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Interactive Comment

Interactive comment on "Evolution of the seasonal temperature cycle in a transient Holocene simulation: orbital forcing and sea-ice" *by* N. Fischer and J. H. Jungclaus

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We would like to thank the two anonymous reviewers for their constructive comments and suggestions on the manuscript. In particular, with respect to the recommended publications to be included in the discussion and the structure of the results section. After re-ordering this section, we hope the presentation of the results is more straight forward. Unfortunately, we had to correct for a sign error in the definition of the latitudinal insolation/temperature gradient in the manuscript, that, obviously, has lead to some confusion in the second part of the results section. We respond to the particular points and questions raised by the two reviewers in the following:

Referee \#1:

Major critics:

Introduction:

comment: It should be made clear in the introduction: What is the central question, maybe already what will be the central conclusion of this study.

response: The first paragraph of the introduction has been reformulated.

comment: Further, the reader may wonder why transient simulations are needed (e.g. with sea-ice feedbacks we can have non-linear 'threshold' behavior, similar to what has been discussed for the North African Monsoon (Claussen et al., Geophys. Res. Lett., 1999); or lead-lags between forcing and response can be studied).

response: We addressed this point by adding the following paragraph:

Transient simulations allow us to check whether the climate model exhibits any non-linear responses to the applied orbital forcing that have been found in low latitude vegetation responses previous studies on Holocene climate studies (e.g., Claussen et al. 1999, Liu et al. 2006). Furthermore, an advantage of transient simulations is the improved comparability of the model results to reconstructions from climate-proxies. Climate models tend to have biases in certain simulated quantities and also reconstructed data have uncertainties. Transient simulations enable us to compare the trends in the climate variable and therefore allow for a more robust assessment of features in the climate system.

comment: It is further recommended to add one paragraph about the proxy-based studies of Holocene trends in seasonality.

response: We added the following paragraph: Previous large-scale proxy-based studies that analyzed summer and winter temperatures consist of compilations of many local climate reconstructions and are mainly focused on the mid-Holocene (6ka) because

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of different dating procedures and temporal resolutions of the reconstructed temperature timeseries. (Cheddadi et al. 1996) find higher summer and winter temperatures in northern European high latitudes and lower winter and summer temperatures in the Mediterranean region. Similar results for high and lower northern Hemisphere latitudes are found for Siberia (Tarasov et al. 1999) and in a more recent survey by Sundqvist et al. (2010). There is qualitative agreement between the time-slice studies and the evolution of seasonal temperatures throughout the Holocene over Europe presented in Davis et al. (2003). The results of this study are compared to our simulation results later in the present study.

comment: All these additions could help to lead the interested reader to a more 'motivated' statement regarding the central aspects of this study.

response: We hope to have accomplished that with the improved introduction.

Results and discussion:

comment: The authors should avoid the fragmented presentation of the results. For example, in Section 3.1, sea ice effects are described, but one finds inclusions of text describing the mid- to low-latitude response. Furthermore, it switches from the Arctic to the Southern Ocean. It would be much easier to follow the different mechanisms leading to local (Arctic/ SO) changes if they were described in one paragraph, separately for both regions.

response: We re-organized the structure of the first results section and introduced two subsections dealing with low- and mid-latitudes and high latitudes, separately. The high latitude section discusses the Arctic and Southern Ocean in two different paragraphs.

comment: Furthermore, I don't think that in the current version it becomes clear, why the Arctic sea ice and the Southern Ocean sea ice provide opposing feedback mechanisms. As far as I was able to interpret the text and figures, sea ice concentration responds in the same way when insolation changes are imposed (i.e. more

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spring/summer insolation gives less sea ice in summer, see page 4, lines 97-106 and l.110-118). Hence, I assume that heat flux responses, ocean stratification or other factors must be responsible for the different surface temperature responses. This needs to be described in more detail and should be supported with additional figures, since it is one of the central points in this study!

response: The sea-ice effect is indeed similar in both the Arctic and the Antarctic. The difference is, that in the Arctic Ocean the sea-ice insulation effect acts against the insolation effect, whereas in the Southern Ocean the insolation effect and the sea-ice insulation effect both evolve to increase the amplitude of the seasonal temperature cycle. We reformulated the corresponding paragraphs/sentences to make this point clear. Additionally, we extended the description of the sea-ice insulation effect.

Conclusion:

comment: Having discussed the sea-ice effect on the seasonal cycle in surface temperatures, the conclusion should distinguish carefully what they mean by sea-ice-effect. At least two separate effects are important: a) the sea-ice albedo feedback (which is from my understanding a positive feedback, and amplifies the externally induced shortwave insolation anomalies) and (b) the ‘insulating’ effect for air-sea fluxes.

response: We acknowledge the fact that the “sea-ice effect” described in the discussion version of the current study is not clearly distinguishable from the sea-ice albedo feedback effect. We appreciate the referee’s suggestion and introduced the term “sea-ice insulation effect” to clarify the difference between the two sea-ice effects.

Specific comments:

p.1, l. 9 : remove ‘however’ from sentence?

response: Done.

p.2, l.23: citation (Milankovitch 1941; Berger (1978) or any work following)

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response: Done.

p.2 l. 26: orbital forcing is traditionally not termed ‘millennial time-scale’ in paleoclimate literature. Most of the readers will immediately think of Dansgaard-Oeschger cycles, or oceanic meridional overturning circulation changes.

response: We would like to stick with the statement that orbital forcing acts on timescales of millennia. As is, e.g., also stated in the abstract of Wanner et al. 2008: “The redistribution of solar energy [is] due to orbital forcing on millennial timescales...” Nevertheless, we re-ordered the sentence to avoid confusion.

p.2, l.32-37: maybe worth mentioning that annual mean changes in insolation (irradiance) are caused by obliquity not by precession.

response: Done.

comment: Furthermore, the point here is that it needs non-linear feedback mechanisms to amplify the annual mean response. Please try to rewrite this part of the introduction. Especially emphasize the importance of sea-albedo or the ‘insulating’ feedback as one of the feedbacks that has the power to make the climate system more responsive to one season. (as you will show later)

response: The paragraph has been reformulated.

p.2 l. 45 here you could add some more background information for the interested reader. In particular, please review the past simulations (PMIP2-type, and transient with EMIC as well as GCMs). People have studied this part of the climate history extensively. Renssen et al. (2005), also discuss feedbacks from vegetation (albedo feedback) for the NH Holocene climate evolution.

response: We included the following paragraph: Time-slice simulations of the mid-Holocene with coupled AO-GCMs have been part of the PMIP2-initiative (e.g. Braconnot et al. 2007a,b) and analyzed various aspects of the climate system, but did not investigate the response of the seasonal temperature cycle to changes in insola-

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tion. The same is true for transient simulations of the Holocene performed with either Earth System Models of intermediate complexity (e.g. Renssen et al. 2005) or transient Holocene simulations with AO-GCMs simulations and accelerated orbital forcing (Lorenz et al. 2006).

comment: Sea-ice albedo feedbacks have also been discussed for the glacial termination phase in the Southern ocean (Stott et al., Science, 2007, DOI: 10.1126/science.1143791)

response: Since the sea-ice albedo feedback is not an integral part of the current study and the suggested reference does not discuss its role in terms of seasonality, we would rather not cite it in this context.

p.2-p.3 section model description:

comment: Please mention whether the vegetation can change land surface properties (is there an albedo-feedback for example)

response: We included the following sentence in the corresponding paragraph of the results section: Using a different model, Renssen et al. (2005) showed that the vegetation feedback is indeed important for summer temperature changes in the high northern latitudes. The strength of this effect could potentially increase by including a dynamic soil albedo scheme (Vamborg et al. 2011) in the current model.

p.3 l. 67: what is the acronym's meaning. This might be a standard term in GCM modeling community? I'm not familiar with the paper cited here, can you please explain whether the orbital parameter (eccentricity, obliquity and precession) are comparable to the more often cited computational code of Berger or Laskar?

response: We omit the acronym since it is not decisive and included a sentence stating that the changes in insolation are comparable to the changes one would get using other calculations (e.g., Berger 1978).

p.3. l 72: quick notice of the calendar definition is advised –even though the calendar-

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effect should be less important here for the summer winter season analysis, I suppose. (See “Calendar effect on phase study in paleoclimate transient simulation with orbital forcing” by G.S. Chen et al., Climate Dyn., 2011 DOI 10.1007/s00382-010-0944-6 and references therein to earlier discussions of this modeling issue.)

response: We added a sentence regarding the issue in the results section and respond to the calendar question more extensively further below.

Results:

Section 3.1: Seasonal insolation and sea ice effects

p.3.l.82-90: Consider moving the low and mid latitude results into separate section /paragraph. From the section title I expected results that focus on the polar latitudes.

response: Done.

p.3l.89 add “[not shown]” after “. . . Bracconnot, 2007b)”

response: Done

p.3 l.90-p.4 l.92: Recommended: Add a sentence where you give a possible explanation for the observed trends and follow it with a paragraph supporting this ‘hypothesis’.

response: We re-formulated the paragraph.

p.3.l.100-102: I find this regulating effect form the sea ice on the heat flux and its potential memory effect of one or two seasons very interesting and crucial for the understanding of the opposing seasonality trends in insolation and surface temperature. Please provide more information how this mechanism works and how effective it is (relative to the sea-ice-albedo feedback and net SW irradiance anomalies). (For example a seasonal cycle plot for sea ice concentration, surface temperature, heat flux, SW net radiation for pre-industrial and 6000 BP simulations)

response: The sea-ice-albedo feedback and the net SW irradiance differences be-

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tween mid-Holocene and pre-industrial conditions (we assume that is what is meant with anomalies) in the high northern latitudes only affect the summer sea-ice conditions. In this season, they contribute to the sea-ice-insulation-effect that we describe. It is not possible, however, to clearly separate the contributions from the sea-ice albedo feedback and the sea-ice insolation feedback.

p.3. l.103-105: How do these numbers compare with the direct top of atmosphere and net surface shortwave insolation anomalies?

response: Also here, the top of the atmosphere insolation anomalies are only affecting the summer season. The difference in summer (JJA) top of the atmosphere incoming radiation is 30W/mˆ2 (6.6\%) and 12.66W/mˆ2 (16\%) for the net surface shortwave radiation. We added a corresponding sentence to the manuscript.

p.3.l.115-117: please add one sentence (or more) to describe what is exactly responsible for the different sea-ice effects in the SO compared with the Arctic Ocean (l.100-104).

response: As already mentioned above, there is no difference in the sea-ice insolation effect. It is just that the direct insolation response and the sea-ice insulation effect have opposite sign in the northern high latitudes, whereas they are acting in accord in the Southern Ocean. We hope to have clarified this is the re-formulated version of the manuscript.

p.3 l. 110-118: Note of caution: How much do the numbers depend on the definition of seasons (e.g. Joussaume, S., and P. Braconnot (1997), J. Geophys. Res., 102(D2), 1943–1956, doi:10.1029/96JD01989; or Timm et al, Paleoceanography doi:10.1029/2007PA001461, 2008; or Chen, G. et al. Clim. Dyn. DOI: 10.1007/s00382-010-0944-6, 2010/2011?)

response: We are aware of the effect of changing length of the seasons especially in boreal autumn (austral spring). Joussaume and Braconnot (1997), however, state that

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the effect is stronger in the Eemian than in the mid-Holocene. Timm et al. (2008) state that the calendar definition has the strongest effect over the high latitude continents and is dampened over the oceans due to their heat capacity. Their study shows an increase in the early Holocene (where insolation changes where larger than in the mid-Holocene) of the order of 1\,K in austral spring for the Southern Ocean sea-ice margin, that are even more pronounced in the angular than in the calendar definition (their Figure 4). We acknowledge, however, that the calendar problem potentially has a small effect on our conclusions and added a remark to the manuscript.

comment: Please make sure to describe in Figure caption 4 how the seasonal anomalies were calculated. Three-month averages using present-day definition of months or from daily calculated insolations?

response: Done.

p.3 l.119-124 and p.3 last paragraph to p.4 l.135:

It is suggested to move this mid and low latitude result into separate paragraph or section.

response: The section has been re-organized.

p.4. l.1146-149: Will the vegetation response and feedback be described in an upcoming study? Otherwise, how important is changing vegetation for the changes in seasonality? (Please check also Renssen et al, Climate Dynamics (2005) 24: 23–43 DOI 10.1007/s00382-004-0485-y.)

response: As has been shown in Otto et al. (2009) the vegetation feedback in high northern latitudes in the model setup used is weak compared to previous studies. The dynamic vegetation component of the model used is currently been improved in terms of including vegetation induced changes in surface albedo (Vamborg et al. 2011) that might amplify the vegetation feedback. We added this and the reference to Renssen et al (2005) to the corresponding paragraph in the manuscript.

p.6 l. 170-172: summer meridional temperature gradient trends are reproduced well. Winter would require a formal test, since the proxies show more high-frequency variability. (regression analysis)

response: The correlation between the Winter LTG and the LIG is 0.4 at the 99\% significance level. Added to the caption of Fig. 7.

p.6 l. 176: write "... approaches to reconstruct ..."

response: Done.

p.6,l.177 + 186: "summer cooling" that is: "negative trend in the meridional temperature gradient" ?

response: According to temperature reconstructions (Davis et al. 2003) the weaker latitudinal temperature gradient (LTG) in the mid-Holocene over Europe is caused by a high latitude warming and, additionally, a cooling in the low latitudes around the Mediterranean. The latter is not observed in the model, to the contrary, a warming in southern Europe is simulated. Hence, the weak increase in LTG in the mid-Holocene summer (Fig 7b left). If the whole Northern Hemisphere is considered in the model, there the LTG is weaker in the mid-Holocene and shows a positive trend in the course of the simulation.

p.7, l.202-206: The NAO teleconnection pattern (regression pattern) with temperatures shows a large effect in the Northern European regions, with positive temperature anomalies during the positive NAO years (http://www.cpc.ncep.noaa.gov/data/teledoc/nao_tmap.shtml). Over North Africa a negative temperature is found. Hence, one has to be more precise here, what region is affected.

response: In the model used for the present study, there is a positive winter temperature NAO response over northern European and a negative response over the Mediterranean region and southern Europe. This might not be in full agreement with

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the NCEP-data. In the revised version of the manuscript, we give a more precise definition of what region is affected.

comment: From the modern observations I would have imagined a more positive NAO during the mid-Holocene resulted in a reduced temperature difference (South minus North). Please clarify.

response: There has been a mistake in the sign in the definition of the LIG and LTG in line 170 (or p. 471/l. 4). The gradient is defined as the insolation/temperature difference between northern and southern Europe, i.e., difference between the latitude bands 55 - 75°N and 30 - 45°N. This is probably responsible for the confusion. Under mid-Holocene conditions the LTG is smaller than under pre-industrial conditions. The effect of a positive NAO-phase, i.e., warmer conditions at higher latitudes and cooler conditions at lower latitudes lead to a reduced LTG. More frequent positive NAO-phases in the beginning of the simulation under mid-Holocene conditions enhance the reduction of the LTG.

comment: Please refer also to the work of Gladstone et al. Geophys. Res. Lett.,32., 2005, doi:10.1029/2005GL023596!

response: Done.

p.7 l.223: Write: “Nevertheless, within a limited region such as Europe, the low latitude summer cooling inferred from pollen reconstructions is not captured by the model."

response: Done.

Referee \#2:

1) The introduction is a little short, in particular a short review of some of the available data that can address the problem of seasonality change is encouraged.

response: This has also been suggested by referee #1 and has been addressed in the revised version of the manuscript. Especially, available paleo-data studies on the

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mid-Holocene (e.g., Cheddadi et al 1996,Tarasov et al. 1999, Sundqvist et al. 2010) are now being discussed in the introduction.

2) I found the results section a little confusing, as it is not clearly stated that the authors use the mid-Holocene as a reference point. In general, paleoclimate anomalies are with reference to a modern or control run, and so it is not initially clear what the authors mean when they describe ‘a southward shift of the ITCZ’, for example.

response: We are now stressing at the beginning of the results section that the reference period is the mid-Holocene.

3) I found the comparison between temperature gradients a little confusing. The authors note that the model does not get the summer cooling observed over the south of Europe, and this results in a different gradient from the pollen-based LTG. When the authors consider a gradient across all continents, they do get a LTG trend similar to that of the European pollen (although at a different magnitude). Why is it that including all continents increases the resemblance to Europe? Is there summer cooling elsewhere in the Northern Hemisphere that can compensate for the lack of cooling in Europe? If so, the authors should consider a wider comparison with paleo-data, at least for the initial mid-Holocene time period (e.g. the cooling at latitudes demonstrated over a much larger region by Davis and Brewer (2009)).

response: There is a paper in preparation by B. Davis and collaborators that shows that the line of argument in Davis and Brewer (2009) is also valid if the whole Northern Hemisphere (NH) continents are considered. This means that also for all NH continents the trends in the latitudinal insolation gradient (LIG) and latitudinal temperature gradient (LTG) are qualitatively similar for the last 6,000\,years. The model simulation shows no mid-Holocene summer cooling over southern Europe but over parts of eastern Asia. Nevertheless, the reason for the match between the LIG and LTG could also purely be due to the mid-Holocene warming over the higher northern latitude continents that is not compensated for by a low latitude warming as in the case of Europe.

4) The authors say that there temperature changes are related to changes in the NAO. Can they add more detail to this about how such a relationship would work. Further, the authors should cite and compare the results of the simulated NAO with Gladstone et al (2006; GRL), particularly with respect to the three hypotheses of changes in NAO state at the mid-Holocene (greater amplitude of NAO; more time in positive NAO; change in mean state with no change in variability)

response: We extended the corresponding paragraph. The increase in the simulated southern European and Mediterranean winter temperatures from the mid-Holocene to today, present in the reconstructions and the model, is likely related to a change in the North Alantic Oscillation (NAO, Fig.8). The NAO-index shows a trend from dominating NAO positive states to prevailing NAO negative states. Under mid-Holocene conditions the more frequent positive NAO-states lead to a northward shift in the winter storm tracks that yield relatively warm and wet conditions in northern Europe and cool and dry conditions in southern Europe. Climate reconstructions also indicate a more positive NAO-index during the mid-Holocene (Nesje et al. 2001, Davis et al. 2007). Climate models show an ambiguous response of the NAO under mid-Holocene conditions with a tendency towards more positive NAO phases (Gladstone et al 2005) which is also the case in the present study. We do not find significant changes in amplitude or frequency in the NAO throughput the simulation.

5) The citation Davis et al 2011 is not found in the bibliography.

response: Unfortunately, for this study there is no citation available yet.

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