Joint Interpretation of Magnetotelluric and Gravimetric Data in the Paraná Basin

Edgar B. Santos*, Universidade de São Paulo; Henrique B. Santos, Universidade de Campinas; Ícaro Vitorello and Marcelo B. Pádua, Instituto Nacional de Pesquisas Espaciais

This paper was prepared for presentation at the 13^{th}International Congress of the Brazilian Geophysical Society, held in Rio de Janeiro, Brazil, August 26-29, 2013.

Abstract

In the past years, substantial effort has been directed to improve the magnetotelluric (MT) inversion algorithms. Many different techniques were developed to estimate 2-D/3-D geoelectric models of the Earth. However, to evaluate the deep structural architecture of the lithosphere under a sedimentary basin is a great challenge, requiring the integration of different geophysical and geological studies. In this paper, we present the resulting Paraná Basin lithospheric model, obtained from processing and inversion of broadband and long-period magnetotelluric soundings along an E-W profile across the central part of the basin. Our results are complemented by a qualitative joint interpretation of gravimetric data, in order to obtain a more precise geoelectric model of the deep structure of the region.

Introduction

The Paraná Basin is a large sedimentary basin in central-eastern South America that extends through Brazil, Paraguay, Uruguay and Argentina. Evolved completely over the South American continental crust, this Paleozoic basin is filled with sedimentary and volcanic rocks deposited from the Silurian to the Cretaceous, when a significant basaltic effusion covered almost the entire area of the basin. A series of superposed sedimentary and volcanic rock layers were laid down under the influence of different tectonic settings, probably originated from distant collisional dynamics of continental boards that led to the amalgamation of Gondwanaland (Gabaglia and Milani, 1990). In this work we used MT profiles previously collected in the states of Paraná and Mato Grosso do Sul. The MT data were collected in according to an east-west profile (E − W), in the central region of the Paraná Basin (Figure 1). The MT data collected from INPE was processed and preliminarily interpreted together with gravimetric data.

Bouguer Anomaly of the Paraná Basin

In this work we used the Digital Gravimetric Model of the South America (MGDAS-2004) of high resolution ($5' \times 5'$) developed by Sá (2004). The Figure 2 illustrate the Bouguer anomaly of the Paraná Basin. It is observed that the basin presents a predominantly negative Bouguer anomaly as was expected for a sedimentary basin.

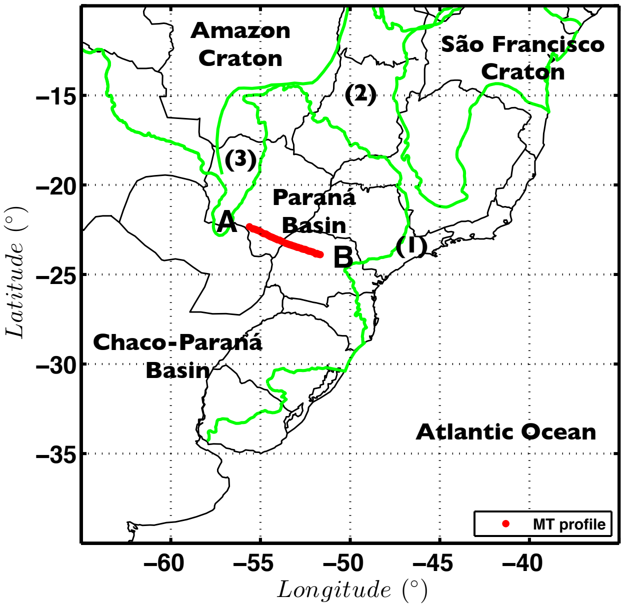

Figure 1: Study area. The green contours and numbers indicate some of the main tectonic provinces within South American lithospheric plate, being (1) Mantiqueira Province; (2) Tocantins Province; and (3) Pantanal Basin. The red line represents the MT profile.

With this data the upward continuation was calculated until $100\,\mathrm{km}$ (Figure 2) of height (z). The upward continuation works as a low-pass filter, attenuating the short wavelength. Thus, it is possible to observe gravity anomalies originated by deeper structures. Even for a $100\,\mathrm{km}$ height (Figure 2) it is still possible to observe a negative gravimetric anomaly across the Paraná Basin.

In the central part of the Paraná Basin we can see a gravimetric feature almost parallel to the Paraná River. One way to amplify the gravimetric data is through the derivation. The vertical derivative of the Bouguer anomaly, g_{zz}, for example, is capable of amplifying the short wavelength. In addition, the g_{zz} component helps in the determination of the spatial position as well as the density distribution of the bodies (Santos and Ussami, 2011). However, the derivation process acts not only in the anomalies due to geological structures, but also in the noise present in the data, hindering the interpretation (Figure 3 at $z = 0\,\mathrm{km}$).

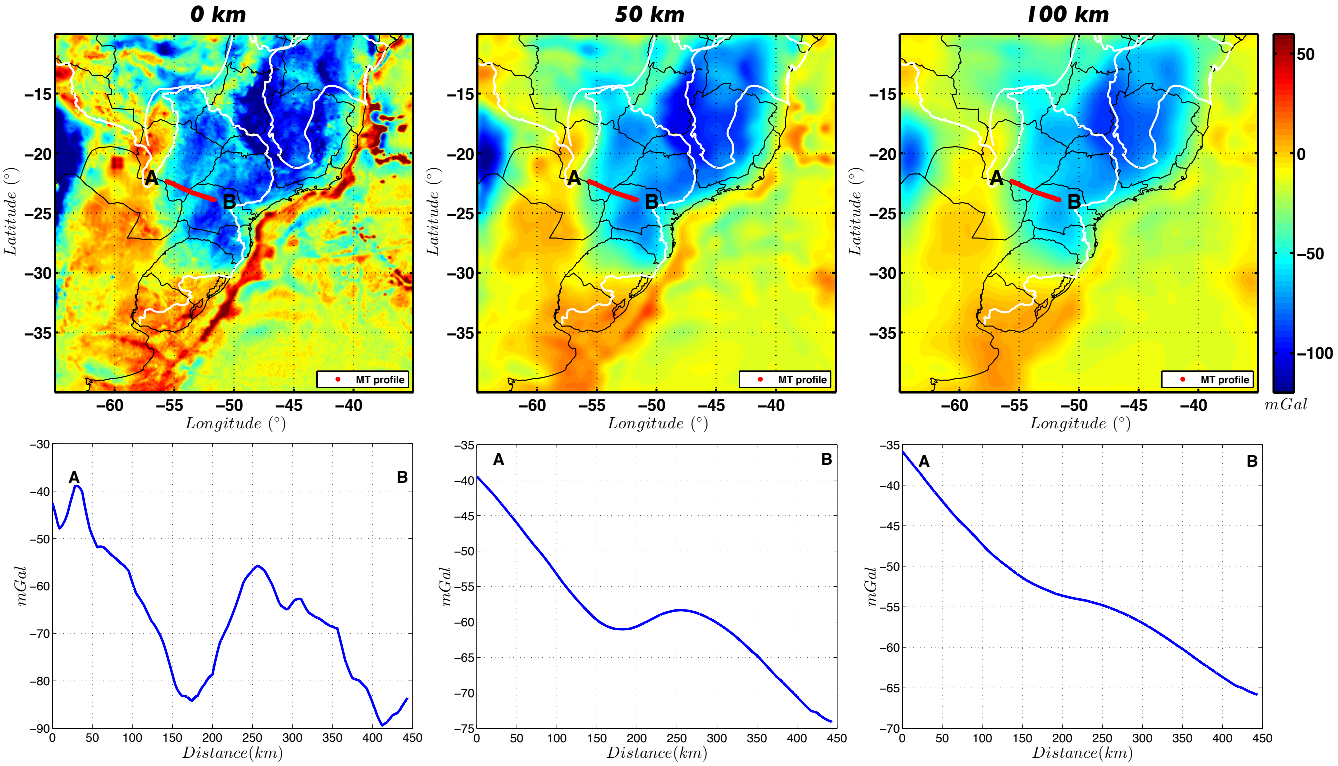

Figure 2: Bouguer anomaly in the surface level ($z = 0\,\mathrm{km}$) and upward continued until $z = 100\,\mathrm{km}$. The points A and B indicate the orientation of the gravimetric profile (blue curve). This profile was made with the same coordinates of the MT stations.

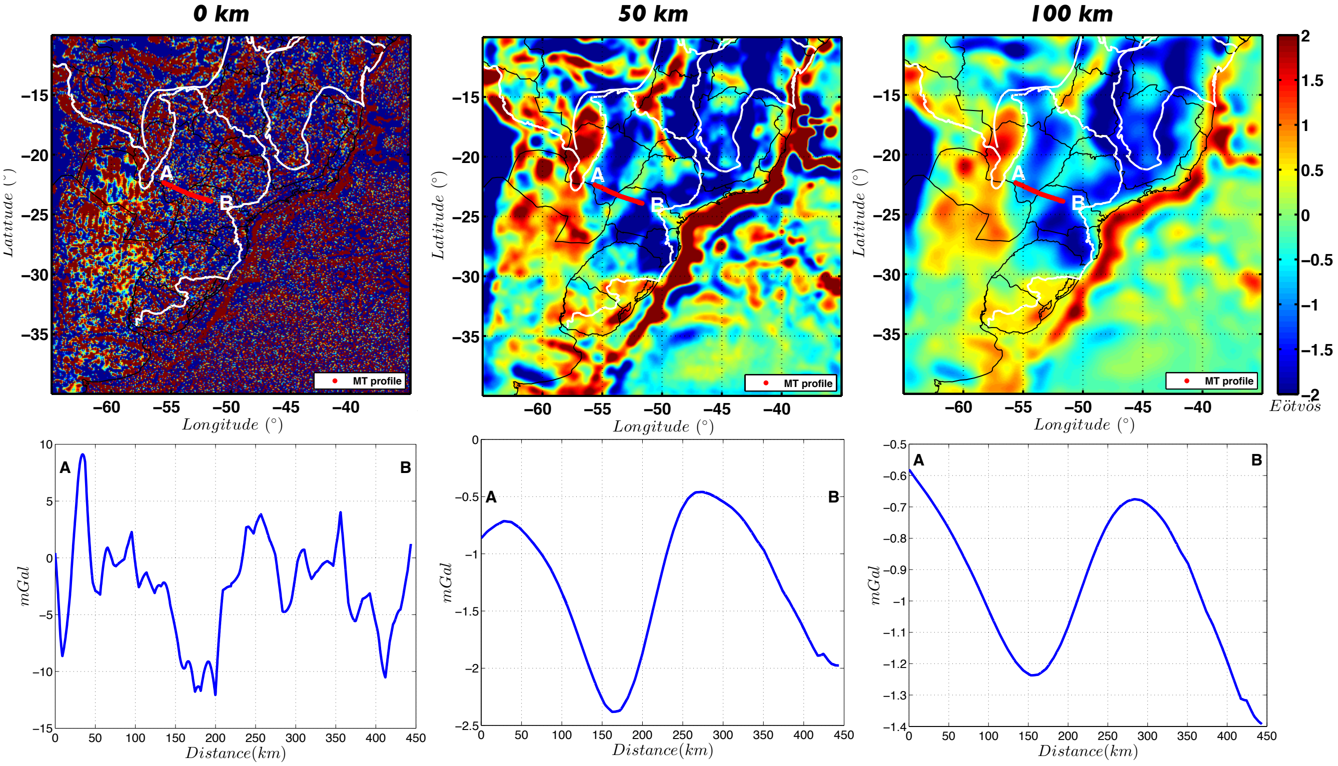

Figure 3: Vertical derivative (g_{zz}) of the Bouguer anomaly in the surface level ($z = 0\,\mathrm{km}$) and upward continued until $z = 100\,\mathrm{km}$. The points A and B indicate the orientation of the gravimetric profile (blue curve). This profile was made with the same coordinates of the MT stations.

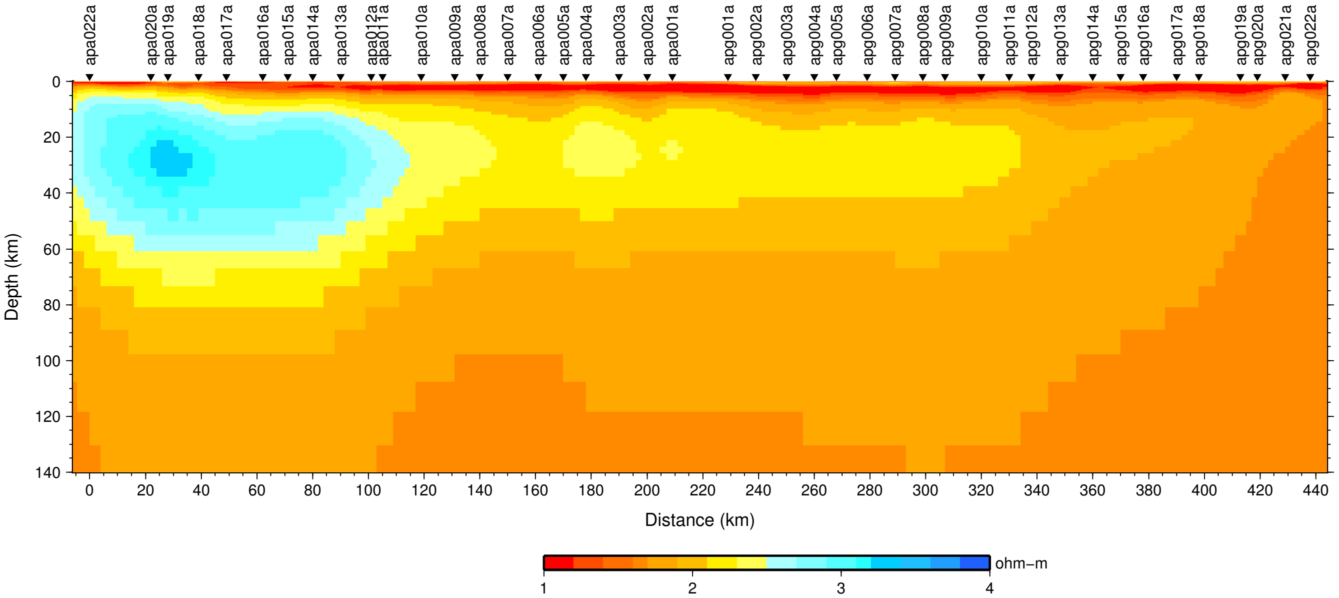

Figure 4: 2-D inversion resistivity model using REBOCC (logarithmic scale). The RMS resistivity for this model is $1.27\,\Omega\mathrm{m}$.

Impedance Tensor

The MT technique is a passive technique that involves measuring fluctuations in the natural electric (E) and magnetic (H) telluric fields on the surface of the earth, and can be used to determine the electrical resistivity distribution in the subsurface. For an anisotropic or a laterally inhomogeneous earth model, the relation between the electric and magnetic fields is given by the impedance tensor (Equation 1).

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix} \tag{1}$$

Thus it is possible to calculate the apparent resistivity (ρ_a) and phase (ϕ) as

$$\rho_{a,ij}(\omega) = \frac{1}{\mu_0 \omega} |Z_{ij}(\omega)|^2 \tag{2}$$

$$\phi_{ij} = \tan^{-1}\left(\frac{\mathrm{Im}(Z_{ij})}{\mathrm{Re}(Z_{ij})}\right), \tag{3}$$

where μ_0 is the magnetic permeability in the free-space and ω is the angular frequency (Simpson and Bahr, 2005). To calculate the impedance tensor we used a robust algorithm developed by Gary Egbert (Egbert and Booker, 1986; Egbert and Livelybrooks, 1996).

Inversion problem

The MT method ordinarily seeks to describe the Earth's geoelectric structure through a mesh of arithmetic spacing in the horizontal direction and geometric spacing in the vertical direction assigning a resistivity value for each block. The inversion problem consists in searching the parameters vector (**p**) that fit with the observed data vector ($\mathbf{y}^0$) with some precision δ through the least squares method.

$$||\mathbf{y}^0 - f(\mathbf{p})||^2 < \delta \tag{4}$$

It is an ill-posed problem, since it has many different solutions, therefore requires additional information to be solved. This information can be imposed by a regularization function ($\Phi(\mathbf{p})$) that must be consistent with prior information. So the problem consists now in finding the parameters (**p**) that minimizes the equation 5

$$\Gamma(\mathbf{p}) = ||\mathbf{y}^0 - f(\mathbf{p})||^2 + \mu\Phi(\mathbf{p}), \tag{5}$$

where μ is the regularizing parameter.

There are some types of algorithms in use for the inversion of MT data. In this work we used the Reduced Basis OCCAM (REBOCC) algorithm, proposed by Siripunvaraporn and Egbert (2000), that benefits from the smoothness and “redundancy” of the MT data.

Furthermore, the dimensionality analysis of the MT data is a necessary step that determines which type of approach is more adequate to perform the inversion: 1-D, 2-D or 3-D. At the same time, it provides information such as variation of the geoelectrical strike direction with depth, which can be correlated with different processes and structure of the subsurface. Both dimensionality and the strike direction can be obtained with support of a computational code known as WALDIM (Martí et al., 2009). Most of data used in this work presents a 1-D dimensionality, and we estimated an inclination of $36°$ for the strike direction.

The Figure 4 shows a preliminary resistivity model for a 2-D inversion with an RMS resistivity of $1.27\,\Omega\mathrm{m}$. We can see the presence of a highly conductivity zone between $0\,\mathrm{km}$ to $10\,\mathrm{km}$ in depth, due to the large amount of sediment present in the Paraná Basin. In the region between $0\,\mathrm{km}$ to $100\,\mathrm{km}$ until a depth of nearly $60\,\mathrm{km}$ we can identify a zone of higher resistivity (approximately $100\,\Omega\mathrm{m}$).

In the resistivity curves presented in Figure 5 show that this model provides a good fit for the collected data. The apa002 station has not been used since it exhibits too much noise. Moreover, all open dots in these figures represent data that was not used in the inversion process because it clearly has too much noise interference.

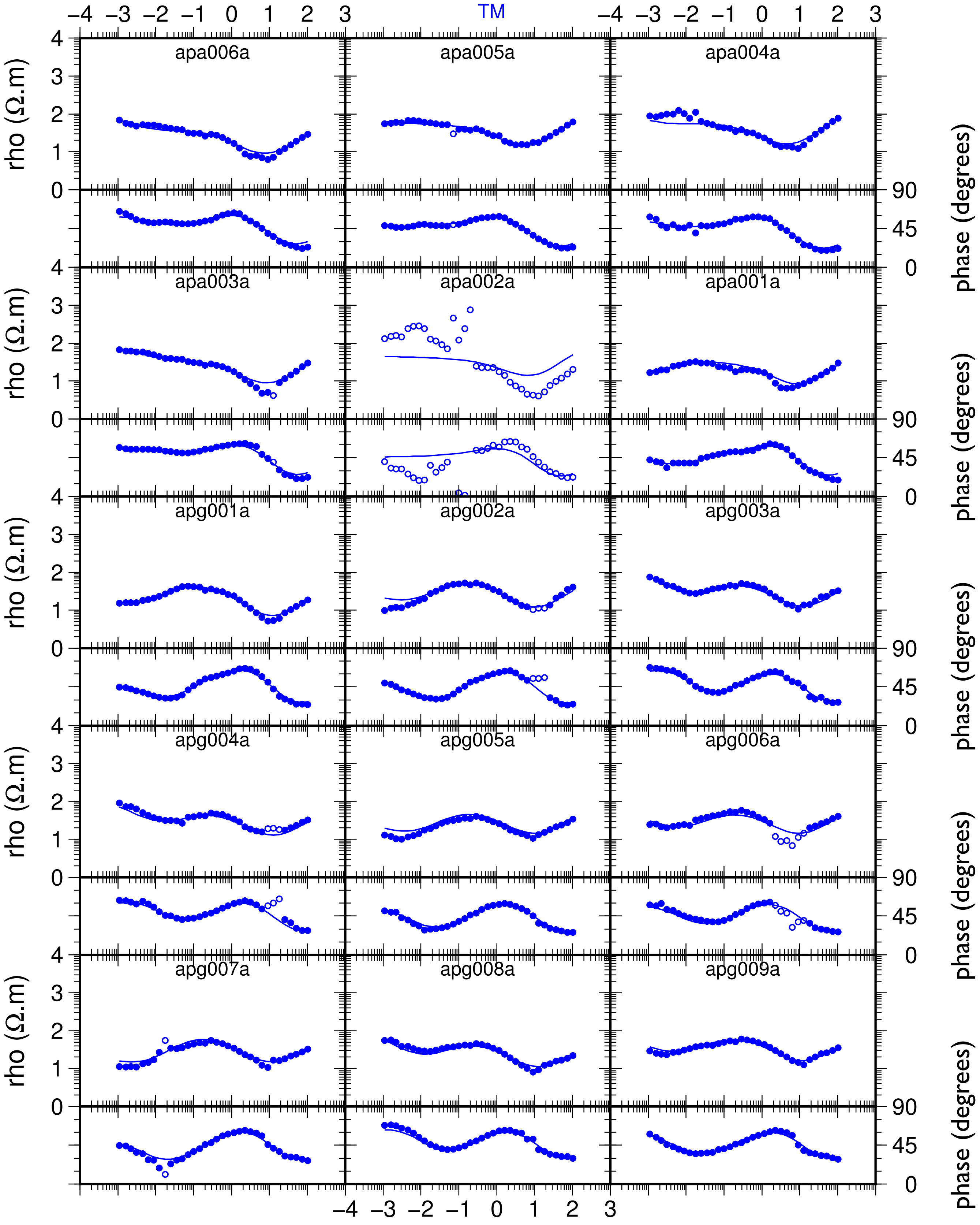

Figure 5: Curves of apparent resistivity and phase obtained with the inversion. The continuous line represents the curves obtained by the model. The points represents the collected data. The open dots represents data that is not used in the inversion.

Conclusions

A qualitative interpretation of gravimetric data contributed with to information for the inversion of the MT data. A gravimetric feature almost parallel and near the Paraná River indicates the presence of an anomalous deep body. We have presented a 2-D geoelectric model of the deep structure in the Paraná Basin by processing and inversion of MT data collected in a profile through the central part of the Paraná Basin. In this model we verify the presence of a high conductivity band in the upper part, that represents the sedimentary basin and a high resistivity body below the area of the basin. Our model may help to understand the geological structure of the Paraná Basin.

Acknowledgments

The authors were supported in this research by a fellowship (EBS) from (CNPq), (HBS) from CGGVeritas–Brazil and (IV and MBP) from INPE. Additional support for the authors was provided by the Brazilian agency FAPESP (grant 2009/50493-8).

References

Egbert, G., and D. Livelybrooks, 1996, Single station magnetotelluric impedance estimation; coherence weighting and regression M-estimate: Geophysics, **61**, 964–970.

Egbert, G. D., and J. R. Booker, 1986, Robust estimation of geomagnetic transfer functions: Geophysical Journal International, **87**, 173–194.

Gabaglia, G., and E. Milani, 1990, Origem e evolução de bacias sedimentares: Petróleo Brasileiro, Serviço de Desenvolvimento de Recursos Humanos, Centro de Desenvolvimento de Recursos Humanos Sudeste.

Martí, A., P. Queralt, and J. Ledo, 2009, WALDIM: A code for the dimensionality analysis of magnetotelluric data using the rotational invariants of the magnetotelluric tensor: Computers & Geosciences, **35**, 2295–2303.

Sá, N. C., 2004, O campo de gravidade, o geóide e a estrutura crustal na América do Sul: novas estratégias de representação: PhD thesis.

Santos, H. B., and N. Ussami, 2011, Tensor gradiente gravimétrico da bacia do paraná: Master's thesis.

Simpson, F., and K. Bahr, 2005, Practical magnetotellurics: Cambridge University Press.

Siripunvaraporn, W., and G. Egbert, 2000, An efficient data-subspace inversion method for 2-D magnetotelluric data: Geophysics, **65**, 791–803.