Review of "Hysteresis of the Greenland ice sheet from the Last Glacial Maximum to the future"
by Gutiérrez-González et al.

The manuscript presents a set of simulations of the Greenland ice sheet, spanning from glacial conditions to warm climate states, with hysteresis experiments. The simulation is conducted using the ice sheet model Yelmo, coupled with the energy balance model REMBO. The hysteresis of the Greenland ice sheet is investigated by temperature anomaly through surface mass balance and oceanic basal mass balances. The hysteresis of the Greenland ice sheet is characterised by the wide range of temperature anomalies, spanning from LGM-like glacial states to warm states just before ice-free Greenland. The analysis focusing on specific region of Greenland ice sheets shows that the threshold of the marine-based ice sheet makes the hysteresis of the Greenland ice sheet.

I think this study's topic is well-suited for Climate of the Past. The model is well developed and the experimental design is carefully chosen, and the figures provide good analysis. The manuscript is well-written and clear. However, I identified some areas for revision in the manuscript; therefore, I appreciate the authors addressing several points before publication.

General comments

[1] As in the abstract and conclusion, one primary finding is that the hysteresis of the Greenland ice sheet is identified near glacial conditions corresponding to -10K to -9K in regional summer temperature. However, the text does not appear to have adequately considered the assumptions that underlie the derivation of this temperature values. The equation (6) $\Delta T_{ocn} = 0.25 \Delta T_{ann}$ is one example. As stated in the main text, this equation uses the same equation as Golledge (2015). However, as the study of Golledge et al. (2015) is for Antarctic ice sheet, it needs some justification arguments why they identified this value. For example, In a more recent study, Garbe et al. (2020) used $\Delta T_{ocn} = 0.39 \Delta T_{ann}$ for the Antarctic ice sheet, based on an analysis of the Antarctic region in a 4xCO_2 climate model simulation.

I agree with using formulation (6) for all experiments in this paper, but as analyzed in additional experiments (Appendix Figure C1) and L344-348, I believe it is important to note that showing temperature values of -10 to -9 K in the conclusions and abstract contains significant uncertainty in relating atmospheric temperature to ocean temperature.

[2] I couldn't fully understand how ocean temperature works in the experiments. According to Section 2.3, if I put the parameters κ =15 and Bref=50 into Equation 5, ΔTocn=-3.33K induces Bgl=0. And using equation (6), Bgl=0 when ΔTjja=-8.89K, and below that temperature anomaly, Bgl=0 as Bgl cannot be negative (L134).
However, according to Figures 6 and 7, basal mass balance is still significantly greater than 0 even if ΔTjja is around -10K.
Accorinding to my calculation above, in Figure 8, both ΔTjja=-9.3K and -9.4K would induce Bgl=0, I'm confused. Maybe I'm doing something wrong.
I have a suggestion. Since Bgl should have a uniform value, I think it would be possible to plot the Bgl values on top of Figure 3. Wouldn't it make it clearer how the basal melting works?

[3] Tabone et al (2018) is one important previous study of this article of this study because the discussion of the evolution of Greenland ice sheet is discussed (final sentence of the abstract). I find there are many improvements and changes in the model setup compared to Tabone et al. (2018). However, the manuscript does not clarify that basal freezing was possible in Tabone et al. (2018), contrary to this study. I like the setup of this study preventing basal freezing, because Antarctic Ocean modeling indicates still active basal melting in the glacial conditions because thermal forcing is positive (Kusahara et al. 2015; Obase et al. 2017). Would it be possible that the presence or absence of basal freezing can have a substantial impact on the hysteresis?

[4] In the experiment, the atmospheric surface mass balance and the ocean basal mass balance change simultaneously in response to ΔTjja. However, an additional experiment in which one of the forcings is turned off, would identify the mechanism. For example, in the -9.3K experiment (Figure 8), if the tipping point does not occur when only Bgl is set to -9.4K, we can strongly argue that the mechanism of MISI is oceanic forcing.

Detailed comments

L4: "global warming to 4K" would be changed to "threshold of ice-free state"?

L7-8: Please clarify that -12 K and +4K indicate regional summer temperature.

L34-35: On the threshold of Greenland ice sheet, recent study (Gregory et al., 2020) addresses this topic, with the effect of ice sheet-climate interactions and the irreversitbility of the Greenland ice sheet.

L41: “regional summer atmospheric temperature” Where? Is it based on ice core site NGRIP?

L80: Is the extent of the ice shelf margin determined only by stress alone? Are there any geographical constraints like continental shelf break positions?

L83-84: As far as I understand, the REMBO needs specific humidity as the input. According to the model results' description, an increase in regional atmospheric air temperature leads to an increase in precipitation over Greenland (e.g., L266). How is the specific humidity treated in temperature changes? Is it assuming the relative humidty as the constant?

L89: “100 km” which model’s resolution? I suppose the resolution of ERA-40 is ~100 km; could you please clarify this?

L90: According to Robinson et al. (2010), the REMBO utilized empirical lapse rate feedback of 6.5 K/km for elevation correction. Is the same elevation-temperature feedback utilized in the current model used in these experiments?

L107: Is δP defined at every 16 km grid cell? It would be helpful to put the map of P and Pcorr in the supplemental Figure

L109: What does “consistent field” mean?

L128: Is The unit m/yr defined as “freshwater equivalent” mass balance? Or ice equivalent? Please clarify.

L156: I think retaining insolation as present-day is one probable experimental design because summer insolation in the northern high latitude at the LGM is similar to present-day. However, I recommend the author consider adding one sensitivity experiment setting reduced sea level and setting LGM insolation values (used in the energy balance model REMBO as in equation 3) to assess the impact of these parameters.

L299: Please clarify at what degree of ΔTjja does basal melting activate?

L349-L354: In Bochow's (2023) experiment, oscillations were not observed in YELMO-

REMBO. However, oscillations were observed in the experiment described in this article. I have identified that the experimental design is not identical with Bochow et al. (2023), the one is the scaling ratio of ΔTjja and ΔTdjf (1.61 in Bochow et al. (2023) while the scaling ratio is 2 in this study. Are there other differences in how ocean melt is determined?
I believe it would be beyond scope of this study to explain why oscillatory solutions appear in the experiments in the current setup. I recommend summarizing the differences in the experimental setup compared to Bochow et al. (2023) and stating that the existence of oscillatory solutions depends on the experimental setup.

L373-L380: Please clarify that Honing (2023) defines temperature as the global mean temperature, which differs from this study and Robinson (2012).

L381-L386: Bochow et al. (2023) derives the relationship between global mean temperature and ΔTjja based on an analysis of the CMIP6 climate model historical and the SSP585 experiment. I recommend summarizing the method of relating global mean temperature and ΔTjja in the manuscript text.

Figure C1: It would be good to have a diagram with Mgl on the horizontal axis, which would allow us to consider whether the basal mass balance of the ocean or the surface mass balance of the atmosphere primarily determines hysteresis.

Other minors:

L5: Yelmo coupled with regional energy balance model REMBO
L47: “regional climate model REMBO” to “regional energy balance model REMBO” to make consistency.
L82: “regional climate model” to “regional energy balance model”
Figure A1: Could you please show the distribution of SMB in the current climate in this experimental setting, with a comparison to SMBMIP (Frettweis et al. 2020)?

References:

Kusahara, K., T. Sato, A. Oka, T. Obase, R. Greve, A. Abe-Ouchi, and H. Hasumi (2015), Modelling the Antarctic Marine Cryosphere at the Last Glacial Maximum, Annals of Glaciology, 56(69), 425-435. doi:10.3189/2015AoG69A792.
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Gregory, J. M., George, S. E., and Smith, R. S.: Large and irreversible future decline of the Greenland ice sheet, The Cryosphere, 14, 4299–4322, https://doi.org/10.5194/tc-14-4299-2020, 2020.
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