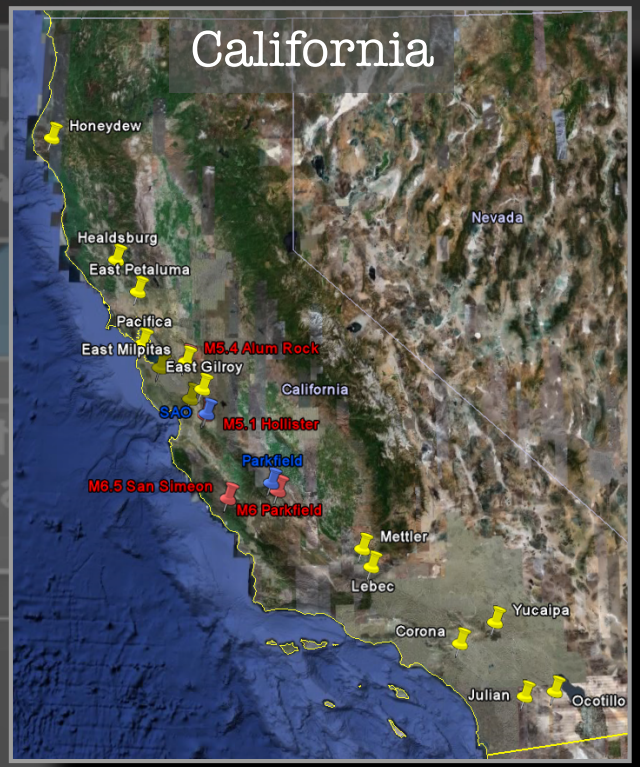
Introduction



Bayesian Detection of Geomagnetic Signals Preceding Earthquakes in California 1998-2010

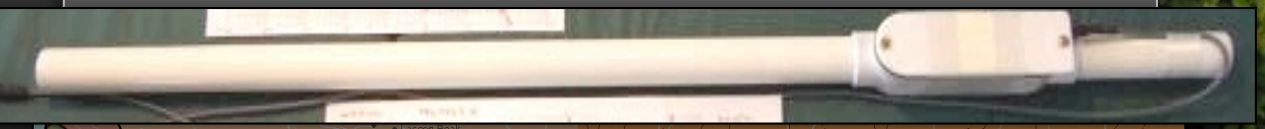
Clark Dunson （克拉克）
cdunson@quakefinder.com

* * * Analysis & Use of Pulse Phenomena * * *

QuakeFinder : Tom Bleier, Bob Camins, John Doering, Clark Dunson, Ciro Helder-Alvarez, Steven Roth, Stephen Pifko
NASA/Ames,JPL/NASA : Dr. Friedemann Freund, Dr. Nevin Bryant, Dr. Ray Bambery
UCLA : Dr. Jacob Bortnik

10 Years and Counting !!!

In 2005, QuakeFinder upgraded to the Zonge ANT4 coil, and state-of-the-art geomagnetic monitoring with QF1005



- Geomagnetic ULF
- Geophone
- Air Conductivity
- Temperature
- Humidity

www.quakefinder.com

Stanford/ USGS

Berkeley

Original Goal: Monitor Geomagnetic Field to look for more signals like those seen before the **1989 "Loma Prieta" m7.1** Earthquake.

Map Keys

QF CalMagNet

High School

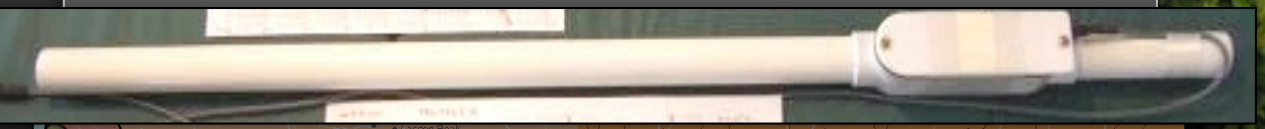
QF-1000

QF-1003

QF-1005
QF-1007

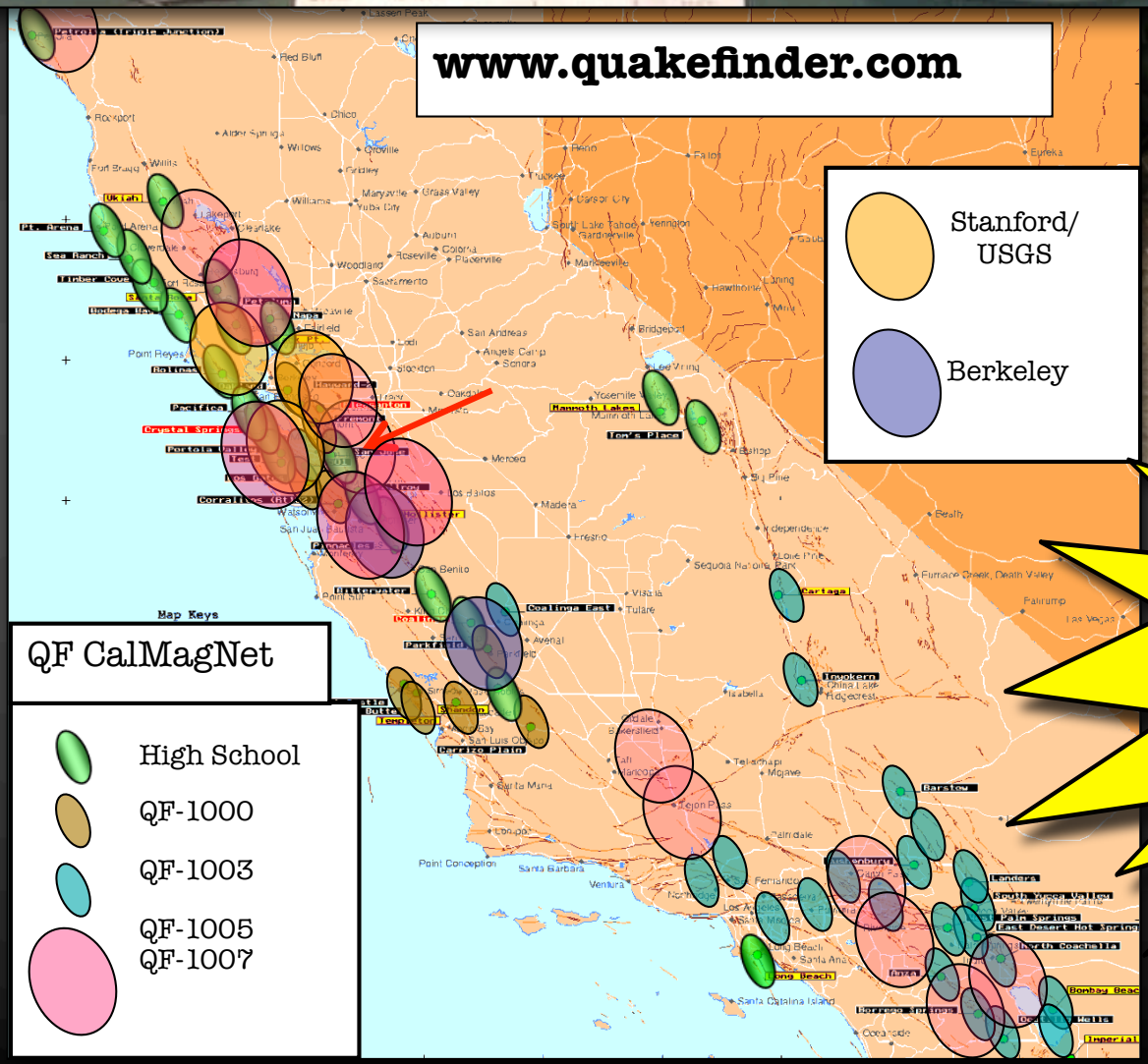
Ultra-Low Frequency (ULF) Monitoring

In 2005, QuakeFinder upgraded to the Zonge ANT4 coil, and state-of-the-art geomagnetic monitoring with QF1005



Zonge Sites	Qty
California	15
Peru	2
Taiwan	2

Coming Soon!

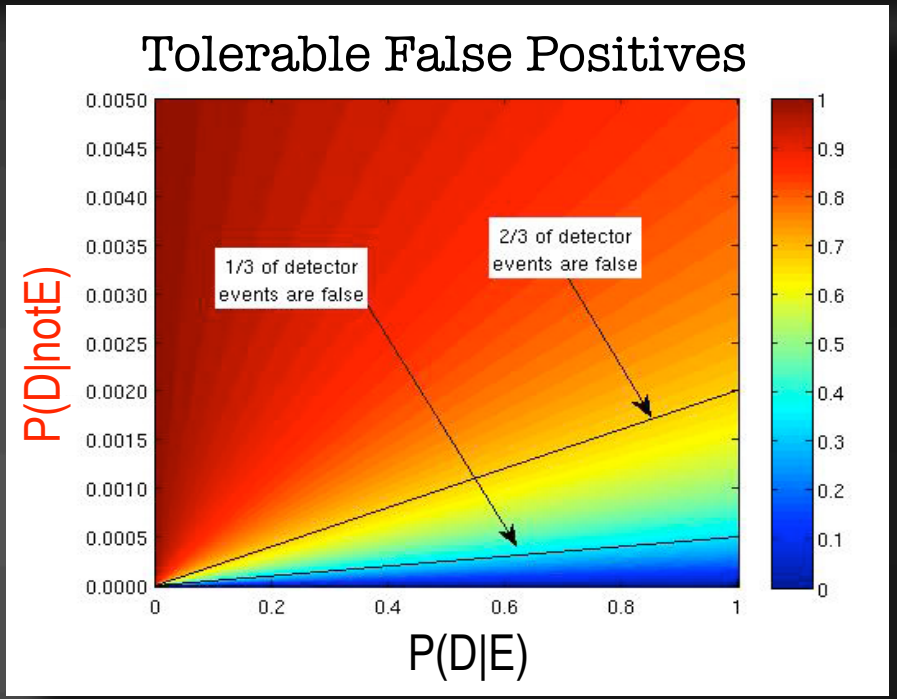


QuakeFinder now operates **17** of the highest-precision **ULF observatories** in the world. (soon in Taiwan!!)

Bayesian Detector Model

Earthquake Forecasting via detection of any pre-cursor is all about building and understanding the Detector!

$$P(E|D) = \frac{P(D|E)P(E)}{P(D)}$$



where:

E = earthquake event.

D = detector event.

P(E) = probability of an earthquake.

P(D) = probability of detector event (earthquake or not).

P(D|E) = probability of a detector event when an earthquake occurs.

P(E|D) = probability of an earthquake when a detector event occurs.

Knowing **P(E|D)** depends on knowing **P(D)**

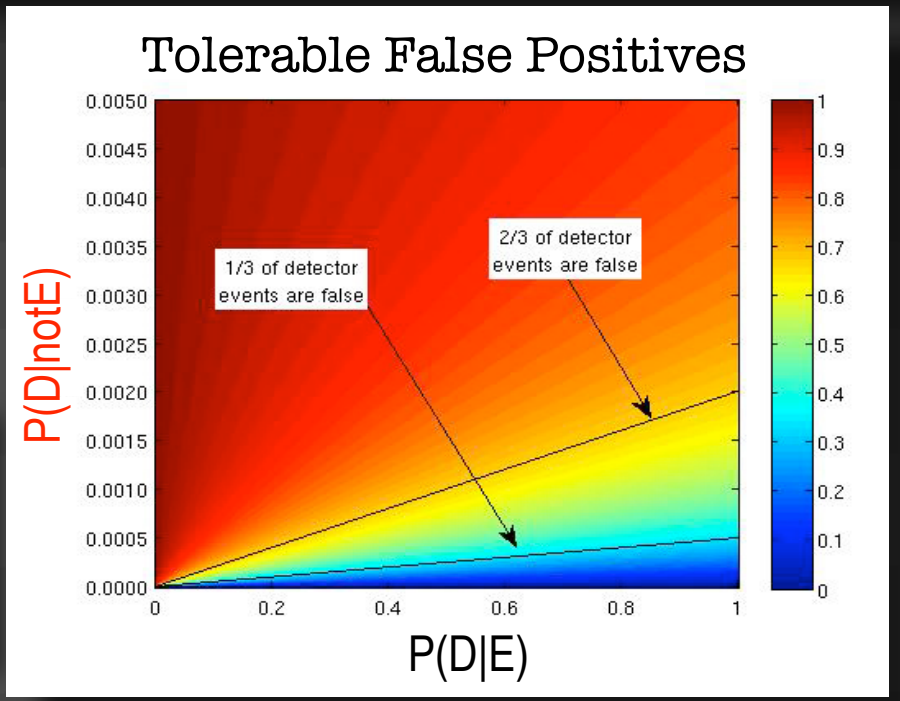
Bayesian Detector Model

Whether modeled or measured, we can state that false positives must be minimized. Can we know P(D|notE) in our lifetime?

$$P(E|D) = \frac{P(D|E)P(E)}{P(D)}$$

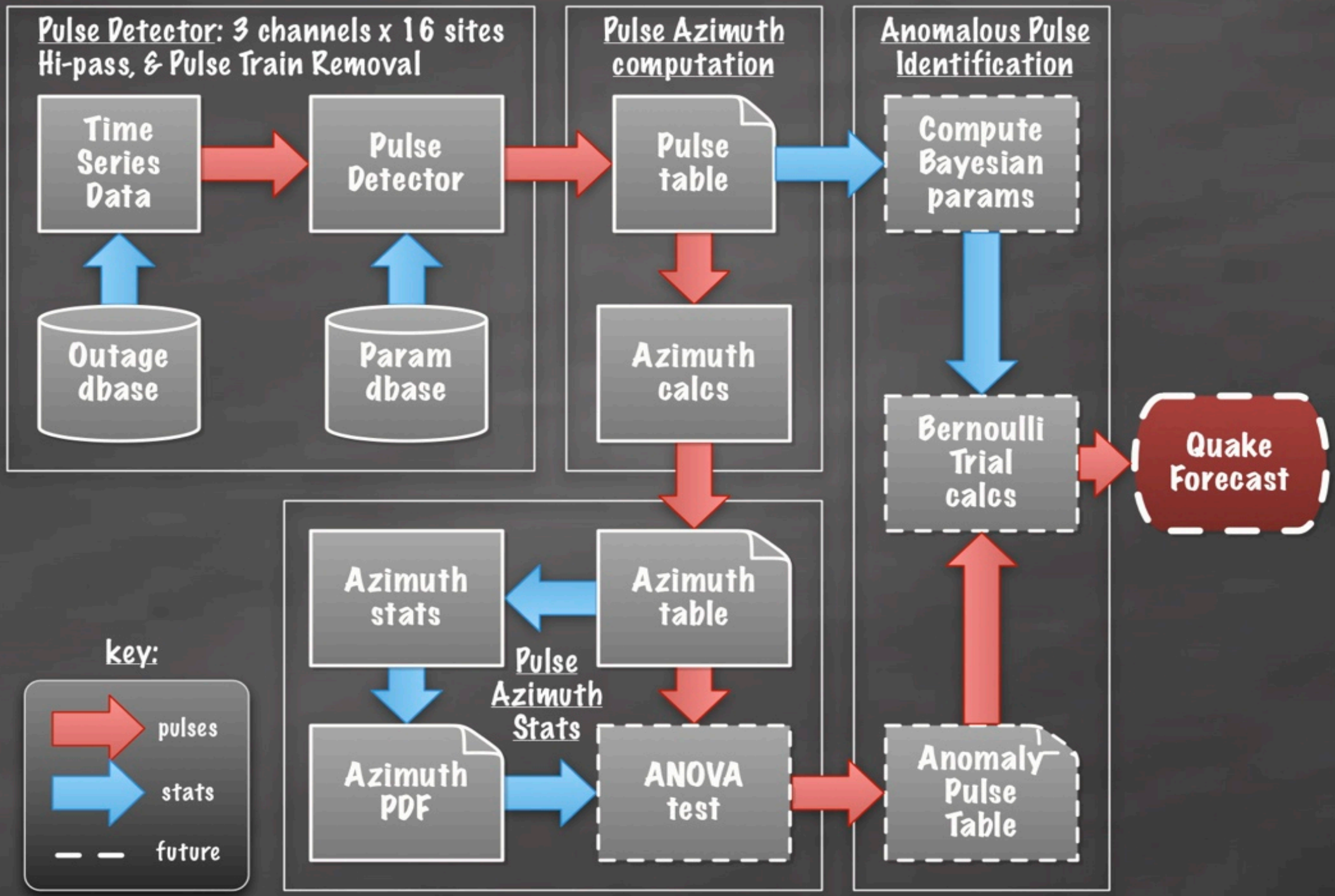
$$P(E|D) = \frac{P(D|E)P(E)}{P(D|E) + P(D|notE)}$$

False Positive Probability



Earthquake Pre-Cursor Detection is very much like a medical test for a rare disease. False positives can easily dominate the results.

Bayesian Forecasting Process



Bayesian Modeling Result

*A primary focus must be on developing detectors that have **strong discrimination** characteristics.*

QuakeFinder is developing a suite of four discriminators:

Discriminator #1

1. Increase in the Rate of Pulses.

Discriminator #2

2. Appearance of Pulse Azimuth Clusters.

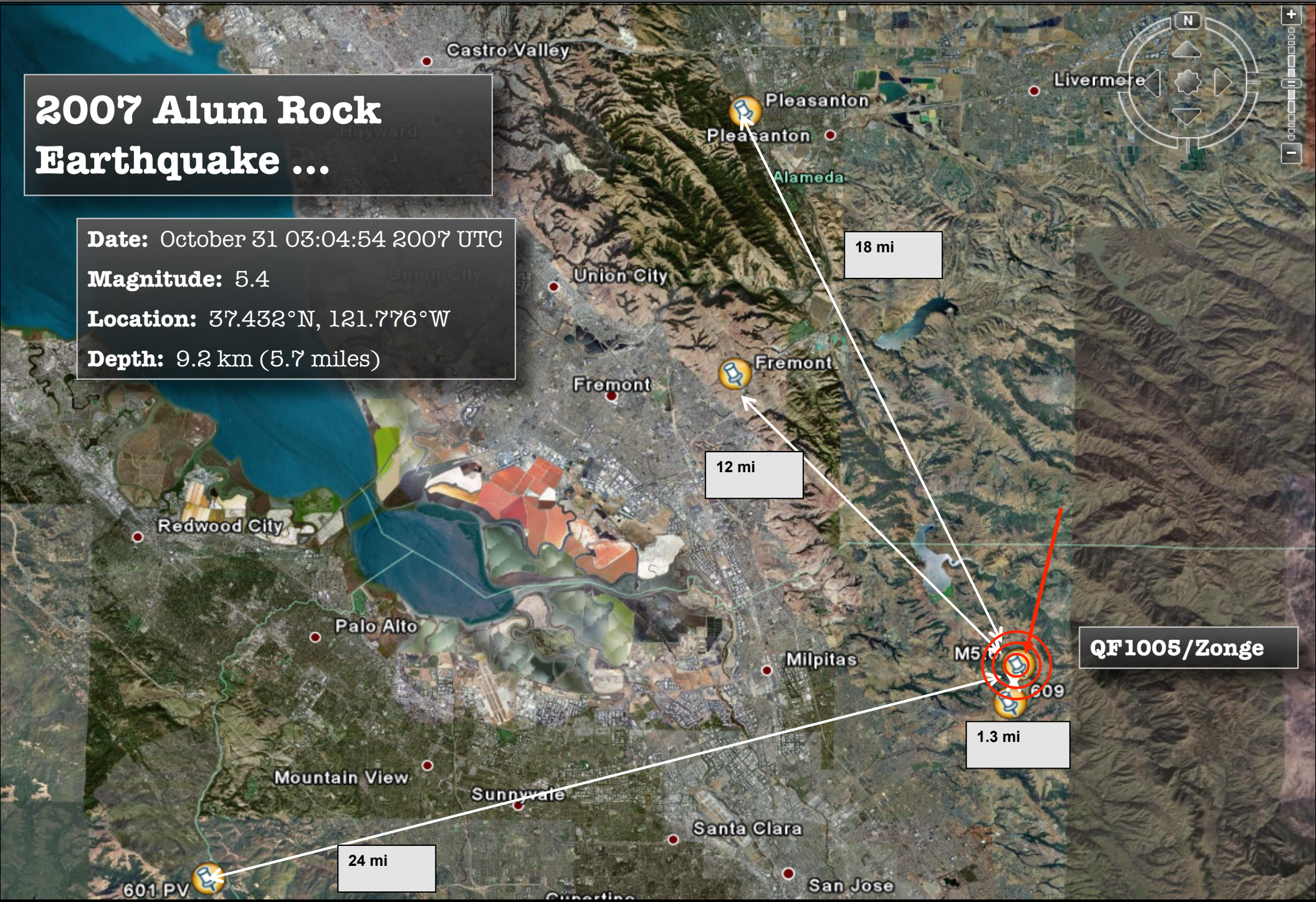
Discriminator #3

3. Increase in Air Conductivity.

Discriminator #4

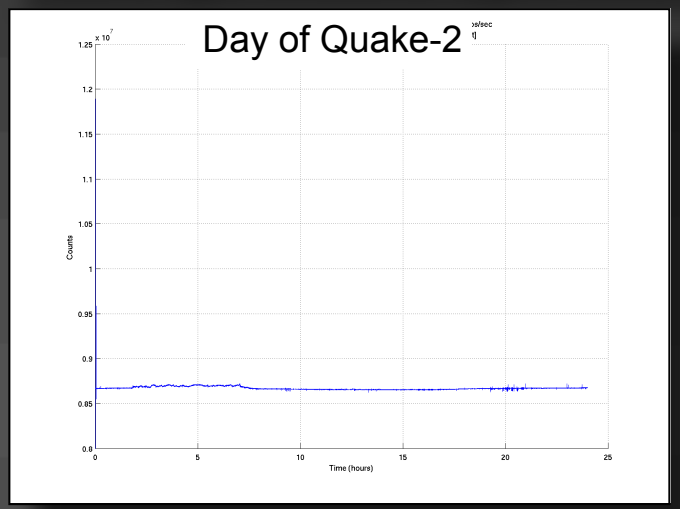
4. Increase in ULF Magnetic Activity (MA).

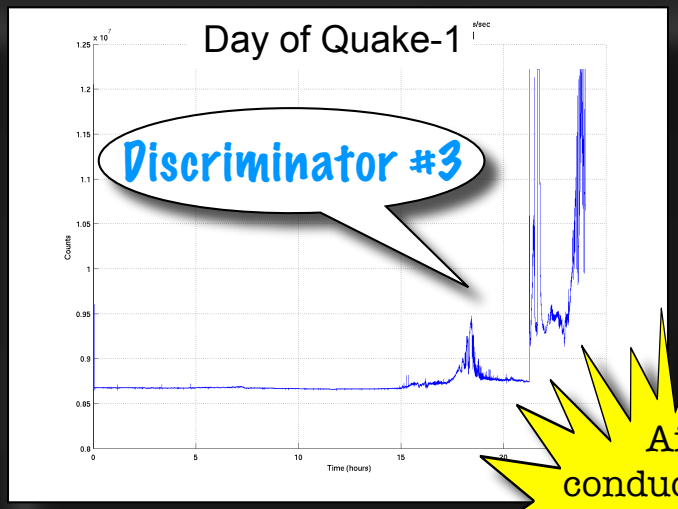
Oct 2007 event near high-precision site

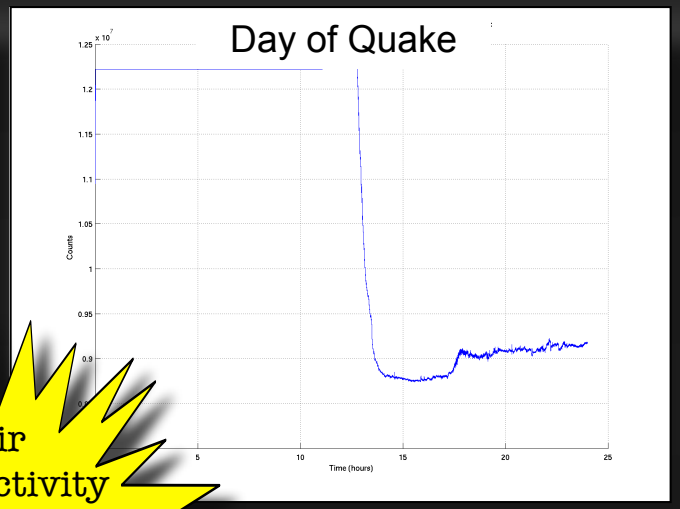


Discriminator #3: Air Conductivity

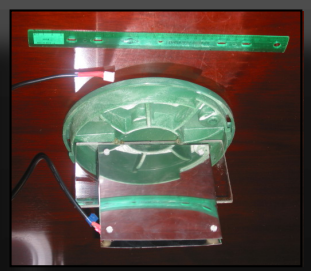
Measured change in charged air particles between two stainless steel plates with 60 VDC, located 3 inches from the ground (protected from fog/rain)



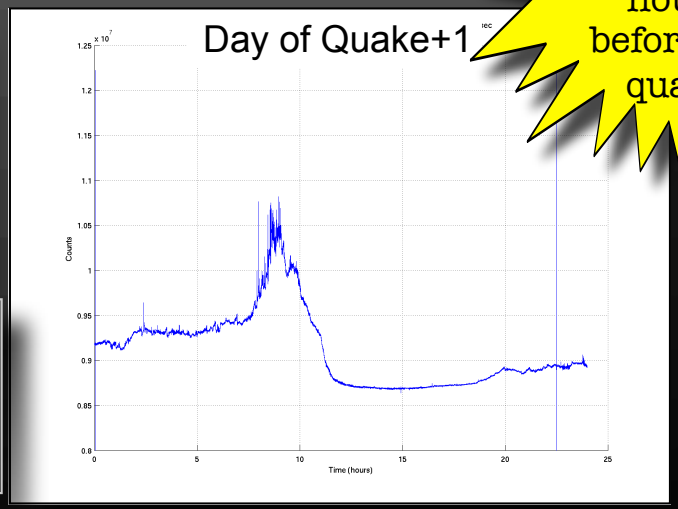


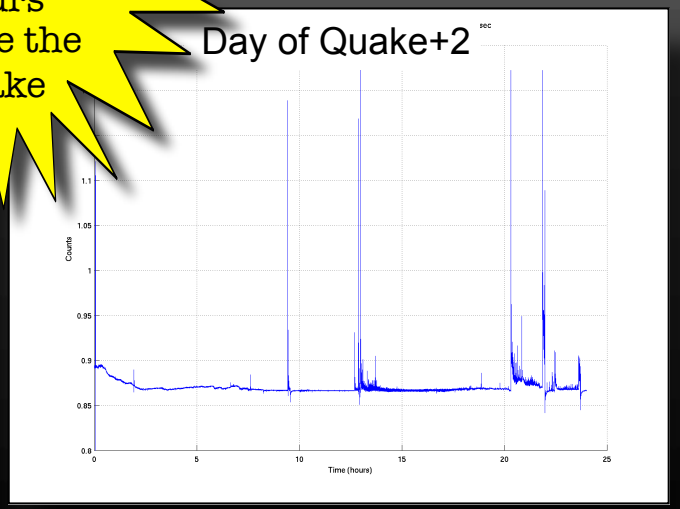


Air conductivity increased 22 hours before the quake



2007 Alum Rock Earthquake





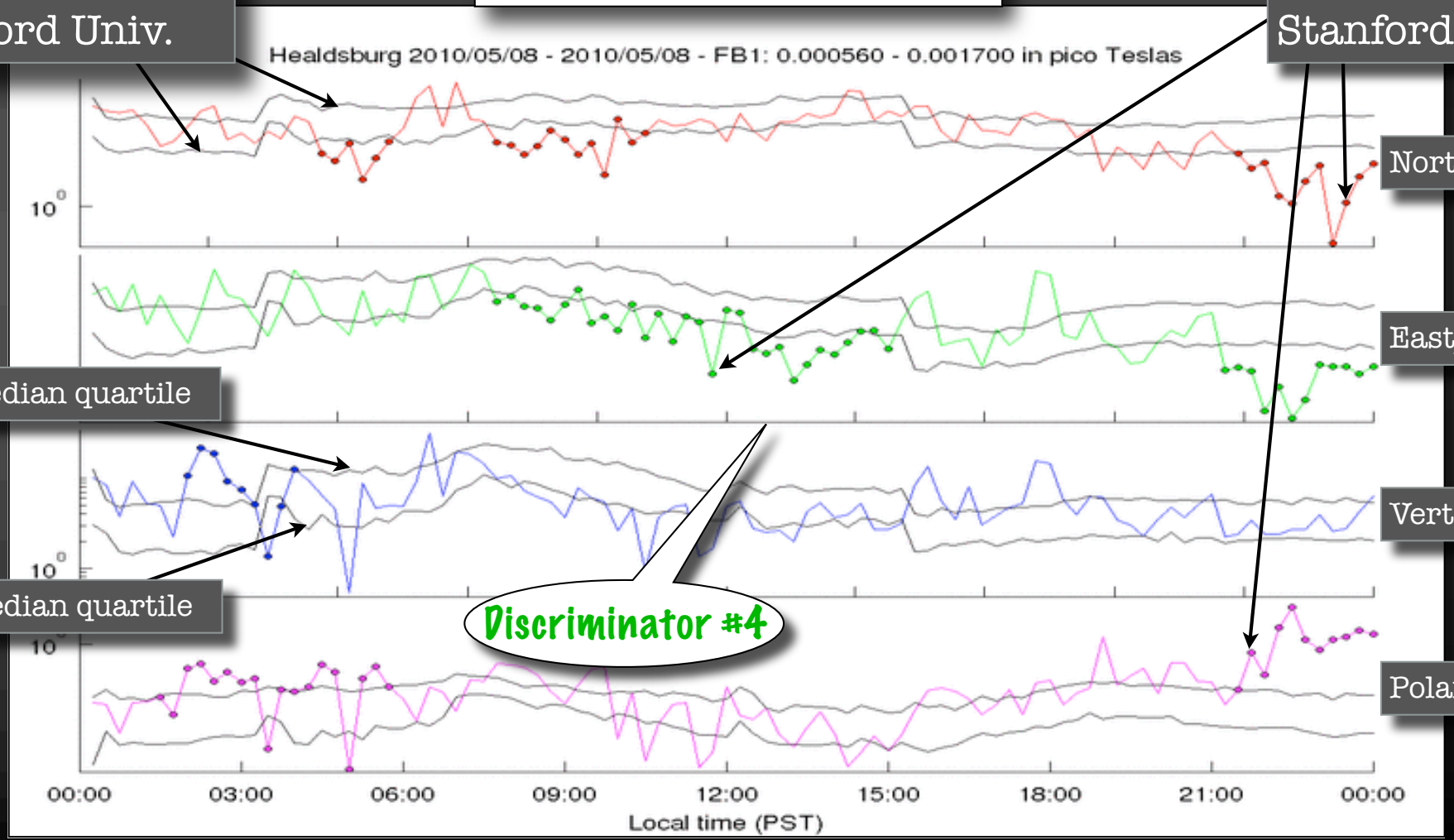
Discriminator #4: ULF MA Excursions

"How to": 30 minute blocks of data, separated into 13 freq. bands (after M. Fullerkrug) catalogued in database.

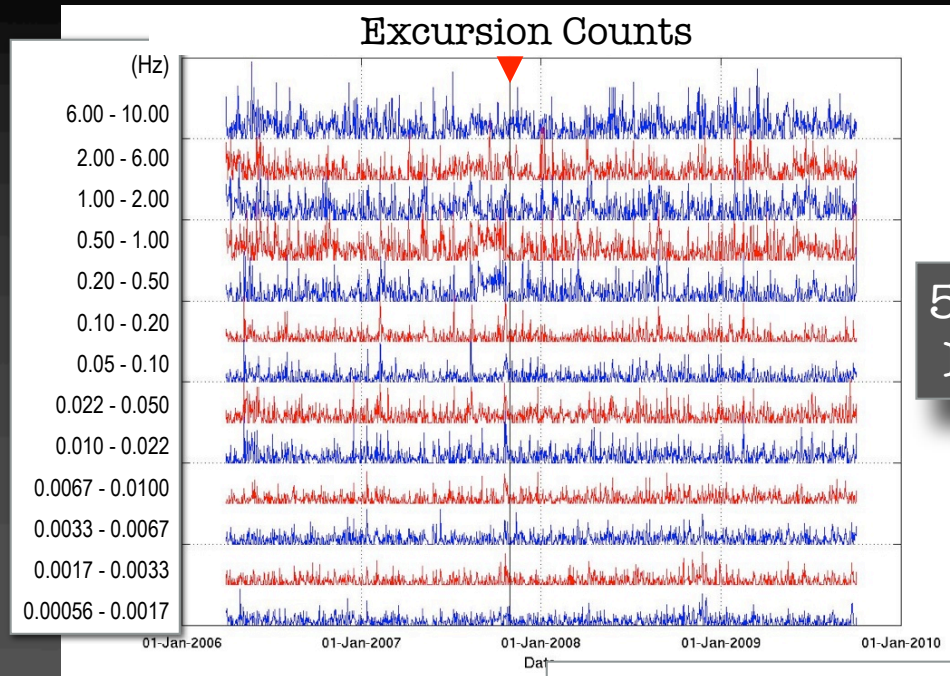
Excursion Limits by: Dr. James Cutler Stanford Univ.

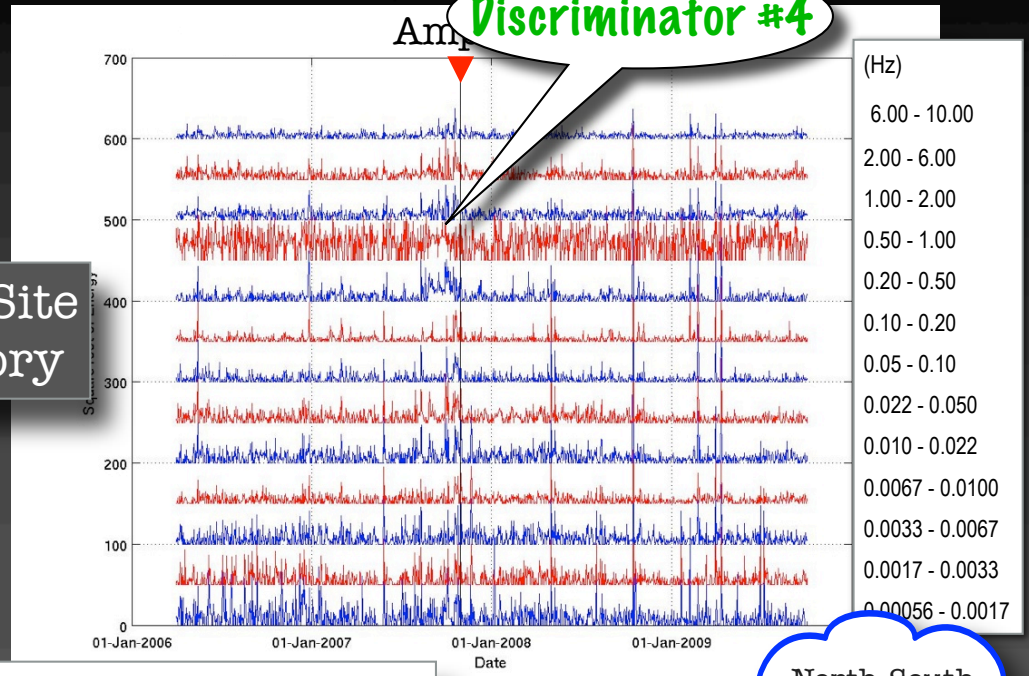
Excursion Limits are driven by Kp, Day of year, Hour of day, and Site history

Excursion Detector by: Steven Pifko Stanford Univ.



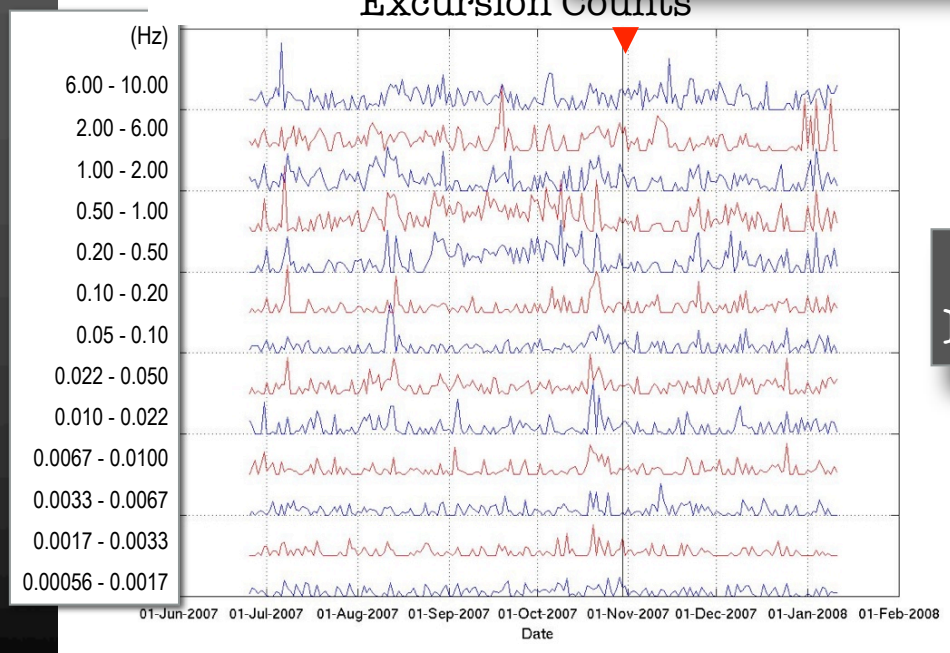
Alum Rock ULF MA Result: East-West



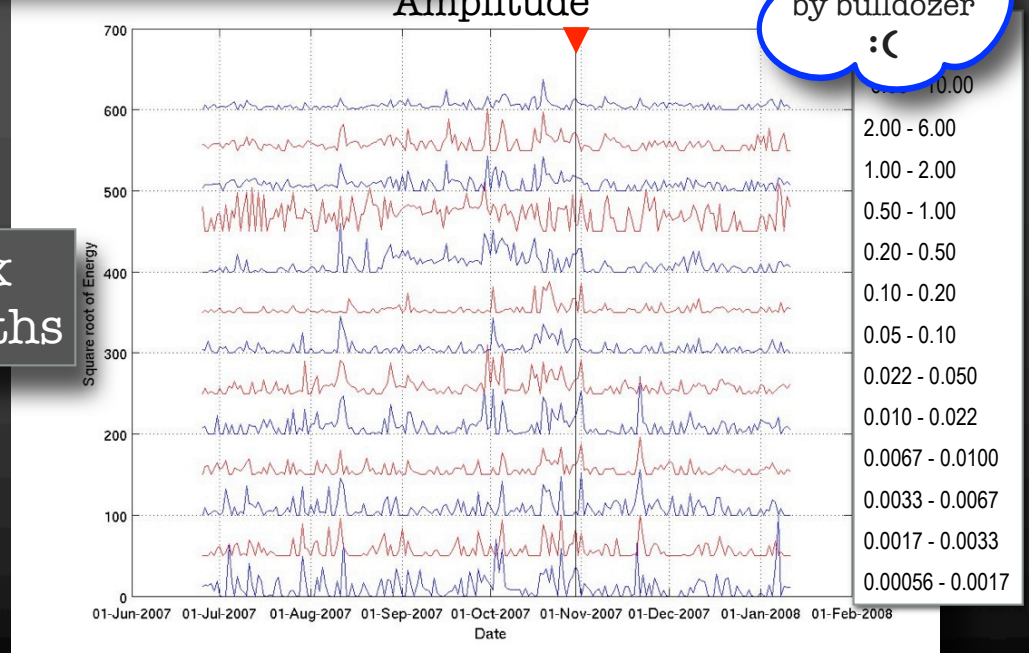


5 yr. Site History

Plotting tools provided by: **Steven Roth**, Notre Dame Univ.

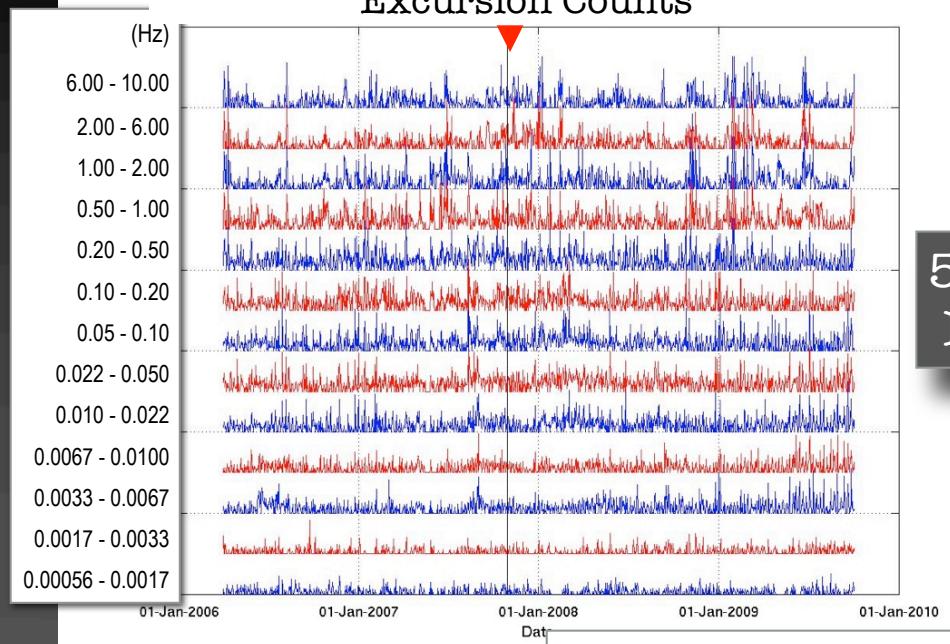


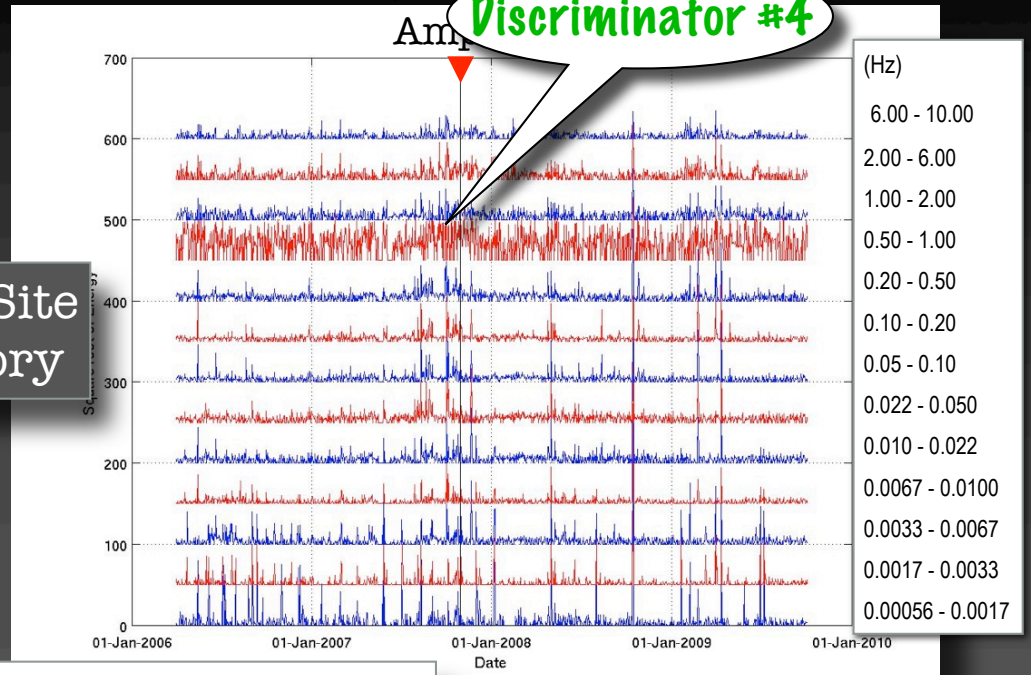
Six Months



North-South Coil damaged by bulldozer :(

Alum Rock ULF MA Result: Vertical





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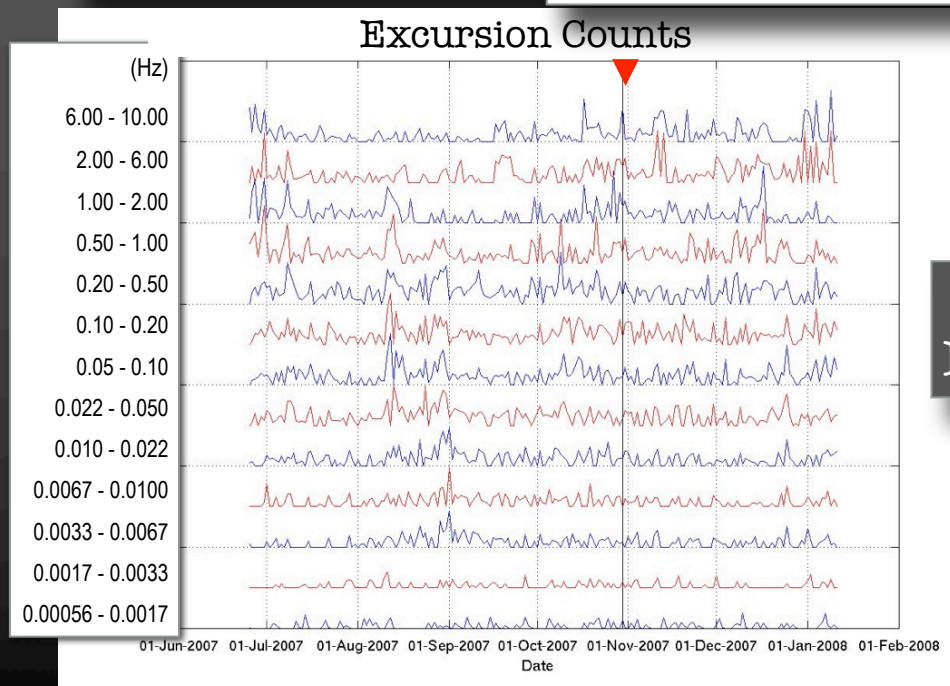
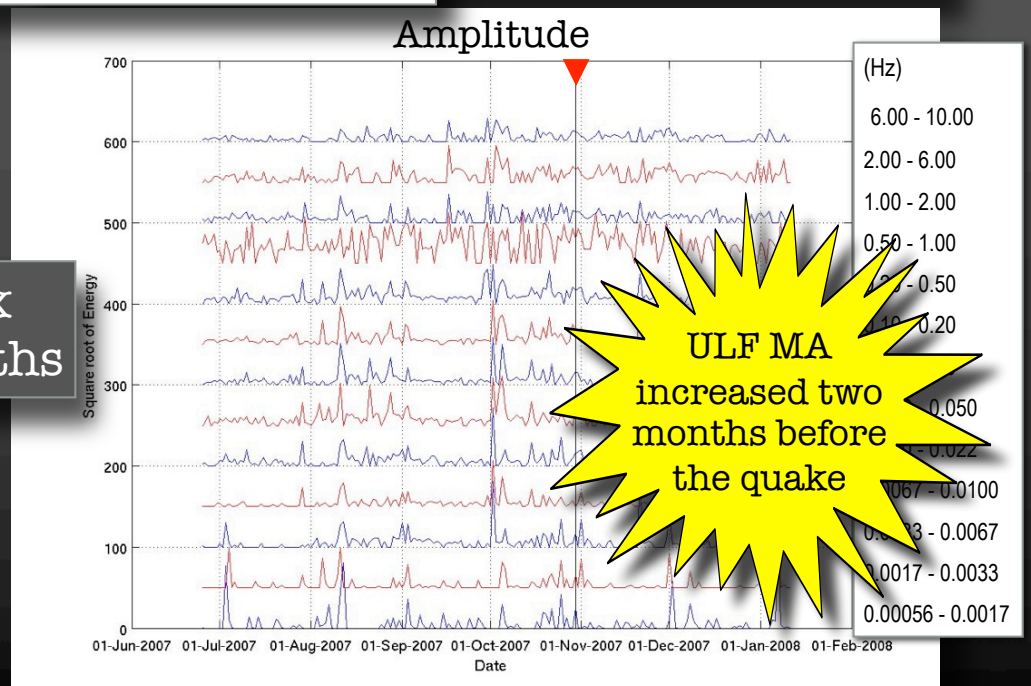
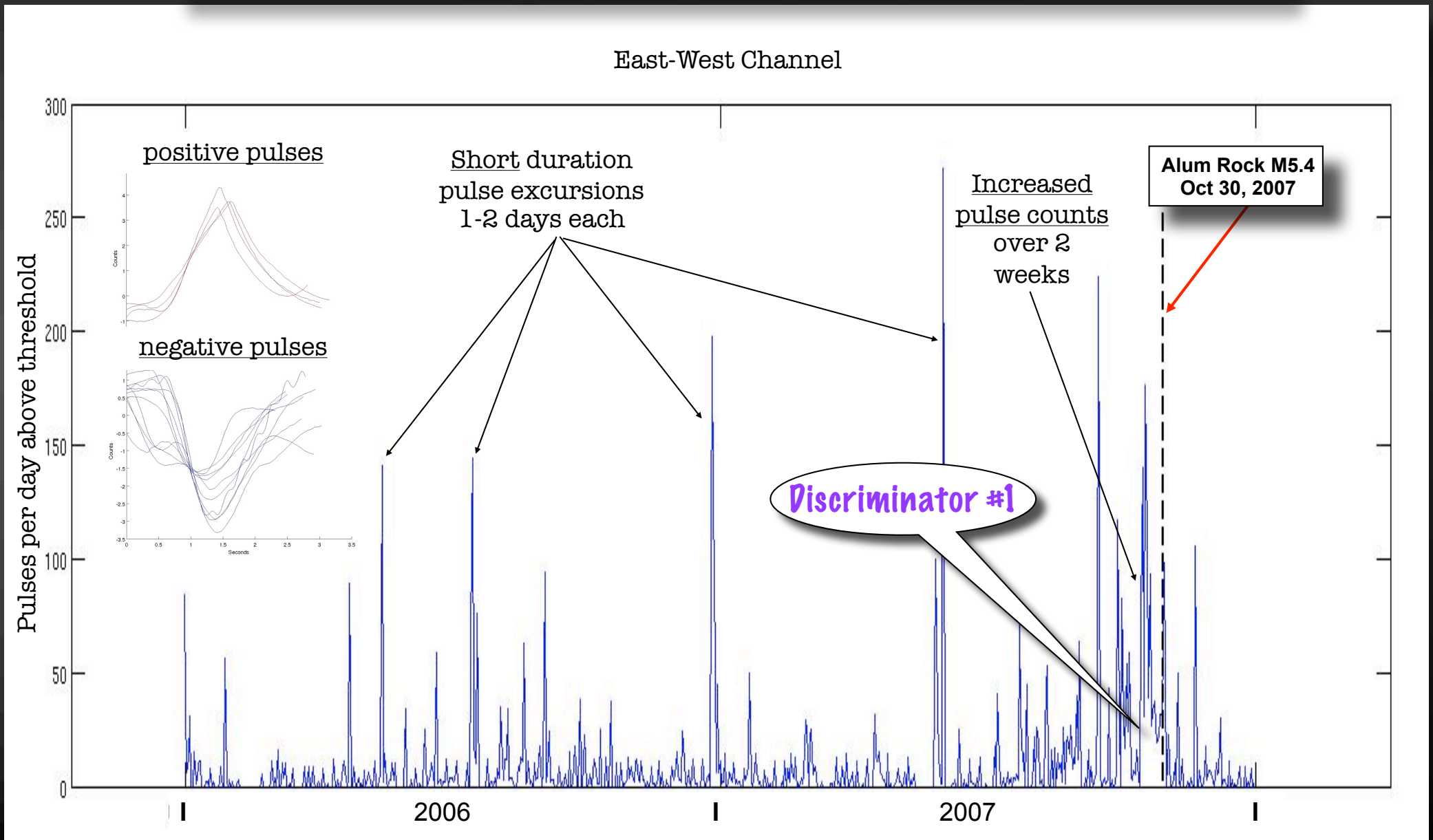


Six Months



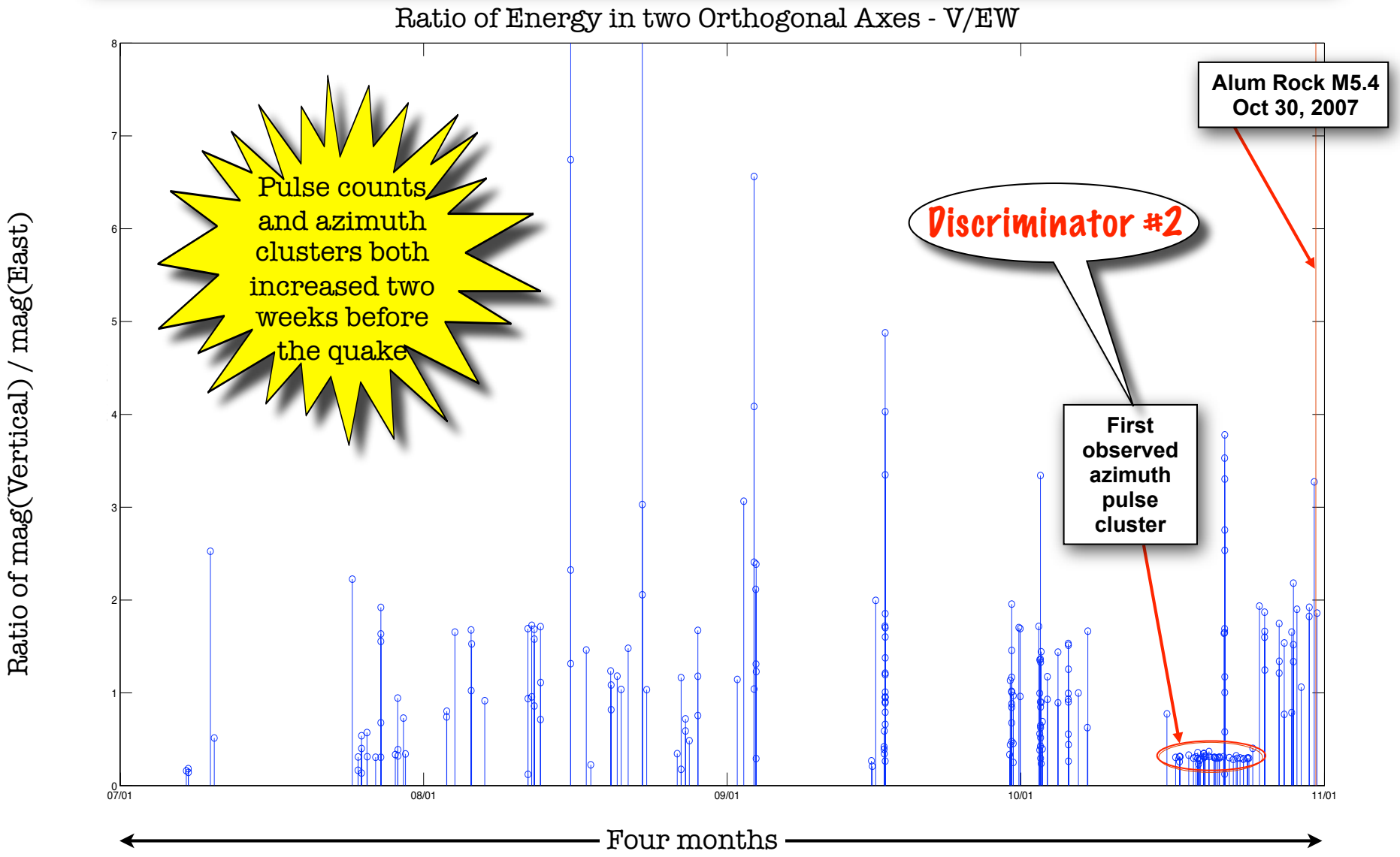
Discovery of Pulses

Pulses were very large, and exhibited complex dispersion characteristics.



Discovery of the Azimuth Effect

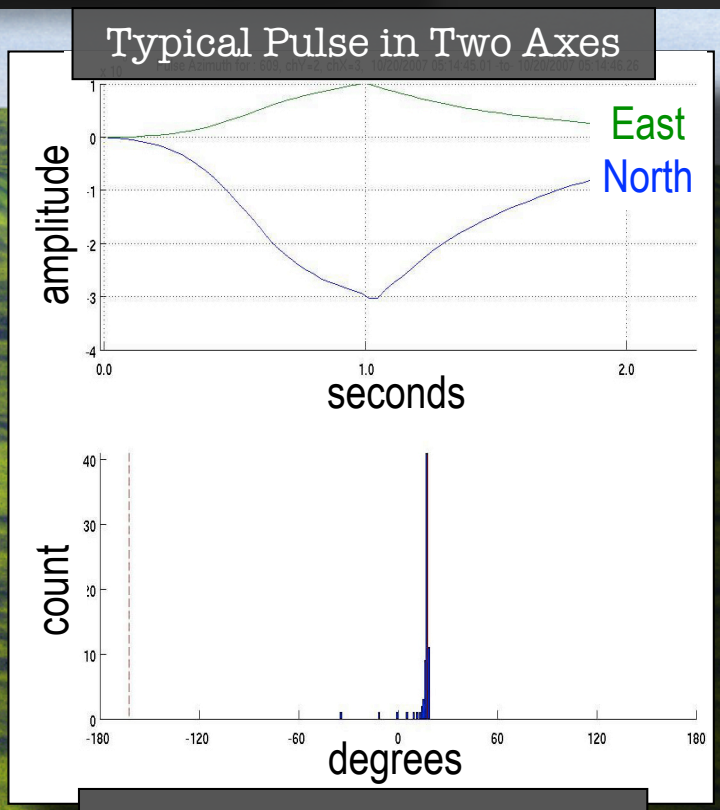
Ratio of pulse amplitudes in pairs of axes remains 'constant.' Pulses occur in unipolar clusters.

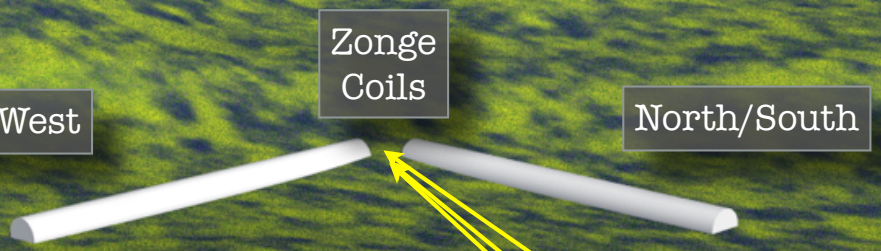


The Pulse Azimuth Effect

Unipolar pulses can be caused by charge migration.
Hypothesis:: Freund currents are the source.

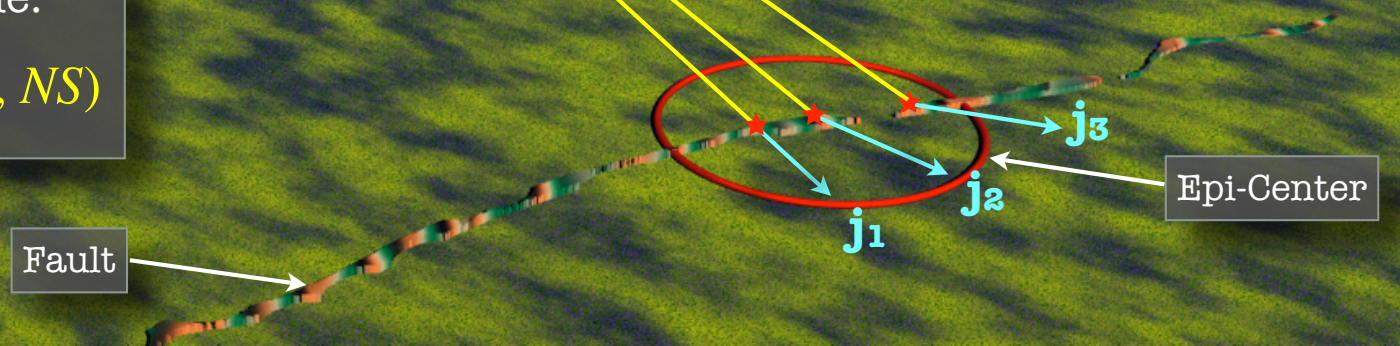
There are two variables in the azimuth angle::
1. Variable position of current flow .vs. site.
2. Variable orientation of current vector **j**.





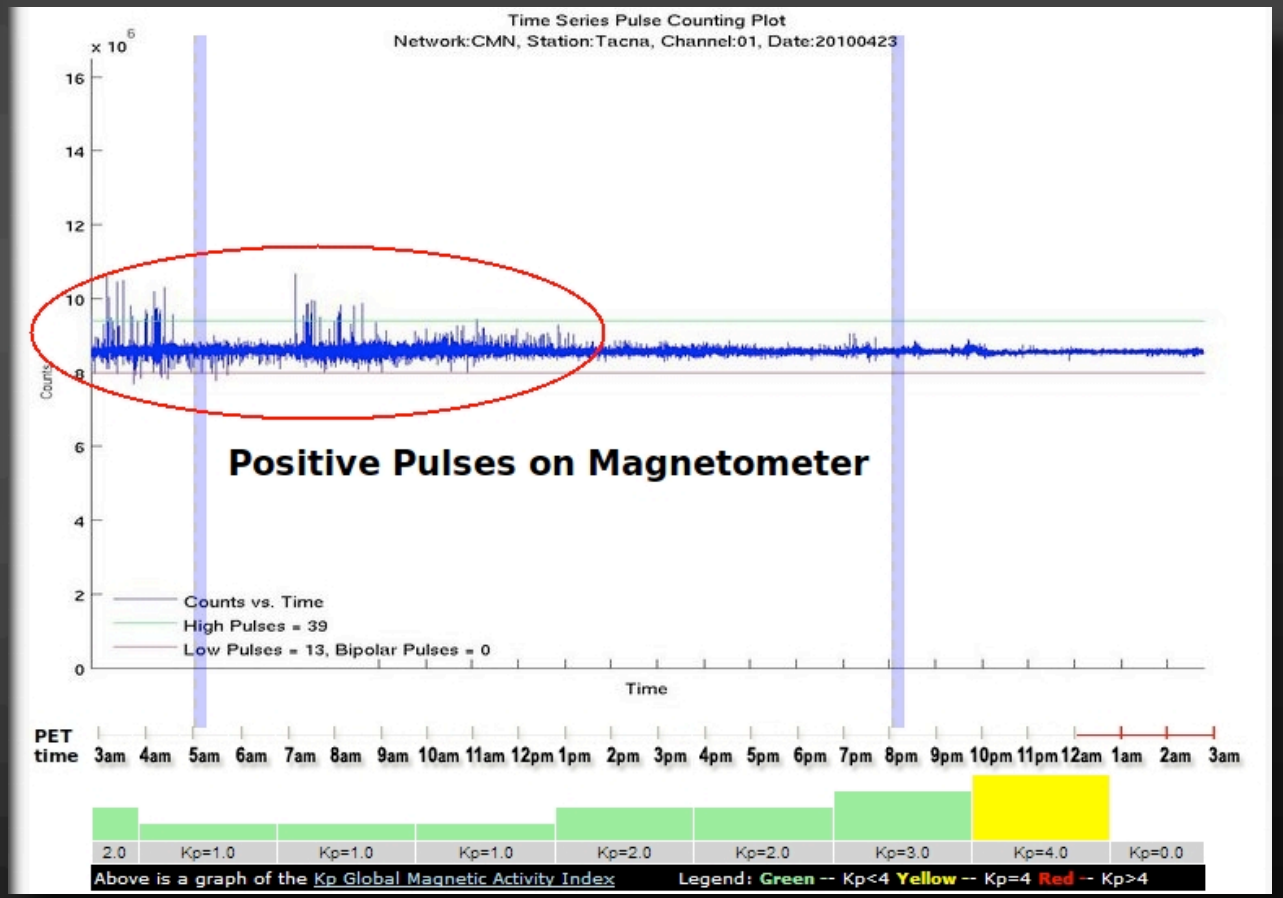
The azimuth effect is not about absolute angle of arrival, but rather pulse arrivals that repeat from the same angle.

$$azimuth = 90 - \arctan 2(EW, NS)$$



m6.2 near our new Tacna, Peru site

This earthquake was 30 Km from our sensor and 35 Km deep.
May 6, 2010 03:42 UTC

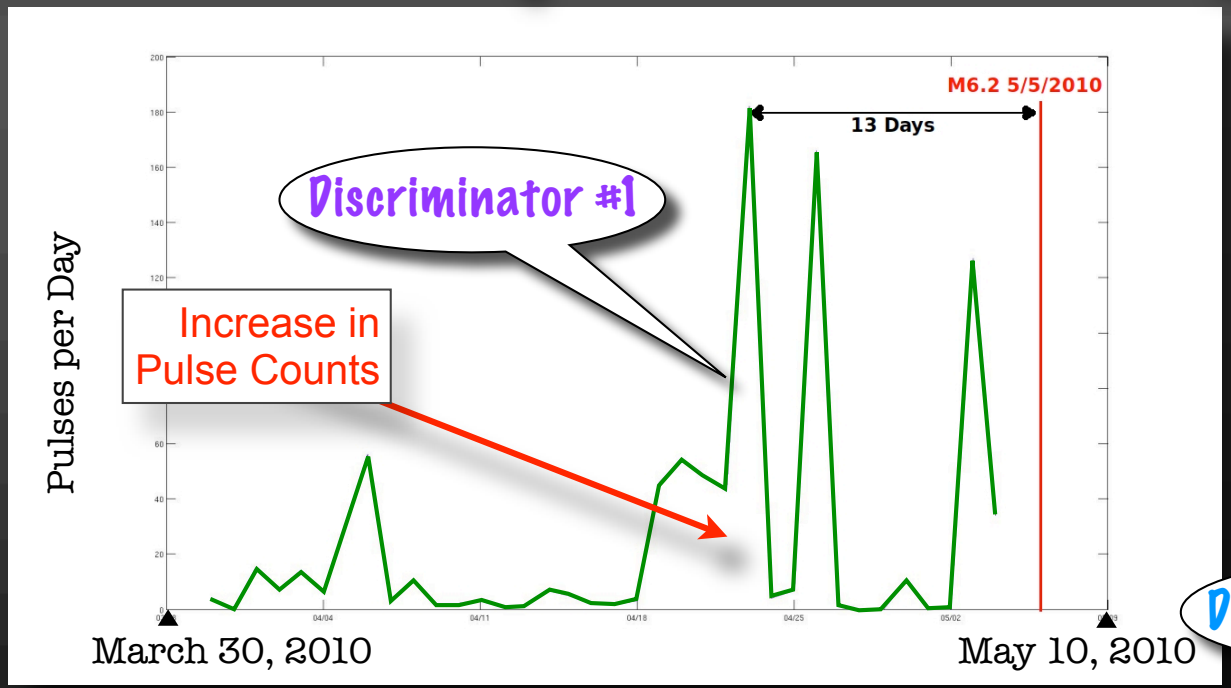


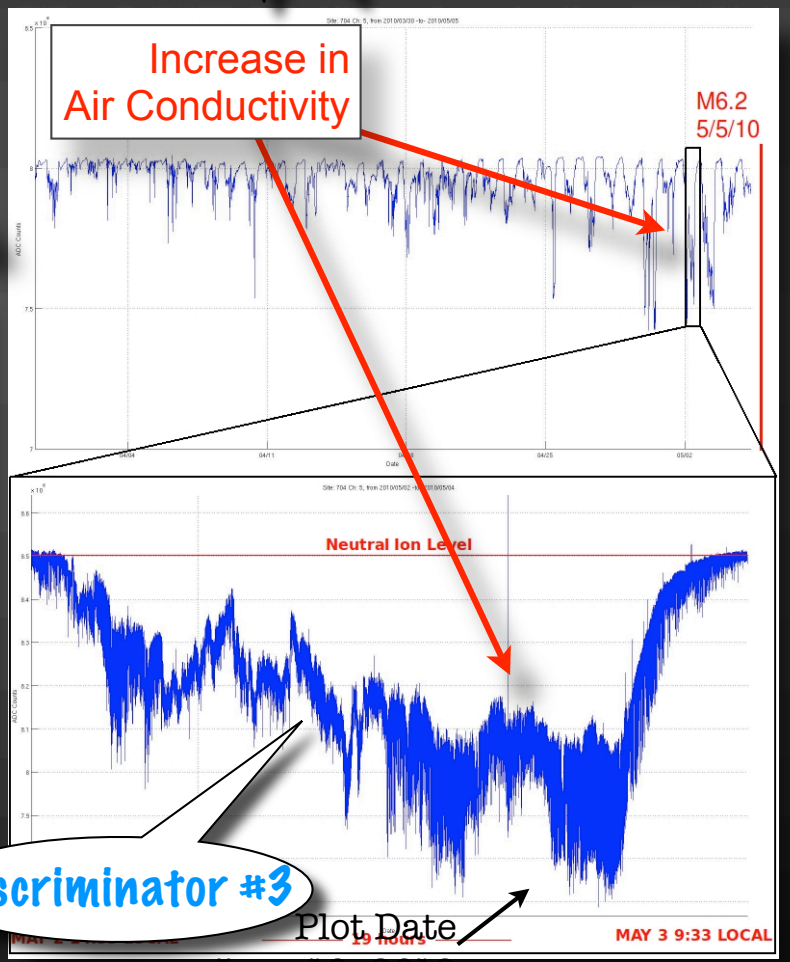
The sensor was installed on March 28, 2010

Tacna Pulse Counts & Air Conductivity

Both the Pulse Count and the Air Conductivity signals change with strong SNR before quake.

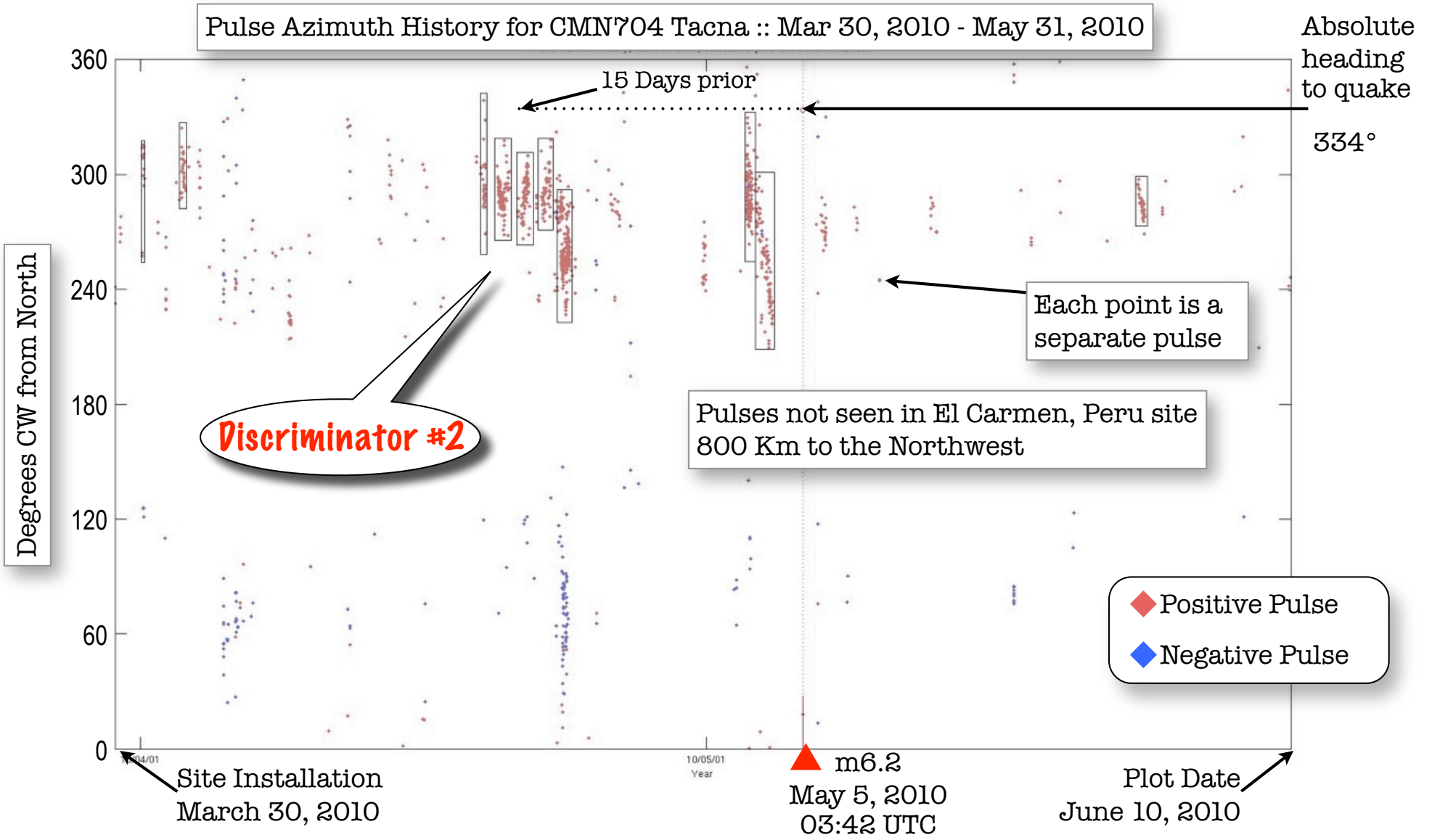
Pulse Counts and Air Conductivity both increased before the quake





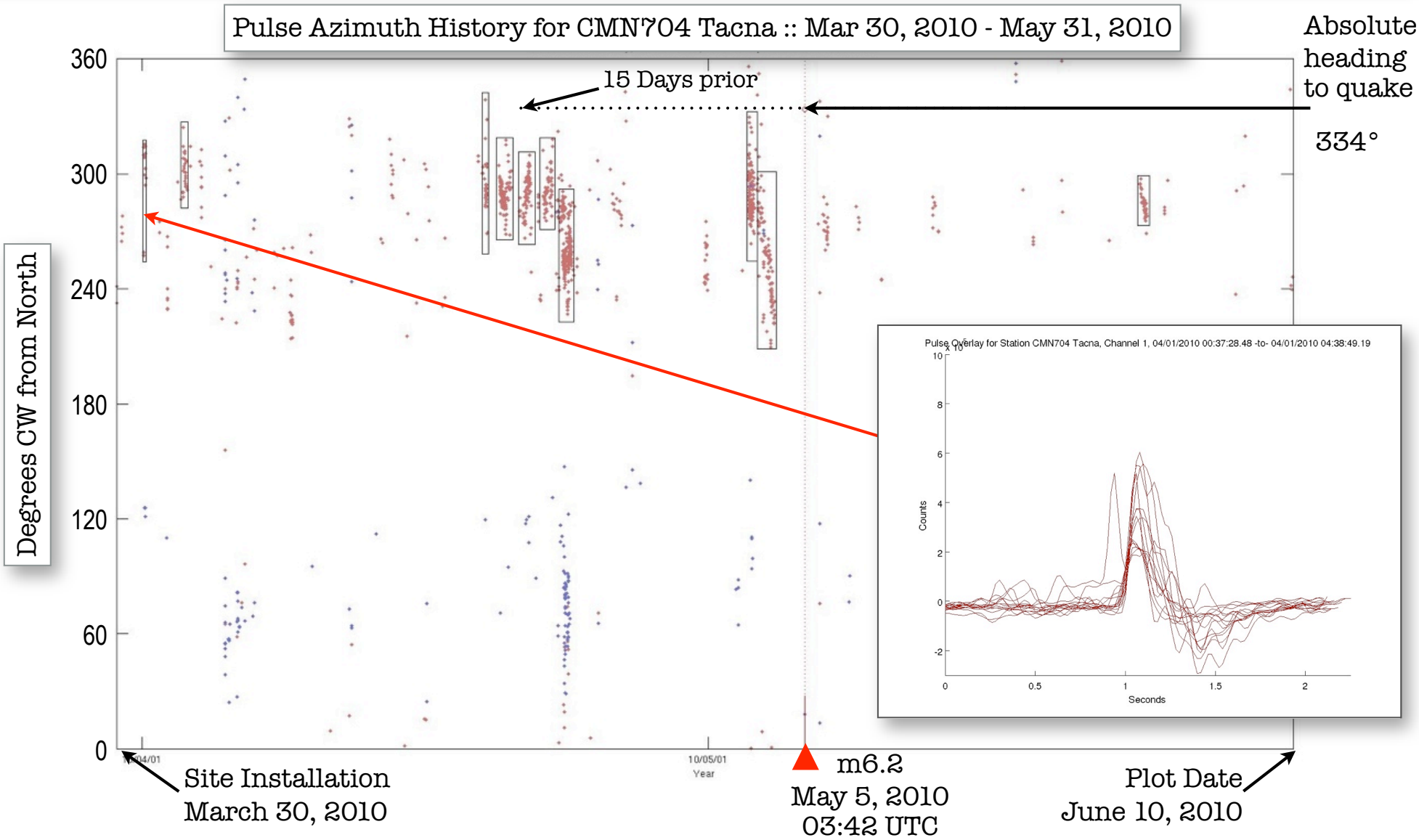
The Pulse Azimuth Effect at Tacna, Peru

The pulse azimuth effect is again seen before the earthquake.



The Pulse Azimuth Effect at Tacna, Peru

Pulses are uni-polar, and they occur in groups, clustered in time and relative amplitude between orthogonal axes.



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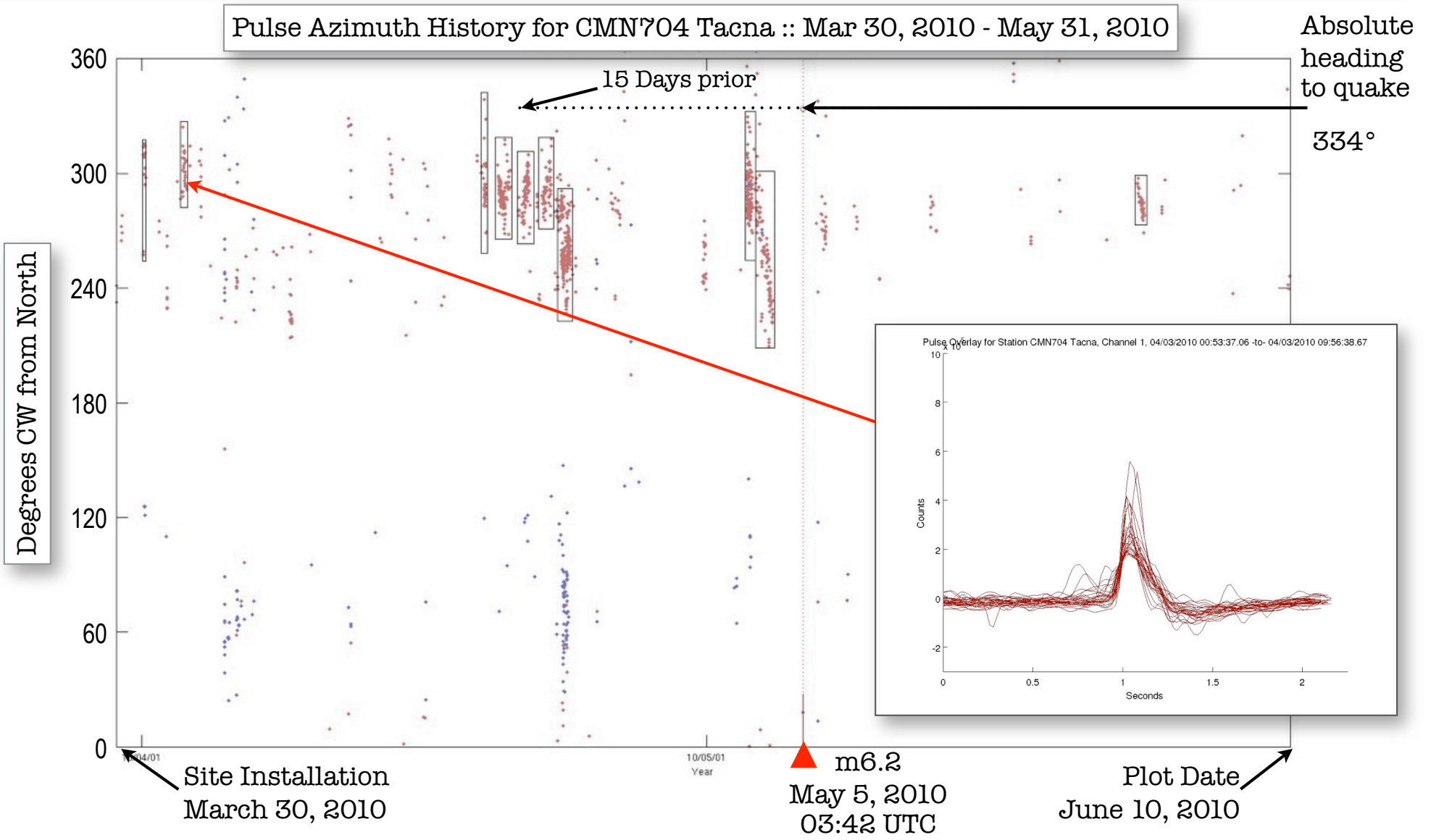

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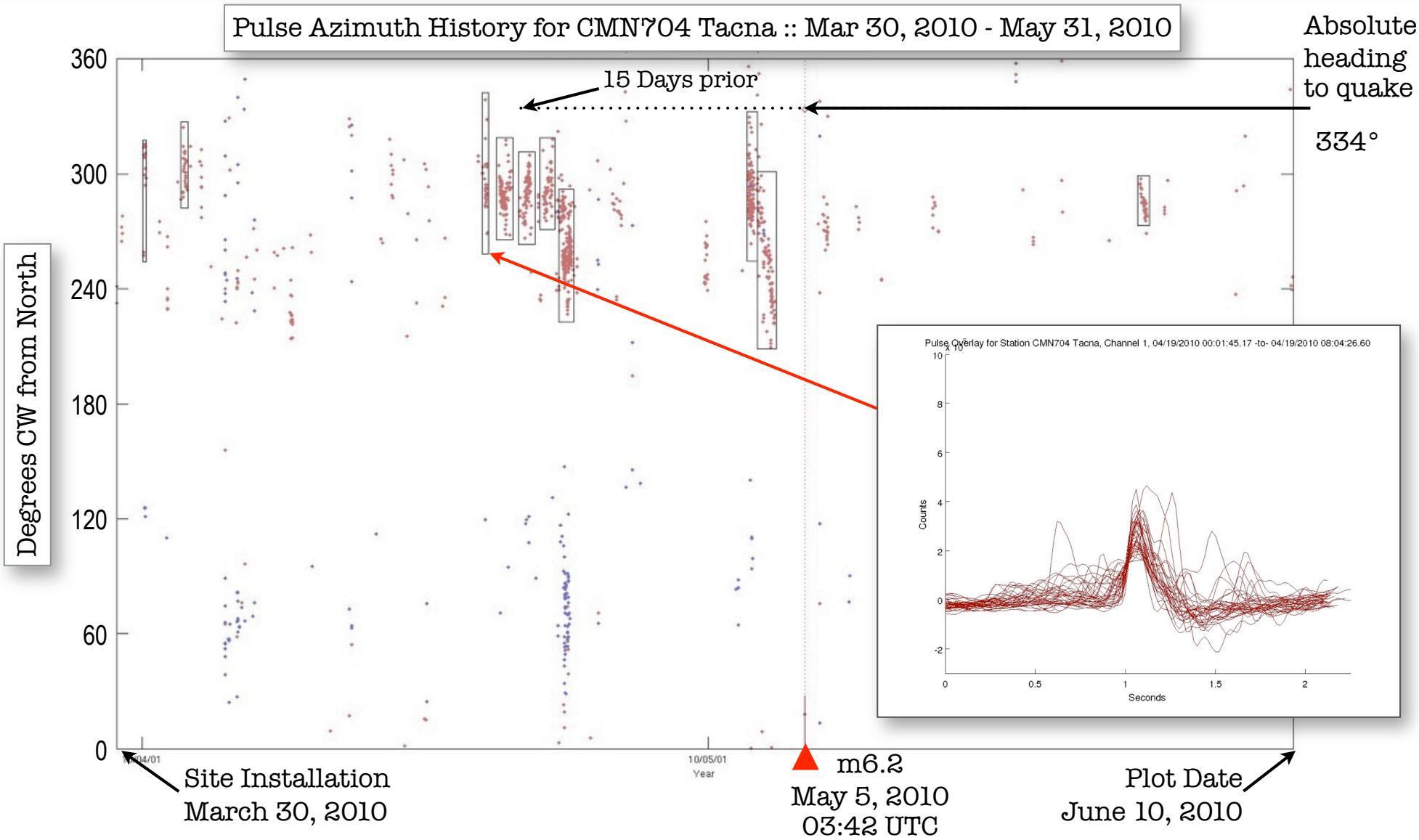

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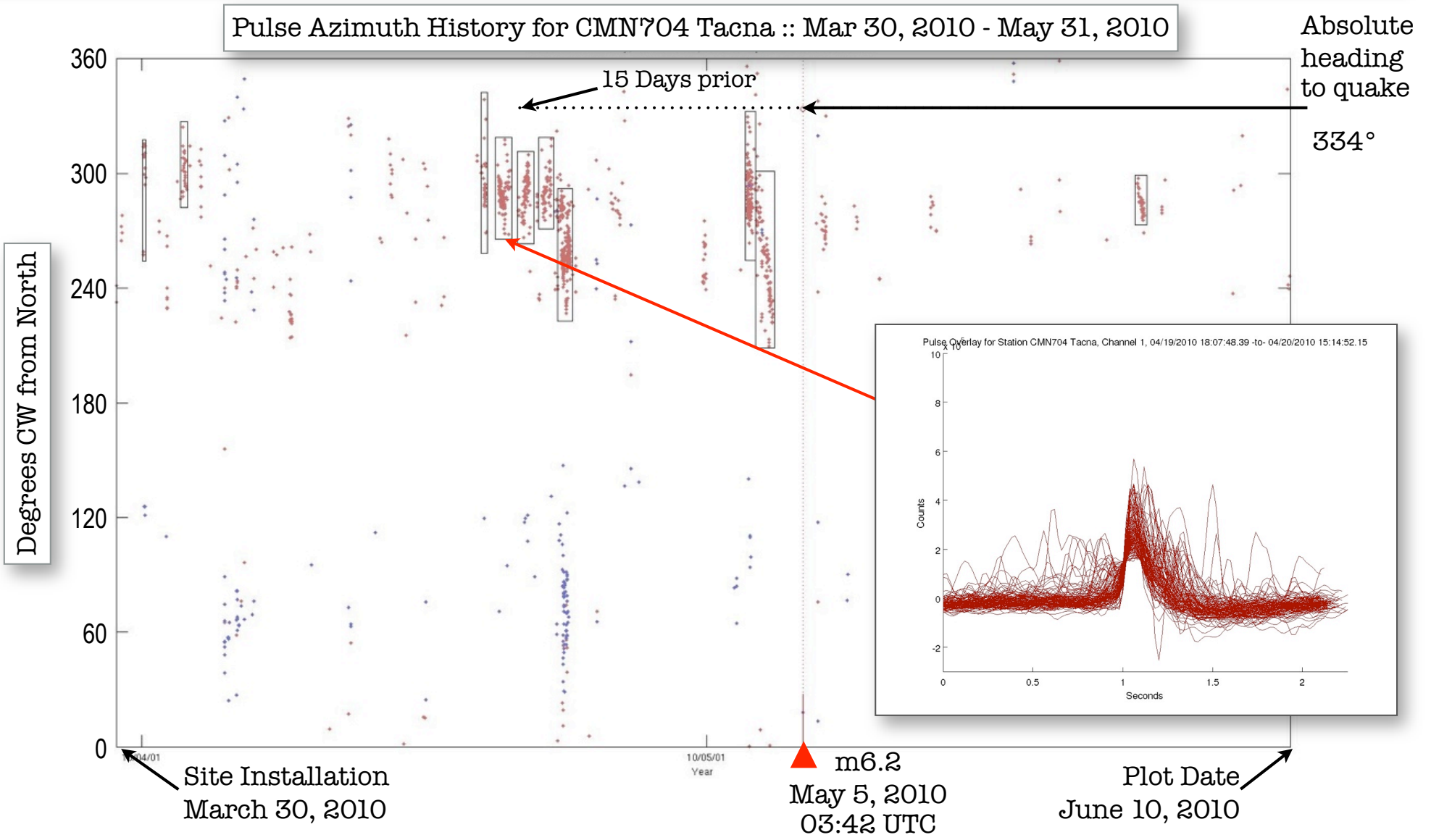

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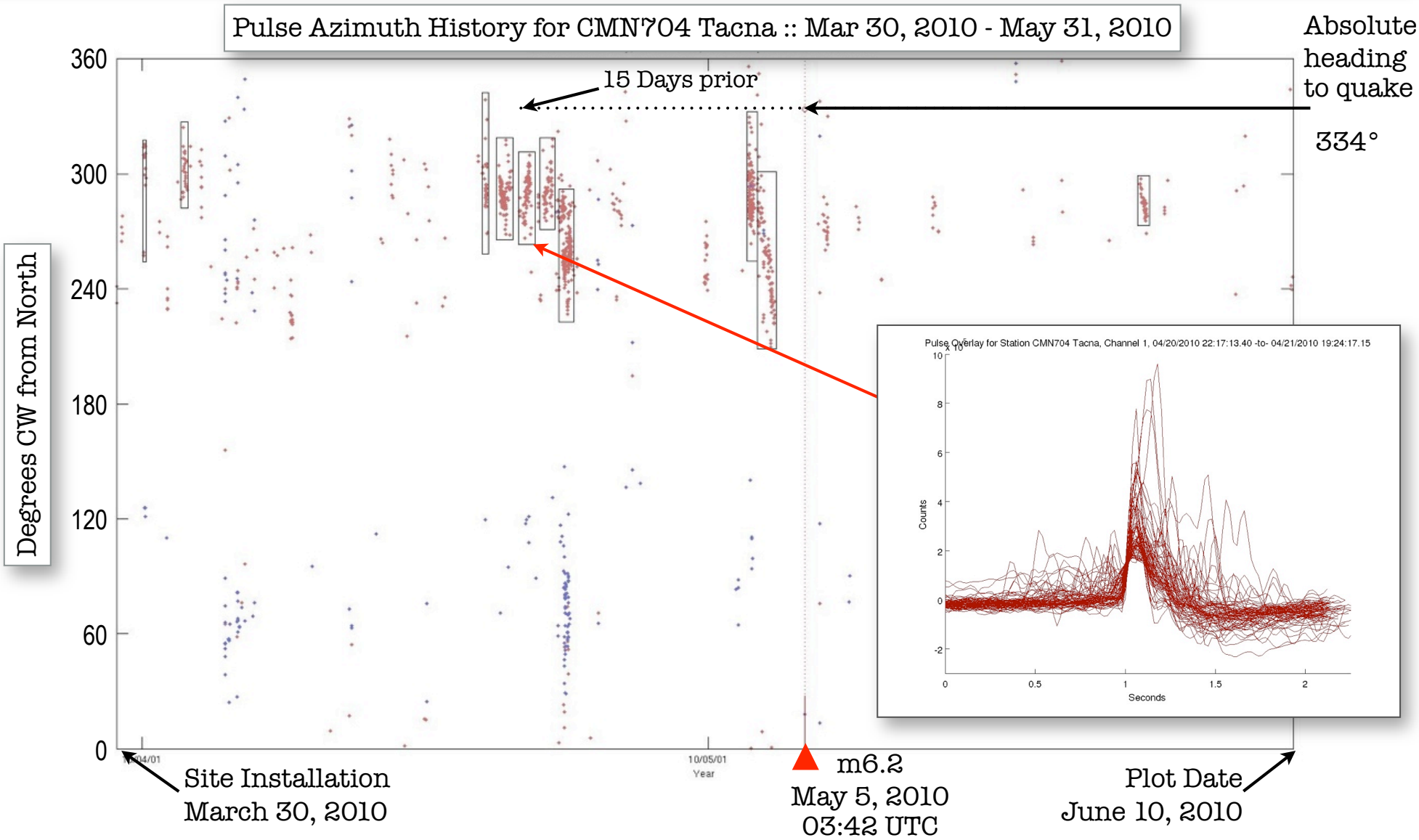

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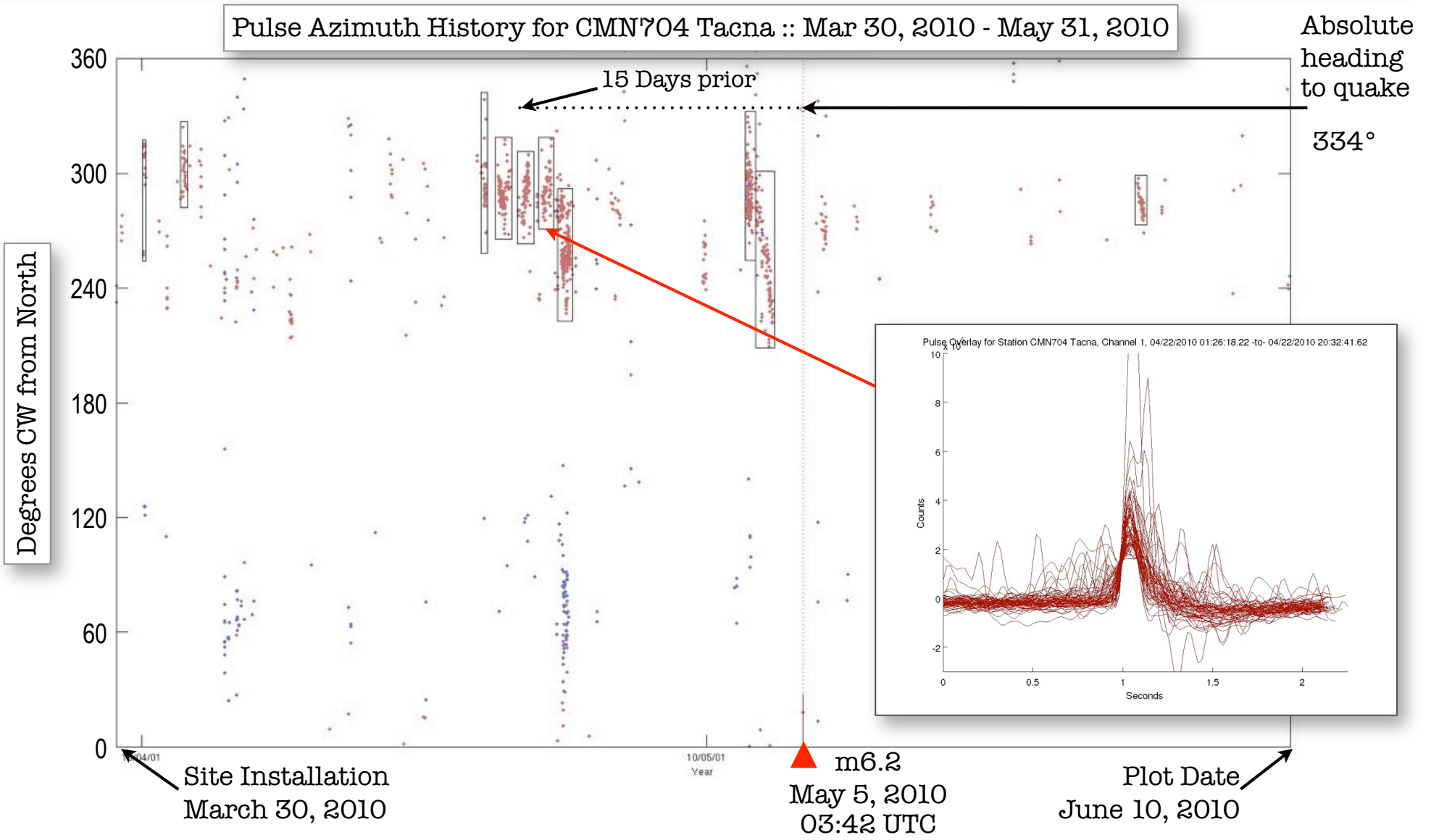

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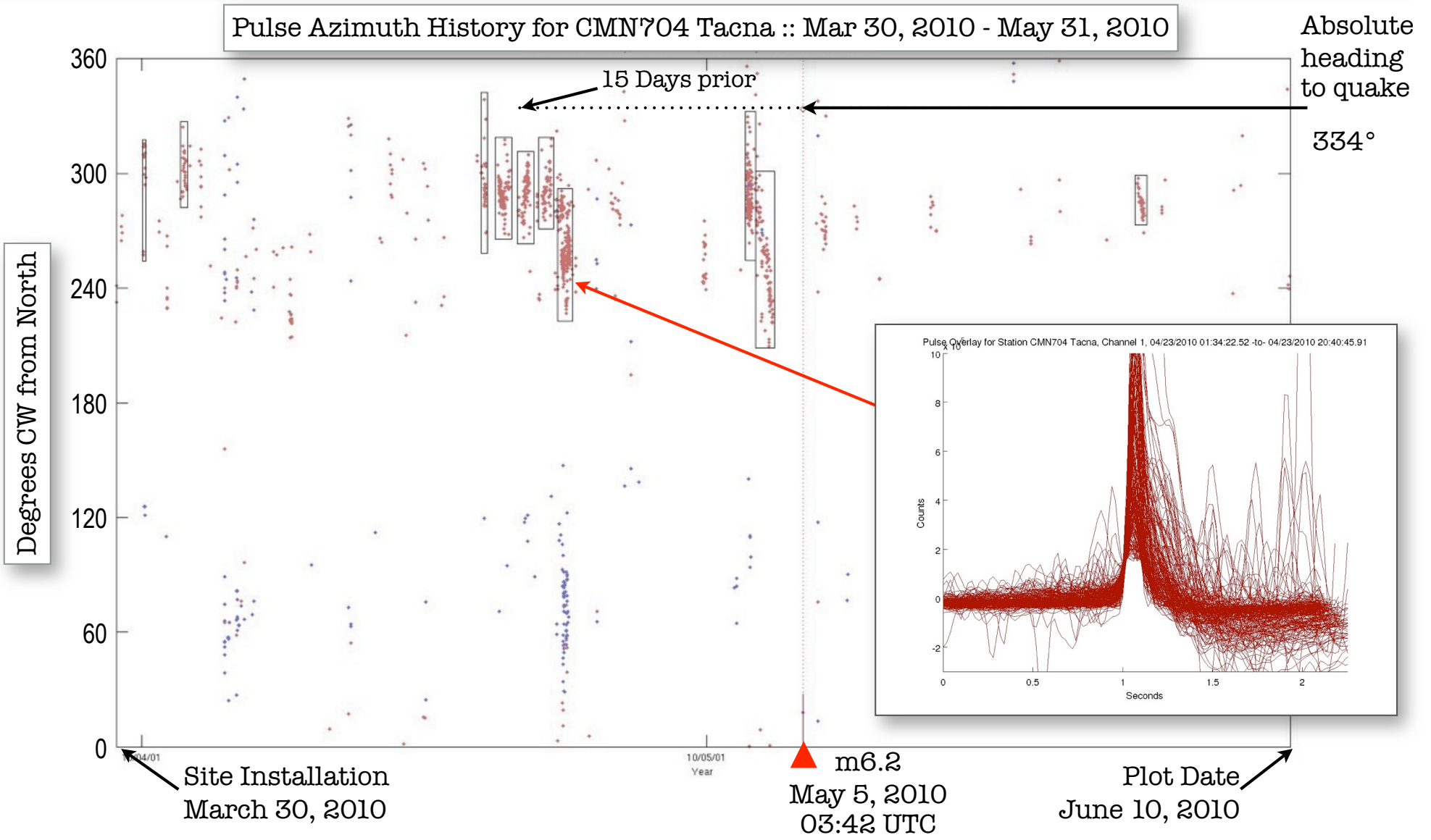

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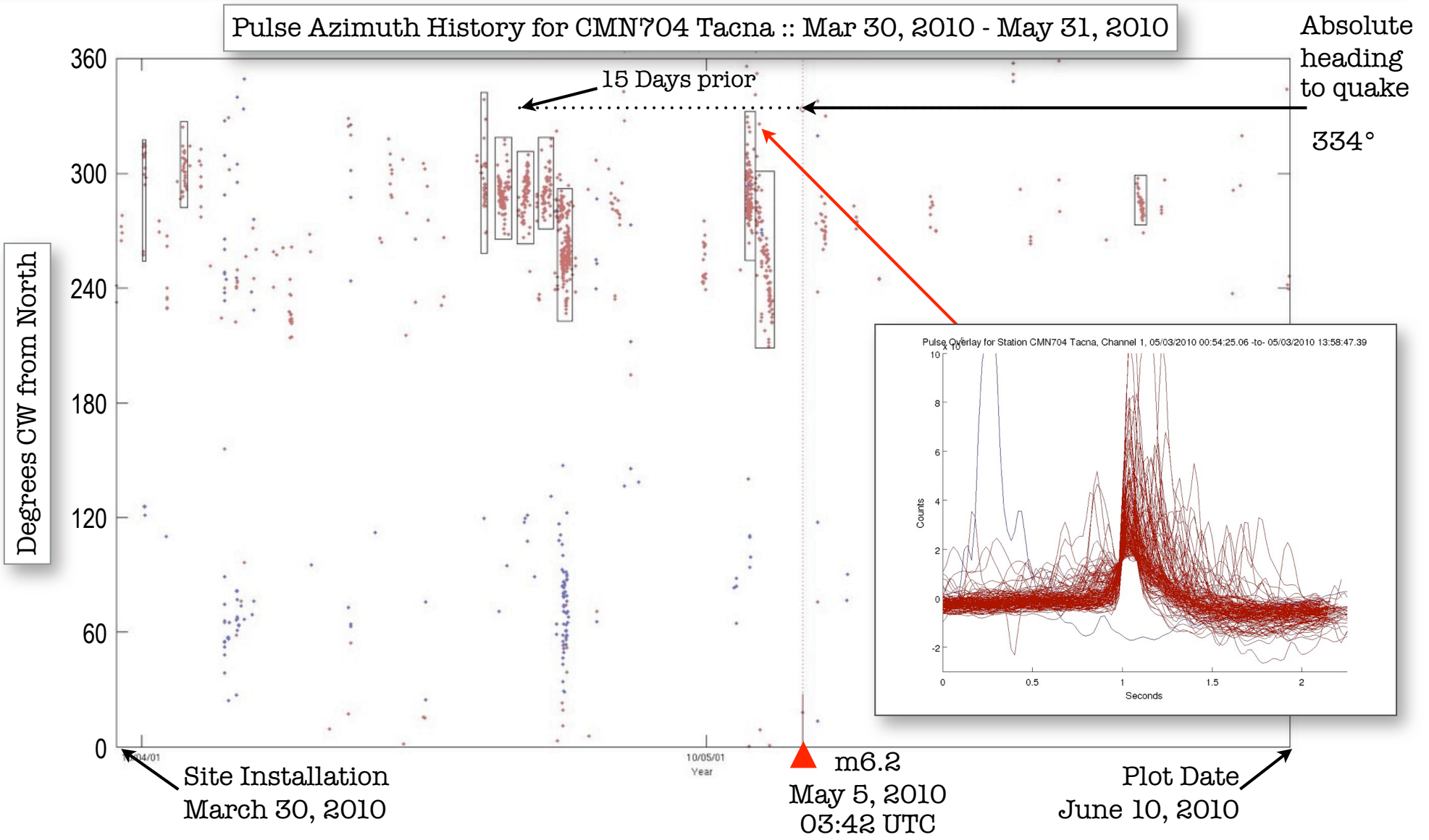

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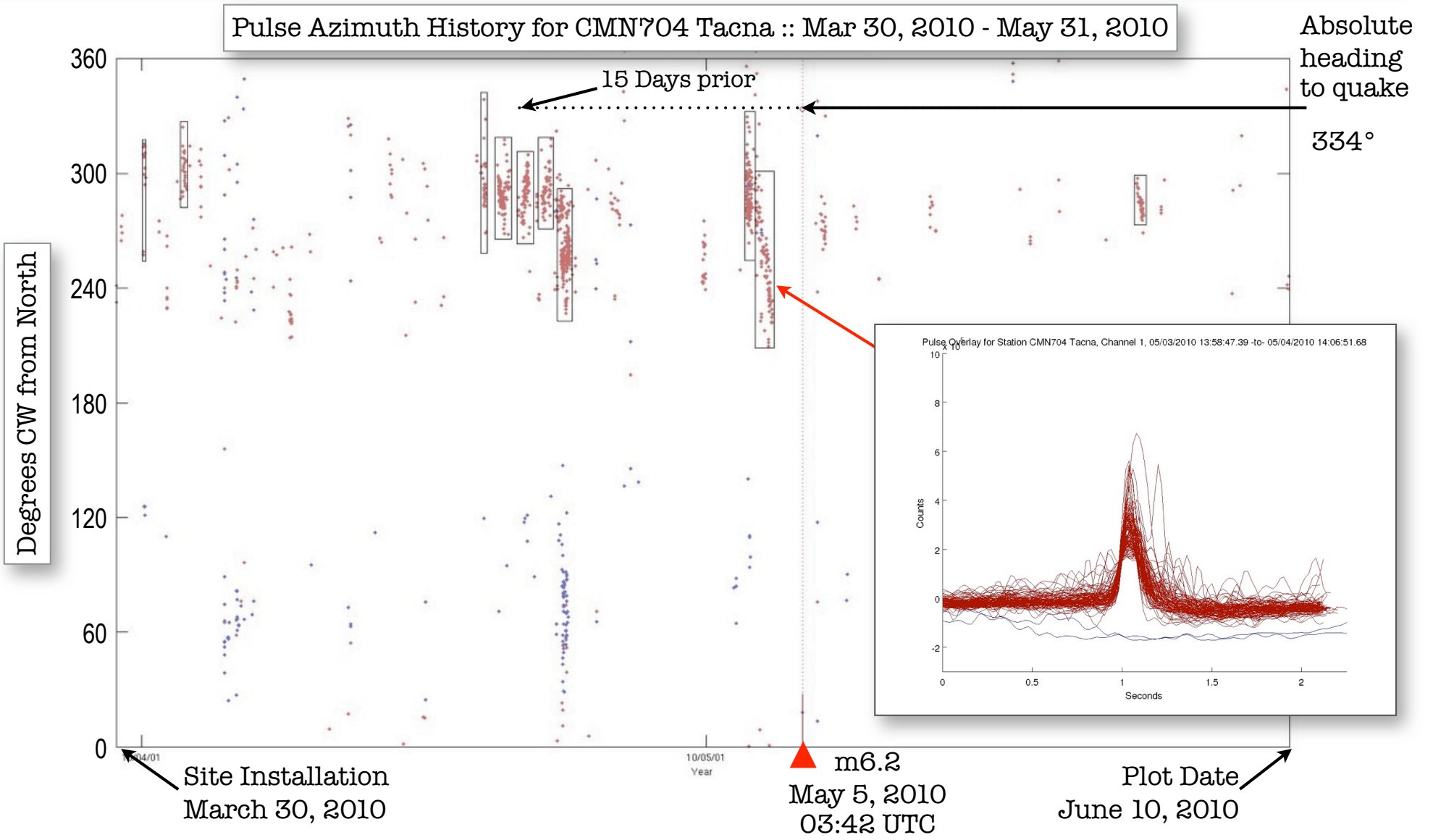

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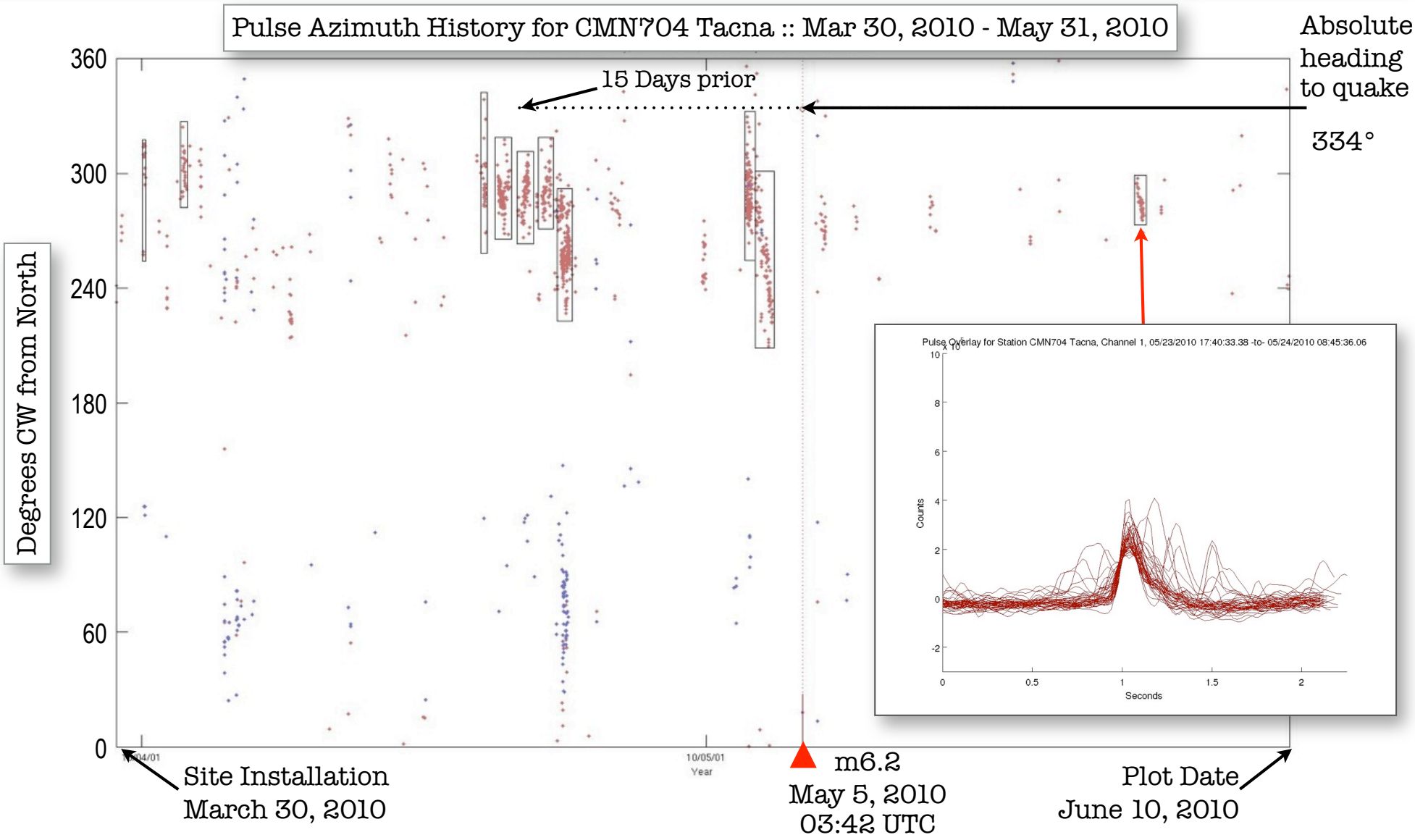

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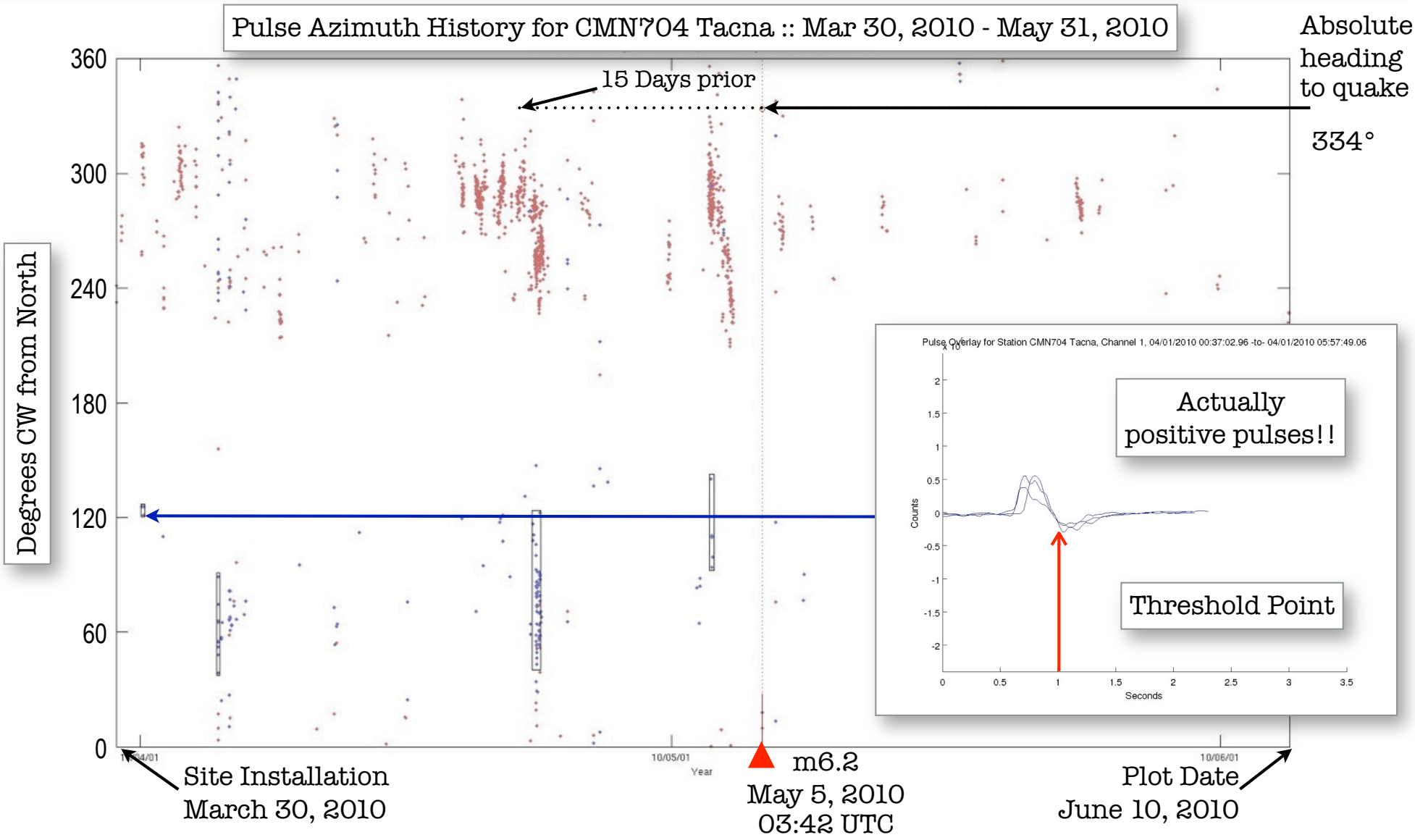

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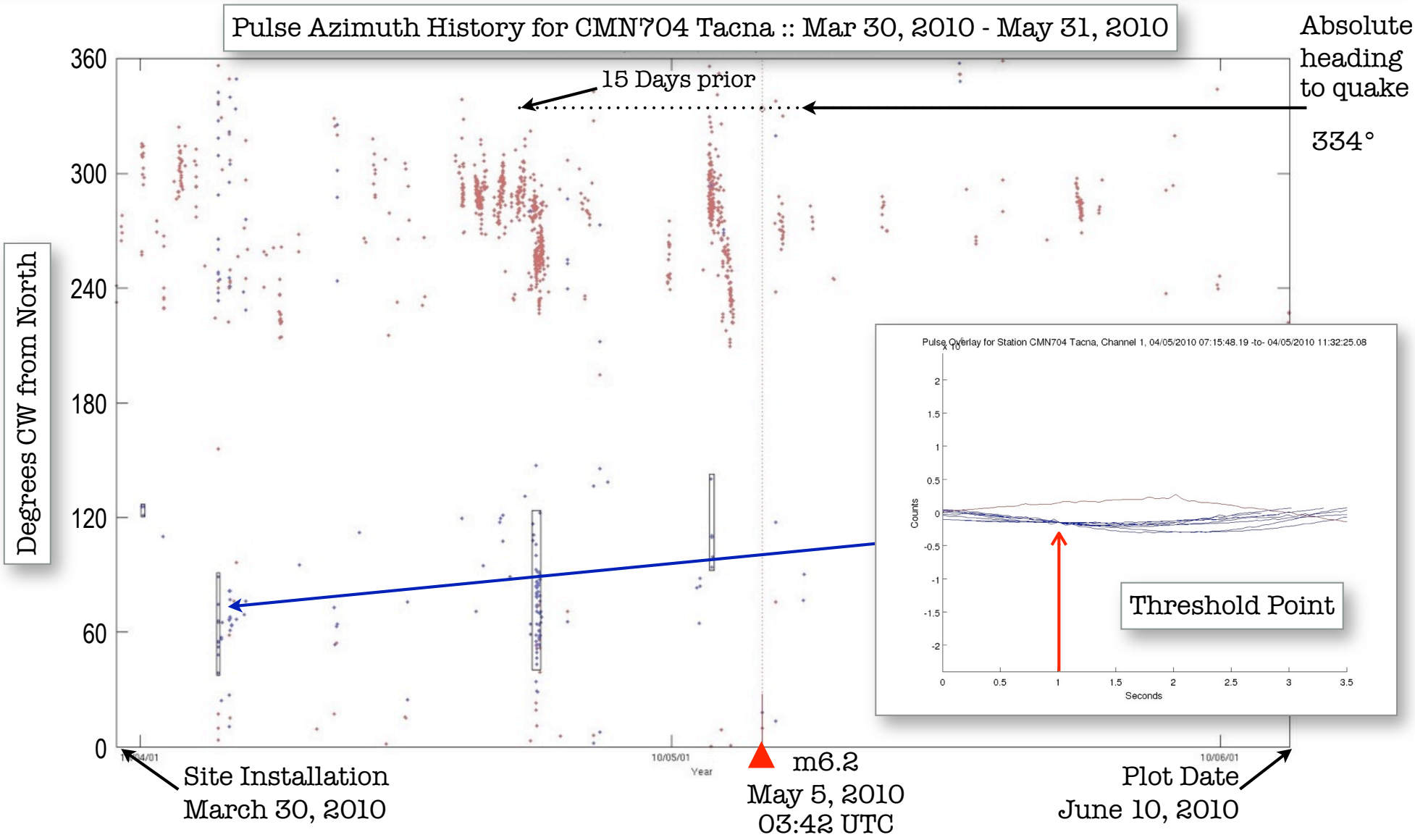

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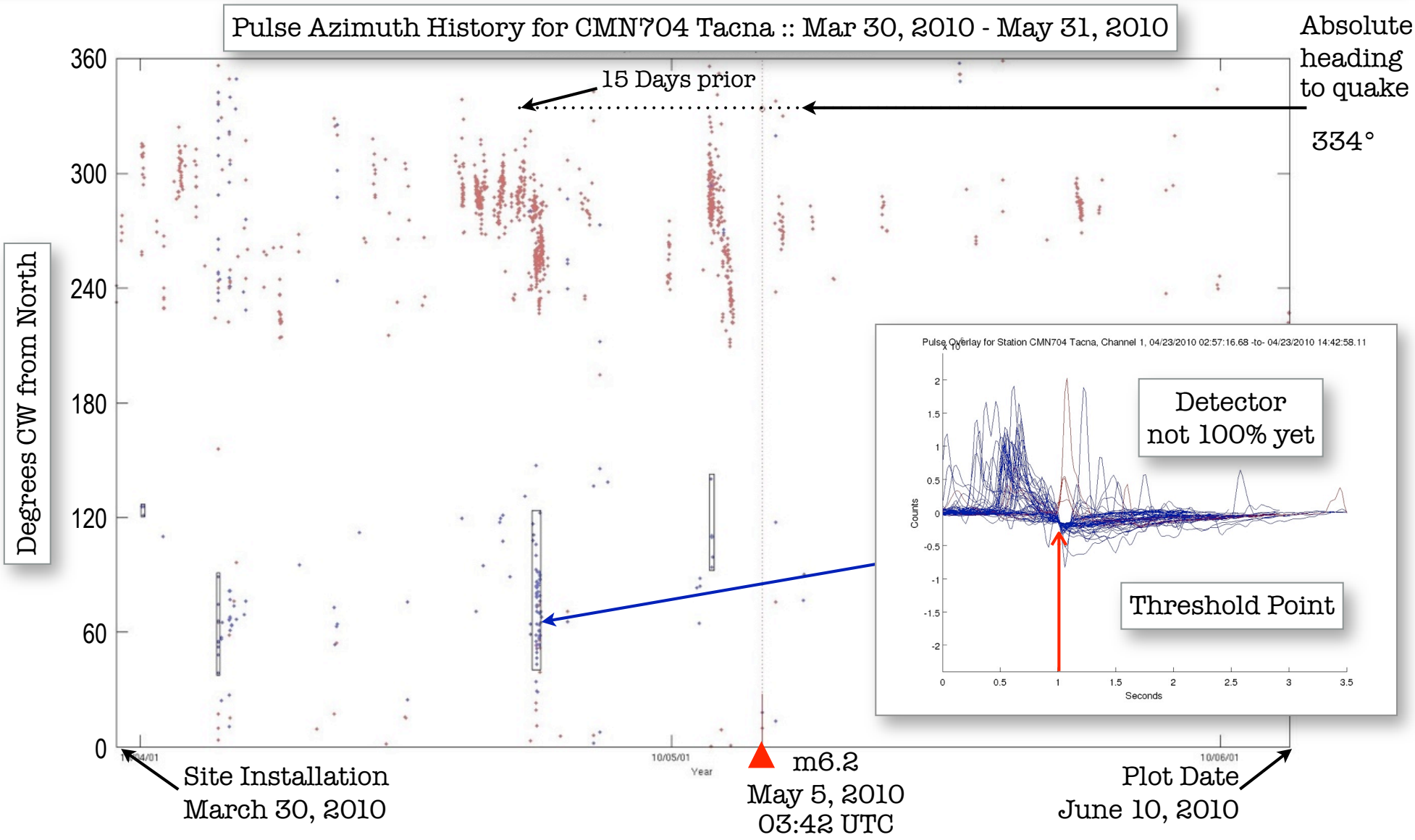

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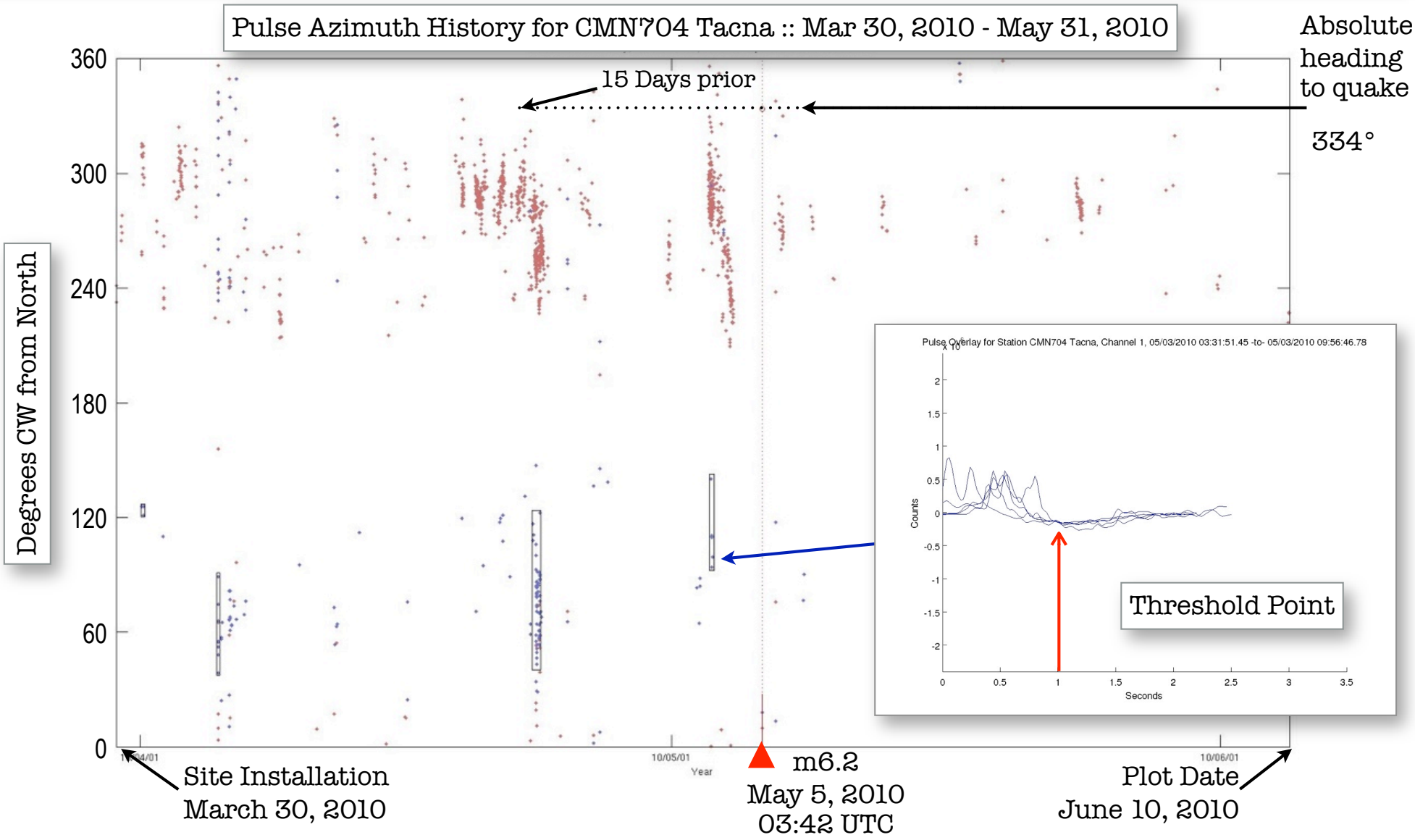
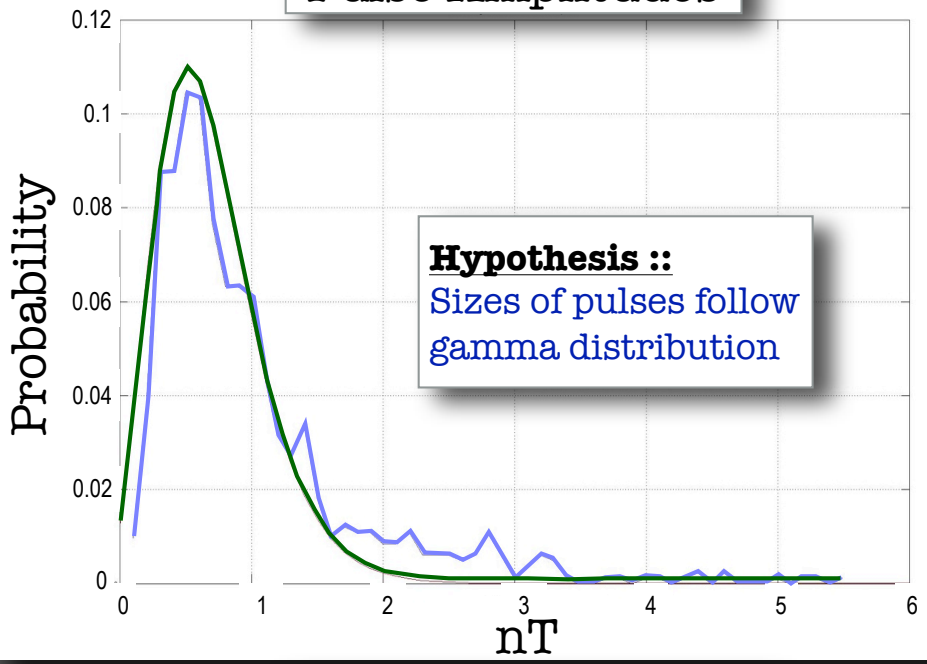
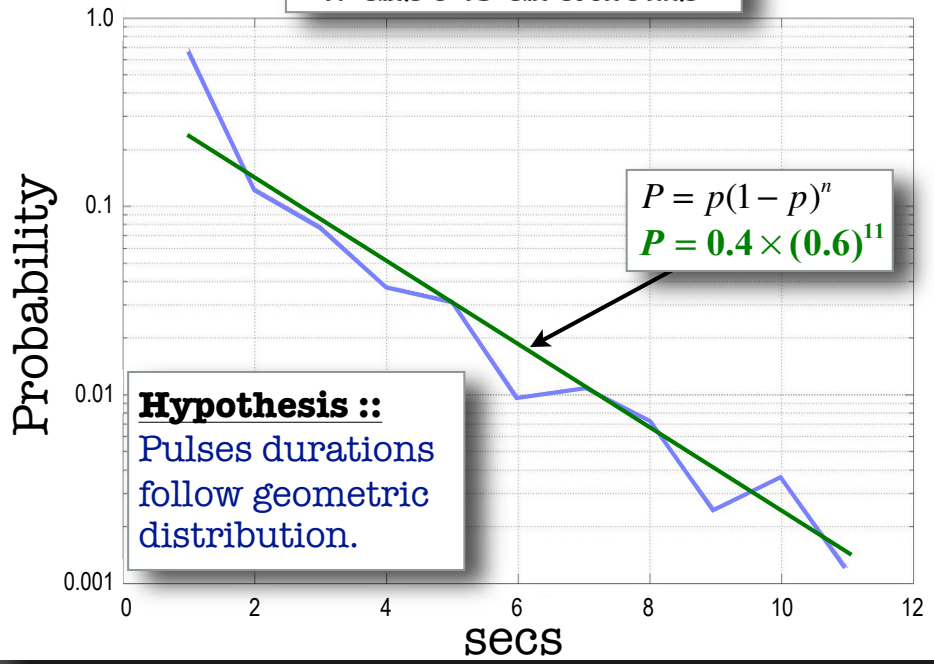


Tacna pulse properties

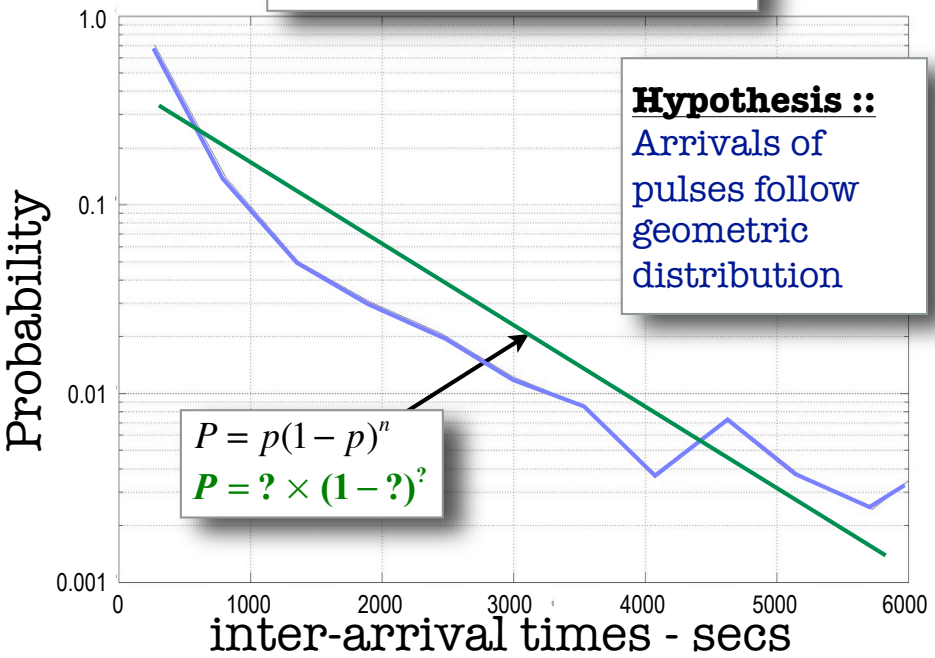
Pulse Amplitudes



Pulse Durations



Pulse Arrival Times

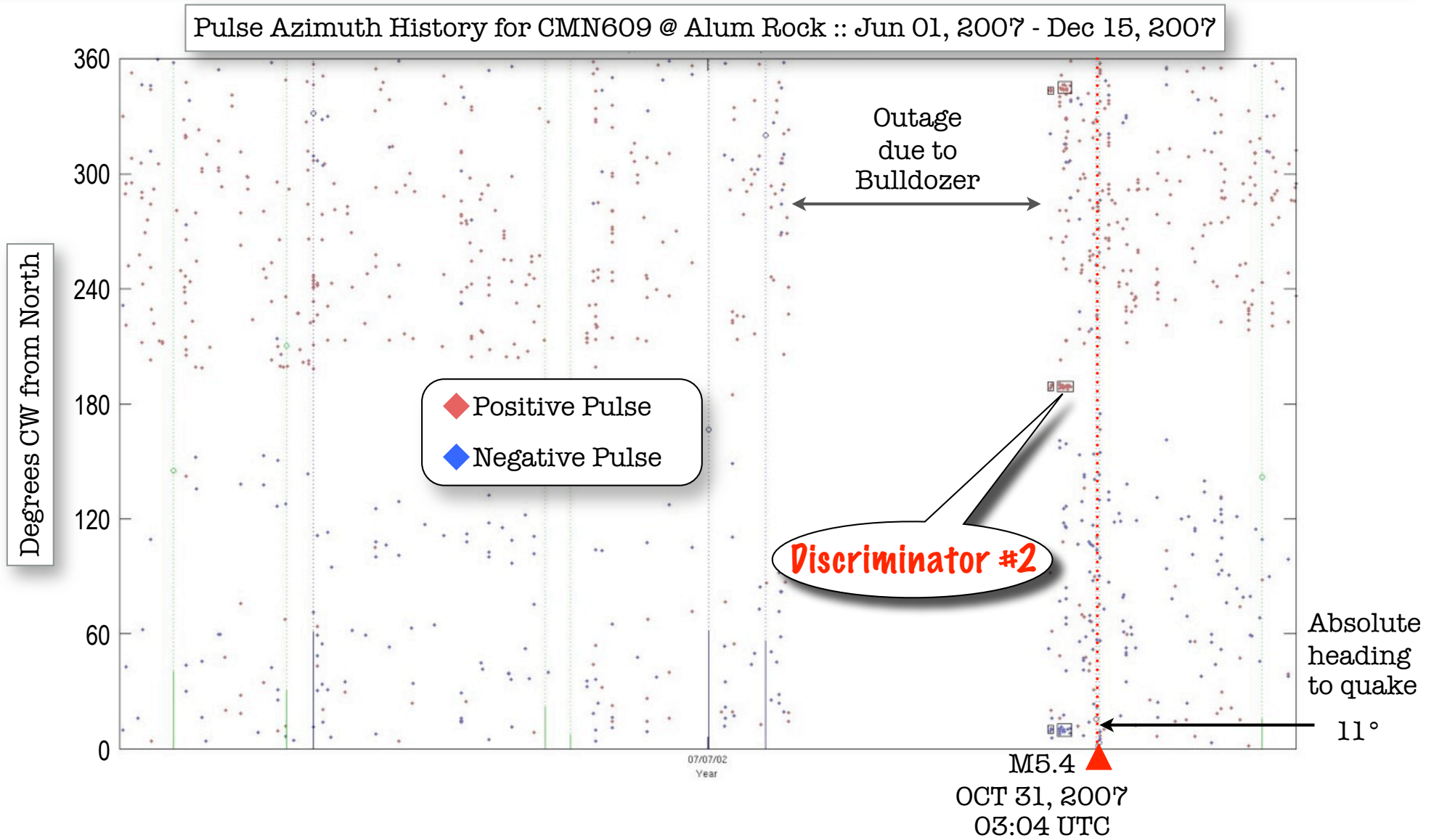


These are neither Gaussian or Periodic, but **Poisson-like** distributions, which supports the idea that the pulses are geophysical.

(The standard earthquake rate model is also based on Poisson statistics.)

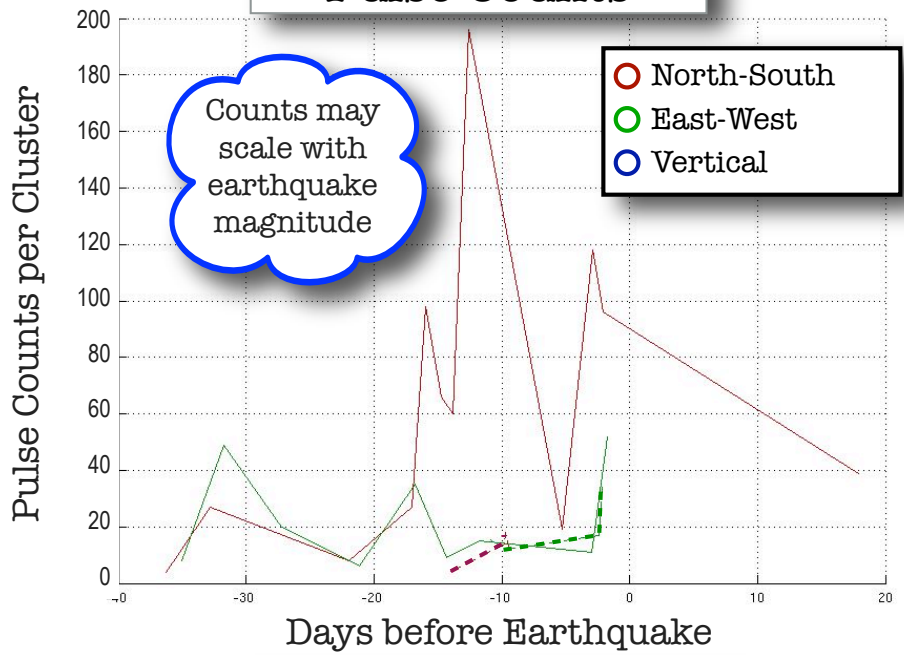
Review of Alum Rock Azimuths

Pulses are uni-polar, and they occur in groups, clustered in time and relative amplitude between orthogonal axes.

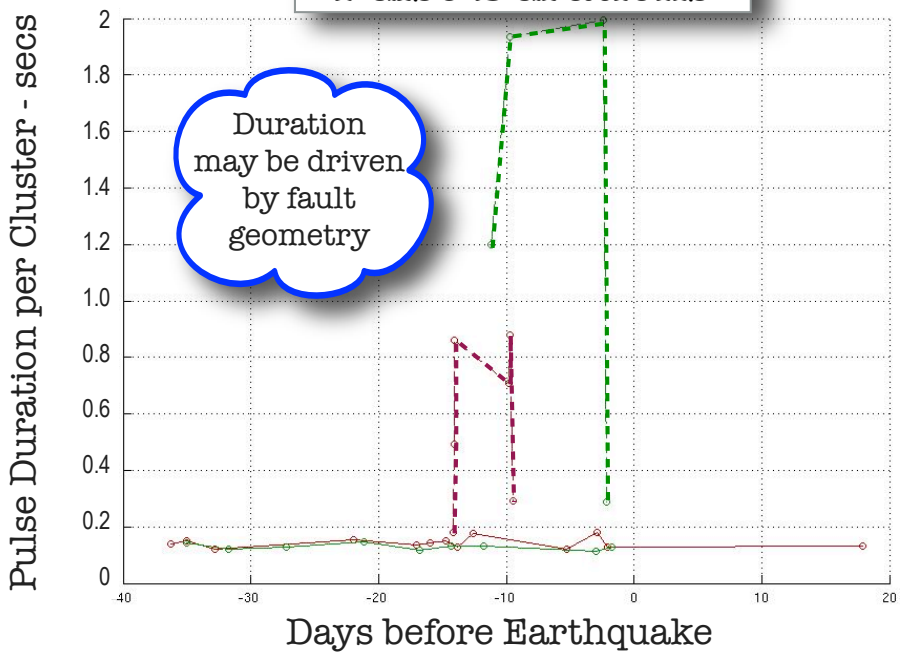


Tacna & Alum Rock pulses compared

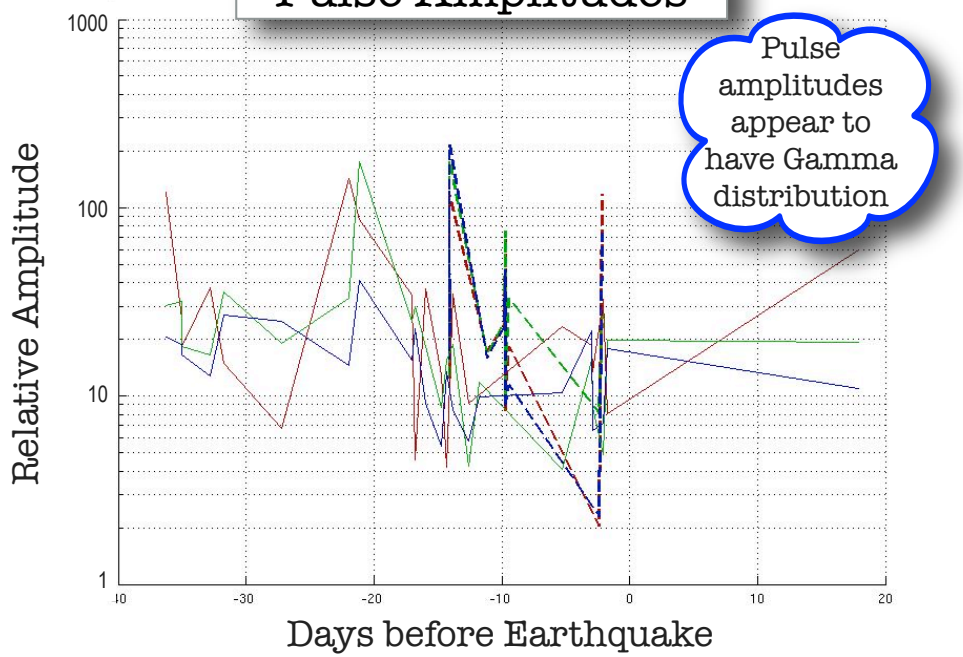
Pulse Counts



Pulse Durations



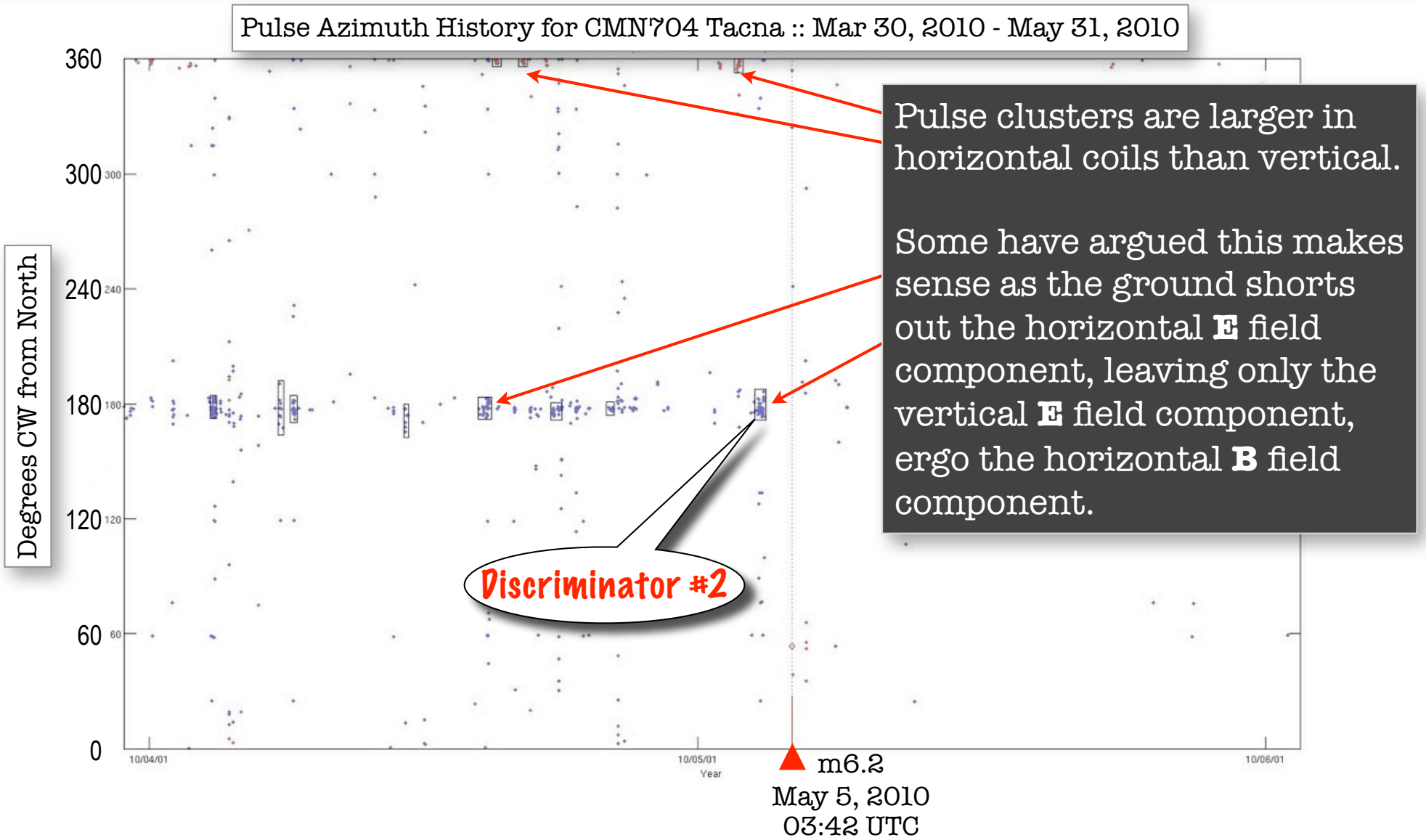
Pulse Amplitudes



Quake	Tacna (solid)	Alum Rock (dashed)
Size	m6.2	m5.4
Range	29.2 km	2.1 km
Depth	35 km	9.2 km
Pulse counts	higher	lower
Pulse durations	shorter	longer
Pulse amplitudes	smaller	larger

Vertical Channel Observations

Pulse clusters are also seen when computing 'azimuth' for Vertical/North-South and Vertical/East-West pairs of axes.



Pulse clusters are larger in horizontal coils than vertical.

Some have argued this makes sense as the ground shorts out the horizontal **E** field component, leaving only the vertical **E** field component, ergo the horizontal **B** field component.

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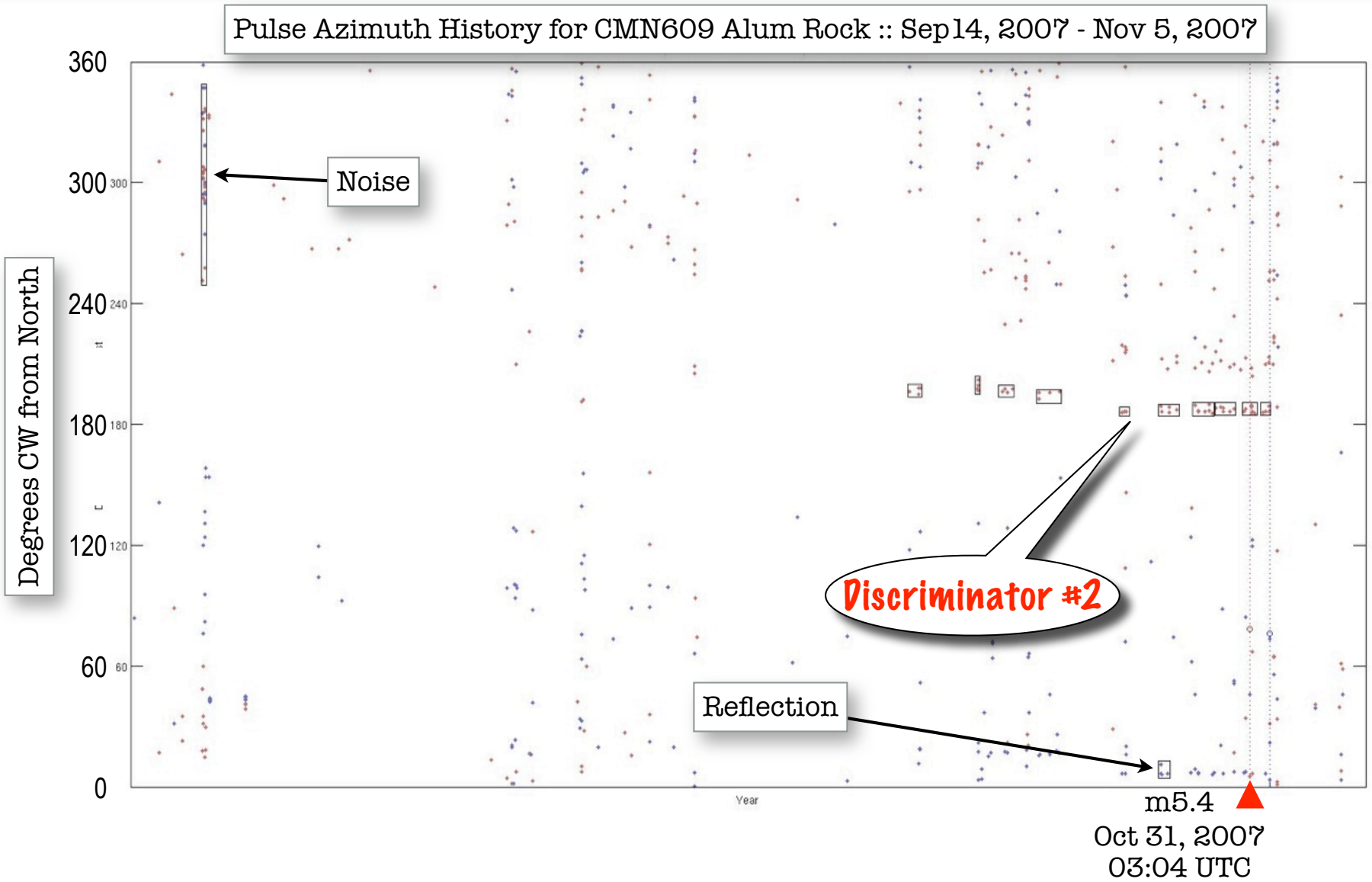
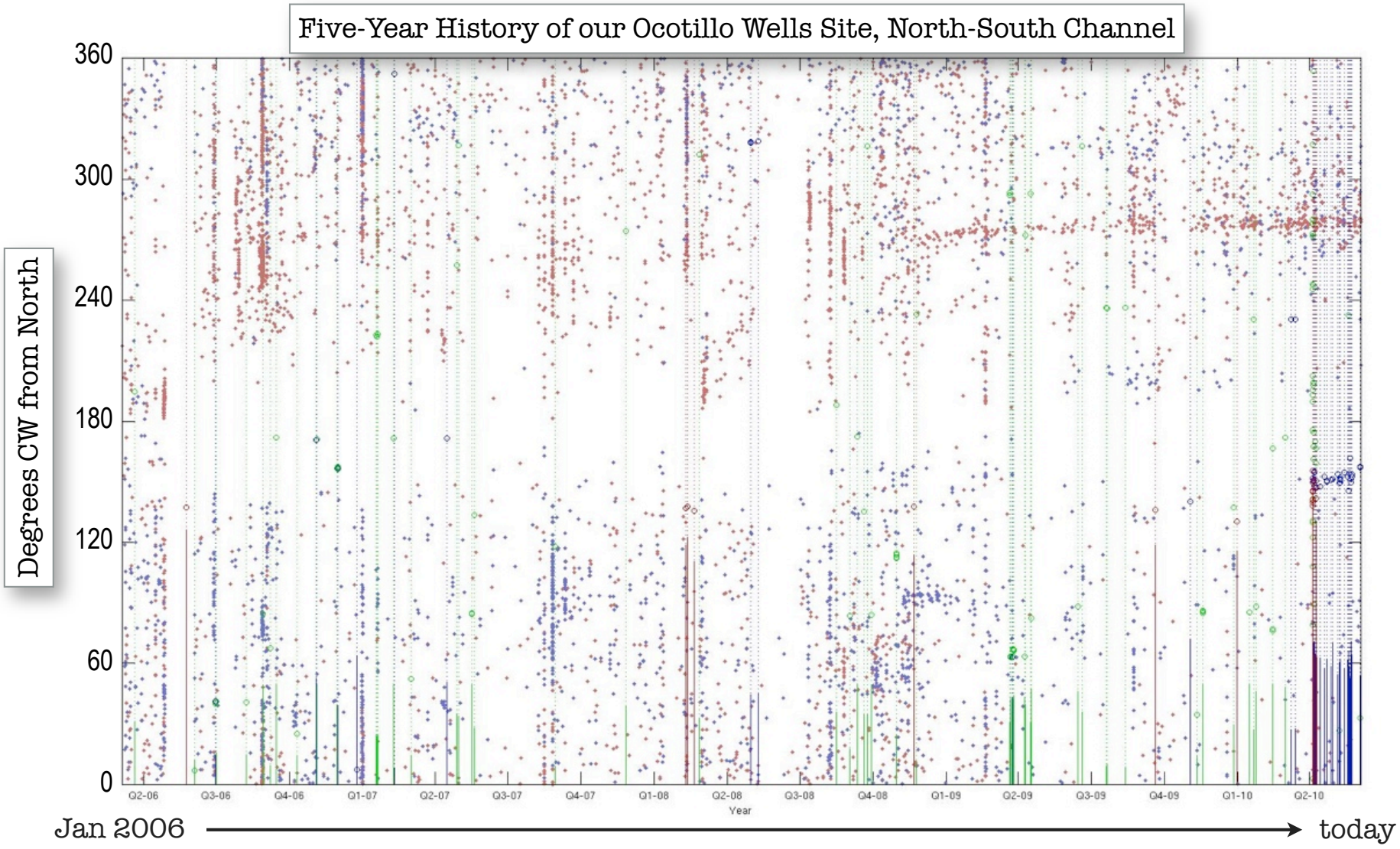


The Bigger Picture

A cursory review of the history of pulses in the remainder of our data sets reveals many azimuth pulse clusters.



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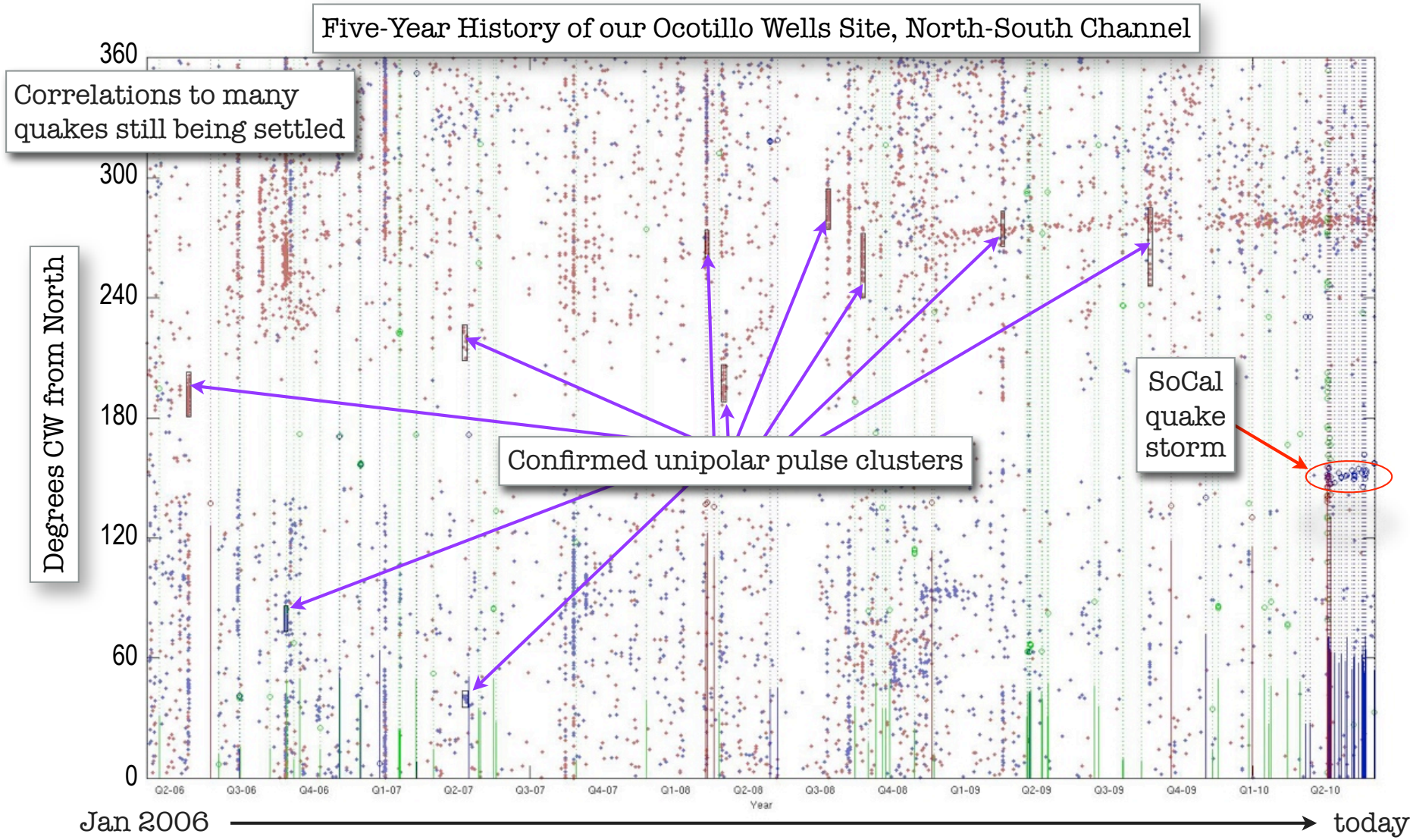
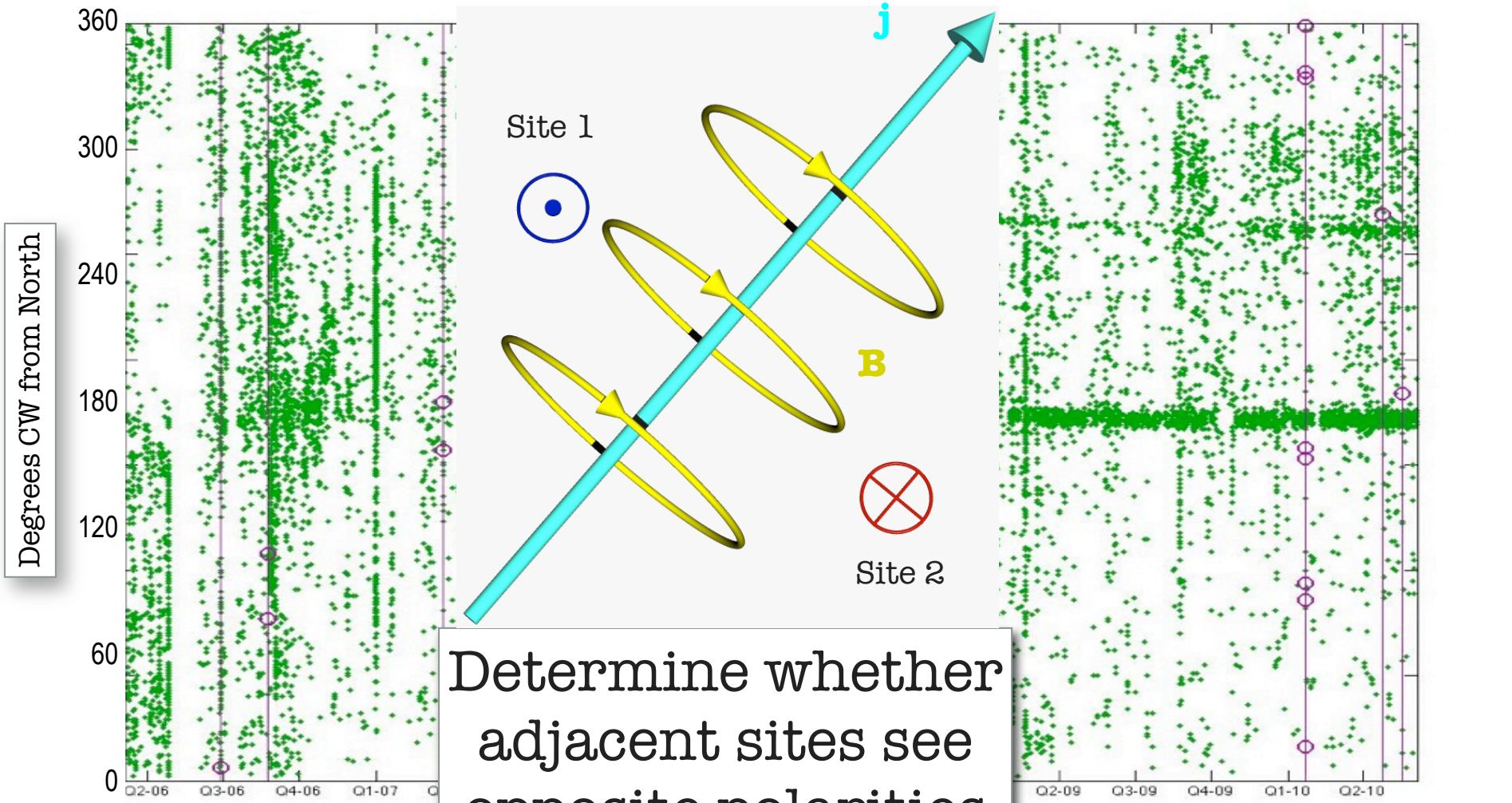


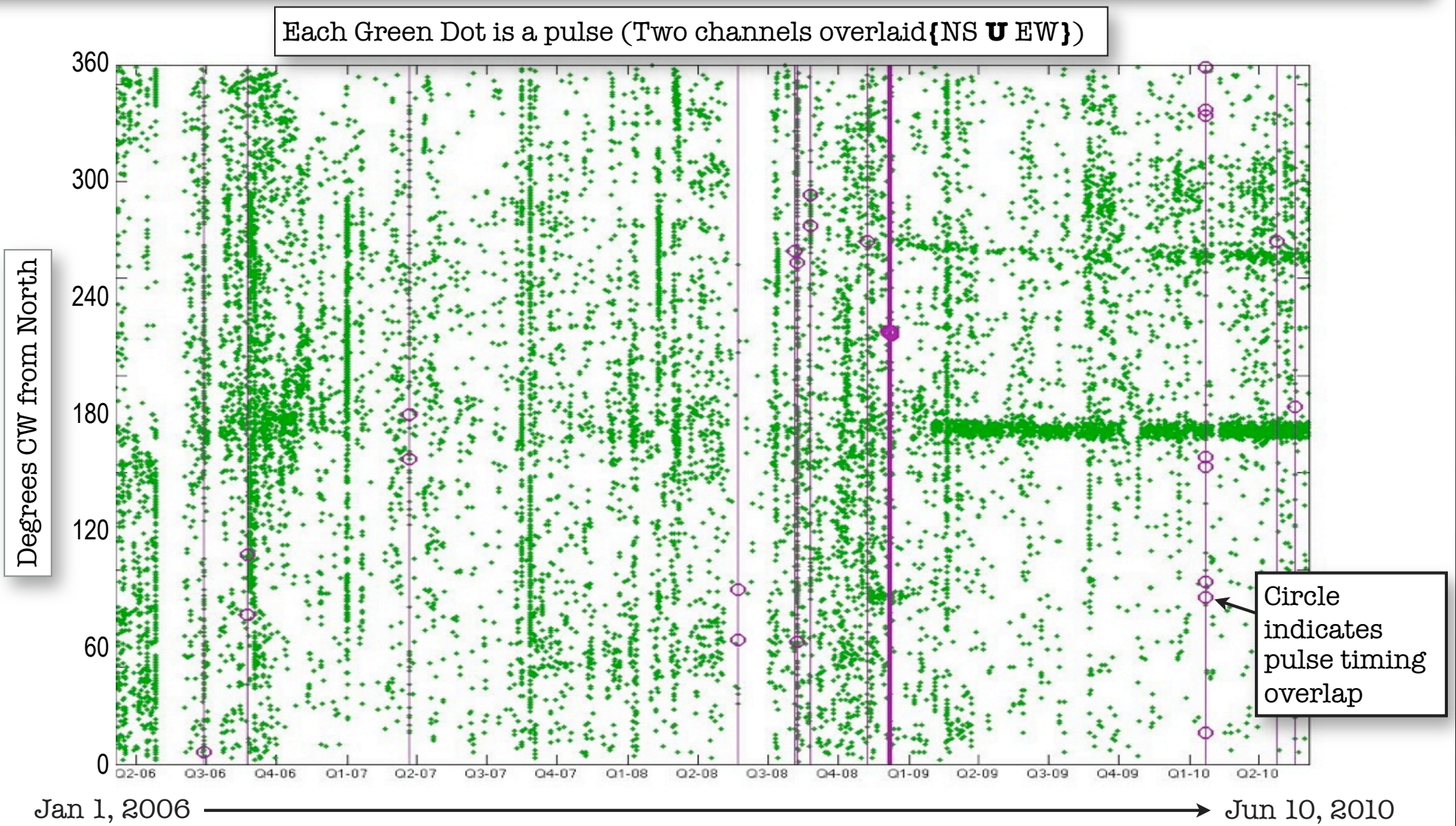
Mutual Observations

A review of pulses at two sites 43 Km apart reveals very few mutual observations of pulses, and underscores the plan for ~200 sites in California.



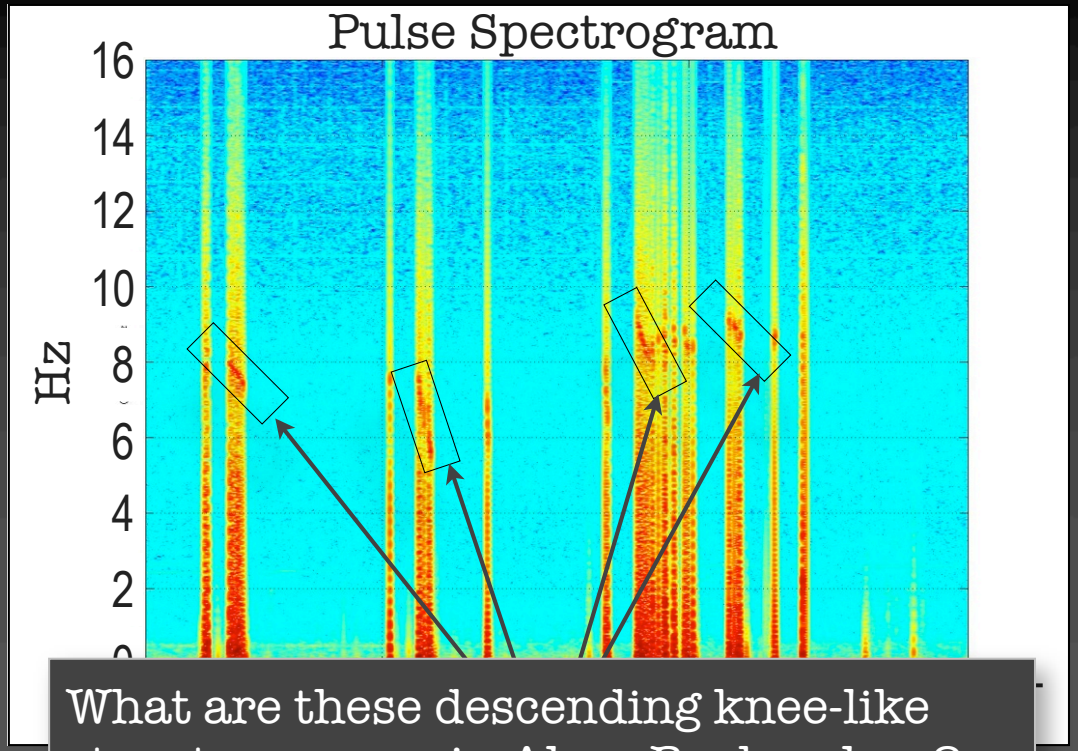
Mutual Observations

Only 74 out of 14995 pulses overlap in two sites 43 Km apart, suggesting that these pulses are local and not ionospheric.

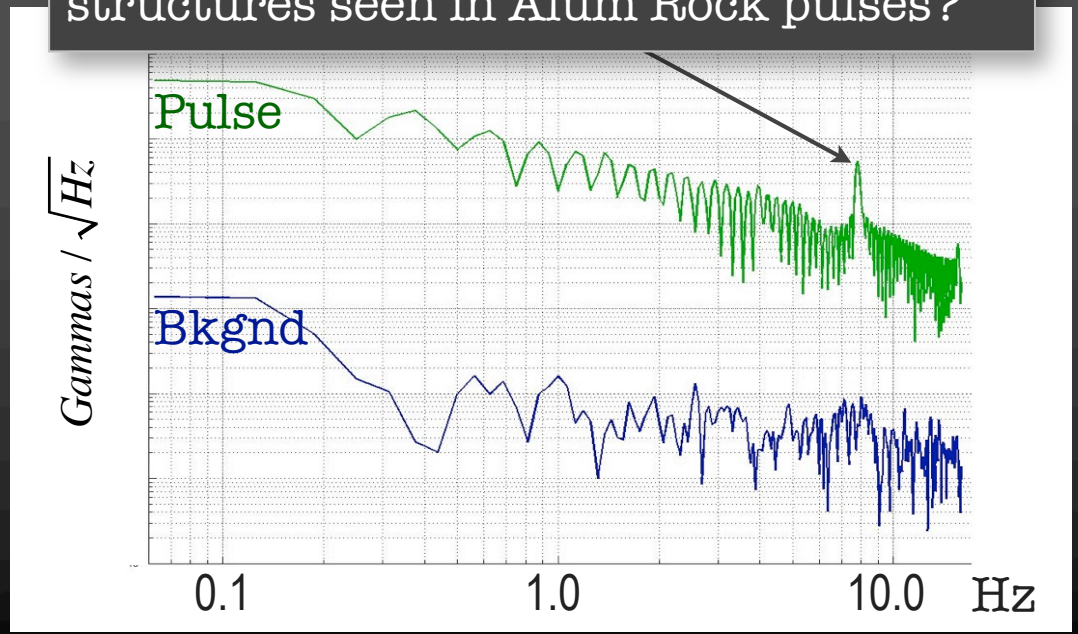


Open Questions

- Are pulses related to earthquakes?
- Why pulse azimuth clusters?
- Are clusters local?
- What is their Observable Range?
- Are clusters ever bi-directional?
- Do pulses scale with earthquakes?
- Induced in STS1 & 2 seismometers?



What are these descending knee-like structures seen in Alum Rock pulses?



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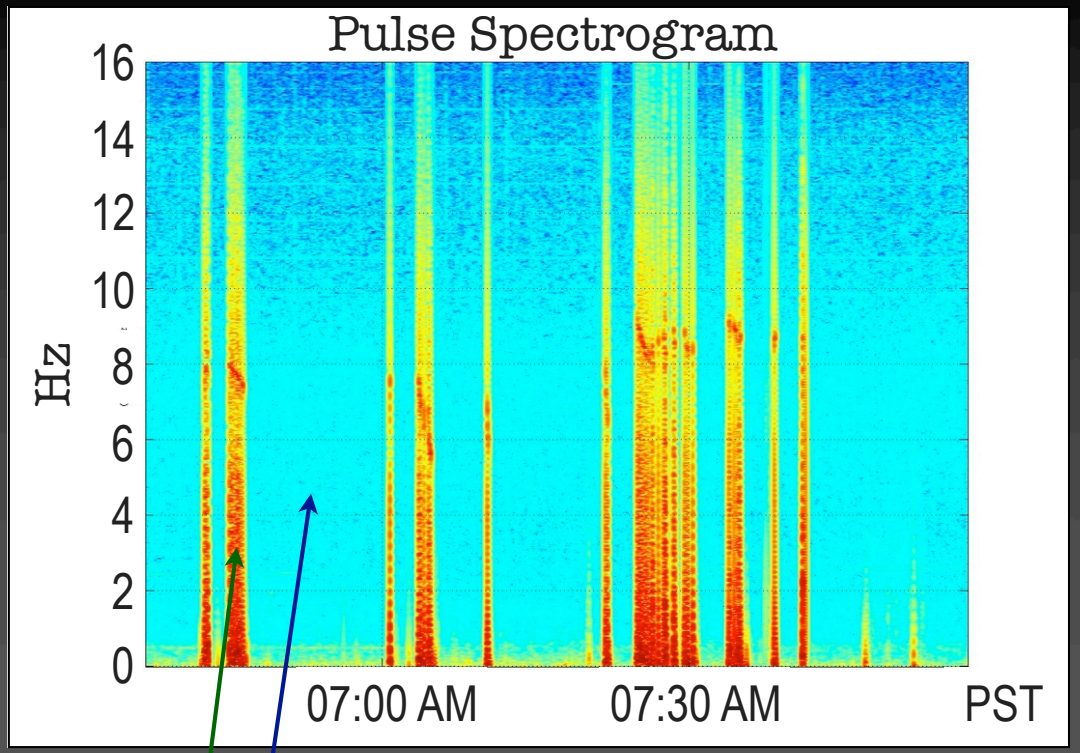
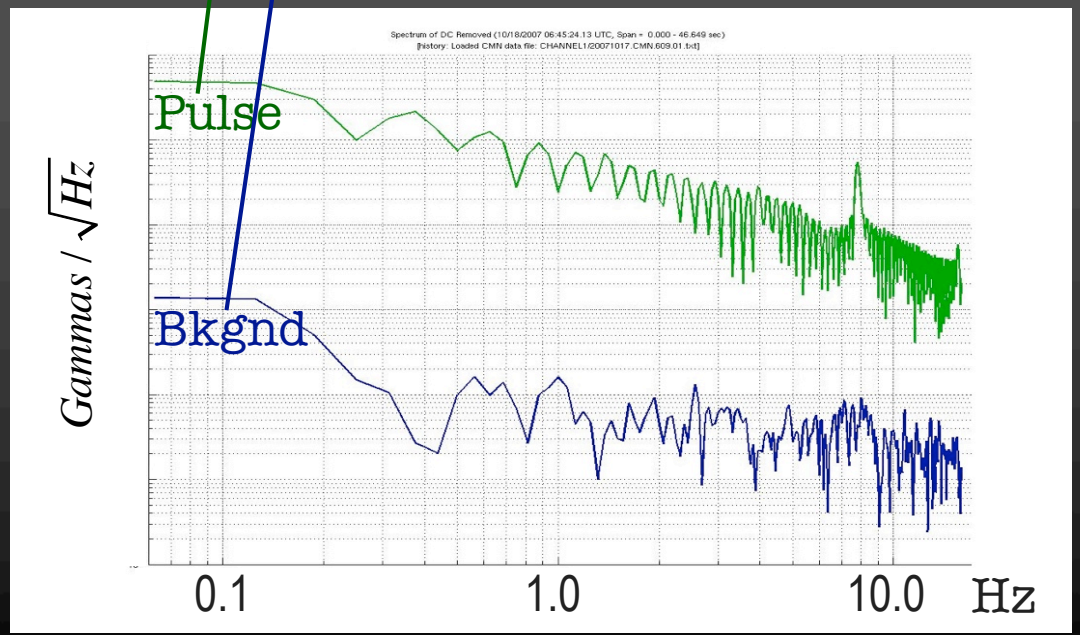


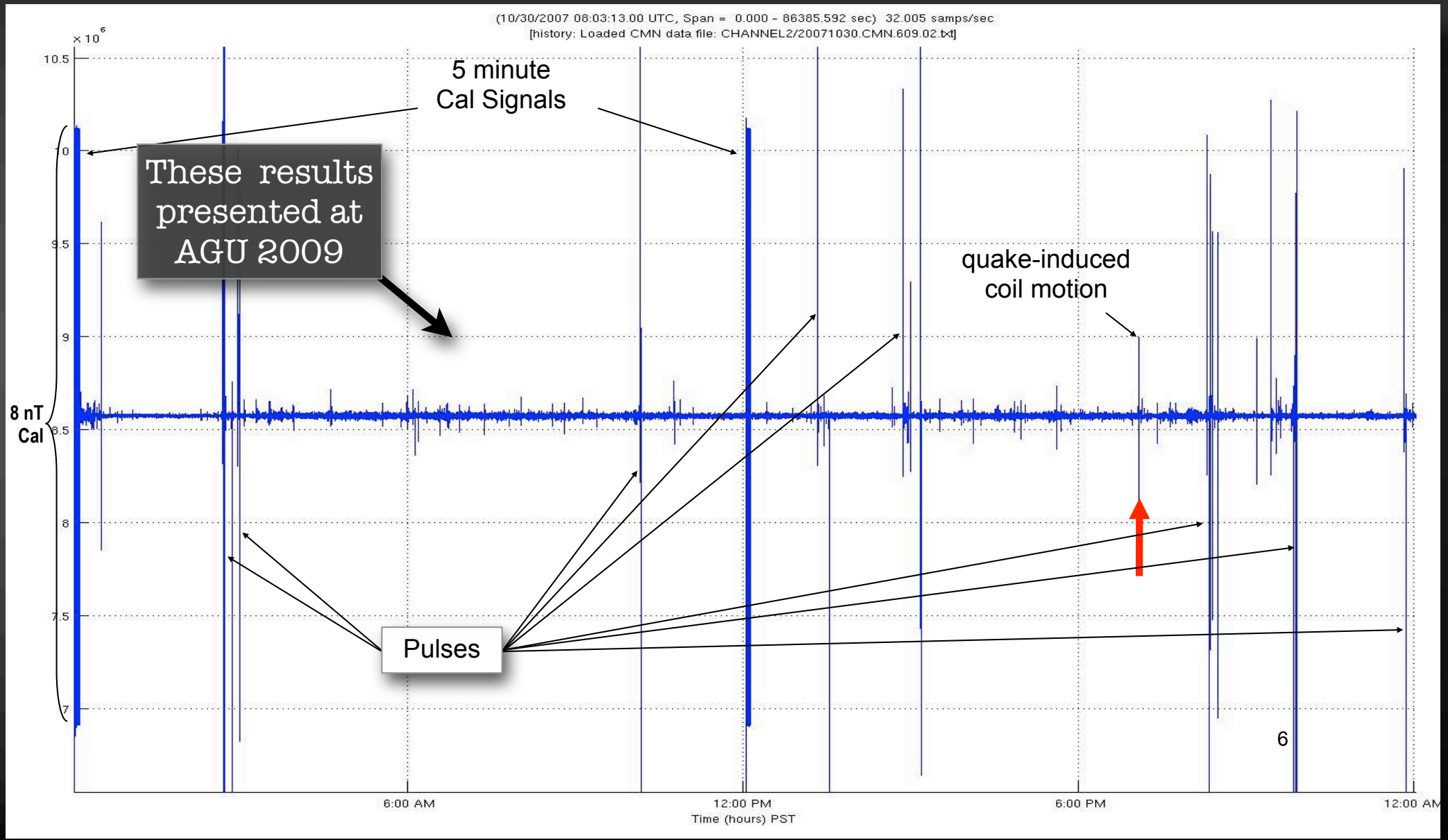


Observations

1. These powerful pulses are unlikely man-made.
2. If geophysical, they merit detailed further study.
3. Pulses and Clusters may be localized in nature.
4. Pulse counts increase before both quakes.
5. Azimuth Clusters seen ~14 days before both quakes.
6. Azimuth Clusters may have Poisson-like properties.
7. Amplitude ratios repeat in orthogonal axes.
8. Pulses are unipolar, as in charge migration.
9. Pulses are short in duration, but large in size.

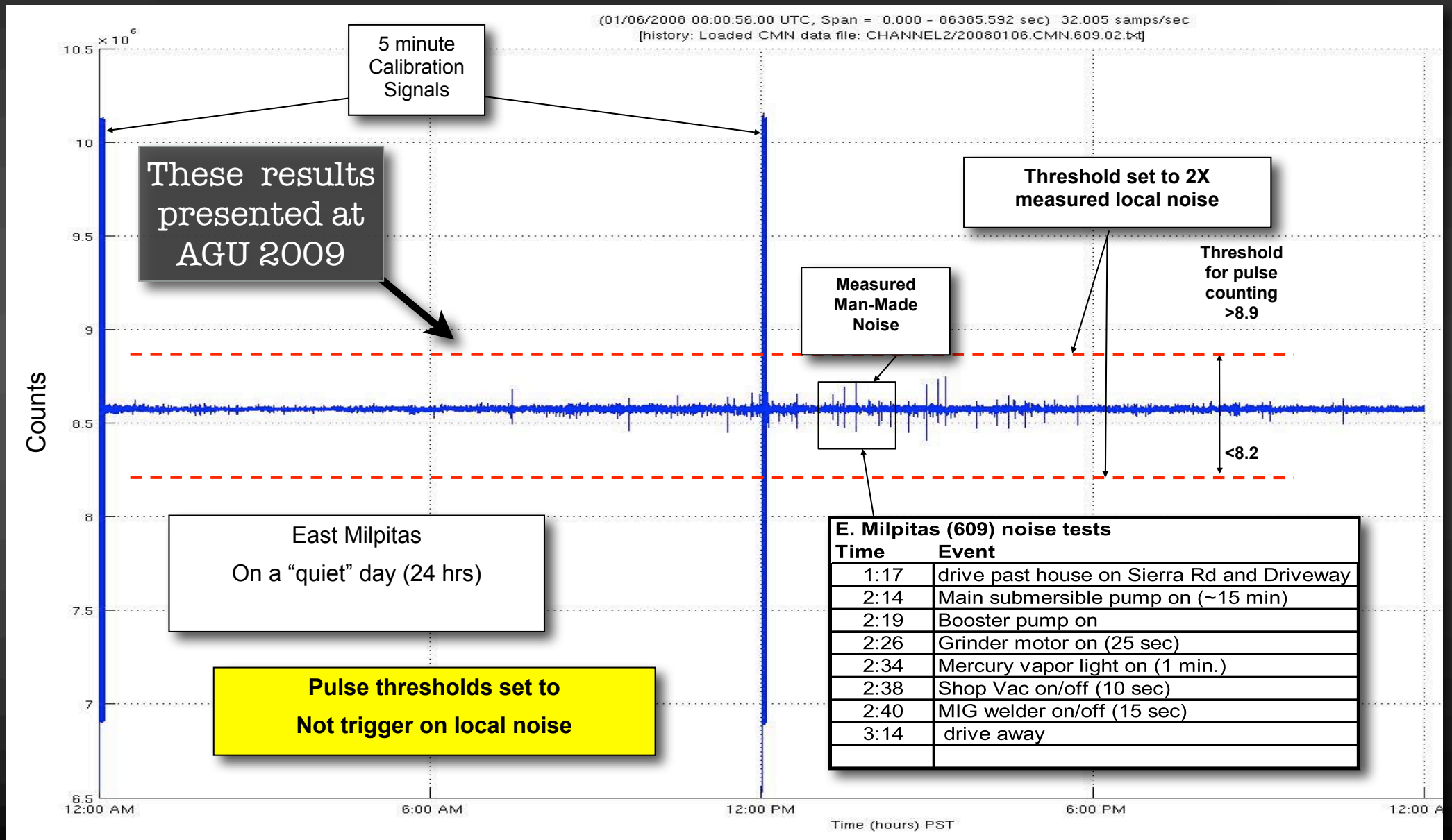
Discovery of Pulses

Pulses were extremely large, and exhibited complex dispersion characteristics.



Discovery of Pulses

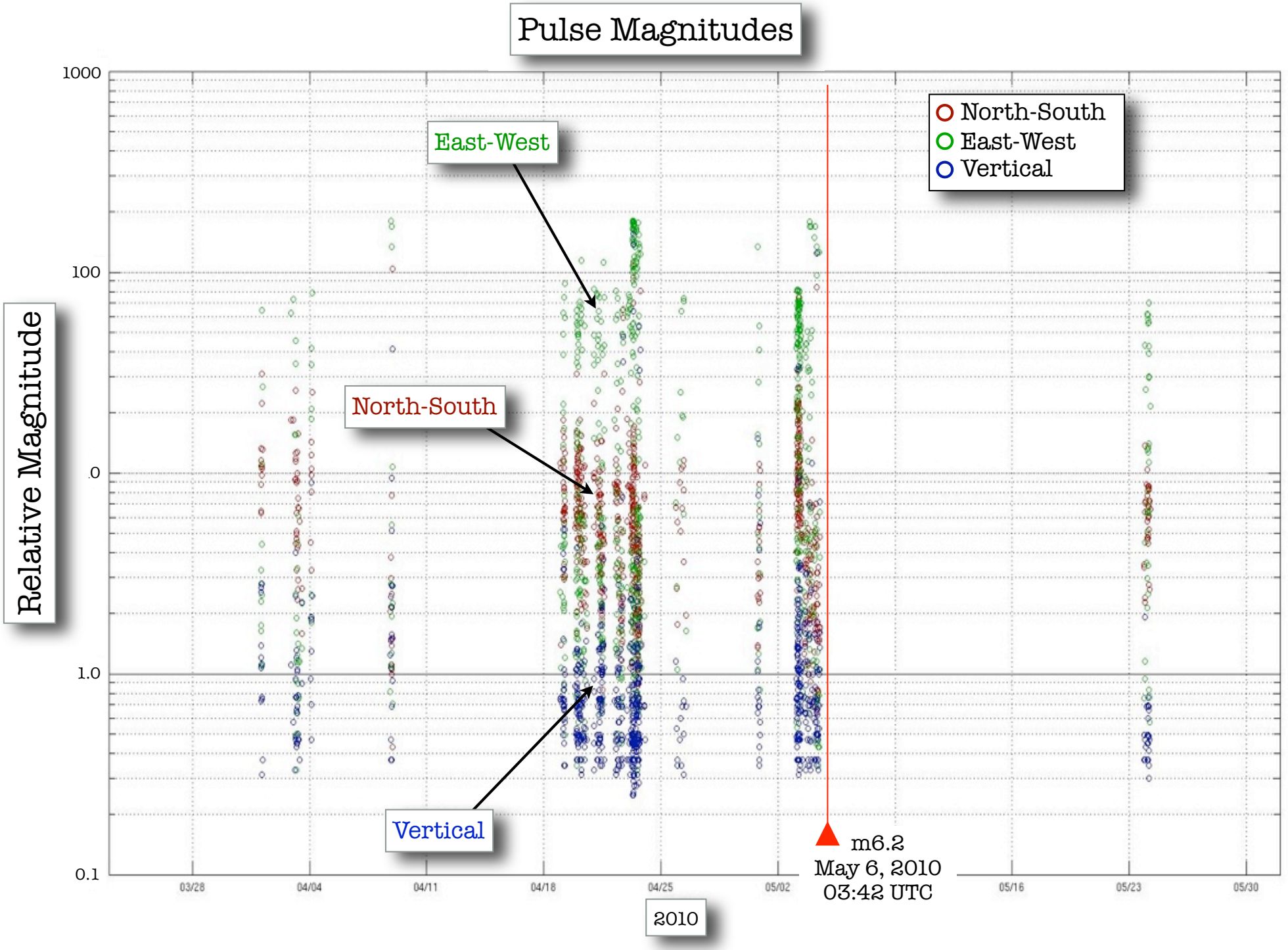
Algorithm Used:
Use a threshold for "Man-Made noise"



E. Milpitas (609) noise tests

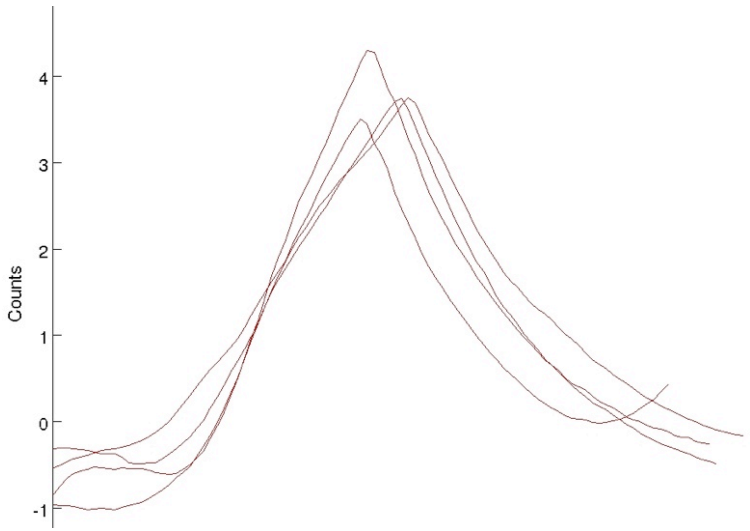
Time	Event
1:17	drive past house on Sierra Rd and Driveway
2:14	Main submersible pump on (~15 min)
2:19	Booster pump on
2:26	Grinder motor on (25 sec)
2:34	Mercury vapor light on (1 min.)
2:38	Shop Vac on/off (10 sec)
2:40	MIG welder on/off (15 sec)
3:14	drive away

Tacna, Peru pulse magnitudes

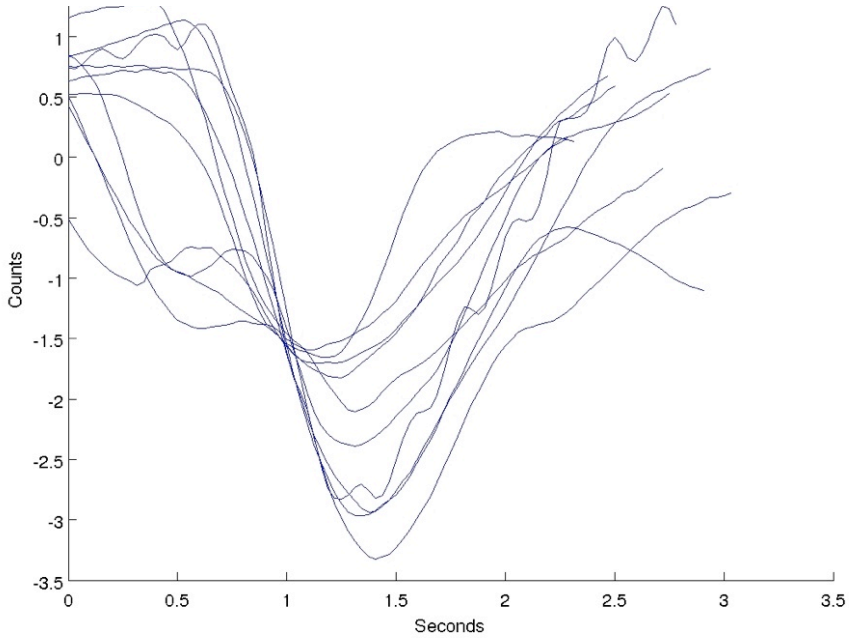


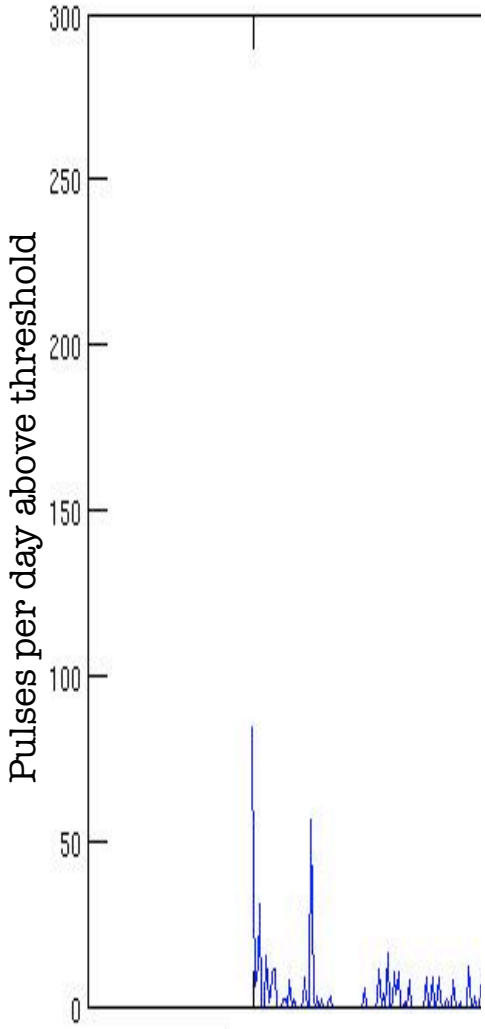
Pulse d complex

positive pulses



negative pulses





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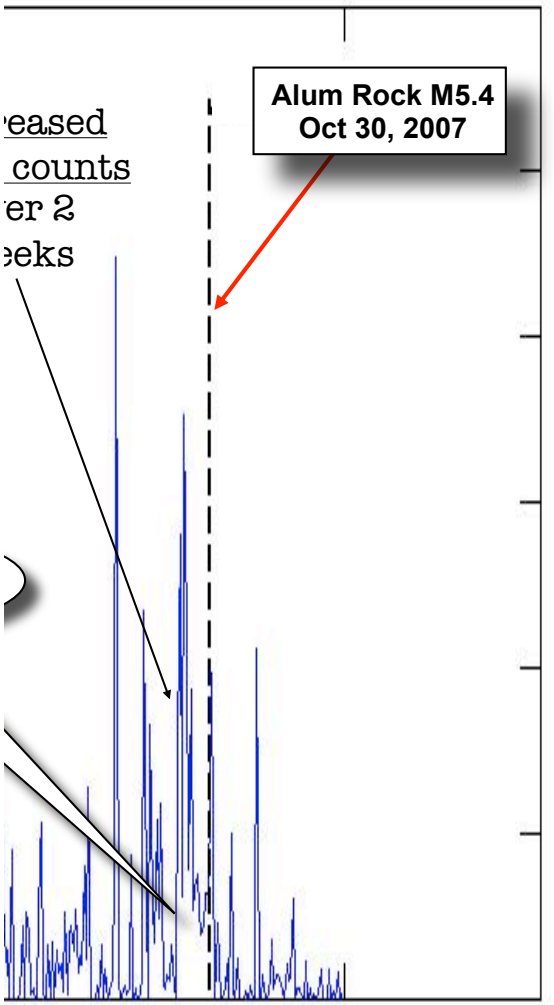

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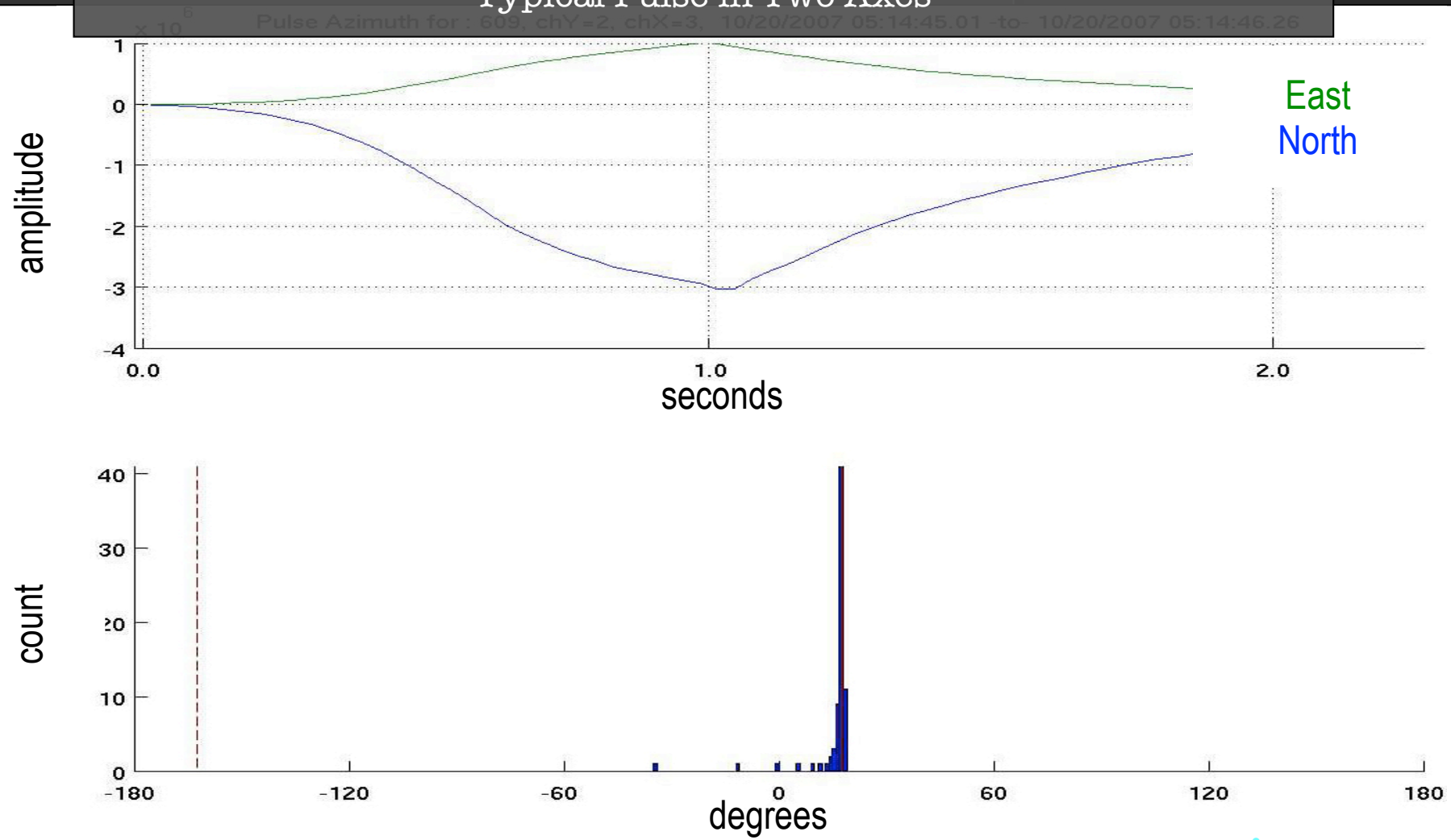
The Pulse Azimuth Effect

Unipolar pulses can be caused by charge migration.

Hypothesis: Freund currents are the source.

Typical Pulse in Two Axes



Azimuth Histogram

Epi-Center

Fault

j_1 j_2 j_3

Alum Rock pulse spectrogram