Analysis of Equatorial Rainfall Characteristics by Drop Size Distributions and Rain Rate-Radar Reflectivity Relation

Manhal Alhilali[1], Hong Yin Lam[2], Siat Ling Jong[3], Jafri Din[1]
[1]Wireless Communication Centre, Faculty of Electrical Engineering, Universiti Teknologi Malaysia,
81310 Johor Bahru, Johor, Malaysia, manhal@ymail.com, jafri@utm.my
[2]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia,
Parit Raja, 86400 Batu Pahat, Johor, Malaysia, hylam@uthm.edu.my
[3]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia,
86400, Batu Pahat, Johor, Malaysia, sljong@uthm.edu.my

Abstract— **In remote sensing, it is vital to do a proper analysis of rainfall for the retrieval of rain data. The rain-induced attenuation and radar reflectivity mainly rely on drop size distribution (DSD). The rain rate-radar reflectivity (ZR) relation varies broadly over different climatic regions, rainfall regimes, and seasonal characteristics, especially in the tropical region. This study examines a one year of continuous measure-ements of DSD using ground-based distrometers at three different equatorial locations and investigates the rain types classification based on the microphysical properties of the rainfall. A large variation in the ZR relation parameters was discovered, highlighting the localized climate nature in the region. Additionally, the accumulated rain amounts were mainly influenced by convective rain although lower occurrence time of convective rain in comparison with stratiform rain.**

***Index Terms*—rain drop size distribution, remote sensing, radar reflectivity.**

I. INTRODUCTION

Characterization of rainfall drop size distribution (DSD) is essential for both weather radar remote sensing [1] and for radio wave propagation [2]. DSDs varies based on location [3] and rainfall types [4]. These variations result in different attenuation and radar reflectivity (Z) values for a certain rain rate value [5]. DSD studies have been conducted in many temperate and tropical locations [6]–[8], however, further data and studies are still required to analyze these variations, especially in the tropical climate where convective rain is dominant. Additionally, different rainfall types cause different rain structure which attenuates the electromagnetic signals differently. Therefore, it is an important challenge to address these issues.

Ground-based measurements such as rain rate and drop size distribution can be obtained easily and could provide a good validation method for radar measurements, which is usually done by using ZR relation [9]. Thus, it is important to characterize the rain by ground-based measurements to validate and ensure the quality of radar measurements. Convective and stratiform rain types are mostly described in the literature, while transitional rain is briefly discussed [4]. In addition, ZR relation parameters are vital for radars operation. The relation usually defined using power law relationship, $Z = AR^b$, where the constants A and b vary as reported by many studies for different locations [5].

This study presents the equatorial rainfall characteristics in terms of DSD and ZR relation for three equatorial locations, investigated through ground-based distrometer measurements. The use of DSD model parameters is also investigated and used for rain classification. Additionally, suitable ZR parameters are identified for these locations.

II. DATA COLLECTION AND PROCESSING

The measurement databases considered in this study are gathered from three different equatorial locations in the south-east Asia region. In Peninsular Malaysia, Johor (JB) (1.56, 103.64) and Kuala Lumpur (KL) (3.17, 101.72), additionally, Manus Island (MI) (-2.12, 146.84) was also considered to cover a more diverse topography. All three locations are shown in Fig. 1. One year of a continuous data record is used from each location. Drop size measurement has been made in Johor and Manus Island using a 2D video distrometer (2DVD) [10], while in Kuala Lumpur RD-69 disdrometer was used [11]. While JB and KL are surrounded by oceans both exhibit some continental effects, in comparison to Manus Island.

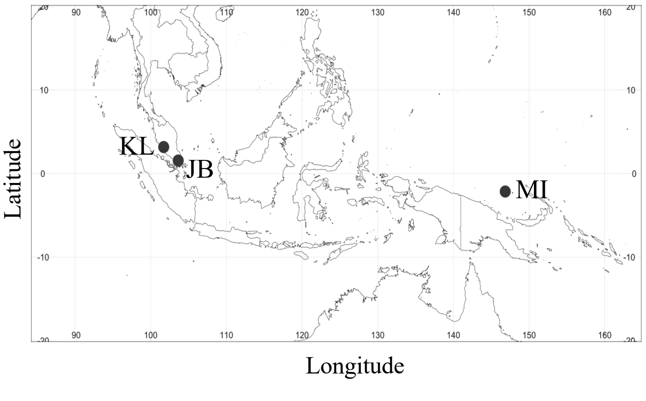

Fig. 1. Locations of the measurement sites.

Authorized licensed use limited to: UNIVERSITY TEKNOLOGI MALAYSIA. Downloaded on December 18,2020 at 07:13:51 UTC from IEEE Xplore. Restrictions apply.

From the three locations, only 1-minute DSD data with a minimum of 100 drops or a rain rate of 0.05 mm/h during at least 3 consecutive rainy minutes were analyzed. This was done to exclude minutes containing only a few small drops of rain, which could skew the analysis [8]. Additionally, the first size bin of the 2DVD centered at 0.1 mm was ignored, to keep the study consistent with the RD-69 findings. The RD-69 data also gone through calibration algorithms as described in [11].

The normalized gamma DSD model was chosen to solve for the integral rain parameters, as it is able to produce a suitable discrepancy between convective-stratiform (C/S) rain types [8]. These parameters are related by

$$N_w = \frac{3.67^4 10^3 LWC}{\pi \rho_w D_0^4} \tag{1}$$

where N_w $(\mathrm{mm^{-1} m^{-3}})$ is the intercept parameter, LWC $(\mathrm{g\,m^{-3}})$ is the liquid water content, D_0 (mm) is the median drop diameter, and ρ_w is the density of water (1 g cm^{-3}). Once the drop size distributions are known, rain rate and radar reflectivity can be calculated as in [12].

III. Results and Analysis

To assess the variation in DSD characteristics for all locations, average DSDs of all rain rates is shown in Fig. 2. Large disparities can be observed for the medium size drops for each location, however, less are observed at both ends of the distribution except for KL which might be due to the used disdrometer type limitations and the well-known continental effects on DSD, where convective rainfall with large raindrops are more common. Raindrop concentrations are highest for KL and lowest for JB for the medium size drops.

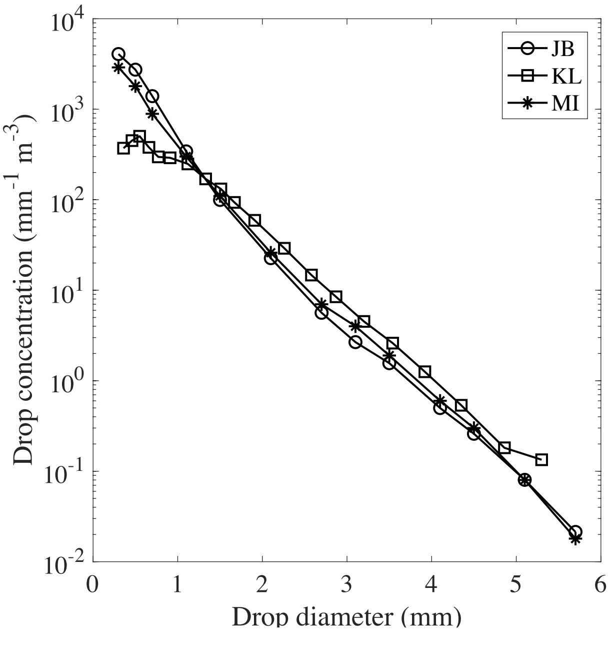

Fig. 2. Average drop size distribution of the measurement locations.

In Fig. 3, average DSDs are classified by their rain rates. Drop concentrations vary from one location to the other, although similar distributions for all locations are observed. Larger drop sizes are more common for higher rain rates. Consequently, the large drops concentrations are higher for high rain rates. A similar trend as discussed previously can be

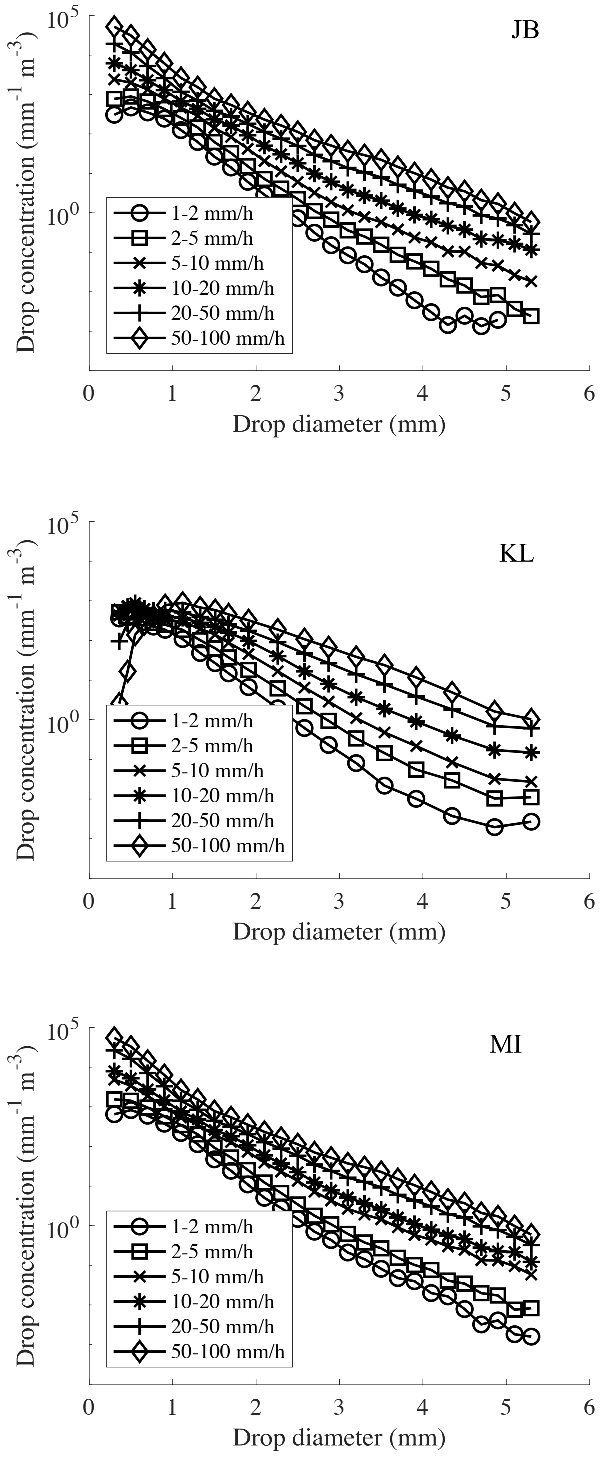

Fig. 3. Drop size Distributions for different rain rate bins.

Authorized licensed use limited to: UNIVERSITY TEKNOLOGI MALAYSIA. Downloaded on December 18,2020 at 07:13:51 UTC from IEEE Xplore. Restrictions apply.

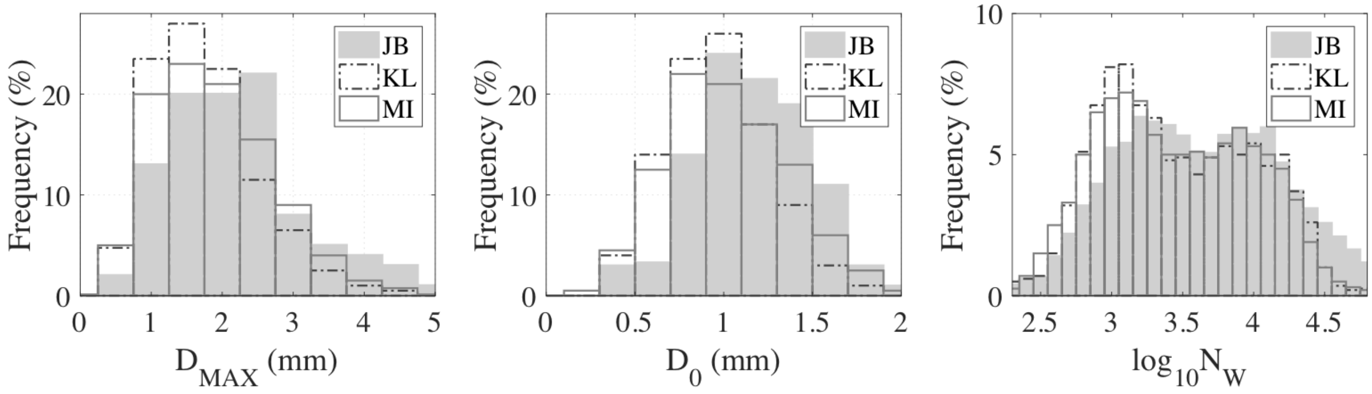

Fig. 4. Histograms of The maximum raindrop diameter D_{MAX}, the median diameter D_0 and the number concentration $\log_{10} N_w$ for all the measurement locations.

seen for KL, where for high rain rate small drops concentrations are lower than the other locations which might be due to the limitation of the used disdrometer. Seasonal DSD characteristics usually vary with locations. However, for this study the selected locations exhibited similar seasonal trends, the only variations occur due to the changes in the proportion of their rainfall types. Thus, it is useful to study the DSD variations due to different rainfall types, and different rain rate ranges. As these characteristics can be retrieved using these ground-based instruments.

The DSD characteristics are further investigated by the mean of the normalized gamma distribution parameter. The maximum raindrop diameter D_{MAX}, the median diameter D_0 and the number concentration $\log_{10} N_w$ histograms are shown in Fig. 4. While similar trends can be observed over the three locations, higher means are detected for KL, indicating the continent effects in comparison to more maritime events in JB and MI. The bimodality in $\log_{10} N_w$ distribution is similar to other maritime locations found by [8]. This is usually associated with different rain types.

Many studies addressed the classification of rain types differently [13]–[15]. Some studies [4], [16] used the previously-mentioned parameters, N_w and D_0, to draw clear separation in terms of the parameters variation, for each rain type. A similar separator line was drawn for this study, after a visual analysis of the databases, any point of data below the separator line classified as stratiform rain while data located above the separator line classified as convective rain. The transitional period is ignored for the purpose of this study.

This rain classification method is then utilized to measure the contribution of each rain type in total rain amount for the measurement locations and given in Table I. It is observable that while the occurrence of convective rain was for a small percentage of the time for all the locations, the accumulated rainfall amount was the highest from convective rain type. While KL exhibit higher occurrences of convective rain, the accumulated rain was less compared to the other locations.

TABLE I. RAIN ACCUMULATION AND OCCURRENCE PERCENTAGES FOR EACH OF THE MEASUREMENT SITES.

Site	**Convective rain**		**Stratiform rain**	
	Accumulation	Occurrences	Accumulation	Occurrences
JB	82 %	28 %	18 %	72 %
KL	64 %	36 %	36 %	64 %
MI	81 %	41 %	19 %	59 %

The ZR relation is usually used for rain types classification. Additionally, it is also used for the retrieval of rain rate from weather radar with a separate relationship provided for each rain type. Thus, the accuracy of rain rate is directly associated with the selection of these parameters. The power law parameters A and b depend on the same factors that effects DSD characteristics, where a higher A values are related to convective rain.

The values of A and b are determined by linear regression of $\log Z$ with R. These values are then shown in Fig. 5, for both convective and stratiform rain types in comparison with other values from the literature. The entire database was used to derive the ZR relation, based only on C/S separation as described previously.

A Large value of A is found for convective rain in KL, which is expected due to the continent effects described earlier. While a higher value of A is observed in JB and MI stratiform rain, which is also reported in other tropical studies [17]. The variation of ZR relation parameters across the three locations clearly illustrate the localized nature of tropical DSDs.

IV. CONCLUSIONS

Characterization of rainfall is utmost important for both remote sensing, and radio wave propagation. The drop size distribution is the main parameter for these characterizations. In this study, three different rain databases from equatorial regions were investigated, providing the analysis of the main features of equatorial rain. Further, integral rain parameters,

Authorized licensed use limited to: UNIVERSITY TEKNOLOGI MALAYSIA. Downloaded on December 18,2020 at 07:13:51 UTC from IEEE Xplore. Restrictions apply.

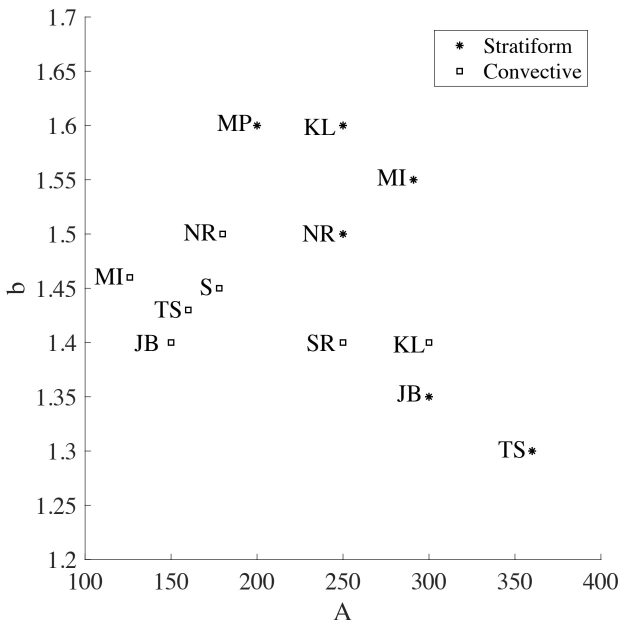

Fig. 5. The ZR relation parameters for the measurement locations. Other values from literature presented as MP [18], NR [19], S[15], TS[20], SR[17].

were measured, to characterize the variation of the drop size distribution, and used for the classification of rain types for all locations. It was found that while the convective rain occurred at a very small percentage of the time for all the locations, the accumulated rainfall amount was the highest from this rain type. Additionally, the ZR relation was described for each rain type, and it was found that parameter A is higher in convective rain in KL, while the higher value of the parameter is associated with stratiform events for the other two locations. This clearly highlights the localized climate in tropical regions. Further investigations on monsoons effects on the variation and the transitional rain type could be the direction of a future study.

ACKNOWLEDGMENT

This work has been funded by Ministry of Education Malaysia and Universiti Teknologi Malaysia under FRGS Vot. No. RJ130000.7823.4F958, and Universiti Tun Hussein Onn Malaysia Tier 1 Grant Vot. No. H160.

REFERENCES

[1] G. Zhang, J. Sun, and E. a. Brandes, "Improving Parameterization of Rain Microphysics with Disdrometer and Radar Observations," *J. Atmos. Sci.*, vol. 63, no. 4, pp. 1273–1290, 2006.

[2] H. Y. Lam *et al.*, "Impact of Rain Attenuation on 5G Millimeter Wave Communication Systems in Equatorial Malaysia Investigated Through Disdrometer Data," in *EuCAP*, 2017, pp. 1802–1806.

[3] B. Dolan, B. Fuchs, S. A. Rutledge, E. A. Barnes, and E. J. Thompson, "Primary Modes of Global Drop Size Distributions," *J. Atmos. Sci.*, vol. 75, no. 5, pp. 1453–1476, Feb. 2018.

[4] M. Thurai, P. N. Gatlin, and V. N. Bringi, "Separating stratiform and convective rain types based on the drop size distribution characteristics using 2D video disdrometer data," *Atmos. Res.*, vol. 169, pp. 416–423, Mar. 2016.

[5] P. Bukovčić, D. Zrnić, and G. Zhang, "Convective-stratiform separation using video disdrometer observations in central Oklahoma - the Bayesian approach," *Atmos. Res.*, vol. 155, no. April, pp. 176–191, 2015.

[6] M. Schönhuber, J. P. Mateos, and K. Plimon, "About Seasonal Variations of Specific Attenuations Derived from DSD Measurements," pp. 1791–1792, 2017.

[7] F. Marzuki, T. Kozu, T. Shimomai, H. Hashiguchi, W. L. Randeu, and M. Vonnisa, "Raindrop size distributions of convective rain over equatorial Indonesia during the first CPEA campaign," *Atmos. Res.*, vol. 96, no. 4, pp. 645–655, 2010.

[8] E. J. Thompson, S. A. Rutledge, B. Dolan, and M. Thurai, "Drop size distributions and radar observations of convective and stratiform rain over the equatorial Indian and West Pacific Oceans," *J. Atmos. Sci.*, vol. 72, no. 11, pp. 4091–4125, 2015.

[9] M. Petracca, L. P. D'Adderio, F. Porcù, G. Vulpiani, S. Sebastianelli, and S. Puca, "Validation of GPM Dual-Frequency Precipitation Radar (DPR) Rainfall Products over Italy," *J. Hydrometeorol.*, vol. 19, no. 5, pp. 907–925, May 2018.

[10] M. Alhilali, J. Din, M. Schönhuber, and H. Y. Lam, "Estimation of Millimeter Wave Attenuation Due to Rain Using 2D Video Distrometer Data in Malaysia," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 7, no. 1, pp. 164–169, 2017.

[11] H. Y. Lam, J. Din, and S. L. Jong, "Statistical and physical descriptions of raindrop size distributions in equatorial Malaysia from disdrometer observations," *Adv. Meteorol.*, vol. 2015, pp. 1–14, 2015.

[12] S. Michaelides, *Precipitation: Advances in Measurement, Estimation and Prediction*. Springer, 2008.

[13] V. N. Bringi, V. Chandrasekar, J. Hubbert, E. Gorgucci, W. L. Randeu, and M. Schönhuber, "Raindrop Size Distribution in Different Climatic Regimes from Disdrometer and Dual-Polarized Radar Analysis," *J. Atmos. Sci.*, vol. 60, no. 2, pp. 354–365, 2003.

[14] B. Chen, J. Yang, and J. Pu, "Statistical Characteristics of Raindrop Size Distribution in the Meiyu Season Observed in Eastern China," *J. Meteorol. Soc. Japan*, vol. 91, no. 2, pp. 215–227, 2013.

[15] A. Tokay and D. a. Short, "Evidence from Tropical Raindrop Spectra of the Origin of Rain from Stratiform versus Convective Clouds," *J. Appl. Meteorol.*, vol. 35, no. 3, pp. 355–371, 1996.

[16] V. N. BRINGI *et al.*, "Rainfall Estimation from C-Band Polarimetric Radar in Okinawa, Japan: Comparisons with 2D-Video Disdrometer and 400 MHz Wind Profiler," *J. Meteorol. Soc. Japan*, vol. 84, no. 4, pp. 705–724, 2006.

[17] T. Kozu, T. Shimomai, Z. Akramin, Marzuki, Y. Shibagaki, and H. Hashiguchi, "Intraseasonal variation of raindrop size distribution at Koto Tabang, West Sumatra, Indonesia," *Geophys. Res. Lett.*, vol. 32, no. 7, pp. 1–4, 2005.

[18] J. S. Marshall and W. M. K. Palmer, "the Distribution of Raindrops With Size," *J. Meteorol.*, vol. 5, no. 4, pp. 165–166, 1948.

[19] T. Narayana Rao, B. Radhakrishna, K. Nakamura, and N. Prabhakara Rao, "Notes and correspondence differences in raindrop size distribution from southwest monsoon to northeast monsoon at Gadanki," *Q. J. R. Meteorol. Soc.*, vol. 135, no. 643, pp. 1630–1637, 2009.

[20] A. Tokay and P. G. Bashor, "An experimental study of small-scale variability of raindrop size distribution," *J. Appl. Meteorol. Climatol.*, 2010.

Authorized licensed use limited to: UNIVERSITY TEKNOLOGI MALAYSIA. Downloaded on December 18,2020 at 07:13:51 UTC from IEEE Xplore. Restrictions apply.