Glacier surge as a trigger for the fastest delta growth in the Arctic

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Peer Review File

Glacier Surge as a Trigger for the Fastest Delta Growth in the Arctic

Corresponding Author: Mr Jan Kavan

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Decision Letter:

** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors **

Dear Mr Kavan,

Your manuscript titled "Glacier Surge as a Trigger for the Fastest Delta Growth in the Arctic" has now been seen by 2 reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns. Specifically, we ask you to:

1. Provide robust evidence that a subglacial meltwater surge at Recherchebreen glacier in Svalbard in 2020 led to rapid progradation and delta formation, and that the reorganization of the subglacial drainage system terminated the surge.

2. Provide detailed information on the feature tracking and NDWI methodologies used for estimating surge velocity and compellingly demonstrate the robustness of correlations between tracked features.

3. Explore and demonstrate the influence of sediment accumulation at the snout on subglacial dynamics and surge rates.

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to address these criticisms, we would be happy to look at a substantially revised manuscript. If you choose to take up this option, please either highlight all changes in the manuscript text file, or provide a list of the changes to the manuscript with your responses to the reviewers.

Please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We are committed to providing a fair and constructive peer-review process. Please do not hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the reviewers' comments with a list of your changes to the manuscript text (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and any completed checklist:

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Please do not hesitate to contact us if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Dr Alireza Bahadori
Associate Editor
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The manuscript describes the progression of a surge event at Recherchebreen, culminating in the formation of a delta on the glacier's true left margin following the deceleration of the surge. The authors employ remote sensing data to delineate the dynamics of the glacier surge and the resultant delta formation. While the succinctness of the manuscript is appreciated, the submission requires additional empirical evidence to meet the publication standards of a journal as prestigious as Nature. Specifically, the claim in the conclusion regarding the release of subglacial water lacks direct evidence. It would be advantageous if the authors could include sediment core data to ascertain 210Pb sedimentation rates and perform grain-size analysis to corroborate the meltwater pulse event and its associated chaotic deposits. Additionally, the inclusion of Chirp sonar or side-scan sonar imagery of the sea floor would greatly strengthen the assertions made.

The manuscript would benefit significantly from more robust supporting data. Moreover, the abstract requires clarification and enhancement. The current phrasing, "The glacier advanced ca 1200 m and suddenly stopped in June 2020 followed by the rapid formation of a delta system in front of its subglacial meltwater outlet," should specify the onset date of the glacier advance to provide a clear temporal context—potentially since 2018 or 2019. This adjustment would aid readers in understanding the annual rate of change.

Furthermore, the statement, "The delta advanced by ca 450 m with probably the fastest progradation rate ever detected in the Arctic region," could be improved by quantifying the rate of progradation, such as approximately 7 meters per day. Additionally, it may be beneficial to emphasize that marine-terminating glaciers typically exhibit much slower delta progradation rates, thereby highlighting the significance of the observed phenomena in this context.

Overall, this study has the potential to contribute significantly to the literature on glacial dynamics, provided that these suggestions are addressed to enhance the robustness and clarity of the manuscript.

Reviewer #2 (Remarks to the Author):

The manuscript presents a study on the Recherchebreen glacier in Svalbard, employing satellite imagery to monitor glacial surge and delta formation at the glacier's snout. The authors suggest that subglacial reorganization contributes to sediment routing across the fjord, which in turn drives the rapid progradation of the delta. Despite observing a significant progradation rate of ~6 m/day, the authors note that deltas in Svalbard are not as extensive as those in Greenland, primarily due to a lower sediment supply.

The paper introduces an original study of glacial surge and coupled delta growth using satellite imagery. However, the manuscript fails to articulate why the findings are of broader interest to the delta or Arctic science communities. The lack of significant sediment transport by these deltas, as noted in the manuscript, may limit their importance in broader discussions of economic prospects or natural hazards.

Further, the focus on a single glacier and its associated delta is too narrow. The manuscript could benefit from a comparative analysis with other Arctic deltas, possibly integrating findings from the Overeem et al., 2022 review to contextualize the Svalbard deltas within broader Arctic delta models.

The methods are not described in adequate detail for reproducibility. The paper lacks sufficient detail on the feature tracking method used for estimating surge velocity. The robustness of correlations between tracked features is not disclosed. For the delta shoreline tracking, it is not clear to what subset of images the authors applied NDWI. The authors should provide more comprehensive details about the feature tracking and NDWI methodologies, including specific parameters and conditions under which these methods are applied. This would improve clarity and allow other researchers to replicate or build upon the work.

The manuscript does not explore whether subglacial dynamics are affected by sediment accumulation at the snout or if surge rates could be influenced by this accumulation. Addressing these questions could enhance the manuscript's contribution to understanding glacier-sediment interactions. Highlighting unique aspects or discrepancies in delta formation processes could underscore the significance of the study within the larger field of Arctic geomorphology.

Useful literature:
Overeem, I., Nienhuis, J.H. & Piliouras, A. Ice-dominated Arctic deltas. Nat Rev Earth Environ 3, 225–240 (2022). https://doi.org/10.1038/s43017-022-00268-x

Bendixen, M. et al. Promises and perils of sand exploitation in Greenland. Nat. Sustain. 2, 98–104 (2019).

Bendixen, M. & Kroon, A. Conceptualizing delta forms and processes in Arctic coastal environments. Earth Surf. Process. Landf. 42, 1227–1237 (2017).

Version 1:

Decision Letter:

Dear Mr Kavan,

Your revised manuscript titled "Glacier Surge as a Trigger for the Fastest Delta Growth in the Arctic" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers, especially the

requested information from reviewer 2 regarding the reproducibility of your study. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table".

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Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Alireza Bahadori, PhD
Associate Editor
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

Overall, the authors made a commendable effort to address the reviewers' concerns. The revisions add clarity to the abstract, provide broader context, and detail the methods more thoroughly. While some of the original suggestions (e.g., direct evidence of water release, sonar imagery, sediment core data) were not fully integrated due to practical constraints, the authors explained these limitations convincingly.

In summary, the revised manuscript has been significantly improved and now better addresses the points raised by both reviewers. The study provides a valuable contribution to our understanding of glacial dynamics and coastal evolution in the Arctic, though there is room for further exploration of some aspects in future work.

Reviewer #2 (Remarks to the Author):

In its current form, the analyses performed by the authors are not yet reproducible. The authors need to include a supplementary document with a table that lists the imagery used, including name, date, and satellite, along with progradation measurements associated with each image. The tidal water level should also be included in this table

What is the water depth into which this delta is building? An order-of-magnitude estimate would be helpful.

Lines 123–136 need revision. What processes are facilitating the slope change? Is this working by distributary channels? In its current form, it's totally unclear.

What is the tidal range at Recherchebreen? How are tides incorporated into the delta progradation analysis?

Rebuttal of manuscript

Glacier Surge as a Trigger for the Fastest Delta Growth in the Arctic

We express our sincere gratitude to the reviewers for dedicating their time to significantly enhance our manuscript, as well as to the editors for affording us the chance to implement these suggestions. We want to thank all reviewers for addressing concerns regarding

1) the lack of details in the methods sections

2) the need for improved implications section in the discussion

Specifically, we want to thank reviewer 1 for

1) remarks for improving the abstract

2) his suggestions that might be useful in the future work (Pb210, grain size analysis and sonar data)

We kindly thank reviewer 2 for drawing our attention to the issue of the broader significance of our discovery for Arctic coastal geomorphological research. Thanks to Reviewer 2 comments, a new paragraph on ‘new type of Arctic deltas’ implications is now included in the manuscript.

We also want to show our gratitude to the reviewers for their appreciation of the novelty and relevance of our study.

We carefully addressed all reviewer comments in the text below, highlighting our responses in italics. All additions and changes made to the manuscript text are highlighted in track changes.

Reviewer #1 (Remarks to the Author):

The manuscript describes the progression of a surge event at Recherchebreen, culminating in the formation of a delta on the glacier's true left margin following the deceleration of the surge. The authors employ remote sensing data to delineate the dynamics of the glacier surge and the resultant delta formation. While the succinctness of the manuscript is appreciated, the submission requires additional empirical evidence to meet the publication standards of a journal as prestigious as Nature. Specifically, the claim in the conclusion regarding the release of subglacial water lacks direct evidence. It would be advantageous if the authors could include sediment core data to ascertain 210Pb sedimentation rates and perform grain-size analysis to corroborate the meltwater pulse event and its associated chaotic deposits. Additionally, the inclusion of Chirp sonar or side-scan sonar imagery of the sea floor would greatly strengthen the assertions made.

We thank reviewer 1 for this encouraging assessment, and for the opportunity to revise.

Specifically, the claim in the conclusion regarding the release of subglacial water lacks direct evidence.

The release of subglacial water at the end of the glacier surge is a commonly accepted mechanism (see for example Kamb et al. 1985; Benn et al. 2019a; Benn et al. 2022). Although it would be great to have direct evidence of it, but it is basically impossible to predict the timing of such an event. Even if we can be prepared for it, that would require quite complicated logistics to capture such an event. There is another indirect example of recorded meltwater release at the end of a surge through observation of frazil ice plumes (see Benn et al. 2019b). Our recording of a delta progradation is a unique opportunity to capture this switch, as usually such release of meltwater and subglacial sediments do not leave any visual tracks – mostly because the marine environment is deep enough and the sediments simply settle down to the bottom. Here the bathymetric records (from 2013) show approximately 10 meters depth in a place now occupied by the delta.

It would be advantageous if the authors could include sediment core data to ascertain 210Pb sedimentation rates and perform grain-size analysis to corroborate the meltwater pulse event and its associated chaotic deposits.

We thank reviewer 1 for suggesting new ideas and approaches, but we do not have observational data or material or archival data to conduct additional studies. We are also not convinced that 210Pb dating would help us in establishing better chronology for

delta formation that occurred in two years and and can be precisely mapped using the optical satellite imagery. We however, thank the Reviwer 1 for this suggestion, as we may target older deltas in front of Recherchebreen in the future projects and integrate remote sensing with suggested. Te deltas connected to the surge cycle are not formed at the same spot, thus they do not superimpose. This is indeed a very good idea for further sites with similar characteristics and in such a way the speed of delta formation might be tested! The suggested approach might help to track formation of past deltas where we don't have any historical sat imagery and we suspect such an abrupt and rapid formation. This might be applied in case of the older deltas closing the current Recherche lagoon, where we only have indirect evidence on the timing of their formation (i.e. between the aerial images acquisition).

As for grain size, we are also not quite sure of the reward, perhaps just in a transect from proximal to distal side of delta, if we want to support the GPR profiles and reconstruct the internal structure. In the current stage, the delta is internally transformed by removing material from the upper parts to its marine limits through intense fluvial erosion/redeposition.

Additionally, the inclusion of Chirp sonar or side-scan sonar imagery of the sea floor would greatly strengthen the assertions made.

This is a fair point, we actually carried out a basic bathymetry mapping in September 2023 to see the submarine shape of the frontal part of the delta. We also made several GPR profiles to see the internal structure and surveyed the delta with high-resolution UAV mapping. This information will be used for a follow up paper focused on the internal structure of the delta itself. Here we don't want to blur the main message of the paper (i.e. glacier surge end hydraulic switching evidenced by formation of the delta and the extremely fast formation of the delta itself) with additional detailed analyses, that don't follow the main story. At the same time, we would like to inform that our team suffered from the sudden loss of one of the co-authors of the paper - prof. Piotr Zagorski, whose data incl. information on the fjord bathymetry are unfortunately not available.

The manuscript would benefit significantly from more robust supporting data. Moreover, the abstract requires clarification and enhancement. The current phrasing, "The glacier advanced ca 1200 m and suddenly stopped in June 2020 followed by the rapid formation of a delta system in front of its subglacial meltwater outlet," should specify the onset date of the glacier advance to provide a clear temporal context—potentially since 2018 or 2019. This adjustment would aid readers in understanding the annual rate of

change.

Furthermore, the statement, "The delta advanced by ca 450 m with probably the fastest progradation rate ever detected in the Arctic region," could be improved by quantifying the rate of progradation, such as approximately 7 meters per day. Additionally, it may be beneficial to emphasize that marine-terminating glaciers typically exhibit much slower delta progradation rates, thereby highlighting the significance of the observed phenomena in this context.

Thanks for these suggestions. We incorporated them into the abstract. However, we are limited by the maximum word count for the abstract. Including these points to the abstract will get us over the word limit – then we ask the editor if such changes are acceptable?

Overall, this study has the potential to contribute significantly to the literature on glacial dynamics, provided that these suggestions are addressed to enhance the robustness and clarity of the manuscript.

REF:

Benn DI, Fowler AC, Hewitt I, Sevestre H. (2019a): A general theory of glacier surges. Journal of Glaciology. 65: 701-716. doi:10.1017/jog.2019.62

Benn et al. 2019b: Mass and enthalpy budget evolution during the surge of a polythermal glacier: a test of theory. Journal of Glaciology 65, http://dx.doi.org/10.1017/jog.2019.63

Benn DI, Hewitt IJ, Luckman AJ. Enthalpy balance theory unifies diverse glacier surge behaviour. Annals of Glaciology. 2022;63(87-89):88-94. doi:10.1017/aog.2023.23

Kamb, B and 7 others (1985) Glacier surge mechanism: 1982–1983 surge of Variegated Glacier, Alaska. Science 227(4686), 469–479.

Reviewer #2 (Remarks to the Author):

The manuscript presents a study on the Recherchebreen glacier in Svalbard, employing satellite imagery to monitor glacial surge and delta formation at the glacier's snout. The authors suggest that subglacial reorganization contributes to sediment routing across

the fjord, which in turn drives the rapid progradation of the delta. Despite observing a significant progradation rate of ~6 m/day, the authors note that deltas in Svalbard are not as extensive as those in Greenland, primarily due to a lower sediment supply.

The paper introduces an original study of glacial surge and coupled delta growth using satellite imagery. However, the manuscript fails to articulate why the findings are of broader interest to the delta or Arctic science communities. The lack of significant sediment transport by these deltas, as noted in the manuscript, may limit their importance in broader discussions of economic prospects or natural hazards.

Thanks for this comment. The findings are especially interesting for the glaciological community as we provide the first direct geomorphic evidence of a hydraulic switching at the end of a surge. The mechanism was previously described based on a number of proxy data and with physical models, however here we have a sedimentary body that was formed at the end of a surge and is clearly visible on satellite imagery, thus easily dated/quantified during the final phase of a surge. We do not claim that this finding has any broader economic impact or introduces any significant contribution to natural hazard mitigation efforts. The significance lay in proving the correctness of the previously described mechanism of glacier surge final phase and more importantly also in emphasizing the significance of extreme events on shaping the recent Arctic coastal zones.

Further, the focus on a single glacier and its associated delta is too narrow. The manuscript could benefit from a comparative analysis with other Arctic deltas, possibly integrating findings from the Overeem et al., 2022 review to contextualize the Svalbard deltas within broader Arctic delta models.

We agree that the focus is narrow, but that is simply the effect of being lucky enough to capture this extreme and unique event. We incorporated basic comparison of progradation rates of other Arctic deltas to emphasize the uniqueness of the Recherche delta progradation rate. At the same time, we must point out that such comparison has to be interpreted with caution as the driving mechanism of delta progradation is different (abrupt surge connected growth X continual sediment transport from the catchment).

The methods are not described in adequate detail for reproducibility. The paper lacks sufficient detail on the feature tracking method used for estimating surge velocity. The robustness of correlations between tracked features is not disclosed. For the delta shoreline tracking, it is not clear to what subset of images the authors applied NDWI. The authors should provide more comprehensive details about the feature tracking and NDWI methodologies, including specific parameters and conditions under which these

methods are applied. This would improve clarity and allow other researchers to replicate or build upon the work.

Thanks for this remark, we fully agree with these shortcomings and included more detailed description of the methods used.

The manuscript does not explore whether subglacial dynamics are affected by sediment accumulation at the snout or if surge rates could be influenced by this accumulation.

In fact, the sediment accumulation in front of a glacier at the end of surge phase will not affect the glacier behavior significantly, as now the glacier is retreating again. It may play a more significant role in case the next surge phase will move over the present delta accumulation – this might be however expected in 30-40 years from now (based on usual surge cycle of Recherchebreen).

Addressing these questions could enhance the manuscript's contribution to understanding glacier-sediment interactions. Highlighting unique aspects or discrepancies in delta formation processes could underscore the significance of the study within the larger field of Arctic geomorphology.

We are very grateful for this suggestion. We have developed new paragraph on the broader significance of our findings to Arctic coastal geomorphology.

Useful literature:

Overeem, I., Nienhuis, J.H. & Piliouras, A. Ice-dominated Arctic deltas. Nat Rev Earth Environ 3, 225–240 (2022). https://doi.org/10.1038/s43017-022-00268-x

Bendixen, M. et al. Promises and perils of sand exploitation in Greenland. Nat. Sustain. 2, 98–104 (2019).

Bendixen, M. & Kroon, A. Conceptualizing delta forms and processes in Arctic coastal environments. Earth Surf. Process. Landf. 42, 1227–1237 (2017).

Rebuttal of manuscript

Glacier Surge as a Trigger for the Fastest Delta Growth in the Arctic

We would like to thank the reviewers for the second round of their comments and suggestions. We carefully implemented the suggestions from reviewer 2, which were helpful and pointed out issues that were forgotten during the first revision.

We have highlighted our responses in italics/yellow. All additions and changes made to the manuscript text are highlighted in the track changes version of the manuscript provided in the editorial system.

Reviewer #1 (Remarks to the Author):

Overall, the authors made a commendable effort to address the reviewers' concerns. The revisions add clarity to the abstract, provide broader context, and detail the methods more thoroughly. While some of the original suggestions (e.g., direct evidence of water release, sonar imagery, sediment core data) were not fully integrated due to practical constraints, the authors explained these limitations convincingly.

In summary, the revised manuscript has been significantly improved and now better addresses the points raised by both reviewers. The study provides a valuable contribution to our understanding of glacial dynamics and coastal evolution in the Arctic, though there is room for further exploration of some aspects in future work.

Thanks again for your suggestions and help provided to improve the manuscript. We appreciate your understanding of the practical constraints that prevent us from using some of your recommendations.

Reviewer #2 (Remarks to the Author):

In its current form, the analyses performed by the authors are not yet reproducible. The authors need to include a supplementary document with a table that lists the imagery

used, including name, date, and satellite, along with progradation measurements associated with each image. The tidal water level should also be included in this table.

Thanks for this remark, we fully agree and provide the table in the supplementary material.

What is the water depth into which this delta is building? An order-of-magnitude estimate would be helpful.

In the paper of Moskalik et al.(2018) the maximum water depth in the lagoon is reported to be approx. 75 m. (https://journals.pan.pl/dlibra/publication/118740/edition/103306/content)

The figure 2b (in Moskalik et al. 2018) suggests that along the coast where the new delta formed the depths were maximum 20 m. Also see figure 9 and profile RI2 which describes exactly the location of the delta. This information was added to the text and the reference incorporated as well.

Lines 123–136 need revision. What processes are facilitating the slope change? Is this working by distributary channels? In its current form, it's totally unclear.

We elaborate more on this issue and add necessary information to support our findings.

What is the tidal range at Recherchebreen? How are tides incorporated into the delta progradation analysis?

The tidal range is approximately 1.5 m. However, there is no direct observation from the site, the nearest tide gauge is located in Longyearbyen (https://kartverket.no/en/at-sea/se-havniva/result?id=966478&location=Longyearbyen) and the tidal range is confirmed by visual observations from a nearby field station Calypsobyen (personal observation by P. Zagórski)

We explain the issue of uncertainty arising from unknown tidal phase in the methods section – end of the "Delta extent mapping" subsection (see lines 245-247).