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Determining the Influence of Soil Water Content Variability on GPR Measurements with Numerical Simulations

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Soil water content in the vadose zone is a key quantity in the hydrological cycle. Atmospheric forcing and soil textural heterogeneity may lead to a high temporal and spatial variability of the soil water content. Due to the large difference between the dielectric permittivity of water and the further soil constituents soil matrix and air, soil water content can be observed using electromagnetic methods. GPR has become a widely used non-invasive method to investigate soil water content dynamics at scales ranging between a few meters and a few kilometers.
In this study, the influence of soil water content variability on the GPR wave field is investigated quantitatively. We consider a two-dimensional model of a measurement site. Transient water content dynamics are simulated by numerical solutions of Richard's equation using rainfall measurements as atmospheric forcing. The resulting water content profiles are transformed into dielectric permittivity profiles by invoking the CRIM formula. For representative states of the permittivity distributions, GPR measurements are simulated numerically by solving Maxwell's equations.
We show the effects on the GPR measurements for these states and for specific features of the water content distribution, for instance sharp infiltration fronts. In addition, we discuss the impact of the often made simplified assumption of a homogeneous permittivity distribution and the necessity to account for spatial soil water content variability in GPR evaluations.