The Cryosphere Discuss., 6, C2693–C2709, 2013
www.the-cryosphere-discuss.net/6/C2693/2013/

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: 3 January 2013

Response to M. Pelto

(CS = Chhota Shigri)

1. Vincent et al (2012) provide a rather cursory model of the Chhota Shigri Glacier mass balance for the 1990's and extend the results to the entire Spiti and Lahaul region. This paper adds little value to the fine study of this group (Azam et al, 2012. The author's title makes a key assertion that is not even supported in the abstract. The study does not utilize the majority of other area glacier studies, does not properly defend basic assumptions, discounts previous results without support and extrapolates without

verification or well established procedure. The shortcomings are detailed below.

Some of the comments by M. Pelto were founded and relevant and we took many of them into consideration. In particular, as also suggested by both reviewers, the text has been weakened given that the slightly positive mass balance is statistically not different from zero.

However, we disagree with many of his comments. Some of his statements reveal that he has not read carefully the original MS and his accompanying supplementary material (see our response to his specific comments for details).

Added value of our paper compared to Azam et al. (2012). Contrary to Azam et al (2012), we bring a unique and new quantification based on accurate field data of the cumulative mass balance of CS glacier between 1988 and 2010. It has never been done before. Azam et al. (2012) used a dynamical approach in order to infer indirectly a steady state of the glacier before 2002. We bring here evidence of a balanced or slightly positive mass budget during the nineties thanks to new data.

2. 3734-7: The title of the paper states there is a mass gain of glacier in the Spiti and Lahaul region in the 1990's. The abstracts notes that the gain for Chhota Shigri is deduced, not observed. The gain is -1.1 m, which is small enough to be in the error range cited of -1.5 m. The hypothesis of the title is not supported by this sentence.

Note that the gain is not -1.1 m but +1.0 m, and the error range is ± 2.5 and not -1.5 m. However, we agree with this comment: due to the large error range, we need to be more cautious, and the title has been changed, as well as all sentences saying that there was a mass gain. See Response #1 to Reviewer#1. By the way, the gain is deduced from observations.

3. 3734-11: This sentence states that the observations indicate no large scale mass wastage until the last decade. This is not the same as a mass gain from the previous decade. Again the title belies the results.

Agree. The sentence has been changed, as well as the title

4. 3735-1: Why is there a generic list of global data references and not to the specific references that abound for glaciers in the area? See extensive list below.

In introduction, we prefer to provide a list of review papers, and papers coming from well-established peer-review journals, or to cite WGMS which is a reference institution for glacier observations. The review paper by Bolch et al. (2012) includes a synthesis (and a list in the Suppl. Mat.) of all papers about area changes. The extensive list given by M. Pelto contains papers from grey literature, references to a blog (?), and we think that it is more appropriate in introduction to cite only peer-reviewed papers from well-established journals. Anyway, in the beginning of our generic list, we added "e.g." to state that this list is not exhaustive.

5. 3735-4: There are studies in the very study area that should be cited. See extensive list below.

The provided list concerns papers (not all peer-reviewed) dealing with glacier retreat or area changes. Our study is focused on glacier MB, explaining why our reference list does not include all papers of M. Pelto's list. Moreover, in our study, we thoroughly checked every information coming from available papers (peer-reviewed and non peer-reviewed). For some of these papers, we have the absolute certainty that part of the provided information is wrong (see our comments below on Kulkarni and others (2007)). Since the objective of our study was not to point out wrong information in papers by others, we decided not to give an exhaustive list of references, especially when we have doubts on their content.

6. 3739-7: A uniform thinning of 5 m to 8 m at 91 points besides the very end of the glacier tongue is noted. How does this end up with a net thinning of 3.8 m? Why given this consistency is it assumed that there would be little or no change at higher elevations?

It is explained in the manuscript. 5 to 8 meters ice thinning is observed in the area between 4500 and 5100 m a.s.l., and above, we are considering 3 different assumptions : no change between 1988 and 2010, same change than lower, and a linear extrapolation leading to a cumulative MB of -3.3, -5.0 and -3.8 m we, respectively. Thinning in the ablation zone and limited elevation changes in the accumulation area are observed in many mountain ranges (see all publications dealing with elevation changes from DEMs or laser altimetry profiles) and, theory, has shown that this is the expected response of the glacier to negative mass balance (Schwitter and Raymond, 1993).

Schwitter m. P. And Raymond C. F. Changes in the Longitudinal Profiles of Glaciers during Advance and Retreat, Journal of Glaciology, 39, 582-590, 1993.

7. 3739-17: The thickening here at the lowest 1% of the glacier does not seem to agree with either the recession observed or the photographs of the terminus from Kulkarni et al, (2007). How is this significant disparity accounted for?

Our results agree with Azam et al. (2012) study. From direct field measurements, Azam et al. (2012) found that the terminus has retreated only 155m between 1988 and 2010. The recession rate obtained by Kulkarni et al. (2007) conflicts with the results of Azam et al. (2012) study . In their paper, Kulkani at al. (2007) estimated the CS Glacier snout retreat by combining field and satellite observations, using in the field non-differential GPS and comparing pictures of the snout between 1988 and 2003 (Figure below, which is Fig. 6 in their paper). The result is a glacier retreat of 800 m between 1988 and 2003. In 1988, the snout position has been determined by Dobhal, who is co-author of our paper, and published in his PhD thesis (Dobhal, 1992). Dobhal's team made also a mapping of the entire glacier at this time (Dobhal and others, 1995). In Kulkarni's paper, no reference is given for the position of the CS snout in 1988, but we believe that this position comes from Dobhal's work, since it was the only survey conducted so far on CS Glacier. According to maps published in Dobhal et al (1995) and Dobhal (1992), a 800 m retreat of the snout since 1988 would locate the snout between 4200 and 4300 m asl in 2003. We have been conducting annual field surveys on CS Glacier since 2002 (Wagnon and others, 2007; Azam and others, 2012), using DGPS and we observed a snout around 4050 m asl, an altitude which is incompatible with a 800 m retreat. Therefore, we believe that the survey done in 2003 by Kulkarni's team is questionable. Looking at pictures of the CS snout on Fig 6 of Kulkarni's paper (reproduced below), it is not possible to clearly identify a large retreat, since no reference points can be distinguished on both photographs which are probably not taken from the same point of view. Moreover, 4200-4300 m asl is the lowest elevation of the debris-free part of the glacier, and therefore we believe that the retreat inferred by Kulkarni and others comes from a misinterpretation of satellite images. They said themselves that "Identification and mapping of glacial terminus in a satellite imagery is normally difficult if glaciers are covered by debris" which is the case for CS Glacier. We ourselves experienced the same difficulty as the inexact CS glacier outlines originally drawn from 2.5-m SPOT5 imagery (Berthier et al., 2007) had to be corrected based on the field measurements (Wagnon et al., 2007) (See legend of Table 3 in the revised MS). In the photographs of the glacier front (below), we can see that the slopes are steep, and may be subject to important rock falls. The avalanche deposition area is not visible in these pictures, because it is located just above the steep part of the snout visible on pictures

Figure 6 from Kulkarni et al., Current Science, 2007, see below

8. 3739-26: Is no change above 5100 m realistic? This might be correct but Bolch et al (2011) noted a significant thinning in the accumulation zone in the Khumbu Region.

We are exploring here 3 different assumptions to capture the entire range of changes, as explained in the original MS. No change above 5100 m is just an extreme assumption, in order to get a conservative error range.

9. 3740-13: The noted error is -1.5 m greater than the net potential gain for the 1990's.

We agree and in the revised MS we are not referring to mass gain but to balanced or slightly positive mass budget.

10. 3741-6: The thickness changes are quite large across many glaciers in Figure 4. These changes are likely not due to just ablation during the interval of 1999-2010, and likely also reflect longer term dynamic changes, that have been underway. What is the case that dynamic thinning due to reduced flux was not underway prior to 1999 as is suggested by the terminus response, downwasting and area extent losses in the region, note Figure 6 (Bhambri and Bolch, 2009). Figure 4 does not allow an inference to be drawn about mass loss in the 1990's for the region.

The observations of a contrasted pattern of elevation difference is not really a surprise, every glacier having his own dynamical response to a given mass balance forcing and thus some of them experiencing enhanced thinning at their front. This is an expected response of glaciers to negative mass balance (Schwitter and Raymond, 1993) and we have discussed this issue in detail for the Mer de Glace (Berthier and Vincent, JOG, 2012). But it is beyond the scope of this paper to discuss the dynamic response. Elevation changes are averaged here for whole glacier bodies or the whole region so that they allow calculating the glacier-wide mass balance. So our calculations are not affected by ice dynamics (although the pattern of elevation is). "Figure 6 (Bhambri and Bolch, 2009)": based on Kulkarni at al. (2007). See our comments above about this paper. "Mass loss in the 1990's for the region": see our detailed response to the same comment by the referees and the revised MS

11. 3742-3: What are these studies?

They are listed in table 1 ; Table 1 is now referred to in the text, together with Fig5.

12. 3742-25: The inferred mass balance loss is not confirmed by the Azam et al (2012) change in state. It may be suggestive but given the response time of glacier flow to climate change a reduction in velocity at the various transects across the glacier would not have likely occurred rapidly do to a mass balance change in state that occurred after 1999. It is more likely that a change in velocity would be the result of a longer term trend in mass balance.

Several studies show that change in mass balance influence the ice flow velocities with a short response time. Span & Kuhn (JGR-2003) report on observations that shows “that ice acceleration follows positive deviations of the mass balance of the accumulation area within 1 year, based on the once-per- year surveys”. In any case, from the ice fluxes analysis, Azam et al. (2012) suggested that this glacier experienced a period of positive or near-zero mass balance before the beginning of this century. Our topic here is not to re-analyse these results but to compare their results with our data. Data shown in the present manuscript confirm this presumption. Anyway, every consideration regarding glacier flow has been removed in the revised MS since it is the topic of Azam et al’s paper, and not the scope of this present MS.

13. 3743-13: Where is the evidence that Chhota Shigri is similar to the mass balance of other glaciers in the area? If it is a thinning pattern, where is the data on this? The range between glaciers and elevations needs to be examined.

Glaciers within a region can have a different thinning pattern and still a similar mass balance because the thinning pattern is strongly influenced by ice dynamics. So a thinning pattern (with altitude) is not a proof of representativity. We have now incorporated in the MS the area-altitude-distribution (AAD) of CS Glacier and the whole region. They were already present in the supplementary material. However, we do not present the AAD as an evidence of similar behaviour. This is a hint but in the case of the Alps, it has been shown to be a poor parameter to extrapolate the observed mass balance to the whole region (Huss, 2012). The question of the representativeness of CS Glacier is discused in Reply 4 to Reviewer #2 and the new version of the manuscript.

14. 3743-25: On what basis do you assume that the mass balance on the Hamtah, Dokriani and Dunagiri glacier do not adequately address the accumulation zone? This is a substantial assertion that cannot be made without documentation. It is worth noting that Chhota Shigri there are not measurements above 5100 meters either.

We did not state that measurements on Dokriani Glacier did not adequately sample

the accumulation zone. Regarding CS Glacier, it was clearly written in the original MS (section 2.2) that mass balance measurements are performed in the accumulation zone (between 5000 and 5500 m a.s.l.),. Hamtah and Dunagiri glaciers have been both surveyed by Geological Survey of India (GSI), and MB data come from their field reports and were never presented in peer-review papers. In these reports, there is no information concerning the accumulation measurements. Second, for Hamtah Glacier, located approximately 15 km from CS Glacier, the inter-annual variability of the MB is in strong disagreement with the same variability on CS Glacier (continuously very negative MB for Hamtah, although CS shows negative and positive years – new Fig7). Third, our geodetic MB measurements on Hamtah Glacier do not agree with the MB series obtained by GSI even within large error bars due to the small size of this glacier. These 3 considerations were listed in the original MS, and on this basis, we arrived at the conclusion that these MB series are questionable. We are now even more cautious than in the submitted MS by stating “This may be the case of Hamtah glaciers for which the MB is strongly negative . . .”. We hope that our statement will stimulate the publication of those MB data in details in well-established peer-review journals. See also Reply 8 to Reviewer #1

15. 3427-28: The authors assert based on their geodetic measurements, which have large assumptions and substantial errors, that the rest of field-based measurements in the region document mass balance losses that are too large. This maybe the case, but where is the detailed evidence that this is the case. The evidence must be able to explain discrepancy that exists.

We are not sure we understood correctly what issue was raised here. Current mass balance compilations for HK are based on available MB data. Consequently, if these data are biased negatively, the HK compilation will also be biased negatively. For example, given the paucity of mass balance data, a strongly and erroneously negative mass balance (such as the one of Hamtah Glacier) can severely biased the mountain range average.

16. 3744-10: Figure 5 does not illustrate any kind of a strong agreement between the mass balance of area glaciers and Chhota Shigri. This graph does show that whenever we have mass balance series the cumulative record in every decade for are negative. This parallel the records of area extent losses and terminus change for the region, they are all consistently trending downward as well, note references below. The only exception is the deduced trend for Chhota Shigri. There is just not support for the statement

It is very risky to compare directly the area extent/terminus losses to mass balance changes. Many studies (e.g. Lliboutry, 1971; Cuffey and Paterson, 2010; Oerlemans, 2007) show that terminus or area changes adjust to mass balance changes with response times of several years to a few decades. Leclerq and Oerlemans (20011) mentioned that glaciers respond slowly to changes in climate so they are a proxy with decadal resolution at best. Consequently, from area/terminus observations carried out with an interval of 10 years (or more), as it is the case in Lahaul Spiti glaciers (see Figure in the last comment to M Pelto), it is not possible to detect a balanced or slightly positive mass budget during the nineties. Detailed studies in alpine regions, for which a lot of data relative to mass balance and area extent/terminus changes are available, show that the terminus fluctuations are not consitent with mass balance changes (e.g. Vincent et al., 2009) at decadal scale. For these reasons, in the present manuscript, we could not use data relative to area extent / terminus changes, to confirm or invalidate our results. Additionally, note the gap of mass balance data between 1990 and 2000. Chhota Shigri data are the only data to fill this gap.

Cuffey, K. M. and Paterson, W. S. B.: The physics of glaciers, Fourth ed., Academic Press Inc, Amsterdam, 2010

Leclerq P W and J Oerlemans 2011. Global and hemispheric temperature reconstruction from glacier length fluctuations. Clim Dyn DOI 10.1007/s00382-011-1145-7

Lliboutry, L. 1971. The glacier theory. Advances in Hydroscience, 7, 81-167.

Oerlemans J (2007) Estimating response times of Vadret da Morteratsch, Vadret da Palu ÂÍ , Brikdalsbreen from their length records. J Glaciol 53(182):357–362

Vincent , C., A. Soruco , D. Six and E. Le Meur . 2009. Glacier thickening and decay analysis from fifty years of glaciological observations performed on Argentière glacier ,Mont-Blanc area, France. Annals of Glaciology, 50, 73-79.

17. 3744-13: The debris cover would reduce the speed of response of a glacier terminus reach to climate change. Since Chhota Shigri has limited debris cover this would tend to make its response faster, yet it has been noted as the glacier responding the least to climate change (Bajracharya et al, 2008). The Parbati, Samudra Tapu and Bara Shigri are more heavily debris covered and are all noted as retreating faster than Chhota Shigri.

Thanks for the information, but our study is focusing on MB and not area changes, or snout retreat. Consequently, response time of glaciers are not considered in our paper.

18. 3744-27: The following studies in the Himcahal Pradesh indicate that this sentence is not well supported by other data. The average rate of the Chhota Shigri Glacier snout recession increased from –7.5 m a–1 from 1970-1989 to –27 m a–1 during the 1989-2000. A comparative analysis of the Chhota Shigri Glacier between1988 geomorphological and the 2000 Landsat image indicated a 12% glacier coverage decrease in the 13-year interval (Vohra, 2010). This is at odds with Vincent et al (2012) findings.

Based on ground measurements, Azam and others (J. Glaciol. 2012) give a retreat of 155 m between 1988 and 2010, consistent with the findings of Vincent and others (2012). See also the response to comment 3739-17, concerning the retreat given by Kulkani and others (2007). Actually, a retreat of ∼300m between 1989 and 2000 would locate the snout above 4150 m asl, although since 2002, we have never measured a snout higher than 4050 m asl. Consequently, we believe that the retreat rates or glacier coverage decrease reported in these studies (Kulkarni et al, Current Science 2007; Vohra, 2010) are wrong, probably because identifying a debris-covered glacier front on satellite images is challenging.

19. For the Spiti Basin as a whole of the 337 glacier inventoried, 169 retreated during the 1962-2001 period with a 16% area loss, the area loss rate increased in the 2001-2007 period with 13% loss (Ramesh, 2011). The adjacent Sara Umaga Glacier has retreated at a rate of 44 meters/year from 1989-2004 (Kulkarni, 2005). The Hamtah Glacier, 10 km west lacks a debris cover and with its noted negative balance was been retreating at 17 m/year during the late 20th century. The Beas Kund Glacier 40 m west retreated 19 m/year during the late 20th century (Bahmbri and Bolch, 2009). The Malana Glacier 10 km southwest is a similar size and the terminus is relatively debris free, it has retreated at approximately 50 m/year (Pelto, 2012). The Samudra Tapu Glacier 30 km northeast had a total recession of 742 m with an average rate of 19.5 m/yr from 1962-2005. The glacier extent is reduced from 73 to 65 km2 between 1962 and 2000, an overall deglaciation of 11% (Dhar et al, 2010). The Parbati glacier in the Parbati river basin, Kullu district, Himachal Pradesh is almost 52 m per year (Kulkarni et al., 2005). Kulkarni et al (2007) identify an areal extent loss of 21% in the Himcachal Pradesh basins of Parbati, Baspa and Chenab overlapping the time period of the Vincent et al (2012) study. The fact that it is not just the termini that are retreating and downwasting is indicated by the number of glaciers separating, tributaries pulling away from valley tongues at elevations well above the terminus. Kulkarni et al. (2007) further noted that the retreat was greatest for the smallest glaciers. This observation was also made by Bhambri and Bolch (2009) using Nagpo Tokpo Glacier as an example. This point is emphasized by Bajarcharya et al (2008) for other regions of the Himalaya. The observation of significant downwastage of glacier termini and glacier area loss was consistent from Chhota Shigri, Patsio and Samudra Tapu Glaciers (Kulkarni et al,2006). In the nearby Garwahl region Dokriani Glacier between 1962 and 1995 was reduced by 20% in glacier volume and terminus retreat was 16.5 m/year (Dobhal et al., 2004). The cumulative mass balance of Dokriani Galcier during the 1990's was -2.5 m. Glaciers in the Saraswati/Alaknanda basin and upper Bhagirathi basin lost 5.7_% and (3.3_of their area respectively, from 1968 to 2006 (Bhambri and Bolch, 2009). The

Staopanth Glacier retreated 22.88 m from 1962-2006 and Bhagirath Kharak 7.42 m (Kulkarni et al, 2007). These are both heavily debris covered glaciers that should respond to climate more slowly. The largest glaciers in the region have been consistently retreating though at rates less than smaller glaciers. The area extent losses have been greater for smaller glaciers. In the Split and Lahaul area what do the authors offer as a rationale that Chhota Shigri Glacier response would be the same as that for the smaller glaciers? Given the above there is a consistent signal of ongoing retreat and downwasting in the region, that does not support the author's conclusions. This does not mean that Chhota Shigri did not have a positive balance in the decade. However, there was no evidence presented that the retreat, volume and areal extent losses in the region halted during the 1990's, beyond Chhota Shigri. Further the Chhota Shigri data for the 1990's at least does not appear robust given other robservations of the glacier in other studies. Most of the area observations are of not of mass balance. Mass balance is not the same as terminus behavior or area loss. The terminus behavior and area losses typically lag the mass balance due to the response time or debris cover. However, on a glacier the size of Chhota Shigri the mass balance over the span of a couple of decades is largely determinative of terminus behavior and area change. Terminus behavior and areal extent changes are driven by cumulative mass balance changes, and this signal is particularly clear on small glaciers lacking debris cover in this region. These glaciers in particular have been in rapid retreat and experienced rapid area loss. An examination of terminus behavior and areal extent changes in the region does not paint a supportive picture for the conclusions of Vincent et al (2012). This does not mean they are incorrect, rather it indicates much stronger evidence is required to address the other studies that indicate ongoing glacier losses in the 1990's regardless of the variable assessed.

This list gives detailed information regarding glacier retreat, and glacier area loss during the last decades (except for the MB data for Dokriani : M. Pelto is giving -2.5 m we for the 1990s, but actually, there are only 6 years of MB during this decade (Dobhal et al, 2008)). Unfortunately, the list given by M Pelto results from a misunderstanding:

in our manuscript, we do not question the shrinking of Himalayan glaciers over the last century or the last fifty decades. Our study reveals a balanced or slightly positive mass budget during the nineties . As mentioned in the reply to the previous comment #16, many studies (e.g. Lliboutry, 1971; Cuffey and Paterson, 2010; Oerlemans, 2007) show that terminus or area changes adjust to mass balance changes with response times of several years to a few decades. It has been confirmed by numerical modeling studies (Luthi et al., 2010; Leysinger et al., 2004). The area and length changes are poorly related to mass balance changes all the more since the terminus or areal extent changes have not been measured at annual scale. It results that the areal extent/terminus changes obtained once a decade (at best), as it is the case in Lahaul Spiti glaciers (see Figure 2 below), are not able to reveal a positive mass balance period spanning over a decade.

Figure 2 below : Snouts fluctuations in Himachal Pradesh. Most of the data have been performed at decadal resolution (or more) and are not helpful to detect a balanced or slightly positive mass budget during the nineties.

Consequently, most of the data relative to area/terminus changes, carried out in the region of Lahaul Spiti over a span of one or several decades, are not relevant to confirm or invalidate our results.

Other studies performed in alpine regions are useful to illustrate the complicated relationships between terminus changes and mass balance changes: In Figure 3 below, we reported some length fluctuations of alpine glaciers which show that (i) the snout fluctuations are very different from one glacier to another glacier, (ii) the snout fluctuations are poorly related to mass balance changes while >50 years of cumulative annual mass balance data for alpine glaciers located 300 km apart reveals very similar fluctuations (Vincent et al., 2004) (see reply 4 to Reviewer #2). From these results, it is clear that it is impossible to detect a period of positive mass balance from terminus changes carried out irregularly, once a decade or with a less frequency.

Consequently, although numerous data provided by M Pelto are certainly of the greatest interest to draw a global picture of Himalayan glaciers evolution over the 20th century, these data are, unfortunately, not helpful to confirm or invalidate our results relative to near-zero mass balance during the nineties. We have to recognize that the mass balance fluctuations in Himalayan region reveal a more complicated pattern than that we have thought until now.

Lüthi, M. P., A. Bauder, and M. Funk (2010), Volume change reconstruction of Swiss glaciers from length change data, J. Geophys. Res., 115, F04022, doi:10.1029/2010JF001695.

Leysinger Vieli, G.J.M.C. and G.H. Gudmundsson. 2004. On estimating length fluctuations of glaciers caused by changes in climatic forcing. J. Geophys. Res., 109 (F1), F01007, doi: 10.1029/2003JF000027.

Vincent, C., G. Kappenberger, F. Valla, A. Bauder,M. Funk and E. Le Meur. 2004. Ice ablation as evidence of climate change in the Alps over the 20th century. J. Geophys. Res. , 109 (D10), D10104. 10.1029/2003JD003857

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Figure 6. Field photograph of terminus region of Chhota Shigri glacier, Lahaul and Spiti district, of HP taken in 1988 and 2003. In 1988, glacial ice is exposed on the surface and small portion of the terminus is covered by debris. By year 2003, the entire terminus zone is covered by debris.

Figure 6 from Kulkarni et al., Current Science, 2007

Fig. 1.

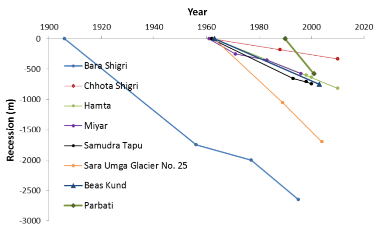

Figure : Snouts fluctuations in Himachal Pradesh. Most of the data have been performed at decadal resolution (or more) and are not helpful to detect a balanced or slightly positive mass budget during the nineties.

Fig. 2.

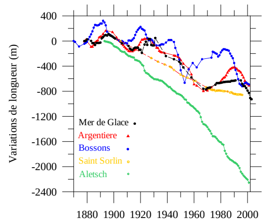

Figure: Snout Fluctuations for some alpine glaciers in France and Switzerland

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Fig. 3.