Quantifying the effect of primary field modelling on TEMPEST data – The importance of uncertainty

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SUMMARY

The TEMEPST system is used widely for large-scale mapping. It is a fixed-wing time-domain system with the transmitter strung around the aircraft and the receiver coils towed in a bird behind and below the aircraft. The TEMPEST data are special in the sense that the data are presented as B-field, 100 % duty cycle data. In this process the system self-response is removed, which means that one needs to compute and reinstate the primary field that was removed to accurately model the measured data.

In this paper we show that it is crucial to assign uncertainty to the reinstating of the primary field because it can be several orders of magnitude larger than the secondary field especially over resistive grounds and at late times. To quantify the effect of the uncertainty we have produced a number of inversions of a line in the Capricorn survey where we have added different levels of uncertainty when reinstating the primary field. The results have all been produced with the Aarhus Workbench which uses the AarhusInv algorithm and compared with results from the GA-LEI algorithm.

We show that reinstating the primary field into the forward calculations is necessary for accurate modelling of TEMPEST responses. Though, to achieve realistic and fitting inversion models (particularly over resistive ground when less signal is measured) it is crucial to allow for a small uncertainty on the primary field when this is reinstated to the forward response. This balances the inversion and allows for misfits in the range of the assumed data noise, which is not possible for the resistive areas without the assumed noise on the primary.

Key words: Airborne time-domain inversion TEMPEST uncertainty

INTRODUCTION

The TEMEPST system is used widely for large-scale mapping. It is a fixed-wing time-domain system with the transmitter strung around the aircraft and the receiver coils towed in a bird behind and below the aircraft as described by Lane et al. (2000). With this setup high acquisition speeds are achieved making it feasible for large and remote area mapping.

The TEMPEST data undergoes a number of pre-processing steps that needs to be modelled appropriately by the inversion software to retrieve images of the subsurface that are accurate and realistic. The TEMPEST data are special within the AEM industry in the sense that the acquired dB/dt data are first deconvolved, then the system self response is removed and finally the data are convolved to B-field, 100 % duty cycle data (Lane et al., 2000). In the removal of the system self-response a certain transmitter and receiver geometry is estimated on the basis of the late-time response, this means that the primary field is uncertain to the degree that the geometry is uncertain. In particular it means that to get the measured (B-field) data one needs to compute and re-enter the primary field that was removed. Effectively, what is computed is the magnetic field that would result from a perfect step transmitter waveform, multiplied by a scaling constant.

In this paper we show that it is crucial to assign uncertainty to the primary field because it can be several orders of magnitude larger than the secondary field especially over resistive grounds and at late times. Without the noise contribution from the primary field, the noise estimates on the late time gates are so small that the inversion gets in-balanced and only tries to fit these few primary field gates at the expense of the rest of the decay-curve. The effect on the final output model is dramatic both in estimated structures and in the depth of investigation for the particular system.

METHOD AND RESULTS

Uncertainty of the system geometry is combined with uncertainty of the primary field. If the system geometry was known precisely the primary field at the towed-receiver could be calculated. For systems where the geometry is not explicitly measured, what is actually measured is a combined total (primary plus secondary) field response. The primary on the other hand cannot be calculated without the unknown ground conductivity. Hence service providers make certain assumptions to estimate the system geometry and the primary field, which differ for each system (Leggatt et al., 2000; Lane et al., 2000 and Smith, 2001).

It has been shown in a number of studies that when inverting airborne EM data it is beneficial to include the key geometry parameters (Tx altitude, Rx altitude Tx-Rx distance, Rx pitch and roll) as inversion parameters (Christiansen et al, 2010, Lane et al, 2001, Ley-Cooper and C. Brodie, 2013). When implementing this, the system geometry will be updated during the inversion process and the system self-response needs to be updated as well with the new geometry.

For TEMPEST data uncertainty has normally only been assumed on the secondary data, which are those delivered by the contractor. Here, we suggest that the model estimation is improved by also adding a small uncertainty estimate on the back-substitution of the primary field data. Without this we show that the data cannot be fitted appropriately and the inversion is unbalanced resulting in unrealistic models. The uncertainty on the primary field comes from the fact that the geometry is unknown, which means that the primary field cannot be calculated with high accuracy but is actually estimated on the basis of the measured signal and an assumed late time asymptotic behaviour of the response.

To quantify the effect of adding uncertainty to the reinstating of the primary field we have produced a number of inversions of a line in the Capricorn survey, Western Australia (Ley-Cooper et al., 2015). The results have all been produced with the Aarhus Workbench (Auken et al., 2009) which uses the AarhusInv algorithm as the inversion and forward modelling work horse (Auken et al., 2015), and compared with results from the GA-LEI algorithm which has been widely used for the inversion of TEMPEST data (Roach, 2012).
We invert for a 30 layer model and include the system geometry in the inversion as well. Lateral constraints are applied between models on both conductivities and system geometries (Auken et al. 2008, Auken et al., 2015).

Results are shown as a stack of sections from the same line in Figure 1. In the top panel no noise has been assumed on the primary, and the result is that the data cannot be fitted to a noise-normalized misfit below 1 as seen with the green line referring to the right misfit-axis. In b) we have assigned just 0.04% relative uncertainty on the primary field and we see that the data are fitted within the noise level. The model has also changed significantly for parts of section. In panel c) the assumed noise on the primary has been increased to 0.4% and we observe that we lose structure both shallow and deep due to the high uncertainty. Also, the very low data misfits suggests that the assigned noise is now too high.

Comparing the AarhusInv/Aarhus Workbench results (panel b)) to the GA-LEI results where the soundings have been inverted individually, we see the major difference mainly in the effect of the lateral constraints. The misfits for the GA-LEI inversion is not shown sounding-by-sounding, but the total is comparable to that of panel a) with Aarhus Workbench. Though, it should be noted that the actual noise models used for these two inversions are not identical.

Figure 2 displays data fits for the Aarhus Workbench inversions shown in Figure 1. We are displaying data from two individual inversions from soundings at coordinates 2500 m and 9000 m, which differ significantly in the geological model. At 2500 m the model is resistive over a conductor and at 9000 m it has a conductor over a resistor. The results show that when no primary noise is assigned the noise on the total field (secondary + primary) becomes very small especially at the late time gates. The inversion then basically only attempts to fit those last few data points at the expense of the overall fit which becomes very bad. Adding just 0.04% noise to the primary field (panel b)) both the low signal and high signal data are fitted, and with 0.4% noise (panel c)) the data are over-fitted.

Current work includes the reprocessing of results for the entire Capricorn survey, which will enables us to show the consequences and outcomes as full maps of conductivity distribution.

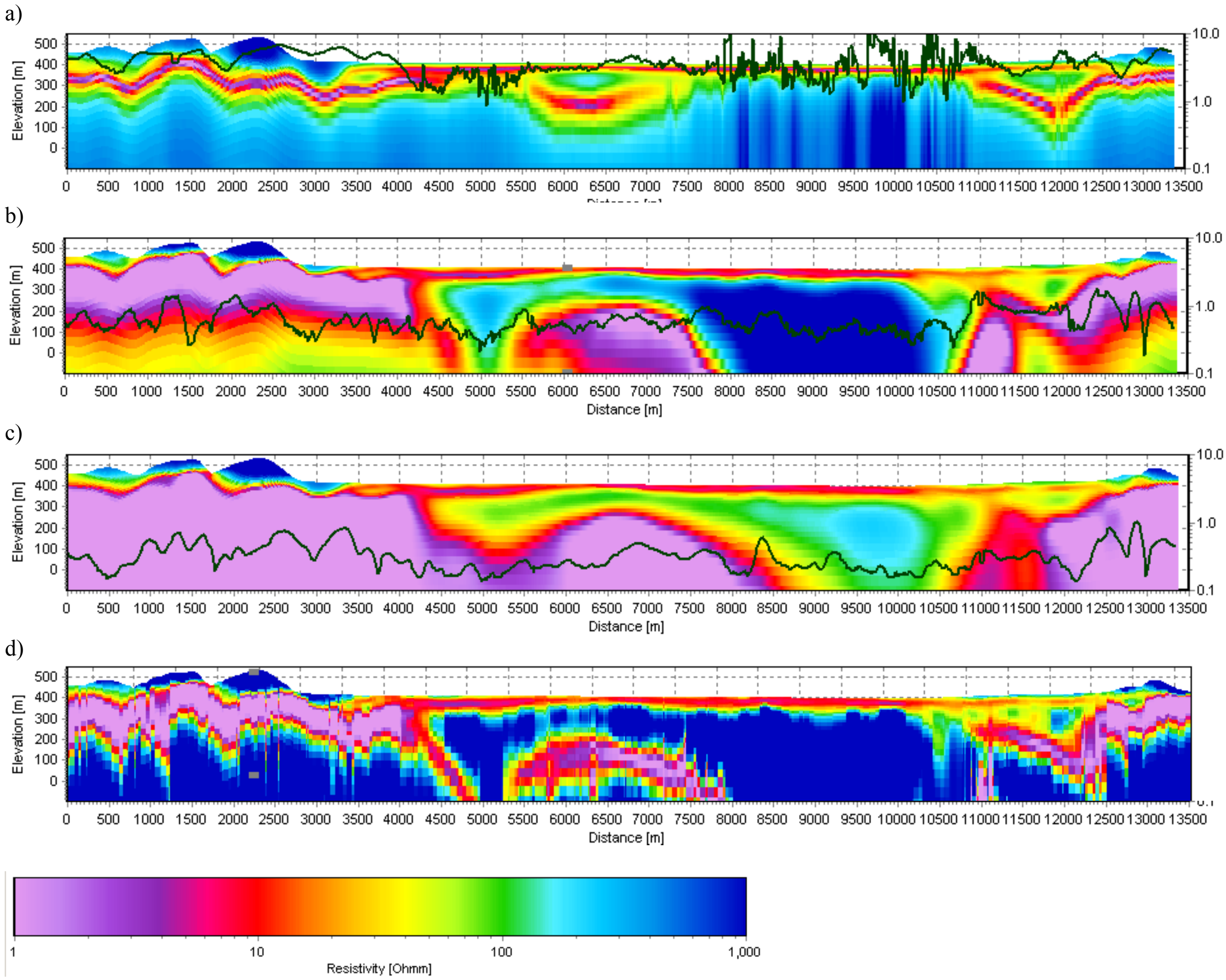

Figure 1: Comparing various TEMEPST inversions. Panel a) shows the Aarhus Workbench model resulting from an inversion without primary noise assumed, b) shows Aarhus Workbench results with 0.4 per mile noise assumed on the primary back-substitution, c) is as b) but with 4 per mile noise assumed and panel d) shows for comparison an independent inversion using Geoscience Australias SBS layer earth Inversion (GA-LEI) where no lateral constraints are enforced and presumably no noise is assumed on the primary. The black line in all panels shows the normalized data residual which should target 1.0 if the data fit in average is with the estimated data noise level.

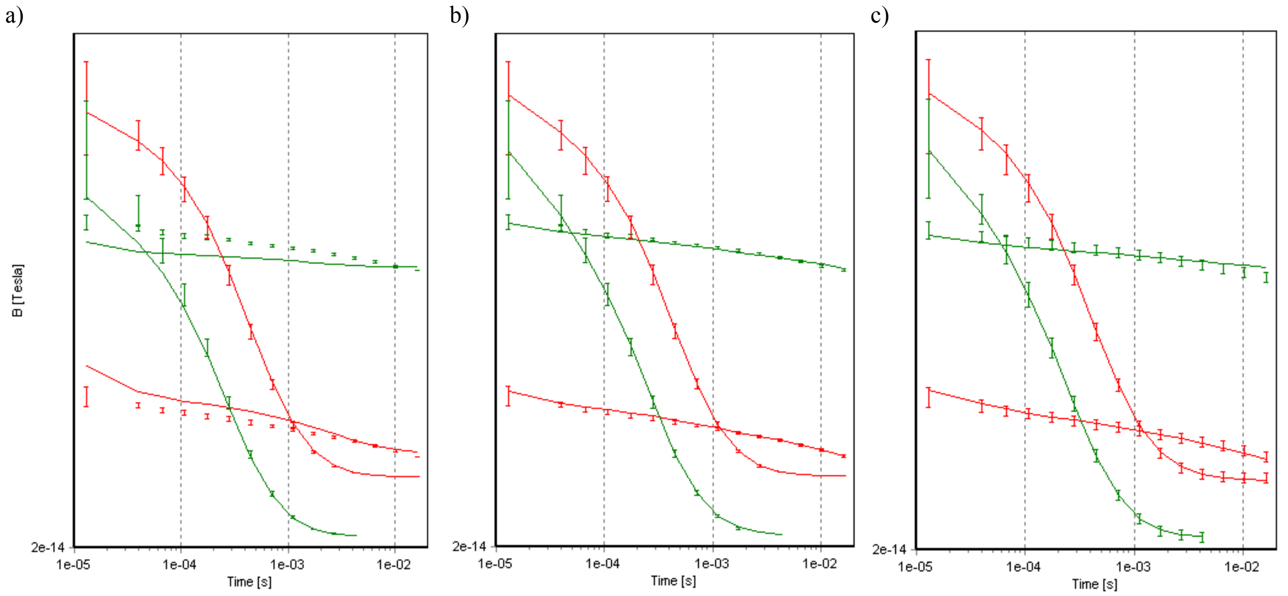

Figure 2: Comparing data misfits from three TEMEPST inversions with different primary noise levels. All panels show the x- (green) and z-channel data (red) at two locations; 2500 m (resistive top, conductive bottom) and 9000 m (conductive top, resistive bottom). Panel a) is without noise on the primary and they data are not fitted at all at early times, b) is with 0.04% relative noise on the primary and c) is with 0.4% relative noise on the primary

CONCLUSIONS

We have shown that reinstating the primary field into the forward calculations is necessary for accurate modelling of TEMPEST responses. Though, to achieve realistic and fitting inversion models (particularly over resistive ground when less signal is measured) it is crucial to allow for a small uncertainty on the primary field when this is reinstated to the forward response. This balances the inversion and allows for misfits in the range of the assumed data noise, which is not possible for the resistive areas without the assumed noise on the primary. The effects are very visible in the inverted models and we therefore argue that it is crucial to consider this in actual modelling.

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