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Bayesian sensitivity analysis of seismic data to van Genuchten parameters in unsaturated and unconsolidated soils

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Increasing anthropogenic and climate pressures on water resources and thermal energy call for a better understanding of the transient water storage and the water fluxes within the Critical Zone (CZ). Recharge, as the main water inflow feeding groundwater (GW), is critical for the proper management of GW systems. GW recharge is defined as the water percolating from the last unsaturated horizon down to the water table and is therefore broadly inaccessible to direct observations. Recharge is spatially heterogeneous and controlled by multiple factors such as porous media properties and hydrogeological conditions. Hydrogeophysics provide valuable approaches to determining hydraulic parameters in unconsolidated and unsaturated soils. In this domain, electromagnetic and electrical methods predominate due to their obvious dependence on water content. While crucial for water-related assessments, the transition to mechanical properties emphasizes the complementary role of seismic techniques. Specifically, seismic refraction tomography and surface-wave dispersion analysis stand out in delimiting boundaries between saturated and unsaturated zones. Recent studies underscore the synergy of employing both 2D electrical and seismic methods, showcasing their collective efficacy in identifying hydrofacieses and delineating the water table. However, these techniques fall short of providing a detailed saturation profile in the unsaturated zone. Recent studies suggest to employ the Van Genuchten model, coupled with a rock physics model that incorporates capillary suction effects, to determine the mechanical properties of the soil, accounting for both depth and saturation dependencies. This method enables the analytical 1D modeling of both P- and S-wave velocities in various hydrofacieses with various water table depths (in static conditions). Then by utilizing these velocity models, it is possible to calculate synthetic P-wave travel times (P-TT) and surface-wave dispersion (SWD) from an artificial seismic setup. This constitute a forward problem from saturation versus depth models towards seismic data. In this study, we propose to do the inverse problem, e.g. estimating the VG parameters (VG) from P-TT and SWD. We use the database provided by Carsell and Parrish to compute synthetic observations in wide a priori ranges. We propose the employment of a straightforward grid search and formulate the results in a Bayesian framework. Our results indicate that both SWD and P-TT are responsive to changes in water saturation, allowing for the retrieval of the VG parameters from observed data. Moreover, our study highlights that the sensitivity of geophysical data varies with soil composition, particularly underscoring the complexities of estimating VG parameters in soils with a high sand content.