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Identifying the contribution of capillary, film and vapour flow by inverse simulation of transient evaporation experiments

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Evaporation from bare soil is an important component of the water cycle and the surface energy balance in arid and semi-arid regions. Modeling soil water movement in dry soil and predicting the evaporation fluxes to the atmosphere still face considerable challenges. Flow simulations rely on a proper conceptual model for water flow and an adequate parameterization of soil hydraulic properties. While the inclusion of vapor flow into variably-saturated flow models has become more widespread recently, the parametrization of the unsaturated hydraulic conductivity function in dry soil is often still based on sparse literature data from the past which do not extend into the dry range. Another shortcoming is that standard models of hydraulic conductivity do not account for water flow in incompletely-filled pores, i.e. film and corner flow. The objective of this study was to identify soil hydraulic properties by inverse modeling, with a particular focus on the medium to dry moisture range. We conducted evaporation experiments on large soil columns under laboratory conditions and used an extended instrumentation, consisting of minitensiometers and relative humidity sensors, to measure the pressure head over a wide range from saturation to -100 MPa. Evaporation rate and column-averaged water content were measured gravimetrically. The resulting data were evaluated by inverse modeling using the isothermal Richards equation as process model. Our results clearly demonstrate that classic models of soil hydraulic conductivity which are based on the assumption that water flows exclusively in water-filled capillaries, cannot describe the observed time series of pressure head and relative humidity. An adequate description of the observations was only possible by accounting for isothermal vapor flow and an additional flow of liquid water. The physical cause of the latter could be film and corner flow as proposed before based on a theoretical analysis of water flow in angular porous media.