Response to Reviewers

Dear Editors and Reviewers:

Thanks for giving us a chance to improve our manuscript. Those comments concerning our manuscript are very helpful for revising, as well as the important guiding significance to our researches.

After receiving the comments, we attached great importance to them and carefully discussed the issues mentioned in the manuscript. Though this period of thinking, we thoroughly revised the manuscript and improved these points, which we hoped meet with approval. Meanwhile, it gave us a special opportunity to interact with other scholars who also study on the microstructure of precipitation. Revised portion are marked in the paper. The main corrections in the paper and the responds to the reviewer's comments are as flowing.

We highly appreciate your time and consideration to allow us resubmit a revised copy of the manuscript. Please let us know if there is anything need to discuss during the review process.

Authors,

Sincerely.

Response:

Reviewer 1

Thanks for the recognition of the manuscript. We will continue to work on the series of researches. And this opportunity makes a lot of sense for us. If the article can be published, it will be the first one after I graduation. Finally, I would like to thank again for the valuable comments, which have made the article better.

Reviewer 2

Rain drop size distribution over the southern slopes, northern slopes and interior of the Qilian Mountains were analyzed in this article. This article helps us understand the micro physical characteristics of precipitation over the complex mountainous terrain in the arid and semi-arid regions, which is meaningful. However, there are the following problems to be solved at present, so I suggest a major revision of the article before considering it for publication.

Main comments:

Issue 1: The influence of different altitudes on DSD is mentioned in line 80, but there is no study or conclusion about it. Please add these contents.

Revision: Thank for the advice. The influence of different altitudes on DSD is understood from the two aforementioned articles. Combination with the geography of the Qilian Mountains, there are certain altitude differences between observation sites (see Table 1), which inspire us to explore this topic. In this manuscript, the DSD differences shown as the results of the southern slopes (average altitude: 2933 m), northern slopes (1845 m) and interior (2398 m) of the Qilian Mountains, firstly prove the existence even at small spatial scale and partly demonstrate the influence of altitude differences. In fact, the sites of interior of the Qilian Mountains are close to ridge from the topography (longitudinal section of mountain). However, because of the limited observation conditions, we would like to have more observation sites to consider this issue.

Issue 2: It is mentioned in line 94 that the main purpose of this study is to improve the accuracy of QPE. However, there is no research to improve QPE in this manuscript. Only the differences of parameters in Z-R relationship are analyzed. What are the implications of the differences for improving QPE accuracy and what specific reference suggestions can it bring to improve QPE accuracy? If possible, please verify the improvement of QPE accuracy through tests, and find out how much improvement?

Revision: Thank for the comments. This part of research is designed mainly from a large number of other studies similar to the DSD. In these studies, the localized Z-R relationships ($Z=AR^b$) calculated from DSD are shown in different research areas, which would replace the general ones like $Z=300R^{1.4}$ or $Z=200R^{1.6}$ (respectively, convective rainfall commonly used in radar and stratiform rainfall commonly used in midlatitude areas). For example, Ma et al. (2019b) obtained the relationship for convective rainfall ($Z=158R^{1.68}$) and stratiform rainfall ($Z=171R^{2.15}$) in Beijing; Zhang et al. (2019) fitted the relationship for convective rain in monsoon season in southern China, with a higher value of A and lower value of b which compared with the standard Z–R relationship; Wang et al. (2021) derived the relationship for convective rainfall ($Z=53.69R^{1.71}$) and stratiform rainfall ($Z=114.79R^{1.34}$) on the Southeast Tibetan Plateau. In a way, choosing the appropriate A and b based on different rain types has a great significance in improving the regional radar QPE. Based on the advice and after careful consideration, we have revised as “refine the local QPE”, which hopes it could play a role in radar applications on the study of precipitation estimation for the Qilian mountains.

Issue 3: In line 174,178, it is stated that the velocity value in the calculation formula of R is based on the ideal velocity rather than the actual observed velocity data. I think it is unreasonable for the statistics of microphysical characteristics. Only the measured value can reflect the real data characteristics. Although there are errors in the measured value, they can be eliminated through necessary quality control methods, which are also done in this study. However, the theoretical value of V is used in the calculation of R in this study. Is there doubt about the quality control method? If so, what is the significance of quality control? In addition, replacing the measured value with the theoretical value makes the feature V unified, which may erase the different characteristics between sites.

Revision: Thank you for the advice. The consideration of theoretical value of V for R was guided by this article Tokay et al. (2014), which illustrated that there would be greater error at the larger end. And in another article Zhang et al. (2019), we saw that the authors used an empirical formula. Combined with the observational environment in this study, there are differences in the subsurface at six sites, and using measured values that have their own errors to calculate would increase the errors in the results. At the time, the results of the two calculation methods were considered in the calculation process and it was found that the differences were relatively small, usually reflected in the second decimal place. Of course, with the advice of the reviewer, we would like to use these rare data for further discussion of the relevant content, including the calculation methods such as the article form Tokay et al. (2014).

Issue 4: There is a conclusion that "the convective events in the Qilian Mountains are more consistent with the continental-like cluster" in lines 367-368. This conclusion is not very convincing. One is all the scatters, and the other is the distribution area of the average values, the two have different meanings and cannot be compared. According to the method of Bringi et al. (2003), the average value should be calculated as well, and compared with the average value region of the two kinds of characteristics obtained in that paper, so that the comparison of the same physical quantity can be more convincing.

Revision: Thank you for your comments. We found that the D_m in the Qilian Mountains was small in both mean or individual samples, which compared with other researches. The results show that the $\log_{10}N_w$ values are not in the range of continental-like cluster or maritime-like cluster, while the D_m values are in the maritime-like cluster. In fact, it could not belong to the maritime-like rain fall. And the results of Bringi et al. (2003) is average value using different samples from different climatic backgrounds, which could be not necessarily comprehensive. In our manuscript, the Qilian Mountains is a special area with unique characteristics of DSD. After considering, there is difficult to say no

way to define whether its precipitation is maritime or terrestrial maritime-like rain fall or continental-like rain fall. Perhaps it can be further discussed in subsequent studies.

Issue 5: The Z-R relationship of DLD is different from that of other sites. Please explain the reasons through specific analysis. The conclusion that "the Z-R relationships of the same section are more consistent" contradicts the unique Z-R relationship of DLD. Why does the Z-R relationship of the TL site with a similar geographical location to DLD differ greatly from that of DLD?

Revision: Thank for the tips. The conclusion that "the Z-R relationships of the same section are more consistent" is seen in conjunction with the previous analysis, where the same section exhibits more similar characteristics such as closer spectral parameters and characteristic variables of DSD. What's more, the distances between the A and b values of any two sites are smallest on the same-side in Figure 11. Based on the above results, it is easily found that the differences in DSD over the southern slopes, northern slopes and interior of the Qilian Mountains are existed with using the data from the eastern and central sites (SD and LB; BLG and HS; DLD and TL) to corroborate each other. However, as the reviewer raised doubt, the uniqueness is still in the specific details, which is mainly due to the fact that each site has its own local climatic influences. In terms of general geographic location, DLD and TL are on the southern slopes of the mountains with in Qinghai Province and at similar elevations. Further analysis, DLD is in Qilian County, which is a narrow valley; while TL is in Menyuan County, which is a relatively open valley. That is to say, DLD is affected by more factors during the rainfall. But if we are in the perspective of the southern slopes of the Qilian Mountains, its uniqueness would not be discussed too much. Of course, as suggested, we have added the relevant content as appropriate.

other comments:

Issue 1: "mass-weighted diameters" should be "mass-weighted mean diameters" in lines 20-21..

Revision: Thank for your advice. We have revised the name of parameter.

Issue 2: The statements should be consistent, such as "southern China" in line 62 and "South China" in line 65.

Revision: Thank for your advice. these statements have been consistently expressed as 'southern China' in the text.

Issue 3: Is "Total minutes without noise (min)" in Table 2 not introduced in the text? If not, it is recommended to delete. I think there is something wrong with the expression of "Available rain minutes" in Table 2. It should be a ratio rather than time, and there is no need to add units to the subsequent data.

Revision: Thank for your advice. "Total minutes without noise (min)" is the second corresponding note in the data quality control. "Available rain minutes" is replaced by "Available data", which is relatively straightforward with using the percentage.

Issue 4: In lines 239-240: "It is noteworthy that the frequency of samples with R around 0.6–1.0 mm h^{-1} was highest", this phenomenon is not clearly visible in Figure 3, please mark it in the figure. In addition, the unit in Figure 3 changes after logarithm is taken, it is better to rewrite the unit. For example, $\log_{10}R(mmh^{-1})$ is changed to $\log_{10}R$ (R in mmh^{-1}), and $\log_{10}N_w$ and $\log_{10}N_t$ are changed in the same way.

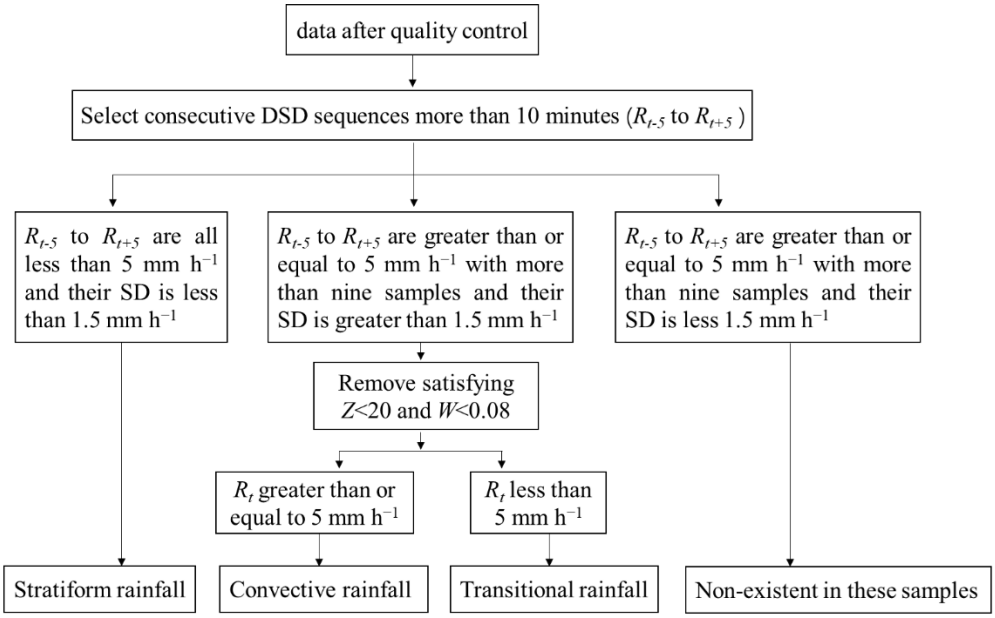
Revision: Thank for your advice. The horizontal coordinate of Figure 3 (e) is "$\log_{10}R$". Corresponding to R in the interval 0.6-1 mm h−1, the values of horizontal coordinate roughly are -0.2-0, which is the highest raised part of the curve in the diagram. As Figure 3 consists of 6 small pictures, it has been maintained for the sake of uniformity of the pictures without marked. In addition, the units have been rewritten in Figure 3, including other figures (Figure 5, Figure 7 and Figure 9) with the similar units.

Issue 5: In lines 286-287:" Ma et al. (2019b) also obtained similar conclusions about D_m and $\log_{10}N_w$". What similar conclusions? They should be clearly stated, otherwise there will be misunderstandings. In addition, what is the significance of comparing with other research results, obtaining uniform laws or other?

Revision: Thank for your advice. Similar conclusion from Ma et al. (2019b) is added to the text. "Ma et al. (2019b) also obtained similar conclusions that D_m values increase with the increased rainfall intensity, while the $\log_{10}N_w$ is not as clear." Other research results are cited mainly to set the stage for explaining the variation between raindrop size and number concentration in the follow-up content.

Issue 6: The precipitation type classification is in lines 337-348. It is suggested to add a table to express it more clearly.

Revision: Thank for your advice. We have added flow chart as suggested



Issue 7: lines 363-366: The unit of N_w is"$m^{-3}mm^{-1}$", but that of $\log_{10}N_w$ is not.

Revision: Thank for your advice. We have updated this statement in the whole manuscript.

Issue 8: "Black solid lines" and "green lines" are not introduced in the title of Figure 7

Revision: Thank for your advice. We have completed in the title of Figure 7

Issue 9: line 408-409: "the DSD characteristics in the Qilian Mountains consist of a larger N_w and smaller D_m" larger or smaller than what?

Revision: Thank for your advice. Compared to the results of studies in other regions, the results of the Qilian Mountains are shown as these characteristics. And we supplemented relevant content in discussion section. As the article covers six sites, it is not convenient to list them directly in the article. There is another article also continuing, which is a selection of one of the sites for analysis, including the relationship between raindrop spectral parameters, and will also compare N_w and D_m in detail with the results of currently available studies.

Issue 10: lines 436-437: "It shows that the Z-R scatter points for HS and BLG were relatively scattered around the 5 mm h $^{-1}$ rain rate." Where is 5mm h^{-1}, please mark it in the figure.

Revision: Thank for your advice. It has been marked in the figure.

Issue 11: lines 437-438 “Besides, the Z-R relationship of total rainfall underestimated the stratiform rainfall at low R values and the convective rainfall at high R values”, underestimate or overestimate? Please confirm.

Revision: Thank for your advice. This section is mainly based on the results of the fitting in the graph, with reference to Ma et al. (2019b). According to the Z-R fit results, the relationship for total rainfall (black line) has more difference where R is greater compared to the relationship for convective rainfall (red line). And the black line is below the red line, so it is an underestimate. Similarly, the relationship for stratiform rainfall (purple line) is the end where R is smaller.

Issue 12: line 456: What is “SR” short for?

Revision: Thank for your advice. “SR” means “stratiform rainfall”. And It has been revised in the article.

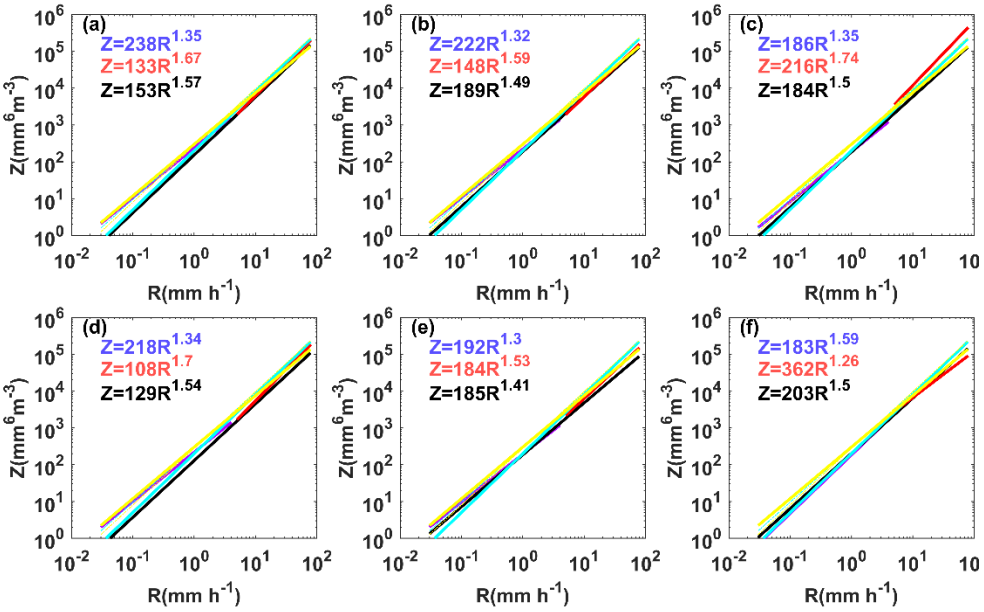
Issue 13: lines 492-495: “Compared to previous studies that focused on eastern, southern and northern China as well the Tibetan Plateau, the Qilian Mountains region has its own unique DSD characteristics and Z-R relationship during the rainy season, including a smaller raindrop diameter with a higher number concentration.” Please provide a comparison of the specific results in each region, otherwise the conclusion is not convincing.

Revision: Thank for your advice. This question is similar to Issue 9. We have provided a comparison of the specific results in each region, which D_m relates to the raindrop diameter and N_w relates to number concentration. “Compared to previous studies that focused on eastern [3.48 for $\log_{10}N_w$ and 1.23 mm for D_m, Pu et al.(2020)], southern [3.86 for $\log_{10}N_w$ and 1.47 mm for D_m, Zhang et al.(2019)], northern [3.60 for $\log_{10}N_w$ and 1.15 mm for D_m, Ma et al.(2019b)] and central [3.48 for $\log_{10}N_w$ and 1.54 mm for D_m, Fu et al.(2020)] China as well the Tibetan Plateau[3.47 for $\log_{10}N_w$ and 1.05 mm for D_m, Wang et al.(2021)],”

Issue 14: lines 543-547: “The Z-R relationships in stratiform rainfall were similar and generally underestimated by the $Z=200R^{1.6}$ model used for midlatitude stratiform rainfall; and the Z-R relationships for convective precipitation varied greatly at different stations, which were overestimated by $Z=300R^{1.4}$ at lower rain rates values and underestimated at higher rain rates values.” What is underestimated or overestimated, precipitation or the parameters in Z-R relationship? This view is not discussed in the manuscript.

Revision: Thank for your advice. This question is similar to Issue 11. And this view is based on the result given in Figure 11. The Z-R relationship graph is not shown again

because of space issues and it does not look intuitive enough when drawing Z-R relationship graph (such as Figure 10) due to the small differences. Differences of the A and b values are clearer in Figure 11. Here, we have placed the results in the response and not continued to add in the article.



Issue 15: There are some clerical errors or formatting problems in the manuscript. Please check it carefully and make corrections.

Revision: Thank for your advice. We have refined them and checked in the whole manuscript.