LegacyClimate 1.0: A dataset of pollen-based climate reconstructions from 2594 Northern Hemisphere sites covering the late Quaternary

Response to comments of Referee #2 (P.J. Bartlein)

1. General comments

Reviewer comment: (1) *This paper describes a set of pollen-based climate reconstructions for the Northern Hemisphere from the LGM to present. The paper is obviously one of three, one describing the pollen data (Herzschuh et al., submitted, which I couldn't find), another describing the chronology (Li et al., 2022, ESSD-Disc), and this one, describing the reconstructions. There are obvious redundancies among the papers, and I think readers and potential users of the data will find it frustrating to have to track down three papers.*

Response: We revised the entire paper. We now refer to the other papers (which became published in the meantime) and kept redundancies only where necessary to understand the dataset and R.

Reviewer comment: (2) *Overall, the paper is not that well organized, with motivations for some of the analyses (e.g. CCA) not appearing until the results section (Section 4, titled "Dataset assessment"), and tutorial material on the nature of pollen data as a palaeo-archive appearing in the discussion, as opposed to the introduction (and presumably also in the first paper of the series, which, with good cross-referencing among the papers, would make it superfluous here). Perhaps this disorganization arose in parting-out the papers.*

Response: We restructured parts of the manuscript. The section about the reconstruction methods are now separated in climate reconstruction and the indication which additional measures were calculated as quality measures. In the results now one-by-one the results of the dataset quality measures are presented.

2. Major issues

Reviewer comment: (1) *Why were January and annual temperature and annual precipitation chosen as the targets for reconstruction? A more appropriate set of climate variables might be those that mechanistically control vegetation like winter cold, summer warmth, and moisture stress. A lot of the paper is devoted to dealing with the obvious correlation between annual temperature and precipitation, but it is never actually established why this is an issue.*

Response: We selected the target variables a priori. We reconstructed T_{July} and P_{ann} because they (or variables that are highly correlated with these variables) are known as major climate variables driving vegetation composition (e..g Cao et al., 2013) and Tann because this is used in many syntheses studies and data-model comparisons.

Reviewer comment: (2) *What was the role of the canonical correlation analysis? To simply explore the data perhaps, but in fact it represents an alternative reconstruction approach. In any case, it's neighther clear what the purpose of the analysis is, nor are the results fully explained.*

Response: We applied CCA to the modern calibration set to explore the modern relationship between the pollen spectra and the climate variables. High values of lambda1 (explained variance of the constrained) vs lambda2 (the unconstrained axis) is commonly considered as a measure how well the target environmental variable is related to the modern pollen data set (e.g. Juggins 2013). We provide this information for users of our data set. They can use it make decisions which sites should be include in their analyses. We explained the rationale in the method part and added further discussion in the discussion part.

New text Method part: We applied a Canonical Correlation Analysis (CCA) to the modern training dataset in order to explore the modern relationship between the pollen spectra and the climate variables and to infer the explained variance in the modern dataset by using the cca function in the vegan R-package (version 2.5-7, Oksanen et al., 2020). The ratio between constrained ($\lambda 1$) and unconstrained ($\lambda 2$) explained variance was determined for all modern training datasets. High values of $\lambda 1$ vs $\lambda 2$ are commonly considered as a measure how well the target environmental variable is related to the modern pollen data set (e.g. Ter Braak, 1988; Juggins 2013).

New Text Discussion part: We a priori selected T_{July}, T_{ann} and P_{ann} as target variables for our reconstructions. However, we provide λ_1/λ_2 (i.e. explained variance of the climate variable in the modern pollen data set relative to the variance explained by the unconstrained first axis; ter Braak, 1988), a commonly used proxy for the assessment of reconstructions. The higher λ_1/λ_2 in the spatial modern dataset higher the chance that this target climate variable has also impacted vegetation over time and is thus reflected in the variation of the fossil pollen dataset. As a rule of thumb a ratio of 1 is considered to indicate reliable reconstructions (Juggins, 2012) though useful reconstruction may also be obtained from datasets with lower values. As expected, maps of RMSEPs reveal similar spatial pattern as the results of constrained ordination. Our results indicate that in particular calibration sets from Europe have low ratios and a high RMSEP for all climate variables (despite we have a high number of modern samples), likely related to the human impact on the modern and fossil data.

Some areas that are known for its sensitivity to precipitation e.g. Eastern Asia show low RMSEPs as expected for P_{ann} but on the other hand show a low sensitivity to T_{ann} and T_{July}.

Reviewer comment: (3) *The two reconstruction approaches, weighted-averaging – partial-least-squares (WA-PLS) and the modern analogue technique (MAT) may be frequently applied, but they are not without issues themselves. WA-PLS, as is the case with some other methods, tends to "compress" the reconstructions toward the center of the distribution of the climate data (see Liu et al, 2020, Proc. Royal Soc. A, https://doi.org/10.1098/rspa.2020.0346). This will reduce the amplitude of the time series of the reconstructions. MAT suffers from the no-analogue problem, typically diagnosed by looking at the dissimilarities. The performance of the two approaches are examined in Fig. 3, but there is no attempt to account for the obvious spatial patterns.*

Response: This manuscript provides and describes the dataset of the reconstruction and in addition of quality measures. Depending on the purpose of the studies that the users implement they can account for potential biases taking our quality measures as guidance.

Reviewer comment: (4) *A number of the analysis steps are not explained much at all, with the results just briefly described before moving on. In particular, the significance testing in Section 4.2 isn't fully explained: What is the "take-home message"? What does this analysis say about the usefulness of the reconstructions.*

Response: See our response before. Whether or not our reconstructions are useful depends much on the purpose of the study that the user of the data will implement. With our quality measures, they can make their decisions based on common numerical quality measures.

Reviewer comment: (5) *The results are described in terms of mid-Holocene minus present (1.5 to 0.5 ka) long-term mean differences, and some unusual time series plots, but there is no attempt to assess the reasonableness of the reconstructions with respect to paleoclimatic first principles or to compare them with simulations or independent observations.*

Response: This manuscript describes the data set and provides measures to assess the data quality. The full assessment of data e.g. by comparing it to other data sets is beyond the objective of this manuscript.

3. Specific comments

Reviewer comment: (1) *line 62: "climate proxy synthesis studies". Do you mean "syntheses of climate reconstructions" or "syntheses of climate proxies" (i.e. the pollen data)? It's the former that can be directly compared with climate-model output.*

Response: We followed your suggestion and changed the phrasing in the text.

Reviewer comment: (2) *line 71: "The evaluation of climate model outputs…" It's actually the climate models that are being evaluated in data-model comparisons (of simulations and observations or reconstructions).*

Response: Revised.

New text: The evaluation of climate observation data and/or the output of simulations or reconstructions, which can be used for data-model comparisons with climate model outputs, is essential for model improvements (Eyring et al., 2019).

Reviewer comment: (3) *line 73: "strong changes in the climate driver" Are you alluding to changes in GHGs during the instrumental record? Changes in insolation, ice-sheet distribution and size, and GHGs between the LGM and present are much larger. For example, the companion CMIP experiment to the LGM is the 4xCO2 experiment. CO2 has yet to double from pre-industrial levels yet.*

Response: Revised.

New text in the introduction: The comparison of climate model outputs with climate data is essential for model improvements (Eyring et al., 2019). The extratropical Northern Hemisphere is of particular interest because it is known for complex spatial and temporal temperature and precipitation patterns. However, the period for which instrumental observations are available is only of limited use to validate simulations in particular when assessing climate response to natural climate drivers because it is too short and because it is impacted by human-induced greenhouse gas forcing. . -. Climate proxy data derived from natural archives are therefore of great value.

Reviewer comment: (4) *line 74: "The extratropical Northern Hemisphere … complex spatial and temporal … patterns." Well, yes, but it's also where most of the pollen data is from. I don't think you need to motivate focusing on the Northern Hemisphere extratropics.*

Response: We shifted this sentence. So the context became a little different and it reads like an introduction sentence now.

Reviewer comment: (5) *line 90: "Regarding the prevalence…". Just say "Pollen data from … have been used…"*

Response: We followed your suggestion and changed the phrasing in the text.

Reviewer comment: (6) *line 94: "high resolution". Temporal? Spatial? Also, the last millennium is part of the Holocene, and the late-Quaternary, so you might get some push-back from dendroclimatologists about this notion.*

Response: Deleted high-resolution.

Reviewer comment: (7) *line 102: delete "the large" (I think we know extratropical Asia is large area.)*

Response: We followed your suggestion and deleted "the large" in the text.

Reviewer comment: (8) *line 103: Whitmore et al. (2005) describes the modern pollen (and climate) data set for North America, not (paleo) precipitation reconstructions.*

Response: We refer to a different reference.

Reviewer comment: (9) *line 108: If "Herzschuh et al., submitted" is "LegacyPollen 1.0: A taxonomically harmonized global…" then how is that different from this paper (and the data sets on Zenodo)? Does it describe just the fossil-pollen data, or the modern data set too?*

Response: This does describe the fossil pollen data set with focus on the harmonization of the taxa and spatio-temporal coverage.

Reviewer comment: (10) *line 110: "Li et al., 2022). So there are three papers, 1) the pollen data set, 2) new chronologies, and 3) this paper, right? Why not just say that?*

Response: We clarified in the text, that this study is the third part of interconnected studies.

New text: In a recent effort, we synthesized and taxonomically harmonized pollen records available in the Neotoma Paleoecology Database (Williams et al., 2018) and additional records from China and Siberia (Cao et al., 2013 and 2020) into a global Late Quaternary fossil pollen dataset (LegacyPollen 1.0; Herzschuh et al., submitted) and revised all chronologies of those records using a Bayesian approach that allows for the inference of temporal uncertainties (LegacyAge 1.0; Li et al., 2022). Here, in the third part of interconnected studies, we present the pollen-based reconstruction of mean July temperature (T_{July}), mean annual temperature (T_{ann}) and annual precipitation (P_{ann}) from these 2594 records from the Northern Hemisphere using WA-PLS and MAT.

Reviewer comment: (11) *line 116: Why reconstruct temperature and precipitation, as opposed to climate variables that are mechanistically related to vegetation?*

Response: We assume that the very specific variable that drives vegetation change at each site is mostly not known and might change temporarily. However, at most sites in the Northern Hemisphere extratropics, this or these specific variable(s) are typically highly correlated to either T_{July} or annual

precipitation which we selected for reconstruction. In numerous studies of modern pollen-environmental relationships, this has been confirmed. These variables and, Tann in addition, are also typically used by synthesis studies and proxy-model comparison studies. Accordingly, we selected these three variables. However, our dataset provides more climate variables and the fossil and modern pollen data, so further customized reconstructions could be implemented using our data and coding environment.

Reviewer comment: (12) *line 136: "For consistency with the amount (number?) of taxa…". This needs to be a little better explained. Why 70 taxa (except for tradition)?*

Response: Explanation added.

New text in method part: We restricted the reconstruction to the 70 most common taxa on each continent to reduce computational power after making sure that higher taxa number would not substantially improve model statistics.

Reviewer comment: (13) *line 147: "2000 km radius". Why 2000 km?*

Response: We fixed the radius to 2000 km, instead of 1500 km as suggested from a study in Eastern Asia by Cao et al. (2017), because the modern dataset density is rather low in northern Asia.

Reviewer comment: (14) *line 150: "metrics". Meaning something other than just the squared-chord distance?*

Response: Revised.

Reviewer comment: (15) *line 151: "square-root transformed pollen percentages". It might be worth pointing out that the same transformation is embedded in the use of the squared-cord distance dissimilarity measure in the MAT approach.*

Response: Revised.

New Text: For all analyses square-root percentages were used if not indicated otherwise.

Reviewer comment: (16) *line 156: "co-variation". Why is this an issue? It might be the case that covariation among predictands wouldn't be an issue if they were mechanistically related to vegetation, as in the case of variables like MTCO and GDD (Wei, et al., 2020, Ecology http://dx.doi.org/ 10.17864/1947.194.*

Response: Explanation added.

New text: In addition to the classic WA-PLS reconstruction, we also use provide WA-PLS_tailored, to address the problem that co-variation of climate variable today in space is directly transferred to the reconstruction because we assume that spatial relationships of in particular temperature and climate is mechanistically not necessarily linked to temporal relationships. We assume that this can be reflected in the composition of the plant assemblages because different taxa have optima in temperature and precipitation and might therefore occur in different co-occurrences and abundances.

Reviewer comment: (17) *line 161: "… partialling out the respective other variable". Please explain.*

Response: Explanation added.

New text: The reconstructed climate parameters were tested as introducing the environmental variable as a single variable in a runs, as well as with partialling out the explained variance in the pollen data by the respective other variable.

Reviewer comment: (18) *line 161: "We applied a Canonical Correlation Analysis…". What were the community, constraining, and conditioning matrices in this analysis? More to the point, what was the objective of this analyisi?*

Response: Explanation added.

New text: "We applied a Canonical Correlation Analysis (CCA) to the modern training dataset in order to explore the modern relationship between the pollen spectra and the climate variables and to infer the explained variance in the modern pollen dataset by the target climate variables…."

Reviewer comment: (19) *line 164: "the ratio … was determined…". Why and for what purpose?*

Response: Explanation added.

New text: The ratio between constrained ($\lambda 1$) and unconstrained ($\lambda 2$) explained variance was determined for all modern training datasets used for climate reconstructions. High values of $\lambda 1$ vs $\lambda 2$ are commonly considered as an indicator measure that how well the target environmental variable is strongly related to the variation in the modern pollen data set (e.g. Juggins 2013).

Reviewer comment: (20) *line 191: Define "RMSEP" on first use in the text.*

Response: Done.

New text: Reconstruction error is provided as root mean square errors (RMSE) derived from the output in the *MAT* and *WAPLS* functions. Model errors of WA-PLS and MAT are reported as root mean square error of prediction (RMSEP) derived from leave-one-out cross validation.

Reviewer comment: (21) *lines 190-220: What accounts for the spatial variations in RMSEPs? Data density? Data quality (of both the pollen and climate data)? Confounding environmental factors?*

Response: We added some discussion in the discussion part.

New text: For fossil pollen records in areas with an insufficient coverage of modern surface pollen samples (e.g., Central Asia or Western Siberia), it might be difficult to create a calibration dataset that maps the required variety of environmental and climatic gradients and therefore find enough modern analogues for reconstructions with a classification approach such as MAT. This is indicated by the high RMSEPs as percentages of gradient length in these areas.

As expected, maps of RMSEPs reveal show similar spatial pattern as the results of constrained ordination. Our results indicate that in particular calibration sets from Europe have low ratios and a high RMSEP for all climate variables (despite we have a high number of modern samples), likely related to the human impact on the modern and fossil data. Some areas that are known for its sensitivity to precipitation e.g. Eastern Asia show low RMSEPs as expected for Pann but on the other hand show a low sensitivity to Tann and T_{July}.

Reviewer comment: (22) *line 221: "significance test". Of what? What hypothesis does the Telford and Birks test address?*

Response: Explanation added.

Reviewer comment: (23) *line 241: "we subtracted those means from every record". There are two mean values (6.5 to 5.5 ka and 1.5 to 0.5 ka), and "every record" implies to me the whole data set, LGM to present. Aren't you just looking at the difference between those two mean values? (And why 1.5 to 0.5 ka?)*

Response: See response to reviewer 2. We now provide results for 6 minus 1 ka including error estimates. 1 ka was chosen as example as more reocrds were available for 1 ka compare with records covering the last 100 years representin 0 ka. The map here is only an example to illustrate the results.

Reviewer comment: (24) *line 243: "warmer and drier" Than what? (Which time period is the warmer and drier one?). Throughout this paragraph, the sense of change in climate has to be made explicit. For parallelism, you should adopt a standard way of expressing the changes, e.g. "warmer than present in the mid-Holocene" or "cooling from the mid-Holocene to present" but don't mix states and trend.*

Response: Revised.

New text: To illustrate analyzing the temporal variation between mid and late Holocene, we calculated means of all three climate variables for the time slices at 6 and 1 ka periods between 6.5 and 5.5 ka BP and between 1.5 and 0.5 ka BP and subtracted those means from every record in order to evaluate the changes between the reconstructed mid-Holocene conditions and those of modern times. Differences between these time periods

reveal warmer and drier conditions during mid-Holocene compared with late Holocene conditions especially in Eastern North America but also in Central and Northern Europe.

Reviewer comment: (25) *line 250: What's a "more gradual pattern"?*
Response: We revised this paragraph.

Reviewer comment: (26) *Figure 6: What exactly is plotted here? Why use a log age axis? An alternative depiction of all of the reconstructions, and their temporal and latitudinal varliations would be a Hovmöller diagram.*
Response: This manuscript describes a dataset of reconstructed climate variables and explores the quality of the data while assessing past climate change, as could be obtained with Hovmöller diagrams is not in the focus of this study.

Reviewer comment: (27) *Figure 8: I guess we're supposed to see that there are more correlation coefficients between temperature and precipitation close to zero in the "tailored" analyses. I've got nothing against violin plots, but I think a standard histogram would work a lot better.*
Response: We prefer to stay with a violin plot.

Reviewer comment: (28) *line 301+: What are the implications of these statistics and their spatial patterns?*
Response: No added further discussion on the potential limitation of the data set as indicated by the quality measures. See discussion part.

Reviewer comment: (29) *lines 315-343: This tutorial on pollen data, chronologies, etc. should probably be in the introduction, not the discussion.*
Response: We revised the entire discussion and always related comments to our data set and tried to avoid general "tuturial" comments.

Reviewer comment: (30) *line 378: "numerical mechanisms … reduce the reliability" Please explain.*
Response: We rephrased the entire section.

Reviewer comment: (31) *line 410: "TraCE 21k" is a transient experiment. The model used was CCM 3.*
Response: Revised.

4. Code and data

Reviewer comment: *I was able to run the example R code without problems. However, the data sets, described and labelled (via the extension) as .csv files (comma-separated values), are instead tab-separated files, which usually have the extension ".tab", or sometimes ".txt". This situation prevents a user from getting a quick look at the data using a spreadsheet program.*

Response: Csv-files can use other separators than comma (also tab-separator). When opening in a spreadsheet program like Excel, it would be necessary to import the file and specify the separator rather than open it by double-click. However, we will provide the dataset now in addition as txt file on Pangaea.