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# Inference of (geostatistical) hyperparameters with the correlated pseudo-marginal method

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We consider non-linear Bayesian inversion problems to infer the (geostatistical) hyperparameters of a random field describing (hydro)geological or geophysical properties by inversion of hydrogeological or geophysical data. This problem is of particular importance in the non-ergodic setting as no analytical upscaling relationships exist linking the data (resulting from a specific field realization) to the hyperparameters specifying the spatial distribution of the underlying random field (e.g., mean, standard deviation, and integral scales). Jointly inferring the hyperparameters and the "true" realization of the field (typically involving many thousands of unknowns) brings important computational challenges, such that in practice, simplifying model assumptions (such as homogeneity or ergodicity) are made. To prevent the errors resulting from such simplified assumptions while circumventing the burden of high-dimensional full inversions, we use a pseudo-marginal Metropolis-Hastings algorithm that treats the random field as a latent variable. In this random effect model, the intractable likelihood of observing the hyperparameters given the data is estimated by Monte Carlo averaging over realizations of the random field. To increase the efficiency of the method, low-variance approximations of the likelihood ratio are ensured by correlating the samples used in the proposed and current steps of the Markov chain and by using importance sampling. We assess the performance of this correlated pseudo-marginal method to the problem of inferring the hyperparameters of fracture aperture fields using borehole ground-penetrating radar (GPR) reflection data. We demonstrate that the correlated pseudo-marginal method bypasses the computational challenges of a very high-dimensional target space while avoiding the strong bias and too low uncertainty ranges obtained when employing simplified model assumptions. These advantages also apply when using the posterior of the hyperparameters describing the aperture field to predict its effective hydraulic transmissivity.