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The Effect of Topography on ZTEM Inversions

V. Kaminski* (University of British Columbia), D. Sattel (Condor Consulting Inc.) & K. Witherly (Condor Consulting Inc.)

SUMMARY

ZTEM is an airborne passive source electromagnetic system surveying in frequency domain (30 Hz - 720 Hz).

In this paper we study the effect of topography on 2D and 3D ZTEM modelling and inversion results. In the synthetic study, the 3D model is introduced and the predicted data are calculated considering the 3D topographic feature (hill) on the Earth's surface. Then the predicted data are inverted using MTZ3D (developed at Geophysical Inversion Facility, University of British Columbia) with and without topography consideration.

The inversion results are compared to the true model. In the field study, ZTEM observed data are compared to data predicted for 100 Ohm m halfspace with considerable topography. The modeling is done in 2D. The 2D response over uniform half-space should be zero, however due to the presence of the topography the amplitude of the predicted half-space response becomes dominant, compared to the response of conductors.

It is further shown that when topographic features are neglected, the inverse models recover false geoelectrical structures. These false electrical structures include near-surface electrical conductors consistent with the positive topographic features (hills) and electrical resistors, consistent with the depressions. The effect is increasingly notable with greater volume of the topographic inhomogeneity.

Summary

ZTEM technology was developed by Geotech, Ltd in 2007 and became increasingly popular in past several years. It has great potential for deep geoelectrical airborne surveying. The technology is a modified representation of magnetovariational response functions theory (Parkinson, 1959; Berdichevsky and Dmitriev, 1997). In this paper we study the effect of topography on 2D and 3D ZTEM modelling and inversion results. In the synthetic study, the 3D model is introduced and the predicted data are calculated considering the 3D topographic feature (hill) on the Earth's surface. Then the predicted data are inverted using MTZ3D (UBC-GIF) with and without topography consideration. The inversion results are compared to the true model. In the field study, ZTEM observed data are compared to data predicted for 100 Ohm m halfspace with considerable topography.

It is further shown that when topographic features are neglected, the inverse models recover false geoelectrical structures. These false electrical structures include near-surface electrical conductors consistent with the positive topographic features (hills) and electrical resistors, consistent with the depressions. The effect is increasingly notable with greater volume of the topographic inhomogeneity.

Method and Theory

ZTEM system measures components of secondary magnetic field produced by natural plane elliptically polarized wave incident vertically on Earth's surface. In classical theory, the magnetic field components H_x, H_y and H_z obey the relationship described in equation (1):

$$H_z = W_x H_x + W_y H_y \tag{1}$$

In this equation W_x and W_y are called Tipper functions (Vozoff, 1972) and they reflect the horizontal asymmetry of excess currents (j_x and j_y), arising in Earth due to lateral variations in the electric conductivity. Topography can be also interpreted as lateral variation in the conductivity, since the contrast of electrical properties in any medium with the air can be quite significant. In order to derive analytic equations for the Tipper functions, two source polarizations are considered (H_1 and H_2). Tipper functions can be written in the form of equations (2):

$$\begin{aligned} Wx &= \frac{J_z^{H2} + (J_y^{H1} J_z^{H2} - J_y^{H2} J_z^{H1})}{1 + J_x^{H2} + J_y^{H1} + (J_x^{H2} J_y^{H1} - J_x^{H1} J_y^{H2})} \\ Wy &= \frac{J_z^{H1} + (J_x^{H2} J_z^{H1} - J_x^{H1} J_z^{H2})}{1 + J_x^{H2} + J_y^{H1} + (J_x^{H2} J_y^{H1} - J_x^{H1} J_y^{H2})} \end{aligned} \tag{2}$$

In these equations J^{H1} and J^{H2} are the convolutions of the excess currents with the magnetic Green tensors due to source polarization (Berdichevsky and Dmitriev, 1997). Forward modelling considerations are described in Aruliah et al, 2001.

The ZTEM transfer functions T_x and T_y (further referred to as in-line and cross-line functions) are very similar to Tipper functions described by Parkinson and Vozoff, with an adjustment due to the fact that H_z is measured in the air, while H_x and H_y are measured at the base station. Therefore ZTEM transfer functions become increasingly sensitive to the excess currents affecting the measured H_z component and the $H_z/H_x(H_y)$ ratios in ZTEM transfer functions can significantly exceed 100%.

3D synthetic example (half-space)

In the first example we consider a 1000 Ohm m half-space. The predicted data set was modelled using MTZ3D (UBC-GIF). The topography consideration includes a 300 m hill and constant flight altitude of 80m (Figure 1). The data prediction was calculated for In-phase and Quadrature components of T_x and T_y for 6 standard ZTEM frequencies (30 to 720 Hz). In Figure 2 the predicted data are shown for in-phase and quadrature components of T_y. In Geotech convention this corresponds to reversed values of T_x (Figure 2c,d). The predicted data were further contaminated with Gaussian noise with standard deviation equal to $5*10^{-3}$ plus 5% of the data.

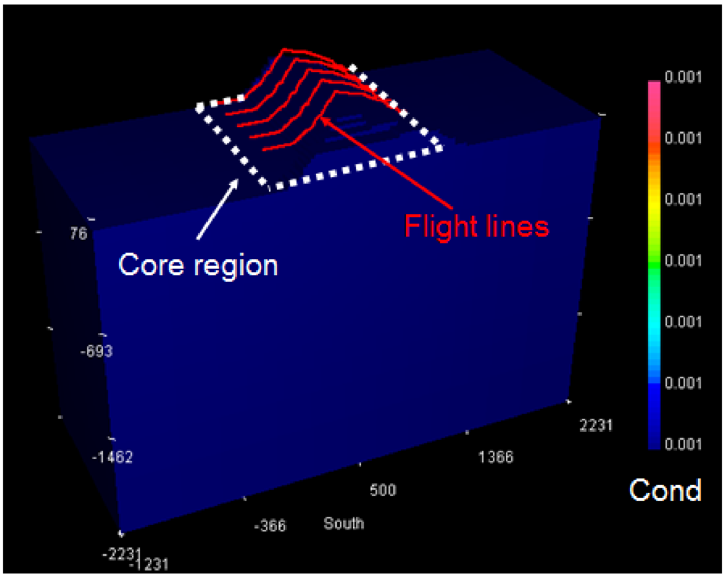

Figure 1. *Synthetic ZTEM survey over a 300 meter hill. The core region of the mesh (white) is populated by ZTEM stations at constant altitude over the Earth's surface (red). The electrical resistivity of the half-space is 1000 Ohm m (0.001 S/m).*

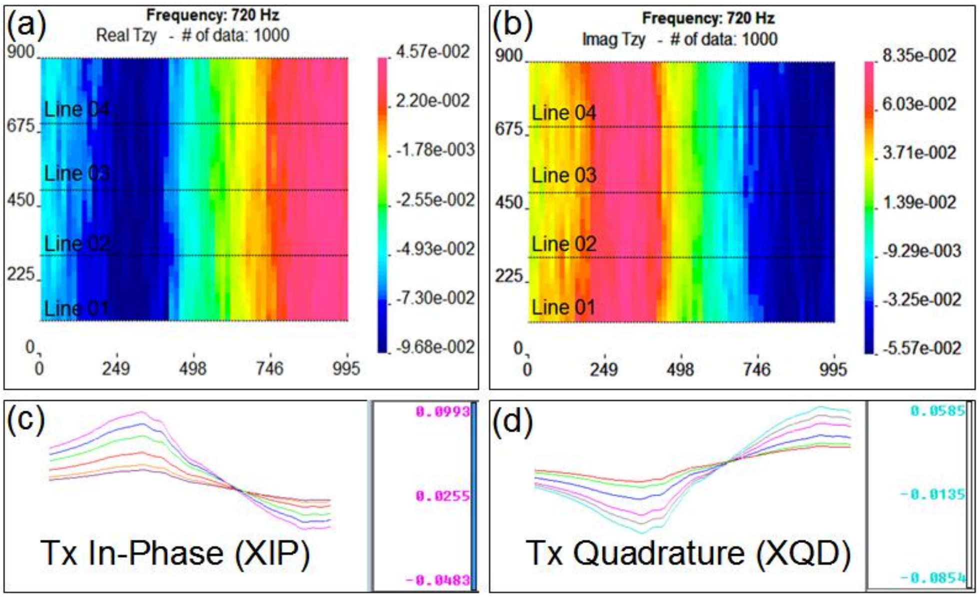

Figure 2 *Predicted data for a synthetic ZTEM survey. (a): In-Phase Ty component for 720Hz; (b): Quadrature Ty component for 720 Hz; (c): Predicted data (In-Phase) shown in Geotech convention XIP=-Re(Ty) for Line 03, all frequencies; (d): Predicted data (Quadrature) shown in Geotech convention XQD=-Imag(Ty) for Line 03, all frequencies.*

In Figure 2 it can be seen that presence of the hill affected the data creating 15% anomaly (peak to peak) in the 720 Hz in-phase and 13.5% anomaly (peak to peak) in the 720 Hz quadrature. The noise-contaminated data were further inverted using MTZ3D. Details of this inversion algorithm are described in Fraquharson et al, 2002.

First inversion was performed using the original survey geometry and with topographic considerations. The mesh was extended 2000 m in each direction to allow padding distance. The inversion converged in 2 iterations, resulting in a model shown in Figure 3a. The second inversion was carried over flat surface. For this inversion the ZTEM stations were edited to accommodate constant 80m elevation (Figure 3b). It has recovered a false conductor in the near-surface region. Furthermore, the false conductor becomes wider and stronger on the edges of the core region, where in addition to the in-line transfer function (T_x) there is also topography affecting the cross-line transfer function (T_y).

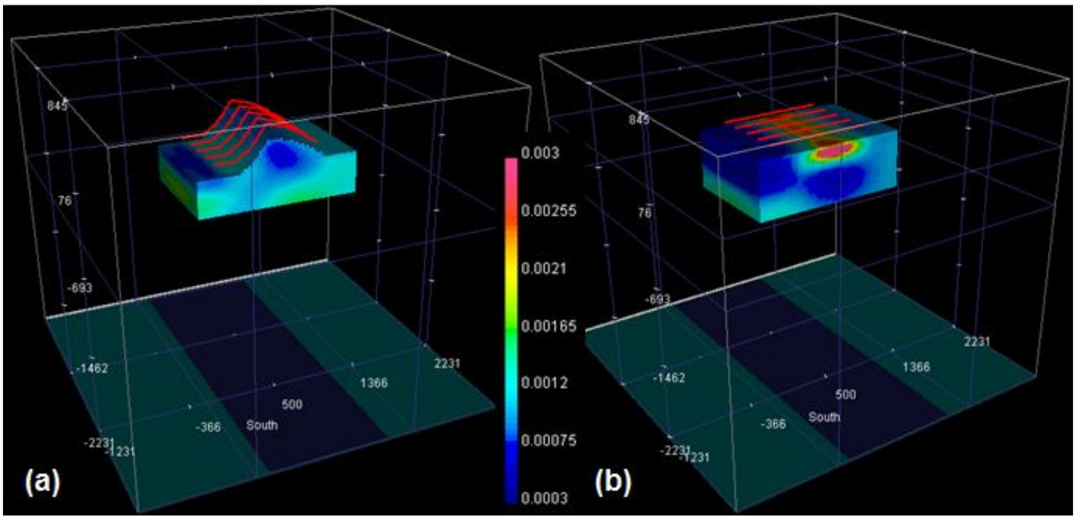

Figure 3. *(a): Model recovered with consideration of the topography, recovered values very close to true model; (b) Inversion carried out without consideration of the topography, false conductive zone recovered in the near-surface region.*

Field example

In the next example a field ZTEM survey in rugged terrain is considered. The Digital Elevation Model (DEM) of the survey area is shown in Figure 4a. The vertical relief across the extent of the block is approximately 700 meters. Predicted ZTEM data were calculated using a 2D modelling code described in Sattel et al. (2010). A 100 Ohm-m half-space model was considered taking into account the observed topography, Images of the observed and predicted 720 Hz in-phase in-line responses are shown in Figures 4b and 4c. The data in Figures 4b and 4c were phase-rotated to line up peaks with conductors and topographic highs. There is a lot of similarity between the images of the DEM, the observed and the predicted data. It is evident, that topographic effect in this study dominates the data.

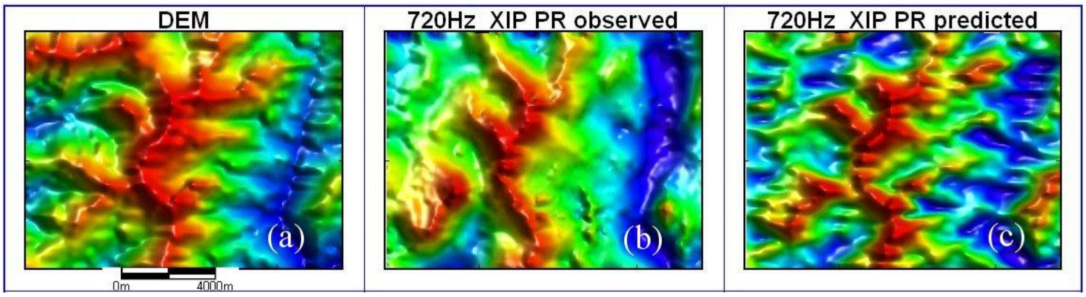

Figure 4. *(a): Digital Elevation Model (DEM), as per ZTEM survey; (b): observed data at 720 Hz, in-phase Tx (in-line) component (phase-rotated); (c): predicted 720Hz in-phase Tx response for 100 Ohm-m half-space.*

In Figure 5a, the cross-section is shown with the corresponding observed in-phase in-line response (Figure 5b). Similar to Figure 4, the observed data show a strong correlation with the topography. Since the ZTEM response across a flat half-space is zero, the predicted anomalous response is caused by the variation in the terrain's topography. The predicted data in Figure 4c agree very well with the observed data, showing that the field data are dominated by the topographic response. The response of the subsurface conductivity structure appears to be secondary to the topographic response, and it is crucial to take into account the terrain's topography for the modelling and inversion of this data set.

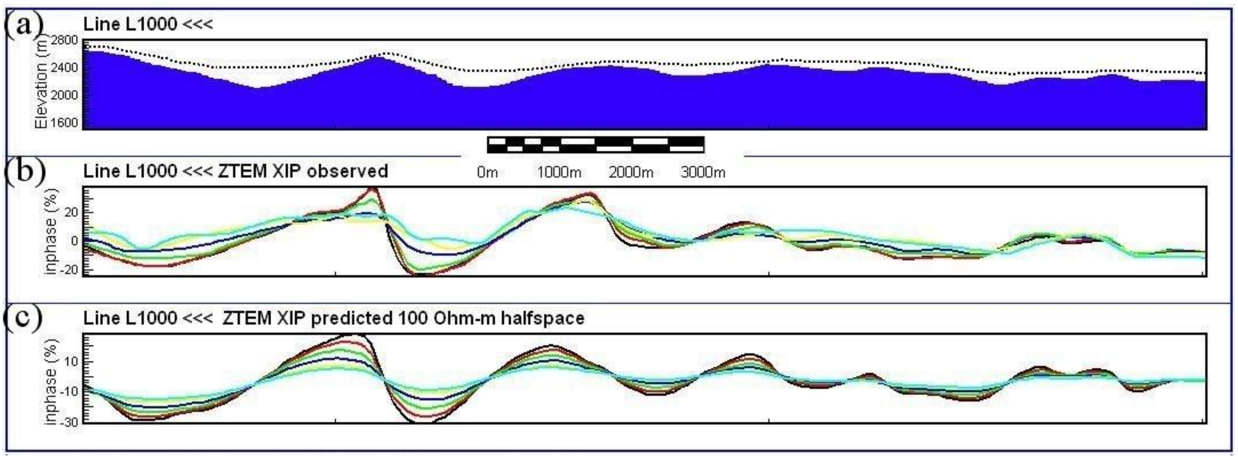

Figure 5. *(a): Topography and bird elevation (dashed line) along ZTEM survey line; (b): observed in-phase Tx (in-line) data (30-720 Hz); (c): predicted in-phase Tx data(30-720 Hz) for 100 Ohm-m half-space.*

Conclusions

This study evaluates the effect of topography on the ZTEM data. It is conclusive that in cases with large and steep hills the topography effect can be significant. In this particular study the 45° slope in a 300 m hill resulted in ZTEM anomalies up to 15% (peak to peak), which can be otherwise mistakenly interpreted as conductive structure with electrical property reaching 1/3 with the background. The topography effect is further confirmed using 2D forward modelling code. It is also conclusive that the false structure can be eliminated if the inversion is carried out with proper considerations regarding the topographic features, rather than carried out considering flat Earth and then draped over the topography.

References

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