# Direct Data Transform for Em Sounding Interpretation

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**DOI**
10.3997/2214-4609.202220051

**Publication date**
2022

**Document Version**
Final published version

**Published in**
83rd EAGE Conference and Exhibition 2022

# DIRECT DATA TRANSFORM FOR EM SOUNDING INTERPRETATION

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## Summary

Over the last years, new techniques are being researched in order directly estimate relevant geological properties of the rocks present in the subsurface without using an inversion process, this can be achieved by obtaining relationships between the data obtained by geophysical surveys and the data obtained in one place by well logging, core analysis or other techniques in which the actual physical properties of the rocks are measured. Using the apparent resistivity measurements from an MT survey and the resistivity measured from an exploratory well, we want to assess if it is possible to obtain a polynomial function that can be used to correct the misfit between the depth-apparent resistivity model obtained by MT surveys and the depth-resistivity model obtained by means of exploratory wells, and we want to assess if the polynomial expression obtained can be used to retrieve an accurate electrical model in nearby areas from the exploratory well in which only apparent resistivity measurements have been acquired.

# Direct Data Transform for EM Sounding Interpretation

## Introduction

Electromagnetic methods (EM) for the exploration of the subsurface have been widely used since the early 20th century to map the electromagnetic properties of the materials in the subsurface (Nabighian, 1991). In general, electromagnetic methods rely on inversion processes using 1D, 2D or 3D reference models. The inversion is highly non-linear and affected by solution non-uniqueness. Global search methods to mitigate this issue are characterized by high computational costs.
Over the last years, new techniques are being implemented for other geophysical data to directly estimate the geophysical model of the subsurface without using an inversion process. This can be achieved by obtaining relationships between the data obtained by geophysical surveys and the local 1D model obtained by well logging, core analysis or other techniques in which the actual physical properties of the rocks are measured at a particular location in the area of interest.
This approach has proved to be useful to retrieve geophysical models for self-potential Florio (2018) and for seismic surface wave dispersion data Socco et al. (2017). The relationships between the model and the data can be applied as a rescaling tool to generate geophysical models in areas in which only surface measurements have been acquired by directly transforming the data into models. Based on these results we explore if the same approach could work for other data from geophysical prospecting techniques such as apparent resistivity obtained from EM measurements.
Using the apparent resistivity measurements from an MT survey and the resistivity measured in an exploratory well, we want to assess if it is possible to obtain a polynomial function that can be used to correct the misfit between the depth-apparent resistivity model obtained by MT surveys and the depth-resistivity ground truth model obtained from wells. In addition we want to assess if the polynomial expression obtained can be used to retrieve an accurate resistivity model in nearby areas where only apparent resistivity measurements have been acquired.
The applicability of the proposed methodology is tested in different scenarios. The testing phase aims to retrieve an electrical model using apparent resistivity data measured in the vicinity of where the data from the exploratory well was acquired. We show with some numerical examples how well the data transform works.

## Method

The main idea is to find a relationship between the model and the data that might be used to predict the model directly from the data. To do so, following the approaches of Florio (2018) and Socco et al. (2017) we define a cumulative resistivity model, we compare it with the apparent resistivity of the data relevant to the model, and we use a polynomial relationship to model the difference in depth of equal resistivity values (cumulative and apparent resistivity respectively). This polynomial function can then be used to rescale the data and directly transform them into a cumulative resistivity model. The cumulative resistivity can then be used to calculate a layered resistivity model through numerical derivative. The polynomial rescaling function is then applied to a different apparent resistivity curve for which the model parameters are different and used to directly transform the apparent resistivity data into a resistivity model.

The input of the MT method will be the natural magnetic field ($\mathbf{B}$) traveling downward in the $z$ direction inducing a perpendicular electric field ($\mathbf{E}$) that does not have a $z$ component ($E_z = 0$). The plane-wave assumptions states that the magnetic field has horizontal components due to the distance from the source, this assumption also implies that ($B_z = 0$). Considering a uniform Earth, the apparent resistivity ($\rho_a(T)$) measured at the surface for a particular period $T$ can be obtained by Vozoff (1991)

$$\rho_a(T) = \frac{T|Z_{xy}|^2}{2\pi\mu_0}. \tag{1}$$

Where $Z$ $(m/s)$ is the electrical impedance and $\mu_0$ is the magnetic permeability of the void. The relation between $\sigma_a$ to a penetration depth $z$ was derived by Niblett and Sayn-Wittgenstein (1960) providing the following relationship

$$\rho_a(T) = \frac{2\pi\mu_0}{T}\left[\int_0^h \sigma(z)dz.\right]^2 \tag{2}$$

Where:

$$h = \sqrt{\frac{T}{2\pi\mu_0\sigma_a(T)}} \tag{3}$$

Equation 2 represents an average conductance times a transverse resistivity which is constant along depth. Using the previous relationships an electrical model can be obtained from the apparent measurements from the MT survey Gómez-Treviño (1996).
However, the electrical model derived from the apparent measurements is different from the model obtained by the exploratory wells, the location in depth for a given resistivity value is different for different models. Based on the previous statement, in this work it is proposed to model the $\Delta z$ difference between models using different regression techniques.
To obtain the differences between models and to properly approximate those differences by means of a regression, it is proposed to use the cumulative resistivity. The cumulative resistivity can be defined as the integrated total resistivity from the surface up to a certain point in depth $z$ and was defined by Price (1949) as

$$\rho_{cumu}(z) = \int_0^z \rho(z)dz. \tag{4}$$

The difference between models were obtained by means of

$$\Delta z = z - z_a \quad When \quad \rho_{cumu} \approx \rho_{cumu-App}. \tag{5}$$

The difference $\Delta z$ then is modeled by means of a polynomial regression considering that a defined relationship between an independent variable $x$ and a dependent variable $y$ is established. The $k_{th} - order$ polynomial model for one variable can be defined as:

$$\mathscr{E}(y_i) = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \ldots + \beta_k x_i^k + \varepsilon \tag{6}$$

To obtain the unknown values the Least Squares Method was used Van Huffel and Vandewalle (1991). Once the polynomial expression is obtained it can be used to correct the misfit between the model obtained from the apparent data and the true model. However, the correction was obtained for the cumulative resistivity values, and to retrieve a non-cumulative model, a numerical derivative must be applied by means of

$$\rho(i) = \frac{z_{Rescaled}(i+1) - z_{Rescaled}(i)}{\rho_c(i+1) - \rho_c(i)}. \tag{7}$$

## Results

First we show that by applying the method to a numerical dataset, we can recover the true resistivity model from the data. Then we apply the rescaling to the data of a modified model and show that we can retrieve a good approximation to the modified model.
A simple layered system was generated and the apparent resistivity measurements were simulated using the EMPYMOD routine **?**, the simple layered system had the following characteristics

***Table 1*** *Parameters of the resistivity model.*

| **Resistivity [Ohm*m ]** | **Thickness of the Layer [m]** |
|---|---|
| 750 | 500 |
| 2500 | 800 |
| 450 | Half Space |

Using the process described in the method section, a polynomial expression able to correct the $\Delta z$ misfit between apparent resistivity and the resistivity measured was obtained. Once the apparent resistivities are rescaled using the polynomial expression the layered system is retrieved and is then compared with the true resistivity model. Figure 1 shows that the proposed method is able to retrieve a smooth version of

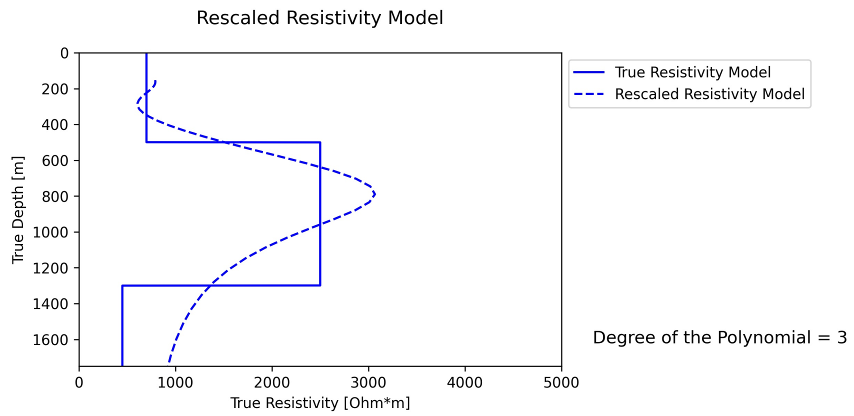


***Figure 1** Rescaled resistivity model (dashed line) obtained with the proposed method assuming the true model (solid line) is known. The rescaled model is obtained using the apparent resistivity values that have been computed using the true model.*

the resistivity model using apparent measurements from an MT survey. One question that arises is if the polynomial expressions generated using the known model can be used to correct apparent measurements from nearby zones in which only apparent measurements have been conducted. We hence created a numerical model with a variation in the resistivity of the target layer and we used it to generate apparent resistivity data and then we applied the previously obtained rescaling function to the new data without introducing any a priori knowledge about the model parameters. In Figres 2 and 3 we show the results of the rescaling and compare them with the resistivity models. In blue the true model and the retrieved model used for retrieving the recalling function (as in Figure1) and in yellow the modified true models (solid) and the retrieved models (dashed) by applying the rescaling function retrieved for the blue model.

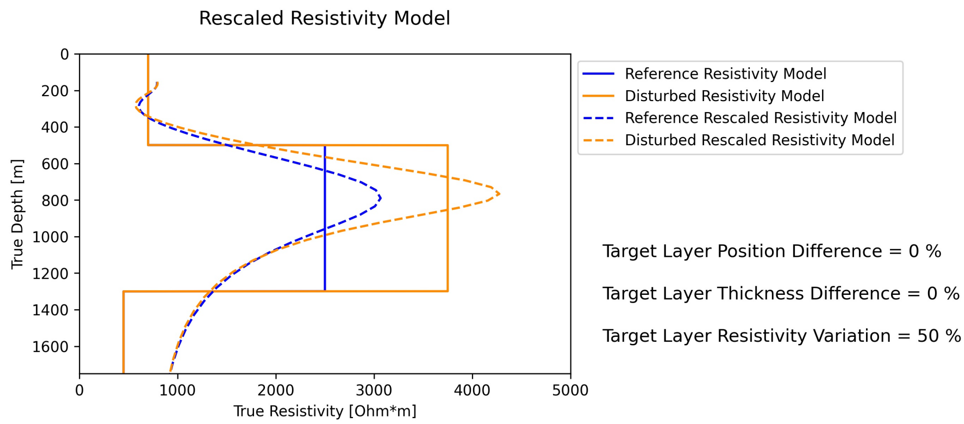


***Figure 2** Rescaled resistivity model for a nearby zone in which the resistivity of the target layer is 50% higher compared to the resistivity of the target layer found in the reference site (Figure 1). The polynomial used to retrieve the electrical model was the one obtained for Figure 1.*

## Conclusions

We showed that, if a local 1D resistivity model is known in an area where EM measurements are available, it can be used to compute a rescaling function that can then be applied directly to the data over

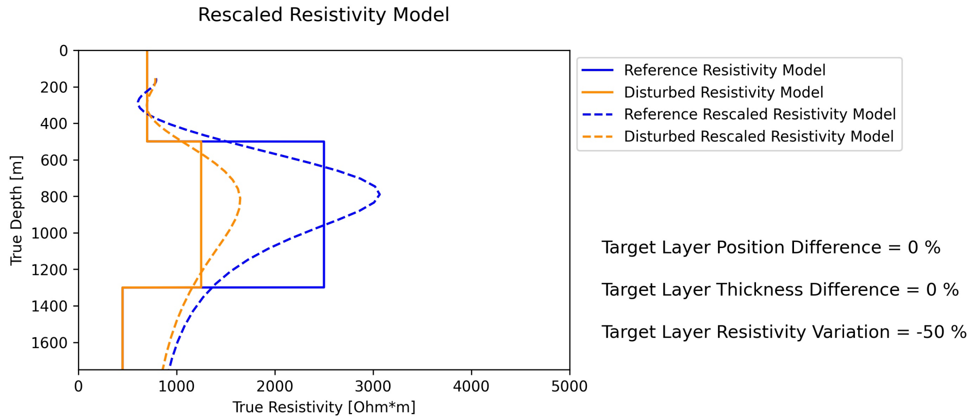


***Figure 3*** *Rescaled resistivity model for a nearby zone in which the resistivity of the target layer is 50% lower compared to the resistivity of the target layer found in the reference site (Figure 1). The polynomial used to retrieve the electrical model was the one obtained for Figure 1.*

larger areas to transform the apparent resistivity data directly into resistivity models without the need of an inversion process. The proposed method seems to have potential for very fast interpretation of EM data where one local model is known and many measurements are available over an area with smooth model parameter changes or for real time monitoring of time lapse measurements. Further research is needed to determine the actual limits of the proposed rescaling process, as a first step, the method seems promising especially for identifying resistivity variations

## Acknowledgements

We would like to thank the ENI project and ENI Mexico for funding the master scholarship of Oscar Ivan Calderon Hernandez.

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