Geophysical Research Abstracts
Vol. 21, EGU2019-1299, 2019
EGU General Assembly 2019

Observation of continuously separated mobile and immobile soil water pools despite temporary full saturation

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Based on data of stable isotopes of water (2H and 18O), a lack of subsurface connectivity of mobile and tightly bound soil water was postulated to affect the recharge mechanisms in the unsaturated zone (Two Water World Hypothesis). However, the dynamics of subsurface water interaction is still poorly understood, and its investigation is usually based on few sampling campaigns (n < 5).
Here we present an extensive data set gathered in the Mediterranean long-term Vallcebre research catchments in the Pyrenees (NE Spain, 42° 12′N, 1° 49′E) with 15 sampling campaigns over 8 months. We applied a unique sampling design that explored the stable isotope compositions of precipitation (open field, throughfall and stemflow), groundwater, and mobile and bulk soil water at various depths using suction lysimeter and cryogenic extraction, respectively. Sampling of the silty loam soil in a Scots pine forest took place every two weeks and covered several intense rainfall events and a dry spell. Rainfall, throughfall and stemflow volumes, groundwater levels, soil moisture, and matric potential were measured in parallel.
Our isotope data reveals that mobile water and tightly bound soil water were continuously separated over the entire study period spanning different soil wetness states. Even after high intense rainfall events, that resulted in a perched groundwater table reaching the soil's surface, mobile and bulk soil water stable isotopes remained significantly different. Groundwater was isotopically similar to the weighted average rainfall signal and of little isotopic variability, which indicates that groundwater is quite well mixed and of relative old age. In contrast, the stable isotope composition of mobile water was more dynamic and its isotopic signal was similar to isotope compositions of recent rainfall, which is indicative for young water. However, the isotopic composition of bulk soil water did not change much in response to rainfall events nor after saturation of the soil, but it remained isotopically depleted, which shows that it contained older water that infiltrated during the previous winter (isotopically depleted rainfall at lower temperatures).
Our findings of a continuous disconnectedness on the pore scale are contrary to the common assumption in hydrological modeling of an advection-dispersion or translatory flow in the subsurface. Instead, our bi-weekly sampling exposes unprecedented dynamics of two mostly disjunct subsurface water pools that even during fully saturation do not mix. These processes observed on the plot scale are highly relevant for catchment scale subsurface flow path connectivity.