Final Technical Report

Award Number:	1434-95-G-2517
Applicant:	The Regents of the University of California Sponsored Projects Office Room 336 Sproul Hall Berkeley, CA 94720
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Project Title:	Monitoring of Electromagnetic Fields and Electrical Conductivity at Observatories in California
Element Designation:	IV

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Non-Technical Project Summary

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These experiments are designed to detect both anomalous electromagnetic signals in California and changes in electrical resistivity in Parkfield prior to earthquakes. Although often controversial, prior work has shown that electromagnetic signals are sometimes emitted and resistivity decreases before earthquakes. We currently do not know what generates these changes, thus casting doubt on the reliability of any prediction based on these observations. It is increasingly clear that fluids have an important role in the earthquake process, and electrical properties are extremely sensitive to fluids and fluid flow. Thus, these experiments may yield key constraints on the role of fluids in earthquakes.

Abstract

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Anomalous electromagnetic signals and resistivity changes have often been reported prior to earthquakes, but the lack of plausible causative mechanisms has cast doubt on these observations. One major problem in many experiments has been the lack of redundant measurements which would allow corroboration of the anomalous signals or changes as well as rejection of noise (defined to be any non-tectonic signal). Through collaborative efforts, we have pooled our magnetic and electromagnetic monitoring stations and a telluric monitoring array to focus on the detection of anomalous signals and changes in Parkfield. Parkfield was chosen because of the dense array of other geophysical measurements (seismicity, deformation, water levels, temperature, precipitation, seismic velocity) which will permit identification of tectonically significant anomalies. Additionally, the broad spectrum of measured properties will aid in the identification of the mechanism(s) responsible for any anomalies detected. With the increasing interest in monitoring electromagnetic signals and resistivity changes for earthquake prediction in Greece, France and Japan, there is a need for the development of highly precise monitoring methods. Existing and new techniques for multichannel processing can generate extremely stable results, and our study will serve as a model for new experiments.

Final Technical Report

Anomalous electromagnetic (EM) signals and resistivity changes have frequently been reported to precede large earthquakes. Although there are a number of physical mechanisms which might explain such EM-seismic phenomena, observations often seem inconsistent (e.g., precursors are reported to be primarily electrical in some cases, but in others are primarily magnetic) or difficult to reproduce (the phenomenon appears to occur in some special locations or circumstances, but not others). As a result, the very idea that tectonic activity might have a measurable EM signature is regarded with skepticism by many scientists.

One major problem with many previous studies of possible EM precursors has been the lack of redundant measurements which would allow signals to be corroborated and separated from natural magnetotelluric (MT) and cultural sources of EM noise. In an effort to address some of these issues systematically, researchers at U. C. Berkeley, Stanford, and U. C. Riverside have established a multi-scale monitoring array focused on the Parkfield segment of the San Andreas Fault. The array currently consists of two standard ultra low frequency (ULF) observatories at Hollister and Parkfield, California (SAO and PKD1) with a future site planned at PKD (Bear Valley Ranch, Parkfield). Each observatory consists of three orthogonal magnetic field sensors (10^{-4} to 20 Hz) and two electric dipoles (DC to 20 Hz). The electric and magnetic field data are continuously sampled at 40 Hz and 1 Hz with a 24 bit Quanterra digitizer. In addition the array includes the telluric monitoring dipoles of S. Park (DC to 1.0 Hz), providing an intermediate scale measurement of possible electric precursors as well as measurements of large-scale changes in electrical resistivity. The participants have agreed to use a common signal acquisition and digitization system and to use existing telemetry and data archiving provided by the Berkeley Digital Seismic Network operated by the U. C. Berkeley Seismological Laboratory.

Using a robust multiple station MT processing scheme developed by G. Egbert, Oregon State University, we have examined the long term stability of the interstation transfer function. Using a very precise transfer function obtained from long runs of the array data, we can effectively filter out the MT signal so that residual noise may be studied in detail. Simply stated, a residual is the difference between the measured field and the field predicted using the transfer function.

Figures 5.1(A) and (B) are examples of residual and signal spectra for one component of the horizontal magnetic field, Hx, at Parkfield, taken during two very short time windows on days 92.5 and 94.25 of 1996. Here we used the interstation transfer function and five EM components at SAO to predict Hx at PKD1. In Figure 5.1(A), the Hx signal power at Parkfield is greater than the Hx residual power. At lower frequencies the difference is more apparent, while at the higher frequencies the curves nearly overlay because the magnetic sensor noise is roughly equal to that of the signal. In Figure 5.1(B), the signal power is generally less than that shown in Figure 5.1(A), while the residual power increases in the frequency band from 0.02 Hz to 0.06 Hz. During this period of time, our magnetic sensors at SAO were in close proximity to battery power cables, resulting in an increase in the measured field. This may account for some of the changes in both the signal and residual power occurring in time and frequency.

In Figure 5.2(A), we show the ratio of Hx signal power at Parkfield and Hollister for two ten-day periods in 1996 ranging from day 90 to 99 on the left side and 260 to 269 on the right side. Each panel is subdivided into three frequency ranges. Since the magnetic source fields are located in the upper ionosphere, the magnetic fields are approximated as plane waves and assumed to be the same at both sites, even though they are separated by more than 150 km. Thus, deviations from 0 dB in the Hx signal power ratio may indicate a local source effect at one of the sites. As mentioned above, data from day 90 to 99 suffer from noise, while data from 260 to 269 were acquired during a relatively noise-free period after the noise source was removed at Hollister. The Hx power ratio on the left shows darker striping at higher frequencies between 10:00 am and 4 pm

local time which indicates a broadband elevation in Hx power at Hollister. One explanation is that during this time of the day, the solar panels were charging the batteries, creating spurious current pulses in the power cables lying close to magnetic sensors at Hollister, resulting in an increase in the measured field at Hollister. Another feature of interest is the reddish yellow line occurring at a constant frequency just below 0.3 Hz. It is noticeable throughout both time sections and may reflect a local noise source at Parkfield.

The ratio of residual to signal power during these same two time intervals is shown in Figure 5.2(B). As previously mentioned, the residual is the difference between the measured field and that which is predicted using a transfer function. In this example we used five EM components at Hollister to predict the Hx field at Parkfield. Residuals at Parkfield from day 90 to 99 are elevated in contrast to subsequent residuals from day 260 to 269. One explanation for the elevated residual power is that there is a noise source at Parkfield from day 90 to 99 which is not predicted by the fields at Hollister. Another more likely explanation is that one or more of the five EM components used to predict the field at Parkfield is contaminated with noise. This could result in a difference with the measured Hx field at Parkfield. To reconcile this ambiguity, one might invoke several different strategies to calculate the residuals. Instead of using all five EM components from Hollister, one could have chosen to use only the electric fields, which may not have been suffering from noise at Hollister, to predict the Hx field at Parkfield. The results from this type of analysis are necessary to fully understand the noise. Alternatively, the power ratio plot is useful in determining if there are additional local noise sources contributiing to the background power spectrum.

In general, the residuals at Parkfield from day 260 to 269 show a decrease in power, reflecting a relatively quiet period of EM activity. However there are several instances of elevated residual power, most noteworthy are the sharp red lines occurring sporadically throughout this section and the previous one. We suspect that these short broadband residual bursts are the result of a truck driving by our magnetic sensors at Hollister (the magnetic sensors at Hollister are located within several meters of a road). Again this may be another example when one or more of the five EM components at Hollister is contaminated with noise, resulting in a residual at Parkfield. Another curious feature are the daily residual power minima occurring around 4 am local time in the frequency band below 0.03 Hz. Efforts are currently underway to characterize this and other noise processes more fully.

We have developed the signal processing and display algorithms for routinely monitoring the residuals at the initial two sites of the array. The data to date can be used to statistically characterize "normal" variations in the residuals. This will permit rapid or automatic identification of anomalous noise at any of the sites.

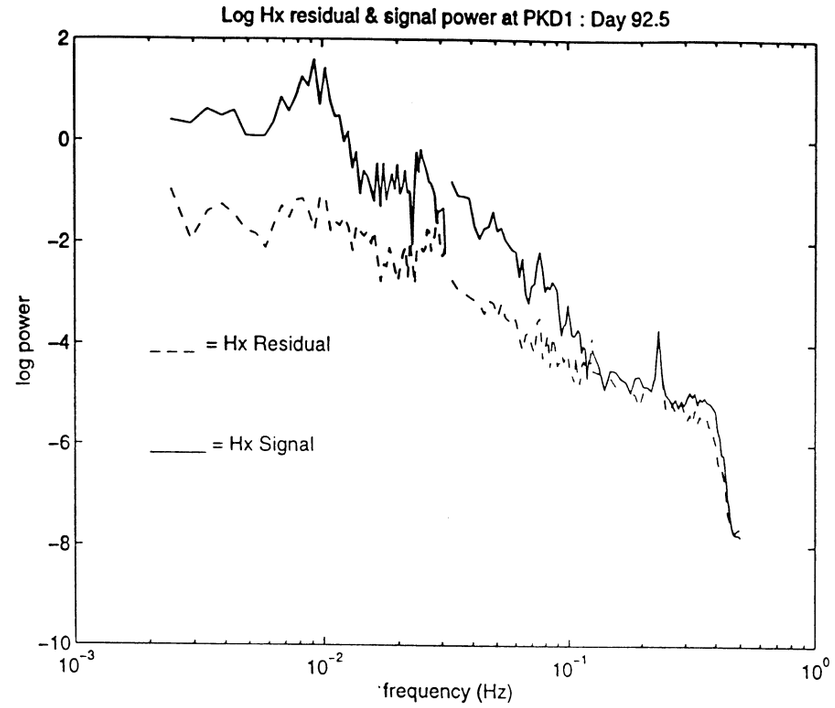
One of the advantages of this project is that using a common data format will facilitate multisite processing procedures to study coherent and incoherent fields on scales varying from the electric dipole separation (100 m), to the telluric area (5-15 km), to the station separation at Parkfield (20 km), and finally to the separation between the sites at Parkfield and Hollister (150 km). It is hoped that this array will serve as a prototype for new arrays established around the world and that data recording and archiving standards can be adopted to facilitate rapid access and exchange of ULF data for earthquake prediction research.

Figures 5.1(A) and (B) Log Hx residual and signal power at PKD1 for day 92.5 and 94.25 of 1996.
Figure 5.2(A) Ratio of Hx signal power at PKD1 and SAO for two ten-day periods in 1996 from day 90 to 99 and 260 to 269. The top section in each plot covers the frequency range from 0 to 0.5 Hz; the middle and bottom sections focus on narrower frequency bands. Missing data are denoted

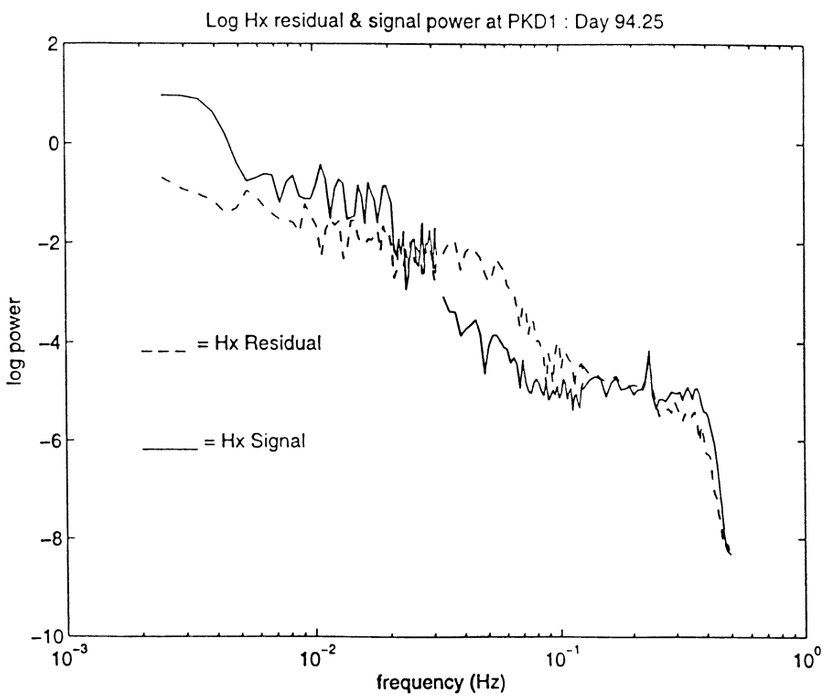
by vertical white bars. Regions of yellow to red shades indicate greater Hx signal power at Parkfield; darker shades indicate greater Hx signal power at Hollister.

Figure 5.2(B) Ratio of Hx residuals at PKD1 (predicted by five EM components at SAO) to Hx signal power at PKD1 for two ten-day periods in 1996 from day 90 to 99 and 260 to 269. Regions of warmer shading highlight instances when the residual power exceeded the signal power, while the darker regions are an indication of times when the signal power was stronger than the residual power.

a)



b)



Figures 5.1 (a) and (b): Log Hx residual and signal power at PKD1 for days 92.5 and 94.25. *Courtesy of S. Boyd*

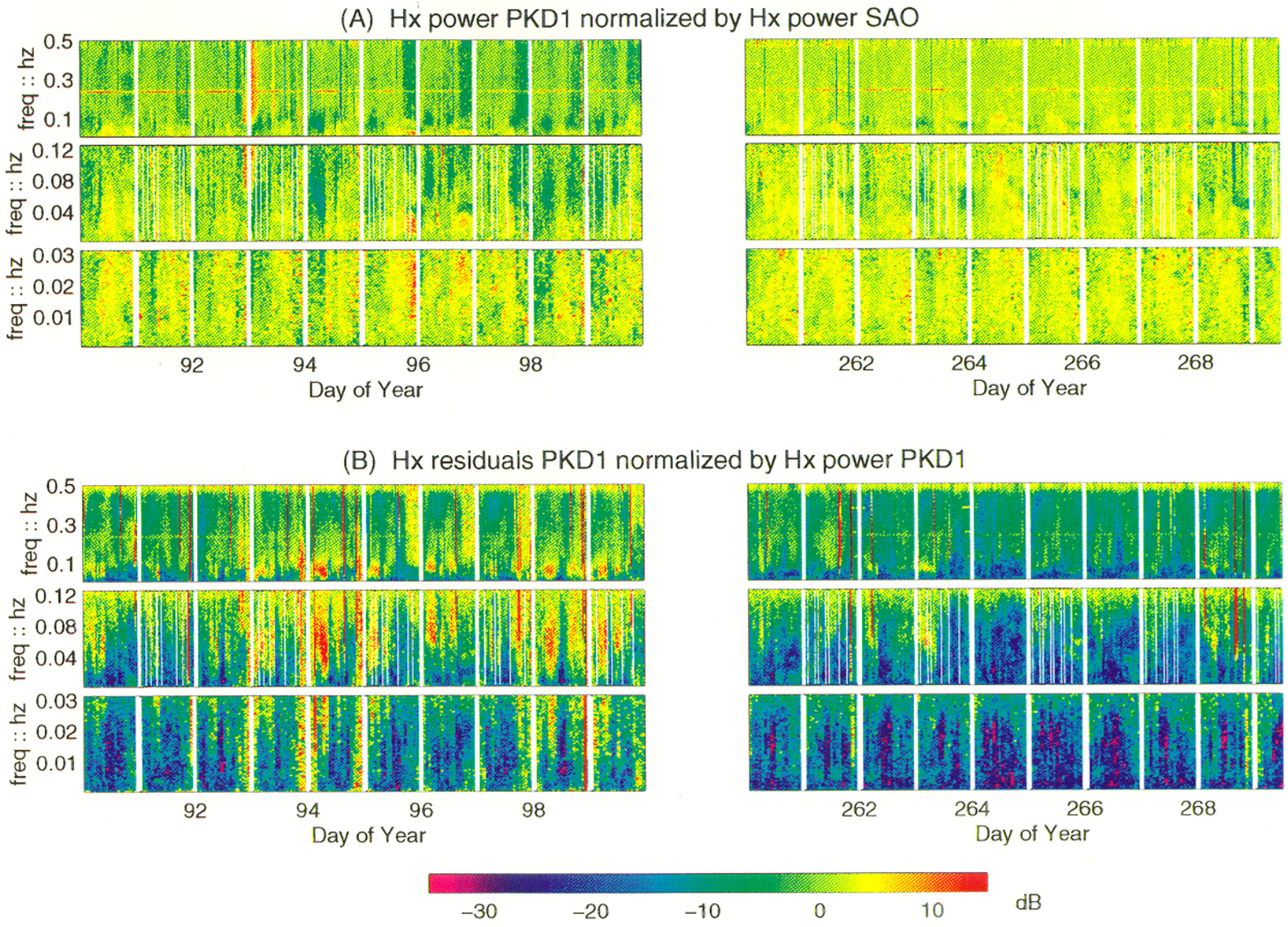


Figure 5.2: a) Ratio of Hx signal power at PKD1 and SAO for day 90 to 99 and 260 to 269. Each panel is subdivided into three frequency ranges. Missing data are denoted by vertical white bars. Regions of lighter shades indicate greater Hx signal power at Parkfield; darker shades indicate greater Hx signal power at Hollister. b) Ratio of Hx residuals to Hx signal power at PKD1 for the same time periods in part a.. Regions of lighter shading highlight instances of greater residual power. *Courtesy of S. Boyd*