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Evaluating of direct ground wave (DGW) method and ground surface-waveform inversion of proximal penetrating radar for mapping shallow soil moisture in the field scale

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Precise measurement of surface soil moisture is essential in different research fields, including agriculture, surface hydrology and meteorology. We presented two different approaches for mapping the shallow soil moisture of a bare soil in the field scale, namely direct ground wave (DGW) using on-ground time-domain ground penetrating radar (GPR) and surface reflection inversion using off-ground frequency-domain GPR. The soil core samplings in different depths were performed as a reference measurements. The field experiments contain two different conditions in the weather namely dry and wet conditions. A vector network analyzer combined with a horn antenna located 1.1 m above the ground was used as the off-ground GPR and the effects of roughness was excluded by operating at the low frequencies (0.2-0.65 GHz). The off-ground inversion based on ground surface wavelet, was applied to retrieve the dielectric permittivity of the surface. On-ground pulse GPR was based on common offset (1.1 m) bistatic method using 2 pairs of 400 MHz bow-tie antenna and the dielectric permittivity of the shallow soil was retrieved using DGW. The GPR profiles were performed following thirteen transects in the field and a differential global positioning system (dGPS) was used for positioning. To convert the GPR derived dielectric permittivity to the soil moisture, the Topp petrophysical relationship was used. The root mean square error (RMSE) between the soil moisture measured by off-ground GPR for the dry condition and soil core sampling was 0.038 $cm^3.cm^{-3}$ in 30 cm depth and for the on-ground GPR was 0.013 $cm^3.cm^{-3}$ in the same depth. The results for the wet condition were 0.015 $cm^3.cm^{-3}$ and 0.011 $cm^3.cm^{-3}$ in the 10 cm depth for off-ground and on-ground respectively. These results show that 1) using on-ground GPR and DGW for retrieving the shallow soil moisture is more reliable and 2) for the dry land the off-ground GPR is not able to estimate the shallow soil moisture.