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Novel MCMC methods for Bayesian inference of spatial parameter fields

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Geostatistical inference (or inversion) methods are commonly used to estimate the spatial distribution of heterogeneous soil properties (e.g., hydraulic conductivity) from indirect measurements (e.g., piezometric heads). One approach is to use Bayesian inversion to combine prior assumptions (prior models) with indirect measurements to predict soil parameters and their uncertainty, which can be expressed in form of a posterior parameter distribution. This approach is mathematically rigorous and elegant, but has a disadvantage. In realistic settings, analytical solutions do not exist, and numerical evaluation via Markov chain Monte Carlo (MCMC) methods can become computationally prohibitive. Especially when treating spatially distributed parameters for heterogeneous materials, constructing efficient MCMC methods is a major challenge.

Here, we present two novel MCMC methods that extend and combine existing MCMC algorithms to speed up convergence for spatial parameter fields. First, we present the *sequential pCN-MCMC*, which is a combination of the *sequential Gibbs sampler*, and the *pCN-MCMC*. This *sequential pCN-MCMC* is more efficient (faster convergence) than existing methods. It can be used for Bayesian inversion of multi-Gaussian prior models, often used in single-facies systems. Second, we present the *parallel-tempering sequential Gibbs MCMC*. This MCMC variant enables realistic inversion of multi-facies systems. By this, we mean systems with several facies in which we model the spatial position of facies (via training images and multiple point geostatistics) and the internal heterogeneity per facies (via multi-Gaussian fields). The proposed MCMC version is the first efficient method to find the posterior parameter distribution for such multi-facies systems with internal heterogeneities.

We demonstrate the applicability and efficiency of the two proposed methods on hydro-geological synthetic test problems and show that they outperform existing state of the art MCMC methods. With the two proposed MCMCs, we enable modellers to perform (1) faster Bayesian inversion of multi-Gaussian random fields for single-facies systems and (2) Bayesian inversion of more realistic fields for multi-facies systems with internal heterogeneity at affordable computational effort.