The Cryosphere

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Discussions

Interactive comment on "Nationwide aerial laser scanning reveals relict rock glaciers and protalus ramparts in Slovenia" *by* Mihaela Triglav-Čekada et al.

Anonymous Referee #2

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1. General comments

The study by Triglav-Čekada et al. presents a detailed inventory of rock glaciers and protalus ramparts in the Slovenian mountains where no comparable record existed so far. In total, 28 permafrost-related landforms have been identified based on a qualitative, visual inspection of the nationwide aerial laser scans (1m resolution). In their descriptive and site-specific catalogue of permafrost-related landforms, the authors summarises the main morphometric and topographic attributes of each landform. In my opinion, even though the study seem to fill a data and knowledge gap in the Slovenian mountains on permafrost landforms such as rock glaciers or protalus ramparts, the manuscript does not represent substantial progress beyond the recent scientific

understanding in this research field. Even though the very detailed landform description is commendable and certainly a valuable basis for subsequent analyses in this area, the study does neither provide new methodical insight in this field of research nor increase the general systemic understanding of mountain permafrost and related landforms. Despite the availability and high methodical potential of regional-scale LIDAR data, the findings remain highly descriptive. Despite the title of the study imply a (strong) focus on the application of LIDAR data, a novel use of the high-resolution data or new concepts to interpret the data are missing. Although the data source is carefully described, the methodology with respect to the techniques/ tools (ArcGIS?) as well as the underlying assumptions are not precisely outlined and are not transparent. Finally, the discussion and conclusion remains rather site-specific and descriptive. A more general discussion and referring to related work would help to provide both substantial conclusions on the (recent or former) permafrost distribution in Slovenia and wider implication for other alpine areas. Therefore, given the current version, I propose to reject the manuscript. Even though the availability of LIDAR data and the very detailed rock glacier inventory compiled by the authors might be a very promising basis, fundamental extending work and analyses would be necessary in future to improve the study. If the editor proposes reconsideration, I suggest major revisions, i.e. significant additional methodical work and a stronger focus on current permafrost-related research gaps. In especially, I would recommend realising the great potential of the high-resolution data and to use statistical spatial analyses or modelling approaches. This could potentially lead to a good and novel publication, where empirical evidence leads to new, maybe unexpected systemic knowledge on the spatial pattern rock glacier pattern or even allow conclusion on the past and future permafrost development.

2. Specific comments

Title: Reading the title for the first time immediately implies a study, which has a strong methodical focus where, e.g., a novel application of LIDAR data or methods are presented in order to increase the systemic understanding of permafrost landforms. How-

ever, the subsequent manuscript does not fulfil these expectations as e.g. a method discussion is missing and no new techncial insights are provided. If the study remains as it is (providing an inventory of landforms), I would recommend changing the title to for example "inventory of rock glaciers and protalus ramparts in Solvenia" without reference to the methods.

Abstract: Unfortunately, the abstract gives no valuable insight into the study and needs to be rephrased significantly. Both, the problem statement, the aims or objectives, the methodical approach as well as the systemic and wider implications are not mentioned and remain unclear. For instance, in line 12, "measure these features" it is unclear, with respect to which parameters? Using which method(s)? Quantifying which parameters? This is quite vague, but necessary to mention for the abstract? Similar to the subsequent text, the abstract is rather a description of singular rock glaciers and protalus ramparts, without generalisation of key findings. The descriptive part could be highly shortened and replaced by important "take home messages" for the readers. I recommend to rewrite the abstract in the style of: 1) Problem statement/relevance of the topic, 2) Aims and objectives plus study area, 3) Methodical and conceptual approach, 4) Key results, 5) Specific and wider implications, 6) Conclusion and, maybe, perspective. Similar structure is recommendable for the entire manuscript.

Introduction (in general): Even though the introduction gives an interesting (but sometimes incorrect) overview on the morphometric attributes of rock glaciers and protalus ramparts, the introductions needs to be restructured and reworked as major points are unclear. First, what are the problem statement and key research gaps that should be filled by this study? It is the lack on data on permafrost-related landforms in Slovenia? Or are there also systemic or methodical shortcomings? More specifically, what are the aims/objectives of the study? This remains unclear in the whole study, as sometimes the focus is on "relict landforms hidden under forest" or "availablilty of nationwide LIDAR data". So, is the aim to compile of an inventory of so far undetected landforms? I would suggest that the study would highly benefit and increase in novelty

if the research purpose would be to increase the understanding on permafrost in the Slovenian mountains, or to provide new technical or conceptual approaches based on LIDAR data to detect permafrost-related landforms.

p.2 - L5: What do you mean with "Talus areas"? To my opinion, this is no official geomorphic term for landforms or unconsolidated sediments. So please rephrase (e.g. talus slopes, rockfall sediments) or define/ refer to a study if the term is commonly used.

p.2- L8ff: "Morphologically...". Besides a morphological description of rock glaciers and protalus ramparts, an overview on the process and typical material is need as it is the key link/driver to the morphology of landforms and the basis for further interpretations with respect to permafrost.

p.2 - L24: ".. talus material in an active rock glacier layer" – without any description of the sediment cascades or landform toposequences this statement is unclear. Instead, an previous explanation of the development, the origin or the sediment cascade of the rock glaciers would be useful. Is every rock glaciers sourced by rockfall, thus talus slopes? Are there also other topological successions of sediment storages and processes, so that rock glaciers can also develop from, e.g., moraine material?

p.2 - L24: Instead of/in addition to describing the subsurface material it would be highly useful to explain the material composition of the surface - as it is later one of the key criteria which can be derived from the LIDAR data.

p.2 - L30-33: Here the authors define relict and active rock glaciers based on the density of vegetation cover. Are these vegetation classes the common definitions for relict and active? If yes, the authors should underline this more clearly and make clear, that this is your conceptual basis for subsequent interpretation. If not, I recommend to rephrase the sentences. For instance, you could write that vegetation can be used as indirect proxy to access the activity of rock glaciers, e.g. in the Alps, a vegetation cover of less than 10 % might indicate ..., whereas dense vegetation of more than 70 %...

p.2 - L30 (and methods in general): It becomes not clear, how vegetation is used as proxy for the activity of rock glaciers in this study. Either in the introduction or in the method chapter, it would be useful to define specific classes of vegetation cover (with respect to type) and thus rock glacier activities as well as how these vegetation classes are identified/quantified based on the LIDAR data.

p. 3- L1: I doubt that "75% of rock glaciers are becoming relict". Are the authors mean, that they "are" relict? Furthermore, this cannot be presented as general trend, as it is just a finding of one study (Cremonese et al. 2011).

p.3 – L3ff: Similar to the paragraphs before, the descriptions are lacking any systemic/process explanations or implications for i.e. permafrost. To make this clear specifically based on this sentence: Why are intact rock glaciers exposed to the north, and intact to the south? What are the key controls? How can therefore the distribution and the topographic parameters of rock glaciers used to make conclusions on permafrost? Furthermore, is this a general rule (I do not suppose!)? The authors should be careful in generalising specific finings of cited case studies.

p3 – L16: Is this the aim/objective of the study? To infer relict permafrost features hidden under vegetation? To compile an inventory of relict features? To provide a method where "hidden landforms under forest" can be detected? The actual aim of the study is unclear and even confusing, as this sentence implies that the study will deal with landforms under forest, and later, no proper approach is provided in this context. I would recommend to precisely formulating the objectives of the study. Furthermore, to increase the novelty and the wider implication of this study, besides the methodical purpose, a second systemic aim could be, e.g., to make conclusion on the former/future permafrost distribution with respect to key controls; or more methodically, to discuss the application of LIDAR data to detect permafrost-landforms e.g. by novel modelling approaches.

Study area: A chapter on the study area is actually missing, but is definitely needed to

make the interpretations and site-specific conclusions more understandable and transparent. Moreover, a clear description of the study sites with respect to their key system properties (lithology, size, aspect, etc) would help to understand if the rock glacier distribution is driven by catchment-related differences or if there are any similarities. To be more clear, rock glacier distribution is probably scale-dependent controlled by site-specific characteristics. Thus, given the regional scale of the analysis, a generalisation or transferability of one study site to findings of another study site is probably not feasible or would need a conceptual framework.

Data: In my opinion, the data chapter could be highly shortened because there are too many unnecessary details (L16: wet and cold summer...). Instead I would recommend focusing more on the technical parameters of the data (resolution, precision, catchment sizes, processing of LIDAR data such as extraction of forest/vegetation cover and possible error sources).

Methods and results (in general): Even though the visual inspection of the authors is highly commendable and certainly a very detailed data base now, the high potential of the 1x1m pixel size LIDAR data is not fully realised. For instance, statistical analyses using e.g. novel modelling approaches are missing. The authors write that landform attributes have been extracted, but it remains unclear how and by which method. Therefore, to make this study to a novel work, I recommend to do more technical work and to complement the qualitative findings by statistical analysis. It would be worth to use promising tools such as machine learning or multivariate statistics to extract the permafrost-related landforms. Moreover, the study lacks a conceptual framework and a proper overview of the underlying systemic assumptions. For instance, the use of vegetation as index for active/inactive landforms can be problematic and the ecological mapping criteria need to be clearly justified by referring to related references/methods. Similarly, a proper explanation and the underlying hypothesis of why specific landform attributes (slope, aspect, water outflow) are of interest would help to interpret the identified landforms with respect to presumed key controls and to make general conclusions.

p. 4 – 10-13: Without a study area chapter and description of how much is forested (in %) and alpine (in %), this description is not transparent without any previous knowledge on the regional setting. p. 6 – L2-4: Please, see general comments above concerning "visual inspection". However, specifically: Do the authors really compare a 1x1m LIDAR data set with Google Maps images? This statement would significantly underline the key argument of the study, that "Lidar is now allowing to detect permafrost landforms which wasn't possible so far". p. 6 – 9ff.: I would recommend to be careful with this statement as it appears that, upon revesion, the authors want to say that fieldwork or geomorphic mapping in the field cannot provide a general overview on geomorphic landforms. This statement is difficult as depending on the scale of interest, different scales of information can be obtained during field work, either rather specific (1:10 or 1:100m) or more general (1: 1000, or 1: 10000). Therefore, even though the aim was to get a general overview, fieldwork is still important to validate specific findings and to increase the systemic knowledge. Otherwise, how can the authors be sure that their identified rock glaciers are really inactive/active rock glaciers? To assume this, a mechanistic understanding of the rock glaciers' form, material and process need to be gained in the field. p.6 – L.22-28: Please be more precise, how the landform attributes were "defined" (L26) or measured. In addition, what is the conceptual basis justifying this specific selection of attributes? An explanation and conceptual basis is need why parameters such as slope, elevation, watercourses are important to determine. Is this selection of attributes random or do the authors have certain hypotheses related to the different parameters?

Results (in general): As already mentioned, the results are rather descriptive and qualitative. Actually, a qualitative analysis does not mean that it cannot increase the systemic knowledge. Indeed, qualitative approaches and findings can be highly valuable for an holistic view on landforms and landscapes. However, then in this case, if this study remains descriptive, conceptual conclusions are needed with systemic implications. The authors should think about if the landform inventory can help to identify types of rock glaciers or even toposequences with respect to specific landform attributes and

activity. Moreover, the individual description of all landforms in chapter 3.2 is redundant and not necessary, as it does not provide further information in addition to chapter 3.1. I would highly recommend to summarise all findings and to identify major patterns and relationships concerning the morphometric parameters. General conclusions or relationships or pattern based on statistical results would highly improve the scientific quality of the manuscript (e.g. correlation between morphometric variables, plots and graphs of different parameters with respect to the lithological setting).

p. 7 – 14: How and why do the authors conclude that all protalus ramparts are talus? Before, "talus" wasn't thoroughly defined both as landform itself and in the context of protalus ramparts. Therefore, this sentence and argument is unclear here.

p. 8 - L4-9: The lithological description of the region is actually part of a study area chapter (which is missing before). Moreover, the findings are rather qualitative, could the authors provide statistical evidence on the lithological dominance of the rock glaciers? Furthermore, in the previous method chapter it became not clear how the lithological classes where extracted and statistically evaluated.

p.9 – L1-19: This paragraph is highly descriptive and the specific descriptions of each rock glaciers are without any context and without any generalisation. Please summarise and highlight key findings in order to find general patterns and to make wider conclusions.

Here I have to stop to review the publication, as the amount of necessary suggestions and corrections would go beyond the scope of the revision. With respect to the discussion and conclusion, both site-specific (for Slovenia) and wider implications (for the permafrost community) are missing. Even though the authors try to refer to other studies, the findings are rarely set in context and systemic conclusions are often missing or sometimes incorrect. I suggest revision of the methodical and conceptual approach and additional technical work (e.g. statistics). This could help to discuss the findings in a broader light and to make interesting, novel conclusions for the research field.

1. Technical corrections

Similar to before, I have to stop to review after the first chapter 3.1 due to the excessive amount of corrections and suggestions for improvement/additional work. Some examples:

p.1- L 13: "all the mountainous areas ... were evaluated". Unclear, please rephrase.

p.1- L 18: "heavy" vegetation cover. Please replace "heavy" by "dense" or "high percentage"

p.2 - L1-3: "only recently enabled" – please rephrase (e.g. allows today)

p.2 - L1-3: It would be nice to cite in the reference list an example of the first and most recent publication in this field. Since 2013 (Colucci et al.) more recent studies have been published.

p.2 - L2: Do you mean "glaciers" or "rock glaciers". Furthermore, it would be valuable to define soon from the beginning "permafrost features".

p.2 - L5: Please cite the specific reference, which your permafrost definition is based on.

p.2 - L6: "Other theories" Other than? The context is unclear, as the sentences before didn't provide any other theory.

p.2 - L13: "Under the definition..." – please rephrase, "Based on the..."

p.2 - L21: Please, shorten the references list in this sentence. 3 publications would probably enough here.

p.2 - L22: "mean annual flow velocities..". With respect to rock glaciers, "flow" velocity might not be correct. Please rephrase.

p.3 – L5: Please provide a date/timeframe for the "Alpine Late Glacial", unless it is unclear. Additionally, the conclusion/implication of the different landform age is not

clear.

p.3 – L7: "...Inventories ... have been made". Please rephrase, e.g. "permafrost inventories exist for different areas around the world, such as in ...( ) ...() ...( )

p.3 – L9: "for the whole of the European Alps..., with only.. ". Please correct and rephrase.

p.3 – L7 and L11: "Permafrost inventory". This expression is probably problematic, as here in this study rock glaciers and protalus ramparts are used as index for permafrost. Thus, prefer "inventory of permafrost-features such as rock glaciers and protalus ramparts"

Figure 1: The legend is misleading and the symbols are not explained enough. E.g. To what does "2014-2011" refer? Furthermore, the legend symbol "2 points/m2" should be corrected into "m2" (besides another symbol would be better, as it implies a white filled area). Lastly, instead of only showing areas higher than 2100 m, an regional-scale elevation map overlain by the transparent shaded map would be recommendable.

p. 4 – L6: "For the first time... to gain a detailed look under the forest " . Please rephrase the sentence, as it sounds quite colloquial.

p. 6 – L: 13: The sentence is misleading, please rephrase and be more clear. "Source of sediments, e.g. transported by secondary processes from talus slopes or moraines to the rock glacier".

p. 6: L23: "Mountain sectors" – what does this mean?

Fig. 2 (p. 7): This figure is misleading and needs improvement. 1) Where can the cross sections (exact course) be found in the smaller pictures/shaded relief a and b? 2) The local context of the specific shaded terrain images is not clear (with respect to map on Fig 1). Please show, coordinates, a north arrow, scale. Especially a scale (also for the cross section) is highly needed.

p. 7 – L5: given the content and the descriptive character of the result chapter, "Statistics" is rather misleading and even incorrect. However indeed, as already mentioned, the study would highly benefit from statistics based on the LIDAR data.

P7 – L12: "..are presented on the general map and in Table.." Avoid those unnecessary sentences and simply refer to figures and tables.

Figure 3: The figures need to be highly revised. On every sub-picture, coordinates and north arrow is missing, on the first even the scale. Furthermore, a uniform scale would be better instead of 32km versus 20km. I would also recommend to insert "a", "b" and "c" for each sub-figure. However, why do the authors need the two figures on the right-hand side? As the size difference to the main figure on the left-hand side is not distinctive and they do not contain more information, they are quite redundant.

p. 8 – L15: "Nevertheless, in Table 1, in the column Water, it states. . ." the sentence is unclear and no proper englisch, please correct and rephrase.

p.9 – L1: "This rock glacier is located on the Austrian side of the border". Why is this sentence necessary?

p.9 – L3: "The 13 rock glaciers.." Which one? Delete "The".

Table 1: As the authors use the percentage of vegetation cover as index for activity, a column or statistics on the vegetation coverage (in %) is needed. So far, simply the differentiation between forest, shrubs and spare vegetation cannot be used proxy for activity of rock glaciers. Furthermore, table 1 seems to present the major morphometric analysis in this study. Why not using statistical plots like boxplots, graphs, bars etc. to present and discuss more quantitatively the LIDAR-based results and to identify patterns between different controlling factors?