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Bayesian inversion of loop-loop electromagnetic data using an Ensemble Kalman method

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Frequency-domain electromagnetic (FDEM) induction measurements are affected by subsurface electrical conductivity (EC) and magnetic susceptibility (MS). For strongly magnetic and resistive environments, a reliable inversion result for EC can only be realized by involving both quantities in the inversion procedure. A Bayesian approach addressing the problem above has, to our knowledge, not been published yet.
We present a Bayesian approach using an Ensemble Kalman method to solve the outlined inverse problem. The algorithm is developed in view of advancing the processing of data from fixed-boom small-loop FDEM devices including multiple coil configurations. The relation between the subsurface EC and MS and the measured magnetic field is described through a one-dimensional, non-linear forward model, following Maxwell's equations. As a starting point, an initial guess of a multi-layer EC and MS profile is required. However, this input does not constrain the number of subsurface layers in advance. Incorporating uncertainties to the initial EC and MS values, a Gaussian probability density function (PDF) is defined. A prior ensemble is then generated by sampling the PDF. Subsequently, the FDEM measurement, the prior ensemble and the forward response for the prior ensemble are combined in the Kalman formula. The Kalman update is the inversion result: an ensemble of EC and MS values of which the mean and standard deviation correspond to the 'best fit' to the measurement data and the associated uncertainty, respectively.
The algorithm first was tested for a one-dimensional, synthetic profile of EC and MS, showing that the systematic underestimation of conductivity in strongly magnetic and resistive environments can be overcome when considering changes in EC as well as in MS in the inversion. Afterwards, the procedure was tested on a field dataset, in an area dominated by vertical EC and MS contrasts. The absence of strong lateral heterogeneity enables covering the entire dataset with a single prior model. A representative transect covering a broad range of measurement responses was inverted. The result shows the ability of the approach to invert all point measurements using a constant prior. We conclude that the presented inversion method is a computationally efficient and reliable inversion method for FDEM data. Additionally, contrary to conventional inversion approaches, the 'best fit' is complemented with a measure for its uncertainty.

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