Efficient multi-scale imaging of subsurface resistivity with uncertainty quantification using ensemble Kalman inversion

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Electrical resistivity tomography (ERT) is widely used to image the Earth's subsurface and has proven to be an extremely useful tool in application to hydrological problems. Conventional smoothness-constrained inversion of ERT data is efficient and robust, and consequently very popular. However, it does not resolve well sharp interfaces of a resistivity field and tends to reduce and smooth resistivity variations. These issues can be problematic in a range of hydrological or near-surface studies, e.g. mapping regolith-bedrock interfaces. While fully Bayesian approaches, such as those employing Markov chain Monte Carlo sampling, can address the above issues, their very high computation cost makes them impractical for many applications. Ensemble Kalman Inversion (EKI) offers a computationally efficient alternative by approximating the Bayesian posterior distribution in a derivative-free manner, which means only a relatively small number of 'black-box' model runs are required. Although common limitations for ensemble Kalman filter-type methods apply to EKI, it is both efficient and generally captures uncertainty patterns correctly. We propose the use of a new EKI-based framework for ERT which estimates a resistivity model and its uncertainty at a modest computational cost. Our EKI framework uses a level-set parameterization of the unknown resistivity to allow efficient estimation of discontinuous resistivity fields. Instead of estimating level-set parameters directly, we introduce a second step to characterize the spatial variability of the resistivity field and infer length scale hyper-parameters directly. We demonstrate these features by applying the method to a series of synthetic and field examples. We also benchmark our results by comparing them to those obtained from standard smoothness-constrained inversion. Resultant resistivity images from EKI successfully capture arbitrarily shaped interfaces between resistivity zones and the inverted resistivities are close to the true values in synthetic cases. We highlight its readiness and applicability to similar problems in geophysics.