Inversion 1D of electromagnetics datas of EM34.

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Abstract

The objective of this work is to use farward modelling and inverse to improve the interpretation of electromagnetic data obtained with the Slingram method, using the Em34 equipment from Geonics Ltda. For this, we want to answer the following questions: Are measurements obtained outside the equipment standard reliable? Does the use of these measurements provide greater precision and stability for the inversion process? Does increasing the amount of data to process increase or decrease processing time? The results were promising, there was a reduction in computational time, numerical solutions with good precision and provided more information on the geological environment.

Introduction

The Slingram is among the most popular Electromagnetic (Em) dipole source methods, being widely used for the characterization of conductive bodies, for example, massive sulfides. The application of the method was expanded to aid in soil, archeological, environmental and engineering studies.

A configuration of the Slingram Method consists of a transmitter coil powered by a battery, carried and operated by a person through a console. Another person operates the receiver consisting of a console and a coil. The receiver reads the phase and quadrature of the total field normalized by the primary field in mutual coupling. For conductivity measurements only the quadrature component is used (Frischknecht et al., 1987).

Conventional (galvanic) resistivity measurements for geological mapping have been used for almost a century. But due to its limitations, it found barriers for engineering purposes, one of them is the use of labor and infrastructure that makes the cost high and, also, the resistivity value is rarely diagnosed. Another common problem is the noise caused by small resistive heterogeneities compared to the depth, close to the electrodes, causing errors in the measurements. These drawbacks led Geonics to develop the EM31 and EM34 equipment to better serve engineering, environmental and other needs. Some of the applications are: Groundwater pollution plume mapping, ground conductivity mapping for electrical grounding, archaeological exploration and other applications. The equipment makes it possible to carry out surveys quickly, at low cost and with better data accuracy (McNeill, 1980).

Our objective is to use direct modeling and inversion to improve the interpretation of data obtained with the Slingram method, through the Em 34 equipment, using additional offsets to the standard determined by the equipment. Thus generating a greater amount of data to have more information and accuracy of the geological environment. In this first stage of the research, we want to answer the following questions: Are measurements obtained outside the standard of the equipment reliable? Does the use of these measurements provide greater precision and stability for the inversion process? Does increasing the amount of data to process increase or decrease processing time?

The idea is to use information provided by the equipment, which is the apparent conductivity, given by equation 2, and calculate the quadrature ratio of the total magnetic field by the primary magnetic field, and use this information for inversion. Similar as used by Moreno (2018) for conductive media with high induction number.

> “a partir de la medición de σ_a podemos obtener la parte imaginaria el cociente de los campos magnéticos, teniendo en cuenta la frecuencia de operación y la distancia fuente-receptor. Así los equipos pueden ser utilizados independientemente de la conductividad, tomando el cuenta sólo el cociente de los campos magnéticos, los cuales pueden ser modelados con el programa, ya que este no tiene ninguna restricción en cuanto a frecuencias de operación y conductividades.”(Moreno, 2018, p69)

Therefore, we will not work with apparent conductivity values, but always with magnetic field measurements for inversion. For this article, we will present results obtained with synthetic data, it has not yet been possible to carry out the actual data collection stage.

Slingram Method (EM34 Geonics)

The system consists of a transmitter coil, fed by an alternating current with a certain frequency, placed on the ground surface and a receiver coil a short distance from the transmitter. The variable magnetic field, produced by the alternating current, generates induced current in the subsurface, which, in turn, generates a secondary magnetic field that is detected by the receiver together with the primary field. Due to the distance between coils, frequency and conductivity, the secondary magnetic field constitutes a non-linear function, which would make measurements by equipment difficult, certain technical restrictions were defined, the fundamental of which is the operation at low induction number that simplifies the calculation of the secondary field, normalized by the primary magnetic field in a homogeneous half-space, thus obtaining a linear function in relation to conductivity (McNeill, 1980).

$$\frac{H_s}{H_p} = \frac{i\omega\mu_0\sigma s^2}{4} \quad (1)$$

Therefore, it makes it possible to build equipment to carry out simple measurements of the linear conductivity of the ground, so the apparent conductivity is:

$$\sigma_a = \frac{4}{\omega\mu_0 s^2}\left(\frac{H_s}{H_p}\right)_{Im} \quad (2)$$

where σ_a is the apparent conductivity, ω is the angular frequency, μ_0 is the magnetic permeability and H_s/H_p the ratio between the secondary magnetic field (homogeneous half-space) and the primary field.

Modeling 1D.

The calculation of the imaginary part of the components H_y and H_z of the magnetic field, respectively, for the Horizontal Magnetic Dipole (HMD) and the Vertical Magnetic Dipole (VMD) are given by the equations below, according to Rijo and Regis (2015), where we can find the equations used for the intrinsic and apparent admittance and the reflection coefficient. Both are normalized by the primary field H0 given by equation 5. The integrals are calculated with filtering techniques, we use the 201-point Wertmuller filter.

$$\frac{H_z}{H_0} = r^3 \int \left(e^{-u_0(z-h_0)} + R_{TE}^{(0)} e^{u_0(z-h_0)}\right) k_r^2 J_0(k_r r)\, dk_r \quad (3)$$

$$\frac{H_y}{H_0} = (r^2 - 2y^2) \int \left(e^{-u_0(z-h_0)} - R_{TE}^{(0)} e^{u_0(z-h_0)}\right) k_r J_1(k_r r)\, dk_r$$

$$+ y^2 r \int \left(e^{-u_0(z-h_0)} + R_{TE}^{(0)} e^{u_0(z-h_0)}\right) k_r^2 J_0(k_r r)\, dk_r \quad (4)$$

$$H_0 = \frac{-m}{4\pi r^3} \quad (5)$$

1D inversion.

We apply joint inversion of HMD and VMD data, adapted from França (2019). We minimize the following objective function (equation 6) using the global smoothness regularizer. The interpretive model for the problem is an n-layer homogeneous and infinite medium in the xy plane.

$$\lambda = \left\| \frac{h_z(p)}{h_z^0(p)} - 1 \right\|^2 + \left\| \frac{h_y(p)}{h_y^0(p)} - 1 \right\|^2 + \mu_r \phi_r(p) \quad (6)$$

sendo:

h_z^0 e h_y^0 são dados observados;

$h_z(p) = Im\left(\frac{H_z}{H_0}\right)$ e $h_y = Im\left(\frac{H_y}{H_0}\right)$ are the calculated data;

ϕ_r functional regularizer

μ_r regularization parameter

The sensitivity matrix is obtained by deriving equations 3 and 4 with respect to the pi parameters.

$$A^{(k)} \equiv a_{ij} = \frac{\partial h_i}{\partial p_j} \quad (7)$$

We apply the Gauss-Newton Interactive Method with Marquardt's criterion to minimize the functional with respect to the p_i parameters.

Results

Synthetic Data

We present the geological model for evaluation. The model consists of a conductive layer in a resistive medium, the first layer with resistivity of 10^2 Ohm-m and thickness of 10m, the second with 10 Ohm-m and thickness of 15m and the basement with 10^2 Ohm-m.

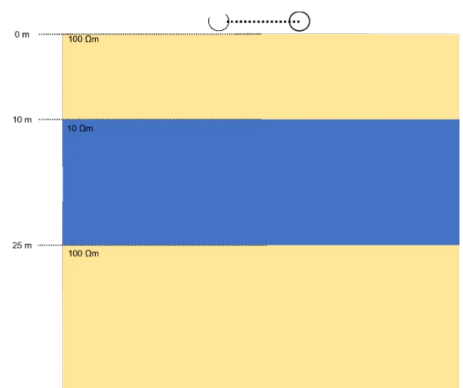

Figure 1: Geological model

The results obtained with synthetic data were promising. First, the inversion result demonstrated that the solution obtained from data produced with extra offsets presented greater precision than the solution obtained from data produced only with the standard offset of Em34. Figure 2 illustrates the improvement in the processing of the parameters that represent the conductivity variation with the discretization of the subsurface into 20 layers.

The second promising result was the reduction of code execution time. Due to the increase in the number of measurements due to the increase in offsets (from 3 to 12), a measurement station started to generate from 6 to 24 measurements, with this, we could be led to imagine that we would have a longer processing time with data increase. However, the processing time was greatly reduced, running the code with just one measurement station and six measurements the execution time was 5 seconds and producing 223 interactions of the Gauss-Newton method, whereas using 24 measurements took 0.8 seconds and produced 14 Gauss-Newton method interactions. Therefore, a very satisfactory result.

Regarding the reliability of measurements of real measurements outside the standard of the equipment, it has not been possible to carry them out so far, but it is planned for the next stage of the research.

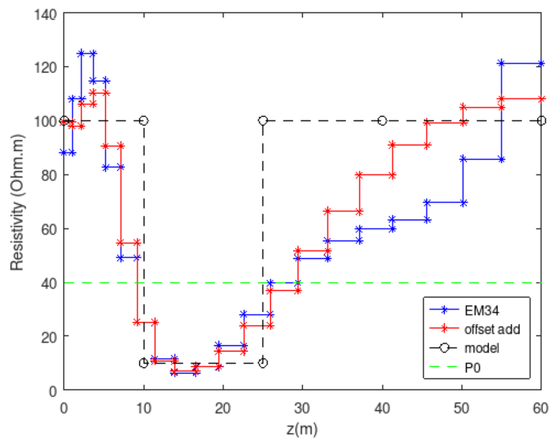

Figure 2: Comparison between the results from using the EM34 standard 3 spacings (blue) and including 9 extra spacings (red).

Figures 3 to 6 show the accuracy of the solution with the inversion results for HMD and VMD modes. Figures 3 and 4 show the values of the H_y and H_z components, normalized by H_0, for 12 coil spacings. Figures 5 and 6 show the values of the components H_y and H_z , normalized by H_0, for 3 spacings between coils which are the offsets used in Em 34. These figures show the accuracy of the solution for each case and, mainly, that there was no loss of accuracy when using more data.

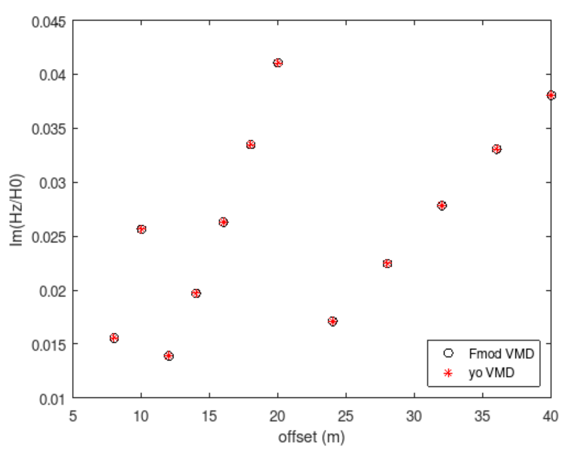

Figure 3: Fitting between the synthetic observations(yo) and the estimated magnetic field (Fmod) from the VMD using 12 offsets.

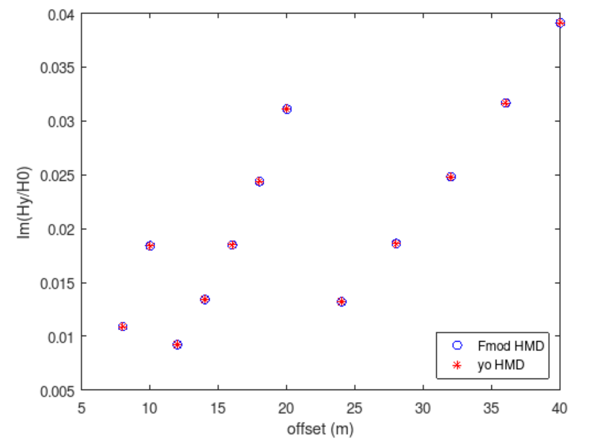

Figure 4: Fitting between the synthetic observations(yo) and the estimated magnetic field (Fmod) from the VMD using 12 offsets..

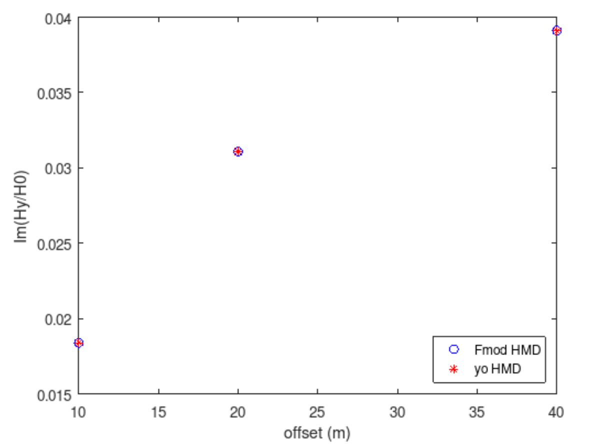

Figure 5: Illustrates the accuracy of the magnetic field component values between the synthetic data (yo) and the numerical solution (Fmod) obtained from the inversion to HMD using 3 offset.

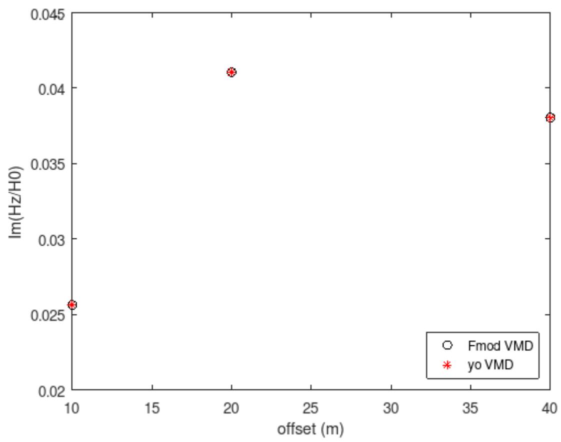

Figure 6: Illustrates the accuracy of the magnetic field component values between the synthetic data (yo) and the numerical solution (Fmod) obtained from the inversion to VMD using 3 offset.

Conclusions

Our approach presented good results, motivating the continuation of our research to improve the modeling and inversion of the Slingram method with data obtained with equipment Em 34 Geonics Ltda, with offset different from its standard to generate more information of the geological environment and reduce the time of processing.

Numerical methods for inversion generated solutions with great accuracy. This will lead us to keep them for the 3D modeling case that will be our next step.

Acknowledgments

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