Response to Reviewer

Manuscript: Brief Communication: The Khurdopin glacier surge revisited – extreme flow velocities and formation of a dammed lake in 2017

Reviewer: D.Quincey

We greatly appreciate the concerns raised by the Reviewer and respond to each of them below. Original comments by the reviewer are in bold, followed by our response. Note that the page and line number are always given twice, once for the document with markups which is provided at the end of the Response, and once to the revised manuscript without markups, which will be provided later.

The key take-home message is currently a bit hidden. It seems to me that the new findings are: 1. that the surge return period appears to be of the order of 20 years (whilst acknowledging that n=2); 2. that surge velocities may be even faster than previously realised – implications for erosion and sediment transport; 3. that there may be a topographic control on this particular surge (but this needs much greater discussion – see following point); 4. that the ice-marginal lake is posing a hazard to local communities.

If the abstract and the conclusions could be modified to give the key message much greater prominence the manuscript would have greater impact. 2. The relevance of the steep bed topography at 12-km needs some further discussion/ explanation. Is the suggestion that it provides a control on surge dynamics? Or even that it is responsible for the spatial imbalance in flow? Presumably it doesn't provide a bottle-neck to flow (I imagine the opposite if anything)? Is the modelled ice particularly thin above the step and potentially frozen? Some consideration of the possibilities would be a welcome addition. 3. There appear to be many more velocity datasets discussed in the text than presented in the figures. Is there a reason for not showing all of the velocity data? It would really help with visualising the evolution of the surge to have them all (or at least more than the current three) available. 4. The discussion of whether the surge is thermally or hydrologically triggered lacks real evidence so I would suggest toning it down or even removing it. It is likely that both thermal and hydrological processes will be at play as you infer in your own discussion. 5. There needs to be some uncertainty analysis of the dh/dt data. How well coregistered were the DEMs? Showing off-glacier areas of dh/dt data (and velocity data) would help here, as would the distribution of those values. This extra analysis would be a good addition to the Supplementary, with uncertainty shading added to the figures and an error range added to the values stated in the main text.

We would like to thank the reviewer for these suggestions and our response is found below.

We have adapted the abstract and especially the discussion and we have toned down the discussion on the switch hypothesis. We also extended this analysis of the steep topography section at km-12 and this reveals that ice deformation as well as hydrology may be important drivers. By now showing all velocity data of all time steps during the surge, we show the added value of these new satellite products, also for broader applications. We have also added a quantification of the DEM errors and we show this in figure S1 in the supplementary material.

Minor comments:

P1 12: 'during a surge of the Khurdopin Glacier in 2017.' (also elsewhere, glacier should be Glacier where you are referring to it by name).

Thanks for pointing this out. We have amended it throughout the manuscript.

P1 15-16: I'm not sure there is evidence for a surge front in the data you show here?

Thanks for pointing this out and as reviewer 2 has pointed out, the definition of front may have been used too subjectively here. Compared to other surges in the region and as you pointed out in (Quincey and Luckman, 2014), perhaps Khurdopin can be classified as not having a surge front. We have removed the reference to a front in the text.

P1 19-20: do you show these surface observations? It's difficult for the reader to believe the extra lubrication suggestion without seeing evidence.

In the Brief Communication format we are limited in terms of space and we have refrained from showing additional images. We agree however that this is an essential aspect and should be visualized. We have therefore included a 2-panel plot showing this distinct change in surface features in Fig 3.

P1 26: this is maybe misleading: : : has an increase in frequency been reported? Or just an increase in number? And is that not because we have better and better data? Without repeat datasets (like those presented here) we can't say for sure whether frequency is increasing or not.

We have based our statement mainly on the observation in these two papers, where especially (Copland *et al.*, 2011) argues that *"Given that our ability to detect surging using satellite imagery has remained essentially constant since the 1970s, we must therefore consider whether there have been changes in forcing over time."*. We agree however that this cannot be fully ascertained from the data we have and have therefore amended our text accordingly in P1L30 / P1L26. For Khurdopin specifically no increase in frequency can be found. If we can take the main floods from upper Shimshal as a proxy (1979, 1960, 1944, 1923, 1901 or 1904 and possibly 1882), this corresponds to return periods of 22 (19), 19 (22), 21, 16, 19, 20 and 18 years from the end of the 19th century until today (Hewitt and Liu, 2010).

P1. 34-35: what do you mean by 'understanding regional glacier behaviour'? Is 'in order to advance knowledge of basal processes, non-steady flow more generally, and erosion and sediment transport in the region' perhaps a better justification?

We agree that our explanation is too generic and we have replaced it including the suggestions made in P2L1 / P1L36.

P2 3: name the glacier here, and also specify in the next sentence that it's the Khurdopin lake (not Kyagar) that has previously caused destruction.

Thanks for the comment, we have adapted the text at P2L10 / P2L7.

P2 8: maybe 'recent' is better than 'novel' here? Novel implies something a bit different about it.

Thanks for pointing this out, we have changed this as suggested.

P2 9: do you actually quantify the mass transfer somewhere? I don't see it.

We have now provided an estimate of the volume flux based on the height changes in P4L16 / P3L26. As we do not have full glacier coverage with the DEMs (with the areas above the tongue being especially erroneous) and there is uncertainty in the DEMs, we cannot close the mass balance. It is therefore not possible to quantify the total volume/mass flux.

P2 16: was the ASTER DEM derived by USGS? Or by the authors? In either case, some further information is required about its expected vertical accuracy and how well it performs against the TDX DEM.

The ASTER DEM was generated through the AMES pipeline (Shean *et al.*, 2016) and we have now specified this in P2L27 / P2L19 and additionally added a discussion of vertical accuracy and our applied corrections in the Supplementary Material.

P2 22: can you add the value (of mass loss) here?

We have added a value of volume change in P4L16 / P3L26.

P2 23: is it subglacially sourced for sure? I've always imagined it to be plucked from the spur where the two main tributaries meet.

This may indeed also be the case. As Reviewer 1 suggested however this information is not strictly essential for this paper so we have removed the whole sentence.

P2 26-27: is there a reason why you don't show these finer resolution velocity data?

We have initially omitted showing these data for reasons of space in the Figures. However, also in accordance with Reviewer 1, and to further underline the value of the new Planet data we now show all velocity profiles during the surge in Figure 1 and provide all profile data in TableS3 in the Supplementary Material.

P2 31: maybe reword to 'does not always allow the onset, peak and termination of the surge to be accurately identified, the data suggest that'?

We have changed this as suggested.

P2 32: not sure 'build-up' needs italics (here or at line 38)?

This is indeed not necessary and we have amended it.

P2 32-40 change to past tense here ('were below… and quickly rose…increased in1998… and peaked in spring 1999… phase lasted until… glacier had reached… was characterised by… velocities had reached…had further accelerated')

Thanks for taking time for these comments, we have changed to past tense accordingly.

P3 7: I'm not sure Figure 3 really supports this statement

To support this statement we have now adapted Figure 3 to show the ponds before and crevasses after the surge.

P3 9 and 14: if the lowermost 1 km of the glacier is not impacted by the surge is the length change not zero? What is meant by length change here (if not position of the terminus)?
In Section 4 we refer to the changing part as “active tongue”, which is the part of the tongue above the green line in Figure 3. Like on neighbouring Yazghil Glacier, Khurdopin has developed an ice-cored moraine at the terminus that downwastes but does not change position anymore since many years. As such it does not seem to be dynamically connected to the actual tongue anymore. We have clarified this in the text.

P3 20-21: this is a long section between the commas – consider moving ‘at rates comparable to those of the quiescent phase’ before the first comma

Also based on comments by Reviewer 1 we have revised and shortened this sentence.

P3 32-38: it should be a short step to calculate the volumes from the DEM data – these values would be a valuable inclusion here.

We have now added an estimate of ice volume gain in P4L16 / P3L26.

P4 21: not quite true. The recent Hispar paper (doi:10.3390/rs9090888) by Paul et al. show comparable velocities

Thanks for pointing this out, since this publication was published after our submission we have not included it. We have now referred to it accordingly in P6L5 / P4L37.

P4 25-27: as far as I can tell the Planet imagery did not contribute to the data you present here other than the overview in Figure 3.

Also following the main comment from the reviewer we have now made sure to emphasize the value of the Planet data for this study throughout this Section and in the Discussion. Additionally, we show all velocities derived from Planet pairs in figure 1 and in the Supplementary Material.

Figure 1: some co-ordinates either here or in the text would help readers not familiar with the glacier to locate it.

We now refer to figure 3 in figure 1 for a location and have provided coordinates in P2L4 / P2L1

Figure 3: I’m not sure the wiggles are best described as ‘centrelines’? Are they not the contorted medial moraines that have shifted position?

Thanks for the suggestion, we have changed this.

Supplementary: can you provide the image tile names in each case?

We have now expanded table S1 in the Supplementary Material and provide details for each separate scene.

Supplementary: Table S1 should be S2 in second case (and should SRTM be included here?).

We have amended this.

Supplementary: the animation is excellent. Should it not be referred to somewhere in the text (or it may go largely un-noticed)?

We refer to this now in figure 1.

References

Copland, L. *et al.* (2011) 'Expanded and Recently Increased Glacier Surging in the Karakoram', *Arctic, Antarctic, and Alpine Research*, 43(4), pp. 503–516. doi: 10.1657/1938-4246-43.4.503.

Hewitt, K. and Liu, J. (2010) 'Ice-Dammed Lakes and Outburst Floods, Karakoram Himalaya: Historical Perspectives on Emerging Threats', *Physical Geography*, 31(6), pp. 528–551. doi: 10.2747/0272-3646.31.6.528.

Quincey, D. J. and Luckman, A. (2014) 'Brief communication: On the magnitude and frequency of Khurdopin glacier surge events', *The Cryosphere*, 8(2), pp. 571–574. doi: 10.5194/tc-8-571-2014.

Shean, D. E. *et al.* (2016) 'An automated, open-source pipeline for mass production of digital elevation models (DEMs) from very-high-resolution commercial stereo satellite imagery', *ISPRS Journal of Photogrammetry and Remote Sensing*. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS), 116, pp. 101–117. doi: 10.1016/j.isprsjprs.2016.03.012.