The Cryosphere Discuss., 6, C2346–C2358, 2012
www.the-cryosphere-discuss.net/6/C2346/2012/

The Cryosphere
Discussions

Interactive comment on "Quantifying present and future glacier melt-water contribution to runoff in a Central Himalayan river basin" *by* M. Prasch et al.

M. Prasch et al.

m.prasch@lmu.de

Received and published: 5 December 2012

Response to interactive comment on "Quantifying present and future glacier melt-water contribution to runoff in a Central Himalayan river basin" by M. Prasch et al. M. Prasch, W. Mauser and M. Weber m.prasch@lmu.de

Dear Professor Pelto, Thank you very much for your comment which will help to improve our manuscript. In the following you can find our answers to your detailed suggestions, including a detailed explanation to the result of stable ice-melt contribution from the glaciers despite a strong retreat of glacier area extent.

Monika Prasch, Wolfram Mauser and Markus Weber

4560-24: More details on observed glacier change in the region, note Li et al. (2011) and Caiping et al (2010).

Thank you. In the revised manuscript we will include these two references which support the cited glacier retreat in Tibet, also giving details for the Nyainqêntanglha Mountains (Li et al. (2011), p. 12) and for the neighboring Nianchu river basin (Caiping et al. 2010).

4561-2: Quantify the seasonal monsoon precipitation.

In the Lhasa River basin precipitation observations of five meteorological stations are available with an annual precipitation sum between 426 mm and 517 mm from 1971 / 1980 – 2000 in the valleys (see Table 1). About 90% of the amount is falling during the monsoon season from June to September.

We will include in the revised paper: Climatic conditions in the LRB are determined by a strong seasonal course of the precipitation, which falls during the monsoon months in summer (430 - 520 mm/a (see also Table 1), 90% falling from June to September).

4561-11: Break into two sentences, do not start paragraph with "However". Cyclic and anti-cyclic glacier runoff versus the overall hydrograph should be introduced here.

This section will be changed as follows: ... The important synchronous ablation and accumulation period during the monsoon season in summer largely determines the importance of glacier melt for water availability in the LRB similar to large, summer-monsoon dominated areas in the Himalayas. In contrast to man-made reservoirs snow- and ice-reservoirs are filled or emptied by natural processes in either a cyclic or anti-cyclic behavior, and therefore cannot be managed for downstream agriculture, hydropower, industry and households. If snow- and ice-melt occur during the rainy season (cyclic behavior), they may add a small fraction to the large amount of runoff generated by heavy rainfall. When snow- and ice-reservoirs melt during the dry season (anti-cyclic behavior) the generated runoff can be used to compensate potential water shortages. The glacierization is only 2% of the watershed area. Nevertheless it was chosen, because the study wants not only to analyze the contribution of glacier melt water in the highly glacierized head-watersheds. It also wants to analyze the influence of ice-melt in the downstream regions, where usually people live and use water.

4564-23: How is ice thickness determined?

As referenced in the input section (4566-28) this is described in Prasch et al. (2011b, p. 60): “In order to run SURGES, the area–elevation distribution of all glaciers and the ice thickness for all elevation levels is required as input data for all glacierized grid cells in the test basin. In general, the availability of glacier data is poor in the LRB, but the Chinese Glacier Inventory (CGI) provides polygons of the glacier areas of 1970 and additional information of their mean ice thickness (WDC, 2009). By intersecting the glacier boundaries with the ASTER Global Digital elevation model GDEM (ERSDAC, 2009) and aggregating the elevation values to levels at intervals of 100 m, the elevation levels for all glaciers in the LRB are deduced. Within the aggregation steps, the slope is averaged by weighting of the area. In this process, each glacier is considered separately, and so the elevation levels are not aggregated among different glaciers. Next, the area per elevation level is calculated. To consider the different ice thickness distribution of a glacier in more detail than assuming a homogenous ice block, the mean ice thickness provided by the CGI is modified for all elevation levels of the glacier. Thereby a correlation between surface slope and ice thickness (Haeberli & Hoelzle, 1995), and the thinning out of the glacier to its edges and the glacier front are considered.

Validation

While the uncertainty of the glacier area is in the 5% range (Wang et al., 2009), the accuracy of the GDEM varies between ±7–14 m (ERSDAC, 2009). Because the elevation model was recorded in the year 2000 and is combined with the glacier boundaries of 1970, on average about 6–10 m w.e. (water equivalent) (Frauenfelder & Kääb, 2009) has melted away. Consequently, the elevation data are slightly too low. However, this average value is approximately within the range of accuracy of the elevation model.

To check the quality of the deduced ice thickness for the elevation levels as described above, the derivation method was applied in the Eastern Alps, where area and geometry of the glaciers are similar to glaciers in the LRB, because no data are available in the LRB. The deduced ice volumes were compared to the data of the Austrian Glacier Inventory (Lambrecht & Kuhn, 2007). The volume deduced is 2% smaller, which corresponds to a deviation of 1 m ice thickness. Finally, the volumes of the elevation levels of a mountain and a valley glacier were compared. The overall deviation varies between 3 and 6%, which corresponds to a difference of 2 m or 3 m, respectively, of mean ice thickness. In comparison to uncertainties of ice thickness values for the Austrian Alps of between 5 and 10% (Fischer, 2009), the deviation is small. Additionally, the deviations are also within the accuracy range of the digital elevation model.“

ERSDAC (Earth Remote Sensing Data Analysis Center) (2009) The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA): Aster Global Digital Elevation Model (GDEM), available from http://www.ersdac.or.jp/GDEM/E/2.html.

Fischer, A. (2009) Calculation of glacier volume from sparse ice-thickness data, applied to Schaufelferner, Austria. J. Glaciol. 55(191), 453–460.

Frauenfelder, R. & Kääb, A. (2009) Glacier mapping from multi-temporal optical remote sensing data within the Brahmatwinn river basin. Proc. of the 33rd International Symposium on Remote Sensing of Environment (May 2009, Stresa, Italy).

Haeberli, W. & Hoelzle, M. (1995) Application of inventory data for estimating characteristics of and regional climate-change effects on mountain glaciers: a pilot study with the European Alps. Annals of Glaciology 21, 206–212.

Lambrecht, A. & Kuhn, M. (2007) Glacier changes in the Austrian Alps during the last three decades, derived from the new Austrian glacier inventory. Annals of Glaciology 46, 177–184.

Wang., Y., Hou, S.& Liu, Y. (2009) Glacier changes in the Karlik Shan, eastern Tien Shan, during 1971/72 – 2001/02. Annals of Glaciology 50(53), 39–45.

WDC (2009) Chinese Glacier Inventory of the World. Data Center For Glaciology and Geocryology, Lanzhou, China. Available from http://wdcdgg.westgis.ac.cn/DATABASE/Glacier/glacier_inventory.asp.

4565-22: What is the threshold at which this transition occurs in your model at several time steps?

We do not quite get your point. In the referred line alternating accumulation and ablation during the monsoon season is cited. In our model accumulation and ablation are determined in calculating the surface energy balance as described above (4565-11ff). In the case you are interested in the threshold wet-bulb temperature to distinguish between rain and snowfall: it is set to 2°C in this study.

4566-2: The output balance gradient, mass balance change with elevation, should be illustrated with a figure. How does the output compare to Caidong and Sorteberg (2010) who modeled mass balance of Xibu Glacier in the study region?

Caidong and Sorteberg (2010) found a systematic reduction in the mass of Xibu glacier in the past which is in accordance with our results of the past (section 4.2). We compared our modeling results of the past with a detailed glacier change study which was carried out in our study area, the LRB by Frauenfelder and Kääb (2009), Kääb et al. (2008) with remote sensing data. The mass balance change and the decrease of the glacier area are in accordance with our modeling results. Although this is only an overall value for the whole basin it shows that our results can reproduce the mass balance and glacier area change trend in the LRB of the past.

Since no data were available except the calculated mass balance of Xibu glacier by Caidong and Sorteberg (2010) to validate mass balance in more detail, we did not yet include the mass balance change with elevation in our manuscript. Additionally, here,

we focused on the present and past melt-water contribution to runoff.

Furthermore, the comparison with Caidong and Sorteberg (2010) would add a model to model comparison of one glacier of the total basin, for which the area-elevation distribution of the results of Caidong and Sorteberg (2010) is required, but not published in the paper. Therefore we did not add this to our validation.

4568-15: What has been the recent ELA and is the modeled accurately? The ELA is an important validation point that can and has been assessed from satellite imagery.

We agree that the ELA is an important validation point for glacier mass balance modeling besides others for individual glaciers. The ELA can be accessed from satellite imagery, but the access date of the images rarely is the date of the highest elevation of the ELA, so that validation data in using the glaciological method would be required. Nevertheless in remote regions, remote sensing data are very important and useful as validation data. In our model we validated the processes on the glacier such as accumulation and ablation of snow and ice as well as the reproduction of glacier geometry changes over longer time periods in detail. As the study focuses on meltwater release from glaciers, the simulated runoff of a highly glacierized basin was compared to measured runoff, whereby the necessity of the subscale approach was also tested. This was carried out for Alpine sites because for glaciers in our test basin in the Himalayas we do not have time series of these data. Below an example is given for the validation of the specific mass balance of the Vernagt glacier.

We also carried out all possible validation steps, which the limited data availability in the LRB allows. This includes the accuracy of the downscaled CLM meteorological data, the glacier changes and the water balance. The main results are introduced in section 4. Additionally, the derivation of glacier input data was validated in Prasch et al. (2011b). Based on these careful validations of the input and output data and because our approach is based on physical principles and is a process-oriented approach, we believe that it can be transferred from the Alps to the LRB.

see Fig. 1.

Fig. 1. Observed (line) and modeled (squares) specific mass balance in four parts of the Vernagt glacier for the elevation levels in the mass balance season 1999 (Marowsky (2010), p. 78, modified).

MAROWSKY, K. (2010): Die Validierung des Gletschermodells SURGES am Beispiel von Vernagtferner sowie Nördlichem und Südlichem Schneeferner. Diploma thesis at the Commission for Glaciology of the Bavarian Academy of Sciences in Munich and the University of Eichstätt-Ingolstadt, 147 p.

4570-15: The observation that as glacier area is lost glacier runoff does not decline during the study period is not realistic. Why did this happen? In other studies in several different settings where glacier area has been reduced by more than 20%, glacier runoff has already been observed to be in decline. This is because glacier runoff is a product of glacier melt rate and glacier area, a 20% loss in area means a 20% increase in melt rate is needed. This is plausible but this becomes implausible as glacier area is reduced by larger percentages forcing an even higher melt rate increase, from a glacier with a higher mean elevation. A doubling of melt rate has not been observed in the ablation zone of any existing alpine glacier. Here by 2080 Figure 8 indicates an 80% loss in volume, area loss would not be far off that, thus an 8 fold increase in melt is required. Such an increase is not supported in examination of the balance gradient of glaciers from cool to their warmest years.

In the Lhasa River basin glacier retreat of the past will proceed in the future according to our model results, but the glaciers will not completely disappear, because of the altitudes in the Nyainqêntanglha Mountains. Our model results show that the annual fraction of ice-melt on runoff is not decreasing but hardly changes (Fig. 9). The reasons for this might not have been clearly explained, which we try in the following and which will be improved in the revised manuscript.

Looking at the absolute ice-melt contribution to runoff in mm/a (Tab. 6), a future decrease can be seen except for the sub-catchment of Yangbajing. Since overall runoff, which is composed of the separately modeled rainfall, snow-melt and ice-melt, also decreases because of increasing evapotranspiration and a strong reduction in snow-melt (Tabs. 5, 6, 8), the ice-melt fraction stays almost stable. This finding can be interpreted as follows:

Ice-melt, in the model is the water being released by melting ice of the snow-free parts of the glaciers. Snow-melt is seen as snow that melts at the surface of a snow cover be it on the glacier or not (see 4562-14ff). Accordingly in our modeling approach, which we consider physically realistic, ice-melt can only start after the snow-cover on the glacier has melted away.

Following this, the amount of ice-melt on each modeled grid-cell on the glacier is determined by its snow-free duration. Only during this period the incoming energy can cause ice-melt. The number of snow-free model grid-cells for each time step determine the snow-free area of the glacier. The ice-melt water from these model grid-cells is accumulated to the overall ice-melt. The fraction of snow precipitation on the total amount of precipitation clearly decreases in favor of rainfall in the LRB under climate change scenario conditions (Fig. 10). This results in a shift of the snow-conditions of about +500 to +1000 m (see Table below). In turn, the snow-free period is extended by two to three months (Fig. 11) and thereby increases the total amount of ice-melt per area and year. Since this shift is proceeding continuously, similar to glacier retreat, the simulated changes of the snow-free glacier area, decisive for ice-melt, are small despite the shrinking overall areal extent of the glaciers. This can lead to an almost stable ice-melt fraction of the total runoff, which is produced by the glacier. Only at a very late stage in the meltdown of the glacier will the ice-melt fraction start to disappear in that case. This can be seen in Fig. 9 for the eastern and northern parts of the basin. These processes also explain the slight increase of the amount of ice-melt contribution at the gauge of Yangbajing where large glaciers are located and the decrease of precipitation and therefore snowfall is above basin average (Figure 12).

See Fig. 2: Changes in the percentage of snowfall for different elevation levels in the basin.

4571-10: The cyclic and anti-cyclic behavior is well described here. This should be moved to 4561-11. This is a key measure to gauge the hydrograph response against. Thayyen and Gergan (2010) Figure 3 provides a good representation of cyclic versus anti-cyclic hydrographs in the Himalaya. How does your output in Figure 12 match these hydrographs?

We moved the cyclic and anti-cyclic behavior as described in the comment to 4561-11. The hydrograph response and the related importance of ice-melt due to its timing are explained in section 5.3.

The Himalayan cyclic hydrograph of a Himalayan catchment of Fig. 3 in Thayyen and Gergan (2010) shows the almost simultaneous peak of precipitation and discharge similar to our simulated hydrographs at the outlet of the LRB and at Yangbajing of Figure 12.

In the revised manuscript we will refer to the Thayyen and Gergan (2010) Figure 3 in this section and also in the conclusion, because the dominance of precipitation for the discharge is in accordance to the results found by Thayyen and Gergan (2010) for their “Himalayan catchment”. Additionally, we also analyzed the situation under future climate conditions.

4571-25: How has the snowline shifted in the spring, such as May? How do the results compare to Kulkarni et al (2007)? They noted the importance of snowline recession and that spring snowline extent change is key.

As explained in the answer to your comment 4570-15 snow cover duration is the key for the amount of ice-melt. Additionally, snow-melt and its timing are important for runoff due to its significant amount in our river basin. Figure 12 shows the earlier set-in of snow melt and the reduction of its amount (see also Tabs. 6, 8). Accordingly in May

snowline shifted upwards and thereby exposed more glacier ice. In turn, the fraction of ice-melt increases in spring under scenario conditions.

Kulkarni et al. (2007) analyzed glacier retreat in the Indian Himalayas in using remote sensing data. They found a clear reduction of the glacial area and an increase in the number of glaciers because of breaking-up of a glacier in several small ones. Additionally they stated that the retreat of small glaciers was larger than of larger glaciers because of their thinner ice thickness. This is in accordance to our results (that’s why in the northern and eastern part of the basin, glaciers disappear, see Fig. 9). We do not see, however, that changes in snowline are discussed in the mentioned paper.

4574:1: The conclusion is too long? A lack of conciseness will prevent a reader from focusing on a few succinct key points. Why is this first paragraph in the conclusion and not earlier? Ice thickness for example, how is this approximation made? This is not something that should be left or the conclusion.

Thank you for this point. The third and fourth paragraph of the conclusion discusses the modeling approach. This will be inserted as section “3.1.4 Discussion of the modeling approach” in the methods section. We fully agree that shortening the conclusion will support the reader in focusing on the key points. The approximation of ice thickness is explained in the answer to comment 4564-23.

We believe though that our finding that ice-melt is and will be of minor importance for the runoff produced by the LRB (first paragraph) and its concluded relevance for the large summer-monsoon dominated downstream regions in the lowlands following the Himalayas where many people live (second paragraph) should be part of the conclusion. This is also the case for the discussion of the importance of uncertainty in future monsoon precipitation for the model results (fifth paragraph) and the last paragraph.

Please also note the supplement to this comment:

http://www.the-cryosphere-discuss.net/6/C2346/2012/tcd-6-C2346-2012-supplement.pdf

---

Interactive comment on The Cryosphere Discuss., 6, 4557, 2012.

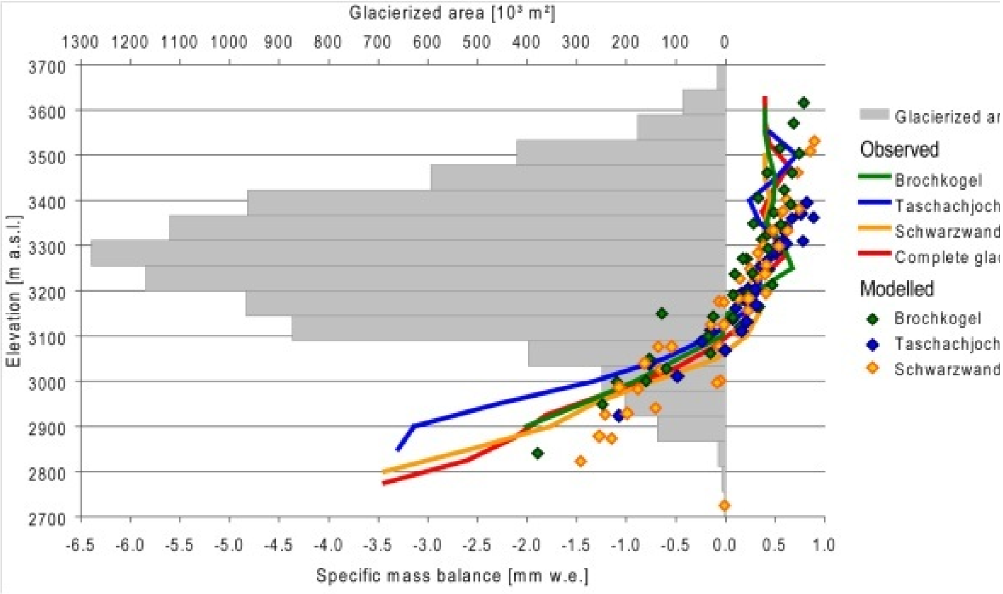
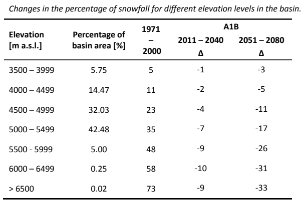


Fig. 1. Observed (line) and modeled (squares) specific mass balance in four parts of the Vernagt glacier for the elevation levels in the mass balance season 1999 (Marowsky (2010), p. 78, modified).



Changes in the percentage of snowfall for different elevation levels in the basin.

Elevation [m a.s.l.]	Percentage of basin area [%]	1971 – 2000	A1B	
			2011 – 2040 Δ	2051 – 2080 Δ
3500 – 3999	5.75	5	-1	-3
4000 – 4499	14.47	11	-2	-5
4500 – 4999	32.03	23	-4	-11
5000 – 5499	42.48	35	-7	-17
5500 - 5999	5.00	48	-9	-26
6000 – 6499	0.25	58	-10	-31
> 6500	0.02	73	-9	-33

Fig. 2. Changes in the percentage of snowfall for different elevation levels in the basin.