Monitoring near surface soil moisture profiles during evaporation using off-ground zero-offset ground-penetrating radar

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1-Introduction

Soil evaporation is important as it controls many processes in the physics of land-surface, including the mass and energy flows between the ground and the atmosphere, and fundamental biological processes such as seed sprouting and plant growth. Resorting to the geophysical methods like ground-penetrating radar (GPR) for the detection of non-uniform and unstable infiltration and drying is vital as a continuous image of the subsurface states can be obtained by applying these techniques. We investigated the potentiality of the zero-offset, off-ground GPR data to monitor drying front of soil evaporation at the laboratory scale.

2-Coupled vapor, heat, water flow model

HEAT TRANSPORT:

$$q_h = -\lambda \nabla T + L q_v$$

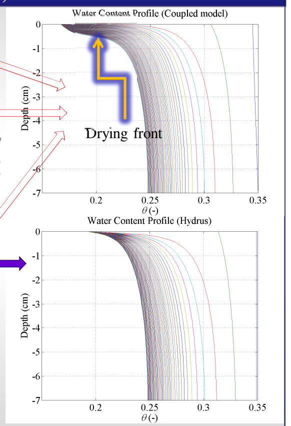
VAPOR TRANSPORT:

$$q_v^* = q_v^i + q_v^T = -D_v c_v' \frac{dh}{dz} - D_v h_s \frac{dT}{dz}$$

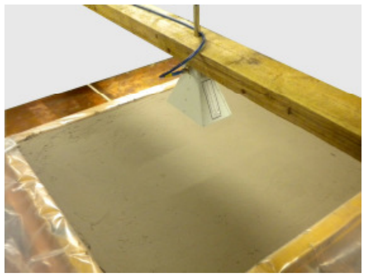
LIQUID WATER TRANSPORT:

Richards' equation:

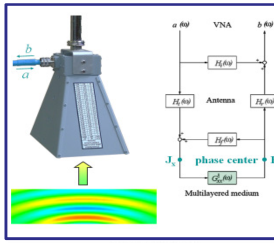
$$\frac{\partial \theta(\psi)}{\partial t} = \nabla.(K(\psi)\nabla(\psi + z))$$



3-Laboratory measurements



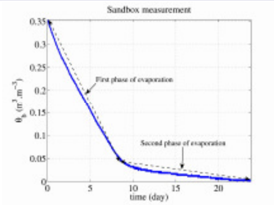
An off-ground zero-offset GPR system was mounted on a sand box filled with the very fine sand. The surface of the sand was exposed to evaporation for a period of 23 days starting from fully saturated sand. The time-lapse GPR signal, temperature and weight of the setup was measured with a constant time step to monitor the upward water flow.



off-ground zero-offset GPR

Lambot *et al.* (2004)

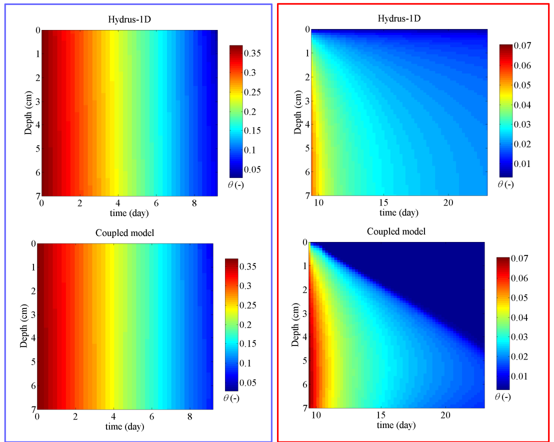
$$S_{11}(\omega) = \frac{b(\omega)}{a(\omega)} = H_i(\omega) + \frac{H_t(\omega)G_{xx}^{\uparrow}(\omega)}{1 - H_f(\omega)G_{xx}^{\uparrow}(\omega)}$$



Bulk water content variations during the evaporation phases derived form the direct measurements of the set-up weight data. The first and second phase of evaporation are clearly seen in the data.

4-Numerical simulations

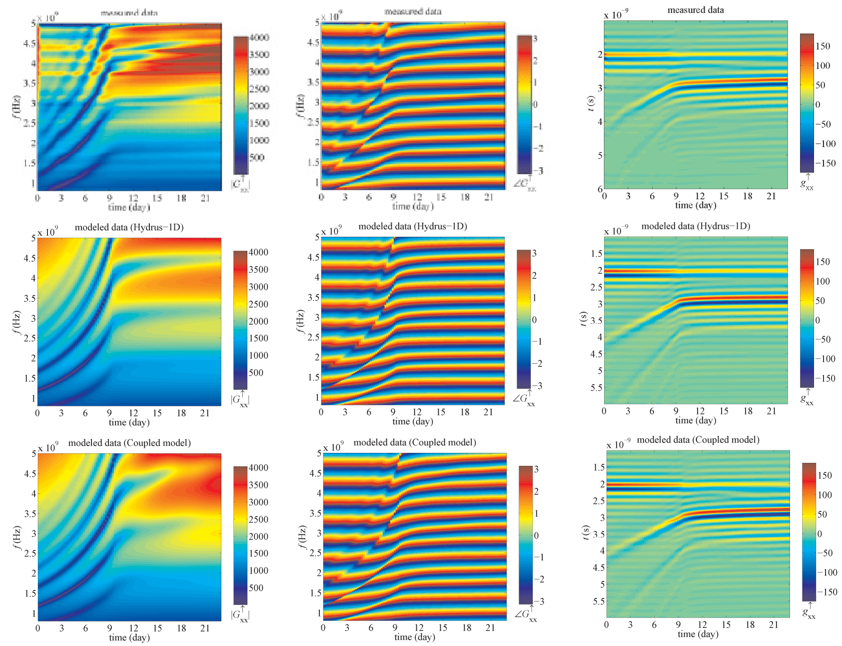
We numerically simulated evaporation of the sand box by using Hydrus-1D and coupled vapor, heat, water flow model for a period of 23 days. We considered the fine sand with 7 cm thickness and 70 layers. We calculated the evaporation rate from the laboratory experiment for Hydrus-1D simulations.



First phase of evaporation

Second phase of evaporation

5-GPR data and forward modeling



Frequency-domain and time-domain measured and modeled GPR signal for the first two phases of evaporation. The effect of drying front on the GPR signal can be clearly seen in the results obtained from the measurements and also those obtained based on the coupled model in particular for the amplitude of the Green's function in the frequency domain. We applied the Complex Refractive Index Model (CRIM) to take into account the frequency dependency of both electrical conductivity and electrical permittivity.

6-Conclusions

Since the GPR method is sensitive to the soil moisture profile close to the soil surface, interpretation of the measured GPR signals with a water flow model in the soil requires the description of vapor flow since models that consider only liquid water flow are not capable of predicting drying fronts that correspond with S-shaped soil moisture profiles. The laboratory and numerical results show that the proposed method is promising for monitoring the effect of evaporation at shallow depths.

7-Acknowledgments

We would like to acknowledge Deutsche Forschungsgemeinschaft (DFG) funded research project Multi-scale Interfaces in Unsaturated Soil (MUSIS).

8-References

Lambot, S., E. C. Slob, I. van den Bosch, B. Stockbroeckx, and M. Vanclooster (2004), *Modeling of ground penetrating radar for accurate characterization of subsurface electric properties*, IEEE Transactions on Geoscience and Remote Sensing, 42, 2555-2568.

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