely proportional to the contour spacing. Dynamic heights are preferred over geometric heights in oceanography and meteorology because energy is generally lost or gained when a parcel of fluid moves along a surface of equal geometric height but not when it moves along a surface of equal dynamic height. This quantity has also been called dynamic thickness, dynamic distance, geopotential height, geopotential thickness, and geopotential distance.

dynamic meter In oceanography, a unit of gravity potential used to express the amount of work that is performed or gained in moving a unit mass from one level to another. A dynamic meter represents the work performed in lifting a unit mass nearly 1 m and is defined as 10^5 dyn-cm/gm or 10 J/kg. The depth in dynamic meters is related to the depth in geometric meters via $D = gh/10$, where g is the gravitational acceleration and h the geometric depth, i.e. 1 dynamic meter corresponds roughly to 1.02 geometric meters. This is used instead of the geometric meter since gravity is the most important of the acting forces and as such a coordinate system based on gravity is advantageous.

dynamic method See geostrophic method.

dynamic thickness See dynamic height.

dynamic topography In oceanography, a field of horizontally varying dynamic heights in the ocean, analogous to, for example, a topography field on land. This is also called geopotential topography.

dynamic velocity See friction velocity.

DYNAMO A European Union MAST–II project carried out between 1995 and 1997 in cooperation with the ocean modeling groups at Kiel (Theoretical and Modelling Group), LEGI Grenoble and SOC Southampton (James Rennell Division). The goal of DYNAMO was an improved simulation of the circulation of the North Atlantic Ocean, including its variability on synoptic and seasonal time scales. A key activity was a systematic assessment of the ability of eddy–resolving models with different numerical formulations of the vertical coordinate to reproduce the essential features of the hydrographic structure and velocity field between 20°S and 70°N.

The models used for intercomparisons of vertical coordinate representations were MOM, MICOM and SPEM. A final report is available at the DYNAMIC web site. See Meincke et al. [2001] and the other papers in that volume, i.e.

> The details of model setup and integration strategies can be found in the first paper which also discusses basin-wide aspects of the model intercomparison. The following four papers focus on particular aspects of the simulations, such as: main thermocline ventilation, Western Boundary Current variability, seasonal cycle of heat transport, and the inflow into the Nordic Seas. Finally, the last two papers are concerned with a mechanism for the generation of eddy energy, and with the assimilation of altimetric observations into one of the models.

`[http://www.ifm.uni-kiel.de/fb/fb1/tm/research/dynamo/index.html]`

DYOME Acronym for the Dynamique Oceanique a Moyenne Echelle, an experiment taking place in 1981-1982. See Astraldi et al. [1990].

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EAC Abbreviation for East Australian Current.

EAC Abbreviation for East Arabian Current.

EAE Abbreviation for Eastern Atlantic Experiment.

EASAP Abbreviation for East Asian Seas Action Program.

East Africa Coast Current See Somali Current.

East Arabian Current A strong northeastward flowing current along the Saudi Arabian coast. It is part of the monsoonal circulation in the area and as such exists from about April through October, being fully established by mid-May with velocities ranging form 0.5-0.8 m/s. It is also part of a strong coastal upwelling system during those months when it flows strongest.

East Arabian Sea Water See Bay of Bengal Water.

East Auckland Current The continuation of the East Australian Current east of New Zealand. It forms and is part of an anticyclonic eddy near 37° S off of East Cape. This eddy is found in the same location throughout the years and as such is thought to be topographically controlled. The further extension of this current has a bimodal nature that changes seasonally. During the summer most of its transport continues along the New Zealand coast all the way to Chatham Rise as the East Cape Current. In the winter part of it separates from the shelf and continues as a zonal flow into the open ocean, forming a temperature front near 29° S that is distinguishable from another shallow front near 25° S called the Tropical Front, the northern limit of eastward flow in the subtropical gyre. See Tomczak and Godfrey [1994].

East Australian Current The western boundary current of the southern hemisphere in the Pacific Ocean. It is the weakest of the world's boundary currents, carrying about 15 Sv in the annual mean near 30° N, yet is also associated with strong current instabilities. The relative weakness is due mostly to the flow through the Australasian Mediterranean Sea and the instabilities probably result from the current following the coast and then suddenly separating somewhere near 34° S to follow the east coast of New Zealand (where it is known as the East Auckland Current). It is stronger and reaches further inshore during the summer, with flow speeds reaching 1 m/s during the summer, and the maximum transport has been estimated at around 30 Sv (although the intermittent nature of the current makes such estimates somewhat suspect).

The path it follows from Australia to New Zealand is called the Tasman Front, which separates the warmer waters of the Coral Sea from the colder waters of the Tasman Sea. This front develops meanders which travel westward, impinge upon the Australian coast, and ultimately separate from the current and form eddies. About 3 eddies are spawned per year (with 4-8 existing at any one time in recognizable form) with most being anticyclonic or warm core eddies since the meander closest to the coast always extends to the south. The meandering and eddy-shedding behavior of the current combined with its weak flow sometimes make it difficult to even distinguish it as a current, and the location of the Tasman Front can be meaningfully defined only in statistical terms.

The pronounced seasonal cycle is described by Ridgway and Godfrey [1997]:

> Maps of the annual-frequency component of the surface and depth-integrated steric heights (h and P) show the development and progression of the EAC flow regime through a complete seasonal cycle. The EAC has a strong seasonal cycle from 25S to 45S, with

strongest southward flow in austral summer. The seasonal cycle in surface flow over the continental shelf is documented by two independent methods, geostrophically, using cross shelf sea level gradients derived from coastal tide gauge data and steric heights at the continental shelf edge, and directly from merchant ship observations. The two estimates are in good agreement. The seasonal cycle in the EAC is more pronounced than in other mid-latitude western boundary currents for which data are available. At 28S, the strength of the total Tasman Sea transport (southward flow) varies between a minimum transport of 7 Sv in winter (July) to a maximum of 16 Sv in summer. The semiannual frequency components of h and P is important near 30S near the EAC outflow, but not elsewhere. The seasonal cycle of the EAC is not due to strong seasonal variations in Tasman Sea wind stress curl east of the region of interest. Seasonally reversing zonal flows occur offshore north of 25S, which are apparently locally forced by reversing wind stress curls; but if these flows were fed from the south by the EAC current system, the EAC would have to be weaker in summer, not stronger. The Leeuwin Current Extension along Australia's west and south coasts may pass up the east coast of Australia, providing an important contribution to the enhanced southward flow of the EAC in summer. The vigorous anticyclonic eddies of the EAC also show a marked seasonal cycle and this is probably an important part of the mechanism for the strong seasonal cycle of the EAC south of 25S. The location of the strongest anticyclonic eddy in the EAC moves steadily southward throughout the summer season, and the phase of the coastal EAC appears also to move southward contrary to the expectations of linear theory, and to the hypothesis that the Leeuwin Current Extension is the major cause of the seasonal cycle.

See Ridgway and Godfrey [1997] and Tomczak and Godfrey [1994].

East Cape Current See East Auckland Current.

East China Sea See Tomczak and Godfrey [1994], Guan [1994], Hu [1994], Jilan [1998], Katoh et al. [2000] and Lee and Chao [2003].

East Coast Ocean Forecast System (ECOFS) A cooperative program among NOS, NCEP, GFDL, and AOS to develop a system capable of producing useful nowcast and forecast information for the east coastal region of the United States. See the ECOFS Web site[30].

East Greenland Current More later. See Foldvik et al. [1988] and Woodgate et al. [1999].

East Greenland Ice Stream See Wadhams [1986].

East Greenland Polar Front See Johannessen [1986].

East Icelandic Current See Swift [1986].

East Icelandic Water A water mass found in the area of the Iceland–Faroe Ridge. See Hansen and Osterhus [2000].

East India Coastal Current See Shankar et al. [1996].

East Indian Current A seasonal and northward flowing current found in the western part of the Bay of Bengal from about January until October. The weak and variable currents found early in the year strengthen with the Northeast Monsoon, exceeding 0.5 m/s by March and ranging from 0.7-1.0 m/s through May and June. This current flows counter to the wind, apparently as an extension of the North

[30] http://www.aos.Princeton.EDU/htdocs.pom/CFS/

Equatorial Current, although a convincing dynamical explanation has yet to be offered. The northward flow gradually weakens with the advent of the Southwest Monsoon, with the currents to the north and close to the shelf beginning to reverse in September. By late October, the East Indian Current has completely reversed into the East Indian Winter Jet. See Tomczak and Godfrey [1994].

East Indian Winter Jet A seasonal southwestward flowing western boundary current found in the western Bay of Bengal from late October through around late December. It features velocities consistently above 1 m/s as it flows southwestward, eventually turning west and following topographic contours as it passes Sri Lanka and feeds all its waters into the Arabian Sea. In late December its northern part fades, eventually to become the East Indian Current, and the southern part merges with the developing North Equatorial Current.

East Korea Current See Tsushima Current.

East Sea A semi–enclosed, marginal sea surrounded by Korea, Japan and Russia. See Preller and Hogan [1998].

[http://key.kordi.re.kr/home/pores.htm]

East Siberian Sea One of the seas found on the Siberian shelf in the Arctic Mediterranean Sea. The western boundary passes from the meridian at the northern tip of Kotelny Island along the continental shoal margin (79° N, 139° E) to the northern end (Anisiy Cape), then along the western shore floolwing the eastern boundary of the Laptev Sea. The northern boundary passes by the edge of the continental shoal from 76° N, 180° E, then along the eastern boundary along meridion 180° up to Wrangel Island, then along the northwestern shore to Blossom Cape, and then down to Yaken Cape on the mainland. The southern boundary passes along the mainland coast from Yakan Cape to Svyatoy Nos Cape. It adjoins the Laptev Sea to the west, the Chuckchi Sea to the east and the Arctic Ocean proper to the north. The largest span is about 640 nautical miles, and the largest width about 506 nautical miles. The bathymetry is very level and comparatively shallow compared with the other marginal seas of the Arctic Basin. The prevailing depths of the western and central regions are 10–20 m, and 30–40 m in the eastern region.

The first scientific data from this sea was collected on the 1922–1924 expedition of the Maud and published by Sverdrup [1929]. This remained the only accessible data until the military vessels USS Barton and USCGS Northwind surveyed the area in 1962 and 1966. The first U.S. research vessel to enter the East Siberian Sea was the RV Alpha Helix in 1995. It deployed surface drifters in the ice–free summer shelf waters and conducted hydrographic surveys to investigate the influence of the Kolyma River on the shelf circulation.

The freshwater input of the Kolyma River is of prime hydrographic significance to the East Siberian Shelf Sea. The annual discharges vary from below 2000 m^3s^{-1} to nearly 5000 m^3s^{-1}, with the 1936–1996 mean about 3160 m^3s^{-1}. The discharge is highly seasonal with more than 90% occurring between June and September, increasing from a May average of less than 1000 m^3s^{-1} to a June average of more than 10,000 m^3s^{-1} (with the average monthly discharge during the winter from November through April less than 500 m^3s^{-1}). The Lena River to the west also contributes fresh water, with a peak discharge that can exceed 100,000 m^3s^{-1} in June.

The waters of the East Siberian Sea are fresh and cold, with surface temperatures varying between 0° and 2°C and bottom temperatures near the freezing point. Large horizontal salinity (although not temperature) gradients are found at depth. The shelf waters are generally colder, saltier, and thus denser than the offshore waters. The salinities range from almost 0 near the Kolyma River mouth to a maximum of 33. The three most significant water masses are resident shelf waters, freshwater from river discharges, and freshwater from seasonal ice melt.

The buoyancy forcing due to the freshwater input would be expected to result in an eastward bound buoyancy–driven flow coastal current, but the drifters in a 1995 survey (Münchow et al. [1999]) indicated a 50-day mean westward flow reaching 0.1 ms^{-1}. The river waters were found to be predominant only in the immediate vicinity of the Kolyma Delta. The observed circulation was postulated to be due to some as yet unknown combination of:

- a line source of buoyancy caused by the melt water left by an ice edge that retreated 100 km in less than two weeks;
- large–scale barotropic and/or baroclinic pressure gradients imposed from the Laptev Sea in the west through Laptev Strait; and
- decadal–scale scale climate oscillations (i.e. atmospheric pressure anomalies) that induce alternating cyclonic and anticyclonic circulation regimes.

See Sverdrup [1929], Pavlov [1998], Münchow et al. [1999] and Münchow et al. [1999].

East Spitsbergen Current See Pfirman et al. [1994].

East Wind Drift The westward flowing current close to the Antarctic continent driven by the polar easterlies.

Eastern Atlantic Experiment (EAE) A 1996–1997 experiment that was one of the three main components forming the MAGE component of ACSOE. EAE was an extensive study of the speciation of sulphur and nitrogen in both clean and moderately polluted atmospheres, and involved the measurement of DMS and other gases in the ocean and the calculation of fluxes into the atmosphere, combined with the measurement of the speciation of sulphur and nitrogen in both gas and size–fractionated aerosol phases. The objectives were:

- to quantify the input of DMS into a parcel of air;
- to examine the oxidation of DMS and its reaction with nitrogen species with time;
- to investigate the formation of new particles that result from these transformations; and
- to discriminate between natural and anthropogenic fractions of sulphur and nitrogen using isotopic measurements.

[http://www.uea.ac.uk/~acsoe/easta.htm]

eastern boundary current See Wooster and Reid [1963].

Eastern Equatorial Pacific (EEP) See Wyrtki [1966].

Eastern Mediterranean Deep Water (EMDW) A water mass found in the Mediterranean Sea. EMDW extends from the overlying Levantine Intermediate Water (LIW) to the bottom, although the layer of EMDW between 700 m and 1600 m is considered transitional since it is modified by LIW. This layer has been called Transitional Mediterranean Water (TMW). The Adriatic Sea is considered the source of cold and less saline EMDW, which is formed in the winter in the Ionian Sea by the mixing of deep and cold Adriatic water (that enters the Ionian via Otranto Strait) with transformed LIW and, to a lesser extent, by mixing with deep Cretan waters. The core values of the EMDW are remarkably invariant through the basin with $\theta < 13.4°$ C, T = 13.6° C, S = 38.7, and $\sigma_\theta \geq 29.17$ kg m^{-3}. See POEM Group [1992], Roether et al. [1996], Malanotte-Rizzoli et al. [1997], Stergiou et al. [1997] and Theocharis et al. [1999].

Eastern Mediterranean Transient A large change in the thermohaline circulation of the Mediterranean Sea since 1988. Theocharis et al. [2002] supply the details:

> From 1988 onwards, started the most important changes in the thermohaline circulation and water properties basin-wide ever detected. A shift in the formation site of the deep and bottom waters from the Adriatic to the Aegean Sea occurred. The new source has produced large quantities of a very dense water mass (σ_θ up to 29.4), namely the Cretan Deep Water (CDW), that after its overflow through the Cretan Arc Straits provided the eastern Mediterranean with waters denser (σ_θ¿29.2) than the previously existing deep and bottom water mass (EMDW) (σ_θ 29.18). Additionally, warm and saline Cretan waters with density about 29.16, namely the Cretan Intermediate Water (CIW), were detected in 1987, outside the Cretan Arc Straits and south of Crete in layers between 700 and 1100 m. After 1990, a new, less dense (σ_θ ~29.1) intermediate water mass with characteristics similar to Levantine Intermediate Water (LIW) appeared to be formed in the South Aegean. The name CIW has been retained for the recent modified types of the water mass. This warmer and more saline CIW exits the Aegean mainly through the western straits of the Cretan Arc since 1991 and spreads through major parts of the Ionian Sea in the depth range of the LIW, blocking the westward route of the LIW.
>
> Furthermore, the Rhodes gyre area in the NW Levantine Basin, being primarily the source of the LIW, appeared in 1987, 1989, 1990, 1992 and 1995 as a formation site of waters denser than LIW (σ_θ from 29.16 to 29.25) but with distinctly warmer and more saline characteristics than the Eastern Mediterranean Deep Water (EMDW). These changes have altered the deep/internal and the upper/external conveyor belts of the Eastern Mediterranean, respectively. This abrupt shift in the Mediterranean "ocean climate" has been named the Eastern Mediterranean Transient (EMT).

See Theocharis et al. [2002].

Eastern North Atlantic Water (ENAW) A water mass defined by Harvey [1982] and Pollard et al. [1991] to describe water found west of Ireland and Iberia. This and Western North Atlantic Water (WNAW) are varieties of North Atlantic Central Water (NACW).

Nomenclatural history is summarized by Pérez et al. [1995]:

> The different characteristics of ENAW compared with WNAW have already been described by several authors (Iselin, 1936; Helland–Hansen and Nansen, 1926). In the past decade [1985–1995], different definitions for the central waters have been used in different geographic areas of the North Atlantic. From IGY data, Harvey [1982] described the formation of several mode waters from south of the subpolar gyre as far as 45°N in the Bay of Biscay. The characteristics are very close to those given by Helland–Hansen, with maximum values of 35.66 in salinity and 12° in temperature. [Others] describe ENAW characteristics east of the Azores, also dominant in water of the Iberian upwelling system, with a lower limit of 35.7 in salinity. Subsequently, Ríos et al. [1992] summarized both descriptions of ENAW and classified ENAW as being of subpolar or subtropical origin, depending on whether the salinity was lower or higher than 35.66, and gave its distribution in the eastern North Atlantic.

This ENAW split is further detailed by Pollard et al. [1991]:

> ENAW can itself be divided into two varieties, colder $ENAW_P$ (subPolar) moving southwards west of Galicia and warmer $ENAW_T$ (subTropical) moving northwards between the Azores and Portugal. $ENAW_P$ is the major Mode Water created east of 20°W and north of 40°N and circulating anticyclonically with temperatures less than 12.4°C. $ENAW_T$ we believe to be warmer (>13°C) WNAW that flows east in the Azores Current then breaks off to the north. Both varieties of ENAW have their salinity modified by winter mixing...

Changes in ENAW between 1974 and 1992 are detailed by Pérez et al. [1995], which they summarize as:

> We shall show that the salinity fell from 35.8 to under 35.6 between 1974 and 1982, remained fresh until 1990, and then increased by 0.12 within one year. It is likely that winter mixing and cooling is responsible for such a rapid increase.

See Pérez et al. [1995], Pollard et al. [1991] and Read [2001].

Eastern North Atlantic Central Water (ENACW) An alternate name for Eastern North Atlantic Water. See Poole and Tomczak [1999].

Eastern North Pacific Central Water (ENPCW) In physical oceanography, a water mass formed in the region of the surface salinity maximum just south of 30° N where salinities greater than 35 are found year round. This is reflected in the portion of ENPCW above 17° C, which has salinities higher than those of all other water masses in the vicinity. It is fresher than both WNPCW and NPEW at temperatures below 17° C, and saltier in the upper thermocline waters warmer than this. It is bounded to the west from WNPCW at about 170° E, and to the south from NPEW at about 12-14° N. See Tomczak and Godfrey [1994], p. 165.

Eastern South Atlantic Central Water (ESACW) See Poole and Tomczak [1999].

Eastern South Pacific Central Water In physical oceanography, a water mass formed between 150-180° W (by processes not yet well understood) and separated from the WSPCW by a gradual transition zone from 145-100° W., from which it is distinguished as being fresher at all T-S values. It is bound to the north by SPEW, from which it is also distinguished by being fresher at all T-S points, to the south by the STC, and to the east by a not yet well understood area having salinities as low as 34.1 east of 90° W. See Tomczak and Godfrey [1994], p. 164.

EASTROPAC Acronym for Eastern Tropical Pacific, a research project.

EASW Abbreviation for East Arabian Sea Water.

EATSS Acronym for European Atlantic Time and Space Series study, a proposed program for establishing coordination of European research activities along the historically studied 20°W meridian from 20 to 60°N. EATTS will be sponsored under the auspices of SOMARE.

[http://www.pml.ac.uk/amt/somare/workshop%201/WS1-Report.htm]

EAZO Abbreviation for Energetically Active Zones of the Ocean.

ebb current The tidal current existing during any time the height of the tide is decreasing. These generally flow in a seaward direction. This has been erroneously called ebb tide.

ebb interval The interval between the transit of the moon over a meridian and the time of strength of ebb of the following tide.

ebb strength See strength of ebb.

ebb tide See falling tide.

EBC Abbreviation for eastern boundary current.

EBDW Abbreviation for Eurasian Basin Deep Water.

ECCO Acronym for Estimating the Circulation and Climate of the Ocean, a consortium consisting of MIT, JPL and SIO formed under the NOPP and funded by NSF, NASA and ONR. The consortium intends to bring ocean state estimation from its current experimental status to that of a practical and quasi–operational tool for studying large–scale ocean dynamics, designing observational strategies, and examining the ocean's role in climate variability. The central goal is the production and evaluatino of continuing 3–D estimates of the global state of the ocean, and the main task is to bring together a global GCM with existing global data streams to obtain the best possible estimate of the time–evolving ocean circulation and related uncertainties.

[http://www.ecco.ucsd.edu/]

echograph A recording echo sounder.

echo sounder An instrument used to determine ocean depth by measuring the time needed for a sound wave to travel from the ship to the ocean floor and return. The first reliable acoustical sounding machine was built by A. Behm in 1919, who called it an echo sounder. An echo sounder consists of three main components: the sound transmitter, the sound receiver, and a device to measure time. See Dietrich [1963].

Eckart, Carl (1902–1973) According to Platzman [1992]:

> Carl Eckart began his scientific work as a quantum physicist, and in midcareer turned towawrd continuum mechanics. He was a member of the physics faculty at the University of Chicago from 1928 until he joined the faculty at the University of California in San Diego (La Jolla) in 1946, where he had been engaged in research on underwater sound for the U.S. Navy since 1941. In La Jolla, he was appointed director of the Marine Physics Laboratory, and for two years was director of the Scripps Institution of Oceanography.

See Munk and Preisendorfer [1976].

[http://scilib.ucsd.edu/sio/archives/siohstry/eckart-biog.html]

ECLAT Acronym for Etudes Climatiques dans l'Atlantique Tropical, a multidisciplinary program designed to become the French contribution of CLIVAR in the tropical Atlantic. The PIRATA program will be part of ECLAT. See the ECLAT Web site[31].

ECOANTAR A research cruise carried out on the R/V *Hesperides* from Jan. 2 to Feb. 1, 1994 in the eastern basin of the Bransfield Strait. A total of 130 hydrographic stations were occupied, and 180 surface to bottom profiles collected. See López et al. [1999].

ECOMARGE A program to study shelf edge exchange processes in the Gulf of Lions. See Monaco et al. [1990].

eddy correlation technique A method for estimating the ocean surface wind stress wherein the directional components of the near–surface turbulent stress covariance in the atmospheric boundary layer are measured. The vertical stress is defined as:

$$\tau(z) = -\rho\,\overline{\mathbf{u}w}$$

where $\mathbf{u}$ is the horizontal vector velocity and w the vertical velocity component. In terms of its scalar components, the magnitude of the wind stress is given by:

$$\tau = \rho\left[(\overline{uw})^2 + (\overline{vw})^2\right]^{1/2}$$

[31] http://www.cru.uea.ac.uk/link/eclat.html

and its angle to the mean wind is:

$$\theta = \tan^{-1}\left(\frac{\overline{vw}}{\overline{uw}}\right)$$

where u and v are the horizontal velocity components. The overbar represents the mean value over a suitable averaging interval. The data must be measured over sufficiently large time and space scales to capture all scales of variability, a task that inevitably presents logistical difficulties.

eddy conduction See eddy heat flux.

eddy conduction coefficient See eddy conductivity.

eddy conductivity The exchange coefficient for the transfer of heat by eddies in turbulent flow, i.e. eddy heat flux. This is also called the eddy conduction coefficient.

eddy diffusivity

eddy heat conduction See eddy heat flux.

eddy heat flux In physical oceanography, the total meridional heat transport due to mesoscale eddies. This has also been used to refer to the correlation of time-dependent fluctuations of velocity and temperature across a section, which is not indicative of the total heat transport due to eddies. Eddies can also induce a thermally driven, overturning cell in subtropical gyres that is analogous to the Ferrel cell in the atmosphere. This cell contributes to the time-averaged transport and its contribution may be as large as that of the time-dependent correlations. This is also called eddy conduction or eddy heat conduction. See Cox [1985].

eddy-induced transport velocity An additional velocity which must be added to the large-scale velocity to properly advect large-scale tracers in numerical circulation models. This is due to the effective transport velocity not being equivalent to the Langrangian-mean velocity when the diffusivity is not spatially homogeneous. This is defined in isopycnal coordinates as:

$$\mathbf{u}^* = \frac{\widetilde{z'_\rho \mathbf{u}'}}{\tilde{z}_\rho}$$

where $\mathbf{u}$ is the horizontal velocity, z_ρ the isopycnal thickness, and the tilde represents an average along an isopycnal surface. This quantity is important since average tracer quantitues are advected by not just the Eulerian mean velocity $\tilde{\mathbf{u}}$ but by the total transport velocity given by:

$$\hat{\mathbf{u}} = \tilde{\mathbf{u}} + \mathbf{u}^*$$

This velocity is a turbulence correlation and therefore must be specified by some type of turbulence theory or parameterized. One attempt at the latter defines it as:

$$\mathbf{u}^* = -\frac{1}{\tilde{z}_\rho}\partial_\rho(\kappa\nabla_\rho\tilde{z}$$

where ∇_ρ is the horizontal gradient in isopycnal coordinates and κ is a scalar diffusivity coefficient. This is also known as the bolus velocity. See Gent et al. [1995] and Dukowicz and Greatbatch [1999].

eddy viscosity A coefficient used to achieve closure in the Reynolds equations for turbulent flow. The assumption is made that the Reynolds stresses are related to the velocity gradients of the flow by a viscosity analogous to the molecular viscosity, i.e. a turbulent or eddy viscosity. The utility of the analogy is strained by the fact that while the molecular viscosity is a property of the fluid, the eddy viscosity is a property of the flow. As such the specification of the eddy viscosity has more than a little of the air of the ad hoc about it since it is usually found via a trial-and-error procedure wherein it is varied until a numerically simulated flow reasonably replicates a known flow. The value thus obtained diagnostically is then used for prognostic simulations, a procedure that is questionable due to the abovementioned fact of the eddy viscosity being a property of the flow rather than the fluid. That is, if the flow is remarkably different, then the eddy viscosity may also be remarkably different.

In the ocean eddy viscosity values range typically from 10 to 10**5 m2/s in the horizontal and from 10**-5 to 10**-1 m2/s in the vertical, with both values more often found towards the higher ends of their ranges.

edge wave A wave which travels parallel to a coastline with crests normal to the coastline. The height of the wave diminishes rapidly offshore.

EDQNM Abbreviation for Eddy Damped Quasi-Normal Markovian, a subfilter closure model applied in spectral wavenumber space rather than physical space which considers interactions between resolved and subfilter wavenumbers by considering the statistics of their possible interactions. The EDQNM achieves closure by modeling the 4th spectral moments. The is one of several closure techniques used when applying large eddy simulation model. See Mason [1994].

EEP Abbreviation for eastern equatorial Pacific.

effective scattering cross-section The ratio of backward scattering intensity to density of irradiation flux. See Kagan [1995].

effective transport velocity The sum of the large-scale velocity and the eddy-induced transport velocity. This is velocity at which tracers are advected in large-scale circulation models. See Gent et al. [1995].

e-folding time The time it takes a system to reduce an imposed displacement to a factor of 1/e of the displaced value. This is a common way of expressing the equilibration time of a system. The e-folding concept is often applied to distances as well as times.

EGCM Abbreviation for Eddy-resolving General Circulation Model.

EHUX Acronym for the European Emiliania huxleyi program, a comprehensive experimental and modeling program focused on the calcium carbonate and organic carbon productivity and ocean carbon flux induced by E. huxleyi in the Northeast Atlantic region. It is a component of and complementary to the GEM program. This project aims to characterize the nonlinear nature of the biological involvement in ocean chemistry and the coupling of the fluxes of particulate organic carbon (POC) and particulate inorganic carbon (PIC).

The fundamental objective is the improve understanding of the processes involved in the growth, distribution and role of E. huxleyi in the oceanic carbon cycle. The specific aims include the morphological and genetic characterization of clones from different areas and elucidation of the life cycle; characterization of PIC, POC, biomarker and CO_2 productivity as a function of cellular and molecular organization and life cycle stages; parallel mesocosm experiments; quantification of these processes in natural blooms at different stages of development and development of carbon budgets for well defined spring bloom conditions; and the development of descriptive and predictive models. See the EHUX Web site[32] and Harris [1996].

EIC Abbreviation for Equatorial Intermediate Current.

[32] http://www.soc.soton.ac.uk/SUDO/tt/eh/index.html

18° Water A variety of Subtropical Mode Water (STMW) that forms in the western subtropical gyre of the North Atlantic Ocean, i.e. the area known as the Sargasso Sea. This has also been called Sargasso Sea Water (SSW). See Worthington [1959] and Talley and McCartney [1982b].

EIL Abbreviation for entrainment interfacial layer.

EIMWT Abbreviation for Echo Integration–Midwater Trawl.

EKE Abbreviation for eddy kinetic energy.

Ekman current meter A mechanical current meter that comprises a propeller with a mechanism to record the number of revolutions, a compass and a recorder with which to record the direction, and a vane that orients the instrument so the propellor faces the current. It is mounted on a free-swinging vertical axis suspended from a wire and has a weight attached below. The balanced propellor, with from four to eight blades, rotates inside a protective ring. The position of a lever controls the propeller. In down position the propellor is stopped and the instrument is lowered, after which reaching the desired depth a weight called a messenger is dropped to move the lever into the middle position which allows the propeller to turn freely. When the measurement has been taken another weight is dropped to push the level to its highest position at which the propeller is again stopped.

The propeller revolutions are counted via a simple mechanism that gears down the revolutions and counts them on an indicator dial. The direction is indicated by a device connected to the directional vane that drops a small metal ball about every 100 revolutions. The ball falls into one of thirty-six compartments in the bottom of the compass box that indicate direction in increments of 10°. If the direction changes while the measurement is being performed the balls will drop into separate compartments and a weighted mean is taken to determine the average current direction.

This is a simple and reliable instrument whose main disadvantage is that is must be hauled up to be read and reset after each measurement. Ekman solved this problem by designed a repeating current meter which could take up to forty-seven measurements before needing to be hauled up and reset. This device used a more complicated system of dropping small numbered metal balls at regular intervals to record the separate measurements. See Sverdrup et al. [1942].

Ekman repeating current meter See Ekman current meter.

Ekman dynamics In oceanography, the process of surface wind stress driving a relatively shallow upper ocean flow that transports water to the left/right and the southern/northern hemisphere.

Ekman layer To be completed. See Price and Sundermeyer [1999].

Ekman number In oceanography, a dimensionless number expressing the ratio of frictional (or viscous) to Coriolis forces. It can be expressed as

$$Ek = \frac{\nu}{D^2 f}$$

where ν is the kinematic viscosity, D a vertical length scale, and f the Coriolis parameter. A small Ekman number can be interpreted as the condition that frictional forces are sufficiently weak such that the natural decay time due to viscous dissipation in the Ekman layer is large compared to a rotation period, i.e. that the spin-down is dominated by rotational rather than frictional processes. See Kraus and Businger [1994] (p. 31) and Pedlosky [1982] (p. 180).

Ekman pumping In oceanography, a process that is the result of a combination of Ekman dynamics and horizontal variations in the wind stress. The resulting convergence and divergence of the surface flow will force vertical water motion called Ekman pumping or suction, respectively.

Eliassen–Palm flux A concept originally developed as a diagnostic tool for studying the interaction between eddies and the zonal–mean flow in the atmosphere. The Eliassen–Palm flux vector is used to represent eddy momentum and heat transport in such a way that the total eddy–inducing forcing is the divergence of the Eliassen–Palm flux. It can also be used to provide information about wave activity for quasigeostrophic flows, with this application relying on the equality between the divergence of the flux and the eddy potential vorticity flux under the quasigeostrophic approximation. See Lee and Leach [1996].

ELISA Acronym for Eddies and Leddies Interdisciplinary Study off Algeria, a MAST-3/MATER program and companion to the ALGERS project. ELISA was an interdisciplinary project to investigate the Western Mediterranean Sea, looking at the role of the Algerian Basin through the detailed study of the Algerian Current. The field work took place between July 1997 and July 1998 and involved 44 scientists from 8 countries. The objectives were to study:

- the general circulation of the water masses, i.e. MAW, LIW and WMDW;
- the Algerian eddies origin, structure and trajectories;
- the biological activity associated with the mesoscale dynamic phenomena; and
- the role of the mesoscale dynamics on the biological functioning of the Algerian Basin.

See Puillat et al. [2002].

`[http://www.com.univ-mrs.fr/LOB/ELISA/]`

El Niño A term originally applied as a description of an annual weak warm current running southward along the coast of Peru and Ecuador during the Christmas holiday, i.e. the Spanish word for “the boy Christ–child” is Niño.a The name El Nño eventually became associated with unusually large warmings that occur every few years and effect large changes on the local, regional, and even global climate. It gradually became known that the coastal warming was part of a much larger warming of the upper waters of the Pacific extending as far as the international date line. There is an associated atmospheric phenomenon called the Southern Oscillation, with the combined changes in atmosphere and ocean termed El Niño/Southern Oscillation or ENSO, with El Niño properly referring the warm phase of ENSO. A typical El Niño event begins in the nothern spring or sometimes summer, peaks from November to January in SSTs, and ends the following summer. The opposite phase is similarly called La Niña, i.e. Spanish for “the girl,” and features a basinwide cooling in the tropical Pacific. The entire system is called El Niño in many if not most popular accounts.

More quantitative definitions have been proposed for classification purposes. Although none is recognized as official, several objective methods have proved useful. Most involve calculating the deviation from average of temperatures in rectangular regions in the tropical Pacific, with the averaging period, baseline temperatures, qualifying deviation, and specific region varying from definition to definition. The defined averaging regions include: Niño 3 (5°N–5°S, 90°–150°W); Niño 3.4 (5°N–5°S, 120°–170°W); and Niño 3.5 (5°N–10°S, 120°–180°W). A typical calculation would find periods during which 5 month running means of monthly SST anomalies in a given area are +0.4°C or more for at least six consecutive months. According to Trenberth [1997], applying this particular procedure to Niño 3.4 picks out most historically prominent El Niño events. See Cane [1986], Enfield [1989], Neelin et al. [1994], Neelin et al. [1998], Philander [1990], Philander and Rasmusson [1985] and Stockdale et al. [1998].

El Niño/Southern Oscillation See El Niño.

ElbeEstuary See Kuhl [1972].

electromagnetic fields See Tyler et al. [1997].

EMDW Abbreviation for Eastern Mediterranean Deep Water.

EMEX 1. Acronym for Equatorial Mesoscale EXperiment, an experiment conducted over the tropical oceanic area north of Australia in Jan.-Feb. 1987. It explored the vertical air motions and other kinematic properties of tropical mesocale convective-cloud systems by direct aircraft penetration. The objectives of EMEX were to document, as intensively and directly as possible, the vertical profile of vertical velocity and other kinematic structures over the ocean near the equator with the most up-to-date instrumentation available and to investigate the physical mechanisms responsible for the convective and stratiform components of the observed cloud systems. See Webster and Houze Jr. [1991]. 2. Acronym for Equatorial Monsoon Experiment.

emissivity The ratio of the emittance from a body to that of a black body emitter at the same temperature, i.e. the degree to which a real body approaches a black body radiator.

emittance The rate at which radiation is emitted from a unit area.

empirical normal mode (ENM) Basis functions that have both the statistical properties of empirical orthogonal functions (EOFs) and the dynamical properties of normal modes, although the orthogonal products used to define orthogonality are related to conserved wave activities such as pseudomomentum or pseudoenergy. These are obtained in a manner similar to EOFs by the diagonalization of a general hermitian problem but with the use of a quadratic form instead of the Euclidean norm, with the quadratic form being a global invariant of the linearized equations about a basic state. ENMs are a diagnostic tool for studying wave behavior and wave interactions, and can also be used as predictors in a long–range forecasting system. They typically beat EOF-based forecasts at long lead times but have slightly poorer scores at short lead times since ENMs are less efficient for data compression than EOFs. See Brunet and Vautard [1996].

empirical orthogonal function (EOF) EOF analysis provides a convenient method for studying the spatial and temporal variability of long time series of data over large areas. It splits the temporal variance of the data into orthogonal spatial patterns called empirical eigenvectors. A set of orthogonal spatial modes can be identified such that, when ordered, each successive eigenvector explains the maximum amount possible of the remaining variance in the data, and each eigenvector pattern is associated with a series of time coefficients that describe the time evolution of the particular spatial mode. The modes are orthogonal, which means that any two modes are uncorrelated in space and time and, as such, no one mode is related to any other. See Peixoto and Oort [1992] and Preisendorfer [1988].

EMW See Eurafrican Mediterranean Water.

ENACW Abbreviation for Eastern North Atlantic Central Water.

ENM Acronym for empirical normal mode.

ENPCW See Eastern North Pacific Central Water.

ENSIP A coordinated study to compare the simulations of ENSO in coupled ocean–atmosphere models. Latif et al. [2001] summarize the results of the study:

> Almost all models (even those employing flux corrections) have still problems in simulating the SST climatology, although some improvements are found relative o earlier intercomparison studies. Only a few of the coupled models simulate the El Nio/Southern Oscillation (ENSO) in terms of gross equatorial SST anomalies realistically. In particular, many models

overestimate the variability in the western equatorial Pacific and underestimate the SST variability in the east. The evolution of interannual heat content variations is similar to that observed in almost all models. Finally, the majority of the models show a strong connection between ENSO and the strength of the Indian Summer Monsoon.

See Latif et al. [2001].

[http://www.clivar.org/organization/wgsip/projects/ensip.htm]

ENSO See El Niñno/Southern Oscillation.

enstrophy This is defined as half of the area-mean vorticity squared in a fluid, mathematically expressed by

$$E = \frac{1}{A}\int_A \frac{1}{2}\zeta^2 \, dA$$

where A is the area over which the calculation is being made and ζ the vorticity. The relation between vorticity and enstrophy is similar to that between velocity and kinetic energy, and the enstrophy budget is used in the study of large-scale motions in the ocean and atmosphere as an alternative to the more cumbersome vorticity budget. See Wiin-Nielsen and Chen [1993].

EOF Acronym for empirical orthogonal function.

EOS–80 Abbreviation for International Equation of State for 1980, the officially recognized equation used by oceanographers to calculate the density of seawater. Why and how EOS–80 was developed are given in JPOTS [1981b]:

> Virtually all the computations of density of seawater made since the beginning of the [20th] century have been based on the direct measurements of density, chlorinity and salinity, made by Forch, Knudsen and Sörensen, published in 1902, and of compression of seawater, made by Ekman (1908). A new equation of state was considered urgently desirable because newly acquired data indicated slight discrepancies with the Knudsen–Ekman equation of state of seawater (Grasshoff, 1976). This old equation was obtained from measurements of density of natural seawater in which the proportions of the various ions are not exactly constant. To be consistent with the new definition of the Practical Salinity, 1978, the new equation of state is based on measurements of density of standard seawater solutions obtained by weight dilution with distilled water and by evaporation. As the absolute density of pure water is not known with enough accuracy, the density of distilled water used for the measurements was determined from the equation of the SMOW (Standard Mean Ocean Water) whose isotopic composition is well defined (IUPAC, 1976). Intensive work was then carried out in different laboratories with different measuring equipment. This resulted in considerable data on which the new International Equation of State of Seawater is based. The full equation is composed on a one atmosphere equation based on 467 data points, combined with a high pressure expression based on 2,023 data points. The density computed with these equations is relative to the IUPAC (1976) recommended equation for density of SMOW.

The density of seawater at one standard atmosphere is computed from the practical salinity (S) and the temperature (t) with the following equation:

$$\begin{aligned}
\rho(S,t,0) &= \rho_w + (8.24493 \times 10^{-1} - 4.0899 \times 10^{-3} t + 7.6438 \times 10^{-5} t^2 \\
&- 8.2467 \times 10^{-7} t^3 + 5.3875 \times 10^{-9} t^4) S \\
&+ (-5.72466 \times 10^{-3} + 1.0227 \times 10^{-4} t - 1.6546 \times 10^{-6} t^2) S^{3/2} \\
&+ 4.8314 \times 10^{-4} S^2 \qquad (2)
\end{aligned}$$

where ρ_w, the density of Standard Mean Ocean Water (SMOW) taken as pure water reference, is given by:

$$\begin{aligned}\rho_w &= 999.842594 + 6.793952\times10^{-2}t - 9.095290\times10^{-3}t^2 \\ &+ 1.001685\times10^{-4}t^3 - 1.120083\times10^{-6}t^4 + 6.536332\times10^{-9}t^5\end{aligned} \tag{3}$$

This equation of state is valid for practical salinity values from 0 to 42 and temperature values from -2 to 40°C.

The density of seawater at higher pressures is computed from the practical salinity (S), the temperature, and the applied pressure (p, bars) with the following equation:

$$\rho(S,t,p) = \frac{\rho(S,t,0)}{1 - p/K(S,t,p)} \tag{4}$$

where $\rho(S,t,0)$ is the one atmosphere value and $K(S,t,p)$ is the secant bulk modulus given by:

$$K(S,t,p) = K(S,t,0) + Ap + Bp^2 \tag{5}$$

where:

$$\begin{aligned}K(S,t,0) &= K_w + (54.6746 - 0.603459t + i1.09987\times10^{-2}t^2 - 6.1670\times10^{-5}t^3)S \\ &+ (7.944\times10^{-2} + 1.6483\times10^{-2}t - 5.3009\times10^{-4}t^2)S^{3/2} \\ A &= A_w + (2.2838\times10^{-3} - 1.0981\times10^{-5}t - 1.6078\times10^{-6}t^2)S + 1.91075\times10^{-4}S^{3/2} \\ B &= B_w + (-9.9348\times10^{-7} + 2.0816\times10^{-8}t + 9.1697\times10^{-10}t^2)S\end{aligned} \tag{6}$$

The pure water terms K_w, A_w and B_w of the secant bulk modulus are given by:

$$\begin{aligned}K_w &= 19652.21 + 148.4206t - 2.327105t^2 + 1.360477\times10^{-2}t^3 - 5.155288\times10^{-5}t^4 \\ A_w &= 3.239908 + 1.43713\times10^{-3}t + 1.16092\times10^{-4}t^2 - 5.77905\times10^{-7}t^3 \\ B_w &= 8.50935\times10^{-5} - 6.12293\times10^{-6}t + 5.2787\times10^{-8}t^2\end{aligned} \tag{7}$$

The high pressure equation of state is valid for practical salinity from 0 to 42, temperature from -2 to 40°C, and applied pressure from 0 to 1000 bars.

Poisson and Gadhoumi [1993] extended EOS–80 at one standard atmosphere, which was limited to salinities between 2–42, up to 50. A polynomial was developed from laboratory measurements via least–square regression fitting. The equation is:

$$\begin{aligned}\rho(S,t,0) - \rho_w &= S(A_0 + A_1t + A_2S + A_3t^2 + A_4tS \\ &+ A_5S^2 + A_6t^3 + A_7t^2S + A_8tS^2 + A_9S^3)\end{aligned}$$

where S is the salinity, t the temperature, and the coefficents are:

$A_0 = 82.4427 \times 10^{-2}$	$A_5 = -14.791 \times 10^{-6}$
$A_1 = -52.753 \times 10^{-4}$	$A_6 = 67.90 \times 10^{-8}$
$A_2 = -51.17 \times 10^{-5}$	$A_7 = -15.886 \times 10^{-7}$
$A_3 = 40.261 \times 10^{-6}$	$A_8 = -52.228 \times 10^{-8}$
$A_4 = 11.5114 \times 10^{-5}$	$A_9 = 20.750 \times 10^{-8}$

The coefficients were calculated with eight decimal places and rounded off to obtain a value of density that differs from the one calculated with the eight decimal digit coefficient polynomial by $< 2\times10^{-4}$ kg m^{-3}. The quantity ρ_w is the density of pure water and is calculated the same as above. The standard deviation of the differences between the measured and calculated densities is 4×10^{-3} kg m^{-3}. This equation is valid within the salinity range 35–50 and the temperature range 15–30°C. See Millero et al. [1980], Millero and Poisson [1981], JPOTS [1981b], JPOTS [1981a], JPOTS [1983], Poisson and Gadhoumi [1993] and Feistel [2003].

EOSS Acronym for the European Sea–level Observing System, a project under which various European sea level activities are coordinated. The objectives of EOSS include:

- optimization of tide gauge networks;
- implementation of geodetic fixing of all relevant tide gauge benchmarks;
- establishment of a regional sea level monitoring network;
- data production for the determination of detailed spatial patterns of sea level rise;
- improvement of tidal modeling capabilities;
- a better understanding of the climatological contributions to sea level rise; and
- improvement of flood warning capabilities.

[http://www.nbi.ac.uk/psmsl/eoss/eoss.html]

epeiric sea A shallow inland sea with limited connection to the open ocean and having depths less than 250 meters. Compare to epicontinental sea and inland sea.

EPIC (CLIVAR) Acronym for Eastern Pacific Investigation of Climate processes in the coupled ocean–atmosphere system, a process–oriented study of the VAMOS element of CLIVAR. EPIC focuses on the eastern Pacific Ocean, specifically the cold tongue ITCZ region and the stratus dreck region. The goal is to understand coupled ocean–atmosphere processes in these regions with the intent of building toward better models and prediction.

[http://www.cdc.noaa.gov/~ajr/epicwksh.html]
[http://www.physics.nmt.edu/raymond/epic2001/overview/]

EPIC Acronym for Equatorial Pacific Information Collection, a system for management, display, and analysis of oceanographic in-situ data. This was developed at the NOAA PMEL to manage the large numbers of hydrographic and time series oceanographic in-situ data sets collected as part of NOAA climate study programs such as EPOCS, TOGA, WOCE and CLIVAR. There are over 100,000 individual data sets within the database, some of which can be accessed via a Web interface. See the EPIC Web site[33].

epicontinental sea A shallow sea on a wide portion of a continental shelf or in the interior of a continent. The former type is also known as a shelf sea. Compare to epeiric sea and inland sea.

epilimnion The layer of water above the thermocline in a fresh water lake, as opposed to the hypolimnion. This is equivalent to the mixed layer in the ocean.

EPILOG Acronym for Environmental Processes of the Ice age: Land, Oceans, Glaciers, an IMAGES program. See Mix et al. [2001].

[http://www.images.cnrs-gif.fr/epilog.html]

epineutral Along a neutral surface.

[33] http://www.pmel.noaa.gov/epic/

epipelagic zone One of five vertical ecological zones into which the deep sea is sometimes divided. The epipelagic zone extends from the surface downward as far as sunlight penetrates during the day. It is a very thin layer, less than 100 meters thick in the eastern parts of the oceans in regions of upwelling and high productivity and up to 200 meters thick in clear subtropical areas. The endemic species of this zone either do not migrate or perform only limited vertical migrations, although there are many animals that do invade the epipelagic zone from deeper layers during the night or pass their early development stages in the photic zone. The epipelagic zone overlies the mesopelagic zone. See Bruun [1957].

EPOC Acronym for Eastern Pacific Oceanic Conference.

EPOCS Acronym for the Equatorial Pacific Ocean Climate Studies program, a project of the NOAA ERL initiated in 1979 to investigate the role of the tropical Pacific Ocean in influencing large–scale interannual climate fluctuations. The principal working hypothesis was that interannual variability of SST in the equatorial Pacific is intimately related to atmospheric fluctuations assocated with the Southern Oscillation, with the coupled signal known as ENSO. The goal of EPOCS was an improved understanding of the ENSO phenomena leading to the development of the capability to simulation the tropical Pacific and atmosphere conditions in near real time and to predict various aspects of the evolution of these conditions. EPOCS is a contribution to the large U.S. TOGA effort. See Hayes et al. [1986].

EqPac Acronym for Equatorial Pacific Project, a U.S. JGOFS process study conducted in the central and eastern equatorial Pacific from 95–170°W in 1992. The purpose was to determine the fluxes of carbon and related elements, and the processes controlling these fluxes, between the euphotic zone and the atmosphere and deep ocean. The pelagic studies principally addressed the mechanisms that make the equatorial Pacific a high nutrient–low chlorophyll (HNLC) zone, and the factors that control CO_2–gas exchange and new and export production. Benthic studies investigated the fate of carbon in the deep sea and the preservation of the primary productivity signal in buried sediments.

Thirteen separate cruises were conducted consisting of 433 days of ship time on the R. V. *Thompson*, R. V. *Wecoma*, R. V. *Baldridge* and R. V. *Discoverer*. Remote sensing data were collected on NASA–sponsored P–3B aircraft overflights, an ONR–sponsored iron study (FeLine II) was conducted in March–April 1992, and data from the TOGA–TAO buoy network was obtained.

The scientific lessons learned during EqPac included:

- the equatorial Pacific is the largest ocean source of CO_2 to the atmosphere, and is thus an important term in the balance of atmospheric CO_2;
- the flux of CO_2 during the 1991–1992 El Niño was reduced by a factor of three from its average value, with the reduced flux primarily controlled by changes in ocean physics rather than biology;
- changes in biology were associated with changes in upwelling even though the macronutrients were always available in excess relative to biological requirements;
- the equatorial undercurrent (EUC) should be considered an iron source at the equator;
- the quantification of variability in phytoplankton biomass and primary production rates related to Kelvin waves and tropical instability waves (TIW) as well as diel processes by using new interdisciplinary moored and drifter instrumentation;
- bacterial production (i.e. a proxy for the flux of labile dissolved organic matter, i.e. DOM) was low relative to primary production in equatorial waters, i.e. a ratio of 0.10 compared to a typical 0.3 for other ocean ecosystems;
- rates of carbon export production fall within the range of earlier estimates, although the form of the export appears to be dissolved as well as particulate, i.e. the equatorial Pacific is more like the oligotrophic central gyres than an active coastal upwelling site;

- there appears to be no $CaCO_3$ accumulation in the underlying sediments at present; and
- the paleoceanographic record over the past 1 Ma shows that the terrigeneous input of iron has no consistent relationship with any biogenic accumulation or the proxies of export production, i.e. the input of iron from the atmosphere or the EUC appears to be unrelated to the final sequestering of carbon on the glacial/interglacial time frame.

See Murray et al. [1992] and Murray et al. [1995].

[http://usjgofs.whoi.edu/research/eqpac.html]
[http://www.aoml.noaa.gov/ocd/oaces/eqpac92.html]
[http://usjgofs.whoi.edu/jg/dir/jgofs/]

EQUALANT A component of the ECLAT (Etudes Climatiques dans l'Atlantique Tropical) program, the French component of CLIVAR.

[http://www.aoml.noaa.gov/phod/COSTA/abstracts/equalant.html]

EQUAPAC Acronym for Cooperative Survey of the Pacific Equatorial Zone, a joint France/Japan/USA project.

equation of mass continuity An equation stating that because the mass of a fluid parcel is constant, the density must decrease/increase if the flow diverges/converges. This is mathematically expressed by

$$\frac{d\rho}{dt} = \rho\nabla\cdot v = 0$$

where ρ is the fluid density and v the vector velocity. See Dutton [1986].

equation of state See Fine et al. [1974], Millero et al. [1980] and Brydon et al. [1999].

equatorial beta plane An approximation for oceanic and atmospheric motions near the equator where the substitutions $\sin\phi \approx \phi$ and $\cos\phi \approx 1$ are made into the governing equations of motion. In this approximation, beta is a constant given by

$$\beta = 2\Omega/r$$

where Ω is the rotation rate of the earth and r its radius, and f is given by

$$f = \beta y$$

where $y = r\phi$ is distance northward from the equator. See Hendershott [1981], p. 304 and Gill [1982], p. 434.

Equatorial Countercurrent In physical oceanography, a subsurface eastward flow that is about 100-200 m thick and 200-300 km wide. It is centered approximately on the equator, and its core lies just beneath the base of the mixed layer in the top of the equatorial thermocline. Such a current is found in all three oceans, although it appears to be a seasonal phenomenon in the Indian Ocean. See Leetmaa et al. [1981].

EquatorialIC A westward flowing equatorial current in the Pacific Ocean that underlies the eastward–flowing Equatorial Undercurrent (EUC). See Delcroix and Henin [1988].

equatorial radius of deformation A form of the Rossby radius of deformation applicable to wave motions near and at the equator. It is defined as

$$a_e = c/\beta^{1/2}$$

where c is the gravity wave speed, i.e. $gH^{1/2}$ where H is the depth (or equivalent depth). This radius is about 2000 km (c = 200 m/s) for barotropic waves in the ocean, making it marginally applicable for use with the equatorial beta plane concept. The approximation is much more valid for the case of baroclinic waves where, for typical atmosphere (20-80 m/s) and ocean (0.5-3.0 m/s) values of c, the equatorial deformation radius is, respectively, 650-1300 km and 100-250 km.

equatorial trough A region of lower pressure located between the subtropical highs on each side of the equator. Within this zone the trade wind airstreams from either hemisphere meet causing ascending motion and large amounts of precipitation. It constitutes the equatorward, ascending portions of the Hadley mean meridional circulation cells of both hemispheres. Energetically this results in an import of water vapor concentrated in the trade wind layer and an export of geopotential energy and sensible heat in th eupper troposphere. This results in a net atmospheric heat export from the trough zone to the higher latitudes. This region, commonly called the doldrums, is centered near 5° S in January and $12 - 15°$ N in July. Its migration between these extremes influences the seasonal distribution of cloudiness and rainfall and the formation of tropical storms, and its annual mean position is known as the meteorological equator.

Equatorial Undercurrent (EUC) In physical oceanography, a subsurface eastward flow centered approximately on the equator whose core lies just beneath the base of the mixed layer in the top of the equatorial thermocline. The flow generally ranges from 100-200 m thick and 200-300 km wide. Such a current is found in all three oceans, although it appears to be a seasonal phenomenon in the Indian Ocean. In the Atlantic its core is around 100 m deep with speeds exceeding 1.2 m/s and transports up to 15 Sv. It alternates between extreme positions 90 km on either side of the Equator on a 2-3 week time scale with speed and transport fluctuating between the previous figures and 0.6 m/s and 4 Sv.

The Pacific EUC was originally discovered and identified as a swift, subsurface current flowing eastward on the equator in opposition to the winds by Cromwell et al. [1954] and, as a result, is sometimes known as the Cromwell Current. Further studies by Cromwell showed it to be continuous along, symmetric about, and tightly confined to the equator with transports comparable to other major ocean currents. The Pacific EUC flows eastward as a narrow (about 500 km wide) tongue within the equatorial thermocline from north of New Guinea to the Galapagos Islands in the eastern Pacific. It has a thickness of only about 200 m, and typical velocities of 1.5 m s^{-1}, with the core depth ranging from 200m in the west to 40 m in the east. It is characterized by a high salinity core and a high concentration of dissolved oxygen. Results from hydrographic and modeling studies estimate a mean transport of 30–40 Sv, although instantaneous peaks of over 80 Sv have been calculated from various measurements.

The details are much more complicated and less well known for the Indian Ocean, although it appears to be present primarily during the northeast monsoon. This is also known as the Cromwell Current in the Pacific Ocean after Cromwell et al. [1954].

The dynamical explanation for a an undercurrent has an appealing qualitative explanation, i.e. fluid converging towards the equator conserves absolute vorticity. As a result, relative vorticity has to increase to make up for the vanishing of planetary vorticity there, with this providing a source of eastward momentum to drive the undercurrent. The balance of forces at the equator reduces to

$$\frac{\partial p}{\partial x} = \frac{\partial}{\partial z}\left(\nu\frac{\partial u}{\partial z}\right)$$

where p is the pressure (baroclinic), x the coordinate along the equator, ν the momentum diffusion coefficient, z the vertical coordinate, and u the along equator velocity component. This is a linear equation, and although the addition of nonlinearities has brought model results and observations into closer concordance, it is thought that they are not essential for maintaining the undercurrent and serve only to modify the linear dynamics. The unsteady flow represented by the dynamics of equatorial waves has also been postulated as an explanation for the observe time-varying characteristics of the undercurrent. See Cromwell et al. [1954], Knauss [1960], Knauss [1966], Philander [1973], Philander [1980], Leetmaa et al. [1981], Peterson and Stramma [1991], Tomczak and Godfrey [1994], Blanke and Raynaud [1997] and Lu et al. [1998].

equatorially trapped gravity wave

equatorially trapped Kelvin wave An equatorially trapped wave similar in character to coastally trapped Kelvin waves. The motion is unidirectional and parallel to the equator everywhere, and in each vertical plane parallel to the equator the motion is the same as for a nonrotating fluid. A required geostrophic balance between the east-west velocity and the north-south pressure gradient leads to solutions that decay away from either side of the equator on a length scale called the equatorial radius of deformation. These dispersionless waves propagate eastward at the same speed as they would in a nonrotating fluid, with the dispersion relation being $\omega = kc$. The magnitude of c for the first baroclinic mode for typical ocean values is around 2.8 m/s, which would take a Kelvin wave across the Pacific in about 2 months. See Gill [1982].

equatorially trapped Poincare wave See equatorially trapped gravity wave.

equatorially trapped Rossby wave

equatorially trapped wave A wave that is confined to propagate on and near the equator due to the local waveguide properties. The waveguide is caused by the vanishing of f_0 at the equator. This means that the conditions for geostrophic balance theoretically fail there, although practically any wave motion having a finite expanse across the equator will feel the Coriolis force on either side. This will serve to turn that motion back towards the equator on either side, thus serving as a trap or a waveguide for motions there. See Gill [1982].

Equilant cruises A series of research cruises in 1965-1966 that performed tightly organized surveys of the tropical Atlantic. Simultaneous data on temperature, salinity and currents were obtained for the then little-known area off the west coast of Africa. These cruises were done with ships from the U.S., the Soviet Union, France, Brazil and other nations. See Idyll [1969].

equilibration time The time it takes for a system to re-equilibrate after being subject to a perturbation. This is usually expressed in terms of an e-folding time. Some typical equilibration times are: the atmosphere, 11 days; the ocean mixed layer, 7-8 years; the deep ocean, 300-1000 years; mountain glaciers, 300 years; ice sheets, 3000 years; the Earth's mantle, 30 million years.

equilibrium tide The hypothetical tide which would exist if the ocean responded instantly to the tide producing forces and formed an equilibrium surface. The effects of friction, inertia, and the irregular distribution of land masses are ignored.

equivalent barotropic An atmospheric state in which the temperature gradients are such that the isotherms are parallel to the isobars.

equivalent depth When the solution of a differential equation set (e.g. the equations of motion for a baroclinic atmosphere or ocean) is approximated using the normal mode technique, each of the independent normal or baroclinic mode solutions obtained behaves equivalently to a homogeneous system with a depth that is called the equivalent depth. See Gill [1982].

equivalent potential temperature In meteorology, the equivalent temperature of an air sample when it is brought adiabatically to a pressure of 1000 mb. It is a conservative property for both dry and saturated adiabatic processes.

ERBE Acronym for Earth Radiation Budget Experiment. See Barkstrom [1984].

ergodic hypothesis The assumption that a process is statistically stationary, and therefore ensemble averaging is equivalent to averaging over time. See Kagan [1995].

ERICA Acronym for Experiment on Rapidly Intensifying Cyclones over the Atlantic, a field study designed to determine physical mechanisms and processes, and their critical spatial and temporal combinations, which can account for the wintertime phenomenon of explosively developing over–ocean atmospheric storms. The field study took place from Dec. 1, 1988 to Feb. 1989. See Hadlock and Kreitzberg [1988].

error of representativeness The spatial spectrum of the atmosphere or ocean shows variance at all scales, with generally less variance at smaller scales. The observation network, however, has a finite spacing between observation stations. If a network has an average spacing of, say, L between stations, then samples with scales much greater or smaller will be sample, respectively, very well or very poorly by the network. For instance, a network with 1000 km spacing will not see a tornado or thunderstorm with a 10 km characteristic length scale if it is between stations, but will see it if it overlies a station and, in addition, will misrepresent it as a larger scale motion. This is occasionally known as aliasing. See Daley [1991].

Ertel, Hans The "potential vorticity" guy. According to Schroder [1988]:

> Ertel's fundamental work in theoretical meteorology and the application of fluid dynamics to meteorological and geophysical problems, culminating in his general vortex theorem, provided a key element in the transition from classical to modern meteorology and geophysical hydrodynamics. His results meanwhile have found manifold application in all parts of meteorological and geophysical science.

See Schroder [1988].

[http://huhu.franken.de/history-geophysics/hans_ertel.htm]

Ertel potential vorticity A rigorous formulation of potential vorticity for any compressible, thermodynamically active, inviscid fluid in adiabatic flow. The Ertel potential vorticity π is defined by

$$\pi = \nabla S \cdot \left(\frac{2\Omega + curl V}{\rho} \right)$$

where S is some conservative thermodynamic property of the fluid (the potential temperature, e.g.), Ω is the angular velocity of the coordinate system, ρ is the density, and V the velocity of the fluid relative to the coordinate system. See Muller [1995].

Ertel's theorem A theorem stating that in an incompressible Boussinesq fluid that is homogeneous and inviscid a quantity called the potential vorticity is conserved. See Hide [1978].

ESACW Abbreviation for Eastern South Atlantic Central Water.

escarpment The official IHO definition for this undersea feature name is "an elongated, characteristically linear, steep slope separating horizontal or gently sloping sectors of the sea floor in non–shelf areas; also abbreviated to scarp."

ESPCW See Eastern South Pacific Central Water.

ESTAR Acronym for Electronically Scanned Thinned Array Radiometer, a proposed remote sensing technique for monitoring the large scale distribution of surface salinity. It depends on the influence of salinity on microwave emissions, strongest at 1.4 GHz. Since temperature has a larger effect, high accuracy temperature measurements must also be made using another band at either 2.65 or 5.0 GHz. This yields a salinity accuracy of 0.05 parts per thousand, although this can be achieved only via long time (30 days) and space (100 km) averaging. A resolution of 10 km would degrade salinity measurement accuracy to 2 parts per thousand. See Swift [1993] and Schmitt [1995].

ESTOC Acronym for European Station for Time–Series in the Ocean Canary Islands, established to complement existing open ocean stations in the eastern boundary regime of the North Atlantic. Regular observations started in 1994 at a nominal station position of 29° 10' N, 15° 30' W, a site about 100 km north of the islands of Gran Canaria and Tenerife at a depth of 3600 m.

`[http://www.ifm.uni-kiel.de/ph/general/estoc.html]`

estuarine Richardson number A form of the Richardson number that gauges the relative effects of stratification and mixing in estuaries. It is given by

$$R = \frac{(\delta\rho/\rho)gQ_f}{WU_t^3}$$

where U_t is the RMS tidal velocity, W the channel width, $\delta\rho$ the difference in density between river and ocean water, ρ the average density, g gravitational acceleration and Q_f the fresh water discharge rate. If R is large the estuary will be strongly stratified the flow dominated by density currents, and if it is small the estuary will be well mixed and density effects can probably be neglected. There is also a modified version of this in which U_t is replaced by the shear velocity u^* to include the effect of varying bottom friction. See Fischer et al. [1979].

estuary A semi-enclosed body of water having a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage. The term has traditionally been applied to the lower reaches of rivers into which sea water intrudes and mixes with fresh water as well as to bays, inlets, gulfs and sounds into which several rivers might empty and in which the mixing of fresh and salt water occurs.

Distinctions between estuaries are usually made based on the prevailing physical oceanographic conditions (principally the salinity distribution) which are governed by the geometry of the estuary, the magnitude of fresh water flow into the estuary, and the magnitude and extent of the tidal motion. The four principal categories into which estuaries are divided using these criteria are well mixed, stratified, arrested salt wedge and fjord entrainment estuaries, although a single estuary can vary seasonally from one type to another. See Emery and Stevenson [1957], Officer [1976], Hansen and Rattray Jr. [1966] and Scott [1993].

ETAMBOT A French research program that took place from 1993 until April–May 1996. It was a program in the western Equatorial Atlantic Ocean wherein hydrographic cruises with tracers were conducted along three meridional and one zonal section off Northeast South America in the region west of 35° W and south of 7.5° N. This was followed up by the ARCANE program.

ETDP Abbreviation for Expert Tsunami Database for the Pacific.

etesian A Greek term for winds that blow at times in summer (May to September) from a direction ranging from northeast to northwest in the eastern Mediterranean. In Turkey these winds are known as "meltemi".

ETOPO5 A digital database of land and sea floor elevations on a 5 minute lat/lon grid. The resolution of the gridded data varies from true 5-minute for the ocean floors, the USA., Europe, Japan,and Australia to 1 degree in data-deficient parts of Asia, South America, northern Canada, and Africa.

[http://www.ngdc.noaa.gov/mgg/global/seltopo.html]
[http://fish.cims.nyu.edu/project_aomip/forcing_data/merged_topography.html]

ETP Abbreviaton for Eastern Tropical Pacific.

EU Abbreviation for Eurasian Oscillation.

EUBEX Acronym for the Eurasian Basin Experiment.

EUC Abbreviation for Equatorial Undercurrent.

Euler equations More later.

Eulerian mean circulation In oceanography, the time-averaged flow field in a fixed coordinate system. This can be remarkably different from the synoptic mean circulation. See Schmitz and McCartney [1993].

Eulerian velocity That velocity which would be measured by a current meter at a fixed point. Compare and contrast to Lagrangian velocity and Stokes velocity

euphotic zone In the ocean, the sunlit layer from the surface to the depth of 1% light level wherein most of the primary productivity takes place. The depth varies geographically and seasonally and can range from a few meters in turbid, highly productive waters near the shore to around 200 m in tropical waters. The ocean average is around 100 m. It is a zone with sharp gradients in illumination, temperature and salinity, and overlies the aphotic zone. It is also known as the photic zone.

Eurafrican Mediterranean Water (EMW) In physical oceanography, a water mass that leaves the Strait of Gibraltar with a temperature of about 13.5° C and a salinity of 37.8 but is transformed by mixing to a temperature and salinity of 11-12° C and 36.0-36.2 within 250 km. From there it spreads isopycnally across the ocean, mixing gradually with the water above and below.

Eurasian Basin Deep Water See Hansen and Osterhus [2000], section 5.3.

EUROFLOAT A MAST program for the observation and modeling of the large–scale movement of the Mediterranean Water (MW) and Labrador Sea Water (LSW) in the eastern North Atlantic Ocean. The principal objectives are:

- determining the mean circulation of the MW and LSW in the intergyre region of the eastern North Atlantic, and;
- discovering if there is a Stokes drift or eddy mixing of the MW and LSW.

A large part of EUROFLOAT will be a lagrangian circulation experiment wherein subsurface neutrally buoyant floats will be used to observe the movement of deep water masses over a period of 3 years. The ARCANE project is a companion study to this.

[http://www.ifremer.fr/lpo/eurofloat/]

EuroGOOS A program to support the European component of the GOOS. It exists to maximize the benefits to Europe from operational oceanography and the aims include indentifying European priorities for operational oceanography, promoting the development of various systems (i.e. scientific, technological, and computer) for operational oceanography, and establishing methods of routine collaboration between European national and multi–national agencies for the conduct of operational oceanography. See the EuroGOOS Web site[34].

eustatic Descriptive of global sea level variations due to absolute changes in the quantity of seawater, the most recent significant examples of which have been caused by the waxing and waning of continental ice sheets during glaciation cycles.

eutrophic A situation in which the increased availability of nutrients such as nitrate and phosphate (e.g. from the use of agricultural fertilizers and the combustion of fossil fuels) stimulates the growth of plants such that the oxygen content is depleted and carbon sequestered. It is hypothesized that this might serve as a negative feedback to an increase in atmospheric CO2.

evaporative cooling A phenomenon wherein the evaporation of water from saturated air (when, for example, it mixes with drier air) cools the air due to the absorption of latent heat.

evolution of the ocean See Holland [1984] and Walker [1977].

exergy A concept and word invented in Rant [1956] for a quantity which can be defined as the available work of a system in connection with its environment in thermodynamic equilibrium, with the equilibrium characterized constant values of temperature and pressure. This is related to the concept of available potential energy (APE) in that it can be used to find the portion of potential energy in a system that can be transformed into kinetic energy. In the classical exergy concept, a state of thermodynamic equilibrium with constant temperature is used as a reference state. In meteorology, it has been shown that, in the case of stable stratification, a state of hydrostatic equilibrium will suffice as a reference state from which no portion of energy is available for conversion into kinetic energy. The APE theories can be derived from the exergy concept in certain situations. See Kucharski [1997].

explicit scheme In numerical modeling, an integration algorithm that temporally advances an approximate solution via discrete steps using only information from previous time steps. These are computationally simpler than implicit schemes but require shorter time stepping intervals. See Kowalik and Murty [1993].

export flux That organic matter (particulate and dissolved) exported from the upper productive layer of the ocean into the deep sea to balance primary production over large time and space scales. This is primarily studied with sediment traps moored in the deep ocean and with freely drifting traps in the upper 1000 m. See biological pump.

export production In biological oceanography, the loss rate of organic carbon (and nitrogen) from the surface ocean layer to the ocean interior.

extensive parameter A determining parameter of a system that is proportional to the size and mass of the system, e.g. volume, internal energy, enthalpy and entropy, as opposed to an intensive parameter.

extinction coefficient A coefficient measuring the rate of extinction, or diminution, with distance of transmitted light in sea water. It is the attenuation coefficient for visible radiation.

[34] http://www.marine.ie/eurogoos/

0.4 F

FACTS Acronym for Florida Atlantic Coast Transport Study. See Rinkel [1986].

Falkland Current See Malvinas Current.

falling tide That interval of the tidal cycle between a high water and the following low water. This is also known as ebb tide.

FAMOUS Acronym for French–American Mid–Ocean Undersea Study. See Heirtzler and Van Andel [1977].

fan The official IHO definition for this undersea feature name is "a relatively smooth, fan–like, depositional feature normally sloping away from the outer termination of a canyon or canyon system; also called a cone."

far infragravity waves Waves in the nearshore zone at periods ranging from 100 to 1000 seconds. These were first discovered in 1986 as substantial energy in the velocity field in that period range, although no accompanying sea surface elevation signal was found, and their celerities were about an order of magnitude too slow to be consistent with a gravity wave explanation. They were eventually identified as shear waves arising from an instability of the strong mean longshore current. The dynamics are analogous to large scale flows, but with the role of the Coriolis force played by the shear of the longshore current. See Bowen and Holman [1989] and Holman [1995].

Faroe Bank Channel See Saunders [1990] and Greenland–Scotland Ridge.

Faroe Current See Hátún and McClimans [2003].

Faroe Shetland Channel See Turrell et al. [1999] and Greenland–Scotland Ridge.

FASINEX Acronym for Frontal Air-Sea INteraction EXperiment, conducted from 1984 to 1986 in the subtropical convergence zone southwest of Bermuda. The overall objective was to study air-sea interaction on 1- to 100-km horizontal scales in a region of the open ocean characterized by strong horizontal gradients in upper ocean and sea surface properties. Among the specific questions addressed by this investigation were how lower atmospheric fluxes vary horizontally on scales determined by scales of oceanic variability, how strong horizontal sea surface temperature gradients associated with fronts affect the structure of the marine atmospheric boundary layer, what the magnitudes of changes in surface roughness, stress, and drag coefficients associated with cross-frontal gradients in SST are, and others. See Weller [1991] and Geernaert [1990].

`[http://uop.whoi.edu/data/fasinex/fasinex.html]`

FAST 1. Acronym for flow actuated sediment trap. 2. Acronym for fore–aft scanning technique.

FASTEX Acronym for Fronts and Atlantic Storm Experiment, an experiment scheduled to take place from Feb.-Mar. 1997 whose aim is to advance the understanding and prediction of wintertime, oceanic, extra-tropical weather systems. It is designed to improve the forecasting of North Atlantic storms. See Joly et al. [1997].

`[http://www.cnrm.meteo.fr/dbfastex/]`

feedback Most generally this is a phenomenon where the output of a system is fed or cycled back into the input of the system, thus changing the output, etc. This is equivalent to saying that a system is nonlinear.

feeder current See rip feeder current.

Ferrel, William (1817–1891) See Peterson et al. [1996].

Ferrel cell A mid-latitude mean atmospheric circulation cell for weather proposed by Ferrel in the 19th century. In this cell the air flows poleward and eastward near the surface and equatorward and westward at higher levels. This is now known to disagree with reality, although it is sometimes used to describe a mid-latitude circulation identifiable in mean meridional wind patterns.

fetch In surface gravity wave generation theories, the length of water over which a wind is blowing. The wave height is completely determined in such theories by the fetch, the duration over which the wind blows, and the velocity of the wind. See Kinsman [1984].

FETCH Acronym for Flux, Etat de la mer et Télédétection en condition de fetCH variable experiment in the Mediterranean Sea, which took place in March and April 1998. The objective was to measure and parameterize the turbulent fluxes at the ocean/atmosphere interface. See Hauser et al. [2000].

FGGE Acronym for First Global GARP Experiment, which took place in 1970 and whose research objectives were to obtain a better understanding of atmospheric motion for the development of more realistic models for weather prediction and to assess the ultimate limit of predictability of weather systems. See Peixoto and Oort [1992] and the FGGE Web site[35].

FIBEX Acronym for First International BIOMASS Experiment.

Fick's law A law stating that the mass of a solute crossing a unit area per unit time in a given direction is proportional to the gradient of solute concentration in that direction. For a 1-D process it can be stated as

$$q = -D\frac{\partial C}{\partial x}$$

where q is the solute mass flux, D the coefficient of proportionality, C the mass concentration of diffusing solute, and x the direction coordinate. The negative sign indicates that transport is from high to low concentrations. D is called the diffusion coefficient or the molecular diffusivity. This was named for Adolf Fick, a German physiologist who published a paper in 1855 entitled "Uber Diffusion" in which he described the molecular diffusion process and derived his law. See Fischer et al. [1979].

FIDO Acronym for Fluxes in the Deep Ocean instrument.

filter In data or signal analysis, a function that selectively discriminates against some of the information passing through it. The discrimination is usually performed on the basis of frequency.

filtered equations Equations derived by modifying the equations of motion in various ways. They are called filtered because the modifications filter out or remove certain dynamical processes or solutions that are deemed irrelevant to the phenomena being studied. Some oceanic examples are the spherical, shallow water, beta plane and the f plane approximations.

filtering approximation See filtered equations.

Findlater jet The atmospheric equivalent of an oceanic western boundary current. An example originates with the southwest monsoon that, fed partly from a northward extension of the easterly trade winds over the southern Indian ocean, develops in May. It turns northward and crosses the Equator in the vicinity of the African coast, confined by the highlands of Kenya and Ethiopia. This causes the winds to assume the familiar jet-like structure seen in western boundary currents in the oceans. See Findlater [1974] and Kraus and Businger [1994].

[35] http://gds.esrin.esa.it:80/B7A7183F/T0xclcce622_0x00021225

Findlay, Alexander George (1812–1875) See Peterson et al. [1996].

Fine Resolution Antarctic Model FRAM is a primitive equation numerical of the Southern Ocean between latitudes 24S and 79S based on the Cox/Bryan model. See Group [1991] and the FRAM Web site[36].

fingerprint method A statistical technique developed to permit early detection of possible greenhouse warming. This method requires finding a multivariate signal (i.e. changes in a number of different climate parameters or changes in the same parameter at a number of different locations) unique to enhanced greenhouse effect model simulations and its accompanying identification in the observed climate record. Thus the method simultaneously satisfies two essential requirements, that the signal be both strong and unique. See Wigley and Barnett [1990].

finite element method A numerical approximation method in which data is represented over some domain by a discrete series of functions. The domain is divided into a finite number of subregions called elements, whence the name. A series of functions is built up by defining a simple function, e.g. a low-order polynomial, on each element and requiring continuity between functions on adjacent subregions. The points where values are used to define the functions are conventionally called nodes and the defining parameters nodal values.

Finite elements are distinguished from spectral methods in that their approximations are local and not global, and they are distinguished from finite differences because the function is defined over a whole region rather than just a discrete points. Their use is more prevalent in modeling solid structures such as buildings or airplanes than it is for geophysical fluid flow, although several authors have constructed circulation models using finite elements. Perhaps their greatest advantage is the relative ease with which highly irregular boundaries can be handled as opposed to with the aforementioned spectral and finite difference methods.

first–year ice A type of sea ice defined by the WMO as:

> Sea ice of not more than one winter's growth, developing from young ice; thickness (typically) 30 cm to 2 m. May be subdivided into thin first–year ice/white ice, medium first–year ice and thick first–year ice.

The thin first–year ice is 30–70 cm thick, the medium 70–120 cm thick, and the thick over 120 cm thick. It may be thicker than 200 cm when it takes the form of ridges. See WMO [1970].

fission-track dating A radioisotopic dating method that depends on the tendency of uranium to undergo spontaneous fission as well as the usual decay process. The large amount of energy released in the fission process ejects the two nuclear fragments into the surrounding material, causing damage paths called fission tracks. These number of these tracks, generally 10-20μ in length, is a function of the initial uranium content of the sample and of time. The usefulness of this as a dating technique stems from the tendency of some materials to lose their fission-track records when heated, thus producing samples that contain fission-tracks produced since they last cooled down. The useful age range of this technique ranges from 100 to 100 million years BP, although error estimates are difficult to assess and rarely given.

A problem with fission-track dating is that the rates of spontaneous fission are very slow, requiring the presence of a significant amount of uranium in a sample to produce useful numbers of tracks over time. Additionally, variations in uranium content within a sample can lead to large variations in fission track counts in different sample sections. This method is used more often in archaeology than

[36] http://www.mth.uea.ac.uk/ocean/fram.html

in paleoclimatology, with other dating methods, e.g. argon-argon dating, preferable for the purposes of the latter field, although it can provide useful results in the 30,000 to 100,000 years BP window that strains the upper and lower limits of the other widely used dating methods. See Bradley [1985].

fjord The term fjord, from the old Norse *fjorthr*, has been rather loosely applied to geological structures develoed by glacial erosion and partly filled with seawater. Its original Norwegian usage also included freshwater lakes and, more recently, the term 'fjord-lake' has been used to describe lakes in glacially carved valleys, but we shall here be strictly concerned only with semi-enclosed coastal inlets. The same coastal structures have been alternatively called sounds, inlets or arms. Given this rather general nomenclature it is not surprising to find a broad variety of topographical features covered by the same heading, including complex, interconnected channels. Nevertheless, we can identify several features characteristic of most fjords:

- they are usually long relative to their width;
- they are steep sided and deep (often deeper than the adjacent continental shelf);
- they typically possess one or more submarine sills which define the deep basin(s) of the fjord and which may be remnant moraines; and
- there is usually a river discharging into the head, with the head used to describe the inland termination of the fjord (and the mouth the seaward opening).

Since fjords are associated with glacial carving, they occur at higher latitudes where there are mountainous coasts. The principal areas are the western coasts of North and South America (above about 45°latitude), the Kerguelan Islands and parts of Kamchatka, the western coasts of Europe and Britain (north of 56°N in Scotland), the coasts of Spitsbergen, Iceland and Greenland and the islands of the Canadian Arctic Archipelago, the coasts of Labrador and Newfoundland, the southwest coast of South Island, New Zealand, the open coasts of Antarctica and of South Georgia and other high latitude islands.

Several classification schemes for fjords have been proposed. **?**] developed a purely descriptive scheme that categorizes vertical profiles of salinity and other properties.

Hansen and Rattray Jr. [1966] derived a more quantitative scheme based on similarity solutions. It is based on two parameters representing the circulation and stratification, with different estuarine regimes occuring for different parameter values. The parameters create a 2-D parameter space, with the ordinate, the stratification parameter, denoting the ratio of the tidally averaged salinity difference from top to bottom to the depth and tidally averaged salinity at a given location. The abscissa, the circulation parameter, denotes the ratio of tidally averaged net circulation velocity at the surface to the cross-sectionally averaged net river run-off flow velocity. The scheme distinguishes among deep fjord estuaries with relatively thin and highly sheared near-surface circulation, shallow and partially mixed estuaries, and arrested salt wedge estuaries.

?] developed a scheme based on the assumption of steady hydraulic control at a constriction. Under steady conditions, it can be shown that there is an upper limit to the two-way transport capacity of a constriction. After Farmer and Freeland [1983].

fjord entrainment estuary One of the four principal types of estuaries as distinguished by prevailing flow conditions. This type features a relatively stagnant, deep water mass overlain by a thin river runoff flow, e.g. prevailing summer conditions for the Norwegian fjords.

Fjortoft's theorem A theorem that is a consequence of both vorticity and enstrophy being conserved in the two-dimensional flow an inviscid homogeneous fluid. It states that the transfer of energy from one scale to a smaller (larger) scale must be accompanied by the simultaneous transfer to a larger (smaller) scale. This result of 2-D turbulence contrast strongly with those from 3-D turbulence where 3-D stretching and twisting terms allow other avenues for energy transfer. This is also known as the anti-cascade theorem. See Hide [1978].

FLAME Acronym for Family of Linked Atlantic Model Experiments, a framework for several numerical ocean modeling projects that study the physics and biogeochemistry of the Atlantic Ocean. The goal of FLAME is to perform a series of sensitivity studies with respect to key parameters of the ocean's dynamics.

[http://www.ifm.uni-kiel.de/to/FLAME/]

FLEX Acronym for Fladen Ground Experiment, a part of JONSDAP 76.

[http://www.gotm.net/html/0-CASES/FLEX.html]

FLIP Acronym for Floating Instrument Platform. See the FLIP Web site[37].

Flores Sea See Gordon et al. [1994].

Florida Bay See Wang [1998].

Florida Current See Schmitz and Richardson [1991].

fluorescence The re-emission of light energy at a lower frequency by an absorber illuminated with optical energy. The response is usually immediate and on order 1 to 3% of the incident intensity.

fluorometer A device used to measure the concentration of chlorophyll in sea water. It does this by mimicking the sun and emitting a flash of light at a specific wavelength and causing the phytoplankton present to fluoresce at another wavelength. The light emitted by the plankton is measured and converted to a chlorophyll measurement via a calibration obtained from discrete measurements of known quantities of chlorophyll. An a-c meter is also used to measure chlorophyll.

flux adjustment See flux correction.

flux correction An ad hoc procedure by which the values of dependent variables at the air-sea interface in coupled atmosphere-ocean model runs are adjusted to better conform to observed values. For example, heat flux is corrected by first running the ocean model and calculating the heat flux needed to correct the differences between the observed and calculated surface temperatures. Next the atmospheric model is run with observed values of SST and the net heat flux from the atmosphere is calculated. The coupled model is then run with the difference between these ocean and atmospheric heat fluxes added to those calculated by the coupled model at each time step. A similar procedure can be followed with other variables. These methods are designed to remove most of the tendency of coupled models to drift towards their own climate replete with systematic errors. The most difficult area to apply this procedure is over ice. It is expected that this will become much less of an issue as the model components are improved. See Sausen et al. [1988] and Meehl [1992].

flux Richardson number A dimensionless number expressing the ratio of turbulent energy lost to buoyant forces to the energy gained by eddy stress acting on the mean shear. It is the crucial nondimensional number for turbulence in stratified, shearing flow and can be expressed in a couple of different ways by

$$Rf = \frac{K_H}{K_M} Ri = \frac{K_M}{k u_* L}$$

[37] http://sio.ucsd.edu/supp_groups/shipsked/FLIP/FLIP.html

where K_H and K_M are eddy viscosity or vertical transport coefficients for heat and momentum, respectively, Ri the gradient Richardson number, u_* the friction velocity, k is von Karman's constant, and L a length scale. The definition of this is different than that for the overall and gradient Richardson numbers. See Turner [1973] and Dutton [1986].

FOCAL Acronym for Programme Français Océan et Climat dans l'Atlantique Èquatorial, a program to describe and model the response of the tropical Atlantic to the wind stress on a seasonal scale. Data was obtained from nine cruises of the research vessels **Capricorne** (of IFREMER) and **Nizery** (of ORSTROM). These were undertaken every three months in the equatorial Atlantic from the Brazilian coastline to the Gulf of Guineau, starting in July 1982 and ending in August 1984. Temperature, salinity, and dissolved oxygen were measured between the surface and 500 m with a CTDO system, and horizontal velocities were measured via current profiling using a free floating surface buoy. FOCAL, along with SEQUAL, amounted to the first time an equatorial ocean was fully monitored over a period of two years. See Katz [1987], Richardson and Reverdin [1987], and Henin and Hisard [1987].

FOCI Acronym for Fisheries–Oceanography Cooperative Investigations, a collection of NOAA programs attempting to understand the influence of environment on the abundance of various commercially valuable fish and shellfish stocks in Alaskan waters and their role in the ecosystem.

[http://www.pmel.noaa.gov/foci/]

FOCUS Acronym for Future of Ocean Chemistry in the U.S., a workshop for chemical oceanographers held at Seabrook, South Carolina from Jan. 6–9, 1998. The goal was to evaluate the current status of research in chemical oceanography and to identify future opportunities and infrastructure needs. Similar workshops were held at the time for biological oceanography (sf OEUVRE), physical oceanography (APROPOS) and marine geology and geophysics (FUMAGES).

Areas identified as emerging objects of intense scrutiny included:

- the replacement of the classical picture of simple control of marine life by major nutrients is being replaced by numerous variations on the theme involving trace elements, organic matter cycling and/or changing nutrient ratios;
- the changes in the role of ocean margins as processors of material in the ocean due to massive human colonization of the coastline;
- the significant difference between organic matter in ocean water and rivers, despite the rivers being a large source of ocean carbon;
- the significane to chemical fluxes of fluids emanating from sediments overlying aquifers on continental margins and around rift zone flanks and crests;
- the relationship between changing climate and radiatively important gases moving between the ocean and the atmosphere;
- how the euphotic zone exports carbon to deep water in response to various physical forcings and biological transformations; and
- the advances in geochemical concepts and analytical technology allowing the measurement and interpretation of the earth's past climates and chemical changes.

[http://www.joss.ucar.edu/joss_psg/project/oce_workshop/focus/]

foraminifera See Van der Zwaan et al. [1999].

Forbes, Edward (1815-1854) A British scientist considered by many to be the founder of the science of biological oceanography. In a time when most investigations were concerned with zoology, Forbes produced some of the first ecological generalizations about marine life to receive wide notice, the most famous of which was his recognition of distribution by bathymetric zones. His belief that no life existed in the zone below 300 fathoms was incorrect yet ultimately useful in that it did much to spur the investigation of the depths of the ocean.

Forbes was also one of the earliest systematic biogeographers, recognizing a series of provinces in the European (i.e. Arctic, Boreal, Celtic, Lusitanian, Meditteranean and Black Seas) seas. His book about these seas, Natural History of the European Seas (completed after his death by Robert Godwin-Austen), is considered to be the first treatise on marine ecology. He also was the first to consider population dynamics in the sea, and founded the science of paleoecology in a report in which he described the fossil record which might be expected in the Aegean Sea if it were to be elevated or filled with sand. See Hedgpeth [1957c].

foreshore The sloping portion of a beach profile that lies between a berm crest (or, in its absence, the upper limit of wave swash at high tide) and the low water mark of the backrush of the wave swash at low tide. This term has been used synonymously with beach face, although the foreshore can also contain some of the flat portion of the profile below the beach face. See Komar [1976].

FORMEX Acronym for Formation Experiment, an Antarctic CRC project to define the mechanisms underlying the formation of sea ice and its role on the formation of Antarctic Surface Waters and air–sea interaction. Specific goals including obtaining:

- quantitative estimates of the rate of formation of Antarctic surface waters in the ice pack during winter,
- quantitative estimates of the transfer of heat between ocean and atmosphere and the role of advection of surface and circumpolar deep water on these transfers, and;
- a better understanding of the processes and mechanisms involving in the mixing of Polar Zone waters with complex zone waters near the Antarctic Shelf.

`[http://www.antcrc.utas.edu.au/antcrc/research/polar/oceanproc/formex.html]`

fossilized mixing region In physical oceanography, this refers to the water trapped between the depths of the summer and winter mixed layers. This is a key feature in the formation of Central Water via the process of subduction. See Tomczak and Godfrey [1994].

fossil turbulence In the ocean, temperature microstructure that remains after the turbulence that presumably created it decays, i.e. there is no velocity microstructure. See Turner [1973].

Fourier analysis The determination of the harmonic components of a complex waveform, i.e. the terms of a Fourier series that represents the waveform.

FOX Acronym for Fishery–Oceanography Experiment.

f plane approximation In oceanography, a coordinate system approximation where the Coriolis parameter f is, in a simplified form of the equations of motion, assumed to be a constant. The dynamics as such take place in a plane tangent to the surface of the Earth where f everywhere takes its value at the point of tangency. This approximation holds reasonably well over latitudinal distances over which f doesn't vary much (i.e. a few degrees) or over a few tens of degrees near the poles where f varies slowly.

The f plane equations are obtained by neglecting all terms of order ε in the beta plane equations. The resulting equations (after Muller [1995]) are:

$$\begin{aligned}
\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - f_0 v &= -\frac{1}{\rho_*}\frac{\partial \delta p}{\partial x} \\
\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} - f_0 u &= -\frac{1}{\rho_*}\frac{\partial \delta p}{\partial y} \\
\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} &= -\frac{1}{\rho_*}\frac{\partial \delta p}{\partial t} - \delta\rho g \\
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} &= 0 \\
\left(\frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}\right)\delta\rho &= wN^2\frac{g}{\rho_*}
\end{aligned}$$

where (u, v, w) are the horizonal and vertical components of the velocity, f_0 is the constant angular frequency at the given latitude,

See Gill [1982] and Muller [1995].

fracture A sea ice term defined by the WMO as:

> Any break or rupture through very close pack ice, compact pack ice, consolidated pack ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with nilas and/or young ice. Length may vary from a few metres to many kilometres.

See WMO [1970].

fracture zone The official IHO definition for this undersea feature name is "an extensive linear zone of irregular topography, mountainous or faulted, characterized by steep–sided or asymmetrical ridges, clefts, troughs or escarpments."

FRAM Acronym for Fine Resolution Antarctic Model.

Fram Strait A deep reaching passage with a sill depth of about 2200 m separating the Arctic Ocean to the north from the Nordic Seas to the south. This is the primary path for water exchanges between these two oceanic regions. See Hunkins [1990].

Franklin, Benjamin (1706–1790) See Peterson et al. [1996], p. 40.

f–ratio The ratio of new production (i.e. resulting from new nutrients coming into the system) to total production (i.e. new plus regenerated, i.e. production from nitrogen recycled within the euphotic zone). In oligotrophic waters, this is around 0.1, while in eutrophic waters is is around 0.8. See Eppley and Peterson [1979] and Garside and Garside [1993].

frazil ice A type of sea ice defined by the WMO as:

> Fine spicules or plates of ice, suspended in water.

This represents the first stage of sea ice growth. The crystals are usually suspended in the top few cm of the surface layer, and give the water an oily appearance. See WMO [1970].

FRED Acronym for Frontal Eddy Dynamics experiment. See Boicourt et al. [1998].

freezing point (of seawater) The freezing point of seawater in °C is given by:

$$t_f(S,p) = -0.0575S + 1.710523 \times 10^{-3} S^{3/2} - 2.154996 \times 10^{-4} S^2 - 7.53 \times 10^{-3} p$$

which fits measurements to an accuracy of ±0.004 K. See Gill [1982].

friction velocity A velocity calculated via dimensional analysis that defines the velocity scale for the flow near a wall. This is also called the dynamic velocity. See Kagan [1995].

fringing reef One of three main geomorphological types of coral reefs, the other two being barrier reefs and atolls. These are formed close to shore on rocky coastlines by the growth of corals and associated hydrozoans, alcyonarians and calcareous algae. Fragments of limestone derived from such bioherms are welded together by the encrusting calcareous algae as well as by the deposition of interstitial calcium carbonate cement, the latter brought about by geochemical reactions and possibly bacterial action. The zone of living corals is separated from the shore by a shallow reef flat where reduced circulation, periods of tidal emersion, and the accumulation of sediments inhibit coral growth. See Barnes and Hughes [1988].

Froude number In fluid mechanics, a dimensionless number expressing the ratio of nonlinear advection to the pressure gradient acceleration associated with the variation of fluid depth, i.e. of the fluid speed to a measure of the internal wave speed. It is defined by

$$Fr = u/\sqrt{gH}$$

where u is the flow velocity, g the gravitational acceleration, and H the fluid depth, and $\sqrt{gH}$ the approximate phase speed of shallow water gravity waves. A Froude number greater than unity is indicative of what is called supercritical flow, and one less than unity of subcritical flow.

When dealing with internal waves, an internal or densimetric Froude number is defined which corresponds to the ordinary Froude number with with the reduced gravity g' replacing g in the above. See Turner [1973] and Houze [1993].

FRRF Abbreviation for Fast Repetition Rate Fluorometer. See Kolber and Falkowski [1993].

fully developed sea A hypothesized situation in wave prediction methods in which storm duration and fetch are both long enough such that energy is being dissipated internally and radiated away at the same rate at which it is being transferred from the wind to the water in the form of waves. In a fully developed sea a steady state of maximum wave development is achieved. See Komar [1976].

FUMAGES Acronym for the Future of Marine Geology and Geophysics, a workshop for geological oceanographers and marine geophysicists held at Ashland Hills, Oregon from Dec. 5–7, 1996. The goal was to evaluate the current status of research in marine geology and geophysics and to identify future opportunities and infrastructure needs. Similar workshops were held at the time for biological oceanography (sf OEUVRE), physical oceanography (APROPOS) and chemical oceanography (FOCUS).

Common issues and directions identified in the summary of the final report include:

- the societal imperative of making rapid progress in understanding complicated, nonlinear systems;
- the central role of focused fluids in producing volcanic, tectonic, and thermal modification of the planet;
- the recognition that present–day conditions may be unrepresentative of the whole of geologic history;

- the importance of explicitly incorporating effects of and on the biosphere into marine geology and geophysics;
- the appreciation that we must move beyond steady–state models to study geological events as they happen; and
- the limitations of present funding structures and technology for problems that span the shoreline.

[http://www.joss.ucar.edu/joss_psg/project/oce_workshop/fumages/]

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GAB Acronym for Great Australian Bight.

GABEX I Acronym for Georgia Bight Experiment I. See Lee and Pietrafesa [1987].

GABEX II Acronym for Georgia Bight Experiment II. See Paffenhöfer et al. [1987].

GAGE Acronym for Guiana Abyssal Gyre Experiment.

[http://www.aoml.noaa.gov/phod/COSTA/abstracts/miamigage.html]

GALE Acronym for Genesis of Atlantic Lows experiment. See Bane [1989] and Lee et al. [1989].

GAME Acronym for the GEWEX Asian Monsoon experiment, the goal of which is to understand the role of the Asian monsoon in the global climate system and develop methods for long-range forecasting.

[http://www.ihas.nagoya-u.ac.jp/game/]

GANES [http://www.pol.ac.uk/oshi/ganes.html]

gap See passage.

GARP Acronym for the Global Atmospheric Research Program, planned and coordinated jointly starting in 1968 by the WMO and the ICSU.

Gaspé Current A current in the Gulf of St. Lawrence usually recognized as a baroclinic coastal jet driven by runoff and reinforced by transverse currents from the gulf's north shore. It has a peak near surface speed of 50 cm s^{-1}, and a substantial fraction of the transport appears to recirculate in the northwest gulf. See Benoit et al. [1985] and Han et al. [1999].

GATE Acronym for GARP Atlantic Tropical Experiment, the first large scale international field experiment of GARP. It was conducted in 1974 and aimed at the study of energetics and dynamics of cloud clusters that drift from the African continent out over the Atlantic Ocean, where they modulate convection in the ITCZ. See Geernaert [1999].

GATE Acronym for Global Acoustic Transmission Experiment.

GBRUC Abbreviation for Great Barrier Reef Undercurrent.

GCD Abbrevation for General Circulation Drifter.

GCM See general circulation model.

GCOS Acronym for the Global Climate Observing System, a global observing program planned jointly by ICSU, WMO, UNEP, and IOC of UNESCO. It was established to develop a dedicated observing system designed specifically to meet to observation requirements for monitoring climate, detecting climate change, and for predicting climate variations and change. The objectives of GCOS are to meet the observational needs for climate system monitoring, climate change detection and response monitoring, especially in terrestrial ecosystems; data for application to national economic development; and research toward improved understanding, modeling, and predicting the climate system. A Joint Scientific and Technical Committee (JSTC) and a Joint Planning Office (JPO) were set up to develop the plans and strategy for implementation of the system. See the GCOS Web site[38] for more information.

GDC Abbreviation for Global Drifter Center.

[38]http://www.wmo.ch/web/gcos/gcoshome.html

GDEM Abbreviation for General Digital Environmental Model, a four-dimensional (latitude, longitude, depth, and time) digital model of temperature and salinity for the North and South Atlantic, the Pacific, the Indian Ocean north of 40° S, the Arctic Ocean, the Mediterranean Sea, and the Black Sea. It consists of coefficients of mathematical expressions describing vertical profiles of temperature and salnity on a half degree latitude-longitude grid for seasonal and annual time frames, with the actual profiles generated by combining the coefficients with the equations. Some regions are being updated to 10 minute resolution. Data for creating the GDEM were obtained from the Master Oceanographic Observational Data Set (MOODS) as well as from the Levitus climatology. It is used by the U.S. Navy for most of its operational systems. See Teague et al. [1990].

GDP Abbreviation for Global Drifter Program.

GDSIDB Abbreviation for Global Digital Sea Ice Data Bank.

GEBCO Acronym for GEneral Bathymetric Chart of the Oceans, a map series established by Prince Albert I of Monaco in 1903. This is at present an activity of the IOC.

[http://www.bodc.ac.uk/projects/gebco/]
[http://www.ngdc.noaa.gov/mgg/gebco/gebco.html]

GEK Abbreviation for geomagnetic electrokinetograph.

Gelbstoff Dissolved material in sea water that is resistant to bacterial attack. Its name comes from the yellow color it imparts to the water. Brown algae, the principal algae group growing in coastal waters of temperature and higher latitudes, excrete phenolic compounds. These polyphenols are converted into a brown polymer by secondary reactions with carbohydrates and proteins of algal origin. The properties of the resulting substance are identical with Gelbstoff. Its concentration in sea water is around 1 mg/l and it is removed mainly by precipitation since its phenolic nature renders it resistant to bacterial attack. This is also known as yellow substance or gilvin. See Riley and Chester [1971].

geodesy A branch of applied mathematics which determines by observation and measurement the exact positions of points and the figures and areas of large portions of the earth's surface, the shape and size of the earth, and the variations of terrestrial gravity. See Torge [1991].

[http://164.214.2.59/GandG/geolay/toc.htm]

GEODYME Acronym for Geochemistry and Dynamics of the Mediterranean, an MTP Core Sub-project whose aims are to monitor the evolution of the physical and chemical characteristics of western deep water and the detect similar changes in the different Mediterranean basins, to describe and quantify transfer processes at air–land–sea interfaces, and to give a new picture of phytoplankton distribution, new production and chemical transfers. See the GEODYME Web site[39].

geological oceanography More later. Compare to biological, chemical and physical oceanography.

geoid A hypothetical, global, and continuous sea-level surface perpendicular to the direction of gravity at all points.

geophysical model function A function used in wind scatterometry to relate the actual measured parameter σ_0i, the normalized radar cross-section, to the near–surface wind speed and direction. At a given frequency, the function can be expressed as:

$$\sigma_0 = f(|U|, \chi, \cdots ; \theta, p)$$

[39] http://www.cadrus.fr/madam/doc/projects/geody/qd_geod

where σ_0 is the normalized radar backscatter coefficient, $|U|$ is the wind speed, χ the relative azimuth angle between the incident electromagnetic wave, $\cdots$ represents the (possibly small) effects of non–wind variables such as long waves, atmospheric stratification, water temperature, etc., θ the incidence angle, and p the polarization.

There are many existing model functions that differ in various details, although some common features are shared. These include:

- at fixed incidence angle all model functions predict an increase in σ_0 with wind speed (for moderate wind speeds);
- the wind speed dependence at a fixed incidence and azimuth angle is frequently expressed as a power law; and
- for a given wind speed, σ_0 exhibits a biharmonic dependence on the wind direction.

See Naderi et al. [1991].

GEOS Acronym for Geodynamics Experimental Ocean Satellite, a series of satellites designed exclusively for geodetic studies. They were flown as part of the National Geodetic Satellite Program. The instrumentation varied with each mission. The objectives were to:

- locate observation points (geodetic control stations) in a 3–D earth center–of–mass coordinate system within 10 m of accuracy;
- determine the structure of the earth's gravity field to 5 parts in 10 million;
- define the structure of the earth's irregular gravitational field and refine the locations and magnitudes of the large anomalies; and
- compare results of the various systems on board the spacecraft to determine the most accurate and reliable system.

GEOSAT Acronym for Geodetic Satellite, a U.S. Navy satellite designed to measure sea surface heights to within 5 cm. It was launched on March 12, 1985 with a primary mission of obtaining a high–resolution description of the marine geoid up to latitudes of 72 degrees. This first or geodetic mission (GM) was completed 18 months after data collection began on March 30. During this mission the ground track had a near–repeat period of of about 23 days (330 revolutions in 23.07 days, average orbital period of 6039.84 sec). The GM data were initially classified but released to NOAA for public distribution in 1995.

The satellite orbit was changed at the conclusion of the GM on September 30, 1986, followed by the start of the scientific Exact Repeat Mission (ERM) on November 8, 1986. The ERM produced sea level profiles along tracks that repeated themselves within 1–2 km at intervals of about 17 days (244 revolutions in 17.05 days, average orbital period of 6037.55 sec). It covered 62 complete 17–day cycles before the failure of the second tape recorder on October 1989 terminated the mission. See Douglas and Cheney [1990].

GEOSECS Acronym for Geochemical Ocean Sections Study, a global survey of the three-dimensional distribution of chemical, isotopic and radiochemical tracers in the ocean. It was designed to establish a baseline database for assessing future chemical changes in the world's oceans and to provide a better understanding of large–scale oceanic transport and mixing processes. The expeditions were in the Atlantic from July 1972 to May 1973 (121 stations); the Pacific from August 1973 to June 1974 (147 stations); and the Indian Ocean from December 1977 to March 1978 (141 stations). The logistics and handling of GEOSECS cruises and analyses were coordinated by SIO and directed by Arnold

Bainbridge. The ^{14}C analyses for all three oceans are summarized in Stuiver and Ostlund [1980], Ostlund and Stuiver [1980] and Stuiver and Ostlund [1983].

[http://ingrid.ldgo.columbia.edu/SOURCES/.GEOSECS/]

GEOSTAR Acronym for Geophysical and Oceanographic Station for Abyssal Research, a project to develop an innovative deep sea benthic observatory devoted to continuous and long–term geophysical, oceanographic, and geochemical observations.

[http://web.ingv.it/~wwwgeostar/]

general circulation model Generally a three-dimensional time-dependent model of the atmosphere and/or ocean circulation. The solution to a set of mathematical equations governing the motions of a layer of fluid on a spherical planet is numerically approximated on a three-dimensional discrete grid of points to obtain temperatures, velocities, rainfall, pressure and any of several other dependent variables that collectively comprise the state of the climate. Often abbreviated as GCM. See Washington and Parkinson [1986].

geophysical fluid dynamics (GFD) An interdisciplinary field of study for understanding fluid flows which occur naturally, e.g. the general circulation of the atmosphere, oceanic circulations, mantle convection, and the motions which drive the geodynamo. This is accomplished through mathematical, numerical and experimental modeling.

geopotential The potential energy per unit mass of a body due to the Earth's gravitational field as referred to an arbitrary zero reference level. A unit of geopotential is the potential energy acquired by a unit mass on being raised a unit distance in a gravitational field of unit strength.

geopotential distance See dynamic height.

geopotential height See dynamic height.

geopotential surface A surface to which the force of gravity is everywhere perpendicular and equal. No work is necessary for the displacement of mass along a potential surface as long as no other forces act in addition to gravity. This can also be defined as a surface of equal dynamic height below the level of the sea surface, using the ideal sea surface level as a reference surface with the potential value 0. This has also been called a potential surface or a level surface.

geopotential thickness See dynamic height.

geostrophy That which is due to geostrophy.

geostrophic adjustment The mutual adaptation of mass and momentum toward a steady geostrophic state in rotating fluids. The adjustment problem was first considered by Rossby [1938], who derived the geostrophically balanced steady end state for an ocean to which momentum is impulsively imparted. The end state always possesses less energy than the initial state, a fact due to the end state being achieved through decaying inertial oscillations which disperse energy away in pulses of Poincare waves. See Blumen [1972] and Kuo and Polvani [1997].

geostrophic approximation The use of the geostrophic wind as an approximation to the actual wind in the equations of motion.

geostrophic balance See geostrophy.

geostrophic current A current resulting from geostrophy. Analogous to the geostrophic wind concept in meteorology.

geostrophic force A virtual force used to account for the change in direction of the wind relative to the Earth's surface. It results from the Earth's rotation and the Coriolis force.

geostrophic method A method for determining the relative geostrophic flow field in the ocean from the distribution of density in the ocean. An absolute geostrophic flow field can additionally be found with the additional assumption of a level of no motion.

geostrophic turbulence The large amplitude motion of the energy–containing eddies in the oceans and the atmosphere. See Rhines [1979].

geostrophic velocity Those velocities exhibited by geostrophic currents due to geostrophy.

geostrophic wind The result of geostrophy in the atmosphere. Analogous to the geostrophic current in oceanography.

geostrophy The balance between the Coriolis force and the horizontal pressure gradient that determines the first order circulation patterns in the open ocean. This balance is expected to hold for most latitudes but to break down near the equator where the local vertical component of the Coriolis force vanishes, although comparisons between geostrophic estimates and direct measurements have shown it to hold within fractions of a degree from the equator. Geostrophy allows the large scale flow of the oceans to be determined by mapping the horizontal pressure distribution, although such solutions are degenerate in that they only allow the current fields to be determined relative to an absolute reference level.

Various methods have been used to determine absolute current fields via the assumption of geostrophy. Inverse methods use constraints such as mass conservation or tracer balances to find a reference velocity for each station pair [Wunsch 1996]. A more traditional method is to find the reference velocities using geostrophy and mass conservation along with qualitative determinations of flow reversals based on tracer fields [Reid 1986 1989 1994]. Satellite altimetry is making it possible to determine the absolute height of the sea surface relative to a geoid and thus be usable as a reference level.

Gerard barrel A barrel used to collect water samples in oceanography. It holds 250 liters of sea water.

German Deep–Sea Expedition An investigation of the physical and biological conditions of the Atlantic and Indian oceans during 1898 and 1899 by a research team aboard the "Valdivia." This expedition penetrated into the Antarctic as far as the ice would permit. The results were issued as a series of memoirs under the editorship of Chun, the leader of the expedition. See Murray and Hjort [1912], p. 16.

Gerstner wave A wave theory developed for periodic waves of finite height to surpass the limitations of Stokes wave theory. The equations are simple to use and the solutions are exact and satisfy continuity as well as the pressure conditions at the water surface, and experimental studies have shown that the theory closely approximates the profiles of real waves on a horizontal bottom. Drawbacks include that mass transport is not predicted, the velocity field is rotational, and the particle movements are opposite to that expected in real waves (and found in other theories).

The predictions of both Gerstner and Stokes wave theories agree equally well with measured wave profiles. This is well explained by the fact that if the Gerstner wave equations are expanded into a series the first three terms are identical to those in the Stokes solution. This similarity in predictive ability and greater ease of use lead to the preferential use of Gerstner wave theory in many engineering applications where its limitations are not significant. This has also been called trochoidal wave theory since the elevation profile takes the form of a trochoidal curve. See Komar [1976] and LeMehaute [1976].

GEWEX Acronym for the Global Energy and Water Cycle Experiment. Initiated in 1988 by the WCRP to observe and model the hydrologic cycle and energy fluxes in the atmosphere, at the land surface, and in the upper oceans. It is an integrated program of research, observations, and science activities leading to the prediction of global and regional climate change.

GEWEX hydrometeorology and land-surface projects include the GRDC, ISLSCP, GCIP, BALTEX, GAME, LBA, and MAGS. Radiation projects include the BSRN, CPRP, GPCP, GVaP, ISCCP, and SRB. Modeling and prediction projects are GCSS, G-NEP and PILPS. See the GEWEX Web site[40].

GDD Abbreviation for geophysicalfluiddynamics. GeophysicalFDL.

GHCC Abbreviation for Global Hydrology and Climate Center.

Gibb's phenomenon An artifact of attempting to approximate a function or waveform with a discontinuity using a Fourier series or some other global, continuous basis function. The fit is poor in a region near the discontinuity, usually characterized by large oscillations within the region. Increasing the number of components in the approximation decreases the region of poor fit, which theoretically vanishes with an infinite number of components.

Gibraltar Experiment See Kinder and Bryden [1987].

gilvin See Gelbstoff.

GIN Sea Abbreviation for Greenland/Iceland/Norwegian Sea, an area that has also variously been called the Norwegian Sea and the Nordic Seas. The GIN Sea together with the Polar Sea constitute the Arctic Ocean in some classification schemes (with others including the GIN Sea within the confines of the Atlantic). The former may perhaps be preferred for geomorphological as well as hydrographical reasons. The bottom is continuously oceanic in crust and depth through the connecting passage (to the north) of Fram Strait, while the southern connection is over a continental ridge, i.e. the Greenland–Scotland Ridge. Also, the deep thermohaline circulation processes of the GIN and the Polar Sea are closely linked.

The GIN Sea comprises two major basins: the Greenland Basin and the Greater Norwegian Basins (i.e. the Norwegian Basin and the Lofoten Basin) separated by the Mohn Ridge. It has six open boundaries through which important exchanges occur: Fram Strait connecting to the Polar Ocean to the north, three boundaries over the Greenland–Scotland Ridge that connect with the Atlantic Ocean, and two boundaries connecting to continental shelf seas, i.e. the North Sea and the Barents Sea. See Hopkins [1991].

Global Drifter Center (GDC) An AOML data center located in Miami, Florida that manages the deployment of drifting buoys around the world. Global Lagrangian Drifters (GLD) are placed in areas of interest using research ships, VOS, and U.S. Navy aircraft. Once they are operationally verified, the data is telemetered to the GDS and disseminated to interested parties everywhere. See the GDC Web site[41].

Global Drifter Program (GDP) A NOAA AOML program whose objectives are to: (1) described mixed–layer velocity on a 5 degree resolution global basis and produce new charts of seasonal surface circulation; (2) provide an operational data stream for SST, sea level pressure, and surface velocity data; (3) verify global climate models; (4) compute single particle diffusivities, eddy statistics, and interannual to annual variability; (5) construct models of wind–driven currents; and (6) obtain high resolution

[40] http://www.cais.com/gewex/gewex.html
[41] http://www.aoml.noaa.gov/phod/dac/gdc.html

coverage in special regions for process studies. The program was started in 1978. See the GDP Web site[42].

Global Energy and Water Cycle Experiment GEWEX was initiated in 1988 by the WCRP as a program designed to observe and model the hydrologic cycle and energy fluxes in the atmosphere, at the land surface, and in the upper oceans. The International GEWEX Project Office (IGPO) is the focal point for the planning and development of all GEWEX projects and activities. See Chahine [1992] and Chahine [1992] and the GEWEX Web site[43] for further information.

Global Hydrology and Climate Center A research center, abbreviated GHCC, whose objective is to address global hydrological processes. See the GHCC Web site[44].

Global Precipitation Climatology Project A GEWEX-affiliated project, abbreviated GPCP, designed to provide global data sets of area, time-averaged precipitation for a minimum period of 10 years (1986-1995). This data will be produced by merging geostationary and polar-orbiting satellite microwave and infrared data with rain gauge data from more than 6000 stations. More information can be found at the GPCP Web site[45]. See Arkin and Xie [1994].

Global Runoff Data Center A GEWEX project, abbreviated GRDC, to compile a global data base of stream flow data for the development and verification of atmospheric and hydrologic models. More information can be obtained at the GRDC Web site[46].

Global Terrestrial Observing System The GTOS is a global observing program planned jointly by FAO, UNESCO, ICSU, WMO, and UNEP.

GLOBEC Acronym for Global Ocean Ecosystem Dynamics, a component of IGBP developed and sponsored by SCOR, the IOC, the ICES, and PICES. Its goal is advance our understanding of the structure and functioning of the global ocean ecosystem, its major subsystems, and its response to physical forcing to where we can develop and capability to forecast the marine upper trophic system response to scenarios of global change. GLOBEC concentrates on zooplankton population dynamics and its response to physical forcing in pursuit of this goal. See the GLOBEC Web site[47] or the U.S. GLOBEC Web site[48].

globigerina ooze A type of calcareous ooze composed of the shells of unicellular creatures called globigerina that live in the waters of warmer ocean regions. These oozes are seldom found above 5000 m depth and cover about 35% of the surface of the sea floor. See Neumann and Pierson [1966] and Tchernia [1980].

GLOCOPH Acronym for Global Continental Palaeohydrology Project, an activity of INQUA.

GLORI Acronym for Global Land-Ocean River Inputs database.

GLOSS Acronym for the Global Sea Level Observing System, an IOC-coordinated project for the establishment of a strategic gloval core network of about 300 tide gauges around the world for long term climate change and oceanographic sea level monitoring. These gauges are spaced about 1000 km apart along coastlines and on oceanic islands and provide hourly-resolution standardized sea level data. See Tolkatchev [1996] and the GLOSS Web page[49].

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[42] http://www.aoml.noaa.gov/phod/dac/gdp.html
[43] http://www.cais.com:80/gewex/gewex.html
[44] http://wwwghcc.msfc.nasa.gov:5678/ghcc_home.html
[45] http://www.cais.com/gewex/gpcp.html
[46] http://www.cais.com/gewex/grdc.html
[47] http://www.igbp.kva.se/globec.html
[48] http://www.usglobec.berkeley.edu/usglobec/globec.homepage.html
[49] http://www.nbi.ac.uk/psmsl/gloss.info.html

GLOUP Acronym for Global Undersea Pressure data set, a global data bank for ocean bottom pressure measurements established by a 1999 IAPSO resolution and maintained by PSMSL. The GLOUP data are archived in either high frequency (typically hourly or every 15 minutes) or daily format. The high frequency data contain the total pressure, predicted pressure from a tidal analysis, and residual pressure. The tidal analysis is performed using 63 constituents for records longer than 12 lunar months, and 55 independent and 2 related constituents for records longer than 6 lunar months. Records shorter than 25 days contain no tidal predictions or residuals. Daily values are only produced for records longer than 25 days, and contain two values for each day calculated from residual pressures from the high frequency data. The first value is a simple average of the residual pressures during that day, and the second a value filtered with a Doodson X0 filter to remove any residual signal at tidal frequencies.

[http://www.pol.ac.uk/psmslh/gloup/gloup.html]

GMP Abbreviation for Gulf of Mexico Program.

GNAIW Abbreviation for Glacial North Atlantic Deep/Intermediate Water.

GOALS Acronym for the U.S. Global Ocean Atmosphere Land System program, scheduled to run from 1995-2010. This program focuses on improving the coupled ocean-atmosphere models used to simulate the structure of El Nino events under the TOGA program, and also to expand the investigation of predictability beyond the tropical Pacific to other oceans and land masses. See McPhaden [1995] and the GOALS Web site[50].

GODAE Acronym for Global Ocean Data Assimilation Experiment, a GOOS pilot project whose goal is to demonstrate the practicality and feasibility of routine, real–time global ocean data assimilation and prediction. The general objective is to demonstrate real–time global ocean data assimilation, with sub–objectives including:

- extending predictability of coastal and regional subsystems;
- providing several up to 20 day high–resolution, upper open ocean forecasts and nowcasts;
- integrated analyses for research and development as well as reanalysis;
- initial conditions for climate forecasts; and
- sustaining and designing for a permanent global ocean observing system, including remote and direct sensing.

The GODAE experiment was defined in 1997, feasibility studies and scoping were performed in 1998–1999, pre–operational testing is ongoing from 1999–2002, with the full test scheduled for 2003–2005.

[http://www.bom.gov.au/bmrc/ocean/GODAE/]

GODAR Abbreviation for Global Oceanographic Data Archeology and Rescue Project, an IODE project started in 1993 to increase the volume of historical oceanographic data available to climate change and other researchers by locating sets not yet in digital form and ensuring their submission to one of the national data centers. The specific goals of the project include:

- digitization of data currently existing only in manuscript and/or analog form;
- ensuring that all oceanographic data available for international exchange in archived at two or more data centers in digital form;
- preparing inventories of data currently available only in manuscript or analog form, and digital data not presently available internationally; and

[50] http://www.noaa.gov/ogp/goals.html

- making all data accessible on various media.

[http://ioc.unesco.org/iode/activities/godar.htm]

GODC Abbreviation for German Oceanographic Data Center. See DOD.

GOES Acronym for Geosynchronous Operational Environmental Satellite. See Menzel and Purdom [1994].

[http://rsd.gsfc.nasa.gov/goes/]

GOEZ Acronym for Global Ocean Euphotic Zone study, an IGBP project.

Goldsborough-Stommel circulation A circulation pattern found in models of enclosed basins where the boundary condition is surface water forcing using the natural, mass-flux boundary condition rather than a rigid lid with virtual salt forcing. This results in a barotropic circulation pattern that is similar to the wind-driven subtropical and subpolar gyres but rotating in the reverse direction. See McWilliams [1996] and Huang and Schmitt [1993].

GOMAP Acronym for Global Ocean Monitoring and Prediction, an SERDP program for monitoring and predicting ocean processes at a resolution sufficient to depict features such as fronts and eddies. It covers both deep and shallow water and uses a combination of numerical ocean models, remotely sensed data, and in situ data to develop ocean and ocean/atmosphere interface models aimed at predicting the natural variability of the global ocean system and its effect on short and long term climate variability. A major aspect of this research is to determine the origin of observed ocean anomalies and understand their dynamics using a combination of satellite data, an eddy–resolving global ocean model, and a comprehensive coastal model. This is an NRL program whose principal investigators are Harley Hurlburt and Ken Ferer. See the GOMAP Web site[51].

GOOS Acronym for Global Ocean Observing System, a joint ICSU/IOC-UNESCO/WMO program whose main elements are the collection and timely distribution of oceanic data and products, including assessments, assimilation of data into numerical prediction models, the development and transfer of technology, and capacity building within participating member states to develop analysis and application capability. See Smith [1993], the International GOOS Web site[52], and the U.S. GOOS Web site[53].

GOSIC Acronym for Global Observing Systems Information Center, the central repository for information about the G3OS.

[http://www.gos.udel.edu/]

GOSTA Acronym for Global Ocean Surface Temperature Atlas.

GOTM Abbreviation for General Ocean Turbulence Model, a one–dimensional numerical model aimed at accurately simulating vertical exchange processes in the marine environment where mixing is known to play a key role. The goals of GOTM are to:

- learn about the physics and numerical treatment of vertical mixing processes;
- compare the performance of various turbulence schemes under various oceanic regimes;
- easily be able to introduce new features in the modular models, e.g. a new turbulence scheme;
- couple GOTM with biological, ice, etc. models; and

[51] http://clean.rti.org/geca.htm
[52] http://www.unesco.org/ioc/goos/IOCGOOS.HTML
[53] http://www.usgoos.noaa.gov/goos.html

- integrate GOTM into 2– and 3–D hydrodynamic codes.

GPCP Abbreviation for the Global Precipitation Climatology Project.

GPP Acronym for Gross Primary Production.

GRACE Acronym for Gravity Recovery And Climate Experiment, an experiment wherein twin satellites are used to make detailed measurements of Earth's gravity field. The twin satellites will fly in formation over the Earth, with the precise speed of each satellite and the distance between them constantly communicated via a microwave K-band ranging instrument, with a Superstar Accelerometer on board each satellite is used to separate out the effects of nongravitational forces. The gravitational field changes beneath the satellites, which change the orbital motion of each, correlate to changes in the density of the surface beneath. The change in orbital motion causes the distance between the satellites to change, with such changes detected with a resolution of 10 micrometers. This data will be combined with GPS data to produce monthly maps of Earth's gravitational field.

The expected geophysical applications include:

- tracking water movement on and beneath Earth's surface;
- tracking the movement and changes in ice sheets and changes in global sea level;
- studying ocean currents both near the surface and far beneath the waves; and
- tracking changes in the structure of the solid Earth.

[http://www.csr.utexas.edu/grace/]

gradient Informally this connotes the changing of some property over space or time, e.g. there is a gradient in the density of the atmosphere as one proceeds vertically upward or a gradient in SST as one travels from the equator to the poles. Formally, the gradient is the result of a gradient operator operating on some scalar quantity. The gradient of some scalar quantity f can be mathematically expressed as

$$\nabla f = i\frac{\partial f}{\partial x} + j\frac{\partial f}{\partial y} + k\frac{\partial f}{\partial z}$$

where ∇ is the gradient operator and i, j, k and $\frac{\partial}{\partial n}$ the component unit vectors and differential operators in a Cartesian coordinate system. See Dutton [1986].

gradient operator A differentiation operator, usually expressed by ∇, that operates on scalar functions or with a scalar or vector product on a vector. See gradient, divergence, and curl.

gradient Richardson number A dimensionless number expressing the ratio of the energy extracted by buoyancy forces to the energy gained from the shear of the large-scale velocity field. It is expressed by

$$Ri = N^2 / \left(\frac{\partial u}{\partial z}\right)^2$$

where N is the buoyancy frequency, u the velocity, and z the vertical coordinate. A flow is said to be stable if Ri is greater than 1/4, and if it is less than 1/4 an instability may occur. This form of the Richardson number therefore provides important quantitative information on the relation between the stabilizing effect of buoyancy and the destabilizing effect of velocity shear. The definition of this is different than that for the overall and flux Richardson numbers. See Turner [1973] and Dutton [1986].

gradient wind A wind that theoretically exists as a balance between the pressure gradient, Coriolis, and centrifugal forces. It blows along curved isobars with no tangential acceleration. In the case of rotation around a high/low pressure area the centrifugal force is in the same/opposite direction as the pressure gradient force and leads to an increase/decrease in wind speed compared to that calculated for the geostrophic wind resulting from a balance between the Coriolis and pressure gradient forces.

Grashof number A dimensionless number indicating the decay period of internal wave fields. It is the square of ratio of the dissipation or diffusion time to the internal wave period and is given by

$$Gr = \frac{N^2 H^4}{\nu^2}$$

where N is the internal wave frequency, H the depth, and ν the kinematic viscosity. A Grashof number greater than one indicates that the wave field will decay very slowly, and if Gr is less than one viscous dissipation damps the waves as fast as they are formed. See Fischer et al. [1979].

gravitational acceleration The acceleration with which a body would freely fall under the action of gravity in a vacuum. This actually varies with the distance from the center of the Earth as well as with geographical location (due to the inhomogeneities in the solid Earth), but the internationally adopted value is 9.80665 m/s2 or 32.1740 ft/s2.

grease ice A type of sea ice defined by the WMO as:

> A later stage of freezing than frazil ice when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the surface a matt appearance.

This behaves like a viscous fluid. See WMO [1970].

Great Australian Bight The southern part of the Australian coastline stretching from the Recherche Archipelago at 124°E to the South Australian gulfs at 136°E. The continental shelf is wide throughout the Bight, reaching over 200 km width at around 131°E. See Herzfeld [1997].

Great Barrier Reef Undercurrent See Church and Boland [1983].

Great Salinity Anomaly A low salinity and temperature event that propagates around the North Atlantic. The first event identified as such – and now called GSA '70s – was a freshening of the upper 500–800 m that propagated around the North Atlantic subpolar gyre over a period of about 14 years. It left the region of Iceland in the mid–to–late 1960s and returned to the Greenland Sea in 1981–1982. The second event occurred in the 1980s and is called GSA '80s. Belkin et al. [1998] compare and contrast the two events, identifying two GSA modes:

> The advection speed of the GSA'80s seems to be greater than the one of the GSA'70s: The 1980s anomaly reached the Barents Sea 6 to 7 years after peaking in the West Greenland Current, while the 1970s anomaly traveled the same route in 8 to 10 years. These anomalies, however, seem to be of different origin. The GSA'70s was apparently boosted remotely, by a freshwater/sea ice pulse from the Arctic via Fram Strait. Consequently, the GSA'70s was accompanied by a large sea ice extent anomaly in the Greenland and Iceland Seas, which propagated into the Labrador Sea. In contrast, the GSA'80s was likely formed locally, in the Labrador Sea/Baffin Bay mainly because of the extremely severe winters of the early 1980s, but supplemented with a possible contribution of the Arctic freshwater outflow via the Canadian Archipelago (facilitated by strong northerly winds) which would have enhanced stability and ice formation. This anomaly was also associated with a positive sea ice extent

> anomaly in the Labrador Sea/Baffin Bay which, however, had no upstream precursor in the Greenland Sea. Thus the GSAs are not necessarily caused solely by an increased export of freshwater and sea ice from the Arctic via Fram Strait. These results are corroborated by the early 1990s data when a new fresh, cold anomaly was formed in the Labrador Sea and accompanied by a large positive sea ice extent anomaly. The harsh winters of the early 1990s were, however, confined to the Labrador Sea/Baffin Bay area while the atmospheric and oceanic conditions in the Greenland, Iceland, and Irminger Seas were normal. The Labrador Sea/Baffin Bay area appears therefore to play a key role in formation of GSAs as well as in propagation of the GSAs formed upstream. A likely contribution of the enhanced Canadian Archipelago freshwater outflow to the GSA formation also seems to be significant. Two major modes of the GSA origin are thus identified, remote (generated by an enhanced Arctic Ocean freshwater export via either Fram Strait or the Canadian Archipelago) and local (resulting from severe winters in the Labrador Sea/Baffin Bay).

See Dickson et al. [1988] and Belkin et al. [1998].

greenhouse effect Short-wave solar radiation can pass through the clear atmosphere relatively unimpeded, but long-wave radiation emitted by the warm surface of the Earth is partially absorbed and then re-emitted by a number of trace gases in the cooler atmosphere above. Since, on average, the outgoing long-wave radiation balances the incoming solar radiation, both the atmosphere and the surface will be warmer than they would be without the greenhouse gases. A historical perspective and tutorial can be found in Jones and Henderson-Sellers [1990].

greenhouse gas Those gases that contribute to the greenhouse effect by trapping heat within the earth's atmosphere. The chief greenhouse gases are carbon dioxide and water vapor. Other potentially important trace gases are chlorofluorocarbons, methane, ozone, and nitrous oxide. See Watson et al. [1990] for a general overview and Ramanathan et al. [1985] and Ramanathan et al. [1987] for information on the trace gases.

Greenland Basin A basin in the North Atlantic Ocean defined to the east by Greenland, the west and south by the Mohn Ridge, and to the north by Fram Strait. It has two abyssal plains separated by the Greenland Fracture Zone (at about 0° W, 76° N), with the Boreas plain to the north being smaller and shallower (around 3200 m) than the Greenland plain to the south (around 3600 m). The Greenland Sea is completely contained within the confines of the Greenland Basin.

Greenland–Scotland Ridge The bathymetry of this important area for deep water formation processes is described in Hansen and Osterhus [2000]:

> The Greenland–Scotland Ridge extends from East Greenland to Scotland and below a depth of 840 m it forms a continuous barrier between the North Atlantic and the ocean regions north of the ridge. At higher levels, Iceland and the Faroe Islands divide the ridge into three gaps which have different widths and sill depths.
>
> From northwest to southeast the first gap is the fairly wide Denmark Strait with a sill depth of about 620 m. Between Iceland and the Faroe Islands is the Iceland–Faroe Ridge, a broad ridge with minimum depths along the crest of 300–500 m, generally deepening from the Icelandic to the Faroese end. The deepest passages across the Iceland–Faroe Ridge are in the form of four channels, with sill depths between 420 m close to Iceland and 480 m close to the Faroes.
>
> Between the Faroes and Scotland the bottom topography is more complex. The relatively broad, deep Faroe–Shetland Channel is blocked at its southwestern end by the Wyville–Thomson Ridge with sill depth around 600 m. The Wyville–Thomson Ridge joins the Scottish

> shelf at its southern end and at the northern end joins the Faroe Bank rather than the Faroe Plateau and these two are separated by the narrow, deep Faroe Bank Channel with sill depth around 840 m. This channel, which is a continuation of the Faroe–Shetland Channel, thus exceeds all other passages across the Greenland–Scotland Ridge by more than 200 m in sill depth.

The Ridge separates the basins of the Nordic Seas to the north from the basins of the North Atlantic Ocean to the south. The latter are, from west to east, the Irminger Basin, the Iceland Basin and the Rockall Channel or Trough. See Hansen and Osterhus [2000].

Greenland Sea The regional sea in the North Atlantic Ocean which comprises the waters in the Greenland Basin. The average depth is about 2866 m.

In the summer, the volume of the Greenland Sea consists of about 85% of the deep and bottom water masses (i.e. Greenland Sea Deep Water (GSDW) and Norwegian Sea Deep Water (NSDW)), 9% Arctic Intermediate Water (AIW), and 9% surface water masses, mostly Atlantic Water (AW). See Swift [1986] and Hopkins [1991].

Greenland Sea Deep Water (GSDW) In physical oceanography, a water mass formed during the winter only in the central of the gyre Greenland Sea, where the cooling of surface water causes intense vertical convection. The water sinks to the bottom in events related to the passage of storm systems that last less than a week and occur in regions only a few kilometers across. GSDW is the densest water mass in the Greenland Sea, characterized by a salinity typically 34.88 to 34.90 and very cold temperatures, i.e. always under 0° C and typically -1.1 to -1.3° C. See Swift [1986] and Tomczak and Godfrey [1994].

gregale A strong northeast wind occurring chiefly in the cool season in the south central Mediterranean. This is also used for the same phenomenon in other parts of the Mediterranean, e.g. a "gregal" in France and a "grecale" in the Tyhrrenian Sea.

grey ice A type of sea ice defined by the WMO as:

> Young ice 10–15 cm thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.

See WMO [1970].

grey–white ice A type of sea ice defined by the WMO as:

> Young ice 15-30 cm thick. Under pressure more likely to ridge than to raft.

See WMO [1970].

gross primary production See primary production.

ground truth data Geophysical parameter data, measured or collected by means other than by the instrument itself, used as correlative or calibration data for that instrument data, including data taken on the ground or in the atmosphere. Ground truth data are another measurement of the phenomenon of interest; they are not necessarily more "true" or more accurate than the instrument data.

group velocity See Trefethen [1982].

GSDW Abbreviation for Greenland Sea Deep Water.

GSP Abbreviation for Greenland Sea Project, a co–sponsored AOSB/ICES project aimed at observing and modeling the atmospheric, ice, oceanic and biological processes relevant to understanding the role of the Nordic Seas in the climate system. The GSP was in operation from 1987–1993 and has been superseded by ESOP. The data collected during GSP can be found at the GSP Web site[54].

GTD Abbreviation for Gas Tension Device, an instrument which allows in–situ measurements of the rate at which gases pass through the ocean surface to be made. This was developed at the IOS.

GTOS Abbreviation for Global Terrestrial Observing System.

G3OS Abbreviation for the Global 3 Observing Systems, the collective name for the GCOS, GOOS and GTOS systems. Information about all three can be found at GOSIC.

[http://www.unep.ch/earthw/g3os.htm]

GTSPP Abbreviation for Global Temperature and Salinity Pilot Program, the primary goal ofwhich is to make global measurements of ocean temperature and salinity quickly and easily accessible to users. It seeks to develop and maintain a global ocean T-S resource with data that are both up-to-date and of the highest possible quality. The objectives of the GTSPP are:

- to create a timely and complete data and information base of ocean temperature and salinity data of known quality in support of the WCRP;
- to improve the performance of the IOC, IODE and IOC/WMO IGOSS data exchange systems;
- to disseminate information on the performance of the IODE and IGOSS systems;
- to improve the quality and completeness of historical databases; and
- to distribute copies of portions of the database and selected analyses to interested users and researchers.

[http://www.nodc.noaa.gov/GTSPP/gtspp-home.html]

GUFMEX Acronym for GUlF of MEXico experiment, a field experiment taking place during February and March 1988 to gather data on two phenomena: air mass modification over the Loop Current, and return flow characteristics of modified polar air returning to the southern shores of the United States. See Lewis et al. [1989].

Guiana Abyssal Gyre A gyre thought to fill the western basin of the North Atlantic from the equator to nearly 30°N, with the strongest recirculation in the tropical Guiana Basin and over the Nares Abyssal Plain. The gyre is comprised of southward deep flow along the western boundary of the Basin, the deep western boundary current, and a northward interior flow in the eastern part of the western basin. The eastern limb is estimated at up to 27 Sv northward flow near 10°N, in opposition to the 40 Sv in the southward flow of the deep western boundary current. The northward interior flow is hypothesized from the estimated strength of the deep western boundary current. The latter is too large to represent the net export of cold water to the South Atlantic if compared to heat transport estimates from independent oceanic, sea surface and atmospheric budgets. The disparity requires a northward flow in the interior of the basin to bring the net cold water export to 15–20 Sv.

Guiana Basin An ocean basin located off the Venezuela, Guiana and Brazilian coasts in the west-central Atlantic Ocean. This comprises the western Demerara Abyssal Plain and the eastern Ceara Abyssals Plain, separated by the Amazon abyssal cone. This has also been called the Makaroff Deep. See Fairbridge [1966].

[54] http://www.ices.dk/ocean/project/gsp.htm

Guinea Basin An ocean basin located on the equator off the west coast of Africa. It includes the Guinea Abyssal Plain and has also been called the West African Trough. See Fairbridge [1966].

Guinea Current The part of the cyclonic gyre that forms the Guineau Dome that flows northwestward along the west African coast.

Guineau Dome A doming of the thermocline in the summer at approximately 10° N and 22° W off the coast off of Dakar in west Africa. This is due to a small cyclonic gyre driven by part of the North Equatorial Countercurrent heading north combining with the North Equatorial Undercurrent.

gulder See double tide.

Gulf Common Water A water type originating from the dilution of Caribbean Subtropical Underwater.

[http://www.terrapub.co.jp/journals/JO/abstract/5005/50050559.html]

Gulf of Aden The circulation in the Gulf of Aden is summarized in RSMAS [2000] as:

> he Gulf of Aden is influenced at depth by the outflow of Red Sea waters moving toward the Indian Ocean, and at the surface by inflow from the Arabian Sea. The signature of the Red Sea outflow is seen throughout the Gulf of Aden and northern Indian Ocean as an intermediate salinity maximum near 600 m depth, spreading southward along the western boundary as far as 20 S. As the Red Sea water spills over the Bab el Mandeb sill, it appears to follow at least two pathways in the western Gulf of Aden, one along the southern boundary of the Gulf in the expected sense, and another along the central or northern part of the Gulf (Federov and Meschanov [1988]). These different pathways appear to be related in part to the complicated topography of the western Gulf, including the Tadjura Rift that extends westward to just outside the Bab el Mandeb. Different mixing behavior along these flow pathways may lead to different penetration depths between 400-1200 m and varying properties of the Red Sea water in the Gulf of Aden. Little detailed knowledge is available on the eastward spreading of Red Sea water in the central Gulf of Aden or how this takes place, either in the form of continuous boundary currents or isolated eddies. The pathways by which surface waters navigate their way westward through the Gulf to provide the required surface layer inflow to the Red Sea are also poorly known.
>
> The upper layer circulation of the Gulf of Aden appears in remotely sensed SST imagery and a few available AXBT survey data to contain large eddies - mostly anticyclones - that are comparable in size to the width of the Gulf (Fig. 3d). These features appear to propagate westward from the mouth of the Gulf toward the Red Sea, and their origin may be linked to the propagation and decay of eddy features generated in the western Arabian Sea. In addition, the seasonally reversing winds over the Gulf may generate localized responses consisting of gyres and seasonal boundary currents along the northern and southern boundaries of the Gulf. Direct evidence for these gyres, eddies, or seasonal boundary currents from in situ observations is almost entirely lacking, however.
>
> Seasonal upwelling with the onset of the SW monsoon is quite pronounced in SST imagery in the western Gulf of Aden. Cool upwelled waters are brought to the surface along the southern coast of Yemen beginning in May and are presumably advected eastward by a wind driven coastal current. The lifting of the thermocline and depression of the sea surface in the western part of the Gulf caused by this seasonal upwelling process is believed to play a major role in the reversal of the surface flow in the Bab el Mandeb Strait in summer, and the associated intrusion of Gulf of Aden thermocline water into the Red Sea. A front is often observed near the mouth of the Gulf (Fig. 3d) during the SW monsoon which marks a water mass boundary between the cool upwelled waters advected northward along the Somali

coast and the warmer waters in the Gulf of Aden. Very little is known of the 2–dimensional circulation of the Gulf of Aden or its causes.

See Federov and Meschanov [1988].

[http://mpo.rsmas.miami.edu/~zantopp/AMSG-report.html]

Gulf of Alaska The circulation of the Gulf is characterized by the cyclonic flow of the Alaska Gyre, part of the more extensive subarctic gyre of the North Pacific. According to Musgrave et al. [1992] ...

> ... the circulation around the Alaska Gyre consists of the eastward flowing Subarctic Current at about 50°N, the Alaska Current in the northern Gulf of Alaska, and the southwestward flowing Alaska Stream along the Alaskan Peninsula. Some of the water from the Alaska Stream recirculates into the Subarctic Current, but the strength and location of the recirculation, though poorly described, appear extremely variable. The northward flow of the broad, diffuse, eastern boundary current along the west coast of North America at about 50°N is considered to be the origin of the Alaska Current. At the head of the Gulf of Alaska, this flow converges into the swift, narrow Alaska Stream, which has characteristics of a western boundary current. The easternmost extent of the Alaska Stream cannot be rigorously defined, but common nomenclature refers to the extension of the Alaska Current between 150 and 180°W as the Alaska Stream.

See Favorite et al. [1976], Royer and Emery [1987] and Musgrave et al. [1992].

Gulf of Arauco A water body located at around 37°S on the Chilean coast. According to Strub et al. [1998], the summer circulation in the Gulf can be characterized ...

> ... as an alternation between a simple two–layer upwelling pattern and more complex basin modes. During steady southerly winds, water flows north out of the bay at 0.05–0.1 m s^{-1} in a surface layer that is deeper (15 m) on the western side of the bay and intersects the surface on the eastern side, due to upwelling on the east and downwelling on the west (the bay is somewhat larger than the local internal deformation radius). Weak (<0.05 m s^{-1}) return flow occurs beneath the surface layer. The raised layer interface on the eastern side tends to rotate cyclonically to the southeast corner, where it is 'arrested' by strong wind–driven vertical mixing, creating the colder temperatures found at the southeast of the bay during strong upwelling. When winds relax or reverse, the raised interface continues to rotate cyclonically to the western side of the basin, where observations of stronger currents, vertical shear and low Richardson numbers indicate intense vertical mixing as the basin mode dissipates. The resumption of southerly winds reestablishes the initial pattern. Enhanced mixing processes during both relaxations and upwelling may help maintain the high primary productivity within the Gulf of Arauco. Furthermore, the geostrophic circulation tends to follow the bathymetry along the shelf outside the Gulf, which may help maintain the high primary productivity rates by confining the waters to stay within the gulf, on the inshore side of the shelf.

See Strub et al. [1998].

Gulf of Bohai See Bohai Sea.

Gulf of Bothnia The northern section of the Baltic Sea. It is further divided into the northern Bay of Bothnia and the southern Bothnian Sea, the latter of which adjoins the Aland Sea to the south.

Gulf of California A water body separating Baja California from the Mexican mainland. It is connected to the Pacific Ocean through a southern opening between 20–23°N. The principal mechanisms forcing the Gulf are the Pacific Ocean circulation, the tides, the fluxs of heat and moisture exchanged with the atmosphere, and the wind. See Alvarez-Borrego [1983], Bray and Robles [1991], Beier [1997] and Badan-Dangon [1998].

Gulf of Carpenteria According to Church and Craig [1998]:

> The Gulf of Carpenteria is a shallow (maximum depth about 70 m) semienclosed body of water. Most of the exchange with the open oceans occurs through its western entraces, as Torres Strait is extremely shallow. In winter, temperatures are at their minimum and salinities at their maximum, and vertically well–mixed conditions predominate. In the austral summer monsoon season, tidal currents are only sufficiently strong to mix the bottom 30 m of the water column, and as a result, the central Gulf is stratified, principally through the input of surface heat but also from lower surface salinities due to rainfall and runoff. In the shallower water near the coast, well–mixed conditions prevail, but there is considerable influence of monsoonal river runoff. It appears that significant changes in gulf water properties are the result of local processes rather than exchange with the surrounding Arafura or Banda Sea waters. A channel model indicates there is little seasonal transport through Torres Strait.
>
> The northwest monsoon winds, density–induced currents and nonlinear tidal rectification all result in a clockwise circulation in the gulf. However, the southeast trades drive a counterclockwise circulation. There is a coastal boundary layer that does not mix rapidly with the central gulf waters, and coastal jets forced by the wind are confined to this boundary layer. The existence of such a layer explains the persistence of the low–salinity regions observed near the coast.

See Forbes and Church [1983], Wolanski et al. [1988] and Rothlisberg et al. [1989].

Gulf of Elat One of two narrow, northward extensions of the Red Sea. The Gulf of Elat is 180 km long, 14–26 km wide, and has an average depth of 800 m and a maximum depth of 1800 m. The southern end of the Gulf is separated from the Red Sea by a shallow sill with a maximum depth of 270 m at the Straits of Tiran. See Berman et al. [2000].

Gulf of Finland A part of the Baltic Sea which adjoins the Aland Sea and the main Baltic to the west and is landlocked elsewhere.

Gulf of Mexico A 1990 review of U.S. coastal oceanography (NAS [1990]) summarizes the general circulation features of the GOM as follows:

> The large–scale water mass distribution in the Gulf of Mexico reflects the limited exchange the gulf basin has with the adjacent oceans. In general, the gulf waters consist of three distinct water masses: subtropical underwater, antarctic intermediate water, and North Atlantic deep water. The subtropical underwater enters the gulf from the Caribbean at depths of 200 to 500 m and is found throughout the eastern portion of the gulf. This water is readily recognized by its high salinity, >37.00 ppt. Antarctic intermediate water also enters the gulf through the Yucatan Strait and is found throughout the gulf between depths of 500 to 1,200 m (in the eastern gulf) and 600 to 800 m (in the western gulf). This water mass is recognized by a distinct minimum, <34.00 ppt, in salinity. North Atlantic deep water is found below 1,200 to 1,400 m throughout the Gulf of Mexico. McLellan and Nowline (1963) suggested that waters deeper than 1,500 m in the Gulf of Mexico have long residence

times (300–500 years) are are not frequently exchanged with outside waters. Hydrographic observations indicate that additional water masses – gulf water, for example – are formed locally in the Gulf of Mexico during periods of intense winter cooling.

Numerous studies have shown that the general large–scale circulation in the upper 1,400 m of the Gulf of Mexico is anticyclonic (clockwise). The transport in the northern limb of the anticyclonic gyre is a combination of flow from the Texas shelf and from the southern portion of the gyre. The contribution from the Texas shelf can at times be as high as one–third of the total transport of the easterly flow in this limb of the gyre. The westerly flow in the southern part of the anticyclonic gyre is composed predominantly of water recirculating in the southern gulf, although at times water separating from the Loop Current can contribute to this transport. Average geostrophic velocities and volume transports associated with the large–scale anticyclonic circulation of the Gulf of Mexico are 10 cm/s and 5 $\times$ 10^6 $m^3 s^{-1}$. Additionally, large–scale cyclonic (counterclockwise) circulation gyres are found in the Bay of Campeche and over the northern portion of the wester Florida shelf.

Superimposed upon the large–scale circulation of the gulf are two major circulation features, the Loop Current and Loop Current rings. Both of these have considerable influence on the circulation characteristics of the Gulf of Mexico.

The Loop Current is a swift, narrow current that enters the Gulf of Mexico through the Yucatan Strait. This current can be traced as a coherent feature that extends into the northern portion of the eastern gulf, where it turns to the easter and then flows southward along the west Florida shelf. At the southern extent of the Florida shelf, the Loop Current again turns east and exists the Gulf of Mexico through the Straits of Florida. The Loop Current is part of a large circulation system that feeds into the Gulf Stream along the eastern boundary of the United States.

The Loop Current can be readily distinguished in vertical density distributions down to depths of 1,000 to 1,200 m in the region where it enters the gulf. Surface geostrophic velocities into the gulf associated with the Loop Current have been estimated to be 100 to 150 cm/s and the corresponding volume transport has been estimated to be 25 to 35 m^3/s. Surface velocities diminish somewhat as the Loop Current extends into the gulf and widens. Outflow surface velocities are on the order of 50 to 100 cm/s and the corresponding volume transport about the same as into the gulf.

The warm core (anticyclonic) rings that separate from the Loop Current are a major circulation feature. Observations show that these rings typically separate from the Loop Current at the time of the maximum northward penetration of this current into the gulf. On average, one to three rings per year may separate from the current.

Rings are approximately 300 to 400 km in diameter and have a depth signature that extends to approximately 1,000 m. After detaching from the Loop Current, the rings move westward across the gulf, with observations showing them to exist as identifiable features for periods of several months. Geostrophic surface velocities have been estimated to be on the order of 25 to 100 cm/s, with associated volume transports on the order of 5 to 10 $\times$ 10^6 m^3/s. These rings therefore represent a major mechanism by which properties such as temperature and salinity are transported from the eastern to the western gulf. One in the western gulf, they encounter the Texas or Mexican continental shelf. The fate of the rings at this time is not fully understood.

On the Texas–Louisiana continental shelf, west of 92.5°W, the predominant feature of the circulation is a cyclonic (counterclockwise) gyre, elongated in the alongshelf direction. The inshore portion of this gyre is directed westward (downcoast). An eastward flowing countercurrent at the shelf break constitutes the outer portion of the gyre. Flow in the western extent of the gyre is directed offshore, while that in the eastern gyre – near Louisiana

– is directed onshore. The alongshore wind stress is the primary mechanism driving the circulation of this cyclonic gyre. Thus the gyre exhibits seasonal variability in strength and occurrence that reflects the seasonal variability in the wind patterns. In July, when the downcoast (to the west) wind stress is diminished, the cyclonic gyre on the shelf disappears and is replaced by an anticyclonic gyre centered off Louisiana. In August and September, the prevailing wind direction changes abruptly and the gyre is re–established.

Gulf of Oman The circulation features have been well summarized in RSMAS [2000] as:

> The northern Gulf of Oman is strongly influenced by outflow from the Arabian Gulf. From fall through mid-spring, satellite SST's suggest a plume of Gulf water flowing as a coastal current along the Oman and Emirate coast to Ras al Hadd at the edge of the Arabian Sea. This would imply that at least through part of the year the outflow from the Gulf consists of a deep water (PGW) layer and a modified surface layer that must together balance the inflow component. This and the absence of any sill to confine the flow differentiates the Gulf from marginal seas such as the Red Sea and Mediterranean. The manner in which the PGW enters the deep Gulf of Oman is not clear from available data. Data from the U.S. and German WOCE cruises in 1995 and Navoceano AXBT surveys suggest that the PGW layer is dominated by sub-mesoscale eddies. Are these formed at the outfall of the paleo-river channel at the shelf edge or by shelf edge meandering as the plume proceeds southeastward down the shelf break? What are the range of sizes and dynamics of the resulting Peddies? The final issue is the nature of the PGW and associated surface flows. Is the flow a coherent shelf break one or a train of eddies? The interaction of these with the other elements of the Gulf of Oman circulation is also of interest.
>
> Other important elements involved in the Gulf of Oman's circulation are the seasonal upwelling along the coast of Iran to the north and the complicated mesoscale dynamics associated with the extension of the south coastal Oman upwelling system into filaments extending off Ras al Hadd. The latter is complicated by the shallow Murray Ridge that extends across the mouth of the Gulf. The Ras al Hadd jet is highly variable, sometimes extending out to the east as shown in the figure and extending northeastward or southeastward at other times. This feature is also referred to as the Ras al Hadd front because it forms the seasonal boundary between the northern Arabian Sea and the Gulf of Oman. During the SW monsoon the transport of the Ras al Hadd jet is believed to be at least 10 Sv (Elliot and Savidge [1990]). Flagg and Kim [1998] discovered that the Ras al Hadd jet intensified in August 1995 following the reversal of the flow along the northeastern Oman coast from northward to southward, thereby adding to the flow along the Ras al Hadd front. It is speculated that the reversal of the flow along the northeastern Oman coast in August is related to the intensification and/or propagation of a cyclonic eddy in the Gulf of Oman during this period. Similarly, it has been suggested that such an eddy can play a role in the dynamics of the Ras al Hadd Jet, which may become tied to a double vortex as it extends offshore. It is speculated that to the south, an anticyclonic eddy forms, while to the north in the Gulf of Oman, a cyclonic eddy forms, both of which are driven by the extension of the Ras al Hadd jet into the open Arabian Sea. While the anticyclonic eddy to the south has been observed, no direct connection has yet been established between the Ras al Hadd jet and the cyclonic eddy in the Gulf of Oman. The interaction of the Ras al Hadd front with the coastal flow, the Murray Ridge and the eddies are not well understood. In some of the remote SST data, shifts in the dipole lead to its breakup and the propagation of the cyclonic component northwards into the Gulf of Oman. The interaction of these surface intensified features with the thermocline layer Peddies and the PGW outflow is probably complicated.

The interannual variations are large, as are those in the interactions with the Murray Ridge and upwelling on the Iranian coast.

The seasonal and interannual variations in the circulation in the Gulf of Oman appear to be significant. The nature of the flow along the southern side of the Gulf appears to be better organized in June through December although this may be tied to the lower thermal contrast in January through May. The northern side of the Gulf has consistent upwelling associated with the SW monsoon along the Pakistani coast. Upwelling along the western, Iran coast is more variable. In 1995, for example, this coast was associated with upwelling filaments that moved to the west and even entered the outer edges of the Strait of Hormuz. Other years suggest less extensive upwelling although there is localized upwelling at the mouth of the Strait in all years examined. One clear need is a better depiction of winds over the Gulf of Oman in relationship to this variability.

See Elliot and Savidge [1990] and Flagg and Kim [1998].

[http://mpo.rsmas.miami.edu/~zantopp/AMSG-report.html]

Gulf of Papua A semi–enclosed body of water on the southern side of Papua New Guinea. It has the shape of a half–moon with a radius of about 200 km, and covers an area of over 50,000 km^2. The shelf slopes gently to depths of 100 m a the shelf break, from where the sea floor drops rapidly to the basin of the Northwest Coral Sea and depths greater than 3000 m. Freshwater input from riverine and estuarine systems on the northwest coastline supplies about 15,000 m^3 s^{-1}, with the supply having minimal seasonal fluctuations.

The freshwater input causes the entire gulf to be stratified in salinity in the top 20 m. This halocline inhibits tidal mixing, even in shallow coastal areas where tidal currents are greater than 1 m s^{-1}. The dominant forcing of the circulation is the eastward flowing Coral Sea Coastal Current in the Northwest Coral Sea. It appears to generate a counter–clockwise rotating eddy in the Gulf. Wind forcing is a secondary factor, causing the brackish water to leave the Gulf alternatively at its western and eastern sides. See Wolanski et al. [1995].

Gulf of Riga A part of the Baltic Sea connected to both the Gulf of Finland to the north and the Baltic Sea proper to the west via straits between the islands of Saaremaa and Hiiumaa and the mainland. The Irbe Strait is wide and relatively deep compared to the seasonal halocline, with the Suur Strait narrow and shallow. Several rivers supply fresh water to the Gulf, with the significant ones being the Daugava in southeast and the Pärnu in the northwest. The mean annul freshwater input is about 36 km^3 yr^{-1}, about 9% of the volume of the Gulf. Water exchange through the straits is restricted, keeping the mean salinity of the Gulf at about 5.5 PSU. This is about 1.5-2.0 PSU lower than the salinity of the Baltic Proper surface waters. The residence time for water in the Gulf is about 3 years.

As with the rest of the Baltic, winds are most frequently southwestern, giving a general tendency towards cyclonic circulation. In the Gulf the water from the Baltic Sea Proper enters along the southern side of the Irbe Strait and flows around the Gulf. The large amount of river water entering from the south flow along the eastern coast towards the north. In summer months, this circulation may be reversed, with riverine and nutrient–rich intermediate waters transported along the western coast into the nutrient–depleted surface layers of the Irbe Strait, where the outflow is along the northern side. In the Suur Strait to the north, the flow is more or less unidirectional, but changes direction frequently. The currents can be large compared to elsewhere in the Gulf, allowing the transport through the Suur to be comparable to that of the larger Irbe Strait. The transport in the Suur is driven mostly by wind forcing, whereas horizontal density and surface gradients drive the transport through the Irbe.

This circulation pattern explains the observed long–term stable salinity difference between the Baltic Proper and the Gulf. The convergence of in– and out–flowing current support the persistent Irbe Front in the strait area. The slow and steady decrease in the deep water salinity in the Baltic Proper between 1977–1991 is reflected in the deep water of the Gulf. There is a large annual temperature cycle, with autumn cooling and spring warming overturning most of the water column.

Current measurements in the Suur Strait indicate the simultaneous coexistence of several flow regimes. There is a slow regime with surface outflow of gulf water along the northern part of the strait and a deep inflow of Baltic Proper surface water along the southern part. These are separated by a salinity front, i.e. the Irbe Front. Superimposed on this slow regime are high–frequency, unidirectional currents driven by sea level fluctuations. The most energetic movements diurnal and low–frequency oscillations, the the diurnal oscillation part of the eigen–oscillations of the Baltic Sea, Irbe Strait and Gulf of Riga system.

`[http://www.giwa.net/areas/GoR-project.htm]`

Gulf of St. Lawrence See Doyon and Ingram [2000] and other papers in the special Volum 47 Deep–Sea Research II issue. See also Koutitonsky and Bugden [1991] and Han et al. [1999].

Gulf of Suez A large, elongated semi–enclosed sea of about 10,000 square kilometers area bounded by the Sinai Peninsula on the east and the Eastern Desert of Egypt on the west. It extends for 300 km and is about 50 km wide at its widest point. It has a flat bottom with an average depth of 50 m and slopes steeply at its mouth to the greater depths of the Red Sea. It connects with the Mediterranean Sea through the Suez Canal and with the Red Sea via the Strait of Jubal. It is an arid basin with little fresh water inflow. Evaporation exceeds precipitation and runoff by over 2 m per year, a deficit that produces a surface inflow from the Red Sea and a longitudinal salinity gradient with the highest salinities near the head of the Gulf. Thus the Gulf is categorized as an inverse or negative estuarine system. See Rady et al. [1998].

Gulf of Thailand `[http://www.start.or.th/got/]`

Gulf of Thermaikos The Gulf of Thermaikos occupies the northwestern continental margin of the Aegean Sea. It includes an extended shelf area bounded by approximately the 150 m isobath, with narrow shelf areas toward east (Chalkidiki peninsula) and west (Greek mainland). At south, it communicates with the deep Sporades basin. At north, a shallow embayment is found (Thessaloniki Bay or inner Thermaikos Gulf), with depths less than 20 m and an opening of about 10 km toward the Gulf. Four major rivers are the main sources of freshwater, nutrient and sediment supplies for the Gulf: the neighboring Axios, Loudias and Aliakmon rivers at north and the Pinios River further south.

The annual surface flow for the continental margin of the Gulf of Thermaikos (depths less than 100 m) is characterized by southward currents, due to the prevailing northerlies. Near the rivers waters are lower in both temperature and salinity. Lower-temperature waters are also found at the southeastern part of the domain, due to influence of deeper Aegean waters. The rivers cause a reduction of salinity over a large part of the domain, with branches along the western and eastern shelf areas, due to the proximity of the two coasts. At mid-depth, there is a northward return flow along the western boundary, while the deeper sea influence causes flow that only affects the southern part of the domain. The open sea signal is still fresher, but also cooler than the interior. The coldest waters are found near the river area.

During Winter, two coastal jets are evident in the surface: southward along the western boundary and northward along most of the eastern boundary. The west coast southward jet is buoyancy- and wind-driven (enhanced river runoff and northerly winds), while the east coast northward jet is presumably due to Aegean influence. Two small cyclonic eddies can also be seen; it should be noted that this is a seasonal average and several energetic features have been averaged out. Coldest waters are found at the inner Gulf and near the river area, which is also where the largest salinity gradients occur. The low temperatures are mainly due to heat flux cooling, which has a strong effect in shallow depths, as well as to the river waters that are colder than the interior. As is common in winter well-mixed conditions, the distributions at mid-depth resemble the surface ones.

During Spring, a tongue of low-salinity and low-temperature waters extends from the river area across the upper part of the Bay. This is the season of large river runoff and it marks the onset of stratification. Vertical gradients are strongest near the rivers, due to river-induced low-salinity surface waters. The horizontal gradients are characterized by cooler and fresher waters near the rivers with cooler and more saline waters at the deeper parts of the domain.

During Summer, surface temperatures are considerably warmer, with slightly cooler waters near the rivers and intruding along the eastern boundary. River runoff is low, so the salinity gradients are small. The temperature distribution is different at mid-depth, as expected due to summer stratification that is mainly driven by heat flux.

During Autumn, vertical stratification is diminished and flows are somewhat similar to the Winter ones, although weaker. The temperature and salinity distributions depict north to south gradients, as opposed to the east to west gradients that prevailed in the winter season. After Kourafalou et al. [2004].

Gulf of Valencia The concave sea area off Valencia in the southern Balearic Sea to the north of the Ibiza Channel. The bottom topography forms a trough deeper than 1000 m bounded by the wide continental Ebro margin to the north and Cape La Nao to the south. See Pinot et al. [2002].

Gulf St. Vincent A gulf located on the southern coast of Australia, Gulf St. Vincent is part of a South Australian gulf system that experiences extreme high salinities in the summer months. The seasonal cycle of evaporation increases the salinity of the head of Gulf St Vincent (GSV) from 39.0 in winter to over 42.0 in summer, while average salinity across the mouth (Cape Jervis to Troubridge shoals) changes little from 36.5. Of the north-to-south salinity decrease, 60% occurs in Upper Gulf St Vincent (UGSV), the northernmost 47 km of the region bounded in the south by the latitudinal line through Long Spit. In the region between Price and Ardrossan the summer/autumn (annual maximum) salinity gradient is typically 0.610-4 m-1 (1.2/20 km). These salinity gradients maintain a strong density gradient, positive toward the head of the GSV, although the effect of differential heating associated with the depth variation and vertical mixing somewhat modulates the latter gradient.

Salinity observations imply a clockwise general circulation in GSV, in which less saline shelf water entering through Investigator Strait flows headwards along the western side, confining the saline outflow to the eastern side. In UGSV, it has been observed that the lateral circulation is hindered or even reversed on occasion, depending on the relative strengths of the barotropic and baroclinic pressure fields. The eventual transport of saline gulf waters to the continental shelf proper occurs through both Investigator Strait (IS) and Backstairs Passage (BP). However, as in Spencer Gulf, the outflow of GSV water in summer is influenced by the formation of fronts over the western end of the Strait, between the warmer water of GSV and the cooler water of the shelf, thus diminishing the shelf/gulf exchange. After Samarasinghe et al. [2003].

Gulf Stream Much, much more later. See Fuglister [1963].

Gulf Stream '60 From Fuglister [1963]:

> In the Spring of 1960 a comprehensive study of a large portion of the Gulf Stream System was undertaken by the Woods Hole Oceanographic Institution. This work, which was given the code name of "Gulf Stream '60", was planned and directed by the author and sponsored by the U.S. Navy, Office of Naval Research.

"Gulf Stream '60" extended over a period of 2 1/2 months, from 2 April to 15 June. The W.H.O.I. research vessels *Atlantis*, *Crawford* and *Chain* participated udring the entire period and the International Ice Patrol oceanographic vessel U.S.C.G.C. *Evergreen* took part in the first phase. At regular intervals throughout the year, moreover, the Institution's DC-3 and a long-range Navy patrol plane tracked transponding drift-buoys which were set out during the cruise.

The area studied encompasses approximately 1/2 million square miles, extending from the continental shelf south to the latitaude of Bermuda and from the Grand Banks of Newfoundland west to Georges Bank, off Cape Code. The ocean depth over most of the region is between 5000 and 5500 m; on the continental shelf at the northern boundary, however, the depth is generally less than 200 m; furthermore, a range of seamounts crosses the area, some of whose peaks reach to within 1500 m of the sea surface.

"Gulf Stream '60" was divided into three phases each lasting 3 weeks. The general plan was to obtain during the first phase a grid of oceanographic stations covering the entire area and then, in the next two phases, to trace out the current pattern in detail and make direct deep current observations in the Gulf Stream. The specific plans for the latter two periods were to be drawn up at Bermuda when the ships met there between periods.

In the first phase the *Atlantis* occupied stations on sections I-III consecutively, making measurements of temperature, salinity, dissolved oxygen and pH at 25 levels from the sea surface to very near the bottom. Concurrently, the *Crawford* made sections IV-VI; the *Chain*, sections VII-IX; and the *Evergreen*, sections XI and X. pH was not measured on these three ships nor was dissolved oxygen determined on the *Evergreen*. Because of its commitments to the regular work of the International Ice Patrol, the *Evergreen* could not spare the time to extend its sections to the latitude of Bermuda. On three occasions during the period the naval patrol plane made radiation measurements and obtained visual observations of various portions of the sea. At the end of 3 weeks the W.H.O.I. ships met in Bermuda.

The second phase of "Gulf Stream '60" was confined to the western half of the region surveyed during the first period. After a 3-day stop in Bermuda, the ships began this phase by making bathythermograph sections north from Bermuda to the Gulf Stream along meridians 63°30', 64°30', and 65°30'; the *Chain* also obtained continuous records of temperature to a depth of 450 ft with towed thermistors. For the remainder of the period the *Atlantis* followed neutrally buoyant Swallow floats set out directly in the Gulf Stream at depths between 2000 and 4000 m, and made deep stations to bracket the float tracks. In addition she set out several transponding surface buoys which were then located at periodic intervals by airplane. The *Crawford* also set out neutrally buoyant floats in the Stream, but at depths of 400 and 700 m; she followed these for over a hundred miles and ended by making a series of latitudinal bathythermograph sections crossing a cold trough which extended south near the 60th meridian. The *Chain* studied the thermal structure of the surface layer along the northern edge of the current and then mapped the pattern of intense current using the geomagnetic electrokinetograph (GEK). At the end of 3 weeks the ships again returned to Bermuda for a 3-day rest and conference.

The third phase started with a series of deep stations to relocate certain major features of the current pattern. Then the *Atlantis* and *Crawford* both made deep current observations, while the *Chain*, using the GEK technique developed earlier, followed the surface currents to the eastern end of the region. On 15 June the three ships arrived at Woods Hole, ending the cruise. The transponding surface bujoys, however, continued to be located periodically by airplane for several more months, the last observation being made in December 1960.

See Fuglister [1963].

Gunther Current See Poleward Undercurrent.

Guyana Current A northwestward flowing current along the eastern coast of South America from the Equator to around 10° N after which point the northwestward flowing current is called the Caribbean Current. Below the equator the northward flow component that becomes the Guyana Current is called the North Brazil Current. The currents in this region have not been extensively studied, with this one being perhaps the least well known, even to the point that some researchers doubt its existence as a continous feature of the general circulation. The fact remains that there is some sort of average northward flow in this area since the fresh water signal from the Amazon River does reach the Mediterranean Sea as a surface layer of low salinity. The matter of calling it a current or perhaps just an average northward drift can only be decided via further measurements.

guyot The official IHO definition for this undersea feature name is "a seamount having a comparatively smooth flat top; also called tablemount; see also seamount."

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HAB Abbreviation for harmful algal blooms, also known as marine phytoplankton blooms or red tides. In this naturally occurring phenomenon for which instances are reported for around 300 species blooms with cell concentrations of several million per liter occur. About a fourth of the species produce toxins which cause damage or kill other flora and fauna in the area of the bloom.

HAB Program An IOC program originating with the formation of an Ad hoc Intergovernmental Panel on Harmful Algal Blooms (IPHAB) in 1991. The panel was requested to identify adequate resources for a sufficiently broad program to solve some of the problems caused by algal blooms. The first session of IPHAB was held in 1992 and the HAB Program plan was adopted in 1993. See the HAB Program Web site[55].

hadal More later.

Hadley Cell A part of the atmospheric circulation system extending from the Equator to 30° latitude on both sides of the Equator. It is a thermally-driven system in which heated air rises at the Equator, flows poleward, cools and descends at subtropical latitudes, and then flows back towards the Equator. This description was suggested by Hadley in the 18th century.

hadopelagic zone One of five vertical ecological zones into which the deep sea is sometimes divided. The is the lowest of the levels and is separated from the overlying abyssopelagic zone at about 6000 meters. See Bruun [1957].

Haida Current A narrow, poleward flowing surface current over the continental slope of northwestern British Columbia and southwestern Alaska. It is seasonal, occuring predominantly between October and April with maximal flow taking place in midwinter from November through February. Its characteristics include a minimal length of 200-300 km, a width of 20-30 km, a depth scale of 500 m, a near-surface speed typically around 0.1 m s^{-1}, and a near-surface temperature signature about 1° C greater than ambient. The temporal variability is not well known, although it evinces spatial variability in the form of large-amplitude (around 10 km) mesoscale waves and eddies. The primary driving mechanisms are wind stress and alongshore sea surface slope. See Thomson and Emery [1986].

haline Related to salinity.

Halmahera Eddy See Arruda and Nof [2003].

Halmahera Sea A regional sea located in the central eastern part of the Australasian Mediterranean Sea. It is centered at about 1° S and 129° E and is bordered by the Pacific Ocean to the north, Halmahera to the west, Waigeo and Irian Jaya to the east, and the Seram Sea to the south. It covers about 95,000 km^2 and the topography comprises a number of separate basins and ridges, the chief of which is the Halmahera Basin reaching a depth of 2039 m. Other prominent geographic features include Kau Bay (between the two northward pointing lobes of Halmahera), Buli Bay (between the two eastward pointing lobes), Weda Bay (between the two southward point lobes), the Jailolo, Bougainville and Dampier Straits connecting it to the Pacific, and the Obi Strait connecting it to the Molucca Sea.

The surface salinities range from 34 (March through May) to 34.6 (September through November) and the temperatures from 25.7° C in August to 28.6° in May. The surface currents are variable with the seasonal monsoon winds. The deep water in the Halmahera Basin is renewed by water from the Pacific which passes from north to south over sills 700 m and 940 m deep. The surface waters are a mixture of oxygen rich Pacific water and oxygen poor water from the Seram Sea. See Fairbridge [1966] and Cresswell and Luick [2001a].

[55] http://www.unesco.org/ioc/oslr/hab.htm

halocline In oceanography, a relatively sharp change in salinity with depth.

halocline catastrophe A process wherein deep convection and the formation of bottom waters ceases if the ocean surface salinity decreases sufficiently via enhanced freshwater input. This process is thought to have shut down the thermohaline overturning cell in the Atlantic in the past. See Bryan [1986].

HAMOCC Acronym for Hamburg Model of the Ocean Carbon Cycle.

Happel, Eberhard (1647-1690) A German writer of epics, romance and adventure who published a book entitled Groste Denkwurdigkeiten der Welt oder Sogenannte Relationes Curiosae in 1985 which contained the second chart ever to depict the global ocean circulation. His chart and explanations were very similar to those of Kircher's previous and first-published chart. He also favored the explanation for the tides that had water being withdrawn from the oceans through the north pole and expelled from the south pole, although differing slightly from Kircher on the matter of timing. Happel had the water being withdrawn and discharged at special hours rather than just being rhythmically passed through the earth. See Peterson et al. [1996].

harbor wave A type of seiche found in harbors. The Japanese word "tsunami" means "harbor wave" but is a misnomer for what is really a seismic sea wave, more popularly (and even more incorrectly) known as a tidal wave.

harmonic A frequency that is a simple multiple of a fundamental frequency. A second harmonic, for example, would have twice the frequency of the fundamental.

Haro Strait Experiment See the Haro Strait Experiment Web site.

Harrison, John (1693–1776) See Peterson et al. [1996], p. 53.

Hauraki Gulf After Zeldis et al. [2004].

Bernard Haurwitz (1905–1986) An atmospheric scientists who published many basic contributions to the study of short–period atmospheric wave motions, planetary waves (including atmospheric tides), and vortex motions in tropical cyclones. He also published on atmospheric radiation, the wave structure of noctilucent clouds, and internal tides in the oceans.

[http://www.nap.edu/readingroom/books/biomems/bhaurwitz.html]

Hawaii-Tahiti Shuttle Experiment See Wyrtki et al. [1981].

Heard Island Feasibility Test (HIFT) An ocean acoustical tomography experiment in which computed geodesics (minimum paths) for acoustics transmissions were compared with observations. The acoustic source was suspended from the R/V Cory Chouest 50 km southeast of Heard Island located about halfway between Africa and Australia at about 50° S in the South Indian Ocean. Receiver arrays were located on various research vessels throught the oceans as well as at South Africa, Bermuda, India, Christmas Island, Samoa, Hobart (Tasmania) and Monterey (California). See Baggeroer and Munk [1992] and Munk et al. [1995].

heat capacity of water The heat capacity of a body is the product of its mass and its specific heat. See Millero et al. [1973] and Feistel [2003].

heat equator See thermal equator.

HEBBLE Acronym for High Energy Benthic Boundary Layer Experiment. See Nowell et al. [1982] and Nowell and Hollister [1985].

Helium-3 An isotope of helium that is useful in ocean tracer studies. There are two sources for Helium-3 in the ocean: volcanic sources at mid-ocean ridge crests and the decay of man-made tritium. The former source makes helium-3 a unique tracer due to its being injected into the middle of the water column. This leads, for example, to a stark contrast in helium-3 content between incoming and outgoing deep waters in the Pacific. It also provides a dramatic picture of the relative movement of helium poor NADW and helium rich (due to sources in the Pacific) ACC water. The helium-3 tritium decay (sometimes called trituigenic) source is much larger than the deep sea sources, with the global average of the latter being about 4 at/cm2/s as opposed to a northern hemisphere average of about 32 at/cm2/s for the former.

Helium-3 is used in combination with tritium to date water on timescales of 0-10 years with a resolution of around 0.1 years (in North Atlantic surface waters). It is better to treat them as separate but related tracers on longer timescales or in the presence of extensive mixing. Their relationship is a diagnostic of vertical versus horizontal mixing, and has been used to assess an upper limit to vertical mixing that is consistent with physical estimates. This has also been used to show that horizontal mixing is the dominant mechanism of thermocline ventilation in subtropical gyres. See Sarmiento [1988] and Broecker and Peng [1982].

Helland-Hansen, Bjorn More later.

hemipelagic Or or pertaining to continental margins and the adjacent abyssal plains.

heton To be completed.

HEXOS Acronym for Humidity Exchange Over the Sea, a 1986 program to measure water vapor and droplet fluxes from sea to air at moderate to high wind speeds. HEXOS was the first comprehensive open ocean air–sea flux field project to emphasize surface exchange processes. It was conducted on the Dutch Noordwijk platform, and featured the largest range of windspeeds over which momentum, sensible heat, and latent heat fluxes had been measured. It provided the physical basis for linking aerosol, sea spray, and sensible and latent heat fluxes under a common framework. See Katsaros et al. [1987], Geernaert [1990], Smith et al. [1992] and DeCosmo et al. [1996].

HIDEX–BP Acronym for High Intake, Defined Excitation Bathyphotometer, a vertical profiler for measuring stimulated bioluminescence. The features include statistically rigorous sampling (faciliatated by high pumping rates), hydrodynamically calibrated excitation at the entrance to the large volume detection chamber, and the capability of rapid vertical deployment to depths of 500 m at descent velocities up to 50 m min^{-1}. See Widder et al. [1993].

HIFT Acronym for Heard Island Feasibility Test[56].

high Abbreviated form for high pressure center.

high pressure center In meteorology, a region of relatively high barometric pressure. These are characterized by subsidence at altitude and by divergence near the surface. They predominate at 30 and 90° latitude where the global generation circulation patterns exhibit downward motion. This type of circulation feature is also known as an anticyclone and as such rotates clockwise/counterclockwise in the norther/southern hemisphere. High pressure systems are generally characterized by clear skies and fair weather since cloud development is impeded therein, and winds are also generally light.

High Resolution Profiler (HRP) An oceanographic instrument designed to collect fine– and microstructure data during vertical profiles. As the HRP is lowered has two profiling modes, with the transition

[56] HeardIFT

between the fine and micro modes triggered by the onboard CTD pressure sensor reaching a user–defined threshold value. The fine structure sensors are sampled at 10 Hz and the microstructure sensors at 200 Hz, with the fine sampling continuing simultaneously with the micro sampling. The HRP is designed to minimize ship–induced noise in the measurements, and as such profiles while falling freely from the ship until it releases a set of weights and ascends to the surface to be recovered. The nominal descent rate is 0.6 ms^{-1} with a 1000 meter dive typically taking thirty minutes during which half a megabyte of fine data and two megabytes of micro data will be acquired and stored. The data is downloaded from instrument memory to a shipboard computer once it has been loaded on deck. See Schmitt et al. [1988].

HiHo HiHo Experiment Acronym for Harmonious Ice and Hydrographic Observations – Heat In, Halide Out Experiment, a Antarctic CRC experiment to study the Antarctic pack ice during winter. The project aims include: (1) providing a quantitative assessment of the mass budget and Antarctic winter sea ice and to relate this to the rate of water mass modification; (2) providing a quantitative estimate of the surface energy exchanges in the winter Antarctic sea ice zone and, in conjunction with FORMEX, to relate surface vertical energy exchange to the ocean heat budget and advection; and (3) describing the processes by which new ice deforms and thickens and the atmospheric and ocean forcing which determine these processes. See the HiHo Web site[57].

hill The official IHO definition for this undersea feature name is "an isolated (or group of) elevations(s), smaller than a seamount; see also abyssal hills and knoll."

HNLC An abbreviation for high nutrient–low chlorophyll regions. These are mainly the waters of the subarctic Pacific, the Southern Ocean around Antarctica, and the equatorial Pacific. These are regions in which the biological pump is inefficient, i.e. the phytoplankton standing stocks are not large enough to assimilate the N and P in the surface waters to deplete them at any time through the year. See iron hypothesis.

HNODC The **H**ellenic **N**ational **O**ceanographic **D**ata **C**entre is located at the Institute of Oceanography at the National Centre for Marine Research (NCMR) in Athens, Greece. It was established in 1986 as part of the NCMR and operates as a national agency responsible for processing, archiving and distributing marine data. HNODC is also responsible for the coordination of IODE in Greece.

[http://hnodc.ncmr.gr/]

hole The official IHO definition for this undersea feature name is "a small local depression, often steep sided, in the sea floor."

HOME Acronym for Hawaii Ocean Mixing Experiment, an effort to observe and model mixing along the Hawaiian Ridge, a salubrious location for such an investigation since the topography is steep and energy available in the form of tides that strike the Ridge at nearly normal incidence.

[http://chowder.ucsd.edu/home/]

HOPE Abbreviation for a primitive equation ocean circulation model developed and used at the DKRZ.

Hopen–Bjornoya Current See Pfirman et al. [1994].

HOT Acronym for Hawaii Ocean Time-series, a program for making repeated observations of the hydrography, chemistry and biology at a station north of Hawaii since October 1988. The objective of this research is to provide a comprehensive description of the ocean at a site representative of the central North Pacific Ocean. See Karl and Lukas [1996].

[http://hahana.soest.hawaii.edu/hot/hot_jgofs.htmlhttp://hahana.soest.hawaii.edu/hot/hot_jgofs.html

[57] http://www.antcrc.utas.edu.au/antcrc/seaice/HiHores.html

Hough functions The eigenfunctions of a linearized form of the governing equations of motion on a sphere, i.e. Laplace's tidal equations, as first discovered by Hough [1898]. Each Hough mode is a function of latitude and longitude and has three components: (1) a zonal (eastward) wind component, (2) a meridional (northward) wind component, and (3) a geopotential component. A distinct horizontal scale and frequency is associated with each mode, and the modes are orthogonal over the sphere in the continuous case. They are sometimes divided into two classes: (1) low-frequency Rossby-Hough modes that tend to satisfy the geostrophic relation and (2) higher frequency Hough modes that correspond to inertia-gravity waves. They can also be thought of as a generalized Fourier series in which the basis functions are the normal modes of a resting atmosphere. See Daley [1991].

Hoxton, Walter See Peterson et al. [1996].

horse latitudes The belts of variable, light winds and fine weather associated with the subtropical anticyclones The name originated with the historical sailing practice of throwing the horses being transported to America or the West Indies overboard when these latitudes were reached and the light winds caused the voyage to be overly extended.

HRP Abbreviation for High Resolution Profiler.

HRTWN Abbreviation for Hawaii Regional Tsunami Warning Network.

HSSTD Abbreviation for Historical Sea Surface Temperature Dataset.

Huanghai Sea See Yellow Sea.

Hudson Bay A large inland Arctic sea exceeding 1 million square kilometers in area, connected to the Arctic Ocean at its northern end through Foxe Basin. It can be characterized as shallow, with a mean depth of less than 150 m. The details of the circulation and water masses are not well known, although the water properties depend mainly on exchanges with Foxe Basin and Hudson Strait and the large freshwater input from both rivers surrounding the bay and sea ice melt in the spring and summer. A cyclonic circulation is maintained by the inflow/outflow forcing at the northern end, with the wind and buoyancy driven circulations serving to enhance the cyclone. There is also strong steering of the flow by the bathymetry.

According to Ingram and Prinsenberg [1998]:

> The open–water circulation of Hudson Bay is primarily driven by wind forcing and buoyancy input. In the summer, northerly winds dominant north of about 60°N, with northwesterly winds in the southern half of the bay. The freshwater runoff generates and estuarine–type circulation in the bay as a whole, such that the upper–layer low–salinity flux to Hudson Strait is balanced by an inward flux of higher–salinity ocean water in the lower layer. The incoming higher–salinity and colder water enters at the northern boundary of Hudson Bay and through estuarine–like processes modifies the fresher surface waters. Typical mean surface flow values are 0.04 m s^{-1}, equivalent to a two–year period to complete a trajectory around Hudson Bay.

Ingram and Prinsenberg [1998].

[http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/publications.htm]

Humboldt Current See Peru Current.

humidity mixing ratio The ratio of the mass of water vapor in a sample of moist air to the mass of dry air with which it is associated.

Hunter Channel One of two gaps in the Rio Grande Rise that allow the export of Antarctic Bottom Water (AABW) from the Argentine Basin into the Brazil Basin (the other being the Vema Channel). It is located near 28°W with a sill depth of about 4200 m. The mean transport estimated from moored current meters (during the Deep Basin Experiment) was 2.92 (±1.24) $\times 10^6\, m^3 s^{-1}$, with the the transport equatorward 89% of the time. See Zenk et al. [1999].

HURL Acronym for Hawaii Underwater Research Laboratory.

hurricane More later. See Gray [1979].

HYD93 Abbreviation for the Hydrographic Surveys Data Exchange Format for bathymetric soundings and hydrographic features as specifed by the HYD93 Task Group in a meeting at the NGDC in December, 1993. The HYD93 digital format is intended to be used for the transmission of data to and from a data center and may be useful for the exchange of data between marine institutions. This format was based on the earlier MGD77 format for marine geophysical data. The details of the format are available in documents at the HYD93 FTP site.

hydrochlorofluorocarbon (HCFC) A class of chemicals being used to replace CFCs since they deplete stratospheric ozone to a much lesser extent than CFCs. These have ODPs ranging from 0.01 to 0.1. The production of these chemicals is being gradually phased out, with those with the highest ODPs going first. These will be replaced by HFCs or some other types of chemicals.

hydrofluorocarbon (HFC) A class of chemicals being used to replace CFCs. They do not contain chlorine or bromine and therefore do not deplete ozone in the stratosphere. These all have an ODP value of zero but can have high GWP values.

hydrodynamic modulation A type of modulation of backscattered ripple waves measured by SAR that arises through variations in the energy of the Bragg backscattering ripples causes by hydrodynamic interactions betwen the short ripple waves and the longer waves. See Komen et al. [1996].

hydrographic theorem An expression, developed using the continuity equation, for water budget estimates in two-layer channels with different salinity values in each layer. It was first developed by Knudsen. See Dietrich [1963].

hydrography The study of the physical features of water bodies like oceans and lakes (in analogy to geography being the study of the physical features on land). Oceanic features of interest include the location and spatial extent of water masses as identified by their characteristic properties such as salinity, temperature and micronutrient concentrations. Early systematic attempts at applying hydrography to the oceans were the core layer method and the isopycnal method in the 1920s and 1930s by Wust, Iselin, Montgomery, Defant and others, and variants of these methods are still used today to provide a first-order general classification of the waters of the world ocean. Much care, however, should be taken when attempting to use the results of these mostly static classification methods to understand the dynamical aspects of the ocean (although the latter is much more closely related to dynamical fields). This is best exemplified by the classic apothegm "the hydrographer's ocean is much smoother than the dynamicist's ocean".

hydrological cycle The importance of the oceanic component of the hydrologic cycle is evidenced by estimates indicating that 86% of global evaporation and 78% of precipitation occur over the ocean. The global water reservoirs are the ocean, the land, and the atmosphere, holding 1,400,000,000 km^3, 59,000,000 km^3, and 16 km^3 of water, respectively. About 13.5 Sv evaporates from the ocean (2.2 Sv for land) while 12.2 Sv are precipitated (3.5 Sv for land).

The major regional features of the cycle include rainfall dominating over evaporation in the tropics within the ITCZ, with the subtropics characterized by an excess of precipitation except for the SPCZ. Precipitation again dominates in subpolar latitudes, with data near the poles being too sparse to form any generalizations. The ocean must of course compensate for these latitudinal differences, moving water into evaporation zones and away from regions where precipitation dominates. This transport accounts for a significant percentage of the total poleward heat transport on the planet.

Interbasin differences include the Atlantic being saltier than the Pacific due to the dominance of evaporation in the former and precipitation in the latter. The difference is thought to be maintained by water vapor transport across Central America and the lack thereof into the Atlantic from the east. These differences in surface water fluxes lead to interbasin transports in the ocean, although these are known even less accurately than the precipitation and evaporation patterns. See Schmitt [1995].

hydrology More later.

hydrometeor Any condensed water particle in the atmosphere of size much larger than individual water molecules, e.g. fog, cloud, some hazes, rain and snow.

hydrosphere This consists of all water in the liquid phase distributed on the Earth, including the oceans, interior seas, lakes, rivers, and subterranean waters.

hydrostatic approximation This approximation assumes that the vertical pressure gradient is almost balanced by the forcing due to buoyancy excess. Then the vertical acceleration remains as a much smaller term and can be omitted. A more stringent argument is given by Jones and Marshall [1993]:

If, in standard notation,

$$\frac{Dw}{Dt} + g + \frac{1}{\rho}\frac{\partial p}{\partial z} = 0 \tag{8}$$

is the vertical momentum equation with the height z as the vertical coordinate and $w = Dz/Dt$, then in the hydrostatic approximation the term Dw/Dt is omitted. But the condition for the validity of the hydrostatic approximation is much more stringest than $Dw/Dt \ll g$, the acceleration due to gravity, because almost all of g is balanced by the inert hydrostatic pressure gradient associated with the resting reference state.

More helpfully, we can isolate the hydrostatically balanced and dynamically inactive pressure gradient by writing the Boussinesq form of the previous equation as

$$\frac{Dw}{Dt} + g\frac{\rho'}{\rho_0} + \frac{1}{\rho_0}\frac{\partial p'}{\partial z} = 0 \tag{9}$$

where the primes denote a deviation from the hydrostatically balanced reference state and ρ_0 is a standard (constant) value of density. Now it can be clearly seen that the condition for the neglect of Dw/Dt is that it should be much smaller than $g' = g(\rho'/\rho_0)$ rather than g. Let us now try and estimate typical scales for which the hydrostatic approximation is valid, according to this more stringent condition.

Consider a convective event (in an unstratified ocean) which has a characteristic horizontal scale l and vertical scale H with horizontal and vertical velocity scales u and w, respectively. The time scale of a particle of fluid moving through the convective system is of order l/u and a typical w will be

$$w \sim \frac{uH}{l}. \tag{10}$$

So

$$\frac{Dw}{Dt} \sim \frac{u^2 H}{l^2} \tag{11}$$

and hence Dw/Dt , g' if

$$\frac{u^2 H}{g' l^2} \ll 1. \tag{12}$$

If this last condition is not satisfied, then the full vertical momentum equation must be used.

See Jones and Marshall [1993].

hydrostatic equation An equation relating the vertical pressure gradient to the vertical distribution of density in a fluid (atmosphere or ocean) at rest. It is given by

$$\frac{\partial p_h}{\partial z} = -g\rho$$

where p_h is the static pressure, z the vertical coodinate, g the gravitational acceleration, and ρ the density.

hydrostatic pressure See static pressure.

hypolimnion The layer of water below the thermocline in a fresh water lake, as opposed to the epilimnion.

hypoxia See Kamykowski and Zentara [1990].

hypsographic curve See hypsometric curve.

hypsometric curve A plot of the percentage of elevation and depth distribution on the continents and oceans, i.e. the representation of the statistical distribution of elevations over the entire planet. Such a curve was first prepared by Krümmel in 1897, with a more modern version prepared by Kossinna in the 1920s and 1930s.

hypsometric equation In meteorology, a relation stating that the thickness of an atmospheric layer bounded by two isobaric surfaces is proportional to the mean temperature of that layer and the pressure change across it, i.e.

$$z_2 - z_1 = a\,\overline{T_v}\,\ln\left(\frac{P_1}{P_2}\right)$$

where $\overline{T_v}$ is the average virtual temperature between heights z_1 and z_2, a is equal to $R_d/g = 29.3\,m/K$ (where R_d is the gas constant for dry air), and P_1 and P_2 are the pressures at the two levels. See Salby [1992] and Stull [1995].

hypsometry The study of the elevation and depth distribution on the continents and oceans.

hysteresis More later.

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IABO Abbreviation for International Association for Biological Oceanography. See the IABO Web site[58].

IABP Abbreviation for the International Arctic Buoy Program, a network of automatic data buoys for monitoring synoptic-scale fields of pressure, temperature and ice motion throughout the Arctic Basin. See the IABP Web site[59].

IACOMS Acronym for International Advisory Committee on Marine Sciences. This was replaced by SCOR.

IAMSLIC Abbreviation for International Association of Aquatic and Marine Science Libraries and Information Centers.

iAnZone Acronym for the international Antarctic Zone program, an affiliated program of SCOR. According to the official site:

> The primary goal of the international Antarctic Zone (iAnZone) program is to advance our quantitative knowledge and modeling capability of the seasonal cycle and interannual variability of the ocean and its sea ice cover, with emphasis on climate relevant fluxes which couple the Antarctic Zone to the atmosphere and to the Global Ocean.
>
> The first internationally coordinated iAnZone field activity was Ice Station Weddell in 1992, directed at exploration of the environmental conditions along the western margin of the Weddell Sea and the formation and spreading of Antarctic Bottom Water. The second activity was the Antarctic Zone Flux (AnzFlux) experiment in 1994 , in which heat fluxes within the winter mixed layer, sea ice and atmospheric boundary layer were precisely measured. ... These two activities focused upon processes associated with ocean ventilation within the polar waters.
>
> The third iAnZone coordinated program, Deep Ocean VEntilation Through Antarctic Intermediate Layers (DOVETAIL) will take place in 1997-98. It builds upon the two preceding iAnZone programs which dramatically improved our understanding of the water mass modification processes within the Weddell Gyre. DOVETAIL purpose is to better define and understand the export of the cold water products produced within the Weddell Gyre into the global ocean and climate system. DOVETAIL proposes to focus on escape of the recently ventilated deep water from the Weddell Sea into the Global Ocean - the final stage in its role of ventilating deep ocean waters.

`[http://www.ldeo.columbia.edu/physocean/ianzone/]`

Iapetus Ocean A paleogeographic term for the ocean that lay between Baltica and Laurentia during the late Precambrian and early Paleozoic. It was subducted during the early Paleozoic and is thought to have disappeared completely by the Late Silurian-early Devonian (around 400 Ma).

IAPO Abbreviation for International Association for Physical Oceanographers, the name of what is now known as the IAPSO from 1948 to 1967.

IAPP Abbreviation for International Arctic Polynya Program, an AOSB project to address the physical and biological role of polynyas in the Arctic.

`[http://www.aosb.org/IAPP.html]`

[58]http://www.lmcp.jussieu.fr/icsu/
[59]http://iabp.apl.washington.edu/

IAPSO Abbreviation for International Association for the Physical Sciences of the Ocean, one of seven assocations of the IUGG, itself one of the unions of the ICSU. The IAPSO had its genesis in the formation of a Section of Physical Oceanography (with Prince Albert of Monaco as its first president) at the meeting establishing the IUGG in Brussels, Belgium in 1919. This Section was renamed the Association of Physical Oceanography (APO) at a meeting in Seville, Spain in 1929 held separately from the IUGG General Assembly. In 1948 it was further renamed to the International Association of Physical Oceanography (IAPO) at an IUGG General Assembly in Oslo, Norway. It obtained its present acronym at an IUGG General Assembly held in Bern, Switzerland in 1967 where it was renamed to International Association of Physical Sciences of the Ocean, and its present slightly modified name at an IAPSO General Assembly in Vienna, Austria in 1991. The IAPSO General Assemblies were split off from those of the IUGG starting at a meeting in Tokyo, Japan in 1970.

The primary goal of IAPSO is "promoting the study of scientific problems relating to the oceans and the interactions taking places at the sea floor, coastal, and atmospheric boundaries insofar as such research is conducted by the use of mathematics, physics, and chemistry." This goal is addressed through four objectives:

- organizing, sponsoring, and co–sponsoring format and informal international forums permitting ready means of communication amongst ocean scientists throughout the world;
- establishing commissions, sub–committees, and organizing commensurate workshops to encourage, stimulate, and coordinate new and advanced international research activities;
- providing basic services significant to the conduct of physical oceanography; and
- publishing proceedings of symposia, meetings, and workshops, and fundamental references on the current state of the art and knowledge of physical oceanography.

These objectives are carried out through the efforts of the IAPSO Bureau (consisting of the President and Secretary–General) and the IAPSO Executive Committee, with most of the organization and work carried out via various commissions periodically constituted to address particular areas of interest. It maintains formal liasons with both SCOR and IOC.

The presently (1998) constituted IAPSO commissions are the Commissions on Mean Sea Level and Tides, on Sea Ice, on Natural Marine Hazards, and for Cooperation with Developing Countries. There is also a Tsunami Commission jointly constituted with the IASPEI. Other services are a Permanent Service for Mean Sea Level (PSMSL and a Standard Seawater Service. IAPSO publications include a Publications Scientifiques series (of which 35 have been printed between 1931 and 1995), a Process Verbaux series of General Assembly reports, a Reports and Abstract of Communications series of abstracts presented at General Assemblies, and a general series of yearly reports from commissions and other activities.

`[http://www.olympus.net/IAPSO/]`

IBC Abbreviation for International Bathymetric Chart.

IBCCA Abbreviation for International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico, an ocean mapping activity of the IOC.

IBCAO Abbreviation for International Bathymetric Chart of the Arctic Ocean, an initiative to develop a digital database containing all available bathymetric data north of 64 degrees north.

`[http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html]`

IBCEA Abbreviation for International Bathymetric Chart of the Central Eastern Atlantic, an ocean mapping activity of the IOC.

IBCM Abbreviation for International Bathymetric Chart of the Mediterranean and Its Geological and Geophysical Series, a series of 1:250,000 maps of the bathymetric, geological and geophysical characteristics of the Mediterrean Sea area. This is an activity of the IOC.

[http://www.ngdc.noaa.gov/mgg/ibcm/ibcm.html]

IBCRSGA Abbreviation for International Bathymetric Chart of the Red Sea and Gulf of Aden.

IBCWIO Abbreviation for International Bathymetric Chart of the Western Indian Ocean, an ocean mapping activity sponsored by the IOC, UNESCO, and the German government. The initial mission of the project is to create a new bathymetric mapping of the Western Indian Ocean, with future missions involving the mapping of other measurements such as sediment thickness, potential fields, and geological structure. The German Hydrographic Office (GHO) is taking the responsibility for providing project coordination, editing, conversion to digital media, printing, and distribution of the new bathymetry. The IBCWIO is coordinate with four other international regional ocean mapping projects sponsored by the IOC: IBCCA, IBCWP, IBCEA, and IBCM, with the project also coordinate with GEBCO.

[http://www.ngdc.noaa.gov/mgg/ibcwio/ibcwio.html]

IBCWP Abbreviation for International Bathymetric Chart for the Western Pacific, an ocean mapping activity of the IOC.

IBEX Acronym for Ice Backscattering Experiment, a project of the APL at the University of Washington School of Oceanography. It was part of ONR's Sea Ice Mechanics Initiative (SIMI) and was conducted during April 1994. The goal of IBEX was to use the CABEX array to image sea ice at 400 Hz and to hopefully observe crack formation and display the resulting images in near real–time. See the IBEX Web site[60].

Iberia Basin An ocean basin located to the west of Spain in the eastern North Atlantic Ocean. This is connected to the West Europe Basin to the north via the Theta Gap and includes the Tagus Abyssal Plain and the Horseshoe Abyssal Plain. This has also been called the Spanish Basin. See Fairbridge [1966].

Ibiza Channel The passage intersecting the Balearic topographic ridge between Ibiza and the Iberian peninsula at Cape La Nao. It connects the Balearic Sea to the north with the Algerian Basin to the south. Its width is 80 km at the surface, but drastically narrows with depth down to a sill at 800 m. See Pinot et al. [2002].

iceberg These are defined by the WMO as:

> A massive piece of ice of greatly varying shape, more than 5 m above sea–level, which has broken away from a glacier (or an ice shelf), and which may be afloat or aground. Icebergs may be described as tabular, dome–shaped, sloping, pinnacled, weathered or glacier bergs (an irregularly shaped iceberg).

Icebergs are not a form of sea ice, as they originate on land. See WMO [1970].

ice shelf An ice sheet that extends over the sea and floats on the water. These range in thickness from a few hundred to over 1000 meters and are connected to land at coastal grounding lines and where they flow around islands. They calve icebergs at their seaward fronts and gain mass by flow from grounded ice sheets and glaciers and from new snow accumulation. Iceberg calving is the primary ablation process with melting providing a secondary mechanism. Ice shelves are key indicators of climate change since

[60]http://wavelet.apl.washington.edu/IBEX/top.html

they respond much more rapidly than grounded ice sheets or glaciers to changes in climate. The continent of Antarctica is surrounded by ice shelves, with the largest being the Ross Ice Shelf, covering over 500,000 km^2.

iceberg Large floating chunks of ice formed by the breaking off, i.e. calving of ice sheets at their seaward edges.

Icelandic low A center of action between Greenland and Iceland and extending to the Canadian Arctic over Baffin Island. It persists year round with some variation in intensity, extent, and central location. The center has a mean surface pressure of around 994 mb in January. See Angell and Korshover [1974].

Iceland Basin See van Aken and de Boer [1995].

Iceland–Faroe Front An oceanic front topographically locked to the Iceland–Faroe Ridge. The front separates the waters of the Atlantic Ocean to the south from the cold, low salinity waters of the Arctic Mediterranean to the north. More specifically, it separates the Atlantic water from colder and fresher water which is in most areas a mixture of water from the north and recirculated Atlantic Water either from the North Iceland Irminger Current or from the Faroe Current. The near surface expression of the Iceland–Faroe Front is usually well represented by the path of the 35.00 isohaline.

The Front extends from the southeast coast of Iceland where the Iceland–Faroe Ridge impinges upon the Icelandic shelf. The Front is generally sharp with abrupt cross–frontal temperature and salinity changes as it begins close to Iceland. As it progresses eastwards, it becomes more diffuse so that north of the Faroes, cross–frontal gradients become considerably smaller. There is an associated progressive change in the vertical slope of the front, from 0.015 at 400 m depth close to Iceland to a factor of 5 less northeast of the Faroes. The Front maintains contact with the bottom until it reaches the sharp eastern corner of the Faroe Plateau, where its near–surface expression has also become much more diffuse.

The Front is not a smoothly varying boundary, but is typically distorted by meanders and eddies of 30–50 km scale. The frontal meanders are probably due to baroclinic instability, and move eastwards along the front. The meanders have been measured to propagate with an average speed of 3.3. km/day and were discernible for 2–3 months. Eddies derived from unstable meanders are found on both sides of the Front, with observed scales ranging from 15 to 70 km. Eddy production is estimated to be about one per day. The eddies are most pronounced in the 70 km wide uppermost 100 m layer of the Front, although the effects can usually be seen down to the typical 400 m depth of the crest of the ridge or deeper. See Read and Gould [1992] and Hansen and Osterhus [2000].

Iceland–Faroe Ridge See Greenland–Scotland Ridge.

Iceland–Scotland Overflow Water A deep water mass found over the slopes of the Iceland–Scotland Ridge in the Iceland Basin. The typical characteristcs at around 20°W are $\Theta = 2.5$°C and S = 34.98. The main source for ISOW is assumed to be the NSDW found below the permanent pycnocline in the Norwegian Sea. The O_2 and Si concentrations in ISOW are also slightly lower than in NSDW. See van Aken and Becker [1996].

Iceland Sea A marginal sea located in the North Atlantic Ocean. It is roughly defined as the waters lying to the west of Jan Mayen Ridge at about 7° W. It adjoins the waters of the Norwegian Sea to the east, the Greenland Sea to the north, the Denmark Strait to the west, and the North Atlantic Ocean to the south. The average depth of this region is about 1128 m.

In the summer, the volume of the Iceland Sea is composed of about 60% Greenland Sea Deep Water (GSDW), 30% upper and lower Arctic Intermediate Water (AIW), with the remaining 10% distributed among the Polar Intermediate Water (PIW), surface water masses (i.e. Polar Water (PW), Atlantic Water (AW), and Arctic Surface Water (ASW)). See Swift [1986], Hopkins [1991] and Buch et al. [1996].

ICES Acronym for International Council for the Exploration of the Sea, a scientific forum for the exchange of information and ideas on the sea and its living resources and for the promotion and coordination of marine research by scientists within its member countries. ICES, the oldest intergovernmental organization in the world concerned with marine and fisheries science, was established in Copenhagen in 1902. While it was established in 1902, it had its genesis in an international conference convened by King Oscar II of Sweden in Stockholm in the spring of 1899. Both good and bad fishing years had started to so greatly affect seafaring nations in the 19th century that several governments had appointed committees and commissions to study fishing in their territorial waters. The 1899 conference was proposed to create a larger and more comprehensive program of research not confined to the territorial waters of any single nation. The delegates were a who's who of reknowned ocean scientists at the time including John Murray, Victor Hensen, Friedrich Heincke, Otto Krummel, Otto Pettersson, Gustav Ekman, Theodor Cleve, Fridtjof Nansen, and Johan Hjort. After three years of resolving various political and scientific differences, the ICES was finally established in 1902 with charter members Britain, Denmark, Finland, Germany, Holland, Norway, Russia and Sweden. See Thomasson [1981].

`http://www.ices.dk`[61]]

Ice Station Weddell A research program designed to study the physics of the ocean, sea ice and atmosphere in the western Weddell Gyre of Antarctica. Ice Station Weddell (ISW–1) took place from January through June, 1992. According to the LDEO site:

> Researchers, their equipment and living accomodations were placed on an ice floe in the southwestern Weddell. As the floe drifted to the north, measurements were taken at the ice camp, using instruments placed near the camp, on snowmobiles, and from helicopters which flew up to 100 miles from the camp. Additional measurements were carried out on board Russian and US icebreakers during the drift of the ice station.
>
> ISW involved researchers, technicians, teachers, students and support personnel from many institutions in the US and former Soviet Union. The US component was funded by the Office of Polar Programs of the National Science Foundation. Logistics support was provided by Antarctic Support Associates. ...
>
> An effective way to gather extensive observations in the ice cluttered western Weddell is to borrow a successful method from the Arctic: deployment of a scientific station on a drifting ice floe. In 1988 the concept for the US/USSR Ice Station Weddell #1 (ISW), the first ice station of the Southern Ocean was initiated, with detailed planning in 1989-1991 and field deployment in 1992. The extensive experience of Russia and the United States in ice station operation formed a natural basis for a collaborative effort to meet the many challenges of establishing a scientific ice station in an unexplored part of the southern ocean.
>
> In the spirit of basic exploration of an unknown region the science program spanned many disciplines. Included were measurements of full water column thermohaline and tracer fields; current measurements; estimations of turbulent fluxes within the oceanic and atmospheric planetary boundary layers; sea ice physical, chemical and biological characteristics; sea ice dynamics; and water column biology. US and Russian science programs complimented each other to yield a more complete picture of the environment. Observations were made at the ISW site, from remote instrumented drifters, from helicopters and from the ships associated with the various phases of the work. The ISW drifted roughly along 530W at a northward drift rate of 6.2 km/day between 71.40S and 65.80S, experiencing temperatures mostly about -250C, but getting as low as -360C.

[61] http://www.ices.dk

See Gordon and Ice Station Weddell Group of Principal Investigators and Chief Scientists [1993].

[http://www.ldeo.columbia.edu/physocean/proj_ISW.html]

ICITA Acronym for International Cooperative Investigation for the Tropical Atlantic, an IOC project.

ICOIN Acronym for the Canadian Inland Waters, Coastal and Ocean Information Network. See the ICOIN Web site[62].

ICSEM Acronym for International Commission for the Scientific Exploration of the Mediterranean Sea.

ICSPRO Abbreviation for Inter–Secretariat Committee on Scientific Programs Relating to Oceanography, composed of UN/FAO/UNESCO/WMO/IMO.

ICW Abbreviation for Indian Central Water.

ideal gas law A simplifed equation of state that can be used to relate the pressure, density and temperature of gases in a dry atmosphere. The law can be stated as

$$P = \rho R_d T$$

where P is the pressure, ρ the density and T the temperature. R_d is the gas constant for dry air and equal to 287.053 $JK^{-1}kg^{-1}$ or 0.287053 $kPaK^{-1}m^3kg^{-1}$. This can also be used for calculations with moist air via the virtual temperature concept.

IDEAS Acronym for International Decade of Exploration and Assessment of the Seas. Now defunct.

IDMS Abbreviation for International Directory of Marine Scientists.

IDOE Abbreviation for International Decade of Ocean Exploration, an IOC initiative lasting from 1971–1980. IDOE was a long–term, multipurpose oceanographic research program carried out on an international cooperative basis during the 1970s. The idea was first proposed by the U.S. President in March 1968, and endorsed by the U.N. in December 1968. The NSF was charged with planning, managing and funding the U.S. part of IDOE in late 1969. The goals of IDOE were to:

- provide the scientific basis needed to improve environmental forecasting;
- determine the potential resources of the ocean floor;
- determine the quality of the ocean world environment, evaluate the impact of human activities on that environment, and establish a scientific understanding of the basis for corrective actions needed to preserve it;
- improve worldwide data exchange through updating and standardizing national and international marine data colllection, processing and distribution; and
- provide basis knowledge of biological processes needed for the intelligent use of living ocean resources.

The cooperative projects accomplished in pursuit of these objectives included GEOSECS, MODE, NORPAX, CLIMAP, ISOS, POLYMODE, CUEA, the Seabed Assessment Program, Project FAMOUS and the Living Resources Program.

[http://www.nap.edu/books/0309063981/html/index.html]

[62]http://192.139.141.30/

IEO Abbreviation for Instituto Españal de Oceanografía, the national oceanographic institute of Spain. See the IEO Web site[63].

IES Abbreviation for inverted echo sounder.

IFREMER Acronym for Institut Français de Recherche pour l'Exploitation de la Mer. See the IFREMER Web site[64].

IFYGL Abbreviation for International Field Year on the Great Lakes. See Csanady [1974].

IGBP Abbreviation for International Geosphere–Biosphere Program, a scientific research program built around a family of core projects whose mission is to deliver scientific knowledge to help human societies develop in harmony with Earth's environment. The core projects are:

- BAHC (Biospheric Aspects of the Hydrological Cycle);
- GAIM (Global Analysis, Integration and Modeling);
- GCTE (Global Change and Terrestrial Ecosystems);
- GLOBEC (Global Ocean Ecosystem Dynamics);
- IGAC (International Global Atmospheric Chemistry);
- IGBP–DIS (Data and Information Services);
- JGOFS (Joint Global Ocean Flux Study);
- LOICZ (Land–Ocean Interactions in the Coastal Zone);
- LUCC (Land–Use and Land–Cover Change);
- PAGES (Past Global Changes);
- START (System for Analysis, Research and Training);

[http://www.igbp.kva.se/]

IGOM Acronym for integrated global ocean monitoring.

IGOS Acronym for Integrated Global Observating Strategy, a program to unite the major satellite and surface–based systems for global environmental observations of the atmosphere, oceans and land. The major objectives of IGOS include:

- strengthening space–based/in situ linkages to improve the balance between satellite remote sensing and ground– or ocean–based observing programs;
- encouraging the transition from research to operational environmental observations within appropriate institutional structures;
- improving data policies and facilitating data access and exchange;
- stimulating better data archiving to build the long–term time series needed to monitor environmental change; and
- increasing attention to harmonization, quality assurance, and calibration/validation so data can be used more effectively.

[http://ioc.unesco.org/igospartners/igoshome.htm]

[63] http://www.ieo.rcanaria.es/
[64] http://www.ifremer.fr/

IGOSS Acronym for the Integrated Global Ocean Services System. See the IGOSS Web site[65].

IGSP Abbreviation for International Greenland Sea Project.

IGY Abbreviation for International Geophysical Year, and ICSU project during 1957–1958.

IHB Abbreviation for International Hydrographic Bureau, later replaced by IHO.

IHO Abbreviation for International Hydrographic Organization, located in Monte Carlo, Monaco. The IHO is an intergovernmental consultative and technical organization working to support the safety of navigation and the protection of the marine environment. The genesis of the IHO was at a Hydrographic Conference in London in 1919 where 24 nations met and decided to create a permanent body. This led to the creation of the International Hydrographic Burea (IHB) in 1921 with 19 Member States. The IHB was provided with headquarters in the Principality of Monaco at the invitation of Prince Albert I. The name of the organization was changed to IHO (with the headquarters in Monaco remaining the IHB) in 1970. As of 1998, the IHO has 62 maritime States with ten more in the process of becoming members. The official representative of each Member State is usually the national Hydrographer or Director of Hydrography, with these persons (along with their technical staffs) meeting every 5 years in Monaco for an International Hydrographic Conference. There progress is reviewed on current projects, new projects are adopted, and a Directing Committee of three senior hydrographers is elected to guide the Bureau until the next conference.

The chief activities of the IHO are:

- working towards standardization in the specifications, symbols, style and formats used for nautical charts and related publications;
- producing a common, worldwide chart series (INT charts) to a single set of agreed specifications, with the program for INT small scale (i.e. 1/10,000,000 and 1/3,500,000) charts started in 1971 completed and those for large and medium scales proceeding rapidly;
- managing radio navigational warnings via the Global Maritime Distress and Safety System (GMDSS);
- coordinating the development of Electronic Chart Display and Information Systems (ECDIS) to ensure the standardization of specifications, including the establishment of the IHO Data Center for Digital Bathymetry (DCDB) located at the NGDC;
- creating and publishing (along with the Fédération Internationale des Géomètres, or FIG) a comprehensive set of standards of competence for hydrographic surveyors;
- providing technical assistance for establishing and strengthening the hydrographic capabilities of developing nations;
- examining and archiving copies of every unclassified new chart and publication of each Member State (with the archives holding more than 21,000 charts);
- overseeing a computerized Tidal Constituent Data Bank (TCDB) which archives and supplies data for over 4,000 tidal stations;
- encouraging the establishment of Regional Hydrographic Commissions and advising those thus established;
- overseeing such services as the World Series of Bathymetric Plotting Sheets and the General Bathymetric Chart of the Oceans GEBCO; and
- publishing associated material.

[65] http://www.unesco.org/ioc/igoss/igoshome.htm

Among the more than 40 publications of the IHO are the semi–annual International Hydrographic Review (containing original papers on technical aspects in the fields of hydrography, descriptive oceanography, and cartography), the monthly International Hydrographic Bulletin (containing topical news of worldwide hydrographic activities including lists of charts and nautical publications of member states), a Yearbook, an Annual Report, and numerous other limited, specialty publications.

[http://www.iho.shom.fr/]

IIOE Abbreviation for International Indian Ocean Expedition, an IOC project carried out in 1964. It included the first intensive measurements of simultaneous momentum, heat and moisture fluxes using profile methods. See

IMAGES Acronym for International Marine Global Change Study, a joint project of SCOR and PAGES whose primary goals are to quantify climate and chemical variability of the ocean on time scales of oceanic and cryospheric processes, determine the sensitivity of the ocean to identified internal and external forcing functions, and determine the ocean's role in controlling atmospheric CO_2. A global program including at least 30 dedicated oceanographic expeditions from 1994–2004 is planned to answer questions concerning how changes in ocean properties controlled the evolution of global heat transfer through to deep and surface ocean and so modified the climate, how changes in ocean circulation, chemistry, and biological activity have interacted to generate the observed record of pCO_2 over the past 300 Ka, and how close continental climate has been linked to ocean surface and deep water properties.

IMDC Abbreviation for Irish Marine Data Center. See the IMDC Web site[66].

implicit scheme In numerical modeling, an integration algorithm that temporally advances an approximate solution via discrete steps using information from present as well as from previous time steps. These are computationally more complex than explicit schemes but allow longer time stepping intervals and usually have better numerical stability properties. See Kowalik and Murty [1993].

IMR Abbreviation for Institute of Marine Research, a research institute located in Bergen, Norway. See the IMR Web site[67].

INAMHI Abbreviation for Instituto Nacional de Meteorología e Hidrología, located in Ecuador.

INDEA Acronym for Inlet and Nearshore Dynamics Experiment: Algarve. See the INDEA Web site[68].

INDEX Acronym for Indian Ocean Experiment, which took place from 1976–1979.

independent variable See dependent variable.

Indian Central Water (ICW) See Poole and Tomczak [1999].

Indian monsoon The seasonal reversal of the wind direction along the shores of the Indian Ocean, especially in the Arabian Sea. The winds blow from the southwest during half of the year and from the northeast during the other half. The reversal of direction (from that due to the normal zonal circulation pattern) is due to the effects of differential heating as the Himalayan plateau heats up during the summer, causing the air to rise and be replaced by the warm, moist air from over the Indian Ocean.

Indian Ocean The history of Indian Ocean investigations is summarized in Schott and McCreary Jr. [2001]:

[66] http://www.marine.ie/datacentre/
[67] http://www.imr.no/imr.htm
[68] http://www.pol.ac.uk/jjw/Indea.html

> During the past 40 years, an intensive coordinated study of the Indian Ocean has taken place every decade or so. The first coordinated investigation was carried out during the International Indian Ocean Expedition (IIOE) in 1964–66. It consisted of a basin-wide survey that subsequently resulted in a comprehensive hydrographic atlas (Wyrtki [1971]) and of a number of regional studies, including the first survey of the monsoon circulation of the Somali Current. The next intensive study was the Indian Ocean Experiment (INDEX) during the first GARP Global Experiment (FGGE), which investigated the summer-monsoon response of the Somali Current. In the following decade, only a few individual or bilateral studies were carried out. ...
>
> In the context of the World Ocean Circulation Experiment (WOCE), a fresh increase in research activities began in the early 1990s, which culminated in a coordinated ship survey of the entire Indian Ocean during 1995–96. This effort yielded high-quality data sets of the distributions of hydrographic properties and various tracers, also current profiles measured by both a shipboard Acoustic Doppler Current Profiler (ADCP) and an ADCP lowered with the CTD rosette (LADCP). In addition, deep float and surface drifter deployments, moored arrays, repeat XBT sections, and especially high-precision TOPEX/Poseidon (T/P) altimetry, which has been operational since 1993, have provided new insights into physical variability and its relations to the forcing fields. In the northern Arabian Sea, a large observational program within the context of the Joint Global Ocean Flux Study (JGOFS) was carried out during 1994–96, including intensive studies on the monsoon response and mixed-layer deepening as well as the regional circulation and upwelling off Oman.

The Indian Ocean water masses have been summarized by Schott and McCreary Jr. [2001]. The following is a modified version of their summary.

> Three basic kinds of water masses can be distinguished: those that are generated within the open Indian Ocean by subduction, those that are mixing products of other water masses, and those that enter from outside.
>
> Two shallow water masses are formed by subduction and enter the upper thermocline. Arabian Sea Water (ASW) is formed in the northern Arabian Sea during the northeast monsoon and spreads as a salinity maximum just underneath the surface–mixed layer. Another shallow salinity maximum–water forms in the subtropical gyre of the southern hemisphere, where evaporation exceeds precipitation. This is Subtropical Surface Water (SSW), which has a core density of σ_θ=25.8 kg/m^3. When it joins the South Equatorial Current (SEC), it has a core depth of 200–250 m, it spreads with the westward flow toward the western boundary, and shallows to about 100 m. In the northern Bay of Bengal, waters of very low salinities are generated through the combined effects of large river discharge and excess precipitation. These low salinity waters can spread around India/Sri Lanka and be identified in the eastern Arabian Sea. Another northern salty near–surface water mass, which is clearly distinct from ASW, is Persian Gulf Water (PGW). It spreads at a core depth of σ_θ=26.6 kg/m^3, corresponding to a depth of about 250–300 m. The influence of PGW doesn not extend very far beyond the northern Arabian Sea.
>
> Indian Central Water (ICW) is formed in the subtropics of the southern hemisphere, marked by a near–linear T/S relation above about 7°C and a T/S maximum associated with SSW below 7°C. The SSW spreads westward with the SEC and then northward across the equator with the Somali Current, where it finally participates in supplying the upwelling water off Somalia and Arabia. In the Northern Hemisphere, it is referred to as North Indian Central Water, an aged type of ICW.
>
> The water masses entering through the Indonesian passages originate mostly from the thermocline in the North Pacific. Initially they are marked by a salinity maximum, but

become transformed by strong vertical mixing as they flow over the various sills of the Indonesian passages, and so assume new characteristics, showing a relative salinity minimum in the Indian Ocean environment. They are referred to as Banda Sea Water (BSW) or as Austalian Mediterranean Water (AAMW) in the Indian Ocean.

The equatorial regime has its own specific thermocline water mass, Indian Equatorial Water (IEW), marked by small vertical salinity differences. It is a mixing product of Indonesian Throughflow water coming from the east and Indian Ocean waters from the north and south.

At intermediate depths, Antarctic Intermediate Water (AAIW) with a core density of $\sigma_\theta =$ 27.1–27.3 kg/m^3 enters the basin in the southeastern region. It is generated by subduction in the Subpolar Frontal Zone (SFZ), and marked by low salinities because of the precipitation excess over evaporation in that area, and by an oxygen minimum. At that same density, warm and saline Red Sea Water (RSW) spreads from the north, out of the Gulf of Aden. Its preferred spreading route into the Indian Ocean is through the passage between Socotra and the African continent, and then further south into the Mozambique Channel. Its distribution in the northwest Indian Ocean is very inhomogeneous as a result of the intense eddy activity in the Somali Current and the northern Arabian Sea.

At greatest depths, Lower Circumpolar Deep Water (CDW) enters the Madagascar and West Australian basins, although direct entry into the central Indian Basin is obstructed by the deep ridges. Indian Deep Water (IDW) is a water mass specific to the northern Indian Ocean; it flows in the density range just about CDW, and presumably is generated by deep upwelling out of the CDW. It is oxygen–poor and has high salinity as a result of its mixing with older intermediate waters above; it is also high in silica derived from the discharges of the northern rivers. In the southwest, it has the characteristics of diluted North Atlantic Deep Water (NADW), i.e. increased oxygen and salinity.

See Sparrow et al. [1996], Stramma and Lutjeharms [1997], Shetye and Gouveia [1998], Ganachaud et al. [2000], Schott and McCreary Jr. [2001], Schott et al. [2002] and Reid [2003].

INDIGO Acronym for the Indien Gaz Ocean project, a series of three cruises taking place aboard the RV Marion Dufresne from 1985-1987. The INDIGO 14C activities[69] are available from the CDIAC.

INDOEX Acronym for Indian Ocean Experiment, a project whose goal is to study natural and anthropogenic climate forcing by aerosols and feedbacks on regional and global climate. It will incorporoate field studies where pristine air masses from the southern Indian Ocean including Antarctica and not–so–clean air from the Indian subcontinent meet over the tropical Indian Ocean to provide a unique natural laboratory for studying aerosols.

`[http://www-indoex.ucsd.edu/]`

INDOMED Expedition A research expedition taking place from 1977-1979. See Scripps Institution of Oceanography [1979b].

Indonesian throughflow See Godfrey [1996].

INDOPAC Expedition See Scripps Institution of Oceanography [1978].

Indo-Pacific Deep Water See Yu et al. [1996].

inertial circles The paths followed by inertial waves.

inertial dissipation method An observational technique for inferring the ocean surface wind stress magnitude. See Fairall and Larsen [1986] and Geernaert [1990].

[69] http://cdiac.esd.ornl.gov/oceans/ndp036.html

inertial frequency The frequency f of rotation of inertial waves.

inertial motion See inertial wave.

inertial oscillation See inertial wave.

inertial wave A limiting form of a long Poincare wave that oscillations at the inertial frequency. In this limit the effects of gravity are negligible and the fluid particles are moving under their own inertia, whence the name. See Webster [1968], Hendershott [1973] and Gill [1982].

infragravity wave More later.

infralittoral zone The third (from the top) of seven zones into which the benthos has been divided. This has also been called the inner sublittoral zone. See Fairbridge [1966].

infrared That part of the electromagnetic radiation spectrum from approximately 0.75 to 1000 μm. This is between the visible and microwave regions of the spectrum. It is further divided into the near (0.75 to 1.5 μm), intermediate (1.5 to 20 μm), and far (20 to 1000 μm) ranges. Most of the energy emitted by the Earth and its atmosphere is at infrared wavelengths, and it is generated almost entirely by large-scale intramolecular processes. The tri-atomic gases such as water vapor, CO2, and ozone absorb infrared radiation and play important roles in the propagation of infrared radiation in the atmosphere.

InFront Acronym for Inner Front program, a research program that took place in the southeastern Bering Sea from 1997 to 2000. According to Macklin et al. [2002]:

> The InFront investigators hypothesized that elevated primary production at the inner front continues longer than production in the upper mixed layer of non-frontal waters, and that front-related production provides an energy source throughout the summer for a food web that supports short-tailed shearwaters (Puffinus tenuirostris), juvenile fish, and their zooplankton prey. Research focused on the role of the structural front between the well-mixed waters of the coastal domain and the two-layer system of the middle domain. Three spring and three summer/fall cruises addressed the temporal and spatial variability of this system at four principal sites, as well as at several areas that were visited opportunistically. Each year millions of short-tailed shearwaters migrate from Australia to the Bering Sea to forage over the inner shelf. The evolution of this annual trans-equatorial migration implies that extraordinary amounts of prey must be readily available to these birds in the Bering Sea. Because earlier workers had described shearwater foraging as concentrated near the inner front, it was hypothesized that this region should support processes conducive to an unusually great abundance or availability of prey. This is also a region where young fish and some species of crab larvae congregate to forage.
>
> To test this hypothesis, InFront investigators collected and interpreted observations on physical and biological features in the vicinity of the inner front. The project has shown that the inner front can facilitate the vertical flux of nutrients and, where this occurs, there is enhanced production at and near the front. Although data collection was restricted to the coastal regions of the southeastern Bering Sea, the results of InFront should be relevant to numerous continental shelf tidal fronts and ecosystems. Thus, the results have a general applicability to understanding and managing some of the world's most productive seas.

See Macklin et al. [2002].

inland sea A sea surrounded by land and connected to the open ocean by one or more narrow straits. Examples include the Baltic Sea, the Red Sea, and the Black Sea. Compare to epeiric sea and epicontinental sea.

INMARSAT Acronym for International Maritime Satellite Organization.

inner sublittoral zone See infralittoral zone.

INO Abbreviation for Institute for Naval Oceanography.

INOUT A part of JONSDAP 76.

INPOC Acronym for Subarctic North Pacific Hydrographic Surveys, a cooperative program among Russia, the U.S. and Canada from 1991–1993 that addressed the variability of the circulation in the subpolar and northern subtropical gyres of the North Pacific.

[http://sam.ucsd.edu/inpoc/inpoc.html]

inshore The zone or portion of a beach profile extending seaward from the foreshore to just beyond the breaker zone. See Komar [1976].

Inshore Countercurrent One of the two narrow, poleward–flowing boundary currents in the California Current system (the other being the California Undercurrent). The IC has been reported as a seasonal flow, appearing in fall and winter. It is found over both the shelf and slope and transports shallow, upper ocean waters derived largely from CC waters with some modification by coastal processes. This is sometimes called the Davidson Current or Davidson Inshore Current at locations north of Point Conception. See Collins et al. [2000].

Inshore Peru Current The name sometimes given to the combination of the Chile Coastal Current (CCC) and the Peru Coastal Current (PCC).

in situ data Data associated with reference to measurements made at the actual location of the object or material measured, by contrast with remote sensing (i.e., from space).

insolation The radiation received from the Sun.

INSROP Acronym for International Northern Sea Route Project, a program organized by the Fridtjo Nansen Institute in Norway.

instrument error An error that is a function of the instrument design and the ambient conditions under which it must operate. For example, the mercury barometer for surface (not mean sea level) pressure measurements has an expected instrument error of about 0.25 mb for a single reading due to ambient temperature and wind effects. See Daley [1991].

instrumental data This refers to data, e.g. temperatures, rainfall amounts, atmospheric pressure, etc., that have been gathered via direct measurement as opposed to proxy data. Most of these records (at least the reliable ones) are on the order of a hundred years or less in duration, with perhaps the longest being a temperature record for central England prepared by Manley [1974] that extends back to 1659.

INTECMAR Acronym for Instituto de Tecnología y Ciencias Marinas, located in Venezuela.

intensive parameter A determining parameter of a system that does not depend on the size and mass of the system, e.g. temperature, pressure, and concentration, as opposed to an extensive parameter.

interbasin exchange In physical oceanography, the active exchange of waters and/or water mass properties between basins. Evidence for this process is provided by the similarities in water masses in the three major oceans despite quite different water mass conversion processes in each. The three avenues for this in the world ocean are: the Bering Strait, which provides a conduit for North Pacific-North Atlantic exchange via the Arctic Ocean; passes in the Indonesian Archipelago, which connect the Indian and

Pacific Oceans at low latitudes; and the Southern Ocean, in which the ACC flows through several broad passages between Antarctica and the other southern hemisphere continents. The conveyor belt paradigm was the first attempt to tie these together into a unified theory of interbasin circulation.

The most up-to-date scenario for these interbasin circulation processes starts with 14 Sv of upper and intermediate level water being converted to NADW in the North Atlantic and flowing southward across the equator to join the ACC. This loss from the Atlantic is compensated by 10 Sv of upper level entering via the Drake Passage and 4 Sv entering from the Indonesian throughflow through the Australasian Mediterranean and around Africa. The Indian Ocean receives 24 Sv of lower level cold water from the ACC, returning 14 Sv as cold water and transforming 10 Sv to upper level water. This latter 10 Sv flows south of Australia, across the South Pacific, and through the Drake Passage into the Benguela Current regime. This joins the afore mentioned Indonesian Throughflow, crosses the equator, and flow with the Gulf Stream into the North Atlantic to replace the lost NADW. The Pacific takes 20 Sv of cold water from the ACC and returns it as less cold water, with about half of it traversing the North Pacific.

This is a simplified two-layer version of a more complicated four-layer circulation scheme developed by Schmitz [1995] which includes intermediate and upper layer compensations flows as well as abyssal and deep interbasin thermohaline circulation layers. The greatest uncertainties remain in the Indian and Pacific Oceans, especially with the flows associated with vertical exchange, which in itself is perhaps the least well established feature of ocean circulation.

interferometer A device, e.g. imaging radar, that uses two different paths for imaging and deduces information from the coherent interference between the two signals. Paths with spatial and temporal differences have been used to measure, respectively, terrain height and ocean currents.

intermediate models A class or group of equations that have been formulated in an attempt to extend the formal validity of the quasi-geostrophic equations while also avoiding the complications of the full primitive equations. The usual approaches attempt to extend the quasigeostrophic or planetary geostrophic equations. This is done by either proceeding to a higher order in an asymptotic expansion (or similar procedure) in the Rossby number (or some other small parameter) or by attempting to extend the validity of the equations at their lowest order. A disadvantage of the former approach is that it does not extend the regime of validity of the new equations beyond that of the lowest order system. The latter approach, usually less mathematically formal, attempts to include terms neglected or inaccurately approximated in the original equations which restrict their range of applicability. These include terms involving large variations in depth, Coriolis parameter, and the advection of relative vorticity. The ultimate goal is to develop a set of equations valid for both planetary and synoptic scales. See Mundt et al. [1997].

internal Froude number See Froude number.

internal tide Internal waves somehow excited at or near tidal periods. It is generally accepted that these are generated by energy scattered from surface to internal tides by bottom roughness. See Hendershott [1981], p. 329.

internal wave A gravity wave propagating in the interior of the ocean with typical spatial and temporal scales of kilometers and hours. The amplitudes are on the order of 10 meters, much larger than their surface counterparts.

Internal waves can be classified according to the density distribution of the fluid in which they propagate:

- interfacial waves, which occur at the interface of a two–fluid system;

- plane waves, which occur when the density of the fluid increases linearly with depth; and
- waves of mixed type, which included internal waves occuring in a fluid whose density varies continuously, but not necessarily linearly.

Peter Rhines reviewed recent progress in understanding internal waves (at the APROPOS conference). His remarks give some of the overall flavor of internal wave research from 1970–2000:

> Internal wave research reached a feverish pitch in the 1970s as an appreciation for the spectrum of observed waves was gained, and weak interaction theory produced useful results about the production of turbulent mixing, and induction of mean currents. The theory of critical-layer absorption and reflection (where the mean flow speed U equals the phase speed, c, of the wave in the direction of mean flow) showed us how such interactions can also be "strong", and localized in space. Generally, the power of geometrical optics (ray theory) was demonstrated in wholly new classes of problems. Attention then drifted toward nonlinear waves that are outside of the random-phase approximation of triad interaction theory: solitary waves and undular bores for example. Inverse-scattering theory allowed one to trace uniquely the distribution of solitons emerging from complex initial conditions. This gives one of many examples where a significant GFD discovery (here traceable back to Scott-Russell riding along canals in Victorian England on horseback) radiated outward into many areas of physics and engineering.

See LaFond [1962], Cox [1962], Baines [1986], Roberts [1975], Briscoe [1975a] and Munk [1981].

International Hydrographic Bureau More later.

International Hydrographic Organization More later.

International Indian Ocean Expedition (IIOE) A research program under which scientists of twenty-two nations collected data in the Indian Ocean from 1959-1965. This was done under a plan coordinated by the Scientific Committee on Oceanographic Research (SCOR) of UNESCO. See Currie [1966].

International Year of the Ocean (IYO) The United Nations declared 1998 to be the International Year of the Ocean with the overall objective being to focus and reinforce the attention of the public, governments and decision makers at large on the importance of the oceans and the marine environment as resources for sustainable development.

`[http://ioc.unesco.org/iyo/]`

Irbe Strait According to Laanearu et al. [2000]:

> The Gulf of Riga is a semi-enclosed basin in the eastern part of the Baltic and is strongly influenced by river-water inflow. The sea water which is diluted in the gulf has two outlets; the Irbe Strait, which is a direct gap into the Baltic proper, and the Suur Strait, which leads to the open sea via a shallow area of straits. The flux of salt water from the Baltic proper is the main source of the almost permanent salt content in the gulf, where the precipitation–evaporation balance is positive. The baroclinic flow through the Irbe Strait provides the largest contribution to the transport of sea water from the open Baltic into the Gulf of Riga. (According to the Knudsen formula, the mean volume flux of salt water into the gulf should be around 3300 m3 s-1.)...
>
> In general, a three-layer density structure was observed; below the seasonal thermocline a two-layer contra-directional flow was found, which in turn was modulated by sub-inertial fluctuations. The average volume flux of bottom-water (with salinities higher than 6.2 psu) was estimated to be around 5200 m3 s-1

See Laanearu et al. [2000].

Irish Marine Institute A national agency of Ireland whose mission is to undertake, coordinate, promote and assist in marine research and development and provide such services related to ma rine research and development that, in the opinion of the institute, will promote economic development and create employment and protect the environment. See the IMI Web site[70].

Iselin, Columbus O'Donnell (1904-1971) See Stommel [1993] (reprinted in first volume of Stommel's collected works).

ISMARE Acronym for Irish Marine Data Center, a part of the Irish Marine Institute that collects, manages, processes, quality controls, and archives data collected by Irish institutions. See the ISMARE Web site[71].

International Ship Operators (ISO) An open international forum of research ship operators from 14 countries and representatives of EC, FAO and OCEANIC who meet annually to discuss research fleet barter/exchange arrangements and research fleet status as well as report on staff exchanges and lost equipment. See the ISO Web site[72].

Intertropical Convergence Zone A narrow low-latitude zone in which air masses originating in the northern and southern hemispheres converge and generally produce cloudy, showery weather. Over the Atlantic and Pacific it is the boundary between the northeast and southeast trade winds. The mean position is somewhat north of the equator, but over the continents the range of motion is considerable. Often abbreviated as ITCZ.

intransitive In dynamical systems theory, a system is said to be intransitive if different sets of initial conditions evolve to more than one alternative resultant state. Compare to transitive and almost intransitive. See Lorenz [1979].

INTIMATE Acronym for INTegration of Ice-core, MArine and TErrestrial data for the North Atlantic region from 25 to 9 ka BP. The goal of this INQUA project is to integrate data sets from ice-core, marine and land records to produce a series of paleoenvironmental maps for the interval between the Last Glacial Maximum and the Early Holocene. The primary objective is to study the ice-sea-land-atmosphere interactions and the feedbacks operating during a glacial-interglacial transition. See Walker et al. [2001].

`[http://www.geog.uu.nl/fg/INTIMATE/]`

intrinsic frequency See buoyancy frequency.

inventory-box model technique A method for analyzing transient tracer data where a time dependent box model is used to simulate the inventory or mean concentration of a tracer in a prescribed reservoir. The model is driven by the time dependent surface water concentration and parameters representing exchange times or volume transports are determined by fitting the model to observations. See Sarmiento [1988].

inverse methods More later.

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[70] http://www.marine.ie/
[71] http://www.marine.ie/datacentre/
[72] http://www.cms.udel.edu/ships/isom/

inverted barometer effect An effect wherein an increase/decrease in atmospheric pressure produces a drop/rise in sea level. An equation relating the two is:

$$\eta(t) \; = \; -\frac{{p_a}'(t)}{\rho_0 g} \tag{13}$$

where g is the local gravity, ρ_0 is the water density, η the change in sea level and p_a the change in atmospheric pressure. See Wunsch and Stammer [1997] and Roden and Rossby [1999].

inverted echo sounder (IES) An instrument used to monitor oceanic fronts since Rossby [1969] first introduced the concept of using variations in acoustic travel time to measure changes in the depth of the main thermocline. They were initially deployed in the MODE project and have been used extensively in many other regions. The use of an IES requires calibration of travel time measurements into other scientific quantities of interest, with calibration requiring knowledge of the variations in temperature and salinity stratification and the resulting density and sound speed profiles in the region where the IES is to be deployed.

From the University of Rhode Island Physical Oceanography Department's web site:

> The inverted echo sounder (IES) is an ocean bottom moored instrument which measures the time for an acoustic pulse to travel from the sea floor to the ocean surface and back. The acoustic travel time is an integral quantity that depends on the density and sound speed profiles of the water column though which it travels. Optional measurements on the IES include hydrostatic pressure and temperature. Typically the IES is moored on the bottom attached to an achor with a 1 meter nylon line, however, a frame can be used to keep it motionless.
>
> IESs have been used to monitor oceanic fronts since the 1970s after Tom Rossby first introduced the concept of using travel time variations to monitor the depth of the main thermocline. Since then IESs have been successfully deployed around the world by several different investigators to study major oceanic fronts.
>
> A http://www.po.gso.uri.edu/dynamics/IES/iesbib.ps of published journal articles and data reports which deal with inverted echo sounder measurements has been compiled.

See Watts and Rossby [1977].

IOC Abbreviation for Intergovernmental Oceanographic Commission, a UNESCO commission that focuses on promoting marine scientific investigations and related ocean services, with a view to learning more about the nature and resources of the oceans. The four themes on which the IOC focuses are:

- to develop, promote and facilitate international oceanographic research programs;
- to ensure effective planning, establishment and co–ordination of an operation global ocean observing system;
- to provide international leadership for education and training programs as well as technical assistance for systematic observations of the global ocean; and
- to ensure that ocean data and information are efficiently handled and made widely available.

The IOC is composed of an Assembly, an Executive Council, a Secretariat, and a number of Subsidiary Bodies. The Assembly meets every two years and consists of one seat for each member state, of which there are currently 125. The Executive Council meets every year and is elected by the Assembly. The Secretariat is the executive arm and is headed by an Executive Secretary elected by the Assembly. It ensures the implementation of activities decided upon by the Assembly.

The presently (1998) constituted Subsidiary Bodies are divided into scientific/technical and regional categories. The former category includes:

- Ocean Science in Relation to Living (and Non-Living) Resources (OSLR and OSNLR),
- Ocean Mapping (OM),
- Marine Pollution Research and Monitoring (MPRM),
- Global Ocean Services System,
- Ocean Observing Systems, and
- Oceanographic Data and Information Exchange.

The latter includes:

- the Sub–commission for the Caribbean and Adjacent Regions (IOCARIBE),
- the Regional Committee for the Southern Ocean (IOCSOC),
- the Regional Committee for the Western Pacific (WESTPAC),
- the Regional Committee for the Co–operative Investigation of the North and Central Western Indian Ocean (IOCINCWIO),
- the Regional Committee for the Central Indian Ocean (IOCINDIO),
- the Regional Committee for the Central Eastern Atlantic (IOCEA),
- the Regional Committee for the Black Sea (IOBS), and
- the Joint IOC–WMO–CPPS Working Group on the Investigations of El Nino.

IOC services available online include:

- IAMSLIC, a directory of aquatic libraries;
- GLODIR, a directory of ocean scientists;
- Ocean Pilot, a guide to Web resources;
- an International Marine Meeting List; and
- an Electronic Library containing many recent publications in PDF format.

See the IOC Web site[73].

IOCARIBE Acronym for IOC Sub–commission for the Caribbean and Adjacent Regions.

IOC-TEMA Abbreviation for IOC Committee for Training, Education, and Mutual Assistance in the Marine Sciences, formerly known as TEMA.

IOC-VCP Abbreviation for IOC Voluntary Cooperation Program.

IODC Abbreviation for the ICES Oceanographic Data Center, a bank of oceanographic data supplied by ICES member countries that dates back to the early 1900s. See the IODC Web site[74].

IODE Acronym for International Oceanographic Data and Information Exchange, an IOC project established in 1961 to "enhance marine research, exploration and development by facilitating the exchange of oceanographic data and information between participating member states." The IODE system is composed of a committee which governs the development and operations of the system and a number of data centers that carry out the activities established by the committee. The data center structure is composed of three components: NODCs, RNODCs, and WDCs.

[http://ioc.unesco.org/iode/]

[73] http://www.unesco.org/ioc/
[74] http://www.ices.dk/ocean/ocean.htm

IOF Abbreviation for the International Oceanography Foundation, whose mission is to encourage scientific investigation of the sea amongst other things. See the IOF Web site[75].

ION Acronym for International Ocean Network, a committee established in June 1993 with the goal of facilitating international cooperation in the development of ocean botton observatories. While originally created for the purposes of seismology, in 1995 it was enlarged to include all geosciences.

[http://www.seismo.berkeley.edu/seismo/ion/]

Ionian Sea One of the seas that comprise the eastern basin of the Mediterranean Sea. It is surrounded by Italy, Hellas, Libya and Tunisia, and has a volume of 10.8×10^4 km^3. It connects to the Cretan Sea via the Kithira (160 m deep, 33 km wide) and Antikithira (700 m deep, 32 km wide) Straits, the Levantine Sea via the Cretan Passage, the western Mediterranean via the Strait of Sicility, and the Adriatic Sea via Otranto Strait (780 m deep, 75 km wide).

The major water masses of the Ionian Sea are Modified Atlantic Water (MAW), Levantine Intermediate Water (LIW), and Eastern Mediterranean Deep Water (EMDW). The MAW spreads eastward from the Sicily Straits in the surface layer and is identified as a subsurface salinity minimum between 30 and 200 m depth. It overlies the LIW that enters through the Cretan passage and is identified by a salinity maximum between 200 and 600 m depth. Below this, the colder and less saline EMDW, the main source of which is Adriatic Deep Water (ADW), occupies the layers below 1600 m. A transitional mixture of LIW and EMDW occupies the range between 700 and 1600 m. In the summer Ionian Surface Water can be differentiated from the MAW as saltier and warmer.

Prominent circulation features in the upper thermocline and intermediate layer include the Atlantic–Ionian Stream (IAS), the Ionian Anticyclones (IA), the Pelops Anticyclone (PA), the Mid–Mediterranean Jet (MMJ), and the Cretan Cyclone (CC). The AIS enters the Ionian Sea from the northwest via the Sicily Straits, meanders west and then south, and then turns northeast to flow between Sicily and the IA. At around 17° E and 37° N it bifurcates, with a southward flowing branch combining with the IAS to the west to form the IA region. The northeastward flowing branch continues to the heel of Italy where it turns to the south and flows past the PA, continuing past there until it passes to the south of the CC and turns west through the Cretan passage, becoming the MMJ. See Fairbridge [1966] and Malanotte-Rizzoli et al. [1997].

Ionian Surface Water (ISW) A water mass formed at the surface in the Ionian Sea. See Malanotte-Rizzoli et al. [1997].

IO-PAS Abbreviation for Institute of Oceanology of the Polish Academy of Sciences, founded in 1983 as the successor to the Marine Station of the Academy in existence in Sopot since 1953. The institute is divided into departments for marine physics, hydrodynamics, marine chemistry and biochemistry, and marine ecology. See the IO-PAS Web site[76].

IOS Abbreviation for Institute of Ocean Sciences, a research facility of the Canadian Department of Fisheries and Oceans (DFO). The IOS is located in Sidney, British Columbia and is one of a network of nine major scientific facilities across Canada run by the Science Sector of the DFO. See the IOS Web site[77].

IOSDL Abbreviation for the Institute of Oceanographic Sciences, Deacon Laboratory, an institute whose mission is to advance understanding of the ocean environment and processes of environmental change in the oceans and to predict future change by carrying out multidisciplinary studies on the oceans and their boundaries with the air and seabed. More information can be found at the IOSDL Web site[78].

[75] http://www.rsmas.miami.edu/iof.html
[76] http://www.iopan.gda.pl/
[77] http://www.ios.bc.ca/
[78] http://wofiles.nwo.ac.uk/

IOUSP Abbreviation for Instituto Oceanografico da Universidade de Sao Paulo.

IPAB Abbreviation for International Program for Antarctic Buoys.

IPAR Acronym for Intercepted Photosynthetically Active Radiation.

IPAST Acronym for IGOSS Pilot Project on Altimetric Sea Surface Topography Data.

IPDW Abbreviation for Indo-Pacific Deep Water.

IPSLN Abbreviation for Indo–Pacific Sea Level Network.

IPTS–48 See ITS–90.

IPTS–68 See ITS–90.

Iribarren number A surf similarity parameter developed by Battjes in 1974. It is expressed as:

$$I_N = \frac{\tan\beta}{\sqrt{H_\beta/L_0}}$$

where H_β is the breaker height measured at the toe of the slope, β is the beach slope angle, and L_0 the deep water wavelength, i.e.

$$L_0 = gT^2/2\pi$$

where T is the wave period. The Iribarren number is used to generally predict when various beach states are likely to occur. The states are spilling ($I_N < 0.4$), plunging ($0.4 < I_N < 2.3$), collapsing ($2.3 < I_N < 3.2$) and surging ($3.2 < I_N$).

Irish Sea A marginal sea located between Ireland and Wales. It extends from the Mull of Galloway in the north to a line connecting St. David's Head (in Wales) to Carnsore Point (in Ireland) in the south. Horsburgh et al. [2000] provide a general review of the dominant circulation processes:

> Knowledge of non-tidal currents in the Irish Sea has improved gradually since Bowden (1950) inferred a weak ($\sim$1 cm s^{-1}), northward residual flow on the basis of salinity distribution. This view of the long-term, basin-wide circulation was supported by subsequent tracer observations and modelling studies. The dynamics of the Irish Sea are dominated by the semi-diurnal tide. Tidal currents in most of the Irish Sea are of the order 1 m s^{-1} and tidal ellipses are predominantly rectilinear, but to the west of the Isle of Man, in a region that coincides with a deep (>100 m) water channel, tidal currents are less than 30 cm s^{-1}. Unlike the rest of the Irish Sea, which is well-mixed by the strong tides, the western Irish Sea stratifies in spring and summer each year because the combination of weak tides and deep water produces insufficient tidally-generated vertical mixing to overcome the input of surface buoyancy generated by solar heating.
>
> Beneath the seasonal thermocline is a dome-shaped mass of cold water that becomes trapped after the onset of stratification. The suppression of vertical mixing by the stratification means that this water warms very slowly and is therefore a persistent feature over the heating season. Limited exchange of the cold pool with surrounding warm water is also implied by dissolved oxygen minima. A large database of hydrographic results confirms that the cold dome is an annual feature. The transition from vertically mixed to stratified water occurs rapidly (over $\sim$10 km) at tidal mixing fronts, which are located at critical contours of h/u^3. Within the transition zone are strong, horizontal density gradients that intersect the bed and drive a geostrophic cyclonic circulation (i.e. the flow is parallel to isopycnals with the denser bottom water to the left).

See Bowden [1955], Fairbridge [1966] Howarth [1984] and Horsburgh et al. [2000].

Irminger Current A branch of the North Atlantic Current that curves north near Iceland, where a minor part of it splits to flow north along the west coast of Iceland and the major part curves to the west and joins the southward flowing East Greenland Current. Both branches ultimately rejoin the North Atlantic Current. The transport of this current has been estimated ar about 8-11 Sv. See Fairbridge [1966] and Tomczak and Godfrey [1994].

Irminger Sea A body of water in the North Atlantic recognized as such for oceanographic if not official purposes. It lies roughly between the east coast of Greenland and the west coast of Iceland, with the Labrador Sea on its southwest corner and the Greenland Sea to the northeast. The southern boundary is marked by hydrographical rather than geographical features. The basin of this sea is mostly occupied by the eastern part of the Labrador Basin which ranges up to 4600 m in depth. The chief circulation feature is the Irminger Current. See Stefánsson [1968].

IronEx I An experiment taking place in October 1993 that marked the first attempt to experimentally manipulate an ocean ecosystem. A single pulse of iron was added to a 64 square kilometer patch of water in the eastern equatorial Pacific HNLC zone. The fertilized patch was tracked using a Chl fluorescence and a sulfur-hexafluoride (SF6) inert tracer. After 2 to 3 days researchers measured a doubling of phytoplankton biomass, a tripling of Chl, and a fourfold increase in net primary productivity (NPP), with no measureable drawdown of either NO3 or CO2. See Martin et al. [1994] and Coale et al. [1998].

IronEx II The follow–up to IronEx I in which a 64 square kilometer area of the ocean in the eastern equatorial Pacific was fertilized three times over a week with a total of 225 kg of FeSO4. The repeated pulsing was used to prevent the rapid sedimentation that occurred in IronEx I. The patch was again tracked with Chl fluorescence and SF6, and a drogued drifter was deployed in the center of the patch to make it easier to follow. The patch persisted for 19 days, drifting 10 to 100 km per day. The observed consequences included:

- a doubling in phytoplankton growth rates;
- an increase in CHl by a factor of 25;
- a decrease in NO3 by 50%;
- a 15X increase in NO3 uptake;
- a decrease in ocean to atmosphere CO2 flux by 60%;
- growth due mostly to large diatoms, which accounted for <15% of total phytoplankton before and 85–98% afterwards; and
- a doubling of micro– and mesozooplankton biomass.

See Coale et al. [1996] and Frost [1996].

IronEx III This has apparently been renamed SOFeX.

iron hypothesis The hypothesis that iron plays a major regulatory role in phytoplankton productivity. While the potential role of iron as a limiting factor in phytoplankton productivity was appreciated by researchers as early as the 1930s, it wasn't until John Martin convincingly pieced together several lines of evidence in the late 1980s that the oceanographic community gave notice to the point of planning major experiments to test it. The threads of Martin's argument included that:

- the primary source of iron to the surface waters of the oceans is from the land;

- the dissolved iron concentrations in offshore areas are extremely low, i.e. two orders of magnitude less than thought by the investigators in the 1930s;
- atmospheric dust deposition in the two major high nutrient, low chlorophyll (HNLC) areas of the oceans – the Antarctic and equatorial Pacific Oceans – are the lowest in the world; and
- laboratory experiments in which bottles filled with surface waters from NHLC regions and incubated at simulated *in situ* light and temperature for about a week showed that iron–enriched bottles always ended up with higher total chlorophyll that the control bottles without iron.

See Chisolm [1995].

[http://earth.agu.org/revgeophys/chisho00/chisho00.html]

irradiance The radiant energy that passes through a unit horizontal area per unit time coming from all directions above it. The irradiance F_i is defined by

$$F_i = \int_0^{2\pi} I \cos\theta \, d\omega$$

where I is the radiance, θ the zenith angle, and $d\omega$ the infinitesimal solid angle. The rate at which radiation is incident upon a unit area.

irrotational In geophysical fluid dynamics this refers to fluid motion in which there is no vorticity.

ISABP Abbreviation for International South Atlantic Buoy Program, a DBCP program.

isallobar A contour line on a weather map that signifies the location of equal changes of pressure over a specified period.

isallobaric wind A theoretical wind component originating from the spatial non-uniformity of local rates of change of pressure.

isentropic coordinates The replacement of the z coordinate in an x-y-z coordinate system with the potential temperature. This can be done when horizontal scales are large compared to vertical scales, i.e. when the hydrostatic approximation can be made. See Gill [1982], p. 180.

ISHTAR Acronym for Inner Shelf Transfer And Recycling, a program for investigating ocean processes in and near the Bering Strait.

ISHTE Abbreviation for In–Situ Heat Transfer Experiment, a project of the APL of the University of Washington School of Oceanography.

ISLP-PAC Abbreviation for IGOSS Sea Level Program in the Pacific, a program established for the purpose of making monthly mean sea level data available to a wide circle of users in a timely fashion and to generate products that would be valuable for scientific analysis of climate–related processes. See the ISLP-PAC Web site[79].

ISO Acronym for International Ship Operators.

isobar In physical oceanography, a contour of constant pressure.

isobaric Descriptive of a surface that is an isobar.

[79] http://www.soest.hawaii.edu:80/kilonsky/islp.html

isobaric coordinates The replacement of the z coordinate in an x-y-z coordinate system with the pressure. This can be done when horizontal scales are large compared to vertical scales, i.e. when the hydrostatic approximation can be made. This set of coordinates is widely used in meteorology. See Gill [1982], p. 180.

isobaric surface A surface on which the pressure is everywhere the same.

isogram See isopleth.

isohaline In physical oceanography, a contour of constant salinity.

isopleth A general term referring to lines drawn on a map or chart to display the distribution of any element, each line being drawn through places at which the element has the same value. See, for example, isohaline, isobar, etc. Isogram is sometimes used as a synonym.

isopycnal In physical oceanography, a contour of constant density.

isopycnal form stress A horizontal pressure force averaged in longitude and time over a material surface of constant potential density. This is associated with a combinatino of transient (mesoscale) and standing (time-mean, longitudinally varying) eddies. See McWilliams [1996].

isopycnal method A scheme to systematize the classification of the hydrography of the oceans developed by Montgomery in the late 1930s. He developed this to overcome limitations he saw in the earlier core layer method of Wust. In this method variable properties (e.g. salinity, temperature, etc.) are examined on surfaces of constant potential density along which it is assumed that maximum mixing and flow occur. The variations in depth of such surfaces can also be used as a diagnostic tool for locating geostrophic currents since rapid changes in depth are indicative of their presence.

The isopycnal method was originally applied such that all densities were calculated relative to the ocean surface, i.e. as either sigma-t or sigma-θ. This was later modified when it was found that, due to the nonlinearity of the equation of state for seawater, maximum values could exist well above the ocean bottom – ostensibly signifying a hydrostatic instability. The problem was rectified by the use of potential densities calculated relative to different pressures as was required by the situation, i.e. sigma-1 for densities relative to 1000 decibars (db), sigma-2 for 2000 db, etc., a procedure that is still followed today.

ISOS Acronym for International Southern Ocean Studies, a program to study the Southern Ocean, especially the fronts and energetics in the regions of Drake Passage and southeast of New Zealand. The monitoring of the transport of the Antarctic Circumpolar Current also had high priority.

isostasy The tendency of the crust of the earth (i.e. the lithosphere) to maintain a near equilibrium state in relation to the denser, underlying asthenosphere or upper mantle. For example, a continental block might sink or rise due to the presence or absence of an ice sheet in a process called glacial isostatic adjustment.

isostere In meteorology, a line on a chart joining points of equal specific volume, the volume of unit mass.

isotach In meteorology, a line or contour of constant wind speed. An alternative is isovel.

isotherm In physical oceanography, a contour of constant temperature.

isotope Each of two or more varieties of a particular chemical element which have different numbers of neutrons in the nucleus, and therefore different relative atomic masses and different nuclear (but the same chemical) properties.

isotope dilution analysis A technique for determining the unknown quantity of an element of known isotopic composition. A spike, i.e. a known quantity of the same element with a known different isotopic composition, is mixed with the sample and the composition assessed via the resulting isotopic composition of the mixture.

isotope fractionation See Fairbridge [1966].

isotope reference standards Neither absolute abundances of minor isotopes nor absolute values of isotope ratios can be determined accurately enough for geochemical purposes. As such, differences in such absolute isotopic ratios between two substances are substituted. These comparisons are made between the laboratory samples and various internationally accepted standards known as isotope reference standards. Examples of these are SMOW (standard mean ocean water) and V-SMOW (a SMOW artificially prepared in Vienna) for oxygen and PDB (a Cretaceous belemnite) and V-PDB (the same prepared in Vienna) for oxygen in carbonates. See Bowen [1991] for a thorough discussion.

isotope stage A division of a deep-sea core on the basis of oxygen isotope ratios. There have been 19 isotope stages since the reversal of the Earth's magnetic field 700,000 years ago.

isovel See isotach.

ISOW Acronym for Iceland–Scotland Overflow Water.

Istrian Coastal Countercurrent (ICCC) See Supic et al. [2000].

ISW Abbrevation for Ionian Surface Water.

ITCE Abbreviation for the International Turbulence Comparison Experiment, performed in Australia in 1976. See Kraus and Businger [1994].

ITCZ See Intertropical Convergence Zone.

ITIC Abbreviation for International Tsunami Information Center, established in Nov. 1965 by the IOC. The ITIC monitors the activities of the Tsunami Warning System in the Pacific, making use of 31 seismic stations, 79 tidal stations, and 101 dissemination points scattered across the Pacific. It also has a public education program directed towards coastal residents and other interested parties. See the ITIC Web site[80].

ITPO Abbreviation for International TOGA Project Office.

ITRIS Abbreviation for Integrated Tsunami Research and Information System.

ITS–90 Abbreviation for International Temperature Scale of 1990, a temperature scale approved by the International Committee for Weights and Measures at its annual meeting in September 1989. It replaces the International Practical Temperature Scale of 1968 (IPTS–68) and took effect on Jan. 1, 1990. ITS–90 takes advantage of technological advances and more closely approximates the thermodynamic temperature scale than previous scales.

The features of oceanographic interest were outlined by Saunders [1990]:

> Of particular interest to oceanographers are the properties of ITS–90 in the range -2°C to +35°. The single most important property is that the triple point of water remains unchanged at 273.16 K or 0.010°C; however at standard atmospheric pressure the boiling oint of water falls to 99.974°C. Consequently in the interval 0–100°C temperatures measured

[80] http://www.unesco.org/ioc/oceserv/itic.htm

on the ITS–90 scale are lower than values measured on the IPTS–68 scale. But below 0° they are higher. The differences are expressed in the following table.

Over this range (although slightly nonlinear) the relation between the temperature scales can be adequately represented by the expression

$$t_{90} = 0.99976 t_{68}$$

Initially it is expected that oceanographers will employ the above expression to correct temperatures measured on the IPTS–68 scale but new calibration procedures will be introduced in National Standards Laboratories commencing 1990 and it is hoped these practices will rapidly spread to oceanographic calibration facilities. The value for the fixed points on the ITS–90 scale and the instruments and interpolation equations to be employed for the measurement of temperature are described in a text to be published in the Journal *Metrologia*, early in 1990.

Although the impact of the new temperature scale on ocean temperature measurements and their climatology is likely to be small (or even negligible), unfortunately this is not true for its knock–on effects. Corrections will be required for the computation of salinity and other state properties of sea water.

The conversion between IPTS–48 and IPTS–68 is given by Fofonoff and Bryden [1975] as:

$$t_{68} = t_{48} - 4.4 \times 10^{-6} \cdot t_{48}(100 - t_{48})$$

IWEX Acronym for Internal Wave Experiment. See Briscoe [1975b] and Müller et al. [1978].

IWP Abbreviation for Intergovernmental WOCE Panel, a subsidiary body of the IOC and the WMO established to meet the scientific, managerial, implementation, and resource needs of WOCE. See the IWP Web site[81].

IWSOE Abbreviation for International Weddell Sea Oceanographic Expedition.

IYFS Abbreviation for ICES International Young Fish Survey, a project that has been undertaken in every year in January/February in the North Sea since about 1970. This survey includes station observations of hydrochemical measurements which has resulted in a comprehensive North Sea data set of over 20 years duration. Maps of the temperature and salinity distributions measured during these surveys can be obtained at the IYFS Web site[82].

IYO Abbreviation for International Year of the Ocean.

Izmir Bay A bay situated at the western coast of the Anatolian peninsula, and connected to the Aegean Sea. Izmir Bay is roughly L-shaped, with the leg about 20 km wide and 40 kkm long, and the base about 5-7 km wide and 24 km long. It has been divided into Outer, Middle and Inner Bays, with the Outer Bay further divided into Outer I, II and III sections. There are a series of islands parallel to the west coast of the Bay (Outer II). The narrow Mordogan Strait, which is situated between Uzunada Island and the west coast of the Bay, has a sill depth of 14 m. From time to time Aegean Sea surface water can flow in the surface layer through the narrow Mordogan Strait into the small Gulbahce Bay, situated at the southwest end of the Izmir Bay. Another important constriction is Yenikale strait between the Inner Bay and the Middle Bay. The physical and chemical characteristics of water change

[81] http://www.soc.soton.ac.uk/OTHERS/woceipo/iwp.html
[82] http://www.ices.dk/ocean/project/iyfs.htm

drastically both sides of the Yenikale sill. The depth in the Outer Bay is about 70 m, decreasing significantly towards the Inner Bay to about 10 m depth.

The hydrographic characteristics of Izmir Bay are determined by the anthropogenic load of fresh water into the Inner Bay, atmosphere-ocean interactions, water exchange with the Aegean Sea, the variable topography in the Bay, sea level changes due to large-scale motions in the Aegean Sea, the accumulation of waters as a result of the prevailing wind-driven circulation, and winter convection.

The horizontal and vertical distributions of temperature and salinity are influenced by the Gediz river discharge, Aegean Sea water, and by strong evaporation occurring in summer time. As a result both temperature and salinity vary significantly spatially as well as seasonally. Turbulent mixing causes the vertically homogeneous water column properties in certain areas of the Bay even in the summer time.

On average, the outflow occurs in the lower layers at the coast of Foca. This outflowing water shows T-S characteristics similar to those measured near the coast of Urla. At the southern coast water sinks to the bottom due to conservation of mass and flows as a bottom current towards the Aegean Sea.

Izmir Bay seawater has five different water masses: (1) Anthropogenically polluted Inner Bay water, (2) Outer Bay water under the influence of Gediz River and Agean Sea (here after ASW or Outer III), (3) upwelling water in Glbahe Bay (Outer II), (4) Outer I water located in a salt production shallow area and (5) Middle Bay water, a transient water mass between Outer I and Inner Bay. Generally the Aegean Sea surface water enters the Bay between Karaburun and Foca. Relatively 'pure' ASW is found in Outer III. This region has the largest volume because it is relatively deep basin. The highly anthropogenic influenced Inner Bay water is vertically and horizontally stratified during all seasons and has the smallest volume. The Outer Bay water has very variable characteristics in space and time under the influences of the meteorological forces and the Gediz River discharge water. A completely different types of water mass was observed in the upper 20-30 m of the water column near the Karaburun coast by insitu measurements. This water mass is thought to originate in the Black Sea, and is assumed to enter the Bay as part of the large-scale cyclonic circulation of the Aegean Sea.

In summer two-layer stratification occurs in the water column, with the previous winter water found in the bottom layer during summer and early fall months. This two layer system is destroyed in late fall and winter as a result of convective and turbulent mixing. The circulation in the Izmir Bay is not only wind-driven, it is also density-driven especially in summer time and the circulation due to sea level elevation is not negligible. After Sayin [2003].

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jackknife method A statistical procedure in which, in its simplest form, estimates are formed of a parameter based on a set of N observations by deleting each observation in turn to obtain, in addition to the usual estimate base d on N observations, N estimates each based on N-1 observations. Combinations of these give estimates of both bias and variance valid under a wide range of parent distributions. This method has deposed distribution-based methods in many applications due to its simplicity, its applicability in complicated situations, and its lack of distributional assumptions, resulting in greater reliability in practice. An elementary review can be found in Efron and Gong [1983] and the extension of such methods to time series analysis (with several geophysical examples) is reviewed in Thomson and Chave [1991].

Jacobsen's method A method suggested by Jacobsen [1927] to compute eddy coefficients using T-S diagrams. See Neumann and Pierson [1966].

JADE See Fieux et al. [1994] and Molcard et al. [1994].

JAMRI Acronym for Japan Maritime Research Institute.

JAMSTEC Acronym for Japan Marine Science and Technology Center.

Jan Mayen Current (JMC) An eastward flow emanating from the East Greenland Current (EGC) in the Greenland Sea. Its axis is north of Jan Mayen and centered on 72–74° N. Its position in the winter is often associated with an ice odden, a persistent eastward extension of the East Greenland Ice Stream. The upper layer baroclinic flow shows that about half of the JMC is a wide meander in the EGC and about half continues eastward to close the Greenland Gyre system on the south. Beneath the halocline the meander dissipates and the flow becomes more barotropic, with the barotropic flow steered to the east by the Jan Mayen Fracture Zone. This has also been called the Jan Mayen Polar Current. See van Aken et al. [1995] and Bourke et al. [1992].

JAPACS Acronym for Japanese Pacific Climate Study.

Japan Sea A marginal sea of the western Pacific Ocean bounded on the east by the Japanese islands, the west and southwest by Korea, and the north and northwest by the former Soviet Union. It is connected to the East China Sea in the south, the Okhotsk Sea in the north, and the Pacific Ocean in the east via narrow passages whose sill depths don't exceed 100 m. It comprises the Japan Basin (with depths exceeding 3500 m) north of about 40° N, and the Yamato Basin (with depths around 2500 m) south of 40° N, the the basins separated by the Yamato Ridge. The dimensions are are about 1600 by 900 km, an area of 978,000 km^2, the average depth 1750 m, and a maximum depth of about 3700 m.

The Japan Sea is a meeting place for warm currents from the south and cold currents from the north, with the confluence being the Polar Front. Prominent circulation features in the Japan Sea include the Tshushima Current, the Tsugaru Current, the Liman Current, the North Korea Current and the Mid-Japan Sea or Maritime Province Current. Water masses found there include Japan Sea Middle Water (or Intermediate Water) and Japan Sea Proper Water.

The Tsushima Warm Current (TWC) transports warm, salty water into the sea through the Tsushima Strait. It either splits into three branches, takes a single meandering path, or takes both patterns alternately. In the contemporary literature, these branches are called (from east to west), the Nearshore Branch, the Offshore Branch and the East Korean Warm Current (EKWC). The Nearshore Branch flows eastward along the coast of Honshu and exits into the Pacific via the Tsugaru Strait. The more variable Offshore Branch flows along the continental shelf. The EKWC flows northward along the continental slope off the east coast of Korea up to about 37–38°N, where it meets the southward flowing North Korea

Cold Current (NKCC). At their confluence, the currents separate from the coast and flow east–northeast toward the Tsugaru Strait along the Polar Front. Most of the flow exists via the Strait, while the rest continues north as an eastern boundary current along the coast of Hokkaido called the Soya Warm Current (SWC). Some of the SWC flows into the Okhotsk Sea, while the rest flows southward along the Siberian coast as the Liman Cold Current (LCC) (or Primoriye Current) and (south of Vladivostok) as the NKCC. This forms a cyclonic gyre in the northern part of the basin. See Tomczak and Godfrey [1994], Zenkevitch [1963], Preller and Hogan [1998] and Chu et al. [2001].

Japan Sea Bottom Water (JSBW) See Japan Sea Proper Water.

Japan Sea Deep Water (JSDW) See Japan Sea Proper Water.

Japan Sea Middle Water (JSMW) A water mass found in the Japan Sea. It is found in the depth range 25-200 m and characterized by a rapid drop in temperature from 17 to 2° C as well as an oxygen maximum of 8 ml/l near 200 m depth. The warmer layers are advected in by the Kuroshio and the colder layers formed by sinking at the Polar Front and on the shelf to the north.

Japan Sea Proper Water (JSPW) A water mass in the Japan Sea that comprises all the water below 200 m (and thus the overlying Japan Sea Middle Water). It is characterized by uniform temperature (1-2° C) and salinity (34.1) which result from its isolation from other basins by shallow sills. It is formed via winter convection facilitated by the salt imported by the Tsushima Current, with the instabilities in the Polar Front serving to transport this salt into the northern formation regions. Some authors differentiate Japan Sea Deep Water (JSDW) (200 - 2000 m) and Japan Sea Bottom Water (JSBW) (2000 m - bottom), and occasionally the entire water mass is referred to as Japan Sea Deep Water. See Tomczak and Godfrey [1994] and Kawamura and Wu [1998].

Japan Stream See Kuroshio Current.

JASADCP Abbreviation for Joint Archive for Shipboard ADCP, a collaboration between the E. Firing ADCP Laboratoary at the University of Hawaii and the NODC. This center, formerly known as the Shipboard ADCP Center (SAC), is responsible for the acquisition, review, documentation, archiving, and distribution of shipboard ADCP data sets. It primarily handles U.S. national cruises, but also supports such multi–national programs as TOGA COARE, WEPOCS, and US–PRC cruises. The JASADCP is also a Data Assembly Center for WOCE in collaboration with the JODC.

`[http://ilikai.soest.hawaii.edu/sadcp/]`

JASIN Acronym for the Joint Air-Sea Interaction experiment, conducted in 1978 primarily north and west of Scotland. The emphasis was on marine boundary layer dynamics. See Nicholls et al. [1983] and Geernaert [1990].

JASMINE Acronym for the Joint Air–Sea Monsoon INteraction Experiment, a cruise taking place in the east Indian Ocean and the Bay of Bengal between April 7 and June 8, 1999. The goal of JASMINE was to observe the atmosphere and ocean environment during a monsoon onset event, including both an active and break period, to understand the conditions responsible for the variability of the monsoon season on short time and space scales.

`[http://paos.colorado.edu/~jasmine/]`
`[http://www.atmos.washington.edu/~serra/JASMINE/jasmine.html]`

JavaSea A shallow body of water located in the southwestern part of the Australasian Mediterranean Sea. Centered at about 114° E and 5° S, it has average depths of around 40-50 m, and an area ranging from 367,000 to 433,000 km^2 depending on where the boundaries are specified. It is connected to the

Sulawesi Sea to the northeast by the Makassar Strait, adjoins the Flores Sea to the east, connects to the South China Sea to the northwest via the Karimata Strait, and abuts the Bali Sea to the south and Kalimantan to the north. It is sometimes grouped together with the shelf sector of the South China Sea as the SundaSea, and also variously spelled as Jawa Sea.

The Java Sea was formed when two large river systems, now forming shallow channels in the shallow sea floor, were drowned out at the end of the last ice age. The circulation and hydrography are determined by the annual cycle of monsoon winds, with currents flowing westward from June to August and eastward during the rest of the year. During this latter period a tongue of high salinity water from the South China Sea pushes salinity values of 32 as far east as 112° E. See Tomczak and Godfrey [1994].

Jawa Sea See Java Sea.

JEBAR In oceanography, an acronym for the Joint Effects of Baroclinicity And Relief, a term that arises from the derivation of the vertically integrated vorticity equation. See Huthnance [1984], Mertz and Wright [1992], Slordal and Weber [1996] and Cane et al. [1998].

JECSS Acronym for Japan and East China Seas Study.

Jeffreys' theorem A theorem that concerns the conditions under which hydrostatic equilibrium obtains. It states that hydrostatic equilibrium is impossible if density variaitons occur on level surfaces. See Hide [1978].

JENEX Acronym for Japanese El Niño Experiment.

Jerlov water types A scheme for classifying the optical properties of various waters based on their irradiance transmissivity in the upper 10 m. The scheme divides them into oceanic (Types I to III) and coastal (Types 1 to 9) categories. See Jerlov [1976].

jet stream A well-defined core of strong wind, ranging from 200-300 miles (320-480 km) wide with wind speeds up to 200 mph (320 kph), that occurs in the vicinity of the tropopause. See Reiter [1963].

JGOFS Acronym for Joint Global Ocean Flux Study, a subprogram of the IGBP whose goal is to improve our knowledge of the processes controlling carbon fluxes between the atmosphere, surface ocean, ocean interior and its continental margins, and the sensitivity of these fluxes to climate changes. JGOFS originated in Feb. 1987 when SCOR sponsored a meeting of experts in Paris where the goals, scientific elements, topics of emphasis, and organizational structure of JGOFS was established. An international planning Committee for JGOFS was established in Oct. 1987, which met for the first time in Jan. 1988.

The first JGOFS regional process study was the 1989 North Atlantic Pilot Study, which involved Germany, UK, Netherlands, USA and Canada. Soon after this, links were established with WOCE and TOGA. In 1989, an agreement between SCOR and ICSU established JGOFS as a core project of IGBP, although it would be responsible directly to SCOR.

[http://ads.smr.uib.no/jgofs/jgofs.htm]

JIC Abbreviation for Joint Ice Center, a U.S. Navy/NOAA facility that produces sea ice analyses and forecasts on global, regional, and local scales. There are global analyses for both the northern and southern hemispheres with consist of a determination of the ice edge, the concentration of the ice, leads in the ice, and an estimation of the age of the ice. Regional ice analyses are produced twice per week for the Bering, Chuckchi and Beaufort Seas. Local scale analyses are available for ships operating in the Antarctic during the Austral summer. The JIC also produces 7- and 30-day ice forecasts as well as long-range outlooks. The 7-day forecasts are produced weekly for the eastern and western Arctic and give the expected position of the ice edge, while the 30-day forecasts are produced twice a month for the predicted ice edge position and ice concentrations in the eastern and western arctic. The long-range outlooks forecast the expected severity of ice conditions and are verified about 90 days after issuance. See Smith et al. [1995].

JIMAR Acronym for Joint Institute for Marine and Atmospheric Research.

JISAO Acronym for Joint Institute for the Study of the Atmosphere and Ocean.

JODC Abbreviation for Japan Ocean Data Center, established in the Hydrographic Department of the Maritime Safety Agency in 1965 to fulfill the role of the marine data bank of Japan, acquiring marine data sets obtained by various research institutes and providing users with the data. See the JODC Web site[83].

JOI Acronym for Joint Oceanographic Institutions, a consortium of U.S. academic institutions for organizing the collective capabilities of the individual oceanographic institutions on research planning and management of the ocean sciences. JOI was established as a private, non–profit organization in 1976.

`[http://www.joi-odp.org/]`

JOIDES Acronym for Joint Oceanographic Institutions for Deep Earth Sampling, a program to obtain cores of deep ocean sediments.

`[http://joides.rsmas.miami.edu/]`

Joint Institute for Marine and Atmospheric Research (JIMAR) A Joint Institute formed in 1977 between the University of Hawaii and the NOAA ERL. The purpose of JIMAR is to increase the effectiveness of oceanic, atmospheric, and geophysical research of mutual interest to NOAA and the University, with the principal research interests being equatorial oceanography, tsunamis, fisheries oceanography, and climate and global change. See the JIMAR Web site[84].

Joint Institute for the Study of the Atmosphere and the Ocean (JISAO) A Joint Institute formed in 1980 between the University of Washington and the NOAA ERL. This was established in 1980 and has five core research areas: (1) climate variability; (2) global environmental chemistry; (3) estuaries; (4) recruitment of fish stock; and (5) policy, impact and response strategies with respect to climate variability. See the JISAO Web site[85].

Joint Skagerrak Expedition An ICES sponsored 1966 program to further knowledge of the hydrography of the Skagerrak as a transition zone between the Baltic Sea and the North Sea. The expedition took place from June 20 to July 15, 1966 and involved Germany, Finland, Norway, the UK and Sweden. The particulars included:

- measurements of temperature, salinity, oxygen and phosphate – and in some cases pH and silicate – made at 21 sections covering 233 stations, most of which were repeated;
- current measurements made at 7 anchor sations, 8 drifting stations, and by 17 self–recording current meters laid out over periods of up to 20 days;
- about 100 vertical soundings of temperature and chlorinity (via bathysonde), temperature and salinity (via membrane salinometer), temperature (via bathythermograph) and transparency;
- continuous recordings of the surface layer temperature between 0 and 70 m via Delphin towing gear covering 36 profiles of nearly 1200 nm total length; and

[83] http://www.jodc.jhd.go.jp/jodc.html
[84] http://www.soest.hawaii.edu/JIMAR/jimar.html
[85] http://tao.atmos.washington.edu/

- use of the vessels *Skagerak*, *G. O. Sars* and *Meteor*.

The data from the expedition were published in 1969 as "Joint Skagerrak Expedition 1966" Vols. 1–4 in the "ICES Oceanographic Data Lists" series, with the expedition atlas following as Vol. 5 in 1970.

[http://www.ices.dk/ocean/project/data/jskag66.htm]

JONSDAP Acronym for Joint North Sea Data Acquisition Project, a cooperative data collection program begun in 1970 by the countries bordering the North Sea. The first phase of JONSDAP involved the systematic collection of data from moored stations and coastal observation sites in the North Sea from 1971 to 1973. The second phase, JONSDAP 73, was a program of tide and current measurement in the Southern Bight of the North Sea from September to October 1973. The third phase, JONSDAP 76, consisted of two intensive measurement programs:

- **FLEX**, the Fladen Ground Experiment to study the development of the thermocline and the dynamics of the plankton bloom; and
- **INOUT**, a program concerning the general circulation of the North Sea and the storm surge problem.

JONSIS Acronym for Joint North Sea Information System.

JONSWAP Acronym for JOint North Sea WAve Project. See Hasselmann et al. [1973].

JONSWAP spectrum A wave spectrum developed for fetch–limited wind waves. This is basically the Pierson–Moskowitz spectrum multipled by an extra peak enhancement factor and fetch–dependent scale parameters. See Hasselmann et al. [1973].

JPOTS Abbreviation for Joint Panel on Oceanographic Tables and Standards, a panel sponsored by UNESCO, ICES, IAPSO, and SCOR which first met in 1962 (in an earlier form not yet called JPOTS) to study and decide upon standards to measure the properties of sea water.

Jutland Current See North Sea and Skagerrak.

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Kamchatka Current One of two currents (the other being the Alaskan Stream) in the northwest Pacific that combine to form the Oyashio Current. The Kamchatka brings water southward from the Bering Sea, where it is associated with the quasi-permanent anticyclonic eddies found close the the western shore. These eddies are caused by bottom topography and coastline configuration and result in countercurrents along the coast. See Tomczak and Godfrey [1994].

KAPEX Acronym for Cape of Good Hope Experiments. From Richardson et al. [2003]:

> During WOCE it became clear that an important part of the general circulation – the circulation of intermediate water around southern Africa and in the eastern South Atlantic – had been omitted from the WOCE float program leaving a huge gap of float coverage and a lack of direct current measurements there. In order to remedy this shortfall a major effort was called for. The serendipitous manner in which this was achieved is perhaps characteristic of how many successful research programs come about. Walter Zenk at the Insitut f—r Meereskunde in Kiel and the German float group there had been tracking floats in the western South Atlantic and proposed to follow up their measurements in the South Atlantic Current by shifting attention to the eastern part of the basin-wide anticyclone in the Cape Basin. Tom Rossby at the University of Rhode Island and Johann Lutjeharms at the University of Cape Town proposed a float program in the Agulhas Current proper with the intent of directly measuring its contribution to the South Atlantic. Phil Richardson at Woods Hole and Silvia Garzoli at NOAA in Miami proposed a float experiment in the Benguela Current on the foundation of the successful BEST (BEnguela Sources and Transports) program in the same region. It was foreseen that each of these individual experiments would be expensive and therefore difficult to get funded unless the groups could share in maintaining an acoustic sound source array. Through informal discussions at various meetings starting in 1994, the research groups from Germany, South Africa and the US teamed up, merging the sources into an extensive array that could be shared by all in a synergetic and cost- effective manner. The three components were combined into a coherent study baptized the Cape of Good Hope Experiments (KAPEX). It soon became clear that a central coordinator would be essential, and when a grant was awarded to Olaf Boebel to work with Johann Lutjeharms at the University of Cape Town, the whole project came together in a most exciting way. Informal planning meetings of the KAPEX team were held in Bremen, Germany; Rondebosch, South Africa; Brest, France; Lihge, Belgium; Woods Hole, USA, and Mar del Plata, Argentina, whenever and wherever a sufficient number of participants was available.
>
> The KAPEX program consisted of three overlapping RAFOS float experiments focused on the Agulhas Current, the South Atlantic Current, and the Benguela Current. The first, conducted by Olaf Boebel, Tom Rossby, and Johann Lutjeharms, deployed three groups of floats in the Agulhas Current upstream of its retroflection. Isopycnal RAFOS floats were tracked on the 26.8 and 27.2 sigma theta surfaces. The second experiment, conducted by Olaf Boebel, Claudia Schmid, and Walter Zenk, tracked isobaric RAFOS floats in the intermediate water of the South Atlantic Current where it enters into the Benguela Current in the Cape Basin. The third experiment, conducted by Silvia Garzoli and Phil Richardson, launched isobaric RAFOS floats in the Benguela Current and its extension downstream of the Walvis Ridge.
>
> The floats were tracked acoustically by means of an array of 11 moored sound sources maintained by the KAPEX group. Overall, 105 eddy-resolving float trajectories were obtained during 1997–1999.

See Boebel et al. [1998] and Richardson et al. [2003].

Kara Sea One of the seas found on the Siberian shelf in the Arctic Mediterranan Sea. It is located between the Barents Sea to the west and the Laptev Sea to the east, and adjoins the Arctic Ocean proper to the north. The western boundary is defined by a line connecting the Kol'zat Cape with the Zhelaniya Cape at Novaya Zemlya. This boundary passes along the eastern shores of Novaya Zemlya and Vaigach Island, crossing the Matochkin Shar, Kara Gate and Yugorsky Shar Straits. The Kara Gate Strait is 45 km wide, 33 km long and up to 119 m deep. The other two straits are narrow than 2.5 km and shallower than 36 m. The Kara Sea is separated from the Laptev Sea by the Northern Land Archipelago and the Shokal'sky and Vil'kitsky Straits, with the boundary passing along the eastern periphery of these straits. The Vil'kitsky Strait is about 130 km long, has a minimum width of 56 kim and depths reaching 210 m. The Shokal'sky Strait is 110 km in length, has a minimum width of 20 km, and a depth of 200–250 m. The northern boundary proceeds from Kol'zat Cape to the Arktichesky Cape (in the Northern land), and the southern boundary is along the mainland coast.

Its area is about 883,000 km^2 and its volume 98,000 km^3. Over 80% of the area and 77% of the volume constitutes a shelf zone with depths less than 200 m. The mean depth is 111 m and the maximum 620 m (located in the northern section at about 80° N and 71° E). The seafloor is chiefly a series of platforms or broad terraces stepping downward from the southeast to the north and west. The most prominent features are the St. Anna (up to 610 m deep) and Voronin (up to 450 m deep) troughs. Between these is the Central Kara plain with depths less than 50 m. Along the Novaya Zemlya coast is the Novozemel'sky depression reaching depths greater than 400 m.

Zenkevitch [1963] gives the history of the exploration of the Kara Sea to 1955:

> The first data on the Kara Sea were collected by the Swedish expeditions of O. Nordenskjöld in 1975 (in the *Pröven*), in 1876 (in the *Imer*) and in 1878 (in the *Vega*). In 1882 and 1883 biological work was carried out there by a Dutch expedition in the *Varna* and by a Danish one in the *Dymphna*. In 1893 the Kara Sea was surveyed by Nansen's famous *Fram*, in 1900 by Toll's Russian expedition in the *Zarya*, in 1907 by the expedition of the Duke of Orleans in the *Belgica* and in 1918 by R. Amundsen in the *Mod*. All these expeditions have contributed to the study of the Kara Sea fauna.
>
> A comprehensive study of the Kara Sea and its fauna was begun as recently as 1921 by the expedition of the Oceanographic Institute in the *Malygin* and by that of the Hydrographic Directorate in the *Taimyr*. In subsequent years a number of Soviet expeditions of the Arctic Institute and the Committee of the Northern Sea Route cruised in the Kara Sea. Among them the voyages of the *Sedov* (1929, 1930 and 194), *Lomonosov* (1931), *Rusanov* (1931 and 1932) and others, and particularly the expeditions of the *Sadko* (1936, 1936 and 1937) which sailed to the north of the Kara Sea far into the Arctic basin and which was the first to haul bottom fauna from depths of almost 4,000 m, are of especial interest. The results of the expedition of the trawler *Maxim Gorky* in 1945 were of importance. During the Soviet period the number of expeditions working in the Kara Sea has been more than doubled in comparison with those of all previous years.

A significant feature of the Kara Sea is the large input of freshwater from rivers. The total volume is about 1525 km^3 yr^{-1} and is chiefly from the Ob (400 km^3 yr^{-1}), the Pur (30 km^3 yr^{-1}), the Taz (34 km^3 yr^{-1}), the Yenisey (630 km^3 yr^{-1}) and the Pyasina (50 km^3 yr^{-1}). The water masses are controlled by this contintal runoff as well as by water inflows from the Arctic Basin and Barents Sea. In the southwest, bottom water forms from winter cooling and increased salinity from ice growth. Above this are saline Barents Sea water (-1.90–6.00° C, 35.30–35.60) and Arctic surface water (-1.80° C, 32.00). In the north deep Atlantic water penetrates into the Kara Sea from the Arctic Basin via the St. Anna and Voronin troughs. On top of this are the Arctic surface water and, below that, the winter Kara Sea surface water (-1.40° C, 22.00–25.00).

The general circulation is influenced by the relative strengths of the Arctic High and Icelandic Low. When the former prevails, water masses are transported from south to north, river outflow increases, the inflow of Barents Sea water decreases. These combine to reduce surface water salinity, increase sea level, thicken the surface layer, and position the Atlantic water nearer to the surface layer. When the Icelandic Low is prevalent, water masses are transported from west to east, Barents Sea inflows increase, Kara Sea outflows to the Arctic surface water increase, the sea level and and the surface water layer both decrease, and the depth of the Atlantic water increases. See Zenkevitch [1963], Fairbridge [1966], Pavlov and Pfirman [1995], Pfirman et al. [1995] and Johnson et al. [2000].

`[http://www.nadn.navy.mil/Oceanography/courses/SO426/atlas_summer/html/intro/-intro_ks.htm]`

katabatic wind A phenomenon that originates with a layer of cold air forming near the ground on a night with clear skies and a low pressure gradient. If the ground is sloping, the air close to the ground is colder than air at the same level but at some horizontal distance. The result is downslope gravitational flow of the colder, denser air beneath the warmer, lighter air. This occurs on the largest scale as the outflowing winds from Greenland and Antarctica. Contrast with anabatic wind.

Kattegat A sedimentary basin that provides part of the connection (along with Skagerrak) between the North Sea and the Baltic Sea. It is surrounded by Denmark to the southeast and southwest (with the connections to the Baltic in the former direction), Sweden to the northeast, and Skagerrak to the northwest. It is a shallow basin with a maximum depth of about 50 m in the southeastern part.

The circulation consists of two northwestward flowing surface currents originating from the two passages providing connections to the Baltic, one on either side of the basin, and a southeastward flowing countercurrent to the west of the eastern current that flows along the Swedish coast. The flow from the two northwestward currents, jointly called the Baltic Current, eventually combines and joins the North Jutland Current (NJC) as it turns around and becomes the Norwegian Coastal Current. The countercurrent originates as part of the NJC turning and flowing southeast. See Svansson [1975] and Danielssen et al. [1997].

Kau Bay A bay formed by the two northern arms of the island of Halmahera in the Australasian Mediterranean Sea. It is located at about 1° N and 128° W and is considered part of the Halmahera Sea. It is composed of an inner basin 500 m deep separated from the outer depression by a shallow sill ranging from 40-50 m in depth. The shallow sill results in oxygen concentrations within the bay decreasing with depth until they reach zero below 400 m, with hydrogen sulfide becoming important near the bottom. See Fairbridge [1966].

Kelvin–Helmholtz instability See ocean turbulence.

Kelvin wave A type of coastally trapped wave motion where the velocity normal to the coast vanishes everywhere. The wave is nondispersive and propagates parallel to the shore with the speed of shallow water gravity waves, i.e. sqrt (gH). The profile perpendicular to shore either decays or grows exponentially seaward depending on whether the wave propagates with the coast to its right or left (in the northern hemisphere). For vanishing rotation, the decay or growth scale becomes infinite and the Kelvin wave reduces to an ordinary gravity wave propagating parallel to the coast. The dynamics of a Kelvin wave are such that it is exactly a linearized shallow water gravity wave in the longshore direction and exactly geostrophic in the cross-shore direction.

KERE Acronym for Kuroshio Extension Region Experiment, a field investigation of the Kuroshio and the deep western boundary current east of Japan.

Kerguelan Plateau A ridge located at approximately 75° E in the Southern Ocean that impedes the flow of the Antarctic Circumpolar Current at depths below 2000 m. Most of this broad plateau is between 2000 and 3000 m deep with some flow occurring below 3000 m in a narrow gap between itself and Antarctica.

KESS Acronym for Kuroshio Extension System Study, a study designed to investigate the Kuroshio Extension System from 2001 to 2005. The goal is to understand the mechanisms that govern the Kuroshio Extension and associated recirculation gyre variability, and to identify the processes responsible for interannual variations in upper–ocean heat content and SST in the region. The objectives of KESS are:

- to demonstrate the capability of tomographic techniques in monitoring the variabiity of the 1000 km scale 3–D oceanic structures; and
- to obtain information about the acoustic environment for the design of the tomography array.

KESS will deploy eight reciprocal tomography moorings in the Kuroshio Extension (centered on 35°N, 150°W) for four years to study the climatological relevance of the Kuroshio Extension/mode water variability.

Kerhallet, C.P. de See Peterson et al. [1996], p. 76.

Kibel number See Rossby number.

Kircher, Athanasius (1602-1680) A Jesuit priest who published the earliest chart of the global ocean circulation in 1664/1665 in an encyclopedia entitled Mundus Subterraneus. This chart reflected Kircher's concurrence with Aristotle's primum mobile theory in that the Pacific and Indian Oceans were shown as regions of broad westward flow. The Atlantic Ocean, being much better known at the time, was more detailed. It was shown with a closed subtropical gyre in the South Atlantic whose flow split near the equator off the coast of Brazil. The northward flowing branch continued along South America and on into the Gulf of Mexico, there flowing in a clockwise gyre around the edge of the Gulf and turning northward after reaching and rounding the tip of Florida. This flow joined with other waters moving north and northeast through the North Atlantic and on into the region north of Scandinavia.

It was at this point that Kircher launched into the realms of sheer speculation. The broad north Atlantic flow into the northern regions was supposed to be drawn into the earth's interior at the north pole and released at the south pole, with the process occurring rhythmically to additionally offer an explanation for the periodicity of the tides. He also included small spotlike features on the map that were supposed to be locations of whirlpools and entrances to a vast system of subterranean channels, one example being an entrance/exit pair on either side of Panama to facilitate the postulated broad western flow pattern. See Peterson et al. [1996].

Knight Inlet A fjord located on the west coast of Canada approximately 300 km north of Vancouver. It exhibits the characteristic steep sides, deep basins, and sills of a fjord estuary, and first reaches inland eastward from the mouth to Sallie Point and after an abrupt turn reaches sinuously northward to the head. Two sills – on 64 m deep at the mouth and the other 68 m deep about 72 km from the head – separate the inlet's 120 km length into two basins. The outer basin has a maximum depth of 250 m and the inner basin 540 m.

According to Baker and Pond [1995]:

> Heavy precipitation (rain at lower elevations and snow higher) during the fall and winter leads to a year–round stratified water column with a peak freshet during the summer. This stratification governs the inlet dynamics, with a surface outflow above the pycnocline that

entrains saltwater as it flows seaward and a salt compensating inflow below. A tidal range of 4 to 8 m, the seasonal availability of replenishment water for deep–water renewal, and strong winds all modulate this general circulation pattern.

See Farmer and Freeland [1983] and Baker and Pond [1995].

knoll The official IHO definition for this undersea feature name is "an elevation somewhat smaller than a seamount and of rounded profile, characteristically isolated or as a cluster on the sea floor; see also hills."

knot A speed of 1 nautical mph. It is equal to 1.15 mph or 1.85 kph and used in navigation and meteorology.

KNOT Acronym for Kyodo North Pacific Ocean Time Series, an ocean time series station established in 1998 at the southwestern margin of the subarctic gyre at 44°N, 155°E. The objectives include studies of CO_2 uptake and its relationship to biological activity in the seasonally variable ocean. The planned measurements include CTD sampling, JGOFS core measurements, deployment of moored sediment traps at 1.3 and 5 km, a shallow optical buoy, and free–drifting sediment traps.

`[http://ads.smr.uib.no/jgofs/ghligh.htm]`

Knudsen, Martin (?-?) A Danish physicist who worked on a set of tables for the determination of chlorinity, salinity, temperature, and density from in situ measurements. He suggested at the ICES meeting in 1899 that such tables should be published to facilitate the standardization of hydrographic work. He also suggested that Standard or Normal Water (i.e. water of known and unvarying salinity) be distributed to oceanographic laboratories as a standard against which all other salinities could be compared. Knudsen set up a Hydrographic Laboratory for ICES in Copenhagen for the purpose of producing such standard water samples. He and his co–workers also improved the accuracy of measurements by devising special burettes and pipettes with which to perform the measurements. See Schlee [1973].

Knudsen buret A buret developed (along with a pipet) by Knudsen and others to obtain salinity values sufficiently accurate enough for oceanographic use via the chlorine titration method. See Dietrich [1963].

Knudsen pipet See Knudsen buret.

Knudsen number More later.

Knudsen's Tables A series of tables published in 1901 that allowed one to find the density of a sea water sample (relative to pure water) as a function of its measured chlorinity (Cl), salinity (S) and temperature (T). These tables allowed the easy determination of the density (at atmospheric pressure and in situ salinity and temperature, i.e. σ_t) and the thermosteric anomaly from measured quantities.

The complete Tables consisted of seven tables. These were:

1. Table of the corresponding values of Cl, S, σ_0 and $\rho_{17.5}$ where Cl is the weight of chlorine (in grams) in 1000 grams of sea water, S is the total weight of salt in grams in 1000 grams of sea water and calculated from Cl as $S = 0.030 + 1.8050\,Cl$, $\sigma_0 = (s_0 - 1)$ where s_0 is the specific gravity of sea water at 0° C referred to distilled water at 4°, calculated as:

$$\sigma_0 = -0.069 + 1.4708Cl - 0.001570Cl^2 + 0.0000398Cl^3,$$

$\rho_{17.5} = (s_{17.5}/\mathsf{s}_{17.5} - 1)$ where $s_{17.5}$ is the specific gravity of sea water at 17.5° C referred to distilled water at 4° C and $\mathsf{s}_{17.5}$ is the specific gravity of distilled water at 17.5° C in proportion to distilled water at 4° C, with $\rho_{17.5}$ calculated as

$$\rho_{17.5} = (0.1245 + \sigma_0 - 0.0595\sigma_0 + 0.000155{\sigma_0}^2) \times 1.00129.$$

2. Table of titration for the correction k to be added to the titration reading for finding the amount of chlorine (Cl).
3. Table of constants Σ_t, A_t and B_t for the exact calculation of the density s_t of sea water when σ_0 and the temperature are given. The density s_t is calculated from

$$s_t = 1 + (\sigma_t/1000)$$

where σ_t is given by

$$\sigma_t = \Sigma_t + (\sigma_0 + 0.1324)[1 - A_t + B_t(\sigma_0 - 0.1324)].$$

The constant $\Sigma_t = (\mathsf{s}_t - 1) \times 1000$ where s_t is the density of distilled water at $t°$ referred to distilled water at 4° C can be calculated from

$$\Sigma_t = -\frac{(t - 3.98°)^2}{503.570} \frac{t + 283°}{t + 67.26°}$$

and the constants A_t and B_t from

$$A_t = t(4.7867 - 0.098185t + 0.0010843t^2) \times 10^{-3},$$

$$B_t = t(18.030 - 0.8164t + 0.01667t^2) \times 10^{-6}$$

4. Table of $D = \sigma_0 - \sigma_t$ for the calculation of σ_t when σ_0 and t are given.
5. Table of $D = \sigma_0 - \sigma_t$ for the calculation of σ_0 when σ_t and t are given.
6. Hydrometer corrections K with regard to normal glasses 16^{III}. K is to be added to the hydrometer reading α_t to obtain $\rho_{17.5}$.
7. Table of the correction K' which is added to K to obtain the corrections for other kinds of hydrometer glasses. The table gives K' for different reading temperatures and different coefficients of cubical expansion γ. For normal glass (i.e. 59^{III}) this is given by

$$\gamma = 10^{-6}[17.039 + 0.00746(t + 17.5)]$$

KODC Abbreviation for Korean Oceanographic Data Center.

[http://www.nfrda.re.kr/kodc/e-index.html]

Kolmogorov scale A length scale at which viscous and inertial forces are of the same order of magnitude. It is defined as:

$$L_K = \left(\nu^3/\varepsilon\right)^{1/4}$$

where ν is the kinematic viscosity of seawater and ε is the rate at which turbulent kinetic energy is lost, i.e.

$$\varepsilon = 2\nu {e_{ij}}^2$$

where

$$e_{ij} = \frac{1}{2}(u_{ij} + u_{ji})$$

is the rate of strain tensor (with units of $m^2 s^{-3}$ or $W kg^{-1}$). See McDougall et al. [1987].

Kolmogorov spectrum An energy spectrum developed by Kolmogorov [1941]. It states that for local homogeneous isotropic turbulence at very large Reynolds numbers, the energy spectrum varies with the wave number n according to:

$$E(n) = \alpha \varepsilon^{2/3} n^{-5/3} \tag{14}$$

where ε is the turbulent kinetic energy dissipation and α is a constant (measured for 1–D turbulence to be $\alpha_1 = 0.47$–0.54 and for 3–D to be $55/18\alpha_1$).

The historical background to Kolmogorov's advance is discussed by Hunt and Vassilicos [1991]:

> The great new approach of Kolmogorov (1941) was to show how to combine some of the methods and ideas of statistical physics (although Kolmogorov used the term probability theory) with those of dimensional analysis and scaling, and to apply them to fluid mechanics, in particular the study of turbulence. From the earliest studies of turbulence the analogy had been drawn between turbulent eddy motion and the motion of gas molecules, and it was hoped that the kinetic theory of gases might provide a useful model for turbulent motions. Kolmogorov in fact relied on these concepts for modeling the turbulent shear stresses produced by the larger energy containing eddies in turbulent shear flows, in a generalization of the earlier ideas of Prandtl (1925).
>
> But in 1941 he introduced the more general idea from statistical physics of a state of statistical equilibrium. Further, he made the hypothesis that the structure of the small–scale motions are uncorrelated with the large–scale motions of the flow and therefore their statistics must be universal, provided these motions are defined in terms of relative velocities. The large–scale motions and the overall dynamics of the flow determine the magnitude of the motions in any given flow.
>
> ...
>
> To apply dimensional or scaling analysis to the small–scale relative motions, it was necessary to introduce a physical quantity representative of the dynamics in this relative frame; it was the brilliant idea of Kolmogorov to defined this as ε, the average rate of transfer of energy between large and small scales of motion (where viscous stresses are negligible), but which was also equal to the rate of energy dissipation by viscous stresses for the smallest scales of motion. Clearly the kinematic viscosity ν had to be the other dimensional quantity introduced to define these scales.

See Phillips [1991] and Hunt and Vassilicos [1991].

KORDI Acronym for Korean Ocean Research and Development Institute.

[http://key.kordi.re.kr/]

Krümmel, Otto (1854–1912) A German professor of geography (at the University of Kiel) considered by some as the first research–oriented academic oceanographer in the modern sense. Among his research accomplishments were a description of the seasonal variability of what is now known as North Equatorial Countercurrent (NEC) in the Atlantic, the first detailed investigation of the Falkland Current that determined it to be an unambiguous, deep–reaching current, and the first explicit description of what is now known as the Subtropical Front.

In 1887 Krümmel published the monumental Handbuch der Ozeanographie, which immediately attained status as the standard reference source for physical oceanographic information. The Handbuch contained a global chart of the ocean surface circulation that depicted all of the major currents in the proper locations. This chart also showed the monsoonal cycle in the northern Indian Ocean via an inset, a new cartographic technique that has since come into wide use. Extensive descriptions of surface circulation features were included, although theory was dealt with from a historical point of view as the field was still in its nascent stages in the latter part of the nineteenth century. He did discuss the work of William Ferrel and Henrik Mohn regarding the effects of the earth's rotation, although the results of some tank experiments led him to believe that the deflecting force would be relatively small in most cases. See Peterson et al. [1996].

Kruzenshtern Strait See Okhotsk Sea.

krypton-85 A radiactive inert gas with a half-life of 10.76 years that is useful as a tracer in ocean studies. It forms when uranium and plutonium undergo fission, making its chief atmospheric sources nuclear weapons testing and nuclear reactors used for commercial power and weapons plutonium production. Most of the krypton-85 sources are located in the northern hemisphere which, due to slow mixing across the ITCZ, has about a 20% higher atmospheric concentration than does the southern hemisphere.

Its source to the ocean is well known due to extensive measurements of the atmospheric concentrations over time. This, along with its chemical inertness, are valuable properties for an ocean tracer to have. It enters the ocean by gas exchange, equilibrating with surface water on a time scale of about one month. This equilibrium concentration can be calculated from krypton solubility, a function of temperature and salinity, and from the atmospheric krypton concentration. This procedure won't apply in regions of rapid vertical mixing since the surface water doesn't have time to come into equilibrium with the atmosphere, but direct measurements in those regions can alleviate this problem. A measurement requires a water volume of 250 l, and the dynamic range of the measurement of krypton-85 (i.e. the ratio of the surface water concentration to the minimum detectable amount) is around 100. Measurement precision is +/- 4% for surface samples and +/- 25% for samples with concentrations 3% that of surface water.

Kr-85 is used as a tracer for study processes that occur on a decadal time scale, e.g. thermocline ventilation, mixing, circulation, and deep water mass formation, due to it being introduced to the atmosphere only in the last 35-40 years. See Sarmiento [1988] and Broecker and Peng [1982].

Kuroshio Current In oceanography, a western boundary current located in the western North Pacific Ocean. The Kuroshio begins where the North Equatorial Current approaches the Philippines and continues northward east of Taiwan. It then crosses a ridge between Kyushu and the Okinawa Islands, responding by forming the East China Sea meander, and proceeds through the Tokara Strait, after which it takes a sharp turn to the left (north).

At this point is takes one of two paths, commonly called the large–meander (LM) and non–large–meander (NLM) paths. The LM path is located offshore, while the NLM path is close to the Japanese coast west of the Kii peninsula. The paths diverge offshore of Aburatsu, where the LM begins an offshore loop extending to about 31°S, after which it loops back towards Japan, flowing to the west of the Izu Ridge and rejoining the typical path of the NLM north of Miyake–jima. The path of the NLM undergoes another variation further downstream. It usually passes over the Izu Ridge north of Miyake–jima, keeping close to the main island, but occasionally shifts such that it loops offshore and passes over the ridge south of Hachijo–jima, looping back to rejoin the reunited LM/NLM path at around 141°E, 35°N.

The development of an LM path is apparently related to the current velocity of the Kuroshio. An LM path originates with the generation of a small meander southeast of Kyushu and its downstream (eastward) propagation to the Kii Peninsula, where it develops into a Large Meander. The generation of the initial small meander is associated with a maximum in the velocity of the Kuroshio. The Kuroshio velocity usually decreases after its formation and remains small throughout the period of propagation of the small meander and for several months after the formation of the large meander. The decay of the LM phases seems to be associated with large Kuroshio velocities, particularly for the process of the eastward shift of the large meander to lie over the Izu Ridge. The LM formation process is also associated with the position of the Kuroshio in the Tokara Strait, with the LM path usually beginning about four months after the Kuroshio shifts north in the Strait, and terminating four or five months after it returns to the south. The lag time corresponds to the formation (i.e. the propagation of the small meander) and decay periods of the large meander.

After the LM/NLM paths merge, the Kuroshio separates from the coast and turns east at about 35° N, at which point it technically changes into the Kuroshio Extension. The Kuroshio Current is part of the overall wind-driven subtropical gyre circulation cell that exists in the North Pacific Ocean. This has also been called the Black Stream and the Japan Stream. See Stommel and Yoshida [1972], Tomczak and Godfrey [1994], Kawabe [1995] and Kawai [1998].

Kuroshio Extension That which the Kuroshio Current becomes when it separates from the continental rise at about 35° N in the western North Pacific Ocean. It flows eastward from this point as a strong jet which, given the proclivities of such things, evinces a strong instability. This is seen in two regions of north- and south-ward shift called the "First Crest" and the "Second Crest", centered at approximately 140° E and 152° E, respectively, with a node near 147° E. East of these features the Shatsky Rise produces another region of alternate (but less regular) paths, followed by a passage over the Emperor Seamounts where it breaks up into filaments which partly comprise the North Pacific Current. The Kuroshio Extension is part of the overall wind-driven subtropical gyre circulation cell that exists in the North Pacific Ocean. See Stommel and Yoshida [1972] (especially Kawai [1972]), Tomczak and Godfrey [1994] and Hurlburt and Metzger [1998].

Kuroshio Deep Water (KDW) A water mass found in the East China Sea. KDW is usually located at depths of 900–100 m in the Okinawa Trough, and originates mainly from the passage between the Okinawa islands. The temperature and salinity are fairly stable at, respectively, 3.7° C and 34.48. KDW is formed mainly via convection. See Yu-song and Xue-chuan [1994].

Kuroshio Intermediate Water (KIW) A water mass found in the East China Sea. KIW originates from northwest Pacific water, with the major part entering from east of Taiwan and most of the rest from between Okinawa and Miyako-Jima. It is located at around 900–1000 m and has a thickness range of 500–600 m, with the latter rapidly decreasing in the shallow area of the Okinawa Trough. The temperature and salinity ranges and averages of KIW are, respectively, 5.8°–9.5° C (7.8° C) and 34.26–34.38 (34.32). A major feature is a low salinity core with small variations in temperature and salinity. Some KIW upwells on the continental slope. See Yu-song and Xue-chuan [1994].

Kuroshio Subsurface Water (KSSW) A water mass found in the East China Sea. KSSW originates from the near–surface water of the subtropical North Pacific, although in the winter its upper boundary is the sea surface as it merges with the Kuroshio Surface Water (KSW). In the summer the upper boundary ranges from 50–75 m depth with the lower boundary at about 400 m and shallowing towards the upper slope. The temperature decreases with depth from >20° C to about 15° C, and a salinity maximum is found between 125–200 m. The temperature and salinity range of this salinity core are, respectively, 17.0°–23.2° C and 34.67–34.97. See Yu-song and Xue-chuan [1994].

Kuroshio Surface Water (KSW) A water mass found in the East China Sea. KSW exists only in the warm half of the year. It is modified and merges with Kuroshio Subsurface Water (KSSW) via strong convective interaction during the cold half. This is the warmest water mass in the East China Sea, and is usually located in the upper 75 m although seasonal variations can push this up to 100 m. Its salinity is less than that of the underlying KSSW due to rainfall and runoff. The annual temperature and salinity ranges and means are, respectively, 21.9°–29.6° (25.60°) and 33.95–34.95 (34.44). See Yu-song and Xue-chuan [1994].

Kuroshio Water Mass A group of water masses produced by modified Pacific water in the Kuroshio area in the eastern East China Sea. The four water masses comprising this are, from top to bottom: Kuroshio Surface Water (KSW), Kuroshio Subsurface Water (KSSW), Kuroshio Intermediate Water (KIW), and Kuroshio Deep Water (KDW). All four layers only exists in summer, as the KSW merges with the KSSW in winter. See Yu-song and Xue-chuan [1994].

kymatology The science of waves and wave motion.

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Labrador Basin A ocean basin situated between Labrador, Greenland and Newfoundland. It underlies the Labrador Sea as well as most of the Irminger Sea.

Labrador Current A current that flows southward over the continental shelves and slopes of Labrador and Newfoundland from Hudson Strait at 60°N to the Tail of the Grand Banks of Newfoundland at 43°N. It was first described by Smith et al. [1937] as a continuation of the Baffin Island Current, which transports the cold and relatively low salinity waters flowing out of Baffin Bay, and the warmer and more saline waters of a branch of the West Greenland Current. It appears as two branches at Hamilton Bank on the southern Labrador Shelf, a small inshore stream carrying about 15% of the transport and the main stream over the upper continental slope carrying about 85%.

Measurements indicate that the Labrador Current carries a transport (relative to 1500 db) of 3.8±0.9 Sv, 85% of which occurs in a 50 km wide jet over the shelf break between the 400 and 1200 m isobaths. An additional barotropic component has been identified over the 1000 m isobath. It has a maximum monthly speed of about 0.09 m s^{-1}, which adds about 7.2 Sv to the transport estimate.

Another southward flow has been identified over the 2500 m isobath from current meter observations, seaward of the traditional Labrador Current. The southward flow is over the full water depth, with a current half–width of order 70 km. This flow is weakest in summer and strongest in winter, as opposed to the baroclinic Current being strongest in late summer and weakest in winter. It is speculated that the traditional Labrador Current over the upper slope is primary buoyancy driven, while the deeper current centered at the 2500 m isobath is part of the North Atlantic subpolar gyre. See Lazier and Wright [1993] and Han and Tang [1999].

Labrador Sea A part of the north Atlantic recognized as a separate body of water for hydrographic purposes although not officially recognized as such. The southern boundary is a line from the southern tip of Greenland to Cape St. Charles on the coast of Labrador and the northern boundary the 66° N latitude line that joins Greenland and Baffin Island north of the Arctic Circle.

The circulation features include the West Greenland Current and the Labrador Current. The Labrador Sea is part of the pathway through which the low salinity outflows of the Arctic Ocean move southward and downward toward denser surfaces. This low salinity can follow two pathways: mixing across fronts and subsequent incorporation into the subpolar and eventually the subtropical gyre circulation; or the water can move offshore into the Labrador and Irminger Seas and be mixed down the following winter as Irminger Sea Water or LSW.

Observations indicate considerable fluctuations of salinity in the upper waters on both a seasonal and interannual basis, which renders it difficult to create an average picture of the hydrography from historical data (of which there is much in this region). Climatologically, this is a region where the first effects of atmospheric warming induced by CO2 or other greenhouse gases might be seen. Milder winters would lead to less overturning and accumulation of low salinity waters in the upper layers, an affect which would be exacerbated by increased glacial and polar ice melt as well as increased high latitude precipitation. This could very well turn off the production of LSW with possible global consequences. See Tomczak and Godfrey [1994] and U. S. Science Steering Committee for WOCE [1986].

Labrador Sea Convection Experiment An experiment whose purpose is to improve the understanding of the convective process and therefore the fidelity of parameteric representations used in large–scale models by a combination of field observations, laboratory studies, theory and modeling. The goals of the experiment are to investigate:

- the characteristic scales and properties of convective plumes;
- how plume parameters depend on the forcing and local environment;
- the fluxes of mass, heat and salt from the ensemble of plumes;
- how convection is related to its mesoscale environment;
- the relative importance of lateral (eddy) versus vertical (convective) flux of heat and salt inside/outside the convective region;
- what controls the volume and T/S properties of created water masses;
- how the convected water mass is accomodated into the general circulation; and
- the mean and seasonal variation in the gyre circulation.

The field work for this experiment includes floats and drifters, basin–wide hydrographic surveys, moored instruments to measure the usual variables, and aircraft observations for detailed measurements of the marine boundary layer. See Lab Sea Group [1998].

[http://www.ldeo.columbia.edu/~visbeck/labsea/]

Labrador Sea Water (LSW) A water mass which forms in the Labrador Sea via deep convection in the winter months in a strong cyclonic circulation gyre. It is a large volume of nearly homogeneous water with temperatures ranging from 3.0 to 3.6° C, salinities from 34.86 to 34.96, and consistently high dissolved oxygen content (above 275 μmol). It is formed by the final modification of Subpolar Mode Water (SPMW) in the Labrador Sea and contributes to the formation and modification of various types of North Atlantic deep waters. Observations indicate considerable interannual variable in the formation process, with no water being formed at all in an estimated 4 out of 10 years. This variability leads to significant interannual variations in LSW properties.

LSW mixes with ABW and eventually becomes part of NADW, although the abovementioned variability is not wholly passed on to NADW. The ABW/LSW mixture recirculates around the Labrador Sea an estimated 2 to 3 times over 12 to 18 months, a process which serves to smooth out interannual fluctuations and results in NADW receiving water with about half the original variation in magnitude of LSW. See Clarke and Gascard [1983], Talley and McCartney [1982a] Tomczak and Godfrey [1994] and Paillet et al. [1998].

lacustrine Of or pertaining to a lake or lakes, or of plants and animals growing in or inhabiting lakes.

LADCP Abbreviation for Lowered Acoustic Doppler Current Profiler. According to Firing [1998]:

> An LADCP is a self-contained ADCP that is lowered and retrieved with a hydro wire, usually as part of a CTD rosette package. The ADCP pings as fast as possible, typically about once per second, yielding a large number of overlapping velocity profiles, each with a range of 100-200 m from the instrument, and each relative to the unknown velocity of the instrument. These unknown velocities are removed by differentiating the profiles in the vertical. The resulting overlapping shear profiles are then interpolated to a uniform depth grid and averaged to give a composite shear profile. Integrating this shear profile in depth gives a velocity profile relative to a single unknown constant of integration. If the vertical mean of the relative velocity profile is subtracted out, then the constant that remains to be determined is just the depth–averaged velocity. This can be calculated by a method closely analogous to that used in shipboard ADCP work. The depth–averaged absolute water velocity is the time–average of the velocity of the water relative to the instrument, plus the time–average of the ship velocity as calculated from the position difference between the start and end of the cast, minus a small correction (usually less than 1 cm/s) calculated from

the time–integral of the relative velocity profile. If the vertical velocity were a constant during the downcast, and another constant during the upcast, then the time–integral would be equivalent to a depth integral – which is of course zero for the de–meaned relative velocity profile. Hence the calculation of the depth–averaged velocity is very insensitive to the accuracy of the relative velocity profile.

See Fischer and Visbeck [1993] and and Firing [1998].

`[http://www.ldeo.columbia.edu/~visbeck/ladcp/]`

L-ADCP Abbreviation for Line–Acoustic Dopper Current Profiler.

Lafondstables

Lafond's tables A set of tables compiled by E. C. Lafond for the purpose of correcting reversing thermometers and computing dynamic height anomalies. These were published by the U.S. Navy Hydrographic Office as H. O. Pub. No. 617.

Lagrangian velocity That velocity that would be measured by tracking a dyed particle in a fluid. Compare to Eulerian velocity and Stokes velocity.

Lake Baikal See Kipfer et al. [2000].

Lake Ontario See Pickett [1977].

Lakshadweep Sea See Shenoi et al. [1999].

Lamb wave To be completed.

LAMP Acronym for Long–Term Autonomous Microstructure Profiler, an instrument designed to autonomously collect microstructure profiles over deployments of several months duration. It consists of an autonomously profiling ALACE float outfitted with two microtemperature probes and a hard disk for data recording. The prototype was deployed in the eastern subtropical North Atlantic in the area of the NATRE study. See Sherman and Davis [1995].

Langmuir circulation A marine boundary layer phenomena in which wind shear tends to organize convective perturbations into adjacent, counterrotating roll vortices. The surface signature of this Langmuir circulation is wind-rows, i.e. parallel bands of foam, seaweed and slick water that have undoubtedly been familiar to sailors since long ago. The first systematic observations were performed by Langmuir [1938] after whom the phenomenon was eventually named. He studied it in the surface layers of Lake George, New York using sophisticated tracers like leaves, corks, and submerged umbrellas buoyed with light bulbs.

Langmuir circulations tend to carry water with near surface properties down to below the surface convergence zones, with plankton, seaweeds, surface detritus, and dissolved gases tending to be concentrated in the sinking currents. Conversely, water with different temperature and salinity properties and which is also usually richer in nutrients is brought toward the surface. See Langmuir [1938], Leibovich [1983], Weller and Price [1988] and Kraus and Businger [1994].

La Perouse Strait See Okhotsk Sea.

Laplace's tidal equations The equations developed by Laplace in 1775-1776 for his dynamic theory of tides. They were obtained from the continuum equations of momentum and mass conservation written in rotating coordinates for a fluid shell surrounding a nearly spherical planet. Assumptions central to their derivation were a perfect homogeneous fluid, small disturbances relative to a state of uniform rotation, a spherical earth, a geocentric gravitational field uniform horizontally and in time, a rigid ocean bottom, and a shallow ocean where both the horizontal component of the Coriolis acceleration and the vertical component of particle acceleration are neglected. The equations are

$$\frac{\partial u}{\partial t} - 2\Omega \sin\theta v = -\frac{\partial}{\partial \phi}(\zeta - \Gamma/g)/a\cos\theta$$

$$\frac{\partial v}{\partial t} + 2\Omega \sin\theta u = -\frac{\partial}{\partial \theta}(\zeta - \Gamma/g)/a$$

$$\frac{\partial \zeta}{\partial t} + \frac{1}{a\cos\theta}\left[\frac{\partial}{\partial \phi}(uD) + \frac{\partial}{\partial \theta}(vD\cos\theta)\right] = 0$$

where (ϕ, θ) are longitude and latitude with corresponding velocity components (u, v), ζ the ocean surface elevation, Γ the tide-generating potential, D the variable depth of the ocean, a the earth's radius, g the gravitational acceleration at the earth's surface, and Ω the earth's angular rate of rotation.

These equations were eventually found to not be uniformly valid, a problem that was eventually fixed by relaxing the assumption of homogeneous fluid to allow stratification and developing a similar equation set called the long wave equations. Both sets are used to investigate such long ocean waves as Rossby waves, Poincare waves, Kelvin waves and the like, although these are more commonly and easily studied using an equation set written in cartesian coordinates on a beta plane or an f-plane. For example, the LTEs simplified for long waves in a uniformly rotating flat-bottomed ocean, i.e. an f-plane, are

$$\frac{\partial u}{\partial t} - f_0 v = -g\frac{\partial \zeta}{\partial x}$$

$$\frac{\partial v}{\partial t} + f_0 u = -g\frac{\partial \zeta}{\partial y}$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (uD)}{\partial x} + \frac{\partial (vD)}{\partial (vD)}$$

where f_0, equal to 2Ω, is the Coriolis parameter. See Lamb [1932], sect. 213-221 and Hendershott [1981].

LAPS Acronym for Large Aggregate Profiling System.

lapse rate The rate of decrease of temperature with height. This can be either an environmental or a process lapse rate. An environmental lapse rate is a static measure of the state of the environment, e.g. finding the rate of temperature decrease by measuring the vertical temperature profile in some way. A process lapse rate, on the other hand, gives the temperature associated with some action or process, e.g. a rising or sinking air parcel.

Laptev Sea One of the seas found on the Siberian shelf in the Arctic Mediterranean Sea. It sits between the Kara Sea to the west, the East Siberian Sea to the east, and adjoins the Arctic Ocean proper to the north. The western boundary begins at the Arctic Cape (Komsomolets Island), proceeds along the eastern shores of the Northern Land, through the Red Army Strait, along the eastern shore of October Revolution Island, to the Anuchin Cape and through Shokal'sky Strait to Bol'shevik Island, along the coast to the Vaigach Cape, along the eastern boundary of Vil'kitsky Strait to the head of Khatanga Bay. The northern boundary starts at the Arktichesky Cape, and passes through the crossing point of the meridian of the northern tip of Lotel'ny Island (139°E) and the edge of the continental shelf (79° N, 139° 00' E). The eastern boundary begins at the western side of Sannikov Straita, passes around the western shores of the Large and Small Syakhovsky Islands, and then along the western extent of Dmitry Laptev Strait. The southern boundary is the continental shore from Svyatoy Nos Cape to the head of Khatanga Bay.

The width along parallel 75° N is 717 km, and the length from Cheluskin Cape to Dimitry Laptev Strait is 1126 km. The area is around 540,000 km^2 with about 66% being less than 100 m deep. The southern and southeastern areas, comprising 45% of the total, have water depths ranging from 10 to 50 m. Depths in excess of 2000 m are found in the northern parts. An incline starting at 100 m and ending at 3000 m divides the sea into the northern and southern parts along the parallel of the Vil'kitsky Strait. This has also been called the Nordenskjold Sea.

Zenkevitch [1963] gives the history of the exploration of the Laptev Sea to 1955:

> Nordenskjöld's expedition on the *Vega* (1878–1879) marked the beginning of the exploration of the fauna and flora of the Laptev Sea, which was continued by the Russian expeditions of Toll on the *Zarya* (1900–1903) and Vilkitsky on hte *Taimyr* and *Vaigach* (1913). In the Soviet era the Norwegian expeditions on the ship *Mod* (1918–1920 and 1921–1924), and the Soviet expeditions of Khmisnikov (1926) and of Yu. Tchirikhin (1927) on the icebreakers *Lithke* (1934) and *Sadko* (1937) have worked in the Laptev Sea.

The runoff into the Laptev Sea from the five major rivers – the Khatanga, Anabar, Lena, Olenek and Yana) is about 767 km^3 yr^{-1}. This runoff, shelf water exchange with the Arctic Ocean, and perennial ice cover are the main factors determining the water masses. In the upper Laptev Sea, Arctic surface water (-1.80° C, 32.00) and Laptev Sea surface water (-1.40° C, 22.00–25.00) Sea surface water dominate and show only weak seasonality. Warm Atlantic water (2.25° C, 34.98) is spread in the north in the deep water troughs under the Arctic surface water. Below 800–1000 m is cold bottom water with a temperature of 0.4–0.9° C and a salinity of 34.90–34.95. This water is formed by the sinking of cooled water from the continental slopes. The temperature and salinity fields show large gradients between the mixing zones of river and sea water and the uniform thermohaline structure in the north. The thermohaline structure is relatively homogenous in the winter due to a decrease in runoff, increase in ice cover, and decrease in convection.

The currents are influenced by the position and intensity of the Icelandic Low and the Arctic High, water exchange with the Arctic Basin and with the Kara and East Siberian Seas, and by river freshwater input. A well–defined cyclonic circulation exists in the surface layer of the Laptev Sea. A current from west to east along the mainland coast is intensified by the Lena Current. As it approaches the New Siberian Islands, it is directed to the northwest and then the north in the form of the New Siberian Current, finally merging with the Trans–Arctic Current moving from east to west. Near the Northern Land the waters in the southern part of the Trans–Arctic Current are generally headed southward and, in the form of the East–Taimyrskoye Current, reach the coast eastern flow to complete the cyclonic gyre. Part of the New Siberian current moves eastward through the Sannikov Strait into the East Siberian Sea.

The current velocities are small, usually not exceeding 10 cm/s. During the times when the Icelandic Low dominates the Arctic High, there is a well–developed transport of water masses from south to north, and the center of the cyclonic gyre shifts toward the Northern Land. A wind–driven gyre exists in the southeastern region. It is cyclonic when western atmospheric transports prevail over the eastern Laptev Sea, and anticyclonic when eastern transports dominate.

The Laptev Sea is covered by ice of different thickness and age categories from October to May. Formation begins in late September, with extensive fast ice up to 2 m thick formed in winter in water depths of less than 20–25 m. A significant area of polynyas and young ice is preserved to the north of this fast ice zone. The width of the zone varies from 10 to several hundred kilometers, with the ice edge changing its position in summer according to wind and currents. See Zenkevitch [1963], Fairbridge [1966] and Pavlov [1998].

[http://www.nadn.navy.mil/Oceanography/courses/SO426/atlas_summer/html/intro/-intro_lp.htm]

Large Aggregate Profiling System (LAPS) A system for counting the number and size distribution of particles in sea water ranging from 250 microns to several millimeters in size. LAPS consists of a video camera synchronized with a strobe light which flashes at predetermined intervals as the instrument is lowered through the water column. The light is focused so it illuminates only a narrow slab of water where the video camera records images of the large particles in the water. The video images are analyzed using software which counts the number of particles and determines their maximum and minimum dimensions if they are not circular, and this data is used to estimate a volume and mass of the imaged particles. LAPS is an integral part of the Particle and Optics Profiling System (POPS).

large eddy simulation A compromise between explicitly simulating everything down to the smallest scales of motion via direct simulation and simulating only the mean flow via Reynolds averaging when modeling turbulent flows. This is accomplished by first applying a local spatial filter to the equations of motion. Then the large-scale turbulent motions are explicitly simulated while a turbulence model represents or parameterizes the influence of the unresolved small-scale motions that the filter has separated. The scale of the filter operation is usually within or close to the inertial subrange of 3-D turbulence, where it is expected that the resolved motions will describe the energy-producing mechanisms and associated fluxes of heat and momentum and the unresolved subgrid motions the dissipation of the resolved turbulence energy. This technique originated in meteorology and weather prediction where the aim is to predict the evolution of large-scale eddies over their lifetimes, i.e. the weather, while parametering the effects of not well understood processes like moist convection and radiative transfer. See Mason [1994].

LARVE A component of the RIDGE initiative whose goal is to investigate larval dispersal and gene flow in vent environments and evaluate the potential role of these processes in generating and maintaining biogeographic patterns along mid–ocean ridges and across ocean basins.

[http://ridge.oce.orst.edu/larve/larve.html]

latent heat The quantity of heat absorbed or emitted, without change of temperature, during a change of state (from solid to liquid or from liquid to gas) of a unit mass of a material. It is a hidden heat (i.e. it can't be sensed by humans) that doesn't occur until phase changes ocur. An example is the evaporation of liquid water cloud droplets cooling the air by removing heat and storing it as latent heat. Phase changes that cool the air are vaporization (liquid to vapor), melting (solid ice to liquid) and sublimation (solid to vapor), while phase changes in the opposite direction that warm the air are condensation (vapor to liquid), fusion (liquid to solid) and deposition (vapor to ice). The latent heat is $2.5 \times 10^6\,\mathrm{J/kg^{-1}}$ for condensation or evaporation, $3.34 \times 10^5\,\mathrm{J/kg^{-1}}$ for fusion or melting, and $2.83 \times 10^6\,\mathrm{J/kg^{-1}}$ for deposition or sublimation, with the sign depending on the direction of the change.

latent heat flux The exchange of heat between a moisture-containing surface and atmosphere resulting mainly from the evaporation at the surface and the later condensation within the atmosphere. This is an indirect transfer of heat associated with the phase transitions of water, between liquid and vapor at the surface and later between vapor and liquid or solid phases. See Peixoto and Oort [1992].

LATEX Acronym for Louisiana–Texas Experiment, sponsored by the MMS of the Department of the Interior. LATEX was a six–year project with the principal objective of identifying the key dynamical processes governing the circulation, transport, and cross–shelf mixing of the waters on the Texas–Louisiana shelf. The program had three components:

- LATEX A - shelf circulation and transport processes (administered by Texas A&M University);
- LATEX B - Mississippi River plum hydrography (administered by Louisiana State University); and
- LATEX C - Gulf of Mexico eddy circulation (administered by Science Applications International Corporation).

[http://ocean.tamu.edu/LATEX/welcome.html]

Laurasia The name given to a hypothetical northern hemisphere supercontinent consisting of North America, Europe, and Asia north of Himalayas prior to breaking up into its separate components. It was formed in the early Mesozoic by the rifting of Pangaea along the line of the North Atlantic Ocean and the Tethys Sea. The southern hemisphere analogue was called Gondwanaland and both comprised a hypothetical single supercontinent called Pangaea before their splitting up.

Laurentia The Precambrian craton of central eastern Canada. It forms the ancient core of Canada, the remainder having been accreted via orogeny.

layer coordinates In numerical modeling, a system of vertical coordinates where an arbitrary number of layers are specified in which some fluid property (e.g. density) remains constant, i.e. an independent variable. The dependent variable is the vertical extent of each layer. Pressure coordinates are an example of layer coordinates. Compare to level coordinates.

layer method See core layer method.

layering In physical oceanography, this is a consequence of the double diffusion phenomena. If a layer of colder, fresher water overlies a layer of warmer, saltier water, the differences in molecular diffusivities between salt and heat will cause the water just above/below the interface to become lighter/heavier than that above/below it and thus it will tend to rise/sink. The phenomenon, called layering, can lead to fairly homogeneous layers separated by thinner regions with large gradients.

LCD Abbreviation for low cost drifter.

LDEO Abbreviation for Lamont Doherty Earth Observatory, a research division of Columbia University dedicated to understanding how planet Earth works. See the LDEO Web site[86].

lead An opening in pack ice which forms as the result of a local divergence in its drift. These occur at weak points in the ice and are characteristically long, narrow channels meters to hundreds of meters wide and kilometers to tens of kilometers long. They have no fixed location, although their occurrence may be predictable by region or season, and the are more prevalent in regions of thinner ice and marginal ice zones. Leads typically cover at least 1% of the total ice area, with the average distance between them varying from 5 km in the marginal ice zone to 275 in the central Arctic pack ice.

A lead is defined by the WMO as:

> Any fracture or passage-way through sea ice which is navigable by surface vessels.

See SMith et al. [1990] and WMO [1970].

LEADEX Acronym for Lead Experiment, a 1992 experiment to study the effect of leads (cracks in the ice) on the polar ocean and atmosphere. See Fett et al. [1994] and Persson et al. [1997].

[http://nsidc.org//NASA/GUIDE/docs/campaign_documents/arctic_leads_ARI_campaign_document.gd.html]
[http://www.cmdl.noaa.gov/star/agasp2.html]

[86] http://www.ldeo.columbia.edu/

leddies Baroclinic eddies composed of LIW as hypothesized by Millot [1999]. These are posited to form as the LIW becomes unsable as it passes the open southwest corner of the Sardinian slope. They propagate into the interior of the Algerian Basin and contribute to the occurrence of recent LIW there.

[http://www.com.univ-mrs.fr/LOB/ELISA/]

Leeuwin Current The eastern boundary current along the west coast of Australia. This differs from other eastern boundary currents in that an abnormally large pressure gradient overrides the usual scenario of equatorward winds producing surface upwelling, an equatorward surface flow, and a poleward undercurrent. The Leeuwin Current flows strongly poleward against equatorward winds due to a difference in dynamic height of 0.5 m along the coast. This difference is related the the throughflow from the Pacific to the Indian Ocean through the Australasian Mediterranean Sea which serves to maintain the same steric height on either side of the throughflow. The same height cannot be maintained by the colder waters off southwest Australia and thus the lower steric height. The result is a self-perpetuating process where the southward flow of warm water leads to surface cooling which keeps the steric height lower which leads to southward flow, etc.

The annual mean transport of the Leeuwin Current has been estimated at 5 Sv with average current velocities ranging from 0.1-0.2 m/s, although its intensity and southward extent vary seasonally. It is strongest in May when the countering wind is weakest with speeds up to 1.5 m/s. The strong fronts on both sides of the current tend to produce eddies during this period. See Godfrey and Weaver [1991], Holloway [1995] and Batteen and Huang [1998].

length scales A thorough, unified investigation of the length scale relationships in the steady linear theory of rotating stratified fluids on the beta plane can be found in Blumsack [1973]. He obtains the following table of length scales and their nondimensional and dimensional thicknesses:

		Thickness	
Name	Symbol	Nondimensional	Dimensional
Ekman	h_E	$E^{1/2}$	$(A_V/f_0)^{1/2}$
Thermocline[a]	h_T	$(El/\beta S)^{1/4}$	$(A_V f_0^2 l_*/\sigma\beta_* N^2)^{1/4}$
Carrier–Munk[b]	l_M	$(E/\beta)^{1/3}$	$(A_H/\beta_*)^{1/3}$
Upwelling[c]	l_U	$E^{1/2}$	$(A_H/f_0)^{1/2}$
Buoyancy[d]	l_B	$(E^2\delta^2/S)^{1/4}$	$\sigma^{-1/4}(A_H/N)^{1/2}$
Stewartson[e]	l_S	$(E\delta h)^{1/3}$	$(A_H h_*/f_0)^{1/4}$
Hydrostatic Lineykin[f]	l_H	$S^{1/2}h$	$\sigma^{1/2}(N/f_0)h_*$
Viscous–hydrostatic[g]	l_V	$Eh^{-1}S^{-1/2}$	$\sigma^{-1/2}(A_H/h_* N)$
Stokes[h]	l_K	δh	h_*
Western	l_W	$E(\beta h^2 S)^{-1}$	$f_0^2 A_H/\sigma N^2\beta_* h_*^2$
Eastern	l_E	$(\beta E\delta^2 h^2)^{1/3}$	$(A_H h_*^2\beta_*/f_0^2)^{1/3}$

[a] Stommel and Veronis [1957], Pedlosky [1969]
[b] Munk [1950]
[c] Pedlosky [1968 1969]
[d] Veronis [1967]
[e] Stewartson [1957]
[f] Blumsack [1972]
[g] Blumsack and Barcilon [1971]
[h] Blumsack and Barcilon [1971]

where:

- A_H and A_V are the horizontal and vertical eddy viscosities,

- f_0 is the Coriolis parameter,
- l_* is the dimensional horizontal length scale (and l its dimensionless counterpart),
- h_* is the dimensional vertical length scale (and h its dimensionless counterpart),
- σ is the Prandtl number,
- β_* is the dimensional gradient or variability of f, i.e. $|\nabla_* f_*|$ (and β its nondimensional counterpart),
- N is the buoyancy frequency,
- $E = A_H/f_0L^2$ is the Ekman number,
- $S = \sigma N^2\delta^2/f_0^2$ is the stratification parameter, and
- α is the ratio of the horizontal and vertical eddy viscosities, i.e. $(A_V/A_H)^{1/2}$.

LEPOR Acronym for Long-Term and Expanded Program of Oceanic Exploration and Research, an IOC project.

LES In the modeling of fluid turbulence, this is an abbreviation for Large Eddy Simulation, a technique in which eddies above a certain size are directly simulated and the effects of those of smaller size are parameterized in terms of some variable at the larger scale.

levanter An easterly wind in the Straits of Gibraltar, most frequent from July to October and in March. It is usually associated with high pressure over western Europe and low pressure to the southwest of Gibraltar over the Atlantic or to the south over Morocco.

Levantine Intermediate Water (LIW) The saltiest water mass that forms in the eastern Mediterranan Sea. It is exclusively formed in several areas of the Levantine Basin and the southern Aegean Sea in February and March under the influence of dry and cold continental air masses. Mesocale processes play an important role in the formation and spreading of LIW. After its formation, it forms a layer identified by a salinity maximum between the overlying Modified Atlantic Water (MAW) and the underlying Eastern Mediterranean Deep Water (EMDW). The core depth fluctuates from 50 to 600 m. The LIW flows eastwards and westwards, with part of the portion formed in the Levantine Basin entering the Aegean through the eastern straits of the Cretan Arc with core temperature and salinity values at the sill depths of 14.5○C and 38.9. Some of this water is ventilated and transformed by convective processes to become a slightly denser intermediate water mass called Cretan Intermediate Water (CIW).

While the characteristics of the source waters generated at different regions vary (14.70–16.95°C, 38.85–39.15°C), mixing results in homogeneity and the loss of heat and salt as the LIW spreads westward. The slow spreading and long renewal time give LIW as relatively low oxygen content of less than 4.5 ml/l. The winter properties of LIW as it leaves the Levantine Sea are $15° \leq \theta \leq 16°$ C, $39.0 \leq S \leq 39.2$, and $28.9 \leq \sigma_\theta \leq 29.0$. In the Ionian Sea the properties are transformed into $14° \leq \theta \leq 15°$ C, $S \geq 38.8$, and $29.0 \leq \sigma_\theta \leq 29.1$. See Perkins and Pistek [1990], Özsoy et al. [1993], Stratford and Williams [1997], Stergiou et al. [1997] and Theocharis et al. [1999].

Levantine Sea See Özsoy et al. [1993] and Theocharis et al. [1999].

Levantine Surface Water (LSW) A warm and saline water mass occupying most of the surface layer of the Eastern Mediterranean Sea during the warm part of the year. It is the product of intense evaporation, with the salinity reaching maximum values of around 39.5 by the end of the summer, especially in the northwest Levantine and southeast Aegean Seas around Rhodos. See Balopoulos et al. [1999].

leveche A hot, dry, southernly wind which blows on the southeast coast of Spain in front of an advancing depression. It frequently carries much dust and sand, with its approach being signaled by a strip of brownish cloud on the southern horizon. This corresponds to the scirocco of North Africa and is named after the direction from which it blows. It is also known as the solano.

levee The official IHO definition for this undersea feature name is "a depositional natural embankment bordering a canyon, valley or seachannel on the ocean floor."

level coordinates In numerical modeling, a vertical coordinate system in which a arbitrary number of height or depth levels are specified at which the changing values of the various dependent variables are calculated. Thus the level heights or depths are independent variables. Compare to layer coordinates.

level of known motion See reference level.

level of no motion A reference level at which it is assumed the horizontal velocities are practically zero. See Wunsch and Grant [1982], Killworth [1983] and Olbers and Willebrand [1984].

level surface See geopotential surface.

LEWEX Acronym for Labrador Extreme Wave Height Experiment. See Beal [1991].

lexicographer A writer or compiler of a dictionary or a glossary, i.e. a (relatively) harmless drudge.

LGM Abbreviation for Large Scale Geostrophic model, an ocean circulation model developed at MPI. It is based on the primitive equations and designed specifically to model global scale geostrophic circulation. The nonlinear advection of momentum is neglected and fast gravity waves are strongly damped via an implicit time integration scheme that uses a time step of 30 days. An upstream advection scheme us used for salinity and temperature transport and vertical convective mixing is applied when the stratification becomes unstable. The Arakawa E-grid is used for horizontal discretization and a small horizontal diffusion specified to alleviate the inherent mode-splitting problems of this grid scheme. Sea ice is computed from a heat balance and by advection by ocean currents with a simplified viscous rheology.

LHPR Abbreviation for Longhurst–Hardy Plankton Recorder. See Dunn et al. [1993].

libeccio A strong, squally southwesterly wind in the central Mediterranean, most common in winter.

LIE Acronym for Line Islands Experiment, a GARP project.

light compensation depth An ocean depth above which the intensity of photosynthetic assimiliation is greater than losses by respiration, and below which the reverse situation takes place where phytoplankton can exist only due to the organic matter that has been previously formed, i.e. due to conversion to heterotrophic nutrition. See Kagan [1995].

Ligurian Sea One of the seas that comprise the western basin of the Mediterranean Sea. It is located to the north of Corsica between the Balearic Sea to the west and the Tyrrhenian Sea to the east. See Fairbridge [1966] and Astraldi et al. [1990].

Liman Current A cold current that flows from the Okhotsk Sea into the Japan Sea. Part of this current continues south along the western coast and eventually becomes the North Korea Current.

Lincoln Sea A part of the Arctic Mediterranean Sea located on the Greenland-Canadian-Alaskan shelf. It is situated northeastward of Ellesmere Island and northwest of northern Greenland. See Newton and Sotirin [1997].

linear Characteristic of a system (the climate, etc.) wherein the output is always proportional to the input. As such, the output from a linear system can be predicted from knowledge of the input. An equivalent definition of a linear system is a system that satisifies the superposition principle, i.e. the combined effect on the output of two separate and distinct inputs can be found simply by combining, or superposing, their individual effects.

LISST Acronym for Laser In-Situ Scattering and Transmissometer, an instrument manufactored by Sequoia Instruments which measures the in-situ size distribution of particles from 5 to 250 microns in diameter in water with sediment loads exceeding 200 μ/l based on the principle of laser diffraction. It is usually attached to the POPS system and together they generate diagrams of the size distribution of particles and small aggregates in the water column without disturbing them via collection in water bottles. Particle aggregates in water bottles tend to fall apart before they can be measured, making the measurements of optical properties and settling dynamics obtained that way incorrect.

The LISST measures particle sizes by projecting a laser beam towards a series of concentric ring-shaped detectors. The angle at which the laser light is scattered depends on the particle size, with the smaller/larger particles scattering light toward the outer/inner detector rings. The distribution of particle sizes is proportional to the volume scattering function which is inverted to obtain the particle concentration and size spectrum. The LISST/POPS system converts this information into graphs showing the abundance of particles of each size. The original LISST-100 model measures particle size spectra, while an advanced model called the LISST-ST also measures in-situ settling velocity distributions. It does this by trapping a water sample and performing a series of measurements of the type described above over time. See the Sequoia Instruments Web site.

Little Climatic Optimum A period of time lasting from AD 750 to 1200 when the climate of Europe and North America was clement, even as far north as Greenland and Iceland. See Lamb [1985], p. 435-449.

Little Ice Age A return to colder climatic conditions beginning in about 1450 and ending around 1890. This was an era of moderate, renewed glaciation that followed the warmest known part of the Holocene. It was marked by the advance of valley glaciers in the Alps, Alaska, Swedish Lapland and New Zealand far beyond their present limits as well as by snow on the high mountains of Ethiopia where it is now unknown. The evidence points to two main cold stages, each lasting about a century, during the seventeenth and nineteenth centuries. Regional timings of the cold periods differed and thus some doubts have been raised as to the global nature of this phenomenon. See Grove [1988] for a book-length treatment of this period.

LIW Abbreviation for Levantine Intermediate Water.

LIWEX Acronym for Levantine Intermediate Water Experiment, which took place during winter–spring 1995 in the Levantine Basin to study the formation and spreading of Levantine Intermediate Water (LIW).

[http://earth.esa.int/symposia/data/santoleri2/]

LLWI Abbreviation for lower low water interval.

LODYC Abbreviation for Laboratoire de Physique de Océans.

LOICZ Abbreviation for Land Ocean Interactions in the Coastal Zone, an IGBP project directed at an assessment of:

- fluxes of matter between land, sea and atmosphere through the coastal zone;
- the responses of the land-sea interface to global change, particularl sea level rise;

- the biogeochemical responses of coastal systems to global change, with emphasis on the carbon cycle and exchanges of certain atmospheric trace gases; and
- socio-economic implications of the degradation of the coastal zone and the need for development of new policies for the integrated management of coastal environments.

The project began in 1993 with the establishment of the International Project Office (IPO) at the Netherlands Institute for Sea Research (NIOZ). The IPO is supported by the Dutch government and scheduled to run for ten years.

[http://www.nioz.nl/loicz/info.htm]

LOIS Acronym for Land-Ocean Interaction Study, the U.K. contribution to LOICZ. The project aims to quantify and simulate the fluxes and transformations of materials, e.g. sediments, nutrients, contaminants, into and out of the coastal zone, extending from the catchment to the edge of the continental shelf. The main study area is the U.K. East Coast from Berwick upon Tweed to Great Yarmouth, concentrating on the Humber River and its catchment. See the LOIS Web site[87].

Lombok Strait A strait located at 155°37'E–116°02'E and 8°20'S–8°50'S between the islands of Lombok and Bali in the Australasian Mediterranean Sea. This is one of many possible and the second largest of the passages for throughflow from the Pacific to the Indian Ocean, and connects the western Flores Sea to the Indian Ocean. The strait spans a length of about 60 km with a north–south orientation. It is about 40 km wide and 1000 m deep at its northern opening, but only 18 km wide and 300 m deep at the sill in the southern opening.

Despite its small size, the Lombok Strait is considered critical for the Indonesian Throughflow. This is because of a 600 m deep trough along the edge of the Sunda Shelf extending from south of Makassar Strait to north of Lombok Strait that effectively funnels a maximum salinity water mass from Makassar Strait directly to Lombok Strait. Its position at the edge of the Sunda Shelf also allows it to transport both Java Sea and Flores Sea surface waters to the Indian Ocean.

It is one of the few passages where measurements have been made. The transport has been found to vary semiannually between about 1 Sv in March to 4 Sv in September, comprising about 20–50% of the total Indonesian Throughflow. Currents in the Strait are bidirectional in the northeast–southwest direction, with large spatial and temporal variability. In the upper 100 m the currents are 150 m s^{-1} in the midstrait region and increase to 350 m s^{-1} toward the sill. The currents decrease with depth, although tidal currents of 80 cm s^{-1} are observed at 800 m. See Arief [1998].

Lombok Strait Experiment See Murray and Arief [1988].

longshore bar A ridge of sand running roughly parallel to the shoreline which may become exposed at low tide. There can be a series of these running parallel to one another at different water depths. See Komar [1976].

longshore current See Komar [1976].

longshore trough An elongated depression extending parallel to the shoreline and any longshore bars that are present and, like the longshore bars, there may be more than one present. See Komar [1976].

Loop Current The continuation of the Mediterranean Current through the Yucatan Strait and on into the Gulf of Mexico. It is dynamically a western boundary current that separates from the shelf north of the Yucatan Strait, becomes unstable, and intermittently sheds anticyclonic eddies or rings into the Gulf of Mexico. The speed of the current has been estimated to be 1.0 m/s in Yucatan Strait, falling off to

[87]http://www.pol.ac.uk/bodc/lois/lois.html

0.4 m/s at 1000 m depth. A highly irregular southward flowing undercurrent has also been found in the 200 m above the sill depth. See Maul and Vukovich [1993].

LOPACC Acronym for Late Quaternary Ocean Paleocirculation and Climate Change.

LOREX Acronym for Lomonosov Ridge Experiment, a 1979 Canadian Department of Energy, Mines and Resources multi–discliplinary project to study the nature and origins of the Lomonosov Ridge, an underwater 3000 m high mountain range running from the continental shelf off Greeland and Ellesmere Island to the Siberian continental shelf.

LOS Abbreviation for Law of the Sea.

LOSS Acronym for LAPS Observing System Simulation.

Lost Instrument Network A clearinghouse created at WHOI to collect and broadcast information about lost and found oceanographic research equipment. It is implemented as a moderated mailing list to which interested parties can subscribe.

[http://woodshole.er.usgs.gov/mmartini/lostlist/]

LOTUS Acronym for Long Term Upper Ocean Study, a two year Woods Hole study beginning in 1983 designed to acquire and analyze a continuous set of measurements of currents and temperatures throughout the water column in the open ocean. A total of ten moorings were deployed in about 5365 meters of water near 33deg N, 70deg W.

[http://uop.whoi.edu/data/lotus/lotus.html]

low Abbreviated form of low pressure center.

Low Density XBT Network A GOOS project to determine the monthly to interannual variability in the large–scale upper ocean heat constant via the operational deployment of XBT instruments from volunteer merchant ships.

[http://ioc.unesco.org/igossweb/xbt.htm]

low pass filter In data or signal analysis, a filter that passes frequencies below some cutoff frequency while attenuating higher frequencies.

low pressure center In meteorology, a region of relatively low barometric pressure. These are characterized by upward moving air at altitude and convergence near the ground. These predominate in midlatitudes, i.e. around 40-50°. These are also known as cyclones and as such rotate clockwise/counterclockwise in the southern/northern hemisphere. Low pressure systems are generally characterized by clouds, precipitation, and occasionally thunderstorms, all of which are facilitated by the upward movement of moist air from near the ground.

lower high water (LHW) The higher of two high waters on a day when the tide is neither The lower of two low waters on a day when the tide is neither predominantly diurnal nor predominantly semidiurnal but rather intermediate to either (a situation sometimes called a mixed tide).

lower high water interval (LHWI) The time interval between the transit of the moon over either the local or Greenwich meridian and the next lower high water (LHW). This is generally used when the diurnal inequality is large.

lower low water (LLW) The lower of two low waters on a day when the tide is neither predominantly diurnal nor predominantly semidiurnal but rather intermediate to either (a situation sometimes called a mixed tide).

lower low water interval (LLWI) The time interval between the transit of the moon over either the local or Greenwich meridian and the next lower low water (LLW). This is generally used when the diurnal inequality is large.

LPO Abbreviation for Laboratoire de Physique des Océans.

LROD Abbreviation for Long–Range Overwater Diffusion, an experiment that took place in the Pacific Ocean northwest of Kauai, Hawaii in July 1993. The objective was to improve transport and diffusion models by improving the understanding of alongwind diffusion. The experiment involved a series of airborne SF_6 releases from an Air Force C–130 transport aircraft, which flew perpendicular to the prevailing wind direction and released lines of SF_6 in the marine boundary layer. A second aircraft with a continuous SF_6 analyzer sampled the plume at distances up to 100 km downwind, with six small boats also tracking the plume to similar distances. Analyses indicated that both vertical and downwind diffusion components are needed for highly accurate model simulations.

[http://www.noaa.inel.gov/frd/Projects/lrod.html]

LSG Abbreviation for Large Scale Geostrophic model, an ocean general circulation model (OGCM) developed at the Max–Planck–Institut für Meteorologie in Hamburg, Germany. See Maier-Reimer et al. [1993].

LSS Abbreviation for Light Scattering Sensor, an instrument built by SeaTech and used to obtain in-situ measurements of light scattering in sea water. This measurement also provides a crude measure of the particle abundance in the water. The instrument works by projecting a beam of light into the water and measuring the amount of light scattered back to a detector place next to the source. The OBS is a similar instrument.

LSW Abbreviation for Labrador Sea Water.

LTE See Laplace's tidal equations.

Luzon Undercurrent A subsurface countercurrent located on the shoreward side of the Kuroshio Current with an upper boundary at about 500 m. The current is about 50 km wide and, despite considerable variability in both velocity profile and intensity, is apparently a permanent feature. The maximum speed relative to 2500 db is calculated to be 7 cm s^{-1} at about 700 m and the mean geostrophic volume transport 3.6 Sv. The latter was composed of about 28% NPIW. See Tangdong et al. [1997].

lysocline The upper portion of the transition zone in sediments between supersaturated (shallow) and undersaturated (deep) sediments in the ocean. The transition is between the burial and dissolution of CaCO3 sediments. See Najjar [1991].

0.11 M

Mach number More later.

MADAM Acronym for Mediterranean Assistance and Data Management in Oceanography, an initiative to set up and run an infrastructure to provide assistance in the field of oceanographic data management to the MTP, including the different subprojects and associated MAST projects. The general objective of MADAM is to compile and produce an up–to–date dataset, the MTP Data Set, comprising data from the MTP as well as a set of basic tools for the scientific use of the data. Secondary objectives include managing and making available the data set during the course of MTP, set up and running a network to provide links between associated scientists, and providing support for subprojects for specific data handling problems.

[http://bali.cetiis.fr/madam/]
[http://www.gets.cadrus.fr/madam/]

Madden-Julian oscillation See Madden and Julian [1994].

Madeira Mode Water A type of Mode Water formed north of Madeira in the North Atlantic Ocean. It is characterized by a summer thermostad at 70-150 m depth and provides a major contribution to the formation of North Atlantic Central Water (NACW). See Siedler et al. [1987].

Mad Sea An instance of the meteorological tsunami phenomenon in the Strait of Sicily. See Candela et al. [1999].

maestro A northwesterly wind in the Adriatic, most frequent on the western shore and in summer. This is also applied to northwesterly winds in other parts of the Mediterranean.

MAGE Acronym for Marine Aerosol and Gas Exchange, an IGAC activity beginning in 1990 to study the major sources and sinks of trace species that affect the radiative balance of the earth either directory or indirectly by altering the photochemistry of the marine atmosphere. The scientific goals of MAGE were:

- to understand the chemical, biological and physical mechanisms that control the exchange of trace gases and particulate material between the atmosphere and ocean surface;
- to develop formulations of ocean exchange processes for inclusion in global–scale climate and air chemistry models; and
- to extend the experimental knowledge of air–sea interchange to conditions with strong winds, rough seas and spray.

[http://web.mit.edu/igac/www/sub_pages/mage.html]

MAHLOVS Acronym for Middle and High Latitude Ocean Variability Study, an investigation whose aim is to study and characterize bio–physical interactions and variability in the atmosphere–ocean–biology system.

Maine Bottom Water (MBW) See Bisagni et al. [1996].

Maine Coastal Current See Bisagni et al. [1996].

Maine Intermediate Water (MIW) See Bisagni et al. [1996].

Maine Surface Water (MSW) See Bisagni et al. [1996].

Makaroff Deep See Guiana Basin.

Malabiss Expedition See Rice [1986b].

Mallorca Channel A passage between Ibiza and Mallorca with a sill depth of 500 m. See Pinot et al. [2002].

Maluku Sea See Molucca Sea.

Malvinas Current A jet-like northward looping extension of the Antarctic Circumpolar Current located in the southwest Atlantic Ocean. The cold waters of this current form an intense front with the warm waters of the Brazil Current as it separates from the continental shelf at around 35° S. This is also called the Falkland Current. See Tomczak and Godfrey [1994] and Vivier and Provost [1999].

MAMBO Acronym for Mediterranean Association of Marine Biological Oceanography, an ICSU project.

map projections Any of an extremely large number of methods for mapping, or projecting, the spherical (well, almost) Earth onto a two-dimensional surface. An overview of map projections[88] is available on the Web.

MARE Acronym for Mixing of Agulhas Rings Experiment. See Boebel et al. [2003].

marginal ice zone (MIZ) The interface between seasonal sea ice and open water. This is not a clear–cut boundary but a complex belt with distinct characteristics. The MIZ may be up to 100–200 km wide, with the poleward parat comprising broken ice in the early stages of melting. The geographic location of the outer edge can vary over relatively short time scales due to compaction and release caused by variations in wind stress.

MARGINEX Acronym for Margin Experiment, an Antarctic CRC large–scale hydrographic experiment along the continental shelf and slope region of Antarctica from 80° to 165° E whose objectives include:

- estimating the rate of formation of surface and Antarctic Bottom Water (AABW) masses;
- defining the evolution and modification of Antarctic water masses along the shelf and slope in this region;
- estimating the relative importance of air–sea interaction and advection of surface and deep waters on property changes in the major water masses; and
- constructing numerical models of the formation and dynamics of water masses south of the Antarctic Convergence over the full seasonal cycle.

The MARGINEX experiment consisted of two components. The first was carried out from March through April 1995 in the eastern region from 150deg to 165deg E. The Nathaniel B. Palmer was used for CTD and tracer work on a 45 day cruise from March 16 to April 30. The second component was carried out in early January 1996 on the Aurora Australis on a cruise to study both the hydrography and the krill population. The experiment was timed to coincide with the minimum sea–ice extent for the region, and was the optimum period for the sampling of the summer water masses and krill abundance on the continental shelf. The hydrographic measurements covered the region from 80 to 150deg E with eight north–south transects connected by sparse zonal sections in the deep water. This CTD network created a total of seven closed volumes against the Antarctic coast. The transects were spaced at approximately every 10deg of latitude and were designed to extend from the coast to the Antarctic Divergence.

`[http://www.antcrc.utas.edu.au/antcrc/research/polar/oceanproc/marginex.html]`

[88]http://www.utexas.edu/depts/grg/gcraft/notes/mapproj/mapproj.html

Margules' equation In physical oceanography, an equation that allows the estimation of the slope of the surface density discontinuity associated with geostrophic motions in the sea and of fronts in the atmosphere from a knowledge of the component speeds of geostrophic motion along the interface and the density difference across the interface. The equation is given by

$$\frac{\delta z}{\delta n} = \frac{f}{g} \frac{\rho' c' - \rho c}{\rho - \rho'}$$

where δz is a finite increment of vertical distance, δn a finite increment of horizontal distance along the dip of the interfacial slope, f the Coriolis parameter, g the gravitational acceleration, ρ the density, and c the geostrophic velocity parallel with one side of the interface, and the primed variables the values of corresponding properties on the other side. This equation is helpful in clarifying the sometimes confusing problem of estimating the change of frontal slope as a function of latitude or a change in density contrast across the front at the same latitude but with different velocities of flow. See Von Arx [1962].

Mariana Basin See Siedler et al. [2004].

marine biogeography See Hedgpeth [1957a].

marine bioluminescence See Tett and Kelly [1973].

marine palynology The study of pollen deposits in marine sediment records. See Stanley [1969].

marine pollution See Duursma and Marchand [1974].

marine snow Oceanic particles which are amorphous, heterogeneous aggregates greater than 500 μm and composed of detrital material, living organisms and inorganic matter. See Fowler and Knauer [1986] and Alldredge and Silver [1988].

Marine XML A project to create a universal marine data standard within the XML or Extensible Markup Language environment.

[http://ioc.unesco.org/iode/activities/marine_xml.htm]

MARIS Acronym for the MARine Information Service, a project in the Netherlands to improve the overview of and access to marine expertise, information, and data related to the sea and its uses. See the MARIS Web site[89].

Maritime Province Current See Mid-Japan Sea Current.

Marmara Sea A marginal sea centered near 28.5° E and 40.5° N whose primary significance is to serve as part of the connection between the Black Sea and the Mediterranean Sea. It reaches 75 km in width, 250 km in length, has a surface area of about 11,500 km^2, and a maximum depth of 1390 m. It is located between the Bosporus Strait to the northeast (which connects to the Black Sea) and the and the Dardanelles to the west (which connects to the Aegean Sea).

The northern part of the Marmara comprises three topographic depressions. The eastern (1240 m), central (1389 m) and western (1097 m) basins are connected by sills about 750 m and widths (from west to east) of 20 km and 40 km. The southern continental shelf is shallow (100 m) and wide (30 km), while the northern shelf is much narrower (< 10 km).

The mean upper layer circulation is a basin scale anticyclonic gyre driven mainly by the sea level differences between the Black Sea and the Aegean Sea. This gyre is modified by the Bosphorous jet

[89] http://www.ssynth.co.uk/north-holland/maris/

during high outflow conditions in spring and early summer and by the wind stress during the winter. See Besiktepe et al. [1994].

Marrobbio See Mad Sea.

MARSEN Acronym for the Maritime Remote Sensing Experiment, an experiment to measure ocean surface waves with a high frequency radar that took place from Sept. 10, 1979 to Oct. 15, 1979. MARSEN was originally a ground truth campaign to provide and calibration and validation of SEASAT's microwave instruments, although that focus was somewhat relaxed when SEASAT failed after gathering data for only 90 days. MARSEN included a collection of studies on wave dynamics, air–sea fluxes, and remote sensing via aircraft and ground–based systems, and was carried out in the North Sea. Key results included that drag coefficients depended on sea state and wave age, and that shallow water waves produce higher drag than deep water waves. See Hasselmann and Shemdin [1982] and Geernaert [1990].

Count Marsigli (1658–1730) See Peterson et al. [1996], p. 32.

MARVOR Abbreviation for Marvor float, a multicycle RAFOS type float developed by IFREMER and TEKELEC (now MARTEC). A MARVOR float cycles several times between the surface and its planned depth during its mission. When it surfaces it sends the data collected to the ARGOS satellite which relays it to land-based stations. It is equipped with a hydraulic system that controls its depth by transferring oil from an internal reservoir to the external ballast. See Ollitrault and et al. [1994].

`[http://www.ifremer.fr/lpo/eurofloat/technic.html]`

MASFLEX From Tsunogai et al. [2003]:

> As a part of Japanese Joint Global Ocean Flux Study (JGOFS) of IGBP/SCOR study, marginal sea flux experiments in the West Pacific (MASFLEX) was performed in the East China Sea. This project was also a part of Japan-China Joint Program on material flux in the East China Sea (MAFLECS) and the first land-ocean interactions in the coastal zone (LOICZ) study within IGBP. The project began in April 1992 and continued for 5 years under the support of Science and Technology Agency of Japan (STA). Its main goal was to clarify a role of marginal and coastal seas in the biogeochemical cycles of carbon, nitrogen and other substances relating to global change. Participants of this project came from 17 research groups in many different disciplines (chemistry, physics, biology, and sedimentology). This multi-disciplinary approach made possible to elucidate the highly complex nature of biogeochemical cycle of materials in the marginal sea. The outcome of his program is shown by the many MASFLEX publications at the end of this preface.
>
> The MASFLEX project was divided into two phases, phase I (April 1992–March 1995) and phase II (April 1995–March 1997). During the first phase, we chiefly occupied stations along an observation line, PN line, from the China coast to the Kuroshio region in the central part of the East China Sea. Three cruises were conducted by the R.V. `Kaiyo` of Japan Marine Science and Technology Center, JAMSTEC (15 February-10 March 1993; 26 September–3 November 1993; 20 July–30 August 1994). Additional cruises were carried out on other vessels (22 February–5 March 1994 by R. V. `Natsushima` of JAMSTEC; 3–21 June 1994 by R.V. `Tansei` of University of Tokyo; 26 September–12 October 1994 by R.V. `Bosei-Maru` of Tokai University). The second phase was concentrated in the continental shelf and slope zones to evaluate the material exchange between the shelf region and the open sea during two cruises of R.V. `Kaiyo` of JAMSTEC (21 October–25 November 1995; 22 August–30 September 1996).

See Tsunogai et al. [2003].

MASIG Abbreviation for Mesoscale Air–Sea Interaction Group.

masl Abbreviation for meters above sea level.

mass spectrometry A method for making isotope abundance measurements on gases in geochemical work. The instrument separates and detects ions on the basis of the motions of charged particles with different masses in magnetic or electrical fields.

MATE Acronym for the Midocean Acoustic Transmission Experiment, a project of the APL of the University of Washington Department of Oceanography. It was conducted near Cobb Seamount in the Northeast Pacific Ocean about 450 km off the coast of Washington during June-July 1977. In this experiment simultaneous measurements of temperature and velocity time series, vertical and horizontal temperature profiles, and acoustic transmissions were performed to attempt to ascertain the effects of internal waves on acoustic transmissions. See Ewart and Reynolds [1984].

MATER Acronym for the Mediterranean Targeted Project, a multidisciplinary project carried out within the MAST framework. MATER combined physical and ecological modeling with intensive field activity carried out in the three sub–basins of the Mediterranean Sea that show a progressive eastward gradient of oligotrophy. The project objectives were:

- to study and quantify the triggering and controlling transfer processes of mass (water, particles, natural and anthropogenic, stable and radioactive elements) and energy between the different compartments (land-sea, sea-atmosphere, upper-deep waters, water-sediment, living-nonliving, pelagos-benthos) in contrasting environments (from eutrophic to oligotrophic);
- to appraise the time and space scales of the phenomena, in identified structures of the Mediterranean system; and
- to investigate the ecosystem response to these transfers.

See Monaco and Peruzzi [2002].

Maury, Matthew Fontaine (1806–1873) See Peterson et al. [1996], p. 79.

MAW Abbreviation for Modified Atlantic Water.

MBL 1. Abbreviation for Marine Biology Laboratory, located at WHOI. 2. Abbreviation for marine boundary layer.

MCDW Abbreviation for Modified Circumpolar Deep Water.

MCM Abbreviation for mechanical current meter.

MCSST Abbreviation for multichannel sea surface temperature, a satellite SST data set derived from the TIROS-N/NOAA series satellite AVHRR. SST estimates are obtained from AVHRR radiances by first using radiative transfer theory to correct for the effects of the atmosphere on the observations. This is done in so–called windows of the spectrum where little or no atmospheric absorption occurs. Channel radiances are transformed (through the use of the Planck function) to units of temperature, and then compared to a prior temperatures measured at the sruface. This yields coefficient which, when applied to AVHRR data, provide SST estimates with a nominal accuracy of 0.3°C. See Wick et al. [1992].

`[http://podaac.jpl.nasa.gov/mcsst/]`

MCTEX Abbreviation for the Maritime Continent Thunderstorm Experiment, conducted from Nov. 13 to Dec. 10, 1995 over the Bathurst and Melville Islands located approximately 50 km off the coast of Australia's North Territory. The basic objective was to improve knowledge of the dynamics and interaction of the physical processes involved in the organization and life cycle of tropical island convection over the Maritime Continent and the role of this convection in the atmosphere energy and moisture balance.

[http://www.atmos.washington.edu/~gcg/Mctex.site/]

mean meridional circulation An average circulation feature or cell defined to consist of the zonal-mean meridional and vertical velocities. In the tropics and subtropics this mean meridional circulation cell is known as the Hadley cell and in midlatitudes as the Ferrel cell.

mean sea level (MSL) A concept defined differently in the fields of tidal analysis and geodesy. In tidal analysis, MSL means the still water level averaged over a period of time such as a month or year so periodic changes in sea level due to, e.g. the tides, are also averaged out. MSL values are measured with respect to the level of benchmarks on land, and as such a change in an MSL can result from either a real change in sea level or a change in the height of the land on which the tide gauge is located (e.g. from isostatic rebound). In geodesy, MSL usually means the local height of the global Mean Sea Surface (MSS) above a level reference surface called the geoid. See Lisitzin [1963].

[http://www.nbi.ac.uk/psmsl/puscience/]

MECBES Acronym for Marine Environment Changes and Basin Evolution in the East Sea of Korea, a KORDI project.

[http://key.kordi.re.kr/home/mecbes.htm]

MECCA Acronym for Model for Estuarine and Coastal Circulation Assessment.

MEDATLAS A project to create a hydroraphic data bank for the Mediterranean Sea. The objectives are to create a data project which includes an update of currently available data sets, a quality control of the data set in conformance with IOC and MAST recommendations, revised climatological statistics for the Mediterreanean Sea, and making the final product available electronically.

[http://www.ifremer.fr/sismer/program/medatlas/gb/gb_medat.htm]
[http://ioc.unesco.org/medar/]

meddy A coherent, clockwise–rotating lens of warm salty Mediterranean outflow water. Meddies are typically 40–150 km in diamter and contain maximum salinities of around 36.5 psu and maximum temperatures of around 13.0°C in the depth range 800–1400 m. As they translate westward from the eastern boundary of the Atlantic into cooler and fresher water, their core waters become apparent as large anomalies that can reach 1 psu and 4°C. The anomalously warm and salty meddy core water extends vertically from around 600 to 1700 m, and density sections show the lens shape frequently extending from the surface down to at least 2000 m, with the dynamical structure extending beyond the layers occuped by temperature and salinity anomalies. They are often found in the vicinity of the Azores Current which flows eastward near 34°N, its cut–off rings, and other eddies.

Meddies are generated along the southwestern boundary of the Iberian Peninsula, usually where the downstream topography takes a sharp bend to the right and the Mediterranean Undercurrent separates from the coast. They typically translate northwestward near the boundary, then more westward, and finally southwestward with a typical speed of 2 cm/s. About 70% are inferred to collide with the Horseshoe Seamounts, either disintegrating or being greatly weakened, with the remaining 30% passing northward around the seamounts and into the Canary Basin. Many of the meddies that make it into the Basin end up colliding with the Great Meteor Seamounts.

The central core region of a meddy rotates with nearly solid body rotation at each depth between about 500 and 1500 m. Maximum rotation rate and swirl velocity $\sim$ 30 cm/s are found near the central depth of the core, i.e. $\sim$1000 m, although the central depth varies from 700 to 1200 m depending on density structure. The diameter of maximum swirl velocity ranges from 20 to 50 km, and beyond the region of solid body rotation swirl velocities appear to decay exponentially with radius. Some axes have been observed to tilt due to the background geostrophic shear.

The mean lifetime of a newly formed meddy has been estimated to be about 1.7 years, although some have been observed to last over 5 years. An estimated 17 meddies form each year, which when combined with the typical lifetime suggests that about 29 meddies coexists in the North Atlantic at any one time. Some meddies have been observed to coalesce and others to split, although there are no percentage estimates for these phenomena.

Over the long term these meddies, each slowly releasing its surplus of heat and salt, inject their contents into and serve to partially form the upper part of North Atlantic Deep Water (NADW). The term 'meddy' originated with the discovery by McDowell and Rossby [1978] of a subsurface eddy containing a clockwise rotating core of warm salty water in the western North Atlantic north of Hisponola. After concluding that the eddy water had characteristics of Mediterranean Water from the eastern Atlantic, they called it a meddy. See Richardson et al. [1991] and Richardson et al. [2000].

MEDEA/JASON The first academic remotely operated vehicle (ROV) system. MEDEA/JASON was developed in 1982 and included a dynamically controlled surface ship, shipboard control center, fiber optic wire and winch system, the MEDEA relay vehicle, the ROV JASON, a satellite link, and shore–based control and data processing centers. The long–term objective of the program is to permit scientists to have full access to the at–sea operations from shore–based satellite downlink sites, including full control of the vehicles from shore. The primary purpose for the original development was to bridge the gap between seafloor data gathered by acoustic and visual imaging systems. It was found to be difficult to cross–correlate acoustic and visual data sets. Although the former allowed the mapping of a much larger area than the latter, the latter offered much greater detail on smaller scales. Thus the goal was to combine the use of high–frequency acoustic sensors and low–light level large–area visual sensors on the same platform. See Ballard [1993].

MedGLOSS A sea level program for the Mediterranean and Black Seas under the auspices of the CIESM and IOC.

`[http://medgloss.ocean.org.il/]`

MEDI A directory of information about marine related datasets that consists of metadata, i.e. data about other datasets. The aims of MEDI are to catalog which data is available, when and where it was collected, and where it is located. It is intended as a reference point for locating marine and coastal datasets, and as a means for advertising the availability of new datasets.

`[http://www.aodc.gov.au/IODE/MEDI/]`

median valley The official IHO definition for this undersea feature name is "the axial depression of the mid–oceanic ridge system."

mediolittoral zone The second (from the surface) of seven zones into which the benthos has been divided. In this zone organisms are more or less regularly emerged and submerged, usually by the action of the tides. Species are here adapted to resist prolonged emersion and are generally incapable of living if continually emerged. See Fairbridge [1966].

MEDIPROD See Millot et al. [1997].

mediterranean sea A generic term used to describe a class of ocean basins that have limited communication with the major ocean basins and in which the circulation is dominated by thermohaline forcing. This causes a circulation that is the reverse of that found in the major basins, i.e. it is driven by salinity and temperature differences and only modified by wind action. Mediterranean seas exhibit the dynamics of estuaries rather than those of open oceans. Examples include the Arctic Mediterranean Basin, Australasian Mediterreanan Basin, and of course the Mediterranean Sea.

Mediterranan seas can be further distinguished by their balance of precipitation and evaporation. If evaporation exceeds precipitation, the deep vertical convection occurs and the water below the sill depth is frequently renewed. The open ocean connection features inflow in the upper layer and outflow in the lower layer since the inflow is driven by the freshwater loss in the upper layer. This is called a concentration basin.

If precipitation exceeds evaporation, then the surplus of fresh water in the upper layer drives an outflow of surface water into the connecting major basin. The decrease in surface density also results in an increased pressure difference at the connecting sill which in turn results in inflow in the lower layer and even more outflow in the upper layer. A very sharp pycnocline is established which inhibits the renewal of the deep waters. This type of basin can be depleted in oxygen even to the point of anoxia in the lower layer. This is known as a dilution basin.

Mediterranean Sea A semi–enclosed basin containing many of the characteristics found in the open ocean, e.g. deep and intermediate water formation, jets, eddies, and intense air–sea interaction. It is an evaporation basin wherein the average heat loss is -7 W m^2, with the most significant heat loss occuring in the northern portion, particularly in the Gulfe de Lion and northern Adriatic Sea were deep water is formed.

The general pattern of the circulation of the deep and intermediate waters in the Mediterranean was first schematized by Wüst [1961]. Relatively fresh water from the Atlantic flows in through the Strait of Gibraltar and through a series of eddies and jets to replace the water convectively overturned by intense air–sea interaction, with the latter flowing out of the Mediterranean through the Strait of Gibraltar. Deep water is produced in the Gulfe du Lion and the Adriatic Sea. It fills the deepest portions of the western and eastern Mediterranean basins which are separated by the Strait of Sicily. Levantine Intermediate Water (LIW) is formed in the eastern Mediterranean near the Rhodes gyre and spreads at intermediate depths, i.e. near 300 m in the eastern basin and between 200 and 800 m in the western basin. Most of the Mediterranean outflow is LIW, with only about 10% consisting of Western Mediterranean Deep Water (WMDW).

A more recent summary is provided by Theocharis et al. [1998]:

> A schematic pattern of the Mediterranean circulation can be described in terms of four basic constituents:
>
> 1. The nonreturn flow of the low–salinity Modified Atlantic Water (MAW) from the Gibraltar to the eastern end of the Levantine in the upper 150–200 m.
> 2. The formation and westward spreading of the warm and saline Levantine Intermediate Water (LIW) from the formation region in the northwest Levantine and South Aegean Seas to the Gibraltar, where it enters the Atlantic Ocean.
> 3. The formation of a cold and dense water in the Adriatic Sea and the subsequent southward and then eastward spreading as it fills the deepest parts of the East Mediterranean to form the East Mediterranean Deep Water (EMDW).
> 4. The formation in the Gulf of Lions of the West Mediterranean Deep Water (WMDW), which then spreads to the deep layers of the West Mediterranean and occasionally participates in the Mediterranean outflow into the Atlantic.

> The actual circulation picture, however, is rather complex, consisting of basin–scale, subbasin–scale and mesocale structures. Permanent, recurrent and transitional cyclonic and anticylonic gyres and eddies, usually locked over topographic escarpments are interconnected by currents and jets. The complexity of the circulation is caused by the combination of the wind forcing with the surface and lateral thermohaline fluxes imposed by water exchange through straits and river input, the topographic and coastal effects, and the internal dynamics characterized by a Rossby internal deformation radius around 10–15 km. There is strong evidence of seasonal, interannual and multiannual variability. The water formation processes are active in both the open–sea and shelf areas under the influence of intense winter air–sea interactions and local circulation patterns that favor the atmospheric exposure of subsurface water.

See Wüst [1961], Robinson et al. [1992], Theocharis et al. [1998], Baringer and Price [1999], Send et al. [1999] and Balopoulos et al. [1999].

Mediterranean Surface Water See Perkins and Pistek [1990].

Mediterranean Undercurrent A current originating from the dense Mediterranean Sea water overflowing the Strait of Gibraltar It cascades down the continental slope and equilibrates at depths of 500–1500 m in the northern Gulf of Cadiz, forming a westward flowing boundary current. Large segments of the Undercurrent separate from the boundary in the form of 40–100 km diameter lenses of warm, salty Mediterreanean Water called meddies. See Baringer and Price [1997], Baringer and Price [1999] and Richardson et al. [2000].

Mediterranean Water (MW) In physical oceanography, a water mass formed in the arid eastern Mediterranean Sea that flows westward and sinks in the Algero-Ligurian and Alboran basins to depth of about 500 m due to its relatively high salinity of 36.5 to 39.1. It continues westward into the Atlantic Ocean through the shallow Straits of Gibraltar (at depths below 150 m) where it sinks to about 1000 m, forming a distinctive water mass with a temperature of 11-12° C and a salinity of 36.0-36.2. It can be recognized as a salinity and temperature maximum near 1000 m. This is also denoted as EMW or Eurafrican MW to distinguish it from Australasian MW. See Tomczak and Godfrey [1994].

MEDMEX Acronym for Mediterranean Models Evaluation Experiment, whose aim is to achieve an intercomparison of existing models that have been applied to the Mediterranean Sea.

[http://modb.oce.ulg.ac.be/MEDMEX/]
[http://sit.iuav.unive.it/mednet/ocean/medmex.html]

MEDOC Acronym for MEDiterranean Ocean Circulation, an international cooperative hydrographic investigation of the sources of deep water formation in the Mediterranean Sea. The original investigation was planned for January to March 1969.

A preliminary survey was mude during the first half of January by the British ship H.M.S. *Hydra* with the scientific work directed by Dr. J. C. Swallow of the National Institute of Oceanography. It occupied a grid of STD stations with 20 nautical mile (37 km) spacing, with the stations placed on a strip 60 nautical miles (110 km) wide from north to south centered on a line running parallel to the French coast from 41°40' N and 4°10' E to 43°20' N and 8°15' E.

The main campaign ran from Jan. 24 through Mar. 31 and involved the following ships and chief scientists:

- the N.O. *Jean Charcot* from the Laboratoire d' Océanographie Physique, Paris with principal scientists H. Lacombe and P. Tchernia;

- the F.N.V. *Origny* from the Bureau d'Études Océanographiques, Toulose and the La Bouée Laboratoire from the Centre Nationale pour L'Exploitation des Océans, Paris with principal scientists M. Ribet and J. Bonnot;
- the R.V. *Bannock* from Occanoboe, San Terenzo with principal scientist R. Frassello;
- the R.R.S. *Discovery* from the National Institute of Oceanography, Wormley with principal scientist J. C. Swallow; and
- the R.V. Atlantis II from Woods Hole Oceanographic Institution and MIT with principal scientists A. R. Miller and Henry Stommel.

The work done included water bottle stations, STDs, bathysondes, measurements of SST and meteorological parameters, and current measurements. Two aircraft were used to make airborne radiation measurements.

A supplementary campaign called MEDOC 1970 to planned for February to March 1970, although it was a smaller expedition. Only the N.O. *Jean Charcot* and the R.R.S. *Discovery* participated in the second investigation, whose goal was to discover the repeatability of the phenomena discovered the previous year, as well as to apply refined observational techniques. See Group [1969].

MEDS Acronym for Marine Environmental Data Service, a branch of Canada's DFO whose mandate is to manage and archive physical and chemical oceanographic data collected by DFO regions or acquired through various arrangements from Canadian researchers and from foreign research conducted in the major ocean areas adjacent to Canada. See the MEDS Web site[90].

Megapolygon–87 An experiment taking place in the Pacific subarctic frontal zone in 1987. See Maximenko et al. [2001].

Meinardus Line See Polar Front.

MEIW Abbreviation for Modified East Icelandic Water.

Mellor–Yamada model A general turbulence closure model often used in atmospheric and ocean general circulation models. The components or assumptions used to develop the model are:

- a hypothesis relating the pressure–velocity and pressure–density gradient covariance terms to linear functions of the Reynolds stress and density flux;
- the extension of the Kolmogorov hypothesis to dissipation terms involving the fluctuating density gradients;
- Fickian type gradient terms for turbulence diffusion terms;
- the definition (from the above) of four length scales and a nondimensional constant, all of which are assumed proportional to one another or to a master length scale, leaving five constants to be determined (usually from measure laboratory turbulence data); and
- a process of formula simplification based on assumed small departures from isotropy, leading to a hierarchy of model versions.

See Mellor and Yamada [1982] and Mellor [2001].

Menai Strait See Campbell et al. [1998].

[90]http://www.meds.dfo.ca/

Menard, Henry (1920-1986) A marine geologist at Scripps who in 1958 suggested a continuous process of mid-ocean ridge development.

`[http://scilib.ucsd.edu/sio/archives/siohstry/menard-biog.html]`

MER Acronym for the Marine Ecosystem Response program, a research initiative jointly supported by NOAA and NSF geared toward the generation of quantitative scenarios for the impact of the climate system on marine ecosystems such as the economically significant fisheries in the northeast U.S. See the MER Web site[91].

Merian's formula In the study of seiches and harbor resonance, this is an equation that gives the natural period of a long and narrow basin in terms of its length and depth for the various modes of oscillation. It is given by

$$T = \frac{2a}{n\sqrt{gh}}$$

where T is the period, a is the length of the basin, n is the mode number, g gravitational acceleration, and h the basin depth. See Raichlen [1966].

MERIS Acronym for Medium Resolution Imaging Spectrometer, an ocean color sensor. It is a push-broom instrument that measures the radiation reflected from the Earth's surface and from clouds in the visible and near-infrared range during the daytime. The 1150 km wide swatch of the instrument is divided into 5 segments covered by 5 identical cameras having corresponding fields of view with slight overlap between adjacent cameras. The geophysical parameters derived from MERIS measurements include ocean color in open and coastal waters, e.g. chlorophyll, gelbstoffe, and other pigments, qualitative parameters such as presence ofclouds and emerged land, and atmospheric parameters like aerosol optical thickness, cloud albedo, Angstrom exponent, top pressure, and water vapor column contents. See the MERIS Web site[92].

MERMAIDS Acronym for Mediterreanean Eddy Resolving Modeling and Interdisciplinary Studies, a study whose main goal is to assess the internal variability of the Mediterranean thermohaline circulation as induced by deep and intermediate water formation processes and the inflow/outflow system at Gibraltar on the seasonal and interannual time scales.

`[http://www.imbc.gr/biblio_serv/mast/X0043_172.html]`
`[http://www.imga.bo.cnr.it/mermaids/SYNFIN.html]`

Mersa Matruh Gyre The strongest sub–basin scale feature of the Eastern Mediterranean general circulation. This gyre exhibits upper thermocline velocities reaching 20–30 cm s^{-1} and is located in the southwestern Levantine Basin. It is found north of the Egyptian coast and generally between 26–30°E and 32–34.5°N, and has a diameter of 250–350 km. There are variabilities associated with the location, orientation, strength and number of centers of the gyre, but it is a quasi–permanent feature of the circulation in the area. This gyre was defined and named during phase I of the international research program POEM. See Golnaraghi [1993].

mesopelagic zone One of five vertical ecological zones into which the deep sea is sometimes divided. This is the uppermost aphotic zone from 200 to 1000 m deep where little light penetrates and the temperature gradient is even and gradual with little seasonal variation. This zone contains an oxygen minimum layer and usually the maximum concentrations of the nutrients nitrate and phosphate. This overlies the bathypelagic zone and is overlain by the epipelagic zone. See Bruun [1957].

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[91] http://www.noaa.gov/ogp/mer.html
[92] http://acri.cica.fr/English/Studies/Spatial/MERSS.html

mesoscale To be completed.

Meteor Expedition See Spiess [1985].

meteoric water Water produced by or derived from the atmosphere. Meteoric waters start as precipitation in the hydrologic cycle, and the source thereof is evaporation from oceanic surfaces.

Meteoric Water Line An equation expressing a correlation between deuterium and oxygen-18 in meteoric waters. The equation is expressed as del D = 8 * del oxygen-18 + 10. See Bowen [1991].

meteorological equator The latitude of the mean annual position of the equatorial trough. This is located at about 5° N rather than on the geographical equator. See Riehl [1954].

meteorological tsunami The excitation of short period (on the order of minutes) sea level oscillations near a coast by the passage of atmospheric pressure gravity waves. See Rabinovich and Monserrat [1996].

Meteosat A European geostationary meteorological satellite operated by EUMETSAT.

method of dynamic sections See dynamic method.

Mexican Current (MC) See Badan-Dangon [1998].

MGD77 Abbreviation for the marine geophysical data format established in 1977 for the exchange of digital underway geophysics data. It was created at a workshop held at the NGDC in January, 1977 and is sanctioned by the IOC. The later HYD93 data format was based on this. Documents providing the details of the standard are available at the MGD77 FTP site.

Michael Sars A Norwegian research vessel with which the first meticulous systematic measurements were made at many stations in the Norwegian Sea. See Murray and Hjort [1912] and Wüst [1964].

MICOM Acronym for the Miami Isopycnic Coordinate Ocean Model, a ocean circulation model that uses isopycnic coordinates in the vertical. See the MICOM Web site[93].

micronutrients Mostly nitrate, phosphate and silicic acid. See Spencer [1975].

Middle Atlantic Bight The region of the continental shelf off the eastern United States beginning at Cape Hatteras and extending northeast to Cape Cod. The shelf topography is relatively smooth throughout the Bight, with depth increasing linearly from shore to shelf break except near submarine canyons. Several estuaries provide fresh water to the shelf, with the most important being Chesapeake Bay. The Bight has a mean along–shelf current moving southwest towards Cape Hatteras, except during periods of strong northward winds and low river discharge. The along–shelf current turns offshore as it approaches Cape Hatteras, entraining the relatively cool and fresh shelf water into the warmer and saltier Gulf Stream.

A sharp frontal boundary exists along the shelf break, separating the cooler shelf water from the warmer, more saline slope water. Most of the variability observed in the MAB is due to forcing by strong winds from synoptic storms. The waters are well mixed in the winter, with the coolest water near the shore. Stratification increases during the summer as increased fresh water discharge and solar heating induce buoyancy forcing at the surface. The stratification is destroyed in the fall by storm passages and surface cooling. See Beardsley and Boicourt [1981].

[93] http://www.rsmas.miami.edu/groups/micom.html

Mid-Japan Sea Current A slow southward cold water movement into the Polar Front in the Japan Sea. This is also known as the Maritime Province Current.

mid–oceanic ridge See ridge and rise.

Milankovitch forcing The name given to the changes in the amount or seasonal distribution of solar radiation that reaches the Earth as caused by the orbital changes predicted by Milankovitch theory.

Milankovitch theory The theory that changes in the geographic distribution of solar insolation due to planetary perturbations of the Earth's orbital characteristics are the primary driving force for the cycles of glaciation seen in geological and fossil records. See Berger [1988].

mild slope equation See Mei [1990].

MILDEX Acronym for MIxed Layer Dynamics EXperiment, multi-institutional cooperative experiment which took place in a deep water region (4700 m) about 650 km off Pt. Conception in central California. Two ships and two floating platforms were used to make measurements of the surface meteorological forcing and the temperature and current response of the near–surface layers in the ocean. See Paduan et al. [1989].

MILE Acronym for MIxed Layer Experiment. See Levine et al. [1983] and Halpern et al. [1981].

MIMR Abbreviation for Multifrequency Imaging Microwave Radiometer, a passive microwave radiometer successor to the Special Sensor Microwave/Imager (SSM/I) that provides greater frequency diversity, improved spatial resolution, increased swatch width, and improved antenna performance. It is used to observe atmospheric and oceanic parameters such as precipitation, soil moisture, global ice and snow cover, SST, wind speed, atmospheric cloud water, and water vapor. See the MIMR Web site[94].

Mindanao Current A southward flowing boundary current along the Philippine coast (from about 13 to 8° N at about 127° W) that closes the counterclockwise wind-driven gyre of which the North Equatorial Current (NEC) and the North Equatorial Countercurrent (NECC) are the northern and southern limbs, respectively. The westward flowing NEC splits at the Philippine coast and the Mindanao Current (MC) flows southward, carrying North Pacific subtropical thermocline and surface waters toward a region of confluence with South Pacific waters near 5° N. Part of the flow continues along the Philippines and on into the Celebes Sea, with the remainder turning eastward at the confluence and contributing to the aforementioned NECC as well as the Equatorial Undercurrent and the Northern Subsurface Countercurrent. This eastward turn also serves to spin-up a recirculation feature historically called the Mindanao Eddy, although the Eddy may be an intermittent rather than a persistent feature.

The MC is an energetic coastally trapped jet with speeds reaching over 0.9 m s^{-1} at the shelf break, with a standard deviation of measured velocities of less than 0.1 m s^{-1} indicating low current variability. It is broadest at the surface and narrows to a width of 150 km at 300 m depth. The average transport above the thermocline has been estimated from direct measurements to be $24 \pm 4 \times 10^9$ kg s^{-1}, with the estimate from hydrographic surveys virtually identical.

The MC contains distinct cores of high salinity North Pacific Central Water (NPCW) and low-salinity North Pacific Intermediate Water (NPIW), with each salinity core associated with elevated concentrations of dissolved oxygen indicative of the source connection with the subtropical gyre. See Wijffels et al. [1995].

Mindanao Dome See Mindanao Eddy.

[94]http://rimeice.msfc.nasa.gov:5678/mimr.html

Mindanao Eddy A cyclonic circulation gyre or eddy sometimes found to the east of Mindanao centered at about 8° N and 135° E. The southward flowing section near the coast is part of the Mindanao Current, and the Eddy can be thought of as the recirculation cell of this current. The southward flow does not extend beyond a depth of 250 m and is underlain by a deep western boundary current flowing northward (from about 250 to 500 m) at a rate of 16-18 Sv. The transport has been estimated at around 25-35 Sv with strong interannual variations. At least one investigation of the Mindanao Current at 8 ° N noted the absence of the Eddy, and as such it may be an intermittent feature of the circulation field. This has also been called the Mindanao Dome. See Tomczak and Godfrey [1994] and Wijffels et al. [1995].

Mindanao Sea See Bohol Sea.

Mindanao Undercurrent A northward flowing current beneath and offshore of the Mindanao Current. This has been estimated by some investigators to have speeds ranging from 0.15 to 0.30 m s^{-1} and transports between 8 and 22 $X\,10^9$ kg s^{-1}, although others have found it to be more of a transient phenomena than a permanent circulation feature. See Wijffels et al. [1995].

mistral A northwesterly or northerly wind which blows offshore along the north coast of the Mediterranean from the Ebro to Genoa. In the region of its chief development its characteristics are its frequency, its strength, and its dry coldness. It is most intense on the coasts of Languedoc and Provence, especially near the Rhone delta. Its speeds are usually around 40 knots, but can reach over 75 knots in the delta.

mixed layer In oceanography, a nearly isothermal surface layer of around 40 to 150 m depth caused by wind stirring and convection. Brainerd and Gregg [1995] defined this as “the envelope of maximum depths reached by the mixing layer on time scales of a day or more, i.e. the zone that has been mixed in the recent past. It generally corresponds to the zone above the top of the seasonal pycnocline.”

In the winter, low surface temperatures and large waves (with their accompanying turbulent mixing) can deepen the mixed layer all the way to the permanent thermoclinethermocline. Higher temperatures and a less energetic wave climate in the summer can lead to the development of a seasonal thermocline at the base of the mixed layer that overlies the permanent thermocline.

Various objective definitions for the mixed layer depth have been proposed and used, e.g.:

- Price et al. [1986] defined the mixed layer as a quasi–homogeneous surface layer where the temperature was uniform to within 0.2°C (with the stratified layer between the mixed layer and the undisturbed fluid beneath called the transition layer);
- Levitus [1982] defined the mixed layer depth as the depth at which the density increases by 0.125 density units from the surface value.

The general criteria that have been used are summarized by Brainerd and Gregg [1995]:

> Two types of mixed and mixing layer depth definitions have been most commonly used. The first is based on specifying a difference in temperature or density from the surface value; for density
>
> $$\sigma_\theta(D) - \sigma_\theta^0 = (\delta\sigma_\theta)_C \qquad (15)$$
>
> where σ_θ^0 is the value of the surface and $(\delta\sigma_\theta)_C$ is the specified difference. This type of criterion suffers from difficulties in defining the surface value, particularly during convection. The second type of criterion is based on specifying a gradient in the temepratùre or density;
>
> $$\frac{\delta\sigma_\theta}{\delta z} = \left(\frac{\delta\sigma_\theta}{\delta z}\right)_C \qquad (16)$$

where $\delta\sigma_\theta$ is the difference in σ_θ within a vertical bin of thickness δz and $(\delta\sigma_\theta/\delta z)_C$is the specified gradient criterion. This criterion is sensitive to the vertical scale over which the (first–differenced) gradients are computed.

. . .

Criteria of both types based on temperature rather than density have been extensively used, as temperature has been easier to measure reliably than density. This works well in many locations, as both the daily and seasonal cycles in surface forcing have large heat fluxes, and weak salt fluxes. However, intense rainfall can produce strongly stratified pools of fresh water that necessitate accounting for salinity in determining both mixed and mixing layer depths.

They state that the density difference criteria is more stable than the gradient criteria, with values of $(\delta\sigma_\theta)_C = 0.005$ and 0.01 kg m^{-3} giving the best results for determining mixing layer depths. The best mixed layer depth results were obtained with $(\delta\sigma_\theta)_C = 0.05$ to 0.5 kg m^{-3}. They conclude, however, that while both criteria are able to find the mixed layer depth rather well, neither consistently returns the mixing layer depth. The latter requires measurements that resolve the turbulent overturns within the mixing layer.

Peter Rhines reviewed recent progress in understanding the mixed layer (at the APROPOS conference). The ocean mixed layer is one of the ...

... The double turbulent boundary layers through which the ocean and atmosphere communicate. Classical models begin with the Ekman layer, still a viable object because of its robust (integral) independence from the detailed turbulent stress. The Krauss-Turner process of "solving" the energy equation with assumed dependence of energy dissipation and mixing on the surface stress led to the most widely used models, particularly after later inclusion of bulk momentum dynamics. More detai led attempts at modelling effects of fully developed turbulence have led to more complex mixed-layer models, and a generation of "large-eddy-simulation" models. Here and in the atmospheric boundary layer community the power of theory seems not up to the task of relating fluxes of heat, momentum, tracers to their mean gradients, given the variety of environments in which boundary layers occur. Important observations of mixed-layer structure made in the 1980s began to "test" or "calibrate" the models, and emphasized the importance of time-dependence, including diurnal heating effects on stability. The difficulties of turbulence have been soothed, at least, by direct turbulence measurement. But of greater importance was the discovery or rediscovery of distinct events in the mixed layer, particularly Langmuir roll vortices aligned with the wind. Innovative observations of bubble clouds with acoustic imaging, and 3-dimensional Lagrangian particle histories with floats, in company with a series of theories involving surface-wave/mean flow interaction and with laboratory experiments in wave flumes, have led to significant advances. Key elements of the Craik-Leibovitch theory of their generation appear to be present, yet with important contributions from wave-breaking.

Theory has moved on, in other directions, by taking more seriously the large-scale environment in which the boundary layers are embedded. Stable density stratification and convection, and time-dependent forcing produce a new set of constraints. We see "Ekman demon" interaction of downward pumping by wind-stress and seasonal mixing and a family of calculations trying to relate water-mass creation to surface boundary conditions ("warm", subtropical- and "cold", subpolar subduction). A group of "geostrophic adjustment" theories, developed after the pattern of Rossby's original calculations, add vital time-dependence. The study of sharp density fronts begun in atmospheric sciences is found to have many applications in the oceanic mixed layer: determining for example whether lateral wind-driven

> Ekman transport remains at the surface or is channeled to the interior when it encounters a front. These are familiar lessons of oceanographic theory: we cannot and should not wait for a 'theory of turbulence' before working on the many aspects of theory of the communication of the mixed layer and the geostrophic interior. Often, by proceeding with a GFD problem with new physical effects added, one can circumscribe and perhaps avoid the missing elements of turbulence.

See Kara et al. [2000].

mixed layer models According to Ranvindran et al. [1999], models of the surface layer of the ocean can be classified into two groups: differential models and depth–integrated bulk models. The bulk models originate with Kraus and Turner [1967], and are developed by integrating the heat and energy conservation equations over the mixed layer. These models are limited by the assumptions used in the model formulations, two notable ones being that (i) a well–mixed layer exists a priori and (ii) there is a density discontinuity at the base of the mixed layer. The differential models can be traced to the paper of Mellor and Yamada [1974] on turbulent closure models for boundary layers. These are useful but limited by substantial computational requirements. See Ranvindran et al. [1999].

mixed layer ocean See slab ocean.

mixing layer Brainerd and Gregg [1995] define this as "the depth zone being actively mixed from the surface at a given time, generally corresponding to the depth zone in which there is strong turbulence directly driven by surface forcing." Compare to mixed layer.

mixing length A concept used in the parameterization of turbulent transport processes. According the this model, fluid masses called eddies, distinguishable from the ambient fluid, spring into existence in some undefined way and then, after moving unchanged over a certain path length, become indistinguishable from the surrounding fluid. This path length, over which the eddy mixes with the surrounding fluid, is called the mixing length. This model is analogous to the mean free path of a molecule or atom between collisions. See Liou [1992], p. 219.

mixing ratio See water vapor mixing ratio.

MIZ Abbreviation for marginal ice zone.

MIZEX Acronym for Marginal Ice Zone Experiment. See Quadfasel et al. [1987] and Geernaert [1990].

MLIW See Modified Levantine Intermediate Water.

ML-ML Abbrevation for Marine Light-Mixed Layers, a research program designed to study mixed layer dynamics and bioluminescent plankton production. The program focuses on seasonal changes in upper layer physics and the successive populations that are responsible for bioluminescence. See Marra [1989].

`[http://uop.whoi.edu/data/mlml/mlml.html]`

moat The official IHO definition for this undersea feature name is "an annular depression that may not be continuous, located at the base of many seamounts, oceanic islands and other isolated elevations."

MOBY Acronym for Marine Optical Buoy, an instrument deployed off the coast of Lanai, Hawaii in Feb. 1994 to measure visible and near-infrared radiation entering and emanating from the ocean. The variations of the visible reflected radiation are referred to as the ocean color, a property from which other quantities such as the abundance of phytoplankton can be derived. MOBY will thus provide a time-series database for bio-optical algorithm development and the calibration of such satellite instruments as SeaWiFS, MODIS, and MERIS. See the MOBY Web site[95].

[95] http://spso.gsfc.nasa.gov/eos_observ/1_2_94/p17.html

MOCE Acronym for Marine Optical Characterization Experiment, a series of field experiments at different ocean sites to obtain a comprehensive set of bio-optical measurements such as radiometry, pigment analysis, total suspended matter, beam transmittance, and physical properties. See the MOCE Web site[96].

MOCNESS Acronym for Multiple Opening Closing Net and Environmental Sampling System, a multiple net system used in biological oceanography to sequentially sample zooplankton at different depths or for collecting serial samples at the same depth. See Wiebe et al. [1976].

MODB Abbreviation for Mediterranean Oceanic Data Base, a project to deliver advanced data projects for oceanographic research in the Mediterranean Sea. See the MODB Web site[97].

MODE Acronym for the Mid-Ocean Dynamics Experiment, an program carried out between March and July 1973. The project explored – using different instruments to measure the same phenomena from dissimilar views – the role of mesoscale eddy motions in the dynamics of general oceanic circulation. MODE was also one of the first large–scale, extensively instrumented experiments performed by physical oceanographers. Henry Stommel was the chief motivating factor for MODE, the plans for which were solidified at a meeting at WHOI on July 20–24, 1970. Responsibility and authority for the experiment were in the hands of a 21 member MODE Scientific Council, with the membership consisting of the principal investigators from each of the experiments projects and representatives from the MODE Theoretical Panel. A six member Executive Committee additionally monitored the operation of the experiment. The principal source of funding was the NSF's Office for the Decade of International Ocean Exploration, with other sources including ONR, NOAA and the British NERC.

MODE was conducted in two phases between November 1971 and July 1973. The MODE–1 field program was carried out between March and July 1973. It was the culmination of a 16–month theoretical and observational field study known both as MODE–0 and PREMODE. It was a collection of 12 experimental and theoretical projects performed simultaneously, with the field program concentrated on a 600 square kilometer test site that extended from 28° N 69° 49' W, an area in the ocean between Bermuda and Florida. An important experimental component was the use of different instruments to measure the same phenomena from dissimilar views. It employed six ships, two aircraft, and new and sophisticated instruments such as neutrally buoyant floats, free fall velocity profilers, and air–dropped current probes. The design of the experiment relied heavily on objective mapping.

The experimental phase was followed by a two–month summer institute program at the University of Rhode Island in July and August of 1974, during which discussions with the ten–member Russian delegation led to the planning of POLYMODE. See McWilliams [1976a] and McWilliams [1976b].

[http://www.aip.org/history/ead/mit_mode/19990043_content.html]

Mode Water A type of water created by property modification in the vicinity of ocean fronts, especially during winter. Convection creates a deep surface layer containing water of nearly uniform temperature and salinity in regions that usually feature strong horizontal and vertical gradients. A Mode Water core is defined by the existence of minima in vertical gradients. Commonly used properties are temperature and potential density anomaly, with the minimum gradient layer then being known as, respectively, a thermostad or pycnostad.

The mode water sinks along isopycnal surfaces, retaining its properties since they can only be changed by mixing with the surrounding water. Since deep mixing processes are much weaker at depth than near the surface, mode waters tend to retain their characteristics for great distances as they move

[96] http://spso.gsfc.nasa.gov/eos_observ/1_2_94/p17.html
[97] http://modb.oce.ulg.ac.be/

around the ocean basins. Their persistent properties make them excellent tracers for climate change studies since they retain a record of surface conditions at the time of their formation.

There are two general varities of mode water: subtropical mode water and subpolar mode water. Types of subtropical mode waters include:

- Eighteen Degree Water
- North Pacific Subtropical Mode Water
- North Atlantic Subtropical Mode Water
- Madeira Mode Water

Types of Subpolar Mode Waters include:

- Subantarctic Mode Water
  - Antarctic Intermediate Water
  - Southeast Indian SAMW
- North Atlantic Subpolar Mode Water

See McCartney [1982] and McCartney and Talley [1982].

Modified Atlantic Water (MAW) A water mass that originates as Atlantic Water (AW) entering the Mediterranean Sea via the Gibraltar Straits. It spreads via the Sicily Straits into the eastern Mediterranean as MAW in a layer confined to the upper 200 m. The Levantine Intermediate Water (LIW) flowing westward beneath it exits into the northern Atlantic where it constitutes the salty Mediterranean outflow water. MAW becomes progressively saltier along its route from the Sicily Straits to the Levantine basin, but exhibits little seasonality. See Perkins and Pistek [1990] and Malanotte-Rizzoli et al. [1997].

Modified Circumpolar Deep Water (MCDW) A Southern Ocean water mass located below the Antarctic Surface Waters (ASW) and above the Antarctic Bottom Water (AABW). MCDW is differentiated from Circumpolar Deep Water (CDW) by being defined as colder and fresher than the regional CDW for a given density. Although the distinction between CDW and MCDW is admittedly fuzzy, it can be generally said that most of the CDW found in the open ocean will be unmodified, and that most on the shelf and slope will be modified. According to Whitworth et al. [1998], one could expect to find MCDW throughout the Antarctic slope region and anyplace else where upwelling causes enhanced entrainment into the surface layers, such as in the central dome of the Ross and Weddell gyres, or where local bathymetry produces upwelling, such as at Maud Rise in the Weddell Gyre.

Various other names have been applied to water masses now subsumed under MCDW. These include modified Circumpolar Water, slope water, Modified Warm Deep Water, anomalous water, Warm Core, Prydz Bay Bottom Water and Weddell–Scotia Confluence Water. See Whitworth et al. [1998] and Orsi et al. [1999].

Modified East Icelandic Water (MEIW) A water mass comprising part of the Iceland–Faroe Ridge overflow. This water mass has also been called NI/AI (for either 'North Icelandic (NI) Winter water/Irminger Sea (AI) water' by Meincke [1974], or 'North Icelandic (NI) Winter water/Arctic Intermediate (AI) water' by Müller et al. [1979]), and is commonly called Arctic Intermediate Water (AIW) when it reaches the Faroe–Shetland Channel. It was denoted MEIW by Read and Gould [1992].

MEIW acquires its main character in a region close to the ridge by the mixing of different water masses and sinking in the frontal zone. It is identified as a salinity minimum with salinities typically from

34.70 to 34.90 and temperatures 1.0 to 3.0°C. It is considered to be a mixture of Modified North Atlantic Water (MNAW), Norwegian Sea Arctic Intermediate Water (NSAIW), East Icelandic Water (EIW) and Norwegian North Atlantic Water (NNAW). It can be seen forming a cold tongue along the Jan Mayen Front and then sinking and progressing southwards towards the Faroe Islands in between MNAW and NNAW. See Hansen and Osterhus [2000].

Modified Levantine Intermediate Water (MLIW) A modified form of Levantine Intermediate Water (LIW) found in the Adriatic Sea. It has a temperature of 14°C and a salinity of 38.7 psu. See Artegiani et al. [1993].

Modified Warm Deep Water (MWDW) A type of water in the seas surround Antarctica that separates overlying Winter Water (WW) from underlying AACW.

MODIS Abbreviation for Moderate-Resolution Imaging Spectroradiometer, an instrument built to fly on EOS AM-1 and that will view the entire Earth's surface every 1 to 2 days acquiring data in 36 spectral bands to improve our understanding of globa dynamics and processes occurring on the surface of the Earth, in the oceans, and in the lower atmosphere. See the MODIS Web site[98] and King et al. [1992].

modon To be completed.

Mohn, Henrik (1835–1916) See Peterson et al. [1996], p. 100.

MOIST Acronym for Moored Oceanographic Instrument SysTem.

Molucca Sea One of the seas that comprise the Australasian Mediterranean Sea. It is centered at approximately 127° E and 2° N and is bordered by Sulawesi to the west, Halmahera to the east, the Sula Islands to the south, and Mindanao and the Pacific to the north. The approximately 200,000 sq. km area of this sea are underlain by a fairly complex series of troughs, basins and ridges that are usually divided into three north-south zones. The westernmost zone is the Sangir Trough connecting Davao Gulf in Mindanao with the Gorontalo Gulf; the central zone a broad ridge outlined by the 2000 m isobath which bears the Talaud and Miangas islands in the north; and the eastern zone a series of depressions and basins. This is also variously called the Maluku Sea.

The Molucca Sea is an important passageway for deep water flowing from the Pacific Ocean through the Australasian Mediterranean and on into the Indian Ocean. One branch of flow through the Molucca is composed of deep flow from the Pacific through the Sangir Trough and on into the Sulawesi Sea, while another branch has flow entering via the Morotai Basin and exiting via the Gorontalo Basin south of Sulawesia as well as through the Lifamatola Strait into the Banda and Ceram Seas. Surface salinities depart at most 0.3 from an annual average of 34.0, although higher salinities have been recorded late in the year in the north and southern extremities. The surface salinities range from 28.3° C in June to 27.0° C in January.

The monsoon winds drive the surface circulation, changing slowly in direction from northeast to north-northwest during the southern summer and generally reversing direction during the winter months. As such a slow current flows southwestward along the eastern margin of the sea along with an opposite (northward) flowing current of similar strength in the western half in the winter months. The northward flow is maintained throughout the year except in the northern reaches where an east-southeast directed current occurs in the summer months. See Fairbridge [1966] and Cresswell and Luick [2001b].

MOM 1. Acronym for Modular Ocean Model, a primitive equation general ocean circulation model developed at GFDL. It is intended to be a flexible tool for exploring ocean and coupled air-sea applications

[98] http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html

over a wide range of space and time scales. See the MOM Web site[99] for further information. 2. Acronym for Musée Océanographie de Monaco.

Monaco Deep See Canary Basin.

MONEX Acronym for the summer and winter Asian Monsoon Experiments, a component of FGGE designed to study monsoonal circulations. See Luyten and Roemmich [1982].

monsoon A periodic wind caused by the effects of differential heating, with the largest and most notorious being the Indian monsoon found in the Indian Ocean and southern Asia. The word is thought to have originated from the Arabic word mausim meaning season. See Webster et al. [1998].

[http://paos.colorado.edu/~webster/mw/jgrpaper/jgrmonsoon1.html]

Monterey Bay See Breaker and Broenkow [1994].

Monterey Bay Aquarium Research Institute (MBARI) A research institute established in 1987 with the goal of developing state-of-the-art equipment, instrumentation, systems, and methods of scientific research in the deep waters of the ocean. See the MBARI Web site[100].

Montgomery potential A quantity defined as

$$M_o = \alpha p + \phi$$

where α is the specific volume, p the pressure, and phi the geopotential, i.e. gz. The Montgomery potential represents an exact stream function on specific volume anomaly surfaces. This is also known as the Montgomery stream function and the Bernoulli function in the geostrophic approximation.

Montgomery stream function See Montgomery potential.

MOODS Acronym for Master Oceanographic Observational Data Set. See Teague et al. [1987].

Moored Profiler (MP) An instrument designed and built at WHOI to acquire repeated, high vertical resolution, full water column profiles of ocean currents and water properties at a fixed site. It does this by climbing up and down a fixed mooring via a traction system using a highly efficient electric motor, with battery capacity providing for over one million meters of vertical profiling. Data are stored on a hard disk during a deployment and and downloaded once the instrument is on deck. The MP can also return real–time data via satellite using inductive telemetry through the mooring cable. It is designed to carry a wide variety of sensors including a CTD and an acoustic phase–shift current meter (ACM). See the MP Web site[101].

MOOS Acronym for MBARI Ocean Observing Systems, a research program to improve the understanding of the relationships between climatic variability, ocean circulation, marine chemistry, and phytoplankton biomass, composition and production with the use of moored platforms with unattended sensors, satellite imagery, and shipboard surveys. See the MOOS Web site[102].

MORENA Acronym for the Multidisciplinary Oceanographic Research in the Eastern Boundary of the North Atlantic project, with the general objective of measuring, understanding, and modeling shelf-ocean exchange in a typical coastal upwelling region of the eastern boundary layer of the subtropical ocean. See the MORENA Web site[103].

[99] http://www.gfdl.gov/ kd/MOMwebpages/MOMWWW.html
[100] http://www.mbari.org/
[101] http://hrp.whoi.edu/hrpgrp/mvp/mvpcover.html
[102] http://www.mbari.org/Ocean_Research/1996/MBARI-Ocean-Observing-Systems.htm
[103] http://www.mth.uea.ac.uk/ocean/morena.html

Mornington Abyssal Plain One of three plains that comprise the Pacific-Antarctic Basin (the others being the Amundsen and the Bellingshausen Abyssal Plains. It is located at around 85-95° W.

Mosely Deep See Cape Verde Basin.

Mozambique Current A western boundary current that flows south-southwestward between the African coast and Madagascar from about 10 to 35° S. The flow has been estimated at about 6 Sv near 15° S increasing to 15 Sv near 20° as the northward looping East Madagascar Current turns back towards the south and joins it. This combined flow eventually becomes the major part of the Agulhas Current.

MP Abbreviation for Moored Profiler.

MSL Abbreviation for Mean Sea Level.

MSP Abbreviation for Multi–Scale Profiler, a dropsonde that resolves horizontal velocity over scales ranging from the ocean depth to microscale by combining electromagnetic, acoustic and hydrodynamic lift data on small airfoils. See Winkel et al. [1996].

MSR Abbreviation for Microstructure Record, an instrument developed by the APL.

mss Abbreviation for mean square sea slope, a quantity used to provide an estimate of the sea surface roughness for wind stress calculations. The directionally integrated mss of the sea surface is defined by

$$s^2 = \int_{\infty}^{\infty}\int_{\infty}^{\infty} k^2 \psi(\mathbf{k})\, d\mathbf{k}$$

where $\psi(\mathbf{k})$ is the directional wavenumber and $\mathbf{k}$ the wavenumber vector. See Banner et al. [1999].

MSW Abbreviation for Mediterranean Surface Water.

MTOC Abbreviation for Monitoring Transport of Ocean Currents, a project of sorts.

MTP An abbreviation for Mediterranean Targeted Project, a CEC/CGXII/MAST2 project engaged in oceanographic research activities in the Mediterranean Sea area during the period 1993–1996. It covers the disciplines of physics, chemistry, biology, geology, and biochemistry and involves approximately 180 scientists from 40 European instiutions and 14 countries. See the MTP Web site[104].

MTPR Abbreviation for miniature temperature pressure recorder.

MUDAB A project of the BSH operated by the DOD. It serves as the central German data base for marine data within the framework of international and national conventions for the protection of the North Sea and Baltic Sea. See the MUDAB Web site[105].

Multiple Current Hypothesis A hypothesis advanced by Fuglister [1951] that the Gulf Stream system is irregular, varying and discontinuous east of the Grand Banks. The dearth of observations available in 1951 led him to suggest that an instantaneous chart, if available, would show a number of disconnected filaments of current rather than a continuous stream. This is an obvious foreshadowing of later developments predicated on more extensive theoretical and observational work that showed the instabilities to which the Gulf Stream is prone as it leaves the coast and heads east. It wanders and sheds eddies both north and south, processes that do indeed lead to the impression of a number of disconnected filaments. See also Stommel [1966].

[104] http://bali.cetiis.fr/madam/doc/mtp/mtpdesc.htm
[105] http://www.bsh.de/abtm/m5/dod/mudab10e.htm

multi–year ice A type of sea ice defined by the WMO as:

> Old ice up to 3 m or more thick which has survived at least two summers' melt. Hummocks (hillocks of broken ice that have been forced up by pressure) even smoother than in second-year ice, and the ice is almost salt-free. Colour, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system.

This is more common in the Arctic than the Antarctic, being confined mostly to the western Weddell Sea and isolated embayments in the latter. See WMO [1970].

Murray, John More later.

MW Abbreviation for Mediterranean Water.

MWDW See Modified Warm Deep Water.

MWR Abbreviation for Mixed Water Region, a name given to the region between the Kuroshio Extension and the Oyashio Front because it is a location where waters of subtropical, subpolar, and Sea of Japan origin meet and are transformed. This has also been referred to as the "perturbed area" by Kawai [1972]. See Talley et al. [1995].

0.12 N

NAAG Acronym for North Atlantic Arctic Gateways Program, a JOIDES project.

NABE Acronym for North Atlantic Bloom Experiment, a 1989–1991 experiment that was one of the first major activities of JGOFS. It was a multidisciplinary and multinational study of the spring phytoplankton bloom in the North Atlantic and its associated biogeochemical processes. It was decided to conduct the pilot study in the North Atlantic because of its proximity to the founding nations of the project, the size and predictability of the bloom, and its fundamental impact on ocean biogeochemistry. The U.S. component took place from April through July 1989 on two cruises of the RV Atlantis II and one cruise of the RV Endeavor, with the stations located from 18–72deg N and from 8–47deg W. Research vessels from Canada, Germany, The Netherlands, and the U.K. also participated, along with over 200 scientists and students from more than a dozen nations.

Key scientific findings and technical advances during NABE included:

- the development and refinement of analytical techniques for CO_2, and the collection of a large data set on seasonal and spatial trends in spatial pCO_2;
- phytoplankton blooms are driven by an excess of production over consumption and export, leading to accumulations of biogenic material in surface waters;
- high rates of new production during blooms are supported by high concentrations of nitrate supplied during winter mixing;
- supplies of regenerated nutrients are abundant during the bloom;
- the unexpected importance of microbial activities during the bloom; and
- grazer activity may have stimulated bacterial production, e.g. a bacterial bloom lagged the phytoplankton bloom by 10–20 days.

See Ducklow [1989] and Ducklow and Harris [1993].

[http://www1.whoi.edu/mzweb/nabe.htm]
[http://usjgofs.whoi.edu/research/nabe.html]

NAC Abbreviation for North Atlantic Current.

NACOA Acronym for National Advisory Council on Oceans and Atmosphere, a U.S. committee.

NACW Abbreviation for North Atlantic Central Water.

NADW See North Atlantic Deep Water or North Adriatic Deep Water.

NAME Acronym for North American Monsoon Experiment, an effort to determine the sources and limits of predictability of warm season precipitation over North American, with emphasis on time scales ranging from seasonal to interannual.

[http://www.cpc.ncep.noaa.gov/products/precip/monsoon/NAME.html]

Jerome Namias (1910–1997) A meteorologist who was one of the best long–range forecasters. See Rasmusson [1998] and Cayan [1998].

[http://scilib.ucsd.edu/sio/archives/siohstry/namias-biog.html]
[http://www.nap.edu/readingroom/books/biomems/jnamias.html]

Namib Col Current An eastward–flowing current near 22°S east of the Mid–Atlantic Ridge in the Angola Basin. It forms a continuous circulation structure from the Namib Col (a saddle on the Walvis Ridge of depth 3000–3250 m) west past the Mid–Atlantic Ridge into the western trough, and is identified by salinity and oxygen maxima. The transport estimate from hydrographic sections is about 3.6×10^6 $m^3\ s^{-1}$. Associated with the current is a basin–wide salinity and oxygen front of varying intensity (weaker in the east) marking the transition to deep water whose North Atlantic characteristics have been partly erased by mixing with Circumpolar Deep Water (CDW) in the southwest South Atlantic. This current is a pathway for North Atlantic Deep Water (NADW) to cross and eventually leave the South Atlantic Ocean south of Africa. See Speer et al. [1995].

NAML Abbreviation for the National Association of Marine Laboratories, organized in the late 1980s and representing marine and Great Lakes laboratories. It is composed of three regional associations:

- Northeastern Association of Marine and Great Lakes Laboratories (NEAMGLL);
- Southern Association of Marine Laboratories (SAML); and
- Western Association of Marine Laboratories (WAML).

[http://www.mbl.edu/labs/NAML/]

nanoplankton Phytoplankton whose lengths range from 10 to 50 μm. Compare to microplankton and ultraplankton.

NANSEN Acronym for North Atlantic and Norwegian Sea Exchange, an experiment whose objectives were to study the hydrography and circulation of the Iceland Basin and to study the temporal and spatial variability of the flows across the Greenland–Scotland Ridge. The ship observations in support of NANSEN were collected from 1986 to 1989. It consisted of a series of loosely connected research cruises conducted by different nations and laboratories in the area of interest, with the planning and execution of the program also seen as a pre–WOCE phase in the eastern North Atlantic. The main topics addressed by NANSEN were:

- the origin and characteristics of the upper ocean water masses feeding the Norwegian Sea;
- the characteristics and fate of the outflowing cold water in the North Atlantic; and
- pathways and variations of the inflows and outflows.

See van Aken and Becker [1996].

[http://www.ices.dk/ocean/project/data/nansen.htm]

Nansen, Fridtjof A Norwegian scientist, diplomat and humanist who did much to advance the field of oceanography from the last decade of the 19th century until his death in 1930. He is the only oceanographer to ever win the Nobel Prize (in 1922), although he won it for his humanitarian work to aid refugees throughout Europe and Asia. He investigated many aspects of the northern polar regions, crossing the Greenland inland ice on his first polar expedition at the age of 27 in 1888 (after defending his dissertation in zoology on the histology of the central nervous system of the hagfish).

In 1892 he started planning what became known as the FRAM expedition, named after the polar vessel he specially constructed for this North Pole expedition. The significant results gained from that expedition included the discovery of a deep Arctic Ocean, the confirmation of the existence of a Transpolar Current, and observations of pack ice drift relative to the prevailing wind direction which provided the impetus for the later identification of the Ekman spiral (one of the cornerstones on which the modern theory of wind-driven circulation is built). The FRAM expedition and those that followed were also marked by careful measurement and compilation of data, detailed planning, and forceful execution, qualities that provided a firm baseline for all future expeditions.

Nansen had a strong practical bent as a scientist and explorer, improving old equipment and even inventing new equipment when the need arose. The most famous of his inventions was the Nansen bottle for sampling ocean water at various depths. He also strongly supported international cooperation in oceanography and, as a direct result, was one of the founding fathers of the International Council for the Exploration of the Sea (ICES) in 1902.

He become heavily involved in politics in his native Norway and played an important role in 1905 when Norway declared full independence from Sweden, which resulted in his being appointed the first Norwegian ambassador in London. After two years as ambassador, he returned to oceanography for several years until the advent of World War I, publishing the book The Norwegian Sea with B. Helland-Hansen during this period. He spent the remainder of his life after World War I engaged in various humanitarian activities until his death at age 60 in 1930, receving his Nobel Prize in 1922.

Nansen bottle A reversing water bottle comprising a water bottle and a pair of thermometers on a reversing frame. This was developed by Fridtjof Nansen around 1910. See Schlee [1973].

NAO Abbreviation for North Atlantic Oscillation.

NAS Abbreviation for National Academy of Sciences.

NASA Acronym for National Aeronautics and Space Administration.

NASCO Acronym for National Academy of Sciences (NAS) Committee on Oceanography, now replaced by OAB.

Natal Pulse Large, solitary meanders in the path of the Agulhas Current between Cape St. Lucia and the Agulhas Bank south of Africa. The pulses seem to originate in the region of the Natal Bight, a distinct offset in the coastline north of Durban. They manifest themselves as a cyclonic eddy in the current, move downstream at 10–20 km per day, and have diameters ranging from 30 to 200 km (growing steadily in size as they move downstream). It has been suggested that the Pulse may play a central role in the upstream retroflection of the Agulhas Current, and in the shedding of eddies from the seaward side of the current. See Lutjeharms and Roberts [1988] and de Ruijter et al. [1999].

NATFE Abbreviation for North Atlantic Transect Fluorescence Experiment, conducted between May 28 and June 6, 1993 aboard the CSS Hudson as the second leg of a collaborative research cruise between the IRSA of Italy and the BIO of Canada. Water was collected along a cross–basin transect from up to 13 depths between 0 and 120 meters, concentrated by gentle filtration, and a pump–and–probe fluorometer was used to estimate the minimum and maximum fluorescence yields on phytoplankton.

`[http://me-www.jrc.it/other/data/atlatext.html]`

National Academy of Sciences (NAS) An organization formed in 1863 to provide independent, objective scientific advice to the nation. The Environment and Earth Sciences Program Unit provides funding for oceanographic research.

`[http://www4.nationalacademies.org/nas/nashome.nsf]`

National Aeronautics and Space Administration (NASA) `[http://www.nasa.gov/]`

National Estuarine Research Reserve System (NERRS) A protected areas network of federal, state and local partnerships to enhance informed management and scientific understanding of the U.S. estuarine and coastal habitats. It was created with the 1972 Coastal Zone Management Act. As of

1996, 22 estuarine reserves encompassing over 425,000 acres of estuarine waters, wetlands, and uplands have been designated, with another 6 reserves in development.

[http://inlet.geol.sc.edu/cdmohome.html]

National Ice Center (NIC) A multi-agency operational center which includes personnel from two NOAA departments, the NESDIS and the NWS. Its mission is to provide worldwide, operational sea ice analyses and forecasts for the armed forced of the U.S. and allied nations as well as for other U.S. government agencies and the civil sector. These products are provided for the Arctic, Antarctic, Great Lakes and Chesapeake Bay.

[http://www.natice.noaa.gov/]

National Marine Sanctuary Program (NMSP) A NOAA program whose mission is to identify, designate and manage areas of the marine environment of special national significance due to their conservation, recreational, ecological, historical, research, educational, or aesthetic qualities. The program was established under Title III of the Marine Protection, Research and Sanctuaries Act of 1972 and is administered by the Sanctuaries and Reserves Division of NOAA.

The twelve sanctuaries (as of 1997) are the Channel Islands (California), Cordell Bank (California), Fagatele Bay (America Samoa), Florida Keys (Florida), Flower Garden (Florida), Gray's Reef (Georgia), Gulf of the Farallones (California), Hawaiian Islands Humpback Whale (Hawaii), Monitor (North Carolina), Monterey Bay (California), Olympic Coast (Washington), and Stellwagen Bank (Massachusetts) National Marine Sanctuaries.

[http://www.sanctuaries.nos.noaa.gov/welcome.html]

National Oceanic and Atmospheric Administration A branch of the U.S. Dept. of Commerce whose mission is to promote global environmental stewardship to conserve and wisely manage the nation's marine and coastal resources, and to describe monitor, and predict changes in the Earth's environment to ensure and enhance sustainable economic opportunities. NOAA comprises the following program offices: NESDIS, NMFS, NOS, NWS, OAR, COP, OGP and HPCC.

[http://www.noaa.gov/]

National Sea Grant A partnership program between NOAA and various universities that encourages the wise stewardship of marine resources through research education, outreach and technology transfer. It began in 1966 when the U.S. Congress passed the National Sea Grant College Program Act. There are at present 29 Sea Grant Colleges engaged in marine research.

NATRE Abbreviation for North Atlantic Tracer Release Experiment, an experiment that took place in the east–central Atlantic Ocean in March 1992 between 20–35° N and 35–10° W. See Montgomery et al. [1992].

natural variability The range of climate variations that would theoretically exist in the absence of anthropogenic forcing. Information on this hypothesized spectrum of climate variability can be derived from instrumental data, paleoclimatic reconstructions, and numerical model results.

Naval Oceanographic Office (NAVOCEANO) The mission of the U.S. Naval Oceanographic Office is to acquire and analyze global ocean and littoral data to provide specialized operationally significant products and services for warfighters and civilain, national and international customers. It is located at Stennis Space Center, Mississippi, USA and consists of around 1000 combined military and civilian personnel.

NAVOCEANO has its origin in 1830 when the U.S. Navy established the Depot of Charts and Instruments (DCI) to maintain a supply of navigational instruments and nautical charts for issue to naval vessels. Given the paucity of the available data, the DCI was soon enough obtaining its own data to produce charts, with the first products being four engraved charts published in 1837. These were published from the results of a survey by Charles Wilkes (later to lead the U.S. Exploring Expedition) that ranged over the eastern Atlantic to Antarctica, the coasts of both Americas, and into the west and southwest Pacific. The next five years saw 87 more chart published from the results of that survey.

A greater range of data became available after 1842 when Matthew Maury assumed commmand of the DCI. He suggested that all shipmasters submit reports to a central agency where it could be compiled and published for the benefit of all. This led to the submission of over 26 million reports to the DCI over the next five years, almost swamping the agency given its different and smaller original mission. These growing pains led to the name being changed to the U.S. Naval Observatory and Hydrographical Office in 1854, and again in 1866 when the two functions were separated with the latter half becoming the Naval Hydrographic Office with an expanded mission including carrying out surveys, collecting information, and printing charts.

The office continued to expand into the 20th century, with a significant landmark being the Titanic disaster of 1912 which led to the establishment of an ice patrol to document sea hazards. Shortcomings in the available data made obvious by the navigational needs of WWI led to the development of the first practical sonic sounding machine in 1922, a device allowing a quantum leap to be made in both the quality and quantity of available data. After Pearl Harbor and a forty–old increase in the demand for charts, the Office was moved to Suitland, Maryland and placed under the Chief of Naval Operations. Additional ships were obtained and outfitted such that 43 million charts were printed and issued in one year at the peak of WWII.

The office was given its present name in 1962 and relocated to its present location at NASA's Stennis Space Center in Mississippi in 1976, where it shares the facilities with over 20 other Federal and State agencies. The post–Cold War focus of the office has also shifted from deep water to coastal regions.

`[http://www.navo.navy.mil/]`

Navier-Stokes equations The fundamental equations of the dynamics of an incompressible and Newtonian. When $\nu = 0$, i.e. for infinite Reynolds numbers, the Navier-Stokes equations reduce to the Euler equations.

naviface The interface between the atmosphere and the ocean. This was proposed, along with the adjectival form navifacial, in Montgomery [1969].

NAVOCEANO Acronym for U.S. Naval Oceanographic Office. This is sometimes shortenedd to NAVO.

Nautilus Expedition More later.

NBC Abbreviation for North Brazil Current.

NCAAS Abbreviation for NOAA CoastWatch Archive and Access System, a part of the CoastWatch program that handles its data archival and distribution tasks.

`[http://www.nodc.noaa.gov/cwatch/ncaas-home.html]`

NCAR Acronym for the National Center for Atmospheric Research located in Boulder, Colorado. NCAR comprises five divisions: (1) Atmospheric Chemistry Division (ACD), (2) Atmospheric Technology Division (ATD), (3) Climate and Global Dynamics Division (CGD), (4) Mesoscale and Microscale Meteorology Division (MMM), and (5) Scientific Computing Division (SCD).

`[http://www.ncar.ucar.edu/ncar/]`

NCC Abbreviation for Norwegian Coastal Current.

NCCCS Abbreviation for Northern California Coastal Study, an experiment taking place from 1987–1989. See Bray and Greengrove [1993].

NCDC Acronym for National Climate Data Center, a branch of the NESDIS division of the Office of Environmental Information Services[106] of NOAA that is the collection center and custodian for all U.S. weather records.

[http://www.ncdc.noaa.gov/]

NCEP Abbreviation for National Centers for Environmental Prediction, a NOAA program to provide timely, accurate, and continuually improving worldwide forecast guidance products.

[http://www.ncep.noaa.gov/]

NDBC Abbreviation for National Data Buoy Center, a NOAA site that is the source of buoy-measured environmental data.

[http://www.ndbc.noaa.gov/]

NEADS Acronym for Northeastern Atlantic Dynamics Study, an array of instrumentation moorings anchored in the northeastern Atlantic basin in the early 1980s. This was a collaboration between West Germany, England and France and complementary to the contemporanous MODE program.

NEADW Abbreviation for Northeast Atlantic Deep Water.

NEAFC Abbreviation for Northeast Atlantic Fisheries Commission.

neap tide The tides produced when the gravitational pull of the Sun is in quadrature, i.e. at right angles to, with that of the Moon. These occur twice a month at about the times of the first and last quarters. In these situations the gravitational pull of the Sun/Moon produces high/low water or vice-versa, and as such the differences between high and low tides are unusually small, with both the high tide lower and the low tide higher than usual. The tidal height is about .375 that of maximum during neap tides. See also spring tide.

NEAR–GOOS The North–East Asian Region–GOOS is a regional pilot project of GOOS in the Northeast Asian region. It is implemented by China, Japan, the Republic of Korea, and the Russian Federation as a WESTPAC activity. The purpose of the project is to demonstrate the usefulness of a regional ocean observing system to encourage further such efforts. The primary aim of NEAR–GOOS is to share oceanographic data in real time via the Internet to support the daily mapping of sea conditions in the marginal seas bordered by NEAR–GOOS countries. Other goals include improving ocean services in the region, providing data and information useful in the mitigation of natural disasters, increasing the efficiency of fishing vessels, providing information for pollution monitoring, monitoring parameters useful to mariculture, and providing data sets required for data assimilation, modeling and forecasting.

The essential elements of NEAR–GOOS are two databases. The Real Time Data Base (RTDB) exists for the daily mapping of sea conditions and is maintained by the JMA for online access via the Internet. Data are kept in the RTDB for thirty days and then transferred to the Delayed Mode Data Base (DMDB), which exists for archiving data. The DMDB is maintained by the JODC. Associate data bases include the Chinese Delayed Mode Data Base (CDMDB) and the Korea Coastal and Ocean Information Service (KCOIS). Observations included in the NEAR–GOOS database include temperature, salinity, current and wind wave data from the GTS. They also contain observations carried out by users in participating countries using moored buoys, drifting buoys, platforms, coastal stations, research vessels, voluntary observing ships, and remote sensing data.

[http://ioc.unesco.org/goos/neargoos.htm]

[106] http://www.esdim.noaa.gov/

nearshore zone A zone extending from the upper limit of a beach to the offshore. In terms of the beach profile, it consists of (progressing seawards) the backshore, foreshore and inshore. In terms of the wave and current regimes, it consists of (again progressing seawards) the swash zone, surf zone and breaker zone. See Komar [1976].

NEAT GIN Acronym for North East Atlantic, Greenland–Iceland–Norwegian Sea Experiment, an experiment which took place during Sept.–Oct. 1989 at the Norwegian shelf edge near 68° N and comprised seven moorings, five in a closely spaced cross–slope section.

[http://www.pol.ac.uk/oshi/neatgin.html]

NEC Abbreviation for North Equatorial Current.

NECBRE Acronym for North Equatorial Current Bifurcation Region Experiment, an experiment planned by JAMSTEC to start in around 2006. The plan is to make tomographic observations of the North Equatorial Current bifurcation region in the Philippine Sea after the conclusion of the KESS program.

NECC Abbreviation for North Equatorial Countercurrent.

NECOP Acronym for Nutrient Enhanced Coastal Ocean Productivity, a NOAA/OAR/AOML program to study the dynamics of physical, geological, chemical and biological processes as they are influenced by the runoff from the Mississippi River and Atchafalaya Bay. The main objectives of the study include describing a clear anthropogenic signal and any resultant nutrient-enhanced productivity of significant magnitude and demonstrating the impact of enhanced production on coastal environmental quality.

[http://www.aoml.noaa.gov/ocd/necop/]

negative feedback A type of feedback in which a perturbation to a system causes a damping of the process, and thus opposes itself.

NEGOM Acronym for Northeastern Gulf of Mexico Physical Oceanography Program.

[http://negom.tamu.edu/negom/]

nekton One of three major ecological groups into which marine organisms are divided, the other two being the benthos and the plankton. Nekton are strongly swimming pelagic animals such as fish, some crustaceans, cephalopods, and whales which are capable of progressing against most water currents.

NEONS Acronym for the Naval Environmental Operational Nowcasting System, a software package that provides the capability to mange oceanographic and meteorological data in near real-time. It provides a set of tools to access, create and manage environmental data which is stored in a NEONS schema within a relational database.

[http://www.ncdc.noaa.gov/neons.html]

NEP Abbreviation for net ecosystem production, the rate at which carbon from the atmosphere (as CO_2) is accumulated in the biosphere. It is equal to the NPP minus heterotrophic respiration. See Woodwell [1995].

NEP Abbreviation for National Estuary Program, an EPA program to identify problems in estuaries and recommend solutions.

[http://www.epa.gov/owow/estuaries/nep.html]

NEPTUNE Acronym for North East Pacific Time–series Undersea Networked Experiments, a project to establish a network of underwater observatories within the depths of the northeastern Pacific Ocean. A 2000 mile network of fiber optic cable will provide power and communications to the scientific instruments. NEPTUNE will be located in the northeastern Pacific and will be spatially associated with the Juan de Fuca tectonic plate.

[http://www.neptune.washington.edu/]

neritic Living in coastal waters as opposed to living upon the high seas, i.e. oceanic. A division of the pelagic portion of the ocean that overlies the continental shelf.

NERRS Abbreviation for National Estuarine Research Reserve System.

NESDIS Acronym for the National Environmental Satellite, Data and Information Service, a NOAA office that manages U.S. civil environmental satellite systems as well as global data bases for meteorology, oceanography, solid-earth geophysics, and solar-terrestrial physics. NESDIS consists of the Offices of Environmental Information Services[107], Satellite Operations[108], Satellite Data Processing and Distribution[109], Research and Applications[110], and Systems Development[111].

[http://www.nesdis.noaa.gov/]

NESS Acronym for National Environmental Satellite Service, a NOAA program.

nested modeling In climate modeling this is a method for obtaining improved regional climate change predictions by the use of a spatial hierarchy of simulation models. Output from GCM simulations is used to provide initial and driving lateral boundary conditions for high resolution regional climate model (RegCM) simulations. There is no feedback from the ReGCM to the GCM. Different nesting techniques have been used, ranging from the standard technique of directly interpolating output from the coarse grid to the fine grid to the more sophisticated technique of spectral nesting. In the latter method the GCM forces the low wavenumber component of fields in the regional domain while the RegCM calculates the high wavenumber components. See Houghton and Filho [1995].

net irradiance The sum of the irradiance and the exitance.

net primary production See primary production.

NEUC See North Equatorial Undercurrent.

Neumann, Gerhard More later.

neural network See Hsieh and Tang [1998].

neuston More later.

neutral density A density for which three properties should ideally hold:

- it should be constant on approximate neutral surfaces;
- its horizontal gradients should coincide with the horizontal gradients of the *in situ* density; and
- its vertical gradient should be proportional to the static stability of the water column.

[107] http://www.esdim.noaa.gov/
[108] http://www.noaa.gov/nesdis/nesdis_oso.html
[109] http://pegasus.nesdis.noaa.gov/osdpd.html
[110] http://www.noaa.gov/nesdis/nesdis_ora.html
[111] http://www.noaa.gov/nesdis/nesdis_osd.html

The rub is that no variable can satisfy all these conditions in the ocean, i.e. the concept is mathematically ill–defined. It is, though, possible to define and use approximate neutral densities that constitute a compromise between these properties. ee Eden and Willebrand [1999].

neutral surface A surface on which no work is required to move a water parcel, as opposed to isopycnal surfaces where work is required due to the nonlinearity of the equation of state for seawater. Neutral surfaces are defined such that:

$$\alpha \nabla_n \theta = \beta \nabla_n S$$

where θ is the potential temperature, S the salinity, α the thermal expansion coefficient, β the saline contraction coefficient and ∇_n refers to the two–dimensional gradient in the neutral surface.

If θ and S are split into their mean (as averaged over many eddy scales) and fluctuating parts, neutral surfaces can be defined for the mean field rather than the instantaneous or local field. Fluid parcels will not move exactly in this mean field surface, though, due to nonlinearities in the equation of state. It is nonetheless assumed that the tensor describing eddy diffusion by mesoscale eddies and small–scale processes is diagonal if axes are chosen in and normal to this surface. See McDougall [1987a], You and McDougall [1990], Jackett and McDougall [1997] and Eden and Willebrand [1999].

neutral trajectory A three–dimensional path in the ocean defined such that no buoyancy forces act on a water parcel when it is moved a small distance along the path. Neutral trajectories are mathematically well defined but do not generally coincide with particle trajectories. See Eden and Willebrand [1999].

New Guinea Coastal Current (NGCC)

New Guinea Coastal Undercurrent (NGCUC)

new production Photosynthesis due to the uptake of nitrate. It is so-called because ocean circulation is the only source of nitrate to the euphotic zone and, as such, the nitrate can be thought of as newly available to phytoplankton. See Najjar [1991].

Newfoundland Basin An ocean basin lying between Newfoundland and the Azores whose floor is transected by the Mid-Ocean Canyon joining the Labrador Basin with the Sohm Abyssal Plain. It is separated from basins to the south by the Southeast Newfoundland Ridge. See Fairbridge [1966].

NEWLAND Acronym for Northeast Water Polynya Project.

Newtonian fluid A fluid in which deformation is proportional to velocity gradients.

NGCC Abbreviation for New Guinea Coastal Current.

NGCUC Abbreviation for New Guinea Coastal Undercurrent.

NGDC Acronym for National Geophysical Data Center, a branch of the NESDIS division of the Office of Environmental Information Services[112] of NOAA that manages environmental data in the fields of solar-terrestrial physics, solid earth geophysics, marine geology and geophysics, paleoclimatology, and glaciology. It operates a World Data Center[113] for each field.

[http://www.ngdc.noaa.gov/ngdc.html]

[112] http://www.esdim.noaa.gov/
[113] http://www.ngdc.noaa.gov/wdcmain.html

NGWLMS Abbreviation for Next Generation Water Level Management System, an automated system for collecting sea level and other data. The NGWLMS platform measures sea level position, air and water temperature, water density, wind speed and direction, and atmospheric pressure. Data is collected at various rates, stored every three minutes, and relayed via the NOAA GOES satellite to a central collection facility in Rockville, MD every three hours. See Beaumariage and Scherer [1987].

[http://www.pol.ac.uk/psmsl/gb/gb1/noaa.html]

NHRC Abbreviation for North Hawaiian Ridge Current.

nilas A type of sea ice defined by the WMO as:

> A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers." Has a matt surface and is up to 10 cm in thickness. May be subdivided into dark nilas and light nilas.

The dark nilas is less than 5 cm thick and very dark, while the light nilas is 5–10 cm thick and reflects proportionately more light, depending on its thickness. See WMO [1970].

Ninetyeast Ridge Current See Warren and Johnson [2002].

NIO Abbreviation for National Institute of Oceanography, an institute of India and Pakistan.

NIOF Abbreviation for National Institute of Oceanography and Fisheries, an Egyptian institute.

NIOMR Abbreviation for Nigerian Institute for Oceanography and Marine Research.

NIOZ Acronym for Nederlands Institut voor Onderzoek der Zee or, in translation, the Netherlands Institute for Sea Research.

[http://www.nioz.nl/]

Niskin bottle A plastic sampling bottle with water tight clsoures at top and bottom used to collect seawater samples for discrete chemical and biological measurements. It is equipped with a subsampling spigot and an air vent and can be triggered at pre-determined depths to collect samples. It is made of polyvinylchloride (PVC), an unreactive substance, to minimize possible contamination of highly sensitive measurements.

nitrate/nitrite Nitrate is ...

According to Kamykowski and Zentara [1991]:

> Nitrite occupies an intermediate oxidation state in the marine inorganic nitrogen cycle between the most reduced form, ammonia, and the most oxidized form, nitrate. Nitrite accumulation therefore identifies either loci of importation across the ocean boundaries (allocthonous sources) or of water column nitrogen fluxes where nitrite produce exceeds nitrite utilization (autochthonous sources). The most significant biological processes contributing to nitrite production are denitrification including assimilatory and dissimilatory nitrate reduction and nitrification dominated by ammonia oxidation. Nitrite accumulation occurs when at least one of these processes exceeds the uptake capabilities of phytoplankton and/or bacteria.

See Carpenter and Capone [1983], Sharp [1983] and Kamykowski and Zentara [1991].

NITREX Acronym for Nitrogen Saturation Experiment.

nitrification The process by which ammonia formed by the bacterial decay of marine organisms or excreted by marine animals is oxidized to nitrite and then nitrate. It is inhibited by light and proceeds very slow if at all in the euphotic zone. See Najjar [1991].

NIWW Abbreviation for North Icelandic Winter Water.

NMAT Abbreviation for Night-time Marine Air Temperature. This is a temperature defined and measured so as to avoid the effects of the daytime heating of the decks of ships, the platforms on which such things are usually measured.

NMC Abbreviation for National Meteorological Center (USA).

NMDIS Abbreviation for National Marine Data and Information Service, located in China.

NMFS Acronym for the National Marine Fisheries Service, a program office of NOAA that administers programs that support the domestic and international conservation and management of living marine resources.

[http://www.nmfs.noaa.gov/]

NOAA Acronym for the National Oceanic and Atmospheric Administration.

NOAMP Acronym for Nordostatlantisches Monitoring Program, a field program designed to investigate regional flows at great depths, particularly mesocale dispersion and pathways of suspended matter in the deep ocean within the near–bottom layers. The field phase of NOAMP ran from September 1984 to May 1986, and comprised six cruises of the R. V. *Meteor*. During each leg, 7 to 9 current meter moorings were deployed in the central NOAMP box (47°05'N–47°35'N, 18°45'W–20°32'W), with standard measuring heights 10, 30, 70 and 150 meters above the bottom. Short moorings also had instruments at 250 and 750 meters above the bottom, while long moorings had them at 200, 300, 400 and 500 m. A quasi–Lagrangian experiment with 14 3500 m deep drifting SOFAR floats was carried out from May 1985 to June 1986. See Klein and Mittelstaedt [1992].

NOARL Abbreviation for Naval Ocean and Atmosphere Research Laboratory, the precursor to the NRL. The precursor to NOARL was the Naval Environmental Prediction Research Facility (NEPRF), established in 1971 and functioning as a field activity of the Naval Air Systems Command. In 1989 NEPRF was combined with the Naval Oceanography Research and Development Activity and the Institute for Naval Oceanography – both located at the Stennis Space Center in Mississippi – to form a single naval ocean sciences laboratory called NOARL. In 1992, NOARL was incorporated into NRL.

NOBREX Acronym for NOrth BRazilian current EXperiment.

NOCN Abbreviation for NOAA Communications Network, a system created to serve the communications and data quality enhancement needs of the NOAA ocean community.

NODC Acronym for National Oceanographic Data Center, a centralized facility for providing ocean data/information on a continuing basis in a usable form to a wide user community as established within the framework of the IOC IODE structure. These facilities acquire, process, perform quality control, inventory, archive and disseminate data in accordance with national responsibilities. They are also charged with the responsibility of conducting international data exchange. Member states without an established NODC assign the responsibility of international exchange of data to another agency referred to as a Designated National Agency (DNA). The fundamental responsibility of the NODC/DNA as regards international exchange is to actively seek and acquire data which are exchangeable internationally, process and perform quality control on the data, and submit the data in a timely fashion to the approriate WDC for Oceanography or to a RNODC. See the IODE Web site[114].

[114] http://www.unesco.org/ioc/oceserv/iodestr.htm

NODC Abbreviation for National Oceanographic Data Center, a branch of the NESDIS division of the Office of Environmental Information Services[115] of NOAA that develops and maintains a national marine database. The NODC consists of three divisions:

- Ocean Climate Laboratory,
- Coastal Ocean Laboratory,
- NOAA Central Library.

[http://www.nodc.noaa.gov/]

NODDS Acronym for the Navy Oceanography Data Distribution System, a state-of-the-art methodology that makes environmental products and satellite data available worldwide via the Web. This was developed at the FNMOC for the distribution of their products.

NODS Acronym for NASA Ocean Data System, the former name of what is now known as PODAAC.

NOI According to Schwing et al. [2002]:

> We introduce the Northern Oscillation Index (NOI), a new index of climate variability based on the difference in sea level pressure (SLP) anomalies at the North Pacific High (NPH) in the northeast Pacific (NEP) and near Darwin, Australia, in a climatologically low SLP region. These two locations are centers of action for the north Pacific Hadley–Walker atmospheric circulation. SLPs at these sites have a strong negative correlation that reflects their roles in this circulation. Global atmospheric circulation anomaly patterns indicate that the NEP is linked to the western tropical Pacific and southeast Asia via atmospheric wave trains associated with fluctuations in this circulation. Thus the NOI represents a wide range of tropical and extratropical climate events impacting the north Pacific on intraseasonal, interannual, and decadal scales. The NOI is roughly the north Pacific equivalent of the Southern Oscillation Index (SOI), but extends between the tropics and extratropics. Because the NOI is partially based in the NEP, it provides a more direct indication of the mechanisms by which global-scale climate events affect the north Pacific and North America.
>
> The NOI is dominated by interannual variations associated with El Niño and La Niña (EN/LN) events. Large positive (negative) index values are usually associated with LN (EN) and negative (positive) upper ocean temperature anomalies in the NEP, particularly along the North American west coast. The NOI and SOI are highly correlated, but are clearly different in several respects. EN/LN variations tend to be represented by larger swings in the NOI. Forty percent of the interannual moderate and strong interannual NOI events are seen by the SOI as events that are either weak or opposite in sign. The NOI appears to be a better index of environmental variability in the NEP than the SOI, and NPH SLP alone, suggesting the NOI is more effective at incorporating the influences of regional and remotely teleconnected climate processes.
>
> The NOI contains alternating decadal-scale periods dominated by positive and negative values, suggesting substantial climate shifts on a roughly 14-year 'cycle'. The NOI was predominantly positive prior to 1965, during 1970–1976 and 1984–1991, and since 1998. Negative values predominated in 1965–1970, 1977–1983, and 1991–1998. In the NEP, interannual and decadal-scale negative NOI periods (e.g. EN events) are generally associated with weaker trade winds, weaker coastal upwelling-favorable winds, warmer upper ocean temperatures, lower Pacific Northwest salmon catch, higher Alaska salmon catch, and generally decreased macrozooplankton biomass off southern California. The opposite physical and biological

[115] http://www.esdim.noaa.gov/

> patterns generally occur when the index is positive. Simultaneous correlations of the NOI with north Pacific upper ocean temperature anomalies are greatest during the boreal winter and spring. Lagged correlations of the winter and spring NOI with subsequent upper ocean temperatures are high for several seasons. The relationships between the NOI and atmospheric and physical and biological oceanic anomalies in the NEP indicate this index is a useful diagnostic of climate change in the NEP, and suggest mechanisms linking variations in the physical environment to marine resources on interannual to decadal climate scales.

See Schwing et al. [2002].

NOIC Abbreviation for National Oceanographic Instrument Center, established by the Naval Oceanographic Office as a facility to establish criteria and procedures for testing and calibrating certain types of instruments. This office was active in the 1960s and 1970s, but is no longer in existence.

`[http://www.lib.noaa.gov/edocs/stratton/chapter6.html]`

noise In geophysical data processing this is most simply defined as any unwanted signal, and given that one person's signal can be another person's noise, this is ultimately a relative term. For example, if a time series is created by taking the temperature at some location every hour for five years, then the daily cycle of temperature that will be seen in such a record is a signal for someone looking for the daily cycle but is noise to someone looking for monthly or seasonal temperature variations.

NOMADS Acronym for North Sea Model Advection Dispersion Study, a program for the intercomparison of advection–dispersion models for the North West European continental shelf. The objectives were to compare the spatial and temporal coherence of simulation results for a well-defined realistic test and to compare the characteristics of the models by direct point–by–point comparison for an idealized 3-D test case. The project ran for two years starting in February 1995.

`[http://www.pol.ac.uk/coin/nomads/]`

nonlinear Said of a system (an electronic circuit, the climate, etc.) in which the output is not strictly proportional to the input. One consequence of this is that small changes in input can lead to very large and unpredictable changes in output.

NORCSEX Acronym for the Norwegian Continental Shelf Experiment, a pre-launch ERS field investigation carried out during a 25-day period in March 1988 on the continental shelf off the coast of Norway centered at 64° N. The overall goal was to investigate the capability of the ERS 1 type active microwave sensors to measure marine variables such as near-surface wind, waves and ocean surface current and their interaction in weather conditions ranging from moderate to extreme.

The primary objectives of NORCSEX included studies of SAR imaging of surface current features, SAR imaging of ocean surface gravity waves, combined airborne SAR and ship-mounted scatterometer measurements of near-surface wind fields, radar altimeter measurements of sea surface topography, significant wave height, and wind speed, integrated use of SAR and radar altimeter for significant wave height measurements, and comparison and validation of numerical ocean circulation model results to remote sensing and in situ observations. See Johannessen [1991].

Nordenskjold Sea See Laptev Sea.

Nordic Seas A term used to collectively refer to the fairly shallow Barents Sea and three deep ocean regions: the Norwegian Sea, the Greenland Sea and the Iceland Sea. The deep parts of the latter three are separated from another by deep submarine ridges. The Nordic Seas are separated from the North Atlantic to the south by the Greenland–Scotland Ridge, and are connected to the Arctic Ocean to the north via the 2200 m deep Fram Strait. The Nordic Seas along with the Arctic Ocean are collectively referred to as the Arctic Mediterranean. See Hansen and Osterhus [2000].

normal modes A decomposition solution procedure based on the eigenvectors of the linearized dynamical equations, i.e. an inherently linear concept. For example, the equations of large-scale motion in the atmosphere or ocean yield a sum of normal mode solutions for which each has a fixed vertical structure and behaves in the horizontal dimension and in time in the same way as a homogenous fluid with a free surface. Assuming the validity of the assumptions leading to the normal mode solution, the complete solution to the original differential equation is then approximated as a sum of the normal mode solutions. This technique can be applied to either a continuously or discretely stratified ocean model, with the former yielding an infinite set of normal modes and the latter a finite number of modes.

NORPAX Acronym for the NORth PAcific eXperiment, a shuttle experiment that took place from Feb. 1979 through Jun. 1980. It included 15 approximately monthly cruises on a track running directly south from Hawaii to 4°S, east to 153°W, north to 12°N, east to 150°W, and then south to the island of Papeete at around 18°S. The ships involved collected CTD data every 1° of latitude or longitude, and occupied profiling current meter stations every 1° between 6°S and 10°N (with additional half–degree stations with 3° of the equator). Acoustic Doppler current profiles were collected continuously along the ship's track, which was traversed in alternate directions. A set of three vector–averaging current meter moorings were also maintained during the experiment. See Wyrtki et al. [1981].

North African Trough See CapeVerdeBasin.

North American Basin A large depression centered around the Bermuda rise at about 85° W and 30° N in the western North Atlantic Ocean. It includes the Sohm Abyssal Plain to the northeast, the Hatteras Abyssal Plain to the west, and the Nares Abyssal Plain (or Nares Deep) to the southeast. Other prominent features in this basin include the Vema Gap, the Blake-Bahama Outer Ridge, and Blake-Bahama Basin and the Puerto Rico Trench. See Fairbridge [1966].

North Atlantic Central Water (NACW) A water mass occupying the upper 500 m of a weakly circulating intergyre zone in the North Atlantic, bounded to the north by the North Atlantic Current (NAC) and the south by the Azores Current. As with all Central Water, is is a water mass with well–defined T/S characteristics formed primarily via air–sea interaction across a wide band of latitudes.

It was recognized by Iselin [1936] that Central Waters in the eastern North Atlantic are more saline (usually by less than 0.1) than those in the Western North Atlantic. This led to to the coinage of Western North Atlantic Water (WNAW) to describe Central Water with the characteristics found in the Sargasso Sea, and Eastern North Atlantic Water (ENAW) for the more saline variety.

According to Pollard et al. [1991]:

> The term NACW is a generic term covering all three Central Water types described, WNAW, ENAW and freshened WNAW, with a range of θ/S properties. These three t ypes of NACW cannot always be distinguished by differences in their θ/S properties, because they change from year to year, and it is this which has led to confusion between them. WNAW has the most stable properties for densities greater than 27.0 kg m^{-3}, because it occupies a large volume of the recirculating subtropical gyre, where it is found beneath the seasonal thermocline, and is the end product of ventilating Mode Waters. WNAW lighter than 27.0 kg m^{-3} displays as much temporal variability as ENAW described here... ENAW is variable in its characteristics, because it is restricted to the anticyclonic gyre northeast of the Azores..., is modified annually by winter convection, and subducts only weakly to the south in the vicinity of the Azores to influence the θ/S characteristics of WNAW around 11–12°C. The weak subduction of ENAW is probably related to the weakness of the wind stress curl in its formation region, which lies only just southeast of the line of zero wind stress curl. Freshened WNAW is only found in the North Atlantic Current (NAC). It's θ/S properties too are variable because of long term changes in the properties of its parent water masses, WNAW and SAIW.

See Pollard et al. [1991] and Poole and Tomczak [1999].

North Atlantic Current (NAC) A western boundary current (WBC) that flows north along the east side of the Grand Banks in the northwestern Atlantic from 40° to 51° N, where it turns sharply to the east at a location than has come to be known as the Northwest Corner. It is part of the subtropical gyre circulation in the North Atlantic and begins where the Gulf Stream curves north around the Southeast Newfoundland Rise. The path of the NAC is delineated by a well–defined front while it flows north as a WBC, but broadens into a widening band of eastward drift without a sharp or permanent front after it makes its turn at the Grand Banks. Some authors limit the extent of the NAC to point at which it turns east and refer to the more diffuse eastward extension as the subpolar front, while others have it extending further downstream.

The northward flowing front features currents with maximum speeds typically near 1 m s^{-1} in the upper 300 meters and maximum transports more than 40 Sv (decreasing to around 20 Sv when the extension crosses the Mid-Atlantic Ridge). The NAC also meanders greatly, although unlike in the Gulf Stream the meanders appear to be stable, with only one recorded instance of one breaking off to form an eddy. The meanders have been observed to grow, recede, and disappear entirely, but not to propagate other than in the case of the one exception. The meanders appear to be induced by and bound to several major topographic features along the current path, i.e. the Southeast Newfoundland Rise, the Newfoundland Seamounts, and the Flemish Cap. Strong recirculation cells develop on the concave sides of some meanders, with the strongest and most persistent located at the first meander at about 44° W and 42° N. This is hypothesized to be a permanent feature and is called the Mann eddy. The recirculation regions to the east of the NAC can combine to form a narrow, extended recirculation cell with a north–south extent of around 600 km, although isopycnal float data suggest that this occurs only infrequently.

The permanence of the NAC is evidenced by a couple of lines of evidence. The persistence of the Northwest Corner where the NAC turns east is evidenced by its remaining a sharp feature even in hydrographic data data averaged over 50 years. Isopycnal float trajectory data indicate that it acts effectively as a boundary between the gyres on shallow density surfaces since only a very few floats have crossed the current entirely. Thus the NAC functions as an effective barrier between the subtropical and subpolar waters in the Northeast Atlantic.

The NAC extends the WBC regime in the North Atlantic further poleward than is seen in any other ocean, and thus tranports a greater volume of warm water into the polar regions. It is not known exactly why the Gulf Stream continues as a WBC in the form of the NAC rather than heading east after it leaves the coast in a manner similar to the Kuroshio Current. The reasons for this are thought to be some unknown combination of the unique demands of the Atlantic thermohaline circulation, the strong bathymetric control experienced by the NAC, and the wind forcing. See Krauss [1986], Sy et al. [1992], Rossby [1996], Kearns and Rossby [1998] and Carr and Rossby [1999].

North Adriatic Deep Water (NADW) A water mass formed in the north Adriatic Sea. It is formed during strong bora wind events when evaporation can be as high as 15 mm/day (compared to an annual average total of 1000 mm). The very dense deep water formed is characterized by temperatures less than 10°C and a relatively low salinity of about 38.3. After formation, the NADW flows southwards along isobaths near the bottom of the Italian shelf. The flow partially sinks into the Jaluka Pit, although the major portion moves further southwards to reach the shelf off Bari, where a canyon intersects the shelf and the water deepens. At this point the NADW plays some role in the formation of Adriatic Bottom Water (ABW). See Artegiani et al. [1993].

North Atlantic Deep Water (NADW) A water mass that fills the depth range between 1000 and 4000 m in the Atlantic Ocean. It is seen as a layer of relatively high salinity (above 34.9) and oxygen (above

5.5 ml/l) extending southward from the Labrador Sea to the Antarctic Divergence.

NADW originates in the northern North Atlantic in the GIN Sea. The main sources in are the dense overflows on either side of Iceland from intermediate depths in the Nordic Seas, the lower part of the Labrador Sea Water (LSW) layer including both a recirculating and an entraining component, and a recirculating Antarctic Bottom Water (AABW) derivative of southerly origins in the deepest layers of either basin.

The total direct transport of the dense overflows is about 5.6 Sv, about equally divided east and west of Iceland over the various sections of the Greenland–Scotland Ridge. The sill depth in the Denmark Strait to the east of Iceland is 600 m. To the west is is 450 m on the Iceland–Faroe Ridge and 850 m in the Faroe Bank Channel. The most saline of the overflows in through the Faroe Bank Channel which, although it overflows as a relatively fresh source, mixes intensely with overlying warm saline water from the local thermocline to become more saline. This water has been labeled by some as Northeast Atlantic Deep Water (NEADW). The coldest and densest of the overflows is the Denmark Strait Overflow, which has a characteristic salinity minimum. This overflow has been sometimes labeled as Northwest Atlantic Bottom Water.

The AABW component passes into the eastern GIN Sea basin through the Vema Fracture Zone at 11° N at a rate of about 2.0–2.5 Sv. This eventually combines with the overflows east of Iceland to give an estimated 6.6 Sv of flow west through the Charlie Gibbs Fracture Zone. This flows west to combine with the overflow west of Iceland, which has mixed with the LSW to contribute to a total eventual southward flow of NADW east of Newfoundland of about 13 Sv. The recirculation and entrainment processes that increase the 5.6 Sv of overflow water to the 13 Sv of NADW flowing south are the least well known parts of NADW formation. See Dickson and Brown [1994] for the present best summary of NADW formation processes.

The resulting mixture, as it moves south, is often separated into upper, middle and lower NADW. Upper NADW (UNADW) comes from Mediterranean outflow spreading into the Central and North Atlantic at depths of 1000 to 1500 m, and is identified by a salinity maximum. Middle NADW (MNADW) is formed by ocean convection in the Labrador Sea flowing into the Western North Atlantic Basin. Lower NADW (LNADW) is formed by a complex series of mixing flows over the Greenland-Scotland Ridge and thereafter, and comprises the bulk of the totality of NADW. The middle and lower forms of NADW are both identified by oxygen maxima in the subtropics at 2000-3000 m and 3500-4000 m, respectively.

More recent work has identified four different water types within the southward flowing NADW comprising the DWBC. The shallowest part of the upper NADW – called either Shallow Upper NADW (SUNADW) or Upper Labrador Sea Water (ULSW) – has a salinity maximum correlated to elevated concentrations of tritium and chlorofluorocarbons, with the salinity maximum near 1600 m at the equator and deepening to 2500 m at 25°S. The LSW below the SUNADW shows a lower CFC signal than the SUNADW in the tropics, and is additionally differentiated there by an oxygen maximum. The LNADW also exhibits internal differences, with an CFC minimum located above a CFC maximum. This has been separated into:

- old LNADW with a CFC minimum originating from the Charlie Gibbs Fracture Zone Water; and
- overflow NADW (OLNADW) with CFC and oxygen maximums originating from the Denmark Strait Overflow Water.

As the thickness of the NADW decreases southwards – with a depth range from about 1200 to 3900 m near the equator and 1700 to 3000 m in the Brazil–Falkland Confluence zone – the various NADW water types merge, with the extrema either broken or merged. See Warren [1981], Dickson and Brown [1994], Smethie Jr. et al. [1999] and Stramma and England [1999].

North Atlantic Drift The northward limb of the anticyclonic subtropical gyre in the North Atlantic Ocean. It is a northerly extension of the Gulf Stream but, due to a different dynamical regime, is a broader, slower current that carries warm water towards Europe, serving to ameliorate the climate there.

North Atlantic Oscillation (NAO) An index defined as the normalized winter pressure differential between the Icelandic Low and the Azores High centers of action. Low (high) NAO index values occur when sea level pressure is above (below) average in the vicinity of the subpolar Icelandic Low and below (above) average near the subtropical Azores High pressure cell. See Van Loon and Rogers [1978] and Rogers [1984].

North Atlantic Subpolar Mode Water A type of Subpolar Mode Water that forms in the North Atlantic. North Atlantic SPMW is a dense, cool (8–10°C) pycnostad spreading northwards past Ireland and turning westwards through the Iceland and Irminger Basins. It follows a cyclonic circulation within which the density gradually increases as temperature decreases to eventually form the coldest, densest pycnostad in the Labrador Sea. See McCartney and Talley [1982].

North Atlantic Subtropical Mode Water A type of Subtropical Mode Water that forms in the North Atlantic.

North Atlantic Water (NAW) A water mass transported by the Continental Slope Current from the North Atlantic into the Nordic Seas. It has typical property values in the Rockall Channel region of the Greenland–Scotland Ridge of 9.5–10.5°C and 35.35–35.45. This makes it the saltiest and warmest of the waters exchanged over the Ridge. The origins of the high salinity are to date a matter of debate, with some postulating a Mediterranean source, and others conjecturing that the high salinity is acquired by a combination of winter cooling at constant temperature (i.e. sea ice formation and the resultant brine release) for intermediate depths and evaporation and advection from southern areas for near–surface layers. See Hansen and Osterhus [2000] and references therein.

North Brazil Current (NBC) A current that flows in the western South Atlantic Ocean along the Brazilian coast from about 10 to 3° S along around 35° W. Geostrophic calculations (relative to 1000 m) show a broad (300 km wide), northwestward current transporting about 37 Sv at 5° S. It is concentrated in a subsurface core at 100-200 m depth. It continues as a coherent feature until the subthermocline layers retroflect at between 3 and 5° N to feed the North Equatorial Undercurrent (NEUC) and then the upper layers retroflect at between 5 and 8° N to feed the North Equatorial Countercurrent (NECC).

The NBC originates south of the equator where the South Equatorial Current approaches the coast. Historically, it was thought to be simply the northward flowing part of the bifurcation of the Central South Equatorial Current (CSEC) at near 5° S (with the Brazil Current (BC) the southward flowing part), but recent investigations have shown a more complicated picture. The simple view was prompted by surface current distributions obtained from ship drift and surface drifter trajectories, which turn out to have obscured the overall geostrophic flow patterns.

Geostrophic calculations have shown that the NBC originates just south of 10° 30' S where the convergence of the southern branch of the CSEC with part of the Southern South Equatorial Current results in a transport (relative to 1000 m) of about 21 Sv at near 10° S. It continues north from there and eventually merges with the northern branch of the CSEC just north of 5° S where the transport has increased to the aforementioned 37 Sv.

The NBC is believed to have a pronounced annual cycle where during March–June most of it moves northwestward up the coast of South America to eventually enter the Caribbean Sea via the passages of the Lesser Antilles, while during the rest of the year it separates sharply from the coast at 6–7°N and curves back on itself (i.e. retroflects) to feed the North Equatorial Countercurrent (NECC). During the retroflection phase the NBC occasionally curves back upon itself sufficiently to pinch off large anticyclonic current rings, which move northwestward toward the Caribbean.

Immediately following separation the rings are about 400 km in diameter and translate northwestward at 8–15 cm s^{-1}. They have a typical sea surface height anomaly of 15 cm at the center, penetration depths from 950 to 1500m, a mean radius of maximum velocity of 100–150 km, a maximum swirl velocity of 80 cm s^{-1}, and swirl velocities greater than 20 cm s^{-1} beyond a radius of 200 km. This ring shedding is thought to account for as much as one–third of the net warm water transport across the equatorial–tropical gyre boundary into the North Atlantic to compensate for the southward export of North Atlantic Deep Water (NADW). The annual mass flux from all eddies formed during a year is estimated as 2.6–4.0 Sv, or roughly 20–30% of the total strength of the Atlantic meridional overturning circulation. It is speculated that waves or eddies leaving the equatorial waveguide near the western boundary may translate northward along the coast of South America embedded within the North Brazil Current, and may serve as a catalyst for the shedding of the rings. See da Silveira et al. [1994] and Johns et al. [1998].

North Brazil Undercurrent (NBUC) A current underlying the North Brazil Current (NBC) off the northeast coast of Brazil. The NBUC shows a subsurface core at about 200 m with velocities of up to 90 cm/s, resulting in large northward transports of more than 22 Sv in the upper 1000 m. See Stramma et al. [1995].

North Cape Current See Pfirman et al. [1994].

North Cape Eddy After Zeldis et al. [2004].

North Equatorial Countercurrent (NECC) An eastward flow in the Atlantic and Pacific located approximately between 5 and 10° N. It is located between the NEC and the SEC and called a countercurrent because it flows counter to the direction of the easterly trade winds. The NECC is strongest during July and August and weak in the northern winter and spring, and is known to migrate from a northernmost position in the northern summer to a position closest to the equator in the northern winter. Some evidence indicates that during this latter period the NECC is discontinuous and may even vanish in parts of the eastern Pacific. Even so, it is the most well developed of any of the equatorial currents. In the Indian Ocean this and the NEC are seasonally controlled by the monsoon circulation patterns.

According to Richardson et al. [1992], in the Atlantic Ocean ...

> ... the geostrophic NECC continues to flow eastward throughout the year, fastest in fall and slowest in spring. Drifting buoys and historical ship drifts show that the near–surface Countercurrent reverses each spring even when systematic errors due to windage are taken into account. The seasonally fluctuating winds drive an Ekman surface current that is eastward in fall, adding to the geostrophic current, and westward in spring, countering and overwhelming the geostrophic current. The reversal of the Countercurrent in spring occurs in the near–surface layer and is driven by the Northeast Trades. Thus the near–surface velocity in the Countercurrent is determined by a competition between local wind stress and the larger field of wind stress curl, both of which have large seasonal variations in the tropical Atlantic.

See Leetmaa et al. [1981], Richardson et al. [1992] and McPhaden [1996].

North Equatorial Current (NEC) A westward flow in the Atlantic and Pacific located north of the NECC past 10° N. In the Indian Ocean this and the NECC are seasonally controlled by the monsoon circulation patterns. See Leetmaa et al. [1981],

North Equatorial Undercurrent (NEUC) A permanent eastward flowing feature of the equatorial Atlantic circulation whose core is located near 200 m depth a few degrees north of the Equator. A satisfactory dynamical explanation for this is as yet nonexistent. See Cochrane et al. [1979] and Tomczak and Godfrey [1994], p. 260.

North Hawaiian Ridge Current (NHRC) A current that exists in the mean along the coasts of the Hawaiian Islands. It originates as a northern branch of westward moving interior flow and flows coherently along the islands at an average speed of 0.10–0.15 m s^{-1}. It veers westward at the northern tip of the Hawaiian Islands. It exists due to the imbalance between the interior Sverdrup transport and the net southward transport as constrained by the Hawaiian Islands. See Qiu et al. [1997].

North Icelandic Irminger Current A current containing the westernmost of Atlantic water inflow to the Nordic Seas, flowing northwards through the Denmark Strait between Greenland and Iceland, and then turning eastwards around the northern tip of Iceland. The name indicates an origin in the Irminger Current which, as it flows northward through the Denmark Strait, splits into two branches. One branch turns west and then southwest to run parallel to the East Greenland Current. The other turns northeast and then east to become the North Icelandic Irminger Current. It feeds the North Icelandic shelf area with relatively warm, saline water which rapidly loses its Atlantic character (heat and salt) so that the percentage of Atlantic water is reduced to less than 30% by the northeastern corner of Iceland. See Swift [1986] and Hansen and Osterhus [2000].

North Icelandic Winter Water (NIWW) A water mass identified and named by Stefánsson [1968]. It is homogenized in winter north of Iceland from a mixture of Modified North Atlantic Water (MNAW) from the North Icelandic Irminger Current and water from the near–surface layers of the Iceland Sea plus some coastal water influenced by runoff. The typical properties of NIWW are a temperature from 2–3°C and a salinity of 34.85–34.90. See Hansen and Osterhus [2000].

North Korea Current A current that flows along the western coast in the Japan Sea. It is the southward continuation of part of the Liman Current and ultimately turns east and then northward (at around 38-40° N) to become part of the flow in the Polar Front.

North Pacific Central Mode Water (NPCMW) A type of mode water found in the subtropical gyre in the North Pacific, and first discussed by Nakamura [1996] and Suga et al. [1997]. NPCMW is distributed mainly between 30–40°N and 170°E–150°W as a 9–13°C thermostad. It is formed by wintertime deep convection north of its distribution area. See Nakamura [1996], Suga et al. [1997] and Yasuda and Hanawa [1997].

North Pacific Current The eastward continuation of the Kuroshio and Oyashio Extensions, with which it forms the southern limb of the North Pacific subpolar gyre. This is a broad band of eastward flow around 2000 km wide that, at some not well known location east of the Emperor Seamounts, becomes well distinguished from the two aforementioned narrower and strongly frontal flows that eventually merge into its broader flow. This current eventually turns north and, along with the Alaska Current, forms the eastward limb of the North Pacific subpolar gyre. See Tomczak and Godfrey [1994].

North Pacific Equatorial Water (NPEW) In physical oceanography, a water mass formed at the boundary between the subtropical gyres via mixing in the Equatorial Countercurrent and the Equatorial Undercurrent. NPEW is a mixture of WNPCW and SPEW. This combination of formation process and ancestral water masses makes NPEW one of the few water masses not formed through air-sea interaction. See Tomczak and Godfrey [1994], p. 166.

North Pacific Intermediate Water (NPIW) A water mass present mostly in the northern Philippine Sea. NPIW was originally identified as such by Sverdrup et al. [1942]. According to Talley [1993], it is identified by S < 34.4 psu and $2.5 < O_2 < 3$ ml l^{-1} on density surfaces of 26.5–26.8σ_θ, defined as the main salinity minimum in the subtropical North Pacific, and found in the depth range 300–700 m. Other published definitions of NPIW have defined it more generally as:

- the salinity minimum;
- all water in some density interval around the salinity minimum; and
- the isopycnal 26.8 σ_θ.

According to Talley [1993]:

> NPIW occurs throughout the subtropics in the region where potential vorticity suggests wind–driven circulation, thus north of about 20°N. It appears to "leak" into the subpolar gyre near the eastern boundary and into the Mindanao Current. It is not found consistently in the broad California Current. Throughout most of its domain, NPIW is a vertically smooth salinity minimum with gradual spatial variations in density. Its density shifts from lowest in the northwestern subtropical gyre to highest in the Kuroshio, presumably along a very long path around the gyre. Oxygen is highest and salinity lowest in the northwest as well. Vertical profiles through the NPIW in the northwestern subtropical gyre are markedly different from elsewhere, being strongly intrusive and sometimes having associated temperature minima.
>
> These observations lead to the conclusion that NPIW is "formed" as a salinity minimum in the northern part of the mixed water region just east of Hokkaido and the northern coast of Honshu.
>
> ...
>
> While salinity minima occur at many densities in the North Pacific, and especially in the mixed water region, NPIW as a large–scale salinity minimum because it reflects the bulk, large–scale outcropping properties of a fairly large region of the western subpolar gyre; that is, cold, fresh subpolar waters at densities greater than 26.6 σ_θ are advected into the mixed water region by the Oyashio to meet warmer, more saline subtropical and Tsugaru waters. Cooling of the latter and an increase in salinity of the former produce winter surface waters at all densities between 26.2 σ_θ and 26.6 σ_θ, with salinity decreasing with increasing density. The coldest, freshest, densest surface layer then either slides beneath or mixes laterally beneath the saltier surface layers, forming the salinity minimum and erodes from above to produce NPIW. NPIW, thus, is just below the boundary between the densest outcropping subpolar waters of the western Pacific outside the Okhotsk Sea and the part of the water column that is not ventilated outside the Okhotsk Sea.

See Talley [1993], Qu et al. [1999] and You et al. [2000].

North Pacific Subtropical Mode Water (NPSTMW) A type of mode water found in the subtropical gyre in the North Pacific. The NPSTMW thermostad has a core temperature range of 16°–19° C centered at 150°–160° E south of the Kuroshio Extension. The formation area is centered just north of 30° N and west of 155° E. The temperature of the layer decreases eastward. Two processes contribute to the thickness of this mode water:

- large winter heat loss due to advection of warm water into the region; and
- cold, dry air blowing off the continents, with the tilt of isopycnals in the Kuroshio Extension and recirculation creating a bowl of warm water between the Extension and the recirculation.

See Suga et al. [1997].

North Pacific Tropical Water (NPTW) A water mass characterized by high salinity ($34.75 < S < 35.25$) and high oxygen concentration (>4.0 ml l^{-1} on density surfaces around 24.0 σ_θ. It is thought to form at about 20°N, 140°E–160°W as the result of excess evaporation. It extends westward from its formation area in the North Equatorial Current (NEC) between 10° and 25°N. At the western boundary, part of the NPTW seems to continue southward, coinciding with the Mindanao Current.

According to Suga et al. [2000], NPTW has also been called Tropical Water (Tsuchiya [1968]) and Northern Subtropical Lower Water (Wyrtki [1961]). They summarize the origins and destinations of NPTW:

> NPTW is thought to form at the surface in the central North Pacific roughly along the Tropic of Cancer, where evaporation is far higher than precipitation. NPTW is then advected westwards in the North Equatorial Current (NEC), and forms a subsurface salinity maximum. At the western boundary, part of NPTW flows northward in the Kuroshio and the other flows southward in the Mindanao Current. Remnants of NPTW in the Kuroshio are recognizable as the subsurface salinity maximum to the south of Japan, and then presumably contribute to the formation of the broad subsurface salinity maximum that is typical in the northwestern part of the subtropical gyre. NPTW carried by the Mindanao Current enters the Celebes Sea and flows either on into the Indian Ocean or back to the North Pacific.

They go on to discuss the possible climatic significance of NPTW:

> Since NPTW originates as a result of the predominance of evaporation in the subtropical North Pacific and then spreads widely, thereby contributing to the subsurface salinity maximum, it can be regarded as the saline counterpart of the North Pacific Intermediate Water (NPIW). NPIW is characterized as the intermediate salinity minimum in the subtropical gyre, intimately reflecting the dominance of precipitation in the subpolar North Pacific. Thus, NPTW is a major source of 'salt' in the North Pacific, while NPIW is a major source of 'fresh water'. Wong, Bindoff and Church (1999) recently detected concurrent increases in salinity in NPTW and a freshening of NPIW, along with similar change in the South Pacific, and related them to an intensification of the global hydrological cycle. This suggests that NPTW is not only important for the mean state of salinity distribution but also one of sensitive components of the climate system so that its variability carries useful information whereby climate change may be detected and understood.

See Qu et al. [1999] and Suga et al. [2000].

North Sea An epicontinental sea occupying the shelf area between the British Isles and Norway, Denmark, Germany, Holland and Belgium. The oceanic boundaries are a line across the Straits of Dover to the south, a line running from the northern tip of Scotland to the Orkney and Shetland Islands and then directly east to the coast of Norway to the north, and the Skagerrak to the east. It covers about 575,000 km^2, has an average depth of 94 m, and a volume of 54,000 km^3.

According to Rodhe [1998]:

> The mean currents of the North Sea form a cyclonic circulation. The bulk of the transport in this circulation is concentrated in the northern part of the North Sea and in the region of the Norwegian Trench, with the main outflow along the Norwegian coast. The amount of water leaving along the Norwegian coast is estimated at 1.3–1.8 $\times 10^6\, m^3 s^{-1}$, with most of this outflow compensated for by an inflow along the western slope of the Norwegian Trench. Considerable inflows also take place east of Shetland and between Shetland and the Orkney Islands. Less than 10% enters through the English Channel. Most of the water in the inflows

from the northwest is guided eastward to the Norwegian Trench by the topography along the 100 m depth contour. Only a small part flows southward along the coast of Scotland and England.

See Fairbridge [1966], Lee [1970], Otto et al. [1990] and Rodhe [1998].

North Subsurface Countercurrent An eastward flow in the Pacific Ocean whose core is located near 600 m depth a few degrees north of the Equator. A satisfactory dynamical explanation for this is as yet nonexistent. See Tomczak and Godfrey [1994], p. 128.

North Subtropical Front (NSTF) The northern boundary of the Subtropical Frontal Zone (STFZ).

North Water A polynya region occupying a large region in Baffin Bay and Smith Sound situated between Greenland on the east and Ellesmere and Devon Islands on the west. This region is undefined in summer when Baffin Bay is ice free, but well defined during the winter. The northern boundary is an ice arch that blocks the southward flow of ice through Smith Sound. Ice forms continually through the winter in the polynya and drifts southward due to both local northerly winds and southward currents. The southern boundary is more poorly defined, although it does expand southward in spring as the ice melts until it joins the northward expansion of open water associated with the West Greenland Current (WGC). The North Water, being a coastal polynya and highly dependent on synoptic meteorological processes, occurs intermittently.

Ingram et al. [2002] discuss North Water history, water masses and circulation:

> In 1616, William Baffin sailed through heavy sea ice up the west coast of Greenland until reaching a large area of open water within a region now known as northern Baffin Bay. Later, whalers called this area of open water the "North Water". The North Water, which extends over the northern end of Baffin Bay and the southern part of Smith Sound, is a recurring polynya. Although the boundaries of the North Water vary interannually, for our purposes we define the polynya to be bounded by the coasts of Ellesmere Island and Greenland between latitudes 76 and 78.5N, excluding Jones Sound. ...
>
> An extensive survey of T and S in the North Water, as part of NOW, in both 1997 and 1998 improved the temporal and spatial coverage of water-column characteristics. Recognizing that specific water types and masses occurred in distinct groupings in northern Baffin Bay and the North Water, [the water column can be described] in terms of water-mass assemblies (following the definition by McLaughlin et al. [1996]). A first 'northern assembly' originates in the Arctic Ocean and is carried south by outflows through Smith and Jones Sounds. It is characterized by a linear, two end-member mixing line on the T–S diagram, wherein temperatures lie well above the freezing temperature. A second 'southern assembly' originates in the North Atlantic and Baffin Bay and is carried north with the WGC. It consists of a cold halocline (where temperatures roughly track the freezing temperature of water as salinity increases) overlying a warm halocline (wherein temperatures remain above freezing as salinity increases) characterized by the presence of Atlantic-derived water (T¿0C). The data ... suggest that southern assembly waters are strongly constrained by the bathymetry of Baffin Bay, such that most of the warm Atlantic-derived water is redirected south before entering the polynya region. Only a minor portion of southern assembly waters advances under the North Water, where they are altered rapidly by topographic steering, salt input, and mixing with northern assembly waters. The northward transport of WGC Atlantic Water is usually considered to stop in the vicinity of the Carey Islands under the influence of a shallow 200–m bank. However, the analysis ... indicates that the northward flow of WGC Atlantic Water continues above a deep narrow channel east of the Carey Islands bank and that some of the

warm water circulates cyclonically around the islands, spreading west. The frontal interaction of northern and southern assemblies over the complex bottom topography of the North Water generates the 'North Water assembly', which is characterized by density-compensating thermohaline intrusions throughout its permanent halocline and defines the Baffin Current outflow into the rest of Baffin Bay. ...

The main features of the mean circulation that emerge from the literature are a southward cold and fresher Baffin Current along the coast of Ellesmere, a northward warmer and saltier WGC along the Greenland coast, and the eastward Jones and Lancaster Sound net outflows. ... The Baffin Current is considered highly baroclinic, while the WGC is believed to be at least partly barotropic. Surface speeds in the Baffin Current are strong (up to 0.75 m/s, including tidal flows, south of Lancaster Sound), with a large baroclinicity that can be observed down to 400 m. The general circulation is cyclonic, with the WGC branching westward at three locations: in Melville Bay (following the 600-m isobath), near the Carey Islands, and in Smith Sound. These three main branches later join the Baffin Current. The main features of the surface circulation inferred from hydrographic observations are confirmed in the sea-ice motion tracked by satellite. ...

Features found using dynamic height calculations include the Baffin Current, the inflows along the northern shores of Jones and Lancaster Sounds, the outflows alongxi the southern shores and the presence of the WGC up to 77.5N. The maximum northern latitude reached by the WGC is still poorly defined. The dynamic heights ... show a surface current penetrating into Nares Strait and turning cyclonically to form an ice–edge jet. ... Preliminary hydrographic data from September 1999 suggest a surface flow into Nares Strait. However, since most of the water from the WGC has already turned south either near Cape York or the Carey Islands, the remaining portion of the WGC transports little heat north of 77.50N. The northern extent of the WGC is believed to vary seasonally, but more data are needed to characterize properly the spatial, seasonal and interannual variations.

See SMith et al. [1990], Ingram et al. [2002] and Bâcle et al. [2002].

Northeast Atlantic Deep Water (NEADW) A water mass that originates from flow through through passages between Iceland and Scotland. This includes about 1.7 Sv through the Faroe Bank Channel and about 1 Sv over the Greenland-Scotland Ridge. The latter component is about evenly split between the main channel immediately east of Iceland and four lesser channels further east. See Swift [1984] and Dickson and Brown [1994].

Northeastern Atlantic Basin See West Europe Basin.

Northern South Equatorial Countercurrent (NSEC) One of three distinct branches into which the South Equatorial Current splits in the western South Atlantic Ocean. See Stramma [1991].

Northern Subsurface Countercurrent An eastward flowing countercurrent that flows beneath the surface at around 4° N in the North Pacific Ocean. It flows between the eastward flowing North Equatorial Countercurrent (NECC) to the north and the westward flowing South Equatorial Current (SEC) to the south. See Gouriou and Toole [1993].

Northwest Atlantic Bottom Water A water mass that originates from flow through the Denmark Strait, i.e. the Denmark Strait Overflow. See Swift et al. [1980], Swift [1984] and Dickson and Brown [1994].

Northwest Corner See North Atlantic Current.

Norwegian Atlantic Current See Swift [1986] and Pfirman et al. [1994].

Norwegian Coastal Current See Skagerrak.

Norwegian North Atlantic Water (NNAW) A water mass formed in the recirculating gyre of the Norwegian Basin of the Norwegian Sea as a mixture of mainly Modified North Atlantic Water and Norwegian Sea Arctic Intermediate Water (NSAIW). See Hansen and Osterhus [2000].

Norwegian Sea A marginal sea of the North Atlantic Ocean which consists of the waters between the continental shelves of Norway and Spitsbergen to the east and the Mohn Ridge and Jan Mayen Ridge to the west. It adjoins the Barents Sea to the northeast, the Greenland Sea to the northwest, the Iceland Sea to the west, and the North Sea to the southeast. It covers an area of 1,383,000 km^2, has a volume of 2,408,000 km^3, and a mean depth of 1742 m. The term Norwegian Sea has also been used to collectively refer to the sea described here along with the Greenland Sea and the Iceland Sea. See Hopkins [1991] and Fairbridge [1966].

Norwegian Sea Arctic Intermediate Water (NSAIW) A water mass whose typical values are -0.5–0.5°C and 34.87–34.90. See Hansen and Osterhus [2000].

Norwegian Sea Deep Water (NSDW) The densest water mass in the Norwegian and Iceland Seas, although it is also found on the periphery of the Greenland Sea. The NSDW in the deep parts of the Norwegian Basin results from a fairly even mixture of Greenland Sea Deep Water (GSDW) and Eurasian Basin Deep Water (EBDW), thought to enter the Norwegian Basin via the Jan Mayen Channel. NSDW is characterized by salinities from 34.90 to 34.94 with the 0° C isotherm traditionally used as the upper limit of NSDW. Most is colder than -0.4° C, with typical NSDW -0.5 to -1.1° C and 34.92.

This so-called classical description of the origins of NSDW is based on an actively convecting Greenland Sea, a situation that began changing in the last couple of decades of the 20th century. The diminished production of GSDW began having effects on the production of NSDW, including a warming of the deepest layers of the Norwegian Basin (by 0.015–0.020°C). The upper parts of NSDW freshened during this period, with the salinity maximum decreasing and descending to greater depths. See Swift [1986], Swift and Koltermann [1988] and Hansen and Osterhus [2000].

NOS Acronym for the National Ocean Service, a program office of NOAA that monitors, assesses and forecasts conditions in the coastal and oceanic environment. More information can be found at the NOS Web page[116].

NOSAMS Acronym for the National Ocean Sciences Accelerator Mass Spectrometer Facility, established in 1989 at WHOI to serve the ocean sciences community with high-precision C-14 AMS measurements. See the NOSAMS Web site[117].

Nova Scotian Current A current located in the Gulf of St. Lawrence. See Han et al. [1999].

Novaya Zemlya Current See Pfirman et al. [1994].

NOW Acronym for the International North Water Polynya Study, part of the IAPP. NOW is a program to understand the functioning and importance of the North Water ecosystem. From Deming et al. [2002]:

> With Canadian scientists leading the way and eight other countries contributing expertise in kind, the International North Water Polynya Study (NOW) was conceived and developed over the course of numerous international workshops (beginning in 1993). Research funding was provided by the relevant national agencies (beginning in 1996), with major input from the Canadian National Science and Engineering Research Council, the US National Science

[116] http://www.nos.noaa.gov/
[117] http://ams245.whoi.edu/nosams.html

Foundation, and the Japanese National Institute of Polar Research. The NOW was undertaken as a combined icebreaker/ice-camp endeavor over a 3-year period, from 1997 to 1999, with follow–up time for data analysis and exchange. Canadian Coast Guard ice–breaking vessels served as the sea–going platforms in all years: the *Louis S. St. Laurent* in 1997 and the *Pierre Radisson* in 1998 and 1999. Particularly striking logistical successes were achieved in 1998, when an unprecedented continuous 5–month research effort enabled study of the opening of the polynya and parallel start of the bloom season to its summertime open–water and biological maxima. In 1999, a unique pooling Canadian, American, and Japanese resources, allowed a third year of ice–breaking exploration that captured the late–summer features and fall closing of the polynya and enabled meaningful exchange with the local Inuit of Aujuittuq (Grise Fjord), Canada, and Qaanaaq, Greenland.

[http://www.fsg.ulaval.ca/giroq/now/]

NPCMW Abbreviation for North Pacific Central Mode Water.

NPEW See North Pacific Equatorial Water.

NPIW See North Pacific Intermediate Water.

NPO Abbreviation for North Pacific Oscillation.

NPP Abbreviation for Net Primary Productivity, the net annual uptake of carbon dioxide by vegetation. It is equal to the GPP minus autotrophic respiration. This is difficult to measure directly in terrestrial ecosystems, not only because it requires a direct measurement of gross photosynthesis, but also because it requires measurement of the respiration of the plant or plant community, including roots. See Woodwell [1995].

NPPS Acronym for North Pacific Process Study, a JGOFS program from July 1998 through February 2000 whose goals were to quantify CO2 drawdown by physical and biological pumps in the northern North Pacific by identifying and studying the regional, seasonal to inter-annual variations of the key processes, and to understand their regulating mechanisms. The NPPS was composed mainly of Japanese programs conducting extensive surveys, intensive biogeochemical process studies, time-series observations at station KNOT at 440N, 1550E, ocean color satellite observations, and modeling.

In April 1996, the JGOFS SSC established a North Pacific Task Team (NPTT) to coordinate the NPPS. According to Saino et al. [2002]:

> JGOFS Japan put most of their effort in establishing a time-series station in the western subarctic Pacific. From the very beginning of the NPTT there was a strong desire for a time-series station, but due chiefly to the logistic problems, it was thought to be very difficult without designated funding. Fortunately, the plan proposed by Yukihiro Nojiri was approved as one of the projects of Core Research for Evolutional Science and Technology (CREST) supported by Japan Science and Technology Corporation from 1997 through 2002, and the KNOT (Kyodo–cooperative in Japanese–North Pacific Ocean Time Series) station was established.
>
> There were 5 [NPPS] component activities with data management as a framework activity. The extensive observations included the SubArctic Gyre Experiment (SAGE), a post–WOCE program supported by the Science and Technology Agency, and the Canada–Japan Cargo Ship monitoring program using the M/S Skaugran. One of the objectives of the SAGE program, relevant to the JGOFS NPPS, was the formation, transformation, and transport of the North Pacific Intermediate Water (NPIW). The Skaugran monitoring program provided

comprehensive maps of the sea surface pCO2 and nutrients with an unprecedented coverage in temporal and spatial scales in the study region. The time-series station KNOT was in operation from June 1998, and was occupied 20 times by February 2000, the end of intensive observation phase of NPPS. The research vessels that made observations at station KNOT were the Hokusei maru of Hokkaido University, the Mirai of Japan Marine Science and Technology Center, the Bosei maru of Tokai University, and the Hakuho maru of the University of Tokyo. In addition to KNOT, the Japan Fisheries Agency has maintained, from the early 90s, a monitoring line running from the east coast of Hokkaido Island in the southeastward direction, crossing the Oyashio, a cold western boundary current of the western subarctic gyre. The intensive observations and shipboard experiments on biogeochemical processes were also conducted on cruises to the northern North Pacific, and were not limited to the western subarctic Pacific. In addition to the ships listed above, the Hakurei maru I and II, supported by the Ministry of International Trade and Industry, were engaged in the Western Pacific Environmental Study on CO2 Ocean Sequestration for Mitigation of Climate Change (WEST–COSMIC) project. Another CREST project was established in the Sea of Okhotsk (Masaaki Wakatsuchi), where sea ice is an important component of the climate system and the source water of NPIW.

NPSTMW Abbreviation for North Pacific Subtropical Mode Water.

NPTW Abbreviation for North Pacific Tropical Water.

NPTZ Abbreviation for North Pacific Transition Zone.

NROSS Abbreviation for Navy Remote Ocean Sensing Satellite, a planned mission that apparently collapsed under its own financial weight and never got off the ground.

[http://www.pmel.noaa.gov/pubs/outstand/mcph1720/app-c.shtml]

NSANE Acronym for Near Shore Acoustical Network Experiment, the objective of which was to make comprehensive measurements of the physical processes associated with the surf zone to determine which processes are dominant in determining the acoustic propagation features.

[http://pulson.seos.uvic.ca/nsane/nsane.html]

NSCAT Acronym for NASA Scatterometer, an instrument that will measure wind speeds and directions over at least 90% of the ice-free global oceans every 2 days under all weather and cloud conditions. It is based on the Seasat scatterometer and uses an array of six stick-like antennas that radiate microwave pulses across the Earth's surface. It will orbit the Earth at an altitude of 800 km in a near-polar, sun-synchronous orbit. NSCAT will fly on the ADEOS mission. See Naderi et al. [1991].

[http://podaac.jpl.nasa.gov/nscat/]

NSCC Abbreviation for Northern Subsurface Countercurrent.

NSDW Abbreviation for Norwegian Sea Deep Water.

NSEC Abbreviation for Northern South Equatorial Current.

NSFE Abbreviation for Nantucket Shoals Flux Experiment, conducted across the shelf and upper slope south of Nantucket from March 1979 to April 1980 to measure the flow of shelf water from the Georges Bank/Gulf of Maine region into the Middle Atlantic Bight. The principal objectives of NSFE were:

- to measure the alongshelf flux of heat, mass, salt and nutrients over one annual cycle;

- to measure the vertical and cross–shelf structure of the low–frequency current and temperature fluctuations over the upper slope and near the shelf–water/slope–water front; and
- to examine the relationship between the alongshelf volume transport and the cross–shelf pressure fields.

The field experiment contained two principal components: a moored array of current meters and bottom instrumentation deployed at six locations across the shelf and upper slope, and a series of 27 hydrographic surveys made along or near the moored array transect during the experiment. The six–element array of moored instrumentation was deployed along a transect across the continental shelf and upper slope south of Nantucket Island near 70°W. It was chosen to start about 10 km south of Davis South Shaols, the shallow southernmost section of Nantucket Shoals, since little alongshelf transport was believed to occur over the shoals. The transport was approximately perpendicular to the local isobaths and cut across the upper slope about 10 km west of Atlantic Canyon and about 10 km east of Alvin Canyon. The six mooring locations were separated horizontally by 16–23 km and in water ranging from 46 m to 810 m deep. See Beardsley et al. [1985].

NSIDC Abbreviation for National Snow and Ice Data Center, a data and information resource for snow and ice processes, especially for interactions among snow, ice, atmosphere and ocean. This is one of the DAACs.

[http://nsidc.org/index.html]

NSTF Abbreviation for North Subtropical Front.

NTF Abbreviation for the Australian National Tidal Facility, which operates the Australian Baseline Sea Level Monitoring Network and is involved in several others.

[http://www.ntf.flinders.edu.au/]

Nuevo Gulf According to Piccolo [1998], this gulf on the Argentine coast ...

> ... is a 2500 km^2 basin that is 65 km long in its major diameter. It is oriented east–west, although its entrace is at the southeast. Its maximum width is 50 km and its entrance is only 16 km wide. The mean depth is 100 m. The annual hydrography of the Nuevo Gulf shows great changes in the density field. Minimum density values are found in the summer season (σ_t = 25.5) comparing with the adjacent shelf. The gulf behaves as a dilution basin where precipitation exceeds evaporation. There are no river flows into the gulf. Therefore, the low density values are produced by reduced evaporation and summer heating. On the other hand, the gulf behaves in winter as a concentration basin with increased density compared with the adjacent shelf. Water exchange between the gulf and the shelf changes seasonally because of the density behavior. There is gulf bottom water flowing into the shelf in winter and a shelf water bottom flow during summer. Current circulation suggests that tides and wind are the main forcing mechanisms.

See Piccolo [1998].

numerical stability In numerical modeling, a numerical computational scheme is said to be stable if the infinite set of computed solutions of the discrete algebraic equations created by the process of discretization of some original continuum differential equations is always below some uniformly bounded upper-limit as the computational grid spacing is shrunk to zero. There are reasonably efficacious methods for exploring the stabilility of a given linear set of discretized equations, although it is much trickier with nonlinear equations, with the most popular option for the latter being the linearization thereof.

NURC Abbreviation for National Undersea Research Center. See NURP.

NURP Acronym for National Undersea Research Program, a NOAA program whose mission is to advance knowledge essential for wise use of the nation's oceanic, coastal, and large lake resources. It supports NOAA and local research needs through a partnership with regional, university–based National Undersea Research Centers (NURCs).

[http://www.ucc.uconn.edu/~wwwnurc/nurp.html]

nutrients The nutrients used as tracers in physical oceanography are essential dissolved chemicals eaten by plants in the ocean, i.e. phytoplankton. The basic nutrients are carbon, nitrogen and phosphorous, with all three having to be present for plant material to grow. Additionally, calcium and silicon are used as skeleton building materials. Micronutrients are those nutrients used in very small quantities. These are magnesium, iron, vanadium, molybdenum and selenium. Also used in small quantities but of no known value are cadmium and barium. See Barnes [1957].

nutrient measurement Until the 1980s nutrient measurements were performed manually using spectrophotometric methods, but were gradually replaced with automatic methods. The pre-automation bible for such things was (and still is, mostly) Strickland and Parsons [1972].

On the matter of measurement error, a categorization of random errors and biases in nutrient determinations is given in Gouretski and Jancke [2001], where the factors are divided into four problems areas.

- Instrument, mechanical and chemical factors, including refractive index problems, bubble production and its effect on mixing, sample contamination, drift within a run via changes in the reagent,a nd differences in sample wash time.
- Standardization, i.e. working calibration standards differ among laboratories by type, supplier, batch, quality and preparation technique. Also, standards prepared in low nutrient sea water are less stable than in distilled or artificial sea water because of the organisms present.
- Sampling and storage. Contamination or losses can produce systematic or random errors and vary with the method, length of storage, and container type.
- Chemical methodology, with possible error sources including the choice and proportions of reagents, salt corrections and the use of constant temperature baths, i.e. temperature effects can be considerable.

See Strickland and Parsons [1972], Koroleff et al. [1977], Conkright et al. [1994] and Gouretski and Jancke [2001].

NVODS Acronym for National Virtual Ocean Data System, a framework for the distribution and analysis of oceanographic (and other) data from researchers and other data providers to intermediate and end users, including other researchers, government and commercial managers and planners, educators, students at all levels, and the general public.

[http://www.po.gso.uri.edu/tracking/vodhub/vodhubhome.html]

NWABW Abbreviation for Northwest Atlantic Bottom Water.

NWLON Abbreviation for National Water Level Observation Network, a network of water level measurement stations in the U.S. coastal ocean, including the Great Lakes and connecting waterways, and in U.S. Trust Territories and Possessions. This is administered by OLLD through the National Water Level Program. The NWLON consists of about 140 continuously operating stations in U.S. tidal regions, 49 continuously operating stations in the Great Lakes, and about 50 temporary stations operated each year in support of NOS mapping, charting, and hydrography and Great Lakes water resources management.

NWLP Abbreviation for National Water Level Program, a program being updated with the NGWLMS.

NWT Abbreviation for northern warm tongue, a tongue of relatively warm water located at the eastern boundary of the WPWP. It is located at around 7 ° N. See Ho et al. [1995].

NYBE Abbreviation for New York Bight Experiment, a joint U.S.–Russian internal wave remote sensing experiment taking place in July 1992 in the New York Bight region near Long Island. It used arrays of aircraft, ships, buoys and satellites from both nations to observe the ocean surface to study how remote sensing can reveal important information on sea surface conditions and air–sea interactions.

[http://www6.etl.noaa.gov/projects/nybe.html]

Nyquist frequency In sampling theory, this is defined by

$$f_N = 1/(2\delta t)$$

where δt is the sampling interval. It is the maximum frequency that can be detected from data sampled at time spacing δt. Higher frequencies are subject to aliasing which can cause the spectrum to differ from the true spectrum. See Nyquist theorem. See Peixoto and Oort [1992].

Nyquist theorem In sampling theory, no information will be lost from a temporal or spatial series of data in the sampling interval is smaller than $1/(2f_{max})$, where f_{max} is the maximum frequency present in the series. In other words, the Nyquist frequency must be higher than the maximum frequency present in the series. See Peixoto and Oort [1992].

NZOI Abbreviation for New Zealand Oceanographic Institute.

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OACES Acronym for the Ocean-Atmosphere Carbon Exchange Study, a program designed to gain a predictive understanding of the magnitude of the atmospheric carbon dioxide that is ultimately dissolved in the ocean and removed from the atmosphere for a period of time.

[http://www.aoml.noaa.gov/ocd/oaces/]

OAMEX Acronym for Ocean–Atmosphere Materials Exchange.

OAR Acronym for the Office of Oceanic and Atmospheric Research, the primary research and development unit of NOAA. It conducts and directs research programs in coastal, marine, atmospheric and space sciences through its own laboratories and offices as well as through networks of university–based programs throughout the country.

[http://www.oar.noaa.gov/]

OASIS Acronym for Optical–Acoustic Submersible Imaging System, an instrument developed for 3–D acoustic tracking of zooplankton with concurrent optical imaging to verify the identity of the insonified organisms. OASIS also measures *in situ* target strengths of freely swimming zooplankton and nekton of known identity and 3–D orientation. The system consists of a 3–D acoustic imaging system (Fish TV), a sensitive optical CCD camera with red–filtered strobe illumination, and various ancillary oceanographic sensors. See Jaffe et al. [1998].

OAXTC Abbreviation for Ocean/Air Exchange of Trace Compounds, a NOAA CMDL program whose goal was to determine the atmospheric mixing ratio of HCFC-22 and its partial pressure in surface waters of the Western Pacific Ocean and to assess the possible existence of an oceanic sink for this compound. This cruise took twelve weeks aboard the RV John V. Vickers in 1992, beginning at Long Beach, California and ending at Noumea, New Caledonia.

[http://www.cmdl.noaa.gov/hats/ocean/oaxtc92/oaxtc92.html]

OBL Abbreviation for oceanic surface boundary layer, one of the two types of PBL.

obligate chemotroph A species of phytoplankton that has no photosynthetic pigments and cannot photosynthesize, as opposed to facultative chemotrophs.

obliquity Also called the obliquity of the ecliptic, this term is used to denote the tilt of the earth's axis with respect to the plane of the earth's orbit. This is one of the three main orbital perturbations (the other two being eccentricity and precession) involved in the Milankovitch theory and as such varies from about 22 to 25°. at a period of about 41,000 years. Obliquity perturbations tend to amplify the seasonal cycle in the high latitudes of both hemispheres simultaneously, with the effect small in the tropics and maximum at the poles. See Williams [1993].

OBS Abbreviation for Optical Backscattering Meter, an instrument built by Downing Associates and used to obtain in-situ measurements of light scattering in sea water. This measurement also provides a crude measure of the particle abundance in the water. The instrument works by projecting a beam of light into the water and measuring the amount of light scattered back to a detector place next to the source. The LSS is a similar instrument.

OCAVE Acronym for Ocean Color Algorithm Validation Experiment, a part of POCEX.

OCCAM Acronym for the Ocean Circulation and Climate Advanced Modelling Project, a project whose aim is to build a high resolution model of the world ocean. The OCCAM model is a primitive equation model of the global ocean based on the GFDL MOM version of the Bryan–Cox–Semtner ocean model with the addition of a free surface and improved advection schemes. It uses a regular latitude–longitude grid for the Pacific, Indian and South Atlantic Oceans and a rotated grid for the Arctic and North Atlantic Oceans to overcome the singularity found at the North Pole in other models. The two grids are connected with a channel model through the Bering Strait.

[http://www.soc.soton.ac.uk/JRD/OCCAM/welcome.html]

OCCM Abbreviation for Ocean Carbon Cycle Model.

OCD Abbreviation for Ocean Chemistry Division, one of four scientific research divisions within NOAA's AOML. Its work includes projects important in assessing the current and future affects of human activities on the coastal, deep ocean and atmospheric environment.

[http://www.aoml.noaa.gov/ocd/]

OCEAN Acronym for Ocean Colour European Archive Network, a project of CEC and ESA established in 1990. The aim of the project was to generate a data base of CZCS data for the European seas and to set up the scientific tools needed for its exploitation. OCEAN processed about 25,500 CZCS images at various levels in its five years of activity and generated an archive of about 400 GB of data from this processing. Some of the processed images are available online.

[http://me-www.jrc.it/OCEAN/ocean.html]

OCEANIC Acronym for Ocean Information Center, a data center that maintains information on WOCE, TOGA, research ships and cruise schedules, and other oceanographic information sources.

[http://diu.cms.udel.edu/]

oceanic expeditions The deep–sea expeditions that have taken place through the history of ocean sciences have been grouped into four eras:

- Era of Exploration (1873-1914)
- Era of National Systematic and Dynamic Ocean Surveys (1925-1940)
- Era of New Marine Geological, Geophysical, Biological and Physical Methods (1947-1956)
- Era of of International Research Cooperation (1957-Present)

The Era of Exploration is considered to have begun – along with modern oceanography – with the British Challenger expedition from 1873-1876. The era was characterized by widely–spaced stations alongs isolated profiles, and the combined results of several such expeditions provided a first overall picture of the bathymetry, stratification and circulation of the water masses and conditions for life in the deep oceans. Other significant expeditions in the era included the German Gazelle (1874-1876), National (1889), Valdivia (1898-1899), Gauss (1901-1903) and Deutschland (1911-1912) expeditions; the U.S. Blake (1877-1886) and Albatross (1887-1888) expeditions; the Russian Vitiaz (1886-1889) expedition; the Hirondelle and Pricesse Alice expeditions of Monaco (1888-1922); the Norwegian Fram (1893-1896), Michael Sars (1904-1913) and Armauer Hansen (1913-Onward) expeditions. These were single, long–term expeditions on large vessels until the Scandinavian school pioneered the use of smaller vessels for more systematic research, e.g. with the Armauer Hansen.

The Era of National Systematic and Dynamic Ocean Surveys was initiated in 1925-1927 by the German Atlantic Expedition on the RV *Meteor*. This expedition took closely spaced measurements at standard intervals all the way to the sea floor along fourteen latitudinal cross–sections of the Atlantic Ocean between 20°N and 65°S. This stimulated other nations to undertake similar expeditions, e.g. the Dutch Willebrord Snellius Expedition (1929-1930) in the East Indian seas, the British Discover Expeditions (since 1930) mostly in the Antarctic oceans, the American Atlantis Expeditions (since 1931) mostly in the North Atlantic, the Danish Dana II (1928-1930) around the world expedition, the Carnegie (1928) and Ryofu Maru and E. W. Scripps (since 1937) Pacific Ocean expeditions, the quasi–synoptic survey of the Gulf Stream northwest of the Azores by the Altair and Armauer Hansen in 1937, and the Russian icebreaker Sedov initiating research in the North Polar Sea in 1938. See Wust [1964].

Oceanic Peru Current
Another name used for the Peru Current.

Oceanic Polar Front See Polar Front.

oceanic province The process was rationalized by Hooker et al. [2000], who created an objective methodology for identifying oceanic provinces in hydrographic data. Their provinces are identified via the positions of localized extrema in the first spatial derivative of the near surface density. They identify 14 provinces in the Atlantic Ocean using data obtained via the Atlantic Meridional Transect cruises. These provinces and their descriptions are:

1. European Continental Shelf Water (ECSW) province, extending from 50.0–48°N. This is composed of North Atlantic Drift water advected onto the shelf, but subjected to the annual seasonal heating and stratification cycle. For a shelf sea, this produces a three-layer vertical structure: the surface mixed layer (typically 20–40 m); a shallow seasonal thermocline (over a limited depth range of 40 or 60 m); and a tidally-mixed bottom layer.
2. North Atlantic Drift (NAtD) province, extending from 48–39°N. The near-surface waters are dominated by Eastern North Atlantic Water being advected south and west by the North Atlantic Current, which feeds into the Portugal Current. From north to south, there is a gradual increase in T and S, leading to a steady decrease in near-surface σ_t.
3. North Atlantic Subtropical Gyre (East) (NASE) province, extending from 38–27°N. The Portugal Current encounters the Azores Current at approximately 37°N, which changes the properties of the water mass to Eastern North Atlantic Water Tropical. The slope of the T-S relationship increases, and near-surface σ_t decreases. The Portugal Current is a component of the North Atlantic Subtropical Gyre; farther south (around 30°N) it is referred to as the Canary Current.
4. Canary Current (CanC) province, extending from 27–20°N. The Canary Current is a broad region of moderate flow wherein waters of the Azores Current are converted into the subtropical water that feeds into the NEC. The region marks the start of the tropics, and is distinguished by a salinity maximum for the Northern Hemisphere.
5. Canary Current Upwelling (CCUp) province, extending from 20–16°N. The coastal upwelling along the western coast of Africa occurs within a narrow (20–30 km) strip along the continental margin. The main impact of the upwelling is confined to the coastal waters, yet the influence can be seen in the sea surface temperature up to 300 km offshore. This distance represents the lateral extent of mesoscale ocean eddies, at approximately 20°W,20°N. The AMT transects encounter a feature with a width of approximately 4°.
6. North Equatorial Current (NEqC) province, extending from 16–12°N. The NEC is a component of the NAG and is a region of broad and uniform flow towards the south and west. At approximately 13°N, the NEC turns westward where it becomes one of the defining bands in the zonal flow system of the equatorial Atlantic.
7. Guinea Dome (GDom) province, extending from 12–8°N. The Guinea Dome is a seasonal mid-ocean upwelling. The main period of upwelling is between July and September and is a result of increased divergence of surface water in response to the seasonal increase in the strength of the southeast Trade Winds. The increase in wind stress increases the flow in the SEC, which in turn produces a north-south slope in the thermocline. Over time, the thermocline slope becomes so

steep it intersects the surface, thereby allowing deeper water to upwell, which produces a dome in the thermocline.

8. North Equatorial Counter Current (NECC) province, extending from 8–1°N. The easterly flowing NECC, is highly seasonal and weakest in the boreal winter and early spring when the Trade Winds in the Northern Hemisphere are strongest. The current is known to transport Amazon Water westward; a core of Amazon Water is seen between 4–5N and is evident as a salinity and density minimum.
9. South Equatorial Current (SEqC) province, extending from 1°N–15°S. Like much of the equatorial system, the SEC is seasonally forced and is strongest during the austral winter. The westwardly flowing SEC is multibanded and has a velocity maximum just north and south of the equator; a relative minimum at the equator is caused by the Equatorial Undercurrent (which has no surface expression and is not detected). A distinct branch of the SEC originates from the Bengula Current; this branch bifurcates at approximately 10–12°S with the main portion feeding northward into the North Brazil Current (NBC) and the rest into the BC.
10. South Atlantic Tropical Gyre (SATG) province, extending from 15–31°S. This region is greatly influenced by the Brazil Current (BC) which flows south and west along the continental shelf of South America. There is a relatively stable T-S relationship, with a gradual decrease in the T and S levels and a commensurate gradual increase in near-surface σ_t. The transect crosses two seamounts (at approximately 34W, 20S) leading to a localized drop in surface σ_t.
11. Brazil Current (BraC) province, extending from 31–35°S. This province is dominated by the BC which is closely confined to the South American continental shelf.
12. South American Shelf (SASh) province, extending from 35–40°S. This province is significantly influenced by the River Plate.
13. Sub–Antarctic Convergence (SAnC) province, extending from 40–46°S. Within this region, the transect follows the Sub-Antarctic frontal boundary between the FC and the BC. The confluence of the two currents results in extreme heterogeneity. Frequently, large warm core rings detach from the warm jet with resultant temperature gradients of up to 6°C over 10 km.
14. Falkland Current (FalC) province, extending from 46–50°S. The water in the region from the Falkland Islands to 46°S is dominated by the fresher Sub-Antarctic Surface Water flowing north in the FC. The T and S are low and show a stable relationship, and the surface σ_t shows an increase.

See Longhurst [1995], Longhurst et al. [1995] and Hooker et al. [2000].

oceanograph See bathythermograph.

ocean heat transport See Bryan [1982] and Covey and Barron [1988].

ocean modeling See McWilliams [1996].

oceanic Living upon the high seas as opposed to living in coastal waters, i.e. neritic.

Ocean Margins Program (OMP) According to Bauer [2002]:

> Thus, the Ocean Margins Program (OMP) was born, with a primary mission to evaluate all the major pools, biogeochemical transformations, and fluxes of carbon (and associated biogenic elements) in its various forms more fully than any previous program conducted in continental shelf and slope waters and sediments. The OMP was the largest coastal ocean program, and one of the largest single-system oceanographic programs, ever undertaken.

> The MAB is arguably now the single most intensively studied ocean margin system in the world from physical, biological, and geochemical perspectives. The program employed the scientific expertises and skills of up to 71 PIs and numerous additional research associates and graduate students from 1992 to 1998. These researchers utilized many months' worth of total ship time on seven major oceanographic research vessels and submersibles, with the majority of the field effort being concentrated between 1993 and 1996. The field effort embraced four major components: (1) whole-shelf and upper slope "surveys" extending from Cape Cod to Cape Hatteras, intended to evaluate the major inventories, sources, and sinks of organic and inorganic carbon pools, (2) hydrographic surveys and the deployment, maintenance and retrieval of an array of between 23 and 26 highly instrumented (including both hydrographic and chemical sensors) moorings, distributed between the mouth of Chesapeake Bay and Cape Hatteras, (3) intensive "process-based studies" focusing on microbial food-web structure and function, primarily in the southern part of the MAB between Chesapeake Bay and Cape Hatteras, in the region of the moored array, and (4) outer shelf and slope sediment biogeochemical and benthic flux studies, also in the southern part of the study area.

According to Verity et al. [2002]:

> The central objectives of the OMP were (1) to quantify the processes and mechanisms that affect the cycling, flux, and storage of carbon in its various organic and inorganic forms and other biogenic elements at the land/ocean interface; (2) to define ocean–margin sources and sinks of carbon in global biogeochemical cycles; and (3) to determine whether ocean margins, including continental shelves, are quantitatively significant in removing carbon dioxide from the atmosphere and isolating it via burial in sediments or by export to the interior ocean, or elsewhere. To achieve these objectives, an integrated multidisciplinary field program was conducted during 1993–1996 to quantify the physics and biogeochemical processes affecting carbon fluxes, nutrient cycles, and ecological dynamics in shelf and slope waters of the entire MAB and at Cape Hatteras, where conditions for carbon burial in sediments and carbon export to the interior ocean were expected to be optimal. In this context, the Ocean Margins Program was an ambitious attempt to decipher not only the physical interactions that occur in the area but also the biogeochemical clues to the processes responsible for the cycling of carbon and other biogenic elements prior to their advection into the North Atlantic.

See Verity et al. [2002] and Bauer [2002].

oceanography More later.

oceanography history See Borgese [1992], Brekhovskikh et al. [1991], Deacon [1971], Deacon [1978], Deacon [1997], Herdman [1923], Idyll [1969], McConnell [1982], Mills [1989], Schlee [1973], Schott [1987], Sears and Merriman [1980] and Thomasson [1981].

`[http://scilib.ucsd.edu/sio/archives/histoceanogr/mills-handlist.html]`

Oceanography Society A society founded in 1988 to disseminate knowledge of oceanography and its application through research and education, to promote communication among oceanographers, and to provide a constituency for concensus-building across all the disciplines of the field. They also publish a magazine called, strangely enough, "Oceanography".

`[http://www.tos.org/]`

ocean optics See optical oceanography.

Ocean Storms Experiment A measurement program taking place from August 1987 to June 1988 that focused on the interactions of atmospheric forcing, mixed layer dynamics and inertial motions, with the aim of improving understanding of upper ocean response to atmospheric forcing. The experiment took place in the autumn in the northeast Pacific, and was concentrated just south of the normal storm track since historical data suggested that it would be a place of rapid mixed layer deepening and strong, storm–forced inertial currents. It was also an area where a low level of mesoscale eddy energy minimized advection and the interaction of eddies and inertial currents. See D'Asaro [1995].

ocean stratosphere The lower layer of the ocean as defined by Defant in 1928. The stratosphere is a sluggish, cold layer which is homogeneous vertically and horizontally in its basic properties. It is a region of slow exchanges. See Defant [1961], Ch. XIX and Tchernia [1980].

ocean troposphere The upper layer of the ocean as defined by Defant in 1928. The troposphere is a region of relatively high temperature where there are strong vertical and horizontal variations of properties. It is a zone of perturbations and strong currents. See Defant [1961], Ch. XX and Tchernia [1980].

ocean turbulence Turbulence in the ocean and atmosphere is chiefly involved with the roles of momentum transport and scalar mixing. In the former role, turbulent motions behave somewhat analogously to molecular viscosity in reducing the differences in velocity between different regions of flow. Scalar mixing is the homogenization of fluid properties such as temperature by random molecular motions, with mixing rates proportional to spatial gradients. These gradients are greatly amplified by the stretching and kneading (i.e. stirring) of fluid parcels by turbulence.

Most classical research results about turbulence are based on the assumptions of homogeneity, stationarity and isotropy in three–dimensional flow, each of which reflects a symmetry in space or time. Turbulence in geophysical flows, or geophysical turbulence, is usually modified by phenomena such as shear, stratification and boundary proximity, each of which breaks one or more of the classical symmetries and therefore invalidates or greatly modifies that which can be deduced or transferred from classical results.

Shear breaks the symmetries of homogeneity and isotropy by deforming turbulent eddies, with the resulting anisotropy allowing the eddies to exchange energy with the background shear via the mechanism of Reynolds stresses, i.e. they allow the turbulence to transport momentum. If this transport is counter to the direction of the shear flow, energy is transferred from the flow to the disturbance. This mechanism represents one of the most common generation mechanisms for geophysical turbulence, with perhaps the most well known example being the Kelvin–Helmholtzinstability.

Stratification leads to buoyancy forces, which break flow symmetry by favoring the direction in which the gravitational force acts. Buoyancy effects can either force (the case of unstable density stratification) or damp (the case of stable stratification) turbulence. In the ocean, surface cooling or evaporation – both of which increae the density of the surface layer – cause unstable stratification which results in convective turbulence. When the stratification is stable, fluid parcels displaced from equilibrium do not convect but rather oscillate vertically at the buoyancy frequency, i.e. we have internal gravity waves.

If the stratification is strongly stable, turbulent motions become in effect two–dimensional, with the turbulent motions taking place in horizontal surfaces that undulate with the passage of internal gravity waves. Three–dimensional turbulence is possible in moderately stable stratification, although its structure is modified by the buoyancy effects. The suppression of vertical motion inhibits the energy transfer from the background shear flow. The relative importance of stratification and shear depends on the relative magnitudes of the vertical gradient of the shear (S) and the buoyancy frequency (N), i.e. if the former is greater turbulence is amplified, if the latter dominates it is suppressed. Key overturning length scales for this situation are the Ozmidov and buoyancy scales, depending on whether internal waves are present.

The distinction between stirring and mixing in stably stratified turbulence is critical. Stirring is the advection and deformation of fluid parcels by turbulent motions, while mixing involves changes in the scalar properties of the parcels, i.e. mixing can only be achieved via molecular diffusion. In stable stratification, changes in the density field due to stirring are reversible, but mixing is irreversible.

The majority of turbulent mixing in the ocean takes place near boundaries, i.e. the ocean bottom and surface as well as lateral obstacles to the flow. Such boundaries obviously suppress perpendicular movement, thus breaking both the isotropy and homogeneity symmetries. If there is any motion, the fact that the velocity must be zero at the boundary sets up a shear leading to the formation of a turbulent boundary layer. The flexibility of the surface boundary leads to such phenomena as surface gravity waves and Langmuir cells, which contribute greatly to upper ocean mixing and therefore air–sea fluxes of momentum, heat and chemical species. See Gargett [1989] and Caldwell and Moum [1995].

ocean water cycle The distribution of evaporation and precipitation over the ocean is the ocean component of the global water or hydrological cycle. Since the ocean covers 70% of the Earth's surface and contains 97% of its free water, it plays a dominant role in this cycle. The terrestrial component of the cycle is understandably much more well understood, although the estimated 86% of global evaporation and 78% of precipitation that occur over the ocean should be better understood given the dramatic consequences small changes in the ocean cycle could have over land.

The ocean water cycle also directly impacts the thermohaline circulation, a key component of the climate system, especially for variations on decadal to millennial time scales. The poleward transport of heat by the atmosphere and ocean moderates high latitude temperatures, with meridional ocean heat transport about equal to that of the atmosphere. A large portion of the ocean heat transport in the northern hemisphere is carried by the thermohaline overturning cell in the Atlantic which, if disrupted, has major consequences for high and mid–latitude continental climate. This cell is thought to have collapsed in the past due to what is called the halocline catastrophe, where the ocean surface salinity is decreased sufficiently via enhanced freshwater input to cause deep water formation processes to cease. The primary factors determining the ocean surface salinity are the distribution of evaporation, precipitation, ice and continental runoff, so it behooves us to adequately understand the ocean water cycle.

Some major features of the ocean water cycle are:

- rainfall dominating over evaporation within the ITCZ in the tropics;
- an excess of evaporation over most of the subtropics except for the SPCZ, a band of net precipitation trending to the southeast away from the western equatorial Pacific;
- dominance of precipitation in subpolar latitudes, more so in the North Pacific than the North Atlantic;
- the amplitude of the water cycle is reduced at high latitudes by the low water vapor capacity of a cold atmosphere;
- the processes of freezing, melting and transport of ice are significant factors in the water cycle at high latitudes;
- patterns of E–P are generally strongly zonal, except for in the North Indian Ocean where evaporation dominates in the Arabian Sea and precipitation in the Bay of Bengal.

A necessary consequence of regional differences in evaporation and precipitation over the ocean is compensating flows within the ocean and atmosphere. Water must be transported into evaporation zones and away from precipitation zones. For instance, there is an excess of precipitation in the North Pacific, especially in the eastern tropical Pacific, and a dominance of evaporation in the Atlantic. This difference is thought to be maintained by water vapor transport across Central America as well as the lack of any similar transport into the Atlantic from Africa. See Schmitt [1995].

[http://earth.agu.org/revgeophys/schmit01/schmit01.html]

OCI Abbreviation for Ocean Color Imager, an all–refractive spectral radiometer with six spectral bands spanning from visible to near infrared.

[http://www.oci.ntou.edu.tw/en/oci/]

OCMIP Abbreviation for Ocean Carbon-Cycle Model Intercomparison Project, a GAIM project to compare the results of global 3-D ocean models being used to study the ocean's carbon cycle.

[http://www.ipsl.jussieu.fr/OCMIP/]

OCSEAP Acronym for Outer Continental Shelf Environmental Assessment Program, a NOAA/BLM project.

OCTOPUS Acronym for Ocean Tomography Operational Package and Utilization Support, a project whose goals are:

- to turn tomography into a routine, affordable, and operational tool for ocean research, monitoring and forecasting for even non–specialist users;
- to increase the acceptance and usage of tomography results as routine data; and
- to enable small and medium enterprises to carry out operational applications and provide instrument services in tomography.

[http://www.ifremer.fr/sismer/program/octopus/]

OCTOPUS Acronym for Ocean Colour Techniques for Observation, Processing and Utilization Systems, a CEC project.

OCTS Acronym for Ocean Color and Temperature Scanner, a visible and infrared multispectral radiometer designed to measure global ocean color and sea surface temperature with high sensitivity. It will show the amount of chlorophyll and dissolved substances in the water along with the temperature distribution. The data will also be used for determination of ocean primary production and the carbon cycle and for monitoring ocean conditions for fisheries and environmental needs. It is a successor to the CZCS.

OCTS scans the Earth's surface using a rotating mirror in the direction perpendicular to the satellite flight path. It has eight bands in the visible and near–infrared region and four bands in the thermal region, with the bands determined by the spectral reflectance characteristics of the objects being observed as well as atmospheric window and correction considerations. The spatial resolution is about 700 meters with a swath width of about 1400 km on the ground, and the orbit allows the same area on the ground to be observed every three days. This instrument will fly on the ADEOS mission.

[http://www.eoc.nasda.go.jp/guide/satellite/sendata/octs_e.html]

ODAS Acronym for Ocean Data Acquisition System, a NOAA project to study phytoplankton blooms in the Chesapeak Bay using aircraft remote sensing from 1990 to 1996. ODAS is a relatively simple ocean color instrument developed in the mid-1980s at the NASA GSFC. It consists of 3 radiometers in the blue–green region of the visible spectrum that measure radiance leaving the water at 460, 490 and 520 nm, a spectral region sensitive to changes in chlorophyll concentrations. The measurements were made in low altitude (150 m) surveys using a De Havilland Beaver aircraft, with over 200 flights made during the program.

[http://noaa.chesapeakebay.net/odas_sas.html]

ODP Abbreviation for the Ocean Drilling Program, which conducts basic research into the history of the ocean basins and the overall nature of the crust beneath the ocean floor using the scientific drill ship, JOIDES resolution. This was originally called the DSDP.

[http://www-odp.tamu.edu/]

ODP Abbreviation for ozone depletion potential.

OEUVRE Acronym for Ocean Ecology: Understanding and Vision for Research, a workshop for biological oceanographers and marine ecologists held at Keystone, Colorado from March 1–6, 1998. The goal was to develop an assessment of the field and an attempt to provide a vision of what it could become over the next few decades. Similar workshops were held at the time for physical oceanography (sf APROPOS), ocean chemistry (FOCUS) and marine geology and geophysics (FUMAGES).

[http://www.joss.ucar.edu/joss_psg/project/oce_workshop/oeuvre/]

offshore The comparatively flat portion of a beach profile extending seaward from beyond the breaker zone to the edge of the continental shelf. See Komar [1976].

OFS Abbreviation for Office of Oceanographic Facilities and Support, a NSF office.

OGP Acronym for the Office of Global Programs, a program office of NOAA. The OGP leads the NOAA Climate and Global Change (C&GC) Program, and assists NOAA by sponsoring focused scientific research aimed at understanding climate variability and its predictability.

[http://www.ogp.noaa.gov/]

OGS Abbreviation for Osservatorio Geofisico Sperimentale, a geophysical research institution located in Trieste, Italy. The OGS has a Department of Oceanology and Environmental Geophysics that performs research in physical ocenaography, especially in the Adriatic Sea, Eastern Mediterrean, Sicily Channel, and the Messina and Otranto Straits.

[http://www.ogs.trieste.it/]

OHTEX Acronym for Ocean Heat Transport EXperiment, a Japanese program.

Okhotsk Sea A marginal sea on the northern rim of the Pacific Ocean centered near 55° N and 150° E. It is bounded by the Siberian coast to the west and north, the Kamchatka Peninsula to the east, and the Kurile Islands to the south and southeast. It covers an area of about 1,600,000 km, has an average depth of about 860 m, and a maximum depth of 3370 m in the Kurile Basin. It is connected to both the Pacific Ocean and the Japan Sea via narrow passages, the most important ones being (for the former) the Boussole Strait (2318 m) and the Kruzenshtern Strait (1920 m) and (for the latter) the Tatarskyi Strait (50 m) and the Soya (or La Perouse) Strait (200 m).

The bathymetry consists of a moderately broad shelf, defined by the 200 m contour, to the north which gradually steepens to depths greater than 3000 m to the south. Two shallow bays, the Shelikov and the Penzhinskaya, occur at the northeastern boundary. Depths shallower than 200 m extend about 100 km off the coast of the Kamchatka Peninsula and Sakhlain Island. From there the bathymetry deepens to a braod area with depths between 1000 and 2000 m in the central part of the sea. The slope steepens near the Kuril Basin, with depths changing from 1000 m to mean depths of 3300 m in the Basin.

The circulation of the Okhtotsk Sea has been summarized by Preller and Hogan [1998], and is presented here in slightly modified form:

The predominant pattern of circulation is cyclonic. Flow from the East Kamchatka Current (EKC) in the Pacific enters the sea predominantly through Kurzenshtern Strait, with smaller amounts of Pacific water entering through several of the other straits to the north. A two–layer flow exists in Kruzenshtern Strait, with a northerly inflow in the upper 50 m with velocities up to 1.0 knot. There is a southerly flow of 2.5 Sv between 100 and 200 m. Strong variability exists on time scales of less than day, with the flow dominated by a strong tidal component, and with the geostrophic component being of secondary importance.

The flow entering through the Kruzenshtern and northern straits turns northward. The transport through the northernmost straits flows along the Kamchatka Peninsula. Flow through the Kurzenshtern Strait splits with part flowing north and west an dpart flowing along the Peninsula. The current continues its cyclonic motion through the shallow Shelikov and Penzhinskaya Bays. Upon exiting the bays, the flow moves westward across the northern part of the sea. It is not known whether this flow is along the shallow northern shelf or in the deeper water just beyond the shelf. The continuation of the cyclonic circulation to the south is called the East Sakhalin Current, which may be weak or absent in summer. It is stronger in winter, extending farther south along the Sakhalin Island coast.

In the southwestern part of the Okhotsk Sea, water originating from the Tshushima Current in the Japan Sea enters via the Soya Strait and flows southeast along the northern Hokkaido coast as a narrow boundary current called the Soya Current. This current varies seasonally, with maximum flow in the summer (around 1 knot) and temperatures ranging from 12–19°C. In winter, the speed diminishes by a factor of two when the region north of Hokkaido is covered by sea ice. The Soya Current continues to flow past Hokkaido and turns to the northeast, with part exiting through the southern straits, part flowing along the Kuril Islands at least to Etorofu, and part flowing into the central Kuril Basin.

The circulation of the Kuril Basin consists of a large, anticyclonic gyre and two anticyclonic eddies. The eddies appear each year, developing in summer and decaying in winter. The Okhotsk Sea water leaves the basin and flows into the north Pacific Ocean through the Bussol Strait and several shallower straits in the southern half of the Kuril chain. A two-way flow has also been calculated for the Bussol Strait, with a southerly outflow of 6.4 Sv for the upper 600 m and a northerly inflow of 4.3 Sv below 600 m. The outflow is found in the upper layers of the western side, and the inflow in the eastern half down to depths of 1700 m.

See Zenkevitch [1963], Tomczak and Godfrey [1994], Freeland et al. [1998], Preller and Hogan [1998], You et al. [2000] and Polyakov and Martin [2000].

Oleander Project An multiyear program to monitor the structure and variability of the Gulf Stream. This is accomplished by a container vessel Oleander operating on a weekly schedule between Port Elizabeth, New Jersey, and Hamilton, Bermuda. It is equipped with a 150 kHz narrowband acoustic Doppler current profiler (ADCP) to measure currents from the surface to about 300 m depth. A major objective of the program is to study the annual cycle and interannual variations in velocity structure and transport by the Gulf Stream. See Rossby and Gottlieb [1998].

OLLD Abbreviation for Ocean and Lake Levels Division, a part of the NOS section of NOAA. It is responsible for the management of the U.S. National Water Level Program (NWLP), the foundation of which is the National Water Level Observation Network (NWLON). See the OLLD Web site[118].

Ombai Strait One of the three main passages for waters in the Indonesian archipelago to flow into the Indian Ocean. The Ombai Strait between Alor and Timor Islands is 3250 m deep, and has an observed

[118]http://www.olld.nos.noaa.gov/

mean westward volume transport of 5±1 Sv. There is a weak annual period in the upper layer flow, and a semi–annual period at depth. See Molcard et al. [2001].

omega equation More later.

OMEX Acronym for Ocean Margin EXchange project, a component of the MAST program. This project aims to study the biogeochemical fluxes and processes across the European continental shelf break facing the North Atlantic. See van Weering et al. [1998].

[http://www.pol.ac.uk/bodc/omex.html]

OMISAR Acronym for Ocean Model and Information System for APEC Region, a project of the Marine Resource Conservation Working Group sponsored by APEC and EPA of Chinese Tapei. See the OMISAR Web site[119].

OMLET Acronym for Ocean Mixed Layer ExperimenT, a Japanese research program taking place on the vessel Hakuho Maru from Jan. 11–Feb. 5, 1991.

OMP 1. Abbreviation for Ocean Margins Program. 2. Abbreviation for Optimum Multiparameter Analysis.

OOPC Acronym for Ocean Observations Panel for Climate, a panel succeeding and formed from the OOSDP. It is sponsored jointly with WCRP, GOOS, and GCOS. The OOPC continues the design of the ocean observing system begun by OOSDP, in addition to addressing:

- areas not considered by the OOSDP;
- prioritizing recommended elements;
- considering alternate sampling strategies; and
- assisting in making inventories of available data and products needed for the GCOS/GOOS common module.

[http://www.bom.gov.au/bmrc/ocean/OOPC/]

OOSDP Acronym for Ocean Observing System Development Panel, established in 1990 by the CCCO of SCOR/IOC and the Joint Scientific Committee (JSC) of the ICSU/WMO. The panel's task was to formulate a conceptual design of a long–term, systematic observing system to monitor, describe, and understand the physical and biogeochemical processes that determine ocean circulation and the effects of the ocean on seasonal to decadal climate changes and to provide the observations needed for climate predictions.

The panel published seven background reports and a final report in 1995 before reforming as the OOPC. The reports were:

- **The Role of Models in an Ocean Observing System** – Neville Smith
- **Scientific Rationale for Recommending Long–Term, Systematic Ocean Observations to Monitor the Uptake of CO_2 by the Ocean – Now and in the Future** – Liliane Merlivat and Alain Vezina
- **Surface Conditions and Air–Sea Fluxes -** Robert Weller and Peter K. Taylor
- **The Ocean Freshwater Cycle** – Raymond Schmitt
- **Monitoring Global Ocean Carbon Inventories** – Douglas Wallace

[119] http://sol.oc.ntu.edu.tw/OMISAR/index.html

- **The Role of the Indian Ocean in the Global Climate System: Recommendations Regarding the Global Ocean Observing System** – J. S. Godfrey et al.
- **Sea Ice in the Global Climate System: Requirements for an Ocean Observing System** – Ian Allison and Richard E. Moritz
- **Scientific Design for the Common Module of the Global Ocean Observing System and the Global Climate Observing System: An Ocean Observing System for Climate** – OODSP Final Report

The final report is available online.

[http://www-ocean.tamu.edu/OOSDP/oosdp.html]

OPA Acronym for Océan PArallélisé, an ocean general circulation model developed by the ECUME team at the Laboratoire d'Océanographie Dynamique et de Climatologie (LODYC). It is a primitive equation model applied to both regional and global ocean circulation. It can be interfaced with several sea ice models, a passive and biogeochemical tracer model, and several AGCMs. It also has adjoint and tangent linear models.

[http://www.lodyc.jussieu.fr/opa/]

OPC Abbreviation for Optical Plankton Counter. See Herman [1992].

open boundary conditions See Palma and Matano [1998].

OPERA Acronym for Observatoire Permanent de l'Atlantique Tropical.

Operation Cabot A multiple-ship cruise to survey the Gulf Stream in 1950. See Fuglister and Worthington [1951] and Stommel [1966].

operational oceanography The activity of routinely making, disseminating, and interpreting measurements of the seas and oceans so as to provide continuous forecasts of the future condition of the sea for as far ahead as possible, provide the most usefully accurate description of the present state of the sea including living resources, and assemble climatic long term datasets to provide data for the description of past states as well as time series showing trends and changes. This usually proceeds via the rapid transmission of observational data to computerized data assembly centers. There they are processed through numerical models to generate products for various applications.

operator splitting In numerical ocean circulation modeling this is a technique for splitting the fast and slow dynamics into separate subproblems. When the partial differential equations governing large-scale ocean dynamics are discretized to achieve numerical solutions, dynamical phenomena with many temporal and spatial scales are usually included in the discretized equations. Most prominent in discretizations of the primitive equations are external and internal gravity waves, where the characteristic wave speeds are, respectively, 200 m/s and 1-2 m/s.

The size of the discrete time step used to integrate the equations is limited by the fastest motion that has to be resolved, in this case the external gravity waves. One way to get around this limitation is to separate the fast and slow motions into separate subproblems. The fast external motions are essentially 2-D due to approximate independence from depth, which leads to the common option of obtaining the 2-D velocity field from a vertical average of the horizontal velocity field in the original 3-D equations.

This procedure can give rise to computational instabilities since the operator splitting method is inexact except for the case of a linearized flow with a horizontal bottom and a rigid lid. In this case one solution is exactly independent of depth and the horizontal velocity field obtained corresponds exactly to the vertically averaged velocity. However, if any of the restrictions are relaxed the fast and slow motions can be mixed by variable bottom topography or nonlinearities and can result in numerical instabilities if an explicit method with a long time step is used to advance the slow motion component in time. See Higdon and Bennett [1996].

optical depth See optical thickness.

optical oceanography See Mobley [1994] and Reynolds and Lutz [2001].

optical thickness A measure of the attenuation of solar radiation by the atmosphere that allows the convenience of considering as a single unit the losses due to scattering and absorption processes. The greater the thickness, the greater the attenuation of incoming solar radiation. This is also referred to as the optical depth.

Optimum Multiparameter Analysis (OMP) A tool to analyze the water mass mixture in a water sample by calculating the contributions from the original water masses (the source water masses) to the sample. OMP is based on a simple linear mixing model that assumes all water mass properties undergo the same mixing processes, i.e. their mixing coefficients are identical. This allows their distribution is space to be determined via a linear set of mixing equations.

Mathematically speaking, OMP is an inversion of an overdetermined system performed individually for each observation point. The source water type contributions for each data point are obtained by finding the best linear mixing combination in parameter space defined by temperature, salinity, oxygen, nutrients and other water mass properties that minimizes the resisuals in a non–negative least squares sense.

[http://www.ifm.uni-hamburg.de/~karstens/omp_std/]

OPTOMA Acronym for Ocean Prediction Through Observation, Modeling, and Analysis, a program that consisted of a lengthy set of surveys of the eddy field in the California Current. See Rienecker et al. [1985].

OPUS Acronym for Organization of Persistent Upwelling Structures, a program taking place in 1983 that studied the inner part of a filament near Point Conception, California. See Atkinson et al. [1986].

OPYC Abbreviation for an isopycnic ocean circulation model developed and used at the DKRZ. See Oberhuber [1993].

ORCA Acronym for Oceanographic Remotely Controlled Automaton, a diesel powered semi–submersible designed to survey water depths from 10 to 300 meters. This instrument was designed for the cost effective collection of hydrographic and oceanographic data. See the ORCA Web site[120].

organic matter pump Then name given to the cycle of organic matter and nutrients in the ocean. Since photosynthesis exceeds respiration only in the euphotic zone, there is a net sink of CO2, phosphate and nitrate in the euphotic zone and a net source in the aphotic zone. Thus a downward flux of organic matter and an upward flux of nutrients connects the euphotic zone sink and the aphotic zone source of nutrients. This has also been called the soft tissue pump, but the present name was suggested in recognition of the possible role of dissolved organic species in the transport cycle. See Najjar [1991].

orthobaric density A density variable empirically corrected for pressure. It is constructed by first fitting compressibility (or sound speed) computed from global ocean datasets to an empirical function of pressure and in situ density (or specific volume). An exact Pfaffian differential form is then obtained by replacing true compressibility by the best–fit virtual compressibility in the thermodynamic density

[120] http://www7440.nrlssc.navy.mil/orca/index.html

equation. The orthobaric density has advantages as a vertical coordinate variable for both descriptive and modeling purposes. The advantages of this over the potential density include:

- a geostrophic streamfunction exists for the momentum equations transformed to orthobaric density coordinates such that the gradients of orthobaric density surfaces give precisely the geostrophic shear;
- a form of Ertel's potential vorticity can be defined whose evolution equation contains no contribution from the baroclinity vector; and
- orthobaric density surfaces are invariant to the choice of reference pressure.

See de Szoeke et al. [2000].

O-SCOPE Acronym for Oceanographic Systems for Chemical, Optical, and Physical Experiments, a program addressing the need for next generation autonomous near real–time long-term time series measurements in critical regions of the world oceans. The goal is to systematically obtain high resolution, long–term, interdisciplinary oceanic data by improving the variety, quantity, quality and cost–effectiveness of observations using a network of strategically placed moorings. O-SCOPE capitalizes on several recent technological advances (e.g. pCO_2, pH and TAlk sensors, nitrate analyzers, spectral optical sensors, and data telemetry) to meet this goal.

The scientific goals of O-SCOPE are:

- quantification of trends in biogeochemical and bio-optical variables which can be caused by major changes in wind–driven and thermohaline circulation and seasonal, interannual, and decadal changes in upper ocean biogeochemical and bio–optical variability and carbon fluxes which affect global climate; and
- monitoring trends in "ocean health" in the form of chemical, biological, and optical indicators.

[http://www.pmel.noaa.gov/oscope/]

OSCR Abbreviation for Ocean Surface Current Radar, a measuring system that uses high frequency radio pulses to probe the ocean surface to deduce near–surface currents. The shore–based system consists of two units which are deployed several kilometers apart. Each unit makes independent measurements of current speed along radials emanating from its phased–array antennae system. The data are then combined via UHF or telephone communication to produce accurate vector currents, store them to disk, and display them in near real time. Measurements can be made simultaneously at up to 700 grid points at either 1 km or 250 m resolution. The OSCR samples for about 10 minutes and then processes radar returns for about 10 minutes to create a quasi-synoptic surface current map every 20 minutes. See the OSCR Web site[121].

OSLR Abbreviation for Intergovernmental Committee for Ocean Science and Living Resources, an IOC committee.

OTEC Acronym for Ocean Thermal Energy Conversion, the use of the temperature difference between surface and deep sea water to generate electric power. This is done by taking a working fluid with a low boiling point, turning it to vapor by heating it up or depressurizing it, and then using the pressure of the expanding vapor to turn a turbine. The liquid used may be either the sea water or ammonia. The OTEC is called open–cycle if the ocean water itself functions as the refrigerant, transferring heat energy by changing between the liquid and gaseous phases. It is called closed–cycle if ammonia is used.

[121] http://exxon.eng.miami.edu/presentation/oscr/

The idea was first propounded by a French engineer named Jacques D'Arsonval in 1881, although it was a student of his named Georges Claude who first tested the idea. Claude used warm seawater to create a low pressure vacuum system, i.e. an open–cycle system. D'Arsonval's original idea was to use another fluid such as ammonia, i.e. a closed–cycle system. At present the only operating OTEC plant is at the Natural Energy Laboratory of Hawaii.

OTH Abbreviation for over–the–horizon radar, a type of radar originally developed to detect military targets far beyond the optical horizon. Radio waves in the 5 to 28 MHz range are reflected from the ionosphere and reach up to 3500 km in one hop. Properties of the ocean surface are extracted from the energy backscattered from the ocean surface. Properties that can be measured include surface wind direction, radial surface currents, sea state, surface wind speed, and more. See the OTH Web site[122].

OTRANTO A research project whose goal is to improve the knowledge about the hydrodynamics of the Straits of Otranto and the evaluate the water and particulate fluxes across this strait at synoptic, seasonal, and interannual time scales. This MTP Core Project took place from Dec. 1993 to May 1996. See the OTRANTO Web site[123].

otter trawl A device used in biological oceanography to trawl for pelagic organisms. As opposed to the beam trawl, the opening to this is kept open not by a rigid rectangular frame but rather by otter boards attached to either side of the net opening. These boards are forced apart by the force of the water when the trawl is towed and close when it is not being towed, an eventuality convenient for retaining the organisms caught. The open may be 20 to 26 m wide and the net up to 40 m in length. See Sverdrup et al. [1942].

outer sublittoral zone See circalittoral zone.

overall Richardson number A dimensionless number expressing the ratio of the removal of energy by buoyancy forces to its production by the shear in a flow. It is expressed by

$$Ri_0 = g' L/U^2$$

where g' is the reduced gravity and L and U are, respectively, length and velocity scales imposed by the boundary conditions of the problem. The name comes from the fact that this is an overall parameter describing a whole flow as opposed to the gradient and flux Richardson numbers. See Turner [1973].

OVERFLOW '60 An ICES investigation of cold, sub–arctic, deep water overspill into the North Atlantic Ocean from the Iceland–Faroe Ridge. It was carried out from May 30 to June 18 in 1960 under the leadership of J. B. Tait and was an optimal coordination of 9 research ships in a small region to reach a maximum of synoptic work. This experiment is considered to be the starting point of current measurements in deep water by self–recording anchored instruments.

`[http://www.ices.dk/ocean/project/data/ov60.htm]`

OVERFLOW '73 An ICES expedition whose core period of observation was between August 15 and September 15 in 1973. The principal objective of this experiment was to describe in detail the kinematic and dynamical processes which lead to the renewal of the sub–Arctic bottom water of the northern North Atlantic across the Iceland–Faeroe Ridge and the Denmark Strait. This experiment, a follow–up to OVERFLOW '60, consisted of over 1700 hydrographic stations and 52 current meter moorings as well as numerous XBTs, tide measurements and drogue tracking. The chief scientist was J. Meincke of the University of Hamburg.

`[http://www.ices.dk/ocean/project/data/ov73.htm]`

[122] http://www1.etl.noaa.gov/othr/othmain.htm
[123] http://www.cetiis.fr/madam/doc/projects/otran/qd_otran.htm

overmixing A condition that can exist in strongly stratified estuaries with net circulation out in the upper layer and net circulation in in the lower layer. This limits the amount of salt water available for mixing inside the estuary. This condition begins as mixing proceeds within the estuary by whatever processes are dominant. The mixing causes more salt water to be added to the net circulation and volume flow out of the estuary up to a critical condition past which any more increased mixing has no further effect on the discharge flow or the exiting salinity. See Officer [1976].

overturning potential energy In a stratified ocean, the locally averaged change in potential energy produced by vertically rearranging the water column to achieve static stability. See McDougall et al. [1987].

OVIDE A tomography experiment planned by IFREMER to study the variability in the subpolar gyre from seasonal to decadal time scales. The goals are to document the transformation of the subpolar mode water and the amplitude of the thermohaline circulation. OVIDE is planned to start in 2002 and includes hydrography, profiling floats, and tomography. It will be based on four tomography moorings that will be installed in the Western European Basin for monitoring the heat content varability of the waters entering and leaving the basin.

oxycline A layer of maximum downward decrease in oxyty.

oxygen See Richards [1957].

oxygen isotope analysis The use of stable oxygen isotopes to extract paleoclimatic information from ice cores. The theoretical basis Bradley [1985] of the method is that two paleoclimatically important heavy isotopes (one containing deuterium and the other 18O) have vapor pressures lower than that of pure H20. Thus, evaporation leads to water vapor depleted in deuterium and 18O as well as a water body enriched in the same. Further, condensation of the vapor preferentially removes even more of these heavy isotopes, leaving the vapor even more depleted in deuterium and 18O. Therefore, to a first approximation isotopic concentration in the condensate can be considered as a function of the temperature at which the condensation occurred, although other considerations come into play.

A major use of this method is to gauge the waxing and waning of glacial periods since the deposition of large amounts of water on land in the form of glaciers leaves the water enriched in and the water depleted of the heavy isotopes.

oxygen isotope ratio The ratio of oxygen-18 to oxygen-16, used as an indicator of paleotemperatures since it is related to ocean temperature.

oxystad A layer of relatively small vertical change in oxyty as proposed in Seitz [1967].

oxyty The concentration of dissolved oxygen. This was proposed as an analogy to salinity in Montgomery [1969]. For a line of uniform oxyty, both isoxygen and isooxygen have been proposed, with isooxygenic as the adjectival form.

Oyashio Current The western boundary current of the subpolar gyre in the North Pacific Ocean. Divergence in the center of this gyre causes the Oyashio to carry cold water rich in upwelled nutrients and full of marine life – hence the meaning of the name as "parent current". The Oyashio is formed by the confluence of the Alaskan Stream and the Kamchatka Current west of the Kamchatka Peninsula at about 55° N. It flows southward and splits into two paths called the First and Second Oyashio Intrusion just south of Hokkaido, after which the First Intrusion proceeds southward along mainland Japan (Honshu) where it turns west at about 38° N to rejoin the First Intrusion, which has proceeded more or less directly south from the splitting point. They merge at about 39° N and 145° E where the southern boundary of the Oyashio defines the Polar Front. This boundary and the northern edge of the Kuroshio maintain their identities at least through the Kuroshio Extension, although it is not well known how much further east they continue to be distinguishable and distinct from the broader eastward flow of the North Pacific Current. Thus the Oyashio forms the western and part of the southern limb of the North Pacific subpolar gyre. See Tomczak and Godfrey [1994].

Oyashio Front A front delimiting the southern limit of subpolar waters in the North Pacific. According to Talley et al. [1995]:

> The Oyashio Front is defined for our purposes as the southern limit of waters that we characterize as "subpolar" based on their temperature–salinity relation, and which are often referred to as "subpolar water." The Oyashio commonly meanders twice (the "first and second intrusions") after leaving the coast of Hokkaido. The meanders are separated by a warm core feature shown to originate from northward movement of warm core rings produced by the Kuroshio, possibly with interaction from westward propagating offshore warm core rings, and with considerable modification due to winter cooling and mixing with surrounding water. The warm core separating the Oyashio "intrusions" is not necessarily always a closed ring. The Oyashio is fairly barotropic, with little vertical shear, and has apparently more transport than can be inferred from a shallow reference level calculation. The Oyashio Front, if defined as a water mass boundary, continues eastward across the Pacific along 40–42°N as the Subarctic Front, forming the boundary between the subarctic and modified subtropical water masses. Much farther east, past the date line, the surface Subarctic Front and the deeper front that forms the northern boundary of the subtropical water become separated, with the surface front found farther south.

See Talley et al. [1995].

Ozmidov scale An important length scale in stratified flow representing the vertical length scale at which the buoyancy force is of the same order of magnitude as the inertial forces. This is expressed as:

$$L_O = \sqrt{\epsilon/N^3}$$

where ϵ is the kinetic energy dissipation rate and N the buoyancy frequency. The Ozmidov scale is the largest that can overturn, i.e. buoyancy has only a minor effect at smaller scales but dominates at larger ones. Overturning can occur at scales greater than L_O if internal waves are present, however, with the buoyancy scale used instead of the Ozmidov scale if vertical velocity fluctuations due to internal waves are small compared to those due to turbulence. This scale varies from a few cm in the thermocline to several hundred meters in weakly stratified and/or highly energetic flows. See McDougall et al. [1987].

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Pacific-Antarctic Basin One of three major basins in the Southern Ocean. It extends from its western border with the Australian-Antarctic Basin at the longitude of Tasmania (about 145° E) to its eastern border with the Atlantic-Indian Basin at the Scotia Ridge and Drake Passage (about 70° W). It consists of the Amundsen, Bellingshausen, and Mornington Abyssal Plains and is separated from the basins further north in the Pacific by the Pacific-Antarctic Ridge and the East Pacific Rise in the east and by the Chile rise in the east.

Pacific Basin Extended Climate Study (PBECS) A proposed CLIVAR program to put in place in the Pacific Ocean a long–term process experiment to test and improve dynamical models of the ocean processes that participate in climate variability. Specific program objectives are:

- to obtain a quantitative description of the low–frequency, three–dimensional circulation and associated thermohaline structure of the upper Pacific Ocean with sufficient accuracy to measure advective fluxes and their divergences;
- to test models of this circulation and its intrinsic modes of variability as well as those due to coupling with the atmosphere; and
- to understand the processes that couple the tropical and subtropical Pacific oceanic gyres on climatic time scales and to test hypotheses about the role of the ocean in basin–scale variability on a broad range of climate time scales.

[http://www.usclivar.org/publications.html]
[http://www.soest.hawaii.edu/~rlukas/PBECS/pbecs_v3.1.html]

Pacific Decadal Oscillation (PDO) A long–lived El Niño–like pattern of Pacific climate variability. The PDO is distinguished from El Niño by two characteristics:

- 20th century PDO events have persisted for 20 to 30 years, while typical ENSO events persist for 6 to 19 months; and
- the fingerprints of the PDO are most visible in the North Pacific and North American sector, with secondary signatures in the tropics, while the opposite is true for ENSO events.

Two full PDO cycles have been identified for the 20th century. Cool regimes prevailed from 1890–1924 and again from 1947–1976, while warm regimes domained from 1925–1946 and from 1977 through at least the mid–1990s. PDO fluctuations are most energetic in the 15–25 year and 50–70 year bands. The PDO Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20°N for the 1900–1993 period).

Large changes in Northeast Pacific ecosystems have been correlated with PDO phase changes. Warm eras are characterized by increased coastal ocean productivity in Alaska and inhibited productivity off the coast of the contiguous U.S., while cold eras show the opposite behavior. See Zhang et al. [1996] and Mantua et al. [1997].

[http://tao.atmos.washington.edu/pdo/]

Pacific Deep Water (PDW) In physical oceanography, a water mass found in the Pacific Ocean in the depth range from 1000-3000 m. It does not participate much in the overall circulation and as such its properties are determined mostly by slow mixing processes. It is composed of a mixture of AABW, NADW and AAIW, and has a characteristic salinity from 34.60-34.65 and a temperature around 2° C. It is also has an oxygen minimum and a silica maximum, with the latter's lateral origin in the northeastern Pacific. This is separated from the bottom AABW by a benthic front in the southern and western North Pacific. See Tomczak and Godfrey [1994], p. 159.

Pacific Equatorial Water In physical oceanography, the water mass that occupies the largest volume of the Pacific thermocline waters. The NPEW and the SPEW are two varieties of this separated, as one might guess, by the Equator. They differ in T-S properties above 8° C but merge into a single curve below this, which reaches T-S combinations showing high salinities indicative of mixing with deep water. See Tomczak and Godfrey [1994].

Pacific High A center of action centered off the coast of Baja, California at about 30° N and 140° W in winter. It moves northwestward to about 40° N and 150° W and intensifies in the summer and effectively fills in the Aleutian Low. See Angell and Korshover [1974].

Pacific Marine Environmental Laboratory (PMEL) A part of the NOAA ERL network the carries out interdisciplinary scientific investigations in oceanography, marine meteorology, and related subjects. See the PMEL Web site[124].

Pacific Ocean The largest and probably least understood of the world oceans. Early attempts at synthesizing and charting the currents of the Pacific are summarized in Peterson et al. [1996]. Wüst published the first modern (i.e. using his core layer method) treatise on the deep circulation of the Pacific in 1929. This treatise, published four years before his better known work on the Atlantic, outlined the basics of the deep circulation reasonably well given the poor database with which he worked. More recent summaries (e.g. Reid [1965], Reid [1981], Reid [1986], Talley [1995], Myers and Weaver [1996] and Reid [1997]) provide a much more detailed look at the circulation at all depths, the variability, and the water masses of the Pacific Ocean.

The surface current structure of the Pacific consists of (from north to south) a cyclonic subpolar gyre, an anticyclonic North Pacific subtropical gyre, a cyclonic and very narrow northern tropical cell including the North Equatorial Countercurrent (NECC), the westward flowing South Equatorial Current (SEC) at and to the south of the equator, an anticyclonic subtropical gyre in the South Pacific, and the Antarctic Circumpolar Current (ACC). The subropical gyre circulations shrink poleward with increasing depth in the North and South Pacific. The western parts of these gyres are C–shaped wherein the western boundary current has a westward and equatorward recirculation just equatorward of and east of the boundary current and its eastward flowing separated extension. This recirculation reconnects to the eastward flow of the gyre at a lower latitude.

The dominant water masses consist of (proceeding from the surface downward): an upper ocean with alternating bands of fresh and saline water directly influenced by surface exchanges, relatively fresh intermediate layers in the Antarctic and North Pacific, Pacific Deep Water (PDW) formed in the north via upwelling and diffusion which intrudes southward, Circumpolar Water (CW) intruding northward, and Antarctic Bottom Water (AABW) intruding northward. The northward spreading CW and AABW are separated from the overlying PDW by a jump in temperature around 1–2° C associated with a vertical stability maximum.

pack ice A type of sea ice defined by the WMO as:

> Term used in a wide sense to include any area of sea ice, other than fast ice, no matter what form it takes or how it is disposed.

Pack ice is described as very open (ice concentration of 0.1 to 0.3), open (0.4 to 0.6 with many leads and polynyas, with the floes generally not in contact), close (0.7 to 0.8, composed of floes mostly in contact), very close (0.9 to less than 1.0), and compact (1.0, with no water visible, and called consolidated pack ice if the floes are frozen together). See WMO [1970].

[124]http://www.pmel.noaa.gov/

PACS Acronym for PanAmerican Climate Studies, a proposed program in the 1995-2004 time frame directed toward the goal of improving the skill of operational seasonal-to-interannual climate prediction (with emphasis on precipitation) over the Americas. It is a sequel to the NOAA EPOCS program. PACS includes the process studies EPIC, NAME and MESA.

[http://tao.atmos.washington.edu/pacs/]

PAGES Acronym for Past Global Changes, an IGBP Core Project charged with providing a quantitative understanding of the Earth's past environment and defining the envelope of natural climate variability within which we can assess anthropogenic impact on the Earth's biosphere, geosphere, and atmosphere. PAGES seeks the integration and intercomparison of ice, ocean, and terrestrial paleorecords and encourages the creation of consistent analytical and database methodologies within the paleosciences.

[http://www.pages.unibe.ch/]

PALACE Acronym for Profiling ALACE float, a float with all of the capabilities of an ALACE float as well as a longer lifetime and a CTD profiler to obtain vertical temperature and salinity profiles. See Davis et al. [2001].

PALE Acronym for Paleoclimate of Arctic Lakes and Estuaries, an NSF/ARCSS and PAGES initiative to study the paleoclimate of arctic lakes and estuaries. The goal is to reconstruct Arctic climate variations over the past 150,000, 20,000 and 2,000 years and understand its interation with the global climate. PALE ended circa 2001 and was expanded to become PARCS.

paleobiogeography The study of the spatial distribution of ancient organisms, including analysis of the ecological and historical factors governing this distribution. In contrast to paleoecology, most paleobiogeographical studies have dealt with distributions of individual taxa or with questions of global or regional provincialism. See Briggs and Crowther [1990], pp. 452-460.

paleobiology The science dealing with the fields of evolution, ecology and the subsequent taphonomy of extinct animals and plants. See Briggs and Crowther [1990].

paleocalibration method A method for calculating the relationship between paleoclimates and the future climate. For a given time interval, one obtains both the difference from present-day globally averaged surface temperature (DT) and the difference from the present-day globally averaged radiative forcing (DQ). DT is obtained from whatever geologic proxies are available. DQ is obtained by calculating or estimating the total effect of the heat trapped by greenhouse gases and the changes in absorption of solar radiation due to changes in solar luminosity, surface albedo and atmospheric aerosol content. Finally, the ratio DT/DQ is defined as the climate sensitivity, i.e. the global temperature response to the radiative forcing. See Covey et al. [1996].

paleolimnology The branch of limnology that studies of past fresh water, saline and brackish environments. This is done in large part by taking cores from a limnological sediment system and examining the geological, biological and chemical components preserved in the core.

paleothermometry The use of various paleoclimate proxy data to attempt to gauge paleotemperatures.

paleotide The theories of the tidal evolution of the Earth-Moon system show that the effects of tidal friction are such that the Moon's motion and the Earth's rotation can drastically change on geologic time scales. The theories gained empirical support from the paleontological studies of skeletal growth increments in fossil marine invertebrates by Wells [1963] showing an increasing number of days per year, days per lunar month, and lunar months per year going back through the Phanerozoic. Models of the evolution of the Earth-Moon system show the Earth and Moon to have been much closer together in the distant past with the separation increasing with time.

The first models of the Earth as a phase lagged ellipsoid with a constant phase lag angle showed the Earth and Moon to have been close enough together at some point in the past 2.5 billion years (b.y.) to result in tides 1 km high with tidal energy sufficient to not only boil off the oceans but also to melt a part of the Earth and the lunar mantle. It would also have increased the surface air temperature to 1700 K (via an increased greenhouse effect due to increased water vapor in the atmosphere) and eliminated life on Earth. The complete absence of physical evidence for such an event led to relaxing the assumption of a constant phase lag via the incorporation of the effects of continental drift, i.e. a change in continental configuration will change the resonance properties of the ocean and the tides and tidal dissipation therein and therefore the evolution of the Earth-Moon system. Numerical modeling studies have shown the consolidation of continents to attenuate/amplify semidiurnal/diurnal oscillations and the dispersal of continents to have the opposite effect. The inclusion of this effect leads to a more reasonable scenario for the Earth-Moon tidal evolution history. See Kagan and Sündermann [1996].

paleowind A wind of the geological past. The practical geological indicators of paleowind are several scalar properties (bed thickness, grain size and sorting, mineral proportions) and directional structures (dune forms, yardangs and wind furrows, dune cross-bedding, windblown trees, wind ripples, adhesion ripples, flues and grooves). Such an indicator can be an effective paleoclimatic tool only if it is reasonably common, of high geological preservation potential, easily recognized and measured, and capable of unique or at least statistical interpretation.

PAN Acronym for Peroxyacetyl Nitrate.

PANASH Acronym for Paleoclimates of the Northern and Southern Hemispheres program, a proposed project of PAGES.

pancake ice A type of sea ice defined by the WMO as:

> Predominantly circular pieces of ice from 30 cm to 3 m in diameter, and up to 10 cm in thickness (unrafted), with raised rims due to the pieces striking against one another. It may be formed on a slight swell from grease ice, shuga or slush or as the result of the breaking of ice rind, nilas or, under severe conditions of swell or waves, of grey ice.

See WMO [1970].

pancake cycle A process of sea ice development in the Antarctic. The pancake ice pieces start with a diameter of tens of centimeters, but aggregate with loose frazil ice crystals through wind and wave action to increase in diameter, and raft with other pieces to increase in thickness. This can cause rapid growth to a few meters in diameter and up to 1 meter thick. The pancakes eventually can freeze together into either large floes or a consolidated ice cover.

Panthalassa The Early Mesozoic world ocean. It was a single ocean reaching from pole to pole, probably consisting of single southern and northern gyres, deep water formation at both poles, and slothlike deep-water circulation. See Bowen [1991].

PAR Abbreviation for Photosynthetically Available Radiation, a quantity used in studies of photosynthesis as a measure of total available light. It is defined as a flux of quanta rather than energy and is usually considered to be the total photon flux between 400 and 700 nm (with the lower limit sometimes moved to 350 nm). This is around 38% of the total extraterrestrial solar irradiance. PAR is defined, as a function of depth, by

$$PAR(z) = \frac{1}{N_0}\int_{400}^{700} E_{\lambda 0}(z)\,(\lambda/hc)\,d\lambda$$

where N_0 is Avagadro's constant, h is Planck's constant, c the speed of light, λ the wavelength, and E the irradiance. The units of PAR are einsteins per square meter per second, and it is measured underwater using a device called a quantum meter.

parabolic approximation See Mei [1990].

paradox of the plankton The long–term coexistence of plankton species that might be expected to compete. This is due to the degree to which chance encounters dictate the degree to which intra– or interspecific competition occurs. This, in turn, is due to plankton be unusually dependent on their physical environment for support, transport and food. See Rigby and Milsom [2000].

Parallel Community Climate Model (PCCM) A parallel version of the NCAR Community Climate Model (CCM2) implemented for MIMD massively parallel computers using the message passing programming paradigm. It can be implemented on a massively parallel machine supporting message passing or across a network of machines with the PVM software package. See the PCCM Web site[125].

parameterization In numerical modeling, the method of incorporating a process by representation as a simplified function of some other fully resolved variables without explicitly considering the details of the process. The classic example is the representation of sub-grid scale turbulence as the product of a function of the velocities at the local grid points and an empirically derived eddy viscosity coefficient (in analogy to the molecular viscosity coefficient). This analogy has been known to fail. See, for example, the classic (and wonderfully titled) monograph of Starr [1968].

The processes that must be parameterized in ocean circulation models, as summarized by James McWilliams at the APROPOS meeting in 1998, include:

- effects of surface gravity waves on currents (vortex forces and mean Lagrangian transport);
- turbulent transports within the planetary boundary layers and entrainment/detrainment at their interior edges (convective plumes, shear vortices, Langmuir cells);
- interior diapycnal mixing processes (gravity waves, Kelvin–Helmholtz vortices, double diffusion);
- topographic roughness effects (form stress, gravity wave generation, local secondary circulations);
- mesocale eddy transports of momentum and tracers, including potential vorticity (isentropic mixing and mean Lagrangian transport);
- topographic barriers (sills and straits);
- effects of deep convection and its preconditioning (in shallow seas, over topographic features, in interior regions); and
- transports by gravity currents over sills and off of continental shelves.

PARCS Acronym for Paleoenvironmental ARCtic Science, a part of ARCSS program. The theme is to explore the importance of land–ocean interactions and the variation in freshwater and chemical fluxes within the total arctic system.

[http://www.ngdc.noaa.gov/paleo/parcs/]

Particle and Optics Profiling System (POPS) An assembly of instruments designed to count and measure particles and to determine optical and environmental properties of water as a function of depth. The main part of the POPS system is the Large Aggregate Profiling System (LAPS) package used to measure particles ranging from 250 microns to several millimeters in diameter. It also usually carries an LISST which measures smaller particles ranging from one to 250 microns in diameter. Other

[125] http://www.epm.ornl.gov/chammp/pccm2.1/index.html

instruments found on POPS include a CTD, a transmissometer (for measuring particles less than 20 microns in diameter), a fluorometer and an a-c meter (for measuring chlorophyll), LSS (for measuring particle abundance).

particulate matter The suspended particle load that controls the chemistry of the oceans. The physical and chemical properties of the particles control how rapidly a chemical species is removed from solution and incorporated in sediment. The four main sources of this in the oceans are: (1) fluvial input of terrigenic material; (2) aeolian input from wind erosion of continental masses, volcanism and anthropogenic sources; (3) resuspension of sedimentary material by current erosion, earthquakes and slumping; and (4) authigenic production by biota, submarine volcanism and the precipitation of inorganic minerals. See Simpson [1982].

passage The official IHO definition for this undersea feature name is "a narrow break in a ridge or a rise; also called a gap."

PATCHEX Acronym for the Patches Experiment, which took place off the California coast in October 1986. See Brainerd and Gregg [1993].

patchiness According to Martin [2003]:

> Spatial heterogeneity or "patchiness" in phytoplankton distributions is one of the oldest oceanographic observations. As early as the eighteenth century, explorers, such as de Ulloa and Cook, report seeing strongly localised patches of coloured water associated with heightened phytoplankton concentrations (see [Bainbridge, 1957]). Despite this there is still little consensus on the causes and consequences of what is a ubiquitous phenomenon. Many theories have been advocated and numerous specific instances have been investigated but a general theory remains a distant goal. It is still uncertain whether such a general theory actually exists. As spatial heterogeneity can strongly influence ecosystem stability ([Steele, 1974]), diversity ([Hobson, 1989 and Bracco, Provenzale and Scheuring, 2000]), dynamics ([Brentnall, Richards, Brindley and Murphy, 2003]) and regional productivity ([Martin, Richards, Bracco and Provenzale, 2002]), an understanding of patchiness is clearly vital to an understanding of the marine ecosystem as a whole. More specifically, the current inability of climate prediction models to resolve ecosystems at the mesoscale and smaller makes it imperative to understand the consequences of failing to do so.
>
> The subject of phytoplankton patchiness has received relatively little theoretical attention subsequent to a surge in interest in the late 1970s. A combination of factors, however, means that the situation is changing rapidly. The advent of a new generation of colour-sensing satellites means that near global, one kilometre-resolution data of phytoplankton distributions is now easily available on a near-daily basis??bar the inevitable cloud problem. Advances in instrumentation technology mean that we can now continuously ship-survey measures of phytoplankton, nutrients, and zooplankton abundance, in three dimensions in some cases. Theories of physical turbulence have changed radically over recent years and are starting to percolate into models of phytoplankton patchiness. Powerful new mathematical techniques for the analysis of structure in spatial and temporal distributions are being developed. It is the aim of this paper to set existing theories for the generation of patchiness in the context of current knowledge. A critical review of extant theories is central to this. By understanding the limitations of old theories, and by appreciating new techniques and observations, it should be possible to form the questions relevant to a major revision of the study of patchiness.

See Martin [2003].

PATHS Acronym for Pacific Transport of Heat and Salt, a joint program among Canada, Japan and the U.S. See WMO [1983].

PBECS Acronym for Pacific Basin Extended Climate Study.

PBL Abbreviation for planetary boundary layer.

PBL-LIB This is a collection of programs that deal with data pertaining to the PBL. See the PBL-LIB Web site[126].

PCA Abbreviation for principal component analysis, usually used synonymously with EOF.

PCCM Abbreviation for Parallel Community Climate Model.

PCIS Abbreviation for Pacific Climate Information System, a comprehensive information system containing statistical information on rainfall clmiatology and variation with the ENSO cycle for almost 300 Pacific islands.

`[http://lumahai.soest.hawaii.edu/Enso/pcis/pcis.html]`

PCMDI Abbreviation for the Program for Climate Model Diagnosis and Intercomparison, whose mission is to develop improved methods and tools for the diagnosis, validation and intercomparison of global climate models.

`[http://www-pcmdi.llnl.gov/]`

pCO2 The equilibrium partial pressure of CO2.

PCSP Abbreviation for Polar Continental Shelf Project, a Canadian program.

`[http://polar.nrcan.gc.ca/]`

PDO Abbreviation for Pacific Decadal Oscillation.

PDR Abbreviation for Precision Depth Recorder.

PDW See Pacific Deep Water.

PE Abbreviation for primitive equations.

PEAC Acronym for Pacific ENSO Applications Center, a NOAA project established to conduct research and produce information products on climate variability related to the ENSO climate cycle in the U.S.-affiliated Pacific Island. See the PEAC Web site[127].

peak The official IHO definition for this undersea feature name is "a prominent elevation either pointed or of a very limited extent across the summit."

PECHORA Acronym for Paleo Environment and Climate History of the Russian Arctic, a project whose main purpose is to increase the understanding of climate changes and the impact these changes have on the environment in arctic Russian during the last interglacial–glacial cycle. The goals are:

- reconstruction of the Barents and Kara Ice Sheets through time;
- reconstruction of fauna, vegetation and climate history; and
- reconstruction of the history of human settlement.

[126] http://www.atmos.washington.edu/misc/PBL_LIB.html
[127] http://naulu.soest.hawaii.edu/

[http://www.geomar.de/~hbauch/king/html/Svend.htm]

PEGASUS An acoustically tracked velocity profiler. See Spain et al. [1981].

PEQUOD Acronym for the Pacific Equatorial Dynamics Experiment. See Eriksen [1987].

Peclet number A dimensionless number expressing the ratio of advection to thermal diffusion. It is expressed by

$$Pe = \frac{UL}{\kappa}$$

where U is a velocity scale, L a horizontal length scale, and κ the thermal diffusivity. Molecular diffusion of heat is negligible when $Pe \gg 1$. In practice, the Peclet number is almost always large except for extremely small-scale phenomena with low velocities. This is similar to the Reynolds number except that the kinematic viscosity ν has been replaced by the thermal diffusivity κ. See Kraus and Businger [1994], p. 32.

pelagic Descriptive of organisms that inhabit open water, as opposed to benthic. This is sometimes divided into five separate ecological zones which are, proceeding from the surface to the bottom, the epipelagic, mesopelagic, bathypelagic, abyssopelagic and hadopelagic zones. See Bruun [1957].

Pelagic Fisheries Research Program (PFRP) A research program established in 1992 to provide scientific information on pelagic fisheries to the Western Pacific Regional Fishery Management Council (WPRFMC) after the Magnuson Fishery Conservation and Management Act of 1976 was amended to include highly migratory fish. It is located at JIMAR at the University of Hawaii.

[http://www.soest.hawaii.edu/PFRP/pfrp1.html]

PELAGOS Greek acronym for 'Hydrodynamics and Biogeochemical Fluxes in the Straits of the Cretan Arc', a project designed to research the hydrodynamics of the South Aegean Sea and the southeastern Ionian and northwestern Levantine Seas, with the aim of investigating biogeochemical fluxes through the Straits of the Cretan Arc. The project was launched within the framework of the Mediterranean Targeted Project (MTP) of the Marine Science and Technology Programme (MAST) of the European Union (EU), and included scientists from Greek, British and French institutions. The National Centre for Marine Research (NCMR) in Athens coordinated the program during its contracted duration from September 1993 to March 1996. The study area originally covered the Straits of the Cretan Arc (Eastern Mediterranean Basin), but was eventually extended further, first into the South Aegean Sea, and then to the southeastern Ionian Sea and the northwestern Levantine Sea.

The field programme of PELAGOS lasted from March 1994 to June 1995, during which time four major synoptic surveys were undertaken in the Cretan Sea, the Straits of the Cretan Arc and adjacent seas (northwestern Levantine and southeastern Ionian). In addition, four seasonal surveys (for the investigation of specific variables) were undertaken along a west-east section of the Cretan Sea. Finally, several short cruises were undertaken in connection with current meter and sediment trap deployments, recoveries, and re-deployments. The synoptic cruises were carried out on board R/V Aegaio for hydrographic, chemical (nutrients, dissolved oxygen) and biological (phytoplankton, chlorophyll-a, zooplankton) sampling. The other surveys were directed mainly towards biological and geochemical sampling, undertaking ADCP measurements, and the deployment/recovery of current meters and sediment trap moorings.

The primary tasks were the measurement of various physical, chemical, biological and geochemical parameters; together with the water circulation controlling their basin-wide distribution and disposition. Particular emphasis was placed upon the processes across the Straits of the Cretan Arc and their seasonal time-scales. Hence, expanded horizontal coverage and dense vertical sampling/measurement of temperature and salinity was established. Concurrently, data on nutrients, dissolved oxygen, trace elements dissolved in seawater and the geochemical characteristics of suspended particulate matter (SPM) were collected at selected depths, to enable their subsequent vertical and horizontal integration with the various water exchanges. The chemical analyses of dissolved trace elements, together with SPM trace and major elements, were related mainly to the Straits of the Cretan Arc and along an east-west section of the Cretan Sea. Self-recording current meters were deployed within the Straits of the Cretan Arc for a year. These deployments improved the understanding of the prevailing flow patterns and controlling mechanisms, together with their variability; similarly, they permitted the estimation of fluxes of water and associated (dissolved or suspended) material through the various Straits. At the same time, moored sediment traps provided independent (time-series) assessments of the vertical flux of settling particles and the nature of material deposited in the western Straits (Antikithira Strait). Size-fractionated chlorophyll-a and primary production determinations were undertaken, to estimate productivity. In addition, phytoplankton and zooplankton sampling was performed, to obtain qualitative and quantitative estimations of the aforementioned parameters and their variability.

See Balopoulos and Collins [2000] and the other papers in Volume 44 of "Progress in Oceanography" for further details. Project data and results are archived at the HNODC.

PEP Acronym for Pole–Equator–Pole, a PAGES sponsored inter–American paleoenvironmental research program focuses on the dynamics of transequatorial atmospheric and ocean linkages.

peristaltic pumping velocity See eddy-induced transport velocity.

permanent thermocline A relatively sharp change in temperature (and therefore density) beneath the seasonal thermocline maintained by a balance between downward diffusion of heat and the gradual upwelling of deep, cool water.

Persey Current See Pfirman et al. [1994].

Persian Gulf A marginal sea of the Indian Ocean centered at approximately 52° E and 27° N. It is surrounded by Iran to the north, Kuwait, Saudi Arabia, Qatar, and the United Arab Emirates to the east and south, and connects with the Gulf of Oman (and on into the Arabian Sea) through the Strait of Hormuz to the east. It has a length of 990 km, ranges in width from 56 to 338 km, covers an area of 241,000 km^2, occupies a volume of 10,000 km^3, has a mean depth of 40 m, and a maximum depth of about 170 m.

The circulation features have been well summarized in RSMAS [2000] as:

> The basic features of the Arabian (or Persian) Gulf can be divided into a northern and southern or eastern regime. The northern regime is dominated by wind forcing to the south along the axis of the Gulf and the riverine input at the Gulf's head. The wind-driven response of the Gulf appears to be the typical adjustment of the pressure field such as to produce a down-wind flow, i.e. there is downwelling on the western coast and upwelling on the coast of Iran, and evidence for a southeastward flowing coastal current along both the northern and southern coasts (Reynolds [1993]). The flow along the Kuwait and Saudi coast is augmented by the freshwater input from the north which forms a riverine plume. The river inflows are approximately split between the flow out of the Shalat Ariabi (Tigris and Euphrates) and rivers flowing out of the highland of Iran (the Hendijan, Hilleh, and Mand). In current times the flow of the Shalat Ariabi is much smaller than it once was because of massive dam projects in Turkey. It is not clear what changes this decline in freshwater input has made. The center of the northern Gulf appears to be fairly stagnant (Reynolds [1993]). The southern end of this regime corresponds roughly to the longitude of Qatar and Bahrain,

although the termination of the northern circulation is poorly understood. The flow along the Iran coast seems to continue into the southeastern basin as a tightly trapped coastal current extending perhaps as far as the Strait of Hormuz. This flow becomes very complex in proximity to the island of Jazareh in the northern portion of the Strait.

The northern Gulf is separated from the southern regime by a front that typically is found off Qatar. This front is most intense in summer and weakest, at least in sea surface temperature, in the late winter and spring. The location of this front appears in both climatological hydrographic data and remotely sensed SST to be tied to the penetration of fresh inflow into the Gulf from the Strait of Hormuz. The available data suggests that much of this inflow may terminate in a counter-clockwise, cyclonic flow to the east of the mid-Gulf front. This cyclone appears in circulation climatologies and appears as a coherent SST anomaly in satellite imagery. East of this front the available data suggest a flow out of the Gulf around the tip of the Musandem peninsula and into the northern Gulf of Oman. The large evaporation over the Gulf leads to an inverse estuarine circulation with the highly saline waters leaving the Gulf through the deep part of the Strait of Hormuz and being replaced by a fresh surface inflow from the Gulf of Aden. The saline bottom waters that flow out through the Strait may originate from several locations in the Gulf. Historical salinity data and SST data implicate a broad region of high salinity waters extending from Qatar eastward along the Emirate coast. Waters in this shallow region can reach very high salinities (>42 psu) and appear to form a warm and salty endpoint of the Gulf outflow. The temperature salinity relationships of the observed outflowing waters imply a fairly complicated set of water mass modifications in the Gulf. Colder and somewhat fresher waters are also found in the deep outflow from the Gulf and suggest another source, probably from the northern Gulf. Modeling results suggest that some of the outflow arises from sinking in the shallow high salinity area off the Emirates, but that further sinking occurs in the vicinity of the variable mid-Gulf front.

The deep water arising from these sources exits the Gulf on the southern (deepest) side of the Strait of Hormuz at a maximum depth of $\sim$100 m. Unlike the Mediterranean or Red Sea the Gulf is shallow ($<$100 m) and there is no prominent sill to constrain the outflow. The annual mean outflow of the deep waters and compensating fresh surface inflow is estimated from the Knudsen relations to be approximately 0.2 Sv, assuming a mean evaporation rate of approximately 1.5 m/yr and net freshwater input from rivers of $\sim$0.2 m/yr. Estimates of the exchange rate from available models span a range from 0.1 Sv to nearly 0.4 Sv. Seasonal variability of the deep outflow and surface inflow is not clearly established, although recent measurements suggest that the deep outflow may be fairly steady throughout the year.

See Elliot and Savidge [1990], Reynolds [1993], Flagg and Kim [1998], Bower et al. [2000] and RSMAS [2000].

`[http://mpo.rsmas.miami.edu/~zantopp/AMSG-report.html]`

Peru–Chile Countercurrent (PCCC) One of two branches into which the Pacific Equatorial Undercurrent (EUC) splits when it encounters the Galapagos Islands. The Poleward Undercurrent (PUC) is one branch, while the other branch flows to the southeast of the Islands and approaches the coast at about 6–7°S to form the Peru–Chile Countercurrent. Tongues of minimum phosphate distributions and surface drifters have been used to identify this current.

According to Strub et al. [1998]:

Evidence for the location and variability of the Peru–Chile Countercurrent is less conclusive, especially off Chile. It is better documented off Peru, where it appears 200 m offshore

> in mean sections at 10°S. South of 15°S is was originally thought to flow straight south along approximately 75–77°W. More recently, three years of satellite altimetry data show a continuous band of poleward currents 100–300 km from the coast that extend from approximately 8–35°S, following the coastline. The poleward currents in the altimeter data are maximum in austral spring and minimum in fall.

See Strub et al. [1998].

Peru–Chile Undercurrent Another name for the Poleward Undercurrent (PUC).

Peru Coastal Current (PCC) According to Strub et al. [1998] ...

> ... water mass properties suggest that the equatorward surface flow [of the current] is strongest in austral winter, when equatorward winds are maximum. It carries colder and saltier upwelled water to the north in the equatorial cold tongue, characteristic of the South Equatorial Current (SEC). Its confluence with the warm and fresh water moving southward out of the Panama Bight creates the strong Equatorial Front (EF). Low temperatures in the cold tongue are maintained by upwelling along the equator and the extent of the cold tongue is maximum at the end of austral winter (September–October). In austral spring and summer, the cold tongue collapses back toward the coast as the trade winds weaken in the eastern equatorial Pacific. At this time the Equatorial Front is unpredictable, weak or absent and a warm tongue extends southwest along an offshore region from the equator to northern and central Chile, which may be related to the Peru–Chile Countercurrent (PCCC).

This and the Chile Coastal Current (CCC) are together sometimes referred to as the Inshore Peru Current. See Strub et al. [1998].

Peru Current A component of the eastern limb of the counterclockwise-flowing southern subtropical gyre in the Pacific Ocean. The flow rate has been estimated at around 15 Sv, although variations from this can be considerable. This current is part of the most impressive upwelling system in the oceans, with the upwelling driven by prevailing winds from the east that push the surface water westward, allowing the cold, nutrient-rich water beneath to well to the surface. Without the upwelling, this current lowers the temperatures along South America several degrees belows the zonal average, and the upwelling serves to lower the temperatures without about 100 km of the coast another 2 to 4° C. The nutrient content of the upwelled water makes this region the most productive upwelling region in the world ocean, although a combination of overfishing and the effects of the El Nino phenomenon put an end to what was the largest fishery in the world before 1973.

The southern part of the Peru Current is sometimes called the Chile Current. Other names used for the entire current have been Chile–Peru Current, Humboldt Current and Oceanic Peru Current. See Tomczak and Godfrey [1994].

Peterson grab A type of bottom sampler used in biological oceanography to for the quantitative investigation of benthic organisms in relatively shallow waters. It comprises a set of heavy hinged jaws that are held open during descent but are released when the device hits bottom. The jaws close on an area of benthic material (usually around 0.1 m2) when the cable is drawn tight and the device returned to the surface. The organisms thus caught are screened from the bottom sediments, classifed and counted to develop statistics for organisms per square meter in the study area. See Sverdrup et al. [1942].

Pettersson, Hans Head of the Swedish Deep Sea Expedition and son of Otto Pettersson. See Guberlet [1964].

Pettersson, Otto A Swedish chemist and physical oceanographer who organized many of the earliest co-operative cruises in Scandanavian waters and promoted the idea of what would become the ICES. See Schlee [1973] and Pettersson [1894].

PEX Acronym for Baltic Sea Patchiness Experiment, an ICES investigation which took place in the Gotland Basin during April through May in 1986 under the leadership of B. Dybern. The basic objective of the experiment was to study the heterogeneous and patchiness in the distribution of physical, chemical and biological properties in the region. Almost all of the Baltic Sea countries contributed to a total of 15 research vessels used in this experiment.

[http://www.ices.dk/ocean/project/data/pex86.htm]

PF Abbreviation for Polar Front.

PFRP Abbreviation for Pelagic Fisheries Research Program.

PFZ Abbreviation for Polar Frontal Zone.

phagotrophic Descriptive of a heterotrophic phytoplankton species that feeds on phytoplankton or detritus.

Philippine Sea See Qu et al. [1998].

Phleger Bottom Sampler A bottom sampler used for quantitative studies of foraminifera, designed to take a short core of the upper sediment layers without disturbing the surface layer. This sampler, first used in 1951, is a short weighted tube with a removable lining tube and a replaceable cutting edge. The liner is a clear plastic tube with a diameter of 3.5 cm. It can be operated with a light winch in depths up to 500 m when weighted with 35-40 pounds of molded lead, and to depths of 4600 m in more cohesive sediments. See Hedgpeth [1957b].

phosphorus Phosphorus is an essential nutrient used by all organisms for energy transport and growth. One of the most important aspects of the phosphorous cycle is its role in governing productivity, thereby acting with the exogenic part of the carbon cycle.

Known P oceanic sources are:

- rivers, the predominant source, with a total estimated flux of 7.4–15.6 $\times 10^{11}$ mol P yr^{-1};
- aeolian deposition, with an estimated flux of 4.5 $\times 10^{10}$ mol P yr^{-1}; and
- volcanic emissions, a more local and intermittent source.

The known P sinks are:

- biological uptake and incorporation into sinking particulate organic matter, the predominant sink, is estimated to have a total flux of 2.8–3.1 $\times 10^{11}$ mol P yr^{-1};
- absorption onto the surface of shells via iron oxyhydroxide coatings, estimated to be 4.0–5.3 $\times 10^{10}$ mol P yr^{-1};
- the burial of phosphorites, estimated to be $>8 \times 10^{10}$ mol P yr^{-1}; and
- hydrothermal processes, estimated at 0.65 $\times 10^{10}$ mol P yr^{-1}.

The global marine inventory of dissolved P is about 3.2 $\times 10^{15}$ mol P, with the residence time relative to the known P sources estimated to be 20,000 to 80,000 years. The residence time relative to the known sinks is thought to be less than 10,000 years, down from previous estimates as high as 80,000 years as the role of coastal regimes and phosphorite deposits as sinks have become better understood. See Föllmi [1996] and Benitez-Nelson [2000].

photic zone See euphotic zone.

photosynthesis The process in plants by which carbon dioxide is converted into organic compounds using the energy of light absorbed by chlorophyll, which in all plants except some bacteria involves the production of oxygen from water.

phototrophic Descriptive of a phytoplankton species that lives primarily by photosynthesis.

phycology The study of algae, especially seaweeds. This is also called algology. Professional organizations for phycologists are the Phycological Society of America and the British Phycological Society.

Physical Oceanographic Real–Time System (PORTS) An information acquisition and dissemination technology developed by the NOS that supports safe adn cost–efficient navigation by providing ship masters and pilots with accurate real–time information required to avoid groundings and collisions. PORTS provides real–time water levels, currents, and other oceanographic and meteorological data from bays and harbors to the maritime user community in a variety of formats. It also provides nowcasts and predictions of these parameters via the use of numerical circulation models.

[http://www.co-ops.nos.noaa.gov/d_ports.html]

physical oceanography The study of physical conditions and physical processes within the ocean, especially the motions and physical properties of the ocean. This is usually further divided into the activities of descriptive and theoretical oceanography, the former being concerned with observing the oceans to prepare maps of the spatial and temporal variations of its properties, and the latter with constructing theoretical models to attempt to explain the observations. As in most natural sciences, most significant advances are the result of the interaction between theory and observation. Physical oceanography is not a pure but an applied science in which the knowledge of many disciplines is relevant, e.g. fluid mechanics, optics (optical oceanography), acoustics (acoustical oceanography), thermodynamics and, especially in the age of satellites, electromagnetics (satellite oceanography). This is one of four sub-fields into which the general field of oceanography has been divided, the others being biological. chemical and geological oceanography.

phytobenthos That part of the benthos consisting of plant life.

phytoplankton One of two groups into which plankton are divided, the other being zooplankton. Phytoplankton comprise all the freely floating photosynthetic forms in the oceans, i.e. they are free-floating microscopic plants which, having little mobility, are distributed by ocean currents. Most marine phytoplankton are found in one of five Phyla: Cyanophyta, Chrysophyta, Chlorophyta, Cryptophyta, and Pyrrophyta. See Johnson [1957] and Riley and Chester [1971].

PIC Abbreviation for particulate inorganic carbon.

PICES Abbreviation for North Pacific Marine Science Organization, whose purpose is to promote and coordinate marine scientific research in order to advance scientific knowledge of the living resources in the North Pacific. It was founded in 1992 and the members now include Canada, Japan, the People's Republic of China, the USA, the Russian Federation and the Republic of Korea. This is sort of a version of the ICES but for the North Pacific rather than the North Atlantic.

[http://www.pices.int/]

PICOLO Acronym for Production Induite en Zone de Convergence par les Ondes Longues, a program to attempt to understand how a heavy catch of tun occurs in a region considered biologically poor although prone to tropical instability waves.

PIDCAP Acronym for Pilot Study for Intensive Data Collection and Analysis of Precipitation, a component study of BALTEX. The objectives are:

- to collection and analyze measured and estimated precipitation from different data sources;
- to compare different precipitation data sets against each other to identify and establish reliable standards for model validation;
- to validate the output of BALTEX Regional Models against such data sets; and
- to deveop, test and establish necessary data management and analysis procedures.

[http://w3.gkss.de/baltex/pidcap.html]

Pierson, Willard More later.

Pierson-Moskowitz spectrum A wave spectrum devised for fully developed wind waves in an open sea. This method assumes that both duration and fetch are large enough to permit an equilibrium state between the mean wind, turbulence and waves. If this is true, then all other variables are determined by the wind speed. It can be expressed as

$$\phi(\omega) = \alpha g^2 n^{-5} e^{\left[-\beta\left(\frac{\omega}{\omega_0}\right)^{-4}\right]}$$

where $\alpha \sim 0.0081$, $\beta \sim 1.25$, $\omega_0 = g/U$ is the frequency of the spectral peak, g is gravitational acceleration, U the wind speed, and ω the wave frequency considered. That is, if the spectral peak is known, then the spectrum and the energy content of the wave field are determined. See Pierson and Moskowitz [1964].

PIM Abbreviation for Particulate Inorganic Matter.

pinnacle The official IHO definition for this undersea feature name is "any high tower or spire–shapred pillar of rock, or coral, alone or cresting a summit."

PIP Abbreviation for principal interaction patterns, a method of reducing the complexity of a full covariance matrix by combining an EOF-type pattern expansion in the spatial domain with an ARMA-type dynamical modeling approach in the time domain. This technique is useful for constructing simple dynamical models for forecasting or diagnostic purposes and as an approximate multivariate spectral compression technique. See Hasselmann [1988] and Hasselmann [1993].

PIPOR Acronym for Program for International Polar Oceans Research.

PIPS Acronym for Polar Ice Prediction System.

PIRATA Acronym for Pilot Research Moored Array in the Tropical Atlantic, a plan for an observing system to support tropical Atlantic climate studies from 1997-2001. PIRATA will install and maintain an array of 12 moored ATLAS buoys as part of a multinational effort involving Brazil, France and the U.S. It consists of 12 ATLAS moorings spanning along the equator and two meridional lines. This configuration was chosen to provide coverage along the region of regions of strong wind forcing in the western basin and significant seasonal to interannual variability in SST in the central and eastern basin. The meridional arrays cover the regions of high SST variability associated with the SST dipole mode.

The purpose of PIRATA is to remedy the crucial lack of oceanic and atmospheric data in the tropical Atlantic. The scientific goals are:

- to provide an improved description of the seasonal-to-interannual variability in the upper ocean and at the air-sea interface,

- to improve understanding of the relative contributions of the different components of the surface heat flux and ocean dynamics to the seasonal and interannual variability of SST within the tropical Atlantic basin,
- to provide a data set that can be used to develop and improve predictive models of the coupled Atlantic climate system,
- to design, deploy, operate and maintain a pilot array of moored buoys similar to those used during the TOGA program in the tropical Pacific; and
- to collect and transmit via satellite in real–time a set of oceanic and atmospheric data to monitor and study the upper ocean and atmosphere of the tropical Atlantic.

A pilot phase is proposed for 1997-2000 to be followed, if successful, by a long-term operational system to monitor the area maintained by GOOS and GCOS. See Servain et al. [1998].

[http://www.pmel.noaa.gov/pirata/]
[http://www.ifremer.fr/orstom/pirata/pirataus.html]
[http://www.brest.ird.fr/pirata/pirataus.html]
[http://www.aoml.noaa.gov/phod/COSTA/abstracts/piracosta.html]

piston velocity The velocity with which gas diffuses across the air-sea interface in the stagnant film model. It is proportional to the molecular diffusivity of the gas in sea water and inversely proportional to the thickness of the stagnant film across which it travels. The piston velocity has been found to be a function of the Schmidt number, with different dependencies at high and low wind speeds. The velocity is also a function of wind speed, increasing nonlinearly with wind speed and having a greater sensitivity to wind changes at higher wind speeds, with the change in sensivity occurring fairly abruptly at around 10 m/s. Due to the variability of real winds and this variable sensitivity, the piston velocity at the average wind speed will be lower than the average piston velocity. The general functional form of the piston velocity is usually taken to be

$$k_w \propto Sc^{-n} f(V)$$

where Sc is the Schmidt number and V the wind speed. This is also occasionally known as the transfer velocity. See Najjar [1991].

PIW Abbreviation for Polar Intermediate Water.

planetary boundary layer A generic term for either oceanic boundary layer (OBL) or atmospheric boundary layer (ABL). These layers are fundamentally turbulent and extend from near the surface to the boundary layer depth or height, defined as the limit to which boundary layer eddies can penetrate in the vertical.

planetary geostrophic equations A set of filtered equations in which the advection of momentum is neglected in the momentum equations, i.e. the inertia–gravity wave modes have been filtered out. Their use in inappropriate for anything but large–scale, i.e. planetary, circulation. Unlike the quasi-geostrophic equations, these do allow large variations in both the Coriolis parameter and layer depth. These were first developed by Robinson and Stommel [1959] and Welander [1959] to investigate the thermocline problem.

They can be expressed in spherical coordinates (following Muller [1995]) as

$$\begin{aligned}
\left(\frac{\partial}{\partial t} + \frac{u}{r_0 \cos\theta}\frac{\partial}{\partial \phi}\right. &+ \left.\frac{v}{r_0}\frac{\partial}{\partial \theta} + w\frac{\partial}{\partial z}\right)\rho' = 0 \\
fv &= \frac{1}{\rho_*}\frac{1}{r_0 \cos\theta}\frac{\partial p'}{\partial \phi} \\
fu &= \frac{1}{\rho_*}\frac{1}{r_0}\frac{\partial p'}{\partial \theta} \\
\frac{\partial p'}{\partial z} &= -\rho' g \\
f\frac{\partial w}{\partial z} &= \beta v
\end{aligned}$$

where r_0 is the mean radius of the Earth, (ϕ, θ, r) are polar coordinates where ϕ is longitude, θ latitude and r radial distance, v is specific volume, (u, v, w) are the velocity components, ρ' is the variation of the density from a reference state, ρ_* is the reference density, p' is the variation of the pressure from a reference state, $f = 2\Omega \sin\theta$ is the vertical component of the planetary vorticity vector, and β is the beta parameter, i.e.

$$\beta = \frac{1}{r_0}\frac{\partial f}{\partial \theta}$$

.

The first equation is the density equation, a prognostic equation governing the dynamical evolution of the flow. The other equations are diagnostic relations. Another prognostic equation can be found by first decomposing the pressure

$$p = \rho_* g\xi + g\int_z^0 dz'\,\rho'$$

where the first part is the barotropic component due to the displacement ξ of the surface, and the second the baroclinic component due to density fluctuations. The evolution of the baroclinic part is governed by the density equation, and the barotropic part by the kinematic surface boundary condition, i.e.

$$\frac{\partial}{\partial t} = w$$

at $z = 0$ in the planetary geostrophic limit. This is usually converted to an equation for the mass transport stream function since lateral boundary conditions are simpler for the stream function than for surface displacement.

The planetary geostrophic equations are usually used in their steady–state form to study the thermocline problem. See Hasselmann [1982], Salmon [1994] and Muller [1995].

planetary vorticity See vorticity.

plankton One of three major ecological groups into which marine organisms are divided, the other two being the nekton and the benthos. Plankton are small aquatic organisms (animals and plants) that, generally having no locomotive organs, drift with the currents. The animals in this category include protozoans, small crustaceans, and the larval stages of larger organisms while plant forms are mainly diatoms.

plateau The official IHO definition for this undersea feature name is "a flat or nearly flat elevation of considerable areal extent, dropping off abruptly on one or more sides."

pleuston Marine organisms associated with the water surface or the uppermost water layer that possess special adaptations allowing them to passively float there. This term was originally used in freshwater biology to refer to microscopic plants and animals associated with the surface film and supported by surface tension, but it is now also used by marine biologists to describe organisms found in the upper 100 meters of the ocean. Pleuston was historically used especially by Soviet scientists, with their western counterparts more likely to group the pleuston in with the neuston. See Cheng [1975].

plumes Convective elements that carry fluid particles vertically over distances comparable to the depth of the ocean. The horizontal scale is about 1 km, and they are driven by intense cooling at the sea surface that reaches $\sim$1000 W m^{-2}. They are ascending and descending currents that can reach speeds in excess of $\sim$10 cm s^{-1}. Plumes penetrate most of the water column and efficiently homogenize its properties, forming deep, cold mixed layers called chimneys. The chimneys are maintained close to neutrality, geostrophically adjust, and break up into fragments called cones on a time scale of a few days. The cones have a spatial scale of several kilometers. See Jones and Marshall [1993].

Plum Island Sound See Vallino and Hopkinson Jr. [1998].

PMEL Abbreviation for Pacific Marine Environmental Laboratory.

PNA Abbreviation for the Pacific/North American teleconnection pattern, a prominent mode of low frequency variability in the extratropics of the northern hemisphere. It appears in all months except June and July, and reflects a quadrapole pattern of height anomalies. Anomalies of similar sign are found south of the Aleutian Islands and over the southwestern U.S., while those with opposite sign are located near Hawaii and over the intermountain region of North American (central Canada) during the winter and fall (spring). The spatial scale of the PNA is largest in winter, when the Aleutian center covers most of the northern latitudes of the North Pacific. It contracts in the spring when the subtropical center near Hawaii reaches a maximum. It disappears in June and July and reappears in the late summer and fall. During this period, the midlatitude centers are dominant and appear as a wave pattern emanating from the eastern North Pacific. The PNA pattern shows substantial interseasonal, interannual and interdecadal variability. See Wallace and Gutzler [1981] and Horel and Wallace [1981].

P-N-J method A wave spectrum method for wave forecasting developed by Pierson, Neumann and James (Pierson et al. [1955]) in the mid-1950s. Each wind velocity produces a certain range of wave periods with a well-defined maximum, with the total range of periods increasing with the wind velocity along with the energy within the total spectrum. The significant wave height can be found with method along with the spectrum information. See Komar [1976].

POC Abbreviation for particulate organic carbon.

POCEX Acronym for Pacific Ocean Color Experiment, See the POCEX Web site[128].

PODAAC Acronym for Physical Oceanography Distributed Active Archive Center, an element of EOSDIS and located at JPL, is responsible for archiving and distributing data relevant to the physical state of the ocean. Most of the data archived at PODAAC is derived from sensors on satellites.

`[http://podaac-www.jpl.nasa.gov/]`

PODS Acronym for Pilot Ocean Data System.

POEM Acronym for Physical Oceanography of the Eastern Mediterranean. See Malanotte-Rizzoli and Robinson [1988] and Robinson et al. [1992].

`[http://sit.iuav.unive.it/mednet/ocean/poem.html]`

[128] http://sol.oc.ntu.edu.tw/POCEX/

POGO A free–fall vertical velocity profiler. POGO is an acoustically–tracked dropsonde intended to measure the depth–averaged horizontal velocity from the sea surface to some preselected depth. See Rossby et al. [1991].

POGO Acronym for Partnership for Observation of the Global Oceans, an international network of major oceanographic institutions established to promote the integration and implementation of global oceanographic activities.

[http://www.oceanpartners.org/]

Poincare wave A gravity wave in a rotating system. One of the fundamental wave solutions of the linearized barotropic equations. The properties of these waves depend on how the wavelength compares with the Rossby radius. If they are short compared with the Rossby radius, then they are ordinary nondispersive shallow-water waves (when the Rossby radius is additionally large compared to the fluid depth). If they are long compared with the the Rossby radius, the frequency is approximately constant and equal to f or twice the rotation rate. Gravity has no effect in this limit and thus fluid particles move under their own inertia at the inertial frequency f and are called inertial waves. The dispersion relation for Poincare waves is where is the square of the horizontal wavenumber. (The use of this term is occasionally restricted to those waves that satisfy the boundary conditions for a channel.) See Gill [1982], pp. 196-197, 249-256.

polar domain The northernmost of three hydrographic domains into which the waters of the North Atlantic Ocean are sometimes divided for the purpose of describing water mass formation in the region, with the other two being (to the south) the arctic domain and the Atlantic domain. The polar domain provides an upper layer source water mass for the arctic domain that is colder ($< 0°$ C), less saline (30 to 34), and less dense (σ_t ranging from 24 to 27.6) than those from the Atlantic domain. The low salinity of this surface water is derived from both river runoff and through the melting of ice and it is carried southward through the western Denmark Strait by the East Greenland Current. Small amounts of this water are carried eastward into the interior basins of the arctic zone by the Jan Mayen Current and the East Icelandic Current. See Swift [1986].

Polar Front (PF) In physical oceanography, a region of rapid transition in the Southern Ocean (SO) between the Polar Frontal Zone (PFZ) and the Antarctic Zone (AZ). The position of the PF is usually indicated by the large temperature gradient along the temperature minimum of the Antarctic Surface Water (AASW). where it starts to rapidly descend northward. The PF is the northern boundary to cold (1.5° to 2°C) near–surface water formed by winter cooling, i.e. the Antarctic Surface Water.

The property indicators within the front are $\theta < 2°$ along the θ-minimum at Z $<$ 200 m, a θ-minimum at Z $>$ 200 m, and $\theta > 2.2°$ along the θ-maximum at Z $>$ 800 m. The PF is one of three distinct fronts in the Antarctic Circumpolar Current (ACC), the others being the Subantarctic Front (SAF) to the north and the Southern ACC Front (SACCF) to the south.

This has previously been referred to as the Meinardus Line (1926), the Oceanic Polar Front (1928), the Antarctic Convergence (1933) and the Antarctic Polar Front (1960). See Orsi et al. [1995], Belkin and Gordon [1996], Peterson and Stramma [1991] and Moore et al. [1999].

Polar Frontal Zone In physical oceanography, the name given to a transition region in the Southern Ocean (SO) or Antarctic Circumpolar Current (ACC) between the Subantarctic Front (SAF) to the north and the Polar Front (PF) to the south. This was first called the Antarctic Polar Front Zone in the mid–1970s but later modified to the present name. It is identified as a region bound between the 3–9° C surface isotherms. The PFZ is one of four distinct surface water mass regimes in the Southern Ocean, the others being the Subantarctic Zone (SAZ) to the north and the Antarctic Zone (AZ) and Continental Zone (CZ) to the south. See Orsi et al. [1995].

Polar Front Survey An investigation in the North Atlantic that took place during IGY under the auspices of ICES. See Dietrich [1969].

polar halocline catastrophe A hypothesized and modeled situation where the presently dominant mode of thermohaline circulation is unstable and evolves to a much weaker overturning circulation pattern. See McWilliams [1996].

Polar Intermediate Water (PIW) A water mass found in the polar domain in the Northern Atlantic Ocean. It is identified as a distinct temperature minimum layer underneath the East Greenland Current and has salinities in the range 34.4 to 34.7 and is colder than 0° C. Since there is no sharp interface between this and the upper Arctic Intermediate Water, it is distinguished chiefly by geographic location. See Swift [1986].

polar orbit An orbit in which a satellite passes directly over or close to the poles. The characteristic orbital period is around 90 minutes at an altitude of between 500 and 1500 km. Such satellites are usually Sun synchronoussunsynchronous, and have a field of view such that it takes about 15 orbits to cover the globe, with a specific location being seen about twice a day.

Polar Water (PW) Any water with salinity values less than 34.4 that enters the arctic domain from the polar domain in the North Atlantic. The temperatures of PW are typicall lowy ($< 0°$ C) although they can reach 3 to 5° C in the summer. The lowest salinities observed are summer salinities less than 30 in the East Greenland Current. The total transport of PW into the arctic domain is not well known but usually estimated at around 1 Sv. See Swift [1986].

POLARIS A GPS–navigated ocean acoustic current profiler. See Leaman et al. [1995].

polarization relations The relationships between the velocity components and pressure for a progressive wave. They are found by substituting the assumed wave form into the relevant equations. See Gill [1982], p. 262.

POLDER Acronym for Polarization and Directionary of the Earth's Reflectances, a wide field of view imaging radiometer that will provide the first global, systematic measurements of spectral, directional and polarized characteristics of the solar radiation reflected by the earth/atmosphere system. POLDER will better allow the radiation scattered in the atmosphere from that reflected by the surface. The data will be processed to determine the physical and optical properties of aerosols so as to classify them and study their variability and cycle; improve the climatological description of certain physical, optical and radiative properties of clouds; precisely determine the influence of aerosols and clouds on the earth's radiation budget; and quantify the role of photosynthesis from the continental biosphere and oceans in the global carbon cycle. It will fly on the ADEOS mission and the results will contribute to the WCRP and the IGBP. See the POLDER Web site[129].

POLE Experiment See Davis et al. [1978] and Simpson and Paulson [1979].

POLES Acronym for Polar Exchange at the Sea Surface, a component of the NASA EOS program that investigates the exchange of mass and energy at the air-ice-ocean interface in the polar regions. See the POLES Web site[130]. See also Barry et al. [1993].

poleward energy flux The flux process on Earth made inevitable by the fact that more heat is incipient on and absorbed at low than high latitudes and that the Earth is surrounded by a fluid envelope. This excess heat then moves from the tropics to the poles in both hemispheres, i.e. down the gradient, via

[129] http://www-projet.cst.cnes.fr:8060/polder/Mission2.html
[130] http://psc.apl.washington.edu/poles/POLES.html

the atmosphere and the oceans. The partitioning of this flux between the atmosphere and the oceans is as yet not well estimated. If there were no fluid envelope on the Earth, then the tropics would be much warmer and the poles much colder.

Poleward Undercurrent (PUC) A current that flows from Peru to northern and central Chile over the slope and outer shelf, and is identified by a subsurface maximum. According to Strub et al. [1998]:

> The Poleward Undercurrent is clearly identified by its water mass characteristics. At a given location it is saltier, richer in nutrients and lower in oxygen than the surrounding water. Maps of salinity at approximately 150 m depth and of the minimum value of oxygen found beneath 50 m depth depict its path within 100 km of the coast from 20°S to approximately 42°S. Alongshore sections of salinity next to the coast from 15 to 42°S reveal a tongue of high salinity between 100 and 300 m depth, spreading from north to south, descending from 150 m depth north of 20°S to 200–300 m depth south of 25°S. It has been traced to 48°S using geostrophic velocities and T–S characteristics.
>
> The Poleward Undercurrent is also evident in onshore–offshore sections of geostrophic velocity from hydrographic cruises. A section of mean, north–south geostrophic velocities shows it to be maximum over the continental slope at 150–200 m depth. Off Chile at 30°S, hydrographic sections made in each season in 1991–1992 show it within 40 km of the coast, often extending to the surface. Consistent with the values of these geostrophic velocities, direct measurements of velocities from shipboard profiling current meters and parachute drogues have found values ranging from 0.1 to 0.5 m s^{-1} a depths of 100–300 m.

This has also been called the Gunther Current (after Gunther [1936]) and the Peru–Chile Undercurrent. See Wooster and Gilmartin [1961] and Strub et al. [1998].

POLEX Acronym for Polar Experiment, a FGGE project.

POLYGON An oceanographic program to measure the eddy currents in the North Atlantic Equatorial Current for several months using moored current meters and hydrographic surveys. This was a program carried out in 1970 by the Soviet Union. See Brekhovskikh et al. [1971].

POLYMODE A joint US/USSR oceanographic program to study mesoscale processes in the North Atlantic in the late 1970s and early 1980s. It included a Synoptic Dynamical Experiment (SDE), a Local Dynamics Experiment (LDE), and a statistical geographical experiment. The field phase of POLYMODE ended in 1979.

The seven intensive hydrographic surveys of temperature, salinity and oxygen of the LDE took place between May 15 and July 15, 1978 and were carried out in a 200 km wide octagonal region centered at 31°05'N, 69°30'W, a location within the southern portion of the Gulf Stream recirculation region. The recirculation region is a northwestern intensification of the wind–driven subtropical gyre in the North Atlantic. The location was chosen as a compromise among a desire to work well within the gyre, with its associated large m ean and eddy currents, a conflicting desire to avoid the peculiar measurement problems associated with especially intense currents, such as those of Gulf Stream rings, and a desire to use the familiar MODE results (from 28°N, 70°W) as a basis for LDE experimental design. The LDE was designed to meet five scientific objectives:

- to design sampling schemes to yield estimates of the various components in the dynamical balance equations for mesoscale eddies, i.e. to demonstrate the degree of potential vorticity balance and to diagnose dynamical processes from the manner of the balance;
- to provide a high resolution sampling of the energetic eddy scales in all four dimensions, i.e. 50 km horizontally, 500 m vertically and 15 days temporally;

- to obtain a statistical description for the low–frequency, hence plausibly geostrophic, variability on finer scales, both in flow variables and passive tracers;
- to take measurements near the ocean surface to allow a description of mesocale variability in the surface layer during a time of general warming and formation of the seasonal thermocline; and
- to make a further contribution to mapping the means, variances and covariances of currents, density and other observables in the North Atlantic subtropical gyre.

See McWilliams et al. [1983] and Taft et al. [1986] (and several other related papers in the same issue as the latter).

[http://www.aip.org/history/ead/mit_jointsoviet/19990041_content.html]

polynya This is defined by the WMO as:

> Any non-linear shaped opening enclosed in ice. Polynyas may contain brash ice and/or be covered with new ice, nilas or young ice; submariners refer to these as skylights. Sometimes the polynya is limited on one side by the coast and is called a shore polynya or by fast ice and is called a flaw polynya. If it recurs in the same position every year, it is called a recurring polynya.

More expansively, a polynya is an oceanic area which remains either partially or totally ice free at times and under climatological conditions where the surface waters would be expected to be ice covered. They appear in winter when air temperatures are well below the freezing point of sea water and are bordered by water that is covered with ice. They are typically rectangular or elliptical in shape and occur quasi-continuously in the same regions. The size of polynyas can range from a few hundred meters to hundreds of kilometers.

Polynyas are of interest for several reasons. They are sites for active brine formation which may affect the local water density structure and current field and may also influence large-scale water mass modification. They are also a locus for gas exchange between the ocean and atmosphere in polar regions. The large sensible heat fluxes (along with fluxes due to evaporation and longwave radiation) tend to dominate regional heat budgets. They are also of biological interest since their regular occurrence makes them important habitats, e.g. the open water can lead to localized plankton blooms and large mammals tend to use them as feeding grounds.

There are two mechanisms for polynya formation. In the first ice may form within a region and be continually removed by winds, currents, or both. Here the heat required to balance loss the atmosphere and hence to maintain the open water is provided by the latent heat of fusion of the ice being continually formed. The second mechanism involves oceanic heat entering a region in quantities sufficinet to prevent local ice formation. The first mechanism creates "latent heat polynyas" and the second "sensible heat polynyas", and both mechanisms may operate simultaneuously in the same region. See WMO [1970] and SMith et al. [1990].

POM Abbreviation for Particulate Organic Matter. This is usually split into large (or sinking) POM and small (or suspended) POM. Large POM is typically greater than 50 μm in diameter, sinks at rates around 100 m/day, and is usually sampled with sediment traps. It consists mainly of marine snow, zooplankton fecal pellets and intact organisms. Small POM is typically between about 1 and 50 μm in diameter, sinks very slowly (if at all), and is sampled by filtering sea water. See Najjar [1991].

POMME Acronym for Programme Océan Multidisciplinaire Méso Echelle. According to the web site:

> A team of researchers from the CNRS, the Service hydrographique et océanographique de la marine (SHOM – Hydrographic and oceanographic department of the Navy), Ifremer

(Institut francais de recherche pour l'exploitation de la mer – National Institute for Oceanic Research and Exploitation), Météo France (French Meteorological Institute), and several universities will be taking part in the first series of oceanographic measurements in the framework of the POMME project1 (Programme Océan Multidisciplinaire Méso Echelle – Multidisciplinary Meso Scale Ocean Program2). The aim of the project is to improve our understanding of how the climate is influenced by the ocean, due to the amount of carbon, heat, and transformed living matter stored in its waters. Four measurement campaigns are scheduled to take place between September 15, 2000 and October 2001 in the North Atlantic Ocean, halfway between the Azores and the Iberian Peninsula.

[http://www.cnrs.fr/cw/en/pres/compress/CampPomme.htm]
[http://www.cnrs.fr/cw/fr/pres/Pomme/]

PONAM Acronym for Polar North Atlantic Margins, an LESC program to investigate the Late Cenozoic evolution of the Polar North Atlantic Margin. This project features scientists from seven European nations studying the major climatic variations over the last 5 million years and their impact on the environment in European Arctic regions during a period when glacial cycles dramatically changed the landscape and depositional environment along the Polar North Atlantic margin.

The program studied the long-term climatic signal documented in the marine sediment fans deposited adjacent to glacially overdeepened fjords and shelf troughs, the latest interglacial–glacial cycle by absolute dating and high resolution stratigraphic work to obtain environmental parameters such as ice distribution and oceanic circulation patterns, and the present-day interglacial setting as an interpretational tool for studying the glacial–interglacial sedimentary record with emphasis on sediment transfer processes. See the PONAM Web page[131].

ponente A westerly wind blowing in the Mediterranean area.

POP Abbreviation for principal oscillation patterns. In linear cases, PIPs reduce to damped normal modes or POPs, that represent the eigenoscillations of the reduced linear dynamical system. See Hasselmann [1988] and Hasselmann [1993].

POPS Abbreviation for Particle and Optics Profiling System.

PORES Acronym for Physical Oceanography Research of the East Sea, a subproject of the MECBES program of KORDI.

[http://key.kordi.re.kr/home/pores.htm]

pororoca The tidal boretidalbore of the Amazon River.

PORTS Acronym for Physical Oceanographic Real–Time System.

POSAF Acronym for Permanent Oceanic Station at the Azores Front. See Alves et al. [2002].

positive feedback A type of feedback in which a perturbation to a system causes an amplification of the process, and thus enhances itself. An example is the ice-albedo feedback mechanism.

potassium-argon dating A radioisotopic dating method based on the decay of the radioisotope ^{40}K (potassium) to a daughter isotope ^{40}Ar (argon). This has been used to date sea-floor basalts as well as to provide the accurate dating needed to establish and correlate on a world-wide basis the geomagnetic polarity time scale. It has also seen limited use in dating lava flows juxtaposed with glacial deposits,

[131] http://durnik.unis.no/projects/geology/ponam/ponam.html

thus enabling the glacial event to be dated. The ^{40}K decays into both ^{40}Ar and ^{40}Ca with a half-life of 1.31×10^9 years, although the relative of abundance of the latter precludes its use for dating purposes.

Rocks of volcanic origin are dated using this method since argon is driven off by heating which leaves the samples argon free as they initially cool. The ^{40}K builds up over time as the potassium decays until it is heated, released, and measured in the laboratory. The ^{40}K content is derived from a measurement of the total potassium content or by measurement of another stable isotope, ^{39}K, since the abundance ratios of the potassium isotopes are known. The potassium and argon measurements have to be made on different parts of the same sample, which led to the development of the argon-argon dating method. The extremely long half-life of the argon restricts the use of this procedure to samples greater than 100,000 years old, with volcanic rocks formed over the last 30 million years the most common specimens dated.

This dating method assumes that no argon was present in the material after formation and that the system remains closed from the time of formation. The first assumption can be violated in the case of the formation of deep-sea basalts which retain argon during formation under high hydrostatic pressure, and some material can retain argon from argon-rich source materials during formation. This can result in an overestimation of the sample age. The second assumption can be violated when argon is absorbed on to the surface and interior of a sample, although the degree of atmospheric concentration can be adjusted using known atmospheric isotopic argon ratios. See Bradley [1985].

potential evaporation The amount of water that would be evaporated from a land or water surface if the water supply were unlimited, as opposed to actual evaporation. The latter will fall below the former when the water at the evaporating surface is somehow limited.

potential evapotranspiration The theoretical maximum amount of water vapor that can be convyed to the atmosphere by the combined processes of evaporation and transpiration by a surface covered by green vegetation with no lack of available water in the soil.

potential density A physical oceanographic term for the density of a sample calculated from its salinity, potential temperature, and at a selected pressure, i.e. $\sigma_\theta = \sigma(S, T_\theta, p)$. This is the effective density of a parcel of water after removing the heat associated solely with the effects of compression. Up until about 1970 calculations of potential density values were routinely performed with atmospheric pressure at the sea surface as the selected pressure, but later investigators found it sometimes convenient to instead calculate potential densities at other pressure levels. The 4000 dbar pressure level (abbreviated σ_4) is probably the next most often used level. Other levels (usually at 1000 dbar increments) are also sometimes used and similarly abbreviated.

potential surface See geopotential surface.

potential temperature A physical oceanographic term for the temperature that a water sample gathered at depth would potentially have if brought adiabatically (i.e. without thermal contact with the surrounding water) to the surface, i.e. the effective temperature of a water parcel after removing the heat of the parcel associated solely with compression. A sample brought from depth to the surface will, due to the slight compressibility of sea water, expand and therefore tend to cool, and as such potential temperatures at great depths are always less than measured temperatures.

In meteorology this is defined as a measure of temperature that removes the effects of dry adiabatic temperature changes experienced by air parcels during vertical motion. This can be calculated as

$$\theta = T \left(\frac{P_0}{P} \right)^{R_d/C_p}$$

where θ is the potential temperature, P_0 a reference pressure, R_d the gas constant for dry air and C_p the specific heat.

potential thickness In physical oceanography, a quantity equal to the local thickness of a water layer divided by the local sine of latitude. See Stommel [1987].

potential vorticity Rhines [1986] provides ample motivation for this concept:

> The potential vorticity q is the fundamental field variable for the circulation and for the eddy motions upon it. Knowledge of q, of its boundary conditions, and of the basic stratification of density is enough to determine the three–dimensional distribution of velocity and density perturbations in the fluid. The effectiveness of studying the q–field is all the greater, for it is a conservative advected scalar (albeit, a dynamically active one) having many properties in common with the vast family of advected chemical and biological tracers in the oceans. Forcing and dissipation of q are important to its life cycle, but there are likely to be large regions of the deep ocean interior in which conservation following the fluid is a good first approximation.

In the simplest case, this is a quantity equal to

$$\frac{\zeta + f}{D}$$

in a barotropic fluid (or at least in a fluid layer of constant density within a larger body of fluid) where ζ is the relative vorticity, f the planetary vorticity, and D the depth. This relation permits predictions to be made about how vorticity will change in a column or parcel of water if it moves northward or southward or into shallower or deeper water, assuming that frictional processes are negligible. More general and complicated versions of this quantity can be defined, but this simplest case well illustrates the essential physical processes without confusing the issue.

To confuse the issue, a general form with wide applicability is Ertel's potential vorticity. It follows from his potential vorticity theorem and, according to Muller [1995], plays the most fundamental role of all potential vorticity theorems because:

- it is most general, i.e. other vorticity and circulation theorems can be derived from Ertel's theorem;
- potential vorticity becomes conserved in a variety of circumstances, thus making the theorem a conservation law; and
- Ertel's potential vorticity equation is the governing equation for an important class of motion where the equation becomes the sole prognostic equation determining the time evolution of the flow, with all other variables expressed in terms of the potential vorticity by diagnostic equations.

The most general form of Ertel's theorem for a materially conserved property ψ is

$$\frac{D}{Dt}q = \upsilon J(p, \upsilon, \psi)$$

where D/Dt is the material derivative, q is Ertel's potential vorticity, υ is the specific volume, p is the pressure, and J the Jacobian given by

$$J(p, \upsilon, \psi) = (\nabla p \times \nabla \upsilon) \cdot \nabla \psi$$

. The corresponding potential vorticity is

$$q = \upsilon(\omega + 2\Omega) \cdot \nabla \psi$$

where ω is the relative vorticity, Ω is the constant angular velocity of the rotating frame, i.e. the Earth's rotation rate,

Ertel's theorem in the Boussinesq approximation is

$$\frac{D}{Dt}\left[\frac{1}{\rho_*}(\omega + 2\mathbf{\Omega})\cdot\nabla\psi\right] = \frac{1}{\rho_*^3}J(\rho', p_r, \psi)$$

ρ_* is a constant reference density, ρ' is the deviation of the density from a reference state, and p_r is a reference pressure. The corresponding potential vorticity is

$$q = \frac{1}{\rho_*}(\omega + 2\Omega)\cdot\nabla\psi$$

where the constant density ρ_* can be dropped.

In the f plane approximation, where spherical effects are neglected, the expression for the potential vorticity is:

$$q = f_0 + \omega_z - f_0\frac{\partial\zeta}{\partial z} - \omega\cdot\nabla\zeta$$

where

See Rhines [1986], Bryan [1987] and Muller [1995].

potentiotropic Of any fluid whose density is function only of pressure and potential temperature, i.e.

$$\rho = \rho(p, \theta)$$

where p is the pressure and θ the potential temperature.

power spectrum The presentation of the square of the amplitudes of the harmonics of a time series as a function of the frequency of the harmonics.

PPP
1. Abbreviation for principal prediction patterns, used synonymously for EOF.
2. Abbreviation for Pool Permutation Procedure, a method for testing the significance of difference in the means, temporal and spatial variances, and spatial patterns between two data sets. See Preisendorfer and Barnett [1983].

Practical Salinity Scale (PSS–78) In oceanography, a scale on which the salinity of ocean water is evaluated. It is a unitless scale that was developed to unify two separate salinity determination methods that were previously used for laboratory and in-situ measurements. The results are reported in a unitless manner since it is based on chlorinity ratios rather than measurements of absolute quantities, although the results are mostly consonant with earlier ones reports in units of parts per thousand.

The practical salinity is defined in terms of the ratio of the electrical conductivity of a seawater sample at atmospheric pressure at 15°C to that of KCl solution containing 32.4356 g of KCl in a mass of 1 kg of solution at the same pressure and temperature. This ratio K_{15} defines practical salinity of a sample according to

$$S(^\circ/_{\circ\circ}) = a_0 + a_1K_{15}^{1/2} + a_2K_{15} + a_3K_{15}^{3/2} + a_4K_{15}^2 + a_5K_{15}^{5/2}$$

where a_o = 0.0080, a_1 = -0.1692, a_2 = 25.3851, a_3 = 14.0941, a_4 = -7.0261, and a_5 = 2.7081. This definition suffices for laboratory determination of salinity for samples at the aforementioned pressure and temperature, but corrections must be made for in-situ measurements in water of salinity S and temperature T. These are available in the form of additional tables and equations. This equation is valid for a practical salinity S from 2 to 42.

The history and development of PSS–78 is summarized in JPOTS [1981a]:

In 1964, a panel of scientists were appointed jointly by UNESCO, ICES, SCOR and IAPSO to advise on the establishment of international tables and standards. The first task of this Joint Panel of Oceanographic Tables and Standards (JPOTS) was the preparation of tables for computing salinity of seawater from determinations of electrical conductivity. Before these tables could be prepared, it was necessary to redefine salinity in terms of conductivity. After discussions (UNESCO, 1965), the JPOTS recommended (UNESCO, 1966a) a definition of salinity based on determinations of chlorinity and conductivity on samples of natural seawater from all the oceans of the world. In October 1966, the "International Oceanographic Tables" (UNESCO, 1966b) for computing salinity from conductivity, based on the above definition, were published. They included a tabulation of this definition at 15°C for salinities from 29 to 42 ppt, along with a correction table for measurements at temperatures other than 15°C, from 10 to 31°C.

However, the use of *in situ* measurements of conductivity for estimating salinity increased rapidly in the early seventies, rendering the "International Oceanographic Tables" unsuited for use in the majority of *in situ* measurements because the tables do not go below 10°C. Furthermore, a comparison to the conductivities of seven batches of standard seawater, relative to a KCl solution revealed that the conductivity of some batches was higher than than calculated from the certified chlorinity (UNESCO, 1976). This raised the problem of the calibration of the conductivity salinometers and CTD probes, as well as the definition of salinity itself. After discussion, the principle of calibrating standard seawater in electrical conductivity with a potassium chloride solution, was adopted and the establishment of a practical salinity scale was recommended by the JPOTS (UNESCO, 1978). Intensive work was then carried out in differnet laboratories with radically different measuring equipment. This resulted in considerable data on which are based the Practical Salinity Scale 1978, as well as the recommended algorithms for the calculation of practical salinity from the conductivity ratio at all temperatures and pressures over the range of oceanographic interest (UNESCO, 1979). This was finally adopted by the JPOTS during its meeting in Sidney, B.C., Canada, 1–5 September 1980 (UNESCO 1981a).

Whereas the previous salinity scale (UNESCO, 1966b) was based on a conductivity–chlorinity relation using natural seawater, the Practical Salinity Scale 1978 is different in that the standard seawater used was diluted by weight with distilled water or evaporated to obtain other salinity values. This procedure was followed to ensure the constancy of composition of this seawater over the salinity range of interest. A precisely specified solution of potassium chloride was chosen as a reproducible electrical conductivity standard; an evaluation was then made of the concentration of this solution which yields a conductivity ratio of unity at 15°C with respect to a standard seawater (from the North Atlantic Ocean) whose certified chlorinity was 19.3740 ppt, i.e. its salinity was exactly 35 ppt on the previous salinity scale. By convention, its practical salinity, on the new Practical Salinity Scale 1978, is 35, to ensure continuity at that salinity with the previous scale.

Poisson and Gadhoumi [1993] extended PSS–78, which was was limited to salinities between 2–42, up to 50. A polynomial was developed from laboratory measurements via least–square regression fitting. The equation is:

$$\begin{aligned} S = 35R_t \quad &+ \quad R_t(R_t - 1) \times \\ (A_0 \quad &+ \quad A_1 R_t + A_2 t + A_3 R_t^2 + A_4 R_t t + A_5 t^2 + A_6 R_t^3 + A_7 R_t^2 t + A_8 R_t t^2 + A_9 t^3 \end{aligned}$$

where R_t is the measured conductivity ratio, t the measured temperature, and the coefficients are:

$A_0 = 77.37 \times 10^{-1}$ $A_5 = 39.89 \times 10^{-4}$
$A_1 =$ -98.190×10^{-1} $A_6 =$ -26.25×10^{-1}
$A_2 = 34.73 \times 10^{-3}$ $A_7 = 48.205 \times 10^{-3}$
$A_3 = 86.635 \times 10^{-1}$ $A_8 =$ -66.82×10^{-5}
$A_4 =$ -10.018×10^{-2} $A_9 =$ -46.56×10^{-6}

The coefficients were calculated with eight decimal digits and rounded off to obtain a salinity value that is different from the salinity calculated by the eight decimal digital coefficient by $< 2 \times 10^{-4}$. The standard deviation of the difference between the experimentally measured salinities and those calculated using this equation is 3×10^{-3}. This equation is valid for the temperature range 10–30°C and the salinity range 35–50. See Lewis [1980], Lewis and Perkin [1981] Poisson and Gadhoumi [1993] and JPOTS [1981a].

Practical Temperature Scale A temperature scale created to provide an operational method for measuring temperatures that is precise and reproducible. See Comite International des Poids et Measures [1969].

Prandtl number A dimensionless number expressing the ratio of the Peclet number to the Reynolds number. It is expressed by

$$Pr = \frac{Pe}{Re} = \frac{\nu}{\kappa}$$

where Pe is the Peclet number, Re the Reynolds number, ν the kinematic viscosity, and κ the thermal diffusivity. When $Pr = 1$, the viscous time scale is equal to the time scale of thermal diffusion, and similarity exists between viscous dissipation and thermal diffusion. The Prandtl number is equal to about 0.7 for air, and is about 13 at 0°C and 7 at 20°C for water. See Kraus and Businger [1994], p. 33.

precession Also called precession of the equinoxes, this component (the other two being eccentricity and obliquity) of the orbital perturbations that comprise the Milankovitch theory is actually two components. The first is axial precession, where the earth's axis of rotation wobbles likes a spinning top due to the torque of the sun and the planets on the non-spherical earth. Therefore the North Pole describes a circle in space with a period of 26,000 years. The second is elliptical precession in which the ellipse that is the earth's orbit is rotating about one axis. Both effects combined are known as the "precession of the equinoxes" where the equinox (March 20 and September 22) and solstice (June 21 and December 21) shift slowly around the earth's orbit with a period of 22,000 years. The eccentricity modulates and splits the precession frequency into periods of 19,000 and 23,000 years. The precession causes warm winters and cool summers in one hemisphere and the opposite in the other, with the effect being largest at the equator and diminishing towards the poles.

precision The repeatability of an instrument, measured by the mean deviation of a set of measurements from the average value. Contrast this to accuracy. As an example of the difference, an instrument can measure a quantity a hundred times and if all the measurements are within a percent of each other it is a precise instrument, but if it has measured the correct value as, say, twice the correct value every time then it is not an accurate instrument or, alternatively, it is precisely wrong.

predictability of the first kind The prediction of sequential states of the climate system at fixed values of external parameters and assigned variations of initial conditions. See Lorenz [1975] and Kagan [1995].

predictability of the second kind The prediction of an asymptotically equilibrium response (of the limiting state) of the climatic system to prescribed changes in external parameters. See Lorenz [1975] and Kagan [1995].

pressure coordinates A vertical coordinate system often used in numerical circulation models in which the vertical coordinate is pressure. The equations are created by replacing the vertical velocity in the equations of motion with the total derivative of the pressure following the motion.

Prestwich, Joseph (1812–1896) See Peterson et al. [1996], p. 96.

prewhitening A method for dealing with nonstationarity in time series analysis where a new series is creating by forming the differential of the original series. In practice this is done by taking the difference between successive points in the original series, although to be strictly correct this should be done between successive midpoints. This procedure removes both the trend and low-frequency components of the original series while retaining information about the short-variance. Another method for dealing with this problem is detrending. See Burroughs [1992].

primary productivity/production The amount of organic material produced by organisms from inorganic material or, more technically, the amount of carbon fixed by autotrophic organisms through the synthesis of organic matter from inorganic compounds such as carbon dioxide and water using energy derived from solar radiation or chemical reductions. This should be compared with:

- gross primary production, the total amount of organic matter produced by photosynthesis or chemosynthesis per unit time; and
- net primary production, the amount that remains after plants metabolize and respire.

Most of the primary production in the oceans is due to photosynthesis of phytoplanktonic algae. in the upper 100 m, i.e. the euphotic zone. Primary production is expressed in units of gC m^{-2} yr^{-1} where gC is grams of carbon. The total ocean productivity ranges from 75–150 gC m^{-2} yr^{-1}, with photosynthesis accounting for around 95% of this and chemosynthesis the rest. See Fogg [1975] and Woodwell [1995].

PRIMER An experiment taking place during the summer of 1996 and the winter/early spring of 1997 that focused on the shelfbreak front just south of Cape Code on Nantucket Shoals. See Pickart et al. [1999].

primitive equations A set of filtered equations obtained from the fundamental equations of motion of a fluid by applying the hydrostatic approximation and neglecting the viscosity. They comprise three prognostic and three diagnostic equations, the former of which are the x and y (or horizontal) components of the momentum equation and the thermodynamic equation of energy, and the latter the continuity equation, the hydrostatic equation and the equation of state. These equations form a closed set in the dependent variables which are the three components of velocity, pressure, density and temperature. The PEs filter out vertically propagating sound waves.

primum mobile A theory of literally a "first mover" expostulated by Aristotle that was used to explain a perceived general broad pattern of westward flow in the world oceans. The first mover, a theological being, was itself unmoved but acted on the circumference of the universe to cause it to move. The theory asserted that the shape of heaven is spherical and it encloses successively smaller spheres down to the center, i.e. earth, with the motion of the outermost sphere being uniform and that of the inner spheres increasingly irregular as the center was approached. Since the sun and stars appeared to move to the west and they were in an outer sphere, the first mover must be moving things in that direction and therefore the motion of the seas should be generally to the west, although more irregular. This theory and the consequent belief in general westward motions in the seas held sway for many centuries until the weight of observational evidence made it untenable. See Peterson et al. [1996].

Prince Henry the Navigator (1394–1460) The third surviving son of Portugal's King John I who, to help attain his goals of conquest and the conversion of pagans to Christianity, founded what some have called the first modern school of oceanography in the town of Sagres. He summoned seamen, cartographers, astronomers, shipbuilders and instrument makers from all over Europe to engage in activities that would provide a large part of the foundation for the European exploration of the world. His efforts earned him the surname the Navigator.

Significant advances initiated by the school included the systematic keeping of logbooks and annotation of charts, replacing the astrolabe with the quadrant, and the development and construction of the Portugeuse caravel as a durable ship for long voyages of exploration. Although Henry (who never participated in any significant voyages himself) did manage to convince someone (Gil Eannes) to sale beyond the Cape of Bojador (on the western Sahara coast southeast of the Canary Islands) in 1433, his men did not cross the equator in his lifetime. See Peterson et al. [1996].

Prince William Sound Prince William Sound is located along the southern coast of Alaska in the North Pacific Ocean. It is about 60 km by 90 km with maximum depths ¿ 350 m, with one area ¿ 700 m deep. The ocean boundary is the Gulf of Alaska, with a continental shelf 100–150 km wide and numerous topographic features affecting circulation in the border zone. The features include islands, e.g. Kayak and Middleton, as well as shelf bathymetric troughs which serve as conduits for shelf–deep water exchange. Exchange between the Sound and the Gulf is restricted vertically by glacial moraine sills in the troughs, and horizontally by many small islands in the border zone. The major passages linking the bodies are the Hinchinbrook Entrance (11 km wide by 320 m deep) and Montague Strait (8 km wide by 240 m deep) on either side of Montague Island. The Sound is can be classified as a large, complex, fjord–type estuarine system, although it also exhibits characteristics of a small inland sea with appreciable horizontal circulation.

The general circulation pattern of Prince William Sound is defined by a portion of the westward flowing Alaska Coastal Current on the Gulf of Alaska shelf that enters Prince William Sound through Hinchinbrook Entrance and transists the sound from east to west before exiting through Montague Strait and rejoining the coastal current. However, there is much variability in this circulation, especially in the transport through Hinchinbrook Entrace.

In addition, some of the water entering the sound becomes involved in the cyclonic circulation in the northern sound and so has a longer residence time. The circulation is strongly mediated by seasonal and interannual variations in winds and freshwater runoff as well as by local topography both inside and outside the sound. In winter, the strong cyclonic winds over the Gulf of Alaska cause costal downwelling and strong flow in the upper layers into Prince William Sound through Hinchinbrook Entrace and out through Montague Strait. In summer, the downwelling ceases, allowing subsurface denser water to rise above the sill and flow into the sound through the bottom layers of Hinchinbrook Entrance.‘ After Niebauer et al. [1994].

Princess Elizabeth Trough A gap in the topography between the Kerguelan Plateau and the Antarctic continent, with a sill depth of 3750 m. It provides a route for the exchange of Antarctic Bottom Water (AABW) between the Australian–Antarctic Basin and the Weddell–Enderby Basin. See Heywood et al. [1999].

PRIRODA A Russian remote sensing module (named for the Russian word for nature) planned to provide the experimental basis for a scientific research program for the development and verification of remote sensing methods and investigations of regional and global problems in climatology, oceanography, and ecology. The module carries optical and infrared scanners, an imaging spectrometer, a LIDAR, scanning and pointing microwave radiometers, SAR, and high resolution digital (stereo) cameras. The launch data for PRIRODA is March 1996 and the operation is expected to cover 1996–97. This mission is conducted by the Russian Space Agency (RKA). See the PRIRODA Web site[132].

[132]http://www.ba.dlr.de/NE-WS/ws5/priroda.html

PRISM The Pliocene Research, Interpretation, and Synoptic Mapping Project, the goals of which include providing modelers with improved quantitative global paleoenvironmental information associated with the warm climates of the Pliocene and providing a forum for data and modeling experts to collaborate in establishing what boundary conditions are needed, planning model experiments, and interpreting and evaluating model results. See Dowsett et al. [1994] and the PRISM Web site[133].

PROBES Acronym for Processes and Resources of the Bering Sea Shelf.

PROFILE Acronym for Processes in Regions of Fresh Water Influence, a project whose overall aim is to develop process understanding and tested numerical models for regions of freshwater influence (i.e. ROFIs). This EC MAST project studies the role of the physical processes controlling water property distributions and the role of suspended sediments in controlling the availability of light, nutrients, and phytoplankton growth. See the PROFILE Web site[134].

prognostic In numerical modeling, an equation is prognostic if the future value of a dependent variable is predicted from the present value(s) of one or more dependent variables.

Project FAMOUS The French American Mid–Ocean Undersea Study began in 1971 as part of the IDOE. It was based on the general acceptance of the plate tectonic theory and investigated the possibility of underwater hot springs. The site selected was along the Mid–Atlantic Ridge near the Azores, and was selected after detection of particularly strong magnetic stripes in that region. During FAMOUS over 100,000 photographs were taken and nearly 1,300 kg of geological samples were collected by Alvin and two French submersibles. Water samples were also collected and a data logger was developed to automatically record depth, altitude, heading and time.

[http://www.nap.edu/books/0309063981/html/index.html]

PROMISE Acronym for Pre-Operational Modeling in the Seas of Europe, a project whose primary objective is to optimize the application of existing dynamical models of the North Sea such that the rates and scales of sediment exchange between the coast and the nearshore zone can be quantified for management applications. See the PROMISE Web site[135].

promontory The official IHO definition for this undersea feature name is "a major spur–like protrusion of the continental slope extending to the deep seafloor; characteristically, the crest deepens seaward."

PROTEUS Acronym for Profile Telemetry of Upper Ocean Currents, a NOAA PMEL project to develop a real–time capability for satellite transmission of ADCP data from deep water surface moorings. The first PROTEUS mooring was successfully deployed in April 1990 at 0°, 140° W as part of the EPOCS program. See McPhaden et al. [1990].

Joseph Proudman (1888–1975) From Platzman [1992]:

> Joseph Proudman occupied the chair of applied mathematics at Liverpool University from 1919 to 1933, then the chair of oceanography until his retirement in 1954. On his initiatives, the Tidal Institute (now the Proudman Oceanographic Laboratory) at Bidston Observatory, near Liverpool, was founded (1919) and, much later (1949), the National Institute of Oceanography (now the Institute of Oceanographic Sciences), headquartered near Godalming, Surrey. Of Proudman's published scientific work, about two–thirds is on the theory of ocean tides, and most of the rest is about other aspects of oceanography.

[133] http://geochange.er.usgs.gov/pub/info/html/gd/prism.html
[134] http://www.pol.ac.uk/appl/profile.html
[135] http://www.pol.ac.uk/promise/index.html

See Cartwright and Ursell [1976].

Proudman-Taylor theorem See Taylor-Proudman theorem.

PROVESS Acronym for PROcesses of Vertical Exchange in Shelf Seas, a joint European funded project for an interdisciplinary study of the vertical fluxes of through the water column and the surface and bottom boundaries based on the integrated application of new measuring techniques, new advances in turbulence theory, and new models.

[http://www.pol.ac.uk/provess/index.html]

province The official IHO definition for this undersea feature name is "a region identifiable by a number of shared physiographic characteristics that are markedly in contrast with those in the surrounding areas."

proxy data Paleoclimate data inferred indirectly via the use of transfer functions. The underlying idea is that organisms exhibit a high degree of differentiation according to their physical environment, and that physical variables can be estimated from biotic distributions once the degree of relationship has been objectively established. For example, some present plankton species live in cold waters and others prefer warmer waters. If we make the additional assumption that fossil assemblages of these species (or their related ancestors) exhibited similar temperature tendencies, then we can infer, within limits, the temperature of the water in which they existed. See Crowley and North [1991], Appendix B. Compare to instrumental data.

Prydz Bay The third largest embayment in the Antarctic continent. Prydz Bay lies in the Indian Ocean sector, with typical depths of 500–600 m. A deep basin in the inner part of the bay descends to 800 m in places, and to 1085 m adjacent to the Amery Ice Shelf. Moving offshore from within the Bay, the bed rises from approximately 800 m to a sill at 400–500 m along 67–68°S, and then falls to 699 m at the edge of the continental slope some 100 km seaward. The sill has a saddle point with 500 m depth at about 67°S, 71°30'E, where the bathymetry rises zonally and falls meridionally. Relatively shallow banks (Frame Bank to the west and Four Ladies Bank to the east) rise to 200 m depth and extend over much of the shelf width to either side of Prydz Bay, so deep connections between the ocean and the Bay are concentrated through a broad region at the central longitude of about 73°E. A much narrow deep connection to the shelf waters of the West Ice Shelf region east of the Bay is found along a trough in the inner part of the shelf north of Davis station. The waters of the southwestern part of the Bay come into direct contact with a large floating ice shelf, the Amery Ice Shelf.

The large–scale circulation is dominated by a large cyclonic gyre centered on the mid– to western part and extending from within the Bay to the Antarctic Divergence northwest of the Bay (at about 65°S). The gyre is associated with a relatively narrow coastal current running from the southern limits of the Bay past the Amery Ice Shelf, and continuing westward after leaving the Bay along the MacRobertson Land Shelf (with velocities reaching 1 m/s in the latter part). Part of the current flows offshore near 63°E, while another unknown fraction continues westward. See Nunes Vaz and Lennon [1996].

Prydz Bay Bottom Water (PBBW) A type of regionally modified Circumpolar Deep Water (CDW) which, along with several other types of regionally modified and previously defined types of CDW, is now usually defined as one of several regional types of a more general water mass called Modified Circumpolar Deep Water. See Middleton and Humphries [1989] and Whitworth et al. [1998].

pseudoenergy See Andrews and McIntyre [1978].

pseudomomentum See Andrews and McIntyre [1978].

pseudospectral method In numerical modeling, an approximation which uses interpolating functions to estimate derivatives of fields represented on a grid in physical space. It is so-called because the interpolating functions used are usually the same as are used in the spectral method. All operations other than differentiation are carried out in the physical space defined by the grid rather than in spectral space. This allows, for example, the calculation of the nonlinear terms, a dauntingly onerous task in spectral space, to be easily performed. The trade-off is that the calculations are aliased, although various remedies for the problem have been proposed. See Gottlieb et al. [1984].

P17N A WOCE hydrographic program in the North Pacific.

[http://blackburn.ims.uaf.edu:8000/~musgrave/P17N/]

PSMSL Abbreviation for Permanent Service for Mean Sea Level, an archive based at the Proudman Oceanographic Laboratory which contains monthly and annual mean sea level information from over 1600 tide gauge stations from around the world.

[http://www.pol.ac.uk/psmsl/]

PSS–78 See Practical Salinity Scale.

psychrometrics The study of the physical and thermodynamic properties of the atmosphere. The properties mainly of concern are dry-bulb temperature, wet-bulb temperature, dew-point temperature, absolute humidity, relative (or percent) humidity, sensible heat, latent heat, enthalpy (or total heat), density and pressure.

psychrosphere One of two regions into which the ocean depths are sometimes divided according to temperature, the other being the thermosphere. The psychrosphere is those ocean depths where the temperature is less than 10° C, which can range anywhere from 100 to 700 m beneath the surface depending on oceanic conditions. This coincides with the ocean stratosphere.

pteropod ooze Ooze composed of the shells of small, planktonic swimming molluscs with a calcareous shell that live in tropical and subtropical waters. These are coarser than globigerina oozes, are found between 1500-3000 m depth and cover no more than 1% of the sea floor. See Tchernia [1980].

Purdy, John (1773–1843) See Peterson et al. [1996], p. 59.

PW Abbreviation for Polar Water.

pycnocline In physical oceanography, a layer where density changes most rapidly with depth. It can be associated with either a thermocline or a halocline.

pycnostad In physical oceanography, a layer where the vertical change of density is very small and displays a local minimum.

0.15 Q

QBO Acronym for Quasi-Biennial Oscillation.

Quasi-Biennial Oscillation The alternation of easterly and westerly winds in the equatorial stratosphere with an interval between successive corresponding maxima of 20 to 36 months. The regimes start at about 30 km and propagate downwards at about one kilometer per month.

quasi-geostrophic approximation A set of filtered equations to the equations of motion governing atmospheric or oceanic flow, the chief of which is the vorticity equation. In this, the horizontal wind is replaced by the geostrophic wind in the term representing the vorticity but not in the term representing the divergence.

quasi-geostrophic equations A set of equations developed using the quasi-geostrophic approximation. These are formally valid only when the planetary vorticity is large compared to the relative vorticity of the fluid, when the variation in the Coriolis parameter over the domain is small compared to its mean value, and when free surface and topographic fluctuations are both much smaller than the average fluid depth. See Pedlosky [1987].

quantum meter An instrument used to measure PAR.

QuikSCAT Acronym for the NASA Quick Scatterometer Mission, a satellite launched from Vandenberg Air Force base aboard a Titan II vehicle on June 19, 1999. QuikSCAT was a quick recovery mission to fill the gap created by the loss of data from the ADEOS–1 satellite, which lost power in June 1997. It was launched into a sun–synchronous, 803 km, circular orbit with a local equator crossing time at the ascending node of 6:00 AM ± 30 minutes. The recurrent period is 4 days (57 obits), the orbit period 101 minutes (14.25 orbits per day) and the inclination 98.616°. QuikSCAT consists of two major systems, the spaceborne observatory and the ground data processing system.

The main sensor on QuikSCAT is the SeaWinds scatterometer, an active microwave radar designed to measure winds over the oceans. It is a conically scanning pencil–beam scatterometer, which provides a higher SNR, is smaller, and provides better coverage than a fan–beam scatterometer. It measures near–surface wind speed and direction under all weather and cloud conditions over the oceans.

`[http://podaac.jpl.nasa.gov/quikscat/]`

Q–vector method A method for diagnosing vertical motion from measured data in the atmosphere or ocean. The Q–vector method is similar to the quasigeostrophic equations, except it introduces an ageostrophic component neglected by the latter. In the ocean, the vertical velocity is estimated from the following Q–vector equation:

$$\left(\nabla^2 + \frac{f_0^2}{N^2}\frac{\partial^2}{\partial z^2}\right) w = \frac{2}{N^2}\nabla\cdot\mathbf{Q}$$

$$\mathbf{Q} = \frac{g}{\rho_0}\left(\frac{\partial u_g}{\partial x}\frac{\partial \rho}{\partial x} + \frac{\partial v_g}{\partial x}\frac{\partial \rho}{\partial y}, \frac{\partial u_g}{\partial y}\frac{\partial \rho}{\partial x} + \frac{\partial v_g}{\partial y}\frac{\partial \rho}{\partial y}\right)$$

where f is the Coriolis force, N is the buoyancy frequency, g is gravitational acceleration, ρ_0 is a reference density, ρ is the density, and $(u,v)_g$ are the horizontal geostrophic velocities. A detailed derivation and discussion can be found in Pollard and Regier [1992]. See also Wang and Ikeda [1997].

0.16 R

RACER Acronym for Research on Antarctic Coastal Ecosystem Rates, a JGOFS program designed to test several hypotheses regarding the interaction of biological and physical processes in antarctic coastal regions in general, and the importance of the study area as nursery ground for antarctic krill in particular. The principal objective of this 1986–1987 program was the study of the physical and biological processes causing the high productivity in the coastal waters of the Antarctic Peninsula. RACER was a comprehensive, 4–month field study conducted in a 25,000 km^2 region of the western Bransfield Strait during the 1986–1987 austral summer.

Some of the significant results of the RACER program were:

- the documentation of an extensive phytoplankton bloom in the northern Gerlache Strait with biomass estimates >750 mg Chl *a* m^{-2} and primary production rates in excess of 4 g C m^{-2} day^{-1}, the initiation, continuation, and demise of which was controlled largely by the physical conditions of the water column and, specifically, by the depth of the surface mixed layer;
- the partial pressure of CO_2 was reduced to ≤ 100 μatm in the regions of extensive bloom formation, thereby creating a potentially large sink for atmospheric CO_2;
- investigations of the population dynamics, distribution, abundance and growth of the krill species *Euphausia superba* identified at least two year classes of immature and adult populations in the study area, with three biogeographic zones identified;
- comprehensive hydrographic surveys confirmed the presence of several different water masses, two major frontal structures, and a flow from the southwest to the northeast across the study area called the Bransfield Current; and
- a second RACER field experiment was designed for November–December 1989, which would focus more closely on the initial stages of the spring bloom phenomenon in a smaller geographic area.

See Huntley et al. [1991].

[http://hahana.soest.hawaii.edu/racer/racer.html]

radar An acronym for radio detection and ranging, the use of reflected electromagnetic radiation to obtain information about distance objects. The wavelength used in normally in the radio frequency spectrum between 30 m and 3 mm.

RADARSAT An earth observation satellite developed by Canada to provide information for researchers in such fields as agriculture, cartography, hydrology, forestry, oceanography, ice studies, and coastal monitoring. The satellite, launched on Nov. 4, 1995 by the Canadian Space Agency (CSA), carries a C-band SAR capable of imaging a ground swath 500 km wide at 100 meter resolution. The expected lifetime of RADARSAT is five years.

RADARSAT–1 circles the Earth at an altitude of 798 km and an inclination of 98.6 deg. to the equatorial plane. It has a sun–synchronous orbit, making its overpasses always at the same local mean time. The satellite's SAR can shape and steer its beam from an incidence angle of 10 to 60 degrees, in swaths from 45 to 500 km in width, with resolutions ranging from 8 to 100 m. It covers the Arctic daily and most of Canada every three days, with data downlinked in real time or stored onboard until the satellite is within range of a receiving station. A RADARSAT–2 is in the planning stages.

[http://www.space.gc.ca/csa_sectors/earth_environment/radarsat/]

radar altimeter An instrument that uses radar to determine a vehicle's (e.g. a satellite) height above the surface and for measuring the height of small objects (e.g. waves, hills) on a planetary surface. In oceanography, the former capability is used to obtain the absolute sea surface height in relation to the geoid, and the latter to gather information about oceanic wave fields.

An altimeter works by transmitting an electronic pulse in the microwave frequency to the Earth's surface. The pulse reflects off the surface and returns to the sensor, with altitude determined from the pulse travel time and from the waveform of the returned pulse.

radiance The radiation energy per unit time coming from a specific direction and passing through a unit area perpendicular to the direction.

radiant flux density See irradiance.

radiation stress A mechanism whereby waves can exert a stress on the fluid in which they propagate. This stress tensor was discovered and named by Longuet-Higgins and Stewart [1964] and defined as the excess flux of momentum due to the presence of waves. Gradients in this quantity therefore correspond to a net addition of loss of momentum to a water column, i.e. a net force, arising from the processes of wave shoaling and breaking. The theoretical work was prompted by laboratory experiments with breaking waves that showed a mild depression or set-down in sea level in the vicinity of the wave breaking point and a larger elevation or set-up throughout the rest of the surf zone.

If longshore uniformity is assumed, then the The x-directed flux of x-directed momentum is given (correct to second order) by

$$S_{xx} = E\left(\frac{2kh}{\sinh 2kh} + \frac{1}{2}\right)$$

where k is the wavenumber, L the wavelength, h the depth below still water, and E the wave energy density given by

$$E = \frac{1}{8}\rho g H^2$$

where ρ is the fluid density, g the acceleration due to gravity, and H the wave height. This will given, for equilibrium conditions, a momentum balance of the form

$$\frac{dS_{xx}}{dx} + \rho g(\bar{\eta} + h)\frac{d\bar{\eta}}{dx} = 0$$

where $\bar{\eta}(x)$ is the adjustment of the sea level away from still water level, i.e. the sea level will adjust until the radiation stress gradients are everywhere balanced by the sloping sea level. See Holman [1990],

radio altimeter See radar altimeter.

radiocarbon See carbon-14.

radiocarbon dating See carbon dating.

radioisotopic dating methods Dating methods that take advantage of the fact that unstable atoms called radioactive isotopes undergo spontaneous radioactive decay by the loss of nuclear particles and may transmute into a new element. If the decay rate is invariable a given amount of a radioactive isotope will decay to its daughter product in a known interval of time, creating a geological clock by which large time intervals can be measured. Measuring the present isotope concentration indicates the amount of time that has passed since the sample was emplaced and the clock, i.e. the decay process, started. An important factor is the time it takes for the material to decay to half its original amount, i.e. its half-life, an indicator of the length of the time interval over which it can be used.

A radioisotope's usefulness for dating is dependent on whether it or its daughter products occur in measurable quantities and can be distinguished from other isotopes or have a measureable decay rate.

It must also have a half-life appropriate to the period being dated, a known initial concentration, and some connection between the event being dated and the start of the radioactive decay process.

Radioisotopic dating methods can be divided into three major groups:

- those that entail the direct measurement of radioisotopes or decay products, e.g. carbon-14 dating and potassium-argon dating;
- those that measure the degree to which members of a chain of radioactive decay are restored to equilibrium following some initial external perturbation, e.g. uranium-series dating; and
- those that measure the effect of some local radioactive process on the sample materials compared to the environmental flux, e.g. fission-track dating and thermoluminescence dating.

See Bradley [1985].

radiolaria See Racki and Cordey [2000].

radiolarian ooze A deep-sea sediment composed of at least 30% of the remains of siliceous radiolarians. These sediments occur in the equatorial Pacific and Indian ocean regions where the depth exceeds the carbon compensation depth and therefore aren't overwhelmed by calcareous ooze. These form deep deposits covering 1-2% of the ocean floor, and are a type of siliceous ooze along with diatom ooze. See Tchernia [1980].

radiometer A device that uses a photocell to measure the power of a specific light field.

radiometry The use of a radiometer to quantitatively describe the power from a specific light field. The description can be made in terms of several properties including magnitude, geometrical distribution (or direction), spectral distribution, state of polarization, and time variability. Before the advent of satellite oceanography, the primary use of radiometry was to sample the radiant power in the vicinity of an organism to obtain quantitative information about how it reacts to light. Now the use of radiometers in instruments aboard satellites to measure various properties of incident, reflected and emitted radiation is nearly ubiquitous, with new types of radiometers seemingly developed for each new mission. See Tyler [1973] for a discussion of the physics of radiometry and its appliation to studying the responses of organisms to light.

radium-228 An isotope of radium that is useful as a tracer in ocean studies. It is the 5.75 year half-life daughter of thorium-232. Thorium, a highly insoluble substance, is delivered to shelf and deep ocean sediments chiefly in detritus of continental origin. This decays into radium which dissolves off the particles and diffuses into the water column where it is mixed by diffusion and advection. This leads to a generic profile with a relative maxima at the surface and near bottom with the surface concentration decreasing with increasing distance from the shore (and the near-surface shelf sediment sources). See Sarmiento [1988] and Broecker and Peng [1982].

radius of deformation See Rossby radius of deformation.

RAFOS A subsurface float introduced by Thomas Rossby in 1985 that listens to acoustic signals instead of transmitting (like the earlier SOFAR float). At the end of its mission it surfaces by dropping a weight and uploads to the Argos satellite all the information it collected at depth, including the Times of Arrovals (TOAs) of pulses sent by sources at known geographical positions. See Rossby et al. [1986].

rafting A sea ice process defined by the WMO as:

> Pressure process whereby one piece of ice overrides another. Most common in new ice and young ice.

A type called "finger rafting" involves the formation of interlocking thrusts, with each floe thrusting "fingers" alternately over and under each other. This is commonly found in nilas and grey ice. See WMO [1970].

random variable A function (or mapping) from the sample space of possible outcomes of a random experiment to the real line, the complex plane, or some other such mappable entity. Basically, it's a variable denoting and containing the outcome of a random experiment, families of which comprise a stochastic process.

RAR Abbreviation for Real Aperture Radar.

RARGOM Acronnym for Regional Association for Research on the Gulf of Maine, an association of institutions which have active research interests in the Gulf of Maine and its watershed. It was founded in 1991 and is housed at Dartmouth College. The missions of the association are to advocate and facilitate a coherent program of regional research, to promote scientific quality, and to provide a communication vehicle among scientists and the public. See the RARGOM Web site[136].

Ras al Hadd Jet An intense offshore jet that forms at the easternmost tip of Oman as the East Arabian Current (EAC) separates from the coast at the eastern tip of the Arabian Peninsula. The RAH Jet is found at the northern edge of EAC during the southwest monsoon, and may be considered as its offshore extension. As the wind regime reverses and the EAC weakens, the RAH Jet becomes the southern edge of the warm circulation in the Gulf of Oman. See Böhm et al. [1999].

RASCALS Acronym for Research on Antarctic Shallow and Littoral Systems.

Rayleigh–Bénard convection See Bodenschatz et al. [2000].

Rayleigh number A dimensionless number used for describing unstable stratified flows. It expresses a balance between thermal expansion, temperature, thermal diffusivity, viscosity, and the thickness of a convecting layer, with the most significant parameters being the depth and viscosity of the layer. The Rayleigh number can be defined as:

$$R_a = \frac{g\alpha\Delta T d^3}{\nu\kappa}$$

where g is gravitational acceleration, α the thermal expansion coefficient, ν the kinematic viscosity, κ the thermal diffusivity, and d a width scale. This is equivalent to:

$$R_a = G_r P_r$$

where G_r is the Grashof number and P_r is the Prandtl number. It expresses the competition between overturning due to top–heavy density due to temperature expansion and viscous and diffusive smearing of the buoyancy.

Convection begins at a Rayleigh number of around 2000, with irregular chaotic convection being near 10^6. The higher the number, the more mixing occurs in the substance being convected. It is around 10^{16} in the ocean thermocline and 10^{17} in the atmosphere boundary layer. This is the natural convection equivalent of the Peclet number used in forced convection.

recirculating current See recirculating gyre.

[136] http://fundy.dartmouth.edu/rargom/

recirculating gyre Strong opposing flow elements adjacent to western boundary currents, e.g. the Gulf Stream in the upper ocean and the deep western boundary current in the deep water of the North Atlantic. These are a subbasin-scale component to the large-scale gyre flow, and can dominate the distribution of transport in the basin interior. See Schmitz and McCartney [1993], Hogg and Johns [1995] and McCartney [1992].

Alfred Redfield (1890–1983) Discover of the Redfield ratios.

[http://www.nap.edu/readingroom/books/biomems/aredfield.html]

Redfield ratios These represent the relatively constant proportions maintained between the elements C, N, P and O taken up during the synthesis and released by subsequent remineralization of organic matter by marine organisms. It was originally suggested that during organic matter cycling, carbon, nitrogen, phosphorous and oxygen are cycled in the ratio C:N:P:O2 = 106:16:1:138, i.e. for every phosphate ion taken up during photosynthesis, 16 nitrate ions and 106 molecules are taken up and 138 molecules of oxygen are produced. More recent studies have modified the ratios to 140:16:1:172. See Redfield et al. [1963] and Takahashi et al. [1985].

red noise Noise with relatively enhanced low frequency power that results simply from serial correlation. The resulting power spectrum will have a negative slope. This is usually a good model for the noise component in a variety of climatic time series including proxy records, historical sea and air surface temperatures, and precipitation records. This type of noise can be explained in terms of the slow-response components of the climate system, such as the thermal inertia of the oceans, providing a memory that effectively integrates the forcing of such fast-reponse and more white noise-like components such as the weather. The produces a temporal persistence that leads to great noise energy at lower frequencies. Contrast with white noise.

Red Sea A long, narrow marginal sea centered at about 38° E and 22° N which separates the African and Asian continents. Its total length is 1932 km and the average width 280 km, with a maximum width of 306 km and a minimum width of 26 km. The area is about 450,000 km^2 and the volume around 50,000 km^3. The average depth is about 491 m with the greatest depths over 2500 m in the trough between 19 and 22° N. The Sinai peninsula divides the northern part into the shallow Gulf of Suez to the west and the deep Gulf of Aquaba to the east. The southern limit, which separates it from the Gulf of Aden, is a line joining Husn Murad and Ras Siyan.

The circulation in the Red Sea is summarized in RSMAS [2000] as:

> The Red Sea is similar to the Arabian Gulf in that it acts as an inverted estuary, with dense, salty water formed by evaporation and deep convection in the northern Red Sea flowing out into the Gulf of Aden underneath a fresher inflowing layer from the Gulf of Aden (Fig. 3b). Unlike the Arabian Gulf, however, the exchange is known to be highly seasonal, with maximum exchange occurring in winter. Indirect estimates of the transport of Red Sea water through the Bab el Mandeb Strait suggest an annual mean transport of 0.33 Sv (Siedler, 1968), varying from approximately 0.6 Sv in winter to nearly zero in late summer (Patzert [1974]). The winter period (November-May) is characterized by a classical two-layer exchange flow (Siedler, 1968). However, in summer the northwesterly winds apparently drive a three-layer exchange, consisting of a thin surface outflow from the Red Sea, an inflowing layer of Gulf of Aden thermocline water, and a weak outflowing deep layer (Maillard and Soliman [1986]).
>
> Estimates of the annually averaged rate of Red Sea deep water formation range from 0.06 Sv to 0.16 Sv (Cember [1988]). This water forms in the northern Red Sea predominantly during winter, and fills the deep basin below the Bab el Mandeb Strait sill depth

(approximately 160 m) with a nearly homogeneous water mass of temperature 21.7 C and salinity 40.6 psu (Neumann and McGill [1962]). A second source of somewhat less dense Red Sea water, or Red Sea "intermediate" water, is believed to be formed also predominantly in winter by an open sea convection process in the northern Red Sea that remains poorly understood (Morcos [1970]). This process appears to be distinct from the Red Sea deep water formation process that occurs in the northern gulfs of the Red Sea (Gulf of Suez and Gulf of Aqaba) and that fills most of the deep volume of the Red Sea. Another class of intermediate waters may be formed on shallow shelves in the southern Red Sea. Volumetrically, the rate of intermediate water formation appears to be greater than the rate of deep water formation, and is thought to supply the main contribution to the lower layer outflow from the Red Sea through Bab el Mandeb.

The seasonal cycle of the Red Sea exchange through the Bab el Mandeb is driven primarily by the seasonal change in winds over the southern Red Sea and Gulf of Aden (Fig. 1). In winter the southeasterly winds act to reinforce the thermohaline circulation of upper layer inflow and deep outflow. Conversely, in summer the northwesterly winds act in opposition to the thermohaline forcing and this may partly explain the reversal to outflow in the surface layer of the strait in summer. Upwelling in the western Gulf of Aden during summer is also believed to play a role in forcing the surface current reversal in the Strait and thermocline layer intrusion into the Red Sea, by changing the stratification and sea level in the western gulf and hence affecting the alongstrait pressure gradient (Patzert [1974]). The relative importance of these two wind-forced effects, one direct and one indirect, is not yet clear. Seasonal changes in surface buoyancy forcing may also affect the seasonality of the exchange, but this possibility has yet to be investigated.

The Red Sea water exits the Bab el Mandeb strait with a sill depth of ~160 m and spills down the topography of the western Gulf of Aden where it entrains resident Gulf waters and sinks to an average depth of about 600 m. Hydraulic control of the outflow is much debated and there is as yet no consensus on the exact nature of hydraulic controls that may govern the exchange. The overflow character of the outflowing Red Sea water is suggestive of hydraulic control. However, there is no evidence of a Gibraltar-like internal bore, a feature that would serve as indirect evidence for hydraulic control. Recently, a three-layer hydraulic model that reproduces the gross characteristics of the stratification and exchange in both summer and winter has been constructed. However the critical conditions required in the summer and winter solutions differ considerably from direct wave speed calculations based on data collected by at the sill and narrows.

The horizontal circulation of the Red Sea appears to consist of a number of gyres or eddies distributed along the length of the Sea (Fig. 3b), of which some may be semi-permanent (Quadfasel and Baudner [1993]). There is little detailed information on this circulation as most studies have tended to treat the Red Sea as a two-dimensional basin. Most oceanographic measurements are therefore confined to its central axis. In the northern Red Sea, drifter trajectories point to a cyclonic gyre at least in winter (Clifford et al. [1997]). This gyre may be linked to the aforementioned intermediate water formation process in the northern Red Sea, and could possibly serve in a preconditioning role for the intermediate water formation. In the central Red Sea the circulation appears to be dominated by anticyclones that occur most regularly near 23-24 N and 18-19 N. These locations may be tied to coastline and topography variations (Quadfasel and Baudner [1993]). Both cyclonic and anticyclonic features are found in the southern Red Sea but no persistent gyre pattern seems to exist there. When present, these gyres usually span most of the width of the Red Sea and can have horizontal velocities of 0.5 m/s or more. Thus they are energetic compared to the 0.1 m/s mean flows in the surface layer associated with the large scale thermohaline circulation of the Red Sea.

Coastal boundary currents may exist both in the southern Red Sea off Yemen and in on both sides of the northern Red Sea (Eshel and Haik [1997]) Little direct evidence is available for these currents, however. Particularly in the northern Red Sea, the opposing influences of the wind and thermohaline forcing throughout the year make it unclear what sense should be expected for these boundary currents.

The central axial zone of the Red Sea contains a series of 0.02–60 km^2 basins between 1500 and 2800 m deep. These are filled with anoxic, dense and hot brines whose temperatures range from 23.25–44.60°C and salinities from 144 to 270 ppt. The transition zone between brines and overlying seawater is marked by strong gradients, and therefore extremely stable, i.e. the transfer of properties across it is controlled mostly by molecular diffusion. See Neumann and McGill [1962], Siedler [1969], Morcos [1970], Patzert [1974], Maillard and Soliman [1986], Cember [1988], Quadfasel and Baudner [1993], Tomczak and Godfrey [1994], Clifford et al. [1997] Eshel and Haik [1997] and Bower et al. [2000].

[http://mpo.rsmas.miami.edu/~zantopp/AMSG-report.html]

red tide More later.

redox discontinuity layer A zone of rapid transition between areas of aerobic and anaerobic decomposition in oceanic sediments. Its depth within the sediment depends on the quantity of organic matter available for decomposition and the rate at which oxygen can diffuse down from the overlying water. For example, in organic muds, relatively impermeable to oxygen-carrying water, the upper aerobic layer may only be a couple of millimeters deep, while in permeable sands with a low rate of organic input aerobic conditions can extend for tens of centimeters. See Barnes and Hughes [1988].

reduced gravity In oceanography, a term that arises when the Boussinesq approximation is made where variations in density are neglected when they affect inertia but retained when they affect buoyancy, i.e. when they occur in the combination

$$g' = \frac{g\rho'}{\rho_0}$$

where g' is the reduced gravity, g the normal gravitational acceleration, ρ' a density perturbation, and ρ_0 a standard reference density. See Turner [1973].

reef The official IHO definition for this undersea feature name is “a mass of rock or other indurated material lying at or near the sea surface that may constitute a hazard to surface navigation.” See coral reef.

ReefBase A global database on coral reefs and their resources. This is available on CD-ROM from ICLARM. See the ReefBase Web site[137].

reference level A depth, pressure or density level at which the horizontal current field is either known from direct measurements or indirectly estimated. This may be zero velocity surface or one with non-zero horizontal velocities. This reference level is combined with the relative velocity fields obtained via the geostrophic method to obtain fields of absolute geostrophic velocitiesa The techniques of satellite altimetry have provided another possibility for a reference level, i.e. the ocean surface. If the vertical departure of the ocean surface from the local geoid can be measured with sufficiently accuracy then it can be used as a reference level. This is also known variously as the level of no motion, the level of known motion, the zero velocity surface, etc.

reflectance In radiation transfer, the fraction of incoming radiation that is reflected from a medium. The sum of this, the transmittance, and the absorptance must equal unity.

[137] http://www.cgiar.org/iclarm/resprg/reefbase/

regenerated production The uptake of ammonium by phytoplankton in the euphotic zone. It is so-called because ammonium is a product of internal processes within the euphotic zone and it is therefore recycled or regenerated nitrogen. See Najjar [1991].

regional modeling In climate modeling this is defined as simulating the climate over a limited area or region rather than over the entire globe using Regional Circulation Models (RegCM). The boundary conditions needed to drive these models are supplied either from GCM output via a procedure called nested modeling or from analyses of observations. The RegCMs perform consistently better when driven by observations than by GCM output. This is largely due to the lack of regional scale geographical features (e.g. coastlines, lakes, etc.) and their concomitant climate effects in the output of GCMs, effects which are implicitly included in observations. Increased GCM resolution is found to improve RegCM simulations. This is a felicitous result since a lack of adequately dense observational data is the major limitation of using observations to drive RegCM simulations. See Houghton and Filho [1995].

regional sea A body of water smaller than the main sections of the world ocean that is bound by geographic and/or hydrographic regions. Regional seas whose names can be encountered in the literature include the Adriatic Sea, Aegean Sea, Aland Sea, Alboran Sea, Amundsen Sea, Andaman Sea, Arabian Sea, Arafura Sea, Aral Sea, Australasian Mediterranean Sea, Sea of Azov, Balearic Sea, Bali Sea, Baltic Sea, Banda Sea, Barents Sea, Beaufort Sea, Bellingshausen Sea, Belt Sea, Bering Sea, Bismarck Sea, Black Sea, Bohol Sea, Bothnian Sea, Burma Sea, Camotes Sea, Caribbean Sea, Caspian Sea, Catalan Sea, Celebes Sea, Celtic Sea, Ceram Sea, Chukchi Sea, Chukotsk Sea, Coral Sea, Cretan Sea, East China Sea, East Siberian Sea, Flores Sea, GIN Sea, Greenland Sea, Halmahera Sea, Iceland Sea, Ionian Sea, Irish Sea, Irminger Sea, Japan Sea, Java Sea, Jawa Sea, Kara Sea, Labrador Sea, Laptev Sea, Levantine Sea, Ligurian Sea, Lincoln Sea, Maluku Sea, Marmara Sea, Mediterranean Sea, Mindanao Sea, Molucca Sea, Nordenskjold Sea, Nordic Seas, North Sea, Norwegian Sea, Okhotsk Sea, Red Sea, Ross Sea, Samar Sea, Sargasso Sea, Savu Sea, Sawu Sea, Scotia Sea, Seram Sea, Sibuyan Sea, Solomon Sea, South China Sea, Sulawesi Sea, Sulu Sea, Sunda Sea, Tasman Sea, Tethys Sea, Timor Sea, Tyrrhenian Sea, Visayan Sea, Weddell Sea, White Sea, and the Yellow Sea.

relative humidity The ratio of the observed mixing ratio in a sample of moist air to the saturation mixing ratio with respect to water at the same temperature. It is given by

$$U = \frac{q(1 - q_w)}{q_w(1 - q)}$$

where q is the specific humidity and q_w the saturation specific humidity.

relative vorticity The vorticity imparted to a parcel or column of fluid by fluid motion. It is a characteristic of the kinematics of the fluid flow which expresses the tendency for portions of the fluid to rotate. Technically speaking, this is the curl of the fluid velocity vector, although in oceanography and meteorology it is usually only the vertical component of the curl of the horizontal velocity vector since all other components are usually negligible.

Rennell, James (1742–1830) See Peterson et al. [1996], p. 47.

Rennell's Current "A relatively strong (1.0 to 1.5 knots) nonpermanent current that sets northward across the western approaches to the English Channel. The current appears to be independent of the North Atlantic Drift or local winds and occurs most frequently during winter." From Baker, Jr. et al. [1966].

research submersibles More later.

`[http://itri.loyola.edu/subsea/toc.htm]`

research vessels See Estok and Boykin [1976], Guberlet [1964], Nelson [1971], Rice [1986a], Treadwell et al. [1988], Wust [1964] and the oceanography history section for further details.

[http://scilib.ucsd.edu/sio/archives/histoceanogr/mills-handlist.html]

Research Vessel Technical Enhancement Committee (RVTEC) An organization of technical support personnel associated with the university oceanographic Research Vessel fleet of the U.S. RVTEC is charted by UNOLS and publishes a newsletter called "INTERFACE." See the RVTEC Web site[138].

resolution In numerical modeling, the distance between contiguous points in the computational grid. This can refer to either temporal or spatial resolution, with the two being dependent in procedures using both.

resonance angle The angle at which the component of the wind speed acting in the direction of a wave field is equal to the wave speed. From Baker, Jr. et al. [1966].

resurgence A general class of phenomena where, after a storm surge, the water level falls, rises, falls again, rises again, and so on for many hours after the passage of a hurricane. This has been variously explained as being due to oscillating long waves, edge waves, Kelvin waves or some combination thereof. See Wiegel [1964].

retardation See daily retardation.

retroflection In oceanography, this refers to a geographical looping of a current away from its original direction to a substantially different direction. See Schmitz and McCartney [1993].

Revelle, Roger (1909-1991) More later.

[http://scilib.ucsd.edu/sio/archives/siohstry/revelle-biog.html]
[http://www.nap.edu/readingroom/books/biomems/rrevelle.html]

Revelle factor See buffer factor.

reversed tide A tide completely out of phase with the apparent motions of the principal attracting body, i.e. the lowest heights are directly under the body on opposite sides of the earth. See also direct tide. From Baker, Jr. et al. [1966].

reversing current See Baker, Jr. et al. [1966].

reversing thermometer

Reynolds equations An equation set for turbulent flow wherein the instantaneous values of the dependent variables in the equations of motion are split into mean and fluctuating parts, e.g. $\tilde{u} = U + u$ where U is the mean and u the turbulent or fluctuating part. These are substituted into the equations of motion and an average is taken over a suitable period of time (where "suitable" means an averaging interval large compared to the timescale of the turbulent fluctuations yet small compared to the timscale of the change of the mean flow) to obtain the Reynolds equations. These have the same form as the original motion equations – with mean quantities replacing total quantities – except for new terms involving velocity fluctuations that arise from the nonlinear terms in the original equations. These terms represent the effect of velocity fluctuations or turbulence on the mean flow, and are called Reynolds stresses since

[138] http://www.gso.uri.edu/unols/rvtec/rvtec.html

the turbulence has an effect equivalent to stress on the mean flow. The Reynolds equations can be expressed as:

$$
\begin{aligned}
\frac{\partial U_i}{\partial x_i} &= 0 \\
\frac{\partial U_j}{\partial t} + \frac{\partial}{\partial x_k}(U_k U_j) + \varepsilon_{jkl} f_k U_l &= -\frac{1}{\rho_0}\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_k}\Sigma_{kj} - g_j \rho - \frac{\partial}{\partial x_k}\left(\overline{u_k u_j}\right) \\
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_k}(U_k \rho) &= \frac{\partial}{\partial x_k}\left(k_T \frac{\partial \rho}{\partial x_k}\right) - \frac{\partial}{\partial x_k}\left(\overline{u_k \rho}\right)
\end{aligned}
$$

where U_i and u_i are the mean and fluctuating velocity components, respectively, x_i are the spatial components, ε_{ijk} is the alternating, third–order tensor, $f_k = \delta_{k3} 2\Omega \sin\theta$ is the vertical component of the rotation vector (i.e. the Coriolis force), ρ_0 is a constant reference density, P is the pressure, Σ_{ij} is the mean part of the second–order, symmetric viscous stress tensor defined as:

$$
\Sigma_{ij} = 2\nu \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)
$$

where ν is the kinematic viscosity, g_j is gravity, ρ is the density,

The Reynolds equations give rise to what is known as the closure problem, where the averaging procedure results in new unknowns in the form of the fluctuating quantities obtained from the nonlinear terms. Specific expressions for these fluctuating quantities can be obtained but at the price of generating yet more unknowns, ad infinitum. At some point a closure assumption must be made and the fluctuating quantities parameterized in terms of known quantities like the mean flow. The use of the eddy viscosity concept is the simplest way of obtaining closure.

This is ultimately a problem of flow resolution. If we could explicitly model the flow at a sufficiently high resolution (i.e. on a sufficiently small grid) then we wouldn't need to use an eddy viscosity since the molecular viscosity would suffice. Unfortunately, the length scale required for this is on the order of a millimeter or less, rendering it infeasible to explicitly model flow in a pipe (much less atmospheric or oceanic flow) without parameterizing the turbulent, i.e. unresolved, portion of the flow in terms of the mean, i.e. resolved, portion of the flow.

Reynolds stresses Stress terms obtained by transforming the equations of motion into the Reynolds equations. They are so–called in analogy to the terms in the original motion equations involving the molecular viscosity, and to further the analogy the concept of an eddy viscosity is used to perform closure on the Reynolds equations and render them soluble.

The forces that give rise to the stresses are due to the fact that in a turbulent flow there are rapidly fluctuating as well as mean components. The fluctuating components oppose the mean motion and redistribute energy and other properties via a physical effect analogous to molecular friction, i.e. turbulent friction. This causes a more rapid distribution of momentum, heat and salt than would occur solely via molecular processes, and the analogous stresses are called Reynolds stresses.

Reynolds stress tensor A quantity arising in the development of the Reynolds equations defined as

$$
\tau_{ij} = -\rho_0 \, \overline{u_i u_j}
$$

where ρ_0 is a constant reference density and $\overline{u_i u_j}$ is a matrix of the time average of the products of the turbulent velocity components. The instantaneous velocity $\tilde{u}_i$ has been decomposed into average and fluctuating quantities, i.e. $\tilde{u}_i = U_i + u_i$ and the overbar indicates a time average.

Reynolds number A dimensionless number expressing the ratio of viscous to inertial forces. It is expressed by

$$Re = \frac{UL}{\nu}$$

where ν is the kinematic viscosity, U an appropriate velocity scale, and L a horizontal length scale. If this is at least one order larger than unity then viscosity cannot significantly affect the motion; if it is much less than unity then molecular viscosity plays a significant role. See Kraus and Businger [1994], p. 29.

RGPS Acronym for RADARSAT Geophysical Processor System, a computer system that takes RADARSAT SAR images of Arctic sea ice for input and creates geophysical data products for output. These include sea ice motion, the thickness distribution of new ice, and the backscatter history of the ice. See the RGPS Web site[139].

RH Abbreviation for relative humidity.

Rhodes Gyre See Milliff and Robinson [1992].

Richardson, Lewis Fry More later.

Richardson number A ratio of buoyancy to inertial forces which measures the stability of a fluid layer. There are several different definitions of this for various situations,including the overall, gradient, and flux Richardson numbers. See Turner [1973].

ridging A sea ice process defined by the WMO as:

> The pressure process by which sea ice is forced in ridges. A ridge is a line or wall of broken ice forced up by pressure. It may be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed in ice keel.

Antarctic ridges a commonly point features, whereas they are more often long and linear in the Arctic. See WMO [1970].

The official IHO definition for this in the context of undersea feature names has three meanings:

- an elongated narrow elevation of varying complexity having steep sides;
- an elongated narrow elevation, often separating ocean basins; and
- the linked major mid–oceanic mountain systems of global extent; also called mid–oceanic ridge.

RIDGE Acronym for Ridge Inter–Disciplinary Global Environments Initiative, a coordinated program aimed at understanding the geology, physics, chemistry and biology of processes occurring along the global mid–ocean ridge system. See the RIDGE Web site[140].

rigid lid approximation A filtering approximation incorporated into oceanographic models to increase their computational efficiency. This approximation filters out the fast barotropic gravity waves by setting the time variation of the surface elevation in the equations of motion equal to zero. A computational price is paid for this approximation since it requires that a prognostic Poissonlike elliptical equation be solved for the barotropic stream function (or surface pressure) at each model time step. This can be a problem as the condition number increases faster than linearly with the resolution of the computational grid, causing the equations to become increasingly difficult to solve.

[139] http://psc.apl.washington.edu:80/RGPS/
[140] http://ridge.unh.edu/

This approximation also has dynamical effects that can be non-negligible. For example, although a surface elevation can be calculated from the prognostic surface pressure solution, it is strictly applicable only in the limit of a steady-state and as such the surface height cannot be accurately computed for transient and nonequilibrated flow. Additionally, this approximation effectively makes the phase speed of all barotropic Poincare waves infinite and equilibrates them at all scales. This is a reasonable approximation at mid- and high-latitudes where Poincare waves exist at high frequencies, but not so good near the equator where they evolve on a time scale equivalent to the Rossby waves. Finally, this approximation affects the phase speed of Rossby waves with wavelengths greater than the Rossby radius of deformation. See Dukowicz and Smith [1994] and Thacker and Raghunath [1994].

Rim Current A permanent, strong current system encircling the Black Sea basin cyclonically over the continental slope zone. It is accompanied by a series of anticyclonic mesoscale eddies as well as transient waves with an embedded train of mesoscale eddies propagating cyclonically around the basin. According to Oguz and Besiktepe [1999]:

> The Rim Current is identified as a well-defined meandering jet stream confined over the steepest topographic slope and associated cyclonic–anticyclonic eddy pairs located on both its sides. It has a form of highly energetic and unstable flow system, which, as it propagates cyclonically along the periphery of the basin, is modified in character. It possesses a two-layer vertical structure with uniform upper layer speed in excess of 50 cm/s (maximum value ≈100 cm/s), followed by a relatively sharp change across the pycnocline (between 100 and 200 m) and the uniform sub-pycnocline currents of 20 cm/s (maximum value ≈40 cm/s) observed up to the depth of ≈350 dbar, being the approximate limit of ADCP measurements. The cross-stream velocity structure exhibits a narrow core region (≈30 km), flanked by a narrow zone of anticyclonic shear on its coastal side and a broader region of cyclonic shear on its offshore side.

See Oguz and Besiktepe [1999].

Río de la Plata Estuary After Sepúlveda et al. [2004], the Río de la Plata Estuary is located in South America on the Atlantic coast, at 35°S, 57°W, between Argentina and Uruguay. It has an approximate length of 320 km and a width of 230 km at the mouth. The average depth is 10 m. It drains the second largest basin of South America, receiving the combined discharge of the Paraná and Uruguay rivers, the two major tributaries, with a total yearly average discharge of 22,000 m3/s, comparable to the discharge of the Mississippi river. Freshwater discharge to the Río de la Plata exhibits monthly variations with the combined peak discharge appearing in the austral fall and the lowest discharge occurring in the austral summer. The Paraná River has an average discharge 3 to 4 times greater than the Uruguay River but its volume shows low seasonal variability. Episodic events in the Uruguay River exhibit high discharge rates, comparable to those of the Paraná River that can modulate the runoff into the Ro de la Plata.

The estuary can be divided, on the basis of hydrodynamical considerations, in two regions separated by the turbidity maximum zone. In the inner or upstream portion, between the turbidity maximum and the head of the estuary, the regime is predominantly fluvial, i.e. the inner part is dominated by river flow interacting with tidal currents and affected by winds. In the outer or downstream portion the estuary width increases rapidly. It is mostly in this area where riverine discharge interacts with saline shelf waters. Shallow areas (4–10 m) and channels dominate the bottom topography, with the deepest channels (20-25 m) located along the Uruguayan coast.

The tides in the estuary are mixed with semidiurnal dominance. The main tidal constituents are M2, S2, N2, K1, and O1. The M2 constituent is the most energetic explaining 80% of the total variance; the O1 is the main diurnal component and produces a difference in the amplitude of the two maxima during one day, the diurnal inequality, which is characteristic in the area. Tidal amplitude varies across the estuary with greater values along the Argentinean coast (amplitude 1 m) than along the Uruguayan coast (amplitude 0.3 m). Due to the considerable length of the Río de la Plata, semidiurnal constituents have the very unusual feature of a nearly complete wavelength within the estuary at all times. The distribution of the phase and amplitude for these tidal constituents has been described as the result of a Kelvin wave that propagates northward around the continental shelf and enter the estuary, in general, from the southeast. Tides in the estuary can be strongly modified by meteorological events; storm surges of over 4 m have been recorded during strong southeasterlies.

The orientation of the buoyant plume presents a bimodal pattern: In the spring and summer, when freshwater discharge is lowest and northeast winds are predominant, a buoyant strip of water extends along the Argentinean coast. During the fall and winter, freshwater discharge peaks and downwelling favorable winds combine with Coriolis acceleration to move the buoyant waters along the northern coast. Bottom salinity is controlled by bathymetry and exhibits weak seasonality. Temperature patterns follow atmospheric variability (air–sea heat flux) with a seasonal range of about 10°C. The warm period spans from December to March while the cold period is from June to September. During the summer, coastal upwelling is observed at the mouth of the estuary along both coasts. Coastal upwelling modifies the estuarine outflow, favoring a buoyancy outflow off the coast of Argentina, and also reinforces a southward ambient current.

A characteristic feature in the estuary is the turbidity front, located approximately in the vicinity of the Barra del Indio. The front is the surface signature of the transition between fresh and more saline shelf waters. The position of the turbidity front exhibits strong seasonality. During the summer months (low freshwater discharge and northeasterly winds) the turbidity front is at its northwesternmost position. During winter and fall, the turbidity front extends seaward. After Guerrero et al. [1997] and Sepúlveda et al. [2004].

rip current A narrow seaward return flow caused by waves breaking in the surf zone and piling up water against the coast. This establishes a hydraulic head which, combined with bathymetric irregularities along the coast, causes the narrow seaward flow. See Komar [1976].

rip feeder current A current that flows parallel to the shore before converging and forming the neck of a rip current.

rise The official IHO definition for this undersea feature name has two meanings:

- a broad elevation that rises gently and generally smoothly from the sea floor; and
- the linked major mid–oceanic mountain systems of global extent; also called mid–oceanic ridge.

RISP Abbreviation for Ross Ice Shelf Program or Project, a New Zealand project.

Rissaga An instance of the meteorological tsunami phenomenon in the harbor of Ciutadella on the Island of Menorca in the Balearic Islands. See Monserrat et al. [1991].

RNODC Abbreviation for Responsible National Oceanographic Data Center, a facility established within the framework of the IOC IODE structure to take on the responsibility of assisting the WDCs. This scheme was developed to enable to international exchange system to cope with an increasing variety and volume of oceanographic data being collected by providing special data processing and compilation support for specific programs and certain areas.

The RNODCs as of mid-2001 are:

- RNODC–SOC, operated by the NODC of Argentina for data from the Southern Oceans;

- RNODC for Drifting Buoys Data, operated by MEDS, Canada for data from drifting buoys;
- RNODCs for IGOSS, operated by the NODCs of Japan, the USA and the Russian Federation for BATHY and TESAC datasets;
- RNODCs for MARPOLMON, operated by the NODCs of Japan, the USA and the Russian Federation for holding worldwide marine pollution data;
- RNODC-WESTPAC, operated by the NODC of Japan for data from cruises in the WESTPAC region;
- RNODC-Waves, operated by the BODC for archiving instrumented wave data;
- RNODC-JASIN, operated by the BODC for archiving data from the JASIN project;
- RNODC-Formats, operated by the Service Hydrographique of ICES for international or project oriented oceanographic data formats;
- RNODC-ADCP, operated by the NODC of Japan for archiving and processing ADCP data; and
- RNODC-INDO, operated by the NODC of India for storing data from research activities in the Indian Ocean.

[http://ioc.unesco.org/iode/structure/rnodc/rnodc.htm]

RNODC-SOC Abbreviation for RNODC from the Southern Oceans, a data center commissioned in 1988 within IODE to acquire the physical and chemical data obtained by the international scientific community in cruises and research programs carried out in the Southern Oceans, control their quality, store them in standard format, and distribute them upon request. This center is a part of CEADO. See the RNODC-SOC Web site[141].

roaring forties The region between 40 and 50° S latitude where the prevailing westerly winds blow largely unobstructed by land over the open oceans, and also the winds themselves. They are constant and of great velocity, whence comes the term "roaring". The weather is stormy, rainy, and comparatively mild in the wake of constantly appearing depressions. The land areas that do obstruct them, the western mountainous coasts of southern Chile, Tasmania and New Zealand, experience tremendous rainfall through the year on the western sides (up to 100 in.) and much less on the eastern sides (around 20 in.). These are also known as brave west winds.

ROLAI^{2}D A free vehicle benthic lander designed to characterize reaction at and transport across the sediment–water interface. ROLAI^2 was designed for long duration deployments (i.e. greater than 30 days) to measure the small fluxes and low reaction rates typical of most of the deep ocean. The lander does this my autonomously collecting sediment and pore water samples as well as samples from benthic chambers. Tracers can be released into the chambers to define such processes as non–diffusive exchange across the interface. See Sayles and Dickinson [1991].

Romanche Fracture Zone See Mercier and Morin [1997] and Messias et al. [1999].

RONMAC Acronym for Red de Observacion del Nivel del Mar para America Central, or Water Level Observation Network for Latin America. RONMAC was initiated as a response to the 1998 impact of Hurricane Mitch on El Salvador, Guatemala, Honduras and Nicaragua, with the objective being to provide support for the development and improvement of the geodetic framework of Central America. The development phase will be executed from June 2000 to Dec. 31, 2001, with the project continuing on an operational basis thereafter. The activities include:

[141] http://www.conae.gov.ar/~ceado/rnodcsoc.html

- installing six sea–level and meteorological monitoring stations;
- installing a ground station and facilitating real–time access to and distribution of information;
- development of a national and regional capacity to install and maintain the stations and to conduct data acquisition, analysis, archiving and dissemination using automated database management technology; and
- strengthening the skills of host–country agencies via technology transfer and capacity building.

[http://www.oas.org/ronmac/]

ROPEX Acronym for the Ronne Polynya Experiment, carried out in the southern Weddell Sea in January and February 1998 using the HMS *Endurance*. The primary goal of the program was to obtain oceanographic, sea–ice and atmospheric measurements to improve the understanding of the physical processes coupling the southern Weddell Sea to the circulation and properties of the global ocean and atmosphere.

[http://www.esr.org/ropex/ronice.html]

ROSCOP Acronym for Reports of Oceanographic Cruises and Oceanographic Programs, a program conceived by the IOC in the late 1960s to provide a low level inventory for tracking oceanographic data collected on research vessels. It is a form to be completed by a scientist on each cruise that provides various metadata about what kinds of data were taken on the cruise. It was renamed the Cruise Summary Report (CSR) in 1990 but the acronym ROSCOP persists. See the ROSCOP Web site[142] where digitized forms of collected ROSCOP info from the 1960s through the present can be obtained.

ROSIS Acronym for Reflective Optics System Imaging Spectrometer, a compact airborne imaging spectrometer. This device was designed for the detection of spectral fine structure in coastal waters. See the ROSIS Web site[143].

Ross, James Clark More later.

Ross Sea See Jacobs et al. [1970], Arrigo et al. [1998] and Jacobs and Giulivi [1999].

Rossby, Carl-Gustav Arvid (1898-1957) Rossby was born in Sweden and joined a group studying under V. Bjerknes in 1918 after receiving his "Kandidat" in theoretical mechanics. There he started his career in meteorology as well as his interest in oceanography. In 1921 he followed Bjerknes to the University of Leipzig for a year and then returned to Stockholm in 1922 to a position with the Swedish Meteorological Hydrologic Service. Over the next three years he accompanied, as a meteorologist, oceanographic expeditions to Jan Mayen in the Nordic Seas, around the British Isles, and to Portugal and Madeira. He also studied mathematical physics at the University of Stockholm during this time and received his "Licentiat" in 1925.

In 1926 Rossby moved to the United States and continued his research at the only extent meteorological center, the Government Weather Bureau in Washington, D.C. He wrote several significant papers on atmospheric turbulence and stratospheric dynamics during this period and also organized the first airway meterological service on an experimental basis in California which provided the pattern for future systems. In 1928 he organized the first university level meteorological program in the United States at the Massachusetts Institute of Technology 9MIT), in which he soon became a full professor.

He spent eleven years at MIT and contributed to such areas as the thermodynamics of air masses, turbulence in the atmosphere and in the oceans, lateral mixing, and the interaction of the ocean–atmosphere boundary layers. He gradually turned his attentions to large–scale motions and the general

[142] http://ices.dk/ocean/roscop.htm
[143] http://www.man.ac.uk/Arts/geography/rs/emac.html

circulation of the atmosphere, to which he began to apply the concepts of vorticity and momentum that permeate the field today. In 1939 he became the assistant chief of research at the U.S. Weather Bureau and in 1940 the chairman of the Department of Meteorology at the University of Chicago, during which time he developed his theory for the long waves in the atmosphere that later came to be called Rossby waves.

During World War II he organized the training of military meteorologists and continued his research on long waves in the atmosphere. After the war he recruited many outstanding future researchers for the University of Chicago and played a significant role in the development of equations for the prediction of weather using electronic computers. In 1947 he became the director of the newly formed Institute of Meteorology in Stockholm and divided his time between there and Chicago (although, for convenience, his American affiliation was transferred to Woods Hole in the early 1950s.

At Stockholm Rossby's principal activities were concerned with developing numerical prediction systems for European weather. He also founded the geophysical journal Tellus. In 1954 he turned his attention to the field of geochemistry and also became interested in deep circulation processes in the ocean. He worked in these areas until his death in 1958. See Lewis [1996] and Phillips [1998].

Rossby-gravity wave See Yanai wave.

Rossby number A non-dimensional number expressing the ratio of inertial to Coriolis forces in the atmosphere or oceans. The Rossby number R_0 is defined by

$$R_0 = U/fL$$

where U is a characteristic velocity scale, f the Coriolis parameter, and L a characteristic length scale. If the Rossby number is large, then the effect of the Earth's rotation on the phenomenon in question can be neglected. This is also called the Kibel number.

Rossby radius of deformation The fundamental horizontal length scale in fluids that are affected by both gravity and rotation. It is the length scale at which rotation effects become as important as buoyancy effects. In transient problems an initial disturbance at a scale small compared to the Rossby radius will result in an adjustment process about the same as would occur in a nonrotating system. If the disturbance is on a scale comparable to the Rossby radius, the Coriolis acceleration becomes as important as the pressure gradient term and the response is markedly different than would be seen in the nonrotating system.

In a homogeneous layer of fluid the barotropic Rossby radius λ is given by

$$\lambda = c/f$$

where c is the gravity wave propagation velocity $\sqrt{gH}$, g the gravitational acceleration, H the water depth, and f the Coriolis parameter. In the deep ocean where H is 4 or 5 km, the baroclinic radius is around 2000 km, but on the continental shelves with depths closer to 50 to 100 m it is around 200 km.

In a stratified fluid the baroclinic Rossby radius is similarly computed, except that c is now the wave speed of the nth baroclinic mode as would be found in a normal mode decomposition of the system. The baroclinic radius is a natural scale in the ocean associated with boundary phenomena such as boundary currents, fronts, and eddies. The first mode baroclinic radius is typically around 10-30 km in the ocean. See Gill [1982].

Rossby wave Large scale waves in the ocean or atmosphere whose restoring force is the β-effect of latitudinal variation of the local vertical component of the earth's angular rotation vector, i.e. the Coriolis force. In the atmosphere they are easily observed as the large-scale meanders of the mid-latitude jet stream that are responsible for prevailing seasonal (via blocking) and day-to-day weather patterns. They are more difficult to detect in the ocean as their sea surface height signature is on the order of 10 cm, their propagation speeds of order 10 cm/s, and their wavelengths hundreds to thousands of kilometers.

Rossby waves in the ocean are responsible for establishing the westward intensification of circulation gyres, the Gulf Stream being one example of this. They are also the dynamic mechanism for the transient adjustment of the ocean to changes in large-scale atmospheric forcing, e.g. information is transmitted from the tropical oceans to mid- and high-latitudes via Rossby waves acting in concert with coastal trapped waves. They are generated by wind and buoyancy forcing at the eastern boundaries and over the ocean interior. They are also known to be generated by perturbations along the eastern boundaries caused by coastal trapped waves originating at low latitudes. They subsequently freely propagate away from their source regions.

Standard theory derives the properties of freely propagating Rossby waves from the linearized equations of motion for large-scale, low-frequency motion about a state of rest, which yields an equation for normal modes. These normal modes can be found by specifying surface and bottom boundary conditions and solving an eigenvalue problem that depends only on the local stratification. There are an infinite number of wave modes ordered by decreasing phase speed, which are westward for all modes. Solutions for low frequencies and long wavelengths are zonally nondispersive, i.e. the phase speed is independent of the wavelength.

The lowest mode is the barotropic mode. It is uniform vertically and propagates across an ocean basin in about a week. The next gravest, or first baroclinic, mode is surface intensified, depends strongly on the stratification profile, has a velocity profile that changes sign at the depth of the thermocline, and takes months to cross the same basin as the first mode does in a week. The surface height variations of this mode are mirrored as thermocline depth variations of the opposite sign, which are also about three orders of magnitude larger, i.e. a 5 cm surface elevation variation would correspond to a 50 m depression in the thermocline.

History. Platzman [1968] thoroughly reviewed the historical development of the Rossby wave concept:

> Rossby was himself explicit about the antecedents of his trough formula. In his paper of 1939 he said: "In the attempt to understand the dynamics of the upper level trough over the United States, the author found great help in a remarkable paper by J. Bjerknes (1937) which offers a simple explanation for the displacement of perturbations imposed upon the zonal pressure distribution which normally prevails in the upper parat of the troposphere." He then reproduced the 'isobaric-channel' diagram from Bjerknes's paper, and referred to this paper again the the second part of his work, published in 1940.
>
> An earlier source of inspiration which Rossby cited in both of his planetary-wave papers, and to which he often alluded in conversation, was Ekman's classic papers of 1923 and 1932. Here Ekman formulated in detail the central role played by vorticity in the quasi-geostrophic control of ocean circulations, and distinguished clearly between the various types of induction of relative vorticity. In particular, he referred to the effect of variation of Coriolis parameter with latitude as the "planetarische Wirbelwirkung," and the effect of change of depth as the "topographische Wirbelwirkung." Ekman's work certainly must have had a strong influence on Rossby's formulation of the potential-vorticity theorem. Of course, any correct historical perspective on this subject must include the great circulation theorem of V. Bjerknes (1898).
>
> I believe Rossby was at first not aware of the fact that the global counterpart of the regional planetary wave is a limiting case of a class of solutions of the equations for free oscillations of an ocean on a rotating sphere - Laplace's 'tidal' equations as they are called.

Margules in 1893 had shown that these equations admit two quite different classes of solutions: first, oscillations of predominantly gravitational type, mainly of importance for the analysis of the semidiurnal and diurnal tides; and second, oscillations of predominantly inertial type, which owe their existence entirely to the rotation of the Earth, and may be important for the long-period tides. Margules called the gravitational modes "Wellen erster Art" and the rotational modes "Well zweiter Art." Hough, about five years later, without knowledge of Margules' work, made the same discovery and used virtually the same terms, namely "oscillations of the first class" and "oscillations of the second class." It is sometimes said that these categories were noticed by Laplace but that is not true – and I daresay his reputation can not be much affected by this oversight! However, there seems to be little awareness of the fact that in the second edition of `Hydrodynamics` (the first with that title), published in 1895, Lamb worked out some details of the oscillations in a rotating cylindrical basin with parabolic law of depth, and discussed explicitly the rotational as well as the gravitational modes. Like Hough, he was at that time not aware of Margules' work.

Margules' investigation of the tidal equations was the first in which the global planetary wave was explicitly studied from the standpoint of applications to meteorology. It was not taken up again from this point of view until the late 1920s and early 1930s when the Leipzig school enlisted it in an attempt to find a theoretical basis for numerous 'empirical' periodicities then believed to exist in meteorological data, ranging from a few days to 37 or more days. The principal theoretical outcome of these efforts was a paper by Haurwitz in 1937, in which Margules' calculations were extended and improved, using the more powerful methods developed by Hough. When in 1939 the trough formula was announced, Haurwitz saw its connection with the theory of oscillations of the second class that had come down from Margules and Hough, and through his own hands. He showed how the formula could be extended to allow for finite width, first on the 'beta plane' (Haurwitz 1940a) and then on the sphere (Haurwitz 1940b). In the latter paper the westward-drift formula $2\Omega/n(n+1)$ – first stated by Hough – was deduced directly for Rossby's prototype 'barotropic nondivergent' atmosphere, rather than indirectly from the intricate context of Laplace's 'tidal' equations.

See Platzman [1968], Dickinson [1978] and Kuo [1973].

roughness height In atmospheric boundary layer dynamics, the height above a surface where the wind speed reaches zero. This is used when surface irregularities are larger than the 1 mm depth of the layer where molecular diffusion dominates and an analogous "turbulent" diffusion depth is needed. It is a constant in expressions used to find the logarithmic velocity profiles in boundary layers, and ranges from about a millimeter for average seas to more than a meter for cities with tall buildings. See Hartmann [1994].

ROWS Acronym for Remote Ocean Wave Spectrometer, an airborne remote sensor used to support the development and refinement of satellite radars that measure the ocean surface. It is an instrument which uses the specular backscatter from a rotating near–nadir radar to estimate the two-dimensional ocean surface wave spectrum. ROWS is implemented from aircraft flying 5–10 km above the ocean. See Jackson [1987].

`[http://rows.wff.nasa.gov/]`

RSMAS Abbreviation for Rosensteil School and Marine and Atmospheric Sciences. See the RSMAS Web site[144].

[144] http://www.rsmas.miami.edu/

RSVP Abbreviation for Rapid–Sampling Vertical Profiler, a free–fall instrument tethered on a thin fiber optic cable designed for making repeated vertical profiles rapidly and continuously. See Caldwell et al. [1985].

Rumford, Count See Benjamin Thompson.

RV Abbreviation for research vessel.

RVTEC Abbreviation for Research Vessel Technical Enhancement Committee.

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SAA Abbrevation for Satellite Active Archive, a digital library of real-time and historical satellite data from NOAA's POES. SAA allows users to search inventories of satellite data, preview representative Earth images of that data, and to download the data for further processing and analysis.

[http://www.saa.noaa.gov/]

SAARI Acronym for the South Atlantic Accelerated Research Initiative, an ONR research program primarily directed toward improvement of the description of the subtropical South Atlantic. It focused on the poleward corners of the subtropical gyre, i.e. the separation of the Brazil Current and its confluence with the Malvinas or Falkland Current in the southwest, and the Agulhas Retroflection and Benguela Current in the southeast. See Gordon [1988].

SABRE Acronym for South Atlantic Bight Recruitment Experiment, a NOAA program to stud the birth-date history of survivors (larvae, late larvae, and juveniles) to determine which life history phase or passage (spawning, transport across the shelf, inlet ingress, estuarine development, inlet egress) regulates recruitment variability in annual cohorts of transgressive species like Atlantic menhaden.

[http://www.ccpo.odu.edu/~wheless/sabre.html]

SABSOON Acronym for South Atlantic Bight Synoptic Offshore Observational Network, a NOPP funded program to develop a real–time observational network on the continental shelf offshore of South Carolina and Georgia. The network consists of eight large offshore platforms – currently operated by the U.S. Navy for flight training – being instrumented to provide a range of oceanographic and meteorological observations on a continuous, real–time basis. The grid covers an area of 155 km by 50 km and a depth range from 25 to 45 m, with an existing communcations system allowing high bandwidth, real–time data transmission to shore.

[http://www.skio.peachnet.edu/projects/sabsoon.html/]

SAC Acronym for Shipboard ADCP Center, now renamed to JASADCP.

SACCF Abbreviation for the Southern ACC Front.

SADCO Acronym for the South African Data Centre for Oceanography, a center that stores, retrieves and manipulates multi-disciplinary marine information from the areas around Southern Africa.

[http://fred.csir.co.za/ematek/sadco/sadco.html]

S-ADCP Abbreviation for Salinity–ADCP.

saddle The official IHO definition for this undersea feature name is “a broad pass or col, resembling in shape a riding saddle, in a ridge or between contiguous elevations.”

SAF Abbreviation for Subantarctic Front.

SAFDE Acronym for the Sub–Antarctic Flux and Dynamics Experiment, a program designed to collect observations of the ACC south of Tasmania that would permit direct evaluation of the momentum, energy and vorticity budgets. The experiment lasted two years - from April 1995 to March 1997 - and collected multi–year observations of currents and temperatures in both a small current meter mooring array with a diameter of about 70 km, and along a SSW–NNE section perpendicular to the expected mean axis of the ACC at the Subantarctic Front. The measured variables were found to be coherent horizontally and vertically in broad, sub–inertial frequency bands, a rarity with such oceanic measurements.

The center of the SAFDE array consisted of nine subsurface, nearly full depth moorings deployed as a local dynamics array (LDA), of which four were fully and three partially recovered. The array also included a suite of 17 (15 recovered) horizontal electrometers (HEM) and 18 (all recovered) inverted echo sounders (IES) to obtain time series of the vertically averaged horizontal water velocity, the temperature structure, and the dynamic height structure. The HEMs measure the horizontal electic fields which are theoretically related to the conductivity–weighted, vertically–averaged horizontal water velocity Chave and Luther [1990].

[http://www.soest.hawaii.edu/~dluther/SAFDE/]

SAHFOS Abbreviation for Sir Alister Hardy Foundation for Ocean Science, whose mission is to further the understanding of marine pelagic ecosystem processes through:

- the maintenance and expansion of the Continuous Plankton Recorder (CPR) survey;
- cooperation in the establishment of global long–term oceanic plankton monitoring programs;
- the development of new sampling and sensor systems; and
- the dissemination of the results of original research.

It was originally established in 1990 to operate the CPR survey, a program started in 1931 by Alister Hardy.

[http://www.npm.ac.uk/sahfos/sahfos.html]

saline contraction coefficient A quantity arising from taking derivatives of the density in the (p, θ, S) representation of the equation of state. This is defined in seawater as:

$$\beta = \frac{1}{\rho} \left.\frac{\partial \rho}{\partial S}\right|_{\theta,\rho} = \frac{1}{\rho} \left.\frac{\partial \rho}{\partial S}\right|_{T,\rho} + \alpha \left.\frac{\partial \theta}{\partial S}\right|_{T,\rho}$$

where ρ is the *in situ* density, θ is the potential temperature, S is the salinity, and T is the temperature. In practice, $\frac{\partial \rho}{\partial S}$ can be obtained from the International Equation of State of seawater, and $\frac{\partial \theta}{\partial S}$ from Bryden [1973].

McDougall [1987b] gives a polynomial expression for β:

$$\begin{aligned}
\beta \;=\;& 0.785567 \times 10^{-3} - 0.301985 \times 10^{-5}\theta + 0.555579 \times 10^{-7}\theta^2 \\
-\;& 0.415613 \times 10^{-9}\theta^3 + (S - 35.0)[-0.356603 \times 10^{-6} + 0.788212 \times 10^{-8}\theta \\
+\;& 0.408195 \times 10^{-10}p - 0.602281 \times 10^{-15}p^2] + (S - 35.0)^2[+0.515032 \times 10^{-8}] \\
+\;& p[-0.121555 \times 10^{-7} + 0.192867 \times 10^{-9}\theta - 0.213127 \times 10^{-11}\theta^2] \\
+\;& p^2[+0.176621 \times 10^{-12} - 0.175379 \times 10^{-14}\theta] + p^3[+0.121551 \times 10^{-17}]
\end{aligned}$$

The units of β are psu^{-1} and the rms error of this fit is 0.163×10^{-6} psu^{-1}. A test value is 0.72088×10^{-3} psu^{-1} at $S = 40$ psu, $\theta = 10.0$°C and $p = 4000.0$ db. See McDougall et al. [1987] and the related thermal expansion coefficient and adiabatic compressibility.

salinity An oceanographic concept conceived to provide a measure of the mass of salt per unit mass of seawater. The first systematic attempt to define this was made by a commission appointed by the International Council for the Exploration of the Sea in 1899 and chaired by Knudsen. Attempts to measure salt content by drying samples were accompanied by losses of volatile compounds along with the water, and the hygroscopic nature of the residue also served to complicate matters. A dry residue method where the sample was evaporated and dried to a stable weight at 480° C after processing with hydrochloric acid was offered as an alternative method. This led to the definition of the salinity as "the total amount of solid material in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, all the bromine and iodine replaced by chlorine, and all the organic material oxidized."

When this dry residue method also provided practical difficulties aboard ship the commission defined a chlorinity that could be determined via a volumetric titration using silver nitrate. This measurement could be combined with the assumption of constant ionic ratios in seawater to obtain a measure of the salinity, with the relationship between the two quantities being defined as

$$\mathrm{S}(^{\circ}/_{\circ\circ}) = 0.03 + 1.805\,\mathrm{Cl}(\circ/_{\circ\circ}).$$

A small adjustment was made in the definition of chlorinity in the late 1920s, but it remained basically the same until the development of reliable and precise electronic instrumentation in the 1950s led to a qualitative redefinition of the chlorinity, and therefore the salinity, in terms of measurements of the electrical conductivity of a water sample. This led to the creation and publication of the the International Oceanographic Tables giving salinity as a function of conductivity ratio above 10°. These tables were adequate for the laboratory determination of salinity, but could not be used with in-situ salinometers since most such measurements were made at temperatures below 10° C. A separate set of tables were developed in the mid-1960s that covered the range 0-30° C, although this led to discrepancies between in-situ and bench measurements of salinities and many separate attempts to patch together the two data sets. This in turn led to confusion in the comparison of salinity data amongst the major oceanographic institutes.

A solution was found in 1978 in the form of a new definition called the Practical Salinity Scale (PSS–78) where the practical salinity is defined in terms of the ratio of the electrical conductivity of a seawater sample at atmospheric pressure at 15°C to that of KCl solution containing 32.4356 g of KCl in a mass of 1 kg of solution at the same pressure and temperature. See Lewis [1980] and Lewis and Perkin [1978].

SALR Abbreviation for saturated adiabatic lapse rate.

salt fingering See double diffusive instability.

salt fountain A hypothesized perpetual fountain where a long, narrow heat-conducting pipe inserted vertically through a region of ocean where warm, salty water overlies colder, fresher (and therefore denser) water. Water pumped upwards through the pipe would reach the same temperature as the surroundings at the same level (by conduction of heat through the wall of the pipe), while it remained fresher and therefore lighter. A fountain started thusly (in either direction) will continue to flow so long as there is a vertical gradient of salinity to supply potential energy. The idea was first advanced by Stommel et al. [1956] and is discussed in Turner [1973].

Samar Sea A small sea contained within the Visayan Islands that comprise the central portion of the Philippines. It is centered at approximately 124° E and 12° N and connected to the Visayan Sea to the southwest, the Philippine Sea to the northeast via the San Bernardino Strait, and the Sibuyan Sea to the northwest.

SAMBA Acronym for Sub–Antarctic Motions in the Brazil Basin, a component of the WOCE float program aimed at describing the absolute general circulation of the Antarctic Intermediate Water (AAIW) as it spreads northward at about 800 m depth in the Brazil Basin. During the SAMBA experiment a total of 100 MARVOR floats were launched between February 1994 and December 1998 at 800 ± 30 dbar in the Brazil Basin.

[http://www.ifremer.fr/lpo/samba/]

sample In signal processing, to pick out values from an analog signal, usually at regular intervals, to create a corresponding digital signal.

SAMW Abbreviation for Subantarctic Mode Water.

sand More later.

Sandstrom's Theorem An ocean circulation theorem that states that a closed steady circulation can only be maintained in the ocean if the heat source is situated at a lower level than the cold source. Sandstrom considered to momentum balance of the steady circulation of the oceans, and concluded that, to overcome friction, there should be a net input of mechanical energy over each closed streamline, i.e.

$$w = -\int_s \nu \, dp > 0 \tag{17}$$

where ν and p are the specific volume and pressure, and the integration is taken along closed streamlines s. He modeled the oceanic circulation in terms of a heat engine by assuming four idealized stages within each cycle of the oceanic heat engine:

- heating–induced expansion under a constant pressure;
- adiabatic transition from the heating source to the cooling source;
- cooling–induced contraction under a constant pressure; and
- adiabatic transition from the cooling source to the heating source.

Within this cycle, the net amount of work would be negative if the system is heated under low pressure, and cooled under high pressure. Positive work is only possible when heating takes place at a higher pressure and cooling at a lower pressure.

The application of this theorem to the ocean was a vexing issue for years, as is summarized by Huang [1999]:

> However, the application of Sandstrom's theorem to the oceanic circulation does pose a serious puzzle. The ocean is mostly heated and cooled from the upper surface. Due to thermal expansion, the sea surface level at low latitudes where heating takes place is about one meter higher than the sea level at high latitudes where cooling takes place. Therefore, according the Sandstrom's theorem, there should be no convectively driven circulation.'

According to Huang [1999], the resolution lies in Sandstrom's original model excluding diffusion and friction. He used an idealized loop model of the oceanic thermohaline circulation that included mixing to discover that the circulation can be classified into two types, depending on the vertical locations of the heating and cooling sources.

- When the cooling source is at a level lower than the heating source, the circulation is mixing controlled and the rate of thermal circulation is primarily controlled by the amount of external energy available for mixing. Without the external energy the support mixing, the mixing rate would be at a very low level determined by molecular diffusion, and there would be no detectable thermal circulation as per Sandstrom's theorem. With an external energy source, e.g. wind stress, tidal dissipation, etc., there can be a strong thermal circulation even if the cooling source is below the heating source.
- If the cooling source is at a level higher than the heating source, the circulation is friction controlled, and the amount of external energy available for mixing is unimportant.

An unexpected result from the same study was that geothermal heating can contribute a substantial portion of the energy for the mixing of deep water. Another interesting result was finding the diapycnal mixing rate due to tidal energy and geothermal heat flux to be about 0.22–0.28 $\times 10^{-4} m^2 s^{-1}$. See Defant [1961] and Huang [1999].

San Matías Gulf A gulf located at around 42°S along the Argentine coast of eastern South America. According to Piccolo [1998]:

> It has a significant interaction with the adjacent shelf. A sill at a depth of 74 m is found at the entrance of the gulf. It is a basin with 200-m depths at its center. Unfortunately, very few studies were performed to learn its circulation and dynamics, and therefore only a brief review is presented here. The temperature structure of the gulf in winter reveals a well–mixed water column indicative of deep–reaching and bottom water ventilation. Near 41°50'S a relatively intense thermohaline front is found. Relatively cold fresh waters similar to the open shelf waters are found south of the front, while warm salty waters typical of the gulf are found north of the front. This front is produced by tidal mixing. The gulf circulation is dominated by a cyclonic gyre about 70 km in diameter located north of the front. South of the front the thermocline structure is complex and not well resolved by the observations. The San José Gulf communicates with the San Matías Gulf, and there is a strong water interaction between both coastal bodies.

See Piccolo [1998].

Santa Barbara Channel A 100 km long (east-west) and 50 km wide (north-south) channel bounded by the U.S. mainland to the north and island to the south. The Santa Barbara Channel (SBC) has relatively deep topography (100-500 m) except for narrow shelves (about 5 km wide) to the north and south. The SBC is a mixing zone between the warm water of the Southern California Bight and the cooler upwelled water of the central California shelf/slope. The strongest east-west thermal contrast - about 5-6°C near the surface - occurs during the summer at the time of peak upwelling off CCSS and the warmest sea surface temperature in the SCB.

The SBC is partially sheltered from intense north and northwesterly wind by a mountain range along the channel's northern coast, allowing for large differences in wind strength from west (stronger) to east along the channel. The resulting wind stress curl can be an order of magnitude greater than the values found farther offshore over the California Current. The winds also tend to be strongest in midchannel, tapering off north and south near the coasts. The combination of strong therrmal contrast and large changes in wind stress curl over relatively small distances leads to an especially complex circulation. See Harms and Winant [1998] and Oey et al. [2004].

SAR Abbreviation for Synthetic Aperture Radar, a side-looking imaging radar system that uses the Doppler effect to sharpen the effective resolution in the cross-track direction. Basically, high resolution is achieved by measuring the travel time of short emitted pulses, while comparable resolution is achieved in the azimuthal (flight) direction by collecting the amplitude and phase histories of the returned signals from a large number of individual pulses to reconstruct the signal of a large virtual antenna. An SAR on a polar orbiting satellite at 800 km can typically scan a swath about 100 km wide with a resolution of 20 m by 20 m at incidence angles of 20 to 25°.

Incident electromagnetic microwaves resonantly interact with short ocean ripple waves and backscatter via the mechanism of Bragg scattering. An SAR system is capable of detecting a variety of large scale oceanic phenomena which modulate the short (Bragg) ocean ripple spectrum, e.g. fronts, internal waves, natural surface films or man-made slicks, bottom topography, and ocean gravity waves. These modulations may be of either the tilt moduluation or hydrodynamic modulation varieties. See Komen et al. [1996].

Sargasso Sea A clockwise-circulating region in the North Atlantic Ocean bound by the Gulf Stream on the west and north and less definitely to the east at 40° W near the Canary Current and to the south at 20° N near the North Equatorial Drift Current. It is so named because of the indigenous, yellow-brown seaweed called Sargassum that is found there in great abundance. The Sargasso is part of the subtropical gyre circulation system in the North Atlantic and comprises a large part of its interior circulation, covering an area of around 5.2 million square kilometers.

A large volume of a type of mode water known as 18° water forms in the Sargasso in the winter and is seen as a thick layer of water at that temperature between 250 and 400 m depth. In the summer an excess of evaporation over precipitation results in a thick (nearly 900 m deep near the center) lens of water warmer and more saline than surrounding waters. The anticyclonic sense of the circulation causes this water to pile up such that it is almost a meter higher than the sea level along the eastern U.S. coast. This water lens also serves to inhibit the upwelling of nutrient-rich, colder water which results in a sparsity of marine life in the region. It is has been called the clearest, purest and biologically poorest ocean water ever studied.

The northwestern part of the Sargasso is a region of recirculation for the Gulf Stream. This recirculation region is dominated by cold core eddies pinched off from the Gulf Stream, with as many as 10 clearly identifiable rings found there at any one time. This makes this northwestern region one of the most energetic in the world ocean.

Sargasso Sea Water (SSW) See 18° Water.

Sargassum The name given to about eight species of seaweed that float in clumps and long windrows in the Sargasso Sea. It was so named by Portuguese sailors who followed the voyages of Columbus through the region and noticed the resemblance of the small air bladders that allow Sargassum to float to a type of grape called Salgazo.

SASS Acronym for the SEASAT-A Scatterometer System, an active backscatter scatterometer operating at a frequency of 13.0 GHz which produced earth locatino and time tagged backscatter coefficients, surface wind stress, and surface wind vectors (with a 180 degree directional ambiguity).

satellite altimetry See Fu. and Cazanave [2001].

satellite oceanography More later.

saturated adiabatic lapse rate The temperature lapse rate of air which is undergoing a reversible natural adiabatic process. Abbreviated SALR.

saturated humidity mixing ratio The humidity mixing ratio of air which is saturated at a specified temperature and pressure, with saturation defined with reference to either liquid water or ice.

saturation mixing ratio An atmospheric quantity given by

$$m_s = \frac{0.622 e_s}{p - e_s}$$

where m_s is the ratio, e_s the saturation vapor pressure and p the atmosphere pressure.

saturation vapor pressure Usually measured with respect to water, this is the maximum water vapor pressure that can occur when the water vapor is in contact with a free water surface at a particular temperature. It is the water vapor pressure that exists when effective evaporation ceases.

SAUW Abbreviation for Subantarctic Upper Water.

SAVE Acronym for South Atlantic Ventilation Experiment, an experiment taking place from 1987-1989.

Savonius rotor A rotor originally developed for power generation (i.e. it's a propellor in reverse that spins when placed in moving water) that has been extensively used as a sensor on various ocean current meters. Its advantages are that it is rugged, omni-directional and linear in steady flow, but its response to time-varying flow and susceptibility to contamination by vertical flows make it unsuitable for measurements near the surface where wave action creates both time-varying and vertical flow fields. See Heinmuller [1983].

Savu Sea See Sawu Sea.

Sawu Sea One of the several connected seas that comprise the Australasian Mediterranean Sea. This is centered at approximately 123° E and 9° S and is situated between Timor to the south and east, Sumba to the south and west, and Flores to the north. The basin is mostly greater than 1500 m deep and reaches depths greater than 3000 m over most of its northern and eastern parts.

SAXON-FPN Abbreviation for Synthetic Aperture Radar and X Band Ocean Nonlinearities-Forschungsplatform Nordsee program, a 3-year effort to investigate radar backscatter from the ocean and synthetic aperture radar (SAR) imagery of the ocean. A secondary objective was to explore the relationship between acoustic and microwave scattering from the ocean surface. This joint U.S./Federal Republic of Germany program consisted of Phase I, a major field experiment in the North Sea on and around the German Forschungsplatform Nordsee during November 1990, Phase II, a second and smaller field experiment on the same platform in November 1991, and a series of four data analysis workshops. See Plant and Alpers [1994].

SAZ Abbreviation for Subantarctic Zone.

scale depth A means of characterizing a (oceanic or atmospheric) density field. It is defined by $H = c^2/g$ where c is the speed of sound and g gravitational acceleration. In the ocean this is on the order of 200 km. The largeness of this in comparison to the water depth (5 km) is one of the key assumptions in the Boussinesq approximation.

scale height In the atmosphere, the height at which the pressure has fallen to e^{-1} (i.e. the e-folding scale) of its value at the surface. This occurs at about 370 mb which, for a temperature of 250 K, is about 7.4 km.

scarp See escarpment.

scattering The process by which some of a stream of radiation is dispersed to travel in directions other than that which from it was incident by particles suspended in the medium through which it is travelling.

scatterometer A high-frequency radar instrument that transmits pulses of energy towards the ocean and measures the backscatter from the ocean surface. It detects wind speed and direction over the oceans by analyzing the backscatter from the small wind-induced ripples on the surface of the water. See the NASA JPL scatterometer site[145].

[145] http://www.jpl.nasa.gov/winds/scatterometry/#what_is

SCAVE Acronym for the Sound Channel Axis Velocity Experiment, where SOFAR explosive charges were fired at the depth of the sound axis off Antigua and the resulting signals received and processed at Eleuthera and Bermuda. In this experiment, taking place in 1961, travel times were ascertained to within 30 ms with rms variations estimated at at 200 ms over a period of 27 months with time scales of a few months. The variations were most likely caused by the mesoscale variability that characterizes this region. See Munk et al. [1995].

SCAWVEX Acronym for Surface Current and Wave Variability Experiment, an EC MAST project whose primary objective is to measure the spatial and temporal variability of waves and currents in coastal regions using the full range of state of the art measurement techniques and models. The measurement systems used in this experiment include HF radar, synthetic aperture radar (SAR), satellite altimetry, accelerometers, ADCP, current meters, pressure cells, and X-band ground-based radar since one of the primary goals is the intercomparison of these techniques.

[http://www.shef.ac.uk/~sceos/environmental/scawvex/home.html]

Schlutsky-Yule effect A consequence of smoothing a time series with a low-pass filter. In a relatively short time series, even purely random fluctuations can give the impression of there being significant quasi-cyclic fluctuations present if they are smoothed by some sort of running mean. This is name for two statisticians who demonstrated in 1927 that some trade cycles that had been apparently discovered in some 19th century data could be reproduced from a series of random numbers. See Burroughs [1992], p. 20.

Schmidt number A nondimensional number that relates the competing effects of gas diffusion and fluid viscosity on the piston velocity, a key variable in measuring gas transfer across the air-sea interface. The Schmidt number is given by

$$Sc = \frac{\nu}{D}$$

where ν is the kinematic viscosity and D the molecular diffusivity of gas in sea water. See Najjar [1991].

SCICEX A 5–year program (1995–1999) in which the U.S. Navy made available a Sturgeon–class, nuclear powered attack submarine for unclassified science cruises in the Arctic Ocean. A test cruise in 1993 started a collaboration between civilian scientists and Navy personnel wherein a variety of information on the geology, physics, chemistry and biology of the Arctic was gathered. The 100,000 miles of shiptrack traveled during the program allowed data to be gathered from regions that have never before (at least officially) been visited.

[http://www.ldeo.columbia.edu/SCICEX/]
[http://psc.apl.washington.edu/scicex/scicex2000.html]

scirocco A warm, southerly wind in the Mediterranean region. Near the north coast of Africa the wind is hot and dry and often carries much dust. After crossing the Mediterranean, the scirocco reaches the European coast as a moist wind and is often associated with low stratus.

SCOPE Acronym for San Clemente Ocean Probing Experiment, a NOAA ETL program conducted in September 1993. It was an experiment to study the effects of the atmosphere on active and passive microwave remote sensing measurements of the ocean surface.

[http://www6.etl.noaa.gov/projects/scope.html]

SCOPEX The South Channel Ocean Productivity Experiment was a multidisciplinary study of a whale–zooplankton predator–prey system in the southwestern Gulf of Maine that focused on the oceanographic factors responsible for the development of dense patches of the copepod *Calanus finmarchicus*, the major prey resource for right whales. See Kenney and Wishner [1995].

SCOR Acronym for Scientific Committee on Oceanic Research, the oldest interdisciplinary committee of the ICSU, established in 1957 for the promotion and coordination of international oceanographic activities. SCOR doesn't directly fund research although its scientific groups organize international meetings, publich scientific literature, and propose and plan large international collaborative efforts such as JGOFS and GLOBEC. SCOR consists of its members – the national committees for oceanic research of its 39 member countries, each represented by three individual oceanographers. An Executive Committee, elected at biennial General Meetings, also includes ex officio members from allied disciplinary organizations including IAPSO, IABO, CMG, and IAMAS. A SCOR Secretariat located at Johns Hopkins University in Baltimore, Maryland provides routine administrative support for SCOR activities as well as publications such as the JGOFS and GLOBEC Report Series, the annual SCOR Procedings, and the directory or SCOR Handbook.

There are two major categories under which SCOR work can be subsumed. The first is the traditional mechanism of the SCOR working group wherein small international groups address narrowly focused scientific problems that will benefit from such a cooperative effort. These groups generally have about ten members, meet two or three times, and produce either a book or special journal volume or organize an international conference or workshop to complete their efforts. They are estblished on the basis of proposals received from national committees, other organizations, or even individual scientists. While the working group exists for short term (four years or less) projects, longer term and more complex activities are the province of the second mechanism, i.e. scientific committees.

The names of the currently (1998) constituted SCOR working groups (along with their respective numbers) are:

- Ecology of Sea Ice (86),
- Sea Level Rise and Erosion of the World's Coastlines (89),
- Pelagic Biogeography (93),
- Sediment Suspension and Sea Bed Properties (95),
- Acoustic Monitoring of the World Ocean (96),
- Physiological Ecology of Harmful Algal Blooms (97),
- Worldwide Large–scale Fluctuations of Sardine and Anchovy Populations (98),
- Linked Mass and Energy Fluxes at Ridge Crests (99),
- Sediment Coring for International Global Change Research (100),
- Influence of Sea State on the Atmospheric Drag Coefficient (101),
- Comparative Salinity and Density of the Atlantic and Pacific Ocean Basins (102),
- The Role of Wave Breaking on Upper Ocean Dynamics (103),
- Coral Reefs Responses to Global Change (104),
- The Impact of World Fisheries Harvests on the Stability and Diversity of Marine Ecosystems (105),
- Relative Sea Level and Muddy Coasts of the World (106),
- Improved Global Bathymetry (107), and
- Double Diffusion (108).

[http://www.jhu.edu/~scor/]

Scorpio Expedition A name of a 1973 expedition, led by Henry Stommel, to perform trans-Pacific hydrographic sections at 28 and 43° S. See Stommel et al. [1973].

Scotia Front (SF) A front located north of the Weddell–Scotia Confluence which marks the boundary between the Weddell and Scotia Seas in the Southern Ocean. The SF is a distinct subsurface front marked by a maximum thermal gradient in the maximum temperature core layer (200–700 m) of the Circumpolar Deep Water (CDW). Crossing the SF from north to south, the temperature maximum decreases from 1.5°–2.0° C to below 0.5°, with the CDW salinity maximum in the 800–1200 m layer similarly decreasing southward across the SF from 34.70–34.72 to 34.67–34.68. In the minimum temperature layer, the SF appears as a thermal front across which the minimum temperature decreases southward from 0°–0.5° C to below -1.0° C. There is usually no distinct sign of the SF in the surface layer. The 1° isotherm in the 300–500 m layer is considered a good single indicator of the SF axis. See Belkin and Gordon [1996].

Scotia Ridge A ridge connecting South American and Antarctica located at about 70° W in the Southern Ocean that, along with the narrowing of the Drake Passage 2000 km to the west, impedes the flow of the Antarctic Circumpolar Current (ACC). It is generally less than 2000 m deep with some openings at the 3000 m level. After the ACC accelerates to squeeze through the Drake Passage it hits to Ridge and an increased speed and shifts northward.

Scotia Sea See Garabato et al. [2002].

SCSMEX Abbreviation for South China Sea Monsoon Experiment, a large–scale experiment to study the water and energy cycles of the Asian monsoon regions. The goal is to provide a better understanding of the key physical processes for the onset, maintenance and variability of the Southeast Asian monsoon. See Lau et al. [2000].

[http://ncc.cma.gov.cn/scsmex/html/scsmex_e.htm]
[http://www.bom.gov.au/bmrc/wefor/research/scsmex.htm]
[http://www.siesip.gmu.edu/Science/sci_scs.html]

sea breeze A wind blowing from the ocean towards land caused by the effects of differential heating. In the summer when the land surface is warmer than the ocean, the air over the land heats up more than over the ocean, expands and becomes less dense, and rises. This rising air is replaced, due to the constraints of continuity, with moisture–rich air from over the oceans.

seachannel The official IHO definition for this undersea feature name is "a continuously sloping elongated discrete depression found in fans or abyssal plains and customarily bordered by levees on one or both sides."

Sea Grant The idea of a Sea Grant College Program was first suggested by Athelstan Spilhaus at a meeting of the American Fisheries Society in 1963. He predicted the proposed sea–grant colleges would spur advancements in the ocean sciences that would be "modernized parallels of the great developments in agriculture and the mechanical arts which were occasioned by the Land–Grant Act of about a hundred years ago." In 1965, Senator Claiborne Pell of Rhode Island introduced legislation establishing Sea Grant colleges on campuses nationwide, leading to the adoption of the National Sea Grant College Act in 1966.

The first four universities to achieve Sea Grant College status were Oregon State, Texas A&M, the University of Rhode Island and the University of Washington in 1971. As of 2001, there are 30 Sea

Grant Colleges divided into Great Lakes, Northeast, Mid–Atlantic, Southeastern Atlantic and Gulf of Mexico, and Pacific Regions.

[http://www.nsgo.seagrant.org/]

sea ice Sea ice is defined by the WMO as:

> Any form of ice found at sea which has originated from the freezing of sea water.

See WMO [1970] and Weeks and Ackley [1986].

sea ice formation The various processes comprising sea ice formation are described by ASPeCt:

> The first stage in sea ice development is the formation of individual ice crystals in the surface layer of the ocean. These crystals, known as frazil, form in open water areas when the temperature of the water is below -1.8 deg. C. Frazil ice gives the water an oily appearance and with further freezing the crystals coagulate together to form a soupy layer at the surface known as grease ice.
>
> How the sea ice proceeds to develop depends on whether the surface is calm or disturbed. With calm conditions the frazil and grease ice may consolidate into continuous flexible sheets called nilas. Nilas may be up to 10 cm thick, but is easily rafted under pressure, which can rapidly increase its thickness. Ice 10-30 cm thick is termed young ice, and with further rafting and ridging it develops into first–year ice (>30 cm). Finger rafting is a common process observed with nilas, where interlocking fingers of ice are thrust alternately over and under each other where two nilas sheets converge.
>
> A common process of sea ice development in the Antarctic, which occurs under rougher conditions, is the "pancake cycle". With the influence of wind and wave action the frazil crystals coagulate, eventually consolidating into small circular discs of ice called pancakes. The pancakes have raised rims due to collisions with other pancakes, and grow by accumulating ice crystals from the surrounding water. By rafting and bonding together the pancakes may rapidly increase to a few metres in diameter and up to 40 cm thick, and eventually freeze together to form larger floes or a consolidated ice cover.
>
> Although new ice forms most rapidly in open water areas with the development of frazil crystals, ice also grows on the underside of existing floes as heat is conducted from the ice-water interface through the floe. This ice is called congelation ice and consists of characteristic long columnar crystals, distinct from the small randomly oriented crystals of frazil ice.
>
> New ice may also be formed from the freezing of flooded snow overlaying the sea ice. When the weight of the snow is sufficient, the ice surface may be depressed below sea level. The influx of sea water through the permeable snow saturates the lower layers of snow which may subsequently refreeze to form "snow-ice". Snow ice has a similar texture to ice formed from coarse grained frazil but may be discriminated from frazil by stable isotope analysis. Compared with sea water, Antarctic snow is relatively depleted in the heavy stable isotope, 18O, and therefore has a highly negative del18O value.

sea level Much more later.

sea level change Recent analyses indicate that the global or eustatic sea level has risen about 2 mm per year over the last century, with the rate probably being much smaller for the previous several millennia. The rate is predicted to be larger over the next century – although how much larger is still uncertain. Quantifying sea level change is a difficult task given the complexity of the contributing processes including:

- the regional submergence or emergence of tide gauges due to Post Glacial Rebound (PGR) that continues from the last deglaciation, as well as to other tectonically–induced vertical crustal movements;
- the thermal expansion and contraction of the ocean due to climate change, along with possible accompanying changes in circulation and necessarily water levels;
- the contribution of the Greenland and Antarctic ice sheets as they shrink or expand;
- the shrinking or expanding of smaller glaciers; and
- water storage in artificial reservoirs that would otherwise have flowed into the oceans, e.g. one estimate that storage in above–ground reservoirs over the last 40 years was equal to a fall of global sea level of 0.7 mm per year.

See Douglas [1995].

Sea of Azov See Azov, Sea of.

Sea of Candia See Cretan Sea.

Sea of Crete See Cretan Sea.

Sea of Japan See Japan Sea.

Sea of Okhotsk See Okhotsk Sea.

sea state More later.

SeaBASS Acronym for SeaWiFS Bio–Optical Archive and Storage System, a product of the calibration/validation element of the SeaWiFS project which provides an interface to the project holdings of bio–optical and laboratory instrument calibration data.

[http://seabass.gsfc.nasa.gov/]

SEA LION Acronym for SEa ice in the Antarctic LInked with OceaN–atmosphere forcing, a project whose aim is to assess and improve the performance of coupled global atmosphere–sea ice–ocean models in reproducing sea ice in the high southern latitudes.

[http://www.iup.physik.uni-bremen.de/iuppage/sealion_ed1.html]

seamount The official IHO definition for this undersea feature name is "a discrete (or group of) large isolated elevation(s), greater than 1000m in relief above the sea floor, characteristically of conical form; see also guyot."

seamount chain The official IHO definition for this undersea feature name is "a linear or arcuate alignment of discrete seamounts, with their bases clearly separated."

SEAREX Acronym for Study on Sea–Air Exchanges program. See Riley and Chester [1989].

SEAS Acronym for Study of the European Arctic Shelf, an LESC program.

SEAS Acronym for Shipboard Environmental (Data) Acquisition System, a program developed by NOAA to provide accurate meteorological and oceanographic data in real time from ships at sea through the use of satellite data transmission techniques. The shipboard data is transmitted to NOAA via either the GOES or INMARSAT C satellites.

[http://www.dbcp.nos.noaa.gov/seas/seas.html]

SEASAR Acronym for Synthetic Aperture Radar for Sea Studies.

SEASAT A NASA satellite that operated from June 1978 to October 1978. Instruments on board included SASS, an altimeter, SMMR, a microwave SAR, and VIRR. The altimeter was an active radar altimeter which produced earth location and time-tagged satellite heights, significant wave heights, and geoid information. The SAR produced 25 meter resolution surface roughness imagery on a 100 km wide ground swath. See Stewart [1988].

SeaSoar An open ocean undulating data acquisition vehicle originally designed and built by the Institute of Oceanographic Sciences (now the Southampton Oceanography Center, UK). SeaSoar is capable of undulating from the surface to 500 m at tow speeds of up to 12 knots (with a faired cable) following a controlled and adjustable undulating path through the ocean. Data obtained from sensors mounted in SeaSoar are transmitted to the towing vessel via a multi–core tow cable.

[http://www.chelsea.co.uk/Vehicles%20SeaSoar.htm]

seasonal thermocline In oceanography, a weakly stratified layer of water that appears when the mixed layer makes a rapid transition between its winter maximum and its summer mimimum. It is created by deep convection during the winter, and several processes are responsible for its restratification during the rest of the year. These processes, in chronological order starting in early spring, are the creation of a fossil thermocline during the ascent of the mixed layer, solar heating below the mixed layer, geostrophic advection, and thermohaline intrusion.

seasonal thermostad See seasonal thermocline.

sea spray See Andreas et al. [1995].

sea surface film A microlayer hundreds of microns thick located at the sea–air interface. These are the site of intense accumulation of organic matter from underlying waters or atmospheric deposition. See Romano [1996].

sea surface slick A sea surface film in which organic accumulation exceeds a threshold such that it becomes visible as a slick, i.e. a sea surface feature that appears as smooth grey spots or stripes in contrast to the surrounding deep blue waters. The smoothing effect is due to the accumulation at the sea–air interface of organic compounds, many of them surface–active, which enhance solar reflection at the surface by damping the capillary waves. Slicks are thought to play a significant role in heat flux and gas exchange, biogeochemical cycles, and pollutant dispersion dynamics as a consequence of the organic enrichment and their location at the boundary between atmosphere and ocean. See Romano [1996].

sea valley See valley.

seawater See Fofonoff [1962] and Fofonoff [1985].

SeaWiFS Acronym for Sea-viewing Wide-Field of view Sensor, an ocean color sensor to study ocean productivity and interactions between the ocean ecosystems and the atmosphere. For more information see the SeaWiFs Web site[146].

SeaWinds A scatterometer flown aboard the QuikSCAT mission.

[146] http://seawifs.gsfc.nasa.gov/SEAWIFS.html

SEBSCC Abbreviation for Southeast Bering Sea Carrying Capacity, a NOAA PMEL investigation whose goal is to document the role of juvenile pollock in the eastern Bering Sea ecosystem, to examine the factors which affect their survival, and to develop and test annual indices of pre–recruit abundance.

According to Macklin et al. [2002]:

> The goal of SEBSCC was to increase understanding of the southeastern Bering Sea ecosystem, to document the role of juvenile walleye pollock (Theragra chalcogramma) and factors that affect their survival, and to develop and test annual indices of pre-recruit (age-1) pollock abundance. SEBSCC was divided into monitoring, process, modeling, and retrospective and synthesis components. They focused on four central scientific issues: (1) How does climate variability influence the Bering Sea ecosystem? (2) What limits population growth on the Bering Sea shelf? (3) How do oceanographic conditions on the shelf influence biological distributions? (4) What influences primary and secondary production regimes? These broad issues supported SEBSCC's narrower goal of understanding the ecosystem in terms of pollock and provided a basis for selection of research components. SEBSCC also was envisioned as a source of information to support the regional fishing industry and its management. For example, results from SEBSCC research related to short-term forecast of pollock recruitment may improve stock assessments used to recommend "allowable biological catch" estimates to the North Pacific Fishery Management Council. Similarly, research results pertaining to the availability of juvenile pollock to apex predators could assist Council decisions regarding restriction of fishing around marine mammal rookery areas. SEBSCC's focus on ecosystem response to changes in environmental conditions provides a context for resource management in a changing environment.
>
> SEBSCC research spanned disciplines from atmospheric physics to marine ornithology and addressed questions on processes ranging from atmospheric teleconnections to intimate associations between juvenile pollock and tentacles of jellyfish. The centerpiece of SEBSCC research was a time series of physical and biological data from an oceanographic mooring located in 70 m water at site M2. First deployed in 1995, the site M2 mooring measured vertical profiles of temperature and salinity and time series of currents and fluorescence year around. SEBSCC shipboard studies were repeated several times annually along transects from the Bering Sea basin to the 70 m isobath, then northwestward along this isobath. One summer cruise and five fall cruises investigated the region around the Pribilof Islands that is believed to be an important nursery for young pollock. Annual, collaborative, summer cruises aboard the Japanese fishery training vessel Oshoro Maru enabled sampling and abundance estimates of juvenile pollock.

[http://www.pmel.noaa.gov/sebscc/]

Secchi disk A white target lowered from a vessel and viewed from above the surface in full solar illumination to estimate the attenuation in the water column. This is done by empirically relating the depth at which the disk disappears to the attenuation. This method was devised in the 1860s by an Italian astronomer named Angelo Secchi who used it while he worked in the Mediterranean aboard the papal vessel Immacolata.

The Secchi disc is usually 20–30 cm in diameter, and is either all white or has four quadrants, two painted white and two black. The empirical relation used is:

$$Z_S = \frac{F}{C + +K \sin\theta}$$

where Z_S is the Secchi depth, C is the attenuation coefficient for directional light, K is the diffuse attenuation coefficient for non–directional light (sometimes known as the extinction coefficient), F is a background factor depending on the reflectivity of both the disc and the background and the observer's threshold perception of contrast, and θ is the sighting angle from the horizontal. Typically, F ranges from about 8.7 in clear oceanic water to 6 in turbid estuarine water.

The disc is typically used to estimate the diffuse attenuation coefficent K or the attenuation coefficent C. For the former, it has been found that the product of K and Z_S is relatively constant, with measurements in many types of water indicating that $1.4 < K \times Z + S < 1.7$. An empirical relationship has also been derived for the latter, i.e. $V = 0.7Z_S$.

SEC Abbreviation for South Equatorial Current.

SECC Abbreviation for South Equatorial Countercurrent.

SECHIBA Acronym for Schematisation des Echanges Hydriques a l'Interface entre la Biosphere et l'Atmosphere, an LSP. See Ducoudre et al. [1993].

SECTIONS Acronym for a research program which translates to Energetically Active Zones of the Ocean and Climate Variability. This was a joint program among Poland/USSR/Bulgaria/Germany/Cuba that gathered the largest data set ever collected in the tropical Atlantic. The six ships used in the program were the **Academic Vernadsky** and the **Mikhael Lomonosov** from the Marine Hydrophysical Institute (MHI) of the Ukrainian Academy of Science in Sevastopol and the **Volna**, **Jakov Gakkel**, **Dmitry Ushakov**, and **Parshin** of the State Oceanographic Institute (SOI) of the USSR. The MHI vessels collected hydrographic data at 5 m vertical intervals with 65% of the stations extending to 1200 m, while the SOI vessels collected data at 10 m intervals (although it was archived only at 16 standard levels). The combined data set archived at MHI consists of 4931 temperature and salinity profiles collected during 26 surveys carried out from 1984 to 1990.

The surveys were divided into three stages. The first stage (1984–1985) comprised eight surveys conducted near the South American coast between 2° S and 20° N, with each survey consisting of 8 to 10 hydrographic sections perpendicular to the coast. The sections were 100 km and the stations 50 km apart in a survey designed to define the seasonal cycle in the northwest. The second stage (1986–1988) comprised twelve surveys conducted between 2° S and 12° N latitude and 58° and 5° W longitude. During the first two years of this stage the sections were 166 km and the stations 55 km apart, with the between-section spacing increased to 333 km durin the final year. Two or three vessels were usually simultaneously collecting data in a survey designed to investigate the seasonal variability of the North Equatorial Countercurrent (NECC). The third stage (1989–1990) saw seven surveys organized into three experiments designed to observe synoptic variability, with one experiment in the west and one in the central basin. The first experiment took place in the spring of 1989 with two vessels in the western region; the second was in the fall of 1989 in the east with two vessels; and the third took place in the winter of 1990 using two vessels in the west. See Chepurin and Carton [1997].

SEEP-I A program to examine shelf edge exchange processes on the outer margin of the U.S. Mid Atlantic Bight. The SEEP program began in 1980 when a group of investigators met to propose an interdisciplinary, inter–institutional program called SEEP (Shelf Edge Exchange Processes) to test what was known as the "shelf–export hypothesis." This was a conjecture that the large fraction of the spring phytoplankton bloom that was observed to not be consumed by the local pelagic food web was exported from the continental shelves to the central ocean basins or to the sediments of the upper continental slope. It was predicted that the net export of particles across the shelf–slope break would increase with successive, more southerly experiments because of an expected southerly increase in primary productivity, and also because of a southerly decrease in the width of the shelf. A primary problem with the hypothesis was the existence of a strong temperature–salinity front separating the continental shelf and slope, the sort of barrier particles would find difficult to cross. However, iseveral other mechanisms for exporting particles from the shelf – e.g. entrainment of shelf water by passing warm core eddies, sinking across the front, advection by the benthic boundary layer – were identified and thought to be collectively sufficient for the task. They were also collectively referred to as "diffusive" processes.

SEEP–I took place from July 1983 to October 1984 in the waters of the Mid–Atlantic Bight (MAB) shelf and slope south of Cape Cod and Long Island. The field program consisted of two experiments run by two different groups, with little overlap between them. This fragmentation of effort led to estimates of particle export ranging from <10% diffusive exchange across the shelf edge (with some indication of an increase towards the southwest), to 10–20% with most oxidized on the shelf, to from <10% to nearly 40% in model results. This led to the design and implementation of SEEP–II. See Walsh et al. [1988].

SEEP-II A program to examine shelf edge exchange processes on the outer margin of the U.S. Mid Atlantic Bight. This follow–up to SEEP–I took place from February 1988 to June 1989, during which 10 cruises took place and 10 moorings were placed at 12 locations on the shelf and upper slope south of the Delmarva Peninsula. The vanishing likelihood of a SEEP–III led to the moorings being deployed in two transects parallel to the mean isobaths and 90 km apart, the latter to attempt to identify the hypothesized increase in across–shelf particle flux to the south. SEEP–I was more integrated than SEEP-I, with the instrumentation from different institutions intercalated throughout the experiment. The result was perhaps the most extensive set of moored, synoptic measurements of temperature, salinity, phytoplankton chlorophyll fluorescence, macrozooplankton, oxygen, current conditions and verticle particle flux yet acquired in an oceanographic program.

According to Biscaye et al. [1994]:

> The results of the SEEP–II study overwhelmingly show that the hypothesis of export of a large proportion of the MAB [Mid–Atlantic Bight] shelf primary productivity is untenable. All the observational data suggest that although a small fraction of carbon is exported across the shelf–slope break and through the front to the slope decpocenter, the principal fate of shelf carbon is, in fact, oxidation on the shelf. That small portion that does escape the shelf to the shelf water and depocenter appears to increase from the northern to the southern MAB.

Several key questions remained unresolved, though, including:

- the sources of nitrogen for the shelf to support the measured production are unclear, i.e. it is difficult to reconcile the flux of nitrate onto the shelf without imposing an export flux of water (or particles);
- the rate of the oxidation of phytoplankton carbon and its fate do not appear to be that previously proposed for the metazoic metabolism, i.e. there was not a monotonic increase in phytoplankton phase–lagged by a monotonic increase of zooplankton;
- food web dynamics in the shelf ecosystem are still not well understood, e.g. the microbial oxidation of carbon is much more significant than previously acknowledged; and
- most of the shelf water leaves the shelf before it reaches the southern terminus of the MAB (i.e. Cape Hatteras), and the amount of slope water incorporated into the shelf water along the way leads to an estimate of water discharged into the slope of 125–150% of the initial alongshelf transport, i.e. it has yet to be quantified exactly where, how much, and by what mechanisms water leaves or comes onto the shelf; and
- horizontal as well as vertical gradients of physical and biological quantities will have to be measured to fully understand their interactions, and probably on a nested grid due to the range of time and space scales involved.

See Biscaye et al. [1994].

seiche More later.

seismic sea wave Much more later.

Seismic Sea-Wave Warning System A network of seismographs across the Pacific Ocean to serve as an early warning system against the arrival of seismic sea waves (SSW) (also called tsunamis or, in an egregious misnomer, tidal waves). The SSWWS was established in 1946 after a particularly destructive SSW originating at Unimak, Alaska struck Hawaii and killed 159 people. Its headquarters are in Honolulu, Hawaii and it is operated by the Coast and Geodetic Survey of the U.S. Dept. of Commerce.

SEMAPHORE An experiment that took place in the northern Canary Basin from July to November 1993. A large data set was obtained from three hydrographic arrays, current meter moorings, surface drifters drogued at 150 m, and 2000 m deep RAFOS floats. See Eymard [1998].

semidiurnal Descriptive of a tide that has a cycle of approximately one-half a tidal day, as opposed to diurnal.

semi-geostrophic equations According to Roulstone and Sewell [1997]:

> The semigeostrophic equations are an approximation to Newton's second law for a rotating fluid, in which the acceleration is replaced by the time derivative (following the particle) of the so–called geostrophic velocity. The hydrostatic approximation is used in the vertical direction. These equations are regarded as a good approximation for certain two– and three–dimensional atmospheric motions on a synoptic scale, such as warm and cold fronts, and solutions can be continued in time beyond the point of the formation of a discontinuity modelling a front.

Delving a bit deeper, they are a set of balanced equations that filter out the high frequency inertia–gravity waves while exactly conserving low Rossby number approximations to the energy and the potential vorticity on particles. Unlike the quasi–geostrophicequations (QGE), they do not demand that the fluid depth and vertical separation between isothermal surfaces be nearly uniform. The main problem with the semi–geostrophic equations (SGE) is that they are significantly harder to solve numerically than the QGE.

In the case of a constant Coriolis parameter, the semi–geostrophic equations are equivalent to the primitive equations wherein the velocities in the total derivative, i.e. $D/Dt(u,v)$ are replaced with the geostrophic velocities, i.e. $D/Dt(u_G,v_G)$. In the case of a non–constant Coriolis parameter, the complexities found using ordinary physical coordinates led Salmon [1985] to propose a generalization involving a transformation to geostrophic coordinates, defined implicitly by:

$$\begin{aligned} x_s &\equiv x + \epsilon \frac{v_G}{f(x_s,y_s)} \\ y_s &\equiv y + \epsilon \frac{u_G}{f(x_s,y_s)} \\ z_s &\equiv z \end{aligned}$$

where:

$$\begin{aligned} u_G &\equiv -\frac{1}{f(x_s,y_s)}\frac{\partial \pi}{\partial y} \\ u_G &\equiv \frac{1}{f(x_s,y_s)}\frac{\partial \pi}{\partial x} \end{aligned}$$

and

$$\pi \equiv g(\eta - z) - \int_z^\eta \theta dz' \tag{18}$$

is the hydrostatic pressure.

Roulstone and Sewell [1997] write that Hoskins [1975] contained the first use of the adjective "semi-geostrophic" to describe the equations, although the latter remarked that they had also been introduced by Eliassen [1948] and Fjortoft [1962].

Salmon [1985] further developed a version of the equations with an additional assumption that the flow has horizontal length scales larger than the internal deformation radius. These are called the large–scale semi–geostrophic equations (LSGE) and, unlike the regular semi–geostrophic equations, are much easier to solve. See G. and Flierl [1981], Salmon [1985] and Roulstone and Sewell [1997].

semi-implicit method A numerical approximation algorithm that allows longer time steps than an explicit method and is less computationally onerous than a fully implicit method. Algorithms can usually be designed using this compromise method that both allow the longer time step and don't sacrifice numerical accuracy.

sensible heat The portion of total heat associated with a temperature change, as opposed to latent heat. This is so-called because it can be sensed by humans. The sensible heat is calculated by

$$\Delta Q = m\, C_p\, \Delta T$$

where C_p values are

$$C_{pd} = 1004.67\,\mathrm{J\ kg^{-1}K^{-1}}$$

for dry air,

$$C_p = C_{pd}\,(1 + 0.84\,r)$$

for moist air (where r is the mixing ratio of water vapor), and

$$C_{\mathrm{liq}} = 4200\,\mathrm{J\ kg^{-1}K^{-1}}$$

for liquid water.

sensible heat flux The flux of heat between the ocean surface and atmosphere that results mainly from their difference in temperature. The heat exchange is accompished via molecular conduction in the first few millimeters above the surface and via turbulent mixing and convection above that. The flux is usually from the ocean to the atmosphere during the day and opposite during the evening and night. See Peixoto and Oort [1992].

separation formula A method for computing the adiabatic inter–hemispheric meridional transport. See Nof [1998].

SEQUAL Acronym for the Seasonal Response to the Equatorial Atlantic research program. See Katz [1987] and Richardson and Reverdin [1987].

Seram Sea One of the seas that comprise the Australasian Mediterranean Sea. This is centered at about 130° E and 2–3° S and surrounded by Buru and Seram to the south and by Halmahera and the wester part of Irian Jaya to the north. It connects with the Arafura Sea to the southeast, the Banda Sea to the southwest, and the Halmahera Sea to the north. It is variously spelled Ceram Sea.

Seven Seas A term used long ago to collectively refer to the Indian Ocean, the Red Sea, the Persian Gulf, the Black Sea, the Sea of Azov, the Adriatic Sea and the Caspian Sea. The term is no longer much used although it is generally conceded that a modern and more geographically generous grouping would be the Arctic Ocean, the Southern Ocean, the Indian Ocean, the North and South Atlantic Ocean and the North and South Pacific Ocean.

shallow atmosphere approximation In meteorology, an approximation made to simplify the equations of motion in spherical coordinates where the radial distance r is replaced by a+z, where the altitude z is much smaller than the radius of the Earth r. See Salby [1992].

shallow scattering layer A layer of marine organisms found over a continental shelf which scatter sound. These layers are usually composed of patchy and horizontally discontinuous groups whose horizontal dimensions are usually less than their vertical dimensions. There are also surface and deep scattering layers.

shallow water approximation In oceanography, an approximation made for motions where the aspect ratio $\delta = H/L$ (where H is the vertical length scale and L he horizontal scale) is small. An example arises in the study of the tides, where the horizontal scale of the wave motion is thousands of kilometers and the vertical scale in constrained by the maximum depth of the oceans, and as such the applicable dynamics are those of shallow water gravity waves, i.e. gravity waves that "feel" and are influenced by the bottom.

The shallow water equations are obtained (after Muller [1995]) by applying the spherical approximation to the Boussinesq equations, expanding them with respect to δ, and keeping only zeroth order terms. One obtains:

$$\begin{aligned}
\frac{\partial u}{\partial t} &+ \frac{u}{r_0\cos\theta}\frac{\partial u}{\partial\phi} + \frac{v}{r_0}\frac{\partial v}{\partial\theta} + w\frac{\partial u}{\partial z} - \frac{uv}{r_0}\tan\theta - fv \\
&= -\frac{1}{\rho_* r_0\cos\theta}\frac{\partial p}{\partial\phi} \\
\frac{\partial v}{\partial t} &+ \frac{u}{r_0\cos\theta}\frac{\partial v}{\partial\phi} + \frac{v}{r_0}\frac{\partial v}{\partial\theta} + w\frac{\partial v}{\partial z} + \frac{u^2}{r_0}\tan\theta - fu \\
&= -\frac{1}{rho_*}\frac{\partial p}{\partial\theta} \\
0 &= \frac{\partial\rho'}{\partial z} + \rho' g \\
\frac{\partial w}{\partial z} &= -\frac{1}{r_0\cos\theta}\frac{\partial u}{\partial\phi} - \frac{1}{r_0\cos\theta}\frac{\partial(v\cos\theta)}{\partial\theta} \\
\frac{\partial\rho'}{\partial t} &+ \frac{u}{r_0\cos\theta}\frac{\partial\rho'}{\partial\phi} + \frac{v}{r_0}\frac{\partial\rho'}{\partial\theta} + w\frac{\partial\rho'}{\partial z} = 0
\end{aligned}$$

where (u, v, w) are the velocity components, r_0 is the mean radius of the Earth, (ϕ, θ, r) are spherical polar coordinates where ϕ is longitude, θ latitude, and r radial distance, f is the Coriolis parameter, ρ_* is a constant reference density, p is the pressure, ρ' is the deviation from the reference density and g is gravitational acceleration. See Muller [1995].

shallow water equations See shallow water approximation.

SHEBA Acronym for the Surface Heat Budget of the Arctic project, a WCRP program to address the interaction of the surface energy balance, atmospheric radiation, and clouds over the Arctic Ocean.

[http://sheba.apl.washington.edu/]

shelf The official IHO definition for this undersea feature name is "a zone adjacent to a continent (or around an island) and extending from the low water line to a depth at which there is usually a marked increase of slope towards oceanic depths."

shelf break See shelf edge.

shelf edge The official IHO definition for this undersea feature name is "the line along which there is marked increase of slope at the seaward margin of a continental (or island) shelf; also called a shelf break."

shelf sea A shallow sea that occupies a portion of a wide continental shelf. This is one type of epicontinental sea. Compare to epeiric sea and inland sea.

Shelikof Strait A strait located between the Alaska Peninsula and Kodiak Island at around 58°N, 154°W. See Reed and Bograd [1995].

SHIVA Acronym for Studies of the Hydrology, Influence and Variability of the Asian summer monsoon, a project sponsored by the European Commission. The project goals are:

- to improve the simulation of the mean evolution of the monsoon, including its intraseasonal characteristics;
- to assess the ability of models to simulate the intraseasonal characteristics, particularly active/break phases, monsoon depressions, and sensitiivty of the simulations to horizontal resolution;
- to investigate the mechanisms involved in the intraseasonal variability through coordinated sensitivity experiments, i.e. to study the roles of land surface processes, atmosphere–ocean interactions over the Indian Ocean and Arabian Sea, and internal dynamics; and
- to investigate the relationship between intraseasonal and interannual variability.

[http://www.enm.meteo.fr/ufr/umt/shiva/main.html]

shoal The official IHO definition for this undersea feature name is "an offshore hazard to surface navigation with substantially less clearance than the surrounding area and composed of unconsolidated material."

short-crested waves A propagating surface gravity wave with a free surface elecation which is doubly periodic in two perpendicular directions, along and normal to the direction of propagation. These can be produced either by the interaction of two progressive waves angles to each other or by oblique reflection from a maritime structure. The doubly periodic nature is characterized by the pattern of island crests that are formed at intersections of the component waves, rendering the surface shape of such a wave system much more complex than its wave components. The isolated crests thus produced propagate in a combined direction with a wavelength and a definite crest length equal to the distance between successive crests normal to the former at the same time. The transverse distance between adjacent crests is finite as opposed to the original two-dimensional wave motions that combine to form short-crested waves, thus giving them their name. See Hsu [1990].

shuga A type of sea ice defined by the WMO as:

> An accumulation of spongy white lumps, a few centimeters across; they are formed from grease ice or slush and sometimes from anchor ice rising to the surface.

See WMO [1970].

Siberian Coastal Current See Weingartner et al. [1999].

Siberian High One of the centers of action that tend to control large scale weather patterns around the globe. This center forms over Siberia during the winter and is centered around Lake Baikal. The sea level pressure exceeds 1030 millibars from late November to early March. The resulting anticyclonic circulation pattern is enhanced by the tendency of the surrounding mountains to prevent the cold air from easily flowing away. This pattern is replaced by a low pressure pattern in the summer related to the monsoon circulation.

SIBEX Acronym for Second International BIOMASS Experiment.

Sibuyan Sea A regional sea contained within the Philippines between the northern island of Luzon and the central island group the Visayan Islands. It is centered at about 122.5° E and 12.3° N and connected to the Visayan Sea to the southeast, the Samar Sea to the east, the Sulu Sea to the southwest via the Tablas Strait, and the South China Sea to the northwest via the Verde Island Passage. Geographical features of note include Sibuyan Island and Marinduque Island as well as the Ragay Gulf in the southeast arm of Luzon.

Sierra Leone Basin An ocean basin located to the west of Africa at about 3° N in the east-central Atlantic Ocean. See Fairbridge [1966].

SIGMA Acronym for Significant Interactions Governing Marine Aggregation, a group that conducted an investigation of the aggregation of a diatom bloom in a laboratory mesocosm to test the ability of coagulation theory to predict aggregation in complex marine systems. See Alldredge and Jackson [1995].

sigma-t (σ_t) A conventional definition introduced into physical oceanography for purposes of brevity. It is the remainder of subtracting 1000 kg m^{-3} from the density of a sea water sample at atmospheric pressure, i.e.

$$\sigma_t = (\rho_{S,T,0} - 1000)$$

where S and T are the in situ salinity and temperature. The density of water ranges from 1000 kg/m3 to about 1028 kg m^{-3} for the densest ocean surface water, so sigma-t ranges from about 0.00 to 28.00, with the units usually omitted.

sigma-theta (σ_θ) A measure of the density of ocean water where the quantity sigma-t is calculated using the potential temperature θ rather than the in situ temperature, i.e.

$$\sigma_\theta = (\rho_{S,\theta,0} - 1000)$$

where S is the in situ temperature.

significant wave height A quantity defined by Walter Munk in 1944 (in an SIO technical report) as the average height of the one–third highest waves. He stated that this was about equal to the average height of the waves as estimated by an experienced observer. The quantity is usually written as $H_{1/3}$ or H_S and estimated using the calculated root–mean–square height of the observed waves. The latter is calculated as

$$H_{rms} = \sqrt{\frac{1}{N}\sum_{j=1}^{N} H_j^2}$$

where N is the total number of observed waves and H their heights. The significant wave height is estimated via:

$$H_S \approx \sqrt{2} H_{rms}.$$

See Bauer and Staabs [1998].

significant wave method See S-M-B method.

silica One of the major nutrients in marine ecosystems, which is also used as a tracer in physical oceanography. According to Greenwood et al. [2001]:

> Silicon, as ortho-silicic acid, is a major nutrient in marine ecosystems. The uptake of silicic acid from surface waters by siliceous organisms (mainly diatoms) to form amorphous silica skeletons, and their post mortem dissolution are important biogeochemical processes. Dissolution begins in the water column when the silica skeleton is exposed to the undersaturated seawater, and can continue after deposition at the seafloor. Rapid sedimentation of skeletal material incorporated in faecal pellets may partly avoid dissolution resulting in the burial of biogenic siliceous sediments. Equally though, grazing may enhance dissolution as a result of physical or chemical changes to the frustule silica. Further interest in the dissolution of biogenic silica arises not only from the speculation that silicon may limit new production at times in ocean waters, coastal waters and estuaries, but also from concerns about the integrity of the sedimentary record of biosiliceous remains.

See Broecker and Peng [1982], Dugdale et al. [1995] and Greenwood et al. [2001].

silicate pump A mechanism that acts in diatom–dominated communities to enhance the loss of silicate from the euphotic zone to deep water compared to nitrogen, which is more readily recycled in the grazing loop, thus leading the system to silicate limitation. The silicate pumping to deep water results in low silicate, high nitrate conditions in the mixed layer. In such situations silicate dynamics may control and dominate new production processes and consequently control the rate at which newly upwelled CO_2 in the surface regions is reduced by the phytoplankton. See Dugdale et al. [1995].

siliceous ooze A fine-grained sediment of pelagic origin found on the deep-ocean floor. It contains more than 30% siliceous material of organic origin and is usually found below the carbon compensation depth at depths greater than 4500 m. Two types of this are radiolarian oozes and diatom oozes.

sill The official IHO definition for this undersea feature name is “a sea floor barrier of relatively shallow depth restricting water movement between basins.”

SIMIP Acronym for Sea Ice Model Intercomparison Project, an international effort to develop an improved representation of sea ice in climate models. SIMIP is carried out in the framework of ACSYS within the WCRP. A hierarchy of sea ice rheologies is evaluated on the basis of a comprehensive set of observational data. Four different sea ice rheology schemes are compared:

- a viscous–plastic rheology;
- a cavitating–fluid model;
- a compressible Newtonian fluid model; and
- a simple free drift approach with velocity correction.

The same grid, land boundaries, and forcing fields are applied to all models, with the prognostic equations solved on a spherical grid for the whole Arctic with a resolution of 110 km and a daily time step. The results as summarized at the project web site are:

> Overall, the viscous-plastic rheology yields the most realistic simulation. In contrast, the results of the very simple free drift model with velocity correction clearly show large errors in simulated ice drift as well as in ice thicknesses and ice export through Fram Strait compared to observation. The compressible Newtonian fluid cannot prevent excessive ice thickness

buildup in the central Arctic and overestimates the internal forces in Fram Strait. Because of the lack of shear strength, the cavitating-fluid model shows marked differences to the statistics of observed ice drift and the observed spatial pattern of ice thickness. Comparison of required computer resources demonstrates that the additional cost for the viscous-plastic sea ice rheology is minor compared with the atmospheric and oceanic model components in global climate simulations.

See Kreyscher et al. [2000].

[http://www.ifm.uni-kiel.de/me/research/Projekte/SIMIP/simip.html]

Singular Spectrum Analysis A method of time series analysis, sometimes abbreviated as SSA, designed to extract as much information as possible from short, noisy time series without prior knowledge of the dynamics underlying the series. It is a form of Principal Component Analysis applied to lag-correlation structures of time series. It was developed by Broomhead and King [1986] and applied to the analysis of paleoclimate time series by Vautard and Ghil [1989] and Vautard et al. [1992]. The SSA Toolkit[147] includes SSA amongst several time series analysis tools.

SSA performs better than traditional Fourier analysis at separating closely spaced relevant spectral peaks, but retains problems such as the requirement of stationarity and the limitation to situations of high SNRs. See Ruiz de Elvira and Bevia [1994].

singular vector Singular vectors are the perturbations that, under dynamics linearized about a basic flow state, grow most rapidly over a given time interval and in a given measure of amplitude, or norm. These optimal perturbations have been advanced as explanations for midlatitude cyclogenesis, and have been applied to forecast error growth and ensemble forecasting. See Buizza and Palmer [1995].

SIO Abbreviation for Scripps Institution of Oceanography.

SIR-C Acronym for the Shuttle Imaging Radar-C used for geologic, hydrologic, and oceanographic studies. It can image the Earth through cloud cover and its sensitivity to surface roughness, soil moisture, and sea-ice-water contrast makes it useful in studies of geological features, canopy morphology, sea-ice dynamics, and ocean surface temperature. See the SIR-C Web site[148].

SISMER Acronym for Systemes d'Informations Scientifiques pour la Mer or, in translation, the French National Oceanographic Data Center. See the SISMER Web site[149].

SIW In physical oceanography, a water mass. See Tomczak and Godfrey [1994], p. 161.

Six thermometer A self-registering maximum and minimum thermometer invented by James Six (1731?-1793) of England in 1782. It consisted of a U-shaped tube with mercury in the bend, one side filled with alcohol, and the other partially filled. Indices marked the highest and lowest temperatures. This was the most widely used thermometer for taking deep sea temperatures up until the 1870s. See Deacon [1971].

SIZEX Acronym for Seasonal Ice–Zone Experiment.

Skagerrak A circulation controlled sedimentary basin that provides part of the connection (along with Kattegat) between the North Sea and the Baltic. It is surrounded by Norway to the northwest, Sweden to the northeast, Denmark and Kattegat to the southeast, and the North Sea to the southwest. It is

[147] http://www.atmos.ucla.edu/~weibel/ssa/ssa_kit.html
[148] http://www.jpl.nasa.gov/mip/sirc.html
[149] http://www.ifremer.fr/sismer/

centered at approximately 9° E and 58° N and is the deepest part (> 700 m) of the the Norwegian Trench.

The circulation in Skagerrak is counterclockwise with North Sea water masses entering via the Jutland Current in the southwest, proceeding northeastward along the Denmark coast, combining with some of the brackish Baltic Current, turning and flowing northwestward along Sweden, turning again and becoming the Norwegian Coast Current (NCC) as it flows southwestward along Norway, and finally leaving Skaggerak and turning northwards as the NCC. There is also a deep countercurrent beneath the NCC that injects high salinity Atlantic water into the Skagerrak deep. See Svansson [1975], Rodhe [1996] and Danielssen et al. [1997].

SKAGEX Acronym for Skagerrak Experiment, an ICES experiment carried out from spring 1990 to spring 1991 in the Skagerrak. The main stage lasted four weeks with shorter and less intensive stages occurring at other times. The objectives of the experiment were to identify and quantify the various water masses entering and leaving the Skaggerak area and their variation over time, to investigate the mechanisms that drive the circulation in the area and its link with biological processes, and to investigate the pathways of contaminants through the Skagerrak. The project leader was B. Dybern.

[http://www.ices.dk/ocean/project/data/jskag66.htm]
[http://www.ices.dk/ocean/project/data/skagex.htm]

skin effect A temperature inversion in a thin near-surface ocean layer with a thickness of several millimeters. This is a source of uncertainty in radiometric measurements. The inversion layer, created mainly by evaporation, results in an underestimation of the SST compared with what it would be as determined by conventional methods in a layer with a thickness ranging from several tens of centimeters to several meters. See Kagan [1995].

skin temperature The temperature of the millimeter thick skin layer at the surface of the ocean. The skin temperature is 0.1–0.5°C cooler than the water a few millimeters below the surface. The skin is cooler than the layer just beneath because the net heat balance at the surface is from the ocean to the atmosphere, even during strong solar insolation and weak winds. This is because the sensible and latent heat fluxes at the air–sea interface are usually net losses from the ocean. The net longwave emission at the surface is also usually a heat loss. The incoming shortwave solar radiation is absorbed by the upper layers, with the infrared absorbed in the upper meter, the ultraviolet in the upper 3–5 m, and the visible in the upper 100 m. The shortwave absorption at the surface is therefore small, and the ocean surface loses heat. The heat lost is obtained from a flux from the interior via molecular conduction since turbulence is damped close to the surface. A large temperature gradient is required to accomodate the surface heat losses, which causes the skin temperature to drop sufficiently such that the resulting gradient can handle the flux from the interior. See Kantha and Clayson [2000].

slab ocean A simple, non-dynamic ocean model used in coupled model simulations. SSTs are calculated from surface energy balance and heat storage in a fixed-depth mixed layer but there are no ocean currents, i.e. we account for the effects of local and temporal but not non-local processes. The salient equilibration time of this type of model is that of the slab ocean, usually on the order of about 20 years for a 50 m thick slab.

SLEUTH Acronym for System for Locating Eruptive Underwater Turbidity and Hydrography.

slippery sea A phenomenon occurring in the wind-driven layer at the surface of the sea. In conditions of strong surface heating, a well-mixed warmer (and lighter) layer if formed, which is of limited depth because the stabilizing density distribution inhibits vertical mixing with the deeper, colder water. At the bottom of this surface layer is a strong density gradient where the turbulence is suppressed and the Reynolds stresses are small. A given wind stress at the surface can thus accelerate the water to produce stronger surface currents in this case compared to an unstratified ocean. This is true because both the depth of the layer involved is smaller and the retarding stress below it is reduced. This creates the slippery sea phenomenon. See Turner [1973].

slope The official IHO definition for this undersea feature name is "the deepening sea floor out from the shelf edge to the upper limit of the continental rise, or the point where there is a general decrease in steepness."

Slope Water (SW) A water mass that forms between the Gulf Stream and the continental shelf in the northwestern Atlantic Ocean. It is isolated by the Stream from contact with oceanic water masses in its depth range and therefore forms via interactions among shelf water, water from the Labrador Current, and water from the Gulf Stream. The Slope Water thus formed extends over the upper 1000 m of the water column north of Cape Hatteras along the continental rise and has a nearly linear T-S curve similar to that evinced by North Atlantic Central Water (NACW). The T-S curve typically extends from 21° C-36.0 to 15° C-35.1. Slope Water is intermittently transported by cyclonic rings across the Gulf Stream and into the Sargasso Sea. See Tomczak and Godfrey [1994].

slow manifold A hypothetical N-dimensional manifold (i.e. surface) embedded in the 3N-dimensional phase space of a primitive equation model that is devoid of gravity waves. This has been called the Holy Grail of initialization schemes for weather forecasting since if a numerical weather prediction model could be initialized with observations filtered to retain just their components on the slow manifold, then the large-amplitude gravity waves that have wrecked numerical forecasts since Richardson would no longer be a problem. The concept was introduced by Leith [1980] and is reviewed by Boyd [1995].

SLP Abbreviation for sea level pressure.

slush A type of sea ice defined by the WMO as:

> Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after heavy snowfall.

See WMO [1970].

S-M-B method A method of wave forecasting developed by Sverdrup, Munk and Bretschneider, whence comes the name. This approach yields predictions of significant wave height $H_{1/3}$ and significant wave period $T_{1/3}$ from known storm conditions, i.e. wind velocity U, fetch distance F and storm duration t. This method can be used for a partially arisen sea. Predictions are made empirically using graphs of all the available data in terms of the dimensionless ratios gF/U^2, gt/U, gH/U^2 and gT/U. The empirical equations used to develop the graphs are:

$$
\begin{aligned}
\frac{gH}{U^2} &= 0.283 \tanh\left[0.0125\left(\frac{gF}{U^2}\right)^{0.42}\right] \\
\frac{gT}{2\pi U} &= 1.20 \tanh\left[0.077\left(\frac{gF}{U^2}\right)^{0.25}\right] \\
\frac{gt}{U} &= K\, e^{\left(\left\{A\left[\ln\left(\frac{gF}{U^2}\right)\right]^2 - B\,\ln\left(\frac{gF}{U^2}\right) + C\right\}^{1/2} + D\,\ln\left(\frac{gF}{U^2}\right)\right)}
\end{aligned} \tag{19}
$$

where g is the gravitational acceleration, U is the estimated wind velocity, F is the fetch length, t is the wind duration, T is the significant wave period and H is the significant wave height. The constant values are $K = 6.5882$, $A = 0.0161$, $B = 0.3692$, $C = 2.2024$ and $D = 0.8798$. See Komar [1976].

smeddie See Pingree and LeCann [1993].

SMHI Abbreviation for Sveriges Meteorologiska och Hydrologiska Institut or Swedish Meterological and Hydrological Institute. See the SMHI Web site[150].

SMILE Acronym for Shelf Mixed Layer Experiment, a WHOI research program designed to study the response of the oceanic surface boundary layer over the continental shelf to atmospheric forcing. SMILE took place over the northern California shelf between Pt. Arena and Pt. Reyes from mid–November to mid–May 1989. See Alessi et al. [1991].

[http://uop.whoi.edu/data/smile/smile.html]

SMMR Abbreviation for Scanning Multichannel Microwave Radiometer, an instrument that has been on board both SEASAT and NIMBUS-7. It produced earth location and time-tagged SSTs, surface wind stress, atmospheric water vapor, liquid water content, and precipitation rate information. See Liu [1984].

SMONEX Acronym for Summer Monsoon Experiment, a program taking place from May 1 to August 31, 1979 in eastern African, the northern part of the Indian Ocean, the Arabian Sea, the Bay of Bengal, and in adjacent continental areas.

[http://www.meteo.ru/fund/inter.html]

SMWG Abbreviation for Synthesis and Modeling Working Group, a WOCE committee.

Snellius Expedition An oceanographic expedition taking place in 1929–1930 in the southwest Pacific Ocean.

Snellius II Expedition See van Aken et al. [1988].

SO See Southern Oscillation.

SOAR Acronym for Satellite Ocean Analysis for Recruitment, a OSLR project.

SOEST Acronym for the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa. It was established in 1988 and currently has approximately 700 faculty and staff. It consists of departments in Geology and Geophysics, Meteorology, Oceanography, and Ocean Engineering, as well as three institutes:

- Hawaii Institute of Geophysics and Planetology (HIGP)
- Hawaii Institute of Marine Biology (HIMB)
- Hawaii Natural Energy Institute (HNEI)

[http://www.soest.hawaii.edu/]

SOFAR 1. Acronym for Sound Fixing and Ranging channel, another name for the sound channel. 2. Acronym for SOund Fixing And Ranging floats, subsurface floats used since the mid 1970s that freely drift at prescribed pressures. These provide direct measurements of the ocean circulation by sending acoustic pulses, typically at 300 MHz, once a day which can be used to calculate their positions from their Times of Arrivals (TOAs) at listening stations moored near the SOFAR channel depth at known geographical positions. See Rossby and Webb [1970].

[150] http://www.smhi.se/

SOFeX Acronym for Southern Ocean Iron (Fe) Experiment. The original name for this was IronEx III.

SOFIA Acronym for Surface of the Ocean, Fluxes and Interactions experiment. See Dupuis et al. [1993].

soft tissue pump See organic matter pump.

SOI See Southern Oscillation Index.

SOIREE Acronym for Southern Ocean Iron RElease Experiment, an experiment taking place from January 31 to March 1 1999 on the R.V. Tangaroa in the Southern Ocean. A patch of seawater was enriched with iron to test the hypothesis that iron limits the primary production of phytoplankton.

The iron and sulphur hexafluoride (as a tracer) were initially released on Feb. 10 at a site with a mixed layer depth of about 65 m and with low chlorophyll α levels. The dissolved iron concentration was considerably elevated over the 50 square kilometer area, although the levels quickly decreased leading to three more iron infusions during the 13–day experiment. The patch moved about 40 nautical miles eastward and expanded to about 150 square kilometers during the experiment.

Five days after the initial release significant increases in algal photosynthetic competence were observed, followed by elevated algal biomass. Chlorophyll α and upper ocean dimethylsulfide levels increased significantly by the end of the experiment, while macronutrient levels, the partial pressure of carbon dioxide, and the contnet of total dissolved inorganic carbon decreased. See Boyd et al. [2000] and Boyd and Law [2001].

[http://tracer.env.uea.ac.uk/soiree/index.html]

solitary wave See soliton.

soliton A fundamentally nonlinear wave that propagates undistorted over great distances. The soliton or solitary wave was discovered by Scottish engineer John Scott Russell (1808–1882) in 1834 while conducting experiments to determine the most efficient design for canal boats. He describes his first observations of what he called a "Wave of Translation" Russell [1845]:

> I was observing the motion of a boat which was rapidly drawn along a narrow channel by a pair of horses, when the boat suddenly stopped - not so the mass of water in the channel which it had put in motion; it accumulated round the prow of the vessel in a state of violent agitation, then suddenly leaving it behind, rolled forward with great velocity, assuming the form of a large solitary elevation, a rounded, smooth and well-defined heap of water, which continued its course along the channel apparently without change of form or diminution of speed. I followed it on horseback, and overtook it still rolling on at a rate of some eight or nine miles an hour, preserving its original figure some thirty feet long and a foot to a foot and a half in height. Its height gradually diminished, and after a chase of one or two miles I lost it in the windings of the channel. Such, in the month of August 1834, was my first chance interview with that singular and beautiful phenomenon which I have called the Wave of Translation.

See Bullough [1988] and Sander and Hutter [1991] for the historical development of the concept of solitary waves, which weren't wholly appreciated until the advent of digital computers made it possible to much more thoroughly investigate their characteristics and use them to model physical situations. Today solitons or solitary waves are used as a constructive element to formulate the complex dynamical behavior of wave systems in almost all facets of science, e.g. hydrodynamics, nonlinear optics, plasmas, shock waves, tornados, the Great Red Spot of Jupiter, etc.

[http://www.ma.hw.ac.uk/~chris/scott_russell.html]

SOLO Acronym for Sounding Oceanographic Langrangian Observer, a second–generation ALACE float designed to correct the design flaws of the latter. The SOLO uses a single–stroke hydraulic pump allowing full up–down control, and eliminates the internal oil bladder. See Davis et al. [2001].

Solomon Sea More later.

solubility pump The process by which the ocean maintains a vertical gradient in DIC (CO2 plus bicarbonate and carbonate ions) – such that DIC is concentrated in the deep ocean – as a result of gas exchange. Surface water at equilibrium with a given CO2 concentration will increase its DIC concentration (uptake CO2) when the water temperature decreases since the solubility and dissociation of CO2 increase in cold water. The regions of deep water formation are located in high latitudes so the deep ocean is filled with cold water with relatively high DIC concentration. It is estimate that about 50% of the vertical DIC gradient can be accounted for by this process. See Najjar [1991] and Chisolm [1995].

solution drift See climate drift.

Somali Current A current near the western boundary of the Indian Ocean that flows southward during the boreal winter and northward during the summer. The southward flow during the northeast monsoon is limited to south of 10°N. It occurs first in early December near the equator and expands rapidly north in January with velocities from 0.7–1.0 m/s. The surface flow reverses in April during the inter–monsoon period, and develops into an intense jet during the southwest monsoon with velocities reaching 3.5 m/s in June. During the southwest monsoon a two gyre system develops in the region – the Great Whirl between 5–10°N with clockwise rotation and a secondary eddy towards its south. This two gyre system is stable until August or September, when the southern gyre propagates northward and merges with the Great Whirl. This has also been called the East Africa Coast Current.

After Schott and McCreary Jr. [2001], the details of the annual cycle of the Somali Current system are:

- *March-May*: Before the onset of the monsoon the southern Somali Current is an extension of the East African Coast Current (EACC) that flows northward across the equator to about 3-4N. There, it turns offshore, and a cold wedge develops along its shoreward shoulder. Farther north, alongshore winds cause an upwelling regime to develop with a shallow northward coastal flow overlying a southward undercurrent (see Section 4.3). Its width scale is of the order of 50-100 km.
- *June-July*: With the monsoon onset in June, the Great Whirl develops from 4-10N, and a second cold wedge appears at the latitude where it turns offshore (10-12N). The onset of the Great Whirl is thought to be a response to the very strong anticyclonic wind-stress curl offshore from the Somali coast by long Rossby waves reflecting into short Rossy waves at the boundary and accumulating energy there.

  The cross-equatorial flow continues during this time, now transporting about 20 Sv in the upper 500 m. It leaves the coast south of 4N, where part turns eastward and part flows back across the equator in a circulation pattern referred to as the 'Southern Gyre'.
- *August-September*: In the late phase of the summer monsoon the Great Whirl has become an almost-closed circulation cell with very little exchange between its offshore recirculation branch and the interior Arabian Sea.
- *October-November*: When the Southwest Monsoon dies down, the cross-equatorial Somali Current turns offshore again at 3N, while the Great Whirl continues to spin in its original position.
- *December-February*: During the Northeast Monsoon, the winds blow away from the Indian subcontinent and the surface Somali Current reverses to flow southward. After crossing the equator,

it encounters the northward-flowing EACC, resulting in a confluence and eastward turnoff at 2-4S that supplies the South Equatorial Countercurrent. At the equator, the southward Somali Current is quite shallow, carrying 5 Sv in the upper 150 m, because there is a northward undercurrent at this time.

The northern Somali Current during this time is characterized by an inflow from the east that causes a divergence to develop at the coast somewhere near 6-8 deg. N, with northward surface flow north of these latitudes and equatorward flow south of them. The northward surface flow passes through the Socotra Passage, but also veers eastward along the southern banks of Socotra. It then flows northward through the region occupied by the Socotra Eddy during the summer.

See Schott [1983] and Schott and Fischer [2000].

Somali Jet See Halpern and Woiceshyn [1999].

SOMARE Acronym for Sampling, Observations and Modeling of Atlantic Regional Ecosystems, a program whose overall goal is to unify the diverse European research groups investigating the functioning, effects and responses of the regional ecosystems of the Atlantic Ocean and shelf seas to anthropogenically forced and climate related changes. The scientific goals of SOMARE include improving knowledge of:

- biogeochemical and bio–optical provinces of the ocean basins and marginal seas of the Atlantic Ocean in terms of bio–optical, physical and biogeochemical properties;
- bio–optical properties and biological processes including primary and secondary production, plankton community structure and nutrient cycling using on–line, autonomous and towed sensor methods;
- spatially extensive calibration, validation and quality assurance of remotely sensed observations of oceanic biology;
- novel climatologies of key biological state variables and process rates; and
- development of sub–models of key biological processes for incorporation in basin–scale productivity models.

[http://www.pml.ac.uk/amt/somare/]

SOOP Abbreviation for Ship of Opportunity Program, an IOC project that uses merchant and other volunteer ships that transit a series of tracklines over existing trade routes. These ships deploy XBTs and other sampling instrumentation to obtain upper ocean thermal and salinity data. The primary goal of SOOP is the fulfill upper ocean data requirements established by GOOS and GCOS, which can be met at present by measurements from ships of opportunity.

[http://www.ifremer.fr/ird/soopip/]

SOPRANE Acronym for Systéme Océanique de Prévision en Atlantique Nord–Est, an ocean mesoscale forecasting system aimed at routinely providing real–time nowcast and forecast bulletins of the mesoscale ocean circulation in the Eastern North–Atlantic basin to support sea activities such as naval operations and oceanographic research cruises. According to the web site:

> The system is based on routine assimilation of TOPEX/POSEIDON and ERS-2 real time altimeter data into a quasi-geostrophic ocean model of the Eastern North Atlantic basin. The system modules include:
>
> - operational external data acquisition and processing (altimetry, meteorology, hydrology),

- quasi-geostrophic modelling (SIMANE),
- the computation of derived oceanographic variables (temperature, salinity, sound velocity).

SIMANE is a high-resolution 10-level 1/10 deg. quasi-geostrophic model extending from 24N to 54N and from 35W to the eastern coastal 200 m isobath. It is derived from the Blayo et al. [Blayo, 1994] North-Atlantic QG model. The model is designed to perform sequential assimilation (P. De Mey's optimal interpolation assimilation scheme SOFA) of ERS-2 and TOPEX/POSEIDON altimeter data in real time conditions, and real-time daily wind-stress forcing from the Mitio-France meteorological model ARPEGE forecasts.

The system retrieves and processes Topex (JPL and NAVOCEANO) and POSEIDON (CNES) IGDRs in real time, both with a 48-hour Doris orbit provided by CNES, and ERS-2 (ESA) FDPs with a 3-day orbit provided by DEOSDelft Institute of Earth-Oriented Space Research (Delft).

SOPRANE provides a complete depiction of the mesoscale ocean circulation from October 1992 to the present day ("hindcast" mode). Every week, a new assimilation cycle is processed with the latest altimeter tracks available in near real time (3-day latency max. for TOPEX/POSEIDON and ERS-2 data), to provide a "nowcast" bulletin. The model run provides reliable "forecasts" of ocean changes for up to two weeks.

[http://sirius-ci.cst.cnes.fr:8090/HTML/information/publication/news/news6/bahurel_uk.html]

Soret effect In fluid mechanics, mass diffusion caused by a temperature gradient. See Hurle and Jakeman [1971].

SOSUS Acronym for Sound Surveillance System, a component of the U.S. Navy's Integrated Undersea Surveillance Systems (IUSS) network used for deep ocean surveillance during the cold war. SOSUS consists of bottom–mounted hydrophone arrays connected by undersea communication cables to on-shore facilities. The arrays are primarily installed on continental slopes and seamounts at locations optimized for undistorted long range acoustic propagation. Beginning around 1990, the Navy allowed SOSUS to be used for various research activities. See Nishimura and Conlon [1994].

[http://www.pmel.noaa.gov/vents/acoustics/sosus.html]

sound channel A narrow channel in which sound waves can be effectively trapped. A region of minimum sound speed is created where the bottom of the thermocline meets the top of the deep isothermic layer. The velocity of sound slows as water temperatures decrease approaching the thermocline from above. The temperature is relatively constant below the thermocline, but increasing pressure causes the speed of sound to increase downwards. This causes obliquely traveling horizontal sound waves to vertically bend back and forth within the sound channel and travel great distances with relatively minor energy loss. This is also known as the SOFAR channel.

sound speed See Del Grosso [1974] and Yaremchuk and Krot [2002].

source water type In physical oceanography, a point on a T-S diagram indicative of a water mass. In practice, few if any water masses have T-S values identical to that of their source water types due to transformation by atmosphere-ocean interface processes and/ mixing, but they are almost inevitably within the theoretical standard deviation and as such readily identifiable as to their origin. See Tomczak and Godfrey [1994].

South Atlantic Bight See Boicourt et al. [1998].

South Atlantic Central Water (SACW) A variety of Central Water found in the Atlantic Ocean south of about 15°N. It shows uniform properties throughout its range, with the T–S curve well described by a straight line between the points 5°C, 34.3 and 20°C, 36.0. Part of the SACW is thought to be Indian Central Water (ICW) brought into the Atlantic by Agulhas Current intrusions. See Stramma and England [1999].

South Atlantic Current The current band of increased zonal speeds associated with the Subtropical Front (STF) in the South Atlantic Ocean. It originates in the western Atlantic as the STF becomes clearly distinguished from the Brazil Current front somewhere between 40 and 45° W. It then flows eastward typically to the north of the STF and closes the circulation in the South Atlantic subtropical gyre by becoming its southern limb. The SAC is clearly separated from the ACC by a region of weak flow just to the south of the STF, and is seen to not follow the STF exactly in some observations. It is recognizable as an enhanced current core at depths of 800–1000 m and has an average volume transport of about 30 Sv in the upper 1000 m in the western Atlantic (reaching as high as 37 Sv). The transport diminishes to less than 15 Sv in the vicinity of southern Africa where it turns northward to feed the Benguela Current. See Stramma and Peterson [1990] and Peterson and Stramma [1991].

South China Sea A regional sea in the western Pacific Ocean centered at about 115° E and 12° N that includes the Gulf of Thailand and the Gulf of Tonkin. It is bordered to the west by Vietnam, Thailand and the Malay Peninsula, to the south by a line joining the southern tip of the Malay Peninsula to Borneo, to the east by Borneo, the Phillipines and Taiwan, and to the north by the Taiwan Strait and China. It covers an area of 3,685,000 km^2, has a volume of 3,907,000 km^3, a mean depth of 1060 m, and a maximum depth of 5016 m.

It is connected to the East China Sea via the Taiwan Strait, the Andaman Sea via the Strait of Malacca, the Java Sea via the Karimata Strait, and to the Philippine Sea via Luzon Strait, and the Sulu Sea via the Balabar Strait and the Mindoro Channel. The main freshwater input from rivers is from the Red and Mekong Rivers of Vietnam and the Si Kiang River of southern China. See Qu et al. [2000].

Southeast Indian Subantarctic Mode Water (SEISAMW) A type of Subantarctic Mode Water formed in the southeastern Indian Ocean south of Australia. It is the dominant mode of ventilation for the Indian Ocean, leading to a subsurface oxygen maximum layer extending northward into the tropical and northern Indian Ocean.

Southeast Pacific Deep Water (SPDW) The SPDW flows through the Drake Passage with the ACC south of the Polar Front, at which point it is identifiable by its potential temperature ($0.2°C < \theta < 0.6°C$), salinity (34.703 < S < 34.710), and its silicate maximum (reaching 140 μmol kg^{-1}). It is the densest water mass of the ACC system in the Drake Passage.

When crossing the Scotia Sea, it is drastically cooled (by 0.14°C) and freshened (by 0.018) along isopycnals via mixing with WSDW and WDW in the Weddell–Scotia Confluence. This results in the SPDW south of the Southern ACC Front being transformed into WDW and becoming incorporated into the ACC, while north of the front two cores carrying modified SPDW exit the Sea. One of these is on the northern flank of the Southern ACC Front south of South Georgia, having followed the front from Drake Passage. The other overflows the North Scotia Ridge through Shag Rocks Passage and can be found just south of the Polar Front skirting the Falkland Plateau. See Siecers and Nowlin Jr. [1984].

South Equatorial Countercurrent An eastward current in the Atlantic and Pacific that flows between 5 and 10° S., the limited evidence for which shows it to be much less well developed than the North Equatorial Countercurrent (NECC). In the Indian Ocean the SECC is almost totally confined between the equator and the northern boundary of the South Equatorial Current (SEC) at 4° S. This was first described by Reid [1959] and the evidence is later reviewed by Leetmaa et al. [1981].

South Equatorial Current A westward flow in the Atlantic and Pacific located south of the North Equatorial Countercurrent (NECC) generally below 5° N. It flows between about 3° N and 10° in the Pacific with speeds estimated at around 50 to 65 cm s^{-1} and an average mean transport of 17 SV, although this latter quantity annually varies by about 10 Sv about the mean. The SEC is strongest during July and August and usually vanishes during the northern winter and spring. This is also seen in the Indian Ocean south of 4° S. See Leetmaa et al. [1981] and Stramma [1991].

South Equatorial Current Bifurcation The phenomenon wherein the Atlantic South Equatorial Current (SEC) – upon approaching the easternmost tip of South America – splits into the Brazil Current flowing to the south and the North Brazil Current flowing northwestward along the northern coastline of Brazil.

South Equatorial Undercurrent An eastward flow in the Atlantic Ocean whose core is located near 200 m depth a few degrees south of the Equator. A satisfactory dynamical explanation for this is as yet nonexistent. See Tomczak and Godfrey [1994], p. 260.

South Java Current See Tomczak and Godfrey [1994].

South Subtropical Front (SSTF) The southern boundary of the Subtropical Frontal Zone (STFZ).

South Tropical Countercurrent See Donguy and Henin [1975].

Southern ACC Front A front in the Southern Ocean that separates the Antarctic Zone (AZ) to the north from the Continental Zone (CZ) to the south. The position of the SACCF is usually indicated by a distinct temperature gradient along the σ-maximum of the Upper Circumpolar Deep Water (UCDW) as it shoals southward to near 500 m. The property indicators of the SACCF are $\theta > 1.8°$ along θ-maximum at Z > 500 m, $\theta < 0°$ along θ-minimum at Z < 150 m, S > 34.73 along S-maximum at Z > 800 m, and $O_2 < 4.2$ ml/l along O_2 minimum at Z > 500 m. The SACCF is one of three fronts found in the Antarctic Circumpolar Current (ACC), the others being (to the north) the Polar Front (PF) and the Subantarctic Front (SAF). See Orsi et al. [1995].

Southern Ocean In oceanography, an unofficial term used to describe the oceans surrounding the continent of Antarctica, which cover approximately 30,000,000 km2, or about 20% of the total world ocean area. While Southern Ocean is not considered an official term by the International Hydrographic Bureau (IHB), it is considered sufficiently distinct by oceanographers to merit a separate designation. The northern limit is generally considered to be the broad zone of transition where the permanent thermocline reaches the surface at the Subtropical Convergence/Front (STC/STF), and the southern limit the continent of Antarctica. It is distinguished from the other oceans by the relative uniformity of its characteristics of hydrography and circulation and that it influences more than it is influenced by the others.

The Southern Ocean bathymetry consists of three major basins where the depth exceeds 4000 m separated by three major ridges that reach at least to the 3000 m level. The major basins are:

- the Atlantic-Indian-Antarctic Basin (or African-Antarctic Basin or Valdivia Basin), bounded to the north by the South Orkney-Sandwich Ridge, the Atlantic-Antarctic Ridge, and the Prince Edward-Crozet Ridge, and to the east by the Kerguelan-Gaussberg Ridge;
- the Eastern Indian-Antarctic basin (or Australian-Antarctic Basin or Knox Basin), bounded to the west by the Kerguelan-Gaussberg Ridge, the north by the Amsterdam-St. Paul Plateau, and to the south by the Indian Antarctic Ridge; and

- the Pacific-Antarctic Basin (or Bellingshausen Basin), bounded to the west and north by Pacific-Antarctic Ridge and the South-Eastern Pacific Plateau.

See Belkin and Gordon [1996].

Southern Oscillation The name given to the atmospheric component of the El Nino/Southern Oscillation (or ENSO) phenomenon. The SO is a large-scale shift in atmospheric mass between the western and eastern Pacific, monitored by computing the SOI. An SOI indicating El Nino conditions means that there is reduced rainfall over the Indonesian region and that the west Pacific convective center is displaced eastward along the equator.

Southern Oscillation Index An index that is calculated to monitor the ENSO phenomenon. It is defined as the pressure anomaly at Tahiti minus the pressure anomaly at Darwin, Australia. Anomalously high pressure at Darwin and low pressure at Tahiti are indicative of El Nino conditions.

Southern South Equatorial Current (SSEC) One of three distinct branches into which the South Equatorial Current splits in the western South Atlantic. See Stramma [1991].

Southern Subsurface Countercurrent (SSCC) An eastward flowing countercurrent that flows beneath the surface east of 155° in the South Pacific Ocean. It flows between the eastward flowing South Equatorial Countercurrent (SECC) to the north and the westward flowing South Equatorial Current to the south. See Gouriou and Toole [1993].

South Pacific Equatorial Water (SPEW) In physical oceanography, a water mass partly formed by convective sinking of surface water at SSTs of 26° C and above in the tropics in the area of Polynesia. It is identified at temperatures greater than 20° C by a higher salinity than WSPCW, although below 20° C it seems to be a mixture of WSPCW and ESPCW. See Tomczak and Godfrey [1994], p. 166.

South Pacific Tropic Water (SPTW) A water mass identified as a salinity (>35.25 psu) maximum with homogeneous oxygen concentration (about 3.3 ml l^{-1}) around $25\sigma_\theta$. it is found in the equatorial region south of 5°N. See Qu et al. [1999].

South Trench Current See North Sea.

Southwest Area Monsoon Project (SWAMP) A NSSL project begun in 1990 to measure the central Arizona thunderstorm environments, examine the local monsoon structures and moisture fluxes, and study Mexican convective systems. The field operations for SWAMP began in 1990 and included scientists and technicians from several institutes and laboratories. See the SWAMP Web site[151].

Southwest Monsoon Current See Vinayachandran et al. [1999].

SOWEX Acronym for Southern Ocean Waves Experiment, an international collaborative air-sea interaction experiment in which a specially instrumented meteorological research aircraft simultaneously gathered atmospheric turbulence data in the marine boundary layer and sea surface topography data over the Southern Ocean for a wide range of wind speeds. The aim was to increase present knowledge of severe sea state air-sea interaction. SOWEX was carried out from June 10–16, 1992 over the Southern Ocean off the southwest coast of Tasmania, Australia at 42–45°S, 143–147°E. See Banner et al. [1999] and Chen et al. [2001].

[151] http://doplight.nssl.uoknor.edu/projects/swamp/

Soya Current An extension of the Tsushima Current that flows northward from the Japan Sea into the Okhotsk Sea via the Soya Strait. It is a fairly rapid curent with velocities reaching 1 m/s and traveles close to the coast with the character of a boundary current.

Soya Strait See Okhotsk Sea.

S-PALACE Abbreviation for Salinity–Profiling ALACE float.

Spanish Basin See Iberia Basin.

SPCZ Abbreviation for South Pacific Convergence Zone, an atmospheric convergence zone in the southwestern Pacific Ocean that is characterized more by a convergence in wind direction than as a wind speed minimum. It extends from east of Papua New Guinea in a southeastward direction towards 120° E and 30° S. See Philander and Rasmusson [1985].

specific heat A thermodynamic quantity indicating the rate of change of heat content with temperature. More specifically, this is the heat required to raise the temperature of a unit mass of a given substance by one degree. It is normally expressed in units of calories/gm °K. The specific heat of water is 1.00 cal/gm °K (although this varies about 1% with temperature), and the specific heat of dry air at constant pressure (C_p) is 0.240 cal/gm °K and at constant volume (C_v) 0.171 cal/gm °K. For water vapor the constant pressure (C_{pv}) value is 0.441 and the constant volume (C_{vv}) value 0.331 cal/gm °K.

For seawater, the specific heat at surface pressure is calculated in two stages. First, the value in joules per kilogram per degree Kelvin for fresh water is calculated as:

$$c_p(0,t,0) \;=\; 4217.4 - 3.720283t + 0.1412855t^2 - 2.654387\times 10^{-3}t^3 + 2.093236\times 10^{-5}t^4$$

. Then, the value at a given salinity is calculated with:

$$c_p(S,t,0) \;=\; c_p(0,t,0) + S(-7.64444 + 0.107276t - 1.3839\times 10^{-3}t^2) + S^{3/2}(0.17709 - 4.0772\times 10^{-3}t + 5.3539\times 10^{-5}t^2)$$

. The standard deviation of the algorithm fit is 0.074, and a check on the formula is given by $c_p(40,40,0) = 3981.050$. See Millero et al. [1973] for the derivation and details. Values at nonzero pressures are found using the following relation:

$$\left(\frac{\partial c_p}{\partial p}\right)_T \;=\; -T\left(\frac{\partial^2 v_s}{\partial T^2}\right)_p$$

where v_s is the specific volume. See also Cox and Smith [1959].

specific humidity The ratio of the mass (m_v) of water vapor to the mass ($m_v + m_a$) of moist air in which m_v is contained, where m_a is the mass of dry air, or

$$q \;=\; \frac{m_v}{m_v + m_a}$$

.

specific volume The reciprocal of density. In the determination of the specific volume of sea water, the specific volume $\alpha_{S,T,p}$ is decomposed as

$$\alpha_{S,T,p} \;=\; \alpha_{35,0,p} + \delta_S + \delta_T + \delta_{S,T} + +\delta_{S,p} + \delta_{T,p} + \delta_{S,T,p}$$

where the second through seventh terms on the right-hand-side are called the specific volume anomaly and the second through fourth terms the thermosteric anomaly.

specific volume anomaly The portion of the specific volume differing from a standard specific volume determined at a salinity of 35 ppt, a temperature of 0° C, and the pressure at the depth at which the sample was taken. This has also been known as the steric anomaly and the anomaly of specific volume.

spectral element method A method for approximating solutions to the governing equations of fluid motion in the ocean. It was developed to combine the geometrical flexibility of the traditional low-order finite element methods with the accuracy and high convergence rates of spectral methods. See Iskandarani et al. [1995].

spectral nesting See nested modeling.

spectral signature This refers to the particular form or shape evinced by the power spectrum calculated from the data comprising the time series of a process. For example, if the spectrum shows peaks at around 20, 40 and 100 thousand years it might be said to have the spectral signature of Milankovitch orbital variations.

SPEW See South Pacific Equatorial Water.

spherical approximation The fundamental geometric approximation in oceanography. It maps the approximate oblate spheroidal shape of the geoid on a sphere and introduces spherical polar coordinates (ϕ, θ, r) where ϕ is longitude, θ is latitude, and r radial distance. This approximation also assumes that the metric coefficients do not vary with radial distance, and that gravitational acceleration is constant.

This approximation represents the lowest order in an expansion of the metric with respect to two small parameters $d^2/4r_0^2$ and H_0/r_0 where d is the half distance between the foci of the geoid, r_0 the mean radius of the Earth, and H_0 the ocean depth. A vertical coordinate $z = r - r_0$ is also introduced. See Stommel and Moore [1989] and Muller [1995].

Spice Experiment An exploratory experiment to observe spiciness in the upper ocean, including the mixed layer, at horizontal scales of 10 m to 1000 km. The objectives of the Spice Experiment are:

- to quantify the density ratio in the mixed layer and seasonal thermocline;
- to find if salinity varies on shorter horizontal scales than temperature;
- to confirm that there is more spiciness in the mixed layer than in the seasonal thermocline; and
- to find where and over what length scales the reduction in spiciness occurs.

The data for the experiment were taken from a cruise in the eastern North Pacific between 25 and 35deg N from Jan. 24 to Feb. 20, 1997. Measurements were made using a SeaSoar equipped with a CTD and a fluorometer.

[http://chowder.ucsd.edu/~rudnick/spice/spice.html]

spiciness The variability of temperature and salinity along a surface of constant density due to air–sea fluxes, turbulent mixing and advection.

Spilhaus, Athelstan (1912-1998) Inventor of the bathythermograph and possibly the only oceanographer to have ever authored a regular comic strip.

According to his obituary in The Economist, Spilhaus can also apparently be blamed for the Roswell Incident that's spawned an entertainment industry:

In 1947 the Americans were working on ways to monitor nuclear tests in the Soviet Union. One plan was to put aloft balloons equipped with the necessary detection equipment. The first experiments were failures. The balloons all blew away. Mr Spilhaus, then a professor of meteorology at New York University, was brought in. As a weather man, so the reasoning went, surely he would know how to ensure that the balloons stayed quite steady in the stratosphere.

On June 4th 1947 the Spilhaus prototype was launched. On July 7th it came down with a bump, disintegrating on a ranch near Roswell in New Mexico. The rancher phoned the local sheriff. He thought the debris might have come from "a flying disc". By the time the story got into the newspapers the "disc" had become a flying saucer. A neighbour of the rancher later said that in the debris there was "something like aluminium, something like satin, something like well-tanned leather in its toughness, yet was not precisely like any one of those materials". Could this have been a dead alien, or possibly several? Many people came to think so.

An air force team removed every scrap of debris, assuring reporters that it was just an ordinary balloon, nothing to be bothered about; and compounding suspicions that the federal government was trying to cover up the fact that aliens had landed, fearing panic by the public. It was not until 1994 that it disclosed the background to the incident. Even now, the government version is widely disbelieved. The myth was much more interesting. Mr Spilhaus could say little: this was a secret of the cold war. But the fact that he was known to be associated with the incident only added to public speculation about it. Mr Spilhaus enjoyed playing the role of a slightly dotty scientist, a bit of a dreamer, or, as he called himself in later life, a "retired genius".

[http://www.whoi.edu/media/news_spilhaus.a.obit.html]
[http://vh1.economist.com/editorial/justforyou/11-4-98/sf1047.html]

spin up In numerical modeling, this refers to the transient initial stages of a numerical ocean simulation when the various fields are not yet in equilibrium with the boundary and forcing functions. Three techniques are generally used to initialize and spin up the ocean components of coupled models: (1) initializing with climatological values of temperature and salinity (typically using the Levitus climatology) throughout the volume of the ocean; (2) start with the aforementioned Levitus ocean and then spin it up for about 100 years using surface climatological forcing; (3) run the ocean to equilibrium by either combining surface forcing terms with atmospheric model fluxes or just using the surface forcing (and perhaps using an acceleration method with either option). The entire ocean is not in equilibrium using the first two methods, although the second method does allow the thermocline to adjust to equilibrium. This is due to both systematic errors and other shortcomings in the Levitus data. The third method may produce and ocean in equilibrium, but it may differ considerably from the observed ocean and the circulation may be distorted. For example, the deep ocean is often too warm using this method.

spiral eddy Frequently observed, distinct sea surface patterns with a horizontal scale of around 10 km. The eddies are large–scale arrangements of sea slicks or streaks with a spacing on the order of 1 km and width 100 m. The streaks are domains of reduced surface roughness that make them visible to remote instruments such as SAR and space shuttle cameras, and are caused by surface convergence.

The eddies have been observed in both hemispheres in both coastal areas and the open ocean. They generally appear in an interconnected pattern. They range from 100-25 km in size and are overwhelmingly cyclonic. See Munk et al. [2000] and Eldevik and Dysthe [2002].

SPMW Abbreviation for subpolar mode water.

spring retardation See age of tide.

spring tide The high tides of greatest amplitude caused by the Earth, Sun and Moon being almost co-linear. This causes the gravitational pulls of both the Sun and Moon to reinforce each other. The high tide is higher and low tide is lower than the average, and spring tides occur twice a month at the times of both new moon and full moon. See also neap tide.

SPTW Abbreviation for South Pacific Tropical Water.

spur The official IHO definition for this undersea feature name is "a subordinate elevation or ridge protruding from a larger feature, such as a plateau or island foundation."

SPURV Acronym for Self-Propelled Underwater Research Vehicle. See Widditsch [1973].

SQM Acronym for SeaWiFS Quality Monitor. See Hooker and Aiken [1998].

squall A violent wind that begins suddenly, lasts for a short time, and dies suddenly. It is sometimes associated with a temporary change of direction.

squall line One of the most severe kinds of storms in the tropics. The system is typically hundreds of miles long and consists of a line of active thunderstorms. The cumulonimbus clouds representing individual storms have lifetimes on the order of an hour or less, but new ones replace dying cells allowing the system as a whole to last from hours to days. They form preferably over land and move with speeds from 10-20 m/s.

In a squall line warm moist air enters the base of the cloud at its leading edge and rises in a convective updraft with accompanying condensation. An extensive cloud anvil forms to the rear of the convective tower with precipitation falling from both the main cloud column and the anvil. The evaporation of this precipitation into dry mid-tropospheric air leads to cooling and downdrafts concentrated in the region of intensive convection although extending to the rear of the squall line. This downward rushing cold air causes a pseudo cold front or gust front at the leading edge. This front undercuts the warm moist air ahead, causing more convection and new cumuliform clouds ahead of the line and fostering the propagation of the convective region. See Hastenrath [1985].

SSA See Singular Spectrum Analysis.

SSALT Acronym for the single–frequency solid–state radar altimeter flow flown as an experimental instrument on the TOPEX/POSEIDON mission (with this being known as the POSEIDON instrument). The SSALT, a solid–state Ku–band (13.65 GHz) altimeter, was developed by the French (CNES) as a demonstration project for a low–power, low–weight altimeter for future Earth–observing missions. It shares the same antenna with ALT, the operational altimeter, and thus cannot be operated at the same time. The SSALT was operated 12.5% of the time during the 6 month verification phase of the mission, and thereafter for one (10 day) cycle approximately every 10 cycles.

SSCC 1. Abbreviation for Southern Subsurface Countercurrent. 2. Abbreviation for subsurface countercurrent.

SSEC Abbreviation for SouthernSouthEquatorialCurrent.

SST Abbreviation for sea surface temperature.

SSTF Abbreviation for South Subtropical Front Zone.

SSW Abbreviation for Sargasso Sea Water.

SSWWS Abbreviation for Seismic Sea-Wave Warning System.

stability 1. See numerical stability. 2. In physical oceanography, a measure of the tendency of a water parcel or particle to move vertically in comparison with its surroundings. Neglecting adiabatic effects, the stability is defined (over short vertical distances) by

$$E = \frac{1}{\rho}\frac{d\rho}{dz}$$

where ρ is the density and z the vertical coordinate. There is a correspondingly more complicated expression for the stability when adiabatic effects are taken into account as is usually necessary at great depths. Typical values of E in the upper 1000 m range from 100 to 1000 x 10^{-8}/m, with the largest values generally occurring in the upper few hundred meters. Below 1000 m values decrease to less than 100 x 10^{-8}/m and can get as small as a hundredth of that in deep trenches.

stability frequency See buoyancy frequency.

STABLE Acronym for Stable Antarctic Boundary Layer Experiment.

STACS Acronym for Subtropical Atlantic Climate Study, a NOAA project directed at increased understanding of the role of western boundary currents of the Atlantic ocean in meridional heat flux and development of strategies to monitor important western boundary features. See Molinari [1989].

staggered grid In numerical analysis this refers to a computational grid in or on which separate dependent variables are represented on alternate or staggered grid points. For example, a 1-D equation set for pressure and velocity would be solved on a grid where the pressure is represented at points n, n+2, n+4, etc. while the velocity is represented at n+1, n+3, n+5, etc. This procedure can confer numerical advantages and is also used for problems with more than one spatial dimension. See Kowalik and Murty [1993].

stagnant film model The simplest of several models developed to understand the processes that determine the gas flux in and near the liquid boundary layer that is the air-sea interface. It assumes that the boundary layer is a discrete, stagnant layer in which only molecular diffusion takes place. This stagnant layer sits on top of a well-mixed, purely turbulent layer. The flux across the interface is assumed to be equal to the flux in the stagnant film which, using Fick's law, gives a linear concentration profile within the film. This leads, with the additional use of Henry's law, to an expression for the flux involving the gas concentration at the base of the film (C_w), the partial pressure of the gas in the atmosphere (p_a), the solubility of the gas in seawater (α), and the piston velocity (K_w), i.e. $F = K_w(C_w - \alpha p_a)$. See Najjar [1991].

Standard Atmosphere An idealized, dry, steady-state approximation of the atmospheric state as a function of height that has been adopted as an engineering reference. It was not computed as a true average but rather approximates average atmospheric conditions at mid-latitudes. It is a piecewise continuous curve consisting of straight-line segments with breaks at 11, 20, 32, 47, 51 and 71 km. The surface temperature is 15° C and the gradients, starting from the surface, are -6.5, 0.0, 1.0, 2.8, 0.0,-2.8, and -2.0 K/km. Pressure variations can be found from this by combining the hydrostatic equation with the equation of state for dry air and integrating the result, i.e.

$$\frac{1}{p}\frac{dp}{dz} = \frac{-g}{RT}$$

with respect to height. See Minzner [1977].

standard density A conventional value for the density of mercury, adopted for the sake of uniformity in the conversion of pressure readings from units of pressure to units of height (or the converse). The value adopted by the WMO is the density at 0° C, i.e. 13.5951 gm/cm^3.

standard gravity A conventional value for the acceleration due to gravity, adopted for the sake of uniformity. The value adopted by the WMO is 980.665 cm/sec^2.

standard seawater See Culkin and Smed [1979], Culkin and Ridout [1998] and Bacon et al. [2000].

STARE Acronym for Southern Tropical Atlantic Regional Experiment, a project within BIBEX. STARE is an aircraft– and ground–based measurement program initiated in May 1990 by a committee of scientists from Europe, Brazil and the U.S. to investigate the sources of trace gases, their atmospheric transport, and the chemical processes in the atmosphere which lead to elevated levels of O_3, CO, and other trace gases over the southern tropical Atlantic Ocean. The field campaigns conducted under STARE were TRACE-A, SAFARI, and SA'ARI. See Andreae et al. [1996].

stationarity The property requiring that certain statistical properties of a stochastic process be invariant with respect to time. As some have noted, the strict satisfaction of this requirement is impossible if one lends creedence to the Big Bang theory of universal origin, although inroads can be made towards satisfaction on less strict and more pragmatic grounds.

stationary planetary wave Departures of the time average of the atmospheric circulation from zonal symmetry. They result from east-west variations in surface elevation and temperature associated with the continents and oceans. See Hartmann [1994].

statistical downscaling A procedure wherein local or regional climate characteristics are inferred from the output of GCMs that don't explicitly resolve such scales. Statistical relationships between observed local climate variables, e.g. surface air temperature, precipitation, etc., and observed large-scale predictors are developed and then applied to the same large-scale predictors in the GCM output to predict the local climate variables. This method has been shown to produce local temperature and precipitation change fields that were significantly different and had a finer spatial scale structure than those generated by directly interpolating large-scale GCM fields. See Houghton and Filho [1995].

statistically robust Statistical results which are relatively insensitive to the presence of a moderate amount of bad data or to inadequacies in the statistical model being used, and that react gradually rather than abruptly to perturbations of either. See Chave et al. [1987] for a discussion of this in relation to geophysical data.

STC 1. See Subtropical Convergence. 2. See South Trench Current.

STD Abbreviation for Salinity-Temperature-Depth. See CTD.

STEP A temperature profiler for measuring the oceanic thermal boundary layer at the ocean–air interface. See Mammen and von Bosse [1990].

steric anomaly Another name for the specific volume anomaly.

steric height In oceanography, a quantity introduced to determine the distance or depth difference between two surfaces of constant pressure. The steric height h is defined by

$$h(z_1, z_2) = \int_{z_1}^{z_2} \delta(T, S, p)\, \rho_0 dz$$

where z_1 and z_2 are the depths of the pressure surfaces, δ the specific volume anomaly, T the temperature, S the salinity, p the pressure, and ρ_0 a reference density. It has the dimension of height and is expressed in meters.

STERNA Expedition A two–ship study carried out in the Bellingshausen Sea, Southern Ocean from October to December, 1992. The STERNA project, carried out aboard the Royal Research Ships *James Clark Ross* and *Discovery*, was the final field–work phase of the NERC–funded BOFS (the major U.K. contribution to the IGBP JGOFS over the period 1989–1993). The study was originally developed to also include an investigation of biogeochemical fluxes during the spring ice–melt in the Greenland Sea, and was named STERNA after the migrations carried out by the tern *Sterna paradisea*, during which individual commonly spend alternate summers in each polar region. The northern component was cancelled because of major refitting work on the research ships, but the name was retained.

The objectives of the STERNA Expedition were:

- to determine ocean–atmosphere exchanges of radiatively active gases, and the factors influencing such fluxes, over a wide latitudinal range;
- to investigate the interactions among the biological, chemical and physical processes that control carbon fluxes in the euphotic zone;
- to assess the impact of sea–ice on biogeochemical fluxes; and
- to determine the export of biogenic material from the upper ocean.

See Turner and Owens [1995].

STF Abbreviation for Subtropical Front.

STFZ Abbreviation for Subtropical Frontal Zone.

still water level The level of the sea with high frequency motions such as wind waves averaged out. See also mean sea level.

STMW Abbreviation for Subtropical Mode Water.

stochastic process A reasonably strict definition of this (also called a random process) is a family of random variables indexed by t, where t belongs to some index set T (which may denote time, space, or whatever else one wishes). A more intuitive definition might call this the set of all possible outcomes of an experiment (this set also being called the ensemble) inherently involving some degree of randomness along with the mechanism by which individual outcomes, or realizations, selected.

stochastic resonance Stochastic resonance (SR) is a resonance-like response of a dynamical system to stochastic forcing. This phenomenon was first introduced by as a possible explanation of long-term climatic variability, but has since been widely observed and studied in many different fields of science. According to Paldor and Dvorkin [2000]:

> The essence of the phenomenon of SR in a dynamical system is the detection of a signal only due to the presence of noise. There are two main types of dynamical systems where SR was studied. The paradigm of the first one is an overdamped particle in a bistable potential well, which is rocked by a subcritical periodic forcing. Subcritical here implies that this periodic forcing, in itself, is insufficient to cause a particle to overcome the potential barrier, so that no switching between the two steady states can occur. When a small noise is added, there arises a nonzero probability for the particle to cross the potential barrier from the basin of one steady state to the other. As the noise amplitude grows, so does the

> number of crossings in a given time interval, until the hopping over the potential barrier reaches a saturation level at which point it is entirely dominated by noise. The ratio of the crossing probability (which can be calculated in several ways) to the noise amplitude will exhibit a global maximum at the saturation noise level where any further increase of the noise amplitude is not accompanied by an increase in the hopping probability.
>
> The second type of dynamical systems where SR was demonstrated has no periodic forcing. Instead, the signal in these systems is a coherent motion, which can be quantified into a signal-to-noise ratio (SNR) by resorting to the spectral density function.

Paldor and Dvorkin [2000] investigate SR as a mechanism for allowing cross-equatorial flow. See Moss [1994] and Gammaitoni et al. [1998] for reviews.

STOIC Acronym for Study of Tropical Oceans in Coupled Models, a project for the intercomparison of tropical ocean behavior in coupled ocean–atmosphere models on seasonal and interannual scales. It focuses on the Atlantic and Indian Ocean regions and their relationship to the Pacific Ocean. This project is designed to be complementary with the ENSIP program.

`[http://www1.imgw.gdynia.pl/lustro_dkrz/clivar/stoic.html]`

Stokes drift A mean Lagrangian current that can be generated by surface gravity waves. This is caused when water particle orbits are not closed in surface gravity waves. A steady drift results even if no mean currents are present. See Stokes [1847] for the original work and McWilliams and Restrepo [1991] for a review of possible effects on ocean circulation. See also Ianniello and Garvine [1975].

Stokes' theorem A theorem of geophysical importance in that it enables one to calculate whether there is a tendency for a flow to be circulating around a curve C, e.g. the Earth. It is mathematically expressed as

$$\int\int_S \eta \cdot (\nabla \times v)\, d\sigma \;=\; \int_C \tau \cdot v\, ds$$

where η is the normal vector to a surface S, τ the tangent vector to the curve C bounding S, and v the velocity vector field. This theorem, dealing with the integration of the curl of the velocity field (or, equivalently, the vorticity vector), allows us to evaluate whether or not the fluid is circulating (as well as rotating or spinning via the calculation of the vorticity vector itself). See Dutton [1986].

Stokes velocity A velocity in fluids that derives from the wave Reynolds stresses. See the Stokes wave entry and compare to Lagrangian velocity and Eulerian velocity. See Wunsch [1981], p. 345.

Stokes wave A wave theory whose theoretical development is the same as that for Airy waves except that second and higher order terms involving the wave height are retained. The expression for the wave surface elevation includes the Airy wave expression as the first term and a number of additional terms (depending on the order of the theory) that modify the elevation profile. The added terms generally enhance the amplitude of the wave crest and detract from the trough amplitude such that the crests are steeper and the troughs flatter.

The particle orbits in Stokes theory, unlike those in Airy wave theory, are not closed. This leads to a nonperiodic drift or mass transport in the direction of wave advance with an associated speed called the Stokes velocity. Stokes wave theory is generally limited in applicability to waves with steepness (i.e. H/L where H is the wave height and L the length) less than 1/100 in deep water, with even more severe restrictions in shallow water. See Komar [1976] and LeMehaute [1976].

Stommel, Henry Melson (1920-1992) A physical oceanographer who has been called "the most significant scientific contributor to the development of oceanography", Stommel's long and distinguished career was marked not only by many significant scientific contributions to his field but also by his unsurpassed ability to help others in their research efforts and to catalyze the development of major research programs.

His scientific contributions included proposing the use of T-S correlations to estimate missing salinity values from measured temperatures in order to calculate dynamic heights, the beta spiral method for determining absolute geostrophic circulation fields, the initiation of studies of double diffusion, and the development in the early 1960s (along with Arnold Arons) of a model of abyssal circulation that still serves as the fundamental basis for further investigations today. His most famous contribution was his 1947 paper in which he developed an analytical model showing how the westward intensification of ocean currents is caused by the variation of the Coriolis parameter with latitude (i.e. the beta effect).

His efforts to foster research programs included the genesis of the long-term measurements of the deep waters off Bermuda in 1953, the planning (with K. Yoshida) of a survey of the Kuroshio Current in the late 1960s, the proposal of a dense network of oceanographic stations off the coast of Bermuda that resulted in the Mid-Ocean Dynamics Experiment (MODE), and the motivation of the geochemistry community to carry out the GEOSECS program.

His work led to hundreds of publications under his name and with dozens of collaborators. His books included Science of the Seven Seas (1945), The Gulf Stream (1966), Kuroshio (co-edited with K. Yoshida in 1972), Volcano Weather (co-written with his wife Elizabeth in 1983), Lost Islands (1984), A View of the Sea (1987) and Introduction to the Coriolis Force (co-written with Dennis Moore in 1989). He inspired the 1981 festschrift entitled Evolution of Physical Oceanography: Scientific Surveys in Honor of Henry Stommel (edited by B. Warren and C. Wunsch). The Collected Works of Henry M. Stommel (edited by N. Hogg and R. Huang) were published in three volumes in 1995. This set includes introductory essays for each chapter written by his many colleagues as well as previously unpublished material, e.g. about a hundred pages from his unpublished autobiography. See Veronis [1992], Warren and Wunsch [1981], and Hogg and Huang [1995].

[http://www.nap.edu/readingroom/books/biomems/hstommel.html]

Stommel-Arons thermohaline circulation A model of global thermohaline circulation developed by Henry Stommel and Arnold Arons in a series of papers starting in 1961. This model combines sources of abyssal water at either pole, the turbulent mixing of warm surface water downward, the broad and slow upward flow of cold deep water, and deep western boundary currents in a dynamically consistent manner to provide a first-order explanation for that part of the general ocean circulation driven by spatial differences in the salinity, temperature and, therefore, density of sea water.

Stommel's demon In the theory of the ventilated thermocline, a deepening mixing layer allows only a narrow range of density to subduct at any geographical location. Only water of a particular density class is able to enter the thermocline at a given position. Stommel likened the process to the role of the demons in Maxwell's theory of gases. This has led to referring to the selection process of subducted density as Stommel's demon. See Stommel [1979], Williams et al. [1995] and Pedlosky [1996].

Stommel transitions A transition in which the state of a shallow coastal basin, or estuary, in an arid climate, switches suddenly between classical and inverse states. In the classical state the basin has a lower density than the ocean, while in the inverse state the reverse is true. The classical state is due to heating (no river flow is assumed), and the inverse state is hypersaline. A classical, well-mixed basin features gravitational circulation that flows from the basin to the ocean at the surface, and from the ocean to the basin at the bottom. In a Stommel transition these flow directions are reversed, as is the sign of the density gradient from oceean to basin. The possibilities were originally discovered by Stommel [1961]. After Hearn and Sidhu [2003].

storm surge A phenomena wherein sea level rises above the normal tide level when hurricanes or tropical storms move from the ocean along or across a coastal region. Technically, this is defined as the difference between the actual sea (tide) level under the influence of a meteorological disturbance (storm tide) and the level which would have been reached in the absence of the meteorological disturbance. This sea level rise can consists of three components, the first of which results from low barometric pressure, i.e. the so-called inverse barometer effect, where lower atmospheric pressure on the surface of the water allows it to rise. The second component is wind set-up where the winds drag surface water to the shore where it piles up. The third component of the rise is due to coupled long waves where the peak of the wave coincides with the shoreline. See Wiegel [1964] and Heaps [1967].

Strait of Gibraltar A shallow strait that separates the eastern Atlantic Ocean from the Mediterranean Sea. See Gascard and Richez [1985].

Strait of Hormuz A strait joining the Persian Gulf to the west and the Gulf of Oman to the east. It is located at about 56° E and 27° N.

Strait of Magellan According to Strub et al. [1998], "Despite the strong southwesterly winds characteristic of the area, tides are the dominant forcing function for the currents, especially on the Atlantic side." See Medeiros and Kjerfve [1988] and Panella et al. [1991].

Strait of Messina A narrow strait between between the southwestern tip of Italy and Sicily that connects the Tyrrhenian Sea in the north with the Ionian Sea to the south. It is a narrow channel whose smallest cross–sectional area is 0.3 km^2 in the sill region where the mean water depth is 80 m. The depth increases more rapidly in the southern than in the northern part, with the depths 15 km from the sill to the north and south being 400 m and 800 m, respectively. Both Tyrrhenian Surface Water (TSW) and Levantine Intermediate Water (LIW) are present year–round, separated at a depth of around 150 m. A seasonal thermocline is also present for most of the year with the difference across this interface generally much larger than than across the TSW/LIW boundary. Large gradients of tidal displacements are present despite generally small tides in the Mediterranean since the predominantly diurnal tides to the north and south are approximately in phase opposition. The tides combine with the topographic restrictions to allow current velocities to reach as high as 3.0 m s^{-1} in the sill region. There is also a weak mean exchange flow directed toward the Ionian Sea with a velocity of about 0.10 m s^{-1} in the surface layer, and toward the Tyrrhenian Sea at about 0.13 m s^{-1} in the lower layer. See Bignami and Salusti [1990].

Straits of Sicily A strait located at around 12° E in the Mediterranean Sea that separates the eastern and western basins. Its shallow sill separates the deep waters of the Tyrrhenian Sea to the northwest from those of the Ionian Sea to the southeast. See Fairbridge [1966].

stratification In oceanography, the vertical density structure resulting from a balance among atmospheric heating, surface water exchange, freezing, stirring and diffusion of heat, and the horizontal and vertical motion (advection) of waters with different temperature and salinity characteristics.

stratified estuary One of four principal types of estuaries as distinguished by prevailing flow conditions. This type is stratified with a halocline between the upper and lower portions of the water column of nearly constant salinity. The James and Mersey estuaries are examples of this type.

stratified fluid See Fernando [1991].

stream function wave theory A surface gravity wave theory wherein the wavelength L, coefficients $X(n)$, and the the value of the stream function on the free surface ψ_η are numerically determined given the wave height z, the water depth h and the wave period T. The expression for the stream function ψ in a reference frame moving with the speed of the wave C is

$$\psi = \left(\frac{L}{T} - U\right) z + \sigma_{n=1}^{NN} X(n) \sinh\left[\frac{2\pi n}{L}(h + z)\right] \cos\left(\frac{2\pi n x}{L}\right).$$

The unknowns are determined to best satisfy the dynamic free surface boundary condition in the least squares sense.

The advantages of this wave theory are that it is one theory that can be applied to the full range from shallow to deep water and from small to breaking wave heights, and that fairly comprehensive tables are available for design purposes (and, more recently, computer programs). The original irrotational version of the theory has been extended to some rotational flows. Other representations in terms of the stream function or velocity potential have also been developed since the stream function theory was first described in 1965. See Dean [1990].

streaming velocity A small first–order mean velocity near the bottom in the direction of wave motion that occurs in the presence of the vortical bottom boundary layer in water of finite depth. See Phillips [1977] and Longuet-Higgins [1986].

strength of ebb In the description of tides, the magnitude of the ebb current at the time of maximum speed. This is usually associated with lunar tide phases at spring tides near perigee or with maximum river discharge. This is also known as ebb strength.

STRESS Acronym for Sediment Transport Events over Shelves and Slopes. See Sherwood et al. [1994].

STREX Acronym for Storm Transfer and Response Experiment, a joint meteorological–oceanographic experiment carried out in the northwestern Pacific Ocean during November and December 1980. The purpose was to examine the response of the atmospheric and oceanic boundary layers to the passage of storms. See Fleagle et al. [1982], Paduan and DeSzoeke [1986] and Geernaert [1990].

Strouhal number A dimensionless number or parameter proportional to the reciprocal of vortex spacing. It is expressed as a number of obstacle parameters and generally used in momentum transfer calculations, e.g. Von Karman vortex street and unsteady flow calculations. It is expressed as:

$$S_r = \frac{f\,L}{V}$$

where f is a frequency, L a characteristic length scale, and V a characteristic velocity.

SUAVE Acronym for Submersible System Used to Assess Vented Emissions, an integrated instrument system consisting of an advanced chemical analyzer and an array of physical property sensors. SUAVE is used to investigate the chemical properties of hydrothermal vents. The chemical analyzer is based on the principles of flow analysis and colorimetric detection, and its main components include:

- a 12–channel peristaltic pump allowing the simultaneous operation of up to four of the chemical methods employed;
- three miniature 3–way pinch valves to allow selection between sample intake and up to three *in situ* standards;
- 8 reagent reservoirs and 4 standard reservoirs, with an auxiliary bin with a 12 bottle capacity for extended deployments;

- an intake filter to prevent clogging of the sample intake, and manifolds for mixing samples before testing; and
- six LED–photodiode detector channels.

The auxiliary sensors include:

- a CTD including an SBE 4 conductivity sensor and an SBE 3 temperature sensor;
- a Sea Tech 25 cm transmissometer and a Sea Tech LS6000 Light Scattering Sensor; and
- glass enscapsulated thermisters.

SUAVE was built in 1991 and has been deployed over 200 times to date, accumulating more than 1500 hours of in situ analysis time, all directed toward hydrothermal vent research. Over 1000 km of ridgecrest with hydrothermal plumes have been investigated, with the thermochemical attributes determined with spatial detail seldom achieved anywhere on the sea floor. See Massoth et al. [1992].

[http://www.pmel.noaa.gov/vents/geochem/suave/about_suave.html]

Subantarctic Front In physical oceanography, a region of rapid transition in the Southern Ocean (S)) between the Polar Frontal Zone (PFZ) to the south and the Subantarctic Zone (SAZ) to the north. Its position is generally identified by the rapid northward sinking of the salinity minimum associated with the Antarctic Intermediate Water (AAIW) from near the surface in the PFZ ($S < 34$) to depths greater than 400 m in the SAZ ($S < 34.30$). The property indicators within the front are $S < 34.20$ at $Z < 300$ m, $\theta > 4$-5° at 400 m, and $O_2 > 7$ ml/l at $Z < 200$ m. The SAF is one of three distinct fronts in the Antarctic Circumpolar Current (ACC), the others being (to the south) the Polar Front (PF) and the Southern ACC Front (SACCF). This has also been called the sf Australasian Subantarctic Front. See Orsi et al. [1995].

Subantarctic Mode Water (SAMW) In physical oceanography, a water mass in the Subantarctic Zone of the Southern Ocean. This is one type of Subpolar Mode Water. The SAMW is the deep surface layer of water with uniform temperature and salinity created by convective processes in the winter. It can by identified by a temperature of around -1.8° C and a salinity of around 34.4 and is separated from the overlying surface water by a halocline at around 50 m in the summer. Although it is not considered to be a water mass, it contributes to the Central Water of the southern hemisphere, and is additionally responsible for the formation of AAIW in the eastern part of the south Pacific Ocean. This has also previously been called Winter Water. See McCartney [1977], Piola and Georgi [1981] and Tomczak and Godfrey [1994].

Subantarctic Surface Water (SSW) A water mass found in the Southern Ocean between the Subtropical Front (STF) and the Subantarctic Front (SAF) and above the salinity minimum of the Antarctic Intermediate Water (AAIW). At the surface the SSW is fresher than the surface waters of the Polar Frontal Zone (PFZ) in the Drake Passage, although by the time it reaches the Greenwich Meridian surface salinities are 0.3–0.4 higher than in the Drake Passage and more saline than those in the PFZ. Below the surface the SSW shows monotonically decreasing temperature as well as a maximum in salinity and a minimum in oxygen, both of the latter induced by the underlying AAIW. See Whitworth and Jr. [1987].

Subantarctic Upper Water (SAUW) In physical oceanography, a water mass located in the Subantarctic Zone of the Southern Ocean. It is characterized hydrographically by temperatures ranging from 4-10° C in the winter and 4-14° C in summer, with salinities between 33.9 and 34.9 and reaching as low as 33.0 in the summer as the ice melts. See Tomczak and Godfrey [1994], p. 82.

Subantarctic Zone The name given to the region in the Southern Ocean between the Subantarctic Front to the south and the Subtropical Front to the north. This zone is characterized by the presence of SAUW at and near the surface. The SAZ is one of four distinct surface water mass regimes in the Southern Ocean, the others being (to the south) the Polar Frontal Zone (PFZ), the Antarctic Zone (AZ) and the Continental Zone (CZ). See Tomczak and Godfrey [1994] and Orsi et al. [1995].

Subarctic Intermediate Water (SIW) In physical oceanography, this is a water mass which originates from the Polar Front formed between the Kuroshio and the Oyashio in the western North Pacific Ocean. It is formed chiefly by the process of mixing of surface and deeper waters and subducted into the subtropical gyre, filling the northern Pacific south of 40° N from the east. This is one of the few water masses whose formation process has little to do with atmosphere-ocean interaction. It is characterized by a salinity minimum ranging from about 300-1000 m depth and a large east-west salinity gradient in the South Pacific. See Tomczak and Godfrey [1994] (p. 161) and Ahran [1990].

subduction In physical oceanography, a process whereby Ekman pumping injects surface water into intermediate depths along isopycnal surfaces. This process is responsible for the formation of the water masses in the permanent thermocline. Although it is a permanent process, water mass formation occurs only in late autumn and winter due to variations in the seasonal thermocline. See Tomczak and Godfrey [1994].

Subduction Experiment An experiment that took place in the subtropical North Atlantic near the eastern flank of the Bermuda/Azores atmospheric high pressure system from June 1991 to June 1993. That region is a preferred one for convergence of the wind–driven or Ekman circulation which leads to subduction, the process by which mixed layer water is injected into the main thermocline. See Spall et al. [2000].

[http://uop.whoi.edu/data/subduction/subduction.html]

subjective analysis In meteorology, the name given to synoptic weather charts prepared by hand since the resulting diagnosis or analysis relied extensively on the subjective judgment of the preparer. Compare to objective analysis. See Daley [1991].

submarine valley See valley.

Subpolar Mode Water (SMW) See McCartney and Talley [1982].

subsurface countercurrent (SSCC) Another name for the Tsuchiya jets found in the equatorial Pacific Ocean.

subtropical Of the subtropics.

Subtropical Convergence The name given by Deacon (Deacon [1933], Deacon [1937]) to the hydrographic boundary between the Southern Ocean and subtropical waters to the north. This was replaced by the term Subtropical Front (STF) in the mid-1980s.

Subtropical Countercurrent An eastward flowing current found in the region from 20-26° N. In geostrophic current calculations these currents extend to the bottom of the thermocline and occasionally to 1500 m, while they've been identified in ship drift data with speeds reaching 0.15 m/s. They do not exist east of Hawaii and, given also the fact that they are in the middle of the subtropical gyre, are thought to be caused by a modification of the Sverdrup circulation by those islands. No satisfactory explanation has as yet been advanced. See Tomczak and Godfrey [1994] and Kubokawa and Inui [1999].

Subtropical Front (STF) In physical oceanography, a region of pronounced meridional gradients in surface properties that serves as the boundary between the Southern Ocean and the waters of the subtropical regime to the north. This was originally called the Subtropical Convergence (DTC) by Deacon but the newer terminology arose in the mid-1980s. This is generally a subduction region for various types of Central Water.

The STF separates the Subantarctic Surface Water (SASW) to the south from the Subtropical Surface Water to the north. The surface hydrographic properties of the STF include a rapid salinity change from 35.0 to 34.5 and a strong temperature gradient (from 14-10° C in winter and 18-14° C in summer) as one crosses from north to south. At 100 m its approximate location is within a band across which temperatures increase northward from 10 to 12° C and salinities from 34.6 to 35.0, with the salinity gradient usually the more reliable indicator. The position as well as the intensity of sinking or rising motion in the STF is more variable than in any other front or divergence in the Southern Ocean. See Tomczak and Godfrey [1994], Tchernia [1980] and Orsi et al. [1995].

Subtropical Frontal Zone (STFZ) A broad zone up to 4°–5° latitude wide consisting of several cores or fronts interspersed by zones of relatively homogeneous waters. The STFZ is thought to be a more accurate desciption of what was formerly thought to be single front called the Subtropical Front, with the STFZ boundaries being the North Subtropical Front (NSTF) and the South Subtropical Front (SSTF). See Belkin and Gordon [1996].

subtropical gyre A clockwise/counterclockwise circulation in the northern/southern hemisphere that is forced by the wind and features western intensification in the form of a western boundary current. In the northern hemisphere the gyres span the width of the oceans and extend from about 10 to 40 °N with the boundary currents in the Atlantic and Pacific called, respectively, the Gulf Stream and the Kuroshio. There are analogous features in the southern hemisphere. The polar boundaries between these and the subpolar gyres coincide with the latitude at which the curl of the wind stress vanishes, the latter being largely the mechanism of causation. See Schmitz and McCartney [1993].

Subtropical Mode Water (STMW) A type of water mass found along the equatorward side of the separated western boundary currents of each of the subtropical gyres. They are identified as a layer of reduced stratification found below the seasonal thermocline and above the main thermocline. They are formed by winter mixing and cooling, with restratification occurring in the surface layer during summer. The STMW thermostads can be traced for a considerable distance away from the formation regions following the equatorward flow of the gyre interiors.

In the North Pacific, deep convection occurs offshore of both the Kuroshio and the Kuroshio Extension in winter. Vertically homogeneous water is formed in the deep convective mixed layer which remains as a pycnostad between the seasonal and main thermoclines through the succeeding surface warming. This pycnostad is found over a much wider region in the western subtropical North Pacific than its formation area, and the water therein is the North Pacific STMW.

According to Suga and Hanawa [1995]:

> The Kuroshio Countercurrent composing the Kuroshio recirculation system advects STMW formed in the wintertime thick mixed layer immediately off the Kuroshio Current and the Kuroshio Extension. During the non–large–meander period, the recirculation system has a single anticyclonic gyre centered near 30°N, 137°E and advects STMW formed off the Kuroshio Extension, or east of 140°E, to the meridian of 137°E south of Honshu within a few months. Heavier STMW formed farther eat is advected along an outer path, taking several months longer. During the large–meander period, the recirculation system is separated into two anticyclonic gyres west and east of 140°E, and no substantial westward advection of

> STMW across the 140°E meridian occurs, while minor advectionof STMW along the outer path can occur. The climatological hydrography also suggests that the STMW formed in one winter will be dissipated considerably within a year or so.

In the South Pacific, the STMW thermostad is less pronounced than in either the North Pacific or North Atlantic. According to Roemmich and Cornuelle [1992], the South Pacific STMW ...

> ... is a thermostad, or minimum in stratification, having temperatures of about 15–19°C and vertical temperature gradient less than about 2°C per 100 m. Typical salinity is 35.5 psu at 16.5°C. The STMW layer is formed by deep mixing and cooling in the eastward–flowing waters of the separated East Australia Current (EAC). Surface mixed layers are observed as deep as 300 m north of New Zealand in winter, in the center of a recurring anticyclonic eddy.

See Masuzawa [1969], McCartney [1982], Bingham [1992], Roemmich and Cornuelle [1992], Hanawa and Suga [1995], Suga and Hanawa [1995] and Hautala and Roemmich [1998].

subtropics Generally the part of the Earth's surface between the tropics and the temperate regions, or between about 40° N and S.

Sulawesi Sea Part of the Australasian Mediterranean Sea centered at approximately 122° E and 3° N. It is surrounded by the Sulu Archipelago and Mindinao to the north, Kalimantan to the west, the Makassar Strait and Sulawesi to the south, and the north part of the Moluccan Sea to the west. It covers about 280,000 sq. km with the deepest part being around 6200 m just southwest of Mindanao. The entire Sulawesi is mostly a deep, flat (4600-5200 m deep) plain with steep sides.

The deep water Pacific Ocean water that passes through the northern Molucca Sea and enters the Sulawesi over a 1400 m deep sill. This water eventually passes through the Makassar Strait and on into the Flores Sea to the south. The surface temperatures range between 28° C in April and 27° C in February, and the salinities range through four patterns during the year (i.e. 31-34 from SW to NE during Dec.-Feb., 32.8-33.9 from SW to NE during Mar.-May, 34 from Jun.-Aug., and 33.5-34.1 from NW to SE during Sep.-Nov.).

The monsoon pattern dominates the wind forcing, with the winds blowing from the north to northeast during the northern winter and more weakly from the south and southwest during the summer. This creates a surface current directed from Mindanao towards the Makassar Strait during the summer. This regime is largely maintained through the winter although westward currents are additionally found along Sulawesi. See Fairbridge [1966].

Sulu Sea A regional sea contained within the Australasian Mediterranean Sea at the southwestern edge of the Pacific Ocean. It is centered at about 120° E and 8° N and connected to the Sulawesi Sea to the southeast via many passages through the Sulu Archipelago, the Bohol Sea to the east, and the South China Sea to the west and northwest chiefly via the Mindoro, Linapacan, North Balabac, and Balabac Straits. It borders the Philippine islands of Mindanao, Negros, and Panay to the east, Mindoro and the Calamin Group to the north, Palawan to the west, and the aforementioned Sulu Archipelago to the southeast. The Malaysian portion of the island of Borneo lies to the southwest.

sumatra A squall that occurs in the Malacca Strait, blowing from between southwest and northwest. These usually occur at night and are most frequent between April and November. They are generally accompanied by thunder and lightning and torrential rain, and their arrival is accompanied by a sudden fall of temperature.

Sunda Sea A marginal sea in the southwest Pacific Ocean. This is a name sometimes given to the combined areas of the Java Sea and the shelf sector of the South China Sea.

Sunda Shelf One of the largest continental shelves in the world. It covers around 1,800,000 km^2, is centered around 108° E and 2° N, and occupies the regions of the Java Sea, the southern parts of the South China Sea, and the Gulf of Thailand. See Fairbridge [1966].

SUPER Acronym for Subarctic Pacific Ecosystem Research, a research program in the north Pacific. See Miller [1993].

SURATLANT A French project to make systematic hydrographic observations in the North Atlantic subpolar gyre. Observations are made with the merchant ships Godafoss (between Iceland and the U.S. sine 1993) and Nuka Arctica (between Denmark and Greenland since May 1997). The sampling is mostly for temperature with XBTs and for sea surface salinity.

[http://www.obs-mip.fr/omp/legos/english/rech/var/var4.htm]

surf beat The rising and falling of the water level in the surf zone at intervals in the vicinity of 2 to 5 minutes, especially noticeable on a flat beach. This is caused by the pattern of incoming waves being such that groups of high waves and low waves follow each other at the same intervals. This is in turn due to the interaction of wave groups with slightly different frequencies, a process that leads to a much longer envelope or beat frequency modulated the short wavelength waves. See Wiegel [1964].

surf zone The portion of the nearshore zone in which borelike translation waves occur following wave breaking. It extends from the inner breakers shoreward to the swash zone. See Komar [1976].

surface energy balance The balance of energy terms at the ocean surface in a climate model. The terms are the absorbed solar flux (S), the downward infrared flux (Sd), the upward infrared flux (Su), the sensible heat flux (H), and the latent heat flux (LE). The balance can be expressed as

$$S + Sd - Su - H - HE = 0.$$

surface renewal theory A method for evaluating turbulent fluxes at the ocean surface. See Clayson et al. [1996].

surface Reynolds number See Kagan [1995].

surface scattering layer A group of marine organisms in the surface layers of the ocean which scatters sound. The layer may extend from the surface to depths as great as 600 feet, and several layers or patches may comprise the layer. There are also shallow and deep scattering layers.

surface tension More later.

SURVOSTRAL A French project started in the austral summer of 1992/1993 for monitoring climate variability at high latitudes. The objective of the program is to monitor the seasonal and interannual changes in upper ocean thermal content and salinity, as well as changes in the position, structure and transport of the polar fronts between Tasmania and Antarctica. SURVOSTRAL uses the French Antarctic supply ship Astrolabe to make measurements between Hobart, Tasmania and the French base Durmont D'Urville. Sampling is performed with XBTs and XCTDs to obtain vertical profiles of temperature and salinity, and a thermosalinograph is used to obtain continuous measurements of surface salinity and temperature.

[http://www.obs-mip.fr/omp/legos/english/rech/var/var4.htm]

SUW Abbreviation for Subarctic Upper Water.

Sverdrup, Harald Ulrik (1888–1957) Sverdrup started his scientific career by enrolling as a student in "physical oceanography and astronomy" at the University of Oslo, where his early interests leaned towards the latter. This changed when he received an assistantship to study under Professor V. Bjerknes, under whom he published twenty papers and a dissertation entitled Der nordatlantische Passat (in which he calculated energy and momentum budgets for the North Atlantic trade winds) over the next six years.

He took charge of scientific work on Roald Amundsen's North Polar expedition at the age of 29 in 1918. He did not return until late in 1925 as the expedition ship Maud attempted to duplicate the voyage (and ice drift) of the Fram. At one point during the seven years of this expedition Sverdrup left the ship to spend eight months with the nomadic Chukchi tribe of northeastern Siberia, an experience he later recounted in a book (which has never been translated into English). The collected observations of the expedition were a notable achievement, with Sverdrup's most significant contribution being a paper entitled "Dynamics of tides on the North Siberian Shelf."

Sverdrup succeeded V. Bjerknes as the Chair of Meteorology at the Geophysical Institute in Bergen, Norway upon his return, and he additionally became a research professor at the Christian Michelson Institute in Bergen in 1931. The ten years following his return from the Maud expedition were the most productive of his career, with his accomplishments including publishing over fifty papers on results from the expedition, spending two half-year periods in Washington, D.C. to help analyze the results from a cruise of the Carnegie, taking charge of the scientific work on the Wilkins Ellsworth North Polar Expedition aboard the submarine Nautilus in 1931, and spending two months in the snow fields of Spitzbergen which resulted in the first quantitative heat budget of glaciers.

In 1936 he accepted the Directorship of the Scripps Institution of Oceanography in La Jolla, California, leaving the Michelsen Institute for three years, although the war resulted in his not returning to Norway until 1948. At Scripps Sverdrup initiated the Marine Life Research Program (still ongoing today), organized the first systematic course in oceanography given in the United States, and taught and collaborated such future reknowned scientists as Gifford Ewing, Donald Pritchard, Roger Revelle, Robert Reid and Walter Munk. He spent a great deal of time and effort during the pre-war years collaborating with Martin Johnson and Richard Fleming to write the classic text The Oceans, with his chapter on the water masses and currents of the oceans still one of the best reviews of the subject available.

He returned to Norway in 1948 at the age of sixty and retired from research, dividing his time variously as Director of the Norsk Polar Institut, the President of the ICES, Prorector and Director of the Summer School for foreign students at the University of Oslo, and as Chairman of a committee for reorganizing the Norwegian educational system. He continued in these activities until a stroke weakened him and led to his death in 1957.

`[http://www.nap.edu/readingroom/books/biomems/hsverdrup.html]`

Sverdrup A unit of transport used in oceanography equivalent to 10^6 m^{3}s^{-1} and abbreviated as Sv.

Sverdrup balance A vorticity balance in which meridional advection in the presence of the planetary vorticity gradient is balanced by the stretching of fluid columns. It is most simply stated as

$$\beta v = f \frac{\partial w}{\partial z}$$

where β is the meridional gradient of the Coriolis parameter f, v the meridional velocity, and w the vertical velocity. This indicates that the stiffness imparted to a large scale fluid by planetary rotation leads to the conservation of the separation of marked fluid surfaces measured parallel with the rotation vector.

Sverdrup transport The net meridional flow of mass in the interior of the ocean gyres away from the lateral boundaries.

SVP Abbreviation for Surface Velocity Program, a WOCE project.

Swallow float A neutrally buoyant float used as a subsurface drifter to study mesoscale circulation and small-scale motions in the oceans. Swallow floats approximately track isobaric surfaces, and as such are not strictly Lagrangian followers of water parcels.

Rossby et al. [1985] describe a modified version of the float that follows isopycnal rather than isobaric surfaces, and thus better approximates Lagrangian motion. This is accomplished by the addition of a compressor within the float that adjusts its effective compressibility to approximate that of seawater. See Swallow [1955] and Rossby et al. [1985].

swamp ocean The simplest ocean model used in coupled model simulations. SSTs are computed but from surface energy balance (local effects) only, i.e. there is no accounting for heat storage (temporal) or ocean current (nonlocal) effects. Only mean annual forcing can be applied when a swamp ocean is used since the lack of the capability to store heat in the oceans would allow sea ice to freeze into the mid-latitudes in the winter hemisphere. On the plus side, the dominant equilibration time is that of the atmosphere since the ocean surface response time is almost instantaneous.

SWADE Acronym for Surface WAve Dynamics Experiment, an experiment performed in the fall of 1990 off the coast of Virginia which was primarily concerned with the evolution of the directional wave spectrum, wind forcing and wave dissipation, the effect of waves on air-sea coupling mechanisms, and the microwave radar response of the ocean surface. The scientific goals were to understand the dynamics of the evolution of the wave field in the open ocean; to determine the effect of waves on the air-sea transfers of momentum, heat and mass; to explore the response of the upper mixed layer to atmospheric forcing; to investigate the effect of waves on the response of various airborne microwave systems; and to improve numerical wave modeling. See Weller et al. [1991] and Willemsen [1995].

SWAMP 1. Acronym for Sea Wave Modeling Project. See group [1985]. 2. Acronym for Southwest Area Monsoon Project.

SWAN Acronym for Simulating WAves Nearshore, a third–generation wave model that computes random, short–crested, wind–generated waves in coastal regions and inland waters. The physics accounted for in the SWAN model includes:

- wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents, and nonstationary depth;
- wave generation by wind;
- three– and four–wave interactions;
- whitecapping, bottom friction, and depth–induced breaking;
- wave–induced setup;
- propagation from laboratory up to global scales; and
- transmission through and reflection from obstacles.

A copy of the FORTRAN code is available upon registration. See Booij et al. [1999].

`[http://swan.ct.tudelft.nl/home.htm]`

SWAPP Acronym for Surface WAve Processes Program, an experiment conducted off the coast of California in 1990 and concerned with wave breaking and the interaction between surface waves and upper ocean boundary layer dynamics. The scientific goals were to improve the understanding of processes involved in wave breaking (e.g. what determines the occurrence of breaking in space and time, the processes of bubble and fluid injection, the generation of turbulence in the upper layer of the ocean by waves) and in determining the structure of the upper ocean (e.g. the role of surface waves in air-sea transfers and in mixed layer dynamics, with particular emphasis on the structure and dynamics of Langmuir circulation. See Weller et al. [1991].

SWARM95 Acronym for Shallow Water Acoustic Random Media 1995 experiment, an ONR sponsored joint operation between the NRL Acoustic Signal Processing Branch and Woods Hole. The goal is to explore the effects on acoustic propagation of random ocean environments in the water column and the bottom sediments. The experiment was performed on the continental shelf about 100 miles of the coast of New Jersey in the Hudson Canyon area in July–August 1995, and deployed a significant number of acoustic and oceanographic equipment to characterize the acoustic propagation environment. See apel:1997.

[http://www.oal.whoi.edu/swarm.html]

swash zone The portion of the nearshore zone in which the beach face is alternately covered by the uprush of wave swash and exposed by the backwash. See Komar [1976].

Swedish Deep Sea Expedition A research cruise taking place from 1947–1948 aboard the vessel "Albatross," The expedition was headed by Hans Pettersson who also edited the ten–volume series of research reports published starting in 1957. The contents of the reports were:

1. The ship, its equipment, and the voyage
2. Zoology
3. Physics and chemistry
4. Bottom investigations
5. Sediment cores from the East Pacific
6. Sediment cores from the West Pacific
7. Sediment cores from the North Atlantic Ocean
8. Sediment cores from the Mediterranean Sea and the Red Sea
9. Sediment cores from the Indian Ocean
10. Special investigations

See Guberlet [1964].

SWIM Acronym for Shallow Water Intercomparison of wave prediction Models, and extension of the SWAMP project to shallow water. See group [1985].

SWIMS Acronym for Shallow Water Integrated Mapping System, an instrument developed by the APL.

SWIMSAT Acronym for Surface Waves Investigation and Monitoring from SATellite, a project to design, develop and use systems to measure directional wave spectra from satellites using the real–aperture technique rather than the traditional SAR technique. The system is a dual–beam radar (capable of nadir viewing and off–nadir viewing at an angle of 10°) operating in the K_μ frequency band (13.565 GHz) and flying on a polar–orbiting satellite at an altitude of 450–600 km. The nadir beam is operated to measure significant wave height and wind speed in the same way as spaceborne altimeters. An innovative feature is its operation in off–nadir viewing mode by tilting the radar beam to measure wave spectral characteristics. The principle is based on measuring modulations of the radar backscatter coefficient inside the swatch covered by the tilted beam. The tilted beam is rotated to perform a conical scan around the vertical axis to acquire measurements in all directions of wave propagation. SWIMSAT should be capable of measuring wave spectral properties under wind–sea (provided the dominant wavelength is greater than about 70 m) and swell conditions (provided the significant wave height is greater than 1.5–2 m, depending on wind). See Hauser et al. [2001].

SWODDY Acronym for Slope Water Oceanic eDDY, a term coined in Pingree and LeCann [1992] to describe jet–like extensions of the slope current off northern Spain and France in the southern Bay of Biscay in the winter that develop into anticyclonic eddies with an upper core of slope water. A typical SWODDY has a lifetime of about a year and, if not trapped by topography, propagates or advects westwards out of the Bay of Biscay at typical speeds of about 2 cm s^{-1}.

SWT Abbreviation for southern warm tongue, a tongue of relatively warm water located at the eastern boundary of the WPWP. It is located at around 10 ° S. See Ho et al. [1995].

SYMPLEX An experiment (also called ERS–SYMPLEX) carried out in the Sicily Channel during April–May 1996 to compare sea level anomalies obtained from ERS–1/2 and TOPEX/POSEIDON altimeters with in situ data. A dense network (about 5 km spacing) of XBT and CTD casts were made along all ERS–1/2 and TOPEX/POSEIDON tracks at the same time of each satellite pass.

`[http://earth.esa.int/symposia/data/santoleri2/]`

SYNOP Acronym for the SYNoptic Ocean Prediction experiment, an observational and modeling experiment designed to understand the physics governing large amplitude meandering of the Gulf Stream and the shedding and interactions of rings east of Cape Hatteras to the Grand Banks. The moored instrument program consisted of four arrays:

- the Inlet Array near Cape Hatteras, consisting of 9 inverted echo sounders (IES) and 5 deep current meters, and designed to monitor the inflow conditions as the Gulf Stream leaves the continental margin;
- the Central Array near 68°W, consisting of 24 IESs (12 with bottom pressure gauges) and 12 tall current moorings, each with four levels (400, 700, 1000 and 3500 m) instrumented, with three having upward–looking ADCPs above the topmost current meter;
- the East Array near 55°W; and
- the 50°W array.

Observations were made between 1987 and 1990.

A significant finding of SYNOP was the presence of strong, deep cyclones and anticyclones beneath the Gulf Stream, with the spin–up of the deep flow field occuring during the passage of the steep meander crests and troughs of the Stream. Velocities at 3500 m were observed to be as high as 35-40 cm s^{-1} during the strong events. See Tracey and Watts [1991].

`[http://mail.po.gso.uri.edu/dynamics/SYNOP/]`

synoptic Descriptive of data simultaneously obtained over a large area.

synoptic mean circulation In oceanography, the time-averaged flow field obtained in a coordinate system whose axes are parallel and perpendicular to the instantaneous axis of a particular strong current such as the Gulf Stream. This coordinate system can and does change with time. Compare to Eulerian mean circulation. See Schmitz and McCartney [1993].

systematic errors Stable errors in model simulations that result from model deficiencies in the component (e.g ocean and atmosphere) models alone, additive errors from the component models after they are coupled, or errors that are produced by the coupled interactions between imperfect component models. Sometimes called climate drift. See Meehl [1992].

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tablemount See guyot.

Tahiti Shuttle Experiment See Hawaii-Tahiti Shuttle Experiment.

Taiwan Strait The Taiwan Strait is summarized by Jan et al. [2002] as: **?**]he Taiwan Strait is an essentially meridional channel connecting the East and South China Seas. There is often a northward current on the east side and a southward current on the west side. The source water feeding the eastern boundary current is South China Sea Water in summer and Kuroshio Branch Water in other seasons. The current on the west side carries colder and fresher China Coastal Water southward. Both currents are modulated by the annual cycle of monsoon wind forcing, which reinforces the northward current in summer but southward current in other seasons. Further, both currents are partially impeded by a bottom ridge (Changyun Rise) in the middle reaches of the strait. They summarize the seasonal differences as: **?**]n winter, the northward intrusion of Kuroshio Branch Water is severely blocked by the northeast monsoon, and the southward penetration of China Coastal Water is maximum. A portion of the China Coastal Water is deflected by the Changyun Rise and turns back northeastward. In spring, relaxation of northeast monsoon unleashes the northward intrusion of the Kuroshio Branch Water, and the China Coastal Water retreats northward. With the aid of summer stratification and southwest monsoon, the northward intrusion of the South China Sea Water in summer is relatively unimpeded by the Changyun Rise; only the bottom flow is deflected anticyclonically. Further, the China Coastal Water fails to enter the TS. The fall pattern is similar to the summer pattern, except for the emergence of the China Coastal Water in the northwestern reaches of the strait. See Jan et al. [2002].

TAMEX Acronym for Taiwan Area Mesoscale Experiment. The planning phase of this took place from 1985-86 and the field operations phase during 1987.

TAO Acronym for Tropical Atmosphere Ocean array, a TOGA experiment, an array of approximately 70 moorings in the tropical Pacific Ocean that telemeter oceanographic and meteorological data to shore in real–time via the Argos satellite system. The development of TAO was motivated by the 1982–1983 El Nino event, the strongest of the century up to that time. It was neither predicted nor detected until it nearly reached its peak, prompting the need for real–time data from the tropical Pacific for monitoring, prediction, and improved understanding of El Nino.

PMEL began the development of the ATLAS mooring in 1983 with support from the NOAA EPOCS program. Prototype ATLAS moorings were field tested in early 1984, with a modest array deployed along 110W in late 1984. Additional ATLAS deployments were made beginning in 1985 at the start of the 10–year TOGA program. The array, now named TAO, grew slowly during the first half of TOGA, and then rapidly during the second half as the ATLAS moorings proved a great success. The full array was not completed until the final month of TOGA (Dec. 1994). During the 10 years TAO was under development, over 400 buoys were deployed on 83 cruises using 17 ships from 6 countries.

After TOGA ended, TAO continued under the sponsorship of CLIVAR, GOOS and GCOS. NOAA was comissioned to service the array east of 165E in 1996, and in 1997 the U.S. Congress authorized long term sustained support of the array as part of an operational ENSO observing system. On Jan. 1, 2000, it was officially renamed the TAO/TRITON array, with sites west of 165E occupied by TRITON buoys maintained by Japan's JAMSTEC.

The current operationally supported measurements of the array consist of winds, SST, relative humidity, air temperature, and subsurface temperature at 10 depths in the upper 500 m. Five moorings along the equator also measure water velocity. Additional moorings or enhancements to existing moorings are occasionally added in support of specific research objectives. See Hayes et al. [1990] and McPhaden [1995].

[http://www.pmel.noaa.gov/tao/]

TAO Acronym for Transport Processes in the Atmosphere and the Oceans, a program to study transport processes in geophysical fluids mainly from a theoretical point of view. See the TAO Web site[152].

TAO/TRITON The new name of the TAO mooring array as of Jan. 1, 2000. See TAO.

TAP Acronym for Transarctic Acoustic Propagation experiment, carried out in April 1994 at an ice camp north of Svalbard. A joint US/Russian scientific party deployed an experimental 20 MHz source and transmitted various signals to listening stations in the Beaufort and Lincoln Seas for 5 days. TAP was a feasibility test to see if acoustic signals could be used to study the Arctic and monitor it on a long term basis. See Pawlowicz et al. [1995] and the TAP Web site[153].

TAPS Acronym for Tracor Acoustic Profiling System, a family of instruments developed by TRACOR to study the size and extent of populations of very small marine life by measuring the acoustic signals backscattered from them at frequencies in the MHz range. The TAPS sensors can be lowered through the water column in cast mode, attached to net systems such as the MOCNESS, or deployed on a SeaSoar unit.

[http://www.aard.tracor.com/home/eco/MarEco.html]

TAS Abbreviation for Tropical Atlantic Study, a part of the TTO program.

TASC Acronym for Trans-Atlantic Study of Calanas finmarchicus, an EU-funded program to understand the physical and biological processes which control the population dynamics of the copepod Calanus finmarchicus, a key zooplankton species in the northeast Atlantic. A key goal is to establish the relationship between the physical and biological factors affecting annual recruitment and reproduction of the species as a step towards predicting the consequences of future climate change. See the TASC Web site[154].

Tasman Front See Stanton [1981].

Tasman Sea A marginal sea located in the southwest Pacific centered at about 160° E and 37° S off the southwest coast of Australia. It is also surrounded by New Zealand to the east, Tasmania to the southwest, and the Coral Sea to the north. The maximum depth is 5943 m. The bathymetry is essentially composed of the east Australian Basin in the westerly part and the depression of New Caledonia to the east, with the two separated by the Lord Howe Sill. See Rotschi and Lemasson [1967].

Tatarskyi Strait See Okhotsk Sea.

Taylor column If relative motion is created in a rotating container by heating or by stirring and if an obstacle is placed on the bottom of the tank so that the moving fluid must flow around it, then the streamlines of the flow will form a column, going around the obstacle as if it extended to the top of the water. This is called a Taylor column. The same sort of phenomena can occur in real world analogues of this experimental example. This is a consequence of what is known as the Taylor-Proudman theorem. See Dutton [1986].

Taylor-Proudman theorem A two-dimensional fluid flow theorem that states that geostrophic motion of a homogeneous fluid will be the same in all planes perpendicular to the axis of rotation. This has also been known as the Proudman-Taylor, Proudman or Taylor theorem. See Hide [1978].

[152] http://www.esf.c-strasbourg.fr/lp/lp_017a.htm
[153] http://pinger.ios.bc.ca/people/rich/tap.html
[154] http://calanus.nfh.uit.no/TASC.HTML

TCIPO Abbreviation for TOGA COARE International Project Office.

teleconnections The ability of a phenomenon in one part of the world to influence phenomena in another part of the world. Examples include the influence of the ENSO phenomena on the Indian monsoon and the droughts in the Sahel region of Africa. Teleconnection pataterns are recurring and persistent large–scale patterns of pressure and circulation anomalies spanning vast geographical areas. They are also referred to as preferred modes of low–frequency or long time–scale variability. The patterns typically last for weeks to several months, although they can occasionally be prominent for several years and thus influence both the interannual and interdecadacal atmospheric and oceanic variability.

Teleconnection patterns are a naturally occurring part of the chaotic atmosphere, and arise primarily from internal atmospheric dynamics, although some are forced by changes in tropical SSTs and convection associated with the ENSO cycle and the Madden–Julian Oscillation. The patterns reflect large–scale changes in the wave and jet stream patterns in the atmosphere, and influence temperature, rainfall, storm tracks and jet stream location and intensity over large areas. For example, they can be responsible for abnormal weather patterns occurring simultaneously at widely separated locations.

A technique called Rotated Principle Coordinate Analysis (RPCA) has been used to determine the most prominent teleconnection patterns in the northern hemisphere extratropics. They are:

- North Atlantic Oscillation (NAO);
- East Atlantic Pattern (EA), appears in aall months except May–August and consists of a north–south dipole of anomaly centers spanning the entire North Atlantic from east to west;
- East Atlantic Jet (Ea–Jet), appears between April and August and consists of a north–south dipole of anomaly centers, one over the high latitudes of the eastern North Atlantic and Scandinavia and the other over Northern Africa and the Mediterranean Sea;
- East Atlantic/Western Russia pattern (EA/WR) (also known as the Eurasia-2 pattern), prominent in all months except June–August, with two anomaly centers (over the Caspian Sea and western Europe) in winter, and three in the spring and fall;
- Scandinavia pattern (SCA) (also known as the Eurasia-1 pattern), seen in all months except June and July, with a primary center over Scandinavia and larage parts of the Arctic north of Siberia and two weaker centers with opposite sign over western Europe and Mongolia/western China;
- Polar/Eurasia pattern (POL), the most prominent mode from December through February, consisting of one center over the polar region and centers of opposite sign over Europe and northeastern China;
- Asian Summer pattern (ASU), prominent from June to August, this is a monopole pattern with anomalies of the same sign throughout southern Asia and northeastern Africa;
- West Pacific pattern (WP), prominent in all months, consisting of a north–south dipole during winter and spring, with a third prominent center appearing in the summer and fall;
- East Pacific pattern (EP), prominent in all months except August and September, consisting of a north–south dipole of height anomalies over the eastern North Pacific;
- North Pacific pattern (NP), prominent from March through July, consisting of a primary center spanning the central latitudes of the western and central Pacific and a weaker region of opposite sign spanning eastern Sibera, Alaska and the western mountains of North America;
- Pacific/North American pattern (PNA);
- Tropical/Northern Hemisphere pattern (TNH), prominent from November to February, consisting of a primary center over the Gulf of Alaska and a separate center of opposite sign over Hudson Bay; and

- Pacific Transition pattern (PT), prominent between May and August, consisting of a wave–like pattern of height anomalies extending from the Gulf of Alaska eastward to the Labrador Sea along 40 deg. N.

See Barnston and Livezey [1987] and Trenberth et al. [1998].

[http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.html]

temperature inversion In meteorology, a region of negative lapse rate.

temperature lapse rate The rate of decrease of temperature with height.

temperature ramp A coherent structure found in the upper ocean that has been observed in both stable and unstable conditions. These are found in the upper few meters, are aligned with the wind, and marked by horizontal temperature changes of 0.1 K over 0.1 m. They indicate the upward transport of cool/warm fluid during stable/unstable conditions, and are driven by an instability triggered by the wind thought to be similar to the Kelvin–Helmholtzinstability. These are as yet not well understood.

TEP Abbreviation for Transparent Exopolymer Particles, an organic ocean particle that is not normally detectable because it is transparent. These gel–like polysaccharide particles form the matrix of marine snow and play an important role in the coagulation of some algal blooms. TEP are operationally defined as transparent particles formed from acid polysaccharides that are stainable with alcian blue.

A larger context is provided by Passow [2002]:

> In marine ecosystems, polysaccharides are an important component of the labile fraction of DOC. Because of their high molecular weight they predominantly belong to the colloidal fraction of DOC. Many aquatic organisms, including phytoplankton and bacteria generate large amounts of extracellular polysaccharides. Diatoms are especially well known for excreting copious quantities of polysaccharides during all phases of their growth. Such exopolymeric substances, called EPS, range in structure from being loose slimes to tight capsules surrounding the cells. One type of EPS, the transparent exopolymer particles, called TEP, has received increasing attention because the TEP exist as individual particles rather than as cell coatings or dissolved slimes. The role of TEP in aquatic systems differs from other forms of EPS, because as individual particles not only can they aggregate but also they can be collected by filtration; whereas dissolved substances can only mix with the surrounding water.

See Alldredge and Jackson [1995] and Passow [2002].

TEPPS Acronym for Tropical Eastern Pacific Process Study cruise, a 1997 PACS study whose purpose was to document the clouds and precipitation of the tropical eastern Pacific from the surface. The timing and location of the cruise were designed to permit the ship's instruments to sample storm structure when and where there is the greatest difference between the different satellite precipitation estimates. The scientific objectives were:

- to estimate precipitation with radar and compare it with the two satellite estimates; and
- to understand the physical reasons behind the difference in precipitation estimates based on infrared and microwave satellite data.

[http://www.atmos.washington.edu/gcg/MG/tepps/]

terrace The official IHO definition for this undersea feature name is "a relatively flat horizontal or gently inclined surface, sometimes long and narrow, which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side."

Tethys Sea A paleogeographic term for a sea that partly intersected Pangaea in the Permian and later separated the two Mesozoic supercontinents of Laurasia and Gondwana.

TEW Acronym for Transport of Equatorial Waters, a research project.

Texas Current See Vastano et al. [1995].

THEP Acronym for TOGA Heat Exchange Program.

thermal diffusivity A number that characterizes the rate of molecular diffusion of heat in a liquid. In the temperature range from 0 to 30°C, this varies from 0.1809 to 0.284 cm^2/s for air and from 0.0013 to 0.0015 cm^2/s for water.

thermal equator An imaginary line connecting those points around the globe with the highest mean temperature for the given period. As such, the position of the thermal equator varies with the season. Due to the thermal inertia of the ocean, the position of this moves north and south with the Sun but is always between the Sun and the geographic equator. The mean position is north of the geographic equator due mainly to the majority of land masses being in the northern hemisphere.

thermal expansion coefficient A quantity arising from taking derivatives of the density in the (p, θ, S) representation of the equation of state. This is defined in seawater as:

$$\alpha = -\frac{1}{\rho}\frac{\partial\rho}{\partial\theta}\bigg|_{S,\rho} = \left[-\frac{1}{\rho}\frac{\partial\rho}{\partial T}\bigg|_{S,\rho}\right]\left[\frac{\partial\theta}{\partial T}\bigg|_{S,\rho}\right]^{-1}$$

where ρ is the *in situ* density, θ is the potential temperature, S is the salinity, and T is the temperature. In practice, $\frac{\partial\rho}{\partial T}$ can be obtained from the International Equation of State of seawater, and $\frac{\partial\theta}{\partial T}$ from Bryden [1973]. In general, a < 0, and -a increase with increasing temperature and pressure.

McDougall [1987b] gives a polynomial expression for α/β (with a similar expression for β found in the saline contraction coefficient entry used to find just α):

$$\begin{aligned}\alpha/\beta &= +0.665157\times10^{-1} + 0.170907\times10^{-1}\theta - 0.203814\times10^{-3}\theta^2\\ &+ 0.298357\times10^{-5}\theta^3 - 0.255019\times10^{-7}\theta^4 + (S-35.0)[+0.378110\times10^{-2}\\ &- 0.846960\times10^{-4}\theta - 0.164759\times10^{-6}p - 0.251520\times10^{-11}p^2]\\ &+ (S-35.0)^2[-0.678662\times10^{-5}] + p[0.380374\times10^{-4} - 0.933746\times10^{-6}\theta\\ &+ 0.791325\times10^{-8}\theta^2] + 0.512857\times10^{-12}p^2\theta^2 - 0.302285\times10^{-13}p^3\end{aligned}$$

where the rms error of the fit is 0.000894 psu $°C^{-1}$ and a check value is 0.34763 psu $°C^{-1}$ at $S =$ 40 psu, $\theta = 10.0$°C and $p = 4000$ db. See McDougall et al. [1987] and the related saline contraction coefficient and adiabatic compressibility.

thermal wind equations These allow the calculation of the vertical variation of velocity from the density field. The name thermal is an artifact from the original meteorological use where the temperature field was used as a proxy for the density field. In oceanography, the fact that salinity can also significantly contribute to variations in the density field leads to the use of density rather than temperature. The thermal wind equations are derived from the horizontal equations of motion and the hydrostatic equation, beginning with the equations of motion reduced to the geostrophic equations, i.e.

$$fv = \frac{1}{\rho}\frac{\partial p}{\partial x}$$

$$fu = -\frac{1}{\rho}\frac{\partial p}{\partial y},$$

where $f = 2\Omega \sin\phi$ is the Coriolis parameter, u and v the horizontal velocity components, p the pressure, and ρ the density. The vertical derivative of each equation is taken, the order of differentiation switched for the pressure, and the hydrostatic equation ($dp/dt = \rho g$) substituted to obtain

$$\frac{\partial(\rho f u)}{\partial z} = -g\frac{\partial \rho}{\partial x}$$

$$\frac{\partial(\rho f v)}{\partial z} = g\frac{\partial \rho}{\partial y}.$$

These equations only give the variation of the velocity with depth. Further information must be supplied to obtain absolute velocities.

thermobaric coefficient A quantity defined as:

$$b = \frac{1}{2}\left(\frac{1}{\beta}\frac{\partial \beta}{\partial p} - \frac{1}{\alpha}\frac{\partial \alpha}{\partial p}\right)$$

where β is the saline contraction coefficient, α is the thermal expansion coefficient, and p is the pressure. It can also be defined in terms of the adiabatic compressibility κ as

$$b = \frac{1}{2}\left(\frac{1}{\beta}\frac{\partial \kappa}{\partial S} - \frac{1}{\alpha}\frac{\partial \kappa}{\partial \theta}\right)$$

where S is the salinity and θ is the potential temperature. See McDougall [1987b].

thermobaricity A phenomena related to the pressure dependence of the thermal expansion coefficient for the density of seawater. The dependence of the compressibility of seawater on both potential temperature and salinity means that water parcels displaced laterally without doing any work against gravity will not follow neutral surfaces defined in terms of spatially averaged (rather than instantaneous or local) potential temperature and salinity. They will move off this surface in a process called thermobaricity. For example, stirring by mesoscale eddies leads to a net motion of fluid across neutral surfaces. The process called cabbeling leads to the same result of moving fluid across neutral surface, although by mixing at the molecular level rather than by stirring. See McDougall [1987b].

thermocline Specifically the depth at which the temperature gradient is a maximum. Generally a layer of water with a more intensive vertical gradient in temperature than in the layers either above or below it. When measurements do not allow a specific depth to be pinpointed as a thermocline a depth range is specified and referred to as the thermocline zone. The depth and thickness of these layers vary with season, latitude and longitude, and local environmental conditions. In the midlatitude ocean there is a permanent thermocline residing between 150-900 meters below the surface, a seasonal thermocline that varies with the seasons (developing in spring, becoming stronger in summer, and disappearing in fall and winter), and a diurnal thermocline that forms very near the surface during the day and disappears at night. There is no permanent thermocline present in polar waters, although a seasonal thermocline can usually be identified.

The basic dynamic balance that maintains the permanent thermocline is thought to be one between the downward diffusive transport of heat and the upward convective transport of cold water from great depths. A review of the governing dynamics of the permanent thermocline can be found in Pedlosky [1987].

thermocline zone See thermocline.

thermoelectric Schlierenmeter An instrument used in the mid-20th century to record rapid temperature changes in the ocean. It consisted of a constantin wire soldered to copper wires in two places. One junction was exposed to the sea water, and the other embedded in compact insulation material. The thermoelectric current induced depended on the temperature difference between the two junctions, and was indicated by means of a remote galvanometer. This instrument therefore measured the temperature difference between the sea water and the insulated junction rather than the temperature itself. See Dietrich [1963].

thermogram See thermograph.

thermograph A recording thermometer which measures a continuous trace of temperature called a thermogram. The classical version of this featured a bi-metallic strip attached to a lever holding a pen. As the strip expanded and contracted in response to temperature changes, the pen moved across a piece of paper on a drum rotating via some clockwork mechanim. Such things are done using solid state devices sending binary data to other solid state devices in these modern times.

thermohaline In oceanography, descriptive of a combination of temperature and salinity effects.

thermohaline circulation That part of the ocean circulation driven by temporal and spatial differences in both the salinity and temperature of the waters that comprise the world ocean. A simplified schematic model of this circulation is the conveyor belt model.

thermohaline convection See double diffusive convection.

thermohaline intrusions According to Ruddick and Kerr [2003]:

> Inversions in temperature and salinity occur in most oceanic CTD casts, and are a signature of thermohaline intrusions, produced by lateral sheared advection across lateral water mass gradients. They are typically 'thermohaline' in origin – self-driven by the release of potential energy via vertical double-diffusion, and cause lateral mixing that is slow and steady, but comparable to the stirring by baroclinic eddies.
>
> The dynamic mechanism behind thermohaline intrusions is simple but subtle, and was first elucidated by Stern (1967) and later in laboratory experiments by Turner (1978). Consider a situation with lateral gradients of temperature and salinity (Fig. 1), and a vertical stratification that supports salt fingering. If a perturbation consisting of alternating shear zones is superposed, the lateral advection and lateral T/S gradients act to produce alternating vertical T and S gradients that will alternately enhance and weaken the existing salt fingers. This produces flux convergences that tend to reduce the T and S perturbations. However, because the buoyancy flux for salt fingers is up-gradient (a downward density flux), the fluxes will make the warm, salty perturbations become less dense but will make the cool, fresh perturbations more dense. If the initial perturbation has a slight slope (as shown) such that the warm, saline perturbations slope upwards from the warm, salty side, then the density perturbations will act to reinforce the initial motion. The warm salty layers thus become anomalously light because of the flux convergence, and 'slide upwards' from the warm salty side, whereas the converse occurs to the cool fresh layers. The linear instability works via a positive feedback loop:
>
> 1. Lateral, along-intrusion, sheared advection;
> 2. Alternately strengthened and weakened gradients and salt finger fluxes;
> 3. Alternately positive and negative density perturbations;

4. Sloping density perturbations create pressure perturbations;
5. Pressure perturbations accelerate the original advective motions.

Since velocity is anti-correlated with the S and T perturbations, the lateral intrusive heat and salt fluxes are down-gradient. Since there is a systematic density perturbation, there is an along-intrusion (and slightly downwards) density flux towards the warm, salty side. If the diffusive fluxes dominate, the slope and along-intrusion density flux are reversed.

See Ruddick and Kerr [2003].

thermometric depth A depth determination that actually represents a pressure determination and is used more for the determination of the position of bottle samplers and instruments on research vessels than for the determination of the depth of the water above the seafloor. This sort of depth control is needed because of the large wire angles that can frequently occur when a ship is at station and currents at depth move the wire away from the vertical position, causing the true depth of the instruments to not correspond to the length of the wire. The method uses two mercury thermometers, one pressure protected which measures the temperature in situ and the other unprotected and subject to elastic deformation by the pressure of the water column. The unprotected thermometer thus registers not only a rise in mercury corresponding to the in situ temperature but also a rise proportional to the hydrostatic pressure and, therefore, to the depth. The accuracy of this method, first determined and extensively discussed by Wüst during his work aboard the Meteor, is ±20 m at 5000 m depth. See Dietrich [1963].

thermosolutal convection See double diffusive convection.

thermosphere One of two regions into which the ocean depths are sometimes divided according to temperature, the other being the psychrosphere. The thermosphere is the upper regions of the ocean where the temperature is greater than 10° C. This coincides with the ocean troposphere.

thermostad A layer where the vertical change of temperature is very small and displays a local minimum.

thermosteric anomaly The portion of the specific volume anomaly that accounts for most of the effects of salinities and temperatures differing from the standard calculation levels of 35 ppt and 0° C, respectively. These three terms account for the individual effects of salinity and temperature perturbations as well as their combined effect.

THETIS Abbreviation for Tomography System for Monitoring the Western Mediterranean Basin, a project that started in October 1993 and was completed in September 1995. The objective of the project was to use tomography to study the Western Mediterranean Sea. THETIS-I investigated changes on the 100 km scale, and THETIS-II was aimed at observing basin scale heat content changes at scales up to 600 km. The second experiment consisted of a network of seven moorings with tomographic transceivers, current meters, and temperature sensors deployed in January 1994 and recovered in October 1994. See the THETIS Web site[155].

Thompson, Benjamin (1753–1814) See Peterson et al. [1996], p. 48.

Thomson, Charles Wyville (1830–1882) See Peterson et al. [1996], p. 93.

Thorpe scale In a stratified ocean, a vertical profile may contain regions of static instability. Vertical displacements can be created by reordering the profile to achieve static stability. An RMS value of these displacements within a specific depth range is a length scale called the Thorpe Scale. It can empirically be related to the Ozmidov scale. See McDougall et al. [1987].

[155]http://www.cadrus.fr/madam/doc/projects/theti/qd_theti.htm

Thracian Sea The northern part of the Aegean Sea.

THRUST Acronym for Tsunami Hazards Reduction Utilizing Systems Technology, a NOAA PMEL project to demonstrate the use of satellite technology with existing tsunami warning methods to create a low–cost, reliable, local tsunami warning system. See Bernard [1991].

Tiburon A remote operated vehicle (ROV) developed at MBARI. See the Tiburon Web site[156].

tidal bore To be completed.

tidal ellipse

tidal epoch The phase lag of the maximum of a given constituent of an observed tide behind the corresponding maximum of the theoretical equilibrium tide.

tidal evolution The changing of the Earth–Moon tidal characteristics over time. See Kagan [1997].

tidal friction The first quantitative theory of the tidal evolution of the Earth-Moon system was presented in a series of papers by George Darwin (Darwin [1879], Darwin [1880b], and Darwin [1880a]) in the latter part of the 19th century where he showed that tidal friction can radically change the Moon's motion and the Earth's rotation on geologic time scales. One consequence of this theory is that paleotides had different periods. See Kagan and Sündermann [1996], Munk [1968], Munk and MacDonald [1960] and Munk [1997].

tidal wave An egregious misnomer for a type of wave that has nothing to do with tides or tide-producing forces. See the more apt term seismic sea wave for a description.

tide The periodic rising and falling of the water that results from the gravitational attraction of the moon and sun acting on the rotating earth. There are related phenomena that occur in the solid earth and the atmosphere called, strangely enough, earth tides and atmospheric tides. The forces that significantly effect the tides of the oceans are the gravitational forces of the sun and moon, the centrifugal force due to the movement of the earth in its orbit, the Coriolis force, and the frictional force due to the movement of the water with respect to its boundaries. See Cartwright [1999], Doodson and Warburg [1941], Douglas et al. [2000], Emery and Aubrey [1991], Open University [1989], Pirazzoli [1996], Pugh [1987], Rahman [1988] and Wiegel [1964].

Tide Chart A map showing the water levels throughout a bay or estuary at a particular point in time. Tide Charts normally show the water levels on an hourly basis after high tide. They are available for a relatively few locations around the U.S. Contrast with Tide Table.

`[http://co-ops.nos.noaa.gov/faq2.html]`

Tide Table A tidal prediction table showing the daily high and low tide predictions for a particular location. Contrast with Tide Chart.

`[http://co-ops.nos.noaa.gov/faq2.html]`

TIME Acronym for Tsunami Inundation Modeling Exchange, an IOC project.

time series Any series of observations of a physical variable that is sampled at changing time intervals. A regular sampling interval is usually presumed although not required.

[156] http://www.mbari.org/~audo/Tiburon/index.htm

time step The basic unit of temporal resolution in a numerical model created by discretizing a continuum differential equation to create an analogous discrete algebraic equation. The model time advances by discrete steps as opposed to the (at least perceived) continuum nature of time in the real world.

Timor Sea A regional sea located in the Australasian Mediterranean Sea and centered at about 12° S and 127° E. It consists of Timor Strait to the north and the Sahul Shelf to the south, with the former having a width of 80 km and a maximum depth of 3 km in the Timor Trench. Sills to the west (1860 m) and east (1400 m) control the allowable flow at depth. Overall, the flow is strongest in the strait and extends with decreasing velocities onto the shelf.

Current measurements show a transport from east to west on the order of 7 Sv through the strait and a seasonally varying 1-3 Sv on the shelf. The currents on the shelf flow northeastward along the shelf (to about 12.5° S where they turn more northward) from September until January. The onset of the monsoons in March turns the flow toward the southwest which continues until September, except near the coast where the southwestward flow reverses in May. See Cresswell et al. [1993].

TIWE Abbreviation for Tropical Instability Waves Experiment, a project of the APL of the University of Washington Department of Oceanography. This study, taking place from 1990–1991, studied the life cycle and energy sources for tropical instability waves in the eastern Pacific. See Qiao and Weisberg [1995].

Tizard Deep See Brazil Basin.

TMA spectrum A wave spectrum developed to incorporate finite depth effects into the JONSWAP spectrum. See Bouws et al. [1984].

TMAP Abbreviation for Thermal Modeling and Analysis Project. See the TMAP Web site[157].

TMR Abbreviation for TOPEX microwave radiometer, an instrument on the TOPEX/POSEIDON mission. The TMR measures sea surface microwave emissivity at three frequencies (18, 21, and 37 GHz) to estimate to total water vapor content in the atmosphere. This estimate is used to correct to the water vapor–induced errors in the altimeter measurement. The 21 GHz channel is the primary channel for water vapor measurement, with the 18 GHz and 37 GHz channels used to remove the effects of wind speed and cloud cover, respectively. See Ruf et al. [1994].

TOBI Acronym for Towed Ocean Bottom Instrument, a deep–towed multi–sensor sonar sytem that comprises a two–sided 30 kHz sidescan sonar, a 7.5 kHz sub–bottom profiler sonar, a magnetometer, a temperature probe, a transmissometer, and a range of vehicle handling instruments. TOBI is towed on a 200 meter umbilical behind a 600 kg depressor weight attached to the surface ship via the main 0.68 in. armored coaxial cable, which reduces ship–induced heaving that influences the stability of the vehicle. The sidescan sonar has a range of 6 km and a seabed footprint ranging from 4 by 7 meters close to the vehicle to 42 x 2 meters at longer ranges, and the profiler sonar can penetrate up to 60 meters into soft sediments with a vertical resolution of better than 1 meter. This instrument was developed by the IOSDL. See Flewellen et al. [1993] and the TOBI Web site[158].

TOCS Acronym for Tropical Ocean Climate Study, a project commenced by JAMSTEC in 1993 as a follow–up to the JAPACS program as a Japanese contribution to TAO. The objective of TOCS is to achieve a better understanding of the western Pacific warm pool and its effects on ocean circulation, the ENSO phenomenon, and global climate change.

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[157] http://tmap.pmel.noaa.gov/
[158] http://www.soc.soton.ac.uk/OTD/seasys/TOBI/index.html

TOGA Acronym for Tropical Ocean and Global Atmosphere program, a WCRP program beginning in 1985. The objectives of TOGA were:

- to gain a description of the tropical oceans and the global atmosphere as a time–dependent system, in order to determine the extent to which this system is predictable on timescales of months to years, and to understand the mechanisms and processes underlying that predictability;
- to study the feasibility of modeling the coupled ocean–atmosphere system for the purpose of predicting its variations on timescales of months to years; and
- to provide scientific background for designing an observing and data transmission system for operational prediction if this capability is demonstrated by the coupled ocean–atmosphere system.

The objectives were addressed by:

- building the TOGA Observing System;
- conducting a major process study in the tropical Pacific, i.e. COARE;
- developing a sequence of coupled ocean–atmosphere models of the tropical Pacific;
- conducting a program of prediction studies through the TOGA Numerical Experimimentation Group;
- conducting analytic and diagnostic studies of the ENSO phenomenon; and
- relating ENSO to seasonal–to–interannual variability in other tropical regions, especially in the monsoon region.

Significant results from the TOGA program include:

- documentation of the ENSO cycle and related phenomeno, such as the mean seasonal cycle and intraseasonal variability, with unparalleled resolution and accuracy;
- testing of ENSO theories such as the delayed oscillator;
- development of new theoretical concepts relating to ocean–atmosphere interactions on seasonal–to–interannual time scales;
- development of ocean, atmospheric, and coupled ocean–atmosphere models; and
- development of ocean data assimilation systems for improved climate analyses and for initializing climate prediction models.

See Halpern [1996]. McPhaden et al. [1998].

[http://www.ncdc.noaa.gov/coare/toga.html]
[http://www.ncdc.noaa.gov/coare/]
[http://www.pmel.noaa.gov/pubs/outstand/mcph1720/TMP938460841.htm]

TOGAMA Acronym for TOGA Marégraphies Atlantique.

Tokyo Bay Tokyo Bay is a semi-enclosed bay situated in the central part of Japan, which is connected to the Pacific Ocean through narrow Uraga Strait between Futtu-Misaki and Kan-non-zaki. Tidal currents with amplitudes of about 50 cm s-1 dominate in Tokyo Bay. The wind-driven current is generated by a northerly wind from autumn to spring and a southerly wind in the summer. Moreover, 13 rivers empty into Tokyo Bay and the density-driven current is accompanied by an estuarine front in the northwestern part of the bay where four large rivers discharge. Residual flow consisting of tide-induced residual, wind-driven and density-driven currents plays the most important role in long-term material transport in the bay, although its speed is about a tenth of the tidal current because the tidal current is an oscillatory flow. After Yanagi et al. [2003].

TOPEX Acronym for Typhoon Operational Experiment, a WMO 3–year project for testing the typhoon warning system under real typhoon conditions.

[http://www.wmo.ch/web/www/TCP/Projects.html]
[http://www.unescap.org/enrd/water/disaster/watdis6.htm]

TOPEX/POSEIDON A cooperative project between the U.S. (NASA) and France (CNES) which was the first space mission specifically designed and conducted for studying the circulation of the world's oceans. TOPEX is the collective name for the instruments comprising the U.S. portion of the mission and POSEIDON that for the French portion. The satellite uses a state of the art altimetry system to measure the precise height of sea level from which information about the ocean circulation can be obtained. It was launched on August 10, 1992 and began making measurements in late September of the same year. The unprecedented accuracy required for obtaining useful information about the ocean circulation from altimetry measurements led to a number of innovations. These included the first dual–frequency space–borne radar altimeter capable of retrieving the ionospheric delay of the radar signal, a three–frequency microwave radiometer for retrieving the signal delay caused by water vapor in the troposphere, an optimal model of the Earth's gravity field, and multiple satellite tracking systems for precision orbit determination. These innovations produce single–pass sea level measurements with a root–sum–square accuracy between 4.7–5.1 cm, better than the requirement for useful data of 13.7 cm. The mission is designed to last for at least 3 years with a possible extension to 6 years.

The orbit configuration was chosen to avoid aliasing tidal signals into the frequencies of ocean current variabilities. The chosen inclination of 66 degrees avoids this as well as the aliasing of different tidal constituents to the same frequency. A 9.916 day repeat period allows an equatorial cross–track separation of 316 km. An orbital height of 1336 km satisfied several constraints including maximizing the accuracy of orbit determination and minimizing the power needed to achieve the required level of signal to noise ratio. The satellite circles the world every 112 minutes between latitudes 65° N and S, allowing it to measure sea surface height over 90% of the world's ice–free oceans.

The mission payload consists of six scientific instruments. The four operational sensors are:

- the dual–frequency radar altimeter (ALT),
- the TOPEX microwave radiometer (TMR),
- the laser retroflector array (LRA),
- and the Doppler orbitography and radiopositioning integrated by satellite (DORIS) dual Doppler tracking system receiver.

The two experimental sensors are the single–frequency solid–state radar altimeter (SSALT) and the Global Positioning System (GPS) demonstration receiver (GPSDR). See Fu et al. [1994].

[http://topex-www.jpl.nasa.gov/]
[http://podaac.jpl.nasa.gov/toppos/]

topographic form stress The integrated horizontal pressure force on the bottom. See McWilliams [1996].

topographic Rossby wave To be completed. See Hendershott [1981], p. 309.

topographic steering The deflection or steering of flow required to keep the potential vorticity constant. For large scale processes in the interior of the ocean, we can neglect the relative vorticity and the potential vorticity reduces to f/D. As such, if a water column stretches, i.e. D increases, (shrinks, i.e. D decreases) to accomodate a greater (lesser) depth, then it must move toward (away from) the nearest pole to increase (decrease) f to keep its ratio to D constant.

TOPS Acronym for Total Ocean Profiling System.

Torres Strait See Gulf of Carpenteria.

TOU Abbreviation for True Oxygen Utilization. See AOU.

TOURBILLON A study of mesoscale eddies in the northeast Atlantic Ocean. See Le Group Tourbillon [1983].

TOWARD Acronym for Tower Ocean Wave and Radar Dependence Experiment, an experiment conceived to provide a data base to resolve the disparity among different Synthetic Aperture Radar (SAR) ocean surface imaging theories. The specific objectives were to investigate the hydrodynamics of short waves and their modulation by long waves, to assess the assumptions stipulated in radar backscatter theory that are used in SAR ocean surface imaging, and to develop a verifiable theory for SAR imaging of the ocean surface. See Shemdin [1990].

TPOP Abbreviation for the TOGA Program on Prediction. See the TPOP Web site[159] for more information.

TPPN Abbreviation for Trans–Pacific Profiler Network, a joint NOAA/University of Colorado project.

TPS24 Abbreviation for the series of Trans-Pacific expeditions along 24° N in 1985.

TPS47 Abbreviation for the series of Trans-Pacific expeditions along 47° in 1985.

TPTMS Abbreviation for Tropical Pacific Thermal Monitoring System.

TRACMASS Acronym for Tracing the Water Masses of the North Atlantic and the Mediterranean, a project to use a Lagrangian trajectory method to investigate the North Atlantic and Mediterranean water mass circulation as they result from numerical simulations of the global ocean. The major goals of the project are to investigate:

- the origin and formation of NADW;
- the fate and transformation of NADW;
- the Mediterrean Water mass circulation; and
- the Lagrangian trajectory methods to be used.

The OCCAM, OPA and GIM circulation models will be used in the investigation.

`[http://www.knmi.nl/onderzk/oceano/special/mast.html]`

trade winds The trade winds, or tropical easterlies, are the winds which diverge from the subtropical high-pressure belts, centered at 3-40° N and S, towards to equator, from north to east in the northern hemisphere and south to east in the southern hemisphere.

transfer efficiency In marine ecology, the ratio of the production of one trophic level to that of the next. This is a reasonable estimate of the ecological efficiency if it is assumed that the energy extracted from a given trophic level is proportional to its production. See Barnes and Hughes [1988].

transfer function A device used in paleoclimate data analysis to obtain proxy data. An equation, or transfer function, is developed using mathematical techniques of regression that relates the actual data (.e.g. planktonic fossil assemblages) to some desired physical variable (.e.g. water temperature). See Imbrie and Kipp [1971], Kipp [1976] and Crowley and North [1991].

[159]http://www.atmos.washington.edu:80/tpop/

transfer velocity See piston velocity.

Transitional Mediterranean Water (TMW) A transition water mass found between the overlying Levantine Intermediate Water (LIW) and the underlying Eastern Mediterranean Deep Water (EMDW) in the eastern Mediterranean Sea. The TMW is relatively colder (14.25°C) and slightly less saline (38.88–38.90) than LIW. See Theocharis et al. [1999].

transitive In dynamical systems theory, a system is said to be transitive if different sets of initial conditions all evolve to a single resultant state. Compare to intransitive and almost intransitive. See Lorenz [1979].

transmissometer An instrument for the measurement of the transmission of light of a given wavelength over a known distance in a seawater sample. The wavelengths are usually chosen based on the particles being studied, with about 660 nanometers the wavelength most often used. The changes in transmission are primarily related to changes in the abundance and type of particles present, with most variations resulting from particles less than 20 microns in diameter.

transmittance In radiation transfer, the fraction of incoming radiation that is transmitted into or through a medium. The sum of this, the absorptance, and the reflectance must equal unity.

TRANSPAC Acronym for TRANS-PACific experiment. See White and Bernstein [1979].

TRE Abbreviation for Tracer Release Experiment.

TREMORS Acronym for Tsunami Risk Evaluation through Seismic Moment from Real–Time System.

trench The official IHO definition for this undersea feature name is "a long, narrow characteristically very deep and asymmetrical depression of the sea floor, with relatively steep sides."

trench wave See Mysak et al. [1979].

TRISTAR A type of drifter. See Niiler et al. [1995].

tritium A hydrogen isotope useful as a tracer in ocean studies. It is the heaviest isotope of hydrogen, and emits a low energy beta particle in its decay to helium-3. Being hydrogen, it exists almost exclusively as water and is thus transported only by fluid motion and vapor exchange, making it an ideal hydrologic tracer. Tritium is produced naturally in the upper atmosphere by cosmic ray spallation, with pre-nuclear concentrations in precipitation around 5-10 Tritium Units (TU) and surface water concentrations ranging from 0.1 to 0.5 TU. The pre-nuclear natural inventory was around 3.6 kg.

Atmospheric nuclear weapons testing in the 1950s and 1960s produced tritium in quantities that dwarfed the natural inventory which, given the subsequent cessation of such testing, offered a unique opportunity to study the long-term transport through the ocean of a large spike of an important and readily identified tracer. About 500 kg of tritium was produced by the weapons testing programs, boosting the concentration in precipitation to as high as 10,000 TU in places, with surface seawater concentrations reaching 20-30 TU in the northern hemisphere. The latitudinal distribution of weapons tritium delivery to the ocean is characterized by mid-latitude maxima (near 45-50°) with about a five-fold asymmetry between northern and southern hemisphere. The time history of surface delivery is a spike for the northern hemisphere and more extended for the southern hemisphere.

The usefulness of tritium as a tracer is due to its time history not monotonically increasing (i.e. the weapons source is no more) which gives independent time information, the strong hemispheric asymmetry in its delivery which is valuable in the study of cross-equatorial flow and, finally, its nature as an ideal fluid tracer since, being part of the water molecule, it is unaffected by biological and chemical processes. The long-term evolution of its large-scale distribution will provide much useful information about ocean circulation processes. See Sarmiento [1988], Broecker and Peng [1982], and Broecker et al. [1986].

Tritium Unit A unit defined as 10**18 times the atom ratio of tritium to normal hydrogen.

TRITON Acronym for Triangle Trans Ocean Buoy Network, a a buoy for measuring surface meteorology and upper ocean data. These Japanese moorings are used in the TAO/TRITON array west of 165E.

[http://www.jamstec.go.jp/jamstec/TRITON/]

trochoidal wave See Gerstner wave.

TROPEX Acronym for Tropical Experiment.

TROPIC HEAT Acronym for Tropical Pacific Upper Ocean Heat and Mass Budgets, a process–oriented study within the TOGA observing system for examining the processes controlling SST in the equatorial eastern Pacific. It was designed to explore the characteristics and dynamics of the mixing in the equatorial Pacific Ocean in greater detail and to establish the basis for realistic parameterizations of the mixing. A two ship study was conducted southeast of Hawaii in November and December 1984 in which intensive fine– and microscale observations were made. See Eriksen [1985] and Heert et al. [1991].

tropical cyclone A non–frontal, synoptic scale, low pressure system originating over tropical or subtropical waters with organized convection and definite cyclonic wind circulation.

tropical depression A tropical cyclone with maximum sustained winds of 33 knots or less near the center.

tropical instability waves Waves that derive their energy from the large–scale, seasonally varying zonal equatorial currents through shear instability (and possibly through SST frontal instabilities). They were first observed in the Pacific in 1977 in satellite SST imagery, and have since been detected in ocean currents, temperature and salinity fields, and in satellite altimetry data. They typically appear as well–organized, cusplike features that propagate westward with zonal wavelengths of 800–2000 km and periods of 20–30 days. They are seasonally and interannually modulated, being weakest during the boreal spring and during the warm phase of ENSO.

These waves provide a significant source of drag on the South Equatorial Current (SEC) and the Equatorial Undercurrent (EUC). They heat the cold tongue via large downgradient (i.e. equatorward) eddy heat transports. They can also affect the stability of the atmospheric boundary layer, the distribution of cloudiness, latent heat fluxes, and the distribution of nutrients and chemical species in the eastern equatorial Pacific. Instability waves have also been detected in the Atlantic during the boreal summer. They potentially provide a large source of aliased energy which can add noise contamination to measurements of lower frequency signals. See McPhaden et al. [1998].

tropical SST paradox This refers to an apparent contradiction between tropical SSTs as inferred from various proxy data and as calculated by the present generation of computer models for past warm periods. The measurements for the Pliocene, Eocene and Cenomanian suggest that tropical SSTs were not significantly greater than those at present, while model simulations for these times show significant differences. See Crowley and North [1991].

tropical storm A tropical cyclone with maximum sustained winds of 34 to 47 knots near the center.

troposphere The narrowest of the atmospheric layers, extending from the surface of the Earth to about 10 km at the Equator and 6 km at the poles near the 200 mbar level. This layer contains about 80-85% of the atmosphere's total mass and almost all of the water vapor and clouds. Temperatures fall with height at the rate of about 0.5° F per 100 feet. It is bounded above by the tropopause which varies with latitude and season. This layer is characterized by strong vertical mixing associated with latent heat effects and clouds.

tropospheric aerosols See Haywood and Boucher [2000].

trough The official IHO definition for this undersea feature name is "a long depression of the sea floor characteristically flat bottomed and steep sided and normally shallower than a trench."

truncation error That which occurs when a function, theoretically represented exactly as the summation of an infinite (or otherwise bloody huge) number of terms, is represented by a smaller subset of these terms. The difference between the exact function and the function represented by the finite number of terms is called the truncation error. This is one of several kinds of errors inherent in representing a continuous world discretely on computers.

T-S curve See T-S diagram.

T-S diagram A graph showing the relationship between temperature and salinity as observed together at, for example, various depths in a water column. A T-S diagram for a given station is typically prepared by plotting a point for the temperature/salinity combinations at a range of depths and then joining them by straight lines in order of depth. The resulting line is called the T-S curve. Isopleths of constant density are often also drawn on the same diagram as a useful additional interpretation aid. In the ocean certain T-S combinations are preferred which leads to the procedure of identification via the definition of water types and water masses and their distributions.

T-S-t diagram An extension of the T-S diagram concept to include information about the temporal evolution of the properties of ocean waters in specific areas. It is created by plotting, on a standard T-S diagram, the temperature and salinity of a given area at regular time intervals (say, monthly or quarterly values).

T-S-V diagram An extension of the concept of a T-S diagram to display the distribution of temperature and salinity in the world ocean waters in proportion to their total volume. This is created by dividing a T-S diagram into a grid of squares with each square containing a number indicating the volume of water whose properties lie within it. A 3-D graphic of the results can also be created by replacing each number with a proportionally long vertical bar. See Montgomery [1958] and Worthington [1981].

Tsuchiya jet Narrow eastward currents in the Pacific that bracket the equator just below the equatorial thermocline. They form the poleward boundaries of the 13°C equatorial thermostad. The northern jet begins west of 141°E at 325 m depth, and the southern jet near 155°E at 300 m depth. Both start 3° from the equator, then gradually diverge and shoal to the east until they are 6° from the equator and 150 m below the surface at 110°W. The typical core speeds are 35 cm s^{-1}, and the transport 5–10 Sv each. There is some evidence for a secondary southern jet south of the main southern jet in the eastern Pacific. These are also known as subsurface countercurrents (SCC).

One model of their dynamics considers a linear, vertically diffusive model which simulates the Tsuchiya jets as lobes of the Equatorial Undercurrent (EUC) which are formed at the poleward edge of a broad diffusive equatorial boundary layer (McPhaden [1984]. Downward vertical diffusion of cyclonic relative vorticity is balanced by the poleward advection of planetary vorticity within the boundary layer, with the advection of planetary vorticity balanced by vortex stretching creating a pycnostad outside of it.

The jets are the result of a geostrophic balance across the pycnostad. An inertial jet model has the conservation of the Bernoulli function and potential vorticity combining with th eastward shoaling of the tropical pycnocline to determine its structure. See Tsuchiya [1972], Tsuchiya [1975], Johnson and Moore [1997] and Rowe et al. [2000].

Tsugaru Current A current flowing east from the Japan Sea through the strait between mainland Japan and Hokkaido and on into the Pacific Ocean. This is also known as the Tsugaru Warm Current. The Tsugaru originates in the Tsushima Current, which splits off from the Kuroshio Current and enters the Sea of Japan through Tshushima Strait where it is modified before exiting through the Tsugaru Strait. In summer and autumn, the Tsugaru tends to expand eastward and into a small anticyclonic gyre as it meanders eastward past the northern tip of Honshu, and then turns southward along the Sanriku coast. In winter and spring, it usually turns directly southward along the coast. See Tomczak and Godfrey [1994] and Talley et al. [1995].

Tsugaru gyre See Nof and Pichevin [1999].

Tsugaru Warm Current Another name for the Tsugaru Current.

tsunami A Japanese word meaning "harbor wave". This is often used (along with the even more incorrect "tidal wave") as a name for what is more correctly called a seismic sea wave. A true harbor wave is a type of seiche and can be excited by, among other things, seismic sea waves. Tsunami originally applied to all large waves including storm surges but is now more or less restricted to seismic sea waves, and has mostly supplanted both seismic sea wave and tidal wave in the literature.

Tsunamis are primarily created by vertical movements of the sea floor caused by tectonic activity. This causes rapid vertical movements in the sea surface over a large area which leads to the formation of a train of very long period waves, with periods exceeding one hour not unusual. Secondary mechanisms for tsunami formation are landslides and volanic activity, with the effects of the resultant waves more localized than those of the tectonic variety which may travel across ocean basins. See Camfield [1990].

Tsushima Current A branch of the Kuroshio Current that flows into the Japan Sea via the Korea Strait. This brings in warm water which is ultimately exported to the Pacific via a continuation of the Tsushima called the Tsugara Current. The Tsushima splits into two branches near 35° N when it encounters the Tsushima Islands, with the western branch following the Korea coast and eventually turning east to join the Polar Front and the eastern branch closely following the Japanese coast until it becomes the Tsugara Current. The transport varies seasonally, with August transport about 1.3 Sv (at up to 4 m/s) and January transport only 0.2 Sv (below 0.1 m/s). Most of the increased August transport passes through the western branch as the eastern branch is weak year round. Both branches are prone to major pathway shifts and the western branch tends to shed large eddies where it separates from the Korean coast. The western branch has also been called the East Korea Current. See Lie and Cho [1994] and Tomczak and Godfrey [1994].

TTO Abbreviation for Transient Tracers in the Ocean. This comprised two separate studies: the TTO North Atlantic Study (TTO/NAS) and the TTO Tropical Atlantic Study (TTO/TAS). The 1981 North Atlantic Study (NAS) experiment cruise consisted of seven legs and visited 250 hydrographic stations across the North Atlantic in 200 days. About 9000 water samples were taken for analysis of salinity, oxygen, and nutrients; 3000 samples were taken for tritium analysis; and 1000 samples for radiocarbon analysis. The TTO/NAS data[160] is available from the CDIAC.

turbidity current See Johnson [1964].

[160] http://cdiac.esd.ornl.gov/oceans/ndp004r1.html

turbulence As defined by a subpanel of SCOR working group 69 in 1987:

> Turbulence is a condition of fluid flow in which:
>
> - each of the components of velocity and vorticity is irregularly and aperiodically distributed in both space and time;
> - energy is transferred between large and small scales where it is dissipated; and
> - there is diffusion of properties at a rate much in excess of the molecular rates that would occur in a laminar flow with the same average distribution of flow and scalar properties.
>
> Kantha and Clayson [2000] list the characteristics of turbulent flows as:
>
> - randomness, i.e. high irregularity in both time and space;
> - intrinsic three–dimensionality;
> - high vorticity, i.e. the deformation of fluid particles involves rotation;
> - strong diffusivity, i.e. turbulent diffusivities of mass, momentum, heat, etc. typically several orders of magnitude larger than molecular viscosities;
> - strong dissipation, i.e. energy is extracted from the mean flow by turbulent shear stresses acting against the mean shear;
> - instrinsic nonlinearity, i.e. it is the nonlinear terms in the Navier–Stokes equations that effect the cascade of energy from large eddies to small eddies on down the spectrum;
> - a broad and red spectrum where energy is concentrated in larger scales or lower wavenumbers;
> - anisotropy of large scales, i.e. large scales are continuously being oriented and elongated in the direction of the mean flow by the mean strain rate; and
> - loss of memory, i.e. initial conditions are quickly forgotten due to the intense scrambling of the flow.
>
> Small–scale, active turbulence is defined as a nearly isotropic, eddy–like state of fluid motion where the inertial forces in the eddies are larger than the buoyancy and viscous forces. It consists of random motions, with Reynolds and Froude numbers that exceed critical values. The length scales of such three–dimensional turbulent motion are smaller than about $0.6L_R$ and larger than about $11L_K$, where L_R is the Ozmidov length scale and L_K is the Kolmogorov length scale.

Small scale fluctuations that satisfy the first three requirements but not those of active turbulence are sometimes described as fossil turbulence, i.e. remnants of previously active turbulence. See McDougall et al. [1987] and ocean turbulence.

turbulence kinetic energy (TKE) The energy contained within the turbulent portion of a flow.

turbulent stress tensor See Reynolds stress tensor.

Turner angle A quantity delineating the stability of a water column to double diffusion and salt fingering. It is given by:

$$T_u = \tan^{-1}\left(\frac{R_\rho + 1}{R_\rho - 1}\right)$$

where R_ρ is a density ratio defined as:

$$R_\rho = \frac{\beta_T \delta T}{\beta_S \delta S}$$

where $\beta_T t$ and β_S are the coefficients of thermal and saline expansion, and δT and δS the vertical gradients of temperature and salinity. The angle obtained is interpreted as:

- 45 to 90 - salt fingering occurs;
- -45 to 45 - double diffusion is not possible;
- -45 to -90 - diffusive convection occurs; and
- all other angles - the fluid is statically unstable.

See Ruddick [1983] and You [2002].

turnover time A time scale defined as the ratio of the mass of a reservoir to the rate of its removal from that reservoir. In the context of the climate this can be seen as the total amount of carbon dioxide in the atmosphere and its rate of removal via land and ocean processes.

TWATE Acronym for Two-Way Acoustic Transmission Experiment. See Worcester [1977].

TWIST The Turbulence and Waves over Irregularly Sloping Topography Experiment is a WHOI program to discover what dictates the magnitude, frequency and spatial scales of internal waves in continental slope regions. The study area is on the continental slope of the North Atlantic Ocean near Norfolk Canyon. The area is centered at 37.25°N and 74.66° W and was chosen for the evenly spaced topographic waves that run orthogonal to the slope. In the deployment phase, planned to last from May 10 to June 8, 1998, three Moored Profilers (MP) will be deployed in a closely spaced array (about 500 m separation). This should allow the assessment of horizontal internal wave scales. High Resolution Profiler (HRP) dives will also be made to quantify the smallest scale components of vertical mixing. See the TWIST Web site[161].

TWP Abbreviation for tropical western Pacific.

typhoon A tropical cyclone with maximum sustained winds of 64 knots or more near the center.

Tyrrhenian Sea One of the seas that comprise the western basin of the Mediterranean Sea. It is separated from the Balearic Sea to the west by Sardinia and Corsica and from the eastern basin by the Straitsof-Sicily. It has a central abyssal plain along with some smaller plains located witin slope basins. The central plain is pierced by a large seamount that rises 2850 m above the sea floor to within 743 m of the surface. See Fairbridge [1966].

[161] http://hrp.whoi.edu/hrpgrp/liwi/twist1.html

0.19 U

UHSLC Abbreviation for University of Hawaii Sea Level Center. See the UHSLC Web site[162].

ultraplankton Phytoplankton whose lengths range from 0.5 to 10 μm. Compare to nanoplankton and microplankton.

uncentered statistics Statistics that retain information on the spatially-averaged changes in the fields being compared, i.e. the spatial-mean components are not subtracted so as to compare only the anomalies about the means as would be the case with centered statistics.

UNCLOS Acronym for United Nations Conference on the Law of the Sea, which took place in Montego Bay in 1982.

undersea feature This is defined in the IHO's "Standardization of Undersea Feature Names" (3rd Ed., April 2001) as "part of the ocean floor or seabed that has measurable relief or is delimited by relief."

undersea feature names The labeling and description of undersea bathymetric features is detailed in the IHO Bathymetric Publication No. 6, i.e. "Standardization of Undersea Feature Names" (3rd Ed., April 2001). This contains the guidelines, a name proposal form, and a list of terms and definitions, as worked out through collaboration between the GEBCO Sub-Committee on Undersea Feature Names and the Working Group on Maritime and Undersea Features of the United Nations Group of Experts on Geographical Names (UNGEGN).

The officially accepted terms and definitions included in the report are abyssal hills, abyssal plain, apron, archipelagic apron, bank, basin, borderland, caldera, canyon, continental margin, continental rise, continental shelf, escarpment, fan, fracture zone, gap, guyot, hill, hole, knoll, levee, median valley, mid-oceanic ridge, moat, passage, peak, pinnacle, plateau, promontory, province, reef, ridge, rise, saddle, scarp, sea valley, seachannel, seamounts, seamount chain, shelf, shelf break, shelf edge, shoal, sill, slope, spur, submarine valley, tablemount, terrace, trench trough and valley.

UNESCO Acronym for United Nations Educational, Scientific and Cultural Organization, a UN organization founded in 1945 to contribute to peace and security in the world by promoting collaboration among nations through education, science, culture and communication. See the UNESCO Web page[163].

University National Oceanographic Laboratory Systems (UNOLS) An organization of 57 academic institutions and national laboratories involved in oceanographic research and joined for the purpose of coordinating ship schedules and research facilities. The original UNOLS charter was written in 1972. See the UNOLS Web site[164].

UNOLS Acronym for University National Oceanographic Laboratory System.

UOR Abbreviation for Undulating Oceanographic Recorder. See Aiken and Bellan [1990].

UOTC Abbreviation for Upper Ocean Thermal Center.

Upper Ocean Thermal Center (UOTC) A data center charged with the collection, dissemination, and use of volunteer observing ship (VOS) XBT data for the Atlantic Ocean to satisfy WOCE objectives in the upper part of the water column. See the UOTC Web site[165].

[162] http://www.soest.hawaii.edu/UHSLC/
[163] http://firewall.unesco.org/
[164] http://www.gso.uri.edu/unols/unols.html
[165] http://www.aoml.noaa.gov/phod/uot/

upwelling See Smith [1995] and Summerhayes et al. [1995].

USIPS Abbreviation for Under Sea Ice and Pelagic Survey, a project whose goal is to use the Autosub AUV to investigate the physical and biological environment of the Antarctic Marginal Ice Zone (MIZE), and to assess the potential of AUVs for improving acoustic estimates of the biomass of fisheries resources.

[http://www.marlab.ac.uk/USIPS/USIPS.htm]

UWM/COADS This is a data set that contains raw and objectively analyzed fields of surface marine anomalies of fluxes of heat, momentum and fresh water along with several other parameters. It was produced at the University of Wisconsin-Milwaukee by A. M. da Silva and C. C. Young. These monthly fields were derived from the COADS data set and are available in an electronic archive[166] along with some documentation.

[166] ftp://niteroi.gsfc.nasa.gov/pub/uwm_coads/

0.20 V

VACM See Vector Averaging Current Meter.

Vaisala frequency See buoyancy frequency.

valley The official IHO definition for this undersea feature name is "a relatively shallow, wide depression, the bottom of which usually has a continuous gradient; this term is generally not used for features that have canyon–like characteristics for a significant portion of their extent; also called submarine valley or sea valley."

vapor concentration See absolute humidity.

vapor pressure The vapor pressure of water vapor in moist air is given by

$$e' = \frac{pr}{(0.62197 + r)}$$

where p is the pressure and r the mixing ratio.

Varen, Bernhard (1622-1650?) A German physician who is commonly accredited with being the founder of modern general geography. He summarized, amongst many other things, the current state of knowledge about the sea in his book Geographia Generalis (later published in English as A Compleat System of General Geography), first published in 1650. The book was important for being the first comprehensive and objective collection of geographical knowledge since the Greek Classical Age and for its reflection of a growing appreciation and use of empirical knowledge to guide explanations rather than the reliance on fantasy and speculation that had prevailed for more than a millenia (although Varen did indeed lapse into the latter on more than a few occasions).

Varen's most important contribution to oceanography was probably the discussions in his book about steady currents being driven by the wind, the first time this notion had seen print. This led to motions in the sea finally being considered in terms other than Aristotle's primum mobile. He also attempted to categorize the motions of the sea, separating them into a continuous western flow, an observed periodic rise and fall of the sea surface that is the tide (although their connection with the moon was suspected though not as yet well-known), and various special flows including what are now known as the Florida, Kuroshio and Mozambique Currents.

Varen also discussed varying theories as to the causes of the perceived general westward flow and the tides. The explanations for the former included a magnetic pull from the moon, thermal expansion as a result of moonlight, downward pressure from the moon as trasmitted through an endless atmosphere, the sun pulling the water after it, the inability of the sea to keep up with the earth's rotation, and more. He concluded that the cause was uncertain although he favored the wind as a cause at least of the general westward currents in the tropics as well as of other non-tidal currents flowing counter to the supposed general western flow. He considered the moon as responsible for the tides although via a mechanism as yet unknown (and to be identified by Newton in 1687). See Peterson et al. [1996].

variance ellipse

Vector Averaging Current Meter A current meter used in oceanography that senses speed with a Savonius rotor and direction relative to its case with a vane assembly. An internal compass senses the orientation of the case relative to magnetic north. Temperature is also recorded. The data recorded by the internal electronics is a true vector average with the sampling rate for speed and direction partly determined by the rotor rotation rate. See Heinmuller [1983].

Vector Measuring Current Meter A current meter used in oceanography that is effective at measuring near-surface currents since it is not as susceptible as some other meters to contamination from vertical currents and high frequency horizontal currents. It uses two orthogonal propellors to achieve insensitivity to current flow at right angles to the propellor axis. See Weller and Davis [1980].

veering Said of the clockwise change of the direction of a wind, as opposed to backing.

VEINS Acronym for Variability of Exchanges in Northern Seas, a project whose overall objective is to measure and model the variability of fluxes between the Arctic Ocean and the Atlantic Ocean with a longer term view of implementing a system for taking critical measurements needed to understand the role of the high latitude oceans in decadal climate variability. This objective is based on the fact that interannual to decadal climate variability plays an important role in the water mass conversion processes in the northern seas. The VEINS scientific objectives are:

- to obtain time series measurements of heat, salt and water fluxes for the exchange routes through the Northern Seas, i.e. between the Atlantic Ocean and the Nordic Seas and between the Nordic Seas and the Arctic Ocean;
- to quantify the magnitude and variability of these fluxes;
- to improve the understanding of the processes responsible for the variability; and
- to develop a conceptual model of exchanges and water mass alterations between the Atlantic and Arctic Oceans which will be used to estimate the integrated effect of exchanges from the four measurement areas as well as to design an optimal measurement program for the long term.

VEINS started in Feb. 1997 and was designed to run for 3.5 years and possibly longer with a funding extension.

[http://www.ices.dk/ocean/project/veins/]

velocity potential A scalar function that exists in irrotational fluid motion. If we denote the velocity potential by ϕ, then it is defined by the equation

$$\mathbf{V} = -\nabla\phi$$

where $\mathbf{V}$ is the velocity vector. This equation implies that $\mathbf{V}$ is normal to the equipotential lines and is directed from high to low potential.

Vema Channel See Vema Gap.

Vema Gap A deep-sea channel that connects the Hatteras Abyssal Plain to the Nares Abyssal Plain in the North American Basin. This is an important passasge for northward traveling deep water formed in the Antarctic. This is also known as the Vema Channel. See Fairbridge [1966], Hogg and Zenk [1997] and McDonagh et al. [2002].

vendavales A name given to strong, squally, southwest winds in the Straits of Gibraltar and off the east coast of Spain. It is associated with depressions and occurs mainly between September and March. They usually bring stormy weather and heavy rain.

VENTEX Acronym for Vent Experiment.

ventilated thermocline See Luyten et al. [1983] for the original concept and Huang [1991] and Pedlosky [1990] for reviews.

VENTS A NOAA PMEL program established in 1984 to focus research on determining the oceanic impacts and consequences of submarine hydrothermal venting, with most of the effort directed towards achieving an understanding of the chemical and thermal effects of venting along northeast Pacific Ocean seafloor spreading centers. See the VENTS Web site[167].

Veronis effect See Gough and Lin [1994].

VERTEX A multidisciplinary study of VERtical Transport and EXchange of material in the upper ocean performed in the California Current. It was organized to investigate the vertical exchange of materials between the photic zone and deeper waters in the Pacific Ocean. VERTEX was one of the first larger scale programs to focus on the couplings between new production and export. Components involved the use of particle traps and subsequent analyses of trapped particles for major elements, trace elements, radionuclides, fecal pellets and microbial populations to estimate vertical particulate fluxes. See Martin et al. [1987] and Broenkow et al. [1992].

vertical coordinates Currently there are three main types of vertical coordinate systems in use in ocean models, each representing specific generalized vertical coordinate systems. These types are z, σ or ρ vertical coordinates.

The simplest type is z coordinates, where z represents the vertical distance from a resting ocean surface (i.e. a static ocean under hydrostatic balance) at z = 0, with z positive upwards and z = -H(x,y) the topography. Griffies et al. [2000] list the advantages of z coordinates as:

- allowing the simplest of numerical discretization approaches;
- easy representation of the horizontal pressure gradient for a Boussinesq fluid;
- clean and accurate representation of the equation of state for seawater; and
- natural parameterization of the surface mixed layer using a z–coordinate.

The disadvantages are:

- cumbersome representation of tracer advection and diffusion along inclined density surfaces in the ocean interior;
- unnatural representation and parameterization of the bottom boundary layer; and
- difficult representation of bottom topography.

Another choice for vertical coordinate is the potential density ρ referenced to a given pressure. This is a close analogy to the use of the entropy or potential temperature in atmospheric models. In a stably stratified adiabatic ocean, potential density is materially conserved and defines a monotonic layering of the ocean fluid. The advantages are:

- well–suitedness for representing the dynamic of tracer transport in the ocean interior since it has a strong tendency to occur along directions defined by locally referenced potential density;
- representation of the bottom topography in a piecewise linear manner;
- better representation of the physics of overflows;
- easy representation of the horizontal pressure gradient in an adiabatic fluid; and
- conservation of the volume (Boussinesq fluid) or mass (non-Boussinesq fluid) between isopycnals.

The disadvantages are:

[167] http://www.pmel.noaa.gov/vents/home.html

- cumbersome representation of the effects of a realistic, nonlinear equation of state; and
- an inappropriate framework for representing the surface mixed layer or bottom boundary layer.

The third popular vertical coordinate choice is the terrain following or σ coordinate, originally introduced in atmospheric modeling in 1957 and usually defined as:

$$\sigma = \frac{z - \eta}{H + \eta}$$

where $\eta(x, y, t)$ is the displacement of the ocean surface from its resting position $z = 0$, and $z = -H(x, y)$ is the ocean bottom. The usual convention is that $\sigma = 0$ is the ocean surface and $\sigma = -1$ the ocean bottom. Sine σ is monotonic, the relation defines a unique mapping between the depth z and σ. The advantages of this coordinate are:

- a smooth representation of the ocean bottom topography with isolines concentrated where bottom boundary layer processes are most important; and
- good representation of the thermodynamic effects associated with the equation of state.

The disadvantages include:

- variable representation of the surface mixed layer, i.e. more surface layers in shallow than in deeper water;
- cumbersome representation of advection and diffusion along inclined density surfaces in the ocean interior;
- difficulty in accurately representing the horizontal pressure gradient, which is the difference of two relatively large numbers.

vertical diffusivity An elusive quantity to obtain for the ocean. Indirect and direct (e.g. via the release and measurement of inert tracers) measurements show that mixing across density surfaces within the thermocline is on the order of $\sim 10^{-5}$ m^2 s^{-1}. This is about a tenth of the value predicted by most ocean circulation models. The discrepancy is thought to be due to intense localized mixing at the boundaries, especially around sea mounts, i.e. topographically induced mixing. See Munk [1968] and Munk and Wunsch [1998].

virtual potential temperature A temperature defined to include the buoyant effects of liquid water in the air. It is calculated identically to the virtual temperature.

virtual temperature The temperature a sample of dry air at pressure P would have in order that its density equal that of the sample of moist air at temperature T, pressure P, and water vapor mixing ratio r. It is given by

$$T_v = T\,(1 + 0.6078\,r).$$

a If there is also liquid water in the air this is modified as

$$T_v = T\,(1 + 0.6078\,r - r_L)$$

where r_L is the liquid water mixing ratio (in grams of liquid water per gram of dry air). The virtual temperature is thus defined because it allows the ideal gas law to be used for situations in which the air is not dry, i.e. moist air of temperature T behaves identically to dry air of temperature T_v.

Visayan Sea A small sea located in the midst of the Visayan Islands that comprise the central portion of the Philippines. It is centered at about 124° E and 12° N and connected to the Sibuyan Sea to the northwest, the Samar Sea to the northeast, the the Camotes Sea to the southeast, the Bohol Sea to the southwest via the Tanon Strait, and to the Panay Gulf to the southwest via the Guimaras Strait. Prominent geographic features include the Asid Gulf (in Masbate Island) and Bantayan Island.

viscous sublayer That part of a boundary layer where the viscous stress is much larger than the Reynolds stress. See Kagan [1995].

Vivaldi A synoptic hydrographic survey carried out in the northeast North Atlantic in 1991. The details are supplied by Pollard et al. [1991]:

> During the six week period from 27 April to 8 June 1991, a survey of the northeast North Atlantic was carried out on the RRS *Charles Darwin* with CTD and SeaSoar between 39°N and 54°N and between 12°W and 34°W. Full depth CTD casts were made with a Neil Brown Mark 3 CTD at 32 positions sparsely spaced on a 3° (latitude) by 300 km (longitude) grid.

See Pollard et al. [1991].

VMCM See Vector Measuring Current Meter.

volumetric analysis A technique for the analysis of water masses wherein the volume of each water type or mass is ascertained. One use of this technique is to quantitatively examine changes in the character of the water in a region in the interval between surveys, although the spatial and temporal resolution of sampling in most areas has thus far made this a promising rather than a realized technique.

The procedure for performing a volumetric T–S or θ–S involves: (1) preparing a suitable data set, preferably one composed of relatively closely spaced hydrographic stations consisting of surface–to–bottom data with all coverage within a single season; (2) determining the area represented by each station; (3) partitioning the temperature and salinity fields into an array of T–S classes; (4) determining the depth interval within each T–S class; (5) multiplying the depth intervals by the area represented by each station to obtain the volumes of each class; and (6) summing these volumes over the desired region. See Swift [1986].

von Humboldt, Alexander (1769–1859) See Peterson et al. [1996], p. 64.

von Lenz, Emil (1804–1865) See Peterson et al. [1996], p. 64.

von Waitz, Jacob (1698–1776) See Peterson et al. [1996], p. 47.

vortex stretching Later.

vorticity A fluid property defined as twice the local rate of rotation of a fluid element or the curl of the velocity field, i.e.

$$\omega = \nabla \times \mathbf{u}$$

where $\mathbf{u}$ is the velocity vector. In a rotating frame of reference like the earth, there is additionally a quantity known as the planetary vorticity, i.e.

$$2\Omega = \nabla \times \mathbf{U}$$

where $\mathbf{U} = \Omega \times \mathbf{u}$ is the velocity of the rotating frame at position x. Together these comprise the absolute vorticity, i.e.

$$\omega^a = 2\Omega + \omega.$$

It is a three-dimensional property of the field of motion of a fluid, although in large-scale geophysical fluid dynamics the vorticity component in the horizontal plane (i.e. rotation about the vertical axis) is usually the only non-negligible component. The vorticity equation governs the evolution of vorticity in a geophysical fluid.

vorticity equation This is an equation used in large-scale geophysical fluid dynamics that relates the rate of change of the vertical component of vorticity to the horizontal divergence. It is derived by eliminating pressure (or geopotential) from the equations of motion. It can be expressed as

$$\begin{aligned} \frac{D}{Dt}(\omega + 2\Omega) &= (\omega + 2\Omega) \cdot \nabla \mathbf{u} - (\omega + 2\Omega)\nabla \cdot \mathbf{u} \\ &- \nabla \upsilon \times \nabla p \end{aligned} \tag{20}$$

where D/Dt is the material derivative, ω the relative vorticity, 2Ω the planetary vorticity, $\omega + 2\Omega$ the absolute vorticity, $\mathbf{u}$ the three–dimensional velocity vector, υ the specific volume, and p the pressure. The terms on the right–hand side describe, respectively, vorticity changes due to:

- vortex stretching and twisting,
- volume changes, and
- the baroclinicity of the flow.

See Muller [1995].

vorticity vector A measure of the rotational component of a velocity field. This is calculated by taking the curl of the velocity vector $\mathbf{u}$, mathematically expressed as $\nabla \times \mathbf{u}$.

VOS Acronym for Volunteer Observing Ship. See Rossby et al. [1995].

0.21 W

WADIC Acronym for Wave Direction Measurement Calibration Project, a program held in the vicinity of the Edda platform in the Ekofisk field in the North Sea during winter 1985–1986. Several wave buoys, platforms and wave staffs were intercalibrated in this project. See Allender et al. [1989].

Walker circulation A name coined by Bjerknes for two circulation cells in the equatorial atmosphere, one over the Pacific and one over the Indian Ocean. Schematically these are longitudinal cells where, on one side of the ocean, convection and the associated release of latent heat in the air above lifts isobaric surfaces upward in the upper troposphere and creates a high pressure region there. The lack or lesser degree of the same process on the other side of the ocean results in lower pressure there, and a longitudinal pressure gradient is established which, being on the equator, cannot be balanced by the Coriolis force. Thus a direct zonal circulation is driven in the equatorial plane with countervailing winds at the surface and in the upper troposphere, with concomitant rising and sinking branches on the appropriate sides of the ocean.

The normal Walker circulation in the Pacific consists of air rising over Indonesia, west winds in the upper troposphere, sinking air off the west coast of South America, and east winds near the surface. A reversed but weaker Walker circulation (and an enhanced Hadley circulation occurs during ENSO years. In the Indian ocean the circulation cell proceeds in the opposite sense (to the normal Pacific Walker cell), with sinking air over cold waters off the Somali coast and a low-level acceleration from west to east along the equator in the lower atmosphere. See Henderson-Sellers and Robinson [1986] and Kraus and Businger [1994].

Walvis Basin See Cape Basin.

WAMDI Acronym for Wave Model Development and Implementation group, an organization created to advanced sea surface state models. See Group [1988].

WAMEX Acronym for the West African Monsoon Experiment, a component of FGGE designed to study monsoonal circulations. See WAMEX [1990].

Warm Deep Water See Antarctic Circumpolar Water.

WASA Acronym for Waves And Storms in the North Atlantic, a project whose goal is to verify or falsify the hypothesis of a worsening storm and wave climate in the Northeast Atlantic and its adjacent seas in the 20th century. The main conclusion of the project is that the storm- and wave–climate in most of the Northeast Atlantic and in the North Sea has undergone significant variations on times scales of decades, that is has indeed roughened in the past decades, but that the present intensity seems to cmopare with the intensity at the beginning of the century. Part of the variability was found to be related to the North Atlantic Oscillation. See WASA [1998].

[http://www.knmi.nl/onderzk/oceano/special/wasa/index-en.html]

WAT-BEE Acronym for WOCE/Atlantic/Tropical–Boundary Eastern Equatorial.

water mass In physical oceanography, a body of water with a common formation history. A water mass is identified through relationships on a T-S diagram, although additional information about the degree of spatial and temporal variability during its formation as expressed by a standard deviation is almost always needed as well. A single T-S point, i.e. a water type, along with its standard deviation, may be sufficient for identification (especially with deep water masses), although generally a set of T-S combinations, i.e. a function in T-S space, is needed along with a standard deviation envelope. Generally the standard deviation decreases with depth. In practice not enough data is usually available to calculate a standard deviation, so a point or line in T-S space is specified around which the water mass properties are presumed to vary. See Emery and Meincke [1986a].

Examples include AAIW, AASW, SAMW, SAUW, AACW, WDW, AABW, ABW, GSDW, ASW, PDW, SIW, WSPCW, ESPCW, WNPCW, ENPCW, NPEW, SPEW, JSMW, JSPW, IDW, PGW, ICW, AAMW, BBW, LSW, EMW, AIW, SACW, NACW, MMW, MDW, AW, and LIW.

See Emery and Meincke [1986b] and Wright and Worthington [1970].

water mass analysis A technique introduced by Jacobsen [1927] as a graphical method for determining mixing coefficients in a T–S diagram. It was extended by Wüst in 1935 who developed his core layer method. This was further extended by Tomczak [1981] who developed a multi–parameter analysis technique by adding oxygen and nutrients as additional quasi–conservative parameters. This idea was further developed into what is currently known as Optimum Multiparameter Analysis (OMP). See Rees and Aiken [1995].

water mass assembly From Bâcle et al. [2002]:

> In the following discussion we distinguish between terms that describe water masses (based on straight theta-S diagrams and origins) and those that describe the structure of the water column that comprises these water masses (based on theta and S profiles, sections and maps, e.g., haloclines, layers, mode waters). Following McLaughlin et al. [1996], the term water-mass assembly is used to describe the basic arrangement or vertical stacking of water masses within the region, recognising that components within an assembly can vary spatially.

See McLaughlin et al. [1996] and Bâcle et al. [2002].

water mass characteristics A property value or, more often, range of property values by which a water mass can be identified and tracked through the ocean. The most commonly used are temperature, potential temperature, salinity, potential density or the density referenced to a particular depth or pressure. Less often used by still quite valuable for certain applications are oxygen, nitrate, phosphate, silicate, chlorofluorocarbon, carbon 14 and tritium. See also the entry on ocean tracers.

water type In physical oceanography, a point on a T-S diagram.

water vapor feedback A positive feedback loop in the atmosphere wherein an increase in temperature increases the water holding capacity. This will lead to an increase in the amount of atmospheric water vapor which, being a greenhouse gas, will in turn lead to another temperature increase. This process is better understood in the lower troposphere where there is reasonable certainty as to the feedback process. The upper atmosphere, while not as well understood in this regard, has a preponderance of evidence pointing to this. The temperature change is not uniform with height and the resulting changes in the vertical temperature gradient can partially compensate for the water vapor feedback.

water vapor mixing ratio The ratio of the mass of water vapor to the mass of dry air in a specified volume as expressed in grams per kilogram.

water vapor pressure The part of atmospheric pressure due to the water vapor in the atmosphere.

WATOX Acronym for Western Atlantic Ocean Experiment. See Ray et al. [1990].

WATTS Acronym for Western Atlantic Thermohaline Transport Study.

wave action See Andrews and McIntyre [1978].

wave climate The general condition of sea state at a particular location, the principal elements of which are the wave height, period parameters, and the wave direction. The significant wave height is usually used as the heighter parameter with the period parameter either the significant wave period as determined from time-series analysis, the period corresponding to the spectral peak frequency, or the mean wave period from time-series or spectral analysis. The wave direction is usually expressed with the 16-point bearing system (i.e. NNE, WSW, etc.). The wave climate is described in terms of months, seasons and years. See Goda [1990].

wave–current interaction See Peregrine [1976] and Johsson [1990].

wave forecasting Predicting the development and characteristics of ocean surface gravity waves via semiempirical methods. These methods use some theory in their foundation but require basic data for the evaluation of various constants and coefficients. Advances in the state-of-the-art are usually a matter of collecting a larger database of winds and the wave they generate. The two main approaches to wave forecasting are the significant wave method and the wave spectrum method. See Komar [1976] and Bates [1949].

wave model A general term for numerical models designed to simulate the generation, propagation, shoaling, interaction, refraction, reflection, etc. of wind waves. These are used to predict wave fields for complicated wave fields and bathymetry.

First generation wave models include:

- SOWM
- ODGP (Reece and Cardone [1982])
- GSOWM

Second generation models include:

- SAIL (Greenwood et al. [1985])
- NOW
- WINCH
- ODGP-2

Third generation models include:

- CSOWM (Khandekar et al. [1994])
- SWAN
- WAVEWATCH

[http://www.oceanweather.com/owiwav.html]

wave set-down See wave set-up.

wave set-up A phenomenon local to the surf zone wherein wave breaking causes a stress or a landward push of the water which causes it to pile up against the shore until the seaward slope of this set-up is sufficient to oppose the wave stresses. This is called wave set-up to distinguish it from storm set-up or storm surge and from wind set-up, both of which occur over a larger scale. Wave set-up can range from 17-50% of the incident wave height on natural beaches which can give values of up to 1 m during large storms, which can result in a shoreward indundation of 50 m on a beach with a 1:50 slope. A related wave set-down is found in the vicinity of the wave breaking point in the surf zone, while the set-up occurs shoreward of this. of the wave breaking point on the beach profile, with a small set-down also found at The mechanism by which waves can exert a stress on the fluid in which they propagate is via a phenomenon called radiation stress. See Holman [1990].

wave spectrum A method for describing the characteristics of irregular waves in which parameterized formulae are developed by spectral analysis of measured wave data. Several wave spectra have been developed including:

- Pierson–Moskowitz spectrum
- JONSWAP spectrum
- TMA spectrum

See Komen et al. [1996].

wave spectrum method A method of wave forecasting that describes the waves generated by storms in terms of a complete spectrum of periods and energies rather than in terms of a single significant wave height or period. An example of a wave spectrum method is the P-N-J method, while a significant wave method is the S-M-B method. See Komar [1976].

WAVEWATCH A series of wavemodels, i.e.

- WAVEWATCH I, developed at Delft University (Tolman [1991]),
- WAVEWATCH II, developed at NASA GSFC (Tolman [1992]), and
- WAVEWATCH III, developed at NOAA/NCEP.

WAVEWATCH III is a third–generation wave model that solves the spectral action density balance equation for wavenumber–direction spectra. It is implicitly assumed that the medium (i.e. depth and current) as well as the wave field vary on time and space scales much larger than the corresponding scales of a single wave. The source code and complete documentation are available for WAVEWATCH III.

[http://polar.wwb.noaa.gov/waves/wavewatch/wavewatch.html]

WBC Abbreviation for western boundary current.

WDC Abbreviation for World Data Center, a system of facilities established within the framework of the IOC IODE program to receive oceanographic data and inventories from NODCs, RNODCs, marine science organizations, and individual scientists. The data are collected and submitted voluntarily from national programs or arise from international cooperative ventures. The WDCs are also responsbile for monitoring the performance of the international data exchange system. See the See the IODE Web site[168].

WDW See Warm Deep Water.

Weber number A dimensionless number that relates the inertial force to the surface tension force. It is given by

$$W = \frac{\nu^2 l \rho}{\sigma}$$

where ν is the kinematic viscosity, l a characteristic length scale, ρ the fluid density and σ the surface tension. It is generally used in momentum transfer calculations such as bubble/droplet formation and breakage of liquid jets.

[168] http://www.unesco.org/ioc/oceserv/iodestr.htm

WECOMA See Barber [1992] and other papers therein.

Weddell Gyre See Deacon [1979], Orsi et al. [1993] and Schröder and Fahrbach [1999].

Weddell Gyre Boundary See Continental Water Boundary.

Weddell Sea More about which later.

Weddell-Scotia Confluence The zone separating the waters of the Weddell Sea from those of the Scotia Sea in the Southern Ocean. This is a line extending from the South Shetland Islands near the Antarctic Peninsula in a northeastward direction across the southern Scotia Sea to as far as 30° E. The deep waters on either side of the boundary are distinguishable on the basis of their temperature and salinity properties, with those to the north of the line (from the southeast Pacific) being warmer and slightly saltier.

The water column in the western WSC itself is nearly homogenuous due to vertical mixing that is active to one degree or another throughout the year. As one proceeds eastward lateral mixing processes gradually mix this homogenous water with the stratified waters to the north and south until such stratification is restored on the WSC is no longer in evidence. The complex bathymetry in the region is thought to play a major part in inducing the lateral mixing processes. See Patterson and Sievers [1980].

Weddell Sea Bottom Water (WSBW) A type of water found in the seas surrounding Antarctica with temperatures ranging from -1.4 to 0.8° C and salinities of 34.65 ppt. It underlies Antarctic Bottom Water (AABW) and is found on the slopes and southern and western ages of the Weddell Sea basin.

Weddell Deep Water (WDW) In physical oceanography, a water mass type formed in the Weddell Sea by surface cooling and subsequent convection in the polyna. This water has stable properties with a potential temperature between 0.4-0.7° C. WDW mixes with water above the continental slope in the Weddell Sea to serve as one source for Antarctic Bottom Water. See Gordon [1982] and Tomczak and Godfrey [1994].

Wedderburn number A dimensionless number expressing a balance between surface wind stress and the pressure gradient resulting from the slope of the interface. It is given by:

$$W_n = \frac{g'h}{U_*^2} \frac{h}{L}$$

where h is the depth of the thermocline, L is the fetch length (the length of the reservoir at the thermocline in the direction of the wind), U_* is the surface friction velocity, and g' is the reduced gravity. U_* is given by:

$$U_* = C_d \frac{\rho_a}{\rho_0}^{1/2} U_{10}$$

where U_{10} is the wind velocity at 10 meters, ρ_a is the density of the air, and C_d is the drag coefficient. Meanings for various values of the Wedderburn number have been defined:

- $W_n >> 1$ - the buoyancy force is greater than the applied wind stress, i.e. there is strong vertical stratification with very little horizontal variation;
- $W_n \sim 1$ - wind stress and buoyancy forcing are nearly equal, and therefore horizontal mixing is important;
- $W_n << 1$ - the time scale for vertical mixing is small compared to horizontal advection.

well mixed estuary One of four principal types of estuaries as distinguished by prevailing flow conditions. In this type the water column is (as you might have guessed) well mixed with essentially no variation in salinity in a vertical column. The Thames estuary is an example of this type.

WENPEX Acronym for Western North Pacific Experiment, a Japanese program taking place on the Hakuho Maru from Jan. 11–Feb. 5, 1991. See Fujiyoshi et al. [1995].

WEPOCS Acronym for Western Equatorial Pacific Ocean Circulation Study, a program taking place from 1985–1988 to examine the complex current structures in a relatively poorly explored part of the tropics. See Lindstrom et al. [1987] and Lukas et al. [1991].

WEPOLEX Acronym for the U.S.-U.S.S.R. Weddell Polynya Expedition of 1981 aboard the Soviet icebreaker SOMOV. See Chen [1982].

`[http://cdiac.esd.ornl.gov/oceans/ndp_028/ndp028.html]`

West African Trough See Guinea Basin.

West Europe Basin An ocean basin located in the eastern North Atlantic Ocean off the west coast of Europe (and also called the Northeastern Atlantic Basin). This includes the Porcupine Abyssal Plain west of Britain, the Biscay Abyssal Plain, and is connected to the Iberia Basin to the south by the Theta Gap. See Fairbridge [1966].

West Spitsbergen Current A current flowing offshore of West Spitsbergen Island in the eastern part of Fram Strait. This current carries comparatively warm water from the Atlantic into the Arctic Ocean. See Perkin and Lewis [1984], Swift [1986], Pfirman et al. [1994] and Richez [1998].

western boundary current (WBC) The intensification of the western limb of an oceanic circulation gyre. This is inevitable given a rotating earth, a meridional boundary, and a zonal wind stress pattern that reverses direction at some latitude as was shown using a simple dynamical model in the classic paper of Stommel [1948]. Common features of such currents include their flowing as swift narrow streams along the western continental rise of ocean basins, their extension to great depth well below the thermocline, and their separation from the coast at some point and continuation into the open ocean as narrow jets that develop instabilities along their paths. The most well-known western boundary currents are the Gulf Stream and the Kuroshio Current. See Hogg and Johns [1995].

Western Mediterranean Circulation Experiment (WMCE) A program to study the circulation of the western Mediterranean Sea from the Strait of Sicily to the Strait of Gibraltar using scales ranging from basin size to 1 km and depths from the surface to the deepest layers. The specific goals were to study the major features of the circulation and their variation in space and time, the physical forcing mechanisms, the affects of the circulation on the chemical, biological and optical properties of the western Mediterranean, and to implement the knowledge gained into numerical models.

The field study began in November 1985 and ended in March 1987, and consisted of the placement of long-term current meter moorings as well as campaigns for procuring measurements from aircraft. The field campaigns ran concurrently with those of two other experiments: POEM and the Gibraltar Experiment, with some effort being expended to make the three campaigns complementary to each other. See La Violette [1990].

`[http://sit.iuav.unive.it/mednet/ocean/WMCE.html]`

Western Mediterranean Deep Water (WMDW) See Perkins and Pistek [1990].

Western North Atlantic Central Water (WNACW) See Poole and Tomczak [1999].

Western North Atlantic Water (WNAW) A water mass defined by Iselin [1936] and Pollard et al. [1991] to define water found in the North Atlantic Current. The WNAW definition can be subsumed into the broader definition of North Atlantic Subpolar Mode Water, and thus can be seen as a variety of the latter. Se Read [2001].

Western North Pacific Central Water (WNPCW) In physical oceanography, the dominant water mass in the northern subtropical gyre, formed and subducted in the northern STC. This is fresher than NPEW at all temperatures and saltier than ENPCW except at temperatures above about 17° C (the upper thermocline). It is separated to the east from ENPCW at around 170° W and to the south from NPEW at around 12-15° N. See Tomczak and Godfrey [1994], p. 165.

Western Pacific Warm Pool (WPWP) An ENSO-related phenomenon conventionally defined as SSTs greater than or equal to 28 °C. It is a large area of heat accumulation in the global ocean and related to the development of El Nino. See Ho et al. [1995].

Western South Atlantic Central Water (WSACW) See Poole and Tomczak [1999].

Western South Pacific Central Water (WSPCW) In physical oceanography, a water mass which is one of six distinguishable Central Water masses in the Pacific Ocean. Its T-S properties are almost indistinguishable from those of ICW and SACW, indicative of similar atmospheric conditions during formation. It is formed and subducted in the STC between Tasmania and New Zealand, and is geographically restricted by that and Australia at 150° W. It is separated to the east from the fresher ESPCW in a broad transition zone between 145 and 100° W, and to the north from SPEW, fresher above 8° C and saltier below, at around 15° S. See Tomczak and Godfrey [1994], p. 164.

Western Tropical Atlantic Experiment (WESTRAX) An international field program conducted during 1989–1991 in the western boundary region of the tropical Atlantic between 0° and 10° N. Moored current meter observations were collected in the North Brazil Current (NBC) near the equator, near 4° N, and near 6° N to investigate the structure and variability of the NBC. See Brown et al. [1992].

WESTRAX Acronym for Western Tropical Atlantic Experiment.

WESTROPAC A 1982 cruise in the western tropical South Pacific Ocean whose goal was to reassess the regional distribution of the water masses in the area, to identify possible fronts in the region, and to get some idea of the frequency of occurrence of water mass layering, intrusions or interleaving. WESTROPAC was performed using the R. V. *Sprightly* of the CSIRO. It consisted of three individual cruises identified as *Sprightly* cruises Sp9/82 (from Sydney to Honiara), Sp10/82 (from Honiara to Nouméa), and Sp11/82 (from Nouméa to Sydney). See Tomczak and Gu [1987].

wet-bulb temperature The temperature obtained by covering the bulb of a dry-bulb thermometer with a silk or cotton wick saturated with distilled water and drawing air over it at a velocity not less than 1000 ft/min. This is often accomplished by swinging the covered thermometer on the end of a string or rope. If the atmosphere is saturated with water vapor, the water in the wick will not evaporate and the dry and wet bulb temperatures will be the same. If the atmosphere is not completely saturated, the water will evaporate from the wick at a rate depedent upon the degree of saturation. The evaporation will cool the bulb and lower the temperature reading over that of the dry-bulb temperature to that of the wet-bulb temperature.

white noise Noise that results in a spectrum where all frequency components have the same amount of energy. This can also refer the the resulting spectrum as well as the process. Compare to red noise.

White Sea One of the seas found on the Siberian shelf in the Arctic Mediterranean Sea. It is located to the west of the Barents Sea and is otherwise landlocked. See Zenkevitch [1963].

WHOI Abbreviation for Woods Hole Oceanographic Institution.

WHPO Abbreviation for WOCE Hydrographic Program Office. See the WOCE entry.

[http://whpo.ucsd.edu/]

WHYCOS Acronym for World Hydrological Cycle Observing System.

WIBP Abbreviation for Western Iberian Buoyant Plume. See Peliz et al. [2002].

Wilkes, Charles (1798–1877) See Peterson et al. [1996], p. 72.

williwaw A violent squall in the Straits of Magellan. This is a region where the winds are almost constantly strong and westerly.

wind chill temperature The hypothetical air temperature in calm conditions that would cause the same heat flux from the skin as occurs for the true winds and the true air temperature.

wind scatterometry A method wherein a specialized radar called a scatterometer is used to measure the near–surface wind speed and direction. The technique is indirect, i.e. the instrument tranasmits microwave pulses and receives backscattered power from the ocean surface. Changes in wind velocity cause changes in ocean surface roughness, modifying the radar cross–section of the ocean and the magnitude of backscattered power. This backscattered power is measured by scatterometers to obtain an estimate of the normalized radar cross–section of the sea surface. The cross–section varies with both wind speed and direction when measured at moderate incidence angles, allowing the development of a transfer function called a geophysical model function relating the former to the latter. Multiple, collocated, nearly simultaneous cross–section measurements acquired from several directions can be used to simultaneously solve for wind speed and direction. See Naderi et al. [1991].

[http://www.ee.byu.edu/ee/mers/Ocean-1.html]

wind stress The dominant driving source for the surface layer of the world's oceans. The wind stress τ represents a complex interfacial momentum exchange process between the wind and the underlying wind waves and surface currents. Historically, the measurement of the wind stress has been a problematic task. It is usually measured above the sea surface from fixed towers, ships or low–flying aircraft. The most direct approach is a technique called the eddy correlation method wherein the directional components of the near–surface turbulent stress covariance in the atmospheric boundary layer are measured.

A popular alternative technique for measuring the magnitude of the wind stress is based on equilibrium turbulent boundary layer modeling. The vertical wind profile is taken to have the form:

$$U(z) = \frac{u^*}{\kappa}\left[\ln\left(\frac{z}{z_0}\right) - \psi_m\left(\frac{z}{L}\right)\right]$$

where $U(z)$ is the wind speed at height z meters above the surface, u^* is the surface wind friction velocity given by $(\tau/\rho_a)^{1/2}$, ρ_a is the density of air, z_0 is the aerodynamic roughness length, $\kappa = 4$ is the von Kármán constant, ψ_m is a thermal stratification function given for unstable conditions $(z/L < 0)$ by:

$$\psi_m\left(\frac{z}{L}\right) = \ln\left[\left(\frac{1+x^2}{2}\right)\left(\frac{1+x}{2}\right)^2\right] - 2\arctan x + \frac{\pi}{2}$$

where $x = (1-16z/L)^{1/4}$, and for stable conditions $(z/L > 0)$ by:

$$\psi_m\left(\frac{z}{L}\right) = -5\frac{z}{L}$$

. L is the Monin–Obukhov stability length scale defined by:

$$L = \frac{-T_\nu u_*^3}{g\kappa \overline{wT_\nu}}$$

where T_ν is the virtual temperature and g the gravitational acceleration. The associated drag coefficient is:

$$C_d = \frac{u_*^2}{U_{10}^2}$$

where U_{10} is the wind speed 10 meters above the sea surface.

The roughness length varies according to conditions. At low wind speeds with aerodynamically smooth flow over the surface it is given by:

$$z_0 = 0.11\nu/u_*$$

where ν is the kinematic viscosity of the air. As the winds grow stronger, the roughness length is given by:

$$z_0 = \alpha u_*^2/g$$

where α is known as the Charnock coefficient, which ranges from 0.011 for well–developed ocean conditions to 0.0145–0.018 for coastal sites with less mature waves. High variability among various measurements led to a proposed extension of the Charnock relation in which the roughness length is a function of the wave age, i.e.

$$z_0 = \frac{u_*^2}{g} f(c_p/u^*)$$

where c_p is the phase speed of the spectral peak waves. Several forms for this function have been proposed.

Another technique for estimating the wind stress is the inertial dissipation method, which depends on an assumed dependent on the friction velocity u^* in the spectral level of the inertial subrange of the turbulence spectrum. See Banner et al. [1999].

Winter Intermediate Water (WIW) A water mass ... See Perkins and Pistek [1990].

Winter Water See Antarctic Surface Water (AASW).

Winter Weddell Sea Experiment An experiment taking place in 1986.

WITS Acronym for Wave Identification and Tracking System, a collection of tools for wave spectral partitioning with automated swell tracking and storm source identification capabilities. The WITS spectral partitioning steps are:

1. Peak isolation via identifying the paths of steepest ascent leading to each peak in the spectral matrix.
2. Identification and combination of wind sea peaks.
3. Combination of mutual swell peaks.
4. Removal of partitions whose total energy is below a given threshold.
5. Calculation of partition statistics.

Swell-tracking is a two step process, with the first being the formation of preliminary groups of swell partitions likely to have been generated by the same source. Next, specific swell events are located within the preliminary groups. Distinct swell source times and locations are calculated from each specific group of swell partitions. See Hanson and Phillips [2001].

WIW Abbreviation for Winter Intermediate Water.

WKB approximation More later.

WMCE Abbreviation for Western Mediterranean Circulation Experiment.

WMDW Abbreviation for Western Mediterranean Deep Water.

WMONEX Acronym for Winter Monsoon Experiment, a program taking place from Dec. 1, 1978 to Mar. 5, 1979 in the Indian Ocean, the western part of the Pacific Ocean, and in adjacent continental areas.

[http://www.meteo.ru/fund/inter.html]

WNACW Abbreviation for Western North Atlantic Central Water.

WNPCW See Western North Pacific Central Water.

WOCE Acronym for the World Ocean Circulation Experiment program, a component of the WCRP that is a cooperative scientific effort by more than 30 nations to provide essential strategic research on ocean circulation. The primary goals of WOCE are (1) to develop models useful for predicting climate change and to collect the data necessary to test them and (2) to determine the representativeness of the specific WOCE data sets for the long–term behavior of the ocean, and to find methods for determining long–term changes on time scales from ten to one hundred years. The field phase of the program is from 1990 to 1997 and the analysis, interpretation, modeling and synthesis (AIMS) phase continues until the year 2002. Some WOCE observations will be continued by the CLIVAR program. For more information see the U.S. WOCE Office Web site[169], the WOCE International Project Office (IPO)[170], the WOCE Hydrographic Program Office (WHP)[171], or the WOCE Data Information Unit (DIU)[172].

Woods Hole Oceanographic Institution (WHOI) See the WHOI Web site[173].

WOCE cruises WOCE sponsored many hydrographic programs, most of which were given abbreviations based on geographic location and latitude or longitude. The Pacific cruises included:

- P1
- P2
- P6
- P9
- P10
- P12
- P13
- P14C
- P14N
- P15N
- P16C

[169] http://www-ocean.tamu.edu/WOCE/uswoce.html
[170] http://www.soc.soton.ac.uk/OTHERS/woceipo/ipo.html
[171] http://whpo.whoi.edu/
[172] http://diu.cms.udel.edu/personnel/wdiu.html
[173] http://www.whoi.edu

- P16N
- P16S
- P17C
- P17E
- P17N
- P17S
- P18
- P19A - 11/01/92 to 12/08/92, *James Clark Ross*
- P19C - 2/22/93 to 4/13/93, *Knorr*
- P19S - 12/04/92 to 1/22/93, *Knorr*
- P21
- P31
- S04P - 2/14/92 to 4/6/92, *Akademik Ioffe*
  `[http://whpo.ucsd.edu/data/onetime/southern/s04/s04p/s04pdo.txt]`
- S4
- SR4
- T10
- T24
- T47
- TEW

`[http://whpo.ucsd.edu/]`
`[http://sam.ucsd.edu/pacwoce/]`

WOMARS According to Povinec [2003]:

> [T]he research programme on Worldwide Marine Radioactivity Studies (WOMARS) [was] carried out by the IAEA's Marine Environment Laboratory in Monaco in collaboration with over 30 research institutes. The primary objective of the project was to develop an understanding of the present open-ocean distribution of radionuclides in the water column and sediment and thus predict the radiological impact to be addressed, and to encourage and support marine radioactivity studies by methodological assistance and analytical quality management. The programme was designed with the intention of reviewing and contributing to scientific knowledge of the processes that affect radionuclide distributions and the sources that have introduced radionuclides to the world's oceans. Three anthropogenic radionuclides – 90Sr, 137Cs and 239,240Pu – have been chosen as the most representative of anthropogenic radioactivity in the marine environment, comprising beta, gamma and alpha-emitters, which have the highest potential contribution to radiation doses to humans via seafood consumption.
>
> The specific objectives of the project were to: identify the major sources of anthropogenic radionuclides in the world's oceans; develop present knowledge of the distributions of key radionuclides (90Sr, 137Cs and 239,240Pu) in water and sediment of the world's oceans; and study the development of radionuclide concentrations in water with time using good quality historical data and new comprehensive data sets.

The success of the project was due to the active collaboration with participating institutions as well as with other numerous marine institutions that provided radionuclide data for the IAEA's Global Marine Radioactivity Database (GLOMARD). The IAEA would like to express its gratitude for the information provided and for most fruitful collaboration.

The results obtained in the framework of the WOMARS project provide (after the GEOSECS (Geochemical Ocean Sections Programme) carried out during the 1970s) the most complete data set available on levels of radionuclides in the world's ocean. The results will be used as the international reference source on the average levels of anthropogenic radionuclides in the marine environment so that any further contributions from nuclear reprocessing plants, radioactive waste dumping sites, nuclear bomb test sites, and possible nuclear accidents can be identified.

WOTAN Acronym for Wind Observations Through Ambient Noise, an oceanographic instrument for the determination of wind stress from measurements of ambient noise. See Vakkayil et al. [1996].

WPWP Abbreviation for Western Pacific Warm Pool.

WRINCLE The Warm Ring Inertial Circle Layer Experiment took place in March 1990 in the northwest Atlantic between 37–45° N and 75–60° W. The goal of the experiment was to investigate the rates and types of mixing associated with a Gulf Stream warm core ring. A high resolution profiler (HRP) was used to complete 78 profiles in and around one warm core ring during a 21 day cruise, with the complete depth of the ring resolved by profiling to 1000 m. The HRP measurements were accompanied by 26 CTD profiles, 55 expendable current profiler (XCP) profiles, a Richardson Number float deployment, and two XBT surveys to precisely define the position of the ring. See Kunze et al. [1995] and Schmitt and Montgomery [1991].

WSACW Abbreviation for Western South Atlantic Central Water.

WSBW See Weddell Sea Bottom Water.

WSDW See Weddell Sea Deep Water.

WSPCW See Western South Pacific Central Water.

WW See Winter Water.

Wust, Georg More later.

WWSP Abbreviation for Winter Weddell Sea Project.

Wyrtki, Klaus More later.

`[http://www.soest.hawaii.edu/Wyrtki/]`

Wyrtki Center for Climate Research and Prediction (WCCRP) A research center established at JIMAR whose mission is to conduct research on the predictability of the coupled ocean–atmosphere–land system, to develop the methods for making predictions of the evolution of this system, and to make experimental predictions to determine their usefulness. The focus of WCCRP is on the Asian–Australian Monsoon system and its interactions with ENSO. See the WCCRP Web site[174].

Wyville–Thomson Ridge See Greenland–Scotland Ridge.

[174] http://www.soest.hawaii.edu/WCCRP/

0.22 X

XBT Abbreviation for expendable bathythermograph. The accuracy of modern XBT probes is about 0.05° C and most used are rated to 760 m depth.

XCP Abbreviation for Expendable Current Profiler, an instrument developed at the APL. These use electric field measurements to estimate horizontal velocity relative to an unknown offset. They typically cost 40 times more than an XBT.

XCTD Abbreviation for eXpendable Conductivity, Temperature and Depth instrument. The accuracy of XCTD probes is 0.02° C in temperature and 0.03 psu in salinity, and they are rated to about 1000 m depth. They typically cost 20 times more than an XBT.

0.23 Y

Yanai wave An equatorially trapped wave that behaves like a mixture of gravity and Rossby waves. Yanai waves exhibit an eastward group velocity at all wave numbers k, although for large positive k is behaves like a Rossby wave and for large negative k like a gravity wave. For the case k=0 it is a standing wave for which the surface moves sinusoidally up and down with opposite sign on opposite sides of the equator. Fluid particles move anticyclonically around elliptical orbits. with eastward motion when the surface is elevated and westward motion when it is depressed. To be completed. See Hendershott [1981], p. 306 and Gill [1982].

Yellow Sea A marginal sea centered at around 124° E and 37° N in the western Pacific Ocean that is distinguished traditionally although not hydrographically from the adjoining East China Sea to the south. It is also called the Huanghai Sea. The name comes from huge quantities of sediment discharged into the Bohai Gulf by the Yellow River in China. The traditional demarcation line between the Yellow and East China Seas varies but usually lies somewhere around 33° N. The Yellow Sea can be separated into a northern part, the aforementioned Bohai Bay, and the Yellow Sea proper to the south and east of Bohai Bay. The average depth of the Yellow Sea is 44 m. A shallow trough runs through it and can be traced south to the northern end of the Okinawa Trough in the East China Sea.

The hydrographic and circulation properties of both the Yellow and East China Seas are controlled by their proximity to the Kuroshio Current and the seasonal variation of the monsoon winds. The chief currents are a northwest trending branch of the Kuroshio called the Yellow Sea Current (or Yellow Sea Warm Current), the southward flowing China Coastal Current, and an unnamed current flowing southward along the west coast of Korea that carries low salinity water from the Bohai Gulf. Frontal regions separate the currents in this alternating flow pattern which is identifiable through the year, although the flow strength of the individual currents varies seasonally with the monsoons.

In the winter, strong northerly winds and cold, dry continental air vertically homogenize most of the Yellow and Bohai Seas. The winds also excite subtidal sea level fluctuations that propagate southward along the west coast of the sea all the way to the South China Sea. In the summer, solar forcing and weak wind mxing warm the upper part of the water column, leaving a conspicuous bottom pool of cold water called the Yellow Sea Cold Water, which is formed from the remnant winter water. The stratification usually appears in April and disappears in November. See Tomczak and Godfrey [1994], Guan [1994], Hu [1994], Jilan [1998] and Teague et al. [1998].

Yellow Sea Current A northwestward flowing current in the central Yellow Sea that brings warm water from the Kuroshio Current with velocities that are a maximum of about 0.2 m/s at the surface and decrease rapidly with depth. This keeps the central waters several degrees warmer than those near the coast. The is also known as the Yellow Sea Warm Current. See Teague and Jacobs [2000].

Yellow Sea Warm Current See Yellow Sea Current.

Yoshida jet See Gill [1982], p. 460.

Younger Dryas A post-LGM European climate regime where the retreat of the ice was reversed. The evidence for this event, which started at about 9000 BC, is strongest for the North Atlantic Basin, although there is some evidence for it in other parts of the world. The most probable hypothesis as to the cause of this involves the significant amount of glacial meltwater inducing changes in the atmosphere-ocean circulation, i.e. the outflow of low-salinity water into the subpolar North Atlantic may have affected the rate of deep-sea mixing and thus the production rate of North Atlantic Deep Water. It was preceded by the Allerod oscillation and followed by the Pre-Boreal period. See Crowley and North [1991], Broecker [1988] and Lamb [1985], pp. 371.

young ice A type of sea ice defined by the WMO as:

> Ice in the transition stage between nilas and first–year ice, 10–30 cm in thickness. This may be subdivided into grey ice and grey–white ice.

See WMO [1970].

0.24 Z

zero velocity surface A reference level at which the horizontal velocities are thought to be practically zero.

Zimmerman, W. F. A. (1797–1864) See Peterson et al. [1996], p. 91.

zonal mean wind The distribution of the zonal mean of the eastward component of the wind through latitude and height. This is westerly through most of the troposphere, and peaks at speeds exceeding 30 m/s in the subtropical jet stream. Near the surface the zonal mean winds are westerly at most latitudes between 30 and 70°, with easterly winds prevailing a latitudes less than 30°. See Hartmann [1994].

zooplankton One of two groups into which plankton are divided, the other being phytoplankton. Zooplankton are a large group of micro- and macroscopic animals ranging in size from a fraction of a millimeter to 30–50 millimeters, with a few, such a certain jellyfish, being up to a meter in diameter. Some plankton, called permanent plankton or holoplankton, are adapted to a pelagic mode of existence and remain floating or feebly swimming throughout their entire life cycle. Others, called temporary plankton, are the transitory floating stages such as eggs, larvae, and juveniles of the benthos and nekton. This latter category is usually seasonal in occurrence and the abundance is primarily neritic since it derives from the benthos and nekton of shallow areas.

According to Rigby and Milsom [2000]:

> Members of the zooplankton have the widest geographical spread and greatest numerical abundance of any animals. Modern zooplankton are important contributors to global biomass and to the chemistry of the oceans, a dominant means of flux to the seabed, and a source of food for many large animals. The microzooplankton are dominated by flagellate protists, including some dinoflagellates and zooflagellates, and by amoebae such as foraminifera and radiolarians. Planktic ciliates are common, although the major group of these, the tintinnids, have proteinaceous tests and leave little record in the sediment. The macrozooplankton include a wide range of solitary and colonial cnidarians, chaetognath and polychaete worms, and holoplanktic gastropods. Crustaceans are among the most common macrozooplankton, with copepods, euphausiids, amphipods, ostracodes, and decapods all abundant and diverse. Urochordates are widespread with two planktic groups, appendicularians and salps. Larval stages of invertebrates and fish make up a significant proportion of the heterotrophic plankton in the modern ocean, remaining as part of the plankton for periods ranging from minutes to years.

See Johnson [1957], Riley and Chester [1971] and Rigby and Milsom [2000].

Zoppritz, Karl A German fluid dynamicist who was a pioneer in applying modern fluid dynamical methods to questions of the large–scale oceanic circulation. See Peterson et al. [1996], p. 98.

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