First of all, we would like to thank the second Referee for the constructive comments on our manuscript. We will endeavor to integrate them into the revised version. Here is the response to the main concerns.

Review of "Sensitivity of atmospheric forcing on Northern Hemisphere ice sheets during the last glacial-interglacial cycle using output from PMIP3" by Niu et al.

The study aims to investigate the role of atmospheric forcing on the Northern Hemisphere ice sheets evolution during the glacial cycle. The reports on a set of sensitivity experiments carried out with a continental ice sheet model. The climate forcing is generated by linear interpolation between atmospheric fields representative for the LGM and the present day climate. LGM fields are taken from and earth system model that was applied for the LGM whereas present day climate is represented by a reanalysis product. The uncertainty of model results was estimated by repeating the experiments with a series of atmospheric forcing data sets provided by suite of PMIP3 model output. The response of continental ice sheets to climate change is an important topic in current climate research and is highly relevant for paleoclimatic questions addressing glacial interglacial climate cycles. While the results self are interesting I see a number of shortcomings and lack of information that prevent me from publication this study in CP in its present form.

General Comments

1) The present day climate is represented by a reanalysis product for the period 1981-2010. Why did you not take climate model output for the pre-industrial period? There are numerous preindustrial equilibrium outputs available from cmip3 and cmip5 models (which I think would be more consistent as also for the LGM a climate model output is used). A reanalysis product 1981-2010 contains the hottest years of the previous century and represent a climate that is already perturbed especially in high northern latitudes. This should be discussed somewhere. E.g. how does this influence climate forcing you generate etc.. What is the effect on the obtained results?

Response: We use the present day reanalysis products to keep present day climate the same for all of the PISM simulations.

We also ran experiments by using the PMIP3 preindustrial output instead of the reanalysis product. Fig. 1 shows the sea level equivalent evolution through the last glacial. Comparing with the simulations with reanalysis product (Fig. 7 in the MS), the curves are more variable. The sea level equivalent differences for Greenland at present day can be up to 6-7 meters. The ice thickness differences at the LGM for different models are shown in Fig. 3. For most models, the difference is not as pronounced. For MIROC-ESM, the ice thickness difference of the Laurentide Ice sheet can be up to 600 m. Comparing with the climate forcing, the summer surface air temperature in MIROC-ESM is warmer than the present day reanalysis product (Fig. 4). Using the present day conditions do influence the simulated results, with the warmer climate contributing to lower ice sheet volume and colder climate result in larger ice sheet volume. We will put the figures into the supplementary materials. More discussion can be added in the revised version.

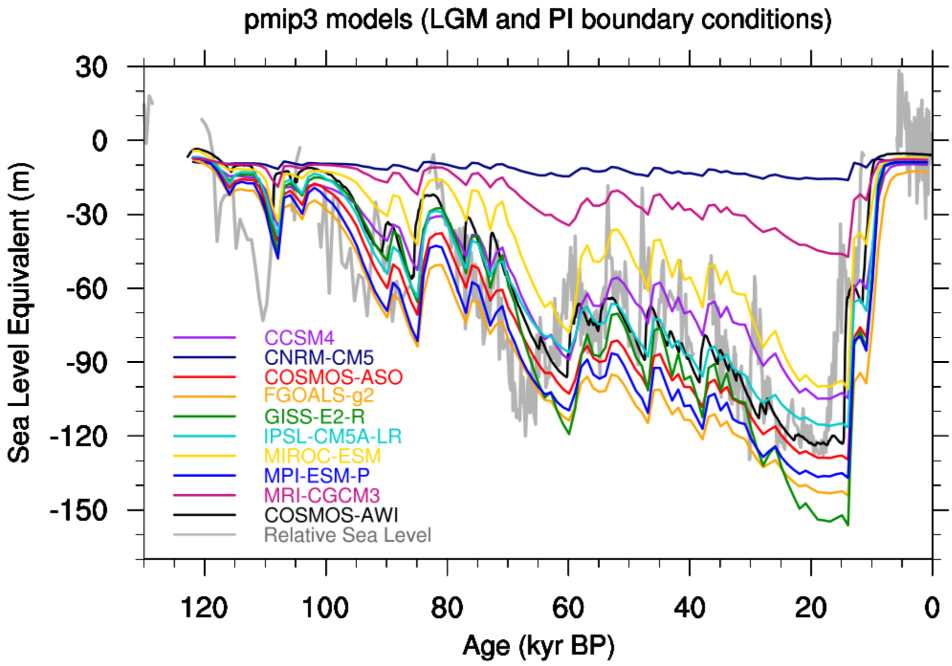

Figure 1. Modelled sea level equivalent of Northern Hemisphere ice sheets change through the last glacial cycle using PMIP3 LGM and PI output.

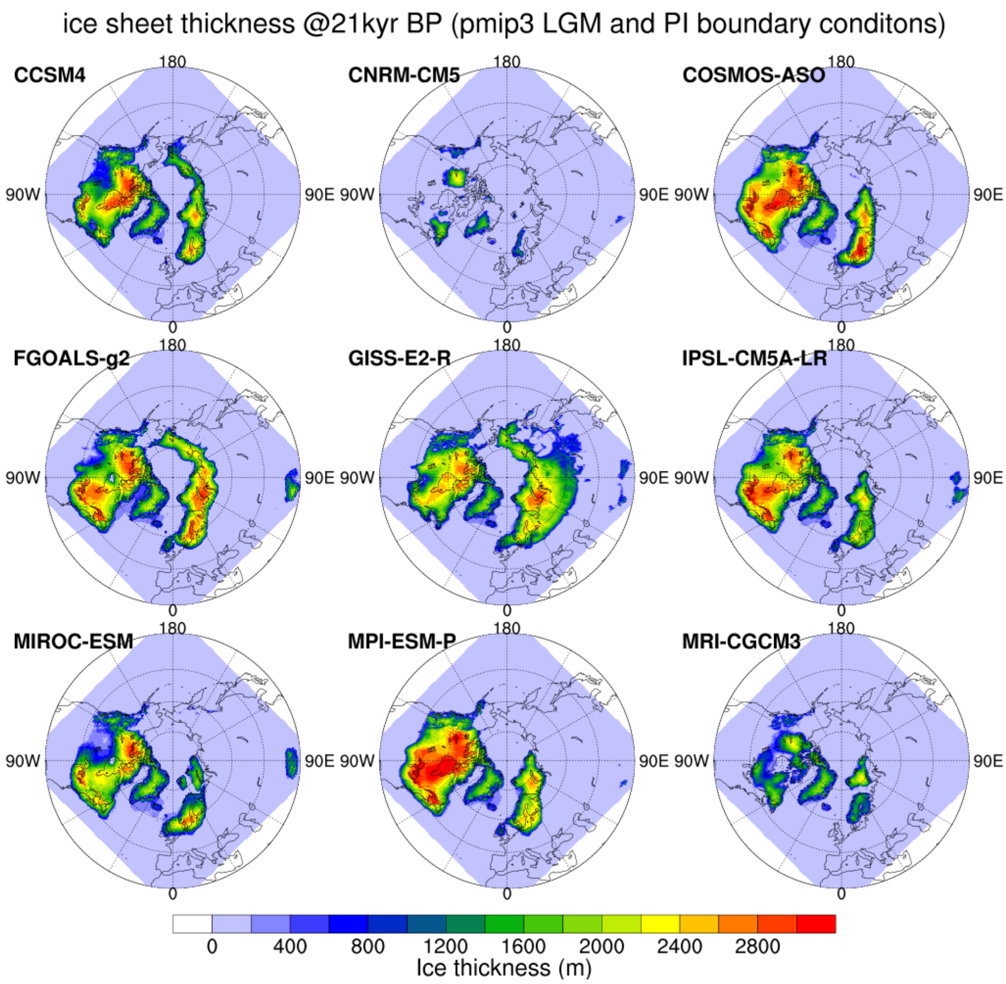

Figure 2. Modelled ice thickness at the LGM using the PMIP3 LGM and PI output

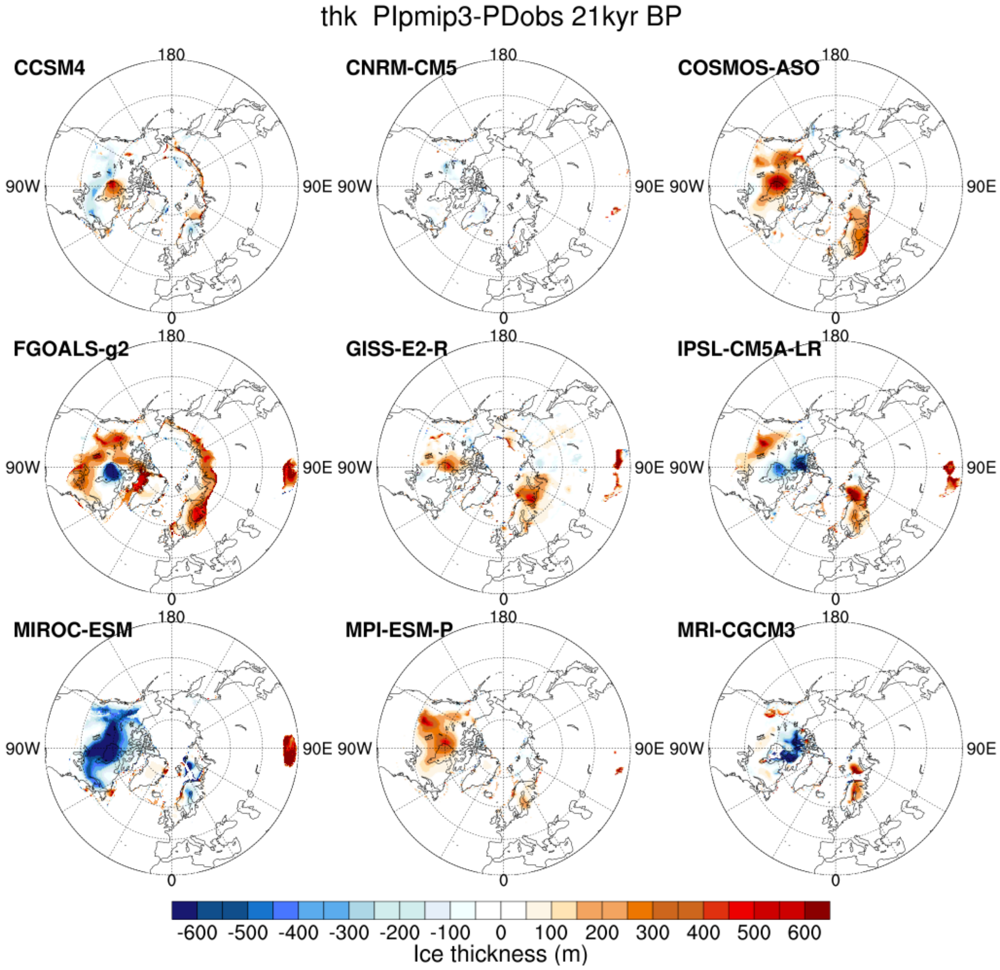

Figure 3. Ice thickness difference between simulations forced by reanalysis product (PDobs) and simulations forced by PMIP3 preindustrial model output (PIpmip3)

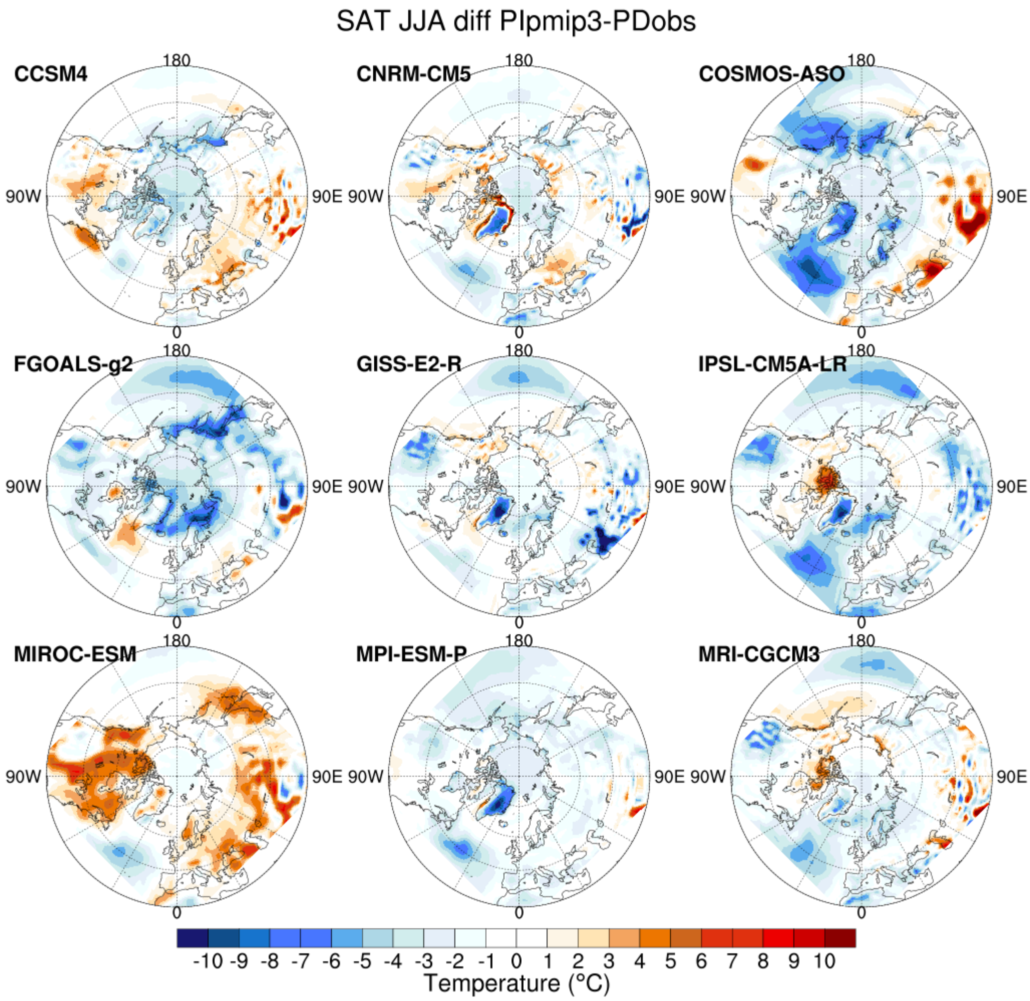

Figure 4. Summer (JJA) surface air temperature differences between simulations forced by reanalysis product (PDobs) and simulations forced by PMIP3 preindustrial model output (PIpmip3)

2) Generation of forcing. a) Section 2.2 describes the generation of the forcing for the period LGM (~21kyrBP) and PD (0 kyrBP). But section 4 starts with a discussion of modeled sea level equivalent time series that goes back to 120 kyBP. I tried to figure out how the forcing was generated before 21 kyBP but didn't succeed. Or did I oversee something? b) Furthermore, for those readers that are not so familiar with ice sheet modeling a bit more on the theoretical background would be good. It may be surprising that radiative heat fluxes are not explicitly given in the forcing. What is the reason for?

Response: a) The description in Sec. 2.2 is the method for generating the forcing that goes back to 120 kyr BP. Based on the two extreme conditions (LGM and PD), the other climate conditions are interpolated with the corresponding NGRIP δ^{18}O values.

b) The positive degree day (PDD) is a semi-empirical method that widely used for computing the surface mass balance. It is computationally fast since it only requires the surface air temperature and snow accumulation. The radiative heat flux is included in the calibration of the PDD factors with the measurements from glacier surface. This discussion can be added in the revised version.

3) Discussion of results. The main conclusion supports previous evidence that summer temperature dominates the evolution of ice mass and its distribution. While this appears plausible already from a basic theoretical point of view a deeper discussion on the individual roles of temperature and precipitation (which solely represent the atmospheric forcing in this study) would be helpful. The role of precipitation during periods of ice accumulation is already mentioned. Here the study could really benefit from twin experiments in which on forcing (e.g. temperature) is kept fixed to LGM conditions whereas the other forcing (precipitation) follows the transient dynamics calculated as described in section 2.2. If this is reasonable given the available computational resources, this would help to really isolate individual effects of precipitation and temperature changes.

Response: We start the simulation from a warm state (around 120kyr BP) in order to have a reasonable ice sheet build-up process. If the temperature is kept fixed to a cold condition (LGM) over the transient period, the initial condition will also change, and probably result in larger ice sheets. We propose to keep forcing (e.g. temperature) fixed to COSMOS climate output, while using precipitation from other PMIP3 model output or the other way around to have a thorough discussion in the revised version.

The study estimates a threshold value -5 degree to foster ice accumulation. Is there evidence from real present day distribution and temperature records that support this. There are a lot of high quality reanalysis products available with sub daily output frequency that might be used to support the deduce relationship for at least the Asian glaciers. Or is there literature available to discuss this further?

Response: Figure 5 shows a scatter plot between snowfall and 2 m temperature from the ERA-40 reanalysis product (1991-2000) over Greenland. With a threshold of around -5 degrees the snowfall value goes to a maximum, which can foster ice accumulation.

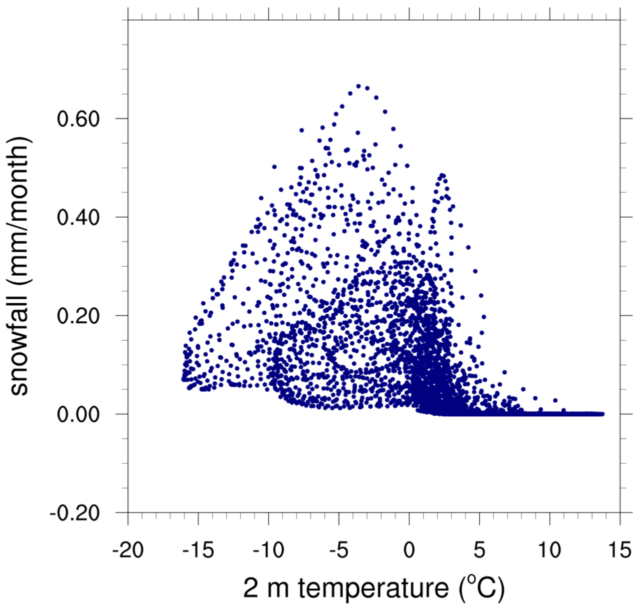

Figure 5. Scatter plot between 2 m temperature and snowfall over Greenland during summer by using the ERA-40 reanalysis product

4) No attempt has been undertaken to validate the model in the present day climate period. This would be helpful to get an impression of the validity of the model results for individual regions like Asia or Greenland.

Response: As is shown in Fig. 1, the modelled sea level equivalent can be different by up to 6-7 meters from different PMIP3 preindustrial simulations for the Greenland ice sheet. This will be discussed in the revised version.

5) Sensitivity experiments using PMIP3 model output. Here a discussion is provided about the effects of ablation due to warmer temperature and accumulation due to winter time precipitation. This could be deepened. Why accumulation dominant during winter in LGM. Geological evidence shows that larger ocean parts in the N-Hemisphere were ice covered during LGM compared to today which one might suppose to affect accumulation negatively while partly ice free condition during summer might foster ice accumulation? Here a discussion about available geological/paleoceanographic evidence would be useful. What is the known about the atmospheric moisture transports and sources during the LGM?

Response: The surface ablation is a dominant process during summer, while during winter accumulation is more prominent because of the relatively low temperature. The figures below show the seasonal cycle of the Preindustrial and the LGM precipitation over Greenland, North America and Eurasia ice sheets. The season with the most precipitation is in September, October and November for the Greenland ice sheet, North American ice sheets and Eurasian ice sheets respectively. For the Greenland ice sheet, the moisture transport in winter was less at the LGM than in present day. This might be because during the glacial winter, a much more zonal circulation prevents the effective transport of moisture to the Greenland ice sheet (Werner et. al, 2000). The atmospheric moisture transports and sources can also be inferred from Fig. 4 in the manuscript. This will be discussed more in the revised version.

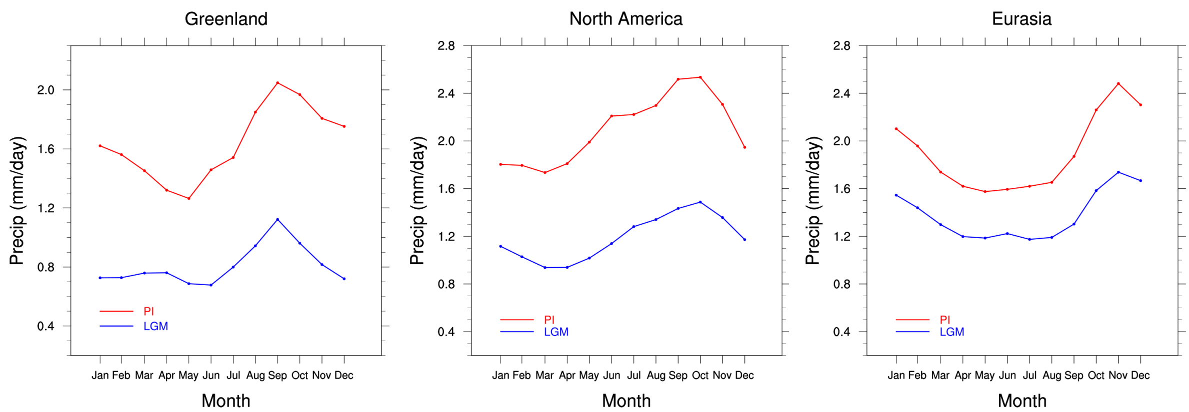

Figure 6. Seasonal cycle of precipitation from COSMOS output at Preindustrial (PI, red line) and the Last Glacial Maximum (LGM, blue line) over Greenland ice sheet (left), North American ice sheets (middle) and Eurasian ice sheets (right).

Specific Comments

Page 1 Titel. What is the message here? Do you aim to investigate the sensitivity to the ice sheet configuration or the other way round the sensitivity of ice sheets to the atmospheric forcing. I suggest to check the whole MS by a native English speaker.

Response: We aim to investigate the sensitivity of ice sheets to atmospheric forcing. The whole MS will be checked by a native English speaker.

line 21 change climate system to climate system compartments. We probably have only climate system that can operate in obviously very different modes.

Response: Yes, "climate system compartments" would be more precise. It will be changed in the revised version.

line 22 ocean circulation feedback. Be more precise. What is meant ? ocean heat transports? Vertical mixing dynamics?

Response: The processes of the ocean circulation feedback related to the ice sheets include both the ocean heat transports and the vertical mixing dynamics. We will be more precise in the revised version.

Page 2 line 16. Missing processes are not only a problem in EMICS but in more complex earth system models as well. Often EMICS include even more processes the model of advanced complexity but are higher parameterized.

Response: We aimed to address the missing smaller spatial scale processes (more regional processes) in the EMICs, which is a result of the coarse resolution. This can be written more explicitly in the revised version.

page 3 line 7: in section 2.2 so far I see only the production of forcing LGM -> PD is described. How is the forcing from 122.9 -> LGM produced Or do I miss something? Please give a reference or discuss the choice of present day condition for the ice sheet model initialization. Ice sheets have perhaps the longest memory in the climate system and thus will probably never reach equilibrium with any kind of external forcing (especially not the fast atmosphere). In turn one would assume initial condition have particular importance.

Response: The forcing at the LGM is treated as a cold condition while the PD is treated as a warm condition. Combining with the NGRIP data (spanning from 122.9 kyr BP to present day), the index is computed as shown in Eq. 6. This is also valid from 122.9 -> LGM.

The choice for the ice sheet model initialization is also used in other studies like Marshall et al. (2002) and Charbit et al. (2007). During the Last Interglacial, the climate conditions were similar to present day. We start the simulations from the Last Interglacial is to eliminate the influence of the initial condition.

page 5 line 3-4. How is this white noise generated and is that step really necessary? As i understood you form a glacial index from NGRIP (section 2.2) which is smoothed by 50 year averages.

Response: The original climate forcing data at the LGM and PD are monthly mean data. The white noise is generated to account for the synoptic variations within the month. Otherwise for some areas with monthly mean temperature around 0 degrees, it will result in some bias, either too much melt with temperatures slightly above 0 degrees or no melt at all below 0 degrees for the whole month. As a result, we consider this as being necessary. The white noise is applied to the monthly data, not the NGRIP data.

line 12ff. why not use GCM output for the preindustrial period instead of using a reanalysis product which would be physically more consistent.

Response: As discussed to the first general comment, we also ran experiments by using the GCM output from preindustrial period instead of the reanalysis data. Related discussion of how it influences the results will be added in the revised version.

page 7 line 14: Ok but the Rohling sea level reconstruction was also used to force the model, well? Figure 5 show also interesting mismatches between the curves. E.g at arounf 65 kyp present we see opposing trend in sea level. It seems that the Rohling curve sometimes leads the modeled curve. Could that be caused by a mismatch of age model between NGRIP isotope curve (which is tuned orbitally, I would guess?) and the the Rohling sea level curve?

Response: Yes, we agree. The modelled ice sheet evolution is mainly driven by the NGRIP signals. It is possible that the leading signal from Rohling sea level curve is caused by a mismatch of age model between NGRIP isotope curve and the Rohling sea level curve.

The NGRIP data is from Greenland while the Rohling sea level reconstruction is from the eastern Mediterranean. It may be also possible that the ocean dynamics response in Mediterranean played a role of the relative sea level change. The discussion can be added in the revised version.

line 27: Section 4.1.1 is rather descriptive as a whole. It is clear that D-O cycles arise from the NGRIP forcing. Is it possible further elaborate which regions are mainly contributing to these variations. Figure 5 distinguishes only Eurasia, North America, and Greenland. It could be worth to identify the key regions that most respond to D-O cycles and discuss this with available literature.

Response: Figure 7 shows the ice sheet thickness difference responding to one D-O warming between 61 kyr BP and 58.5 kyr BP, during which the modelled sea level equivalent rose around 30 meters. The most contributing areas are around the edges of the ice sheets. The thickness difference is up to 2400 m around the east coast and the Great Lakes for Laurentide ice sheet, and over North Sea and Southern Baltic Sea for Scandinavian ice sheet. Detailed discussion will be added in the revised version.

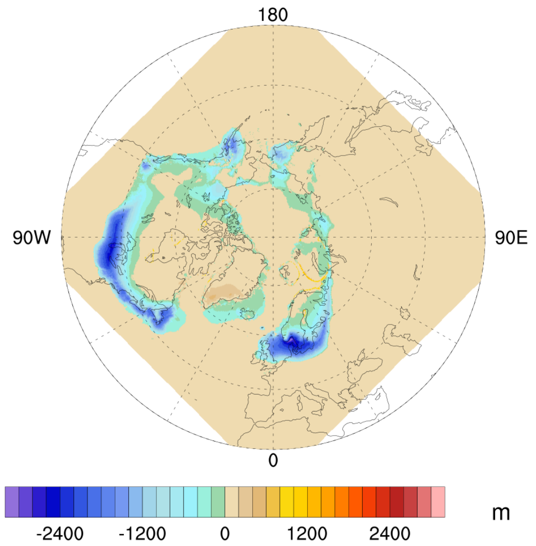

Figure 7. Modelled ice sheet thickness difference between 61 kyr BP and 58.5 kyr BP (58.5 kyr BP-60 kyr BP) from COSMOS-AWI.

References:

Charbit, S., Ritz, C., Philippon, G., Peyaud, V., and Kageyama, M.: Numerical reconstructions of the Northern Hemisphere ice sheets through the last glacial-interglacial cycle, Climate of the Past, 3, 15–37, doi:10.5194/cp-3-15-2007, https://www.clim-past.net/3/15/2007/, 2007.

Marshall, S. J., James, T. S., and Clarke, G. K.: North American ice sheet reconstructions at the Last Glacial Maximum, Quaternary Science Reviews, 21, 175–192, 2002.

Werner, M., Mikolajewicz, U., Heimann, M., and Hoffmann, G.: Borehole versus isotope temperatures on Greenland: Seasonality does matter, Geophysical Research Letters, 27, 723–726, doi:10.1029/1999GL006075, http://dx.doi.org/10.1029/1999GL006075, 2000.