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Tropical Flood Estimation Model Derived from Weather Radar Information

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Abstract

Floods are among the most frequent and costliest natural disasters. Conditions that can cause floods include heavy or/and long-steady rain for several hours or days where excess water saturates the ground. Long term precipitation forecast may not be totally dependable, therefore a new estimation method capable of predicting upcoming flood events with high degree of accuracy is required. The information from rain gauges and radar data can be critical inputs for the new flood warning system. A flood estimation method was developed incorporating an algorithm that processes inputs namely the rainfall rate information, horizontal and vertical profile of radar reflectivity values. The rainfall rate data, cloud thickness values, and the sizes of the clouds during the 2014 flood disaster were acquired and analyzed. The periods of measurement involve rain events before, during and after the flood tragedy. The study was carried out using 14 days of precipitation phenomena observed in Kota Bharu, Kelantan, Malaysia from 13 December 2014 until 26 December 2014. The derived flood estimator algorithm acquired in this research can be very useful to predict flood tragedy in the future. This can also be the development model that to be integrated into the radar system.

Keywords*: Radar, Flood Model, Flood Estimation Model, RHI, CAPPI*

1. Introduction

Flood disaster estimation based on cloud characteristic derived from radar data in Malaysia are not yet being fully explored. In order to accurately forecast floods in Malaysia, a new coefficient needs to be derived. Previous researchers had proposed

Numerous attempts have been made to forecast Flood occurrence using modeling approaches for different conditions of complex terrain, urban and rural areas, and ungauged zones or in the tropics [1]. Other studies have taken advantage of the finer resolution of radar rainfall and operated in real or near real time [2]. One major issue in early flood research concerned the forecast uncertainty and its significant dependence on meteorological inputs (rainfall) [3]. Basically a new flood estimation model for the tropical country need to be derived.

According to Tam *et al.* (2010), methods of estimating rainfall techniques can be divided into two groups: indirect and direct method [4]. Direct method refers to measurement based method while indirect method based on equation or coefficient [5]. Conventionally, flood estimation can be derived from rainfall rate information. Bouilloud *et al.* had proposed a method for rainfall estimation based on post event analysis [6]. This approach is based on a careful analysis of the observation conditions for the radar system available for the considered case. A study in Italy proposed a method for detecting extreme rainfall event for heavy precipitation event which known as Generalized Extreme Values (GEV) [7]. The method, involved a set of long-term data that were acquired over

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the duration of 30 years. Similar procedure had been previously employed by (Crisci *et al.*, 2002) to predict occurrences of heavy rain [8]. Whereas another researcher, Pandey had carried out analysis involving extreme point rainfall events measured over the period of 50 years in Gorakhpur, India [9]. In this paper, a flood estimation technique was established using an algorithm deduced from rainfall rate information, horizontal and vertical profiles of radar reflectivity values. The rainfall rate data, cloud thickness values, and the sizes of the clouds during the 2014 flood disaster were acquired and analyzed. The derivation procedure was carried out using 14 days of precipitation phenomena observed in Kota Bharu, Kelantan (Malaysia) from 13 December 2014 until 26 December 2014.

2. Vertical Radar Data Analysis

The vertical radar data is used to generate the thickness of the cloud. In order to acquire the thickness value of the cloud, we need to find the rain height value first labelled as step 1 in Figure 3. The illustration of 5 out of 12 cross section selection based on 30° azimuth angle is shown in Figure 2. The cross section (XSECT) or vertical radar profile of a cloud, shown in Figure 2 were observed during the most intense event occurred on 17/12/2014. The colour bar on the right shows the reflectivity value in dBZ. The thickness of the cloud for XSECT of each 30° azimuth angle were retrieved as mention in step 2 by deducting the rain height in step 1. The mean values of the cloud thickness were calculated.

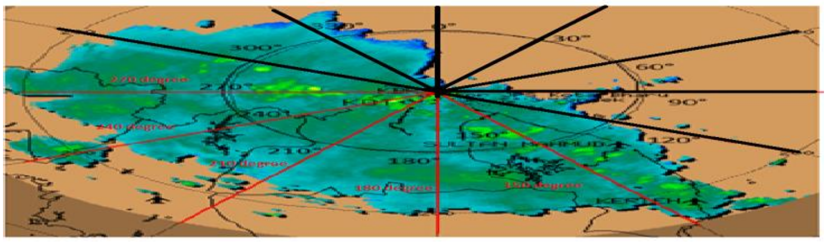

Figure 2. The Vertical Radar Profile

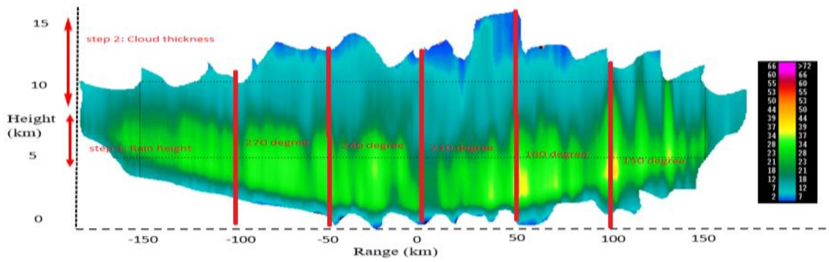

Figure 3. The Illustration of the XSECT

The example of reflectivity value converted into graph is shown in Figure 4 below. These indicate the 5 cuts out of 12 in Figure 3 above to show the process in gaining the thickness values of the cloud. The height level for the cloud is shown in the Y-axis and the reflectivity value in the X-axis. This analysis aimed for the cloud thickness reflectivity value less than 15 dBZ as it indicates the reflectivity value of the cloud [10].

The thickness of the cloud then being analyse by calculating the average of the mean value as tabulated in Table 1. Where A, B, C, D are the mean value for each event and y is the total number of the event.

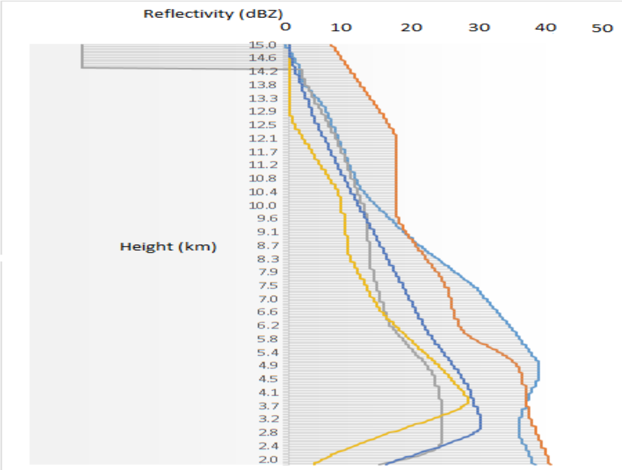

Figure 4. Vertical Profile Reflectivity for Rain Height during most Intense Cloud

Table 1. Average Cloud Rain Height Value

Date (17/12/2014)			
Time (hh:mm:ss)			
18:32:20	19:02:24	19:32:19	20:02:20
Rain Height Value (km)			
9.5	6.6	7.3	7.3
8.2	8.4	7.7	7.0
6.9	8.4	6.9	6.2
9.2	7.3	7.0	7.2
7.6	6.6	7.0	6.9
8.0	7.0	8.1	7.1
9.6	9.0	7.3	7.3
8.2	7.5	7.6	7.1
6.8	6.7	7.1	6.0
6.4	7.7	7.4	7.7
7.6	7.6	6.9	7.6
8.3	7.5	7.4	7.1
Mean (A) = 8.0	Mean (B) = 7.5	Mean (C) = 7.3	Mean (D) = 7.0

The final value of x obtained is 7.4 km for the cloud thickness. It can deduce that the value of the reference CAPPI height is 7.6 km as the height of the entire cloud is calculated at 15 km height.

The thickness of the cloud above the reference rain gauge at Kota Bharu station also being analysed for every 30 minutes during the duration of 17 hours and 30 minutes. This result is crucial in order to create the algorithm stated in the objectives of this research. The thickness value tabulated in the Table 2 and the trend of the thickness value is being demonstrated in the graph at Figure 5.

Table 2. Thickness of Cloud during the Most Intense

Date	Time	Thickness(km)	Date	Time	Thickness(km)
17/12/2014	14:32:21	7.6	18/12/2014	0:02:25	8.5
	15:02:21	6.7		0:32:24	8.0
	15:32:21	8.2		1:02:19	6.6
	16:32:19	6.3		1:32:22	5.4
	17:02:23	5.7		2:02:24	4.7
	17:32:24	6.9		2:32:22	3.7
	18:02:22	6.3		3:02:22	4.2
	18:32:20	6.5		3:32:24	4.1
	19:02:24	7.9		4:02:22	4.4
	19:32:19	7.1		4:32:22	4.1
	20:02:23	7.8		5:02:23	3.5
	20:32:21	6.6		5:32:21	2.4
	21:02:21	5.6		6:02:21	5.1
	21:32:23	8.4		6:32:25	5.8
	22:02:20	7.6		7:02:23	5.8
	22:32:24	7.1		7:32:21	4.8
	23:02:24	6.7			
	23:32:24	7.9			

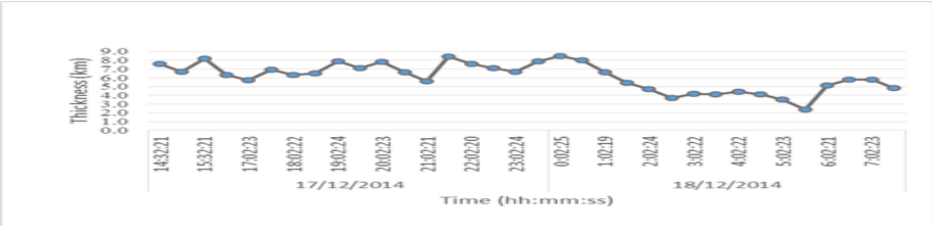

Figure 5. Trend for the Thickness of the Cloud above Reference Rain Gauge

3. Horizontal Radar Data Analysis

Once the reference CAPPI value is available, the size of the cloud during the flood event can be examined. This can be achieved by using IRIS Vaisala software by setting the height of the CAPPI of 7.6 km as illustrated in Figure 6. Afterwards Microsoft® Excel is used in order to calculate the size of the cloud. Table 3 below show the result for the size of the cloud throughout the 17 hours and 30 minutes of intense rainfall during the 2014 flood tragedy. The trend of the cloud size, then being demonstrated using the line graph in Figure 7 below. The identification of the most immense cloud is based on the size of the cloud at 7.6 km height. From the graph, the highest value of the cloud is during the 22:02:20 at 17 December 2014.

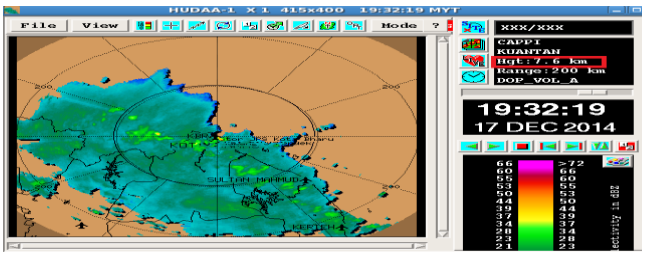

Figure 6. The CAPPI View for 7.6 km Altitude Height for 17 December 2014 at 19:32:19

Table 3. List Size of Cloud during the Most Intense Rainfall Event

Date	Time	Size (km^2)	Date	Time	Size (km^2)
17/12/2014	14:32:21	24649.2	18/12/2014	0:02:25	29720.2
	15:02:21	24864.6		0:32:24	31901.7
	15:32:21	28018.0		1:02:19	31226.7
	16:32:19	26499.2		1:32:22	28035.3
	17:02:23	26874.8		2:02:24	24157.8
	17:32:24	27049.8		2:32:22	24429.7
	18:02:22	26926.7		3:02:22	24553.5
	18:32:20	24938.4		3:32:24	22417.0
	19:02:24	29115.6		4:02:22	23299.1
	19:32:19	30785.4		4:32:22	20104.0
	20:02:23	36894.4		5:02:23	17736.1
	20:32:21	35981.4		5:32:21	16407.7
	21:02:21	35311.1		6:02:21	15679.3
	21:32:23	36482.4		6:32:25	16286.7
	22:02:20	39277.5		7:02:23	18078.7
	22:32:24	38764.8		7:32:21	18865.1
	23:02:24	36377.7			
	23:32:24	35082.0			

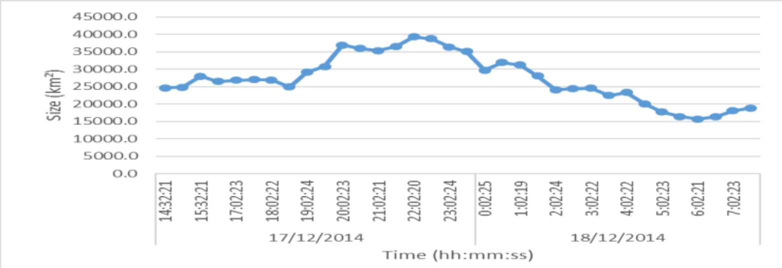

Figure 7. Trend of the Cloud Size at 7.6 km Altitude Height

4. Designing the New Model

In this subsequent section, the results achieve is based on objective that point towards developing a new coefficient applicable to predict future rainfall activity that contribute to the flood hazards as the use of radar for rainfall forecasting. Collecting all the result obtain and tabulate it into the Table 4. Followed by analyzing the method need to apply to generate the algorithm or the coefficient that applicable to predict future rainfall, which can be the cause of the flood to happen.

Table 4. Tabulation of the Result

Date	Time	Rainfall rate(mm/hr)	Thickness(km)	Size(km²)
17/12/2014	14:32:21	3.6	7.6	24649.2
	15:02:21	6	6.7	24864.6
	15:32:21	3.6	8.2	28018.0
	16:32:19	2.4	6.3	26499.2
	17:02:23	8.4	5.7	26874.8
	17:32:24	2.4	6.9	27049.8
	18:02:22	4.8	6.3	26926.7
	18:32:20	1.2	6.5	24938.4
	19:02:24	1.2	7.9	29115.6
	19:32:19	68.4	7.1	30785.4
	20:02:23	64.8	7.8	36894.4
	20:32:21	15.6	6.6	35981.4
	21:02:21	8.4	5.6	35311.1
	21:32:23	16.8	8.4	36482.4
	22:02:20	30	7.6	39277.5
	22:32:24	4.8	7.1	38764.8
	23:02:24	3.6	6.7	36377.7
	23:32:24	7.2	7.9	35082.0
18/12/2014	0:02:25	1.2	8.5	29720.2
	0:32:24	19.2	8.0	31901.7
	1:02:19	2.4	6.6	31226.7
	1:32:22	19.2	5.4	28035.3
	2:02:24	6	4.7	24157.8
	2:32:22	1.2	3.7	24429.7
	3:02:22	2.4	4.2	24553.5
	3:32:24	1.2	4.1	22417.0
	4:02:22	12	4.4	23299.1
	4:32:22	6	4.1	20104.0
	5:02:23	1.2	3.5	17736.1
	5:32:21	57.6	2.4	16407.7
	6:02:21	73.2	5.1	15679.3
	6:32:25	46.8	5.8	16286.7
	7:02:23	2.4	5.8	18078.7
	7:32:21	28.8	4.8	18865.1

5. Results and Findings

Multiple regression analysis is used to find the coefficient that correlates between all the variable obtain from the rain gauge and radar analysis. Multiple regression analysis is a powerful technique used for predicting the unknown value of a variable from the known value of two or more variables also called the predictors

This step is then repeated for B_1X_1 with B_3X_3 and B_2X_2 with B_3X_3 as there are three variables involve in this analysis, which are thickness of the cloud, the CAPPI size of the Cloud and rainfall rate. Microsoft Excel ToolPack analysis of the multiple regression, as shown in Figure 5.1 is used to generate the flood predictive model. Analysis of the data based on multiple R, R square, adjusted R square, Standard error, and observation are tabulated in Table 5 showing the table of regression statistics and Table 6 tabulate the coefficient value and P-value.

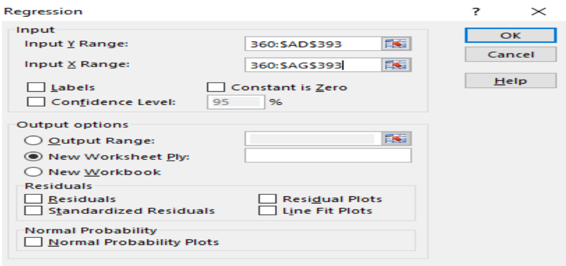

Figure 8. Regression Data Analysis

Table 5. Table of Regression Statistics

Analysis Data	Value
Multiple R	0.856738
R Square	0.734001
Adjusted R Square	0.707401
Standard Error	0.272623
Observations	34

Table 6. Table of the Coefficient and P-value

	Coefficients	p-value
Intercept	-1.43085	2.31E-07
Thickness	0.059597	0.154772
Size	5.28E-05	4.97E-06
rainfall rate	0.004357	0.062108

The predictive value or P-value as tabulate in Table 5.2 of each independent variable value must be tested. In any predictive value that is greater than 0.15 will be excluded as this particular independent variable value is not significant for the predicting the outcome. Since all the independent variable values of the P-value is lower than 0.15, it is considered as strong predictive value and really significant to the model. As a result, the coefficient is significant in generating the predictive model stated in equation (1).

The final model of the analysis would be,

$$Y' = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \tag{1}$$

$$Y' = -1.43 + 0.06X_1 + 5.28\text{x}10^{-5}\ X_2 + 0.0044\ X_3$$

Where Y' is equal to the binary value between 1 or 0 which indicates the characteristics of the cloud and rainfall rate that can cause flooding. If the value is 1 or more it means the cloud characteristic and rainfall rate during that specific time may cause flooding to happen. While for value 0 or less, it indicates that the cloud characteristic and rainfall rate is in a secure condition.

The method and tools used give the result needed in creating the algorithm. It is based on the studies from the previous researcher and the ability of the radar in flood estimating. Further test with more previous flood event need to be carry out to enhance the implementation. The result can be suggested to the meteorological radar operator to be implemented in their system to predict flood occurrence.

6. Conclusion

The development of tropical flood estimation technique derived from weather radar is presented. The aims of this research are to develop the method or algorithm model to estimate flood which is very crucial in order to reduce the impact of flood disaster to the tropical country have been accomplished.

The first objective was successfully being achieved as the parameter of the cloud characteristics for the cloud size and the cloud thickness along with the rainfall rate during the Malaysian flood disaster 2014 was able to identify and characterize. All the information gather was needed to develop the algorithm.

Subsequent objective was accomplished by the means of developing the coefficient that applicable to predict any rainfall activity that capable to cause flood disaster. This prediction technique allows us to predict flood so that in anywhere after this if we noticed the similar behaviour of the rainfall and the cloud characteristics it will create an alarm system.

The procedure proposed in this research allowed the estimation of the rainfall based on rain gauge and radar data. Such procedure is based on horizontal profile and vertical profile of radar. This paper focused on the rain gauge data and radar data during Malaysia worst flood in 2014. The method then will be validated with another flood event occurred in Kuantan, Malaysia during year 2013.

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