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Accounting for parameter correlation in the stochastic estimation of unsaturated zone hydrological properties from ground-penetrating radar data

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Geophysical methods such as ground-penetrating radar (GPR), when collected in a time-lapse fashion during an infiltration experiment, can provide valuable information on the hydrological properties of the unsaturated zone. In particular, the stochastic inversion of such data has been shown in a number of studies to provide a significant reduction in uncertainty regarding the van Genuchten parameters describing soil water retention characteristics. In all previous work on this topic, the van Genuchten parameters were assumed a priori to be uncorrelated in the inversion procedure. However, a wide body of evidence indicates that (i) these parameters are in reality strongly correlated, and (ii) parameter covariances can be effectively estimated using pedotransfer function databases. Here, we investigate the effect of including realistic prior knowledge regarding parameter correlation on the stochastic inversion of time-lapse GPR travel time data collected during an infiltration test. We first conduct two sensitivity investigations using the Fourier amplitude sensitivity test (FAST) methodology, one assuming that the van Genuchten model parameters are uncorrelated and the other accounting for realistic correlations based on the USDA Rosetta soil database. Unsaturated flow is simulated using the Hydrus 1D software package, whereas GPR travel time data are modeled from the resulting water content distribution using a finite-difference solution of the eikonal equation. In both cases, we observe that the GPR travel time data are most sensitive to the van Genuchten shape parameter n. More importantly, the difference between the sensitivity indices for all parameters in the two cases clearly points to the importance of accounting for parameter correlation. Next, we perform a Bayesian Markov-chain-Monte-Carlo inversion for the van Genuchten parameters from the GPR travel time data using both uncorrelated and correlated priors. The corresponding results do indeed indicate that accounting for parameter correlation allows for a significant reduction of posterior uncertainty compared to the uncorrelated case.