Abstract

We are developing a data fusion center to facilitate analysis in the seismo-electromagnetics community of geophysical measurements related to earthquake activity. Past researchers have reported anomalous behavior in electromagnetic measurements from the ground and in space near earthquakes. An international research effort has focused on deploying sensors and mining data to understand these reported seismo-electromagnetic anomalies. However, due to the subtle and poorly understood nature of earthquake precursor activity, it is imperative to examine as many data sets as possible in order to gain a more complete understanding of the physical mechanisms involved in the precursor signal generation. The goal of our work is to fuse distributed data streams and provide common analysis products, tools via web-services, and computing nodes to these distributed researchers.

A Data Fusion Center for the Seismo-Electromagnetics Community

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1. Introduction

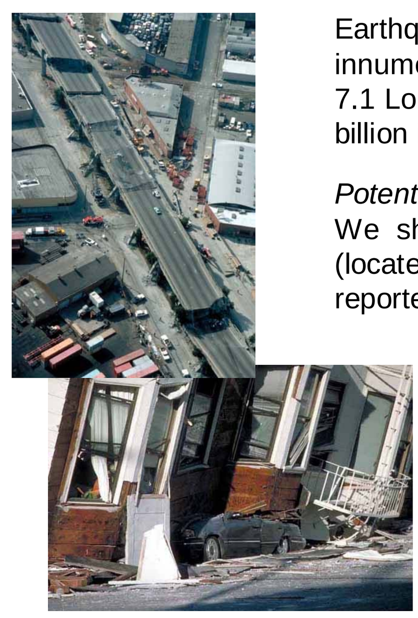

Figure 1a: Damage from the 1989 Loma Prieta earthquake in California.

Earthquakes are among the most destructive forces of nature, causing innumerable loss of lives and financial damage. For example, the 1989 Ms 7.1 Loma Prieta resulted in 62 deaths, 3000 injuries, and a minimum of $8.3 billion in direct damage (see Figure 1a).

Potential electromagnetic precursors:
We show in Figure 1b a number of ULF signals recorded in Corralitos (located ~7km from the epicenter) before, during, and after the quake and reported by Fraser Smith et al. [1990] and Bernardi et al. [1991].

The recorded data shows the appearance of a tone in the 0.05-0.2Hz band beginning on Sept 12th (~5 weeks before quake), and a substantial increase in power in all bands starting Oct 5th (~2 weeks before quake). Followed by a sharp decrease in strength about one day before the quake was a dramatic increase to very high levels in the 0.01-0.5 Hz band, approximately 3 hours before the earthquake. Given that there was no substantial ground shaking or geomagnetic activity, these measurements offer compelling evidence for a magnetic precursor.

Electromagnetic signals potentially linked to earthquakes have also been measured aboard satellites and reported in the literature (see Figure 1c) [Serebryakova et al., 1992, Molchanov et al., 1993, Parrot 1994].

Aim of This Work:
An international research effort has focused on deploying sensors and mining data to understand these reported seismo-electromagnetic anomalies. However, due to the subtle and poorly understood nature of earthquake precursor activity, it is imperative to examine as many data sets as possible in order to gain a more complete understanding of the physical mechanisms involved in the precursor signal generation. The goal of our work is to fuse distributed data streams and provide common analysis products, tools via web-services, and computing nodes to these distributed researchers.

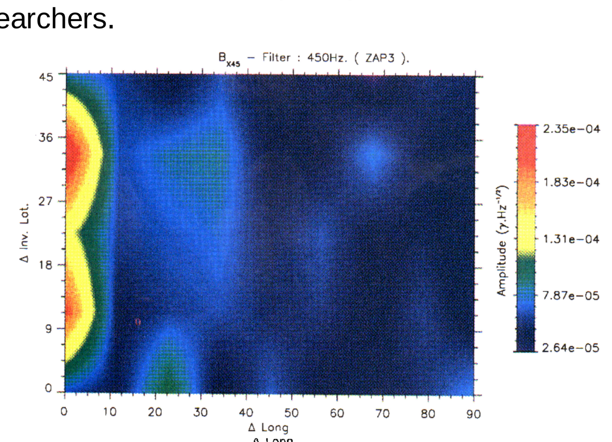

Figure 1c: Increase in 450Hz signal as seen from space along longitudinal lines where quakes occurred.

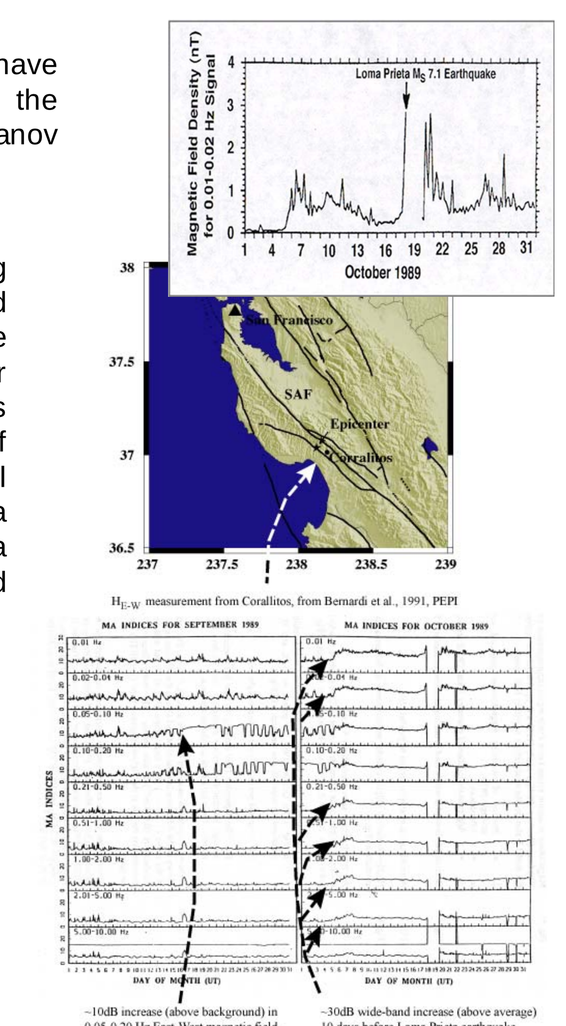

Figure 1b: Potential precursors at Loma Prieta.

3. Data Streams

Our data fusion center currently integrates data from six systems, including space and ground sensors, global event catalogs, and environmental indices.

ANSS Catalog
Portions of the composite earthquake catalog of the Advanced National Seismic System (ANSS) are mirrored to provide local access to earthquake events. Events are ingested nightly. Alerts and processing can be deployed based on these events.

Kp Index
Kp is a planetary measure of magnetic activity. Often, the dominant signal sources in our fused data streams are solar in origin, and Kp provides an indicator for these time frames.

Figure 2a: DEMETER satellite

Figure 2b: QuakeSat-1 satellite

Stream Name	Sensors	Dates Available
CalMagNet – ground network by QuakeFinder	3-axis search coils, air conductivity, Geophones.	2000 - Present
QuakeSat-1 – a nanosatellite developed by QuakeFinder	Single axis search coil, Polar orbit at 750km.	06/2003 - Present
DEMETER – a CNES satellite	3-axis search coils, Langmuir probe, particle detector, E-field antennas, plasma analyzer. Polar orbit at 710km.	08/2004 - Present
Berkeley Digital Seismic Network	3-axis search coils, E-field antennas, broadband seismometers, temperature, pressure.	05/1995 - Present
GOES – NOAA geostationary weather satellites.	Proton and electron particle detectors (other sensors not yet fused).	1996 - Present

Future Streams
There are numerous other potential streams that we are considering and seeking partnerships for integration into our data fusion center. These include, but are not limited to, the following:

- **Ionospheric TEC Data** – We are working with Eric Calais at Purdue University to study anomalies in total electron content (TEC) of the ionosphere over earthquake preparation regions. We are currently working with TEC data derived from GPS receiver networks in California.
- **VLF Receivers** – Shifts in terminator times derived from received VLF transmitter signals have been reported to occur before large earthquakes.
- **InSAR** – Minor deformations in surface features that may precede earthquakes are potentially measurable by interferometric synthetic aperture radar systems on orbiting satellites.
- **Infrared Surface Imaging** – Anomalies in infrared emissions have been reported in earthquake preparation zones.

4. Product Examples

Multiple Stream Plotting And Visualization

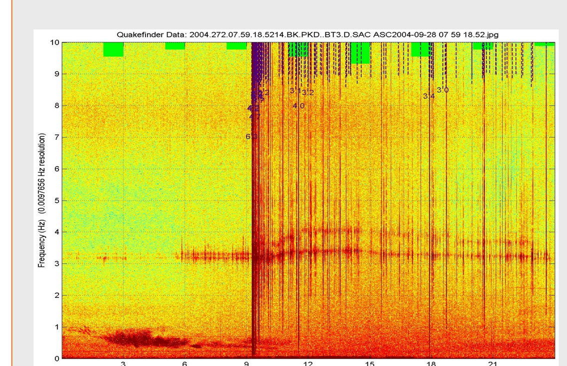

Figure 3a: UCB search coil data with Kp and earthquake catalog overlays, 9/28/2004.

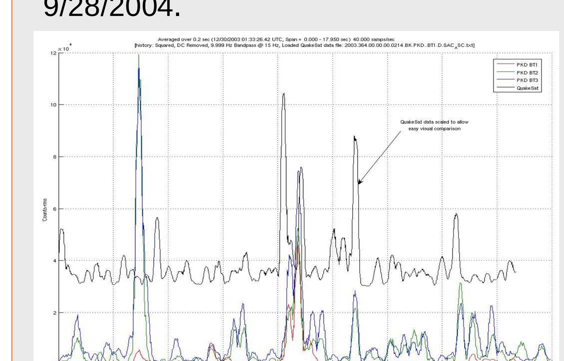

Figure 3b: Simultaneous plotting of search coil data from ground and space systems.

Event Detection and Plotting

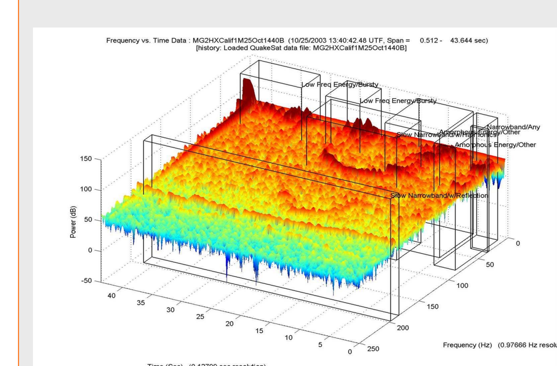

Figure 3c: Automated feature detection and tools for plotting events.

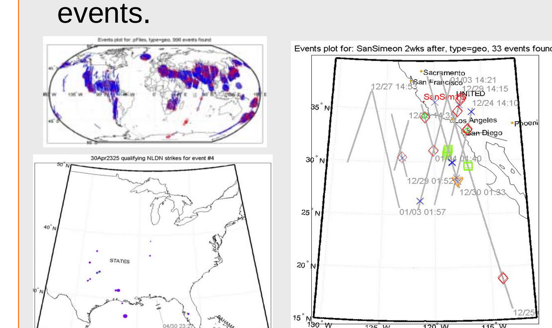

Figure 3d: Automated plotting of events and satellite passes on maps.

Community Specific Analysis

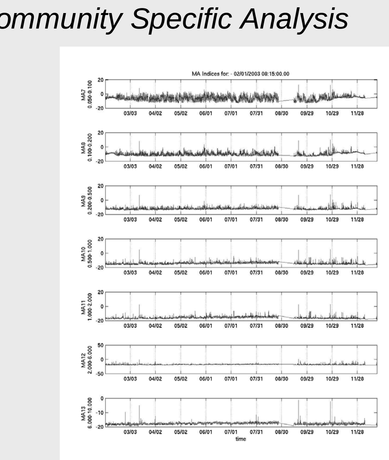

Figure 3e: MA indices showing energy in specific frequency bands.

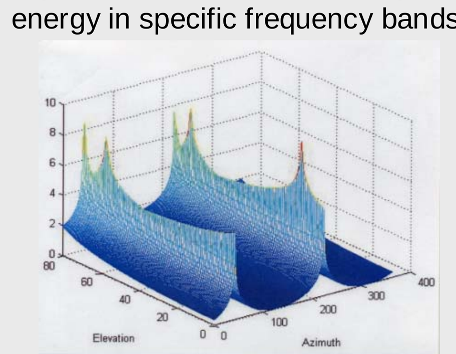

Figure 3f: Direction finding on three-axis search coil data.

Mapping Tools

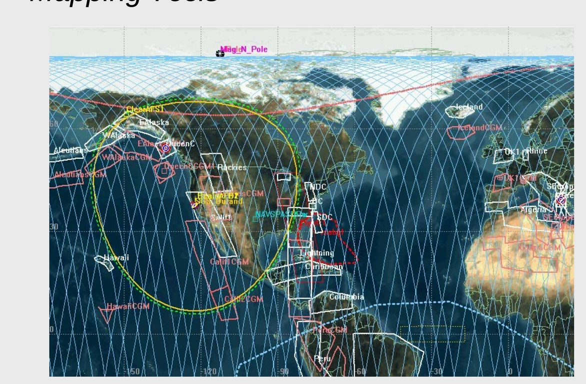

Figure 3g: Satellite targets, ground station connectivity, and orbits based on STK data.

Figure 3h: Mapping of lightning events and satellite position.

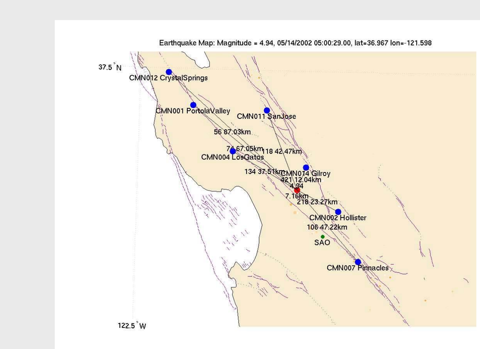

Figure 3i: Automated mapping of earthquake events and proximity to ground sensors.

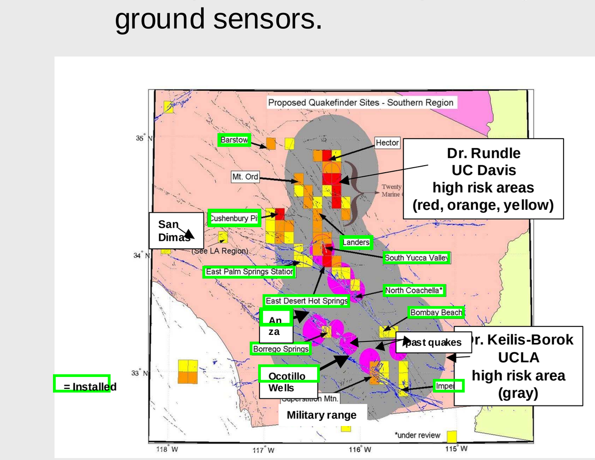

Figure 3j: Mapping of high probability earthquake zones.

2. System Architecture

The goal of our data fusion center is to enable simultaneous study of heterogeneous systems of distributed sensors and information streams. The four primary elements are:

1. Control of sensors (tasking, downloads, etc.)
2. Data retrieval of streams.
3. Fusion and processing of data streams.
4. Analysis of results
5. Data and product distribution.

See Figures 2a, 2b, and 2c for example architectures.

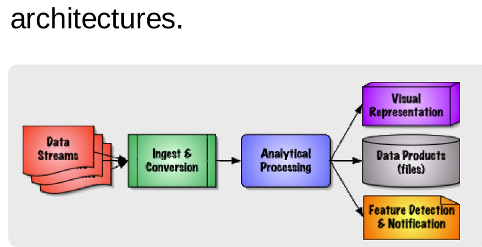

Figure 2a: General fusion architecture

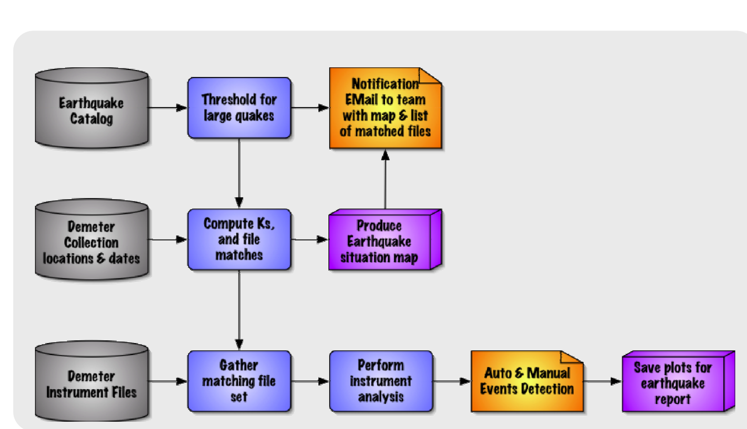

Figure 2b: This process retrieves quake events; determines DEMETER coverage of them back to 60 days prior; and generates a map, a listing of coverage files, and kicks off the instrument analysis for the report.

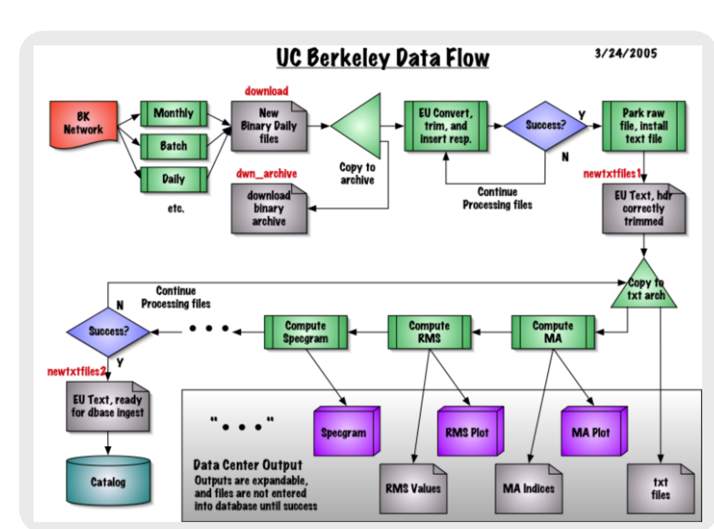

Figure 2c: Example data flow for our ingest of Berkeley Digital Seismic Network

5. Future Work

Distribution
Tools for remote access and distribution of data fusion center products are now under development. We are currently working with researchers in France, Japan, and the U.S. We are exploring the use of GRID and web-services tools for accessing our analysis products as well as our computational resources.

Fusion of New Streams
As mentioned earlier, there are numerous other potential streams that we are considering and seeking partnerships for integration into our data fusion center. These include, but are not limited to, the following:

- Ionospheric TEC data from GPS networks in California.
- VLF Receivers .
- InSAR.
- Infrared Surface Imaging .

Sensor Deployment
QuakeFinder will be deploying ten new electromagnetic observatories in California during the summer of 2005. They will contain three-axis search coils from Zonge Engineering, air conductivity meters, and Geophones. Site selection is currently underway.

A current challenge for our new observatories is the communication link for the retrieval of approximately 20MB per day per site. They will be located in remote areas where telecommunication infrastructure is limited.

We have not yet found a cost-effective solution to our communication problem and are actively searching for solutions and partnerships.

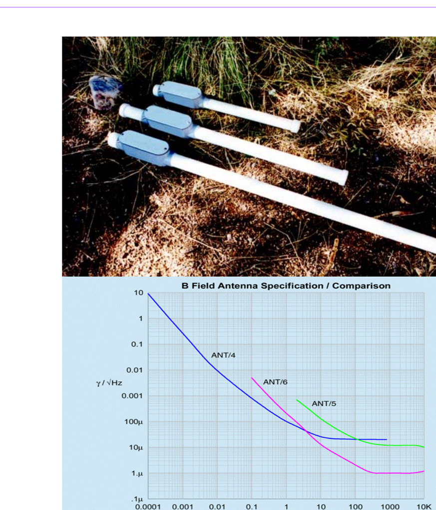

Figure 5a: Examples of the Zonge search antennas to be deployed at new QuakeFinder observatories. The ANT4 will be used and installation will take place during the summer of 2005.

6. Summary

1. An international community is studying electromagnetic anomalies associated with earthquake processes.
2. This seismo-electromagnetics community requires tools to study multiple data sets and mine information to understand the physical mechanisms involved.
3. QuakeFinder is developing a data fusion center to aggregate heterogeneous data streams and provide analysis tools to the community.