Thank you for your thoughtful and constructive review on our manuscript, *Evaluation of climatic predictors of surface ponding on Antarctic ice shelves*. Your comments are in gray text below, with our responses in black. Line numbers refer to the submitted version of the manuscript.

The manuscript evaluates the effectiveness of three metrics, i.e., temperature, MOA, and a newly proposed GLPI: Grounding Line Proximity Index, in predicting the distribution of surface meltwater ponding across Antarctic ice shelves. Given the implications posed by surface ponds, identifying accurate predictive ponding thresholds can be vital for forecasting future ice-sheet stability. The authors utilize several satellite-derived meltwater products and RACMO outputs at multiple resolutions to evaluate these thresholds. Their findings demonstrate that the widely used theoretical threshold of MOA ≥ 0.7 largely underpredicts present-day ponding. An empirical threshold combining MOA and GLPI provides a much more accurate prediction. When applied to future projections under the SSP1-2.6 emissions pathway, this empirical threshold predicts 2.3 times more lake coverage by 2100 than the theoretical threshold.

The study concludes that MOA-based thresholds are most effective when applied at coarse spatial scales, calibrated against depth-based meltwater observations, and augmented to account for grounding-line proximal processes like downslope winds. By quantifying the uncertainty introduced by threshold choice, this work underscores the necessity of using observation-constrained empirical models for reliable future projections of Antarctic surface hydrology.

The manuscript is generally well structured with clear text and formulation and adds significant value to the future understanding of the Antarctic surface hydrology. I recommend the manuscript for publication once the following (major) comments have been addressed.

GENERAL COMMENTS

1. Figures formatting and clarity: The current figures would benefit from enhanced visual clarity and appeal. I suggest re-aligning and enlarging the panels in most figures to ensure that the features discussed in the text are easily identifiable. To avoid potential confusion between the main text and appendices (e.g., Fig. A1 or B1), I recommend renaming the figure panels using lowercase letters (e.g., Fig. 1a, 1b, 1c as against Fig. 1A, 1B, 1C). Additionally, the text size of labels in Figs. 1, 2, 4, 5, 6, A1, A2, and A4 should be increased for better legibility. Finally, please include a colorbar for the F1 score values in Fig. 7 and Fig. A3 to assist in the interpretation of the results.

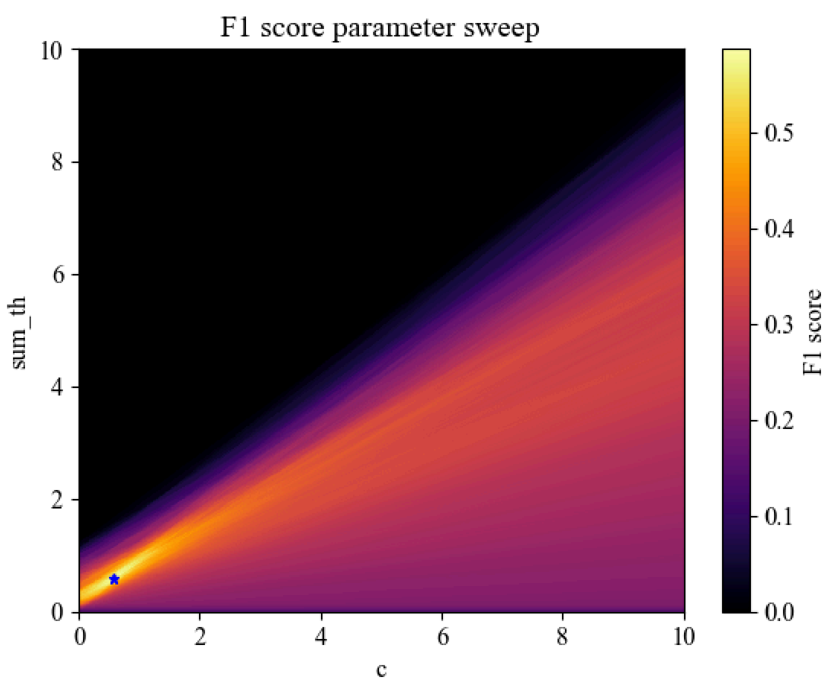
We will make the following changes to our figures to enhance clarity:

- Change the colorbar shapes in Figures 1, 4, 9, and A4 to indicate that values extend beyond what is shown
- Make the maps of Dronning Maud Land larger and realign the panels in Figures 1, 4, 6, and 9
- Change all of the subfigure labels (and references in the text) to be lowercase
- Add arrows to Figure 9c to indicate the location of the negative projected MOA values
- Increase the text size in Figures 1, 2, 4, 5, 6, 7, A1, A2, and A4
- Add an F1 score colorbar to Figures 7 and A3

2. Could the authors provide more detail on how the MOA+GLPI thresholds, and their respective weights were evaluated to identify the optimal values discussed in the text? Wouldn't it also be beneficial to include a plot of "F1 score vs. Weighted Sum MOA+GLPI" similar to the performance curves provided for temperature and MOA in Fig. 5?

To make this method more clear, we will add a sentence to line 145 (and shorten the sentence on line 144) so that the paragraph reads, "We systematically varied both *c*, the weight coefficient on GLPI, and sum_{th}, the weighted sum itself. A grid search was performed over all combinations of *c* and sum_{th}, with values ranging from 0 to 10 in increments of 0.01 for both variables."

We considered including plots of the F1 score for different sum and weight thresholds, but determined that they would complicate rather than clarify the results. The plots would have to be three-dimensional, since we are considering three variables (*c*, sum_{th}, and F1), and wouldn't be physically meaningful. Below is an example of what we considered, for the VW-27k comparison scenario:



We decided that the impact of GLPI is better represented by juxtaposing the performance of MOA with and without the index, i.e., in Fig. 6 (panels (ii) and (iii)).

3. The current discussion regarding downslope winds (Section 4.3) is primarily focused on foehn flows within the Antarctic Peninsula. It would be beneficial to expand this section to include the influence of both katabatic and foehn winds in other key regions, such as Dronning Maud Land, the Amery Ice Shelf, and the McMurdo Dry Valleys. See Saunderson et al., 2022; Mahagaonkar et al., 2025; Hofsteenge et al., 2022; etc to add relevant context.

Thank you for bringing up this point and for including the helpful references. We will amend section 4.3 to also discuss the influence of downslope winds in other regions. The sentence starting on line 413 will be changed to: “Foehn winds are especially prominent on the Antarctic Peninsula and in regions of East Antarctica.” At the end of line 416, we will add a summary of the findings in East Antarctica: “In Dronning Maud Land, both katabatic and foehn winds have been shown to increase the presence of lakes near grounding zones through snow erosion, scouring, and surface warming (Mahagoankar et al., 2025). Similar influence of downslope winds on melt has been observed elsewhere in East Antarctica, including the Shackleton Ice Shelf (Saunderson et al., 2022) and the McMurdo Dry Valleys (Hofsteenge et al., 2022).” To tie this back to our results, on line 419, we will say, “We also see that in Dronning Maud Land, the incorporation of GLPI removes some false negatives at the grounding line and some false positives further from the grounding line (Fig. 6 (A) (ii, iii)).”

Furthermore, we will add the following passage to the end of section 4.4 (“Limitations of a MOA threshold”), starting on line 460, in order to discuss how downslope winds could contribute to the need for region-specific climate thresholds: “Due to the multitude of processes contributing to surface pond formation, region-specific climate thresholds are likely necessary for accurate ponding predictions. The role of downslope winds in driving surface melt varies across regions, depending on local topography and prevailing atmospheric conditions. East Antarctica experiences a high proportion of wind-driven surface melt (Laffin et al., 2023), so likely corresponds with a higher dependence on GLPI or a similar index than West Antarctica.”

4. While the use of GLPI is a valuable addition, it remains a proximity proxy rather than a physical parameter. Used to generalize physical processes and dynamics at the grounding zone using a simple 81km radius, this metric ignores the inherently directional nature of downslope winds, as melting typically occurs on the downwind side of mountain barriers. As a consequence, the index may over-predict meltwater on the upwind side of topographic features. I suggest the authors acknowledge this limitation and discuss how a directional component might refine the index's physical accuracy.

Downslope winds are inherently directional, and it is correct that GLPI is a first-order proximity proxy. Our analysis is restricted to ice shelves, which we assume are generally located downwind of mountain barriers and other topographic features. That said, GLPI does not account for along-shelf variability in wind direction or topographic irregularities. As a result, it may not capture localized differences in wind-induced melt, and could overestimate melt likelihood in regions that are not aligned with dominant wind directions, as you said. We will acknowledge this limitation in the manuscript in section 4.3, line 420 as follows: “GLPI does not account for the direction of these winds, and may overestimate melt on the upwind side of local topographic barriers. Future work could incorporate a directional component that would refine the index’s physical accuracy.”

5. The application of present-day calibrated thresholds to projections out to 2100 assumes a stationary relationship between MOA and surface ponding. However, the study mentions that ice lens formation is expected to increase as the climate warms, which lowers firn permeability and can facilitate ponding at lower melt rates than a simple MOA threshold would predict. If these preconditioning processes become more prevalent, ponds could form at a significantly lower MOA (e.g., 0.1) by 2100 compared to the current empirical threshold of ~0.25. I suggest the authors clarify if their projections might therefore be conservative and recommend adding a discussion on the risks of applying static thresholds to an evolving firn environment.

We will add a the following text to the revised manuscript, to emphasize the important point that the relationship between MOA and ponding may not be static, and thus our projections may be conservative:

- In results section 3.4 (Future projections), at line 321: “However, even these projected increases in lake coverage may be conservative. We cannot necessarily expect the relationship between MOA and ponding to remain static over time, as processes that precondition the firn for ponding, such as ice lens formation, are expected to increase as the climate warms (Veldhuijsen et al., 2024) (see Discussion Sect. 4.4 for more details).”
- In discussion section 4.4 (Limitations of a MOA threshold), at line 457: “This implies that the MOA threshold for ponding may decrease over time with complex spatial heterogeneity.”
- At the end of discussion section 4.4, after line 459 (and after the text we are adding in response to your point #3): “East Antarctic ice shelves contain more widespread ice lenses within the firn than other regions (Tuckett et al., 2025), and both East Antarctic and Antarctic Peninsula shelves are predicted to experience increased ice lens formation between now and 2100 (Veldhuijsen et al., 2024). This suggests lower future MOA thresholds in these regions. As ice lens formation intensifies under future warming, these regional differences in ponding susceptibility may become increasingly pronounced.”

SPECIFIC COMMENTS

L61/65: In Eq.2, where does the variable Tf appear? Please check and correct.

Thank you for catching this. T_f is meant to indicate the firn temperature, but the equation uses ΔT, to indicate temperature increase needed for firn to reach the melting point. We will change "T_f = -15 ℃" to "ΔT = 15 ℃" on line 64.

L86 and elsewhere: Is it necessary to describe what the figure shows in text? To make text more readable, I suggest just citing figures where they can be cited.

We will replace the descriptions to simple figure references at the following lines to make the text more readable:

- Line 86: "Average air temperature and annual average MOA were calculated over the full RACMO time span, from 1979 to 2022 or 2023, depending on the model iteration (see Table 1, Fig. 1 panels (i) and (ii), Fig. 2 (a-c), Appendix Fig. A1).")
- Lines 110 and 112: "For the three Tuckett data products and the Dell-27k product, we used normalized lake presence thresholds, based on the number of times each ice-shelf pixel within a grid cell was identified as a lake (Fig. 2 (d-f), see Appendix B2 for details). For VW-27k, we used a threshold of 20 mm of aggregate meltwater depth, following the process of van Wessem et al. (2023) (Fig. 1 panels (iii))."
- Line 116: "With our chosen thresholds, 4.6% of ice-shelf grid cells in Tuckett-27k, 8.5% in VW-27k, and 9.6% in Dell-27k are classified as lake locations (Figure 4)."
- Line 322: "The uncertainty arising from threshold choice is comparable in magnitude to uncertainty due to emissions pathways (Fig. 8)."

L133: How and why was 81 km radius used as a threshold? I notice some information in this regard in the discussion (L271-275) but might be relevant to add it here, in Methods.

We will amend the sentence on line 134 to say, "More explanation of the GLPI variable, including the choice of an 81 km radius, is provided in Results Sect. 3.3." The radius reflects physical processes that we think would overcomplicate the Methods section if we were to include them there, so we choose to instead point readers to the Results. In the results section 3.3, we explain that the 81 km radius balances the local influence of albedo with the broader reach of downslope winds (which have been shown to enhance surface melt as far as 100 km from the grounding line). The radius captures the dominant length scales of both processes while also aligning neatly with the width of three 27 km RACMO grid cells.

L246: Recommend adding the F1 value after 'nearly double that of the optimal temperature threshold'.

We will add the F1 score from the optimal temperature threshold (0.261), in parentheses at the end of line 246.

L247,248: Cite Fig. 6d (ii) and Fig. 6a (ii) in the text here instead.

"… Western Ross Ice Shelf (Fig. 6d (ii)) and many in Dronning Maud Land (Fig. 6a (ii))…"

We will amend lines 247-249 as follows: "However, even this optimized threshold misses nearly all the lakes near the grounding line in the western Ross Ice Shelf (Fig. 6 (d) (ii)) and many in Dronning Maud Land (Fig. 6 (a) (ii)), while overpredicting lakes on the Amery Ice Shelf (Fig. 6 (c) (ii)) and the Antarctic Peninsula (Fig. 6 (b) (ii)), particularly at sites far from grounding lines."

L265: Delete 'to'. "… and to have steeper surface slopes, …"

Please see our response to your following comment, in which we break up this sentence to enhance clarity.

L264-268: Might be a good idea to break down this stretch into smaller sentences for the ease of the reader.

We will restructure the paragraph as follows: "Here, we adopt a crude proxy to approximate these effects at each resolution: using proximity to the grounding line as an indicator of processes that enhance melt. Ice near the grounding line is more likely to contain exposed rocky outcrops or blue ice, both of which lower the local albedo (Kingslake et al., 2017). Furthermore, steeper surface slopes near the grounding zone increase the warming effects of atmospheric dynamics such as foehn winds (Datta et al., 2018, 2019; Laffin et al., 2022). These effects are not incorporated into RACMO, so may explain why a uniform MOA threshold misses lakes in regions close to the grounding line (i.e., in Dronning Maud Land and western Ross Ice Shelf, see Fig. 6 (a, d) (ii)). Similarly, this threshold overpredicts lakes in regions with higher MOA far from the grounding line (e.g., on Larsen C and Amery ice shelves, see Fig. 6 (b-c (ii))."

L279: Delete 'upon'. "Incorporating GLPI improves upon the predictive performance of MOA alone in all five comparison scenarios"

Will do.

L281, 292 and elsewhere(?): Should *MOA + x (GLPI) y* be *MOA + x (GLPI) ≥ y* ? Please check and correct.

Yes - thank you for catching this formatting error. We will fix on lines 281 and 292.

L340: Since you are using directional inference ‘southwest’ in the text, would it be a good idea to have the North arrow on the image? Particularly because in Amery’s case here, North is not to the top, but to the right.

To clarify the location of the southwest region, we will add an arrow pointing to it in Figs. 6(c)(i-iii). We will also add a sentence to the end of the Figure 9 caption at line 355 that reads: “Location of the negative projected MOA values, in the southwest corner of Amery Ice Shelf, is indicated with orange arrows in panels (c) (i-iii).”

L384,385: Add relevant MOA threshold values in these sentences, easing the text for the reader.

We will amend the sentence to read, “Secondly, the optimal MOA threshold over the Antarctic Peninsula in Tuckett-11k (1.17) is similar to that of the rest of the continent (1.11). For the other two resolutions, the threshold is much higher on the Peninsula (0.91 vs. 0.32 for Tuckett-27k, and 1.01 vs. 0.59 for Tuckett-2k).”

L405: add reference after ‘… are a primary driver of surface melt near grounding lines’.

We will add references to Laffin et al. (2023) (“Wind-Associated Melt Trends and Contrasts Between the Greenland and Antarctic Ice Sheets”) and Mahagaonkar et al. (2025).

REFERENCES

1. Saunderson, D., Mackintosh, A., McCormack, F., Jones, R. S., & Picard, G. (2022). Surface melt on the Shackleton Ice Shelf, East Antarctica (2003–2021). The Cryosphere, 16(10), 4553-4569.

2. Mahagaonkar, A., Moholdt, G., Glaude, Q., & Schuler, T. V. (2025). Katabatic and foehn winds control the distribution of supraglacial lakes in Dronning Maud Land, Antarctica. Earth and Planetary Science Letters, 666, 119482.

3. Hofsteenge, M. G., Cullen, N. J., Reijmer, C. H., van den Broeke, M., Katurji, M., & Orwin, J. F. (2022). The surface energy balance during foehn events at Joyce Glacier, McMurdo Dry Valleys, Antarctica. The Cryosphere, 16(12), 5041-5059.

Thank you again for your comments. Please don’t hesitate to reach out with additional questions or concerns.

Best,
Emily Glazer and Kirsty Tinto