

We would like to thank Dr. Adina Racoviteanu for reviewing our paper and giving us insightful comments and suggestions which will significantly improve the flow and content of our paper. We repeat the comments in *italic* and write our reply below in **bold** letters.

*Reviewer 1 (Dr. Adina Racoviteanu)*

*This paper describes a glacier inventory in two basins in the Karakoram, and glacier changes from 1973 to 2011 based on Hexagon and Landsat images from various years. With recent focus on glacier changes across the Himalaya, the focus of the paper is important in filling gaps in the understanding of glacier changes in an area of Hindu-Kush Himalaya which is less explored. The papers shows interesting results, confirming different behavior of Karakoram glaciers (little or no change in area) compared to the Himalaya, where the tendency is of glacier shrinkage. However, there are a few general aspects of the paper that I feel could use much improvement:*

- 1. The paper is cluttered with numbers, which make the big picture less evident. It would be desirable to refer to tables, and rather than having all the numbers in the text, to focus on their significance. A lot of the results read like reporting of numbers. It is also not clear if the focus is on comparing the different behavior of the two basins chosen, or to extract a common signal of these two basins. This should be clarified.*

**We will compare the different behavior of the glaciers in both basins in our manuscript and will focus on significance. We will also remove as more as numbers from the text in results section as suggested.**

- 2. Concepts of glacier area change are mixed with glacier dynamics (notably glacier surges) and a few references to climate. However, neither the concept of glacier surge nor the climate trends are well argued. Overall, it is not clear whether the lack of area change, or the glacier growth is due to climate influences or, simply to glacier dynamics (surges). These two effects should be discussed in more detail.*

**The climate-glacier interaction in the investigated remote region is indeed not clear as instrumental records at higher altitude are nonexistent. Hence, we discussed possible trend based on published instrumental climate records studies from India and Pakistan Karakoram (for e.g. Fowler and Archer, 2006; Shekhar et al. 2010). We will provide information about area changes for the non surging and will improve the discussion on the glacier area changes and the climatic trends.**

- 3. The delineation of debris-covered glaciers is not described at all. Especially since the Karakoram glaciers are heavily covered with debris, and this is an area of high uncertainty, the authors should explain in detail how the debris-covered glaciers were delineated. Also, I would be interested to see the area change treated differently for clean glaciers vs. debris-covered glaciers.*

**Debris-covered area for the investigated glaciers is only 1%, surprisingly very less in comparison to western Karakoram or Garhwal Himalaya (26%; Bhambri et al. 2011). Mostly debris cover related with medial moraines and not entire tongues as typical for other regions. We used high resolution Orbview data as additional information for the glacier delineation. This was mentioned in manuscript. However, we will put more emphasis on this issue in the revised version.**

*Specific comments:*

*Abstract*

*L 9-10: “On average, the glacier area in Chang Chenmo basin exhibited no changes during the study period”*

*I think the authors mean “no significant change on average”, since they do show some change (1.11, -0.7 +/- 0.03 km<sup>2</sup>). So, the term “no change” is not adequate in this case.*

*Numbers here are less relevant than % area change. I suggest presenting % area change to make it easier for readers to put it in context with other studies.*

**We will improve abstract as suggested by reviewer.**

*Introduction*

*P1 L 21 – 24: please be more specific when talking about glacier melt. It is glacier ice melt?*

*Also, specify which basins you refer to, and also what you mean by glacier melt not being influenced by summer monsoon PPT. These phrases are used very often in publications, but they should be clarified.*

**We will improve the manuscript for clarification.**

*P1 l.25: “lesser shrinkage” should be “less shrinkage”*

**This will be improved as suggested.**

*P1 l.25- 26: this statement needs reference*

*P2 l3: Kulkarni et al 2011 reference is not right, their paper talks about glaciers in Himachal Pradesh and Zaskar, not in the karakoram. They do not show glacier advance, but overall 16% glacier change in that area in the last decades. Please clarify, or remove this reference.*

**This will be improved as suggested.**

*P2 l8 – 10: the climate connection is not clear here. What do you mean by “diverse trends?”. Also, it should be explained what the connection is between T decrease and glacier growth in this area of the Himalaya (talk about its impact on precipitation at high altitudes, etc...)*

*P2 l 23 add “s” to “region”*

*P2 l 24 “abundant potential” sounds vague.*

*P2 l 24 clarify “regular intervals”- days, weeks, months?*

*P2 l 26 “influencing variables” sounds awkward remove influencing or specify what is influenced*

*P2 l 30: GLIMS reference- need to explain what GLIMS is for readers not familiar with it. Also, mention other global studies such as Randolph inventory (Arendt et al 2012)*

**This will be improved as suggested.**

*Study Area*

*P3 l 6 – 10: the order of the basins is quite irrelevant, I suggest removing it*

**We think order of the basins is important because this is based on classical hydrological basins (Müller et al. 1977) and can be linked with previous Geological Survey of India (GSI) study in discussion part.**

*P3 L 15: reference?*

**This is a statement about the topography and no reference is needed here.**

*P3 l 20 – 25: “Chemical investigations of snow and glacier ice...”  
What do you mean here? Isotope studies?*

**Yes we mean “Studies of isotopes”**

*I also suggest mentioning the glacier regime in this area (see for example Thayyen and Gergan paper for a discussion of the regimes across the Himalaya and Karakoram)  
Thayyen, and Gergan (2010), Role of glaciers in watershed hydrology: a preliminary study of a “Himalayan catchment”, The Cryosphere, 4(1), 115-128.*

**This will be improved as suggested.**

*Methods*

*P4 l 1 “spatial resolution 30 m)- add in the multi-spectral  
**This will be improved as suggested.***

*P4 l 7: what do you mean by :”reference imagery”? please explain.*

**This will be improved as suggested.**

*P4 l 13 “images matched well”- sounds descriptive, please quantify. P4 l 16 :*

**This will be improved as suggested.**

*P4 l16: “projective transformation algorithm” - I am not sure what algorithm you are talking about, please clarify/detail.*

**This will be improved as suggested.**

*P4 l 16 – 19: “Hexagon KH-9 (1973, 1974) images were divided in 8 parts and each part were co-registered based on ~ 50 ground control points (GCPs) derived from the 2002 Landsat ETM+ imagery by spline adjustment using ESRI ArcGIS 9.3”*

*I do not fully agree with the approach used here. First off, why were the Hexagon images split into 8 parts? This should be explained. Secondly, the Hexagon images need to be ortho-rectified, not only geo-referenced (in my experience, a spline algorithm is not appropriate in the case of Hexagon images, but a full orthorectification using a camera model with no parameters and a DEM). This is a standard procedure. Please address this issue in detail, as the lack of orthorectification can introduce substantial errors in the area change estimate.*

**We agree that the best way of rectification for Hexagon KH-9 would be a full photogrammetric approach. However, no respective software was available for the study. In addition, the camera parameters for Hexagon data would need to be estimated as this information is not available like for modern satellite data. This would also introduce uncertainties.**

**Hence, we used the best available adjustment method in ArcGIS the available software. “Spline adjustment” is a kind of rubber sheeting which is a suitable method in case enough GCPs are used. We especially focused with the adjustment on the glacier tongues where most of the changes occur. The provided image and the outlines shown in paper prove the accuracy of our adjustment. We provide now even more information and discuss the method and the possible uncertainty in detail now. We divided Hexagon KH-9 into 8 parts because of the large size of the image and the low computational power.**

*P5 l 16: remove “glaciers” before “outlines since it is repeated after*  
**This will be improved as suggested.**

*P5 l 19: what you refer to as “average length of stripes with 50 m distance” - this is unclear*

**This will be improved as suggested.**

*P6 l1 – 9: this paragraph should be moved before the previous one*

**This will be improved as suggested.**

*P 6 l 5: need citation for these studies mentioned*

**This will be improved as suggested.**

*P6 l 6: this is the first time you introduce identifying surges as a concept. This is not mentioned in the objectives of the paper, and should be clarified*

**We do not introduce identifying surges as a concept. However we will improve the sentences:**

**“This enabled us to identify surge cycles taking into account that the Kumdan glaciers have blocked the Shyok river flow several times and created hazardous situation for downstream area”**

*Results*

*Overall, results contain a lot of numbers. I suggest, rather than listing all the numbers, to refer the readers to tables, and instead, to discuss the results in light of other studies (for example, the mean elevation results, the distribution of glacier area, which are common in other studies as well). Otherwise the results section reads like reporting.*

**This will be improved as suggested.**

*P7: In glacier characteristics section, it is not clear whether you focus on a comparison between Shyok and Chang Chengmo basins, since the description oscillated between the comparison, and the results on a regional scale. The focus should be clearer here, to tell the reader what the message is.*

**This will be improved as suggested.**

*P6 l 18: Remove “whereas” from the beginning of the phrase, this is not correct unless part of the previous phrase.*

**This will be improved as suggested.**

*p 7 l7: not sure it is worth mentioning there is no correlation between glacier size and median elevation, unless you provide background, i.e, why would you expect a correlation between the two?*

**This will be improved as suggested.**

*P7 l 10- 14: Again, there is no detail on how debris covered glacier were identified. This needs to be addressed.*

**See our reply to the general comment 3 above.**

*P7 l 15: “Glacier variability” – I think here you mean glacier “change”. Variability refers to an inherent characteristic of a phenomenon, which differ in space or time.*

**This will be improved as suggested.**

*P7 l 16: “glaciers..exhibited no change in area”- again, check the language here. I thin you mean no change on average, no significant change, or similar, since on the following line you show that there WAS a change of – 07 to +0.2 km2, and that some glaciers exhibited growth. Please revise this throughout the manuscript.*

**This will be improved as suggested.**

*P7 l 26: “It was found that there is no significant relationship...” sounds awkward, and the verbs should be both in the past tense. Delete “It was found that...” , it is unnecessary. What statistical relationship do you refer to” Correlation” Linear regression? Please clarify.*

**This will be improved as suggested.**

*Again, explain what the reasoning is between conducting a correlation between area change and topographic parameters.*

**This will be improved as suggested.**

*P 8 l 3 -8: here you focus on one glacier only, but this is not mentioned in the methods. I suggest adding the various scales of analysis in the methods to guide the reader.*

**This is well mentioned on page 7, line 1-5. Please see.**

**Three selected glaciers (Chong Kumdan, Kichik Kumdan and Aktash, Fig. 1) were studied in detail. The selection of glaciers is based on previous studies that have documented surging activities during last two century. Kumdan glaciers are of special interest as they have blocked the Shyok river flow several times leading to the development of a lake which created hazardous situation for downstream area (Mason, 1930; Hewitt, 1982; Raina and Srivastava, 2008; Hewitt and Liu, 2011).**

*P 8 l 11-13: first phase of this section is redundant with the results, please rephrase The discussion of the differences with the GSI maps is confusing, as this is not presented in the methods or data sources. Did the authors compare their outlines with GSI numbers, or with the actual glacier outlines from GSI? In the methods, it is specified that old outlines come from the Hexagon images. If the purpose is to re-establish a baseline dataset based on Hexagon maps, this should be mentioned. Otherwise, I do not see the point of the discussion of the GSI maps here.*

**We will slightly rephrase the first lines. However, we think that there is no need to present in methodology or data sources as this is the comparison of our study results (numbers) with an existing previous study by GSI. The information about the glaciers in the GSI study is given in a table and we do not have the GSI glacier outlines for comparison.**

*P8 l23 “The objective of a study has an influence on the glacier count” –*

*This phrase makes no sense, please rephrase or remove.*

**This will be improved as suggested.**

*P8 l 24-28: these lines belong to methods*

**This will be improved as suggested.**

*P 9 l 8: reference for this statement?*

**This will be improved as suggested.**

*P9 l 11- 12: here the OrbView3 images are introduced, but there is barely a mention of them before. How were they used (visual comparison, etc.?) The authors skim over the delineation of debris cover.*

**We mentioned the use of the OrbView data on page no 6 line 5-6 and also included in table 1.**

**"The identification of debris-covered termini was found to be difficult using Landsat TM/ETM+ imagery. Hence, high-resolution OrbView 3 images were used to support the identification of the glacier margins."**

*P9 l 14: "here we report for the first time." – What do you mean by "first time"? First time in this area? Please clarify.*

**This will be improved as suggested.**

*P9 l 19 – 20: "These advanced in glacier area can mainly be attributed to known surging activity of the glaciers in the area"- this sounds like an overstatement, the authors do not show results of the surging activity. This should be marked as a possibility, not a certainty.*

**The surging activity is well known for the Karakoram and clearly shown by images of selected glaciers (Fig. 5 and 7). We also extended the area coverage of Fig. 5 for more surging glaciers like Chong Kumadan. In addition, the visible looped moraines are an additional indication of the surge activities. Former literature confirmed also periodic surges in the study region (Mason, 1930; Hewitt, 1982; Raina and Srivastava, 2008; Hewitt and Liu, 2011).**

*Also, here the concepts of glacier area increase and glacier mass gain are confused. Glacier area increase and mass increase are not comparable at the same time scale. Glacier area change may be a result of cumulative positive mass balance over a few decades (in this area), whereas glacier mass balance is an annual response to climate. So, comparing the results directly with Gardelle et al 2012 is not entirely appropriate, or a more complete discussion is necessary.*

**This will be improved as suggested.**

*P 9 l 26 – 30: this is a new topic, does not fit here. I appreciate that the authors bring up the topic of uncertainty in the Hexagon images- however; the discussion is brief and does not provide much information.*

**This will be improved as suggested.**

*P 10 l 1 “Surging glaciers”*

*Again this is not one of the objectives, as stated in the beginning of the paper. It should be clearly stated that focusing on one glacier and studying its evolution in detail is one of the goals here. Also, how representative is this glacier of the entire range? A discussion is needed.*

**We will state clearly in the beginning that one of the objectives is to identify possible glacier surges. It is not our focus to study only one surge; we have presented evidence for surges of several glaciers. However, we put emphasis on this glacier as it is well covered in previous studies (Mason, 1930; Hewitt, 1982; Raina and Srivastava, 2008; Hewitt and Liu, 2011) and might cause a hazardous flood wave in case the valley will be blocked. Nevertheless, we will improve the discussion with respect to other glacier surges.**

*P 10 l 4 “Our results show that figures (number and area)*

*This is awkward language- either refer to the numbers directly or remove this*

*Similar to my comments above, there is a lot of reporting of results rather than referring to a table and discussing of the results here.*

**This will be improved as suggested.**

*P10 l 22 -29 and p 11 l 1 -5: This is a lot of general discussion and does not seem to fit*

*P 10 l 5 -12 here the authors introduce a discussion of climate trends, mixed in the surging section. This seems out of context, and without a rigorous climate analysis it does not provide much convincing info.*

*P 10 l 13: “mystical”??? Please replace this word, it does not belong to scientific language*

**This will be improved as suggested.**

*P 10 l 13 – 20 this whole paragraphs is vague and contains a mix of concepts related to surges and glacier volume. Please revise / rewrite with more concise info.*

**It is important to investigate both changes in glacier velocity and volume to obtain a better understanding of the glacier surges. We think that our statements are clear and fit well at the end of the discussion and also indication of our future research work.**

*Tables and figures*

*Table2: This would work much better as a figure (frequency distribution vs glacier area)*



**This will be improved as suggested.**

*Table 4: ;'variability" should be "change". Also, not sure it is so interesting to the readers, since it's a list of numbers of glaciers retreating, advancing, or no change. Please keep in mind the big picture when reporting these results.*

**We do not agree. It is important to present these numbers which show heterogeneity of the glacier changes.**

*Table 6: in Area numbers, there are either 1 decimals, or two. Please check. I think one decimal is enough.*

*Table 7 does not do much. I suggest removing*

**This will be improved as suggested.**

*Fig 2 is redundant info with table 2, so remove Table 2*

*Fig 3: not necessary since there is no significant trend. Same with Fig 4*

**This will be improved as suggested.**

*Fig 6: Maybe I missed this, but is there a discussion of the different response of these two glaciers, and potential explanations?*

**This is due to surging and was discussed in manuscript in section 5.2 .**

*Fig 7: I would rather see, instead of just two glaciers shown in detail, also an image of glacier change over a selected subset area, which shows the advances of glaciers compared to one time (for example 1974 – 2011). Again, consider the big picture.*

**We agree that showing the glacier changes over a larger area would support the understanding of the glacier changes in the study region and included therefore a figure as suggested. But it is also important to show the detailed behavior of selected surge-type glaciers.**

## **References**

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**Mason, K.: The glaciers of the Karakoram and neighborhood, Records of Geol. Sur. of India, 214–278, 1930.**

**Hewitt, K.: Natural dams and outburst floods of the Karakoram Himalaya, in: Hydrological Aspects of Alpine and High Mountain Areas, edited by: Glen, J., Exeter, UK: International Hydrological Association, (I.A.H.S.) Publication No. 138, 259–269, 1982.**

**Hewitt, K. and Liu., J.: Ice-dammed lakes and outburst floods, Karakoram Himalaya: Historical perspectives and emerging threats, *Phy. Geog.*, 31, 528–551, 2010.**

**Raina, V. K. and Srivastava, D.: Glacier atlas of India, Bangalore: Geol. Soci. of India, 316 pp., 2008.**