REVIEWER 1

Minor comments:

Minor comment 1: Page 3, Line7ff: What is the horizontal and vertical resolution of the HadCM3 simulation ensemble?

Response to minor comment 1: In answer, the following text has been added to the manuscript to make this point clearer.

Page 3, Line 5: "The atmosphere component has a horizontal grid spacing of 2.5° (latitude) by 3.75° (longitude) and has 19 vertical levels (Gordon et al., 2000). The horizontal grid resolution of the ocean component is 1.25° by 1.25° with 20 vertical levels (Gordon et al., 2000)."

Minor comment 2: P3L21ff: The usage of the second simulation ensemble is less clearly described. No information of the change in GIS extent for the different simulations is found in the text or the appendix. It also remains unclear, how the different influence of GIS extent, GIS height and sea ice changes can be separated from this ensemble, as all three parameters are apparently changed at the same time.

Response to minor comment 2: Following the reviewer's comment, we have added a new figure (Fig. A2) in the appendix A, run new simulations, and provided additional information of the change in GIS extent for the different simulations in the main text. The new figure shows the GIS extent (land-ice mask) for each of the 32 simulations that examine the joint impact of modified Arctic sea ice retreat and modified GIS morphology. New text on simulations:

Page 4, Line 24: "The resulting 32 LIG GIS morphologies show strong variation in terms of both height and ice extent (Fig. A1 and Fig. A2). Some morphologies show a rather small retreat of the GIS, and others a possible division of the GIS into two domes, some display strong ice loss in the south, while others show substantial ice retreat in the north."

And on the reviewer's concerns on how to separate the influence of GIS extent, GIS height and sea ice changes:

The objective of the set of 32 simulations is to study the joint impacts of sea ice change and GIS change. To examine the influence of GIS height changes alone, we use the set of 16 simulations with idealised variations in the elevation of the GIS, where the present-day GIS extent (land-ice mask) is unmodified. Similarly, the sea ice retreat simulations of Malmierca-Vallet et al. (2018), which only include sea ice forcing changes, help to isolate the influence of $\delta^{18}O$ due to sea ice variations. The GIS extent is the only parameter whose effects cannot be isolated from any of our ensemble of simulations, which should be rather smaller compared to sea ice influences. We acknowledge that this approach has limitations as the interaction among the three factors (GIS elevation and extent and sea ice) could lead to smaller/larger effects than predicted from the sum of single parameter effects. Following the reviewer's suggestion, the authors have added a new appendix (Appendix B) that explores the robustness of this approach. We also run eight additional LIG simulations with the purpose of separating the effect of sea ice changes versus GIS shape changes.

Page 37, Appendix B: To calculate the sea-ice-corrected δ^{18}O anomalies we deduct the sea-ice-associated δ^{18}O effect from the total δ^{18}O anomalies (see section 3.2). In particular, we use the sea ice retreat simulations of Malmierca-Vallet (2018) to isolate the impacts of δ^{18}O due to sea ice variation (Fig. A6). We acknowledge that this approach has its limitations as the interaction among GIS shape and sea ice factors could lead to smaller/larger effects than predicted from the sum of single parameter effects. In order to test the robustness of our approach, we run eight additional LIG simulations with the purpose of separating the effect of sea ice changes versus GIS shape changes. From the ensemble of 32 simulations, which explore the joint impacts of sea ice change and GIS change over Greenland, we select 4 simulations (GIS1-SIE-11.49, GIS2-SIE-11.52, GIS13-SIE-14.98 and GIS31-SIE-19) and rerun them with: (1) only the sea ice forcing implemented and, (2) only the modified GIS shape implemented (see Table A1).

We find that the 4 simulations that explore the joint impact of GIS shape changes and sea ice changes result in smaller/larger δ^{18}O anomalies (compared to the 125 ka control) than the predicted from the sum of single parameters effect (Table. B1 and B2). Nevertheless, differences are not higher than around ±1‰. This is within the model uncertainty of annual mean δ^{18}Op (Malmierca-Vallet et al., 2018).

Table B1. Simulated δ^{18}Op anomalies compared to 125 ka control on six Greenland deep ice cores: NEEM, NGRIP, GRIP, DYE3, GISP2 and Camp Century. For each pair of simulations, it is shown δ^{18}Op anomalies due to (1) GIS shape changes, (2) sea ice changes and, (3) sum of single parameter effects

Sum of single parameter effects						
	NEEM	**NGRIP**	**GRIP**	**DYE3**	**GISP2**	**Camp Century**
GIS1	-0.9	0.0	0.2	2.1	0.6	0.4
SIE-11.39	1.3	1.5	1.6	0.5	1.4	2.0
SUM	**0.4**	**1.4**	**1.8**	**2.6**	**1.9**	**2.5**
GIS2	0.4	0.6	0.0	3.2	0.5	-1.6
SIE-11.83	1.4	1.6	1.3	0.3	1.1	2.0
SUM	**1.8**	**2.2**	**1.3**	**3.6**	**1.6**	**0.5**
GIS13	-1.8	-0.7	1.1	-1.2	1.2	-2.1
SIE-15.65	0.6	1.1	1.1	0.2	0.9	0.6
SUM	**-1.2**	**0.4**	**2.2**	**-1.0**	**2.1**	**-1.5**
GIS31	2.5	1.5	0.4	3.1	0.9	1.2
SIE-20.09	-0.6	-0.4	-0.3	-0.7	-0.4	-1.2
SUM	**1.9**	**1.2**	**0.1**	**2.4**	**0.5**	**0.0**

Table B2: Simulated δ^{18}Op anomalies compared to 125 ka control on six Greenland deep ice cores: NEEM, NGRIP, GRIP, DYE3, GISP2 and Camp Century. δ^{18}Op anomalies due to the joint impact of GIS shape changes and sea ice changes.

Simulated joint impact						
	NEEM	**NGRIP**	**GRIP**	**DYE3**	**GISP2**	**Camp Century**
GIS1-SIE-11.49	0.1	1.1	1.8	3.4	2.0	2.3
GIS2-SIE-11.52	2.6	2.6	1.7	4.2	2.3	1.8
GIS13-SIE-14.98	-0.3	1.0	2.5	-0.3	2.4	0.0

GIS31-SIE-19	2.5	1.4	0.9	3.3	1.3	1.3

Minor comment 3: P4L5ff: Some information about the overall (dis)agreement between modelled LIG-PI d18O anomalies as compared to ice core data should be added.

Response to minor comment 3: Following the reviewer's suggestion, the authors have added the following discussion in the manuscript.

Page 11, Line 7: **Implications for NEEM $\delta^{18}O$ and elevation reconstructions**

"Considering the NEEM elevation reconstruction, which indicates NEEM elevation differences of +45±350 m at 126 ka relative to present-day (NEEM community members, 2013), we find a most likely increase in $\delta^{18}O$ values of between +0.8‰ to +3.5‰ relative to PI (Fig. 8). This relatively falls within the lower end of the uncertainty range of the reconstruction by Domingo et al. (2020): most likely LIG $\delta^{18}O$ peak of +3.6‰ and uncertainty range between +2.7‰ to +4‰. The relatively small overlap between the $\delta^{18}O$ record and the elevation reconstruction has already been discussed in Domingo et al (2020) and, could possibly reflect uncertainties attached to the air content NEEM elevation reconstruction method. The methodology depends on making corrections to air content measurements related to insolation and temperature in conjunction with secular variations in surface pressure and winds (Raynaud et al., 2007; Martinerie et al., 1994; Krinner et al., 2000; Eicher et al., 2016). In addition, NEEM air content measurements between 127 and 118.3 ka are known to be affected by surface melting (NEEM community members, 2013)."

Minor comment 4: P4L5: A reference for the difference between NEEM drill site and deposition site should be given.

Response to minor comment 4: In answer, the following reference has been added to the manuscript to make this point clearer.

Page 5, Line 5: "NEEM community members (2013)"

Minor comment 5: P4L9ff: References to some plots of Fig. 1 are wrong in this paragraph. E.g, NGRIP delta 18O changes are shown in Fig. 1e (not 1f), GISP2 values in Fig. 1m (not 1p), etc. Fig. 1z does not exist, at all.

Response to minor comment 5: Corrected.

Minor comment 6: P5L2: Are the differences in temperature lapse rate (0.47C/100m to 0.44C/100m) statistically significant or within the model-intrinsic uncertainty?

Response to minor comment 6: In answer, the following text has been added to the manuscript.

Page 6, line 7: "Averaging across six ice core sites (Camp Century, NEEM, NGRIP, GRIP, GISP2 and DYE3), temperature lapse rates vary slightly from 0.47°C per 100 m for the lowered GIS states to 0.44°C per 100 m for the enlarged GIS states (Fig. 1), however these changes are not statistically significant."

Minor comment 7: P5L6: Figure 5 is discussed before Figure 3+4 have been mentioned. This figure order could be improved.

Response to minor comment 7: Done.

Minor comment 8: P5L32: Is there an explanation for the non-linear behavior of precipitation changes?

Response to minor comment 8: Precipitation is a highly non-linear phenomena; elevation is one of the main topo-climatic drivers of precipitation gradients, however the relationship between elevation and precipitation can be idiosyncratic (Spreen, 1947; Basist et al., 1994; Daly, 1994). In many regions including over the GIS, local changes in precipitation with elevation can approximate a curved distribution and best estimated by non-linear models (e.g. Marquínez et al., 2003; Körner, 2007; van de Berg et al., 2013).

Minor comment 9: P6L4ff: At Camp Century, the same sign in precipitation changes for increased and decreased elevation is explained by winter sea ice conditions in the Baffin Bay. The changes show in Fig.3d, 3f are only subtle and it is hard to believe that these minor differences have any effect on precipitation formation. They will barely change the high mean winter sea ice concentration of the 125k control simulation shown in Fig. 3e.

Response to minor comment 9: We agree with the reviewer that changes in winter sea ice in the Baffin Bay are rather small and therefore, have probably minor effects on precipitation formation. We propose a new argument; the different behaviour found at Camp Century site is likely linked to its coastal position. Slope areas receive more moist air masses which are orographically lifted and consequently condensate and precipitate.

Page 7, Line 13: At Camp Century site, precipitation tends to increase with increasing surface elevation (-0.091 mm/year per 100 m elevation increase) (Fig. 1w). Removing the Camp Century site increases the core-average precipitation gradient to 0.029 mm/year per 100 m elevation increase. The different behaviour found at Camp Century site is likely linked to the orographic enhancement of precipitation (Johnson and Hanson, 1995; Frei and Schär, 1998; Petersen et al., 2004; Roe and Bakker, 2006) among the enlarged GIS states. Reductions in Camp Century height results also in marginal increases in precipitation rate (0.05 mm/year per 100 m) which are probably related to the weakening of the Greenland anticyclone and smaller barrier effect.

Minor comment 10: P6L11: For a better assessment of the simulated PI mean sea ice extent (5.8 mil km2), it should be compared to observed/reconstructed values.

Response to minor comment 10: In answer, the following text has been added to the manuscript to make this point clearer.

Page 3, Line 9: "The HadCM3 sea ice output over the Arctic Ocean has been previously validated against observational sea ice data (Meier et al., 2017; Peng et al., 2013) by Malmierca-Vallet et al. (2018). Under PI conditions, HadCM3 simulates rather little summer sea ice over the central Arctic Ocean, and too much winter sea ice over the Norwegian, Barents, Labrador and Bering Seas. For a full validation of the sea ice model, interested readers are referred to Malmierca-Vallet et al. (2018) and Gordon et al. (2000)."

Minor comment 11: P6L31: The reference to Fig. C1 would be better placed after the next sentence ("Since the surface [: : :] center of basin.").

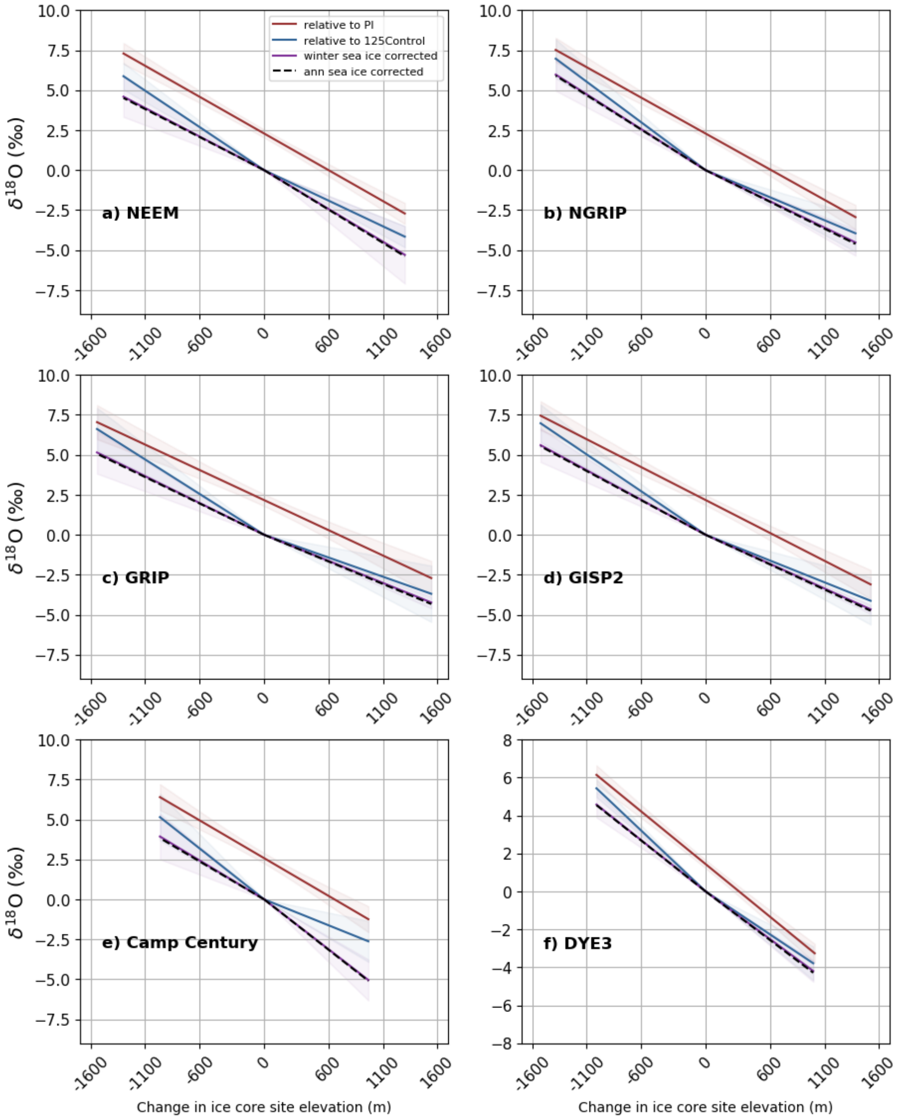
Response to minor comment 11: Done.

Minor comment 12: P7L8: The method of isolating the impacts of delta 18O due to sea ice variation should be explained in more detail. E.g., how is a potential effect of changed GIS extent treated in this analysis. And why is this analysis performed for winter sea ice retreat, only? Are summer SIC changes negligible?

Response to minor comment 12: We have added a new Appendix B that explores the robustness of the method used to isolate the impacts of $\delta^{18}O$ due to sea ice changes. See also response to minor comment 2.

We performed this analysis for winter sea ice retreat because summer sea ice changes tend to be smaller and present more noise than changes in winter sea ice. In order to test our method, we also calculate $\delta^{18}O$ anomalies (compared to 125 ka control) corrected for annual sea ice changes. In particular, we use the sea ice retreat simulations of Malmierca-Vallet et al. (2018) to isolate the impacts of $\delta^{18}O$ due to annual sea ice variation; we calculate the change in $\delta^{18}O$ as a function of annual sea ice retreat.

To calculate $\delta^{18}O$ anomalies corrected for annual sea ice changes, we deduct the annual-sea-ice-associated $\delta^{18}O$ effect from the total $\delta^{18}O$ anomalies. The figure above is very similar to Fig. 9 of the main paper. It shows $\delta^{18}O$ anomalies as a function of the ice core site elevation change (m) relative to: (1) PI (red fit), (2) 125 ka control (blue fit), (3) winter-sea-ice corrected $\delta^{18}O$ anomalies relative to 125 ka control (purple fit) and, (4) annual-sea-ice corrected $\delta^{18}O$ anomalies relative to 125 ka control (black dashed fit). It is evident that the resulting $\delta^{18}O$ anomalies corrected for both annual and winter sea ice changes are very similar, almost identical (Figure above – purple curve fit and black dashed curve fit).



This figure is identical to Fig.9 of the main paper but adding a fourth fit; annual-sea-ice corrected $\delta^{18}O$ anomalies relative to 125 ka control (black dashed fit).

Minor comment 13: P8L26ff: In this paragraph simulated temperature lapse rates are compared to observed mean lapse rates, but also to changes in temperature lapse rates for a warming climate. These two quantities (mean state and its temporal deviation) should not be mixed in this comparison.

Response to minor comment 13: Following the reviewer's suggestion, the following text has been removed from the manuscript.

Page 9: "Our results are also in agreement with Erokhina et al., 2017, who point to a non-stationarity response of the climate to GIS elevation changes during the Holocene and Last Glacial Maximum (LGM). Erokhina et al., 2017 propose that following the transition from the LGM to the Holocene, mean annual temperature lapse rates over the GIS decreased by almost 20 %."

Minor comment 14: P9L21ff: How large is the modelled modern spatially derived delta 18O-elevation gradient? How does it compare to the cited values of Dansgaard/Johnsen et al./Vinther et al.?

Response to minor comment 14: In answer, the following text has been modified/added to the manuscript.

Page 10, Line 30: "Interestingly, LIG isotopic lapse rates and the PI spatially derived isotopic lapse (0.37‰ per 100 m) modelled with HadCM3, are lower than the modern spatially derived gradients of 0.62‰ per 100 m and 0.72‰ per 100 m in central and northwest Greenland respectively (Dansgaard et al., 1973; Johnsen et al., 1989; Vinther et al., 2009)."

Page 11, Line 5: "The HadCM3 resolution does not permit it to represent the steep GIS margins; this may be behind some of the model-data mismatches (Toniazzo et al., 2004)."

Minor comment 15: Fig. 1: The last column of plots (Fig, 1d, 1h, etc.) lacks an explanation. Why is the plot of winter sea ice extent vs. GIS elevation changes different for the various ice core sites?

Response to minor comment 15: In answer, the following text has been added to the manuscript to make this point clearer.

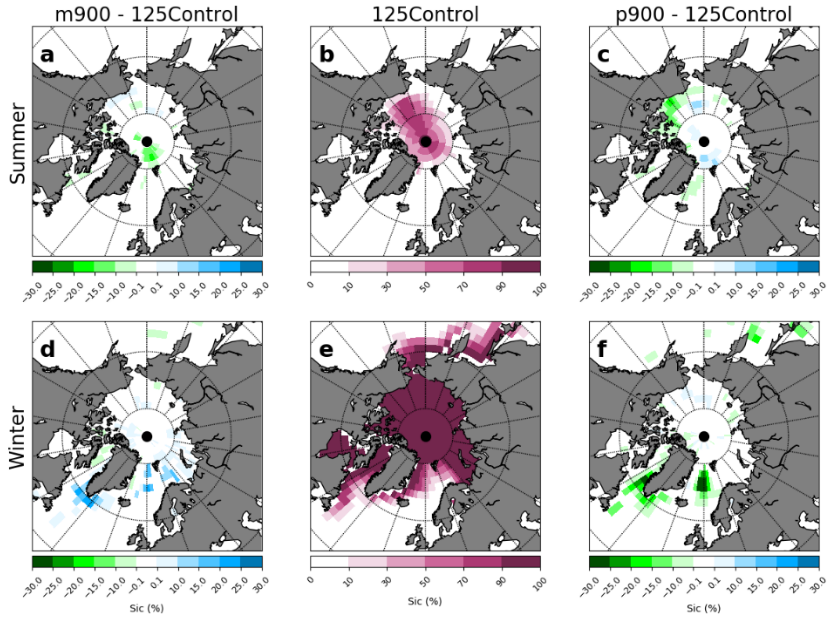
Page 19: In the last column of plots, winter sea ice extent vs GIS elevation changes differs for the various ice core sites because of the different elevation changes at each ice core site compared to the 125 ka control.

Minor comment 16: Figs. 2/3/5/6: Are all anomalies shown in the plots statistically significant? No nonsignificant values can be detected in these figures.

Response to minor comment 16: All anomalies shown in the plots are statistically significant at the 95% confident level.

Minor comment 17: Fig. 3: The color bar values in the plots range from 0..1, but the figure caption states that sea ice concentration and its anomalies are given in percent (0..100%).

Response to minor comment 17: In answer, we have changed the bar values in the plots which range now from 0% to 100%. See figure below:



Updated Fig. 5 in revised manuscript.

REFERENCES

Basist, A., Bell, G. D. & Meentemeyer, V. Statistical Relationships between Topography and Precipitation Patterns. *J. Clim* 7, 1305–1315 (1994).

Daly, C., Neilson, R. P. & Phillips, D. L. A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain. *J. Appl. Meteorol.* 33, 140–158 (1994).

Körner, C. The use of ‘altitude’ in ecological research. *Trends Ecol. Evol.* 22, 569–574 (2007).

Marquínez, J., Lastra, J., García, P. Estimation models for precipitation in mountainous regions: the use of GIS and multivariate analysis. J. of Hydrology, 270, 1-11, 2003. doi:10.1016/S0022-1694(02)00110-5.

Spreen, W. C. A determination of the effect of topography upon precipitation. *Eos Trans. Am. Geophys. Union* 28, 285-290 (1947).

Van de Berg, W.J., van den Broeke, M. R., van Meijgaard, E., Kaspar, F. Importance of precipitation seasonality for the interpretation of Eemian ice core isotope records from Greenland. Climate of the Past, 9, 1589-1600 (2013). doi:10.5194/cp-9-1589-2013.