Reply to comments by L. Copland on "Rock glaciers in the Daxue Shan, southeastern Tibetan Plateau: an inventory, their distribution, and their environmental controls"

Dear Editor and Reviewers,

We would like to thank you very much for the very constructive and motivating review concerning our manuscript entitled "Rock glaciers in the Daxue Shan, southeastern Tibetan Plateau: an inventory, their distribution, and their environmental controls". These comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied comments carefully and have made corrections which we hope meet with approval. The responds to the reviewer's comments are shown below.

All the best, Zeze Ran and Gengnian Liu

General comments:

This paper provides the first inventory of rock glaciers in the Daxue Shan, including an analysis of the topographic controls on them, so fits the general scope of the The Cryosphere. However, there are a few major issues that will need to be addressed before the paper can be published: 1. The outlines provided in the supplementary material often appear to provide outlines of basins which may contain rock glaciers, but they don't do a good job of outlining the actual rock glaciers themselves. Many of the outlines also appear to define talus deposits or debris-covered glaciers, rather than rock glaciers. For example, from a quick review of a few outlines:- ZDSRG-363 seems to contain a rock glacier in its upper and central parts, but the outline extends into forested areas where no rock glaciers are present - ZDSRG-373 seems to mainly consist of the lower part of a debris-covered glacier on the left and talus deposits on the right, with no clear evidence of any rock glacier - ZDSRF-350: there appears to be at least a couple of different rock glaciers in this basin, and the current outline includes surrounding rock cliffs in addition to the rock glaciers themselves. The outlines therefore need to be much better defined, and the text also needs to be improved to more clearly describe exactly what is and isn't a rock glacier and how they can be defined in satellite imagery.

Reply: We thank Dr. L. Copland for his comments on our paper! We also appreciate his careful consideration and detailed comments. Our replies are highlighted in blue. We revised the outlines of the rock glaciers provided in the supplementary material and improved the text.

We have added the relevant sentences to define the outlines of rock glaciers, and how they can be defined in satellite imagery. As shown below:

"Depending on the mobility and permafrost presence, rock glaciers are usually divided into active, inactive, and relict rock glaciers three types (Sattler et al., 2016). In general, the presence of ice within an active/inactive rock glaciers have a steep (>35°) frontal slope (Ikeda and Matsuoka, 2002) and a well-developed flow-like morphology defined by sets of parallel and curved ridges separated by long V-shaped furrows (Barsch, 1996; Roer and Nyenhuis, 2007), the absence or the sparse occurrence of vegetation (Onaca et al., 2013). Inactive rock glaciers also contain ice, but are immobile. In contrast, relict rock glaciers are characterised by surface collapse features as a result of permafrost degradation, with gentler frontal and marginal slopes, and often vegetation cover (Wahrhaftig and Cox, 1959; Haeberli, 1985; Scotti et al., 2013).” (P5L2-P5L9)

2. It’s stated in the abstract that accurate ground truthing was completed in the field, but this isn’t described anywhere in the text. A comprehensive description of field validation would help to strengthen the paper and address some of the issues brought up in the previous point.

Reply: Thank you for pointing out our mistaken expression and we have removed the relevant sentences “as well as upon scientific validation in the field” and “Ground truthing was only possible at a limited number of rock glacier sites within the Daxue Shan, and no fossilized glacier-derived features were visited.” in the paper. At present, due to the inconvenience of transportation in the Daxue Shan, it is difficult for humans to go to the field to obtain field data. Therefore, we mainly identify rock glaciers through visual interpretation of google earth remote sensing images.

3. The statistical analysis of the topographic influences on rock glacier distribution does not properly take into account the collinearity between explanatory variables. As detailed below, Principal Components Analysis provides one way to do this, and without doing this I don’t have high confidence that the stated topographic relationships are real.

Reply: Your advice is very important. Indeed, there may be collinearity between the terrain variables, and principal components analysis (PCA) is a good way to determine the relationships between them (White and Copland, 2015). We also used PCA in some of our previous studies (Ran, 2017), PCA uses the idea of dimensionality reduction to convert multiple indicators into a few comprehensive indicators, and retains the original variable information as much as possible through a few principal components, which is helpful to simplify the problem. However, PCA pays a price in the process of variable dimension reduction, resulting in a loss of principal component information that is smaller than the original variable. In this study, we performed the KMO and Bartlett's Test with a KMO value of 0.387<0.5 (Table 1), the original variable is not suitable for PCA, there is weak collinearity between the terrain variables. Therefore, in the case of convenient interpretation and calculation (not too many dimensions), without dimensionality reduction, the original variable information is retained as much as possible to obtain more terrain information that affects the development of the rock glaciers.

As you said, PCA is very important. Therefore, we are also concerned about it, so we have added the sentences of the PCA “There may be collinearity between the terrain variables, and principal components analysis (PCA) can used to determine the relationships between them (White and Copland, 2015; Ran, 2017). However, in this study, we performed the KMO and Bartlett's Test with a KMO value of 0.387<0.5 (Table 1), the original variable is not suitable for PCA, there is weak collinearity between the terrain variables. Therefore, in the case of convenient interpretation and calculation (not too many dimensions), without dimensionality reduction, the original variable information is retained as much as possible to obtain more terrain information that affects the development of the rock glaciers.” in the paper. (P7L10~P7L15)

Table 1. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.387
Bartlett's Test of Sphericity	Approx. Chi-Square	1216.315
	df	28
	Sig.	.000

Specific Comments:

P1, L14/15: can delete the text in brackets: '(i.e., slopes facing north, northeast…)'

Reply: We have deleted the text in brackets: '(i.e., slopes facing north, northeast, east, southeast, south, southwest, west and northwest)'.

P1, L16: it would be useful to mention what the key topographic controls are in the abstract.

Reply: Thanks very much for your insightful suggestion. We have added the sentence "The analysis of rock glaciers parameters indicates that the formation of rock glaciers is closely related to local topographical parameters." in the abstract. (P1L16~P1L17)

P2, L8: millions is a gross over-estimate. The most recent near-global estimate for the number of rock glaciers is ~73,000: https://www.nature.com/articles/s41598-018-21244-w.

Reply: Thanks for pointing out this. We have rewritten the relevant sentences to "there are ~73,000 rock glaciers in the world (Jones et al., 2018a)". (P2L8)

P2, L11: please provide more refs to back up the statements here, e.g., in relation to the hydrological cycle.

Reply: We have provided references to back up the statements that "The freeze-thaw process experienced by the ice masses within rock glaciers can exert a major impact on the hydrological cycle (Azócar and Brenning, 2010; Jones et al., 2018a; Jones et al., 2018b)". (P2L11)

P2, L22: should also include the new Jones et al. (2018) inventory mentioned above: https://www.nature.com/articles/s41598-018-21244-w.

Reply: We have added references:(Jones et al., 2018a). (P2L20)

P3, L12: I don't think what 'matric' is a word. Do you mean 'matrix'?

Reply: Thanks for pointing out this, and we have changed "matric" to "matrix". (P3L12)

P4, L4: please provide some actual elevation values for the study area description

Reply: We have provided some actual elevation values for the study area description: "resulting in a great altitudinal range (1349 m asl ~ 7321 m asl)." (P4L3)

P4, L18: I don't think that it's accurate to say that Google Earth contains the best available imagery, as there are other data sources with higher resolution (e.g., WorldView imagery). However, it's probably the best freely available source.

Reply: Thank you for pointing out our mistaken expression, and we have added the word "freely". (P4L18)

P4, L21 – P5, L3: a clearer explanation of the unique features that you used to identify rock glaciers is needed; the current description is ambiguous. You also mention in the abstract that your inventory is based upon 'scientific validation in the field', but not mention of this is made in the methods.

Reply: We have added the relevant sentences to elaborate topographic specifications of rock glaciers in our paper. As shown below:

"Depending on the mobility and permafrost presence, rock glaciers are usually divided into active, inactive, and relict rock glaciers three types (Sattler et al., 2016). In general, the presence of ice within an active/inactive rock glaciers have a steep (>35°) frontal slope (Ikeda and Matsuoka, 2002) and a well-developed flow-like morphology defined by sets of parallel and curved ridges separated by long V-shaped furrows (Barsch, 1996; Roer and Nyenhuis, 2007), the absence or the sparse occurrence of vegetation (Onaca et al., 2013). Inactive rock glaciers also contain ice, but are immobile. In contrast, relict rock glaciers are characterised by surface collapse features as a result of permafrost degradation, with gentler frontal and marginal slopes, and often vegetation cover (Wahrhaftig and Cox, 1959; Haeberli, 1985; Scotti et al., 2013)." (P5L2-P5L9)

Thank you for pointing out our mistaken expression and we have removed the relevant sentences "as well as upon scientific validation in the field" and "Ground truthing was only possible at a limited number of rock glacier sites within the Daxue Shan, and no fossilized glacier-derived features were visited." in the paper. At present, due to the inconvenience of transportation in the Daxue Shan, it is difficult for humans to go to the field to obtain field data. Therefore, we mainly identify rock glaciers through visual interpretation of google earth remote sensing images.

P5, L4: the ASTER GDEM is not a program, it's a dataset

Reply: Thanks for pointing out this, and we have changed "program" to "dataset". (P5L10)

P5, L5: please clarify the date: is November 2015 the date when you undertook the analysis, or the date on which the satellite imagery was acquired? In figure 2 you show some images from October 2014, so why isn't that date mentioned here?

Reply: Thank you for pointing out our mistaken expression, October 2014 and November 2015 are the date on which the satellite imagery acquired, we have removed the relevant sentences "for November 2015" in the paper and in Figure 2 shown the date of the acquired satellite imagery.

P5, L11: please provide more details for these values; e.g., does length refer to centerline length? What does width refer to – average, maximum? What does altitude refer to – highest, lowest, average?

Reply: We have rewritten the relevant sentences to "centerline length (m), average width (m), average altitude (m asl)". (P5L17)

P7, L3: similar to above comment, please clarify what these elevations refer to – e.g., mean elevation? Highest elevation at which rock glaciers are found? Lowest elevation at which rock glaciers are found?

Reply: We have clarified the average altitude in Figure 4a. (P31L4)

P7, L8: please clarify whether the upper elevational for rock glaciers occurs due to lack of topography above this altitude, or because of some other factor (e.g., presence of ice glaciers)

Reply: This because of some other factor (e.g., presence of ice glaciers), and we have added the sentence "at higher altitude there are often present some ice glaciers." (P8L13~ P8L14)

P7, L3-L22: this is a very long paragraphs. I would suggest splitting it into two or more shorter paras.

Reply: We are grateful for the suggestions. We have deleted some sentences in the revised manuscript and the paragraph have been shortened.

P9, L10: it would be useful to make some comparisons between the location and characteristics of rock glaciers found in your study vs. the location and characteristics of ice glaciers found by others in the Daxue Shan region. For example, this 2017 paper provides a good recent review of Daxue Shan ice glaciers: https://www.cambridge.org/core/journals/journalof-glaciology/article/changes-of-glaciers-and-glacial-lakes-implying-corridorbarriereffects-and-climate-change-in-the-hengduan-shan-southeastern-tibetanplateau/F0C89671AA75211650FA02FD66AE4DE0/core-reader

Reply: We are grateful for the suggestions, and we have made some comparisons between the location and characteristics of rock glaciers found in our study vs. the location and characteristics of ice glaciers found by others in the Daxue Shan region. As shown below:

"In addition, compared with the distribution of glaciers in the Daxue Shan (Wang et al., 2017), the distributions of rock glaciers also has the characteristics of small differences between the south and north, owing to a north–south corridor effect for water and heat transport and diffusion through the longitudinal gorges in the Daxue Shan. It is the result of climatic and topographical comprehensive control on rock glaciers." (P12L17~ P12L20)

P9, L15: a significant problem with interpretation of the topographic influences is that there is significant collinearity between many of the parameters (as shown in Table 2). This means that it's almost impossible to understand what the true topographic factors are. To address this issue in other similar studies, several authors use Principal Components Analysis to collapse the original explanatory variables into new components that are uncorrelated with each other. See, for example, the Discussion section in: White, A. and Copland, L. 2015. Decadal-scale variations in glacier area changes across the Southern Patagonian Icefield since the 1970s. Arctic, Alpine and Antarctic Research, 47(1), 147-167.

Reply: Your advice is very important. Indeed, there may be collinearity between the terrain variables, and principal components analysis (PCA) is a good way to determine the relationships between them (White and Copland, 2015). We also used PCA in some of our previous studies (Ran, 2017), PCA uses the idea of dimensionality reduction to convert multiple indicators into a few comprehensive indicators, and retains the original variable information as much as possible through a few principal components, which is helpful to simplify the problem. However, PCA pays a price in the process of variable dimension reduction, resulting in a loss of principal component information that is smaller than the original variable. In this study, we performed the KMO and

Bartlett's Test with a KMO value of 0.387<0.5 (Table 1), the original variable is not suitable for PCA, there is weak collinearity between the terrain variables. Therefore, in the case of convenient interpretation and calculation (not too many dimensions), without dimensionality reduction, the original variable information is retained as much as possible to obtain more terrain information that affects the development of the rock glaciers.

As you said, PCA is very important. Therefore, we are also concerned about it, so we have added the sentences of the PCA "There may be collinearity between the terrain variables, and principal components analysis (PCA) can used to determine the relationships between them (White and Copland, 2015; Ran, 2017). However, in this study, we performed the KMO and Bartlett's Test with a KMO value of 0.387<0.5 (Table 1), the original variable is not suitable for PCA, there is weak collinearity between the terrain variables. Therefore, in the case of convenient interpretation and calculation (not too many dimensions), without dimensionality reduction, the original variable information is retained as much as possible to obtain more terrain information that affects the development of the rock glaciers." in the paper. (P7L10~P7L15)

P10, L15-25: the discussion here would be helped by a better comparison with the present and historical location of ice glaciers in this region, so that the connection to glacial landforms such as moraines can be better understood. E.g., are current rock glaciers found in close association with current ice glaciers? Do you observe any direct evidence of a present ice glacier transforming to a rock glacier?

Reply: We are grateful for the suggestions, and we have made some comparisons with the present and historical location of ice glaciers in this region. As shown below:

"We found that the distribution of rock glaciers in close association with ice glaciers in the Daxue Shan, the upper boundaries for rock glaciers were ~4,600 m asl, at higher altitude there are often present some ice glaciers. In the context of global warming, it is widely accepted that the majority of glaciers on the Tibetan Plateau (TP) and its surroundings have experienced accelerated reduction (Bolch et al., 2012; Yao et al., 2012). The rate of glacier decline in Daxue Shan was -0.25 ± 0.20% a^{-1} during 1990-2014 (Wang et al., 2017), some ice glaciers transforming to rock glaciers." (P11L12- P11L16)

P11, L23: change 'highly' to 'high'

Reply: Thanks for pointing out this, and we have changed "highly" to "high". (P13L7)

P12, L8: this seems to be the only location in the paper where you refer to ground truthing, and the uncertainty here contrasts with the 'scientific validation in the field' stated in the abstract. In the paper you need to much better describe what kind of field validation you did, any inherent errors or uncertainties with it, and adjust the wording in the abstract and elsewhere as appropriate.

Reply: Thank you for pointing out our mistaken expression and we have removed the relevant sentences "as well as upon scientific validation in the field" in the abstract and "Ground truthing was only possible at a limited number of rock glacier sites within the Daxue Shan, and no fossilized glacier-derived features were visited." in the paper. At present, due to the inconvenience of transportation in the Daxue Shan, it is difficult for humans to go to the field to obtain field data. Therefore, we mainly identify rock glaciers through visual interpretation of google earth remote sensing images.

P13, L3: similar to the comment for p7, define whether the upper altitudinal limit is due to lack of topography above this altitude or some other factor.

Reply: We have added the sentence “at higher altitude there are often present some ice glaciers.” (P14L21~ P14L22)

P13, L12: have there been any field measurements in your study area that can help to define the distribution of permafrost? E.g., have there been any direct ground temperature measurements? Or ground probing or digging of pits?

Reply: At present, due to the inconvenience of transportation in the Daxue Shan, it is difficult for humans to go to the field to obtain field data. We mainly identify rock glaciers through visual interpretation of google earth remote sensing images, and then compared our manual mapping with the Gruber’s (2012) global Permafrost Zonation Index (PZI) map, found that the rock glaciers distribution in the Daxue Shan is in good agreement with the PZI on the whole (Fig. 3) (P12L13~P12L16). Therefore, we have removed our mistaken expression “as well as upon scientific validation in the field” and “Ground truthing was only possible at a limited number of rock glacier sites within the Daxue Shan, and no fossilized glacier-derived features were visited.” in the paper.

Fig. 1a: it seems that this data is plotted in lat/long (i.e., unprojected), which makes it look strange at this scale as it seems to be squashed in a north-south direction. This would be better plotted in a projected coordinate system

Reply: Indeed, Fig. 1a was produced using a temporal resolution of 30 arc-seconds (<1km) on a WGS84 lat/lon grid (Gruber, 2012) and we mentioned in the paper. We try to use the first figure (*i.e.* Fig. 1a) to show the spatial representation of the study area in the real world, and then conduct subsequent research. Simultaneously, Fig. 1a indicating the location of the study area in the permafrost zone of the TP rather than the TP. Therefore, it looks like be squashed in a north-south direction.

Fig. 1c: it would be more useful to show a satellite image of the study area (perhaps with a contour map superimposed over it), rather than the topographic map that basically repeats what is already shown in Fig. 1b. No regional satellite imagery is currently provided in the paper, which makes it difficult to understand the general characteristics of the region and location of other features such as ice glaciers.

Reply: We are grateful for the suggestions. In this paper, we focus on exploring the control of topography on the rock glaciers. Therefore, we magnified Fig. 1c based on the thumbnail Fig. 1b to highlight the trend of elevation changes in the study area. With regard to regional satellite imagery, we have shown the general characteristics of the region and location of other features such as ice glaciers in the KML file provided with the supplemental material.

Fig. 2: the scale on these figures need to be clearer

Reply: Thanks for pointing out this, and we have made the scale on these figures be clearer.

Fig. 3: a zoom-in of some of the areas with the largest rock glacier concentration (e.g., Mt. Zheduo) would be useful to add, preferably with the rock glacier outlines superimposed on a satellite

image

Reply: Thank you very much for your constructive suggestions. We have transformed Fig. 3 to explore the correlation of the spatial distribution of rock glaciers and permafrost zonation index in the Daxue Shan.

Fig. 4: add labels to different figure parts: (a), (b), (c), (d)

Reply: We have added labels to different figure parts: (a), (b), (c), (d)

Fig. 5: add labels to different figure parts: (a), (b), (c), (d). Also define acronyms used in bottom two figures: MTRG, MLRG, TTRG, TTLG

Reply: We have added labels to different figure parts: (a), (b), (c), (d) and defined acronyms used in bottom two figures: MTRG, MLRG, TTRG, TTLG. (P32L4~P32L6)

Fig. 6: this is a pretty low quality figure that's difficult to follow. Please make clearer and prevent number labels from overlapping.

Reply: We have made Figure 6 clearer and prevented number labels from overlapping.

Fig. 7: several of the colours in this figure are similar (lots of pinks/purples), which makes it difficult to distinguish between the various rock types. It's also unclear what the letters/numbers on the map refer to: e.g., T2-3zg-z? T3xd? These need to be described in the legend or deleted.

Reply: Due to the large number of groups, there are some look similar pink/purple in this picture, so we used the $T_{2\text{-}3}$zg-z, T_3xd, etc. to mark different geochronological stratigraphic units, which are international standards for geochronological stratigraphic units and recognized in the geological world, please refer to http://www.stratigraphy.org/ for details. In this figure, we showed the correlation between the spatial distribution of rock glaciers and local different geochronological stratigraphic units through lithologic geological maps, in order to explore the impact of local lithological geological conditions on rock glaciers in the Daxue Shan.

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