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ANALYSIS OF CONVECTIVE STRUCTURES USING METEOROLOGICAL RADAR DATA AND SURFACE DATA

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Abstract:

Storms of convective origin are generally known to be responsible for most of flash flood events in Malaysia. Flood problems are aggravated by rapid urbanization which modified the hydrological processes of a catchment. This study is aimed to compare spatial distribution of convective rainfall between meteorological radar data and observed surface data (rain gauge). The convective events were analyzed in terms of timing and spatial distribution. The spatial distributions of convective rainfall, derived from meteorological radar data and those observed on the ground are compared. Convective storm occurred most frequently during inter-monsoon months. A variety of storm shape is evident. Most of the convective events occurred over short durations. A 35 mm/hr threshold intensity is used for separating convective from non-convective storms for local conditions. The areal distributions derived from radar and those from rain gauge are poorly correlated. Each storm is unique in term of the movement of its storm center. Some have long paths while others are circling within a limited area. Overall, there is no specific pattern on the four storm movements studied in this section. There are possibilities that wind direction influenced the movement of the rain bearing clouds, hence resulting in ambiguous patterns.

Key Words: Convective storm, Storm movement, Threshold intensity, Spatial distribution

1. BACKGROUND OF STUDY

Forecasting of convective initiation is important for flood modeling. It has been widely known that storms of convective origins are responsible for major flash flood events that have caused significant loss of life, property damages, disruption to ecological habitats and other socio-economic problems.

In Malaysia, flash flood events occur frequently in urban areas such as the Klang Valley (Desa, 1997). These events occur mainly during inter monsoon periods. Damages and losses caused by flash floods have been mounting. A convective storm is characterized by a sudden burst of heavy rainfall over a short period of time. This short outburst of rain is usually heavier than normal rainfalls. Since convective storms are more intense, they are associated with many flash flood events, especially in urban areas. Unfortunately, the behavior of convective storms especially their spatial distribution and storm movements are still

poorly understood. This study examines the characteristics of convective rain and their coverage using both surface rainfall data and radar data.

2. INTRODUCTION

The storms of convective origin are generally known to be responsible for much of flash flood events in Malaysia. Urban drainage systems, often cannot cope with intense convective rainfall events. It is also difficult to forecast convective rain in terms of timing and spatial distribution. This is because convective

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rain develops over a short period and can happen any time, during day or night and can cause much disruption to the livelihood of the people. Thus far, no specific guideline for characterizing convective rainfalls has been established in the tropics. For that reason, an in-depth study on the temporal and spatial characteristics along with the characterization of local rainfall processes is deemed vital. Despite great improvements over recent years on general weather forecasting techniques, the ability to forecast the occurrence of convective rains is still poor. Predicting where a storm will break out or start abruptly is still one of the major challenges faced by meteorologists today. This situation motivates many researchers to study convective rain.

The intensity of rainfall is dependent on the rate at which a storm processes the water vapor. Many researchers used intensity as a method to differentiate between convective and stratiform rainfall. Dutton and Dougherty (1979) and Watson *et al.*, (1982) set a threshold rainfall of 50 mm/hr to separate convective from non-convective storms. Llasat and Puigcerver (1997) divided rainfall events into four categories: (1) non-convective (2) convective with rain $\leq$ 0.8 mm/min (3) convective with rain $\geq$ 0.8 mm/min; and (4) thunderstorms. Llasat (2001) used 35 mm/hr as threshold intensity and a parameter β for the characterization of convective rain. Nevertheless, Houze (1993) distinguished stratiform from convective precipitation on the basis of vertical air velocity, w. If w is less than the terminal fall velocity of ice crystals and snow, it is a stratiform storm. Nowadays, radar can differentiate these two types of rainfall. Using 4-D radar imagery, the 'bright band' near the melting level is a signature that helps to distinguish convective mode from stratiform mode (Llasat, 2001). Steiner *et al.* (1995) proposed two methods for distinguishing stratiform from convective precipitations in radar echo patterns. Radar used reflectivity to measure the intensity of rain which is usually expressed in dBZ. Dong and Hyung (2000) used 35 dBZ to determine convective rainfall. Pascual *et al.* (2004) in Spain used four reflectivity thresholds, i.e. 30 dBZ, 35 dBZ, 40 dBZ and 45 dBZ in identifying convective cells origin. On the other hand, Rigo and Llasat (2002) used 43 dBZ to analyse convective event which is derived from meteorological radar.

Studies of convective rain using meteorological radar were also carried out by Pascual *et al.*, (2004) and Callado *et al.*, (2002). They analyzed the origin of convection identified in radar data with low levels convergence zones. Later, Pascual *et al.*, (2004) studied convective activities during summer and relate it with convergence areas associated with terrain characteristics and the interaction between different flows at low levels. Hara *et al.* (2006) conducted a cloud-resolved simulation using regional climate model to clarify the mechanism of diurnal cycle of convective activity around Borneo Island. The convective activities on top of mountain tend to decay in the evening. Dong and Hyung (2000) studied heavy rainfall with Mesoscale Convective Systems (MCSs) over the Korean Peninsula using WSR-88D radar data. MCSs are complex thunderstorms which become organized on a scale larger than individual thunderstorms, and normally persist for several hours. The movement of the convective storms also was investigated by tracking the edges of the storms. It is found that the storm boundaries changed into a very complex shape.

The main objectives of this study are to compare spatial distribution of convective rainfall between meteorological radar data and observed surface data (rain gauge). The benefits of this study, it can be as basis for improving various hydrologic designs and develop a better modeling of local flood.

3. METHODOLOGY

To analyze and characterize convective rain in the Klang Valley, the temporal pattern and the spatial distribution between meteorological radar data and surface rainfall (rain gauge) need to be explored. The first step to analyze the characteristics of convective rain is selection of an appropriate region. Next is the selection of rain gauge stations in the study area. After that, the objective of this study was carried out where it is to determine & compare spatial distribution of convective rainfall between meteorological radar data & ground data. Both data is shown in

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rainfall contours where the contours from rain gauge are derived from Kriging method whilst rainfall contours from radar were made by digitizing the image. Radar image need to digitize layer by layer according to the colour in that image. Next, rainfall contour from ground data will produce by Kriging Method in ArcGIS. For comparison purposes, 4 events which coincided with major flood events were selected. These events occurred on 06th Jan, 26th Feb, 06th Apr, and 10th May 2006. By matching the same occurrence time, rainfall contour from surface data (Kriging) were compared with rainfall contour from radar image (digitized image). Finally, a relationship between areas of rainfall contour (derived from Kriging) with rainfall depth was examined

Next, is to see the movement of rainfall. In this step, the same storm is selected, where the storms that led to the flash floods had exhibited convective characters. A value of 35 dBZ was taken as the reflectivity threshold. Then, the highest reflectivity, which is greater than 35 dBZ is chosen as center of the storm for convective events. The centre of the storm is used as a reference point to track the movement of the storm. And lastly, the duration, direction and the distance of the storm movements will be identified.

3.1. Study Area

The study area covers the whole Klang Valley, comprises Kuala Lumpur and its surroundings and suburbs. Twenty rain gauges in this area were used for spatial distribution analysis. Figure 1 shows the area of Klang Valley magnified from the map of Peninsular Malaysia as well as twenty rainfall stations from where data for analysis of convective rain was obtained.

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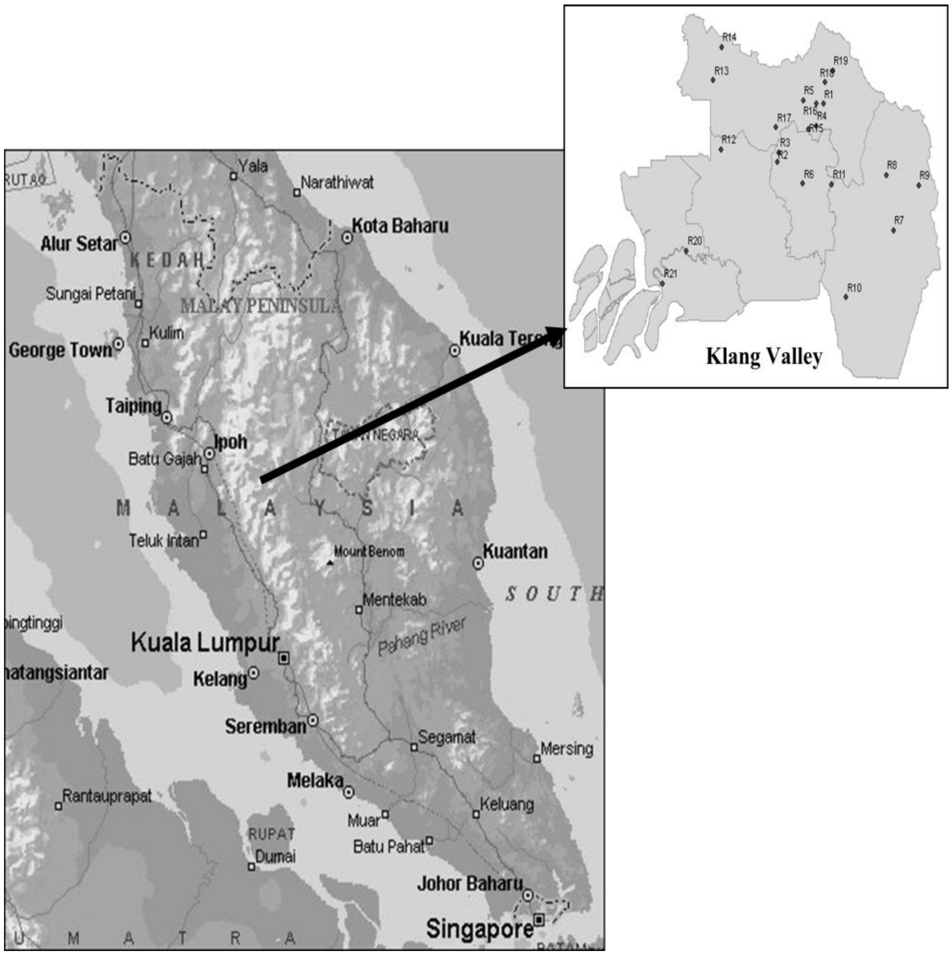

Figure 1. The study area in Klang Valley

3.2. Radar Image

The radar images were derived from the Terminal Doppler Weather Radar (TDR) located at Bukit Tampoi, about 10 km north of Kuala Lumpur International Airport (KLIA), Malaysia. The station is used for the detection and warning of wind shear and micro bursts in the vicinity of KLIA. RADAR stands for Radio Detection and Ranging which is used for detecting the position, velocity and characteristic of target (bearing, range, and altitude). The difference between a conventional weather radar and Doppler weather radar is that the former can only detect the characteristic, size, direction and distance of precipitations while the latter, in addition to the above parameters can also measure radial wind speed, wind shear and microburst.

In radar image, the colors represent the values of energy reflected toward the radar. Figure 2 shows a sample of radar image. The Doppler radar image has too many colours for various intensity scales. In this study, to simplify the data analysis the color scales was reduced to by re-digitizing the radar image. Figure 3 shows the new scales. These scales were used in determining and constructing rainfall contours. In this study, to identify convective rainfall in radar images, a value of 35 dBZ was taken as the reflectivity threshold. Figure 4 shows the digitized images of rainfall contour using GIS (ArcGIS 9.1).

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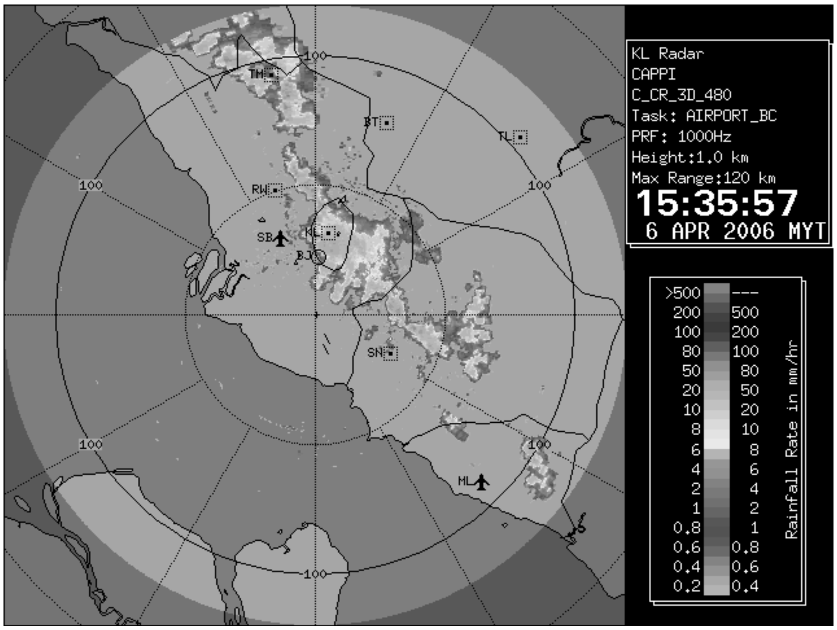

Figure 2. Sample of radar image

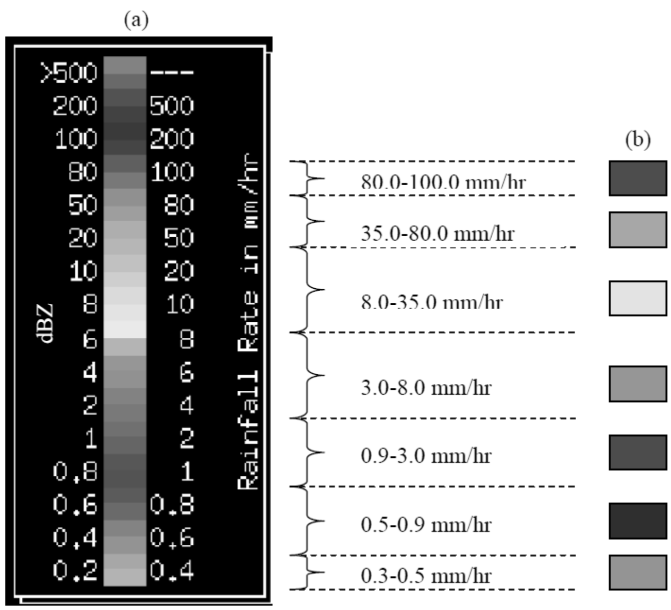

Figure 3. Various level of reflectivity colour derived from radar image (a) and simplified rainfall intensity colour after digitization (b)

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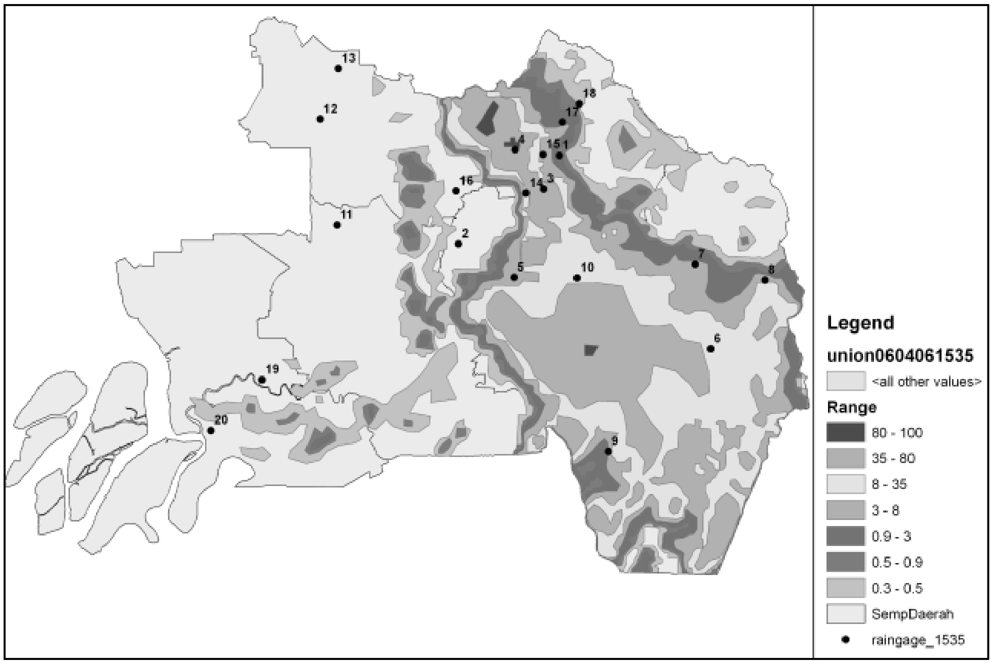

Figure 4. Radar image using ArcGIS 9.1

3.3. Rainfall Data

In this study, rainfall data from 20 rain gauges (9 rain gauges in Wilayah Persekutuan and 11 rain gauges in Selangor) were selected to achieve the second objective, which is to determine the spatial distribution between meteorological radar data and observed surface data (rain gauge). Ground data was obtained from DID while radar data were taken from the Meteorological Station at KLIA in Sepang. Heavier rainfalls were selected for this analysis. These events coincided with major flood events on June 10, 2003; Nov 5, 2004; Jan 6 Feb 26, Apr 6, and May 10, 2006.

4. RESULTS AND DISCUSSION

In this analysis, out of four storms, only one event on January 6, 2006 produced smooth circular isohyetal lines. The rainfall contour patterns for this event exhibits very similar patterns with radar data. This storm started at 18:10hr and lasted for about two hours. This storm also shows increasing intensity as its center moves from northeast to southwest. However, the other three storms (February 26, April 6 and May 10), failed to show good agreements between radar and rain gauge data.

Most of the isohyet lines derived from the rain gauge data are not smooth compared to those derived from digitized images. Moreover, the spatial distributions of the radar and surface rainfall are remarkably different. This might be due to the small number of rain gauge station employed in the study and further complicated by the occurrence of missing data for some of the events. Kriging method requires a large number of rainfall stations to produce smooth curves. Prediction errors tend to be larger in areas with small number of rainfall station. Besides, the discrepancies arise from the way Doppler radar estimate rainfall intensity. Doppler radar does not determine actual rainfall intensity, but measure the returned energy which is reflected back toward the radar (National Weather Service, 2006). The more intense the precipitation, the greater the reflectivity. Figure 5 shows a comparison of spatial rainfall distributions derived from rain gauge and radar for event on January 6, 2006.

Comparison of the areal rainfall derived from radar and surface rainfall was carried out using GIS software (ArcGIS 9.1). The color represents the intensity level. The analysis used

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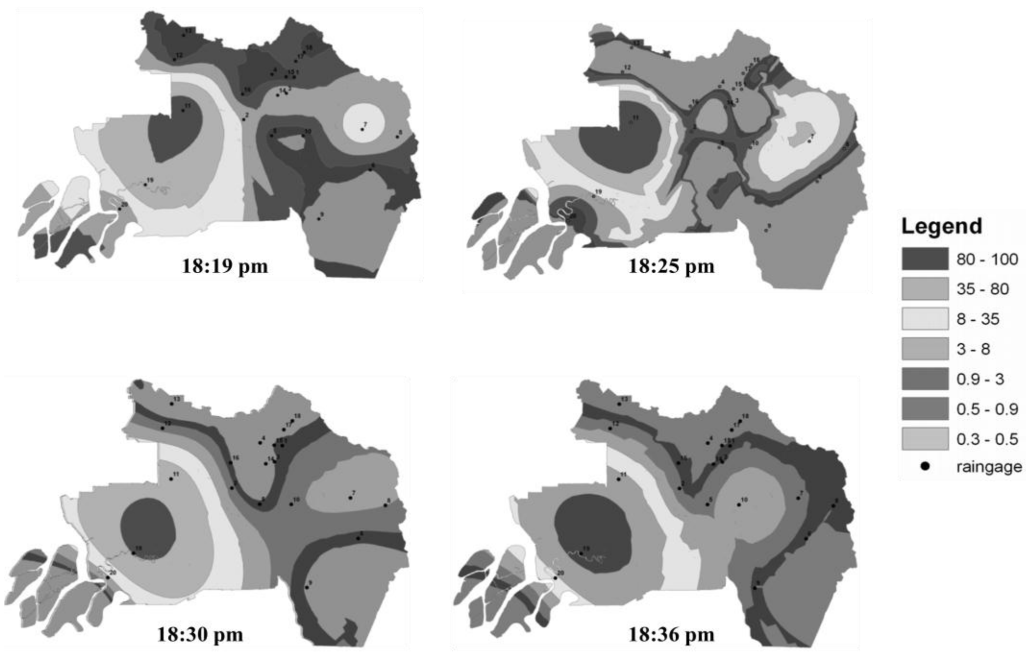
four selected storms. Three of the storms analyzed occurred in the afternoon. Table 1 compares the areal coverage of rainfall intensity derived from radar against those from rain gauges. On the whole, it is evident that the two analyses produced remarkably different results. Such discrepancies could be attributed to the interpolation process in the Kriging Method. The spatial interpolation requires an estimate of unknown values of a variable at unsampled points by using measured values from other points (Weise, 2001). Moreover, a few rain gauges had missing data. This has worsened the interpolation process in Kriging compared to the digitized images (radar).

DERIVED FROM RAIN GAUGE USING KRIGING



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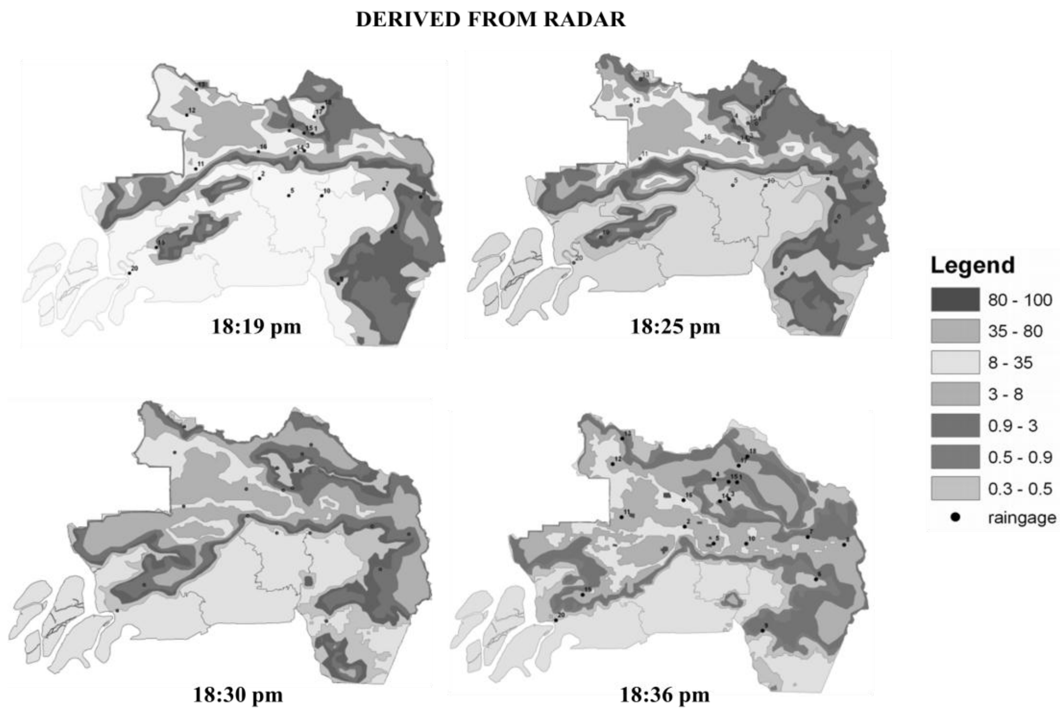

Figure 5. Comparison of spatial rainfall distributions derived from rain gauge and radar for event on January 6,2006

Table 2 shows the correlation of coefficient (R) of areal coverage for different intensity between radar and rain gauge data for four selected storms. The R values are very small with a maximum of 0.49 for event on 26 February 2006. All correlations are not significant as the P values are all greater than 0.05. These suggest that the correlation between radar and rain gauge were very poor.

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Table 1. Areal distribution of storm intensity obtained from radar and rain gauge

Date	**6-Jan-06**		**26-Feb-06**		**6-Apr-06**		**10-May-06**	
Time	**18:36**		**04:55**		**15:29**		**15:12**	
Intensity (mm/hr)	**Area (km^2)**		**Area (km^2)**		**Area (km^2)**		**Area (km^2)**	
	Radar	**Raingauge**	**Radar**	**Raingauge**	**Radar**	**Raingauge**	**Radar**	**Raingauge**
0.3-0.5	309.86	767.68	463.11	893.28	303.83	765.27	213.81	1270.45
0.5-0.9	277.37	560.18	408.87	331.33	159.15	223.4	189.88	375.71
0.9-3.0	457.4	425.49	539.74	306.71	167.55	1423.71	237.34	999.32

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3.0-8.0	555.11	206.00	370.48	411.08	128.86	408.68	239.36	151.87
8.0-35	234.24	285.05	202.63	500.26	240.51	29.07	303.98	44.42
35-80	186.24	549.19	94.90	413.16	362.60	5.42	284.56	11.11
80-100	5.76	62.24	0.00	0.00	3.03	0.28	2.38	2.95

Meanwhile, Table 3 shows the result of storm movements for the four selected storms. Overall, there is no specific pattern on the four storm movements studied in this section. There are possibilities wind direction influenced the movement of the rain bearing clouds, hence resulting in ambiguous patterns.

Table 2. Correlation of coefficient (R) of areal distribution of storm intensity between radar and raingauge

Date of Event	Correlation of Coefficient (R) Between Radar and Raingauge	Significance level, P
6-Jan-06	0.1737	0.71
26-Feb-06	0.4947	0.26
6-Apr-06	0.0295	0.95
10-May-06	0.1062	0.82

**Note: P > 0.05 is not significance

Table 3. Result on storm movements

	6^{th} Jan 2006	26^{th} Feb 2006	6^{th} Apr 2006	10^{th} May 2006
The highest intensity, dBZ (mm/hr)	65 dBZ (90 mm/hr)	65 dBZ (90 mm/hr)	80 dBZ (100 mm/hr)	80 dBZ (100 mm/hr)
Duration	65 minutes	1 hour 16 minutes	20 minutes	30 minutes
Distance	32.14 km	46 km	17.7 km	14 km
Direction	From Northeast to southwest	From Northwest to Southeast	Very difficult to determine	

CONCLUSIONS

Knowledge of temporal and spatial characteristics of tropical storms is still lacking for effective engineering design and planning. This is so especially for convective storm which has been associated with the occurrences of major flash floods in many urban areas. It is imminent that extreme weather events such as more intense rain, longer dry spells and rapid changes in global

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temperature make tropical weather more difficult to predict. Of particular importance is properties of convective storms which have strong influence on flash flood. This study makes a contribution to these needs by providing a greater understanding of convective rain behaviors. By integrating results of temporal and spatial distribution in term of intensity, rainfall depth and area of rainfall, the characteristics of convective rain were examined.

Comparison of spatial distribution between radar and surface rainfall was carried out in terms of intensity, areal coverage and storm movements. The intensity values between raingauge and radar show large differences. The main difficulty in determining the *Z-R* (with *Z* in mm6/m3 and *R* in mm/hr) relationship arises from the fact that radar measures precipitation in the atmosphere while gauges measure it at the ground. Winds may also carry precipitation away from beneath the producing cloud.

The areal rainfall for each interval of isohyets between radar and surface rainfall was compared using ArcGIS software. The ground rainfall data produced remarkably different areal rainfall for various intervals of isohyets. The areal distributions derived from radar and those from raingauge are poorly correlated. Overall, the areas of each interval derived from raingauge are bigger than those derived from radar.

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