

Manuscript title: A computationally efficient statistically downscaled 100 m resolution Greenland product from the regional climate model MAR

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General comments

This study uses a statistical downscaling technique to enhance the horizontal resolution of the Modèle Atmosphérique Régional (MAR) regional climate model and produce an improved surface mass balance (SMB) product. The authors use an impressive breadth of datasets and tools both for statistically downscaling and for evaluating the final product. The product itself is clearly an improvement, is of notably high spatial resolution, and likely has many valuable applications. The high resolution over such a large area is computationally remarkable. The manuscript is well-organized and the flow of ideas is very logical.

My main concern is the final step of the methodology, which leaves the reader wondering how well the statistical downscaling works without applying physical constraints. I have also described two minor comments and several line-by-line comments that are mostly concerned with improving the writing itself. Some clarity of the research is lost due to longer/confusing sentences, so I have suggested some improvements below.

Major comments

Description of final step of methodology: There is an insufficient description of the “physical constraints” applied in the final step of the downscaling in section 3.1 This needs further elaboration, especially since it differs from Noël et al. (2016) and is later referred to in section 4.1. The authors should (1) provide a reason as to why the mass conservation issues did not arise in Noël et al. (2016), (2) describe exactly what these physical constraints are, and (3) report on how they affect the final product. Without any additional information, the application of the physical constraints could be interpreted as forcing the final product to fit within the expectations. As this is likely not the case, a description of these steps will give the reader more confidence in the methodology.

Minor comments

Scale break: I am unsure of the meaning of “scale break” (first used in section 4.1). Is that a term used in variogram analysis? If so, please describe it in the methods, as I (and I imagine many people) are not very familiar with variograms. I see the term “sill” has been used in section 3.2—is that what the scale break is? If so, please only use one term, define it, and then explain what different values may mean. For example, in Figure 5, what is the significance of the different scale break values?

SMB units: Throughout the manuscript, SMB is reported in units of millimeters (mm). However, SMB is generally reported as a unit of mass change over time such as mm w.e. yr⁻¹, m w.e. yr⁻¹, or Gt yr⁻¹ (Lenaerts et al., 2019). In the manuscript, SMB units of mm should instead be reported as mm w.e. yr⁻¹.

Line-by-line comments

Comments are numbered as “[page number].[line number]”. For example, “1.12” refers to line 12 on page 1.

Abstract

1.12: Change “over next decades” to “over the next decades”

1.12: Change “evolution surface mass loss” to either “evolution of surface mass loss” or “evolving surface mass loss”

1.19: Please also mention the other variables that are assessed and mentioned later in the manuscript (air temperature and surface temperature)

1.21: Specify which variable is being discussed here (SMB?)

Introduction

2.1–2.2: The use of “extension and persistency” is confusing here. I understand what the authors mean by “persistency” but not by “extension.” If this refers to the surface melt increasing in strength and duration, consider rewriting this sentence as: “The persistency and intensity of surface melting has also been increasing since 1979, as measured by passive microwave satellite observations [citations].”

2.4: Change “evolution surface mass loss” to either “evolution of surface mass loss” or “evolving surface mass loss”

2.5–2.6: Specify what is meant by “actual mass loss.” As compared to what? The authors could specify that remote sensing observations can provide information about surface height changes but are unable to attribute height change to a mass change without more information about snow/firn compaction (e.g., Smith et al., 2023).

2.11–2.16: These statements could benefit from references to specific examples where a finer spatial resolution would have improved results. Several broad examples are mentioned, but citing papers that specifically mention the limitations of the spatial resolution could be helpful.

Datasets

3.6–3.7: Change “Greenland ice sheet” to “GrIS”

3.27: Specify what type of dataset is being referred to in “we used the dataset collected by Machguth”. In other words “...the PROMICE dataset...” or “...the SMB dataset...” Though this section (2.3) contains “PROMICE” in its title, nowhere in the text of this section does it say “PROMICE”.

4.8: What is meant by “SMB variable”? I thought there were only two model outputs (original and downscaled), but this reads as if there are three.

4.13: Change “Greenland ice sheet” to “GrIS”

Methods

5.3–5.5: Consider rewording these first two sentences for clarity; the phrases in parentheses feel disjointed. Something like: “We adopted the approach used by Noël et al. (2016), in which a statistical downscaling method was applied to RACMO to achieve a 1-km horizontal resolution. Here we use a similar methodology applied to MAR, but instead downscale the product to 100 m horizontal resolution.”

5.8: Change “Greenland ice sheet” to “GrIS”

5.15–5.17: The specific description of the pixel and line colors is unnecessary in the text. I suggest either removing these sentences (“The local linear...” and “The dashed red...”) or moving them to the figure caption if not already mentioned in the caption.

5.28–5.31: Consider editing this sentence for concision and removing/rewording “embarrassingly parallel problem”.

6.2: Consider changing “I/O” to “input/output” to avoid computer science jargon/abbreviations that may be unfamiliar to some.

6.13–6.16: Modify or move this to the Figure 2 caption (see early comment on lines 5.15–5.17).

6.20: Change “constrains” to “constraints”

6.20–6.21: Please expand on this statement. Why was this not necessary in Noël et al. (2016)? What exactly are the physical constraints and how are they applied?

6.23: Is the citation referring to this manuscript? If so, I believe it is unnecessary to add.

6.25: Change “slop” to “slope”

7.1–7.2: Please reword the sentence beginning with “The knowledge of...” I am confused by its meaning.

7.22: Change “th” to “the”

Results and discussion

8.21: Change “remains unvaried, being equal to 2.6 °C” to “remains unvaried at 2.6 °C”

8.24–8.25: Please reword or expand on this sentence in order to clarify the meaning. Specifying the actual physical constraints applied (either here or in the methods as earlier mentioned) could help with clarity and thoroughness.

8.30: I believe this is the first use of “semi-variogram” in the manuscript. How does this differ from just “variogram”? The prefix “semi” is also used in Figure 5 and 6 but not mentioned in the methods section describing variograms. Please either define it or only use “variogram”.

8.32–9.1: Please refer to Figure 5 at the end of this sentence, especially since Figure 3 was just mentioned. Additionally, are the numbers reported here meant to match those shown in Figure 5 (13,373, 11,384, and 24,171 km)? If so, the rounded values should be reported as “13.4 km”, “11.4 km”, and “24.2 km”, respectively.

9.12: Is “break scale” correct or should it be “scale break”?

10.1: Remove “from a quantitatively point of view”

11.4: Should “negative” instead be “positive”? Or should the equation be flipped? As it is written, if $RMSE_{100m}$ is smaller than $RMSE_{6km}$ (and thus the downscaled product shows improvement), $\Delta RMSE$ would be positive, not negative. Based on Figure 8 and its caption, I believe the equation should be flipped so its $RMSE_{100m} - RMSE_{6km}$

Conclusions

12.5–12.11: Please reword these sentences since they are very long. Splitting each sentence into two would help.

12.17-19: Reword for clarity.

Figures

Figure 1: Consider changing the northing/easting values to latitude/longitude. This is not a necessity for publication, but would be more helpful for the reader if it is not too much trouble, especially since Table 1, Table 2, and Figure 8 all use lat/lon. Also, if the range of the color bar is adjusted to 0–3200 m, it will show more contrast on the map. As it is now, it all looks like one shade of grey. Summit is at an elevation of ~3200 m, so extending the color bar to 4000+ m is unneeded.

Figure 2: Either change “Latitude” and “Longitude” to “Northing” and “Easting” or report values of lat/lon in panel (a). The caption needs further details and should mention all of the features in the figure itself. The small black dots in (a) and the the blue circles in (a) and (b) need to be described in the caption. The text from the body of the manuscript that describes the blue dots (see earlier comment) could be moved here.

Figure 3: Either change “Latitude” and “Longitude” to “Northing” and “Easting” or report values of lat/lon. The color bar needs to be larger so it’s easier to see and should be labeled as “surface temperature”. The caption should also specify “surface” temperature. Also, where (geographically) is this figure showing? Please either include an inset map of the ice sheet or refer to where it is in the caption. If it is one of the regions in Figure 1, please indicate so in the caption.

References used in this review

Lenaerts, J. T., Medley, B., van den Broeke, M. R., & Wouters, B. (2019). Observing and modeling ice sheet surface mass balance. *Reviews of Geophysics*, 57(2), 376-420. <https://doi.org/10.1029/2018RG000622>

Smith, B. E., Medley, B., Fettweis, X., Sutterley, T., Alexander, P., Porter, D., & Tedesco, M. (2023). Evaluating Greenland surface-mass-balance and firn-densification data using ICESat-2 altimetry. *The Cryosphere*, 17(2), 789-808. <https://doi.org/10.5194/tc-17-789-2023>