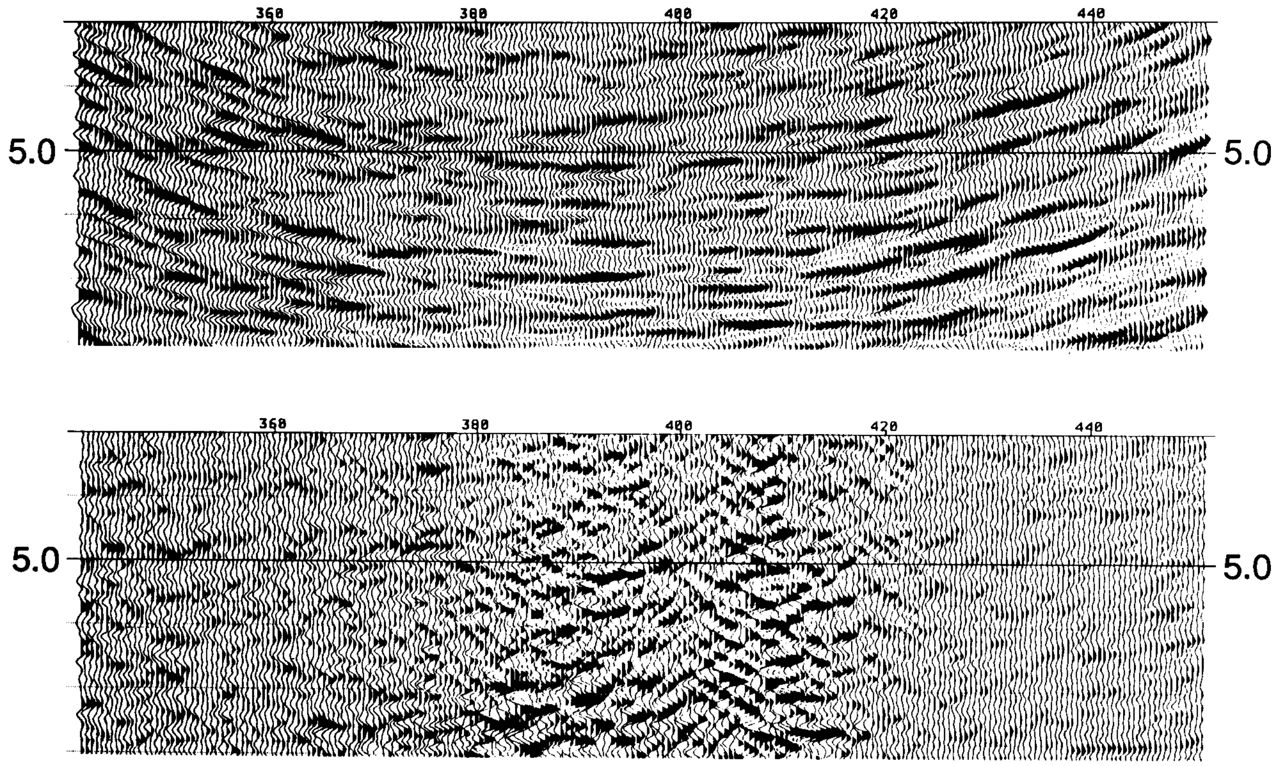

FIGURE 6
Migration with vertical velocity function (top), constant 1600 m/s (bottom).

Transfer Function Estimation for Natural Electromagnetic Fields

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Summary

Four techniques are compared for estimating the transfer function between fields measured at one site with fields measured at another site, or with different fields measured at the same site. The techniques are:

(1) Linear, point-to-point time domain estimation (LPP),
(2) Conventional frequency domain transfer function estimation (FD),
(3) Multichannel Wiener estimation in the time domain (WE), and
(4) Adaptive filter processing in the time domain (AFP).

These four transfer function estimation methods have been applied to high precision SQUID magnetometer array data collected in Grass Valley, Nevada and Long Valley, California, using natural fields in the frequency band 10^{-4} to 1.0 Hz. To monitor the 'signal' introduced by motion of the sensors in the Earth's large static field, high sensitivity cryogenic tiltmeters were used in each magnetometer. The transfer function estimation methods above have accounted for more than 50 db of the signals received at one site using fields measured at another site. Removal of motion-induced magnetic signals provides as much as 10 db further reduction in the residual signal compared to using solely electromagnetic field signals.

Introduction

As the depth of exploration for electromagnetic methods increases, the natural electromagnetic fields become the limiting factor in measurement accuracy. Increasing either measurement averaging time or source moment become impractical for efficient exploration programs. One solution is to develop schemes for removing or cancelling the background 'noise' at the measurement site using fields measured at a remote site. We demonstrate this principle via four different processing methods applied to multicomponent array data acquired in surveys in Grass Valley, Nevada and Long Valley, California. In these experiments, signals from four magnetometers were recorded simultaneously. Two magnetometers were located at the base vault on the same granite slab, and one along each arm of an L-shaped array. Each magnetometer was placed in an insulated vault, on a granite slab as is shown in Fig. 1. Three independent 18-bit data acquisition systems were used to acquire the array data at 9 different stations with separations ranging from 1 m to 9 km.

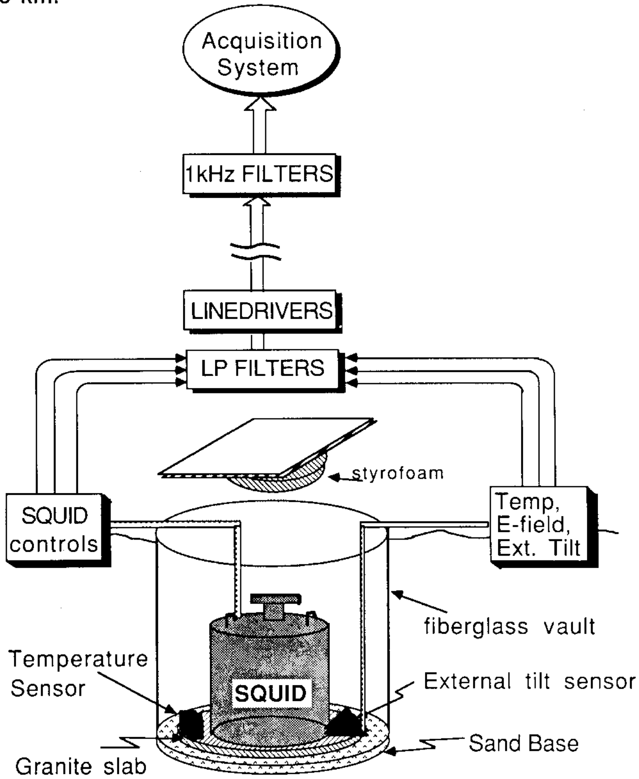

FIGURE 1
Magnetometer vault setup

Data analysis

Given a uniform incident field excitation, the observed natural electromagnetic fields on the surface of the earth are related by point-to-point linear transfer functions which are determined solely by the conductivity of the ground. In frequency bands where the transfer functions possess very small imaginary components, i.e. little phase shift between input and output, the transfer function estimation process can be simplified to solve for real coefficients relating the input and output time series. A least squares minimizing procedure (LPP) can solve for these coefficients directly in the time domain. Such coefficients account for orientation and sensitivity differences and make a first-order correction for the motion of the magnetometers. Figure 2 illustrates the reduction of the horizontal magnetic field at one site using a 1 km remote site. The residual signal is progressively reduced by 20, 50 and 63 db using the parallel magnetic component, all 3 components plus tiltmeter outputs from each site, respectively. The observed magnetic fields are generally reduced 40-60 db by this method.

The LPP method does not allow frequency dependence of the transfer functions and, consequently, works less effectively for the secondary fields (Ex, Ey, and Hz) at sites where the conductivity structure is different. Estimating the transfer function estimation consists of inverting the cross-power

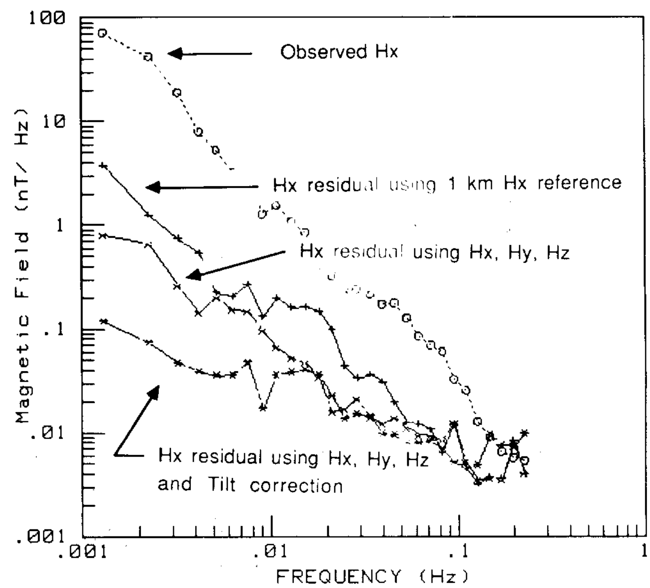

FIGURE 2
Observed and residual magnetic spectra for 1 km separation.

mean square residual error at each frequency. FD transfer function estimation consists of inverting the cross-power matrix calculated at each of the constant-Q frequency windows of the Fourier transformed data. The frequency dependence formulation yields a better physical description of the electromagnetic field behaviour than the LPP method and gives rise to more robust solutions.

Multichannel Wiener estimation theory (Robinson, 1983) was implemented in the time domain as well. In this case, we assumed a moving average process (MA) and proceeded to parameterize the transfer function estimation task. Wiener estimation hypothesizes second order stationarity and is not suited for strictly random source phenomena. To overcome this limitation, we performed the estimation over a number of data segments sufficiently long to account for all the frequencies of interest. Results from this exercise are presented for different length MA operators, and they are comparable to those of the frequency domain transfer function estimation process.

Finally, we employed the rudiments of adaptive filter theory (Haykin, 1986) to effect signal enhancement. This strategy allows for time-varying statistics of the source phenomena and thus provides a dynamic transfer function estimation scheme. As with the multichannel Wiener estimation, we parameterized the desired transfer function to correspond to a MA process. For the filter adaptation process we have performed both least mean squares (LMS) and recursive least squares (RLS) methods. Filter coefficient variability with time may be indicative of source polarization phenomena.

References

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