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Rapid 3D inversion of airborne TEM data from Forrestania, Western Australia

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SUMMARY

VPem3D performs 3D inversion on time-integrated (resistive limit) data. Conversion to resistive limits delivers a massive increase in speed since the TEM inverse problem reduces to a quasi-magnetic problem. The time evolution of the decay is lost during the conversion, but the information can be largely recovered by constructing a starting model from CDIs or 1D inversions.

We have carried out preliminary inversion of VTEM dB_z/dt data from the Forrestania EM test range. The inversion places a weak conductor at a depth and location consistent with the known target. Run time is a few minutes, a fraction of that required by a full 3D EM inversion.

Key words: Airborne electromagnetics, 3D inversion, moments.

INTRODUCTION

Full three-dimensional inversion of airborne electromagnetic data is feasible but very computationally demanding, and is beyond the capabilities of current desktop PCs. This has motivated the development of an approximate 3D inversion algorithm based on electromagnetic moments (Schaa and Fullagar, 2010; Fullagar et al., 2014).

VPem3D performs 3D inversion of resistive limit data on a 3D geological model. Geological constraints can be applied to improve the reliability of the inverted models. In addition models can be conditioned via application of weights, e.g. depth and conductivity weights.

In the form of the algorithm applied to the Forrestania data, each model cell contributes a magnetic dipole response to the resultant resistive limit response. The dipole moment, $\vec{s}$, of a cell is given by

$$\vec{s} = \vec{B}_0 V \tau$$

where V is the volume of the cell, $\vec{B}_0$ is the primary field at its centre, and τ is the time constant of the body to which the cell belongs. Thus τ plays the role of susceptibility in conventional magnetic inversion with the result that, strictly speaking, the inverted property is time constant rather than conductivity. Time constant is proportional to conductivity for simple homogeneous bodies.

Three inversion styles can be applied: homogeneous property inversion and geometry inversion as well as the more conventional heterogeneous property inversion. The inverse problem is solved via the method of steepest descent. The inversion *per se* is therefore fast, because no matrix inversion is required.

METHOD

Forrestania Test Range

The Forrestania EM Test Range is located near Hyden, Western Australia. The test range contains two bedrock conductors, known as IR2 and IR4. Both conductors have been drilled and have been shown to be pyrrhotite-rich semi-massive to massive sulphides. Although non-economic, the conductors provide excellent targets for testing of electromagnetic systems.

The Forrestania EM test range has been flown by several AEM systems, including VTEM, HeliTEM, SkyTEM[508] and ZTEM (Sattel et al., 2010; Mulè et al., 2012). The first three of these systems have all successfully detected the shallower of the two targets (IR2). The conductor lies at relatively shallow depth (60 – 100 m), has dimension 75 × 75 m, conductance ~7000 S and dips to the north at 30 – 40°. The deeper target (IR4), although of large strike extent and high conductance, lies at depths of 300 – 400 m and has not thus far been detected by any AEM systems flown at the test range.

Figure 1 shows the VTEM flight path at Forrestania, and the location of the IR2 conductor. Figure 2 shows profiles of dBz/dt and Bz from Line 1075, which crosses directly over IR2, along with the EMax_Air CDI calculated from the dBz/dt data.

Inversion procedure

The steps involved in the inversion are as follows:

- Calculate the moment from the VTEM time-decays. For the Forrestania data, the first 12 VTEM channels (delay times < 682 μs) were omitted from the moment calculation in order to further emphasise the late-time response from IR2.

- Discretise the area of interest. The Forrestania model mesh has dimension 200 m (equal to the flight line spacing) in the east-west direction, and 10 m in the along-line direction. The mesh extends from elevation 0 m to surface (~400 m). Vertical cell size increases with depth (factor 1.2 applied to thickness of successive cells) in order to reduce the number of model cells while preserving reasonable vertical resolution.

- Interpolate EMax_Air CDI results (based on delay times > 682 µs) into the VPem3D model mesh to provide a starting model. This is useful to restore conductivity vs depth information "lost" when the moment is calculated from the dB/dt time decays.

- Calculate conductivity and depth weights. Depth weighting allows only limited near-surface conductivity changes and increasingly large variations at depth. Conductivity weights are based on EMax_Air conductivities and allow greatest parameter variation in areas of high conductivity. Conductivity and depth weights are combined into a single weight using a power mean with exponent 0.25.

- Run inversion and assess results. For discrete conductors, this would usually involve sequential application of homogeneous-unit, geometry and full heterogeneous-unit inversion.

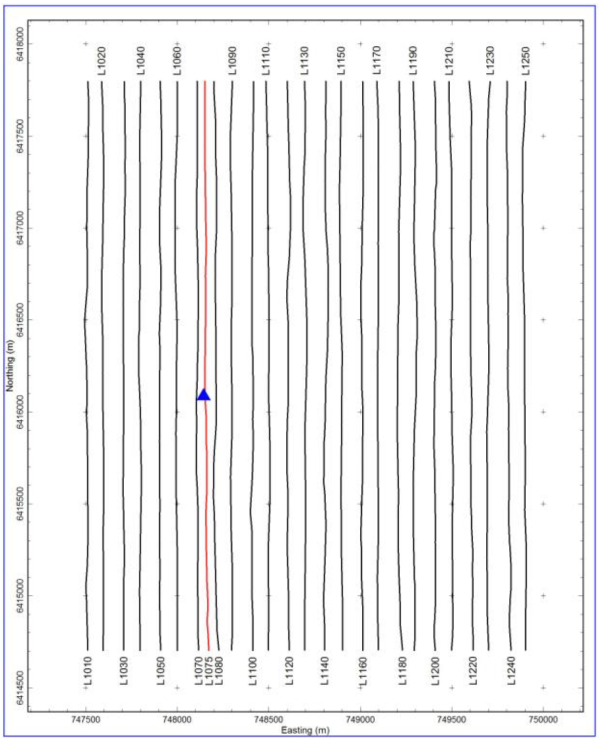

Figure 1 VTEM flight path map for the Forrestania test range. The location of conductor IR2 is shown by the blue triangle. Flight line 1075 is shown in red.

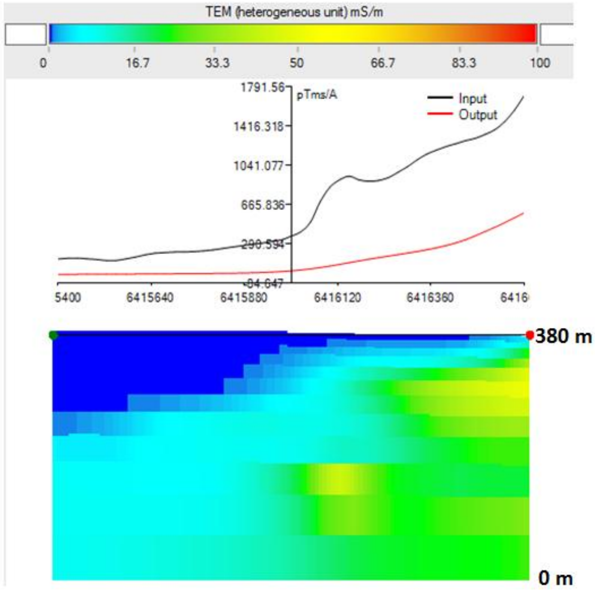

Figure 3 VPem3D starting model and moment response for Line 1075. The starting model has been based on the EMax_Air CDI for times > 682 µs**. In the upper panel, the 'observed' moment data are shown in black and the calculated data in red.**

RESULTS

Figure 3 shows the VPem3D starting model on Line 1075, which is derived from the interpolated EMax_Air CDIs for times > 682 µs. The upper panel shows a comparison of the observed and calculated model responses. The IR2 anomaly in the centre of the profile is quite subtle, and its expression in the CDI is very deep (> 200m). The interpolated CDI starting model does not provide a particularly good fit to the "observed" moments.

Figure 4 shows the Vpem3D model and moment response following inversion. The model provides a very close fit to the observed data. Comparison of Figures 3 and 4 shows that the inversion has introduced a weak conductive zone centred at a depth of around 70 m in order to fit the anomaly due to IR2. This is consistent with the known location and depth of the conductor (e.g., Mulè et al., 2012). Total run-time for the entire Forrestania survey was less than 30s on a Toshiba Portege laptop PC (2.67 GHz dual core processor with 4 GB RAM).

Figure 5 shows the combined conductivity and depth weights applied to the inversion. Model changes are focussed on the deeper parts of the model and those areas of high conductivity from the EMax_Air CDI. Calculation and application of the model weights is a straightforward process using the VPem3D utilities in GOCAD.

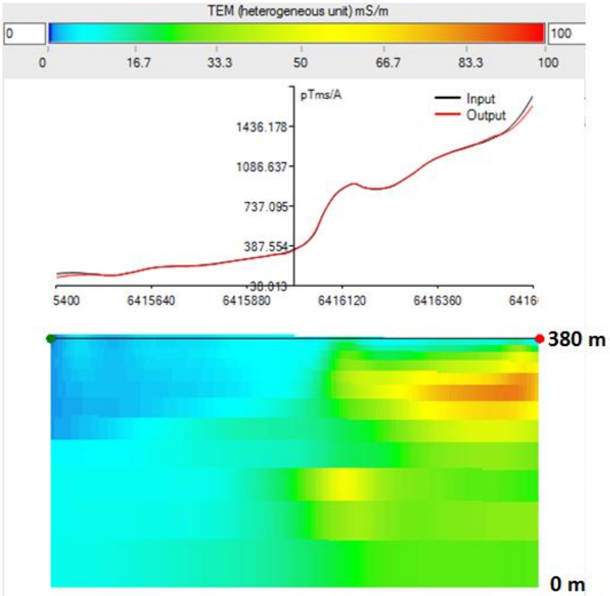

Figure 4 VPem3D inverted model and moment response for Line 1075. In the upper panel, the 'observed' moment data are shown in black and the calculated data in red.

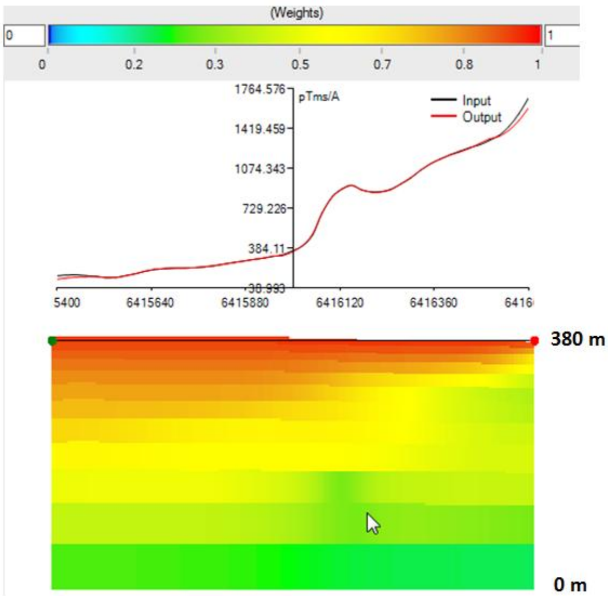

Figure 5 Combined depth and conductivity weights for Line 1075. Low weights (cool colours) indicate cells which are allowed most variation during inversion.

CONCLUSIONS

Preliminary VPem3D inversion of VTEM data from Forrestania has provided encouraging results. The inversion placed a weak conductive feature at a depth of ~70 m, consistent with that of the known mineralisation. In comparison the EMax_Air CDI, based on a one-dimensional model, places the conductor at a depth of over 200 m. Total run-time for the entire Forrestania survey was less than 30s on a laptop PC. Inversion of the Forrestania dataset is complicated because the strongest moment responses are associated with conductive cover rather than with the conductive target. This was addressed by restricting attention to late times and by applying combined conductivity and depth weights during the inversion. Conductivity weights were derived from an EMax_Air CDI. It is possible that improved results will be obtained by inverting the B-field data, in which the anomaly from IR2 is more prominent.

ACKNOWLEDGMENTS

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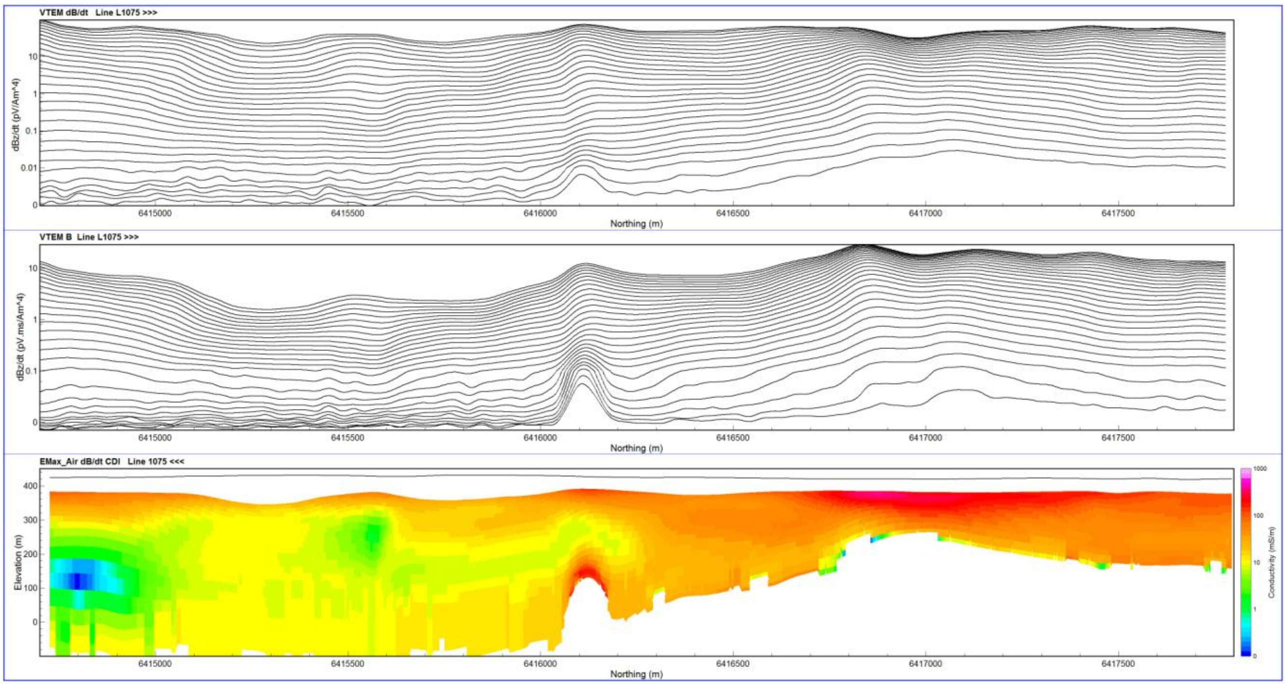

Figure 2 VTEM data from Line 1075: dB_z/dt (top); B_z (centre) and EMax_Air dB/dt CDI (bottom). The anomaly due to conductor IR2 is clearly evident at late times in the centre of the profile. The Emax_Air CDI significantly overestimates the actual depth of the conductor (60-100 m).