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Advanced Computational Methods of Rapid and Rigorous 3-D Inversion of Airborne Electromagnetic Data

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Abstract. We develop a new computational method for modeling and inverting frequency domain airborne electromagnetic (EM) data. Our method is based on the contraction integral equation method for forward EM modeling and on inversion using the localized quasi-linear (LQL) approximation followed by the rigorous inversion, if necessary. The LQL inversion serves to provide a fast image of the target. These results are checked by a rigorous update of the domain electric field, allowing a more accurate calculation of the predicted data. If the accuracy is poorer than desired, rigorous inversion follows, using the resulting conductivity distribution and electric field from LQL as a starting model. The rigorous inversion iteratively solves the field and domain equations, converting the non-linear inversion into a series of linear inversions. We test this method on synthetic and field data. The results of the inversion are very encouraging with respect to both the speed and the accuracy of the algorithm, showing this is a useful tool for airborne EM interpretation.

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1 Introduction

Modern computational methods have become widely used in exploration geophysics. For many years, the basic model for interpretation in electromagnetic (EM) geophysics was a one-dimensional (1-D) model of a layered earth or a two-dimensional (2-D) model with the resistivity varying with the depth and along the profile of observation only.

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However, in recent years geophysicists more often use full three-dimensional (3-D) models for interpretation of practical data. This requires developing the corresponding mathematical methods of interpretation, based on the modern achievements of EM theory and advanced computational methods of modeling and inversion. To date, this has not been successfully accomplished for airborne electromagnetic data (AEM). In this paper we will demonstrate how the recent advances in 3-D numerical modeling and inversion of EM data help in developing effective methods for 3-D interpretation of AEM geophysical data.

A typical frequency domain airborne EM survey is based on the same principles as a ground inductive EM survey. In the airborne case, several transmitter and receiver coils are attached to an aircraft. There are several configurations, but typically the transmitter-receiver pairs are housed in a 'bird' towed behind the aircraft. The platform flies over the survey area towing this bird and continuously transmits an electromagnetic field with specific frequencies excited by transmitter coils. The EM field propagates into the ground and reaches some geoelectrical target such as an ore body. The electric currents induced in the ground and within the anomalous body generate a secondary electromagnetic field. The receiver coils measure the total EM field (a superposition of the primary field generated by the transmitter and the secondary EM field) at the bird's location. The goal of the survey is to find the location and electrical parameters of the underground geoelectrical formations. Note that the typical airborne EM system has several transmitter-receiver pairs. For example, typical AEM systems have transmitter-receiver pairs forming coplanar arrays, where both the transmitter and receiver coils of which can transmit/measure the vertical components of the EM field only, and coaxial arrays, with the transmitter and receiver coils transmiting/measuring the horizontal components of the EM field only.

The airborne platform creates a very powerful tool for surveying large areas rapidly and relatively inexpensively. Surveys may cover thousands of line kilometers with multi-component and multi-frequency soundings every few meters. This enables collecting a huge amount of data about the electrical properties of the earth. However, interpreting the massive amounts of data gathered poses a significant challenge. Any 3-D inversion must discretize the earth into thousands of cells representing the conductivity distribution. Computationally, this problem is exacerbated by the fact that for each sounding point and channel, a new electric field is introduced into the earth. This requires solving a large number of equations simultaneously for a full rigorous inversion.

These problems have been addressed in the past by attacking one single sounding location at a time and assuming a 1-D earth, usually with conductivity depth transforms (CDT) [6, 11, etc.] or layered earth inversions (LEI) (e.g., [2]). The CDT methods are extremely fast, but do not model the earth correctly in the sense that the theoretical EM response for one dimensional earth recovered does not necessarily fit the observed data. LEIs, while significantly slower than CDTs, produce the correct response of a 1-D layered earth. Yet they do not take into account the true three dimensional nature of the subsurface. As shown by [1], even when the predicted 1-D model response is within a few percent of the observed data, the resulting conductivity model may be a poor approxi-