Hyper-Reduction Techniques for Efficient Probabilistic Inversions of 3D Magnetotelluric Data

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Abstract

Magnetotelluric (MT) data provides a critical source of information for understanding the physical state of the crust and lithospheric mantle, including the detection of hydrogen and fluid/melt pathways. The electrical conductivity of rocks, which is highly sensitive to hydrogen content, temperature, mineralogy, and fluid/melt contents, underpins this capability. However, the computational demands of solving the forward problem in three-dimensional (3D) MT data have historically impeded the feasibility of probabilistic inversions based on extensive Markov chain Monte Carlo (MCMC) simulations, thus limiting robust uncertainty quantification of the subsurface images derived from MT.

Recent advancements have demonstrated that Reduced-Order Models (ROM) can significantly cut down the computational time required for solving the 3D MT problem, thereby enabling fully probabilistic inversions. Nevertheless, the complexity of the MT problem can diminish the advantages of ROM due to the substantial computational cost of constructing the discrete operators. Hyper-reduction techniques, traditionally used for nonlinear problems, will be tested for the fast construction of discrete operators during a Bayesian inversion. The integration of ROM and hyper-reduction techniques presents a promising avenue for overcoming current limitations in the probabilistic inversion of high-resolution 3D MT datasets, facilitating joint inversions of MT with other datasets, and establishing new industry standards for exploring critical minerals and deep geothermal systems.

The primary objective of this project is to propose and evaluate novel hyper-reduction techniques within the context of 3D MT, and to develop hybrid hyper-reduction+ROM methodologies that meet the efficiency and accuracy demands of Bayesian inversion schemes driven by MCMC simulations.

Keywords: Model Order Reduction, Hyper-reduction, Magnetotellurics, Bayesian Inversion Techniques.