The Cryosphere Discuss., 6, C2055–C2063, 2012
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The Cryosphere Discussions

Interactive comment on "Mass gain of glaciers in Lahaul and Spiti region (North India) during the nineties revealed by in-situ and satellite geodetic measurements" *by* C. Vincent et al.

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Received and published: 1 November 2012

General: The topic of the paper is very relevant as it is an important contribution to the ongoing discussion on glacier changes in the Himalaya where mass balance measurements are rare and, if existing, short-term. This is especially true as information about the possible mass change for the 1990s is presented, a period for which almost no mass balance data is available. In addition, geodetically derived mass changes for 1999-2010 and a reassessment of the 1999 - 2004 data published earlier (Berthier et a. 2007) are presented.

This manuscript was already submitted elsewhere and has clearly improved but un-

fortunately some of my earlier major concerns were not addressed satisfactorily. My major concerns are:

- The authors back up the “mass gain” based on geodetic mass budget estimates for one glacier only measured for one time period (1988-2010) which has an overall negative budget of -0.17 $\pm$ 0.08 m w.e. a-1. The “mass gain” in the 1990s is estimated based on a comparison with geodetic measurements for 1999-2010, and is not significant given the high uncertainty (+0.09 $\pm$ 0.23 m w.e. a-1). Hence, the authors should be very careful with such a prominent statement. By the way: I appreciate the thorough estimation and discussion of the uncertainty.

- One important shortcoming of the measurements at Chhota Shigri Glacier is that the authors do not consider glacier flow which can have an important impact on the point measurements. This needs to be considered if possible or at least discussed.

- The authors claim that the results for Chhota Shigri Glacier are representative for a larger region and back up their statement of the similar mass loss of the glaciers compared to the whole region for the 1999-2010 period. This is a hint but may also be random. Further evidence for the representativeness needs to be presented, e.g. dh-curves, evidence from other glaciers in the same period, length and area changes. In addition, the glacier has only little debris cover while several others have large amounts of debris on their tongues.

- The paper lacks a more in depth discussion, e.g. no real (e.g. climatic) hypothesis about the causes of the mass gain is presented. The authors should also compare their results with other available mass balance data from the 1990s in the Himalaya and possibly also with area and length changes (considering the response time).

- Hence, the overall conclusion is weak, is not fully supported by the data and needs to be extended. One of the real interesting results of the study is the reassessment and new data of the mass change since 1999 for a larger region, but this information is a bit hidden in the supplement. I suggest that the authors include most parts of

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the supplementary information in the main text as there is no length limitation for The Cryosphere.

More specific comments:

Title:

The title needs to be changed as it does not reflect the content of the study well. The mass gain for the glaciers in Lahaul and Spiti is only a hypothesis but not confirmed. In addition, the performed measurements confirm an overall mass loss between 1988 and 2010. Maybe something like "Investigations on Chhota Shigri Glacier 1988 to 2010 (. . .) indicate the possibility of slightly positive mass budgets (. . .)"

Abstract

The abstract needs to be improved after the revision of the paper. I would suggest to include also the rate per year which makes comparisons to other studies easier. In addition, the absolute ice loss should be presented.

L.11. Results of the study provide important additional information about one glacier in particular in the Himalaya but the statement "This contrasts to the most recent compilation of MB data in the Himalayan range that indicates ice wastage since 1975, accelerating after 1990." is exaggerated. Bolch et al. (2012) write in their recent review: "These measurements suggest that the mass budget over large parts of the Himalaya has been negative over the past five decades, that the rate of loss increased after roughly 1995 but also that the spatiotemporal variability is high." There is e.g. no evidence provided in the study that there was a real mass gain until 2000 for Chhota Shigri Glacier and all of Lahaul and Spiti. It could e.g. also well be that there was slight mass gain from 1988 until roughly 1995 and a mass loss thereafter. In addition, this study on Chhota Shigri and Lahaul/Spiti confirms a mass loss on average since 1988 with an acceleration later. Hence, from my point of view the results of the study are generally in line with Bolch et al. (2012) but provide important further details which

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help to refine our knowledge about the glaciers in the Himalaya. Please revise this statement. You may for example write "A positive mass balance in the 1990s would contrast the most recent compilation of MB data in the Himalayan range that indicates ice wastage since 1975. However, we confirm an acceleration towards more negative balance since perhaps the late 1990s."

1. Introduction

P. 3735, L. 24: ICESat data is available until 2009. However the cited study by Kääb et al. (2012) uses only data until 2008. Please revise.

L. 26ff: Please show the boundary of "Western Himalaya" in figure 1. Usually the ridge north of the Indus River is not included in the Karakoram but in the Western Himalaya. Also the eastern boundary can be a political boundary but a topographical one as suggested by Bolch et al. (2012) based on Shroder (2011) and discussions with ICIMOD. Bolch et al. (2012) present a glacier coverage of $\sim$8950 km^2 for Western Himalaya based on recent inventory data (Fig. S1, TableS2)

2. Site description, data and methodology

P. 36, L. 20: Provide more details about the nature of the debris cover (thickness, form (medial moraines?)).

L. 21: Please provide some more details about the amount of seasonal precipitation in this region. Is the glacier more of summer-accumulation or winter-accumulation type? This information would then also help later in the discussion about the possible causes of a slight mass gain/less negative budgets in the 1990s.

P. 37, L. 1: Who is "we"? All authors? Maybe it is better to name institutions.

P. 37, 1st paragr.: This information is not needed in this detail for this paper. The authors may consider shortening and mainly refer to the references for further reading.

L 20ff.: At the lower part of the tongue the measurements are concentrated along the

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centerline. However, it was shown that using only the centerline is not representative for the entire width of the glaciers (Berthier et al. 2010). This should be at least discussed shortly.

P. 38, L. 7: Using 900 kg m-3 is fine and well established. However, the correct density of ice is 917 kg m-3.

L. 12f: Please write here clearly that you adjusted the DEMs following the method suggested by Gardelle et al. (2012a).

L. 23: I appreciate that the authors consider a correction. This correction might be even a bit too high. More information in the beginning about the precipitation and accumulation regime would be also important for this estimation.

3.1 Changes in Chhota Shigri Glacier thickness. . .

General: It would be very helpful if figures 2 and 3 could be improved. The lower dots on the glacier are hardly visible in Fig. 2 and information about the debris cover should be included here. My suggestion is to show a suitable remote sensing image in the background and show only each second contour line in a grey colour. Fig. 3: Please include the information about which measurements are affected by debris-cover. I have also concerns about the polynomial interpolation. The curve is strongly influenced by the measured point at ∼4090 m asl. (which I by the way cannot identify in fig. 2.). Please include the used values for the 50m intervals mentioned on page 38, L. 4. Provide also evidence that the surface elevation change of ∼+20m in the ablation region is real true. The significant thickening does affect the overall volume change. How did you deal with this thickening in terms of glacier mass balance?

3.2 Representativeness . . .

See my general comments at the beginning

3.3 Mass gain. . .

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Please revise heading and the statement L. 23. Given the high uncertainty it is not clear whether there was a slight mass gain or mass loss.

Please include all numbers here to understand your calculation. I suggest to include table A2 here. The authors need also to be a bit more careful with the date 1999. Currently one has the impression that the mass balance was positive until 1999 and negative thereafter. But this year might have been also earlier or later. It is just that there are measurements (or a DEM) available. Is there any other evidence which can also support the positive value in the 1990s? e.g. repeat photographs or remote sensing imagery? Is there evidence of a short glacier advance caused by this positive MB period or could it be expected in the future due to the delayed response?

3.2. Comparisons with other western Himalayan glaciers

This section as it is currently written can be almost entirely omitted as this information is presented in table 1 and figure 5. I suggest to move this section to the discussion. The focus should be on the comparison of the obtained data with the existing one including MB values. Any further evidence from other measurements (length, area taking the possible response time into account) besides the important remarks based on Azam et al. (2012) which might support a mass gain in the 1990s for the larger region should also be discussed.

4. Discussion

General: Please include in the discussion also some climatic evidence which may support the hypothesis of a slight mass gain or little mass loss during the 1990s.

P. 42, L. 21. The authors should not directly compare length changes with mass changes for the same period without considering the response time.

L. 22. “slightly positive”. . . see my comments above.

P. 43, L. 15f. Please revise this sentence. The statement in Bolch et al. (2012) is different. See my comment on the abstract. However, I agree with the authors that the

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information about the 1990s is very limited and more information is needed.

L. 25: The geodetic estimate for Hamtah is very valuable because the undocumented glaciological measurements published for this glacier are quite negative and might be an outlier as mentioned. Please show therefore also a zoom of this glacier (see my comment on Figure 4).

P. 44, L. 6ff. I fully agree with these points. But this heterogeneity is also true for the Lahaul and Spiti and also provides a rationale for why the authors should be careful with generalizing the results of one glacier to the larger region.

L. 13. It is true that thick debris insulates the glacier ice. The authors need to consider that several debris-covered glaciers are significantly losing mass despite thick debris cover (Bolch et al. 2011, Nuimura at al. 2012, Kääb et al. 2012). This can be explained by enhanced melting at ice cliffs and supra-glacial ponds (Sakai et al. 2000) while the debris cover favours the developments of these lakes.

5. Conclusions

Please revise the conclusions according to the revised manuscript. P. 45, L. 9ff: I don't see a reason why mass balance results from the 1990s should support findings from a later period. Please revise.

Table 1:

Please refer to the original reference and not to Dyurgerov and Meier (2005) to the degree possible. Dyurgerov and Meier (2005) also collected the data from elsewhere but unfortunately no reference is given there. You will find some information about the original references in Bolch et al. (2012, Supplement Table S6).

Figure 1:

Please include the boundary of "Western Himalaya" and the coverage of the geodetic estimate (Fig. 4) and a scale bar. Please also include the information that the political

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boundaries are tentative only (or similar) as these are not fixed and such a map could unfortunately cause problems. What is the source for the glacier outlines?

Figure 2 and 3:

See my suggestions above.

Figure 4:

I would be pleased if the authors could show the DEM differencing for the entire region and not only for the glaciers (Maybe in the supplement and enlarged a bit in case glacier changes would not be visible anymore in addition to the figure in the main text). Please also indicate the area where there are data gaps. In this way the reader can better justify the quality. Please show a zoom of Chhota Shigri and Hamtah Glacier, the glaciers which are directly mentioned in the text. Show also the DEM difference for the non-glaciated area and not only for the glaciers. What are the sources for the outlines?

Supplement

Please include the units in the table (They are missing for MB). As stated above this information is of high interest and I would include the most important information (or even all) in the main text. E.g. the problems with calculating the geodetic mass balance for small glaciers and Table A2 and Figure A1 should be in the main text from my point of view.

References:

Berthier, E., Y. Arnaud, R. Kumar, A. Sarfaraz, P. Wagnon, and P. Chevallier (2007), Remote sensing estimates of glacier mass balances in the Himachal Pradesh (Western Himalaya, India), Remote Sens. Environ. 108(3), 327–338.

Berthier, E., E. Schiefer, G. K. Clarke, B. Menounos, and F. Rémy (2010), Contribution of Alaskan glaciers to sea-level rise derived from satellite imagery, Nature Geoscience

3, 92-95.

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Kääb, A., E. Berthier, C. Nuth, J. Gardelle, and Y. Arnaud (2012), Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas, Nature 488(7412), 495–498.

Nuimura, T., K. Fujita, K. Fukui, K. Asahi, R. Aryal, and Y. Ageta (2011), Temporal Changes in Elevation of the Debris-Covered Ablation Area of Khumbu Glacier in the Nepal Himalaya since 1978, Arct. Antarct. Alp. Res. 43(2), 246–255.

Sakai, A., N. Takeuchi, K. Fujita, and M. Nakawo (2000), Role of supraglacial ponds in the ablation process of a debris-covered glacier in the Nepal Himalayas., IAHS Publication 264(=Debris-Covered Glaciers), 119–130.

Shroder, J. F. (2011), Himalaya, in Encyclopedia of Snow, Ice and Glaciers, Encyclopedia of Earth Sciences Series, edited by V. P. Singh et al., pp. 510–519, Springer Science+Business

Interactive comment on The Cryosphere Discuss., 6, 3733, 2012.