Geophysical Research Abstracts
Vol. 21, EGU2019-18572-1, 2019
EGU General Assembly 2019

Cave monitoring in Gibraltar and reconstruction of δ18O in Last Glacial precipitation

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The δ18O of past rainfall is important in palaeo-climatology because it can be simulated directly by isotope-enabled General Circulation Models, enabling data-model comparisons. We describe a methodology for reconstructing it from Last Glacial speleothems in Gibraltar. Three factors determine the δ18O of dripstone calcite: the δ18O of drip water, the cave temperature (that determines equilibrium fractionation between water and calcite), plus non-equilibrium fractionation caused by CO_2 degassing and/or surface reactions. Reconstructing seepage water δ18O requires independent constraints on the second and third factors. It is also necessary that the relationship between seepage δ18O and rainfall be well-constrained.

A merged record from flowstone and stalagmite (Gib10d/10e) from the same chamber of Ragged Staff Cave spans 30 – 110 ka. δ18O variations between 40 and 62 ka align closely with NGRIP's GICC05modelext timescale (1) but there is divergence before and after this. We therefore restrict our reconstruction to 40-62 ka.

To constrain temperature we used Uk'37 estimates of annual average sea surface temperatures (SSTs) in core ODP-977A in the Alboran Sea, after converting its original timescale to that of NGRIP (2). We assume that in coastal Gibraltar Mean Annual Air Temperatures (MATs) equalled SSTs. Cave temperatures probably lagged behind MATs due to the thermal capacity of the bedrock, but with the possibility of a much smaller lag because of heat advection from outside by cave winds. To deal with the uncertainty this imposes, we use a 1-D heat flow model to set up two bounding scenarios for the evolution of cave temperatures. In one the full effects of heat storage and conduction are computed for 100 m depth whereas in the other the lag is zero. Both scenarios are used to determine fractionation factors (3) and time-series of 'equilibrium' values for δ18O in cave water.
The effects of non-equilibrium are difficult to assess. The δ18O records for the two speleothems overlay almost exactly despite their different morphologies and implied drip discharges. We take a similar approach to 'disequilibrium' as for cave temperature, defining a bounding scenario of 'no disequilibrium' but alternatively using the 'Tremaine curve' that takes disequilibrium into account (4).

This approach gives rise to a 2 x 2 set of scenarios that define an 'envelope' for δ18O in palaeo-seepage. Cave monitoring shows that average seepage δ18O is currently 0.6 to 0.75 ‰ less than rainfall, because of complete evaporation of summer rains. This bias would have been less in cooler climates, so we adjust the reconstructed envelope by amounts related to prevailing SST, to obtain estimates and uncertainties for the average δ18O of palaeo-precipitation in the western Mediterranean that can be compared directly with GCM output and with other records on the NGRIP timescale.