Response to reviewers

The reviewers' comments reproduced in black, our response is given in blue.

Preambule

In revising our manuscript, we considered the reviewers' comments, but we have also:

- updated the results to include 2 more models for which the PMIP4-CMIP6 data became available on ESGF;

- presented our results in terms of sea ice area as well as sea ice extent, for them to be comparable to previous CMIP5 work presented in the fifth assessment report of the IPCC, and to the work on CMIP6 carried by SIMIP (Sea ice Model Intercomparison Project). The definition of these quantities is added to the manuscript for clarity.

- included a discussion on the "calendar" effect (in Section 3.2).

- verified and updated the reconstructions, in particular by being more cautious with data from Arctic cores having uncertain chronology, but also in terms of interpretation and updated the data-model comparisons accordingly.

Our detailed response to the reviewers follows.

Response to Julie Brigham-Grette

As part of the Paleoclimate Modeling Intercomparison project, the purpose of this paper within the 6th phase of the coupled model intercomparison project (CMIP6) is to review the results from 12 climate models in terms of Arctic sea ice. The point of the project is to compare how the models produce Arctic sea ice during the Last Interglacial (LIG). I would like to say up front that what I most enjoyed about this paper is the honesty expressed in the evaluation. They admit that they cannot accurately state what sea ice was like during the last interglacial, but they can frankly say how the models compare.

I make suggestions to make the paper a bit more accessible to non-modelers like me. I have added comments to the pdf and created a comment summary.

The results show a wide range of minimums for summer sea ice but the mean of the12 models suggests a 59% reduction in summer sea ice; they found that winter sea ice extend was about the same in LIG compared to Pre-Industrial (PI) (not thickness mind you, only extent). For "ground truth" they used only sediment cores from the Arctic Ocean and Fram Strait region (Table 1) with sea ice presence or absence heavily weighted toward proxies like dinocycsts and IP25, both of which have large errors associated with them. For example, the calibration of the dinocycsts for sea ice used 1955 to 2012 (page 6) and the error of prediction is +/- 12%. So one has to propagate the error in the proxies along with the differences in the models to compare with the same data.

One strong point for the results of this paper is that all version 6 models focused on a uniform set of model experimental protocols, because version 5 failed to do this and the results were more difficult to evaluate. For this simulation, they used sea ice base line for 1982 to 2001 (this is what they consider most realistic for PI), given that most remote sensing of sea ice started in 1979. True preindustrial sea ice extent and thickness can only be judged from historical data.

We wish to thank Julie Brigham-Grette for her helpful comment. To us, it is important that this manuscript can be understood by a wide audience.

More detailed comments:

Comment 1, page 4: The decrease in summer sea ice is also supported by the migration of treeline documented by Lozhkin and Anderson 1995 showing range extensions of 600km for many tree species; treeline was north of the Brooks Range and similar extensions are shown in some sites on Baffin Island containing 80% birch pollen. One could go on but the paper is focused on ocean records. Note that the models used in this paper do include land surface processes, but only 2-3 models allow interactive vegetation (shown in Table 2).

We chose to remain focused on ocean records in this manuscript. The comparison with continental records, with a discussion on sea ice, can also be found in the companion paper on the PMIP4 LIG experiments, by Otto-Bliesner et al.

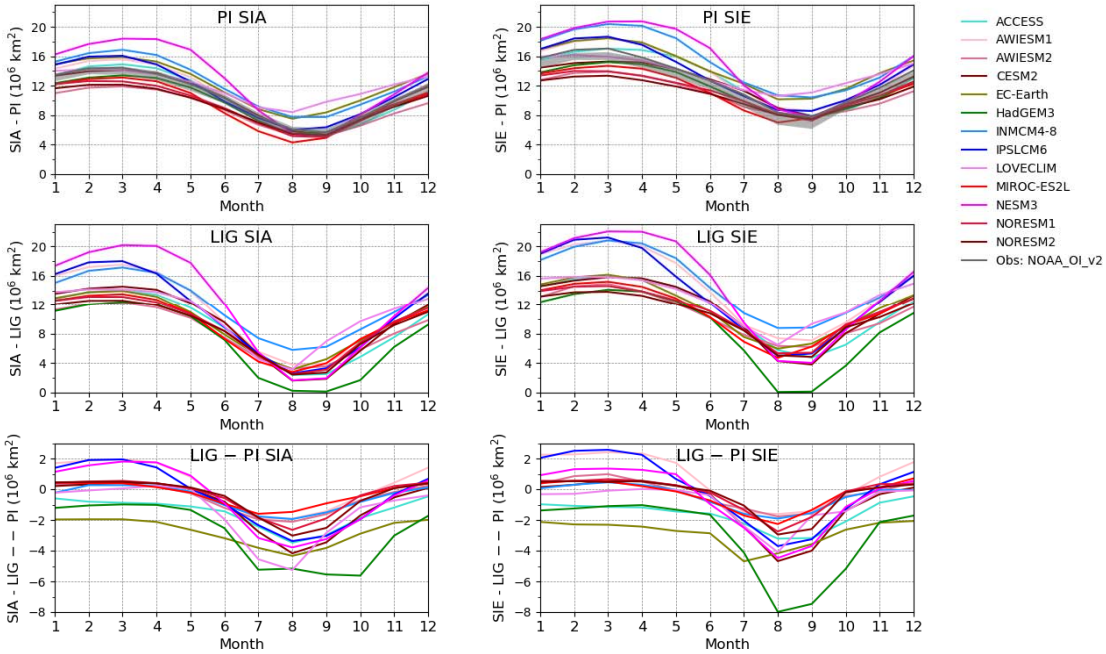
Comment 2, Page 10: It is now pretty widely accepted that Greenland gave up at least 2 meters of sea level equivalent during MIS 5e (LIG). Dorthe Dahl-Jensen supports this now which is significant! So it would seem to make much more sense that CMIP6 should use the best current configuration of a 5e Greenland Ice sheet. I suggest for clarity that the authors here include an explanation why CMIP6 is not using smaller ice sheets. Lots of examples like The Cryosphere Discuss, https://doi.org/10.5194/tc-2018-225; Stone et al, 2013 C-P; Helsen et al. 2013 also published in CP.

This is now summarised in section 2.4, to which we will add the following lines:

"Both the Greenland and Antarctica ice sheets are known to have shrunk during the interglacial, with different timings, and therefore taking PI characteristics for the *lig127k* protocol is an approximation, in particular for the Antarctic ice sheet which was possibly smaller than PI at that time (Otto-Bliesner et al., 2017). The Greenland ice sheet likely reached a minimum at around 120 ky BP and was probably still close to its PI size at 127ka BP. Given the dating uncertainties and the difficulty for models to include the largest changes in ice sheets for 127 ka BP, i.e. changes in West Antarctica, the choice of the PMIIP4 working group on interglacials was to use the PI ice sheets as boundary conditions for the Tier 1 PMIP4-CMIP6 experiments presented here, and to foster sensitivity experiments to ice sheet characteristics at a later stage. In terms of the Greenland ice sheet, the approximation is considered as quite good and ideal for starting transient experiments through the whole interglacial."

Comment Figure 2 – Add axes labels to all boxes. Increase the font on the key, there is plenty of space for that.

This has been done. We now include a description in terms of sea ice area (SIA, sum of (sea-ice concentration x ocean cell areas)) and in terms of sea ice extent (SIE, sum of the ocean cells areas for which sea ice concentration is larger than 0.15). The new figure will be similar to the following one, but updated with the latest available models:



Comment 3 page 14 – I could be wrong but what about propagating the error from the proxies given that dinos are +/_ 12%. Evaluate the proxy error vs the model comparison miss match?

The reviewer is right. The marine core community still needs to resolve proxy-related uncertainties, but this is out of the scope of the present contribution. However, the discrepancies are not so large in the subarctic seas and marginal Arctic seas, notably when comparing dinocysts and IP25 data that are providing complementary information on sea-surface productivity. The problem remains in the

central Arctic Ocean, where the issue is related both to the chronostratigraphy and the interpretation of the proxies. Hence, we are now more cautious and avoid proxy-data quantification for most central Arctic sites. Section 2.1 and conclusions are modified accordingly.

Page 15 – You start here using 1pctCo2 for the first time. Please add something to explain this, like... Idealized 1% per year increase in Atmospheric CO2? Etc etc. Remember that not everyone reading this is a modeler so this term should be defined and add why it's important.

We now introduce this experiment at the end of section 2, in a new section:

"2.5 1pctCO2 CMIP6 protocol

We compare the response to the lig127k forcings to idealised forcings for future climate. We have chosen to use the 1pctCO2 simulation from the CMIP6 DECK (Diagnostic, Evaluation and Characterization of Klima, Eyring et al., 2016). These simulations start from the PI (piControl) experiment and the atmospheric CO2 concentration is gradually increased by 1% per year for at least 150 years, i.e. 10 years after atmospheric CO2 quadrupling."

Page 16 – consider this additional important point. Low sedimentation rates in the Arctic Ocean also means that the proxy resolution from the cores you are using are low enough to be missing 1000 yr intervals of no summer sea ice etc. These limitations may also complicate or explain the mixed messages from the 12 models. You should add this to the discussion – a few sentences.

We have taken this comment very seriously in our revised manuscript, where we specifically point to problems in chronology, in particular in the Central Arctic. On the map of Fig. 1, we now use different symbols for records for which the chronology is uncertain and which should be subject to caution. The consequences of these uncertainties are further discussed in the conclusion.

Smaller comments are attached to the text using comment boxes. See the file named "Supplement" for details and picky editorial comments .I suggest this paper be published with minor revisions.

Please also note the supplement to this comment:https://www.clim-past-discuss.net/cp-2019-165/cp-2019-165-RC1-supplement.pdf

Abstract, "21C" is now spelled out.

Line 85: the repetition of "the Northern Hemisphere" will be removed.

Comment 1, page 11 ("Does this also mean late August/early September?"):

We are not sure about the line this comment refers to. In the original manuscript, when we refer to "summer minimum monthly area" (e.g. at the beginning of the second paragraph of section 3.1), we refer to the minimum in the monthly time series of sea ice area, which occurs during summer. This minimum occurs in August or September if the 1850 calendar is used. This can change by 1 month if the 127 ky BP calendar is used, as is shown below for the IPSL model. A short discussion on this "calendar" effect is added in section 3.2.

Comment 2, page 11, about the Bering Sea sea ice not being included in the computation.

Indeed, the Bering Sea is South of 60°N and was therefore not included in our computation of sea ice area shown on Fig.2. In our updated manuscript, for consistency with the SIMIP paper on future sea ice changes, we will consider integrating sea ice cover over the whole northern hemisphere. We will therefore include the Bering Sea sea ice to be more consistent with the maps on Figures 3,4, 6 and 7.

Comment 4, page 11: "CO2 was between 340 and 370 during this interval afterall".

The first paragraph of section 3.1 on sea ice now reads:

“For the present-day we have satellite and in-situ observations with which to evaluate the models. The use of present-day sea ice data implies that we might expect the simulated PI sea ice to be generally somewhat larger than the observed mean. Indeed the atmospheric CO2 levels for the years for which we chose the observation data set (1982 to 2001) were between 340 and 370 ppm, to be compared to the PI level of 280 ppm. Figure 2 shows the mean seasonal cycle of the Arctic sea-ice extent simulated for the PI and LIG alongside the observed Arctic sea-ice extent.“

Comment on line 213:

This has been corrected (“To” has been changed to “We”.

Comments on Figures 2, 8 and 9:

The axes will be better labelled, as shown on the figure above for Figure 2.