Responses to Reviewers' Comments

We sincerely appreciate the time and effort devoted by the reviewers and editor. We thank the reviewers for these constructive and professional comments. Our point-to-point responses can be found below. The reviewer comments/suggestions are in *italic* font, and our responses are underlined and in blue. The file name "Manuscript with marked changes" is abbreviated as "mms".

Referee #1 Evaluations (Eric Bruning):

The authors analyze a single case study of an isolated thunderstorm over land to the northeast of Guangzhou, China. Analysis of differential reflectivity and specific differential phase columns over the lifecycle of this storm allows the authors to analyze how the cloud microphysics lead to lightning, and the lead time that polarimetric radar allows in inferring the onset of lightning.

The case study largely repeats previous findings. There are a few valuable advancements in analysis methods (column identification methodology; inferring supercooled rain water content using a method from the late 1990s / early 2000s; lead time calculations by different methods). There are also some process inferences related to different pathways by which lightning might be produced that could be valuable and clarifying, but the universality of which is hard to judge on the basis of a single case study.

The authors have therefore engaged substantively in an ongoing tradition of analysis of polarimetric radar and lightning signals, with fair-to-good scientific significance, and good scientific and presentation quality. Below I note additional areas that could improve the manuscript, adding some missing information and clarifying the interpretation.

We sincerely appreciate your evaluation and insightful comments, which helped us improve this manuscript. The comparison between this study and your results is valuable for deepening our knowledge of the polarimetric structures related to lightning activity.

Major comments

1) *The authors do a nice job of reviewing the literature. I wanted to also mention our just-published paper, Bruning et al. (2024, 10.1175/MWR-D-24-0060.1), which pursues a very similar analysis on a large sample of storms. The authors' detailed look at the time-series perspective here is valuable (and something we did not yet*

do), and I would be interested to see where this study fits in the distribution of lightning and polarimetry of storms sampled by Bruning et al., which were probably similar small, isolated, subtropical storms.

Reply: We have added more discussion about this study fits in the distribution of lightning and polarimetry of storms sampled by Bruning et al. (2024), which were probably similar small, isolated, subtropical storms. Moreover, more cases have been added to strengthen our results (Table 1, including the original analysis case in the manuscript). In addition, the results revealed in this study are discussed with those of Sharma et al. (2024) and Sharma et al. (2021). Please see in mms (Lines 194−199; 579−639; 719−748).

Table 1. The information of cases

Cases number	Time information [CST]	CAPE [J kg^{-1}]
#1	17:18 to 19:00, 20 June 2016	1277
#2	12:12 to 13:18, 26 June 2016	1225
#3	15:36 to 16:36, 3 July 2016	961
#4	16:06 to 17:06, 5 July 2016	412
#5	11:00 to 12:12, 6 July 2016	1202
#6	16:18 to 17:06, 6 July 2016	1202
#7	15:00 to 16:06, 16 July 2016	1425
#8	13:24 to 14:12, 27 July 2016	1203
#9	14:36 to 15:18, 27 July 2016	1376
#10	14:54 to 15:18, 27 July 2016	1286
#11	13:24 to 15:00, 29 May 2016	1339
#12	09:18 to 10:48, 18 June 2016	1437
#13	12:18 to 13:00, 18 June 2016	1375
#14	15:48 to 16:36, 18 June 2016	1475
#15	13:06 to 14:12, 7 July 2016	2537

In our study, these 15 cases involved isolated thunderstorm cells, which produced lightning. Each of them has a Z_{DR} column; however, the absence of a K_{DP} column is possible (Figure 5a and b, Figure 10 a1-a7, b1-b7, Figure 11 a1-a7, b1-b7). The results of our study support the observations of Bruning et al. (2024), namely, that lightning is not observed in the absence of a Z_{DR} column and that a K_{DP} column is not observed without a Z_{DR} column. Moreover, the highest lightning flash frequency (in case #11) is observed when the Z_{DR} and K_{DP} columns are co-present, which is consistent with the observations of Bruning et al. (2024).

In addition, our results suggest that the signal in the K_{DP} column within these small, isolated, subtropical thunderstorms over South China is not as steady as that in the Z_{DR} column during the life cycle.

To further explore the characteristics of the microphysics related to the Z_{DR}/K_{DP} column and lightning within these thunderstorms, hydrometeor identification method involving the fuzzy-logic algorithm (as in Zhao et al., 2021b) and the microphysical fingerprint (following Kumjian et al., 2022) are conducted. Identifying polarimetric radar "fingerprints" of ongoing microphysical processes was introduced by Kumjian (2012); these fingerprints are defined as vertical changes in two (e.g., Z_H, Z_{DR}) or more of the dual-polarization radar variables (Kumjian et al., 2022). More detail can be found in **Section 2.2** and **Section 3.2**.

Lines 194−199 in mms:

"This study included 15 isolated thunderstorm cells that produced lightning, which was observed via an S-band dual-polarization radar deployed in Guangzhou city (GZ radar) and a low-frequency E-field detection array (LFEDA) (Table 1). The average 6-hourly convective available potential energy (CAPE) of these thunderstorms was obtained from ERA-Interim reanalysis data, as in Zhao et al. (2022). The detailed examination of lightning activity with related dynamics and microphysics in case #1 was conducted first, and then the statistical results of all cases were given."

Lines 579−639 in mms:

"**3.4. Statistical results**

To determine the relationship between lightning activity and the quantified Z_{DR} columns, the height and volume of the Z_{DR} column are calculated via the "3D mapping column" method; the volume is based on the accumulation of all grids within the Z_{DR} column, and the volume of a single grid is 0.03125 km^3, with 0.25-km horizontal and 500-m vertical resolutions. The height of the Z_{DR} column is determined by counting the grid number (n) from the melting level to the highest grid within the Z_{DR} column; if n is determined, the Z_{DR} column height is n×0.5 km.

The variations in the Z_{DR}/K_{DP} column height and volume with the life cycle of the remaining fourteen cases are displayed in Figures 10 (cases #2 to #8) and 11 (cases #9 to #15), as are the variations in the percentages of hydrometeor types and microphysical fingerprints. The grid is assigned to specific particle type based on the results of hydrometeor identification, and the percentage of grids for each hydrometeor type is calculated. Similarly, this process is applied to determine the percentage of grids associated with microphysical fingerprints. Each of them has a Z_{DR} column (Figure 10 a1-a7, Figure 11 a1-a7); however, the absence of a K_{DP} column is possible (Figures 10 b1-b7, Figures 11 b1-b7). The results of our study support the observations of Bruning et al. (2024), namely, lightning is not observed in the absence of a Z_{DR} column, and a K_{DP} column is not observed without a Z_{DR} column. Moreover, the highest lightning flash frequency (in case #11) is observed when the Z_{DR} and K_{DP} columns are co-present, which is consistent with the observations of Bruning et al. (2024). In addition, our results suggest that the signal in the K_{DP} column within these small, isolated, subtropical thunderstorms over South China is not as steady as that in the Z_{DR} column during the life cycle.

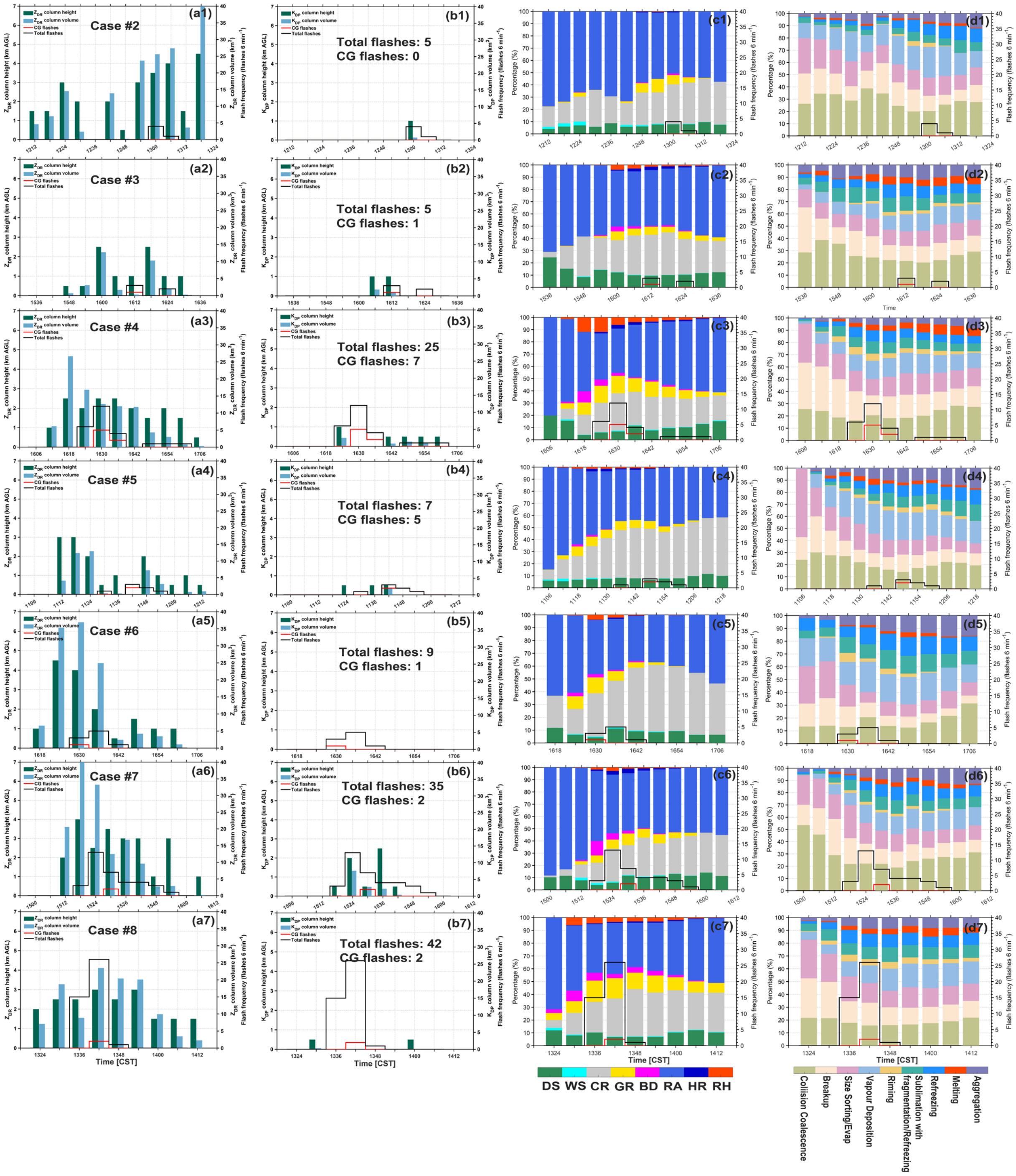

Figure 10. The variation in Z_{DR} column height and volume with the life cycle of thunderstorms (cases #2 to #8) (a1-a7). The variation in the K_{DP} column height and volume with the life cycle of

thunderstorms (cases #2 to #8) (b1-b7). The dark green bars indicate the column heights, and the light blue bars indicate the column volumes. The texts display the number of total flashes and CG flashes in a thunderstorm. The variation in percentages of hydrometeor types with the life cycle of thunderstorms (cases #2 to #8) (c1-c7). The variation in percentages of microphysical fingerprints with the life cycle of thunderstorms (cases #2 to #8) (d1-d7). The black stair lines indicate the total flashes, and the red stair lines indicate the CG flashes.

The results show that the percentages of identified graupel particles and riming process are closely related to lightning activities (Figures 10 c1-c7, d1-d7 and Figures 11 c1-c7, d1-d7), which are consistent with that in Figure 7. The cross-correlation approach can be used to examine the correlation considering the time lag, which is important for verifying whether a parameter is appropriate for forecasting another parameter. To further determine the correlation between lightning activity and the polarimetric structure. The cross correlations between the lightning activity and polarimetric structure during the life cycles in all the cases are examined, and the results are displayed in Figure 12.

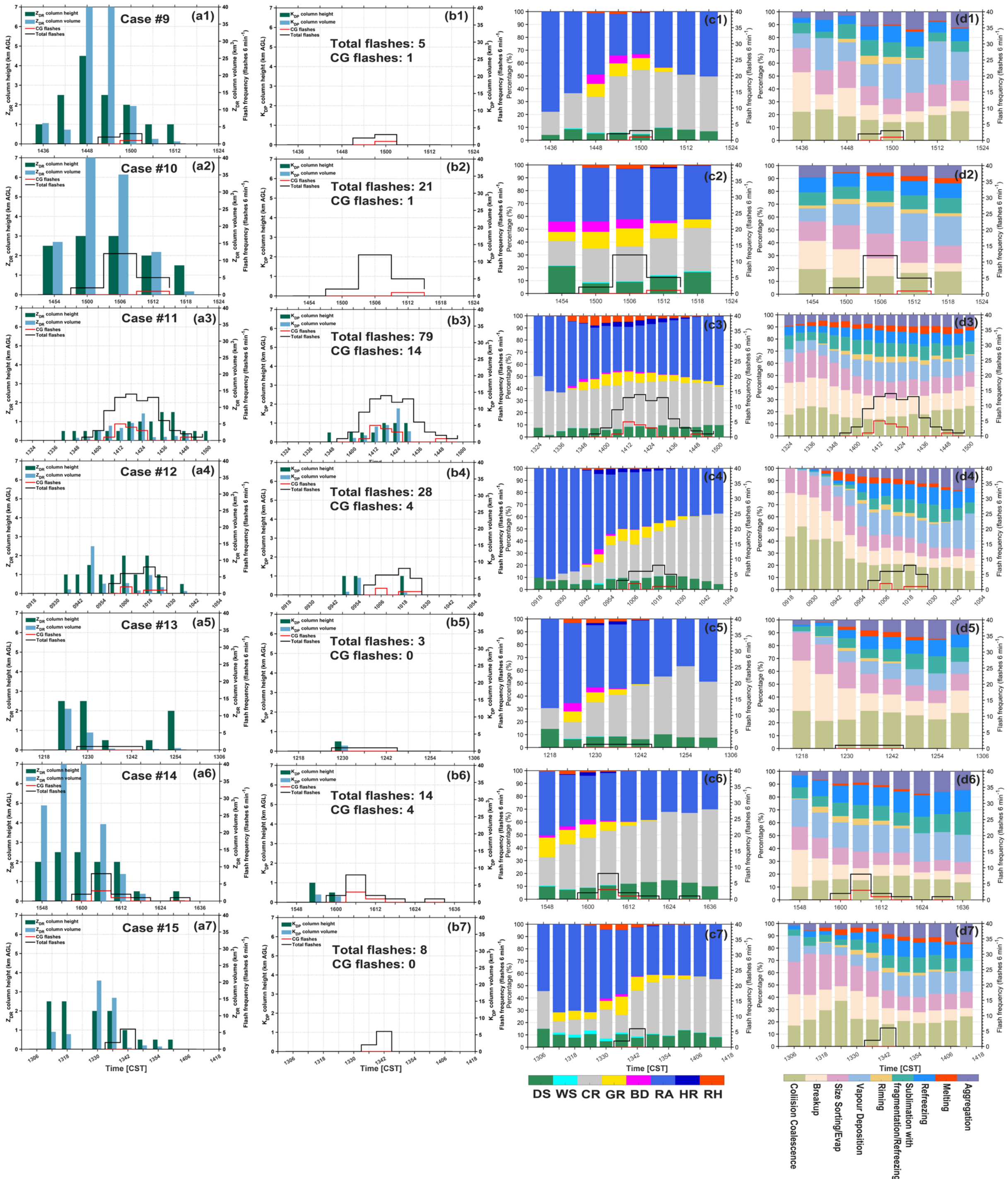

Figure 11. The variation in Z_{DR} column height and volume with the life cycle of thunderstorms (cases #9 to #15) (a1-a7). The variation in the K_{DP} column height and volume with the life cycle of thunderstorms (cases #9 to #15) (b1-b7). The dark green bars indicate the column heights, and the light blue bars indicate the column volumes. The texts display the number of total flashes and CG flashes in a thunderstorm. The variation in percentages of hydrometeor types with the life cycle of thunderstorms (cases #9 to #15) (c1-c7). The variation in percentages of microphysical

fingerprints with the life cycle of thunderstorms (cases #9 to #15) (d1-d7). The black stair lines indicate the total flashes, and the red stair lines indicate the CG flashes.

Figure 12a shows that the variation in the graupel or rain water content above the melting level within the cloud can predict the lightning activity (total flashes) after 6 minutes well, and the correlation coefficient is approximately 0.8. However, other parameters (e.g., Z_{DR} column volume, ice content above the melting level, and graupel volume) also exhibit good performance in forecasting lightning activity, and the correlation coefficient can reach approximately 0.7. The graupel volume is calculated based on the identification results of hydrometeors. Although the variation in the graupel or rain water content above the melting level within the cloud can also forecast the lightning activity (CG flashes) after 6 minutes, the correlation coefficient decreases to approximately 0.56 (Figure 12b). Notably, the trend of the Z_{DR} column volume implies that it may perform well with a longer warning time (e.g., 12 minutes) for lightning activity.

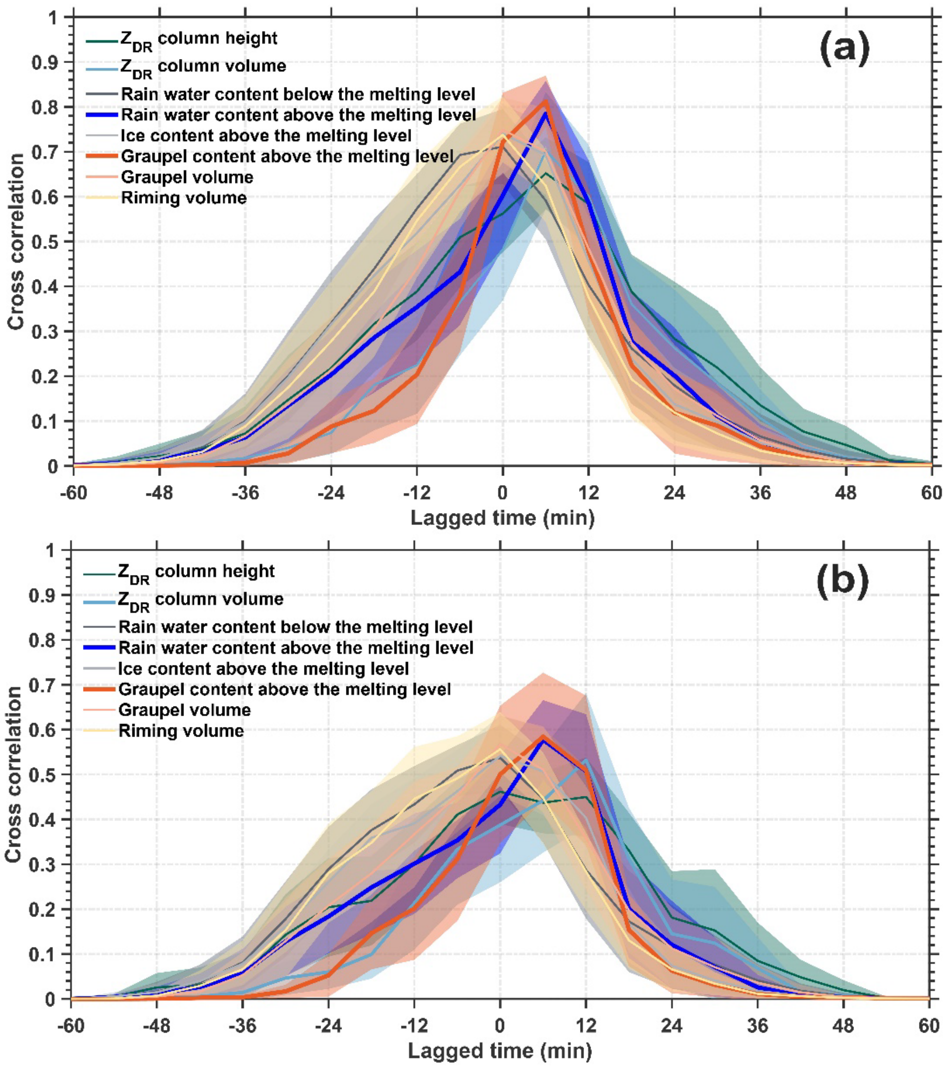

Figure 12. Cross-correlations between flash frequency (total flashes (a), CG flashes (b)) and eight radar-retrieved variables (Z_{DR} column height/volume, rain water content below/above the melting level, ice content above the melting level, graupel content above the melting level, graupel volume, and riming volume); the lines indicate the mean values and the shaded area indicates the 95% confidence interval. The lagged time is for flash frequency lags these eight radar-retrieved variables."

Lines 719−748 in mms:

"As discussed in Section 3.2, lightning activity is indeed related to dynamic variation and impulses in vertical velocity, which is consistent with the findings of previous studies (e.g., Bruning et al., 2024; Sharma et al., 2024; Sharma et al., 2021). The unsteady Z_{DR} and K_{DP} columns are tied to unsteady updrafts associated with thermal bubbles, which are relatively short-lived and thus indicate an impulse in vertical velocity. In this way, the variations in the Z_{DR} and K_{DP} columns can indicate lightning activity. Although this hypothesis is reasonable and supported by observations through the microphysical signatures of large-drop lofting and glaciation corresponding to the Z_{DR} and K_{DP} columns (Bruning et al., 2024; Fridlind et al., 2019); however, the observations of Sharma et al. (2024) and Sharma et al. (2021) revealed that the K_{DP} column volumes (or mean K_{DP} values within a segmented K_{DP} column) have noticeably different pattern than the Z_{DR} column volumes (or mean Z_{DR} values within a segmented Z_{DR} column), which has remained a question in Sharma et al. (2021).

In this study, we explore the polarimetric and microphysical structures related to impulse events and lightning activity. The results indicate that the column within the reflectivity core is only the Z_{DR} column in which the impulse event initially develops; then, the supercooled raindrops indicated by the Z_{DR} column transfer to abundant graupel and/or hailstone particles, releasing latent heat and thus invigorating convection; accompanying the Z_{DR} column within the reflectivity core, it collapses, and lightning intensifies. Moreover, the formation of the K_{DP} column requires melting and shedding processes from large ice particles (e.g., graupel or hailstones) that produce many raindrops of moderate-to-large and small sizes, which contribute to high Z_{DR}/K_{DP} values. These raindrops can recirculate into updrafts and be lifted to the mixed-phase region, forming the Z_{DR} column first, but then, it collapses as graupel and/or hailstone particles increase. Convection and lightning are enhanced, and a K_{DP} column is formed, which is associated with an increasing number of small-to-moderate hailstones with a significant water fraction. Thus, the Z_{DR} and K_{DP} columns within the reflectivity core are associated with the different stages of an impulse event, the Z_{DR} column indicates the stage in which cold cloud processes are weak, and the K_{DP} column is the opposite of the Z_{DR} column. This may explain the remaining question in Sharma et al. (2021), namely, why the K_{DP} column has a noticeably different pattern than the Z_{DR} column does. Notably, the Z_{DR} column is located at the periphery of the reflectivity core when the Z_{DR} column collapses within the reflectivity core."

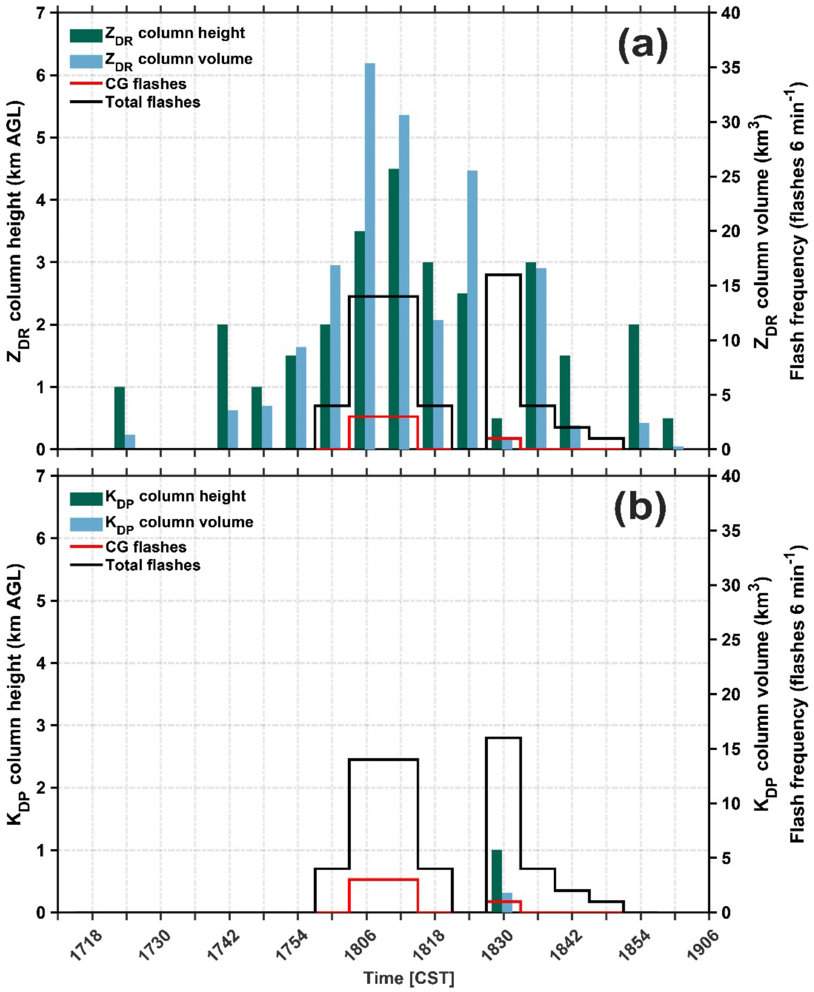

Figure 5. Time–height (volume) variation in the Z_{DR} column (a) and K_{DP} column (b). The dark green bars indicate the column heights and the light blue bars indicate the column volumes. The black (red) stepped line indicates the total flashes (CG flashes) from the LFEDA. AGL (above ground level).

Bruning, E. C., Brunner, K. N., van Lier-Walqui, M., Logan, T. and Matsui, T.: Lightning and Radar Measures of Mixed-Phase Updraft Variability in Tracked Storms during the TRACER Field Campaign in Houston, Texas. Monthly Weather Review, 152, 2753-2769, https://doi.org/10.1175/MWR-D-24-0060.1, 2024.

Fridlind, A. M., van Lier-Walqui, M., Collis, S., Giangrande, S. E., Jackson, R. C., Li, X., Matsui, T., Orville, R., Picel, M. H., Rosenfeld, D., Ryzhkov, A., Weitz, R., and Zhang, P.: Use of polarimetric radar measurements to constrain simulated convective cell evolution: a pilot study with Lagrangian tracking. Atmospheric Measurement Techniques, 12(6), 2979-3000, https://doi.org/10.5194/amt-12-2979-2019, 2019.

Kumjian, M. R.: The Impact of Precipitation Physical Processes on the Polarimetric Radar Variables. Ph. D. Dissertation, The University of Oklahoma, Norman, OK, USA, 327p., 2012.

Kumjian, M. R., Prat, O. P., Reimel, K. J., van Lier-Walqui, M. and Morrison, H. C.: Dual-Polarization Radar Fingerprints of Precipitation Physics: A Review. Remote Sensing, 14, 3706, https://doi.org/10.3390/rs14153706, 2022.

Sharma, M., Tanamachi, R. L. and Bruning, E. C.: Investigating Temporal Characteristics of Polarimetric and Electrical Signatures in Three Severe Storms: Insights from the VORTEX-Southeast Field Campaign. Monthly Weather Review, 152(7): 1511-1536, https://doi.org/10.1175/MWR-D-23-0144.1, 2024.

Sharma, M., Tanamachi, R. L., Bruning, E. C. and Calhoun, K. M.: Polarimetric and Electrical Structure of the 19 May 2013 Edmond–Carney, Oklahoma, Tornadic Supercell. Monthly Weather Review, 149(7): 2049-2078, https://doi.org/10.1175/MWR-D-20-0280.1, 2021.

Zhao, C., Zheng, D., Zhang, Y. J., Liu, X., Zhang, Y., Yao, W., and Zhang, W.: Characteristics of cloud microphysics at positions with flash initiations and channels in convection and stratiform areas of two squall lines, Journal of Tropical Meteorology, 37: 358-369, doi:10.16032/j.issn.1004-4965.2021.035, 2021b.

2) *355-57: It is not clear to me that the Zh signal is better related to lightning. – for instance, the Zh signal is quite noisy, while there is a very clear max in high LWC values just before each of the peaks in lightning that is much less noisy – and the authors conclude later that the LWC signal is the most robust. So this claim confused me.*

Reply: Thank you for your careful review. This description is indeed confusing. We have deleted the confusing description ("However, the relationship between the liquid water content within the Z_{DR} columns and the lightning flash frequency is not as strong as that between the Z_H values within the Z_{DR} columns and the lightning flash frequency"). Please see in mms (Lines 524−527).

3) *369: how does the collapse of the column result in an increase in lightning if graupel (which is thought to be necessary for electrification) is inferred as decreasing or absent in the column? Further discussion of the process would be valuable here; there are some hints in the discussion/conclusion section here, but I felt that further information and data was needed to verify the interpretation of the two different pathways to lightning the authors have identified.*

Reply: Yes. We agree with your insightful comment and suggestion. We have added the related analysis and discussion in **Section 3.2**. Please see in mms (Lines 451−508).

Lines 451−508 in mms:

"**3.2 Vertical structures of microphysics related to lightning activity**

To study the vertical thunderstorm structure related to lightning activity, we explore the vertical structures of polarimetric radar variables and microphysics, in combination with 3D lightning location data. Figure 7 displays the cross sections of polarimetric radar variables (Z_H, Z_{DR}, and K_{DP}) and microphysics (hydrometeor types and microphysical fingerprints) from the Cartesian grid of the studied isolated thunderstorm. At 18:00 CST (Figure 7 a1-e1), the lightning activity begins, and the locations of the flash sources are high and correspond mainly to graupel particles. Riming occurrence surrounds the flash sources. The Z_{DR} column and reflectivity core (≥ 40 dBZ) begin to separate, having previously been overlapping during the initial development stage of the thunderstorm (Figure 4a, b). Then, at 18:06 CST (Figure 7 a2-e2), riming begins obviously, the echoes strengthen (≥ 55 dBZ), and the heights of the strong echoes are lifted. This finding indicates that the convective strength or updrafts are obviously increased and that the cold cloud processes are heavily. The lightning activity reached the first peak, where the locations of the flash sources mainly corresponded to graupel and ice particles. Moreover, the Z_{DR} column is located at the periphery of the reflectivity core, and high K_{DP} values occur and correspond to heavy rain particles, which are associated with large ice particles (e.g., hailstones) melting, raindrops coalescence and/or break. This phenomenon is consistent with that the K_{DP} tends to be directly proportional to the rain mixing ratio (Snyder et al., 2017).

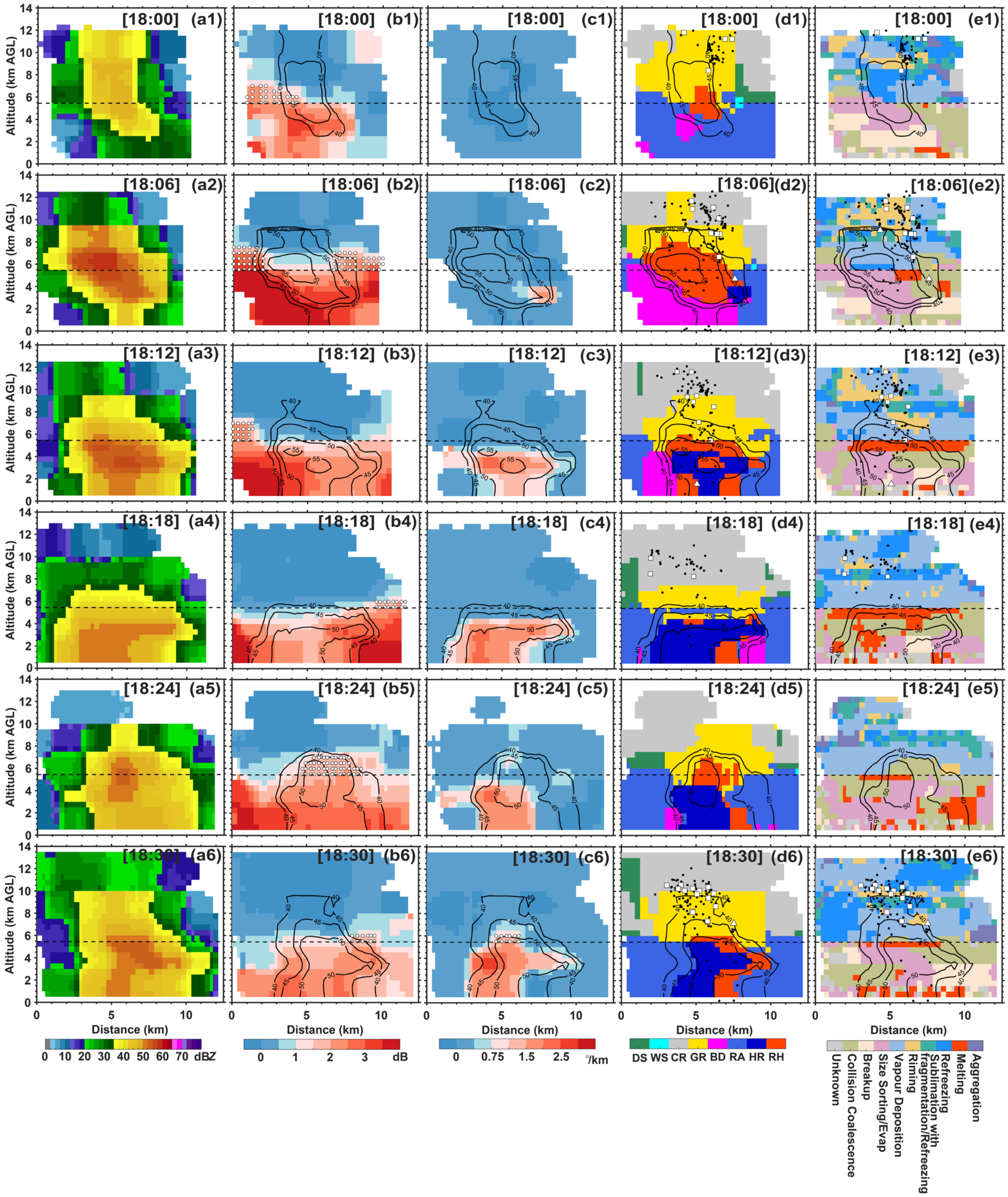

Figure 7. Cross sections of polarimetric radar variables (Z_H, Z_{DR}, and K_{DP}) and microphysics (hydrometeor types and microphysical fingerprints) from the Cartesian grid of the isolated thunderstorm (case #1). At 18:00 CST (a1-e1), 18:06 CST (a2-e2), 18:12 CST (a3-e3), 18:18 CST (a4-e4), 18:24 CST (a5-e5), and 18:30 CST (a6-e6). The black dashed line indicates the 0°C isotherm height. The white dots indicate the areas of the identified Z_{DR}/K_{DP} columns. The black contours with values indicate the reflectivity structure. The black dots indicate the flash

sources, the white square represents the first source of the intracloud flash, and the triangle represents the CG flash.

Subsequently, the lightning activity weakened at 18:12 and 18:18 CST. During this stage (Figure 7 a3-e3, a4-e4), the reflectivity core is landing and large ice particles above the melting level decrease, corresponding to heavy melting and indicating increasing downdrafts. Although Z_{DR} columns are present, they can only indicate updrafts around the reflectivity core. However, the reflectivity core was lifted again at 18:24 CST (Figure 7 a5). The contents of rain and hail mixtures and graupel clearly increased (Figure 7 d5). This indicates that the convective strength or updrafts are increased. Notably, the Z_{DR} column and reflectivity core overlap again, just as occurred during the initial development of the thunderstorm (Figure 4a, b; Figure 7 b5). Although a few high K_{DP} values occurred above the melting level, a K_{DP} column formed during the next 6 minutes (Figure 7 c5, c6). At 18:30 CST (Figure 7 a6-e6), the lightning activity reaches the second peak, and the riming process surrounds these flash sources. The Z_{DR} column within the reflectivity core quickly collapses with the occurrence of abundant graupel particles.

In total, this thunderstorm shows two impulses in vertical velocity, which correspond to two lightning activity peaks. When the first impulse event initially develops, the Z_{DR} column is obvious and overlaps with the reflectivity core; however, the region of the Z_{DR} column within the reflectivity core will collapse, with abundant graupel particles forming by riming or freezing, stimulating updrafts and intensified lightning. When large ice particles (e.g., graupel or hailstone) subsequently decrease, indicating the end of the first impulse event, melting and shedding processes occur, resulting in more raindrops (many moderate-to-large and small raindrops) contributing to high Z_{DR}/K_{DP} values. These raindrops could recirculate into the updrafts and be lifted to the mixed-phase region, forming the Z_{DR} column first, and raindrops could transfer to abundant graupel and even hailstones, releasing latent heat and thus invigorating updrafts again (indicating the second impulse event). However, the Z_{DR} column within the reflectivity core will collapse with increasing amounts of graupel and/or hailstone particles, but the K_{DP} column will occur; this can be explained by the increased K_{DP} values at the column top being associated with an increasing number of small-to-moderate hailstones with significant water fractions (Snyder et al., 2017). The lightning activity also reaches a peak value.

Thus, the Z_{DR} column within the reflectivity core is likely an indicator of imminent convection invigoration via latent heat release and then the formation of abundant graupel particles promotes lightning activity via noninductive charging; the K_{DR} column is highly related to cold cloud processes, replacing Z_{DR} column to indicate updrafts within the reflectivity core when obvious graupels and hailstones occur."

4) *393: note, however, that the correlation with Zdr is relatively large and increases (0.6) for about 20 min before the maximum in lightning, but falls off rapidly by 12 min after the lightning increases. From a practical point of view, the timing of the maximum correlation is less important than a trend toward confidence for lightning, and so in that sense the Zdr signal is more helpful.*

Reply: Yes, we agree with your opinion. Now, we added more cases (fifteen cases in total) to present the statistical results in **Section 3.4**, replacing the results of a case study in the raw manuscript. Moreover, we conclude and discuss the results in **Section 4**. Please see in mms (Lines 624−639; Lines 762−808).

Lines 624−639 in mms:

"Figure 12a shows that the variation in the graupel or rain water content above the melting level within the cloud can predict the lightning activity (total flashes) after 6 minutes well, and the correlation coefficient is approximately 0.8. However, other parameters (e.g., Z_{DR} column volume, ice content above the melting level, and graupel volume) also exhibit good performance in forecasting lightning activity, and the correlation coefficient can reach approximately 0.7. The graupel volume is calculated based on the identification results of hydrometeors. Although the variation in the graupel or rain water content above the melting level within the cloud can also forecast the lightning activity (CG flashes) after 6 minutes, the correlation coefficient decreases to approximately 0.56 (Figure 12b). Notably, the trend of the Z_{DR} column volume implies that it may perform well with a longer warning time (e.g., 12 minutes) for lightning activity.

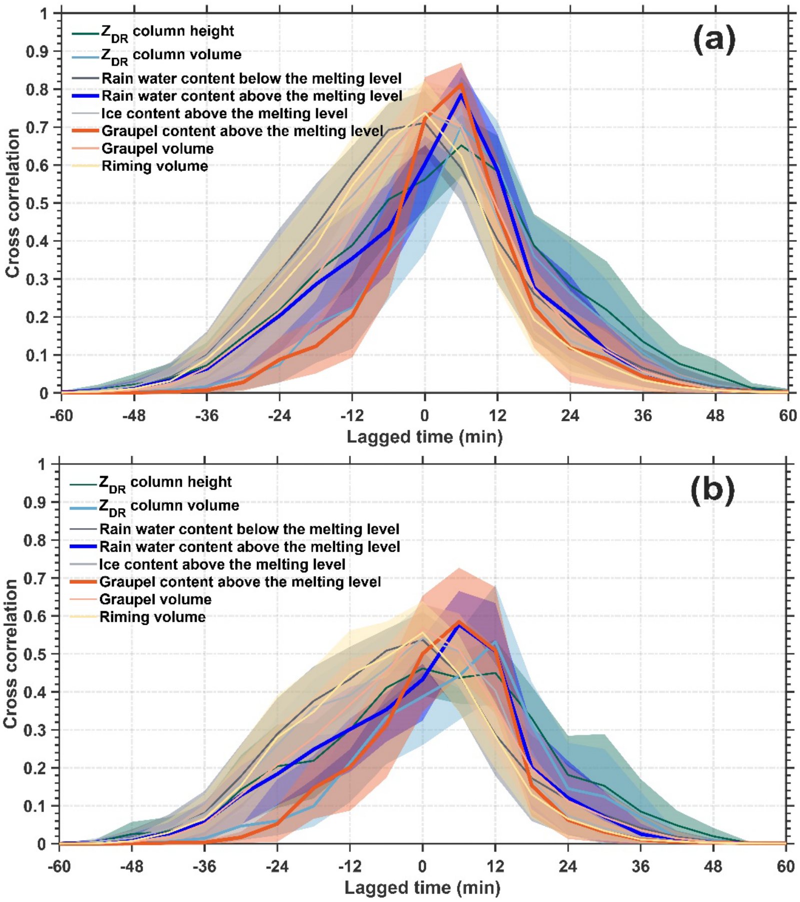

Figure 12. Cross-correlations between flash frequency (total flashes (a), CG flashes (b)) and eight radar-retrieved variables (Z_{DR} column height/volume, rain water content below/above the melting level, ice content above the melting level, graupel content above the melting level, graupel volume, and riming volume); the lines indicate the mean values and the shaded area indicates the 95% confidence interval. The lagged time is for flash frequency lags these eight radar-retrieved variables."

Lines 762−808 in mms:

"We bridged the polarimetric structure (the Z_{DR}/K_{DP} column, supercooled liquid water, and graupel content below 0°C) and lightning activity on the basis of observations of fifteen isolated thunderstorm cells (the variation curve is conceptualized in Figure 13). The two peaks of lightning activity in Figure 13 suggest multiple impulse events in convection; specifically, the first peak refers specifically to the initial impulse event, but the second peak suggests subsequent impulse events. The magnitude of the amplitudes among these curves has no practical meaning; it is merely for visualization purposes.

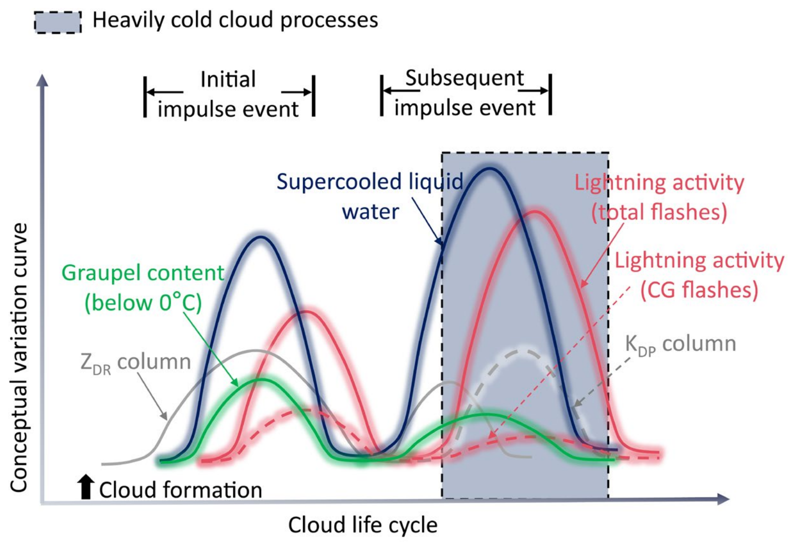

Figure 13. A conceptual model bridging the polarimetric structure and lightning activity.

In our opinion (Figure 13), the Z_{DR} column within the reflectivity core is likely an indicator of imminent convection invigoration via latent heat release, after which the formation of abundant graupel particles promotes lightning activity via noninductive charging. Therefore, microphysics (e.g., graupel content) are more directly related to lightning activity than are dynamics (e.g., the Z_{DR} column). Moreover, the observations reveal that the microphysical variations in supercooled liquid water and graupel yield better correlation coefficients for the prediction of lightning activity at short warning times (e.g., 6 minutes in this study) than do the dynamical variations in the Z_{DR} column volume. However, the trend of the Z_{DR} column volume implies that it may perform well with a longer warning time (e.g., 12 minutes in this study) for lightning activity. The K_{DR} column is highly related to cold cloud processes. Thus, the K_{DP} column is likely absent when the impulse event initially develops; however, it will be present later with heavily cold cloud processes, replacing the Z_{DR} column to indicate updrafts within the reflectivity core when obvious graupels and hailstones are occurring. In addition, the 6-min or 12-min warning time in our results is likely due to the temporal resolution (6 minutes) of the radar data used in this study; high temporal resolution observations of phased-array radar may decrease the uncertainty.

Notably, the threshold value for identifying the Z_{DR} column (≥1.5 dB) in this study is different from that (≥1 dB) in previous studies (e.g., Sharma et al., 2024). Although this threshold value is selected according to the retrieved raindrop diameter, which should exceed 2 mm within the Z_{DR} column during the initial phase of a storm (Kumjian, et al., 2014), the results for quantifying the Z_{DR} column (i.e., height and volume) may be different from those of previous studies that used the 1 dB threshold (e.g., Sharma et al., 2024). However, this study focuses on the trend of the Z_{DR} column height or volume; thus, the differences resulting from different thresholds are relieved. The threshold value for identifying the K_{DP} column (≥1°/km) in this study is consistent with that used by Sharma et al. (2024). However, the different estimation methods for K_{DP} may introduce additional uncertainty, as discussed in Sharma et al. (2021).

Moreover, the height of the melting layer (0°C), which is derived from environmental soundings, is assumed to be constant for identifying and quantifying the Z_{DR}/ K_{DP} column; however, the melting level is frequently elevated within updraft cores because of latent heat release, which is influenced by the strength of updrafts relative to the ambient environment. Thus, a more accurate melting level will decrease the biased estimations of the "3D mapping columns" method in this study. In addition, although our results support some observations in Bruning et al. (2024) and seem to explain the remaining question in Sharma et al. (2024) and Sharma et al. (2021), whether there are differences between such small, isolated, subtropical thunderstorms and other thunderstorm types (i.e., mesoscale convective systems, supercells, or tropical thunderstorms) should be further analysed to reduce the probability of uncertainty in our study. Finally, although the results retrieved from hydrometeor identification and microphysical fingerprint methods are reasonable and obey theoretical cognition in this study, the potentially biased estimates may result from isothermal height and the status of the hydrometeor (e.g., canting angle)."

5) *423-6: These correlation coefficients do not seem different enough to allow the authors to say one is best, especially on the basis of a single case study. Values all >0.8 are quite high for each of these variables.*

Reply: Thank you for your comment. We absolutely agree with your suggestion. We have corrected all of these descriptions. In addition, more cases have been added to strengthen our results. Please see in mms (Lines 624−639; Lines 762−808). The related content has already been presented in the last reply.

6) *449: After studying the lead times and identifying and emphasizing a 6 min lead time in their results section, the authors return to quoting the 36 min lead time in their conclusions, which does not seem supported by the detailed analysis the authors undertook. Of course, the 36 min lead is there in the data, but it is not well-correlated to lightning. Many moderately vigorous storms will produce a small Zdr column without going on to produce lightning. Likewise on 476-477, I would be reluctant to forecast lightning on the basis of a 36 min lead - that cell is simply one to keep an eye on for future lightning.*

Reply: Yes. This description is unreasonable; we have deleted the related content and corrected this opinion on the basis of the statistical results. Please see in mms (Lines 624−639; Lines 762−808). The related content has already been presented in your 4th comment.

7) *Fig. 12: the authors indicate that no Kdp column was present in their data, but do not show Kdp in Fig. 6. I would like to see further data on this, as it may explain the relatively fewer cases in Bruning et al. (2024) that had Zdr columns and lightning but did not have a Kdp column.*

Reply: Yes, more information about the K_{DP} column is helpful for comparing the results of this study with those of other studies (e.g., Bruning et al., 2024). Now, we have presented more information about the K_{DP} column in context (Figure 5). Our results indeed support the observations of Bruning et al. (2024). Please see in mms (Lines 586−597).

Lines 586−597 in mms:

"The variations in the Z_{DR}/K_{DP} column height and volume with the life cycle of the remaining fourteen cases are displayed in Figures 10 (cases #2 to #8) and 11 (cases #9 to #15), as are the variations in the percentages of hydrometeor types and microphysical fingerprints. The grid is assigned to specific particle type based on the results of hydrometeor identification, and the percentage of grids for each hydrometeor type is calculated. Similarly, this process is applied to determine the percentage of grids associated with microphysical fingerprints. Each of them has a Z_{DR} column (Figure 10 a1-a7, Figure 11 a1-a7); however, the absence of a K_{DP} column is possible (Figures 10 b1-b7, Figures 11 b1-b7). The results of our study support the observations of Bruning et al. (2024), namely, lightning is not observed in the absence of a Z_{DR} column, and a K_{DP} column is not observed without a Z_{DR} column. Moreover, the highest lightning flash frequency (in case #11) is observed when the Z_{DR} and K_{DP} columns are co-present, which is consistent with the observations of Bruning et al. (2024). In addition, our results suggest that the signal in the K_{DP} column within these small, isolated, subtropical thunderstorms over South China is not as steady as that in the Z_{DR} column during the life cycle."

Minor comments

1) *31: The grammar implies lightning flashes can be detected with polarimetric structures; this is not directly possible. The polarimetric signatures are proxies for lightning with some associated error. Please rephrase.*

Reply: Corrected. Please see in mms (Lines 31−32).

Lines 31−32 in mms:

"Polarimetric structures detected by radar can characterize cloud microphysics and dynamics."

2) *37: "establish" — this study is not the first to use this method, as many of the authors' citations show. "Build on" or "improve" would be a better choice, since "establish" implies that the authors have made a pioneering advancement. There are some thoughtful adjustments to past methods here, but they are incremental refinements.*

Reply: Corrected. "establish" → "improve". Please see in mms (Line 38).

3) *124: "later" - do the authors mean a time scale immediately following the Zdr column (~5 min) or subsequent updraft pulses in a multicellular sequence (~20-30 min per cell)?*

Reply: We have corrected this confusing sentence. Please see in mms (Lines 136−138).

Lines 136−138 in mms:

"Thus, the formation of a K_{DP} column is tied to cold cloud microphysics, which usually lag behind the appearance of the Z_{DR} column."

4) *125: "attempted to determine the constraints of" should be "attempted to constrain"*

Reply: The draft has been revised as suggested. Please see in mms (Line 139).

5) *140-141: "therefore the correlation coefficient … was not high." What does "therefore" mean here? It typically indicates that a conclusion has been reached, so the facts supporting the conclusion need to be stated first. They seem to be in the sentence following "therefore".*

Reply: Yes, this word is inappropriate here. We have revised the related content. Please see in mms (Lines 150−167).

Lines 150−167 in mms:

"Sharma et al. (2024) conducted a study on the basis of hypotheses, namely, that the deeper and wider the Z_{DR} and K_{DP} columns were in cases with robust and wide updrafts (e.g., Homeyer and Kumjian, 2015; Snyder, et al., 2017), the more an increase in the volumes of the Z_{DR} and K_{DP} columns would correspond to an increase the mixed-phase ice mass flux, resulting in an increase in the total flash rate; the correlation coefficient (−0.47~0.37 for the Z_{DR} column; 0.54~0.74 for the K_{DP} column) between Z_{DR} or K_{DP} columns and lightning activity was not as high as the microphysical parameters explored in previous studies (e.g., Carey and Rutledge 2000). Moreover, the results seem to be inconsistent with those of Sharma et al. (2021), who reported that the variability in flash rates is best explained by fluctuations in the Z_{DR} column volume, with a high correlation coefficient value (0.72). One possible explanation is that the effect of the time lag may decrease this correlation coefficient. As reported by Carey and Rutledge (2000), they obtained a very high one-lag (7 minutes) correlation coefficient (ρ = 0.9) between the graupel mass within the mixed-phase zone and the CG lightning flash rate, suggesting that the directly related microphysics with noninductive charging have a greater correlation coefficient with lightning activity. Another possible way is that the interactions of the Z_{DR}/K_{DP} column with dynamics and microphysics are uncertain, which affects the results under the current hypotheses. This is also emphasized in Sharma et al. (2021) and raised as a retained question in the appendix. Thus, further exploration is needed."

6) *175-181: what Kdp calculation method was used? Kdp is a very noisy measurement, and so is very sensitive to algorithm design and configuration choices.*

Reply: Yes, the K_{DP} calculation method must be displayed. We have added this information. Please see in mms (Lines 214−218).

Lines 214−218 in mms:

"We utilized two methods to smooth the differential phase Φ_{DP}, namely, "lightly filtering" (2-km) and "heavily filtering" (6-km), as in Park et al. (2009). Two estimates of K_{DP} were subsequently obtained from a slope of a least squares fit of the filtered Φ_{DP}; a lightly filtered K_{DP} was subsequently used in the case of horizontal reflectivity > 40 dBZ, and a heavily filtered K_{DP} was selected otherwise (Ryzhkov and Zrnić, 1996)."

Park, H. S., Ryzhkov, A. V., Zrnić, D. S., and Kim, K.: The Hydrometeor Classification Algorithm for the Polarimetric WSR-88D: Description and Application to an MCS. Weather and Forecasting, 24: 730-748, https://doi.org/10.1175/2008WAF2222205.1, 2009.

Ryzhkov, A., and Zrnić, D.: Assessment of Rainfall Measurement That Uses Specific Differential Phase. Journal of Applied Meteorology and Climatology, 35: 2080-2090, https://doi.org/10.1175/1520-0450(1996)035<2080:AORMTU>2.0.CO;2, 1996.

7) 220: here and throughout the paper, melting level is preferable, since melting always begins at this level for any hydrometeor but freezing might not.

Reply: Thanks for the suggestion. The draft has been revised as suggested.

8) 221: What are other parameters (CAPE, etc.) of this sounding? They would be helpful in placing this storm in the context of other environments globally.

Reply: The CAPE values of these thudnerstorms are provided in Table 1.

9) 227: "automatically" should be "automatic"

Reply: Corrected.

10) 271: A new sentence should start after "(Figure 2e,f)".

Reply: Corrected.

11) 281: "resulted by" should be "resulting from"

Reply: Corrected.

12) 447: I suggest dropping "inappropriate". Any algorithm choice requires some judgment, and reflectivity thresholds have a sound physical basis and are in wide use. Of course, using fewer or improved variables and thresholds is also good, and in that way the authors have made a nice methodological contribution, but "inappropriate" is unnecessarily harsh.

Reply: Thanks very much for this suggestion. The draft has been revised as suggested. Please see in mms (Line 694).

Line 694 in mms:

"…avoiding the utilization threshold value of Z_H."