

Large-Scale Electromagnetic Modeling for Multiple Inhomogeneous Domains

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Abstract. We develop a new formulation of the integral equation (IE) method for three-dimensional (3D) electromagnetic (EM) field computation in large-scale models with multiple inhomogeneous domains. This problem arises in many practical applications including modeling the EM fields within the complex geoelectrical structures in geophysical exploration. In geophysical applications, it is difficult to describe an earth structure using the horizontally layered background conductivity model, which is required for the efficient implementation of the conventional IE approach. As a result, a large domain of interest with anomalous conductivity distribution needs to be discretized, which complicates the computations. The new method allows us to consider multiple inhomogeneous domains, where the conductivity distribution is different from that of the background, and to use independent discretizations for different domains. This reduces dramatically the computational resources required for large-scale modeling. In addition, using this method, we can analyze the response of each domain separately without an inappropriate use of the superposition principle for the EM field calculations. The method was carefully tested for the modeling the marine controlled-source electromagnetic (MCSEM) fields for complex geoelectric structures with multiple inhomogeneous domains, such as a seafloor with the rough bathymetry, salt domes, and reservoirs. We have also used this technique to investigate the return induction effects from regional geoelectrical structures, e.g., seafloor bathymetry and salt domes, which can distort the EM response from the geophysical exploration target.

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1 Introduction

The integral equation (IE) method represents an effective computational technique for electromagnetic modeling. In the framework of the IE method, the conductivity distribution is divided into two parts: 1) the background conductivity, σ_b , which is used for the Green's functions calculation, and 2) the anomalous conductivity, $\Delta\sigma_a$, within the domain of integration, D . One principal advantage of the IE method over the other numerical techniques is that the IE method requires discretization of the anomalous domain D only.

It is very well known, however, that the main limitation of the IE method is that the background conductivity model must have a simple structure to allow for an efficient Green's function calculation (Weidelt, 1975; Hohmann, 1975; Wait, 1981; Wannamaker et al., 1984; Xiong, 1992; Pankratov et al., 1995; Zhdanov and Fang, 1997; Zhdanov et al., 2000; Avdeev et al., 2002; Hursán and Zhdanov, 2002). The most widely used background models in EM exploration are those formed by horizontally homogeneous layers. The theory of the Green's functions for layered one-dimensional (1D) models is very well developed and lays the foundation for efficient numerical algorithms. Any deviation from this 1D background model must be treated as an anomalous conductivity.

In many practical geological applications, however, it is difficult to describe an earth structure using the horizontally layered background conductivity model, which is required for the efficient implementation of the conventional IE approach. As a result, a large domain of interest with anomalous conductivity distribution needs to be discretized. This discretization may become too large, however, for a feasible calculation of the fields generated by the geoelectrical structures. Zhdanov et al. (2006) have recently developed a method to address this problem, the inhomogeneous background conductivity (IBC) IE method. This method is based on the separation of the effects due to excess electric current, $\mathbf{j}^{\Delta\sigma_b}$, induced in the inhomogeneous background domain, from those due to the anomalous electric current, $\mathbf{j}^{\Delta\sigma_a}$, in the location of the anomalous conductivity. As a result, we arrive at a system of integral equations which uses the same simple Green's functions for the layered model as in the original IE formulation. In order to take into account the return induction effects of the anomalous domain to the inhomogeneous background domain, the IBC IE method can be applied iteratively (Zhdanov et al., 2006; Endo et al., 2007).

We have extended this iterative IBC IE method to the modeling of multiple inhomogeneous domains. In the framework of this method, we can construct a model with any number of inhomogeneous domains and take into account the return induction effects between any pairs of the inhomogeneous domains by using the iterative method. The important point is that by using this method we can evaluate the individual response from every domain, which includes the possible EM coupling effects between the different domains. A rigorous separate calculation of the EM fields produced by different anomalous domains representing different geological structures (e.g., a salt dome and a hydrocarbon (HC) reservoir) represents an important practical problem of EM explo-