Geophysical Research Abstracts
Vol. 12, EGU2010-8275, 2010
EGU General Assembly 2010

Methodologies to extract regional scale climate signals from site-specific noise in speleothem stable isotope records

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Speleothems can provide reliable well-dated archives of past climatic conditions on the continents. However, unambiguous attribution of temporal changes in δ^{18}O and δ^{13}C to specific climate variables such as air temperature, rainfall amount and palaeo-aridity remains difficult. This issue is particularly acute in the case of Holocene speleothems, because their low-amplitude δ^{18}O and δ^{13}C signals can be superimposed on variability that is unrelated to climate (e.g. stochastic water-routing effects, isotope disequilibrium effects). Methodologies to distinguish between true climate signals and such extraneous 'noise' have not yet received much attention. Replication of records from the same cave or region is one approach, but in practice is often limited for conservation and resource reasons. Two other methodologies can reduce the uncertainties. Traditionally, a multi-proxy approach of using mineralogical, textural, growth-rate and trace element proxies within speleothems (e.g. calcite/aragonite transitions, trace element ratios, δ^{13}C, Δ^{14}C) has been used to provide additional constraints on interpretations. Some speleothems exhibit highly correlated Mg/Ca, δ^{13}C and δ^{18}O time-series trends for example, indicating strong prior calcite precipitation (PCP) and/or kinetic isotope fractionation effects that complicate palaeoclimate interpretations. Crucially, all such processes lead to elevated δ^{13}C and δ^{18}O values suggesting that sub-samples with the lowest δ^{18}O and δ^{13}C values within noisy time-series data may best reflect the climate-related signal, but this approach may be adversely affected by site-specific effects. A second, potentially more robust, but under-utilised approach is to consider individual stable isotope time-series datasets in the context of regional scale spatial isotope gradients. A recent compilation of data from >50 European Holocene speleothems for example has demonstrated persistent systematic zonal trends of decreasing $\delta^{18}O_{spel}$ consistent with progressive rainout from a predominantly westerly (Atlantic) derived moisture source through the Holocene. Crucially, the slope of this rainout trend ($d\delta^{18}O_{spel}/dx$) changes markedly from the late glacial period to the late Holocene, with steeper eastward decreases in δ^{18}O across Europe in the period 12-8 ka. Steeper $d\delta^{18}O_{spel}/dx$ trends are a reflection both of (i) higher $\delta^{18}O_{spel}$ in samples from the western margin of Europe in the early Holocene, attributed to higher δ^{18}O in the Atlantic oceanic source and colder conditions (ii) lower values of $\delta^{18}O_{spel}$ in the mid- to east-European sites in the later part of the Holocene. Deviations from these regional-scale gradients may be used to; (i) identify cave sites that are sensitive to different vapour sources (e.g. Mediterranean sources) and (ii) isolate site-specific effects such as disequilibrium or evaporative effects that cause local enrichment in δ^{18}O above the regional rainout trends. The significance of temporal changes in the O isotopic gradient during the Holocene will be modelled in terms of climate parameters such as air temperature and humidity gradients.