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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Glacier detachments and rock-ice avalanches in the Petra Pervogo range, Tajikistan (1973–2019)" *by* Silvan Leinss et al.

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Final response letter

Adressing comments by anonymous Referee #2, including references to comments and answer by Referee #1.

We thank both reviewers for their timely response, for carefully scrutinizing the manuscript, and for the time spent on the manuscript and for their valuable comments to improve the paper. Here, we first address the general comments of both referees, followed by a list of brief technical corrections and brief responses to detailed comments.

General comment 1, Referee #1: "(..) this paper lacks key information on the method-

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ology used to identify and classify detachment and other mass flow events. (. . .) I would recommend adding a section to the introduction that describes the dichotomy of event types which are addressed throughout the paper." in agreement with the general comment 1 of Referee #2: "The authors (. . .) missed more detailed description of their methods to detect the glacier dynamics because clear definitions are missing"

Author response 1: We totally agree with both reviewers and will start the paper with an introductory description/dichotomy of different types of catastrophic mass flows (CMFs) following (Evans and Delaney, 2015). Further, we will add a paragraph to the method section 3.1 where we describe how we distinguished the observed CMFs using optical imagery (For details see answer to general comment 1 in AC1 the interactive discussion). Following that, We will try to structure the subsequent method sub section according to data attribute collection (as suggested by the specific comment 4 of Referee #1). We will also thoroughly check the entire paper for consistend usage of the terms detachment, ice/rock/rock-ice avalanche and glacial debris flows. The above points are in agreement with answers to specific comments 1), 2) and 4) of referee #1 in the interactive discussion.

General comment 2, Referee #1: "the conclusions drawn about climate change and temperature are largely unsubstantiated given that the inventory of detachment events was collected from data with varying resolution and quality, and may therefore be biased towards more detections with higher quality (recent) imagery."

Author response 2: As already outlined in the interactive response to Referee #1 (general comment 2), we fully agree with that our inventory is very likely biased towards more recent events where a larger number of different satellites are available, and where a much higher spatial, radiometric and temporal resolution is available. To support this, we will add a graphic (attached) which visualized the increasing number of satellite imagery. However, we like to stress that we think to be able to compensate for this bias, because in Fig. 9 we compare the annual mean air temperatures of the events with the temperature from the linear trend of annual mean temperatures of

the past 46 years. We do not draw our conclusion from the recent increase in event observations but from the fact that most events happen in years with above-trend temperatures. We will clarify this in the conclusion and will mention that despite of an observational bias of the inventory, the comparison of the annual mean temperature with the long term annual temperature trend allows for the conclusion that during rising temperatures, where frequently new record temperatures are observed, more detachments can be expected. (Answer in agreement to specific comment 3 of referee #1 in interactive discussion).

General comment 3, Referee #2: "there might be more scenes of declassified data (KH-4a/b or KH-9) which have a high resolution up to 2m and could give further insights into glacier states in the past (1960 - 1980). This data would also show glacier surface structures like crevasses. This could also improve the lack of highquality data from early Landsat missions."

Author response 3: We have checked the USGS Earth Explorer dataset and found in total 22 acquisitions from KH-3, KH4, KH4a/b, and KH-9 dating back untip 1961-08-30. In only seven of them, the surface is well visible. Other imagery shows dense clouds or too much snow cover. In the high resolution imagery, we found in the entire area strongly crevassed glaciers but, except for the 1973 event, no clear evidence of major mass flows. In some valley, missing vegetation could origin from past mass flows but these could also be simply erosion patterns. We will have a closer look at this imagery but do not expect much additional information.

General comment 4, Referee #2: "Another idea to improve the variability of datasets is to analyse Russian topographic maps. The maps at least in 1:100.000 are available online and maybe it is possible to find 1:50.000 as well."

Author response 4: There seem to be some inofficial sources of Russian topographic maps found on vlasenko.net. However, on https://maps.vlasenko.net/soviet-military-topographic-map/ only the scale 100'000 seems to be available. Examples

for the PetraPervogo Range are: https://maps.vlasenko.net/smtm100/j-42-034.jpg and https://maps.vlasenko.net/smtm100/j-42-046.jpg. Scale 50'000 is not provided for the region of interest. However, as these maps have are derrived products, they don't provide any precise enough information about the status of glaciers or topography.

General comment 5, Referee #2: I like the idea of DEM differencing to detect glacier changes but how reliable are the DEM datasets? Especially in steeper regions (and that is one of your cases) the DEMs show quality issues.

Author response 5: See line 134 where we wrote: "Volume uncertainties associated with all DEM differences were estimated follow the method described in (Miles et al., 2018).". Based on our experience with radar DEMs, slopes oriented in the azimuth direction (north/south) can be observed quite well. As all glaciers for which we studied DEM differences show an exposition towards north, they are not affected by layover or shadow. Using optical imagery (WorldView) we studied the DEM differences only for slopes lower than 30 degree where no significant quality issues are present. We will add the information to the method section that "derived volumes were estimated only on glaciers with slopes lower than 30 degree" (See also Table 1 and 3).

General comment 6, Referee #2: What about other DEMs? You would get more difference images to better investigate changes over shorter periods.

Author response 6: We are not aware that other DEMs with specific time stamps and sufficient quality are available for the region.

General comment 7, Referee #2: "Your results section is very difficult to follow. Please make the structure clearer. Maybe it would make sense to combine the results and discussions section so that the reader can better connect the different cases." We will follow the suggestion in the specific comment 4 of Referee #1: "I would also recommend removing or shortening the portions of the Results section that highlight the smaller events that are not discussed further. Highlighting them with reference to Table 1 may be sufficient. Instead I would focus more on the major events which you have

more data for and include in the discussion."

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All technical corrections / detailed comments will be considered as listed below:

Answers to technical corrections from referee #1: - L2: typo corrected. - L7: annual mean temperatures. - L7: rephrased this and the following sentence to "Digital elevation model (DEM) differences indicate a surge-like behavior about 10 years before the two largest detachments, but different to other detached glaciers, one glacier retreated before detachment while the other remained stagnant before increased sliding pronounced the impending detachment." - L8: Inserted "Digital" in the above sentence. - Unclear what is meant by "pronounced" in this context. Would "preceded" be a better description here? – we meant "signalized" but as increased velocities do not signalize a detachment, preceded is the better choice. - L18: subsection label 1.1 removed. - L21: Removed "a"; changed "low slopes" to "low-angle slopes". - L22: reformulated as suggested. - L23: We mean: "Glacier surges are favoured by an envelope of climatic conditions (sevestre 2015). - L24: Yes, we will distinguis and include rock avalanches (observed in the Shikorchi catchment). - L25: replaced by "For all three classes, potential energy is transformed. . ." - L26: replaced by ", and also additionally entrained sediments, " - L27: suggestion accepted. - L29: accepted "which increases the potential for such events to reach inhabited areas." - L35-36: removed "which". - L46: Removed "of a series of". - L48: Changed as suggested. - L49: Chose present tense. - L58-59: Corrected citation format for in-line citations according to journal standard "by Kääb (2020)". L60-61: we checked that "runout" is used consistently throughout the manuscript. - L61: Inserted "the". - L72: Missing word "events" added. - L79: Year for Ibrohim et al. reference? Unfortunately, we neither found a year nor received a response to a possible copyright request to reproduce the map. - L89: wording changed as suggested. - L90-91: run-out replaced by runout. - L102: change irrelevant as we will replace the paragraph by a graphic and table. - L108: Wording changed as suggested. - L111: typo corrected. - L116: Should rock

avalanches also be included in this? At some points throughout the text you distinguish between rock and ice avalanches, while at others you seem to use the terms “ice avalanche” and “rock avalanche” interchangeably. Please clarify your terminology and make it clear to readers whether your use of “ice avalanche” encompasses both rock and ice (and rock-ice) avalanches or is distinct. – Will be done as sugessted in the general author response 1. - L118 done. - L118-119: How did you distinguish the runout zone from the source (detachment) zone? – We did not distinguish and mapped the entire avalanche area. We will clarify this. - L128: Please write out the full name prior to introducing an acronym. – As we do not use this acronym further in the text, we replaced “using SETSM (ref)” by “using the SETSM-algorithm (ref)” - L129: typo corrected. - L132: How did the DEM differencing reveal a previously unknown event? What criteria was used to classify this as an event? – The DEM difference revealed a negative height change of a suspicious shape. Using optical satellite imagery, we could classify the event according to the described classifiers. - L134: typo corrected. - L134-135: inline reference formatting checked. I think “in (author+year)” is correct, and also “by author (year)”. But not “in author (year)” and also not “by (author year)”. - L135-136: Are clouds the only cause for large differences in your images? Please discuss other potential sources of error. What about snow cover? What is the intrinsic error of individual DEM layers based on processing etc.? – Yes, clouds were the only cause for large DEM errors. We will still mention whether snow cover posed a problem and will mention intrinsic DEM errors. L142: Was this [studying DEM differences] only done for the events that you know are detachments or also for rock/ice avalanche events? If so, how were detachments distinguished from the other event types? I would work to clarify your terminology surrounding detached glaciers versus rock/ice avalanches and make it clear whether you are using the overall term for both types of events. – This was only done for the two largest detachments. For differentiation between different events, see suggestion in answer to general comment 1. L147: grammar corrected. L152: “Earthquake” used throughout the paper. L152: What was your screening criteria for determining whether an event was triggered by an earth-

quake or not? – As written, we checked for earthquakes (> mag 5, within 14 days of event and within 100 km radius). Then we discuss smaller earthquakes (> mag 4.5) within a closer temporal/spatial proximity to the events. L170: Terminology of mass flow, detachment, rock/ice avalanche will be defined earlier in the text. L191: typo corrected. L197: changed “leading and” to “leading to”. L203: terminology will be clarified. L211: replaced “unusual crevassing” by “Crevasses, surrounding the detaching area, become increasingly visible”. L212: removed “heavy crevassing” L232: typo corrected. L287: long term trend -> 46 year trend. L290: “Earthquake” used throughout the paper. L314: Grammar corrected. L329: large = Mass flows with runouts larger than two kilometers or wider than 50 - 100 m. L335: In reference to your point about vegetation being missing in strongly eroded valleys, what about areas/ecosystems/elevations that would not be expected to sustain vegetation in the first place? – It depends on how fast any surface reaches its “equilibrium color” after perturbation by an external event. L336-337: how do you distinguish between snow and clouds? - Clouds are at a higher elevation and show therfore stronger scattering of SWIR radiation which is absorbed by moisture in the atmosphere before reaching snow cover. L342: typos corrected. L345: typo corrected. L355: sentence corrected. L362-363: Here you briefly describe the criteria used to distinguish glacier detachments from other types of mass flow events. I would recommend moving this discussion to the methods section and expanding on it in more detail. This is a critical piece of how you collected your results, but has yet to be mentioned in the text. – Will be moved to methods in accordance to the general comment 1. L363, 381; typos corrected. L414: “Earthquake” corrected. Figure 1: We will add a north arrow and specify what we modified (borders and labels added). Table 1: other events = glacier avalanches, rock avalanches and rock-ice avalanches. Events will be distinguished according to the general comment 1. Table 1: What does “yes” in parentheses mean under the “surge observed” category? – It means, in the past, but not directly before the detachment, a surge-like dynamics was observed. Table 1: What does your Slope measurement correspond to? – It’s the slope of the detached area.

Figure 3: The presence of increased crevassing in a) and b) is not visible at this scale. Can you show a more detailed image or indicate what area of the image you observed the crevassing in? - Arrows added. Figure 3: Is increased crevassing not expected normally throughout the season? How do you distinguish between snow melt which exposes more crevasses and an otherwise significant increase in crevassing? – The location of the crevasses does not match with crevasses exposed by melt. We will discuss this in the caption/text.

Figure 4: Is this the same area that is shown in Figure 3 (with the exception of Figure 3d)? If so, it would be helpful to indicate such with a common point or lat/long ticks. – It's not exactly the same area. We will either add some common points or lat/long ticks. Figure 4: Can you point out what you mean by "strong crevassing" in part d? - strong crevassing at the glacier outline.

Figure 5: suggestion accepted.

Figure 6: Could you compare the final "detachment" image with an image from the previous year around the same time period (July) to show what the area looked like prior to the detachment, but with similar snow conditions? – Yes, we will add such an image.

Figure 9: color corrected. Used "large and small black dots" as suggested. Figure 10: Resolution will be improved.

Answers to detailed comments from Referee #2: - L18, L35: typos corrected. - Fig1 credits of the background image are covered by the map insert. - > Credits are also in the caption. - L61: missing word added. - L78, typo done. - L85-89: added "respectively" (two times) - L102: the paragraph will be replaced by a figure and table showing acquisition times, number of acquisitions per year and bands/resolution used for each satellite. - L110 KH-3 data? You do not mean KH-4/Corona data? – No, KH-3 is correct. See USGS documentation https://www.usgs.gov/centers/eros/science/usgs-eros-archive-

declassified-data-declassified-satellite-imagery-1?qt-science_center_objects=0#qt-science_center_objects. There might be other datasets of Corona, especially KH-4B with resolutions up to 1.8m and Hexagon? – Yes, see authors response 3. - L118,134: typos corrected. - TDX might be a more common abbreviation for TanDEM-X. - Might be true. As TanDEM-X is a satellite formation consisting of two satellites, TerraSAR-X and TanDEM-X, I prefer to use TSX and TDX to refer to the individual satellites and use TDM to refer to the formation of both satellites. This is also consistent with the L1B Product naming convention, therefore we prefer to keep the abbreviation TDM. - L147, L149, L161: typos corrected. - Fig3: maybe add glacier outlines; maybe mark the heavily crevassed areas. – We will add arrows to where crevasses are opening and will change the caption to "From (a) to (b) crevasses opening around the glacier outline are visible (arrows)." - L178 maybe show the two images from 2nd and 3rd August 2019? - These two images show a partial cloud cover. Instead, we show images from 28 July and 07 August which reveal the pre- and post-detachment situation more in detail. - L188 Are you sure that it reached this height? Which type of baserock/sediment is situated there? Is it possible that just the slope slided down when the lowest parts were scratched off by the ice flow? – As the apparent flow pattern indicate a very continous line along the topography, and because the flow line crosses over several gully in the topography, we conclude with a high certainly that this height was reached. The slope shows very little pattern where material could have slid down and we could not identify any new erosion gullies or eroded arcs indicating slides triggered by scratched off material. In this curve, shown by the arrows in Fig. 3d, the left slope of the valley is not very steep (max. 35 degree) making it again unlikely that the slope slided down. Comparison of high resolution Google Earth Imagery from 2016-05-31 vs. 2019-08-20 does not indicate any slope with slide down. - L191, L196: typos corrected. L199: Sentence rephrased, comma added. L246: we made sure to use "runout" in general. L249: typo corrected. L270 how can the glacier be not existent but build up mass until 2019? – In the valley where this glacier was located, we did not identify any ice in 2013. However, it seems that at this location ice or snow

(and very likely large amounts of sediments) are building up and form a multi-year ice body showing crevasses. As the glacier has the GLIMS ID G070995E39014N we consider it as a glacier. Fig9 caption, L299, L314, L355: typos corrected. L379 add year for “Ibrohim et al.” : Unfortunately, we could not find any year for this reference. L414: typo corrected.

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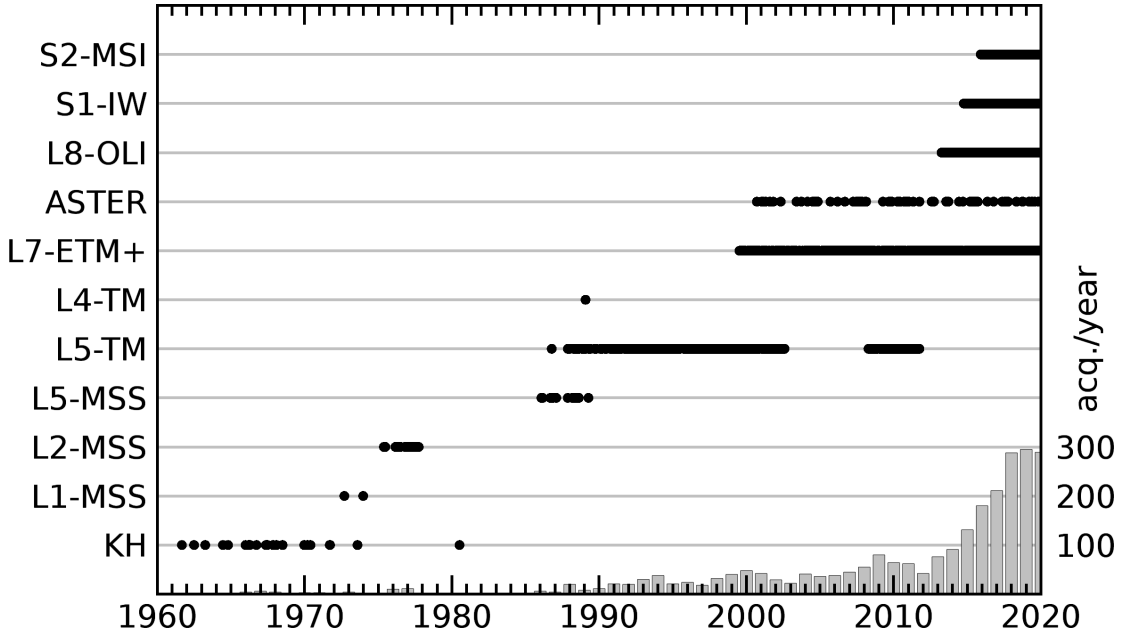

Fig. 1.

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