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Water as a critical zone currency: linking water storage and age to root uptake and biogeochemical transport

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Efforts to grasp hydrological functioning in landscapes have gradually been evolving from inferring *when* water output fluxes respond to precipitation and energy inputs in catchments, towards tracking down *which water* is present in the different flow pathways of the critical zone (CZ). In the CZ where almost all terrestrial life developed, quantifying water storage and age (residence times in stores and transit times in fluxes) is key to the understanding of how water is *i*) available to supply root uptake, *ii*) in interaction with regolith minerals and biota, and *iii*) a medium for solute transport. We propose an approach to characterize the dynamics and non-linearities of CZ functioning first by mapping time-varying transit times of water exiting as plant transpiration as well as soil evaporation and stream discharge, against the corresponding water storage states. This picture is then extended by assessing the resulting relationships between hydrological states and patterns of nutrient concentration in, and export out of, the critical zone. This analysis considers several spatial scales, from the hillslope to the whole catchment. To this end, we use simulations from a cascade of spatially-distributed numerical tools: a process-based ecohydrological model – accounting for the coupling between energy balance, critical zone hydrology and vegetation dynamics, and a modular chemical weathering model – simulating dissolution/precipitation rates of mineral phases based on kinetics laws. We particularly focus on the long-term experimental tropical catchment of Mule Hole in Peninsular India (part of both the Indian Kabini CZ observatory and the French CZ observatory network OZCAR), with a highly seasonal hydroclimate and deep unsaturated profile, and where extensive hydrometric and chemical datasets are available for model calibration and evaluation. We discuss the interplay between distinctively mobilized critical zone compartments for each output flux, and the time-varying spatial organization of flow pathways.