

Author's response to the Reviews–editor decision of the paper tc-2016-46 resubmitted to The Cryosphere (Mauro Fischer, corresponding author):

Dear Editor,

We want to thank you for your positive comments and final report on our paper resubmitted to The Cryosphere.

We answered and commented on all your technical comments/corrections points ~~raised by the two reviewers below~~. – Reviewer–Editor's comments are formatted in Times 12 italic, our response in Times 12 normal, and the corresponding revised text including information about the corresponding line numbers in the new TC manuscript version in Times 10 normal/bold.

Comments by J. I. López Moreno:

~~- Title: I wonder if the use of "ultra long range" is relatively standard, as it seems to me a bit "excessive". May be that using very long range is enough, or at least the text should inform that is a distance that has been very little used in previous research. As the work deal more in validating the measurements rather than explaining the dynamics of the glacier, may be better to include some reference to the validation itself or the comparison to direct glaciological method (just a suggestion)P1. Line 51: I would delete the 'even' together with the 'notably' there are bit too many such words.~~

~~We now replaced “ultra long range” with “long range” everywhere in the manuscript, including the title. Done.~~

~~According to the reviewer’s comments, we changed the title of our manuscript to “Application and validation of long range terrestrial laser scanning to monitor the mass balance of very small glaciers in the Swiss Alps”. To keep the title short, we did not directly include that validation is done against dense in situ measurements/direct glaciological mass balances.~~

~~- Introduction. In page 2 line 4 when the importance of studying small glaciers is mentioned, it can be also stated that this is the very likely evolution of many current mid size glaciers in areas like the Alps, and it is better to properly understand the dynamics of small glaciers when they are indeed very deterioratedP3 caption fig 1, line 3: insert '(on left side)' after 'study glaciers'~~

~~Now implemented accordingly with a new sentence.~~

Page 1, Lns 58ff:

~~“It is likely that currently medium sized or even large glaciers become very small glaciers due to disintegration and substantial area loss over the next decades in areas like the European Alps (Zemp et al., 2006). A better understanding of their dynamics and sensitivity to climate change is thus important (Huss and Fischer, 2016).”~~

~~- Study site: Page 5, line 9. “...were comparatively moderate during” The use of “moderate” is rather ambiguous, I would state that area losses were less than...or similar. In some part of~~

~~the manuscript, probably here, a brief description of climate characteristics of the analyzed glaciers (and main differences if exists) and mentioning how was the climate during the two analyzed years compared to long-term climate (last decades) in the Swiss Alps would help to better interpret the presented data on mass balance. P4 table 1 line 1: correct 'parafs' to 'parameters'~~

~~We now implemented the first point as suggested~~Done.

Page 2, Lns 104f:

~~“Observed area losses were smaller than for the other studied glaciers during past decades (Tab. 1).”~~

~~Concerning the reviewer’s second point, we agree that data about the climate characteristics and variability of the study sites would help to better interpret the presented mass balance data (comparable to, for instance, López-Moreno et al., The Cryosphere 2016). However, we argue that such analyses go beyond the scope this study, which aims at validating TLS-derived annual geodetic mass balances of very small alpine glaciers with direct glaciological mass balances from dense in-situ measurements. We now refer to a new study by Huss and Fischer (2016, Frontiers in Earth Science) in the revised version of the manuscript (Page 1, Ln 63) which is about the sensitivity of all very small glaciers in Switzerland to climate change. Further, we now also refer to the 2014 and 2015 annual climate bulletins of MeteoSwiss, which, if desired, will help the reader to better link the resulting measured mass balances as well as their regional and interannual variability to the prevailing atmospheric conditions during the observation periods 2013/14-2014/15 (cf. Page 10, Lns 24ff).~~

~~- Data and methods: Page 6 line 31: Which is the consequence of range ambiguity? A slightly expanded explanation (or a reference) might be useful. P4 line 27: there is something wrong in this sentence around '...to the importance...'. It says 'pointed out' so the 'to the importance' can refer to 'pointed'. If you leave away the 'out' it may work (or replace 'pointed out' by 'referred'). Does this then still say what you want?~~

~~Now a slightly expanded explanation as well as a corresponding reference are given.~~We rephrased the sentence as follows:

Page 45, Lns 256ff:

~~“Huss pointed out the remarkable small-scale variability in accumulation and melt processes, and referred to the importance of snow redistribution and the influence of albedo feedback mechanisms on the mass balance of this very small glacier.”In order to avoid range ambiguity and associated possible uncertainty due to several laser pulses simultaneously in the air (Rieger and Ullrich, 2012), the pulse repetition frequency was always set to 30 kHz.”~~

~~- Page 7. Even if supplementary material inform of the characteristics of the point clouds, I would mention here some numbers about the most usual (or minimum) density of points acquired for this study. What is an octree filter? P5 line 44: can you confirm that it is V 2.1 (in your review response you said 10.1).~~

~~Now implemented accordingly~~Yes. 10.1 corresponds to the ArcGIS version used, and 2.1 is indeed the version of the RiscanPRO software used here. We're sorry for this error in the review response.

Page 5, Lns 33ff:

~~“This enhanced the ground resolution of target reflections (point density) to an important extent. For all scans, average point density was 30 m^{-2} (range 1 to 95 points m^{-2} , cf. Supplementary Tab. 1).”~~

~~An octree filter segments the point cloud into cubes of selected length x , width y , and height z , reducing the data within each cube to a single point. We now complemented this sentence with an exemplary reference.~~

Page 6, Lns 5ff:

~~“An octree filter (e.g., Perroy et al., 2010) was applied to the registered scans to remove noise and generate point clouds with equal numbers of reflections per area.”~~

~~-Page 9, line 5: Some reference to support the used densities for ice, annual and multi-annual firn? P5 line 58: 'were' instead of 'was' ('a number of ... were..')~~

~~We argue that the density for ice chosen is standard. We added a reference supporting the chosen densities for annual and multi-annual firn. Done.~~

Page 6, Lns 42ff:

~~“Corresponding densities of 900 kg m^{-3} for ice ρ_{ice} , 550 kg m^{-3} for annual firn ρ_{af} , and 700 kg m^{-3} for multi-annual firn ρ_{mf} (e.g., Sold et al., 2015) applied to calculate a glacier-wide volume-to-mass change conversion factor...”~~

~~- Page 9, line 20, again, although this is presented as supplementary material some numbers on the density of snow depth measurements may be better than just saying "...with a sufficient spatial coverage..." P6 line 44/45: is Sold et al. 2015 the right reference, in the author response you referred to Cuffey and Paterson 2010.~~

~~Here, we do not refer to winter snow accumulation measurements, but to snow probings performed if there was a significant amount of fresh snow at the time of the annual LiDAR survey in autumn (as mentioned in the text). Autumnal fresh snow covers are, from our experience, usually spatially much more homogeneous than end-of-winter snow accumulation patterns, so a smaller density compared to the winter surveys was enough. We now refer to the recorded median density (as a number of measurements per square kilometer) of autumnal snow probings on the respective glaciers. Yes, Sold et al. 2015 is indeed the right reference, we're sorry for not having updated this in the author response.~~

Page 6, Lns 74ff:

~~“Snow probings on the glaciers with a complete spatial coverage and a median density of about 200 measurements km^{-2} were performed on the same days as the LiDAR surveys, and measured snow depth values inter- and extrapolated to the entire glacier surfaces.”~~

~~-P6 line 61 and also line 62: few 10^0 m/y ? why not say 'few metres'? I would think it should probably be $10^{(-1)} \text{ m/y}$ as it says in response. Maybe something went wrong here. check and correct accordingly. Uncertainty assessment: Page 10 lines 22-24. Even if ground is stable, small instabilities may occur between the tips of the tripod and the bare rock, or if the ensemble of the tripod, or the tripod with the TLS is not properly ensured.~~

~~We fully agree. That's why we wrote “**Provided that** the RiegIVZ-6000 used here~~

~~operated reliably and ground motion was prohibited while scanning, ...". So our formulation already implies that for instance small instabilities between the tips of the tripod and the bare rock may occur. 10^0 m/y is right, we're sorry for this error in the author response. We now wrote 'few metres'.~~

~~-P10 line 25: I would replace 'stronger' with 'higher', mass loss can not be 'strong' but high or low. I guess because it is a negative number you wanted to avoid confusion but you talk about 'mass loss' and if this is 'high' it is more negative. Where comes from that uncertainties of volume change for ice is set to $\pm 20 \text{ kg m}^{-3}$?~~

~~This is just a conservative estimate for a range in ice density for small mountain glaciers. Now clarified. Now implemented accordingly.~~