5th International Symposium on Three-Dimensional Electromagnetics
Sapporo, Japan, May 7-9, 2013

Importance of the MT diagonal tensor coefficients for 3D inversion

Sophie Hautot[1] and Pascal Tarits[2]
[1]Imagir, IUEM, Place Nicolas Copernic 29280 Plouzané, France
[2]IUEM, Place Nicolas Copernic 29280 Plouzané, France

SUMMARY

Three-dimensional (3D) inversion of magnetotelluric (MT) data has increased dramatically both in industry and academic projects. Some 3D inversion codes are in use and some are under development. The 3-D inversion of real data showed the difficulty to handle data sets of various quality, distribution and at variable number of frequencies. The results are dependent on data analysis, selection and correction, on the chosen mesh and inversion parameters as well as the data actually inverted. Here we investigate the usefulness of the diagonal terms of the MT tensor in the inversion for different 3D models for which these coefficients are either small or large. We discuss the importance of the error floor threshold of off-diagonal and diagonal coefficients. Finally we emphasis the need of high quality data acquisition and analysis in order to obtain correct estimate of the diagonal coefficients.

Keywords: magnetotellurics, inversion, diagonal tensor coefficients, data analysis

INTRODUCTION

In 2011, a workshop on 3D MT inversion was organised at The Dublin Institute for Advanced Studies. The comparison of 3D inversion results of a same data set by different users with different codes and/or approach evidenced the importance of choice in the data set and the error floors (Miensopust et al., in press). The use of a same code with and without the diagonal elements led to different modelling results. With the growing experience in real data 3D inversion, one question is indeed raised about the usefulness of the diagonal terms of the MT tensor. While theoretically these coefficients carry a most important information about strike and heterogeneities, they are often let aside in the analysis. They are in general small and not necessarily correctly recovered in the data processing because of their weakness. Furthermore inversion techniques using highly smoothed parametrisation cannot fit large diagonal terms because they are caused by large resistivity contrasts. Here we want to investigate further the issue of the diagonal elements in 3D inversion.

THE 3D INVERSION TECHNIQUE

Most 3D MT inversion methods are based on numerical solutions of the Maxwell equations with techniques involving a very large number of parameters, sometimes with the computation of the Jacobian matrix, and strong smoothness constraints (eg: Newman and Alumbaugh, 2000; Mackie et al., 2001; Siripunvaraporn et al., 2005). These methods perform well but require huge amount of computer memory.

We developed a 3D inversion code that allows to invert large sets of MT sites with a number of parameters commensurate with the number of data. Our inversion method is based on a downhill descent technique. An iterative procedure was developed to minimize a misfit function between the observed data and the model response using a non-linear steepest gradient method with a regularization term (Hautot et al., 2007). The data is the MT tensor (the four complex components) at all available frequencies. The 3-D model is parameterized by blocks in the x,y,z directions. The size and the initial meshing of the 3D volume are determined according to the MT sites distribution and the depth of investigation of the data. The 3D grid used for the inversion is different from the grid used for the forward calculation. In the uppermost layers of the model, the size of the blocks increases with the distance from the MT sites. In the deeper layers, the size of the blocks is larger in order to take into account the resolution decreasing of MT data with depth (Hautot and Tarits, 2009). The model parameters for inversion are the resistivity of each block. The gradient with respect to the parameters is not calculated but at the cost of a large number of calls to the solver (about 10 times the number of parameters).

The inversion starts with a homogeneous half space although this is not required. Once a good agreement is obtained between the 3D model response and the data, a regularization factor is added to the error function and a new solution is searched again. The regularizing term controls the resistivity contrast between blocks and is the sum over all vertical and horizontal squared differences in the logarithm of the resistivity between two adjacent blocks.

CASE STUDY 1: SMALL DIAGONAL ELEMENTS

We first consider a 3D MT data set collected in the Omo basin in SouthWest Ethiopia. This data set was selected because the setting is a sedimentary basin with a main NS geoelectrical strike over a basement. As a consequence, in a NS-EW coordinates system, the diagonal terms are small at all sites (Fig. 1 left), the larger being observed at sites close to the contact between the sediments and the basin and at periods > 1 second (Fig. 1, right). In order to reduce the computation time required for our different tests, we selected a subset of 13 MT sites representative of the regional context. A grid of 12 (y) x 10 (x) x 12 (z) cells was generated with a minimum mesh size of 2400m. The volume is 31 x 26 x 12 km.

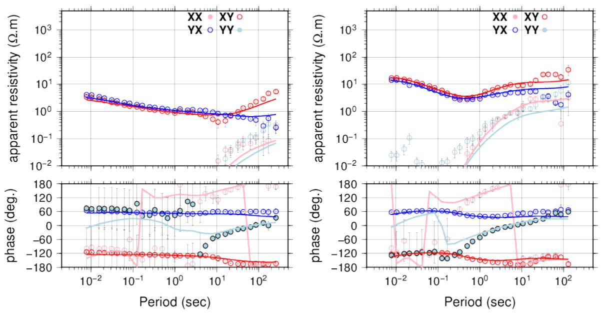

Figure 1. Example of MT impedance tensor at two sites in the Omo Basin, Ethiopia. Symbols: observed data. Solid lines: Response of the 3D model (full tensor inversion).

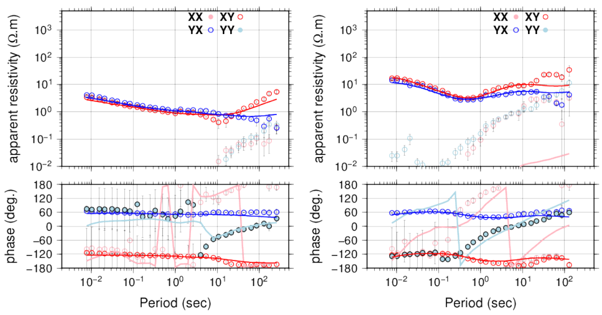

Figure 2. Same as Fig. 1 but the solid line show the synthetic response of the 3D model obtained from the inversion of the off-diagonal tensor elements only.

We first inverted the four components of the MT tensor. The error floor is 3% for all components. However it is numerically difficult to model very small value of the amplitude of the tensor elements. For this reason, we apply an error floor of 20% to diagonal elements data with apparent resistivity smaller than 0.5. The best fitting model was obtained with a rms error of 3.3. Despite the coarse grid, the model reproduces well most of the data (Fig. 1). Second, we inverted the same data set with the same model parameters but only the off-diagonal of the tensor are now considered in the inversion. We obtain a final model with a rms error of 2.8. Now, if we calculate the full response of the model, the rms is 4.0 most of the residual being obviously in the diagonal elements.

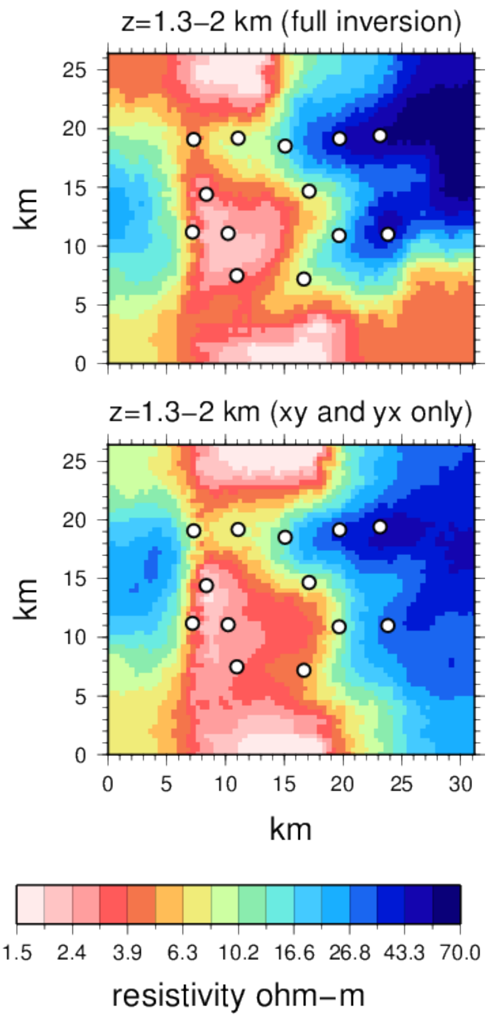

Figure 3. Case study 1. Plan view of the 3D model obtained from full tensor inversion (top) and off diagonal elements inversion (bottom) at depth 1.3-2 km.

For this case study, the diagonal tensor elements are generally small, the MT tensor calculated at the different sites are fairly similar, with no strong structural signature. Therefore, do we obtain similar models whether we invert or not the diagonal components? Figure 3 shows a plan view from both model at depth 1.3-2km, in the depth range where the largest differences are observed. Overall, the models show only local differences as to the southeast in Fig. 3 where the MT sites show the largest diagonal elements amplitude. Apart from local details in terms of structures, the interpretation of the two models would led to similar conclusions.

CASE STUDY 2: LARGE DIAGONAL ELEMENTS

The first case study was in a context where MT diagonal elements measured are small. However, we observed that the models obtained from the 3D inversion of the full MT tensor and of the off-diagonal elements only show local differences than can be of importance in a detailed structural interpretation.

We now present the results of a second case study in a different context, the Isle of Skye (Scotland), where large amplitude of diagonal elements were measured, at some sites larger than the one measured for the off-diagonal components (Fig. 4). The geological context of the Isle of Skye corresponds to the well-known problem of sub-basalt imaging. The aim of the study was to image sedimentary structures beneath extrusive basalt units (Hautot et al., 2007).

In this study, we again selected a subset of 13 MT data in order to perform two 3D inversions, one using the full MT tensor and one with the off-diagonal terms only. (Fig. 4). The size of the grid generated for the inversion is 12 (y) x 8 (x) x 12 (z) cells with a minimum mesh size of 1600m. The volume is 20.8 x 14.4 x 12 km.

Again, we first inverted the four components of the MT tensor. The error floor is 3% for all components. (error floor of 20% to diagonal elements data with apparent resistivity smaller than 0.5). The best fitting model was obtained with a rms error of 5.9. The model reproduces well most of the data (Fig. 1) but failed to reproduce most of the diagonal terms at periods < 1 second (Fig. 4, left). This is probably due to the size of the mesh, not small enough to reproduce small scale heterogeneities. At periods > 1 second the model response fits well the four components of the MT tensor even when the diagonal elements are larger than the off-diagonal elements.

In a second step, we inverted the same data set considering only the off-diagonal elements of the MT tensor. The final rms error is 2.2. However if we compare the response of this model to the four elements of the tensor, the rms error is 10.4. The difference between the two model misfit is much larger here than for case study 1. Figure 5 shows the full tensor response of the 3D model obtained considering only the diagonal elements. The model fits well the off-diagonal terms and therefore is a good example of how can be interpreted such results. Figure 6 shows a plan view of the two models at a same depth. We note very significant differences between both models. The difference between the two models for that depth is representative of what is observed in most of the layers of the model. Clearly the strong diagonal terms control the size and limits of the resistivity contrasts. In this example, it is not possible to exclude those terms in the inversion.

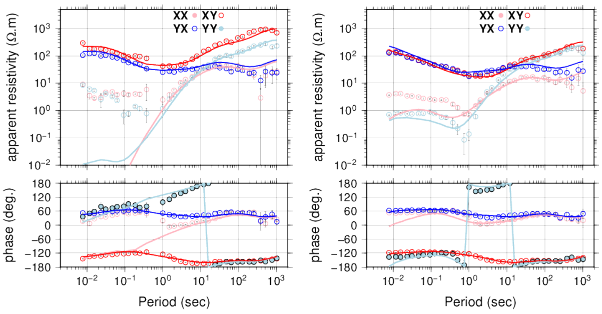

Figure 4. Example of MT impedance tensor at two sites on the Isle of Skye, Scotland,. Symbols: observed data. Solid lines: Response of the 3D model (full tensor inversion).

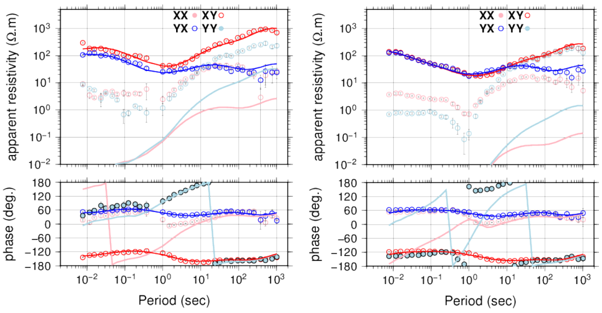

Figure 5. Same as Fig. 4 but the solid line show the synthetic response of the 3D model obtained from the inversion of the off-diagonal tensor elements only.

DISCUSSION

The two end members case study considered in this work illustrate well how the diagonal terms in the MT tensor control the geometry of the resistivity contrast in the resulting best fitting model inverse model. Small diagonal terms (case study I), although not mandatory at large scale, reveals small scale feature which may be of importance in geology. Large diagonal terms (case study II) are essential in the inversion. These terms are therefore of importance provided they are correctly determined. This issue needs to be addressed for small diagonal terms for which the error bars seems in practice too small.

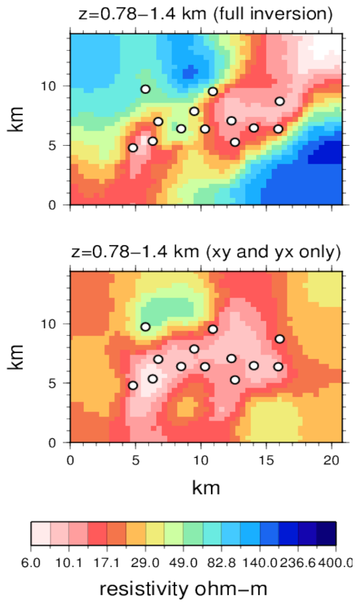

Figure 6. Case study 2. Plan view of the 3D model obtained from full tensor inversion (top) and off diagonal elements inversion (bottom) at depth 0.78-1.4 km.

REFERENCES

Hautot, S., and P. Tarits, 2009, A new coarse-to-fine 3D magnetotelluric inversion method: Application to field data for hydrocarbon exploration: 71st EAGE Conference and Exhibition, Extended Abstracts.

Hautot, S., R. Single, J. Watson, N. Harrop, D. A. Jerram, P. Tarits, K. A. Whaler,, and G. Dawes, 2007, 3-D magnetotelluric inversion and model validation with gravity data for the investigation of flood basalts and associated volcanic rifted margins: Geophysical Journal International, **170**(3), 1418-1430.

Mackie, R.L., W. Rodi, and M.D. Watts: 2001, 3-D Magnetotelluric Inversion for Resource Exploration: 71st Annual International Meeting, SEG, **20**, 1501–1504.

Miensopust, M., P. Queralt; A. Jones, and the 3D MT modellers, Magnetotelluric 3D inversion – a recapitulation of two successful workshops on forward and inversion code testing and comparison, Geophysical Journal International, in press.

Newman, G.A, and Alumbaugh, D.L., 2000, Three-dimensional magnetotelluric inversion using non-linear conjugate gradients: Geophysical Journal International, **140**, 410-424.

Siripunvaraporn, W., Egbert, G., Lenbury, Y., and Uyeshima, M., 2005, Three-dimensional magnetotelluric inversion: data-space method: Physics of the Earth and Planetary Interiors, **150**, 3-14.