Full-Range Soil Hydraulic Properties from Numerical Inversion of Transient Evaporation Experiments

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Introduction

- The assessment of the soil water balance in semi-arid regions requires an accurate quantification of bare-soil evaporation.
- Actual evaporation from dry soil cannot be predicted without detailed knowledge of the complex interplay between liquid, vapor and heat flow.
- Soil hydraulic properties (SHP) exert a strong influence on evaporation rates during stage-two evaporation because classic models of unsaturated hydraulic conductivity are often inadequate to model evaporation from bare soil.

Research Questions

- How strong is the variation in the SHP which are obtained from the inversion of different experiments conducted at the same system using the Richards equation?
- Can we predict the measured evaporation rates with a coupled model (water, vapor, heat flow and surface energy balance) driven by atmospheric boundary conditions using the SHP identified with the Richards equation?

Evaporation experiments

- We conducted laboratory evaporation experiments on large packed soil columns using different soil materials (sand, silt, loam).
- Water potential was monitored with tensiometers and relative humidity sensors. Evaporation rates were determined gravimetrically.
- Multiple experiments were performed on the same system with different atmospheric forcings (wind, radiation, radiation on/off).

Numerical Modeling

- HYDRUS-1D Code (Šimunek et al., 2008)
- Forward modeling: coupled model of water, vapor and heat flow, to examine effects on physical soil properties, surface energy balance, and atmospheric boundary conditions (Saito et al., 2009).
- Inverse modeling: isothermal Richards equation, measured evaporation rates as flux boundary condition (top), measured pressure head data in the objective function.

Fig 1: Left: Observed evaporation rates for three evaporation experiments and the corresponding cumulative evaporation. Right: Measured and fitted pressure head data. All data are shown for three different boundary conditions (top: wind, center: constant radiation, bottom: radiation on/off) applied to the same soil column. The fit obtained with the VGM cannot describe the pressure head data. The fit with the PDI model leads to a much better description of the observed data. However, pressure head data in the dry range cannot be described well for the experiment with varying radiation.

Fig 2: Comparison of the identified SHP for the three experiments under different boundary conditions. Although a simulation analysis (not shown) shows that the SHPs should be almost identical, variations become clearly evident. They are most pronounced for the experiment with wind. The most likely reason is hysteresis; it was the first experiment after packing.

Prediction with the coupled model

Fig 3: Simulation results with the coupled model with surface energy balance. Top: Experiment driven by wind, center: experiment with constant radiation, bottom: experiment with radiation turned on/off. PDI outperforms VG for wind. Surprisingly, VG outperforms PDI for radiation conditions. This contradicts the fitting results.

Conclusions

- The PDI model of the SHP which accounts for capillary, non-capillary (film and corner) and isothermal vapor flow leads to a much better description of the experimental data than the VG model.
- The inversion of different experiments conducted at the same system leads to a small variation in the estimated SHP. The stronger mismatch for the wind experiment is likely caused by hysteresis.
- The prediction of the observed data with a coupled model of water, vapor and heat flow is promising, but the outperformance of the VG parameterization contradicts the fitting results.

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