Review of Geissler et al. The potentials of high-resolution photogrammetry for analyzing glacier retreat in the Ötztal Alps, Austria

Geissler et al. present a photogrammetric study using modern aerial photographs of the Vernagtferner and other glaciers in the Ötzal Alps. They calculate geodetic glacier mass balance for three periods between 2009–2018 from these photographs. They then compare these results with existing glaciological data for Vernagtferner and find a good overall comparison. The authors employ a UAV survey in 2018 to measure height change between the photographs and the glaciological observations, and produce a correction curve from these data. This robust method would be best served were it related to local meteorological data so that it could be employed more convincingly for the other two periods, and thus offer a pathway to other studies which commonly face the same temporal challenge of using photogrammetry to compare with glaciological data. The geodetic mass balance and associated error analysis is well done, but the study is lacking in depth in a few areas. The calculation of ice dynamics, here emergence and submergence, is insufficient and likely erroneous. A number of other points are introduced with insufficient detail, such as debris cover. A small extra effort on some of these points will greatly strengthen the paper. This manuscript will benefit from additional citations, and careful proofreading. Overall, I believe that this study is compelling and represents a valuable addition to The Cryosphere in both data and methodology, but requires further efforts to maximize the impact and relevance of the study. While I have numerous comments on the paper, I do not believe addressing these points will take a major investment of time.

Major comments:

Discussing emergence and submergence needs to be handled with caution absent stake observations of emergence and submergence, or model estimates of emergence and submergence. Given the magnitude of emergence and submergence, which is generally less than 0.5 meters, and the uncertainty in glaciological and geodetic mass balance, determining a change in, or even magnitude of vertical ice velocity is questionable. Further, as you indicate, the elevation of maximum volume loss, the rate of mass loss has increased and the ELA has increased. All three of these factors would trend towards a higher elevation where submergence occurs. Lacking more specific data or a more rigorous approach, I suggest caution in drawing conclusions from your estimates of emergence and submergence velocity.

Are GPS surveys conducted for the ablation stakes? If so there are a few methods from which you can estimate emergence and submergence velocities (Beedle Vincent 2020). If such data exist, then they must be incorporated here.

The coregistration procedure is not well described. In L159-160 you state that “The horizontal shift lies between 10 and 20 cm depending on the acquisition year and thus within the ground resolution of the images". Is this the pre-coregistration horizontal shift? This also sounds a bit small, if this is pre-coregistration, that’s excellent. You also state that “Based on this mean vertical shift over stable ground, all DSMs except for the reference DSM were adjusted in height relative to the reference DSM of 2015.” Does this mean that the coregistration was only vertical? Robust coregistration algorithms now exist to implement the method detailed in Nuth and Kääb

(2011). Should this be tested? This method removes not only vertical but also horizontal and rotational bias. Your Figure 6 and section 5.1.2 detail these errors well. Perhaps this is enough, I'm just curious why a full coregistration wasn't used, but having the error well described is sufficient.

For your altitude-related density function, additional explanation is required. This sounds like a good idea, but the particulars aren't clear enough. Over the ablation zone is the density held at 900 kg m3? Or does the density start to change prior to the equilibrium line? Klug et al. (2018) mapped snow/firn as one unit and ice as one unit and assigned a density to each. Pelto et al. (2019) mapped snow, firn and ice separately and assigned a density to each. If I'm reading this correctly, your function is only applied over the equilibrium line, i.e. holding density at 900 for the ice area, and 550 for snow, but using the linear function around the equilibrium line. This is unclear. If so, I think this an excellent approach. Also, does your method take into account the annual (or average) ELA position during each interval or a fixed ELA for the entire period?

Section 4.2. Your correction method is robust for 2018, nice Figure 3. I wonder whether a degree day function could be employed to reproduce the melt you observe in 2018, and then apply that function to the other two periods to adjust or produce a curve just like in 2018? Perhaps too much work for the small adjustment, but might be simple if there is some local temperature data. The correction method is one of the main selling points of your manuscript. I would suggest exploring a simple DDF or similar approach. If it proves reliable, this would greatly improve the applicability of your results. As you mention, using photogrammetric surveys to assess glaciological mass balance is challenging, because of time differences. By providing a simple framework to apply a present-day UAV survey to other time periods where none exist would be of great value and interest to the community (at least for relatively modern air photos).

The discussion is too wordy and redundant. Some sections could be combined and streamlined. Too often the discussion is restating the results section. The discussion should then better discuss questions raised by the reviewers and other under explained details.

Not enough references for previous photogrammetric work are given. Ensure that this is properly referenced and discussed in the intro and methods sections. Some suggested literature include (Baltsavias et al., 2001; Etzelmüller et al., 1993; Gudmundsson & Bauder, 1999; Magnússon et al., 2016; Nolan et al., 2015; Redpath et al., 2018)

Specific comments:

L11 Perhaps change to "are experiencing increasing mass loss...".

L14-15 Perhaps change "a significant glacier area" to something like "a heavily glacierized area".

L11-29 There is a mix of past and present tense in the abstract. Ensure you stick to one tense here.

L25-27 Awkwardly worded. Be clear that you find that the geodetic data can detect local details and deviations better.

42 Comma after geodetic is unnecessary.

45 Perhaps swap in “details” for demonstrations.

54 Start the sentence with “By combining” or move “This study presents” to the start of the sentence and end with “allowing the extraction...”

L69 Ensure consistency with numbers, here a dot is used, other times the number is presented without a dot (e.g. L77).

L105 Please explain what the two numbers in overlap mean in the caption.

L109 Change to “have been acquired...”.

L112 The meters ice equivalent, or meters water equivalent? I’m not familiar with ice per water equivalent.

L128 Any citation for this at Vernagtferner? This has certainly been observed at many glaciers, but a couple citations here would be of value.

L131 Only up to 300-400 mm in the accumulation area? Can this be determined with only 4-5 measurements per year for what should be a 1-3 km2 accumulation area?

L132 Add parentheses around (2013). Ensure in-line references match TC style guide.

L176 Remove “additionally”.

L177 Remove “as well”.

L188 Define “SD”.

L240 Nice figure. Add a scale bar?

L245 Nice figure. Add a scale bar to one of the panels?

L278-280 Why compare two different elevation bins?

L278-280 Should “Million” be lowercase? Change all instances if so.

L313-315 Suggest changing to “... , neglecting debris-covered areas within the glaciological interpolation led to an...”.

L313-315 How was this debris cover value determined? (0.1m± 0.08w.e.a-1(0.8±0.6%). I suggest adding a few lines to the results and discussion on debris cover to better detail what you found. E.g. “...debris covered area experiences x.xx m of ablation on average versus x.xx m of proximal ice. This suggests that xxxx.”

L325 Shorten the y-axis label and correct spelling and capitalization errors. Move x axis elevation labels to the top or bottom away from data points.

L352 Change to “quadrupled”.

L349-L361 How do your results from these two periods compare with other regional estimates of mass balance?

L359 Exceed? It’s hard to keep track of your comparisons of glaciological and geodetic mass balances. I recommend being explicit, rather than “greater than” “exceed”, “lower”, “higher” etc., use more positive or more negative, or express as more mass loss vs. less mass loss. Or if you stick with greater, lesser, etc, be sure to explain what each means here and use the same terms to discuss throughout. I found myself looking at figures and re-reading sections often to determine which method measured greater mass loss over given altitudes or time periods.

L376 Cut superfluous language. Here remove “As a result, for instance,” and start the sentence with “We were able...”.

L382 Why not calculate the height change for this dead ice body as an example if you’re going to mention it here? Nice little advertisement of the detail and value of high resolution digital photogrammetry. You could even compare this to the mass loss on the toe of the glacier if desired.

L392 Insert “the” to make it “the SD”.

L433-435 Useless? I think not, and you have just proved that they can be used, provided a correction. Instead end with something like “therefore require correction using geodetic survey data or other methods”.

L469-470 I’m not sure of the value of this line, or why this is relevant here. Did the study at all address this topic?

References

Baltsavias, E. P., Favey, E., Bauder, A., Bosch, H., & Pateraki, M. (2001). Digital Surface Modelling by Airborne Laser Scanning and Digital Photogrammetry for Glacier Monitoring.

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Etzelmüller, B., Vatne, G., Ødegård, R. S., & Sollid, J. L. (1993). Mass balance and changes of surface slope, crevasse and flow pattern of Erikbreen, northern Spitsbergen: an application of a geographical information system (GIS). *Polar Research*, *12*(2), 131–146. https://doi.org/10.3402/polar.v12i2.6709

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