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# *Interactive comment on* "Brief Communication: Glaciers in the Hunza Catchment (Karakoram) are in balance since the 1970s" *by* Tobias Bolch et al.

**Tobias Bolch et al.**

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We'd like to thank the reviewer for the constructive review. Please find below our reply to the comments. We will provide a more detailed reply along with the revised manuscript.

RC: This study utilizes digital elevation models extracted from satellite imagery (historical Hexagon and modern SRTM and ASTER) to calculate a regional geodetic mass balance for glaciers in the Hunza River basin, Karakoram region, using DEM differencing. The authors show that given the uncertainties of the methodology, the regional geodetic mass balance is not statistically different from zero change, consistent with previous mass balance studies on shorter more recent timescales. Their results suggest that the so-called "Karakoram anomaly" is not limited to the past _15 years, but



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Discussion paper

extends back to at least 1973. This is the first study using elevation differences to confirm this finding over a several-decade timespan, which supports previous studies showing no significant changes in debris cover or glacier area in the Karakoram over similar (1970's-present) time periods. Overall, it is a nice paper, and is ready for publication after a few minor additions.

Reply: Thank you.

RC: A table of values showing the standard deviation of mean elevation change between the ASTER and SRTM DEMs for assumed stable (non-glacier) terrain is needed to better assess the relative vertical accuracy of the DEMs.

Reply: We included an established uncertainty assessment for estimate the accuracy of the results. These results are assigned as uncertainty range to each resultant number and given in table1. We will include the information about the standard deviation of the elevation difference between the final ASTER DEM and the SRTM DEM, and also the differences between in the KH-9 and ASTER and KH-9 and SRTM DEMs.

RC: Regarding the satellite imagery datasets, a paragraph, table, or figure to clearly show which DEMs are being subtracted from one another for each given time period, i.e. SRTM minus Hexagon for 1973-1999, and ASTER minus SRTM for 1999-2009. This would serve the clarify the methods section significantly.

Reply: There is a figure in the supplementary material which shows the boundaries of the utilized images. There is no overlap of the Hexagon DEMs, hence it is clear which area was substracted. We agree, however, that this is not so straight forward for the ASTER DEMs. In case an area is covered by more than one DEM, we used the mean of all available DEMs. We will clarify in the revised manuscript.

RC: Since the primary motivation of the paper is to extend the geodetic mass balance record further back in time, I would recommend an additional calculation of the full timespan (1973 - 2009) mass balance. This would also serve to validate the 1973-

1999 and 1999-2009 mass balances, and remove the significant uncertainty regarding SRTM penetration into the ice.

Reply: We have done so for few glaciers to clarify that the results agree well to the results of the individual periods. We agree, however, that it would be beneficial to also include the DEM difference for the entire period. This will therefore be done for the revised manuscript.

RC: The equations used for estimating uncertainty lean toward the more conservative side (i.e. large error bars). For example, linearly adding up the errors in Eq. 3 instead of adding in quadrature, which assumes that the error components in Eq. 3 are completely correlated with one another. The authors should make clear in the conclusion of the manuscript - results show no statistical difference from zero change, given the somewhat large/conservative uncertainties used with the DEM differencing method.

Reply: We understand the concern, but think the uncertainty is more realistic when adding the uncertainties of the radar penetration, volume to mass conversion etc. and considering the error propagation would underestimate the uncertainty from our point of view. This is especially as the approach by Gardelle et al. 2013 provides rather conservative error estimates. However, even with smaller uncertainty estimates the general statement that there we no significant differences between the period before and after 2000 holds true. We will discuss this issue in the respective section and mention it also in the conclusions.

Specific comments:

P3 L6 Were any glaciers covered only partially by scenes from different years? If so, it may be best to use a weighted mean (weighted by the percentage of a glacier's area covered by each scene).

Reply: Yes, especially the larger glaciers are covered by more than one scene. We will used the mean value for the overlapping parts. We will use now the weighted mean of

all the scenes used for a glaciers considering the area coverage as suggested.

P3 L8 It is still somewhat unclear to me how the Cartosat-1 data is being used. I assume the authors compute Cartosat minus SRTM, then compare to ASTER minus SRTM in order to check consistency between the datasets. This should be further clarified in the text.

Reply: Yes, it was done to compare to the ASTER derived which have significant lower resolution. We will write: “Two high-resolution Cartosat-1 stereo scenes captured on 11 July 2010 (Table 1) were used to compare and investigate the consistency of the results gained with the lower resolution ASTER DTM.”

P2 L18 "assuming a full penetration of the radar beam into snow..." - regarding the ablation region. What about additional penetration into the ice itself, is this taken into account?

Reply: Yes this is taken into account. We applied the correction suggested by Kääb et al. (2012) who analysed the penetration depth for a similar region.

P2 L20 It would be useful here to refer to the later section (3.2) so the reader can easily find the discussion regarding void filling with the ASTER GDEM2 and associated uncertainties.

Reply: We will refer to the section 3.2. as suggested.

P3 L24 "All stereo images have been processed with a RMS of < _1.5 pixels." Which aspect of the stereo photogrammetry is this referring to? Is this the reprojection error of triangulated ground control points after bundle adjustment, or something to do with the reseau grid distortion removal, or something else? A more detailed explanation is needed to interpret the meaning. P3 L28 See previous comment regarding P3 L24

Reply: We refer to the RMSE of the GCPs after triangulation. We will clarify in the revised manuscript and improve the caption of Table S2 accordingly.

P3 L32 What kind of spatial trend corrections were made? Rotation, translation, or perhaps polynomial surface corrections... if so are they first order (linear), or higher order polynomials, or some other method?

Reply: We applied a first order trend correction. We will clarify this in the revised manuscript.

P4 L12 Was the outlier threshold applied to both Hexagon and ASTER data, or to Hexagon only? If no outlier filtering was needed for the ASTER DEMs, this should be stated explicitly in the text. P4 L17 It would be helpful to know the percentage of total pixels excluded (using the outlier threshold filter) for each glacier, to ensure that no large regions were interpolated using the ordinary kriging; otherwise unrealistic elevations could result. The text later discusses the percentage of voids in the SRTM data, but says nothing regarding the percentage of data gaps in the Hexagon data. P6 L13 Going back to the previous comments regarding P4 L12 and P4 L17 – Since both time periods use different data sources and therefore contain differing amounts of data voids - a percentage of voids for each would help eliminate doubts regarding direct comparisons between the two time periods, which use SRTM - Hexagon for 1973-1999, and ASTER - SRTM for 1999-2009. Could a difference in data gaps/holes make a significant difference when comparing these datasets/time periods?

Reply: The outliers were filtered for all DEM differences, but it was more important for the DEM differencing using Hexagon data. We will clarify this in the revised manuscript and also provide the information about the resultant voids in the different data sets. The impact of the outlier filtering and the gap filling will be discussed in the discussion section.

P6 L11 "we confirm for the first time using elevation differences..." Should specify: over this longer time period (because elevation differences have been used over shorter time periods in previous studies).

Reply: We agree and will now specifically mention “for the period since 1973”.“

P6 L17 What is meant by "different surge stages in the two periods..."? What is different between the two periods regarding surges, the magnitude, timing, or something else? Or is the word "different" simply being used in a fashion equivalent to "separate"?

Reply: We simply meant that, e.g. one period covered the active surge of the glacier while the second probably the quiescent phase. We will be now more explicit and provide few examples of selected glaciers.

P8 L1 When calculating the mass budget with the non-void-filled version of SRTM for comparison, were the voids interpolated, or was the mass balance computed using only the volume change of existing pixels, then divided by the glacier area only covered by existing pixels? More details would be helpful.

Reply: We will clarify and write: “Using the latter we calculated the surface elevation change for the existing pixels only. The resultant value of the mean surface elevation change for both periods differs only by about 0.02 m a-1”

Technical corrections:

P2 L7 complicate the

Corrected

P3 L10 “The major advantage of this dataset is besides the high spatial resolution and also the 12 bit pixel depth” – strange wording. Should change to something like: “The major advantages of this dataset are the high spatial resolution and 12-bit pixel depth.”

Reply: The sentence will be rewritten to: “The major advantage of this dataset is besides the high spatial resolution the 12 bit radiometric resolution.”

P7 L11 “: : : ASTER DEMs where lower: : :” change “where” to “were”

Reply: Corrected

P8 L6 voids

Reply: Corrected

P8 L4 versions

Reply: We think the singular is correct here: “We compared therefore the results of the void filled and the non-void filled version.”

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