

Quantitative assessments of moisture sources and temperature governing rainfall $\delta^{18}\text{O}$ from 20 years long monitoring records in SW-France: Importance for isotopic-based climate reconstructions

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In the mid-high latitude region, variations of stable isotopic compositions of atmospheric precipitation ($\delta^{18}\text{O}_p$ and δD_p) were commonly regarded as reflecting the “temperature effect”. However, some studies have indicated that changes in moisture sources are important controlling factors for $\delta^{18}\text{O}_p$. To clarify whether there are connections between $\delta^{18}\text{O}_p$ and variations of moisture sources in Southwest France (SW-France), whose implications for speleothem $\delta^{18}\text{O}$ are of great importance, we have used among the longest isotopic time-series from SW-France (Le Mas and Villars stations) and a 5 days’ reconstruction of air mass history during the 1997–2016 A.D period based on the HYSPLIT tracking model. We found the percentage of initial moisture sources (PIMS) as important factors controlling the oxygen isotope composition of precipitation in SW-France, whether monthly or inter-annual timescale was considered. Additionally, we observed that the $\delta^{18}\text{O}_p$ preserved the signal of local temperature, supporting the “temperature effect”, while no evidence for its “amount effect” has been observed. These quantified links between PIMS/local-temperature and $\delta^{18}\text{O}_p$ appear useful references to understand the link between stable oxygen isotopes and climate parameters. Our long-term monitoring of $\delta^{18}\text{O}_p$, d-excess, and moisture sources reveals decadal trends, highlighting a tight coupling in hydrologic systems and relatively fast changes on rainfall sources controlled by atmospheric circulations in SW-France.

Semi-Quantitative Estimates of Rainfall Variability during the 8.2kyr Event in California using Speleothem Calcium Isotope Ratios

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A multi-proxy record from a fast-growing stalagmite reveals variable hydroclimate on the California coast across the 8.2kyr event and a precursor event likely caused by initial drainage of proglacial Lake Agassiz. Using speleothem $\delta^{44}\text{Ca}$, we develop the first semi-quantitative estimates of paleo-rainfall variability for California through calibration with measurements of the modern climate and cave environment. We find that the magnitude of rainfall variability during the 8.2kyr event approached the multi-year variability observable in the recent past (1950–2019) and the magnitude of variability during the precursor event likely exceeded this range. Additionally, we observe other instances of multi-decadal variability comparable in magnitude to the precursor event during the record. Our work suggests that speleothem calcium isotope ratios are a powerful semi-quantitative means to reconstruct paleo-rainfall, although numerous factors must be assessed in each cave system before applying this approach.

Deglacial freshenings and cooling events during MIS 6 recorded in NISA stalagmites

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The ice sheet distribution of the Penultimate Glacial (MIS 6) is characterized by a much larger European Ice Sheet (EIS) compared to the Last Glacial. The timing of the EIS maximal extent likely occurred before the glacial maximum but evidences are sparse. A high-resolution NISA stalagmite isotope record provides insights into the MIS 6 ice sheet dynamics based on $\delta^{18}\text{O}$. Early deglacial phases suggest intermittent collapses of the EIS. Using our stalagmite splice as a reference record to align and compare with other climate records from the North Atlantic region improves the understanding of MIS 6 climate. The absolute U-Th chronology of this stalagmite record constrains the timing of millennial scale climate variations and deglacial phases, which well correlate with mid-latitude summer insolation increases. The $\delta^{13}\text{C}$, reasonably interpreted as temperature signal, indicates deep glacial conditions early during MIS 6 coinciding with a first EIS maximum at around 185 kyr followed by a stepwise EIS collapse within a few thousand years. A second EIS maximum with evidence of a coalescence of the Fennoscandian and British-Irish Ice Sheets established between 160 to 155 kyr. Abrupt and high amplitude freshening events support the hypothesis of EIS meltwater events transported southward to the mid-latitudes. The freshening signal is further enhanced by local input into the Bay of Biscay. Such abrupt freshenings are related to cooling events, which occur due to reduced AMOC strength.

Environmental or microbiological factors controlling moonmilk vs. columnar speleothem fabrics?

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Calcite moonmilk speleothems are atypical cave deposits significantly different from the classical, layered and compact sparitic speleothems used in palaeoclimate research. Moonmilk is a porous, soft and plastic deposit composed of an open mesh of different types of fibrous calcite crystals, microbes, organic matter and water contents up to 94 wt%. It appears to grow through the accretion of fibrous microcrystalline calcite mostly on the outer surfaces, resulting in peculiar morphologies, such as flat-bottomed stalactites that internally show a faint, irregular lamination. There is evidence that moonmilk speleothems host specific microbiota in caves, however, questions remain open regarding the specific role of microorganisms on the fibrous habit of calcite and the precise environmental conditions required for moonmilk precipitation.

Here, we present results from extensive, morphologically diverse, active and fossil moonmilk deposits occurring in Potočka Zijalka (1630 m a.s.l.), Snežna jama (1556 m a.s.l.), Brezno za Hramom (650 m a.s.l.) and Košelevka (634 m a.s.l.) in Slovenia. Our multidisciplinary approach includes monitoring the cave's environmental parameters (T, RH, pCO₂), inorganic and organic chemical analysis of the moonmilk and its feeding waters and microbiological investigations. The aim is to discover the factors controlling the distinctive morphology of calcite and, ultimately, the moonmilk formation mechanisms. CryoSEM has allowed us to observe the original 3D-structure of extremely hydrated moonmilk, whereas, optical petrography of thin sections has shown a striking variety of microcrystalline fabrics in lithified samples. Moonmilk has metabolically active microbes, is rich in microbial biomass and nutrients and its drip/pool-waters show relatively high TOC values. This may indicate that biological activity plays an important role in moonmilk formation. However, we still need to distinguish if this organic carbon derived *ex situ* from a particularly organic-rich infiltration water or was produced *in situ* by autochthonous microbial communities. We speculate that the growth of the peculiar fibrous habit of calcite in moonmilk is not necessarily induced by local microbial activity, but is rather influenced by the presence of organic molecules, including microbial exopolymeric substances (EPS).

Since moonmilk deposits are relatively rare in caves and are often restricted to certain areas, we aim to constrain the specific biogeochemical environmental conditions leading to the precipitation of moonmilk instead of the classic sparitic speleothems. Such understanding is critical for the potential use of moonmilk speleothems in the interpretation of cave stratigraphic records.

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Holocene stable isotope record of insolation and rapid climate change in a stalagmite from the Zagros of Iran

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We explore Holocene climatic changes recorded by geochemical proxies in a single, well-dated stalagmite from the northern Zagros Mountains of Iran, a montane environment bordering the ‘fertile crescent’, where stalagmite records have so far only provided short glimpses of Holocene climatic changes. Long-term trends in multiple proxies follow the reduction in summer insolation and agree with model-simulated changes in total rainfall and rainwater isotopes over the Holocene. Additionally, carbon isotope values show ~1.5‰ centennial-scale variability, with three of these events corresponding with Rapid Climate Change (RCC) events, which are associated with an intensified Siberian High.

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Hydroclimate reconstruction since Pre-Roman times: western Mediterranean stalagmites multi-proxy records

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We present the first speleothem-based hydrological reconstruction for the central-western Mediterranean during the last 2.7 kyr (653 yr BCE-1880 yr CE). A multi-proxy strategy has been followed combining analysis of five stalagmites from two caves of Mallorca: architectural elements description, mineralogical X-Ray Diffraction characterization, $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and trace element analyses and U/Th dates.

The overall coherence in the variability of the produced $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and Mg/Ca records in the different speleothems allows interpreting changes in the hydrological conditions as the dominant effect over the three proxies. Drier conditions would enhance degassing (more enriched $\delta^{13}\text{C}$), prior carbonate precipitation (higher Mg/Ca ratios) and also the residence time in the thin solution layer (more enriched $\delta^{18}\text{O}$).

According to our results, overall wet conditions dominated for the early Roman Period, the first half of the Early Middle Ages and the Little Ice Age while drier conditions occurred during the late RP, the late EMA and the entire Medieval Climate Anomaly. Terrestrial and marine approach has been followed taking into account reconstructions based on marine records previously published and from the same study area and time-period (Cisneros et al., 2016; 2019) and conducting Principal Component Analyses in all the records (58 % of common variability).

A multi-proxy record of increased aridity during the Maya Terminal Classic from Columnas Cave, NW Yucatán.

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During the Terminal Classic Period (c.800-1000CE) most major Maya centers in the lowlands of the Yucatán Peninsula declined and were abandoned, in what is now known as the Classic Maya Collapse. The causes of this societal transformation remain open for debate in modern archaeology. Over the past 25 years, palaeoclimatic records from lake sediments and speleothems have prompted discussion about the role abrupt climate change may have played in the decline. These records largely indicate the existence of a period of increased drought frequency approximately contemporaneous with the Collapse. However, the large spatiotemporal precipitation variability over the Peninsula means a larger dataset is required before conclusions can be drawn.

Here we report the geochemical characterization of HOBO-5, a stalagmite from Columnas Cave in north-western Yucatán. We present absolutely-dated high-resolution (100 μ m) records of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ variations – including some regions measured via SIMS at 10 μ m resolution, as well as $\delta^{44}\text{Ca}$, Mg/Ca and Sr/Ca.

A significant positive $\delta^{18}\text{O}$ excursion occurs in HOBO-5 during the Terminal Classic, coupled with the onset of an extended period of more positive $\delta^{13}\text{C}$ and $\delta^{44}\text{Ca}$ values. We interpret a period of decreased rainfall year-round, followed by a transition to a more seasonal arid regime into the Postclassic.

Last Interglacial hydroclimate reconstructed from flowstones from Bigonda Cave, N.E. Italy

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Climate reconstructions from the Last Interglacial (LIG) period can provide a testbed for modelling a warm climate without the influence of anthropogenic sources. However, local to regional-scale climate proxy records for this period are lacking in many locations, particularly those vulnerable to climate changes, such as mountainous regions. In particular, in the foothills of the European Alps in northeast Italy, the rapid change in topography, from the low-lying, flat Po Plain to the steep mountainous terrain of the Alps could have strongly influenced the local climate during the LIG period, causing conditions that may deviate from the state of the global climate. Here, we present proxy information from two flowstones of LIG age, from Bigonda (BG) Cave, located in the S.E. Prealps in N.E. Italy. The speleothems provide a record from 133 ka to 106 ka, covering the deglaciation following Termination II, the entire Eemian period, and the climate demise towards the last glaciation. Our multiproxy, U-series dated records include petrography, stable isotopes and trace elements to provide detailed information about the LIG climate.

Knowledge of the local geology and glacial history of the site has been crucial for the correct interpretation of the records and, thus, a robust climate reconstruction for the LIG period. The cave is principally a horizontal cave and is cut in the Dolomia Principale dolomite, with the entrance at 370 m a.s.l. on the valley flank. However, two different catchment areas feed the infiltration water to the cave; one from the valley flank (~900 m a.s.l.) and the other from the mountain plateau above the cave (~1700 m a.s.l.). Water infiltrating from the valley flank through the dolomite host-rock generally yields an isotope signature for a warm and well-vegetated setting (high $\delta^{18}\text{O}$ and low $\delta^{13}\text{C}$ values), with high Mg concentrations (from dissolution of dolomite) and low Sr concentrations (no Sr source). Water infiltrating at the higher altitude plateau was derived from two diverse sources. One is from direct precipitation onto the plateau catchment area, while the second is from ice melt from a nearby glacier in the upper catchment area. The rock comprising the plateau is the Calcari grigi limestone that, after the prior glaciation, was covered by very fine grained limestone particles and Sr-rich loess deposits. The plateau-derived water infiltration signals within the speleothems are, thus, strongly negative to low $\delta^{18}\text{O}$ values (ice melt and cool temperatures), high $\delta^{13}\text{C}$ values (due to lower soil efficiency), low Mg concentrations (limestone dissolution) and high Sr concentrations (derived from the Sr-rich loess). Furthermore, the $\delta^{18}\text{O}$ values were strongly influenced by the vapour source of precipitation, guided by the changing position of the ITCZ linked to the strength of solar insolation associated with orbital forcing, and modified by the amount-effect during low insolation periods and the weighting-effect during high insolation periods. Multiproxy records are, thus, required to help unravel the complex $\delta^{18}\text{O}$ signal at this site, to ultimately provide a robust LIG climate reconstruction for the N.E. Italian Prealps.