

## ***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***

**Anonymous Referee #2**

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The paper presents UAV survey results from the Cordillera Blanca, Peru. The data are novel, in that they provide information on a comparatively little-studied area and add to the limited number of UAV surveys on high-altitude glaciers. However, for me, the study does not really address its objectives. It measures changes over a portion of the glacier, but does not capture the full volume change. I also question why the velocities were determined manually and for 72 points, rather than using more spatially comprehensive feature tracking. For objective three, the study does not explicitly investigate the role of debris thickness and its links to melt: it identifies debris as a secondary control, because it is thick at the terminus, but does not look at smaller scale varia-

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tions or assess its impact on melt rates at higher elevations. It also does not consider that the debris may well be the reason for the tongues existence and characteristics (e.g. presence of ice cliffs). Overall, the discussion of debris cover is a little simplistic. Similarly, I felt Objective 4 was not properly addressed, and was a more limited discussion of the expansion of melt pools between two surveys, with some speculation about the potential for rapid drainage and lake expansion. I'm not sure how much this section extends our understanding of the interaction between the glacier and the lake. Overall, the paper has some valuable and interesting data, but it needs to be more specific about what the data can actually tell us (in terms of glacier dynamics, ice loss, lake interactions etc.) and the objectives should be re-focused accordingly. It would be good to see more comparison of these processes (e.g. melt cliffs, pools, lake formation) with analogues in the Himalaya: we have quite a bit of data and process knowledge from there, so it would be good to link these results to this literature and to make the comparison between different regions and sizes of glacier. My detailed comments are below. Page 1 Line 10: What about thinning, as well as retreat? Also, altering THE timing. Line 19: Why the only the tongue and not the whole glacier? This would be important for water resources. Line 23: I don't follow how this shows a continued connection to the glacier tongue: the pieces of detached ice could just be melting away in-situ, completely dynamically detached from the glacier. Line 27: First statement needs a reference and give % for the Cordillera Blanca. Page 2 Line 1: Rise in glacier terminus elevation sounds odd. Line 8: is>are Line 13: what is meant by 'geomorphic change for a debris covered glacier'? Do you mean glacier change, e.g. shrinkage / retreat? Line 19: I'm not sure this paragraph is needed. It's pretty general. I think it would be better to just say which approach was used and why, maybe at the start of the methods. I feel like all of section 1.1. is stepping too far back in terms of explanation and would be much better if it cut out the general material about each method, and focused specifically on its previous application to the study area (or relevant comparison glaciers, e.g. debris-covered glaciers) or why it hasn't been used previously. The paper does link to the study area at points, but it would benefit from

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a tighter, more focused argument throughout. Page 5 Line 4: I like that the objectives are clearly stated. Line 15 & 16. Reference if possible. Line 26: How was this determined? By this study or previous work? Needs to be cited if it is the latter. Page 7 Line 22: dated for use? Line 28: Was this why only the lower portion of the glacier was surveyed? Page 8 Line 16: DEMs (remove the ') Page 9 Line 1: Why do this manually? Why not use e.g. Cosi-Corr or Imgraft? This should give you a much more spatially extensive velocity field, so you don't need to interpolate. The glacier is quite small, but 72 points does not seem a lot when you have a heterogeneous surface (pools, cliffs, debris cover). Based on Line 5, I'm not clear if these offsets were then used to calculate the distance the cliffs were advected by the flow or to determine how much they had melted back (i.e. by taking out the velocity component and then subtracting the two DEMs). If the data are being used to estimate ice cliff melt rates, then can we really accurately separate out the local flow velocity from the melt rates (which are likely to be a few tens of cm, to a couple of meters) using just 72 points? Page 10 Line 12: For me, this shows a limitation to addressing objective 2 (and 4, to a lesser extent). We can't assess total volume changes or its potential future evolution, without accounting for the entire glacier. Line 23: As noted above, how confident can we be of removing the horizontal velocities local to the ice cliff, when 72 points were used across the glacier? Line 27: Needs a reference. Line 31: Quite vague and speculative. Do you have any data on debris thickness? Page 11 Line 6: I don't think you can say debris cover is secondary here. First, the differential melt associated with ice cliffs is at least partly due to the removal of the debris layer. Second, the presence of the thick debris layer may well be why this tongue still exists at these altitudes (you note earlier in the paper this is a comparatively low altitude for the region), so although it doesn't increase melt rates, it is still an important control on them. There are no in-situ measurements of melt versus debris thickness, so I think it is hard to make this statement, particularly as the study only focuses on the tongue where the debris cover is thick. Debris may well be important here for suppressing melt, then accelerate melt further up. Line 10: I'm unclear how much of the change discussed earlier in 5.2. is due to this movement

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of large objects, versus net change. We need to distinguish the two for e.g. forecasting water resources. Line 32: How? It would be tricky for the lake water to get very far up glacier. Could also relate to basal topography. Figure 4: I would make the dots bigger, so they are easier to see. A black outline would help. Figure 7: Make the scale bars categorised, rather than stretched, as it's easier to read of individual values. Figures 9-12. It would be useful to have some context about where these sites are, e.g. using extentboxes on Fig. 1 or 2.

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