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Effects of petrophysical uncertainty in Bayesian hydrogeophysical inversion and model selection

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Hydrogeophysical studies rely on petrophysical relationships that link geophysical properties to hydrological proprieties and state variables of interest; these relationships are frequently assumed to be perfect (i.e., a one-to-one relation). Using first-arrival traveltime data from a synthetic crosshole ground-penetrating radar (GPR) experiment, we investigate the role of petrophysical uncertainty on porosity estimates from Markov chain Monte Carlo (MCMC) inversion and on Bayes factors (i.e., ratios of the evidences, or marginal likelihoods, of two competing models) used in Bayesian model selection. The petrophysical errors (PE) are conceptualized by a correlated zero-mean multi-Gaussian field with horizontal anisotropy with a resulting correlation coefficient of 0.8 between porosity and radar wave speed. We consider four different cases: (1) no PE are present (i.e., they are not used to generate the synthetic data) and they are not inferred in the MCMC inversion, (2) the PE are inferred for but they are not present in the data, (3) the PE are present in the data, but not inferred for and (4) the PE are present in the data and inferred for. To obtain appropriate acceptance ratios (i.e., between 35% and 45%), it is necessary to infer the PE as model parameters with a proper proposal distribution (simple Monte Carlo sampling of the petrophysical errors within Metropolis leads to very small acceptance rates). Case 4 provides consistent porosity field estimates (no bias) and the correlation coefficient between the "true" and posterior mean porosity field decreases from 0.9 for case 1 to 0.75. For case 2, we find that the variance of the posterior mean porosity field is too low and the porosity range is underestimated (i.e., some of the variance is accounted for by the inferred petrophysical uncertainty). Correspondingly, the porosity range is too wide for case 3 as it is used to account for petrophysical errors in the data. When comparing three different conceptual models of the subsurface (multi-Gaussian models), we find the largest evidence values for case 1. Nevertheless, the ranges of the Bayes factors obtained for case 1 and case 4 are similar. For case 2, the range is so small that it is difficult to determine the most appropriate conceptual model, while in case 3 the range is too large, which implies that there is a tendency to be overconfident. These results suggest not only that petrophysical uncertainty must be considered for reliable uncertainty quantification and model selection, but also that an appropriate model of the PE is needed. We will present initial results for porosity and permeability estimation for a real case study using crosshole GPR traveltime data from the South Oyster Bacterial Transport Site in Virginia (USA).