A parallel adaptive finite-element method for 3-D large-scale controlled-source electromagnetic forward modelling with hierarchical tetrahedral grids

Zhengguang Liu[1,2], Zhengyong Ren[1], Hongbo Yao[1], Jingtian Tang[1], Xushan Lu[2], Colin Farquharson[2]
[1] School of Geosciences and Info-Physics, Central South University
[2] Department of Earth Sciences, Memorial University of Newfoundland
Email: liuzhengguang@csu.edu.cn

SUMMARY

Three-dimensional forward modeling software that can quickly solve large-scale problems, provide precise electromagnetic responses for complicated geo-electrical models, and can be easily incorporated into inversion algorithms are required to effectively and efficiently model and interpret controlled-source electromagnetic (CSEM) data acquired in areas with the kinds of arbitrary topography and complex geological environments that are typical of real-life situations. We have developed a parallel, adaptive, finite-element approach for frequency-domain 3-D CSEM forward modeling. Our algorithm is capable of using hierarchical tetrahedral grids with an adaptive mesh refinement (AMR) technique, which yields more accurate electromagnetic responses for large-scale complex models. Our algorithm solves the total electric field vector equation. The geo-electrical model is discretized by unstructured tetrahedral grids which can deal with complex underground geological models with arbitrary surface topography. Unlike previous adaptive finite-element software working on unstructured tetrahedral grids, we implemented a novel mesh refinement technique named the longest edge bisection method to generate hierarchically refined grids. New cells obtained from the refinement method are all part of the original cells in the coarser grid. Therefore, a one-to-one mapping relationship between the newly refined cells and the original cells could be efficiently and precisely obtained such that the conductivity model represented by the refined mesh stays the same as that represented by the original mesh. This means there will be no inconsistency in the conductivity model in the inversion while transitioning from early-stage coarser meshes to late-stage refined meshes to obtain better recovered models. In addition, we employ a parallel domain-decomposition technique to accelerate the computational speed of our forward modeling algorithm. The flexible generalized minimum residual (FGMRES) iterative solver with an auxiliary-space Maxwell preconditioner is used to solve the final large-scale linear system of equations. We validate the performance of the proposed scheme using one synthetic model and one realistic model. We demonstrate that accurate electromagnetic fields can be obtained by comparison with the analytic solutions and that the code is highly scalable for large-scale problems with millions or even hundreds of millions of unknowns. For the realistic model with complex geometry, our solutions match well with the results calculated by the existing 3D CSEM forward modelling code. Both synthetic and realistic examples demonstrate that our newly developed code is an effective, efficient forward modeling engine for interpreting CSEM field data acquired in areas of complex geology and topography.

Keywords: Numerical simulation; Large-scale; Goal-oriented adaptive mesh refinement; Longest edge bisection method; Parallel iterative solver