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Modeling dune-induced hyporheic exchange and nutrient reactions in stream sediments

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The exchange of water across the streambed plays an important role in the ecology of fluvial environments, since it assures the connections of surface and subsurface waters, which have very different peculiarities. Water-borne chemicals are also involved in the process: they enter the sediments with the water and they are transformed into oxidized or reduced substances by biogeochemical reactions, mediated by the hyporheic microbiota. In particular, organic substances can be used as electron donors in a series of redox reactions, with different electron acceptors, e.g., oxygen and nitrate. Nitrification and other secondary reactions also occur as soon as water enters the streambed. These pore-scale transformations concur to affect subsurface solute concentrations and, consequently, the chemistry of upwelling water and the quality of the stream environment. The exchange with the hyporheic zone occurs in response to variations in bed topography, with a very wide range of spatial and temporal scales. For instance, small-scale exchanges are mainly induced by river bed forms, like ripples and dunes, while large-scale exchanges depend on larger geomorphological features.

In this work we focus on small-scale exchange induced by the presence of dunes on the streambed, investigating the interplay of hydrological and biogeochemical processes and their effects on solute spatial distribution in the sediments. We numerically simulate the turbulent water flow and the pressure distribution on the streambed and then we evaluate the coupled flow field and biogeochemical reactions in the hyporheic zone in steady-state conditions. Four representative reactive compounds are taken into account: dissolved organic carbon (DOC), oxygen (O_2), nitrate (NO_3^-) and ammonium (NH_4^+). Sensitivity analyses are also performed to analyze the influence of hydrological and chemical properties of the system on solute reaction rates.

The results demonstrate that the stream water quality can strongly affect the reactive behavior of the sediments. For instance, the DOC availability has shown to be a discriminating factor for determining a net nitrate production or consumption at the bed surface. Stream velocity and sediment permeability have also displayed a direct influence on the chemical zonation, by affecting the transport efficiency and the reaction rates. This study represents an initial step for a better understanding of the complex interactions between hydrodynamical and biogeochemical processes in the hyporheic zone.