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Explicit simulation of environmental tracers with a physically based integrated surface and subsurface flow model

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Environmental tracers have the potential to inform complex groundwater dynamics as a complement to traditional observations such as groundwater levels and stream flow. Tracers concentrations measured in the field are usually interpreted with lumped parameter models such as linear boxes. These simplified approaches are conceptually at odds with the high degree of complexity found in natural systems.

We propose to directly simulate environmental tracers concentrations in a fully coupled physically based model (HydroGeoSphere). Transport processes such as advection and dispersion are explicitly considered for each tracer. Thus, the concentrations do not have to be interpreted and direct simulations can be more easily compared with field data. We demonstrate the feasibility of the proposed approach with the simulation of synthetic yet realistic small-scale heterogeneous alluvial sand and gravel aquifer close to a loosing river. These conductive groundwater flow aquifers are commonly used to support the development of productive yet vulnerable groundwater well fields where predictions on age-distribution and mixing ratios are particularly relevant. For such systems, a more complex age pattern is expected that cannot be captured by simple models.

Specifically, we focus on the simulations of tracers produced in the subsurface such as ^{4}He, ^{222}Rn and ^{37}Ar, covering all relevant time scales for alluvial systems. The production is considered through the application of a modified zero-order production that considers a partitioning coefficient between the aqueous/gas phases for the unsaturated zone. Moreover, a depth-dependent parameterized equation for ^{37}Ar production is considered so that ^{37}Ar has a decreasing production with increasing depth. The proposed synthetic multi-tracer simulation study is a first step toward a comprehensive inverse modeling approach where tracers would be used at their full potential in reducing uncertainties of model predictions.