

Referee comments – RC2 – on 'Comment on egusphere-2026-414'

Anonymous Referee - <https://doi.org/10.5194/egusphere-2026-414-RC2>

Referee comments by RC2 in black

Author comments (AC) in purple

This is an interesting and potentially valuable study from Schmidt et al and I am confident that it would make a great addition to *Climate of the Past*. The manuscript applies an innovative frequency-domain approach to high-resolution lacustrine geochemical data from an underrepresented palaeoclimatic region, and the attempt to group XRF proxies based on shared spectral behaviour is original and promising. The Lake Sidi Ali record has clear potential to contribute meaningfully to discussions of Holocene hydroclimatic variability in northwest Africa. I really enjoyed reading this manuscript and learnt a lot about the methodology.

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

Comments:

The abstract is detailed and methodologically informative, which I appreciate. However, the main scientific findings and their broader significance could be communicated more clearly. The key conclusions are present, but they appear rather late and are somewhat overshadowed by methodological detail. I suggest ending with one or two more direct sentences that state the principal findings and why they matter for clarity.

Thanks. We adjusted the abstract based on your comment and added information about further analyses we did during the review process.

The statement of aims is slightly inconsistent in structure. The manuscript first presents aims (i)-(iii), then follows with an additional summarising aim introduced differently. It would read more clearly either to frame (i)-(iii) explicitly as objectives and have the final sentence as the overarching aim, or to keep all aims in the same format.

Thanks. Very good point. We have framed the specific “aims” as objectives complemented by the overarching aim.

Line 97 - “with individual trees exceeding 800 years in age” may read more smoothly than “trees reaching up to more than 800 years”.

Thanks. Corrected.

Table 1- Because the temporal resolutions are given as approximate values throughout, it may be clearer to title the relevant column “Approximate temporal resolution” rather than repeating an approximation symbol in each cell.

Thanks. Corrected. It reads better this way.

Figure 2 is a helpful conceptual illustration. However, the label “significant spectrum” in panel C is difficult to read at page size. Please consider improving legibility, for example through font size, or revised labelling.

We have revised the figure and the label. Thanks.

Please justify more clearly why a third-order polynomial regression was selected for detrending. Polynomial detrending can remove genuine low-frequency climate variability as well as edge effects, so it would be useful to explain why this choice is appropriate here, or ideally to show that the principal spectral results are not overly sensitive to the detrending method.

Cubic polynomial regression detrending is common in palaeoclimatic time series detrending. For example, Zielhofer et al. (2017a), who also worked at the Holocene sediment sequence of Lake Sidi Ali, chose a cubic polynomial fit (and many studies more). A linear or quadratic fit may be too restrictive, whereas a cubic term allows inflection points and better represents smooth, low-frequency structure without overfitting. Higher-order polynomials can begin to fit higher-frequency variability, which are our signals of interest in the periodicity analysis. A cubic polynomial is, therefore, a pragmatic upper limit that removes only the broadest trend component.

Concerning edge effects: A (windowed) LOESS-based detrending (span = 0.75) was also tested exemplarily to evaluate edge effect sensitivity to the detrending method. Of course, it introduces its own bias in edge asymmetry. Nevertheless, the resulting spectra are consistent with those obtained using a third-order polynomial, indicating that the identified spectral features are not an artifact of the detrending approach. We therefore revised and expanded the methodological description in order to present the workflow more transparently and clearly, allowing the robustness and limitations of the approach to be more easily assessed by the reader.

We added the following sentence: “The order of the model was chosen to ensure that variability with periods longer than approximately half the length of the record is removed prior to spectral analysis.”

Grouping proxies based on correlations among significant Redfit spectra is innovative, but the robustness and limitations of this procedure deserve further discussion. For example, how sensitive are the groups to the chosen significance threshold, detrending approach, interpolation method, or age uncertainty? A short sensitivity analysis, or at least a fuller discussion, would strengthen confidence in the grouped interpretations.

Thanks for the important comment. Of course, limitation and robustness are important to strengthen the main interpretations. We therefore expanded Section 5.1 and clarified that the RPGs should be interpreted as groups of proxies with coherent spectral behaviour rather than as direct process classifications. We further discuss the influence of the conservative AR(1) significance threshold, detrending and interpolation procedures, as well as chronological uncertainties. In particular, we emphasize that the Redfit-based grouping itself is independent of interpolation, because the Redfit analyses were conducted on the unevenly spaced original datasets.

Additionally, to further evaluate the robustness of the identified periodicity structures, we conducted supplementary PCA analyses on both the original proxy dataset (PCA_{time}) and the extracted spectral information (PCA_{freq}). The first principal components (PCA_{time}) show periodicity patterns comparable to those obtained from the original proxy records. These additional analyses, now included in the Supplementary Materials (Supplementary Figures 7-9), support the robustness of the identified millennial-scale spectral structures.

The manuscript would benefit from a clearer explanation, earlier in the paper, of why these particular elements and element ratios were selected and what process hypotheses they are expected to represent at Lake Sidi Ali. While the later discussion develops these interpretations, readers would benefit from more guidance before reaching that section. I would agree with Reviewer 1 and suggest that a PCA could be used here as I have no doubt that the chosen elements are grouped together, but visually it would be good to see. Perhaps this could go into the supplementary information if not needed in the main manuscript.

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 $\delta^{18}\text{O}$ 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.

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 Materials (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 a short 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.

Additionally, we performed a PCA in the frequency domain (PCA_{freq}) to evaluate the robustness of the grouping approach. The PCA results independently confirm the proxy groups identified by the correlation matrix shown in Fig. 2D. The corresponding PCA results (biplot with loadings) are now provided in the Supplementary Materials (Supplementary Figure 8).

We further added a new subchapter in the material and methods section, that explains and describes our PCA analyses (3.3.2).

Figure 5 presents an interesting summary of proxy evolution through time, but I found it difficult to extract the main message. If the figure is retained in its current form, I suggest adding annotations or a clearer explanation in the caption and main text to direct readers toward the major patterns and take-home points.

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.

More generally, I encourage the authors to distinguish carefully between proxies that show similar frequency behaviour and proxies that can be confidently interpreted as reflecting the same environmental process. The grouping is compelling, but the mechanistic interpretation remains an inference and should be framed as such.

Thank you for this important comment. We agree that a clearer distinction between coherent spectral behaviour and environmental process interpretation is necessary. We therefore added a short paragraph at the beginning of the Discussion section (Section 5.3) to explicitly clarify that the environmental interpretation of the RPGs is based on the integration of the XRF-derived frequency analyses with independent palaeoenvironmental proxies and established process understanding.

In addition, we carefully revised the manuscript throughout and reformulated several interpretations more cautiously in order to better distinguish between statistical proxy coherence and inferred environmental mechanisms.

The manuscript usefully notes that age uncertainty constrains the robustness of shorter periodicities and that comparisons with lower-resolution non-XRF proxies are partly visual. These caveats are important and could be made more visible where the shorter-period features and cross-proxy comparisons are discussed in the Results and Discussion.

We expanded Section 5.1 regarding the robustness and sensitivity of the frequency analyses, and the associated caveats should now be more clearly visible throughout the manuscript. In addition, we included several short notes within the interpretation sections of the individual proxy groups to explicitly highlight the need for caution when interpreting shorter periodicities and cross-proxy similarities.

Furthermore, the robustness assessment following Hatvani et al. (2022) indicates that periodicities with cycle lengths of approximately ≥ 300 years can be interpreted robustly within

the constraints of the chronology and temporal resolution of the record. Consequently, shorter periodicities were not used as a basis for the main palaeoenvironmental interpretations presented in the manuscript.

You change between hydro-climatic and hydroclimatic. I believe either is fine, but best be consistent throughout.

Thanks. We changed all instances of the term to “hydroclimatic”.