A summary of relevant changes made in the revised manuscript

Thank you very much for your efforts to review my paper. According to the referee's comments, I have revised the main text in the revised manuscript. A summary of relevant changes made in the revised manuscript is as follows. The responses to the referee's comments can be found after this summary page.

1. Title: Changed to ' Observed relationship between drop size distribution and environmental properties near Kumagaya in eastern Japan' in the revised manuscript, which is related to Referee 1's Specific comment 1.
2. Introduction: It has altered in the revised manuscript, which is related to Referee 1's Specific comment 2, Technical comments 1--3.
3. **Data and Methods: I have added detailed procedure for the ground-based disdrometer and the polarimetric weather radar to get DSD parameters**, which is related to Referee 1's Specific comments 2, 3-1--3-10, 3-13--3-14, 4, 5, Technical comments 4--5, and **Referee 2's Major comment 1--2**.
4. **Results: It has modified in the revised manuscript**, which is related to Referee #1's Specific comments 3-12, 4-1--4-6 and 5, Technical comments 6, **Referee #2's Major comments 3-i**.
5. **Discussion: It has significantly altered in the revised manuscript**, which is related to Referee 1's Specific comments 6-2--6-6, Technical comments 7--8, and **Referee 2's Major comment 3-ii**.
6. **Conclusions: It has slightly altered in the revised manuscript**, which is related to **Referee 2's Major comment 3-ii**.
7. Deleted Table 1.
8. Added new Fig. 1, which is mainly related to Referee 1's Specific comments 3-4, and Technical comment 6.
9. Added new Fig. 2, which is mainly related to Referee 1's Specific comments 3-3, 3-5, and 3-6.
10. **Added new Fig. 3**, which is related to **Referee 2's Major comments 2-i and 2-ii**.
11. Modified Fig. 1 of the original manuscript as Fig. 4 in the revised manuscript, which is related to Referee 1's Specific comments 3-2, 3-5, 3-9, and 3-11.
12. Added new Fig. 5, which is mainly related to Referee 1's Specific comment 3-1.
13. Added new Fig. 6, which is mainly related to Referee 1's Specific comments 3-1 and 5.
14. Changed figure number of original Fig. 2 to Fig. 7 in the revised manuscript.
15. Changed figure number of original Fig. 3 to Fig. 8 in the revised manuscript.

16. Changed figure number of original Fig. 4 to Fig. 9 in the revised manuscript.
17. Changed figure number of original Fig. 5 to Fig. 10 in the revised manuscript.
18. Changed figure number of original Fig. 6 to Fig. 11 in the revised manuscript.
19. **Modified Fig. 7 of the original manuscript as Fig. 12 in the revised manuscript**, which is related to Referee 1's Specific comments 4--5, and **Referee 2's Major comment 3-i**.
20. **Modified Fig. 8 of the original manuscript as Fig. 13 in the revised manuscript**, which is related to Referee 1's Specific comments 4--5, and **Referee 2's Major comment 3-i**.
21. **Modified Fig. 9 of the original manuscript as Fig. 14 in the revised manuscript**, which is related to Referee 1's Specific comments 4--5, and **Referee 2's Major comment 3-i**.
22. Changed figure number of original Fig. 10 to Fig. 15 in the revised manuscript.
23. Changed figure number of original Fig. 11 to Fig. 16 in the revised manuscript.

Responses to the comments by Referee #2

Takashi Unuma

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

General comments

This study focuses on the relationship between the drop size distribution (DSD) of convective clouds and environmental properties in eastern Japan. It conducts research using multiple observational data and analysis methods. The topic holds significant scientific importance and contributes positively to understanding precipitation processes and mechanisms. The research content is comprehensive, the methods are reasonable, and the data are abundant. However, there is still room for improvement. With revisions and refinements, it has the potential for publication.

> **Reply:** Thank you very much for taking the time to read my paper and for your comments. I am very encouraged by your evaluation of the submitted manuscript. I have responded to your comments as appropriately as possible. Details are as follows.

Major Comments

R2-MC1. Lines 116–118: The four parameters discussed here are central to the manuscript's analysis. While the authors cite relevant literature, further clarification is warranted. Specifically, the manuscript should explicitly outline the calculation methods for these variables and elaborate on their physical significance within the context of this study. This addition would enhance reproducibility and help readers interpret the results more effectively.

> **Reply:** Thank you for pointing this out. According to your comments, I have added the procedures of calculating the DSD parameters retrieved from C-band polarimetric radar data in Sect. 2.2 of the revised manuscript as follows.

‘On this method, β (mm^{-1}) need to be calculated as follows;

$\beta = a\ (K_{DP}/Z_H)^b\ (10^{0.1ZDR} - \kappa)^c$, (9)

where coefficients of *a*, *b*, *c*, and κ are 2.55, 0.355, 0.439, and 0.8 based on Gorgucci and Baldini (2009)’s Table 1. The units of K_{DP}, Z_H, Z_{DR} are degree km^{-1}, dBZ, dB, respectively. Then, D_0, N_w, and *LWC* were calculated as following equations;

$D_0 = 0.59\ Z_H^{0.083}\ (10^{0.1ZDR})^{0.021\beta-1.16}$, (10)

$\log_{10} N_w = 3.01\ Z_H^{0.054}\ (10^{0.1ZDR})^{-0.02\beta-1.25}$, (11)

and

$LWC = 1.73 \times 10^{-5}\ N_w\ D_0^4$, (12)

where coefficients are based on Gorgucci et al. (2000,2002). Λ (mm−1) is calculated with $\Lambda = 3.67/D_0$. These DSD parameters were calculated only if the conditions of Z_H > 35 dBZ, Z_{DR} > 0.2 dB, and K_{DP} > 0.3 degree km^{-1} are satisfied simultaneously.’

(In Lines 165-177 in the revised manuscript)

R2-MC2. DSD Data Sources and Uncertainties: The drop size distribution (DSD) is derived from both radar retrievals and ground-based disdrometer measurements. To strengthen the validity of the findings, the authors should:

R2-MC2-i. Address whether comparative analyses were conducted between the radar and disdrometer datasets to assess consistency or discrepancies.

Reply: Thank you very much for your suggestion. I have added a figure to compare the DSD parameters retrieved from C-band polarimetric radar data and obtained from ground-based disdrometer data as shown in below (Fig. 3 in the revised manuscript).

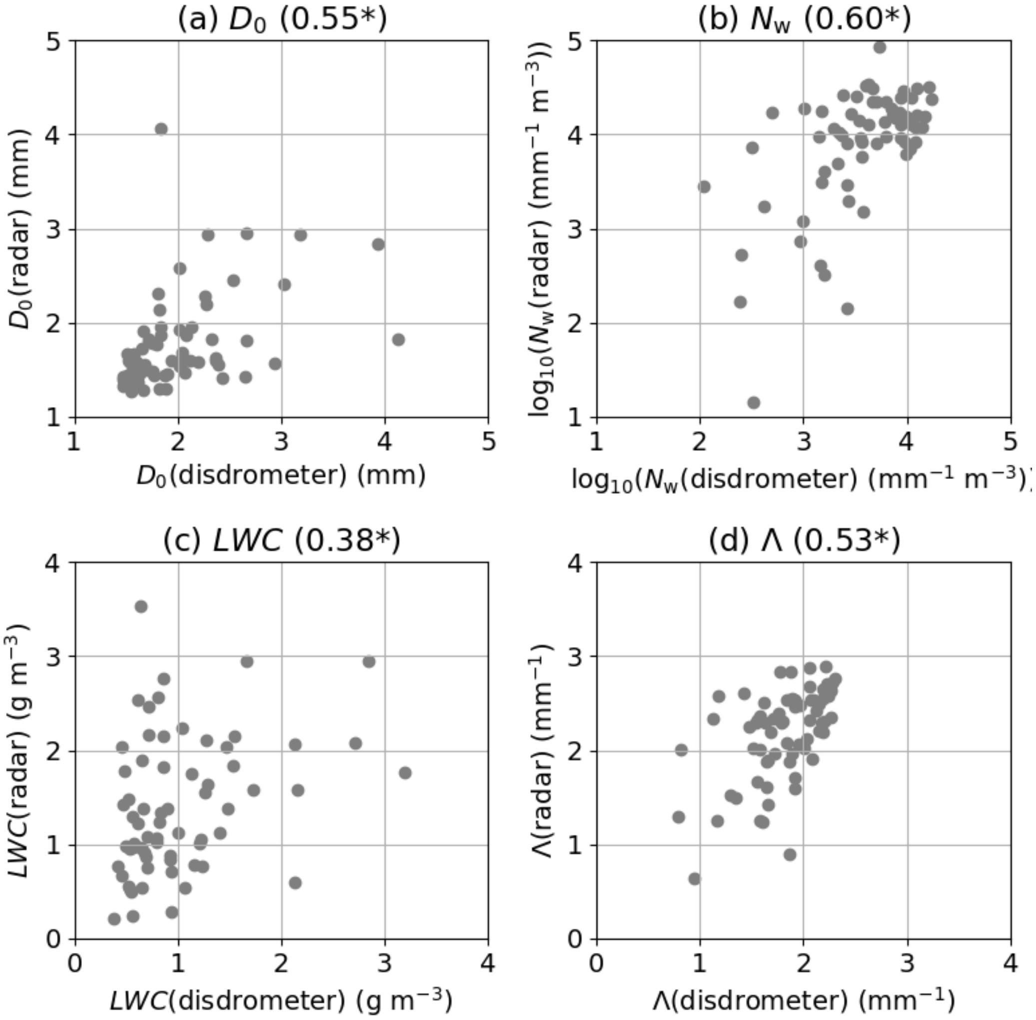

Fig. S1: The scatter diagram of the drop size distribution parameters of median volume diameter (D_0; mm), generalised intercept parameter (N_w; mm^{-1} m^{-3}), liquid water content (*LWC*; g m^{-3}), and slope parameter (Λ; mm^{-1}) retrieved from Tokyo radar data against the disdrometer data at Kumagaya. Correlation coefficient values are displayed each panel and an asterisk $*$ is added if the *p*-value for the correlation coefficient is less than 0.05.

R2-MC2-ii. Discuss potential uncertainties inherent in radar-based retrievals (e.g., calibration errors, resolution limitations) and their implications for the DSD estimates.

Reply: Thank you for pointing this out. I have added a sentence describing potential uncertainties during the radar-based retrievals as follows.

‘Observational errors caused by such as radar calibration, range/azimuth resolution limitations, wet antenna radome, low signal-to-noise ratio, and nonuniform beam filling may affect the DSD parameter retrievals, which are potential uncertainties of the radar-based retrievals used in this study.'

(In Lines 179-181 in the revised manuscript)

R2-MC3. Figures 7 and 8 (Relationships and Causality):

R2-MC3-i. While these figures illustrate associations between environmental parameters and shape parameters, the strength of the correlations remains unclear. Incorporating statistical analyses (e.g., correlation coefficients, p-values, or confidence intervals) would quantitatively substantiate these relationships.

Reply: Thank you for your suggestion. The correlation coefficient and *p*-value were calculated, and an asterisk was added to the figure when the correlation coefficient and *p*-value were less than 0.05 (Figs. 12-14 in the revised manuscript). Also, I have significantly altered the main text in the revised manuscript as follows.

'Here, the relationships between the DSD parameters at 2 km height and CAPE were investigated (Fig. 12). D_0 is positively correlated with CAPE (Fig. 12a), whilst Λ is negatively correlated with CAPE (Fig. 12d), whose *p*-value is less than 0.05, respectively. The variability of the scatter points in N_w and *LWC* is relatively higher than in D_0 and Λ, which are reflected to no apparent relations on N_w and *LWC* with CAPE value (*p*-value > 0.05).'

(In Lines 328-331 in the revised manuscript)

'Figure 13 shows relationships between D_0 and KI, D_0 and TLR, D_0 and PW, and LWC and PW integrating 1–2 km height (PW12), respectively. Note that the height of the DSD parameters selected in Fig. 13 is near the ground because the higher correlation coefficient values is obtained among the other analysis height. The larger D_0 seems to be related to the larger KI (Fig. 13a), but the correlation coefficient is much smaller. D_0 is proportional to TLR (Fig. 13b) and shows positive correlations between D_0 and TLR with *p*-value < 0.05. D_0 is negatively correlated with PW (Fig. 13c), whilst the relationship between them were weaker than TLR due to the higher variance of the distribution. The larger value of *LWC* seems to be related to the larger value of PW12 (Fig. 13d), whose relationship is statistically significant (*p*-value < 0.05).'

(In Lines 337-343 in the revised manuscript)

‘The relationships between the environmental vertical shear of the horizontal winds and the DSD parameters were further investigated (Fig. 14), as the DSDs tend to be affected by the environmental vertical shear as described in Sect. 1. The value of D_0 is likely to be large when the value of MS03 is large (Fig. 14a), whilst the value of N_w is likely to be small (Fig. 14b). The relationships between the environmental directional shear of horizontal winds and the DSD parameters were also investigated. The D_0 value tends to be smaller when the EH03 value is larger (Fig. 14c), whilst the N_w value tends to be larger when the EH03 value is larger (Fig. 14d). These trends are different from those in MS03 but are not statistically significant (p-value > 0.05).’
(In Lines 348-355 in the revised manuscript)

R2-MC3-ii. The discussion should explicitly acknowledge that correlation does not imply causation. For instance, the observed trends could be influenced by unaccounted variables or confounding factors. Revising the text to temper causal language and highlight the exploratory nature of these relationships would improve scientific rigor.

Reply: Thank you for your suggestion. I have revised the main text to avoid expressions that suggest a causal relationship based on correlation in the revised manuscript as follows.

‘When the instability indices such as CAPE and TLR are high, D_0 tends to be large, and Λ tends to be small (Figs. 12 and 13); that is, a broader shape of the DSD is likely to be formed concerning the gamma DSD with shape parameter μ is larger than zero value. Here, the three-parameter gamma distribution $N(D)_{gam}$ is defined as following;
$N(D)_{gam} = N_0 D^{\mu} \exp(-\Lambda D)$.
This form is quite similar to $N(D)_{exp}$ in Eq. (8) but with the shape parameter μ. If μ is negative, the smaller value of μ results in smaller value of Λ due to its shape is to be concave. As shown in Fig. 5, almost all of the observed DSD shape is convex, envisaging μ is larger than zero in the present study. On the other hand, the weaker vertical shear affects the liquid water content within the convective clouds (Fig. 14d). This is probably related to the higher precipitation intensity under the weaker vertical shear condition (Unuma and Takemi, 2016; Unuma, 2024). Unuma and Takemi (2016) extracted the quasi-stationary convective systems and divided them into those with the faster- and slower-moving systems, and compared their characteristics. As a result, the slower-moving convective systems tended to occur under the weaker vertical

shear environment compared to the faster-moving systems. In addition, precipitation intensity tended to be stronger and its area tended to be smaller in the cases of slower-moving systems, which may be one of the reasons for the resulting larger rainfall amount because the systems remain to be located nearly same location.

In terms of microphysical perspectives, collisional coalescence between raindrops tends to occur under the stronger vertical shear environment, which promotes to producing larger (> 2 mm diameter) raindrops. At the same time, smaller raindrops are likely to evaporate more easily under the stronger vertical shear. On the contrary, the probability of collisional coalescence between raindrops and that of evaporation are decreases under the weaker vertical shear environment. In such cases, smaller (< 2 mm diameter) raindrops are more likely to form, contributing to higher number concentrations. In fact, the number concentration of raindrops with the diameters of ~ 1–2 mm was high regardless of *R*, as observed in the ground-based DSD observation (Fig. 5).

The amount of water vapour in the surrounding atmosphere may increases *LWC* for the DSD parameters, as shown in Fig. 13d, and the intensity of precipitation in the DSD that has approached an equilibrium shape can be more sensitive to the amount of water vapour.'

(In Lines 402-425 in the revised manuscript)