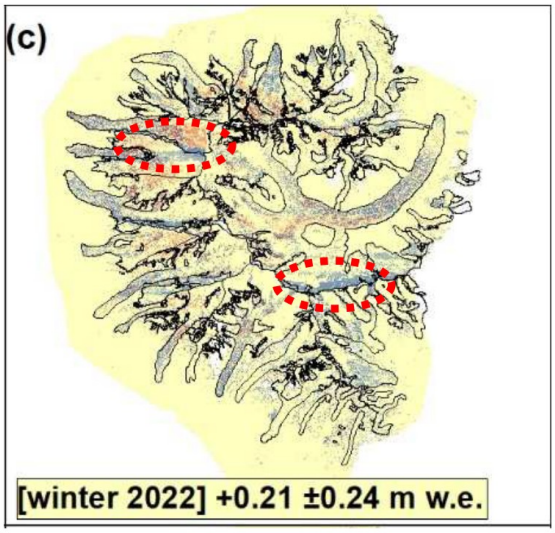
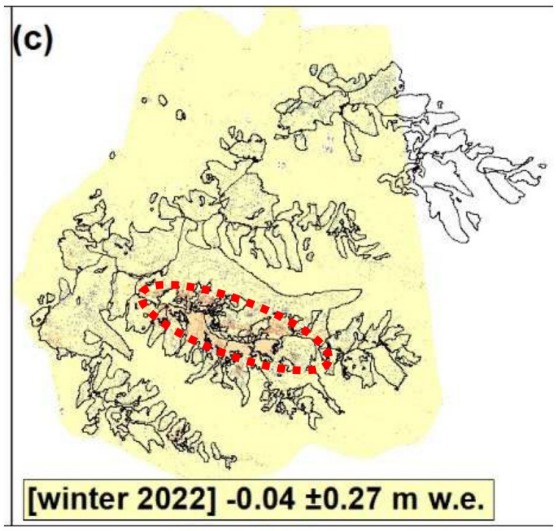
Annual to seasonal glacier mass balance in High Mountain Asia derived from Pléiades stereo images: examples from the Pamir and the Tibetan Plateau

Falaschi et al. TC Discussion
Review by César Deschamps-Berger

This article presents a time series of three annual and two seasonal mass balances for two glacerized massifs in High Mountain Asia. In line with previous studies, it is found that the Pamir glaciers have a mass balance close to equilibrium between 2019 and 2022 while the glaciers from the Tibetan Plateau have a negative mass balance. Various satellite products (Pléiades, Sentinel 1 and 2) were combined to identify the surface elevation change and the accumulation and ablation areas. The snow/firn density and the firn densification are taken into account based on field measurements. The authors put the measured mass balance in longer time scale context and improve the description of the glacier accumulation regimes. It is a detailed work which combines advanced methodologies with good knowledge of the region. I think this article will be a valuable contribution after the following main concerns are addressed.

1. The winter elevation changes show disturbing patterns (Figure 4, 6 and blue lines in Figure 5). In Western Nyainqêntanglha, elevation loss in winter are stronger at the highest elevation. On the contrary, elevation loss in winter are measured in the Muztag Ata between 6000 m asl and 7000 m asl with areas of elevation gain below and above.
Are these elevation change significant or within the calculated uncertainties?
What process could explain such altitudinal distribution of elevation change?
I wonder if it could be related to remaining errors in the elevation change map (jitter correction, gap filling, shaded areas, see areas highlighted below). Jitter correction might not be perfect due to the lack of stable terrain, especially for Muztag Ata. Better highlighting and explaining these errors might impact the conclusions on the accumulation regimes (e.g. L496, 5.2) and on the sources of uncertainty of the mass balance estimation (e.g. L595-601 and 5.1.2).





Left: Figure 4. c. Muztag Ata; Right: Figure 6.c. Western Nyainqêntanglha,

2. I estimate that this manuscript would result in an article of more than 20 pages. The article readability would benefit from being more concise. I would advise the authors to revise the manuscript with that in mind. Some of my minors comment should help to gain space (e.g. L89, L108, L125, L194, L283...).
If a radical choice was to be made, moving to supplement or removing the parts about the correlation of mass balance with climatological variables might not alter the value of the article. It is almost a distinct topic from the core of the article (see title). The data used partly come from other articles and finally, few (or no) significant correlation are found.

3. The quality of the figures should be improved. Almost all the plots with lines are hard to read due to the style and colour of the lines. For instance, it is very hard to distinguish several lines of Figure 5, the

individual glaciers in Figure 7, Mass balance from Solid precipitation in Figure 8. Select better colour and line style.

Minor comments and suggestions

L26. Pl**é**iades. Throughout the text.

L31. delete « previously observed »

L32-33. delete « *on average* ». « *mean*» is already stated at the beginning of the sentence.

L33. « *increased* » compared to what?

L33. Why is Western Nyainqêntanglha qualified here as summer accumulation type when summer mass balance (-0.66 m w.e.) is more negative than the winter one (-0.04 m w.e.)? Besides, this conclusion (Western Nyainqêntanglha being summer accumulation type) seems based on other studies in the dedicated Discussion paragraph (L696-698).

« *The 2022 winter (+0.21 ±0.24 m w.e.) and summer (-0.31 ±0.15 m w.e.) mass budgets in Muztag Ata and Western Nyainqêntanglha (-0.04 ±0.27 m w.e. [winter]; -0.66 ±0.07 m w.e. [summer]) suggest winter and summer accumulation-type regimes, respectively.*» I suggest rephrasing as: « The seasonal mass balance in Muztag Ata (winter: XX m w.e., summer : XX m w.e.) and Western Nyainqêntanglha (winter: XX m w.e., summer : XX m w.e.) suggest... ».

L80. Not only WorldView-2 (see Shean et al., 2020). Simply put « WorldView ».

L86. Des**c**hamps-Berger.:)

L89. «*(e.g. Ice, Cloud and land Elevation Satellite-2 -ICESat-2)*» ICESat-2 is not further used. Give only the acronym.

L92. Quit the brackets.

L96. «*displayed dissimilar mass change rates.*» precise over which epoch, otherwise it sounds like an article's result is given away.

L97. « *mass balance for longer period* » Longer than what?

L104. In 2.1., provide the max elevation as in 2.2. Tell if the whole massif is covered.

L108. Delete «*(along with the nearby Kongur Shan mountains).*» It is never mentioned again.

L124. «*glacier ~~ice~~*»

L125. «*Glaciers in the arid NW Tibetan Plateau are predominantly continental-type, cold–based (with their basal part entirely below the pressure melting point) and receive little precipitation.*» Might be deleted? All these informations are repeated in the next lines.

L131-134. Give periods for each mass balance epoch, confusing otherwise.

L147. « *~230 km in length reaches* » => « extend over ~230 km in length and reaches... »

L163. « *in their model* »? An energy balance model is not a source of information about precipitation.

L165. « > » => « more than ». Delete « here ».

L168. Why use []? And why « accelerated »? compared to what?

L170. Keep giving MB with two digits precision « (–1.0X m) ».

L172. « *Zhadang glacier*» first time it is mentioned. Introduce shortly the glaciers of interest (size, specificities).

L192. Delete «*relatively*».

194. « *separated in time on most occasions (Table 1). In all cases, partial acquisition dates were no more than 2 weeks apart.* » => « separated by two weeks in the worst case (Table 1).»

L195. Was the DEM produced in one run from the raw stereo images to a high-resolution DEM? A common practice to reduce errors is to first project the images on a low-resolution DEM (idea for future work).

L196. « *implementing* » => « using »

L197. Why «although»? The first part of the sentence refers to a method of this work, the second refers to results from other studies. Grammatically hard to understand.

L200. « *Pléiades DEMs are currently amongst the most common very high resolution DEMs used in geodetic mass balance assessments*». Maybe not necessary as there are anyway few high resolution photogrammetric satellite and studies exists with WorldView (Shean et al., 2020).

L203. « *beyond the higher spatial resolution,* » not true for WorldView satellites, could be deleted.

L205. *«saturated areas»* => « areas prone to saturation »

L209. Did you request that the images were acquired with reduced Time Domain Integration (TDI)? It can help preventing saturation (Deschamps-Berger et al., 2020).

L223. I understand that the lower resolution saves computational time but less the number of images. Is the opening and closing of the images really a bottleneck in the treatment?

L232. delete « *see also* »

L235. «*To this ends, it implements an automatic threshold to the near-Infrared*» => « It determines automatically a threshold for the NIR band values ».

L241. Move the « Muñoz » citation after « daily data ».

L257. Delete « see e.g. ».

L260. Move the UTM info somewhere else more generic.

L265. In future work, you might want to first co-register your reference DEM to an external reference (e.g. Copernicus DEM) to ensure a better absolute co-registration.

L269. «*reprocessed 2019 Pléiades DEM from Bhattacharya et al. (2021)*» is confusing. Was the 2019 DEM eventually calculated like the others of this study? Then, the Bhattacharya reference could be deleted. Maybe, the link between this study and Bhattacharya et al. (2021) should be better explained in introduction. At least better introduce the Bhattacharya et al. (2021) study as some products are used here (L 472).

L270. Which metric is used to correct the vertical biases? The mean, the median?

L271. Delete « *(reference)* »?

L275. «*implemented*» to be clarified. It sounds like you implemented the code (i.e. wrote the code). However in the acknowledgement the tools of Etienne Berthier are mentioned. Also note that it is a different method than the one used in Deschamps-Berger et al. (2020). The first one fits polynomial functions to the residual while the second calculates and modifies the Fourrier transform spectrum of the residual. Make sure which one was used or implemented.

L277. « *on- and* » missing blank

L283. « *We chose a 3-cell buffer so as not to remove valid cells from the original dDEM grids.* » This kind of sentence could be deleted to make the article more concise.

L284. « *mosaiced*»? merged? How are managed areas where there is overlap between tiles (concisely)?

L305. « *in the energy balance model comprising Muztag Ata N15 and Zhadang glaciers (in Muztag Ata and Western Nyainqêntanglha districts, respectively) by Zhu et al. (2018a). According to the authors, this density value was retrieved from snow pits.*» Maybe no need to repeat the districts if the glaciers are introduced before. Why mention the energy balance model if the density actually come from pits measurements? Merge sentences concisely.

L318. « time interval » dt might be more clear than *t*?

L321. Eqn (2) « k » is missing. Replace «i»?

L326. It is not clear what the « i » of Ai refers to? Ice? The previous sentence mentions ice and snow areas.

L330. I cannot find easily in this paragraph if the correction is applied on a pixel scale or at the firn area scale? Please clarify.

L346-347 () [] to homogenise

L346. «*most recent elevation grids available* » => « most recent elevation **change** grids »? Since period are provided in brackets (2013-2019, 2018-2019).

L374. « *is not to be expected* » => « is not expected ».

L395. what does « *addressed* » mean? Calculated, defined?

L397. By construction, the mean elevation difference over stable terrain is zero or close to it. Depending whether the mean or median elevation residual was used for vertical coregistration (to be added in 3.1.4). This underestimate potential systematic error. Besides, I do not find sigma_sys further in the uncertainty calculations.

L410. Delete « *see also* »

L415. Eqn 7. What is « f »?

L424. Huang et al. (2022) missing in the bibliography.

L433. The **i**ndex

L433. Please repeat that firn area is measured at the end of the winter and the wet snow area at the end of the summer. Or clarify this point if I misunderstood.

L449. « the influence of XX to YY » Is this grammatically correct? Otherwise replace «*to govern*» by «on».

L452. Put the citations at the end of the sentence. Why mentioning the period of availability of the data? Idem L463.

L456. Delete « *either* »?

L458. Cite APHRODITE along with ERA5, HARv2 in the previous sentence and delete « (APHRODITE, ERA5, HARv2) » in this one.

L459. «*(or instrumental records*» to delete

L461. «*Muñoz-Sabater*»

L463. « *to monthly time step* » Was ERA5 initially at a daily or monthly time step? Mention it in the previous sentence.

L468. «*found*» => « calculated »?

L468. Redundancy with « mean » and « average » in the same sentence.

L472. « *added the geodetic mass balance values in Bhattacharya et al. (2021)* » see comment about L269.

I understand that data from Bhattacharya et al. (2021) are not at a yearly or seasonal resolution. Do you think that mixing periods of different durations could have an impact on the correlation calculated?

L481. Cite « Table 3 » only once in this paragraph.

L483-484. Please provide value in brackets for each year. Or alternatively do not provide any.

L486. « *the (largest and debris-covered) Kekesayi Glacier* » hard to read. Rephrase without ().

L502. « > » => «above»

L510. « *but interestingly, recovered during the 2022 winter season* » why is it interesting? It slightly implies that there is a causal relationship between the summer and winter mass balance.

L546. 2019 does not seem to be an extrema for wet snow area ration in Muztag Ata in Figure 7. Why would it be the most negative mass balance year?

L561 « *departures* » => anomaly

L565 « *Of the last 16 years, summer air temperatures have experienced positive anomalies.* » To be deleted? This is expected from a series of anomalies. Maybe the number of summer with positive anomalies is missing.

L567. «*rather strong (though not significant*...» It is hard to interpret this results.

L570. « *respect**i**vely* ». Move « *scale* » before the brackets.

L571. « *likely had an impact* » => « contributed to »

L571. Is « *in turn* » necessary?

L587. Cite a study which used this method. One that comes to my mind is Nuth et al. (2013, 10.3189/2012JoG11J036) but there must be others.

L588. «*glacier-wide*» sounds like a single glacier. Maybe find another term like massif-wide? Check throughout the manuscript.

L594. Give respectively, the value for each glacier.

L607. How can two scenarios with the same dh grid but different densities result in the same mass balance for Muztag Ata?

L615. I would rephrase in: « variable density should be used for time spans of 3 years or less. » No conclusion can be drawn on longer time span periods since solely a 3 years period is studied here.

L630. Too long phrase.

L633 « *bias* » => errors. Bias often refers to systematic error.

L641 « Around our reported biases, » rephrase. Does bias means error?

L642. Delete +-, the standard deviation is a single value, not a range of uncertainty.

L644. Cite Höhle and Höhle (2009, https://dx.doi.org/10.1016/j.isprsjprs.2009.02.003) along with Dehecq et al. (2016).

L656. First paragraph of 5.2. It sounds like an introduction paragraph not a discussion one. Maybe only keep the first sentence.

L666. Too long sentence.

L674. « *as* » => that.

L686. Avoid intricating () and [], please rephrase.

L688. No undercatch of the weather station is expected ?

L691. « *have allowed us* » => allows

L700. « *too* »=> also

L711. «*Several of the stronger correlations between glacier mass balance and temperature and solid precipitation were not significant,*» Which one were significant ?

L715. What is a « *relevant development* »? Not clear.

L757.« *trend* » sounds like there is a continuous decrease or increase of the mass balance while only two periods are compared. Replace with « period »?

L810. Provide the « period ». Idem as previous comment about the term «trend»

Figure 1. Top panels : Legend for « investigated glaciers » does not match with the figure. The bottom panels should be merged to show both study sites on the same map. Consider changing the geographical features (topographical map ? countries borders ?), the colours and texts. It is blurry and very hard to read.

Figure 3. Which map is in winter and which one is in summer?

Figure 4. f is not annual but multi-annual. I would put all annual mass balance on the upper row (move e map to c position).

Figure 5. Improve readability, change line colours, increase line width.

Figure 7. Hardly readable. Change the line style and/or the marker style.

Figure 8. Highlight which mass balances comes from this study.

Figure 9. Zadang line style is too similar to annual time step of this study.

Table 1. Consider adding a « Difference (days) » column?

Table 2. What are these values of SE 10-4? Cite Höhle and Höhle (2009) for the NMAD. Would be nice to have the same number of significant digits. SD and SE in full letter in the first line. Caption says on-glacier too but not found.