



Reconstructing western Türkiye's hydroclimate since the Late Last Glacial using Börüce Cave (Kula, Manisa) stalagmites

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Abstract. This study presents preliminary results regarding hydroclimate dynamics in western Türkiye since the late Last Glacial using high-resolution oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) isotope records from Börüce Cave. Our analysis indicates that calcite deposition occurred under near-isotopic equilibrium, ensuring the records reflect climatic signals. The isotope profiles seem to capture major climate events, such as the Bölling–Allerød interstadial and the Younger Dryas stadial, suggesting a strong linkage to high-latitude climate systems, likely driven by Atlantic Meridional Overturning Circulation variability. The records indicate wet conditions during the Early Holocene, attributed to a southward shift in the westerlies. This was followed by a progressive trend toward aridity from the Middle Holocene (~6 ka onward), consistent with other regional proxy records.

1. Introduction

Türkiye is highly sensitive to variations in large-scale atmospheric circulation systems due to its position in a transition region between atmospheric polar and tropical climate circulation systems, including the mid-latitude westerlies, the Azores and Siberian high-pressure systems, all of which strongly modulate the climate dynamics of the Mediterranean region. In addition, regional factors such as the surrounding seas and complex topography exert substantial influence on spatial and temporal climate variability across the country (Bozkurt & Şen, 2011; Deniz *et al.*, 2011; Karaca *et al.*, 2000). The interplay between these

large-scale circulation patterns and local geographic controls collectively governs Türkiye's hydroclimate. Situated in the Eastern Mediterranean, recognized as one of the most climate-sensitive regions globally, Türkiye is projected to experience profound impacts from anthropogenic climate change, including an increased frequency and severity of droughts and extreme heat events during the 21st century (Lelieveld *et al.*, 2012; Zittis *et al.*, 2022). Advancing accurate projections of future climate change and its implications for water and ecological resources requires a robust understanding of past climate variability in this region, considering

the short duration of most modern climate records.

Our study investigates hydroclimate dynamics in the Eastern Mediterranean since the late Last Glacial using high-resolution oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) isotope records from

speleothems in Börtlüce Cave, western Türkiye (Fig. 1). We present $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records from two stalagmites (BC-3 and BC-7L), spanning the last ~46 ka, aimed at assessing their linkages with both low- and high-latitude climate systems.



Figure 1. The location of Börtlüce Cave (red point) and proxy records (yellow points) used in this study; the NGRIP ice core, Greenland (Andersen et al., 2006; Rasmussen et al., 2006; Vinther et al., 2006); the GISP2 ice core, Greenland (Alley, 2000); the LC21 core in the eastern Mediterranean Sea (Grant et al., 2012); Soreq Cave, Israel (Bar-Matthews et al., 1997); Dim Cave in southwestern Türkiye (Ünal-İmer et al., 2015); Sofular Cave, northwest Türkiye (Fleitmann et al., 2009; Göktürk et al., 2011); the abundances of arboreal pollen from Lake İznik, northwest Türkiye (Miebach et al., 2016).

2. Materials and methods

Fieldwork in 2022 resulted in the collection of nine stalagmites from Börtlüce Cave. Cave air temperature and relative humidity were monitored with two data loggers from August

2023 to July 2024. Stable isotope compositions were analyzed along the growth axis of the stalagmites at 0.5 mm interval using Thermo-Scientific Delta V Plus with Gas-bench II at the High-Precision Mass Spectrometry and Environment Change Laboratory

(HISPEC), Department of Geosciences, National Taiwan University. Stable isotopes values of oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) are reported in per mil (‰), relative to the Vienna Pee Dee Belemnite (VPDB). U-Th dating was performed on 45 subsamples, using a Thermo-Finnigan Neptune multi-collector inductively coupled plasma mass spectrometer at the HISPEC, Department of Geosciences, National Taiwan University.

3. Results and discussions

The present-day climate of Börtlüce Cave is defined by nearly constant temperatures, high humidity close to saturation, and limited ventilation (Fig. 2). Additionally, the weak correlation ($R = -0.17$ to 0.16 ; $p < 0.05$) between $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ along growth layers, together with the high degree of coherence among individual $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ profiles from speleothems in the cave, indicates that calcite deposition occurred under near- or quasi-isotopic equilibrium conditions, reflecting climatic signals rather than kinetic effects within the cave environment.

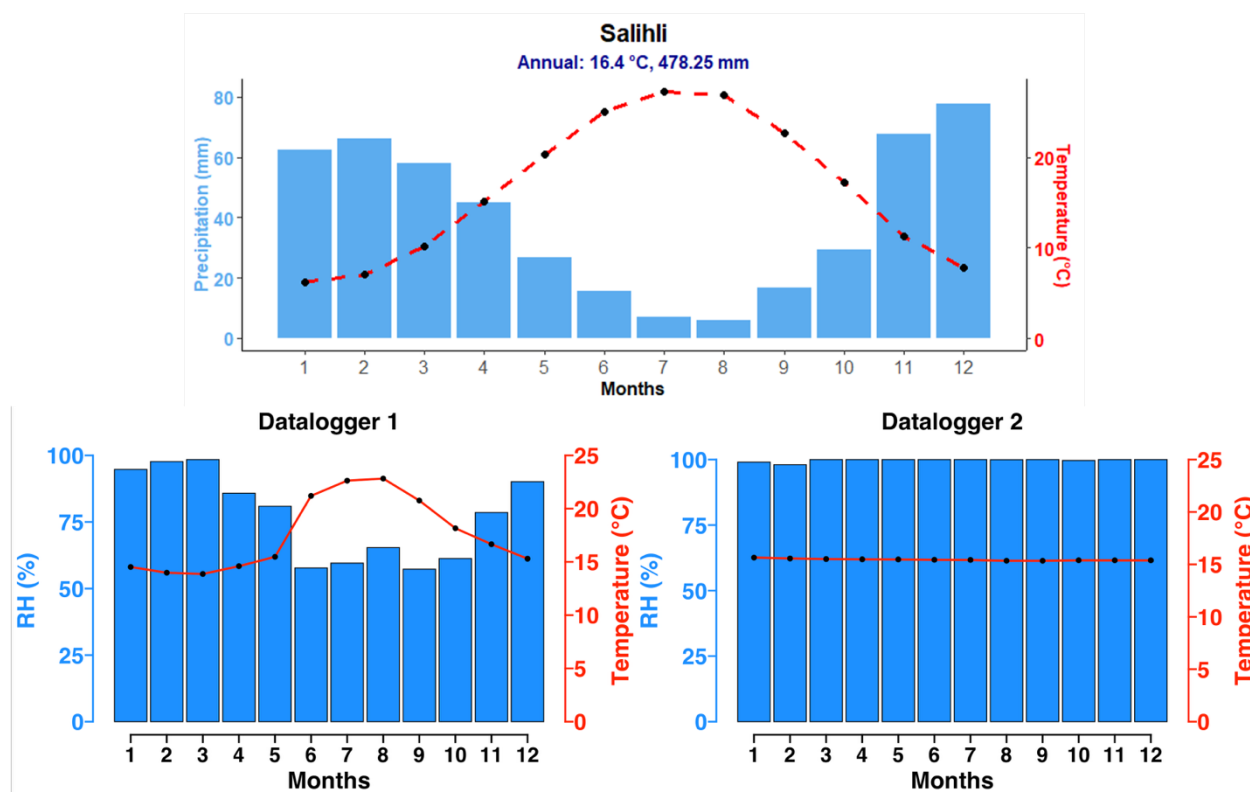


Figure 2. The top graph displays long-term monthly average temperature (red dashed line, right y-axis) and total monthly precipitation (blue histograms, left y-axis) from a close meteorological station in Salihli District (37 km far away from the cave). The bottom graphs show relative humidity (blue histograms, left y-axis) and temperature (red line, right y-axis) recorded by dataloggers from July 2023 to July 2024. Datalogger 1 represents the cave entrance; Datalogger 2 represents the interior of the cave where the samples were collected.

The similarity between individual $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ profiles of two speleothems from Börtlüce Cave indicates a robust climatic signal, providing valuable insights into past hydroclimate variability (Fig. 3). The records seem to capture major climate events such as the Bølling–Allerød interstadial and the Younger Dryas stadial, reflecting shifts in atmospheric circulation systems. A key driver of western Türkiye’s climate is linked to changes in the Atlantic Meridional Overturning Circulation (AMOC) and stalagmite from this cave could be useful for reconstructing past AMOC variability. Isotope time series

indicate wet conditions during the Early Holocene, possibly driven by North Atlantic variability through a southward displacement of the westerlies and a prevailing negative phase of the North Atlantic Oscillation (NAO). A similar pattern emerges in regional high-resolution records, such as those from Dim and Soreq caves (Bar-Matthews *et al.* 1997; Ünal-İmer *et al.* 2015). From the Middle Holocene onward, the records reveal a progressive trend toward aridity, particularly after ~6 ka, consistent with widespread drying trend reported across the Eastern Mediterranean.

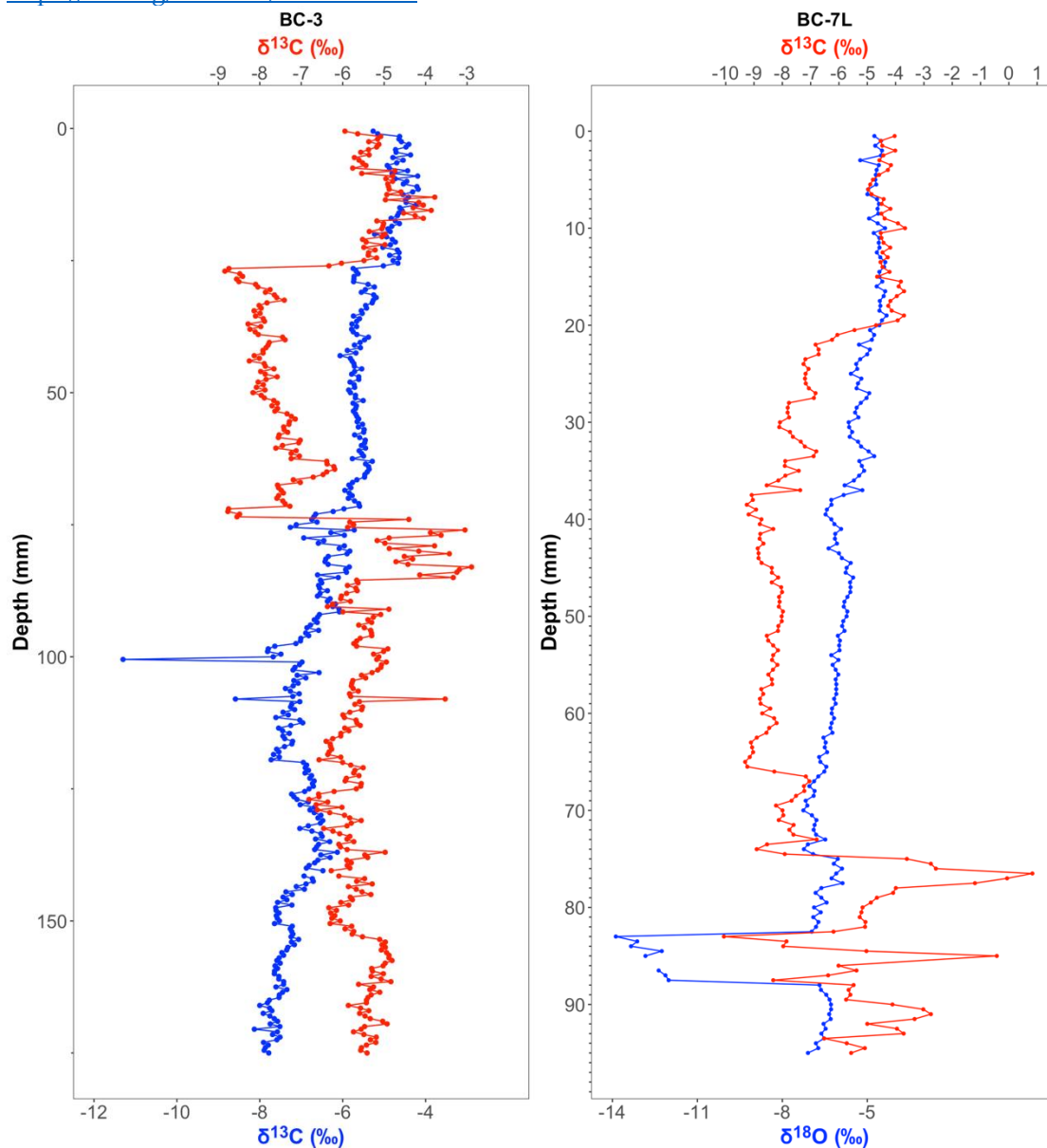


Figure 3. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ profiles of BC-3 and BC-7L measured along the growth axis (mm).

4. Conclusions

The stalagmite records from Börtlüce Cave provide a robust, high-resolution history of western Türkiye's hydroclimate since the late Last Glacial. Our preliminary findings, based on $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ analyses, indicate significant climate variability, including a wet Early Holocene and a distinct aridification trend commencing in the Middle Holocene (~6 ka). These

shifts correspond to major climatic events, highlighting the region's sensitivity to large-scale atmospheric circulation, particularly the AMOC and NAO.

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