QuakeFinder: 2011
Multiple Electromagnetic
Pre-Earthquake Indicators

Tom Bleier
tbleier@quakefinder.com
(650) 473-9870
Reasonable Hypothesis to Explain EM Signals?

**Data**
- NASA (F. FREUND) Lab Experiments
- Small Currents
  - IR
  - Air Conduct.
- Earthquake lights

**Instrumentation**
- Air Conductivity Sensor
- ULF magnetometers
- ULF magnetic pulses

**Hypothesis**
- Defect Electron Migration
- P-Hole Carriers

**Source**
- Continental Crust
Evidence used to support or reject these hypotheses

Air Conductivity

Surface Charge

Magnetometers

Before

After

Airborne Ion Levels

7 metric ton Yosemite Granite

30 sec.

4 sec. 3 sec. 2 sec.

Magnetic Pulsations

Calibration Signal

Yo semite Gran ite Magnetometers
**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:** 0.1 pT per root Hz @1 Hz; 0.02 pT per root Hz @10 Hz
- **Sampling Rate:** 50 sps
- **Analog Filters:** 100 db 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:** 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](http://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)

Plus:
Honeydew, Kneeland, Ukiah, Mammoth Mt., Tom's Place
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)
Earthquake Pulses
0.1-20nT
0.1 to 20 sec.

Pc1 Micropulsations (solar noise)

Tacna, Peru 23 April, 2010

Approx. 60 seconds
Pulse Discriminator: Duration

Distribution of Pulse Durations

Number of occurrences

Pulse Durations (seconds)
Increased pulse counts over 2 weeks

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

East-West Channel

positive pulses

Short duration pulse excursions 1-2 days each

Alum Rock M5.4 Oct 30, 2007

negative pulses

Increased pulse counts over 2 weeks

Discriminator #1
Second quake near Alum Rock

Table 5. Earthquakes discussed in this paper.

<table>
<thead>
<tr>
<th></th>
<th>Alum Rock 1</th>
<th>Alum Rock 2</th>
<th>Tacna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>31 Oct 2007</td>
<td>7 Jan 2010</td>
<td>6 May 2010</td>
</tr>
<tr>
<td>UTC</td>
<td>03:04:54</td>
<td>18:09:35</td>
<td>03:42:00</td>
</tr>
<tr>
<td>Mag</td>
<td>5.4</td>
<td>4.02</td>
<td>6.2</td>
</tr>
<tr>
<td>Lat</td>
<td>37.432° N</td>
<td>37.4765° N</td>
<td>18.056° S</td>
</tr>
<tr>
<td>Lon</td>
<td>121.776° W</td>
<td>121.797° W</td>
<td>70.5490° W</td>
</tr>
<tr>
<td>Depth</td>
<td>2.2 km</td>
<td>8.98 km</td>
<td>37 km</td>
</tr>
<tr>
<td>Dist</td>
<td>2 km</td>
<td>6.93 km</td>
<td>30 km</td>
</tr>
</tbody>
</table>

CMN609 Channel2 Detector exp5: Number of Pulses for 01-Jan-2006 - 13-Oct-2010

M5.4 Alum Rock
M4.0 Alum Rock 2
Pulse and Quake Activity: Tacna Apr. 1 to Nov 10

- May 5, 2010, M6.2
  - Dist.: 27 km
  - Depth: 37 km

- Apr 23, 2010, M4.1
  - Dist.: 18 km
  - Depth: 32 km

- Oct 22, 2010, M4.7
  - Dist.: 77 km
  - Depth: 52 km

- Nov 6, 2010, M5.2
  - Dist.: 140 km
  - Depth: 103 km

- Nov 3, 2010, M4.8
  - Dist.: 58 km
  - Depth: 50 km
Tacna Pulse Azimuth Clusters

Pulse Azimuth History for CMN704 Tacna: Mar 30, 2010 - May 31, 2010

Site Installation: March 30, 2010
m6.2: May 6, 2010, 03:42 UTC
Plot Date: June 10, 2010

Absolute heading to quake: 334°

15 Days prior
Air Conductivity at Alum Rock

Air Conductivity

13.5 mm rain: 100% RH
26.2 mm rain 100% RH

Negative charges
Rain Noise
Unusual Positive Charges
74% RH

Date
Oct 4 5 6 7 8 9 10 11 12 13 14 15 16

Date
Oct 18 19 20 21 22 23 24 25 26 27 28 29

Unusual Positive Charges

How is “noise” treated in the analysis process?

<table>
<thead>
<tr>
<th>Noise source:</th>
<th>Example</th>
<th>Suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quake Signal</td>
<td>Uni-Polar</td>
<td>N/A</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Pattern (bi-polar)*</td>
<td></td>
</tr>
<tr>
<td>Lightning</td>
<td>Pattern (fast rise)*</td>
<td>Weather Reports</td>
</tr>
<tr>
<td>Pc1 and Pc3 (solar)</td>
<td>High Pass Filter</td>
<td></td>
</tr>
<tr>
<td>Man-made</td>
<td>Multiple Wave Classifier*</td>
<td>* Under development</td>
</tr>
</tbody>
</table>

Pc1 and Pc3 are solar-generated noise
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
3 independent, correlating indicators with Alum Rock quake
• **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

![Normalized EM Comparison Chart](chart.png)
• **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

\[ \Theta_c = 0.01 \text{ deg.} \]

1. Vertical incidence
2. \( \theta < \Theta_c \)
   Oblique incidence
3. \( \theta = \Theta_c \)
   Critical incidence
4. \( \theta > \Theta_c \)
   Total internal reflection (evanescent surface wave)
5. \( \theta >> \Theta_c \)
   Weak surface wave with rapid vertical decay

\( \Theta_c = 0.01 \text{ deg.} \)
Attenuation by Frequency (ELF-VLF) for Below Ground to Air

Transmission Power $P(z)/P(z_0)$

Medium 1: Ground

Medium 2: Air

Frequency: 0.1 Hz and 0.001 Hz

- 1 Hz
- 2 Hz
- 5 Hz
- 10 Hz

Height above ground [km]
Attenuation by Frequency (ELF-VLF) for Ground to Satellite Propagation

The graph shows the normalized power $P(z)/P(0)$ as a function of altitude $z$ in kilometers. The x-axis represents altitude ranging from 0 to 1000 km, while the y-axis represents the normalized power on a logarithmic scale ranging from $10^{-7}$ to $10^0$. The graph includes lines for different frequencies: 10 Hz (blue), 100 Hz (green), 1 kHz (red), 10 kHz (cyan), and 100 kHz (magenta).