What can vadose zone physics tell us about hillslope flow processes?

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Abstract. Studies of hillslope-scale hydrologic processes often invoke simplifications that fragment time (discrete rainfall-runoff events), fragment space (division into saturated and unsaturated domains), or fragment process (separating vertical infiltration from lateral interflow). This study explores the hillslope flow behaviors that emerge from continuous simulations that solve the Richards' equation for variably saturated subsurface flow. Simulations use the finite element numerical model, HYDRUS-2D, which can represent continuous, dynamic subsurface flow processes. This model is used in an exploration of how soil characteristics, hillslope shape, and climate affect hillslope flow behavior. A series of simulations are created for two-dimensional (vertical, lateral/downslope) hillslope slices with variable shapes and water retention characteristics. Each simulation is forced with continuous hourly measurements of precipitation and evapotranspiration. Simulated hillslope outflow hydrographs and soil water content / pressure head patterns are saved at hourly time steps. Results show that some hillslope configurations and water retention behaviors result in continuous, gradual responses to rainfall, whereas other configurations exhibit pronounced threshold responses to rainfall. Shapes of soil moisture patterns and saturated zones in the simulations vary significantly with different hillslope characteristics and timing of rain events. Although hypothetical, the simulations show a wide range of possible hillslope flow behaviors and moisture patterns that can be produced with natural rainfall and a full solution of the Richards' equation. Including the dynamic, non-linear behavior of unsaturated zone flow in hillslope hydrology studies has strong potential to guide hypothesis development in future research on hillslope scale flow mechanisms.