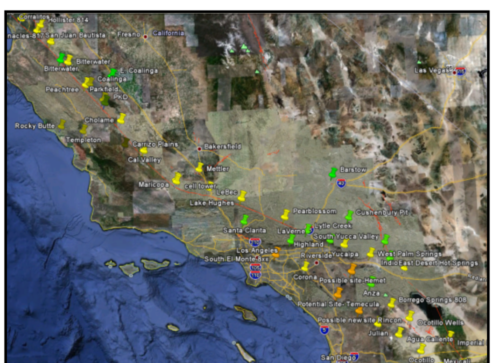
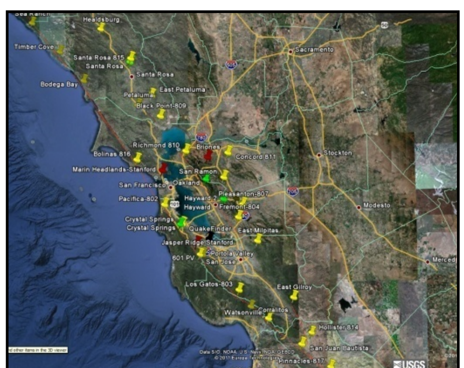
# QuakeFinder: 2011

## Multiple Electromagnetic Pre-Earthquake Indicators



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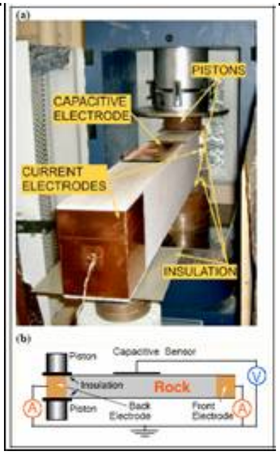
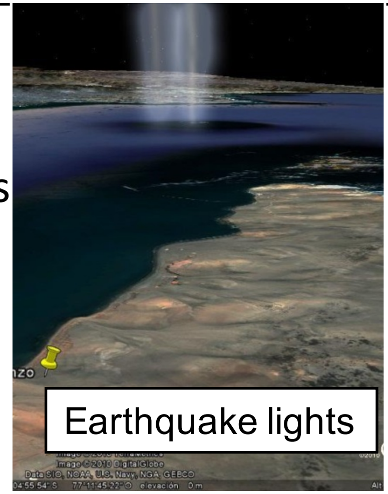
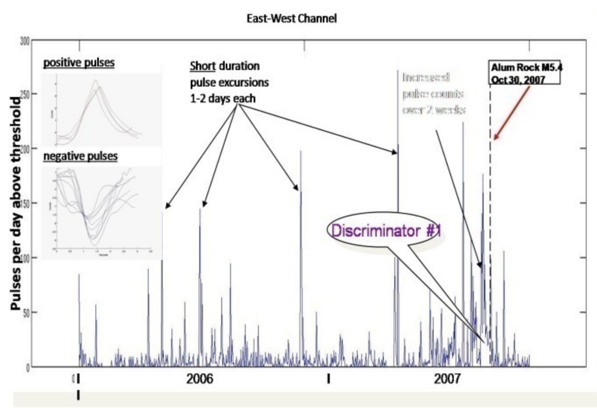
# Reasonable Hypothesis to Explain EM Signals?

Data




Small Currents
IR
Air Conduct.




ULF Magnetic Pulses

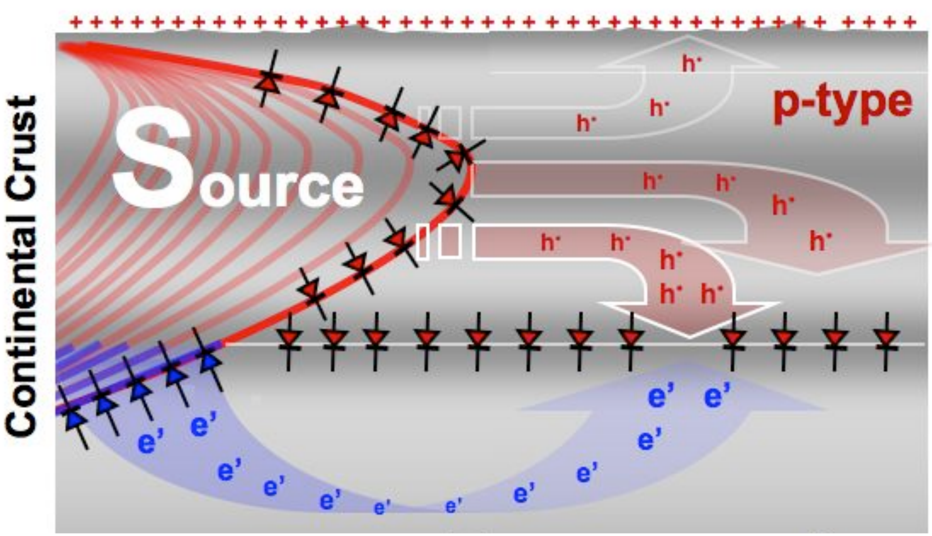
NASA (F. FREUND)
Lab Experiments

Instrumentation

Air Conductivity
Sensor

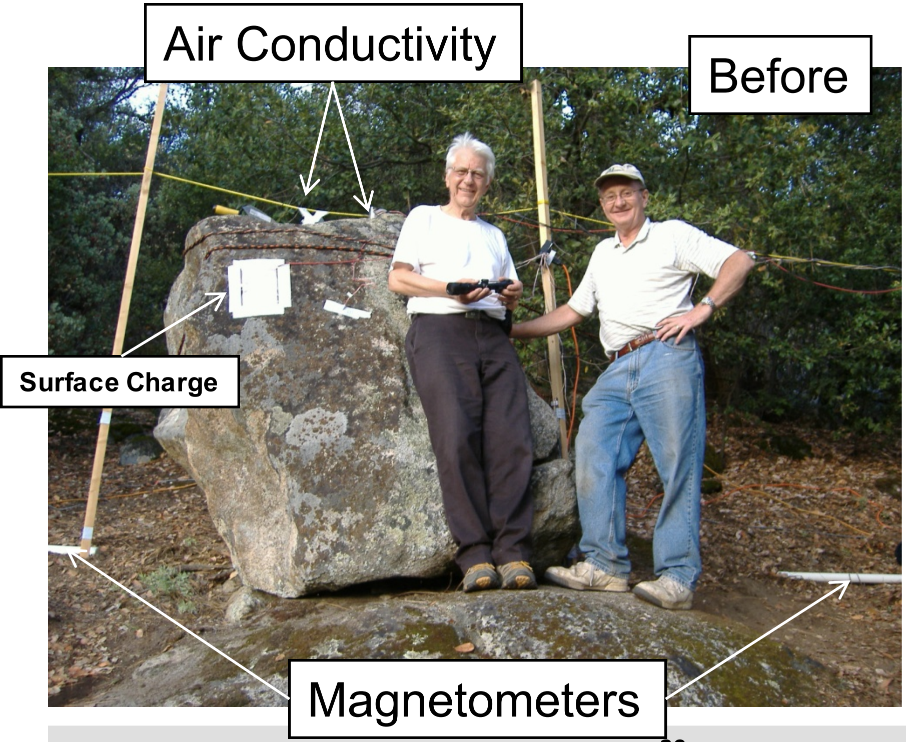
ULF magnetometers

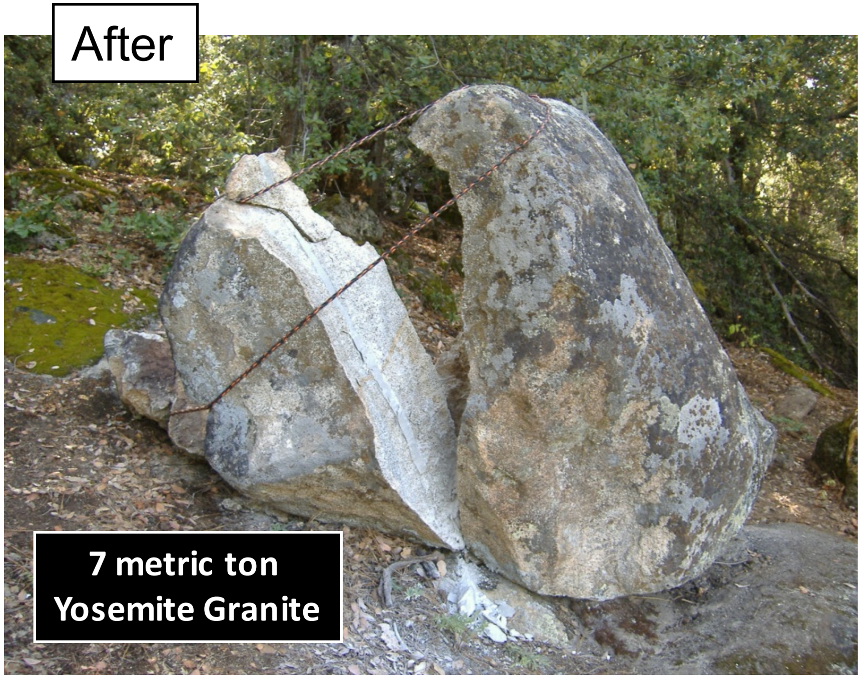
Hypothesis

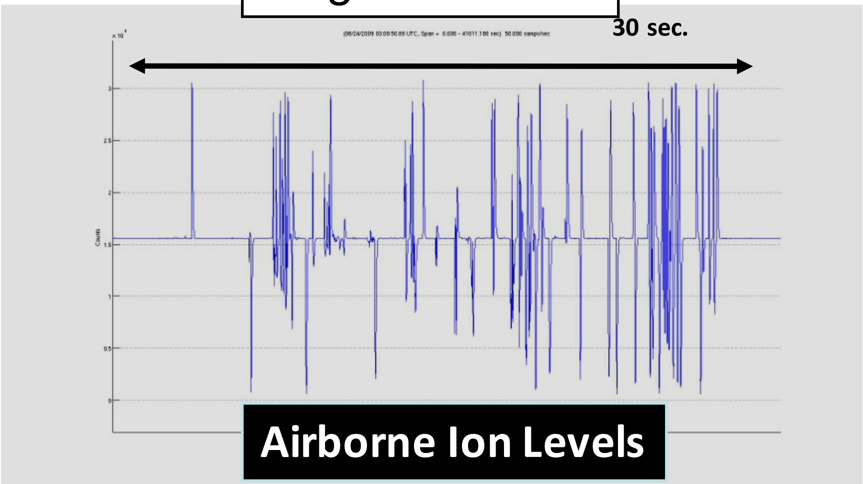


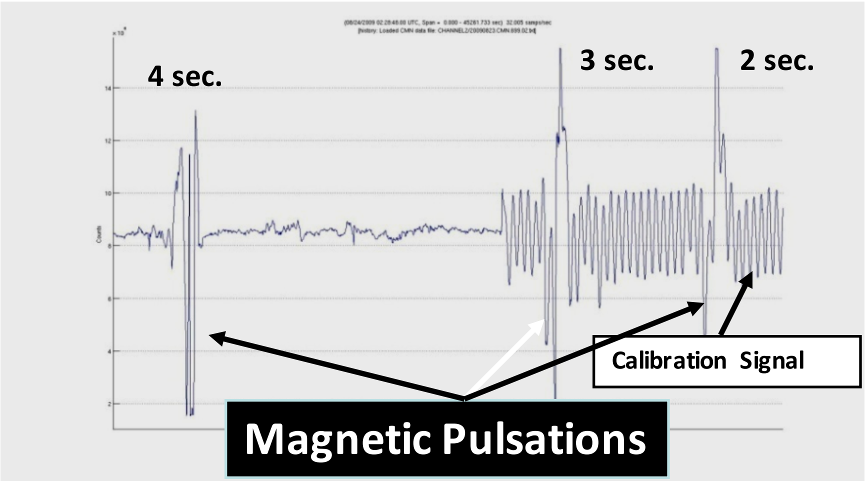

Defect Electron Migration
P-Hole Carriers

# Evidence used to support or reject these hypotheses



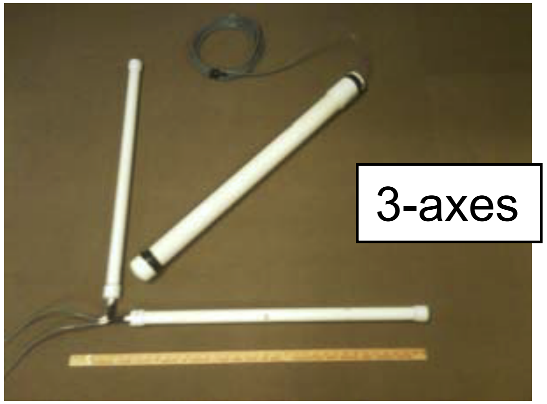



# QF Magnetometer Instrument Description

**QF-2010 Magnetometer Instrument Specifications 3/8/11**

**Magnetometers: (3)**

| | |
|---|---|
| Type: | Search Coil-Induction Magnetometers |
| Length: | 76.2 cm (30 In.) |
| Width: | 3.8 cm (1.5 In.) |
| Weight: | 0.927 kg. (2lb. 0.7 oz) |
| Frequency Range: | 0.01 to 12 Hz (low pass filter @12 Hz) |
| Sensitivity @1Hz: | 1.0 Volt per nT |
| Noise Level: | 0.1pT per root Hz @1 Hz; 0.02pT per root Hz@10Hz |
| Sampling Rate: | 50 sps |
| Analog Filters: | 100db for 60 Hz suppression |
| Output range: | +/- 40 V (differential coupled) |




**Air Conductivity Sensors: (2) 1 positive ions; 1 negative ions**

Type: "Gerdien Tube", with a fan which draws air at a calibrated rate

Unit is enclosed in a static-shielded, PVC tube with cover for rain

Air Ion Counter -10°C to 50°C, Wind Speeds < 15 km/hr (9mph)

| | |
|---|---|
| Range/Resolution: | 1 million (ions per cc per sec)/500 ions/cc/sec |
| Accuracy: | +/- 25% of reading |
| Noise: | 10 ions/cc (2 second averaging) |


\+ -

**Communications:**

Raven XE Cell Modem

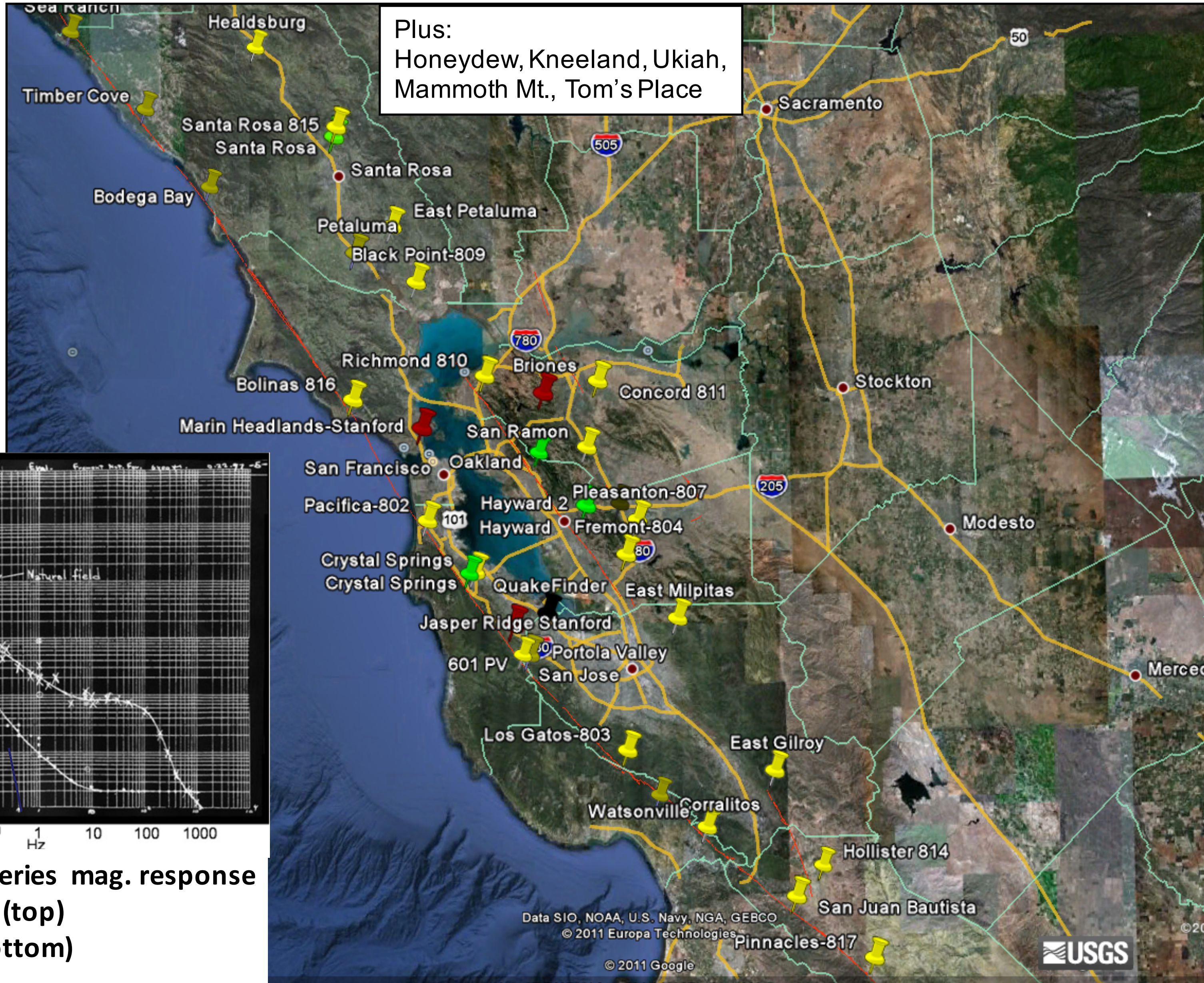
Heartbeat: 1 per 15 sec.: Data File 30 MB per day per site (1+ MB per Hr.)

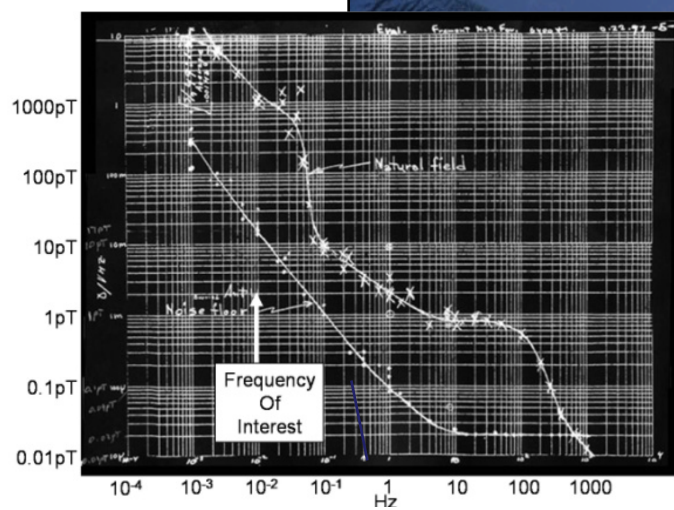
# What data are used?

- **What is the spatial and temporal extent of the data?**
  - Instruments approx every 30 km along major faults
  - 45 upgraded sites, 21 old sites (RMS data w/ local raw storage)
- **How often are there gaps in the data?**
  - None, if working (Model 100 & 300 replaced with 600, 700, 800)
- **What uncertainties exist in the data?**
  - Pulses verified with 2 separate sites/different designs, 100m apart
  - Spatial: Beyond 30km
  - Spectral: Sample rates 32 and 50 sps (low pass filter @13 Hz)
- **Are there authoritative data sources, openly available?**
  - 600, 700, 800 sites use science quality magnetometers
    - Calibrated magnetometers on all, Daily calibration signals @ midnight/noon
    - Calibrated ion detectors on 800 series only
  - All site data plotted on web each day www.quakefinder.com
    - RMS, some raw, 13 spectrograms, pulse counts, azimuth clusters, inter-site coherence, geophone, humidity, inside and outside temps.

# Northern California Magnetometer Networks Spatial Extent

- QuakeFinder (QF) new 600, 700, 800 series (sends daily raw data)
- QF 100 series (old) (sends daily RMS data)
- Stanford/USGS Sites (sends daily raw data)
- QF Data Center Palo Alto, CA

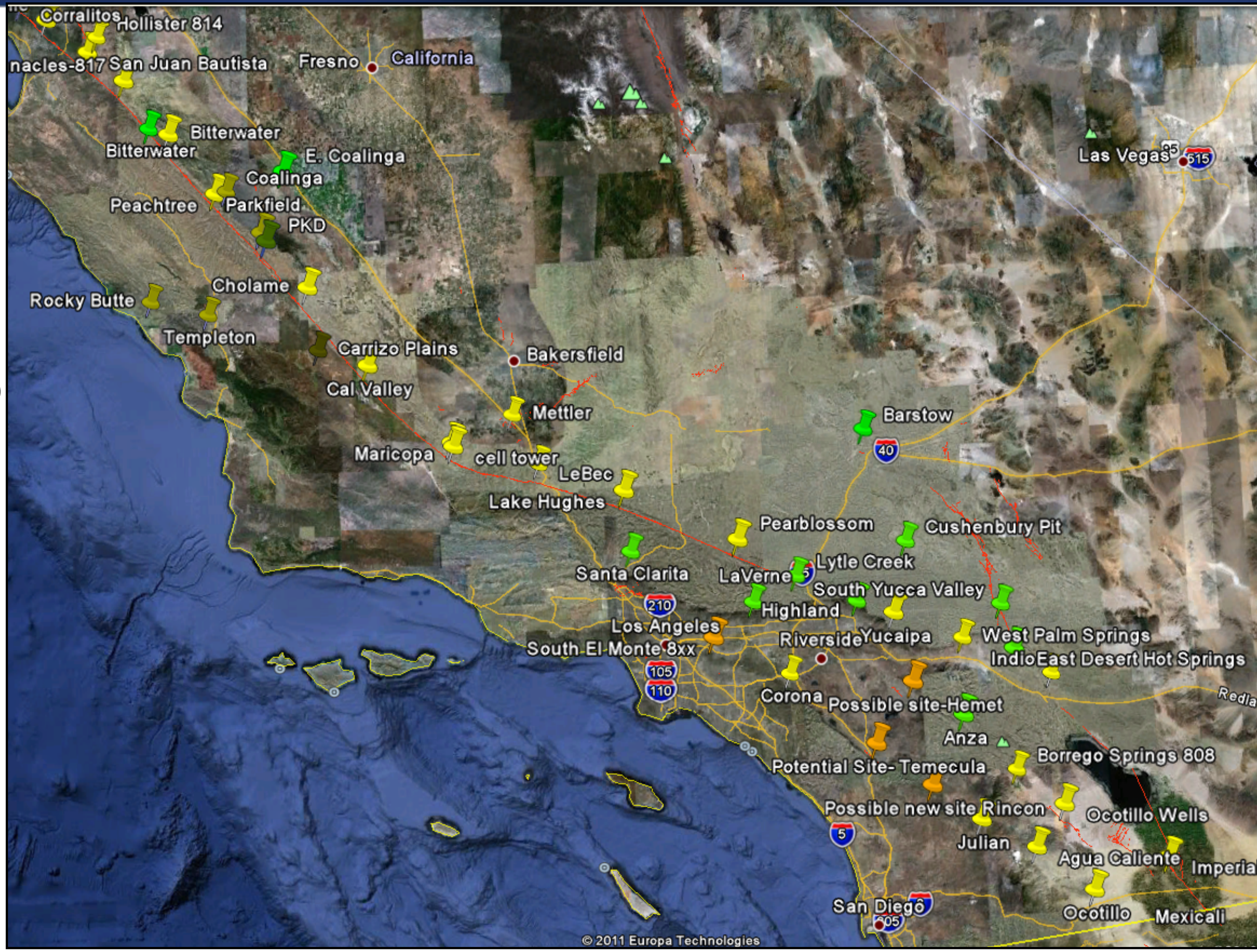


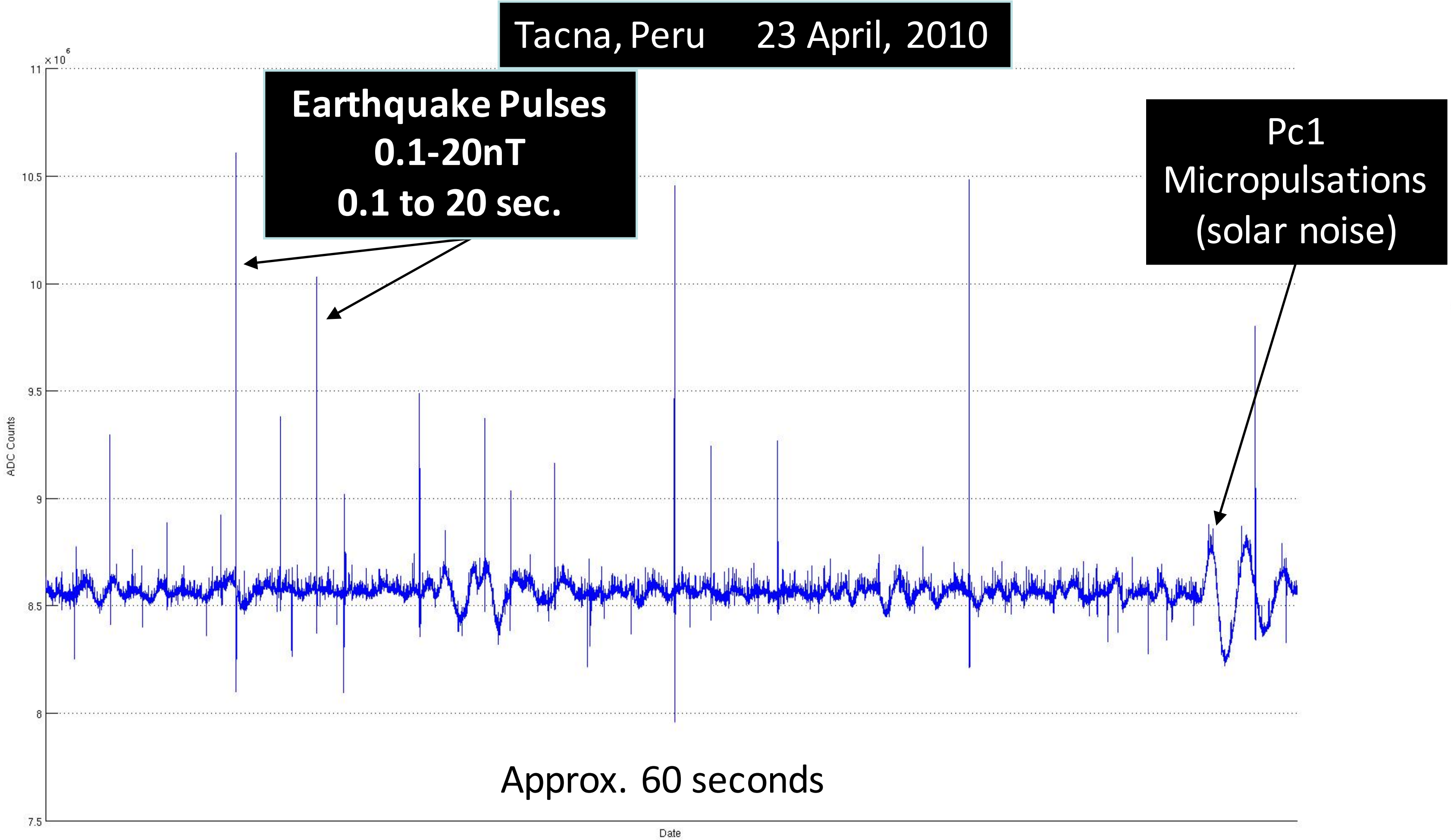

600, 700, 800 Series mag. response
Ambient signal (top)
Noise floor, (bottom)

# Central/Southern California Magnetometer Networks

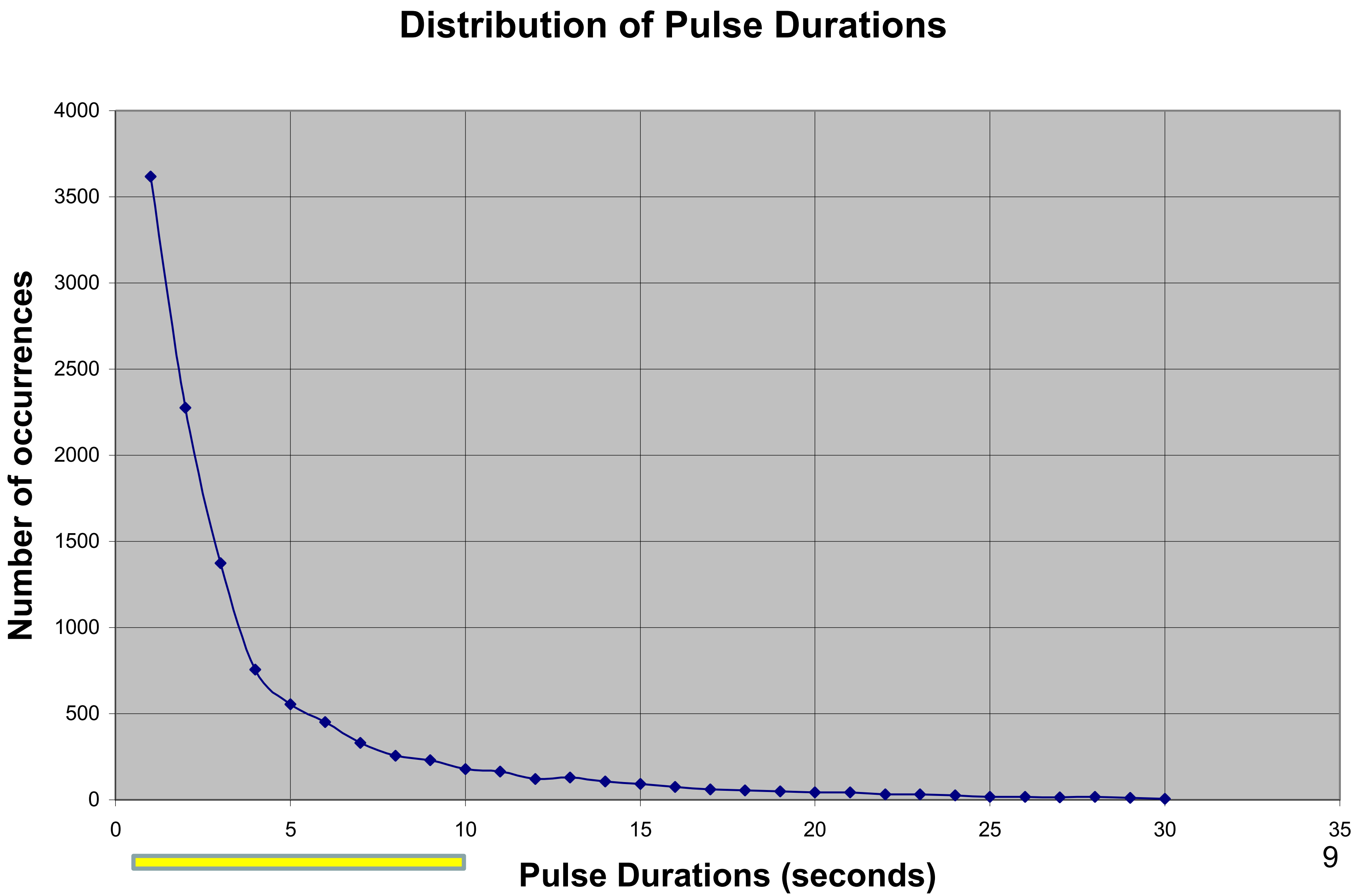
- QuakeFinder (QF) new 600, 700, 800 series (sends daily raw data)
- QF 100 series (old) (sends daily RMS data)
- QF Future sites
- Berkeley site (Parkfield)



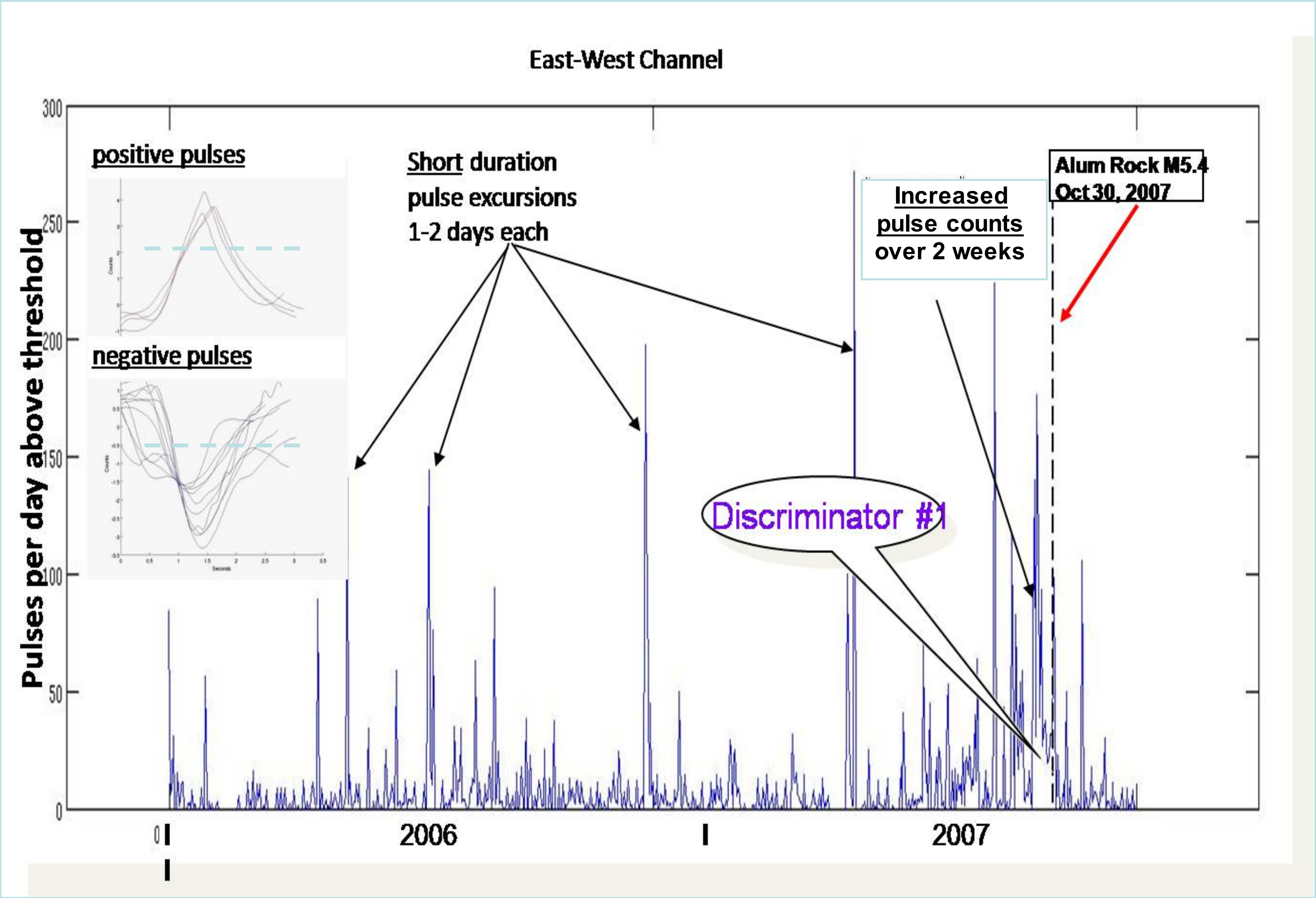
# “Uni-polar Magnetic Pulses”



# Pulse Discriminator: Duration



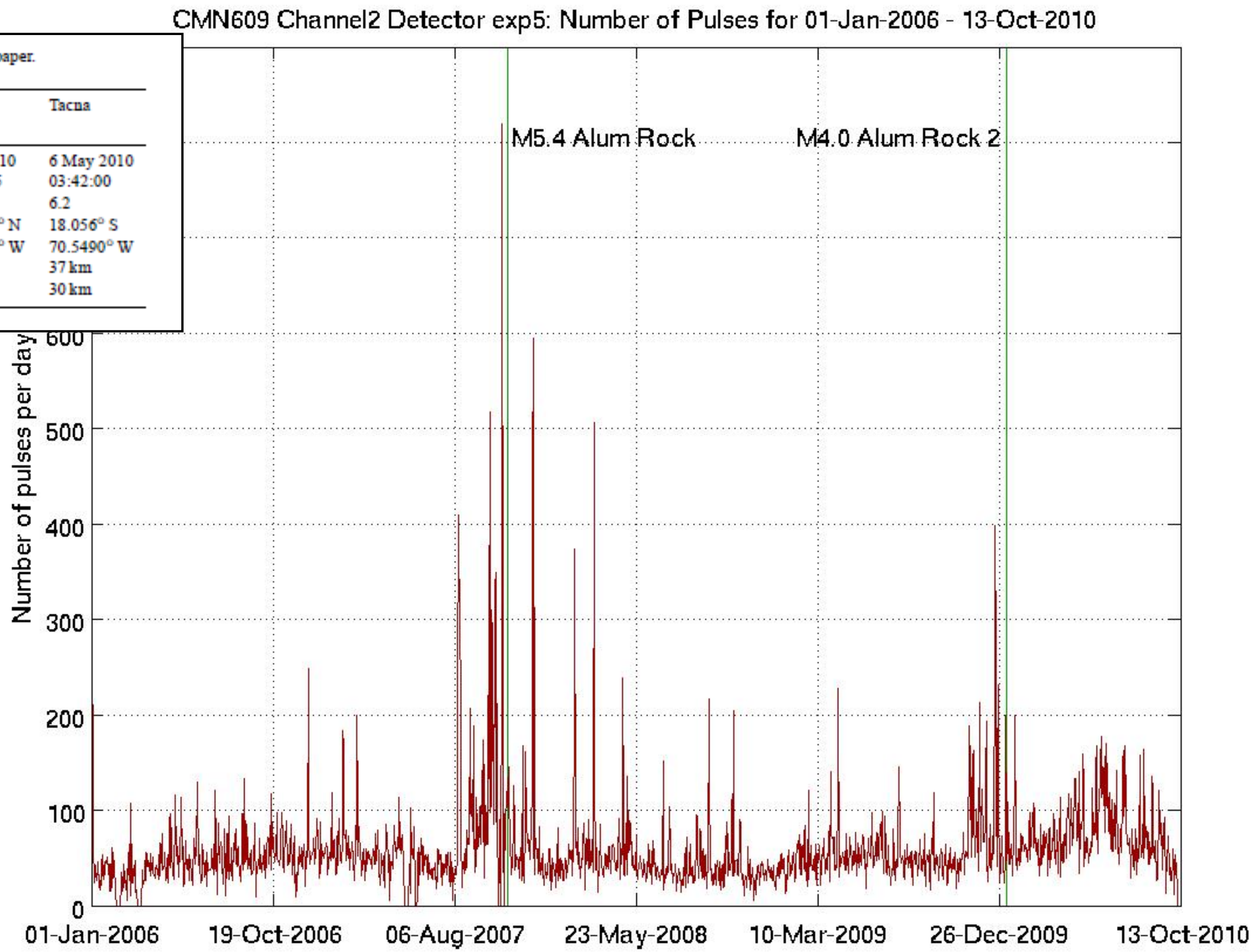
# Ultra Low Frequency (ULF) Magnetic Pulses (Alum Rock, CA)



# Second quake near Alum Rock

Table 5. Earthquakes discussed in this paper.

| | Alum Rock 1 | Alum Rock 2 | Tacna |
|---|---|---|---|
| Date | 31 Oct 2007 | 7 Jan 2010 | 6 May 2010 |
| UTC | 03:04:54 | 18:09:35 | 03:42:00 |
| Mag | 5.4 | 4.02 | 6.2 |
| Lat | 37.432° N | 37.4765° N | 18.056° S |
| Lon | 121.776° W | 121.797° W | 70.5490° W |
| Dpth | 9.2 km | 8.98 km | 37 km |
| Dist | 2 km | 6.93 km | 30 km |



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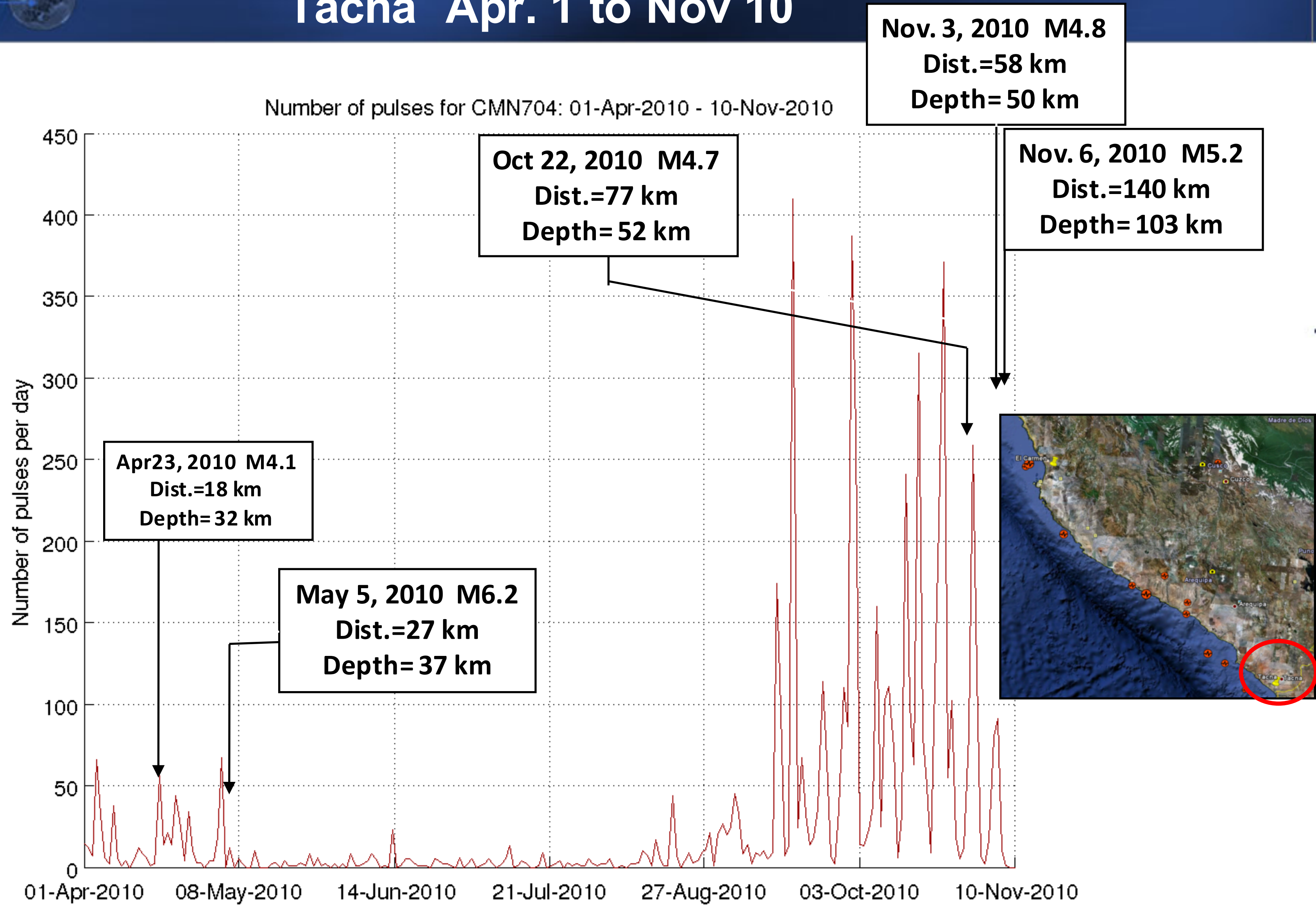
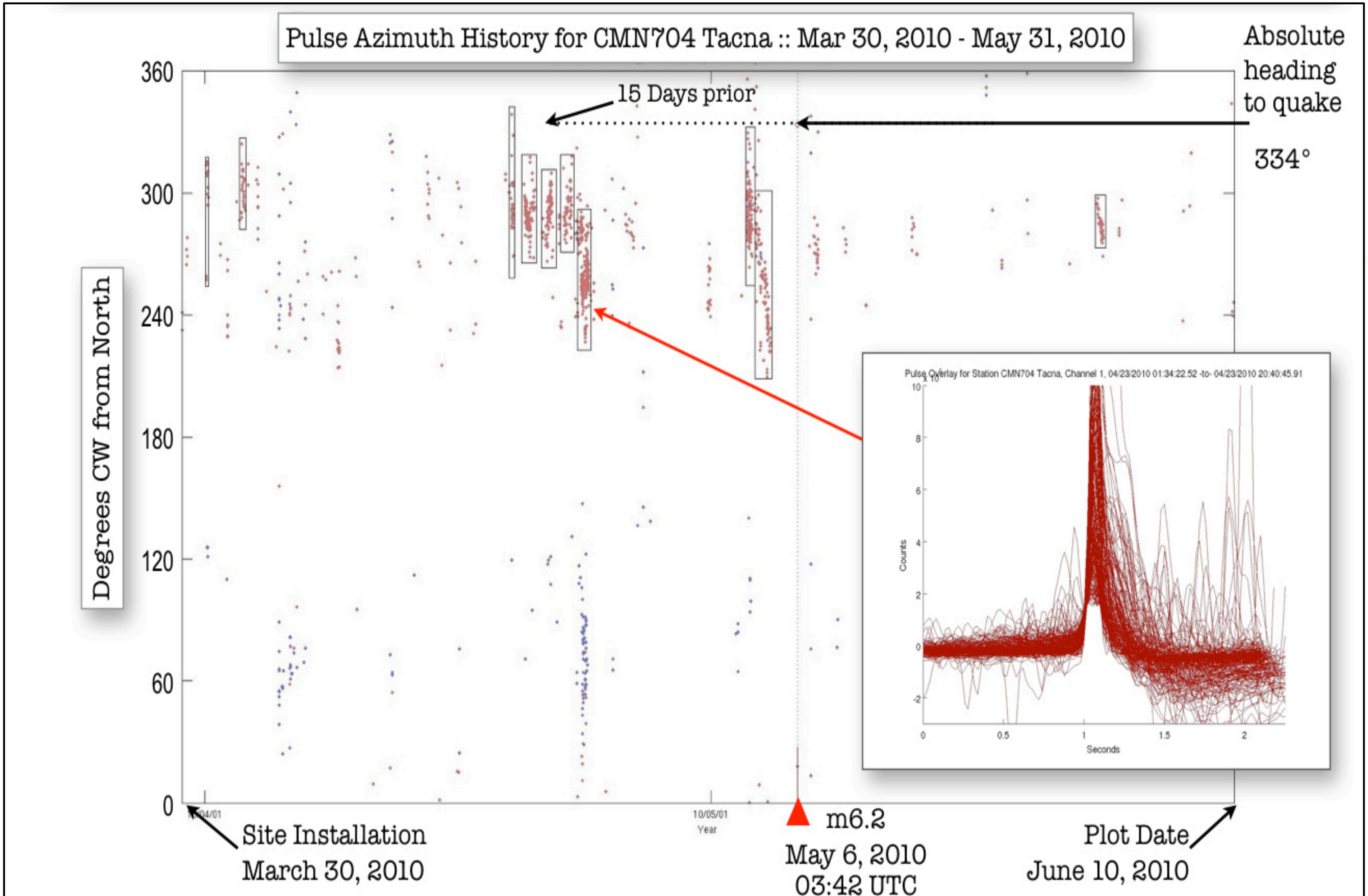
# Pulse and Quake Activity: Tacna Apr. 1 to Nov 10

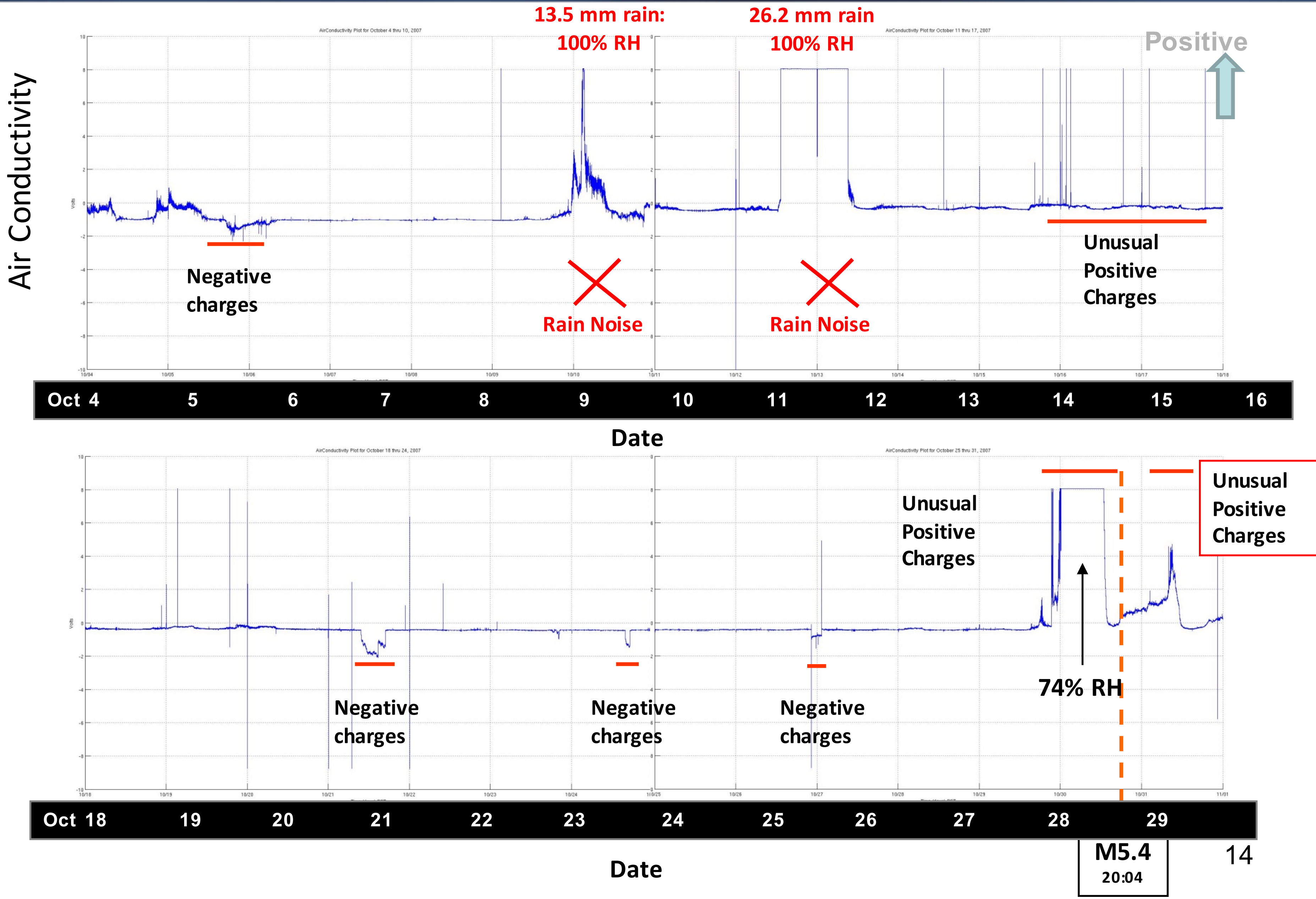


# Tacna Pulse Azimuth Clusters

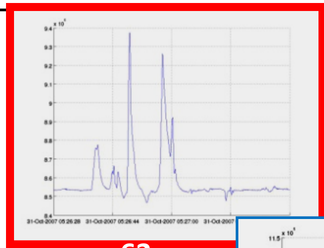
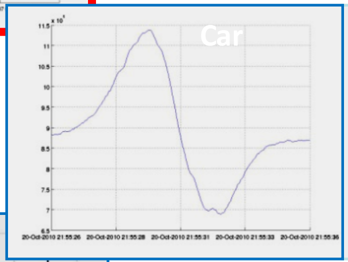
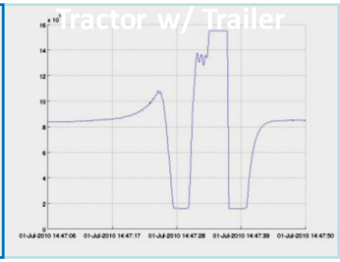
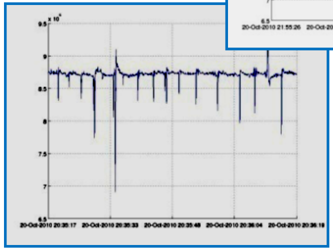
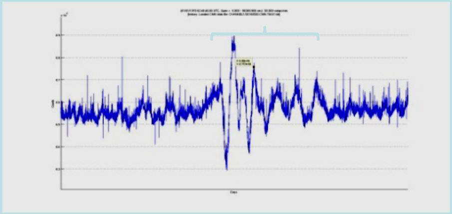
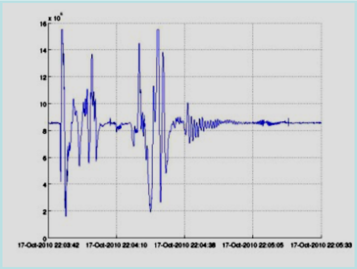


QuakeFinder

# Air Conductivity at Alum Rock



# How is “noise” treated in the analysis process?

| Noise source: | Example | Suppression |
|---|---|---|
| • **Quake Signal** |  Uni-Polar | **N/A** |
| • **Vehicles** |   | **Pattern (bi-polar)*** |
| • **Lightning** |  | **Pattern (fast rise)*** Weather Reports |
| • **Pc1 and Pc3 (solar)** Pc1 and Pc3 are solar-generated noise |  | **High Pass Filter** |
| • **Man-made** |  | **Multiple Wave Classifier*** |

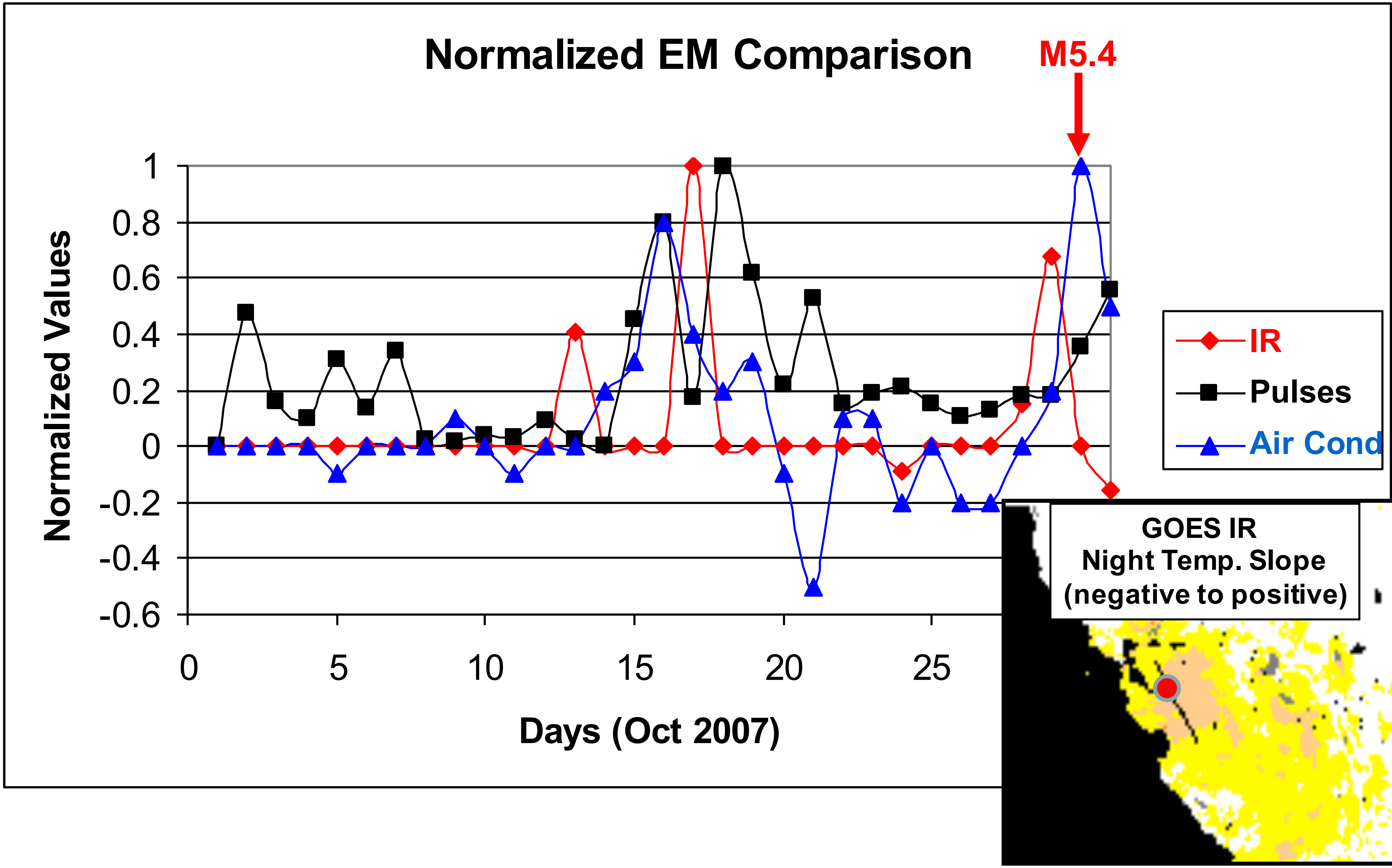
* Under development

# Earthquake-forecasting models?

- **Is the model under development or ready for retrospective or prospective testing?**
  - "Patterns" rather than "Model"
  - Searching for of quake signature –based on lab experiments
  - Modeling noise ("false" signals) e.g. lightning
- **Retrospective testing:** 6 quakes with positive results
  - Quake must be >M5 and within 20 km of instrument site (Size?)
- **Prospective Testing:** 1 quake (not really) Tacna, Peru
  - End of 2011 starting semi-automated testing—always reviewed
  - Need more sites; adding 50 new sites in 2011 ******
    - Stellar Solutions-funded
    - Soliciting NASA and DHS to speed network expansion
- **Are these "Models" automated such that they could be submitted for independent evaluation?**
  - Not ready yet; Still collecting examples and refining algorithms

# Corroborating evidence within a forecast?

**3 independent, correlating indicators** with Alum Rock quake



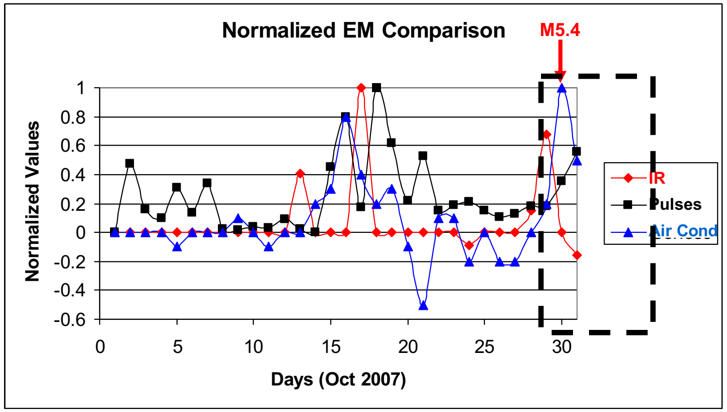
# Failure and False Alarm Rates

- **Failures** (retrospective): 1 Parkfield?
  - Effects of high conductivity? (Unsworth report re Parkfield)
  - There were pulses, but very short, and appeared in Hollister too
- **False Alarm/False Positive** (prospective): 1
  - Dec. 2011 Sent alert to PUCP in Peru (document alert)
  - Actual: Cluster of small quakes in zone, 1 distant quake

# Scale of the Forecast Elements?

(e.g. Time, Location, Magnitude, Depth, Probability)

- **Proposed (being tested)**
  - **Time:** Within 7 day window (tbd)
  - **Location:** Within 20 km radius of a site (tbd)
  - **Magnitude:** Within X+/- 1 on Richter Scale, e.g. M5.5 to M7.5 (tbd: pulse counts, magnitude, sites)
  - **Depth:** NAC (Not a Clue)--honestly
  - **Probability:** Start low and work up with successes



# QF Next steps towards forecasting

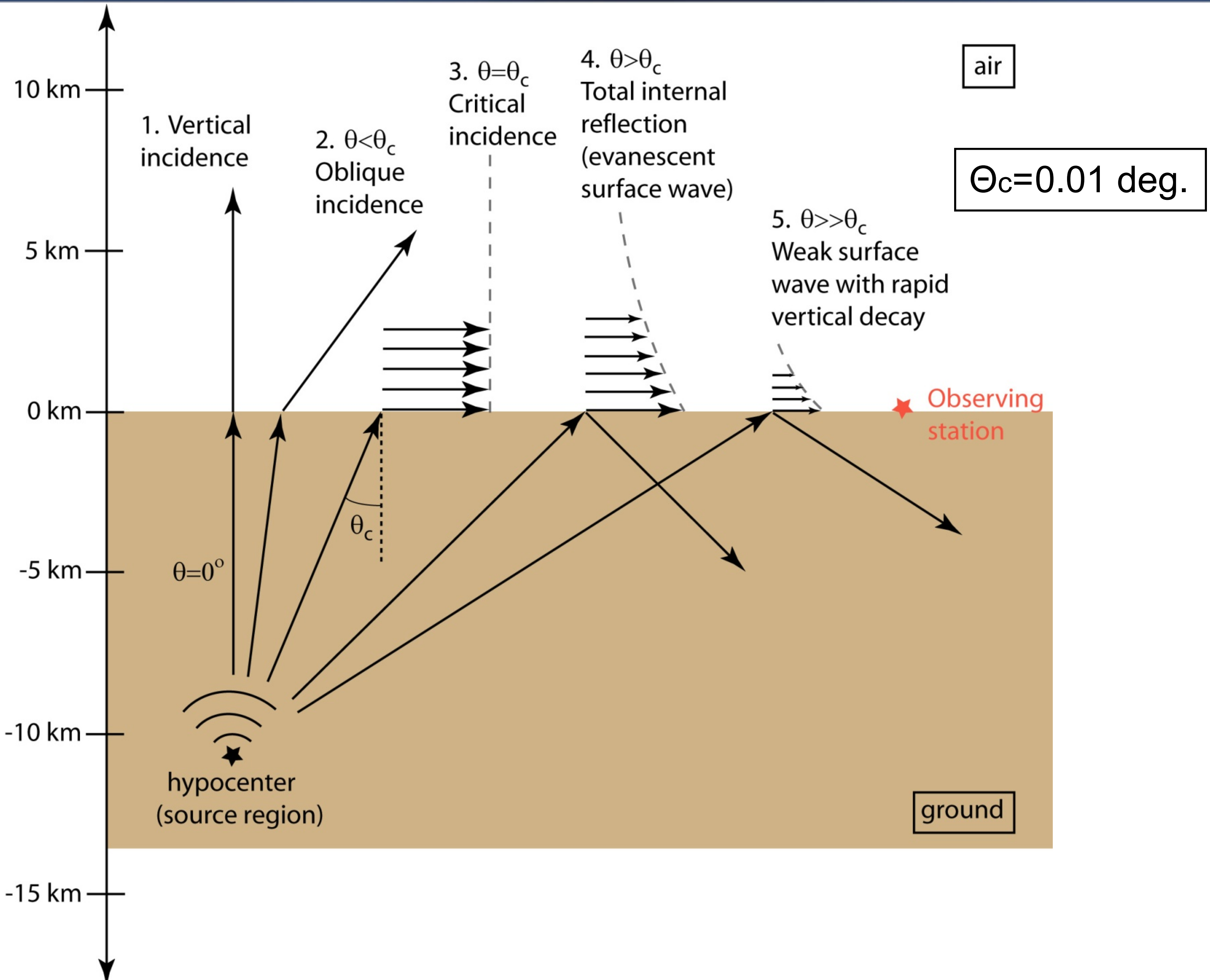
- **Get More Examples (More data)**
  - California: Upgrade 20, add 10 = ~70 sites
  - International: Add 20 (4 in each of 5 countries) =24
- **California needs around 200 sites total**
  - Cover major faults
  - Need calibrated instruments with daily raw data
- **Add GOES IR processing** (Multiple Indicators)
  - Collaborate with other IR and TEC researchers
  - Keep looking for new signals in the lab experiments
- **Refine Algorithms**
  - Pulses, Air Conductivity, Azimuth clustering, multiple sites
  - Characterize and eliminate noise

# Next steps for improving our Understanding of the Physical Hypotheses

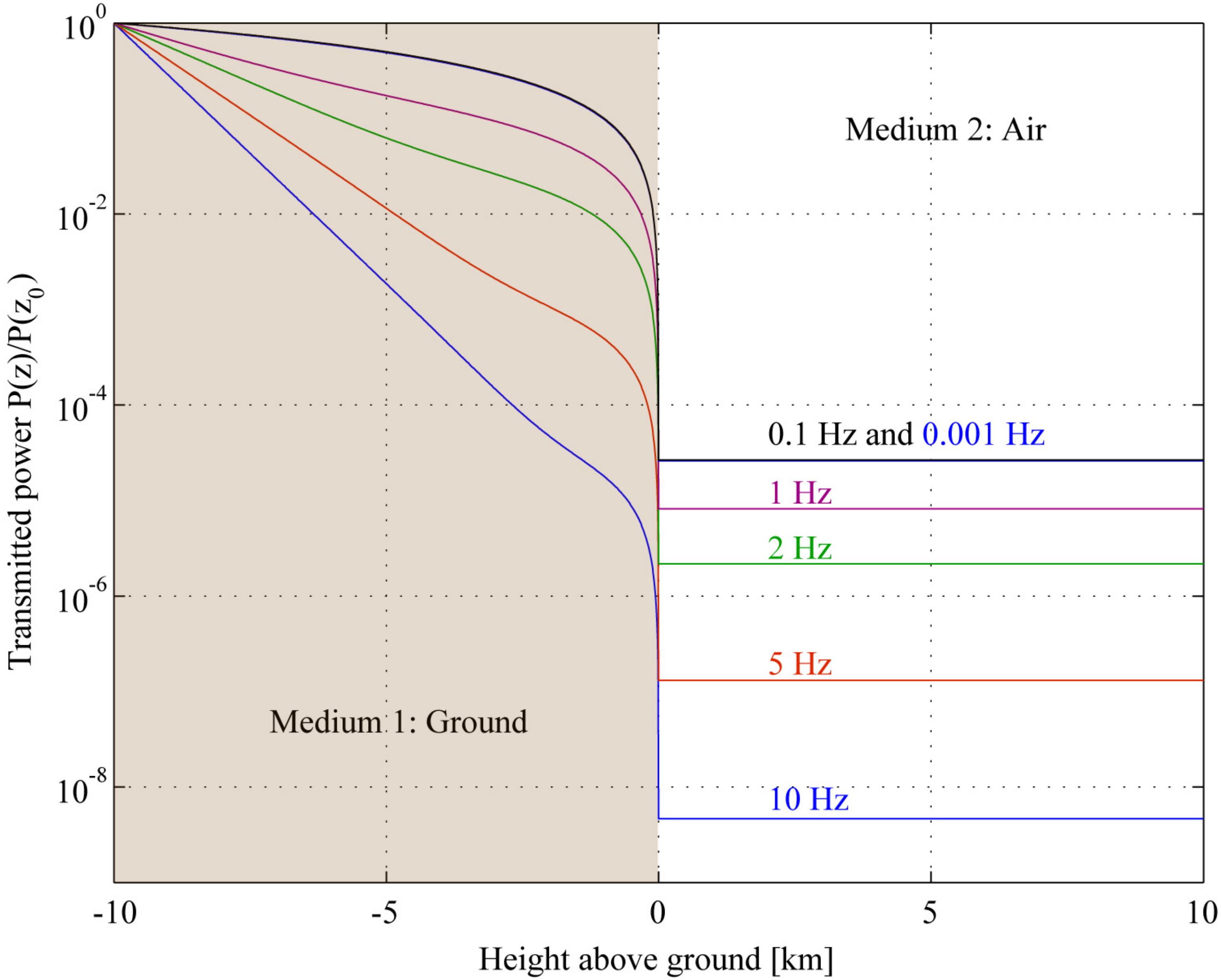
- **Follow lab experiments → look same indicators in field**
  - Pulses, air cond., IR (spectrum?), Radar reflection changes
- **Investigate signal propagation distance/direction**
  - Azimuth clustering
  - Look at multiple sites
    - Noise: Identify and remove BART pulses that happen at the same time in different stations
- **Consider quick deployment of temporary instruments**
  - After initial pattern detected (1-2 week lead time)
  - Placed near area where pulses detected (more complete network)
- **Look for New Correlations?**
  - Episodic tremors/"Slow" Earthquakes?
  - Earthquake Lights, Animal Behavior, Other??

# Thank You

# Signal Refraction



# Attenuation by Frequency (ELF-VLF) for Below Ground to Air



# Attenuation by Frequency (ELF-VLF) for Ground to Satellite Propagation