

Responses to reviewer and editor comments

Quantifying degradation of the Imja Lake moraine dam with fused InSAR and SAR feature tracking time series

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Editor:

Dear George Brencher and co-authors,

Thank you very much for your patience through this process. I well understand the challenges that come from these delays.

A second helpful review has now been received. While one review was positive and supported publication of the manuscript, the second pointed out that this is quite a long paper with two themes of method development and changes to the lake. A reviewer in the first round gave a similar assessment.

For the reasons that you expressed in your review response, I am sympathetic to your desire to keep this as a single manuscript. However, I can also see the benefit for the authors in splitting this manuscript into two and developing a more methods-based paper for a remote sensing journal. I will leave it to the authors to decide on this matter.

If you choose to continue with this single manuscript publication strategy, both reviews point to some recommendations about how to improve the manuscript. I agree with the second reviewer that more attention should be given to the method and less to the speculative aspect. This could be accomplished by shortening the discussion, for instance, by combining the “Ice melt” and “Ice flow” sections into a single section about the lake's seasonal dynamics. Additionally, I agree that the introduction could be streamlined and improved.

Should the authors move forward with this strategy, I will largely assess these writing and organisation matters in the next revision, as the results and scientific quality seem robust.

I wish the authors the best in moving forward with this.

Best regards,
Ian Delaney

Dear Editor,

Thank you for your persistence in finding an additional reviewer for this work. We would like to proceed with publication as a single manuscript. We appreciate the anonymous reviewer's critical reading of both our revised manuscript and previous reviews, and we have made additional revisions based on the insightful feedback we received. In particular, we shortened and streamlined the introduction and removed the more speculative parts of the discussion. The resulting manuscript is shorter and more focused on the methods. To allow for easy navigation of our discussion section, we maintained separate headings for the shortened “Ice melt” and “Ice flow” sections. On the whole, we feel that these revisions have made our manuscript more manageable for readers of *The Cryosphere*.

Sincerely,
George Brencher, on behalf of all authors

Reviewer 3:

I am writing this review taking both the revised manuscript and the reviews into account.

The paper presents different methods based on SAR data to investigate the stability and changes of the Imja Lake moraine dam. This is a highly relevant topic as continued degradation of ice-cored moraine lake dams increases the likelihood of a dam failure causing a glacial lake outburst flood. The work provides relevant insights into the degradation of the moraine, the methods applied are suitable and the results overall reliable so that the study should ultimately be published.

It is also evident that the authors put major efforts in addressing both reviewers' concerns. This led to a clearly improved manuscript. In particular the inclusion of the comparison of the SAR-derived results and the intercomparison of the results of the different SAR methods are very valuable. Considering my knowledge (I am not an SAR expert but have some knowledge in SAR and InSAR and have processed SAR data), I'd judge the methods as sound, relevant influences affecting the accuracy (like the atmospheric noise, influence of the image acquisition geometry) considered and remaining uncertainties discussed. The comparison to the results of the high resolution imagery and results from previous published investigations show the overall reliability of the derived results. Moreover, the observed changes make sense also from the glaciological and geomorphological point of view. However, I am happy to leave the final judgement and possible suggestions for methodological improvements to a real SAR expert.

However, I have also some concerns regarding the current manuscript.

1. The manuscript combines the introduction of a novel SAR based investigation, a detailed description of the relevance of the work and physical/glaciological interpretation of the observed results. These are different topics and from my point of view a bit too broad which leads to a quite lengthy manuscript and is also difficult to find the best journal for the current content. TC is a cryospheric journal, there is value to combine the introduction of a novel combination of the different SAR methods with a cryospheric application. However, as the focus is on introducing the remote sensing methods a Remote Sensing Journal focussing on relevant applications might be the better choice (The methodology could be well applied to other changes at the Earth surface not related to the cryosphere. I do not want to make an advertisement for specific journals, but there are several options of journals which are both read by remote sensing experts and cryospheric scientists. But certainly the study is also interesting for TC).

We appreciate the reviewer's thoughtful comments and opinions. We agree with many points, and touched on several aspects in our initial response to reviewers. Ultimately, we decided to proceed with TC, after streamlining the text.

2. The introduction is quite lengthy has some flaws (e.g. the use of the terminology, references etc.). I understand that one reviewer requested more details. However, from my point of view a one paragraph introducing the importance of investigating the dynamics/degradation of moraine dams will be enough (first introducing in few sentences the general importance of investigating GLOFs and then that weakening of the moraine dam is one of the major causes of GLOFs). In general, the introduction has some flaws as some of the scientific knowledge is not fully correctly summarised and some terms are not used correctly. In the first two sentences the authors first present the future of the glaciers and the past changes of the glacial lakes. It would make more sense to introduce both the current knowledge about the past glacier changes (e.g. as summarised in the recent GlaMBIE paper) and the glacial lakes (mention the cited reference, but also one recent for High Mountain Asia as Shugar et al. missed many glacial lakes). Then the potential future of the glaciers and glacial lakes can be mentioned.

We streamlined the introduction and removed the section on “moraine dam evolution.” While we initially felt that this section contributed useful background information, we now agree that it contained more detail than necessary. In various other locations, we removed superfluous detail. The resulting introduction section is substantially shorter and more focused.

Reading the manuscript gives the impression that all moraines are ice-cored. This is not necessarily the case and also Shugar et al. (2020) do not mention ice-cored moraines. In addition, Ostrem, (1959) is not a suitable reference for the global occurrence of ice-cored moraines or moraines damming proglacial lakes which are addressed in this study. The term risk (L. 104) is incorrectly used. “Risk” in hazards is related to the potential for adverse impacts and includes hazard, exposure and vulnerability. The referencing is overall quite good. However, the referencing is a bit arbitrary, sometimes older relevant references are cited and the recent ones not or vice versa. There are few other issues which might not be present anymore when shortening the intro as suggested above. I would be happy to provide more a detailed review in this regard for a revised version.

We agree that readers could get the false impression from our introduction that all moraines contain buried ice. To address this issue, we removed the phrase “dammed by unstable ice-cored moraines” from the sentence in our first introductory paragraph (Line 29). We updated the following sentence in our second introductory paragraph to communicate that not all moraine dams contain buried ice:

“Where glacial lakes are dammed by moraines, hazard assessments frequently consider moraine dam stability, the presence of buried ice within moraine dams, potential GLOF triggering events, and downstream impacts (Rounce et al., 2016).”

We also removed the “Moraine dam evolution” section, which contained the Ostem (1959) reference and the incorrect use of the term “risk.” We checked the full manuscript and found that this was the only instance of that word. This section also contained most of the older references, and removal improves the cohesiveness of citations.

Few suggestions for potentially relevant references which were not considered (for information only, you may decide to include or not):

Atwood et al. (2010). Using L-band SAR coherence to delineate glacier extent. *Canadian Journal of Remote Sensing*, 36(S1), S186-S195. <https://doi.org/10.5589/m10-014>

Frey et al. (2012). Compilation of a glacier inventory for the western Himalayas from satellite data: methods, challenges, and results. *Remote Sensing of Environment*, 124, 832–843. <https://doi.org/10.1016/j.rse.2012.06.020>

Huggel et al. (2002). Remote-sensing based assessment of hazards from glacier lake outbursts: a case study in the Swiss Alps. *Canadian Geotechnical Journal*, 39, 316–330.

Medeu et al. (2022). Moraine-dammed glacial lakes and threat of glacial debris flows in South-East Kazakhstan. *Earth-Science Reviews*, 229, 103999. <https://doi.org/10.1016/j.earscirev.2022.103999> : The study includes figures which nicely show the existence of ice in moraine dams after outbursts.

Wangchuk et al. (2022). Monitoring glacial lake outburst flood susceptibility using Sentinel-1 SAR data, Google Earth Engine, and persistent scatterer interferometry. *Remote Sensing of Environment*, 271, 112910. <https://doi.org/10.1016/j.rse.2022.112910>

We updated the introduction to include these useful references:

Lines 43-46: Where moraine dam instability is not identified as a primary GLOF trigger mechanism, melting of buried ice can increase lake area, reduce width and height of dams, and provide potential pathways for seepage and piping (Richardson & Reynolds, 2000a; Emmer & Cochachin, 2013, Medeu et al., 2022).

Lines 50-53: Satellite remote sensing has been used to create glacial lake inventories, track glacial lake development (e.g. Fujita et al., 2009; Nie et al., 2018; Shugar et al., 2020), and recently, to monitor glacial lake dam and bank evolution (Haritashya et al., 2018; Scapozza et al., 2019; Wangchuk et al., 2022; Yang et al., 2022; Jiang et al., 2023; Yang et al., 2023; Yu et al., 2024).

Lines 76-79: InSAR coherence can also be used to identify significant change in surface characteristics, and low coherence has been used to map the extent of desert erosion (e.g. Cabré et al., 2020), landslides (e.g. Ohki et al., 2020; Jacquemart and Tiampo, 2021), flooding (e.g. Chini et al., 2019), and debris-covered glaciers (e.g. Atwood et al., 2010; Frey et al., 2012; Lippl et al., 2018).

L141ff: These two paragraphs do not really fit here. They contain mainly a description of the own methods and should be moved to and merged with the methods section.

We partially agree. The first paragraph largely reviews previous work on displacement time series processing and would be out of place in the methods section. The second paragraph largely relates to our method, and we moved the second paragraph to the methods section.

3. The discussion and interpretation contain some interesting and relevant aspects but is quite speculative. It makes sense to include some interpretation but they should not be too speculative and backed up by observations if possible. E.g. the authors write “Backwasting and thermokarst development should...” (L529). Evidence could be provided by the high-resolution imagery. Or “Other processes should ... “ (L549) “...may also be present...” L554. “...potentially experience...” L564. These are only few examples; there are several more.

We removed the more speculative sentences identified above and several others from the discussion, and streamlined interpretations that directly explain our observations.

In sum, I see the major strength in the article in the methodological part which can nicely applied in many aspects, the presented example being one important application. In this sense I have sympathy for the suggestion of splitting the content and submitting two to different journals. This would then also give the opportunity to be more specific on the methods without the manuscript being very long. And then improving the content related to GLOG hazards and degradation if an ice cored moraine.

Having written this I also see value in the combination as the authors argue and certainly leave it to the editor and authors to decide. Also for TC I suggest to shorten the manuscript and focus even more on the method and be less speculative.

We thank the reviewer for their helpful comments. For the reasons we outlined in response to Reviewer 1, we still prefer that this work remains a single manuscript, rather than being split up into two. After streamlining the introduction and removing the more speculative parts of the discussion, the manuscript is notably shorter and more focused on the methods and important cryospheric science results. We feel that these revisions have made the manuscript more manageable and interesting to readers of *The Cryosphere*.