Response File – Climate of the Past Manuscript cp-2026-590

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Title: Advancing Last Glacial Maximum paleoclimate reconstructions in Europe using pollen data: a multi-method (mega)biomization approach

We sincerely thank the reviewers for the time, effort, and thoughtful consideration they devoted to reviewing our manuscript, as well as for their insightful comments and constructive suggestions, which greatly helped improve the quality of this work.

Reviewer comments are shown in *italic*. Our original responses are shown in **bold** and the updated descriptions of how we propose to modify the manuscript are indicated in **bold blue text**. Quotations from the original manuscript are shown in ***bold italics*** and quotations from the proposed manuscript are shown in ***bold blue italics***.

Reviewer #3: RC3: 'Comment on egusphere-2026-1590', Anonymous Referee #3, 10 May 2026

Overview and general recommendation:
I found the manuscript submitted by Fenisse et al. to be very detailed and informative. Although I am not an expert in pollen analyses, their investigation seems highly valuable because it provides an honest attempt to address the complexities, challenges, and limitations of analyzing pollen data for paleoclimate reconstruction. The fact that they compare various approaches and techniques effectively highlights the inherent uncertainty that should be considered when analyzing such data, or when interpreting results derived from it. Overall, the manuscript is well written, and I found only a limited number of places where rewording or minor corrections would be beneficial.

One major suggestion concerns improving how the uncertainty associated with these analyses is presented. Specifically, the table on page 29 provides very broad ranges for each of the analyzed parameters, yet the authors focus primarily on mean values. For example, what does a value of −7 ±1/−12 actually convey? While this clearly suggests cooling, in reality it represents a very large range. I think the authors should make a stronger effort to present and discuss these uncertainties, as they are crucial for the paleoclimate community. Should modelers aim for −7, −10, or −20 in this region? Should geologists expect long-term glaciation or other features? This intercomparison project is a valuable opportunity to explore these uncertainties in greater depth and to indicate which records are more robust than others. For example, can the uncertainty be summarized spatially and temporally, perhaps through maps showing confidence levels alongside the reconstructed climatic parameters? Identifying and possibly excluding problematic archives (i.e., those with large discrepancies or variability), and visually indicating areas of substantial uncertainty, would significantly strengthen the impact of the study.

Uncertainties associated with MAT and WA-PLS reconstructions reflect several sources of error related to the statistical reconstruction framework and the quality of taxonomic information. They include calibration errors in the pollen-climate relationship, uncertainties associated with analogue and non-analogue situations, and the width of taxonomic ecological niches, which depends on the taxonomic resolution of the dataset. These uncertainties do not represent direct errors on fossil assemblages, but rather errors estimated from modern calibration datasets for which the climate is known. RMSEP values are therefore defined as the differences between observed and reconstructed climate values within the modern training dataset.
For clarity, we added the following sentence in the revised manuscript: « *Climate reconstruction uncertainties for WA-PLS and MAT are expressed as root mean square errors of prediction (RMSEP),*

calculated from leave-one-out cross-validation of the modern training dataset, by comparing observed and reconstructed climate values (Birks, 1995)." (line 520-523).

The original reconstruction uncertainties are provided in Table 6 in the Appendix. In the potential revised manuscript, we propose revising this table to report uncertainties at the 1σ level (instead of 2σ in the original manuscript). All climatic errors are now plotted at the 1σ level.

We further provide two levels of aggregation of the reconstructed climatic values.

- i. **Site-level means and uncertainties are computed across the three reconstruction methods, yielding a combined uncertainty that accounts for both inter-method dispersion and individual RMSE-based errors (Appendix 6). Only Appendix 7 presents these total uncertainties in graphical form. A detailed description of the error calculations has been added to the potential revised manuscript: "While MTCO results show greater dispersion across European sites compared to other climatic variables, MTCO internal errors are generally higher than those associated with annual and summer temperatures (Appendix 6), consistent with the validation uncertainties discussed in Section V.2. Seasonal uncertainties are then derived as the quadratic sum of summer and winter temperature errors. Mean errors for these two climatic variables are reported in Appendix 8, also accounting for external uncertainties derived from inter-site dispersion." (#line).**
- ii. **We provide European-scale multi-method means and uncertainties (aggregating all sites), where only the dispersion (standard deviation) of mean values is reported. These results, labelled "mean SD", are also included in Appendix 6. This approach is intended to provide a representative mean climatic state at the European scale. We propose providing additional information in the caption of Table A6 in the Appendix.**

#Minor suggestions:

L22 – Replace "resolved" with "utilized." "Resolved" implies a definitive interpretation, whereas pollen data have multiple limitations (e.g., source area, sedimentation regime, preservation).

We therefore propose replacing "resolved" with "highest-resolution" to better reflect the spatial and temporal scales of pollen datasets, without overstating their interpretative capacity. *"Pollen records are among the highest-resolution spatial and temporal proxies for reconstructing past vegetation dynamics, environmental changes and climate variability" (first line in abstract).*

L61 – Similarly, consider replacing "robust" with a milder term.

To better nuance this statement, we propose replacing "robust" with "quantitative" (line 62).

L66 – Please provide examples of such "key periods."

We propose clarifying the term "other key periods" in this sentence (line #) by providing examples. *"(e.g., Paleolithic, Charton et al., 2025 and Marine Isotope Stage 3 (MIS3), Zumaque et al., 2025)." (line #).*

L72 – Revise the time notation according to the journal's policy (e.g., ky, ka).

Thanks, the time notation has been revised to comply with Climate of the Past guidelines (e.g., ka for thousands of years). At the same time, we propose changing "kyr cal BP" with "cal ka cal".

L75 – Please rephrase: the methods are not developed from pollen data, but rather utilize pollen data.

Alternatively, we propose replacing "has been developed from" with "has been used based on" (line 75).

L149 – Please explain what "physiognomic" means.

"Physiognomic" refers to the structural characteristics of vegetation (e.g., growth form, canopy structure, and plant stature), whereas "physiological" relates to the functional and metabolic processes of plants.

We propose providing brief definitions of these technical terms.

"physiological (metabolic processes) and physiognomic (vegetation structure) data" (line 149).

L214 – Use "ranges from X to Y."

We propose adding the term "ranges" before the k-value intervals.

"("k" ranges from 8 to 10)." (line 469).

L297 – Please plot the data on a map alongside current Köppen–Geiger climate and vegetation groups.

Sampling site locations have been superimposed onto Köppen-Geiger climate zones related to vegetation groups (Beck et al., 2018). This figure is provided in Appendix 1.a. Une description synthétique des répartitions des analogues modernes et leur assignation aux classes Köppen-Geiger est proposée en réponse au review « Anonymous Referee #2, 10 May 2026 ».

Page 10 – The table contains many acronyms that should be explained in the caption.

Thanks for this remark. The (mega)biome acronyms used in this table are defined later in Sections IV.1.2 and IV.1.3, which describe the (mega)biome reconstruction procedures. Since Table 1 is intended to present the raw dataset, we propose removing the last two columns containing these acronyms, which are introduced later in the manuscript. This acronym information has therefore remained available in Supplementary Material A (figure 1).

L365 – Please clarify what is meant by "harmonized," including the specific procedures used (e.g., labeling, data organization).

This harmonization procedure consists of standardizing taxon labels into a common nomenclature shared by both modern and fossil pollen spectra prior to dataset comparison. This first processing step aims to homogenize pollen assemblage compositions according to common taxonomic standards. The harmonization of pollen sample labels ensures consistent correspondence among genera, families, and species across datasets, while also allowing the exclusion of aquatic taxa considered as indicators of local environmental conditions.

The harmonization table is provided in Supplementary Material E (HarmonizationTable).

We propose adding the following wording: "Standardization of taxonomic labels".

"The modern pollen dataset was harmonized (standardization of taxonomic labels) using the same table used for the fossil pollen data (i.e., LegacyPollen 2.0)." (line 290-293).

L373 – Please include scatter plots illustrating relationships between key geographic variables (latitude, altitude, distance from the ocean) and the main climatic variables (mean temperature, precipitation, hottest/coldest month, wettest/driest periods).

We agree that illustrating the relationships between geographic and climatic variables would improve the readability of the modern calibration dataset. We therefore added scatter plots showing the relationships between the main geographic parameters (latitude, altitude, and distance from the ocean) and the principal climatic variables (mean annual temperature and temperature of the warmest/coldest month).
These new figures are now included in Appendix 2 and further illustrate the geographic climatic gradients discussed in the manuscript, particularly latitudinal influences.
"[…] and represented by colored points in Appendix 2" (line 297-298).

Only mean annual temperature and summer temperature exhibit robust latitudinal gradients. No significant longitudinal signal, which would be expected under a continentality effect, is detected for any of the temperature variables. We further exclude modern precipitation from the analysis, as its reconstructions remain highly uncertain under reduced atmospheric pCO_2 conditions, potentially biasing representations of LGM climate states.

L433 – Please present the RMSE as an equation for the readers.

We propose revising the manuscript to clarify the affinity score methodology and improve its readability. Meanwhile, this formulation does not correspond to a Root Mean Square Error (RMSE) calculation, as no squared residuals (error minimization) are involved. Instead, the square-root transformation is applied solely to stabilize variance and to enhance the contribution of less abundant taxa, following Overpeck et al. (1985).

Then, we propose changing "follows the sum of square root procedure (square-root transformation) to assign pollen taxa to biomes" with *"[…] proceeds from taxa to PFTs and then from PFTs to biomes through a square-root transformation using pollen taxon abundances (Prentice et al., 1996; Prentice and Webb, 1998)." (line 358).*

L462 – Replace "to" with "from."

Corrected. Done

L528 – This section is somewhat confusing, as it reads like an RMSE is being calculated from a categorical classification. Please clarify and revise.

Climate reconstruction uncertainties for MAT and WA-PLS are expressed as root mean square errors of prediction (RMSEP). These RMSEP values are derived from leave-one-out cross-validation of the modern calibration dataset. Each sample is sequentially removed from the dataset, and its climatic value is reconstructed using the remaining samples. The reconstructed values are then compared to the observed climatic variables, and the differences are used to compute the RMSEP.

We propose replacing "Climate reconstruction uncertainties of WA-PLS and MAT are provided as root mean square errors of prediction (RMSEP) derived from leave-one-out cross-validation." with *"Climate reconstruction uncertainties for WA-PLS and MAT are expressed as root mean square errors of prediction (RMSEP), calculated from leave-one-out cross-validation of the modern training dataset, by comparing observed and reconstructed climate values (Birks, 1995)."*

L695 – Why is the word "correlation" in parentheses?

We propose replacing the term "correlation, r" with the "r correlation coefficient" associated with the linear relationship to avoid any ambiguity.