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Assessment of spatial and temporal dynamics of carbon and nitrogen turnover in groundwater along a hill slope transect

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The analysis of biogeochemical transformations of carbon and nitrogen in the subsurface is complicated as the subsurface is spatially heterogeneous and responds to surficial temporal dynamics, both of which leading to a strong spatial and temporal variability in subsurface microbial and nutrient dynamics. Given this complexity and the limited observation opportunities, it is difficult to predict the impact carbon and nitrogen cycling in subsurface environments. This is a major challenge in understanding microbially driven nutrient degradation and in quantitatively assessing the relevance of individual processes. To address this issue, a travel time-based modeling approach is used to simulate reactive carbon and nitrogen species in groundwater along a hill slope transect of the Hainich Critical Zone Exploratory (CZE), located northwest of Thuringia (central Germany). Travel time distributions derived from a three-dimensional numerical groundwater flow model are integrated with a set of numerical one-dimensional simulations describing the biogeochemical transformations of carbon and nitrogen along groundwater flow paths. The comprehensive reaction network describes the transformation of carbon and nitrogen along individual groundwater flow paths. It encompasses a variety of microbial functional groups, accounting for both heterotrophy and autotrophy in the subsurface, under both aerobic and anaerobic conditions, as well as key microbial life processes across various redox conditions. The model is suitable to determine the responsiveness of the subsurface reactive system at various spatial and temporal scales, and model results were used to assess the drivers of microbial activity, carbon and nitrogen transformations, as well as their hot spots and hot moments in the groundwater system.