The QuakeFinder Earthquake Forecasting Technology –

A Signal Processing Problem

NASA Ames Research Center
Advanced Modeling and Simulation
Seminar Series

September 22, 2015

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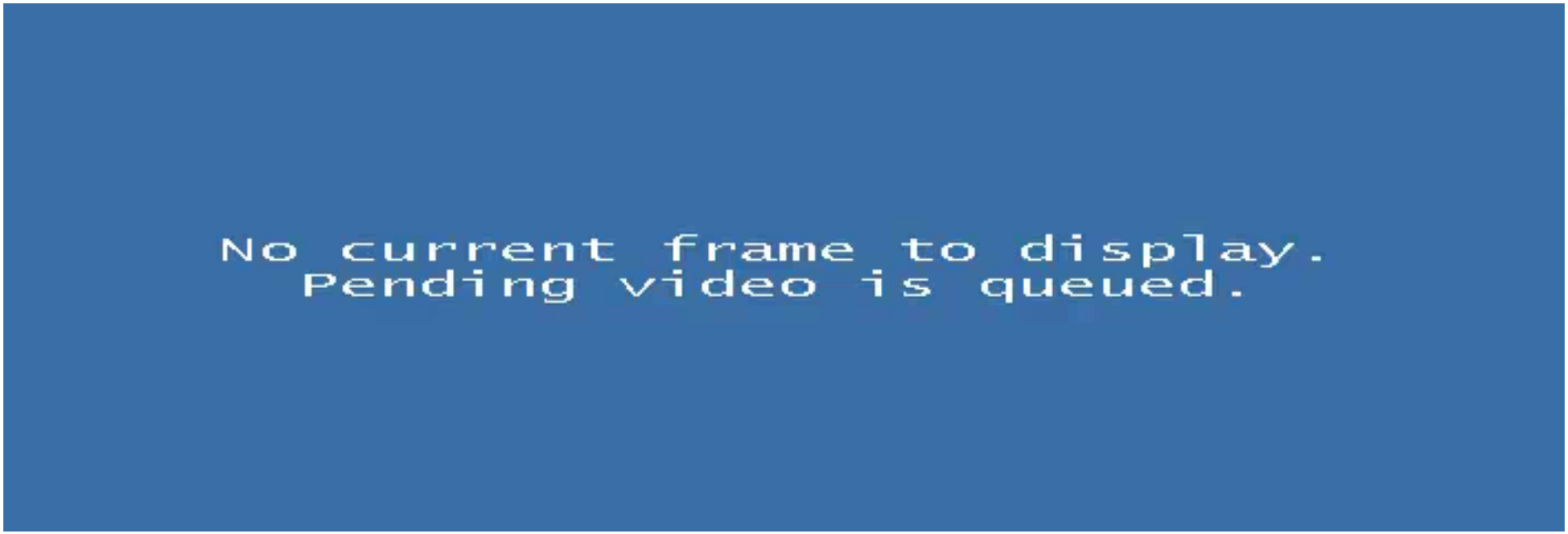
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Stellar Solutions, Inc.

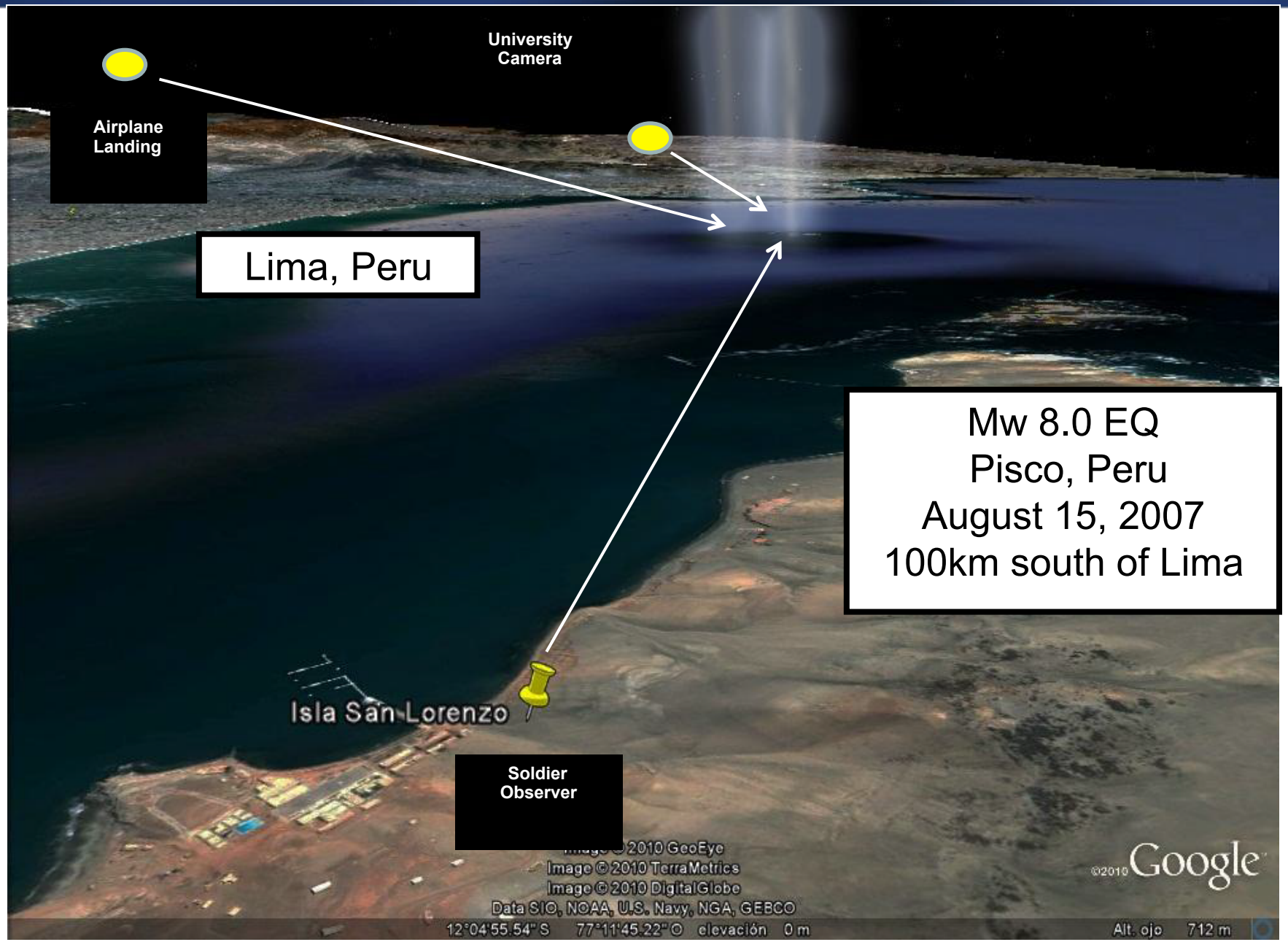
Earthquake Lights

There are Electrical aspects to earthquakes

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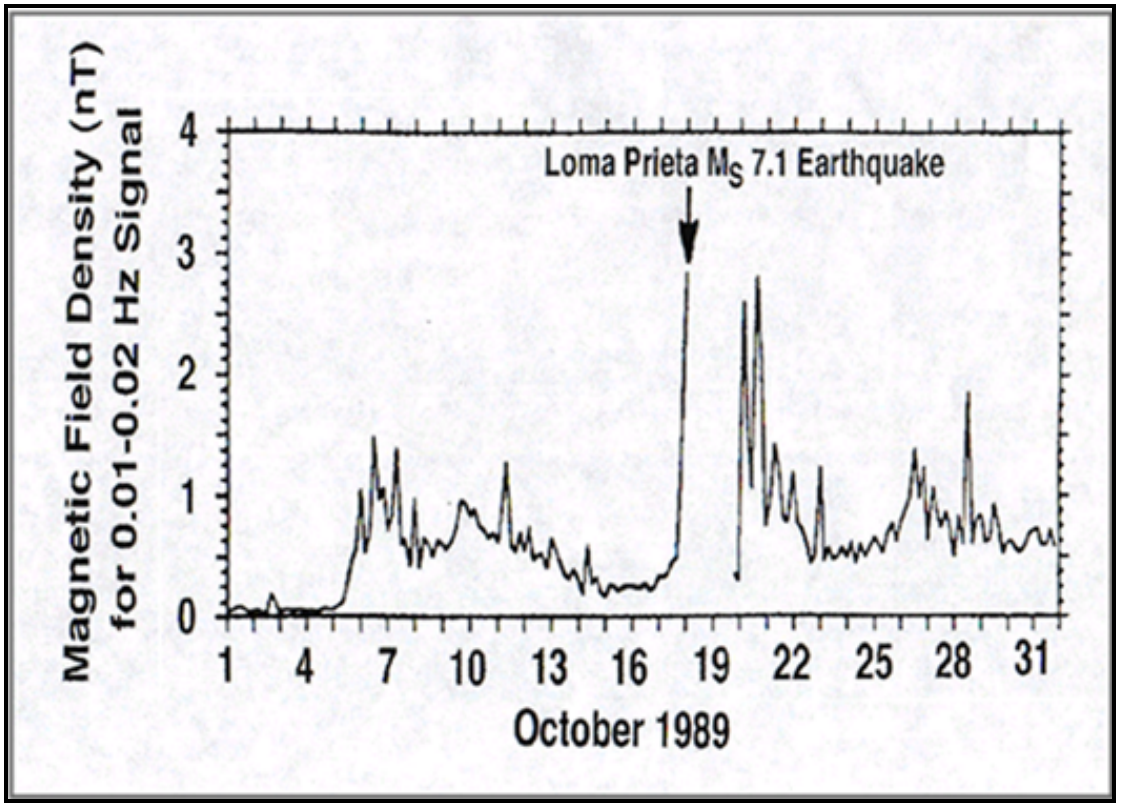

No current frame to display.
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Source: Small Island in Harbor



The Beginning

- Dr. Tony Fraser-Smith (Stanford)
  - 1989
  - M7.1 Loma Prieta
  - >$6 B in damage



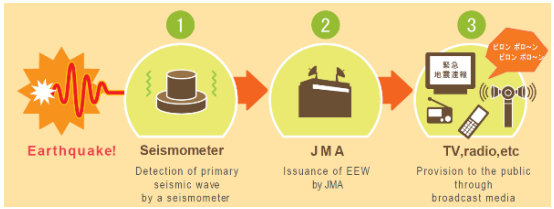
Earthquake "Forecasting" Ecosystem - Today

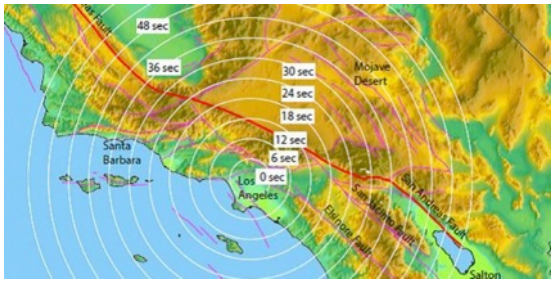
Comparison:



Seconds of warning

- Earthquake "Early" Warning (EEW) systems
- Based on seismic detection of a quake after it has occurred





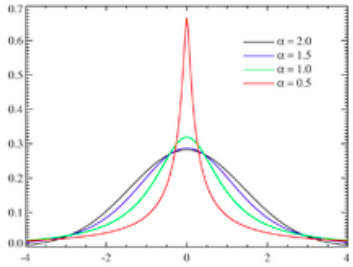
Weeks-Days of warning



developing technology to provide forecasts

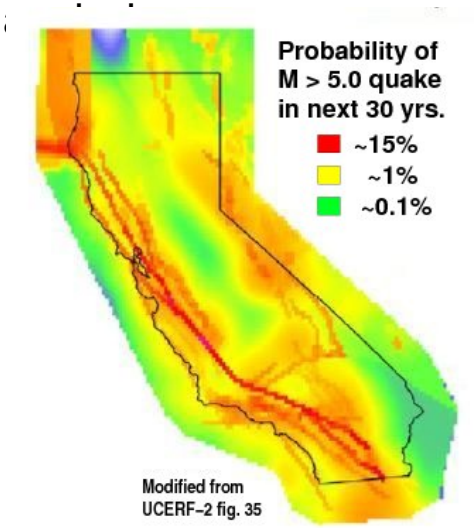
Weeks, Days in advance

Localized



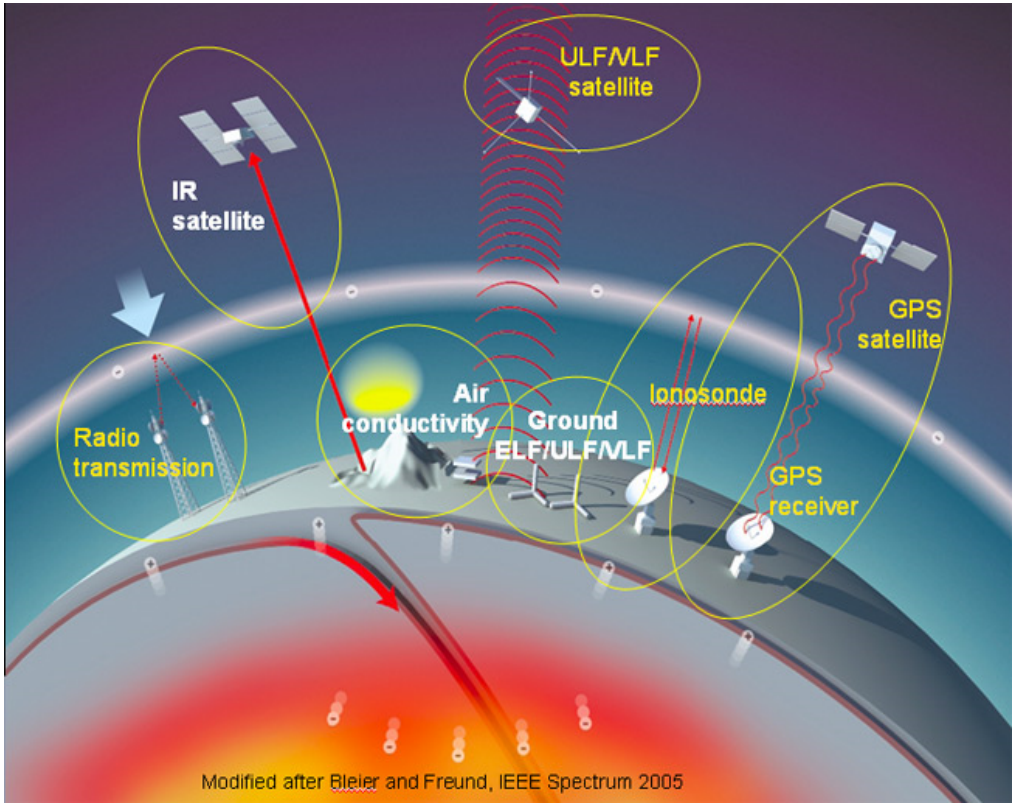
Decades of warning

- 30-year probabilities
- Based on statistical



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Forecasting System Elements



- QuakeFinder is focused on:
  - Ultra Low-frequency ground signals using magnetometers
  - Air conductivity using air ionization sensors
  - Infrared using satellite data

QuakeFinder's goal is to collect and integrate the data, identify the precursor signals, and enable an alert system.

QuakeFinder

- Established in 2000 in Palo Alto, CA.
  - Humanitarian R&D effort of Stellar Solutions
- A dedicated and passionate team
- ~$20 M investment to-date
  - Largely self-funded
  - Augmented with sponsor funding and donations: NASA, PG&E, Musk Foundation, Vodofone, Telefonica
- Outside QuakeFinder:
  - International EM community: 100+ researchers
    Magnetometers, IR, TEC, ions, others

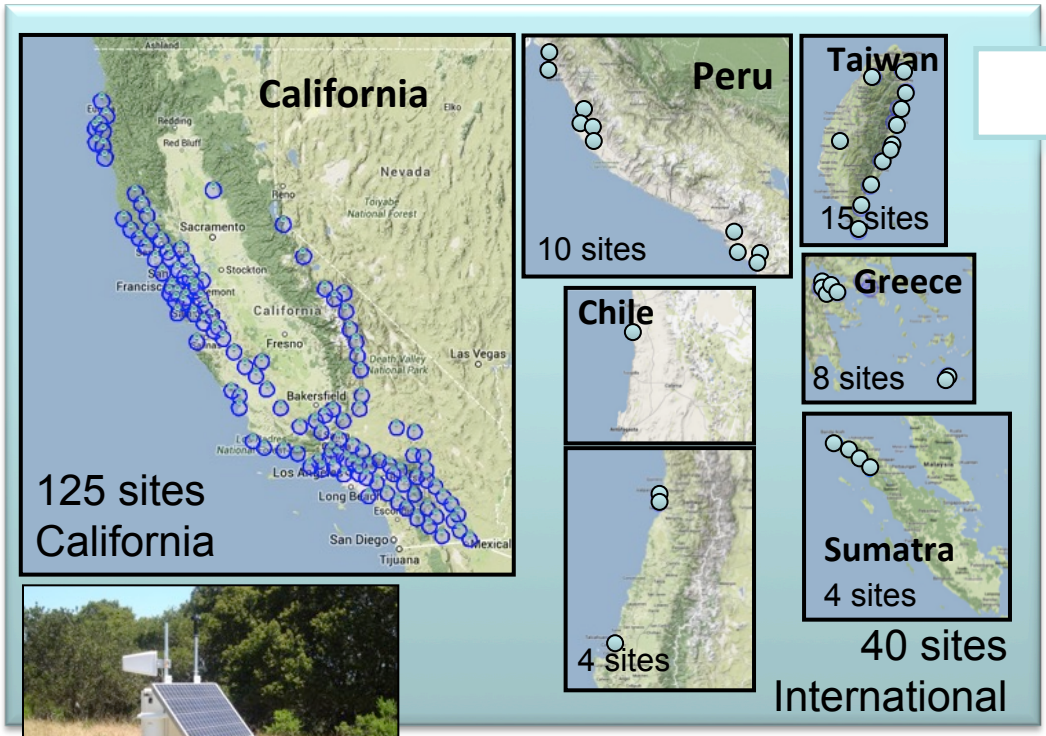
Mission:

Save Lives By Forecasting Earthquakes

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QuakeFinder System

Instruments/sensors



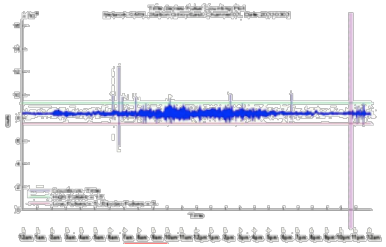
50 Hz sample rate
Data transmitted via cell or sat

Data Center



Palo Alto, CA
65 TB of data to date

Processed daily
Available to researchers

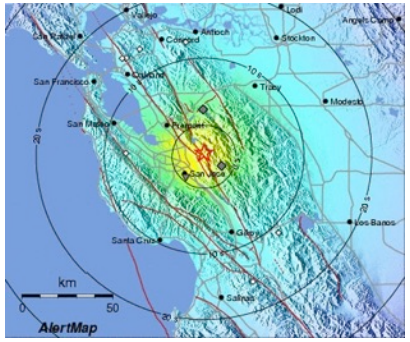


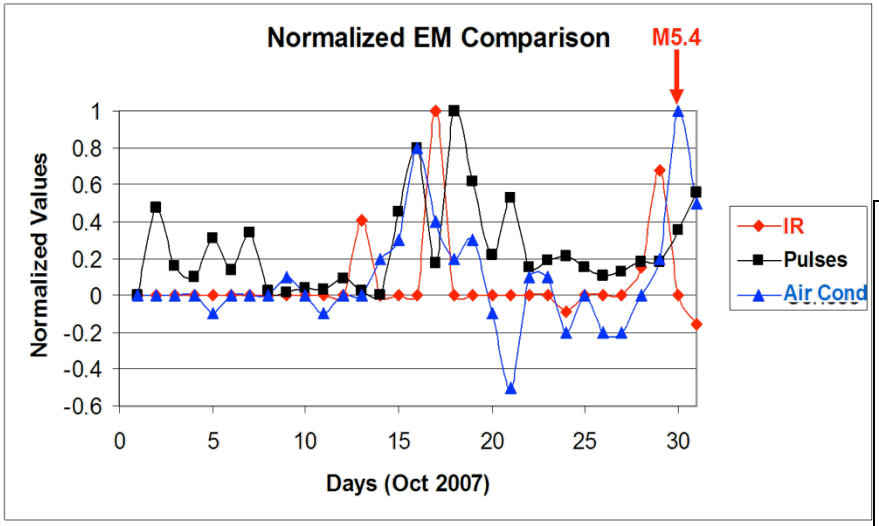
QuakeFinder.com

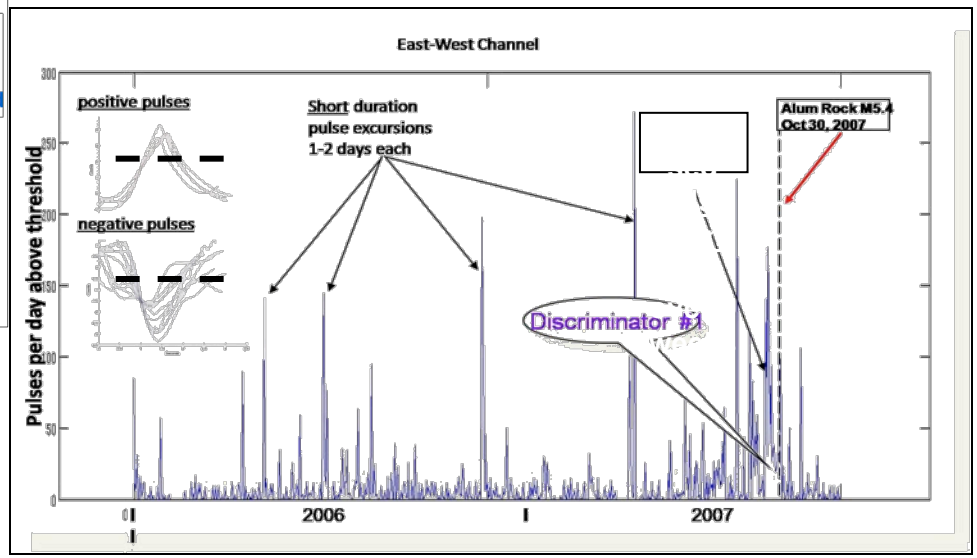
Place instruments within 10 miles of quake areas
Build algorithms to detect earthquake precursor signals

Alum Rock Results

- **M 5.4 Oct. 30, 2007**
  - **Near San Jose, CA**







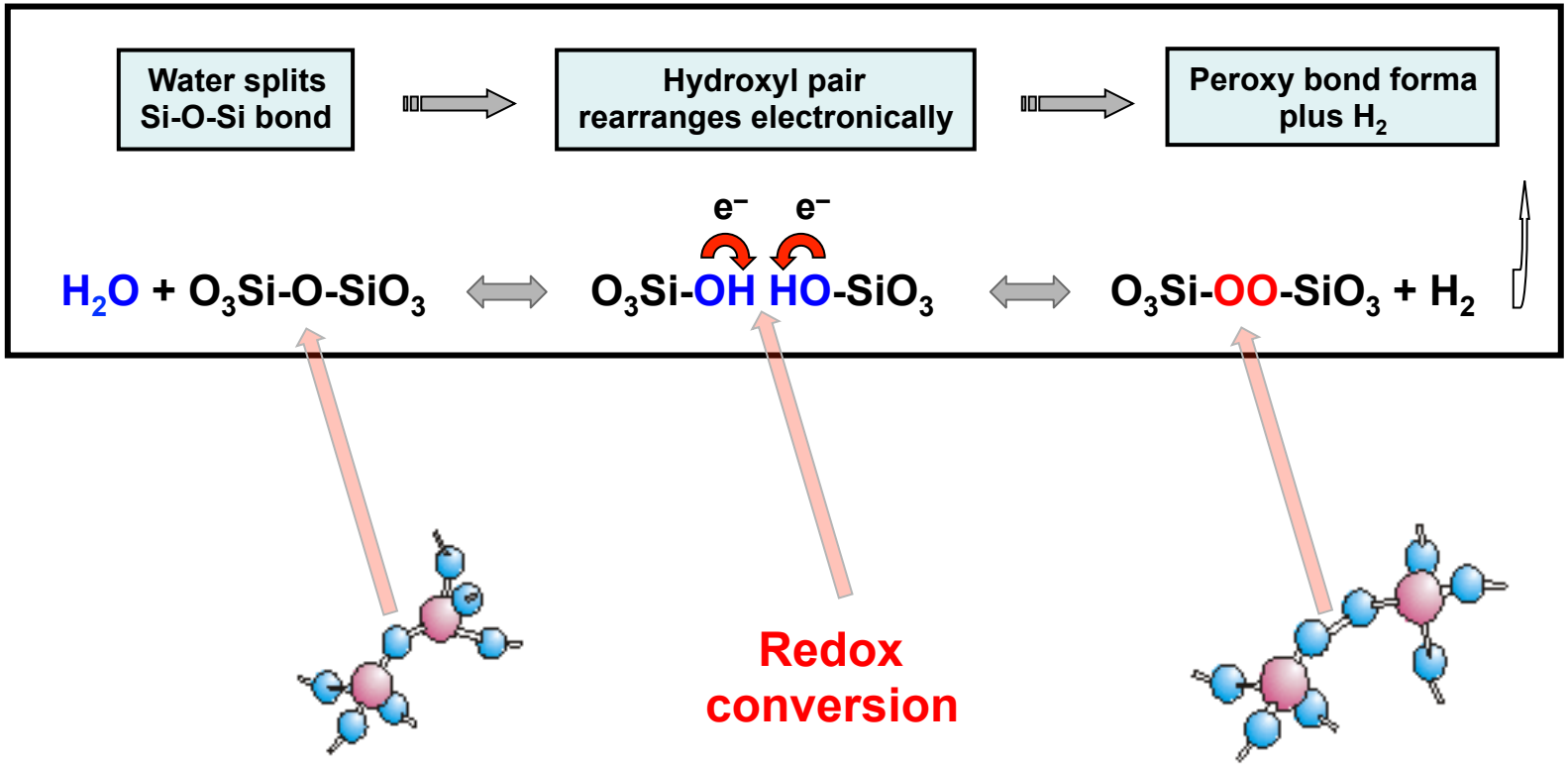
Electromagnetic Research showing promise to provide 6-15 day forecast

Dr. Friedemann Freund

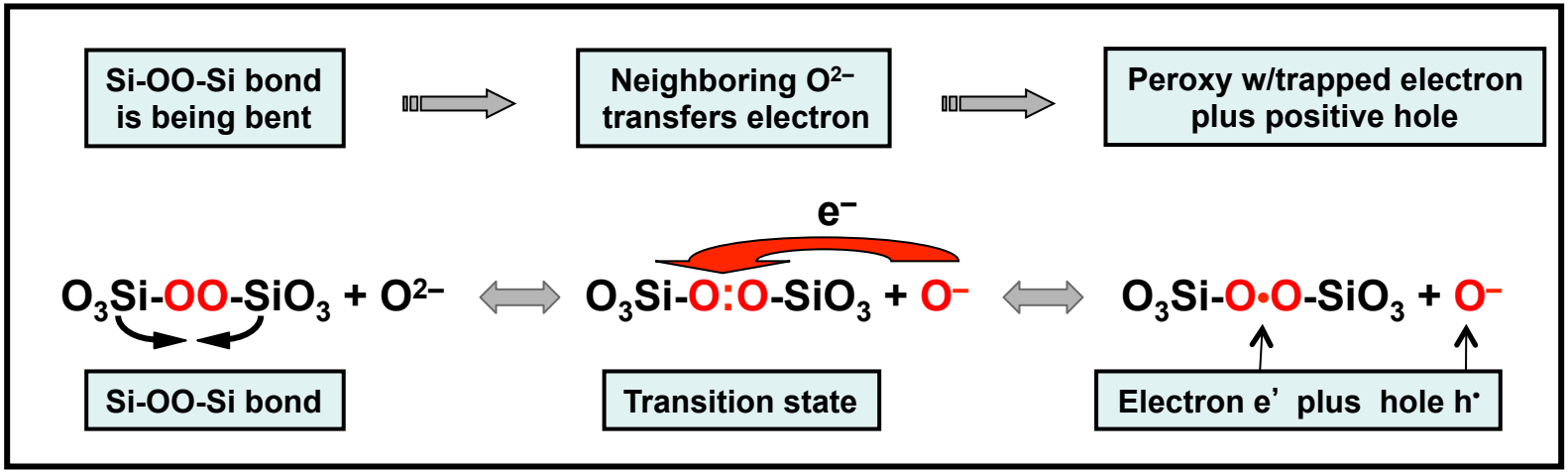
Ames Research Center

SETI Institute

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How peroxy defects are introduced into rocks



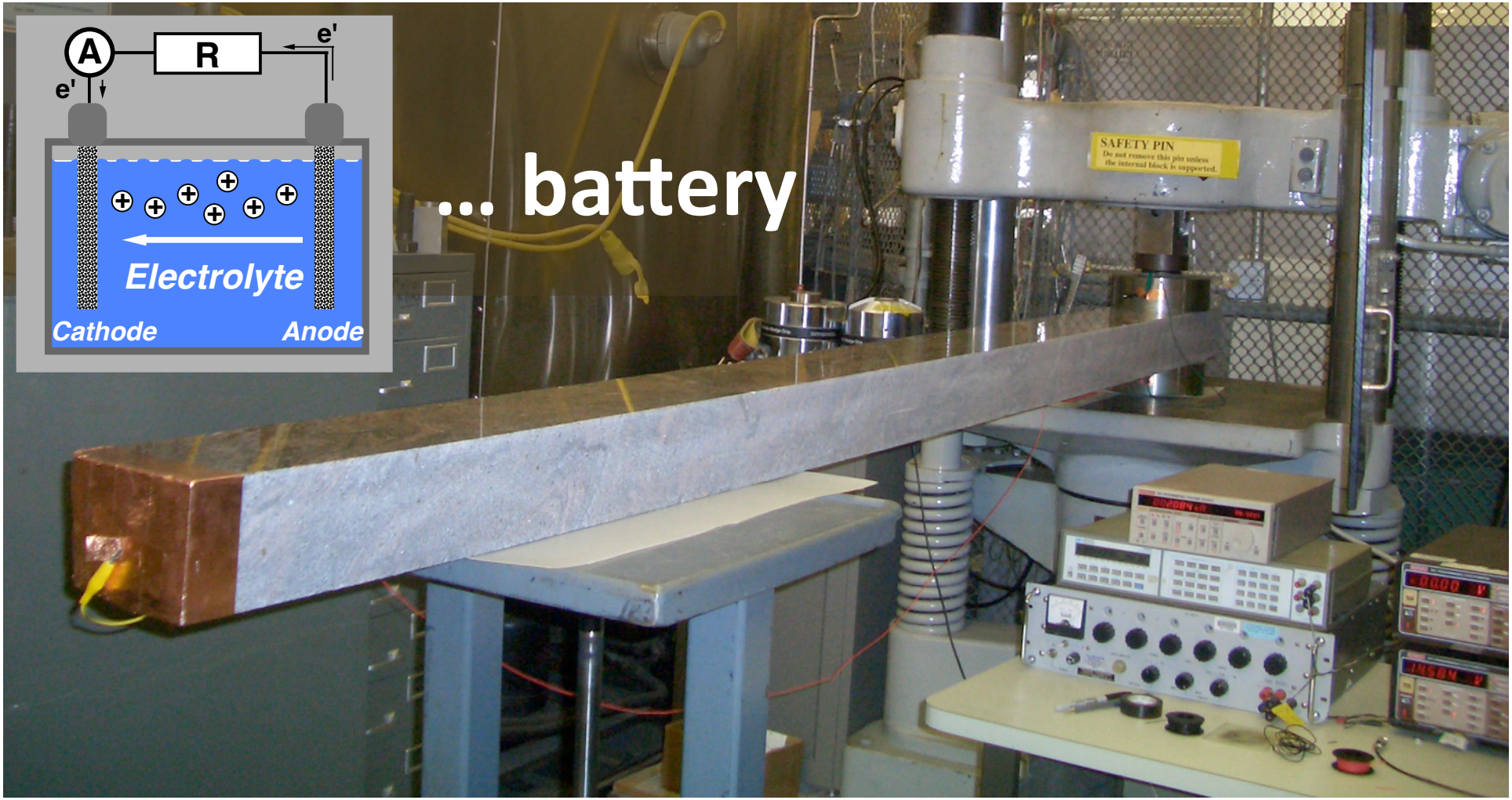
Slight deformation

breaks peroxy bond

electron–hole pair

How peroxy defects release positive holes

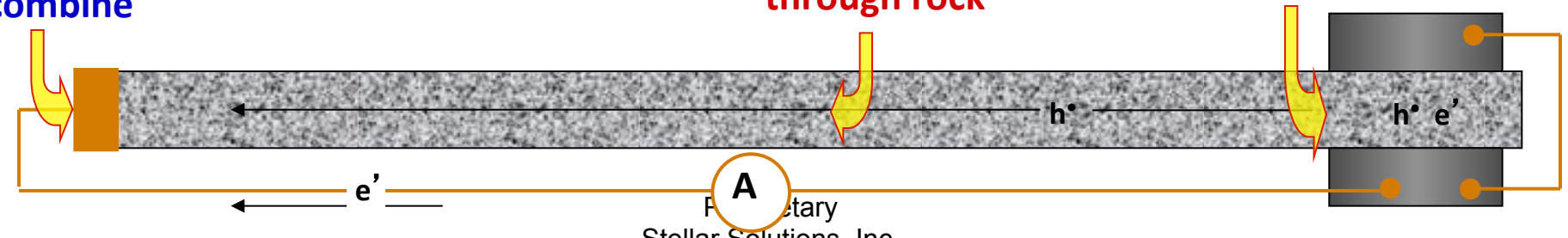
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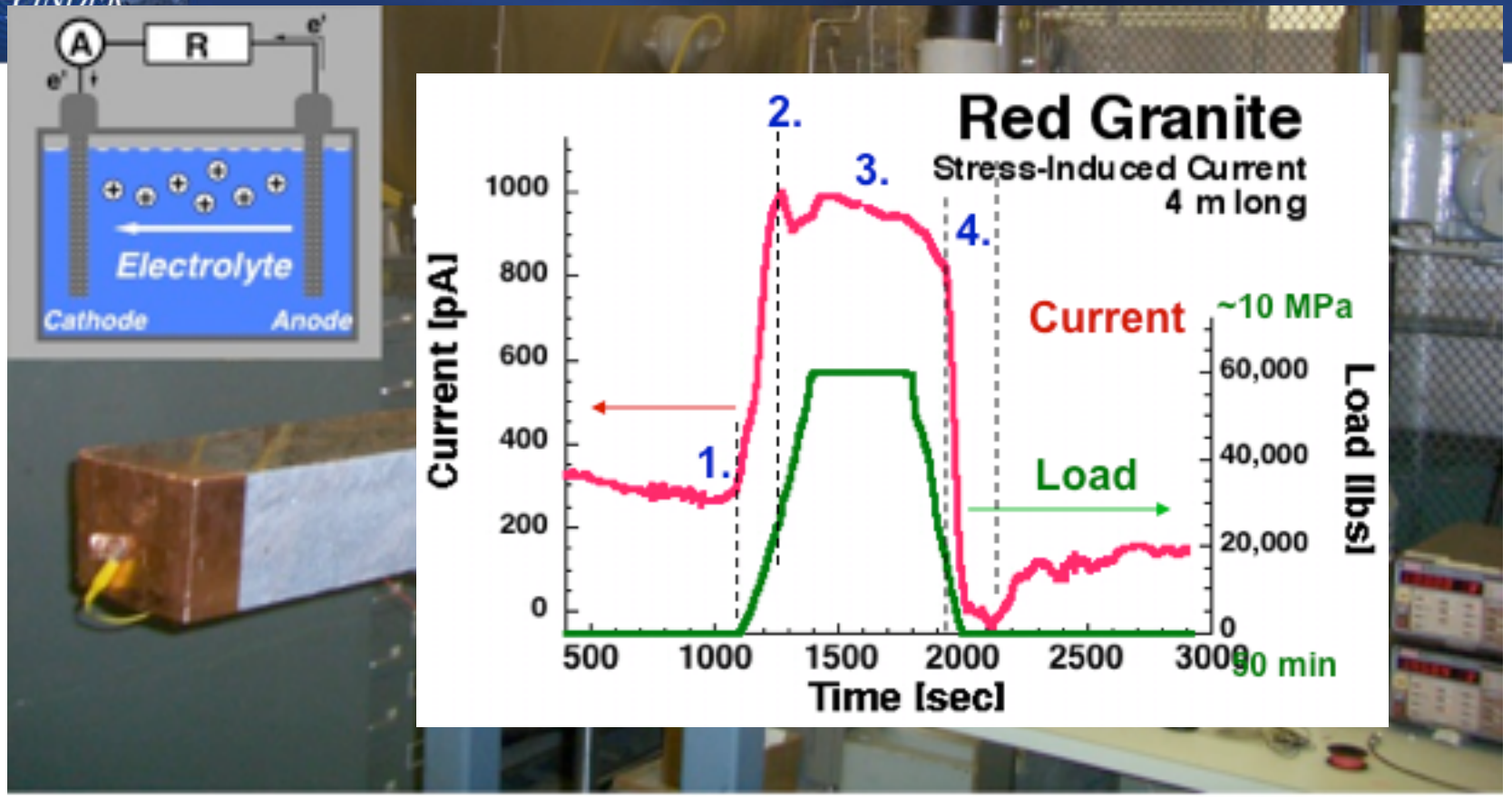


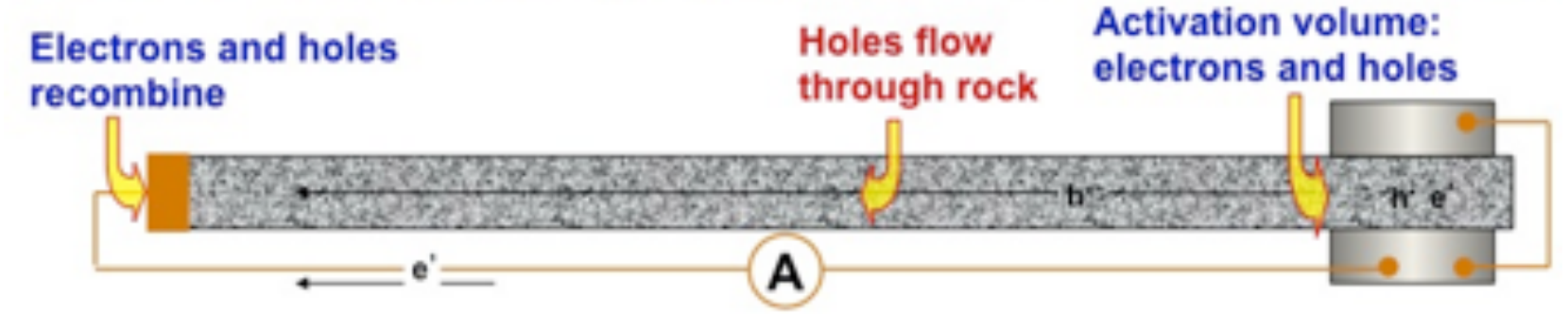
Electrons and holes recombine

Holes flow through rock

Activation volume: electrons and holes



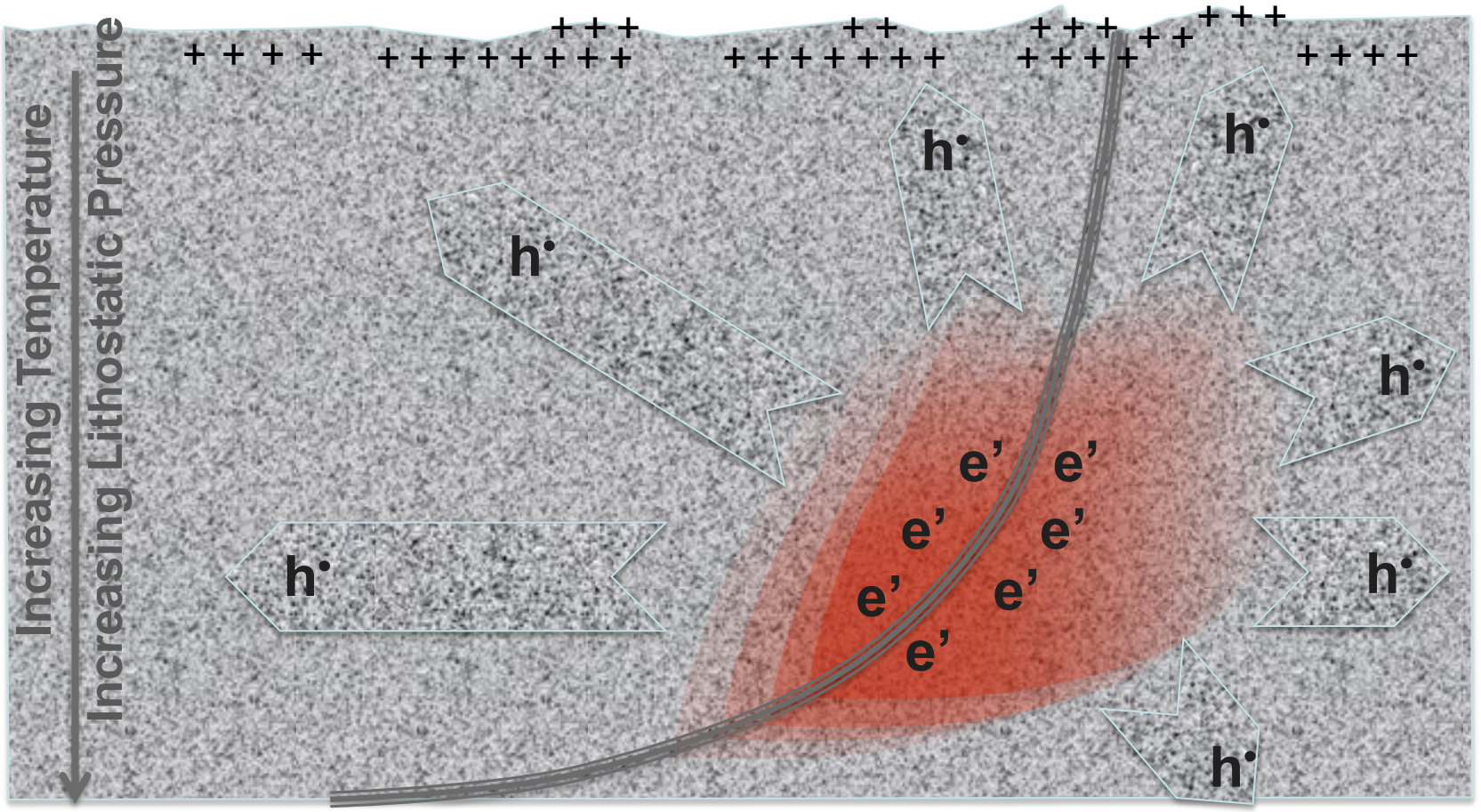




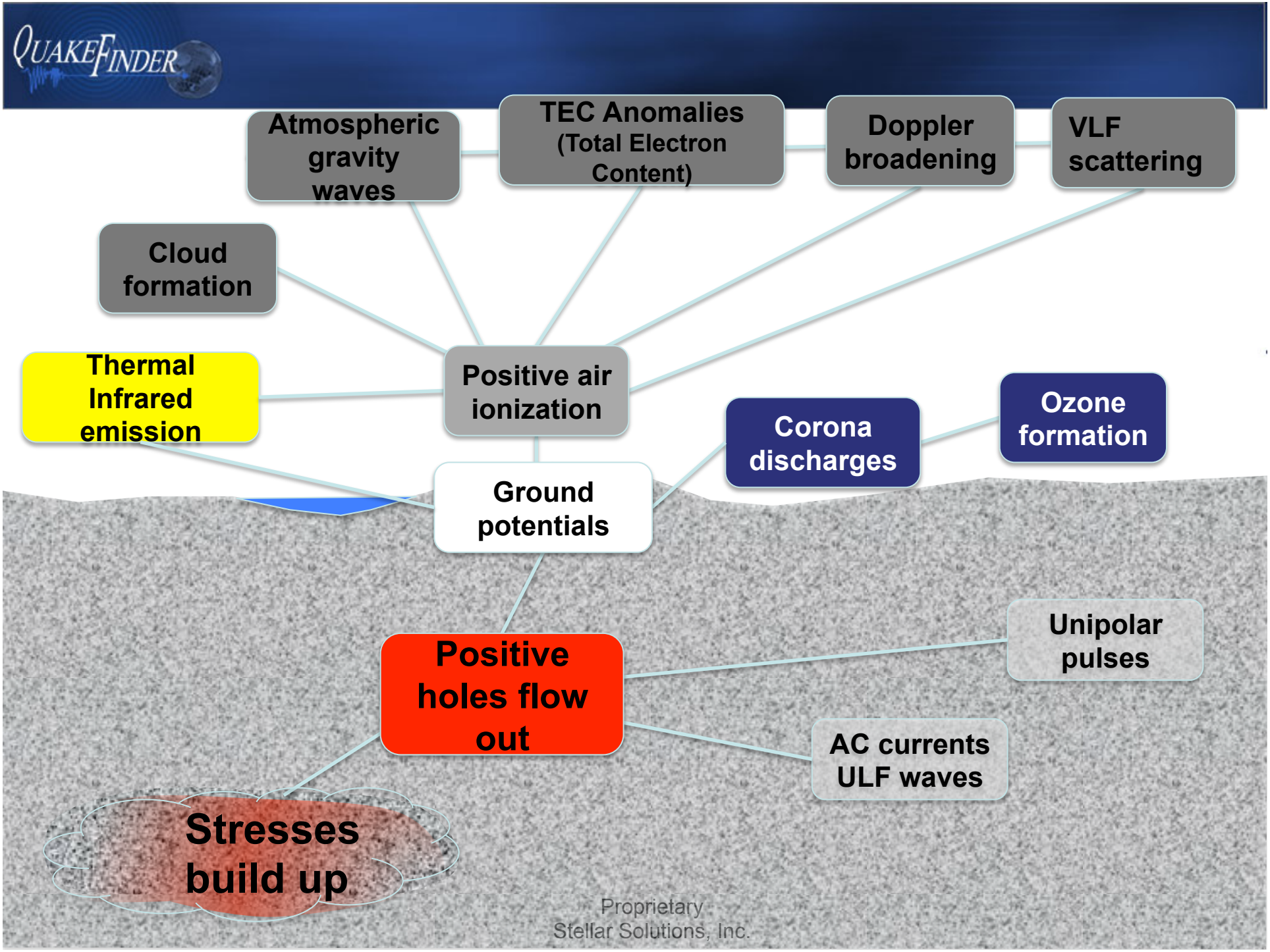
Friedemann Freund

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Outflow of positive holes



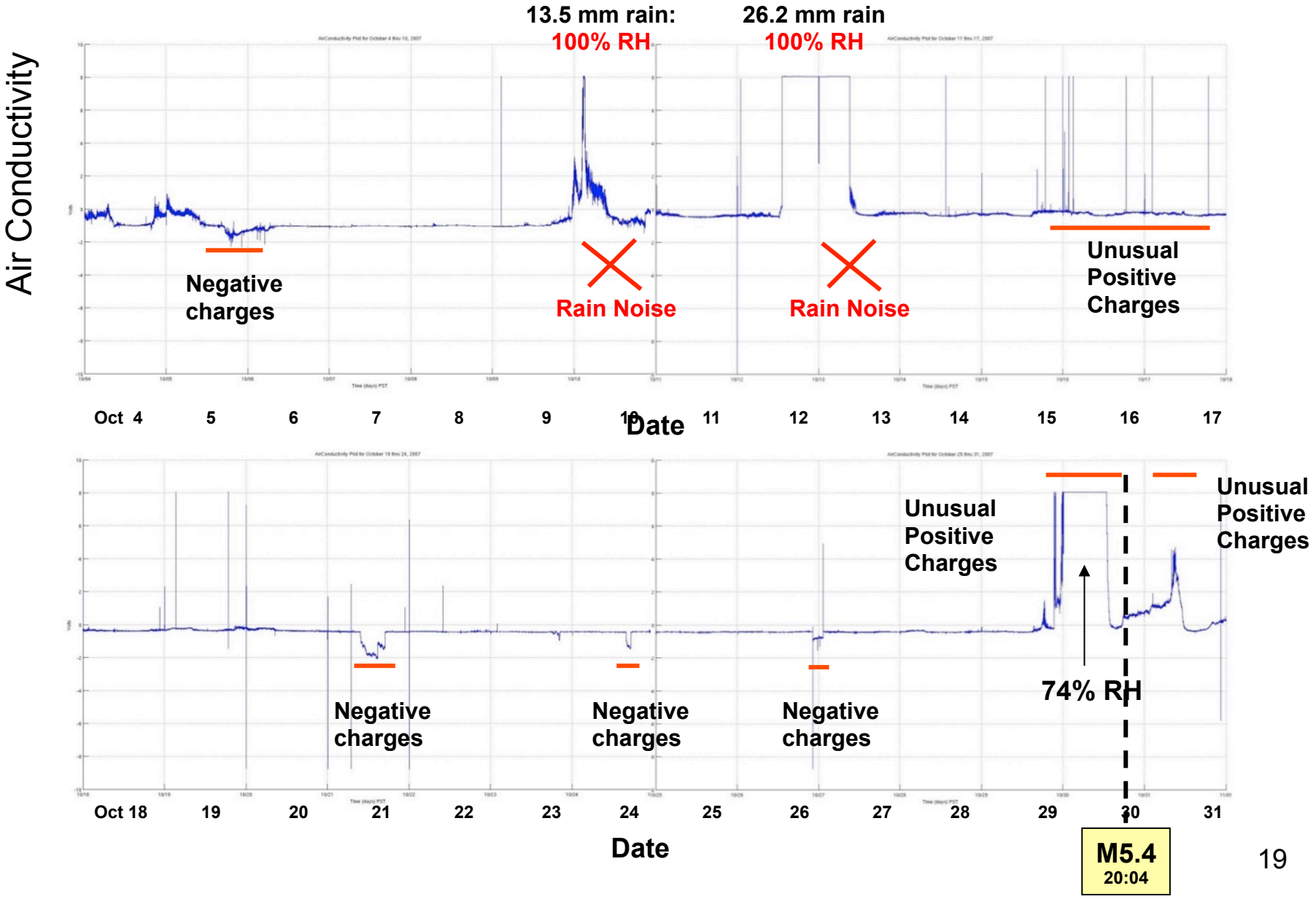
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Example:
Air Conductivity Changes
at Alum Rock M5.4 quake

Air Conductivity at Alum Rock



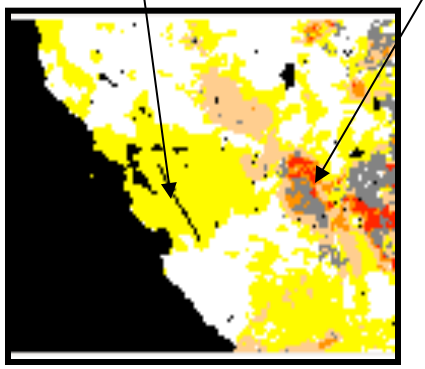
IR night time cooling slopes

Calaveras Fault

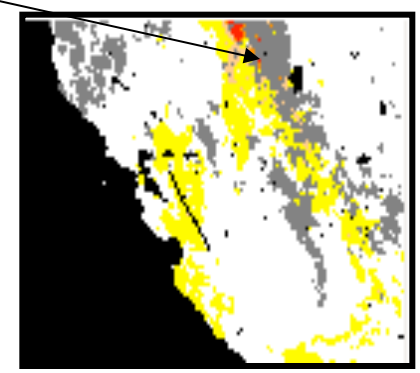
Cloud Covered (Gray/Red)

3 yr avg. slope: -0.0991

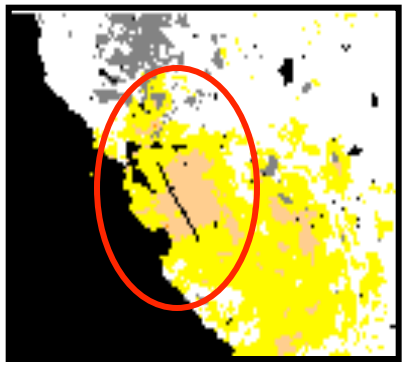
Yellow >+0.1 slope
Pink >+0.3 slope



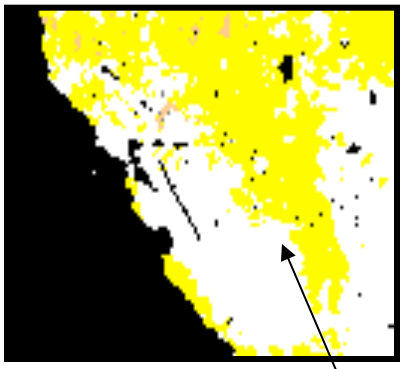
Oct 13, 2007
+0.1465



Oct 16, 2007



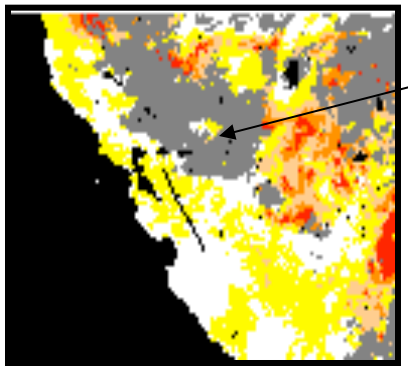
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+0.3616



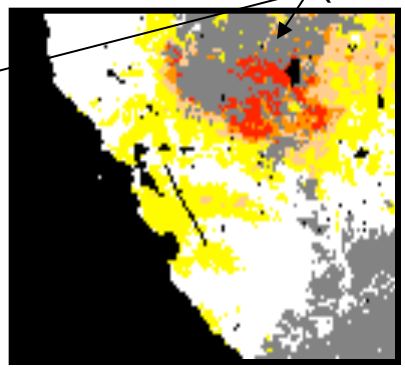
Oct 18, 2007

Cloud Covered (Gray/Red)

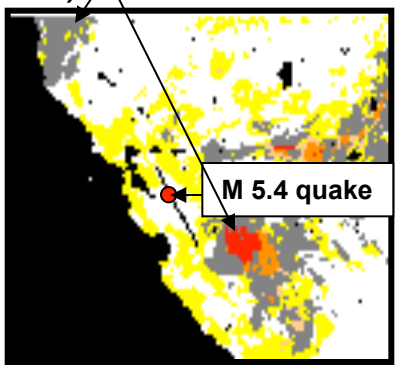
Compression heating



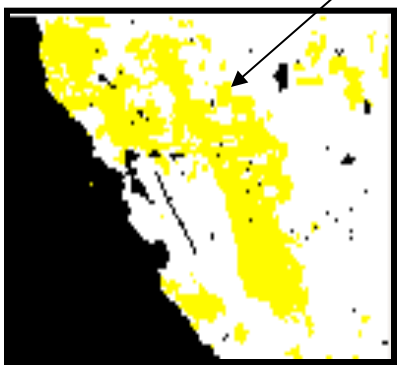
Oct 28, 2007



Oct 29, 2007
+0.2447

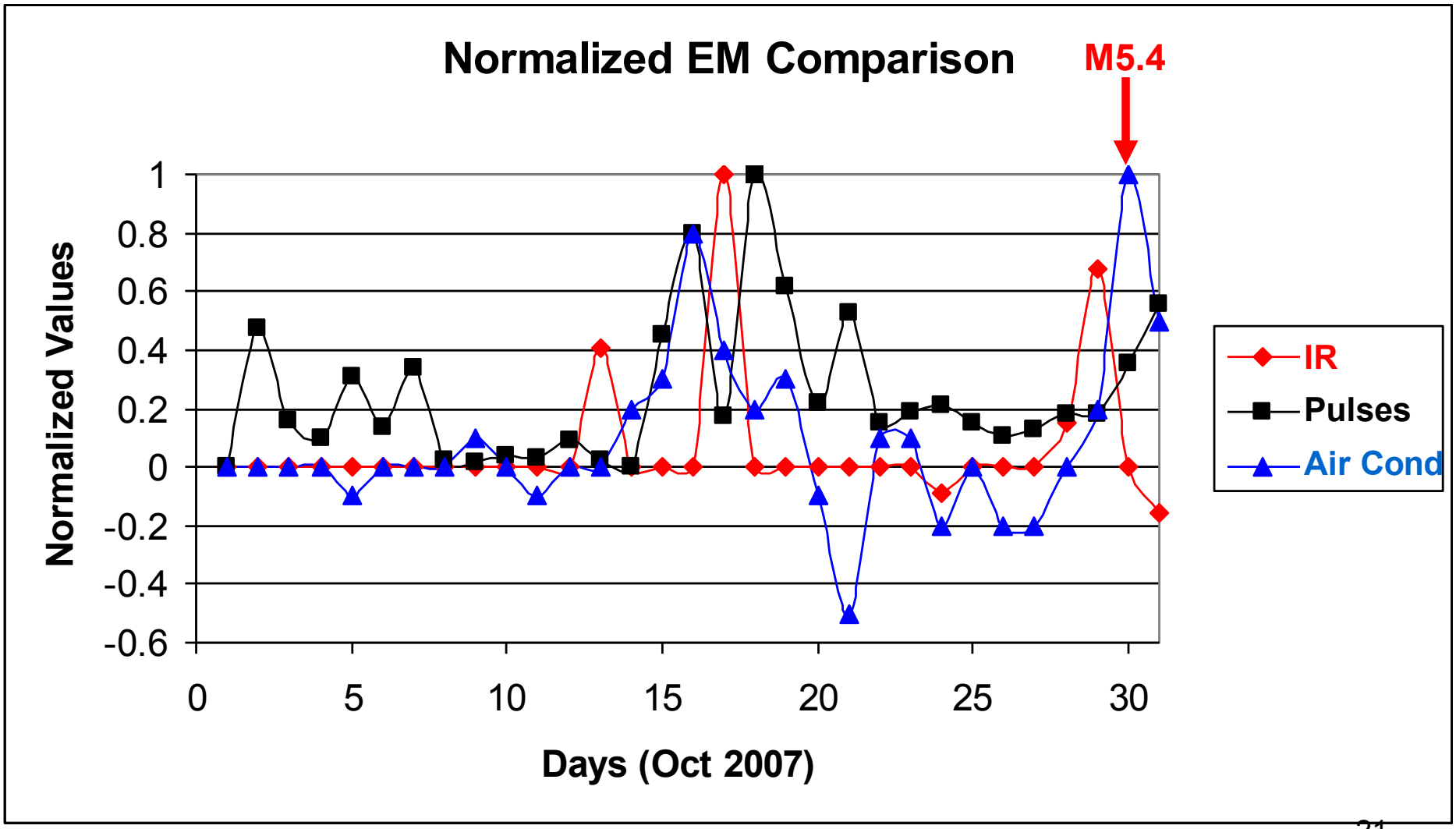


Oct 30, 2007



Oct 31, 2007
-0.0584

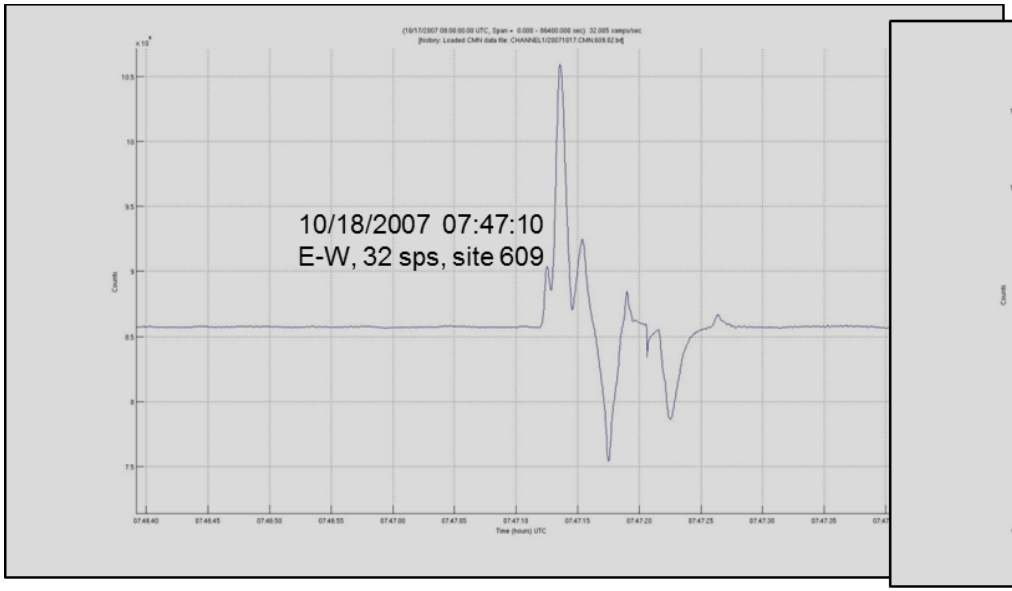
EM Signature Comparison
Alum Rock M5.4

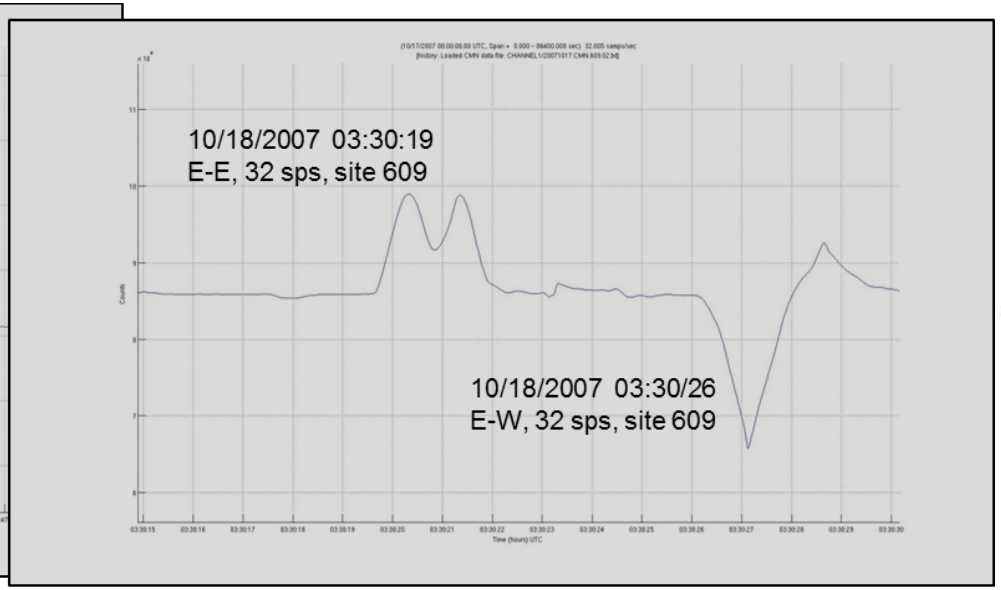


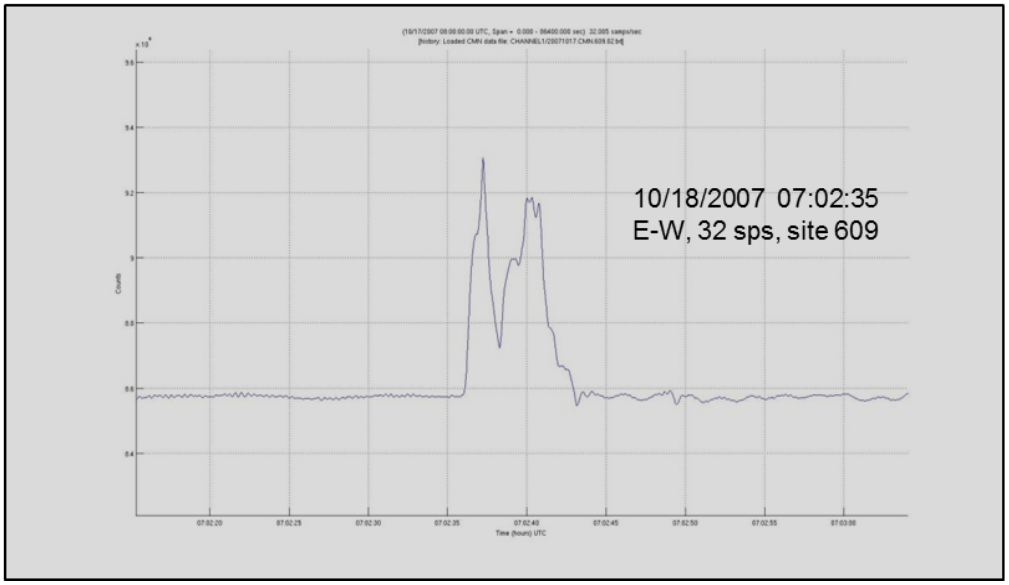
The Problem:



Signal Examples: Unipolar Pulses



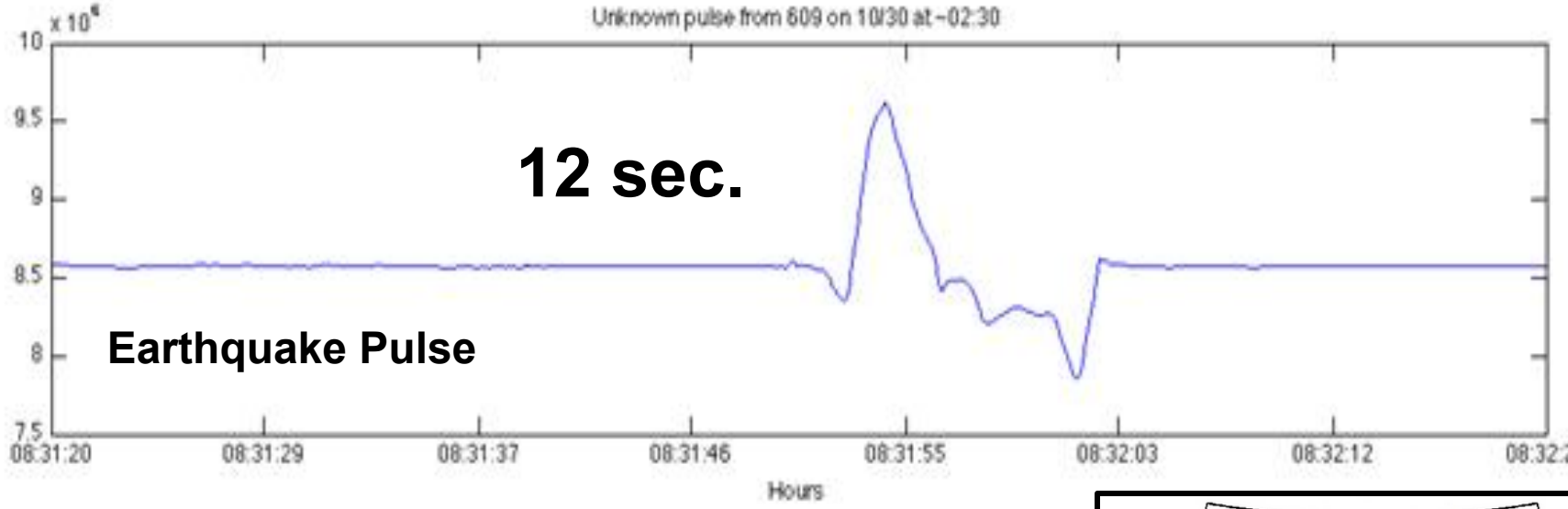


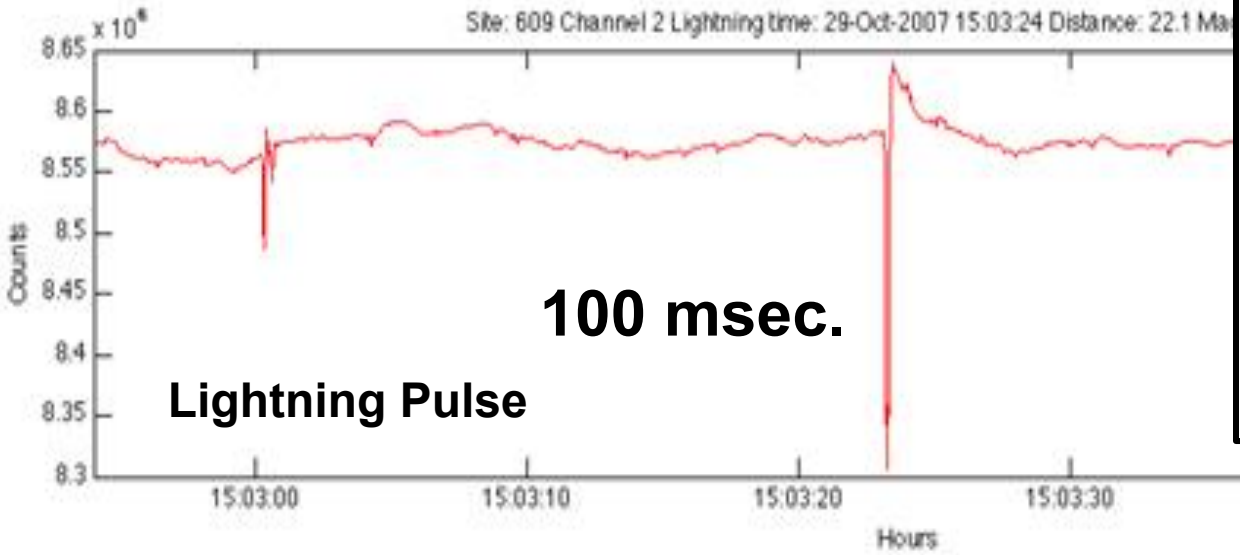


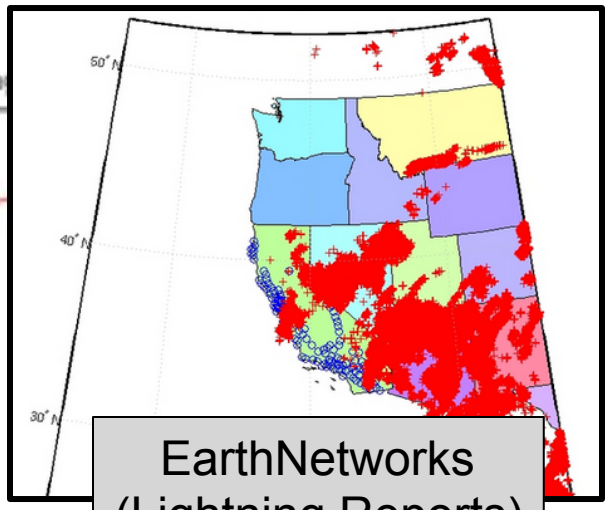
Noise Examples: Nearby Vehicles



Noise Example: Lightning

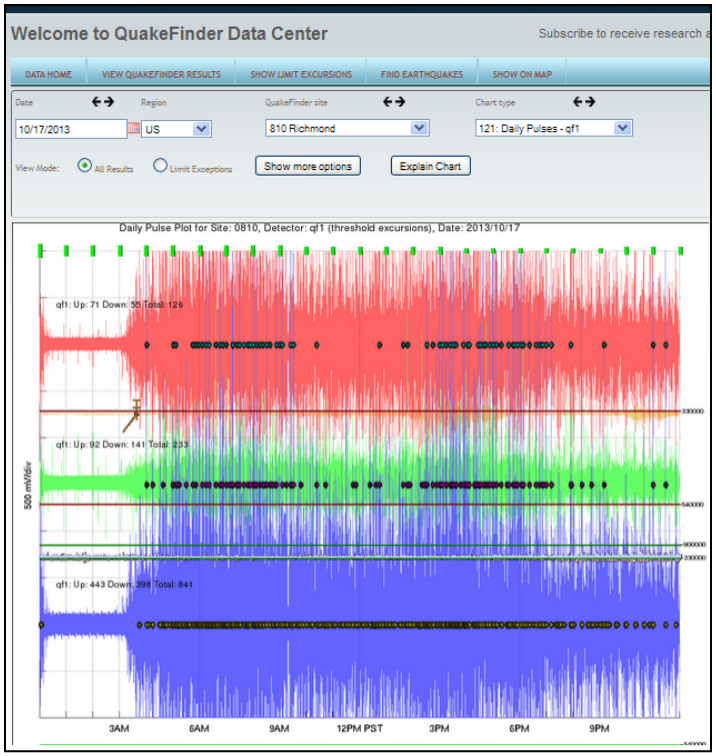




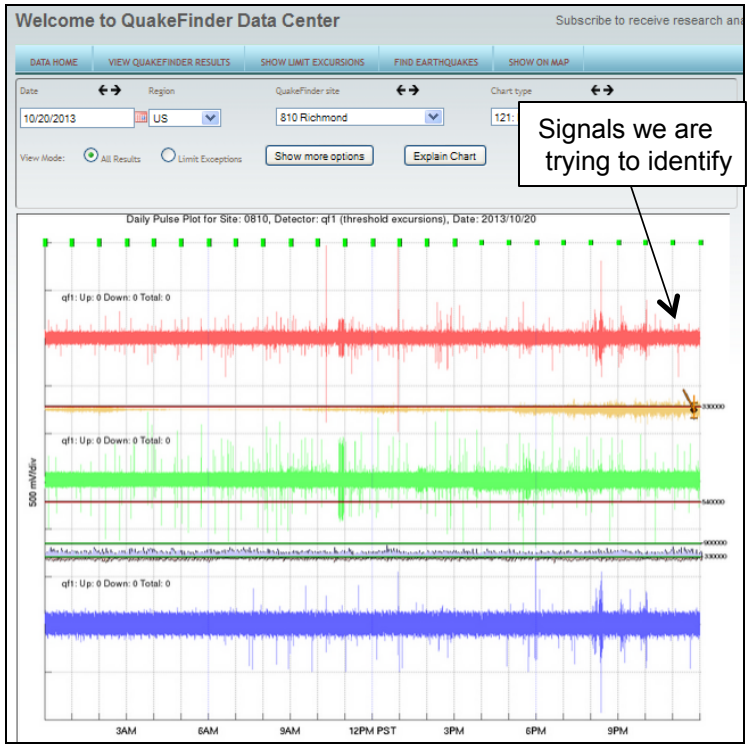


EarthNetworks
(Lightning Reports)

Noise Example: BART trains

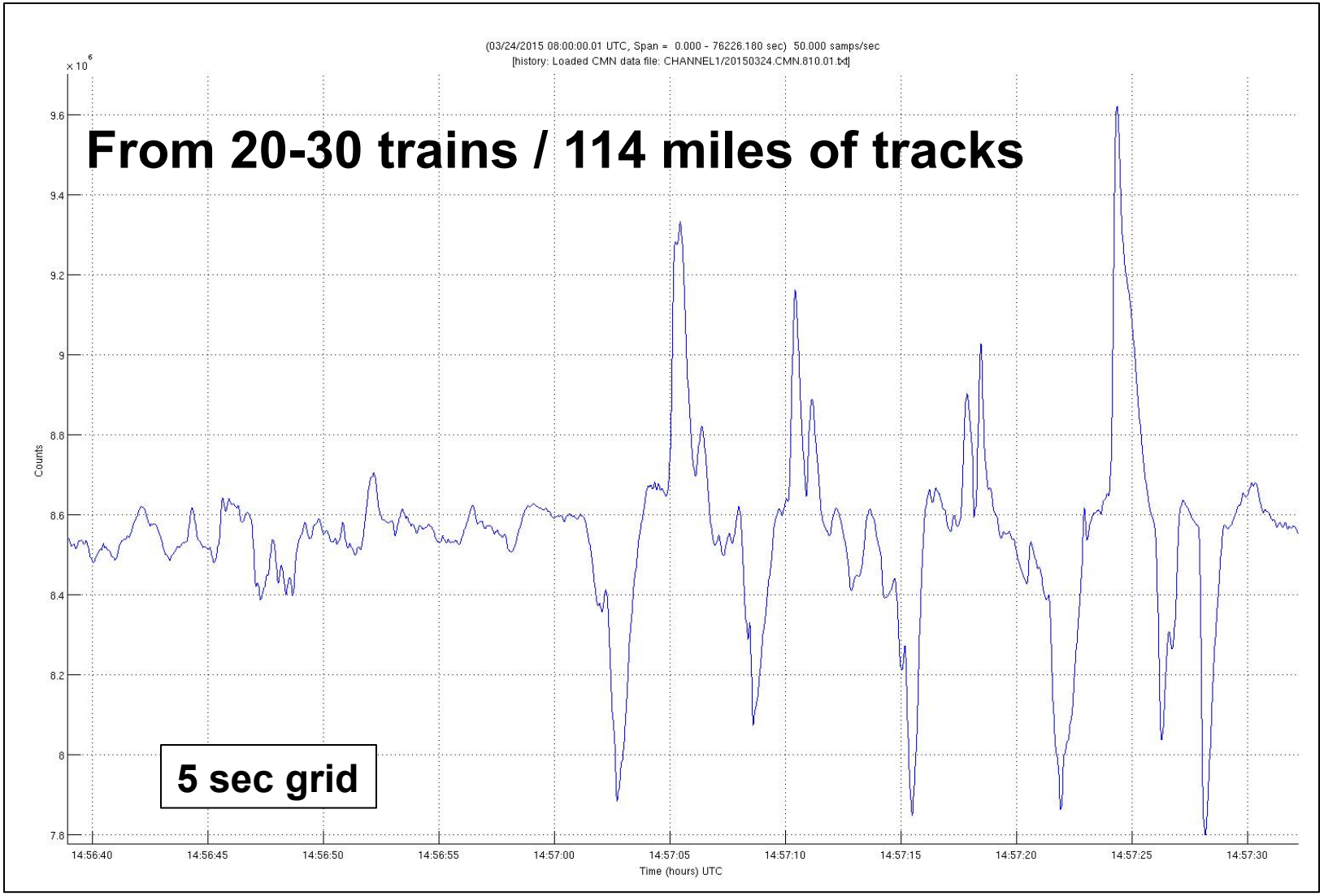


24 Hr time plot
Site 810 Richmond CA.
<5 miles from the tracks



24 Hr time plot
Site 810 Richmond CA.
with BART <u>on Strike</u>

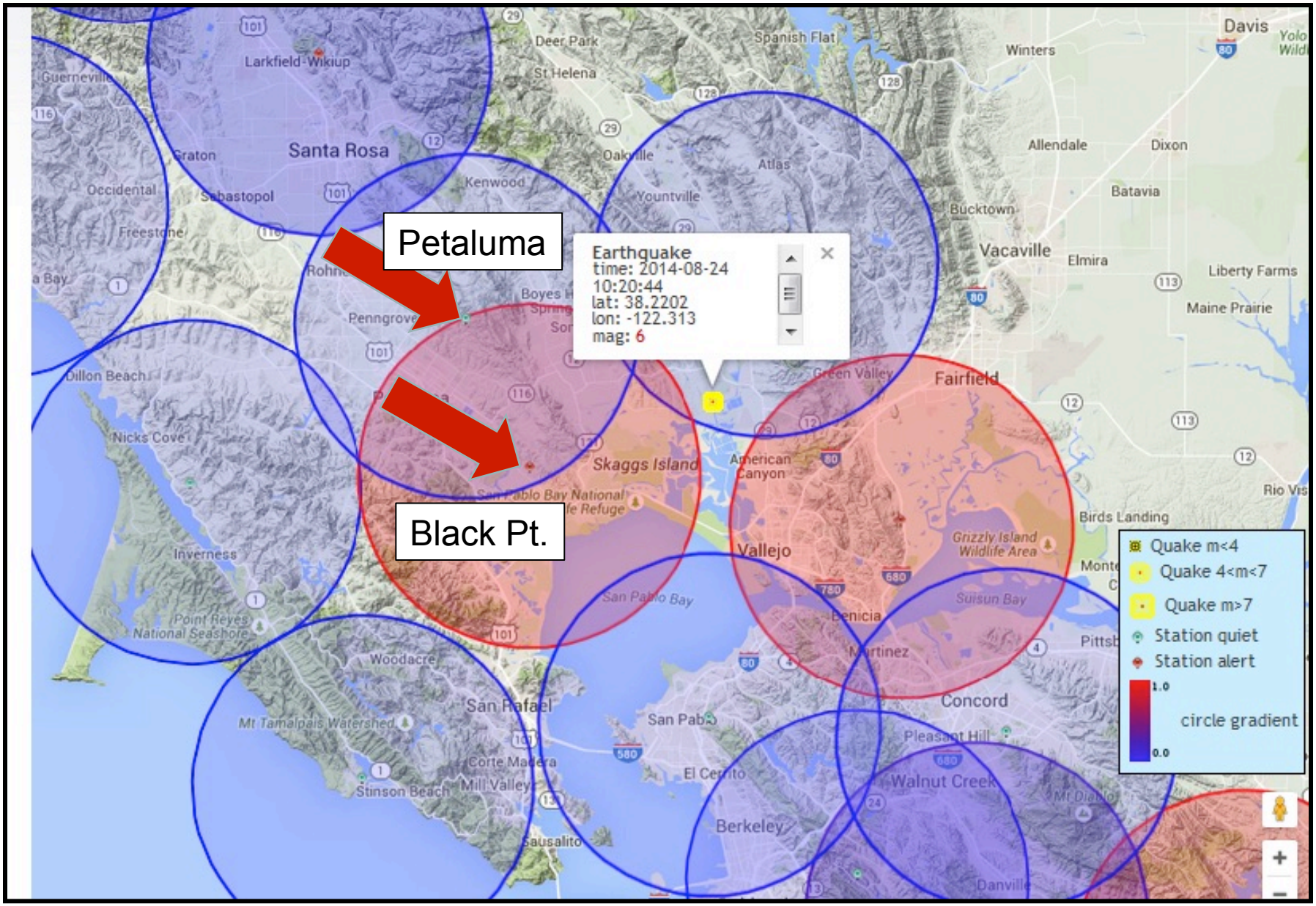
BART Noise Signatures



Some Helpful Techniques

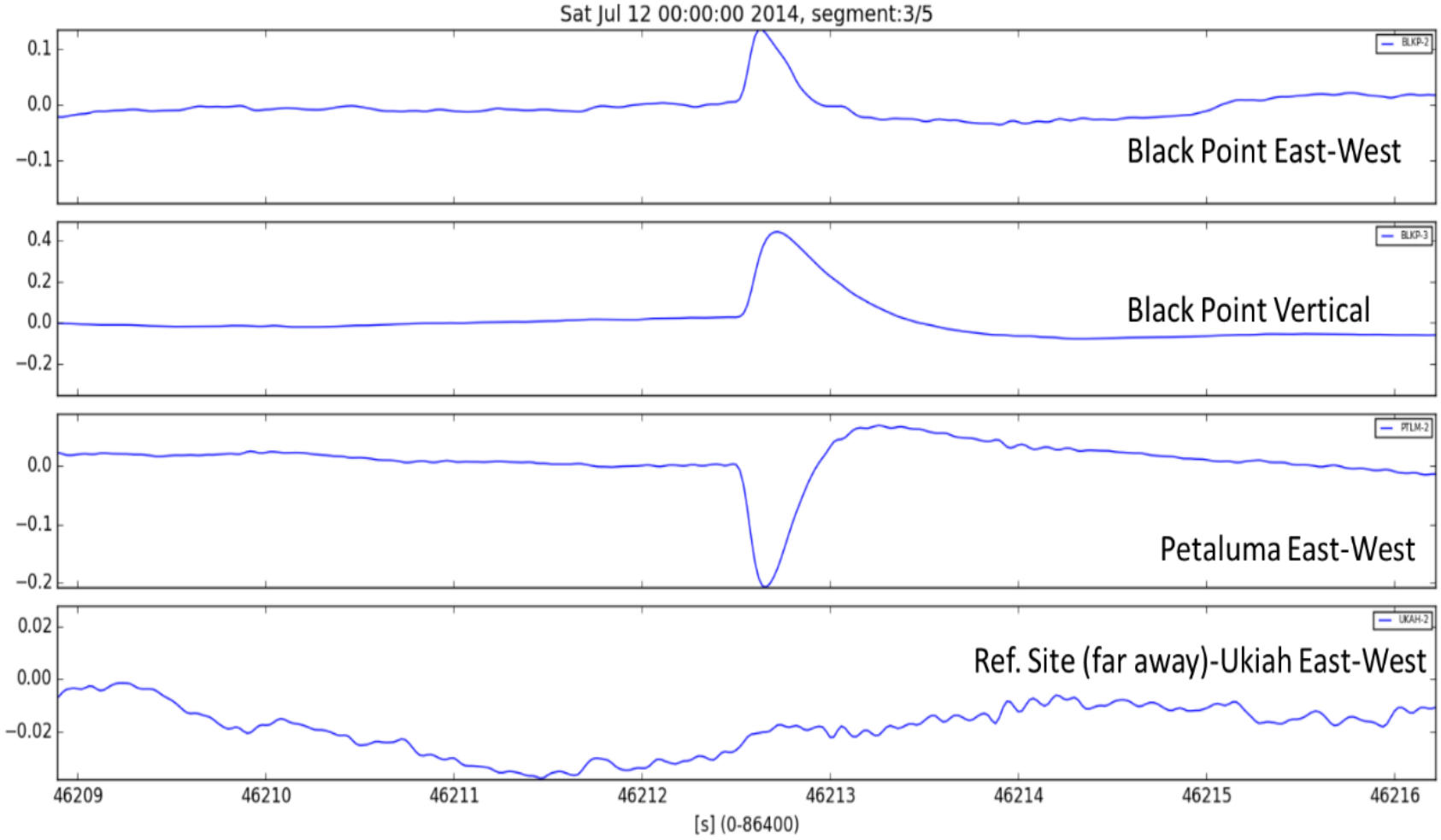
Simultaneous Signals Observed at Adjacent Sites

Aug. 2014 M6 Napa quake near QF Sites



Example: Simultaneous Pulses

Only count pulses that appear on adjacent sites



Summary

- Difficult Signal to Noise Problem
- Identify and subtract each noise element (10-20):
  - Not efficient
- Using Adjacent/Reference sites:
  - Better
- Need outside help to get to “Operational”
  - More sites, more data, more processing
  - Need efficient algorithms, or super computers?
- Ames Interested?