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Process-based hydrological modeling: accounting for subsurface heterogeneity by integrating pedology, geophysics and soil hydrology

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As most hydrological processes are highly nonlinear and controlled by time-varying boundary conditions, numerical models are required for their comprehensive representation. However, one of the major difficulties in vadose zone processes modeling is due to the fact that soils are heterogeneous at all spatial scales. The identification and accurate representation of such heterogeneity can be crucial for quantifying the subsurface hydrological states and water fluxes but it is still a challenge in soil hydrology.

We present an integrated approach for process-based modeling of the vadose zone for a typical hillslope. The approach builds on the integration of classical soil mapping, on accurate monitoring of soil water content as well as on geophysical measurements for characterizing the subsurface heterogeneity. It finally integrates the gathered information into a physical model for simulating the vadose-zone processes with high spatial and temporal resolution.

Starting with a simple soil representation, we present the modeling results for different scenarios of increasing complexity with focus on the discretization and corresponding hydrological parameterization of the soil structures in three dimensions. We highlight and discuss the key challenges that need to be addressed when continuous information about the subsurface heterogeneity is to be mapped in the field and represented in a numerical model.

We argue that linking state-of-the-art experimental methods to advanced numerical tools, and bridging the gap between different disciplines such as pedology, hydrology and geophysics can be the key for improving our ability to measure, predict and better understand the vadose-zone processes. This will provide important knowledge needed for transferring this approach to larger scales where the accurate quantification of the soil water fluxes is required for a more efficient water management in the context of sustainable food production and climate change.