Extracting information from ZTEM data with 2D inversions

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SUMMARY

A 2D Occam inversion algorithm for modeling ZTEM data is described that takes into account topography and EM receiver terrain clearance. The responses of hills and depressions are shown for synthetic models. These results show that hills and depressions produce responses that could be confused with the responses of conductors and resistors, respectively.

The analysis of ZTEM data acquired at different flight-line directions at the Forrestania test site, WA, shows great consistency and repeatability of the ZTEM data. 2D inversion results indicate that the derivation of pseudo tipper profiles, perpendicular to the survey flight-line direction, from across-line data contain valuable information, especially where the local strike is not perpendicular to the flight-line direction.

Key words: AFMAG, airborne electromagnetics, EM data modelling, inversion, terrain effects.

INTRODUCTION

The ZTEM system (built and operated by Geotech Ltd.) measures the AFMAG responses of naturally occurring subsurface currents, induced by far-away lightning discharges (Legault et al., 2009). The vertical component is measured from a moving helicopter platform, while the horizontal components are recorded on the ground at a base station. The ZTEM response is extracted from the recorded dB/dt time series at discrete frequencies in the range 25-600 Hz or 30-720 Hz for survey areas with 50 and 60 Hz electric power grids, respectively. Various methods used for the modelling and interpretation of ZTEM data, including 2D inversion, Karous-Hjelt filters (Karous and Hjelt, 1983) and the derivation of apparent conductivity (Becken and Pedersen, 2003) have been discussed by Sattel et al. (2010).

After a brief discussion of a 2D algorithm used for the forward modelling and inversion of ZTEM data, ZTEM responses are shown for synthetic models to demonstrate the effect of topography and receiver terrain clearance.

For the interpretation of survey data, the in-line tipper (Tzx) profiles are generally modelled with a 2D inversion. A 3D inversion (Holtham and Oldenburg, 2010) would make use of the across-line (Tzy) data, but the 3D inversion of entire survey data sets is only now be attempted and is hence considered still experimental. In areas where the geology is not two-dimensional and/or the flight-line direction is not perpendicular to strike, useful information may be extracted from tipper profiles derived for a direction that is different from the survey line-direction. The value of this approach is demonstrated on a data set acquired at Forrestania, Western Australia.

MODEL ALGORITHM

The 2D algorithm is based on a 2D MT algorithm developed by Constable and Wannamaker (deGroot-Hedlin and Constable, 1990; Wannamaker at al., 1987; deLugao and Wannamaker, 1996). The algorithm derives the in-line (Tzx) tipper profiles from the computed transverse electric (TE) response. The finite-element algorithm models the effect of topography (Wannamaker et al., 1986) and takes into account the terrain clearance of the airborne platform along the flight line. An example of the model mesh is illustrated in Figure 1.

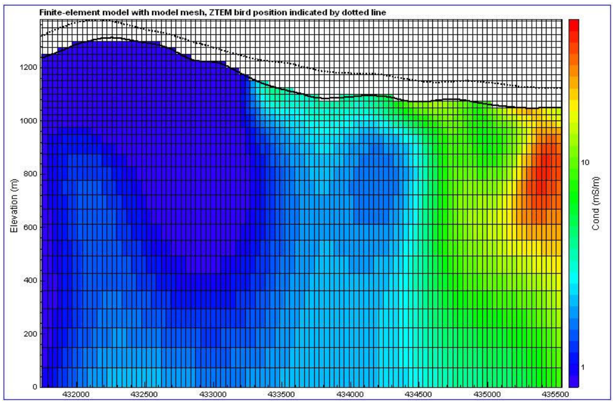

Figure 1. Illustration of model mesh for 2D inversion. Since the algorithm takes into account the topography and ZTEM bird terrain clearance along each line, air cells are an integral part of the finite-element model.

SYNTHETIC ZTEM DATA

Topography and Receiver Terrain Clearance

The effect of topography on the ZTEM response is demonstrated in Figure 2. The top panel shows a right-to-left crossover in the inphase response above the hill. When inverting these data with an algorithm assuming a flat earth, the data can be fit very well, but recovered conductivities will be distorted. The derived conductivity-depth model (draped on the true topography) indicates more conductive material at the top of the hill and more resistive material elsewhere. A left-to-right crossover in the inphase response is recorded across a depression. Inverting these data with a flat-earth model results in more resistive material being mapped at the center of the depression and more conductive material along the surface.

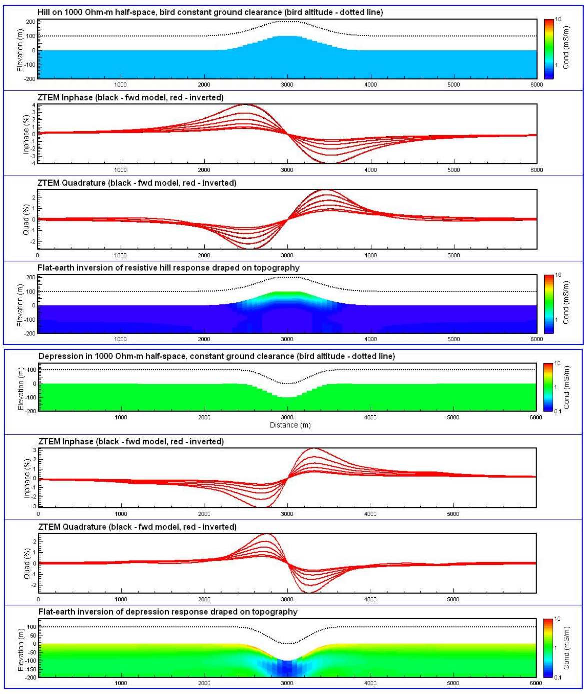

Figure 2. The ZTEM response of a hill (top panel) and depression (bottom panel). A constant EM receiver terrain clearance of 100 m was modelled. Each panel shows the input model of constant conductivity (top), the corresponding inphase and quadrature responses (centre) and the inverted section (draped on topography) assuming a flat-earth model (bottom).

The ZTEM response of a resistive hill flanked by conductive overburden is shown in Figure 3. The receiver was modelled for a constant terrain clearance of 100 m. Despite the presence of the hill, the gap in the overburden results in a left-to-right crossover in the inphase response. The quadrature response changes polarity between 25 and 600 Hz. The response of the same model for a receiver elevation of 200 m is shown at the same vertical scale in Figure 4. A comparison with Figure 3 indicates that, even though amplitudes are smaller, the response fall-off with receiver elevation is much less severe than for active-source EM systems.

Across a layered-earth, a change in the sensor terrain clearance alone does not result in a tipper response. Since the tipper response across a 1-D earth is zero, the profile with variable sensor terrain clearance is also zero (see Figure 5).

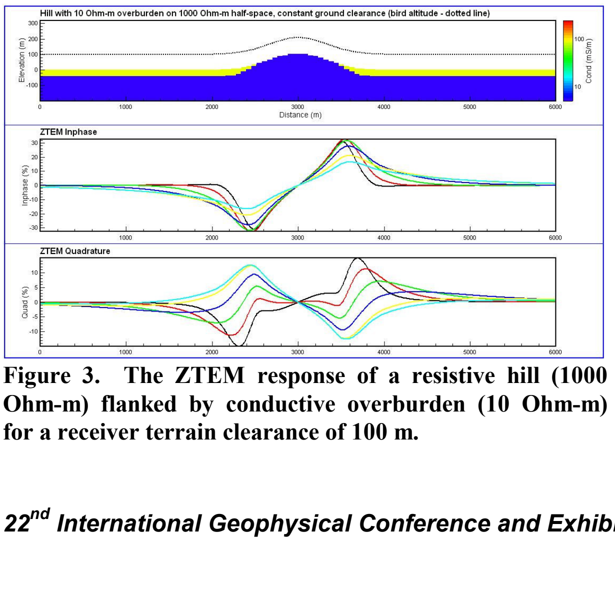

Figure 3. The ZTEM response of a resistive hill (1000 Ohm-m) flanked by conductive overburden (10 Ohm-m) for a receiver terrain clearance of 100 m.

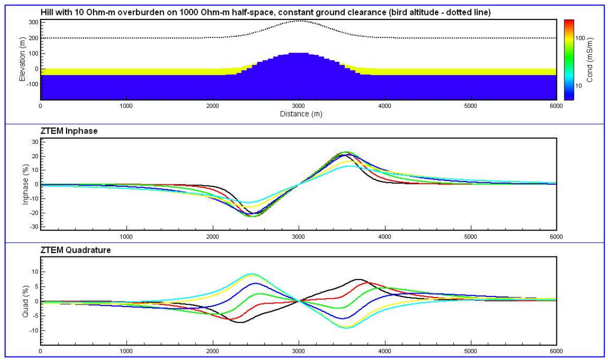

Figure 4. The ZTEM response of a resistive hill (1000 Ohm-m) flanked by conductive overburden (10 Ohm-m) for a receiver terrain clearance of 200 m.

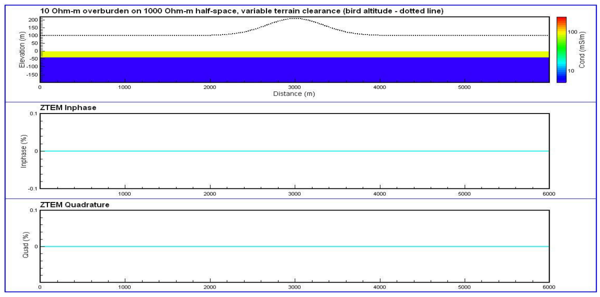

Figure 5. The ZTEM response across a layered-earth (50 m of 10 Ohm-m on 1000 Ohm-m half-space) for variable sensor terrain clearance.

2D INVERSION OF TZY DATA

A ZTEM survey data set contains in- and across-line tipper data Tzx and Tzy. Generally, the in-line Tzx data are modeled with a 2D inversion, because the flight-line direction is normally chosen to be perpendicular to the geological strike and the data sampling is densest along line. However, most ZTEM surveys are flown at a line spacing that allows for the derivation of in-line tipper profiles for any flight-line direction by projecting the nearest points onto that pseudo-line and by combining the Tzx and Tzy data into in-line tipper values. If the pseudo-line is perpendicular to the flight-line direction, the derived in-line tipper profile is made up of Tzy data, picked from the measurement points closest to the pseudo-line. The derived tipper profile can be modeled with a 2D inversion, which can provide useful results, where the geological structure is not two-dimensional and/or where the local strike is not perpendicular to the flight-line direction. The usefulness of Tzy data inversion is demonstrated with ZTEM data acquired at Forrestania, WA.

FORRESTANIA SURVEY

Figure 6 shows the flight lines of a survey flown at the Forrestania, WA EM test range, which is described on the website of Southern Geoscience Consultants (www.sgc.com.au). The ground covered by the ZTEM survey includes two drilled, barren, semi-massive to massive sulphides (IR2 and IR4), hosted in highly resistive bedrock under a conductive overburden (10-20 S). Previous analysis has indicated that there is no indication for sulphide IR4 in the ZTEM data set, but that a conductor has been mapped from the ZTEM data at the location of sulphide IR2 (Sattel et al., 2010). IR2 is described as shallow (<100 m), highly conductive (>7,000 S), small (<75x75 m) and dipping 30-40 degrees to the north. East-west and north-south lines have overflown IR2, which allows checking for repeatability and consistency between the two data sets.

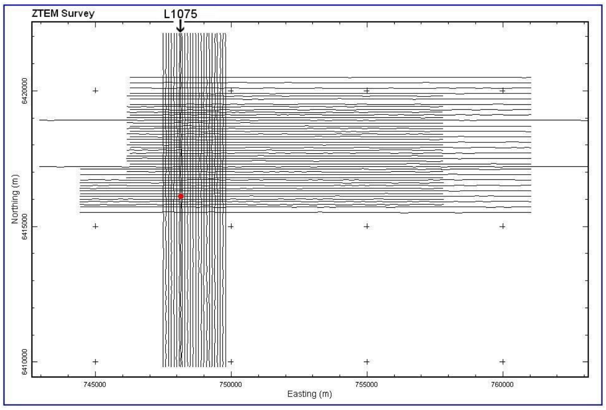

Figure 6. Flight lines of ZTEM survey at Forrestania, WA. The location of sulphide IR2 is indicated by a red dot.

The 2D inversion of the north-south line shown in Figure 7 indicates a conductive structure at the location of the sulphide body. Due to the small strike length of the sulphide a strong response was not expected. It should be noted that the response might be due to a geological structure with long strike length that hosts the sulphide. The 2D inversion result of the east-west line (not shown) does not give any indication of the presence of the conductor.

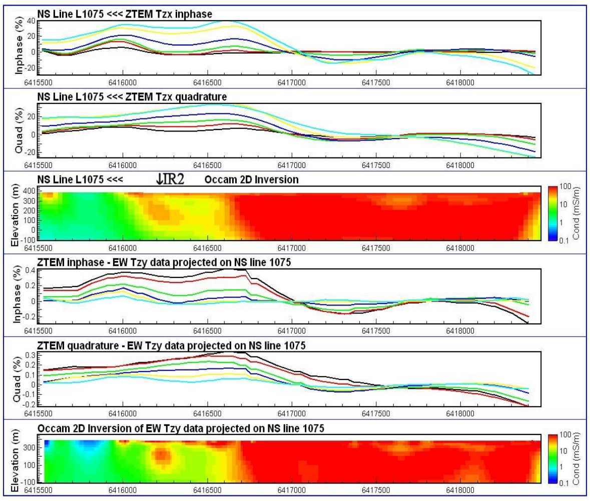

Figure 7. Forrestania ZTEM profiles across sulphide IR2, indicated by arrow, with corresponding inversion results. A portion of Tzx profiles of north-south line 1075 are shown in the top panels; the profiles derived from the Tzy data of the east-west lines are shown in the bottom panels.

For a more appropriate comparison between the east-west and north-south data sets, Tzy data from the east-west data set were extracted to derive a profile of in-line tipper values directed north-south. For this step, each east-west line contributes one point to the pseudo north-south line, and the data spacing on the pseudo profile is determined by the line spacing of the east-west data set. Due to the small flight-line spacing of the Forrestania survey (mostly 100 m) the anomaly shapes are expected to be recovered well. A comparison of the original north-south Tzx profile (line 1075) and the pseudo profile derived from Tzy data of the east-west survey is shown in Figure 7. The corresponding inversion results are also shown. Despite the rougher appearance of the derived profile, the comparison shows excellent agreement between the two data sets and their inverted conductivity-depth sections. This indicates excellent consistency and repeatability between the two data sets flown at different flight line directions and acquired at different times.

These results also suggest that for 2D inversions to extract the maximum information of some structures, survey data might have to be projected and rotated into profiles with more appropriate flight-line directions. Since Tzx and Tzy are available for the entire survey, any angle can be chosen for reprojecting the data.

With the existence of two data sets for the Forrestania survey, each containing Tzx and Tzy data, 2D inversions were performed on 4 different sets of tipper profiles: original E-W and N-S Tzx profiles as well as pseudo N-S and E-W profiles derived from Tzy data of E-W and N-S surveys, respectively. Results are presented as conductivity-elevation slices at 120 m ASL in Figures 8 and 9. Apparent conductivity images of the 75 Hz data are shown for comparison. The derivation of the latter makes joint use of the Tzx and Tzy tipper data.

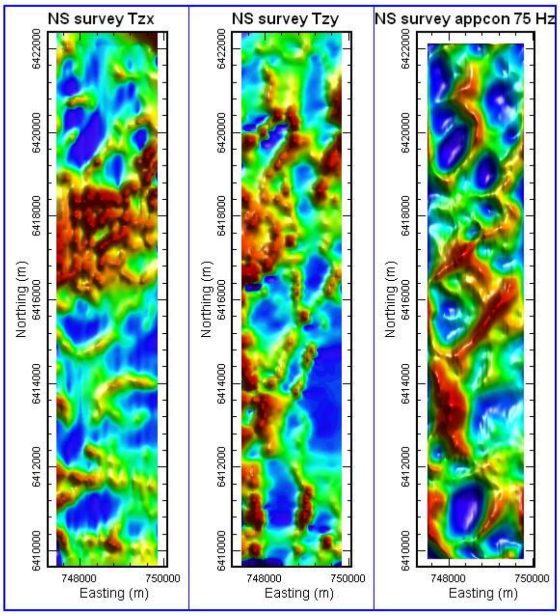

Figure 8: North-south survey data. Conductivity strucure at an elevation of 120 m ASL, derived from 2D inversion of Tzx (left) and Tzy (center) data, and 75 Hz apparent conductivity (right).

As expected, the results between Tzx and Tzy inversions are quite different, since the tipper inversions indicate structures as a function of coupling between sensor orientation and subsurface current flow. For the N-S survey area, most structures appear to run SW-NE and are mapped in a comparable fashion by both tipper orientations. For the E-W data set, some prominent structures run N-S, coupling better with the Tzx data than with the Tzy data. Nevertheless, the inversion of the Tzy data indicate some subtle structures in the western third of the survey area, that are much less obvious in the corresponding Tzx conductivity-elevation slice. For both survey areas, the inversion results complement each other.

Figure 10 shows the overlapping portion of the conductivity-elevation slices shown in Figures 8 and 9. The results in the left panels are expected to agree with the results in the right panels, since the direction of the tipper data used is the same in both panels. As a function of the tipper data orientation, the conductivity structure in the top and center panel should indicate mostly E-W and N-S striking structures, respectively. The above expectations are largely met, except for the results of the Tzx E-W survey data, which don't appear to map any N-S structures and don't agree too well with the results of the Tzy N-S survey data. We assume that the tipper profiles of the Tzx E-W survey data are dominated by the stronger anomalies in the center and eastern half of the survey area, which resulted in a suboptimal data fit of subtler anomalies. The comparison of the apparent conductivity images derived from the N-S and E-W data also indicate that there are some differences in the data and data specifications (eg spatial sampling) between the two data sets.

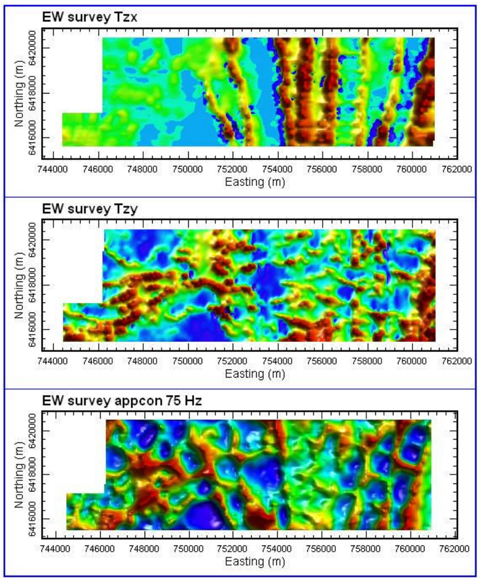

Figure 9: East-west survey data. Conductivity strucure at an elevation of 120 m ASL, derived from 2D inversion of Tzx (top) and Tzy (center) data, and 75 Hz apparent conductivity (bottom).

CONCLUSIONS

The results from synthetic models indicate that taking into account of terrain topography during 2D inversions is important to derive reliable conductivity-depth sections.

The analysis of ZTEM data at Forrestania, WA has shown excellent consistency and repeatability between two data sets flown at different flight line directions and acquired at different times. The derivation of ZTEM profiles along pseudo-lines allows for the 2D inversion of structures not perpendicular to the survey flight-line direction.

ACKNOWLEDGMENTS

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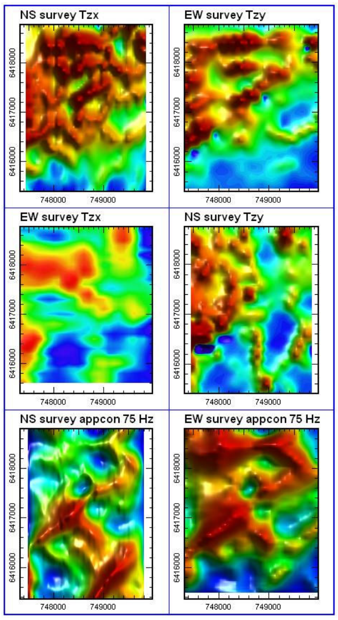

Figure 10: Close-up from Figures 8 and 9 of the overlapping area.

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