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Two-dimensional joint inversion of ZTEM and MT Plane-Wave EM data

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Summary

The performance of two-dimensional (2-D) joint ZTEM/MT inversion is tested over a coincident ZTEM and Titan dense array MT data over the Johnston Lake district, Saskatchewan. A result of this effort is that only very few (e.g., three) MT stations may be needed to correct for background resistivity effects in a ZTEM survey provided the MT sites are appropriately spaced.

Introduction

ZTEM (Lo and Zang, 2008) is an airborne electromagnetic (EM) geophysical technique developed from AFMAG (Ward, 1959; Labson et al., 1985) where naturally propagated EM fields originating with regional and global lightning discharges (sferics) are measured as a means of inferring subsurface electrical resistivity structure. A helicopter-borne coil platform (bird) measuring the vertical component of magnetic (H) field variations along a flown profile is referenced to a pair of horizontal coils at a fixed location on the ground in order to estimate a tensor H-field transfer function.

The ZTEM method is distinct from the traditional magnetotelluric (MT) method in that the electric fields are not considered because of the technological challenge of measuring E-fields in the dielectric air medium. This can lend some non-uniqueness to ZTEM interpretation because a range of conductivity structures in the earth depending upon an assumed average or background earth resistivity model can fit ZTEM data to within tolerance. MT data do not suffer this particular problem, but they are cumbersome to acquire in their need for land-based transport often in near-roadless areas and for laying out and digging in E-field bipole sensors. The complementary nature of ZTEM and MT logistics and resolution has motivated development of schemes to acquire appropriate amounts of each data type in a single survey and to produce an earth image through joint inversion. In particular, consideration is given to surveys where only sparse MT soundings are needed to drastically reduce the non-uniqueness associated with background uncertainty while straining logistics minimally.

Other workers (Holtham and Oldenburg, 2010; Sasaki, 2013) have presented joint 3D inversion studies using sparse but regularly spaced MT soundings and denser ZTEM measurements. The present study investigates the capability of 2D joint MT-ZTEM inversion using a few, irregularly spaced MT soundings along a ZTEM survey line.

Method

Algorithm ZTMT2DIV is a generalization from previous code AV2Dtopo (Legault et al., 2009; 2012) that inverted ZTEM and AirMt data allowing topographic variations and a variable bird height. The performance of two-dimensional (2-D) joint ZTEM/MT inversion by ZTMT2DIV was initially tested using synthetic brick structures below a hill and valley model and proved successful, but is not shown here. Subsequently, separate and joint inversion of coincident ZTEM and Titan dense array MT data over the Johnston Lake district, Saskatchewan, were performed and are presented here. A result of this effort is that only very few (e.g., three) MT stations may be needed to correct for background resistivity effects in a ZTEM survey provided the MT sites are appropriately spaced.

ZTMT2DIV algorithm makes use of the public domain finite element forward problem and inversion parameter sensitivities using reciprocity developed at the University of Utah (Wannamaker et al., 1987; de Lugao and Wannamaker, 1996), together with the regularized Gauss-Newton non-linear parameter step estimate described by Tarantola (1987). The regularization is simple damping of the spatial slope of the model variation across the section. Inversion parameters expand in both width and thickness versus depth in order to help equalize influence of different regions of the earth model upon the EM response. Models described were run on a quad-core desktop computer with a 3 GHz Intel I7 processor and typically took 20-60 minutes to execute.

Johnston Lake Field Example

A test using measured field data is carried out in this section using coincident ZTEM and Quantec Titan-24 dense MT array profiling from the Johnston Lake unconformity uranium prospect, Saskatchewan. The original ZTEM data profile consists of 1152 data points over a span of 10027 m. The frequencies of operation are 720, 360, 180, 90, 45 and 30 Hz. The flight height of the survey line was near 110 m and the topography was considered flat for current purposes. The inversion used just 197 ZTEM locations ~50 m apart for a total span of ~9800 m. The Titan profile consisted of 26 continuous sites at 100-150m spacings that extend for 3150 m length over the central third of the ZTEM profile. Thus the MT only spans a fraction of the full length of the ZTEM. The MT data were binned to four frequencies per decade from 1000 to 1 Hz, 13 frequencies in all.

A ZTEM only inversion is plotted in Figure 1 assuming a 2000 ohm-m background. The model shows a compact central conductor in the 1 km depth range and a weak subhorizontal conductor extending southward at somewhat greater depths. A 2D inversion of the TM mode only of the 26 Titan-24 sites is shown in Figure 2. This yields also a central compact conductor though no clear expression of a deeper, weaker one southward. However, the MT data suggest that the background resistivity is greater than previously assumed, more like 4000 ohm-m.

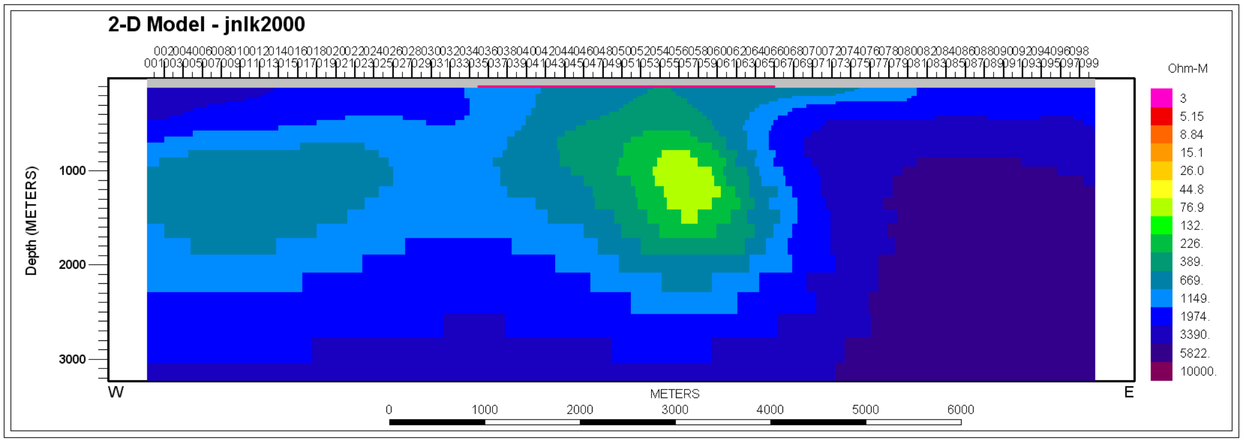

Figure 1: *2D inversion model of 197 binned ZTEM sites along the Johnston Lake profile, assuming a 2000 ohm-m background. Only every other site tick is plotted, thus the labeling 1- 99. Red bar denotes span of the Titan-24 MT array profile.*

Figure 3 shows a joint inversion of the ZTEM results with the whole TM Titan data set. A background of 2000 ohm-m was used. This model shows a strong, compact conductor under the center of the profile with a depth to top <1 km. It extends to depth and then continues southward at a depth >2 km. Note that most of the background increased to ~4000 ohm-m from 2000 given inclusion of the MT data.

Figure 4 shows a similar joint inversion but with only three MT sites at well-separated but otherwise random position. This model strongly resembles Figure 3 and a higher resistivity background is recovered as well. This is quite encouraging and supports the previous synthetic study that only a very few MT sites may be required to greatly improve background constraints and improve image accuracy.

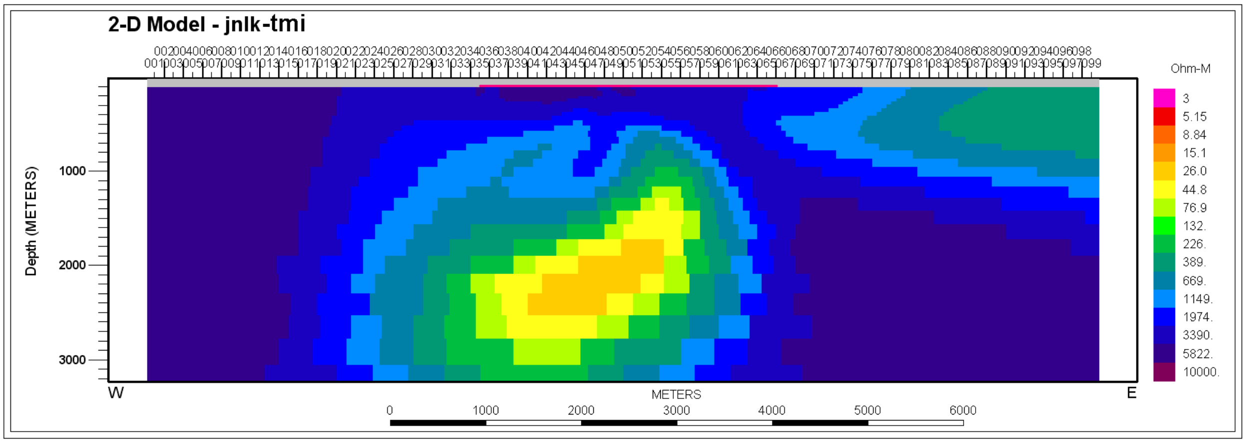

Figure 2: *2D inversion model of TM mode responses of all 26 Titan-24 MT sites along the Johnston Lake profile assuming a 2000 ohm-m background.*

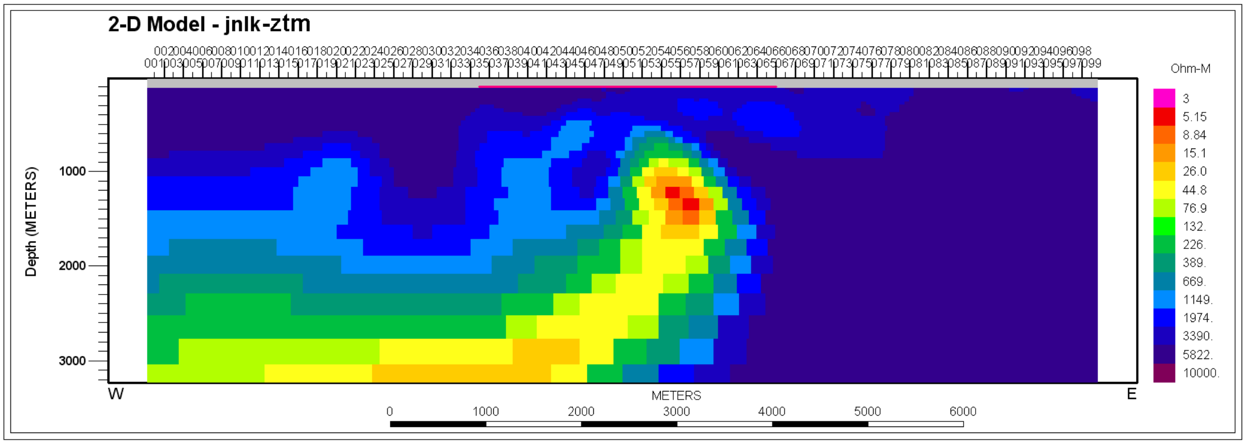

Figure 3: *Joint inversion model of ZTEM and TM mode Titan MT data.*

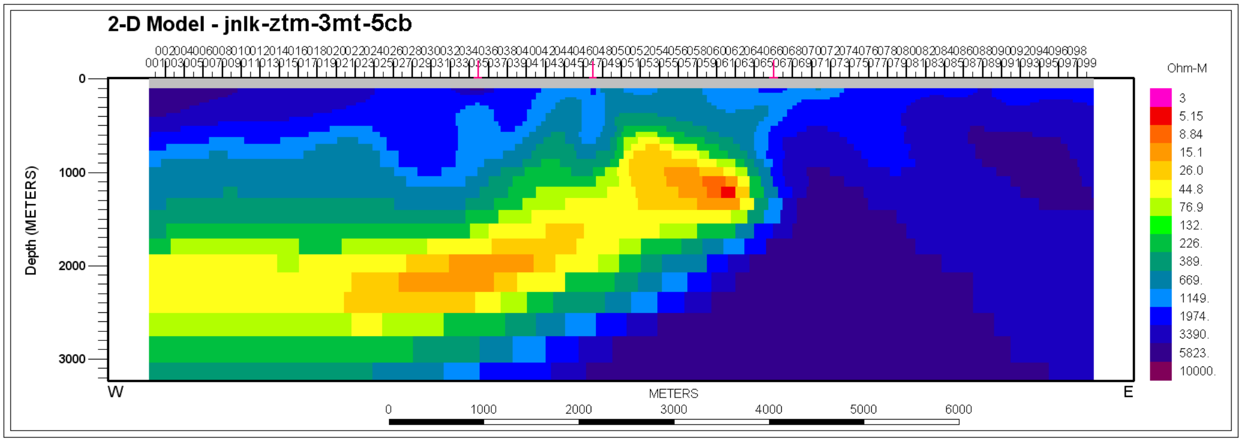

Figure 4: *Joint inversion model of ZTEM and TM mode Titan MT data from only three sites (red ticks).*

Conclusions

Algorithm ZTMT2DIV is able to compute accurate resistivity inversion images over 2-D heterogeneity beneath topography through joint or separate inversion of ZTEM and ground MT data. Including MT, even a sparse number of sites, appears to have good potential for improving the background resistivity and thus placing structure determined primarily by the ZTEM in its correct location. However, the limited number of tests here suggests that the MT sites should approximately span the length of the ZTEM profile to undergo joint inversion or else portions of the ZTEM model may become poorly constrained.

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