Reply to comments by T. Bolch 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:

The study presents the first comprehensive rock glacier inventory of a specific mountain range in the southeastern Tibetan Plateau. Moreover different controls of their occurrence are analysed and described. Currently only little is known about rock glacier occurrence in Tibet and no comprehensive study exists. The topic of the study is therefore relevant and suitable for The Cryosphere. The text is, however, quite descriptive and needs moreover some structural and language improvements. I appreciate very much that the generated inventory is provided as supplementary material to this article. The major shortcoming is that the generated rock glacier inventory contains many errors and needs to be completely revised. Moreover, an analysis or a discussion of uncertainty is entirely missing. More details are provided below.

Reply: We thank Dr. T. Bolch for his comments on our paper! We also appreciate his careful consideration and detailed comments. Our replies are highlighted in blue. We have revised the outlines of the rock glaciers provided in the supplementary material and improved the text. In addition, we have analyzed and discussed about the uncertainty and possible sources of errors. As shown below:

(1) Elaborate topographic specifications of rock glaciers:

"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)Discussed about the uncertainty and possible sources of errors:

"In addition, some aspects of digitisation were challenging based on visual interpretation of

remotely sensed imagery alone and thus inherently associated with uncertainty (Sattler et al., 2016; Jones et al., 2018b). There are some rock glaciers may not be correctly delineated. Especially, delimitation of the upper boundary of rock glaciers through geomorphic mapping, is arbitrary (Krainer and Ribis, 2012); delineation of individual polygons where multiple rock glaciers coalesce into a single body, is inherently subjective (Scotti et al., 2013; Schmid et al., 2015). Moreover, several complex landforms may are delineated as rock glaciers which could also be landslide deposits or relict rock glaciers. Therefore, in the future research, adding additional data sources and geophysical field investigations would be necessary to further increase the accuracy of the outlines of the rock glaciers." (P6L10~P6L17)

Most critical issue:

The authors delineate rock glaciers manually by on screen digitising based on high resolution satellite images available on Google Earth. General characteristics of rock glaciers are described based on the literature which the authors took as the basis for their delineation. However, from figures 2, 3, and 7 and from the provided vector data it is obvious that many rock glaciers are not correctly delineated. Especially the upper boundary of the rock glaciers is often wrong. Moreover, several complex landforms are delineated as rock glaciers which could also be landslide deposits or relict rock glaciers. I provide below two examples below: In both complex landforms are combined into one large rock glacier, but parts of the area are very probably not part of creeping permafrost bodies. Moreover, steep headwalls are also classified as rock glaciers which deliver debris, but are certainly not part of rock glaciers. In addition, some of the delineated features may not be rock glaciers. I am aware that it is partly impossible to clearly identify rock glaciers based on optical imagery alone. However, more effort is needed to correctly classify rock glaciers and hence, the rock glacier inventory needs to be completely revised at best using additional data sources. The newly available High Mountain Asia DEM, information providing information about the surface displacement (e.g. SAR coherence images) and the occurrence of permafrost (e.g. based on the Permafrost Zonation Index (Gruber, 2012, TC) or Chinese permafrost maps) will be important additional data sources. I am aware that this requires huge additional effort, but it is important that the inventory is as accurate as possible in order not to provide a wrong example about how to delineate rock glaciers and in order to not provide wrong numbers. Alternatively the authors may also revise their inventory using at least some additional data, only include intact (active and inactive rock glaciers) into the inventory, and classify them according to the certainty.

Reply: Thanks very much for your insightful suggestion. We have revised the outlines of the rock glaciers provided in the supplementary material, revised the figures 2, 3, 7 and the provided vector data. In addition, we have added the Permafrost Zonation Index (Gruber, 2012) and their take on the Daxue Shan. As shown below:

"The cryosphere reacts sensitively to climate change (Gruber et al., 2017). Compared with Gruber's (2012) global Permafrost Zonation Index (PZI) map, the rock glaciers distribution in the Daxue Shan is in good agreement with the PZI on the whole and some rock glaciers are situated within the PZI fringe of uncertainty (Fig. 3). Strictly controlled by the temperature decreasing with increasing altitude, further indicating the climatic controls on development of permafrost such as rock glaciers." (P12L13~P12L16)

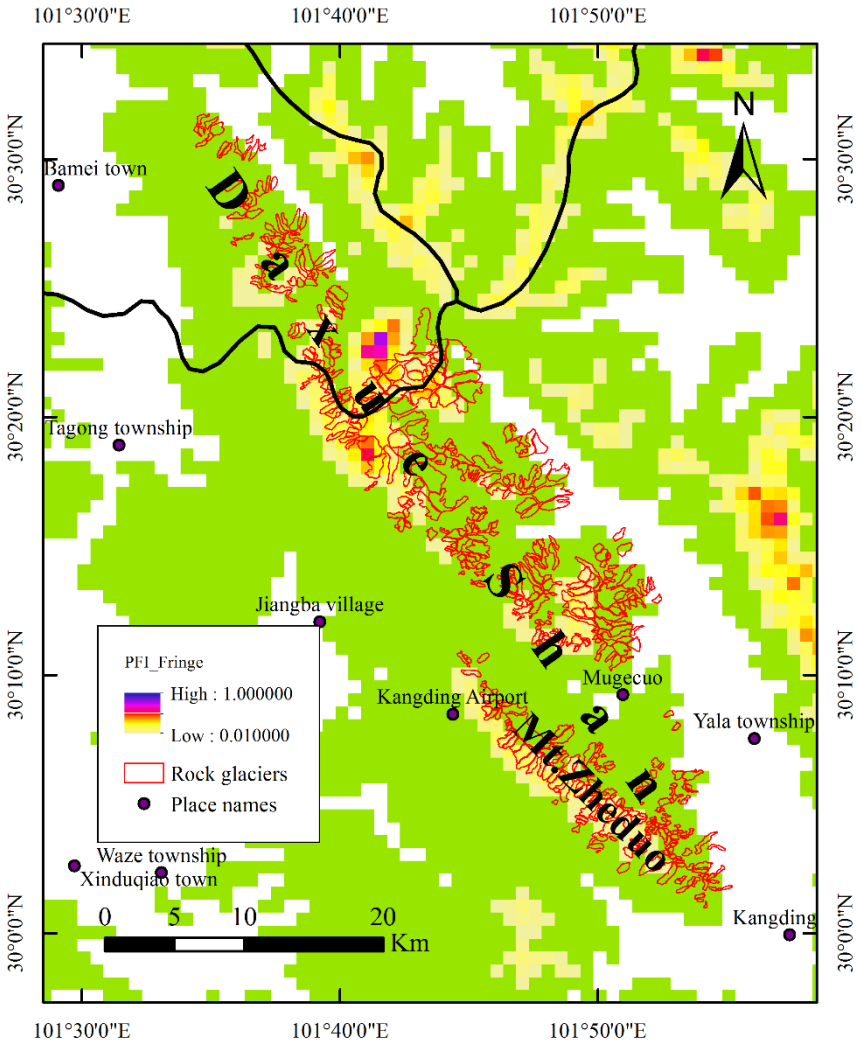

Figure 3: Spatial distribution of rock glaciers and Permafrost Zonation Index (PZI) in the Daxue Shan. The PZI data sources: Gruber's (2012), the green area represent the fringe of uncertainty.

Further major comments:

1. The description of the methodology and the criteria for identification rock glaciers needs to be much more explicitly mentioned and described considering the relevant literature. In addition, an analysis and discussion about the uncertainty and possible sources of errors needs to be included.

Reply: Thanks for pointing out this, and 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)

In addition, we have analyzed and discussed about the uncertainty and possible sources of errors. As shown below:

“In addition, some aspects of digitisation were challenging based on visual interpretation of remotely sensed imagery alone and thus inherently associated with uncertainty (Sattler et al., 2016; Jones et al., 2018b). There are some rock glaciers may not be correctly delineated. Especially, delimitation of the upper boundary of rock glaciers through geomorphic mapping, is arbitrary (Krainer and Ribis, 2012); delineation of individual polygons where multiple rock glaciers coalesce into a single body, is inherently subjective (Scotti et al., 2013; Schmid et al., 2015). Moreover, several complex landforms may are delineated as rock glaciers which could also be landslide deposits or relict rock glaciers. Therefore, in the future research, adding additional data sources and geophysical field investigations would be necessary to further increase the accuracy of the outlines of the rock glaciers.” (P6L10~P6L17)

2. The lower altitude of rock glaciers may provide information about the lower boundary the area where permafrost is probable. However, there are many exceptions. Hence, this concept needs to be applied with more caution. In addition, a comparison with existing information about permafrost occurrence (e.g. Gruber, 2012, Chinese maps of permafrost occurrence) should be provided.

Reply: Thanks for pointing out this. We have added the words “approximation”, “probable” in this paragraph, and rewritten the relevant sentences to “The mean lower permafrost boundary on east-facing (shady) slopes would therefore probable be 104 m lower than that of west-facing (sunny) slopes (Fig. 6).” (P9L22~P9L23)

We have also added the global permafrost distribution maps and their take on the Daxue Shan. (P12L13~P12L16)

3. The results section is too descriptive. Highlight the most important findings and refer to tables for the detailed information.

Reply: Thank you for your suggestions. We provided tables and figures in the results section (Table 2, Fig. 3, Fig. 4, Fig. 5 and Fig. 6 are currently behind the text, which will be moved to the result section of the paper after revision into a publishable version), and the text of the results section is the explanation and findings of the tables and figures.

4. The results should be put much better into context of existing literature and not only to the few existing ones from Chinese Tien Shan. I would help in this respect to separate the results and discussion into own sections.

Reply: We are grateful for the suggestions. We have added recent literature about the other parts of northern Tien Shan (Bolch and Gorbunov, 2014) (P13L19), and performed similar analysis in the paper. Then we adjusted the structure of the paper and separated the results and discussion into two sections.

5. The authors use partly improper terminology, e.g. “marine-type periglacial environment”, “fossilized glacier-derived features”

Reply: Thank you for pointing out our improper terminology. We have changed "marine-type periglacial environment" to "maritime periglacial environment" (P1L19), and deleted the relevant sentences "and no fossilized glacier-derived features were visited." in the paper.

Specific comments:

P. 2 L12f. Provide more details and a reference. What are the phenomena observed in ice margins?

Reply: We are grateful for the suggestions. Considered the continuity and completeness of the logical structure of this paragraph, we have removed ", and is vital to understand when reconstructing the local paleoclimate and paleoenvironment. Rock glaciers are therefore not only characterized by an advanced form of creep movement, but are also complex landforms which incorporate many of the phenomena observed in ice margins" in this paragraph, then we added the relevant sentences elaborating topographic specifications of rock glaciers in the methods.

L. 18ff. Do not cite so many references in a row (max. 5-6). Be more specific and selective.

Reply: We have subtracted some references.

P. 3 L5f: Be more specific. Shukla et al. (2010) address debris-covered glaciers, not rock glaciers.

Reply: Thanks for pointing out this. We have rewritten the sentences "However, compared with ice glaciers, rock glaciers remain poorly described and infrequently studied because they are mixtures of rock fragments of different sizes, and therefore cannot easily be automatically mapped from RS data because they are spectrally similar to their surroundings (Brenning, 2009). Both supraglacial-debris (upon the glacier) and debris along the glacier margins originate from surrounding valley rock (Jones et al., 2018b), and their debris surface does not produce a distinct spectral signal." (P3L1-P3L5), and deleted reference (Shukla et al., 2010) in the paper.

L. 22: Include the info about elevation.

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)

L. 23: Delete "famous". I and probably the vast majority of the readers have never heard about this mountain. Include the elevation.

Reply: Thanks for pointing out this. We have deleted "famous" and added the elevation "(4962 m asl)." (P3L23)

P. 4, L. 1ff: Include more references to prove the statements.

Reply: We have added reference (Zhang et al., 2017) to prove the statements. (P4L2)

P. 5, L. 12. The scale of the geological map is rough. Isn't there a better scale available?

Reply: We are grateful for the suggestions. At present, according to the relevant Chinese laws and regulations, some of the larger-scale geological maps belong to the confidential data and can only be used by units with qualified confidential, social capital units and individuals cannot obtain these geological maps. In Figure 8, we focus on exploring the correlation between local lithologic-

geologic environment (lithological map reconstructed from a 1:500,000-scale digital geological map) and the spatial distribution of rock glaciers. We found that in the Daxue Shan both moraine-type and talus-derived rock glaciers have developed in the monzogranitic areas, and that rock glacier and monzonitic granite exhibit a high spatial correlation and interdependence. The Tertiary monzogranites of the Daxue Shan are clearly highly conducive to the formation and development of rock glaciers. The referee's concern is of importance for our further study. In the related research in the future, we will strive to obtain better scale geological maps based on the above research for more possible detailed results.

L. 23-25. These details are not needed as obvious; just write vs. aspect.

Reply: Thanks for pointing out this. We have deleted ", viz. north-facing (337.5°~360°, 0°~22.5°), northeast-facing (22.5°~67.5°), east-facing (67.5°~112.5°), southeast-facing (112.5°~157.5°), south-facing (157.5°~202.5°), southwest-facing (202.5°~247.5°), west-facing (247.5°~292.5°) and northwest-facing (292.5°~337.5°)" in the paper.

P. 6, L. 12. I think there are much more talus-derived rock glaciers. Provide a clear definition and proof the number better.

Reply: Thanks for pointing out this. We have revised the definition and number of talus-derived rock glaciers.

P. 8, L. 15ff: Consider more recent literature which perform similar analysis, but also older other literature and do not refrain only to Chinese researchers. The northern Tien Shan stretches from Kyrgyzstan in the west to Xinjiang in the east. Hence either write "Northern Tien (or Tian) Shan" in China or (which is preferred) consider also the other parts of northern Tien Shan (e.g. the work authored and co-authors by A. Gorbunov).

Reply: We are grateful for the suggestions. We have added recent literature about the other parts of northern Tien Shan (Bolch and Gorbunov, 2014) (P13L19), and performed similar analysis in the paper.

P. 9, L. 15ff: Move the methodological description to the methods section.

Reply: We are grateful for the suggestions. We have moved the methodological description to the methods section.

P. 11, L. 2ff: The general info about the climate would fit much better in the section about the study area.

Reply: Thank you very much for your constructive suggestions; we have moved the general info about the climate to the section about the study area.

L. 12, section 4.3. This section is not a proper own section: It contains methodological information (e.g. about ground truthing and the used DEM) and also information about the limitations. The respective parts should therefore be moved to the methods and discussion section.

Reply: We are grateful for the suggestions. We have moved section 4.3 to the methods and discussion section.

References: The formatting of the references should be carefully checked so that all meet the

journal specifications.

Reply: Thanks for pointing out this and we have revised the formatting of the references.

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