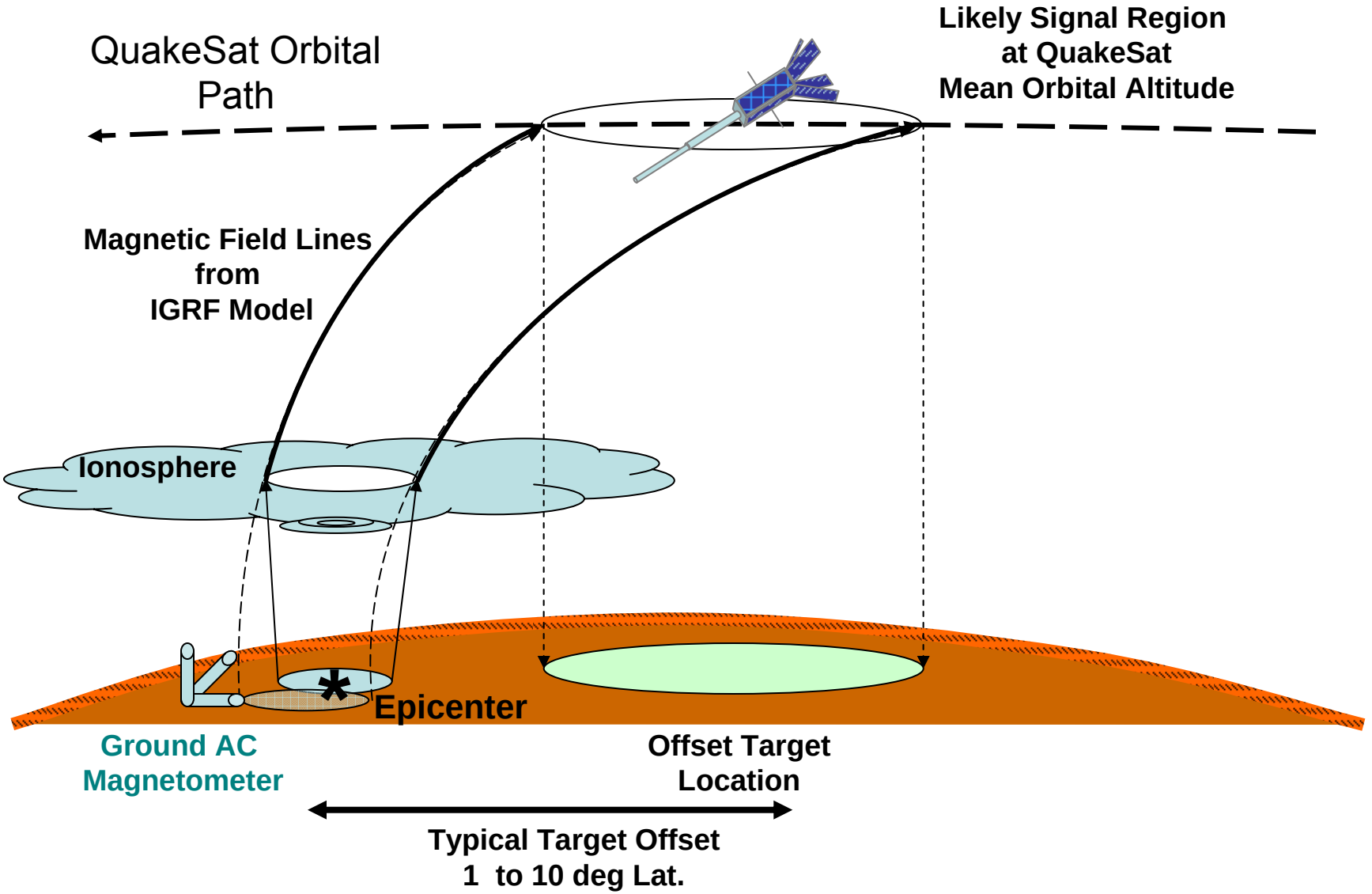
Simultaneous ELF Magnetic Field Monitoring of Earthquakes from a Nano-Satellite (QuakeSat) and a Ground Network

IWSE L3-3

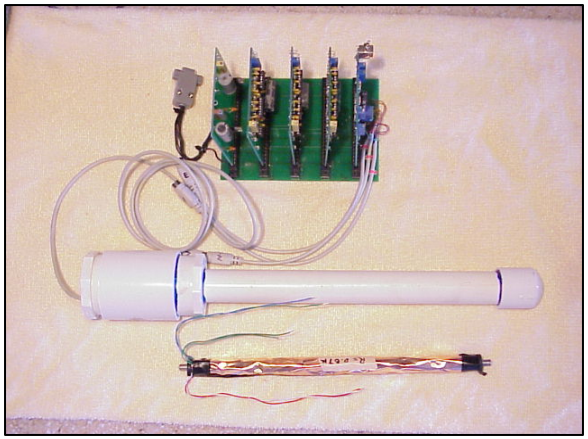
March 17, 2005

Tom Bleier (650) 473-9870 tbleier@quakefinder.com
Clark Dunson (650) 814-4258 cdunson@quakefinder.com

Space and Ground Monitoring



Ground Magnetometers



High School System

Commercial QF 1000 and 1003 Systems

0.3 to 4 Hz BW
3pT noise floor
20 Hz sample rate, raw data stored @ site
300 sec RMS data displayed daily on web site

Coverage Area
www.earthquaketracker.com

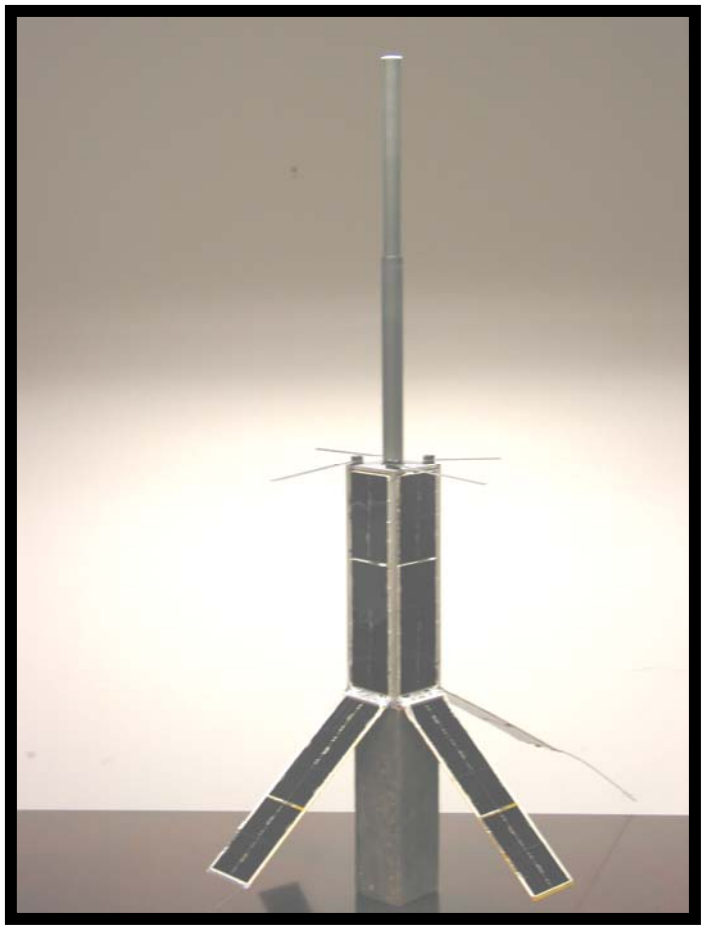
High School
- 3 axis mag.

QF-1000
- 3 axis mag.

QF-1003
- 3 axis mag.
- GPS
- GlobalStar
- Air Conduct.
- Geophone

Satellite-Based Monitoring (QuakeSat)

- **QuakeSat on orbit (June 30, 2003 to Dec 2004)**
  - **840 km circular, sun synch orbit (dawn-dusk)**
  - **Single axis search coil magnetometer, small E-field dipole**
  - **4 channels (one at a time)**
    - **1-10 Hz B**
    - **10-150 Hz B (primary channel)**
    - **130-150 Hz E and B**
    - **10-1000 Hz B**
  - **Sensitivity – noise floor**
    - **5pT at 1000 Hz**
    - **15 pT at 100 Hz**
    - **30 pT at 10 Hz**
  - **2 ground stations**
    - **Stanford**
    - **Fairbanks Alaska**
    - **9600 baud, half duplex**

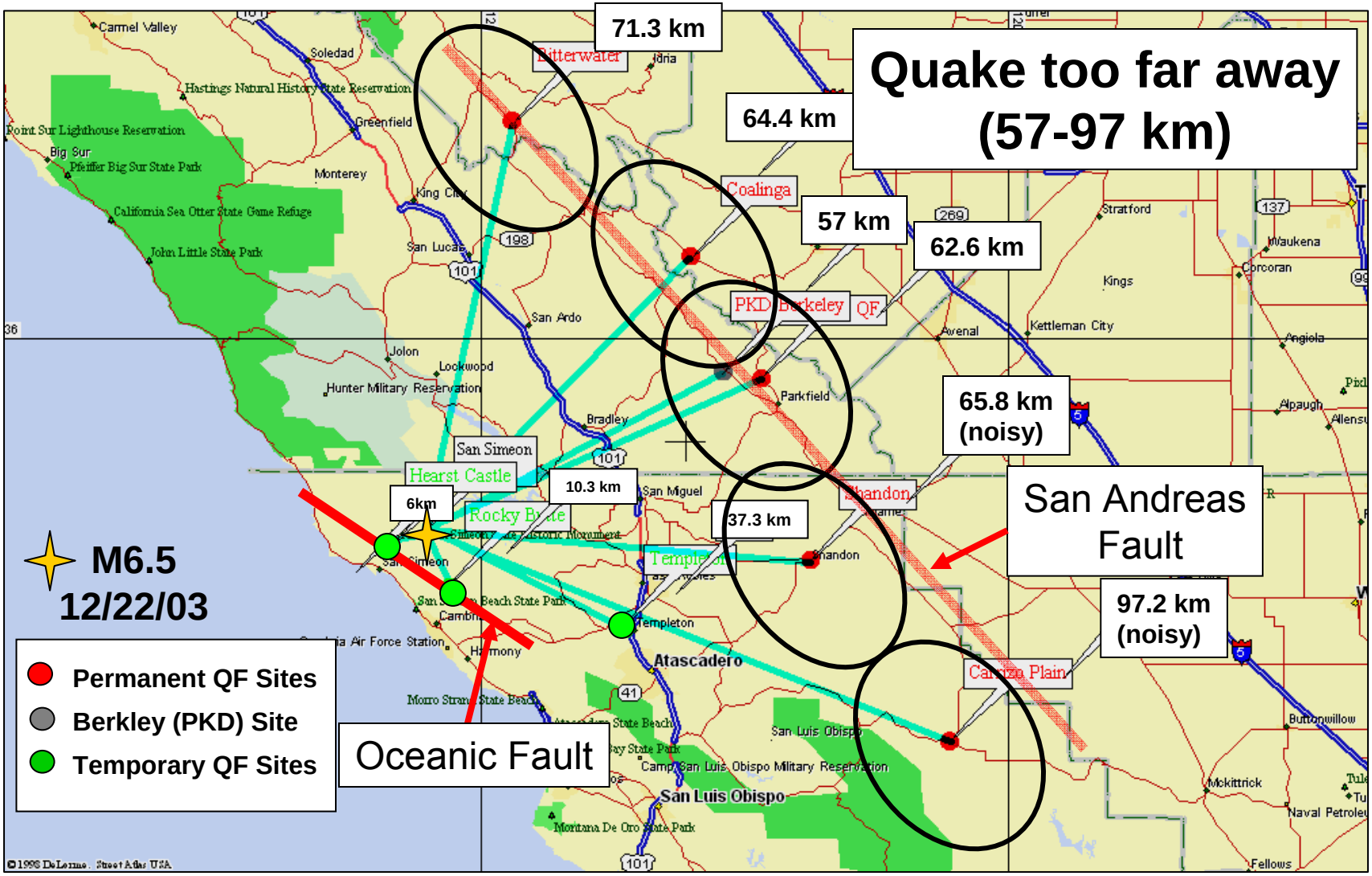


San Simeon
ELF Observations

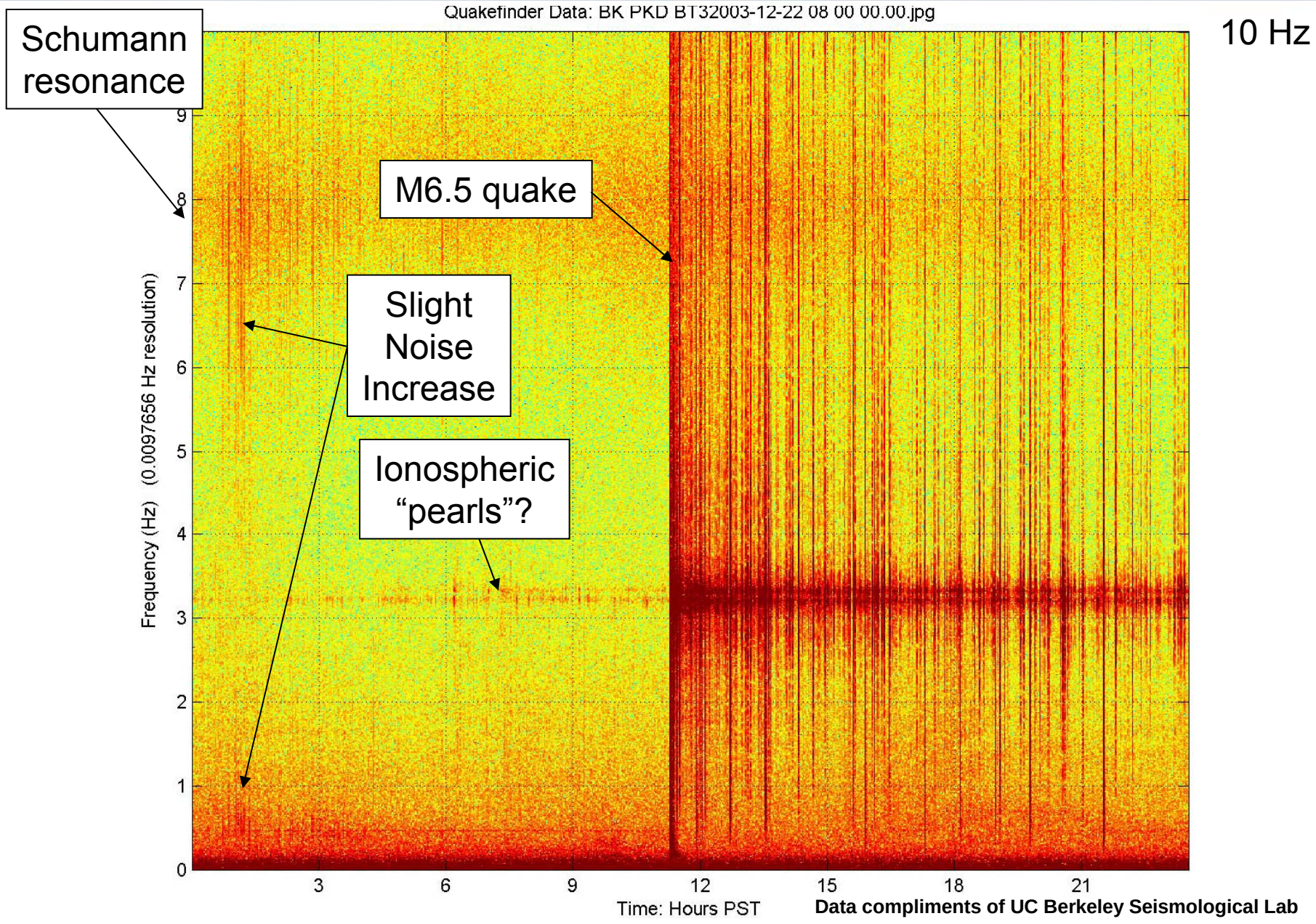
Ground Monitors

(Berkeley and QuakeFinder)

ELF Monitor Site Locations with Distances to San Simeon M6.5



Enlargement: San Simeon M6.5 12/22/03



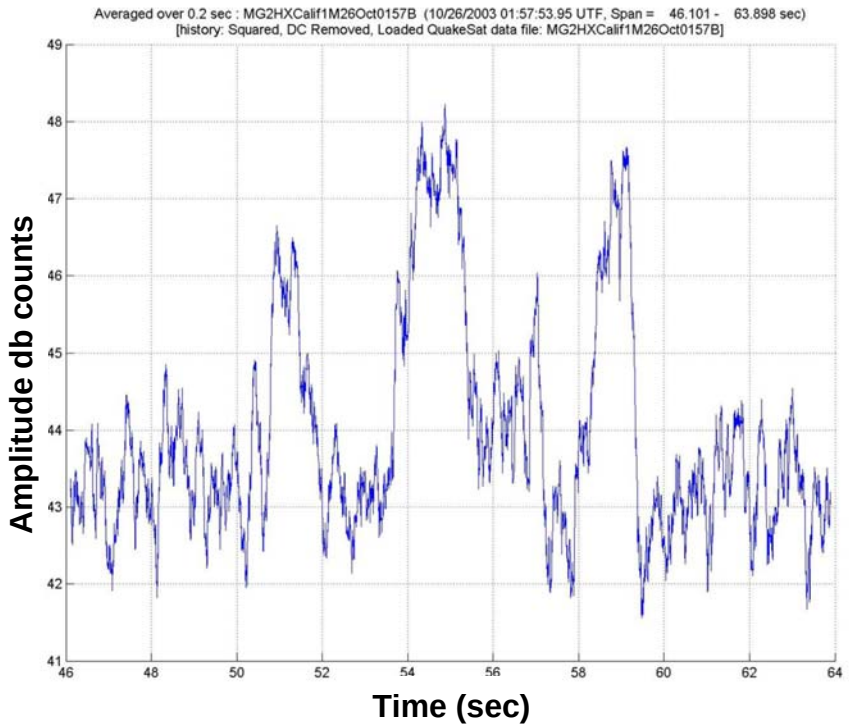
Data compliments of UC Berkeley Seismological Lab

San Simeon
ELF Observations

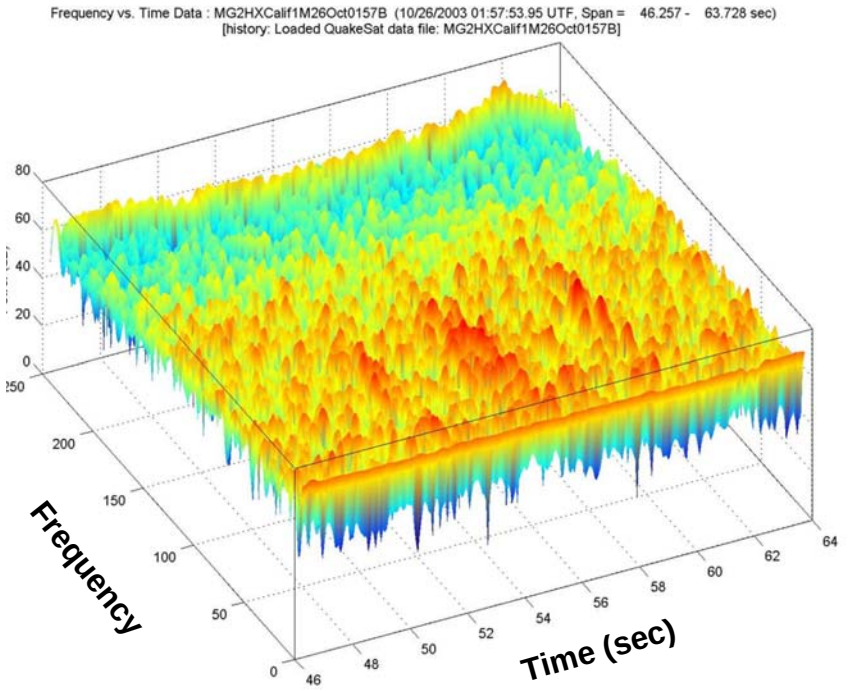
QuakeSat

San Simeon Earthquake -57 days

Power

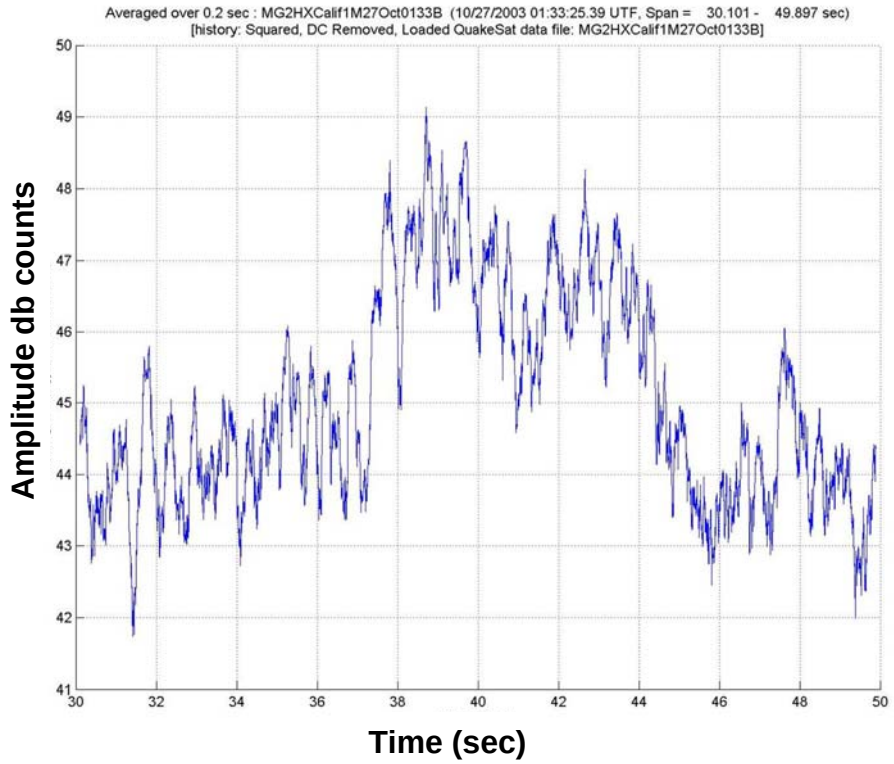


Frequency (10-150 Hz)

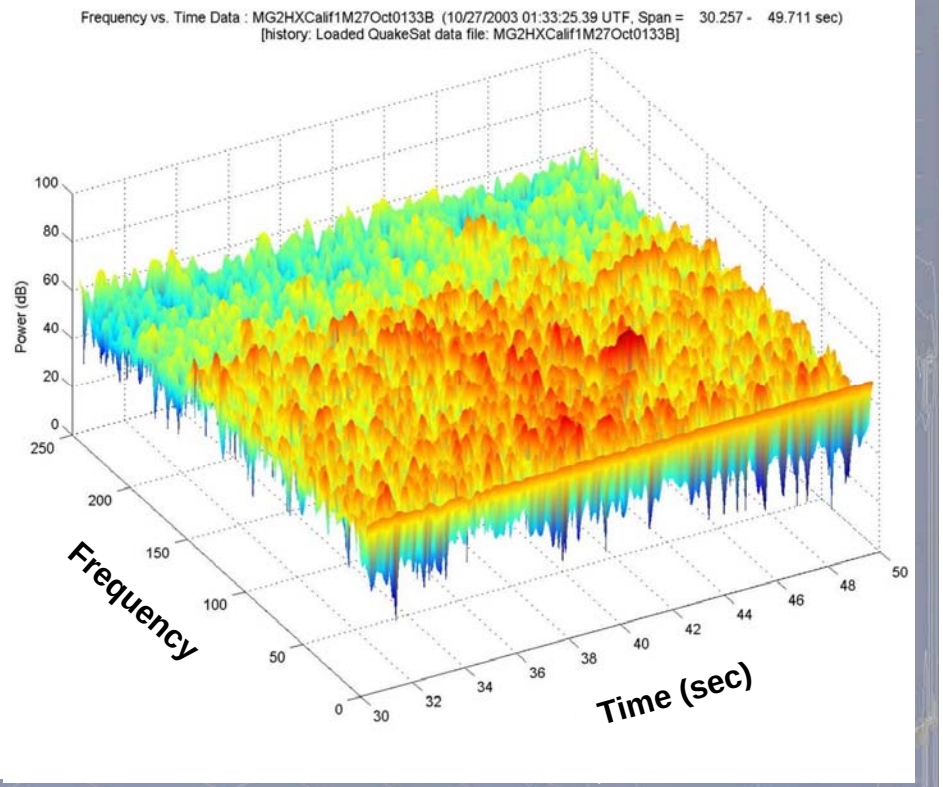


San Simeon Earthquake -56 days

Power

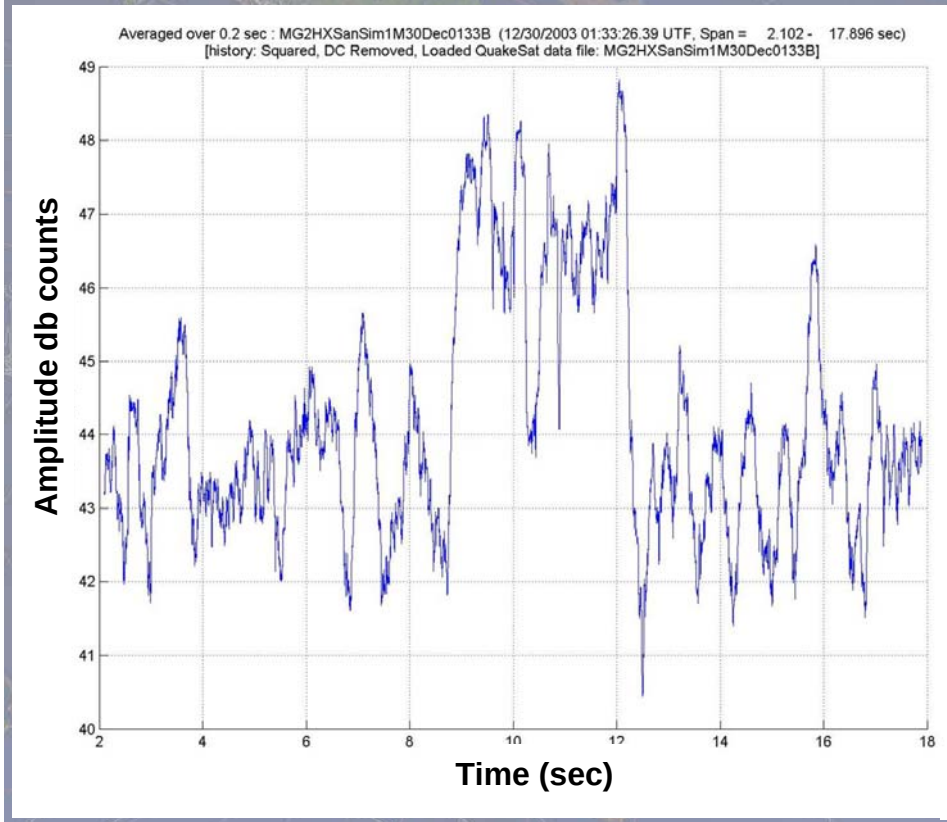


Frequency (10-150 Hz)

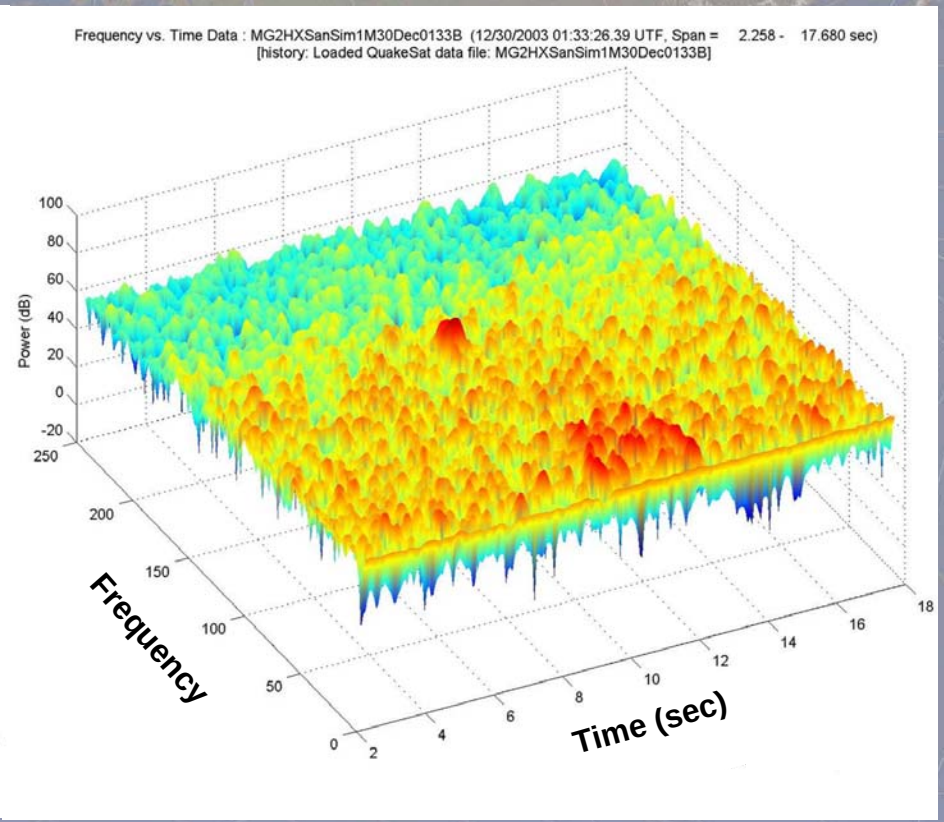


San Simeon Earthquake +8 days

Power

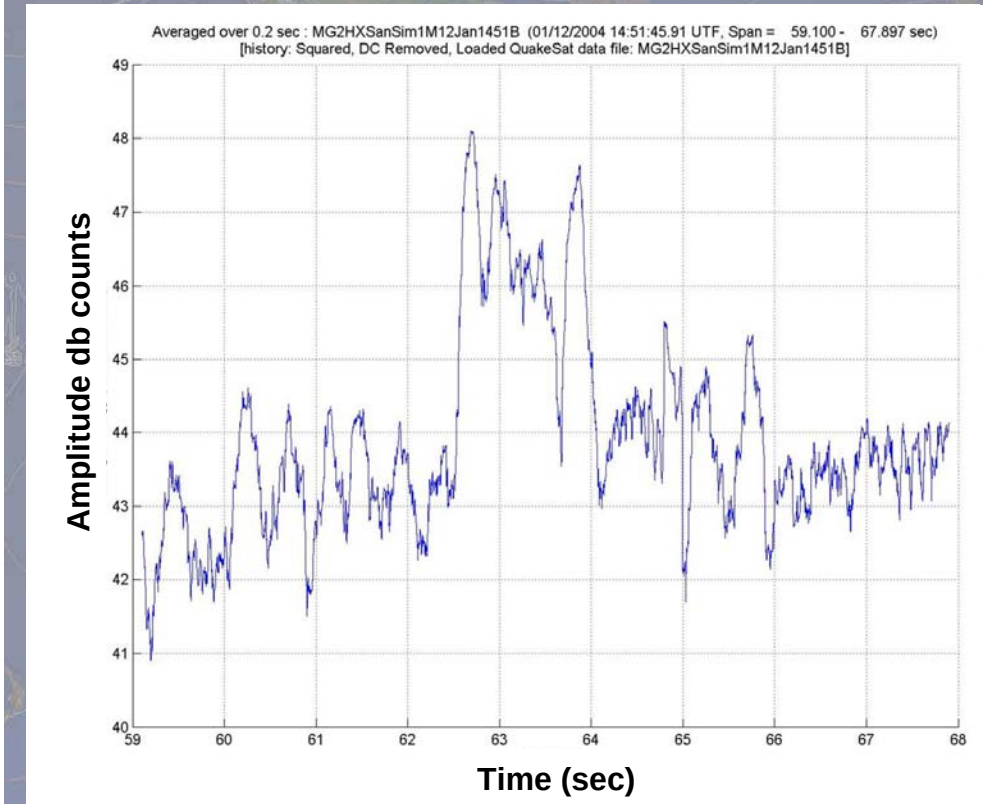


Frequency (10-150 Hz)

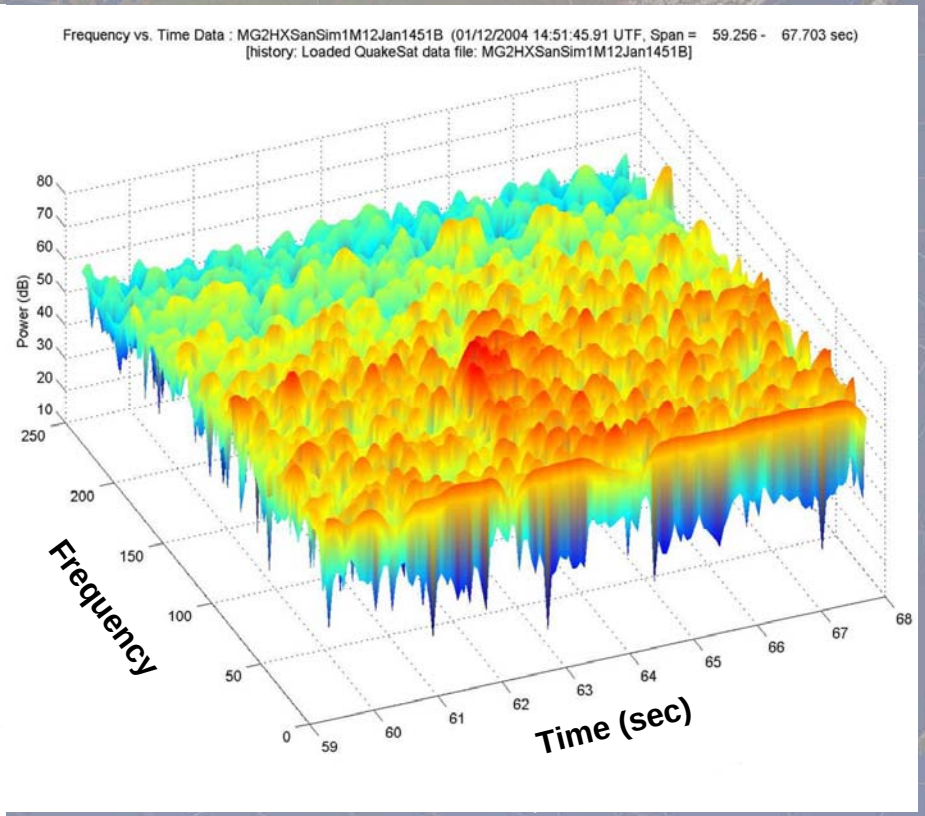


San Simeon Earthquake +21 days

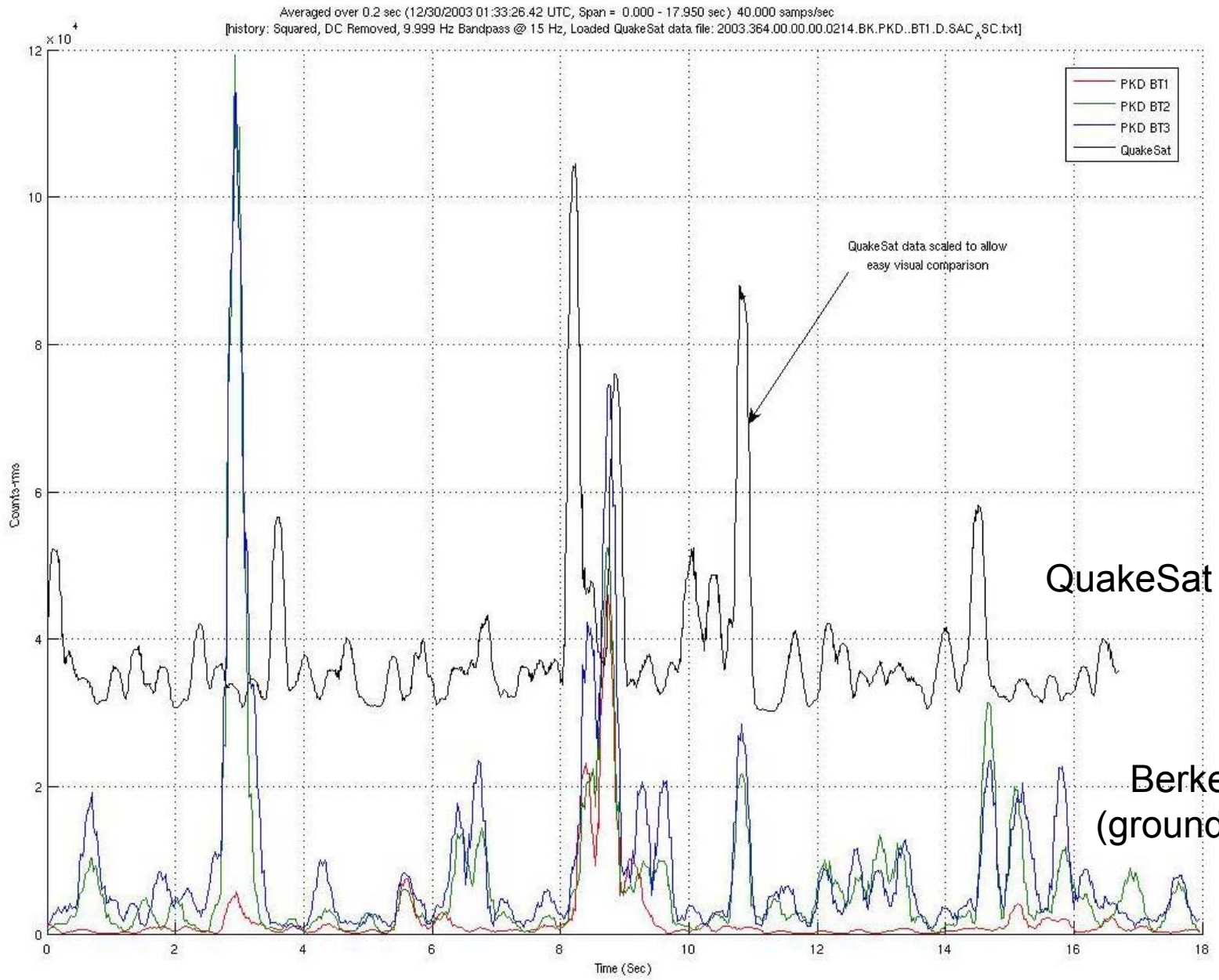
Power



Frequency (10-150 Hz)



Correlation between QuakeSat and Berkeley signals (San Simeon + 8 days)



QuakeSat data

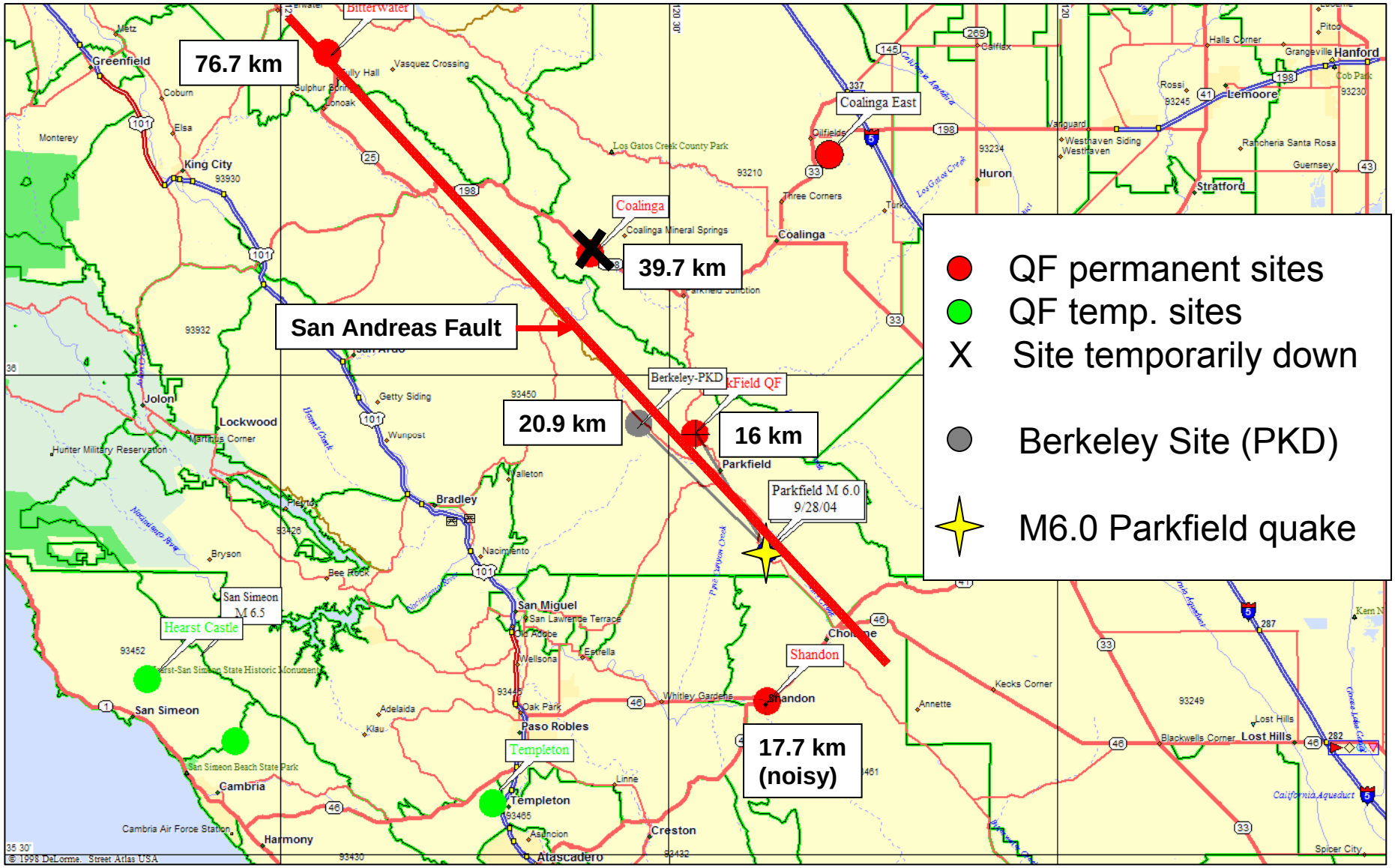
Berkeley (ground) data

Parkfield M6.0 Quake

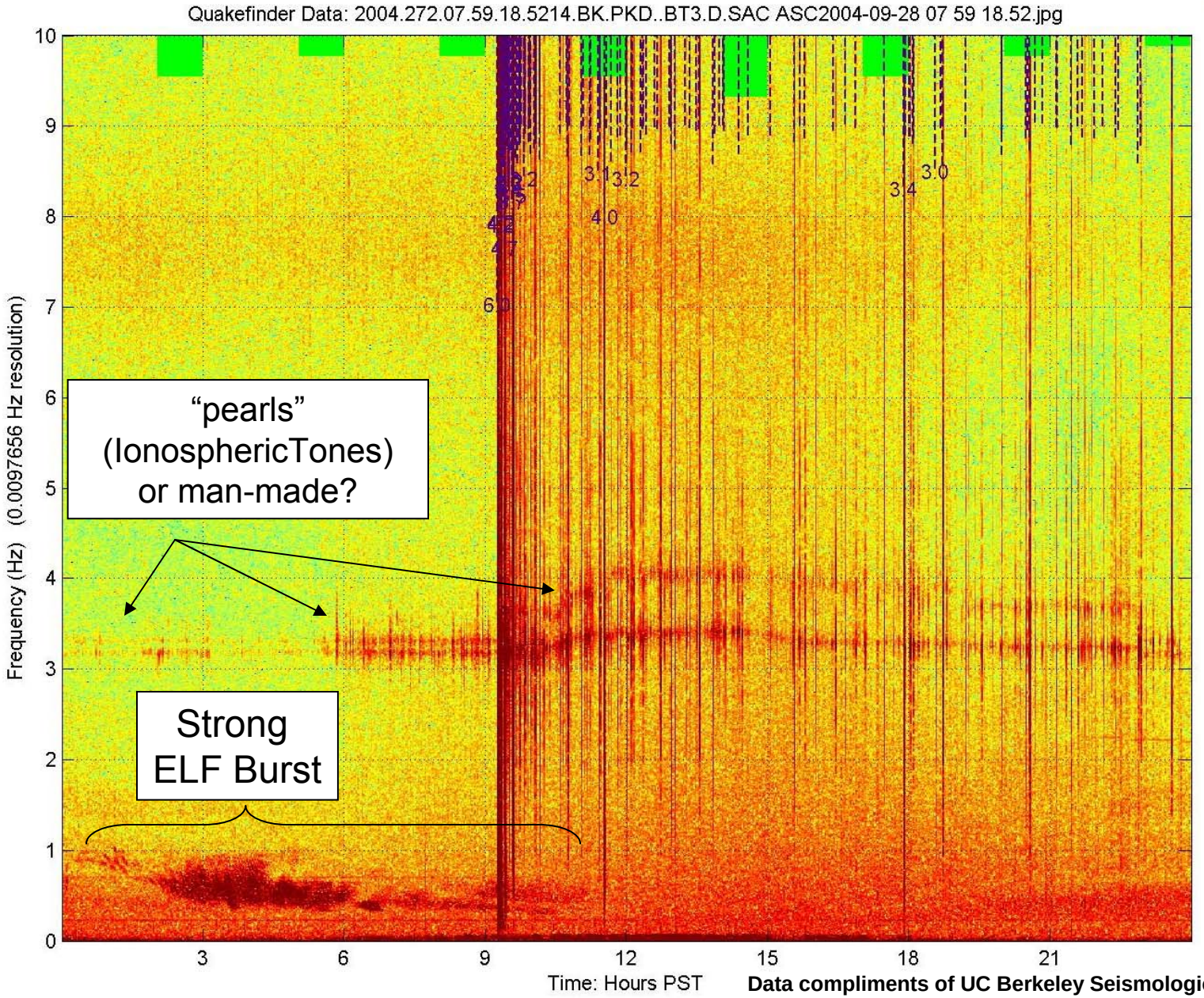
9/28/04

10:15:24 PDT
09:15:24 PST
17:15:24 UTC

Parkfield M6.0 and ELF sites

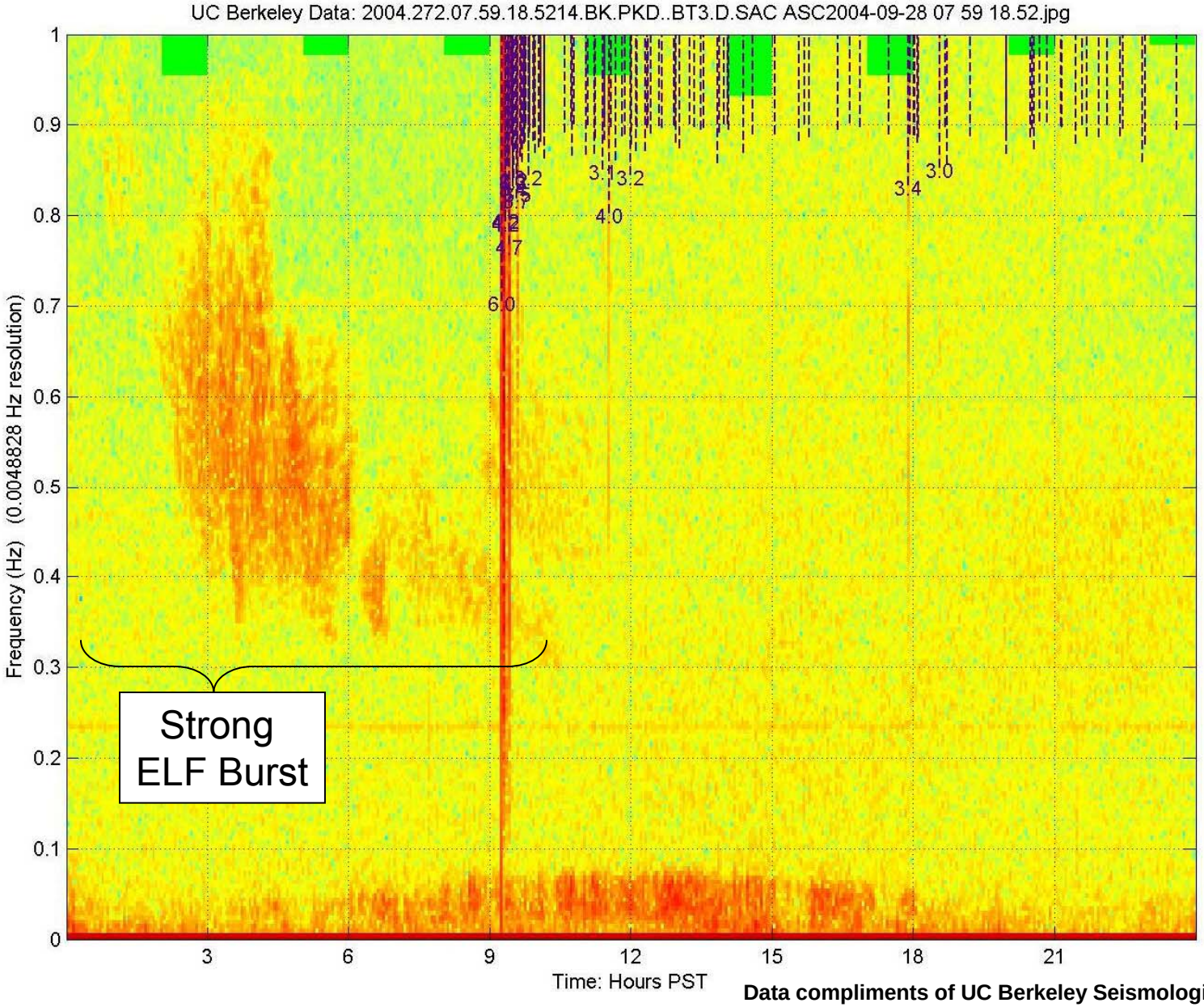


Berkeley Data (0-10 Hz)
Day of quake Sept 28, 20004



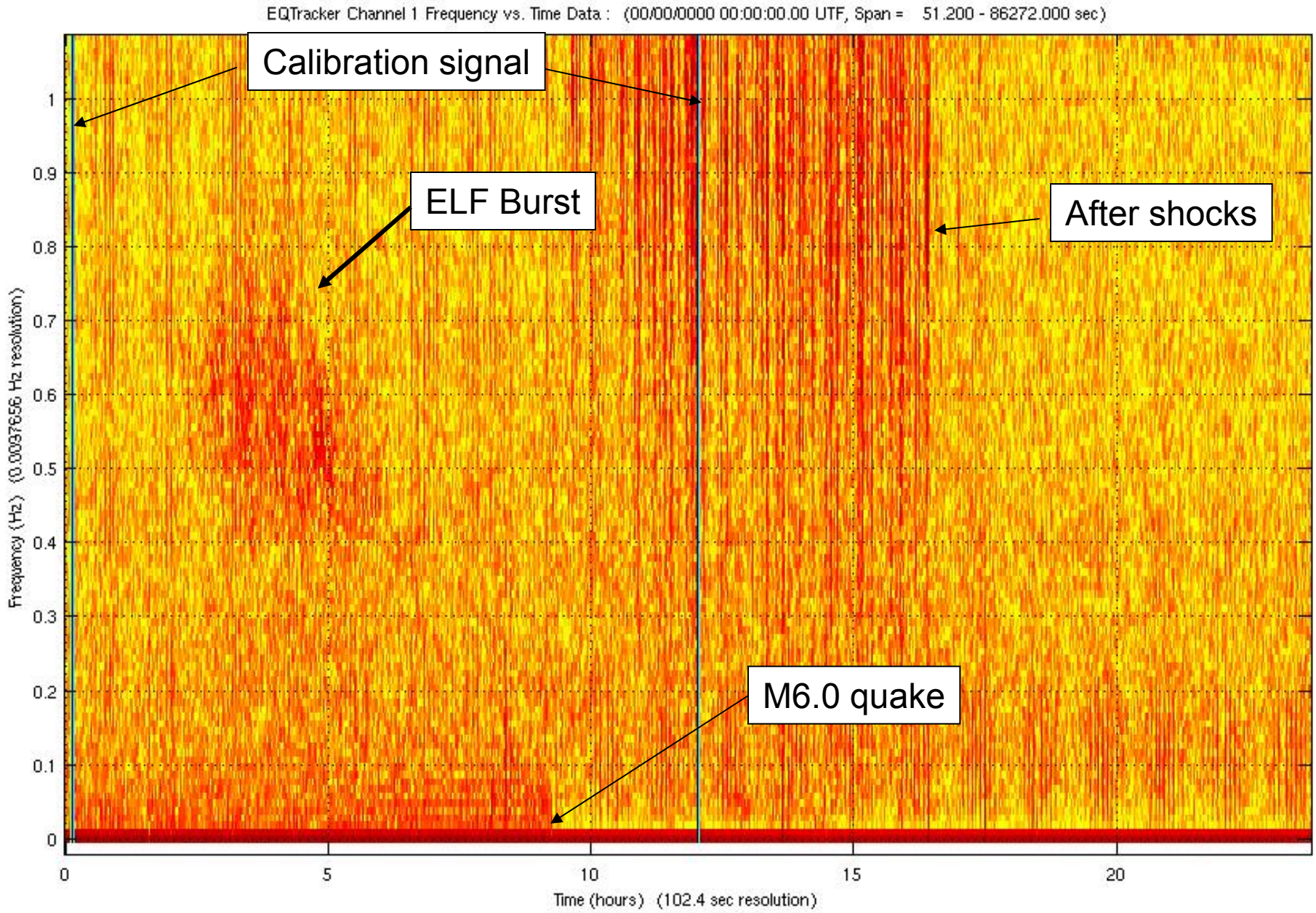
Data compliments of UC Berkeley Seismological Lab

Berkeley Data
Day of quake (Expanded to 0-1 Hz)



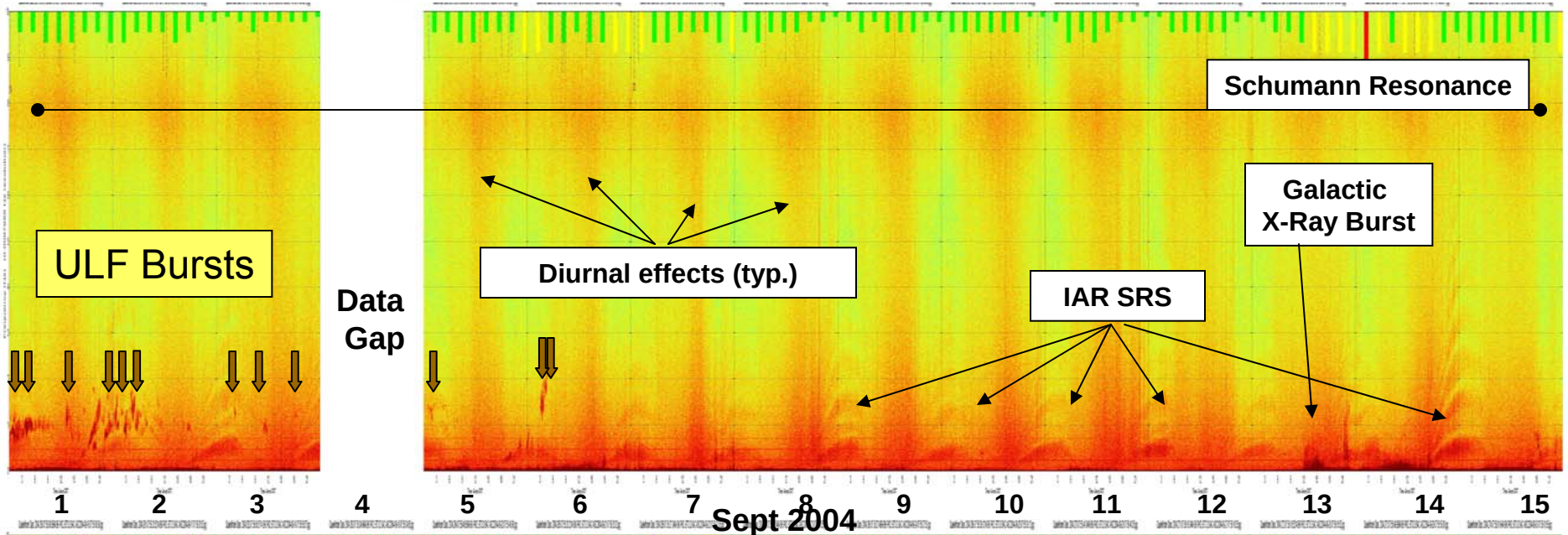
Data compliments of UC Berkeley Seismological Lab

QF Parkfield station (day of quake)

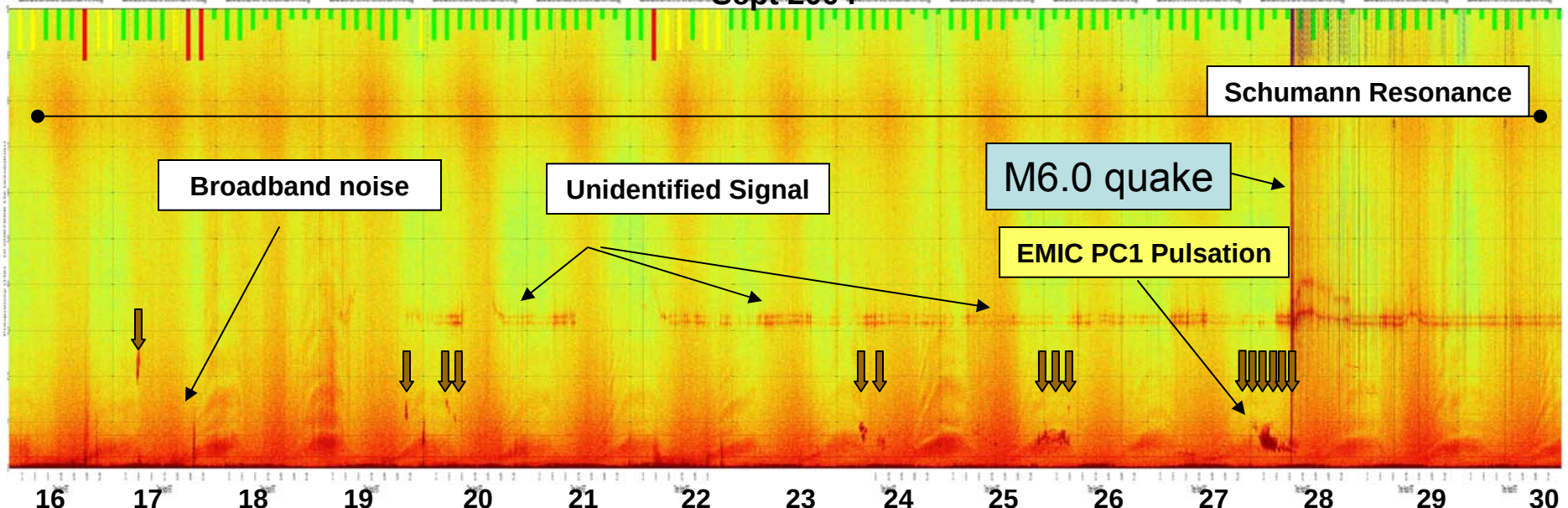


Berkeley Data (0-10 Hz)
Sept 1-30, 2004

Data compliments of UC Berkeley Seismological Lab



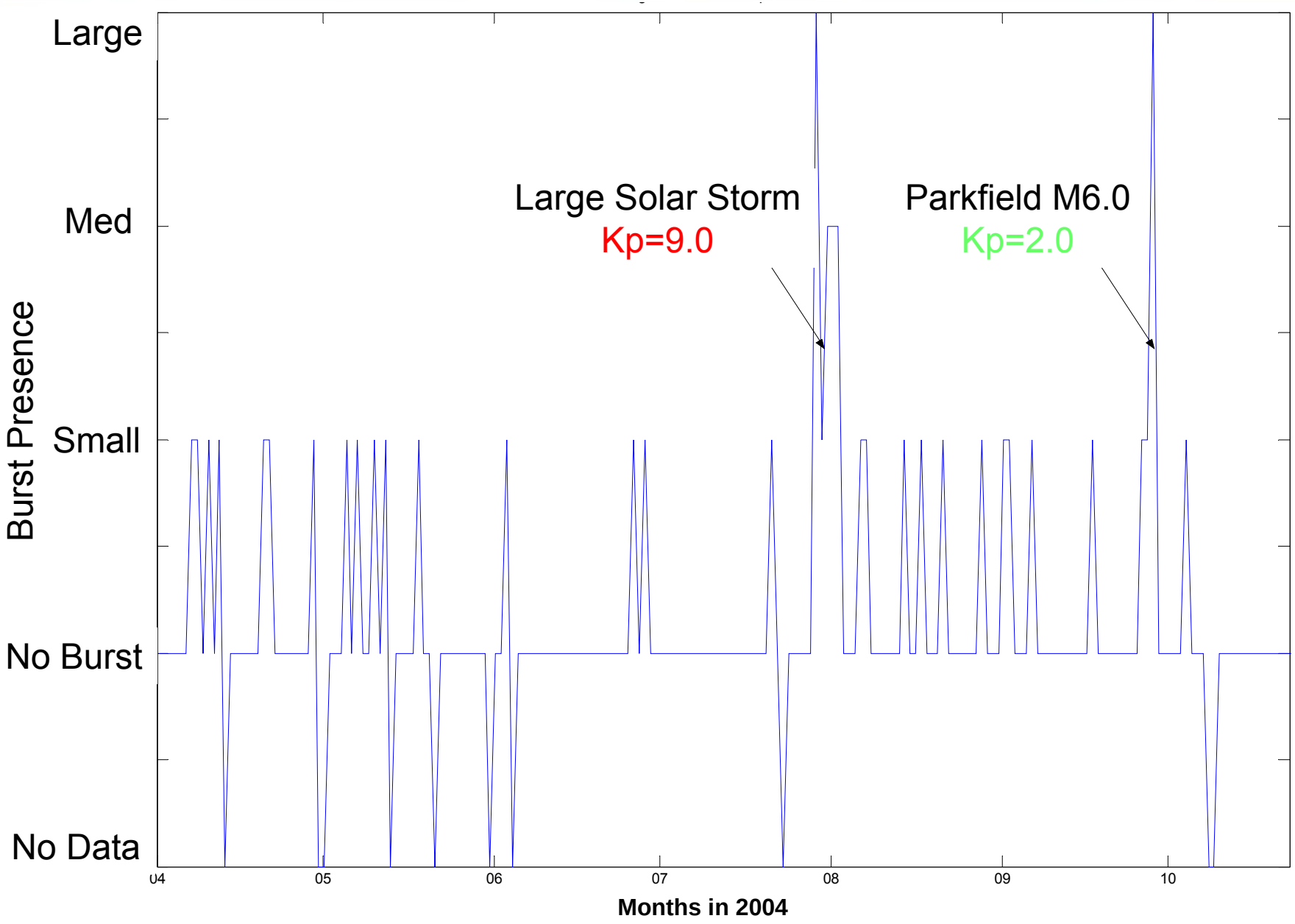
Sept 2004



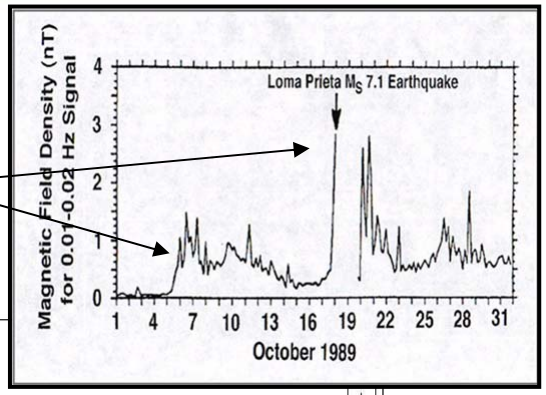
ULF Types

- **Diurnal Effect**
  - **Increased activity due to daytime and solar excitation of ionosphere.**
- **Shumann Resonance**
  - **Resonating cavity between ground and ionosphere.**
  - **Cpatures broadband EM impulses like lightning.**
- **ULF Waves**
  - **EMIC Waves (PC 1-2 pulsations)**
    - **Electromagnetic ion cyclotron (EMIC) instability near the equator.**
    - **Pearls—structured PC1 waves.**
    - **IPDP Pulsations- Intervals of diminishing periods.**
  - **Spectral Resonance Structures (SRS)**
    - **Likely caused by Ionospheric Alfven resonators.**
    - **Varies with time of day, season, and solar activity.**
    - **Harmonics up to second Schumann resonance.**
- **Broadband Noise**
  - **Often related to CME shocks hitting the Earth.**
  - **Galactic X-ray bursts**

Night ELF Bursts: Mar to Oct '04



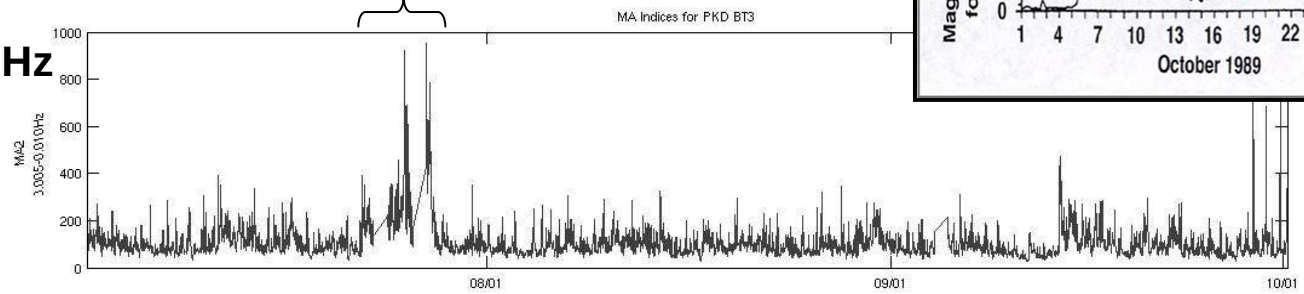
Loma Prieta Vs Parkfield ULF Signals



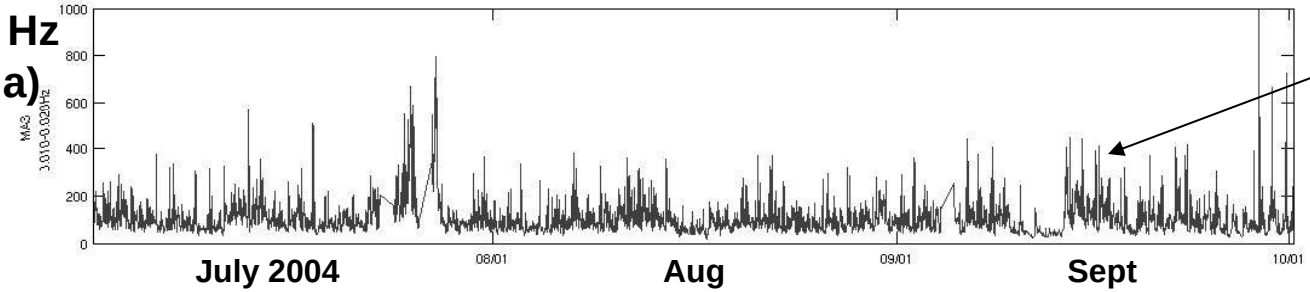
1989 Loma Prieta Quake 20-60x normal

July 23-28 Solar Storms

0.05-0.01 Hz



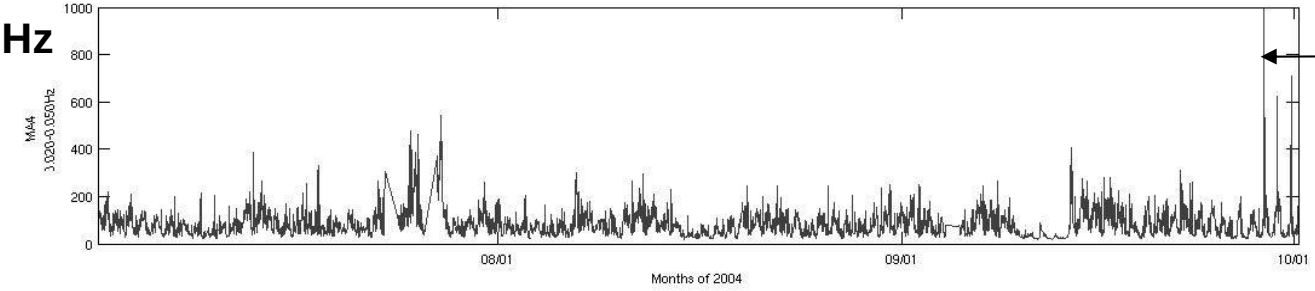
0.01-0.02 Hz (like Loma)



2004 Parkfield Quake 2-3x normal

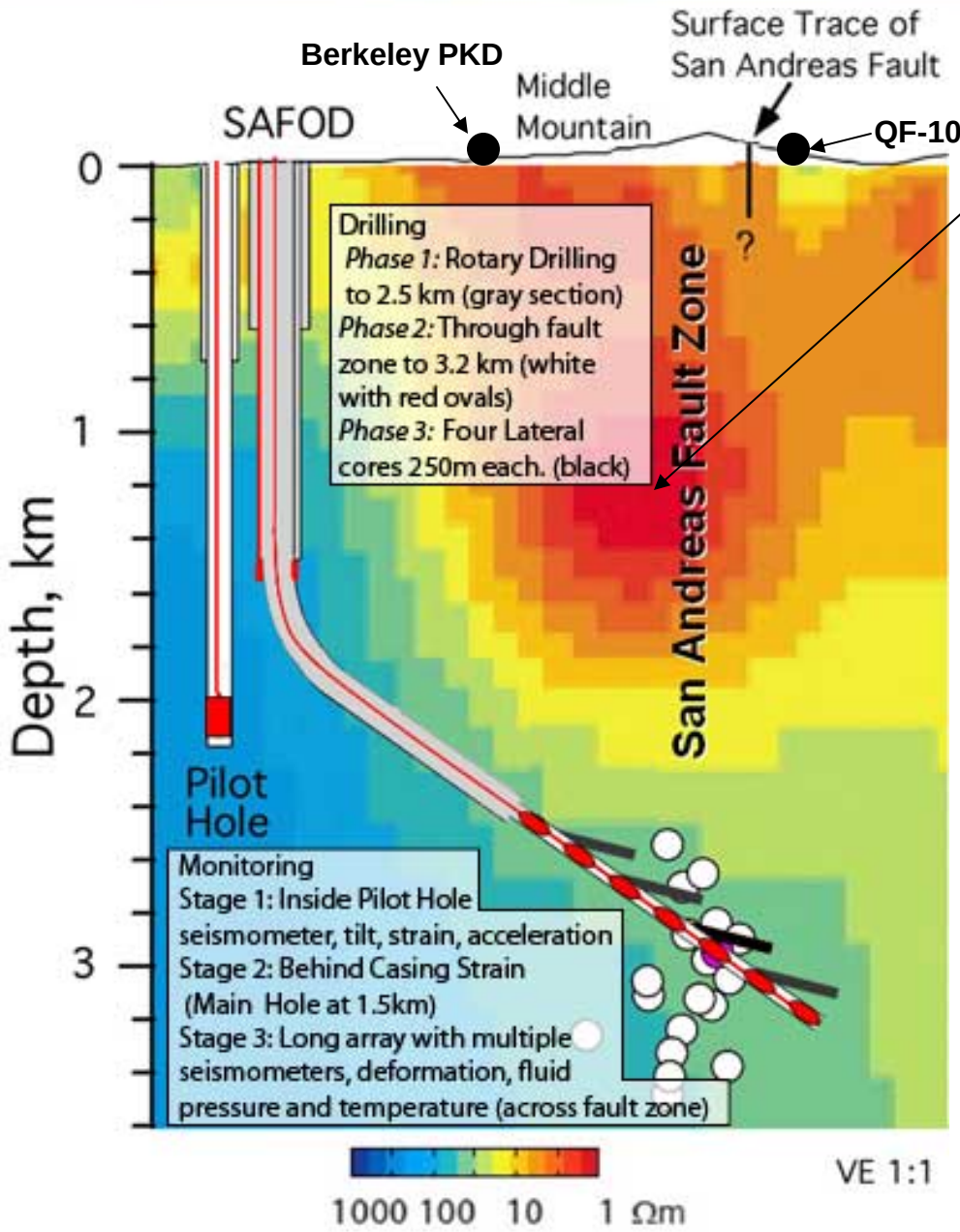
July 2004 **Aug** **Sept**

0.02-0.05 Hz



Parkfield M6 quake

Conductivity of Ground Attenuates Signal



1 Ohm per meter

Magnetotelluric Study: Parkfield Soil Resistivity

(Unsworth 2000)

QuakeFinder Summary – San Simeon quake

- **Ground monitor data**
  - May have been too far away to detect the San Simeon signal (60 km Vs 15 km range est.)
  - Small number of “unusual signals, 3.2 Hz”
- **QuakeSat data**
  - ELF wideband noise (10-140 Hz) bursts seem to appear near several quakes
    - Not confirmed yet-DEMETER data
  - Some correlation with ground data (+8 day)
    - Need more samples

Summary – Parkfield quake

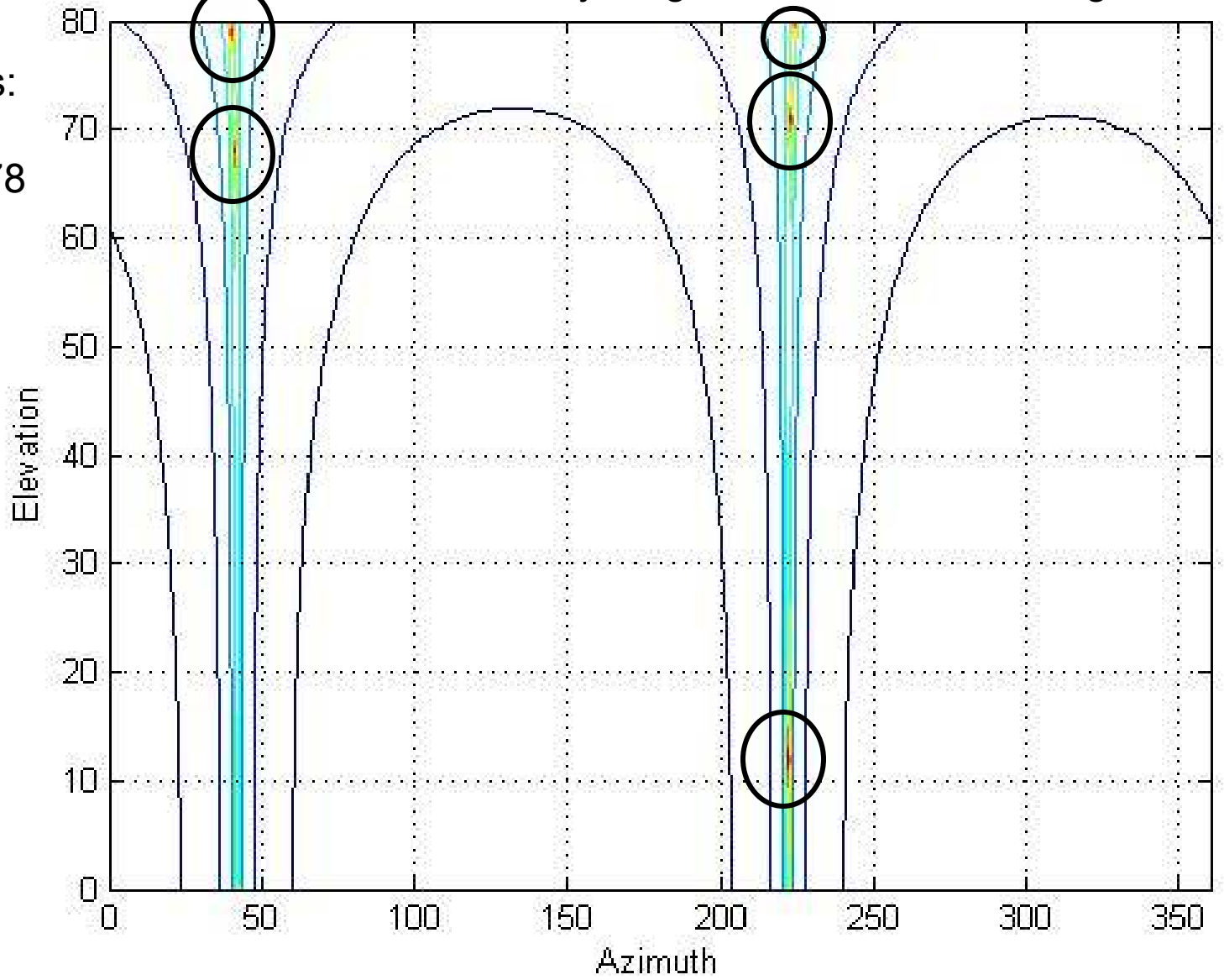
- **Ground monitor data:**
  - Parkfield did not duplicate Loma Prieta
    - No 20 X increase at 0.01 Hz (Brine layer near quake)
  - Strange ELF bursts prior to quake at 0.3 to 0.9 Hz (Ionospheric origin, but low solar activity?)
  - Strange ELF tones (pearls?) at 3.2 Hz
    - Seen at PKD and QF Parkfield vertical channels only
- **Satellite data:**
  - QuakeSat and DEMETER: no valid data

Backup Charts

Direction of Arrival (Preliminary Results)

Parkfield: Berkeley magnetometers, “Music” algorithm

Signal Locations:
Az. 41
Elev. 68,78



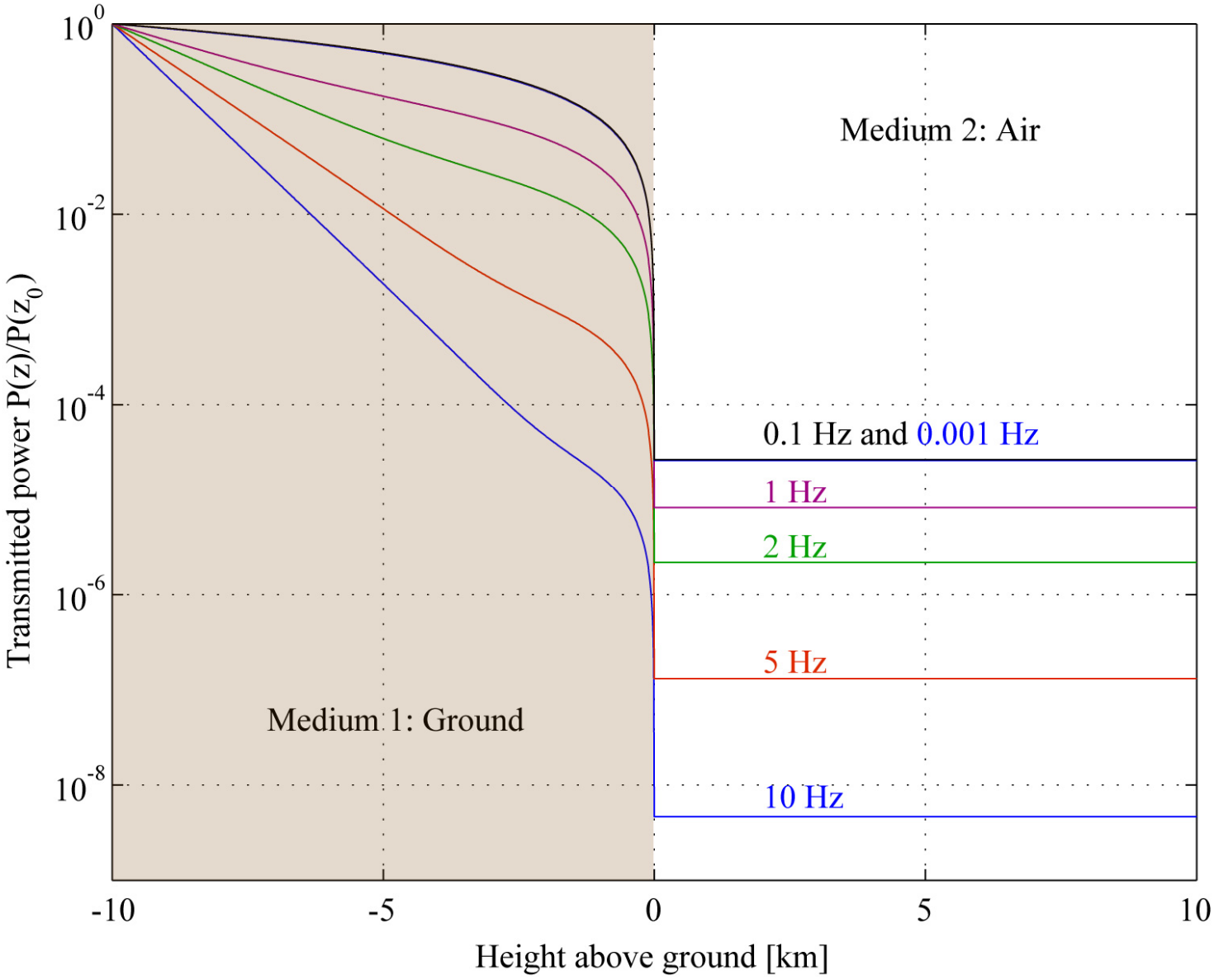
San Simeon Earthquake 12/22/03

Propagation Modeling

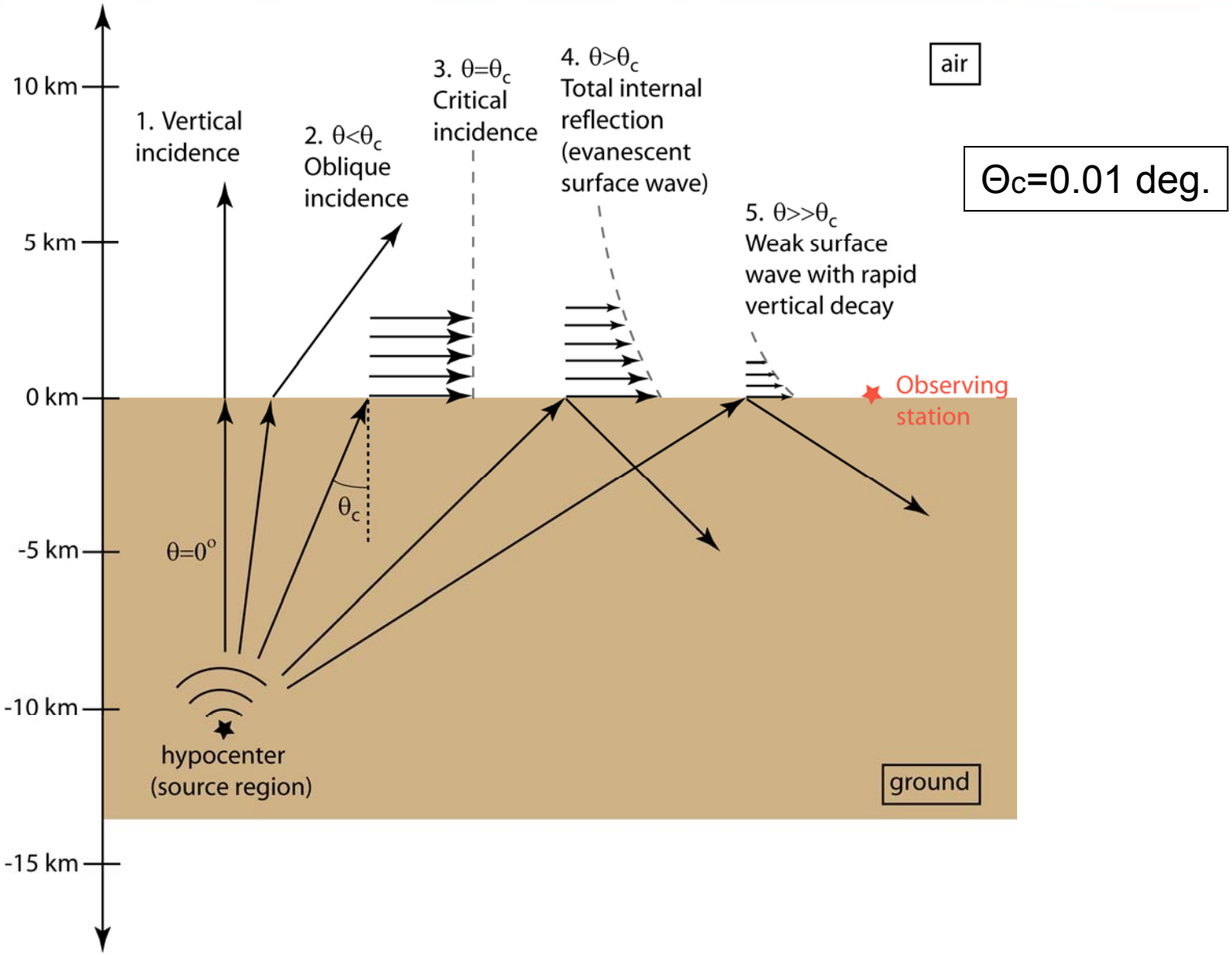
Dr. Jacob Bortnik
UCLA Post Doc

Full Wave Model using Maxwell's Equations

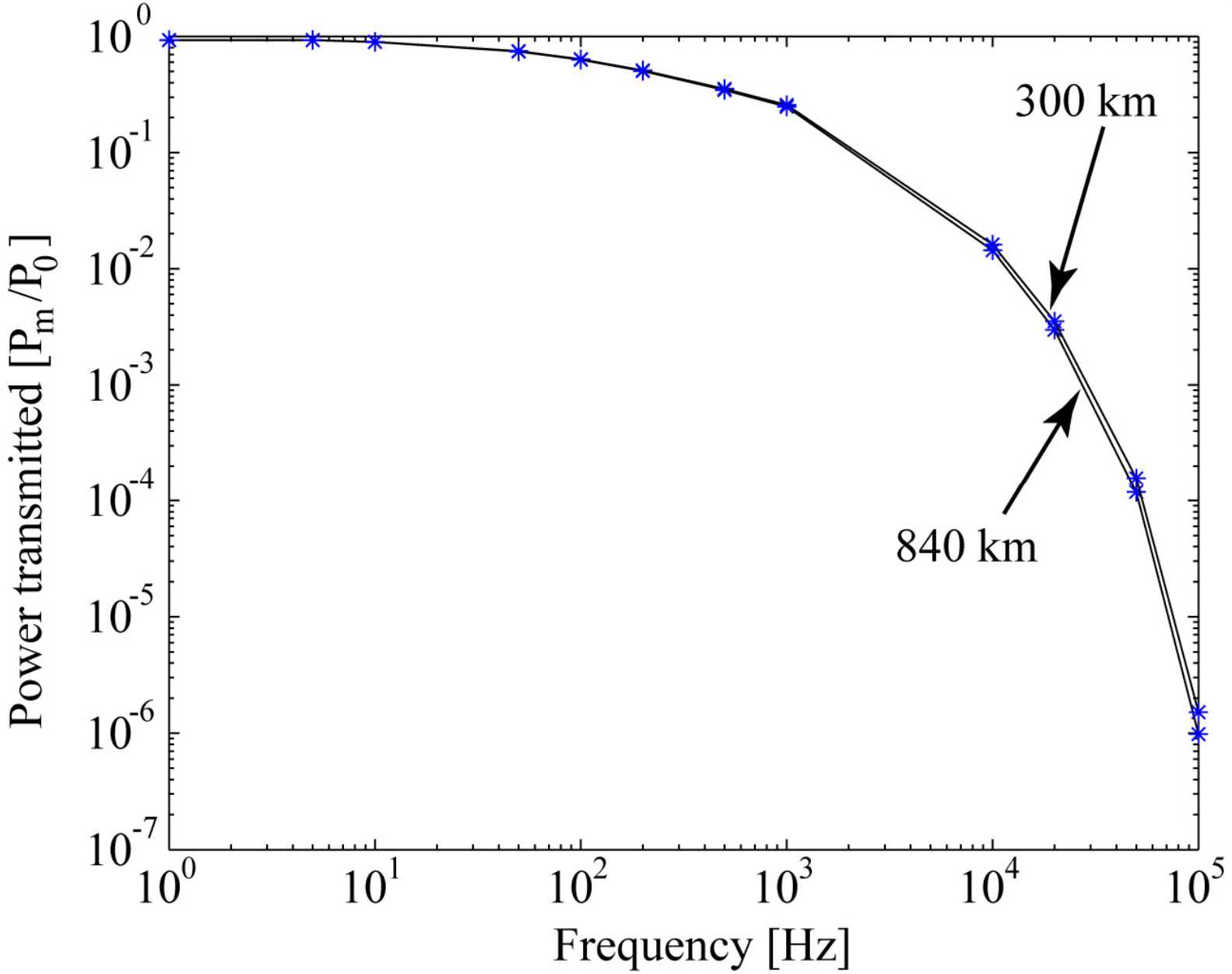
Attenuation by Frequency (ELF-VLF) for Below Ground to Air



Signal Refraction



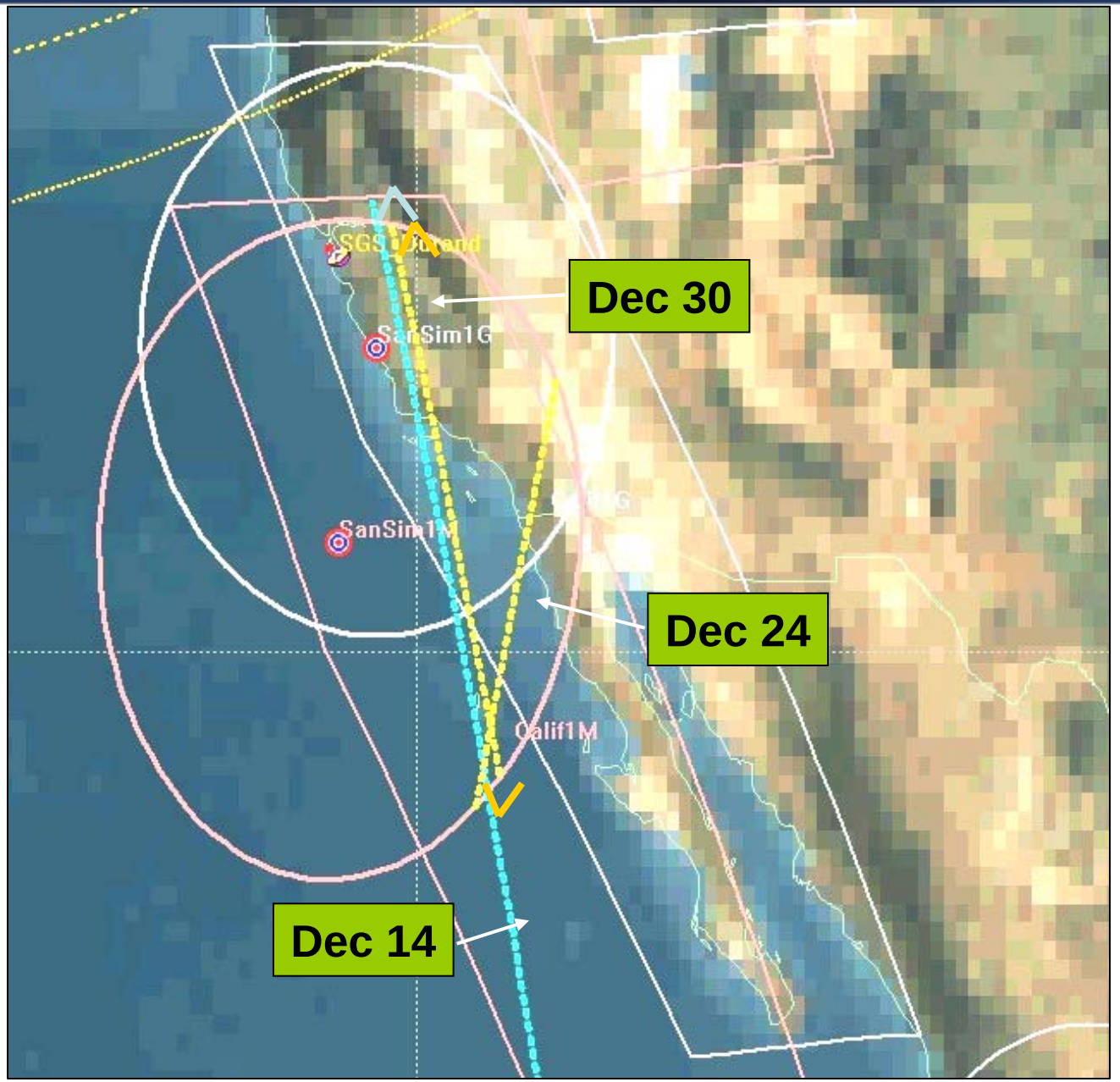
Ionospheric ELF/VLF Attenuation



Status : First 17 mo. (9 mo. mission)

- **2000 + Worldwide Magnetometer Collections**
- **Eliminated most internal noise sources**
  - **Small boom with pico-tesla magnetometer**
  - **Reprogrammed on-board computer**
    - **watchdog, beacon, software processes**
  - **Digital filtering on ground**
    - **telemetry modem**
- **Detected natural signals**
  - **Whistlers (Lightning), Auroral Chorus,**
  - **20+ signatures of unknown origin while targeting active seismic zones**

QuakeSat Collection Geometry



Did we see the same type of signal around other quake events?

Major Earthquakes of Magnitude 6+

Dominican Rep Earthquake	
Signal Date	Days from EQ
9/22/2003	EQ
10/22/2003	+31

Japan Earthquake (9/25/03)	
Signal Date	Days from EQ
9/25/2003	EQ
10/6/2003	+9

Japan Earthquake (10/31/03)	
Signal Date	Days from EQ
10/22/2003	-9
10/23/2003	-8
10/23/2003	-8
10/31/2003	EQ
11/18/2003	+18
12/24/2003	+54

New Zealand Earthquake	
Signal Date	Days from EQ
11/2/2003	EQ
12/24/2003	+52
12/30/2003	+58

Xin, China Earthquake	
Signal Date	Days from EQ
12/1/2003	EQ
12/11/2003	+10
12/13/2003	+12
1/2/2004	+32
1/6/2004	+36

San Simeon Earthquake	
Signal Date	Days from EQ
10/26/2003	-56
10/27/2003	-55
12/22/2003	EQ
12/30/2003	+8
1/12/2004	+21

Iran Earthquake	
Signal Date	Days from EQ
9/10/2003	-67
12/16/2003	-10
12/26/2003	EQ
1/19/2004	+24

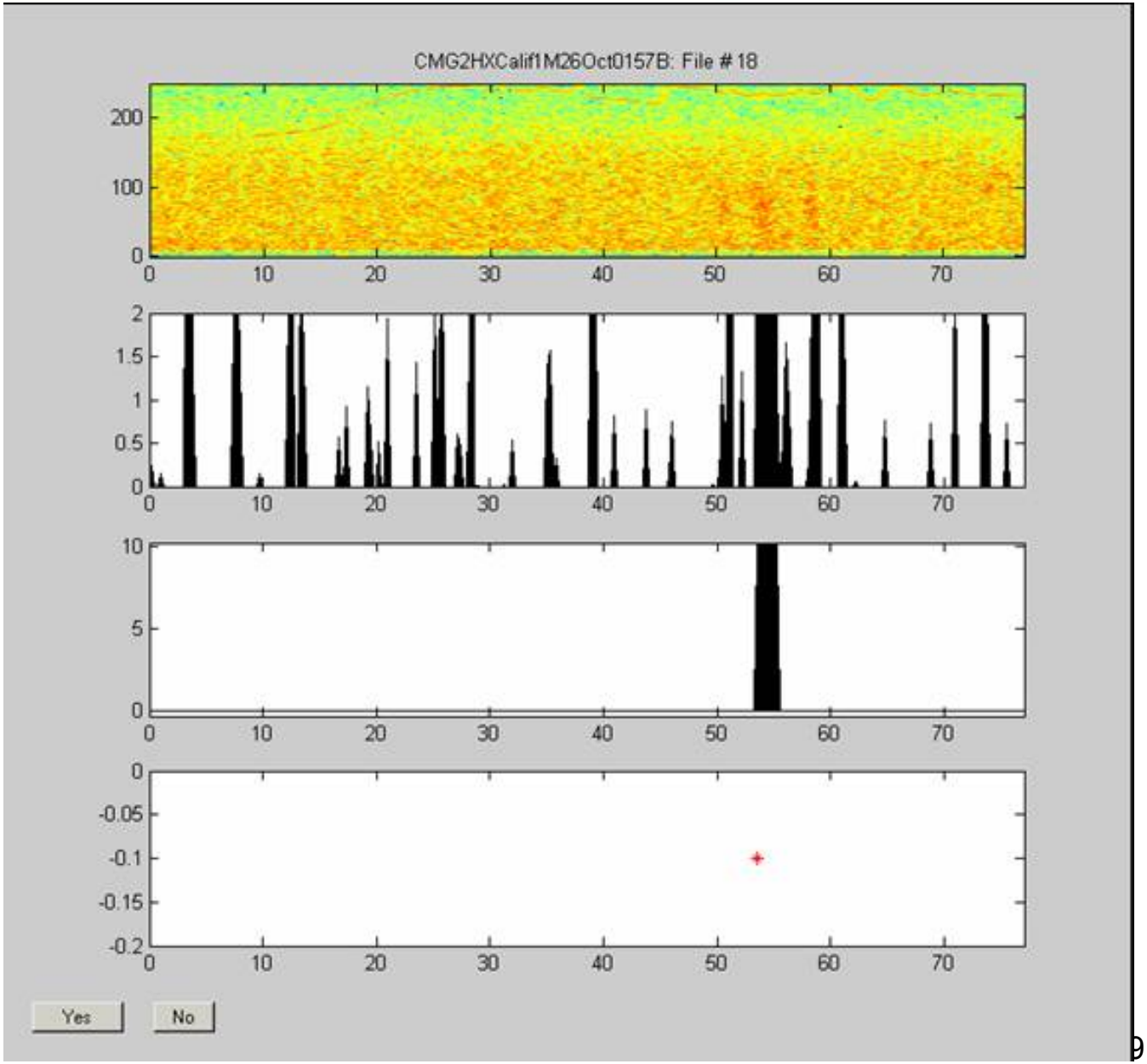
Pattern Recognition (Dr. H. Kuzma-Berkeley)

Sat. Collection
Spectrogram

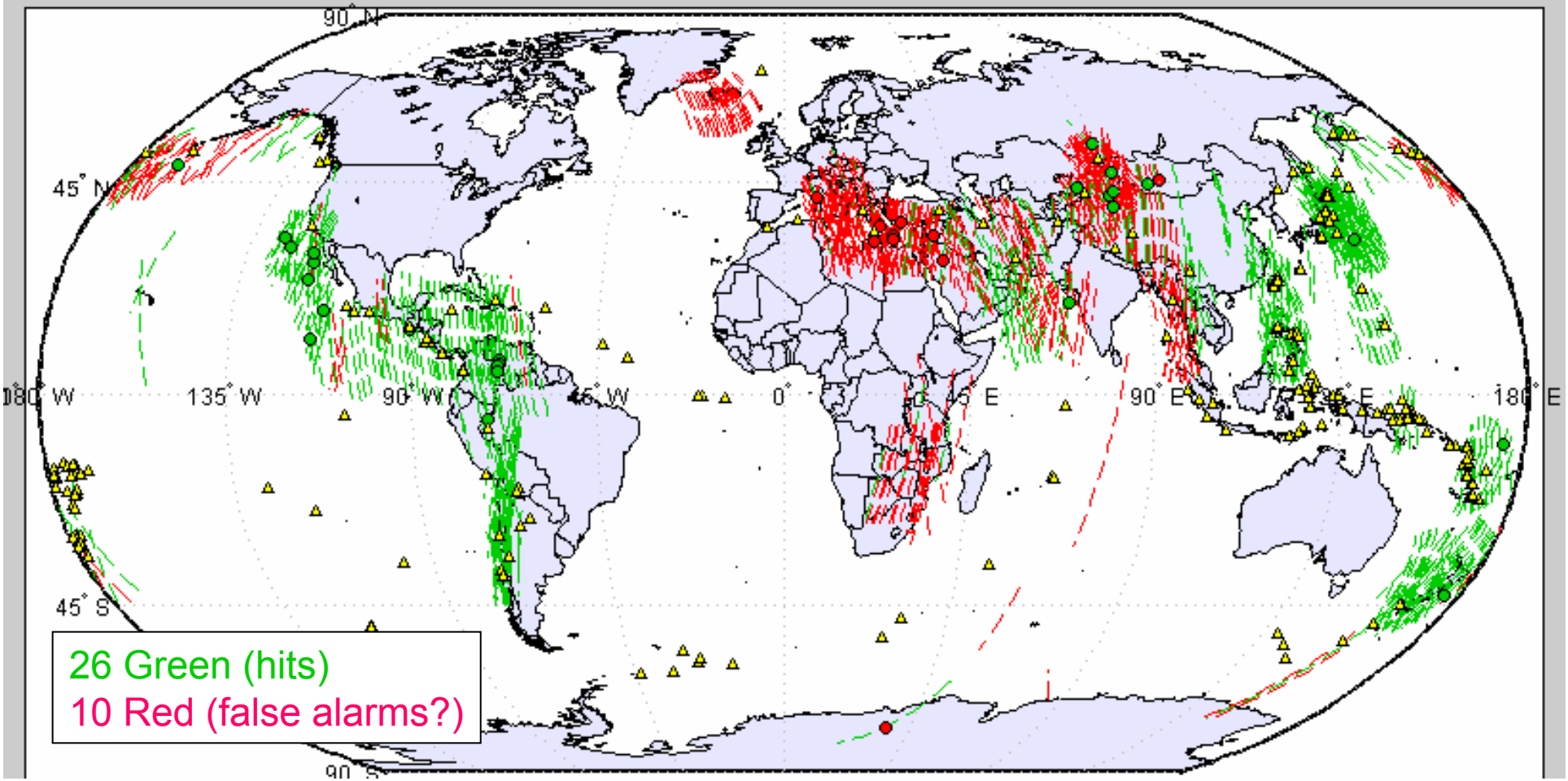
Raw Correlation:
-Matched filter
(0.2 sec by 10-80 Hz)

Refined Correlation:
-Adjustable threshold
(1 Sec, energy spread)

Manual Selection:
-Accept/Reject



World wide hits / false alarms



△ = Earthquake of magnitude 6+ within collection timeline (Sept '03 to Feb '04)

● = ELF Burst: at least one earthquake within 1000 km and +/-60 days of (hit)

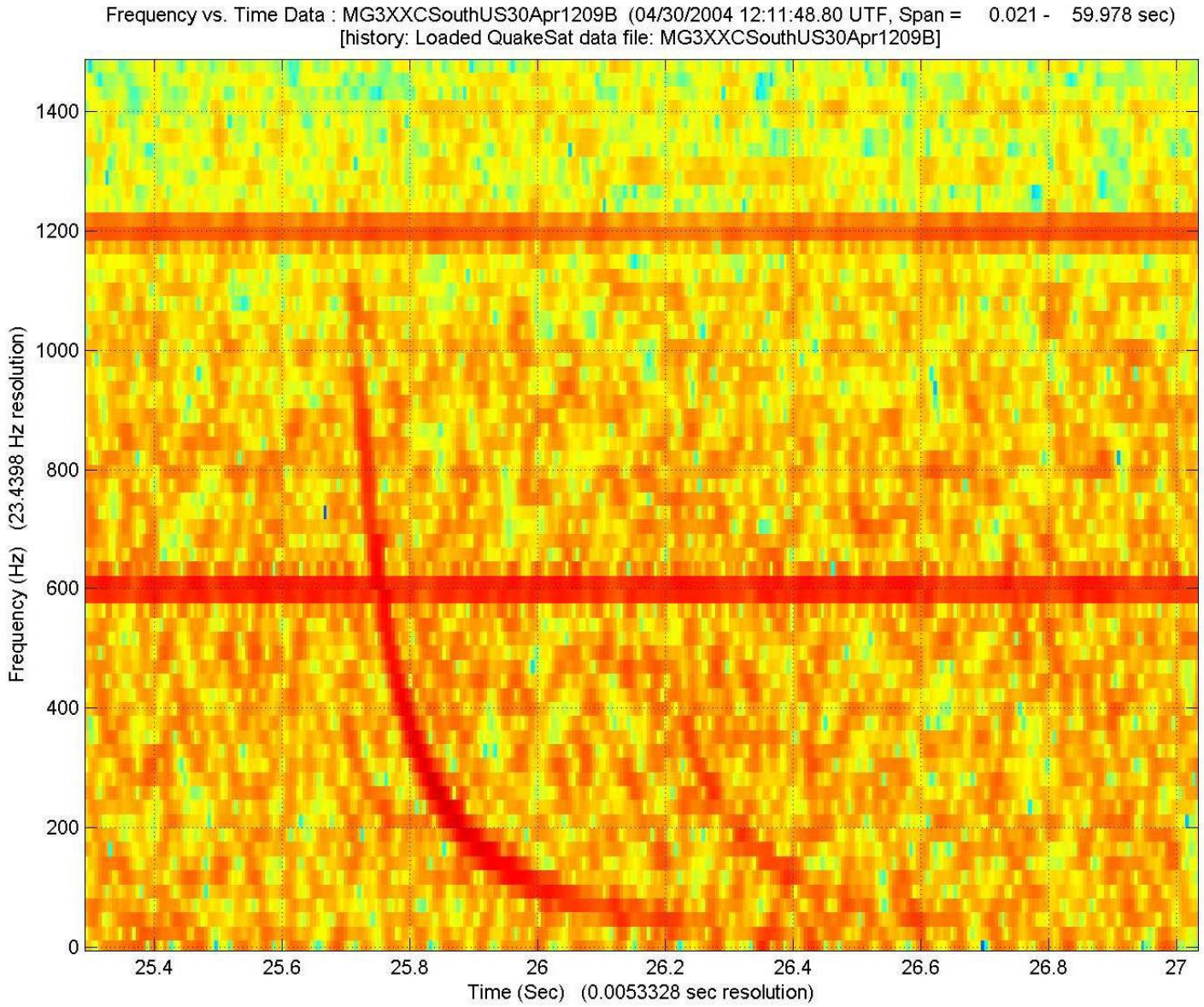
● = ELF Burst: no earthquakes exist within 1000 km and +/-60 days (false alarm)

---- Satellite ground traces: no earthquakes within 1000 km and +/- 60 days

---- Satellite ground traces: at least one quake within 1000 km and +/- 60 days

How can one distinguish
signal originating from the ground
Vs
noise from the satellite or a signal
from space?

Lightning Example SE USA



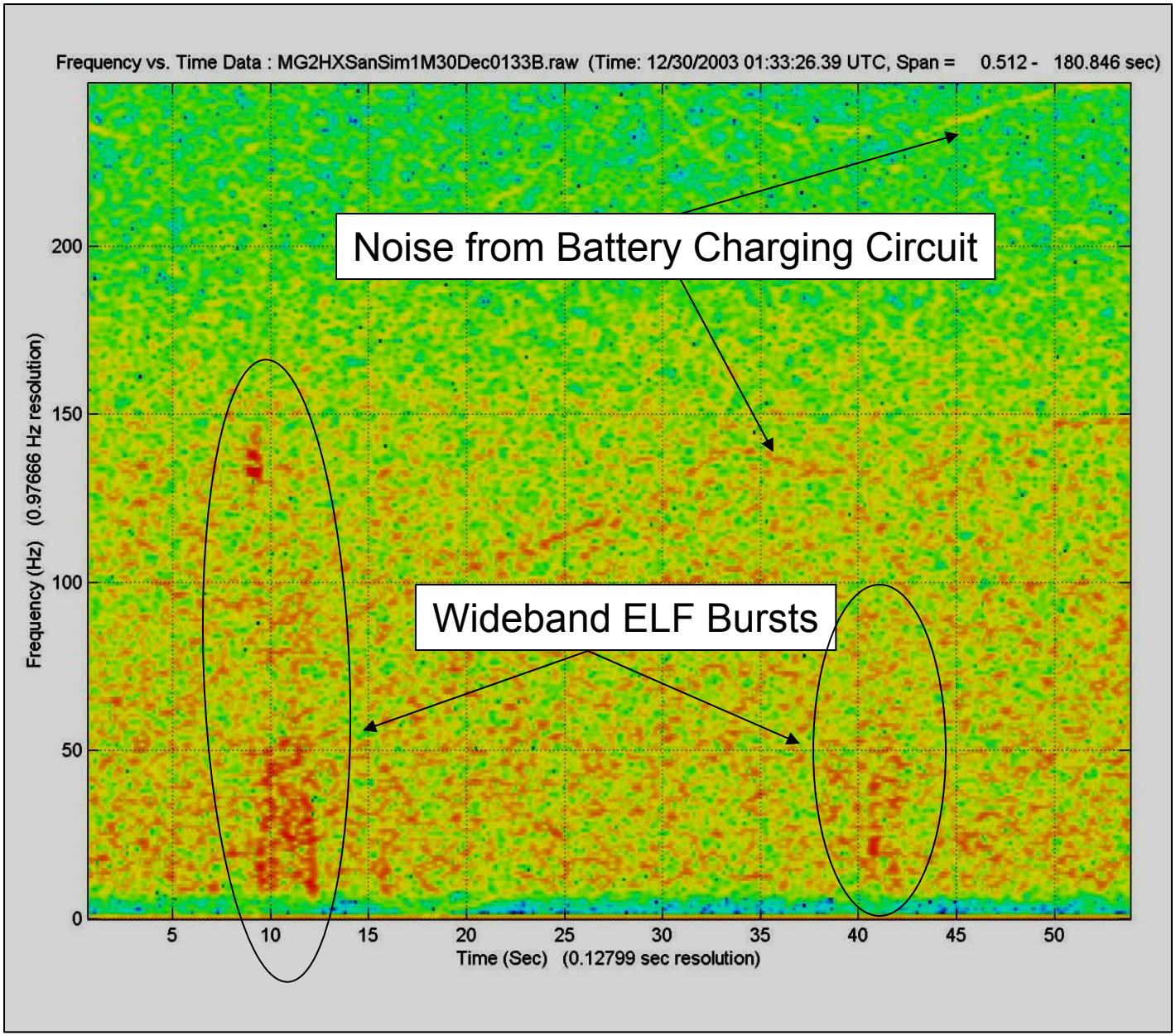
Impulsive signals propagate through ionosphere in a dispersive manner

Higher frequencies arrive sooner

Lower frequencies Arrive later

Is this an important feature for earthquake signatures?

Dec 30, 2003 10-150 Hz



2 important features

- Broadband energy
- Dispersive (right tilt)

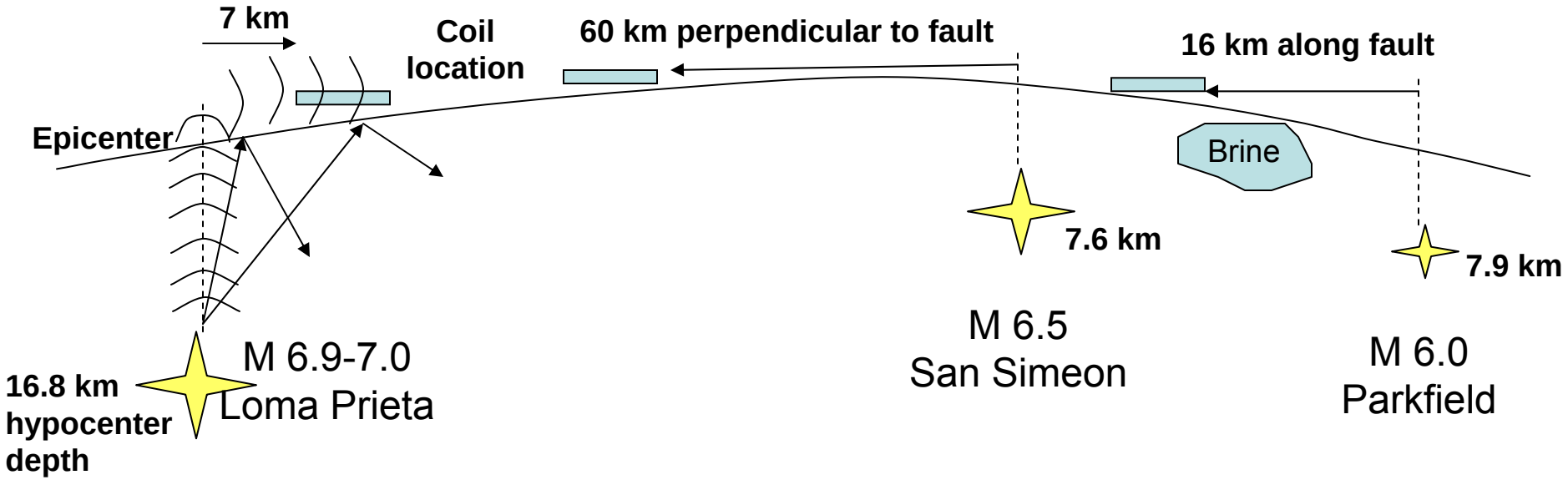
Signal Strength Variations

Why do some quakes have higher ULF/ELF signals?

Loma Prieta Vs San Simeon Vs Parkfield

Factors Influencing Propagation and reception S/N:

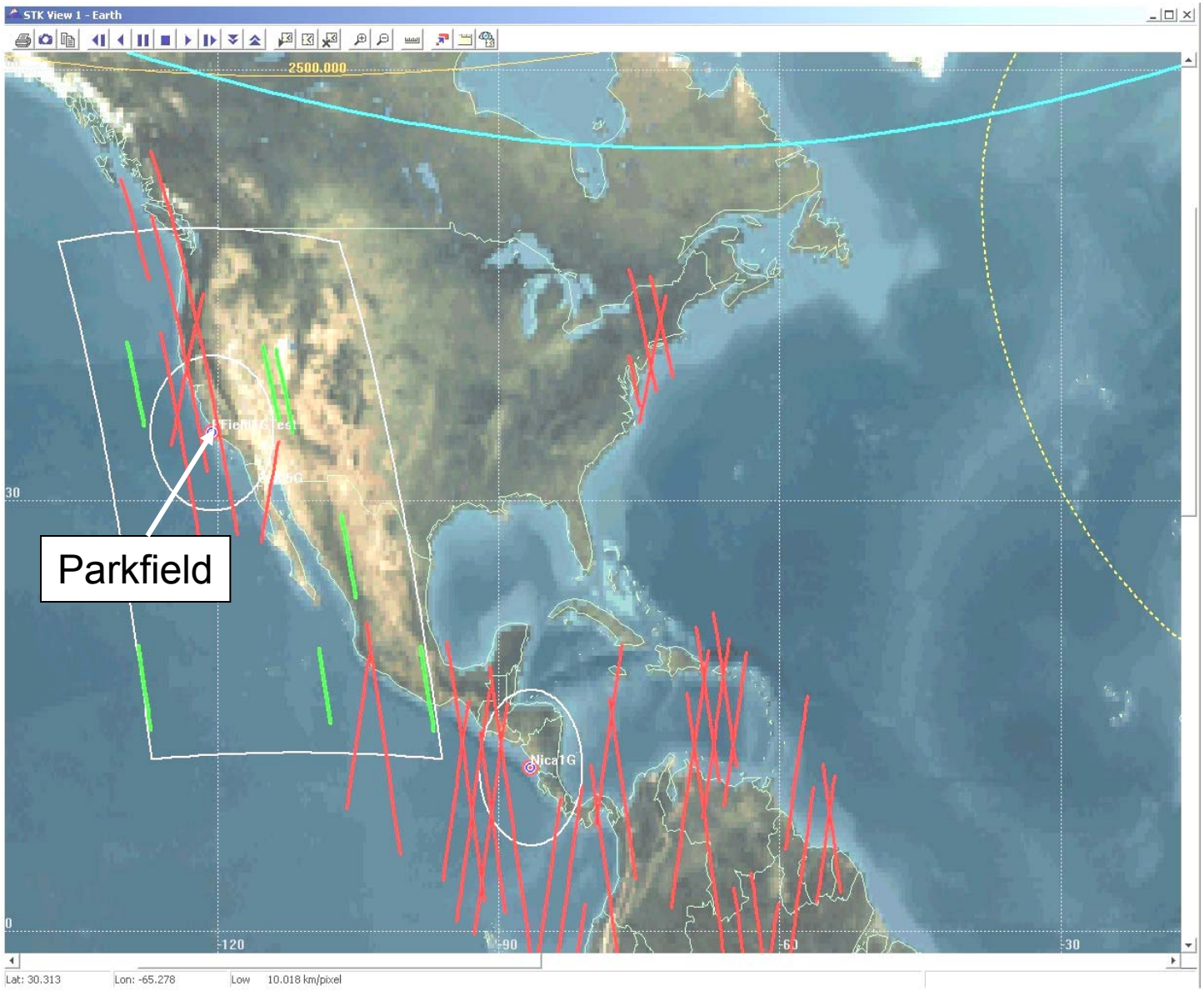
- Magnetic dipole moment (source signal strength)
- Depth of hypocenter
- Conductivity of rock structure
- Frequency of signal (skin effect)
- Distance of epicenter to sensor (coil)
- Direction of sensor from epicenter (along fault?)
- Sensitivity of sensor (instrument noise floor)
- Ambient area (man-made noise)
- Solar activity (noise)



Satellite Coverage

Over Parkfield

QuakeSat and DEMETER



<u>QuakeSat: (green)</u>

- Power starved
- Few collections
- Bad geometry
- No signals

<u>DEMETER: (red)</u>

- Mag Torque coils operating over Parkfield area