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Interactive comment on "Post-LIA glacier changes along a latitudinal transect in the Central Italian Alps" *by* R. Scotti et al.

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Our replies are embedded in the referee's original comment. We wish to thank Philippe Deline for his insightful and constructive review. We hope that our replies are considered satisfactory.

Specific comments

1) On Fig. 3, 2012 extent is represented, while we read at p4082 L9-10: 'The most recent inventor(y) of glacial extent ha(s) been reconstructed from 2012 digital orthophotos'. But it is only p4095 L23-24 that we are informed that 2012 extent was realized for the three glaciers on which mass balance is surveyed since 2007. This should be corrected.

Comment accepted. We have addressed the issue by moving information on 2012 data information to section 3 “Data collection and methods” clarifying that 2012 data were collected for three glaciers only. We have added after p4082 L21: “Manual delineation of glacier limits on summer 2012 orthophotos (0.5-m pixel) was limited to three sample glaciers (Campo Nord (Livigno), Vazzeda (Disgrazia) and Lupo (Orobie)) (Fig. 1b).” and in p4083 L2: “The uncertainty associated with glacier area was evaluated for each glacier by setting a buffer of +/- 10m (LIA), +/- 5m (1954), +/- 2m (1990) and +/- 1m (2003,2007 and 2012) on the digitized glacier limits.”. At p4095 L23-24 the sentence: “(delineated on a 0.5-m grid orthophoto mosaic; planimetric uncertainty $\pm$ 1 m)” has been deleted.

2) By the way, the maximum glacier elevation in 2012 on Fig. 3 is higher than in 2003 and 2007, recovering the foot of the rock wall towering the glacier (Piz Paradisin). This suggests that this larger extension of the glacier top area is in fact due to snow field present this year at the moment of the photo shooting - as confirmed p4082 with remarks about the very limited snow cover in 2003 and 2007. It would be useful to shortly explain this in the caption of the Fig. 3.

The hypothesis put forward by the reviewer is correct. The slightly larger extension of the glacier top area in 2012 is due to a recently developed snow field. We have added relevant information in the caption of figure 3. We changed the caption of figure 3: “Example of multitemporal glacier delineation i.e., Campo Nord glacier (Livigno sub-region) with 2007 orthophoto in the background. The slightly larger extension of the glacier top area in 2012 compared to 2003 and 2007 is due to the presence of a snow-field developed after the 2007 season that was characterized by very limited snow cover.”

3) p4090 L8-10: ‘(: : :) in the Orobie we observe an opposite behaviour between 2003 and 2007, with Emin and Emax overlapping around a null elevation change rate (Fig. 9c), an indication of about volumetric stationarity.’ If (i) change in elevation rates is null, that is to say that top and front of glaciers do not change during the period 2003-2007,

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but (ii) the Orobie glacier surface area continues to decrease (AAD around 0.05 km2 a-1 as shown on Fig. 9c), therefore the total volume of these glaciers would decrease and not be stationary. Moreover, the very hot and dry 2003 Summer melted down ordinary perennial snow fields in the upper glacier areas, that reformed latter and were likely considered to be part of the glaciers in 2007. The huge Emax rate change from 1990-2003 to 2003-2007 is probably due to this bias.

We agree with the reviewer's take and we have modified the text as follows: "...in the Orobie we observe an opposite behaviour between 2003 and 2007, with Emin and Emax overlapping around a null elevation change rate (Fig. 9c). This stability in elevation range, in conjunction with a minor decrease in surface area, suggest volumetric shrinkage mainly caused by a reduction in glacier width".

4) p4091 L1-2: 'Interestingly, in the Orobie (: : :)' Explain what is interesting in the two mentioned observations.

According to the suggestions of shortening this section of the manuscript by Prof. Kuhn we have deleted the above mentioned sentence.

5) p4091 L3-25 and Fig. 11 Would have not been more relevant to compare the relationship between AAD and 'The elevation difference between the Erc and the ELA0', because as mentioned p4084 L17-19 this latter 'is considered to be correlated to both the degree of avalanching contribution to the glacier's mass balance and the shading effect of the rock walls upslope of the glacier', rather than the relationship between AAD and the Erc?

Preliminary note: we have changed the elevation of the ridgecrest abbreviation (Erc) with Eri according to Prof. Kuhn's suggestion (see point n°15 for further informations).

We have plotted AAD (the main dependent variable of our paper) against Eri (independent variable) because we were after a geomorphometry-based proxy that could provide a first-order explanation for the spatial variability of AAD: (i) between sub-regions;

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and (ii) within a sub-region, among glaciers characterized by different aspects. The advantage of Eri is that it represents a stable benchmark through time (LIA-2007). It turns out that Eri does a reasonable good job at constraining meaningful envelopes with AAD, yet highlighting the "anomalous" behaviour of the Orobic cluster.

We agree with the reviewer that testing the relation of Eri with ELA0 could lead to useful implications, but it would address a different research question, which is beyond the objectives of our paper. We have decided not to perform the Eri-ELA0 analysis, given that the Editor (Prof. Stokes) and the second reviewer (Prof. Kuhn) have both asked us to shorten the manuscript. In addition, such analysis would introduce a high degree of uncertainty. In fact, changes in ELA0 (due to glacier area adjustment) across our study period would generate high variability (error) in the Eri-ELA0 datapoints.

In the end, we could not compare the ELA0 with relative and absolute changes in glacier area because we were missing a reconstructed DEM of the LIA glaciers. While Emax and Emin at LIA can be derived with good confidence in the 2007 DSM (as we show in Figure 8), using the 2007 DSM as a topographic base for calculating LIA glacier extension would cause large elevation errors in the computation of the relevant ELA0 for single glaciers. Furthermore, since at LIA we used to have 87 glaciers that increased to 97 in 2007 due to fragmentation, we cannot use the 2007 Eri-ELA0 values to perform a rough comparison with changes in glacier area, as we would need to refer to the former 87 sample. One could sum up the glacier area of the disaggregated glacier to obtain the glacier change since LIA but what would be the meaning or the glaciological significance of an average ELA0 calculated from a number of fragmented glaciers?

6) p4094 L3-5: 'In order to partly solve this issue and conduct a more sound comparison of our results with other inventories, we consider the AAD values associated with the 1860–1990 and 1990–2007 periods.' Would have not been more relevant to compare the three periods: 1860-1954 (trend of a negative mass balance), 1954-1990 (positive mass balance), and 1990-2007 (negative mass balance)?

We decided to aggregate the 1860-1954 and 1954-1990 periods mainly for two reasons: 1) The very small change in glacier area in the 1954-1990 period is small enough to fall within the envelope of uncertainty in Disgrazia and Orobie sub-regions as discussed in p4087 L3-9. 2) Data on the LIA-"∼1970-90" period are much more widely available in the recent literature compared to the LIA-"∼1940-50"period, thus allowing us to compare our findings with other regional studies conducted elsewhere (e.g., Paul et al., 2004; Gonzales Trueba et al., 2008; Gardent and Deline, 2013). It is worth mentioning that our temporal aggregation has been done only for discussion purposes and that disaggregated data are available in Tables 3, 4 and S2.

7) Section 5.3 p4095-4096 and Fig. 12 & 13: caption of Fig. 12 indicates that 'Specific mass balance data are measured with two ablation stakes placed across the ELA0 of each glacier' But how consider that these two ablation stakes (5 on the Fig. 3) are representative of the specific mass balance when they are located at the theoretical ELA (the ELA0), that can be very far from the actual annual ELA? Therefore, the data is surface mass balance at the location of the stakes, not specific mass balance of the glaciers.

We realize there has been a misunderstanding, with the term "specific mass balance" we refer to the surface mass balance at the location of the stakes. In the revised manuscript we have replaced "specific mass balance" with "point mass balance" as suggested by Cogley et al. (2011). At page 4095 (line 25) of the revised manuscript we clarify that the mass balance under consideration does not refer to the whole glacier. We have modified the text as follows: "In particular, the relevant winter and summer point mass balances, measured averaging the data of two ablation stakes across the ELA0 (Figs. 3, 12 and 13) even though referred to three glaciers only, are useful to infer the mechanisms responsible for the differences in glacier retreat observed along our transect (Table 4 and Figure 7)." Despite of this methodological limitation, we are confident that in the three study glaciers, even in years with large discrepancy between ELA and ELA0, the point mass balance measured across the ELA0 is still a reliable

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proxy of the mass balance of the whole glacier. For example, at Campo Nord glacier (Fig. 3) when comparing the mass balance for the whole glacier in 2010-2013 (based on the data of the 5 stakes illustrated in Fig. 3) with that reported in the manuscript (i.e., stakes P3 and P3bis only), the annual difference between the two methods does not exceed 0.53 m w.eq (i.e., worst scenario in year 2012). Most importantly, the "two-stake" annual overestimation is consistent so that the seasonal trend is preserved through time (see figure 1 attached to this reply).

8) And finally, a more general comment: as glaciers are becoming smaller and smaller through the period 1990-2007, each m2 of surface area that is lost represents a larger and larger % of AAD. Then, what is the significance of the AAD expressed in % (see e.g. Fig. 7b), especially for small to very small glaciers?

We are aware of the significance of this issue, however, we think that using the relative changes in glacier area is the only appropriate way to compare the effects of climate forcing on glaciers from different regions. To partly address this issue, we report relevant absolute values in area change (in Km2) for every comparison and calculation made (see Figs. 7a, 9 and Tables 3 and S2).

Technical corrections

9) p4085 L10-13: 'W m2' has to be corrected with 'W m-2'

Comment accepted, the text has been changed accordingly.

10) p4086 L20: replace 'apex' by 'acme'.

Comment accepted, the text has been changed accordingly.

11) p4090 L14: explain what is the 'glacier relative relief' (to do in Section 3, p 4083-4084, as for other attributes). In contrast, p 4091 L4-5: '(i.e., the elevation of the ridgecrest located upslope of the glacier)' is not necessary as Erc has already been explained in Section 3.

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We consider the term “glacier relative relief” as the glacier elevation range (ΔE) calculated as the difference between Emax and Emin of the glacier. We have clarified this statement and have changed “elevation range” with “glacier relative relief” in section 3 p4083 L10 and p4084 L3. We have deleted the sentence in p 4091 L4-5.

12) p4093 L17-18 : correct the AAD values in this sentence ‘(: : :) Les Ecrins (AAD = 0.45% a-1; MAP 1200–1400 mm a-1), the Mont Blanc (AAD = 0.25% a-1; MAP 1400–2000 mm a-1), and the Vanoise (AAD = 0.20% a-1 (: : :)’ with: ‘(: : :) Les Ecrins (AAD= 0.38% a a-1; MAP 1200–1400 mm a-1), the Mont Blanc (AAD = 0.15% a-1; MAP_1400–2000 mm a-1), and the Vanoise (AAD = 0.39% a-1 (: : :)’, as indicated Tab. 4p. 49 in Gardent & Deline (2013).

We have corrected the values in the revised manuscript.

13) p4093 L17: complete ‘(: : :) the Mont Blanc (: : :)’ as follows: ‘(: : :) the French side of the Mont Blanc (: : :)’

The text has been changed accordingly.

14) p4093 L19: correct ‘Gardet and Deline, 2013)’ with Gardent and Deline, 2013)’; same correction to do p4095 L15 and p4103 L8.

The text has been changed accordingly.

15) p4094 L12: correct ‘his’ with ‘this’?

Comment accepted, the text has been changed accordingly.

16) p4098 L2: add ‘(Fig. 11c)’ at the end of the sentence.

Comment accepted, the text has been changed accordingly.

17) p4100 L2: correct ‘: : :(SGL). A non-profit (: : :)’ with ‘: : :(SGL), a non-profit (: : :)’.

Comment accepted, the text has been changed accordingly.

18) p4103 L8: correct ‘francersi’ with ‘francesi’.

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The text has been changed accordingly.

19) p4106 L4: correct ‘Radic’.

The text has been changed accordingly.

20) p4113: correct ‘(see Fig. 6)’ with ‘(see Fig. 4)’.

The text has been changed accordingly.

21) Supplement p1: in Supplementary Table S1, add ‘(n)’ or ‘(number of glaciers)’ as unit to ‘ABR’.

The table has been changed accordingly.

22) Supplement p4: in Supplementary Figure S1, line type used for Livigno on charts is different than in the caption.

The line type in figure S1 has been corrected.

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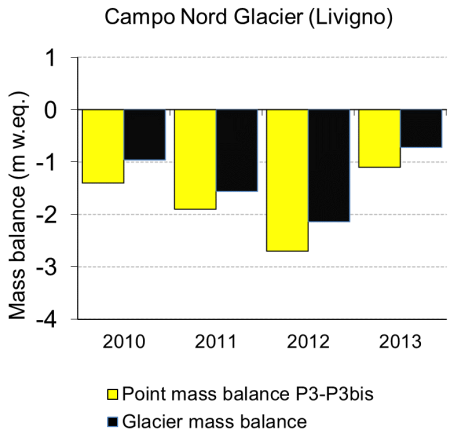

Figure 1. Campo Nord: Glacier vs Point mass balance (2010-2013).

Fig. 1.

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