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Geoelectromagnetic induction in a 3-D sphere: azimuthally symmetric and asymmetric test computations

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We present a new simulator based on an edge-based finite element method for computing global-scale electromagnetic induction responses in a 3-D conducting sphere excited by an external source current for a variety of frequencies. The formulation is in terms of the magnetic vector potential. The edge-element approach used in our simulator assigns the degrees of freedom to the edges rather than to the nodes of the element. This edge-element strictly satisfies the discontinuity of the normal boundary conditions without considering the enforced normal boundary conditions that are usually practiced in a node-based finite element method.

We also propose a new and efficient algorithm for mesh generation. The reason why we developed the algorithm is that little has been reported on tetrahedralization of the three-dimensional domain adopted to analyze geoscientific problems, although mesh generation is an essential pre-requisite for numerical solution. In comparison with the previous mesh generators, the algorithm presented here has an advantage that the generated tetrahedral element's shape is more appropriate for numerical analyses, especially solutions with the finite element method.

In order to verify our simulation code, we compare our results with those of other solvers for two test computations, corresponding to azimuthally symmetric and asymmetric models. We obtain results for the azimuthally symmetric test computations, which are obviously consistent with the solution obtained from the integral equation of Kuvshinov et al. [1999]. Moreover, this test computation shows the effect of the selection of edge-based elements by comparing our edge-based finite element solution with the node-based element solution of Everett and Schultz [1996]. We also compute responses for the azimuthally asymmetric thin shell model. The edge-based finite element method, the modified iterative-dissipative method of Koyama and Utada [1998] and the staggered-grid finite difference method of Uyeshima and Schultz [2000], all show good agreement on the electric field, despite occurrence of strong galvanic effects. In this test, we find out matters to be attended to construction of meshes. When we generate computational meshes, we should take the skin depth of medium into consideration and take care whether lateral refinement level, especially near the discontinuous electrical conductivity boundaries, is enough to simulate phenomena of the Earth's currents induced by external source field.

As a consequence, the two test computations verify our formulation and simulation code and derive the properties of our simulator. The simulation code presented here will serve as an alternative tool of forward modeling to simulate geoelectromagnetic induction in a 3-D sphere.