Response letter

Xiaoxu Shi[1], Martin Werner[1], Carolin Krug[1,2], Chris M. Brierley[3], Anni Zhao[3], Endurance Igbinosa[1,2], Pascale Braconnot[4], Esther Brady[5], Jian Cao[6], Roberta D'Agostino[7], Johann Jungclaus[7], Xingxing Liu[8], Bette Otto-Bliesner[5], Dmitry Sidorenko[1], Robert Tomas[5], Evgeny M. Volodin[9], Hu Yang[1], Qiong Zhang[10], Weipeng Zheng[11], and Gerrit Lohmann[1,2]

[1]Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research, Bremerhaven, Germany
[2]Bremen University, Bremen, Germany
[3]Department of Geography, University College London, London, UK
[4]Laboratoire des Sciences du Climat et de l'Environnement-IPSL, Unité Mixte CEA-CNRS-UVSQ, Université Paris-Saclay, Orme des Merisiers, Gif-sur-Yvette, France
[5]Climate and Global Dynamics Laboratory, National Center for Atmospheric Research (NCAR), Boulder, CO 80305, USA
[6]School of Atmospheric Sciences, Nanjing University of Information Science & Technology, Nanjing, 210044, China
[7]Max Planck Institute for Meteorology, Hamburg, Germany
[8]State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, 710061, China
[9]Marchuk Institute of Numerical Mathematics, Russian Academy of Sciences, ul. Gubkina 8, Moscow, 119333, Russia
[10]Department of Physical Geography and Bolin Centre for Climate Research, Stockholm University, 10691, Stockholm, Sweden
[11]LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029, China

The manuscript presents an analysis of PMIP4 simulations for the PI, MH and LIG and investigates the importance of the definition of the calendar. Although this has been done previously and the new results largely confirm previous ones, this new analysis is still useful as it includes an ensemble of climate model simulations and thus allows one to test the robustness of the findings over multiple models.

Dear Reviewer,

Thank you very much for your positive and constructive comments. In the following, we present our point-to-point responses. Our answers to your comments are written in bold.

Thanks again for your time and efforts.

Best,

Xiaoxu

Major comment:

Lines 92-93: In the literature various methods are presented to adjust monthly data towards a angular calendar. In this manuscript reference is made to Rymes and Myers (2001), but how different or similar are the various methods? So for instance Bartlein and Shafer (2019) and the various other methods that they mention in their publication (Pollard and Reusch, 2002; Timm et al., 2008; Chen et al., 2011). It would be very informative for the reader to know whether the results presented in this manuscript generally hold for all those methods or if some should be avoided.

Thanks for the comment, we added a discussion about those approaches in the revised manuscript:

Various methods for adjusting monthly data towards an angular calendar have been suggested. Rymes and Myers (2001) developed a mean-preserving running-mean algorithm to reconstruct the annual cycle. In Pollard and Reusch (2002), the reconstruction of an annual cycle was based on a spline method, which fits each monthly segment by a parabola, requiring the same monthly means as the originals and continuity of value and slope at the month boundaries. Bartlein and Shafer (2019), used a mean-preserving harmonic interpolation method described in Epstein (1991) and performed the same function as the parabolic-spline interpolation method as in Pollard and Reusch (2002). To sum up, the basic procedure is similar in all the approaches, as they are all based on "mean-preserving" algorithm. In Bartlein and Shafer (2019), a comparison was made between the linear and mean-preserving interpolation methods. They found that the difference between the original monthly means and the monthly means of the linearly interpolated daily values is not negligible for both surface air temperature and precipitation while the difference between an original monthly mean value and one calculated using the mean-preserving interpolation method is negligible.

Bartlein and Shafer (2019) made their code to perform the calendar adjustment freely available and 'user friendly'. It would be great if the same could be done with the code used in this manuscript. A reference to the code could then be added in the manuscript.

Thanks for the suggestion, we have created a Gitlab repository and introduced it in the section of "code availability":

The Python source code and related manual are available from https://gitlab.awi.de/xshi/calendar (last access 02.02.2022).

Minor comments:

Line 60: Scussolini et al. 2019 do show LIG results for precipitation and temperature for both the classical calendar and the angular calendar.

The following texts can now be found in the revised manuscript:

"However, the calendar effect has been investigated in only a few paleoclimate studies. Differences of seasonal ensemble anomalies (LIG minus PI) based on the angular and the classical calendars have been shown by Scussolini et al. (2019) for both precipitation and surface air temperature. Their results indicated pronounced artificial bias for the classical calendar definition: The Northern Hemisphere warming (LIG minus PI) in boreal summer is largely underestimated. Moreover, the Northern Hemisphere monsoon precipitation during the LIG is overestimated in boreal summer but underestimated in boreal autumn. These results are in line with the findings of Joussaume and Braconnot (1997)."

Line 72: Perhaps it is good to mention that in the results section you will first briefly describe the main features of simulated MH and LIG temperatures and precipitation (describe in more detail in previous publications) and after that you will focus on the main topic of the manuscript, namely calendar-effects.

Thanks for the suggestion, now we changed the texts into:

"In the present study, we use the PMIP4 dataset to investigate the calendar effect on the simulated surface air temperatures and precipitation under MH and LIG boundary conditions. The structure of the paper is as follows: In Section 2, we

describe the method for defining an angular calendar based on the Earth's orbital parameters and provide detailed information on the data we used. In Section 3 we first briefly describe the main features of simulated MH and LIG surface air temperatures and precipitation, then we illustrate the effects of the angular season definition on the simulated patterns. We discuss and conclude in Section 4."

Line 110: For consistency it would be better to mention the initialization procedure of all three transient simulations, not just for IPSL.

The transient simulation by AWIESM and MPIESM is initialized from respective 1,000-year mid-Holocene spin-up run. Now we have added this information in the revised manuscript.

Line 141: Perhaps good to not only focus on the comparison to earlier work on PMIP4 results, but also shortly on previous iterations of PMIP and other projects. For instance Lunt et al., 2013; Scussolini et al. 2019.

Thanks for the comment, in the revised version we added the two references:

Our results in terms of the responses of the surface air temperature and precipitation to the MH and LIG boundary conditions are in good agreement with the results from the full PMIP4 ensemble as described in Brierley et al. (2020), Otto-Bliesner et al. (2021), and Scussolini et al. (2019), as well as the studies of earlier PMIP ensemble simulations (Lunt et al., 2013).

Section 3.3: this section is rather long. Consider breaking it up in several sub-sections, for instance one on temperature, precipitation and one on using monthly data to calculate angular-seasons.

Thanks for the comment, now we divided section 3.3 into three subsections: 3.3.1 for surface air temperature; 3.3.2 for precipitation; and 3.3.3 for calendar conversion based on monthly data.

Lines 240-242: The authors say that these are 'significant' differences, but the meaning of the word significant is unclear and undefined in this context. Better to replace it.

We agree that the meaning of 'significant' is not clear, according to the comment, we now re-phrased the contexts as:

We are aware of a slight artificial bias in month-length adjusted surface air temperature for LIG over the high-latitude continents in JJA, which is underestimated by 0.07 K.

Lines 347-359: these lines are rather vague. A reference is made to major model-data mismatches that are being discussed in the literature (e.g. The Holocene temperature conundrum). So what do the results of this manuscript have to add to those discussions? Can an estimate be given on the possible magnitude of calendar effects on this model-data mismatch? Or, if not, how could this be investigated in future work? Please clarify the link between the current manuscript and the work that is mentioned in this last paragraph.

Thanks for the comment, in the revised manuscript we have modified the paragraph and discussed about how calendar conversion impacts the model-data comparison. The new texts are as following:

Proxy-based reconstructions provide us another ability to examine the temperature evolution of the past and can help assess the model's performance in simulating the past climates. Since paleoclimate data often records the seasonal signal

(e.g. local summer temperature), an appropriate choice of calendar is therefore important for temperature comparisons between model results and proxy data. For the mid-Holocene, Bartlein et al. (2011) is an often-cited study that compiled pollen-based continental temperature reconstructions. The question arises whether the consideration of calendar effects could lead to an improved model-data agreement. Here we show in Fig. S11 the simulated classical mean temperature anomalies (MH minus PI) versus continental reconstructions. The expected increased seasonality occurs only over Northwest Europe as indicated by the proxy records. The opposite sign is shown over northern America, with winter warming and summer cooling, and is therefore not consistent with the ensemble model result. Bartlein et al. (2011) attributes such a model-data mismatch to changes in local atmospheric circulation that tend to overwhelm the insolation effect. The calendar impacts, as illustrated in Fig. 4, result in warming of less than 0.2 K over the Northern Hemisphere in both DJF and JJA, implying that model-data consistency is improved for Northwest Europe in summer, and Northern America in winter, while for most other regions using the adjusted calendar results in a poorer match between model and proxy temperatures. These results reveal that for the mid-Holocene the calendar adjustment does not guarantee a better model-data agreement, and the underlying reason might be that, in addition to the solar insolation, the proxy could be strongly influenced by the local environment, such as flow of humid air and increased cloud cover (Harrison et al., 2003) or warm-air advection (Bonfils et al., 2004).

Since there are very few high-resolution reconstructed temperature records for the LIG, we use here the compilation from Turney and Jones (2010) for the annual mean temperature anomalies between LIG and PI, and compare them with modeled classical mean values for boreal summer (Fig. S12). We keep in mind that the summer mean LIG temperatures are usually higher than the annual mean values documented by the proxy records. At high latitudes of Northern Hemisphere continents (e.g. Greenland, Russia and Alaska), as well as over subpolar oceans (e.g. the Nordic Sea and the Labrador Sea), we find that the models underestimate the recorded LIG warming. Part of the bias can be corrected by calendar adjustment which leads to a warming of up to 1 K over Northern Hemisphere continents in JJA (Fig. 3k).

Figures 5-7: It is always a difficult choice whether to show precipitation changes in units of mm/time or as percentages. The authors choose to use mm/month and as a result the tropical regions supposedly show the most marked changes in precipitation while in terms of percentages the picture might look quite different. Consider adding figures to the supplement that show percentage precipitation changes.

Thanks for the suggestion. It is a good idea to examine the calendar effect on precipitation with both the absolute changes and percentage changes. In the revised version, we have added a new supplementary figure to show the percentage changes of precipitation (see Fig. S7 in the new manuscript).

We also updated the related texts:

In LIG, the largest calendar effects on precipitation can be observed for SON over the tropical rain-belt (Fig. 6 shows the anomalies and Fig. S7 shows the percentage changes), with positive anomalies (within 30 mm/month) to the north and negative anomalies (up to -30 mm/month) to the south of the Inter Tropical Convergence Zone (ITCZ). In North Africa, changes in precipitation due to calendar transition account for up to 80% of the classical mean (Fig. S7d). In DJF, we

observe a tripole pattern, with negative anomalies over North (-1 mm/month, -10%) and South Africa (-4 mm/month, -5%) and positive anomalies over equatorial Africa (5 mm/month, 8%). For JJA the adjusted-minus-unadjusted precipitation anomalies present a dryness (up to -15 mm/month, -15%) and wetness (less than 10 mm/month, 16%) over the northern and southern edge of the ITCZ, respectively, opposite to the patterns for SON and DJF.

Technical comments:

Line 44: replace the word ’bunch’

We changed it into *"a number of modelling groups"*

Lines 57-58: “hereafter referred to as fixed-length or classical calendar”. Perhaps better to use only one of the two in the remainder of the manuscript to avoid confusion.

We now used "classical calendar" throughout the manuscript.

Lines 107, 111: use subscripts for the names of the greenhouse-gasses.

We now changed the names for the greenhouse gases into "CO_2, CH_4 and N_2O "

Line 130: replace ‘at the’ by ‘over’ or perhaps ‘in’?

Thanks for the correction. We changed "at the" into "over".

Main article figures and supplementary figures: Just for clarity, mention in the figure captions when the figure shows multi-model-mean results.

Thanks for the suggestion. We have now indicated in the captions when the results are ensemble.

References

Bartlein, P. J. and Shafer, S. L.: Paleo calendar-effect adjustments in time-slice and transient climate-model simulations (PaleoCalAdjust v1. 0): Impact and strategies for data analysis, Geoscientific Model Development, 12, 3889–3913, 2019.

Bartlein, P. J., Harrison, S., Brewer, S., Connor, S., Davis, B., Gajewski, K., Guiot, J., Harrison-Prentice, T., Henderson, A., Peyron, O., et al.: Pollen-based continental climate reconstructions at 6 and 21 ka: a global synthesis, Climate Dynamics, 37, 775–802, 2011.

Bonfils, C., de Noblet-Ducoudré, N., Guiot, J., and Bartlein, P.: Some mechanisms of mid-Holocene climate change in Europe, inferred from comparing PMIP models to data, Climate Dynamics, 23, 79–98, 2004.

Brierley, C. M., Zhao, A., Harrison, S. P., Braconnot, P., Williams, C. J., Thornalley, D. J., Shi, X., Peterschmitt, J.-Y., Ohgaito, R., Kaufman, D. S., et al.: Large-scale features and evaluation of the PMIP4-CMIP6 midHolocene simulations, Climate of the Past, 16, 1847–1872, 2020.

Epstein, E. S.: On obtaining daily climatological values from monthly means, Journal of Climate, 4, 365–368, 1991.

Harrison, S. P. a., Kutzbach, J. E., Liu, Z., Bartlein, P. J., Otto-Bliesner, B., Muhs, D., Prentice, I. C., and Thompson, R. S.: Mid-Holocene climates of the Americas: a dynamical response to changed seasonality, Climate Dynamics, 20, 663–688, 2003.

Joussaume, S. and Braconnot, P.: Sensitivity of paleoclimate simulation results to season definitions, Journal of Geophysical Research: Atmospheres, 102, 1943–1956, 1997.

Lunt, D., Abe-Ouchi, A., Bakker, P., Berger, A., Braconnot, P., Charbit, S., Fischer, N., Herold, N., Jungclaus, J. H., Khon, V., et al.: A multi-model assessment of last interglacial temperatures, Climate of the Past, 9, 699–717, 2013.

Otto-Bliesner, B. L., Brady, E. C., Zhao, A., Brierley, C. M., Axford, Y., Capron, E., Govin, A., Hoffman, J. S., Isaacs, E., Kageyama, M., et al.: Large-scale features of Last Interglacial climate: results from evaluating the lig127k simulations for the Coupled Model Intercomparison Project (CMIP6)–Paleoclimate Modeling Intercomparison Project (PMIP4), Climate of the Past, 17, 63–94, 2021.

Pollard, D. and Reusch, D. B.: A calendar conversion method for monthly mean paleoclimate model output with orbital forcing, Journal of Geophysical Research: Atmospheres, 107, ACL–3, 2002.

Rymes, M. and Myers, D.: Mean preserving algorithm for smoothly interpolating averaged data, Solar Energy, 71, 225–231, 2001.

Scussolini, P., Bakker, P., Guo, C., Stepanek, C., Zhang, Q., Braconnot, P., Cao, J., Guarino, M.-V., Coumou, D., Prange, M., et al.: Agreement between reconstructed and modeled boreal precipitation of the Last Interglacial, Science advances, 5, eaax7047, 2019.

Turney, C. S. and Jones, R. T.: Does the Agulhas Current amplify global temperatures during super-interglacials?, Journal of Quaternary Science, 25, 839–843, 2010.