Reply to reviewer's comments

We would like to thank the reviewer's valuable comments about our manuscript.

(Original comments are in italic, our replies are in bold)

Reviewer#1, Graham Cogley

This paper presents a large-scale glacier inventory covering all of High Mountain Asia, dated to the period 1999–2003 and relying on Landsat imagery and the digital elevation model of the Shuttle Radar Topography Mission (among other data sources). A huge amount of work has been done and documented carefully. Quality control and accuracy tests (leading to an estimate of region-wide accuracy in glacierized area of about 15%) are presented, and the new inventory is compared to an inventory of Bhutanese glaciers relying on ALOS imagery and to the recently published Randolph Glacier Inventory (RGI). The RGI is a global inventory, and in much of the present study area it is in fact the Chinese Glacier Inventory, which is the result of a major effort some 30 years ago based on surveys 20 to 40 years before the date of the new inventory.
Apart from the presentation of what will be a valuable regional-scale (and hopefully global-scale) resource, most readers will see the main result of the present submission as the finding of much less ice (30% less) in High Mountain Asia than is present in the RGI. The authors discuss this discrepancy for the most part reasonably, noting that the passage of more than 30 years will account for some of the difference and that there are quite serious ambiguities in the source imagery that are very difficult to resolve in the absence of field observations. However I am concerned by their apparent assumption that steep slopes which are bright in the imagery represent snow that will avalanche onto the surface of the "real" glacier in the valley below (so the steep slopes are not part of the glacier). This subject needs further consideration in the paper, but it should not be expected that the discrepancy can be resolved within the confines of the present study. My own instinct is to suspect that the exclusion of these steep slopes may in fact tend to underestimate the glacierized area, but I have to admit that is only a suspicion.
The paper is quite well written, and is commendably very short. There are some problems to do with clarity, and some of the Supplementary Information needs further work, but these criticisms are not fundamental. I think that this important new inventory should be documented in the literature, and subject to consideration of my comments below I would be happy to see it published in The Cryosphere.

We have to report the present status of our inventory, before going to reply your comments.

Present version of our GGI has two underestimated area.
1) Higher elevation with relatively steep slope area.
a. We eliminated steep walls from the glacier area, therefore, if steep headwalls include glacier ice, we underestimate glacier area. And hanging glacier tend to be eliminated. These under estimation would be a fault of our inventory.

b. We have a rule for delineation of glacier area, "steep walls, where snow cannot accumulate, are not included in glacier area". But, in the present state, we underestimate glacier area at upper region of glaciers than our rule, and we have eliminated upper glacier area, even where snow can accumulate. We are trying to revise our inventory according to our role of glacier delineation.

2) Shadow part

We used Landsat images taken during winter season, because the Himalayas are affected by monsoon during the summer season, and cloud-free image is difficult to obtain during the summer. Then, we have overlooked the glacier at shadow part.

Now we are correcting. We will evaluate the median elevation derived from our GGI (not including steep walls) by comparing with those from ICIMOD inventory, which include steep walls.

We will add these faults of our inventory in the revised manuscript.

P2800

L4 Why not give the exact number of scenes?

We used 0 to 5 Landsat scenes in 226 path-row sets in Figure 1. Actual number of scenes used to delineation is 322 scenes. We revised it as "322 Landsat ETM+ scenes in 226 path-row sets".

P2801

L13 The distribution of dates in the Chinese Glacier Inventory is actually from ~1956 to ~1983, with the median at about 1970. So repeated references in the paper to the 1970s should probably be to "the 1950s-1980s", although space could be saved by saying here that "for brevity we refer to the Chinese inventory as being from the 1970s.".

Thank you for the precise information. We will revise.

P2804

L13 This protocol for quality control is commendable and very impressive. One point about which more detail is required is the stage in which outlines were "if necessary, revised by a second operator". Although the earlier part of the paragraph describes a sort of training programme, and introduces the delineation tests that are the subject of section 4.2, it sounds as though the final result was determined simply by the second operator. Given irreducible ambiguities of the kind discussed below (P2809 L28), this somewhat reduces confidence in the protocol (although it is not obvious how to improve it given that the final outline has to be the subject of a binary choice).

Delineation works were carried out by field work experienced operators and non-experienced operators. If the glacier polygon was delineated by non-experienced workers as first operator, field work experienced workers reviewed as second operator. Even if the glacier polygon was made by experienced workers, other field work experienced workers reviewed as much as possible. So, quality of inventory depend on the professional person who checked at final.

P2805 As described, the "unique" ID is non-unique. Each Landsat scene may contain hundreds of glaciers. Explain the ID more fully.

The ID is unique because of sequential number begin with id=000001 in p130r037 and it end with id=082776 in p154r033. The largest ID corresponds total number of glaciers in GGI (Table 1). We revised the explanation about the ID.

P2806

L2-3 These biases are ambiguous. With respect to what reference? The other DEM (in which case they are differences, not biases)?

L2: Difference between GDEM2 and ICESat data (GDEM2-ICESat). L3: Difference between SRTM and ICESat data (SRTM-ICESat). We will add the information in the revised version.

P2808

L2 It would be helpful to give the equivalent RGI area for comparison. Its uncertainty is of the order of 10%, so there is a clear discrepancy.

The comparison of three inventories was carried out on same target region between 89—92° E longitude and 27—29° N latitude. We added the coordinate information here.

P2809

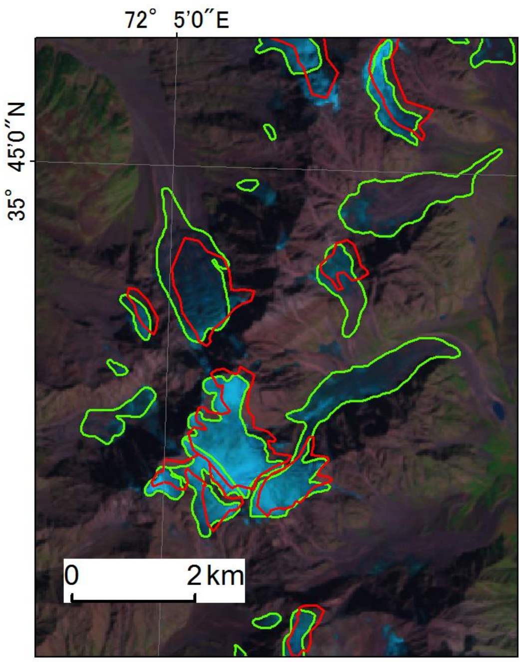
L3-5 This is not true of the RGI coverage of China, only of non-Chinese parts of High Mountain Asia (in the Altai, Tien Shan, Pamir and Himalayas).

This is our mistake. We will revise as "In contrast, the RGI, in particular part of Altai, Tien Shan, Pamir and Himalayas, incorporates glaciers identified automatically using spectral characteristics, potentially resulting in incomplete partitioning (Fig. 10)".

L12-13 The assertion that there are no RGI glaciers in the western part of High Mountain Asia surprises me. As accurately as I can read Figure 11b, the bright red pixel in northern Pakistan is at (72.0, 35.5) (southwest corner) on the Chitral–Swat divide, and in RGI version 3.2 that 0.5-degree cell contains lots of glaciers, including several valley glaciers.

We are sorry for making your misunderstanding due to our short explanation. Our explanation does not mean glaciers do not exist in western part of high mountain Asia, but mean some glacier was not detected by RGI.

Below figure shows the scale-upped images at 72.5-73.0° E, 35.5-36.0° N (large area difference (thick red grid)). Green line indicates GGI, and red line shows RGI (ver. 3.2). Glacier outlines of the RGI are delineated carefully, but some debris-covered glaciers were missed in the RGI. Then, glacier area of the RGI would be less than that of GGI in this region. We will revise the explanation.



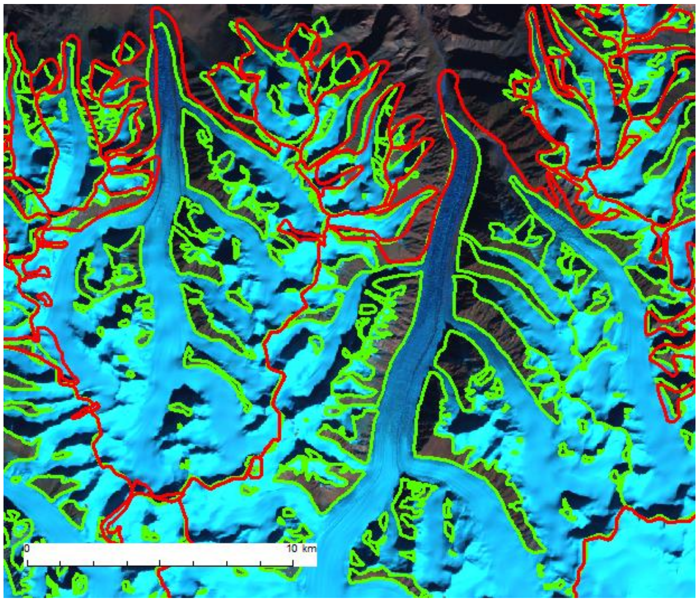
p151r035

L28 “high-relief headwalls”: an important reason for the greater glacierized area in the RGI than in the GGI must be the ~30-year difference in their dates (P2810 L3-5), but the assumption in this sentence that high-relief headwalls ought not to be included raises a complex and open question which needs further discussion in the paper.
One has to decide, usually on the basis of a single satellite image, whether the steep slope is ice-covered; commonly this decision is unreachable because the slope is snow-covered, and a further decision is required about whether the slope is so steep that all the snow will fall off between the image date and the end of the mass-balance year. If it were to do so, and whatever was beneath the snow were thus exposed (and observed, which is unlikely), the question would have an answer. Short of this ideal, I think there is genuine ambiguity given the present state of observational knowledge. Perhaps there is a role for time-lapse photography of steep valley walls in resolving the problem.
A further difficulty is that it is not clear how those who worked on the Chinese Glacier Inventory approached the problem, or even whether the problem was recognized at the time.

As your comment, it is difficult to judge ice or snow covered area by several instantaneous images. We excluded steep walls, where snow can not accumulate, even we found those walls are covered with snow in the images. Because those walls contribute as source of avalanche nourishment, but elevation change due to glacier mass fluctuation are not expected (below figure).

Hanging glaciers are difficult to detect even in high resolution Google Earth images. Then, hanging glaciers might be eliminated in our in our inventory, which would be one of the reason of underestimate of glacier area in our inventory.

For the Chinese Glacier Inventory, glaciers with high-relief headwalls are relatively less (limited at the Hengduan Shan) comparing to southern Himalayas. But, sidewalls of glaciers are usually included as glacier area in the Chinese Inventory (shown an example below picture). Difference of glacier area between our inventory and Chinese inventory might be caused by overestimation of glacier area by including sidewalls in Chinese inventory. But, we have no images in 1970’s, so, this is only our speculation without basis.



Glaciers in the West Kunlun. Green line indicates the GGI. Red line shows the RGI.

P2810

L5 Shangguan et al. 2007 offer only weak support for glacier shrinkage as an explanation of the RGI/GGI discrepancy (10 km^2 of shrinkage, or 0.4% of an initial glacierized area of more than 2700 km^2 in the Kun Lun, in 31 years). Possible alternatives with broader geographical scope are Li, X., et al. 2008 (Global and Planetary Change, 62, 210-218) and Ding, Y.J., et al. 2006 (Annals of Glaciology, 43, 97-105).

Thank you for your information. We checked Li et al. (2008) and Ding et al. (2006). We will add Li et al. (2008) and Ding et al. (2006) instead of Shangguan et al. (2007).

L16 "since the 1970s". But which discrepancy is being discussed here? If it is the discrepancy with Bajracharya and Shrestha 2011, "the 1970s" should be "about 2000".
A related point, which also diminishes the usefulness of Table 3, is that the numbers in Bolch et al. 2012 derive largely from the RGI.

At the sentence 'Therefore, the discrepancy could include both real changes in glacier extent on the Tibetan Plateau since 1970s and misinterpretation of seasonal snow cover at lower elevations (Fig. 10c).', we are discussing on the discrepancy between the GGI and the RGI. We will add the information.

And we did not discussed on the Table 2 and 3, as your comment. We will add "Those discrepancies between the GGI and Bajracharya and Shrestha (2011) (Table 2) or Bolch et al. (2012) (Table 3) are caused by under-estimation of glacier area at steep slopes in the GGI.".

Stylistic Comments
P2800
L2 Delete "the" before "High Mountain Asia", and make this change throughout the text.

We revised.

P2801
L15 "Pfeffer".
L26 "… error respectively in these regions".

We revised.

P2803
L16 "identification of glacier divides".

We revised.

L21-22 Change "glacier area" to " 'glacier' ".

We revised.

P2804
L20 "glacier boundaries were misidentified".

We revised.

P2805

L7 Change “attribute datasets” to “attributes”.

We revised.

L12 Change “are” to “is”.

We revised it.

P2806

L5 The English spelling is “Karakoram”.

We revised it.

L9 Change “less” to “lesser” and “field” to fields”.

We revised it.

P2807

L20 These percentages are ambiguous. The consistency should be described in terms of a percentage difference between the inventories, making sure that the reader knows which is which.

We revised the ambiguous explanation as “(GGI has 1% smaller area from AGI)” and “(RGI has 54% larger in area from AGI)”. We removed comparison of glacier number based on comment by reviewer#4 (Frank Paul).

P2808

L6 “grid cell”. Make this change throughout the text, e.g. at L19 and frequently later.

We revised all “grid” to “grid cell”.

L16 “overestimated”, not “over-delineated”. This too needs to be changed throughout, as well as “under-delineated”.

We revised them.

P2810

L7 “glaciers”.

We revised “glacier” to “glaciers”.

L9 “over the Himalaya”. “summaries”.

We revised “over Himalaya” =>over the Himalaya”.
We revised “summary” =>“summaries”.

L17 Figure 10a, not 10c.

We revised.

L25 Change “in parts of” to “in most of”. In the RGI only small parts of Chinese territory (e.g. part of the Nyainqentanghla Range) are more recent than the Chinese inventory.

We revised.

P2816
Table 2 Add “inventory” after “(2011)”, and right-justify all columns but the first.
We revised. And we also added “inventory” after Bolch et al. (2012) in Table 3.

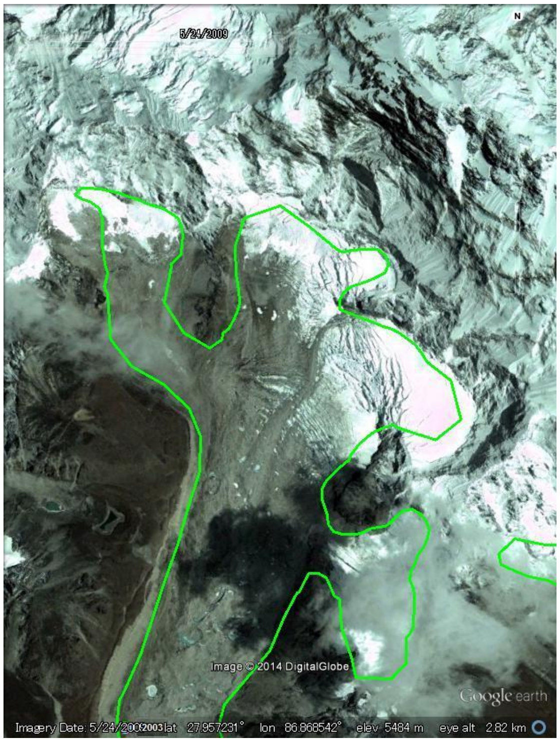
P2817
Table 3 Move “the” to follow “and”.
We moved it and revised the caption based on comment by reviewer#4 (Frank Paul).

P2827
Figure 10 End the first sentence at “boundaries”, then say “Glacier outlines are from the RGI (red) and the GGI (green).”.
We revised.

Supplementary Information
The supplementary information is not adequately documented. The filenames should ideally include the name of the first author and the date, and in any case should be reproduced accurately in the table headers. The main PDF file should begin with full bibliographic data (full list of authors, title of the paper, etc.).
We will revise our supplement file.

Figure S1 This is potentially quite valuable, but needs further documentation.
a: Add an outline of the steep headwall, which I cannot find. If it is the bright white patch at right centre, I need more information before accepting its exclusion from the glacier; it looks like an ordinary accumulation zone to me.

We added outline of glacier in GGI (see below figure). The bright white patch at right centre is not steep headwall which we specified. The steep headwall is located upper of the green coloured outline. And we will move this figure to the main text as reviewer#4 (Frank Paul)'s comment.

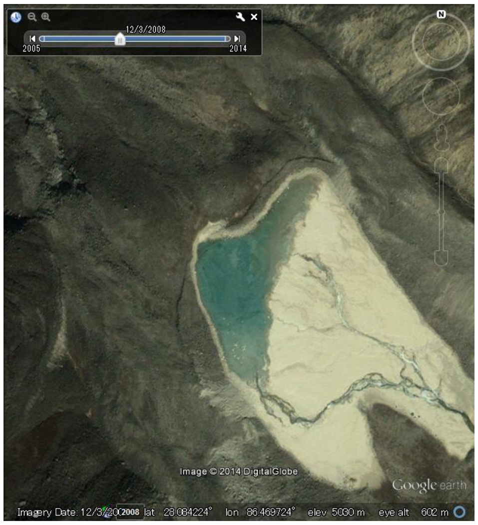


c: Define "true-colour" and "false-colour" (as in the main text, in terms of Landsat bands), and say which panel is which. In fact, say which panel is which in each of b to g.

We will explicitly specify band combination of all background satellite image in the caption of Fig. S1 such as "true-colour (bands 3, 2, 1 as RGB) composite imagery", "false-colour (bands 7, 4, 2 as RGB) composite imagery" or "thermal band imagery (band 6)". And we also revised explanation of (c) as "Glaciers are covered with thin dust layer. Those glaciers can be detected using false-colour (bands 7, 4, 2 as RGB) composite imagery (left), whereas true-colour (bands 3, 2, 1 as RGB) composite imagery (right) shows only black surface".

d: Is the lake in the right panel really “non-glacial”? It looks like a supraglacial lake.

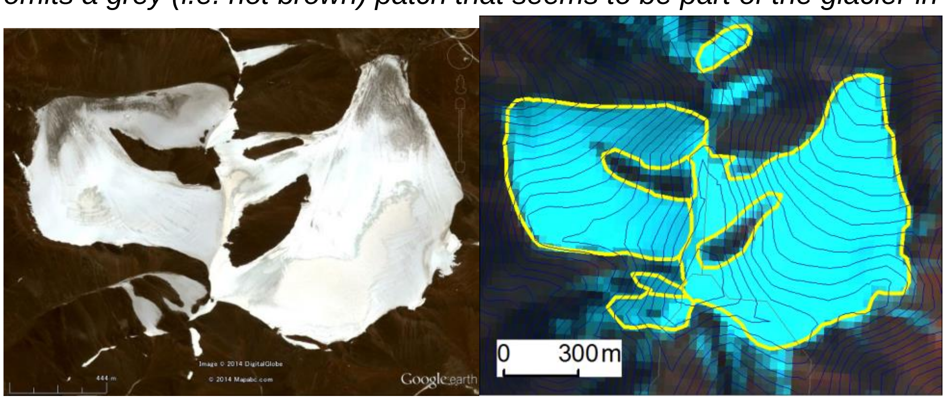
As your comment, the right lake is surrounded by ice cliffs. So, the lake looks like supraglacial lake. Therefore, we will replace the picture.



f: The scales appear to differ between the two panels. I can only guess that the orange rectangle in the left panel represents the extent of the right panel, and I do not know what conclusion I am being invited to draw – that the blue patch on the left is or is not a glacier.

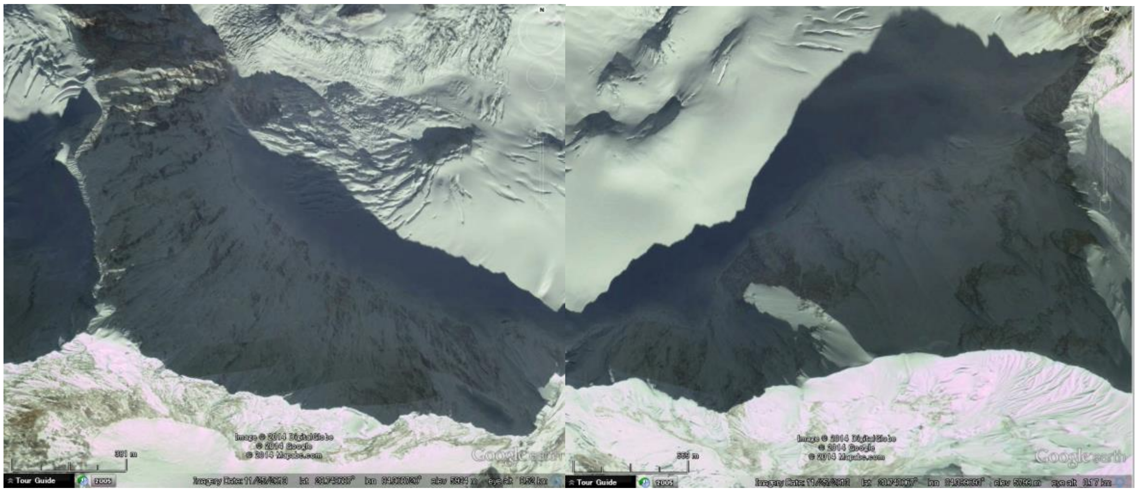
We will replace images. Both images (LANDSAT and Google Earth image) will be extracted in same scale. The Google Earth image (right) shows the snow surface is undulate and looks like covered with thin snow (not smooth glacier ice). Therefore, we can judge there is no ice under the snow cover.

g: “… in Google Earth imagery of appropriate date.”; the typically high resolution of Google Earth imagery is of little value for distinguishing seasonal snow from perennial snow or firn.
On the left of the north-south divide in the left panel, the larger of the two green glacier outlines omits a grey (i.e. not brown) patch that seems to be part of the glacier in the right panel. Why?



Actually, we have found better source image for Fig. S1g, and revised the polygon based on the better image. Still present image have little seasonal snow cover, so, above figure can used as an example that glacier outline can be delineated based on Landsat image with little snow cover supported by clear Google Earth image.

Figure S2 Again potentially valuable, but I do not know which colours represent right and which represent wrong decisions about delineation.
a: In the deep shadow on the south side, I would accept the orange outline (following the topographic divide) as correct, and I can see no basis for the decisions marked in red, green and blue.

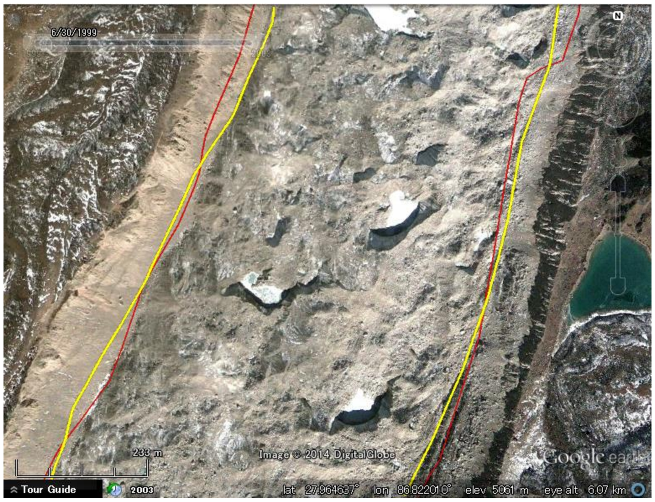


From above Google Earth image, rock wall exposed at the southern steep walls. We, therefore, judged that the orange line is not correct.

b: Here I would also reject the red, green and blue decisions. The main paper seems to suggest that they correctly exclude a lateral moraine, but I am not sure of the basis for this.

We observed many debris-covered glaciers in the field, those were surrounded by lateral moraine ridges. Lateral moraines do not contain glacier ice under the debris and do not flow down with glacier ice. Therefore, in order to evaluate glacier mass change, we have to exclude lateral moraine surrounding debris-covered glaciers.

Further, glacier polygons in the RGI (and other inventories) also exclude lateral moraines. Below figure shows an example at the Khumbu glacier. Red line indicate the RGI and yellow line indicate the GGI. Both lines eliminate lateral moraines. This is not only one case, we could find exclusion of lateral moraines in other glaciers.



Khumbu Glacier

Reviewer#2, Mauri Pelto

Nuimura et al (2014) have completed a detailed inventory (GGI) of the glaciers in the High Mountains of Asia. The inventory relies on Landsat imagery during the 1999-2003 period. This paper focusses on a comparison of the results of this inventory with other inventories, particularly the Randolph Glacier Inventory (RGI). The paper discusses the method in exemplary detail. However the key to understanding the validity of the methods and the resulting issues of differences with RGI is not just with the overall data presentation and description, but can be best exemplified with clear visual comparison of results depicted directly on imagery. We are at a point where an endless supply of glacier inventories based on satellite imagery is emerging. The results of each are quite different between each in areas of overlapping coverage indicating that though inventories can be valuable the accuracy and precision of each needs great attention or the value will not exist. Further that a single inventory is only useful if it can be later replicated to identify glacier change. Hence, the methods have to be repeatable. This paper as a comparison of several important inventories is a valuable step in understanding why inventories differ. There is an opportunity to sharpen identification of the difference to the image classification level visually versus primarily a data comparison. This is an important paper, I am not suggesting the authors redo any portion of the inventory, just provide a visual comparison to stand with the detailed data comparison. This comment is focussed on this bigger issue, not on specific detailed comments throughout.

1) GGI identifies more glaciers than RGI, give us a visual example of where this occurs and that can help explain why. Figure 1 is in the Zanskar region and is not specifically recommended but just a typical area that would be useful in looking at differences in area and number of glaciers where steep slopes are not an issue, yet the glacier count is not straightforward.

Thank you for your recommendations. As Frank Paul's comments, we will eliminate number comparison between GGI and RGI. Instead, we will add the comparison between GGI and ICIMOD in area. The partitioning of glacier polygons in ICIMOD inventory is well done, and the difference in numbers at each 0.5 degree grids are similar. Therefore, we do not need visual example to compare partitioning of glacier polygons.

2) The GGI despite more glaciers has much lower glacier area. Part but not all of this result from using imagery of differing dates. Again provide a visual example indicating how RGI and GGI deal with glacier boundaries in a specific location that has steep avalanche slopes that GGI does not typically classify as a glacier. This comment contains three figures that illustrate the level of visual detail needed for an adequate comparison. Figure 10 and S1 currently serves that role, but there are too many examples with too poor resolution in each. Figure S1 does not compare RGI versus GGI for a specific area. Figure 10 has too many examples and does not provide the detail needed, or supporting tabular results. The steep slope example does not adequately portray which approach is better given the nearly complete snowcover. Figure 2 and 3 in this comment use Digital Globe and Landsat imagery looking at same area to point out specific locations where steep slopes could be differently interpreted. This is the level of detail needed to delineate the ability of the method chosen and contrast it with the RGI. The output from a specific glacier or *watershed comparing GGI and RGI in tabular form is needed. You could focus on a single glacier, such as the Durung Drung Glacier shown in these figures.*

Frank Paul has made comments that comparison GGI with RGI is no suitable since the RGI will be soon revised. And visual examples like Fig. 10 b and c were already published at Pfeffer et al. (2014). Therefore, we will not compare GGI with RGI. Instead, we will compare GGI with ICIMOD inventory, which quality is fairly high, although the inventory can not cover all our target area.

2807-25: Be more precise here since all inventories rely on satellite imagery, what imagery did RGI use beyond China that would lead to this?

Large parts of glacier data in Himalaya are come from GLIMS which originally made in Chinese glacier inventory (GLIMS Technical Report for RGI version 3.2). Around the Bhutan Himalaya, glacier data in RGI is come from GLIMS. As noted by reviewer#3, Chinese glacier inventory are made based on topographic maps from 1956 to 1983, with median at about 1970. And it also come from Landsat imagery. We will add data source of each inventory here.

2811-14: Given the completed inventory value is as a baseline, authors should comment on how easily the inventory can be replicated with Landsat 8 imagery in the near future.

We will add description as “If we make repeat glacier inventory using Landsat 8 imagery, we can get glacier area difference easily based on GGI.”.

Table 3: Does not add value beyond that of Table 2. Are the Bolch et al (2010) numbers different than RGI? Instead or in addition to this a table for a specific watershed such as in Figure 1 where the count, area and boundaries of glaciers could be shown and reported from GGI and RGI.

We have added RGI area in Tables 2 and 3 for comparison in watershed unit and comparison between Bolch et al. (2012) and RGI. And we also modified difference based on comments from you, reviewer#3 (Samjwal Bajracharya) and reviewer#4 (Frank Paul).

Table 2

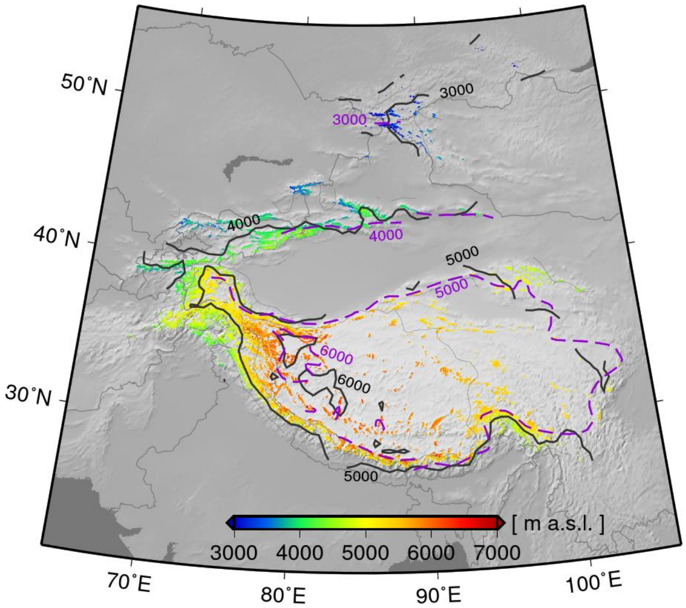
	GGI	Bajracharya and Shrestha (2011)			RGI		
	Area	Area	Difference		Area	Difference	
	[km2]	[km2]	[km2]	[%]	[km2]	[km2]	[%]
Amu Darya	2478	2566	88	4	3314	836	34
Indus	22125	21193	-932	-4	28926	6801	31
Ganges	5999	9012	3013	50	11167	5168	86
Brahmaputra	9417	14020	4603	49	17762	8345	89
Irrawaddy	64	35	-29	-45	75	11	17
Salween	1321	1352	31	2	2237	916	69
Mekong	225	235	10	4	598	373	166
Yangtze	1563	1660	97	6	2378	815	52
Yellow	98	137	39	40	196	98	100
Tarim Interior	2636	2310	-326	-12	2904	268	10
Qinghai-Tibetan Interior	7665	7535	-130	-2	10047	2382	31
Total	53591	60054	6463	12	79605	26014	49

Table 3

	GGI	Bolch et al. (2012)			RGI		
	Area	Area	Difference		Area	Difference	
	[km2]	[km2]	[km2]	[%]	[km2]	[km2]	[%]
Karakoram	16718	17946	1228	7	22077	5359	32
Western Himalaya	7547	8943	1396	18	10192	2645	35
Central Himalaya	6491	9940	3449	53	12032	5541	85
Eastern Himalaya	2701	3946	1245	46	4741	2040	76
Total	33458	40775	7317	22	49042	15584	47

Figure 4: The contours detract from actually seeing the colored elevation depiction.

We reduced number of those contours in the figure.



Reviewer#3, Samjwal Bajracharya

This paper presents a complete picture of Asian glaciers in 1999–2003 based on the Landsat imagery and the SRTM DEM. This is a huge amount of work undertook by Nuimura and his team. The glaciers outlines were digitized manually from the single source of Landsat satellite images with short temporal range which was lacking in the previous published documents.
The author compared the (GAMDAM Glacier Inventory) GGI with two other glacier inventories, the Randolph Glacier Inventory (RGI) version 3.2 (Arendt et al., 2012; Pfeffer et al., 2014) and a glacier inventory derived from high-resolution (2.5 m) Advanced Land Observing Satellite imagery (AGI) from the Bhutan Himalaya. The results were also compared with the data of Bajracharya and Shrestha (2011) and Bolch et al. (2012).
The GGI derived number and area of glaciers are highly consistent with AGI (101% in number and 99% in area), but slightly under estimation than RGI, Bajracharya and Shrestha (2011) and Bolch et al. (2012). The RGI is a global inventory, and in fact the Chinese Glacier Inventory for China and ICIMOD's glacier inventory for Nepal, which are actually the results derived from the topographic maps from 1956 to 1983, with the median at about 1970. Hence the number and area of RGI are greater than the AGI and GGI. The results of Bajracharya and Shrestha (2011) and Bolch et al. (2012) are mostly based on the Landsat satellite images of 2005±3 years with the complements of RGI particularly in the Chinese territory.
In the GGI, glaciers smaller than 0.05 km2 were excluded while in the second generation glacier inventory of China and ICIMOD's inventories excluded only the glaciers smaller than 0.02 km2.
In the context of availability of advanced tools and technologies in remote sensing for glacier mapping and monitoring, the manual digitization is time consuming, hectic and tedious work particularly for the bigger region. The study of Paul et al. 2013 shows the differences of the automatically derived outlines from a reference value are as small as the standard deviation of the manual digitization from several analysts. Based on these results, they concluded that the automated mapping of clean ice is preferable to manual digitization and recommend using the latter method only for required corrections of incorrectly mapped glacier parts (e.g. debris cover, shadow). Almost 90% of the glaciers in the HKH region are clean-ice glaciers (Bajracharya and Shrestha, 2011).
Besides the mapping of glaciers by several professionals for accuracy if the output of the mapping has finalized by one expert it will be far better.
This paper provide up to date information of Asian glaciers. I would be happy to see it published in The Cryosphere.

We have to report the present status of our inventory, before going to reply your comments. Present version of our GGI has two underestimated area.

1) Higher elevation with relatively steep slope area.
a. We eliminated steep walls from the glacier area, therefore, if steep headwalls include glacier ice, we underestimate glacier area. And hanging glacier tend to be eliminated. These under estimation would be a fault of our inventory.

b. We have a rule for delineation of glacier area, "steep walls, where snow cannot accumulate, are not included in glacier area". But, in the present state, we underestimate glacier area at upper region of glaciers than our rule, and we have eliminated upper glacier area, even where snow can accumulate. We are trying to revise our inventory according to our role of glacier delineation.

2) Shadow part

We used Landsat images taken during winter season, because the Himalayas are affected by monsoon during the summer season, and cloud-free image is difficult to obtain during the summer. Then, we have overlooked the glacier at shadow part.

Now we are correcting. We will evaluate the median elevation derived from our GGI (not including steep walls) by comparing with those from ICIMOD inventory, which include steep walls.

We will add these faults of our inventory in the revised manuscript.

Some comments P2800 and in other area Instead of "glacier in the high mountain Asia" "Asian glaciers" sounds better

We can not find the phrase “glacier in the high mountain Asia” in our manuscript. Probably you mentioned “glacier inventory for the high mountain Asia” at P2800L2. We retain the phrase as is for consistency through the manuscript.

P2801 L15 “Pfeffer”.

We revised.

L22 Why not give the exact extension of glaciers. The glaciers below 27.5 deg latitude does not exist in Asia. (Bajracharya and Shrestha, 2011)

The southernmost glaciers locate in the Yulong snow Mountain (27.06° N, 100.18° E). Those glaciers are also included in the RGI. We added exact location in the revised manuscript (27.09-54.08° N, 67.48-103.89° E).

P2804 L26-28 Though 11 operators had delineated the glacier outline in 20 months with review of initial delineation but the error will be minimized if peer reviewed by limited number of reviewers.

Thank you for your comment. We agree with your comment. First delineation works were carried out by both field work experienced operators and non-experienced operators. And glacier polygons, those are delineated by non-experienced operators, were reviewed by field work experienced operators. But, not all glacier polygons were checked by field work experienced operators. Therefore, we included errors by all operators.

P2815 Table 1 show very high glacier number and area compared to the report Bajracharya et al. 2014. The number and area shows not only the glaciers within the territory of Bhutan but also included from the adjoining areas. The inventory of glaciers in Bhutan in 2010 shows 885 glaciers with total area of about 642 km2. (Bajracharya et al. 2014)

Yes, the difference was caused by the difference of target area. We added area extent of Bhutan Himalaya in new Fig. 1 to specify the location.

Table 2 difference (%) subtract from 100 and provide the difference in + and - %

We revised the difference value in Tables 2 and 3.

Reviewer#4, Frank Paul

1. General comments

The study by Nuimura et al. presents a new glacier inventory for glaciers in High Mountain Asia derived from manual delineation of outlines on more than 220 Landsat ETM+ scenes from 1999-2003. The work behind GAMDAM is thus a tremendous collaborative effort filling an important data gap for this region. Unfortunately, the authors have decided to introduce a glacier definition that seemingly excludes all (?) steep rock walls (which is not what is recommended in the GLIMS analysis tutorial). As a first (1) general comment, this makes the new outlines incomparable to other existing datasets and is strongly limiting their usability for other applications when made available.

Another major issue (2) is the rather detailed comparison with the poor-quality glacier outlines of the RGI in this region. The RGI was only designed for global and large regional analysis rather than for analysis on glacier or catchment scale (see RGI technical note). Highquality outlines are available in several subregions for such an analysis from specific studies (and the RGI) and these should be used for a comparison (and cited by themselves). For clean glaciers more accurate (and consistent) outlines can be derived from automated mapping (e.g. using simple band ratios). I recommend (3) using them for accuracy assessment of the manual digitizing and explain why automated processing was not applied here. This brings me to two further critical points. All methods need to be properly described (4) for traceability. As an example: just writing (P2803, L13): 'Contour lines were used to identify glacier outlines' is not sufficient. I would like to know how this is working. And finally (5), the quality control procedure seems to rely on one (?) person ('revised by a second operator') who - in the end - always knows where a glacier outline needs to be and can reshape them to the one and only true position. It is unclear to me how the judgement of this second operator can always be superior and 100% correct? In view of the examples shown on page 7 I have some serious doubts about the quality of the GAMDAM inventory.

We have to report the present status of our inventory, before going to reply your comments. Present version of our GGI has two underestimated area.

1) Higher elevation with relatively steep slope area.

a. We eliminated steep walls from the glacier area, therefore, if steep headwalls include glacier ice, we underestimate glacier area. And hanging glacier tend to be eliminated. These under estimation would be a fault of our inventory.

b. We have a rule for delineation of glacier area, "steep walls, where snow cannot accumulate, are not included in glacier area". But, in the present state, we underestimate glacier area at upper region of glaciers than our rule, and we have eliminated upper glacier area, even where snow can accumulate. We are trying to revise our inventory according to our role of glacier delineation.

2) Shadow part

We used Landsat images taken during winter season, because the Himalayas are affected by monsoon during the summer season, and cloud-free image is difficult to obtain during the summer. Then, we have overlooked the glacier at shadow part.

Now we are correcting. We will evaluate the median elevation derived from our GGI (not including steep walls) by comparing with those from ICIMOD inventory, which include steep walls.

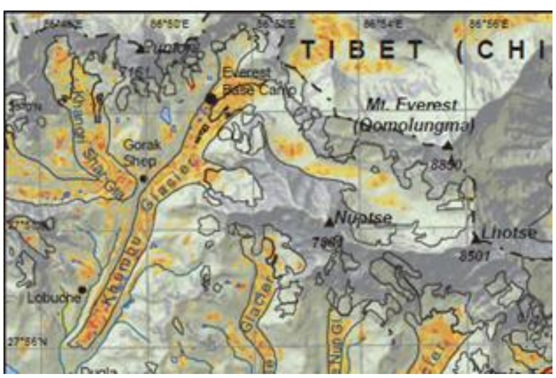
We will add these faults of our inventory in the revised manuscript.

Reply to general comments

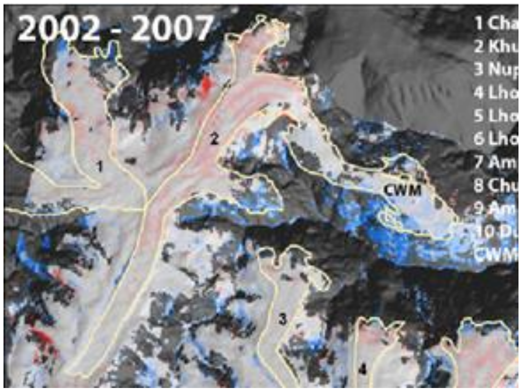
(1) general comment, this (exclusion of steep rock walls) makes the new outlines incomparable to other existing datasets and is strongly limiting their usability for other applications when made available.

We collected the glacier outlines of the Khumbu glacier in the previous study.

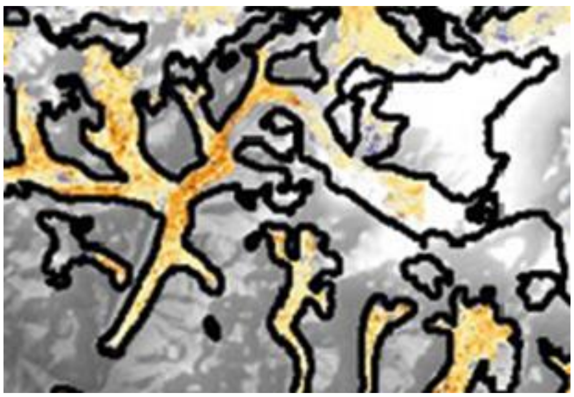
Salerno et al. (2008) JG



Bolch et al. (2008) HESS



Bolch et al. (2011) TC


Gardelle et al. (2013) TC GLIMS and manual correction

Thakuri et al. (2014) TC

These comparisons indicate that the variation of glacier outlines at head steep walls are very large. Area-change, therefore, would be difficult to obtain at glaciers with headwalls based on different inventories.

We did not exclude all steep walls. We excluded steep headwalls, where snowfall flow down as snow-avalanche immediately, in other words, where snowfall can not accumulate, even we found those walls are covered with snow in the images. Because those walls contribute as source of avalanche nourishment, but elevation change due to glacier mass fluctuation are not expected.

Dry slab avalanche tend to occur at walls with larger than 40 degree angle (McClung and Schaerer, 2006). So, if the slope has larger than 40 degree angle, we checked the surface condition of the wall by Google Earth image.

Below three figures show glacier outlines from the RGI (Red), before revision (under-estimated at steep slope) of GGI and after revision (include snow accumulate able area) of GGI.

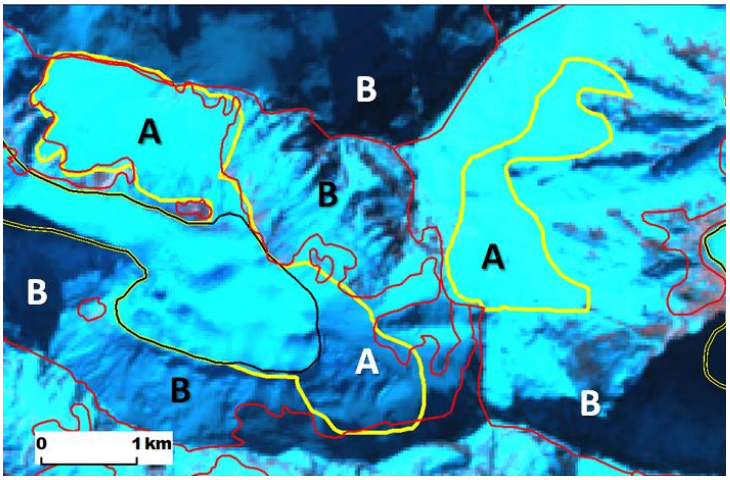


Fig. 1 Glacier outlines are shown. RGI (Red), before revision of GGI (under-estimated at steep slope) (Black), after revision of GGI (include snow accumulate able area) (Yellow) overlapping a Landsat image at Khumbu accumulation area. A: our underestimated glacier area before correction. B: Excluded steep slope area. We will not include the steep slope, since bare rock surface are exposed at some place and the snowfall cannot accumulate at these steep surface.

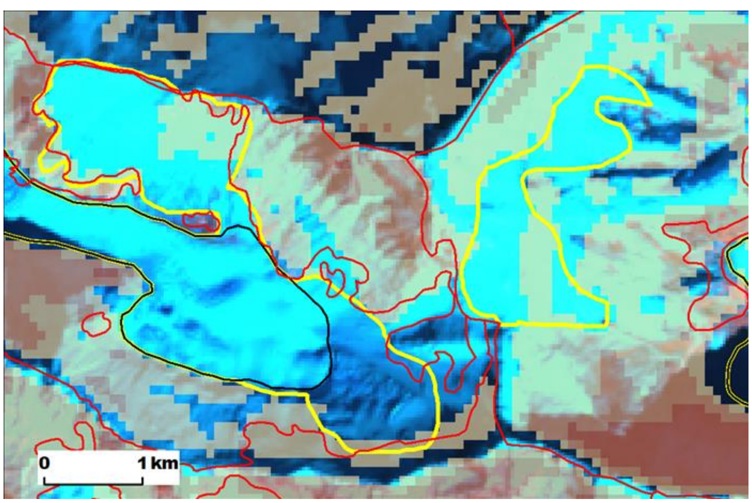


Fig. 2 Glacier outlines overlaying the Landsat image.
Yellow-brown coloured grid indicate the slope angle is higher than 40 degree. Please, notice that the slope angle used for only reference.

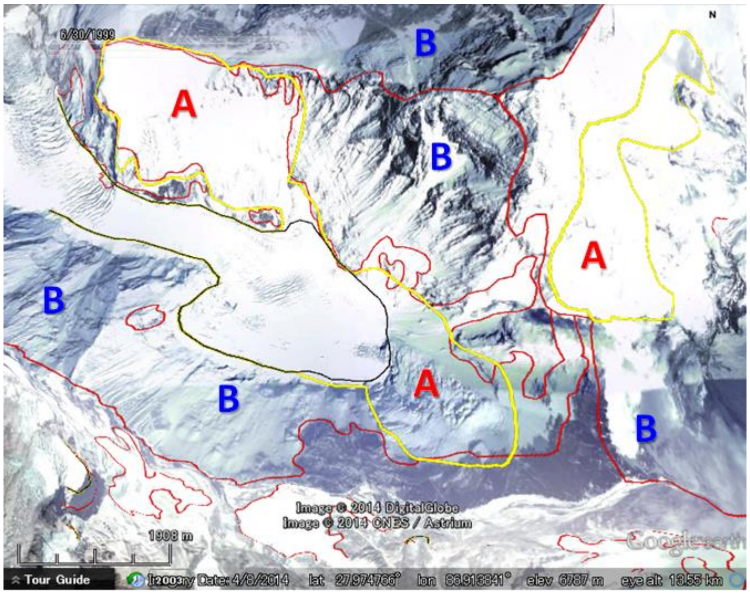


Fig. 3 Glacier outlines overlaying the Google Earth images.
A: our underestimated glacier area before correction.
B: Excluded steep slope area. We will not include the steep slope, since bare rock surface are exposed at some place and the snowfall cannot accumulate at these steep surface.

Example of excluded steep slope, which slope are covered with snow in the Google Earth images. We exclude slopes with longitudinal plicate surface (Fig. 4) or rock exposed walls covered with thin snow layer (Fig. 5).

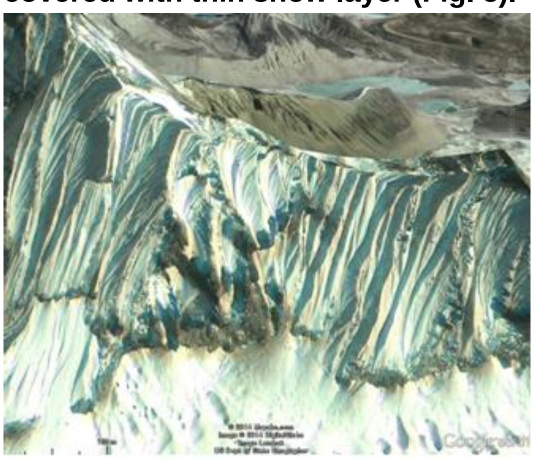


Fig. 4 Visual example of slope with longitudinal plicate surface

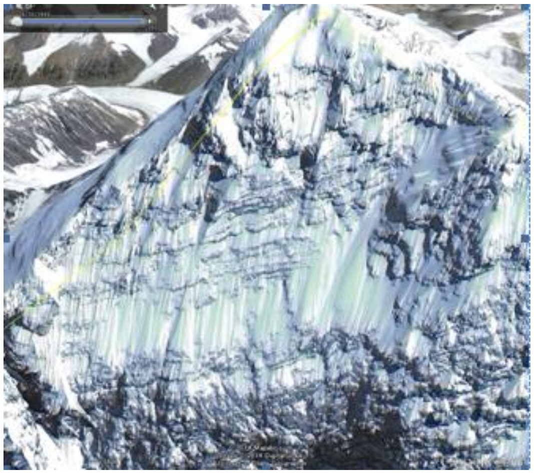


Fig. 5 Visual example of rock exposed walls covered with thin snow layer

(2) the rather detailed comparison with the poor-quality glacier outlines of the RGI in this region

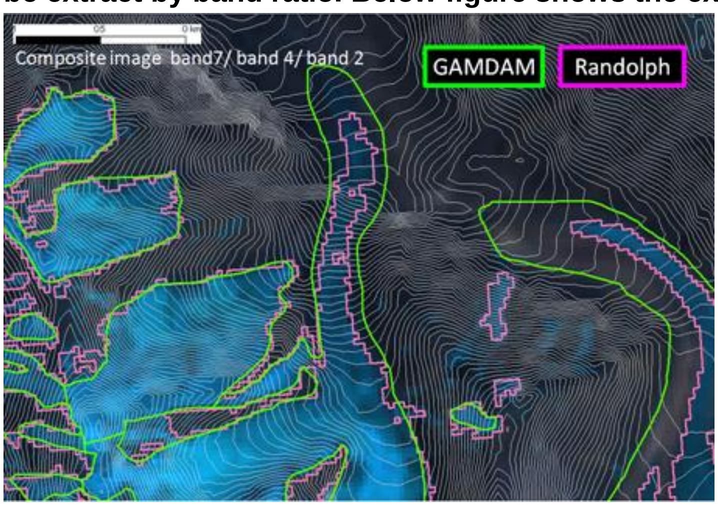
We will delete number-comparison between GGI and RGI. Further, we will add the area comparisons between our GGI and ICIMOD inventory in the revised manuscript.

But, we would not like to eliminate the area-comparison between GGI and RGI. Because target area of GGI covers larger scale, and RGI is only one glacier inventory covering whole our target region. We cannot evaluate quality of whole GAMDAM inventory without RGI. Further, GGI can provide which region are required to correct or add in future RGI, even our delineation rule are different from GLIMS.

(3) why automated processing was not applied here

There are two reasons that we delineated manually all glaciers.

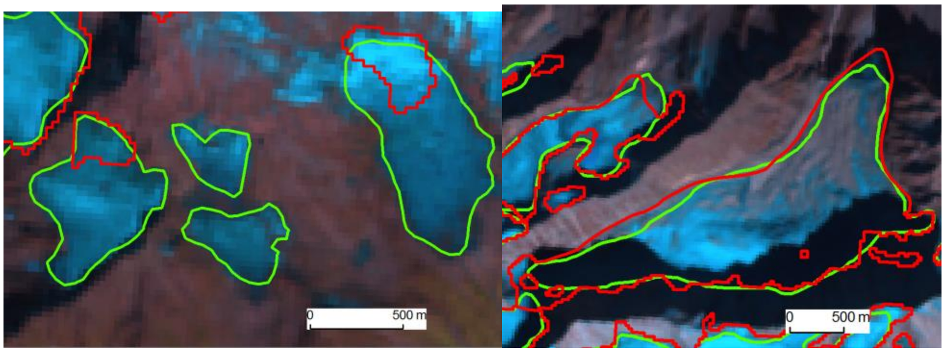
1) There are a lot of debris-covered glaciers in high mountain Asia. Those glaciers can not be extract by band ratio. Below figure shows the example.



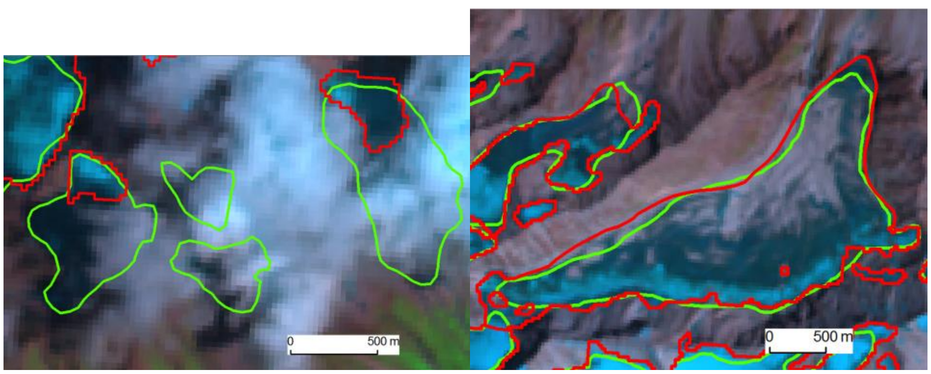
38.338° N, 72.644° E

2) The Asian region tend to covered with seasonal snow or partly cloud cover during the high solar angle season (summer) because of the monsoon. So, it is difficult to get clear seasonal snow-free, cloud-free and shadow-less images. Eventually, a lot of manual corrections for clouds, shadow, debris cover and seasonal snow are required after automated processing. (Rastner et al., 2012)

For example, a Landsat image at path 145 row 039. Image taken in 1 Aug. 2001 has a lot of cloud cover so, automated mapping needs more corrections. On the other hand, an image taken in 20 Oct. 2001 has no cloud, but solar angle is low (a lot of shadow area).



Landsat image taken in 20 Oct. 2001
The image has no cloud (left), but has a lot of shadow part (right). RGI (Red), GGI (Green).



Landsat image taken in 1 Aug. 2001
Part of the image are covered with cloud, so automated method needs more correction.
But, for shadow area, glacier outline can be automatically extracted. RGI (Red), GGI (Green).

(4) All methods need to be properly described. As an example: just writing (P2803, L13): 'Contour lines were used to identify glacier outlines' is not sufficient.

We will add how to delineate glacier outline using contour lines. Shadow part of large glaciers are estimated the glacier outline using contour lines. Contour lines are also used to delineate terminus of debris-covered glaciers. The detail will be also shown with images.

These method will be explained with visual examples and the fault (steep slope can not evaluate without high resolution Google Earth images) in the revised manuscript.

(5), the quality control procedure seems to rely on one (?) person ('revised by a second operator') who - in the end - always knows where a glacier outline needs to be and can reshape them to the one and only true position. It is unclear to me how the judgement of this second operator can always be superior and 100% correct?

Delineation works were carried out by field work experienced operators and non experienced operators. If the glacier polygon was delineated by non-experienced workers as first operator, field work experienced workers reviewed as second operator. Even if the glacier polygon was made by experienced workers, other field work experienced operators reviewed as much as possible. So, quality of inventory depend on mainly the field work experienced operators who checked at final.

page 7

We appreciate your attentive comments on each ice surface. We recognized two faults of our inventory by your comments and by our recheck. Those faults are already reported at the beginning of this reply.

Please notice, that we did not delineate glaciers with smaller than 0.05 km^2 in area, as we described in the manuscript.

White : We agree with your assertion "This is a glacier". We recognised that the glaciers in the shadow part were tend to be missed. We are now revising our inventory using Landsat images taken during summer, high solar angle season.

Green : For us, the ice mass can be separate into two as follows.
Left-upper one has less than 0.05 km^2 in area. We missed right-lower one, and added in the revised version.

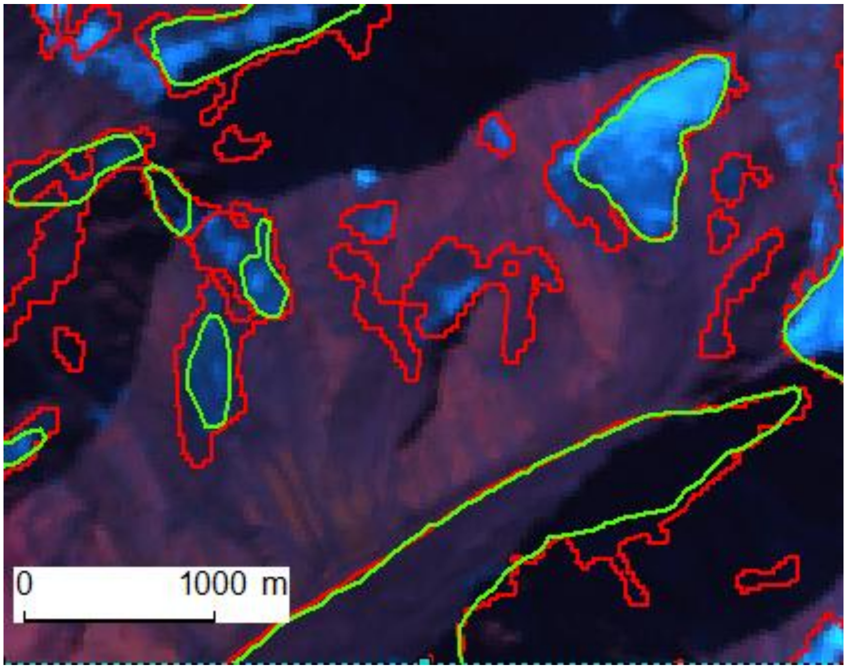
Yellow : This is our serious mistake. We will correct in revised manuscript. And we will add the following description "But, when we revise our inventory in future, we have to revise carefully discriminating debris-covered glacier or rock glacier."

Red : In the case that Landsat image taken in winter are selected, southern side of glacier outline are in shadow, and those glacier outline are not delineated suitably. As we already wrote in the above that we will describe the fault of our inventory (glaciers in shadow part are not delineated suitably) by comparing with other inventory (ex. ICIMOD inventory)

Orange : upper one : Maximum length is 0.11 km and width was 0.11 km =0.01 km^2 in area (<0.05 km^2). Then, we did not include such small glacier.
lower one : Maximum length is 0.17 km and width was 0.11 km =0.02 km^2 in area (<0.05 km^2). Therefore we did not include such small glacier.

Blue arrow : Maximum length is 0.42 km and maximum width was 0.08 km =0.033km^2 in area. Then, we did not include such small glacier.

Then, we revised as follows.



I have some further points to criticise (see specific comments), with the above being the most general ones. Of course, it is now difficult to recommend 'Please do the inventory again and apply the correct glacier definition this time'. This might be senseless as the dataset (GGI) might be useful for its intended purpose, but it is important to pay attention to the other points, in particular explaining why certain decisions have been taken and how the applied methods work. As this study is describing a basic dataset (creation, accuracy, key parameters) I suggest moving Figures S1 and S2 (the revised ones) to the main text as they answer key questions about the approach taken. The comparisons with the entire RGI (which is frequently updated so the comparisons presented here will quickly be outdated) should be replaced with more detailed comparisons of independent studies (having provided high-quality datasets) and results from automated mapping. And please do not compare glacier numbers from different inventories. These are basically arbitrary numbers depending on several external factors (e.g. minimum size, drainage divide rules, separation of tributaries) with a very limited scientific meaning. I hope that my suggestions are helpful in revising the ms.

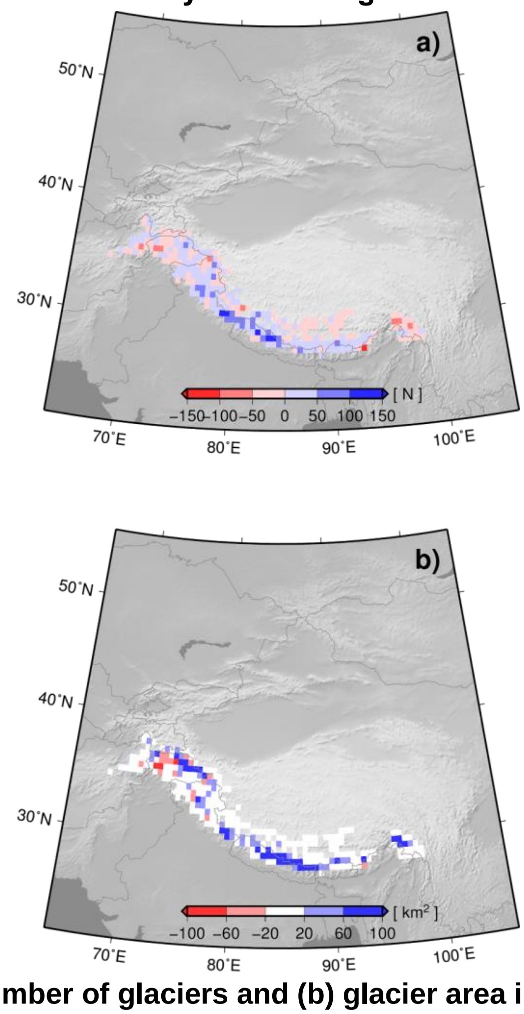
We replied this general comment in specific comments.

2. Specific comments
P2800
L6: This is not the reason; I think the explanation for the good match is that the same DEM is used here. In the void-filled regions of the SRTM DEM the geolocation of the Landsat scenes could be off by about 5 pixels (150 m) resulting in a relatively poor match with other geocoded datasets (e.g. the GDEM).

The void-filled region in SRTM DEM could cause offset as you noted. However, the part of void in SRTM DEM is not so large. Therefore, we revised the explanation as "Geolocations are mostly consistent between the Landsat imagery and DEM due to systematic radiometric and geometric corrections made by the United States Geological Survey".

L16: For this reason more precise (regional) inventories should be used for a comparison (however, the here applied glacier definition requires to only compare complete glaciers).

We compared with ICIMOD's inventory as below figure.



Difference between (a) number of glaciers and (b) glacier area in the ICIMOD and GGI (i.e., ICIMOD – GGI) for each 0.5 grid in high mountain Asia. This figure has been made same manner with Fig.11.

P2801

L17: With this purpose in mind I would also include the upper parts of all glaciers as they might belong to their accumulation area (see page 8 example). In particular when later operating with elevation related variables (like in Sakai et al. 2014) the missing accumulation areas would cause a bias. How have glaciers with an interrupted profile been considered?

Please notice that not all snow covered steep slope are eliminated in our inventory. If snow can accumulate at the surface can contribute glacier mass, we included in the glacier polygon.

Generally, there are three purposes to usage of glacier inventory, as follows.

1) Calculation for glacier mass balance fluctuation or discharge using meteorological dataset.

2) Elevation change of glacier surface (volume change)

3) Volume estimation (application of area-volume relation)

Our direct purpose of making our inventory is second one, to estimate elevation change of glaciers. Therefore, we excluded steep slopes, where snow can not accumulate. Actually, estimating elevation change is not equal to our final purpose (estimating discharge from glacier). But, measuring elevation change of glaciers is equivalent to estimate imbalance of glaciers (only multiplying density of snow or ice or not), which represents the effect of glacier volume change on river runoff as Kääb et al. (2012) reported. We did not wrote the detail of our purpose in the manuscript, we will add in the revised version.

In order to calculate glacier mass, accumulation and ablation cannot calculate by one glacier polygon for a certain glacier with steep headwalls. Because the area receiving precipitation (snow) is different from the glacier area settling snow or ice. If we calculate accumulation excluding ice-free head wall, the accumulation will be underestimated. Eventually, both GLIMS and GAMDAM inventory needs another inventory for glacier accumulation area, like PDS (potential debris-supply, potential material supply) proposed by Nagai et al. (2013). The ideal polygon for calculation of accumulation is depicted in the below figure (Purple dotted line).

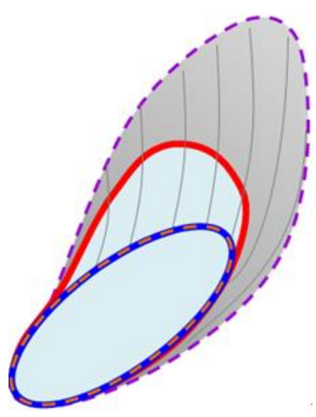


Figure Schematic glacier outline at glacier with head steep wall. GLIMS inventory (Red), GGI (Blue), required polygon for calculation of accumulation (Purple).

We will evaluate the effect of eliminating steep slopes by comparing with the median derived based on ICIMOD's inventory.

P2802

L1: This section should introduce the RGI and AGI datasets used for comparison. However, as mentioned above I recommend not using the entire RGI for this due to its obvious regional deficits and ongoing improvement. Please select high-quality outlines from individual (citable) studies (that can also be found in the RGI dataset).

We will compare our GGI with the ICIMOD' inventory.
We would like to remain area-comparison between GGI and RGI, in order to evaluate whole our inventory.

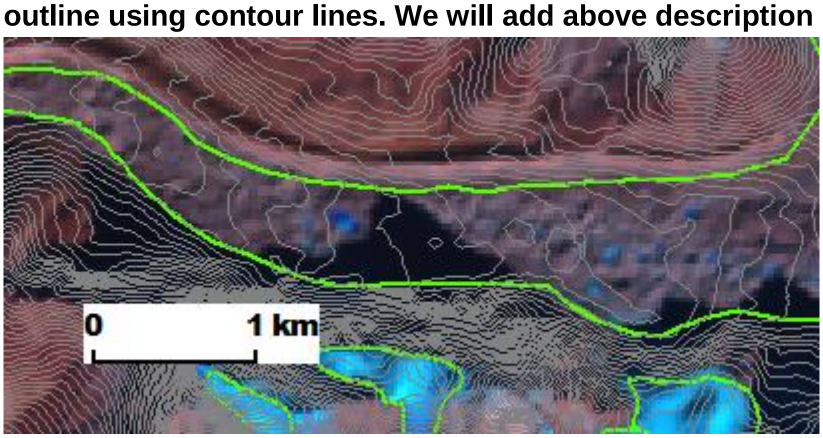
L6: The DEM used for orthorectification is not everywhere identical to the void-filled SRTM DEM but is a merged product (called GLSDEM).

Thank you for your comment. We will revise here as "geometric corrections were performed for the L1T imagery using Global Land Survey digital elevation model (DEM) 2000, which is merged product using SRTM DEM (http://landsat.usgs.gov/Landsat_ Processing_Details.php) and other DEMs".

L11: This is fine but it requires that snow and cloud conditions are substantially different (what is difficult for orographic clouds and perennial snow fields). It needs to be described what the differences among the multiple scenes are and how they were combined. To me it seems that in many regions it was not possible to find scenes with appropriate snow conditions (despite the combination of scenes), as the 3-year period is simply too short for this. Just as an example: For the M. Everest scene 140-041 the supplemental xls table indicates that two scenes from 17.10. 2001 and 5.1. 2002 were selected. The first one shows severe seasonal snow cover hiding the real glacier perimeter. Why has this scene be used? Because of the smaller regions in shadow? Please explain the selection/combination process.

If we cannot obtain perfect (seasonal snow-free, and cloud-free in glacier area) image for one path-row scene, we search another (second) images, which has clear image, where cloud cover or covered with seasonal snow in the first image.

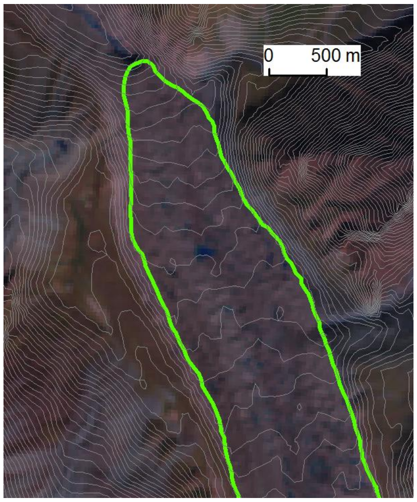
We did not use only summer (high solar angle) images, but also winter season, since those images are not affected by monsoon cloud or seasonal snow. Then, we could found clear images from 1999 to 2003. Some path-row scenes can not find clear image from 1999 to 2003. But, many small glaciers in the shadow part were missed by using winter images. This is the fault of our inventory. Shadow part of large glaciers are estimated the glacier outline using contour lines. We will add above description in the revised manuscript.



Actually, we used other clear images for glacier delineation in p140r041. Supplemental xls table are now including dummy data. We will attach complete table, when we publish as TC.

L14/15: I have no idea how this can work. Please explain it in the methods section.

As we wrote in the above reply, contour line support to delineate glacier outline, where are shaded part. Contour lines makes turnoff points at intersection to glacier outline. Then, contour line support to delineate glacier outline at the terminus of debris-covered glacier.



p145r039

P2803

L6/7: The discrimination of snow from clouds is working because of the strong absorption of ice/snow in the SWIR compared to clouds. The moderate absorption in the NIR has nothing to do with it (and actually snow reflectance is still high in the NIR).

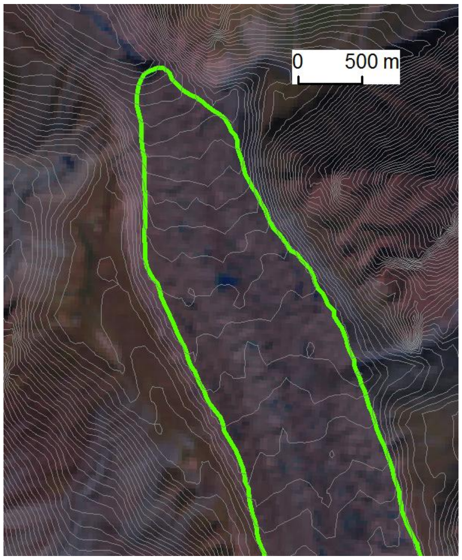
We will revise as "false-colour images enabled us to differentiate ice from cloud because of the strong absorption of ice/snow in the SWIR compared to clouds"

L10: This is fine, but why has automated mapping not been used, at least to have an accurate base for the clean ice? This should be explained here. I assume it has something to do with the poor snow conditions in several images and the difficulties in interpreting them?

We replied in the above "Reply to general comment" (3). We will add the description in the revised manuscript.

L13: As indicated above, this is not a description of a method. Please add all relevant details to understand how this is working (maybe better: do not use it).

Contour lines makes turnoff points at intersection to glacier outline. The method have efficacy for delineation of terminus of debris-covered glaciers. We will add how to use the contour line with a picture in the revised manuscript.



L20-24: This is not the definition as given in the GLIMS Analysis Tutorial. First, all connected feeders (above the Bergschrund) need to be included, and second, also the unconnected glaciers in the steep headwalls are glaciers (maybe hanging glaciers). Finally, several glaciers might have interrupted profiles (e.g. due to a steep slope) and receive ice through avalanches. Of course, the upper parts of these glaciers have to be mapped as well. Only ice-free rock walls (and those covered by seasonal snow) need to be excluded.

We will add difference of our rule from GLIMS Tutorial in revised manuscript. And the detail on exclusion of steep slopes are written in the "Reply to general comments" (1).

L25: According to my experience, it is much more easy to delineate clean glaciers from the false colour composites (where glaciers appear light blue and thus have good contrast) and interpret debris from the true colour composites (also to have a better comparison with the high-resolution data available in Google Earth). In the example of Fig. S1 b) and c) the contrast issue is well visible: The glaciers in c) are clean but the ice is dirty (polluted) and has thus a much lower reflectance. By the way, also these dirty (but debris-free) glaciers can be accurately mapped automatically (e.g. with a simple band ratio).

Thank you for your suggestions. We used many images taken during winter season (low solar angle) to delineate glaciers. Because, more than half area are affected by monsoon during the summer, and we have to delineate glaciers, which have appear in the gap of the cloud cover.

P2804

L2: ‘delineated by reference to topographic data’? How does this work? Does the 100 m SRTM DEM show the glacier boundary clearer then the Landsat imagery at 30 / 15 m resolution? This is hard to believe. Has a hillshade been used or just the contour lines mentioned before? In the latter case: How have they been used to decide where the boundary is? This needs to be described.

Contour lines makes turnoff points at intersection to glacier outline. The method have efficacy for delineation at hillshade or at terminus of debris-covered glaciers. We will add how to use the contour line with a picture in the revised manuscript.

L4: What happens when Google Earth images are snow covered (which is often the case)? Or have all high-resolution images from this source been perfect for all decisions?

A parts of the Hengduan Shan, there are no cloud-free and seasonal snow-free Google Earth images. We delineated using only Landsat images taken before 1999. We will add the description in the revised version.

L6: What is seasonal ice cover?

We revised it as ‘seasonal snow’.

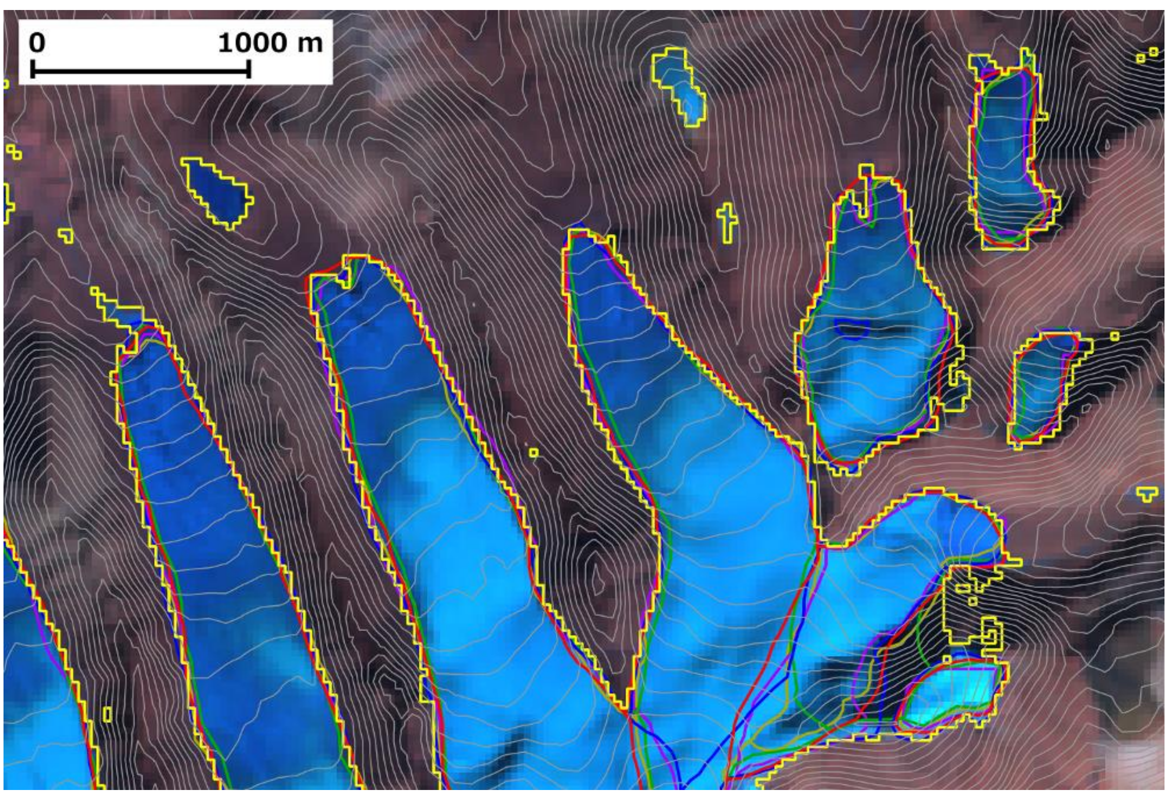
L7: ‘we referred to topographic data’: this is not a description of a method. Apart from the fact that it is an unfortunate decision to define glaciers different from the standard by excluding their steep parts, it needs to be described HOW this method works (I can imagine a threshold value applied to a slope grid, but contour lines?).

We replied in the “replay to general comment” (1).

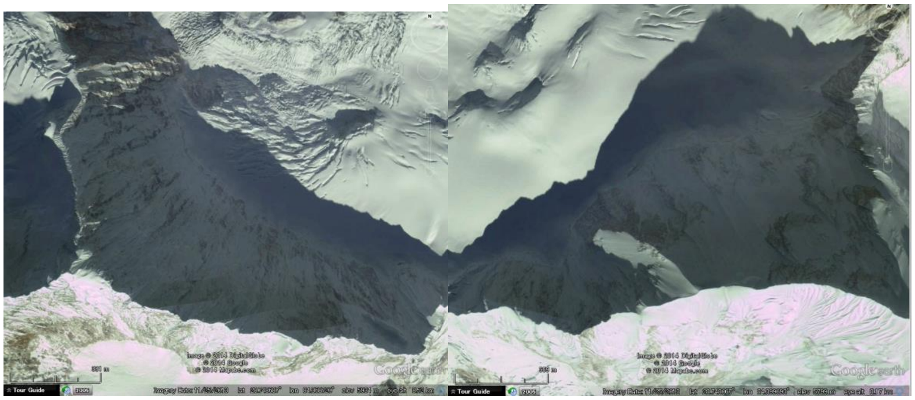
L13ff: This section sounds like there is one person (second operator) knowing everything precisely and thus being able to always give advice for correct interpretation to all others. Given the sometimes wide range of interpretation that is possible (e.g. in cold-dry regions where debris-covered glaciers often have no clear boundaries to rock glaciers), I doubt that such a person (or several?) exists. The examples on pages 7 & 8 also illustrate severe difficulties in correct interpretation. In any case, a comparison with the outlines derived from automated mapping is missing (for clean glaciers) and should be provided. This can even be used as a reference dataset (for accuracy determination) as it is free of generalization effects. Furthermore, other regional studies should be considered (see P2802, L1).

Delineation works were carried out by field work experienced operators and non-experienced operators. Our field work experience on Asian glaciers by experienced operators are limited at only Khumbu region, Langtang region (Nepal), Lunana (Bhutan), Qilian Shan (China) (semi-arid region). So, our project have no professional person, who knows all kinds of Asian glaciers, as you wrote. We will revise the page 7 and 8 you pointed out our mistakes.

We compared automated mapping derived from band ratio method (grid cells with band3/band5 over 1.8 is glacier, Paul et al., (2013)). Yellow lines are glacier boundary by automated mapping, other coloured lines are manually delineated glacier boundary. In general, the boundary of clean glaciers in GGI are consistent with automated mapping. And we will add are comparison in revised manuscript.



L19/20: When specific surface features are obscured by shading, there is no need to assume that there is no ice underneath and exclude these regions. Very likely (as I can judge from Fig. S2a) the orange line is much closer to the correct outline than all others, i.e. that was not a misidentification of the glacier but the correct one.



Above figure shows the Google Earth image of southern walls (dotted circle) of the glacier in Fig S2a. Rock surfaces are exposed at those walls. Therefore, Orange line is not correct.

L22/23: Where these tests performed independently? Please provide details of the method.

We will add detail information of tests as new table in revised manuscript.

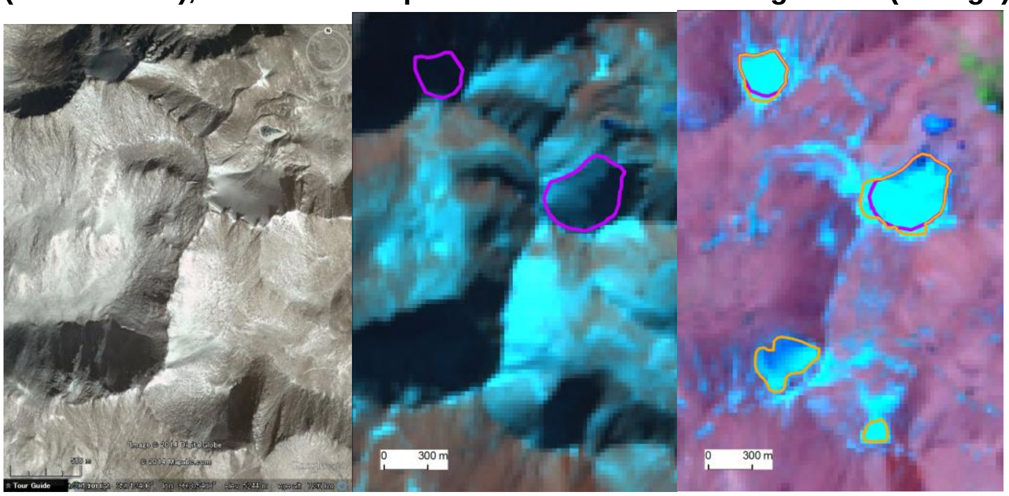
No.	Date	Location		Number of operator
		N	E	
1	May 2012	29.11—29.18°	83.72—83.81°	7
		28.89—28.96°	84.22—84.27°	
		28.73—28.80°	84.28—84.42°	
2	May 2012	28.75—28.79°	85.10—85.18°	7
		28.21—28.28°	85.51—85.63°	
3	March 2013	33.06—33.23°	76.97—77.19°	8
4	July 2013	28.01—28.15°	92.52—92.67°	6
5	March 2014	28.15—28.40°	86.10—86.53°	5

P2805

L1: This reads like the second operator has special knowledge that cannot be shared beforehand with those doing the work and that this expertise is always the correct one. Please show examples of what this second operator is correcting to learn from it (or even better: use the same rules for all operators).

As we wrote above, delineation works were carried out by field work experienced operators and non-experienced operators. If the glacier polygon was made by non-experienced workers as first operator, field work experienced workers reviewed as second operator. Even if the glacier polygon was made by experienced workers, other field work experienced workers reviewed as much as possible.

Below example shows that first operator used Landsat image taken in the winter season (7 Jan. 2003) (Purple), but second operator changed source images in the summer season (12 Jul. 2001), then second operator could add shaded glaciers (Orange).



Google Earth image First operator (Purple) Second operator (Orange)

p133r035 35.701244° N, 99.379732° E

L14: There could be a mismatch with the outlines derived from Landsat as the SRTM DEM with the wrongly interpolated data voids has been used for orthorectification.

We will discuss on those error might cause wrong orthorectification.

L20-25: I would place this into the methods section. It is a description of how calculations have been performed.

We will move this to the methods section.

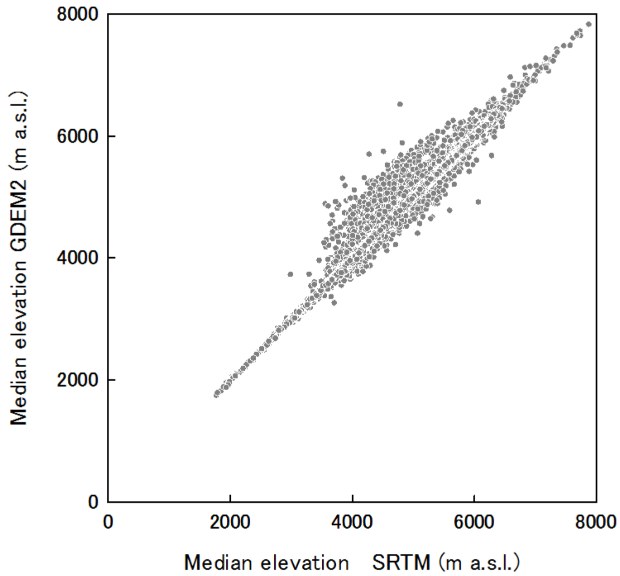
L23: Hayakawa et al. have not investigated the performance over glaciers. This is in general a different type of terrain due to lack of contrast (snow), more gentle slopes and self similarity of surface features (debris). A subtraction of both DEMs should reveal which DEM is more appropriate for the specific purpose and provide better evidence for the selection.

Simple subtraction of both DEMs (SRTM-GDEM2) over the Asian glaciers includes enormous quantity of data. We, therefore, calculated subtraction of median elevations derived from SRTM and from GDEM as next below reply.

P2806

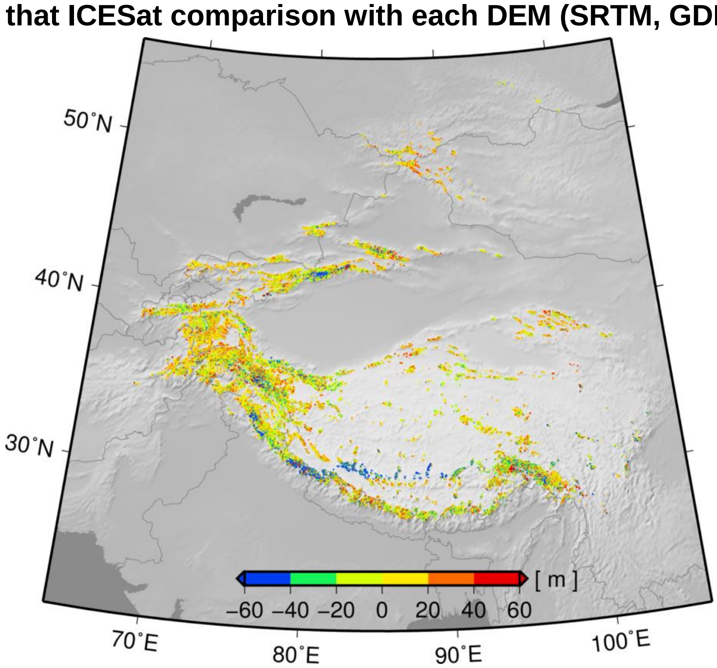
L1-12: This discussion of DEM uncertainties is not really a result. I would either describe this when introducing the datasets or mention it in the discussion section. I am also not sure if this evaluation (ICESat comparison) really matters when considering the applications shown in Figs. 4, 7 and 12.

We will move this section to discussion section.



Above figure shows the relation between each median elevations derived based on SRTM and that based on GDEM2 using GGI. There are relatively large discrepancy from 4000 to 6000 m a.s.l.

Below figure shows the distribution of median elevation difference (SRTM-GDEM2). West Himalaya and Southern Tibet have large differences. But, this figure shows only the difference and we cannot evaluate which DEM is better at certain regions. Then, we thought that ICESat comparison with each DEM (SRTM, GDEM2) are necessary.



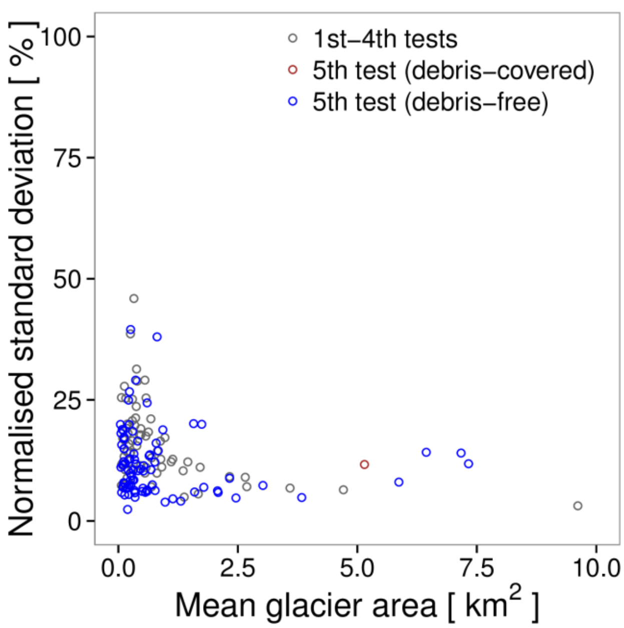
Difference of median elevations derived from SRTM and GDEM2 (SRTM-GDEM2).

L13: I would not place this section before 4.3. The main results are in 4.3 and they should be described first. Section 4.2 itself starts with a description of methods (that might be better placed in the methods section). I would move the reminder of it to the discussion section as it belongs to an overall evaluation of the results. But this is maybe a matter of personal taste. In any case, sections 5.1 and 5.2 are results of this study and have to be in the results section (with the suggested changes) rather than in the discussion.

We will move "4.3 Distribution of glaciers and their median elevations" section to the first in the result. And we will add description of methods for "4.2 Evaluation of uncertainties" and this section will be moved to the second result. And "5.1 Comparison of inventories in the Bhutan Himalaya" and "5.2 Comparison of inventories in high mountain Asia", which will be added comparison with ICIMOD's inventory, will move to the result as your comments.

L17: I suggest using the mean value of all digitizations as a reference for calculating the standard deviation. Otherwise it would imply that the digitiztions are not independent and one is always better than all the others (which seems to be confirmed in L21). When the quality in test 5 is very different from all others, I would assume that the rules for digitization have changed (?) and results are not comparable. Please clarify why this final test was superior in quality to all others and only compare what can be compared.

5th (final) tests were carried out at the end of the project. So, all operators could delineate according to one rule. We revised this figure based on your suggestion that "mean value of all digitization as reference".



L25/26: If these would be 'real' uncertainties, the outlines would not be worth considering in an inventory (as they should be better than 5% in the mean). But as mentioned before, there is likely a bias in the calculation of the accuracy and this should be corrected first (applying the same rules for all digitizations and then use the mean value as a reference).

We will analysis GGI's median elevation of glaciers at certain region by comparing with the ICIMOD's inventory.

P2807

L4/5: How can median elevations be area-weighted? I would understand that only glaciers larger than a certain size are used to calculate a mean value (to reduce the influence of local topographic factors which have a stronger influence on small glaciers) but area weighting?

We would like to represent the median elevation of whole glacier ice in certain grid by area-weighted median elevation. If we eliminate small glaciers, some grids would have no glaciers.

L13: As mentioned above, I see section 5.1 and 5.2 of this study as results rather than a discussion and would suggest moving larger parts of it to sections 4.2 and 4.3 (the current 4.3 should be 4.1). As this would result in a missing discussion, the key findings (e.g. the differences between the compared inventories) should be critically assessed in a revised discussion section. I suggest including a discussion of uncertainties and how they impact on the results (e.g. how does median elevation change when 'correct' glacier outlines are used?), how glacier area changes due to a different interpretation of what a glacier is, and where the largest real differences in interpretation are (when comparing inventories of similar quality), among others (e.g. the derived topographic parameters).

We will move the section 5.1 and 5.2 to result from discussion. In the revised discussion, we will add key findings on the differences between the compared inventories (RGI and ICIMOD).

For the median elevation, we will compare the median elevation derived from GGI and those from ICIMOD.

L13ff: As mentioned before, please use regions for comparison that are worth a comparison rather than those who are wrong for obvious reasons (and do not compare numbers).

We will delete comparison of glacier number as your other comments, however retain comparison of glacier area among inventories.

P2808

L11: The RGI has only assimilated the existing datasets rather than interpreting them (i.e. the obvious errors were in the source material).

We will revise that "Therefore, we suggest that some regional glacier inventories compiled in the RGI has misinterpreted seasonal snow cover as glacier ice."

P2809

L4/5: What has the spectral mapping of glaciers to do with the partitioning? The latter is performed with a DEM.

As your comment, automatical spectral mapping has no relation with the partitioning. And Fig. 10 does not indicate incomplete partitioning. We will delete the description on partitioning.

P2810

L21/22: For clean ice manual delineation is not better than automated methods but more inconsistent and not reproducible. The peer-review process is fine but intransparent (i.e. I do not understand how this works, see comments above). It needs to be explained where the first delineation failed and why the 'second operator' is always right with the interpretation.

Because second (final) operators have experience of field work at glaciers.

p2811

L2/3: 'potentially accounts' sounds like if it is not clear that removing large parts of the accumulation area results in smaller glaciers. I assume that real changes of glacier size since the 1970s are comparably small?

We are discussing on the upper zone of high-relief mountain regions (Fig. 12a) (ex. Karakoram, Himalaya or Hengduan Shan), here. RGI based on the ICIMOD inventory in the Karakoram and Himalayas. ICIMOD inventory based on the recent Landsat images, so, we can not say the area difference between RGI and GGI caused by glacier shrinkage in the Himalayas or Karakoram.

RGI is based on the 1st Chinese inventory in the Hengduan Shan. And, Chinese inventory overestimates the ice-covered area as indicated by Gardelle et al. (2013). Then, we can not declare the upper area difference are derived from glacier shrinkage since 1970s. We will revise the sentence specifically.

L6: Fig. S1c is not about seasonal snow.

This is our mistake. Here, we have to cite Fig. 10c or b. But, we will delete this sentence and Fig. 10c and b as your below comment.

L6: Misinterpretation by whom? The RGI or this inventory? What about comparing glacier outlines in a region with good quality and snow conditions (see suggestions above)?

We will delete this sentence, as your below comment.

L12: Please be aware that the excluded headwalls also include glacier (parts) under the seasonal snow (see page 8 example).

As your comment, if steep headwalls include glacier ice, we underestimate glacier area. We will add in the fault of our inventory.

L13: I do not understand this sentence. What is meant by 'projections of mass balance by in situ observations'? Does this refer to differences in calculated mass changes due to the different techniques of spatial interpolation and averaging applied? How can exclusion of headwalls improve this? As far as I know, these regions are filtered when altimetry is used, are seldom measured in the field, and have small changes anyway.

Gardner et al. (2013) reported that the glacier surface decline values estimated using GRACE and ICESat were less than that observed by field observation.

We would like to suggest the reason of the difference would be that glacier inventory (used for elevation analysis) include those area, where no elevation change due to glacier mass fluctuation were expected. We would like to say 'the no elevation change area' might be steep slope at the glacier head.

Tables

Table 1: Please replace 'Number of excluded small glaciers' with 'Excluded glaciers'

We revised it. And we deleted number of glaciers based on your other comments.

Table 2: Please use the abbreviation AGI also here (instead of the citation). The last column is not the difference in percent (that would be the difference in km2 divided by the total area), but a normalized value (with negative values being changed to positive). If this way of presenting differences should be retained, I suggest using +4 instead of 104 and -4 instead of 96, etc. This would allow for a more easy comparison. It also needs to be shown on a map (in a new Fig. 1) where these subregions refer to (catchment boundaries). The further study sites for area comparison should be marked in this new Figure as well. And please use a more descriptive caption (see Table 3 comment).

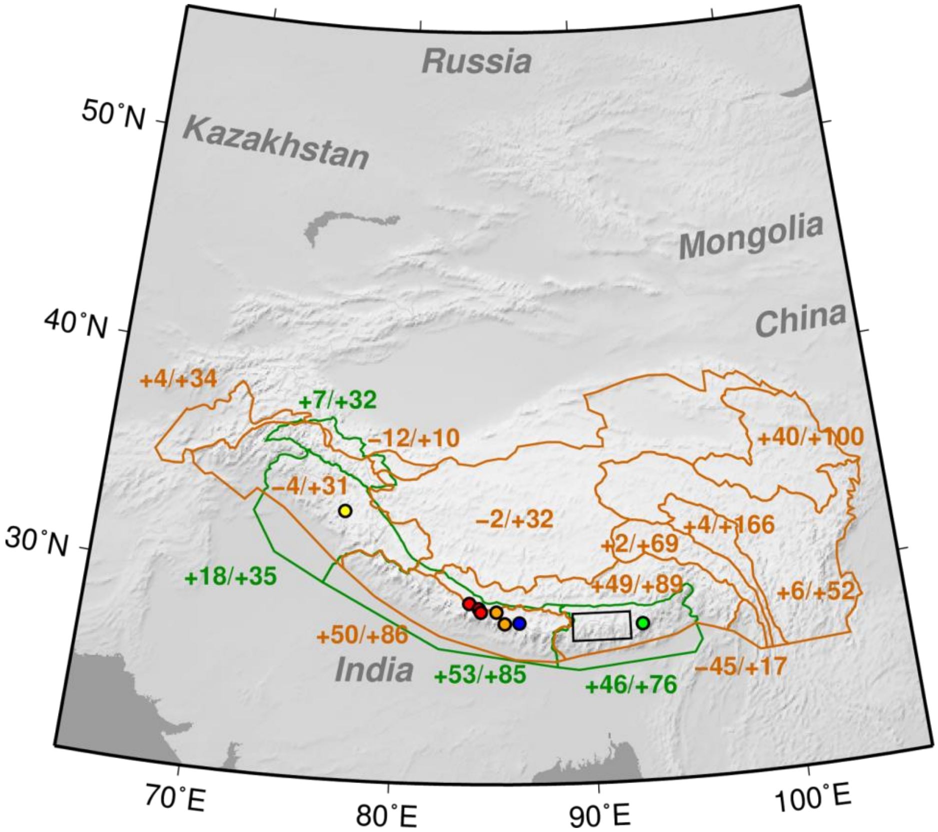
In this study, we noted an inventory made by Nagai et al. (2003, 2004) as AGI. Therefore, inventory made by Bajracharya and Shrestha (2011) differ from AGI. We revised last columns based on comments from you, reviewer#2 (Mauri Pelto) and reviewer#3 (Samjwal Bajracharya). (see reply to comment about Table 2, 3 by reviewer#2)

Table 3: Please use a more descriptive caption, e.g. 'Comparison of regionally aggregated total glacier areas from Bolch et al. 2012 and the GGI'.

We revised it as your comment.

Figures

Please insert an overview Figure showing important subregions/test sites and outlines of catchments (listed in Tables 2 and 3).



We will add above figure in revised manuscript based on your suggestion. Dark green coloured lines show subregion of Bolch et al. (2010) with area difference (Bolch et al. (2010) against GGI [%] / RGI against GGI [%]). Dark orange coloured lines show subregion of Bajracharya and Shrestha (2011) with area difference (Bajracharya and Shrestha (2011) against GGI [%] / RGI against GGI [%]). Black rectangle in Bhutan Himalaya corresponds subregion for comparison among inventories. Red, orange, yellow, green and blue circle show locations of delineation test from 1st to 5th respectively.

Figs. 2a/b, 3, 5, 6, 8, 9 (with their respective revised content): Please add minor tick marks and show them on both sides. I suggest placing the a), b) etc. annotation outside the plot.

We will revise as your comments.

Figs. 10 and S1: Green on light blue is difficult to see, please use another colour (yellow?).

We will try to make clear image in the revised manuscript.

Fig. 2: As a justification for selecting a specific DEM, I suggest to simply subtract the GDEM from the SRTM DEM, add a colour coding in classes of standard deviation, and a layover of glacier outlines (of course, this could only be shown for a subregion). The comparison with ICESat is interesting in general, but in the framework of this study I would suggest showing something more relevant (glacier specific).

Below figure shows difference of median elevation calculated using SRTM DEM and GDEM (SRTM - GDEM) in each glacier. It shows large difference around western Himalaya, Karakoram and Hengduan Shan. However it can not show which DEM caused the large differences. Both SRTM DEM and GDEM have their characteristic superiority and deficiency. Therefore, we consider DEM evaluation against same reference data (ICESat) is reasonable.

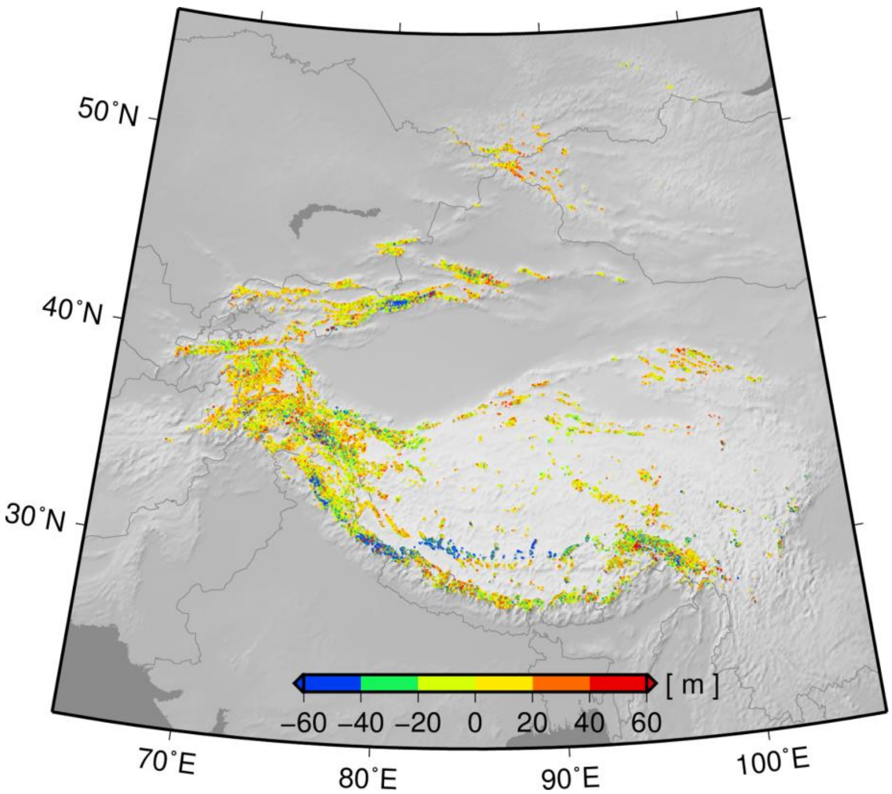


Fig. 3: This plot should be recalculated, after applying the same rules to all tests (also number 5) and using the mean area as a reference.

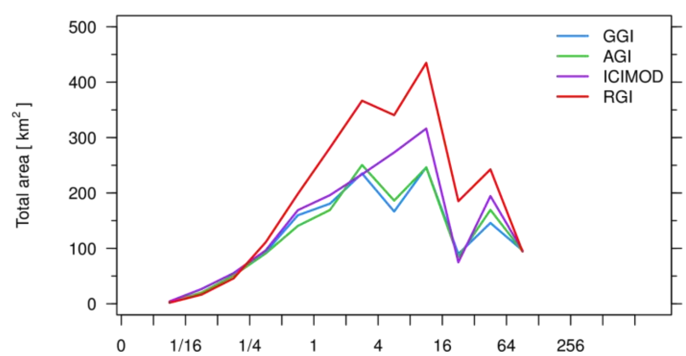
We revised the figure based on your suggestion (see reply to your comment to P2806L17).

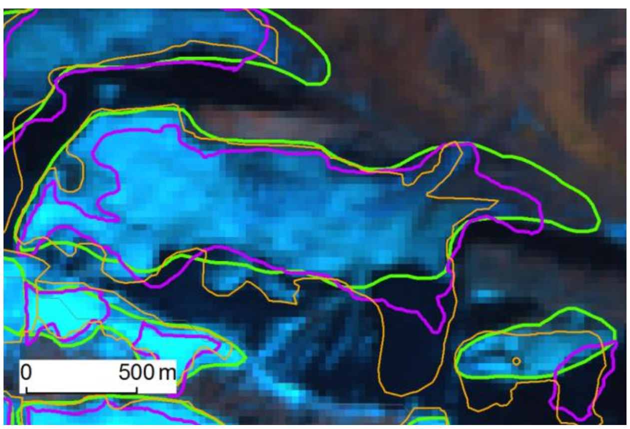
Fig. 4: This plot might change when 'correct' outlines are used. The impact of such a change should be determined for a test region and discussed in the main text.

We will discuss on the impact of difference between 'correct' glacier area including avalanche wall and without wall in the certain test site. We will used ICIMOD inventory as 'correct' glacier inventory.

Fig. 5: I suggest removing this figure. For the GGI vs AGI comparison I would like to see an example (close-up with a few glaciers) showing an overlay of outlines.

At first, we found mistakes in Figs. 5 and 9. Y axis of upper panel (Number of glacier) and lower panel (Total area) were opposite. We are sorry for carelessness mistake. We will eliminate the figure of 'number of glaciers'. But, we would like to retain the figure showing glacier area at each area class, because, our inventory can evaluate only region by region. If our manuscript will be rejected with the area comparison, we will delete the figure (area comparison)





AGI (Purple), GGI (Light green), ICIMOD:Brahmaputra (Orange)

Fig. 6: When retaining this figure, I suggest removing the comparison with the entire RGI and focus on more regional comparisons with other high-quality datasets. When hypsometry is shown, it would be nice to indicate how the sampling is done (e.g. in 100 m bins?).

We will add sampling interval (200 m bins) in the figure caption. And we will add hypsometry comparison with ICIMOD's data as below figure.

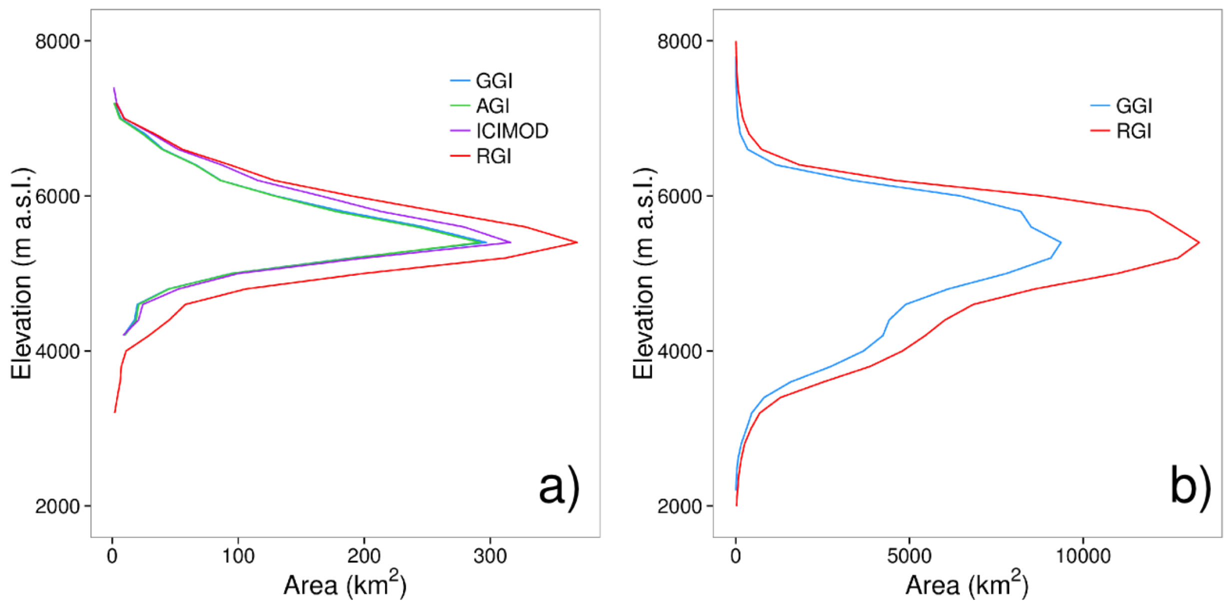


Fig. 7: I suggest removing the comparison with the RGI dataset and instead of c) showing the difference between b) and c)

We will add distribution of median elevation of glaciers derived from ICIMOD inventory as d) in below figure.

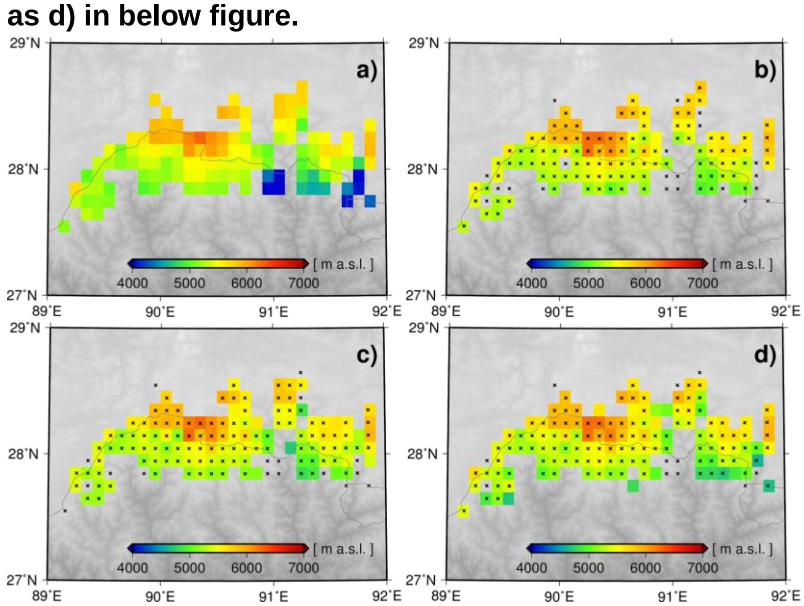


Fig. 8: General remark: For scatter plots with a high correlation, it is most often more insightful to plot the difference between the values vs the values. As mentioned above, I see little value in comparing glacier numbers (what is the message here?) and I would not compare areas or elevations of the entire RGI. Please use a few subregions where the RGI data are of sufficient quality and compare these. The effect of not considering parts of the accumulation area on median glacier elevation should be analysed in detail, in particular when it is foreseen to use this parameter for climatic interpretation (see Sakai et al. 2014).

We will compare the median elevation derived from GGI and those from ICIMOD.

Fig. 9: I suggest removing this Figure.

At first, as mentioned in above reply for Fig.5. Y axis of upper panel (Number of glacier) and lower panel (Total area) were opposite. We corrected y axis.

We will delete the comparison of glacier number, but, we would like to retain the figure of area comparison. Because, the figure indicates the evaluation of 'whole' our inventory. But, if this paper will be reject with this figure, we will delete.

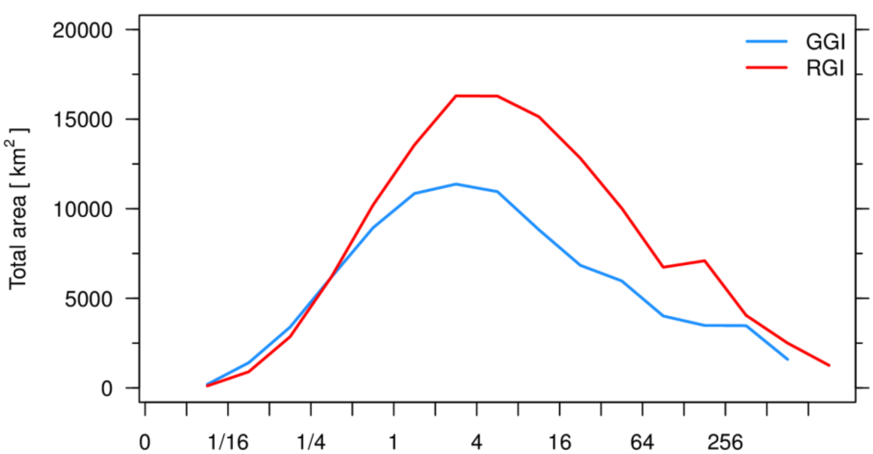
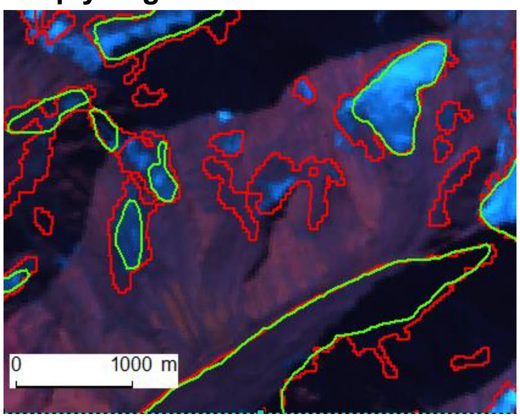


Fig. 10: The comparison with high-quality outlines as shown in a) worries me. I have compiled comparisons with high-resolution screen shots from Google Maps on page 7, showing that the GGI quality is partly rather poor compared to the RGI. It seems that GGI is highly generailzed (like the DCW) and that the second operator has also problems in interpreting glaciers correctly. The poor-quality regions shown in b) and c) have already been documented by Pfeffer et al. (2014) and have been revised in the mean time (for RGI 4.0). There is no need to show them here. The red line on d) is certainly not correct, but why has the glacier in the upper centre and at the Lhotse westface been removed? Please also check the Mt. Everest map from swisstopo or the National Geographic Society for a correct interpretation of glacier extents in this region and see comparison on page 8. Caption: I think the normal way of providing geographic coordinates is latitude, longitude.

We revised the delineation in Fig. 10 a) as follows. Detail of our replies are written at the "Reply to general comments".



We will delete Fig. 10 b) and c). As for Fig. 10 d), accumulation area at Khumbu Glacier. Detail of our replies are written at the "Reply to general comments".

Figs. 11/12: I suggest removing these figures.

These figures indicates the evaluation of whole our inventory. So, we would like to retain in the revised manuscript. But, if this paper will be reject with this figure, we will delete.

Figs. S1 and S2: Some coordinates must be given for all images to have a chance to find these example glaciers (as in Fig. 10). As mentioned above, please integrate these figures in the main text. This is the key work of this study and should be properly documented. Fig. S1: a) Where is the not included steep headwall and the glacier (outline)? b) How is snow discriminated from clouds then? c) glaciers are not debris covered but dirty (i.e. it is clean ice for automated mapping), d) where is the glacier outline here? (this is the interesting stuff!), e) as the thermal signature is not unique and the spatial resolution is much coarser, how is this compensated?, f) where is the glacier in the right hand image?, g) the left image has lots of snow, please adjust the caption for f) and g) to be clear what are the issues here.

As your comments, we will move Figs. S1 and S2 to main text after correction (coordinates and properly document).

a) Steep headwall is not included as glacier (86.87° E, 27.96° N), Background is Google Earth imagery.

b) Clean glacier surfaces are readily delineated with true-colour (bands 3, 2, 1 as RGB) composite imagery (86.72° E, 28.27° N).

c) Glaciers are covered with thin dust layer. Those glaciers can be detected using false-colour (bands 7, 4, 2 as RGB) composite imagery (left), whereas true-colour (bands 3, 2, 1 as RGB) composite imagery (right) shows only black surface (78.82° E, 42.31° N).

d) Thermokarst features and supra-glacial lakes with ice cliffs with Google Earth imagery (left) (86.95° E, 27.91° N) and a non-glacial lake surrounded by smooth terrain with Google Earth imagery (right) (86.47° E, 28.08° N) are used to identify debris-covered glacier surfaces.

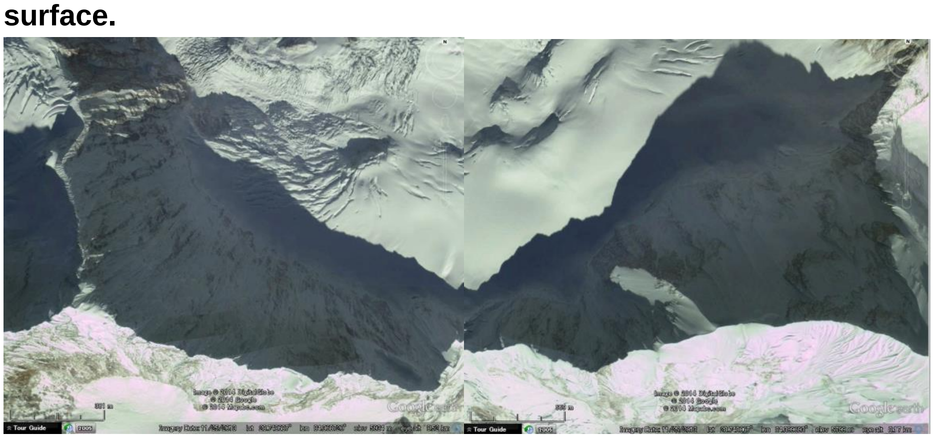
e) The full extent of debris-covered glacier surfaces can be identified using thermal band imagery (band 6) (75.71° E, 35.65° N).

f) Glacier-like seasonal snow with false-colour (bands 7, 4, 2 as RGB) composite imagery (left) and Google Earth imagery (right) (87.65° E, 27.98° N).

g) Glacier ice with false-colour (bands 7, 4, 2 as RGB) composite imagery (left) and Google Earth imagery (right) (81.52° E, 34.60° N).

Fig. S2: The orange line might be more correct than all others (see example on page 8). Is there an image available showing that there is bare rock under the snow?

Below figure shows the closeup image of the southern walls. We can find bare rock surface.



Typo issues
P2801, L4: A glacier inventory …
We revised it

P2801, L15: Pfeffer et al (with f)
We revised it

P2801, L19/21: over high mountain Asia (remove 'the', here and elsewhere)
We revised it

P2802, L7: We selected Landsat scenes
We revised it

P2802, L9: Reference System 2 (WRS1 is for MSS)
We revised it

P2804, L17: were delineated differently (not all are inaccurate)
We revised it

P2806, L4/8: biases: I would call these errors
We will use errors instead of biases here

P2809, 16/17: DN is a unfortunate abbreviation as it is already occupied by 'digital number'.
We will not abbreviate normalised difference

P2818, caption: 'Footprints of Landsat scenes ...'
We revised it

P2827, caption Fig. 10 (last line): These are false-colour composites
We revised it

Cited reference
Sakai, A., T. Nuimura, K. Fujita, S. Takenaka, H. Nagai and D. Lamsal (2014): Climate regime of Asian glaciers revealed by GAMDAM Glacier Inventory. The Cryosphere Discuss., 8, 3629-3663.

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Thakuri, S., Salerno, F., Smiraglia, C., Bolch, T., D'Agata, C., Viviano, G., and Tartari, G.: Tracing glacier changes since the 1960s on the south slope of Mt. Everest (central Southern Himalaya) using optical satellite imagery, The Cryosphere, 8, 1297-1315, doi:10.5194/tc-8-1297-2014, 2014.