

Reviewer 2

General assessment

This paper uses a speleothem as a climate archive, providing a rare high-resolution (seasonal to multiannual) record of climate, particularly hydroclimate, conditions in southern Iberia during a period for which there is a lack of information, the MCA-LIA transition. The location is influenced by both the full Atlantic and Mediterranean atmospheric circulations, adding another layer of importance to the study by enabling the isolation of periods of Atlantic vs Mediterranean influence. To achieve the objectives, the authors develop an age model using both U/Th dating and lamina counting, and integrate a layer analysis of the speleothem's petrographic characteristics with trace elements (measured using different ICP-MS methods, depending on whether the elements are associated with insoluble or colloidal phases), O and C isotopes, and forward modeling.

Combining different methodological approaches is certainly the right way to enable the definition of seasonal-scale processes and multiannual hydroclimatic variability in this Mediterranean karst area. Furthermore, comparing their archive results with other archives is of high importance for a better understanding of the climatic processes in the area and should lend robustness to the conclusions. That is, the scientific approach to the problem is correct and well explained.

The paper is well structured; the methodology is clear and well explained, and the data treatment and results are clearly outlined.

The figures are informative and, in most cases, readable.

The supplementary material is justified and important, with part of it related to the modern calibration study, which is essential for each proxy interpretation.

Response: We thank Reviewer 2 for this positive evaluation of the scientific approach, methodology, chronology, figures, and supplementary data. The request for a clearer hierarchy among multiple proxy controls has guided the proposed revision.

Comment 1. Multi-process controls and identification of the dominant factor

We all know that each proxy reflects a combination of effects from different processes, with the importance of each varying over time; as such, these multi-process and/or multi-factor controls need to be clearly stated or presented in a table format, and the dominant process/ factor identified and justified, in part by integrating and comparing information from independent proxies. If this is not clearly presented, the sequence of processes invoked to explain trace-metal information at any given time, or to reconcile trace-metal data with isotope data, becomes difficult to follow, and the interactions invoked become doubtful.

Response: We agree with the reviewer's request for an explicit hierarchy. The revised manuscript therefore identifies the best-supported first-order interpretation for each proxy and separately lists additional or conditional contributions; where the relative contribution of individual mechanisms cannot be uniquely constrained, this limitation is stated explicitly. Section 5.1 is now organised into three successive levels—the composition of the water reaching the stalagmite or the initial soil–epikarst signal, further modification during calcite deposition, and preservation filtering—and we have prepared a new table that presents this hierarchy and explicitly states its qualitative nature. This table would accompany the revised manuscript. The manuscript also states that the hierarchy integrates the two discrete site-specific campaigns, the high-resolution laminated interval, proxy relationships, PCA, petrography, I-STAL modelling, and published evidence from comparable karst systems, and that its application to the full record assumes broadly comparable first-order karst routing, source mixing, and depositional controls.

Mg/Ca is treated as a recharge-sensitive hydrochemical signal based on the combined modern observations, I-STAL results, proxy relationships, and published process understanding. The site-specific campaigns document a 17-fold contrast in dripwater at the sampling point; this contrast reflects changes in both Mg and Ca concentrations and supports a recharge-sensitive hydrochemical interpretation, although the two discrete campaigns do not allow the relative contribution of the individual processes to be resolved. I-STAL

also indicates that coupled degassing and PCP alone do not reproduce the full calcite range under the adopted conditions, although modification during calcite growth may still provide a secondary, condition-dependent influence. Sr/Ca and Ba/Ca are placed within a growth- and partitioning-sensitive depositional framework, while their source-water contributions remain explicit and unresolved; Al/Ca and Y/Ca are interpreted according to spatial scale as detrital/colloidal or soil-derived indicators. $\delta^{13}\text{C}$ integrates an initial soil–epikarst carbon signal and a possible in-cave overprint, whereas $\delta^{18}\text{O}$ integrates source, amount, temperature, mixing, and possible kinetic effects.

The hierarchy is justified by integrating modern dripwater chemistry, I-STAL simulations, the negative $\ln(\text{Mg}/\text{Ca})$ – $\ln(\text{Sr}/\text{Ca})$ relationship, lamina-specific Mg/Ca – $\delta^{13}\text{C}$ correlations, petrography, and the comparison between LA-ICP-MS and solution profiles. These lines of evidence are treated as complementary rather than fully independent or uniquely causal. The same proxy meanings are then applied consistently in the lamina discussion: dark laminae are not equated with a simple wet end member, $\delta^{13}\text{C}$ is not used independently as evidence of drought or dominant control by coupled degassing and PCP, and preservation filtering is separated from geochemical relationships within deposited calcite. For clarity, Figure 7 now retains only the conceptual Mg/Ca seasonal trajectory, while Sr/Ca is summarized qualitatively in a supplementary summary prepared for the revised manuscript together with Mg/Ca and $\delta^{13}\text{C}$. This avoids assigning a unique monthly quantitative trajectory to Sr/Ca while preserving its growth- and partitioning-sensitive interpretation.

Because the relative importance of secondary controls may vary with hydrochemical and depositional conditions, the revised manuscript does not assume a fixed combination of processes through time. The proposed new table presents the first-order proxy hierarchy, while Sections 5.2–5.3 evaluate changes in proxy relationships between depositional regimes, including the contrasting Mg/Ca – $\delta^{13}\text{C}$ relationships in dark and light laminae.

Comment 2.

In terms of atmospheric circulation, it has been shown that the NAO is not the sole explanation for the climate conditions observed in the Iberian Peninsula records during the last 2000 years, with the EA and SCAND also playing important roles. Their effects on the record should also be exploited.

Response: We agree. As detailed in our response to Reviewer 1 (Comment 4), revised Section 5.5 no longer interprets the record exclusively through the NAO. Reconstructions of the EA (Sjolte et al., 2018) and SCAND (Xue et al., 2026) are shown alongside several NAO reconstructions in Figure 8. We discuss three relevant pathways. (i) EA and SCAND modulate the NAO dipole and its non-stationary relationship with Iberian precipitation (Comas-Bru and McDermott, 2014; Sánchez-López et al., 2016; Mellado-Cano et al., 2019; Hernández et al., 2020). (ii) Summer SCAND may affect the summer water deficit and thus epikarst residence time, seasonal hiatuses, and the chemistry of the water mobilized by autumn recharge; this is an inference from the reconstructed warm-season circulation, not a direct attribution of the Zerolín signal (Xue et al., 2026). (iii) Blocking can modify Iberian precipitation and cut-off-low occurrence in a season-dependent way (Nieto et al., 2007; Sousa et al., 2016). We acknowledge that the EA reconstruction covers winter only and starts in 1241 CE, whereas SCAND represents summer and has reduced amplitude early in the record. Neither provides a one-to-one match with Zerolín, so these modes are discussed as plausible pathways rather than assigned to individual excursions.

Comment 3. Figure 2 caption and visibility

Figure 2 – Figure 2 – The y-axis in the figure is expressed in mm, but in the figure caption you use cm; ...the red line indicates the boundary where annual resolution is lost - Not sure it can be seen. I was not able to identify it. U–Th dates are plotted directly on the speleothem image; - Impossible to see. Consider increasing the size. The approximate growth rate, as derived from the slope of each age model, is shown on the right-hand side of the graph. - To guarantee a clear relation between the model and the growth rate, consider using the same color as the one used to identify the model in this figure.

Response: We thank the reviewer for these helpful comments. The unit in the caption has been corrected from cm to mm, the boundary marking the loss of annual resolution and the U–Th symbols have been made more visible, and the x-axis now uses calendar years. The growth-rate arrows remain neutral because they provide a common reference for age–depth slope rather than corresponding individually to one age model; the caption now states this explicitly.

Location in the prepared revision: Figure 2 and its caption.

Comment 4. Figure 7 caption

Figure 7 – Lines 370 to 374 in the figure caption - Does this paragraph really belong in a figure caption? I would include this information in the main text.

Response: We agree. The mechanistic explanation has been moved from the Figure 7 caption to the main text immediately before the figure. Figure 7 has also been updated, and its caption has been shortened. For clarity, we have further simplified Figure 7 by retaining only the conceptual Mg/Ca seasonal trajectory. Sr/Ca has been removed from the figure to avoid implying a unique monthly hydroclimatic trajectory for a proxy that is interpreted primarily within a growth- and partitioning-sensitive depositional framework. A supplementary table prepared for the revised manuscript summarizes the relative seasonal behaviour of Mg/Ca, Sr/Ca, and $\delta^{13}\text{C}$ qualitatively, together with the associated hydrochemical and depositional interpretation.

Location in the prepared revision: the paragraph preceding Figure 7, Figure 7 and its caption, and the proposed supplementary table summarizing seasonal proxy behaviour.

Comment 5.

Lines 422 – 427 - line 422 should read "... distinct in-cave and environmental processes govern $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ respectively.

Response: We agree. The sentence has been revised to distinguish the controls on both isotope systems: $\delta^{13}\text{C}$ integrates the initial soil–epikarst carbon signal and a possible in-cave overprint, whereas $\delta^{18}\text{O}$ integrates source, amount, temperature, mixing, and possible kinetic effects.

Comment 6. Figure 8- Catalán et al., 2009

Figure 8 - summer–autumn temperature reconstruction from Lake Redon (orange; Catalán et al., 2009)

This temperature is indicated as being diatom-derived (Diatom alq – what does the alq stand for?); however, I have investigated the paper you refer to and could not find it. The reference should be Catalan et al., 2002 (Journal of Paleolimnology); the Temperature is derived from assemblage composition and is expressed in °C.

Response: “Alq” was intended as an abbreviation for alkalinity, although we acknowledge that this terminology could be misleading. The orange series does not represent a direct quantitative reconstruction of air temperature expressed in °C. Instead, it represents lake-water alkalinity inferred from fossil diatom assemblages. In that study, the reconstructed alkalinity was related to summer and autumn air-temperature fluctuations, with higher alkalinity generally associated with warmer conditions during the ice-free period. It is therefore used here as an indirect, relative proxy for summer–autumn thermal conditions, rather than as a direct temperature reconstruction in °C. We agree that Catalan et al. (2002) investigated the response of the Lake Redon ecosystem to reconstructed seasonal air temperatures and presented temperature values in °C. However, that study covers a different record, focused on the last two centuries, and is not the source of the alkalinity series plotted in Figure 8. We have therefore retained Catalan et al. (2009) as the reference and revised the figure label and caption to clarify the nature and units of the proxy. The Figure 8 label has now been revised to identify the series as diatom-inferred alkalinity ($\mu\text{eq L}^{-1}$), and the caption clarifies that it is used only as an indirect relative proxy for summer–autumn thermal conditions (Figure 8 and caption).

Comment 7.

Figure A2 – Line 732 – Y-axis scale and figure caption values for concentration do not coincide, although

Response: We thank the reviewer for identifying this ambiguity in Figure A2 of the original manuscript. Its caption values, $\text{Mg/Ca} = 12.85/3 \text{ mmol/mol}$ and $\text{Sr/Ca} = 0.217/0.069 \text{ mmol/mol}$, refer to maximum and minimum stalagmite ratios in the long-term Zerolín record; they are not the inferred dripwater ratios plotted on the y-axis. We have corrected the caption to make this explicit. We have also prepared a separate supplementary figure showing the proxy relationships described in our response to Reviewer 1 (Comment 1). Both figures would be included in a revised manuscript, where their numbering would be updated accordingly.