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Characterization of conductive soils using on-ground GPR full-waveform inversion

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Ground penetrating radar (GPR) is a technique that enables a quick and effective mapping of the subsurface using the recording of electromagnetic waves. Since GPR is capable of producing high-resolution images, it is increasingly applied for a wide range of applications where the dielectric permittivity and electrical conductivity are determined. Because of the strong correlation between water content and permittivity, GPR is also used to estimate the water content of the subsoil. However, the use of conventional ray-based techniques is less straightforward for lossy soils. Estimates of the conductivity values using the far-field approximation contain relatively large errors for on-ground GPR. In contrast, full waveform inversion uses an exact forward model that is able to describe all phenomena in the subsurface in high resolution including the near-, intermediate-, far-field. Quantitative permittivity and conductivity values can be obtained from full-waveform inversion which in turn enables an improved characterization of the soil water content and the organic material, especially for soils where conduction currents play an important role, such as in silt and clay.

We developed a full-waveform inversion scheme that is based on a three-dimensional frequency domain solution of Maxwell's equations assuming a layered model of the subsurface. Using a start model of the subsurface medium properties, an effective wavelet is estimated from the data using a convolution approach. Using a sequential global and local search the medium properties and the wavelet are optimized and finally a simultaneous optimization returns the inverted medium properties.

Combined hydrogeophysical measurements were performed over a silty loam at the Selhausen test site in North Rhine-Westphalia, Germany, with significant variability in the soil water content. The ground wave present in the on-ground GPR data was inverted using the full-waveform inversion and the obtained permittivity values, converted into soil moisture content via Topp's equation, showed similar trends as the theta probe measurements. Moreover, the obtained conductivity values show similar trends as the ERT and EMI conductivities. These results indicate the high information content that can be extracted from the GPR data using full-waveform inversion which can be used to improve the characterization of conductive soils.