Surface-cave thermal decoupling and its impact on the speleothem oxygen isotope records during a full glacial cycle

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Temperature in inner sections of most caves has limited variability and its value is close to the mean annual temperature above the cave. Nevertheless, any cave atmosphere temperature has long-term changes. Away from the cave entrances and in the absence of streams, the long-term thermal variability of caves is controlled by the surface atmosphere temperature and its transfer to the cave is the result of thermal conduction. The surface thermal signal takes time in its propagation underground by conduction, causing a temporary decoupling between surface and cave atmosphere temperatures. Such thermal decoupling depends on the cave depth and the duration of the thermal anomaly. Since temperature is a main control on the oxygen isotope composition of speleothems, we explored the potential impact of this thermal decoupling in speleothem records from a series of hypothetical caves located at different depths.

We have explored the theoretical impact of thermal decoupling in speleothem oxygen isotope records during the last glacial cycle. A synthetic surface atmosphere temperature record was constructed from sinusoidal signals inspired in alkenone paleotemperature ocean records from the North Atlantic off-shore Portugal and the Western Mediterranean. The synthetic surface atmosphere temperature includes 15 stadial periods and 4 interstadial periods during the MIS5 that are superimposed to a full glacial cycle.

The result of the underground thermal model suggests that thermal decoupling is very limited in shallow caves (e.g., 10 m), whereas in deeper caves (e.g., 500 m) can reach anomalies (either positive or negative) in the order of 4 ºC. The largest long-term temperature change is simulated during the Termination II (i.e., up to 8 ºC within <2 ka).

The delay of the recorded signal is proportional to the duration of the anomaly (i.e., period of the cycle), and the thermal anomalies of a glacial cycle can take hundreds/thousands of years to reach a cave teens/hundreds of meters underground. Our simulations suggest that a full glacial cycle could take several thousand meters before being fully attenuated with depth.

We explore the impact of thermal decoupling on speleothem oxygen isotope records considering the thermal impact during rain condensation and calcite precipitation, but not to any other isotope change related to the hydrological cycle, that are likely to be specific to every location. Speleothem oxygen isotope anomalies are more significant in speleothems from deeper caves and the largest anomalies are recorded during Termination II. The impact of the thermal decoupling on the oxygen isotope composition of speleothems also depends on the on the thermal relationship at the time of rain condensation, but anomalies (either positive or negative) can exceed 1 to 2 ‰.

This research suggests that temperature can be a significant control on the speleothem oxygen isotope glacial records due to the thermal decoupling between surface and cave atmospheres, especially, but not exclusively in deep caves located in mountainous areas.