Determining the appropriate altitude to improve accuracy in rainfall estimation from radar reflectivity data.

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Abstract. In present day, rainfall estimation by weather radar is widely used. Meteorologists use various z-r relationships to appropriate rainfall estimation for different study areas which have different factors such as topography, climate, rain pattern, types of clouds, etc. This research aims to determine the appropriate altitude of radar reflectivity (Z-Level) to provide accurate rainfall estimation. This research will use radar reflectivity data (Z) from Omkoi radar station, which is owned by the Department of Royal Rainmaking and Agricultural Aviation (DRRAA). It uses radar reflectivity data from 1.5 to 13.5 kilometers above mean sea level. We convert it to daily rainfall from radar (R) using Omkoi Z-R relationship (Z=92.4R^1.5) and compare the result to daily rainfall measured by rain gauge stations (G) from 82 rain gauge stations of Thai Meteorological Department (TMD), covering areas within radius of Omkoi radar station (180 km) in the northern of Thailand. The study will consider comparing various statistics of rainfall from radar (R) and rainfall from rain gauges (G), such as correlation coefficients, root mean square error (RMSE) and the characteristic distribution of graphs (Scatter Plot). The results show that the radar reflectivity data in altitude 3.5 km above mean sea level are the most suitable to be used to determine the Z-R Relationship. Therefore, determination of Z-R relationship of Omkoi radar station should be based on the radar reflectivity data at altitude 3.5 km above mean sea level.

1. Introduction

In present day, rainfall estimation by weather radar is widely used. Meteorologists use various z-r relationships to appropriate rainfall estimation for different study areas which have different factors such as topography, climate, rain pattern, types of clouds, etc. This research aims to determine the appropriate altitude of radar reflectivity (Z-Level) to provide accurate rainfall estimation.

Radar reflectivity in each altitude have relationship with rainfall measured by rain gauge. Relationship will vary according to the distribution of reflectivity, which affects the accuracy of radar rainfall estimation and each radar station has different appropriate altitude. Therefore, determining the appropriate altitude is important. It should have a proper altitude before. It will make an assessment of rainfall radar station that has the highest precision.

In this research, the criteria used in determining the proper altitude will consider various statistics, such as root mean square error (RMSE), pearson correlation coefficient, mean absolute error (MAE), bias and consider the distribution graph of rainfall from the radar (R) and rainfall from rain gauge (G) (scatter plot).

2. Literature review

2.1. Radar reflectivity factor

The reflectivity factors at horizontal and vertical polarizations are given by:

$$Z = \frac{\lambda^4}{\pi^5|K|^2}\int \sigma(D)N(D)dD$$

Where D = drop diameter
λ = radar wavelength
$|K|^2$ = refractive index of the hydrometeors (approximately 0.93 for water and 0.20 for ice)
$\sigma(D)$ = backscattering cross section of scatterers
$N(D)$ = drop size distribution

If the scatterers are considered as small water spheres with small radii compared to the radar wavelength, then the approximation of the Rayleigh scattering applies and Equation can be expressed as:

$$Z = \int D^6 N(D)dD$$

2.2. Z-R Relationship

Weather radar can effectively provide high resolution either spatial and temporal rainfall estimation. Rainfall estimation using weather radar in areas with insufficient rainfall stations. Weather radar cannot be used to measure rainfall intensities directly, so relationship between radar reflectivity data (*Z*) and rainfall rate (*R*), called the *Z-R* relationship (Z = aR^b) is used to estimate rainfall intensities using radar. (Mapiam and Sriwongsitanon, 2008)

The Z-R relationship is represented in term of empirical power law equation as below:

$$Z = aR^b$$

Where Z = radar reflectivity ($mm.^6/m.^3$)
R = rainfall intensity (mm./hr.)
a and b = parameters

2.3. Statistical measures

In this study, we use 4 various statistical values to determine the appropriate altitude of radar reflectivity data for rainfall estimation.

2.3.1. Mean Absolute Error (MAE). In statistics, mean absolute error (MAE) is a measure of difference between two continuous variables. Assume X and Y are variables of paired observations that express the same phenomenon. Examples of Y versus X include comparisons of predicted versus observed, in this study we use R and G, R is predicted and G is observed.

2.3.2. Root Mean Square Error (RMSE). RMSE is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed.

2.3.3. Bias. Statistical bias is a feature of a statistical technique or of its results whereby the expected value of the results differs from the true underlying quantitative parameter being estimated.

2.3.4. Pearson correlation coefficient. Pearson correlation coefficient is a measure of the linear correlation between two variables X and Y. It has a value between +1 and −1, where 1 is total positive linear correlation, 0 is no linear correlation, and −1 is total negative linear correlation. It is widely used in the sciences.

3. Methodology

3.1. Data

This research will use radar reflectivity data (Z) from Omkoi radar station, which is owned by the Department of Royal Rainmaking and Agricultural Aviation (DRRAA). It uses radar reflectivity data from 1.5 to 13.5 kilometers above mean sea level and convert to daily rainfall data from radar (R) by using Omkoi Z-R relationship (Z=92.4R^1.5) and use daily rainfall data measured by rain gauge stations (G) from 82 rain gauge stations of Thai Meteorological Department (TMD), covering areas within radius of Omkoi radar station (180 km) in the northern of Thailand. (**Figure 1.**)

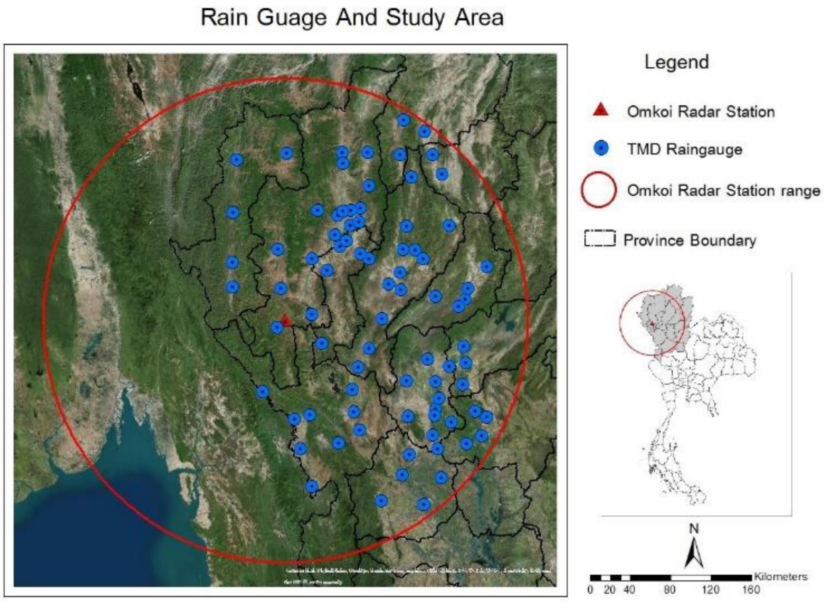

Figure 1. Rain gauge and study area map

3.2. Select altitude

After matching radar reflectivity and rainfall, will then calculate and compare various statistics of rainfall from radar (R) and rainfall from rain gauges (G), such as correlation coefficients, root mean square error (RMSE) and the characteristic distribution of graphs (Scatter Plot).

After calculate the statistics, select data by select by date and station which have correlation coefficient more than average and select altitude (Z-Level) by the statistics which have error less than average and consider the scatter plot of rainfall from the radar (R) and rainfall from rain gauge (G).

4. Result

4.1. Statistical comparison between before and after the selected altitude.

Table 1. Statistics of dataset before and after selected altitude.

Data	N	Pearson	MAE	RMSE	Bias
Before (All Z-Level)	23997	0.27	10.9	17.5	1.22
After (Z-Level 2.5-5.5)	5691	0.57	9.1	14.9	0.82

4.2. Statistical comparison between Z-R relationships obtained from data before and after the selected altitude.

Table 2. Statistics of Z-R relationship obtained from data before and after the selected altitude.

ZR	Pearson	MAE	RMSE	Bias
Z-R Before (a=30.603, b=1.5691)	0.27	15.96	27.73	0.68
Z-R After (a=105.06, b=1.5282)	0.57	8.15	12.98	0.95

4.3. Statistical comparison between each selected altitude.

4.3.1. Use Omkoi Z-R relationship (Z=92.4R^1.5)

Table 3. Statistics of data from each altitude use Omkoi Z-R relationship.

Z-Level	Pearson	RMSE	Bias
2.5	0.58	11.56	1.03
3	0.58	11.45	1.02
3.5	0.58	11.37	1.01
4	0.58	11.64	0.98
4.5	0.58	11.66	0.96
5	0.58	11.68	0.96
5.5	0.58	13.49	0.79

4.3.2. Use Z-R relationship obtained from each altitude.

Table 4. Statistics of data used Z-R relationship obtained from each altitude.

Z-Level	Pearson	RMSE	Bias
2.5	0.41	13.5	1.02
3	0.42	13.3	1.01
3.5	0.43	13.2	1.01
4	0.42	13.6	0.99
4.5	0.42	13.6	0.99
5	0.42	13.6	0.98
5.5	0.35	15.4	0.97

5. Conclusion

The results from all altitude (1.5-13.5km.), the appropriate altitude range for rainfall estimation is 2.5-5.5km. Because the set of data after selected altitude range have more correlation than before selected and have less errors than before selected altitude (**Table 1.**) and the Z-R relationship obtained from the selected altitude range (2.5-5.5km.) also provide more accuracy than before selected altitude range (**Table 2.**) and when evaluate Z-R relationship of each selected altitude and calculate statistics, the appropriate altitude to improve accuracy in rainfall estimation from radar reflectivity data is 3.5 km above mean sea level. (**Table 3.** and **Table 4.**). Because the water droplet in raincloud in altitude 3.5 km is the most relate to rainfall rate measured by the rain gauge station.

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