Referee comments – RC3 – on 'Comment on egusphere-2026-414'

Anonymous Referee - https://doi.org/10.5194/egusphere-2026-414-RC3

Referee comments by RC3 in black

Author comments (AC) in purple

Paper summary

This paper presents an interesting interpretation and summary of a multiproxy dataset from Lake Sidi Ali in Morocco. It identifies recurring periodicities across multiple proxies that may reflect hydrological and climatic variability throughout the Holocene. The results suggest that lake and catchment processes may respond to a combination of external climate forcing dynamics (primarily solar cyclicity) operating at multi-centennial to multi-millennial timescales.

Whilst this paper represents a potentially valuable addition to the journal, there are a number of key weaknesses, particularly in the proxy analysis that require strengthening. These are outlined below.

Thank you very much for reviewing our study and for the overall positive evaluation.

Major Comments

1. Interpretation and presentation of XRF data

A more detailed and earlier description of the XRF dataset in the results is essential. At present, the manuscript lacks:

A substantive section describing what the measured elements represent in terms of lake and catchment processes.

Identification and discussion of key trends within the XRF data and a critical assessment of how the associated lake processes reflect hydroclimatic signals.

A strong rationale for selecting elements and log ratios into the RPGs.

Currently, the only summary provided is a covariance matrix in Figure 2d, which is insufficient for understanding the controls on these geochemical signals. Strengthening the interpretation of the XRF data in the context of lake processes is fundamental for supporting the broader process discussion presented in Section 5.4.

There is no straightforward or universal interpretation of XRF elemental data in lacustrine systems (Davies et al., 2015). Individual elements may reflect different lake-internal or catchment-related processes depending on the specific limnological, geological and hydroclimatic setting of the study site. Therefore, a central aim of this manuscript is not to rely solely on "standard" interpretations of individual elements or elemental ratios, but rather to evaluate their behaviour within the spectral domain.

We used a wide set (based on Davies et al. 2015 and Cohen 2003) of XRF-derived elements and elemental ratios (without directly referring to their interpretation). By analysing the spectral signatures of the XRF proxies and their cross-correlations, we identified two major groups of proxies showing coherent periodicity patterns. Subsequently, we integrated independent and more established environmental proxies from the same sediment core, including *Cedrus* pollen abundance and ostracod-shell δ18O values, in order to constrain the environmental interpretation of these frequency-based proxy groups. Combining the spectral characteristics with these independent palaeoenvironmental indicators allowed us to distinguish between two dominant process domains: (i) hydroclimatic and lake-level variability, and (ii) catchment erosion processes.

To further evaluate the robustness of the identified proxy groupings, we additionally conducted PCA analyses of the XRF proxy dataset (Supplementary Figures 7+8).

2. Need for multivariate analyses (e.g., PCA)

I agree entirely with the comments from Reviewers 1 and 2 that it is unclear why multivariate statistical approaches particularly PCA were not employed to reduce the dimensionality of the XRF dataset and to objectively identify the major sources of variance. Given the complexity of the dataset, a PCA would simplify and clarify the geochemical dataset upon which the paper heavily relies.

It was important for us to retain the analyses as long as possible within the original/raw-data domain and to calculate the spectral properties directly from these proxy records. A PCA can be a useful approach for reducing the dimensionality of XRF elemental datasets (Evans et al. 2019, Bertrand et al. 2024). The use of PCA scores from the dominant principal components for spectral analyses has occasionally been applied in previous studies (Gebregiorgis et al. 2020, Ferreira et al. 2025), however, this procedure mixes the original proxy signals and may alter their spectral characteristics. For example, phase shifts in the original proxy data may lead to distortions in the resulting principal components.

Nevertheless, we performed a PCA on the proxy dataset (PCA_{time}) and additionally used the scores of the first three principal components for the Redfit and wavelet analyses. For this purpose, we applied the same methodological workflow as used for the XRF data in the main manuscript. Both the PCA results and the corresponding Redfit and wavelet analyses have been included in the Supplementary Material (Supplementary Figures 7-9).

However, the grouping of the elemental proxies differs between the PCA-based approaches and the original Redfit Proxy Groups (RPGs). We interpret this discrepancy as a consequence of the linear mixing inherent to PCA ordination. PCA combines the original proxy signals within orthogonal component scores, which may alter their original spectral characteristics and potentially strengthen, weaken or distort periodicities (Gallant et al., 2018). In particular, phase shifts between cyclic proxy signals are not preserved explicitly within the resulting principal components. We therefore decided to retain the RPG concept based directly on the spectral properties of the original ("raw") proxy records, as this approach preserves the individual frequency behaviour of the proxies more directly. We added small discussion chapter in the supplementary materials (Chapter S5).

A more detailed methodological evaluation of the interaction between ordination techniques and spectral analyses in palaeoclimate time series would certainly be highly valuable. However, we consider such a dedicated methodological investigation to be beyond the scope of the present manuscript. Nevertheless, we hope that the additional PCA analyses included in the Supplementary Material may stimulate further discussion about the combined use of ordination methods and spectral analyses in palaeoenvironmental research.

3. Interpretation of redox-related signals (section 5.4.3)

Redox-sensitive elements can be influenced by multiple processes, such as lake circulation and eutrophication, in addition to hydroclimatic forcing. The manuscript does not sufficiently demonstrate that the observed redox trends are primarily climate-driven. A multivariate analysis would again be valuable to determine the relative importance of different redox-sensitive elements to the dataset variability.

Redox-sensitivity (Mn and Fe) is discussed carefully in Section 5.4.3. Our results indicate that Fe is not exclusively controlled by redox-related processes, but is also influenced by the same mechanisms that govern erosional dynamics and the input of detrital mineral material into the lake. In contrast, Mn and the Fe/Mn ratio show a distinctly different behaviour and frequency pattern, suggesting the influence of an additional process domain, which we cautiously interpret as being related to redox-sensitive lake-internal processes. The same pattern can also be observed in the PCA analyses (PCA_{time}) in the Supplementary material, where Mn as sensitive element is related to PC 3.

We therefore revised the respective sections and formulated the interpretations more carefully in order to better acknowledge the potential influence of multiple interacting processes.

4. Ostracod isotopes

The interpretation of the ostracod $\delta^{18}O$ and $\delta^{13}C$ signals requires strengthening. At present, the treatment of these data is incomplete, and the manuscript does not justify the species selected for analysis. Moreover, the potential covariance or anti-correlation between $\delta^{18}O$ and $\delta^{13}C$ – patterns that may have important implications for reconstructing hydroclimatic variability – is not explored. These relationships should be examined and discussed in greater detail to support the claim that the isotopic signals reflect regional climatic forcing rather than just local lake-specific processes.

Thank you for this important comment. In Line 140 we refer to the picked and analysed ostracod species (*Fabaeformiscandona* sp. and *Candona* sp.). We agree that the interpretation of ostracod $\delta^{18}O$ and $\delta^{13}C$ signals requires careful consideration. However, we note that these proxy records have already been extensively presented and interpreted in previous studies (Zielhofer et al., 2017a; Zielhofer et al., 2019), including a detailed justification of species selection and a comprehensive discussion of the hydroclimatic significance of the isotopic signals.

In the present manuscript, our objective is not to re-evaluate these isotope records in isolation, but to build upon the established hydroclimatic interpretations and integrate them with the XRF-based proxy data. We therefore rely on the published interpretations of the $\delta^{18}O$ and $\delta^{13}C$ records and use them as a reference framework for comparison with our geochemical analyses.

We have checked the manuscript to more explicitly state that the isotope data and their interpretation follow Zielhofer et al. (2017a, 2019), and that we focus in this study on the integration of these established hydroclimatic signals in the spectral analyses framework. We hope that the revised manuscript now presents these aspects more clearly to the reader.

5. Additional figure recommendation

The manuscript would also benefit from an additional figure plotting the main proxy datasets against core depth. This would assist in visualising stratigraphic changes and contextualising the proxy interpretations.

Thank you for this suggestion. However, we decided not to include a full stratigraphic plot of all elemental proxy records against core depth in the manuscript, as the focus of this study is not primarily stratigraphic but rather on the frequency-domain behaviour and coupling of the proxy signals. Detailed stratigraphic descriptions and presentations of the Sidi Ali sediment record have already been provided in previous publications on the same core (e.g. Zielhofer et al. 2017a, b).

To improve the readability and contextualisation of the proxy variability, we instead focus on the major trend changes and peak structures of the proxies in Fig. 5, which provides a condensed overview of the temporal behaviour of the different proxy groups while avoiding excessive figure complexity in the main text. Nevertheless, we also improved the description of the figure to provide a clearer understanding and facilitate easier interpretation by the reader (as Reviewer also suggested).

Specific comments

Figure 5: I agree with the comments of Reviewer 2 that I find this figure unclear. Annotations and a clearer explanation of the key trends are required.

Thank you for this comment. We agree that the previous version of Fig. 5 was not sufficiently clear. We hope that the revised figure and caption now provides a clearer overview of the major hydroclimatic and catchment-related trend changes throughout the Holocene.

L319: it is stated that $\delta^{18}O$ and $\delta^{13}C$ values are anti-correlated. This could have important implications for the interpretation of the isotopic signal, but no further information is provided. Either remove this sentence and discuss elsewhere or provide more information on the relevance of this signal.

We have deleted the sentence. $\delta^{18}O$ and $\delta^{13}C$ data of our record were published, interpreted and discussed by Zielhofer et al. 2017 and Zielhofer et al. 2019. See comment above (Point 4: Ostracod isotopes)

L363: Delete accelerated.

Corrected.

L366: Remove 'described to be'

Corrected.

L383-385: Unclear how a 2ka signal in Scotland is relevant to N. African hydroclimate. Either remove or discuss the relevance of this point to the Sidi Ali hydroclimate record.

The sediment sequence and bromine (Br) record from Stewart et al. (2017), derived from a coastal peat bog in northern Scotland, has been interpreted as a proxy for Holocene storminess. This record reflects variability in North Atlantic atmospheric circulation, which is closely linked to the NAO-like (North Atlantic Oscillation) pattern. We include this record in our analyses to compare periodicity patterns with NAO-related variability. A widely used reference in this context is the record by Olsen et al. (2012); however, it extends only back to ~5 ka BP. In contrast, the Stewart et al. (2017) storminess record captures North Atlantic variability back to ~8 ka BP, thereby covering a substantially longer time interval relevant to our study. We, therefore, prefer to retain this record in our comparative framework. Although geographically distant from the study site, it reflects large-scale North Atlantic climate dynamics and, thus, provides valuable context for interpreting supra-regional hydroclimatic variability.

We added the following sentences along the first mention of the record in the discussion chapter. “Stewart et al. (2017) reconstruct past variations in North Atlantic storminess and atmospheric circulation, reflecting changes in the NAO-like. As such, it represents an important archive of North Atlantic climate variability, which is directly relevant for interpreting hydroclimatic changes at Sidi Ali due to the strong influence of NAO-driven westerlies on moisture transport into the Mediterranean region.”