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Radar Hydrology: New Z/R Relationships for Klang River Basin Malaysia based on Rainfall Classification

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***Abstract*—**The use of radar in Quantitative Precipitation Estimation (QPE) for radar-rainfall measurement is significantly beneficial. Radar has advantages in terms of high spatial and temporal condition in rainfall measurement and also forecasting. In Malaysia, radar application in QPE is still new and needs to be explored. This paper focuses on the Z/R derivation works of radar-rainfall estimation based on rainfall classification. The works developed new Z/R relationships for Klang River Basin in Selangor area for three different general classes of rain events, namely low (<10mm/hr), moderate (>10mm/hr, <30mm/hr) and heavy (>30mm/hr) and also on more specific rain types during monsoon seasons. Looking at the high potential of Doppler radar in QPE, the newly formulated Z/R equations will be useful in improving the measurement of rainfall for any hydrological application, especially for flood forecasting.

***Keywords*—**Radar, Quantitative Precipitation Estimation, Z/R development, flood forecasting

I. Introduction

In Malaysia, radar is one of the tools being used to observe and detect the precipitation routine. The utilization of weather radar in quantitative precipitation estimates (QPE) however is still new especially in hydrological modeling work. The study on radars in hydrological application recently shows that the radar has a potential value in developing better rainfall measurement products. [1] calibrated the radar-derived rainfall data for rainfall-runoff modeling in the Upper Bernam river basin in Perak and found that the watershed river flow can be better estimated by using radar-derived rainfall data. Radar has obvious advantages in measuring rainfall with high spatial and temporal resolution and the observations made are in near real time and are consistent. [2] explained that the advantage of using radar for precipitation measurement is the coverage of a large area in real time. Ultimately, the biggest advantages of weather radar is the ability to detect cloud and precipitation structures and also the process of the rainfall system itself by providing real-time regional information [3]. On the other hand, the biggest obstacle in radar application is the multiexisting errors that hinder accuracy. Examples of errors associated with radar are Z/R variability, vertical profile reflectivity, beam attenuation, ground clutter and the stability of the equipment itself.

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Radar rainfall products are very important for flood prediction models, validation of satellite remote sensing and also for statistical characterization of extreme rainfall events. However the sources of error in radar rainfall estimation should be critically checked. Before deducing the rainfall rates from radar reflectivity, hardware checking is a must to ensure equipment stability. Some other requirements include error correction, selecting the most appropriate Z/R relationship and checking the adjustment with rain gauges. Many factors involve in the deployment of radar in quantitative precipitation estimation. One of it is the conversion factor between gauge and radar-rainfall. Conversion from radar reflectivity to rainfall rates is hugely dependent on the type of rain and season as well as topography.

Malaysia is a tropical country that experiences rain almost one whole year around and for some regions, it is heavier. The West Coast of Peninsular is subjected to localized and convective storms generated by the inter monsoon seasons. Convective storms are extremely variable in time and space and can produce very intense rainfall rates that lead to flooding. With annual rainfall volume range from 200bcm (billion cubic metres) to 500 bcm, Malaysia is considered to have an equatorial climate with high humidity. For average annual rainfall, Peninsular Malaysia receives around 2440 mm while Sabah and Sarawak receive 2630mm and 3830mm respectively. The use of radar sensing is then appropriate due to large spatial and temporal variability characteristics of convective rainfall. Flood is a norm in Malaysia since the rain is heavy and can continue for several days. To date, 15 major flood events have been recorded since 1926. Those floods were triggered by the rain in monsoon season which are divided into four main types of monsoon rain: Southwest monsoon, Northeast monsoon and two inter monsoons that carry heavy rain especially during late evening.

II. Z/R Relationship for Radar-Rainfall Measurement

The importance of the Z/R relationship in quantitative precipitation estimation (QPE) is very significant. The rain rate ® obtained from the equation is the main key parameter for many hydrological applications such as rainfall-runoff estimation, water catchment capacity calculation, flood forecasting, watering for agriculture and many other hydrological purposes. Thus the conversion of rain-rate from radar reflectivity factor (Z) plays a crucial part in ensuring better precipitation estimation in the radar hydrology system. The best or the most appropriate Z/R relation must be adopted in order to obtain higher accuracy in radar-rainfall measurement. Many Z/R equations have been established according to the types of rain (stratiform or convective), locations (higher latitude or lower latitude) and other meteorological factors. The suitability of the chosen equations is normally validated with available rain gauge data sets.

Z/R relationships vary from one experiment to another due to the ambiguity characteristic in the drop size distribution (DSD). From the weather radar, Z is proportional to Di^6 where Di is the diameters of individual raindrops in a sample volume while R is proportional to Di^3. It is evident that the radar measurement is biased when dealing with larger rain drops [4]. The variation in distribution of rainfall drop size in both space and time will result in invalid calibration when applied to different rain events [5].

Classification of the precipitation types will reduce the error in Z/R conversion by diminishing the variability in the distribution of rainfall drop sizes. A method proposed by [6] used a storm classification technique to distinguish between convective and stratiform regions within the rainfall event. It has been found that less than 10% of the monthly rainfall statistics are affected by this method. In addition, the Z/R relationship is also affected by different rainfall rates. [7] proved that in his study that various functional relations are obtained for different rates of reflectivity and rainfall rates. He found that a single Z/R relationship may not be valid at higher rainfall rates and suggested to deploy time series analysis in order to establish better relations between radar reflectivity and rainfall rates.

Precipitation types (convective, stratiform or mixed types) are one of the main parameters for Z/R relationships due to variations of rain patterns. [8] presented sets of Z/R equations for different types of rain including equations for drizzle, widespread rain and thunderstorms from various researchers. This information confirmed that the selection of the Z/R equation for particular locations is crucial in order to increase the accuracy of the radar measurement of rainfall. The use of the Marshall-Palmer equation [9] for the Z/R relationship is no longer appropriate for rainfall estimation and the most suitable Z/R relationship for particular locations shall be developed.

In this paper, new Z/ R relationships have been derived according to three main rainfall events (low, moderate and heavy rainfall classes) and also for more specific rain type based on monsoon rain namely Southwest Monsoon, Northeast Monsoon and two inter monsoons for Klang River Basin in Selangor, Malaysia. Statistical measurements have also been performed to compare the error between rain gauge and radar derived rainfall in terms of mean error, mean absolute error, RMSE and bias. The results show significant improvement with the new developed Z/R relationships in producing better rainfall estimation.

III. Case Study and Data Collection

The Klang River Basin in Selangor has experienced flooding for more than a decade. Since it is located in the midst of one of the busiest areas in Malaysia – between Selangor and Kuala Lumpur – it suffers from urbanization and a high population. The size of the Klang River Basin is 1288km2 big with a total stream length of approximately 120km. Located at 3°17'N, 101°E to 2°40'N,101°17'E, it covers areas in Sepang, Kula Langat, Petaling Jaya, Klang, Gombak and Kuala Lumpur. In the case study, only the upper river basin is targeted within an area of 468km2 (Petaling Jaya, Klang, Gombak and Kuala Lumpur). Most of the flooding in the Klang River occurred from soil erosion problems and high rainfall intensity adds to the serious degrading. Since 1998, more than RM20 millions have been spent on flood mitigation on this river. It is essential to study the rainfall intensity effect for the Klang River Basin, and the combination of radar and rain gauge will improve the rainfall estimation. Hence, it can be deployed for further hydrological work.

Radar reflectivity data were obtained from S-band Terminal Doppler Radar in KLIA, which are operated by MMD (Malaysia Meteorological Department) and located at an elevation of 37 m MSL. The conventional radar data are collected every 10 minutes up to the effective range of 230 km for three elevation scans (PPI) with elevation angles of 1.0°, 2.0° and 3.0°. Ground clutter is removed in radar data calibration. The 1°×2 km resolution maps were collected every 10 minutes and converted into rainfall intensity by means of the classical Marshall and Palmer relationship (***$Z=200R^{1.6}$***) using IRIS software Program. The Doppler radar, which is situated in Bukit Tampoi, Dengkil, about 10 km to North KLIA was first introduced in 1998. The prime function of TDR is to detect and to alert KLIA on the wind shear problem and also microburst scenario. Both conventional and Doppler radars can detect rainfall intensity through its signal reflectivity.

The Hydrological data such as rainfall, river discharge and water levels were obtained from the Hydrology Division, DID, Malaysia. 25 rain gauge stations have been selected in this studies which are located near the catchment area: Klang River Basin, Selangor. In this study, hourly rainfall data from DID were used and covered from January 2009 until December 2009. There were more than 100 events throughout the months except for two inter monsoons events that occur in Mac to April and September to October. For Z/R development purposes, seven categories of rainfall have been included; low rainfall (< 10mm/hr), medium rainfall (>10mm/hr but <30mm/hr) and heavy rainfall (> 30 mm/hr), Southwest Monsoon rain, Northeast Monsoon rain, Inter Southwest Monsoon and Inter Northeast Monsoon rain.

IV. Methodology: Z/R Derivation

The statistical method requires a combination of data from radar and rain gauge stations. The Z/R relationship will then be obtained by measuring both data simultaneously. One of the techniques used in statistical estimation for Z/R equation is the optimization method that relates measured values of radar reflectivity to rainfall rate. The approach is motivated by observation of sampling properties and not driven by DSD control of Z/R relations. In the optimization-based approach, some measures of 'closeness' of the radar rainfall products and the surface rainfall reference data obtained by rain gauges is minimized. The optimization approach determines the relationship by using reflectivity data measured by radar and rainfall data by rain gauges stations.

The Z/R relationship is deduced from radar reflectivity data and the surface rainfall rate using rain gauges. The 'best' values of *A* and *b* parameters are obtained by establishing the optimal curve fitting in the graph between reflectivity and rainfall rate. Issues arising from the method are merely from strong wing disturbance and partial evaporation of rain falling. The values of A and B coefficients can also be determined from literature with certain restrictions. The optimization approach implements algorithm and uses the Z/R relationship as an empirical formula to obtain unknown Z/R parameters. For particular application, the products are optimized in an appropriate manner according to the criteria.

V. New Z/R Relationships

At present, the KLIA weather radar has been using the classic Marshall Palmer equation ($Z=200R^{1.6}$) to convert reflectivity to rainfall rate in mm/hr. The data shows that more than 80% of the data obtained from the radar were overestimated when compared to rain gauge observations. The need for new Z/R is crucial in order to improve the results. Applying the optimization approach, new Z/R relationships have been derived for three types of rainfall events, namely: low (<10mm/hr), moderate (>10mm/hr, <30mm/hr) and heavy (>30mm/hr) and also four different types of monsoon rain namely South West, North East and two Inter monsoons. The classification is important to observe the rainfall rates in terms of error measurement.

For low rainfall, the original data can exceed more than 30mm/hr when being converted with MP equation. Using solver analysis, the new Z/R, which is $Z=180R^{1.9}$, is obtained. The results show reduction in the data and improve the accuracy of hourly rainfall data. For moderate and heavy type of rain, the new derived Z/R equations are $Z=212R^{1.9}$ and $Z=262R^{1.9}$ respectively. All three groups show great improvement in terms of rainfall rates when compared to data from gauge stations.

Four monsoon rains namely Southwest, Northeast, Inter Southwest and InterNortheast depict better correlation between radar and rain gauge data with new calibrated Z/R equations which are $Z=500R^{1.9}$, $Z=166R^{1.9}$, $Z=367R^{1.9}$ and $Z=260R^{1.9}$ respectively. Figure 1 below shows the reflectivity (dBZ) versus obtained rain rate (mm/hr) based on different class of Z/R.

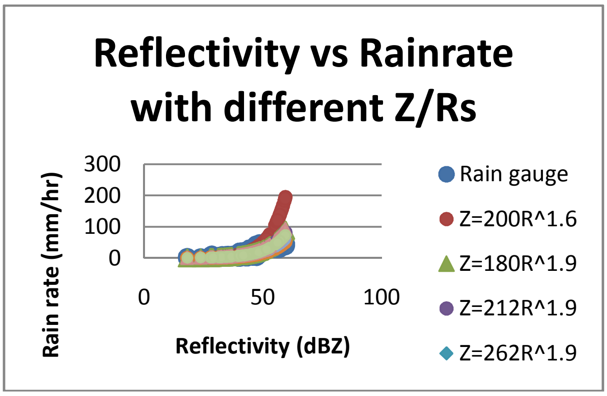

Fig. 1 Plotted graph between reflectivity and rainrate with different Z/Rs

To validate the new Z/R equations, four statistical measurements in terms of Root Mean Square Error (RMSE), Mean Error, Absolute Mean Error and Bias have been performed. Results are shown in Figure 2, 3, 4 and 5. Whereas,

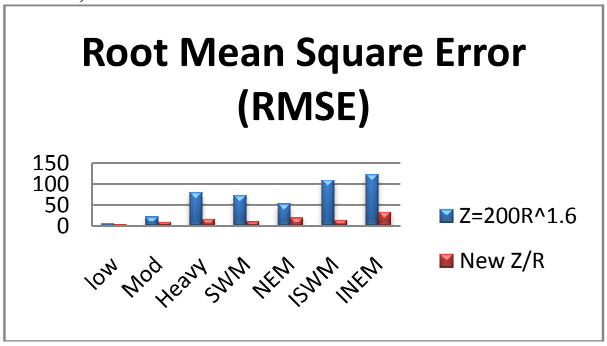

Fig. 2 Root Mean Square Error Analysis

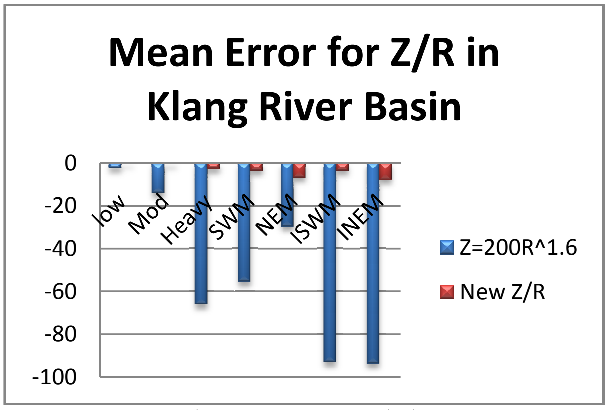

Fig. 3 Mean Error Analysis

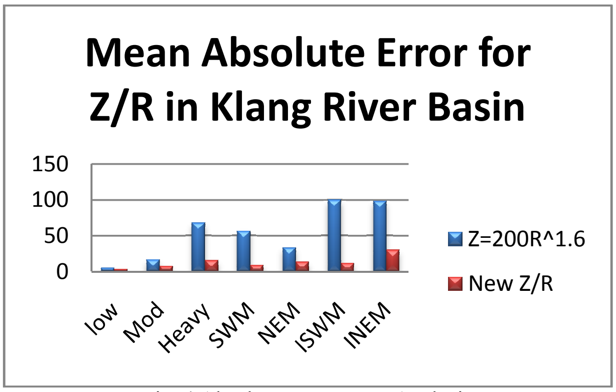

Fig. 4 Absolute Mean Error Analysis

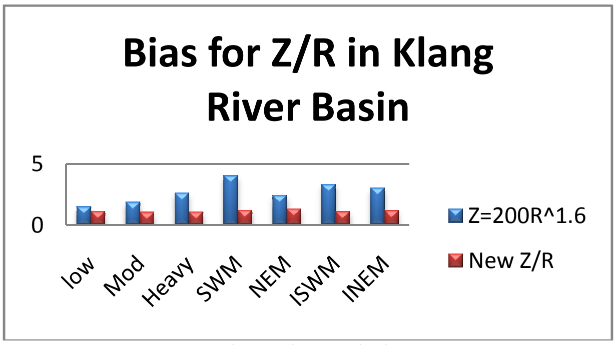

Fig. 5 Bias Analysis

The graphs below show that the current Z/R equation (MP equation) gave significantly bigger amount of radar-rainrate compared to rain gauge. While using the new Z/R based on monsoon rain which is South West Monsoon rain, the results got better. Combination of three general types of rain based on intensities also potrayed great improvement. Still, the SWM Z/R equation gave the smallest error for 24-hour data for event on 27th August 2009. Detail analysis on Air Terjun Sg. Batu also has been performed and substantial result has been observed.

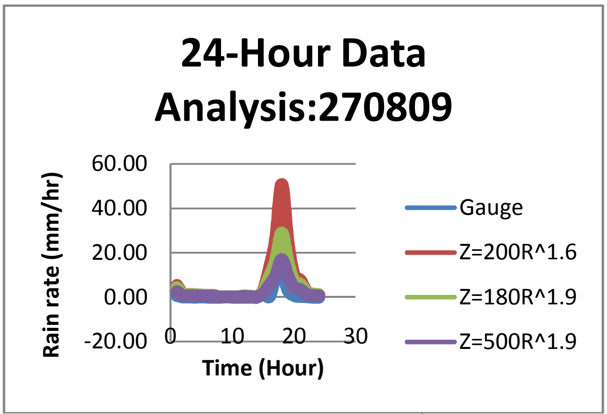

Fig. 6 24-Hour Analysis for event on 27th August 2009

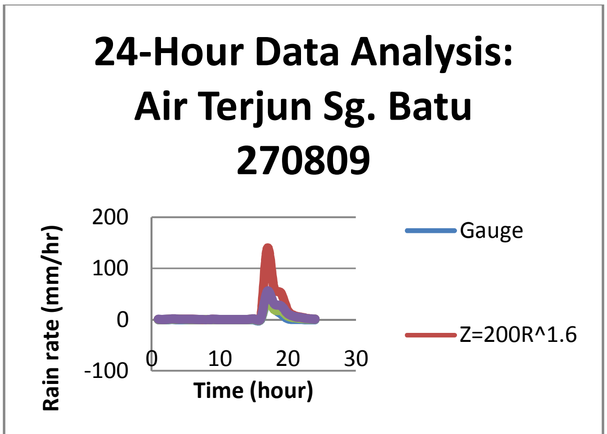

Fig. 7 24-Hour Analysis for Air Terjun Sg. Batu on 27th August 2009

Table I depicts the detail part of statistical measurements for every rain type.

TABLE I
STATISTICAL MEASUREMENT OF ERROR FOR DIFFERENT Z/RS

Statistical Measurement For Different Z/Rs in Klang River Basin					
TYPE OF RAIN	NEW Z/R	Mean error	Mean absolute Error	RMSE	Bias
LOW	$Z=180R^{1.9}$	-0.548	3.083	3.651	1.101
MODERATE	$Z=212R^{1.9}$	-0.661	7.184	9.2049	1.040
HEAVY	$Z=262R^{1.9}$	-2.881	15.041	16.974	1.070
SOUTHWEST MONSOON	$Z=500R^{1.9}$	-3.846	8.658	10.899	1.210
NORTHEAST MONSOON	$Z=166R^{1.9}$	-6.975	13.032	19.679	1.331
INTERSWM	$Z=367R^{1.9}$	-3.798	11.539	14.138	1.091
INTERNEM	$Z=260R^{1.9}$	-10.130	32.042	36.493	1.221

VI. CONCLUSIONS

The rain has been classified into seven categories depending on the rain intensity and season. To improve the results, new Z/R equations have been derived by using the optimization approach. The modified equations show significant improvement in the rainfall rates obtained and the errors are also minimized. The rain regimes are very important characters since the Z/R relationships are hugely dependent on location and type of rain.

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REFERENCES

[1] A. R. M Waleed, M. S. M. Amin, G. Abdul Halim , A. R. M.Sharif and W. Aimrun , "Calibrated radar-derived rainfall data for rainfall-runoff modeling," *European Journal of Scientific Research, ISSN 1450-216X, V*ol. 30, no. 4,pp. 608-619,2009

[2] J. Joss and A. Waldvogel, "Precipitation measurement and hydrology In: Radar in Meteorology. D. Atlas (ED.)," *Am. Meteorol. Soc.,Boston*, pp. 557-606, 1990

[3] L. Peng, S. Xingyuan and T. Wenwen , " A study on Quantitative Radar Rainfall Measurements by the Method of Set-pair analysis," *IEEE, Global Congress on Intelligent Systems,* DOI *1*0.1109/GCIS.2009..75, 2009

[4] S. Hunter, "WSR-88D Radar Rainfall Estimation : Capabilities, limitations and potential improvements," *NWA Digest* ;20:26-36, 2009

[5] S. Chumchean, A. Sharma and A. Seed, "Radar Rainfall Error Variance and its Impact on radar Rainfall Calibration," *Physics and Chemistry of the Earth 28* (2003) 27-39, 2003

[6] M. Steiner, R. A. Houze-Jr and S. E. Yuter, "Climatological Characterization of three dimensional storm structure from operational

radar and rain gauge data," *J. of Applied Meteorology*., 34:1978-2007, 1995

[7] R. Sen , S. Uma and A. Santhakumaran, " Study of Z-R relationship over Gadanki for different rainfall rates," *Indian Journal of Radio and Space Physics*, Vol.38, pp. 159-164, 2009

[8] L. J. Battan, " Radar observation of the atmosphere," The University of Chicago Press, 1973

[9] J. S. Marshall ,and W. Palmer , "The distribution of raindrops with size," J. of Meteor. 5,165-166, 1948.