Accurate modeling of AEM data for oil and gas exploration in semi-layered environments

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Summary

This paper aims at providing more insight into the parameters that need to be modeled during inversion of Helicopter TEM data for accurate modeling in oil and gas exploration applications. We use 2 nominal oil and gas models and synthetic forward data to show in details the effect, both in data and in model space, of the low pass filters, which are present in any system, the waveform repetition, the gate integration, and the current turn on ramp. Results show how low pass filters, gate integration, turn on ramp and waveform repetition are parameters, like frame altitude, Tx Rx timing, ramp turn off and so on, that need to be taken into account and modeled correctly during inversion of HTEM data, in order to recover an accurate geoelectrical model. The shallow to intermediate parts of the model are heavily affected by the filters (and possible gate integration), the deeper parts by gate integration, shape of turn on ramp, and number of waveforms.

Introduction

Airborne electromagnetic (AEM) data are being used routinely to produce models for hydrogeophysical and mineral exploration applications. Even though petroleum and gas targets are not the most commonly tacked with AEM, there are more frequent examples of AEM survey being a part of the exploration process in the quest for hydrocarbons. Examples are given by Walker and Rudd (2008), Smith and Rowe (2008), and Pfaffling et al., (2009). Smith and Rowe (2008) emphasize the utility of AEM in this sector not only for exploration, but also for site evaluation, environmental mapping, groundwater investigations and oil field and pipeline constructions. The mixed results obtained from AEM applied to these targets are due to a number of reasons. Among the others, let us mention the limited depth of exploration, the non unique geoelectrical signatures of the target (especially in the shallows) that hamper survey planning and interpretation of results, the often resistive nature of the main target, the data quality and data modeling. Leaving the first problems aside, we focus only on the issues involved in the recovery of accurate geoelectrical models. The main factors that influence the accuracy of the geoelectrical models recovered from AEM data are the quality of the raw EM data, the way the AEM system is described and modeled, 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 synthetic models.

Theory and/or Method

Auken et al. (2008) showed some of the most important parameters that had to be measured accurately in a HTEM system for groundwater mapping. In this paper, rather than dealing with data quality, we focus on “modeling quality” for hydrocarbons exploration applications. We achieve this setting up a nominal airborne TEM system, and two reference models that could represent oil and gas targets. Calculating forward responses, we show in details the effect of changing the system transfer function of the nominal airborne TEM system. This is shown in data space. In particular, we assess the effect of the low pass filters, waveform repetition, current turn-on, gate integration. To conclude we invert the data, and analyze the consequences that inaccurate modeling of the system transfer function components have on the recovered model, therefore in the model space. The base-system modeled is a sling-load, central-loop system, with the transmitter towed 30 meters above the ground. The transmitter is a 500 m2 circular loop transmitting a trapezoidal waveform in a 25% duty cycle and a turn-off time of 300 µs. First gate-center time is 50 µs after begin of turn-off and the last gate is at 22 ms. In order to focus just on the modeling and inversion, we assume that there are no bias or calibration issues in the data, even though we realize this is often an optimistic assumption.

Examples

For each of the different examples we will use the two different models as presented in Figure 1. Both these conceptual models are based on 1D geoelectric profile over Canadian oil and gas on shore reservoirs, from Walker and Rudd (2008) and Smith and Rowe (2008). In model 1 we have a resistive glacial overburden on top of the Clearwater formation conductive shales, and a resistive layer a the bottom representing oil sands. In model 2 we add another layer between the shale and the oil sands, representing gas saturated unit. The exact resisitivities and thicknesses for both models can be read from figure 1. Notice the shift in the left axis that allows to focus on the relevant part of the model.

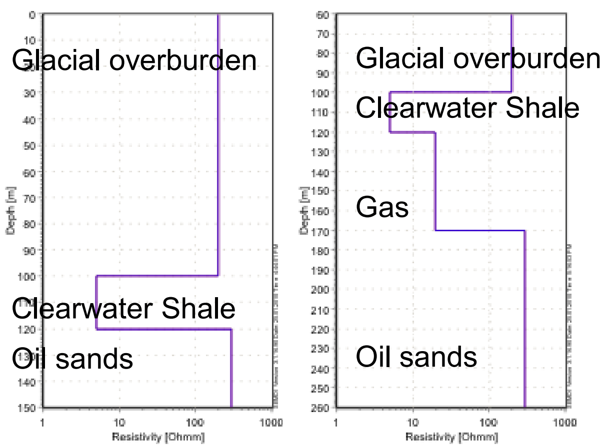

Figure 1. Synthetic models (3 and 4 layers) used for the forward modeling.

The length limitations of this paper do not allow presenting here all modeling issues mentioned above. We select the low pass filter and the gate integration. The full study will be shown at the oral presentation. The theory of the forward algorithm is given in Ward and Hohmann (2008). The algorithm implements a complete modeling of a piece-wise linear current ramp, low-pass filters, gate integration, and as inversion parameters the system altitude and for some systems the system geometry. All airborne TEM systems have a number of low-pass filters coming at least from the Rx coil and the Rx electronics. The cut-off frequency and slope of the filters vary significantly and this information is regrettably often considered proprietary information by the operating companies. The effects of three different filters (Butterworth filters, second order with varying cut off frequency) are shown in Figure 2. It is clear than even for a system with low base frequency and relatively late "early gates" like this one, the forward filters affect significantly their response. The effect of the filters will be much more severe on earlier gates, used by systems that aim at recovering near surface information. This means that an inaccurate description and modeling of the filters during inversion of these forward responses will result in inaccuracies in the parameters of the recovered model.

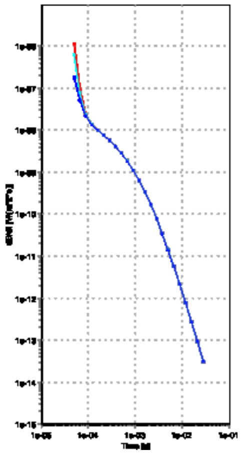

Figure 2. Forward response of nominal HTEM system for model A (see Fig. 1) with second order low pass filters of different cut off frequency (50 KHz, red, 52 KHz, cian, 500 KHz, blue)

This is clearly seen in Figure 3, where we compare the starting models (for model A and B) with those recovered inverting the forward response with erroneous filter description. Notice how the effects are model dependent.

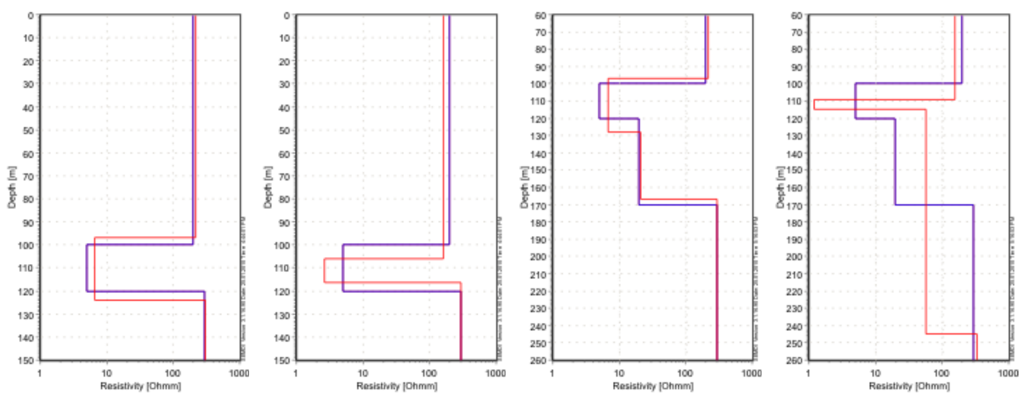

Figure 3. Example of effects in the model space of erroneous description or modeling of the low pass filters of the HTEM system. Starting models in blue, recovered models in red. 3a) Inverting a 50 KHz response with 52 KHz, for model A; 3b) inverting a 50 KHz response with 500 KHz, for model A; 3c) inverting a 50 KHz response with 52 KHz, for model B; 3d) inverting a 50 KHz response with 500 KHz, for model B.

All the parameters of the recovered models in figure 3 show various degrees of inaccurately. It is likely that a geological interpretation of the models of figure 3a, 3b and 3c would still render the correct picture for oil and gas exploration, even though the layer boundaries would be incorrect by as much as 10 m. On the contrary, the model recovered in figure 3a will probably produce a significantly different interpretation, with possible relevant consequences on the exploration activities.

The last example that we present in this abstract deals with the modeling of the time gates of the receiver. To get a reading from a specific time window the signal is integrated over a gate. This integration can be a simple box-car average or more sophisticated trapezoid average filters. For narrow averaging kernels the gate value is well represented by the value at the gate-center time. However, especially for late times, some systems have very wide averaging windows and in that case the gate-center time might not be a fair representation of the actual window average. On top of that, most systems give the gate-center time as the arithmetic mean of the gate-open and gate-close times. Given that the dbdt signal on a homogeneous halfspace decays proportional to t(-5/2) (at late times) the geometric mean is a much better representation of the integrated signal than the arithmetic mean. Hence, if the measured integrated signal is modeled using just a gate-center time, the geometric mean of the gate-times should be used as the time reference. Without showing the effect on the forward responses, we present directly in Figure 4 the comparison between original and recovered models when using arithmetic mean instead of geometric mean for the gate integration.

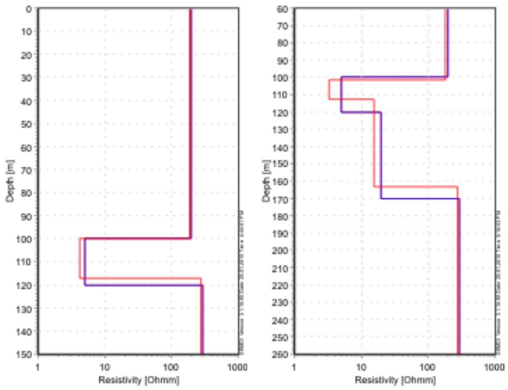

Figure 4. Example of effects in the model space of erroneous description or gate centre time. Starting models in blue, recovered models in red. Inverting using arithmetic mean instead of geometric mean for model A (4a) and model B (4b).

In this case the distortions of the models are less pronounced than before, but still noticeable, especially for the 4 layers model.

Conclusions

The two examples reported here show how different parameters of a nominal HTEM's system transfer function affect the recovered geoelectrical model of the subsurface, and therefore the geological interpretation, if not properly modeled during inversion. Hydrocarbon exploration with AEM is a difficult task, because of depth of investigation, sensitivity to targets etc… A sound modeling of the HTEM system during inversion allows achieving an accurate geoelectrical model, fundamental not only at exploration stage, but also during site evaluation, groundwater exploration, environmental mapping. Adding spatial constraints (see Viezzoli et al., 2008) and incorporating prior information during the inversion produce an even more accurate result.

References

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