Shallow subsurface soil moisture behavior as affected by heat source boundary conditions: Experimental and modeling investigation

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Abstract. In the shallow subsurface below the land-atmosphere interface, it is widely recognized that the movement of water vapor is closely coupled to thermal processes. However, their mutual interactions are rarely considered in most soil water modeling efforts or in practical applications where it becomes necessary to predict the spatial and temporal distribution of soil moisture. The validation of numerical models that are designed to capture these processes is difficult due to the inherent complexities of the problem and the scarcity of laboratory data with accurately known hydraulic and thermal parameters, thus limiting the testing and refinement of heat and water transfer theories. In addition, it is often assumed in traditional soil physics applications that water vapor concentration in the air adjacent to the water phase in soil is always in equilibrium which can result in under prediction of water content or over prediction of evaporation from soil. The goal is to perform controlled experiments under transient conditions using soils with accurately known hydraulic/thermal properties and use this data to develop and validate numerical formulations/codes. In this work, water vapor flow under varying temperature gradients was formulated and implemented based on a concept that allows non-equilibrium liquid/gas phase change with gas phase vapor diffusion. In order to validate this new approach, we developed a long column apparatus equipped with a network of recent sensor technologies and generated data under well-controlled thermal boundary conditions. Water saturation, capillary pressure, temperature, relative humidity and column weight were continuously monitored. Results from numerical simulations based on the conventional equilibrium and new non-equilibrium approaches were compared with experimental data. The new approach yielded good agreement with the experimental results, strengthening the hypothesis that transport in the gas phase needs to be modeled with a non-equilibrium liquid/gas phase change.

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