3D Minimum-structure Inversion for CSEM Problems Using Potentials and Unstructured Tetrahedral Grids

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SUMMARY

Electromagnetic (EM) methods, including profiling and sounding techniques, are used to determine the changes in the electrical conductivity of the earth with both depth and laterally. Frequency-domain EM measurements are conducted at a number of frequencies at fixed source and receiver locations, with the strength of the measured EM fields depending on the earth's conductivity.

Many methods have been used for the numerical modelling of controlled-source electromagnetic methods (CSEM) as a result of developments in computer science. In this study, the finite-element (FE) method in which differential equations are weighted, or a functional minimized whose minimum occurs at the solution to the differential equations is used. CSEM modelling can be done by using either direct E-field methods or potential methods. A potential formulation, specifically the decomposition of the electric field into vector and scalar potentials for the Helmholtz and the conservation of charge equations, namely an $\mathbf{A}$-ϕ decomposition, is used. Vector and scalar basis functions are used for the potentials. The equations are discretized using the weighted residual method, which results in a sparse linear system. The resulting linear system is solved by a sparse direct solver with LU factorization. Modelling domains are subdivided into unstructured tetrahedral grids which are suitable for real geological features such as contacts between rock units and for topography.

Inversion methods can be mainly separated into local (gradient-based) and global methods. Global methods have the ability to reach the global minimum and use less memory. These methods, however, have to call the forward-modelling operator too many times, and hence, gradient-based methods have become more attractive for higher-dimensional inversions. A minimum-structure inversion procedure based on the Gauss-Newton (GN) method which is one of the gradient-based methods is used for the inversion. The procedure aims to find the simplest and most robust model that reproduces the observed data by dividing the problem region into many fine cells. Therefore, the inversion procedure is a highly under-determined inverse problem that achieves the goal by iteratively minimizing an objective function that includes data misfit and model structure terms. Iterative preconditioned conjugate gradient (CG) and nonpreconditioned generalized minimal residual (GMRES) methods are used to solve the linear systems of equations for the model updates. These solvers do not request explicit calculations of the matrices; therefore, this significantly reduces memory demand.

The aim of this study is to develop a powerful and flexible interpretation tool for CSEM problems. The new algorithm was tested with three synthetic examples. One of the three examples was a realistic model that includes an amorphous body and topography. The EM fields (e.g., E_x and H_z) were used as data, and Gaussian random noise was added before inversions. The inversions of models were completed with a common-or-garden laptop and in reasonable time e.g., 85 hr. Both iterative solvers could reduce the residual norms down to the desired level. The recovered models were almost the same for both iterative solvers, and the buried bodies of the three examples were fully recovered.

Keywords: Inversion, Potentials, CSEM, Unstructured Grids