Insights into recharge processes and speleothem proxy archives from long-term monitoring networks of cave drip water hydrology

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Since 2010 we have established cave drip water hydrological monitoring networks in four contrasting climate zones (Mediterranean, montane, semi-arid and sub-tropical) across continental Australia. Deploying over one hundred automated drip loggers, we combine these long-term monitoring datasets with climate and water isotope data, lidar mapping, electrical resistivity imaging and karst hydrological modelling to provide insights into recharge processes and the impact of hydrological variability on speleothem proxy archives.

We identify increases in drip discharge and compare the timing of those events to antecedent climate conditions (rainfall, evapotranspiration). We find rainfall recharge thresholds vary with climate. At our montane site, recharge occurs after 13 to 31 mm rainfall events, depending on antecedent conditions. At the semi-arid site, recharge occurs after 40 mm rainfall events, and at our sub-tropical sites, recharge occurs following all instances where > 93 mm / week of precipitation occurs, with lower precipitation thresholds (down to 33 mm / week) possible depending on antecedent conditions and at sites with limited vegetation cover. We use these recharge thresholds to constrain simple soil moisture balance models to better understand soil and karst storage volumes. Combined with electrical resistivity imaging, we can relate recharge to the caves to subsurface water flow paths and karst water stores.

At our montane and Mediterranean climate sites, relatively consistent drip water isotopic composition confirms the presence of well-mixed water stores. This allows us to quantify the extent of speleothem oxygen isotope variability due to fractionation associated with changes in drip rate. We identify significant differences in long-term mean drip rates between different drip sites within a cave, and significant differences in event-based drip rate responses within a cave. Drip hydrological variability helps explain the within-cave variability of speleothem oxygen isotope composition observed at both sites, and helps identify the primary drip water oxygen isotope signal.
At our semi-arid site, drip water isotopic composition is dominated by epikarst evaporation and our drip water monitoring demonstrates that recharge events are infrequent (~1.6 per year). Using both observational and modelling data, we quantify the relative importance of evaporative fractionation in the epikarst and fractionation during calcite precipitation. Using modern speleothem samples, we demonstrate that the oxygen isotope signal in this water limited environment reflects the balance between the oxygen isotope composition of recharge and its subsequent fractionation in the soil, epikarst and cave.