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INTERPRETATION OF MOVING EM DIPOLE-DIPOLE MEASUREMENTS USING THIN PLATE MODELS

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Introduction

The three dimensional inversion of electromagnetic data is still rather problematic, because forward modelling programs are usually time consuming. They are based on numerical methods like finite element or integral equation methods.

In this study we have chosen a specific model for interpretation: two thin plates, which are located in a horizontally layered earth with two layers. This model is rather limited, but in a few geological cases it is relevant.

We have applied this interpretation method for two geophysical EM-systems, the slingram-system and the airborne electromagnetic system of the Geological Survey of Finland (GTK).

Inversion method

Forward modelling is based on P. Weidelt's integrodifferential eguation (1979) and on the program Leroi made by Amira (1997).

We have used a measure to describe the goodness of the model:

$$\| T(\mathbf{p}) - M \| + u \| s(\mathbf{p}) \| \qquad (1)$$

where T is the theoretical data, M is the measured data, u is a scalar multiplier, **p** is a parameter vector and s is a function of **p**. The norms are L2-norms. The first term measures the goodness of fit and the second, depending on the function s, gives a possibility for regularization, weighting and constraining of the model parameters.

To minimize the measure we have applied the trust region Levenberg-Marquardt optimization method. We have used the programs ODRPACK (Boggs et al, 1989) and TENSOLVE (Bouaricha and Schnabel, 1997). Our simulations showed that ODRPACK requires a lower (or equal) number of forward calculations.

Numerical examples

First the inversion routine has been tested by calculating the theoretical anomalies and interpreting them. The slingram (HLEM) and AEM-system of GTK was used. The time of inversion depends on the number of forward calculations. Jacobian matrices are calculated using finite differences of the numerically evaluated function, which means at least $m+1$ calculations for every iteration, where m is the number of parameters to be estimated.

The forward parametric model is a function of the number of elements. If the number of elements can change automatically (depending on the size of the plate) during iterations, this can cause local minima. Too coarse discretization in forward calculations changes the theoretical data. The coarser the discretization, the more the minimum point moves in the parameter space.

Example 1

We have studied the effect of measurement errors on the interpretation errors in the AEM-system of GTK by Monte Carlo simulations. The examined model is composed of two layers and a plate. Typical errors are due to noise and changes in levelling. The statistics of the added errors are the following: the standard deviation (STD) of the noise is 5 ppm in the in-phase data, 10 ppm in the quadrature data, the STD of levelling errors is 10 ppm for the in-phase data and 15 ppm for the quadrature data, Fig 1 a. The estimated parameters are resistivity of the first layer ρ_1, thickness h_1, depth, profile coordinate, dip and conductivity-thickness product of the plate σt.

The data is first interpreted using TENSOLVE with only the L2-norm of the difference between theoretical and measured data, Fig 1 b. It is also interpreted using regularization and by constraining the resistivity of the first layer ρ_1 to the range 350–400 Ωm with the same program, Fig 1 c. Without regularization and constraining, the parameters of the first layer show large variation, but with a priori information the variation is reduced. The dip angle in particular is rather sensitive to errors.

The minimized sum of squares as a function of the dip angle and the profile coordinate (distance) of the plate shows the global and a local minimum of the measure. The local minimum may be caused by the correlation between the dip angle and the distance. The plate model with the deepest dip angle (Fig. 1 c) is associated with this local minimum. Also the known correlation between the conductivity and the thickness of the first layer is clearly seen in the coordinate system defined by these parameters.

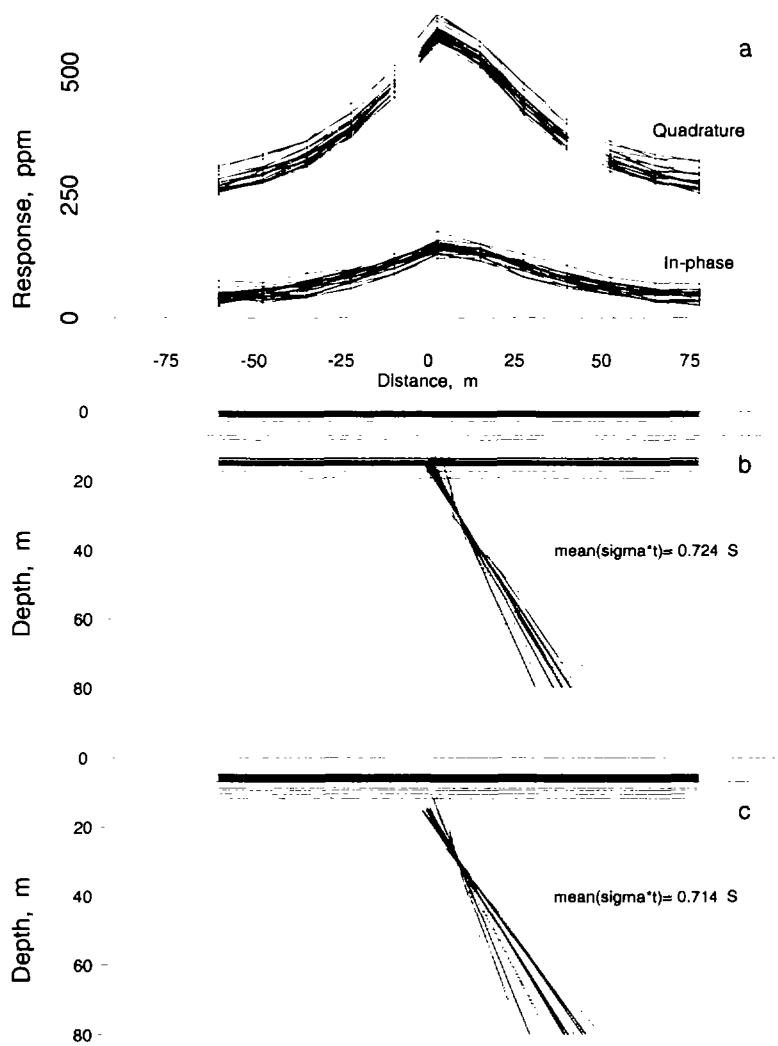

Figure 1. *Effect of simulated measurement errors on the interpretation parameters, a) the data sets, b) and c) interpretations (sigma*t means σt).*

Example 2

Fig. 2 shows the interpretation results of the small scale measurements of two plates. They are made with the slingram system by Ketola (1968). The experimental model curves are digitized and the interpolated data are interpreted. The interpretation prodecure gives the model parameters close to those applied by Ketola. The scaled values for the small scale parameters are: the coil separation is 60 m, the frequency is 3600 Hz, the plates are at 6 m depth, the separation of the plates is 30 m, the sizes of the plates are 300×300 m² and the conductivity-thickness products are 1.02 S.

The estimated sizes are: the average strike lengths are 173 m and 243 m for the left and the right plate, and the conductivity-thickness products are 1.28 S and 1.13 S, respectively. The strike length 173 m is not effectively quite infinite and that's why this plate is estimated to be more conductive. The values of estimated parameters, dip angle especially, depend slightly on the interpolation of the points, data sets 1,2 and 3 in Fig 3.

We have also interpeted this data with one plate model, and then the theoretical and measured curves are clearly different. The difference between one and two plate data was distinct also for the deeper situated plates (18 m).

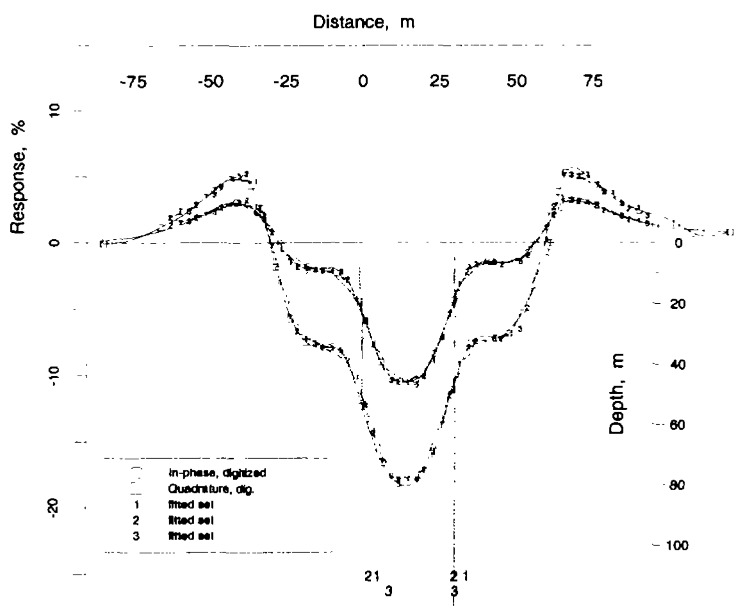

Figure 2. Digitized small scale experiments of Ketola and the results of interpretation.

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