Interactive comment on:

"2001–2010 glacier changes in the Central Karakoram National Park: a contribution to evaluate the magnitude and rate of the "Karakoram anomaly"

by U. Minora et al.

Response to comments by Tobias Bolch

ABSTRACT

a. **P. 2892, L. 1f** Glacier melt water is of high importance for the upper Indus Basin/Pakistan but it is not known if it is really the main water resource. Please revise.

BEFORE: "*Karakoram is one of the most glacierized region worldwide, and glaciers therein are the main water resource of Pakistan.*"

AFTER: "*Karakoram is one of the most glacierized region worldwide, and glaciers therein are* ***an extremely important*** *water resource* ***for*** *Pakistan.*";

b. **L. 9** Please include information about the mapped glacier area.

Not clear what the reviewer is asking for.

1. **INTRODUCTION**

1.a **P. 2892, L. 22** Please use HKH as abbreviation; it is more common.

We'll replace all the HKKH present in the text with **HKH**;

1.b **L. 26** The 60.000 km2 quoted from Kääb et al. (2012) is likely to high for glacier coverage as they also include possible perennial snow fields. The number provided by Dyurgerov and Maier 2005 based on older inventories for the this regions is 55500 km2, Bolch et al. (2012) have 40800 km2 for the Himalaya and Karakoram (without the Hindu Kush) based on recent inventories; the ice cover from the RGI for the KHK

BEFORE: "*The HKKH nests about 60 000 km^2 of ice bodies, glaciers, glacierets and perennial surface ice in varying climatic regimes (Kääb et al., 2012),…*"

AFTER: "*The* ***HKH*** *nests about* ***50 000*** *km^2 of ice bodies, glaciers, glacierets and perennial surface ice in varying climatic regimes* ***(Arendt et al., 2012)****,…*";

1.c **P. 2893, L. 2** The "Third Pole" is not clearly defined but usually the regions includes the Tibetan Plateau and the surrounding mountain ranges such as the HKH rages but not solely the HKH region. Please revise or omit.

REMOVE: "~~*and it is considered the third pole of our planet (Winiger et al., 2005; Smiraglia et al., 2007; Kehrwald et al., 2008).*~~", and update the *Reference List*.

1.d **L. 4** Please write "likely more than 50% of the water in the Indus: : :". The more than 50% are a result of a well know study but are uncertain.

BEFORE: "*and more than 50 % of the water in the Indus river…*"

AFTER: "*and **likely** more than 50 % of the water in the Indus river…*";

1.e **P. 2893, L. 8-13** You may refer here to the comprehensive reviews and studies of Bolch et al. 2012, Kääb et al. 2012 and Yao et al. 2012, Gardelle et al. 2013 and Gardner et al. 2013. Ageta's papers are valuable but do not include the last decade(s).

BEFORE: "*(Ageta, and Higuchi, 1984; Ageta, and Fujita, 1996)*"

AFTER: "*(Bolch et al., 2012; Yao et al., 2012; Gardelle et al., 2013; Gardner et al., 2013)*";

1.f **P. 2894, L. 5f** You may refer here to Gardner et al. (2013) who also investigated the biases between the in-situ mass balance data and the remote sensing derived data.

We will add *Gardner et al., 2013* in the reference list in brackets;

1.g **L. 14** Please provide more details about the "Pamir-Karakoram Anomaly" if you mention it here. You may also discuss this in the discussion section.

"*Pamir–Karakoram Anomaly" name was proposed by Gardelle et al. (2013)**, since they recently observed a slight mass gain of glaciers in western Pamir as well.***" We'll also discuss it in the *Discussion* section;

1.h **L. 14ff** Please include also Bhambri et al. (2012) who also found no significant area changes and several surge-type glaciers in NW-Karakoram close to your study area. You may also refer to Hewitt (2011).

We would add this sentence "Moreover, *Bhambri et al. (2012), reported clearly visible advances in glacier tongues since the end of the 1980s in the Shyok valley as well, in northeast Karakoram.*" **in line 21**.

2. **STUDY SITE**

2.a **P. 2895, L. 26** Please mention the date of the establishment of the park. "newborn" will not be true anymore in few years.

BEFORE: "*The CKNP is an extensive, newborn protected natural area within the Karakoram, Northern Pakistan*"

AFTER: "*The CKNP is an extensive, ~~**newborn**~~ protected natural area within the Karakoram, Northern Pakistan**, estabilished in 2009***";

Modify also **P. 2892, L. 7** **BEFORE**: "*(CKNP, a newborn park of this region, ca. 12 162 km^2 in area)*"

AFTER: "*(CKNP, a ~~**newborn**~~ national park of this region, ca. 12 162 km^2 in area**, estabilished in 2009**)*"

2.b **P. 2896, L. 1ff** The information about the park might be of interest for the general reader but should be shortened for this journal. You may refer to a reference or website for further reading instead.

REMOVE "~~*The park's mission is to preserve unimpaired natural and cultural resources of this peculiar area, supporting the study and interpretation of this heavily glacierized environment and its population of birds and mammals.*~~";

P. 2896, L. 7ff **REMOVE** "~~*The Park is a new protected area, funded in the last decade. Several scientists from Pakistan and Italy are cooperating to develop a Park Management Plan, implementing best practices of environmental surveys within the framework of the SEED (Social 10 Economic Environment Development in the Central Karakorum National Park, Gilgit Baltistan Region) project, funded by the Pakistan and Italian governments, and managed by EvK2CNR Committee.*~~";

P. 2896, L. 1ff **BEFORE**: "*The CKNP is an extensive, newborn protected natural area within the Karakoram, Northern Pakistan (Fig. 1)*"

AFTER: "*The CKNP is an extensive, ~~**newborn**~~ protected natural area within the Karakoram, Northern Pakistan**, estabilished in 2009** (Fig. 1, see http://www.evk2cnr.org/cms/files/evk2cnr.org/Brochure_Seed.pdf for more information).*"

(**Updated in the reference list as well**)

2.c **L. 28f** Please provide more details about the unpublished data. Is it different from Winiger et al, 2005?

The authors of this study have carried out high altitude snow pits within accumulation area of Baltoro glacier (Godwin Austen/Gasherbrum) at an altitude of 5600-5900 masl, and found yearly accumulation for three years (2009-2011) in the order of 3100 water equivalent.

2.d **P. 2897, L. 10ff** The last part of this section should be moved to and merged with the Introduction.

MOVED TO THE INTRODUCTION (with changes as needed) "*It is not fully clear how results from the temperate zones can be applied to understand the dynamics of glaciers within the monsoon-dominated region of HKKH (Kaser et al., 2003), and also in central Karakoram, with a reduced influence of monsoon precipitation, the climate-glacier relation is not investigated in detail. The glacier-climate-hydrology interactions in the lower latitudes are of great interest for both global and regional purposes, and a network of well-*

chosen and carefully monitored glaciers is important to establish a base for investigating these relationships (Kaser et al., 2003). In addition, accurate observation of glaciers' coverage and dynamics is needed to understand the role of cryosphere in hydrology and water resources. The SEED project is focusing upon providing these data base, e.g. by developing the CKNP glacier inventory for different periods. This is a base for (i) describing the present characteristics of glaciation in the Park and its features and, (ii) evaluating glacier changes within a time window of about a decade. The main results from this research activity are presented in this paper, including the interpretation of the observed glacier dynamics against climate trends from meteorological data provided by the Pakistan Meteorological Department (PMD), covering the period 1980–2009, and against maps of snow cover area from MODIS satellite during 2001–2011."

3.1.1 **THE CKNP GLACIER INVENTORY**

3.1.1.a General: The information about how the glaciers were separated into single entities is missing but essential. The scientific community would be very much appreciating if you would provide the outlines with the valuable information to GLIMS.

We tried different types of automatic classification, but we couldn't come up with a good result, except for shadows detection which were excluded from the inventory at the boundary of the glaciers. We then delineate each single glacier manually, so it was easy to obtain single entities this way. We'll explain it better modifying the METHODS section to be clearer;

3.1.1.b **P. 2898, L. 11** What kind of ID do you use? The GLIMS id?

As ID we didn't use the GLIMS' one, but one which is based on the coordinates of a "representative point", (different from the "centroid" which could lie outside the polygon). The representative point is calculated always in the same position for the same polygon everytime the function runs. An example of ID would be "xxxxxxx, yyyyyyy" with "x" representing X coordinates and "y" Y coordinates, in a specific Reference System (in our case we chose UTM-WGS84);

3.1.1.c **P. 2898, L. 11ff** I suggest to mention the main attributes in brackets in a row and not with bullet points This is a bit waste of space. An explanation of ID, coordinates etc. is not needed. Describe in the methods section how the glacier length etc. was derived.

Right, we'll change it accordingly to Your suggestion;

3.1.1.d **P. 2899, L. 16** It is of course nice that you refer to Bolch et al. (2010), but Frey and Paul (2012) would be even more appropriate here.

BEFORE: "*…related studies (Bolch et al., 2010)*"

AFTER: "*related studies (**Frey and Paul, 2012**)*";

3.1.1.e **L. 17f** Please provide more details. Are the utilised Landsat scenes L1G or 1T? Mention this information earlier. Did you perform a co-registration or just tested the accuracy of the geolocation?

The Landsat we've been using are all 1T level as specified in the *Georeferencing error* section afterward (**P. 2900, L. 25**). No co-registration was needed as we tested the accuracy of the geolocation and it gave us good precision;

3.1.1.a **L. 19ff** This section is a bit confusing. Please describe clearly how you mapped the glaciers and the debris-covered parts.

We will modify this part to clarify the used procedure. Anyway, in this section we don't describe how to map the debris, but the glacier outlines in their totality (namely, debris plus clean-ice merged together). Later on we'll distinguish amongst the two classes (see **P. 2902, L. 10**). To summarize the procedure we have used to map the glaciers: after having tried different automatic approaches, we decided the best result would have been obtained digitizing manually the outlines. We then removed the shadow parts from the outlines which were detected automatically in the scenes from the SML classification by means of a GIS software.

3.1.2 GLACIER OUTLINE AND ERROR ASSESSMENT

3.1.2.a **P. 2901, L. 22** 7.5 m is fine if you delineated the glaciers manually but this is not clear. Indeed, we mapped manually, therefore 7,5m should be fine;

3.1.2.b **P. 2902, 1st Paragraph** Here mainly methods are described but you should mention how these errors were considered. The percentage of cloud cover of the entire scene is not relevant. Mention if glaciers are hidden by clouds (similar for Table 1)

"*Seasonal snow, cloud cover and presence of shadows and debris can introduce errors in glacier area determination. Therefore, we selected scenes with the least possible snow and cloud cover ~~(the latter is less than 6 %)~~ **over the glacier bodies**. Concerning snow cover, we minimized its impact by choosing the LANDSAT images where glacier ablation area was as snow-free as possible, and according to their temporal coherence, so as to avoid major differences between the scenes for the same year (similar seasonality, see Table 1). We also referred to other sources (SPOT from Google Earth©) whenever certain glacier features were not **clearly** visible in the Landsat images. Furthermore, we used SML classification to identify shadow areas, that were mostly excluded from the analysis **(i.e. when they intersected the outlines along their perimeters)***".

3.1.3 SUPRAGLACIAL DEBRIS-COVERAGE

This section should be presented before the error assessment. Maybe even merge with the information about the glacier mapping in section. You may restructure in 3.1.1 Glacier mapping, 3.1.2 Glacier inventory, 3.1.3 Uncertainty Assessment.

I assume you already mapped the entire glacier including the debris-covered parts. Hence, the debris-covered parts may be easily obtained with an intersection of the mapped clean ice. It would be interesting in this regard, if your supervised classification is more precise. The accuracy of the debris-mapping should be lower than for clean ice (see e.g. Paul et al. 2013).

During the manual digitization we didn't distinguish amongst clean-ice and debris, we did it later automatically mapping the debris by means of the SML classification. This way the result would have been better because there are always some "isles" of debris which lie inside the clean-ice part of the glaciers, and that could represent an obstacle in mapping. We thought creating a debris mask afterwards to be easier for separating the two classes (clean-ice and debris) with only one click and a more precise result. In general, the accuracy achieved this way is very high, because we've been only working on the glacier mask for the SML (clean-ice plus debris, without the out-of-glacier parts). So the classifier had very little chance to misclassify the pixels (only snow and coulds represent an obstacle to this, but were very few due to the previous accurate scene selection). The the point was to quantify the supraglacial debris, and mostly the SML classification recognized snow pixel within the clean-ice class, so the problem is avoided.

3.2 SNOW COVER DATA

The inclusion of the information about snow cover distribution and trend is interesting. However, a more detailed evaluation of the quality of the data and a quantitative analysis of uncertainty needs to be included (e.g. with few comparisons to snow derived from Landsat). The major problem might be the data gaps due to cloud cover. The best would be to fill the gaps considering the topography and neighbourhood analysis (see e.g. Gafurov and Baradossy 2009) but a least a more detailed analysis of the influence of data gaps and misclassifications need to be included.

On **P 2903, L. 24** we point that "*most of the available dataset have not yet been investigated by the NSIDC group for quality check*", meaning that those available scenes which didn't have the *INFERRED PASSED* flag in the NSIDC quality assessment were not used in the study (and they were the majority of the scenes within the selected time window). This was the major loss of data; **we'll point out that in the text**. Clouds threshold was set not to lose quantity and quality in the remaining dataset. Filling the gaps would not significantly change the situation. Moreover, we didn't propose any comparison with Landsat data as Parajka and Blöschl (2012) already assessed the accuracy of MODIS compared to ASTER images (which are very similar to Landsat), and Tahir et al. (2011) did it as well for an area close to the CKNP. These reported references, along with others in the presently available literature witness the well suited ness of MODIS image to map snow cover worldwide, and specifically in our target area, so we did not carry a specific study upon this topic, which was also beyond the scope of our work.

3.3 **CLIMATE DATA ANALYSIS**

3.3.a General: This section is a bit long and can be shortened and more focussed without loss of relevant information. This is mainly true for the description of the Mann-Kendal test. In addition, information about the homogenisation of the data should be provided.

3.3.b **P. 2905, L. 6-19** This is background information about the study area and should be presented in the respective section and not in the methods section.

3.3.c **P. 2907, L. 10-12** Too many references. 3 to 4 are sufficient.

This section was considerably shortened in response to a prior comment, and some references also dropped.

The indicated lines in Page 2905 contain very specific information, necessary to explain the methodological approach we pursued. We're not very clear with the issue of homogenization. Indeed, manipulation of the data to obtain more homogeneous series may result into masking variability, and possibly trends. We verified that no suspicious (i.e. displaying too large variability) values would be present, which was not the case, but we did not treat the data other than that.

4.1 **GLACIER CHANGES DURING 2001-2010**

4.1.a General: The section is a bit lengthy and could also be shortened and more focussed. The parts where the own results were more in detailed related to other studies should be moved to the discussion (e.g. P. 2911, L. 7-12). The uncertainty term should be presented without brackets.

2911, L. 7-12 We'll move this part in the *Discussion* section. We'll also shorten the chapter, removing all the brackets from the uncertainty terms

4.1.b **L. 24** The uncertainty seems to be a bit small (0.4%) especially when considering the extensive debris cover. The uncertainty is usually around 2-3%. But this might be due to the fact that the mapped glaciers are quite large.

We calculated the uncertainty with Eq. 1, which has been revised.

4.1.c **P. 2909, L. 1** ICIMOD, 2012 is not in the reference list.

We'll add it in the *Reference List*, thanks for pointing this out **(*ICIMOD (2012) International Conference on the Cryosphere of the Hindu Kush Himalayas: State of the Knowledge and Workshop on Hindu Kush Himalayan Cryosphere Data Sharing Policy, 14-18 May 2012. ICIMOD Project Document. Kathmandu: ICIMOD*)**;

4.1.d **L. 17** One reference should be enough for the Italian Alps.

We'll put only one citation;

4.1.e **L. 19** Should be Bhambri et al. (2011)

BEFORE: "*Bolch et al., (2011)*"→**AFTER**: "*Bhambri et al., (2011)*";

4.1.f **P. 2910, L. 12f** This is interesting information and should be discussed; especially as the median elevation is often used as a proxy for the ELA (see e.g. Braithwaite and Raper, 2009).

REMOVE THE SENTENCE: "*It is also interesting to note that the mean elevation of all glaciers sizes is ca. 4990 ma.s.l., i.e. only a few hundred meters below the estimated ELA.*"

ADD: "*Former studies concerning Baltoro glacier, the larger in our area, displayed that equilibrium line altitude (ELA) therein may be placed approximately between 4800 ma.s.l. and 5200 ma.s.l. (Mayer et al., 2006; Mihalcea et al., 2008). Bocchiola et al. (2011), setting up a simplified hydrological model mimicking snow accumulation upon the same glacier found out an approximate ELA altitude between 4700-5300 m a.s.l.. Similarly, our inventory gives an overall median elevation of 4990 ma.s.l., which can be used as a proxy of the ELA (Fig. 2) as suggested by Braithwaite and Raper (2009), and which is in line with the works mentioned here.*"

Reference added:

Mihalcea, C., Mayer, C., Diolaiuti, G., D'agata, C., Smiraglia, C., Lambrecht, A., Vuillermoz, E., and Tartari, G.: Spatial distribution of debris thickness and melting from remote-sensing and meteorological data, at debris-covered Baltoro glacier, Karakoram, Pakistan, Ann. Glaciol., 48, 49–57, 2008.

4.1.g **L. 29** Please present more detailed information (e.g. increase in length/area) about the glaciers advances.

BEFORE: "*Especially glaciers in the size classes from 10 to 50 km2 have shown appreciable advances…*"

AFTER: "*Especially glaciers in the size classes from 10 to 50 km2 have shown appreciable advances **<u>(up to 489 m, with an average of 247 m for the whole period)</u>**.*";

4.1.h **P. 2911, L. 7-11** You may include some more recent studies (e.g. Bhambri et al. 2012, Bolch et al. 2012, Yao et al. 2012, Gardelle et al. 2013).

BEFORE: "*Other neighboring Asian glacierized areas are undergoing a general glacier decline (IPCC, 2007; Bolch et al., 2012; Bhambri et al., 2011; Pan et al., 2012), thus indicating different conditions in the Karakoram.*"

AFTER: "*Other neighboring Asian glacierized areas are undergoing a general glacier decline (**<u>Bolch et al., 2012</u>**; Pan et al., 2012; **<u>Yao et al., 2012; Gardelle et al., 2013</u>**), thus indicating different conditions in the Karakoram.*";

4.1.i **L. 13-28** The information about the advancing and surging glaciers is quite interesting and should be extended. Are there more glaciers which could be of surge-type but were in the quiescence phase during 2001-2010?

Khurdopin, Virjerab (Gardelle et al., 2012), Liligo (Belò et al., 2008), Hispar (possibly, Copland et al., 2011) glaciers are surge type glaciers in a quiescent phase. We'll add information to include these quiescent glaciers.

Do only the larger glaciers show an area gain or also smaller ones?

It is too difficult to assess this by means of Landsat images visual inspection, as the pixel resolution is too weak for small glaciers.

More information about "the diffuse glacier advance activity" needs to be provided.

BEFORE: "*Then the rest (and most) of glacier expansion through recent years could be charged upon diffuse glacier advance activity*"

AFTER: "*Then the rest (and most) of glacier expansion through recent years could be charged upon diffuse glacier advance activity**<u>, as reported by Scherler et al. (2011), whose study revealed the 58 % of his non-surge glacier sample in the Karakoram was stable or slowly advancing.</u>***"

Reference added:

Scherler, D., Bookhagen, B., and Strecker, M., R.: Spatially variable response of Himalayan glaciers to climate change affected by debris cover. Nature Geoscience, Vol. 4, March 2011.

4.2 DEBRIS-COVER CHANGES DURING 2001-2010

4.2.a. **P. 2912, L. 8f** Please provide a reference and discuss shortly the most important sources in this region.

ADD THE SENTENCE: "***<u>In particular, Karakoram is a high and deeply incised mountain range. Because hillslope-erosion rates usually increase with hillslope angle, the</u>***

flux of rocky debris to the glacier surfaces and therefore the formation of debris-covered glaciers are linked to steep (>25°) accumulation areas (Scherler et al., 2011)";

4.2.b. **L. 10ff** I do not agree that the debris-coverage is "likely another cause of the stable conditions". There is extensive debris coverage in many other regions which show significant mass loss. Several recent studies have shown that the glaciers in the Himalaya are losing mass despite thick debris coverage (e.g. Bolch et al. 2011, Gardelle et al. 2012, Kääb et al. 2012, Nuimura et al. 2012).

Clearly, this is a delicate topic, and what we present here is a hypothesis. It is commonly accepted however that in some areas worldwide, under specific climatic and glaciological conditions, the presence of thick debris contributes to slow glacier melting (*e.g.* Hagg et al., 2008; Sherler et al., 2011; Bocchiola et al., 2010) agree with our sentence, saying that glacier melting is reduced (not absent), whenever a thick layer of debris is present upon them.

Albeit this may not be true everywhere, still, debris cover formation may be one of the mechanisms contributing to reduce glacier down wasting within this specific complex area. We now rephrased to mirror this argument.

References added:

- Bocchiola, D., Mihalcea, C., Diolaiuti, G., Mosconi, B., Smiraglia, C., and Rosso, R.: Flow prediction in high altitude ungauged catchments: a case study in the Italian Alps (Pantano Basin, Adamello Group), Adv. Water Resources, 33(10), 1224–1234, 2010;
- Hagg, W., Mayer, C., Lambrecht, A., and Helm, A.: Sub-debris melt rates on Southern Inylchek glacier, Central Tian Shan. Geogr. Ann. 90A (1): 55-63, 2008.

4.3 SNOW COVER VARIABILITY

The performed analysis is a bit thin and should be extended at least a bit. You may e.g. shortly mention the general characteristics of the snow cover and perform analysis with respect to the aspect and more elevation bands. Is there any chance to obtain a late summer snow line which can be related to the ELA? In the discussion you may also refer to Gurung et al. (2011).

We carried out here a more detailed analysis to obtain information concerning snow cover depending upon altitude, and dynamics.

Besides the analysis concerning snow cover dynamics within the three altitude belts as in Tahir et al. (2011), which we carried out for comparison, we studied snow cover area SCA in late summer as per a number of altitude belts. Specifically, we studied SCA in late Summer (Julian day 273, unless for years 2002, day 241, 2003 day 217, 2005, 201, 2006, 169, as per data availability), to evaluate the distribution of remaining snow at the end of the ablation season.

In Figure X1 below (which we will include in the new version of paper), we report average (2001-211) SCA_{LS}, or snow covered area in late Summer, as per altitude bins of 1000 m (i.e. 2000-3000 ma.s.l., etc.), refined into 500 m bins from 3000-6000 masl, where most of the snow dynamics likely occurs, and ELA is expected to dwell. We report within the radar plot snow covered areas in km^2 as per aspect (8 bins), to illustrate variability of snow cover with slope orientation.

From Figure X1, together with evidence of slightly smaller snow covered areas exposed towards south especially at the lowest altitudes, one gathers that considerable part of the snow covered area dwells between 4000 and 6000 ma.s.l., rapidly decreasing for lower and higher altitudes.

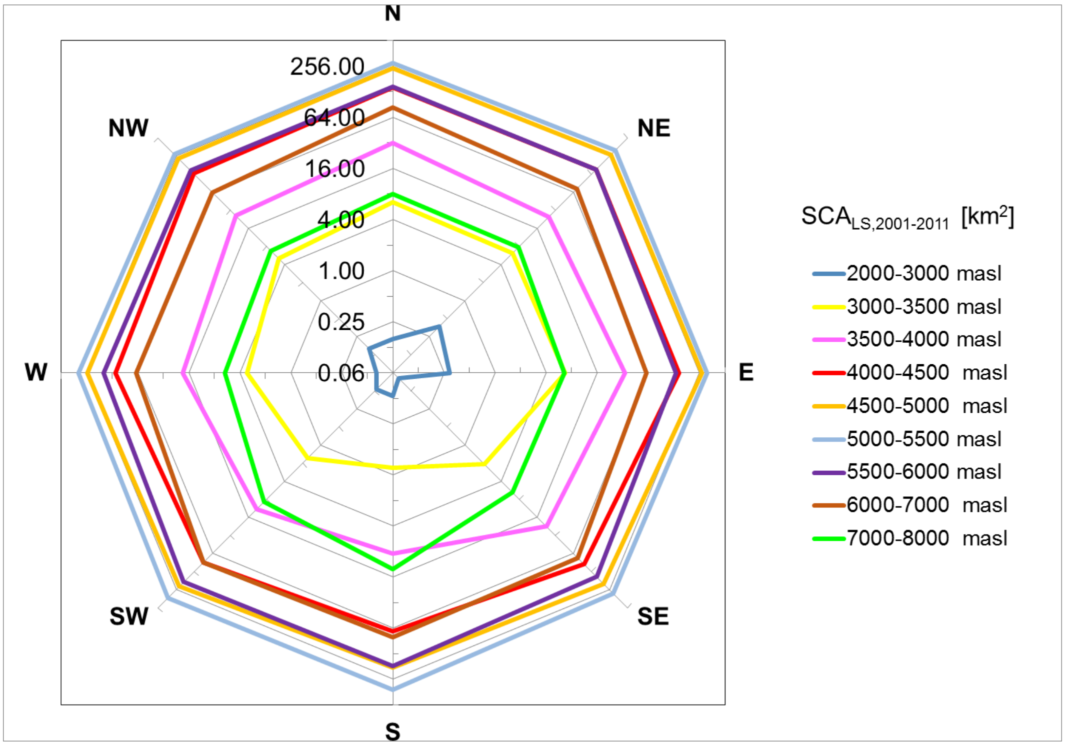


Figure X1. Average snow covered area in late Summer SCA_{LS} as per altitude bins, and aspect. Logarithmic scale (base 2) is used to enhance small snow covered areas at very low (and very high) altitudes.

In Figure X2 below (also to include in the new version of the paper) we report altitude (bins) distribution of three different variables, expressed as percentages, namely i) average snow covered area in late Summer with respect to the whole snow covered area in late Summer in the park $SCA_{LS}^{\%}$, ii) average snow covered area in late Summer SCA_{LS}^{*} with respect to greatest (maximum, beginning of ablation season) observed snow covered area in that bin, and iii) $SCA_{Max}\%$, ratio of greatest snow covered area in each bin to the sum of maximum values of snow covered areas in the whole park. Therein, one sees that on average 88% of the snow covered area at Fall is contained between 4000 and 6000 ma.s.l. ($SCA_{LS}^{\%}$), thus demonstrating how snow dynamics is mostly played in this altitude bin, and that such range of altitude is utmost critical, also in view of potential changes of snow cover in response to climate change. From the shape of SCA_{LS}^{*} curve one clearly sees how on average, above 5500 ma.s.l. or so and up to 8000 ma.s.l., snow cover at Fall is stably at 85% or so of the maximum seasonal value. Below this altitude, SCA_{LS}^{*} decreases quickly.

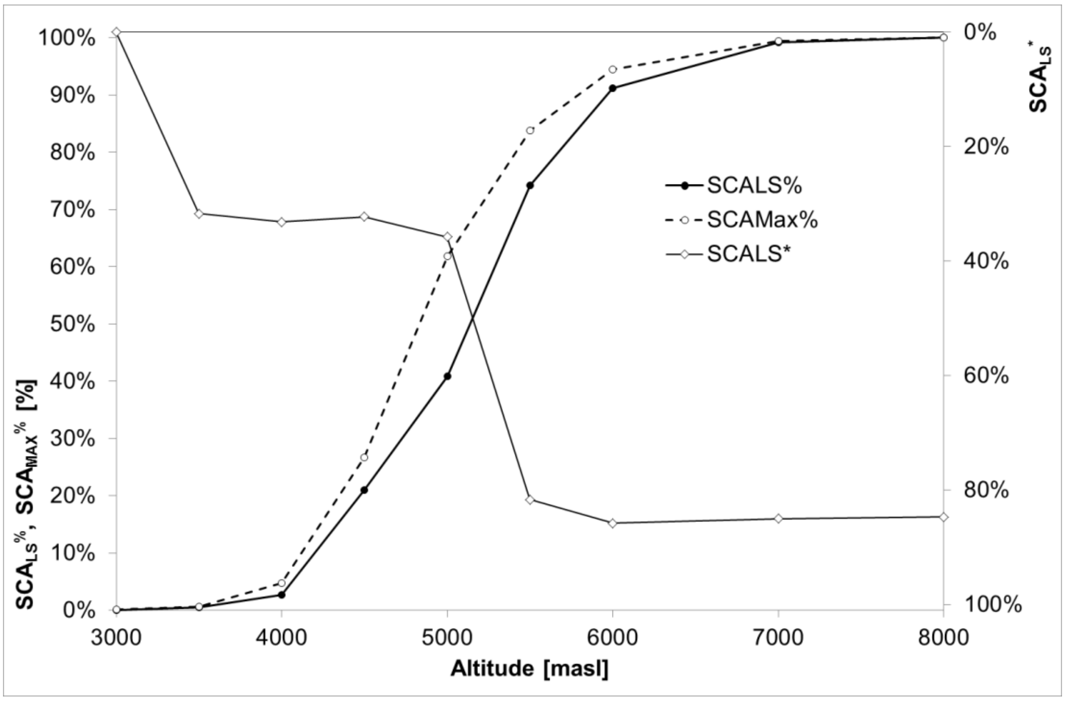


Figure X2. Distribution as per altitude bins of average snow covered area in late Summer with respect to the whole area $SCA_{LS}^{\%}$, of average snow covered area in late Summer SCA_{LS}^{*} with respect to greatest (maximum) snow covered area in that bin, and of the greatest snow covered area in each bin with respect to the sum of maximum values of snow covered areas in the whole park $SCA_{Max}\%$. Logarithmic scale (base 2) is used to enhance small snow covered areas at very low (and very high) altitudes.

$SCA_{Max\%}$ indicates the contribution to snow cover of each altitude belt during Winter time, *i.e.* when snow cover area reaches its largest value. The comparison of $SCA_{LS\%}$ against $SCA_{Max\%}$ quantifies the relative importance of the loss of snow cover at the end of Summer in each belt, i.e. as quantified by SCA_{LS}^{*}. One notices that the greatest cumulated loss of snow cover area (i.e. the vertical distance between $SCA_{LS\%}$ and $SCA_{Max\%}$), is reached towards an altitude of ca. 5000 ma.s.l. (ca. 20%), with decrease there above, meaning that areas above that altitude tend to contribute almost entirely to snow cover even after thaw. This is consistent with the pattern of SCA_{LS}^*, displaying swift increase above 5500 mas.l..

Such circumstances may indicate that above 5500 ma.s.l. snow cover is substantially stable during the season, and one may assume that snow cover is substantially permanent therein, whereas below such altitude more variable dynamic is expected, and snow cover may be considered less likely permanent. Such altitude is therefore taken as a proxy for an average snowline for CKNP, just few hundred meters above the overall median glacier elevation calculated in the present study (5000 ma.s.l. ca.), and close to the ELA estimated by other studies for our study area (Mayer et al., 2006; Mihalcea et al., 2008; Bocchiola et al., 2011).

4.4 CLIMATE TRENDS

The section is a bit descriptive. Please highlight better the main message.

We'll shorten this part, which however is needed to highlight the somewhat articulate behavior of climate in this area.

5 DISCUSSION AND CONCLUSION

This section needs to be significantly improved. Many parts of the discussion present results and are not a discussion.

We have improved this section, avoiding results repetition and concerning more about the real discussion.

5.a **P. 2915, L. 23** "terribly": Please find a more scientific expression.

We'll use "largely".

TABLES

T.a **Table 2** The "Slope" is not well described in the Results section.

We now introduced explanation of Slope parameter (change in snow covered area on a yearly basis, absolute and percentage).

T.b **Table 3** Please only use 1 digit for the Temperature and non for the precipitation. The available data is not so precise. The seasonal distribution of T and P would be of high interest.

Modified accordingly. We added average seasonal temperature and precipitation

Station	North	East	Altitude	Average (P_Y)	Average (T_Y)
	[◦]	[◦]	[ma.s.l.]	[mm]	[◦C]
Astore	35.20′	74.54′	2168	486	9.8
Bunji	35.40′	74.38′	1372	161	17.3
Gilgit	35.55′	74.20′	1460	137	15.8

7.c **Table 4 & 5** The caption is not clear. Again (and Table 5): One digit only.

BEFORE: "Minimum glacier altitude based on the 2001 inventory data."

AFTER: "**Glacier termini elevation** based on the 2001 inventory data."

Minimum glacier altitude [m]	Glacier number	Area coverage [km2]	% of total area	% of total number
2000–2500	3	106	2.3	0.4
2500–3000	12	634	13.8	1.7
3000–3500	24	2153	46.9	3.4
3500–4000	80	95	20.7	11.2
4000–4500	231	437	9.5	32.5
4500–5000	268	253	5.5	37.7
5000–5500	76	36	0.8	10.7
> 5500	17	19	0.4	2.4
Total	711	4587	100	100

Size class [km2]	2001 glacier number	2010 glacier number	2001 glacier area distribution [%]	2010 glacier area distribution [%]	2001 glacier number distribution [%]	2010 glacier number distribution [%]
< 0.5	291	290	1.4	1.4	40.9	41
0.5–1.0	142	142	2.2	2.2	20	20.1
1.0–2.0	117	117	3.7	3.7	16.5	16.5
2.0–5.0	74	72	5	5	10.4	10.2
5.0–10.0	36	36	5.4	5.3	5.1	5.1
10.0–20.0	18	17	5.1	5.2	2.5	2.4
20.0–50.0	16	16	11.4	11.4	2.2	2.3
> 50.0	17	17	65.7	65.8	2.4	2.4
Total	711	707	100	100	100	100

FIGURES

F.a **Figures 1 and 4** Study area, the Central Karakoram National Park (CKNP) in northern Pakistan. AWSs (Automatic Weather Stations) considered in this study are highlighted in yellow.

ADD TO BOTH CAPTIONS: "Boundary line delineation is only a tentative"

F.b **Figure 2** It would be interesting to include the hypsography of the debris-covered areas.

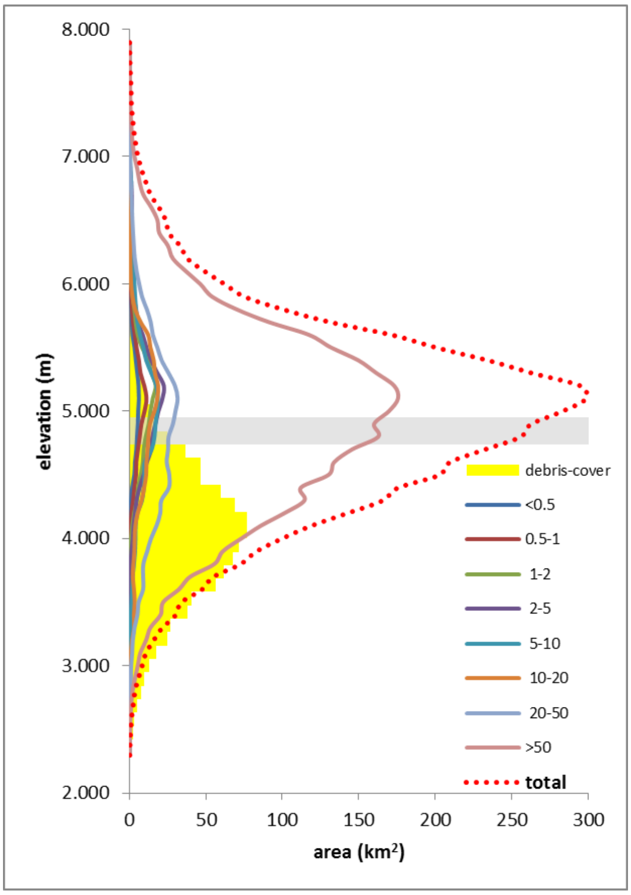
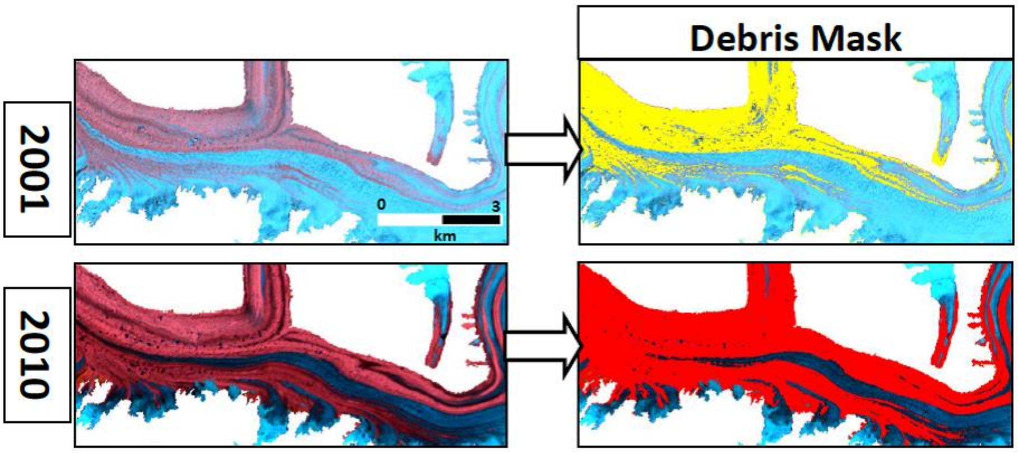


Fig. 2: Hypsography of glacier area distribution per area class **and debris-cover** by 100 m elevation bins (based on 2001). **The grey line represents the ELA.**

F.c **Figure 2** You should not repeat information which is or can be easily shown in the legend ("red line is : : :, yellow outlines represent: : :").

We'll remove the sentence "*The red line marks the study area boundary.*". Anyway, the one regarding the analyzed glaciers should stay as it specifies that the two highlighted glaciers in the picture are further analyzed in-depth in the study;

F.d **Figure 7** Include scale.



Debris Mask
2001
2010
0
3
km