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Exploring the role of mixing between subsurface flow paths on transit time distributions using a Lagrangian model

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Only a minute amount of global fresh water is stored in the unsaturated zone. Yet this tiny compartment controls soil microbial activity and associated trace gas emissions, transport and transformations of contaminants, plant productivity, runoff generation and groundwater recharge. To date, the processes controlling renewal and age of different fractions of the soil water stock are far from being understood. Current theories and process concepts were largely inferred either from over-simplified laboratory experiments, or non-exhaustive point observations and tracer data in the field. Tracer data provide key but yet integrated information about the distribution of travel times of the tracer molecules to a certain depth or on their travel depth distribution within a given time. We hence are able to observe the “effect” of soil structure i.e. partitioning of infiltrating water between fast preferential and slow flow paths and imperfect subsequent mixing between these flow paths in the subsurface and the related plant water uptake. However, we are not able to study the “cause” – because technologies for in-situ observations of flow, flow path topology and exchange processes at relevant interfaces have up to now not been at hand.

In the present study we will make use of a Lagrangian model for subsurface water dynamics to explore how subsurface heterogeneity and mixing among different storage fractions affects residence time distribution in the unsaturated zone in a forward approach. Soil water is represented by particles of constant mass, which travel according to the Itô form of the Fokker Planck equation. The model concept builds on established soil physics by estimating the drift velocity and the diffusion term based on the soil water characteristics. The model has been shown to simulate capillary driven soil moisture dynamics in good accordance with a) the Richards equation and b) observed soil moisture data in different soil. The particle model may furthermore account for preferential non equilibrium infiltration in a straightforward manner by treating event water as different type of particle, which travel initially in a macropore/ coarse pore fraction and experience a slow diffusive mixing with the pre-event water particles within a characteristic mixing time. In the present study we will particularly use the last approach in combination with artificial tracer data and stable isotopes to explore how different assumptions on mixing between different flow paths affect the travel time and residence time distributions of water particles in different fractions of the pore space.