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Innovative sensing techniques and data analysis for characterizing the spatial and temporal dynamics of soil moisture patterns at the hillslope scale

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Soil moisture plays a critical role in every hydrological or meteorological model; nevertheless, it is still a great challenge to provide adequate information on soil moisture distribution beyond the point scale. Mobile geophysical methods such as electromagnetic induction (EMI) have been widely used for mapping soil water content at the field scale with high spatial resolution. Recent advances in wireless sensor technology allow monitoring of soil moisture dynamics with high temporal resolution at varying scales. The objective of this study was to characterize the spatio-temporal pattern of soil moisture at the hillslope scale and infer the controlling hydrological processes, integrating well established and innovative sensing techniques, as well as new statistical methods.
We combined soil hydrological and pedological expertise with geophysical measurements and methods from digital soil mapping for designing the monitoring setup of a wireless sensor network for a grassland hillslope in the Schäfertal catchment, Central Germany. At the same site, we measured soil apparent electrical conductivity (ECa) using EMI devices. Hypothesizing a wet and a dry soil moisture state to be characteristic of the spatial pattern of soil moisture, we tested a new method of analysis based on the Spearman rank correlation coefficient for describing the spatial and temporal evolution of such patterns. Based on this approach, we described the persistence and switching mechanisms of the two characteristic states, inferring the local properties that control the observed spatial patterns and the hydrological processes driving the transitions. The method showed to provide valuable insight into the persistence of characteristic states of soil moisture and the mechanisms of transition, and to be suitable for highlighting events for which specific hydrological processes occurred. The spatial organization of soil moisture was observed to be controlled by different processes in different soil horizons, with time-varying contribution, and the topsoil's moisture does not mirror processes that take place within the soil profile. The EMI investigation at the Schäfertal site appears to be suitable for mapping soil moisture at times when local soil properties control the spatial distribution of soil moisture, but not when topography has a major control on such pattern. The results will help to improve conceptual understanding for hydrological model studies at similar or smaller scales, and to transfer observation concepts and process understanding to larger or less instrumented areas.