

## Joint Interpretation of Magnetotelluric and Gravimetric Data in the Paraná Basin

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### Abstract

In the past years, substantial effort has been directed to improve the magnetotelluric (MT) inversions algorithms. Many different techniques were developed to estimate a 2-D/3-D geoelectric model 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' x 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

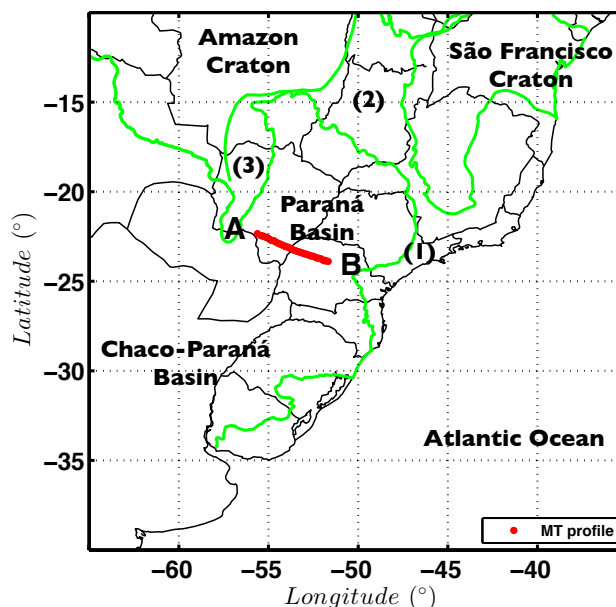


Figure 1: Study area. The green contours and numbers indicate some of the main tectonic provinces within South American lithospheric plate, being (1) Mantiqueira Province; (2) Tocantins Province; and (3) Pantanal Basin. The red line represents the MT profile.

anomaly as was expected for a sedimentary basin.

With this data the upward continuation was calculated until 100 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 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 0 km).

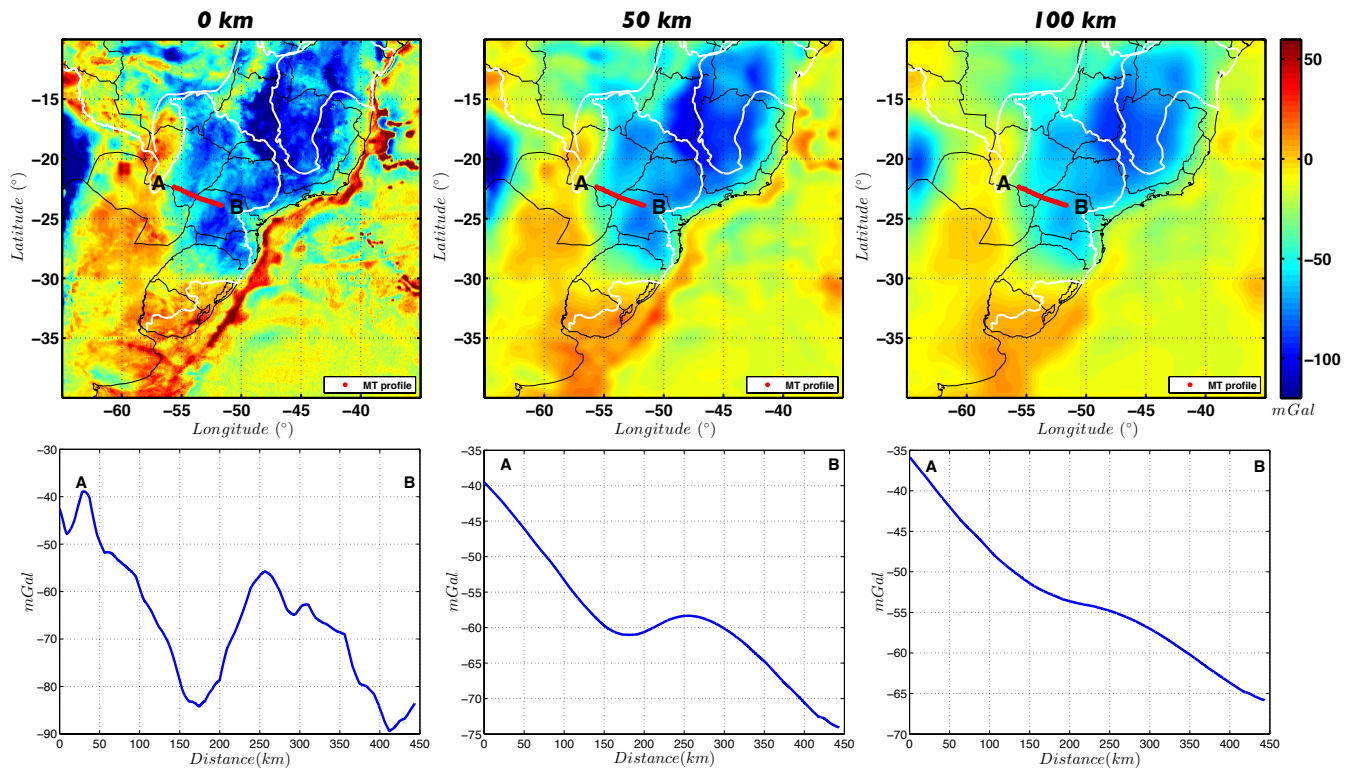


Figure 2: Bouguer anomaly in the surface level ( $z = 0 \text{ km}$ ) and upward continued until  $z = 100 \text{ km}$ . The points A and B indicate the orientation of the gravimetric profile (blue curve). This profile was made with the same coordinates of the MT stations.

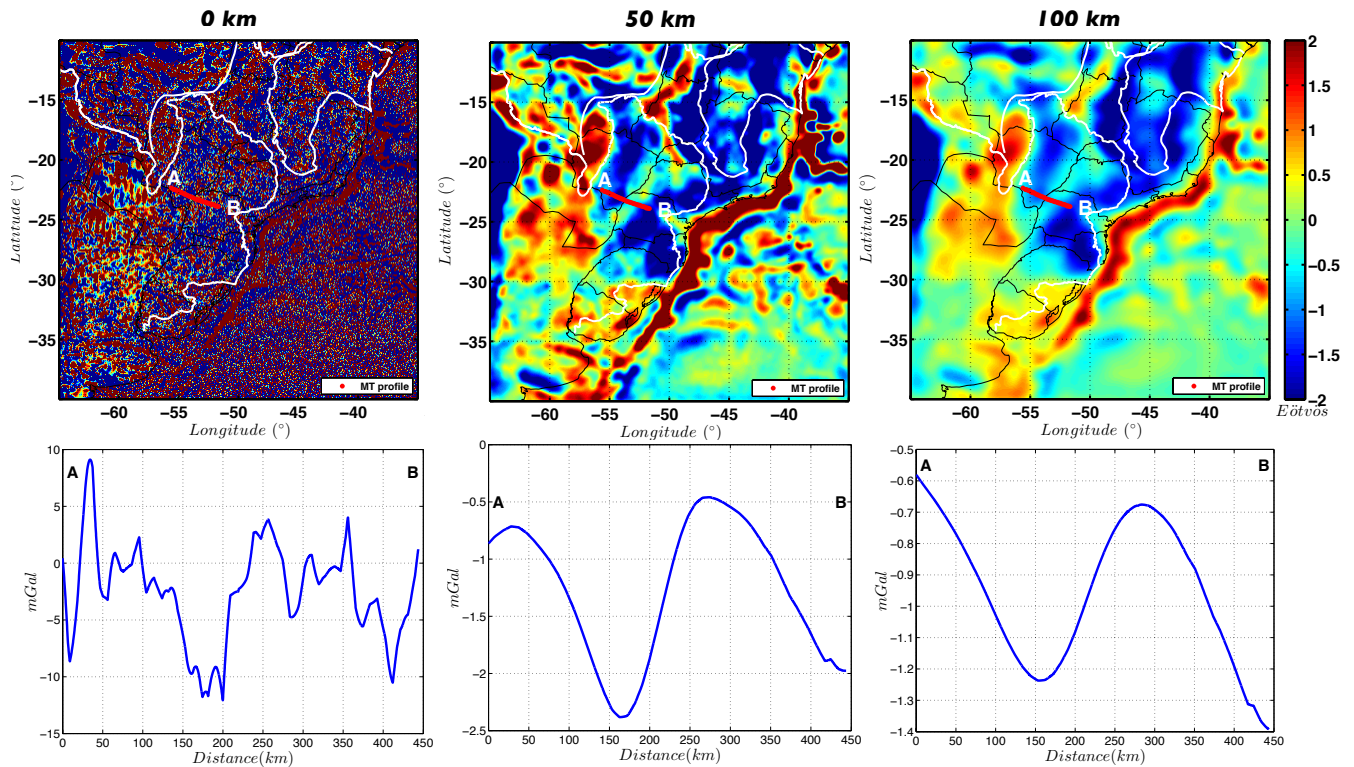


Figure 3: Vertical derivative ( $g_{zz}$ ) of the Bouguer anomaly in the surface level ( $z = 0 \text{ km}$ ) and upward continued until  $z = 100 \text{ km}$ . The points A and B indicate the orientation of the gravimetric profile (blue curve). This profile was made with the same coordinates of the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

## 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).

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

Thus it is possible to calculate the aparent resistivity ( $\rho_a$ ) and phase ( $\phi$ ) as

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

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

where  $\mu_0$  is the magnetic permeability in the free-space and  $\omega$  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 ( $\mathbf{p}$ ) that fit with the data observed vector ( $\mathbf{y}^0$ ) with some precision  $\delta$  through the minimum square method.

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

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 ( $\mathbf{p}$ ) that minimizes the equation 5

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

where  $\mu$  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 takes advantage in the fact that the MT data are smoothness and "redundant".

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 as 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  $36^\circ$  for the strike direction.

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

In the resistivity curves presented in Figure 5 were shown that this model provides a good fit with the collected data. The apa002 station has not been used since it present a lot of noise in the data. Moreover, all open dots in this figures represent data that was not used in the inversion process because clearly it presents much noise interference.

## Conclusions

A qualitative interpretation of gravimetric data contributed with prior information for the inversion of the MT data. A gravimetric feature almost parallel and near the Paraná River indicates the presence of a 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.

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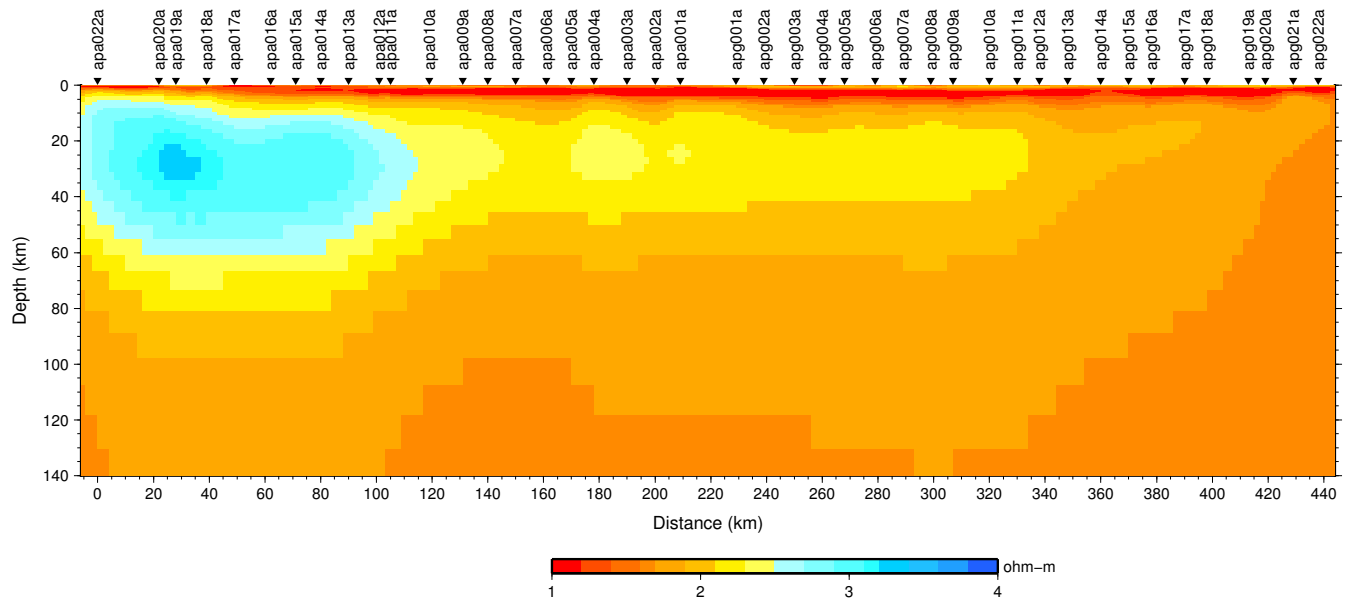


Figure 4: 2-D inversion resistivity model using REBOCC (logarithmic scale). The rms for this model is 1.27.

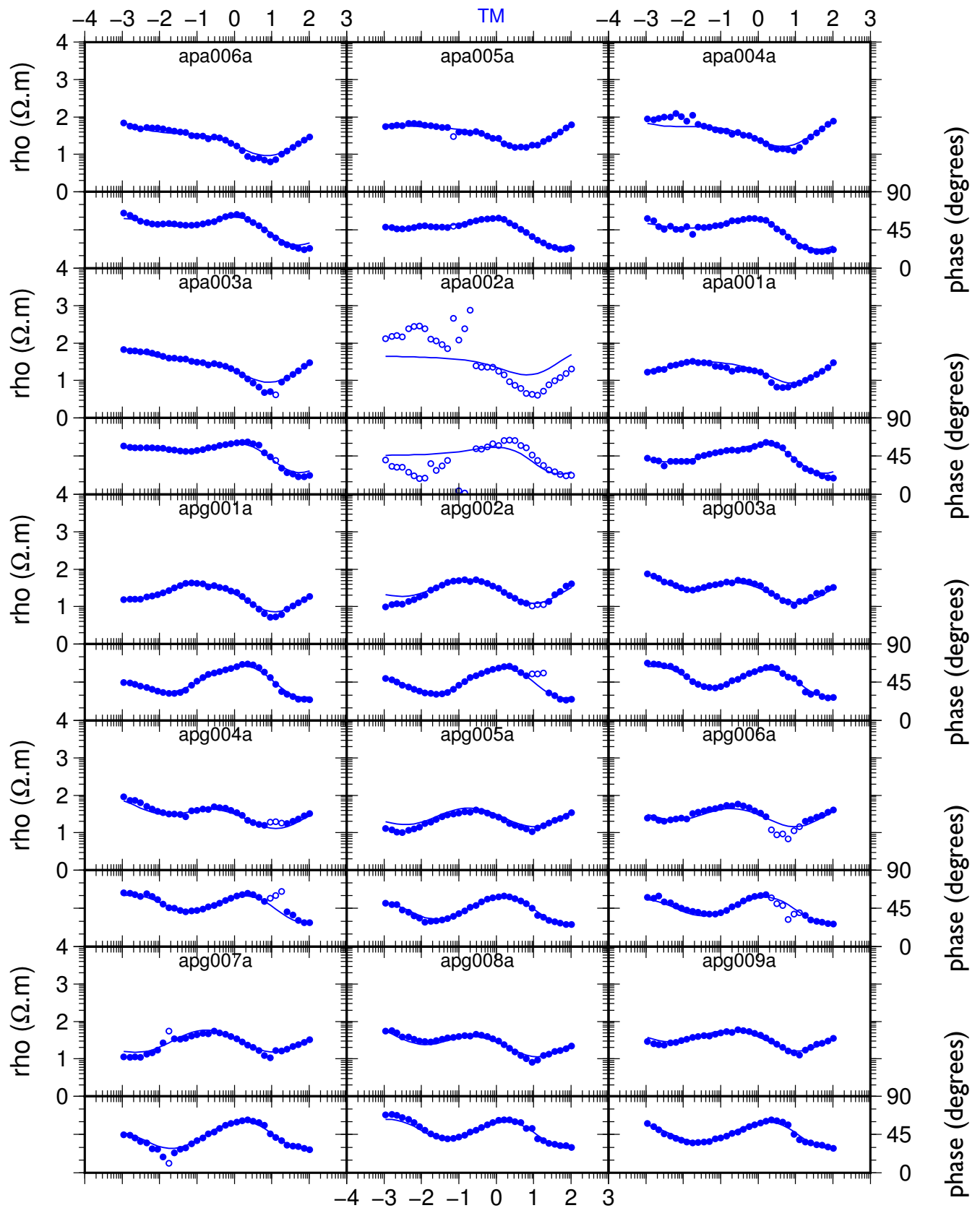


Figure 5: Curves of apparent resistivity and phase obtained with the inversion. The continuous line represents the curves obtained by the model. The points represents the collected data. The open dots represents data that is not used in the inversion.