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Unraveling the critical zone storage structure through in streams tracers sampling: insights from numerical experiments

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Mapping the critical zone groundwater storage structure is critical to understand and predict the resilience of freshwater ecosystems to the global changes in the Anthropocene (e.g. eutrophication, climate change, urbanization). If this structure can be indirectly mapped with geophysical data, we lack any aggregated characterization of how different groundwater storages organize at the catchment scale. Here we explore the potential of in streams geochemical tracers to unravel patterns of the groundwater stored in catchments and how it is released in rivers.

We develop a spatialized, process-based framework to represent how critical zone structure controls groundwater flow paths and transit time distributions dynamics at the hillslope scale. We represent the critical zone structure as three different compartments, i.e. soil, weathered zone and fractured bedrock, and generate numerical flow and transport experiments for different tracers (δ18O, 3H, DSi and δ30Si). We assume that the key process to generate flow in a compartment is locally, the saturation of the compartment right below it. Once saturated the interface between two compartments act as an impermeable layer and promote the apparition of perched groundwater flow paths. This process enhances a wetness-dependent connectivity of the shallower compartments, by increasing the occurrence of fast flow paths as the catchment gets wetter.

We show that while δ18O time series inform shallowest flow paths occurring in the soil compartments and riparian areas, 3H measurements enable to quantify, at snapshots, oldest flow paths that have been stored for a long time in the catchment. Geogenic tracers (DSi) characterize deeper storage groundwater contributing to the streams from the weathered and fractured bedrock and their associated weathering. Combined with isotopic ratios (δ30Si), relative importance of these two compartments for the weathering can be quantified.

These numerical experiments have practical implications for experiments design, to encourage the development of simultaneous, multi measurement monitoring techniques. They have also fundamental impacts about the way we conceptualize the critical zone and what is the level of complexity we are currently able to address with regard to the available data.