3D CSEM Forward Modelling: Testing Adaptive Mesh Refinement Approaches on an Ore Body Model

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We develop a forward modelling code to simulate 3D land-based controlled-source electromagnetic (CSEM) problems in frequency domain with unstructured tetrahedral meshes. The algorithm accounts for isotropic electrical resistivity and magnetic permeability variations in the subsurface. The latest addition to the software is a goal-oriented adaptive mesh refinement strategy driven by error estimators based on “face-jumps” of current density and magnetic flux density. In this study, we demonstrate that the goal-oriented adaptive refinement approaches are suitable to design a problem-specific mesh, which helps to solve 3D CSEM forward problems efficiently and accurately.

In mineral exploration, ore bodies often exhibit a strong resistivity contrast and sometimes a non-negligible contrast in magnetic permeability to their host rock. Accurate 3D modelling of electromagnetic measurement setups is therefore needed for feasibility studies and incorporation of the forward modelling in inversion approaches. To obtain sufficiently accurate solutions in time- and memory efficient computations, one option is to employ guided mesh refinement strategies. The so called goal-oriented adaptive mesh refinement method aims at designing a mesh, which is fine where necessary and coarse where discretisation errors do not influence the accuracy of the solution at the points of interest, typically the receiver sites. We apply the total electric field approach and first order Nédélec basis functions as interpolation functions defined on the edges of the finite elements to solve the electromagnetic diffusion equations. Thus, we achieve continuity of the electric and magnetic fields inside the elements and tangential to the edges and faces. However, the continuity of the normal components of current density and magnetic flux density across element interfaces cannot be ensured, resulting in small errors in the solution. We calculate these so called “face-jumps” and use them in combination with the elemental residuals and the dual solution of the problem to obtain error estimators that guide our adaptive refinement approach. The dual problem simulates influence sources at the receiver sites to weight the elemental error estimators with their influence to the solution accuracy at the receivers.

We utilise a model of an iron ore body in central Sweden with a known magnetic permeability contrast and unknown electrical resistivity to study the behaviour of our implemented adaptive mesh refinement approaches. This is combined with a feasibility study to investigate the detectability of the ore body with CSEM.

From literature examples on magnetotelluric forward modelling we know, that the error estimator based on the continuity of the normal current density shows robust performance, when modelling
for electrical resistivity. We observe the same behaviour after adapting it to the controlled-source problem. The error estimator using the continuity of the magnetic flux density seems mathematically most promising to improve the mesh, when variations in magnetic permeability are significant. Numerical experiments with the ore body model indicate, that best results can be achieved, when mesh refinement guided by both error estimators is applied.

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