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Pore scale model for evaporation dynamics from soil surfaces with patchy wetness

E. Shahraeeni (1,2), P. Lehmann (1), and D. Or (1)

(1) ETH Zurich, Soil and Terrestrial Environmental Physics, Zurich, Switzerland (peter.lehmann@env.ethz.ch), (2) Reservoir Engineering Research Institute (RERI), Palo Alto, California, USA

The gradual reduction in drying rates from soil surfaces under high atmospheric demand is often attributed to constraints imposed by internal transport mechanisms limiting capillary flows from soil interior towards vaporization plane at the surface. Experimental evidence for high evaporation rates under non-limiting capillary flow conditions suggests that interactions between pore-scale diffusive fluxes from gradually drying porous surfaces and diffusive resistance across air boundary layer thickness, play a crucial role in shaping evaporation dynamics. Results from evaporation experiments using sand columns subjected to potential drying rates ranging from 2 to 30 mm/day (defined by prescribed air velocities) show that for high evaporative demands (>5 mm/day), evaporation rates decreased gradually until a transition to diffusion-controlled stage-II evaporation. In contrast, under low air velocities, a constant drying rate was established and maintained irrespective of drying of the surface or receding drying front. A pore scale model for surface coupling shows evolution of vapor density field from 1-D stratified pattern for the uniformly wet surface to 3-D vapor shells forming over active pores as the surface dries. Calculations show that per-pore vapor diffusion flux increases with increased pore spacing, reduced pore size, and boundary layer thickness. Consequently, for low evaporative demand and thick boundary layer, the resulting flux from isolated pores may fully compensate for reduced surface water content (evaporating area) resulting in constant evaporation rates. These results also suggest that flux compensation for patchy wetness is likely to be less efficient than for spatially (uniformly) distributed pores and thus results in reduced evaporation rates even for low atmospheric demand. The study will address the additional key parameter of wetness patch size and the patchiness spatial structure in relation to boundary layer thickness and impact on evaporation dynamics from heterogeneous surfaces.