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From rain to cave drip water: Hydraulic response time and water transfer time at Bunker Cave (NW Germany)

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Speleothem based palaeoclimate studies considerably increased during the last two decades. Processes in the soil and karst zone influence the proxies applied on the speleothem climate archive. Thus, caves are monitored for a wide range of environmental parameters. These monitoring programmes mostly focus on seasonal variations but less so on the multi-annual time scale. The present study analyses long-term trends from a seven year-long monitoring of Bunker Cave, NW Germany, in order to assess the hydraulic response time and transfer time of meteoric water from the surface to the cave. Therefore, drip rates of all sites were measured manually with a stopwatch and rain, soil as well as drip waters were collected in a monthly to bimonthly resolution. Subsequently, the oxygen and hydrogen isotopic compositions of the waters were analysed. Furthermore, the coefficient of permeability was calculated from granulometric analyses performed on soil samples collected above Bunker Cave. The annual mean drip rates of all drip sites except one display the same long-term trend. In the case of Bunker Cave, correlations of the annual mean drip rate of each site with annual precipitation and infiltration demonstrate that the annual infiltration and thus, the annual precipitation control the interannual drip-rate variability. Therefore, the hydraulic response time does not show a temporal offset. The annual mean oxygen isotopic compositions of all drip waters except one display the same long-term trend, whilst the annual mean hydrogen isotope ratios of all drip sites display the same trend. In combination with the results of the coefficient of permeability, correlations of soil and drip water annual mean oxygen and hydrogen isotopic composition with atmospheric temperature reveal water transfer times for soil water of 3 to 6 months for 40 cm soil-depth and ca. 1 year for 70 cm soil-depth. Finally, the water reaches the cave after three years transfer time. As a consequence, a temporal offset between the hydraulic response time and the water transfer time exists. This may lead to difficulties when comparing respective proxies in cases of seasonally or annually laminated speleothems. Conversely, this offset is negligible for speleothems with decadal or lower resolution such as present in Bunker Cave. In NW Germany, the oxygen and hydrogen isotopes of rain water display a clear dependency on the atmospheric temperature and both isotope systems correlate significantly in soil waters and fast dripping drip water, but in the case of oxygen not with the slow dripping ones due to alteration. The hydrogen isotopic composition, however, is unaffected by these processes and the hydrogen isotopic composition of fluid inclusions can therefore be used to reconstruct palaeotemperatures from Bunker Cave speleothems. The interpretation of the oxygen isotope signature of fluid inclusions and calcium carbonate, however, is more difficult. Since winter temperature and precipitation are influenced by the North Atlantic Oscillation (NAO) and long-term variations of temperature and precipitation are recorded in drip water of Bunker Cave, it is most likely that NAO variability is recorded in Bunker Cave speleothems.