Time Series Analysis of Magnetotelluric Data: Coherencies and Orientation

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Abstract

Observatory magnetic data can be used to eliminate the errors caused by the mis-orientation of receivers and noise in magnetotelluric data. Based on the experience on land data, we propose that magnetic observatory data may be used to find the correct orientation of the receivers in the oceanic floor (which is unknown for MMT system without electronic compass), comparing, at different angle values, coherences between magnetic observatory data and single site data. Knowing orientation of the receiver, we use remote reference to generate apparent resistivity and phase of sites.

In this work, magnetic data from Vassouras Magnetic Observatory (VSS, Observatório Nacional, SE Brazil) were used as remote reference (RR) for marine magnetotelluric (MMT) data acquired in Santos basin, to find the right orientation of receivers used in the measurement. To test this procedure, we have compared array data acquired in Pará State, near Tatuoca magnetic observatory, which have known directions, with magnetic data from Tatuoca Observatory(RR in this case), to test the procedure before applying on MMT data.

Introduction

Marine magnetotellurics method is not new in oil exploration (e.g. Filloux 1983, Constable 1998). The magnetotellurics (MT) method (e.g. Vozzof 1991) are usually employed to see beneath the high velocity units over which seismic data quality is low (e.g. Karen 1991, Nagy 2006,). Recent instruments development and techniques interpretation (e.g. Key and Constable 2002) have brought MMT to attention of oil companies. MMT method is relatively new and still needs much attention to produce meaningful result when it is compared to seismic method. Some of problems are related with data acquisition stage. Locating and orienting a receiver is cumbersome and primary source of noise. Another problem is the dip currents in the marine environment which can move or vibrate the receiver. Either case additional information is required to eliminate the noise and ambiguity.

One way of adding external information is to use remote reference (RR e.g. Gamble et al 1979) MT station which helps to improve signal/noise ratio in simultaneously recorded stations. Time series analyses procedure contains all stage of the incorporating external data or using data itself to reduce noise effects. Analyses of the time series (TS) are the first step of the MT method. Basically, it consists of selecting 'clean' windows (or segments) and stacking their amplitudes in Fourier domain for pre-defined frequencies. In case of noise contamination, this approach will cause bias towards noise. RR station can be employed to reduce the bias. RR stations can be a nearby station along the survey line, additional station off the survey line or an observatory station. It is required that the field to be used as RR cannot be too far away from the corresponding MT sounding, having in mind that the external magnetic fields may be considered uniform for sites about 200 – 300 Km apart at maximum. Another important condition is that the noise present at both stations be uncorrelated.

In this work, the result land data were used to check the result of proposed. To test this procedure, we are comparing array data in Pará, near Tatuoca magnetic observatory, which have well known directions.

Time Series Analyzing Methods and Orientation

TS data are recorded at selected sampling interval. up to five component of the EM field can be measured during the land survey while it can be six components in marine survey. In case of noise free field, linear relation between electrical (E) and magnetic (H) fields given as (e.g. Berdichevsky and Zhdanov 1984)

$$E = ZH \qquad (1)$$

where Z is a 2x2 matrix of impedance. Since E and H are column vectors and the solution of the Eq.1 require inverse of H vector, the solution is obtained after multiplying it with another column vector, C

$$Z = (EC^*)(HC^*)^{-1} \qquad (2)$$

where '*' denotes hermitian transpose of a complex matrix. If C is selected as the H field, then, first and second term in RHS are cross-power spectra of E and H, and autopower spectra of H (e.g. Chave and Thomson 1989), respectively. Selecting C as E or H channels of station itself or RR station has been reviewed by many authors (e.g. Sims et al 1971, Larsen 1980, Jones et al 1989). Common points of the results indicate that satisfaction of the techniques rely on the data quality.

The data used in this study were recorded simultaneously in two stations along the surveyed profile. Thus, C vector can be any channel of either neighbor station or RR station. All LMT stations records the TS in four channels with 4 Hz sampling interval. Recording time was 24 hours. In addition, Tatuoca Station has a magnetometer and has been recording the magnetic data as declination (D), horizontal (X and Y) and vertical (Z) components with 1 minute sampling interval over the past years. For that, LMT data were decimated.

To obtain orientation of receiver, coherency between magnetic field from both neighbor station and observation and magnetic field from a station is analyzed; if coherency between same component is not high (>0.5), the time series must be rotated until maximum coherency is obtained. When maximum coherency is obtained, the angle that rotated time series is the angle that must rotate the observatory component direction to obtain the orientation of the receiver. Coherency values are calculated using formula below.

$$coh(A(f_i),B(f_i)) = \frac{1}{2m+1}\sum_{k=j-m}^{j+m} \frac{A_k B_k^*}{\sqrt{(A_k A_k^*)(B_k B_k^*)}} \quad (3)$$

The effect of the angle over coherency is given figure 1. Remote channels rotated and coherencies were calculated in each step. Coherencies approach to one while rotation angle goes to zero and decrease to zero while angle increase to 90.

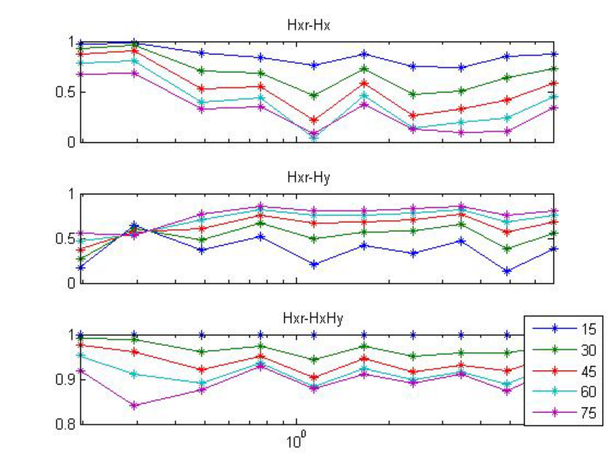

Figure 1: the effect of the rotation angle over coherency

To test whether rotating time series produces reliable results, this procedure will be applied to land data with well known direction ‘near’ magnetic observatory of Tatuoca, Pará, Brasil (near means in a good distance, in the concept of reference remote). The magnetic observatory will be RR, and coherency must be high (> 0.5) when components are in same direction. If tests produce good results, we can apply it in MMT data, even though sea RR should be electric field instead of magnetic, but there’s no electric field measured in magnetic observatories mentioned in this work.

Results

Ongoing researches have indicated that single station MMT processing techniques cannot present reliable curves. Rotating time series to find orientation of receiver combined with remote reference data analysis (apparent resistivity and phase of site) can improve the result and produce reliable impedance subject to their signal/noise ratio and orientation but still has problem in two decades of frequency range due to vibration of coils. Land remote reference has an advantage over directional setting but may have problem with the location. Data from observatory land stations are still helpful for the process even if they do not have electrical fields.

Observations indicate that H field is affected by vibrations and contains heavy noise between 2-10 Hz. Therefore, E field from MMT stations was employed as C data in Equation 2. Example results given in Figure 2 presents recovered apparent resistivity curves. Data given in Figure 2a is a result of single station process while 2b uses a marine RR station. Simple quality control point is the resistivity of water (~1 ohm-m) the curves from TS analysis of single station scatters 4-5 decades for high frequencies. On the other hand, the usage of the RR data in TS process obtained the resistivity of marine correctly but still suffers from noise between 2-10 Hz.

a

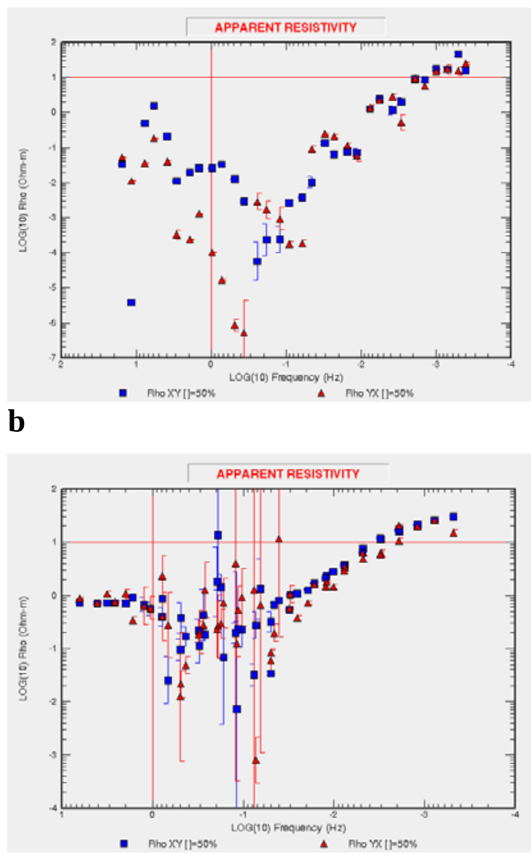

Figure 2: Two results from Station 86. Difference is in selection of C in Eq.2 a) E field from station itself used as C and b) E field from marine RR station used as C.

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