Forward modelling of speleothem $\delta^{18}O$; a critical assessment of their use as high-resolution climate proxies

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Speleothems are used increasingly as repositories of terrestrial palaeoclimate information. Obvious advantages include their mineralogical simplicity, geochemical stability, and the ease with which precise chronologies can be established using U-series methods. However, caves are complex dynamic systems, and the relationship between geochemical signals recorded in speleothem calcite and the contemporaneous climate is often not straightforward. The challenge for palaeoclimatologists is to provide to the climate modelling community, precisely dated palaeoclimate proxies that can either: (i) be calibrated quantitatively (within known error limits) relative to climate parameters such as mean annual temperature, rainfall amount and/or indices of seasonality or (ii) preserve time-series records of meteoric $\delta^{18}O$ against which the output of Isotope-enabled General Circulation Models can be tested. Most speleothem stable isotope time-series records have been interpreted simply in terms of temporal changes in rainfall amount, mean annual temperature, and/or changes in the seasonal distribution of precipitation. Surprisingly, there have been few attempts to establish a framework within which to assess and rank the reliability and likely climate sensitivity of individual records based on objective criteria such as expected signal-to-noise ratio, signal amplitudes, or rates of change in $\delta^{18}O$. Here we present the results of forward modelling of speleothem calcite $\delta^{18}O$ for a wide range of climate regimes that take into account, as a function of geographic position (latitude, continentality), a range of variables. This includes seasonal and multi-annual variability in: meteoric water $\delta^{18}O$, evapotranspiration and infiltration biases, vadose-zone $\delta^{18}O$ signal attenuation, calcite deposition rate, and quasi-equilibrium isotope fractionation. The overall objective of the forward model is to predict, using a Monte Carlo type simulation of the uncertainties, the signal to noise ratio and therefore the minimum amplitude of a climate change (e.g. mean annual temperature, rainfall amount) that is detectable unequivocally in speleothem $\delta^{18}O$ records in a range of climate regimes.