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Reply on RC4

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Author comment on "Baseline data for monitoring geomorphological effects of glacier lake outburst flood: a very-high-resolution image and GIS datasets of the distal part of the Zackenberg River, northeast Greenland" by Aleksandra M. Tomczyk and Marek W. Ewertowski, Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2021-48-AC4, 2021

Dear Reviewer,

Thank you very much for your detailed and constructive review. Please, find detailed responses to your comments below:

General comments:

- **While it is an interesting dataset, I doubt its replicability since it is in a moving terrain and has no DGPS GCPs.**

and

This is a data description of a detailed dataset regarding a GLOF event in Zackenberg. Albeit surely unique, I am wondering if the accuracies hold in an absolute sense, as no GCPs are taken and creep may have been significant and unpredictable since 2014. If this doesn't hold, it is also not a dataset which will be useful for many follow-up studies.

As demonstrated in several studies (e.g., Cook and Dietze, 2019; de Haas et al., 2021), a time series of UAV data can be successfully registered without ground control points using the co-alignment approach. According to de Haas et al. (2021), such an approach outperforms the classic method (i.e., each survey processed individually with GCPs) regarding relative accuracy and change detection. The absolute accuracy will be low (several-m), but relative accuracy within co-aligned series of surveys will be high (up to <0.1 m). Therefore, we provided original unprocessed images to enable future users to perform co-alignments with newly collected surveys. Furthermore, our data cover stable grounds (e.g., buildings of the research station and fragments of marine terraces), so there will be enough stable points to co-register future surveys. Moreover, de Haas et al. (2021) demonstrated that even in such an unstable environment as debris flow torrent, the co-alignment approach gave relative accuracy of change detection better by a factor 3 *than the classical approach with individually processed surveys with GCPs.*

- **Furthermore it is as far as I understand already published (in 2 journal papers and 2 zenodo repositories) and hence does not warrant an additional publication in my opinion.**

Earth System Science Data (ESSD) journal publish articles describing research datasets to facilitate their future re-use. According to ESSD guidelines, datasets presented in the paper must be uploaded to a repository that provides permanent digital object identifiers (DOI) and published under a non-restrictive license. Therefore, we uploaded our data in Zenodo as two repositories (due to the large size of the datasets): one includes raw UAV-generated images and the second with processed products (orthomosaics, DEMs, hillshade, vectors) to fulfil the ESSD guidelines.

In general, our dataset comprises three surveys (before-, during-, and after-the-flood). As we provided both unprocessed images as well as final products, there are several potential applications of presented datasets, including:

- *assessment and quantification of landscape changes as an immediate result of glacier lake outburst flood;*
- *long-term monitoring of high-Arctic river valley development (in conjunction with other datasets);*
- *establishing a baseline for quantification of geomorphological impacts of future glacier lake outburst floods;*
- *assessment of geohazards related to bank erosion and debris flow development (hazards for research station infrastructure – station buildings and bridge);*
- *monitoring of permafrost degradation; and*
- *modelling flood impacts on river ecosystem, transport capacity, and channel stability.*

Moreover, other applications might be possible in the future if new surveys extend the presented time series – to allow that we provided unprocessed images so they can be co-aligned with future surveys (please, see the response to comment #1). We published two papers (Tomczyk and Ewertowski, 2020; Tomczyk et al., 2020) which serve as a proof of concept and demonstrate utilisation of the presented dataset to application 1 (quantification of geomorphological impacts of the flood) - These papers are clearly indicated in the manuscript. However, so far, no publications use the presented datasets in other of the applications mentioned above; therefore, our datasets should be re-used at least several times or more if the long-term monitoring program will be established.

- **Figures are graded colourmaps and I don't think they qualify for barrier-free colour codes for colour blinds. Also, they don't show categories and it is hard to make use of them.**

We provided alternative versions of the figures with contour lines and colour categories. Please, find them attached as a supplement. Detailed changes for each figure are described in responses to "detailed comments" below.

Detailed comments:

- **L8 2x Arctic. Is ‚intense' good wording here?**

We changed "Arctic" to "polar" and "intense" to "widespread". The sentence is now as follow:

"The polar regions experience widespread transformations, such that efficient methods are needed to monitor and understand Arctic landscape changes"

- **L9: sounds as if climate warming was neither low-freq nor high-magn. Suggest expanding**

We meant hydrological and geomorphological events; the text was modified as follow

"[…] Arctic landscape changes in response to climate warming and low-frequency high-magnitude hydrological and geomorphological events."

- **L10: grammar: singular/plural!**

Corrected:

"[…] are glacier lake outburst floods."

- **L18: of a glacier lake…**

Corrected

- **L25: riverscape evolution… sounds weird to me**

Changed to "river system":

Long-term river system evolution is the effect of an interplay

- **L33: and commonly occur: something with grammer there**

Changed to "frequent"

"[..] and frequent in modern glacierised mountain area"

- **L34-36: too many refs that refer to a very broad statement**

We limited references to review studies and couple of regional examples:

"frequent in modern glacierised mountain areas (Russell et al., 2007; Moore et al., 2009; Watanabe et al., 2009; Iribarren et al., 2015; Harrison et al., 2018; Nie et al., 2018; Carrivick and Tweed, 2019)."

- **L38: of a moraine dam**

Corrected

- **L44: in the case of Zack, I believe we will rather see the opposite with glacier thinning??**

The lake, which is the source of GLOF, is located more than 3 km from the current ice margin, so we expect a similar or higher frequency as more water will be stored behind the glaciers. Thus, future monitoring will answer whether the GLOS will be observed more frequently but with lower discharge magnitude or less often but with higher discharge. We added the following explanation:

"The first GLOF at Zackenberg was observed in 1996 and since then floods occurred every year or at the two-year interval (Kroon et al., 2017; Tomczyk and Ewertowski, 2020). The lake, which is the source of GLOF, is located more than 3 km from the current ice margin, so we expect a similar or higher frequency as more water will be melting from glaciers and stored in the lake. Thus, future monitoring is needed to investigate whether the GLOFs will be observed more frequently but with lower discharge magnitude or less often but with higher discharge. "

- **L48: related to a glacier lake…**

corrected

- **L48: leaving behind serious… sounds jargon to me**

Changed to "substantial":

"On 6 August 2017, a flood event related to a glacier lake outburst affected the Zackenberg River (NE Greenland), leaving behind substantial geomorphological impacts on the riverbanks and channel morphology"

- **L61-66: direct repetition of abstract.**

Yes, as we wanted to emphasise potential applications of the presented dataset and stressed that only one of the proposed six applications was already shown in detail in our papers.

- **L71: suggest 'glacier-covered' instead of glaciated**

Changed as suggested:

"[…]its catchment covers 514 km^2, 20% of which is glacier-covered."

- **L69: ZR could warrant an abbreviation**

We would prefer to use the full name, as ZR could make text harder to read or be mistaken Zirconium

- **L74: check refs and GEM database. It is >200 to my knowledge.**

We counted events with discharge > 100 m^3 s^{-1} - There were 14 such events between 1996 and 2018, according to the GEM database. Please, also see the figure attached as a supplement.

- **L77: do Bendixen et al refer to ZR specifically? Check also Landegaard-Pedersen 2017 for the sediment part**

Bendixen et al., 2017 investigated 121 deltas in south Greenland, but not Zackenberg. We added the reference to Ladegaard-Pedersen et al., 2017 and removed Bendixen et al., 2017, to keep only references related to Zackneberg valley:

"Such events had an enormous impact on the riverscape geomorphology (Tomczyk and Ewertowski, 2020; Tomczyk et al., 2020), discharge and sediment transport (Hasholt et al., 2008; Søndergaard et al., 2015; Ladegaard-Pedersen et al., 2017), and delivery of nutrients and sediments into the fiord and delta development (Kroon et al., 2017)."

- **Fig 1: Is it Young Sund or Young Sound in English? Unsure. What is the basis for the isolines? Acquisition date of ice margin extent? The bridge is referred to in the text but not in the map**

We corrected the name to "Young Sound". The base for isolines is 0, and isolines labels were added to the map. The glacier cover is from 2001, and such information is now in the legend. We also provided a new panel (Fig. 1D) with a zoom of the study area – the location of the bridge and extent of the subsequent figures are now indicated in this new panel, as Fig. 1C was too small to fit all extent indicators. Please, find updated Fig.1. attached as a supplement.

- **L91: what is medium-term in this context?**

We meant several years (i.e. changes between 2014 and 2017) in contrast with short-term (i.e. changes over several days). Therefore, the text has been clarified as follow:

"collect data that would enable quantifying medium-term (i.e., temporal scale of several years) changes in the river landscape."

- **L91-95: repetition to the above?**

We would prefer to keep this fragment as it explains the motivation of the surveys.

- **L97: delete: relatively long?**

Deleted as suggested:

covering a 2.1-km-long section of the river from the bridge to the delta.

- **L98-99: delete. It comes later. No ref to TLS (wrong abbreviation used) necessary in my opinion if you don't use it. If at all in the discussion**

The sentence was deleted as suggested.

- **L100-106: add brand of sensors**

We added the brand of the sensor:

The UAV was equipped with DJI 20MP, 1-inch size CMOS RGB sensor and a global shutter – camera model FC6310 (Table 1).

- **2: show in Fig 1 extent. Is it really 0.5 m you get from GoogleMaps?**

Doublecheck

We added the extent of the Figure 2 in Fig. 1. Yes, for this part of the Zackenberg Valley, high-resolution satellite imagery is available from the WorldView2 satellite (by Maxar, which is the current operator of the former DigitalGlobe constellation), which has 0.54 m GSD after pansharpening. Scene ID: 103001001ABA7E00, *details of this scene can be found here:* https://discover.digitalglobe.com/11608746-e421-11eb-ac2b-ee9402db8ad9

- **L123: what are good weather conditions? Specify or omit**

Clarified as follow:

"The weather condition for each day was good (i.e., no precipitation nor strong winds), and illumination conditions were sunny."

- **L129: remove: 'so'**

We hanged "so" to "therefore" to indicate a continuation of the previous sentence.

"Therefore, it was a compromise between photogrammetric quality (i.e., the image network geometry), desired GSD, and rapidly changing flood conditions."

- **L148: why? It is part of the station infrastructure. In 2017 the bridge was there, was it not possible to cross? I am surprised and a bit doubtful by the lack of GCPs**

We did not have access to cm-accuracy survey equipment; only dm-scale GPS available was available. During the flood, the bridge was unpassable as the water level was too high to reach it. We added the clarification

(we did not have access to cm-accuracy survey equipment, and it was not possible to cross the river during the flood, because of the high water level),

- **L150: This is all permafrost, even large boulders may move due to creep, definitely between years. I am doubtful that the accuracy can be achieved down to say 4 mm (Tab1) if no GCPs are taken. Even if we refer to the 0.12 m**

to 0.15 m this may be within the moving conditions of the terrain over 4 summer seasons if you use the COWI DEM. This warrants at least discussion.

Each of the individual camera positions (i.e., every image captured) have 3D position coordinates originated from the onboard UAV GNSS system. These coordinates gave absolute (i.e., external) orientation, further constrained by control points (CPs) obtained from high-resolution 2014 data. We selected CPs located in flat areas which are less likely to move, including stable features like buildings of Zackenberg Research Station. The CPs were used to ensure that absolute accuracy (i.e., the geometry of the reconstructed scene in relation to the outside world) is correct (RMSE on checkpoints was between 0.12 m and 0.15 m). As stated in Table 1 - The 4 mm mentioned by the Reviewer is the mean point coordinate precision of surveys – as indicated in Table 1 and the text. It shows the stability of the reconstructed point cloud and can be used to investigate the spatial uncertainty of each of the point clouds. Therefore, datasets processed by us are characterised by two types of accuracy (as indicated in Table 1):

- *The absolute accuracy (i.e., the position of all surveys in relation to the outside world) is on a dm-level*
- *The relative accuracy (i.e., stability of each individual point cloud) is on cm-level*

Such a level of accuracy is sufficient for most applications, including modelling, because the relative (i.e. internal) accuracy is much higher than absolute accuracy. It is also sufficient for change detection because observed changes were up to 10 m of lateral erosion, so 100 times larger than RMSE on external checkpoints. If better relative accuracy is necessary in the future for some additional applications, co-alignment of UAV time-series can provide better relative (i.e., internal survey-to-survey) accuracy than the classic approach of individual SfM processing of each survey using GCP - as demonstrated in several studies (e.g., Cook and Dietze, 2019; de Haas et al., 2021), Therefore, we provided also unprocessed images so the potential user can perform their own SfM processing. We added the following fragment to Section 3.1 "Structure-from-Motion processing", and to Section 4 "Quality assessment and known limitations"):

Section 3.1

The external orientation of the reconstructed scene was established using coordinates of each camera position obtained from the onboard GNSS system. To further constrain the geometry of the scene, additional control points were used (CPs). […] CPs were then generated post-survey using previous UAV dataset from 2014 (COWI, 2015). In total, 100 points were selected, located mostly on stable, flat boulders, which were easy to identify in the images. CPs were distributed on level terrain to minimize the impact of potential permafrost creep.

Section 4

Although such values are higher than the GSD of all datasets (between 0.018 and 0.028 m), such magnitude of errors was considered acceptable for the quantification and mapping of landscape changes, especially as between 5 August and 8 August the resultant lateral erosion of riverbanks from the flood reached almost 10 m in some sections, (see Tomczyk et al., 2020 for details), therefore the observed changes were up 100 times larger than RMSE. If necessary, lower values of absolute accuracy can be achieved in the future if additional ground control points are surveyed using cm-accuracy survey equipment. Moreover, if better relative accuracy (i.e. survey-to-survey accuracy) is necessary in the future monitoring applications, co-alignment of UAV time-series can provide better relative accuracy than the classic approach of individual SfM processing of each survey using GCP - as demonstrated in several studies (e.g., Feurer and Vinatier, 2018; Cook and Dietze, 2019; de Haas et al., 2021). Therefore, we provided also unprocessed images so the potential user can perform their own SfM processing.

- **L158: which units?**

The units were pixels. Information added as follow:

"[…]with low tie point reprojection errors from 0.28 to 0.44 pixels,"

- **L173: ground-truthing**

Corrected as suggested

- **L173: vector were vectorized… reword**

Modified to shapefiles as follow:

Final shapefile datasets were vectorised on-screen in ArcMap 10.6 software.

- **Fig 3: the color scale of a and e is not useful: use contours and descrete colours as well as contour labels. Also very strange: after the flood the elevation of the orographically left river bank is in the order of 13 m higher than the right river bank?? I have some doubts that this is realistic undercut, also when I look at 3g. if that was the cassse, the yellow colours would likely disappear in 3e and just the plateau remains. Mark extent in fig 1. Scarp and drainage is strange to me here. What is the water body in the upper left corner of the fig? Does a map with different colours related to the slope qualify as 'geomorphological mapping'?**

We changed the scale to discrete colours and added contours with labels. Fig. 3 shows a steep riverbank that is indeed 13 m high in this place and was severely undercut during the flood and mid-channel bar, which was covered by water during the flood but re-emerged after the water level dropped. We hope that indication of the location of this river section in Fig.2. will be helpful to orientate the reader with the overall geomorphological situation. Please, find an additional figure 7 as supplementary data – it shows photographs of this section of the river and a comparison of images before- during- and after the flood. Yes, this is a geomorphological map as it contains several different geomorphological features – floodplain, scrap, slope (divided into different categories).

- **L189: how do you relate this accuracy to potential permafrost creep?**

As mentioned before, external orientation was based on onboard GNSS coordinates constrained by CPs. CPs were located on stable boulders in level ground, so the impact of the permafrost creep was minimized.

- **L194: by then they will have moved again to some extent I fear. It is necessary in such an environment to have DGPS GCPs for each survey if such high accuracy should be obtained.**

As mentioned in response to general comments, our data cover stable grounds (e.g., buildings of the research station and fragments of marine terraces), so there will be enough stable points to co-register future surveys. Moreover, de Haas et al. (2021) demonstrated that even in such an unstable environment as debris flow torrent, the co-alignment approach gave relative accuracy of change detection better by a factor 3 than the classical approach with individually processed surveys with GCPs. Therefore, we provided also unprocessed images so the potential user can perform their own SfM processing.

- **L195-205: please make it very clear what is precision within the 3 DEMs and what is the absolute precision.**

We added the following clarification:

The quality of the presented datasets was assessed in relation to the outside world (i.e., external or absolute accuracy) and in relation to each survey (internal precision). […] The external accuracy was estimated based on root-mean-square errors (RMSE) and standard deviations (SD) of errors on checkpoints, which were between 0.12 and 0.15 m (Table 1). The maximum external error for two checkpoints was -0.4 m and 0.4 m (Fig. 5).

and

The internal quality of the reconstructed scenes was based on tie point precision. […] The internal accuracy of each survey was assessed based on the mean point precision estimates, which varied from 4 to 6 mm for the horizontal component and from 11 to 15 mm for the vertical one (Table 1)

- **Fig 4: the colour scale is unacceptable. Have contours or discrete ones. I cant see anything here. Also indicate where you are in an overview fig**

The Colour scale was changed to discrete classes. The location of the figure is now indicated in Fig 1, as a Fig 1D.

- **Fig 5: same as above. Unclear what is shown. which tie point centroid? So here we have errors of up to 0.4 m?**

It shows the distribution of errors on checkpoints and control points. Such information is used to verify if there are systematic errors with reconstructed geometry, such as doming or dishing of the model (please, see James et al. (2020) for details. Yes, individual external errors measured versus checkpoints were up to -0.4 m and 0.4 m for two of the checkpoints for the 8 August survey. We added the following clarification:

The external accuracy was estimated based on root-mean-square errors (RMSE) and standard deviations (SD) of errors on checkpoints, which were between 0.12 and 0.15 m (Table 1). The maximum external error for two of the checkpoints was -0.4 m and 0.4 m.

And

Figure 6: Spatial distribution of errors on control and checkpoints: (a) Z-error against radial distance from the tie point cloud centroid (i.e. from the centre of the reconstructed scene). The distribution of errors along a straight line (indicated here also as "modelled constant") suggests that no systematic errors such as doming or dishing were observed in the reconstructed scenes (see James et al., 2020 for details); (b) Z-error by colour in plan view (X, Y are distanced from tie points centroid). Note: Each row shows an individual survey.

- **L216-220: it is really unclear why this is relevant there. Stick to topics that occur**

Shortened as suggested:

In general, the interpretation of riverbank conditions can be tampered by vegetation cover and/or bank undercutting (Niedzielski et al., 2016; Hemmelder et al., 2018). While vegetation cover is usually not a problem in the case of Arctic rivers, other obstacles (e.g., shadows, infrastructure) might prevent the direct measurements of the bank's heights. In the case of the presented dataset, some sections of riverbanks were steep, near-vertical, before the flood.

- **L224: do you have pictures of this undercut? It is a bit hard to believe to me**

We provided additional figure with ground-based photos of examples of the undercuts produced by the 2017 flood. Please, find it in the supplement – Figure 7

- **L235: yellowish is jargon I believe**

Changed to "yellow"

"indicated by the lack of transparency and the yellow or brown colours of water in the orthomosaics."

- **L240: how can you assess the character of water flow from orthophotos??**

It can be assessed by the character of the water surface, e.g., gentle and level surface in sections where the water flow was relatively slow vs surfaces covered with small waves, which indicated rapid water flow. Please, find the figure 8 demonstrating different types of water surfaces attached in the supplement.

- **L287: precision? Typo**

corrected

- **Tab 2: why not showing the vectors in all maps (bridge, track). Is it really a 4x4 track??**

We added the bridge and buildings into the Figure 1D (overview map). It is a track used by Argo all-terrain-vehicle. Other figures present detailed examples of small areas and these features are not in their extents.

- **L295-317: largely another repetition**

This section contains a more detailed description of applications that we believe are the most interesting, together with references to some studies on modelling, which can guide future approaches. This information was not presented earlier, merely mentioned at the end of the introduction and in the abstract (which is often read separately from the whole paper). However, we modified this section as follow (changes also include suggestions from Referees #1 and #2)

- Quantification, monitoring and modelling of geomorphological impacts of glacier lake outburst flood – the presented dataset was meant to quantify changes related to the 2017 GLOF (see Tomczyk and Ewertowski, 2020; Tomczyk et al., 2020); however, these studies only described the immediate impacts of a single flood event. An example of geomorphic change detection is presented in Fig. 9, demonstrating the acceleration of debris flows resulting from sediment entrainment at the base of the river bans by floodwater. Overall, the observed changes were spatially variable – erosion dominated along steep banks as expected; however, understanding of differences in erosion rates between sites requires further studies, which will consider differences in lithology as well as modelling of water flow to investigate potential erosion forces in relation to channel characteristics. The first GLOF at Zackenberg was observed in 1996 and since then floods occurred every year or at the two-year interval (Kroon et al., 2017; Tomczyk and Ewertowski, 2020). The lake, which is the source of GLOF, is located more than 3 km from the current ice margin, so we expect a similar or higher frequency as more water will be melting from glaciers and stored in the lake. Thus, future monitoring is needed to investigate whether the GLOFs will be observed more frequently but with lower discharge magnitude or less often but with higher discharge.

- As the high-magnitude low-frequency events are typically rare and difficult to predict, our understanding of the quantitative aspect of geomorphological changes related to them remains limited compared to the “normal” processes (Tamminga et al., 2015b). These arise particularly from difficulties in collecting high-resolution data before and after these innately unpredictable and rare flood events. However, investigation into the geomorphological response of river morphology to “extreme” events is key to understanding the evolution of river morphology and being crucial from the standpoint of river modelling and monitoring (Tamminga et al., 2015a; Tamminga et al., 2015b). Moreover, the relationship between the magnitude of the flood and geomorphological effects is not fully understood. For example, in the case of Zackenberg River, immediate (2-days) lateral erosion compared to three-year erosion was spatially very diversified. In some sections, immediate lateral erosion after the 2017 flood reached up to 10 m, whereas the same section was stable between 2014 and 2017, even though higher peak discharges characterised 2015 and 2016 GLOFs than 2017 GLOF (Tomczyk et al., 2020). Further process-based studies are necessary to observe and model links between the magnitude of a flood and the severity of erosion. It is especially important in periglacial landscapes where lateral bank erosion can be responsible for delivering a large quantity of organic matter and widespread changes in ecosystems. especially combined with other weather extreme events (see Christensen et al., 2021). Using the provided dataset as a baseline for the monitoring of future changes, it should be possible to quantify the difference between geomorphological effects of "normal" (i.e., high-frequency, low-magnitude) processes on the one hand, and extreme (i.e., low-frequency, high-magnitude) events on the other. Also, by linking the intensity of a geomorphological response to hydrological data about flood characteristics, it should be possible to improve modelling routines (cf. Carrivick, 2007a, b; Carrivick et al., 2011; Guan et al., 2015; Staines and Carrivick, 2015).

Please also note the supplement to this comment:
https://essd.copernicus.org/preprints/essd-2021-48/essd-2021-48-AC4-supplement.pdf