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Influence of spatio-temporal heterogeneities on microbial redox dynamics and nutrient cycling in the vadose zone

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Biogeochemical cycles impact most ecosystem functions (and consequently ecosystem services) by controlling the distribution of nutrients in an environmental compartment. Within the Critical Zone, the soil and deeper subsurface compartments account for almost 50% of the global carbon budget, and the subsurface is also one of the biggest stores of nitrogen. Changing climate and occurrence of extreme weather events have an increasing influence on the cycling of these elements in the Critical Zone. Microbial reactions account for nearly all the natural processes contributing to these biogeochemical cycles. While recent advancements in microbial techniques have led to greater insight into the functions of microbial communities for biogeochemical transformations, factors governing these processes in the subsurface are still not sufficiently established, primarily because of limited observational capabilities. In particular, it is difficult to resolve the impact of spatial heterogeneity at small scales on microbial activity thereof. Coupled with increasingly irregular weather events, temporal variability also adds to uncertainty in describing the dynamics of biogeochemical processes, particularly in the shallow subsurface.

In this study, we seek to disentangle the influence of spatial and temporal variability of terrestrial subsurface settings on the in situ biogeochemical function of microorganisms. For this we use a numerical reactive transport modeling approach which considers the response of microbial abundance and activity to fluctuating environmental conditions such as varying water saturation, organic carbon load and quality, availability of electron acceptors or flux induced shear detachment conditions. Simulated scenarios combine different assumptions on the forcing of these temporal fluctuations with different types of subsurface heterogeneities to determine the resulting biogeochemical potential of the subsurface system.

The results of this study support the identification of key drivers of microbial dynamics in the Critical Zone and assist an effective upscaling these process descriptions. This, in turn, contributes towards the regional scale modeling of biogeochemical cycles resulting from microbial dynamics.