

Interactive comment on “Area, volume and mass changes of southeast Vatnajökull ice cap, Iceland, from the Little Ice Age maximum in the late 19th century to 2010” by Hannes Áróttir et al.

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Anonymous reviewer #1

Hannesdóttir et al. investigate area, volume and mass changes of southeast Vatnajökull since the LIA. The article's strength is a well-described and thorough reconstruction of glacier changes which is a useful contribution to scientific literature. There are some methodological details I would suggest to reconsider and I have some suggestions for restructuring the article. Most of that comes in the detailed comments, however, I find 3.2. and 4.1. could be combined to one and checked for redundancy.

Answer: Thank you for this comment. Since the other reviewer had comments on C3054

the methodology section we have decided to keep the data and methods chapters separated, but have minimized redundancy between them.

General Comments: The part where the results are related to climate change could use some refinement.

Answer: The Discussion chapter on the variable response of the outlet glaciers to similar climate forcing has been better organized and is more focused.

In my opinion, the discussion on the scaling laws does not add very much to the paper and I think it could be omitted without big loss of substance as the main outcome is that there is no trend in scaling parameters but also that the sample size is too small and probably also biased in terms of size distribution.

Answer: The discussion on the scaling law has been deleted from the paper as suggested by both reviewers.

In general, the paper is quite long and could be shortened at several locations, especially in 6. Some of them I indicate as a suggestion below.

Answer: We have focused the paper better and shorten it as suggested by both reviewers.

Specific Comments:

p4682

L12: by 164 km²...from xx km² to xx km²

Answer: We agree and have changed this to: “the glacierized area has shrunk by 164 km² or from 1015 km² to 851 km²”

L14: suggest to put the numbers in meter

Answer: We prefer to keep the units in mm.

L17: most negative compared to what? Very different lengths of time periods are C3055

looked at so it is a bit arbitrary

Answer: This has been clarified and the sentence now reads: "The rate of mass loss during the post-LIA period was most negative in the years 2002-2010, ..."

P4683

L11: every place on earth is ...influenced by changes in the atmospheric circulation... Specify

Answer: This sentence is now more detailed: "Iceland is located in northern part of the storm track in the North Atlantic Ocean, at the boundary of warm and cold ocean surface currents."

L13: mean monthly T?

Answer: "the mean temperatures are close to 0°C in winter and 11°C during the summer months in the lowlands."

L19: the '1' in the units should be removed

Answer: This has been changed as suggested.

L20: reads strange after the semicolon. Not a full sentence

Answer: The sentence has been changed and after the comma reads: "which is among the highest in the world (De Woul and Hock, 2005)."

L21: is that also true for snow melt water? To be sure, suggest 'glacial meltwater input' L11:

Answer: We have changed this to glacial meltwater input as suggested.

P4684

L1: repetition to L20 on previous page

Answer: We have now moved this sentence to the previous page.

C3056

L4: ...'at their deepest' as this is not true for all areas at the terminus

Answer: This has been changed as suggested: "since their beds lie even 100-300 m at their deepest below the elevation of the current terminus."

L13: ELA from Modis images is in principle wrong. Snow line is OK, equilibrium line is also acceptable, ELA is the point where the balance profile crosses 0 and therefore not to be acquired from Modis.

Answer: We explain in the methods section that the elevation of the snowline at the end of the ablation season provides an estimate for the ELA on temperate glaciers and refer to several papers. The autumn snowline is thus a proxy for the ELA, and we refer to it in the results section as MODIS-ELA.

L21. The hypsometry comes much later in the paper but actually it could be good if Fig 13 appears already there.

Answer: We consider Fig 13 to be part of the results, and should thus not be in the chapter on the study area. The variable hypsometry is taken out of this section.

L21-end of paragraph: very descriptive. Consider omitting this as all this is visible in the map.

Answer: This has been omitted and we agree that this is visible on Fig. 1. and some information is also found in Table 1.

P4685

L9: I agree with that until the glaciers are small enough not to touch the lakes anymore. It is therefore only partly coupled to climate. Suggest reformulating

Answer: We have reformulated this sentence, which now reads: "The lakes will continue to grow and new ones form in the troughs as the glaciers retreat, assuming current climate conditions or warming, and enhance ablation, at least until they retreat out of the lakes."

C3057

L12: numbers of significant digits?

Answer: We have added a ~ 1 m in this context, and further details are found in the cited reference.

P4686

L10: make location of AWS more prominent in fig 1.

Answer: The weather stations are displayed more clearly in Fig 1. now. L20: How have the 10 yr periods been defined? Is that running average? Explain Answer: We calculated the 10 year mean temperature of the warmest 10 year long periods.

L21: and why now 1884-1890?

Answer: Because measurements only started in 1884 and lasted for 6 years, this has been clarified in parenthesis.

L26: why undercatch only at one of the stations?

Answer: This was not clearly stated. The undercatch is a suggestion for the difference between winter and annual values, i.e. the winter precipitation is only 2 times higher on the eastern side compared to the western side, where the annual precipitation is 3 times higher. The sentence now reads: "The records from Kvísker show more than two times higher winter precipitation than in Skaftafell (Fig. 2), wherea the annual precipitation is three times higher (not shown). This seasonal difference could be related to precipitation undercatch of the rain gauges especially during winter, which is generally more pronounced for snow than rain (e.g. Sigurðsson, 1990)."

P4687

L1-3: not entirely logical there, reformulate or specify.

Answer: The sentence has been reformulated.

L18: define where you have the knowledge from that LIA maximum was at around

C3058

1890 at some point.

Answer: We have added in parenthesis after 1890: "(the timing based on historical documents)".

L22: how has the accuracy been determined? It sounds quite optimistic to me for a reconstruction taking problems as trimline erosion etc into account.

Answer: The method and error estimates are described in Hannesdóttir et al., 2014, and we refer to that paper here for clarification.

P4688

L3: remove 'a'

Answer: This has been removed as suggested.

L15: explanation for abbreviation right after AMS

Answer: The explanation has been given as suggested: "The AMS (Army Map Service)"

L19: is it then valid to use them for the calculation of geodetic MB?

Answer: The surface geometry in the upper accumulation area has been reassessed by using the nunataks on the original images to adjust the contour lines- this is now more clearly explained in the methods chapter.

P4689

L25: have been...

Answer: This has been changed as suggested.

P4690

L3 and entire chapter: so i understand: the shape is assumed to be the same but some vertical displacement is subtracted from the LIDAR DEM. Where do you take

C3059

this from? I assume this is the next paragraph that explains that. However, it remains unclear how these 'upper reaches of the accumulation area' are defined. I consider this an important point to clarify. And in this view, are the accuracies you determine for the individual DEMs realistic? How about other problems in photogrammetry like oversaturation?

Answer: This has been clarified in the following section: "The DEMs are obtained by constructing new contour lines from each contour line of the LiDAR DEM; the new contour has the elevation of the LiDAR plus an elevation shift. The intersection point of the new contour with the valley wall is found by moving the old point up or down the wall by a vertical elevation shift along a line drawn between the old intersection points on the opposite sides of the valley."

L11-13: unclear, specify 'available data points'

Answer: We have now detailed what the available data points are: "Between the data points retrieved from the trigonometric survey points, nunataks and the resurveyed glacier margin from the original aerial images."

L17: how about an abbreviation for the Glaciology Group... that appears several times.

Answer: Glaciology Group at the Institute of Earth Sciences appears only here (once) in the text, but in a table too, so we will use GGIES as an abbreviation.

L28: not in the most recent DEMs... but in previous ones? Clarify.

Answer: This has now been clarified: "We do not however, account for this change in the basal topography in the surface DEMs, as it is smaller than the vertical error estimate."

P4691

L23: bedrock or rock?

Answer: This has been clarified, it now reads: "... shadows had incorrectly been inter-

C3060

preted as rock outcrops or snow-covered gullies. . ."

General with all the accuracies given: would it be a good idea to include a table specifying them to shorten the text?

Answer: The vertical point accuracy estimates are given in Table 3.

P4692

L13: not clear what mosaiced means in this context. Resampled? Which cell size?

Answer: Mosaiced in the meaning of merged or spliced together; we have changed mosaiced to spliced. L19: what is ehf? Is that part of the name?

Answer: L19: ehf is part of the name of the company and has been clarified in the text. L21 and paragraph: so DGPS data from 2000-2003 has been used to derive 2002? and then a seasonal adjustment? And then you get to 1-2m accuracy? How is that estimated?

Answer: The accuracy is estimated by comparing the resulting DEM with the DGPS measurements. P4693

L5: suggest mass balance profile

Answer: We use mass balance gradient: "in their response to climate change through its link with mass-balance gradient."

chapter 4.3- additional to the points i raised before: the average and std depends on the density of points digitized. Answer on that. And how was the end of summer image defined? I guess the latest with clear sky. But how close is that really to the end of the ablation season? And what do you use it for in the end? The snow-line/ELA part does not appear to me to be crucial in the discussion.

Answer: We have indicated the dates of the MODIS images in Table 1. The snowline at the end of summer (Table 1) was manually digitized from cloud free images obtained

C3061

from late summer/early autumn (21 of August to 26 of September). This is the first time that the snowline elevation has been retrieved for the southeastern outlet glaciers, and we think this should be part of the data base presented here. Mass balance is only measured on a transect on Breiðamerkurjökull and Hoffellsjökull, so the ELA is known for those glaciers. Also the change in ELA since 1890 (presented in Hannesdóttir et al., 2014) is worth comparing with the modern proxy-derived ELA.

P4694 isn't 5.2. the principle result and should be mentioned before 5.1?

Answer: The MODIS derived ELA is shown in a number of figures (including Fig. 8, now Fig.7) it will not work to make this section the last sub-chapter of the Results.

P4695

L11-13: here it is relevant how far the images are apart. Suggest table with image acquisition dates.

Answer: The parameters of the MODIS images have been detailed, and are shown in Table 2.

L18: I don't understand how the 164 km² result. I assume this is for the total numbers, i.e. Öraefaj and Eastern (Tab. 2). but I get down to another number. I suggest also in Tab 2 and Tab3 to put the percentage changes in brackets for the overall numbers and not only for the individual glaciers.

Answer: Fortunately the reviewer noticed this error, and the numbers have now been corrected. We have added the percentage of the overall glaciers in brackets.

L24: would DEM differencing be a way to go to detect debris covered ice from rocks? For your multi-temporal GI with high-quality DEMs this could be a way to go?

Answer: Fig. 11b shows that the surface lowering is considerable for Hrútárjökull during the period 1945-2010, in this case the glacier snout thins even though it is covered with debris. DEM differencing could be a way to detect debris covered ice.

C3062

P4696

L4: single year data point??

Answer: single year data point refers to the only information we have on the terminus position (derived from the aerial photographs in 1979. This has been clarified: "...based on the data point from 1979 (Fig. 7)."

Fig. 9 could be saved if an overall bar would be added to fig 10 I would say.

Answer: Fig. 9 shows both the total volume and area loss and the relative changes – we think that Fig. 10 would be too complicated if the information from Fig. 9 would be added.

L22: 'southern outlets' if that is correct?

Answer: To clarify which outlets we have added "all the outlets collectively lost"

L26: very confusing sentence I find...

Answer: The sentence has been clarified and now reads: "All glaciers had lost at least half of their total post-LIA volume loss by 1945"

P4697

L7: add here that there definitely were some years with positive b. It is just with the intervals you are looking at that they are negative.

Answer: This has been changed accordingly: "The average geodetic mass balance of all glaciers was negative during every time interval of the study period (Fig. 12 and Table 4), however, it is likely that some years had positive balance."

p4698

Chapter 5.5: the classification is of limited use. I suggest removing that. The few points where you argue in the discussion with them you can just name the particularities of the class. If it should be kept, I suggest to move it to the method section.

C3063

Answer: We keep the discussion on the glacier hypsometry classification as suggested by comments from Reviewer 2, but have moved the classification to the methods section.

L17-22: How does that relate to other areas in the world? The fluctuations seem to be slightly ahead of for example alpine data.

Answer: A comparison with glaciers in the Alps and Scandinavia has been added, with a reference to Zemp et al., 2011.

P4699

L11: here for example the authors should be clear and always have to add that this is compared to the periods they are investigating. Answer: This has been clarified as suggested: "The annual rate of volume and mass loss of the periods investigated was highest in 2002-2010 for almost all the outlet glaciers."

L14: add which period you are referring to for this comparison. Generally in this discussion it would be nice to add the existing measured glaciological mb time series. For example superimposed in fig 12?

Answer: We have taken out the specific sentence on Hoffellsjökull and Breiðamerkurjökull and have added a new sentence: "The geodetic mass balance during the decade 2000-2010 is similar to the measured specific mass balance of the larger ice caps in Iceland, equal to -1.0 ± 0.5 m w.e. a⁻¹ (Pálsson et al., 2012; Jóhannesson et al., 2013; Björnsson et al., 2013)." The only outlet glacier with a mb series (measured in the accumulation and ablation area) that is included for comparison with the studied outlet glaciers is Hoffellsjökull, and the recently formed proglacial lake has affected the ablation considerably, and thus a direct comparison with measurements and the geodetic mass balance for the time period 2002-2010 would require a more detailed discussion.

P4700

L1-3: the ice volume...?? equals? What equals what? Give numbers! The mb numbers
C3064

that follow in L4 are not equal and if it is volume loss that equals it is not that relevant for different sizes. But maybe i misunderstand

Answer: This has now been clarified: "The ice volume loss (in km³) of the outlets of southeast Vatnajökull ~1890-2010 equals the ice volume loss of Langjökull and Breiðamerkurjökull during the same time interval (references)."

L7: very easily misleading: i assume you mean 25% in terms of mass balance. But the total mass loss will be very different. Reformulate and in this context i would stick to absolute numbers

Answer: The sentence has been clarified and now reads: "For comparison glaciers in the Alps have lost on average -0.31 m w.e. a⁻¹ since the end of the LIA (Huss, 2012), compared to -0.38 m w.e. a⁻¹ of the southeast outlets of Vatnajökull".

L9-17: write more concise.

Answer: The paragraph has been shortened and clarified. L19-21: this has to be changed. In my opinion you can't compare 'after 2000' with the 'mid-90s'. Be clearer about the periods and choose ones that are beyond the natural variability. Whatever is meant by mid-90s but a few years should not be used for such a conclusion.

Answer: Warmer temperatures after 1995, than in the preceding 2-3 decades (Fig.~2b) caused retreat of the southeast outlets, that increased after year 2000 (Björnsson and Pálsson, 2008, Björnsson et al., 2013).

L22: what would this LIA ELA mean in terms of AAR? Is that a common way to determine the ELA for the LIA? I am rather used to the AAR assuming a steady state but maybe that is just as good.

Answer: The text has been clarified and we have added a reference for this method: "the ELA during the LIA maximum has been inferred from the elevation of the highest up-valley lateral LIA moraines of the studied glaciers (Hannesdóttir et al., 2014), a method known as MELM (maximum elevation of lateral moraines, e.g. Hawkins,

C3065

1985).“

L27: 'spatial variability'

Answer: Geographical variability has been replaced with spatial variability.

P4701-P4702

L9: I think this part could be very much condensed. Basically you conclude that hypsometry is the governing factor for the variability in changes and not different climate.

Answer: Details of the response or the magnitude of volume loss is governed by the hypsometry (and overdeepenings and proglacial lakes), but the general response is governed by the climate. We have rewritten this section to make this point more clear.

L15, very long sentence, cut in 2.

Answer: We do not think the sentence should be divided into two and keep it unchanged.

P4703: 'deflation' very unusual in this context to me.

Answer: The word deflation has been replaced with downwasting.

P4704

L29 delete 'not'

Answer: This chapter has been deleted from the paper.

P4705

L15: -1.34m

Answer: We use mass change and a negative sign -1.34 m w.e. a-1.

L16: put overall relative area and volume change numbers and compare to for example the Alps.

C3066

Answer: We have added the mass loss of the European Alps and North Patagonian icefield for the same time period in the conclusion. "The glaciated area decreased by 164 km² (16%) in ~1890–2010, and the outlets collectively lost 60±8 km³ (22%) of ice, contributing 0.15±0.02 mm to sea level rise in the post-LIA period".

P4716

L13: range of the averages of all years? I dont understand that. The ela is from Modis derived, right? Which years?

Answer: The MODIS-derived ELA is now presented as the averages of the years 2007-2011 with the standard deviation.

P4717

add % for total values. Caption very long: remove for instance the sentence with the ice divides.

Answer: The % for total values have beend added and the caption has been shortened.

Fig8: could maybe be omitted? It is not referred to substantially.

Answer: Fig. 8 is now referred to more thoroughly as suggested by reviewer #2.

Fig13: is the AAR related to LIA max?

Answer: The AAR is related to 2010, but we have now also added the AAR for the LIA.

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C3067