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Climate of the Past Discussions

Interactive comment on "Warm Greenland during the last interglacial: the role of regional changes in sea ice cover" *by* Niklaus Merz et al.

Anonymous Referee #3

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Review of:
Merz et al. Warm Greenland during the last interglacial: the role of regional changes in sea ice cover

Summary:
This papers investigates the potential importance of SST and sea ice for the climate conditions in the North Atlantic and Greenland in the Eemian interglacial. Simulations are conducted with CAM3 and CAM4, comparing the pre-industrial (PI) and Eemian

climates using prescribed sea-surface conditions from fully coupled simulations (at different resolutions) with CCSM3. The main conclusion is that sea ice in the North Sea region can have a large impact on the Greenland climate and a reduction of its prevalence generates a substantial warming over the ice sheet. The sea ice in the Labrador Sea is important for the local climate conditions but has a little to no impact on the Greenland climate. The authors conclude that the climate impact is mostly mediated by near surface turbulent fluxes that influence the atmospheric circulation and thereby cause a warming over the ice sheet. The paper is generally well written and is suitable for Climate of the Past, though first after a substantial revision.

Major comments:

1. Model validation and motivation
(i) In all modeling studies it is mandatory to prove that the model is capable of producing a reasonable climate that conforms to observations or proxy data records (climate reconstructions) when studying past climates. This is a first sanity check that tells the reader that it might be worth while spending the time end energy reading the paper. This manuscript only contains difference fields and the reader is never shown the actual climatological states. I suggest adding a figure showing a comparison of the pre-industrial (PI) simulation with either a reanalysis product or a reliable climate reconstruction (show full fields and how they differ from observations). For the Eemian you can compare with proxy data where such are available. Though this type of comparison is mandatory, in this study it is extra important since the model seems to be sensitive to the horizontal resolution.

(ii) I would like to see a better motivation of the study. What is the goal (what do we wish to learn) and why are we interested in this particular problem? The current motivation seems to be that fully coupled models simulate different sea-surface temperature (SST) and sea-ice cover (SIC) in the Eemian. This is perhaps not too surprising given the large model spread in simulations of both present and future climates. It would be better to motivate the study from available proxy data records from ice cores as well as terrestrial and marine records. Given the large model spread, what makes this model better than any other model and can we trust the results presented here (connected to the model validation)? You can also extend the motivation by looking at AMOC in different models and connect that to differences in the sea-surface conditions.

2. Modeling approach

(i) Initially you show that the low and high resolution models yield different results in terms of SST and sea ice in the North Atlantic. It is further mentioned that the low resolution model has known problems and does not simulate a reasonable PI climate in the North Atlantic sector (is this also true for the Eemian?). Despite this claim, the majority of the experiments and figures (according to Table 2) are based on results from the low resolution model. This seems like a very odd choice to me. If the model is biased and has known problems, why base almost all figures and analysis on data from this model? Are there even worse problems associated with the high resolution model? If not, can we expect different conclusions if the same analysis is performed on the high resolution data?

(ii) I am generally skeptical to the approach taken in sections 4.1 and 4.2 and I am afraid that we are not learning very much from this exercise. CCSM3 and CCSM4 are highly dependent models (e.g. Knutti et al., 2013) that are part of the same model family, meaning that the atmospheric components (CAM3 and CAM4) share the majority of the same code base. The biggest difference between the models is the deep convection scheme, which plays virtually no role in the latitude range of your focus. Consequently, the comparison of the two atmospheric models is largely redundant as you basically compare results from two simulations with almost the same model using identical forcing protocols. I argue that you can omit this whole comparison and just state that you use SST/SIC from CCSM3 in CAM4 and then prove that the simulated climates are reasonable with respect to reliable data. Also, the near surface temperature is not the best field to use to evaluate differences between AMIP simulations. If the model is capable of producing a realistic climate with realistic turbulent fluxes (e.g. near

surface gradients), the near surface temperature is by definition largely similar to skin temperature and you basically prescribe the phenomena that you are investigating.

(iii) A large part of the analysis is based on differences between difference fields (EEM-$\mathrm{PI}_{\mathrm{diff}}$). These results are almost impossible to wrap ones head around and I wonder what we can learn from such a comparison, especially since the low resolution model has known biases. Also, it would help the interpretation of the results if you used the same color scale in all figures showing the same/similar quantities.

(iv) My main concern has to do with the sea-ice retreat experiments. First of all, the amount by which you shift the sea ice seems to be arbitrarily chosen and should be motivated. Second, I am not convinced that these perturbation experiments are designed in a way that they will teach us anything useful about the last interglacial climate. In steady state (no drift due to external forcing) the circulation in atmosphere and ocean is by definition what determines the sea-surface conditions; the SST/SIC is essentially determined by the internal heat flux (Qflux) in the ocean mixed layer and the balance between radiative and turbulent surface fluxes in the atmosphere (SST $\sim$ SWnet – LWnet – LHflux – SHflux – Qflux). When you prescribe the sea-surface conditions and introduce local changes in the SST/SIC, you also introduce a local climate forcing that could never happen in the real world as it is not supported by the rest of the climate system (the open water that is introduced is not consistent with the general circulation).

If we assume that the sea-ice cover in the Labrador sea collapsed (for whatever reason), the climate system would do everything it can to rebuild the sea ice over the next few seasons (as is evident from the almost $100\,\mathrm{W\,m^{-2}}$ imbalance in sensible and latent heat fluxes that are reported in the analysis). If we instead assume that we could collapse the Labrador sea ice and keep the region ice free, the rest of the ocean circulation (and atmospheric circulation for that matter) would have to be different to sustain the reduced sea ice; i.e. there would be changes in the SST field elsewhere and the turbulent fluxes would almost certainly be lower as sea-ice otherwise would form. I know that the chosen modeling approach is not new and that other people have done similar experiments before you (e.g. Deser et al., 2010), but I am concerned that this modeling approach does more damage than good in this particular study. I don't have a patented solution to the problem but I argue that it would be better to run a slab ocean model and alter the internal heat flux convergence in the mixed layer (in a conservative way so it doesn't introduce a global climate forcing) so that the sea ice retreats from the desired regions. This is arguably a better solution as the surface temperature and sea-ice margin are determined by the surface energy balance, which means that it is theoretically possible to construct a climate where there is no sea ice in the desired regions but you have sea-surface conditions that are in balance with the circulation and external forcing. Whether or not this climate state is realistic is of course another question.

3. Interpretation of results

(i) Following the previous comment, it is not at all surprising that you get very strong turbulent fluxes in the sea-ice sensitivity experiments. The prescribed SST/SIC implies that the climatological atmospheric circulation is more or less determined by the prevailing sea-surface conditions. When making local changes to the SIC and prescribe SSTs that are not consistent with the circulation, you introduce regions where the climate "wants" to have sea ice, as cold air is advected over open water, but the prescribed sea-surface conditions prevents it from forming. This gives rise to artificial vertical gradients and turbulent fluxes that would never happen in nature as the SST/SIC would respond and go back to an ice covered state. This in turn induces and anomalous atmospheric circulation that has no real world analogue, at least not in a climatological state which is what is investigated here.

(ii) In my mind, one of the most interesting results in the whole paper is the changes in the lower tropospheric wind field (Fig. 9) that results from manipulating the local SST/SIC in the North Sea. However, no explanation is provided as to why the wind field changes the way it does. I want to see a dynamic argument made for the somewhat counterintuitive response where the lower tropospheric winds impinge on Greenland

from seemingly the wrong direction; SE instead of NE where the forcing is located.

Line-by-line comments:

Page 1, line 1: I would be careful suggesting that the Eemian is a possible analog to the climate in the near future. The Eemian was warm primarily as a result of increased insolation whereas future climates are warm because of higher greenhouse gas concentrations. The former only plays a direct role during parts of the year (in high latitudes) whereas the latter influence the longwave radiation in all seasons.

Page 1, line 19: This time interval contains both warm and cold phases.

Page 4, lines 1 & 3: Write out the equivalent grid resolution for T31 and T85.

Page 4, lines 19-25: This is more of a curious comment than anything else but when you regrid the T31 SST/SIC to the T85 grid, you implicitly introduce an outline of the T31 grid but at the higher resolution. Do you have a feeling for if this will influence the results?

Page 5, line 24: How does the absence of inter-annual variability in the SST/SIC degrade the representation of the stormtrack? Add a sentence explaining that.

Page 6, line 7: The -1.8°C temperature is only used for the SSTs underneath sea ice. The actual temperature of the sea ice is determined by the local surface energy balance, which is generally much lower. It is therefore a bit misleading to use the SST as a measure of the surface temperature and I suggest showing the actual surface temperature instead.

Page 7, and of section 4.1: Determine whether the difference in temperature signal is due to the PI, Eemian or both climate states when going to the lower resolution.

Page 7, line 12: with and an excessive... -> with an excessive...

Page 7, line 22: CCSM4 and CCSM4 -> CCSM3 and CCSM4

Page 8, line 1: What is the relationship between the SST and the sub-polar gyre?

Page 8, line 11: Show the PI SST, it is important for the story!

Page 8, line 18: particularly strong on SAT above oceanic grid cells... Don't you use identical SST/SIC in CAM3 and CAM4? If so, you expect to see very similar SAT as it represents the temperature just above the ocean surface.

Page 8, line 19: How much is the winter insolation decreased in winter?

Page 9: What can we possibly learn from $\Delta(\Delta_1 - \Delta_2)$ when at least one of the $\Delta_{\#}$s have known biases?

Page 9, line 6: surface ocean -> ocean surface

Page 9, line 11: Which terms does Qnet contain? Radiative fluxes? Turbulent fluxes? Internal heat sources in the ocean? A combination of all or a subset of the above?

Page 9, lines 21-29: You have prescribed SST, which means that you easily get artificial turbulent surface fluxes as the ocean temperature acts as an infinite source and sink of energy (sign depends on atmospheric conditions).

Page 10, line 5: Write out the resolution used in the "Shift" experiments.

Page 10: Why do you use the low resolution model when it has known biases?

Page 10: Fixed SST is almost certainly the source of the strong turbulent fluxes that are highly artificial as they would never happen in nature in the way described in the manuscript, at least not over a long period of time.

Page 11, lines 1-3: Why does the warming spread over Greenland? Comment on changes in atmospheric circulation.

Page 11, line 8-10: Eq. 1 is written in advective form, not flux form. The terms you refer to are therefore showing temperature advection and not heat flux convergence.

Page 11, lines 16-19: Are you talking about month to month variability or the clima-

tology? The terms have to be identically equal to zero in the latter if the model is in balance.

Page 11, line 20: The temperature tendency has to be identically zero for the model to be in balance. You are looking at a climatology after all, or...?

Page 12, line 6: How much is actually resolved at T31?

Page 12, line 13: How does that hang together with the enormous increase in LH flux? I would expect to see a great moistening of the atmosphere when the LH flux increases that much, which in turn increases the cloudiness.

Page 12, line 33-Page 13, line 9: This paragraph is very confusing because you first talk about what you expect to see and then you show that the expected circulation is in fact not true.

Page 12: What happens to mid- and upper tropospheric winds in these experiments?

Page 13, line 20: I don't see a southeastward transport in the figure.

Page 13, lines 20-23: Is this also true in these experiments? Have you done the proper analysis or is it just a conjecture?

Page 14, lines 15-19: This is the heart of my concern. Everything in the climate system acts to build sea ice where it has been removed but the prescribed SST/SIC don't allow the sea ice to regrow. Since the summer temperature is higher, there will not be any regrowth in the summer season and you don't see equally outrageous turbulent fluxes.

Page 14, lines 27-34: This is not very surprising either. There is a prevailing southwesterly flow over the northeastern Atlantic, meaning that warm and moist air is advected over the region where you remove the sea ice. There is thus a smaller "urge" for the climate system to regrow sea ice there and you don't see equally large turbulent fluxes.

Page 17, line 34: "statistically insignificant warming" sounds strange. Rewrite the sentence in a way that allows you to use something like "not significantly significant".

Page 18, line 9-10: Have you adjusted the Greenland elevation in these simulations?

Page 18, line 15: A 3.1°C temperature difference could in principle be due to a lowering of the ice sheet. Since the sea level was quite a bit higher in the Eemian, this is not a bad first guess that could be explored in a greater detail in the manuscript.

Page 18, lines 29-34: This section is a bit speculative. Maybe you can extend the discussion to include the importance of precipitation seasonality and the temperature inversion relationship recently discussed by Pausata and Löfverström (2015).

Page 19, lines 20-23: You haven't really shown or discussed any proper atmospheric dynamics in this paper. The main focus is on the turbulent fluxes that no doubt will influence the atmospheric circulation. This has not been shown properly though so this statement is merely a conjecture.

Figures: Use the same colorscale in all figures showing the same/similar quantities.

Figure 1: Consider changing the transect to a different color. It is very hard to see black on top of dark blue.

Figure 2: Validate the model by showing full fields as well as a climate reconstruction.

Figure 3: The large sensitivity of SIC to the model resolution is curious. Is there any proxy data you can compare this with?

Figure 3: What is the purpose of this figure when Fig. 4 shows almost exactly the same thing, though extended to show the response over land as well?

Figure 5: Number labels have not been defined.

Figure 10: I am curious as to why there are such large differences in e.g. the Norwegian Sea and southwestern Greenland?

Table 3: Write out the abbreviations and resolutions in the caption.

References

Deser, C., Tomas, R., Alexander, M., and Lawrence, D.: The seasonal atmospheric response to projected Arctic sea ice loss in the late twenty-first century, Journal of Climate, 23, 333–351, 2010.

Knutti, R., Masson, D., and Gettelman, A.: Climate model genealogy: Generation CMIP5 and how we got there, Geophysical Research Letters, 40, 1194–1199, 2013.

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