

# The time-domain electromagnetic response of wedge-like structures

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## SUMMARY

Wedges are structures that vary in thickness from top to bottom over length. Despite their application to modelling the regolith, groundwater and bathymetric problems, wedges have not been studied in any great detail. We simulated the response of wedge-like structures using Tempest and HoisTEM-like AEM systems and a fixed-loop SIROTEM ground system.

We found that it was very difficult to distinguish between the responses of wedges with different dips until smoke rings had penetrated the conductive outcropping wedge. This means that thinner wedges are easier to see than thicker wedges. It also implies that a vertical block might be a useful approximation to thicker wedges.

Differentiation of wedge responses was best achieved using the vertical component of a fixed loop positioned off the wedge. Inline components of central-loop prospecting systems were useful as “bump detectors”.

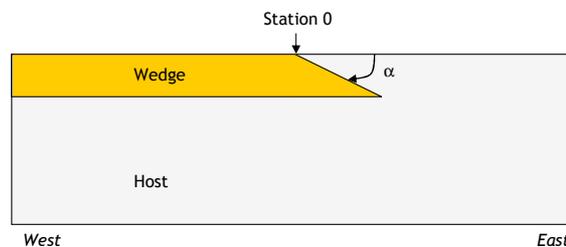
**Key words:** Wedge, airborne, ground, electromagnetic.

## INTRODUCTION

Wedge-like structures are found in regolith geology as well as in groundwater problems. Despite their ubiquity, wedges have not really been studied. Part of the reason for this lies in the computational cost of approximating a dipping structure as a ‘stair-step’. We use edge finite elements (Sugeng et al, 1993; Sugeng, 1998) to simulate wedges using small (less than 73000 node) 3D meshes thus keeping runtimes low.

Runtimes (per station per transmitter per frequency) were around 13 seconds for fixed-loop surveys and around 3 minutes for the airborne programs on 1.7 GHz PC-class machines. Typically, 28 frequencies are required for accurate time-domain results. The difference in runtimes is due to iterative solver which requires a separate solution for each transmitter location.

We define a wedge in Figure 1. Dip is defined from the east so that a 90° wedge resembles an outcropping block. With this definition, wedges with dips less than 90° are useful in groundwater applications while wedges with dips greater than 90° are useful in bathymetric applications. Wedges with dips between 135° and 45° are applicable in regolith applications.



**Figure 1. Definition of a wedge used in this abstract. The outcropping wedge is defined as a dip ( $\alpha$ ) from the East with the portion of the wedge under Station 0 fixed.**

After establishing the accuracy of the code we use to model wedges (LokiAir only), we discuss examples of wedge responses for Tempest and HoisTEM AEM systems and fixed-loop SIROTEM-like system. Moving-loop SIROTEM systems have a similar qualitative response to HoisTEM-like systems and will not be discussed here. Our study extends an earlier one by Annetts (2001) in terms of the range of wedges and the number of prospecting systems.

## CODE ACCURACY

We establish accuracy through comparison of codes over an outcropping block (90° wedge) model. Figure 2 compares vertical-component model responses for an outcropping 1  $\Omega$ -m 50 m thick block in a 100  $\Omega$ -m host. Also shown are the model's layered-earth asymptotes. The asymptote in the west is of a 2-layered earth (50 m of 1  $\Omega$ -m and a 100  $\Omega$ -m basement) while the asymptote in the east is a 100  $\Omega$ -m half-space.

In Figure 2, all responses are for a 25 Hz Tempest-like system flying with the transmitter at 100 m altitude and the vertical-component receiver trailing by 100 m and hanging 50 m below the transmitter. Solid profiles were flown from West to East while dashed profiles were flown from East to West. Comparison between all three codes is generally favourable at 0.04 ms (Figure 2A). Later in time, at 1.12 ms in Figure 2B, the integral-equation formulation breaks down although the two finite-element programs remain in good agreement.

The 2.5D program (ArjunAir) is very quick to run and is often used to check the accuracy of 3D meshes. However, because of the 2.5D assumption, it over-estimates the late-time response of small finite bodies.

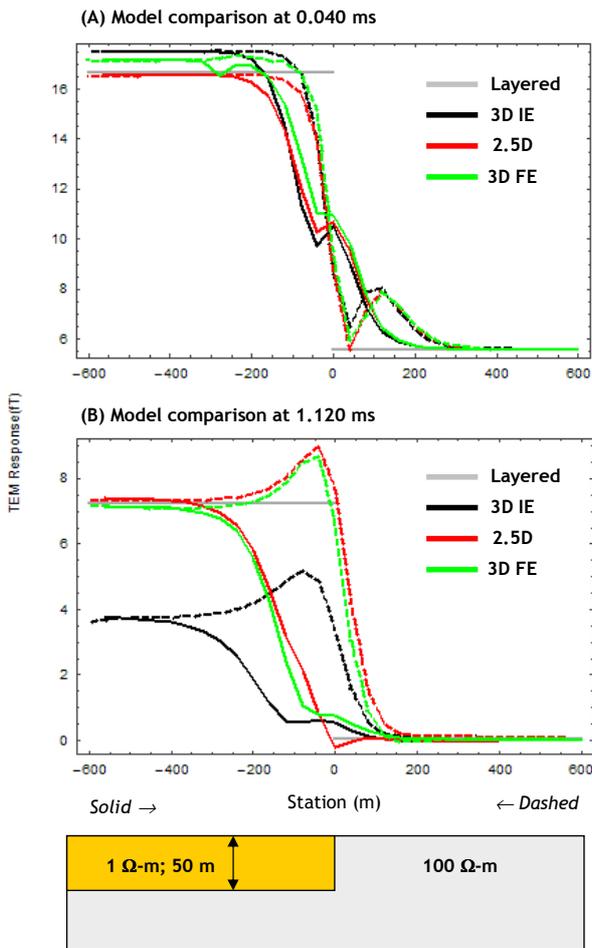


Figure 2. Comparison of data for an outcropping block. Data computed using a 3D finite element program (3D FE) are compared with data from a 3D integral equation program (3D IE) and a 2.5D finite-element program (2.5D FE). At 0.040 ms (Figure 2A), all programs are in good agreement. At 1.12 ms (Figure 2B), the two finite-element programs are in good agreement while the integral-equation program has reduced amplitude because of under-discretisation. All results in the abstract were computed using the 3D finite-element programs Loki and LokiAir.

DISCUSSION AND RESULTS

For continuity and simplicity, we confine our discussion to a model in which the dip of a 50 m thick outcropping 1 Ω-m layer is varied from 30 to 150°. The wedges had a strike length of 2 km and a surface width of 1 km. The host resistivity was 100 Ω-m. We modelled the response of Tempest and HoisTEM AEM systems and the response of a fixed-loop SIROTEM system over these models. The model and surveys are illustrated in section view in Figure 3. All data are plotted at the receiver position.

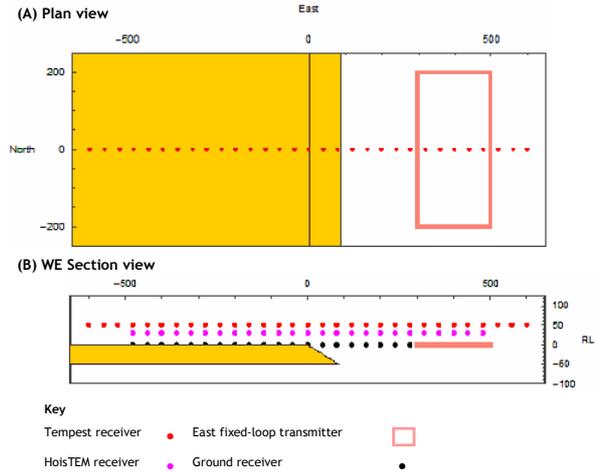


Figure 3. Survey schematics in relation to a 30° wedge. Figure 3A shows a plan view while Figure 3B shows a West-East section view. For the most part, receivers are at the same station for different surveys, only the altitude varies. The Tempest transmitter locations are not shown.

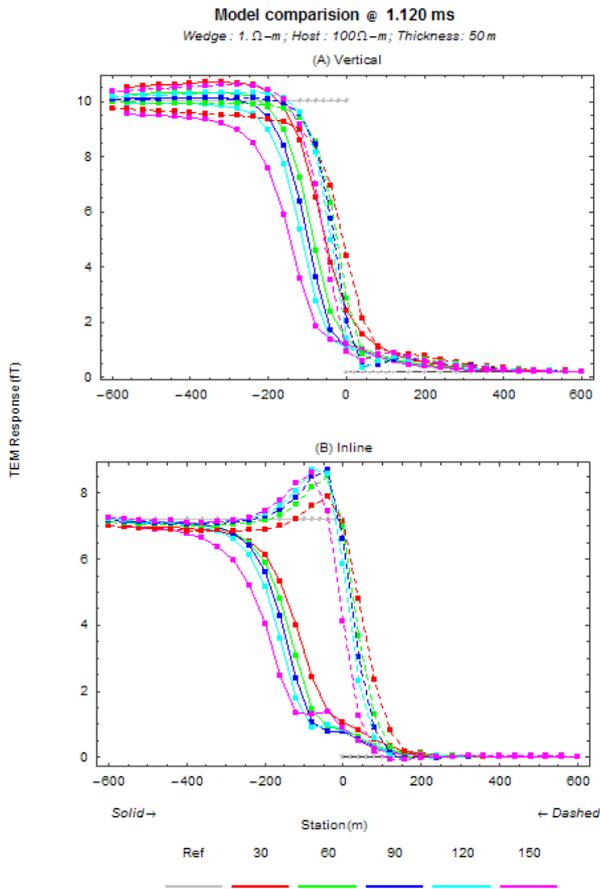
It is not usually possible to distinguish between wedges with different dips at early times because of skin depth. Until the smoke ring has passed through the conductive outcrop, the response of a wedge is very similar to that of a block. An immediate consequence of this is that thin structures at depth are difficult to differentiate. The term “early times” depends on factors such as host and outcrop resistivity. For the models described in this abstract, measurements earlier than 0.5 ms are taken to be early. In a more resistive regime, say with a host of 1000 Ω-m, 0.5 ms could be regarded as late.

In a 1 Ω-m half-space, it takes 1.57 ms for the smoke ring to reach a depth of 50 m. For this reason, we confine discussion to times less than 2 ms. Reid and Macnae (1999) show that a local source can double skin depth.

Tempest System

Figure 4 compares Tempest responses for different wedges at 1.12 ms. Wedges are difficult to distinguish when flying towards the wedge (dashed profiles). When flying away from the wedge (solid profiles), wedges with dips of 30 and 150° can easily be distinguished from other wedge models. It is especially difficult to distinguish the response of wedges with dips of 60, 90 and 120 degrees.

The dependence of response upon flight direction is due to the asymmetric prospecting system. The peaks in the inline-component response for profiles flying towards the wedge in Figure 4b are not directly related to features in the model.



**Figure 4.** Comparison of wedge responses for a Tempest system at 1.120 ms. Solid profiles were flown from left to right while dashed profiles were flown from right to left. Vertical-component data (Figure 4A) show little variation with either wedge dip or flight direction. Inline-component data (Figure 4B) are directionally dependent but otherwise, show little dependence on wedge dip.

#### HoisTEM-like System

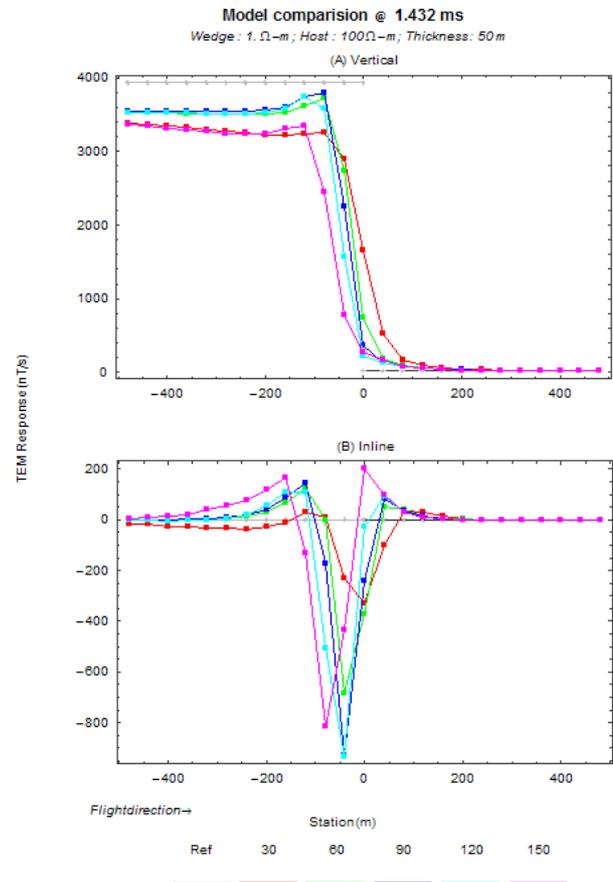
The second system to be discussed is similar to a HoisTEM (Boyd, 2000). Both transmitter and receiver heights are identical to the field system at 30 m. In contrast to the field instrument, we simulate two-component receiver allowing us to measure the inline component as well as the vertical component.

Because it is a symmetric system, the HoisTEM-like response is not directionally dependent as was the Tempest system discussed in the previous section. The vertical-component HoisTEM-like response is plotted in Figure 5A. Two groups of responses are evident and there are only subtle differences between them. Low amplitudes over the conductive portion of the wedge occur because the model is slightly under-discretised in this region. Smaller cells appear to be required in order to properly model the 30° and 150° wedges at low flight heights.

The inline-component in-loop response for a layered earth is zero so that any anomalous response is caused by the wedge.

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Figure 5B compares the inline-component response of a number of wedges at 1.432 ms. Although amplitudes are low, at best around 2.5% of the vertical-component anomalies in Figure 5A, there is good discrimination between wedges with different dips. High noise levels in field data would probably obscure differences in the responses of difference wedges.



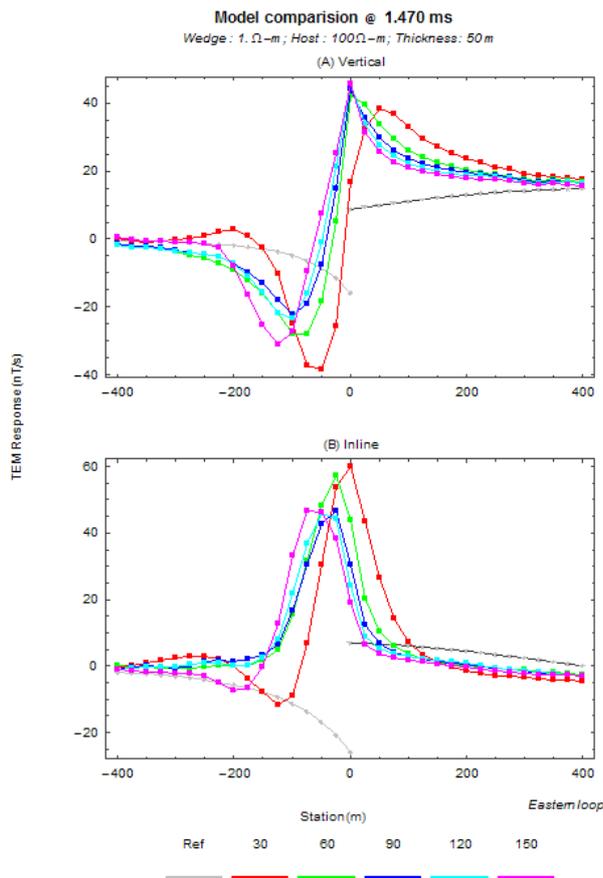
**Figure 5.** Comparison of wedge responses for a HoisTEM-like system at 1.432 ms. Vertical-component data are plotted in Figure 5A while inline-component data are plotted in Figure 5B. Inline-component data show greater variability indicating that they might be used to discriminate between wedges with different dips.

#### Fixed-loop Sirotem

The final system to be discussed is a fixed-loop SIROTEM system. The 200 x 400 m (E x N) loop is centred at Station 400, over the resistive portion of the model. We used a SIROTEM-like waveform with an off-time of 50 ms and a 50% duty cycle. Model data from this system are plotted in Figures 6A (vertical-component) and 6B (inline-component).

It can be seen from Figure 6 that it is difficult to distinguish between the response of wedges with dips of 60°, 90° and 120°. The responses of the 30° and 150° wedges are distinct for vertical-component data (Figure 6A). For inline-component data (Figure 6B), only the 30° wedge response shows any real difference from the response of other wedges.

Extended Abstracts



**Figure 6.** Comparison of wedge responses for a SIROTEM-like system at 1.120 ms. The 200 x 400 m fixed loop was centred under Station 400 over the resistive portion of the model. Vertical-component data are plotted in Figure 6A while inline-component data are plotted in Figure 6B. This configuration has the greatest chance of distinguishing between wedges with different dips.

## CONCLUSIONS

We have modelled the response of wedges with a variety of dips using common prospecting systems. We showed that the Tempest response was dependent on flight direction. For a HoisTEM-like system, we have shown that inline-component data are a useful addition to vertical-component data that are usually collected. We note that collection of inline-component

data would be a significant technical challenge for the HoisTEM system, but could easily be accomplished during ground moving-loop surveys.

Because it is difficult to discriminate between wedges with different dips at earlier times, wedges with a variety of dips may be approximated by vertical structures. For finite-element models, this is very useful since a vertical mesh can be deformed to accommodate dipping structures when new information is available without the addition of nodes.

## ACKNOWLEDGMENTS

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## REFERENCES

- Annetts, D., 2001, Analysis and interpretation of the AEM response of the regolith: Ph.D. Thesis, Macquarie University.
- Boyd, G., 2001, The Normandy heli-borne time domain EM system: 15<sup>th</sup> ASEG Conference and Exhibition, Brisbane.
- Sugeng, F., 1998, Modelling the 3D TDEM response using the 3D full-domain finite-element method based on the hexahedral edge-element technique.: *Exploration Geophysics*, 29, 612-619.
- Sugeng, F., Raiche, A. and Rijo, L., 1993, Comparing the time-domain EM response of 2D and elongated 3D conductors excited by a rectangular loop source: *Journal of Geomagnetism and Geoelectricity*, 45, 873-885.
- Reid, J.E. and Macnae, J.C., 1999, Doubling the effective skin depth with a local source: *Geophysics*, 64, 732-738.