Responses to the comments by Editor in charge

Takashi Unuma

Thank you very much for your constructive comments on the 1st revised manuscript. Your comments are very useful in improving the 1st revised manuscript. I will respond to your comments in the followings. Your comments are written in *grey Italic*, while my responses are written in Roman. I have also included the document with track changes for your reference.

Thank you for the revised manuscript. The reviewers were enthusiastic about your manuscript, and I am confident that it will be accepted for publication in ACP. One of the reviewers still had a few suggestions for your consideration, so I will give you the opportunity to revise the manuscript accordingly.

Reply: Thank you very much for evaluating the revised manuscript and giving constructive comments. I have revised the main text in the 2nd revised manuscript as thoroughly as possible.

Responses to the comments by Referee #1

Takashi Unuma

Thank you very much for your thorough reviews and constructive comments on the 1st revised manuscript. Your comments are very useful in improving the 1st revised manuscript. I will respond to your comments in the followings. Your comments are written in *grey Italic*, while my responses are written in Roman. I have also included the document with track changes for your reference.

General Comment

The revised manuscript improved well. I felt that there were still a few shortages to complete the discussion.

> **Reply:** Thank you very much for your thoughtful and constructive comments. I have revised the main text in the 2nd revised manuscript appropriately to ensure that the discussion is complete. Please see my responses in the followings.

Specific comments

R1-SC1. The title and abstract seem to mention characteristics of general DSD, but going through the revised manuscript, the study focused on equilibrium drop size distribution (break up) in heavy rainfall. Those key phrases should be accounted for in the title and abstract to defile the purpose and uniqueness of this study.

> **Reply:** Thank you very much for your comments. Whilst the presence of raindrop breakup signature is one of the characteristics of an equilibrium shape of drop size distribution, it is difficult to conclusively classify the phenomena as the pure equilibrium shape of drop size distribution from a process-oriented perspective (Unuma et al. 2025). However, recent studies show that the drop size distribution including breakup signature seems to be crucial for heavy rain event (e.g., Ding et al. 2023, Jung and Jou 2023, Unuma et al. 2023, Unuma 2024). I thus decided to investigate cases that exhibit breakup signature statistically to obtain more robust features of it. From this perspective, I have added words of 'including a breakup signature' to the title in the 2nd revised manuscript. Additionally, I have also revised the abstract to reflect the points mentioned

above clearly in the 2nd revised manuscript.

R1-SC2. Why eastern Japan was selected in this study? Was this area meteorologically important?

Reply: Thank you for your comment. From a meteorological perspective, the eastern part of Japan occasionally experiences heavy rainfalls (e.g., Kawabata et al., 2011; Nomura and Takemi, 2011; Seino et al., 2018). However, previous studies have not examined convective systems in this region from the viewpoint of this study, particularly the raindrop breakup signature near the ground. This gap in the literature is why I chose the eastern part of Japan as the focus of my study. I have revised the main text in the 2nd revised manuscript to clarify these points as follows:

‘Whilst heavy rainfalls occasionally occur in the eastern Japan (e.g., Kawabata et al., 2011; Nomura and Takemi, 2011; Seino et al., 2018), previous studies have not examined convective systems in this region from the perspective of this study, particularly concerning raindrop breakup signatures near the ground. Considering that, the eastern part of Japan was selected as the target area for this study.’

R1-SC3. I understand that some of the relationships showed low p-vales in the relationship analysis (e.g. Figs. 12-14), but it is still true that the correlation coefficients for some relationships are not high. Please discuss why those relationships are week (e.g. complexity of microphysics, possible factors, microphysical processes, etc.).

Reply: Thank you very much for your comments. The dominant processes within the targeted convective clouds are reflected in the observations. Additionally, the vertical distribution characteristics indicate that different cloud microphysical processes may occur at various heights (e.g., Fig. 10). These factors interact in complex ways, leading to significant dispersion in the scatter plot, which reduces the correlation coefficient. This suggests that simple correlations may not be adequate for discussions in certain cases. I have added the following sentences in the 2nd revised manuscript to clarify these points.

‘The findings obtained from this study examined the dominant processes occurring within the targeted convective clouds. However, the analysis of vertical distribution characteristics showed that different cloud microphysical processes take place at various heights (Fig. 10). These factors interact in complex ways, resulting in significant dispersion in the scatter plots (Figs. 12-14). This dispersion may reduce a correlation coefficient, indicating that simple linear relationships between the DSD parameters and the environmental parameters may not be sufficient for interpretation in some cases. Naka and Takemi (2025) investigated the relationships between accumulated rainfall values and environmental parameters over Japan, including the possibility of multicollinearity. They found that there is multicollinearity between the water-related environmental parameters. Therefore, incorporating the influence of various cloud microphysical processes that can coincide within convective clouds and the effects of multicollinearity should be clarified in a future study.'

R1-SC4. Section 2.2 and Figure 3: From this figure, it seems to me that there was a large uncertainty in the retrievals. For example, D_0 had ~0.5 – 1 mm uncertainty, and Lambda had also 0.5 – 1 mm-1 uncertainty. The uncertainty in the retrievals could impact the result. Please discuss how the uncertainty in the retrievals could influence the relationships. The uncertainties might be large and influence the relationships that had week correlation coefficients.

Reply: Thank you very much for your invaluable comments. Yes, I agree with your opinion. It is believed that the uncertainty in calculating DSD parameters should affect the relationship between environmental conditions and the characteristics of raindrop size distributions in convective clouds. I have added the following sentences in the 2nd revised manuscript to clarify this point:

'The uncertainty in retrieving DSD parameters may also influence the relationships between environmental conditions and the DSD parameters, potentially resulting in lower correlation coefficients between them.'

R1-SC5. Figure 3: At what height were the radar data compared with the surface data?

Reply: Thank you very much for pointing this out. The elevation angle of the radar data compared with the surface data is 1.1 degree, which is approximately 1.5 km above the ground. I have added the sentence in the main text of the 2nd revised manuscript as follows:

'The elevation angle of the radar data compared with the ground-based disdrometer data is 1.1 degree, whose height is approximately 1.5 km above the ground.'

R1-SC6. Lines 209-211: Do you mean that Lambda captured DSD with larger raindrops and small number concentration that produced weak Z but stronger R? R is generally proportional to D^3-4, while Z is proportional to D^6. So Z could represent more larger raindrops. I might *miss understand, so please clarify more.*

Reply: Thank you for your comments. Overall, your understanding is accurate. The horizontal reflectivity factor does not adequately represent the breakup signature in the equilibrium shape of the drop size distribution itself. In contrast, Lambda can capture this feature as one of the characteristics of the equilibrium shape of the drop size distribution. Specifically, the size distribution that contains higher concentrations of smaller raindrops (less than 0.5 mm in diameter) and relatively larger raindrops (greater than 1.5 mm in diameter) was identified. I have added the following sentence to the main text of the 2nd revised manuscript to clarify our perspective:

‘Lower values of the Lambda obtained from the DSD parameters indicate a medium size of raindrops (approximately 1–2 mm in diameter) alongside a higher concentration of smaller raindrops (around 0.5 mm in diameter) in the size distribution. This scenario may be observed in areas with weaker Z_H value but stronger (R).’

R1-SC7. No discussion about vertical velocity in the manuscript. Vertical velocity can tend to be strong in strong wind shear and can result in producing large hydrometeor particles. Were there no impacts of vertical velocity?

Reply: Thank you very much for pointing this out. As shown in Figure 14 of the 2nd revised manuscript, most of the convective clouds in this study occurred under relatively weak vertical wind shear (i.e., <$1.0x10^{-4}$ s^{-1}). Previous studies have examined the condition through numerical experiments involving organised convective systems under various vertical wind shear/thermodynamic environments (e.g., Takemi, 2010; 2014). The results obtained in this study resemble the previous studies conducted under the weak vertical shear conditions (Takemi, 2014), suggesting that the vertical velocities within convective clouds are expected to be weak, as observed in tropical regions. Also, rather than an increase in raindrop size, the higher number concentration of raindrops around 1–2 mm in diameter is dominant in the size distribution compared to an exponential distribution. This is significantly different from environmental conditions such as squall lines or supercells, where vertical shear is large, resulting in strong vertical flows (e.g., Rotunno et al., 1988; Kumjian et al., 2014). To clarify these points, I have revised the main text in the 2nd revised manuscript as follows:

‘In terms of vertical velocities within the convective clouds, most of the convective clouds in this study developed under relatively weak vertical wind shear conditions (i.e., <$1.0×10^{−3}$ $s^{−1}$) as shown in Fig. 14. Previous studies have examined the condition through numerical experiments involving organised convective systems under various vertical wind shear and thermodynamic environments (e.g., Takemi, 2010, 2014). The findings of this study resemble those of previous studies conducted under the weak vertical shear conditions (Takemi, 2014), suggesting that the vertical velocities within convective clouds are expected to be weak, as observed in tropical regions. From a microphysical perspective, there is a predominant higher number concentration of raindrops measuring 1–2 mm in diameter (Fig. 5), which differs from the exponential distribution often seen, rather than simply resulting in larger raindrop sizes. This scenario contrasts sharply with environmental conditions like squall lines or supercells, which experience strong vertical wind shear and, consequently, strong vertical velocities (e.g., Rotunno et al., 1988; Kumjian et al., 2014). These characteristics warrant further investigation using a numerical model that incorporates the observed relationships discussed in this study, which remains as a future work.'

Technical comments

R1-TC1. Line 69: Convective systems produce heavy rain, not heavy rain produces convection.

Reply: Thank you very much for pointing this out. According to your comment, I have altered the sentence in the main text of the 2nd revised manuscript.

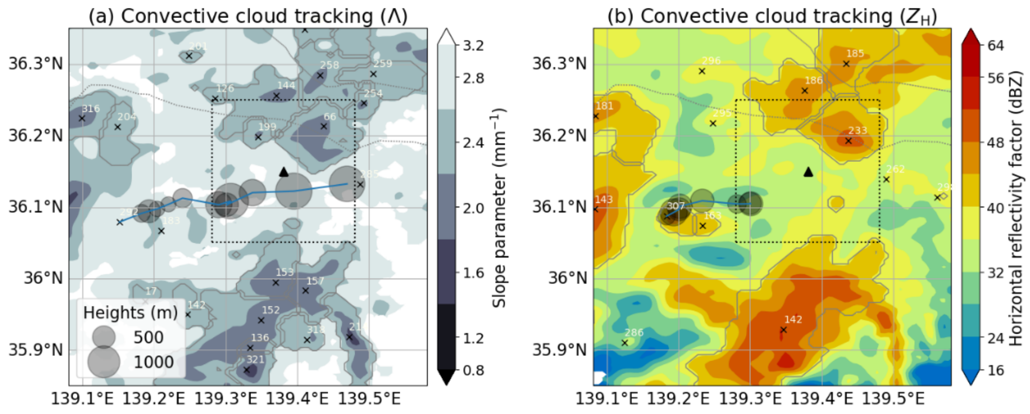
'In addition, recent studies show that such characteristics seem to be important for convective systems that produce heavy rain (Ding et al., 2023; Jung and Jou, 2023; Unuma et al., 2023).'.

R1-TC2. Lines 70: What do you compare with to say "fewer?"

Reply: Thank you for pointing this out. I have changed the expression in this sentence accordingly: '… a few studies …'.

R1-TC3. Figure 4: Use appropriate color range for Z

Reply: Thank you very much for pointing this out. I have improved Figure 4(b) to make it easier to read changes in values by changing the value range to 16–64 dBZ as follows.



R1-TC4. Line 339: "than" is better, not "among"

Reply: Thank you for your suggestion. In accordance with your comment, I have altered the word accordingly in the main text of the 2nd revised manuscript.

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