Increased accuracy in mineral and hydrogeophysical modelling of HTEM data via detailed description of system transfer function and constrained inversion

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ABSTRACT

This paper aims at providing more insight into the parameters that need to be modelled during inversion of Helicopter TEM data for accurate modelling, both for hydrogeophysical and exploration applications. We use synthetic data to show in details the effect, both in data and in model space, of the low pass filters present in any system, and of waveform repetition. Low pass filters affect the shallow to intermediate part of the model, whereas the waveform repetition the deeper part. Results show how filters and waveform are parameters, like frame altitude, Tx-Rx timing and so on, that need to be taken into account and modelled correctly during inversion of HTEM data. We then present an application of this approach on real VTEM data from an exploration survey. The results from constrained inversion of the VTEM, compared with borehole information and with other modelling methodologies, show its validity.

Key words: AEM, filters, waveform, constrained inversion, manganese, VTEM.

INTRODUCTION

Airborne electromagnetic data are being used routinely to produce models for hydrogeophysical and exploration applications. The main factors that influence the accuracy of the resulting geoelectrical models are the quality of the raw EM data, the way the AEM system is described and modelled, and the inversion methodology. In this short paper we focus on the second and third aspect of the problem, for helicopter-borne transient systems (HTEM), using both synthetic models and real data.

METHOD AND RESULTS

Auken et al. (2008) showed some of the most important parameters that influence the system transfer function of a HTEM systems, namely altitude of the Tx-Rx, the waveform, and the Tx-Rx timing. In addition to those there are the general geometry of Tx-Rx (i.e., the attitude of the frame), the waveform repetition, the gate-integration, and the low pass filters. The length limitations of this short paper do not allow dwelling on each of these. Let us just present as example the effect of the low pass filter, and of the repetition of the current waveform. For the first exercise we will use the model in figure 1a, and for the second the one in figure 1b.

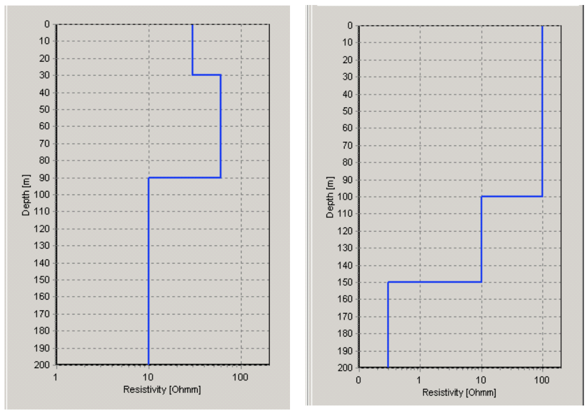

Figure 1. Model 1 and model 2 used for the synthetic examples.

In Figure 2 red curve displays the forward response corresponding to model 1 (cfr figure 1a), for a generic airborne TEM system, with central loop configuration, at an altitude of 30 m. The effect on the forward response of applying a low pass Butterworth filter of 30 KHz, second order (calculated as in Efferso et al. 1999) is clearly shown by the green curve.

The distortion of the transient reaches beyond 100 µs. Filters with higher cut off frequency, or lower orders affect only fewer (earlier) gates, as shown by the blue curve (70 KHz, first order).

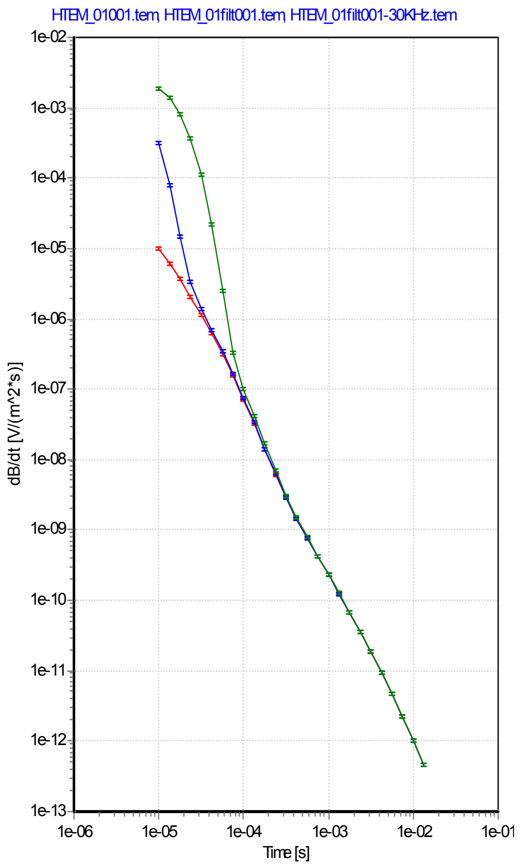

Figure 2. Effect of low pass filters on forward response of AEM system for model 1. no filter (red curve), 70 KHz first order low pass filter (blue), 30 KHz second order (green).

It is clear that even a moderate low pass filter like the first order 70 KHz has a huge effect on the early times of the forward response.

In figure 3 the red curve shows the forward response corresponding to model 2 (cfr figure 1b), when modelling only one polarity (+ 0) of the waveform, and the blue curve the forward response when modelling the full cycle (+ 0 – 0).

The close look at the late times provided in the insert shows for the late times a difference in forward responses in the order of 15 %, larger than noise level.

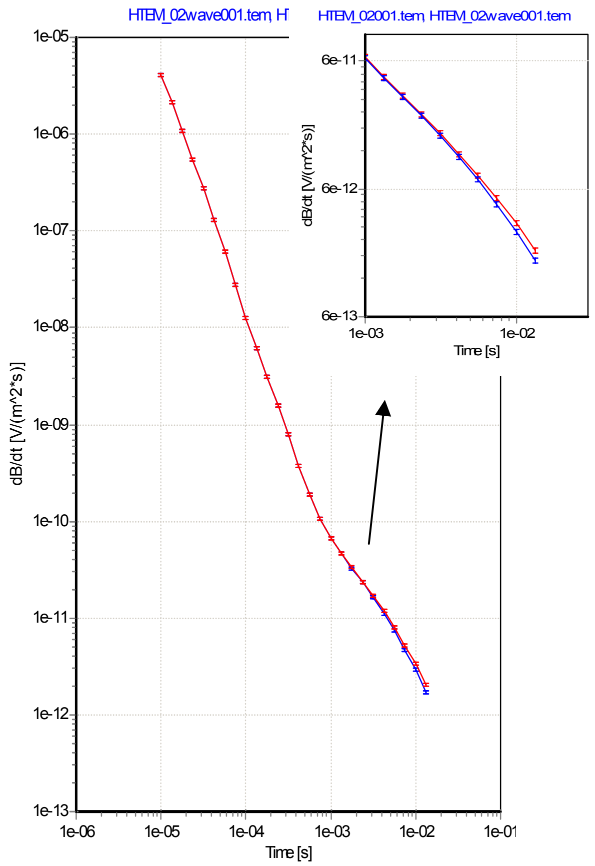

Figure 3. Effect of modelling entire full current waveform cycle (blue curve), with respect to only half cycle (red curve), with close up on the late times.

So, in general, the early to middle time gates of the transient are mostly influenced by the shape of the turn off ramp of the waveform, by the low pass filters, the bias (self response) of the system, the Tx-Rx timing, the altitude of the frame. The late time gates by the shape and repetition of the turn on ramp. Changes in current waveform amplitude, or in the gain, or in bird attitude affect the entire transient.

Auken et al. (2008) showed the importance of having accurate data from the AEM system. It is however as crucial for the recovery of the correct resistivity values and layer boundaries of the 1D model that all these effects are accounted for and modelled in the inversion, as we illustrate below. For inverting the data we use a full non linear damped least squares inversion (EM1DINV, Christiansen and Auken, 2008). In all the results presented below the data were fit well within the assumed noise level of 5%

In figure 4 we display the model recovered when inverting the blue forward response of figure 2 (which was calculated from the model 1, with a first order low pass filter of 70 KHz), describing the cut off frequency filter wrongly only by few % (for figure 4a we used 65 KHz, for figure 4b 75 KHz). The comparison with the starting model (model 1 in figure 1a) shows clearly the consequences on the shallow to intermediate part of the model. Overestimating the cut off frequency (or the order of the filter) has the worst effect on the recovered model. Notice the very thin shallow conductor often seen in models. Also the depth to the conductor at depth is overestimated.

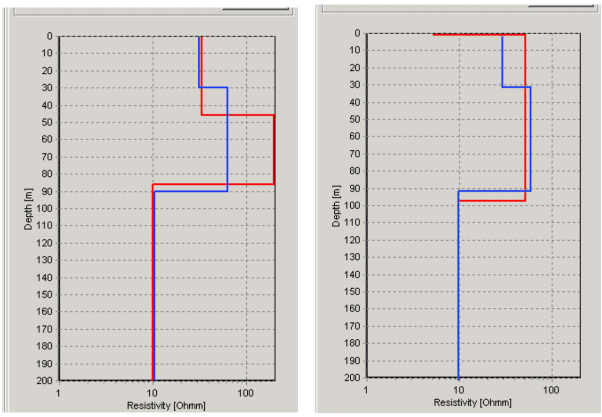

Figure 4. Models recovered (in red) using underestimated cut off frequency (left, 65 KHz) and overestimated (right, 75KHz) in the inversion. Compare with the original model, in blue.

Using for the inversion low pass filters with cut off frequency even more distant form the correct one does not allow the inversion to fit the data at all. The only way to fit the data is then to delete some of the early gates. Often AEM systems have filters of higher order than 1, and/or of lower cut of frequency. To model their low pass filters characteristics correctly while inverting is mandatory if quantitative information about shallow *and intermediate* layer resistivity and boundaries are sought. Failure to do that results either in near surface artefacts, or/or impossibility to fit the data for the earlier gates, and loss of potentially valuable information near surface.

Figure 5 shows in red the model recovered from inversion of the blue forward response of figure 3 (which was calculated from the model 2, modelling the full cycle of the current waveforms) if in the inversion we model only one polarity. In blue the original model. Both the depth to the conductor and its resistivity are slightly overestimated.

When inverting real data from an AEM survey we use either the Laterally or Spatially Constrained Inversion (Auken and Christiansen, 2004, Viezzoli et al., 2008), that allow to add the Tx-Rx altitude as constrained inversion parameter. In this way the possible erroneous height input is corrected for, rather than producing artifacts like “air layers” in the model.

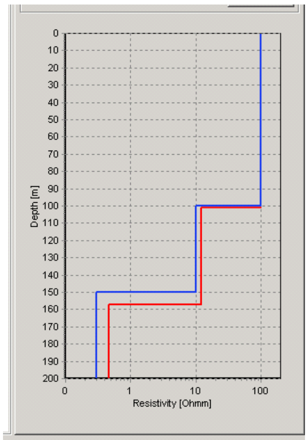

Figure 5. Model recovered using only half cycle of the current waveform (red), compared with original model (in blue).

We now present in Figure 6 an example of inversion of real data from a VTEM survey carried out modelling the system transfer function as correctly as possible (waveforms, low pass filters, altitude of the Tx-Rx as inversion parameter, etc…), and compare it to a set of EMFLOW results. The target was a Manganese deposit imbedded in clays.

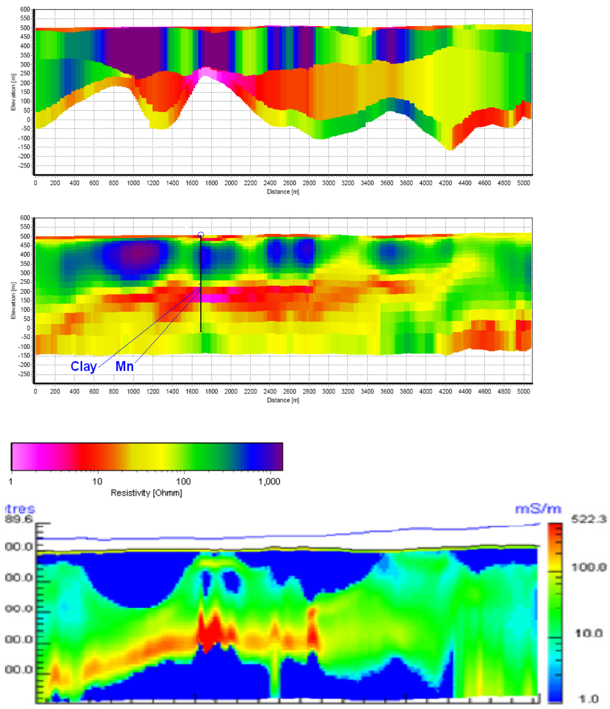

Figure 6. Results of LCI for few and multi layered models of real VTEM data, compared with EMflow results. Borehole control data shown in middle panel.

We used both a multi and few layered model. The agreement with borehole data (superimposed to the models in the middle panel) is very good. Even though it was not the main objective of the study, the shallow part of the model also provides very interesting information for hydrogeophysical modelling.

Comparison with EMFLOW results (please note the plots have different colour scale, but same vertical location) are in favour to the SCI in terms of locating the target, and also in general in terms of producing a more credible model of the subsurface at all depths. The SCI also gives an indication of the presence of another deeper conductor to the right of the known deposit.
At the conference we will present a more complete comparison with other inversion software or methodologies that had been previously applied to the same dataset.
We will also present an example from hydrogeophysical application, where proper description of system transfer function together with constrained inversion produces high quality results also near surface, similar to the case study presented in Viezzoli et al. (2009).

CONCLUSIONS

In order to perform quantitative modelling of HTEM data, both for hydrogeophysical and exploration applications, it is important to describe and model correctly the system transfer function, including all the parameters that have an influence on the forward response. This is obviously valid in general for any AEM system. For fixed wing systems with towed bird also the relative location and attitude TX and RX become relevant.

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