

The manuscript “Microphysical Characteristics of Super Typhoon Lekima (2019) and Its Impacts on Polarimetric Radar Remote Sensing of Precipitation” uses a case study of Typhoon Lekima to demonstrate a new technique for attenuation correction on Z and Z_{DR} . The method is interesting, but much more evidence needs to be presented. It is recommended the authors to include more dual polarization observational signatures to validate their hypothesis instead of theoretical calculation derived speculations. In addition, please revise the manuscript for grammar check.

Response: We sincerely thank the reviewer for the careful review of his manuscript. We have made extensive changes based on the reviewers’ comments: (i) We have included more polarimetric signatures (Figs. 12-17) mainly to describe the vertical evolutions of the falling solid particles. (ii) We also rechecked the grammar to ensure the quality of this manuscript is good.

1. Line 18, consider change “expected values” to “intrinsic values”.

Response: (i) We used “expected values” rather than “intrinsic values” to emphasize the differences between \hat{Z}_{DR} and Z_{DR}^C , the former is calculated through radar-measured Z_H^C and the latter is attenuation-corrected. Their deviation relates to the microphysical process that needed to be explained.

2. Line 19, what is Z_H^C means here? What is different between Z_H and Z_H^C ? The sentence “As a result ... overestimate precipitation” is confusing, please clarify.

Response: (i) Z_H means horizontal reflectivity, Z_H^C means attenuation-corrected horizontal reflectivity for discrimination. We introduce Z_H^M and Z_{DR}^M , which stands for measured Z_H and Z_{DR} (no correction), Z_H^C and Z_{DR}^C which stands for the corrected Z_H and Z_{DR} .

(ii) We have revised this part as “The twin-parameter radar rainfall estimates based on measured Z_H (Z_H^M) and Z_{DR} (Z_{DR}^M), and their corrected counterparts Z_H^C and Z_{DR}^C , i.e., $R(Z_H^M, Z_{DR}^M)$ and $R(Z_H^C, Z_{DR}^C)$, both tend to overestimate rainfall around the GWS of YDM, mainly ascribed to the unique microphysical process in which the breakup-dominated small-sized drops above transition to the coalescence-dominated large-sized drops falling near the surface.” (Lines 20-24). The abnormal overestimation $R(Z_H^C, Z_{DR}^C)$ is strange, but it indeed occurred and it related to an microphysical process.

3. Line 20-23, do you mean the rain rate R from calibrated Z_{DR} (ideally intrinsic Z_{DR}) and Z relationship outperforms the rest? Then is attenuation also part of the radar measurement that is needed here?

Response: (i) Yes. $R(Z_H^C, \hat{Z}_{DR})$ outperforms the rest according to E_{NMA} and E_{RMS} at least in this case. (ii) The attenuation on Z is necessary, therefore, we used Z_H^C which means attenuation-corrected Z_H .

4. Line 27, for flood prediction do you mean Quantitative Precipitation Forecasts (QPF)? QPE has no forecast capabilities. In addition, one of the most important QPE operational platforms is missing here, consider adding this reference:

Zhang, J., Howard, K., Langston, C., Kaney, B., Qi, Y., Tang, L., Grams, H., Wang, Y., Cocks, S., Martinaitis, S., Arthur, A., Cooper, K., Brogden, J., & Kitzmiller, D. (2016). Multi-Radar MultiSensor (MRMS) Quantitative Precipitation Estimation: Initial Operating Capabilities, Bulletin of the American Meteorological Society, 97(4), 621-638. Retrieved Jul 23, 2022, from <https://journals.ametsoc.org/view/journals/bams/97/4/bams-d-14-00174.1.xml>

Response: (i) “for flood prediction” does not mean Quantitative Precipitation Forecasts (QPF). The radar rainfall estimates field needs to be inputted into some hydrological models or treated as an initial radar rainfall field of some extrapolate algorithms for the QPF. So radar QPE indirectly serves for flood prediction. (ii) Thanks for the reminder, Zhang et al., 2016 was indeed missed during the revision process, and we have added it.

5. Line 60, debris blockage (tree leaves, insects, and etc) can also contribute to the surface rain gauge errors.

Response: Thanks for the suggestions, and we have added these factors.

6. Line 108, please spell out the full names for the two city locations. To emphasize the importance of this area, consider adding the population density as the background for Fig 1b.

Response: Thanks. (i) Wenzhou and Taizhou were mentioned for the first time in Lines 79 and 90 (the original manuscript), so we wrote their abbreviations here. (ii) we have added the description of population density into this part.

7. Line 111, “For this aim” change to either “With this aim” or “On this aim”.

Response: Changed as suggested!

8. Line 112, “WZ-SPOL radar is deployed on a mountain”, what is the elevation of this mountain here, I only see almost flat surface in Fig 1a. Also, what is the VCP used here? Any negative elevation scans? I’m asking this because radar on high land could loss significant coverage at low levels.

Response: Thanks for your constructive question, and it enlightens our understanding of the microphysical process around the GWS of YDM.

(i) The height of this radar is 735 m, on a little hill, and the star masks the DEM of the mountain, and we had removed the star.

(ii) VCP 21 is used here with the lowest elevation angle of 0.5° (described in Section 2.2). No negative elevation angles were used; if the negative elevation angles were used, the clutter (i.e., ground or sea clutters) and blockage (i.e., by YDM and KCM) will significantly degrade radar measurements (i.e., Z_H , Z_{DR} , K_{DP} , ρ_{HV}). It is not high enough to avoid such contaminations from these two issues).

9. Line 126-128, is Fig 1b showing all the surface rain gauges or the ones without any interruptions during this event? It is better to show only the rain gauges that will be used in this paper or at least mark the working ones with more highlighted color.

Response: Thanks. The stations marked are all working ones. “The ones without any interruptions” means interruptions in an hour. If gauge rainfall measurements of one station temporally interrupt in one hour, the other measurements without interruption (in another hour) are still used. We have revised this sentence for clarity.

10. Line 129, where is this ratio of 10 comes from? Please add reference if there is any or explain your reasoning.

Response: (i) We first saw this ratio in Marzen 2004: two ratios, 5 and 10, are suggested, but 10 or (or less 0.1 than for intercomparison) is used to remove the strongly suspected gauge rainfall recordings when gauge rainfall recording exceeds 1 mm. It means that if the rain gauge has measured 1 mm (in an hour), radar rainfall needs to exceed 10 mm (significant rainfall) to remove this gauge measurement. In this tropical rain situation (evaporation can be negligible), most gauge measurements will be kept because this ratio is hard to exceed.

Marzen, J. L., 2004: Development of a Florida high-resolution multisensor precipitation dataset for 1996-2001—Quality control and verification. MS thesis, Department of Meteorology, The Florida State University, 86 pp.

11. Line 132-133, “which made it the strongest typhoon landing China in 2019 and the third strongest landing typhoon in history of Zhejiang since 1949”, this is repetitive, consider deleting.

Response: Changed as suggested!

12. Line 135, please clarify 100 mm precipitation was accumulated during how long of a period.

Response: Thanks. Lekima affected mainland China for 44 hours; this 100 mm precipitation refers to the area with rainfall exceeding 100 mm during this period. We add this information to this sentence (Lines 96-97).

13. Line 140, change “or” to “and”.

Response: Changed as suggested!

14. Line 187-188. Both theoretical analysis and observation prove that the intrinsic Z_{DR} of light rain is between 0.25-0.35dB. Usually, even using light rain as a natural calibrator with intrinsic average Z_{DR} of 0.25 dB for $Z = 20 - 22$ dBZ may not be sufficiently accurate, see the figure below, even between 20-22 dBZ, the variability of Z_{DR} is quite large. Since this is a typhoon case, consider using dry aggregated snow technique above the melting layer for calibration purpose, either QVP or RDQVP method will do the trick.

Response: Thanks for your suggestion.

(i) The calibration of Z_{DR} of light rain is usually carried in zenith mode and the falling raindrops tend to exhibit $Z_{DR} \approx 0\text{dB}$ in this situation. Still, Z_{DR} bias recovers after long-term consecutive scanning. So additional Z_{DR} bias correction is necessary.

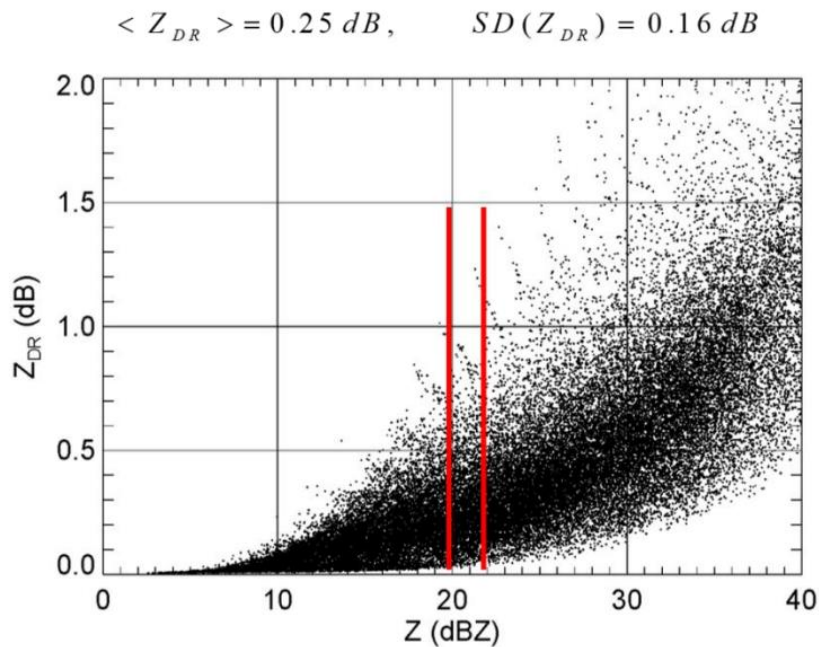
(ii) Z_{DR} of the dry aggregated snow is efficient if one volume gate is fully filled with aggregated snow; $Z_{DR} \approx 0\text{dB}$ for aggregates is an important basis for this method. But it is too over-confident, and it has its own flaws; several fundamental issues of QVP need to be demonstrated here:

(a): the shapes of solid particles above the melting layer are more complex than that of raindrops; dry aggregated snow is not the only form of solid particles. If you use a hydrometeor identification in advance, you will find that any identification algorithm requires that Z_{DR} is well calibrated. Therefore, a potential deadlock: hydrometeor identification requires that Z_{DR} is well calibrated, but Z_{DR} calibration needs aggregated snow to be identified first.

(b) NUBF (non-uniform beam filling) effects can be significant on high elevations for QVP, which present little Z_H^M but large Z_{DR}^M at the far side of radial profile (Z_{DR}^M may be larger than \hat{Z}_{DR}). Positive Z_{DR} bias is anticipated in this situation, which will misguide the Z_{DR} bias.

(c) Wet radome effects may only affect the radial directions with strong horizontal winds (rain pours on one side of the radar radome and flows downward). Z_{DR} bias on QVP (due to average) might be not significant and cannot represent the Z_{DR} bias on the low elevation angles.

(iii) Since the Z_{DR} calibration technique is questioned, some background considerations have to be further described here. It is enlightened by Bringi et al.2001 that all Z_{DR} at the far side of one radial profile is expected to approximate 0 dB if its “intrinsic” $Z_H < 20\text{dBZ}$ (it usually refers to Z_H^C). Accordingly, Z_{DR}^C on one radial profile should approximate to their \hat{Z}_{DR} not only in the rainstorm area ($Z_H^C > 20\text{dBZ}$), but also at the far side of one radial profile where \hat{Z}_{DR} is close to 0dB; \hat{Z}_{DR} will not become very large conditioned by $Z_H^C < 20\text{dBZ}$. Appropriate Z_{DR} bias adjustment effectively helps in this Z_{DR} approximation along the whole range profile.



15. Line 203-205, between 0000 UTC, 09 August 2019 and 0000 UTC 11 August 2019 (looks like you are missing a few hours, Fig 4 stops at 1600 UTC 10 August), I don't see maximum hourly wind mostly over 20 m/s. In fact, most stations wind speed is less than 20 m/s, except around 1600 UTC 09 August

Response: Thanks, this part has been distorted during the revision process before submitting this paper. We have revised this sentence and “Nearly all” is removed. Now it reads “These measurements were variously affected by the strong winds, with the hourly maximum wind speed exceeding $20 \text{ m}\cdot\text{s}^{-1}$, as depicted in Fig. 4”. Lines 225-226.

16. Sec 3.1.1. More explanation is needed here. Especially for equation (5). Is $R(t)$ means the maximum rain fall rate per min for each rain gauge or a period of time? How is C_t determined? It seems C_t is a constant throughout this event but different at each locations. And in all, where is this equation comes from?

Response: Thanks for your question. R_T and C_T have no additional special physical meanings. They just serve for the convenient comparison of different rainfall timeseries.

(i) No. R_T does not mean the maximum rain fall rate per min for each rain gauge or a period of time. It is a hourly rainfall threshold, which is (manually) set a little larger (to avoid the overlap with the other timeseries) than the maximum DSD-derived hourly rainfall (after mitigating the wind effects) during the precipitation period of each station.

(ii) C_T is not constant, and it is (manually) set for each station, and for the convenient comparison with other rainfall timeseries in one figure. For example, C_T of YH and WL are both extremely large (800 and 500), but they are relatively smaller at the other stations.

(iii) R_T and C_T are decided both manually, we designed this equation and R_T and C_T serve for organizing DSD-derived rainfall without any QC and DSD-derived rainfall after QC in the same Figure. Because the former (in the following Fig. 1) is far larger (\gg) than the latter.

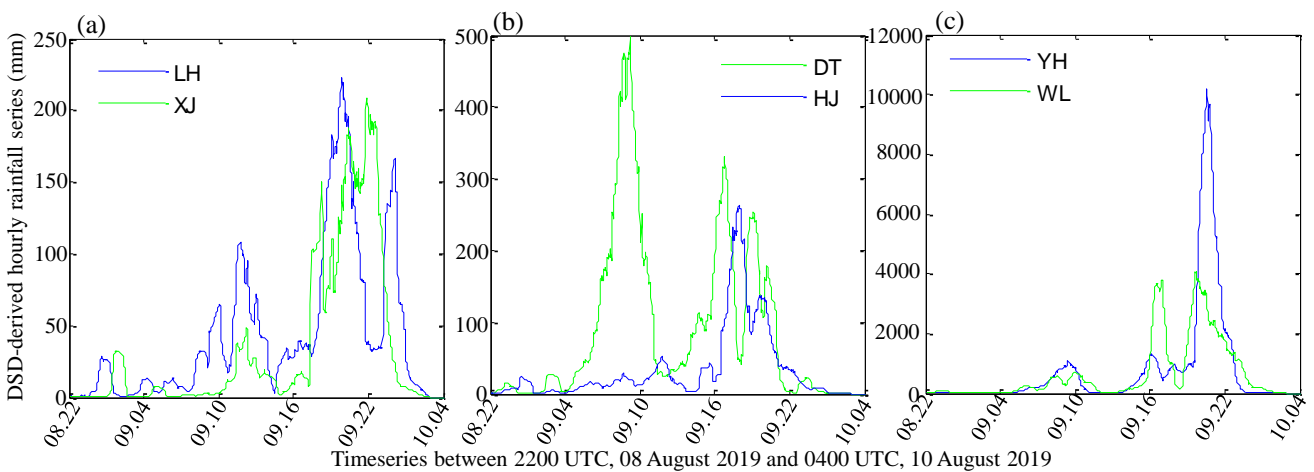


Fig. 1. DSD-derive rainfall timeseries before QC processing.

17. Line 260-270, please provide some supplementary figures like RHIs (Z , Z_{DR} , K_{DP} , and ρ_{HV} preferably) to demonstrate the existence and differences of hail/graupel between WL/YH/DT and XJ/HJ/LH stations.

Response: Thanks sincerely for your constructive suggestions, and they indeed enlighten us to improve the quality of the paper. Considering the advantages of VPR, RHI and CAPPI, the combined utilization of vertical polarimetric radar timeseries upon the stations and the surface DSD-simulated counterparts may better interpret what had occurred during the landfall of Lekema. Therefore, we have added six vertical radar measurements (Z_H , Z_{DR} , K_{DP} , and ρ_{HV} in Figs.12-17) to detail the polarimetric signatures of falling solid particles, and a new part is organized as Section 3.2.1.

18. Line 312-314, please provide some supplementary CAPPI figures for the serious underestimation of Z_{DR} with larger Z near the surface. If this is simply because of size sorting near the eyewall, then it is not an issue, but how it should be. See fig 9 in Hu et al., 2020 and fig 3 in Homeyer et al., 2021.

In addition, based on Fig 11, the distance between typhoon's eyewall and half of its strongest precipitation core looks quite far away from the S-band radar here. Please also include the lowest scan 0.5 degree altitude from sea level with increasing distance line plot in the supplementary figures.

Hu, J., Rosenfeld, D., Ryzhkov, A., & Zhang, P. (2020). Synergetic Use of the WSR-88D Radars, GOES-R Satellites, and Lightning Networks to Study Microphysical Characteristics of Hurricanes, *Journal of Applied Meteorology and Climatology*, 59(6), 1051-1068. Retrieved Jul 23, 2022, from <https://journals.ametsoc.org/view/journals/apme/59/6/JAMC-D-19-0122.1.xml>

Homeyer, C. R., Fierro, A. O., Schenkel, B. A., Didlake, A. C., Jr., McFarquhar, G. M., Hu, J., Ryzhkov, A. V., Basara, J. B., Murphy, A. M., & Zawislak, J. (2021). Polarimetric Signatures in Landfalling Tropical Cyclones, *Monthly Weather Review*, 149(1), 131-154. Retrieved Jul 23, 2022, from <https://journals.ametsoc.org/view/journals/mwre/149/1/mwr-d-20-0111.1.xml>

Response: Thanks, and we have read the figures in your recommended papers.

(i) CAPPI is constructed by interpolating radar measurements from different elevation angles (not only the lowest elevation angle will be utilized, more uncertain). Its coverage is limited at lower altitudes and its capability to represent the Z_H and Z_{DR} near the surface is limited. Most pixels in Fig.11 come from the lowest elevation angles of 0.5° may be better, radar measurements from the second elevation angle of 1.5° only occupies the limited GC-masked pixels (as depicted in Fig.3b).

(ii) HSS only partly accounts for the location/position inconsistency of large values of Z_H , Z_{DR} and K_{DP} , but it cannot account for the large deviation between Z_{DR}^C and \hat{Z}_{DR} when the large values of Z_H , Z_{DR} and K_{DP} coincide. The overwhelming breakup over coalescence account for this phenomenon. Resultantly, more small-sized raindrops for a given Z_H^C but their intrinsic Z_{DR} is relatively smaller due to dominant breakup than dominant coalescence.

(iii) We added the lowest scan 0.5° altitude from sea level with an increasing distance line plot as Fig. 2c, adding the distance and altitude differences of each meteorological station (Fig. 2c).

19. Line 324-336, please provide some supplementary figures like RHIs and CAPPI here to demonstrate your expected hydrometeors do behave as suggest in the manuscript. One of the advantages of dual polarization is to distinguish between different hydrometeors if needed and very much encouraged.

Response: Thanks for your suggestion. We have added consecutive time-series of the vertical polarimetric radar measurements (three-dimensional radar measurement which consists of more CAPPI at different altitude layers) upon each station to detail the possible falling hydrometeors, as depicted in Figs.12-17. In this way, the microphysical evolutions of precipitation upon each station and the connection between falling solid particles and their impacts on the surface measurements can be clearly demonstrated.

20. Fig 11. Are the panels showing 0.5° or CAPPI at certain altitude? Is Z composite? Please specify this information in the caption.

Response: Thanks. They belong to hybrid radar measurements; most pixels are from radar measurements on the elevation angle of 0.5° , only the masked pixels in Fig. 3b are from the elevation angle of 1.5° .

21. Line 365, Z_{DR} is not sensitive to concentration but sensitive to size.

Response: Changed as suggested!

22. Line 375, I would agree on the big raindrops here since it is usually expected to be warm-rain dominating near the eyewall region. The authors need to provide evidence if hail/graupel do coexist here, not from derived internal consistence but dual polarimetric signatures/or maybe lightning distribution spatially.

Response: Thanks. The time series of the vertical polarimetric variables upon WL provide evidence of falling solid particles. In Fig.12, there emerged an important signature that $\rho_{HV} < 0.84$ gradually subsided, accompanying a subsiding near-zero Z_{DR} .

23. Line 384-394, this is the main selling point in this manuscript. In order to demonstrate the “large-sized raindrops tend to break apart during the falling processes but broken droplets resulted in increased concentration of raindrops for higher collision efficiency”, please provide RD-QVP time series for all the dual polarization variables. If indeed breakup dominates in the warm rain levels, one should expect a downward negative gradient of Z (6th moment to the size of raindrop) and Z_{DR} .

Response: Thanks for your comment.

(i) RD-QVP may not be a good choice due to the overall average operations using all scanning measurements on one elevation angle. (ii) We summarized three evidences for the dominant breakup:

(a) Radar-measured Z_{DR}^C - Z_H^C scattergram tends to breakup-dominated little-sized drops since little Z_{DR}^C is anticipated for a given Z_H^C , which agrees well with the simulation result of Kumjian and Prat. 2014, in which Fig. 8 compares the breakup-only and coalescence-only Z_{DR} - Z_H relations and breakup-dominated Z_{DR} is smaller than coalescence-dominated Z_{DR} .

(b) Without significant updrafts, the vertical Z_{DR} columns also presented more decreasing Z_{DR} signatures downward to the lower atmospheric layers in Figs.12-17.

(c) In time series comparison (Fig. 10), radar-measured Z_H^C and K_{DP} agree well with DSD-derived counterparts, but radar-measured Z_{DR}^C is larger than DSD-derived Z_{DR} at HJ, XJ, and LH. If coalescence dominated in the vertical gap between radar measurements and the surface, the latter should be larger than the former (but the converse is true).

Kumjian, M. R., and Prat, O. P. 2014. The Impact of Raindrop Collisional Processes on the Polarimetric Radar Variables, *Journal of the Atmospheric Sciences*, 71(8), 3052-3067

24. Sec 3.3, I highly recommend the authors to include $R(A)$ using specific attenuation result here for comparison as $R(A)$ can be quite accurate in warm rain dominated precipitation processes. As suggested in the manuscript, $R(A)$'s advantages include : (i) insensitivity of A_H to raindrop size distribution (DSD) variability (Ryzhkov et al., 2014); (ii) K_{DP} is a better indicator of rain rate and liquid water content (LWC, g-m-3) than Z_H since K_{DP} is more tightly connected to the precipitation particle size distribution; (iii) $R(K_{DP})$ and $R(A_H)$ inherit the immunity of Φ_{DP} to miscalibration, attenuation, partial beam blockage, and wet radome effects.

Response: Thanks for your recommendation.

(i) We indeed described the advantage in the introduction; however, you are over-confident in $R(A_H)$, everything has two sides. We just did not emphasize its disadvantages which is beyond the scope of this paper: A_H and α are usually simultaneously derived, and the sensitivity of α to temperature cannot be denied, which occurs with the ascending altitude of the propagation of one radar beam. We have to add this issue to avoid confusing the other readers.

(ii) In Gou et al. (2018) and Gou et al. (2019), we tested the practical performances of $R(A_H)$ separately in two cases. Both exhibited an overall overestimation trend and performed inferior to $R(K_{DP})$. It's why we didn't incorporate $R(A_H)$ into this paper (similar results were anticipated). Our results do not deny the advantage of $R(A_H)$, $R(A_H)$ needs to be optimized. However, we notice that the suggested optimization $R(A_H)$ in Ryzhkov et al. 2022 relies on $\alpha(Z_{DR})$, but breakup-dominated Z_{DR} is different from coalescence-dominated Z_{DR} , as indicated in this paper and the simulation results in Kumjian and Prat.2014. Therefore, we need to do more work for such an optimization, which is far beyond the scope of the topic of this paper.

(iii) It is not our primary purpose to determine which radar QPE algorithm performs best among all possible forms. The utilization of $R(Z_H, Z_{DR})$ plays an important role in verifying the dominant breakup over the coalescence and the transition from breakup to coalescence around the GWS of YDM.

Gou Y, Chen H, Zheng J. 2019. Polarimetric Radar Signatures and Performance of Various Radar Rainfall Estimators during an Extreme Precipitation Event over the Thousand-Island Lake Area in Eastern China. *Remote Sensing*, 11(20):2335. <https://doi.org/10.3390/rs11202335>.

Ryzhkov A, Zhang P, Bukovčić P, Zhang J, Cocks S. Polarimetric Radar Quantitative Precipitation Estimation. *Remote Sensing*. 2022; 14(7):1695. <https://doi.org/10.3390/rs14071695>.