Reply to comments by J. Müller 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 authors introduce a novel rock glacier inventory of the Daxue Shan mountain range in the southeastern Tibetan Plateau. They use Google earth imagery to visually identify and map rock glaciers in the entire area. Supplementary data such as the ASTER GDEM and lithological information are implemented to assign localized geomorphometric and subsurface attributes which is used for quantitative and qualitative analysis. The methods applied in this manuscript are well established and the analysis also does not hold any surprises but it is still a novel dataset presenting the rock glacier occurrence and distribution in the southeastern Tibetan Plateau. It is overall a further step towards a global rock glacier map. I therefore recommend the publication of this manuscript after moderate revisions. Please find some remarks in the following and very specific comments in the attached pdf where I implemented some comments.

Reply: We thank Dr. J. Müller for his positive comments on our paper! We also appreciate his careful consideration and detailed comments. Our replies are highlighted in blue.

Specific comments:

Methods P5L2 You need to elaborate more on the topographic specifications of active, inactive and fossil rock glaciers. Be with your approach it is hard to identify between the three but there are certain proxies such as subsidence and vegetation which can be used to determine the state of the RG. You mention in the abstract that you also use field data for the analysis but you never mention what kind of field data you acquired and how you use it. You mention environmental controls like temperature and temperature dynamics like freeze thaw cycles numerous times in the manuscript but you never show any data. Maybe you have access to some high mountain temperature data in the area which you can show and help you with your argument. Not just the annual means as table 3 but also the annual or multiannual dynamics.

Reply: (1) Thank you very much for your constructive suggestions, we have added the relevant sentences to elaborate topographic specifications of active, inactive and fossil 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)

(2) 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.

(3) We have added data and transformed Table 3 into Figure 7 to better illustrate the freezing and thawing effect of rock glaciers in the Daxue Shan. However, there are currently only four meteorological stations. In the future, we hope to seek funding from relevant agencies and establish more meteorological stations in high altitudes.

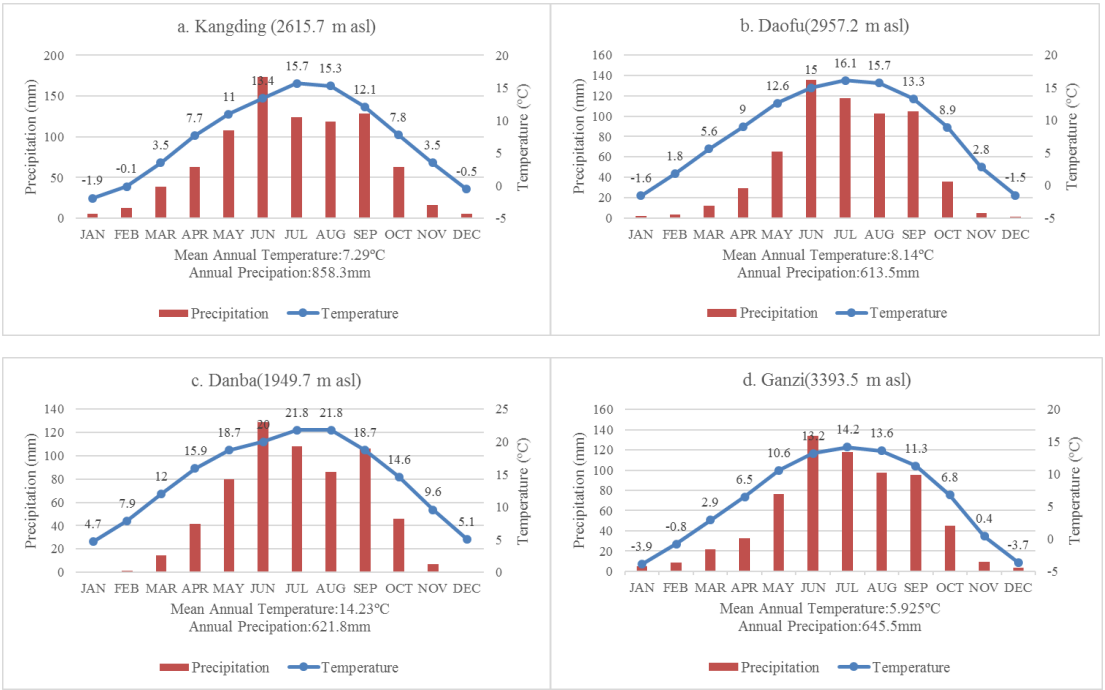

Figure 7: Climatographs for the Kangding (2,615.7 m asl, 30.03°N, 101.58°E), Daofu (2,957.2 m asl, 30.59°N, 101.07°E), Danba (1,949.7 m asl, 30.53°N, 101.53°E) and Ganzi (3,393.5 m asl, 31.37°N, 100°E) meteorological stations. Data sources: Meteorological Data Center of the China Meteorological Administration (calculated for the period 1981–2010, inclusive).

4. Results and Discussion Since you manually derived the RG geometries it would be great if you could elaborate on the accuracy of your method. Did you have several persons working on the

digitization of the RGs and did they perform differently or do you have more accurate field data which you could compare to the manual mapping and are there any differences? I would suggest to refrain from using latitude and longitude to analyse RG properties since lat and long do not describe any environmental parameter but rather the regional topographical setting is more important. And thats the parameter that changes with Lat and Long. Focus more on the regional settings such as aspects, debris sources and valley/slope orientation to interpret RG properties. It would be very beneficial if you include a description of the topographical characteristics of the study site in relation to the formation and evolution of rock glaciers. This would also help to understand the spatial setting which goes with the latitudinal impact.

Reply: Thank you for your advice and it is very important. We have analyzed and discussed about the accuracy and uncertainty of method (P6L10~P6L17), and we have two persons working on the digitization of the rock glaciers and the performance is basically the same. At present, due to the inconvenience of transportation, 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. In addition, we compared our manual mapping and the Gruber's (2012) global Permafrost Zonation Index (PZI) map, and found that the rock glaciers distribution in the Daxue Shan is in good agreement with the PZI on the whole (Fig. 3). (P12L13~P12L16)

Your advice is very important, indeed, longitude and latitude do not describe environmental parameter. However, we can use longitude and latitude to analyze the spatial distribution and aggregation state of rock glaciers from the perspective of geography. Then, we analyze the properties of rock glaciers by using other parameters other than longitude and latitude (*i.e.* the parameter that changes with longitude and latitude). As you said, regional settings are very important. Therefore, we are also concerned about aspects, debris sources and valley/slope orientation to interpret rock glaciers properties, to explore the correlation between the local topographical characteristics and the formation, evolution, spatial distribution of rock glaciers.

We have added the description sentences of the topographical characteristics "With the increase of latitude from the south to the north in the Daxue Shan, the high altitude slopes increase, and flow further downvalley than low altitude, these topographical characteristics result in the rock glaciers altitude asl and length increase with latitude." (P10L13~P10L16)

4.2.3 Lithological controls on rock glaciers. The lithological setting influences RG formation mainly by steepness and sedimentation rates contributing debris to the landforms. Please include this aspect into your elaboration and cite some references supporting the influence of lithology towards RG formation and evolution.

Reply: We have added this aspect and cited some references to support the influence of lithology towards rock glaciers formation and evolution. As shown below:

"In addition, rock glacier formation also controlled by slope and sedimentation rates contributing debris to the landforms (Müller et al., 2016). There are a large sources of sediment and sediment storages in the Daxue Shan, and are controlled by the processes occurring within this setting (Müller et al., 2014). An abundance of steep rock walls and deepened valley sides, provides catchment areas for rock glacier development, combined with intense monsoonal precipitation and tectonic activity, drives sediment transport processes and rock glacier development in the Daxue

Shan.” (P13L14~ P13L18)

Also you mention the existence and application of g in-situ ground truthing data but you never explain how, where and what kind of data you gathered and used. Please include this either in the method or discussion section.

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.

Next is the reply to the supplement to this comment: https://www.the-cryosphere-discuss.net/tc-2017-290/tc-2017-290-RC1-supplement.pdf

P2L5: All Rock glaciers move down valley. Otherwise they would move at all. Also lobate RGs are inclined and creep therefore down valley. Please rephrase...

Reply: Thanks for pointing out this. We have rewritten the relevant sentences to "As the bodies of rock glaciers are similar to moraines in that," (P2L4~P2L5)

P2L7: That's a continuum. Many Himalayan RGs develop out of moraines and it is hard to distinguish where the moraine ends and the RG begins. Please mention that.

Reply: Thanks very much for your insightful suggestion. We have added the sentence "Many Himalayan rock glaciers develop out of moraines and it is hard to distinguish where the moraine ends and the rock glacier begins."(P2L6~P2L7)

P2L12: What does block type mean? It is agreed upon that rock glaciers move due to the viscous creep of the rock-ice melange and can be described and modelled as such. see wahrhaftig & Cox 1959, Olyphant 1983. references in the written comments.

Reply: This is our misnomer and we have changed "block-type movement" to "creep movement". (P2L13)

P2L16: How are they more accurate? I would prefer advanced or powerful.

Reply: We are grateful for the suggestions, and we have changed "accurate" to "advanced". (P2L17)

P3L1: Do you mean underneath the rock glaciers or inside of the rock glacier? or altitudinal? Please rephrase.

Reply: We have rewritten the sentence is "estimations of the distribution of permafrost based on rock glaciers (Allen et al., 2008; Boeckli et al., 2012; Schmid et al., 2015; Sattler et al., 2016) ," (P2L23~ P2L24)

P3L10: What does minimal mean? This sentence is misleading.

Reply: We have rewritten the sentence is "However, the study of the rock glaciers of the Daxue Shan on the southeastern margins of the TP is less involved." (P3L9~P3L10)

P3L15: and natural hazards and or environmental planning/management.

Reply: We have rewritten the sentence is "It is therefore of particular importance to study the environmental controls on the rock glaciers of the Daxue Shan as an aid to the further study of the complex geographical environment, natural hazards, environmental planning and management found on the southeastern margins of the TP." (P3L15)

P5L12: reference?

Reply: The reference "A geological layer (using a geological map with a scale of 1:500,000 from the China Geological Survey)" has been added in the revised version. (P5L19)

P7L22: Isn't this also a function of sediment supply and terrain inclination? Maybe you can

discuss the impact of terrain topography and sediment/ice supply and its impact on flow velocity and RG morphology.

Reply: We are grateful for the suggestions and we have added the sentence "compared with lobate rock glaciers, moraine-type and tongue-shaped rock glaciers have more sediment supplies and last longer on gentle slope, indicating that moraine-type and tongue-shaped rock glaciers flow further than lobate rock glaciers." (P9L2~P9L4)

P8L7: Probably be there are more steep rock walls on the north faces producing debris. Please check.

Reply: Your opinion is really right, and we have added the sentence "However, there are more steep rock walls on the north faces producing debris, north-facing (*i.e.*, N, NW and NE) slopes seem to be more favorable for the formation of lobate rock glaciers than do south-facing (*i.e.*, SW, S and SE) ones (Fig. 5)."(P9L21)

P8L21: How does the regional climate change with the latitude? I would argue that the latitude oer se isn't so important but rather the regional climate, topography and environmental setting.

Reply: Indeed, regional climate, topography and environmental setting are very important, and we have discussed them in the paper. Latitude may have little impact on the regional climate of a single small area. However, when comparing two areas in different latitudes (Daxue Shan: 30°N, Tianshan Mountains: 40°~45°N) (Zhu, 1992; Zhu et al., 1992; Wang et al., 2017), the temperature will decrease with the increase of latitude, resulting in latitude zonal differences in climate between different regions (Daxue Shan and Tianshan Mountains).

P9L1: Because there aren't so many of these W-E facing slopes?

Reply: Yes, the topographical characteristics of the Tianshan Mountains are roughly W-E in presentation, east- and west- facing slopes are less than the north- and south- slopes, these topographical characteristics are not conducive to the formation and development of rock glaciers, except on its north- slopes.

P9L15: You just mentioned in line 11 that local topography and local climate are very important. Latitude and longitude have no impact on these parameters. So I'd say any correlation with these parameters is rather an expression for other local parameters influenced by e.g. topography and any interpretation including lat and long doesn't help much.

Reply: Latitude and longitude may have little effect on other parameters of a single rock glacier; however, it can reflect the spatial distribution and aggregation characteristics of 295 rock glaciers in the Daxue Shan. It is one of the topics (titles) discussed in this paper: "their distribution", which focuses on the study of the relationship between local topography and the spatial distribution (Johnson et al., 2007) of 295 rock glaciers from the geographic space macro perspective. Therefore, we have rewritten the sentence is "In summary, the topography of the Daxue Shan is an important environmental control on the formation, development and spatial distribution of the region's rock glaciers."(P11L5~ P11L7)

P9L17: This is trivial.

Reply: Thanks for pointing out this and we have removed the relevant sentences "a

significantly positive correlation (*p=0.01*) between rock glacier area, length and width."

P9L22: Does this only hold true for active RGs or also for relict RGs?

Reply: Revised data shows that there is not enough evidence and we have removed the sentences "larger-scale rock glaciers occur mainly in the higher mountains".

P10L1: It would be very beneficial if you include a description of the topographical Characteristics somewhere in the discussion.

Reply: We have added the description sentences of the topographical characteristics: "With the increase of latitude from the south to the north in the Daxue Shan, the high altitude slopes increase, and flow further downvalley than low altitude, these topographical characteristics result in the rock glaciers altitude asl and length increase with latitude." (P10L13~P10L16)

P10L7: Why? I would awesome because of temperature but further elaboration would be helpful.

Reply: We have added the further elaboration sentences "with the increase of longitude and the decrease of altitude, the closer it is to warm and humid, which kind of climatic conditions are not conducive to the formation of permafrost landforms such as rock glaciers." (P10L21~P10L23)

P10L13: This hold trues for all the slopes in the world...

Reply: Revised data shows that there is not enough evidence and we have removed the sentences "The fact that mean gradient of slope and aspect exhibit a significantly negative correlation (p=0.01) reflects the topographical realities of the Daxue Shan, where sunny slopes are often less steep than shady ones".

P11L1: Maybe mention the global permafrost distribution maps and their take on the Daxue Shan (e.g. Gruber et al. 2012).

Reply: We have added the global permafrost distribution maps 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)

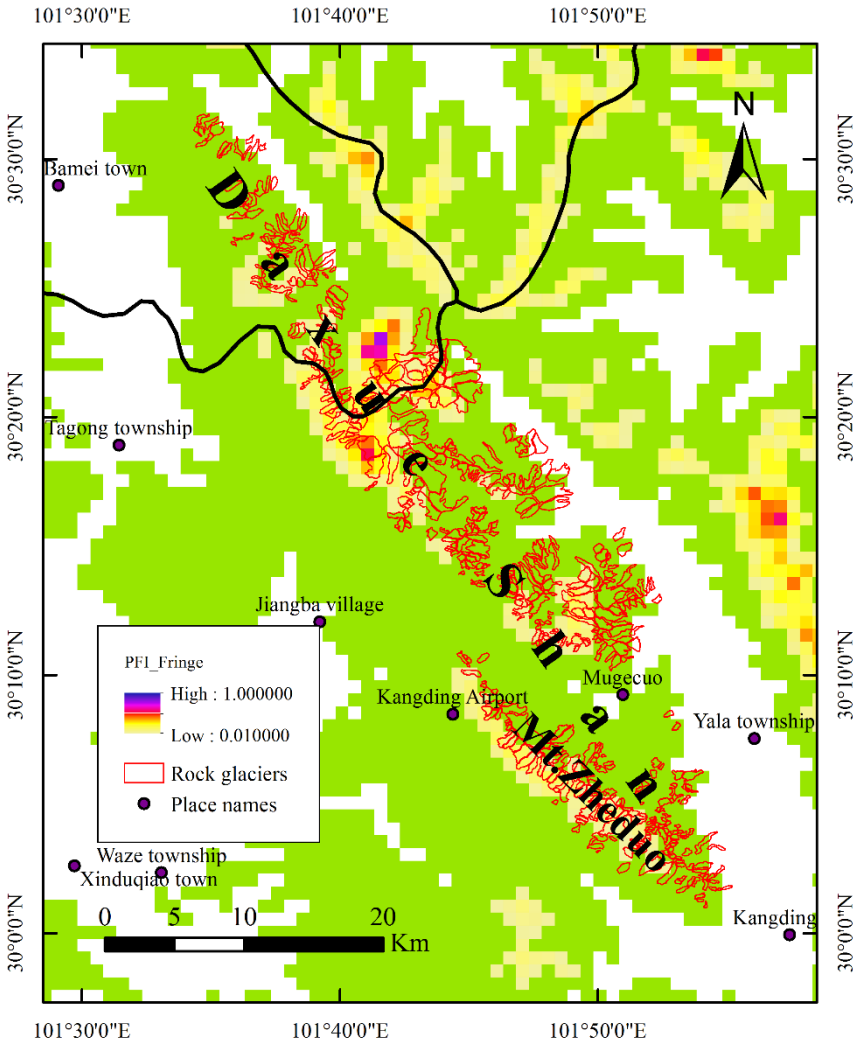

Figure 3: Spatial distribution of rock glaciers and Permafrost Zonation Index (PZI) in the Daxue Shan. The PZI data sources: Gruber's (2012), the green area represent the fringe of uncertainty.

P12L7: Most obvious the determine the state of activity you should check InSAR or mulittemporal high resolution satellite data to derive kinematics of the rock glacier and then you have some insight in the current state of the landforms.

Reply: We are grateful for the suggestions and we have added the sentence "it remains to be determined whether these landforms are currently active, or whether they represent the fossilized remains of inactive rock glaciers; further analysis, when conditions permit, it therefore vital." at the beginning of the paragraph. (P6L7~P6L9)

P12L8: What kind of ground truthing? and how did you use this? Is this temperature or visual inspection or kinematics?

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.

P12L14: This should in some cases be visually applicable.

Reply: Your suggestion is very useful and we will try to use it as much as possible in future related research.

P12L16: Is it possible to quantify these uncertainties? Please say a few words on how strong and persistent these uncertainties are.

Reply: 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)

P12L21: What are the environmental controls?

Reply: The environmental controls are environmental factors that control and influence the formation and development of rock glaciers, such as the local topography, climate and lithology discussed in this paper.

P13L10: This sentence is very hard to understand. Do you mean you found SW-S-SE slopes to be more favorable for tongue shaped RGs of for RGs in general? and N facing better for lobate RGs?

Reply: We have rewritten the sentence is "We found shady (*i.e.*, N, NE and E) slopes more conducive to the formation of moraine-type rock glaciers than sunny (*i.e.*, W, SW and S) ones, while sunny (*i.e.*, W, SW and S) slopes appear more conducive to the formation of talus-derived rock glaciers. In addition, north-facing (*i.e.*, N, NW and NE) slopes appeared more favorable to the formation of lobate rock glaciers than did south-facing (*i.e.*, SW, S and SE) ones." (P15L4~P15L7)

P13L14: You never really elaborated how these controls might influence RG evolution.

Reply: We are grateful for the suggestions. In this paper, we focus on exploring the correlation between local environmental controls and the spatial distribution of rock glaciers in order to preliminary study whether these local environmental controls promote or inhibit the formation of rock glaciers in a maritime setting. Therefore, the referee's concern is of importance for our further study. In the related research in the future, we will further explore how these controls influence rock glaciers evolution in terms of physics and chemistry mechanisms based on the above research results.

P13L17: You have also never showed data supporting this statement.

Reply: We have added the data in Figure 7 to better illustrate the freezing and thawing effect of rock glaciers in the Daxue Shan. However, there are currently only four meteorological stations. In the future, we hope to seek funding from relevant agencies and establish more meteorological stations in high altitudes.

P23L1: Please show these locations on one of the maps. And maybe you have some more stations in high altitudes.

Reply: Thanks for pointing out this. We have added data and transformed Table 3 into Figure 7 to better illustrate the freezing and thawing effect of rock glaciers in the Daxue Shan. However, there are currently only four meteorological stations. In the future, we hope to seek funding from relevant agencies and establish more meteorological stations in high altitudes.

P26L1: This legend does not very look nice and if you would make the polygons hollow you can show the permafrost map underneath.

Reply: We have made the polygons hollow and compared our manual mapping with the Gruber's (2012) global Permafrost Zonation Index (PZI) map. (Figure 3)

P27L4: Please mention the actual number of the population of the different kinds of rock glacier in some table, or you can just pring the number into the boxplots.

Reply: Thanks for pointing out this. We have added the actual number of the population of the different kinds of rock glacier in the brackets of the legend (Figure 4). (P31L6~ P31L7)

P29L1: The numbers are very hard to read. Please relocate them.

Reply: We have relocated these numbers (Figure 6).

P30L1: An underlying transparent hillshade derived from SRTM would make this figure more appealing and more easily to interpret.

Reply: We are grateful for the suggestions. In this figure, we used the $T_{2\text{-}3}zg\text{-}z$, T_3xd, etc. to mark different geochronological stratigraphic units, which are international standards for geochronological stratigraphic units and recognized in the geological world. And directly show 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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