

## ***Interactive comment on “Long-range terrestrial laser scanning measurements of summer and annual mass balances for Urumqi Glacier No. 1, eastern Tien Shan, China” by Chunhai Xu et al.***

### **Anonymous Referee #2**

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General comments: This study describes the use of a novel long-range terrestrial laser scanner (TLS) dataset to calculate annual and summer mass balances and delineate accurate glacier boundary of Urumqi Glacier No.1 in eastern Tien Shan over two consecutive years (2015-17). After introduction of the data used and methodology applied, the authors showed TLS-derived surface elevation and geodetic mass changes. They then compared these results with the conventional glaciological method following the framework proposed by Zemp et al (2013) to validate the accuracy and relevance of the TLS to monitor glacier mass balance. At the end, they give a discussion about the quality of TLS data and DEM differencing, explain the possible causes about differences between the two methods and evaluate the potential of such long-range TLS

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to measure seasonal and annual glacier mass balance. The paper employs advanced instrument of glacier mass balance monitoring and can be seen as a deep-going study of a published paper (Xu et al., 2017, J. Glaciol., doi:10.1017/jog.2017.45). China contains the largest number of glaciers outside the polar regions, very few glaciers have discontinuous glaciological mass balance records, so we need alternative approaches that could complement glaciological method. The presented study is very interesting, which I think to be a valuable contribution to The Cryosphere. However, there are some comments and issues that the authors should be addressed. 1) The discussion about the potential of the long-range TLS to measure glacier mass balance is very weak, which undermines the paper. Please see detailed comments in “Specific ” 2) Uncertainty assessment of the glaciological methods: you have quantified various errors according to other similar studies, but I firmly believe that these values are really different, especially for errors in spatial extrapolation over the entire glacier. Just as you say relative smaller area and accompanying higher density of point measurements of UG1 than other glaciers decide the uncertainty is smaller. Could you compare specific net mass balance with in situ measured stake datasets of UG1 to determine the error of spatial interpolation? 3) Some sentences should be written more clearly and precisely, including P2, L4; P2, L34; - P6, L26; ... 4) Figures: Figures need some improvements in terms of visibility of their content.

Specific comments: 0 Abstract - P1, L10: Delete “typically”. To date the glaciological method is commonly used to measure seasonal and annual surface mass balance. So it is not necessary to emphasize the method using “typically”. - P1, L10: Rephrase “seasonal surface mass balance” - P1, L11: Replace “measuring networks” with “field networks” - P1, L15: “scanner” instead of “scanning”

1 Introduction - P2, L4: Add “are sparse and discontinuous”. Please rephrase to be more accurate. - P2, L7: I would rather delete “entire”. It is not always possible to cover the entire glacier, such as ICESat. - P2, L12: Replace “spatiotemporal” by “time”. I know some images have high spatial resolution at present, e.g. Cartosat-1

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(2.5 m), Pléiades (0.5 m), QuickBird(0.61 m), GeoEye(0.41-1.65 m) etc. - P2, L28-29: Rephrase "...central and bottom elevations were detected due to the glacier area is relatively small." - P2, L34: What the meaning of "best-monitored glacier"? I guess you mean Urumqi Glacier No.1 has the longest and most detailed surface mass balance measurements in China. Please rephrase the sentence to be clear. - P2, L38-40: Rephrase "To date, comparison of glaciological and geodetic mass balances ...for the period 1981-2009 at intervals of several years, geodetic reanalysis of seasonal and annual glaciological mass balance..." - P2, L40: You already have a publication about the reanalysis of glaciological and geodetic mass balances of UG1 (Xu et al., 2018, Cold Reg. Sci. Technol., doi: 10.1016/j.coldregions.2018.08.006), please write here.

2 Study site - P3, L23: Add "...a northeast-orientated small..." - P3, L24: Replace "Fig" by "Figs" - P3, L24 "and consists of two independent small glaciers: the east branch (EB) and the west branch (WB)" would be better at the end of this paragraph and then delete "and consists of two independent small glaciers" - P3, L27 "long-term measurements"? I think you may mean something like glacier mass balance? - P3, L27 Correct "Over the past 50 years" and give a specific time period. - P3, L31-37 I suggest that related literatures should be cited here. - P4, L4-7 This paragraph would be better in section 3.3 as it already mentions methodology

3 Data and methodology - P4, L25: Replace "Fig" by "Figs" - P4, L26: Everywhere else in the manuscript, please replace "GPS" by "GNSS" - P5, L1: Add "...in the range of..." - P6, L9: It seems the authors mixed the triangle ( $\triangle$ ) and capital Greek letter delta ( $\Delta$ ), and whole manuscript: please replace " $\triangle$ " by " $\Delta$ ". - P6, L26: Please rephrase "volume changes are considerable" to be more precise. - P6, L36: Figs - P7, L7: Add "...the glacier and evenly distributed..." - P7, L18: I know what you meaning of "the specific mass balance is calculated from the product of the level change between readings and the ice density" as I have calculated glaciological surface mass balance, but it is not easy to understand for wide readers. Please rewrite the sentence to be clearer. - P7, L29: Which energy-balance model? Please give a brief introduction and

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refer corresponding literatures. - P8, L3: Correct “Figs”

4 Uncertainty assessments - P8, L19: Add “windless weather conditions” - P8, L31: Can you give absolute values of the proportions of the two artefacts over the entire glacier and then quantify the errors related to unscanned areas. - P9, L13: The given errors can be listed with 2 decimal places to reflect appropriate level of certainty. - P9, L35: You should write clearly here that the value you cited indicates point mass balance. - P10, L4: What the meaning of sampling sites? Please rephrase to be more specific - P10, L4: You mean something was given in Table 4? Add some sentences to be clear.

5 Results - P10, L23: Replace “clear” by “clearer” - P10, L29: Correct “Figs” - P10, L29-30: I know debris cover on a glacier may alleviate ablation when the debris thickness exceeds a certainty value. But your argument explaining the phenomena is quite speculative. Please support your opinion by some semi-quantitative or quantitative data. - P10, L33: Use “with” instead of “by” - P10, L33: Please correct “Figs” - P11, L2: Again: please correct “Figs” - P11, L7: Rephrase “. . .all of the four investigated periods” - P11, L9: It makes no sense that the value is rounded to three decimal places, please change everywhere else in the manuscript. - P11, L11: Add “compared to the corresponding values of EB” after “. . . more negative” - P11, L16: Fig. 5 instead of Fig 7? - P11, L17: Replace “sites” with “ablation stakes”

6 Discussion - P12, L30: Add “of each scan positions” - P12, L30: Fig. 4 instead of Fig. 3? - P12, L32: Replace “are” with “is” - P13, L9: I know the number and location of ablation stakes vary from year to year as stakes melt out and sink. Please give a specific period for the average value. - P13, L11: Delete “in” - P13, L13; How did you decide the annual discharge? I guess you use the mean value here, can you calculate the internal and basal ablation using the measured data of each year? - P13, L32: I would delete the first sentence in this paragraph as it had appeared in the introduction. - P14, L7-9: Can you quantify the influences of unscanned areas? - P14, L10: Rephrase “a discrepancy in mass balance elevation distributions of WB was observed

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at...” - P14, L11: Replace “takes” with “take” - P14, L33: The discussion about the potential of the long-range TLS to measure glacier mass balance is very weak and not really satisfying, but I believe that there is more to say. e.g. Comparison with other technologies, such as unmanned aerial systems, terrestrial photogrammetry, and then you can discuss the advantages/disadvantages of each technology. We see some data voids; can you say something about future application of such TLS to monitor glacier evolution. I firmly sure that artefacts will also exist for other glaciological applications. The data voids can be avoided when combining with other approaches? Density conversion is still a challenge at annual and seasonal scales, which assuredly influences the wide application. What do you advise as reduction of the density conversion? I don't really think the majority of glaciers can be measured using the TLS as some of them lie at remote locations. I would rather suggest you to select some representative glaciers (evenly distributed at different mountains, different types and areas, etc.) with easily accessible locations for the geodetic mass balance monitoring. Can you discuss something about application of TLS to monitor the representative glaciers; it would be very interesting and relevant to know additional information of those glaciers for future studies. Can you give more information about TLS-derived geodetic results to validate the distributed glacier mass-balance models; I think it is very important for future glaciological studies since its high spatiotemporal resolution and the shortage of in situ measurements. - P15, L9: I think microwave remote sensing is not an effective technology as the limited time and space resolution. 7 Conclusions Cloud need to be a bit changed after taking account the comments mentioned above. 8 Figures and tables - Figure 2: In the caption, please add some scientific content to illustrate the figure. - Figure 3: Please improve the figure to obtain clear content. - Figure 4: Please again improve the figure to obtain clear content. - Figure 5: Please again improve the figure to obtain clear content. - Figure 6: Please again improve the figure to obtain clear content. - Table 3: Please hold two decimal places. - Table 4: Please again hold two decimal places.

9 References Please check the reference, both in the text and at the end, to meet the

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requirements of the journal. e.g.: - P1, L29: Correct “Liu and Liu, 2016” - P2, L2: Correct “Xie and Liu, 1991” - P18, L19: Lichti et al., 2005 in references not in text - P19, L12: Rolstad after RIEGL - etc.

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Interactive comment on The Cryosphere Discuss., <https://doi.org/10.5194/tc-2018-128>, 2018.

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