Radionuclide Transport from Fukushima to Eastern North Pacific

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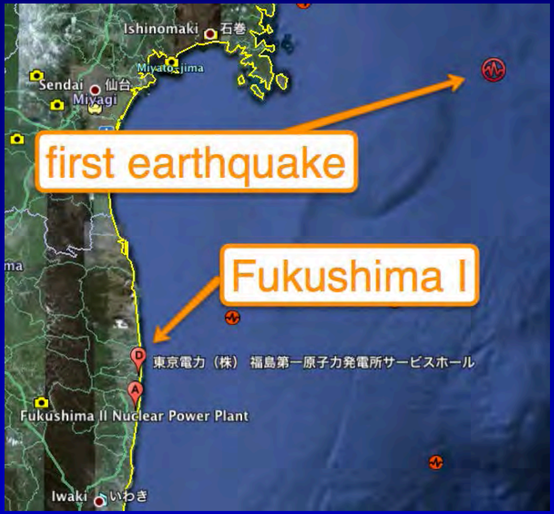
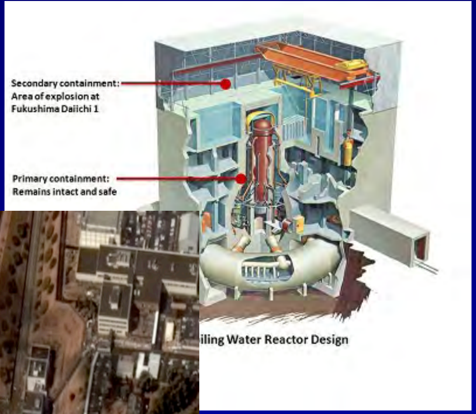
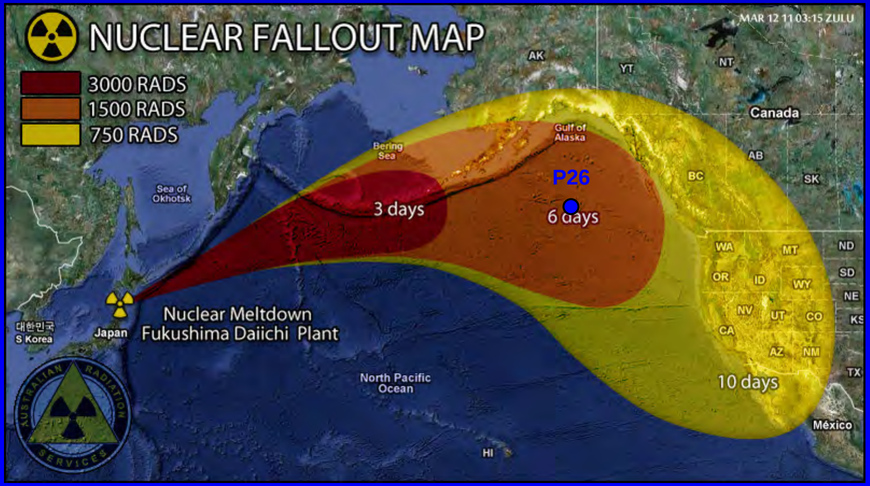
2013 PICES Annual Meeting
Nanaimo, BC
October 15, 2013

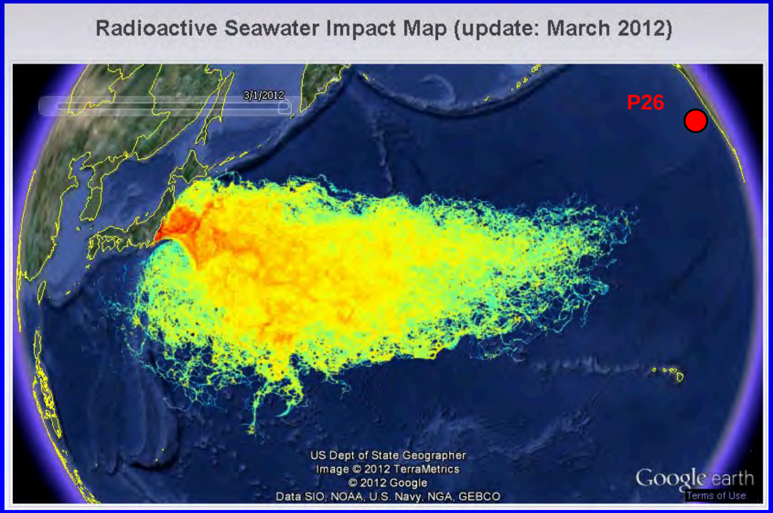




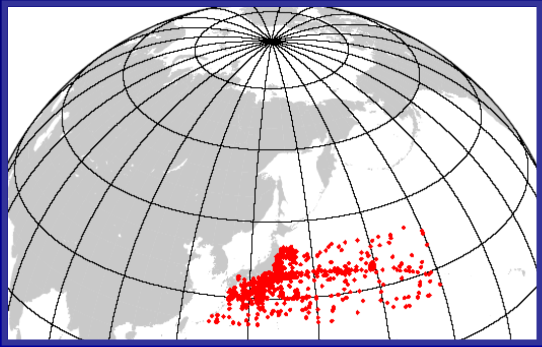
On March 11, 2011 an earthquake-triggered tsunami produced catastrophic damage to the Fukushima nuclear power reactors.

Explosions occurred in secondary containment; Chernobyl had no real secondary containment.

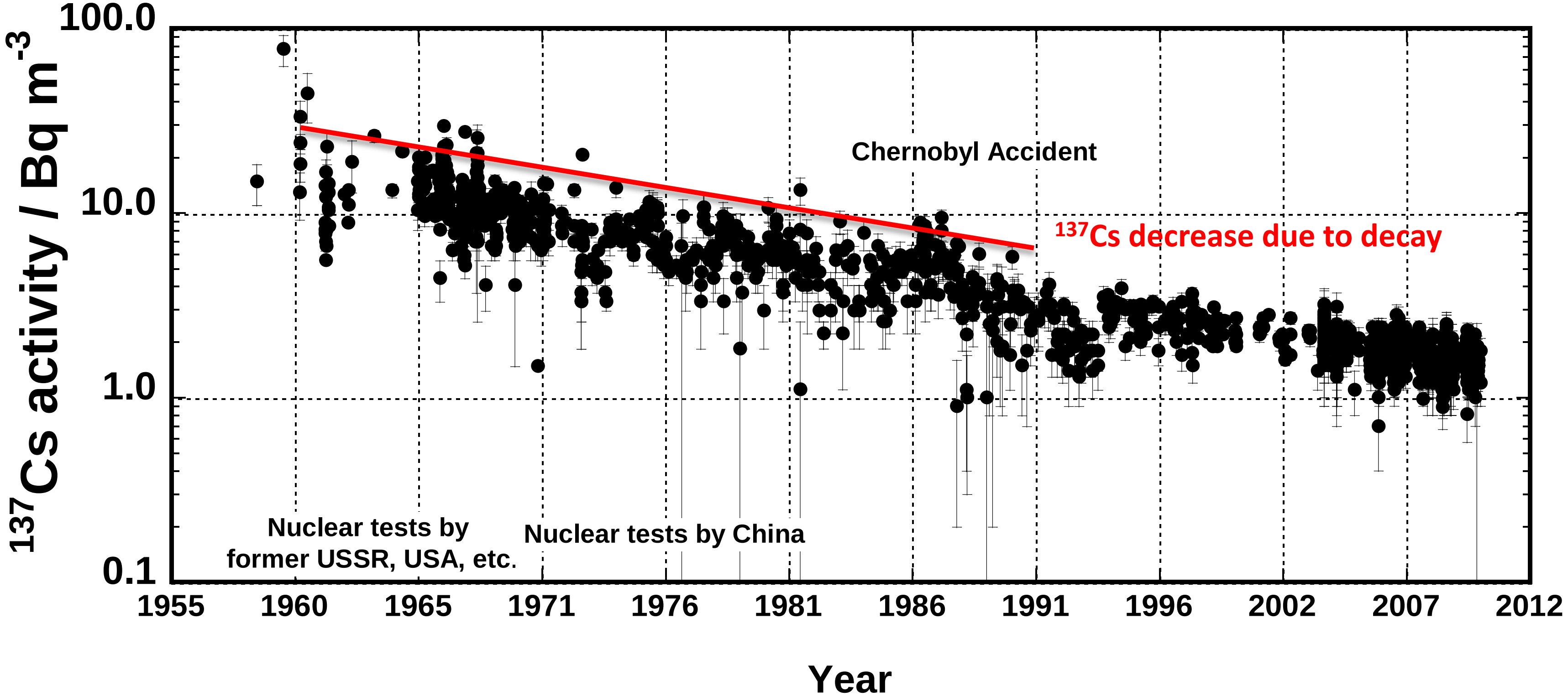




Atmospheric transport of radioactivity plume was directed farther northeastward compared to more eastward transport of water borne plume.



Long-term trend of ^{137}Cs in surface water in the western North Pacific Ocean: pre-Fukushima



Buesseler, 2012

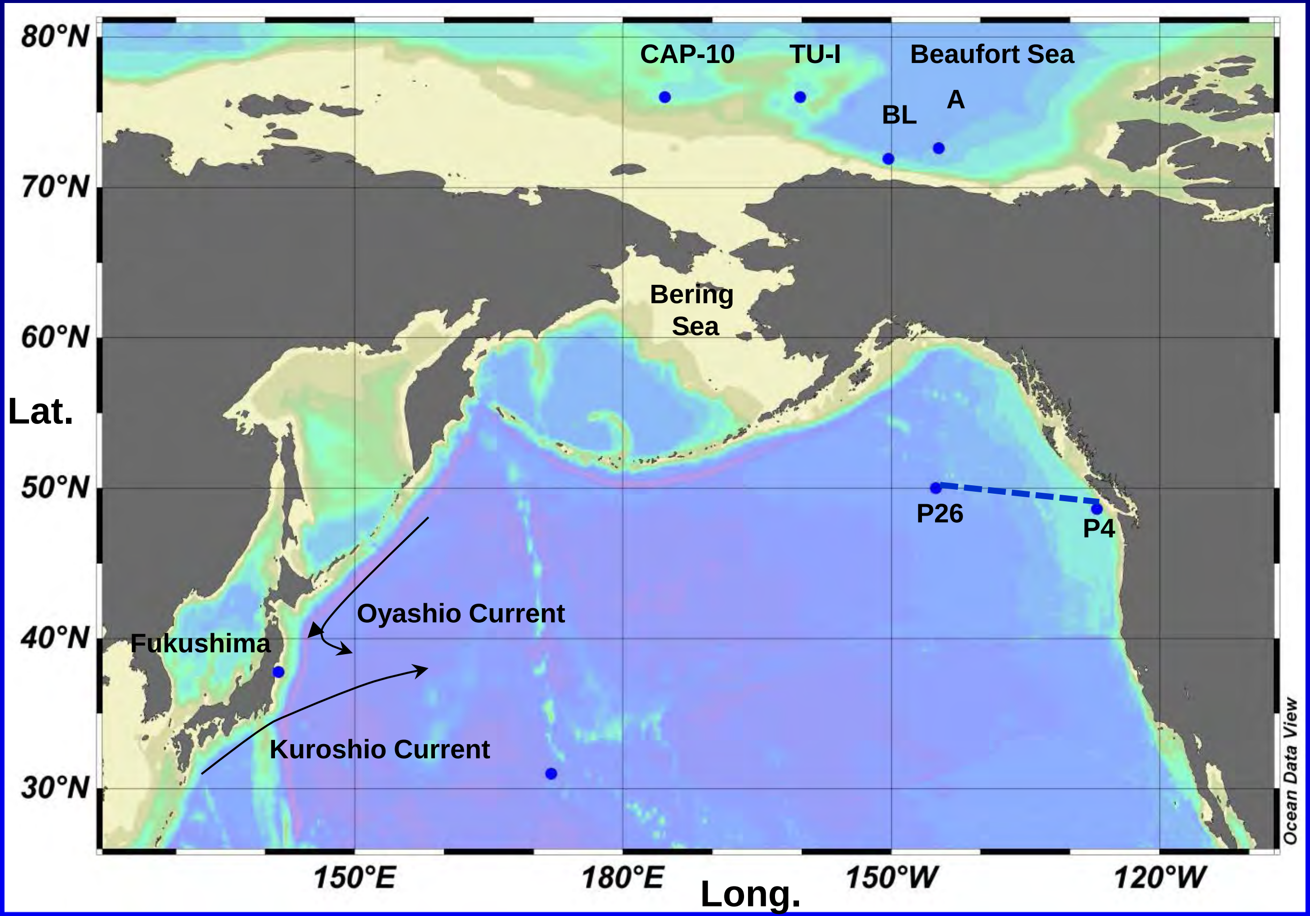
*Aoyama, M., Hirose, K. , TheScientificWorldJOURNAL, **4**, 200-215, 2004 and update*

^{137}Cs Budget Estimates

- Global fallout as of 1970 290 ± 30 PBq [a]
- Estimated N. Pacific pre-Fukushima 69 PBq [b]
- Fukushima direct discharge 3.5-15 PBq [c]
- Fukushima atmospheric release 10 - 16 PBq [d]
- Fukushima deposition on land 2 – 2.9 PBq [e]
- **Total Fukushima in ocean 14 – 31 PBq**
- Chernobyl global release in 1986 85 PBq [f]
- (10-20% of Chernobyl fallout in oceans 9-17 PBq)[g]

*a: Aoyama, M., Hirose, K., Igarashi, Y., J. ENVIRON. MONITOR., **8**, 431-438, 2006*
b: Aoyama unpublished data estimated 3-D distribution of ^{137}Cs
c: Tsumune et al., 2011, Rypina et al., 2012, Charette et al., 2012
d: Chino et al., 2011, Morino et al, 2011, ISRN 2011, Aoyama et al. in prep.
e: Aoyama et al. in prep.
f: IAEA, Proceeding of an International Conference, Vienna, 8-12 Apr. 1996
g: Buesseler, 2012

Canadian Ocean Monitoring Program



Seawater samples (20-60 l) collected at Stas. P4 and P26 in 2011, 2012 and 2013 during CCGS Tully missions on Line P. Seawater passed through KCFC resin cartridges at sea, shipped to BIO and analysed for ^{134}Cs and ^{137}Cs using Ge hyperpure gamma ray detectors. Samples also collected in 2012 at several arctic stations to evaluate Pacific Water inflow of radioactivity to the Beaufort Sea.

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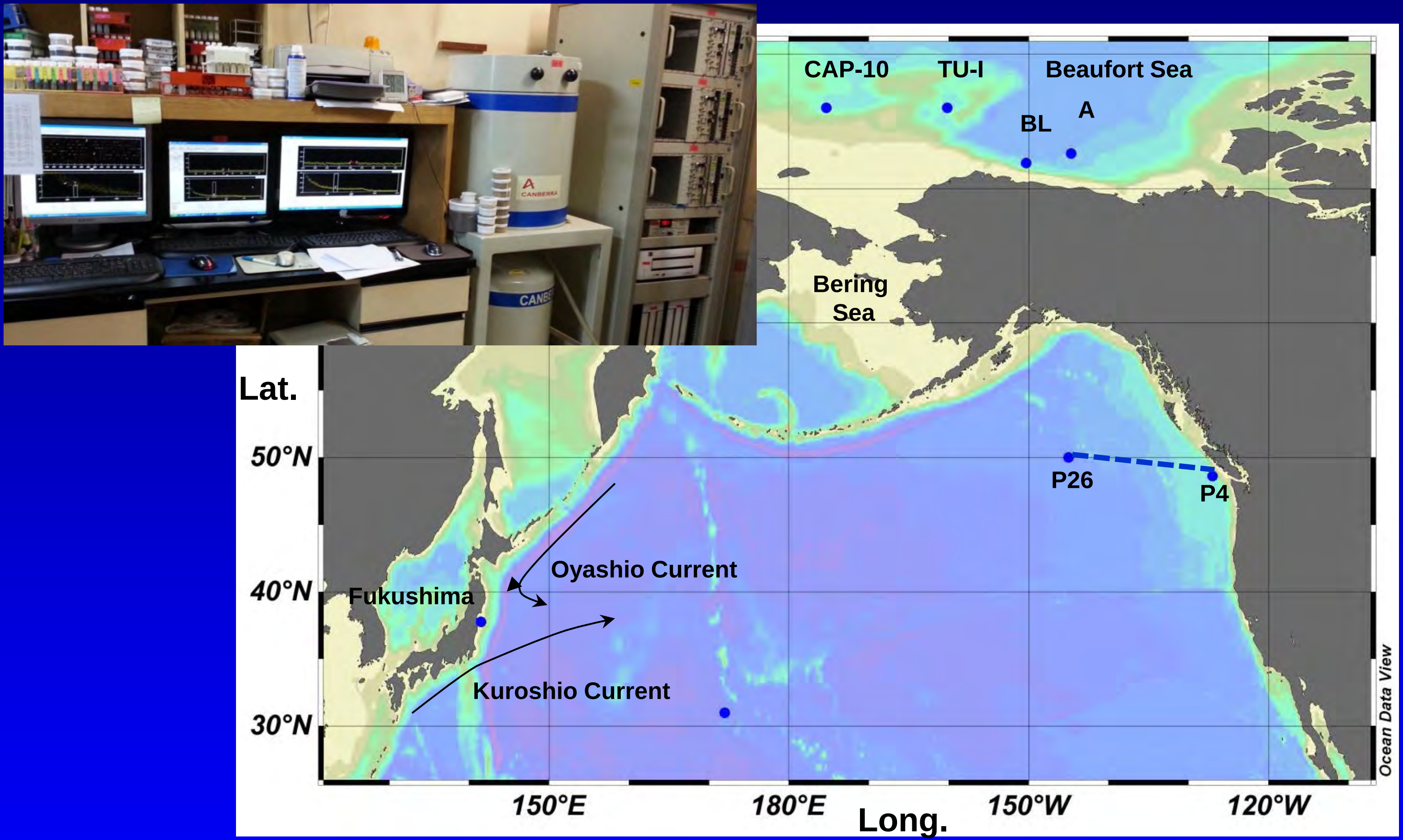

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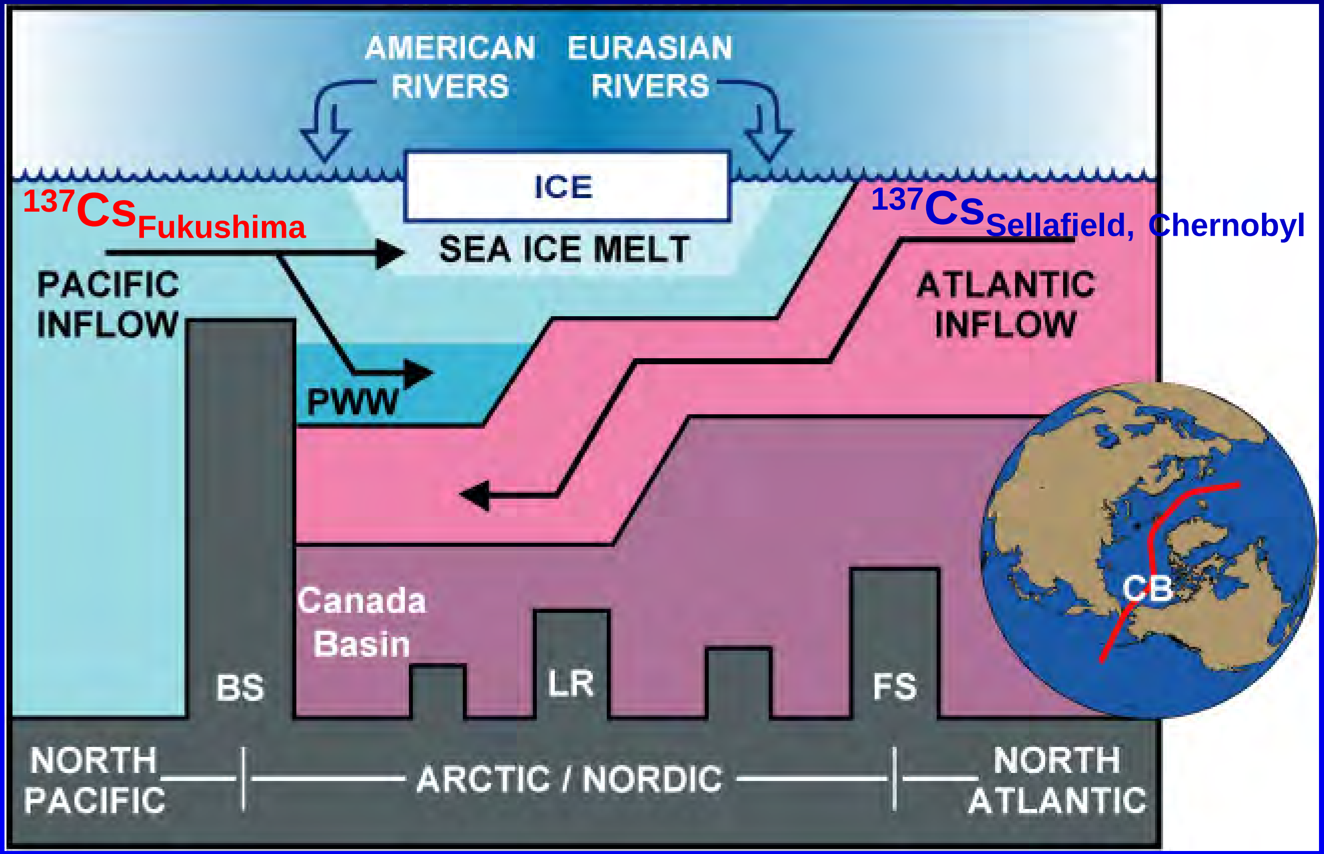
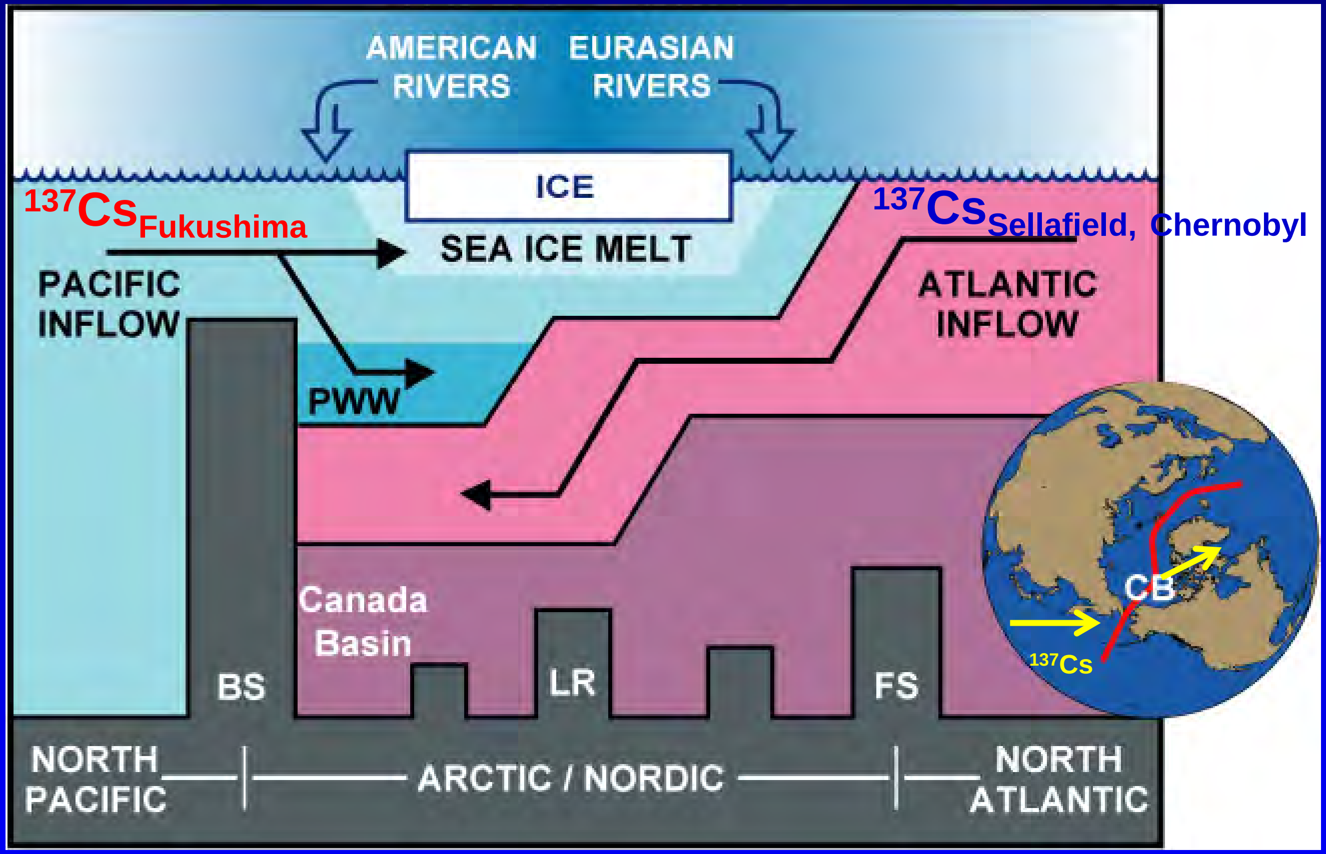
Why Measure ^{137}Cs in Arctic?



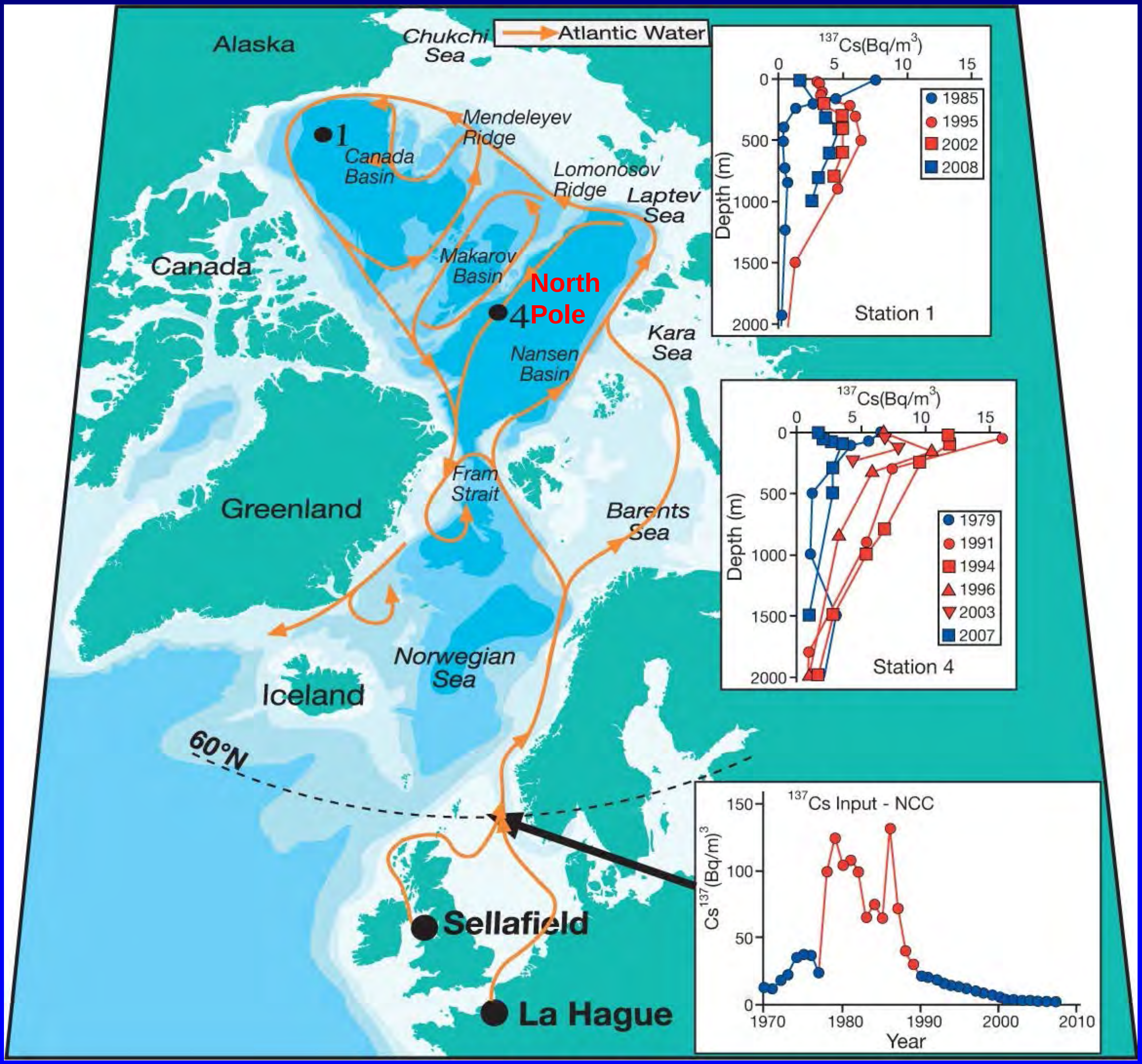
Pacific water contaminated with Fukushima ^{137}Cs flows through Bering Strait and mixes with underlying Atlantic water labeled with ^{137}Cs from Sellafield nuclear fuel reprocessing plant and Chernobyl accident.

Why Measure ^{137}Cs in Arctic?

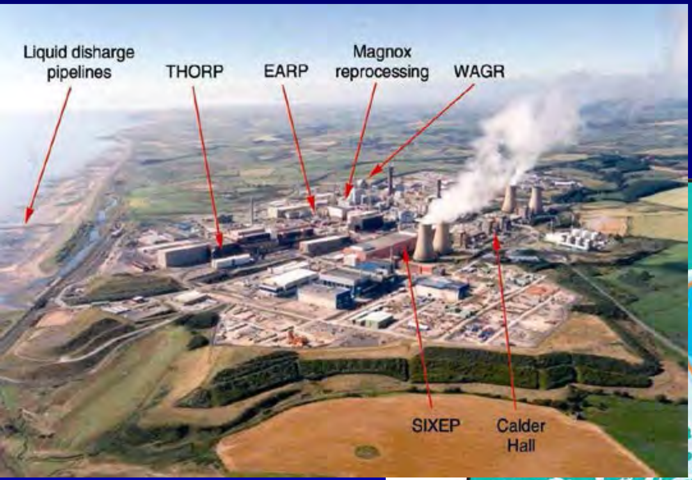


Surface outflow of Pacific water through Archipelago and Fram Strait can potentially contaminate Atlantic water.

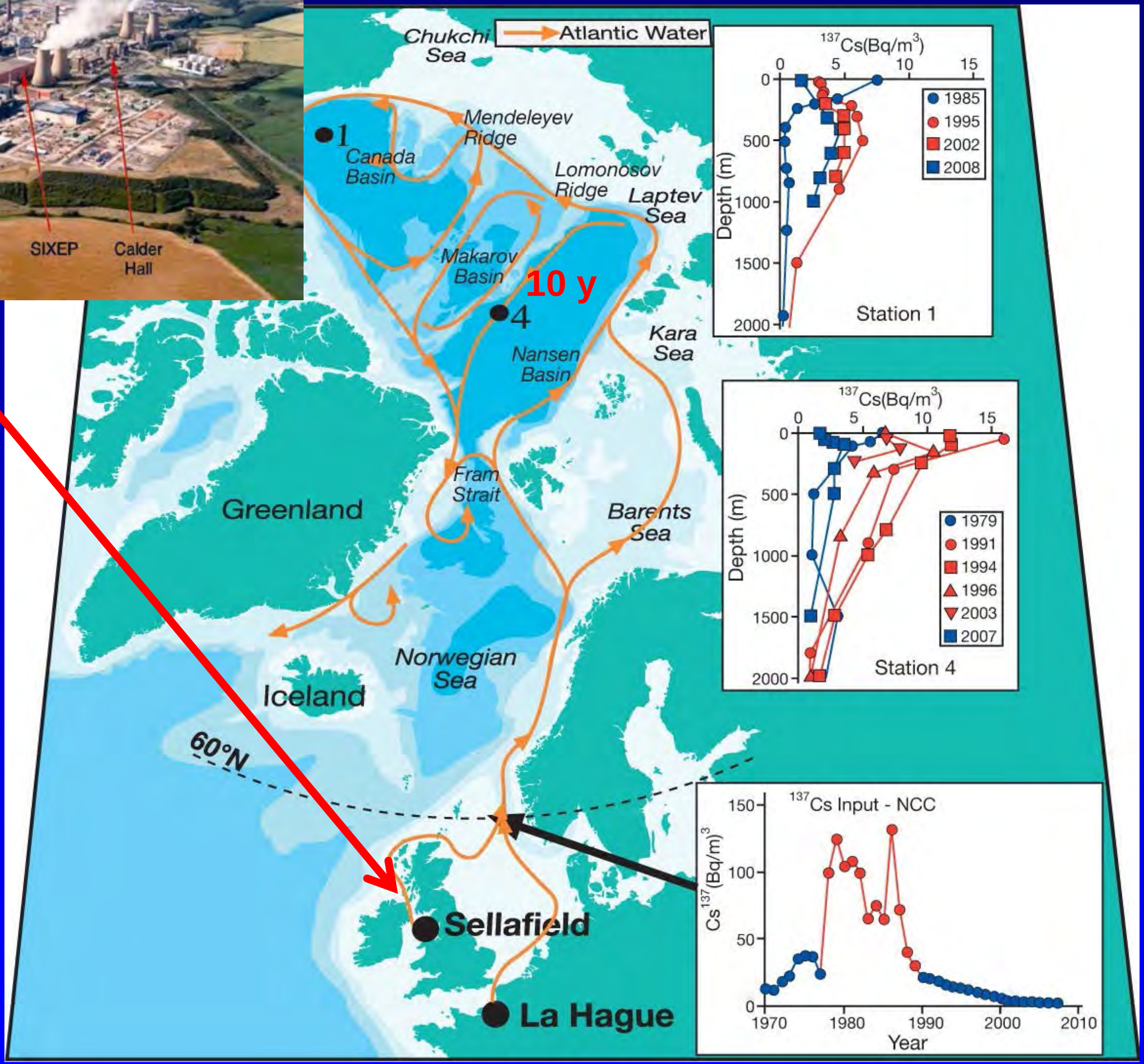
Circulation of ^{137}Cs in Arctic Ocean



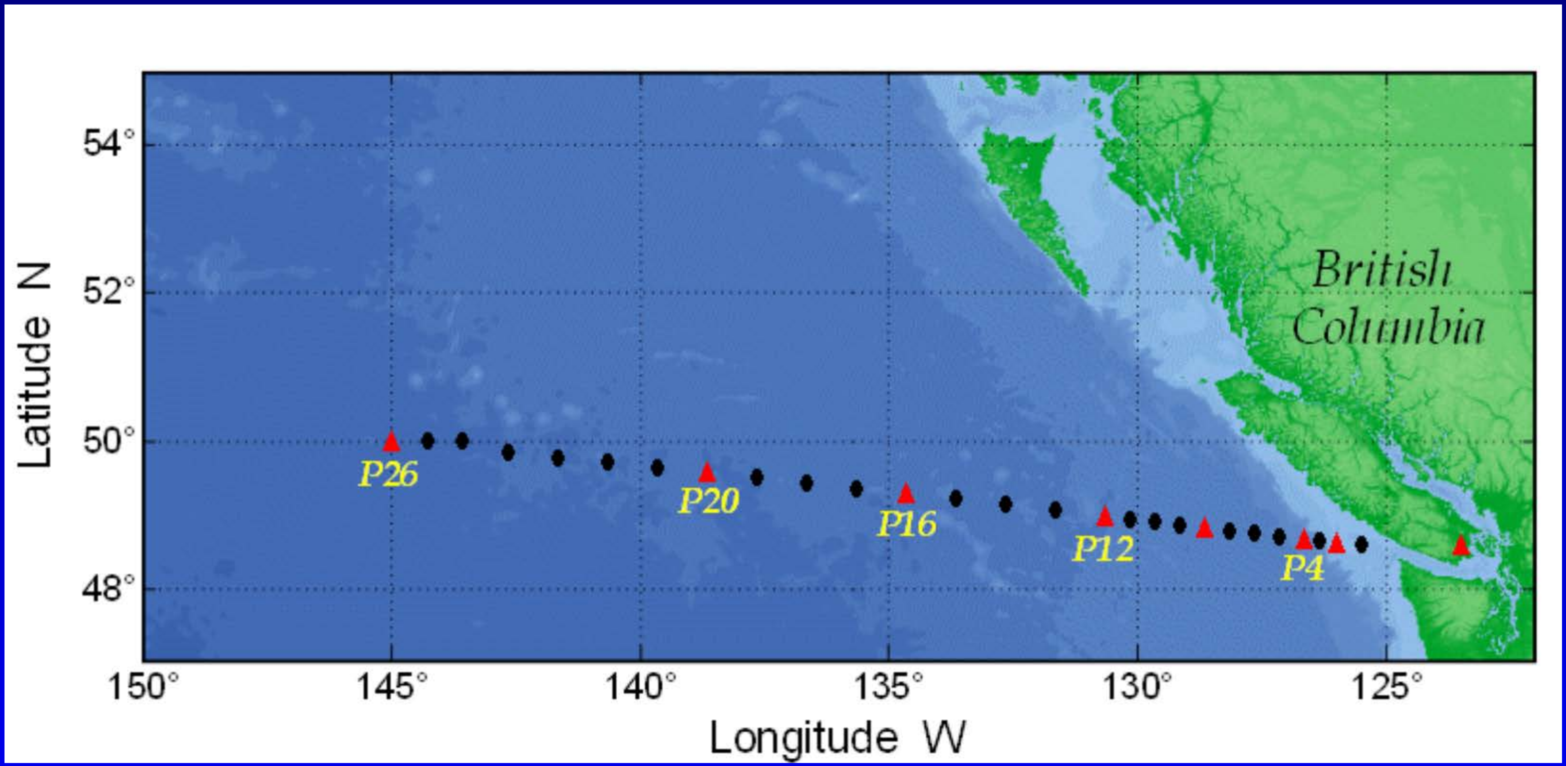
^{137}Cs is transported northward into the Arctic Ocean to the North Pole (Sta. 4) and Canada Basin (Sta. 1). Red water depth profiles (inset) show arrival of peak inputs.



^{137}Cs comes from Sellafield: a nuclear fuel reprocessing plant and the only global source for radioactivity comparable To Fukushima.



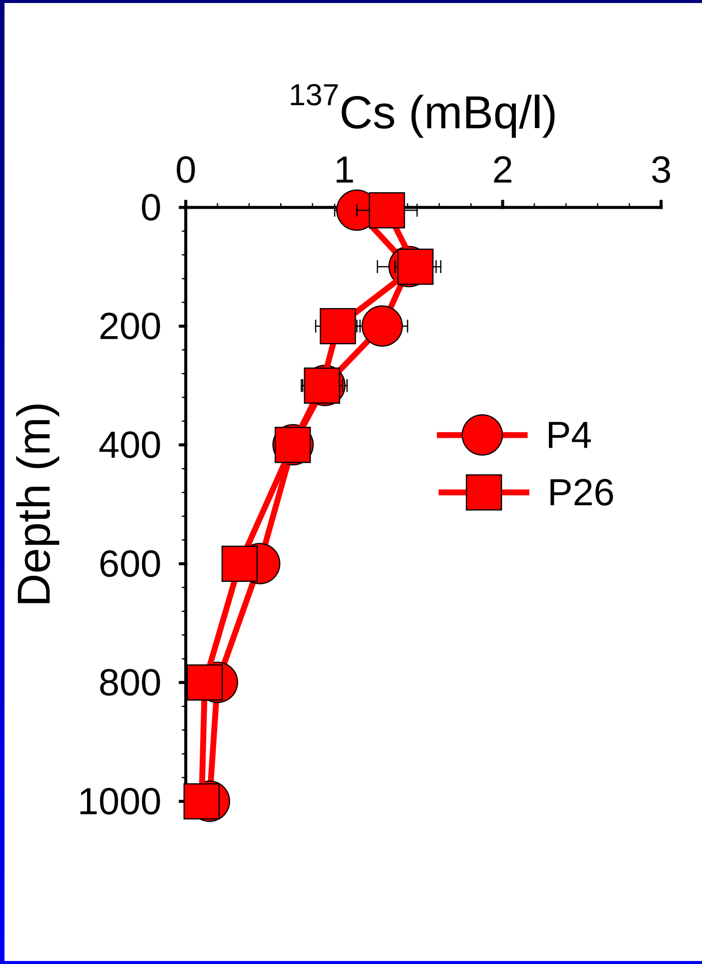
^{137}Cs is transported northward into the Arctic Ocean to the North Pole (Sta. 4) and Canada Basin (Sta. 1). Red water depth profiles show arrival of peak (inset) inputs. Comparison with input function used to estimate circulation time scales, eg. 10 y to North Pole.

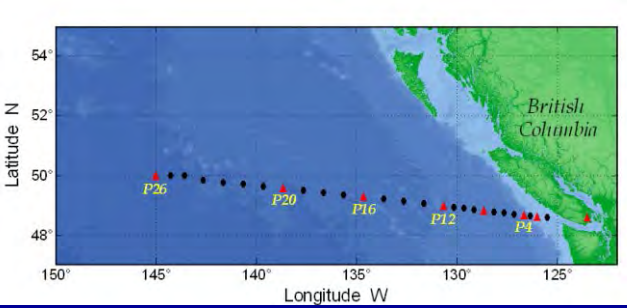


CSGS Tully Cruise – Line P; June 2011

(Chief scientist – M. Robert)

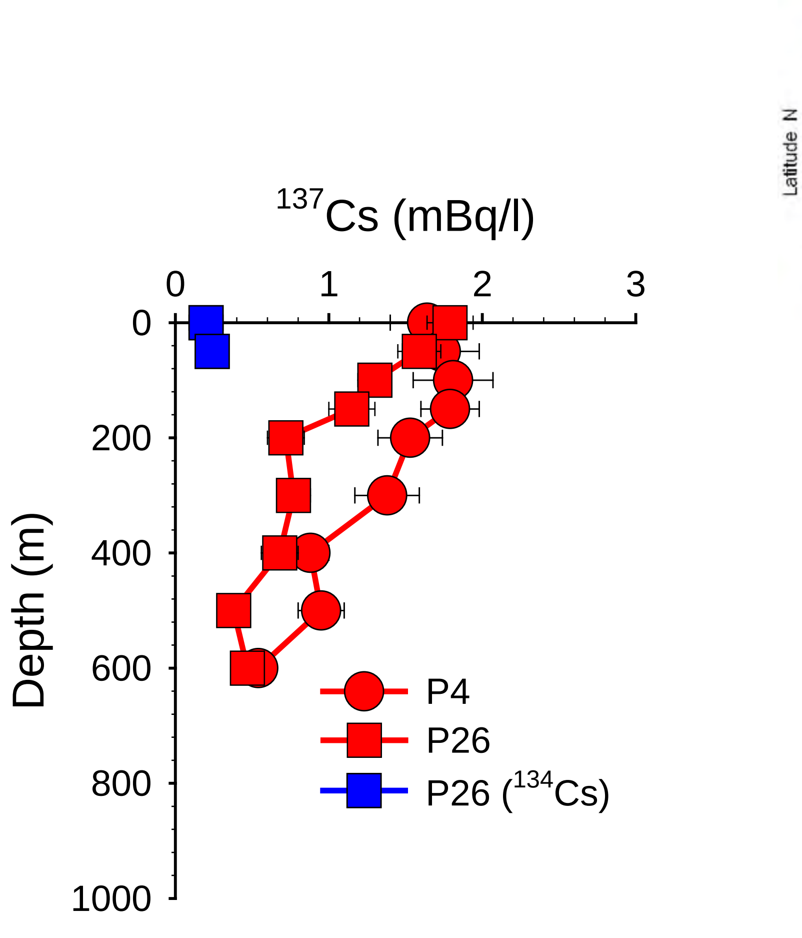
June, 2011 Tully Mission

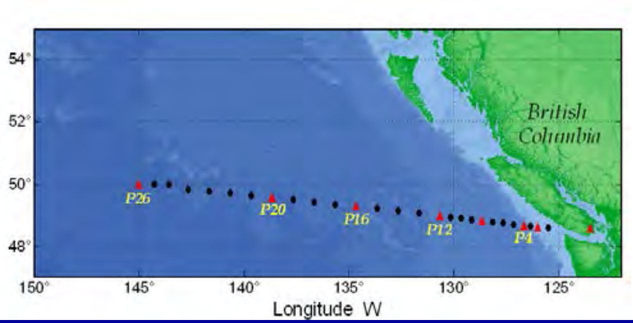




^{137}Cs profiles in 2011 were similar at both Stas. P4 and P26 and represent the background signal from weapons fallout: ^{134}Cs was below detection limit of 0.1 mBq/l.

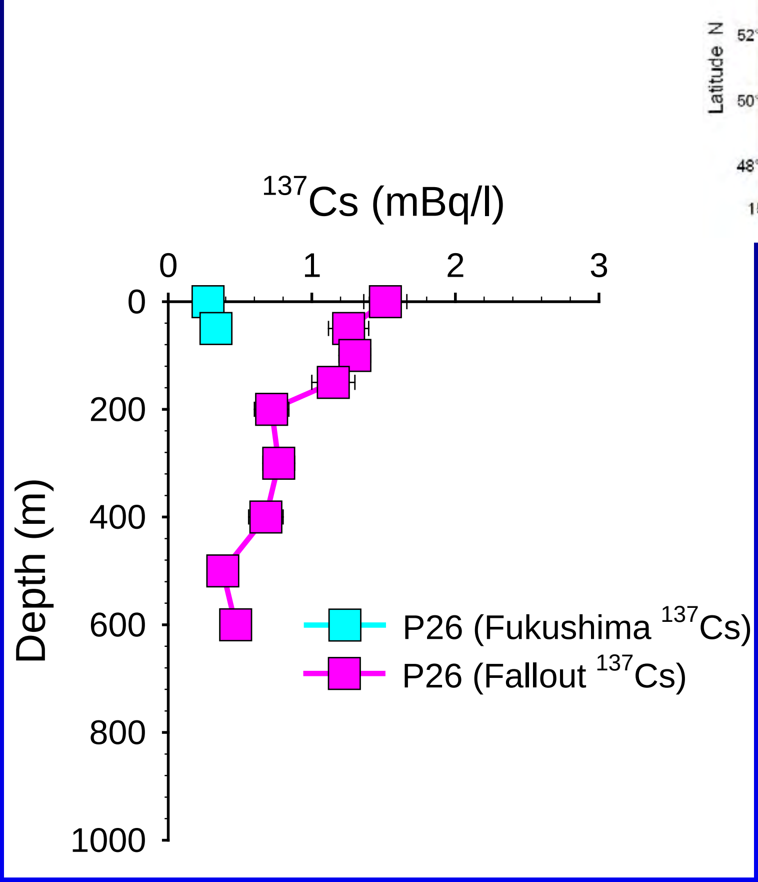
June, 2012 Tully Mission

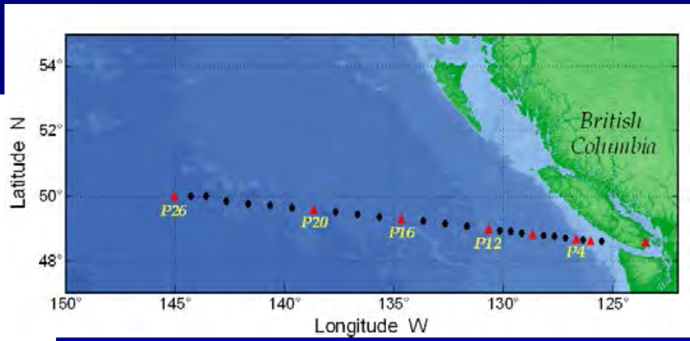




Significantly, ^{134}Cs was detected in two samples in the upper 50 m
At Sta. P26 showing that Fukushima Cs was present.

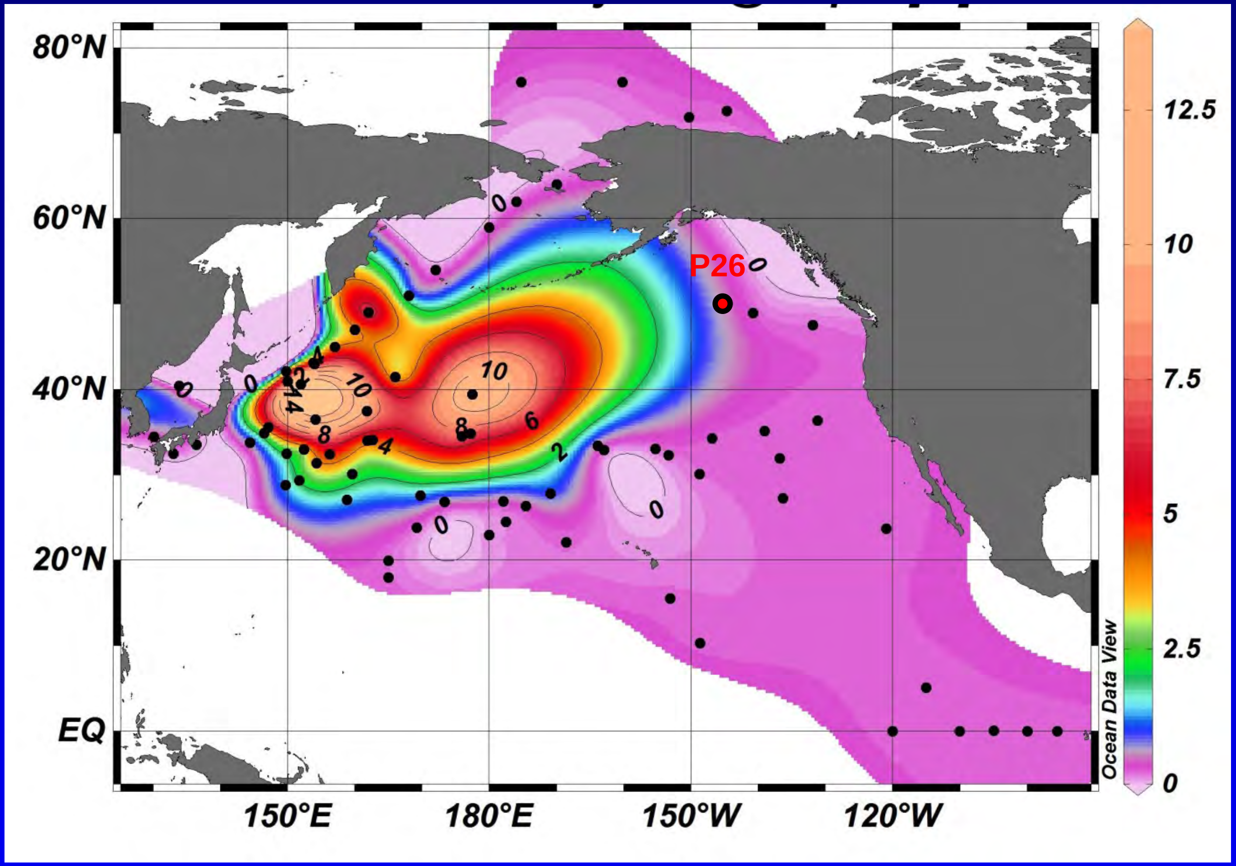
June, 2012 Tully Mission





Decay correction of the ^{134}Cs ($t_{1/2}$ = 2 y) to the time of the accident and knowing that the initial ^{134}Cs/^{137}Cs ratio = 1 permits the separation of the Fukushima ^{137}Cs component from the fallout ^{137}Cs component at Sta. P26. Fukushima ^{137}Cs is undetectable below 50 m.

Surface water distribution of Fukushima ^{137}Cs in 2012

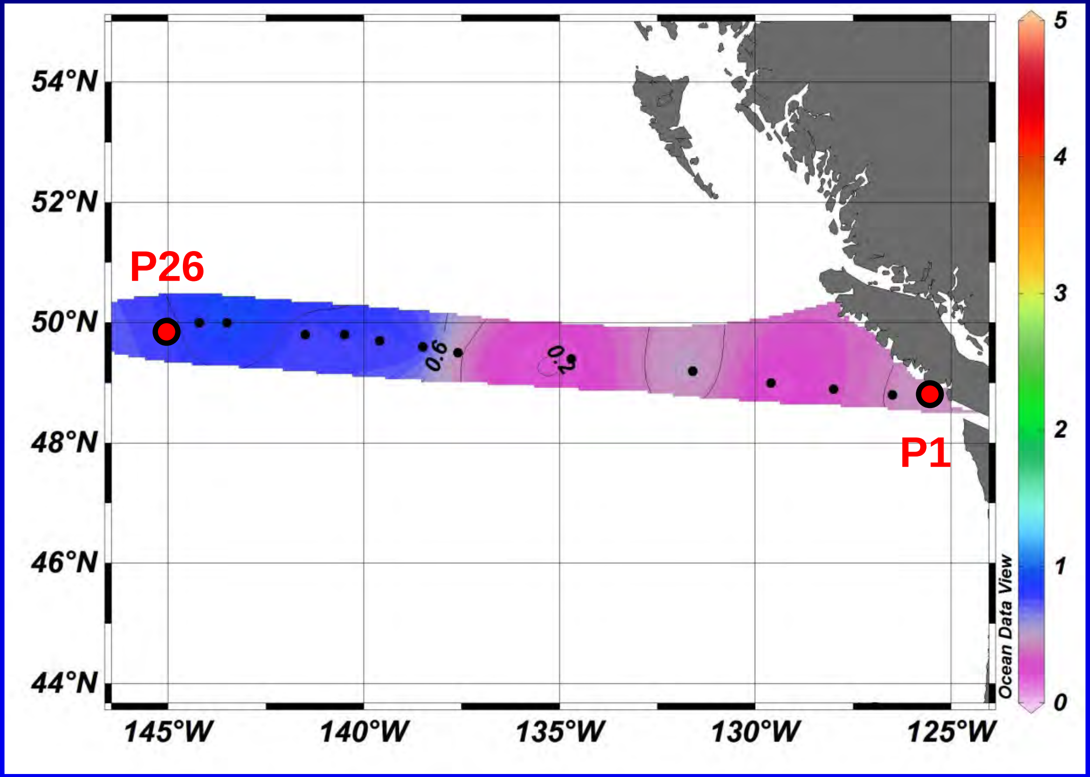


^{137}Cs (Bq/m^3)

(Aoyama et al., 2013; G. Hong, pers. comm.)

Main inventory of Fukushima ^{137}Cs had been transported towards central North Pacific By 2012. Levels of ^{137}Cs equal to 0.3 Bq/m^3 measured at Sta. P26 in 2012 represent Leading edge of Fukushima plume.

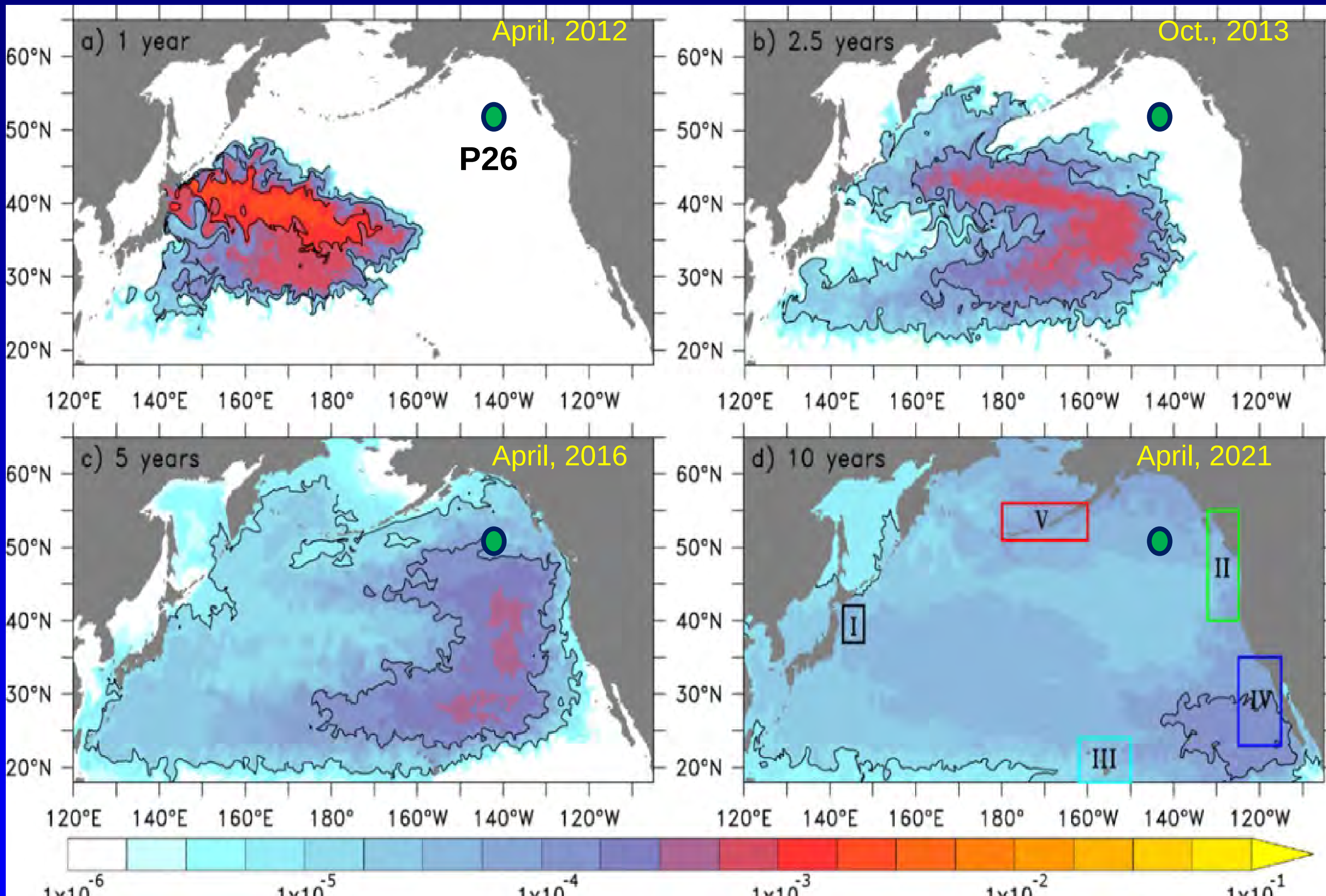
June, 2013 Tully Mission



$^{137}Cs_{Fukushima}$ (Bq/m^3)

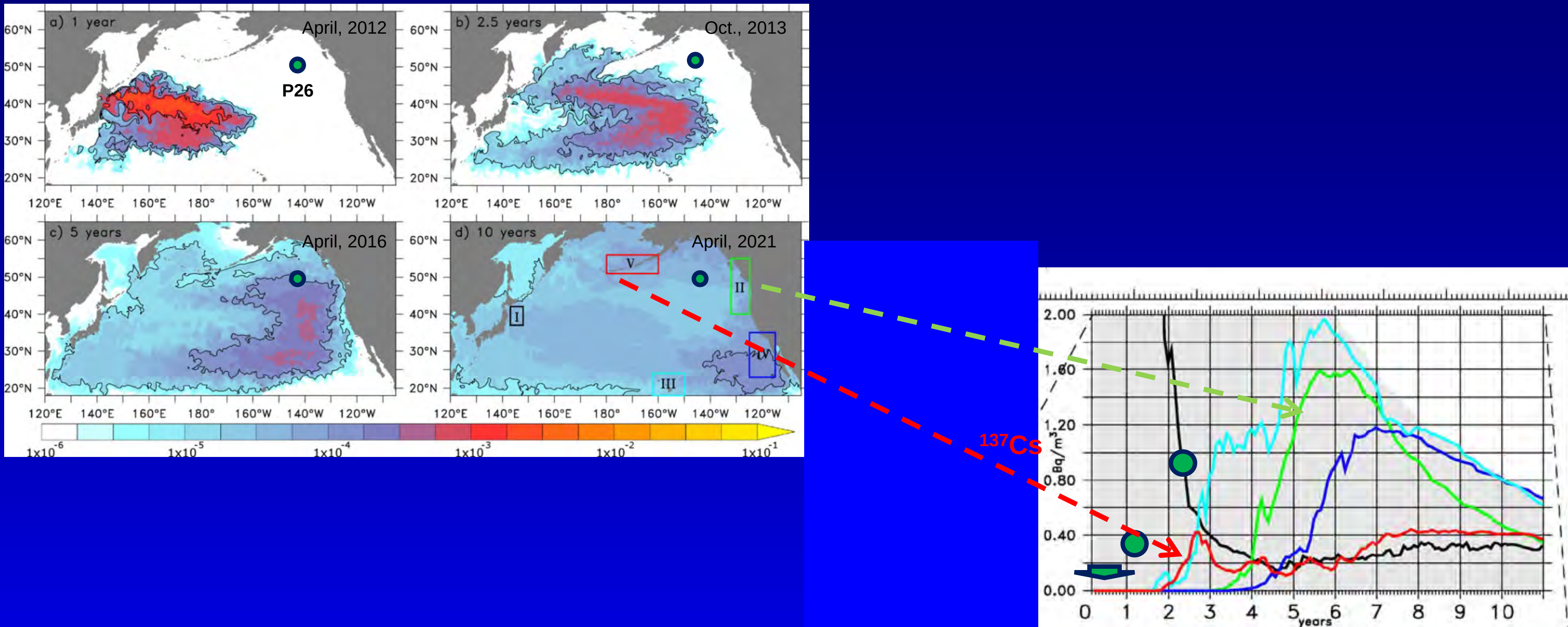
Distribution of ^{137}Cs from Fukushima on Line P in June, 2013 shows highest levels at Sta. P26 decreasing eastward to values < 0.5 Bq/m^3 at Sta. P1.

Behrens et al. (2012) Global Ocean Circulation Model



Behrens et al. (2012) model (based on Nemo; 0.1º horizontal mesh size) estimates an arrival time of the ^{137}Cs plume at Sta. P26 of 3-5 y by current transport.

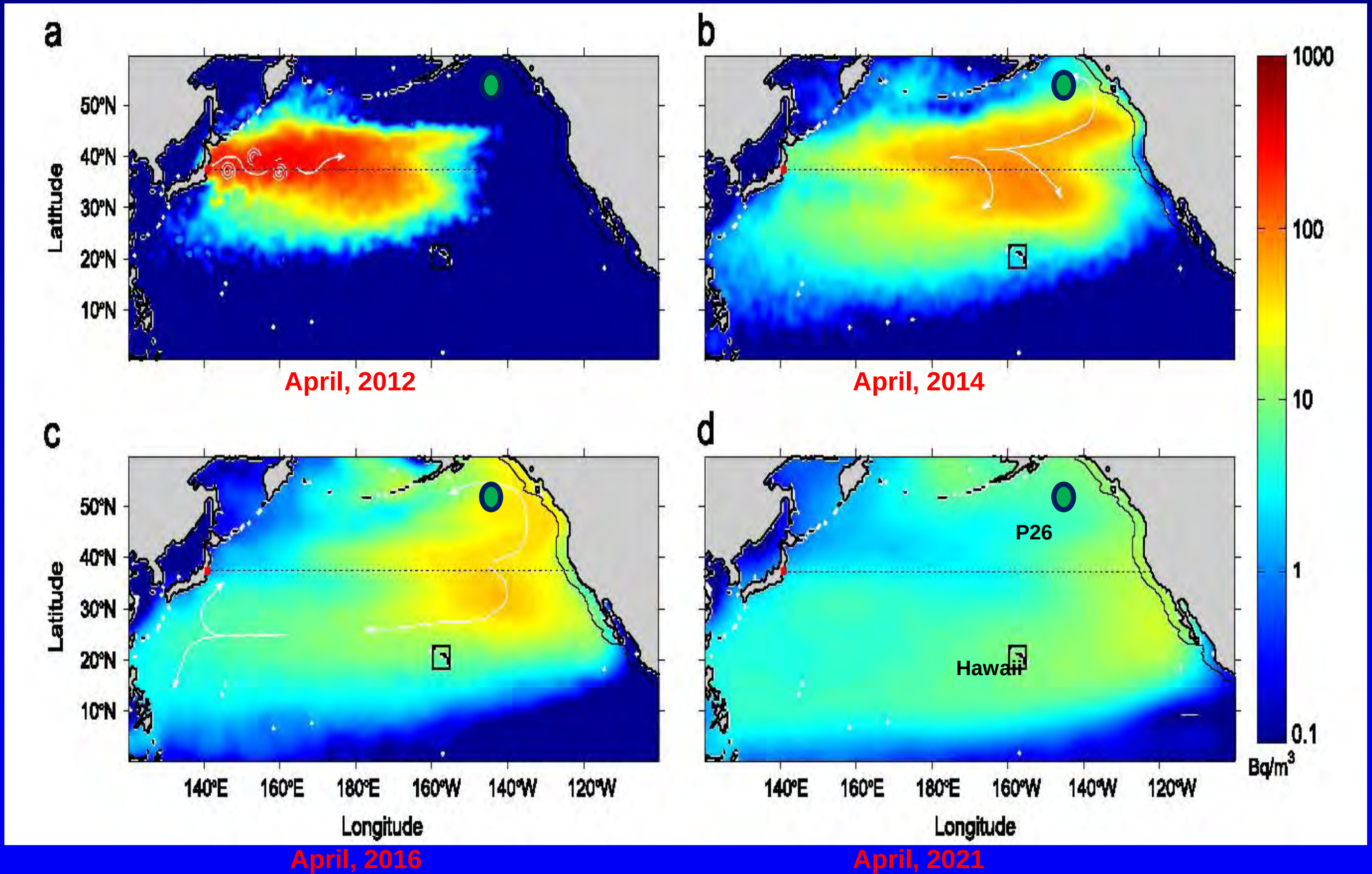
Behrens et al. Model



Coloured lines above represent model predictions of ^{137}Cs levels in coloured boxes (connected by arrows) in uppermost figure. Symbols are ^{137}Cs level measured at Sta. P26 in 2011, 2012 and 2013. Inset is a blow up of main figure, but on a linear scale.

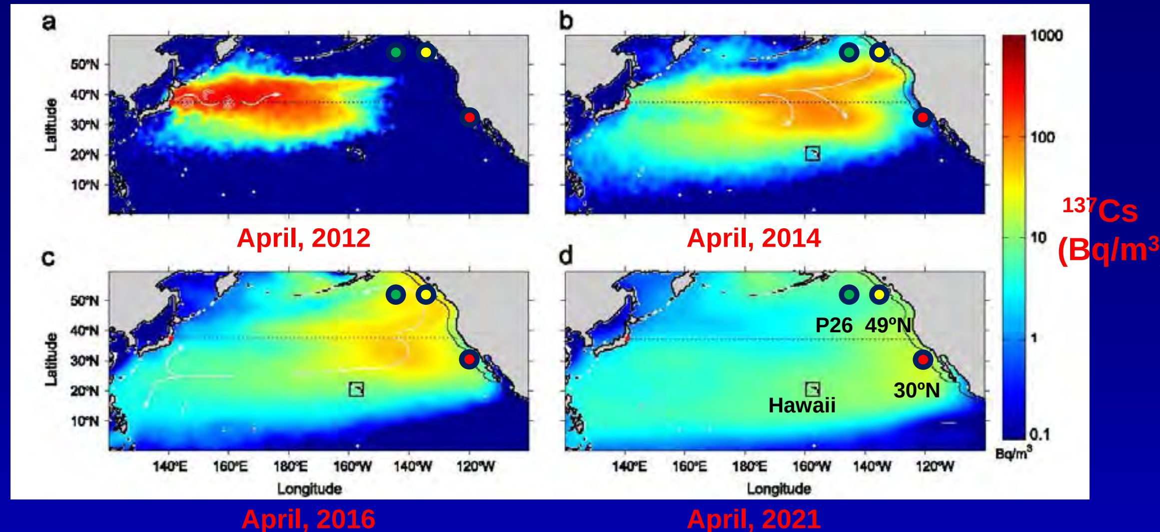
Arrival of ^{137}Cs at Sta. P26 in June, 2012 precedes model predictions by several years.

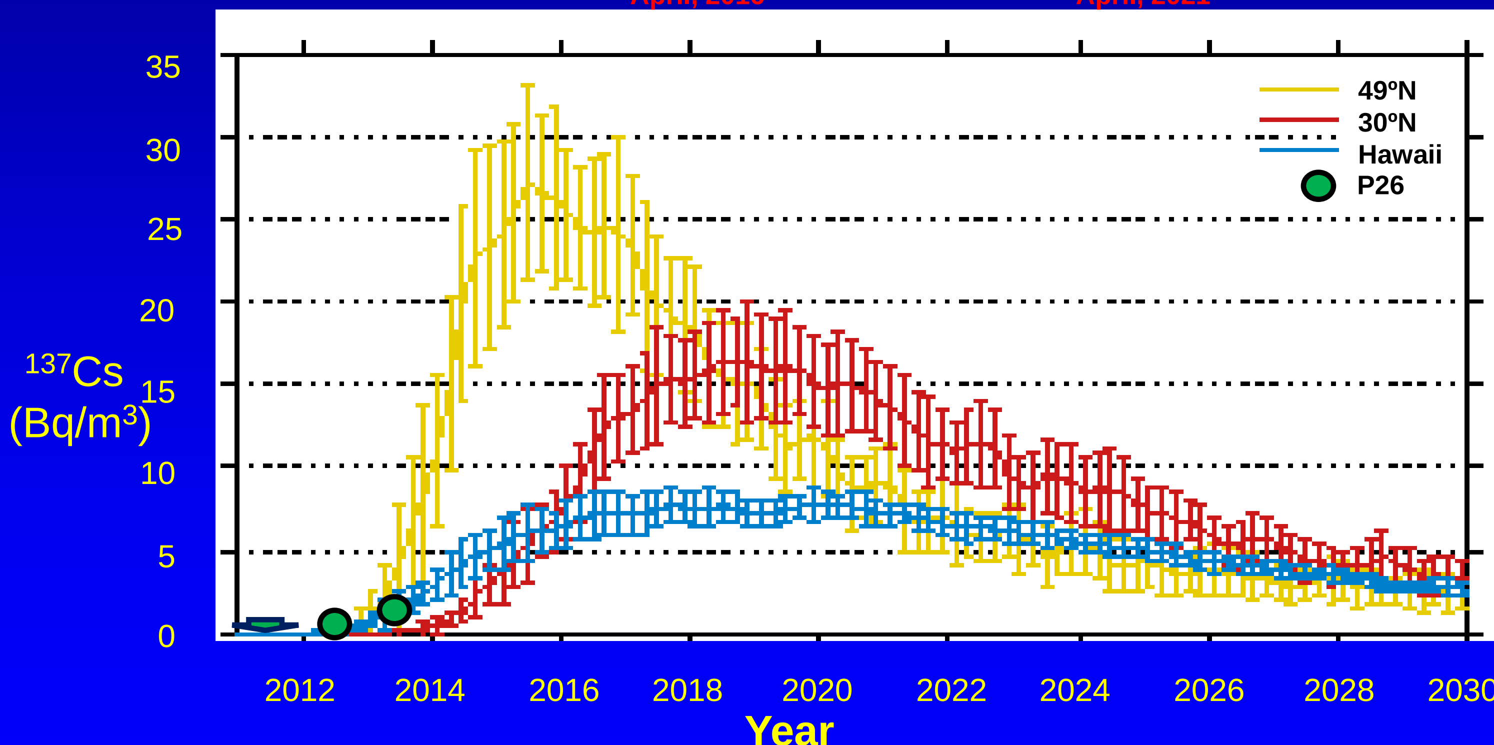
Rossi et al. (2013) Ocean Circulation Model



Maps show progression of ^{137}Cs surface water plume across Pacific for times of 1, 3, 5 and 10 years after accident. Green symbol is for Sta. P26. By 2016, major component of ^{137}Cs inventory has been transported from western to eastern North Pacific.

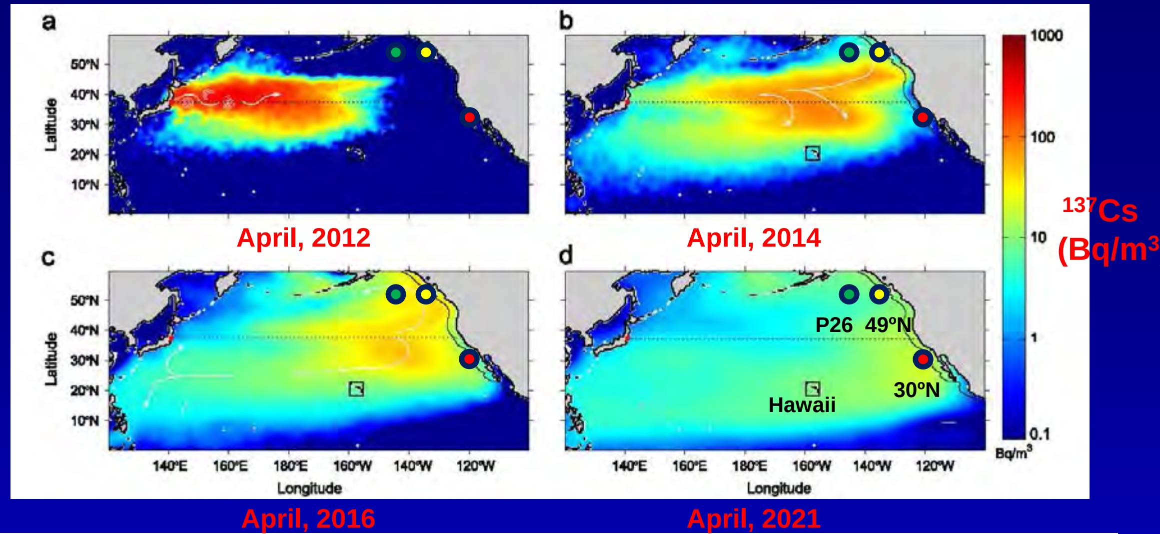
Rossi et al. (2013) Model

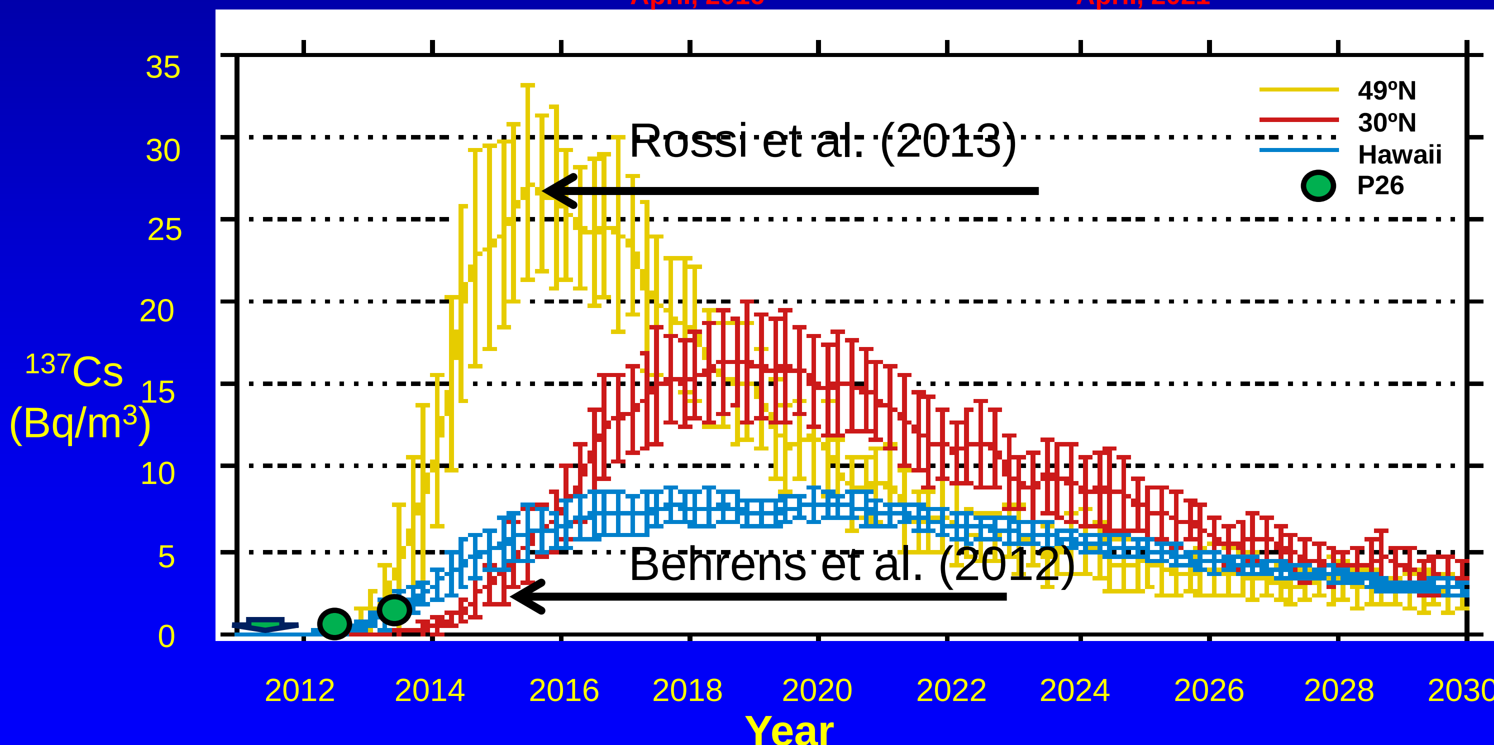




^{137}Cs at Sta. P26 (green symbol) is compared to model predictions for three locations: 49°N on shelf (yellow line); 30°N (red line); Hawaii (blue line). ^{137}Cs arrival at Sta. P26 in June 2012 is in agreement With Rossi model, but increases in June 2013 less sharply than predicted for shelf location at 49°N.

Rossi et al. (2013) versus Behrens et al. (2012) models

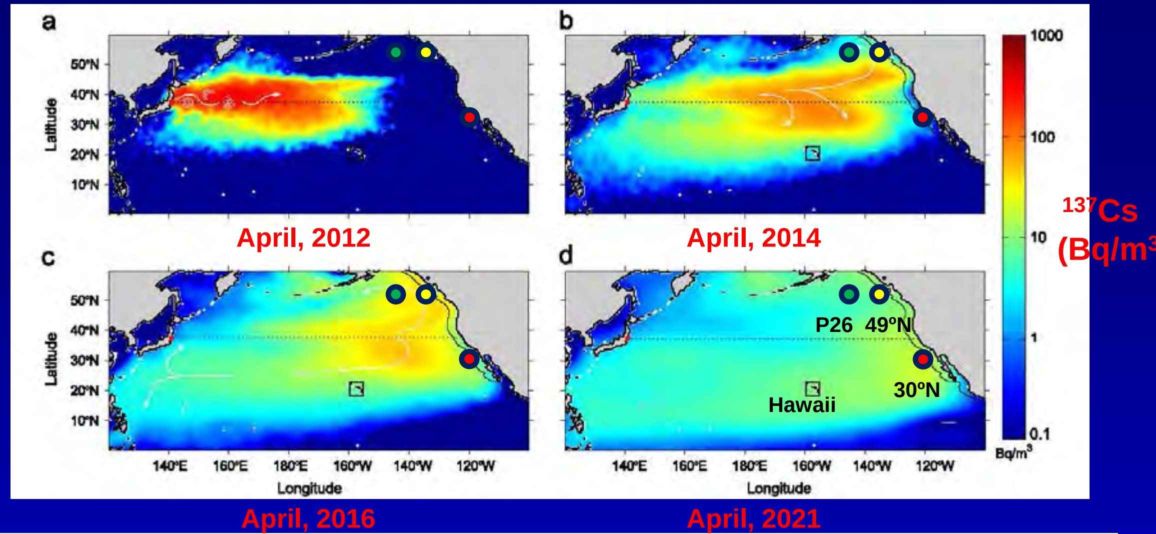


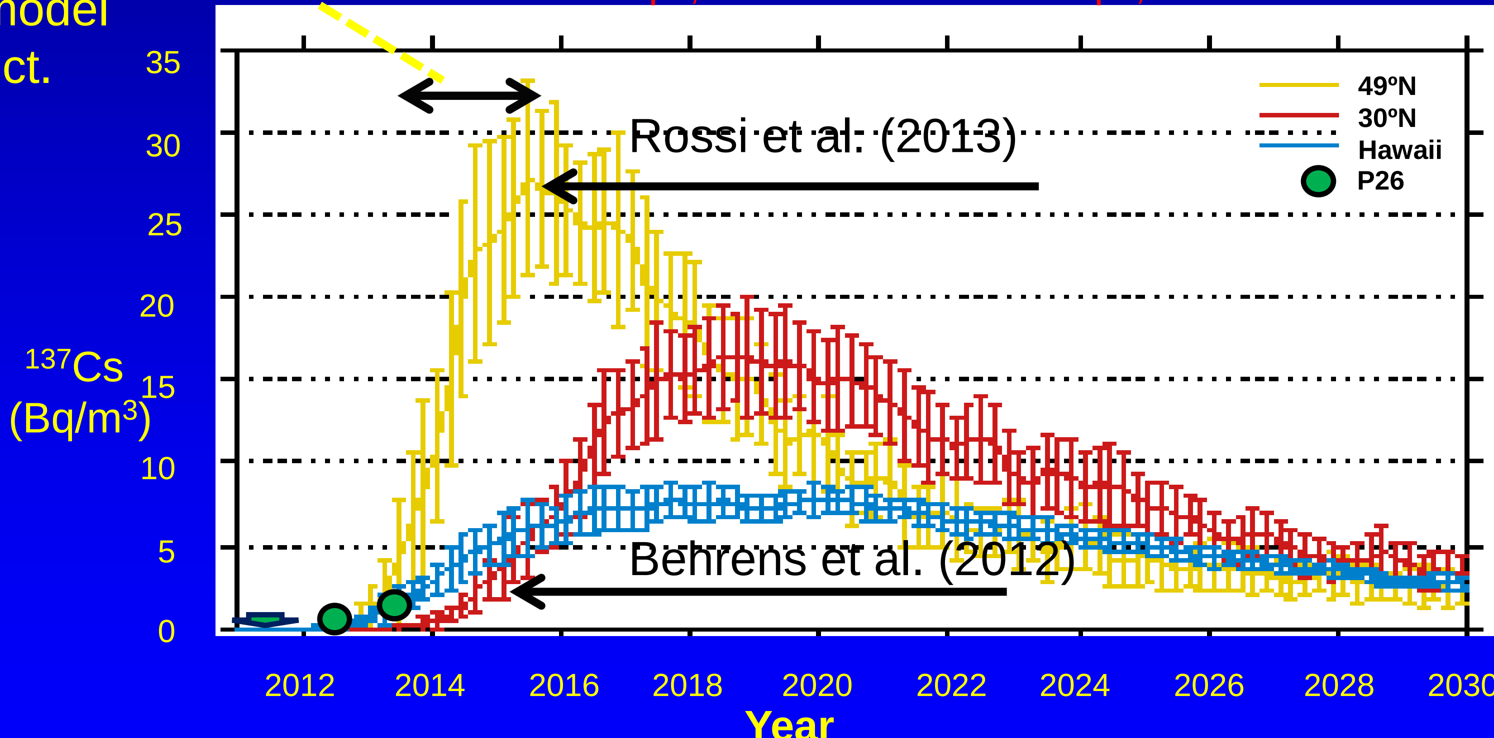


Behrens et al. (2012) predict maximum ^{137}Cs levels of 2 Bq/m^3 near Sta. P26 in 2015 while Rossi et al. (2013) predict 25 Bq/m^3. They can't both be right!

Rossi et al. (2013) versus Behrens et al. (2012) models

The next 2 years will be critical in determining which model Is correct.





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Why the model discrepancies?

1. Each group uses different input functions, has different model resolution and handles eddies differently.
2. The atmospheric input is especially difficult to simulate, because there were no downfield sampling stations in the Pacific Ocean.

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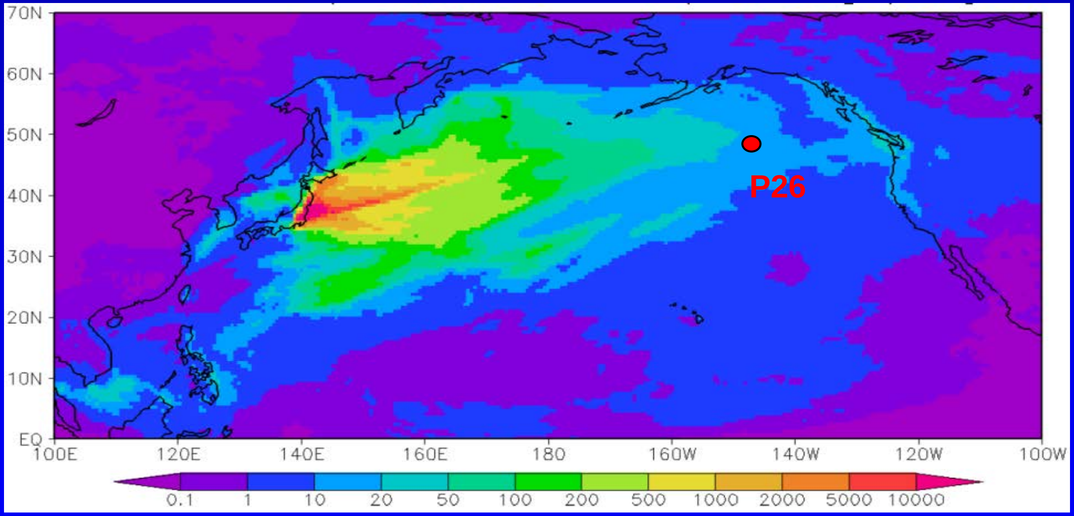
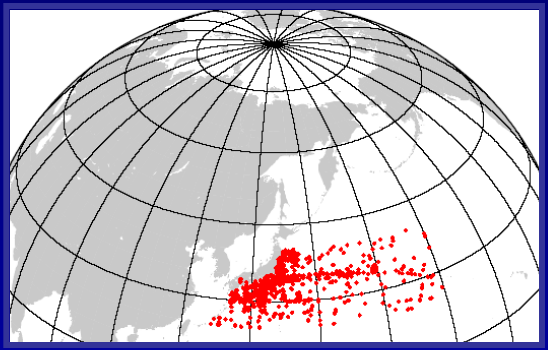
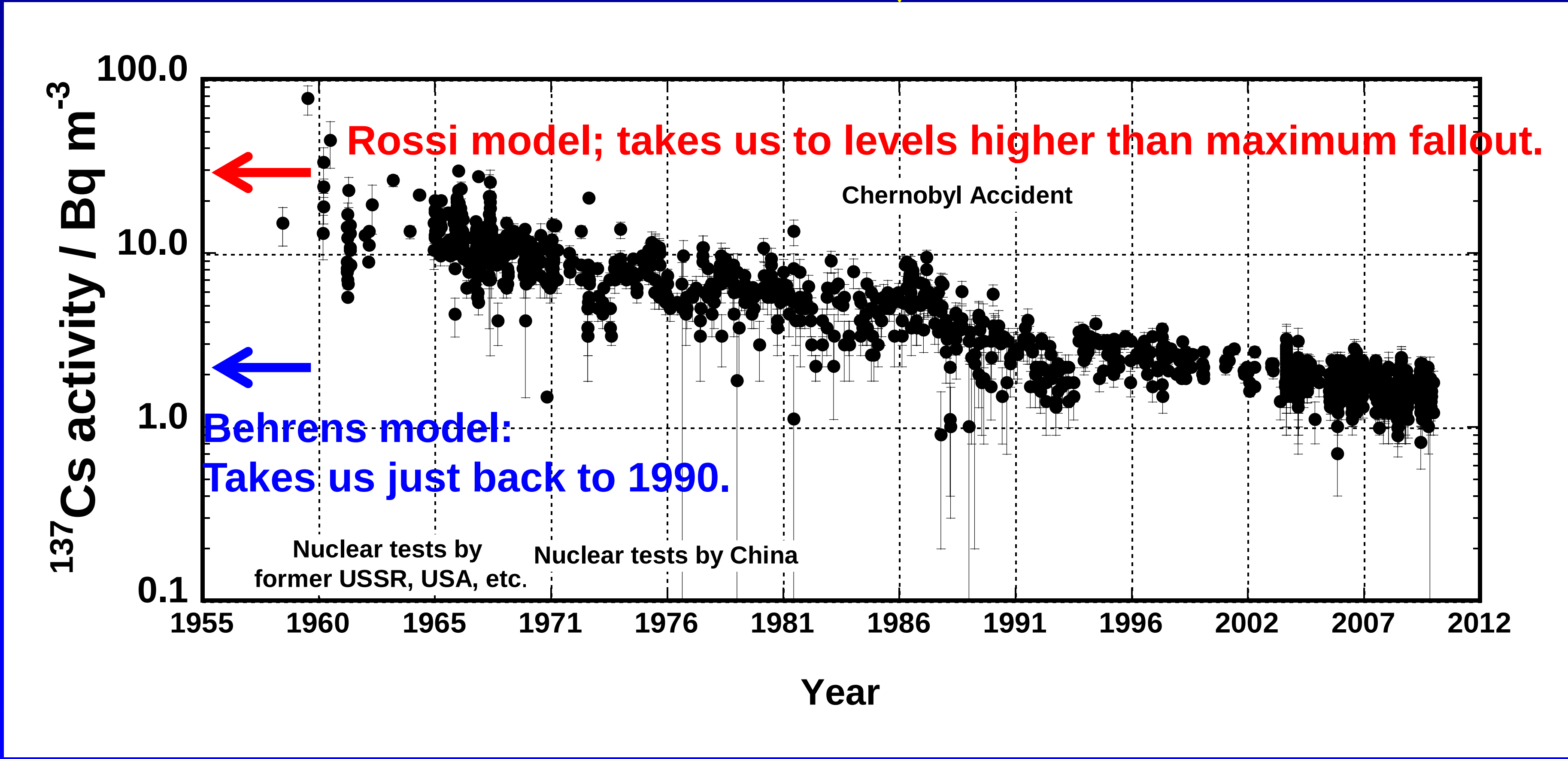


Simulated atmospheric deposition of ^{137}Cs ($Bq\ m^{-2}$) by Masingar II of MRI
Aoyama et al., in preparation



To what historical fallout level does Fukushima return us?

Long-term trend of ^{137}Cs in surface water in the western North Pacific Ocean: pre-Fukushima



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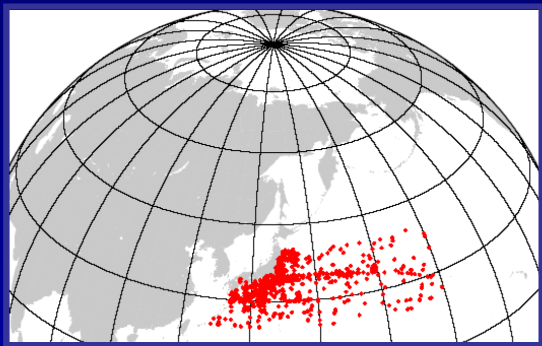
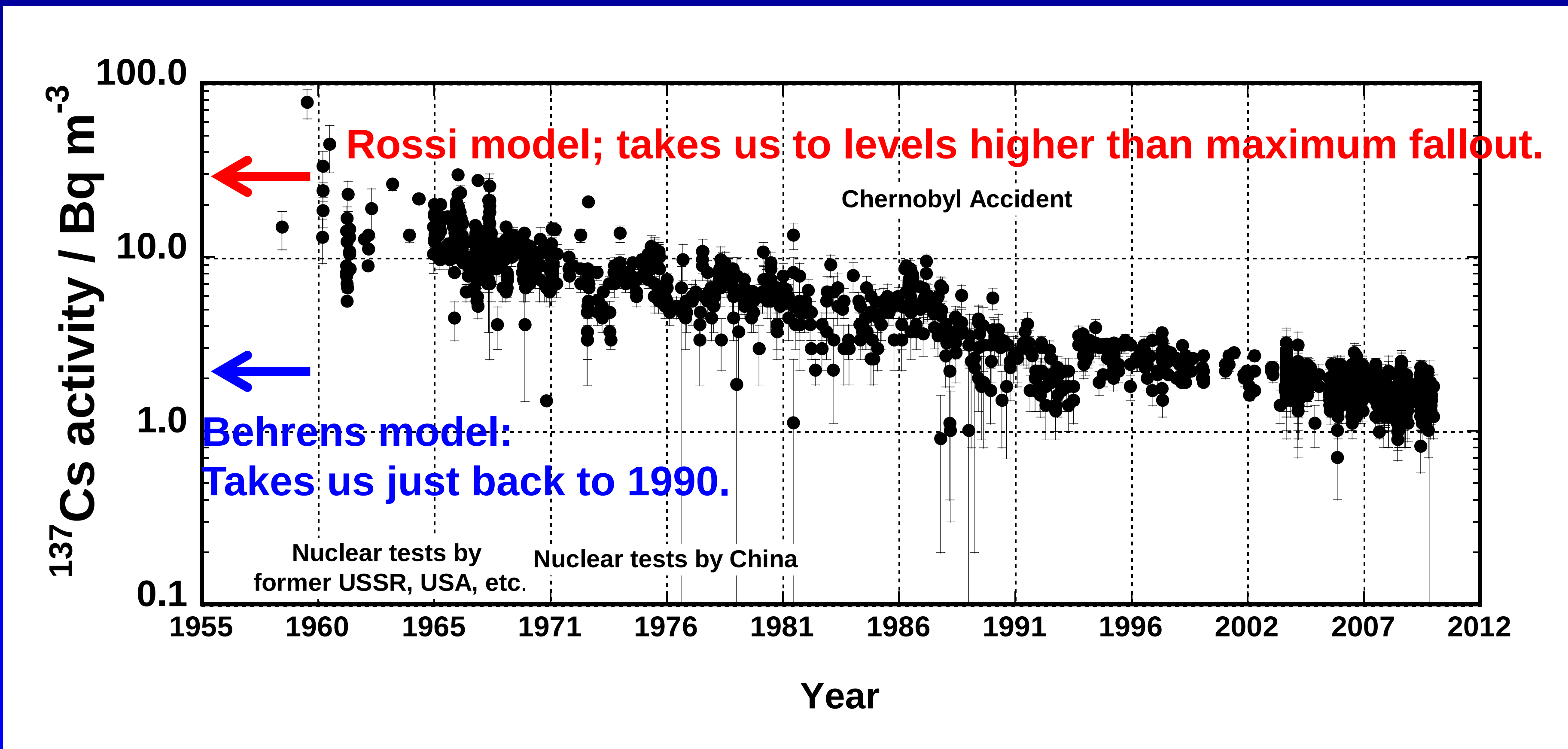


<u>Caveat:</u> These levels are still well below maximum permissible concentrations in drinking water for ^{137}Cs of 10,000 Bq/m^3: Not an environmental or human health radiological threat!



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Conclusions

1. ^{137}Cs levels in upper 1000 m at Stas. P4 and P26 in June, 201 consistent with background levels in North Pacific from atmospheric nuclear weapons tests.

2. Fukushima ^{134}Cs was detectable in upper 50 m at Sta. P26 in June, 2012, but not at Sta. P4 or at arctic stations. Fukushima ^{137}Cs levels were 0.3 Bq/m^3.

3. ^{134}Cs was detectable along the entire Line P in June, 2013. Highest levels of 0.9 Bq/m^3 were measured at Sta. P26.

4. Arrival of Fukushima ^{137}Cs at Sta. P26 precedes model predictions by Behrens et al. (2012), but is in agreement with Rossi et al. (2013). However, 2013 increase in ^{137}Cs is less than predicted by Rossi et al. (2013).

5. Which model is closest to reality? Rossi et al. (2013) predict maximum levels of 25-30 Bq/m^3 for North American shelf while Behrens et al (2012) predict maximum levels of only 2 Bq/m^3. Future measurements on Line W should provide an answer.

Overview

The inventory of Fukushima radioactivity will almost entirely shift from the western to the eastern North Pacific during the next 5 years.

Many reasons for study-

- Human health- internal/external dose assessments
- Radioecology- marine biota
- New ocean tracers in Pacific
- Modeling/predictions of future accidents

PICES can make a contribution through activities of WG30.

Fact is: radioactivity frightens people, almost always disproportionately to the actual threat: gouvernment must recognise this and provide sound, science based knowledge (and wisdom?) on human and environmental risks.