Field scale soil moisture mapping using far-field and near-field ground penetrating radar

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Introduction

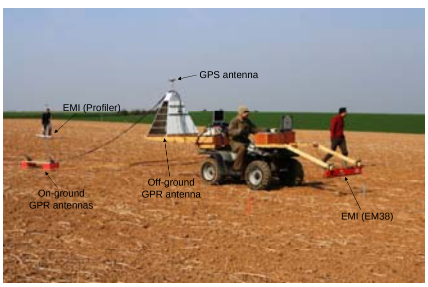
Knowledge of shallow soil water content helps to estimate the water and energy fluxes and its spatial distribution and dynamics is essential in agricultural, hydrological, meteorological, and climatological researches. Ground-penetrating radar has promising potential for field-scale soil moisture mapping with high spatial resolution. Here, we evaluated off-ground and on-ground GPR techniques in the field for different weather conditions.

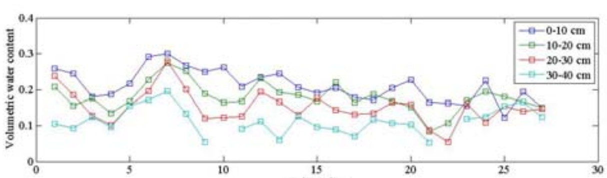
Objectives

(1) Comparing the soil moisture maps derived by off- and on-ground GPR systems for two different weather conditions.
(2) Investigation of the ability of Single Trace Analysis (STA) method for mapping the soil electrical conductivity using the amplitude of radar signal.

Materials and Methods

Field-experiments were performed on a ~5 ha agricultural field located in the Oësling hills in north part of Grand Duchy of Luxembourg with a mean altitude of 450 m. Three soil pits were dug to describe and analyze soil characteristics and soil core sampling was performed in 0-10, 10-20, 20-30, and 30-40 cm depths at 30 points entire the field. Two different GPR systems were used, namely, off-ground frequency-domain and on-ground time-domain GPR.

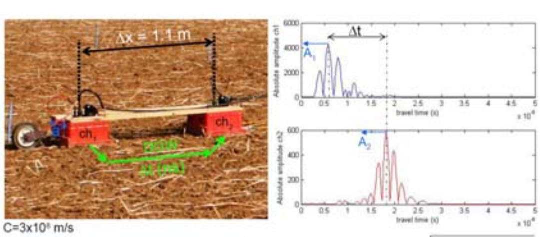




The soil moisture ground-truth for different depths.

On-ground time-domain GPR

The on-ground GPR was setup using two transmitting (Tx) and receiving (Rx) 400 MHz bow-tie antennas with Tx-Rx offsets of 0.15 and 1.1 m setting up a multi-offset system. The direct ground wave travel information was derived from the multi-offset travel time differences. The travel time information provided soil dielectric permittivity and therefore using the Topp model led to soil moisture. The amplitude of the signal for the direct ground wave provided the medium losses and therefore led to electrical conductivity using the simple equation of wave propagation losses in the media.



C=3x10⁸ m/s

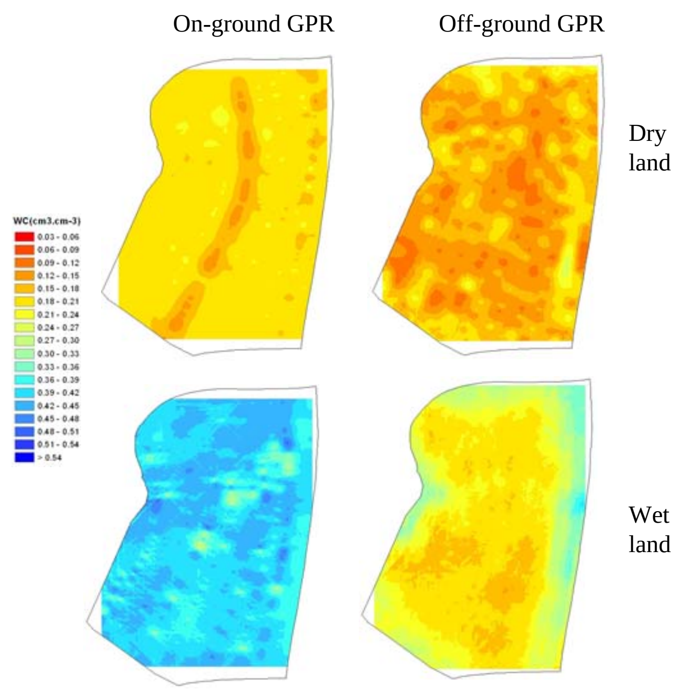
$$\varepsilon_r = (c.\frac{\Delta t}{\Delta x})^2 \qquad \alpha = \frac{-1}{\Delta x}\ln(\frac{A_2}{A_1}\sqrt{\frac{\pi}{a}\Delta x}) \quad \Rightarrow \quad \sigma = \omega\varepsilon\sqrt{(\frac{2(\frac{\alpha}{\omega})^2}{\mu\varepsilon}+1)^2-1}$$

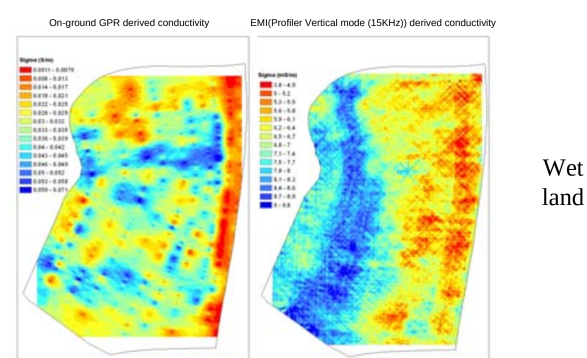
Off-ground frequency-domain GPR

We used a combination of vector network analyzer (VNA) and 200-2000 MHz TEM-horn antenna situated at 1.1 m above the ground as a far-field GPR. The GPR signal was record every 1 second and the positions were taken by dGPS. Thirteen N-S and S-N oriented transects were followed for each land condition. The off-ground GPR signal was processed using the full-waveform inversion in time domain, focusing on ground surface reflection. The soil dielectric permittivity, derived by GPR signal, was converted to the soil moisture using Topp model. Finally the water content map was obtained using the Kriging interpolation method.

Results and conclusions

Both GPR techniques provided consistent soil moisture maps, but comparison with the ground truth was complicated because of different characterization scales, depth, and the local variability of soil moisture. The soil electrical conductivity map derived by on-ground GPR showed some patterns relevant to ERT maps and EMI maps although with different depth and footprint scales.





Acknowledgment

This research was supported by the Université catholique de Louvain (UCL, Belgium), and DIGISOIL project financed by the European commission under the 7th framework program for research and technological development. We also should thank other teams working on DIGISOIL project for providing the information of the land under research.

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