

Response to the comments from the reviewers

We thank all the reviewers and the editor for their work on our manuscript. Please find below in three different sections (page numbers below) the answer to each reviewer and the editor. Our answers are in blue.

Answer to the comments from William Kochtitzky, reviewer #1.	page 2
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Response to the comments from William Kochtitzky, reviewer #1.

I appreciate your response, you have developed an excellent manuscript. Congratulation

We thank again Will Kochtitzky for their careful reading of our manuscript and their comments in the whole review process.

Response to the comments from Mingyang Lv, reviewer #2.

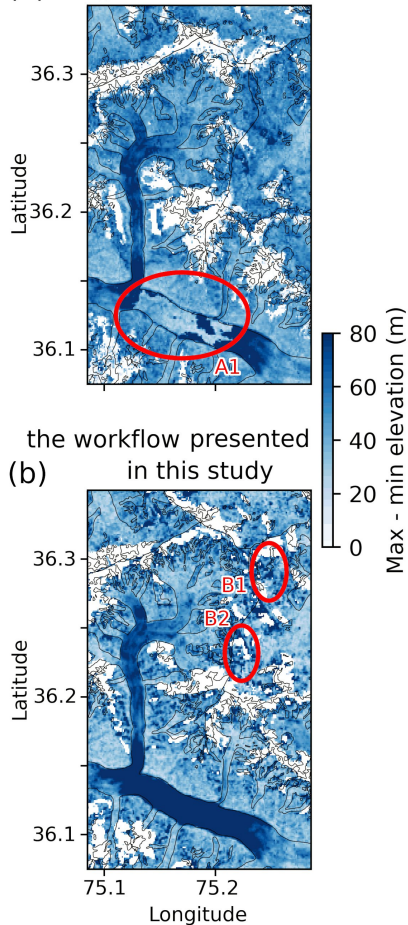
The authors made all necessary changes to my 1st round comments. They also revised the manuscript massively according to other reviewers' comments. Therefore, I suggest it could be considered for publication after some technical corrections, like:

We thank again Mingyang Lv for their review and feedbacks on our manuscript. We have made all the minor changes suggested, please find below our answers in blue.

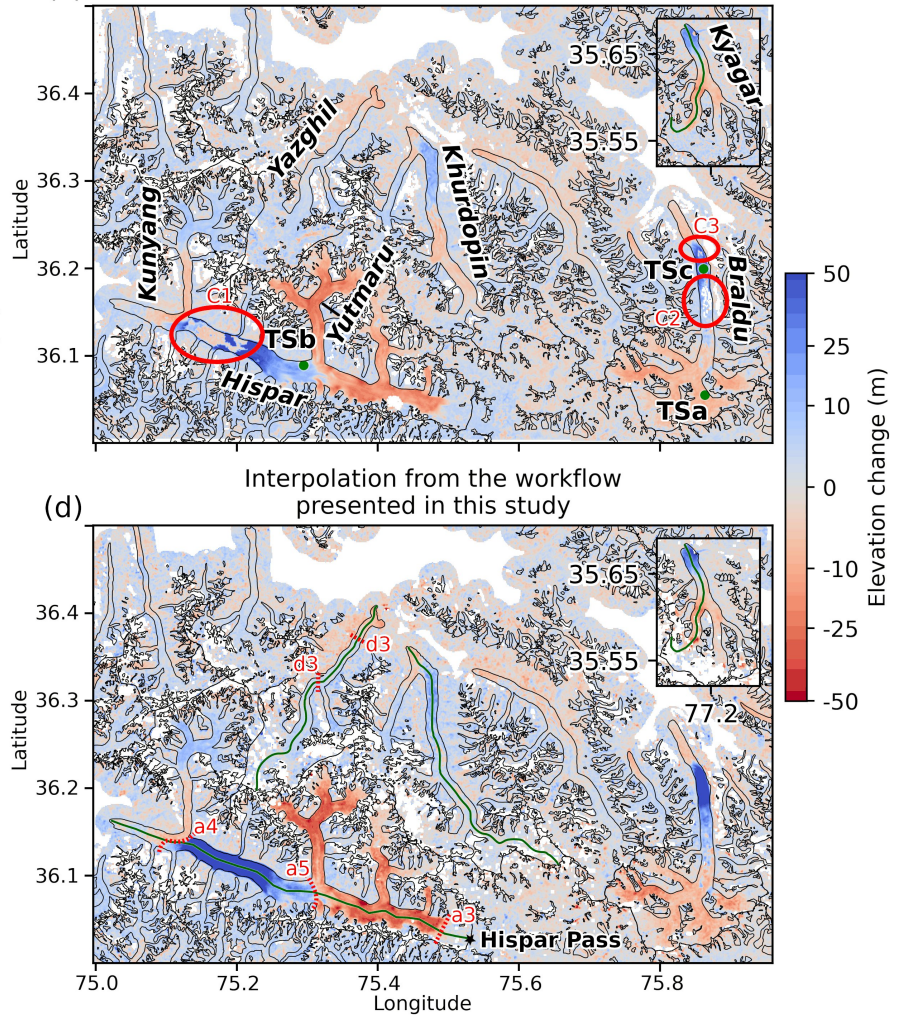
Answers to comments

- Line 18 & line 36: "important" is not commonly used to describe elevation change during surges. These sentences have been removed during the improvement of the whole introduction.
- Line 84: GLO-90 is first used here. Please give more information in this line rather than in the next paragraph.
We replaced the paragraph right after the sentence with the first use. The first sentence of the paragraph has been simplified, as "The Copernicus DEM GLO-90 (European Space Agency and Airbus, 2022) we use as a reference elevation for coarse filtering of very large outliers is edited from data of the TanDEM-X mission acquired between 2011 and 2015."
- Line 266: Wrong use of brackets. Fig. 7d? Also, I suggest to add a sub-figure in top right of Figure 7 and give the centreline of Kyagar Glacier.
We corrected the bracket error.
We added insets of the Kyagar glacier on the main figures. We completed the caption: "The insets for the Kyagar glacier are on the same scale as the main frames.". See below the new figure.

Filtering from:
(a) Hugonnet et al. (2021)



Elevation change: 2014-08-01 - 2016-08-01
(c) Interpolation from Hugonnet et al. (2021)



- Line 274: If time series are not presented in the manuscript or supplement, this sentence may not be present in the manuscript.

We removed the sentence and the mention of this build-up.

- About the mass imbalance during surges in the results section, the authors only give some description on Hispar Glacier. If possible, please also add some to the other four glaciers. Otherwise, you could add a new section to present the results of mass imbalance during surges.

We deleted the presentation of this volume in the results section. We think that there is too little to report on this topic to add a new section. We discuss more thoroughly imbalances and volumes in the discussion / comparison with literature section, and let the reader check at Table 1 for volume details (including imbalance). We added a reference to Table 1: "Time series, extracted at regular intervals along the selected centrelines are shown in Supplement (Fig. S3 to S7), and surge volume transfers are reported in Table 1 for each glacier."

Response to the comments from Wesley Van Wychen, editor.

Dear authors,

Thank you for your revised manuscript. Although two of the reviewers were quite positive about the changes you have made to the manuscript, after my own review of the manuscript, I believe that there is further work to be done before this manuscript can be considered for publication. Specifically, I find that overall, the structure of the manuscript needs to be improved, the content streamlined and more details about the decisions made in the methodology section need to be robustly described. There are certainly some interesting results presented in this work; however it is hampered by poor articulation and organization in many sections of the manuscript. Content is sometimes presented twice, or at least mentioned twice, and this needs to be addressed. Furthermore, in the methods section, you often note the parameter values chosen in the work but provide little (if any) justification as to why you selected these values. This also needs to be addressed. It may be beneficial to change this manuscript from a research article to a communication. At present, what you are essentially presenting is how this work improves surge characterization from previous elevation change detection work (largely Hugonnet et al., 2021). This is not a problem, but I see this more as an iteration on that work, than something that is wholly separate from that work. Throughout the manuscript, there is a great use of colons to connect thoughts/sentences, but the structure does not really work. Please review the manuscript, check for these instances and revise as needed.

Overall, I believe that there are some interesting results presented in this research, however at present, the content is a bit too muddled for these results to be fully appreciated by the reader. I would encourage the authors to go back through the entire manuscript and in detail revise the entire manuscript for clarity and seek opportunities to shorten content and reduce redundancy in the text. Please also address the lack of details in the methodology section and related to this point, I still believe that the uncertainty could be further elucidated within the text. Below, I have provided a non-exhaustive list of detailed changes that should help with the revision.

All the best,

Wesley Van Wychen

We thank Wesley Van Wychen for their positive appreciation of our work and for their detailed review of our manuscript. We tried our best to implement the suggested changes, but we slightly disagree on some aspects of the review. Below we summarize our responses to the general comments:

- manuscript structure that needs to be improved: we re-organized the method section by introducing sub-sections for the different processing steps and we moved the previous section 5.3 “Elevation change comparison” earlier in the discussion. We also added sub-sections to identify each surge event characterized and discussed in the results and discussion sections.
- repetitions: we removed repetitive sentences (mostly from the introduction) and paid particular attention not to present content twice anymore
Also, we abbreviated the numerous references of “Hugonnet et al. (2021)” to “H21”, starting from section 2, except in the figures.
- lack of justification for the choice of the parameters in the methods: we agree that the choices of the filter parameters remain arbitrary, in particular because there is no absolute reference/ground truth to optimize these parameters. However, we think that we made this explicit in the text (e. g., L125-127 and figure 4). We also added a fifth column to figure 4 to show the impact of p and q parameters of the ALPS-REML method.
- suggestion to change from a research article to a communication as our work is seen as an iteration of the work of Hugonnet et al.: We understand that this work may seem like an iteration of the H21 study, as it relies on the same input dataset and with the same goal of obtaining continuous time series, however we disagree that this is a simple “iteration”. Both studies differ on several points: 1) H21 focuses on glacier volume change estimates, while our study focuses on surge analysis. Both topics come with different challenges to address. The time series from Hugonnet et al. are not suitable for surge analysis, as shown in multiple places (fig. S1, fig. 6, fig. 7). On the other hand, our goal is not at all to update/improve the estimates of H21. 2) The two methods for time series regularization are totally independent, even though they produce the same type of output. It is a real challenge to implement a workflow that is able to filter noisy time series and preserve abrupt changes, which is why we had to come up with a totally new

approach. 3) Both methods can be generalized to other datasets. The application to the same ASTER time series is simply imposed by the lack of other dense elevation times series. We therefore decided to keep our original format but tried to better highlight the novel aspects in the revised manuscript (e.g., we added in conclusion “The workflow, applied to ASTER DEMs but which can be adapted to other datasets, can generate [...]”).

- L19: please put surge type in quotation marks

Done

- L22-23: ‘and this subject continues to be the subjects of developments and theories’ ◇ this is awkwardly phrase, please have a look and revise.

Rephrased “and are an ongoing focus of theoretical investigations”

- L32: This first sentence is not really necessary.

Sentence deleted. This now reads as “Remote sensing analysis from satellite imagery can produce a large amount of digital elevation models (DEMs), providing observations of the elevation of the glacier surface and its variation over time.”

- L25-26: you should mention here the different ‘states’, whether they be mass build up related to quiescence in a reservoir area, mass transfer during a surge etc.

This now reads as “Observations of glacier surface elevation change over time are extremely useful to document glacier surges, and can give insight into the current state of a glacier in its surge cycle. The surge period, active phase of the surge-type glacier, is characterised by thinning (i.e. decrease of surface elevation) in a reservoir area and thickening in a receiving area, representative of the ongoing mass transfer. The quiescence period consists in strong thinning in the receiving area of the previous surge, and a thickness increase (mass build-up) before the next surge and mostly in the future reservoir area. The differencing of elevation maps permits one to compute the volume of ice transferred during a surge event and determine the spatial extent affected (ref).”

- L26: ‘it permits one to’

Done

- L27: ‘along with’ change to ‘and determine’

Done

- L28: an information --> information

Done

- L31: at ‘Remote sensing...’ this should be the start of a new paragraph.

Done

- L31: ‘permits one to’

Replaced by a change relative to a previous comment.

- L33: along time --> over time

Done

- L36: Surges are short-term events --> This depends on how you define short, we have observations that surges may last decades, see examples in the Canadian Arctic.

This sentence has been modified, it now reads as “the use of DEMs for the study of surges is often limited to a few dates or specific case studies, because the temporal availability of DEMs does not always match the surge phases. The retrieval of mass transfer variations happening during such surge events requires [...]”

- L40-41: end of sentence, change to 'long enough to capture a number of surge events in their entirety'.
Rephrased to "long enough to capture a number of surge events and a few complete surge cycles."
- L41; 'altimetry missions'
L41: such as ICESat-2, CryoSat-2 etc. --> are there really many more than this to warrant etc?
L42: but 'their spatial sparsity' change to 'their limited spatial sampling'
L43: 'several studies have used dense SAR time series on surge case studies, usually without time series filtering technique' --> this is unclear. Do they use DEMs derived from SAR data to do the analysis or backscatter analysis. At the moment, it is not clear how this statement connects to the previous sentences.
We removed this section of the introduction, which was a bit off-topic.
- L48-49: revise to 'elevation precisions of a similar magnitude'. Also, here do you mean elevation precision of 15 m?
- L49: and sometimes large artefacts caused by clouds, jitter, lack of stereo correlation on saturated/textureless terrain.
This part have been reworked for clarity.
As ASTER is the only systematic optical stereo sensor, we are now specific to this sensor and not broad optical sensors: "The DEMs derived from ASTER have an elevation precision of about 5-20 metres and they can have large artefacts caused by cloud sensitivity, satellite jitter or lack of stereo correlation on saturated/textureless terrain (Berthier et al., 2023; Girod et al., 2017)"
- L51-52: these sentences can be combined and should be revised a bit.
This now reads as "Such noisy DEM time series require specific filtering techniques that preserve surge signals (i.e., preserve elevation observations before, during and after the surge), as basic thresholds and linear methods used to assess long-term elevation changes might misinterpret surge observations as outliers."
- L52: Also, the volume transported or slope should be computed at consistent dates across a whole glacier. --> for what reason? This is a bit of a sentence fragment at the moment.
This should be better: "Furthermore, the estimate of volume transported and the surface slope are sensitive to data gaps and their interpolation. As a consequence, the need to be computed at similar dates across a whole glacier to ensure physical consistency."
- L53: At 'Various' start a new paragraph
Done
- L61-62: sentence needs more revision here.
Done
- L65: In this study we aim at developing --> In this study we develop a workflow
Done
- L66 dataset or datasets?
Done
- L68-69: "We apply it to an ASTER DEM dataset from Hugonnet et al. (2021). We produce a regional dataset in the Karakoram region covering more than 100 surge-type glaciers." ♦ "We apply it to an ASTER DEM dataset from Hugonnet et al. (2021) to produce a regional dataset in the Karakoram region covering more than 100 surge-type glaciers."
Done

L70: 'We also compare the surge characteristics such as volumes transferred to other products and studies.' Please list some of the other products and studies here'

This now reads as "We evaluate the performance of the workflow compared to the results of Hugonnet et al. (2021) and other DEMs (SPOT and HMADEM). We also compare the surge characteristics such as timing and volumes transferred to other studies (e.g., Bhambri et al., 2022; Steiner et al., 2018; Gao et al., 2024)."

- L75: 8. 6% I assume this is meant to be 8.6%?

Corrected

- L76: Guillet et al. (2022) identified 223 surge-type glaciers among glaciers larger than 5 km² (not individualizing tributaries) --> Guillet et al. (2022) identified 223 surge-type glaciers larger than 5 km² not individualizing tributaries.

Done

- L76-77: these studies or this study? Are you referring to both studies above in this paragraph, or just the Guillet et al., (2022) in this instance. If just Guillet et al., (2022), then revise to this study.

Done

- L78-79: We use the DEMs produced in the global study of Hugonnet et al. (2021), which ranged from 07/2000 to 09/2019 in the Karakoram. They are generated from satellite images of the ASTER sensor. Revise to: 'We use the DEMs produced in the global study of Hugonnet et al. (2021), which ranged from 07/2000 to 09/2019 in the Karakoram and were generated from satellite images from the ASTER sensor.'

Done

L84/ L93-94: Can the information about the Copernicus DEM all be presented at the same time that it is mentioned at L84? Also, please revise these sentences, there are some fragments here that could be improved. Here, you also discuss the impact of radar penetration, but no context is given about this topic, please add a sentence to provide some context here about why radar penetration is a factor to consider.

Paragraph moved accordingly to a comment from reviewer 2. The last sentence now reads as "The impact of radar penetration in ice and snow (up to about 10 metres) creating a bias in TanDEM-X elevation estimate is negligible compared to the threshold we use (hundreds of metres) (Berthier et al., 2023; Rizzoli et al., 2017)"

- L96: 'We aim to develop' --> this statement is a bit tentative, you either have or you haven't developed this. So, I would suggest that you change this to: "Here we present a workflow to"

Done

L95-100: So, is the major difference here in the methodology, just your pre-processing steps from what is presented in Hugonnet et al., (2021)?

We clarified a bit this : "We use the ASTER DEMs of Hugonnet et al. (2021), but processed them with a different workflow, because Hugonnet et al. (2021) workflow performs weakly on surge events (see for example figure S1). We use Hugonnet et al. (2021) workflow as a baseline to compare our own workflow to highlight the improvements for the surge cases.". The major difference between our study and Hugonnet et al. (2021) is in our entire workflow : use of LOWESS algorithm versus linear filters, ALPS-REML interpolation versus Gaussian Process Regression...among others. The so-called "pre-processing" step is a minor adaptation step mostly specific to this dataset which are not relevant for other dataset (including ASTER DEMs generated differently) and which we chose to not write in our workflow in this paper to highlight the core of the workflow and make the workflow more clearly applicable to other dataset than the one we use.

- L101: There is some redundancy in this first bullet point.

This is clearer now : "LOWESS workflow, core step of the filtering: we apply an iteration of the LOWESS algorithm"

- L109: Here you mention that the LOWESS sequence will be described in detail later, but you have already mentioned earlier in the manuscript that it will be described in subsection 3.2. This should be revised and harmonized.

Done

L110: There are quite a few fragments here, that could be revised and included in a single sentence.

This now reads as “We filter the elevation time series by two iterations of the non-parametric LOWESS algorithm, which is a moving weighted regression”

- L115: can you provide more detail on why you selected the 0.4 and 0.3 values? This really is not detailed sufficiently enough.

L116: again, please provide a rationale for the choice of 2.

L117-118: again, please provide greater rationale for the choice of ‘symmetric’

We agree that there are a number of parameters that were manually chosen, which might appear a bit arbitrary to the readers. We tried to make this statement more explicit in the revised manuscript: “Here are the main parameters set for each LOWESS iteration. They have been manually tuned after visual evaluation on a number of time series samples, both with and without surge signal (Fig. 4). We caution that these parameters were chosen specifically for the ASTER DEM dataset and might not all be suitable for other datasets (discussed in subsection 5.4).”

- L128: what constitutes ‘worse’ in this case?

We tried to improve the phrasing : “Time series with both large temporal data gaps and a noisy signal can create computational errors for small smoothing parameters.”

- L133: abbreviation needs to come after the fully detailed title.

Done

- L138: drive what over-fitting behaviour? Any over-fitting behaviour?

We now stress that over-fitting is particularly a problem for noisy data like ASTER DEMs : “[...], thus allowing us to narrow down the effect of the regularization/smoothing specifically on the high-frequency components. The latter are responsible for the over-fitting behaviour of the model, i.e., the fact that it fits too closely or exactly to the training data and becomes inaccurate for new data. This is particularly problematic for noisy time series like ASTER DEMs.”

- L142: GCV metric..... --> this sentence is awkward and is in need of some revision.

Done: “The GCV metric quantifies the generalization error of the model by making predictions at data points that were not used to fit the regression model.”

- L150: The same ALPS-REML code as what? Again, please provide more detailed rationalization of the parameters you set.

For more transparency on the choice of parameter values, we added to Fig. 4 the plot of ALPS parametrization. Here is the new figure and caption.

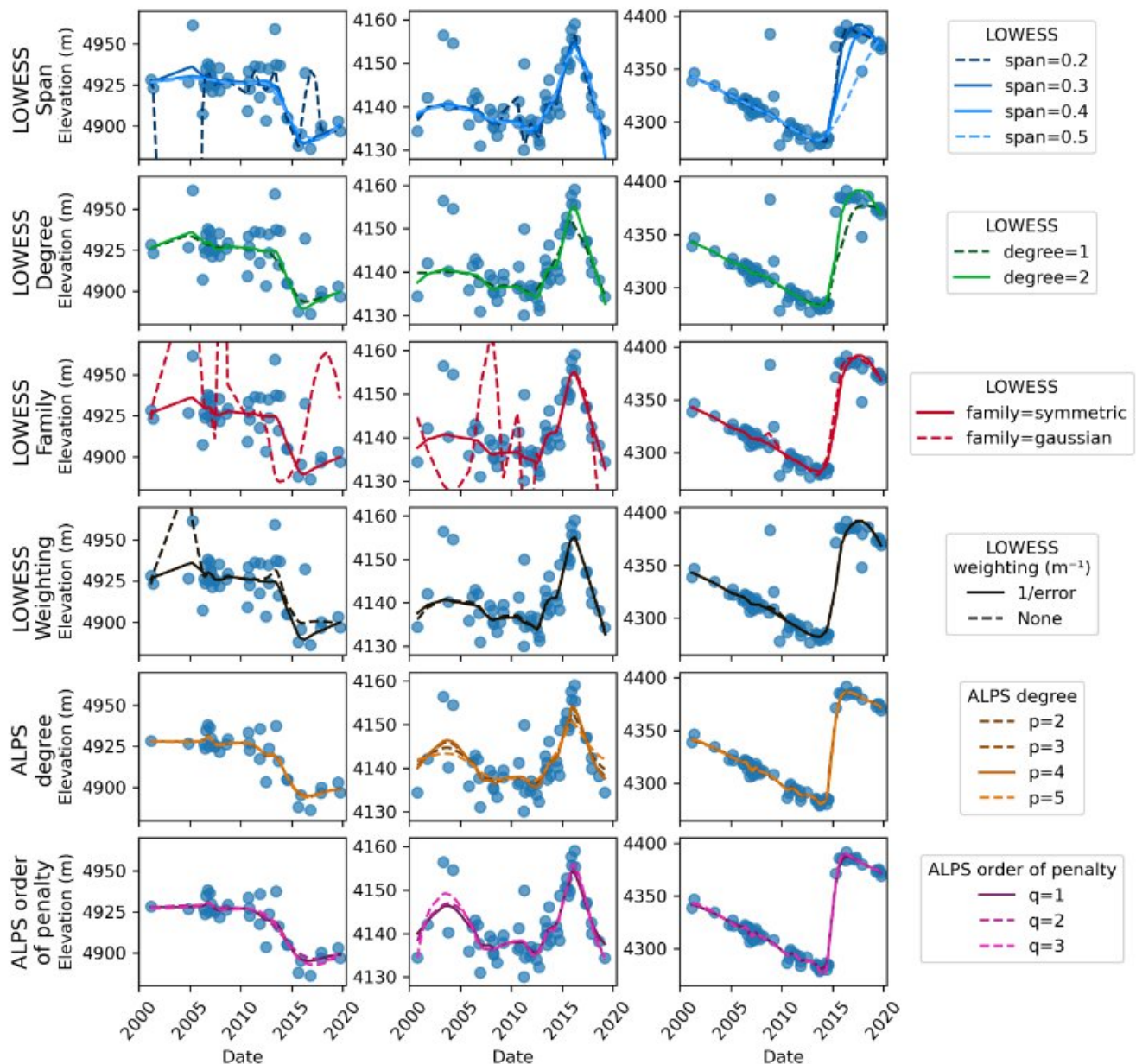


Figure 4. Impacts of the different LOWESS parameters (lines 1 to 4) and ALPS parameters (lines 5 and 6) on the regression/interpolation solutions. Plain lines are the final selected values. The line corresponds to three different data points (TSA-c in the column order, locations shown on Fig. 7.c).

- L189: in metres?
Cubic metres, added to the sentence.
- L 191: elevation change uncertainty --> but what is this value? It seems under described this far in the manuscript.
We removed the whole sentence; such justification is not expected here.
- L230: fewer points?
We deleted this second part of the sentence; it is unnecessary.
- L255: in Figure 6.a2
Done.
- L302: wuth --> with
Done.

- In the results section, please create subsections for each individual glacier surge event: Hispar, Khurdopin, Kyagar and Yazghil, this will help with organization of the text.

We added subsubsection for each case study, both the result section and the discussion section.

- L330: uncertainty representation. This should be moved to the methods section, it also seems confusing that this is mentioned after the reader would have accessed these figures.

Done.

- L337-339: is it possible that areas of large difference is simply due to imperfect comparisons made in areas of very steep terrain where we might expect large differences over short distances?

This might sometimes be possible over limited areas, yes. However, in this case, we identify several cases on glacier areas that are not steep (e.g. Fig. 10.b at the Kunyang-Hispar junction, even though ASTER elevations are consistent with each others along time at this location and period). For another example, we also identify a SPOT DEM with a clear and large artefact of several tens of meters on a glacier tongue (not presented in the paper).

- L338-339: Please revise this sentence, how is a wrong estimate credible?

Rephrased to "can occur", meaning it is possible.

L340: What is meant by moderate? Please be more quantitative in the description.

This now reads as "The map of elevation differences on the glaciers shows differences of a few meters overall, which is moderate compared to the elevation change amplitude of the surge (Fig. 10). The difference may be important such as several tens of metres locally at the surge front (e.g., Fig. 10.a-b at the Kunyang-Hispar junction)."

- L341: is of -4.3 m --> is -4.3 m

Done.

- L342: 2015-10-13, -5.2 m --> this section of the sentence needs revision.

We rephrased as: "Across the entire glacier areas, consistent discrepancies are observed. For instance, on 2015-10-13, the Hispar glacier exhibited a median difference of -4.3 m with a standard deviation of 9.7 m. Similarly, on 2015-11-28, the Braldu glacier exhibited a median difference of -5.2 m with a standard deviation of 8.7 m."

- L350-353: end of paragraph needs revision for clarity.

This now reads as "In such situations, our method of filtering and interpolation usually leads to an underestimate of the transferred volume and an overestimate of the surge duration (e.g., twice its duration for Kyagar glacier). Onset and end dates cannot be determined precisely between two observations separated by more than 6 months or a year, even on filtered series, as it occurs for the Kyagar glacier"

- L355: why 450 days? This should be specified.

The duration of 450 days is arbitrary but realistic, as it is rather common to observe intervals with more than 400 to 500 days without observations after filtering. We added two sentences: "Each iteration results in a period of at least 450 days without observation, which is common in the filtered series. For instance, on the surge-affected area of the Kyagar glacier which is subject to a lack of observation for our processing, there is on average 3 time intervals of 400-to-500 days per time series (1 time intervals for the Hispar glacier, in comparison)."

- L358: larger for larger --> larger for longer

Done.

- L359: Case b) is specific --> it is unclear what is being referred to here.

Done.

- L370: may not permit to observe this phenomena --> may not allow this phenomena to be observed

Done.

- L381-383: this was discussed earlier in the manuscript, correct? Why not just make sure that everything is described once collectively.

L289-291: Okay, but you have a difference of $687 \pm 414 \times 10^6 \text{ m}^3$, so what happened to this ice?

We removed the sentences about volumes from the result section. They are now only presented in the discussion, section 5.2 .

L386-387: it is not clear to me how the reader is meant to understand the information in this sentence.

This now reads as “ Another possible source of imbalance is the impact of crevasse opening during the surge, which can represent a non-negligible volume change. As an example, the opening of crevasses can be equivalent to up to 0.2 m thickness at regional scale of the Greenland Ice Sheet (Chudley et al., 2025). As inland parts of these regions are largely crevasse-free, we can expect such impact on the volume to be significantly larger over the highly crevassed post-surge surface of Hispar glacier.”

- L402: period misplaced after (2018).

Done.

- L404: Is the information here from the Steiner et al., (2018) or from the personal communication?

We do not write the previous volume estimate anymore, only the one reassessed from the personal communication. We removed the citation of the original publication to avoid confusion. This now reads as “The surge started in October 2016 according to Imran and Ahmad (2021), about 7 months later than our estimate (Table 1), and late August 2015 according to Steiner et al. (2018). The volume received in the receiving area is estimated at $1182 \times 10^6 \text{ m}^3$ during late August 2015 (elevation extrapolated linearly from TanDEM-X in 2011) to May 2017 (ASTER) data (Jakob Steiner, personal communication).”.