Earthquake Forecasting Technology and Applications to Geo-Magnetic Disturbances

i-PCGRID Workshop 2016
March 31, 2016
• Use of Ultra Low Frequency (ULF) Magnetic Field Monitoring
  – Earthquake Forecasting
  – Geomagnetic Storm Effects

• Earthquake Forecasting
  – 1 to 14 day patterns prior to large earthquakes
  – ULF magnetic disturbances, Ions, Infrared

• Geomagnetic Storm Monitoring
  – Coupling of Geomag. Storms to Power Lines
  – Potential help in modelling Solar Storm Effects
100 Years Ago
Most people believed weather forecasting impossible

30 Years Ago
There were no accurate hurricane tracking forecasts

10 Years Ago
There were no accurate tornado forecasts

It is a matter of WHEN not IF
Earthquake “Forecasting” Ecosystem - Today

**Seconds of warning**
- Earthquake “Early” Warning (EEW) systems
- Based on seismic detection of a quake after it has occurred

**Days of warning**
- QuakeFinder is developing technology to provide forecasts days or weeks in advance of earthquakes

**Decades of warning**
- 30-year probabilities
- Based on statistical analysis
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.
In this phase of the project, we use known earthquakes near our instruments to build and qualify algorithms to detect earthquake precursor signals.
Alum Rock Results

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

Map showing the location of Alum Rock near San Jose, CA.

Graphs showing earthquake pulses and normalized EM comparison for the event.

Legend:
- IR
- Pulses
- Air Cond

Additional notes or annotations related to the event data.
Peru Algorithm: Napa M6.0 quake

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Inicio: 2014-0701
Fin: 2014-0831

CMN871 Napa Valley
Lat: 38.3445276
Lon: -122.2566369

CMN870 Benicia
Lat: 38.1240361
Lon: -122.1160411

CMN869 Black Point
Lat: 38.167653
Lon: -122.509267

Puente California

Skaggs Island

San Pablo Bay National Wildlife Refuge

INSTITUTO DE RADIOASTRONOMIA

Eventos: Julio - Agosto 2014
TRIANGULACION ELECTROMAGNETICA DE EVENTOS SISMICOS
Status Today

• QF has collected 10 years (50 TB) of data
• Observed similar patterns from dozen quakes
• Predictive ability demonstrated
  – Japan (Hattori) Study (100 quakes)
  – 3 successful forecasts (Peru)
  – Crowd sourcing contest (2 successful algorithms)
  – QF now using advanced signal/pattern algorithms
  – This year: 10 year retrospective algo testing
• 1-14 day Forecasting in 3-5 years?
How to Use these Forecasts?

• **Pre-Position Repair Assets**
  – Similar to preparations for large storms today

• **Better Prepared for Backup Power Switching**
  – Alert Grid Operators and Outside Power Suppliers

• **Should Practice it in Simulations**
GEOMAGNETIC STORM MONITORING
Solar Storm Monitoring Today

“National Priority” to protect Electric Grid from Solar Storms (OSTP directives)

Today: Receive solar storm forecasts from NOAA
• Satellite Data: GOES, SOHO, ACE, and now DSCOVR
How Much Energy Is Transferred to Power Lines?

- Depends on:
  - **Size** of Corona Ejection
  - **Direction** of the Ejection (towards Earth?)
  - **Where** on Earth (sun side, Latitude)
  - **Length** of transmission lines
  - **Ground conductivity**
  - Other factors?

- Monitoring tools today:
  - NOAA Space Wx Site (Grid Dashboard)
  - USGS Fluxgate magnetometer sites (Kp)
QF Sensors vs. Kp Network

- **Higher Sensitivity**
  - QF 1000x more sensitive than USGS magnetometers

- **Higher Sample rates:**
  - QF Induction: 50 sps  Fluxgates: 1 sps

- **Better Spatial Resolution**
  - QF 125 sites across California (Eureka to Mexico)
  - 40 Sites (Peru, Chile, Taiwan, Greece, Sumatra)
  - USGS less than dozen in US
Pre-Solar Storm – Mar 15, 2015

Welcome to QuakeFinder Data Center

Date: 03/15/2015
Region: US
QuakeFinder site: 0872 Parkfield 2
Chart type: 121: Daily Pulse - af1

View Mode: All Results

Kp (3 hour avg)
QF 3 axis Induction mag data (50 sps)

Normal/Quiet Day

North-South
East-West
Vertical
Solar Storm Start – March 16, 2015

QF Network detected 11 hours earlier

QF detects onset (-11 hrs.)

Kp detects onset

Kp

QF

QF Network detected 11 hours earlier
Solar Storm Max – March 17, 2015

Welcome to QuakeFinder Data Center

High resolution data

GIC (Geomagnetic-Induced Current)

Kp

QF
High-Res Solar Storm Observations

Solar Storm (Parkfield)

10-18 sec period
Pc3 waveforms

Lightning (Bolinas)

100 msec. period

Large Solar Storm captured at 50 samples/sec by QF sensors
Solar Storm Aftermath - Mar 21, 2015

Kp: Storm Finished (?)

QF: Storm Not Finished
Kneeland near Eureka
Medium Amplitude

S. San Jose nr PG&E substation
Larger Amplitude

Laguna Beach
Smaller Amplitude

Factors Captured by QF
- Latitude
- Localized ground conductivity
- Diurnal effect
Comparison of QF Vs USGS Sites

USGS Sites:
- Fresno
- Tucson

QF Site:
- Julian
Comparison of QF Vs USGS Sites

All sites zero centered
Fresno offset by 100 nT
Tucson offset by 200 nT
(for ease of comparison)

- Similar magnitudes
- Good Correlations
- Some phase differences at ULF
Comparison: QF Vs USGS Sampling

Expanded View of Sampling Comparison

Julian sampling (50 sps) Blue dots
Fresno sampling (1 sps) Green dots

Missed pulses at Fresno

Green dots are 1 sps data

18 Sec.
Comparison: QF Vs USGS dB/dt

Differentiated data (dB/dt)

Tucson

Lower frequencies only

Fresno

Lower and higher frequencies

Julian

Note:
During solar storms, areas of sustained higher dB/dt corresponds to times of major coupling to power lines and larger induced currents on neutral lines.
One Suggestion:

- **QF has years of Mag Data** – Many locations
- **Grid Operators are concerned about:**
  - Transformer Heating/Damage
  - Grid Instabilities
- **Compare Transformer Data with Mag data**
  - Neutral line currents
  - Heating
  - Transmission Stability
How Can QuakeFinder Help?

• **Partner with Researchers using QF Hi-Res induction data:**
  – Solar Shield & Disaster Apps (NASA)
  – Induction Hazard Research (USGS)
  – Resilient Systems (DHS S&T)
  – Space Weather Center (NASA & USAF)
  – Sun Burst (EPRI)
  – Electric Utilities (PG&E)
  – Universities

• **Collaborate on a pilot program?**
  – Near real-time induction data feed to Solar Shield
  – Bridge space & ground based observations
  – Public-Private Partnership

• **Address National Space Weather Strategy research goals**
  – Detection, modeling and national preparedness
  – “Monitor, Model, Mitigate”
Magnetometers: (3)
- Induction Type Magnetometers (Models ANT4 and QFIDO-3)
  - Length: 76.2 cm (30 In.)-QFido3, 127 cm (50 In.) Ant4
  - Width: 3.8 cm (1.5 In.) QFido3, 8 cm (3 in.) Ant4
  - Weight: 0.927 kg. (2lb. 0.7 oz) QFido3, 25.3 kg. (11.5 lb) Ant4
  - Frequency Range: 0.01 to 12 Hz (low pass filter @12 Hz)
  - Sensitivity @1Hz: 0.1 V/nT QFido3, 1.0 V/nT Ant4
  - 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
  - Sensor sampling: Differential coupled to 8 channel, 24 bit, analog-to-digital converter

Air Conductivity Sensors: (2)
- 1 measuring positive ions; 1 measuring negative ions
- Type: "Gerdien Tube", with a fan which pulls air through the meter at a calibrated rate
- Unit is enclosed in a static-shielded, PVC tube with cover for rain protection
- Conditions: Air Ion Counter -10° C to 50° C, Wind Speeds < 15 km/hr (9mph)
- Range/Resolution:1 million ions / cc / sec. range 500 ions /cc/sec resolution
- Accuracy:+/- 25% of reading

Also: 4 Hz Geophone, Humidity, Temp. health data, solar powered, Verizon cell phone connectivity, 60MB/day, 10 sec “Heartbeat” messages, GPS timing, Processed data shown on web each day