Review of

A high-resolution pan-Arctic meltwater discharge dataset from 1950 to 2021

by Igneczi and Bamber

General

This paper presents a new daily, 250 m resolution, 71-year runoff dataset for the Arctic, partitioning between runoff from ice and tundra. Its main strengths are the high temporal and spatial resolution, long time series and consistent source data treatment. Its main weaknesses are using only a single model product and the lack of detailed (regional) evaluation. This makes it hard to judge whether the (sometimes significant) differences that are found when comparing with previous products represent real improvements. See major comments below.

Reply
Thank you for your suggestions. We have undertaken additional data evaluation steps including a validation against river gauge data, and comparisons of the original and downscaled runoff. This has led to a significant revision of Section 5 and 6. We hope this will aid the evaluation of our manuscript.

Major comments

l. 117: If you go from 90 to 250 m resolution, how do you deal with fractional ice cover?

Reply
To keep data processing streamlined we relied on simple nearest neighbour interpolation for GIMP re-gridding, similarly a grid cell was considered ice covered if its centroid was within RGI ice cover polygons. This simple procedure circumvented the need to consider fractional coverages and allowed us to consolidate all data inputs to the same resolution and grid, which makes our steps less complex. Although ice masks are less precise due to this simplification and their lower resolution, we found that their total area remained within ±1% of the original.

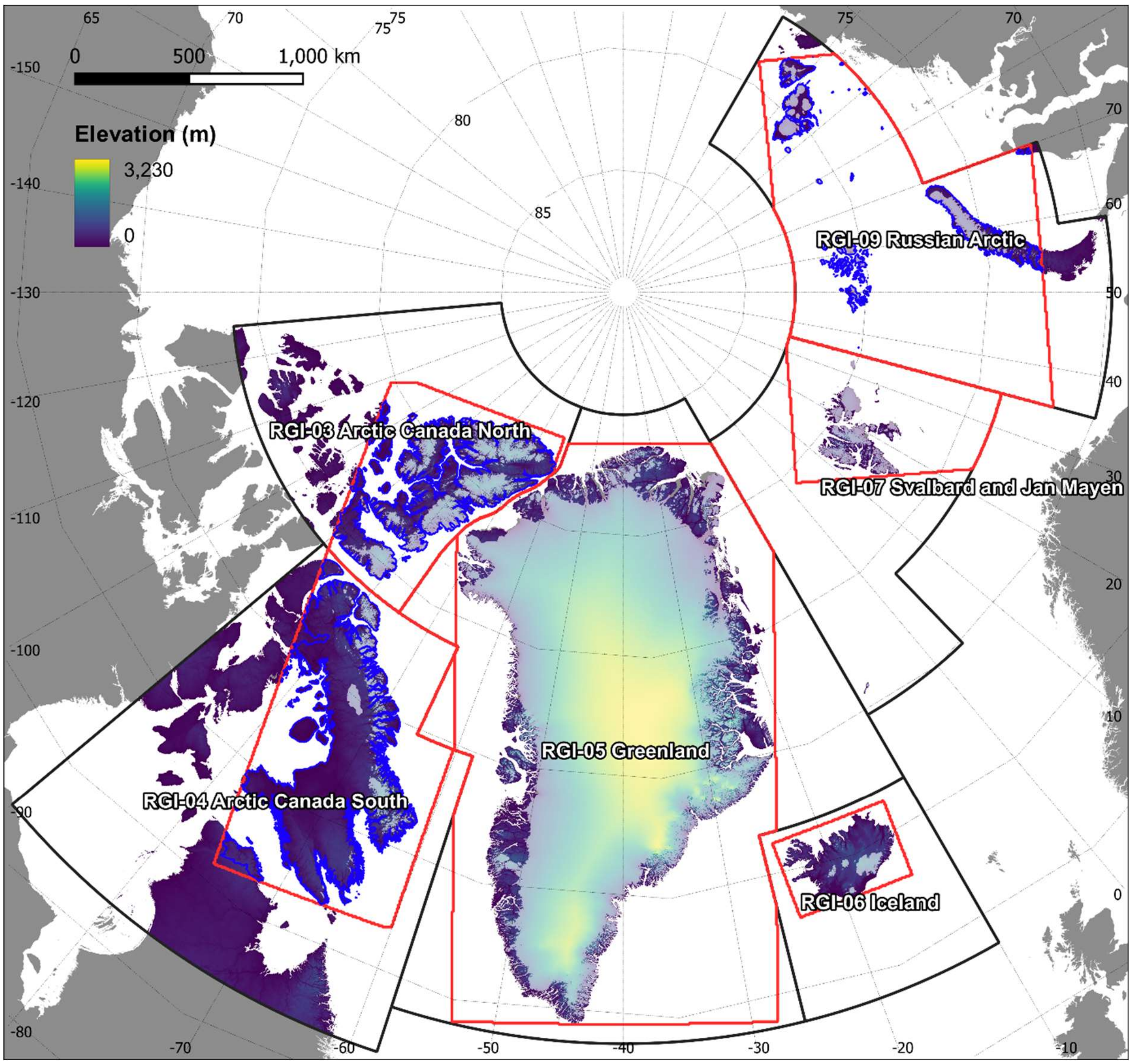
Additional description is provided at the relevant sections to explain the data processing more precisely.

l. 141: Was the RCM forced hourly by ERA5? Usually this is every three hours. How do you assess non-glaciated runoff from regions not covered by the MAR domain?

Reply
Thank you for pointing this out, MAR was forced by 6 hourly ERA5 (we omitted the number by mistake).

We only consider the areas – within the RGI regions - that are covered by MAR.
Fortunately, Greenland, Svalbard and Iceland are covered completely.

However, steps need to be taken to ensure data consistency and quality in the Arctic Canada North and South, and Russian Arctic regions, e.g. we only retain drainage basins that have at least 90% of their area within the MAR domain to limit the extrapolation of MAR outputs. As our study areas (i.e. MAR coverage within RGI regions) are predominantly on islands (e.g. Baffin, Ellesmere, Novaya Zemlya) major drainage basins (potentially transporting water from outside the MAR domain) were not removed by this step (please see that attached map and statistics). The drainage basins are provided with out discharge dataset, so users can precisely investigate the origin of the coastal drainage.



Dissolved drainage basins outline (blue) is shown for the regions affected by the issue of basins covering areas without MAR data. The most significant effect is visible in the Arctic Canada South region (e.g. on the northern tip of the Labrador peninsula).

The relative effect (of the removal of such basins) on total integrated area is
Greenland: 0%
Svalbard: 0%

Iceland: 0%
Canada North: +1.01%
Canada South: -3.85%
Russian Arctic: -2.69%

We now highlight this issue better in the text (starting in Section 3.2.) and point the readers to the relevant sections where we explain in detail how we deal with the situation (when delineating drainage basins in Section 4.1 and when comparing our results with previous studies in Section 5.3).

Section 4.1: Although I appreciate that the authors prefer consistency in their calculations, it would be good to show/discuss the potential impact of solely relying on surface routing over e.g. the Greenland ice sheet.

Reply
We agree with the reviewer that this issue is important to discuss.

We provide more explanation in Section 4.1 as to why we avoided using ice thickness data and routing based on subglacial pressure heads.

Please briefly discuss how findings in this recent paper, which shows that meltwater is stored in the glacial Greenland system for significant amounts of time, could affect your results: https://www.nature.com/articles/s41586-024-08096-3

Reply
We now discuss the effects buffered water storage can have on our coastal discharge data in Section 6.

l. 260: What albedo product was used in MAR? Albedo does typically not vary smoothly, making it harder to downscale as a function of elevation. Allowing albedo only to increase with increasing elevation may not be a valid assumption in many areas. How are the albedo corrections used in the final runoff product?

Reply
Thank you for raising this important point.
MAR uses the CROCUS snow model formulations, which have their minimum albedo set to 0.7, and MODIS based empirical firn and bare ice albedo parameterisations (e.g Fettweis et al., 2013; 2017).
We acknowledge that albedo variability is especially complex, and just relying on vertical gradients will not provide a precise downscaled product. This is the principal reason why we are not using the downscaled albedo product in any way to correct the downscaled runoff (e.g. similar to MODIS data used by Noël et al. 2016); it only provides contextual information (i.e. to estimate the ratio of runoff originating from below the snowline) that some users might find useful. As we only aim to locate the snowline, we are mostly affected by the CROCUS snow model formulations within MAR, which have their minimum albedo set to 0.7 (e.g Fettweis et

al., 2013; 2017). Thus, we are less affected by bare ice albedo from MAR which is particularly uncertain (e.g. Ryan et al., 2019).

We have added a new sentence to Section 2 to state in advance that ice albedo is not used to adjust the downscaled runoff. Section 4.2 was also edited to make this clear.

Section 4: Although useful, a bulk evaluation does not necessarily align with the bulk of the applications and users, which may well predominantly use dingle basin timeseries.

Reply
We agree that more local comparisons are useful. Unfortunately, there are few data sources that allow such an evaluation. In order to try and achieve this we have compared our coastal discharge time-series with corresponding Greenlandic river gauge data, using previously published methodology (Mankoff et al., 2020). This provides information about the localised performance of our data product. To summarise, the performance of our dataset is very similar to the MAR derived product of Mankoff et al. (2020).

l. 374: "We propose...". This and later hypotheses can be -at least partly- confirmed or rejected by comparing the runoff products in elevation bins: is the difference indeed deriving from the lower elevations which are better resolved? Same for non-Greenland ice.

Reply
We have now carried out detailed comparisons between the original and downscaled runoff. We also investigated the topographical configuration of the RGI regions, i.e. histograms and differences between MAR and high-resolution DEMs. Using these insights we have added a new Section (5.2) and several figures in the Supplementary material that deal with this issue.

l. 392: I find it unlikely that resolution is the only/leading explanation for the large differences in Greenland tundra runoff. This can be relatively easily checked by comparing total tundra area, the depth of the seasonal snow cover and rainfall. This can also be used to provide a more robust answer to the question why tundra runoff outside Greenland agrees better (although the variability is again more different).

Reply
We agree that additional information and explanation is needed.
Additional information is now included (Section 5.2) that aids unraveling the origin of this significant difference (Section 5.3 is also significantly revised). Our downscaling procedure increases net tundra runoff by about 7.3% in Greenland, due to better representation of low lying unglaciated valleys (Figure 6, S3, S5). However, the majority of the difference can be attributed to inherent differences in our MAR input i.e. MAR v3.11.5 (this study), versus MAR v3.11 downscaled from 7.5 km to 1 km (Mankoff et al., 2020), and RACMO2.3p2 downscaled from 11 km to 1 km (Bamber et al., 2018).

Bamber et al. (2018) uses a variety of model versions and re-analysis forcings. For Greenland they use RACMO2.3p2, while outside Greenland they use RACMO2.3p1 versions. Also, their RCMs are forced by ERA-40 between 1958-1978 and ERA-Interim between 1979-2016 (Noël et al. 2015 2017). Thus, comparing the alignment of our dataset with the Bamber et al. (2018) product across regions (i.e. Greenland vs. non-Greenland) is difficult. E.g. for non-Greenland tundra their product is in better alignment with our results post ~1980 (roughly the start of ERA-Interim forcing).

IN general, I miss a direct comparison between the non-downscaled and downscaled products. Where/when do the differences occur, and can it be objectively assessed whether the downscaling improves upon the original products? It presumably does, but unless it is somehow quantified this remains speculative.

Reply
We agree with the reviewer this such comparisons are necessary.
In the revision of the manuscript we include comparisons between our downscaled and original MAR runoff, separately for tundra and ice in each investigated RGI region. A new section is now included to explain the findings (Section 5.2). To summarise, bulk ice runoff slightly increases in Greenland due to downscaling (+2.4%) but decreases elsewhere (between -4.4 and -23.5%). Bulk tundra runoff increases due to downscaling in all regions (between 4.2 and 28%). We have also investigated the potential factors that could have influenced the net effect of downscaling on bulk runoff. We have found that differences in the MAR and high-resolution ice- and land masks, and DEMs, along with the topographical configuration of each region provide reasonable explanations.
We reviewed Section 5.3 given these new insights. Overall, we propose that the observed differences between this study and previous products are not primarily caused by our downscaling procedure, as they are mostly inherent to the MAR inputs.

Minor comments

l. 25: warmed -> increased (my strong preference!)

Reply
Done.

l. 159: This equation holds for runoff from land ice, please specify.

Reply
We added that there is no retention or refreezing for tundra runoff.

l. 340: If find the reasoning for distinguishing runoff from above and below the snow line hard to follow. Why is it relevant? Figure 6 suggests that the large majority of runoff comes from below the snow line. Interpretation?

Reply

Distinguishing between liquid discharge sourced directly from seasonal snow (i.e. above the snowline) and from firn/ice which represent a “reservoir” source could be useful for certain perturbation experiments (e.g. examining fjord circulation) that aim to pinpoint the specific effect of melting ice (while controlling for precipitation). We do not consider this as a primary output, but though it might be useful for some users.

Although the annual amount of runoff from above the snowline is small, it could be more significant early in the melt season (the snowline is tracked daily). Also, MAR is prone to the overestimation of bare ice area (Ryan et al., 2019; Fettweis et al., 2020), thus true snowlines might be located lower than our estimates. This is now pointed out prominently in Section 4.4.

l. 410: What is meant by "its overall uncertainty"? I presume you mean the uncertainty in runoff?

Reply
Yes, we have edited the text to make this more clear.