Evaluation of Radar Reflectivity-Rainfall Rate, *Z-R* Relationships During a Stratiform Event in the Tropics

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Abstract—**A number of factors can certainly affect the accuracy of Z-R relationships; including poor hardware calibration. The inaccuracy might also be due to the differences between the ground-level precipitation and the precipitation aloft since a radar does not scan all the way down except at close range. Several Z-R relationships had been proposed in the attempt to achieve better accuracy for rainfall estimates by radar system in the tropical climate. Nonetheless, the most accurate Z-R relationship for Malaysia weather radar is yet to be investigated and identified. This paper presents the analyses of previously proposed Z-R relationships for Malaysia weather using new radar data and ground rainfall rate.**

I. Introduction

Meteorologists used weather radar originally to forecast very short-term weather conditions and issue warnings for hazardous weather phenomena. Weather radars measure the electromagnetic radiation backscattered by cloud raindrops. They have the potential to estimate rainfall rates by exploiting the reflectivity, Z values. Weather maps are particularly important in aviation field especially for flight planning and avoidance of dangerous weather conditions. Malaysian weather radars are expected to scan enough angles to generate a 3D set of data over certain areas of coverage. With the use of reliable radars, it is somewhat easy to ascertain the maximum altitude of rain within the volume as well as the rain intensity. Accurate rainfall rate estimation by weather radar has been the goal of radar designers for decades. It has always been a great fear where unsuitable Z-R relationship was used to estimate rainfall rate and evidently inflict considerable error in quantitative precipitation measurements; even though radar calibration was performed [1].

II. Radar Reflectivity-Rainfall Rate Relationship

The empirical power-law *Z-R* relationship is used to estimate rainfall intensity reflectivity measurements as follows [2]:

$$Z = A\,R^{b} \qquad (1)$$

where the reflectivity, Z is expressed in mm^6/m^3 and the rainfall rate, R in mm/hr. The coefficients A and b are the radar parameters of interest to be estimated that vary according to meteorological, climatic and physiographic conditions of a specific region.

Marshall and Palmer derived the *Z-R* relationship that is also known as MP equation in 1948. It is commonly used for radar rainfall estimate by weather radar as given:

$$Z = 200\,R^{1.6} \qquad (2)$$

Subsequently, Rosenfeld [3] had carried out further investigation involving heavy precipitation event. He formulated a revised *Z-R* relationship exclusively for convective rain as follows:

$$Z = 250\,R^{1.2} \qquad (3)$$

However, large discrepancies had been discovered when (2) and (3) were applied to tropical region especially during heavy rain [4].

III. Previously Proposed *Z-R* Relationships in Equatorial and Tropical Regions

Suzana and Wardah had proposed several Z-R relationships in 2011 for seven identified rain types in Malaysia [5]. Afterwards in 2012, Kamaruzzaman and Subramaniam suggested three Z-R relationships based on data acquired from three radar stations located at Butterworth, Kluang, and Alor Star [6]. The Malaysian researchers had shown that their suggested Z-R relationships managed to offer better rainfall rate estimation compared to that of Marshall-Palmer's and Rosenfeld's. Nonetheless, it was also highlighted that the findings should be treated with caution because of the limitations of the rainfall data used in the study. Another concern is because they did not provide comprehensive coverage to take into account of all possible environmental and physical conditions.

IV. Results and Discussions

The paper intends to highlight some of the findings obtained from the use of radar reflectivity data that were collected from an S-Band Terminal Doppler Weather Radar (TDWR). The radar is located at Bukit Tampoi with 2° 44' N and 101° 42' E, approximately 12km from KLIA. The software utilized is the IRIS Vaisala 8.12.4. In addition, the rain gauge is located about 5km from KLIA.

Fig. 1 shows the constant altitude plan position indicator (CAPPI) scan for the event recorded on 1st September 2009 at 09:10:18 and Fig. 2 shows its corresponding reflectivity cross section in dBZ. Fig. 3 shows the rainfall rate in mm/hr by using *Z-R* relationships proposed by Suzana and Wardah for low rainfall rate in Kuala Lumpur. Meanwhile, Fig. 4 shows the rainfall rate by using *Z-R* relationships suggested by Kamaruzzaman and Subramaniam for Kluang. Their recommended equations were applied to radar data obtained from KLIA TDWR. Fig. 3 and Fig. 4 show that the rainfall rate value is 5.3mm/hr and 20.8mm/hr respectively for 13.3km distance. This distance is the location of the rain gauge for measuring ground truth rainfall rate. Meanwhile, according to MMD data, the ground truth measurements using rain gauge during that particular event is 12.0 mm/hr. The preliminary result shows that the MP and Suzana-Wardah equations under estimate, while Kamaruzzaman-Subramaniam equation over estimate rainfall rate values for this stratiform event.

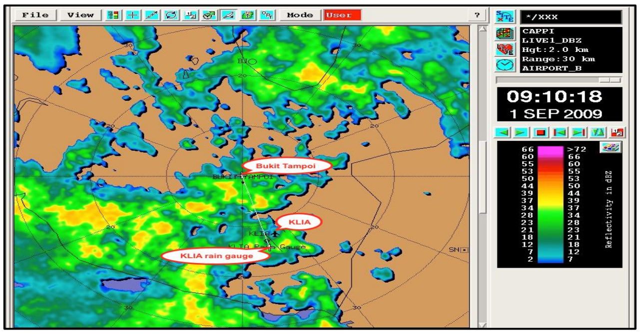

Fig. 1: CAPPI scan with $Z = 200\ R^{1.6}$

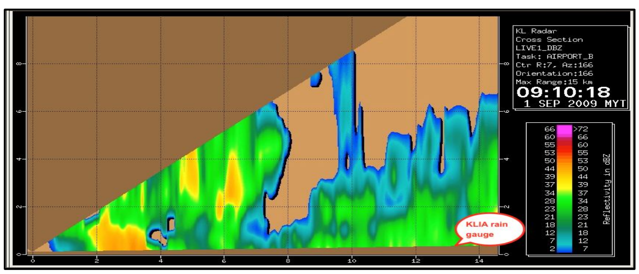

Fig. 2: Cross section in dBZ with $Z = 200\ R^{1.6}$

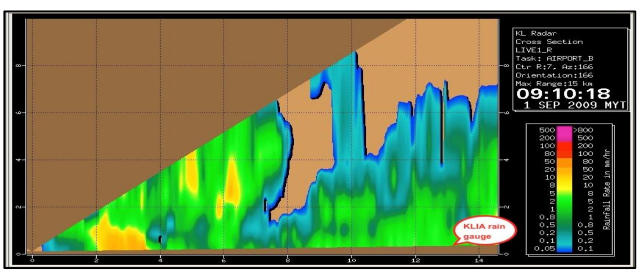

Fig. 3: Cross section in mm/hr with $Z = 180\ R^{1.9}$

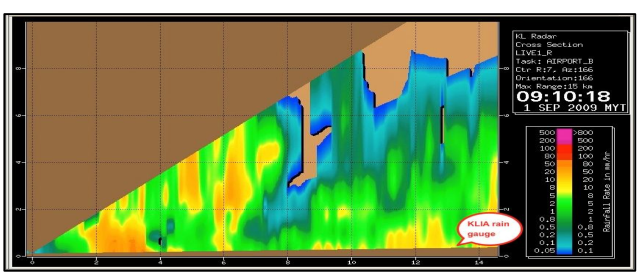

Fig. 4: Cross section in mm/hr with $Z = 13\ R^{2.2}$

Table I summarized the comparison between MP, Suzana-Wardah, and Kamaruzzaman-Subramaniam *Z-R* relationships with the ground truth measurement from the KLIA rain gauge. The table shows that the values of *R* having large differences when compared with the ground truth measurement for these three *Z-R* relationships. The difference might be due to unfitting relationship. It is made aware that previous researchers employed radar data that were obtained at every 10 minutes while the rain gauge measurement were taken hourly. This temporal mismatch and inappropriate used of *Z-R* relationships might be the cause of inaccurate radar rainfall estimates.

TABLE I. COMPARISON OF RAINFALL RATE FOR THREE DIFFERENT *Z-R* RELATIONSHIPS DERIVED FOR MALAYSIA WEATHER

Relationship	Recommended Use	*R* (mm/hr) from rain gauge	*R* (mm/hr)
Marshall-Palmer $Z = 200\ R^{1.6}$	General Stratiform Precipitation	12.0	6.2
Suzana R. and Wardah T. $Z = 180\ R^{1.9}$	Low Rainfall Rate	12.0	5.3
M. Kamaruzzaman M.A and Subramaniam M. $Z = 13\ R^{2.2}$	Kluang	12.0	20.8

V. CONCLUSION AND FUTURE WORKS

From the results obtained, it appears that MP, Suzana-Wardah, and Kamaruzzaman-Subramaniam *Z-R* relationships were not able to precisely estimate the rainfall rate. Nevertheless, these preliminary findings are not yet conclusive. More events need to be processed and validated with other proposed *Z-R* relationships for tropical region, with different precipitation types. Larger variation might occur for heavy precipitation or convective event. Evidently, the best *Z-R* relationship is hoped to be identified in the very near future.

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