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Climate of the Past Discussions



# *Interactive comment on* "Equilibrium simulations of Marine Isotope Stage 3 climate" *by* Chuncheng Guo et al.

**Anonymous Referee #2**

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This is a study that aims to improve the understanding of the climate of Marine Isotope Stage 3 (MIS3) when the millennial-time scale climate variability occurred most frequently during the last glacial period. The authors perform simulations of MIS3 with a comprehensive state-of-the-art climate model and compare the climate and the oceanic circulation, especially the Atlantic Meridional Overturning Circulation (AMOC) with those of the Preindustrial (PI) and the Last Glacial Maximum (LGM). The authors further show the sensitivity of the MIS3 climate and the AMOC to modifications in the boundary conditions, such as the Laurentide ice sheet and CO2. The model does not exhibit a threshold-type behaviour of the AMOC under low Laurentide ice sheet and low CO2 level. This is interesting, and it offers the community a chance to improve our understanding of the AMOC and discrepancies among models. This paper should



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Discussion paper

be published because of two reasons. First, it produces important information of the climate of MIS3, which is still rare compared to that of the LGM. Second, it assesses the sensitivity of the MIS3 climate to modifications in the boundary conditions, which is unique compared to previous studies assessing the sensitivity under the PI and the LGM conditions. Nevertheless, I also feel that the important points of this study are still unclear and the manuscript is too long. Below are some suggestions to improve the manuscript.

—General comments—

1. The author should focus more on the results of the sensitivity experiments and perform more analysis in these experiments, since they are the most important and interesting point of this study. In particular, what happens to surface salinity and density over the North Atlantic Deep Water (NADW) formation region and Antarctic bottom water formation (AABW) region when the Laurentide ice sheet and CO2 are modified? Since previous studies have shown that changes in surface salinity and density are very important in understanding the changes in the strength and the threshold of the AMOC (e.g. Montoya and Levermann 2008, Oka et al. 2012, Sun et al. 2016, Buizert and Schmittner 2015, Sherriff-Tadano et al. 2018, Klockmann et al. 2018, Galbraith and de Lavergne 2018), analysis on this point is very important. This analysis will also give very useful information in comparing the results of your model with other climate models. Further analysis on the depth of the AMOC, as well as sea ice cover over the North Atlantic and Southern Ocean should be conducted (e.g. Klockmann et al. 2016, Kawamura et. 2017, Galbraith and de Lavergne 2018).

2. The manuscript is too descriptive and long, which makes the reader difficult to understand the important message of this study. In particular, sections 3.1, 3.2, and 4 are too descriptive. I do understand that these sections show important results, however, they do not give new results and rather follows several previous studies. Unless you compare these simulation results with proxies and other climate models in detail, you should move some part of this section to the Supplementary section. This will help

shorten the manuscript.

—Specific comments—

1 Introduction

The authors should state the significance of this study compared to previous studies more clearly in the last three paragraphs. These points are vague in the manuscript. I understand that the simulation of MIS3 is important since most previous studies conducted simulations of the LGM when they explore the glacial climate. However, in the manuscript, the significance of this study compared to previous MIS3 modelling studies is vague. This point should be clarified.

2 Methods

P4 L30-32: I couldn't quite understand this sentence. Do you just mean that the shape of the ice sheet is prescribed in the model?

P5 L10: MSI3 → MIS3

3 Results

3.1 Model spin-up

I agree that the model has almost reached a quasi-equilibrium state. However, I feel that this section is too long, which makes the reader tired. Please consider reducing the amount of this section. (See also Comment 2).

P7 L11: Where is the location of the open ocean convection over the Southern Ocean in the MIS3 experiment?

3.2 Simulated MIS3 climate

This section is too descriptive and long. Please consider reducing the amount of this section by moving some part of it to the Supplementary. (See also Comment 2).

P7 L33-P8 L1: The strengthening of the surface easterly wind stress over the Irminger

Sea is also caused by the expansion of the Laurentide ice sheet (Sherriff-Tadano et al. 2018).

P8 L30-P9 L3: Please mention that the lowering of CO2 is important in causing the expansion of sea ice and in decreasing the sea surface temperature.

P9 L27: You may remove the first sentence, which is already mentioned in the Introduction.

P9L30-L31: Did you try to say 'The deeper overturning stream function is associated with contracted and weakened AABW'?

P10L21-L25: Kobayashi et al. (2015) also report similar response in their LGM simulation. The decrease in ideal age of the water is attributed to enhanced open ocean convections over the Southern Ocean. You may cite this paper as well.

P11L18-L20: Merkal et al. (2010) also shows similar results in their MIS3 insterstiadial simulation. You may cite this study as well.

P11L32-L33: Is this difference statistically significant?

P12L2-L3: Is this difference statistically significant?

4 MIS3 simulation forced by stadial conditions Please consider reducing the amount of this section by moving some part of it to the Supplementary. (See also Comment 2).

5 Discussion

5.1 Simulated AMOC in MIS3

P13L13: I rather use 'bottom water formation' than 'open ocean convection'.

P13L26-L30: As far as I know, Montoya and Levermann (2008) first showed the potential role of surface winds over the North Atlantic in intensifying the AMOC, Oka et al. (2012) showed that the LGM surface wind enhanced the AMOC with one model, Muglia and Schmittner (2015) confirmed the study of Oka et al. (2012) by performing

analysis with PMIP3 climate models, and Sherriff-Tadano et al. (2018) investigated the processes by which surface winds anomaly induced by the ice sheets enhanced the AMOC. These studies should also be cited in this sentence.

P13L31: Hu et al. (2015) investigated the impact of the closure of Bering Strait on the AMOC. This study should also be cited in this sentence.

5.2 MIS3 sensitivity to CO2 and ice sheet size

Results presented in this section are really interesting! As mentioned in Comment 1, I strongly encourage the authors to perform more analysis on these sensitivity experiments (surface salinity, density and sea ice cover over the NADW and AABW formation region, and the depth of the AMOC). Based on these analysis, you may further discuss the possible cause of differences among previous modelling studies. (Also, if possible, it may be interesting to discuss changes in surface air temperature and precipitation in the half-size Laurentide ice sheet. This analysis can provide an uncertainty of the simulated temperature and precipitation anomalies arising from the uncertainty in the shape of the MIS3 ice sheet. Just a suggestion.)

P15L13: What do you mean by 'ice inhibiting convection'?

Figures

Fig.2: Can you put labels on the contours?

Fig.11: Can you add a figure showing the anomaly? It's difficult to understand the difference between MIS3 and PI from these figures.

References

Buizert, C., & Schmittner, A. (2015). Southern Ocean control of glacial AMOC stability and Dansgaard-Oeschger interstadial duration, Paleoceanography, âĂĺ30, doi:10.1002/2015PA002795

Hu AX, Meehl GA, Han WQ, Otto-Bliestner B, Abe-Ouchi A, Rosen- bloom N (2015)

Effects of the Bering Strait closure on AMOC and global climate under different background climates. Prog Oceanogr 132:174–196. doi:10.1016/j.pocean.2014.02.004

Kawamura K et al (2017) State dependence of climatic instability over the past 720,000 years from Antarctic ice cores and cli- mate modeling. Sci Adv 3:e1600446

Kobayashi H, Abe-Ouchi A, Oka A (2015) Role of Southern Ocean stratification in glacial atmospheric CO2 reduction evaluated by a three-dimensional ocean general circulation model. Pale- oceanography 30:1202–1216. doi:10.1002/2015PA002786

Merkel U, Prange M, and Schultz M (2010) ENSO variability and teleconnections during glacial climates, Quat. Sci. Rev., 29, 86–100,.

Montoya M, Levermann A (2008) Surface wind-stress threshold for glacial Atlantic overturning. Geophys Res Lett 35:L03608. doi: 10.1029/2007gl032560

Oka A, Hasumi H, Abe-Ouchi A (2012) The thermal threshold of the Atlantic meridional overturning circulation and its control by wind stress forcing during glacial climate. Geophys Res Lett 39:L09709. doi:10.1029/2007gl029475

Sherriff-Tadano, S., Abe-Ouchi, A., Yoshimori, M., Oka, A., & Chan, W.-L. (2018). Influence of glacial ice sheets on the Atlantic meridional overturning circulation through surface wind change. Climate Dynamics, 50, 2881-2903. doi:10.1007/s00382-017-3780-0

Sun, S., Eisenman, I., & Stewart A. (2016). The influence of Southern Ocean surface buoyancy forcing on glacial-interglacial changes in the global deep ocean stratification, Geophysical Research Letters, 43, 8124–8132. doi:10.1002/2016GL070058

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