A discussion about robust and classical magnetotelluric processing techniques: A case study on Santos basin.

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Abstract

In this work we made a statistical treatment of marine magnetotelluric data collected on Santos basin in southeast cost of Brazil. The basin is part of the group of basins of Brazilian pre-salt province. We analyzed the data and performed classical and robust processing as an attempt to avoid effective noise that is critical in many stations of the survey. The suitable processing scheme and correct noise removal are key points of magnetotelluric workflow and can definitively help to improve the data quality at local sites and this way reach better results. Finally, we hope to accomplish a joint inversion using these magnetotelluric data and additional seismic and magnetic data.

Introduction

The called non-seismic methods suffer in comparison with the seismic method, mainly seismic reflection, when the goal is resolution. However even the seismic reflection is unable to provide good responses in areas as carbonates, salt bodies or basement, where the seismic energy is scattered and/or attenuated. The Santos basin is, exactly, in that situation because it is located in a salt bodies province that extends it for about 800 km in front of states of southeast cost of Brazil (Figure 1). This giant structure has approximately 2 km of thickness and represents a setback to obtain a good imaging from the base of salt. In this context the magnetotelluric method shows itself a very good alternative to overcome this problem.

Magnetotellurics (Tikhonov, 1950; Cagniard, 1953) is a passive method of exploration of the subsurface of the earth. The technique basically consists on measuring the horizontal components of electric and magnetic fields incident at the earth's surface. By measuring two horizontal components of electric field and three components of magnetic field, we can compute, after some mathematical procedures as Fourier transform, the impedance tensor. This quantity can give us information about electrical resistivity distribution of the subsurface. The fonts of magnetotelluric method are, respectively, solar wind at low frequencies (about < 1 Hz) and lightning storms (called *sferics*) at high frequencies (about 8 Hz and higher). The technique can be applied to investigate the ocean floor the same way at in land, except for some modifications in acquisition. In marine field works the acquisition behavior is totally unknown and some noise sources as wave motional, biologic activity and microseisms can cause influence in the recordings, especially the conductive water layer that acts as a low pass filter.

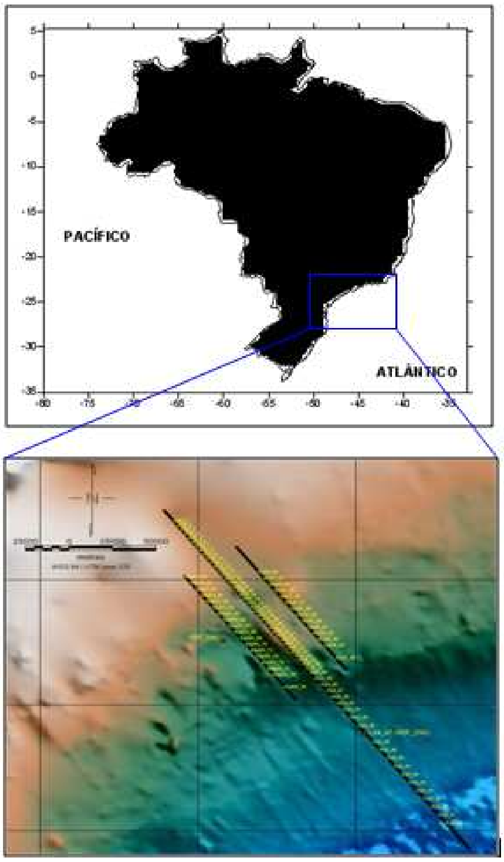


Figure 1: Local map showing Santos basin and the magnetotelluric survey realized. In this work just the data from central profile were analyzed.

Some of these undesirable effects can be avoid using induction coils for magnetic field measures and electric field amplifiers especially developed for marine applications (Constable, et. al., 1998). Although even with these equipments the data are not totally free of noise and processing techniques must be applied to improve the quality and consequently, the resolution of the data.

Processing Workflow

The processing scheme adopted is a comparative way to face the problem of estimating the magnetotelluric transfer functions. Based on the quality of the data we have made a choice to follow the classical or robust processing. We still used some techniques to ensure we have an approximately two-dimensional scenario. In figure 2 are described the steps and logical thinking of processing.

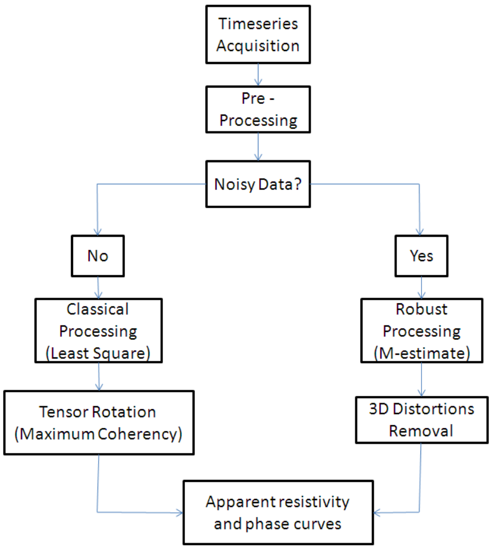


Figure 2: Flowchart showing the steps adopted in processing.

The data were acquired simultaneously and each station has approximately three days of data. The recordings are bigger compared to acquisition in land, it is because of conductive seawater that dissipates the energy contained in lower frequencies. Later, a pre-processing step was applied to the data, this procedure is common in magnetotelluric acquisitions and it is accomplished in order to achieve data as good as possible. Generally, in this analysis are included filters and polynomial fits. After pre-processing step the data are inspected and stored in disk. Depending on the quality of the data, if the data are noisy (many spikes) or not, a choice about how to proceed is made. In both processing modes the final product are the resistivity and phase curves.

Discussion of results

In practice, we followed a kind of “two-way” processing. Initially the data were submitted to a classical processing based on least square regression technique (Sims et. al., 1971). Later, the data were rotated to a particular direction that represents the maximum coherency between horizontal components of electric and magnetic fields. We analyzed each station separately and the values bigger than 0.7 obtained for the coherency were approved as suitable. In this situation we hope to have found the correct direction of two-dimensionality and thus minimize the components of main diagonal. The geoelectric strike found was approximately NE-SW represented by an angle of about 47° in relation to real north. This information can be confirmed by the magnetic anomaly map obtained from the region (Figure 3).

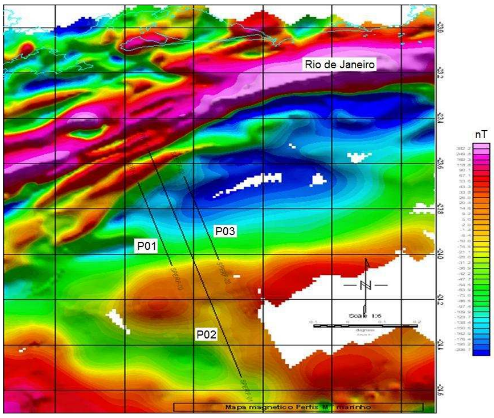


Figure 3: Magnetic anomaly map showing the two-dimensional trend in the region.

However, even after classical processing and rotation applied, the data still showed a great amount of noise, as we can see in figure 4. This problem is due to the fact that the least square method can be strongly affected by outliers in time series and then produces biased estimates. The results provided by these data distribution can generate models not too accurate. Although the data have a behavior approximately 2D this not guarantee the inexistence of galvanic distortions and these effects can generate three-dimensional anomalies on impedance tensor which in fact would explain the noise on the data (Bahr, 1988; Groom & Bailey, 1989).

Following the workflow, an attempt to avoid the biased estimates is to perform the robust processing (Egbert & Booker, 1986) of the data. This methodology of processing can help to avoid these effects on the data. The theory is based on a method called 'Regression M-estimate' (Huber, 1981). Theoretically, what algorithm does is compute the transfer functions but not allowing few bad points *'outliers'* dominate the estimate. It is accomplished by the loss function that controls how deep the influence of a particular measurement in the dataset is. Many authors (Jones, et. al.,1989; Chave & Thomson, 1989) have discussed about difference and influence, on the data distribution, in performing these two philosophies including remote reference.

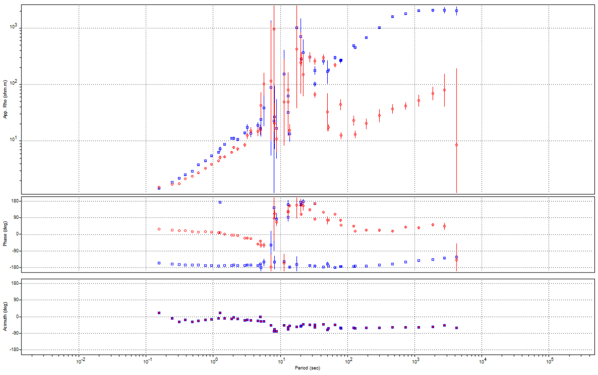
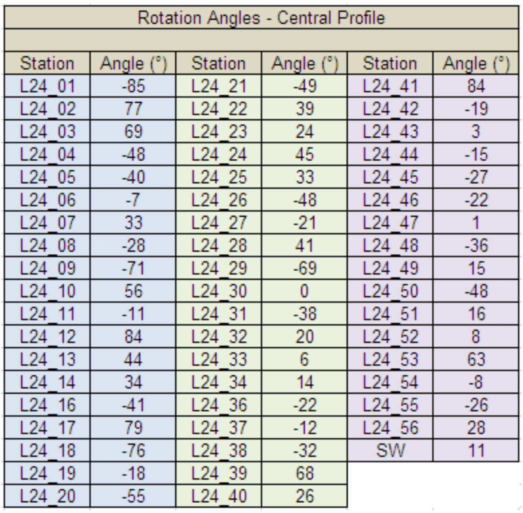


Figure 4: Resistivity and phase data obtained from classical processing. We can see a lot of noise in frequency range of 10^0 - 10^2 Hz.

The data were submitted to the robust processing and 4 levels of decimation were calculated reaching a frequency range from 10^{-3} to 10 Hz. Later, the data were rotated according to angles obtained from Groom & Bailey methodology. The figure 5 shows the distribution of the angle values corresponding for each analyzed station. After rotation we are working with the data in two directions; perpendicular and parallel to regional strike. This fact ensures the knowledge of TE and TM modes. This point is especially important in marine acquisitions because of we can't be ensure about the correct direction of measurement, i.e., when the receiver is dropped out in water he can lands at the ocean's floor in whatever direction.

The robust processing found, on the other hand, results really more accurate as we can see in figure 6. The trend of the curves is smoothest representing a better fit. The absence of outliers can help on the 2D inversion and the model can be evaluated with a computational gain spending less time in iterations of the code.

The two-dimensional models obtained from each one of the two modes of processing are shown on figures 7a and 7b. In the first one we can see clearly many zones where the resistivity is varying but this result is only achieved when we reduce the range of resistivity to force the distribution stops in about 250 ohm.m. As we know even some sedimentary rocks can reach more the 500 ohm.m so is not plausible allows this range. Already the another model show a resistivity distribution varying from 0.1 to 5000 ohm.m allowing a very good resolution to map with accuracy the different zones of profile. In both models some features still remains and probably are due to local bad adjusts.



Rotation Angles - Central Profile					
Station	Angle (°)	Station	Angle (°)	Station	Angle (°)
L24_01	-85	L24_21	-49	L24_41	84
L24_02	77	L24_22	39	L24_42	-19
L24_03	69	L24_23	24	L24_43	3
L24_04	-48	L24_24	45	L24_44	-15
L24_05	-40	L24_25	33	L24_45	-27
L24_06	-7	L24_26	-48	L24_46	-22
L24_07	33	L24_27	-21	L24_47	1
L24_08	-28	L24_28	41	L24_48	-36
L24_09	-71	L24_29	-69	L24_49	15
L24_10	56	L24_30	0	L24_50	-48
L24_11	-11	L24_31	-38	L24_51	16
L24_12	84	L24_32	20	L24_52	8
L24_13	44	L24_33	6	L24_53	63
L24_14	34	L24_34	14	L24_54	-8
L24_16	-41	L24_36	-22	L24_55	-26
L24_17	79	L24_37	-12	L24_56	28
L24_18	-76	L24_38	-32	SW	11
L24_19	-18	L24_39	68		
L24_20	-55	L24_40	26		

Figure 5: Table showing the correct angle values to each station. The SW station means 'shallow water' and corresponds to a remote reference station used in the shallower part of profile.

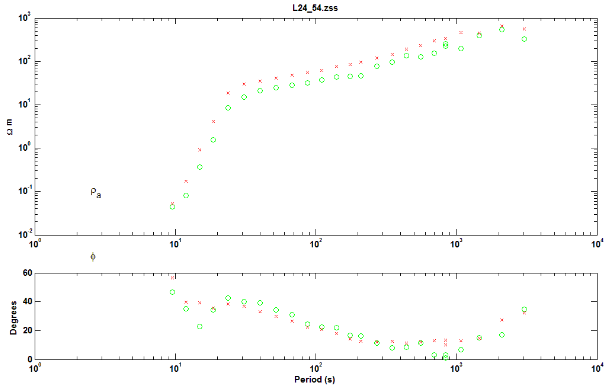


Figure 6: Resistivity and phase data obtained from robust processing. The trend of the curve is clear and the data are smoothest.

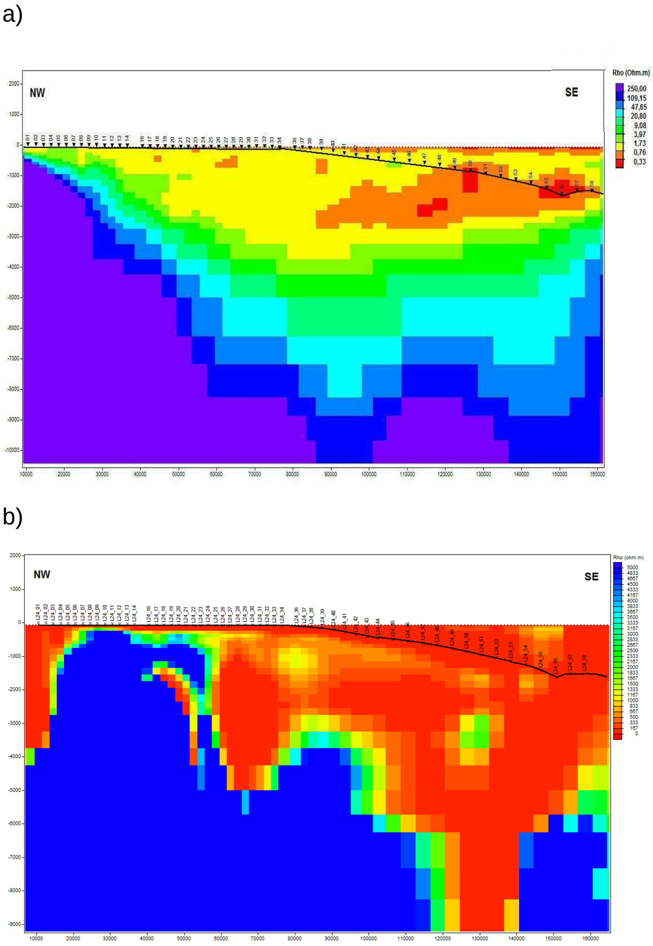


Figure 7: a) Model obtained from classical approach, although the resistivity appears well distributed the range is varying only until 250 ohm.m. b) Model obtained from robust processing, the resolution is higher in comparison with the first.

Conclusions

The marine magnetotelluric method still deserves attention to improve his potential and this way provides a biggest range of solutions for the oil exploration. However, the technique remains perfectly suitable to map resistivity contrasts. We analyzed two distinct ways of processing and using statistical tools compared the both to establish the correct workflow depending on the amount of noise in the data. Some stations of the central profile presented low level of noise and we could chose perform a classical processing but for reasons of comparison we submit all stations to the same processing, or classical or robust. The results from robust approach were better in comparison with classical. The improvement in resolution is clearly showed by the models 7a and 7b. In figure we can see a layer of about 1 km of thickness with resistivities from 1000 to 3000 ohm.m, it can be representing the salt layer present in the basin. Such structure is not perceived in the first model. The basement was mapped extending for about 80 km longitudinally to the basin. As the basement is formed by crystalline rocks as igneous and metamorphic his resistivity can achieve elevated values of resistivity.

These results are part of a biggest effort to perform a joint inversion and interpretation using other geophysical datasets available as seismic, potential and well logs. The idea is join all datasets and realize inversions according to cross-gradients technique (Gallardo & Meju, 2004). In this methodology we can examine the contributions of each datasets (Gallardo, et. al., 2010). The first approach of this project was presented in the Workshop on Electromagnetic Induction in the Earth (Lugão et. al., 2008) and some others results were presented later in Pinto, 2009.

Acknowledgments

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