author reply on reviewer comments *A data set of world-wide glacier length fluctuations*

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reply to A. Fischer

We would like to thank Andrea Fischer for the effort in checking some of the Austrian glaciers included in our data set, and for pointing us towards their updated records based on the reanalysis of the original publications. We acknowledge that differences exist between the WGMS data and our dataset and we will continue to update the data set with the reanalyzed data from Fischer and others [2013]. We will also add a remark in Section 2.4 that further updates and extentions with reconstructions of the Austrian glacier length changes are foreseen in the coming year.

We have added the references for the Hintereisferner to Figure 1. The original source for the first data point is Beschel [1950], which was cited in Greuell [1992].

reply to Referee 1

We thank the anonymous Referee 1 for his/her extensive commentary. Below we give a reply to the specific points mentioned in the review.

- We have corrected the year of the first data point of Untere Grindelwaldgletscher into 1535 instead of 1534.
- The references of Hintereisferner were indeed missing. We have included them in the revised version. The original source for the first data point is Beschel [1950], which was cited in Greuell [1992], not Nicolussi et al. From the contact with Andrea Fischer we learned that at the moment a project is running to compile all reconstruction data of Austrian glaciers in an accessible data set. Therefore, there is good hope that in the coming year more long and detailed length records of Austrian glaciers will become available.
- We have tried to contact Dr. Holzhauser in order to include his reconstructions in the data set, but without succes so far. The reviewer suggests that we have missed other important sources as well. If the reviewer can specify the literature, we are interested in including the data in the compilation.

reply to Referee 2

We thank the anonymous Referee 2 for the review and detailed comments. Below we provide a reply to the general comments and a point by point reply to the specific comments. We have included the specific comments from the reviewer and give a reply in *italic*.

general comment 1

The data set we present here is a continuation of the data set started by Klok and Oerlemans(2004) and Oerlemans (2005) but we have included some fundamental changes including an increase in records, both in quantity and geographic representation, and an increase in glacier length attributes. The number of length records has increased substantially. Of the 169 records included in Oerlemans 2005, about half were from the European Alps. The current data set has 379 out of 471 records outside the Alps such that it now truly has a global character. Furthermore, more details of the length data are included. The most

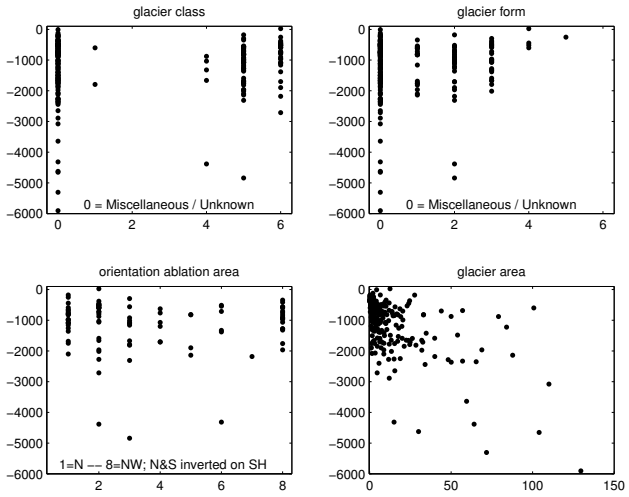

Figure 1: Relation between 20th century length change (m) and glacier class, glacier form, orientation of the ablation area and glacier area.

prominent extension is that we now include the methods used to derive the length change for each separate data point, as explained in section 2.1. This makes it possible to address the quality of each of the records and this information is used in the uncertainty calculations (section 3.1, Figure 9b). We did not find a relation between length change and method of measurement, nor do we expect such relation.

As indicated in section 3.2, we have compared the glacier length changes with other glacier parameters included in the data set, but found no evident relation between elevation or latitude. Following the reviewers suggestion we also looked at a possible relation between glacier class, glacier form, and the orientation of the ablation area as included in the WGI (Figure 1). Almost all glaciers are in the classes: (4) outlet glacier, (5) valley glacier, and (6) Mountain glacier. The most occurring glacier forms are (1) compound basins, (2) compound basin, and (3) simple basin. However, for many glaciers we have no glacier class or form given in the WGI (0, miscellaneous or unknown). The orientation is given in 8 classes: N (=1) to NW (=8), missing values are not shown. For the glaciers on southern hemisphere we have interchanged north and south, such that the results are comparable. We have found no clear relation with observed length change for any of these parameters. In this figure we have included the scatterplot of glacier area versus length change. There seems a week relation, larger glaciers have retreated more. This relation can be explained by the glacier slope as larger glaciers are in general flatter.

general comment 2

The goal of Section 3.1 is to present an overview of global and regional glacier length fluctuations as far as we have information. The reviewer is absolutely right by stating that the interpretation of the presented glacier regional averaged glacier length fluctuations should be done with great care. For certain regions the number of records is limited, and the number of records is limited for all regions prior to the middle of the 19th century. We deliberately show the artifacts to make this point clear to the reader. If large jumps are visible in the regional average, it is clear that the number of records is too small to present a very representative picture of regional glacier length fluctuations. The only way to come to a reliable picture of global or regional glacier fluctuations is to include many records. The data set we describe in this paper is an attempt to do so.

general comment 3

We think the comment of the reviewer that the conclusions section bears new aspects is caused by a misunderstanding. We shaped the conclusion into a short summary, repeating parts of the introduction in the first two phrases. These are not new findings of this paper, and should therefore not have been

explained in Section 3.1. To avoid confusion, we have deleted these phrases in the revised version (see also the specific comments on pp 4790).

We agree with the reviewer that the climatic interpretation of glacier length fluctuations is very interesting. For global and hemispheric temperature fluctuations this has been done (with less length records), and we also agree that a thorough regional climatic interpretation is beyond the scope of this paper.

specific points

Page 4776:

Line 2: write indicators of past climate change

done so

Line 8: Shouldnt it read 1535 (record of Lower Grindelwald Glacier?)

Yes, it should. Year is corrected

Line 9: Why does the number of records decrease after 1962?

Because not all records are up to date. In a few cases, a time series ends because of the disappearance of the glacier, but in most cases more recent data are not available because measurements have not been continued or reported.

Line 12: You mention small fluctuations until the mid-19th century. Is this not an artifact due to the temporal resolution of the available records?

This artifact can not entirely be excluded. In the case of sparse records that rely on reconstructions of former maximum stands intermediate retreats are not included in the reconstruction. We have adjusted the formulation here (in the abstract) and included a short discussion in Section 3.1. See also the specific comments on this Section, p 4788.

Line 15: You mention the behavior of calving glaciers. This is an interesting aspect, including the comparison with the non-calving glaciers. Given the limited number of records of calving glaciers, is it feasible to make the direct comparison? And: Are tidewater glaciers and glaciers calving in fresh water treated separately? Another point is also that many glaciers may become (or became) calving glaciers during (calving in lakes) during certain time periods.

It is of course true that there are less calving glaciers in the data set than non-calving glaciers. And it remains to be seen to what level the entire data set of 470 glaciers is representative for all glaciers. However, 104 records is not that limited, and the results, at least since 1850, are not strongly dependent on the exact number of calving glaciers that are included in the data set. We therefore think the number of calving glaciers is high enough to expect reasonable representativity from the results.

Fresh water and tide water calving glaciers are labelled differently in the data set. However, for the analysis of the length change as presented in Figure 10, there is no distinction made. Calving in a proglacial lake is another, third, category of calving. As this type of calving is typically temporally, it is not included in the analysis of calving glaciers (Figure 10). The data set also includes the year since when, or until when, the glacier is calving, but this information is not available for all glaciers. We have included more information of the treatment of calving glaciers in the paper, but not here in the abstract.

Line 25: I wouldnt limit the discussion here on the sea-level issue alone, but include other more general consequences of glacier changes, and correspondingly give a broader list of suitable key references.

We have included a remark on the effect of glacier changes on mountain hydrology and possible changes in fresh water availability.

Page 4777:

Line 7: Biological evidence sounds rather strange, what do you mean exactly?

Lichens, trees (tree-rings), etc. used in dating of moraines or used directly to derive information of former glacier terminus positions. This is quite a mouthfull which we tried to summarise with biological evidence.

Line 10: I can imagine that the compilation of the records was challenging. But what do you want to express with this sentence here? It could be interpreted that the dataset has some shortcomings that were not possible to be solved, due to the challenges. Therefore it is better to describe here these challenges more precisely.

We have deleted this sentence from the paper.

Line 15: please indicate precisely what you want to analyze (i.e. what you will analyze in the following treatise).

We have reformulated this part of the introduction to give a clearer description of the goal of the paper.

Line 20: Delete At present

done so

Line 24: I suggest to check the English phrasing.

sentence is rephrased

Line 26: Not clear: is it the main goal to address centennial changes?

Yes, the main advantage of length records is that they have the potential to cover a large period of time. On shorter time scales we have measurements of more relevant quantities such as mass balance observations and volume changes. From this perspective is doesn't make sense to include short-term glacier length records. We have rephrased this part to make it more clear what we mean.

Page 4779:

Line 8: For Nigardsbreen, better give (or add) the following reference: strem, G.; Liestol, O. and Wold, B. 1976: Glaciological investigations at Nigardsbreen, Norway Norsk Geografisk Tidsskrift, 30, 187-209.

We have added a reference to Østrem et al (1977)

Lines 11-14: Very general and short description; please reveal more details.

We have added more specific examples of the use of historical information outside Europe.

Line 17/18: Important question: How do you determine these uncertainties??

The uncertainty of 100–200 m is the typical value we found in the literature that we used ain the compilation of the data set. For some data points the uncertainty is smaller or larger, but in general uncertainties fall in this range.

Line 19: rather glacial deposits (after glacier erosion)

We have added a mention of deposition here.

Line 24: What about surface exposure dating? (and radiocarbon dating?)

We have not included data that were obtained from exposure dating. This method has a large uncertainty is generally used for older moraines (more than several centuries old) such that the intermediate between data points is so large that we did not include the record. Radio carbon dating is sometimes used, as mentioned at the end of the paragraph. It falls in category 4.

Line 29: Only if a tree-ring chronology is available!! (a lot of work. . .)

Off course, but only for those regions in which a tree-ring chronology is available this type of information on glacier length fluctuations is available.

Page 4780:

Line 2: Can you give a reference for ecesis time?

These references are at the end of the tree-ring part, line 5: Villalba and others [e.g. 1990]; Luckman [e.g. 2000]; Koch and Kilian [e.g. 2005]

Line 13: Write radio carbon

done so

Line 24: (see also comment above): How do you determine the uncertainty?? (in space and time)

Again (as above), the uncertainty we have used is based on the uncertainties that are given in the different studies that were used to compile the data set.

Lines 28/19: I assume that with trees found in situ, the statements could be much more precise, no?

For in situ damaged or overridden trees the dating can indeed be more accurate. For damaged trees that are still living the accuracy could be even one year. For overrriden trees, the accuracy depends on the match of the tree rings with the tree-ring chronology. As the number of data points from this type of dendrochronology is limited, we chose not to differentiate in the class of measurements based on dendrochronology. As we prefer to overestimate the uncertainty rather than underestimate it, we assign the larger uncertainty to all dendrochronological datings.

Page 4781:

Chapter 2.2: The main and general challenge here is how to handle records with only few data points available?

It is not the main challenge, the records could be used "as they are" for other applications [e.g. Lüthi, 2013], but for several purposes it is very convenient to have some type of interpolation. We use (and provide) interpolated glacier length records in Figures 8 – 10, so we think it is appropriate to describe the interpolation method in this section.

The paragraph starting in line 23 is not clear to me and I suggest rewriting it.
We have rewritten the parts of the paragraph that could have been unclear.

Line 25: The World Glacier Inventory has been updated in 2012 (see the NSIDC web- site).
We have used the updated WGI data set in the revised version of the paper and updated the reference here.

Page 4782:

Lines 9/10: How does this judgment work?
We ask the investigator if he can provide an estimate of the local amount of precipitation.

Lines 15ff: This could be shortened: the classification of your regions is described rather detailed. Also, I suggest not to abbreviate HMA. In addition: Paragraph 2.3. is rather hard to read, check if it can be shortened.
We have removed the abbrevation HMA from the text, but kept it in the table and figures. Furthermore we have shortened the section, the first paragraph in particular, to improve the readability.

Line 26: Only the southern Alps are part of southern Europe.
We have replaced "southern Europe" with "Europe".

Line 29: I notice that above it is stated that data on glacier geometries are taken from the WGI, here you mention the RGI. (The results should be the same, no?)
This was an unclear statement in the original version of our paper: what we meant is that the total glacier-covered area of the regions is taken from the RGI. The glacier area of the glaciers in the data set is, sometimes, taken from the WGI. Sentence is rephrased to clearify this.

Page 4784:

The paragraph lines 9-24 should be checked and rewritten in line with the 2012 update of the WGI (I assume it doesnt affect the results of the present study).
We have re-analyzed the glacier length distribution using the latest WGI verion (Feb 2012) and updated Figure 6 as well. Results are indeed practically the same.

Chapter 2.4: It might be worthwhile to set subtitles for each region. Be careful that this chapter does not become too superficial, e.g. can you reveal more details or interesting regional features to be detected from the dataset?
We have added subtitles, sometimes combining regions. There is much more to say on each of the regions, but we try not to get lost in the details of individual glaciers. We hope to have found a balance between interesting information and too much details.

Page 4786:

Lines 8-10: Is there an explanation for the high number of available records for the southern Andes and the low latitudes? And are those records as detailed as those available for Scandinavia or the Alps?
The Southern and Tropical Andes are, apparently, regions where the circumstances are favourable for reconstructions over a long period of time. In the Southern Andes this is, at least partly, due to the fact that a large number of glaciers decent well below the tree line such that there are many possiblities for dendrochronological reconstructions. In the Tropical Andes there are two studies that use lichenometry to date glacier fluctuations. Therefore, there are quite a few long reconstrutions in South America, but these reconstructions are not as detailed as the reconstructions based on historical information in the Alps. Secondly, it could be that the climate fluctuations in South America were different from those on the Northern Hemisphere where a lot of evidence of former glacier terminus positions was destroyed by a large advance in the middle of the 19th century. This explanation is speculative.

Line 14: This is not a very precise statement (military maps from the 19th century). Is there more information available?
These maps were created by military topographic engineers from Tiflis (now Tbilisi, Georgia) in 1880s. The scale is 1:42 000, therefore the maps used to be secret in the former USSR. They are the first large-scale maps for the Caucasus, and the borders of glaciers were identified, such that we can use them to evaluate glacier changes.

Line 16 starting with Also time. . .: English phrasing?
Sentence has been rephrased.

Line 18: North Asia has the smallest. . .
corrected

Page 4787:

Chapter 3.1: The division into the different time windows may lead to arbitrary results, or can you

exclude that the results are influences by the varying (and partly very low) temporal resolution of the records?

We have checked whether the, indeed arbitrary, windows influence the conclusions by shifting the 40-year window back and forth by 10 years (last time slot being 1950-1990 and 1970-2010 respectively) and using a 30-year window (1820-2000) instead of a 40-year window, but the main conclusions are robust: relatively small fluctuations up to the middle of the 19th century, then an overall retreat which is strongest in the first half (1900-1960/70) rather than in the second half of the 20th century.

The comment on the temporal resolution is answered in the reply to the next comment below.

Page 4788:

Line 9/10: The statement of smaller length changes until the mid-19th century needs to be explained. Again: can you exclude an artifact due to the temporal resolution of the available records? As documented by many studies cited in your article, there are im- pressive glacier advances (and retreats) during the Little Ice Age, e.g. as documented by historical evidence. On the other hand, some glacier records with dated moraines may solely consist of different maximum glacier front position, with no information on the glacier behavior in the time between those maxima. Here it is not possible to draw conclusions about the variability or the full range of past glacier length changes (past minimum glacier extents are always much more difficult to reconstruct).

The reviewer has a good point that for several glaciers we cannot exclude that fluctuations, retreats, in between the data points have been significant. We have included a comment on this issue in Section 3,1 of the revised paper. Despite of this limitation inherent to the compilation of this type of reconstructions, we think the pattern of globally rather little length changes prior to the middle of the 19th century and globally consistent retreat afterwards is robust.

Page 4790:

Line 15: The bed topography has a large influence on all glaciers, not only on tidewater glaciers.

We have deleted "on the length changes of tidewater glaciers"*, such that it now states that the bed topography influences glacier response in general.*

Lines 21/22: Please explain this statement (should have been discussed in Section 3.1).

We were rephrasing the introduction with this statement and therefore do not attempt to present new results that should have been discussed in the previous section 3. We have deleted this phrase in the revised version.

Page 4791:

Line 5ff: Important: The question here is how good the global glacier signal is reflected in the glacier length records. The following statement of a stronger glacier retreat in the first half of the 20th century is interesting, but I question whether this is in line with other records, and whether it is feasible to make such a conclusion. If yes, there is need for a better explanation and a more precise differentiation.

Whether or not our sample of glacier is representative for all the glaciers in the world is a good question, but impossible to answer. Recently, the representativeness of the glaciers for which mass balance observations are available is under renewed attention [e.g. Gardner and others, 2013]. However, for the period we are looking at here, there are no regional or global satellite observations available to test whether the sample presents a representative picture. Our observation of stronger retreat in the first half of the 20th century than in the last half is in line with the findings of a model study of Marzeion and others [2012] and studies of glaciers on individual or regional level [Bjørk and others, 2012; Oerlemans and others, 2011; Leclercq and others, 2012] (which are not independent records as the length records of these studies are also included in the data set). We have added "For the observed glaciers," *to the sentence in order the be more precise.*

Line 14: How could this improvement be achieved? Any suggestions from the authors would be appreciated!

We are not entirely sure to what type of suggestions the reviewer is referring as the entire paragraph following these lines is devoted to the possible improvements. Does the reviewer mean how we could organise a joint program in the cryospheric community? Or, alternatively, which techniques we would recommend?

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