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Climate of the Past Discussions

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Interactive Comment

Interactive comment on "The last interglacial (Eemian) climate simulated by LOVECLIM and CCSM3" *by* I. Nikolova et al.

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We thank the reviewer#2 for the interesting questions and valuable comments to improve the manuscript. Our point-by-point reply is given hereunder. Please refer to the attached supplement for updated manuscript, references, tables and figures.

I would like the authors to comment on why they chose to compare CCSM3 with LOVECLIM and not any other models available for the LIG through PMIP3.

[Authors]: Our model choice is mainly driven by availability. With the same climate forcings in both models, LOVECLIM and CCSM3 have been used in our group to simulate the interglacials of the past 800ka (Yin and Berger, 2010, 2012; Herold et al 2012). These studies focused on the intercomparison between different interglacials, and provide simulations for studying the last interglacial as an additional effort to PMIP3. We included the following paragraph in Section 1: "Yin and Berger (2010, 2012) have simulated the peak climates of the past nine interglacials with LOVECLIM, an Earth system model of intermediate complexity. Using the same boundary conditions, Herold et al. (2012) simulated the climate of five stronger interglacials with CCSM3, a comprehensive Atmosphere-Ocean General Circulation Model. These studies focused on the comparison between different interglacials. Because they used the same climate forcings, these studies provide ideal paired experiments for inter-model comparison, which would be interesting for the modeling community in particular given that LOVECLIM and CCSM3 are often used in climate/paleoclimate modeling and are of different complexity. The MIS-5e simulations provided by these studies and also included in Lunt et al (same issue), are analyzed here. Lunt et al. (same issue) analyzed 12 snapshot simulations between 125ka and 130ka BP performed by several climate models. They focus on the analysis of near surface temperature pointing out large regional deviations in the ensemble mean and between ensemble mean and proxy data. However, due to the large amount of models, it is difficult to address in details the possible reasons for the simulated regional dissimilarities between the models. Given the increasing interest of the paleoclimate community in the last interglacial climate, detailed information about the simulated climates is needed and the mechanisms responsible for the changes of different climatic variables deserve to be investigated."

There is absolutely no significance testing on any of the simulation data. This is essential in order to make more robust conclusions about the patterns of anomalies. Please include this and alter any discussion accordingly, as well as highlighting the areas with significant anomalies in the figures.

[Authors]: We have done the significance test and have included it in the figures and text.

The figures are not easy to read and are a bit messy and inconsistent in style. The legends and axes text are too small, the colour bar limits need to be set so that it is easier

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to see where the anomalies are zero, and make this consistent between ïňĄgures. E.g. make zero or insignificant areas white or grey.

[Authors]: We have revised the figures and made them more clear and easy to read. We made the zero anomaly being white. Thus the contrast is clearer between positive and negative anomalies.

In Figure 11, the higher values in the line plot are off the top of the chart – this also needs changing.

[Authors]: This has been adjusted accordingly.

There is a title to the plot in figure 1 but not for any of the other figures. I would suggest deleting the title to the first figure.

[Authors]: The title in Figure 1 is deleted.

Page specific comments (general and technical):

Page 5295 Line 17 onwards – I would have said that the reason for compilation of 6kyr, LGM, and LIG is not due to the availability of proxy data – rather that these are time periods concentrated on due to having interesting climatic/environmental features.

[Authors]: Agree. We did revise section 1 and these lines are deleted. Section 1 is re-written as follows: "The Earth has experienced quite warm periods in the past (e.g. interglacials). Investigating the climate processes and feedbacks during these warm periods helps to improve our understanding of climate dynamics and to address key questions for the future, in particular when the climate predicted to occur over the next centuries by the Intergovernmental Panel on Climate Change (IPCC, 2007) appears to be unprecedented over the last 150 years. The last interglacial (also called the Eemian interglacial and Marine Isotope Stage (MIS) 5e) was a recent warm interglacial during which the Arctic experienced markedly summer warming, accompanied by sea-level rise and reduction in ice sheets (Otto-Bliesner et al., 2006a; Kukla et al., 2002; Bintanja et al., 2005; Jouzel et al., 2007; McKay et al., 2011). In terms of such climatic

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features, the last interglacial is often considered to be analogue to the future climate (eg. Kukla et al., 1997), though this is still questionable in terms of its completely different astronomical configuration from today and the future (Berger and Loutre, 1996; Berger and Yin, 2012). There are still no detailed datasets compiled for MIS-5e except for the global temperature record of Turney and Jones (2010). This is related to the fact that creating a database based on individual records is complicated (Groll et al., 2005) due to the large uncertainties related to difficulties in estimating the duration of MIS-5e (Shackleton et al. 2003). Given its significance in helping to understand better the future warming, the last interglacial has been included recently in the Palaeoclimate Model Intercomparison project (in its third phase, PMIP3, http://pmip3.lsce.ipsl.fr). Yin and Berger (2010, 2012) have simulated the peak climates of the past nine interglacials with LOVECLIM, an Earth system model of intermediate complexity. Using the same boundary conditions, Herold et al. (2012) simulated the climate of five stronger interglacials with CCSM3, a comprehensive Atmosphere-Ocean General Circulation Model. These studies focused on the comparison between different interglacials. Because they used the same climate forcings, these studies provide ideal paired experiments for inter-model comparison, which would be interesting for the modeling community in particular given that LOVECLIM and CCSM3 are often used in climate/paleoclimate modeling and are of different complexity. The MIS-5e simulations provided by these studies and also included in Lunt et al (same issue), are analyzed here. Lunt et al. (same issue) analyzed 12 snapshot simulations between 125ka and 130ka BP performed by several climate models. They focus on the analysis of near surface temperature pointing out large regional deviations in the ensemble mean and between ensemble mean and proxy data. However, due to the large amount of models, it is difficult to address in details the possible reasons for the simulated regional dissimilarities between the models. Given the increasing interest of the paleoclimate community in the last interglacial climate, detailed information about the simulated climates is needed and the mechanisms responsible for the changes of different climatic variables deserve to be investigated. In this paper, we present a detailed regional and seasonal analysis for the

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surface climates of MIS-5e relative to the Pre-Industrial (PI) period. We investigate the feedbacks of sea ice, monsoon, vegetation and ENSO in the modeled climate system as plausible explanations for the regional similarities/dissimilarities simulated in both models, making it the first detailed intercomparison between CCSM3 and LOVECLIM models with emphasis on MIS-5e. We also give some quantitative comparison with proxy data reported in literature, in order to determine where features are robust and where uncertainties are large. The paper is organized as follows: in Section 2 we give a brief description of CCSM3 and LOVECLIM models and the prescribed boundary conditions. In Section 3 we discuss the similarities and differences in surface temperature between CCSM3 and LOVECLIM. In Section 4 we focus on African, Indian and East Asian monsoons. Vegetation is discussed in Section 5 and ENSO variability in Section 6. Conclusions are given in Section 7."

Line 26/7 – creating a database is complicated due to large uncertainties in chronology that far back in time (no radiocarbon so have to rely on other dating techniques), but I'm not sure what you mean by climate variability making it difïňĄcult. Do you mean regional/spatial variability or temporal variability, and in what sense does this make it difïňĄcult – in linking events/wiggles between records? I'd like it to be made clearer here.

[Authors]: This is related to the fact that creating a database based on individual records is complicated (Groll et al., 2005) due to the large uncertainties related to difficulties in estimating the duration of MIS-5e (Shackleton et al. 2003). We have discussed this in section 1 (see our revised section 1 in the answer to Page 5295 Line 17).

Line 5 change 'remains' to 'remain' Line 11 change 'featured' to 'featuring' Line 13 change 'trough' to 'through'

[Authors]: Corrected.

Page 5296 Line 4 'their response to different forcings' – different to what?

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[Authors]: We meant different forcings than present day.

Page 5298 Line 1-2 Does the sea-ice model have dynamic and thermodynamic components, multicategory ice etc.? The differences may be important for the different sea-ice responses noted in the results.

[Authors]: The sea-ice models of LOVECLIM and CCSM3 are both dynamic and thermodynamic, but it is only one sea-ice thickness category in LOVECLIM but multicategory in CCSM3. This difference in sea ice category at least partly contributes to the different sea-ice response in two models. This has been mentioned in the revised manuscript in section 3.1, as follows: "The sea-ice models of CCSM3 and LOVECLIM are both dynamic and thermodynamic, but it is only one sea-ice thickness category in LOVECLIM but multi-category in CCSM3. This difference in sea-ice category at least partly contributes to the different sea-ice response in the two models. . . ."

Line 5-10 It is not clear exactly what LIG vegetation is prescribed in CCSM3. Do you run BIOME4 from initial CCSM3 climate and then feed the results back in to recaulate the CCSM3 climate again, or is the vegetation prescribed the same as pre-industrial?Please state what the boundary conditions are.

[Authors]: The vegetation in CCSM3 was prescribed the same as pre-industrial. The LIG climate simulated by CCSM3 was used to initialize BIOME4 to see what would be the vegetation given the climate. We did not feed the results of BIOME4 back to recalculate the climate again. This would be interesting to be done in future study.

Page 5299 Line 4 Palaeodata from Turney and Jones (2010) suggest 1.9deg warming at the LIG. Are there any quantified uncertainties bounds to put on this figure? In their paper they state it's warmer than 1961-1990 by 1.5C # 0.1C. Could you include a quantification of this uncertainty (although I realize it will be larger for LIG-pre-industrial) in the text.

[Authors]: The warming of 1.5 degC is for present day. With regard to pre-industrial, this

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warming was given aprox. 1.9degC. Smith and Reynolds, 2005 (A global merged land–air–sea surface temperature reconstruction based on historical observations (1880–1997), Journal of Climate 18: 2021–2036) discussed the warming in 20th century in comparison with PI and estimated a warming of 0.6degC with approx. +/- 0.3 degC uncertainties in their merged land-air-sea temperature.

Line 7 Lack of interactive ice-sheets is put forward as a possible reason for discrepancy in global temperatures between model and data. It would be good to see more detail about this in terms of how much it has been proposed that Greenland and possibly WAIS were from other studies and the impacts. E.g. it would be appropriate to reference Otto-Bliesner et al, Science, 2006, Holden et al, 2010 or similar.

[Authors]: We included a short discussion on this topic in section 3 as follows: " In addition to the possible uncertainty in the estimation based on proxy records, one of the reasons might be due to the lack of interactive ice sheets in both models. Holden et al. (2010) investigated the effect of warming in Antarctica when accounting for dynamic ice sheets. They found that the surface temperature in East Antarctica increased from 1.4 (Dome C) and 2.2°C (Dome F) to 5 (Dome C) and 4.9°C (Dome F) caused by the retreat and meltwater of the West Antarctic Ice Sheet (WAIS). In NH, according to Otto-Bliesner et al (2006a), when Greenland ice sheet is completely removed, there is an additional summer warming of several to more than 10°C localized over Greenland, and the freshwater forcing of inserting 0.1 sverdrup of water in the North Atlantic over 100 years yields to an annual cooling of 1.5°C south of Greenland. In spite of this fresh water induced cooling, the summer temperature anomalies over Greenland remain positive. Lunt et al (2004) also found that the effect of melted Greenland is local for temperature (directly related to changes in altitude and albedo of the surface), precipitation and more widespread for circulation (response to changed orography) but the "principal effect of removing the Greenland ice-sheet is relatively localised". They show that December-January-February (DJF) surface temperature decreases over Barents Sea (2°C for 2m height temperature) as a result of changes in the near-surface meridional wind speed. In the case of melted Greenland, cold air from the pole is advected to the south. This cooling along with the freshening of the North Atlantic increases the sea-ice formation and retains sea ice in June-July-August (JJA) as mentioned by Lunt et al (2004). However, all these sensitivity studies are for a complete melting of Greenland ice sheet, therefore the effects of the MIS-5e Greenland melting would be much smaller and would be important mainly for the regions over and around Greenland. Nevertheless, the shortcoming of prescribing ice sheet to present should be kept in mind when model-proxy comparison is made. "

Line 10. Lack of interactive vegetation put forward as explanation for why LOVECLIM is warmer than CCSM3. I'd like to see more detailed explanation here as well, and link to the vegetation in LOVECLIM described in a subsequent section and prescribed vegetation in CCSM. Are warmer areas where vegetation is significantly altered from pre-industrial?

[Authors]: We put the lack of interactive vegetation forward in order to explain the differences in the simulated LOVECLIM and CCSM3 surface temperatures. The following discussion has been included in our revised manuscript in section 3: "Along with the missing feedback from dynamic ice sheets, the feedback from vegetation could also affect the temperature through albedo change. As we discuss in Section 5, trees expanded deep into the northern high latitudes replacing grassland. The lack of interactive vegetation in CCSM3 could cause unrealistic surface temperature because of the missing response during the replacement. The lack of interactive vegetation in CCSM3 could cause unrealistic surface temperature because of the missing response during the replacement. According to Brovkin (2002), climate exerts a major control on the spatial distribution of vegetation types while vegetation influences climate via changes in the physical properties of the land surface such as albedo, biogeophysical mechanisms, roughness and atmospheric gas composition. For example Crucifix and Loutre (2006) show that during boreal winters the albedo of snow in the presence of grass is about 0.8 (contributing to the cooling of the atmosphere). The presence of trees, however, reduces the albedo to 0.4 and consequently increases the temperature in the atmosphere. Denman et al. (2007) claim that “Shorter vegetation with more leaves has the most latent heat flux and the least sensible flux. Replacement of forests with shorter vegetation together with the normally assumed higher albedo could then cool the surface”. Vegetation induced cooling/warming through albedo change is also discussed in several other studies (Ganopolski et al., 1998; Claussen, 1998; Claussen et al., 2006; Kubatzki et al., 2000). ”

In section 3.2 we added: “A signal from the vegetation feedback could also be related to the simulated warmth in LOVECLIM. LOVECLIM surface temperature in MIS-5e remains higher than in CCSM3 in the areas of expanded vegetation during MIS-5e. However, CCSM3 do not account for the MIS-5e vegetation, hence it will be difficult to assess its effect on surface temperature. “

Line 5-10 From figure 4 it looks like there is a big difference in annual temperature anomalies over Arctic sea-ice regions, which must have a role in the different in global temperature anomalies between CCSM3 and LOVECLIM. Yet sea-ice is not discussed here in this section. I know it is outlined later in discussion of seasonal temperatures but think it may warrant a mention here too.

[Authors]: The signal from DJF is so strong that it is imprinted on the annual signal, too. We have added in section 3.1 JJA surface temperature anomalies the following:...” This warming is caused by the high insolation at the top of the atmosphere during JJA and the large reduction of the sea ice and snow cover. Less sea ice is simulated in both models - about -40% in CCSM3 and up to -60% in LOVECLIM (Figure 3). The sea-ice models of CCSM3 and LOVECLIM are both dynamic and thermodynamic, but it is only one sea-ice thickness category in LOVECLIM but multi-category in CCSM3. This difference in sea-ice category at least partly contributes to the different sea-ice response in the two models.”

Page 5300 Line 6 Change to ‘North Atlantic, Greenland, and Arctic’ – i.e. add a comma

Page 5301 Line 14 ‘Easther Japan’? Page 5302 Line 1 change ‘though’ to ‘through’

[Authors]: Corrected.

Page 5303 Line 15-20 If there is a dramatic impact on the AMOC, do you mean on the average state or its stability or both? Why not look at it in this study brieïňĆy?

[Authors]: We mean the average state. In both models AMOC is weaker in MIS-5e than PI. We have mentioned briefly the AMOC behavior in our revised manuscript in section 3.2 DJF: “a freshening that is consistent with the weakening of the Atlantic Meridional Overturning Circulation (AMOC) simulated in both models during MIS-5e relative to PI. For example, in LOVECLIM, the much higher NH summer insolation during MIS-5e reduces significantly the NH sea-ice concentration and increases the temperature of the source region of North Atlantic deep water all year round, leading to a weaker North Atlantic deep water formation during MIS-5e than PI (Yin, 2013).”

Page 5305 Line 14 and that paragraph – I assume the information here refers to the model and not proxy data – it is not made clear in the text.

[Authors]: We refer to the model. We corrected “was observed” to “was simulated”.

Line 22-23 do you mean that there is good agreement between the models in terms of low-level wind, moisture transport and precipitation, or that in each model there is a match between increased wind/moisture and precipitation. If the latter, it seems a bit of an odd way to say basically that wind/moisture transport are important for the precipitation anomalies to occur.

[Authors]: We mean that, in both models, compared to PI, there is a consistent increase in wind, moisture transport and precipitation during MIS-5e. We have reworded the sentence to: “Compared to PI, the increased low level wind speed and moisture transport during MIS-5e are consistent in both model simulations showing higher tropical boreal summer precipitation.”

Line 17-20 Indian monsoon region also to some extent shows cooling, but surprised how much larger the cooling is in North Africa. Page 5306 Line 4 I'm surprised that, if the summer monsoon is stronger (implying increase cloud/rain over India) that the JJA temperatures are described as warmer summers (page 5305 line 27) rather than cooler (as in N Africa). Looking at Figure 2, both models (CCSM3 especially) seem to show some areas of cooling. Why is the response different to N Africa in this sense? Vegetation changes in LOVECLIM counteract any cooling? Level of cloud cover different? SigniïňĄcance testing would also be useful here I think.

[Authors]: The warmer summer in page 5305 line 27 means that MIS-5e had a warmer summer over most NH continents instead of over India. We have discussed the cooling in section 3.1. The cooling is mainly driven by increased low level moisture and latent heat flux in both models, increased cloudiness and precipitation in CCMS3 and increase in precipitation and vegetation feedback in LOVECLIM (Goosse et al., 2010).

Line 28-29 It could be stated somewhere here how you calculated the Indian Monsoon Index brieïňĆy (I know you've included a reference). Related to this, in Figure 11 why is there not a plot for LOVECLIM as well as CCSM3?

[Authors]: Indian Monsoon Index (Wang and Fan 1999) is calculated by the JJA 850 hPa zonal wind averaged over (5°N-15 °N and 40°E-80°E) minus that averaged over (20°N-30°N and 70°E-90°E). This has been mentioned in the revised manuscript.

Page 5308 Line 2 be consistent in use of 'Fig' or 'Figure' here and throughout the paper

[Authors]: For consistency, we use Figure.

Line 5 At the equator the percentage of trees seems similar in LOVECLIM and CCSM3, but away from the equator to 30degN there is a sharper decline in CCSM3 (in favour of grass/shrub and then warm temperature forest) than LOVECLIM.

[Authors]: At the equator up to 10-15degN LOVECLIM simulates an expansion of trees, while CCSM3 simulates trees distribution no different from present day. Instead, the grassland (at 20degN) in CCSM3-BIOME4 occupies about 80% of the land, while in

LOVECLIM grass share is about 50% and the remaining 50% are mainly trees (about 40% trees and 10% desert). We have updated the manuscript with the following: "Over Africa (between the Equator and 30°N), the increase of tree fraction during MIS-5e as compared to PI is larger in LOVECLIM than in BIOME4 (Figure 13a, d). Grassland simulated in BIOME4 (Figure 13b) occupies about 80% of the land at 20°N while LOVECLIM simulates about 50%, the rest being mainly trees (Figure 13e). On one hand, this difference between the two models could be related to the fact that the vegetation-climate feedbacks are missing in CCSM3 due to the lack of a dynamic vegetation model. On the other hand, it could be related to the fact that LOVECLIM tends to overestimate the precipitation around 30°N and the temperature in the tropics (Goosse et al., 2010) and therefore to amplify the vegetation response. This has also been reflected in the inter-model comparison for the mid-Holocene climate (Braconnot et al. 2007). The expansion of the vegetated area during MIS-5e in Sahel/Sahara in LOVECLIM, which results from the northward shift of the ITCZ and moisture advection, is in line with proxy records showing wetter, more green and vegetated Sahel/Sahara (Jolly et al., 1998). "

Line 12 do you mean expansion of vegetated area 'at the LIG'?

[Authors]: We mean the expansion of vegetation north in Sahel/Sahara. This section has been revised as follows: "). The expansion of the vegetated area during MIS-5e in Sahel/Sahara in LOVECLIM, which results from the northward shift of the ITCZ and moisture advection, is in line with proxy records showing wetter, more green and vegetated Sahel/Sahara (Jolly et al., 1998)".

Line 1-27 So in tropical areas there is less agreement between the two models than at high latitudes. Does this suggest something about regional differences in importance of feedback processes with the land surface, given the different set-ups of the models? I just wondered if any broader inferences could be made here?

[Authors]: It would be difficult to make inferences about feedback processes because

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here the differences in climate models and in vegetation models make the interpretation very complex. Future study separating the impact of vegetation would give more answers.

Page 5311 Line 12 ‘another spectral technique’ Can you provide the details/names of the two spectral techniques were used.

[Authors]: This part has been removed. We used wavelet analysis and FFT which gave the same results.

Line 10-28. Can you compare modeled ENSO spectra with palaeodata? E.g. Hughen et al, 1999, GRL

[Authors]: Yes. We did include a comparison with the suggested reference.

Page 5313 Line 1 and 2 change the ‘from one hand’ and ‘from the other hand’ to ‘on one hand’ and ‘on the other hand

[Authors]: Corrected.

Please also note the supplement to this comment:
http://www.clim-past-discuss.net/8/C3159/2013/cpd-8-C3159-2013-supplement.pdf

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