Reply Review # 1

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1 General comments

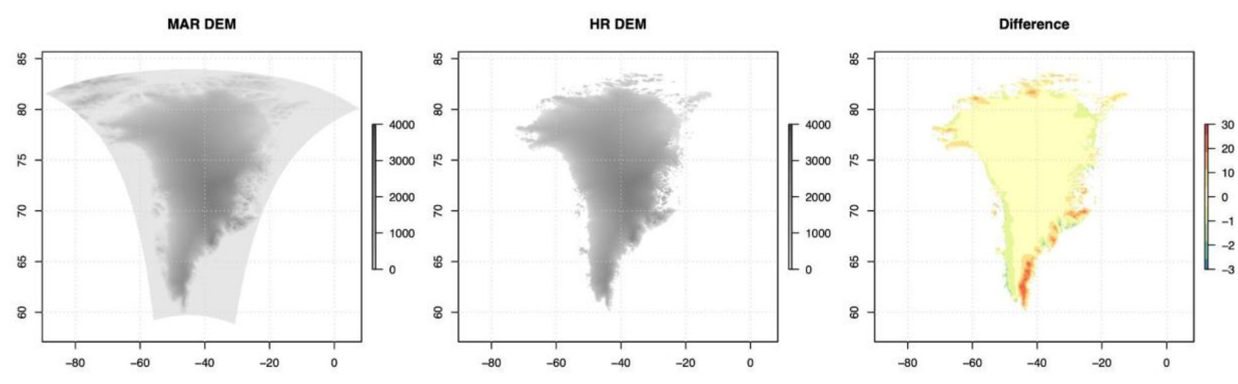
This manuscript presents a Greenland Surface Mass Balance (SMB) product which was downscaled from 6km to 100m reso-lution using output from the regional climate model MAR and demonstrates that the downscaled dataset exhibits an predom-inantly better agreement with observations than the respective original MAR output at its native resolution (which is already at a very high resolution). To my knowledge the data product is unique in its extremely high resolution and Greenland wide coverage. The presented analysis convincingly demonstrates the improved quality of the SMB data and this work could be a valuable source for the community with respect to small scale applications. The manuscript is clearly structured and most parts are easy to understand, even though some sentences could possibly be decluttered and shortened (examples in the specific comments).

Nevertheless, being interested in downscaling approaches in general rather than in small scale applications, I have some major concerns which mostly concern the general approach.

2 Major comments

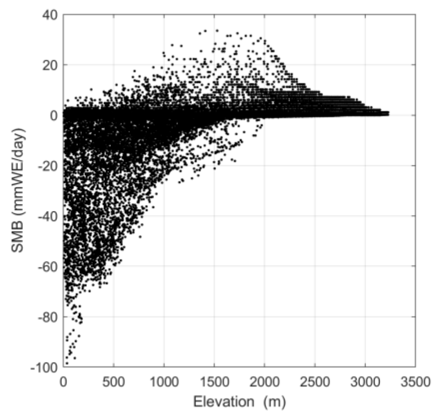
The downscaling approach will be most effective where the MAR topography and the 100m DEM strongly differ and where topographic gradients are large and are dominating the temperature distribution. Towards the coast and on high altitude plateaus the temperature and SMB distribution might be unrelated to elevation. Please provide a map of height difference between the 100m DEM and the native MAR orography, possibly in a supplement.

R: As requested by the reviewer, we are attaching below a figure of the difference between MAR DEM at 6 km and at 100 m. The largest differences, as expected, occur along the coast, where also runoff and temperature are strongly dependent on the elevation. This shows that potential impact of the 100 m spatial resolution vs. the 6 km.

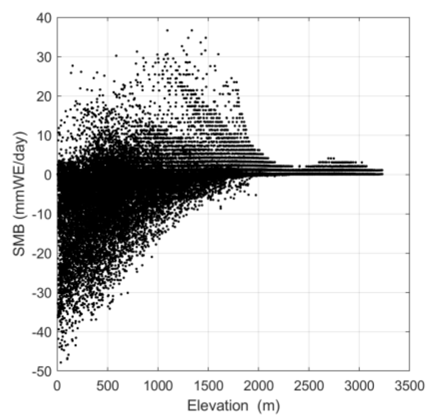


It is not clearly stated, and it should be, where the here applied downscaling approach differs from the one in Noel et al. (2016). An indeed major difference is, that here SMB is downscaled directly (p. 6, l.23), while in Noel et al. (2016) only the SMB components melt, runoff and sublimation are downscaled while precipitation is interpolated and SMB and refreezing are recalculated from the downscaled components. I am not convinced that downscaling SMB in total is a similarly good choice and would be interested to see the correlation of SMB to elevation (similar to Fig.3 in Noel et al. (2016)).

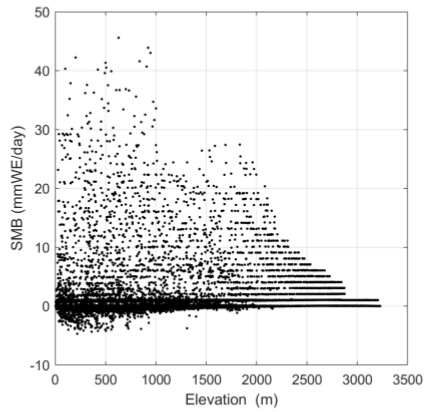
R: We report below examples of the correlation between SMB and elevation for the whole ice sheet for three different dates, as reported in the figure. As we can observe, there is a mild correlation between SMB values and elevation for relatively low elevation values. However, this is also accompanied by a spread (e.g., large bias) and a saturation after a certain elevation. This is the case for days 150 (May 29) and 250 (September 6). In the case of day 350 (December 15) we find no relationship between the two terms. The dependency for low elevation values might be due to the stronger dependency of the SMB values to runoff. In the case of accumulation, indeed, we do not anticipate any relationship. One aspect that the reviewer points out concerns the direct downscaling of SMB instead of its components. When we did that we found that the performance of the algorithm that was directly downscaling SMB values was better than the one using the sum of the terms downscaled (only runoff and sublimation). Therefore, we decided to downscale directly the SMB values.



Day 150 - 1980



Day 250 - 1980



Day 350 - 1980

Furthermore it should be explained how grid points outside of the 6km ice mask are treated.
R: We are excluding pixels where the ice sheet covered area is less than 99 %. In practice, we only perform the downscaling over the ice sheet, excluding ocean, tundra, etc.

I also wonder how much information is actually gained from going to ever increasing resolution (e.g. when going from 6km to 1km to 100m). Is it possible to repeat the SMB downscaling for 1km and compare to stake measurements?

R: We thank the reviewer for this important point. We did perform the downscaling and compared the obtained SMB with measured values, as done in the case of the 100 m. We found that the metrics (e.g., R2, RMSE) for the products at 100 m and 1 km are very similar. Nevertheless, when we computed the spatial autocorrelation of the two products - as done in Figure 5 - we found out that the product at 100 m was able to better match the scale breaks of the measured quantities, pointing to a greater sensitivity to the processes leading to the SMB change.Based on these results, we think the 100 m is a suitable resolution as it doesn't deteriorate the performance at 1 km (similar to what done in Noel et al., 2016) and can better capture spatial variability.

Where the correlation of a variable to elevation is weak, an elevation based downscaling will likely smooth the signal rather than adding finer structure (since regression parameters are interpolated). In these regions I would expect that simple interpola-tion to 100m resolution would produce better results. Therefore it would be interesting to see the same statistics for 6km-SMBs being interpolated to the precise stake location.
R: We are not sure we have properly interpreted the reviewer's request. We suspect they are asking for a comparison between the downscaled results obtained with the method here used and a simple linear interpolation of adjacent pixels. We think this comparison wouldn't be helpful as the linear interpolation would not be able to consider the relationship between temperature change and pixel (or SMB, etc.). We apologize if this was not what the reviewer was referring to.

3 Specific comments

p. 1, l 21: „In the case of the downscaled MAR product“: unnecessary repetition. The formulation “in the case of” is heavily used in general and in some case it is redundant or makes the text a bit clumsy.

R: We will remove that portion of the sentence.

p. 1, ll. 23-24: slope and intercept are interchanged.

R: we corrected in the manuscript, thanks

p. 1, l. 28: specify that this study was analyzing North and Central Greenland
R: We added that, thanks

p.2, l.14: maybe provide references for datasets which provide resolution of 100s of meters.

R: We are not familiar with any specific product currently providing mass loss outputs at 100 m . This is the reason why we developed our product. Remote sensing products exist but they mostly look at surface melt extent, duration rather than mass loss.

p.2, ll. 15-16: this is a bit elusive. Can you specify how understanding englacial systems or ocean interaction would benefit from higher degree of detail at the surface (given that mass is conserved with respect to the source data)?
R: We thank the reviewer for this comment. A higher spatial resolution product would allow to better constraint where the water might go when such information is coupled with a digital elevation model. For example, a 6 km product might suggest that for a specific pixel the SMB value would be , let us say, X mmwe but a large portion of this might be geographically located along a specific side (e.g., west or east) with repercussions on where runoff is reaching the ocean.

p.3,l.12: is the TT variable 3-dimensional air temperature or near surface air temperature? Is it possible to specify the height above surface?
R: TT is the temperature at 2m above the surface.

p.4,l.1: typo, pint-> point
R: Corrected, thanks.

p.4,l.11: precise: values of near surface air temperature
R: We corrected that, thanks

p.4,l.24: . . . we use surface temperature fields from seven different. . .
R: Corrected

p.5,l.13-14: It should be stated that this (I guess) is referring to pixels at the margins of the ice masks
R: Thanks, we have added a note specifying this.

p.6,l.20: specify what the physical constraints are in terms of temperature and SMB.
R: We added a sentence explaining that the physical constraint concerns mass conservation for each pixel.

p.6,l.21: typo, constrains – constraints?
R: Corrected , thanks

p.6,l.25: typo, slop->slope
R: Corrected, thanks

section 3.2: I had a hard time reading this section. Maybe concentrate a bit more on what information this analysis provides and how to interpret it. Introduce scale brakes here.
R: Thanks. We have introduced scale breaks when we define the variogram terms. We hope this is sufficient. We have also re-written some of the sentences and we hope this section is now clear.

p.8,l.5: what do you use for the comparison with the original MAR output? Is it nearest neighbor or do you interpolate to the station location or do you interpolate to 100m grid and then choose the nearest neighbor?
R: We use the nearest neighborhood

p.8,l.18: this is unclear to me. What are the sole pixels?
R: We removed that sentence as it is not necessary. Thanks for pointing this out.

p.8,l.24: reword, maybe: the similarity in mean differences is not surprising. . .
R: we rephrased the sentence according to reviewer's suggestion.

p.9, ll.10-12: confusing sentence. Please rephrase.
R: That sentence was not supposed to be there. Apologies. We removed it.

p.9, ll.28-31: confusing, please rephrase. Maybe: Against our expection. . .
R: Thanks. We used "unexpectedly"

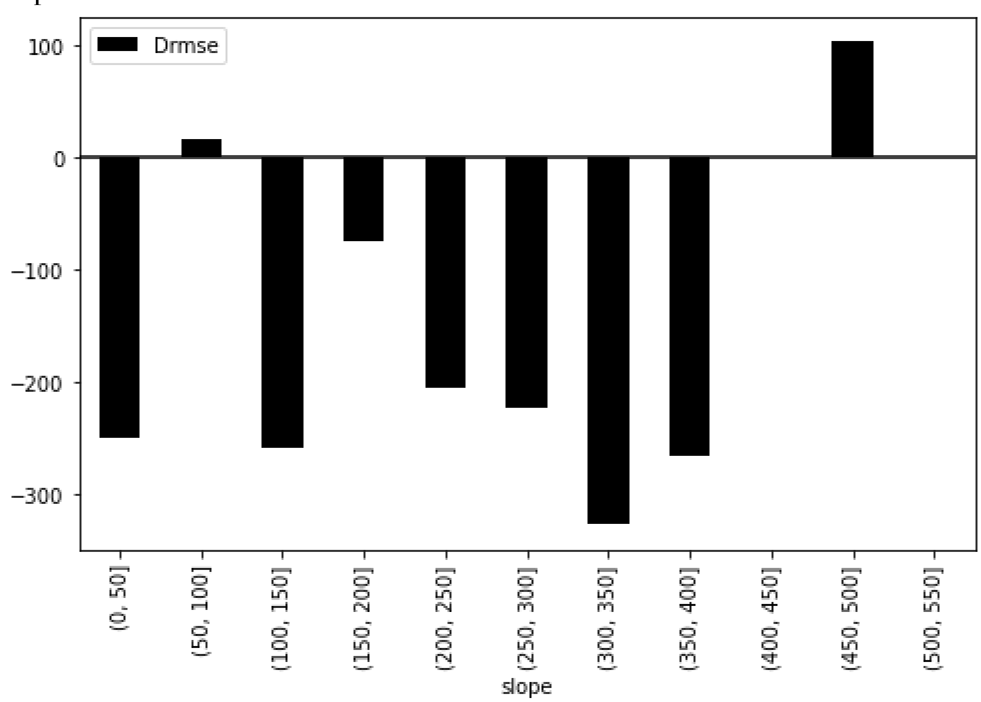
p.10, ll.31-33: It needs to be noted that Fettweis et al. (2020) also applied an elevation correction and interpolated to in stake location.
R: For clarifying, we added the following text:
Indeed, as explained in Fettweis et al. (2020), the SMB was extrapolated (interpolated + corrected) to the common 1km grid by applying an elevation gradient as done here. One of the key issues raised by the first SMB model intercomparison performed by Vernon et al. (2013) was the high dependency of modelled integrated SMB values to the ice sheet mask used. To mitigate

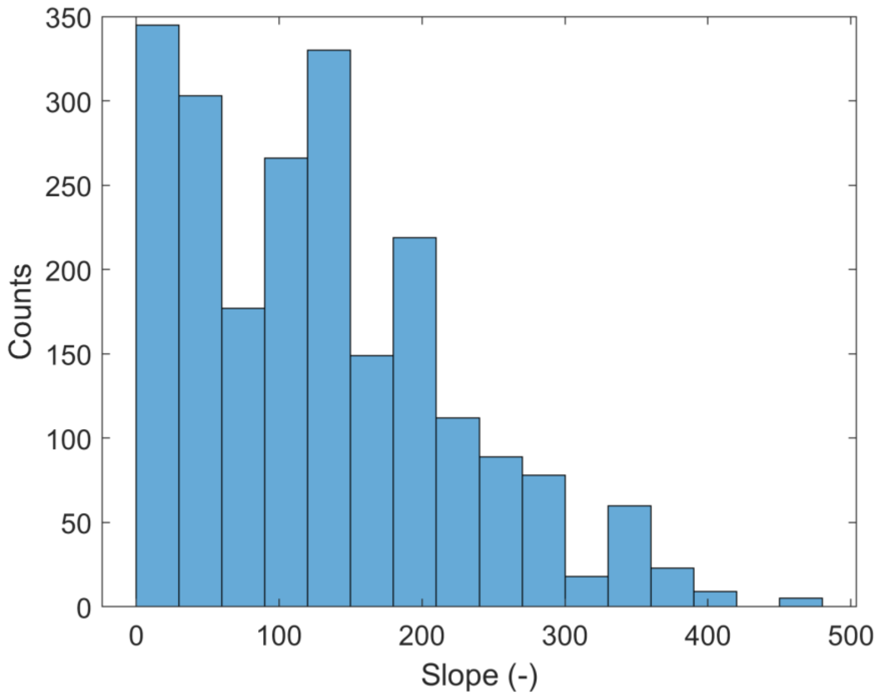
this problem, we interpolate all model outputs to the same 1 km grid used in the Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6). This resolution is chosen because the highest resolution model outputs (e.g. RACMO2.3p2) are available at 1 km and choosing a coarser resolution could compromise their quality. A common grid also allows a comparison on two common ice sheet masks: the contiguous Greenland Ice Sheet, which is common to all the models and the Greenland Ice Sheet plus peripheral ice caps and mountain glaciers, common to all the models except the two PDD models. Unless otherwise indicated, the SMB components have been interpolated to 1 km using a simple linear interpolation metric of the four nearest inverse-distance-weighted model grid cells. Moreover, as done in Le clec'h et al. (2019), the interpolated 1 km SMB and runoff fields have been corrected for elevation differences between the model native topography and the GIMP 250 m topography (upscaled to 1 km here), using time- and space-varying SMB–elevation gradients, similar to Franco et al. (2012) and Noël et al. (2016). No correction was applied to precipitation after interpolation to 1 km.

Figures: please check x and y labels for the maps (distance,longitude, latitude) Fig. 2: m and q are not consistent with Eq. 1 (interchanged)
R: Done, thanks

Fig. 3: check colorbar label
R: Done, thanks

Fig. 8: it would be interesting to also show RMSE by topographic slope.
R: please see below.





350
300
250
200
150
100
50
0
Counts
0
100
200
300
400
500
Slope (-)