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Analysis of rainfall intensity for radar rainfall estimation in the composite area of Takhli and Sattahip radar

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Abstract

This study collected rainfall event data, totaling 510 events between February 2018 and November 2019. The data includes hourly rainfall amounts (R) from 238 ground-based automatic weather stations and reflectivity data (Z) from radar systems within a 240 km radius of the Takhli and Sattahip radars. The study aimed to find the Z-R relationship used to estimate rainfall from the Takhli and Sattahip radars and apply it to assess radar rainfall intensity in the Composite radar coverage area. Analysis for radar rainfall intensity in the Composite area involved five methods: (1) $Z = 138R^{1.6}$ for Takhli radar, (2) $Z = 170R^{1.6}$ for Sattahip radar, and composite rainfall intensity methods from equations (3) $Z = 200R^{1.6}$ (Marshall and Palmer), (4) $Z = 300R^{1.4}$ (Woodley and Herndon), and (5) a combination of $Z = 138R^{1.6}$ for Takhli and $170R^{1.6}$ for Sattahip radars. The assessed rainfall intensity was then compared with ground-based automatic weather station data to determine the most accurate rainfall intensity. This comparison was based on Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and BIAS statistics, aiming for minimal values. The study found that the Composite rainfall intensity assessed from method 5 was the most accurate compared to methods 1–4. Specifically, the RMSE values increased by 22.26%, 10.25%, 3.89%, and 18.02%, while MAE values increased by 29.75%, 23.14%, 14.88%, and 14.88%, and BIAS values increased by 361.54%, 42.31%, 100.00%, and 369.23%, respectively.

Keywords: Radar reflectivity, Takhli radar, Sattahip radar, Rainfall intensity, Automated telemetry station

1. Introduction

Thailand often faces frequent natural disasters, particularly in the eastern, western, and central regions, which are areas that receive water runoff from the high northern mountains. This includes both flooding and drought issues, stemming from problems with inadequate and poorly managed water resource management systems. Effective water resource management requires accurate data showing the quantity and distribution of rainfall both spatially and temporally. Therefore, rainfall measurement using traditional rain gauge stations [1], which cover only a 200 cm² area, along with areas lacking rain gauge stations installed, such as deep forests, mountainous terrain, and remote areas, results in a shortage of accurate spatial rainfall data essential for water management. Currently, there is a preference for employing long-range surveying technology with weather radar for rainfall measurement. Weather radar can continuously detect and measure rainfall immediately when it covers the area within its detection radius. It provides rainfall data with high spatial and temporal resolution [2-7].

Therefore, if the rainfall spatial data obtained from weather radar is used in conjunction with rainfall data from ground-based rain gauge stations, it will enhance the accuracy of the spatial rainfall assessment measured by radar [8-9]. However, because weather radar does not directly measure rainfall, it instead emits electromagnetic waves to conduct rainfall measurements. After these waves interact with raindrops, they are reflected to the radar receiver and converted into radar reflectivity (Z, mm^6/m^3). These Radar Reflectivity values vary depending on the size and characteristics of the rain drop size distribution within a particular volume of airspace. When the Radar Reflectivity data is used to estimate rainfall amounts, it is converted into rainfall intensity data (R, mm/h) using the Z-R (($Z=aR^b$) relationship equation appropriate for the studied area [10-14]. Applying this will enhance the accuracy of assessing the rainfall that reaches the ground when combined with rainfall data obtained from rain gauge stations. Additionally, it will improve the accuracy of assessing radar rainfall in the composite area of the Takhli radar and the Sattahip radar. Therefore, this study applies the Z-R relationship equation suitable for the Takhli radar and the Sattahip radar to assess rainfall collectively, resulting in a more accurate estimation of radar rainfall intensity in the composite area compared to using only the Z-R relationship equation for either the Takhli radar or the Sattahip radar.

2. Materials and methods

The Composite area of Radar Takhli and Radar Sattahip is an area located within a radius of 240 km from Radar Takhli and Radar Sattahip, as shown in Figure 1. This study has collected rainfall events occurring within the 240 km radius of the Royal Thai Meteorological Department (TMD) radar station, Takhli, which is a Dual polarization S-band radar type, measuring every 6 minutes from all 14 elevation angles, namely 0.5°, 1.3°, 2.3°, 3.4°, 4.7°, 6.2°, 7.9°, 9.8°, 12.1°, 14.7°, 17.7°, 21.2°, 25.2°, and 29.8°, respectively, from August 2018 to November 2020. Additionally, rainfall data from the Sattahip Royal Thai Navy radar station, which is a Doppler S-band radar type, measuring every 6 minutes from all 14 elevation angles, namely 0.5°, 1.5°, 2.4°, 3.4°, 4.3°, 5.2°, 6.2°, 7.5°, 8.7°, 10.0°, 12.0°, 14.0°, 16.7°, and 19.5°, respectively, from February 2018 to November 2020, were collected. The data collected includes radar reflectivity (Z) in Volume files format and rainfall data from automatic ground-based weather stations of the Hydro Informatics Institute (HAII). For each rainfall event used in the study, there must be corresponding radar rainfall data and rainfall data from automatic ground-based weather stations that are consistent, and both sets of data must undergo quality control and correction before being used in the study.

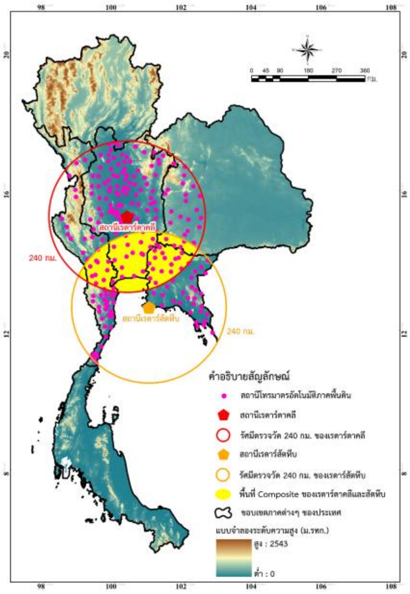


Figure 1 Composite area of radar within the 240 km detection radius of Takhli Radar and Sattahip Radar

This study has examined data quality and corrected discrepancies in the radar wave reflectivity data of Takhli Radar and Sattahip Radar, which were impacted by issues such as radar waves interacting with ground clutter, such as mountains, buildings, or other structures on the ground that are not rain-related, resulting in data discrepancies. To address the data discrepancies caused by ground clutter, this study has constructed a Ground Clutter Map. The reflectivity data of radar waves located in ground clutter areas have been newly adjusted by interpolation method from neighboring pixel reflectivity values [15-16].

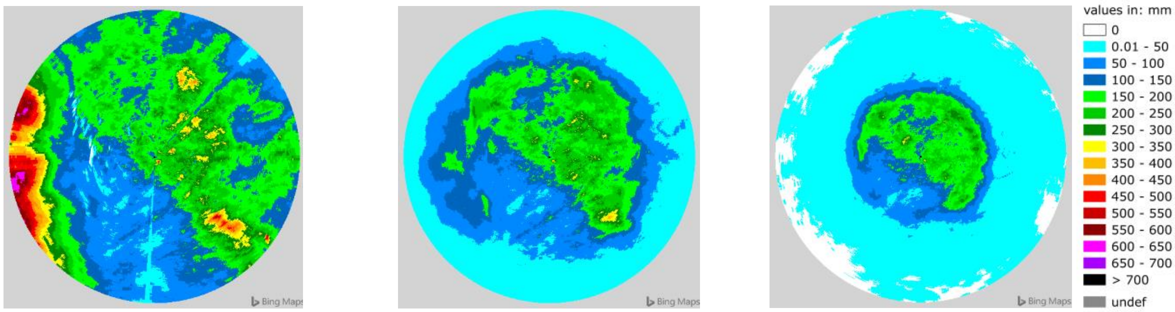
Impact resulting from radar waves interacting with permanent reflectors, causing radar reflectivity values measured in areas behind obstacles to be lower than usual, this study has addressed this by utilizing monthly cumulative rainfall radar reflectivity data to identify locations of beam blockage. Radar reflectivity values of pixels located in beam blockage positions have been adjusted by interpolation method from neighboring pixel reflectivity values [15-16]. While the impact due to radar wave energy being absorbed (attenuation) when passing through gases in the atmosphere, water vapor, oxygen, and rainfall volume [17-18], the energy of radar waves is absorbed and attenuated. The degree of signal sensitivity to energy reduction depends on the wavelength of the radar waves emitted. Energy reduction poses a challenge for X-band and C-band radars, with wavelengths of 2.5 and 5.5 cm, respectively. However, it is not an issue for S-band radars, which have a wavelength of 10.7 cm [19].

Therefore, for Takhli Radar and Sattahip Radar, which are S-band radars, they are not affected by attenuation issues. To avoid the impact on radar reflectivity values, only signals not originating from rain are considered. Therefore, radar reflectivity data with values greater than 15 dBZ are selected. Additionally, to avoid reflections from insects, only radar signals with reflectivity values exceeding 53 dBZ are considered, and any values above 53 dBZ are capped at 53 dBZ [20]. The radar reflectivity data of Takhli Radar and Sattahip Radar, after adjusting for angular measurement errors from the 14 angles, were selectively analyzed to find the most suitable measurement angles. These angles were chosen based on their ability to cover rainfall groups within the detection radius of Takhli Radar and Sattahip Radar, closely approximating the rainfall quantity measured by automatic ground-based weather stations. Additionally, these angles exhibited the least amount of errors after adjusting for ground clutter and beam blockage issues.

The examination of suitable measurement angles for Takhli Radar and Sattahip Radar included examples of the three angles closest to the ground as shown in figure 2 and 3. It was observed that at the first measurement angle (Takhli Radar: 0.5°, Sattahip Radar: 0.5°), there was still a significant issue with beam blockage. However, at the second measurement angle (Takhli Radar: 1.3°, Sattahip Radar: 1.5°), the problem with beam blockage decreased, and rainfall group measurements were still adequately covered within the detection radius of the radar stations.

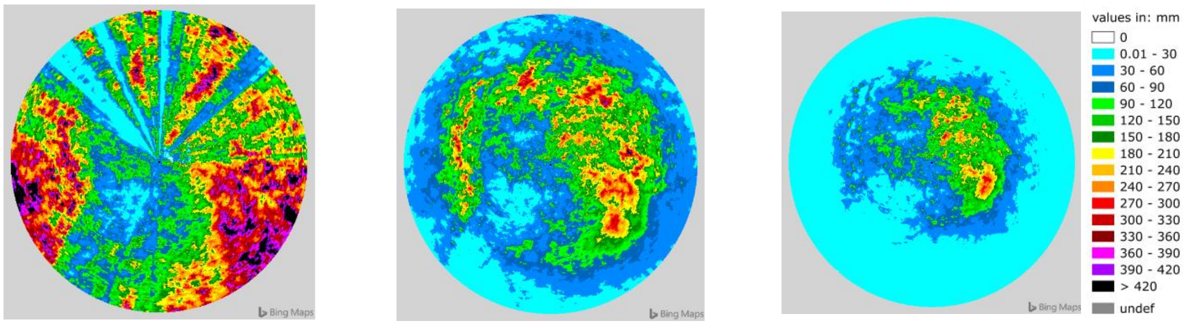
When considering the third measurement angle (Takhli Radar: 2.3°, Sattahip Radar: 2.4°), rainfall group measurements were slightly reduced compared to the second measurement angle (Takhli Radar: 1.3°, Sattahip Radar: 1.5°).

Based on these considerations regarding data quality after adjustments, it was concluded that the most suitable measurement angle for Takhli Radar and Sattahip Radar is the second measurement angle (Takhli Radar: 1.3°, Sattahip Radar: 1.5°). This angle provided the best balance between minimizing errors caused by ground clutter and beam blockage while ensuring adequate coverage of rainfall group measurements within the radar stations' detection radius.



(a) Angle 0.5° (b) Angle 1.3° (c) Angle 2.3°

Figure 2 Example area of accumulated monthly rainfall measured from Takhli radar from three elevation angles of the rainfall event in August 2019



(a) Angle 0.5° (b) Angle 1.5° (c) Angle 2.4°

Figure 3 Example area of accumulated monthly rainfall measured from Takhli radar from three elevation angles of the rainfall event in July 2019

This study examined the quality of hourly rainfall data from automatic ground-based weather stations that passed the validation criteria using the Double Mass Curve method, with an R-squared statistic greater than 0.90, and utilized them for analysis. For the details of the rainfall data quality check using the Double Mass Curve method, the cumulative hourly rainfall data of the station under investigation was plotted against the average cumulative hourly rainfall data of neighboring stations. If the rainfall data of the station under investigation conformed to those of neighboring stations, the slope of the Double Mass Curve graph would remain significantly unchanged or with a constant slope. Meanwhile, the R-squared analysis of the station under investigation's rainfall data involved comparing the cumulative hourly rainfall data with the average cumulative hourly rainfall data of neighboring stations for analysis. If the rainfall data of the station under investigation correlated with those of neighboring stations and had an R-squared statistic greater than 0.90, the station under investigation was considered to pass the data quality validation.

The examination of hourly rainfall data quality from automatic ground-based weather stations collected from January 2018 to November 2020, totaling 238 stations, revealed that 233 stations passed the data quality validation, while 5 stations did not. To ensure accurate rainfall quantity assessment using radar data, this study utilized rainfall data from automatic ground-based weather stations that passed the data quality validation and were not located within the radar blind zone of each radar station (within a 10 km radius from the radar station). This was because radar stations have limited rainfall detection capability within their blind zones. The automatic ground-based weather stations that passed the data quality validation and were used in this study for each area are summarized in Table 1.

Table 1 Automatic Ground-Level Telecommunication Station that has passed quality inspection

Area	**No. of automatic Ground-Level Telecommunication Stations**			
	passed quality inspection	**failed quality inspection**	**Located in a radar blind spot**	**Study**
Area within the Takhli radar detection radius only	124	4	1	123
Area within the Sattahip radar detection radius only	62	1	1	61
Composite area	47	-	-	47

3. Results and Discussion

3.1 Analysis to find the Z-R relationship equation

The results of the analysis to find the suitable Z-R relationship equation for the Takhli radar at an elevation angle of 2 degrees (1.3°) indicate that the equation $Z = 138R^{1.6}$ is appropriate. The estimated rainfall intensity closely matches the rainfall intensity measured by the automatic ground-based rain gauge stations compared to the estimations using the equations $Z = 200R^{1.6}$ [10] and $Z = 300R^{1.4}$ [21], respectively. When considering the Root Mean Square Error (RMSE) values as shown in Table 3, it's found that the RMSE value for the rainfall intensity estimated using the equation $Z = 138R^{1.6}$ is lower than that for the estimations using the equations $Z = 200R^{1.6}$ and $Z = 300R^{1.4}$, in order.

Similarly, the results of the analysis to find the suitable Z-R relationship equation for the Sattahip radar at an elevation angle of 2 degrees (1.5°) indicate that the equation $Z = 170R^{1.6}$ is appropriate. The estimated rainfall intensity closely matches the rainfall intensity measured by the automatic ground-based rain gauge stations compared to the estimations using the equations $Z = 200R^{1.6}$ [10] and $Z = 300R^{1.4}$ [21], respectively. When considering the RMSE values as shown in Table 4, it's found that the RMSE value for the rainfall intensity estimated using the equation $Z = 170R^{1.6}$ is lower than that for the estimations using the equations $Z = 200R^{1.6}$ and $Z = 300R^{1.4}$, respectively.

3.2 Analysis to determine rainfall intensity from radar at pixel locations with composite processing using the Relative Weight Matrix method.

In this study, we present five methods for assessing radar rainfall intensity at pixel locations with composite processing of both the Takhli and Sattahip radars. These methods include:

Method 1: Rainfall intensity estimated solely from the equation Z = 138R^1.6 using only the Takhli radar.
Method 2: Rainfall intensity estimated solely from the equation Z = 170R^1.6 using only the Sattahip radar.
Method 3: Composite rainfall intensity estimated from the equation Z = 200R^1.6.
Method 4: Composite rainfall intensity estimated from the equation Z = 300R^1.4.
Method 5: Composite rainfall intensity estimated from both the equations Z = 138R^1.6 for the Takhli radar and Z = 170R^1.6 for the Sattahip radar.

These five methods will be analyzed to determine the most suitable method for assessing radar rainfall intensity at pixel locations with composite processing of both the Takhli and Sattahip radars in the subsequent section.

3.3 Analyzing methods for assessing radar rainfall intensity at pixel locations with composite processing to determine suitability

The results from the statistical measures RMSE, MAE, and BIAS of the methods for assessing radar rainfall intensity at pixel locations with composite processing of both the Takhli and Sattahip radars, all five methods, are compared with rainfall intensity from automatic ground-based rain gauge stations (mm/h) in Figures 4-6.

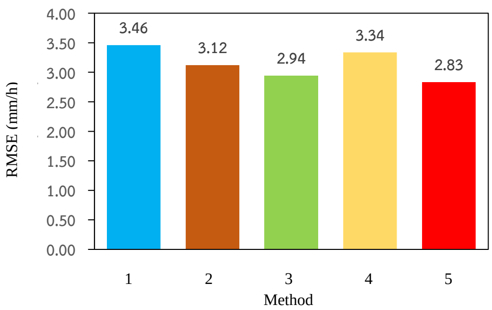


Figure 4 The RMSE of the methods for assessing radar rainfall intensity, all five methods, compared to rainfall intensity from automatic ground-based rain gauge stations.

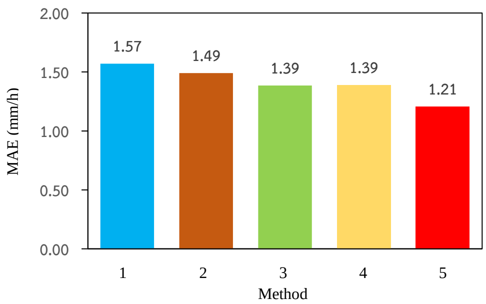


Figure 5 The MAE of the methods for assessing radar rainfall intensity, all five methods, compared to rainfall intensity from automatic ground-based rain gauge stations.

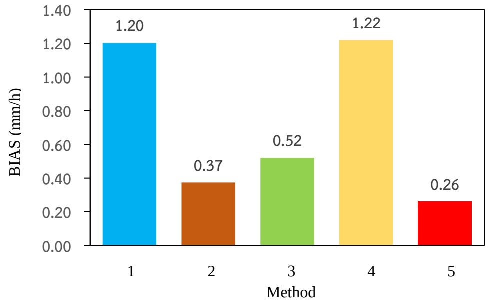


Figure 6 The BIAS of the methods for assessing radar rainfall intensity, all five methods, compared to rainfall intensity from automatic ground-based rain gauge stations.

Considering the RMSE, MAE, and BIAS statistics, it is found that Method 5, which assesses composite rainfall intensity using the equations $Z = 138R^{1.6}$ for the Takhli radar combined with $Z = 170R^{1.6}$ for the Sattahip radar, demonstrates the highest accuracy in rainfall intensity assessment compared to Methods 3, 2, 4, and 1. These findings align with the study's results of [22-26]. Stating that the method for assessing radar rainfall intensity at pixel locations with composite processing, which is far from both the Takhli and Sattahip radar stations, still exhibits some residual error when estimating rainfall using Method 1, which relies solely on the equation $Z = 138R^{1.6}$ for the Takhli radar, and Method 2, which relies solely on the equation $Z = 170R^{1.6}$ for the Sattahip radar. This remaining error is due to the influence of the Earth's curvature and the widening of radar waves over distance. Therefore, when using composite rainfall intensity values obtained from Method 5, Method 3, and Method 4, it helps improve the accuracy of radar rainfall intensity assessment at pixel locations with composite processing of both the Takhli and Sattahip radars [27-29]. As it can help reduce the error in reflectivity measurements when detecting rainfall from both the Takhli and Sattahip radars due to the influence of the Earth's curvature and the widening of radar waves over distance, respectively.

4. Conclusions

- The composite rainfall intensity values obtained from Method 5, Method 3, and Method 4 help improve the accuracy of radar rainfall intensity assessment at pixel locations with composite processing of both the Takhli and Sattahip radars compared to rainfall intensity estimation using Method 1, which relies solely on the equation $Z = 138R^{1.6}$ for the Takhli radar, or Method 2, which relies solely on the equation $Z = 170R^{1.6}$ for the Sattahip radar. This improvement is due to their ability to reduce the error in reflectivity measurements when detecting rainfall from both the Takhli and Sattahip radars, respectively.
- The composite rainfall intensity values obtained from Method 5, when compared to rainfall intensity estimated from Methods 1 to 4, can significantly increase the accuracy of rainfall assessment. When considering the RMSE values, they can enhance accuracy by 22.26%, 10.25%, 3.89%, and 18.02%, respectively. Regarding MAE values, they can increase accuracy by 29.75%, 23.14%, 14.88%, and 14.88%, respectively. Lastly, when considering BIAS values, they can increase accuracy by 361.54%, 42.31%, 100.00%, and 369.23%, respectively.

5. Acknowledgements

This study extends gratitude to the Department of Royal Rainmaking and Agricultural Aviation for providing the radar reflectivity data from both the Takhli and Sattahip radars stored in Volume Files format, as well as to the Hydro Informatics Institute (Public Organization) for providing hourly rainfall data from automatic ground-based rain gauge stations and various facilities throughout the study period.

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