Response to Reviewer 2

General Comments:

In summary, this study analyzed the statistical characteristics of raindrop size distribution (DSD) during rainy seasons (May-October) in Beijing based on a 5-year observation (2014-2018) from a Parsivel2 disdrometer deployed at Tsinghua University, compared the differences in diameter and concentration between rain types, rainfall intensity, urban heat island (UHI) stages and months, and finally explored its implications for two types of radar rainfall estimations. The manuscript is overall detailed and well written with analysis of DSD parameters and suggestions for precipitation forecast, while it has some minor problems and lacks further explanation of precipitation micro physics. Therefore, I suggest a minor revision and encourage the authors to improve this manuscript. Detailed suggestions are listed below. As I'm not working on this specific researching area, some suggestions may not be suitable for this manuscript, and the authors can decide whether or not to accept them.

Response: We thank the reviewer for the kind words. We appreciate all the valuable comments and suggestions provided by the reviewer. We have carefully revised this manuscript based on the reviewer's comments. In the text below we quote the reviewers' comments verbatim and we follow them with our detailed responses in red.

Major Comments:

1. I've noticed the authors actually show their results together with discussions in Section 3 and 4, while I personally prefer an independent Discussion Section to clarify the differences and significance of this study compared to others on DSD characteristics in Beijing (and other cities). For example, the authors derived an opposed conclusion referred to Wen and Zhang's work (P7 L10), and it would be better if the authors mark their observation locations in Fig. 1(b), explain the differences in physical mechanism and show detailed possible causes.

Response: We thank the reviewer for this great suggestion. We have mark the observation locations in Wen et al., (2017) and Ji et al., (2019) in Beijing in fig. 1. The study by Tang et al. (2014) did not detail their disdrometer position clearly, just with a description of position: "Beijing".

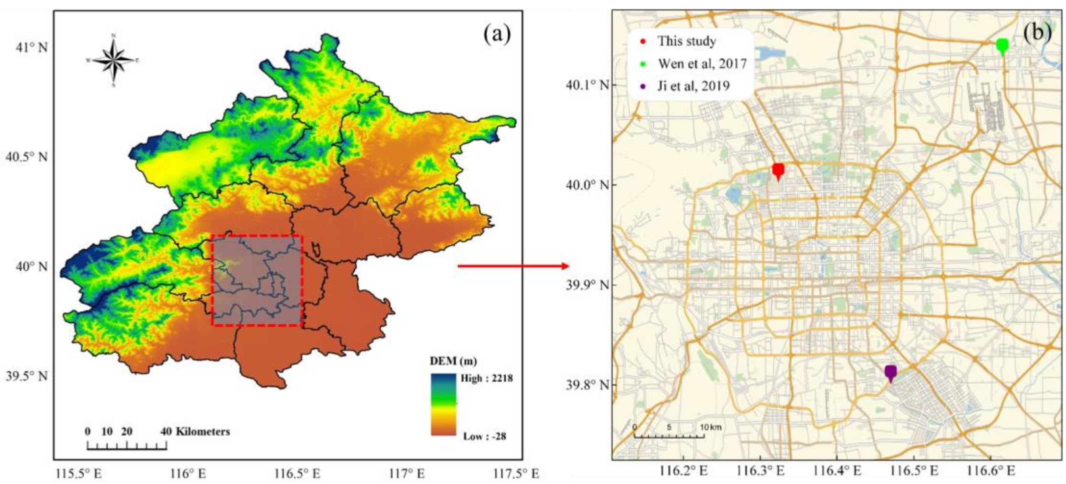

Figure 1: (a) the topography of Beijing, (b) the locations of DSD studies in Beijing area, the red mark represents the location of Parsivel^2 disdrometer deployed at Tsinghua University

campus in this study, the green and purple makers represent locations in the studies by Wen et al., (2017) and Ji et al., (2019), respectively.

The comparison of DSDs in different part of China (i.e., North China, East China, and South China) are indicated in Fig. 5. Even in the same region, the DSDs measured by different instruments have notable differences, such as the differences in Beijing between results from Wen et al. (2017) (2DVD, circle) and Tang et al. (2014) (Parsivel, square). In order to reduce the errors caused by different measurement instruments, in our study, only DSDs measured by Parsivel disdrometers are analyzed. It is concluded that the east part of China has the lowest mean value of $\log_{10}N_w$ (3.42) with highest mean value of D_m (1.66), while southern China has the highest mean value of $\log_{10}N_w$ (3.86) with middle value of D_m (1.46), and the north part of China has the middle value of $\log_{10}N_w$ (3.60) with lowest value of D_m (1.15). There are also differences between Beijing in this study and studies in other parts of China (Wen et al. (2016) in eastern China and Zhang et al. (2019) in southern China). These differences indicates that the DSD characteristics are highly correlated to the specific geographical locations and associated climate regimes.
For Beijing area, the results of this study and Tang et al. (2014) show great differences in convective rain and less differences in stratiform rain. These may be attributed to different convective systems during different years, and the limited measurements from only one season in the study by Tang et al. (2014), which are not sufficient to represent local DSD characteristic. However, we want to note that the detailed comparison in microphysical mechanisms of rainfall is not the main focus of this study, although results from previous studies are briefly summarized. As mentioned, this study presents more of climatological features of local DSD in Beijing, while the referenced studies seem to be event-based. More data would be required to resolve the detailed differences in physical mechanism, which can be a good future study.

2. Abstract Section. I suggest the authors should first clarify the meanings before using symbols or abbreviations such as Dm and lgNw when showing results in Abstract Section. In addition, although P4 L15 defined Nw as "normalized intercept parameter", I have not found its clear physical meaning which expected to be similar to Nt, the total number concentration.

Response: We thank the reviewer for this very important comment. D_m is the mass-weighted mean diameter and $\log_{10}N_w$ is the normalized intercept parameter of a Gamma model of raindrop size distribution (Bringi and Chandrasekar, 2001). We have clarified this in the Abstract Section (P1 line 16 in the clean version). In addition, N_t (m^{-3}) is the total number concentration, representing an integral of the rain drop size distribution at all diameters, and it is different for the distribution parameter N_w (m^{-3} mm^{-1}). The relationship of these two parameter is:

$$N_t = \int N(D)dD = \int N_w f(\mu)\left(\frac{D}{D_m}\right)^{\mu} \exp\left[-(4+\mu)\frac{D}{D_m}\right] dD$$

We have clarified this in the revised manuscript (Page 5, line 4 in the clean version).

3. P6, L15, the authors use specific mean and standard derivation values of rain rate (R) as thresholds to separate convective rain from stratiform rain. However, it seems that R is only related to D spectra considering equation (10) and (3), so in my opinion this classification method is equivalent to solving nonlinear equations and will probably cause the "clear *boundary" in DSD characteristics between rain types mentioned in Abstract Section. The authors should pay attention to the classification method chosen in this study, and it would be better if they obtain more information on rain types from other data sources.*

Response: We totally agree with the reviewer that the classification method may cause a "clear boundary" in the DSD characteristics since both R, $\log_{10}N_w$ and D_m are derived from the raindrop size spectra. We can get the relationship among these three parameters with a power law velocity assumption by Atlas and Ulbrich (1977),

$$v(D) = 3.78D^{0.67}; m/s$$

$$R = (0.6 \times 10^{-3}\pi)(3.78)N_w f(\mu)\Gamma(\mu + 4.67)\frac{D_{\mathrm{m}}^{4.67}}{(4+\mu)^{\mu+4.67}}; mm/h$$

As such, other data sources such as reflectivity profiles are used to classify the rain type in several studies (Cha et al., 2009;Wen et al., 2016). However, it was found that there was no significant differences compared to using R only, and using other data sources may cause different issues since they are not directly related to rainfall intensity (rain rate estimation algorithm should be applied). In addition, since $\log_{10}N_w$ and D_m are different moments of the raindrop spectra compared to the rainfall rate. The "clear boundary" is not really as sharp as one would expect. Provided the ground disdrometer data, the thresholds of mean and standard derivation values are still the most commonly used way to classify rainfall type (Bringi et al., 2003;Chen et al., 2013). Motivated by the reviewer's comment, we have revised the manuscript by highlighting the potential of using auxiliary data in the classification of different rainfall types (last paragraph Page13 line 30-32, in the clean version): *We also want to note that combining additional observations such as the vertically-pointing profiler radar data (White et al., 2003) can further enhance the classification results of different rainfall types, which should be considered in future studies."*

4. There is a mistake in Table 5. The correct UHI stage labels in the table should be UHI D, W UHI, UHI U and S UHI, which is consistent with Figure 9 and 10 indicating UHI W stage has the largest mean concentration and lowest Dm.

Response: We apologize for this mistake. We have corrected this in the revision. The corrected version is listed below for the reviewer's information. Thanks again for pointing this out.

Table 5: Mean and Standard Deviation (SD) Values of R, D_m, $\log_{10}N_w$, N_t, W, μ, and Λ for different diurnal periods based on UHI intensity

	R(mm h^{-1})		D_m (mm)		$\log_{10}N_w$ (m^{-3} mm^{-1})		N_t (m^{-3})		W (g m^{-3})		μ		Λ	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
UHI D	1.88	4.31	1.11	0.42	3.59	0.60	342.15	499.30	0.10	0.19	15.06	13.63	9.32	8.49
W UHI	2.04	4.10	1.10	0.41	3.70	0.58	378.44	398.08	0.12	0.18	15.27	14.48	9.33	8.90
UHI U	2.82	6.94	1.18	0.51	3.57	0.65	380.88	488.27	0.15	0.30	14.09	13.45	8.78	8.45
S UHI	2.60	6.79	1.18	0.46	3.56	0.64	385.00	563.30	0.14	0.30	13.97	13.95	8.61	8.43

5. Figure 13. This figure may mislead the readers as the study focused mainly on low rain rate values (less than 25 mm/h). I suggest the authors should plot it on double logarithmic coordinates, which will make it a linear relationship (i.e. convert Z=238Rˆ1.57 to lgZ=1.57lgR+lg238). Besides, the derived line for total rainfall are below both convective and stratiform lines for low rain rate values, and the authors should explain this.

Response: We thank the reviewer for this very good suggestion. We agree with the reviewer that the double logarithmic plot for *Z-R* relationship might be better. We have revised the figure and rephrased the related descriptions in the main manuscript (From Page 11 line 12-19 in the clean version). The revised figure is repeated here for the reviewer information.

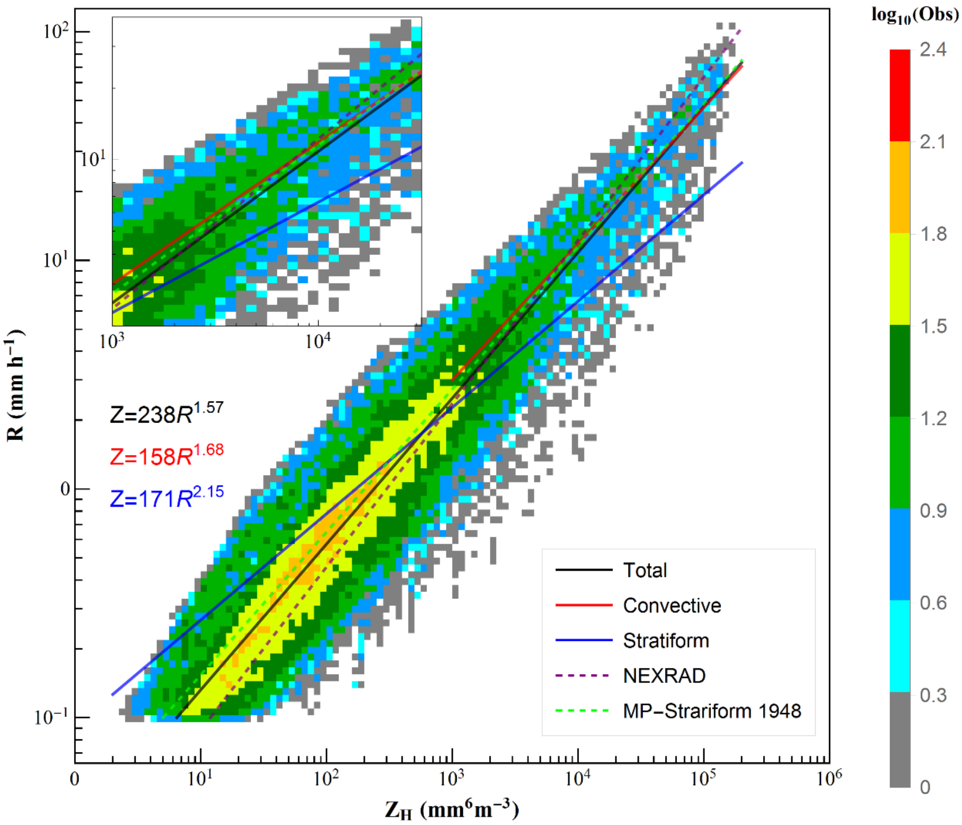

Figure 13: Scatter density plot of R (mm h^{-1}) versus Z_H (mm^6 m^{-3}) for all rain events. The black, red, and blue curves respectively stand for the fitted power-law relations for total rain, convective rain, and stratiform rain. The purple and green dashed lines denote the default NEXRAD $Z-R$ relation (Fulton et al., 1998) and a commonly used continental stratiform rain relation (Marshall and Palmer, 1948), respectively.

6. Section 4.1 and 4.2. How did the authors figure out the relationship equations (14)-(17)? In my opinion, it is more likely that the uncertainty in parameter values, other than suitability of algorithms, may be the main sources of normalized absolute error (NMAE).

Response: We thank the reviewer for this great comment. The relationships in equations (14)-(17) are derived through nonlinear regression using the least square method. We have clarified this in the revision (page 11, line 29 in the clean version). In the nonlinear fitting processing, we attempted to minimize the uncertainty induced by the parameter values. Such power-law relations are typically used by weather radars for quantitative precipitation estimation. Therefore, the uncertainty in the parameter values are essentially the same with the "suitability" of radar rainfall algorithms (or maybe the reviewer is referring to something else?). This type of uncertainty is also called "parameterization" error (Bringi and Chandrasekar, 2001). The values of *NMAE* can be an indicator of such parameterization error of different algorithms. We have clarified this in the revision (From page 12 line 5-10, in the clean version).

Minor Comments:

7. P2, L19-26. These sentences are weird to read with duplicate words such as "high spatial and temporal variabilities". I guess the authors here wanted to elaborate the complexity of *measuring and modeling precipitation in Beijing due to its high urbanization (i.e. densely populated) and large heterogeneity (i.e. high spatial and temporal variabilities), and show the significance of analyzing DSD characteristics which could help us to understand urban precipitation. I suggest that the authors should rewrite this part to keep it concise and clear.*

Response: We apologize for the possible confusion. We have rephrased these sentences as suggested. Now it reads: *"The rapid urbanization and complex topography have further exacerbated the high variability of precipitation in Beijing urban area, posing challenges to precipitation observations and forecast (Song et al., 2014; Yang et al., 2013a; Yang et al., 2016). This also highlights the importance of understanding local DSD characteristics to better quantify the urban precipitation."* (page 2, lines 25-28, in the clean version)

8. P2, L21, ": : : stations network de Vos et al., 2017", add "by" after "network". In addition, I prefer a standard usage of references in the text.

Response: We thank the reviewer for this comment. In the revision, we have added a "by" after "network". In addition, we have standardized the references and formatting in the text.

9. P2, L22, "monitoring networks : : : have been applied", here using "established" may be a better choice.

Response: We totally agree with the reviewer. Changed as suggested!

10. P2, L34, "warn" -> "warm".

Response: Corrected as suggested!

11. P3, L5, "methodologies" -> "methods".

Response: Changed as suggested!

12. P3, L7. I suggest the word "Section" should be capitalized.

Response: Changed as suggested!

13. P3, L15-17 and L25. From the manuscript, I guess these 32 non-uniform bins are set by THUD and fixed for all rainfall events, leaving the maximum observable diameter to be 24.5 mm. However, P5 L20 mentioned that the biggest raindrops ever reported are around 8 mm. The authors should clearly point it out if the latter diameter value can only represent precipitation in Beijing.

Response: We thank the reviewer for pointing this out. The 32 non-uniform bins are set by the second-generation Particle Size and Velocity (Parsivel^2) disdrometer (Loffler-Mang and Joss, 2000) and are fixed for all events. The disdrometer can not only observe raindrops but also other precipitation particles such as hail and snowflakes, which are typically larger than raindrops.

The biggest raindrop ever reported is around 8 mm (Beard et al., 1986;Baumgardner and Colpitt, 1995). Therefore, the maximum diameter is often limited to 8 mm, not only in Beijing, but also other regions in the world. This is commonly recognized in the precipitation community. We have clarified this in the revision (page 5, line 26-28 in the clean version): "*In addition, to focus on rainfall, all the data contaminated by hail are removed, and raindrops at a diameter of larger than 8 mm are eliminated (Bringi and Chandrasekar, 2001) since the biggest raindrops ever reported globally in the literature are around 8 mm (Baumgardner and Colpitt, 1995; Beard et al., 1986)."*

14. P3, L24-25. How to obtain Dj if only the number of raindrops belonging to each bin was recorded? I've noticed that the maximum value of Dmax happened to be 7.5 mm in Table 1, so I guess there should exists a bin ranging from 7 mm to 8 mm, and the authors took its average as corresponding diameter.

Response: We thank the reviewer for this detailed question. For the second-generation Particle Size and Velocity (Parsivel^2) disdrometer, the measured particles are subdivided into 32 different diameter bins. At each diameter bin, it has a specific mid-value and spread. In this study, we consider the mid-value as D_j. For example, the mid-value of the 24th bin is 7.5 mm and the bin spread is 1 mm, which means the raindrops in this category range from 7 mm to 8 mm. Then we take the mid-value of 7.5 mm as D_{24} corresponding to this particular bin. We have further clarified this in the revision (page 4, line 9-11, in the clean version): *"where D_j (mm) is the mid-value of jth diameter bin, $N(D_j)$ is in m^{-3} mm^{-1}; A is the sampling area in m^2; Δt is the sampling time interval in s; A and Δt are respectively 0.0054 m^2 and 60 s in this study; ΔD_j (mm) is the diameter spread for the jth diameter bin; V_i ($m\ s^{-1}$) is the mid-value fall speed for the ith velocity class."*

15. P5, L30. How did the authors figure out the relationship between Dm and D0?

Response: We apologize for the possible confusion. The relationship between D_m and D_0 is derived by Ulbrich (1983). For any reason, this reference was lost. We have clarified this in the revision (page 6, line 11 in the clean version): "*The relationship* $\Lambda D_m + 3.67 = \Lambda D_0 + 4$ *(Ulbrich, 1983) may explain for such phenomenon when* $\Lambda > 0$."

16. P13, L9. I guess the authors missed "(MP-Strariform)" after "NEXRAD".

Response: We thank the reviewer for pointing this out. In the revision, "(MP-Stratiform)" has been added after "NEXRAD".

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