The Cryosphere Discuss., 8, C2125–C2136, 2014
www.the-cryosphere-discuss.net/8/C2125/2014/

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

R. Scotti et al.

francesco.brardinoni@unimib.it

Received and published: 22 October 2014

We would like to thank Michael Kuhn for his thorough and constructive review. Our replies are embedded in the referee's original message.

1) With respect to the "continental to maritime climatic settings" mentioned in the abstract. I feel that abundant precipitation at either margin of the Alps is independent of the presence of oceans, thus not "maritime". It is rather the forced convection when moist air first hits the mountains that cause the two precipitation maxima and the screening of the dry interior.

We appreciate the referee's comment. We are aware of the forced convection origin of the precipitation peaks in the so-called "wet anomalies" (Frei and Schar, 1998) or "wet

bands" (Isotta et al., 2014) of the Alps. On the other hand, in our paper we discuss about continental and maritime climatic setting in relation to the spatial arrangement of the three sub-regions (orographic configuration) with a general geographic connotation (the Mediterranean coast sits just 200 km away from the Orobie). Wet air masses that hit the Orobie first are moist rich because they travel from the Atlantic and the Mediterranean. When using the term maritime in the manuscript we do not make a causal relation between the precipitation peaks in the climographs (Figure 2) during the year and the presence of the Mediterranean Sea or the Atlantic Ocean. However, we think that the presence of the Atlantic and the even closer Mediterranean Sea have a degree of influence on the climate of the Southern Alps that justifies our definition. As an example the oceanic influence in the Orobie climatic setting is assumed by Caccianiga et al. (2008) with the definition: "oceanic prealpine girdle".

2) In the introduction the authors state that "low-elevation glaciers under maritime conditions would display higher sensitivity to climatic fluctuations". Irrespective of their location or climatic conditions, low elevation glaciers tend to be dominated by accumulation rather than by melting, their climate sensitivity is not generally larger than that of large valley glaciers. The smallest group of Austrian glaciers, <0.1 km2, have displayed relative area changes from +10% to -100% in the period from 1969 to 1998 (Kuhn et al., Zeitschrift für Gletscherkunde und Glazialgeologie 43/44, 2012, 3-107).

We have found very scattered and, on average, lower relative changes in glacier area only in the wet climatic zone of Orobie while in Disgrazia and Livigno the climate sensitivity of small glacier is higher. The sentence under examination does not refer to small glaciers only. It is true that in our study region low-elevated glaciers under maritime conditions are mainly small glaciers but the observation by Oerlemans and Fortuin (1992) and Holzle et al. (2003) was meant to apply to all glaciers without size distinction.

3) In the valuable list of references to Italian literature I am missing <Bonardi et al. 2012, I ghiacciai della Lombardia> where individual glaciers have been well documented.

The reference has been added.

4) In chapter 2 obviously Cima de Piazzi is not part of the Livigno subregion. When mean annual air temperatures are given, e.g. for Cancano, the elevation of that station would help the reader. An alternative would be to compare temperatures at one given elevation like 2000 m.

We have problems in the interpretation about the Cima de Piazzi statement, as it is not cited in any part of the manuscript or in any figure. The elevation of the three weather station is reported in p4080 L7-L9-L13 and in Figure 2. We think that one additional citation of station elevation would be redundant. We have not introduced a temperature comparison at 2000 m a.s.l. as the time series of the three weather stations cover different intervals. Temperature values are reported only to provide a general picture of the climate in the three sub-regions (especially the monthly regime).

5) The introduction of the Avalanche Area Accumulation Basin Ratio provides an important parameter that has gained acceptance in recent years. However, "usually occupied by avalanche supply: : :" is a vague definition.

We thank the referee for the constructive comment on the ABR parameter. We do not want to hide a certain degree of subjectivity in the definition of this qualitative attribute and we wish to clarify that the "usually occupied by avalanche supply" refers to the area occupied by avalanche accumulation in seasons of average winter accumulation. Based on field observations in the last 15 years we have recognized that the steeper the rockwall above the glacier surface the more defined is the threshold between avalanche accumulation and avalanche free zones. Possibly, this spatial pattern is caused by a regular (chronic) release of avalanches in very steep rockwalls compared to less steep or more complex slope geometries. In our study areas, the extensive distribution of similar simple and steep rockwall geometries proved to be extremely useful for evaluating ABR with reasonable confidence. Relevant clarifications have been added in the revised manuscript: p4083 L18: "...Avalanche Area Accumu-

lation Basin Ratio (ABR), is the ratio between the area occupied by avalanche accumulation at the end of an average snowfall accumulation season and the area of the accumulation basin (above the ELA0). This classification scheme, which is based on decadal field observations, consists of three classes: low (ABR $\leq$ 0.33), moderate ($>$ 0.33 ABR $\leq$ 0.66) and high (ABR $>$ 0.66)."

6) Most readers will agree that "the lower and upper limit of the glacial domain and their fluctuations are usually related to surface and volume changes".

No action taken. We would welcome any advice on how to proceed.

7) I strongly object to the use of the term "theoretical equilibrium line altitude". Show me a theory that explains why the ELA of a glacier in equilibrium should have an accumulation area ratio of 0.67! I would rather use the median surface elevation as a parameter that describes the glacier topography without referring to any hypothetical mass balance conditions.

We recognize that the classical AAR0 value of 0.67 for alpine glaciers suggested by Gross et al. (1978) is based on a small number of reference glaciers in the Alps (n=12). We are also aware that AAR0 values from mass balance measurements can display high variability depending on hypsometry, accumulation conditions, debris cover, climatic setting (e.g., from 0.22 to 0.72 (WGMS, 2005)) and consequently the assumptions behind the AAR0 method are affected by a number of uncertainties. However, the application of different AAR0' to different glaciers or sub-regions would require a substantial modelling effort that we think is beyond the scope of this work. The low glacier relative relief (ΔE) associated with the small glacier size typical of our study area imparts minimal changes to "balanced budget Equilibrium Line Altitude (ELA0)"when using different values of AAR0 (ie, 0.50 as opposed to 0.67) hence justifying our method that uses a fixed AAR0 in the calculation of ELA0 . In particular, recent work suggests that the ELA0 may be approximated by the median surface elevation of the glacier (AAR0 = 0.50) and that this approximation is particularly suitable for small glaciers (e.g., Braithwaite and Raper, 2007, 2009; Hughes, 2009; Bolch et al., 2010b; Hughes, 2010; Kern and Laszlo, 2010; Carturan et al., 2013; Igneczi and Nagy, 2013). In light of the above findings and taking into consideration referee's comment number 14 we have decided to replace AAR0 0.67 with the median surface elevation of the glacier (AAR0 = 0.50). In addition, given that ELA0 based on a AAR0 = 0.67 has been widely used in paleoclimatic reconstructions and landscape evolution studies (e.g., Maisch et al., 2000; Kerschner et al., 2000; Bavec et al., 2004; Zemp et al., 2007 and Kerschner and Ivy-Ochs., 2008), for completeness, we report 0.67-based ELA0 values as supplementary material.

We have changed p4084 L6-11 with: "The Balanced-Budget Equilibrium Line Altitude (ELA0) (Meier and Post, 1962; Cogley et al., 2011) is a widely used parameter in glacier and paleoclimatic reconstructions (e.g., Miller et al., 1975; Benn and Lehmkuhl, 2000) and it is usually defined with the Balance-Budget Accumulation Area Ratio (AAR0) method (Meier and Post, 1962; Gross et al., 1978). While the high variability of world-wide measured AAR0 (from 0.22 to 0.72) in mass balance data warns about a straight forward use of this parameter (WGMS, 2005; Zemp et al., 2007), we delineate ELA0 (also termed local-topography ltELA0) as the median surface elevation of the glacier (i.e., considering a 0.50 AAR0 (e.g., Hughes, 2009; Bolch et al., 2010b; Hughes, 2010; Carturan et al., 2013; Igneczi and Nagy, 2013)). This value appears to be particularly well suited for small glaciers (e.g., Braithwaite and Raper, 2007, 2009; Kern and Laszlo, 2010) like the ones we are studying. Indeed, low glacier relative relief (ΔE) that is typically associated with small glacier size, imparts very little change to our ELA0 values when using AAR0 = 0.5, as opposed to 0.67 (originally proposed by Gross et al. (1978)). Hence providing a reasonable justification for assuming Emedian = ELA0. Since a number of seminal paleoclimatic and landscape evolution studies have adopted an AAR0 equal to 0.67 (e.g., Maisch et al., 2000; Kerschner et al., 2000; Bavec et al., 2004; Zemp et al., 2007 and Kerschner and Ivy-Ochs., 2008), for completeness, we provide ELA0 based on AAR0 0.67 in the supplementary material."

We have updated all ELA0 values in the text and in the figures.

8) In chapter 4, line 14, I believe that if MAP increases, ELA should decrease.

In chapter 4, line 14 we highlight an increase in ELA0 scattering and accordingly to the comment, the ELA0 decrease with MAP increase.

9) In support of the sky view factor of clear sky radiation the authors may also apply the term "openness" used in recent geo-statistics.

Our set of attributes has been selected with the intent of representing the main environmental factors driving glacier dynamics yet avoiding redundancies in name of the statistical principle of parsimony. In this context, we feel that the term "openness", for being substantially correlated with clear sky radiation, would not provide significant independent explanation to the variance of glacier area change.

10) Is the "increasing scatter" of ELA0 really an effect of increasing MAP, or is it due to a large elevation range in the Disgrazia and to more avalanche activity in the Orobie?

The increase in ELA0 scatter trough the climatic transect is associated with precipitation as shown in the results. We agree with the referee's comment, we have come to the same conclusion in section 5 (discussion): p4092 L24. High precipitation values in the Orobie sub-region appear to impart to these glaciers an increased dependence on avalanching.

11) I suggest to summarize much of chapter 4 in tables or simple maps instead of lengthy verbalizations in the text. E.g. page 4087 is difficult to read. Condense this information into one table or give short comments on Tab. 3 and Fig.7. Section 4.2 could be condensed considerably, details may be given in the supplements, likewise 4.4.

Comment accepted, section 4.2 has been reduced by half and text from p4087 L26 to p4088 L19 has been included in the supplementary material. Section 4.4 has been simplified while some information has been included in the caption of Figure 11.

12) P. 4087, lime 18: “Retreat” refers to length; use “area loss” for size. Mention that losses depend also on Emin; low glacier tongues suffer more ablation.

Comment accepted, the text has been corrected accordingly.

13) P. 4091: It is difficult to compare these results to other publications. I am in favor of the parameters you use, please apply them to some of the Alpine glaciers frequently quoted for comparison.

We agree that the results in the section 4.4 are difficult to compare with other studies. However the inventories we quoted for comparison in this work cover entire mountain ranges and thus we feel it is extremely difficult, if not completely impossible for us to provide all the attributes considered in this work without the availability of high-resolution DEMs. In this respect, the Eri is a good example of a parameter that, without the glacier surface area layer and a high resolution DEM, would be impossible to extract. In order to make the best possible (and rapid) comparison with other inventories we have considered, where possible, MAP and mean glacier size. Last but not least, this additional analysis would significantly complicate/lengthen the manuscript, which the referee and the Editor found already too long and in need of some simplification/reduction.

14) Section 5. Again, use median elevation instead of “theoretical ELA” .

See response to point number 7.

15) Do not use “rc” once for ridge crest and again for regional climate.

Comment accepted, we will change the Erc with Eri

16) What, if Erc = Emax?

This is a good point and gives us the opportunity to discuss briefly on the suitability of Eri at large. In our view, Eri is particularly useful for glaciers that are well confined (contained in) by valley walls and/or amphitheatre-like bedrock structures. Eri is not

applicable in the case of ice caps or glaciers that similarly lack a set of nunataks or a ridgecrest behind the head of the glacier. In our work we did not have any glacier lacking such a structural configuration.

17) 5.2 Small glaciers. By no means can we generalize that the smallest glaciers are the most sensitive, see above.

The text has been rephrased: “Considering the characteristic limited size of our study glaciers, the relatively high sensitivity of mid-to-small sized glaciers (even though associated with high scatter) to climate change (i.e., Haeberli and Beniston, 1998; Paul et al., 2004; Jiskoot and Mueller, 2012; Tennant et al., 2012). . .”.

18) 4094, line 1: ? possible confusion caused by: : :?

Confounding here has a statistical connotation (it stays for experimental confounding). We feel that confounding is a more appropriate term.

19) Line 18: area decrease instead of retreat.

Comment accepted, the text has been changed accordingly.

20) 4095, 7: % per year?

Comment accepted, the % per year have been added to the text: p4095 L 7: “In particular, post-1990 AAD in Livigno, Disgrazia and Orobie is respectively 4.07, 3.57 and 2.47 % a-1, equal to 7.2, 6.6, and 6.1 times the pre-1990 rate.”

21) 4096, 15: <10 ha, or 0.1 km2

The text has been corrected accordingly.

The following references refer to our replies to both referees: Philippe Deline and Michael Kuhn

References: Bavec, M., Tulaczyk, S. M., Mahan, S. A., and Stock, G. M.: Late Quaternary glaciation of the Upper Soča River Region (Southern Julian Alps, NW Slovenia).

Sediment. Geol., 165, 265–283, 2004.

Bolch, T., Yao, T., Kang, S., Buchroithner, M. F., Scherer, D., Maussion, F., Huintjes, E., and Schneider, C.: A glacier inventory for the western Nyainqentanglha Range and Nam Co Basin, Tibet, and glacier changes 1976–2009, The Cryosphere, 4, 419-433, 2010b.

Braithwaite, R.J. and Raper, S.C.B.: Glaciological conditions in seven contrasting regions estimated with the degree-day model, Ann. Glaciol., 46, 296–302, 2007.

Braithwaite, R. J. and Raper, S. C. B.: Estimating equilibrium-line altitude (ELA) from glacier inventory data, Ann. Glaciol., 50, 127–132, 2009.

Caccianiga, M., Andreis, C., Armiraglio, S., Leonelli, G., Pelfini, M., and Sala, D.: Climate continentality and treeline species distribution in the Alps, Plant Biosyst., 142, 66–78, doi: 10.1080/11263500701872416, 2008.

Carturan, L., Filippi, R., Seppi, R., Gabrielli, P., Notarnicola, C., Bertoldi, L., Paul, F., Rastner, P., Cazorzi, F., Dinale, R., and Dalla Fontana, G.: Area and volume loss of the glaciers in the Ortles-Cevedale group (Eastern Italian Alps): controls and imbalance of the remaining glaciers, The Cryosphere, 7, 1339-1359, doi:10.5194/tc-7-1339-2013, 2013b.

Cogley, J. G., Hock, R., Rasmussen, L. A., Arendt, A. A., Bauder, A., Braithwaite, R. J., Jansson, P., Kaser, G., Möller, M., Nicholson, L., and Zemp, M.: Glossary of Glacier Mass Balance and Related Terms, IHP-VII Technical Documents in Hydrology No. 86, IACS Contribution No. 2, UNESCO-IHP, Paris, 2011.

DeBeer, C. M. and Sharp, M. J.: Recent changes in glacier area and volume within the Southern Canadian Cordillera, Ann. Glaciol., 46, 215–221, 2007.

Frei, C., and Schar, C.: A precipitation climatology of the Alps from high-resolution rain-gauge observations, Int. J. Climatol., 18: 873–900, 1998.

Gardent, M. and Deline, P.: I ghiacciai delle Alpi francersi: evoluzione dalla Piccola Età Glaciale al 2006-2009, Nimbus, 69/70, 46–52, available at: http://www.nimbus.it/nimbus.htm, 2013.

González Trueba, J. J., Martín Moreno, R., Martínez de Pisón, E., and Serrano, E.: 'Little Ice Age' glaciation and current glaciers in the Iberian Peninsula, The Holocene, 18, 551–568, 2008.

Gross, G., Kerschner, H., and Patzelt, G.: Methodische Untersuchungen über die Schneegrenze in alpinen Gletschergebieten, Z. Gletscherkd. Glazialgeol., 12, 223–251, 1978.

Haeberli, W. and Beniston, M.: Climate change and its impacts on glaciers and permafrost in the Alps, Ambio, 27, 258–265, 1998.

Hoelzle, M., Haeberli, W., Dischl, M., and Peschke, W.: Secular glacier mass balances derived from cumulative glacier length changes, Global Planet. Change, 36, 295–306, 2003.

Hughes, P.D.: Twenty-first Century glaciers in the Prokletije Mountains, Albania, Arc. Antarct. Alp. Res., 4, 455–459, 2009.

Hughes, P.D.: Little Ice Age glaciers in the Balkans: low altitude glaciation enabled by cooler temperatures and local climatic controls, Earth Surf. Proc. Land., 35, 229–241, 2010.

Ignéczi, Á. and Nagy, B.: Determining steady-state accumulation-area ratios of outlet glaciers for application of outlets in climate reconstructions, Quat. Int. 293/268–274, 2013.

Isotta, F.A. et al.: The climate of daily precipitation in the Alps: development and analysis of a high-resolution grid dataset from pan-Alpine rain-gauge data, Int. J. Climatol., 34: 1657–1675. doi:10.1002/joc.3794, 2014

WGMS (World Glacier Monitoring Service): Glacier Mass Balance Bulletin No. 8 (2002–2003), edited by: Haeberli, W., Noetzli, J., Zemp, Baumann, S., M., Frauenfelder, R., Hoelzle, M., and ICSU (WDS)/IUGG (IACS)/ UNEP/ UNESCO/ WMO, World Glacier Monitoring Service, Zurich, Switzerland, 100 pp., 2005.

Jiskoot, H. and Mueller, M. S.: Glacier fragmentation effects on surface energy balance and runoff: field measurements and distributed modelling, Hydrol. Process., 26, 1862–1876, 2012.

Kern, Z., László, P.: Size specific steady-state accumulation-area ratio: an improvement for equilibrium-line estimation of small paleoglaciers, Quaternary Sci. Rev., 29/19–20, 2781–2787, 2010.

Kerschner, H. and Ivy-Ochs, S.: Palaeoclimate from glaciers: examples from the Eastern Alps during the Alpine Lateglacial and early Holocene, Global Planet. Change, 60, 58–71. doi:10.1016/j.gloplacha.2006.07.034, 2008.

Kerschner, H., Kaser, G., and Sailer, R.: Alpine Younger Dryas glaciers as palaeo-precipitation gauges, Ann. Glaciol., 31, 80–84, 2000.

Maisch, M., Wipf, A., Denneler, B., Battaglia, J., and Benz, C.: Die Gletscher der Schweizer Alpen: Gletscherhochstand 1850, Aktuelle Vergletscherung, Gletscherschwund, Szenarien, Schlussbericht, NFP 31, VdF Hochschulverlag an der ETH, Zurich, 373 pp., 2000.

Oerlemans, J. and Fortuin, J. P. F.: Sensitivity of glaciers and small ice caps to greenhouse warming, Science, 258, 115–118, 1992.

Paul, F., Kääb, A., Maisch, M., Kellenberger, T., and Haeberli, W.: Rapid disintegration of Alpine glaciers observed with satellite data, Geophys. Res. Lett., 31, L21402, doi:10.1029/2004GL020816, 2004.

Tennant, C., Menounos, B., Wheate, R., and Clague, J. J.: Area change of glaciers in the Canadian Rocky Mountains, 1919 to 2006, The Cryosphere, 6, 1541–1552,

doi:10.5194/tc-6-1541-2012, 2012.

Zemp, M., Hoelzle, M., and Haeberli, W.: Distributed modelling of the regional climatic equilibrium line altitude of glaciers in the European Alps, Global Planet. Change, 56, 83–100, doi:10.1016/j.gloplacha.2006.07.002, 2007.

Interactive comment on The Cryosphere Discuss., 8, 4075, 2014.