2D magnetotelluric probabilistic inversion using the transdimensional Hamiltonian Monte Carlo method

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SUMMARY

The magnetotelluric (MT) inversion is well-known to be ill-posed and nonlinear, making its solution prone to be non-unique and dependent upon the choice of the initial model. Therefore, accurate uncertainty estimation is critical for reliable interpretation and quantitative resolution analysis of the inverted model parameters. To rigorously quantify uncertainties associated with the derived model parameters, the MT inversion problem can be formulated within a Bayesian inference framework. This approach approximates the posterior probability distributions of model parameters using a large ensemble of model samples. However, with the increase of the number of model parameters, a significant number of samples is required for accurate uncertainty estimation due to the curse of dimensionality. This makes the widely-used Markov chain Monte Carlo (MCMC) computationally expensive and impractical for 2D or 3D MT inversions.

In this study, we have developed a transdimensional Hamiltonian Monte Carlo (HMC) algorithm for 2D MT probabilistic inversion. The approach combines the merits of both transdimensional MCMC and fixed-dimensional HMC methods. The transdimensional MCMC employs a flexible parameterization where the electrical resistivity model is partitioned by a variable number of Voronoi cells. Consequently, the level of model complexity will be automatically determined and adapted to the spatial resolution of the observed data. In contrast, the HMC method can efficiently explore the model space and produce samples with much high acceptance probabilities by making use of gradient information of the posterior distribution under a fixed model parameterization. Numerical experiments with synthetic and field data demonstrate that the developed transdimensional HMC approach achieves fast convergence to the posterior probability distributions within a moderate number of iterations, indicating superior performance compared to conventional transdimensional MCMC.

Keywords: Magnetotellurics, Uncertainty quantification, Probabilistic inversion, Transdimensional Bayesian inversion, Hamiltonian Monte Carlo.