Responses to Reviewers' Comments

We sincerely appreciate the time and effort devoted by the anonymous reviewers and editor. We thank the reviewers for these constructive and professional comments. And 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:

This technical note provides valuable information on the characteristics of thunderstorms and non-thunderstorms cells based on polarimetric radar and lightning observations over South China.

The manuscript is well written, the methodology is clear, and the results are correct and valuable. They provide quantitative data on the conditions that lead to the occurrence of lightning, and can be helpful to improve lightning forecasting systems. I have some minor concerns before the technical note can be published:

- General: The thunderstorms and non-thunderstorms cell analysed in this study have already been analysed by the authors in two previously published studies, as acknowledged here. In particular, the ZH, the ZDR, the content of graupel and the graupel shape has already been analysed in Zhao et al. (2022, GRL). In this study, the ice microphysics associated with graupel is studied by comparing different thunderstorms and non-thunderstorm cells instead of by only studying the evolution of particular cells. This is novel. However, I would appreciate a more detailed description of the novelty of this work with respect to the two previous studies.

In addition, I would appreciate more information about the analysis of these thunderstorms from the two previously published papers. For example, while reading this technical note I wondered if the content of aerosols could pay a role in this analysis, as they are not mentioned here. Later, I noted that the content of aerosols in these thunderstorms was analysed in Zhao et al. (2022, GRL). Mentioning this in this paper could help the reader understanding the analysed thunderstorms.

Reply: We sincerely appreciate for your evaluation and insightful comment. We have added more description of the novelty of this work with respect to the two previous studies (Zhao et al., 2021a, 2022). Moreover, more information about the analysis of these thunderstorms from the two previously published papers is provided in the revised manuscript as suggested. Please see in mms (Lines 137−138; 150−175).

The information about the content of aerosols has been added to the revised manuscript. Please see mms (Lines 278−284).

This study is substantially different from the two previous studies (i.e., Zhao et al., 2021a, 2022) noted above although they are used the same dataset.

In Zhao et al. (2021a), we first presented the dataset to the public, which included observations of 57 (39) isolated thunderstorms (non-thunderstorms) during 2016/2017 over South China from the S-band polarimetric radar and three independent lightning location systems. The objective of this study was to investigate the turbulence characteristics of thunderstorms before the first flash in comparison to those of non-thunderstorms. We utilized this dataset and derived the eddy dissipation rate from the Doppler velocity to evaluate the role of turbulence characteristics in producing the first lightning flash in the cloud. The results indicated that the eddy dissipation rate of non-thunderstorms was clearly lower than that of thunderstorms.

At the peer review stage of Zhao et al. (2021a), an anonymous reviewer noted the turbulence difference in the first radar volume scan between thunderstorms and non-thunderstorms (i.e., a stronger eddy dissipation rate in non-thunderstorms). However, we also propose the following question: what was the difference between thunderstorms and non-thunderstorms in the first radar volume scan, and did it affect cloud development?

Thus, we utilized this dataset to evaluate the polarimetric radar parameters of the first radar echoes (the first radar volume scan when clouds occurred and were detected by radar) in Zhao et al. (2022). We discovered that the polarimetric radar parameters of the first radar echoes clearly differed between thunderstorms and non-thunderstorms; specifically, a greater echo intensity was present in non-thunderstorms below the −10°C isotherm height. In addition, the ERA-Interim reanalysis data and surface aerosol concentration observations were used to determine the reason. Finally, the graupel and rainwater contents (the value of the 90% quantile at different altitudes during different development stages of storms) were compared, and the results suggested that the difference in the first radar echoes between thunderstorms and non-thunderstorms may play an important role in subsequent cloud development.

In Zhao et al. (2022), the difference in polarimetric radar parameters in the first radar echoes between thunderstorms and non-thunderstorms was determined. In addition, the graupel content was shown during cloud development to suggest convection invigoration according to latent heat release.

However, the error in graupel content estimation is uncertain, and the efficiency of the microphysical process (i.e., riming) associated with graupel is unknown. Naturally, we want to seek a method to quantify differences in graupel magnitude and riming efficiency, while minimizing the error as much as possible.

Therefore, we accomplish this goal by comparing the ice microphysics associated with graupel between isolated thunderstorms and non-thunderstorms during the warm season over southern China and quantifying differences in graupel magnitude and shape (implying riming efficiency) in radar parameters. The radar sample volume, which corresponds to graupel identification, is used to indicate the graupel magnitude instead of the derived graupel content, as in Carey and Rutledge (2000) and Zhao et al. (2022). The variety of Z_{DR} shapes is used to determine the riming efficiency. In addition, the coalescence-freezing mechanism, which is a generally accepted mechanism for graupel formation in warm-based clouds, is explored for the production of the first lightning flash. The results (i.e., the variety of Z_{DR} shapes) could be compared with those in cold-based clouds (Li et al., 2018).

Moreover, in the revised manuscript, the observational characteristics of the first lightning flashes are shown via 3D lightning mapping from LFEDA. The possible microphysics associated with the source initiation and channel of the first lightning flashes are discussed.

It should be noted that the graupel shape is first time analysed in this study, we quantified differences of graupel shape (the change of Z_{DR}, implying the riming efficiency) between isolated thunderstorms and non-thunderstorms during the different stages of cloud development.

Therefore, the goal and method in this manuscript is substantially different from the two papers noted above, although they are based on the same dataset.

Lines 137−138 in mms:

“Furthermore, we discussed the possible microphysics associated with the source initiation and channel of the first lightning flash via 3D lightning mapping.”

Lines 150−175 in mms:

“The dataset used in this study was the same as that used in Zhao et al. (2021a, 2022). In Zhao et al. (2021a), the dataset was first shown to the public, who obtained observations of 57 (39) isolated thunderstorms (non-thunderstorms) that occurred over South China in the warm season (from late May to early September) of 2016 and 2017 from the S-band polarimetric radar and three independent lightning location systems. The role of turbulence characteristics in producing the first lightning flashes was evaluated on the basis of the dataset, and the results indicated that the eddy dissipation rate of non-thunderstorms was clearly lower than that of thunderstorms (Zhao et al., 2021a). Moreover, the polarimetric radar parameters of the first radar echoes (the first radar volume scan when clouds are detected by radar) were compared to determine the early difference between thunderstorms and non-thunderstorms on the basis of this dataset (Zhao et al., 2022). The greater echo intensity occurred in non-thunderstorms below the −10°C isotherm height, and the cause for this feature and effect on subsequent cloud development were simply discussed by integrating comprehensive observations (e.g., the ERA-Interim reanalysis data, surface aerosol concentration, and graupel and rainwater contents derived from radar observations).

The error in the graupel content estimated in Zhao et al. (2022) is uncertain, and the efficiency of the microphysical process (i.e., riming) associated with graupel is unknown; this represents a gap in understanding regarding the role of graupel in the first lightning flash occurrence based on field observations. Naturally, we aimed to identify a method to quantify differences in graupel magnitude and riming efficiency in this study to minimize the error as much as possible. The radar sample volume, which corresponds to graupel identification, was used to indicate the graupel magnitude instead of the derived graupel content, as in Carey and Rutledge (2000) and Zhao et al. (2022). The variety of Z_{DR} shapes was used to determine the riming efficiency. Thus, the goal and method of this study were substantially different from those of the two previous studies noted above, although they are based on the same dataset."

Lines 278−284 in mms:

"In addition, the average 1-hourly surface concentration observations of particulate matter ($PM_{2.5/10}$) were provided by three ground sites (Figure 1, white diamonds) within the analysed area. The $PM_{2.5/10}$ concentration data suggest that the environment prior to these isolated thunderstorms or non-thunderstorms was clean and that the difference in the environmental aerosol concentration between thunderstorms and non-thunderstorms may be small (the mean values of $PM_{2.5/10}$ concentrations prior to thunderstorms and non-thunderstorms were 22.9/42 μg m^{-3} and 20.5/38.8 μg m^{-3}, respectively)."

Zhao, C., Zheng, D., Zhang, Y. J., Liu, X., Zhang, Y., Yao, W., Zhang, W.: Turbulence Characteristics before the Occurrence of the First Flash in Thunderstorms and Non-Thunderstorms, *Geophysical Research Letters*, 48, e2021GL094821, 2021a.

Zhao, C., Zhang, Y. J., Zheng, D., Liu, X., Zhang, Y., Fan, X., Yao, W., Zhang, W.: Using polarimetric radar observations to characterize first echoes of thunderstorms and nonthunderstorms: A comparative study, *Journal of Geophysical Research: Atmospheres*, 127, e2022JD036671, 2022.

- Abstract: I think authors should define Z_{DR}.

Reply: Corrected. The Z_{DR} is defined. Please see mms (Line 39).

Line 39 in mms:

"…with a mean differential reflectivity (Z_{DR}) value of 0.3 dB…"

- Line 61: Mention in-cloud corona discharges when discussing the different types of lightning activity.

Reply: To avoid confusion, this sentence has been revised. Please see mms (Lines 67−69).

Lines 67−69 in mms:

"Moreover, natural lightning flashes are generally defined as intracloud lightning and cloud-to-ground lightning (Uman and Krider, 1989)."

- Lins 69-74: Aerosols play an important role in cloud electrification. Please mention.

Reply: The draft has been revised as suggested. Please see mms (Lines 75−81).

Lines 75−81 in mms:

"…noninductive charging (NIC) of two ice particles of different sizes during rebounding collisions in the presence of supercooled droplets, with the smaller ice particle being the ice crystal and the larger ice particle being the graupel; aerosol provides the cloud condensation nuclei and ice nuclei for hydrometeor formation, thus playing an important role in cloud electrification (Takahashi, 1978; Latham, 1981; Saunders et al., 1991; MacGorman and Rust, 1998; Carey and Rutledge, 2000; Rosenfeld et al., 2008; Zhang et al., 2009; Takahashi et al., 2017, 2019; Qie et al., 2021; Lyu et al., 2023)."

- Line 122: Plotting the analysed area could be helpful for the readers.

Reply: We have added the related plot as suggested. Figure 1 shows the analysed area and the locations of the detection systems.

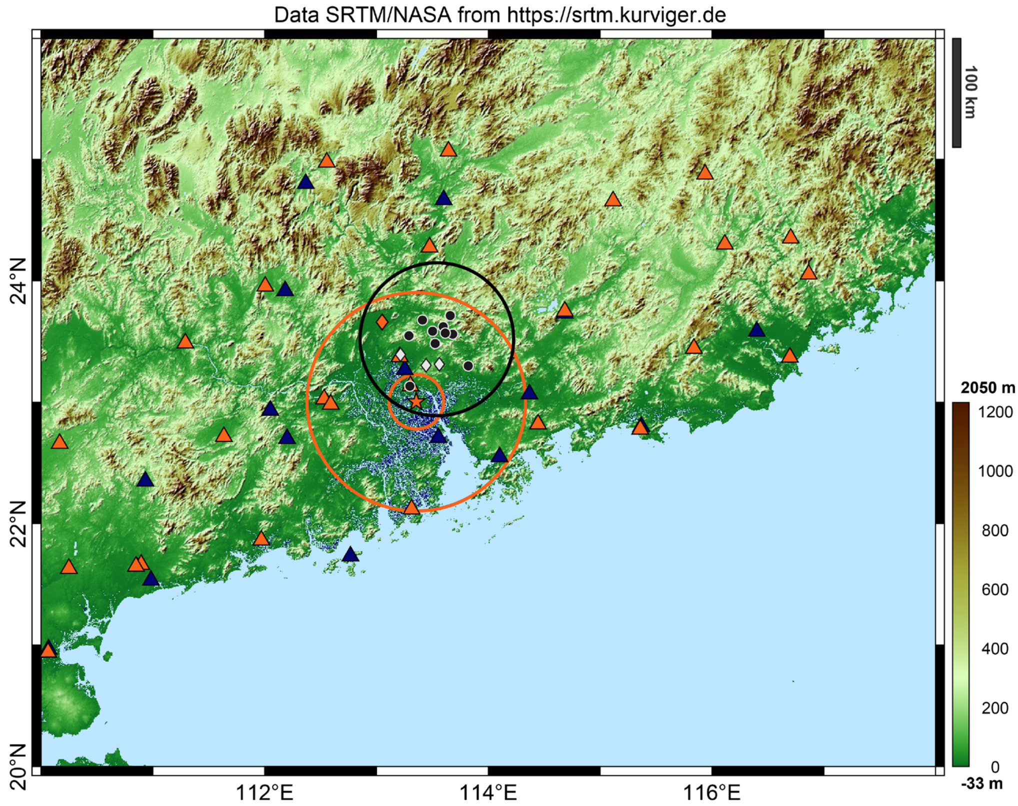

Figure 1. The locations of the detection systems and the analysed area. The orange star indicates the Guangzhou S-band polarimetric radar (GZ radar); the orange circles represent distances from the GZ radar site of 25 and 100 km. The black dots indicate the 10 sensors of the Low-Frequency E-field Detection array (LFEDA); the black circle indicates the distance from the centre of the LFEDA network to 70 km. The blue triangles indicate the 16 sensors of the Earth Networks Lightning Location System (ENLLS), and the orange triangles indicate the 27 sensors of the Guangdong Lightning Location System (GDLLS). The white diamonds indicate the three ground sites of aerosol concentration measurements. The orange diamond indicates the Qingyuan meteorological observatory. The analysed area is restricted to the regions of overlapping coverage between the GZ radar radius of 25−100 km and the LFEDA station network centre radius of 70 km.

- Line 142: Please provide the coverage of LFEDA.

Reply: Yes, we have provided the coverage of LFEDA as suggested. Figure 1 shows the analysed area and the locations of the detection systems.

- Line 153: This has already been said before.

Reply: Corrected.

- Line 190: 98% of total FLF are IC. Could you compare this percentage with other studies? I do not say that the authors have to do this, but this could be interesting.

Reply: Thank you for the suggestion. We agree that the comparison could be interesting.

We have added the related content of the lightning observations (Figure 2) and compared the results with those of a previous study (i.e., Mattos et al., 2017). Please see mms (Lines 258−277).

The results of the first IC and/or CG flashes from the three lightning location systems are shown in Figure 2a. The majority of the first flashes are IC flashes (56/57, ~98%), and only one is a CG flash (1/57). Additionally, the majority of the first flashes (~91%) are determined by LFEDA because of the superior detection efficiency and accuracy of LFEDA for lightning flashes within the analysed area.

The elapsed time between the first radar volume scan and the first IC or CG flash (indicating by the first IC or CG return stroke) is shown in Figure 2b. The results show that the average elapsed time between the first radar volume scan and the first IC flash was approximately 19 minutes, and the first CG flash was approximately 32 minutes (Figure 2b). A recent study (Mattos et al., 2017) also revealed that in ~98% of thunderstorms, an IC flash preceded the first CG flash, and the IC flashes occurred approximately 29 minutes after the first radar echo (any reflectivity value (any value above the local noise floor of the radar) at any height), CG flashes were most frequently delayed by approximately 36 minutes. The definition of the first radar echo may be the possible reason that the first flashes occurring after the first radar echo in Mattos et al. (2017) occurred later than those in our study.

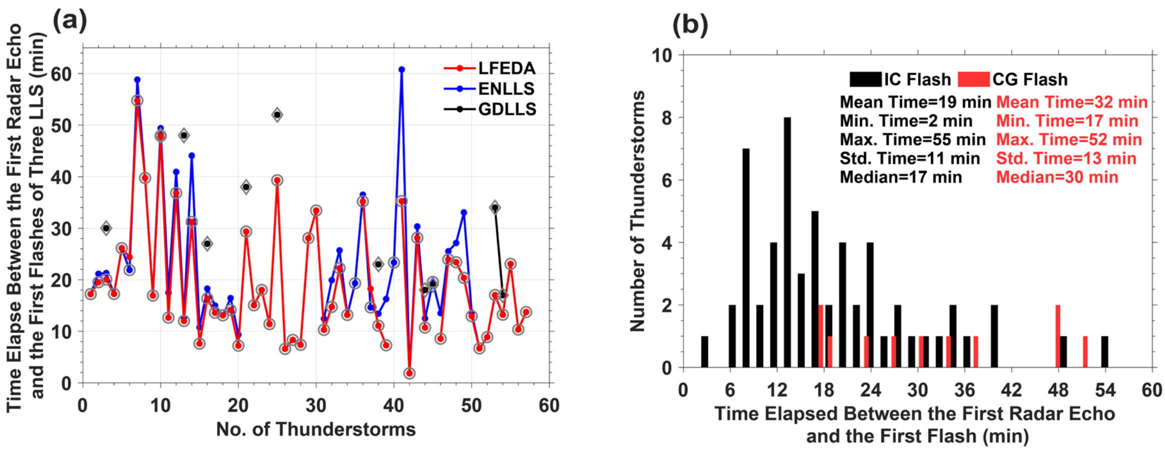

Figure 2. Lightning observations. Elapsed time between the first radar volume scan and (a) the first flashes of three lightning location systems, LFEDA (red line), ENLLS (blue line), and GDLLS (black line), where the grey circles indicate the first IC flashes, the grey diamonds indicate the first CG flashes, and (b) the elapsed time between the first radar volume scan and the first flashes of thunderstorms, the first IC flashes (black columns), and the first CG flashes (red columns).

- Results: I miss an analysis of the significance of the differences between thunderstorms and non-thunderstorms cells, which was for example provided in Zhao et al. (2022, GRL).

Reply: We have added an analysis of the significance of the differences between thunderstorms and non-thunderstorms as suggested. Please see in mms (Lines 301−307; 348−365; 383−389; 481−484; 520−521; 556−562; 583−588).

- Figure 2: Why is the graupel volume larger in non-thunderstorm cells during the first stage? Could you provide an explanation?

Reply: We discovered that the polarimetric radar parameters of the first radar echoes clearly differed between thunderstorms and non-thunderstorms; specifically, the echo intensity was greater in non-thunderstorms below the −10°C isotherm height. Thus, a greater graupel volume in non-thunderstorm cells during the first stage is possible. However, how this phenomenon occurs is uncertain. We speculate that more warm precipitation growth in non-thunderstorms due to cyclic drop growth resulting from coalescence under weaker updrafts may promote greater drops formation (Kumjian et al., 2014; Mather et al., 1986; Stough et al., 2021). These larger drops are lifted above the 0°C isothermal height and freeze to graupel-sized particles via a coalescence-freezing mechanism (e.g., Bringi et al., 1997; Carey and Rutledge, 2000).

A related discussion has been added to the draft. Please see mms (Lines 357−362).

Lines 357−362 in mms:

"We proposed a mechanism for explaining the larger graupel volume in non-thunderstorms during the first stage of cloud development: more warm precipitation growth in non-thunderstorms due to cyclic drop growth resulting from coalescence under weaker updrafts may promote greater drop formation (Kumjian et al., 2014; Mather et al., 1986; Stough et al., 2021). These larger drops are lifted above the 0°C isothermal height and freeze to graupel-sized particles via a coalescence-freezing mechanism (e.g., Bringi et al., 1997; Carey and Rutledge, 2000)."

Bringi, V. N., Knupp, K., Detwiler, A., Liu, L., Caylor, I. J., and Black, R. A.: Evolution of a Florida Thunderstorm during the Convection and Precipitation/Electrification Experiment: The Case of 9 August 1991, *Monthly Weather Review*, 125, 2131–2160, doi: https://doi.org/10.1175/1520-0493(1997)125<2131:EOAFTD>2.0.CO;2,1997.

Carey, L. D., and Rutledge, S. A.: The Relationship between precipitation and lightning in tropical island convection: A C-Band polarimetric radar study, *Monthly Weather Review*, 128, 2687–2710, https://doi.org/10.1175/1520-0493(2000)128<2687:TRBPAL>2.0.CO;2, 2000.

Kumjian, M. R., Khain, A. P., Benmoshe, N., Ilotoviz, E., Ryzhkov, A. V., and Phillips, V. T. J.: The anatomy and physics of ZDR columns: Investigating a polarimetric radar signature with a spectral bin microphysical model, *Journal of Applied Meteorology and Climatology*, 53, 1820–1843, https://doi.org/10.1175/JAMC-D-13-0354.1, 2014.

Mather, G. K., Morrison, B. J., and Morgan, G. M.: A Preliminary Assessment of the Importance of Coalescence in Convective Clouds of the Eastern Transvaal, *Journal of Applied Meteorology and Climatology*, 25, 1780–1784, https://doi.org/10.1175/1520-0450(1986)025<1780:APAOTI>2.0.CO;2, 1986.

Stough, S. M., Carey, L. D., Schultz, C. J., and Cecil, D. J.: Examining conditions supporting the development of anomalous charge structures in supercell thunderstorms in the Southeastern United States, *Journal of Geophysical Research: Atmospheres*, 126, e2021JD034582, https://doi.org/10.1029/2021JD034582, 2021.

- Line 259: "...in this volume These characteristics..." -> "...in this volume. These characteristics..."

Reply: Corrected.