ABE
Agricultural and Biological Engineering
https://ph04.tci-thaijo.org/index.php/abe/index
Published by the Faculty of Engineering, Khon Kaen University, Thailand

Adjustment of radar rainfall using rain gauge measurement

Ratchawatch Hanchoowong*

Department of Civil Engineering, School of Engineering and Industrial Technology, Mahanakorn University of Technology, Bangkok, 10530, Thailand

*Corresponding author.
Email address: Rhanchoowong@gmail.com

Received 22 April 2024
Accepted 10 May 2024

Abstract

This paper aims to apply characteristic of range dependent error in initial radar rainfall estimates to adjust radar rainfall to be equivalent to ground rainfall. Two different bias adjustment methods were tested which included 1) uniform bias adjustment method and 2) range dependent bias adjustment method. Forty-four rainfall events recorded from the Pimai radar and 50 automatic rain gauges data during 2003-2005 were used in this study. The result of this study showed that using range dependent bias adjustment factors which divided into 2 ranges (less than 70 km and greater or equal to 70 km) for each rainfall event gave the smallest RMSE between radar and rain gauge rainfall. This method can reduce RMSE between radar and rain gauge rainfall about 13% (4.7%) and 2.6% (3.8%) for the calibrated and verified rainfall events when compared to using the climatological bias adjustment factor and the varying bias adjustment factor for each rainfall event without consideration of range dependent error.

Keywords: Radar rainfall, Bias adjustment, Radar rainfall estimates, Pimai radar

1. Introduction

Rainfall data is crucial and necessary in meteorological, water resource development, and agricultural fields. Although the specifics of rainfall data requirements may vary among different plans or projects, the common goal is to obtain data showing the quantity and distribution of rainfall, both spatially and temporally. This contrasts with the need for point rainfall data, which only provides information about rainfall at specific points. Therefore, using rain gauges, which may not be densely distributed in an area, may not accurately represent the actual rainfall quantity in that area [1].

Currently, remote sensing techniques such as meteorological radar are receiving increasing interest for detailed examination and behavior analysis of rainfall. Meteorological radar can provide detailed rainfall information covering the area within its radius and can continuously monitor rainfall as it occurs over a wide area, providing high-resolution rainfall data both spatially and temporally. When combined with rainfall data from rain gauge stations, radar data can significantly improve the accuracy of assessing rainfall reaching the ground. However, radar-based rainfall measurements may still have inaccuracies because radar does not directly measure rainfall quantity. Instead, it utilizes data from the measurement of the strength of electromagnetic waves reflected back to the radar receiver after interacting with raindrops. The strength of these electromagnetic waves received by the radar receiver is converted into radar reflectivity (Z), which depends on the quantity and distribution of raindrops within the volume of air being surveyed. Radar reflectivity is then represented as different color layers in radar images [1].

When using Radar Reflectivity data to estimate rainfall quantity, this data is converted into rainfall intensity (R) using the recommended Z-R relationship equation for the studied area [2]. Prior to utilizing Radar Reflectivity values, data quality checks and adjustments of data inaccuracies must be performed. This process serves as the initial step in radar-based rainfall measurement.

Generally, radar measures Radar Reflectivity values above the ground surface. Therefore, when using radar to measure rainfall at locations far away from the radar station, the influence of the Earth's curvature and the widening of radar waves with distance causes the height and volume of the atmosphere being scanned for rainfall to increase with distance from the radar station. Consequently, the error in rainfall estimation from radar increases with distance from the radar station. Therefore, the next step in radar rainfall measurement is the process of adjusting rainfall from radar above the ground surface to be equivalent to rainfall at the ground level. In this study, this adjustment was made to the preliminary radar-derived rainfall data using the average Z-R relationship equation for the studied area ($Z=56.5R^{1.5}$) [2]. Using rainfall data measured from rain gauge stations located on the ground at positions corresponding to radar data as reference data for adjustment.

The objective of this article is to apply the characteristics of the error in rainfall estimation from radar as a function of distance presented in [3] to adjust the rainfall quantity detected by radar to be equivalent to the rainfall quantity that falls on the ground surface, suitable for the studied area.

2. Materials and methods

2.1 The data used in the study

This study utilizes rainfall event data occurring within a 160 km radius of the Rain Radar station at Luang Phimai, Phimai District, Nakhon Ratchasima Province, during the years 2003-2005. The data includes CAPPI radar image data at a height level of 2.5 km and rainfall data from rain gauge stations located within the radar's radius. Both datasets must pass quality checks and outlier removal criteria due to errors in radar rainfall estimation caused by radar wave interference, abnormal radar wave attenuation, electronic issues, and signal measurement errors not originating from rain. These criteria align with those presented in [3]. Quality assessment results show that rainfall events meeting the data quality criteria and suitable for the study, totaled 44 events. These events were divided into two groups: 1) rainfall event data used for calibration during the years 2003-2004, totaling 39 events, used to find appropriate methods for adjusting radar rainfall for the study area. Details are shown in Figure 1 and 2), rainfall event data from the year 2548, totaling 5 events, used for verification to test the confidence in applying the adjustment methods derived from the first group of data. Details are shown in Figure 2.

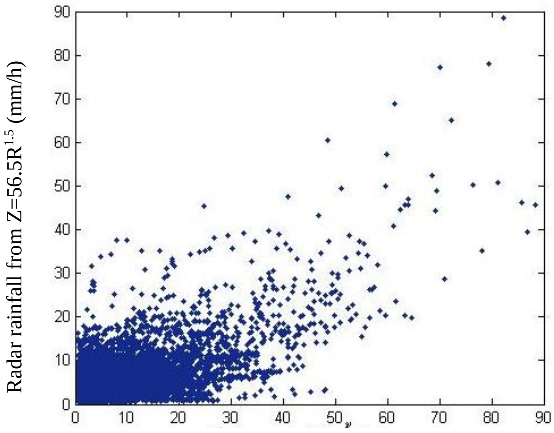

Figure 1 The relationship between radar rainfall and rainfall from rain gauge stations at corresponding positions of rainfall events used for calibration during the period of 2003-2004, totaling 39 events

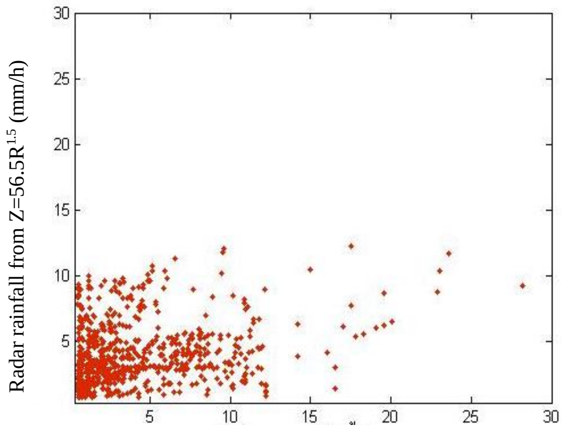

Figure 2 The relationship between radar rainfall and rainfall from rain gauge stations at corresponding positions of rainfall events used for verification during the year 2005, totaling 5 events

2.2 Adjusting radar rainfall to be comparable to rainfall on the ground

Systematic differences between radar rainfall and rainfall from rain gauge stations at corresponding coordinates can be eliminated using rainfall data from rain gauge stations. This can be achieved by finding the Bias Adjustment Factor (G/R), which is the ratio of accumulated rainfall from rain gauge stations (G) to accumulated rainfall from radar (R) calculated using the appropriate Z-R equation. The simplest method to adjust radar rainfall to be comparable to ground-level rainfall is to multiply the Bias Adjustment Factor (G/R) by the radar-derived rainfall quantity calculated using the average Z-R equation for the study area ($Z=56.5R^{1.5}$) [2].

The calculation of the G/R ratio can be done using different methods. For example, methods proposed in [4,5,6,7] offer ways to calculate the G/R ratio based on the distance from the radar station (Range Dependent), which aligns with the findings in [3]. Additionally, each rainfall event may have different characteristics in the distribution of raindrop sizes. Therefore, when calculating the appropriate radar rainfall adjustment factor, it's essential to consider the characteristics of distance-dependent errors caused by the curvature of the Earth and the widening of radar waves with distance [3]. This involves using adjustment factors based on the distance from different radar stations for each event to help reduce errors in radar rainfall estimation. In this study, we examined the appropriate method for adjusting radar rainfall for the study area by comparing two cases of radar rainfall adjustment methods. Case 1) Utilizes a single adjustment factor for all events (Climatological G/R). Case 2) Utilizes different adjustment factors for each rainfall event. In each case, two adjustment methods are employed: 1) Uniform Mean Field Bias Adjustment Factor, and 2) Range Dependent Bias Adjustment Factor.

3. Results and Discussion

The effectiveness of using various radar data adjustment methods on rainfall data, as discussed in section 3, has been evaluated based on the RMSE values between radar rainfall and rainfall measurements from rain gauge stations located at corresponding positions. The study results are presented in Table 1 and Table 2, respectively.

Table 1 The RMSE values for the case of adjustment using the mean adjustment value of all rainfall events.

Case		RMSE (mm/h)					
		$Z=56.5R^{1.5}$		$Z=300R^{1.4}$		$Z=200R^{1.6}$	
		Before adjustment	After adjustment	Before adjustment	After adjustment	Before adjustment	After adjustment
1. the average adjustment method	Calibration	5.31	5.23	7.08	5.42	6.97	5.14
	Verification	5.24	5.20	6.43	5.21	6.29	5.23
2. the distance-based adjustment method (< 70 km) and (≥ 70 km)	Calibration	5.31	5.22	7.08	5.40	6.97	5.14
	Verification	5.24	5.13	6.43	5.14	6.29	5.17
3. the distance-based adjustment method (< 90 km) and (≥ 90 km)	Calibration	5.31	5.19	7.08	5.35	6.97	5.13
	Verification	5.24	5.29	6.43	5.30	6.29	5.31
4. the distance-based adjustment method (< 105 km) and (≥ 105 km)	Calibration	5.31	5.18	7.08	5.34	6.97	5.12
	Verification	5.24	5.30	6.43	5.30	6.29	5.31

Table 2 The RMSE values for the case of adjustment using the adjustment value for each rainfall event

Case		RMSE (mm/h)					
		$Z=56.5R^{1.5}$		$Z=300R^{1.4}$		$Z=200R^{1.6}$	
		Before adjustment	After adjustment	Before adjustment	After adjustment	Before adjustment	After adjustment
1. the average adjustment method	Calibration	5.31	4.67	7.08	4.68	6.97	4.70
	Verification	5.24	5.21	6.43	5.22	6.29	5.24
2. the distance-based adjustment method (< 70 km) and (≥ 70 km)	Calibration	5.31	4.55	7.08	4.59	6.97	4.56
	Verification	5.24	5.01	6.43	5.03	6.29	5.06
3. the distance-based adjustment method (< 90 km) and (≥ 90 km)	Calibration	5.31	4.63	7.08	4.64	6.97	4.65
	Verification	5.24	5.20	6.43	5.21	6.29	5.22
4. the distance-based adjustment method (< 105 km) and (≥ 105 km)	Calibration	5.31	4.65	7.08	4.66	6.97	4.68
	Verification	5.24	5.05	6.43	5.06	6.29	5.07

The study findings reveal that the RMSE values for the case of using the mean adjustment value of all rainfall events obtained from the average adjustment method, both for the entire area and the distance-based adjustment method from the radar stations in all three cases, are higher compared to the case of using separate adjustment values for each rainfall event, as shown in Tables 1 and 2. This is consistent with the theory because rainfall events have different spatial distributions of dispersed water droplets, resulting in different physical characteristics of rainfall events. Therefore, individually considering the adjustment for each rainfall event helps to reduce the error in radar rainfall estimation. Additionally, it was found that evaluating radar rainfall using the $Z=56.5R^{1.5}$ equation both before and after calibration and verification for calibration and verification events yields lower RMSE values compared to using the $Z=300R^{1.4}$ and $Z=200R^{1.6}$ equations in all cases. This demonstrates the benefit of using the $Z=56.5R^{1.5}$ equation derived from radar and rain gauge data comparison [8].

From the results in Tables 1 and 2, it can be concluded that using the equation $Z=56.5R^{1.5}$ to estimate rainfall amounts initially, combined with the distance-based adjustment method from radar stations in Case 1) which is divided into two intervals - the first interval adjusting for distances less than 70 km, and the second interval adjusting for distances greater than or equal to 70 km, for each rainfall event is the adjustment method that provides the least error for the study area. This is because it yields the lowest RMSE values after adjustment for the rainfall events used in calibration and verification, compared to other methods.

The reasons why this method yields lower errors in radar rainfall estimation compared to others are as follows:

Evaluating radar rainfall using the $Z=56.5R^{1.5}$ equation, which is suitable for the study area, helps reduce errors due to the inappropriate use of the Z-R equation.

Rainfall events exhibit different spatial distributions of dispersed water droplets, resulting in different physical characteristics of rainfall events. Therefore, individually considering the adjustment for each rainfall event helps to reduce errors in radar rainfall estimation.

The nature of the error in radar-derived rainfall amounts varies with distance due to the influence of Earth's curvature and the widening of radar beam with distance. Hence, applying distance-dependent error characteristics in calculating radar rainfall adjustment factors helps to reduce errors in radar rainfall estimation better than other methods.

4. Conclusions

1. Each rainfall event exhibits different spatial distributions of dispersed water droplets, leading to varying physical characteristics of rainfall events. Therefore, individually considering the adjustment for each rainfall event helps to reduce the error in radar rainfall estimation even further.

2. Adjusting radar rainfall to be equivalent to ground rainfall by using adjustment factors that vary with rainfall events and considering the distance-dependent error characteristics of radar-derived rainfall amounts helps reduce errors in radar rainfall estimation by 13% (4.7%) and 2.6% (3.8%) for calibration (verification) events, respectively, compared to using a single mean adjustment value for all rainfall events and using adjustment factors that vary with each event without considering distance-dependent errors due to Earth's curvature and the widening of radar beam with distance.

3. Evaluating rainfall from the Phimai radar station using the $Z=56.5R^{1.5}$ equation combined with the distance-based adjustment method from the radar station, divided into two intervals - the first interval adjusting for distances less than 70 km and the second interval adjusting for distances greater than or equal to 70 km, for each rainfall event, results in more accurate radar rainfall estimation from the Phimai radar station compared to the current method. The proposed adjustment method can be practically applied to the Phimai radar station.

5. Acknowledgements

This study extends gratitude to the personnel of the Royal Rainmaking and Agricultural Aviation Center, the Suphan Buri Royal Rainmaking Operation Research Center, and the Hua Hin Royal Rainmaking Operation Research Center for their assistance in data analysis and various facilitations throughout the study.

6. References

[1] Chumchuen S. The impact of checking the quality of rain data from rain gauge stations on the amount of rain from radar. 11th National Civil Engineering Conference. 2006.

[2] Chumchuen S. Analysis and evaluation of royal rain operations, case study: Rainfall assessment with weather radar in the Northeastern region of Thailand. Bangkok; Office of Royal Rainmaking and Agricultural Aviation. 2009.

[3] Hanchoowong R, Chumchuen S, Veesakul U. Distance-based errors in rainwater estimation from radar. 15th National Civil Engineering Conference. Ubon Ratchathani University. 2010.

[4] Wilson JW. Integration of radar and rain gauge data for improved rainfall measurement. J Appl Meteorol. 1970;9:489-497.

[5] Brandes EA. Optimising rainfall estimates with the aid of radar. J Appl Meteorol. 1975;14:1339-1345.

[6] Collinge V K. 1991. Weather radar calibration in real time: Prospects for improvement in: Hydrology Applications of Weather Radar, Eds. Cluckie ID, Collier CG, Ellis Horwood, Chinchester. U.K. 1991. 25-42.

[7] Seo DJ, Breidenbach JP. Real time correction of spatially nonuniform bias in radar rainfall data using rain gauge measurements. J Hydrometeorol. 2002;3:93-111.

[8] Chumchean S, Aungsuratana P, Khommuang A, Hanchoowong R. 2009. Study of Rain-Cloud Characteristics Using Weather Radar Data, 18th World IMACS / MODSIM Congress., Cairns, Australia. 2009.