

Interactive comment on “Monitoring Tropical Debris Covered Glacier Dynamics from High Resolution Unmanned Aerial Vehicle Photogrammetry, Cordillera Blanca, Peru” by Oliver Wigmore and Bryan Mark

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General comments:

This is a paper documenting a pioneering UAV based study in the Cordillera Blanca in Peru. While UAV studies have become widespread over the past few years still very few applications exist on high elevation glaciers, and only a couple of them to date in the tropical Andes. This is among other related to the challenges of operating a UAV at elevations higher than 4000 m or even 5000+ m. The technical (UAV related) part of this paper is basically ok in my opinion. The question is how much insight the UAV data

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provides in terms of understanding of the glaciological processes. In general I think the paper is stronger on the technical side than on the process side. This is also due to the limited temporal and spatial coverage of the UAV data, i.e. one repeat flight, 1 year after the other, and focusing on the terminus area of the glacier. This limitation is totally understandable considering the challenges of operating a UAV in these conditions, on top of further requirements for high-precision geodetic measurements. And I would reiterate the merit of this study to provide high-resolution information on a debris covered glacier terminus in the tropical Andes where such studies are very rare or missing. However, both limited spatial and temporal coverage implies some constraints: 1 year is little to analyze characteristic patterns on a glacier, and the lack of information for the upper glacier areas limits the process understanding as it needs to ignore the dynamics of the entire glacier. The paper should more explicitly acknowledge these limitations.

Concerning the research questions (RQ) I think they are ok but RQ 3 and 4 are not fully addressed. The process of glacier change should be identified more clearly. E.g. can the effect of ice cliff related mass loss be better quantified? Some more evidence may be provided concerning the proposal that the ice cliffs are the primary control on mass loss. A comparison to other mass loss information on glaciers in the Cordillera Blanca could be useful. I'm furthermore unclear whether the large share of positive elevation change is just related to blocks and cliffs and other objects moving through the scenes?

RQ4 is not addressed in much detail in the paper. E.g. much of the connectivity issue remains vague. I suggest to clarify which connectivity is exactly in place here: hydrological connectivity? Can this be addressed using UAV data? The text on future lake changes is not informed by UAV data. Does it tell us more than we know from other debris covered glaciers? E.g. the time frame?

I suggest some major revisions and re-organization of sections 1 and 2. The current organization is rather odd, or at least unusual, not supporting clarity. The research gaps and objectives should be better worked out. An option is that section 1.1 and 1.2



go in a separate background section after the Introduction. Section 2 could then be integrated in the Introduction.

TCD

Overall, I think the paper is mostly fine on the technical side but needs to be enhanced on the glacier process side, i.e. interpretation of the UAV data to the extent possible, comparison with available data from other glaciers in the region or possibly outside, and further dig into literature supported relevant processes. It may be interesting to be more explicit on the potential and limitations of UAV methods for fostering understanding of glacier change. Certainly, UAV's role for glacier monitoring is strong and increasing. But the authors claim that this data is providing unprecedented insights into glacier processes and this needs to be further elaborated and demonstrated. I'm confident that the authors can deliver a valuable and impact-full paper after some major revisions.

Detailed comments:

Page 2, line 1: rise in average glacier terminus elevation? 2,7: Huggel et al should be 2003 2, 19 ff.: I don't think too many people would agree on the distinction of four primary methods to quantify glacier change. A more classical distinction foresees a distinction of glaciological, geodetic and hydrological methods to determine glacier mass change. I think the four methods identified here are somewhat odd, or arbitrarily identified (e.g. I would not see energy balance modeling as a method to determine glacier mass change). This also relates to page 2, 29 which is an incorrect statement in my opinion. 3,4: you may add that energy balance studies are typically limited to point measurements of a weather station. 3, 24: 10-100 m rather than decimeter (and vertical accuracy may also be indicated with a range) 5, 2: there are other recent studies using UAV in the tropical Andes but they are not yet published, at least to my knowledge. 7, 3: spell out SfM the first time used 7, 22: do you mean outdated for use...? 10, 10: I suggest to compare measured elevation changes to other available measurements in the Cord. Blanca. 11, 25 ff: Section 5.3 is very thin. How compare these velocities to other debris covered glaciers? What are the implications? 13, 14: did the UAV fly over 5000m? In the method section it is mentioned that flight height

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was 100 m above ground which would translate into a max of ca. 4800 m asl. In case you have experiences flying over 5000 m it may be interesting to know and report (but be specific). 13, 15: the insights into the processes that control glacier melt could be enhanced in the main body of the text (see above comment).

List of references: please check. Some references are duplicated.

Figure 7: how was the glacier boundary determined? This is often difficult on debris covered glaciers. It would be helpful if the location of figures 10, 11, 12 could be indicated in Fig. 7. The color scale should be improved: especially the 0 value level could be made more clearly visible.

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