This manuscript provides valuable insights into the response of the Greenland Ice Sheet (GrIS) to different warming thresholds using the coupled MAR-PISM model. The study effectively highlights the critical temperature thresholds (e.g., +1.4°C and +2.3°C) for GrIS stability and emphasizes the importance of both the magnitude and duration of warming. The results align with previous research and contribute important findings on GrIS behavior under future climate scenarios, with implications for sea level rise projections and policy decisions. The manuscript is well-structured and well-written. Pending minor revisions addressing the comments below, I support its publication.

Dear Reviewers,

We would like to thank you for your comments and suggestions. We have corrected all the mistakes and improved the conclusion section. See also our answer about how MAR contributes to projecting future GrIS SMB, especially compared to an Earth System Model.
Best,
Alison Delhasse, Christoph Kittel and Johanna Beckmann

(PS: you will find in red the suggested modification in our manuscript)

General comments

While the study uses the coupled MAR-PISM framework to assess the GrIS response to warming thresholds, it lacks sufficient discussion on the added value of incorporating the MAR model. Although SMB processes are briefly addressed in Section 3.1, I would like to see deeper insights into how MAR contributes to projecting future GrIS SMB-- especially given your finding that future SMB plays a more critical role than ice dynamics. Clarifying MAR's specific contribution would strengthen the manuscript and better support your conclusions.

Numerous studies have investigated the future evolution of the surface mass balance (SMB) over Greenland using the MAR regional climate model (RCM), including Fettweis et al. (2013), Hofer et al. (2019), and more recently Glaude et al. (2021), as well as results from the ISMIP6 intercomparison project (Goelzer et al., 2020). Hofer et al. (2019) explored SMB evolution under various forcing scenarios. Delhasse et al. (2024) further demonstrated how coupling MAR with an ice sheet model affects future SMB evolution, in particular through negative feedbacks at the margins resulting from interactions between katabatic winds and changes in ice sheet geometry.

More relevant to your question, several key issues arise:

How does MAR simulate a different SMB compared to other models, including ESMs? To our knowledge, this comparison has not yet been systematically performed for Greenland under future scenarios. However, Fettweis et al. (2020) extensively discuss the advantages of using MAR or other RCMs over simpler models or Earth System Models (ESMs). Kittel et al. (2021) demonstrated the added value of MAR's higher spatial resolution compared to CESM2, particularly for simulating precipitation in regions with complex topography—such as the Antarctic Peninsula or marginal valleys and ridges—highlighted in their Figure 11c–d. A similar improvement could be expected over Greenland's margins.

How does MAR compare to other RCMs in projecting future SMB? Glaude et al. (2021) addressed this by showing that MAR projects nearly twice the annual surface mass loss of RACMO by 2100 (−1735 Gt/yr vs. −964 Gt/yr), using the same CESM2 forcing as in our study. This discrepancy arises primarily from differences in runoff projections, which in MAR trigger a stronger melt–albedo feedback and a larger expansion of the modeled ablation zone.

What is the impact of this higher sensitivity on sea level projections? Goelzer et al. (2020) did not provide explicit RCM-related uncertainty estimates in their SMB-dominated projections of the GrIS, but noted that such uncertainties would likely propagate directly into the sea-level rise estimates. Following Glaude et al. (2025), MAR's greater sensitivity to warming tends to amplify SMB losses, potentially leading to higher projected melt contributions from the GrIS. It is therefore likely that our simulations represent a high estimate of SMB-driven contributions to ice loss, relative to other drivers such as ice dynamics and ocean interactions.

In the context of the H2020 PROTECT project, several ice sheet models have been forced with different RCMs under the same atmospheric boundary conditions. These coordinated efforts (Goelzer et al., pers. comm. 2025) will help quantify the model dependence and uncertainties associated with using MAR versus other RCMs. As this represents an extensive topic beyond the scope of our study, we propose to briefly address it in the discussion to contextualize and nuance our results better. This new paragraph also merges information that we moved from the Conclusion.

Although our results are likely influenced by using MAR and PISM, our results agree with other studies finding stable GrIS up to +1.5-+2°C (e.g. Bochow et al., 2023, Honing et al., 2023). The coupling between these two models enables a better representation of the interactions between the atmosphere and the ice sheet dynamics through the representation of the firn evolution and positive feedbacks such as melt-elevation and melt-albedo feedbacks. However, our simulations may be near the upper end of estimates of contributions for atmospheric–ice sheet feedbacks, relative to oceanic and dynamic ice losses. Glaude et al. (2024) showed that MAR projects nearly twice the annual surface mass loss of another RCM (RACMO) by 2100 (−1735 Gt/yr vs. −964 Gt/yr), using the same CESM2 atmospheric forcing. This difference stems from stronger melt–albedo feedbacks and a more pronounced expansion of the ablation zone in MAR. Since uncertainties in SMB forcing are expected to propagate almost directly into sea-level rise projections (Goelzer et al., 2020). While RCMs like MAR offer improved SMB representation over coarser models (Fettweis et al., 2020), future work should aim to quantify the influence of model choice on projections.

In the Conclusion section, comparisons with other studies would be more appropriately placed in the Discussion. The Conclusion should focus more clearly on summarizing your key findings and highlighting the main insights regarding future GrIS responses to different warming scenarios.

Thanks for the suggestion. We remove the comparisons with other studies.

Specific comments

L28-29: There seems to be a syntax issue with the phrase “in more a recent study.” It should likely be “in a more recent study.” Please revise for clarity.
Indeed it should be “in a more recent study”, corrected accordingly.

L35: Replace “Greenland Ice Sheet (GrIS)” with simply “GrIS,” as the full name has already been introduced earlier
Corrected also for your comments below. Thanks for these corrections.

L56: The term “enhanced SMB estimations” is ambiguous in this context. If you are referring to the MAR model’s improved representation of SMB processes, please state this more precisely. As written, “enhanced” could be misinterpreted as implying increased SMB.
You’re right. Following the other reviewer's suggestion, we modified as:
but results in a more realistic reproduction of surface mass balance (SMB) estimations

L68: Glacial Isostatic Adjustment ---> glacial isostatic adjustment
Changed.

L75: Greenland Ice Sheet (GrIS) ---> GrIS
Done.

L76: The phrase “we randomly sampled the ten years until 2200” is unclear. Please specify the time period from which these ten years were randomly selected.
We completed the first sentence of the paragraph:
The experiments rely on stabilized warming at nine atmospheric temperature thresholds, ranging from +0.2 °C to +5.8 °C relative to pre-industrial levels (1850–1950), each defined based on a 10-year running mean of global temperature.
and now refer to the definition of the 10-year periods.
To extend the projections until 2200, we randomly sampled individual years from the 10-year period used to define each warming threshold, thereby maintaining a constant mean warming while preserving year-to-year climate variability.

L84-85: The sentence "We did not correct the contributions to sea level rise (SLR) by this control run…" is somewhat confusing. As I understand it, you chose not to subtract the model drift (+5.75 cm by 2200 in the +0.2°C run) from the SLR estimates in other scenarios. If this interpretation is correct, I recommend rephrasing for clarity.

Page 5, Figure 2: I recommend repositioning the panel labels (A–F) from the y-axis labels to within each panel—preferably in a consistent location such as the upper right corner—for improved clarity.
Done.

L119: Greenland Ice Sheet (GrIS) ---> GrIS
Done.

L129: What do you mean null? zero or nan?
Yes zero, we propose to improve the sentence:
[...]but eventually declines to zero before 2200.

L131: Can you be more specific about this threshold temperature?
We propose to improve the paragraph:

Previous studies have identified either a timing—between 2046 and 2058 (Hofer et al., 2020, Noel et al., 2021)—or a threshold temperature (around +2.7 °C, Noel et al., 2021) at which the SMB becomes negative, marking the onset of irreversible ice sheet decline. Beyond these thresholds, mass loss intensifies, driven by surface ablation exceeding snowfall accumulation, further exacerbated by dynamic losses through ice discharge. However, these studies do not account for ice sheet dynamics or surface feedbacks such as the melt–elevation feedback. Our findings (also supported by Robinson et al., 2012; Petrini et al., 2025) indicate that, when considering both factors, the temperature threshold is likely to occur at lower levels of warming than previously suggested—implying that the onset of sustained mass loss could also occur earlier in time.

L140: change "darker bare ice albedo" to "darker bare ice"
Corrected as you suggested, thanks.

L152: It would be helpful to quantify this change—how much is the albedo reduced, and over what area or time period

We assume you're referring to: " A sharp decline in albedo is projected around 2050-2075, marking the transition between the +3.4°C and +4.4°C experiments." As numbers for the decline are already mentioned in the previous sentence (albedo step of 0.01 for experiments +0.6 to +2.3°C, and 0.02 for the next ones) to illustrate the changes in slope of this decline, we propose to improve the sentence as following:

As runoff continues to increase, more bare ice areas with water at the surface are exposed, leading to a darkening of the global surface. For the experiments with +0.6 to +2.3°C, the albedo decreases by only 0.01 per 1°C of regional warming, whereas for the +3.4°C experiment (a 1°C increase in regional Greenland warming compared to the +2.3°C scenario), the albedo decreases by more than 0.02. This larger decline in albedo is projected to occur between 2050 and 2075 if warming is not stopped before 2100 (experiment +5.8°C), amplifying the contrasts in albedo between the +3.4°C, +4.4°C, and +5.2°C experiments.

L154: Is the model assuming that if the ice sheet surface becomes flat, meltwater is stored locally without draining away? Is this behavior explicitly represented in MAR?
The horizontal flow of water is not explicitly represented in MAR yet. The sentence is confusing, we will modify it by:
The +4.4°C experiment also exhibits a significant inter-annual variability, likely driven by large fluctuations in the melt extent. As warming increases, the 0 °C isotherm rises to higher elevations where the ice sheet surface becomes flatter, resulting in larger inter-annual fluctuations in melt area.

L177-178: surface mass balance ---> SMB
Changed.

L178: "the mass balance twenty years later"? Do you mean that the mass balance becomes positive after 2180? Can you clarify this?
Yes, we clarified it by explicitly mentioning *2180* in place of *twenty years later*.

L182: Figure 2 and 3 ---> Figures 2 and 3
Thanks.

L211: "This limits the absorption of additional liquid water should the climate warm up again". Correct this sentence.
We changed the sentence while answering a comment to the other reviewer.

L241: Reverse ---> reverse
Done, thanks for this one and all the other similar mistakes.

L275: forcing ---> forcings
Thanks.

L284: The phrase “under certain conditions” is too vague—could you specify what conditions are required for the GrIS to stabilize after exceeding the temperature threshold? Providing more detail would strengthen the conclusion.
We suggest modifying the sentence to ensure consistency with our idealized reverse scenario, while maintaining a more generalized formulation appropriate for broader interpretation and applicability. Thanks for the suggestion.

However, we demonstrate that it is possible to exceed this temperature threshold and, by subsequently cooling the climate at a rate comparable to the preceding warming from 2100 onward, stabilize the GrIS in a new state of equilibrium.