We would like to thank the anonymous reviewers and Mauri Pelto for their careful and constructive reviews of our paper. In response to their suggestions, we did the following main changes to the manuscript:

1) Methodological clarifications have been implemented in Section 3.3

2) The direct mass balance series has been validated testing whether the difference between the direct and the geodetic method is statistically significant, according to the methods and recommendations reported in Zemp et al., (2013)

3) Clarifications on the calculation of the volume response time were added in Section 5

4) A discussion has been added about the current spatial representativeness of the Careser glacier, including a new table reporting the correlation coefficients calculated from the specific annual balances of Careser Glacier and other 15 glaciers in the Alps in the period from 1981 to 2010

5) Table 1 has been modified adding a new column with the mean error; a new column has been added in Table 3 reporting the glacier area used for mass balance calculations; error bars have been added for the cumulated mass balance values reported in Table 3

6) Figures have been edited as suggested. In particular ablation stakes were added in Figure 6, an inset table was added in Figure 8a, the direct curve was overlapped to the geodetic curve in Figure 8b, and the scale bars and north arrow were added to the Figures 6, 7, 9, 10, 11 and 13.

7) we implemented the suggested changes and answered to the specific comments made by the reviewers, as detailed in the following of this document. The comments are reproduced in italic while the authors responses are reported right below. Line and page numbers are referred to the discussion paper.

Reply to the Interactive comment by M. Pelto

Specific Comments:

MP1) 3302-7: What percentage of the stakes have been abandoned?

Ok, rephrased. Figure 6 has been modified to show the location of ablation stakes in 6 different dates.

MP2) 3304-15: How has the elevation of the snout changed from 1897 to 1933 and 1933 to 1961?

Information on the snout elevation have been added where requested and, in addition, throughout the Section 4.1.

MP3) 3304-17: When did the nunatak first develop?

Unfortunately we do not know the exact year of formation of this nunatak. We could only assess that it outcropped in the period from 1959 to 1969. Added in the text

MP4) 3304-27: This comment could be addressed either here or later near 3310-14. Pelto and Hedlund (2001) in a study of North Cascade glaciers noted that a group of glacier that did not advance, similar to Careser Glacier, were those with a slow response time and were still adjusting to the post Little Ice Age climate. There are glaciers with similar histories and characteristics in the Alps with terminus records ie: Cavagnoli, Calderas, Gran Desert, Paradies in Switzerland, and Lobbia or Sforzellina Glacier in Italy. A comparison to Sforzellina Glacier, Cannone et al (2008), would be ideal since there is mass balance and terminus data for this glacier as well.

The work by Pelto and Hedlund (2001) has been cited in section 5 (Discussion), highlighting the physical characteristics which link Careser glacier to the group of glaciers in the North Cascades which behaved similarly. We prefer to avoid mentioning individual Swiss glaciers, which would require the knowledge and discussion of their past behaviour and physical characteristics. Lobbia and Sforzellina actually advanced during the 1970-1980s, therefore their behaviour was different from that of Careser glacier. Moreover, the mass balance series on Sforzellina glacier started in 1987, when the last re-advance of the Ortles-Cevedale glaciers was almost ended.

MP5) 3306-10: The AAR of 0 indicates a lack of an accumulation which a glacier cannot survive without (Pelto, 2010).

Better specified in Section 5, where the suggested reference has been reported.

MP6) 3310-6: The response time of 35 years is based on the ablation rate and glacier thickness? This response time represents the adjustment to 2/3 of the total climate response as defined by Jóhannesson et al. (1989), is that why the correction from Braithwaite and Raper, (2009)?

We have better specified how the response time of 35 years has been calculated. The volume response time calculated by Equation 3, proposed by Jóhannesson et al. (1989), is based on the assumption of a glacier of unit or uniform width with all area changes at the terminus. The correction factor proposed by Raper and Braithwaite, (2009), allows the mass balance-elevation

feedback associated with both the area reduction and lowering of the glacier surface to be accounted for. Better explained in the text.

MP7) 3310-28: There is limited loss of glacier area up to 1980 at a higher elevation indicating a glacier that may have been adjusting to climate change. The maps from 1933-1980 indicate even some areas of thickening at the top of the glacier during some periods. After 1980 the high elevation changes are dramatic indicating disequilibrium response. This is further corroborated by the AAR record which becomes 0 with frequency in 1980. This indicates an important change from an equilibrium response to a disequilibrium response.

These considerations have been added in Section 5.

MP8) Figure 9: At what point are the five stakes in the four separated ice masses discontinued in the Careser Glacier mass balance assessment?

These stakes have not been discontinued. After the separation of the parent glacier into several ice masses, started in 2005, the mass balance calculations have been still performed assuming the glacier as a whole. Clarified in the text (Section 3.3).

Reply to the Interactive comment by Referee 1 (anonymous)

R1-1) Throughout the manuscript it is emphasized that the Careser series is highly valuable. But at the same time it is clearly shown that Careser Glacier is not at all representative for the region. Region-wide geodetic surveys showed that the Careser mass balances are more negative than for all other glaciers. This is explained by the authors with the particular topographic setting of the glacier. With the future decay of the glacier, the representativeness of the glacier will further decrease. For how many more years does it make sense to continue the measurements on Careser? And what might be the implication on the interpretation of Italian glacier mass loss in general, if this series exhibiting more negative balances than in the regional mean is abandoned? I suggest that the authors clearly comment on the issue of representativeness, and better point out the full value of the series in view of the regional glacier behaviour. In particular in connection with the projections of future glacier decay providing a detailed discussion and a time-scale for the potential continuation of the series might be very helpful. Also because several other mass balance series will be facing the same problems in the next years.

Many thanks for highlighting these key points. A discussion about them has been added at the end of Section 5. We also added Table 4, which reports the correlation coefficients calculated from the specific annual balances of Careser glacier and other 15 glaciers in the Alps in the period from 1981 to 2010, in order to explore the issue of representativeness.

Specific comments:

R1-2) page 3299, line 14: It would be helpful, if the years for which maps are available were also mentioned in the text.

Ok, added in brackets few lines above.

R1-3) page 3301, line 7: The uncertainty is given in terms of a RMSE. It would however be important to state both the RSME (stochastic uncertainty in the DEMs) and the systematic differences. If the mean error with the ground control point is significantly different from zero this might indicate that the whole image is shifted vertically, and thus the calculated geodetic balances are systematically wrong.

Thanks for rising this important issue. The mean errors and an explanation of their handling have been added in the text and in Table 1.

R1-4) Page 3302, line 15: Here and elsewhere: It is not quite clear what has been done / added in this study, and which results are already available from previous studies. In terms of the re-analysis of the whole series presented in this paper, it might be useful to re-compare geodetic and glaciological series (see e.g. framework in Zemp et al 2013, TC) and not just to qualitatively state published findings.

Ok, explanations have been added where suggested and also at the beginning of Section 3.3. A reanalysis was carried out comparing geodetic and direct mass balance series during the entire period of overlap. Clarified in the text.

R1-5) Page 3303, line 12: Please be more specific here. What is the misfit at cross-over points?

Ok, clarified and information added.

R1-6) Page 3304, line 15:Is there a reason for the very strong retreat in a short time? Dead ice no longer counted as glacier? Topographic step?

Topographic step, added in the text.

R1-7) Page 3305, line 15: Why "constantly"? The DEMs do not cover decadal periods with glacier mass gain, but the long-term rate of loss is not at all constant.

Ok, rephrased.

R1-8) Page 3305, line 25: See also comment above. Please be more quantitative here. The meaning of the value 0.1 m w.e. is not entirely clear. Provide comparisons of geodetic and glaciological surveys besides the overall period also for the individual DEM periods, and state the differences.

Ok, the differences between the two mass balance estimates have been reported also for the individual DEM periods.

R1-9) Page 3306, line 13: You probably mean "elevation loss" instead of "melting" here.

We mean net ablation, rephrased.

R1-10) Page 3307, line 8: Is there actually an overdeepening in the bedrock? From the last Figure it is clear that there's a confined area of maximum thickness, but with no clear "hollow" in the bedrock as stated here.

Ok, reformulated.

R1-12) Page 3307, line 21: Holocene

Ok, corrected

R1-13) Page 3308, line 28: I cannot quite follow this explanation – please clarify. Furthermore, I do not agree that cumulative / or mean mass balances are used for comparing glaciological and geodetic surveys. It would be much more robust to compare absolute volume (or mass) changes. As the glacier area changed quickly and probably non-linearly during the last period, the area over which the glaciological method is integrated is of major importance to calculate cumulative mass changes from the direct glaciological method. If the area is kept constant (on the 2000 extent) it is not surprising the direct method is too negative.

The rapid change of the area in the last period has been taken into account in direct mass balance evaluations, by updating the calculation area more frequently than in the past. This is now better clarified in Section 3.3. Consequently, the mentioned sentence in Section 5 has been removed, also because the difference between the geodetic and direct methods is almost equivalent to that in the period from 1980 to 1990. As suggested in a following comment (R1-18), we added the calculation areas for each year reported in Table 3. Volumetric changes have been also added in the text (Section 4.2).

R1-14) Page 3310, line 6: the multiplication of the glacier response time with the factor 2.9 given by Raper and Braithewaite (2009) is quite difficult to understand but is relevant for the conclusions that the authors draw from their results: only with using this correction factor the response time of Careser reaches the century time-scale (which in my opinion is exaggerated). The authors conclude that Careser is still dissipating its Little Ice Age thickness based on their very long calculated response time. Some additional argumentation is needed here: How robust is the correction factor? Is it applicable to different glacier types and sizes? How exactly is it motivated. In particular, it might be useful to compare the calculated response time to other published values for alpine glaciers. For example Oerlemans (2009, JG) / Oerlemans (2012, GA) finds much smaller response times for glaciers that are quite a bit larger than Careser (partly less than a decade!)

Motivations for the use of the factor 2.9, rising from the simplifying assumptions made by Jóhannesson et al. (1989), have been better explained in the text. A sentence describing the robustness of the numerical factor and its applicability to glaciers of different sizes has been added. We also added works by Oerlemans (1997 and 2001) and Harrison and Others (2003), which emphasize the underestimation of the response time by the method of Jóhannesson et al. (1989), when the slope of the glacier is small and the altitude–mass-balance feedback becomes important, like for the Careser glacier.

R1-15) Page 3311, line 2: The authors might consider citing Huss et al (2012, JG) here who discuss the two opposing effects mentioned here in some detail for a large sample of alpine glaciers with different morphology.

The citation and a short sentence on the compensating effect of thinning vs. retreat have been added.

R1-16) Page 3311, line 10: When looking at the figures and tables it is really striking to me that in about 1981 a very clear regime shift occurred. Before the glacier often had an accumulation area, whereas after this date almost exclusively ablation took place. What has happened in this year? Several papers document this regime shift for other parts of the Alps, and might be discussed here: Marty, 2008, GRL; Eckert et al., 2011, JG; Thibert et al., 2013, TC.

The regime shift for some long-term monitored glaciers in the European Alps has been exemplified by adding some references.

R1-17) Page 3312, line 28: "series of SEASONAL mass balance measurements". This seems to be important to me because very few long-term series are seasonal.

Ok, added, thanks for this suggestion.

R1-18) Table 3: It might be good to provide the area that was used for evaluating the glaciological mass balance for every year. Only if this information is provided cumulative ice volume changes can be calculated that can be compared to the geodetic surveys.

Ok, done. Please, see also the response to comment R1-13 for further details.

Reply to the Interactive comment by Referee 2 (anonymous)

R2-1) The paper is a comprehensive account of surface mass balance measurements between autumn 1966 and autumn 2012 at Careser Glacier in the Italian Alps. The principal product of the paper is a table of glacier-wide annual values of winter B_w, summer B_s, and annual B_a surface balance. The paper should note that these are evolving-surface values, not reference-surface values; see Elsberg et al. (2001).

Ok, explanation and reference added in Section 3.3.

R2-2) The paper deals with surface mass balance and should state this clearly. See page 7 of Cogley et al. (2011) concerning other components.

Ok, emphasized in Section 3.3.

R2-3) Notably lacking is any information about uncertainties in the tabulated glacier-wide balances. The cumulative B_a values in the table should be augmented to show the width of the uncertainty band as it grows from 1967 to 2012.

Error bars have been added in the column of the cumulative B_a.

R2-4) An evolving-surface mass balance series convolves effects of climate with effects of changing glacier geometry. A possible way of separating these effects and obtaining a series containing mainly climate effects would be to construct a $b_a(z)$ profile for each year and interpolating in it at the same altitude every year. The paper gives very little information on the spatial distribution of point values of b_a, so it is hard for me to tell whether this is feasible. If so, such values would be a valuable addition to Table 2. Whether or not it is feasible, the paper would be improved were it to give more details on the distribution of original balance measurements.

According to this suggestion, the spatial distribution of the ablation stakes in various years has been added in Figure 6. In our opinion, the large geometric changes experienced by the Careser glacier since the beginning of the mass balance series hamper the construction of a series containing mainly climate effects, according to the proposed method. Indeed, the recorded $b_a(z)$ profile was likely much affected by the geometric changes and by the nearly complete disappearance of the central and western parts of the glacier. For example, while the 3050-3100 elevation band is now almost entirely in the eastern part of the glacier, rather flat and with a mean western exposure, in 1967 (at the beginning of mass balance measurements) it was largely extended to the central and western parts of the glacier, more steep and with a south-eastern exposure. Only applying a distributed mass balance model it would be possible to take the effect of these changes into account, which however is not the aim of this paper and would introduce elements of uncertainty

R2-5) Because the bed topography is known under only part of the glacier (3303,14) the statements implying that it is known for the entire glacier (3295,8 and 3307,16 and 3312,8) should be reconsidered.

Ok, rephrased in Sections 4.3 and 6 using the words 'estimated' and 'estimates'.

R2-6) 3293,3 Current glaciological usage would be 'Careser Glacier' not 'the Careser glacier'

Ok, modified throughout the paper.

R2-7) 3295,10 adding to the mass balance record into the past using the geodetic method, because the geodetic method does not provide direct observations.

Ok, reformulated.

R2-8) 3295,12 Mass losses were 1.5 and 2.0 m w.e. per year, not -1.5 and -2.0 because a negative loss is a gain.

Ok, corrected.

R2-9) 3296,6 Clearly variations of glacier length are an indirect and delayed response to climate variations, but how they enhance the signal is not clear.

As reported in Haeberli, 1995 (citation in the text), the geometric adjustment of a few tens of meters in thickness is 'amplified' by a length change of hundreds or thousands of meters. Explanation added for clarity.

R2-10) 3296,15 Continuation of these series depends on financial and organizational circumstances, not on rapid environmental change.

Ok, rephrased.

R2-11) 3297,21 I know no precedent for referring to non-contiguous regions as a single glacier.

We decided to refer to a single glacier, given the current rapid disintegration of the parent glacier into small parts, which in most cases are remnants which could not be mentioned as separate units or 'glaciers'.

R2-12) 3297,26 Should Fig. 1 show an outlet from Careser Lake whereby the Rio Careser drains into the Noce River?

Ok, the figure has been edited.

R2-13) 3299,14 Could the exact dates of the surveys be given in Table 1, not just the year?

Unfortunately we do not know the exact dates of 3 out of 7 surveys. We only know by personal communications that they have been carried out at the end of the ablation season, with minimum snow coverage, as reported in Section 3.2.

R2-14) 3299,17 *too little accuracy*

Ok, corrected

R2-15) 3299,26 Should UTM coordinates be shown on Fig. 1?

We prefer to keep the geographic coordinates, as in our opinion they allow a more immediate understanding of the localization of the study area.

R2-16) 3300,12 Δt would be better than t to denote the length of a time interval, following the use of Δ for changes to other variables.

Ok, modified.

R2-17) 3301,25 The paper should describe the method and accuracy of using the "index values", which has been shown to be successful for other glaciers (see, for instance, Rasmussen and Andreassen (2005) J. Glac 51(175) 601-606).

Available details on the methods have been included. The suggested reference has also been added.

R2-18) 3302,24 'consisted of' not 'was comprised of'

Ok, modified.

R2-19) 3303,9 'maximum accuracy' would be better stated in terms of the error or uncertainty.

Ok, modified.

R2-20) 3303,14 The area of the subglacial topography determined by GPR should be stated. From Table 2 the total glacier area at the time of the surveys appears to be about 2 km^2.

Ok, added in brackets.

R2-21) 3304,29 'deglaciation' would be better than 'consumption of'

Ok, modified

R2-22) 3305,9 The 3.82 km^2 loss since 1933 implies that the area in 2012 was 1.63 km^2. If the area-altitude profile cannot be shown in Table 2 for any years after 2006, at least the total area can be.

We prefer to report the 2012 area in the text, while speaking about the % area loss from 1933 to 2012, rather than adding a column in Table 2 reporting only the total area of the glacier.

R2-23) 3305,19 'emergence'

Ok, done.

R2-24) 3307,16 This implies V (1933) = 324x10^6 km^2, which should be stated.

Ok, added in brackets.

R2-25) 3307,21 'Holocene' in English.

Ok, corrected.

R2-26) 3308,10 Briefly define drainage glacier and reservoir glacier, neither of which is in Cogley et al. (2011).

Ok, definitions added in brackets.

R2-27) 3309,15 Better than comparing it with the mean would be comparing its difference from the mean with the standard deviation of the set of 111 glaciers.

Ok, added.

R2-28) 3310,4 In Eqn (3) it is the mass balance rate b_t that appears, not the mass balance gradient, so the relevance of the gradient is not apparent.

Ok, clarified.

R2-29) 3310,13 A reference on the LIA in the Alps should be supplied.

Ok, modified and reference added.

R2-30) 3311,10 Switching back and forth between 'elevation' and 'altitude' is distracting and might make some readers wonder whether a distinction is being made. Of the two terms, I prefer the one contained in the term area-altitude profile.

We agree on the need of consistency throughout the paper, but we prefer the term 'elevation'. Checked and modified.

R2-31) 3311,15 How the projections to 2020, 2040, 2060 were obtained should be described more clearly.

Ok, rephrased and better explained to improve clarity.

R2-32) 3312,10 The 1959-1980 period would be better described as having only slightly negative balance (Fig. 8b) instead of having reduced imbalance.

Ok, modified.

R2-33) 3312,28 It would be useful here to say how many programs are longer than the one for Careser Glacier.

Only 22 glaciers have longer (continuous) time series of measurements. Clarified in the Introduction.

R2-34) 3320 Table 1 would be enhanced were it to have one more column giving the mean value over each interval, numerical expression for the values shown in Fig. 8a.

The numerical values have been added as an inset table in Figure 8a.

R2-35) 3322 The quantities in the first three columns of Table 3 are glacier-wide averages of surface mass balance: winter, summer, and annual (not net). See Cogley et al. (2011) regarding terminology. The meaning of "index" values should be briefly explained in the caption. An uncertainty band is needed for the last column.

Ok, modified accordingly.

R2-36) 3325 Panel a) shows snout position relative to its 1897 position. Panel b) shows variation of area since 1933. The caption should say that the length in 1897 was 3.8 km (3308,8).

Ok, modified accordingly.

R2-37) 3330 The caption should say that in the lower panel, which should be labeled b), the curves are defined to have zero value when they begin, 1933 for the geodetic and 1969 for the direct. Plotting the direct curve so that it began in 1969 with the interpolated value of the geodetic curve then would emphasize similarity between the two curves after then. Larger tick marks every ten years would make Fig. 8 more readable.

Ok, modified accordingly.

R2-38) 3334 Instead of labeling the middles of the intervals 2675, 2725, ..., 3325 it would be better to label their endpoints 2650, 2700, ..., 3350. This would not only be graphically less cluttered, but also it would avoid the subtle implication that the quantity applies to a single altitude rather than to an altitude interval.

Ok, modified accordingly.

Reply to the Interactive comment by Referee 3 (anonymous)

Technical corrections

R3-1) 3295, 6, 'records'

Ok, corrected

R3-2) 3296, 27 and 3297, 7, replace 'series' with 'sites'

Ok, rephrased

R3-3) 3300, 9, please explain what is meant by 'over the largest area'

Ok, clarified.

R3-4) Page 3300, justify the use of density values of 900 kg m^{-3} and 600 kg m^{-3} for ice and firn, respectively.

Ok, citation added.

R3-5) 3304, 29, replace 'consumption' with 'loss'

Replaced with 'deglaciation', as suggested by Referee #2

R3-6) 3307, 21, do you mean 'Holocene' rather than 'Olocene"?

Yes we do, corrected.

R3-7) 3307, 24, replace 'concause' with 'cause'

We think that 'concause' is more appropriate, because the main cause of the lack of morainic deposits was the lack of snout re-advances in the analyzed period. Rephrased to improve clarity.

R3-8) 3308, 20-26, split this very long sentence into 2 or 3 shorter sentences

Ok, modified accordingly.

R3-9) Figure 1, make the lat/lon labels larger on the upper panel and the text on the lower panel needs to stand out more clearly against the background.

Ok, modified accordingly

R3-10) Figure 8 caption, replace 'above' with 'upper' and 'below' with 'lower'

The two figures have been labeled with a) and b).

R3-11) Figure 10 caption, replace 'above' with 'upper'

Ok, modified accordingly

R3-12) Figure 11, the line labelling needs to be clearer using larger or darker font

We will carefully check readability once we have the final layout.

R3-13) General point: most of the figures are lacking a scale.

Scale bars and north arrows have been added where needed.