Review of egusphere-2026-2836

General comments

The study by Yang et al. presents a new glacier inventory for the larger Karakoram mountain range derived from very high (ZiYuan-3) and high (Sentinel-2) resolution optical satellite images acquired in 2020 and 2021. The authors also use Landsat derived surface temperatures and a 4 m resolution DEM derived from ZiYuan-3 (plus the ASTER GDEM) to derive glacier extents automatically from a combined U-Net/CBAM approach and corrected the outlines manually as required. As I do not work with DL/ML and miss the related expertise, I do not comment on this part of the study.

First, I want to acknowledge the large effort by the authors to create this inventory and confirm that an update of the currently available glacier outlines (from around 2000) is indeed required. As (apart from surging glaciers) area changes are small in the Karakoram, a high-quality dataset is very helpful to reveal them. I also want to acknowledge that the other investigations (e.g. regarding debris cover and glacier type) are interesting, that the study is well written and that the figures are generally good to illustrate the different points. Last, I want to acknowledge that the authors provided image coordinates and glacier outlines for inspection. The latter show that high resolution does not solve all mapping challenges in this region.

Apart from some other points, these challenges are actually the largest problem of the derived dataset. I am aware that the RGI 7.0 dataset for this region is not perfect (e.g. missing or wrong location of ice divides), but overall, I think it is still better than the new one described in the present study. The main problems of the dataset are included seasonal snow, wrongly interpreted debris cover, included glacier forefields and remaining artefacts of the processing. I include at the end six example images to illustrate the various issues. Regarding snow cover, the years 2020 and 2021 were in some regions about ok for glacier mapping, but at the highest elevations snow cover is often hiding the real glacier perimeter (also illustrated in Figs. 6d and 7b). In consequence, many rock outcrops are classified as glaciers or their extent is too small and glaciers have been mapped where no glaciers are. With a focus on the region around Batura Glacier, I also found several glaciers where the lateral moraines from the Little Ice Age (LIA) have been wrongly mapped as glacier extents or debris-covered parts are not or wrongly included. Together, the wrongly included snow cover and LIA extents create too large glacier areas.

So, how to proceed in this regard? I assume the authors would prefer to publish a high-quality dataset and improve it where possible. Given that the workload for reworking everything is likely too high, I suggest correcting at least the largest errors:
(1) As a first step, I would compare the outlines of the present dataset (red lines) with those from RGI 7.0 (in blue, on top) and wherever they are much larger (or smaller) in the ablation region (visible red outlines), please check if LIA extents have been mapped or debris-covered tongues are incorrect (the geolocation issue of Shisper Glacier in RGI 7.0 has to be ignored) As this mostly concerns larger glaciers, I think the workload is feasible.
(2) Correcting the too large extents in the accumulation area is more difficult. At best, RGI 7.0 outlines are used as a mask so that the glacier-covered region in the present dataset will not be larger than this. This can be applied automatically and will only be wrong for a few glaciers that advanced or surged. Unfortunately, geolocation shifts between the two datasets will create wrong corrections and the back-correction will be very demanding. Maybe a buffer or ML/DL techniques will help. Please try!
In the following I list specific comments to the text that should be considered as well.

Specific comments

General

The perimeter used here for the Karakoram is much larger than usually used. It also includes glaciers in Wakhan region of Afghanistan. I suggest restricting the analysis to the perimeter provided by Bhambri et al. (2022), see doi.org/10.1007/978-3-030-47660-1_8.

The ASTER GDEM v3 and the (void-filled) SRTM DEM have locally quality issues, the latter in particular in the interpolated regions with data voids. It is unclear where these DEMs have been used and how they compare to the ZY-3 DEM. Do these DEMs match seamlessly? I also miss a hillshade of the ZY-3 DEM revealing its topographic quality, e.g. compared to other high-quality DEMs such as the HMA-DEM or the Copernicus DEM. This can all be in the supplement, but it should be there.

Please check if the correct RGI 7.0 has been used/displayed. The missing glaciers shown in Fig.13a are all there. Also the small glaciers shown in Fig. 7e are in RGI 7.0.

There is also a book and dataset about a new glacier inventory for Pakistan from Sentinel-2 scenes acquired in 2022, led by Davide Fugazza (EVK2CNR). It would be worthwhile to also compare results from the present study with the dataset created by the student project.

As a general note, for me, medium resolution is MODIS type (100-1000 m) and Sentinel-2, ASTER, Landsat TM (10/15/30 m) is high resolution. 5 m or higher (Planet, ZY-3, etc.) would be very high-resolution. But I am aware that this is not standardized.

Abstract

Please check all statements about previous inventories, e.g. the underestimation of glacier numbers (which is incorrect for RGI 7.0) or the generalization of debris-covered margins (which are also not well captured in the present study, e.g. confused with LIA extents). As the glacier count is a rather arbitrary number, it is maybe not too important to improve it.

What is missing here as a motivation is the high impact of wrongly mapped seasonal snow on glacier area (which is also a major reason for area overestimation in this study), ice divides being at the wrong place (mostly due to errors in the SRTM DEM) and the geolocation shifts of outlines in RGI 7.0 derived from former Landsat images that have been corrected now to better match with the Sentinel-2 geometry.

The statement in L34 is incorrect for the present dataset and shows that higher resolution is not everything. More important is the ruleset applied to distinguish rock glaciers, ice-cored moraines and other ice-debris-landforms from the debris-covered glaciers to be mapped, largely due to the fact that such features only became visible at very high-resolution. As mentioned above, I think the outlines in their present form are not a new benchmark (L37) as RGI 7.0 outlines have overall the better quality. But due to geolocation issues and wrong/missing ice divides, RGI 7.0 outlines should be updated at some point. I hope the authors can improve their dataset to have an alternative.

Specific

L58: Please be precise here. The cited references seemingly refer to RGI 6.0 and the first GAMDAM inventory. These are superseded by GAMDAM II (Sakai 2019) and RGI 7.0 (RGI consortium 2023) and should no longer be used for comparison.

L67: Please check carefully. As far as I can see it, nothing has been omitted in RGI 7.0.

L69: Small glaciers do not necessarily have short response times. They must be thin (steep) with strong ablation near the terminus. When they are flat (thick) with limited ablation (e.g. debris-covered tongues) they can also have long response times.

L70-78: This is all fine, but the impact of resolution is maybe small compared to factors like wrongly classified seasonal snow (leading also in this study to an overestimation of glaci-

er area). The area difference when digitizing the same glacier at 10 or 2 m resolution might be small as outline deviations have a random distribution. What changes is the ruleset, i.e. at higher resolution different features of a glacier become visible (e.g. ice-cored moraines) and digitizing guidelines have to be adjusted accordingly.

L85: I think this is mostly the case for small glaciers, say <0.1 km^2. Towards larger glaciers and less complex forms (ice caps) resolution has a decreasing impact on outline quality.

L87: I think also for DEMs it is not only resolution that is important. Other factors like the time stamp (everything acquired in the same month), artefacts/data voids, radar penetration or cloud/contrast issues are equally important to obtain high-quality ice divides and topographic information. There is nothing against using the ZY-3 tri-stereo images (but please show a hillshade for comparison with other DEMs), but for the comparably large glaciers in the Karakoram also other DEMs provide reliable glacier morphology.

L90: I am not sure how this separation works when there is no break in slope or surface morphology? Usually, DEM differencing is used to see where ice is below the debris.

L96: As mentioned above, it seems that the very high resolution has not always helped to identify debris-covered glacier parts, as in several cases moraine crests from the LIA have been mapped. Please carefully check results against RGI 7.0 to improve the dataset.

L104: I suggest adjusting the extent of the Karakoram to the one by Bhambri et al. (2022).

L117: Please get 'Table 1. Data …' to the next line that it works as a table caption.

L120: Please add somewhere which spectral bands are covered by the multispectral sensor. I assume it does not have a SWIR band and can thus not be used to calculate the NDSI or other band ratios for (clean ice) glacier mapping? As a note, in most of the image examples in Figs. 4, 6 and 7 the white glacier surfaces have a brownish colour. It looks as if bands 1, 2, 3 rather than 3, 2, 1 have been combined as RGB. If so, please adjust, otherwise I assume the strange colours are an artefact of the pan-band fusion?

L124: Please show where Sentinel-2 derived extents are located, e.g. as a footprint in Fig. 1.

L127: Can you also show (in a map) the regions covered by the ASTER GDEM?

L142: I am unclear how the 100 m LST info from Landsat could support glacier mapping with ZY-3 at 2 m resolution. Apart from the fact that the thermal sensor measures just something (i.e. requires careful calibration with field data), the resolution mismatch seems to be too large for a meaningful application. Please better explain how this works. In L147 it is written that the LST info was 'aligned' to the 2 m ZY-3 grid, but not how and what the impact of the resampling (?) was.

L201-203: I would remove this sentence as the contents is about the same as in L151-153.

L204-299: I do not comment on Section 3.3 as this is not my area of expertise. However, I would like to mention that I find the (standard) uncertainty measures listed in Table 2 not very insightful. They can basically mean anything. None of them tell me if seasonal snow has been included or not. In Figures 6, 7 and 13 several outline overlays are shown, but most of the glaciers are clean (and easy to map) and located in the very north outside the Karakoram. I suggest showing also mapping results for a few more challenging examples of (small) debris-covered glaciers in the south of the Karakoram.

L302: How do you know that snow-covered 'glaciers' <0.01 km^2 are glaciers? Considering the partly poor snow conditions (Fig. 6d and 7b), is it meaningful to include them?

L310: How do you know that there is no ice underneath the snow? The higher resolution does not reveal it. For example, for the small glacier in the centre of Fig. 7d all the surrounding snow patches have been included.

L313: As seemingly nothing has been omitted in RGI 7.0, please check the statement.

L320 and elsewhere: Please insert an empty line to separate the figure caption from the text.

L321: Please exchange Figs. 8a and 8b, to start with the more general graph and a before b.
L327: Due to the orange outlier (?) in Fig. 8a (and 11c), there are only small colour differences for the glacier count. Please check values and possibly adjust the legend.
L341/363: The 2mKGI includes/provides …
L342: How is mapped debris per glacier defined? Is one pixel enough to name it debris-covered? If not, what is the threshold?
L344: Has 'debris patch number' any glaciological relevance? How is a 'debris patch' defined? Wouldn't it be better to show the percentage of debris cover per grid cell? Before going abstract in Fig. 9, please show what is meant here for a couple of glaciers.
L345: I do not get the relation between debris distribution and 'valley geometry' or 'low-gradient tongue development' from the figure or the text. How is valley geometry or tongue development quantified? What should this relation be? Please explain. Or should this be the conclusion to the sentence following? Then please move it to the end.
L348: That total amounts scale with glacier size is clear, but what is with the percentage of debris cover per glacier? Is it more similar and size independent?
L360: See general comments. It seems that in several cases lateral moraines from the LIA have been mapped as boundaries. So, very high-resolution is not everything.
L369: I think the maximum is rather broad (5000 to 6000 m).
L372: Ok, but that debris usually melts out below the ELA is a consequence of (vertical) glacier flow dynamics and not special for the Karakoram.
L382: Ok, but this is also well known since a few decades and has actually been used in several studies to map debris-covered glaciers using a slope threshold.
L388: Still, the difference to other (northern hemisphere) mountain ranges is remarkable as these usually have most glaciers (and areas) exposed to the north.
L393: Isn't the snowline be just located somewhere, i.e. depending on the date of image acquisition and snow conditions? Or is the date of the albedo product the same for all glaciers in the sample? Can you demonstrate (in the supplement) that the method works and provides meaningful results?
L407/431: As a note: Many smaller surge type glaciers can be connected to a larger trunk glacier (that does not surge) after their surge. A large number of surge-type glaciers in the Karakoram are isolated, medium-sized glaciers rather than large valley glacier systems.
L418: I would have expected that Alpine-type glaciers have the least extensive areas at low slopes as they are more attached to the topography than the other types.
L428: Should this be Figure 12d and e? Please also cite Fig. 12f (e.g. in L434).
L436: The steep headwalls must at least partly be ice free to provide debris.

L442: The RGI 7.0 includes the glaciers shown in Fig. 13a as omitted, please check.
L445/6: This is what I expected, but it seems the higher resolution has not solved all problems. Please improve your outlines (e.g. as suggested above) to meet this statement.
L454: The 2mKGI chiefly …
L456: As stated above, small glaciers do not necessarily have short response times. Those being attached to rock walls at high elevations (cold ice) might not change for decades. Also those being flat (thick) and well shaded or debris-covered might not change much.
L458: I think this is correct in general, but in the Karakoram? Fragmentation or rapid shrinkage (excluding surging glaciers) has rarely been observed over the past decades.
L490-493: Can this be shown with a figure and some numbers? Many glaciers here are >>10 km^2 (up to 1000 km^2) and it is unclear how the better DEM changes related numbers. I think a 30 m DEM can also be used to create a 'quantitative topographic framework'.
L510: I think this is not unique for the 4 m DEM, other DEMs also allow it.

L512-522: This is now all about the benefits of higher resolution, but only some points of the listings have been shown. Neglecting that the outlines are not yet more reliable than those from the RGI 7.0 and that small glaciers have not been omitted, where are the improved 'narrow divides, upper-basin margins, and debris-covered termini' shown? Or how do uncertainty estimates provide a more reliable geometry when snow has been mapped? Please also note that the DEM has to be provided should hypsometric analysis etc. be supported (the DEM is not listed in the data availability statement). Where is the 'finer glacier-unit subdivision' shown? And why should 'compound valley-glacier systems' be separated? All these benefits might be correct, but they are not shown or yet achieved.

L534/535: The omission is not correct for RGI 7.0 and debris cover is often wrongly determined in this study (see examples at the end). I suggest using other points.

L540: Isn't this just because debris reappears below the ELA?

L541-546: As this is the same text as in the discussion, see comments above.

L545: This requires knowing where the debris-covered parts are, i.e. a good reference dataset.

Comments to Figures and Tables

Fig. 1: The region marked as the Karakoram is too large. I suggest restricting it to perimeter provided by Bhambri et al. (2022). It is unclear to me which DEM is from which sensor. Also the dichromatic red-blue colour table seems sub-optimal for a continuous variable. If at all, please use the usual elevation colour table (as in Fig. 2c). But please also check if it makes sense when glaciers on top hide the info. As a note, the glaciers that are described in Fig.13a as 'omitted in RGI' are included here. The caption should describe for panel c) to which place or region the two graphs refer to.

Table 1: Please add horizontal lines to better distinguish the three main sections.

Fig. 2a: To be honest, I do not see a difference in the viewing geometry of the three images in the top row. Can this be adjusted?

Fig. 2c: I suggest showing glacier outlines on top. And please explain the white areas (I assume these are data voids?). The supplement could be used to show a close-up comparing a hillshade of the DEM derived here and the ASTER GDEM (and other DEMs).

Fig. 2d: I suggest showing glacier outlines in the background for orientation.

Fig. 4b: The region marked as 'cloud shadow' looks partly more like a cloud.

Fig. 5: I suggest showing a close-up, there is not much to see at this scale. And please do not show red lines against a brown background, white might work better here.

Fig. 6a and b: Mapping clean ice is maybe a bit too easy to reveal differences in interpretation. I suggest showing a more challenging example, a debris-covered tongue with a gradual transition to the glacier forefield, i.e. no clear front. The line colours for 'Karakoram' and 2mKGI are nearly the same. Please use colours that are more distinct.

As a general note, the glacier examples shown In Fig. 7 do not belong to the Karakoram.

Fig. 7a: As pro-glacial lakes had to be excluded, I think this is not a specific advantage of very high-resolution (VHR) imagery. However, smaller lakes might be detected.

Fig. 7b: I am a bit unclear how VHR images can help to reveal if there is ice under the snow or not? The decision seems to be ok for the region where the arrow points to, but to the left and right of the line from the arrow, several rock outcrops have not been excluded. And as mentioned in the general comments, the scenes used here partly suffer from adverse snow conditions, i.e. seasonal snow was included rather than excluded. I am thus unclear how VHR imagery could help when there is simply too much snow or when the info is not used to exclude rock outcrops?

Fig. 7c: Ignoring the point that there might still be some ice in the lateral moraine to the right (east) of the glacier, the outline shown here is too large. The boundary to the right runs along the LIA moraine. One can see erosion gullies (Racheln) below which would be destroyed when they were connected to the glacier. Only to the left there is lots of debris-covered ice (extending a bit beyond the end of the clean ice).

Fig. 7d: Also here I am unclear what the VHR offers for mapping ice in terrain/cloud shadow compared to other sensors such as Sentinel-2? Wouldn't it be the spectral resolution and quantization (12 or 14 bits) that help recognizing the ice? Apart from this, it seems that the small glacier in the centre of the image has been connected to the main glacier although the surrounding rock reveals that it is isolated. In RGI 7.0 this glacier is correctly depicted as a separate polygon.

Fig. 7e: Except the yellow outline in the lower left, all these 'small glaciers' are also included in RGI 7.0, i.e. mapped from Landsat. The advantage of the VHR is thus unclear. I would like to see a discussion how these completely snow-covered features can be identified as glaciers? Apart from that, the two larger glaciers to the right are not connected. Again, lateral moraines from the LIA have been wrongly interpreted as glaciers despite the VHR. The moraines could be ice cored, but this does not count for the glacier extent. As a note, we are here deep into the Wakhan National Park, outside the Karakoram.

Fig. 8a: Where does the isolated orange circle come from? Is there really such a strong increase in glacier number in this region?

Fig. 8b/9b: Please consider colour-blind people and use colours different for red/green.

Fig. 9a: Showing the percentage of debris cover per grid box might be more instructive.

Fig. 10: Please use colours that stronger differ from red/green.

Fig. 11c: Again, here is a single orange circle. Where does it come from? If this is an outlier (?) I suggest making the circle white to make better use of the full range of colours. The differences between the glacier types should be better described in Section 3, including images illustrating the differences (could be in the supplement).

Fig. 12: Please avoid using red and green lines in the same plot.

Fig. 13a: The 'RGI' outlines shown here are not those being available in RGI 7.0. The RGI 7.0 includes these glaciers.

Fig. 13c: The outlines shown here are derived from a raster file and could thus not be from RGI 7.0 (but likely from RGI 6.0). Please only use RGI 7.0 for comparison.

Fig. 13d: I suggest adding in the caption that this example from the KGI shows too much seasonal snow being mapped as glaciers (in the inset) and a missed correction for the medial moraine of the glacier in the upper left.

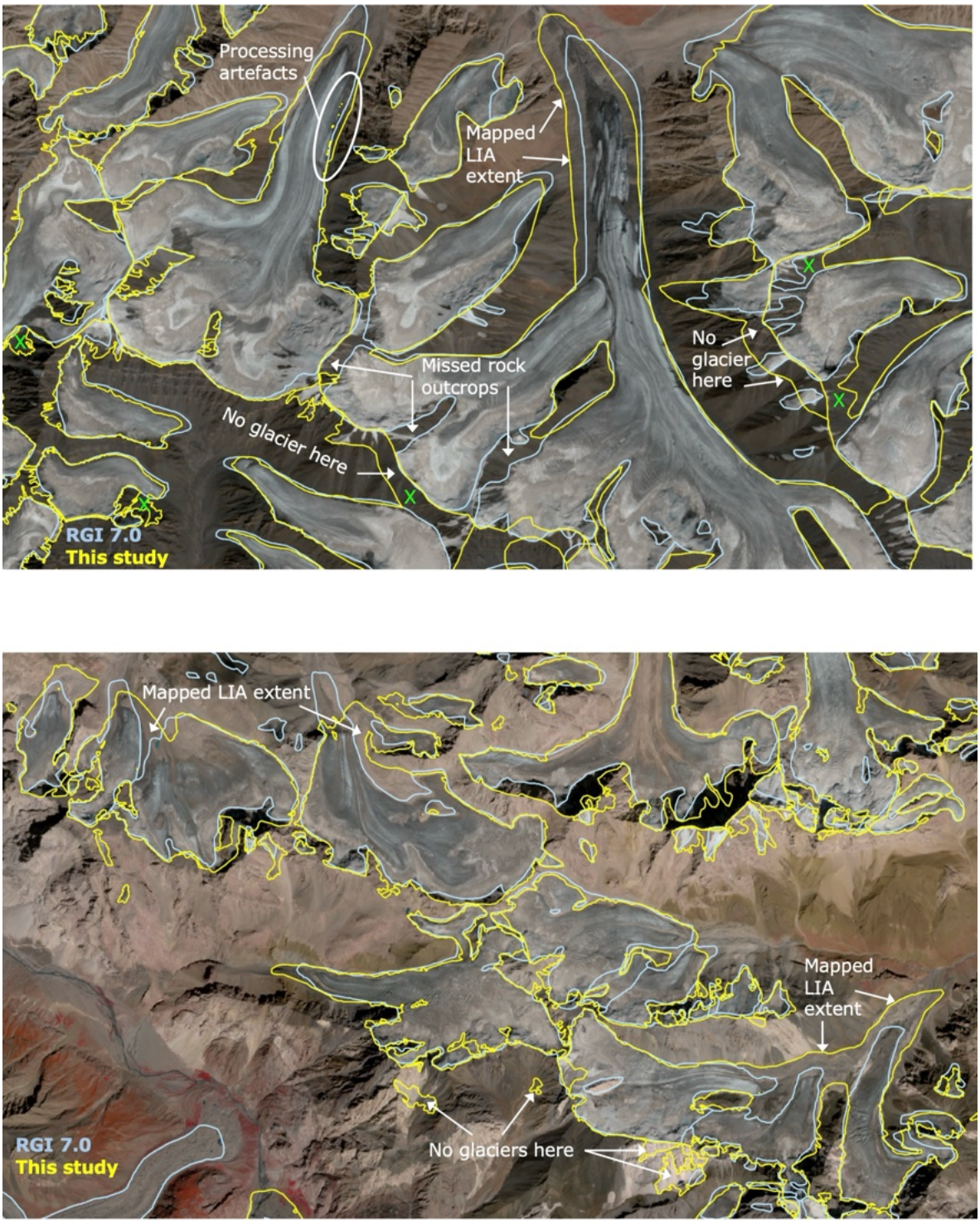
Fig. 14a-d: These plots are rather abstract and summarized. I am also not sure if glacier type is a good separator to reveal dependencies. I suggest showing instead scatterplots with glaciers size (logarithmic) vs. the related differences.

Fig. 14 e/f: It seems these plots show a completely different topic. To avoid confusion, I suggest showing them in a separate figure.

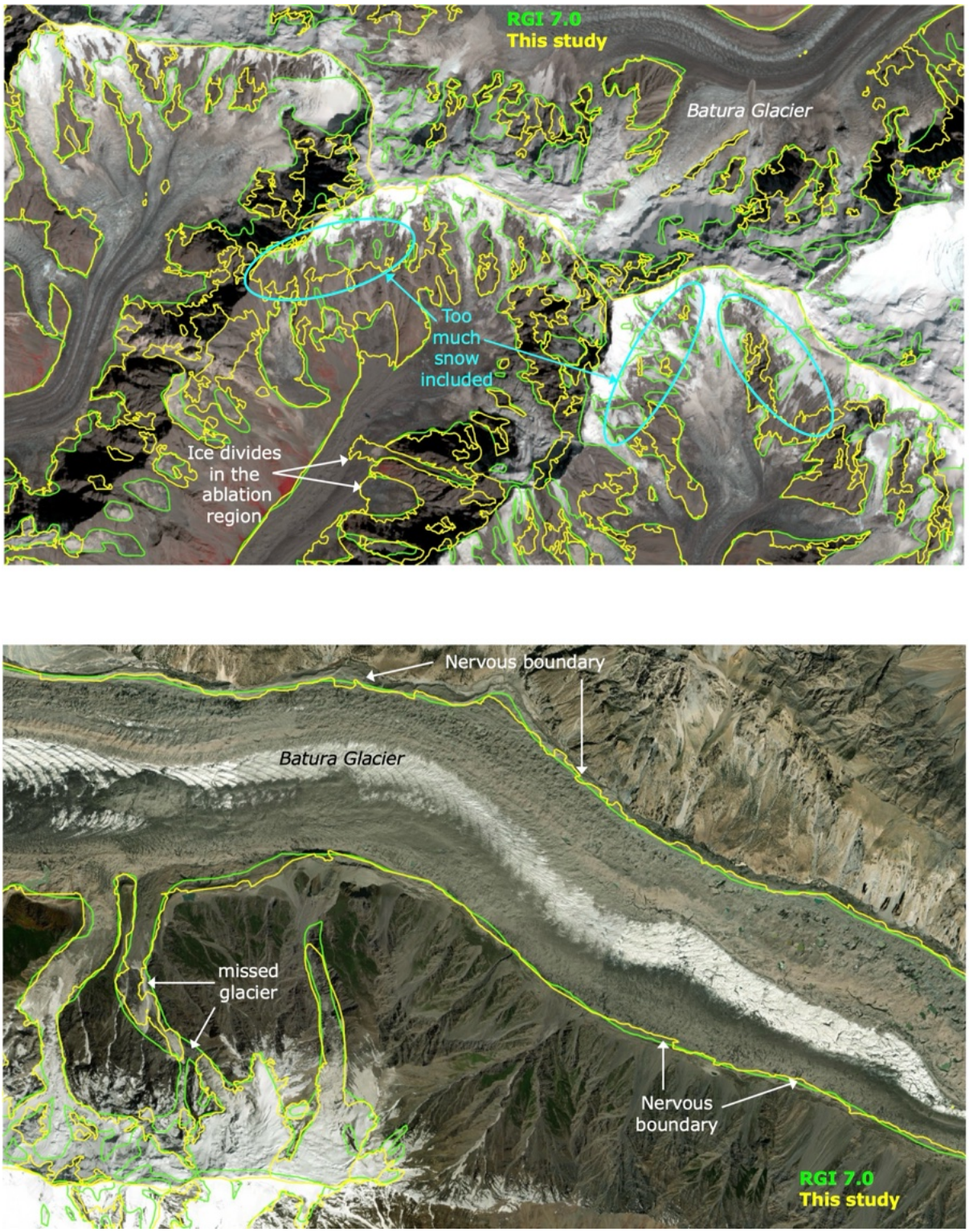
Fig. S1: To better see the subtle changes, I suggest showing the real or final glacier outlines in a different colour on top.

Fig. S3: As this is the supplement (and there is some space) please increase the size of the images and show only two side by side.

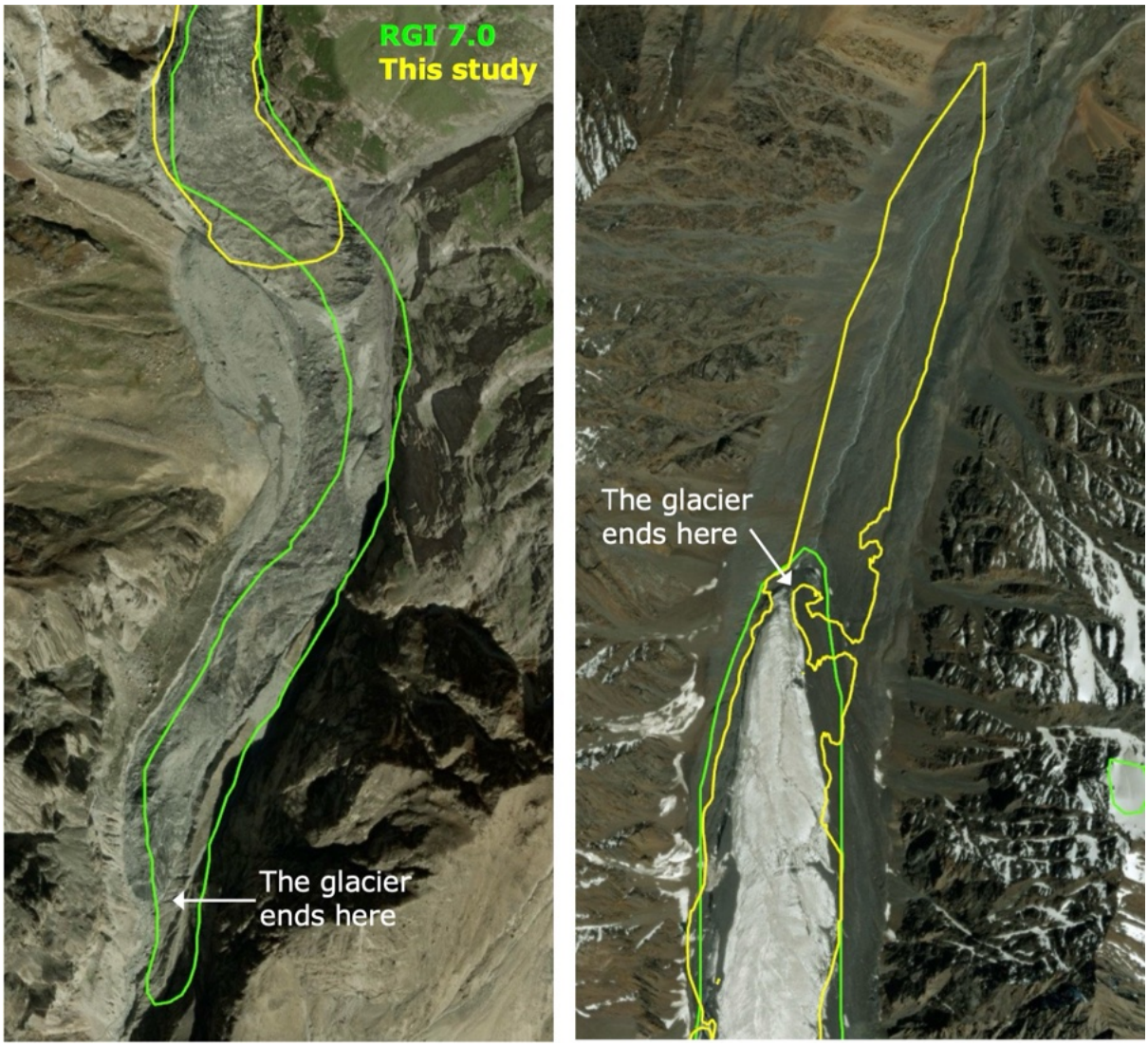
Figs. S4 and S5: Area changes in km^2 depend on the initial area and are thus incomparable across regions. Please show relative area changes.



Examples 1 (top) and 2 (bottom) showing various issues with the 2mKGI inventory (yellow).



Examples 3 (top) and 4 (bottom) showing various issues with the 2mKGI inventory (yellow).



Examples 5 (left) and 6 (right) showing wrongly mapped debris-covered regions in the 2mKGI inventory (yellow).