

Answer to the referee's comments

Anonymous Referee #1

We would like to thank referee #1 for the very careful reading of our manuscript and the numerous and helpful comments. The referee's specific comments are addressed below (blue colored).

The referee is right to point out that a clarification of the scope of the manuscript is needed. Our intention for this paper is to examine glacier changes in the Karakoram with the use of multi-mission satellite data (multispectral and SAR data). Hence, we suggest to exclude the sections about TanDEM-X derived volume changes and parts of the ice dynamics that are not directly related to surge-type dynamics. We now focus on the investigation of termini position changes over a 36 year period (1976 to 2012) and provide ice velocity coverage for the entire region as well as for surge-type glaciers. In accordance with the referees' wishes, we will change the classification of 1219 glaciers into four categories (surge-type, advancing, retreating and stable glaciers). The analysis in this respect has already been done. In that way, existing inventories on surge-type glaciers can be updated (e.g., Barrand and Murray, 2006; Copland et al., 2011; Hewitt, 1998). We appreciate and refer to these previous studies as before. 91 glaciers are known to have shown an active phase of a surge one or various times since the 1860s (Barrand and Murray, 2006; Copland et al., 2011; Quincey et al., 2011; Hewitt, 1969, 1998, 2007; Kotlyakov et al., 2008; Mason, 1931). We identified ten more glaciers, which showed surge-type behavior during the observation period 1976 to 2012 that were not classified as such before. Those glaciers are mostly located in the Sarpo Lago Basin and the Shaksgam Valley. In 2012, ten of the 101 surge-type glaciers were still in the active phase. Surge-type glaciers, which were previously unknown, have been identified by investigating termini position changes between 1976 and 2012, surface velocities, surface features, and/or terminus thickening.

Additionally, we would like to show the regional distribution of each glacier class across the Karakoram Range and compare dimensional glacier characteristics like glacier length, glacier area, mean slope along the main glacier branch, and mean elevation. Glacier surface velocities derived from different SAR sensors (ERS SAR, ENVISAT ASAR, ALOS PALSAR and TerraSAR-X) for different years (1992, 1993, 2003, 2006 to 2013) complement a comparison of each glacier class, and indicate increased surface velocities during the active phase of a surge event. The combination of multi-temporal ice velocities and an improved, Karakoram-wide inventory including glacier termini positions changes and statistics provide in our view relevant new observational information on the current state of glaciers in the Karakoram Range.

General comments

Rankl et al. used data from optical and SAR space-borne sensors in the Karakoram mountain range to (i) measure glacier length changes, (ii) provide the first complete surface velocity mosaic of all glaciers together with velocity variations for selected glaciers and (iii) document volume changes of a few glaciers. The quality and the diversity of the data presented in this paper is impressive and promising for the future monitoring of those glaciers on a regular basis. Unfortunately, the paper lacks a well-defined scope and the amount of new glaciological knowledge is low or, rather, these potential advances in our understanding of Karakoram glaciers are hidden in a long paper focused on technology/remote sensing. Right now, this paper is mostly "data". Those data are needed but in the end, the reader is a bit disappointed. Some work is still needed to make this paper appropriate

for The Cryosphere. The authors need to clarify the scope of the paper. It is not clear if they are studying glacier advance/retreat in relation to climate change or if they are only interested in surge-type glaciers. The distinction between the two categories of glaciers (surging and non-surging) is unclear. The first sentence of the abstract is symptomatic of this ambiguity that persists throughout the paper. In this first sentence, glacier advance and surging behaviour are contrasted to the worldwide retreat of glaciers. There is no reason to contrast surge with worldwide retreat. The authors need to discriminate surging and non-surging glaciers. The same occurs a few lines later (L7-8): is there a difference between “surging glaciers L7” and “surging/advancing glaciers L8”? A glacier can advance without being in the active phase of the surge cycle. This ambiguity in terminology and in the classification of the glaciers persists throughout the text and it alters the proper understanding of the findings. Some important references are missing. In particular the papers by (Scherler and Strecker, 2012; Scherler et al., 2011) are relevant for this study and their results need to be compared to the one of the present study. (Minora et al., 2013) is also relevant although not accepted yet (but the authors cited (Bhambri et al., 2012) which is also still in discussion).

As stated above, we suggest to focus the paper accordingly and we already revised the analysis in order to address the reviewer's statement on surging/advancing glaciers. We now also refer to the papers mentioned by the reviewer.

Specific comments

ABSTRACT

P4066 L5. Not a single inventory but various are needed to study changes with time

We are not completely sure what the reviewer means with this statement. Actually, we provided an inventory of glacier boundaries and temporal updates where changes occurred. We digitized termini changes during the observation period for each glacier and stored them within a GIS database. In that way, we are able to provide a glacier inventory including changing termini positions over time.

P4066 L6. It would be good to also indicate the % of stable glaciers (within uncertainties) and the % of retreating glaciers. It was one shortcoming of the (Scherler et al., 2011) paper to have “stable and advancing” glaciers grouped. I recommend to have three categories (Advancing/Stable within uncertainties/Retreating). A non surging glacier whose length does not change over a decade or two does not have the same climatic significance than a retreating or advancing glacier, so there is no reason to place stable glaciers either in the advancing or retreating category.

Thank you for this helpful advice. We updated our inventory and grouped the glaciers into the categories:

- surge-type glaciers (which surged one or various times since the 1860s)
- advancing glaciers
- stable glaciers and
- retreating glaciers

As a result, we observed that out of 1219 glaciers, 101 were surge-type glaciers, 56 were advancing glaciers, 969 glaciers showed stable front positions and 93 glaciers revealed retreating tongues during the observation period 1976 to 2013. Within the inventory of surge-type glaciers, 91 glaciers were in accordance with the surge-type glaciers mentioned in the papers of Copland et al. (2011) and Quincey et al. (2011). However, we found ten more glaciers, which showed an active phase of a surge in the Karakoram Range during the observation period. Those glaciers are mostly located in the Sarpo Laggo Basin and the Shaksgam Valley (as was shown in Fig. 7). They indicate

remarkable frontal advances of up to ~3.5 km during a five year time span, increased surface velocities close to the glacier snout, looped and folded moraines and terminus thickening. Glaciers are classified as retreating, if a retreat > 60m happened during the study period. Digitized retreats should have been larger than the uncertainty range of ~60m (see comment below). According to the renewed inventory, we updated the comparison of glacier characteristics like glacier length, area and slope in section 4.1, and added a comparison of the elevation ranges the glaciers extent over (see below).

P4066 L7. Surging behaviour is ambiguous. Using “the active phase of the surge cycle” would be clearer.

We agree with the reviewer that our phrasing was perhaps misleading. We suggest to change our wording to surge-type glaciers, when we refer to glaciers that are known to have shown surge-type behavior during or before the observation period. We will address specifically active/passive phases of a surge, when we refer to individual periods or observations. We suggest to rewrite the sentence as follows: “Out of 1219 glaciers, 56 advanced, 969 remained stable and 93 glaciers retreated during the observation period 1976 to 2012. 101 glaciers are known or classified as surge-type glaciers, whereof ten glaciers were still in the active phase in 2012.” We will consider such terminological issue throughout a revised version of the paper.

P4066 L16. “bi-static” not really necessary for the abstract

We will shorten this sentence accordingly. The expression bi-static will not be used anymore since the elevation change section will be removed.

P4066 L17. Why only SAR? The present study used also other type of images (e.g., optical from the Landsat satellite).

Landsat is already regularly acquired, but e.g., TerraSAR-X imagery has to be specifically booked. In this case, we suggest SAR imagery for surface velocities since repeat acquisitions are less cloud and illumination independent. However, of course repeat high-resolution optical data would also be highly appreciated.

We suggest to change the wording to: “We recommend regular acquisitions of high resolution, cloud and illumination independent SAR satellite data and/or high resolution optical data. Further exploitation of the archives is needed in order to generate an improved database for monitoring changes, and to at least partially compensate for the lack of in-situ and long-term climatological measurements in the Karakoram region.”

INTRODUCTION

P4066 L22. (Church et al., 2011) could be replaced by (Gardner et al., 2013) because the latter paper has shown that the database of glaciological mass balance measurements (used in the Church et al. analysis) is biased toward glaciers with higher rate of mass loss. (Kaser et al., 2010) can also be cited regarding significance of glaciers for water resources.

Thank you for the useful advice. We replace the references accordingly.

P4066 L25. (Immerzeel et al., 2010) is of course a possible reference here but the authors will note that their 2013 paper (Immerzeel et al., 2013) is now drawing different conclusions than their 2010 Science paper... Rather than those papers, that speculate about future water resources in a region where model seriously lack observations on which they could be calibrated, I strongly recommend reading the brilliant introduction in the study by (Cook et al., 2013) on the question of water

resources and stress in Pakistan. (Bookhagen and Burbank, 2010) is also a strong paper on the topic.
We are going to change the references according to the referee's suggestion.

P4067 L5. (Gardelle et al., 2013) is more relevant than their 2012 paper for the Himalaya
We thank the reviewer for this useful advice.

P4067 L6. Not really controversial. There is rather now a good consensus that those glaciers are stable.
We will rephrase this sentence accordingly.

P4067 L9. "hosts" rather than "account for"
We suggest to change the sentences to: "Moreover, the Karakoram hosts a high number of surge-type glaciers."

P4067 L25. "surging/advancing". Again this ambiguous mixing. For example, (Hewitt, 2005) have reported advance of glaciers that were not connected to the active phase of the surge cycle (and thus may be climate-driven).
As mentioned above, we updated our inventory into four classes (surge-type, advancing, retreating and stable glaciers). The description is changed accordingly.

P4068 L1. "Normal" is contrasted to "advancing". Not relevant. Better to have retreating and stable glaciers as other categories.
Concerning the updated classification with four classes, this sentence has been rewritten to: "The inventory is fed with dimensional and topographic characteristics of each glacier class. Each glacier class is then compared to each other. "

P4068 L2. "ice dynamics". No. A complete map of the surface velocity field.
We will follow the reviewers suggestion for rephrasing in order to be more precise.

P4068 L9. Not really a small glacier. Braldu is about 20 km long... Maybe provide the area of the three glaciers.
In our revised version of the manuscript, we are going to cut the sections concerning TanDEM-X based glacier volume changes (i.e., section 3.3 and 4.3).

STUDY AREA

P4068 L22. "ranges" -> "is found"
The sentence has been changed accordingly.

P4069 L8. (Immerzeel et al., 2012) provide also useful information for the precipitation on Karakoram glaciers.
Thank you for this useful advice. We are going to consider this references in a revised manuscript.

P4069 L10. A thorough analysis of climate change in the upper Indus Basin can be found in (Bocchiola and Diolaiuti, 2013)
We thank the referee for this suggestion and are going to cite this reference in a revised manuscript.

P4069 L12. 'increase in winter elevation'. Rather 'increase in glacier surface elevation in winter'

The sentence will be changed accordingly.

P4069 L25. Käab et al. did not find “slightly positive overall elevation changes in the region”. They found a rate of elevation changes of -0.07 ± 0.04 m/yr when autumn data are used (their Table 1). So a slightly negative elevation change.

We are sorry for the misleading information we provided here, and appreciate the reviewer's careful reading. We have changed this sentence to: “A comparable study found positive elevation difference trends in winter ($+0.41 \pm 0.04$ m yr⁻¹), and only slightly negative elevation difference trends in autumn (-0.07 ± 0.04 m yr⁻¹) for the Karakoram derived from a six and five year ICESat time-series, respectively (Käab et al., 2012). “

DATA AND METHODS

P4070 L12. Source of the SRTM DEM. Gap filled version of the DEM?

We used version 4.1 of the SRTM DEM, which has the gap filled. We downloaded the data from the CGIAR Consortium for Spatial Information (<http://srtm.csi.cgiar.org/>). We added this reference on P4070, L12.

P4070 L20. Give the equivalent length. Rather than “1-2 pixels”, cannot the authors select one of those two values (1 or 2 pixels) and classify glaciers as stable when their absolute length change is lower than this value.

We agree with the referee that it is more precise to provide an exact value of uncertainty. Since we are mainly using Landsat TM data for the derivation of the glacier inventory, the uncertainty accounts for ~60m. We used that threshold to classify a glacier as retreating, stable or advancing.

P4070 L20-22. Clarify the unclear relationship between “focusing length measurements on glaciers larger than 3 km” and “the seasonal snow cover”. Do the authors understate that larger glaciers reach lower elevations and generally show a snow free terminus?

For the glacier inventory in the present study, we used a database of 1219 glaciers. As an initial base we used the Randolph Glacier Inventory 2.0. Thereof, we chose every glacier with more than 150,000m² in area and with more than 3km in length. The area criteria was established since the semi-automatic calculation of the centerlines was only possible above that threshold. For the classification of the glaciers into surge-type, advancing, retreating and stable, we decided to use glaciers >3km. By doing so, we assure to only use glacier polygons, which can be clearly distinguished from seasonal snow cover and snow fields. Large glaciers with snow-free, debris covered termini are of course included in the inventory, since the length criteria is fulfilled

The referee is right to point out that it is necessary to clarify the wording of this sentence. We suggest to change it to: “We focused the analysis of surge-type, advancing, retreating and stable glaciers on glaciers at least 3km in length and more than 150,000m² in area. Hence, we assure to exclude seasonal snow cover and snow fields from the analysis.”

P4070 L22. “In this study, we did not distinguish between surging and advancing glaciers”: However it is really important for the significance of the present study to distinguish those two categories! Having them grouped alter the glaciological value of the paper.

We updated the glacier inventory having the glaciers grouped into for classes (surge-type, advancing, retreating and stable glacier, see above), in accordance with the referee's wish.

P4070 L26. (Mayer et al., 2011) is also a relevant reference for this statement.

The reference has been added accordingly.

P4072 L14. I thought “speckle tracking” was different from “feature tracking”. If I am right, can the authors clarify which one of the two techniques they used?

Unfortunately, there are various expressions in regard to the methodology and sometimes they are used ambiguously. We use tracking on SAR intensity only, that means it uses surface features, but also speckle where its correlation is possible on the SAR image intensity only. Alternative methods use optimization via coherence, but this method requires coherence between acquisition dates. Latter is difficult in the region with sometimes large temporal baselines between image acquisitions or summer imagery. We will clarify the method description in an updated version.

P4073 L19. Did the authors analyze mean offsets? Did they correct for any residual offset measured on the stable terrain? Is the error level determined by calculating the standard deviations of the offsets? Generally, clarify how the uncertainties are derived.

In our analysis, images of the same viewing geometry are first co-registered using very large windows (global offset of the entire scenes). In a subsequent step, we use smaller “tracking” windows to determine the displacements. The global offset is considered in the displacement fields. We suggest to update this information in the methodological section. Uncertainties in the derived flow fields were estimated by determining displacement values over non-moving terrain (e.g., bedrock) after removing the global offset. In order to receive sample points for static areas, we excluded snow and ice covered areas, glaciers as well as river beds and terraces. For each image pair, 10,000 random samples were chosen to determine the velocity error. The error values given in the table below represent the mean + standard deviation over stable ground, compiled from all image pairs of each sensor (Table 1).

The magnitude of the tracking errors is influenced by various factors including the spatial resolution, temporal baseline, viewing geometry as well as environmental factors affecting the backscatter signal. We will address this in the description. Due to the high number of scenes we cannot address this individually for each image pair within the paper itself, however, we are happy to give a more detailed error analysis in the Supplement Material, including the mean error plus standard deviation for each image pair and sensor, overall tracking errors, and co-registration errors. We suggest rewording the respective paragraph as follows: “ The precision of SAR offset tracking algorithms is dependent on various system, processing, and environmental factors. Those include the temporal and spatial baseline between acquisitions, glacier surface characteristics, and their changes over time as well as spatial representation, spatial resolution, wavelength, temporal changes of surface characteristics, displacements of the glacier in the observation time, tracking window size, step size, search radius, and co-registration accuracy. Those influences are hardly quantifiable and measurable, in particular since they vary from image pair to image pair. However, uncertainties of the specific flow fields were estimated determining displacement values over non-moving terrain (e.g., bedrock) excluding snow and ice covered areas, glaciers, river beds and terraces. Mean velocity errors and their standard deviations were calculated with 10,000 random samples over stable ground for each image pair (Table 1).”

Table 1. Mean uncertainties of displacement fields calculated over non-mowing terrain given for each sensor (in $\text{cm day}^{-1} \pm 1$ standard error, s.e.).

Sensor	Repeat cycle [days]	Uncertainty [$\text{cm day}^{-1} \pm 1$ s.e.]
TerraSAR-X SM	11/22/143	1.3±3.7
ALOS PALSAR FBS	46	2.9±9.0
ENVISAT ASAR	30*/35	2.2±3.0
ERS-1 SAR	35	6.1±9.0

*30 day repeat cycle since November, 2010.

P4073 L27. Refer to Figure 1 for the location of those two glaciers.

Section 3.3 and 4.3 are not included in the revised manuscript. However, we thank the referee for this advice.

We suggest to exclude the section on TanDEM-X/SRTM elevation change. Hence, the subsequent comments will not be addressed.

P4074 L12. “despite very less” is unclear

P4074 L19. Not very clear how the authors managed to identify accurate GCPs from the 90- m resolution DEM on images at high resolution. Maybe clarify the procedure.

P4074 L23. Clarify at what resolution the comparison was made and how the DEMs were resampled. Comparing DEMs of different resolution is not straightforward (e.g., Gardelle et al., 2012a)

P4074 L28. “flat”: did the authors use a threshold on the slope? And did the authors check for any mis-alignment of the DEMs before this comparison (e.g., Nuth and Kääb, 2011)

P4075 L2. Did the authors try to correct for the penetration of the C-Band signal? (Gardelle et al., 2012b) provide a curve of penetration with altitude in this area that the authors may use. The Gardelle et al. correction is probably not perfect but this is better than not correcting at all and putting this in the error bar. If the authors do not correct for this penetration, then the elevation changes will be biased toward positive values.

P4075 L7. 900 not 0.9 kg/m^3 . And the authors also need to justify briefly their choice for the density (+ add uncertainties).

RESULTS AND DISCUSSION

P4075 L11. How did the authors split the glacier complex in individual glaciers? Not explained in the Methods. Also they need to explain how they handled glaciers that are surging during various years. Counted once?

As we used the Randolph Glacier Inventory as a base, glaciers were already subdivided in this region. As we now distinguish in surge-type, advancing, retreating and stable glaciers, glaciers having shown more than one active phase are counted only once as surge-type glacier. We classify glaciers in the inventory, not individual events. This will be clarified in an updated version. We address this issue now in the method section, where it is appropriately placed rather than in the

results & discussion section.

P4076 L2. This sentence was not clear to me.

We suggest to delete this sentence.

P4076 L5. Figure 3 does not really illustrate such a marked increase. Can the authors compare the total number of surging glaciers during 1999-2005 and 2005-2011 to illustrate this large increase in surge activity?

Based on the renewed classification, we analyzed the temporal development of surge-type glaciers in the active phase and advancing glaciers over different time spans (Table 2, Fig. 1). The number of glaciers in the active phase decreased with time, whereas termini advances happened more frequently since 2000. The latter might be probably attributed to a cooling of mean summer temperatures and an increase in precipitation in winter since the 1960s (Archer and Fowler, 2004; Fowler and Archer, 2006; Shekhar et al., 2010). However, the surge behavior of individual glaciers does not follow this climatic signal.

Table 2. Number of glaciers which were in the active phase of the surge cycle or showed termini advances, and their development over time. Glaciers were counted repeatedly, if advancing or active in various time periods.

	Glaciers in an active surge phase	Advancing glaciers
1800s-1989	38	n.a.
1990-1999	33	2
2000-2006	22	45
2006-2012	23	48

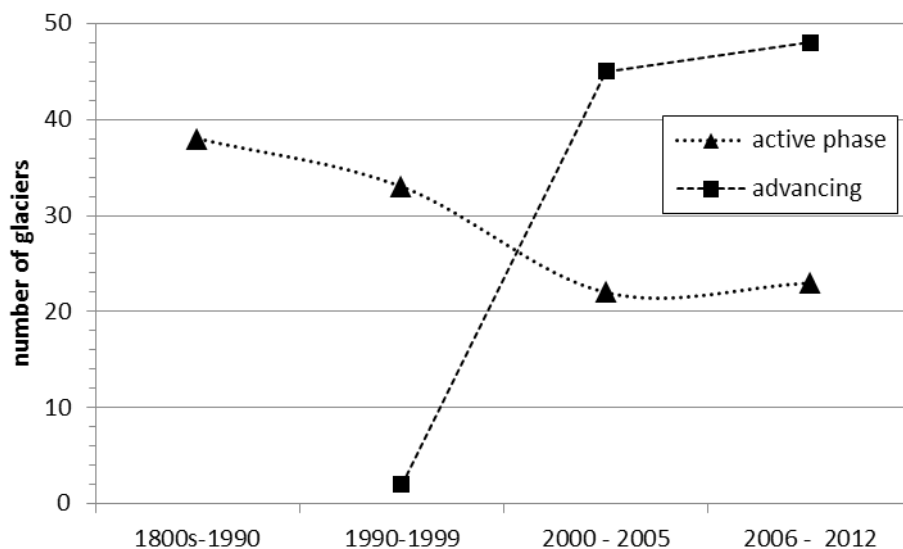


Fig. 1. Temporal course of advancing and glacier in the active phase of a surge during various time periods. Be aware that the first data point covers a very large time interval.

P4076 L10. “Agree” rather than “correlate”
The sentences has been changes accordingly.

P4077 L2. “Strongly” rather then “slightly” because there are many more small glaciers than large glaciers. However, I can understand the reason for selecting the same minimum length to compare the two sets of glaciers. What is the size of each sample? 134 surging glaciers, right. How many non-surging glaciers larger than 3 km?

Due to the updated glacier inventory, we recalculated the statistics about glacier length, area, and slope. The inventory consists now of 1219 glaciers, whereof 101 were classified as surge-type, 56 were advancing, 93 retreating, and 969 were stable glaciers. Hence, 1118 non-surge-type glaciers. The class of surge-type glaciers consists of glaciers, which have been in the active phase one or various times since the 1860s. Similarly to our first version of the manuscript, we chose a minimum length of 3km and a minimum area of 150,000m² for the glaciers to be included into the inventory. Additionally, we broadened the statistical analysis with a comparison of the mean elevation of each glacier class, and the spatial distribution of each glacier class across the Karakoram Range. In the following, we added the new text, which will replace the former part on P4076, L20 to P4077, L23: “In a previous study, Barrand and Murray (2006) analyzed potential morphometric and environmental influencing factors on glacier surges, based on 150 glaciers of which 19 were surge-type glaciers. With the inventory of the present study we can rely on a much larger database (1219 glaciers) over a longer time period. Characteristics of surge-type (101), advancing (56), retreating (93) and stable (969) glaciers, such as glacier length, area of the glacier catchment, mean slope of the main glacier branch, and mean elevation of the glacier were compared. The length, area, slope, and altitude distributions of the different glacier classes (Fig. 2) differed significantly ($p < 0.0001$) referring to a Wilcoxon rang-sum test.

The minimum glacier length of each glacier class was fixed by a threshold of 3km length. Glaciers below this threshold were not considered in the statistical analysis. The maximum length varied between ~28.4km (median = 6.2km) for advancing, ~45.6km (median = 11.3km) for surge-type, ~57.2km (median = 5.1km) for retreating, and ~75.8km (median = 4.4km) for stable glaciers. The longest glacier was Siachen Glacier at the south-eastern part of the Karakoram Range. The median length distribution might be strongly influenced by the high number of glaciers smaller than 10km in length (Fig. 2, a), and by the lower length limit (i.e., 3km) of our analysis. Fig. 2 visualizes that around 90% of each, advancing, stable and retreating glaciers, are smaller than 10km in length. Two thirds of stable glaciers in the inventory are even shorter than 5km in length. Surge-type glaciers (median length of 11.3km) are in general longer than advancing, retreating and stable glaciers. About two thirds of the surge-type glaciers are longer than 10km. The length distribution is comparable with that of Barrand and Murray (2006), who observed a peak in the length distribution of surge-type glaciers at around 10km in length and a comparable median length of 13.6km. The high number of short stable and advancing glaciers could be a result of short response times to changing climate conditions, and might be attributed to the observed increase in precipitation since the early 1960s (Archer and Fowler, 2004; Williams and Ferrigno, 2010; Yao et al., 2012), and decreasing mean summer temperatures (Fowler and Archer 2006; Shekhar et al., 2010).

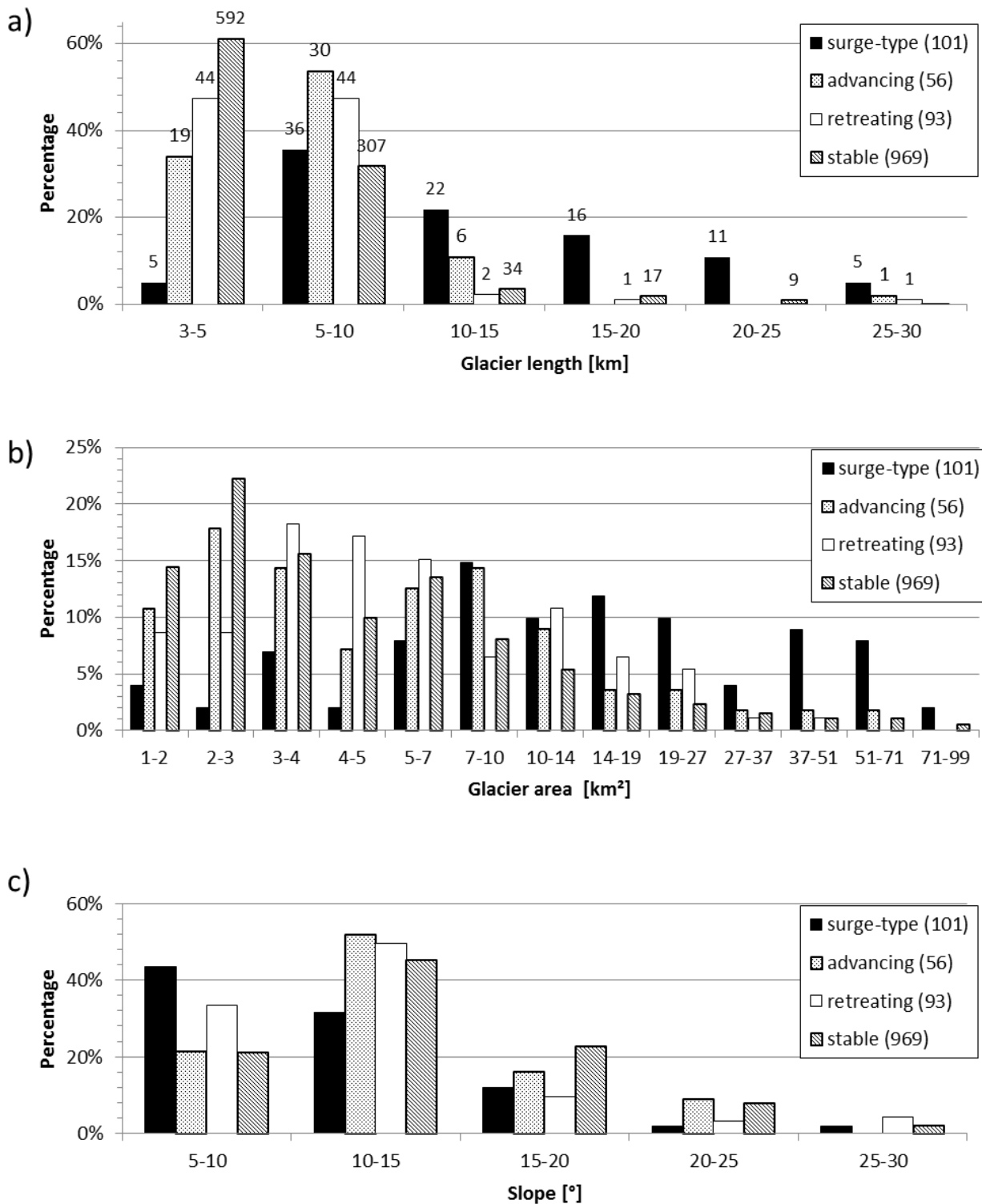


Fig. 2. Percentage of glaciers classified as surge-type, advancing, retreating or stable related to the overall number of each class, divided into a) glacier length, b) catchment area, and c) mean slope along the main glacier branch. The absolute numbers per glacier length class are given above the bars in panel a).

Retreating glaciers are mainly located west of the Hunza River close to the Hindu Raj mountains, north of the Shimshal River, and at the eastern margins of the Karakoram (Fig. 3). 75% of them are found below 5400m a.s.l. with a median of 5200m, whereas the upper quartiles of advancing and stable glaciers are located above that altitude, and also the median elevations are higher for that glacier classes (Fig. 4). The retreating behavior of glaciers in the Karakoram might be due to the lower altitudes they are extending over, and a smaller amount of high altitude snow fall in general (Hewitt 2005). According to Weiers et al. (1995), precipitation in high altitudes is less in the northern part of the Karakoram and towards the Hindu Kush mountains compared to the central part of the Karakoram. Retreating glaciers located in the north and north-west of the Karakoram would be additionally affected by that. In the Hindu Raj and Hindu Kush mountains west of the Karakoram, 70% retreating glaciers were found between the 1970s and 2007 (Sarıkaya et al., 2012, 2013, also: Scherler et al., 2011) as well as negative mass balances between 1998 and 2008 (Gardelle et al., 2013) and between 2003 and 2009 (Kääb et al., 2012). These observations together with the present findings indicate an increasing number of retreating glaciers at the western and eastern margins of the Karakoram Range.

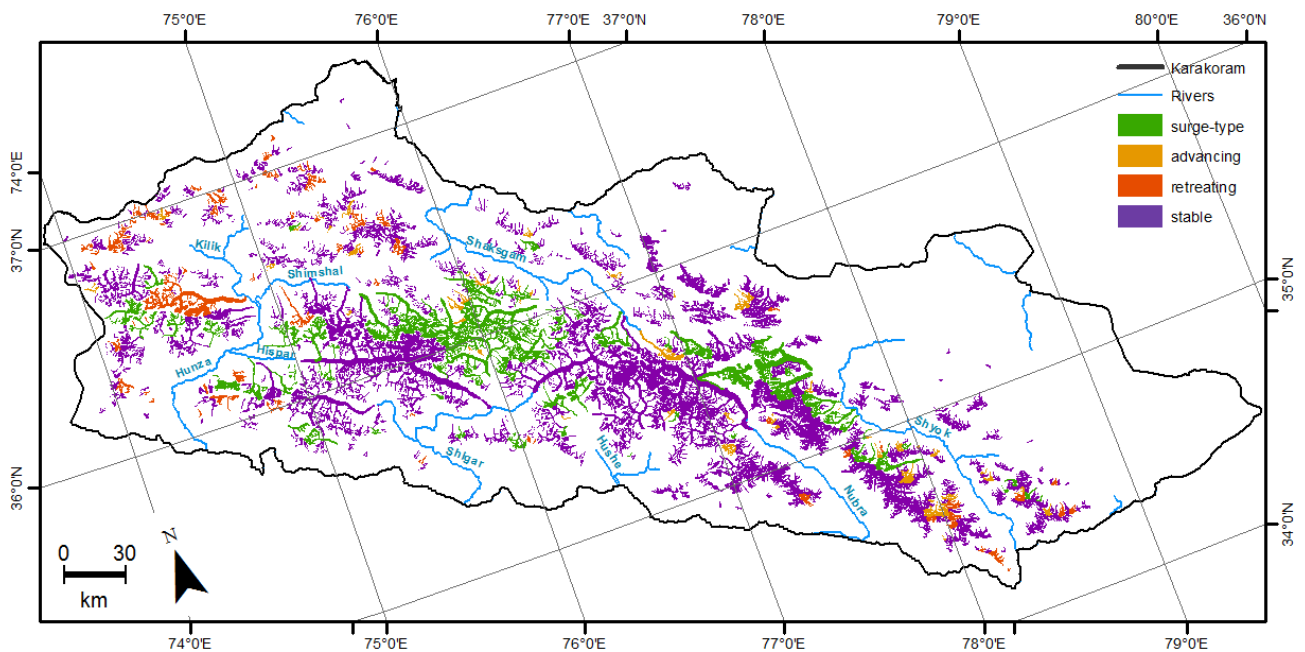


Fig. 3. Spatial distribution of glaciers classified as surge-type, advancing, retreating or stable across the Karakoram Range.

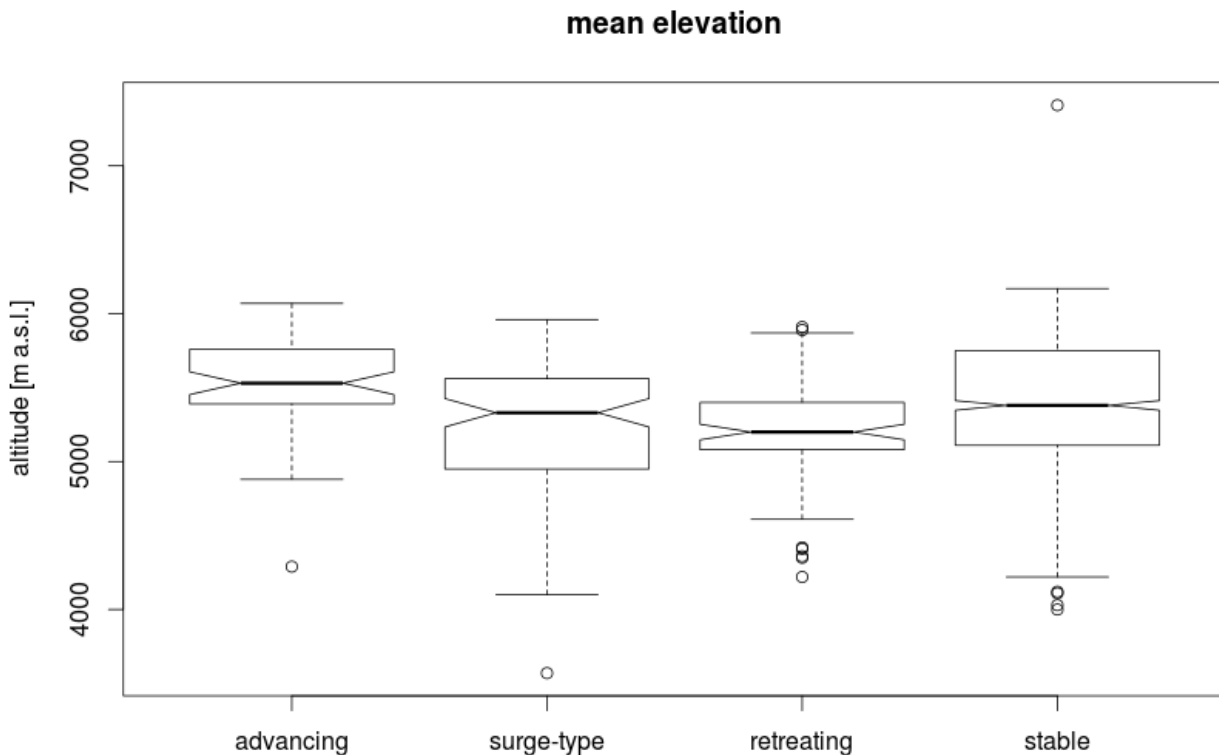


Figure 4. Distribution of different glacier classes along elevation. Boxes indicate lower and upper quartiles and the median of each distribution. Whiskers extend 1.5 times the interquartile data range. Outliers are indicated as dots.

The histogram of the glacier area (Fig. 2, b) visualizes that surge-type glaciers have larger areas (median = 15.3km²) than advancing (median = 4.4km²), stable (median = 3.8km²) and retreating (median = 4.9km²) glaciers in the inventory. This pattern matches the length distribution of the individual glacier classes. Half of the stable glaciers and 45% of advancing glaciers are less than 4km² in area. More than 50% of retreating glaciers are between 3 and 7km² in area.

The analysis of the mean slope along the main glacier branch allows no significant differentiation between the glacier classes. Most glaciers have only slightly inclined surfaces (15°). However, surge-type glaciers are the less inclined ones (median = 9.6°), but the slope of a glacier does not provide a significant correlation to surge-type glaciers.“

P4077 L4. If the median length is 9 km then it means that half of the surging glaciers are longer and the other half shorter... So “most of” is probably not appropriate. This part of the discussion is weak. The median size of non surging glaciers is smaller but the authors states that short glaciers are more likely to experience surges... the evocation of reaction time to climate is also not supported by anything. Suggest that surges are climate-driven which has to be demonstrated...

It was not our intension to evocate anything on climate-driven surges. This resulted from the merge of advancing and surge-type glaciers. For advancing glaciers a climate signal might exist – however, we are aware that our data does not proof this. We suggest to rephrase this paragraph in order to avoid such ambiguous reading. Due to the split of classes we can now also address this matter much better in the formulations.

P4077. L22. “Thus”: the causal relationship between the two sentences is not clear...
That part of the manuscript is going to be changed (see comment above).

L4077. L25. No need to repeat the name of the SAR sensor, I think.
We will remove the names of the SAR sensors. A more precise explanation about the used sensors is given in the corresponding methodological part.

L4078. L12. Maybe refer to a textbook (Cuffey and Paterson?) to back up this statement.
We will do so.

P4079. L5. The figure does not really show a propagation of the surge front. It seems rather stable. Provide the uncertainties with the velocity so that the significance of the velocity change can be assessed.

We refined the respective sentences according to the referee's suggestion (see below). Moreover, we added the uncertainty of TerraSAR-X velocity calculation ($1.3 \pm 3.7 \text{ cm day}^{-1}$) to former Figure 6 (1st Feriole Glacier) (see Fig. 5 below).

“The shape of the center line surface velocity profiles indicate the location of the surge front close to the terminus (Fig. 6d). The surge front seems to remain at ~1km distance from terminus, however the glacier was advancing between March 2011 and June 2013. “

P4078-79-80. The detailed description of the flow behaviour of individual glaciers make the paper very long. I am uncertain if it should be retained. At least probably reduced? Or kept for a further study at the individual glacier level to combine all the observations the authors have on a given glacier target? An example of such a detailed glacier analysis is in (Scherler and Strecker, 2012). Right now it is not clear what the authors want to show with those data. In the case of Batura Glacier, the authors have a nice time series of velocity fields but do not use it much. Again the main problem of the paper is the lack of scope. Those are great measurements but the authors need to reach some glaciological conclusions from them. For example, one implication of this velocity time series is that comparing two snapshots of the velocities a few years apart (for example from 2006 and 2011 for Batura Glacier) may not reflect a “long”-term evolution of the velocity. A good temporal resolution is needed.

We support the referee's point of view that the detailed description of ice dynamics of 1st Feriole, Skamri and South Skamri, as well as Batura Glacier is very long and does not strengthen the focus of the paper. Therefore, we decided to cut the section about Batura Glacier (P4080 L11 to P4081 L15) and shorten the description of the precise flow behavior of 1st Feriole, Skamri and South Skamri Glacier (P4078 L21 to P4079 L8 and P4079 L21 to P4080 L10). The emphasis for a need of high temporal repetition of surface velocities in such areas with different glacier classes will be included in the description.

P4081. L17. Weak statement as is. Delete or explain why.

As mentioned above, the section about TanDEM-X based surface elevation changes/volume changes is going to be removed in the revised manuscript.

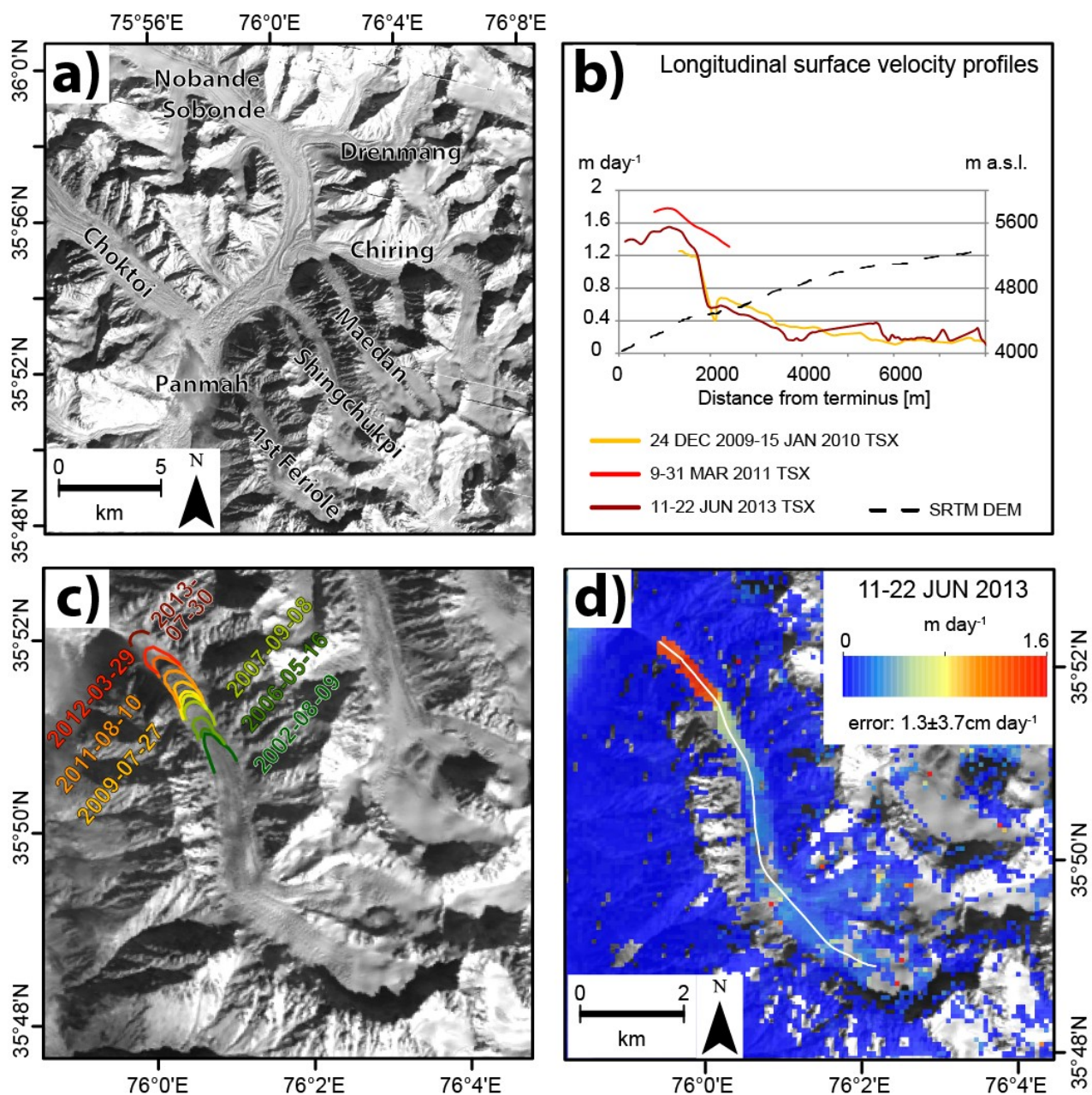


Fig. 5. Termini advances and surface velocities for 1st Feriole Glacier, Panmah Basin (a). (b) comprises the centerline velocity profiles and their changes over time (location of the profiles is marked in (d)). Panel (c) shows the changing terminus positions since 2002. A surface velocity map derived from repeat TerraSAR-X SM imagery between 11 and 22 June 2013 is given in (d).

P4081. L25. Do the authors understate here that debris-covered parts experienced a high ablation rate? Was the tongue stagnant during the whole study period 2000-2012? If this is the case, the authors can estimate a rough ablation rate (or rather a lower bound value) as equal to the elevation change rate because emergence velocity can be neglected. That would be an interesting glaciological contribution in a context where it is not understood why debris covered glaciers are thinning at a similar rate or sometimes faster rates as debris free ones (Gardelle et al., 2013; Käab et al., 2012; Nuimura et al., 2012; Zhang et al., 2013).

This is certainly a very good hint. However, since we will exclude the elevation change

measurements, such estimates have to be spared for a future paper on this topic.

P4082. L1. Clarify why a “marked flow pattern” (what do the authors mean?) would be indicative of different melt rates between debris cover/free parts? Seems an interesting observation that need to be explained and demonstrated.

See above.

P4082. L10. I do not think the elevation gain in the highest areas are related to a surge. They could be due to uncorrected SRTM penetration or to the increased in accumulation. It has been described that surges often do not affect the whole glacier length but often initiate in the central part of the glacier (e.g., Quincey et al., 2011).

We agree that the issue of penetration depth of X- and C-band needs closer consideration and would contribute to improve the paper. However, since the elevation change section is suggested to be removed in an updated version, we will not elaborate more on this issue and leave it for a dedicated paper.

P4082. L12. Are those glacier-wide mass balances? There are unrealistically positive! (they would correspond to an glacier-average thickening of 40 m). Or are they average values only for the parts of the glaciers that are thickening? How did the authors compute the error bars? Need more details. Need to include uncertainty for the volume to mass conversion (not 0.9 but 900 kg/m³)... see (Huss, 2013) on this topic

We are sorry for the imprecise wording of those lines. The numbers we have provided there, showed the mass change rate (2000-2012) for the area close to the glacier snout, where the individual glaciers gained mass during the active phase of the surge in the twelve year period between the DEM acquisitions (Fig. 6). For example Skorga Glacier thickened +2.96±2.52m yr⁻¹ w.e. (Fig. 6). Over the whole glacier area, Skorga glacier gained mass of 1.17±1.54m yr⁻¹. In the following we provide further information on the calculation of different parameters exemplary for Skorga Glacier (Table 3).

Table 3. Parameters used for the mass change rate calculation of Skorga Glacier.

	A _{mass gain} [km ²]	A _{mass loss} [km ²]	ΔH _{mass gain} [m]	ΔH _{mass loss} [m]	V _{mass gain} [km ³]	V _{mass loss} [km ³]	A _{glacier} [km ²]	ΔH _{glacier} [m]
Skorga	0.702	3.776	38.897 ± 33.08	-15.030 ± 8.04	28.67 ± 23.15	56.95 ± 30.21	18.161	15.626 ± 20.58

The mass change rate was calculated with the following equation using a density of ice of 900 kg m⁻³ and a density of water of 1000 kg m⁻³.

$$\frac{1}{n} (\Delta H \pm 1 \text{ s.e.}) * (\rho_{ice}/\rho_{water})$$

where:

n = number of years

ΔH= mass gain/mass loss over 2000-2012

ρ_{ice}= 900 kg m⁻³

ρ_{water}= 1000 kg m⁻³

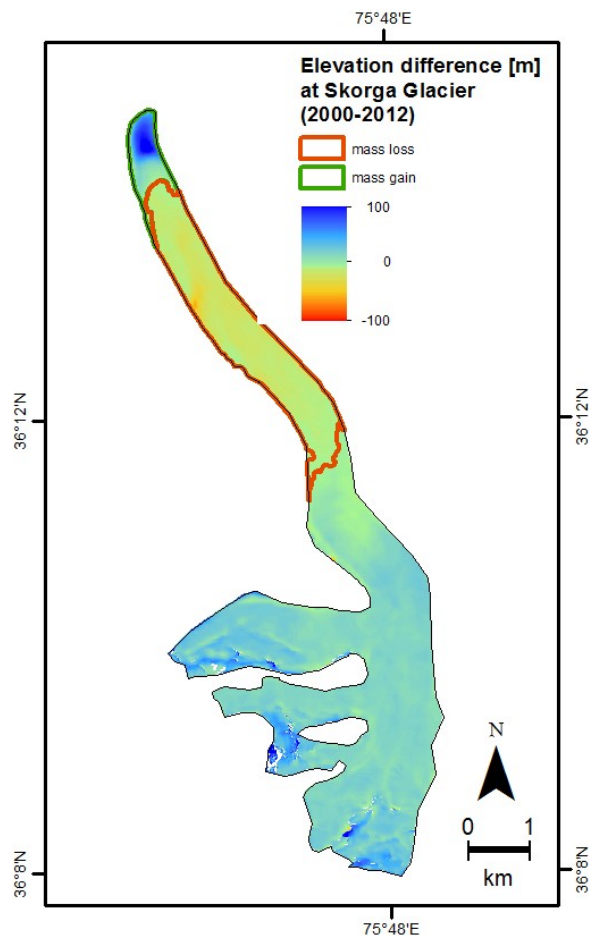


Fig. 6. Elevation difference at Skorga Glacier (2000-2012)

P4082. L20. What about the possibility that the surge did not lead to an advance of the glacier front? Do the authors have some repeat velocity measurement of this glacier to analyze into details? This glacier, like Batura, could be the topic of a dedicated study. Right now it is a bit frustrating because all the data the authors potentially have are not merged to provide a synthetic view of the surge.

As stated above we try to make the paper more concise and therefore decided to skip an extended analysis of the surface velocities of Batura in this paper. We intend to provide a more focused analysis integrating the various data sets we have for this site to a later stage as the reviewer indicated.

CONCLUSIONS & OUTLOOK

Based on the revisions in the analysis and exclusion of the Batura velocity section and elevation changes, we will completely revise the conclusions. Hence, several comments will become obsolete. The conclusions will then focus on the inventory and its statistics as well as the Karakoram-wide glacier velocities and changes over time.

P4083. L7. “proved” rather than “proofed”, I think.

Will be changed.

P4083. L19. Not convincingly demonstrated in the paper.

P4083. L22. Repetition of what was said above. I suggest to separate the methodological and glaciological conclusions of the study.

P4084. L7. The authors did not demonstrate the accuracy of the mass change retrieval (and they actually state it a few lines later in the conclusion). But I fully agree that the lack of bias and the ~3 m standard deviation on the stable region are very encouraging. The penetration will remain an issue though.

Not addressed since section will be removed in a revised version.

TABLES AND FIGURES

Table 2. I thought SRTM was flown during 10-20 Feb. 2000. Can the authors double check their date?

According to NASA's SRTM As-Flown Mission Timeline the SRTM mission was launched on February 11, 2000 for a duration of eleven days (http://www2.jpl.nasa.gov/srtm/SRTM_TIM_AF.pdf). In order to be more precise, we changed the date of the SRTM mission on P4070 L12. However, Table 2 will be excluded from the revised manuscript, because it is related to the TanDEM-X elevation change/volume change section. The modified sentence on P4070 L11-13 is as follows:

“Cloud-free, late summer Landsat scenes from 2009 to 2011, and the SRTM DEM (11-22 February, 2000) were used to improve the glacier outlines.”

Figure 1. What is the source of the background image?

The background is a MODIS image. We will provide a reference to it in the caption.

Figure 6. If possible, it would be good to have panel b and c side by side to facilitate the visual correspondence between the image and the velocity field.

We rearranged the order of panels a) to d) in former Figure 6. The rebuilt Figure is shown above (Fig. 5) in this document.

Figure 7. In the text, I think the authors should mention that useful velocity data are obtained during all seasons; this is an interesting technical results. Any evidence from variation related to the season (spring speed up event)?

Our data does not allow to retrieve seasonal velocity changes. However, from other measurements seasonal and annual variations are known in the region (Mayer et al., 2006).

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