TIPPER MAGNITUDE: REVISITED

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Abstract

To verify the existence of Anomalous Tipper magnitude, hereby referred as ATM (Tipper magnitude more than 1.0), we performed 2-D and 3-D forward modelling tests. ATM period ranges reduces with the increment in distance from the contact of anomalous block. ATM is particularly well developed for large conductivity contrasts between the host medium and the anomalous conductor. A highly conductive near-surface anomaly can produce large tippers close to its contact with the host medium, the tipper as a function of the period is also largely affected by the conductivity structure of the basement. Synthetic 3-D tests results shows that that ATMs produced for shorter periods are similar to 2-D models. So if we restrict the lateral dimension of anomalous conductor unlike 2-D situation, the ATMs can occur only at shorter periods.

Introduction

Tipper magnitude is invariant with the co-ordinate system while tipper components are variant with respect to co-ordinate system (Ting & Hohmann, 1981). Rokityansky (1982) developed a simple and productive technique to estimate the main parameters of a deep 2D conductor using anomalies in the Hz field. Ingerov et al. (2009) estimated tipper response over various types of anomalous bodies, which are common in mining and hydrocarbon prospecting. Siripunvaraporn & Egbert (2000) and Rodi & Mackie (2001) performed inversion of the tipper data. Berdichevsky et al. (2003) studied the tipper data generated from 2D geological models and concluded that the tipper data is less affected by static shift compared to apparent resistivity data. Further, they observed that by inclusion of tipper in inversion the reliability of geoelectrical models can be substantially improved. Tuncer et al. (2006) concluded that the tipper data adds useful information to the inversion and enhance its resolution from the 2D inversion of field MT. Becken et al. (2008) reported that the TE mode magnetic transfer functions are most important for sensing deep conducting anomalies from the 2D inversion example of the synthetic 3D data. Siripunvaraporn & Egbert (2009) have shown that the horizontal position and lateral conductivity contrasts of anomalies are recovered by inverting VTFs. However, vertical positions and absolute amplitudes are not well constrained unless an accurate host resistivity is imposed a priori. They further jointly inverted VTFs and impedances to provide useful additional constraints for the structures with more realistic levels of complexity. Chang-Hong et al. (2011) inverted apparent resistivity, phase and tipper jointly using 3-D conjugate inversion algorithm for differentiating two close targets and recovering the resistivity of the deep target considering some synthetic examples. A priori models and data weighting, i.e., how strongly individual components of the impedance tensor and/or vertical magnetic field transfer functions dominate the solution, are crucial controls for the outcome of 3D inversion (Tietze & Ritter, 2013). Chave & Jones (2012) mentioned that the magnetic field data over conducting terrains are more reliable than the electric field data. In the present study, we discuss the possibility of existence of tipper magnitude, more than 1.0 and its possible implication.

Brief Theory

Tipper is a measure of the "tipping" of the **H** vector out of the horizontal plane. Mathematically, it is represented as:

$$\mathrm{H_z} = T_{zx}\mathrm{H_x} + T_{zy}\mathrm{H_y}$$

Where, T_{zx} and T_{zy} complex coefficients are two components of Tipper or Vertical Transfer Function (VTF) data and gives its variation in two orthogonal directions. Tipper magnitude (*T*) is a dimensionality indicator and is defined as:

$$T = \sqrt{|T_{zx}|^2 + |T_{zy}|^2}.$$

For 1-D structure, tipper magnitude is zero and for 2-D/3-D, it is non-zero.

Tipper data has the following advantages:

1) Tipper magnitude is invariant with the co-ordinate system while tipper components (Tzx and Tzy) are variant with respect to co-ordinate system .

2) The horizontal location of the conductor can be defined using the sign reversal of the real part of Vertical Transfer Functions (VTFs) data.

3) Tipper magnitude varies significantly over varying nature of anomalous conducting zone.

4) The tipper data generated from 2D geological models has been found to be less affected by static shift compared to apparent resistivity data.

5) The inclusion of tipper in inversion the reliability of geoelectrical models can be substantially improved. In many cases the tipper data adds useful information to the inversion and enhance its resolution from the 2D inversion of field MT.

Synthetic Modelling

To verify the existence of Anomalous Tipper Magnitude (Tipper magnitude more than 1.0), we performed 2-D and 3-D forward modelling tests.

2-D

Theoretical models (Models A, B, C, D and E; Fig. 1), have been simulated to understand the behaviour of ATM. Pseudo sections of the tipper magnitude across the strike, defined as , where Hz = TzyHy, where strike is parallel to the x-axis, for a section between 0 - 10 km centring the anomalous block for all three models are shown in Fig. 1 (bottom). Fig. 1 (middle) shows the pseudo-sections of TE and TM modes apparent resistivity and phases along the profile for the models A, B, C, D and E. The TM-mode mainly responds to the transition from the conductive layer to the resistive basement while TE-mode is more sensitive to the anomalous block (Figure 1; models A, B and C) seen in both TE and TM apparent resistivity and phase pseudo-sections. Initially, all the computations carried out with the horizontal and vertical meshes of 445 and 54 steps respectively for the periods 10^{-4} to 10^{3}s. The conducting block of 1 ohm-m resistivity having 520 m thickness and 1.8 km width covered with 23 vertical and 70 horizontal mesh steps. The minimum horizontal mesh steps made 0.008 km (8 m) in the anomalous domain. The minimum vertical step 0.001 km (1 m) just at the surface considered for the forward modelling and increases progressively towards greater depths with a factor of 1.2. A model of highly conducting rectangular block extending down to 520 m from the surface of width 1.8 km and resistivity 1 ohm-m embedded in a moderately resistive host of 500 ohm-m overlying a resistive basement of 10000 ohm-m at a depth of 520m (Fig. 1, Model B, top) was considered. Model B produces ATMs, tipper magnitude more than 1.0, beyond the anomalous conductor for a broad period range in between 10-1 to 103s (Figure 1, bottom). The period range of ATMs narrows with the increment of distance from anomalous conductor and the effect reduces to small period range in between 10^{0} – 10^{2} s at the farthest distance of ~ 5 km from the centre of anomalous block. In order to achieve larger tippers, we tried to make the host medium more resistive to concentrate the induced currents more effectively into the anomalous conductor. Model B was subsequently modified by decreasing the thickness of the conductive non-uniform layer from the original 1.0 km to 170 m overlying the resistive basement commencing from the depth of 170m (Fig. 1A, Model C). By making the basement thicker, the induced currents concentrate into the non-uniform shallow layer only thereby enhancing the current channelling. Now observed ATMs beyond the anomalous conductor shifted to even shorter periods in between 10^{-2} to 10^{2} s for model C and ATMs at farthest distance reduces to smaller period range in between 10^{0}- 10^{1} s in comparison to model B. Model D consists of same anomalous conductor in all respect as of the Model C but embedded in a resistive host of 10000 ohm-m of 1 km overlying a moderately conducting basement of 300 ohm-m. ATM observed in the periods ranging from 10^{-4} s to 10^{1} s nearby anomalous conductor. A double hump character (or two peaks) of ATM is seen while approaching the contact of anomalous conducting block. However, one hump diminishes as we move away from the contact. The model E is same in all respect as that of model D except that the basement resistivity is reduced further by an order, i.e., changes from 300 ohm-m to 30 ohm-m. In this case, bump at longer periods diminishes and the maximum is observed at the shorter period of 10^{-3}s. Model B also modified into model A with changing the resistivity of anomalous block from 1 ohm-m to 10 ohm-m. In this case, we also observed the ATMs like models B and C but the farthest distance up to which ATMs can occur reduces to 3.0 km. Models A, B and C insists that ATM period ranges also reduces with the increment in distance from the contact of anomalous block. ATM is particularly well developed for large conductivity contrasts between the host medium and the anomalous conductor. The models illustrate that, though a highly conductive near-surface anomaly can produce large tippers close to its contact with the host medium, the tipper as a function of the period also largely affected by the conductivity structure of the basement. All modelling results were checked by running the models repeatedly in meshes refined by a factor of 1.5 (horizontal and vertical meshes of 645 x 54). Refining the mesh does not have any visible effect on the tippers and that it does not depend much on the grid refinement.

3-D

To understand the 3-D effects of the anomalous conducting block for the generation of ATMs, we performed 3-D synthetic tests on models C, D and E (Fig. 2) having similar resistivity of anomalous bocks but reduced lateral dimensions from 1.8 to 1.4 km (in Y direction) and from infinite to 2.6 km (in X direction). 3-D model domain was discretized into 57 X 56 X 33 cells in X-, Y- and Z- directions. Ten air layers are also included into the model for all the computations. In both the lateral directions, horizontal cell size kept 100 m uniformly for the entire model and padded with last three cell with the increment of a factor 1.2. In vertical direction, the first cell thickness considered is 1 m, it increases with a factor of 1.2 up to 2 km. The anomalous block have 26 X 14 X 19 number of cells covered in X-, Y- and Z- directions for the anomalous conducting block of the dimension 2.6 km X 1.4 km X 155 m. Similar to 2-D case the horizontal mesh steps in both the directions are not appropriate for the anomalous block. So grid refinement were also tested by reducing horizontal mesh step by a factor of 2 (~ 50 m) and 4 (~ 25 m) for the anomalous block only. Pseudo-sections for both apparent resistivity, phases derived from anti-diagonal impedance components and tipper data along a profile, parallel to Y- axis, (shown in Fig. 2; top) orthogonally crossing the centre portion of anomalous block for all three models are shown in (Fig. 2; middle). Model C depicts ATMs for periods in between 10^{-3}-10^{-2} s; however, models D and E produce ATMs for very short periods in between 10^{-4}-10^{-3} s. These ATMs observed mostly close to vertical contact of anomalous conducting block. Both 3-D and 2-D synthetic tests infer that the ATMs may be simulated in both 2-D and 3-D cases for shorter periods, whereas, long period ATMs mostly produced by regional scale 2-D structures are verified in 2-D tests results.

Conclusions

Models A, B and C though explain ATM for longer periods but are unable to explain it for shorter periods. Models D and E explain the ATM for both shorter and longer periods controlled by the relatively conducting basement rocks. Synthetic 3-D tests for models C, D and E produce ATMs for shorter periods only similar to 2-D models C, D and E. So if we restrict the lateral dimension of anomalous conductor unlike 2-D situation, the ATMs can occur only at shorter periods. The pseudo-sections of TE and TM modes apparent resistivity and phases along the profile for the models A, B, C, D and E senses the presence of anomalous conducting block surrounded with moderately conducting rocks underlain by both conductive as well resistive basement rocks. The TM-mode mainly responds to the transition from the conductive layer to the resistive basement while TE-mode is more sensitive to the anomalous block seen in both TE and TM apparent resistivity and phase pseudo-sections.

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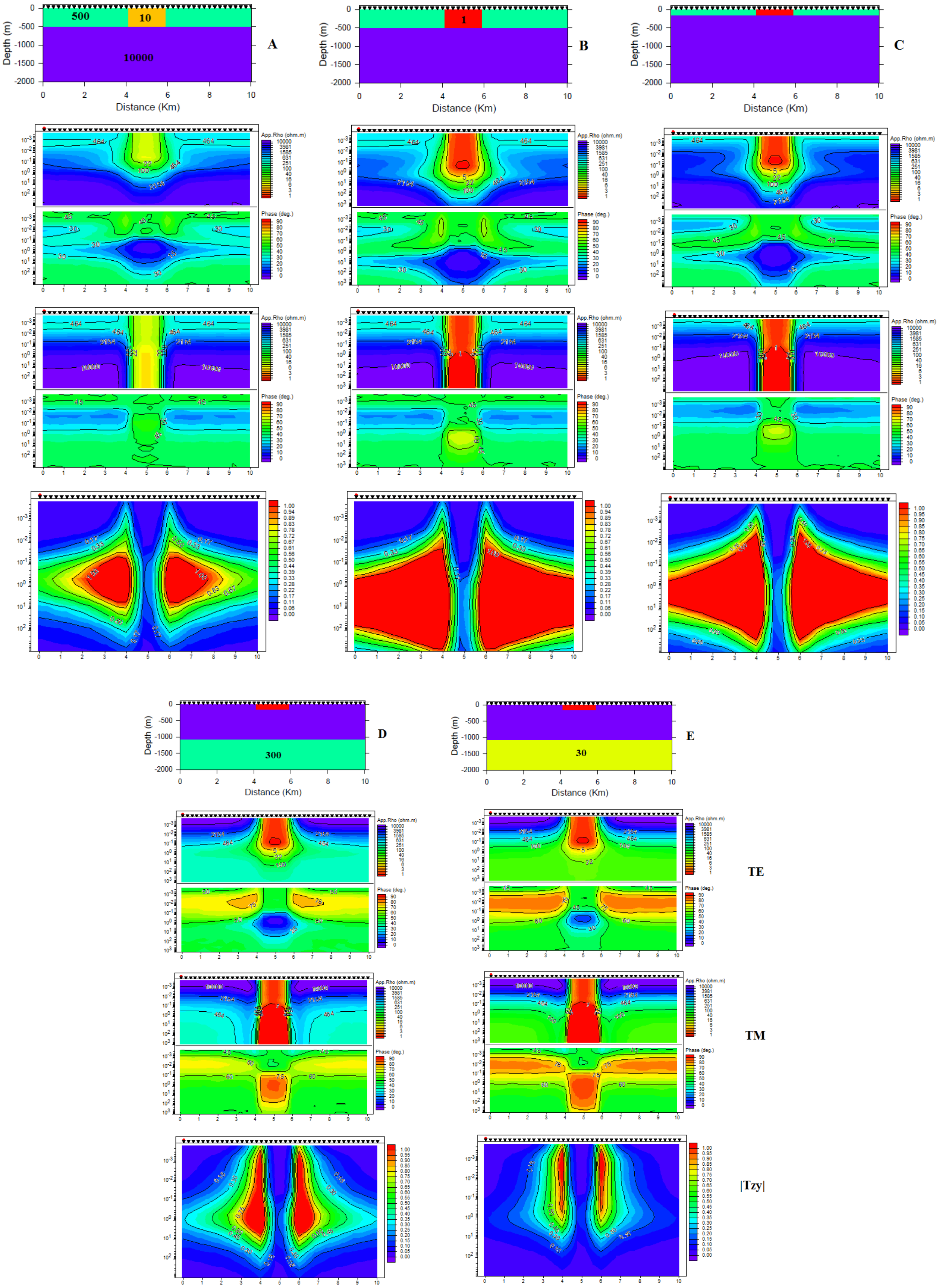
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Figure 1. *2-D synthetic tests for verifying the Anomalous tipper magnitudes (ATMs) for five different type of models (i.e., labeled as A, B, C, D and E). For each 2-D model, TE & TM apparent resistivity, phase and tipper pseudo sections were obtained to model the influence of anomalous conducting block.*

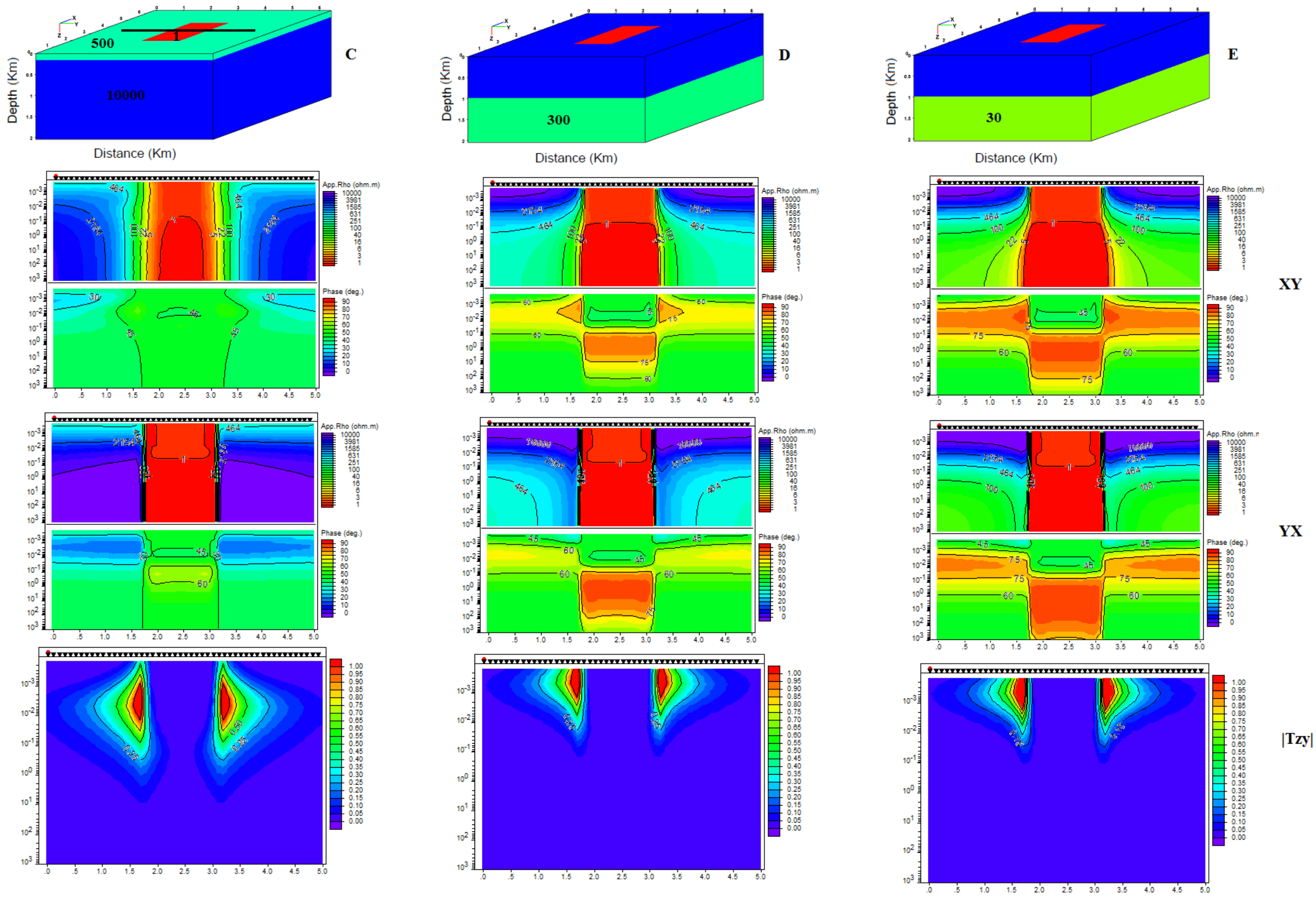

Figure 2. *3-D synthetic tests for the generation of ATMs. The length of the anomalous conducting block in X- and Y-directions are ~ 2.6 km and 4 km and all others parameters was kept same as in Figure 1 Models C, D and E (top), XY and YX components apparent resistivity and phases for above drawn 3-D models along profile XX' (middle) and Tipper magnitude pseudo sections along the same profile (bottom).*