Study of Z-R relationship among different topographies in Northern Thailand

N Auipong and P Trivej
Department of Earth Sciences, Faculty of Science, Kasetsart University
E-mail: fscipntr@ku.ac.th

Abstract. Topography can affect climate. Different topographies have different climates. Rainfall in each area varies by topography. Northern Thailand has been chosen as a study area due to its various topographies such as ridge, flat, plain and valley. This research studies reflectivity data and rainfall rate. Z-R relationship is a relationship between a radar reflectivity (Z) and a rainfall rate (R). Z-R relationship can be used to determine characteristics of precipitation and rainfall and can be applied in hydro-meteorological model to forecast the weather. Data are from Omkoi Radar Station, covering the area of 240 kilometre around the station. Further, daily rainfall data have been gathered from Thai Meteorological Department. In this study, topographies are classified by Topography Position Index, showing highland, flat and valley. The results show that the empirical relations of rainfall rate and reflectivity measured by radar vary among different topographies which are highland, flat and valley, i.e. 

\[ Z = 94R^{1.5} \]

\[ Z = 137R^{1.5} \]

\[ Z = 143R^{1.5} \]

respectively. The data indicates that if A parameter is low, the cloud is cumulonimbus. If value of A parameter is high, the cloud is nimbostratus. The variety of rain-cloud type and Z-R relationship also varies by topography.

1. Introduction
The rain is important for human in many ways, for example in agriculture, transportation, communication and consumption. Too high or too low rainfall affect living things. Moreover, the different topography lead to different rainfall. For weather radar rainfall estimation, consider relationship between the rainfall rate and radar reflectivity called the Z-R relationship [1] as followed by equation (1):

\[ Z=AR^b \] (1)

Z is reflectivity (mm^2/m^3), R is rainfall rate (mm/h), A and b are the relationship parameters which depend on the raindrop number distribution and raindrop diameter. Study the A parameter of the proposed Z-R relationship of cumulonimbus and nimbostratus rain-cloud. A value of cumulonimbus is higher than those nimbostratus. The rainfall intensity of nimbostratus rain-cloud is lower than those of cumulonimbus because the nimbostratus rain-cloud produces a larger amount of raindrop with smaller diameters than the cumulonimbus rain-cloud. In this study, Northern part of Thailand has been chosen as a study area due to various topographies such as ridge, flat, plain and valley. This area is covered by an Omkoi radar station. The purpose of this research is to study the influence of topography on the Z-R relationship.
2. Methodology

Data collection has been gathered from Thailand Meteorological Department and Department of Royal Rainmaking and Agriculture Aviation. Next step is the data processing including topographical classification, Z-R Matching Techniques, and static analysis of rainfall each group. There are different varieties of topography in the Northern part of Thailand. This area covered by mountain, plain, and valley. The area is clearly different from other part of Thailand, it locates in Omkoi radar radius. Omkoi radar station covers 240 kilometres radius covering Mae Hong son, Lampoon, Lampang, Præe, Sukhothai, Chaingmai, Tak, Kamphaengphet, and some parts of Uttaradit, Chiangrai, Payao, Nan and Pitsanulok. There are 82 gauge rainfall station around Northern part of Thailand but only 41 stations are active for collection. The rainfall data and reflectivity data since January 2015 to December 2015. Rainfall station were operated by Thai Meteorological Department (TMD) within the Omkoi radar radius as represented in figure 1.

![Figure 1. The Omkoi radar radius cover daily rainfall station in Northern Thailand.](image)

Finally, the data processing mainly consists of topographical classification by using GIS software and topographic classification by location of rain gauge Z-R matching techniques

2.1 Topographic classification

Topographic classification by using geographic information system (GIS). The input data from a Digital Elevation Model (DEM) has been collected a resolution of 30 x 30 m. To set topographic classify, it depends on slope and topographic position index. The Topographic Position Index (TPI) is an algorithm for classifying and comparing a cell elevation value and the divide elevation of a neighbourhood around that cell. Negative TPI indicates that the location tends to be bottom of valley while position. TPI indicates that locations tend to be top of a hill or ridge and TPI with nearly zero indicates locations tend to be flat area or mid-slope area. In this study, land facet corridor designer tool was used for creating 6-class TPI raster based on TPI standard deviation (SD). In this study, automate topographic classification using criteria derived from GIS [2]. As with the TPI thresholds of each classification, highland was distinguished using a TPI value of > +1 SD, flat were used a TPI value between of ≥-0,5 SD and ≤0,5 SD using a threshold slope value of 5° and valley using TPI value of < -1.0 SD. A full description of each topographic classification can be found [2-3]. The result showed in the Table 1 as follow:
Table 1. Topographic classification in Northern part of Thailand (modified from [2-3]).

| Topography category | Description                      | In Combination with          |
|---------------------|----------------------------------|------------------------------|
| Highland            | Areas are mid TPI shallow slope  | Ridge & Upper Slope          |
| Flat                | Areas are lower than flat and low TPI | Middle Slope & Flat Slope |
| Valley              | Areas are lower slope and very low TPI | Lower Slope & Valley |

2.2 Z-R Matching Techniques

There are several Z-R matching techniques. In this study, Probability Matching Method (PMM), was applied because it is well-understood. The matching is done between the cumulative distribution function (CDFs) of Z value and R from rain gauge measurement [4] as described in equation (2). P(R) is probability density function of rainfall from rain gauge measurement and P (Z) is the probability density function of radar reflectivity values by radar [5], as equation (2):

\[
\int_{R_{l}}^{\infty} P(R) dR = \int_{Z_{l}}^{\infty} P(Z) dZ
\]  

3. Results

There are 385 events of Z-R pairs from PMM for highland, 423 events of Z-R pair from PMM for flat and 316 events of Z-R pair from PMM for valley. b is fixed at 1.5 because b does not affect to RMSE, and A is used in order to set least value of RMSE as shown in table 2.

Table 2. Z-R pairs from Probability Matching Method (PMM).

| Group     | Event | b parameter | A parameter | RMSE |
|-----------|-------|-------------|-------------|------|
| Highland  | 385   | 1.5         | 94          | 2.66 |
| Flat      | 423   | 1.5         | 137         | 5.49 |
| Valley    | 316   | 1.5         | 143         | 2.37 |

The results show that the empirical relationship between rainfall rate and reflectivity measured by radar varying between different topography which are highland, flat and valley for \( Z = 94R^{1.5} \), \( Z = 137R^{1.5} \) and \( Z = 143R^{1.5} \) respectively. The A parameter obtained from the PMM method varies to topography rain-cloud type. The A parameter presents Z-R relationship of rain-cloud type including cumulonimbus and nimbostratus. Therefore, nimbostratus rain-cloud should be lower than cumulonimbus for the similar reflectivity value. Because the nimbostratus produces a large amount of droplets with small size and cumulonimbus produces a small amount of droplets with big size as shown in equation of radar reflectivity factor as equation (3):

\[
Z = \sum_i N_i D_i^6
\]  

Where Z is rain are calculated assuming Rayleigh scattering of the same rainfall intensity, D is diameter of droplets or size of droplets and N is numerical of droplets. Accordingly, when high A parameter rain-cloud tend to be nimbostratus and less parameter A rain-cloud tend to be cumulonimbus [6]. The summary of output in this study, the A parameter of highland is less than that of flat and valley. So, rain-cloud type of highland tends to be cumulonimbus and rain-cloud type of flat and valley tend to be nimbostratus.
From figure 2, adjust value of rainfall measured on different scale to standard common scale. Rainfall in three parts was analysed and it was found that in the valley there was more rainfall than highland in period 0.5 mm. Although in the beginning of the data collecting day it rained heavier in flat and valley rather than highland, but when analysing the amount of rain in whole day, highland have heavy rain more than other areas.

4. Discussion and Conclusion
The study on Z-R relationship among difference topographies. Found that if value of A parameter is low, the cloud is cumulonimbus. If value of A parameter is high, the cloud is nimbostratus. The variety of rain-cloud types and Z-R relationship also varies by topography. However, it should be considered other criteria i.e. season, latitude, longitude, prevailing wind, or other criteria of interest. The result from this study will be useful for observing the behaviour and detailed structure of rainfall events. Individual rainfall events and rain-cloud type can then be used as the input data for hydro-meteorological model and run-off model and flood estimation.

Acknowledgments
The authors are grateful to Department of Royal Rainmaking and Agriculture Aviation (DRRAA) for providing the weather radar data, Thai Metrological Department (TMD) for the rain gauge data for use in this study. Special thank goes to the proof readers throughout the research: Dr. Natthapong Monarumit, and Mr. Manoch Lakkham.

References
[1] Mapiam P and Sriwongsitanon N 2008 SCIENCE ASIA 34 215-22
[2] Jones K B, Heggern D T, Wade T G, Neal A C, Ebert D W, Nash M S, Mahaffey M H, Goodman I A, Hermann K A, Selle A R, Bolgrien D, Augustine S, Pedersen J, Lin C J, Vixger J M, Ciang D, Zhang Y, Baker J and Van Remorter R D 2000 Environ. Monit. Assess. 64 227-45
[3] Jenness J 2005 Topographic Position Index (tpi_jen.avx) Extension for ArcView 3.x Jenness Enterprises. http://www.jennessent.com
[4] Tantanee S and Prakarnrat S 2008 WSEAS 3 304-13
[5] Piman T, Babel M S, Das Gupta A and Weesakul S 2007 Hydrol. Earth Syst. Sci. 11 1361-72
[6] Chumchean S, Aungsuratana P, Khommoang A and Hanchoowong R 2009 18th World IMACS/MODSIM Congress congress (Cairns: Australis) pp 3682-89