

Review of

"Satellite monitoring of glaciers in the Karakoram from 1977 to 2013 .....

by R. M. Brahmhatt et al., submitted to The Cryosphere

Dear Editor,

We sincerely thank referee for spending their valuable time in going through the manuscript and providing useful and valuable suggestions. A reply for each comment has been given in following pages.

# Comments by Referee 1

## General

Glaciers in the Karakoram show a considerable stable behavior in contrast to most other glaciated regions in the world. Especially the glacier area shows almost no changes for the large majority of glaciers, while at the same time the concentration of surging glaciers is unusually high in this region. During the last years an increasing number of studies, mostly based on remote sensing applications, investigated area and elevation change for the Karakoram glaciers. Glacier inventories have been created for different points in time and area changes have been derived. Especially the western part of the Karakoram was in the focus of several glacier change studies (e.g. Gardelle et al., 2013; Minora et al., 2013). This manuscript extends the observation of glacier area changes towards the eastern Karakoram, including the Shyok and Nubra basins. This extension completes the high-resolution investigations of area changes for the entire Karakoram and therefore is a valuable contribution to overall effort of describing the recent glacier conditions in the Karakoram.

We thank referee's comment on present work and highlighting its importance with other concurrent observations on Karakoram region.

Unfortunately, the presentation of the material, the methods and the results show a number of weaknesses and flaws, which considerably decrease the value of this contribution. Especially the systematic presentation of the results and significant conclusions require a much more detailed investigation of the observations. Many results are discussed in the "Findings" chapter without condensing the numbers into easily comparable tables, making the reading of this chapter rather cumbersome.

A main drawback is the missing critical evaluation of the glacier changes with respect to different glacier types and classes. In fact, the majority of debris covered glaciers show almost no area change, even under persistent negative mass balances. Therefore, these glaciers cannot be used for any conclusions regarding climate related glacier response, as long as only the area change is considered.

On the other hand, surging glaciers are connected to the climate conditions in a rather difficult and mostly unknown relation, which also prevents climate related conclusions. Because of these conditions, the overall results structure should much more differentiate between these different glacier types.

The aim of this entire exercise was to demonstrate the variations in glacier extents using satellite images from 1977 to 2013. In view of improving the presentation and observations of this study, manuscript has been reworked and revised accordingly. The results and conclusions of this study written now are much more focused and concise, and related information in the form of table and figure have been modified.

In present study, observations were made on the change in areal extent of glaciers. As referee says that many debris cover glaciers do not show area change even under persistent negative

mass balance, but it is not true. The example of retreat in debris cover glaciers is shown in figure 1. The emergence of stream from debris cover glacier is key parameter for finding change in such type of glacier. This is the way snouts of debris covered glaciers have been identified.

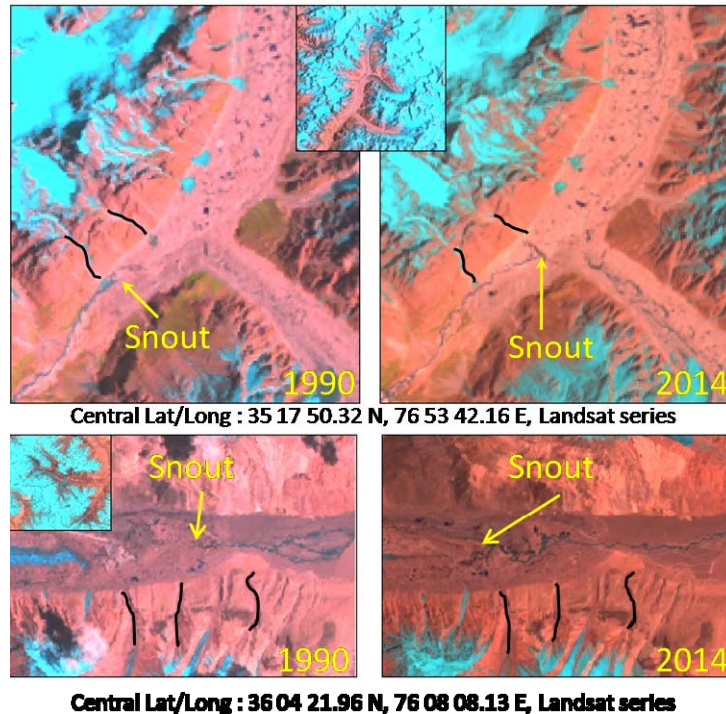


Figure 1: Retreat in debris cover glaciers

The section on the surging glaciers, which is still a complex phenomenon in glacier studies, has been modified in the manuscript as per the referee's suggestions. The reasons for surging or advancing glaciers and their climatic connection need many other parameters which itself is a separate study. But this study shows how annual monitoring can sometimes be very useful to highlight rapid changes in a glacier.

Especially in the “Discussion” section these issues should be elaborated: What are the area changes with respect to debris covered glaciers, surging glaciers, clean glaciers. Is there a dependency of glacier reaction with glacier length, area, location along the Karakoram, elevation and elevation range? Only if the subsets of glaciers are grouped in such sensible ways, conclusions about general causes are possible and meaningful. If this is done, also a comparison with existing studies is required and possible (e.g. with Minora et al., 2013, which covers also considerable parts of this study, but only for one period of time).

Out of many parameters, we attempted to identify the pattern of change in glacier area in context to its areal extent (Figure 2 as shown below) as per the referee’s comment. However, it has been observed that since the area changes are of very small magnitude and most of the glaciers are stable/shows no change during the monitoring period, the analysis of glacier change with respect to glacier parameter does not bring out any significant relation. The analysis of these changes needs generation of multiple parameters of glaciers and precipitation data in each valley glacier which was beyond the scope of this work.

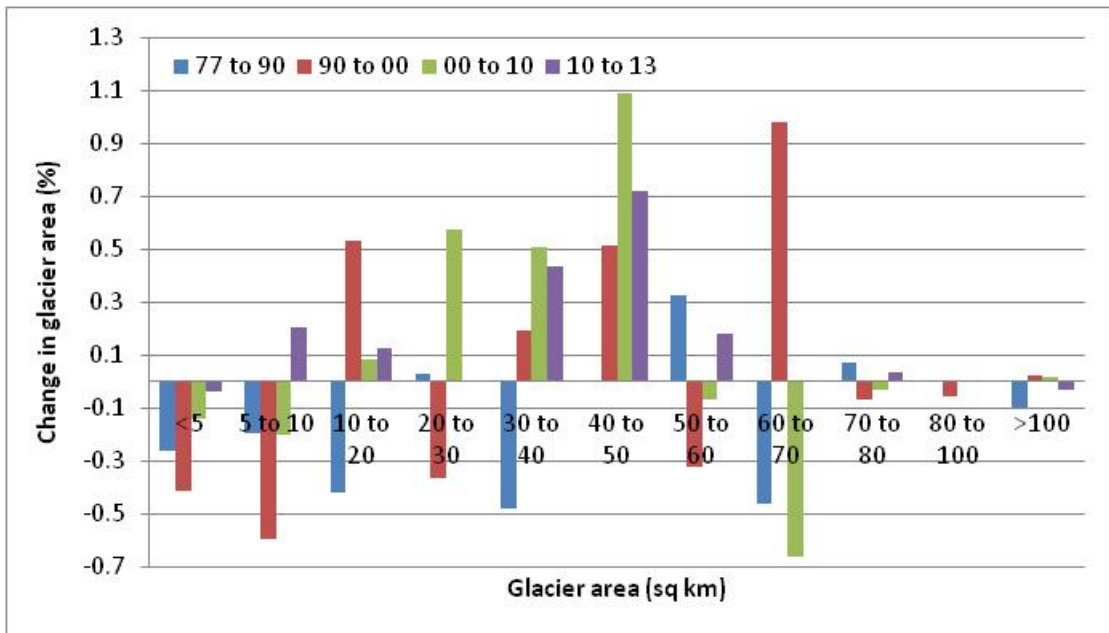


Figure 2: Influence of size of glacier on glacier change

The structure of the manuscript needs improvement. Especially no chapter about the investigated area exists, there is no reason given why this glacier sample has been chosen and the methodology is very crudely described.

All necessary changes were made in the manuscript in view of the comments. The revised manuscript involves following:

1. Modification in the abstract.
2. Modification in the introduction.
3. Inclusion of a section on study area.
4. Modification in the section on methodology.
5. Merging the section of discussion in results to avoid the repetition. Modification in the discussion with respect to other studies and link with this study.
6. Improvement in the section of estimation of uncertainty.
7. Improvement in the section of conclusion.
8. Modifications in tables and Figures for better presentation of contents.
9. References have been updated.

*Detailed comments and its reply*

C 1: Abstract

The abstract speculates about some findings hardly investigated in the Discussion. It should much more focus on the real findings and retain a structure where also the area of investigation, the applied methods and the results are contained. P. 1556, L. 7/8: inconsistencies in behavior: the behavior is surely consistent, but the samples used do not fit to the governing processes. It is no inconsistency if there exists a surging glacier in the neighborhood of a stagnant glacier, but the basic process very likely is different. P. 1556, L. 17-20: The response time issue raised in the Abstract is not discussed further in the text.

The abstract has been revised to focus on the real findings of the work.

Introduction:

Comment: P. 1557, L. 21/22: Gardelle et al. (2913) did not use gravimetric methods.

It has been modified as per the suggestion.

Comment: P. 1558: this part requires a better structure, which authors dealt with which kind of glaciers/processes in which area.

However, in view of the comment by referee, the structure of the introduction has been reworked and complete section has been rewritten. The key findings of the other researchers have been discussed.

Comment: P. 1558, L. 11-16: This part mixes two different papers.

Corrections in text have been made.

Comment: P. 1558, L. 18-21: Only a part of the Karakoram glaciers has been investigated (even though a large part). Not all of the intervals are used in the study. The list of data displayed in Table 1 shows many more scenes than actually used. There should be a clear indication which data have been used for what. Other data have to be discarded from the table.

Table has been modified to match with the text.

Comment: P. 1558, L. 22-24: I agree that this analysis is a very valuable contribution, but it covers a different area and thus cannot be directly compared to other studies. The new temporal resolution is investigated, but not exploited with respect to external drivers in this study.

The text has been modified as per the suggestion.

Comment: P. 1558, L. 26: such a formulation is not suitable for a scientific publication.

Authors agree on that part and it has been modified accordingly.

### Data and methodology

Comment: P. 1559, L. 1-13: The details about the used images and channels are much better concentrated in a table. The description in the text then only states the principle strategy (shorter and not so cumbersome to read).

Table 1 has been modified and suggestions have been incorporated in the text.

Comment: P. 1559, L. 13: Which months are chosen for which years (table)?

Details of data are given in table 1 and incorporated in manuscript for clarity.

- Images of mainly ablation period (July to September) have been used to ensure the minimum snow cover on the ablation zone of the glaciers.
- Sometimes the data, with minimum snow cover cloud free images over snout area, of other months were also utilized

Comment: P. 1559, L. 17-19: Please specify the processing steps.

Methodology has been modified as per the suggestions.

Comment: P. 1559, L. 20-26: this paragraph is rather unclear and should be rewritten. How did you exploit slopes in 2D images?

DEM is draped over images. The snout and the valley slopes are visualized in 3D perception to gain confidence in the interpretation. Suitable correction has been made in the text.

Comment: P. 1559, L. 27/28: I strongly oppose this statement. Glacier area change gives indications about glacier change, but only observations of distributed volume change will provide the necessary details for investigating glacier change in detail.

It was an error in expression of the text which has been taken care of.

Comment: P. 1560, L. 5: You used only one DEM

Yes, we used SRTM DEM.

Comment: P. 1560, L. 9/10: What is the reason for this statement? A glacier could easily cross a former lateral moraine during an advance. Is this connected to delineation problems?

The point was mentioned to ensure the correct boundary delineation. But we realize this point need not to be mentioned as it is understood that the glacier extent should not cross the lateral moraines except when the volume of the glaciers rises above the lateral moraine. Suitable correction has been made in the text.

#### Estimation of uncertainties

Comment: L. 19: I agree that is important to provide clear information about the methodology, but it is not given at the moment (see Data and methodology).

We have modified this section.

Comment: P. 1560/61, L. 26-17: These two paragraphs are a very general statement, without a direct connection to the uncertainty problem as it is discussed further down. This part can be condensed to two sentences without losing any necessary information.

Yes we agree and the section has been condensed.

Comment: P. 1562, L. 8/9: Which reason is behind the 0.5 pixel threshold?

Basically, two images are registered with sub-pixel registration accuracy to minimize error or we aim that registration should be 100%. But when two images are different resolutions it cannot be achieved therefore, an average of a pixel i.e. 0.5 is taken as a threshold for registration. Even if the images are of same resolutions it cannot be achieved 100% due to matching of GCPs on the two images and platform instability during acquisition of the images.



Comment: P. 1562, L. 9-12: This part is not clear to me. Of course, glacier change is usually not as expressed in higher altitudes. But this should not affect the methodology and accuracy.

It has been modified as per the suggestion to increase the clarity in text.

### Findings

In general, most of the findings are insignificant based on the error level. Therefore, the findings section should be structured to clearly present the general changes, but also give more room to the real significant findings. Here, results and discussion are often mixed, speculating about reasons for the observed changes. There should be a clear distinction between the results of the few longer time periods and the investigations relating to the “high resolution” observations in the 2000s.

The results have been modified as per the comments. Each time frame has been discussed in the manuscript. We accept that the results are clearer now in compare to previously written.

Comment: P. 1562, L. 14-17: As mentioned above, a study area section is missing and a reason why this area is selected. Otherwise a statistics table does not make sense and is out of context.

Earlier, information about study area was included in introduction but now separate section of study area is given in manuscript.

Comment: P. 1562, L. 17: The supplement is not necessary. The tables in the supplement can easily be made much smaller and then be introduced in the main manuscript.

We feel that the inclusion of supplementary table of uncertainty will dilute the text. Thus should remain as supplementary information.

Comment: P. 1562/63, L. 19-9: This paragraph is rather unclear. It should be clearly stated which uncertainties relate to which measurement. Also, I suggest to include the absolute error not only the relative error in percent. The readability of the manuscript would improve, if there would be a table with these results.

The section “estimation of uncertainty” has been improved substantially. We understand that we have tried to explain the method of determination of uncertainty in our work. Uncertainty has also been expressed as absolute error in table 2.

Comment: P. 1563, L. 9: The authors should be more specific about the glaciers. If there are glaciers with significant changes, they should be presented including a figure.

The figure has been added as figure 18.

Comment: P. 1563, L. 13: What are trends in this context? It is rather difficult to derive a trend from such a data basis.

The tree given as figure 4 clearly explains the evolution of glaciers in terms of stability, advance and retreat. It shows that only a very small number of glaciers have shown exclusive retreat or advance from 1977 onwards.

Comment: P. 1563, L. 14/15: It is the normal case that the change of individual glaciers is larger than the mean.

Yes. It can be smaller or larger than the mean.

Comment: P. 1564, L. 4: What is the reason for the temporal basis 1977-1990 which has the highest error?

Since, satellite data of 1977 is available on USGS site, it has been used not only in glaciology but in many remote sensing applications. And there is no corresponding data of this time anywhere else available. Though, the map produced from it will have relatively larger error due to its coarse resolution, but it can be used to identify the glacier extents. And with suitable error bar it can be used for change detection studies also. There is no intermediate data available between 1977 and 1989/90.

Comment: 1564, L. 16: Is that a gradual increase in area?

Yes

Comment: P. 1564/65, L. 25-6: This should go into the discussions chapter. It would be much better to discriminate between surging glaciers and non-surging glaciers and then concentrate the discussion on the non-surging glaciers. That's the glaciers which show a real advance signal.

Result and discussion has been given together to avoid repetition in the manuscript. The discussion regarding surging and non-surging advancing glaciers are discussed separately in the manuscript in the time frame 2000-2010-2013.

Comment: P. 1565, L. 7-15: There is a lot of repetition. This paragraph could be shortened.

We have taken care to avoid repetition and duplication of the sentences in manuscript.

Comment: P. 1565, L. 16-29: This paragraph also needs restructuring in order to clearly describe the general trend and the individual evolution of "non-standard" glaciers.

We have tried to modify the text as per the suggestion.

Comment: P. 1565, L. 25-27: How did you account for the glacier change of glaciers which merged with a main glacier? Sometimes a clear area gain is visible on top of the main glacier, which would account for a real area gain if no main glacier would be present. This needs clarification.

The area of overriding tributary glacier has been calculated even it has merged with the main trunk glacier.

Comment: P. 1565, L. 29: A bit more information should be given for these 13 surge-type glaciers.

The detailed about the 10 surging glaciers are given in manuscript in the section of results and discussion and figure has also been modified as location of each glacier has been given in the map.

## Discussion

Comment: The discussion is mostly speculation with no reference to other work done in the Karakoram. Also a reference to the climatic evolution, or papers dealing with such a relation are missing. In this chapter the results should be set into context with the general situation and the

findings of the other research groups. Reasons and mechanisms which support the observations should be discussed. Instead, many statements are provided without a clear reference to their origin. The investigation of the annual observations are only very shortly presented in the findings section and not discussed in the discussion.

The section "Discussion" has been merged with results to avoid the repetition in the manuscript. Our results are compared and discussed with similar work done by others.

### Conclusion

Comment: The conclusion is very short and provides only a short summary of the findings, but no vision of their significance. This needs a fundamental revision.

Conclusion has been modified thoroughly. The important outcome of this study has also been reported. And clue to possible further research is also written.

Comment: Figs. 7-13: It is very hard to read the symbols. Maybe there is another way to represent the changes in a more clear way?

Authors have spent really hard time to present the variation of each glacier on map as it is large amount of data. However, all the figures are modified for clear picture of state of glacier change.

