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Climate of the Past Discussions

Interactive comment on "Last Interglacial model-data mismatch of thermal maximum temperatures partially explained" *by* P. Bakker and H. Renssen

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Anonymous Referee 1

General comments: Due to current limitations in establishing a coherent temporal framework between palaeoclimatic records covering the Last Interglacial (LIG), published data compilations for this time period have focused on the maximum temperature assuming that the maximum warmth occurs simultaneously across the globe. In the present paper, P. Bakker and H. Renssen access the impact of such assumption from a model-based perspective. Although such a study needs to be taken with care since the tools (e.g. climate models) used to investigate the LIG model-data mismatch

are not perfect, the proposed exercise is interesting. The outcomes of this study are helpful in understanding the potential origin of the differences observed currently between reconstructed and simulated LIG temperature. Still, major revisions need to be performed on the current manuscript before its publication in Climate of the Past. In particular, while on one hand I appreciate the concise style of the authors, on the other hand this has the disadvantage on several occasions that some concepts/results miss of a clear explanation/ description. I recommend the authors to better describe their results, carefully explain their interpretations and also to propose a more in depth-discussion section. In particular, the discussion based on the comparison with the results of Otto-Bliesner et al. (2013) requires to be clarified. In the following, I report the sections that should be revised in particular, some more specific comments and some technical corrections that need to be taken into account in the revised version.

We thank the reviewer for his/her detailed comments that have enabled us to improve the manuscript. We have carefully revised the manuscript, have clarified the text where necessary, have included a more extensive analysis of the seasonal aspect of the subject and now provide a more detailed discussion.

Specific comments: -p740: Abstract: The wording of the beginning of the abstract has to be changed (at least the two first sentences) since it does not reflect exactly the "state of the art" knowledge about the timing in temperature peaks during the LIG across the globe. Indeed, there is not yet a precise "global" sequence of events at the start of the LIG from the available paleoclimatic records but there are still various evidences that the Southern Hemisphere started to warm and reached maximum warmth during the LIG before the Northern Hemisphere (e.g. Govin et al. 2012). Thus the first sentence should be changed into a sentence such as "the exact timing of the LIG thermal maximum across the globe remains to be precisely assessed" or similar. **Thanks for this comment. We agree that more is known than this first sentence suggests. It has been changed accordingly.**

Moreover, the authors should not write that the current compilations are based on the assumption that maximum warmth occurred synchronously across the globe in the LIG because of these uncertainties on the event timing. The main reason why available compilations so far are offering only one single "snapshot" of the climate during the LIG is due to the difficulty of establishing a common temporal framework between records from different paleoclimatic archives retrieved in various places around the globe. This is actually something that the authors mentioned in the introduction. The limitations of these compilations are actually mentioned by the authors who published these studies (such as in Turney and Jones's paper). Thus the second sentence in the abstract should be also changed accordingly. **Thanks for this comment. We agree with the point made above that the authors of LIG temperature compilations are very much aware that maximum temperatures are unlikely to have occurred synchronously. We did not intent to imply otherwise. However, we do think that because of the difficulties in construction common age scales, as mentioned by the reviewer, one has to make some kind of assumption, and the synchronicity one is indeed often made. We have incorporated this as follows "Because of difficulties in establishing a common temporal framework between records from different palaeoclimatic archives retrieved from various places around the globe, it has not yet been possible to reconstruct spatio-temporal variations in the occurrence of the maximum warmth across the globe. Instead, snapshot reconstructions of warmest LIG conditions have been presented, which have an underlying assumption that maximum warmth occurred synchronously everywhere."**

-p741, line 4: Similar comment as for the abstract, the sentence "As a consequence..." should be reformulated. It should be mentioned the fact that up to now one single compilation does not allow taking into account for potential asynchronous temperature

changes across the globe during the LIG, leading to the fact that it limits to perform robust model-data comparison since such a unique time slice leads to the underlying interpretation that the maximum temperature peaks are synchronous. **Following up to the reply given above, we have changed the sentence such that it makes more clear that the synchronicity assumption follows from the difficulty in establishing a common age scale for records from different regions. "However, because the LIG lies outside the time span covered by 14C-dating, absolute chronological uncertainties for this period can be up to 5000yr [Waelbroeck et al., 2008] and a common temporal framework can often not be established. This reality has led a number of authors [e.g. Kaspar et al., 2005; CAPE Last Interglacial Project Members, 2006; Turney and Jones, 2010; McKay et al., 2011] to present a global snapshot reconstruction of warmest LIG conditions, with the assumption that LIG maximum warmth occurred synchronously across the globe."**

-p741, line 17: In addition to present the evidence from the models' side that the temperature peaks are likely to not be synchronous everywhere across the globe, the authors should mention the growing evidences in the data too. For instance the authors should refer to the work by Govin et al. published in CP in 2012 and references therein. **Thanks for pointing this out. We have changed the line into: ". Several transient modelling experiments and proxy-based temperature reconstructions for both the Present Interglacial (PIG) and the LIG have shown that there can be large regional differences in the timing of interglacial maximum warmth, in the order of several thousands of years [Renssen et al., 2009, 2012; Bakker et al., 2012; Govin et al., 2012; Langebroek and Nisancioglu, 2013]."**

-p743, line 22:" Determining the temporal resolution...." should be rephrased. The temporal resolution for each record contained in the compilation is known. To me,

the issue that should be highlighted is that the records covering the LIG cover a large range of temporal resolution which could make it difficult to identify when the maximum temperature warmth occurs. Also, the test on the impact of the temporal resolution of the records that the authors propose is not realistic in the context of the LIG. Not many records have a temporal resolution better than 200 years and most of them have a pluri-millennial temporal resolution. The authors need to consider performing tests that reflect better the range of the characteristic temporal resolutions encountered during the LIG. The authors could keep the test with a 250 year-resolution but should also provide a test with a temporal resolution of 2000 years for instance. **Following the comment of the reviewer, we have added an analysis of 2000-year averaged temperature simulations. To clarify this point we have changed the line into: "Determining the temporal resolution of a proxy-based LIG temperature compilation is difficult because the included temperature records typically cover a large range of temporal resolutions. Therefore we test the importance of the temporal resolution by performing a sensitivity experiment with 250-year and 2000-year averaged temperatures instead of 50-year averages."**

-p744, line 5: "for smaller geographical regions....", this statement is not correct for the NH extratropics (0.5 $\pm$ 0.4°C). This sentence needs to be reformulated and the discussion on this point more developed. **We apologize for this mistake. It has been changed into: "For smaller geographical regions the MMM differences in annual LIG thermal maximum temperatures are smaller in case of the tropics and SH extratropics (0.2$\pm$0.2°C and 0.3$\pm$0.3°C respectively) and larger for the NH extratropics (0.5$\pm$0.4°C) while the inter-model spread becomes larger in all three regions in comparison with the mean." The reasons for the regional differences will be discussed later in the manuscript: "The causes of the regional differences in the assessed overestimation of annual mean LIG maximum warmth will be discussed in the final part of the results section." In the final part of the results section, several possible causes of the geographical differences**

are discussed: namely the meridional overturning, Arctic sea-ice evolution and the remnants of NH continental ice sheets from the preceding deglaciation. The discussion has been slightly prolonged with the following: "Bakker et al. (2013) showed for a 7-member subset of the 9 simulations presented here, that sea-ice feedbacks in the Arctic are strongly model dependent causing large differences between the models in the simulated climate evolution at these high NH latitudes. The impact of changes in the meridional overturning will be discussed at the end of this paragraph."

-p745, line 20: "firstly models with reduced resolution...": Please, give more explanation /or reformulate your sentence so it is clearer why this argument could explain why the calculated overestimation of LIG maximum warmth is smaller in low resolution models. **Indeed this line is not very clear. We have changed it into: "Firstly, models with reduced resolution and complexity are known to have generally less internal variability compared to GCMs [Gregory et al., 2005; Bakker et al., 2013], resulting in a climate evolution that is more coherent in space and thus a more spatial homogenous temperature maximum."**

-p746, line 3: the paragraph starting with "to access" should be included in the discussion section rather than in the results section. For instance, the first paragraph of the discussion section should begin with an evaluation of the robustness of the presented results by looking at the impact of the two arbitrary choices (the considered time interval and the temporal resolution). **Thanks for pointing this out. We have moved this section to the first part of the discussion. Furthermore we have added the analysis of 2000-year averages, both in the main text as in the table.**

-p746: line 9: "Not unexpectedly" should be removed and the authors need to better explain why such a result should be expected. **We have changed the line into: "The explanation is that decreasing the length of the analysis period, limits the**

insolation differences between the two hemispheres. Furthermore, larger temporal averages smooth out an increasing part of the spatial differences related to internal variability, again decreasing spatio-temporal differences in the LIG temperature maximum."

-p746, line 23: "....when the comparison is solely for the locations from which the proxyrecords are derived..." : this sentence is unclear, the authors should add one/two sentences to better explain what has been done in Otto-Bliesner et al. (2013). **To make it more clear what is meant here we have reworded the sentence into: "They performed a number of sensitivity experiments with the CCSM3 climate model, with for instance different orbital parameters, and compared their results with proxy-based compilations of Turney and Jones [2010] and McKay et al. [2011], including both continental and oceanic temperature reconstructions. Otto-Bliesner et al. [2013] show that the smallest LIG thermal maximum model-data differences are found in a model simulation forced with 130ka forcings (orbital and greenhouse-gas concentrations). Moreover, the model-data difference is found to be smaller if the comparison is performed at the proxy locations instead of taking the model average over all grid cells within the geographical domain under consideration (see Otto-Bliesner et al. [2013] for thorough model and scenario description).**

-p747: line 16: "In the NH extratropics...". It seems to me that this statement does not stand with the results shown on the figure. Please, can you check this sentence? **Thanks for pointing this out. We have changed the text to better describe the results: "In the NH extratropics the simulated MMM of 0.8$\pm$0.5°C is comparable to the 0.67°C model-data difference, however, the inter-model spread is large with values rangoing from 0.05 up to 1.5°C."**

-p747: line 12-line 25. The authors wrote that a comparison between the CCSM3

simulations and the transient simulations are not easy to interpret, still they do present such a comparison, thus, they should provide a more in depth discussion, or at least, they should list the implications of what they observed/ the future work needed to progress since, in the current manuscript they only provide a description of the results they obtain in comparison to Otto Bliesner et al. (2013) for each geographical region. **Thanks for this comment. We have added the following text to elaborate a bit on the potential differences between equilibrium and transient climate simulations and why we think the differences is not of large importance for the presented comparison: "The difference between the equilibrium experiments presented by Otto-Bliesner et al. [2013] and the transient climate simulations analysed here, can potentially impact the comparison between both studies. Most notably because it is unlikely that in reality the climate was in equilibrium with maximum LIG NH summer insolation and greenhouse-gas concentrations as implied by the set-up of Otto-Bliesner et al. [2013]. However, because this maximum LIG radiative forcing was only applied for 1ky, we deem it unlikely to be of large importance for the presented comparison between both studies."**

-p749, conclusions: The authors need to develop more the implications of their work, the perspectives and future work (both on the model side and data side) that should be performed to be able to progress. **At the end of the conclusion section we have added the following: "Currently, new methodologies are being developed to provide a better age control for LIG temperature reconstructions, potentially decreasing the importance of the overestimation discussed in this manuscript. Another aspect that could greatly improve current model-data comparisons of the LIG temperature evolution, is a better understanding of the reconstructed changes in the SH mid-to-high latitude and its representation in climate simulations."**

Technical corrections: -p740, line 23: “in such an evaluation” should be modified into “in the evaluation” **This has been changed.**

-p740, lines 25-26: Two references for LIG compilations should be added. Kaspar et al. 2005. A model-data comparison of European temperatures in the Eemian interglacial GRL, 32, L11703, doi:10.1029/2005GL022456 Clark and Huybers, 2009. Global change: Interglacial and future sea level Nature 462, 856-857 (doi:10.1038/462856a) **Thanks for pointing this out. A reference to Kaspar et al. and to Clark and Huybers has been added. We note however, that in th work of Kaspar et al. the synchronicity assumption is likely of less impact because the study is limited to a relatively small geographical region, namely Europe.**

-p741, line 2: “ABSOLUTE chronological uncertainties...” **This has been added.**

-p747, line 20: remove “even” **This word has been removed.**

-p747, line 21: “in the CCSM3 model, the model used by...”: replace by “in the CCSM3 model used by ...” **We have clarified this sentence as follows: “. Interestingly, we find that the calculated overestimation of LIG maximum warmth in the CCSM3 model run included in our study, the same model as used by Otto-Bliesner et al. [2013] for their model-data comparison, is always larger than the MMM.”**

-p747, line 23: unclear, the sentence should be reformulated **We think this part is clearer by changing it into: “However, a comparison between the CCSM3 LIG equilibrium simulations presented by Otto-Bliesner et al. (2013) and the transient CCSM3 simulation presented here is far from straightforward and not easily interpreted. Nonetheless, the difference between the equilibrium**

experiments presented by Otto-Bliesner et al. [2013] and the transient climate simulations analysed here, can potentially impact the comparison between both studies. Most notably because it is unlikely that in reality the climate was in equilibrium with maximum LIG NH summer insolation and GHG concentrations as applied by Otto-Bliesner et al. [2013]. However, because this maximum LIG radiative forcing was only applied for 1ky, we deem it unlikely to be of large importance for the presented comparison between both studies.”

-p748, line 18: replace “the final and possibly most important point of critique is the fact that” by “an important limitation of our study is linked to the fact that” **The sentence has been changed into: “A final important limitation of our study is linked to the fact that it is obviously not ideal to use the tools that require evaluation, to evaluate the reference dataset.”**

-p757, Fig 1: replace “based on annual mean temperatures” by “taking into account simulated annual mean temperatures” **This has been changed accordingly.**

-758, Fig 2: replace “based on warmest month temperatures” by “taking into account simulated warmest month temperatures” **This has been changed accordingly.**

-760, Fig 4: please, precise in this caption that the calculated MMM overestimation of the LIG thermal maximum temperature is illustrated by the differences between the compilation-warmest-periods and the warmest-single-period method **Thanks for pointing this out. We have added: “The calculated MMM overestimation is illustrated by the differences between the compilation-warmest-periods and the warmest-single-period methods.”**

-Reference list: It is probably an editing issue that the authors are certainly not responsible for, however, note that at the end of each reference, a number/several numbers is/are added while it/they should not be present. **These numbers are likely the pages on which the particular reference is quoted. Indeed we did not include this and do not know if they are supposed to be there.**

âĂČ Anonymous Referee 2 This study addresses the temperature bias introduced by the assumption that proxybased last interglacial (LIG) maximum temperatures are all peaking at the same time. The authors use transient model simulations from 9 different models to assess this bias. It is a neat idea, timely as well, and the results should be published. The study is well written, but lacks some information and discussion. Also including and discussing a few more analyses will largely enhance the impact of this study. Please find below the comments that I would like to see discussed before publication of the final CP paper.

GENERAL COMMENTS 1) Throughout the publication you sound unsure if the timing of peak warmth occurred simultaneously or not. There are now enough publications (and you mention several) showing that maximum temperature are not reached at the same time across the globe. Also, this assumption is the background for what you quantify in your study. Therefore, I suggest you change the wording of these sections. For example, page 741.27-30: "orbital forcing and its interaction with climate feedbacks cause seasonal differences in the timing of interglacial maximum warmth; e.g. the annual mean, summer or winter temperature maxima did not occur synchronously." **Thanks for this comment. We agree that indeed it is well established that peak warmth did not occur simultaneously. However, it is still uncertain if the assumption that maximum warmth did occur simultaneously, underluing many proxy-based reconstructions, results in a substantial bias in the estimates of LIG maximum warmth. We propose to leave the first sentence of this paragraph**

as it is to reflect the latter: "One partial reason for the mismatch could be that the synchronicity assumption underlying the compilations of the LIG thermal maximum is a non-negligible oversimplification." But to change the wording in the following lines, delete the word 'possibly' at two occasions in order to make it more clear that the assumption has to lead to an overestimation. "Several transient modelling experiments and proxy-based temperature reconstructions for both the Present Interglacial (PIG) and the LIG have shown that there are large regional differences in the timing of interglacial maximum warmth, in the order of several thousands of years [Renssen et al., 2009, 2012; Bakker et al., 2012; Govin et al., 2012; Langebroek and Nisancioglu, 2013]. These temporal differences result from latitudinal and seasonal differences in the evolution of the orbital forcing, from the thermal inertia of the oceans and from a variety of climate feedbacks in the climate system, such as the presence of remnant ice sheets from the preceding deglaciation, changes in sea-ice cover, vegetation, meridional overturning strength and monsoon dynamics. Moreover, these complexities in the orbital forcing and its interaction with climate feedbacks, cause seasonal differences in the timing of interglacial maximum warmth; e.g. the annual mean, summer or winter temperature maxima did not occur synchronously. As a consequence, a compilation of reconstructed LIG temperatures that combines LIG maximum temperatures from different regions, seasons and climatic archives, yields temperature anomalies that are larger than the maximum temperatures that occurred at any given time during the LIG period."

2) Similar comment on the sentence "ongoing debate whether proxy-based temperatures include a seasonal bias" (p743). This is quite accepted; only problem is that often it is not clear to which month/season the proxy is biased, especially as this also depends on geographical location. **Thanks for this comment. We have changed the line into: "Annual mean proxy-based temperatures often include seasonal biases that are in turn dependent on the type of proxy and the region under**

consideration [Schneider et al., 2010; Leduc et al., 2010; Lohmann et al., 2013]."

3) Related to that: why do you only test annual mean and warmest month mean, and not a particular season or month? Proxy temperatures are seasonally biased, but not necessarily to the warmest month. Food availability and other factors (salinity, light, competition, . . .) also play a factor. It would really improve the manuscript to also include a computation based on a spring or summer season, or a particular month. **In line with the suggestion of the reviewer, we have redone the analysis to include summer (JJA and DJF) and spring (MAM and SON) temperatures. The methodology and results of this analysis is now included in the manuscript. Note however, that there is an important difference between, on the one hand, the annual mean and warmest month analysis and, on the other hand, the seasonal analysis. Calculating a period for which regionally or globally MAM temperatures (or one of the other seasons) were at a maximum does not have a meaning since this can be the warmest season at one location while it is the coldest season at another. Moreover, the complexity in which month is the warmest month as shown in the newly added figure, reveals that an approach in which, for instance, JJA for the NH and DJF for the SH are combined is also unlikely to be fruitful. Because of this, we deem it best to only focus on the CWP method for the MAM, JJA, SON and DJF temperatures. From this one cannot directly deduce the possible overestimation, but it does show what the maximum temperatures were locally and during a certain season. Comparing this in turn with the annual mean and warmest month calculations of the overestimation does provide an estimate for these specific seasons as well. A new figure and text in the methods and discussion sections has been added. The text in the method section is: "Moreover, in the discussion we present maximum LIG temperatures following the CWP method for the different seasons: March-April-May (MAM), June-July-August (JJA), September-October-November (SON) and December-January-February (DJF). This will allow us to discuss the**

possible impact of the synchronicity assumption for proxy-based records that are locally biased towards a certain season."

In the discussion part we have added the following: "In the results discussed so far, we focussed on annual mean and warmest month temperatures. However, seasonal biases in proxy-based temperature reconstructions from a specific region can also be towards other seasons, for instance to average summer temperatures or towards the spring/autumn bloom periods [Schneider et al., 2010; Leduc et al., 2010; Lohmann et al., 2013]. To see how such a seasonal bias would impact the results, we compare CWPs for all four seasons with the annual mean and warmest month CWPs (Figure 5). Note that calculating the SWP over a large spatial domain, for instance a global average, for a specific set of months, for instance MAM, is meaningless because such an average would combine temperatures from largely different seasons (see also Figure 3). We find that the CWP temperature anomalies in the NH extratropics are largest in JJA while they are largest in SON over the SH extratropical continents and part of the Southern Ocean. Interpreting the seasonal temperature anomalies in terms of the potential overestimation of the LIG thermal maximum is difficult, because it is the temperature anomaly in combination with spatial differences in the occurrence of the temperature anomalies within the LIG that determine the size of the overestimation. Notwithstanding this limitation, the maximum seasonal temperature anomalies that occurred during the 130-120ka period as found in the MMM provide a good reference for future studies into the seasonality aspects of different temperature proxies."

4) Also, information or preferably a figure indicating which months are the warmest months would improve the clarity of study. **Thanks for this idea. We agree that it is interesting to know which month is the warmest month for a given location**

during the LIG climatic optimum. The figure has been added as well as a short discussion of its contents. The text that is added to the results section is: "It is interesting to note that the simulated geographical pattern in the warmest month of the year during the LIG thermal maximum, does not simply follow the month of highest insolation. We find that over the NH extratropical continents the warmest month is generally June, for the NH extratropical oceans it is August and for the SH extratropical oceans February (Figure 3). In the low-latitudes the land-sea differences are also apparent, but on top of that, monsoon dynamics and other local processes appear to play an important role in shaping the seasonal temperature evolution."

6) Similarly, which 50 yrs time periods simulate the highest temperatures, and how do they differ over different regions (or preferable latitudes). **We agree this is an interesting point. However, a very similar results (for 7 out of the 9 model simulations presented in this study) has previously been presented in Bakker et al. (2013). This study is therefore referred to in the description of the methodology and the discussion of limitations of the presented transient simulations to assess the magnitude of the temperature overestimation. We have added this notion: "For a description of the spatial differences in the timing of the warmest part of the LIG according to the transient climate simulations, we refer to Bakker et al. [2013]."**

7) Why did you choose these regions (extratropics and tropics)? It might be nice to show other regional averages such as for example the Arctic, North-Atlantic, Europe, Southern Ocean, Monsoon regions, etc. Or at least discuss how the decision of your 3 regions affects the results. **The three regions under consideration have been chosen in order to facilitate a comparison to the findings of Otto-Bliesner et al. We deem the discussion of more regions not very beneficial since the maps in**

figure 3 already provide this information to the reader.

8) Related to this: the different regions have very different number of proxy records from which averages are computed (see also the figures in Otto-Bliesner et al., 2013). How does this non-uniform distribution affect the model to model-data comparison in your discussion? Also, mention the number (and possibly type) of proxy temperature values for each region used in your Otto-Bliesners study. **Thanks for this point. We acknowledge that there are many difficulties in calculating regional model-data comparisons of LIG temperatures. However, in this study we solely use the result obtained by Otto-Bliesner et al. to investigate how substantial the calculated overestimation is relative to previously described model-data differences. And thus whether or not it seems likely that the synchronicity assumption can explain a substantial part of the model-data mismatch found in LIG temperatures. For this reason, we deem an in-depth description of the work performed by Otto-Bliesner et al. unnecessary. However, we do agree that in the discussion part, the points that are raised by the reviewer should be discussed in the light of their importance to the presented results. We have therefore added: "Another limitation of the included proxy-based reconstructions in the study by Otto-Bliesner et al. [2013] is the non-uniform spatial distribution of the proxy-records, a feature that will impact the data since the spatial differences in maximum warmth described in the present study are large. However, quantifying the impact of the limited spatial data coverage on the model-data mismatch is far from straightforward.".**

9) You use atmospheric 2-meter temperatures for the entire comparison. Will your results change when you take simulated sea-surface temperatures (SST) and compare those to the proxy SSTs? Please discuss. **Thanks for this comment. Ideally one would use SST's for the oceanic regions. However, we deem the difference be-**

tween surface air temperatures and SST's rather small since we are discussing anomalies. Moreover, on multi-millennial time scales, trends in SSTs and the temperature of the overlying atmospheric layer can be assumed to be closely linked (Jones et al., 1999). Furthermore, the choice for 2-meter temperatures has a practical background because combining SSTs from different models with largely differing land-sea masks is difficult and introduced many problems. In addition, SSTs for all the 9 different models are not available. (ref: Jones, P. D., New, M., Parker, D. E., Martin, S., Rigor, I. G., 1999. Surface air temperature and its changes over the past 150 years. Rev Geophys 37(2), 173-199.)

10) Great that you also assess the time averaging period that you choose (250 vs 50 yrs mean). However, most of the proxy records have a temporal resolution even lower, in the order of 1000-3000 yrs. Would it change your results if you did the averaging over such a (maybe more relevant?) period? **In accordance to this point we have performed additional analysis with a 2000yr averaging period, included this data in table 3 and shortly described this result in the main text.**

11) The data-model temperature offset found by Otto-Bliesner et al. (2013) you mention (0.67 degC) is based on annual mean surface temperature anomalies, right? In the discussion of your results (mostly page 747) you also compare your simulated warmest month values to Otto-Bliesners values. Maybe it would make more sense when you would use Otto-Bliesners warmest month or summer values (if this exists, otherwise it might be worth asking Otto-Bliesner for this information). Also, they compare simulated surface temperature anomalies, in contrast to your 2m air temperatures. Please discuss. **Indeed we compare both annual mean and warmest month temperatures to the annual mean model-data differences described by Otto-Bliesner et al. (2013). Moreover, in the updated manuscript we included MAM, JJA, SON and DJF temperatures. Otto-Bliesner et al. (2013) did**

perform the comparison for JJA/DJF temperatures as well, they describe that for certain regions this improves the comparison, but overall the seasonality aspect was not easy to interpret. Most likely for that reason, they chose not to include numbers for the according model-data comparison for the 4 different geographical regions in the tables. However, there is also a practical argument not to give regional averages, because of course the summer is JJA in the NH and DJF in the SH. Combining this into 1 global value is difficult, even more so since this distinction in NH is JJA and SH is DJF is only true to a first order, as is visible in the newly included figure in this manuscript. For all these reasons, we deem it best to restrict the comparison as presented in the discussion part to the annual mean model-data differences presented by Otto-Bliesner et al.

SPECIFIC AND TECHNICAL COMMENTS Title, and also in the text: "thermal maximum temperatures", change to "thermal maximum" or "maximum temperatures" **Thanks for this comment. We have changed thermal maximum temperatures into the thermal maximum throughout the manuscript.**

(page.line) 740.13-15: rewrite, see also General comment 11) **Indeed this line is not fully correct since for the model-data comparison it is not clear if we are talking about annual mean or warmest month temperatures. We have changed the last two lines of the abstract in order to be more precise: "We find that for annual temperatures, the overestimation is small, strongly model-dependent (global mean 0.4$\pm$0.3°C) and cannot explain the recently published 0.67°C difference between simulated and reconstructed annual mean temperatures during the LIG thermal maximum. However, if one takes into consideration that temperature proxies are possibly biased towards summer, the overestimation of the LIG thermal maximum based on warmest month temperatures is non-negligible with a global mean of 1.1$\pm$0.4°C."**

740.18-22: change the order of the two arguments, second one is more important, and first argument could be disputable as the forcings in the LIG climate models are not the same as those for future climate scenarios. **Thanks for this point. We have reversed the order. However, note that we are not saying that the forcing is the same in the LIG climate simulations and the future scenarios. We only say that both are warmer than present-day climates.**

741.22: include also Govin et al., 2012 (CP) and Langebroek and Nisancioglu, 2013 (CPD) **Both references have been included.**

742.19-24: This is not easy to understand, and very essential. Please better explain the 2 different calculations. Do I understand well that for i) you first averaged the temperatures per region, and then search for the 50 yr period that has the highest temperatures; ii) you select the maximum 50 yr mean (?) temperature per grid cell, and then average over the region? **Thanks for this comment. Indeed you understand it exactly how it is. We agree it is not very easy to understand, but we don't see how to make it more clear. We have made some slight adjustments to the sentence and hope this explains it a bit better: "To investigate the possible overestimation of LIG the thermal maximum, we calculate the temperature anomalies in two different ways: i) we calculate regionally averaged temperature anomaly time-series and from that determine the warmest period (warmest-single-period); ii) we assume synchronicity of the LIG thermal maximum in space and time by calculating for each individual model grid cell the largest LIG temperature anomaly and then combine these single-grid-cell maxima into regional averages (compilation-warmest-periods)."**

745.1-8: This could be an argument for the peak warmth not occurring simultaneously in all regions. Here it would be very interesting to see which months dominate the comparison, and which time periods dominate the compilation-warmest-period, and how they vary depending on latitude. **Thanks for this comment. We agree that the relation between insolation and temperatures is a complex and very interesting one. To see which months are actually the warmest months we have added a new figure and a short discussion of its contents. It shows that for the NH it is mostly JJA with the tendency towards June over the continents and towards August over the ocean. On the SH a similar pattern is visible. In the lower latitudes, the picture is more complex and scattered with large influences of monsoon dynamics in a number of regions.**

For a discussion on which period is the warmest throughout the LIG and how this depends on latitude we refer to a previous publication by Bakker et al. (2012) in which exactly this is described for 7 out of 9 models presented in this manuscript.

745.19: can you add the model resolution in Table 1? **Thanks for pointing this out. We have added the horizontal and vertical resolution of the atmospheric and oceanic components to Table 1.**

746.24: "130 ka forcings", please briefly state which forcings (greenhouse gas, insolation, freshwater forcing?) **We have changed the line into: "...130ka forcings (orbital and greenhouse gas congregations)"**

747.1: change to "0.98 and 0.31 degC annual mean temperature anomalies between 130 ka and pre-industrial" or equivalent **We have changed it into: "(anomalies of**

0.98°C and 0.31°C with respect to preindustrial values in the reconstructions and simulations respectively)"

747.2: "this study" can refer to your study or Otto-Bliesners study. Please rewrite. **Thanks for pointing this out. We have changed it into: "The MMM overestimation of the LIG thermal maximum presented here (0.4±0.3°C),. . ..."**

748.2-3: "model biases for present-day climate". Maybe you can assume that by taking anomalies the present-day biases are not a huge problem? Of course this is based on the assumption that the biases are time independent. . . **Indeed, by taking anomalies the largest impact of model biases in the present-day climate is probably taken care of. We have added the following: "The models included in this study are all known to have specific biases for the present-day climate, notwithstanding that we deem the impact of these biases small since we only use LIG anomalies with respect to the pre-industrial climate"**

748.4-5: That is because the warming did not occur simultaneously. **We agree that indeed the warming was not simultaneously. But here we refer to the large model-data differences with respect to LIG maximum temperatures in the SH. Models generally show a thermal maximum between 120-116ka, while proxies suggest a timing in the order of 132-125ka. We have made this clearer by changing the line into: "Moreover, the included climate models have difficulty to mimic the reconstructed near-synchronicity between NH and SH high latitude warming during the early LIG (Bakker et al., 2013), with most models showing SH maximum LIG temperatures <120ka".**

748.19-20: Not clear, please rewrite. It is not fully clear to us which line the reviewer

is referring to. The first line deals with the possibility that a different deglacial history before the onset of the LIG with respect to the PIG, might impact the results described by Renssen et al (2009). If remnant ice sheets were present during a longer period in the early phase of the LIG compared to the PIG, this might have a different impact on the climate compared to the study by Renssen et al. (2009). **In case the reviewer was referring to the line after this: proxy-based reconstructions are needed to validate climate models, however, if we start using climate models to validate proxy based reconstructions (which we will inevitably have to do), we should not forget that we are entering a precarious circular reasoning.**

Table 2: "present-day" is probably "pre-industrial" **Thanks for pointing this out. It has been corrected.**

Table 2: change to "found in the regionally averaged temperature evolution" **Thanks for pointing this out. It has been corrected.**

Fig 4: "Comparison of" **Thanks for pointing this out. It has been corrected.**

Fig 4: change "thermal maximum temperatures" **It has been corrected.**

Added figures show:
1) Month during which 50-year averaged LIG maximum warmth is found. Median of the nine different models is taken as the multi-model-mean and for the calculations of LIG maximum warmth we applied the compilation-warmest-periods method, e.g. maximum LIG temperatures per individual grid cell.
2) Spatial differences in LIG maximum temperatures (°C) compared to pre-industrial for DJF, MAM, JJA and SON temperatures following the compilation-

warmest-period (CWP) methodology.

Interactive comment on Clim. Past Discuss., 10, 739, 2014.

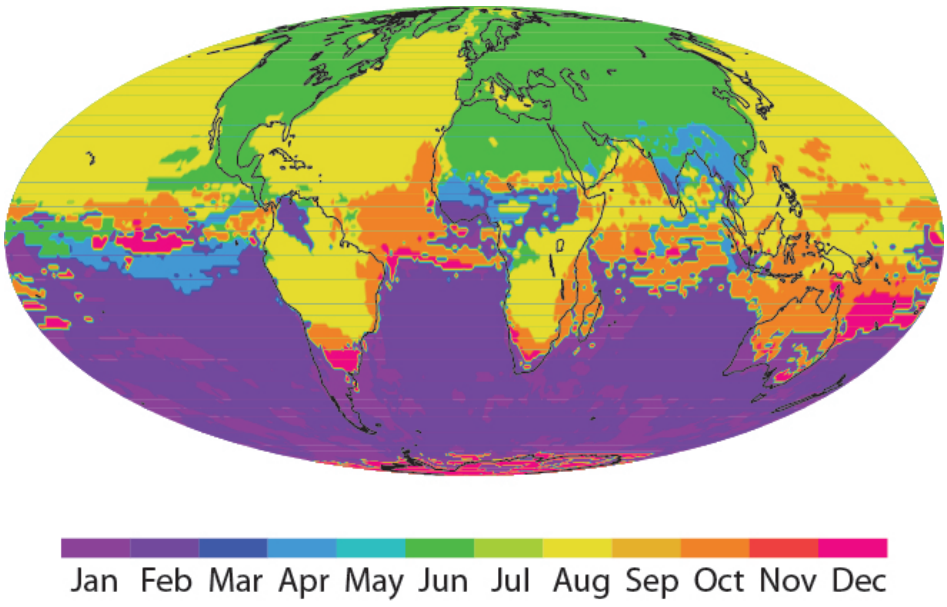

Fig. 1.

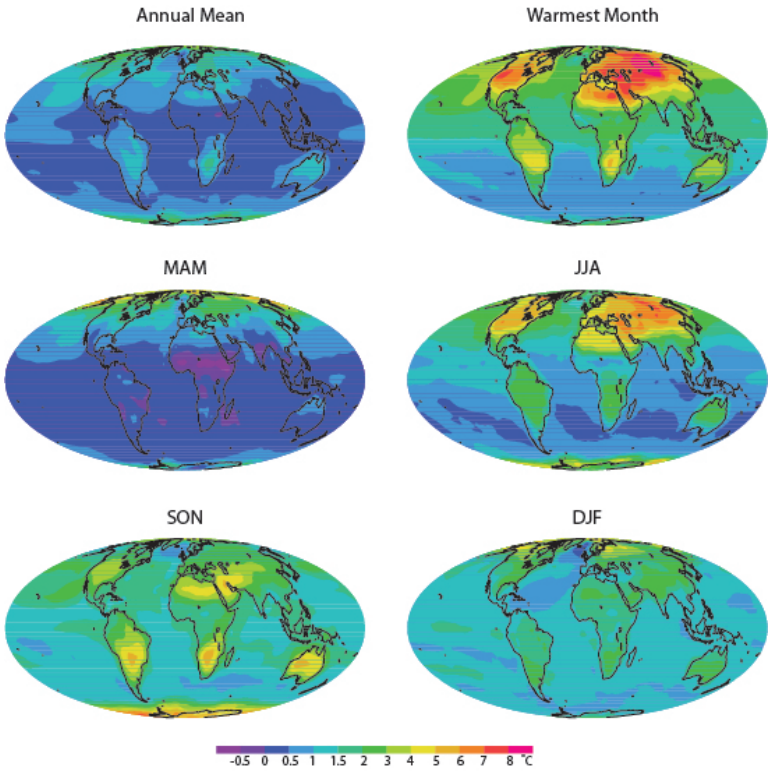
Annual Mean
Warmest Month
MAM
JJA
SON
DJF
-0.5 0 0.5 1 1.5 2 3 4 5 6 7 8 °C

Fig. 2.