

## Referee comments – RC1 – on 'Comment on egusphere-2026-414'

Anonymous Referee - <https://doi.org/10.5194/egusphere-2026-414-RC1>

Referee comments by RC1 in black

Author comments (AC) in purple

Summary: The manuscript presents the analysis of several types of geobiochemically derived proxy data extracted from a lacustrine record in Morocco spanning the Holocene. The proxies are mostly believed to represent broad hydroclimatological conditions in the region. The proxies are grouped into three categories based on their cross-correlation. The time series is subject to a spectral analysis to identify the main periodicities. These periodicities are interpreted, mostly heuristically, as driven by large-scale hydroclimatic conditions or by more local lacustrine processes.

Recommendation: This careful and comprehensive analysis is well reflected in the manuscript, and it is also compared to other records from this region. I have a few suggestions, mostly concerning the statistical analysis, that the authors may want to consider

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

1) The grouping of the proxies seems a bit simplistic: just subjectively grouped by their cross-correlations. A more objective grouping could be achieved simply by principal component analysis. This would have the additional advantage of providing a single time series for each component that could then be compared to a series of reconstructed solar activity, for instance. (see point 2)

Thank you very much for your comment. The grouping of proxies was based on cross-correlations of their spectral properties within the frequency domain.

A principal component analysis (PCA) combines the input variables linearly within the component scores. This can modify the original spectral signal and may strengthen, weaken, or artificially introduce periodicities (Gallant et al., 2018). Therefore, we aimed to conduct the time-series statistics, as far as possible, using the original (“raw”) proxy data rather than transformed component scores. For this reason, the proxy grouping was primarily carried out on the basis of their spectral characteristics.

Nevertheless, we additionally performed a PCA in the frequency domain ( $PCA_{\text{freq}}$ ) 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).

For the comment regarding the use of principal components for spectral analyses, please also see our response to point 2.

2) The physical interpretation is essentially heuristic. The authors visually identify the more important spectral ranges, thereby attributing those variations to known forcings that exhibit similar spectral ranges. Whereas this is common in this type of study, this approach seems a bit superficial, as a common spectral band is a necessary but not sufficient condition: also, the phase of the variations is important for attributing them to, say, solar forcing.

Calculating the PCA components would simplify that comparison. Figure 4 attempts this type of attribution by visually identifying the maxima and minima of the individual time series, but this Figure also illustrates that a confirmation bias is dangerously possible. One can always find maxima or minima that, to some extent, agree.

In this case, to claim the identification of solar forcing, the series of one of the PCs should closely agree with the reconstruction of solar activity of Usoskin et al. 2016 (their figure 3c). Such an agreement would be a much more robust confirmation.

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 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.

#### Particular points

3) ' Further, Sha et al. (2019) presented a speleothem record from the SW High Atlas Mountains, that seems not to be influenced by Atlantic air masses but rather tropical-monsoonal air masses'

The use of commas to introduce subordinate clauses is sometimes incorrect throughout the manuscript, but this is an example that impacts the meaning. With the comma, the sentence indicates that the Atlas Mountains are not influenced by the Atlantic air masses. Without the comma, it is the record that is not influenced by the Atlantic air masses. I guess the authors meant the latter case, so the comma should be deleted.

Thank you very much. We have checked the entire manuscript for correct punctuation and revised the manuscript accordingly.

4) 'Currently, the lake is seprated '

Separated

Thanks. Corrected.

5) 'The red noise background is sensitive to the specific persistence of the data and therefore higher frequencies are often covered by the red noise'

I cannot understand what this sentence would mean. Perhaps they mean that the existence of red noise in a time series blurs the high-frequency variations?

But red noise is not a 'background', it is a property of the time series. Whether or not high frequency variations are blurred or not depends on the relative spectral energy in their respective bands

Thanks. We have deleted the sentence.

6) 'We used the most conservative critical false alarm level (Schulz and Mudelsee, 2002)'

I guess the authors mean that they used the most conservative choice offered by the software. The most conservative option possible is always that no peaks is considered significant.

We used the critical false alarm level, that is determined by the properties of the data and therefore may be more conservative than commonly selected thresholds of 90, 95 or even 99 % confidence. We revised the sentence accordingly.

7) 'Zielhofer et al. (2017a) argued for the Sidi Ali record, that..'

Delete comma

Corrected.

8) 'The latter is in accordance to the 1 ky periodicity of the hydroclimatic  $\delta^{18}\text{O}$  signal '

in accordance with

Thanks. Corrected.

9) 'Stewart et al. (2017) presented a Bromine record from a peat bog in Scotland, which shows a distinct 2 ky cycle pattern'

... Scotland that shows a .....

Again, delete the comma. I guess that Scotland does not present a 2 k cycle pattern.

😊 Correct. Thanks. We have checked and corrected the punctuation of the entire manuscript.