＋Dear Frank Paul, (corresponding to tcd-8-C622-2014)

We thank you for your valuable comments. Here we address how we will revise the manuscript corresponding to your specific comments. The comments are in italic font, which are followed by our replies in bold font.

A. General comments

The study by Nagai et al. aims at presenting how climatic and topographic influences impacts on the glacier distribution for Bhutan as derived from a new inventory. In my opinion this is a worthwhile topic to present, but I have difficulties to find such an analysis in this ms. Instead, it is rather repetitive of what is already reported in Nagai et al. (2013) (N13 in the following) and has several further shortcomings that need to be addressed. My key objections are:

1. *there is too much overlap with N13 (e.g. most of the text on P1320 is copy/paste)*
2. *there are more topographic influences on glacier distribution than PMS slopes*
3. *there are more climatic influences than precipitation*
4. *a real discussion is missing (mostly further results are presented in Ch. 4) and the overall structure is a little bit confusing*
5. *I also miss a visualization of glacier outlines in challenging regions (close-ups)*
6. *though already published, the PMS concept (or PDS in N13) is not convincing to me*
7. *the missing separation of regions supplying debris and avalanches is in my opinion unfortunate, these are different processes acting at different time scales*
8. *nothing is said about the special characteristics of the glaciers in the regions north and south of the divide (e.g. valley glaciers vs. Firnkessel type)*
9. *with the focus on statistics and correlations the process understanding is getting lost*

I provide details to each of the above objections in the next section. Further issues that need to be addressed are listed in section C. Based on point 6, I strongly recommend removing the analysis of PMS slopes in a revised ms, which will likely substantially alter its contents. Based on this, the other points above and the details provided below, I recommend rejection of the ms at this stage. However, I would strongly recommend performing the suggested revisions and resubmit the study.

Here we will change our manuscript substantially. We will remove the analysis on PMS slope and precipitation data. Instead, more detail explanation of glacier delineation method, results of basic topographic analysis, and discussion of delineation accuracy through comparison with other glacier inventories will be added. We aim to revise this manuscript to the following frame.

Temporary tittle: Comparison of glacier inventories in the Bhutan Himalaya

Introduction

- **Introduction of present glacier inventories and their delineation methods**
- **Introduction of the outlines of glaciers in the Bhutan Himalaya generated by Nagai et al. (2013)**
- **Issue: The quality of the inventories in the Bhutan Himalaya is not validated.**
- **Purpose: This study aims to compare the qualities of manual delineation (i.e. our inventory) and semi-automatic delineation (i.e. the ICIMOD inventory, GLIMS database, and the RGI), and**

show sensitive and insensitive variables of glacier distribution in the Bhutan Himalaya.

Data sets

- **Description of the Bhutan Himalaya**
- **Data and processing of ALOS PRISM/AVNIR2 images**
- **Data and processing of ASTER GDEM2 data**

Methods

- **Description of manual glacier delineation**
- **Flowchart of delineation process**
- **Figures of delineation process**

Results

- **Basic statistic and topographic variables obtained by our outlines**
- **Characteristics of the glaciers in the Bhutan Himalaya focusing on north-to-south contrast**

Discussion

- **Quality comparison between pre-revised and revised outlines of ours.**
- **Quality comparison between our revised inventory and other inventories**
- **Analysis of sensitive and insensitive variables among these different inventories**

Conclusion

- **Largely different values and similar values of glacier distribution variables among the different glacier inventories**

B. Details to the general comments

1. Please do not copy/paste larger text sections from N13 into this study (e.g. L3-20 on P1320). This is never a good idea and also supporting the impression that the same story is sold twice. With the strong focus on the PMS slopes in the topographic analysis and the use of the same datasets and their description on page 1309-10, the repetition of large parts from N13 is unavoidable. So please make something new here to better distinguish it from N13.

We will substantially change our focus from PMS slope to fundamental and detail assessment of manual delineation comparing with other glacier inventories. It will remove the repetition of N13.

2. There are abundant topographic factors that can be analysed when glacier outlines are combined with a DEM. This study only shows the overall hypsography, area and number histograms (sorted for aspect or slopes) and mean/maximum elevations, most of them in a nonstandard way (making them incomparable to other studies). Just to give a few examples for further topographic indices:

- *hypsographies can be compared for a couple of individual glaciers (e.g. larger than a certain size) for N vs S side, with or without debris*
- *glacier types (e.g. valley, mountain, cirque, firnkessel) should be assigned for a more detailed analysis of the characteristics of subsets*
- *mean slopes of ablation areas can be plotted against the mean values for accumulation areas using different symbols for glaciers on the N vs S side of the main divide*
- *potential global radiation can be calculated for all grid cells (e.g. for the melting season) and compared for the ablation and accumulation regions and the N vs S side glaciers*

- *glacier size can be plotted against minimum/maximum elevation, and mean slope / aspect*
- *mean elevation can be plotted against aspect (with different symbols for N vs S side and different colours for glacier type)*
- *the median elevation can be shown on a map (hill shade with outlines overlay?) as colourcoded filled circles (for glaciers larger than a certain size), or the grid-based precipitation from the climate data an be shown in the background (maybe using a greyscale coding?). Both would be more illustrative than Fig. 7*
- *maximum elevation, precipitation and maybe further terrain parameters should be used to explain the glaciers distribution*
- *some comments on how to calculate a median elevation for a glacier with an interrupted profile (e.g. nourished by snow/ice avalanches from higher elevations) would be worthwhile The in-depth analysis of the respective plots should allow for results that are sufficiently different from the N13 paper.*

We appreciate your suggestions. Nagai et al. (2013) only explained the difference of debris-covered glaciers between N–S mountain sides. N–S comparison of other variables including debris-free glaciers will be a good focus in this region with referring to Kääb (2008) and Komori (2008). We will show detail results of basic topography in the revised results.

3. When 'climatic influences on glacier distribution' is mentioned in the title as a key topic of this study, I expect a little bit more than precipitation only and Fig. 7. For example, the Ohmura et al. 1992 curve could be repeated for the glaciers in the study region, colour and symbol coded for glacier type, debris-free/covered glaciers and/or located in the N vs S. I also expect to see a map with the precipitation distribution (see point 2) and how this can explain median elevations (and their geographic trends), and where other factors play a role (e.g. snow redistribution by wind and avalanches, preferred nourishment for certain glacier types, etc.). For example, one can calculate precipitation amounts from median elevations and compare them to the climate data. This might be followed by an analysis of the degree of imbalance for the heavily debris-covered glaciers which might only exist due to the debris cover. In short, please add some climate data analysis or remove the topic from the title.

We will remove the analysis on precipitation and 'climatic influences' from the tittle.

4. Ch. 4 is in my opinion not really a discussion. It is presenting several further results related to this study. In a discussion I expect to see a comparison with results from other studies, a critical evaluation of the results, maybe including an error analysis, what has been missed and learned, and what future studies should investigate. I would also suggest to better distinguish data, methods and results and reduce repetition of N13 to a minimum. At first, I suggest introducing separate Chapters for the description of the data sets and the methods. The study site might be described as a part of the datasets. Then introduce sub-headings for glacier outlines, DEMs and climate data. Section 2.2 is basically methods, and should be separated into glacier outlines (please remove the PMS slopes), drainage divides (why have they not been derived from watershed analysis?), DEM-related calculations (hypsometry, statistics), preparation of climate data, and accuracy assessment (this has to be added, you cannot just adopt the uncertainty from another study!). P1313, L14-23 and P1314, L8-15 belongs to the discussion. The first 11 lines in Ch. 4 is a repetition of *results, please remove. Sections 4.1, 4.2 and 4.3 should be rewritten (see details in the other comments) and moved to the results.*

We will reconstruct the frame of this paper as; (1) Introduction: Proceedings of present glacier inventories, (2) Data sets: Place, source, and process of used data, (3) Methods: Explanation of manual delineation and other possible automatic methods, (4) Results: Basic statistical and topographical variables of these inventories in the Bhutan Himalaya, and (5) Discussion: Comparison of ICIMOD/RGI inventories, our pre-revised, and latest inventory (i.e. Which variables are largely affected by delineation error, and personal uncertainty of manual delineation).

5. P1309, L11: This is not a good motivation. The errorrs of the RGI described in Pfeffer et al. (2014) belong to another region (and have been corrected in the meantime) and the glacier outlines from ICIMOD should be fine for Bhutan. Why do it again? Why have your outlines not been compared to those from ICIMOD? Why is the use of panchromatic imagery 'advanced' (L12). As far as I remember, bare ice and rock are often difficult to distinguish (due to poor contrast) and high spatial resolution does not help at all when it comes to seasonal snow cover, in particular in the accumulation region and with panchromatic imagery. I can thus not see why new inventory has an improved quality over what has been available from ICIMOD. If a different interpretation of the accumulation area has been applied, fine. But please show the differences and use this as a motivation to digitize everything again. As I do not remember a specific publication for the ALOS derived inventory (?), please describe its details for Bhutan here. This means a full description of the snow conditions in the satellite images, how seasonal snow and debris cover has been mapped (outline overlay in close-ups), and how low-contrast regions (e.g. shadow) and clouds have been handled. This information is required when a topographic analysis of the glacier distribution is presented afterwards.

The quality of the RGI (ver. 3.2) is worse than that of the ICIMOD inventory in this region. This situation is shown in several figures of specific comments below (Fig. AC6 and AC7). The updated ICIMOD inventory is indeed fine in the Bhutan Himalaya, however several small glaciers which we outlined are not included. We guess that is because the spatial resolution of Landsat ETM+ (15-30m) is larger than that of ALOS PRISM (2.5m). Bare ice and rock are easier to be identified in PRISM image (Fig. AC10). Thus, numerous missed glaciers in a Landsat images can be identified in PRISM images, which is one of our motivation. This paper is the first publication for the ALOS derived inventory because we did not deal with debris-free glaciers in N13. In the revised manuscript, therefore, we will describe the delineation methods more in detail (as mentioned in the specific comments), and evaluate what kind of and how many glaciers are missed in Landsat images with specific values.

6. The PDS concept presented in N13 has in my opinion some flaws. I apologize for not having mentioned this earlier. However, as this study is rather repetitive in this regard, I take the opportunity to point out some of the issues. In N13 it is basically concluded that SW facing slopes and diurnal freeze-thaw cycles provide the debris for the debris-covered glaciers in Bhutan. As far as I know, the debris on the surface of a glacier appears in the ablation region due to emergent flow rather than deposition from above. It is a mixture of

internal/basal material (e.g. forming a medial moraine) and material that has fallen on the glacier in the accumulation region (near the bergschrund). This can happen when the accumulation region is surrounded by some ice-free rock walls (as is the case for the glaciers south of the main ridge). Without these debris providing ice-free rock walls (e.g. as common for ice caps and the glaciers north of the main divide), glaciers are debris free apart from medial moraines resulting from basal/internal material.
Debris that is falling on the glacier from rock walls surrounding the ablation region must be large to get the entire way down to the glacier surface and maybe also jump over a lateral moraine. As far as I know, this is not possible for material resulting from diurnal freeze-thaw cycles as its size is too small. On the other hand, larger rock fall events leave debris of a particular lobate shape that is gradually stretched with glacier flow (as shown in Fig. S1 of N13). To get a homogenous cover, such rock fall events reaching the glacier tongue in the ablation area must be very frequent (is this the case in Bhutan?). The loose material from exposed lateral moraines can only accumulate locally and will likely never provide sufficient material to cover the entire surface. A good example is the glacier Pasterzenkees in Austria (below Grossglockner) where the related processes have been studied and documented in detail (e.g. Kellerer-Pirklbauer et al., 2008). The glacier is only partly debris-covered on its western side as there are no ice-free rock walls in the upper part of the accumulation area but steep slopes with frequent rockfall above its ablation area. There is in general no dependence on the aspect of the rock wall to be expected, neither when the material is entrained in the accumulation region nor when it falls on the glacier in the ablation region. For the Pasterzenkees the rockwalls are facing NE, for the neighbouring Ödenwinkelkees the rock walls are facing N. In the latter case they surround the entire accumulation area so the tongue is completely debriscovered. To some extent also the lithology of the material should play a role for weathering processes, at least compared to terrain aspect. But I think the point is made. I would strongly recommend removing the PMS analysis from this study (see also next point). By the way, PMS is an unfortunate abbreviation that has also a very different meaning.

We understand the first paragraph. In the second paragraph, we do not think that debris materials which 'jump over a lateral moraine' have dominant contribution for debris supply because of highly deposited moraines in the Bhutan Himalaya. Indeed grain size of a debris fragment sometimes reaches several meters. Diurnal freeze-thaw depth is not exceeding 50 cm, and annual freeze-thaw depth reaches several meters. However the contribution of annual freeze-thaw cycle for debris supply is completely denied in N13. We guess freeze-thaw depth is not directly related with debris grain size. Figure S1 of N13 suggests a large rockfall event providing huge amount of debris mantle at once, however this type of debris supply is very rare (i.e. once in one hundred years) (Matsuoka, 1998). Figure 7 in N13 showed a north-facing debris-covered glacier, which suggests continuous debris supply from south-facing slopes, considering its flow rate and debris supply frequency. In order to remove the local influences such as lithology and individual cases of surrounding slopes' location (around ablation area or accumulation area), not only two or three glaciers, but exceeding 200 debris-covered glaciers were analyzed and statistical results were obtained in N13. It denied the previous understanding of 'There is in general no dependence on the aspect of the rock wall to be expected' at least in the Bhutan Himalaya. We will rename PMS slope to P-M slope.

7. By extending the former PDS (from N13) to PMS including avalanches, completely different processes are mixed up. Snow avalanches might be a major source of accumulation for the glaciers in this region and they *do not depend on the availability of ice-free rock walls and likely occur much more frequent. The amount of snow that can accumulate depends (among others) on wind direction and requires low slopes while rock avalanches might preferably occur at steep slopes and depend on lithology rather than wind direction. So when explaining why glaciers are where they are these processes should be distinguished.*

As I replied to the following specific comment for P1312, L5/6, a PMS slopes is defined as 'a continuous slope between glacier margins and mountain ridges tilting towards a glacier'. It has avalanche possibility and debris supply possibility. Ice-free or ice-covered are not concerned at the stage of delineation. After the delineation, we found steeper slopes tend to be located around debris-covered glaciers (Fig. 5). Wind direction is difficult to be estimated theoretically around these steep mountains. Contrast of tectonic condition, such as shatter zone distribution, is more important than lithology in this region (Nagai et al. 2013).

8. When explaining the glacier distribution from topographic and/or climatic characteristics, please consider to separate glaciers of different type. Apart from debris covered or not and being located N vs S of the main ridge, it would make sense to classify glaciers by type (valley, mountain, cirque, firnkessel type, calving, etc.). These types have likely distinct topographic characteristics that could be analysed separately (or for sub-samples, see point 2).

Thank you for your suggestions. We will try it.

9. In my opinion too much of the governing process is 'hidden' in statistics (Figs. 6 to 9) and selected to be relevant based on correlation coefficients. However, there is in general very little that can be derived from r and p values alone, e.g. the glaciological meaning is getting little attention. For example, why show Fig. 8 when there is no correlation to be expected? Median elevation might depend on glacier aspect and precipitation amounts, but not on glacier size (the PMS slope ratio is auto-correlated with size). I have given some examples for correlations under point 2 and hope that these can be evaluated in a revised ms.

At this stage, we will remove PMS slope and climatic data, then basic topographic parameters will be analyzed as you suggested.

C. Specific comments
P1306, L22: Are you sure that glacier melt water is directly used for human consumption? At some point I assume is a filter to remove the sediment?

We will remove this because we have no evidence.

P1307, L7: What does 'highly sensitive' mean? The change in mass balance (or length?) due to a change in temperature or precipitation or some other climate variable? And why 'highly' what does change more than elsewhere.

It means glacier mass balance (e.g. kg m^{-2} yr^{-2}) corresponding to the increase of atmospheric

temperature. Not only temperature increasing itself, but also surface albedo decreasing caused by the change from snowfall to rainfall promotes effective melting in humid regions. We will add this explanation in the revised manuscript.

P1307, L8ff: This argument is difficult to follow: The Randolph Glacier Inventory is available for some years now and combined with the also available SRTM or GDEM we already have the complete information about glacier distribution (spatially and in elevation) and their relation with topography. 'Largely unknown' is something different. Please add and explain what this study is providing compared to what we already have.

We appreciate the great effort of the Randolph Glacier Inventory (RGI), which globally covers glacierized regions including the Bhutan Himalaya, but we cannot utilize it because the released and latest data (v.3.2) has not included any information of elevation on its attribute table (Fig. AC3). Incorrect outlines are still seen in this region (Fig. AC4) which hamper correct topographic analysis with DEMs. Fortunately, the ICIMOD glacier inventory was updated recently and its quality seems to be similar to ours. In the revised manuscript, we will perform comparison and evaluation of these.

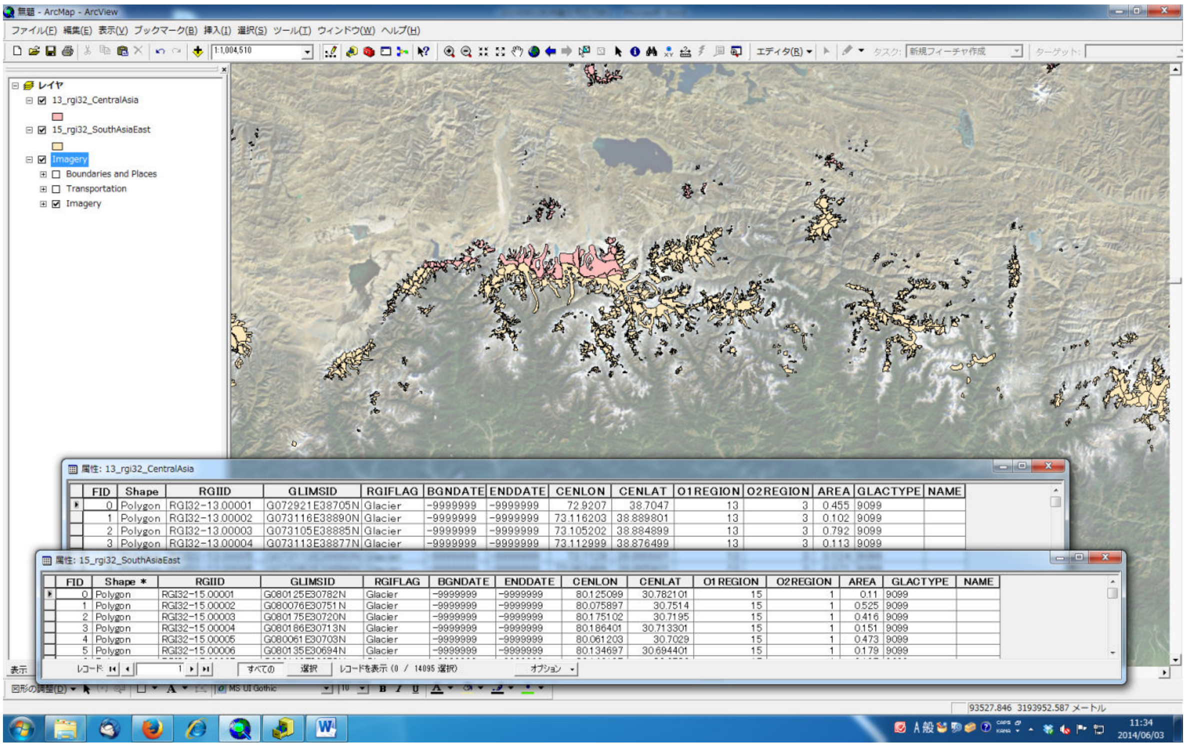

Fig. AC3. Two available files of the Randolph Glacier inventory and their attribute tables which include glaciers in the Bhutan Himalaya. Background image is an ALOS/AVNIR-2 mosaic image.

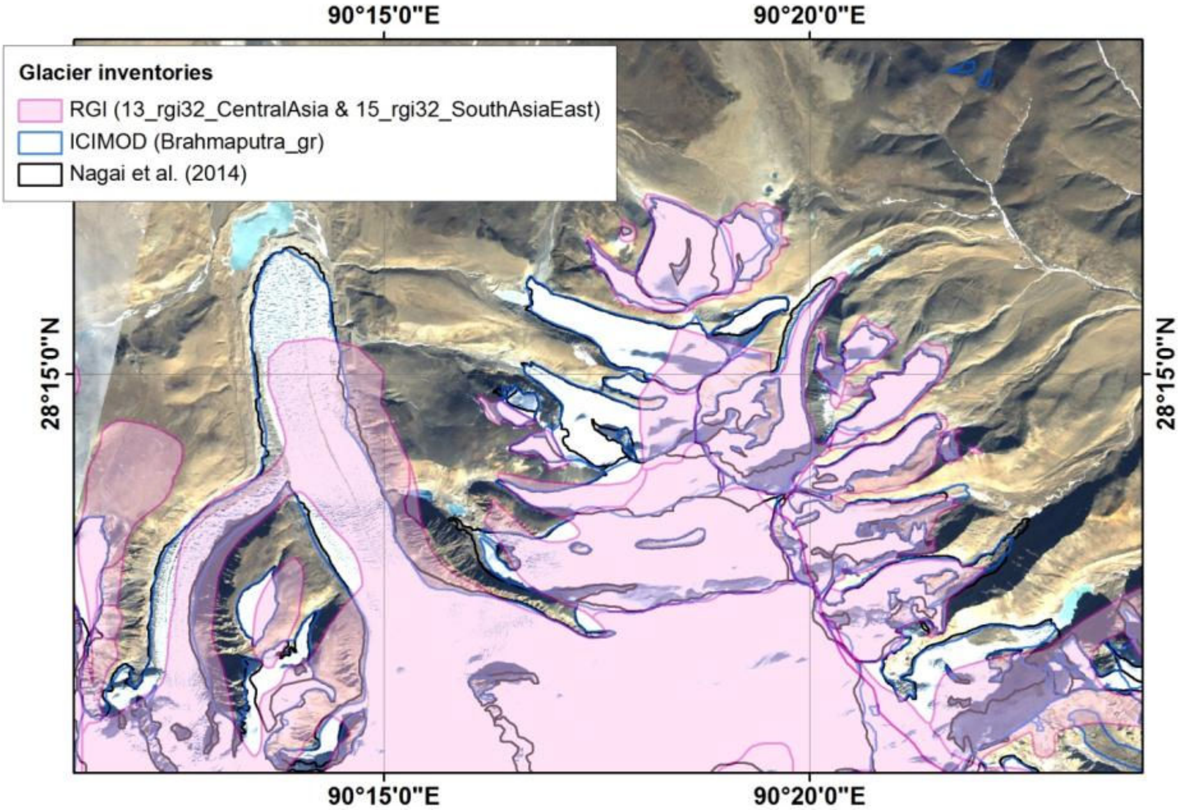

Fig. AC4. Comparison of three glacier inventories in a part of the Bhutan Himalaya. Background image is an ALOS/AVNIR-2 mosaic image.

P1307, L14ff: Please be sure to refer here to the ELA0 (for a balanced budget) rather than the highly variable ELA of a specific year.

Yes. We intend balanced-budget ELA throughout this paper. We will explain it in the revised introduction and methods if necessary.

P1307, L20: How does the median elevation as a proxy for the ELA0 work for glaciers with an interrupted profile?

In that case, median elevation would be located in the larger part (lower half in Fig. AC3) which divides glacier area into half (two of S km2). If the interrupting gap divided the glacier just half, the median elevation would suggest the maximum elevation of the lower part or the minimum elevation of the upper part, but such an exquisite case does not exist in our inventory.

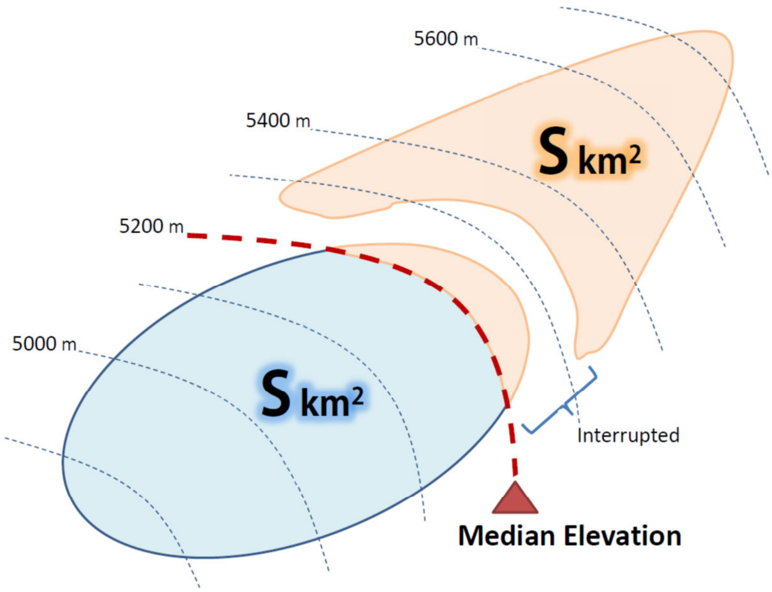

Fig. AC5. A schematic of how median elevation divides an interrupted glacier body.

P1307, L22: Why is debris cover a matter of concern? Please explain. It is certainly a key challenge for mapping glacier extents, but what is the problem when it protects the ice from melting?

Debris-covered glaciers have very complex characteristics of heat transfer which greatly affects glacier mass balance. Melting rate of debris-covered area is controlled by debris thickness (thicker to insulate) and roughness (small ponds and ice walls to melt faster). Mixture of these features makes it difficult to estimate the melting rate correctly from remotely-sensed data. We will change 'concern' to 'complicating' in the revised manuscript corresponding to Dr. Pelto Mauri's suggestion [1307-22]. We will add 'On the other hand, other studies suggested recent faster glacier melting below thin debris-covered areas than debris-free areas (Bolch et al., 2011; Zhang et al., 2011).' at [1307-29] corresponding to Dr. Pelto Mauri's suggestion, too.

P1307, L25: How can a thick debris mantle 'stabilize their termini' and at the same time 'enhance the expansion of debris-covered ablation areas, thus lowering the median elevation'? I see the point that glaciers with debris-cover could become larger than debris-free glaciers during their formation, but afterwards the debris is just keeping the glacier out of balance with climate for some time. So these ice bodies should have much too low median elevations compared to what precipitation and temperature is providing. Please show this imbalance.

Stabilizing their termini is caused by the superiority of surface lowering rather than terminus retreat (Scherler et al., 2011a). We will modify 'stabilize their termini' to 'stabilize the horizontal positions of their termini'. We will delete 'In terms of···thus lowering the median elevation.' because it is difficult to say whether each of debris-covered area was already formed in the advancing period.

P1307, L29: Debris supply is only one factor with a potential influence on glacier extent among many others. There is also topographic shading, elevation and shape of the surrounding topography compared to wind *direction, snow deposition and solar radiation, the hypsometry of the glacier surface, etc. Please investigate these!*

We do not deny other factors as you suggest. To avoid misunderstanding this sentence will be changed as 'Debris supply is one of topographic influences on the extent of glaciers, which appears to correlate…'

P1308, L7/8: Indeed, little is known but their influence might be large. Please show what the local depression of the median elevation due to topography and debris cover is

I tried to show it in the discussion of this study. Outlines of surrounding slope (PMS slope) were therefore necessary.

P1308, L14/5. Yes indeed. Please investigate this.

I tried to show it in the discussion of this study.

P1309, L1: Raup and Khalsa (2007) are practical guidelines for digitizing of glaciers. Please cite Kargel et al. (2005) or Raup et al. (2007) as a reference for GLIMS.

Yes, thank you for your suggestion.

P1309, L2-6: These shortcomings in RGI quality were related to glaciers in the Andes (seasonal snow) and the Tien Shan. For Bhutan, the RGI/ICIMOD inventories are fine

There are numerous shortcomings also in the Bhutan Himalaya in the RGI (Fig. AC4 and AC6). On the other hand, the ICIMOD inventory was updated recently.

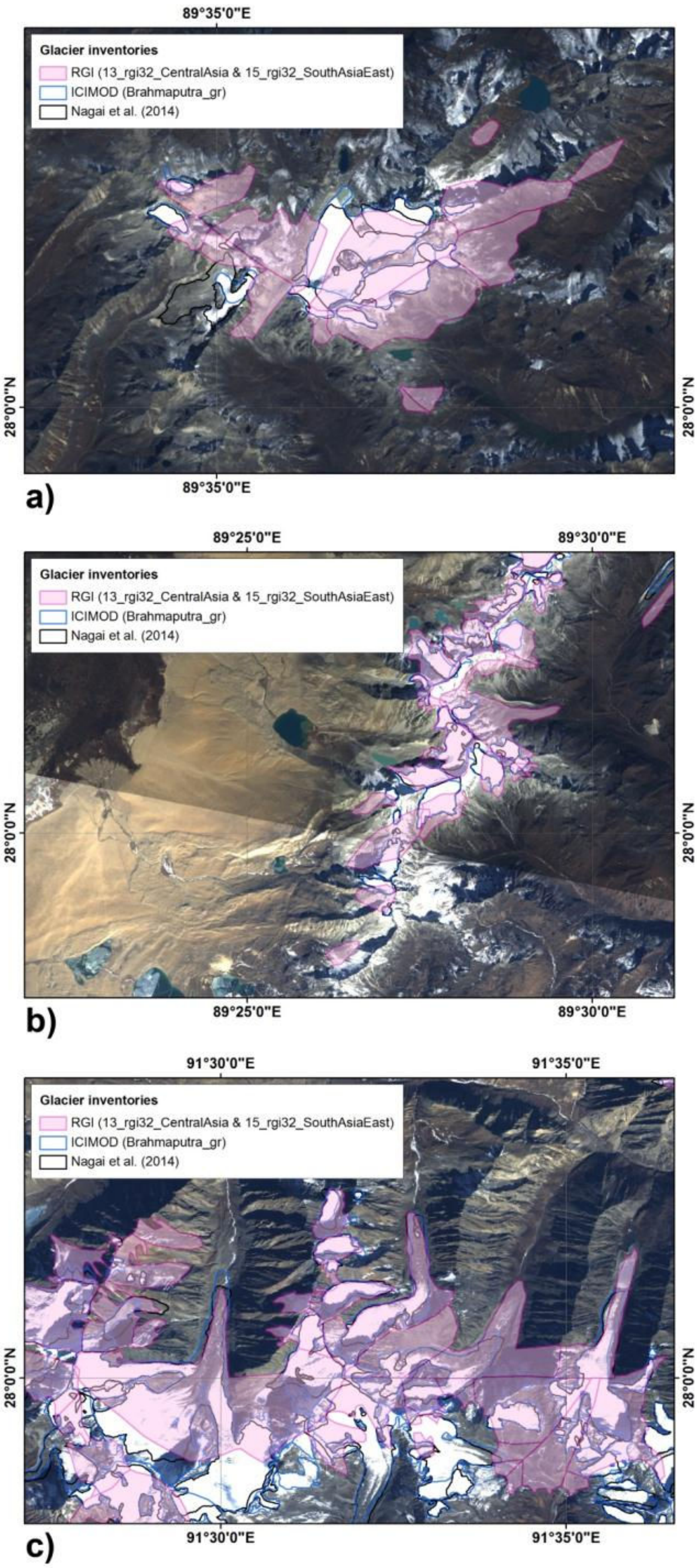

Fig. AC6. Outlines of the RGI, ICIMOD inventory, and our inventory in the Bhutan Himalaya. Background image is an ALOS/AVNIR-2 mosaic image.

P1309, L9/10: Why does complex topography and snow cover not influence the high spatial resolution imagery from ALOS? The ALOS satellite has a much shorter archive than Landsat so that it is likely much more difficult to find appropriate ALOS scenes. You have thus to make very clear (and visualize!) what the advantages of the ALOS inventory are (or publish the inventory paper first and explain it there).

This sentence does not mean that ALOS images are not influenced by complex topography and snow cover, but suggest that the Bhutan Himalaya has inconvenient conditions for previous delineation methods. These surface features are also seen in ALOS/PRISM image, but its higher spatial resolution enables easier visual identification (Fig. AC7). The contrast of smooth glacier surface and rough snow-covered bedrocks is easier to be distinguished in ALOS/PRISM data (Fig. AC7b), which seems to influence on delineation quality of the three inventories. Longer achieve period of Landsat does not overwhelm this superiority because more of less snow cover always exists (Fig. AC7a). We will explain these differences using this figure in the revised manuscript.

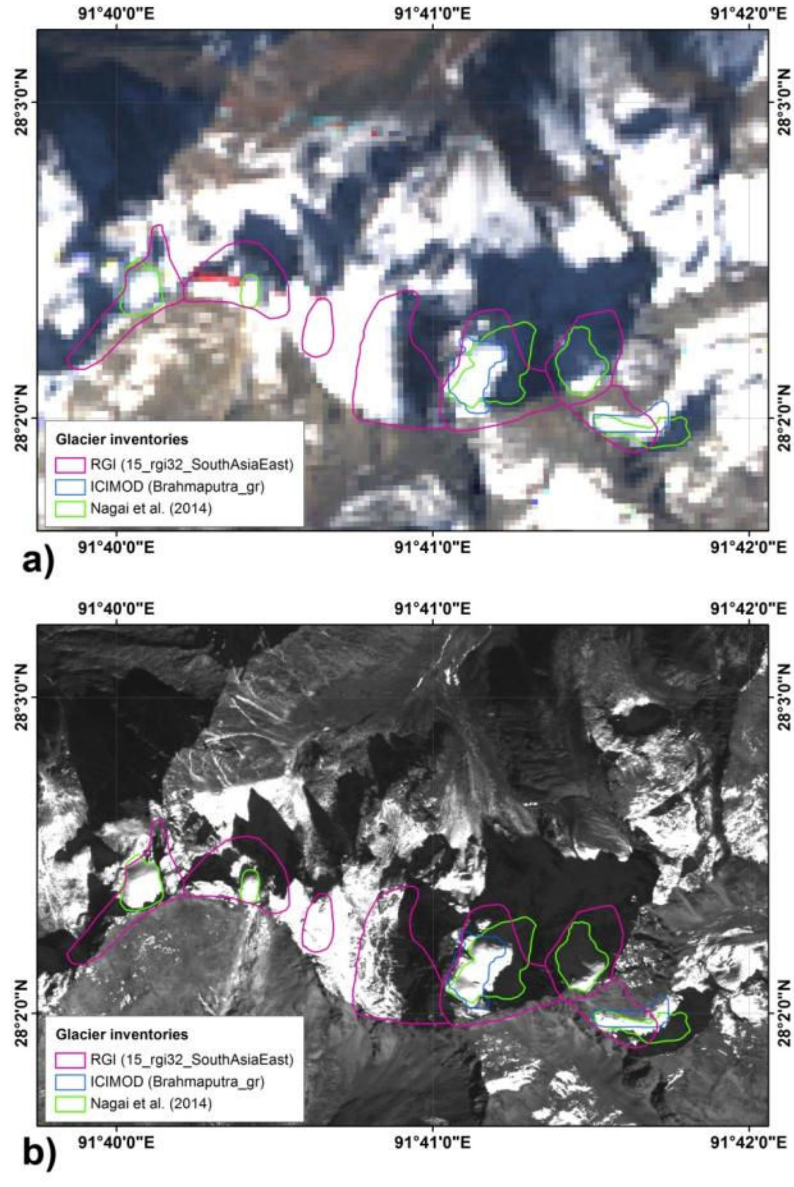

Fig. AC7. Comparison of (a) a Landsat ETM+ image and (b) an ALOS/PRISM image. Outlines of the RGI, ICIMOD, and our inventories are overlaid.

P1309, L22: I would not do this under the same name. These are very different processes.

So, we renamed it from 'PDS slope'.

P1310, L1: Taking the image with the least snow cover is fine, but this is different from an image without snow cover (outside of glaciers). So please show examples of such images and how you have corrected the outlines (overlay).

We chose (a) a PRISM image with less snow cover rather than (b) that with much snow cover, but ambiguous outlines still remain. Then we used (c) AVNIR-2 image and (d) Google Earth image, outlines were revised (orange to green outlines) to the most preferable shape.

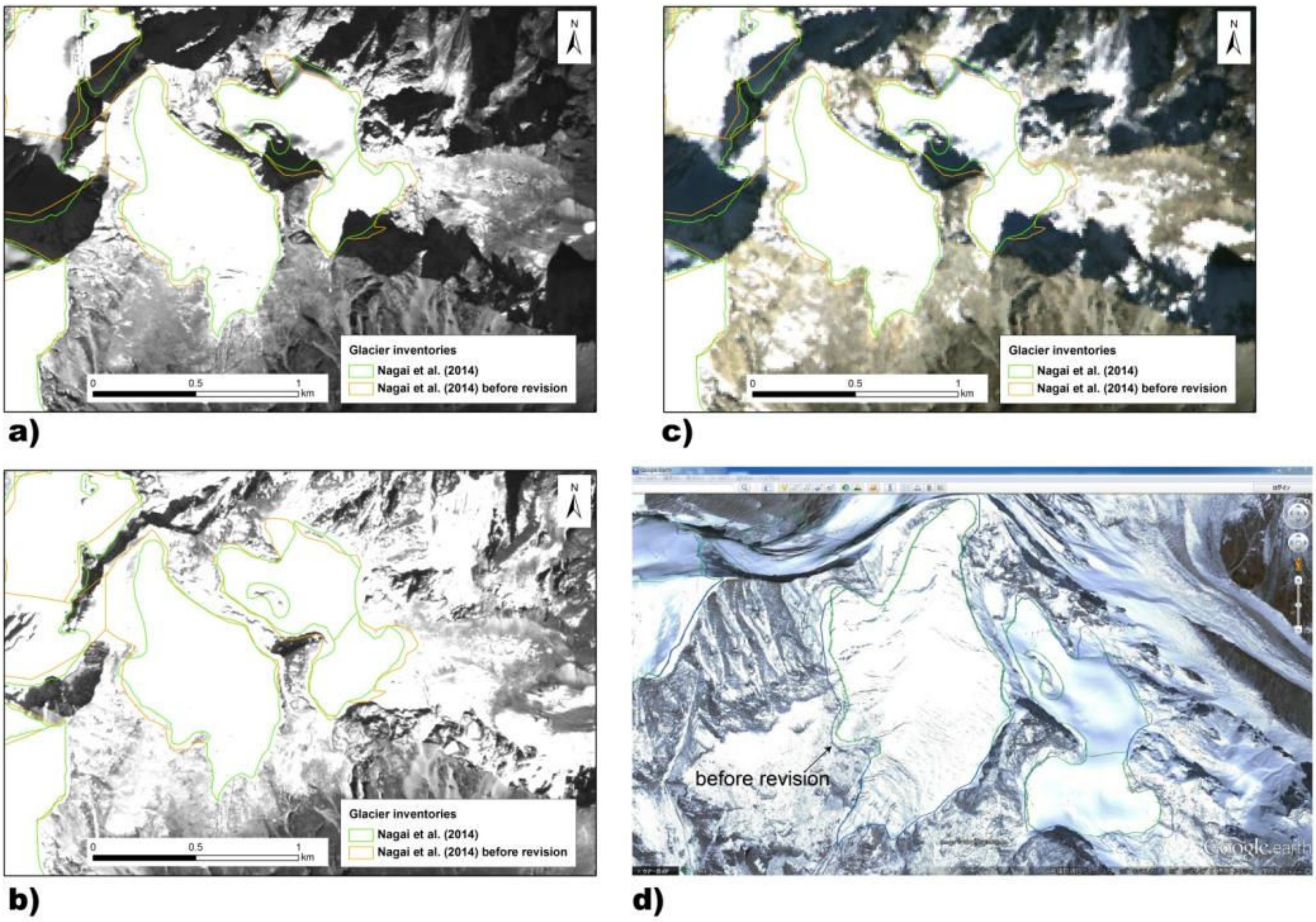

Fig. AC8. Comparison of (a) a less snow-covered, (b) a much snow-covered PRISM image, (c) AVNIR-2 image, and (d) Google Earth image of three glaciers in the Bhutan Himalaya.

P1310, L7: How have drainage divides in the accumulation area been derived from 20 m contour lines, by manual digitization? Please explain this, as for normal (automated) watershed analysis is applied (providing more consistent results).

We performed manual division by;

1. **finding points where a connected glacier outline crosses mountain watershed basins,**

2. from each of these points, cutting the outline along mountain ridgelines (Fig. AC9b) (i.e. preferably cross the contour lines vertically),
3. finding points where glacier flow is divided into each glacier,
4. cutting the outline from these points to the upper already-divided line preferably crossing the contour lines vertically (Fig. AC9c).

Automated method is available but more or less modification may be needed. We will compare them in the revised manuscript.

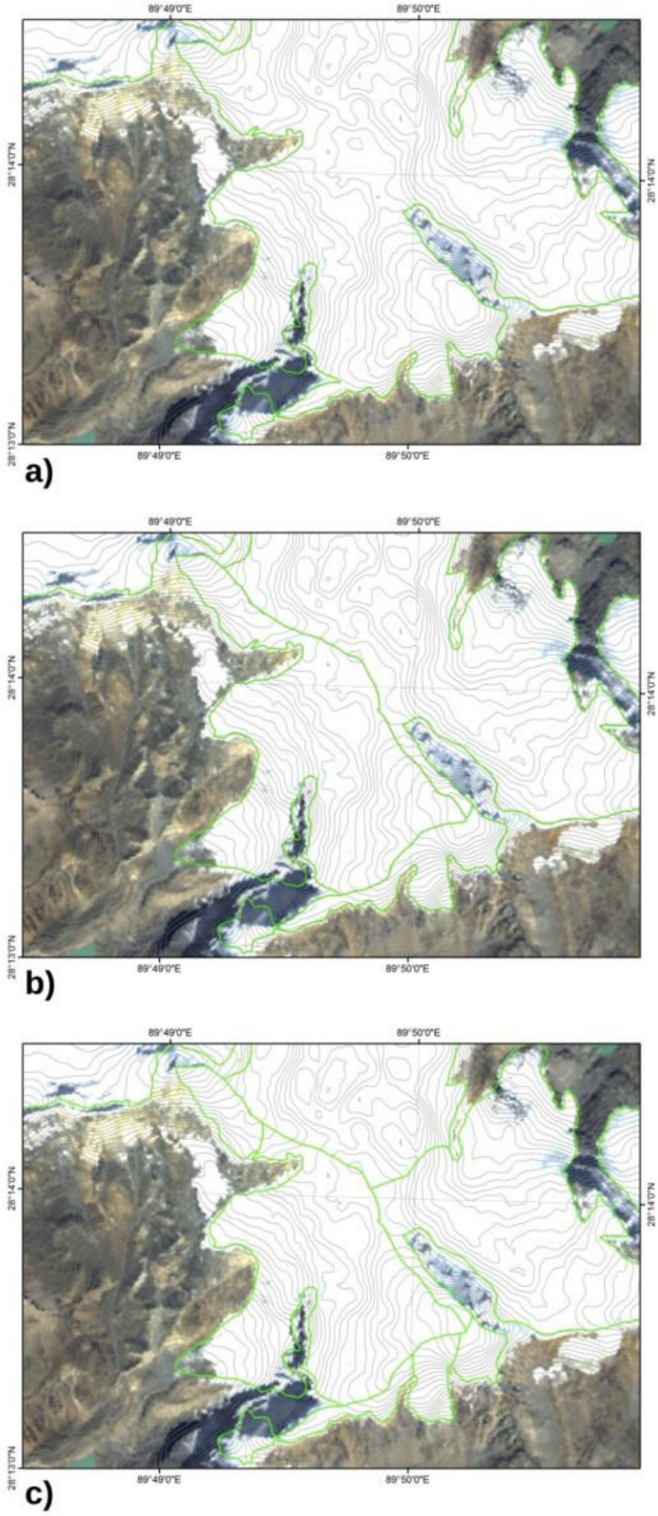

Fig. AC9. Dividing procedure on glaciers in a completely snow-covered area using ASTER GDEM2-derived contour lines. From (a) an outlined polygon, glaciers are divided along (b) main mountain ridges and (c) sub ridges.

P1310, L14/15: Two things are wrong here: First, because of the higher resolution (artifacts!) of the GDEM2, its accuracy is often worse than the SRTM DEM. Please also consider that the details resolved in the GDEM are closer to what SRTM is providing than to 30 m. Secondly, the cited Hayakawa study has not analysed glaciers. Regarding stereo photogrammetry from optical imagery, glaciers are very different from other terrain. They are much more gentle sloped, have often zero contrast over snow-covered regions and the spatial pattern of debris cover can interfere with the image matching algorithm, both resulting in low correlations and poor DEM quality over glaciers (despite their gentle slope). Overall, SRTM has often superior quality over glaciers and other reasons for using the GDEM2 in this study should be provided (e.g. the data voids issue).

Our main focus which was decisive to the conclusion was not glacier surface but surrounding slopes. Generally speaking, since STRM sensor transmits and receives microwave with off-nadir angle, biased values caused by slope aspect and gradient (i.e. forward slope or backward slope against the sensor) should be considered in a steep mountain region. On the other hand, difficult surfaces in ASTER GDEM2 are filled by other preferable data. The DEM2 was used due to these reasons. We will compare and evaluate how much difference appear on glacier variables between use of the GDEM2 data and SRTM data in the discussion of the revised manuscript.

P1310, L21: Please explain why this is possible and maybe show an example illustrating the quality of the digitizing. The images in GE are sometimes heavily snow covered, i.e. please provide evidence that this was not an issue in this study. Please explain the process of correcting an obviously wrong delineation after visual inspection (repeat overlay?).

GE is an assistant tool to avoid fatal misunderstanding of topography and to confirm that it is a glacier. We referred to pre-revised polygons in GE in one PC monitor (Fig. AC10a) and adjust them to be more outer or inner outline in ArcGIS in another monitor (Fig. AC10b). Indeed it is snow covered, but visual interpretation enables the identification of glacier body (or snow-covered bedrocks). We did not adjust it directly in GE because a little distortion of projection was caused by the difference of the source data (i.e. SRTM & Quick Bird for GE) in some cases. In many cases, however, pre- and after-revised polygons are more correct than the ICIMOD inventory.

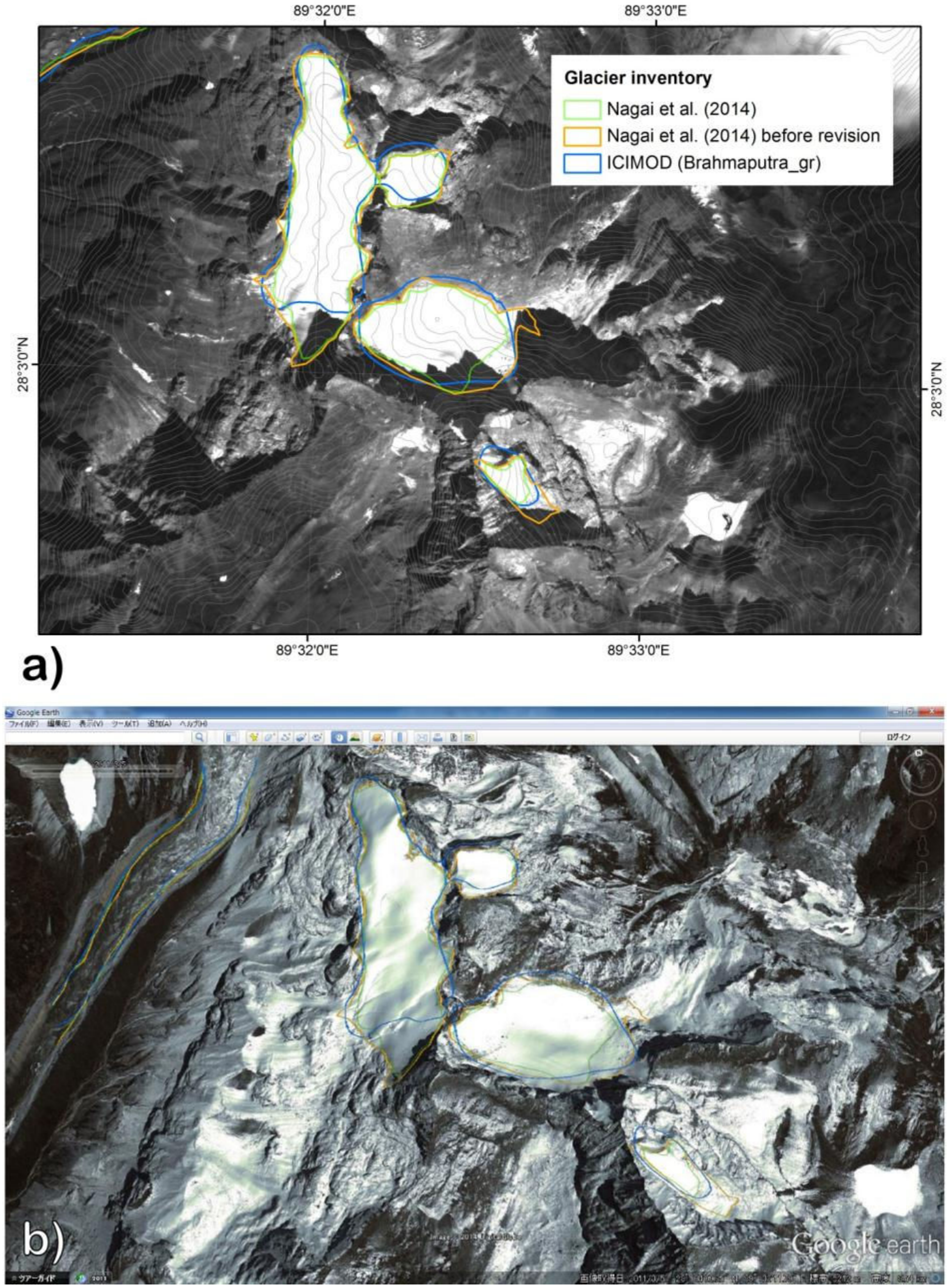

Fig. AC10. Detail visualization of glaciers on (a) a PRISM image and (b) a Google Earth image.

P1311, L7: What are these surface features of unstable steep slopes?

It means traces of something fallen around (and to) a glacier (i.e. rockfall or avalanche). In Fig. AC11, several traces which are going to the glacier surface are recognized in the P-M slope (renamed from PMS slope). On the other hand, traces which is going to outside of the glacier suggest no contribution of material supply. After delineation by contour lines, these considerations ensure correct delineation of P-S slope outlines.

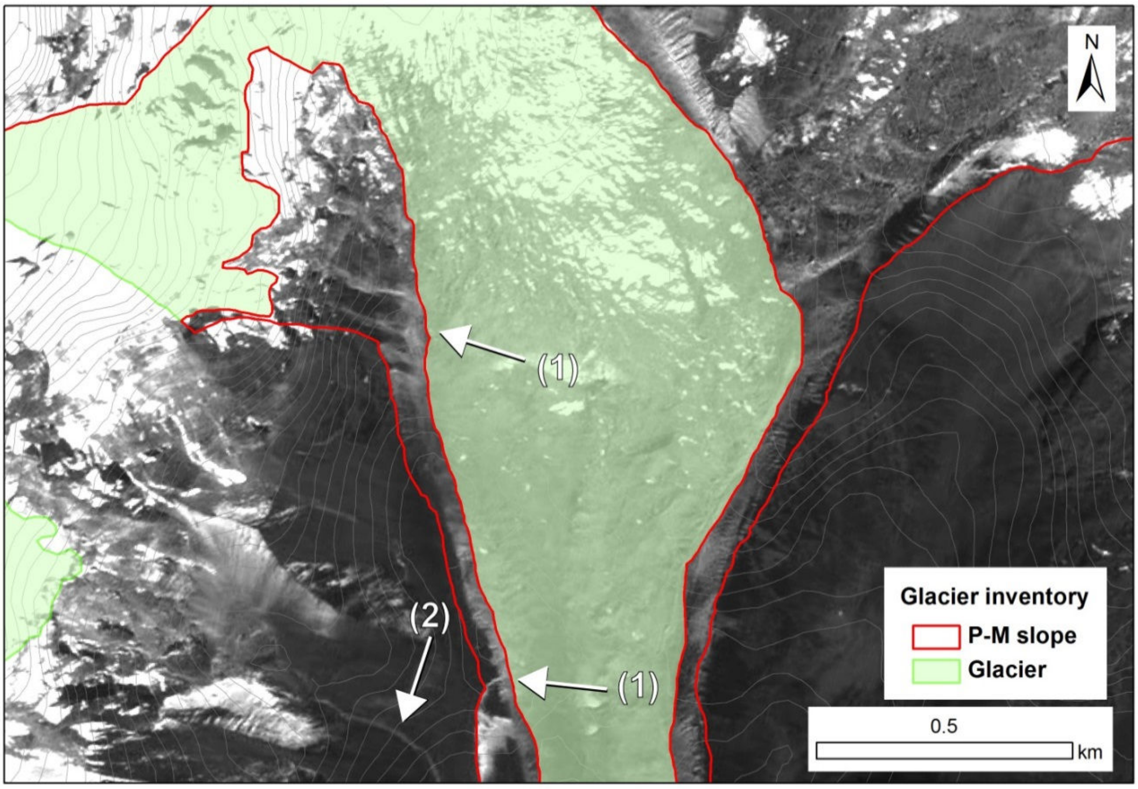

Fig. AC11. A PRISM image of a glacier and its P-M slope. Several traces which are (1) flowing into the glacier and (2) flowing outside of the glacier are recognized.

P1311, L15/16: This external control is fine, but it also worries me. When outlines need to be corrected three times I would conclude that the analyst has problems with the digitizing.

Geomorphological and glaciological consideration was developed from a beginner to a delineation expert for 5-years repeating delineation.

P1311, L23/4: Deriving watersheds from contour lines only, seems rather inaccurate to me. What about using a flow direction grid or any of the other available algorithms?

In some cases, it is modified by PRISM image especially for steep ridge line. Such judgment was also performed through visual interpretation. If the original DEM quality was incorrect by snow cover, other algorithms could not obtain good result, either.

P1311, L26: It is not possible to apply automatic methods with panchromatic imagery, you need a SWIR band for this

You are right. This description does not mean PRISM panchromatic image which we used, but means previous methods by multi-spectral images.

P1312, L1/2: This sounds like serious impacts from seasonal snow. Can you please demonstrate that your glacier outlines do not suffer from misinterpretation of snow?

It is impossible to obtain an image where no seasonal snow cover is ensured, because accumulation area is a snow-covered surface itself. Additionally the boundary position will be moved by glacier dynamics. Therefore, we performed delineation by one of available images with the least snow cover (Fig. AC12c rather than AC12a and AC12b). This is so far the best way.

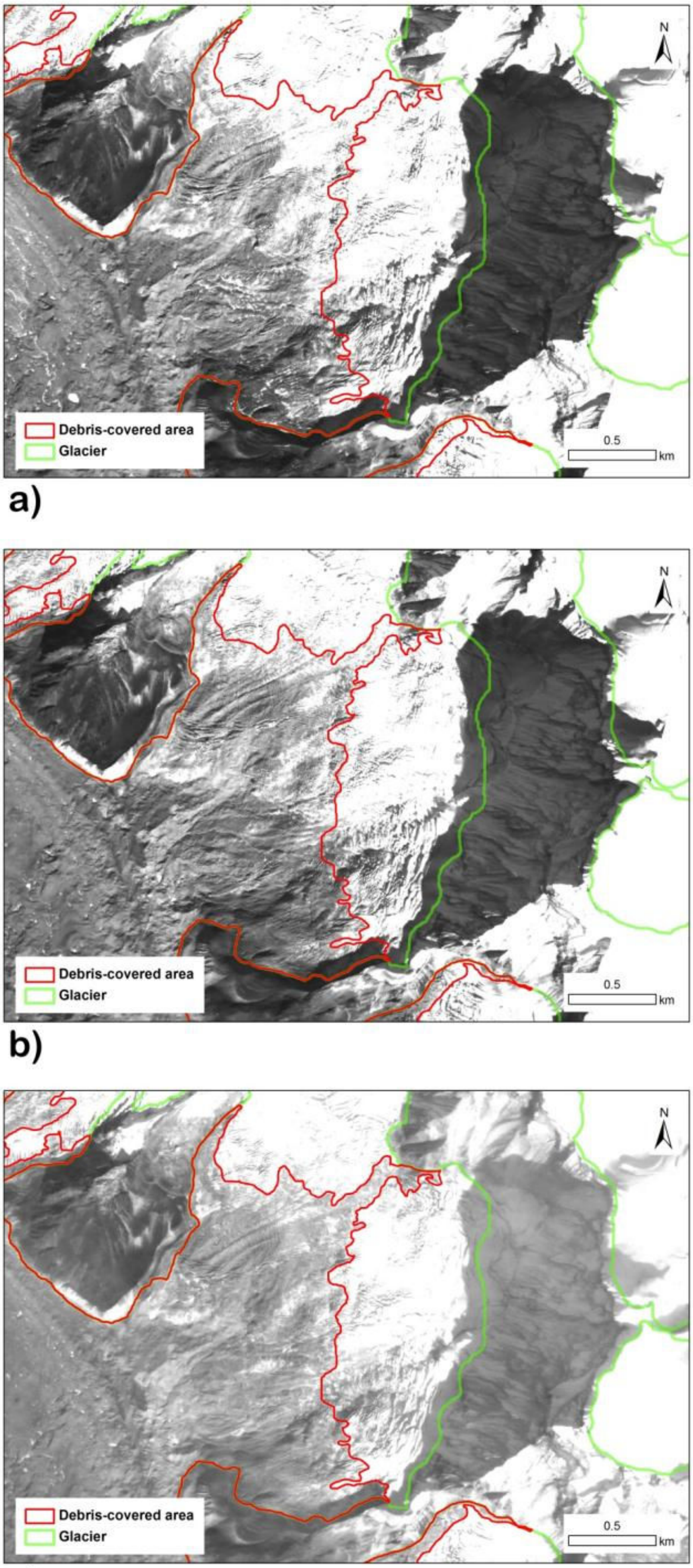

Fig. AC12. Three PRISM images for a boundary of a debris-covered glacier surface. (a) Worse, (b) better, and (c) the best surfaces of debris-covered area are shown.

P1312, L5/6: I would restrict the term 'slope instability' to slopes that are instable. An avalanche that comes down a slope does not mean that the slope is instable. These are completely different processes (see point 7).

We will modify this sentence to avoid misunderstanding. Again, a PMS slopes is defined as 'a continuous slope between glacier margins and mountain ridges tilting towards a glacier'. At the delineation stage, we did not consider whether it seems stable or not, snow-covered or not, and avalanche seems more possibly than debris supply or not in order to compare these different processes. Both possibilities existed in a PMS slope and they were discussed in our manuscript.

P1312, L14/15: How is debris covered vs debris free defined? I assume that only completely covered tongues are counted here? This needs clarification as a glacier with a medial or lateral moraine would also be considered as debris covered.

If we identify any of debris-covered area which covers ice-or-snow surface, we define it as a debris-covered glacier. In that procedure, medial and lateral moraines are excluded.

P1312, L17: That's all fine, but what is now the debris-covered area and the percentage of coverage per glacier (min/mean/max/std)?

We will summarize and show them in the revised manuscript

P1313, L5-13: The hypsometric analysis should be better resolved, e.g. for glaciers of the same size class, N and S of the main divide and/or by glacier type. Just lumping all debris free and debris-covered glaciers in one graph gives little insight to the 'topographic influence on glacier distribution' (see also point2).

We will summarize and show them in the revised manuscript

P1313, L16: Please perform an uncertainty assessment here as well, independent of the results of earlier studies. Take about 10-20 glaciers of different size (with and without debris cover) and digitize them 3 times independently (with one day in between). The standard deviation of the derived glacier areas will be a good measure of the accuracy.

Yes. We will compare them in the revised manuscript

P1313, L25/26: What are ASTER GDEM2 images? Do you mean that aspect has been derived from the GDEM2? If yes, please add the information their.

It means ASTER GDEM2 data to acquire aspect value. We will modify this sentence to avoid misunderstanding.

P1314, L2: I think this statement about the influence of solar radiation on the development of debris-free glaciers cannot be made here. It requires at least some investigations about (potential) solar radiation.

It means one perspective for the reason. We will modify this sentence to avoid misunderstanding.

P1315, L17-21: I see no point for this statement in such a generalized form. Glaciers develop where sufficient solid precipitation (snow) survives summer temperatures. So elevation and precipitation amounts are responsible for glacier development. Aspect (and topographic shading!) or debris cover only modify their general distribution.

As above, we will modify this sentence and background analysis more in detail.

P1317, L3: I do not understand the meaning of Eq. (1). Please explain its physical base.

This did not contain any physical meaning, but inserted to help understanding of the following formulae. We consider removing.

P1317, L21: Please show this on a colour-coded map as described above.

Yes. We will add a map in the revised manuscript.

P1318, L5: There are several papers that have already shown this (e.g. Kuhn 2003)

Thank you, we will refer to them, although this is primal information of our discussion.

P1318, L8: This sounds like a very active process. Please consider that current glacier extents are likely only relicts of better times and that might vanish under current climate conditions. The debris protection is just extending their existence.

I see. We will consider it.

P1319, L1: The entire section 4.3 reads like a self-fulfilling prophecy for the N13 paper. Please write about something different in this study.

It is not a self-fulfilling prophecy. We newly found the relationships of median elevation and PMS slope aspect which was not in N13. Comparing it and the previous finding in N13 (i.e. relationships between debris-covered ratio and PMS slope aspect), elevation distribution affecting by debris cover was explained logically. Additionally debris-free glaciers were not analyzed in N13 at all. Avalanche possibility is, for the first time, able to be discussed excluding debris cover here. However, further PMS analysis will not be performed in the next manuscript because the quality of our inventory is not yet evaluated.

P1320, L3-13: Please remove this copy/paste section from N13 (cf. P1675 in the TCD ms).

Yes, we will remove it.

D. Terminology

Please use region instead of area when reference is made to a geographic region and please use glacier / glacierized instead of glacial / glaciated when referring to contemporary glaciers

Yes, we will change them, thanks.

E. Figures and Tables

I have already provided some suggestions for improvements above (e.g. close-ups, outline overlays, other plots), so I will not repeat this here. In general: Please add tick marks on both sides of the plot (such as Figs. 2 and 6-8) and maybe even dotted grid lines (Figs. 2 and 6).

Yes, we will add them, thanks.

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