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Modelling using receiver waveform and the importance of system geometry

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SUMMARY

Conductivity-depth sections (CDI) produced from a recent airborne TEM exploration survey showed a poor fit to the expected geology of the area (a known conductive layer was appearing deeper than expected). The source of the problem was found to be the use of an incomplete description of the system geometry which had the effect of dramatically scaling the secondary field. In many modelling programs, including in this case EMFlow, the system geometry may be used to determine transmitter-receiver coupling which is used to compute the apparent primary field. This paper explains why system geometry can be critical for precise modelling of TEM data. By specifying the correct transmitter orientation and de-rotating receiver pitch for both primary and secondary fields, the match between known geology and CDI depth was greatly improved.

Key words: AEM, fixed-wing, geometry, CDI

INTRODUCTION

All active-source EM modelling programs require some definition of the excitation provided by the transmitter. Some programs use the transmitter moment (transmitter current waveform, transmitter loop area and number of turns) to define the excitation. Others use the receiver waveform at high altitude which specifies the primary field strength. After calculating the transmitter-receiver coupling, the receiver waveform can be used to calculate the effective transmitter strength and the excitation into the ground. Contrast this to the transmitter current waveform method, where the excitation into the ground is explicitly defined; receiver location only controls coupling to the target.

In EMFlow (Macnae et al, 1998), one specifies the receiver reference waveform and the transmitter-receiver offset. The receiver is (quite often) defined by the user to be a vertical dipole with orthogonal components defined along the Cartesian [x y z] axes. However, the program also has the option to define the shape of the transmitter loop by specifying the locations of wire nodes in [x y z]. This then implicitly allows the nominal transmitter orientation to be assigned.

Because system geometry has not historically been monitored on fixed-wing EM systems, a nominal system geometry is assigned to the fixed-wing system. Error in this nominal geometry (or, incomplete specification during forward modelling) results in the effective transmitter strength calculated by the modelling program to be incorrect (effectively scaling the secondary field up or down). While a small bias in transmitter attitude affects coupling to the ground only slightly, therefore having a small impact on secondary response (Fitterman and Yin, 2004), the impact on the computed transmitter strength and resultant forward-model response can be quite significant.

METHOD

In this section, I calculate and present the impact of transmitter pitch and receiver offset on transmitter-receiver coupling for a fixed-wing AEM system. The GENESIS® system is used here to provide a specific example. In this sytem, each component of the measured voltage response is deconvolved to the ideal step response (Lane et al, 2000) and then normalised by the high-altitude primary field reference to obtain units of ppm. Using the high-altitude primary field, the mean high-altitude receiver offset was found to be 85 m behind and 45 m below the transmitter, which is pitched on average by about 5 degrees (a limitation defined by attachment points on the aircraft). A campaign to monitor system geometry and attitude has recently been initiated. In a recent survey, the receiver was measured to be 86m behind and 48m below the transmitter.

Using Airbeo (Raiche, 1998; 1999), the forward model response using the transmitter current waveform (explicitly defining transmitter moment) and the response computed using receiver waveform for flat and pitched transmitters is compared.

The response using the transmitter current waveform and two different transmitter pitch values (to determine the impact of transmitter-ground coupling on the secondary response) is calculated. The nominal receiver waveform with these two different transmitter pitch angles (not changing the waveform between pitches; this introduces a system coupling error effect in addition to the transmitter-ground coupling error) is used. Figure 1 compares the vertical component secondary response from a 50Ωm halfspace for the two pitch angles. The bottom panel shows the response using the transmitter current waveform resulting in a small difference of 5% due to the altered transmitter-ground coupling. The top panel, showing the response from the receiver waveform, shows that the system coupling error is significant. Use of the receiver reference waveform with the incorrect transmitter pitch had the effect of scaling the forward response by a factor of 1.45, which clearly will cause issues when imaging or inverting data.

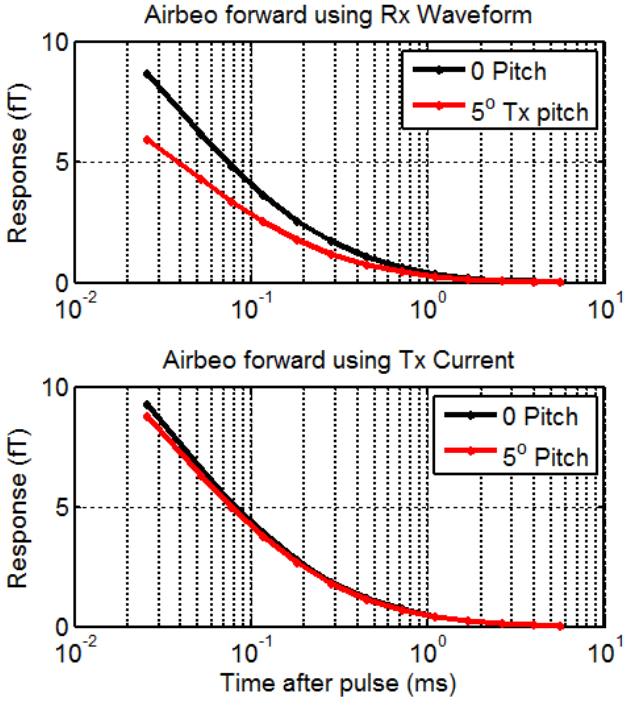

Figure 1 Modelled fixed-wing vertical component 75 Hz response to layered earth using receiver waveform (top) and transmitter current waveform (bottom) for two different transmitter pitch angles.

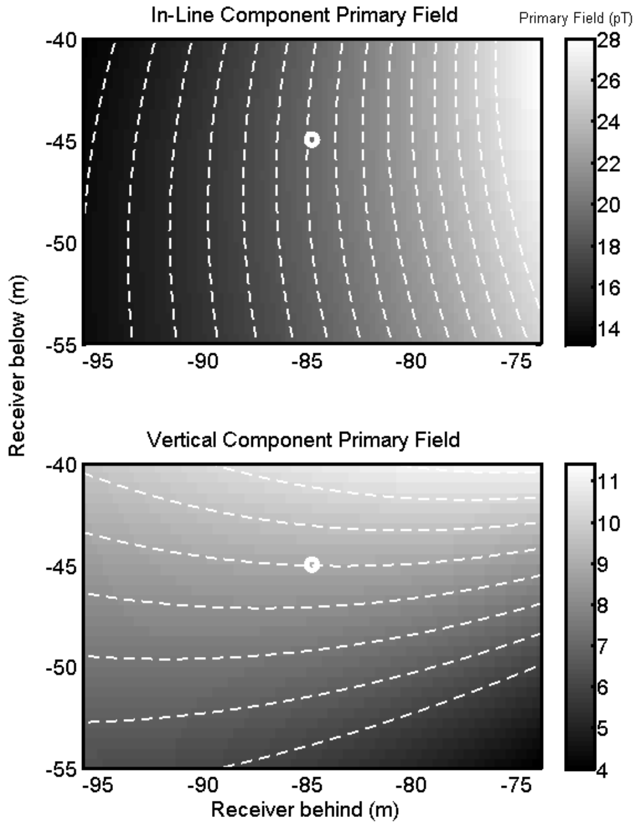

Figure 2 Primary field for a fixed-wing EM system for a range of receiver offsets with the nominal position of [85,45] indicated by the white circles. The transmitter is pitched nose-up 5 degrees. The white contour lines have spacings of 1 pT.

Relative Tx-Rx Offset

Figure 2 shows the calculated primary field for a transmitter with pitch of 5 degrees. For a transmitter moment of 160 Am^2, the in-line component primary field at the nominal position of 85m behind, 45m below is approximately 20 pT, The difference between the primary field for the nominal receiver position and the measured position of 86m behind, 48m below is about 0.5 pT, which equates to an error of about 2.5%. For the vertical component, the error is about 1.25pT; with a nominal primary field of 8 pT, the relative error is about 15% This means that if the nominal (incorrect) position is used in conjunction with receiver reference waveform to estimate transmitter power, the primary field computed bythe modelling program will be incorrect by 15% for the vertical component and 2.5% for the in-line component.

Transmitter Pitch

Often, a dipole assumption is used to specify the transmitter, because, in general, the coupling to the ground will not be greatly affected by the transmitter pitch and can thus be ignored. However, if using the receiver reference waveform, pitch is more significant. Figure 3 shows the effect of transmitter pitch on the primary field for a receiver offset 86m behind and 48m below the transmitter. The impact on vertical component primary is considerable; primary field changes to 6.6pT for a pitched transmitter from 4.7 pT for a flat transmitter, an increase of 40%. This will have a large impact when using reference waveform to model the survey data. The x-component error is also significant; Bx changes from 21.5 pT to 19.5 pT (10% decrease). The effect of transmitter pitch clearly has the potential to impact modelling of data.

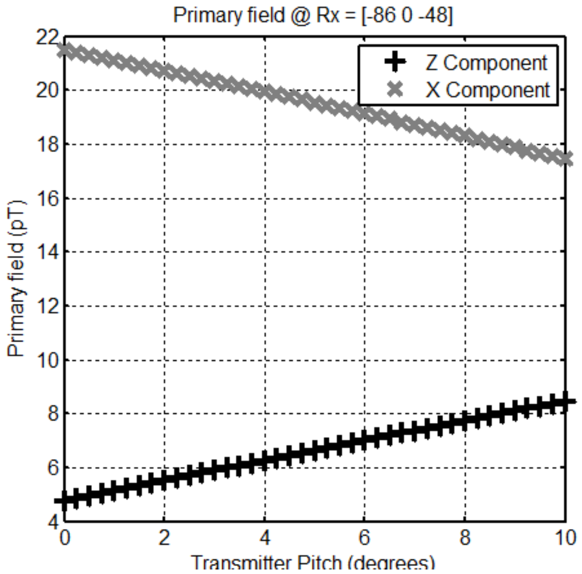

Figure 3 Primary field as a function of transmitter pitch for the measured receiver position of 86m behind and 48m below the transmitter.

Effect of Receiver Pitch

Receiver pitch is another important parameter that affects transmitter-receiver coupling. Receiver pitch is manifested in the modelling in two ways:
(1) when using receiver reference waveform, pitch affects the measured primary field at the receiver and therefore the calculated transmitter moment. If the receiver pitch is not accounted for in the modelling program, the amplitude of the receiver waveform can be adjusted to ensure the transmitter moment is correct.
(2) for either reference waveform model, it modulates the secondary field components. If the receiver pitch is not specified in the modelling program, the secondary signal must be de-rotated to the Cartesian co-ordinates.

A schematic diagram is shown in Figure 4. The magnetic field vector can be either the primary magnetic field or the secondary response from the ground (de-rotation should be applied to both). The mapping of the vector to each of the z- and x- coils is also shown. In this example, the x-coil response is very different in the pitched and non-pitched co-ordinate systems. In the test survey, average receiver pitch during the high-altitude flight and surveying was 3.5 degrees. As such, receiver pitch variation for this survey is expected to have only a small impact when modelling data.

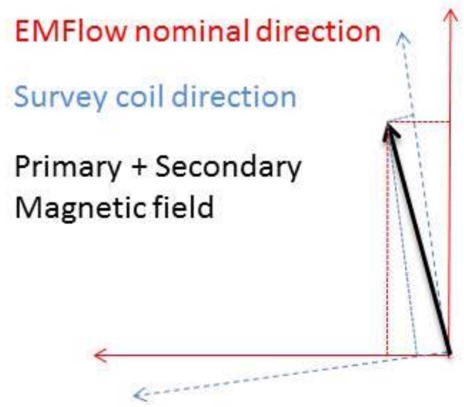

Figure 4 Schematic diagram of (exaggerated) nominal survey receiver coil orientation (blue) with Cartesian receiver coil orientation (red) in comparison to the magnetic field.

RESULTS

This section shows CDI's (generated in EMFlow using data from recent GENESIS tests surveys flown with instrumentation for monitoring relative system position and orientation) to compare the effect of the various adjustments proposed above. The first set of figures present sections using only the vertical component; Figure 5 is for the nominal configuration (flat transmitter, non-pitched receiver 85m behind and 45m below) while Figure 6 is for a transmitter pitch of 5 degrees. The corrections place the first conductive layer 20-30m shallower than the sections generated from the nominal position, which agrees much better with the known geology of the test area. In Figure 7, the transmitter pitch is 5 degrees and the secondary data have been scaled and de-rotated by the measured receiver pitch. Note that there are some locations where the earth conductivity is required above surface; this may be due to bird swing which has not been accounted for in the EMFlow processing.

CONCLUSIONS

When using the receiver waveform in modelling, the transmitter-receiver coupling determines the apparent strength of the transmitter. If the coupling specified in the program is different than that which occurs in the survey, the effect is to scale the secondary field used for modelling. In the offset configuration as used by most fixed-wing AEM systems, this scaling effect is potentially significant. In at least one survey, the scaling effect resulted in the conductive geology being modelled 20-30m deeper than expected. By specifying the correct transmitter pitch and de-rotating receiver pitch for both primary and secondary fields, the accuracy of the results (as shown by the match between known geology and CDI depth) was greatly improved.

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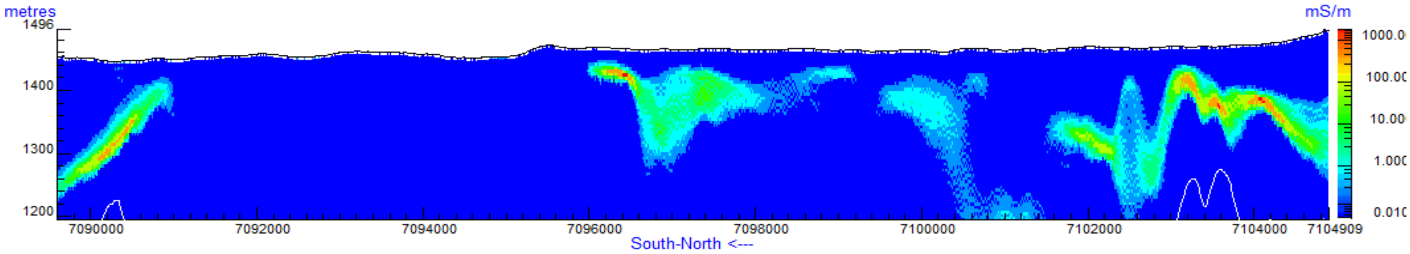

Figure 5 CDI from the vertical component of the test survey calculated using a flat transmitter.

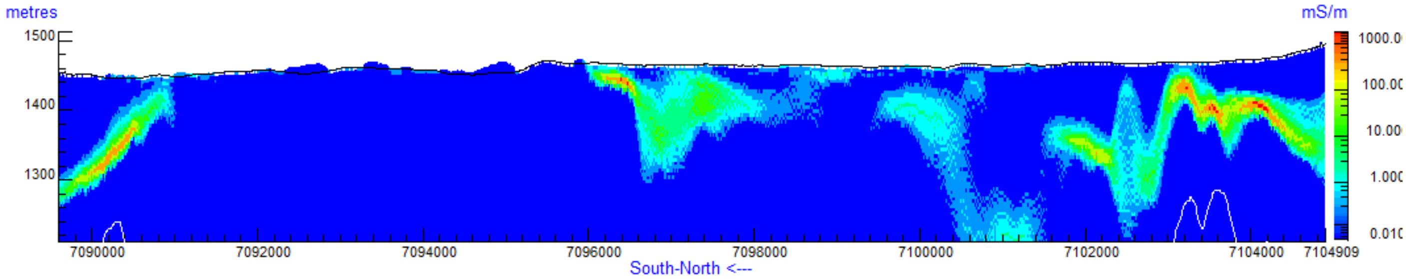

Figure 6 CDI from vertical component calculated using a transmitter pitch of 5 degrees.

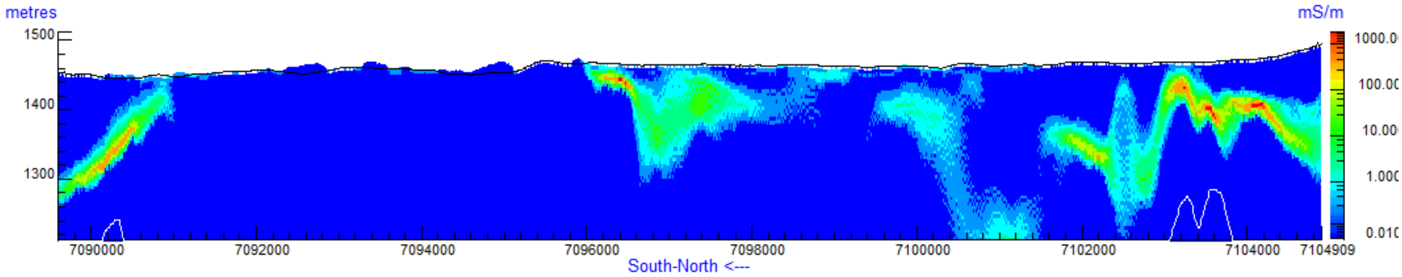

Figure 7 CDI from vertical component calculated using a transmitter pitch of 5 degrees with the addition of the de-rotation of the secondary field data for the measured receiver pitch.