

Electromagnetic Signatures Associated With California Earthquakes

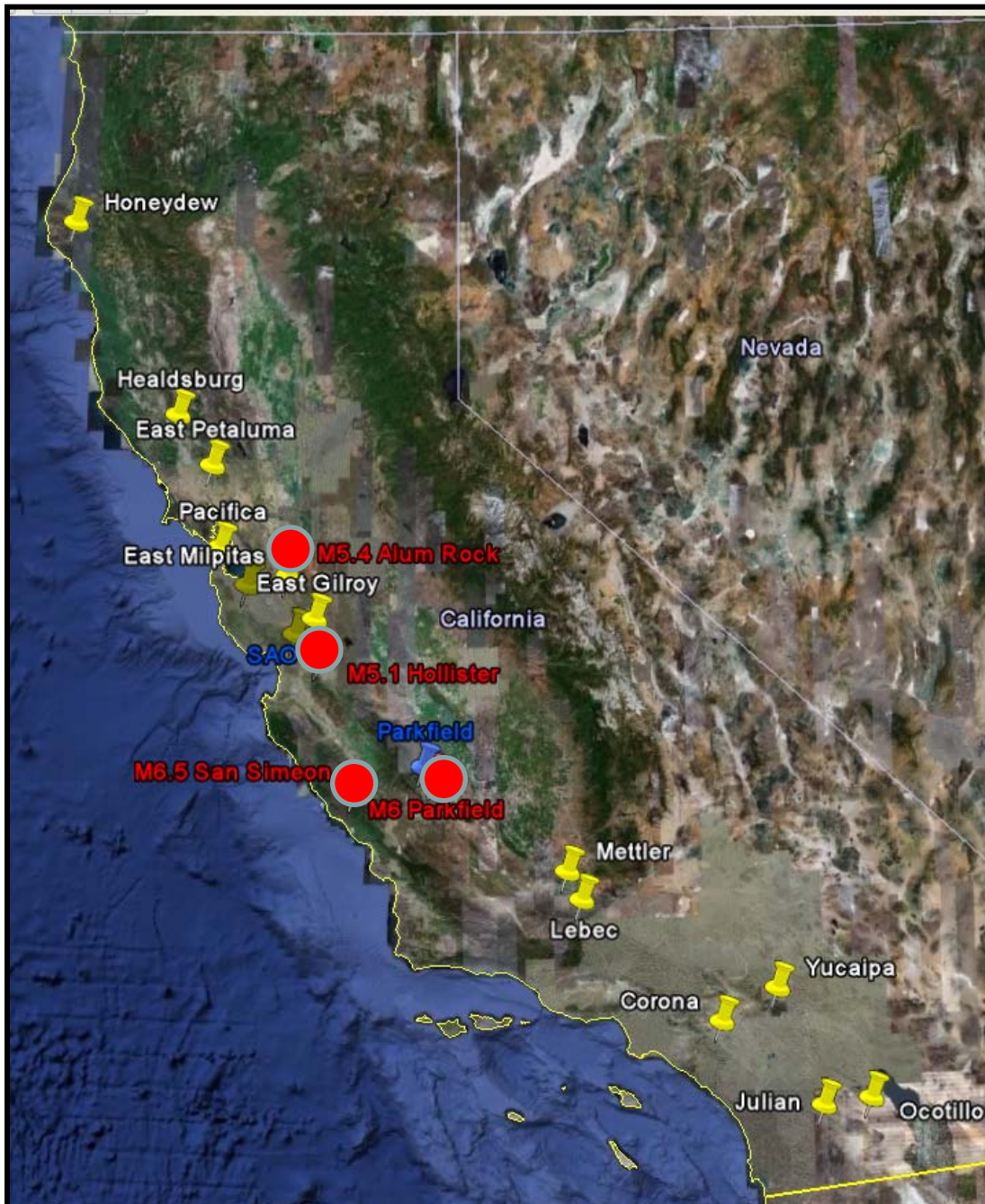
AOGS August, 2009

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NASA/Ames, JPL/NASA : Dr. F. Freund, Dr. N. Bryant, Dr. R. Bamberg**

Electromagnetic Signatures Observed Prior to Earthquakes

- 1) ULF Magnetic Signatures (Pulsations)
 - Long Term Trends
 - Noise Sources
- 2) Air Conductivity Signatures
 - Long Term Trends
 - Noise Sources
- 3) Infrared (IR) Signatures
 - Long Term Terms
 - Noise Sources
- Discoveries, Conclusions and Future Strategies



4 Quakes Investigated:

- 1998 Hollister M5.1
- 2003 San Simeon M6.4
- 2004 Parkfield M6.0
- 2007 Alum Rock M5.4*

* Most detailed data



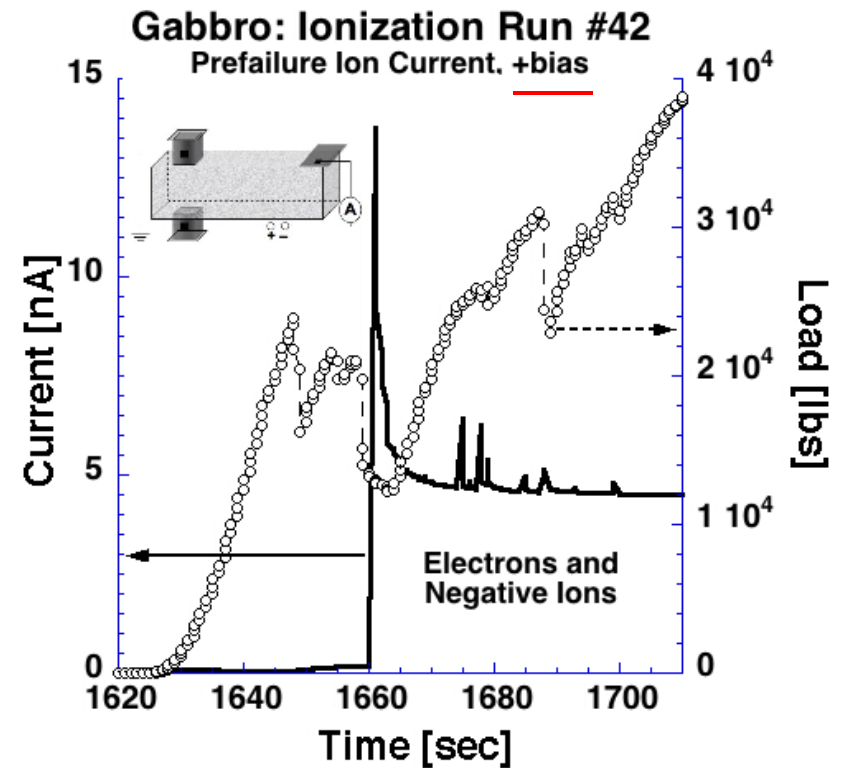
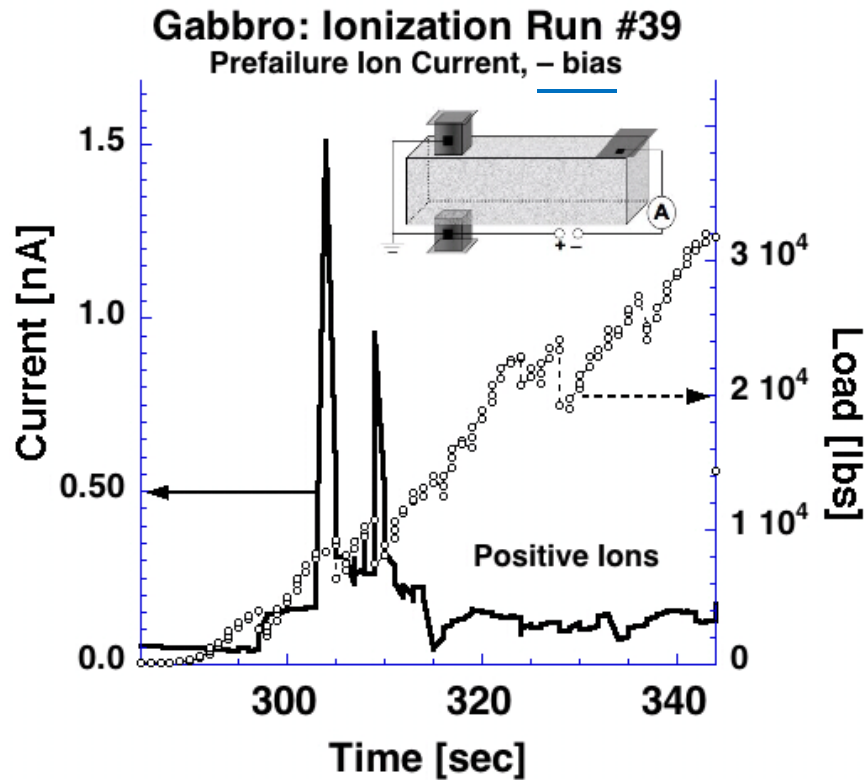
= Hi Res.
magnetometers

Ultra Low Frequency (ULF) Magnetic Signatures

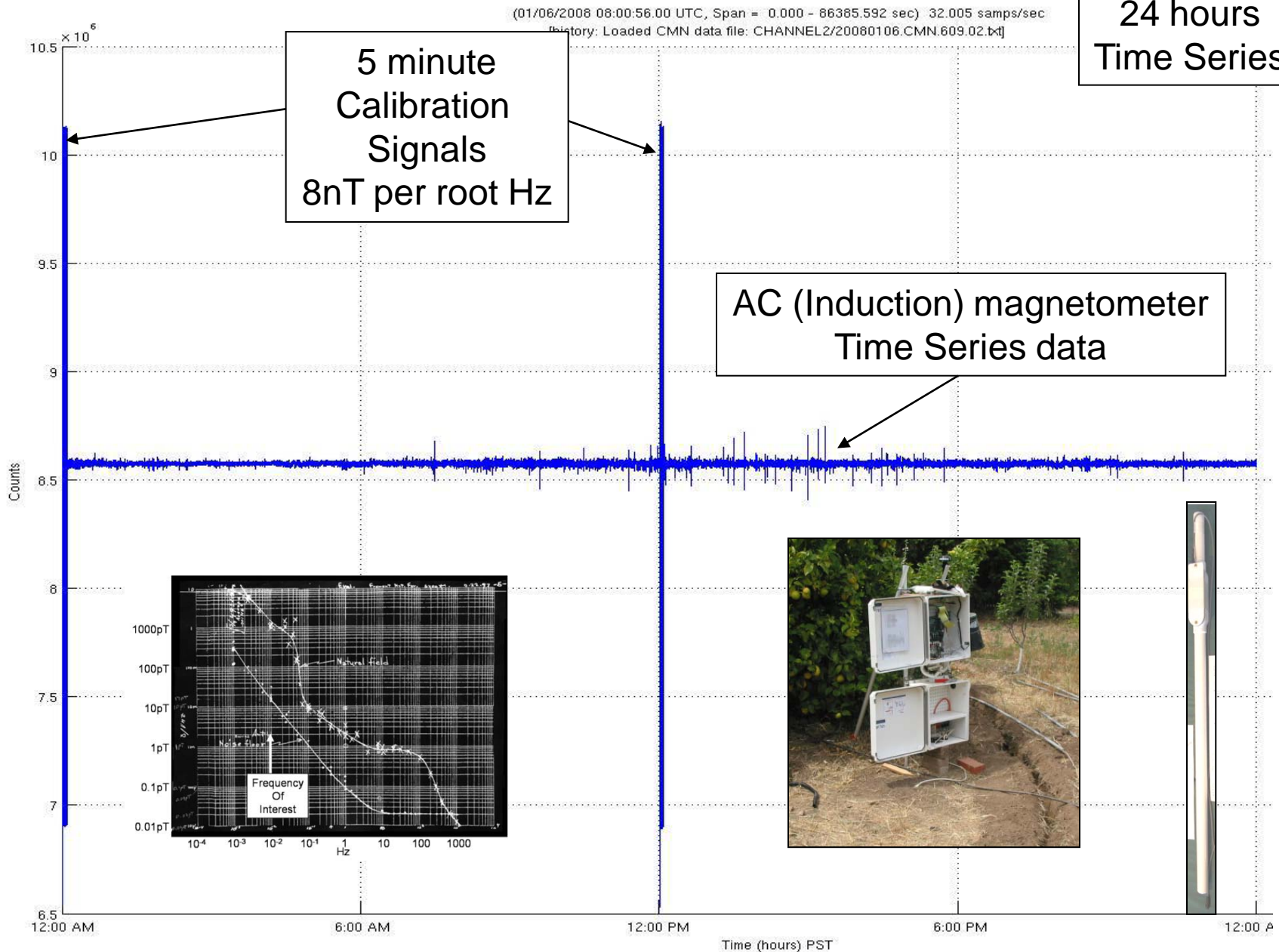
**Any Similarities between Field monitoring
and Lab Experiments (F. Freund – NASA)?**

Lab Tests (Freund):

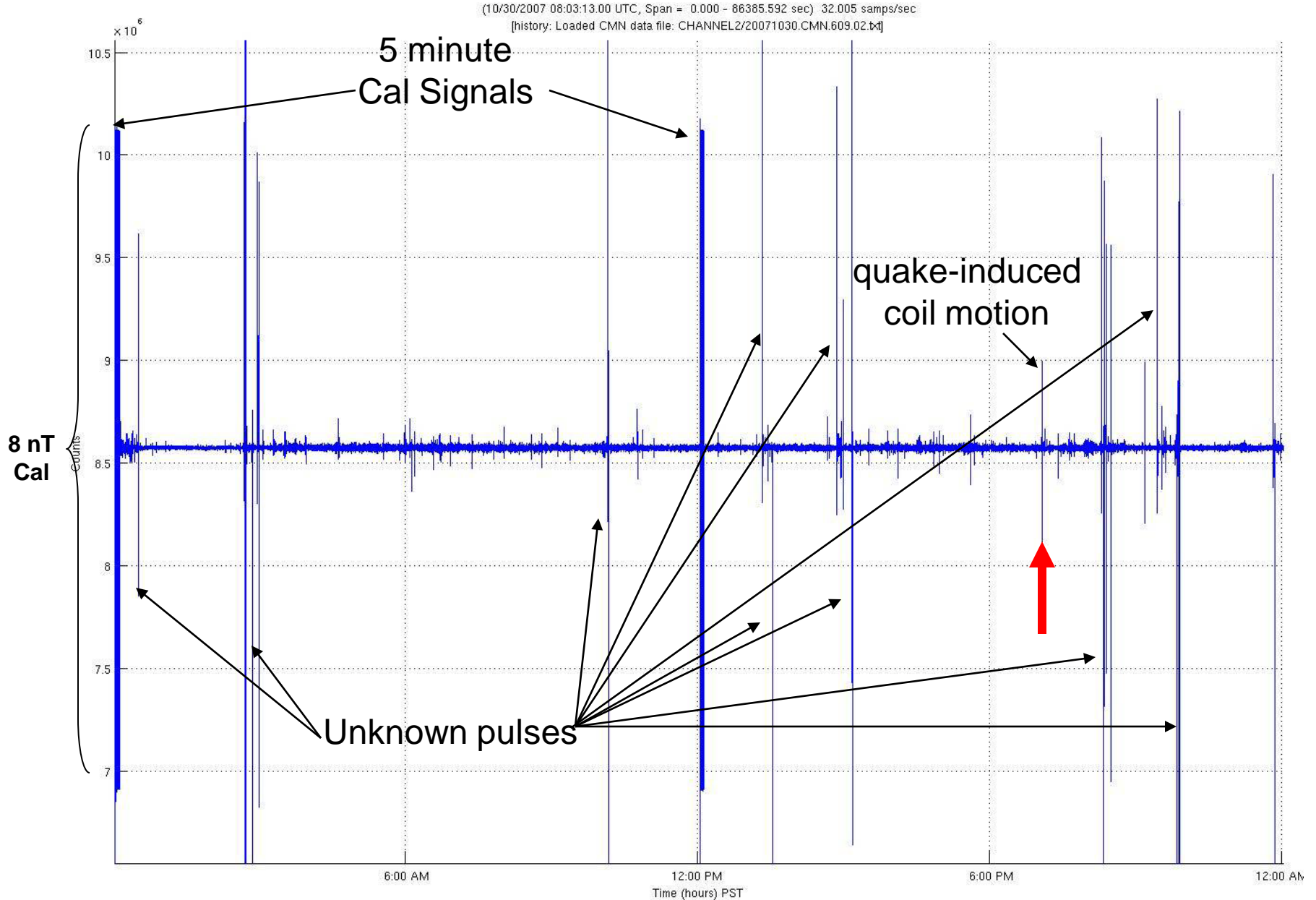
Positive and Negative Currents / Air Ionization



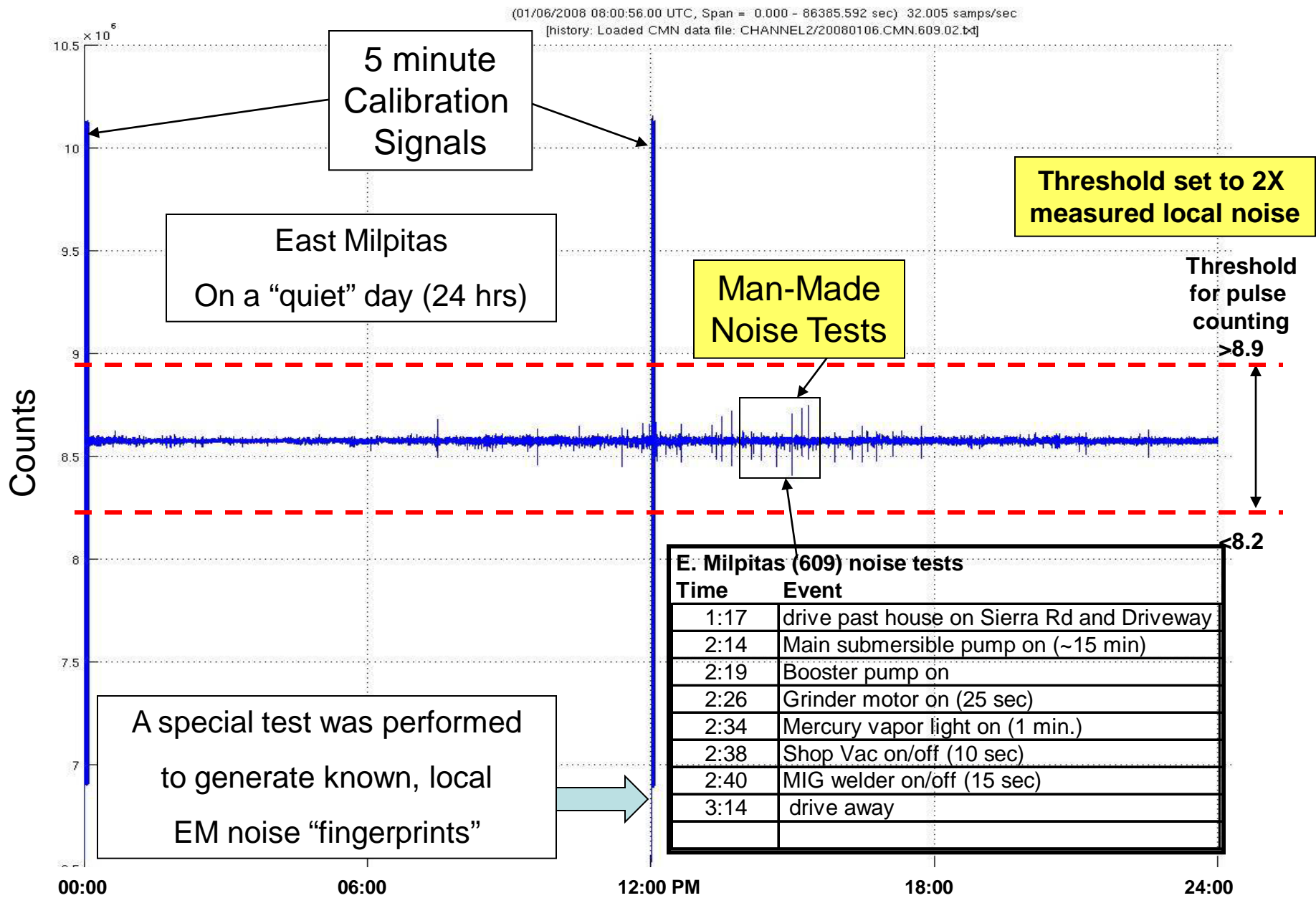
Typical "Quiet Day" at Site 609 near Alum Rock



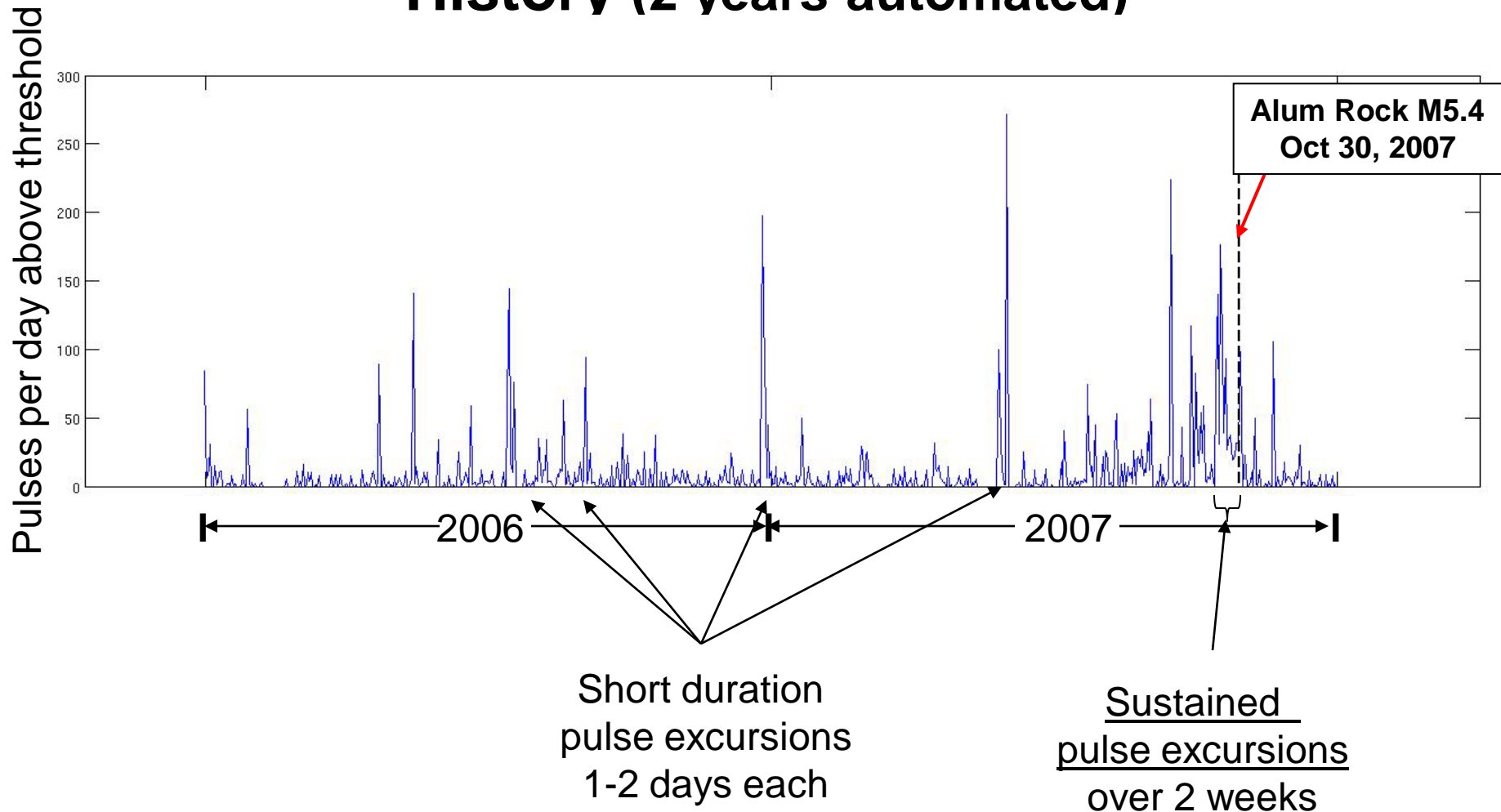
Pulsations observed on day of Quake (10/30)



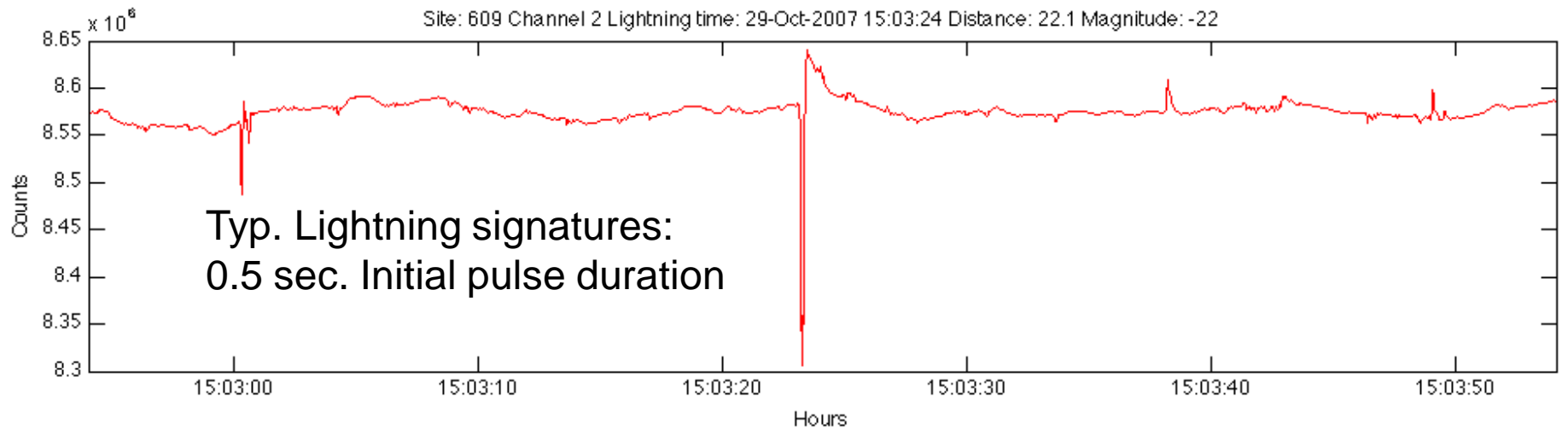
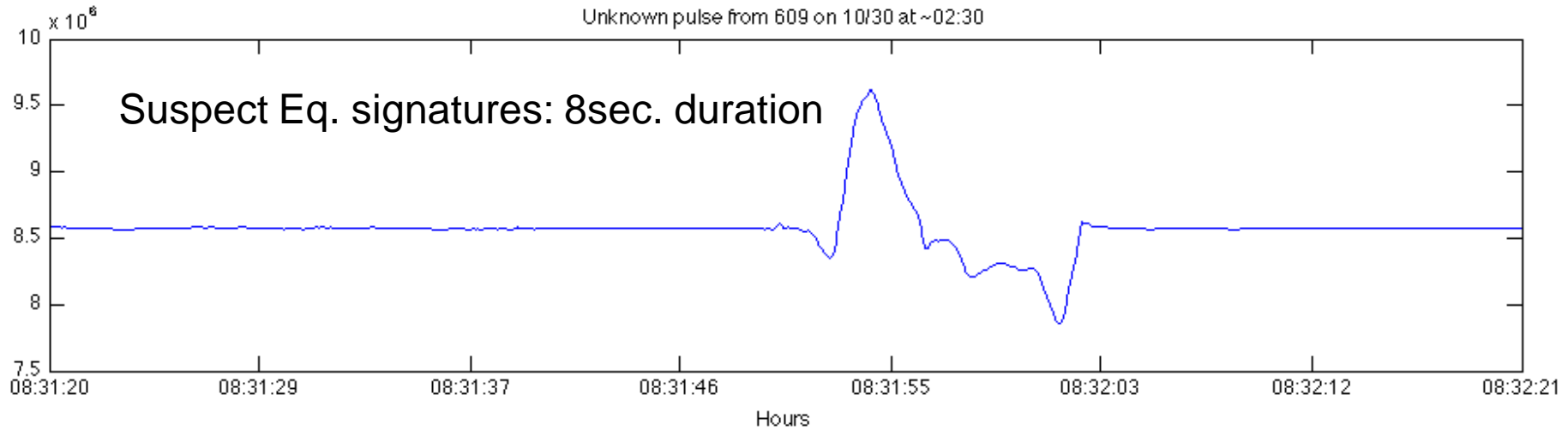
Determine a threshold for local “Man-Made noise”



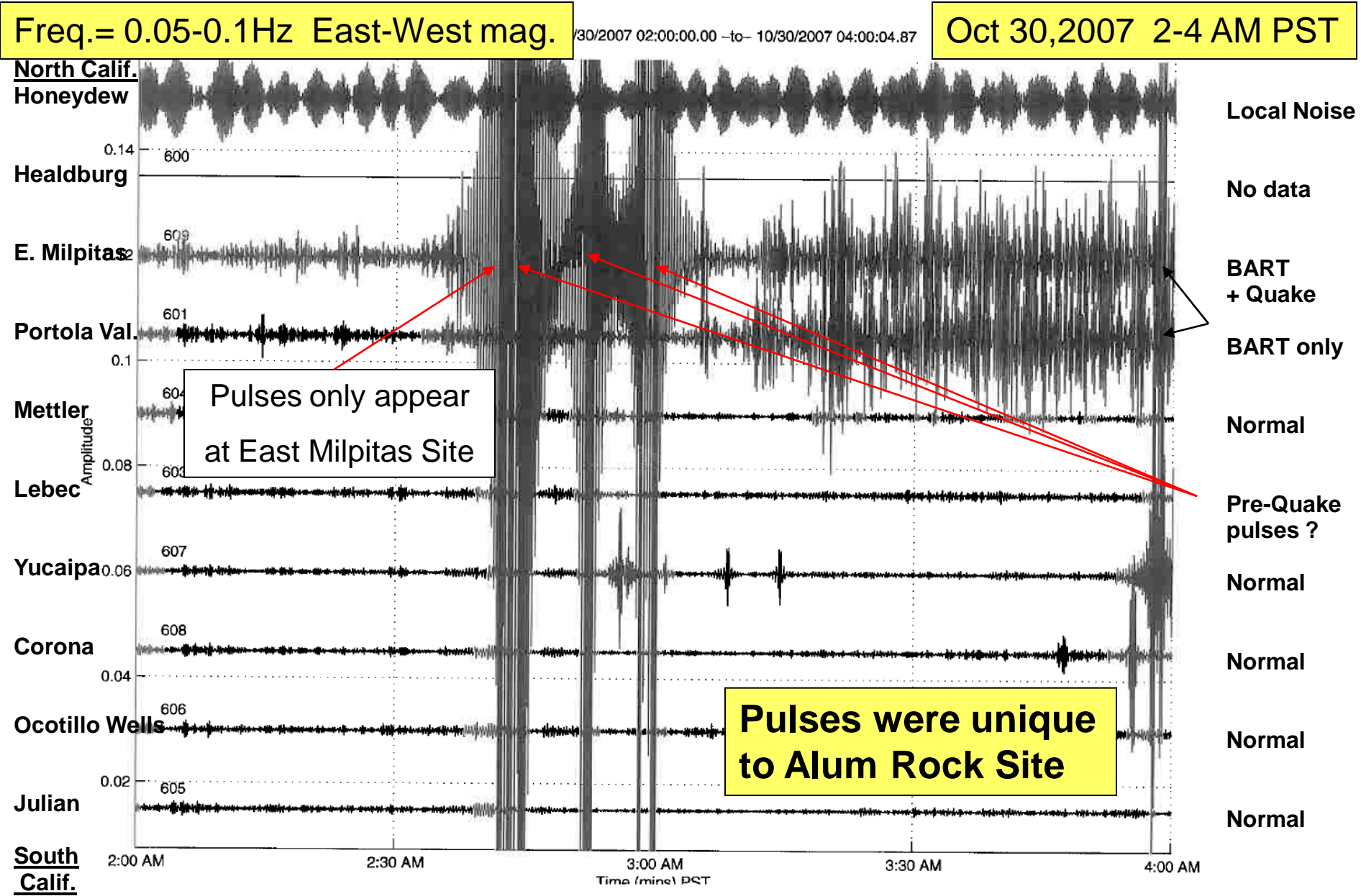
Long Term Alum Rock ULF Pulse Count History (2 years-automated)



Natural Noise: Lightning Comparison



Network Wide Comparisons using Filter Band MA7



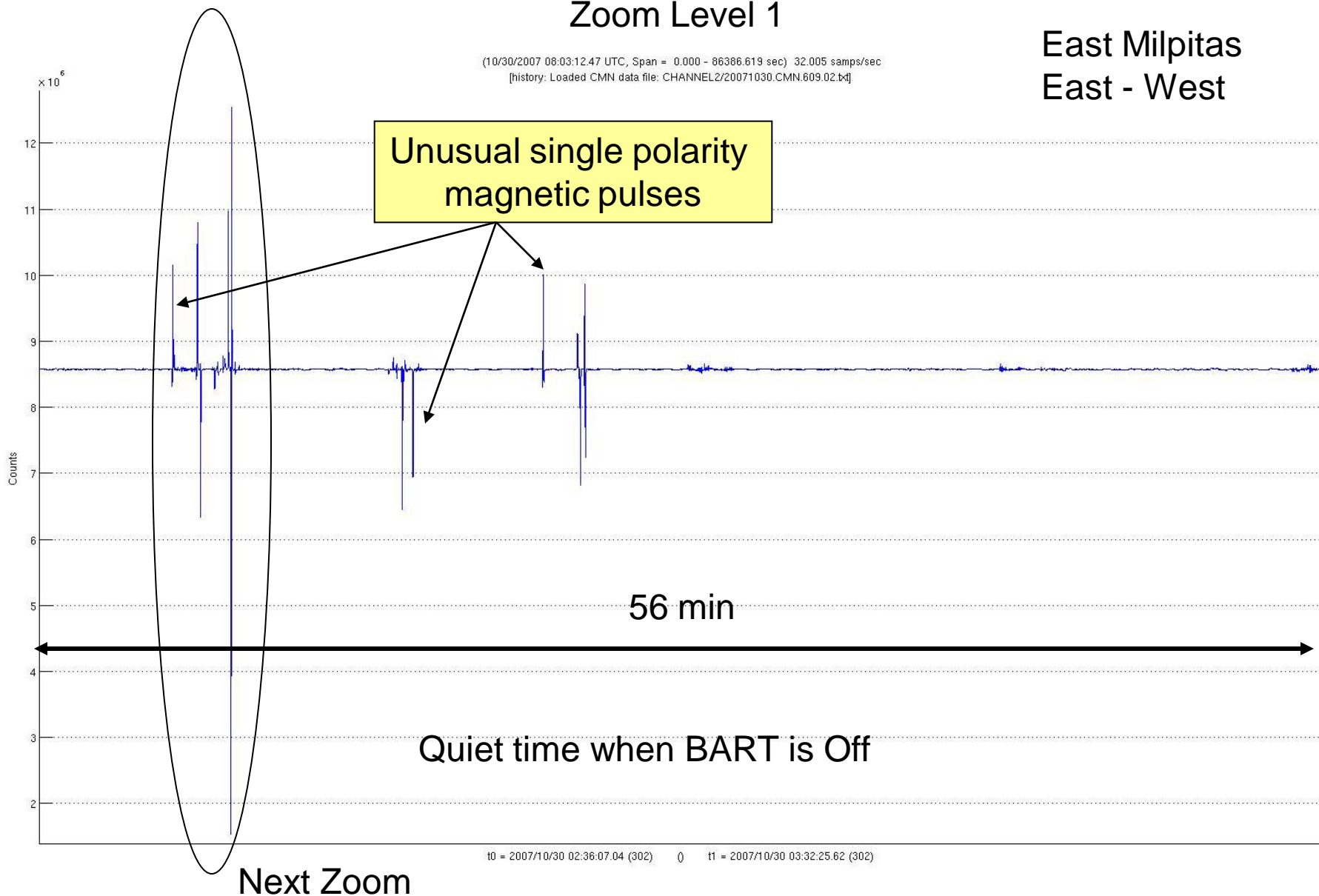
Pulse Shapes/polarities

Time Series Oct 30 02:36-03:32

Zoom Level 1

East Milpitas
East - West

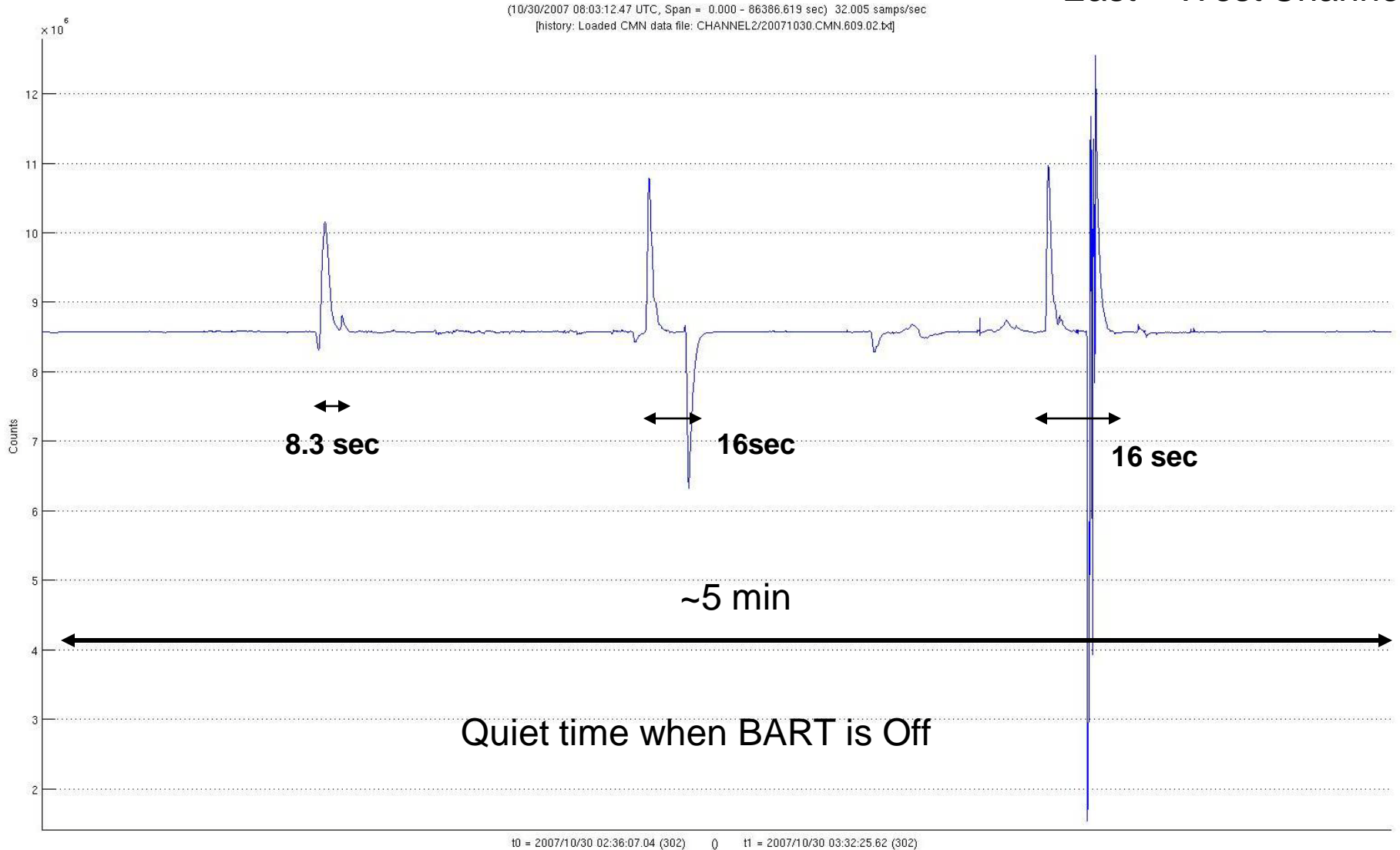
(10/30/2007 08:03:12.47 UTC, Span = 0.000 - 86386.619 sec) 32.005 samps/sec
[history: Loaded CMN data file: CHANNEL2/20071030.CMN.609.02.b4]



Time Series Oct 30 02:40

Expanded scale

East Milpitas
East – West Channel



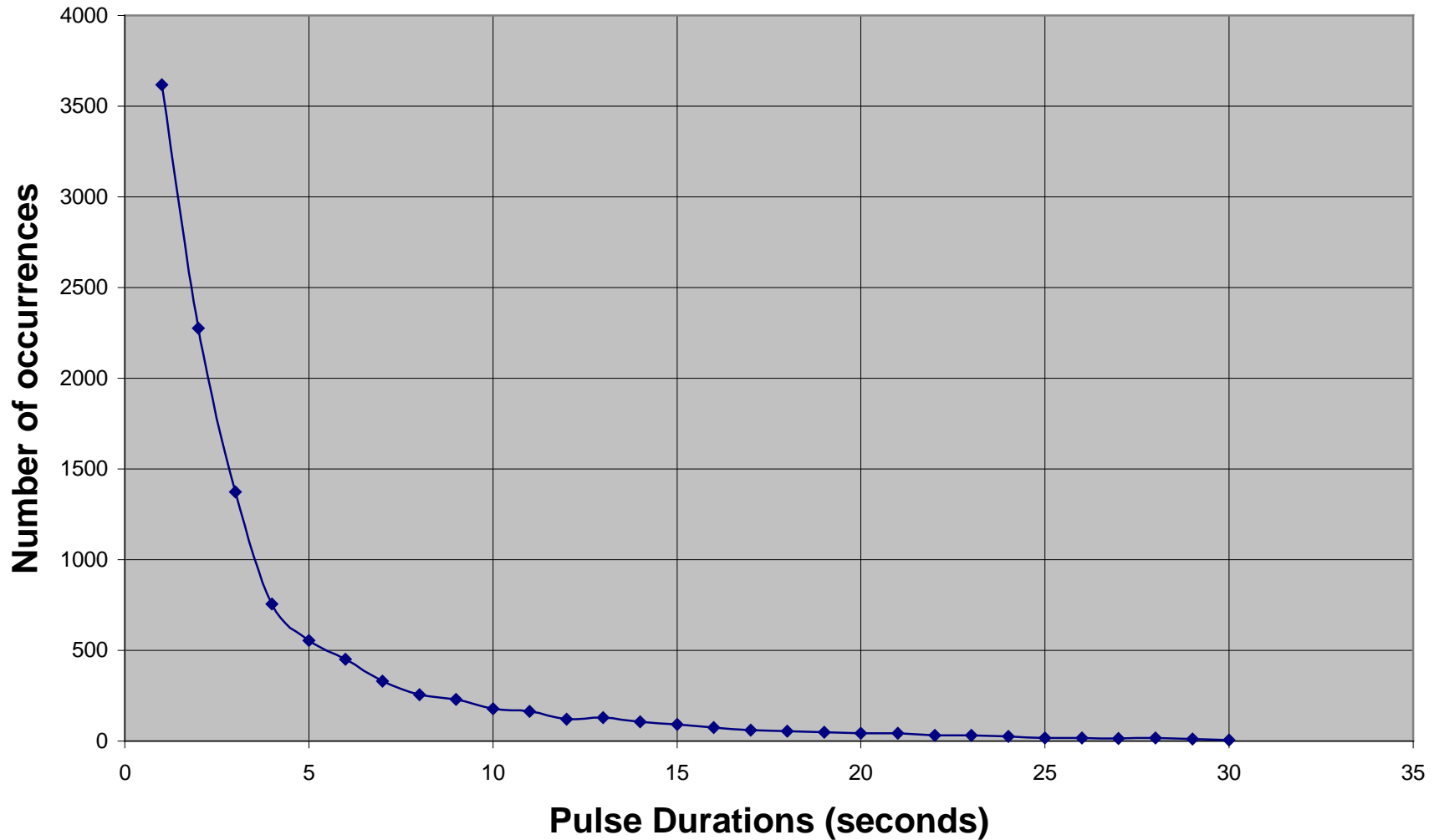
Pulse Characteristics

Pulses	2006-7	Prior to Quake 10-15 to 10-31-07	Prior % of Total
UP	11282	4108	36 %
DOWN	9176	3119	34 %
BIPOLAR: UP	5993	2689	45 %
BIPOLAR: DOWN	4757	1707	36 %

31, 208

Pulse Characteristics

Distribution of Pulse Durations



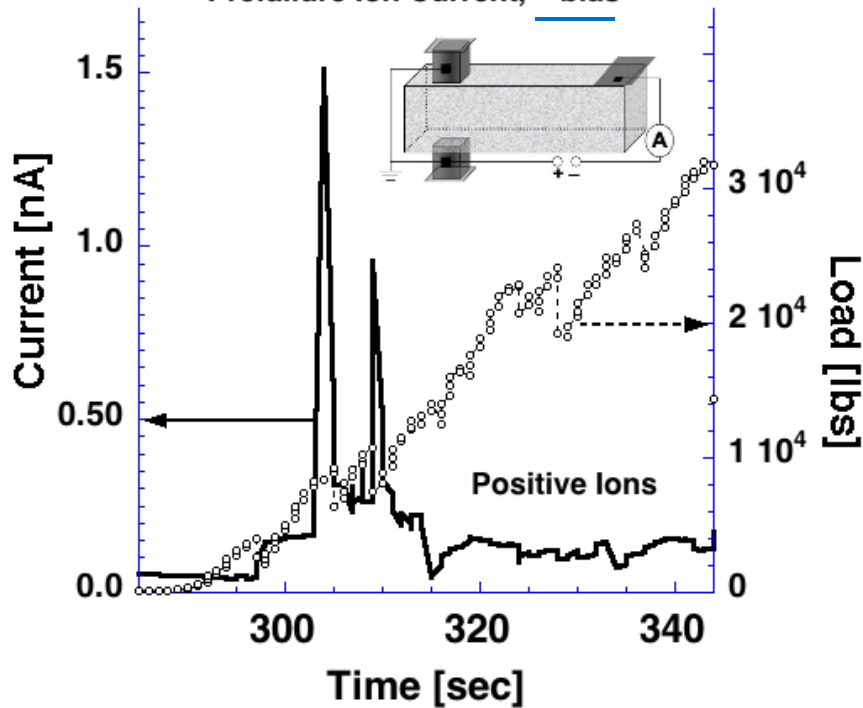
Air Conductivity

Do Positive or Negative Ions
appear near the quake?

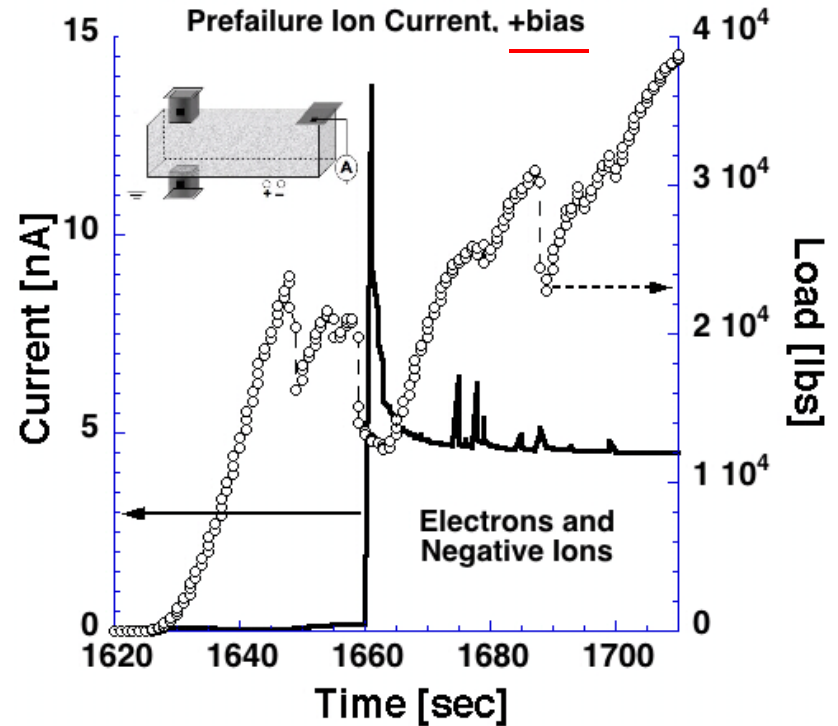
Lab Tests (Freund):

Positive and Negative Currents / Air Ionization

Gabbro: Ionization Run #39
Prefailure Ion Current, - bias



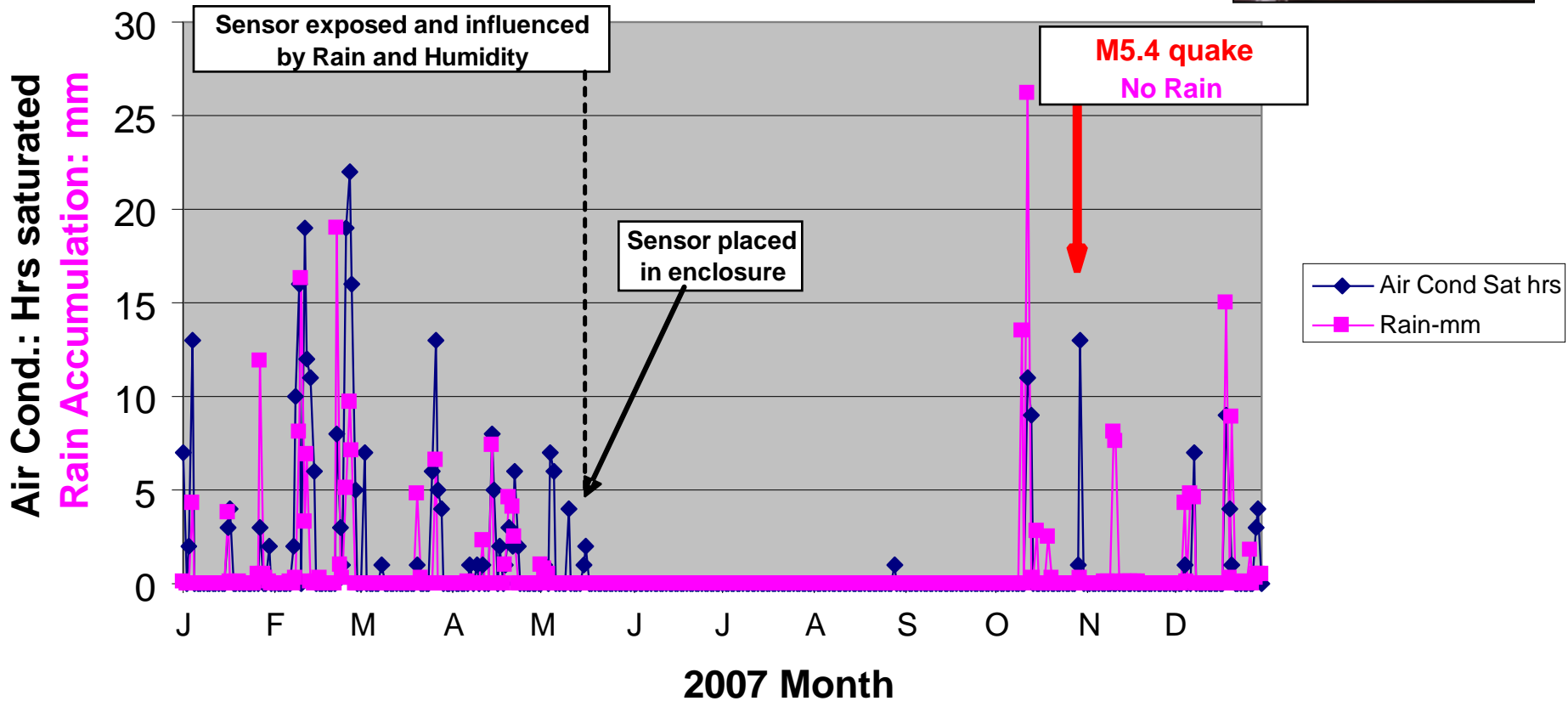
Gabbro: Ionization Run #42
Prefailure Ion Current, + bias



Air Conductivity 1 Year

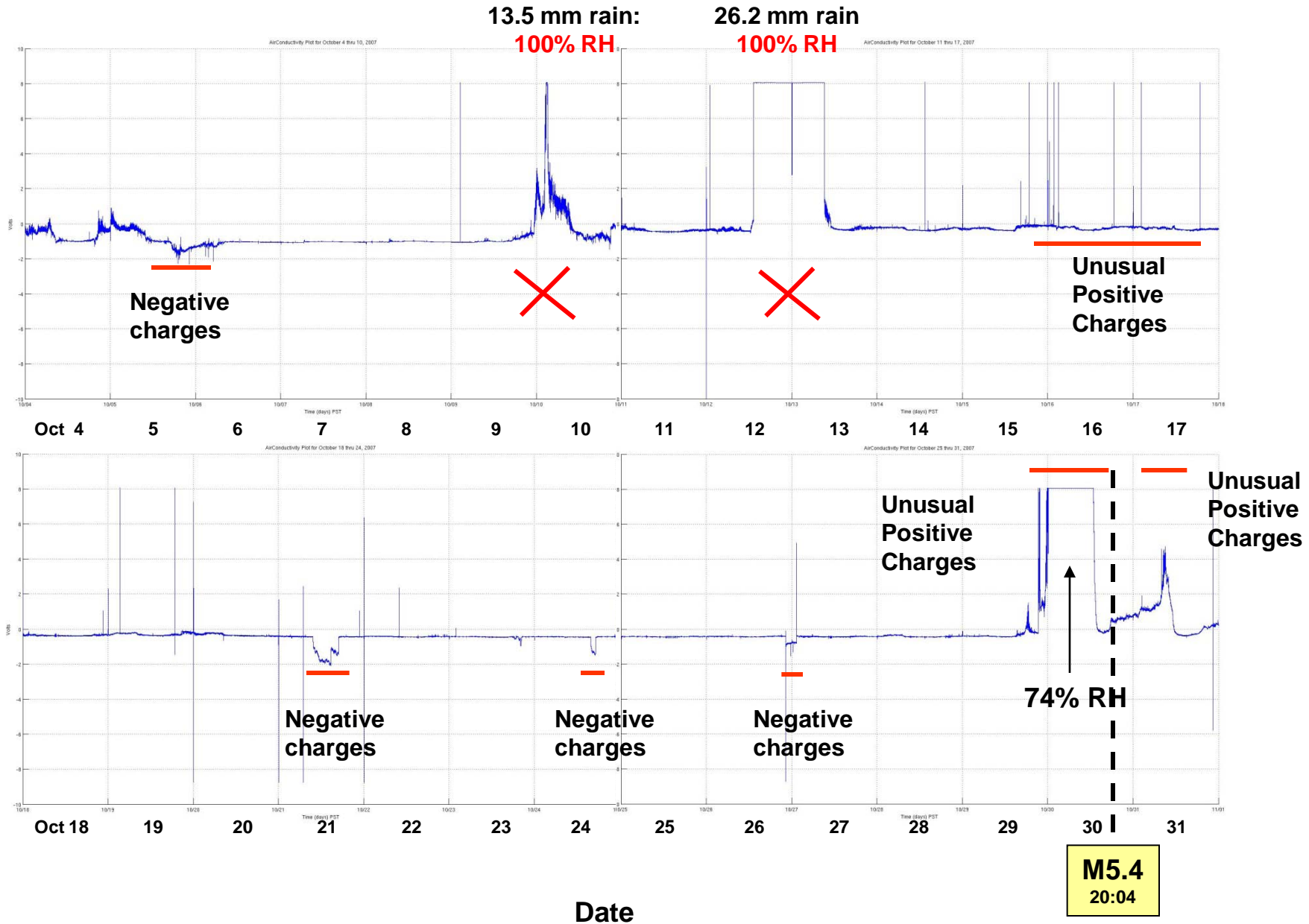


E. Milpitas (Alum Rock) 2007



Air Conductivity at Alum Rock (Rain Noise)

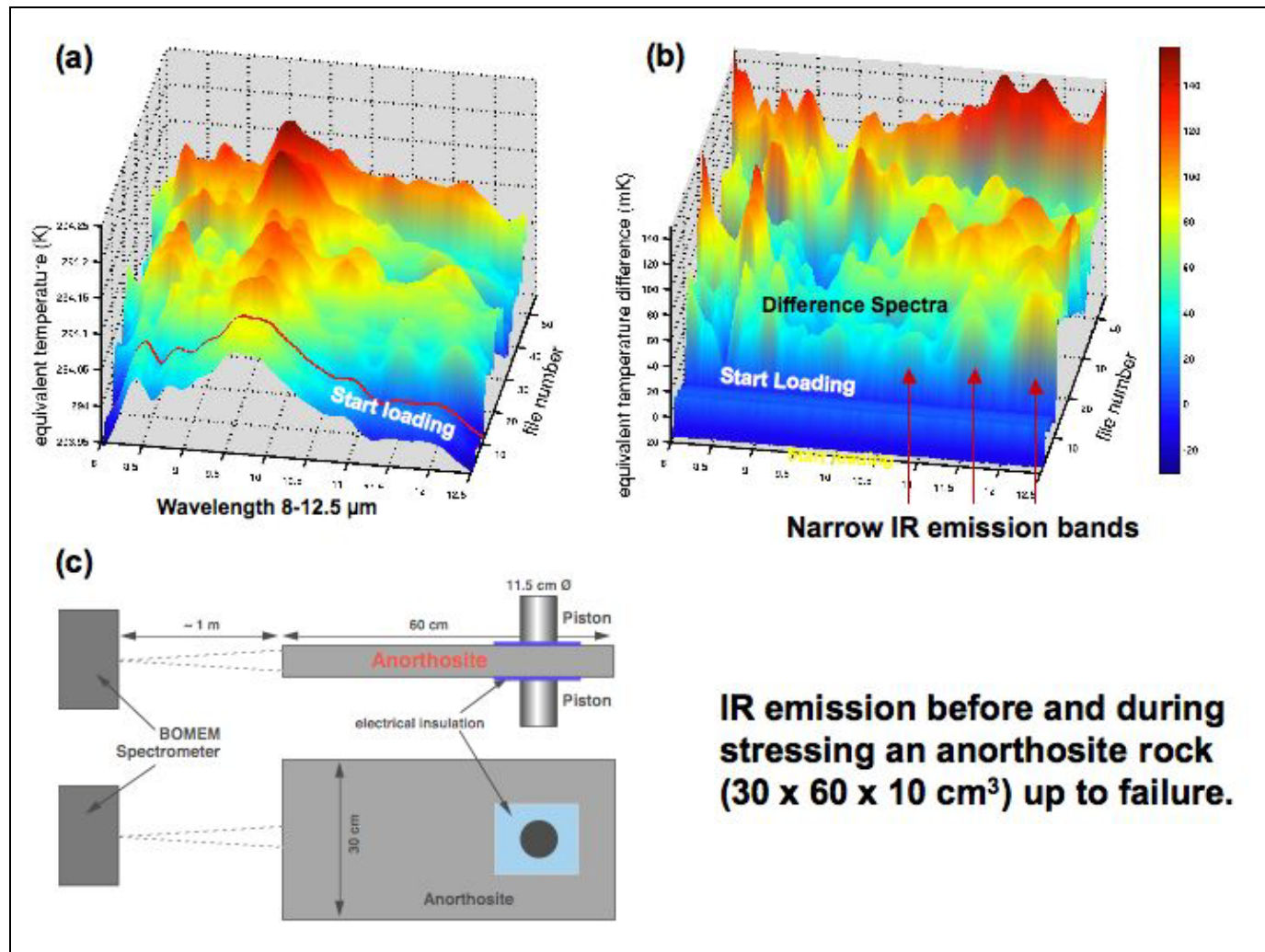
Air Conductivity



Infra Red

Do Infra Red signatures appear
prior to large earthquakes?

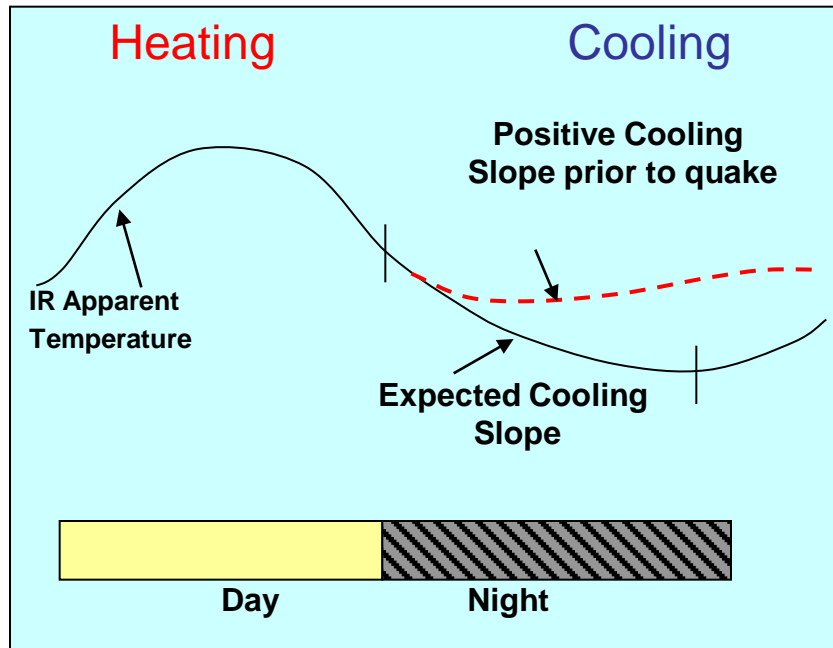
Infrared (IR) Signatures in lab experiments (Freund)



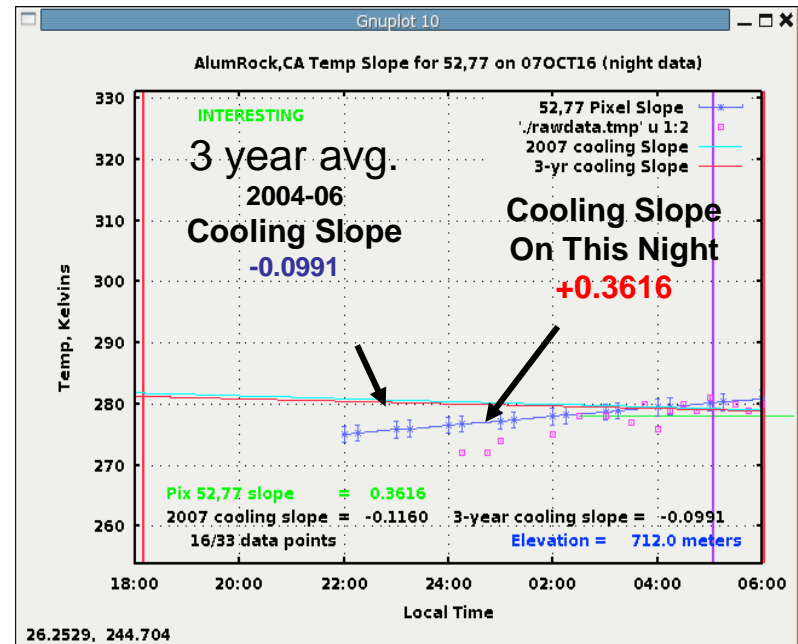
Night time Cooling Slope as observed by GOES-West Satellite



N. Bryant and R. Bambery



For Each Pixel



(10.7um) – (12 um)
(long wave infrared window)
4 km pixel size

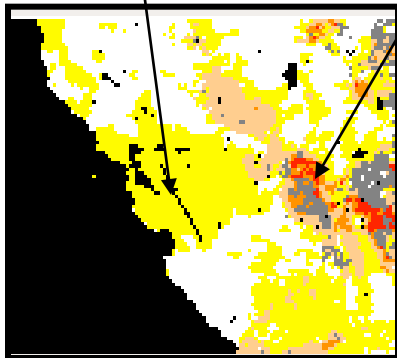
IR night time cooling slopes

Calaveras
Fault

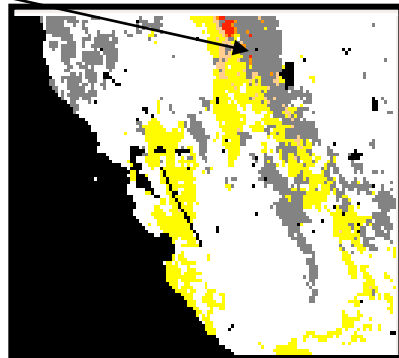
Cloud Covered
(Gray/Red)

3 yr avg. slope: -0.0991

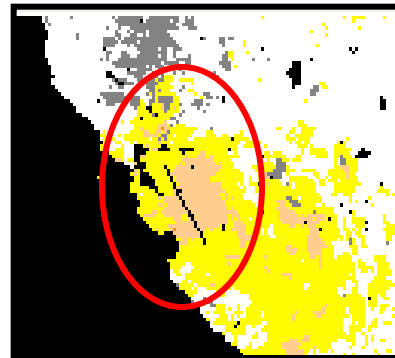
Yellow $>+0.1$ slope
Pink $>+0.3$ slope



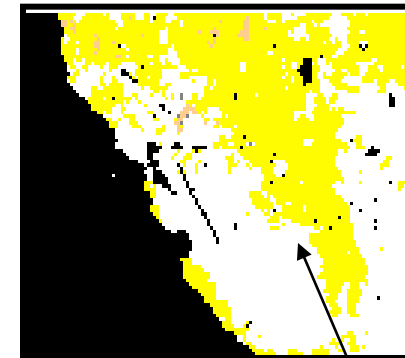
Oct 13, 2007
+0.1465



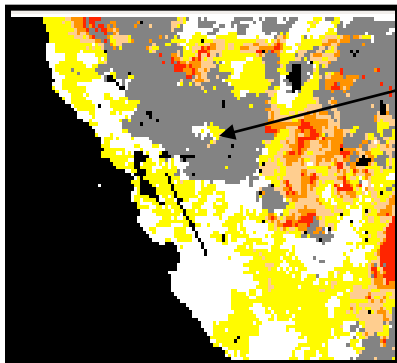
Oct 16, 2007



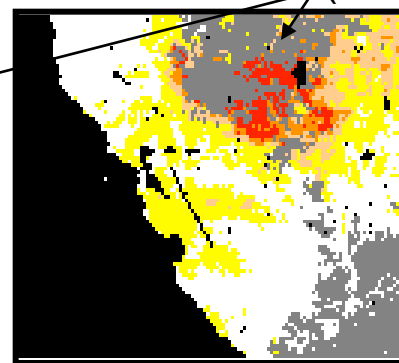
Oct 17, 2007
+0.3616



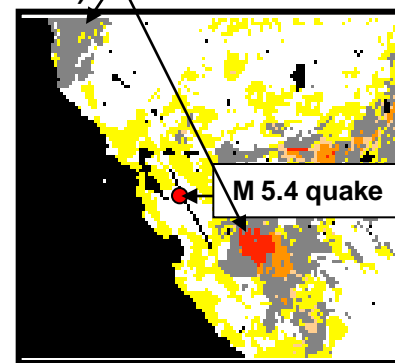
Oct 18, 2007



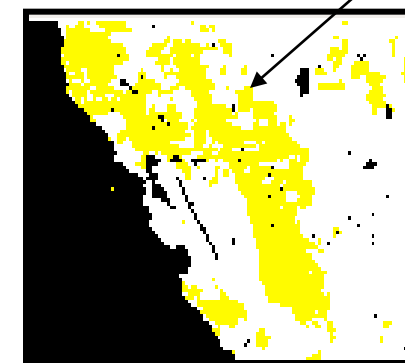
Oct 28, 2007



Oct 29, 2007
+0.2447



Oct 30, 2007



Oct 31, 2007
-0.0584

Cloud Covered
(Gray/Red)

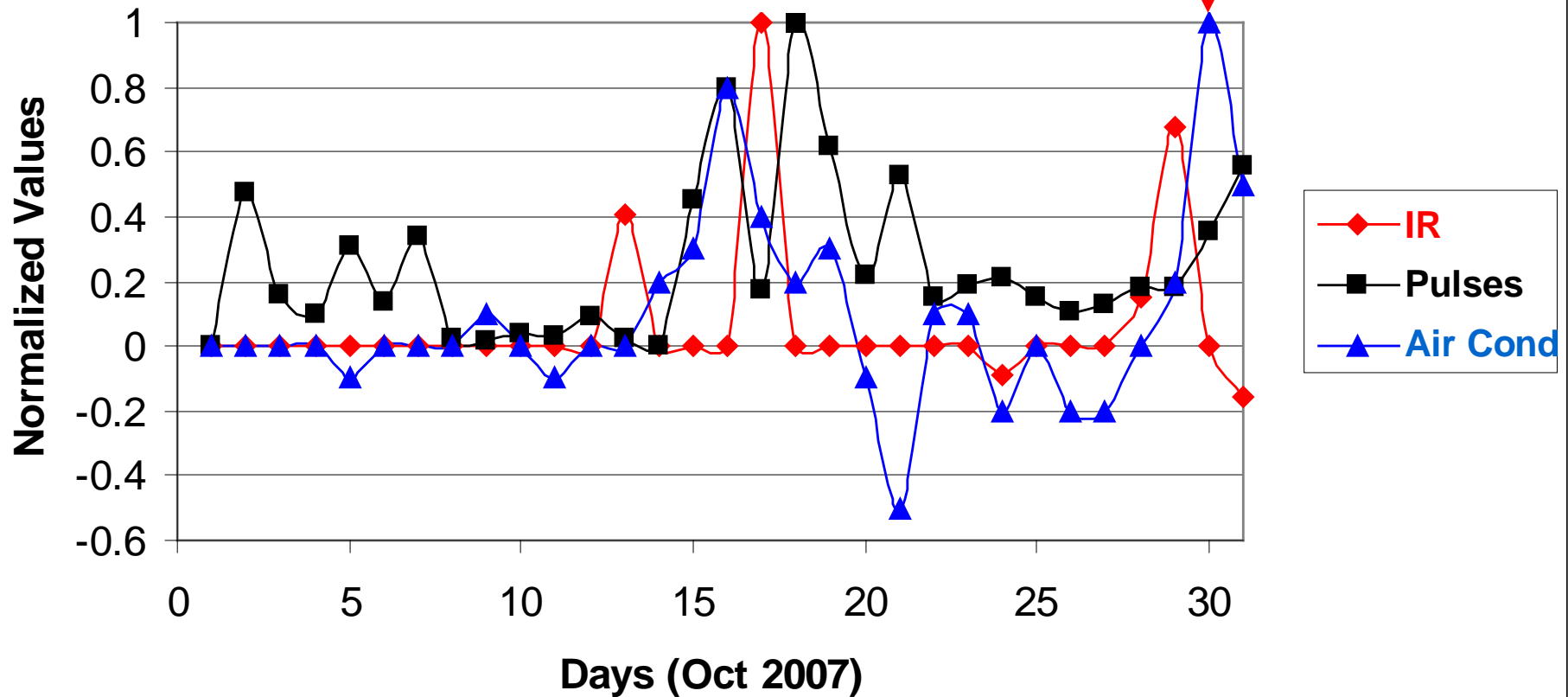
Compression heating

M 5.4 quake

EM Signature Comparison Alum Rock M5.4

ULF	Yes
Ions	Yes
IR	Yes

Normalized EM Comparison

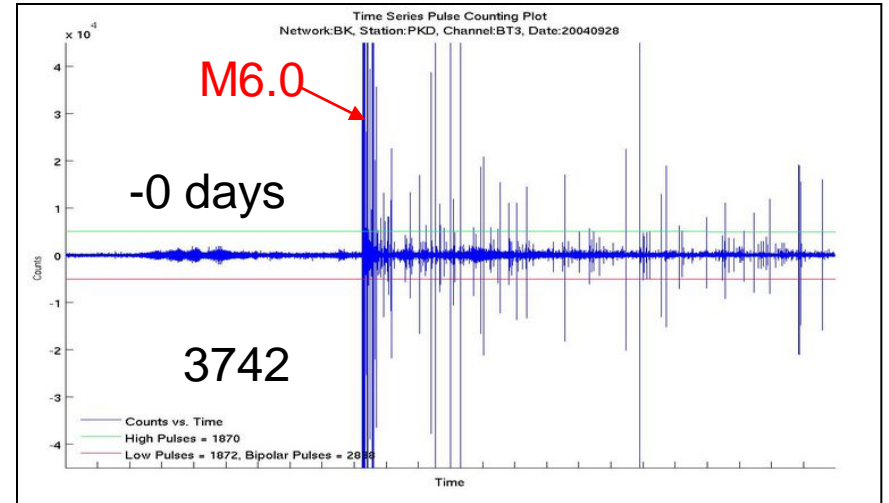
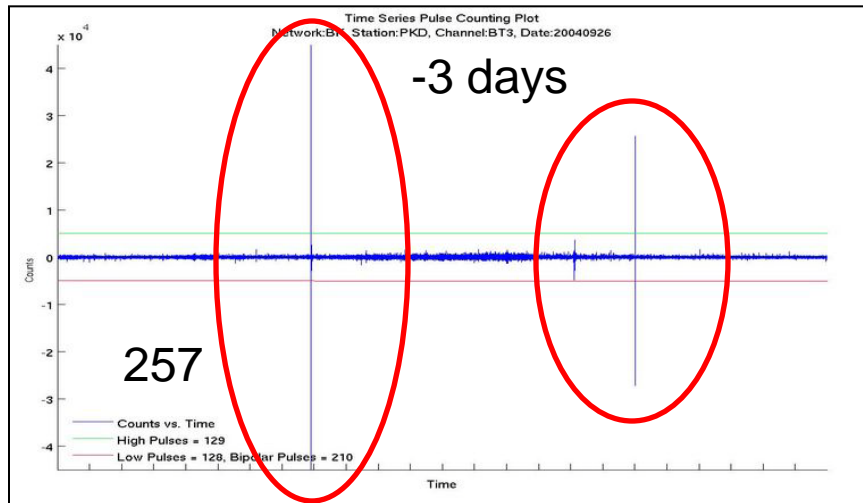
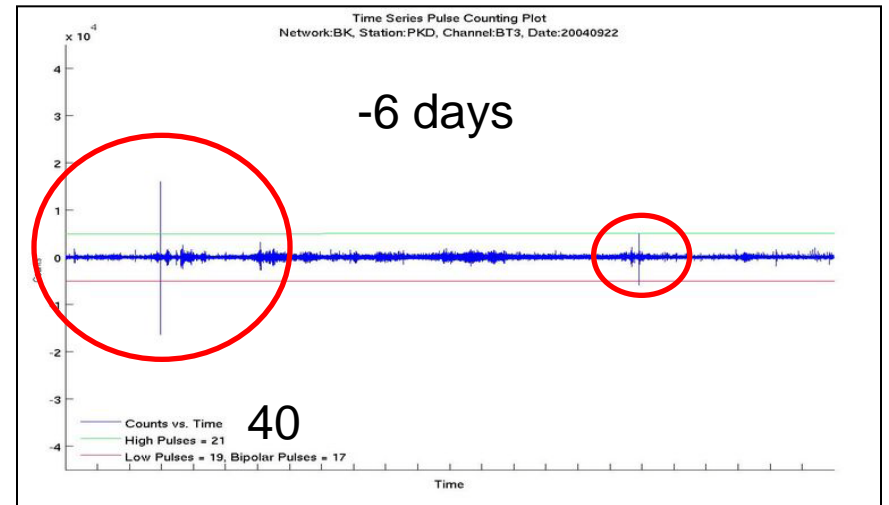
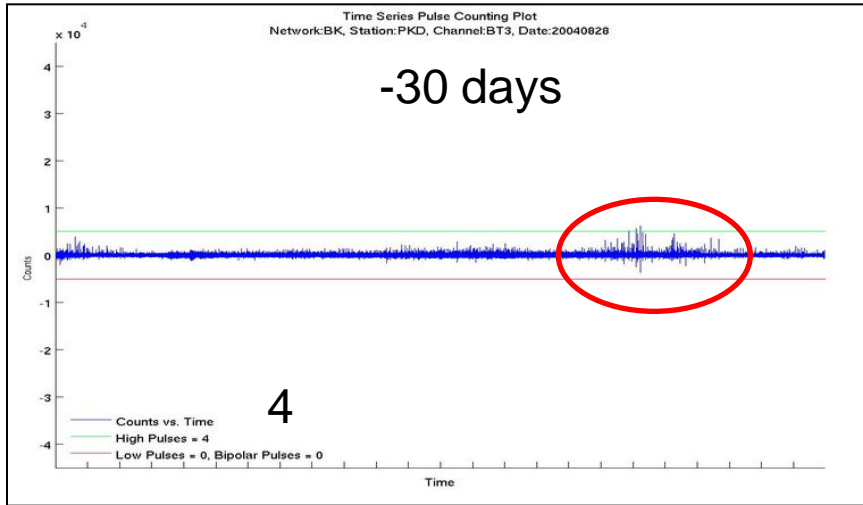


Other California Quakes?

Parkfield 2004

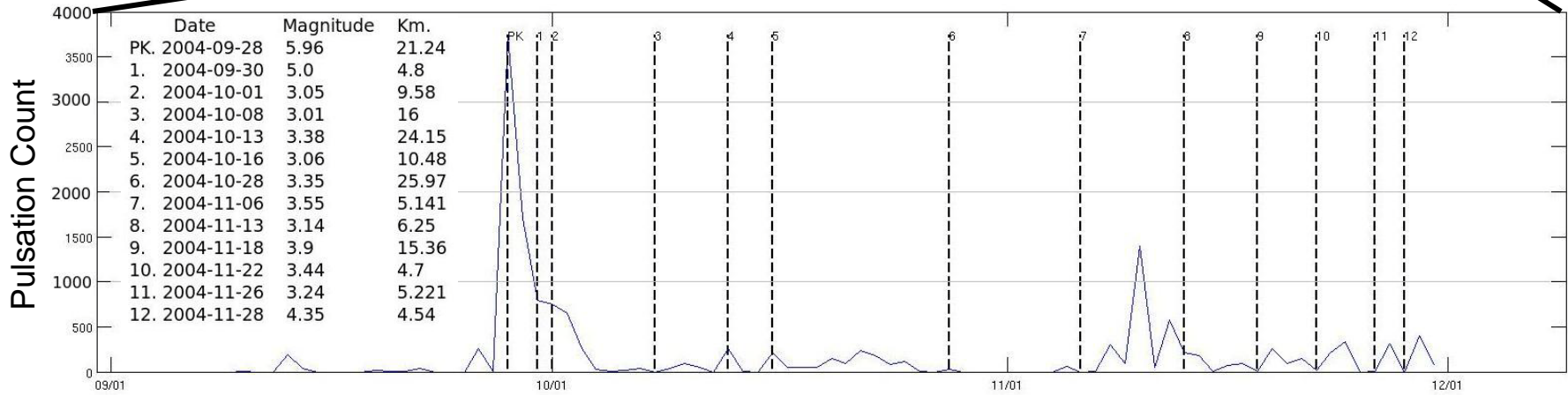
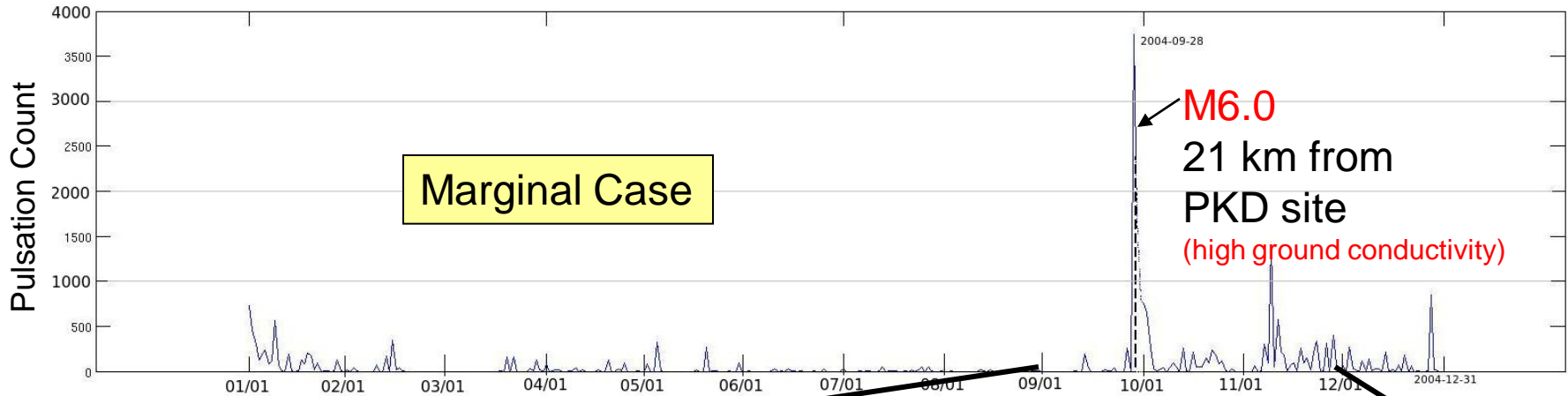
Hollister 1998

Parkfield Magnetic Waveforms 21 km



Parkfield M6.0 Sept 28, 2004

ULF	Yes
Ions	No
IR	No



Infra Red: Parkfield

M6 earthquake

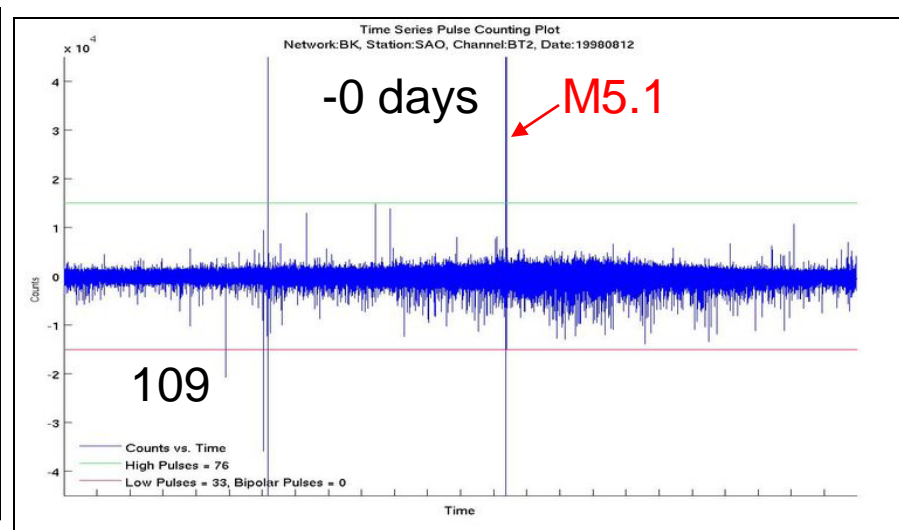
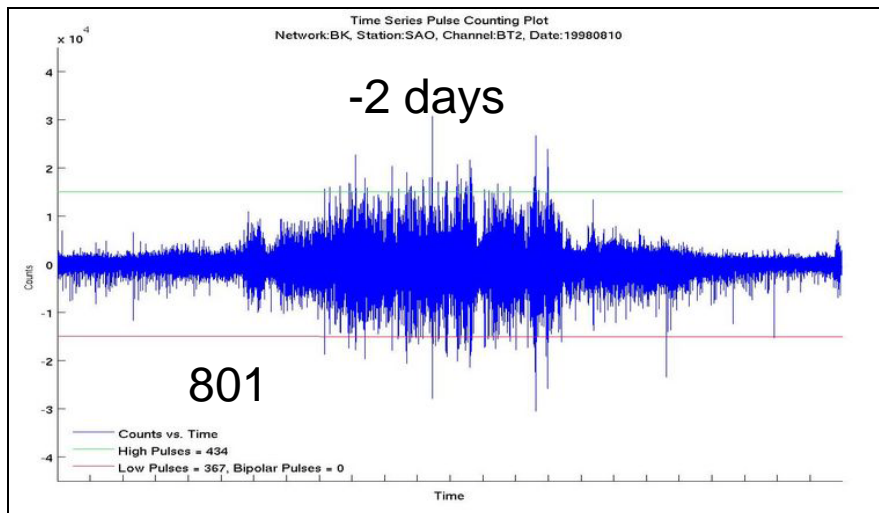
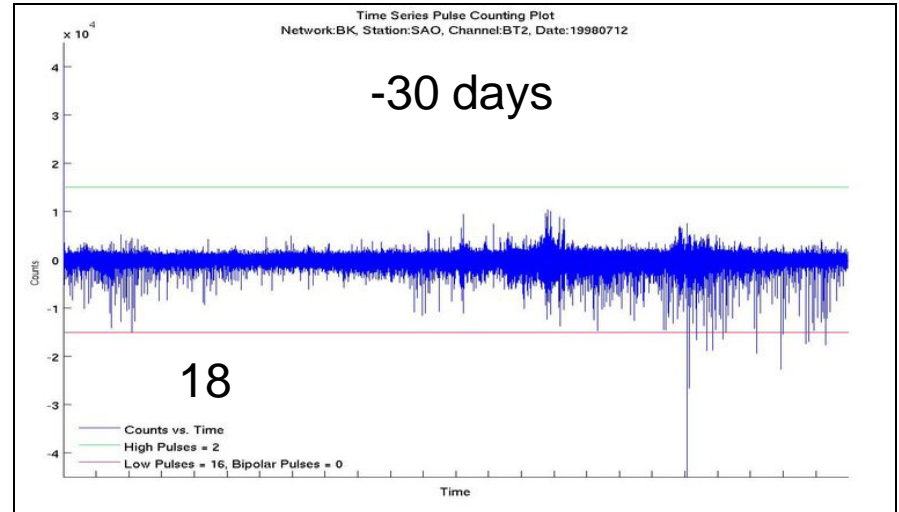
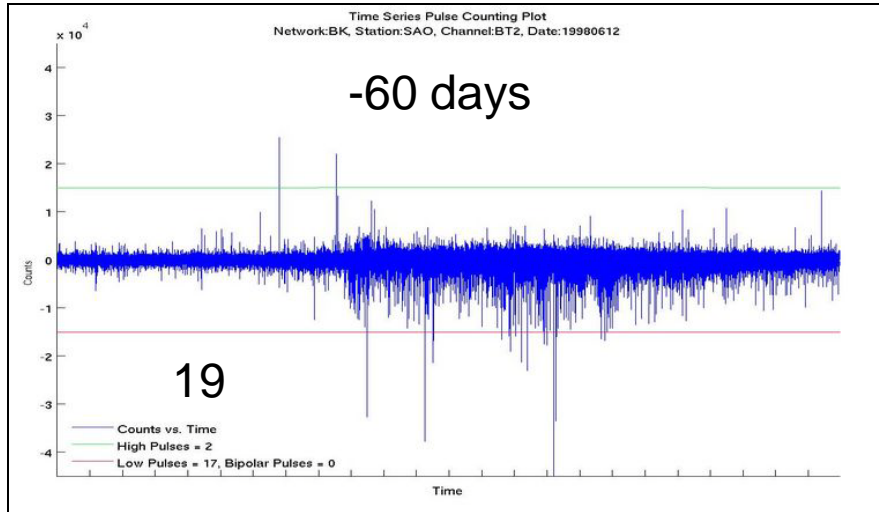
Sept 28, 2004

Goes 10 Band 4 data:

Analyzed 28 days in Sept 2004

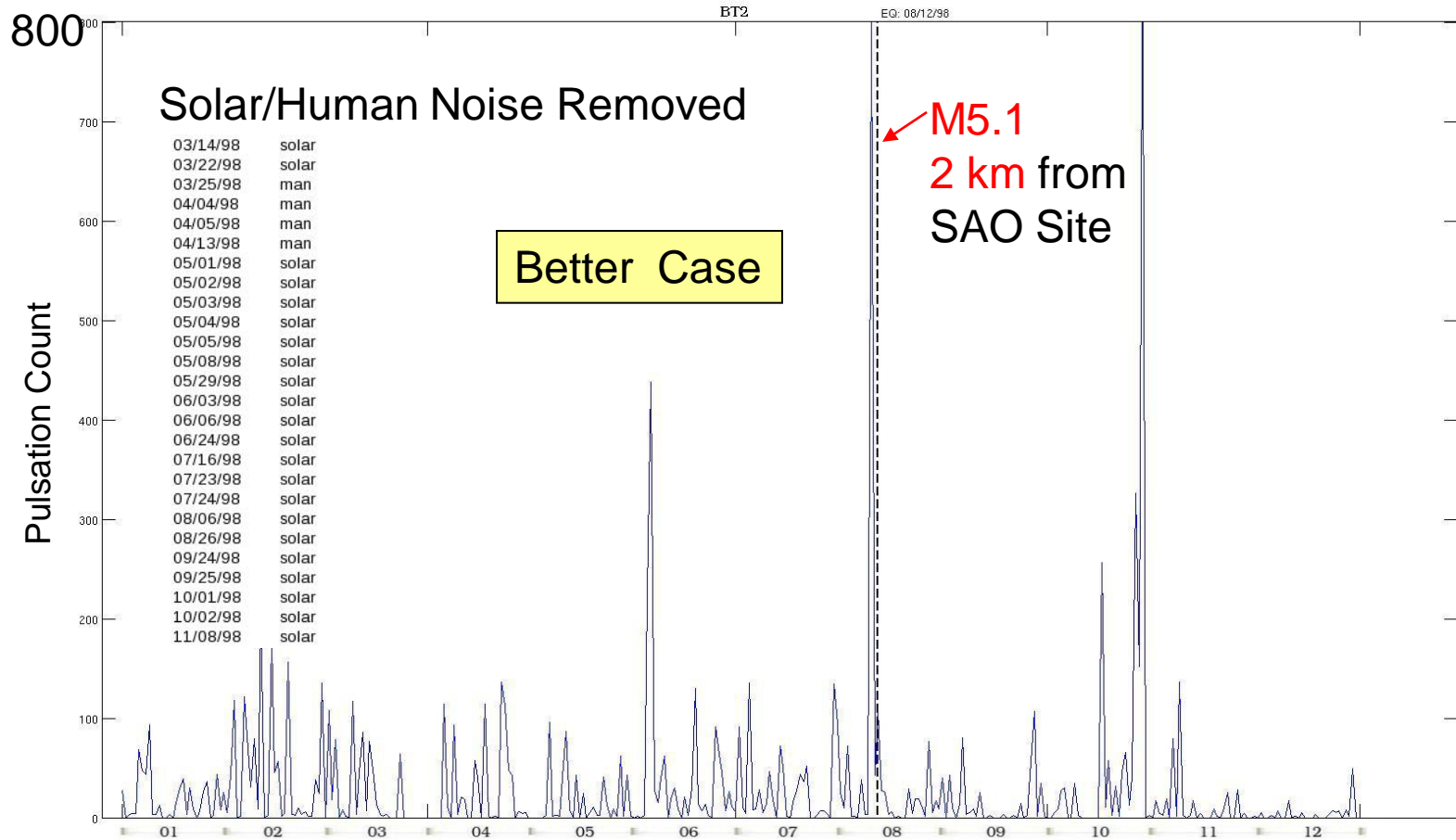
- 5 days prior (4 are cloud contaminated)
- Sept. 27/28 night time cooling---no positive slope
- INCONCLUSIVE

Hollister Magnetic Waveforms



Hollister M5.1 August 12, 1998

ULF	Yes
Ions	No
IR	No

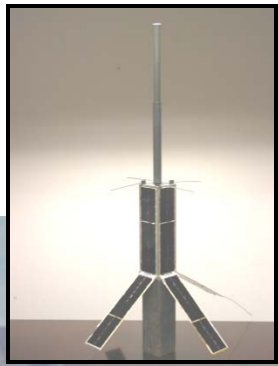


1998

San Simeon Earthquake M6.4

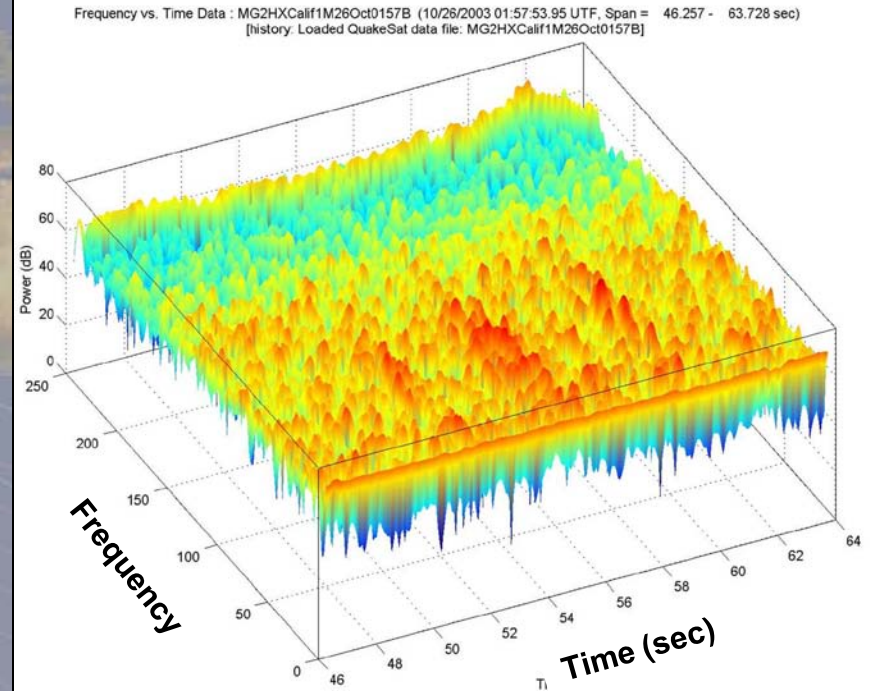
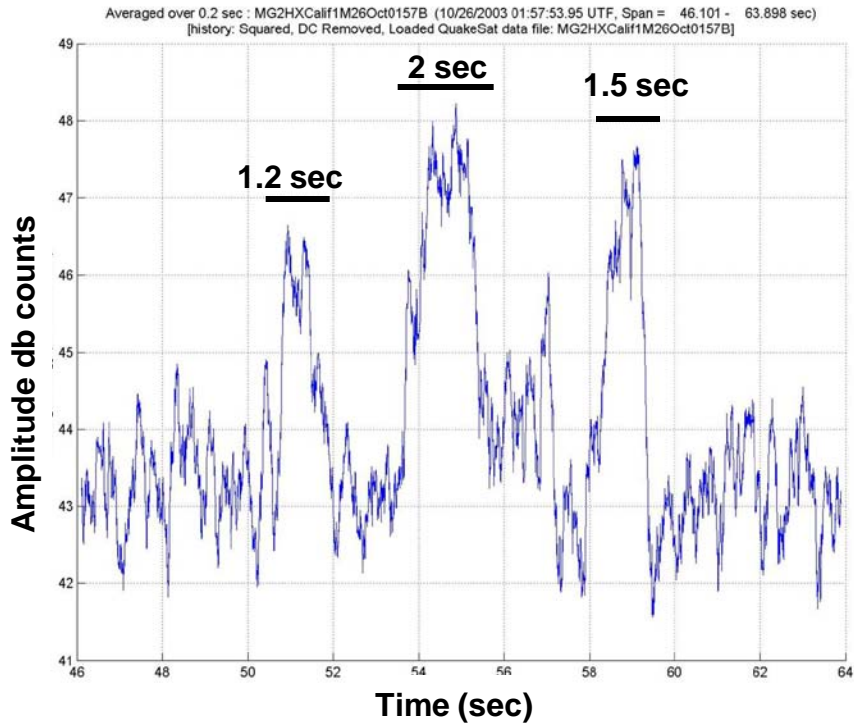
57 days Prior from QuakeSat

ULF	Yes	QS
Ions	No	
IR	No	



Power

Frequency (10-150 Hz)



Conclusions

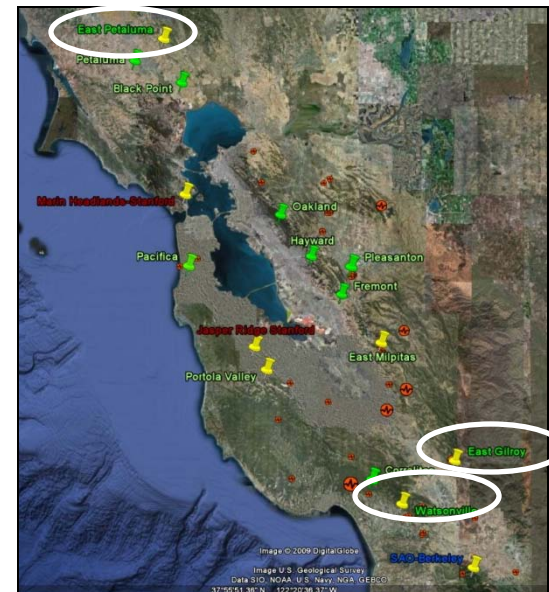
- Alum Rock was an exceptional data set (2 km) **++++**
 - 3 high sensitivity, calibrated magnetometers, air conductivity, GOES IR
 - Continuous recording
 - Removed known noise
- ULF **Pulsations** appeared to increase **2 weeks** prior to quake
- Air **Conductivity** (+) increased **23 hrs** prior to quake
- IR signals **positive night time cooling**
- All 3 signatures demonstrated some **correlation with lab experiments**

- Parkfield (M6) subtle ULF (21 km) **+**
- Hollister (M5.1) more active ULF (2 km) **++**
- San Simeon (M6.4) QuakeSat ULF pulses **+**

Future

- Need more instrumented sites (near quakes >M6)

- California 3 new sites (2009)
 - Petaluma, East Gilroy, Watsonville



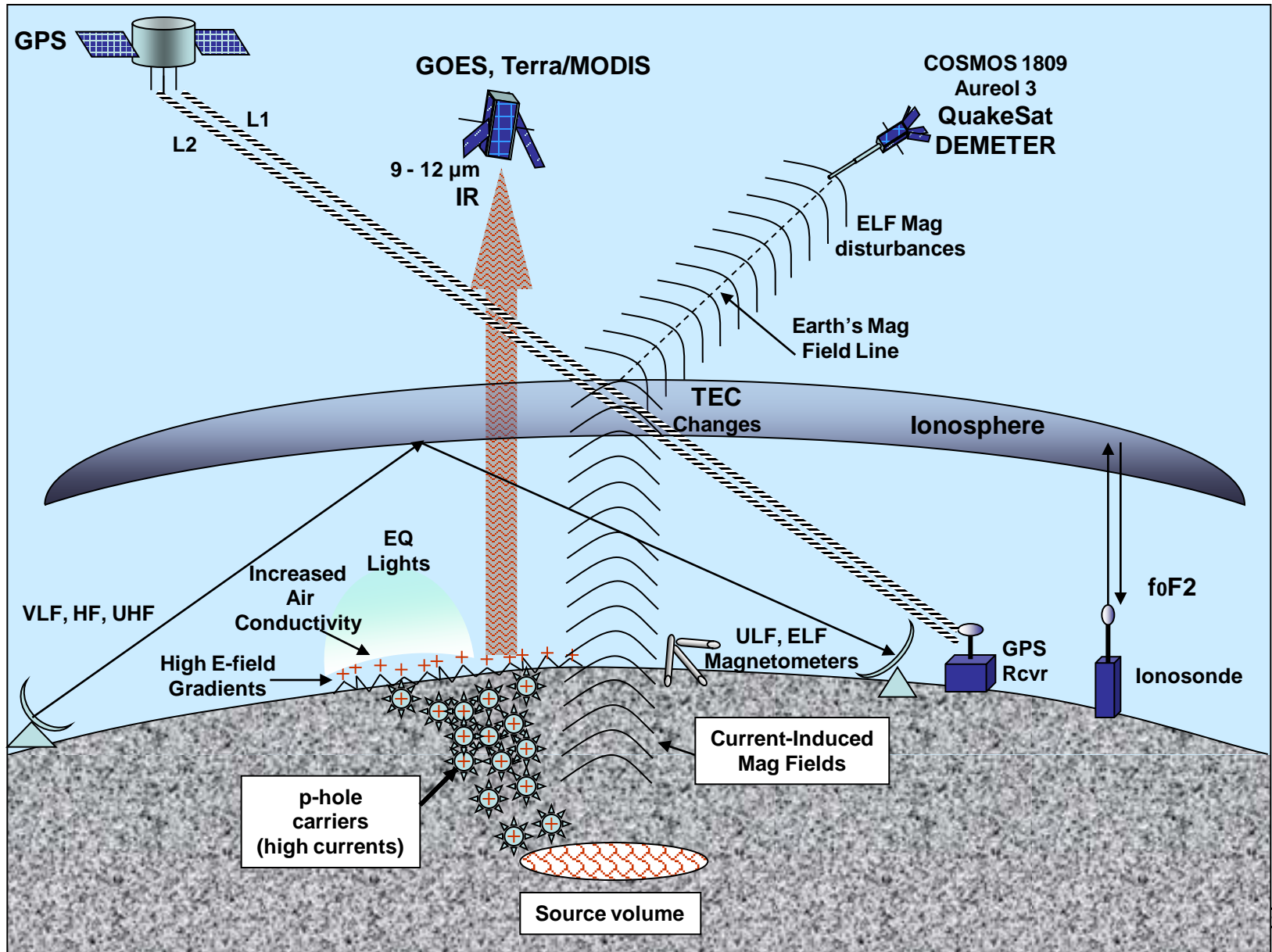
- Peru 2 (2009)
 - Pisco, Tacna
- Need contacts for Sumatra and Turkey

- Need more IR Spectral discrimination (8 and 12 um)

- MODIS
- AVHRR
- New Study at NASA-Ames

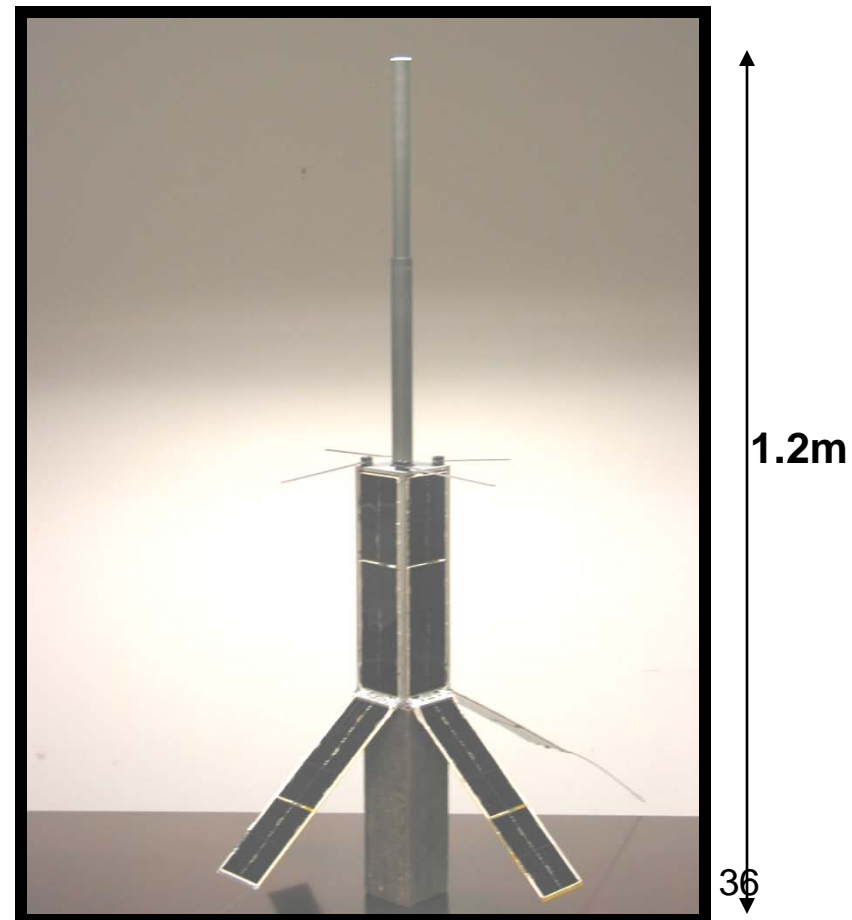
Backup

Detectable Effects

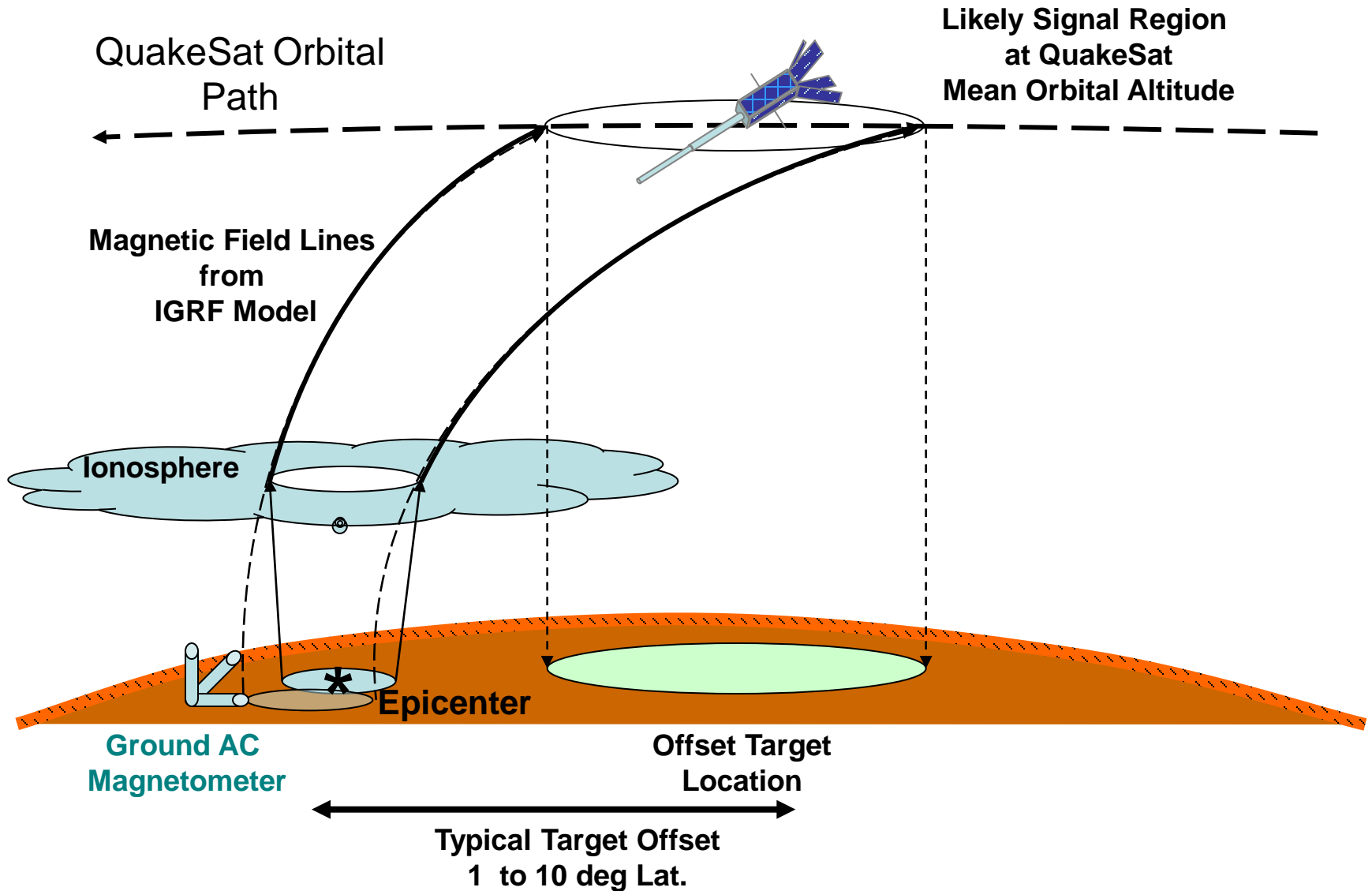


Satellite-Based Monitoring (QuakeSat)

- **QuakeSat on orbit (June 30, 2003 to Dec 2004)**
 - 840 km circular, sun synch orbit (dawn-dusk)
 - Single axis search coil magnetometer, small E-field dipole
 - 4 channels (one at a time)
 - 1-10 Hz B
 - **10-150 Hz B (primary channel)**
 - 130-150 Hz E and B
 - 10-1000 Hz B
 - Sensitivity – noise floor
 - 5pT at 1000 Hz
 - **15 pT at 100 Hz**
 - 30 pT at 10 Hz
 - 2 ground stations
 - Stanford
 - Fairbanks Alaska
 - **9600 baud, half duplex**

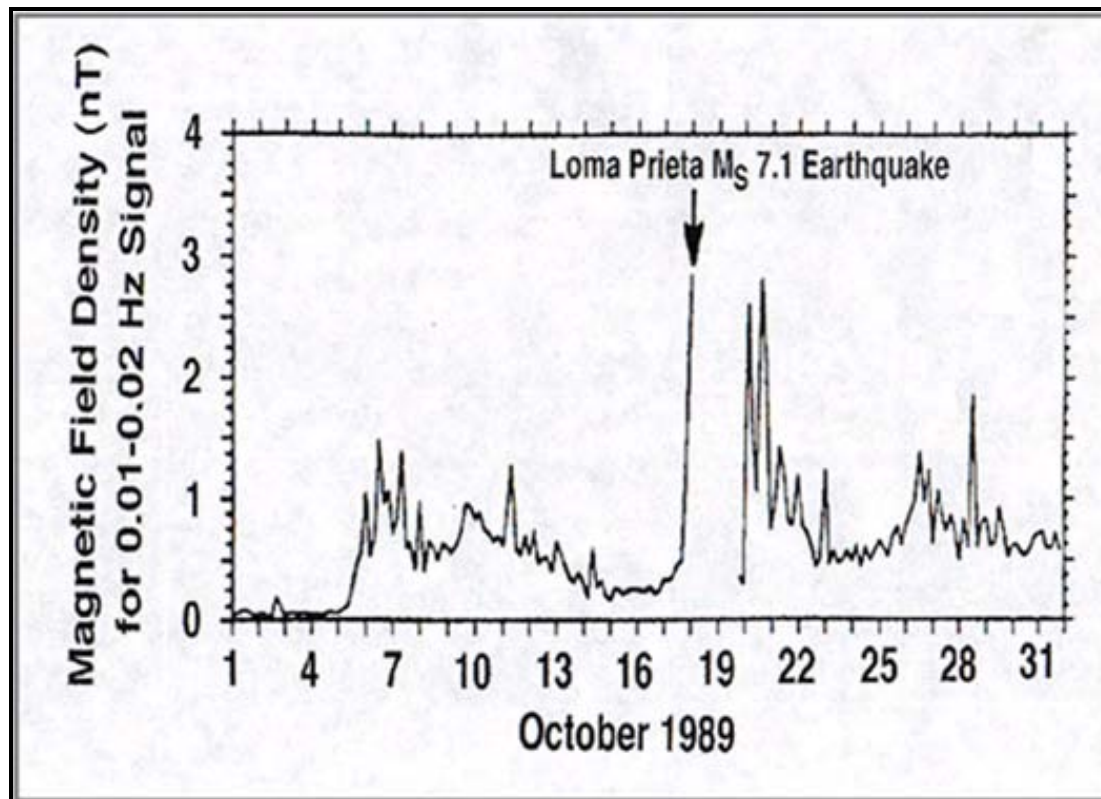


Space and Ground Monitoring



Early Electromagnetic Indications

- Dr Tony Fraser-Smith (Stanford)
 - M7.1 Loma Prieta
 - 30 minute energy averages
 - 13 Frequency bins



Parkfield Raw Cooling Slope: GOES-10 Band 4 over California: 26-Sep-2004--27-Sep-2004

