

Dear Editor,

Thank you very much for the feedback and also for the additional comments and questions. We revised the manuscript accordingly and tried to answer all your questions and comments, but also those of the two reviewers. With a few exceptions, we have entered and modified everything as recommended, and we hope that we have been able to clarify everything to everyone's satisfaction.

Our comments and answers to the detailed questions you will find below.

Thank you very much!

Best regards, on behalf of all Co-authors,

Julius Kunz

Editor:

EC: Dear Julius Kunz and co-authors,

Thank you for your patience. I have now received responses from both reviewers.

I am happy to report that both reviewers noted the improvement of the manuscript and your significant efforts to this end. However, in both cases some improvements were recommended that can further improve the manuscript. Additionally, in my reading of the manuscript, there are some minor changes that I recommend. These are listed below.

I am looking forward to an updated version of the manuscript.

*Best regards,
Ian*

EC: Last paragraph of the Introduction: Key knowledge gaps and research questions are presented, along with a direction or plan for the manuscript. Please consider rephrasing into separate paragraphs to keep these themes more identifiable to the reader.

AR: Thanks for this comment. We have rephrased and modified the last paragraphs and now better separate the research questions from the direction of the manuscript.

EC: Ln 97-98: Citation or reference needed?

AR: Thanks for the comment, we rephrased the sentences and included the citation to Buchelt et al, as reference for the used methodological approach.

EC: Ln 161: should "he" be "The"?

AR: Yes, you are totally right. We replaced “he” by “The”.

EC: Ln 256: confirmed by... reference?

AR: To the best of our knowledge, there is currently no reference that describes this phenomenon for the moraine complex investigated. This statement is based solely on a review of various remote sensing data, as recommended by one of the two reviewers. We have slightly revised the sentence to reflect this.

EC: Ln 273: "suggests..." this sentence refers to interpretations. Given that this in the "Results" section, please rephrase or move to "Discussion"

AR: That is right, it is an interpretation based on the geophysical measurements. However, we specifically titled this chapter “Results and Interpretation” because it makes the chapter much easier to understand and prevents the flow of the text from being disrupted by complicated descriptions of geophysical homogeneous regions. To avoid this, we would like to continue assigning interpretations directly to the detected areas.

EC: Ln 305: Give direction, or something like that "right in flow direction"

AR: That is what is meant by “orographic” in relation to ‘right’ and ‘left’, because it essentially means “in the direction of flow.”

EC: Section 4.3 check formatting

AR: We adjusted the formatting of the section title.

EC: Ln 364: "suggests..." interpretation again, please rephrase or move to discussion.

AR: See comment above.

EC: Paragraph from 404: Consider added comments about how this specifically impacts results.

AR: Thanks for the comment. We have added the following sentence to put these limitations into context in relation to our findings: “However, since the results focus primarily on the relative differences among the individual sub-areas, the limitations mentioned are not critical to the overall interpretation and are of no overarching significance.”

EC: Ln 449: add phrase or sentence about why this component should be ignored?

AR: No, it should not be ignored. But due to methodological limitations it is not possible to measure the movements using the applied DInSAR approach. We simply wanted to point out this limitation once again here to avoid any misunderstandings.

EC: Ln 487: Remove "rather"? consider changing throughout.

AR: We deleted “rather”.

EC: Ln 498: Explicitly state two landform types?

AR: Thanks for the comment. We adjusted the sentence accordingly.

EC: Ln 541: Formatting

AR: We adjusted the formatting accordingly.

Referee #1, Report #2

RC: The paper has well gained in consistency. Many thanks to the authors for having answered to all my comments on their previous version of the manuscript.

I still have some minors comments and maybe here and there some disagreement with the authors. However nothing really fundamental. Most of my comments concern the last section of the discussion and the conclusions, and might a bit repetitive.

AR: Dear Reviewer,

Thank you for your comments and questions and for your very thorough review. We believe that the numerous comments have greatly contributed to improving the manuscript. Once again, we have tried to address all questions and comments and have made respective changes to the text. With a few exceptions, we understood the criticism and have addressed it accordingly.

Below you will find a detailed list of all our answers to your questions and comments.

As for the few exceptions, it is very likely—as you have already mentioned—that we simply differ in our views; however, we find this acceptable, as it is part of the scientific discourse. We nevertheless hope that we have revised the article to your satisfaction and addressed most of the remaining questions.

Thank you very much for your effort!

All the best, on behalf of all Co-authors,
Julius Kunz

RC: l. 54. « ... but also incorporation of massive sedimentary ice”. I suggest to add “might have occurred” as it was significant in some cases, but inexistent in other ones, as illustrated by the references selected by the authors.

AR: Thanks for the comment, that is totally right. We added as suggested.

RC: l. 66. Surface “movements” ?

AR: We replaced “movements” by “morphodynamics”

RC: l. 67-68. “...various causes: permafrost creep, subsidence due to ice degradation, or internal deformation in massive ice”:

- ice melt (not ice degradation), mostly occurring at the base of the protecting layer of surface boulders

- I suggest to order from the surface to the larger depth or the reverse (1, 3, 2 or 2, 3, 1)

AR: We adjusted the text as suggested.

RC: l. 68. “...distribution of ice”: distribution of ground ice ?

AR: Yes, we changed accordingly.

RC: l. 109. Pipji : it might be good to mention the back-creeping morphology along most of the orographic right side of the rock glacier / glacier forefield

AR: We added the following sentence: “The orographically right side of the Pipji forefield, including the former lateral moraine and parts of the rock glacier, shows clear signs of backcreeping processes today. These are morphologically discernible in the forefield and are also evident when examining high-resolution orthoimages (Swisstopo).”

RC: l 112. “the Barrwang Glacier formed a thrust moraine complex (BW_TM)”. I don't understand why not to also talk about a glacier forefield-connected rock glacier ? or a TM transitioning to a RG downslope?

AR: The downslope section could mark a transition to a RG, but the eastern (and most important) part, in particular, is morphologically still dominated by features formed by glacial thrusting and therefore is classified as thrust moraine.

RC: l.127-128 + Fig. 1f. “(the investigated thrust moraine complexe) measures about 850 m in length and about 300 m in width, and typical parallel or subparallel ridge structures characterize its surface due to glaciotectonic deformation”. It also shows obvious signs of current of past back-creeping activity (i.e. toward the former glacier talweg). The step drawn at its internal margin is actually over most of its length the front of the back-creeping mass.

AR: That is right and that is why we highlighted the terrain step already in the map. We added the following sentence to clarify: “In addition, the thrust moraine complex shows distinct signs of back creep towards the glacier forefield, which is evident today in a distinct terrain step.”

RC: l. 128 + Fig. 1f. « A second moraine complex developed further down in the valley...”. A second thrust moraine complex ? Why to separate it from the uppermost one ? The major difference appears to be the direction of the post-deformation movement. Why are they separated by a “glacial” section on the map ?

AR: We separate them because they are also morphologically separated in the field. They are clearly delineated and characterized by distinct features. For this reason, we addressed them separately and would like to continue doing so. We separated them by the “glacial” sign in the map because there is an area, where the moraine does not show any sign of glaciotectonism. Instead, this area shows signs of material adjustment without the presence of permafrost.

RC: l. 249. I would suggest restricting the use of the “active layer” terminology to describe the permafrost structure. Here we face the occurrence of a “debris layer” covering glacier ice. So far this debris layer is not thick enough to act as an active layer, it doesn't prevent the summer melt of glacier ice at its bottom. The evolution of the thickness of this layer depends on the rate of enrichment in debris consecutively to the ice melt. The thickness is so continuously but slowly increasing with time.

AR: There is no general answer to this point. In some areas of the investigated landforms, geophysical measurements have failed to detect any massive sedimentary ice but indicated permafrost conditions; consequently, we must assume that these areas are characterised by an active layer. To maintain consistency in terminology, we will therefore continue to use the term “active layer” throughout the article.

RC: l. 256. “...it is assumed that the entire complex is underlain by a massive ice core” – ... that most of the complex... ?

AR: Thanks for the comment. We adjusted the text as suggested.

RC: l. 294-296. I still disagree with the authors, sorry for that. Glacier ice forming the core the thrust-moraine cannot be so clean as it has itself fed the debris layer protecting it. It also has had to be heavily deformed due to its lateral position. It is also impossible that glacier ice, which has moved for many hundreds of meters could be here just pasted on the ground surface in a very clean way without any sign of movement at this contact.

AR: Unfortunately, we still disagree on this point. Especially in the contact zone, there were indeed high levels of debris and signs of deformation visible in the ice. However, this was not the case throughout the entire block. We would accept the difference of opinion at this point, but we would prefer to stick to our interpretation. In any case, we cannot confirm or refute this without taking specific measurements at the site.

RC: l. 315. 4.2. Surface dynamics

Why not to start this section with the ImCORR-derived surface displacement (surface flow field), both in terms of magnitude and direction, in order to provide a clear overview of the horizontal displacements occurring on the study sites. It will help then the reader to better understand the further developments of the section.

AR: We decided to structure the chapter as it is, because the IMCORR-Analysis is not our main methodological approach and we use it more as validation and reference in this case. Therefore, we would like to present the DInSAR analysis first and then compare it with the reference data.

RC: l. 340. Fig. 5. Thanks for having inserted the two lower boxes (g, h) in the figure (movement direction). I am not used to read the direction with colors only. So, I would suggest :

- to make use of arrows or vectors to indicate the flow direction, and to restrict the color for instance to the velocity,
- or alternatively, to add a figure with the flow velocity,
- in any case the flow direction must only be provided for significant movement (according to the detection limit of the applied method) in order to avoid charging the figure with patchy or uncertain/insignificant information.

AR: Sorry for the inconvenience! If you zoom in a little bit, you will see, that there are arrows for indicating the movement direction. Unfortunately, this presents a dilemma that also stems from the high spatial resolution of the InSAR analysis. If we enlarge the

arrow symbols, overlaps occur that make the map impossible to read. If we increase the spacing between the points, we lose spatial resolution, and comparing the results with those of the InSAR analysis no longer makes sense. We have spent a long time deliberating and experimenting with this ourselves and believe we have found the best compromise for our study. Therefore, we would like to keep the graphic as is.

RC: l. 395. As already mentioned, 10 kohmm is not the lower limit for permafrost, so instead of writing “no permafrost”, I would suggest “permafrost unlikely” or “permafrost rather unlikely”. Moreover, the distinction between ice-poor and ice-rich is based on the volumetric ice content (e.g. Arenson et al. 2007 – The rheology of frozen soils), not on the electrical resistivity and there is no reason to set a limit at 100 kohmm.

AR: As mentioned already in the previous round, this is valid when talking about the threshold in generell. At our sites we have reference data due to temperature sensors installed in boreholes and we know that the threshold in both study sites is even slightly higher than 10 kohmm. Therefore, in this specific case we can use the boundary and we can also use the terminology.

RC: l. 491-492. Ice melts, permafrost thaws. So, we talk here about “melt”-subsidence and not “thaw-subsidence”, namely the subsidence due to the melt of sedimentary ice at the bottom the surface debris cover ?

AR: Thanks for the comment, we adjusted accordingly.

RC: l. 497. Weird title : “Importance of distinct differentiation of different landforms and landform units”. Must be simplified and made more explicit.

AR: We changed the title to “Landform classification and its significance for monitoring Rock Glacier Velocity”

RC: l. 498. “These findings highlight the importance of correct distinction between these two landform types”. Being in the first sentence of a section, we actually don’t know about neither what findings, nor what landform types it is talked about.

AR: We have rephrased the sentence to make it more precise. However, since this is not the right place to summarize the main findings, they have not been listed separately here.

RC: l. 503. “DInSAR-derived surface movement patterns can be used to identify ice-rich glacial or periglacial landforms”. The meaning is far from being clear to me. What is also the exact meaning of “ice-rich glacial” or “periglacial” landforms? Seasonal DInSAR surveys contribute to evidence areas where the melt of subsurface (embedded) glacier ice in periglacial (or glacier forefield-connected) landforms occurs.

AR: Thank you for pointing out, that this sentence might be unclear. We tried to rephrase it to highlight, what potential the DInSAR approach has to differentiate landforms and subunits with different surface movement dynamics: “DInSAR-derived surface movement patterns can be used to differentiate landforms and subunits based on their

varying movement dynamics at a larger spatial scale, whereas geophysical surveys could help to clarify internal structures.”

RC: l. 505. As already pointed out in the previous version, “Following the guidelines of the RGIK (2023), thrust moraines (push moraines) are included in the class of glacier forefield-connected rock glaciers” is a wrong statement. As stated by RGIK 2023 and later precised by Brardinoni et al. (2026) in “RGIK guidelines for compiling consistent rock glacier inventories”: “(the glacier forefield-connected) category encompasses ... push-moraines exhibiting postglacial rock glacier-like morphology due to subsequent (outward or backward) creep activity”. It means only those, but not all push-moraines. In addition, RGIK (2023, p. 11) explicitly states that “Permafrost creeping areas that are detected to be moving ..., but do not express a typical rock glacier morphology (e.g., push-moraines ...) are also excluded from (the rock glacier) definition. Therefore, a RoGI includes only landforms that conform to the technical definition of rock glaciers (...) and exclude other ice-bearing landforms associated with permafrost and periglacial processes.” The reference to RGIK (2023) in the previous sentence (l. 503-504) is also unsuitable.

AR: Thanks for the comment. Thats right, not every push or thrust moraine complex has to be classified as rock glacier following the RGIK. Sorry for the misleading wording. To avoid misunderstandings, we adjusted the sentence as follows: “Following the guidelines of the RGIK (2023), thrust moraines (push moraines) can only be included in the class of glacier forefield-connected rock glaciers, if they exhibit typical morphological structures resulting from postglacial creep (outward or backward).” In addition, we deleted the reference to RGIK in the previous sentence.

RC: l. 508-509. “... as the primary underlying process for the morphodynamics is different (melting of ice vs. permafrost creep)”. To me, it is again a wrong statement, sorry. Both processes are dependent on the internal structure and the ice content. For instance, the burying of glacier ice has not occurred in all thrust moraines and melt-induced subsidence cannot be generalised. Permafrost creep also occurs in many thrust moraines during the post-deformation (post-thrusting) phase (continuing today for many moraines thrust during LIA).

AR: Also regarding this comment we made some changes in the text to clarify.

RC: l. 509-512. “As morphodynamical parameters such as rock glacier velocity are derived as essential climate variable (ECV) based on such inventories (...), a lack of distinction between the different landforms may lead to a distortion of the parameters and thus of the assessment of morphodynamic changes in the context of climate change.” I do not understand what the authors would like mean.

RGV (Rock Glacier Velocity) is the single parameter related to rock glaciers in the ECV Permafrost. It is not based on inventories, but for sure relates to the suited characterization of the landforms on which a RGV time series is extracted. The distinction between the so-called “upslope unit” connection in the RGIK guidelines for

inventorying (characterizing) rock glaciers and the set-up of the categories "glacier forefield-connected and glacier-connected" had precisely the motivation of warning users about the impact that glaciers had and might still (indirectly) have on the current dynamics of such rock glaciers.

I send back the authors to my comment on l. 459-464 in the previous version and suggest them to make use of their answer, which is much more explicit than the current version of the text. They can also more closely relate their work to the RGV concepts (provided by RGK) (see my earlier comment) and use it to confirm/support or not the latter.

AR: We tried to clarify and included the information from our answer to your comment in the previous version.

RC: l. 512-513. "Therefore, it is really important to follow the recommendation of the RGK (2023) during the selection of representative areas and to exclude areas dominated by subsidence." The sentence refers to RGV (Rock Glacier Velocity) as defined by the here missing reference RGK (2023b - Rock Glacier Velocity as an associated parameter of ECV Permafrost: Baseline concepts (Version 3.2)) and not by the inventorying guidelines as it is now referred to.

AR: Thank you for pointing that out. We changed the reference, but chose the practical concepts because the statement in there is more pronounced compared to the baseline concept and clearly reflects what we want to address: "Rock glaciers with surface movement dominantly caused by other processes than permafrost creep (e.g. ice melt-induced subsidence, landform destabilization) must be avoided."

RC: Conclusions :

l. 516. ...and connected rock glaciers ?

AR: Since they are not all directly connected to the thrust moraine complexes we have not added "connected". Nevertheless, to be consistent we added "glacier forefield connected" in front of "rock glaciers".

RC: l. 518-519. Different kinds of permafrost ? What is meant ?

AR: We deleted "and permafrost".

RC: l. 522. "Glacier-permafrost interactions resulted in the incorporation of large blocks of massive ice of sedimentary origin into the thrust moraine complexes" -> might result

AR: We changed the sentence to clarify and added a "partially".

RC: l. 522-524. "Resistivity distribution and, therefore, probably the ground ice distribution within the rock glaciers is much more heterogeneous and characterized by rather small-scale structures". This statement is only valid for the few sites investigated in this study but cannot be generalized on this basis.

AR: That is right, thanks. We changed to "the investigated rock glaciers".

RC: l. 526. *“high seasonality” : it must be here again repeated what it is. Moreover, as it is mostly related to the vertical movement of the surface due to the ice melt, this must be clearly stated.*

I always think that the “seasonality” between both the ice-melt subsidence and the creep process must be disentangle, because they are two fully different /independent processes.

AR: We tried to clarify and changed as follows: “On the thrust moraine complexes, these are dominated by negative vertical changes and high seasonality, so seasonal fluctuations in movement rates throughout the summer months.” The linkage between the parameters is described in the following sentences.

Your point about the seasonality might be right, but this is the next step and would go beyond the scope of this article.

RC: l. 530. *...that surface displacements... (not only “that displacements”)*

AR: Thanks for pointing this out. We changed as suggested.

RC: l. 530. *“...melt of massive ice...” Where is his melt taking place (at depth) ? As it produces a large summer subsidence, it must be at shallow depth, namely at the top of the ice layer.*

AR: We added “top-down” to clarify.

RC: l. 532-533: *“The significantly lower correlation between the parameters in the area of the rock glaciers”. I don’t understand the meaning.*

“... has to be interpreted as signal from the internal rock glacier dynamics, which is not entirely controlled by the ice content”. I again do not understand the meaning. “A signal from the rock glacier dynamics” – what does it mean ? “Not entirely controlled by the ice content” - what does it mean ? In the contrary of thrust moraines ?

AR: We added some information to clarify.

RC: l. 538-540. *“Since many rock glacier inventories do not yet differentiate between these landforms, this omission may lead to inaccuracies in assessing morphodynamic changes, particularly when rock glacier velocity is used as an essential climate variable.” This is not really a finding of this study and I don’t well understand the meaning of the sentence. Moreover, RGV (Rock Glacier Velocity – with capitals), as ECV (with capitals as well), does not intend to assess morphodynamic changes. The RGV concepts (RGIK 2023b) precise that “The RGV product specifically focuses on the generation of rock glacier velocity time series in a climate-oriented perspective. Rock glacier velocity is defined here as the quantification of the surface movement of a landform recognized as a rock glacier (cf. Baseline concepts for inventorying rock glaciers).... In the RGV context, only rock glaciers whose motion mechanism is dominantly related to permafrost creep are considered.” See also Kellerer-Pirklbauer et al. (2024): “Therefore, ‘Rock Glacier Velocity’ or (‘RGV’) became an associated product of the Essential Climate Variable (ECV) permafrost within the Global Climate Observing System in October 2022. RGV,*

contrasting to the generic usage of rock glacier velocity ..., is defined as a spatially averaged interannual horizontal velocity timeseries related to a RG unit or a part of it. Thus, RGV is a climate indicator that reflects impacts from climate change on cold mountain environments without reducing climate change to only temperature.”

AR: This is right, it is not really a finding of this study, but it enables to bring the findings of this study into a broader context. Maybe there is still a misunderstanding, but our study is not a criticism of the RGIK or the usage of RGV. In contrast we fully support the initiative. We just wanted to point out the importance of correct classification and selection of reference areas when calculating the RGV. We hope, that our editing helps to clarify our position and the related message.

Referee #2, Report #1

RC: Dear Julius Kunz and co-authors

Dear editor

The authors have done a thorough job addressing the (quite numerous) reviewer comments from the first round, covering reformulations (including the title) and an additional analysis (IMCOR). This additional analysis (IMCOR) has been well inserted in the existing structure of the paper, rather than merely appended. Where the authors pushed back, notably on the choice of the resistivity classes, they did so carefully, with well-reasoned justification and discussion (L415–420). The two thematic threads/scope, the case study and the methodological implications, are retained, introduced (L90–94), and properly discussed (Sect. 5.3), making the paper more coherent now. I appreciate these decisions and recommend acceptance. Thank you very much for the work.

Minor comments:

Figure 7c–d now shares a common y-axis, which aids interpretation. The decision to plot seasonality in relative terms (%) is appropriate. I would, however, suggest cropping the y-axis at perhaps 200–300% to better support the authors' claim that seasonality is weaker on the investigated rock glacier compared to the thrust moraine (L476), as the full range may obscure this contrast visually.

Please ensure that the title of Sect. 4.3 is styled as a proper section heading.

AR: Dear Reviewer,

Thank you very much for reviewing the article a second time, and thank you also for your positive feedback. Your comments and questions have greatly contributed to improving the manuscript!

Regarding your minor comments, we adjusted the formatting of the respective paragraphs. However, with regard to Fig., 7 we decided to keep the scale as it is to avoid data cut-off. Since the information is still visible in the graph, even if it is somewhat less obvious, we hope you can understand our decision.

Thanks a lot!

All the best, on behalf of all Co-authors,
Julius Kunz