Gutiérrez-Gonzáles et al. study the hysteresis behavior of the Greenland Ice Sheet under a wide range of temperature anomalies, also exploring the effect of cooling for the stability of the Greenland Ice Sheet. They use a state-of the art ice sheet model (Yelmo) and the coupled regional mass balance model REMBO. For the warming of the Greenland Ice Sheet starting at an equilibrium state under temperatures close to the last glacial maximum, the authors find two thresholds for the stability of the Greenland Ice Sheet: starting at an equilibrium with a regional summer air temperature anomaly of -14 K (close to the temperatures of the last glacial maximum) the first threshold is found at temperature anomalies between -10 to -9 K. Here, the marine parts of the ice sheet are lost. The second threshold is found temperature anomalies between +1.2 and +1.8 K and leads to an almost complete loss of the ice. A hysteresis behavior is observed over almost the whole range of temperature anomalies.

The authors analyze both the warming and the cooling branch. They distinguish between oceanic and atmospheric influences, and they undertake a regional study for the warming branch.

General comments:

While this is not the first study on the topic of Greenland Ice Sheet stability, it is to my knowledge the first study which takes the full glacial-interglacial temperature range into account. Even so, while the stability of the Greenland Ice Sheet has been studied with different models and different forcings, many details seem to depend on the type of model, the coupling to the atmospheric conditions and the exact type of forcing. Therefore, it is worthwhile adding another piece of information, in my opinion.

The manuscript is generally well written, clear and easy to understand, however, I have a few methodological and logical concerns.

1) The authors claim that the initial state of the warming branch at a temperature anomaly of -14 K is an LGM-like state and compare it to reconstructions of LGM ice extent. However, some important features do not match LGM, particularly the insolation and the sea level. There is a gap between the attempt of an idealized analysis of the stability landscape and the connection to a realistic paleoclimate, which is not easily bridged. I suggest that the authors use more careful language at this point, so that the idea that the "cold" initial state should be equivalent to the actual LGM configuration of the Greenland Ice Sheet doesn't arise. In addition, a sensitivity analysis with LGM levels of insolation or sea level might be beneficial towards comparing the modeled "cold" state with LGM ice extent reconstructions.
2) The authors undertake some efforts to distinguish different feedbacks which influence or even trigger the tipping of the Greenland Ice Sheet. The claim that the first tipping is driven by ice ocean interaction and MISI in the north-west is

well supported by the data in the following subsection. However, the claim in line 267 “Finally, at ~+1.5 K elevation and albedo feedbacks are triggered and the SMB drops abruptly and becomes negative.” is not supported by a similarly thorough analysis. The data shown in Figure 6 is not sufficient to support the claim of very specific feedbacks at play. Similarly, in line 270 an increase in sub-shelf melting, a reduction of ice shelves and a margin retreat are mentioned, which isn’t visible in Figure 6 either (nor in any other of the presented figures).
I appreciate the attempts to disentangle the different mechanisms at work for the two different tipping points. I would suggest strengthening analysis in section 3.2 and backing it with a more thorough analysis of the data.

Detailed Comments

L25 and l36: consider citing Solgaard et al. (2012) among the other studies on the topic of Greenland tipping

L79: Calving seems to play some role in the crossing of the tipping points. Therefore, I would appreciate if the Von Mises stress criterion for calving would be motivated a little better and ideally discussed.

L85: please define “present day” with an exact time period

L112: Do I understand correctly that the humidity over the ocean is held constant at the boundary conditions and does not increase with increasing temperatures? Does the precipitation within the simulation box adapt to changing temperatures? How much additional effect would be expected from a humidity correction at the boundaries?

L138: express the equation also in terms of ΔT_{JJA}. I was confused by the numbers if line 155 and line 159 because it slipped my attention that ΔT_{ocn} refers to the annual temperature anomaly instead of the “normal” input.

L139: “… for purely floating ice shelves…” The sentence is a bit unclear, as all ice shelves are attached to the ice sheet, by definition. Do you mean in simulation cells with purely floating ice shelves? Does the ice model Yelmo have a mechanism for partially floating and partially grounded ice within a simulation cell?

L162: As mentioned above, the comparison to the LGM reconstructions might imply to the reader, that the starting point for the warming branch is indeed an LGM climate. Please clarify this paragraph.

L174: I suppose the mass balance is negative at the margins of the former ice sheet, not the equilibrium state reached at $\Delta T = +4\ \mathrm{K}$.

Figure 1: Why is the shaded ice not taken into account for the volume calculation?

L239: “These results clearly show the impact of atmospheric feedbacks related to elevation and albedo…” which is not so clear to me from the data. Please clarify or add additional information.

L266ff: This paragraph explains the changes in the surface mass balance, however, all claims in the paragraph are not supported by data which would be available to the reader. This contrasts with the thorough discussion on grounding line shape and ice dynamics on the previous section. Please, support the claims with data or with references.

L298f: I find this sentence surprisingly hard to read. I also kept wondering, why the volume decreases if the tipping point isn’t reached yet. Consider rewriting for clarity.

L301f: I’m not sure if the relationship between initial melting and the acceleration of ice flow is sufficiently explained. And I didn’t quite understand how the spike in calving is related to the previous.

L328ff: As far as I understand the sea level remains constant in these simulations. How would a decrease of sea level to a realistic number during LGM affect the MISI-driven bifurcation?

L358: Is there any interpretation for the existence of intermediate states? How does this compare to the intermediate states found in Robinson et al. 2012?

L360ff: I understand that further analysis might be beyond the scope of the study. I would still be curious to hear more about why the initial ice volume is only regained at temperatures of at $\Delta T = -5\ \mathrm{K}$.

Appendix A: How does the present-day state compare to the equilibrium states at $\Delta T = 0\ \mathrm{K}$ on the cooling and the warming branch? What does it mean for the stability of the present-day state, that it is in the unstable zone between two stable branches?

References

Solgaard, A. M., & Langen, P. L. (2012). Multistability of the Greenland ice sheet and the effects of an adaptive mass balance formulation. *Climate dynamics*, *39*(7), 1599-1612.

Robinson, A., Calov, R., & Ganopolski, A. (2012). Multistability and critical thresholds of the Greenland ice sheet. *Nature Climate Change*, *2*(6), 429-432.