Review of: “Runoff from Greenland’s firn area – why do MODIS, RCMs and a firn model disagree?”

By Horst Machguth et al.

Summary

This paper examines and compares meltwater runoff limits in Greenland (i) derived from MODIS imagery and (ii) predicted by two regional climate models (RCMs), RACMO and MAR. The authors find that in general the runoff limits predicted by RACMO are lower than he observations, and those from MAR are higher than observed. The variability in the MAR limits is more closely aligned with the observations, while the RACMO results show comparatively little interannual variability. The authors attribute much of the difference between the models to differences in the meltwater schemes (bucket schemes). The higher runoff limits in MAR leads to higher predicted runoff volume (up to 29% along the KAN-U transect) than in RACMO.

In general, I found this paper to be scientifically sound and well written. It will make a quality contribution to our understanding of meltwater processes on ice sheets (and limitations in modeling them. There are several issues that should be addressed prior to publication, but I expect that most of these should be quite tenable. I have split my comments into “general comments” and “specific and line by line comments”; note that the line-by-line section includes both small comments (e.g., typos) and larger questions I had as I read the paper.

General Comments

1. My primary comment is that the discussion (particularly Section 5.2) needs to be a bit more substantive and based on the results presented. One of the chief takeaways of the paper seems to be that the formulation of the bucket scheme, but this section only sparsely uses the results to support their claim that the bucket scheme is responsible for the differences. For example, is there information that I can glean from figure 5 to support this?

In part this concern comes from the fact that the comparison uses two RCMs, and there is much more in RCMs than the bucket scheme. For example, are RACMO and MAR predicting similar amounts of snowfall and similar winter temperatures to each other, which could change the melt dynamics? The authors also present on albedo differences between the two, but are there other differences in the terms in the energy balance (e.g. calculation of the turbulent fluxes, downwelling longwave, etc.) that could be different between the two? What about how the models handle heat transfer, especially with phase change and associated latent heat?

I don’t think that the authors need to do a ton of additional analysis to this end, as I agree that the formulation of the bucket scheme is likely to make a difference. But, I do think it would be appropriate to include a paragraph or two about what other factors might contribute to the differences between the model, and why the bucket scheme formulation is the most important one.

2. This could be my ignorance, but throughout the paper the authors seem to use RCM and firn model somewhat interchangeably. I've previously operated thinking that the RCM is an atmospheric model, which is coupled to a subsurface snow/firn model. A bit of language (in section 2.2 perhaps?) clarifying this may be useful.

3. The implications of the paper seem to be mostly limited to a vague paragraph at the end of section 5. Would it be a reasonable amount of work to include the total GrIS runoff from both MAR and RACMO and discuss the uncertainty in runoff with a more detailed discussion of the implications on our understanding of GrIS SMB?

4. Clarity: mostly the paper is well written and clear, but there are a number of instances (especially in the discussion) that were not written clearly. I note some of these in my specific comments below. My recommendation is to try to avoid writing in passive voice.

5. Model settings: can you provide more detail about the firn model settings that were used? How were the firn columns spun up? Are model settings the same to the extent possible, e.g. surface snow density, etc.? Do both models use similar surface energy balance schemes?

6. The figures are creative and well made, but I generally found that soft colors were hard to see and that text (e.g., legends, axis labels) is too small. (There are also specific comments below that I made while reading the paper.)

Specific and Line by line comments

L31 paragraph: It may be worth mentioning here that the ELA and runoff limit vary from year to year (or calling it a "zone" to encompass that variability?), to differentiate between shifts in ELA and runoff limit that change the long term mean SMB.

46: "oppose" – I would choose a different word here. Intercompare? Or just "compare"? "analyze the differences between the runoff limits…"?

47: remove period after 2021

Section 2.2 (related to my general comment 2 above): Can you provide slightly more detail/clarification about the differences between RACMO2.3p2 and IMAU-FDM, especially in the context of how you use them in this paper? My previous impression was that IMAU-FDM was coupled to RACMO as the subsurface scheme – is this not the case? Here, is the only reason you are bringing in the offline version of IMAU-FDM to evaluate model physics and outputs that are not provided from the coupled model, or are you running IMAU-FDM as well for comparison? (Table 1 clarifies this somewhat, but I think it would be helpful to clarify the text slightly as well.)

83: “agree to” → “agree with”

90: I get the gist of what you are doing as described here; however, is it possible to use Figure 1 to help illustrate the polygons?

Section 3.2.2 – regarding the IMAU bucket scheme – can you provide more specific detail about how it handles ice lenses and slabs, as you do for MAR? (this will help a lot with clarity of discussion section.)

151: Please clarify: Is the annual maximum runoff limit the highest elevation where runoff occurs for each year? Given the definition of runoff limit provided in the introduction, why is the maxΥ_{rcm} not simply where runoff is greater than zero? Also, would it make more sense to consider a maxΥ_{rcm} threshold as a percentage of the annual snowfall than just a value?

183: can you speculate why the approach does not work well in that terrain?

Figure 2: The caption and accompanying text needs more detail (text especially) of how to read the various lines. It may help to label the pale lines “IMAU-FDM daily” and “MAR daily”. I initially missed the fact that you say where the transects are at the end of the caption. Perhaps include that detail in the first section of the caption, and make the flowlines bolder in figure 1? Figure 1 legend could also include the flowlines. Also, the axis labels on this figure are too small, and the figure would be easier to view if the colors were bolder. I don’t quite understand the lat/lon labeled at the tops of the figures, as this is a transect and not a point?

200: What difference are you referring to specifically here?

Figure 3: This is a neat figure. However, the text size throughout and the soft colors make it difficult to read. In panel a, is it possible to darken the flowlines as well?

Figure 3/Line 200 – It was surprising to see RACMO1k and IMAU-FDM differing so much. I wrote this comment before seeing the text about this later in the paper. I don’t think you need to add more in this paper, but it is surprising to see and I hope you will investigate further in the future.

Figure 4: perhaps include the region along with the panel label at the top to add clarity, i.e. a: NW and b: K-transect

204: can you quantify this variability with a simple correlation?

208: “shorter in the north than in the south” – is this robust, or just the case for the areas you picked?

212: It May be useful in some cases when talking about a specific RCM to use e.g. Υ_{rcm}^{MAR} or Υ_{rcm}^{RAC}.

217: “appears more step-wise”: Is this just an artifact of the gridding?

219: This looks like it is only true for MAR?

Figure 6: the direction of the y-axis is opposite what I would expect (I would expect time to proceed downward in the direction of reading) – so I recommend switching that or noting this in the caption.

Figure 6: It is not clear to me why the 10m firn temperature at the lower elevations much cooler than at the runoff limit (e.g., Figure 6g). Why does the melt cause 10m temperature at runoff limit to increase to near the freezing point, whereas at lower elevations this does not occur? I suspect this is due to there not being firn at all (figure 7), but it would be good to clarify here. (Perhaps label the figure T_{10m} instead of T_{firn} $10\ m$, as there isn’t actually firn there?

245: Can you explain the odd (discontinuous in distance) 10-m temperatures in MAR? I would expect a (more or less) monotonic change as distance increases.

250: does this mean that in IMAU-FDM, ELA and $\max\Upsilon_{RCM}$ are effectively the same thing?

266: “MAR simulates runoff between the two runoff limits” – not exactly clear what you mean by this. I think you mean the additional runoff simulated by MAR above the IMAU-FDM runoff limit and below the MAR limit, but perhaps there is a clearer way of stating this.

273: “the larger the difference in total runoff simulated by the two RCMs” – even with the below paragraph I think is phrased as too strong of a claim, as I don’t see anything in this regression based on the total runoff in each. I think the claim needs to be a bit more nuanced, along the lines of “the amount of MAR melt above the IMAU-FDM runoff limit increases exponentially as a function of the MAR melt below the IMAU-FDM runoff limit. Assuming the MAR and IMAU total melt below the IMAU-FDM runoff limit are similar, this implies that the difference in predicted melt between MAR and IMAU increases in high-melt seasons”. (or rearrange the section a bit so that the comparison of common area is not at the end.

279: is this $\max\Upsilon_{RCM}^{IMAU}$?

285: “16 % out of which almost four fifths” (and previous sentence) – these statistics are hard to follow – i.e., 80% of 16% - can you make it a bit clearer for the reader (perhaps adding the actual volumes would do this?)

288: “regardless of fundamental differences between runoff processes detected from remote sensing and their simulations.” – clarify the sentence structure here.

306: Aren't bucket schemes instant (all routing occurs within a model time step)? That could be mentioned here instead of "RCM vertical routing is much faster".

311: It is not clear to me how what is described in this paragraph is lack of inertia – can you elaborate what you mean?

315: "This feedback mechanism, by which ice slabs thicken, is challenging to mimic through a relatively instantaneous bucket scheme." I don't necessarily agree with this – in the model domain, once there is meltwater percolating to the slab all snow/firn above the slab is temperate. If the slab is below freezing, some of the meltwater can refreeze (according to the heat transfer scheme in the model). Why would an instantaneous bucket scheme prevent the model from simulating this process correctly, albeit in a single time step rather than over some timescale? If the slab is being buried in IMAU-FDM and not in reality, a simpler explanation to me is that there is too much snowfall and not enough melt in RACMO at KAN-U. Wouldn't this be consistent with your findings that IMAU-FDM has lower-elevation $\max\Upsilon_{RCM}$?

316: "In particular, both RCMs do not permit any slush formation and even thick ice layers must remain "permeable" for meltwater to be routed vertically." I am not sure what your point is with this sentence – can you expand a bit to clarify what you are saying?

330: "in the absence of pore space, even moderate amounts of melt will run off" – isn't this what would be expected in reality? If there is no pore space available to store the water shouldn't all water run off?

332 – 335: in general this paragraph is hard to follow, in part because (as I noted earlier) the description of the bucket scheme in IMAU-FDM is not fully described. Here it is implied that any meltwater is allowed to pass through ice slabs – is that correct?

336: "pronounced step change in surface albedo in 2012" Is this shown anywhere? Is this in time or space? Not exactly clear what you mean here.

337: Why does higher albedo reduce likelihood of "meltwater percolating to the bottom of the firn where it would run off"? Or are you trying to say that the higher albedo above that step change reduces melt and thereby reduces the volume of meltwater percolating to the bottom of the firn and running off?

340: on one hand/on the other – colloquial phrase

358: "As the primary cause we identify the discrepancies between the two maxYrcm": this could be rephrased to be clearer, e.g. the primary cause is the fact that MAR consistently predicts a higher runoff limit (and thereby a larger area producing runoff) than IMAU-FDM"

359: why is this surprising? If both predict similar runoff in the ablation zone, wouldn’t the one with higher runoff limit be expected to produce more runoff?

393: “strongly later water flux” – can you clarify what this means, or perhaps a typo (layered?)?

Figure A4: this is pretty wild to see this much disagreement – I hope you’ll continue work like the present paper to figure out what is going on with the models here.