Reply to comments by reviewer 3: Exploring Holocene temperature trends and a potential summer bias in simulations and reconstructions (egusphere-2023-86)

Christian Wirths, Elisa Ziegler, Kira Rehfeld

Summary of Changes

We thank the reviewer for providing thoughtful comments on our work, which we take into account in the revision. In response, we plan to

- substantially add to the analysis to include additional results analysing the uncertainties in the analysis, supporting the robustness of the results we put forward, and analysing the sensitivity of the simulations to different forcings,
- expand the discussion of the results, in particular to further highlight the novelty of our findings,
- discuss the added analyses and experiments and
- extend the literature review further.

Below, we provide detailed responses to the comments and outline the actions we plan to take in response.

Reviewer's comment:

This paper uses existing datasets from climate models and proxy databases to investigate Holocene temperature evolution. The paper attempts to compare and contrast these pre-existing data sources but fails to put forth new conclusions or findings. Thus, a major restructuring with new evidence and support would be required for publication of this work. My main reasons for this distinction are as follows:

1. **The paper fails to put forth novel findings:** While it is true that the authors compare and contrast pre-existing modeling and proxy datasets, the findings presented in this paper are not novel in comparison to previous literature. Furthermore, many of the claims made by the paper are not substantiated by robust evidence or are not discussed in adequate detail. Therefore, the paper reads closer to a review paper rather than a journal article.

Authors' reply:

We thank the reviewer for their feedback and agree that more detail will help to highlight the novelty of our study. We further agree that the manuscript can be improved by including more of the robustness tests that we performed alongside with the results we already provided, but did not include in the paper so far. As outlined in response to reviewers 1 and 2, we will also further probe the seasonality categorization in the proxy data, the influence of forcings applied

in the simulations — in particular of volcanism — by including sensitivity experiments and overall expand the discussion of uncertainties in support of our results. These results will be incorporated into the existing structure of the manuscript. We are aware that our study, like many others, is not solving the conundrum and is instead excluding explanations that have been suggested in the literature. However, comparing temperature trends from climate models of different complexity and including an unpublished simulation with proxy reconstructions to resolve (dis-)agreement between them in time (by investigating the temperature trend agreement for different parts of the Holocene) and space (by investigating different latitudinal bands) provides a novel perspective on Holocene temperatures appropriate for a journal article. In summary, we will therefore enhance both the review and the original research aspect of the paper which we find useful and timely to resolve the temperature conundrum in the future.

Action:

- We will expand the discussion of our methodology and results, in particular with respect to the novelty of our analyses and findings, the robustness of our results and the uncertainties involved.
- We will include further evidence in support of the robustness of our results by including sensitivity experiments that show the impact of modelled forcings on Holocene temperature trends. Further, we will add to the discussion of seasonality by testing the uncertainty attached to the categorization in the proxy database as outlined in response to reviewer 2.

Reviewer's comment:

2. **Use of TransEBM is not justified:** The authors highlight simulations with TransEBM, a simple energy balance model that has previously been published, as their primary contribution in the modeling space. However, it is never discussed why a low complexity model like TransEBM is suitable or advantageous for the type of analysis conducted here. In fact, as a reader I am left convinced that use of this model is entirely unnecessary as it underperforms the three other models, two of which are even out of date at this point in time.

Authors' reply:

We agree TransEBM does not reproduce reconstructed temperature trends better than many of the other models used. However, the added value of low complexity models, especially when used in addition and comparison to higher complexity models, does not rely on them outperforming the other models. Rather, their strengths lie in their simplicity. For the purpose of this study, the main advantage is that we completely understand the response of the model, e.g., we know that TransEBM is always essentially at equilibrium and that it captures the linear climate response without memory effects. As such, it allows for disentangling the climate signal and understanding how simulated dynamics change with level of complexity (c.f. Held 2005). This simplicity of the model is the reason for its inclusion, a point which we will highlight and

strengthen more in the revision of the manuscript. To this end, we will add the results of our single forcing sensitivity studies to offer further insight into the interplay between forcings, feedbacks and the climate system as discussed in response to reviewers 1 and 2. These sensitivity tests explore, among others, the role of greenhouse gases, sea and land ice, and volcanism. The latter we will contrast to simulations with HadCM3 simulations that we will also add to the manuscript as outlined in response to reviewer 1. This will help highlight the benefits of including simulations from a model of low complexity, as we agree with the reviewer that this was insufficient in the original version of the manuscript.

Action:

- We will include sensitivity studies with TransEBM to explore impact of forcing and the linear climate response further.
- Throughout the manuscript, we will discuss the reasons for including simulations of varying complexity and in particular TransEBM more clearly.

Reviewer's comment:

3. More thorough literature review must be done: In the concluding remarks, the paper makes strong claims, for example that climate models are likely missing boundary conditions such as land cover. Previous studies have investigated these topics at length (for example, see Thompson et al., 2022, Science Advances); however, there is no mention of these articles here. The authors should do a more thorough literature review of the state of science surrounding the Holocene temperature conundrum before attempting to publish on this topic.

Authors' reply:

We agree with the reviewer that a stronger discussion of current literature addressing the impact of different forcings onto the Holocene climate system can improve our manuscript and happily include the suggested and related literature on this topic in a revised version of the manuscript.

Action:

- We will enhance the literature review and the discussion of our results in context of the literature.

Reviewer's comment:

4. Analysis of seasonal bias is not robust: The analysis of seasonal bias in this paper is performed in a simple manner – annual or summer modelled results are compared with annual or summer proxies. Given the statements made about seasonal bias in proxies, a more thorough analysis that considers each proxy and the inherent assumptions present must be done in order to make the claims made by the authors.

Authors' reply:

Our study so far focusses on the comparison of temperature trends in simulations and proxy reconstructions at the proxy sites individually and throughout the different parts of the Holocene. However, we agree with the reviewer the manuscript can gain additional purpose by expanded regarding the robustness of our results and that this will require providing the results of additional tests. Therefore, we will add further new tests investigating the robustness of the seasonal classification of the proxy reconstructions as outlined in detail in response to reviewer 2. First, we will include simulated and reconstructed winter temperatures in the analysis and compare them with each other, as well as with annual and summer temperatures. Second, we will provide upper bounds for the involved uncertainties by comparing simulated temperatures from different seasons. Lastly, the database labels as annual proxy timeseries that cover more than six months in any given year and include June (Kaufmann et al. 2020a and b). We will test the effect of this in the model simulations by contrasting such timeseries with the full annual timeseries at the proxy locations. This will strengthen the analysis provided, which uses the assessment of the recorded season of authors of the Temp12k database, and test the inherent assumptions of our analysis.

Action:

- We will include further analyses exploring the robustness of our results and the seasonality in the proxy records.
- We will expand the discussion of uncertainties in our analysis and strengthen the discussion of seasonality.

References:

Held, I. M. (2005). The gap between simulation and understanding in climate modeling. *Bulletin of the American Meteorological Society*, *86*(11), 1609–1614. https://doi.org/10.1175/BAMS-86-11-1609

Kaufman et al.: Holocene global mean surface temperature, a multi-method reconstruction approach, Scientific Data, 7, https://doi.org/10.1038/s41597-020-0530-7, 2020a

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