Response letter

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1 Comments from Reviewer 2

Calendar effect is a problem in paleoclimate modelling since long. To my knowledge, there are not many studies dedicating to this topic. In this manuscript, the authors investigate the calendar effect on seasonal temperature and precipitation by using the PMIP simulations of the PI, 6ka, 127ka snapshot and the 6-0ka transient experiments. The results could be informative for paleoclimate community and let pay more attention to the calendar problem. In the meantime, some improvements would be needed for clarifications and also to make the manuscript more attractive. Please find my comments and questions here below.

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

General comments:

1. There are not many studies on the calendar effect in paleoclimate simulations. In addition to Joussaume and Braconnot 1997, Bartlein and Shafer 2019 cited in the manuscript, there are also Pollard and Reusch 2002 (https://doi.org/10.1029/2002JD002126

), Timm et al 2008 (https://doi.org/10.1029/2007PA001461) and Chen et al 2010 (https://doi.org/10.1007/s00382-010-0944-6) . These studies and their findings should be mentioned in the manuscript and be compared with.

Thanks for the suggestion. Now in our revised manuscript we added the following texts into the discussion part:

In previous studies, the angular calendar was defined using the true anomaly of the Earth corresponding to the present-day seasons, in other words, each month begins and ends at the same celestial longitude as present-day for any period (Joussaume and Braconnot, 1997; Bartlein and Shafer, 2019; Timm et al., 2008; Chen et al., 2011; Pollard and Reusch, 2002). The work of Chen et al. (2011) and Timm et al. (2008) applied a 360-day year which is, originally, divided into 12 months with 30 days. The VE is set to day 81 in a calendar year. Pollard and Reusch (2002), Joussaume and Braconnot (1997) and Bartlein and Shafer (2019), on the other hand, performed the calendar adjustment based on today's classical calendar with 365 days in a non-leap year. In their studies, an assumption was made that the seasonality defined by the classical calendar is in phase with the insolation and solar geometry for modern-day. In our study, by calculating the onset of present-day months/seasons using the approach described in Section 2.1, we find that the classical "fixed-length" calendar is very similar to the angular calendar for today, but they are not completely the same. This is evidenced in the small shift of months between the two calendars as seen in Table 3. In particular the angular October is delayed by 3 days compared to the classical October, resulting in negative anomalies in the adjusted-minus-unadjusted solar insolation. Though different methods are used in our work from the mentioned previous studies, our results are identical: for the LIG, the adjusted-minus-unadjusted surface air temperature over the Northern Hemisphere is up to 5 K during SON (Joussaume and Braconnot, 1997; Bartlein and Shafer, 2019; Chen et al., 2011) or September (Pollard and Reusch, 2002); and the Northern Hemisphere monsoon precipitation in SON is underestimated by the use of the classical calendar (Bartlein and Shafer, 2019; Chen et al., 2011). Similar biases are found for the early-Holocene (Timm et al., 2008) and mid-Holocene (Joussaume and Braconnot, 1997; Bartlein and Shafer, 2019) but less pronounced . These results are consistent with the findings in our study, however, comparing results of our 3 transient simulations with that from the TraCE-21ka transient simulation, as it was investigated in Bartlein and Shafer (2019), distinct differences emerge for the boreal autumn surface air temperature near present-day. In Bartlein and Shafer (2019), the artificial bias in MH-minus-PI temperature and precipitation totally stems from the bias in MH when the classical calendar is applied (as for PI both calendars are identical). In contrast, our study reveals that such bias is mainly dominated by the deviation between angular and classical calendars for present-day. It should be noted that these discrepancies are not due to the different models used in our studies, but rather to the different approaches adopted for calendar adjustment.

2. It is unclear for me how the conversion of temperature and precipitation on the classical calendar to those on angular calendar was made. A thorough explanation would be needed in section 2.1. Please also see some of my specific comments.

We totally agree to the reviewer that we should give more detailed description on the calendar conversion method. In the revised paper we have done so, please see the updated section 2.1, as well as our responses to your specific comments.

3. The calendar effect at 6 ka and 127 ka was examined using multi-model ensemble. Is the calendar effect on temperature and precipitation similar between individual models qualitatively and quantitatively speaking? Additional analysis on individual

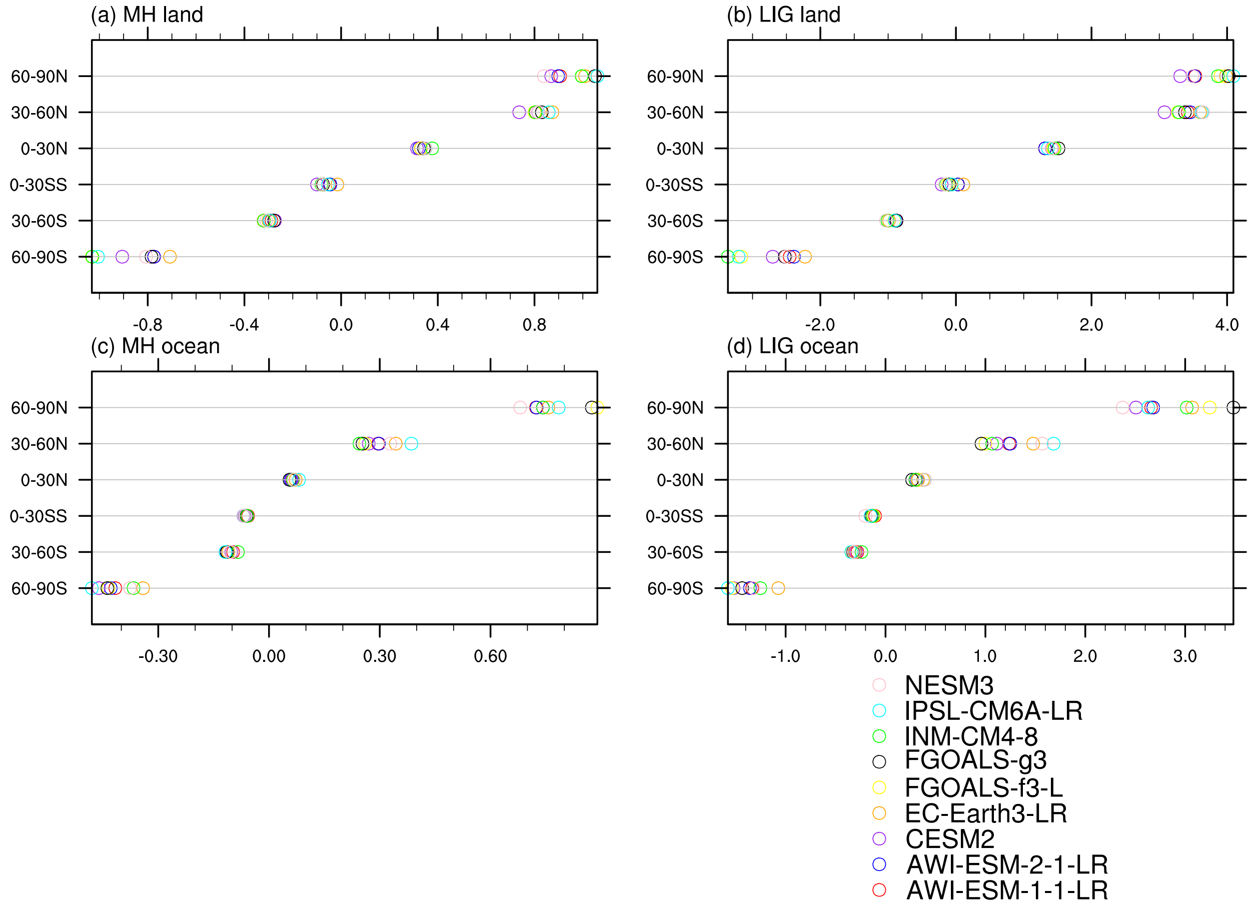

Figure 1. (a,b) Deviation of MH-PI SON surface air temperature between angular and classical means for (a) continents and (b) oceans at different latitude-bands, simulated by individual models. (c,d) As in (a,b), but for LIG-PI surface air temperature. Units: K.

model would be interesting. Moreover, how is the calendar effect compared to the difference between models? For example, the difference between the black and pink lines in Fig.12 appears very small. It is much smaller than the model-model difference. Is such a small effect worth to be mentioned?

Thanks for the constructive comment, in the revised paper we have added two plots for such an analysis (Fig. 1 and Fig. 2 in this letter). We also put our original Fig. 12 to the supplementary. Here are the related plots and texts for the calendar effect on temperature and precipitation between individual models (here we take SON as it has the largest calendar effect and is therefore more interesting than the other seasons):

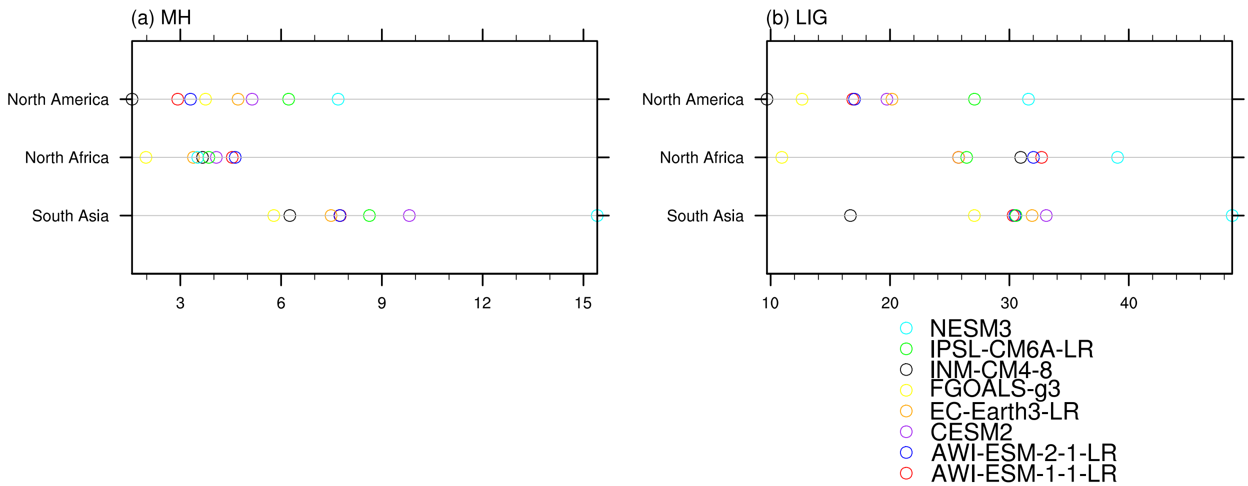

Figure 2. (a) Deviation of MH-PI SON precipitation between angular and classical means for North America, North Africa and South Asia, simulated by individual models. (b) As in (a), but for LIG-PI precipitation. Units: mm/month.

Analysis on individual models reveal a robust calendar effect on the SON surface air temperature for both continents and oceans, which overwhelms the differences between models (Fig. 5). We also observe that the calendar effect on temperature anomalies is more pronounced at higher latitudes than at lower latitudes.

Fig. 9 depicts the calendar impact on the SON precipitation anomaly over the main monsoon domains of the Northern Hemisphere (i.e. North America, North Africa and South Asia). We notice a very large model-model discrepancy for all regions examined in both the MH and the LIG, with the exception of North Africa in the MH. Our results indicate that that during the MH, the precipitation in South Asia is more responsive to a calendar adjustment compared to North Africa and North America. However, for the LIG, no robust conclusion could be drawn about the calendar effects in the different regions due to the large discrepancies between the models.

4. To which extent is the model-proxy comparison improved when calendar effect is considered? It would be interesting to show the comparison with proxy data before and after the calendar conversion.

It is a good idea to discuss about the model-proxy comparison, based on the comment, we added in the discussion section:

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).

5. If I understand well, the calendar effect happens mainly when the seasonal climate between two time slices is compared. Is it worth to consider it when we are interested only in the absolute climate at one given time slice? Does the calendar effect have an influence on the simulated vegetation?

Yes, for example Fig. 1 in the paper illustrates the calendar effect on absolute values of temperature. This is important when comparing reconstructed proxy records with model simulations for the LIG and MH. In order to answer the second question in this comment, in the supplementary we add one plot about the calendar effect on leaf area index, which shows that the lead area index is only slightly affected by the calendar definition. In the discussion section, we add the following:

Not all types of archives are sensitive to calendar definition, for instance bioclimatic indicators might be less dependent on the artificial definition of seasons, a typical example here is the the growing degree-days (GDD). In addition, we examined the influence of the calendar effect on the simulated vegetation. For this we analyzed the simulated leaf area index. As revealed by Fig. S13, even during boreal autumn, the deviation in leaf area index between classical and angular calendars is below 0.06% for PI and MH, and below 0.2% for LIG. Therefore, the calendar effect plays no significant role for this vegetation-related variable.

6. In section 3.4, why only analyze the temperature over continents and ice-free continents? I would suggest to add analysis also on temperature over ocean and ice continents, which would be particularly important for Southern Hemisphere.

Thanks for the constructive comment, we re-plotted the figures to include also the ice sheet regions. In addition, we add two more figures to show the calendar effect on Northern and Southern Hemisphere oceans. We refer to section 3.4 of our revised paper.

Specific comments:

Line 25: change “31” to “21”; is there any other reference date that has been used by other model groups? Is there a reason to use March 21 or other date as the reference date?

Thanks for the correction. We have corrected the date for vernal equinox in the revised manuscript. The reason to use 21th March as vernal equinox is because it is the day that the Sun is exactly above the Equator therefore our Earth have equal length of day and night. According to the reviewer’s comment, we add in the revised manuscript:

In most models the vernal equinox is set to 21th March, when the Sun is exactly above the Equator which leads to equal length of day and night on our Earth.

L32: change “with a periodicity of about 100,000 years” to “with major periodicities of about 400,000 and 100,000 years (Berger, 1978, https://doi.org/10.1175/1520-0469(1978)035<2362:LTVODI>2.0.CO;2; Berger and Loutre, 1991, https://doi.org/10.1016/0 3791(91)90033-Q)”. The 400 ka periodicity is more important than the 100 ka one.

Thanks for the correction and references, we have made the changes accordingly.

L33: what does “periods of perihelion and aphelion” mean?

Sorry for the confusing, we now have made it clearer in the revised version:

When the eccentricity is large, there is also a big difference between the perihelion distance and the aphelion distance, while at a small eccentricity when the orbit is more circular this difference is less pronounced.

L34: 0.0167, 0.0189, and 0.0397 are the values at a given date or an average over a given period? Please make it clear in the manuscript.

We made it clearer in our revised manuscript:

Earth’s orbital eccentricity is 0.016764, 0.018682, and 0.039378 in 1850 CE (pre-industrial), 6 ka B.P. (mid-Holocene) and 127 ka B.P. (Last interglacial) respectively.

L37: with a “major” period of 41,000 years

Thanks for the correction, we added the term "major" in our revised manuscript.

L39: Note that 19,000 and 23,000 years are the major periodicities of climatic precession, not of astronomical precession. Please clarify it in the manuscript and cite Berger (1978) where these periodicities were calculated for the first time.

Thanks for the correction, in the revised paper we changed the texts into:

At the same time, the wobble of Earth’s rotational axis (precession) modifies the direction of the Earth’s tilt and determines which hemisphere is tilted towards the sun at perihelion. The major periodicities of climatic precession are around 19,000 and 23,000 years (Berger, 1978).

L46: Indicating 6ka for MH and 127 ka for LIG could be misleading, because MH and LIG are more than these two dates.

Based on the reviewer’s comment we have corrected in our manuscript:

Two interglacial episodes, i.e., the mid-Holocene (MH, a period roughly from 7 to 5 ka B.P) and the Last Interglacial (LIG, roughly equivalent to 130-115 ka B.P.), are particularly the focus of PMIP.

L51: Herold et al 2012 (https://doi.org/10.1016/j.quascirev.2012.08.020) and Nikolova et al 2013 (doi:10.5194/cp-9-1789-2013) are among the early studies on simulating the 127ka climate and describing its insolation pattern, and deserve to be cited here. Please also be more precise about "enhanced seasonal cycles". In Nikolova et al 2013, it is found a larger seasonal contrast in northern hemisphere but a reduced one in the southern hemisphere.

Thanks. We have added the two references in the updated version. Comparing Fig. 2 and Fig. 4 in Nikolova et al. (2013) for the JJA and DJF surface temperature anomalies between MIS5e and PI, we found both CCSM3 and LOVECLIM present a larger seasonal contrast during MIS5e than PI over most areas of the Southern Hemisphere, especially over the continents, though such effect is less pronounced over Southern Hemisphere oceans in CCSM3. In addition we also find smaller seasonality across specific regions like the Lazarev Sea (in CCSM3) and South Atlantic Ocean (in LOVECLIM).

According to the reviewer's comment, we updated the texts:

Due to the Earth's orbital parameter anomalies with respect to the present, the MH and LIG receive more insolation in summer and less in winter over the Northern Hemisphere, leading to larger seasonal contrast in the two time periods, which holds true for both hemispheres in most model simulations (Kukla et al., 2002; Shi and Lohmann, 2016; Shi et al., 2020; Zhang et al., 2021; Kageyama et al., 2021; Herold et al., 2012). Such effect is much more profound in the LIG than in the MH (Lunt et al., 2013; Pfeiffer and Lohmann, 2016). However, in earlier simulations using CCSM3 and LOVECLIM, Nikolova et al. (2013) found smaller seasonality across Lazarev Sea (in CCSM3) and South Atlantic Ocean (in LOVECLIM) during the Last interglacial as compared to PI.

L67: "we perform ..." is unclear for me. Please give more explanation.

In the revised version, we described:

In Bartlein and Shafer (2019), the "pure" calendar effects have been examined by applying the angular calendar of 6 ka, 97 ka, 116 ka, and 127 ka onto modern observations. In the present study, we perform a calendar adjustment based on the actual past time intervals of the different model experiments. In detail, we apply an angular calendar of 0 ka, 6 ka, and 127 ka for the pre-industrial, mid-Holocene, and Last interglacial simulation respectively.

Section 2.1: Is the calendar conversion method used in this study similar to those used in the five studies mentioned in my major comment 1?

The methods adopted in our study is different, we have written in the discussion (please also see our response to major comment 1):

In previous studies, the angular calendar was defined using the true anomaly of the Earth corresponding to the present-day seasons, in other words, each month begins and ends at the same celestial longitude as present-day for any period (Joussaume and Braconnot, 1997; Bartlein and Shafer, 2019; Timm et al., 2008; Chen et al., 2011; Pollard and Reusch, 2002). The work of Chen et al. (2011) and Timm et al. (2008) applied a 360-day year which is, originally, divided into 12 months with 30 days. The VE is set to day 81 in a calendar year. Pollard and Reusch (2002), Joussaume and Braconnot (1997) and Bartlein and Shafer (2019), on the other hand, performed the calendar adjustment based on today's classical calendar with 365 days in a non-leap year. In their studies, an assumption was made that the seasonality defined by the classical calendar is in phase with the insolation and solar geometry for modern-day. In our study, by calculating the onset of present-day months/seasons using the approach described in Section 2.1, we find that the classical "fixed-length" calendar is very similar to the angular calendar for today, but they are not completely the same. This is evidenced in the small shift of months between the two calendars as seen in Table 3. In particular the angular October is delayed by 3 days compared to the classical October, resulting in negative anomalies in the adjusted-minus-unadjusted solar insolation.

L79: is it necessary to mention "Northern Hemisphere"?

The equinox of the Southern Hemisphere is called "the autumnal or fall equinox" and the "vernal equinox" is only for the Northern Hemisphere. So we agree with the reviewer that the term "Northern Hemisphere" is not necessary here. We have deleted it from the revised manuscript.

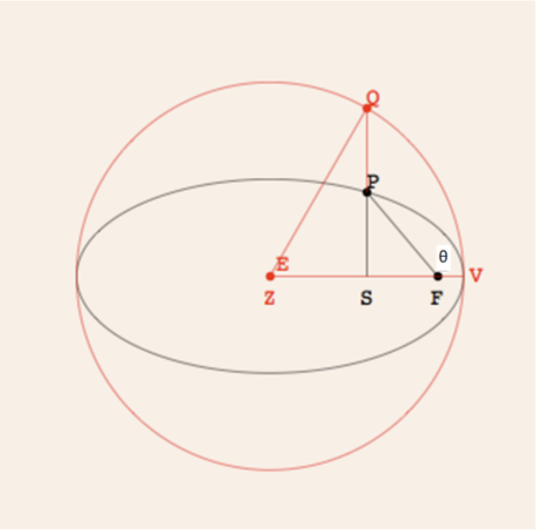

Figure 3. The geometric relationship between the eccentric anomaly E and the true anomaly θ.

L85: "orbital period" is confusing. I assume T is the number of days in one year.

Orbital period is the Earth's revolution period, i.e., the time it takes the earth to revolve around the sun. So T is equal to 1 year or 365 days. To make it clearer in the paper, we have updated the texts:

Here, t_p denotes the time elapsed since Earth passes the perihelion and T is the Earth's revolution period (i.e., 1 year or 365 days), namely the time it takes the Earth to make one complete revolution around the sun.

Equation 2: Please explain what is the principle on which Equation (2) is built.

Equation 2 refers to: $E - \epsilon \cdot \sin(E) = M$, it is called Kepler's equation and is based on Keplers' 1st and 2nd laws. Now we clarify this point in the manuscript:

Equation (2) is called Kepler's equation and is based on Kepler's 1st and 2nd laws. The first law simply states that the orbit of a planet is an ellipse with the Sun at one of the two focus points, and the Kepler's 2nd law states that a line segment connecting the sun and a planet sweeps out equal areas during equal intervals of time.

Equation 3: It is unclear how equation (3) is obtained. Please also give an equation explicitly relating tp to true anomaly.

Equation 3 is obtained from Eq. 3.13b of Curtis (2014) which is based on trigonometric calculations. In detail:

In Fig. 3, starting with the observation that cos(E)=|ZS|/|ZQ|, which follows directly from the definition of cos. That means: |ZS|=cos(E)*|ZQ|=cos(E)*a, where a is the length of the semi-major axis. That gives us a representation of |ZS| in dependence of the eccentric anomaly E. As we want to relate E to the true anomaly θ, we now want to express |ZS| in terms of θ.

We start by simply observing that:

$$|ZS| = |ZF| - |FS| = \epsilon a - |FS| \tag{1}$$

|ZF|=ϵa by the definition of the eccentricity ϵ.

The angle $\angle$ZFQ at F is given by π - θ. Applying the cos at this angle and taking into account that cos(π - θ) = - cos(θ), we gain:

$$|FS| = -cos(\theta) * |FP| = -cos(\theta) * r \tag{2}$$

|FP| = r, the distance between the Earth and the sun. Plugging Eq. 2 in Eq. 1 yields:

$$|ZS| = \epsilon a + r * cos(\theta) \tag{3}$$

Therefore we know that:

$$a * cos(E) = \epsilon a + r * cos(\theta) \tag{4}$$

Which gives the desired relation between the eccentric anomaly E and the true anomaly θ. This equation looks totally different to equation (3) in the manuscript - however, from here on it is only math and handling trigonometric equations to get the equation.

Then we have an explicit representation of tp as a function of θ. It looks like:
$t_p(\theta) = \frac{MT}{2\pi} = \frac{(E - \epsilon \cdot \sin(E))T}{2\pi}$ with $E = 2 \cdot \arctan(\sqrt{\frac{1-\epsilon}{1+\epsilon}} \cdot \tan(\frac{\theta}{2}))$
In our revised paper, we add reference of Curtis (2014), and add one equation of how tp and θ are related.

L94-96: Please be more precise on how each season is defined from the true anomaly that is calculated in equation (3).

We agree with the reviewer's comment that it can make things clearer if we describe it more detailed using the formula. In our updated manuscript the following texts are added:

The relation between the true anomaly θ and the time elapsed since Earth passes perihelion t_p allows to define seasons with respect to Earth's position on the orbit rather than relying on a fixed number of days. Based on the "fixed-angular" approach, there are two ways to define the seasons: 1) The orbit is distinguished into four segments: A true anomaly of $\theta = 0°$) corresponds to March 21st and therefore marks the first day of spring. The length of the summer is gained by calculating t_p ($\theta = 90°$). Similarly, the terms t_p ($\theta = 180°$) and t_p ($\theta = 270°$) mark the beginning of fall and winter, respectively. 2) The other method is based on the "meteorological" definition, in which the spring is defined as March-April-May, as typically done in paleoclimate modelling, although the VE is set to March 21st. The second approach is

adopted in our study, and in this case, we firstly compute the starting and end time for each month, then average over the respective months in order to compare the angular seasonal means with the classical seasonal means. Months can be defined as 30° increments of the true anomaly. Just one additional step has to be executed before calculating angular months: As no months starts at the VE, the starting day has to be shifted from March 21st to April 1st. Since the time between today's March 21st and April 1st may not be true for past calendars, we defined April 1st by the angle. Therefore, we first calculate the angle between today's March 21st, noon (the VE) and the point of time occurring 10.5 days later, denoting April 1st. Finally, starting from the angle corresponding to April 1st, we are able to calculate the starting time of the next month by 30° increments of the true anomaly.

L119: you mean "increased summer insolation"?

The Northern Hemisphere insolation during 6 ka is larger as compared to today for both summer and annual mean. Actually here we mean the annual mean insolation, as we are comparing the annual mean surface air temperature between 6 ka and PI. We now make it clearer in the updated paper.

L124: Please explain what is the delayed effect.

We added in the revised version:

Due to the large heat capacity of water, the ocean responses much more slowly to changes in incoming insolation than the land. Therefore, changes in solar radiation and surface air temperature over the oceans are out of phase. During the MH, the Southern Hemisphere receives more radiation flux in SON in relative to present-day, leading to a warming of the Southern Ocean in DJF.

L143: It is unclear how this calculation has been done, and how the dates in table 2 are obtained. More explanation is needed.

I think this is a follow-up comment to a previous comment related to L94-96 (i.e., Please be more precise on how each season is defined from the true anomaly that is calculated in equation 3.) Here we give a more detailed explanation (can also be seen in section 2.1 of the updated paper):

Months can be defined as 30° increments of the true anomaly. Just one additional step has to be executed before calculating angular months: As no months starts at the VE, the starting day has to be shifted from March 21st to April 1st. Since the time between nowadays March 21st and April 1st may not be true for past calendars, we defined April 1st by the angle. Therefore, we first calculate the angle between nowadays March 21st, noon (the VE) and the point of time occurring 10.5 days later, denoting April 1st. Finally, starting from the angle corresponding to April 1st, we are able to calculate the starting time of the next month by 30° increments of the true anomaly.

L145-146: isn't the velocity always greater at perihelion than at aphelion, whatever at today or any time in the past?

Yes we agree with the reviewer, and we updated our texts:

Since the orbital velocity of the Earth is greater at perihelion than at aphelion, the seasons at aphelion are longer than at perihelion, for example for the present-day we have fewer days in winter and more days in summer, which is reflected both in today's classical calendar (DJF: 90 days; JJA: 92 days) and in the angular calendar (DJF: 89 days; JJA: 93 days).

L235: It is good to refer to Rymes and Myers 2001 when use monthly values for calendar corrections, but it would be helpful for the reader if some information is given on how to transform monthly values to daily values.

Thanks for the comment, now we have added the following:

Daily output takes up much more space than monthly output, so most modelling groups only provide monthly frequency variables. Here, we utilize a calendar transformation method that requires only the raw (i.e., classical "fixed-length" calendar) monthly mean values (Rymes and Myers, 2001). In the study of Rymes and Myers (2001) an approach has been introduced for smoothly interpolating coarsely-resolved data onto a finer resolution, while preserving the deterministic mean. Based on the approach, daily data can be reconstructed using the monthly mean values: The daily data is initialised with the monthly average of the respective month. Then, for each day of the year, its value is recursively recalculated as the average of its own value and the values of the two adjacent days. After 365 iterations, this results in a nicely smooth annual cycle with the original monthly means being preserved.

L280: any idea of why there is a model-dependency of the calendar effect?

It is because the PI temperature response to calendar is not uniform, in the revised paper we clarified this point:

In JJA, besides the slight cooling bias in the original mean surface air temperature for 6-3 ka as revealed by all the 3 models, we observe a model-dependency of the calendar effects for the time interval of 3-0 ka, during which the Northern Hemisphere classical mean temperature in JJA is underestimated by AWI-ESM and MPI-ESM, but very slightly overestimated by IPSL-CM. Such discrepancy between models is related to the spatially varying temperature changes over the Northern Hemisphere continents caused by the calendar effect (Fig. 1k).

Section 4: discussion and conclusion are mixed up, better to be separated.

Thanks for your comment. In the revised version we have separated discussion and conclusion secctions.

L297: what does “the phasing of the insolation curve” mean? Does calendar effect have an influence on the phasing between insolation and temperature, precipitation in the Holocene transient simulation?

Sorry for the confusion, we mean the angle of the orbit of the Earth around the Sun. For a classical "fixed-day" calendar, the insolation and temperature might be, to a certain degree, out of phase. This can be solved by using the angular calendar, defined on the angle of the orbit and the reference date. According to the comment, we now clarify in the paper:

Two important elements should be taken into consideration when comparing paleoclimate simulations of different time intervals: the reference date (usually the VE), and the angle of the orbit of the Earth around the Sun, which defines the phasing of the insolation curve.

L330-331: Please explain why a different definition of season is used in this study, is there any advantage?

The most important reason is that today’s "fixed-length" calendar, strictly speaking, is not an angular calendar, though it is very similar to the angular calendar for modern-day. If we perform a calendar correction based on the

angles defined by present-day "fixed-length" calendar, as done in previous studies, a slight bias could be introduced for the angular calendar for past time periods, especially for boreal autumn.

In the revised paper, we illustrated that the angular calendar for PI has a shift of -1 to 3 days as compared to the classical calendar, therefore we also need to adjust the calendar for PI. The revised text is as follows:

In our study, by calculating the onset of present-day months/seasons using the approach described in Section 2.1, we find that the classical "fixed-length" calendar is very similar to the angular calendar for today, but they are not completely the same. This is evidenced in the small shift of months between the two calendars as seen in Table 3. In particular the angular October is delayed by 3 days compared to the classical October, resulting in negative anomalies in the adjusted-minus-unadjusted solar insolation.

L352: The analysis of this study shows that the calendar effect is most important in autumn. Then would the model-proxy comparison be significantly affected if proxy records mainly reflect summer temperature?

Most proxy records the summer or winter signal, in the discussion part we add two more paragraph to discuss about the implication of calendar on model-proxy comparison. The 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).

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