Re-review of the study by Fischer et al.

General comments

The study by Fischer et al. has been extensively revised and has now a clear focus on the creation of the various inventories for the glaciers in Austria, the various uncertainties of the digitizing and the derived area changes for different mountain ranges. In my opinion, the applied modifications and the removal of the climatic interpretation of the observed area changes has been very beneficial for the ms. I would also like to acknowledge the addition of new figures which better allow to trace what has been done. My major objections are related to wording issues, a partly missing depth of the presentation (e.g. in the discussion), sometimes in favour of points that I would consider as being less important (e.g. the influence of drainage divides on the area instead of the attached snow fields), and the rather unfocused conclusion (the paper offers more than this). I have listed them along with some other comments below. As most of the suggested changes are minor and can very likely be easily addressed by the authors, I recommend accepting the ms once these minor revisions are implemented.

Specific comments

In the following, I do not distinguish between typo / wording issues and some larger issues that should be addressed.

General: Considering the uncertainties of the derived values, I recommend removing the second decimal in most cases (e.g. L33, L38, L242/3). Please also consider editing the English by a native speaker, it partly sounds German.

L1: Title suggestion "Tracing glacier changes in Austria from … a LIDAR-based inventory"

Abstract

L32: Has an inventory been digitized (i.e. incl. all the attribute information) or only the outlines?

L35/36/37: I think it is ok to mention here that advance periods have taken place in-between. But I think it would be even nicer to add numbers that result when such periods are removed (e.g. GI 1 to GI 2 being 13 years long instead of 29). That would give values that are comparable.

L37: Typo between year and . (remove space)

L38: This statement will likely change once only periods without an advance phase are compared (e.g. GI 1 to GI 2 has then also -1.3%).

L39/40: This sentence reads strange ad misses some numbers: I suggest writing "The mean size decreased from xx km^2 (LIA) to xx km^2 (GI 3) with 47% of the glaciers being smaller than 0.1 km^2 in GI 3 (xx% in GI 1).

Ch. 1

L54: I suggest writing: "world glacier inventory … and the one compiled by participants of the GLIMS initiative (Kargel et al., 2014)"

L57: Maybe cite the more recent one (from 2014) in Surveys of Geophysics

L58: I suggest removing Linsbauer et al. (2012) here and adding Grinstedt (2013) instead as the former study is not related to future sea level.

L61: I suggest adding "2012), as well as future glacier evolution."

L64: I suggest citing here Andreassen et al. 2008 and maybe Paul et al. 2011a and b. Paul et al. 2010 and 2013 are not really related to the creation of glacier inventories from satellite

data. There are a large number of further studies that can be cited here that are not from Paul (e.g. Bolch et al., 2010).

L66: Glacier inventories are in particular needed to up-scale the always-limited field measurements to entire mountain ranges.

L70: I suggest giving at least on example "… data such as topographic maps with …"

L74: "Apart from the Randolph Glacier Inventory (Pfeffer et al. 2014) …"

L76: "… are available for the Alps."

L81: When this list goes back in time, I suggest starting with the latest inventory compiled for Switzerland by Fischer et al. (2014a).

L85: I suggest adding "… and recently by Fischer et al. (2014b) for the c. 1985-2010 period."

L90: I suggest adding "1969. However, the outlines were not published then and the related change assessment with later inventories difficult."

L 101: I suggest adding "… question that should be answered by this study is the …"

Ch. 2

L111-120: This description of the previous inventories is very close to what has already been written in the introduction (L86-92). I suggest either extending it there and shorten it here or vice versa.

L119: "i.e. perennial snow patches"

L123: "so that": I do not see the cause and effect relation to the contents of the previous sentences. Why does the number of flight campaigns depend on the glacier definition?

L129: I know that this has been done in the cited previous study to homogenize the dates. However, I think that multiplication with size class specific annual area change rates would give a good approximation as well. Can this method be added here to see the difference?

L131: "km^2. They …" (dot missing)

L133: I think in particular in the 1999 imagery there was quite a lot of seasonal snow left in some of the regions resulting in too large glacier extents. Maybe this can be added as a note of caution and for the later discussion.

L134: "The maximum error of the …"

L134: Can you the method for the error (or uncertainty?) estimate be added?

L137: Can the spatial resolution of the GI 1 and GI 2 DEMs be added?

L142-144: the "so that" "although" sentence structure reads 'bumpy'. Maybe the English can be improved?

L153: Are snow free glacier margins really the case for all years investigated? I remember that some end of summer conditions were not that good for glacier mapping.

L153 & 156: The large temporal heterogeneity of the image/LIDAR acquisition dates for GI 3 should get a more in depth description in the methods and discussion sections.

Ch. 3

L170-180: The ice divide issue is all fine and should be mentioned. However, I think the most important issue requiring a short discussion is the consideration of attached perennial snowfields that were included in both GI 1 and GI 2 but might have disappeared in GI 3 due to the summer of 2003. The key issue here is that these snowfields do not change their extent for decades as their existence is strongly related to topographic characteristics. So keeping them included for consistency among the inventories is fine, but results in an underestimation of glacier area changes. When they disappear a related overestimation would result. I do not say that one method is better than the other, but I think the consequences of this decision should be clearly communicated here.

L185: an excellent solution => a good solution? (The disadvantage already follows in the next sentence.)
L186-188: An even better solution might be to start an inventory with the LIA extents.
L188: What has finally been done here? Have grandparent IDs been introduced?
L193: Should this read "was also quantified"? What does the sentence mean?
L201: "with different illumination angles"
L205/206: What about advancing glaciers?
L210/211: This sounds good but was it a challenging region or easy to see in the LIDAR hill-shade? Maybe it can be indicated where this test site is located?
L207/216: Accuracy estimates: Is there a chance to also provide a 'real' assessment of the uncertainty, for example by using a multiple digitizing experiment as outlined in Paul et al. (2013)? I think for outlines that are fully based on manual delineation and have some flexibility in interpretation, it would more useful to provide an accuracy estimate for the analyst rather than a nominal or theoretical one. I am aware that this might require some extra days of work but I think it is worth doing here.
L219: Should this be section 3.3.1?
L226: digitization & the position (remove one space)
L233: which had wasted down until 1969 => which disappeared until 1969?
L233: might be missing (is still required?)
L236: Why is this a fairly accurate estimate? How has it been derived?

Ch. 4
L242: remove at least the second decimal (941.13 => 941.1), maybe also both?
L244: a bit lower: Is this the 6.5% mentioned above? If yes, maybe just write it.
L248: I suggest extending this section a little bit with further inventory information, maybe all related to GI3. For example, the area and number distribution per size class, the aspect distribution per number or area covered, the mean (or median) elevation vs aspect, elevation range vs glacier size, etc. These must not be assessed also vs time, but for mean or median elevation this would certainly be interesting (even for mid-point elevation in case a LIA DEM is not available).
L250: I would say that from a hydrologic perspective the loss of glacier volume is more interesting than glacier area. However, I would suggest moving the motivation for calculating area changes in the introduction or methods section rather than in the results.
L258: I would not say neglecting, I would say including. When neglecting this period it should be taken out, i.e. the duration of the advance period should be subtracted from the total duration.
L261: I suggest writing "In the first half of this period …"
L262: I would add how these numbers change when the advance period (say 1969-1985) is subtracted, i.e. annual change rates refer to a 13 rather than 28.7 years period. This can be taken up in the discussion.
L262: I suggest writing: "showed no significant advances"
L265: see comment above: when area changes are calculated for the advance-free period only annual change rates are likely as high for GI 1 to GI 2. The change for the first period (GI LIA to GI 1) might be not as high but the 119 year period might be reduced to 100 or 105 years when excluding the 1890s and 1920s advance periods.
L273/4: I suggest writing "glacier area, but only 60.4% to the area loss."
L284/5: It would be nice to provide some explanations for this in the discussion, also in view of the temporal heterogeneity of the input data used for GI 3.

L289: I suggest adding a scatter plot showing initial glacier size vs relative changes in glacier area (annual rates) for one or two periods and all individual glaciers. A potential dependency can be nicely used for up-scaling trends to unmeasured samples.

L301: I would add in this section how mean (or mid-point) elevation has changed through time. If interesting, also spatial trends could be shown on a map. As a further possibility, it could be shown what the AAR is when the mid-point elevation is used a proxy for the balanced budget ELA and how this AAR has changed through time.

L297: most severe loss: In absolute or relative terms?

L298: "Fifty percent of the area loss"?

L308: Please add what the largest size class is.

L312-315: I think it would be better to have the total area in km^2 here rather than the percentage (or maybe both numbers).

Ch. 5

L327: Is this for GI2 or GI 3?

L328: Please add a discussion of the uncertainties derived from multiple digitizing experiments here.

L332: Maybe add a citation here. I also suggest discussing what the impact of the partly very short time periods between GI 2 and GI 3 is. A similar effect of highly increasing area change rates towards shorter time periods was also found in the study by Gardent et al. (2014) and Paul et al. (2011a) and might not be realistic (as uncertainties in the area assessment are higher than the change). I suggest adding a histogram displaying the temporal difference vs the number of glaciers.

L342: I suggest discussing the impact of the attached perennial snowfields in GI 1 and GI 2 on the derived area changes here. Maybe it can even be calculated what the area changes are with and without them for a smaller sub-region. That would allow us for the first time to see what the impacts of such a decision for the comparably small Alpine glaciers are.

L342: Maybe insert a new paragraph before "Moreover"

L348: Taking this and a general … into account, we estimate …

L351: Maybe insert a new paragraph before "In".

L352-355: I think the former method is the standard (summing up all parts). The latter has been tried by Maisch et al. (1999) by introducing 'Totalgletscher' and 'Teilgletscher', but the challenge is that the split of glaciers does not always follow along the position of the medial moraines. What I am not quite clear here: What has been used in this study?

L359/360: Yes indeed. Please calculate them and compare the rates to those published in the cited literature (e.g. Paul et al. 2004).

L363: Please do not compare total area changes as these always depend on the size distribution of glaciers under consideration. Please use annual relative area change rates for comparison.

L369: There are several studies for Alpine glaciers having compared relative area change rates for glacier outlines starting at the LIA (e.g. Maisch et al. 1999, Paul et al. 2004). It would be nice if the results obtained here could also be compared to these (and maybe some others) studies.

L370: I would remove the "global". Most satellite-derived inventories have a regional scale. Please also note that outlines are these days directly digitized in Google Earth using high-resolution (50 cm) satellite imagery, i.e. the spatial resolution effect no longer applies. What is more important for the inventories derived from aerial photography (in specific flight campaigns) is spatial completeness and a better flexibility with an optimal date.

L371: i) Not the inventories have a high spatial resolution (as they are vector outlines) but the input data used.

L371: ii) What is the additional information that can be included in the inventories presented here and why can this not be included in inventories derived from satellite imagery?

L372: iii) If carefully selected yes, but also satellite scenes can be selected in this regard and also aerial photography might have to acquire data in a year with adverse snow conditions (such as 1999 for GI 2). So to me this is not really an advantage.

L372: iv) This is mandatory for all datasets to be handled in a GIS and does apply to satellite derived inventories in the same way. So this is also not an item of distinction. Altogether, I suggest using the points mentioned above (L370 comment) as an important advantage and contrast this with the disadvantage of the comparably high costs for a flight campaign and the required orthorectification (satellite data are available for free and come already orthorectified), as well as the impossibility to acquire aerial photography in some countries (so satellite data are the only possibility to map glaciers).

L375: Also the global inventories are compiled from regional scale (or national) inventories, and satellite data can have similar spatial resolutions. So I suggest arguing that the typically used medium resolution (or Landsat type) satellite images have the special advantage of covering large regions at once (e.g. 180 by 180 km in case of Landsat) and thus map all glaciers on the same day or compile an inventory over large regions (e.g. Greenland's local glaciers) within a reasonable amount of time, but on the expense of a reduced quality in regions where the majority of glaciers is very small (see Fischer et al. 2014b). Something like this.

L382: The differences in spatial scale and the related visibility of details will certainly play a role. But the main reasons for the smaller glacier area in the RGI are likely missing glaciers under debris cover and in shadow as well as unconsidered perennial snowfields (i.e. a different glacier definition).

Ch. 6

L386ff: I suggest completely rewriting the Conclusions section. The current version is listing (repeating) rather specific details from the main text (L390-392), is speculating about causes of specific differences in L397 (this should be in the discussion) and comes several times back to mass balance observations that have not been performed (or discussed) in the study. In short, it reads like an extended discussion section. My suggestion is to add some main results from the more detailed analysis mentioned before (e.g. the mean elevation increase) and structure the Conclusions in the main findings and what these imply.

L392: of 6.2% and will thus likely vanish in the …

L400: "We encourage using the presented data basis for …"

Tables

Table 1: Sensor, Point density (capitalize)

Table 2: Heading: capitalize Group, Year, Data source and change GI II and GI III to GI 2 and GI 3. Last row: capitalize Total area and write "Percentage of LIA area". As a small note: I would prefer to give the respective loss in percent rather than the remaining percentage (i.e. -40, -50, -56).

Table 3: Heading: Mountain group

Table 4: I suggest adding percentages to the number of glaciers and absolute values in km^2 to the % of total section.

Figures

General comment:

I suggest removing the outline overlays depicted in Figs. 2 (top) and 6 as all glacier extents well visible in Fig. 8. This Figure should thus be moved forward.

Fig. 1: This figure is nicely illustrating the complexity of the analysis performed here. However, colour coding of the polygons does not really work (i.e. the colours are basically invisible) and another way of symbolizing the mountain ranges should be found. I suggest adding a colour-filled circle of constant size under the two-letter abbreviation of the respective mountain range (or two circles for Schober, Venediger and Zillertal). I also suggest extending the range of colours, as many of them are difficult to distinguish. This can include a range of grey values from white to black (providing maybe 5 to 6 additional shades) and fully saturated primary colours (red, green, blue).

Fig. 2: remove the top panel (shown in 8). I like the photo but would say it is a little bit difficult to use. It has deep shadows (hiding some glaciers) and has lots of non-glacier area included (i.e. glaciers are rather small). Maybe another one of that region could be found?

Fig. 3: The black annotations on the top panel are difficult to see, maybe change to yellow? I would also suggest adding (not too thick) glacier outlines on the hillshade to ease orientation. L582: The red squares show the position of …

Fig. 4: I suggest increasing the thickness of the red lines somewhat. If possible, I think it would also be good to show the same region on the aerial photograph (CIR) to the right of each hillshade. This might ease interpretation of the hillshades.

Fig. 5: The red line should be a little thicker.

Fig. 6: Please remove (see General comment).

Fig. 7: Please increase the thickness of the outline and annotate on the photo and the hillshade where the terminal moraines from 1850, 1920 (1930?) and 1980 (1985?) are.

Fig. 8: Can label points and glacier IDs be added on this figure (maybe in black)?

Fig. 9: I suggest using a logarithmic scale for the y-axis (rename to "Area (km^2)"). Currently the bars for some mountain ranges are close to invisible. I also suggest adding minor tick marks and use of dotted grid lines.

Fig. 10: I am not sure what the message of this graph is. Data extraction and interpretation is rather difficult. I suggest replacing it with a scatter plot area vs relative change in area (annual or decadal rates) for the GI 1 to GI 2 and GI 2to GI 3 (with a different symbol) period. For the former it could be interesting to divide values by 13 instead of 28 years. It might reveal a size dependent increase or decrease of the change rates.

Fig. 11: Maybe add some more tick marks and add major grid lines (dotted).

Fig. 12: I suggest moving this image to Fig. 2 and introduce it early (e.g. in the Introduction or L113) as I see it as an important input dataset. The snow issue could be described as is.

Literature

Bolch, T., Menounos, B., Wheate, R. (2010): Landsat-based glacier inventory of western Canada, 1985-2005. Remote Sensing of Environment 114 (1): 127-137.

Fischer, M., Huss, M., Barboux, C. and Hoelzle, M. (2014): The new Swiss Glacier Inventory SGI2010: Relevance of using high-resolution source data in areas dominated by very small glaciers. Arctic, Antarctic, and Alpine Research, 46(4), 933-945.

Grinsted, A. (2013): An estimate of global glacier volume. The Cryosphere, 7, 141-151.

Pfeffer, W.T., et al. and the Randolph Consortium (2014): The Randolph Glacier Inventory: a globally complete inventory of glaciers. Journal of Glaciology, 60(221): 537-552.