Review comments on :

Analysis of the mass balance time series of glaciers in the Italian Alps
by L. Carturan and co-authors, manuscript tc-2015-182
The Cryosphere Discuss., 9, 5849–5883, 2015

General comment

L. Carturan and co-authors provide analysis of glacier-wide mass balance times-series for 9 glaciers in the Italian Alps covering a period of record from 10 to 47 years. The link of the mass balance variations to temperature and precipitation chronicles is then investigated. Annual balances are reasonably reported to be highly connected to winter (October-to-May) precipitations and summer (June-to-September) temperatures. For the longest available records, the increase in mass loss observed since the 1980's is related to the warming and lengthening of the ablation season. Changes in correlations between mass balances and summer temperatures/winter precipitations is interpreted as possible milder accumulation seasons in the last years of the time-series, but the changes in glacier topography in response to climate cannot be ruled out.

The main value of this paper is to gather the longest mass balance records available in the Italian Alps and to propose a joint analysis. Moreover, I find the examination of the changes in correlation interesting as climate cannot be assumed in steady state in the time series analysis. Nevertheless, the authors hardly achieve in drawing new and firm conclusions on how the regional and larger-scale climate drives glacier mass changes. Despite the reported material is instructive and of quality, the paper is not enough innovative, and below and in my substantive comments I have suggested some way to strengthen it. I have three key suggestions below.

Despite mountain glaciers being recognised as excellent indicators of climate change, this paper demonstrates once again that inferring the climatic signal from a glacier mass balance series is not an easy task:

1°) A first reason is the intrinsic limit of glacier-wide balance series which includes both the climate signal and the effect of the changing glacier topography in response to climate. A time signal free from geometry changes and site effects should be first extracted from the series before investigating the potential link with the climate.
2°) Secondly, the time-structure of the extracted temporal signal should be analysed quantitatively to detect trends, change point in mean and variance with appropriate empirical statistical tests, or modern and advanced treatment like Bayesian inference.
3°) Third, the authors should take advantage of the stratigraphic-floating date system to analyse how the ablation duration may have changed from year–to–year; and subsequently derive the rates in ablation which is a way to quantify surface energy fluxes responsible for melt.

Different issues can be addressed to extract the climate signal:

- The issue raised by Elsberg and others (2001) of computing a mass balance referred to a constant topography. This requires the time change of the area and elevation of the glacier surface.

- Use point balances as adopted by Huss and Bauder (2009), or Vincent et al., (2004) which removes the effect of the surface change but still requires accounting for the lowering of the surface elevation of the glacier.
- Adopt a variance decomposition to separate the overall annual effect from the spatial variability at the glacier surface (Lliboutry, 1974; Rasmussen 2004; Eckert et al., 2011); this requires also accounting for elevation changes.

Points/limitations of minor extent are:
- Meteorological series are reconstructed locally from a linear composition of climatologies (constant spatial fields) and anomalies (uniform temporal deviations). Implicit is that spatial fields are stable in time and that the climate is in steady state which is a strong hypothesis.
- Time-series in glacier-wide balance should be controlled and if necessary homogenized by the geodetic method (photogrammetry, laser scan or lidar altimetry) to discard any bias/trend that may corrupt the time signal and its link to climate.
- Quantifying the link with NAO for the selected glaciers will be innovative.

There follow several detailed questions, comments, suggestions, and indications of minor flaws in the paper.

Substantive comments

P5850-L22. This is true for glaciers at the melting point. For cold and polythermal glaciers, the atmospheric conditions (atm. temperature and precipitations) control the thermal regime (Hoelzle et al. 2011; Gilbert et al., 2012), and the mass balances of those glaciers are not directly connected to climate (see e.g. Vincent et al. 2007).

P5851-L5. Use here and elsewhere in the paper the terminology "glacier-wide balance" as proposed by Cogley et al. (2011) to whom you refer appropriately.

P5851-L17. I would propose to add at the end of the sentence "reviewed and analysed jointly."

P5851-L22. It is not clear to me what non-linearity means here. Should the link between climate and glacier mass changes be a linear relationship? Is it rather meant that you are in search of a rupture (in mean or variance) in the mass balance time-series?

P5852-L6. Have the mass balance records been controlled by the geodetic method and eventually calibrated as recommended by Zemp et al. (2013)?

P5854-L13. In search of the max/min for the winter and annual balances, the time system in which the mass balances are measured rather refers to the stratigraphic system. An important implication of this floating-date system is the opportunity to retrieve summer ablation duration and rates, and analyse how these may have changed from year to year along the record.

P5854-L16. Regarding error estimations of glacier-wide balance measurements, if not based on a throughout analysis for each mass balance record, I would recommend to use the value of 340 mm w.e. yr^{-1} provided by Zemp et al. (2013) from a data set of 14 glaciers in Europe.

P5854-L19-to- P5855-L19. I understand that this method is basically a linear variance decomposition between space and time effects in weather data. This is a strong hypothesis at it assumes a steady state climate, i.e., steady spatial gradients along the analysed period. It would be interesting to validate this assumption at, at least, a site in the vicinity of one of the studied glaciers where a long record is available from a mountain weather station by a comparison with the reconstructed temporal series. Note that further in the paper, only correlations are in search in the time deviation signal. Then if the absolute (local mean) of the reconstructed time series is biased, it won't affect the correlations.

P5856-L15. Here the limitation I mentioned in the *general comments* is critical. Glacier-wide, i.e. surface-integrated (averaged) balance series provided by WGMS are convolutions between climate signal and glacier geometry changes in response to climate (refer to e.g. Elsberg et al., 2001). This results in two main opposite feedback for retreating glaciers that concerns this study: ablation areas of strong negative budget are removed from the average balance, tending to make it less negative. Oppositely, a lowering of the glacier surface tends to force the surface energy balance in relation with altitudinal gradients. How these 2 feedbacks may or not compensate each other depends on each glacier (Huss et al., 2012), but generally contribute to an additional (non climatic) trend in the series. It is not clear how these 2 effects are to be differentiated in the present analysis. I would proposed to use a mass balance referred to a constant topography (Elsberg et al., 2001) or analyse point mass balances (Huss and Bauder, 2009; Vincent et al., 2004) or temporal signals retrieved from them using variance decomposition (Lliboutry, 1974; Rasmussen 2004; Eckert et al., 2011).

P5856-L18. I would propose to add sub-sections in the 3.1 section to make distinct analyses of B_a, B_w and B_s time series.

P5856-L23. How do you detect quantitatively the change point in the B_a time series? Do you use a statistical tests such as Mann-Kendall, Mann-Whitney or Pettitt tests?

P5857-L13. A winter balance abrupt change point (+23%) has been detected in 1977 in the western Alps (Eckert et al., 2011), and is representative of a regional change in winter precipitations in the French and western Swiss Alps (weather data: Durand et al., 2009ab; glacier winter balances change point 1974-76: Aletschgletscher, Valais-Switzerland, Huss and Bauder, 2009; Sarennes gletscher, France, Thibert et al., 2013;). Do you detect such a change point in your winter mass balance records?

P5857-L15. Even when the AA has disappeared, the winter accumulation still controls the snow-to-ice transition date and influences the summer balance (due to the albedo feed-back). The way B_s is correlated to B_w at Careser Glacier before/after 1981 may help to quantify this.

P5858-L2. "…the decrease in the glacier-average albedo…". Don't you suspect any changes in the debris cover and any albedo change of the ice?

P5858-L12. How B_w correlates with October-May precipitations?

P5858-L19. Can you quantify the effect of the lowering of the surface in that B_s trend?

P5860-L3. Are B_w and B_s significantly correlated? I would add a column in Table 4 with the B_w-to-B_s correlation coefficients for each glacier.

P5860-L11. As proposed for section 3.1, a divide in 2 sub-sections for temperature and precipitation times series may help to structure and clarify the analysis.

P5860-L20-22. As proposed for the mass balance time-series, you should base your detection of change point on a statistical test.

P5860-L23. As the measurements are performed in the floating-date system, could winter precipitations be cumulated according to measurement dates at each glacier, and summer temperatures as well?

P5861-L6-21. The link between mass balance seasonal terms and large scale NAO variable is unfortunately not investigated here but deserves an analysis. How the changes in the different seasonal mass balance terms are controlled by larger-scale synoptic variables remains an open question as contrasted results from bibliography are still hard to interpret. Significant relationships are indeed reported for annual mass balance in Scandinavian glaciers and Svalbard (e.g. Fealy and Sweeney, 2005), with nevertheless substantial differences between northern and southern Scandinavia (Marzeion and Nesje, 2012). For Alpine glaciers, the reported correlation is rather weak for annual balances (Reichert et al., 2001; Six et al., 2001) and decreases from positive to negative as one goes from the eastern to the southwestern Alps (Marzeion and Nesje, 2012). For the French western Alps, Durand et al. (2009b) do not find any correlation between winter/annual NAO anomalies and winter precipitations. Regarding winter balances, Thibert et al. (2013) achieve to the same conclusions at Sarennes glacier (French Alps). Only significant correlations emerge for December to February NAO anomalies, and surprisingly only with the summer balances.
It will be interesting to know if this uncommon finding is confirmed or not for the Italian glaciers to see if their mass balance is connected to the NAO through their winter balance or exclusively through the summer balance.

P5862-L1-12. The correlation between October-May precipitations B_w and temperatures should be investigated.

P5863-L3-23. Again here the analysis is limited because of the geometry artefacts that corrupt the glacier-wide B_a series.

P5865-L18. The geodetic mass balance should also help to control the glacier-wide B_a series, and construct a constant geometry mass balance record (following Elberg et al., 2001) to be connected to climate drivers.

P5866-L1-7. As a principal investigator of mass balance myself, I found that this paper on the longest Italian mass balance series could be an opportunity to associate all persons in charge of the measurements in a common publication.

Figures
Figure 2, 4, 5 and 6 should be enlarged.
Figure 7. The residual sum could also be plotted to highlight deviations along the period.

Stylistic comments
P5850-L12. "precipitation**s**"; "temperature**s**"

P5850-L15. “precipitation**s**”

P5850-L16. “temperature**s** **tend** to become”

P5851-L10. As a first word in the sentence, write “twenty five” in full letters.

P5852-L12. “Nine monitored glaciers **fulfil** these characteristics”

P5852-L19. “in the Ortles-Cevedale (Eastern Alps, Fig. 1) **since** 1967.”

P5853-L10. “…of repeat**ed** readings…”

P5853-L24. Spelling of “grand Etrét” has to be homogenized with upper case letter for “Grand” and acute or grave accent for “Etrèt” in text, table and captions.

P5854-L14. “Typical randon errors…”

P5854-L15. Again, “glacier-wide”

P5856-L19. “The longest available series…”

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