Response to reviews

We thank the reviewers for their constructive feedback, which helps optimizing our contribution and invited perspective. Our response is given below in italics. The italics in Review 1 were replaced by <> marks.

Review 1:

[RG - rock glaciers, DG - debris covered glaciers]

Summary

This invited perspective manuscript discusses the application of criteria for identifying/detecting rock glaciers for two example sites, Gruben and Yerba Loca. A main focus is given to differentiating RG from DG. Following the introduction, Section 2 details how the criteria are applied to the Gruben site to distinguish the Gruben rock glacier from the neighbouring debris covered glacier. Section 3 discusses more complicated cases (contact zones of surface and subsurface ice) and concludes that <“neither the term “rock glacier” nor the term “debris-covered glacier” would be appropriate for such complex contact zones with their characteristically diffuse landforms.”>

Section 4 critically states that contrasting views regarding the definition and genesis of rock glaciers exist in the scientific community, particularly regarding how RG differ and should be differentiated from DG. This section functions as a starting point for the following sections, which compare and contrast specific characteristics of RG and DG: Section 5 highlights that RG move as a result of viscous creep of permafrost. The “coherent movement pattern” of the creeping permafrost is transmitted to the surface debris, which is “interlocked” with the deeper layers. This results in characteristic furrows and ridges. In contrast, the surface debris of DG is not “interlocked” with the ice and there are no “coherent flow patterns” on the surface. Section 6 highlights that RG have oversteepened advancing fronts while advancing DG often show massive ice at the terminus. The Yerba Loca site is used as an example illustrating oversteepened fronts at RG and other features of creeping permafrost. Section 7 focuses on differences in the response of RG and DG to climate warming.

Section 8 reiterates key points made in the introduction and throughout the manuscript and concludes that RG and DG should and usually can be clearly distinguished based on the strategies developed by the IPA. Further, as stated in the introduction, the authors recommend that RG as permafrost phenomena remain under the purview of the GTN-P, while DG remain part of the GTN-G.

General comments

This is an important contribution to the ongoing discussion on identifying rock glaciers, e.g. for inventory purposes, and distinguishing them from debris covered glaciers and other landforms. A consistent approach and clear definitions are needed for RG inventorization and the RGIK/IPA guidelines provide a broadly applicable supporting framework for such efforts, many of which are currently ongoing in mountain regions around the world. The manuscript makes valuable points about separating RG from DG and will further support the development of community strategies and guidelines in this area. I am sure my comments/questions can be resolved and look forward to seeing this published in TC.

Response: This perfectly summarizes our contribution. Thanks. We emphasize that advancing rock glaciers have talus-type fronts. This in fundamental contrast to the ice fronts of advancing debris-covered glaciers.

Terminology and definitions: In my opinion it would be beneficial to explicitly include the wording of the guidelines/criteria that are applied, tested and referred to throughout, as well as clear definitions of RG and other terms. Perhaps the introduction could be expanded by a short dictionary style section listing key terminology. This could also include the brief comment on subsurface and surface ice currently in the supplement.

Response: We follow this well-taken suggestion by adding a new section about terms, characteristics and guidelines (subsequent sections are renumbered accordingly):

2. Terminology, characteristics and guidelines:

The RGIK documents provide rich, detailed and comprehensive explanations. As a short summary of this important source, the following terms and guidelines are adopted here and completed with brief notes on principles of surface and subsurface ice with their geophysical characteristics.

Terms:

Landforms: Rock glaciers are debris landforms generated by the former or current creep of frozen ground (permafrost), detectable in the landscape with the following morphologies: front, lateral margins and optionally ridge-and-furrow surface topography. In coherence with global glacier inventory standards, the minimum rock glacier size to be included into a global compilation should be 0.01 km^2. Rock glaciers should not be confused with debris-covered glaciers, which are glaciers partially or completely covered by supraglacial debris. The discussion in our invited perspective focusses (a) on patterns of ridges and furrows as expressions of cohesive flow, and (b) on frontal characteristics rather than lateral margins.

Surface and subsurface ice:

The term "glacier" is explicitly defined as “on the land surface” (Cogley et al., 2011), *i.e., as surface ice. Therefore, debris-covered glaciers as contained in glacier inventories are, by definition, surface ice. Characteristic forms of surface ice, here also in the sense of debris-covered surface ice, are differentiated between glaciers, glacierets, perennial ice patches and dead ice bodies, because the term "glacier" is not appropriate for most of the often small landforms in question for reasons of size (area and elevation range). The definition of the term "permafrost" explicitly relates to thermal conditions of "ground (soil or rock and included ice or organic material)" (IPA, 2023), i.e., of subsurface materials. Ice contained in permafrost is, therefore, by definition subsurface ice or ground ice, independent on its spatial extent.*

Confusion sometimes arises from the use of the term "glacier" in the misleading but historically established and today generally accepted term "rock glacier" as applied to a landform created by subsurface ice under thermal conditions of permafrost. Such confusion can be avoided by accompanying the term "rock glacier" with process- and material-related expressions like "viscous creep features in mountain permafrost", as done in the title of the present contribution.

Geophysical characteristics:

Geophysical characteristics of perennially frozen subsurface materials and of massive (debris-covered) surface ice show marked differences which can be summarized as follows:

Thermal conditions of rock-glacier permafrost are measured in boreholes (Noetzli et al., 2021), by using miniature data loggers at shallow depth (PERMOS, 2023) or they can be approximated through applying numerical models based on climate data (cf., for instance Haq and Baral 2019, Baral and Haq 2020, Li et al., 2023) optimally in combination and, if possible, supported by geodetic measurements of flow characteristics to define activity levels (cf. Bertone et al. 2023). Results from extended time series document ongoing subsurface warming trends (Etzelmüller et al., 2020). Frozen conditions mostly reach down to depths of tens of meters to more than 100 meters. Vertical temperature gradients and heat flow values at depth are strongly reduced due to historical and ongoing surface warming.

Debris-covered surface ice can be temperate, polythermal or cold. Perennial ice patches from avalanche cones or glacierets are most common in connection with rock-glacier permafrost. Such small/thin surface ice bodies can be assumed to be predominantly cold, because their ice cannot warm up above 0°C during the warm season but cool down far below 0°C during the cold part of the year.

In view of geophysical soundings (e.g., Haeberli and Vonder Mühll, 1996; Hausmann et al., 2007; Hauck and Kneisel, 2008; Merz et al., 2015; Pavoni et al. 2021; Halla et al., 2021; de Pasquale et al., 2022), ice-sediment mixtures in rock-glacier permafrost tend to produce

- *strong scatter causing reduced transparency for electromagnetic waves, while homogenous/massive surface ice – especially if cold – is highly transparent for radio-echo soundings;*
- *heterogenous patterns of seismic P-wave velocities with characteristic values varying mostly between about 2,500 and 4,500 m/s, while homogenous/massive surface ice exhibits more uniform values close to 3600 m/s:*
- *heterogenous patterns of electrical resistivities with characteristic values ranging from about 10 kΩm to near 1 MΩm (cf. Herring et al. 2023), in contrast to massive surface ice with characteristic values of 1 to 10 MΩm for small ice patches and glacierets primarily consisting of superimposed ice, and of > 100 MΩm for glacier ice from warm/wet firn metamorphosis with efficient ion evacuation by percolating meltwater.*

Guidelines for landform interpretation:

In addition to detailed qualitative explanations, RGIK (2022) provides the following check-list table for discriminating rock glaciers from debris-covered glaciers or other forms of surface ice:

Geomorphological/ Kinematic feature	Rock glacier	Debris-covered glacier
Transverse ridges and furrows	Frequent	Non-frequent
Talus-like front	Frequent	Non-frequent
Crevasses with exposed ice	Non-frequent	Frequent
Abundant thermokarst	Non-frequent	Frequent
Abundant supraglacial lakes	Non-frequent	Frequent
Ice cliffs	Non-frequent	Frequent
Supraglacial streams/channels	Non-frequent	Frequent
Subsidence rate	~cm/y^{-1}	~m/y^{-1}
Flow field coherence	Good (unless too fast)	Reduced, due to differential melt

The authors point out repeatedly that DG remain DG no matter what, given that they do not turn into RG (a central message of this manuscript). Accordingly, small dead ice bodies that can remain when glaciers melt and may be partially or completely debris covered are still considered DG ("glaciers") in the sense that they are "not rock glaciers". However, they are also no longer "glaciers" in the typical sense. The authors sometimes use the more descriptive phrase "debris covered surface ice" or similar for such cases, but the usage is not always consistent. Defining "glacier" in some way or always using variations of "surface ice" in the context of "complex cases" could help prevent terminology related confusion. The authors also mention a size limit that separates glaciers from "not glaciers" in glacier inventories. It would be helpful to state what this limit is. The readership of TC can certainly make an educated guess about this and other matters, but the clarity of the manuscript could nonetheless be improved by adding some definitions and consistently using the respective terminology.

Response: Right – thanks. An explanation concerning various forms of surface ice and related minimum sizes as applicable in inventories is now provided in the new section 2.

Complex cases, ambiguous landforms: The authors state in the introduction:

<An objective way of differentiating corresponding landforms and kinematics is essential in creating clarity when utilizing such landforms to assess where and how climate change impacts our planet, specifically the cryosphere, or when used in a regulatory/legal context, for example in view of hydrological significance; or generally, to avoid confusion and duplication.">

It is certainly important to distinguish RG from DG for these purposes. It is also important to have a practical and consistent way of dealing with ambiguous landforms that cannot easily be categorised as either DG or RG particularly for inventorization purposes. When inventorization of cryospheric features is connected to regulatory measures, the measures in question often do not themselves give clear definitions of what exactly should and should not be included in the inventory. Having a community consensus on landform definitions beyond RG and DG and on dealing with ambiguity would be beneficial in such cases. Do the authors have a recommendation or further comments on how to deal with ambiguous landforms (buried surface ice as well subsurface ice other than RG) from an inventory perspective, or how a consensus based community strategy to this end might be developed?

Response: Concerning complex contact or transitional zones between surface ice and creeping perennially frozen ground and rock glaciers, RGIK rightly formulates that "the delimitation between the glacier or the ice patch section and the rock glacier section is not feasible without further direct or geophysical prospection". Such contact zones are not usually included in inventories of visible glaciers/surface ice and should not be part of rock-glacier inventories either. The latter are inventories of well-recognizable landforms, not of permafrost zones.

I do not fully understand what the authors are suggesting related to the application of a size threshold and would appreciate more detail on this. Is the idea that a threshold (smaller than glaciers, thinner than underlying permafrost) helps identify the "complex cases" in a general sense, or should such thresholds be used as additional criteria alongside those of the RGIK/IPA for classification purposes? If the latter, how would this size limit be applied practically, for example when compiling an RG inventory? Should the excluded features be ignored in inventorization efforts?

Response: Features which are not clearly identifiable as surface ice or as rock glaciers should indeed be excluded from inventories. This is common practice in glacier inventories and also recommended for rock-glacier inventories

Contrasting views: The authors point out work by others that presents somewhat differing views on the distinction between RG and DG and RG genesis. Section 4 in particular is critical of these works. The authors have strong arguments that can stand alone and are not further strengthened by dismissive comments towards others. I would suggest revisiting this section and either expanding the overview of contrasting work for a more comprehensive picture (e.g. Knight et al, 2019; Jones et al, 2019, and others) or finding a more concise way of introducing the following sections.

Response: Within the framework of policy-relevant global climate-system observation, scientific contributions and practical work must strictly be based on knowledge and understanding from measured facts. In this sense, the text was reformulated in order to avoid confusing discussions about "views" or "opinions", which remain unrelated to, and mostly even in full contradiction with quantitative data from field measurements (drilling, geophysical soundings) about subsurface thermal and ice conditions with their fundamental impact on material characteristics and related physical processes. Reference is, however, made to the literature overview by Janke and Bolch (2022) and to the community comments submitted by Harrison and Whalley/Azizi with response from our side. The references in our contribution concern publications, which report measured evidence.

Specific comments: Introduction: For clarity and to help the reader, I suggest including:

- the specific "proposed technical recommendations/guidelines" that are to be tested. Since the stated aim of the manuscript is to test and comment on the guidelines, it would be useful to explicitly mention what these guidelines are.

- the "technical definition of rock glaciers'' used by the RGIK/IPA, assuming the authors agree with this definition. A reference to section 4 of the manuscript's supplement (surface vs subsurface ice) could be added alongside the definition of rock glaciers to set the stage for the surface/subsurface arguments that follow in the later sections. Alternatively, the short paragraph explaining this as currently contained in the supplement could simply be added to the main text.

Response: Thanks. The new section 2 does this in a short and summarizing way.

The two RGIK documents cited by the authors list two mandatory "geomorphological criteria" for rock glacier detection (front and lateral margins) and one optional criterion (ridge-and-furrow topography, section 3a in the RGIK (2022) baseline concepts). The manuscript discusses RG fronts (Section 6) and ridge-furrow topography (Section 5) but does not mention the lateral margins criterion. If the aim is to test the RGIK criteria, a brief explanation of why lateral margins as a mandatory criterion are being excluded from this exercise of testing and commenting would be helpful. If criteria other than those listed in the RGIK document are being tested, please clarify.

Response: In the new section 2 we state that our focus is on frontal characteristics rather than lateral margins. As the Yerba Loca site documents, striking frontal characteristics (continued oversteepening and destabilisation, exposure of fresh debris) can also indicate active creep and advance of frozen debris outside clearly defined rock-glacier landforms. In the Gruben case, steep lateral margins mark the overall convex landform but the most striking indication of active creep movement is the advancing, oversteepened front.

Section 2: Rock glacier and cold debris-covered glacier at the Gruben site

L95 <The differences are obvious, and the morphological criteria proposed by the IPA action group are adequate> Consider specifying what these criteria are.

Response: Thanks. The formulation is now " … the morphological criteria (steep front and lateral margins, surface pattern with ridges and furrows for rock glaciers, etc.) proposed by …". More information is in the sequence which follows.

Fig 2: I suggest adding a reference to the very helpful Fig. Sup.-1 in the supplement to the caption of this figure.

Response: This is original work by one of the co-authors as part of the PhD thesis of JW.

Section 3: Complex zones with contacts between surface and subsurface ice

L 125 <not every piece of surface ice is a "glacier"> It might be useful to briefly define your usage of the term "glacier" here or earlier in the manuscript, see general comment.

Response: This is now done in the new section 2.

L 139 <mostly smaller than the lower size limit applied to the term "glacier" in glacier inventories> For clarity, please state what this size limit is / give citations. Not all glacier inventories use consistent size limits and some make a case for including very small, debris covered ice bodies in regions where deglaciation is imminent. (See, e.g. the discussion in Section 5.4 of Fischer et al (2021))

Response: The size limit is now indicated in the new section 2. The inclusion of even smaller bodies of surface ice in glacier inventories should not apply the term "glacier" but more appropriate terms like "perennial ice patches", "dead ice remains" or the like.

Section 4 - debris covered glaciers remain debris covered glaciers

L 148: What would the authors consider “adequate” in this context? Perhaps a statement could be made on minimum required quantitative information.

Response: This statement was eliminated.

L151: can DG turn into “complex cases” of buried surface ice in contact with permafrost features as discussed in the previous section as a third option? If so, should that be added to the list as option C? If not it would be useful to briefly clarify.

Response: Where debris-covered surface ice is in contact with permafrost, complex contact zones often develop. RGIK precisely describes such cases. The former contact zone between the polythermal Gruben glacier and the perennially frozen Gruben rock glacier is a well-documented example. The main source of confusion are “either-or” type discussions – “is it a glacier or is it permafrost?” – which also constitutes the basis of the sometimes proposed equifinality concept of rock glacier origins. We now mention that this aspect is explicitly treated in the community comments with our response to them.

L153 <lavastream-like> Consider omitting in the interest of precise usage of terminology.

Response: Accepted and omitted.

L163 <Nevertheless, it is useful to understand the reason why this is the case ...> Why what is the case? I find this sentence hard to follow, consider rephrasing. See also the general comment.

Response: Reformulated: “ ... why version (b) does not seem to occur in nature and what ...”

Section 6 ... as visible at advancing fronts... L217: <Advancing debris-covered glaciers have become exceptional under conditions of atmospheric temperature rise and predominating glacier shrinkage. In such increasingly rare cases, massive ice of the flowing glacier is usually visible at near- vertical fronts where debris cannot accumulate (Figure 4)> Does this imply that Belvedere Glacier (Fig 4) is currently advancing? Afaik that is not the case.

Response: Ghiacciaio del Belvedere was intermittently advancing when the picture was taken from a helicopter. This is now mentioned in the figure caption.

L220: <The advantages of adequately interpreting over-steepened fronts of creeping frozen talus/debris can be illustrated with an example from the Andes....> Fig 5 shows oversteepened fronts marked by yellow arrows at rock glaciers (1, 2, 3) and ambiguous landforms (4, 5). What information is gained by “adequately interpreting” the oversteepened fronts and what does “adequate” mean in this context? Perhaps it would be informative to walk through all three of the RGIK/IPA criteria for rock glacier detection (fronts, lateral margins, furrow-ridge topography) for the Yerba Loca landforms to clearly show how the criteria can help separate rock glaciers from other landforms.

Response: "adequately" was eliminated. On line 226 we added after "rock glaciers" " … with steep fronts/lateral margins and recognizable ridge-and-furrow surface morphology …".

Section 7 … and its effects on ice loss as a response to long-term warming trends L267: <...and hardly ever appears at advancing fronts> Are there studies showing massive ice at advancing fronts? citations?

Response: We are not aware of any occurrences of large bodies of massive ice at undisturbed rock glacier fronts. Bodies of massive ice up to the meter range have been documented in a deep excavation at a rock glacier front (Fisch et al. 1978).

Section 8

L277 <The rich available quantitative knowledge basis from borehole and geophysical data in combination with advanced material- /process-related understanding enables safe and straightforward discrimination between rock glaciers as viscous creep phenomena in ice-rich mountain permafrost and debris-covered glaciers. The corresponding strategies recommended by experts of the International Permafrost Association are clear and easy to follow.>

I suggest briefly stating again what the recommended strategies are. Borehole and geophysical data are available only for a small fraction of RG, DG, and other landforms. It could be pointed out that since the RGIK/IPA strategies are informed by and developed based on the process understanding and rich quantitative knowledge basis the authors refer to, they may be especially helpful in cases when inventories are being compiled without comprehensive geophysical information or boreholes.

Response: Thanks for this suggestion which we gratefully take over. We now write " … corresponding strategies recommended by experts of the International Permafrost Association are informed by and developed based on the process understanding and rich quantitative knowledge basis from numerous sophisticated field investigations using advanced technologies. They are clear and easy to follow, and may be especially helpful in cases when inventories are being compiled without comprehensive site investigations including geophysical soundings or boreholes.

L283 <Complex contact zones of surface ice (mostly perennial snow and ice patches, glacierets or small glaciers) with creep phenomena in ice-rich permafrost in cases constitute diffuse landforms beyond "either-or"- type landform classification.>

I understand that an in-depth discussion may be beyond the scope of this manuscript, but would the authors consider these ambiguous landforms the responsibility of the GTN-P or GTN-G? How should they be inventoried? I agree that they are “beyond simplistic landform attribution” but they are relevant for inventories as assessments of the changing cryosphere in regulatory and or hydrological contexts.

Response: It is our clear opinion that they should be excluded from glacier and permafrost inventories of exactly defined features but deserve more quantitative research. We explicitly state this in our response to the community comments and added in the summary and recommendations section of our contribution: “Exploring contacts and combinations of surface and subsurface ice with their strikingly different response characteristics concerning atmospheric warming is now indeed a growing field of advanced research. It involves quantitative treatment of the involved material properties and processes. This by far exceeds the possibilities of speculative interpretations based alone on visual surface inspection. A recent example illustrating the potential of multimethod field measurements to be used in such complex cases is the comprehensive investigation at the Chauvet site in the French Alps (Cusicanqui et al. 2023).”

Personally, I would like to see the conclusion link back to the stated aim of the introduction, i.e., testing the application of the guidelines of the RGIK/IPA at the Gruben and Yerba Loca sites. Perhaps a brief summary pertaining to this aspect of the manuscript could be added, maybe with some generalised conclusions regarding the usefulness of the specific mandatory and optional criteria (as per RGIK 2022, 3a) that can be derived from the characteristics of the two test sites, i.e., RG and DG in close vicinity at Gruben and different kinds of creeping permafrost at Yerba Loca.

Response: This suggestion is fine. We added the following paragraph at the beginning of the final section: “A combination of striking morphological and dynamic characteristics makes the difference between rock glaciers as viscous creep features in mountain permafrost and debris-covered glaciers (and smaller forms of surface ice) under conditions of ongoing global warming: convex versus concave shape, sharp versus diffuse edges, structured versus chaotic surfaces, continued coherent flow and advance versus slowing-down, disintegration and down-wasting. The test at Gruben and Yerba Loca illustrates the applicability of such criteria in concrete climate-related inventory and monitoring work but also indicates limits and complexities needing further exploration.”

Typos and such:

L161 & L271: I suggest replacing “safely” with “definitively” or a similar word. L261: Check spelling of Moelg/Mölg in citation

Response: Thanks, done. “safely” was eliminated.

Supplement:

Part 2, kinematics Yerba Loca: Can you indicate which of the numbered features (1-5) in Fig 5 are shown in Fig.-Sup. 1-3? Fig. Sup-2: typos in the caption, "Sub" instead of Sup

Response: Thanks, done

Part 4: not referenced in the manuscript? I suggest moving this forward.

Response: Part 4 is now in the main text (new section 2).

References:

Fischer, A., Schwaizer, G., Seiser, B., Helfricht, K., & Stocker-Waldhuber, M. (2021). High-resolution inventory to capture glacier disintegration in the Austrian Silvretta. *The Cryosphere*, *15*(10), 4637-4654.

Jones, D. B., Harrison, S., & Anderson, K. (2019). Mountain glacier-to-rock glacier transition. *Global and Planetary Change*, *181*, 102999.

Knight, J., Harrison, S., & Jones, D. B. (2019). Rock glaciers and the geomorphological evolution of deglacierizing mountains. *Geomorphology*, *324*, 14-24.

Rock glacier inventories and kinematics [RGIK] (2022). Towards standard guidelines for inventorying rock glaciers: Baseline concepts (version 4.2.2). IPA Action Group Rock glacier inventories and kinematics, 13 p. https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_Baseline _Concepts_Inventorying_Rock_Glaciers.pdf

Review by Adriano Ribolini:

I carefully read the paper by Haeberli et al "Discrimitating viscous creep features...".

Honestly, when I agreed to give my opinion on this contribution, I feared that it would be yet another paper on the old discussion about rock glacier vs debris-covered glacier, which has been ongoing in the cryosphere scientific literature for several decades.

Instead, I found the paper very topical, because the authors' opinion is documented by data collected both decades ago but also in the last years with the employment of up to date techniques. Furthermore, the authors clearly state why it is still important to clearly disentangle the two landforms. There is no doubt that the paper is written in a clear, concise manner and with a very logical structure.

I believe it is a paper that clearly exposes in an extremely effective way the authors' opinion about the distinction between rock glacier and debris-covered glacier. The completeness and clarity of the authors' statements make possible counter-deductions and different interpretations of the same or further data by those who have different opinions. And I believe that this type of paper also serves to stimulate a scientific discussion, free of misconceptions, simplifications, and genericity.

My modest experience in permafrost subject leads me to agree with the authors, although I have almost always had to deal with rock glaciers and little with debris-covered glaciers. I too, as a geomorphologist, believe that in many cases the landforms interpretation must go beyond mere intuitions supported by qualitative observations, even if sophisticated and reasonable, or non-decisive data, but that it is necessary to rely on measurements (or better sets of multi-method measurements) when the understanding of the formation mechanisms is complex and includes depositional and post-depositional (i.e. deformative) processes affecting mechanically thermally inhomogeneous materials.

I agree with the authors that the contact zone between debris-covered glacier and rock glacier is pivotal, both for a complete understanding of the differences among the two landforms, but also for dispelling doubts that may arise from the detection (instrumental or visual) of massive ice buried in the apical area of a rock glacier. In these regards, I would like to suggest the authors to clarify better how bodies of massive ice can be "transferred" from a (debris-covered) glacier to a rock glacier. Are they “syngenetically” incorporated by permafrost creep involving the marginal (ice-cored) deposits of a glacier? Is this the consequence of a glacier overlapping onto the root of a rock glacier? Can a fragment of ice core embedded in a rock glacier be displaced by permafrost creep also toward the mid-frontal parts of a rock glacier? These clarifications could explain how in various geophysical soundings values interpretable as massive ice have been identified in non-apical parts of rock glaciers, fuelling interpretations shifted towards debris-covered glaciers origin.

Response: Thanks for these clear and encouraging words. We added the following paragraph in the section about complex cases: “Concerning the “transfer” of surface ice to creeping (rock glacier) permafrost, there is no simple or straightforward general solution. The Gruben and Yerba Loca examples, however, provide some indications. As mentioned in the caption of Figure Sup.-1, the isolated bodies with resistivities in the low MΩm range, still existing today on top of near 0°C permafrost in the former marginal zone of the LIA glacier are most probably dead ice from the small northern tributary underneath the Senggchuppa slope but could also be remains of a buried and frozen avalanche cone at the origin of the photogrammetrically defined flowlines. The earlier visible surface ice at Yerba Loca cannot be called “glaciers” for reasons of size but are/have been perennial ice patches, mostly from avalanche cones. In both cases, *Gruben as well as Yerba Loca, the buried ice bodies are more or less passively riding on top of thick perennially frozen sediments.*

About the effect of thermal protection acted by the active layer of rock glacier , I would suggest to complete the explanation by adding how the active layer can continue to grow if it is its thickening that makes the degradation of the permafrost increasingly slower.

*Response: We now added the following statement**:** "Further, a thickening of the coarse active layer has a substantial impact on the heat transfer between the atmosphere and the permafrost. First, the thermal resistance of the active layer increases as the thickness of the typically unsaturated debris layer increases. Air has a much lower thermal conductivity than ice or frozen ground (e.g., Andersland and Ladanyi, 2003; Arenson et al., 2021), which is why the thermal conductivity of the active layer tends to decrease as a result of permafrost degradation, contrasting the cover of a debris-covered glacier that cannot change its thermal resistance over time. Secondly and potentially more importantly, a thickening of the dry and coarse active layer allows increased air flow and with that additional cooling through air convection (Wicky and Hauck, 2020). The Rayleigh number, which describes the potential and the strength of natural convection in porous media (Kane et al., 2001; Nield and Bejan, 2017), is directly dependent on the thickness of the active layer. As shown in Figure 3, natural convection can increase, or start to form in the thickening active layer of degrading rock-glacier permafrost over time, but remains unchanged for a debris-covered glacier."*

I hope these opinions of mine can be helpful,

Response: They are indeed. Thanks again.

Best regards

References related to our response and not contained yet in our contribution

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