Response to Reviewer 2

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The authors would like to thank the Editor and reviewers for their careful reading and constructive comments on our first submission.

In response to this feedback, we have made major revisions to the manuscript, including significant additions. We hope that this version addresses the comments of the Editor and referees, and that our manuscript can now be accepted for publication.

We now respond, in more details, to the comments from Reviewer 2.

> L30: it would be useful to describe more explicitly as to which 'combinations of regional… and local… factors encourage instability', and in particular whether these are found in HMA

This has been done following reviewer's 1 recommendation.

> L43: change to 'distribution of surge-type glaciers…'

This has been fixed.

> L45: it's a bit debateable to state that 'no HMA-wide inventory of surge-type glacier exists', as one is already encompassed within the global study of Sevestre and Benn (2015). So I would refine the wording to say something like no 'dedicated' HMA-wide inventory currently exists.

We agree with the reviewer that this statement was debatable. We now have rephrased this sentence to mention the study of Sevestre and Benn (2015).

> L46: state which hazards are being referred to here – e.g., ice-dammed lakes? Perhaps also ice avalanches?

This has been fixed.

> L60: change to 'studies have documented…'

We have fixed this.

> L75: you say here that you identify surge-type glaciers from distinct widely used criteria, but the studies that you quote all use the presence of looped surface moraines as a major criteria, whereas it seems that you don't. It would be useful to add a sentence to make this clear, and to explain why you don't use this criteria.

The main aim of this study was to design an approach which could identify quantifiable changes in glaciological quantities associated with surging such as surface velocity and surface elevation. This methodology needed to be applicable to glaciers across HMA regardless of their surface characteristics (clean or debris-cover). Whilst we agree with the reviewer that incorporating the identification of geomorphological features, such as looped moraines or indeed a variety of other observable features (thrust-block/push moraine or ice strandlines) could be beneficial to validate the identification of surge-type behaviour, it would have limited our ability to conduct our analyses efficiently at a large scale as each glacier would have needed individual investigation to establish the presence of such features and their relation to surge behaviour. As a result, we chose not to incorporate the analyses of geomorphological features into our approach to identify surge-type glaciers.

> L78-80 (and elsewhere, e.g., L85): specify the time period that you're referring to for 'substantial and spatially concentrated surface elevation changes' and 'substantial variations in a glacier's velocity field' to be classified as indicative of surging

We have fixed this and now mention the typical time period considered.

> L97: I believe that the measurement periods for Hugonnet et al. (2021) are 2000-2004 and 2005-2009 (also check caption for Fig. 1, which should be 2010-2019, and elsewhere throughout your paper). See: http://maps.theia-land.fr/theia-cartographic-layers.html?year=2021&month=09&collection=glaciers

We thank the reviewer for bringing this point forward. We have modified the manuscript in agreement with the reviewer's suggestion.

> Fig. 2a: I assume that Fig. 2a shows the velocity patterns for a non-surging glacier, so make this clear in the caption. It would also help to highlight the positive heavy tail in Fig. 2b if you used a symmetrical x-axis scale for Fig. 2b (e.g., -150 to +150), to match the symmetrical scale already used for Fig.

We have fixed the figure's caption and now clearly mention the dynamical regime of each glacier.
The symmetrical x-axis in Fig.2a results from the symmetry in the distribution.
Representing the distribution of 2B on a similar symmetrical axis, would mean representing pixels that do not exist (from -20 to -150), while the shape of the distribution and the colorbar in Fig.2b highlight the disymmetry in that distribution.

> L139: provide the resolution in m that defines VHR

We have fixed this.

> L140: capitalize Bing Maps (and elsewhere, such as L161)

This has been fixed.

> L140: I don't know what 'infirm' means in this context; do you mean 'infer'?

We have now replaced infirm with rebut.

> L163: you provide the resolution of the velocity data here (240 m), but this should also be mentioned in Section 2.2

We now mention the resolution of ITS_LIVE yearly velocity datasets in Section 2.2

> L173: to avoid any potential ambiguity, I would suggest modifying this sentence to say something like 'at least 2 of 3 proposed identification criteria of rapid changes in surface elevation, surface velocity and surface crevassing' (assuming that these are the criteria that you're referring to here!)

We have rephrased this sentence using the reviewer's suggestion.

> L11 and L184: I'm not convinced by the statement that you newly identified 491 surge-type glaciers as it seems that you're only making comparisons with the RGI here? After working with the RGI myself, I know that their inventory is incomplete for their designation of which glaciers are surge-type. Rather, you need to make comparisons with other previously published studies to obtain an accurate number of which glaciers you've newly identified as surge-type, as you already do in Section 4.2 and Table 4. Indeed, Table 4 suggests that you haven't identified many new surge-type glaciers in some regions such as the Karakoram, and may have actually missed large numbers of them in the Pamirs.

We thank the reviewer for bringing this important forward.
We now have made an in-depth comparison between our inventory and the one proposed in Sevestre and Benn (2015) and found 490 newly identified surging glaciers.
We have added a substantial section within the Discussion which reads as follows :
"Sevestre and Benn (2015) proposed the only existing regional inventory of surge-type glaciers in HMA. The number of surge-type glaciers documented in our inventory significantly differs from that of Sevestre and Benn (2015), especially in the Pamirs.
A further examination of the Sevestre and Benn (2015) inventory reveals that, out of the 827 surge-type glaciers documented, 284 correspond to individual tributaries within glacier complexes which are not individualized in the present study.
From the remaining 543 glaciers, 35 documented in the RGI V5.0 (on which Sevestre and Benn (2015) is based) do not exist in the RGI V6.0.
Furthermore, we found that the proposed inventory and the one from Sevestre and Benn (2015) only share 83 identified surge-type glaciers in the Pamirs.
This yields a difference of 390 surge-type glaciers between the two inventories.
Upon further examination of the remaining glacier population we note a median glacier area of $1.6km^2$, a sixth of the median area of the surge-type glacier population described in the present inventory ($9.6km^2$).
Of those 390 in the Sevestre and Benn (2015) inventory, 30% present an area small than $1.0km^2$.
Close examination of these glaciers (Ujsu Glacier and the glaciers in its direct vicinity such as Aldzhaylau and Rakzou glaciers) using the surface elevation and surface velocity change data over the

period 2000-2018 did not yield any evidence of surge-type behavior.
We rather observed constant glacier mass loss and recession, with no clear signal of instability-related velocity anomalies.
Furthermore, no mention of such a high number of surge-type glaciers in the Pamirs can be found in the literature used by Sevestre and Benn (2015).
Kotlyakov et al (2008) indeed refer to Osipova et al (1998), mentioning "630 glaciers with indications of dynamic instability, 51 of them identified as surging", they later state that 55 surge-type glaciers had been documented up to 2006 in the Pamirs.
Given these unclear, conflicting and interpretive records of unstable glacier dynamics, the small sizes of glaciers in that population compared to other surge-type glaciers in the present and other studies (see next section), the lack of evidence for unstable behavior over the 2000-2018 period, as well as the new considerations laid by the enthalpy balance theory (Benn et al, 2019), we here question the surge-type behavior of this subset of 390 glaciers in the Pamirs.
Assuming we were to consider that population of glaciers as indeed surge-type, the estimated glacierized area covered by surge-type RGI polygons in HMA would become 20.6%."

> L199: to reinforce the point that there is high correlation between the geometrical parameters, it might be useful to state how longer glaciers by definition have shallower slopes if they cover the same elevation range as smaller glaciers.

We have rephrased the original sentence following the reviewer's suggestion.

> Fig. 5: please include part labels (a, b, c, d) for these figures, and indicate in the caption as to which geometrical attribute each figure part shows. It's currently a bit cryptic to try and figure out what log_range refers to, for example. Also provide units for each x-axis.

We have changed Figure 5 according to the reviewer's suggestion.

> L235: I dislike sentences with clauses in brackets as it makes them difficult to follow, particularly when there are multiple such sentences back-to-back. It takes about the same amount of space to write out the sentences properly, but makes them easier to understand: e.g., 'We however note that balance distribution for surge-type glaciers in the Karakoram is positively skewed with g = 1.1, and negatively skewed with g = −1.4 for non surge-type glaciers.'

We have rephrased the paragraph following the reviewer's comment.

> L238: I don't follow the comment that the Himalayas are not representative with <10 surge-type glaciers, as Fig. 7 specifies that the Himalayas has n=13 surge-type glaciers, and Table 1 suggests n=14 (unless Himalayas is defined in a different way in Fig. 10 than in other figs and tables, which relates to my comments below)

This typo has been fixed.

> Fig. 7 and 8: please clarify how the six regions here compare to the HIMAP regions listed in Table 1 (perhaps by adding an extra column to Table 1?). For example, I can't figure out which of the six regions the Gangdise Mountains fits into. Some numbers also seem to be inconsistent between Table 1 and Figure 7: e.g., Central + Western + Eastern Himalaya = 14 in Table 1, but n = 13 in Fig. 7. Also present the figure parts in the same order in each figure so that it's easier to compare them (e.g., Tien Shan is shown first in Fig. 7, but Tibet is shown first in Fig. 8)

We have fixed this following the reviewer's comments.

> Fig. 9 and 10: these use 8 regions, compared to the 6 regions in Figs. 7 and 8, and 22 regions in Table 1. This makes it essentially impossible to make comparisons between the different figures, and makes it even more confusing as to which regions in Table 1 are included in which regions in the figures. Please be consistent throughout, and clearly define how the regions relate to each other.

We agree with the reviewer that regular switches between the use of greater HIMAP and standard HIMAP regions was misleading and affected the manuscript's clarity.
Following the reviewer's suggestion, we have added a new column to Table 1 to clarify how regions relate to each other.

> L242 (and elsewhere): formal glacier names should be capitalized when referring to a single glacier: e.g., Khurdopin Glacier, Hispar Glacier

We have fixed this.

> L244: add superscript -1 at the end of: ' -0.22 – 0.3 m w.e. a-1'

This has been fixed.

> Fig. 11: I don't follow the x-axis label for parts a and b: how can the units be both dimensionless and in m yr-1?

This was meant to remind the reader with the original unit of the datasets used in this figure.
We however have removed the unit.

> L260: I've read little, if anything, about previous surges lasting for 18 years in the HMA, so it would be useful to expand on this to provide more information about the location and characteristics of these, and how you can be sure that they surged for that entire time. Presumably it would also be more accurate to say 'at least 18 years', since this is the maximum length of your record?

The surge-type glaciers documented in this inventory are represented using RGI polygons, as tributaries are not individualized. The glaciers displaying surges as long as 18 years hence are glacier complexes showing sequential surges of their different tributaries.

We further wish to mention that the works from King et al. (2021) document surges in the Geladandong involving elevated velocities for ~15 years.

> L261: Is the equation reference here correct? IPR is defined in Equation 3, while Equation 4 defines the surge index.

The reference to Equation 3 has been corrected.

> L271: ‘active phase’ is repeated twice here

This has been fixed

> L278: change to ‘prevents identification of active phases…’

We have fixed this.

> L286-7: this statement is a bit meaningless without anything to back it up; instead, it would be useful to provide some specific numbers here to convince the reader that the patterns you measured are real. For example, provide an average value for the quoted elevation uncertainty in the Hugonnet dataset, and state what the average elevation changes were that you measured on surge-type glaciers. Same for velocity changes.

We thank the reviwer for bringing this point forward. We have provided an average value both for the quoted elevation uncertainty and the quoted surface velocity uncertainty.
The secion has been entirely reworked and know reads as follows :
"'The surge-type glacier identification criteria which we have followed are built on a number of different publicly available datasets generated in previous studies.
Each of these datasets are imperfect representation of real geophysical signals and attributes and present a level of uncertainty.
The error associated with the elevation change datasets of Hugonnet et al (2021)} varies somewhat between different time periods.
Between 2000-2005 and 2005-2010 the mean error over glacier surfaces in our inventory is 1.04 m a-1 and 0.97 m a-1, respectively. The mean error over glacier surfaces in our inventory using data from Brun et al (2017) is 0.43 m a-1, although we note lower coverage of this elevation change dataset over higher reaches of glaciers, where associated error would also be higher.
Error estimates associated with the elevation change dataset of Shean et al (2020) are not freely available, but we would expect similar levels of error to be associated with these data to those of Hugonnet et al (2021). Shean et al (2020) estimate similar levels of uncertainty alongside their geodetic glacier mass balance estimates, and as surface elevation change error tends to dominate the geodetic mass balance budget, the error associated with the underlying elevation change data should therefore be similar.
Importantly, the error associated with elevation change datasets over glacier tongues is predominantly well below the magnitude of the changes associated with surge behaviour (up to 10 m a-1).
The error associated with the surface velocity data similarly varies between different periods, due to the

switch from Landsat7 to Landsat 8 imagery.
Between 2000-2013 and 2013-2018 the median error in glacier surface velocity in the inventory is around 1.35 m a-1 and 0.37 m a-1 respectively.
The maximum error is significantly larger for 2000-2013 than 2013-2018, with 63 m a-1 and 11.3 m a-1.
Errors in the ITS_LIVE surface velocity dataset typically cluster in the accumulation area of glaciers, where trackable features are less abundant.
The use of error-weighted surface velocity fields (Section 2.2) ensures a greater penalization of aberrant surface velocity pixels in the accumulation area.
In the ablation area and over glacier tongues, errors on surface velocity lie well below the magnitude of changes in velocity resulting from a surge (up to 150 m a-1)."'

> L296: remind the reader here of what the discriminatory criteria are, so that they don't have to go searching back through the previous sections

As suggested by the reviewer, we now remind the reader of the diagnostic criteria.

> L302: change to 'certain level of certainty'

This has been fixed.

> L315: you also need to make comparisons with the inventory of Sevestre and Benn (2015) here. You currently do this in section 4.3, but that text would be better moved to here. It would also be helpful to discuss why Sevestre and Benn (2015) identify so many more surge-type glaciers in the Pamirs than you, even after removing their duplicates.

We agree with the reviewer on the importance of a comparison between our inventory and that of Sevestre and Benn (2015). As mentioned earlier, we have added such a discussion where the reviewer suggested it.

> L322: you're missing the inventory of Copland et al. (2011), who identified 90 surge-type glaciers in the Karakoram

We thank the reviewer for bringing this important reference to our atention. It has been added to our manuscript following the reviewer's suggestion.

> L350: change to 'up to 45% of total glacier area…' to make it clear that you're referring to the entire glaciated region here, and not just the proportion impacted on each individual surge-type glacier

We have fixed this using the reviewe'rs suggestion.

> L372: seem to be missing some words here? 'in mass balance a single…' doesn't make sense as written

We have rephrased this sentence.