Menviel and colleagues describe the experimental protocol for numerical climate simulations of the penultimate deglaciation (140-127 ka) in the framework of the Paleoclimate Modelling Intercomparison Project (PMIP). The manuscript gives a comprehensive overview of the planned simulations, the required input and forcing data and paleo information that will become useful for data-model comparison later in the project. The manuscript represents an important contribution for the modelling community to describe, organise and guide climate model experiments for the penultimate deglaciation. Next to the more technical description of the experiments, the work also gives a brief but well-informed overview of the current knowledge and scientific questions for the climate evolution of this period. The manuscript is well written and is an interesting read for the readers of CP, even beyond the group of people directly connected to PMIP. I recommend publication of the article with minor revisions detailed below.

We thank the Reviewer for their positive comment and careful review, which helped improve the manuscript. Please find our answer to comments in blue as well as suggested text changes in green.

P1, Abstract Here you define 'thousand years before present' as 'ka', but in the rest of the text this is not used consistently. E.g. P2 L18-19 you use kyr. Consider revising for consistency.
We have amended the text and are now only using ka.

P2 L3 Depending on the complexity of the Earth system model, some of the elements listed here as boundary conditions could be interactive components (carbon cycle,ice sheets). I suggest to make it clear that the target model configuration for these experiments are standard AOGCMs.
We have modified the sentence as follows:
"It is thus important to investigate, with coupled Atmosphere-Ocean General Circulation Models (AOGCMs), the climate and environmental response…"

P2 L11 Add 'last deglaciation experiments of the' before 'PMIP4 effort'.
We have added "last deglaciation experiments"
"to complement the last deglaciation experiments suggested as part of PMIP4."

P2 L13 Again, clarify that this is typically O-A coupled and not including e.g. the ice sheets.
The sentence has been modified as follows:
"This experiment is designed for AOGCMs to assess the coupled response of the climate system to all forcings."

P2 L24 I can see that the earlier definition of the term 'termination' may not be very useful in the context of this effort. Nevertheless, it is not clear what the new definition really means. Maybe it is not necessary to have a precise definition, but could you try to capture the common understanding in your group. Is this e.g. from peak glacial to peak interglacial in temperature or similar?

In the revised manuscript we have taken out the term "Termination II". We are now only referring to the penultimate deglaciation with the acronym "PDG".

And p4, L26:
"The penultimate deglaciation (~138-128 ka, referred here as PDG), which represents the transition between the penultimate glacial period (MIS 6, also referred to as Late Saalian, 160-140 ka) and the LIG (also referred to as MIS 5e in marine sediment cores) (Govin et al., 2015),"

P2 L32 While I agree that GHG and ice sheets are probably the largest factors, I am not sure other mechanisms can be excluded, like sea-ice and vegetation changes. This could be included in the sentence.

The sentence was modified as follows:
"These amplification mechanisms are related to the large increase in atmospheric GHG concentrations (e.g. atmospheric $CO_2$ increases by 60 to 100 ppm,  Luthi et al., (2008)) (Fig. 1), the disintegration of NH ice-sheets and their associated change in albedo (Abe-Ouchi et al., 2013), as well as changes in sea-ice and vegetation cover."

P3 L1 You could mention here how many glacial terminations have occurred in the past 450 ka.
"A pervasive characteristic of the five glacial terminations of the past 450 ka"

P4 L1 Could add 'global' before CO2 to avoid confusion.
We are now referring to:
" the global atmospheric $CO_2$ concentration"

P5 Reformulate to avoid confusion: Sea-level rise is not the potential cause of HS11.
We cut the sentence in half to avoid this link.
"This is also concomitant with Heinrich Stadial 11 (HS11)…"

P5 L9 Specify over how many ka, or from when to when CO2 increase was sustained.
We have added the time range.
"…associated with a sustained atmospheric CO2 increase of 60 ppm between ~134 and 129 ka…"

P6 L14 Is Berger (1978) the quasi-standard used by everybody in the community?
Would another solution (e.g. Lasker) be accepted? Clarify.

As the PMIP4 LGM (Kageyama et al., 2017) and last deglaciation (Ivanovic et al., 2016) experiments suggest the use of insolation forcing following Berger (1978), we also suggest the use of Berger (1978) to stay consistent with other experiments.

P6 L31 Is it desired that the model configuration is the same for the proposed experiments as for the last deglaciation? Maybe this could be included as a (soft) constraint.

Thank you, that's a good point. We have added this at the beginning of Section 6:

"To maximise the use of the transient simulations, it is suggested to perform the transient simulations of the penultimate and last deglaciations with the same version of the climate model."


P7 L19 I was a bit surprised by some of the wording in the experiment description. I would e.g. interpret 'recommended' as 'other options are also OK'. I don't know if that is intended, but would suggest to carefully reconsider these formulations. I understand that on one hand the MIP cannot be too prescriptive, to not exclude specific groups or modelling approaches. On the other hand, consistent analysis across ensemble members gets very difficult when the ensemble is too diverse.

We understand the point of the reviewer. We have adjusted our terminology so that it is clear that some forcings "should be used" (e.g. insolation, GHG, continental ice-sheets). However, for the flow of the text, we still use the term "recommend", which should be interpreted as this is what should be done.


P7 L29 Will all forcing records be provided by PMIP4? I see that you have a general statement in the "Data availability" section. Maybe it could be mentioned already at an earlier state and in the main text, e.g. around here, where different records are discussed.
All the forcing files will be available on the PMIP4 website. This is also mentioned at the beginning of section 4.

P8 L13 What is meant by 'Glacial geological data'? Could you give some examples?
We have added : "(e.g. glacial deposits, glacial striations...) "

P8 L20 Maybe 'the different' instead of 'all different'. There are not that many.
This was amended.

P8 L21 Also, could you be more specific on how the NHIS and GrIS are merged?
How much of a difference does it make on one degree resolution to use GSM GrIS compared to what is simulated for GrIS by IcIES?
IcIES was not designed to simulate the evolution of the Greenland ice-sheet. As such, experts in both GrIS and IcIES suggested it was best to use GrIS and merge it with the North American and Eurasian ice-sheets simulated by IcIES as well as with the Antarctic ice-sheet model.  The merger involves no extra smoothing (beyond that inherent in the GIA solver which involves transformation to spherical harmonics). The merger involves a simple masking operation with the mask boundary through Nares Strait, Baffin Bay, Davis Strait, and the Labrador Sea. Examination of the resultant topography shows small merger artifacts around Nares Strait ranging to a few hundred metres in elevation difference.
While the climatic impact of using the Greenland ice-sheet evolution as simulated by IcIES instead of the one simulated by the GSM GrIS should be mostly regional, we prefer to provide the best ice-sheet product we can.

P8 L23 Be consistent with symbol GLAC1-D vs GLAC-1D.
Only GLAC-1D is now used.

P8 L19-29 Could you explain this better? Maybe you could start by explaining that you need TII data, but that the SL solver needs a full evolution until present day.

We have added at the beginning of the paragraph:

"As the sea-level solver assumes an equilibrium initial condition, the simulations start at the previous interglacial. As is standard, the solver also requires present-day ice-sheet histories to bias correct against present-day observed topography. Thus, a full 240 ka ice-sheet history is required."

P8 L29 What is 'surface drainage pointer evolution'?, Explain.

This was rephrased as:

"to extract the relevant surface drainage pointer field for each time-slice. This will indicate in which ocean grid cell each terrestrial grid cell will drain into."

P9 L3 Is it true that the ice sheet model is run on a lat-lon grid? That was surprising to me.

Yes, the paleo ice-sheet model runs for North America and Eurasia used here are on lat/lon grids.

P9 L7 Add 'other' before 'numerical simulations'.

This was added.

P9 L10-17 This paragraph could be part of an introduction in the main section 4. Consider revising.

We thank the reviewer for this suggestion, which we have carefully considered. However, we think that the text of the ice-sheet section is more succinct with a direct comparison between simulated and reconstructed ice-sheet changes as currently presented.

P10 L1-10 The level of detail in this description seems a bit unbalanced compared to the limited information given for IcIES. Maybe the IcIES description could be matched to give some similar information on ice flow, parameterisations, ...

We have added to the IcIES description:

"IcIES uses the shallow ice approximation and computes the evolution of grounded ice but not floating ice shelves. The sliding velocity is related to the gravitational driving stress according to Payne (1999) and basal sliding only occurs when the basal ice is at the pressure melting point."

P10 L5 Add 'and bedrock geometry' after ice if that is the case.

The sentence was changed to:

"Model runs start at 240 ka with present-day ice and bedrock geometry and with an ice and bed temperature field ..."

P10 L6 What does '*partly* glacial index based' mean?

The climate field is a composite of two glacial indexed approaches and temperature fields from the 2D energy balance climate model (which does not involve glacial indices).

The text now reads:

"The model is then forced from 240 ka until 0 ka, with a climate forcing that is partly glacial index based, using a composite of a glaciological inversion of the GISP II regional

temperature change (for the last 40 ka) and the synthetic Greenland $\delta^{18}O$ curve that was deduced from the Antarctic EDC isotopic record assuming a thermal bipolar seesaw pattern (Barker et al., 2011). The climate forcing also includes 2-way coupled 2D energy balance climate model (Tarasov et al., 1997) to capture radiative changes."

P10 L14 Could move sentence 'The last 20 kyr ...' before sentence starting 'The simulation presented ...'.
This was changed.

P10 L18 What is 'glacial non-floating ice volume'. Is that ice grounded out on the continental shelf?
Yes, this was changed to:
"glacial grounded ice volume"

P10 L30 Not clear what is meant here. Maybe 'The maximum sea level contribution from Greenland at 123-121 ka ...'.
We have deleted this sentence.

P11 section 5 At first view it seems a bit out of balance to have three pages of text to describe TII sea-level evolution. Is the sea-level evolution used for anything else then the land-sea mask evolution in these simulations?

We are aware that this section is quite long compared to others. However, this is justified by the fact that we are presenting a revised age model for the Red Sea record, rather than just using what was published. Details are necessary to guide the reader, as highlighted by Dr. K. Grant's comment, which asked for additional justifications on the chronology.
The sea level constraints described in that section are amongst the only (indirect) observational constraints that we have regarding ice sheet melting across TII. The sea-level evolution is used to infer changes in the meltwater forcing. This is a crucial parameter in these simulations as meltwater will impact the ocean circulation and therefore climate, the global carbon cycle... It is important that the meltwater scenario gives a reasonable climate evolution across the deglaciation, but also that meltwater input stays within the probabilistic sea-level evolution. Finally, we think that this sea-level section should be of interest to a broad audience.
Nevertheless, we have tried to tighten the text in this section.

P14 L20 What is meant by 'restrictions', clarify?
We deleted 'restrictions'.

P14 L30 Specify (if) what is included in the simulations. A isotope tracer?
The sentence was expanded to be clearer:
"Furthermore, if oxygen isotopes are included in the simulations, the ocean mean $\delta^{18}O$ should be initialized at 1 ‰ and if a carbon cycle model is included, the global mean alkalinity content should be increased by about 80 µmol/L. "

P15 L19 It is difficult for me to imagine how land-sea masks are linearly interpolated. Please clarify.
The sentence refers to the ice mask and topography (L.17), and we are talking about a time interpolation.

P15 L27 How and when will these files be provided? Specify.
We have added that the files will be available from the PMIP4 data repository when the manuscript will be accepted for publication.
"Topographically-self consistent drainage routing maps will be provided on the PMIP4 data repository. "

P16 L17 Please check and specify the units for this equation. P-E would probably be in mm/yr water equivalent, while dH/dt would probably be in ice equivalent if taken from elevation changes of the ice sheet model. What ice density is assumed in the ice sheet models? Is it consistent between IcIES and GSM?

The units were given and the equation and text slightly modified to be clearer:
"the provided downslope routing fields to route the water flux (fwf, cm/yr) from each grid cell:
$fwf = (P-E)_{GCM} - (dH/dt)_{ice-sheet}*0.91$, with P for precipitation (cm/yr), E for evaporation (cm/yr) and $(dH/dt)_{ice-sheet}$ (cm/yr, assuming an ice density of 0.91 g/cm$^3$) the change in ice-sheet thickness over time as described in the ice-sheet forcing files."

P16 L11 There are two Goelzer et al. papers from 2016. The one that would be more appropriate to cite in this context is the one on ice sheet freshwater forcing (doi:10.5194/cp-12-1721-2016)
The citation was amended.

P17 L4 Such massive input of freshwater as given in some of the scenarios may be problematic for some of the models, especially when distributed over small areas, like river mouths. You may want to consider a plan B for such cases.
We have amended the description of the location of the freshwater input on p16, L.14:
"As much as possible, and for all scenarios, meltwater should be added in the appropriate locations to match the evolution of the ice sheets. Freshwater can be added over an appropriate ocean area close to the disintegrating ice-sheet, or a self-consistent paleo surface drainage forcing could also be implemented."

P17 L20 It is not further described what should be done in cases of negative fwf. It seems important to note that the salt flux anomaly should not be applied at the same routing locations as the positive fwf would be. Probably it should be added as a global flux if conservation is required.
We have added p16, L. 20:
"In case of negative meltwater forcing, the artificial salt flux addition should be spread globally over the ocean."

P18 L27 'could be assessed', P19 L2 ' ... should be studied in detail through sensitivity experiments', P19 L5' ... sensitivity simulations forced with different dust-flux scenarios are

encouraged' Is there further guidance from PMIP on these experiments, or is it up to the participants to decide these extensions? Maybe some more details could be given that support the participants in their choices?

In this manuscript, we are recommending one main experiment (described in Table 1) to be performed, and which should be similar across models. Depending on their resources, participants are encouraged to run sensitivity experiments. It is however up to each group to decide which sensitivity experiment to run, depending on the scientific question they are interested in.

P24 L10 Is sea-level not needed to determine changes of the land-sea mask? If not, why is there so much emphasis on this new chronology?

The changes in sea-level across the deglaciation are used to infer changes in the freshwater forcing. Freshwater inputs will significantly affect the deglacial climate history and it is quite important to stay within the sea-level estimates.

P24 L24 Are climate models with interactive ice sheet components not used by any of the potential participants? If they are, how would the protocol have to be adjusted to accommodate the additional capability in the best possible way?

Climate models with interactive ice sheet components are great tools to study the Earth system evolution across deglaciations. Transient simulations performed with Earth system models, which include an interactive ice-sheet component should follow the suggested insolation and greenhouse gases forcings.

The last sentence of the paragraph was reformulated as follows:

"The ultimate goal would be to perform transient simulations of the penultimate deglaciation with Earth system models that include interactive ice-sheets and carbon cycle components. But models might not be quite ready for such a task yet."

Table 4. The caption is very difficult to read at this font size.

The font of the caption was increased.

Figure 2 The grey EDML line is very difficult to see.

The EDML data is now shown in pink.

Figure 3 The caption suggests that the ice mask should be visible, but that is not the case. I see lowest bin colour everywhere.

The caption simply states that the topography is shown only when the ice-mask is greater than 0.5 (i.e. non ice-sheet related topography is not shown).

Figure 5 Remove the 0.99 label from the grounding line.

The choice to show only 132 and 128 seems surprising. Why not show more snapshots including the beginning (140 ka). (the grid could be almost half the size!) .

We are now showing the Greenland ice-sheet as simulated at 140 ka, 130 ka, 129 ka and 128 ka. As can be seen in this figure as well as in the time evolution of changes in Greenland ice mass (Fig. 4c), there is very little change between 140 and 130 ka.

Figure 6 Why not show also 134, 138 and 128 ka? It seems that the x and y axis have different scale. Could this be improved (e.g. matlab axis equal)

Figure 6 now displays the Antarctic ice-sheet evolution at 140 ka, 136 ka, 134 ka, 132 ka, 130 ka and 128 ka. These timeslices are similar to the ones shown in Figure 3 for the Northern Hemispheric icesheet. In addition, the x/y ratio was amended.

Figure 7 Replace 'Rea' by 'Red' in first line.

This was amended.

Figure 9 Line e for Chinese loess is not well visible

The color of Chinese loess in Fig. 9 was changed.