

# USE OF GEOSTATIONARY METEOROLOGICAL SATELLITE, RADAR AND NWP IN QPE/QRE FOR FLOOD FORECASTING

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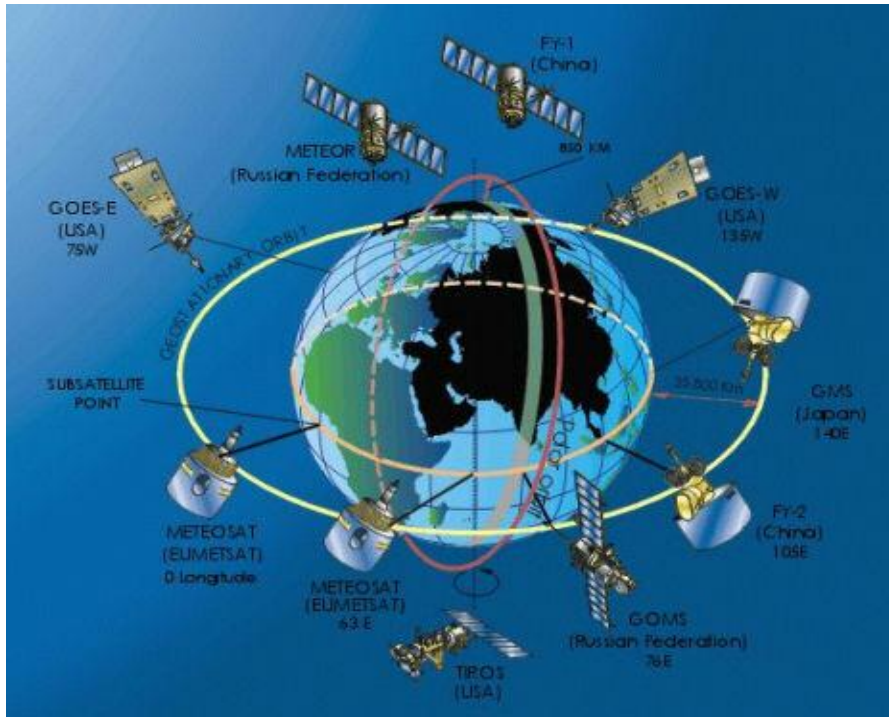
# PRESENTATION CONTENT

- **Use of Geostationary Meteorological Satellite**
- **Use of Radar**
- **Use of Numerical Weather Prediction**



**USE OF GEOSTATIONARY METEOROLOGICAL  
SATELLITE INFRARED IMAGES  
FOR  
CONVECTIVE RAINFALL ESTIMATES**





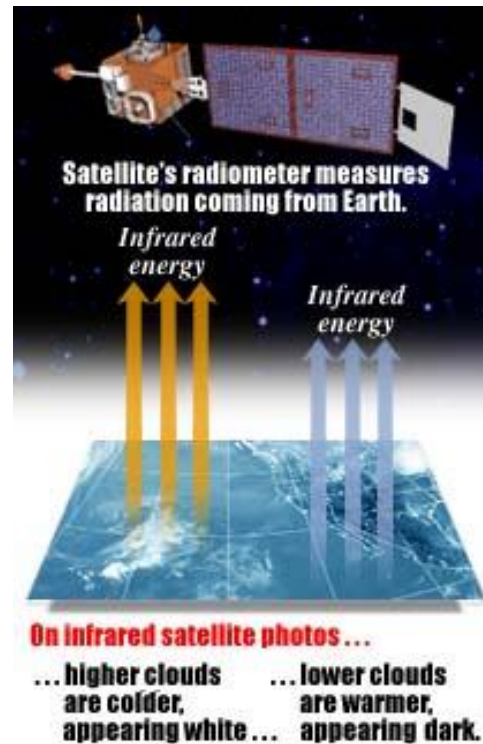
Geostationary meteorological satellites have fixed position. The satellites make observations at 20-30 minute intervals throughout each day over the same area, therefore able to monitor the raining cloud cell development over an area, thus forecast intense storm causing flood



# HOW CLOUD TOP BRIGHTNESS TEMPERATURE FROM THE INFRARED IMAGES ARE RELATED WITH CONVECTIVE RAIN

## How satellites view clouds

Convective rain occurs when heated air is rising and cooled until the condensation occurs and cloud droplets grow then become large enough to fall as rain. The higher the air parcel rises, the colder the cloud temperature.

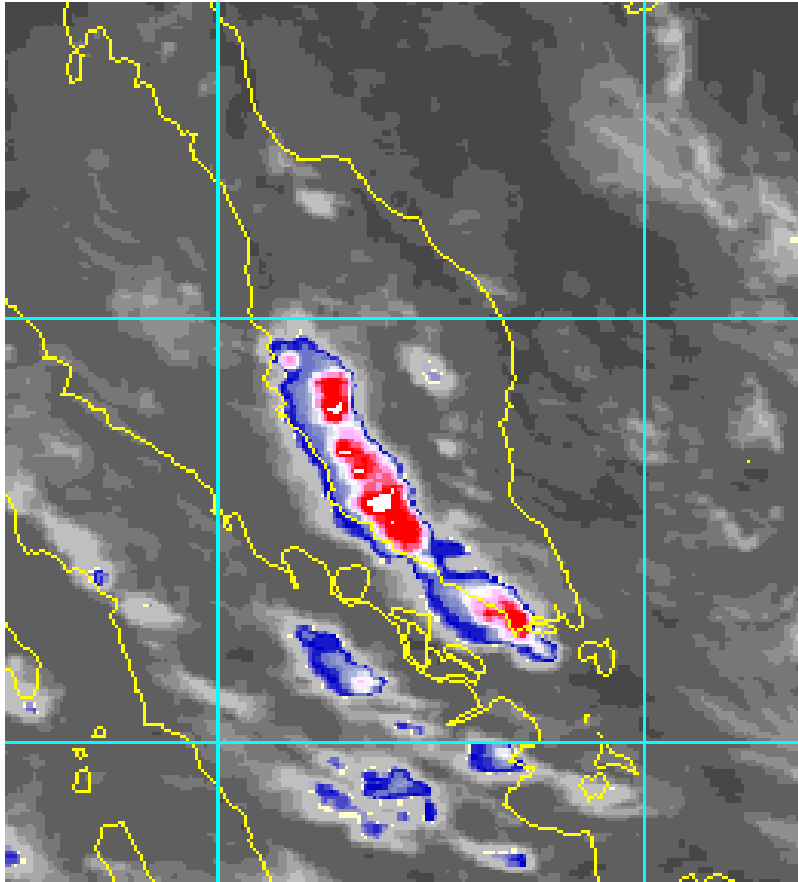


Hence, it is assumed that cloudy satellite image pixels colder than a given threshold temperature are associated with probably precipitating cumulonimbus clouds.

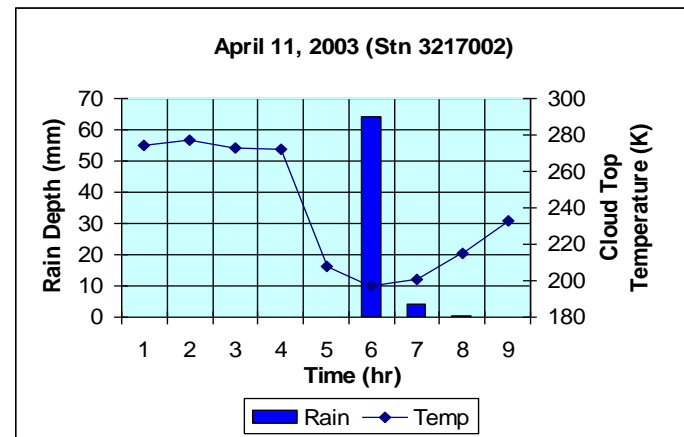
*Source: USA Today*

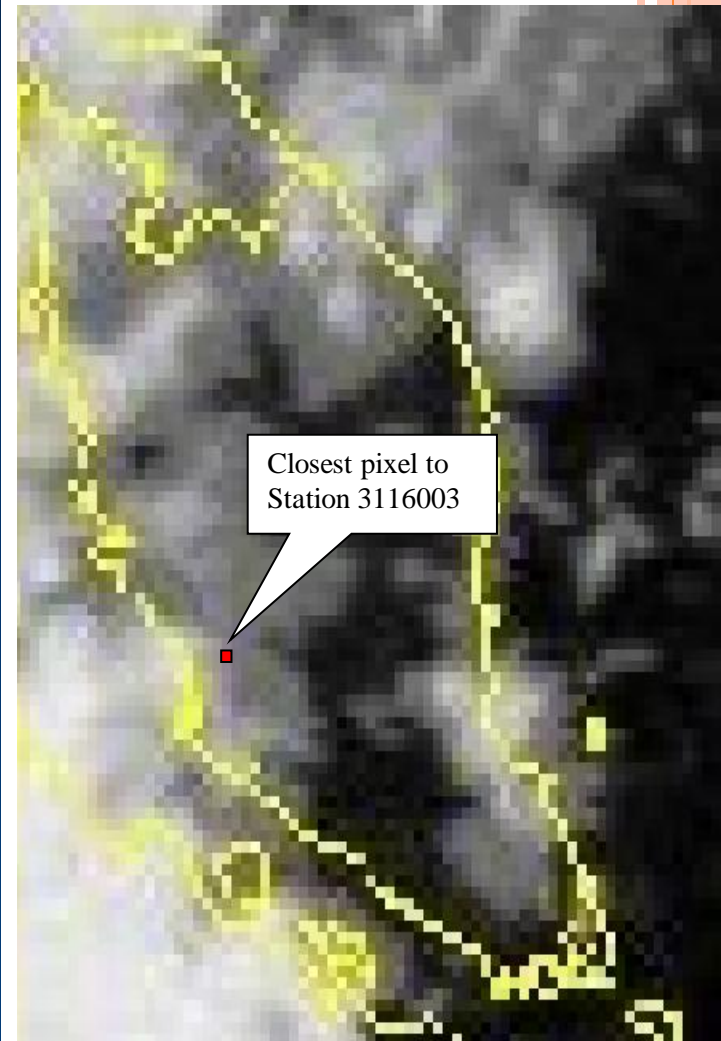
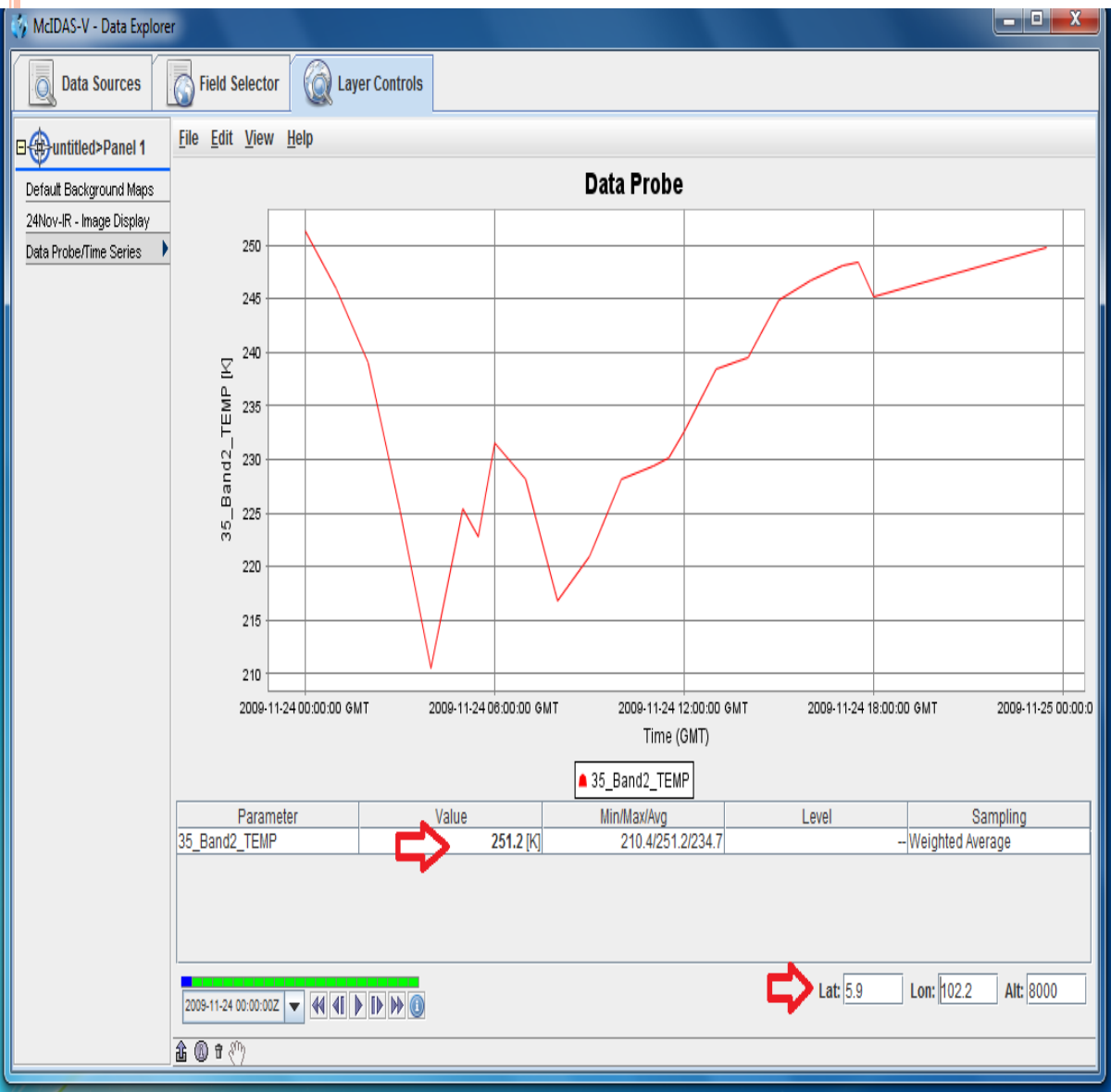


# Example GMS image during a flash flood (June 10, 2003)



Jalan Klang Lama was submerged in water after downpour yesterday. — NST picture by Mohd Sa

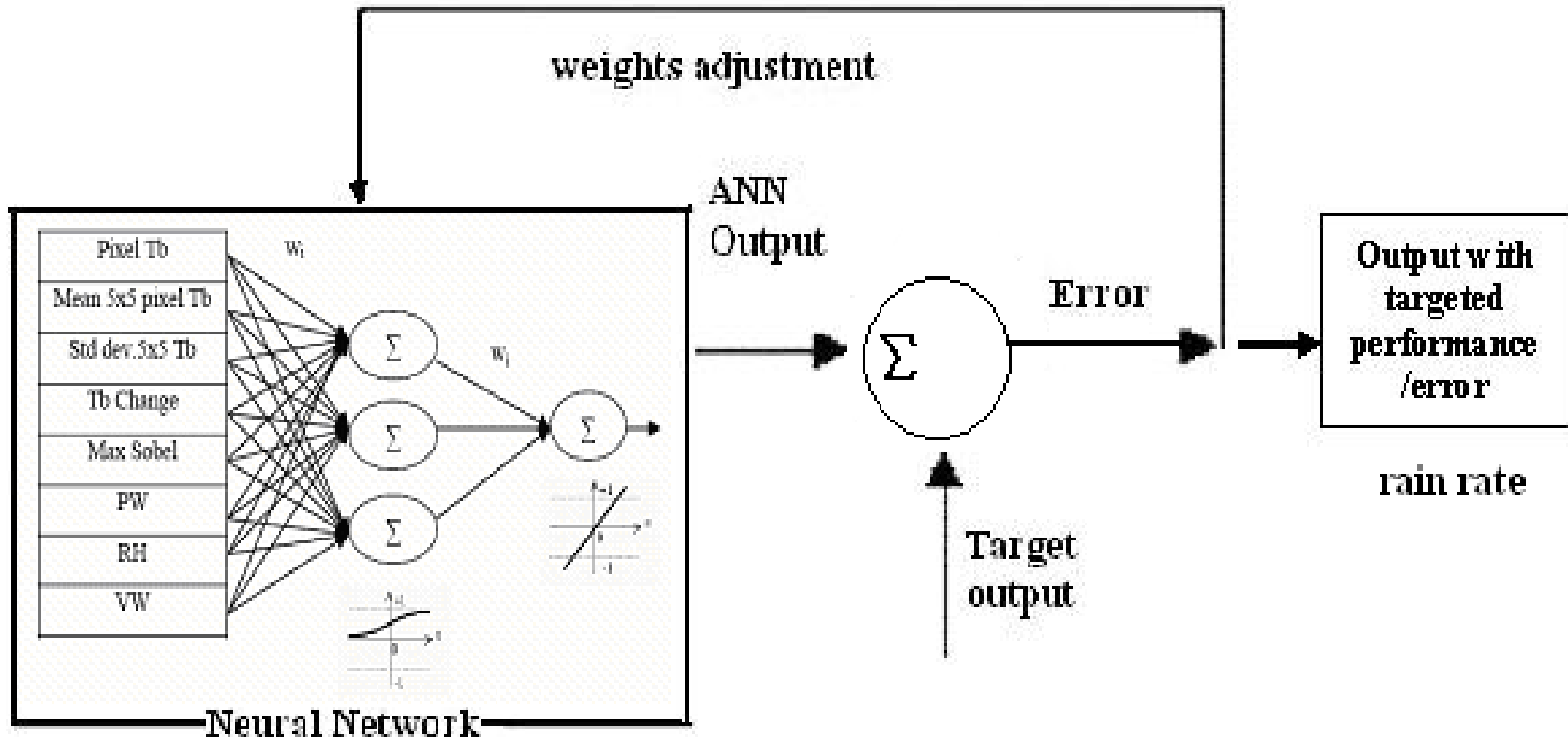




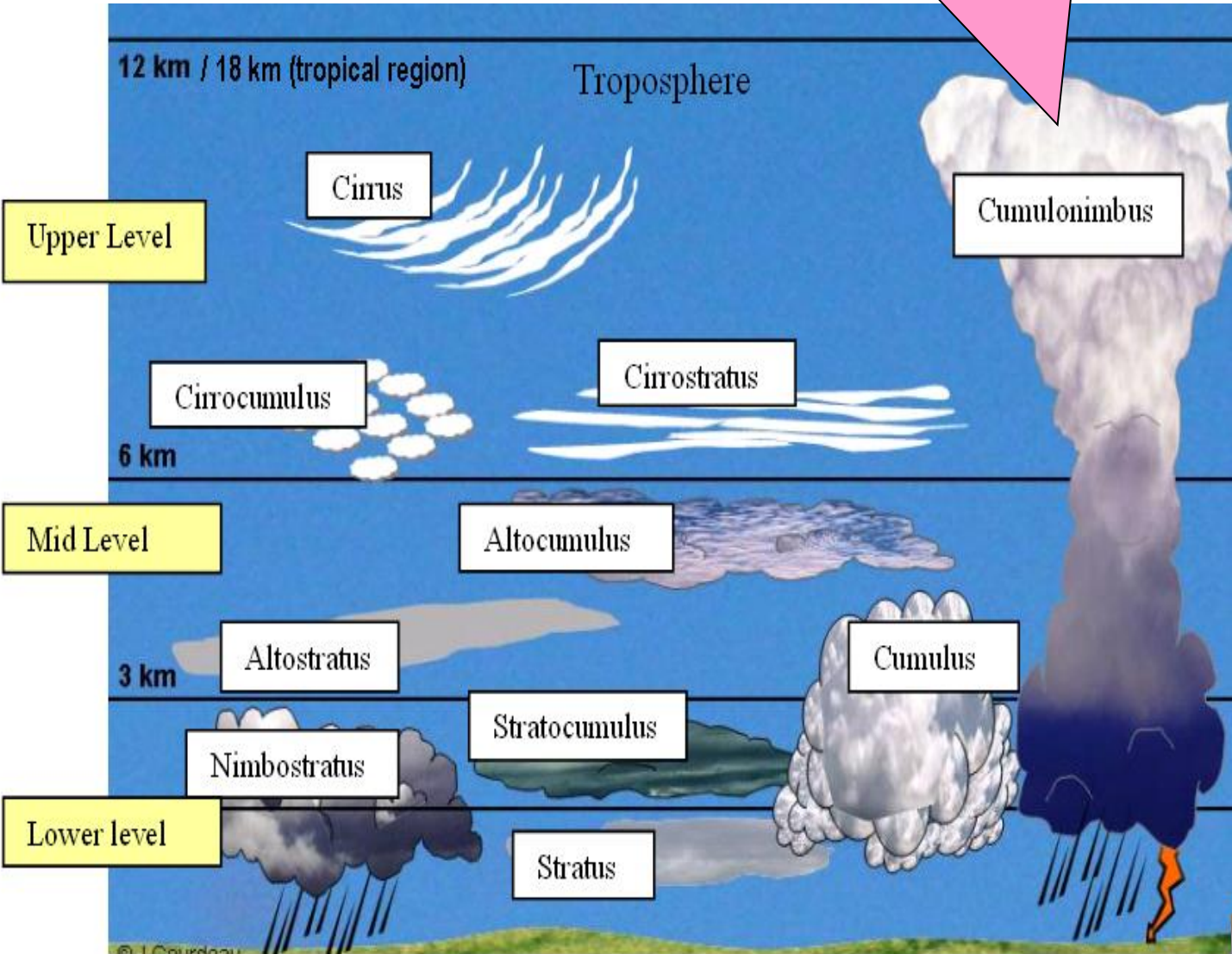
Programming/ image processing using Matlab to determine station pixel intensity value

Use McIDAS-V software to read cloud top brightness temperature

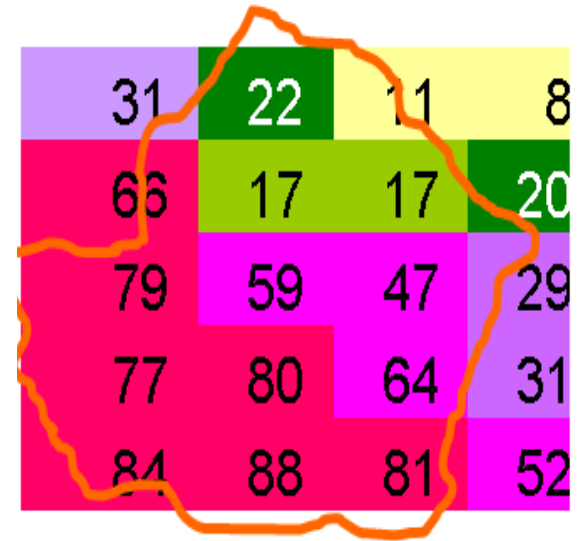
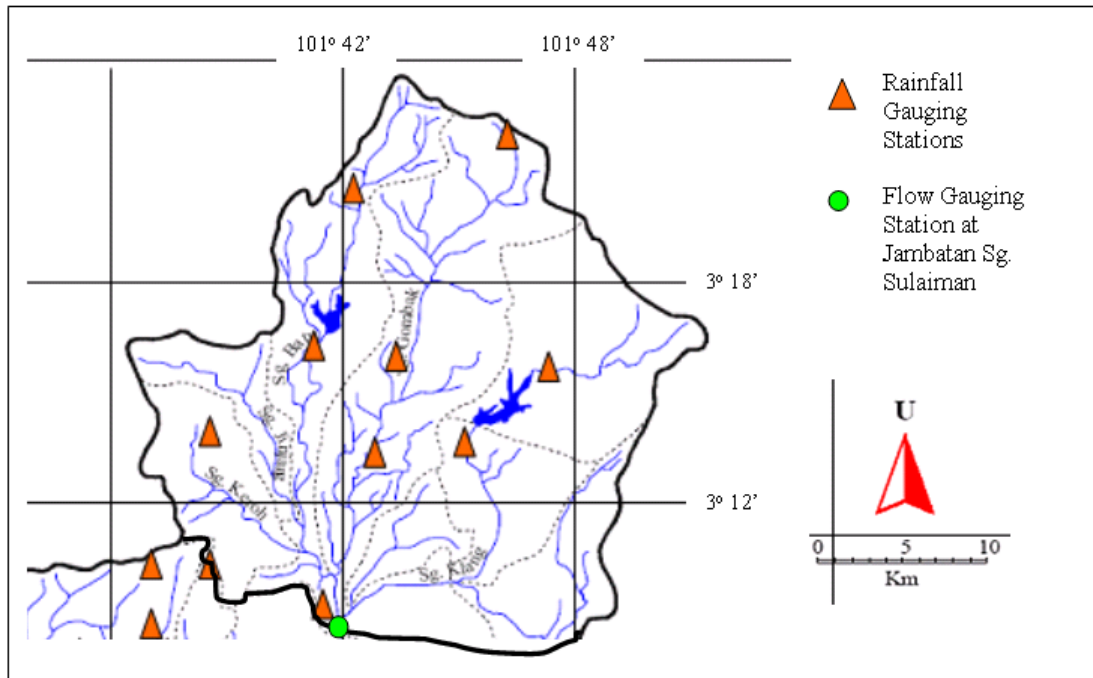
# Development of Satellite Based Rainfall Estimations using Artificial Neural Network



Tall overshooting convective raining cloud indicated by sobel operator



# Validation with gauged- measured rain



Rain Estimation over case study area of  
Upper Klang River Basin  
( 4 pm, June 10, 2003 )



# Example of June 10, 2003 (Flash Flood Event) Rain Estimation comparison using RainIRSat and ANN-based techniques

Cloud Top Brightness Temperature (K)

6:23 UTC

267	269	271	273
268	276	277	281
273	278	279	283
284	281	283	288
284	287	288	288

7:23 UTC

216	217	218	219
224	222	221	216
240	242	242	240
267	261	261	261
269	262	263	263

8:23 UTC

197	200	203	204
195	203	203	201
195	199	201	204
198	196	200	206
196	195	198	206

9:23 UTC

202	202	204	205
199	203	205	204
198	199	201	200
198	199	203	202
198	195	197	199

10:11 UTC

203	202	202	199
206	206	205	203
207	205	205	205
207	204	204	206
206	207	208	211

11:23 UTC

205	205	205	204
208	207	205	205
209	211	211	211
213	215	215	219
216	214	218	222

TOTAL DEPTH  
STANDARD ERROR

Areal averaged rain estimation using back-propagation ANN on every pixel over the catchment

14	14	22	54
5	9	11	24
2	2	2	2
0	0	0	0
0	0	0	0

= 8 mm

31	22	11	8
63	17	17	20
79	59	47	29
77	80	64	31
84	88	81	52

= 48 mm

7	7	6	5
9	7	5	5
11	12	9	12
13	11	6	9
12	35	16	15

= 11 mm

5	6	7	12
4	4	5	6
3	4	4	4
3	5	5	4
4	3	3	3

= 5 mm

4	4	5	5
4	4	5	5
3	3	3	3
2	2	2	2
2	2	2	2

= 3 mm

= 75 m  
= 3.8 %

Areal averaged rain estimation using power law regression on every pixel over the catchment

17	17	18	26
10	12	13	17
3	3	3	4
1	1	2	2
1	1	1	1

= 8 mm

58	50	40	39
68	40	41	46
68	53	46	38
56	65	49	33
65	63	55	34

= 50 mm

0	0	0	0
0	41	0	0
0	0	46	49
0	0	0	44
0	68	60	52

= 18 mm

0	0	44	51
0	0	0	41
0	0	0	0
0	0	0	0
0	0	0	0

= 7 mm

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

= 0 mm

= 83 mm  
= 6.0 %

Thiessen areal averaged rain

= 6 mm

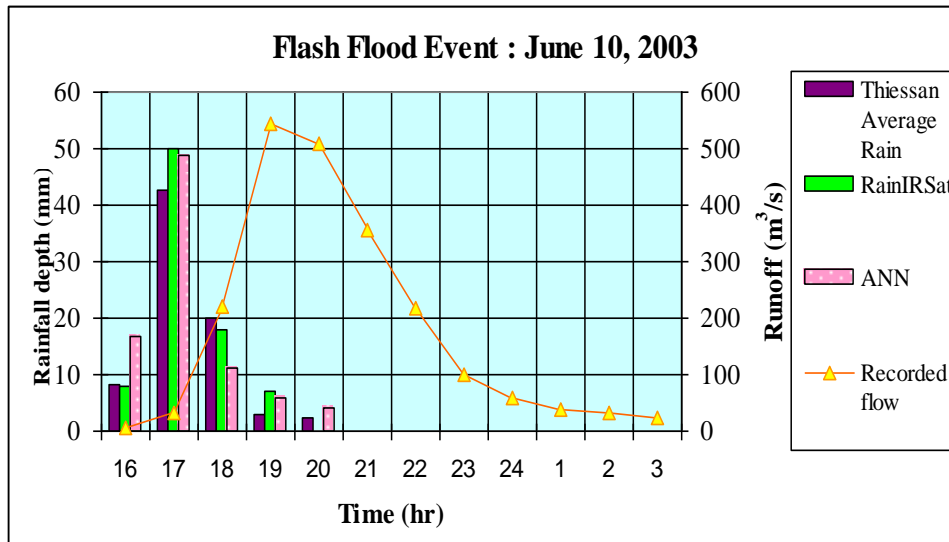
= 43 mm

= 20 mm

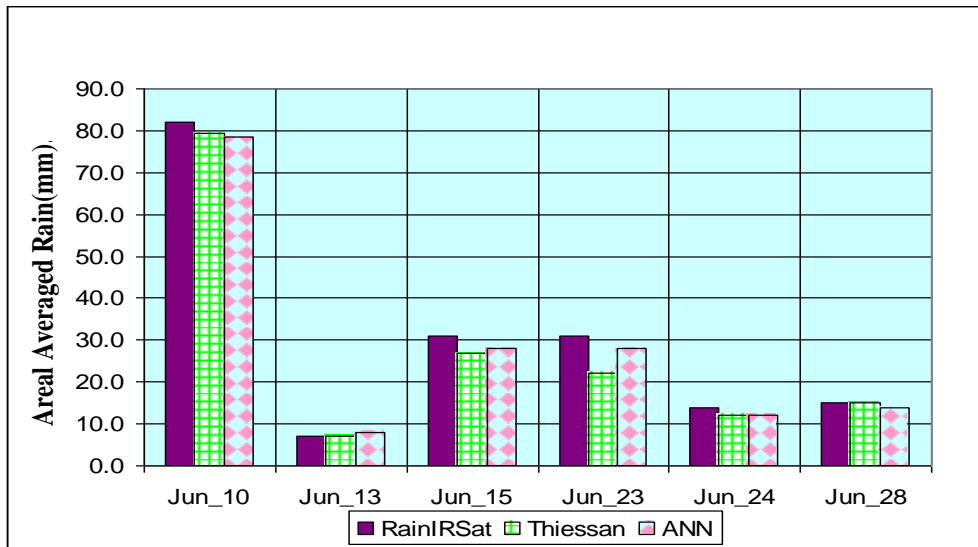
= 6 mm

= 3 mm

= 78 mm



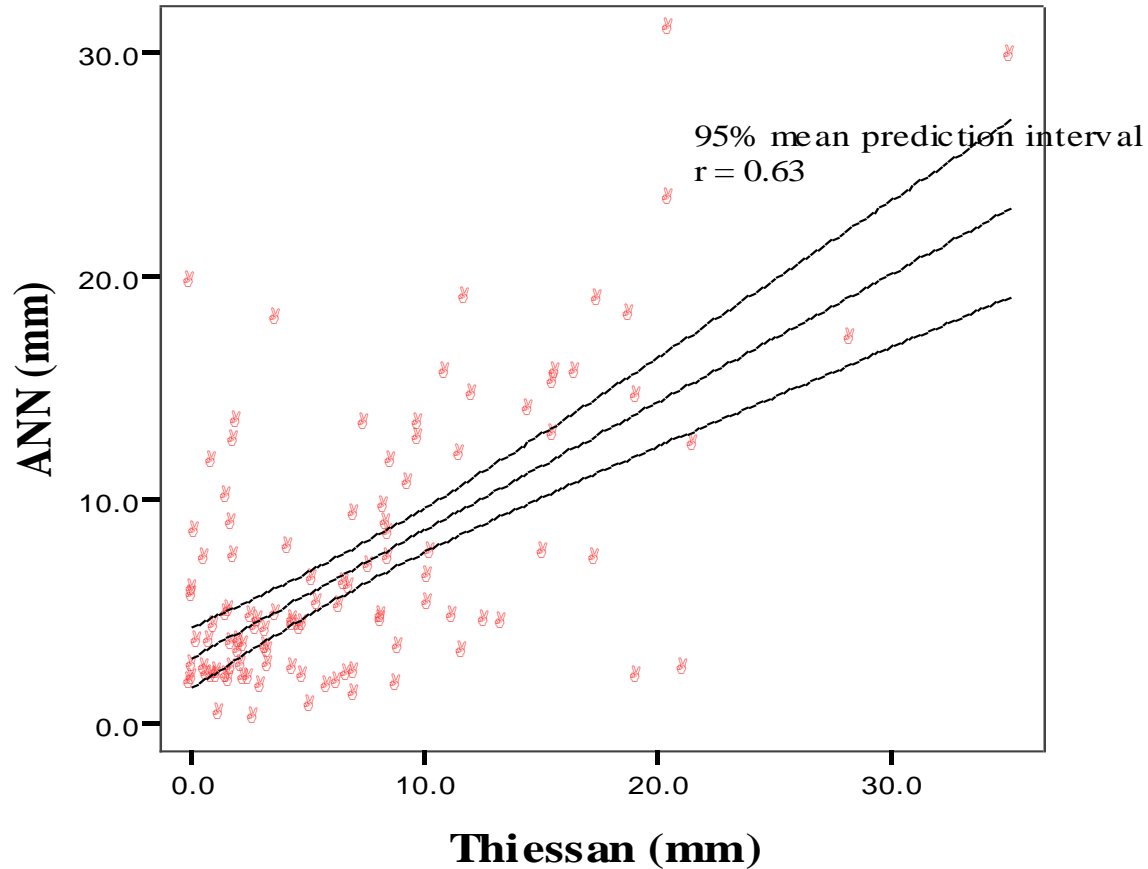
**Hourly estimation of areal averaged rain depth for upper Klang River Basin on June 10, 2003 flash flood event.**



**Estimates of total areal averaged rain depth for upper Klang River Basin for several events**



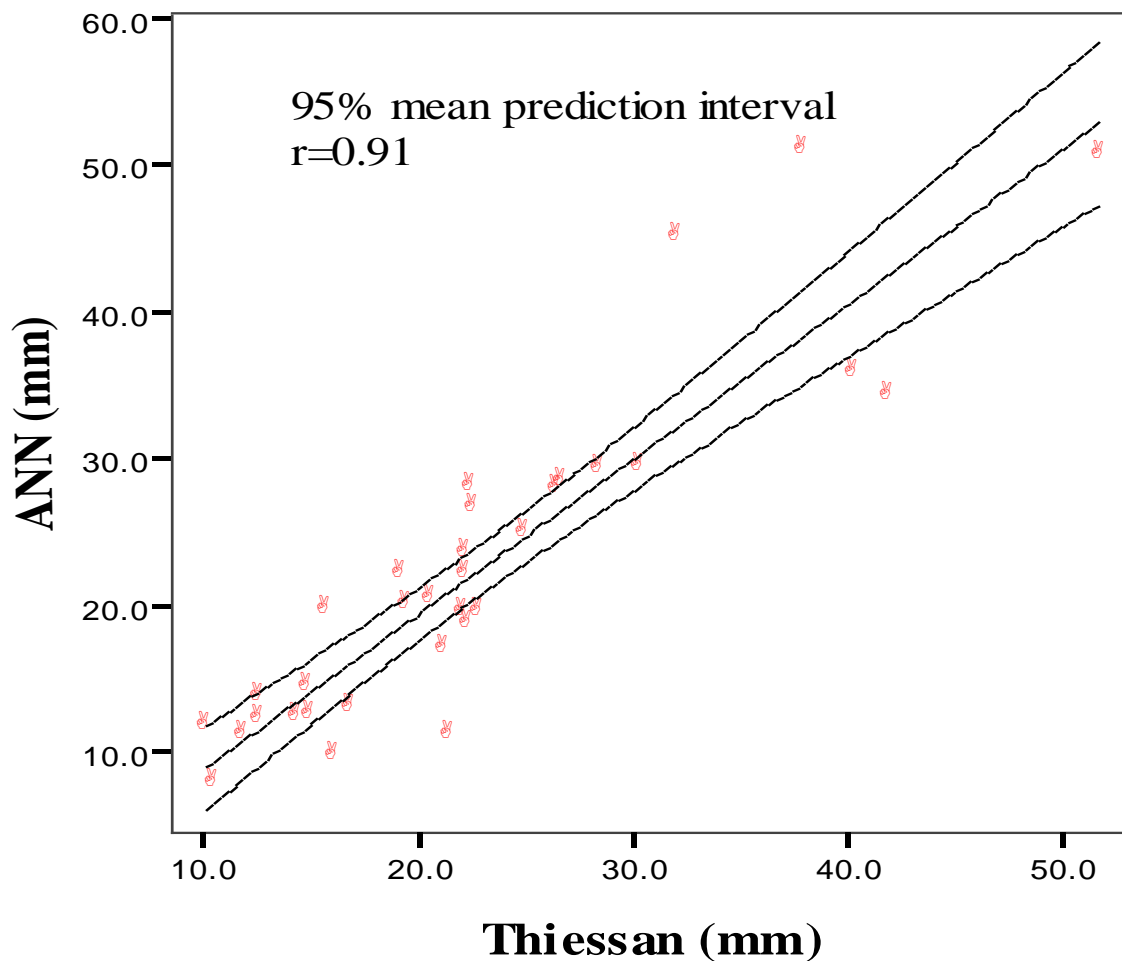
## HOURLY RAINFALL ESTIMATION



Validation of ANN hourly areal averaged rainfall estimation against gauge measured Thiessen areal averaged rain (107 hourly rain from 33 storm events from year 2006 )



## TOTAL RAINFALL ESTIMATION



Validation of ANN total areal averaged rainfall estimation against gauge measured Thiessen areal averaged rain (33 storm events from year 2006)



# Rain-Watch Development

*Rain-Watch*  
Rain Prediction System

Satellite Artificial Neural Network Estimation

Satellite Power Law Estimation

Telemetric Rain Gauge

Radar Rain

Info

UNIVERSITI  
TEKNOLOGI  
MARA

Faculty of Civil Engineering  
Faculty of Information Technology & Quantitative Sciences

Rain-Watch offers four complementary rain estimation options. Users can easily estimate and forecast rainfall for their flood monitoring system or any rainfall-related disaster monitoring system using the user-friendly graphical-user-interface Rain-Watch application



# Application 1

Areal rainfall estimation - The rain measuring system, whether the conventional rain gauges or the more advanced Remote Sensing and Transmission Unit (RSTU) panel, can only be sparsely installed at suitable location, hence it is considered as point rain measurement.



RSTU Panel

**Rain\_Interface**

**Satellite ANN**

Previous Image

Result Image

Color Code Legend (mm)

Black	≤ 1
Blue	1 - 7
Yellow	7 - 11
Green	11 - 42
Purple	42 - 64
Pink	64 - 99
Red	99 - 153
White	> 153

Zoom Off Compare Reference

Load Previous Image

Load Current Image

Select Region Current Image

Crop Region Current Image

ANN Prediction

Rain Forecast

Display Result Compare Reference **11.0225**

Current Image

Selected Region

Please enter the following data :

**Numerical Weather Prediction Values**

Precipitable Water Content : 55 kg/m<sup>2</sup>

Relative Humidity : 65 %

Vertical Wind : 0.2 m/s

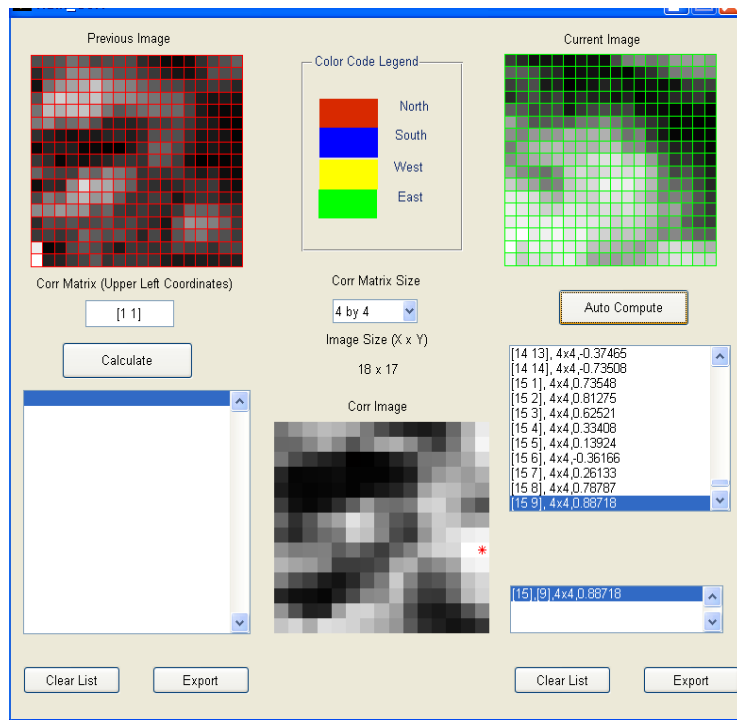
# Application 2

Rainfall estimation over inaccessible areas to rain-gauge or radar beam

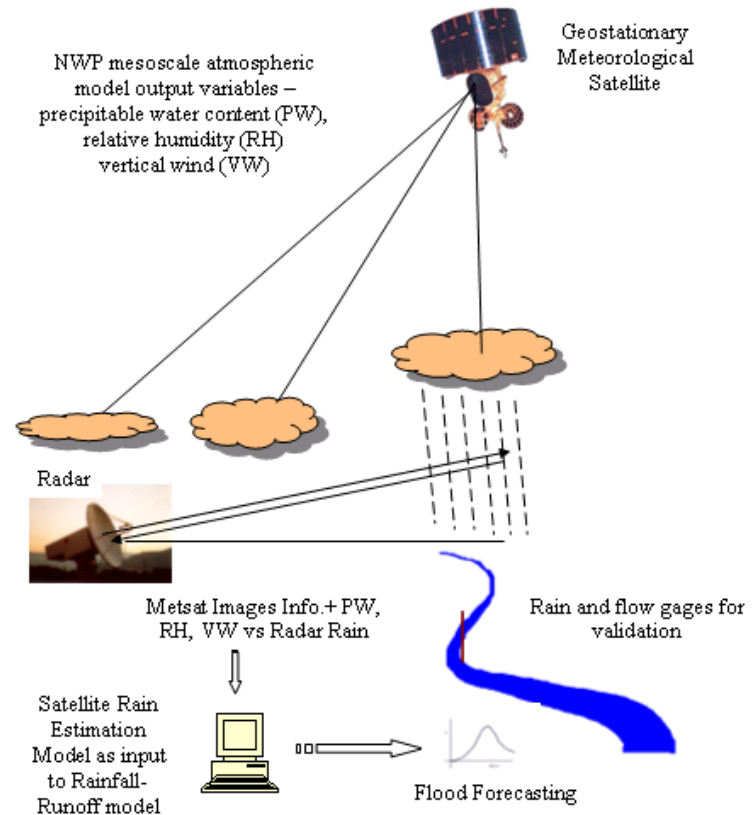


# Application 3

Flash flood forecasting for an improved lead time of flood warning



Cross-correlation option in Rain-Watch for rainfall forecast

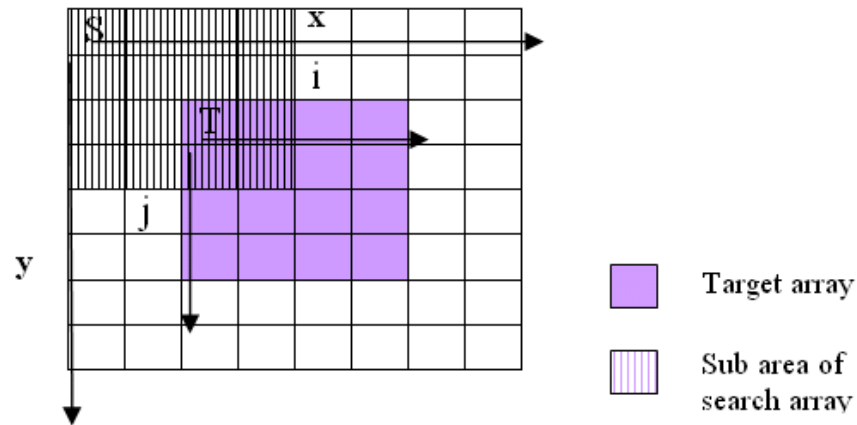


A coupled hydro-meteorological flood forecasting system.



**EARLY FLOOD WARNING WOULD ALLOW  
ENOUGH TIME  
TO SAVE PROPERTIES**

Catchment with short response times requires improved flood forecasting technique. By coupling meteorological and the hydrological model the lead time between occurrence of a storm event and flood warning can be extended.

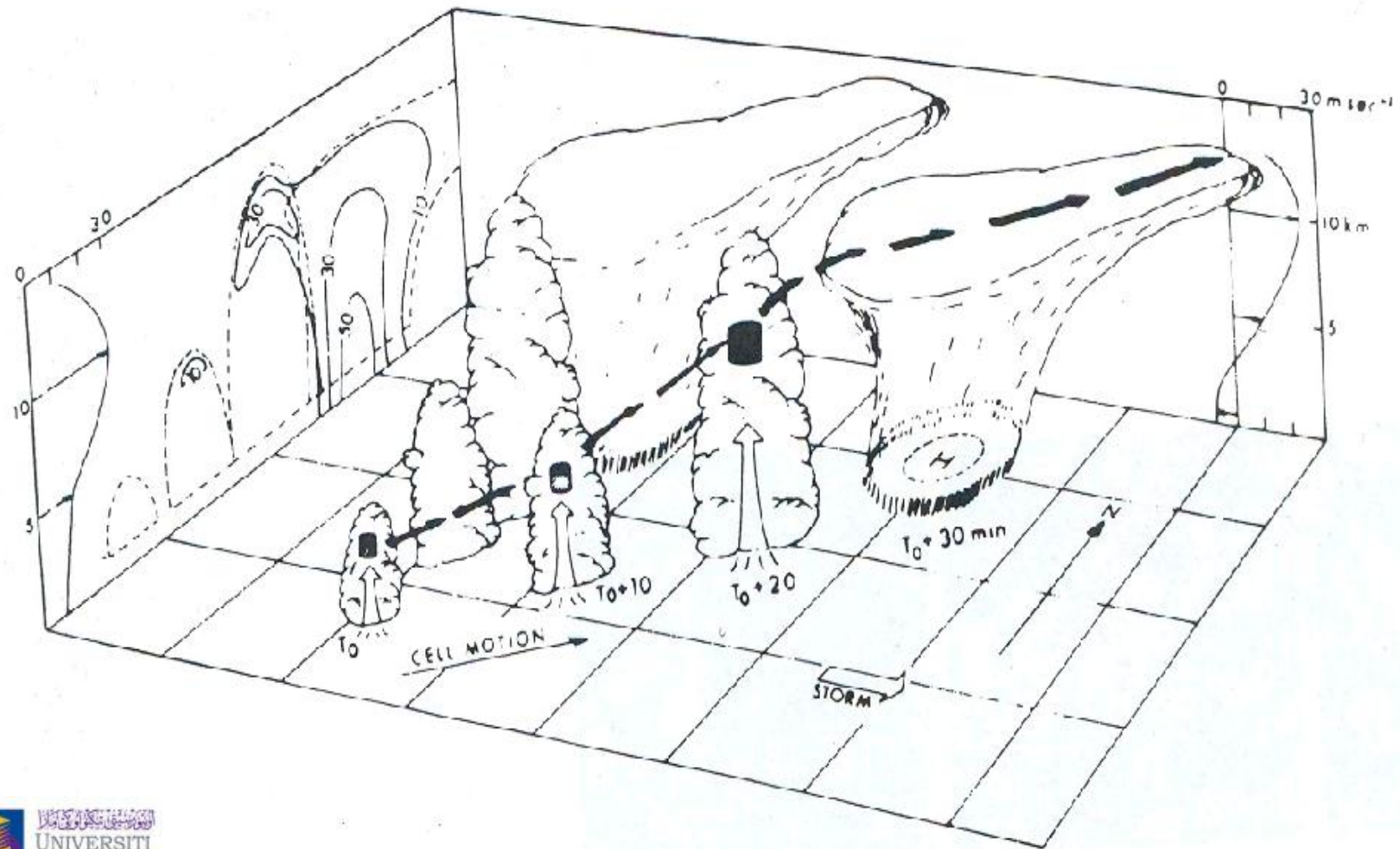


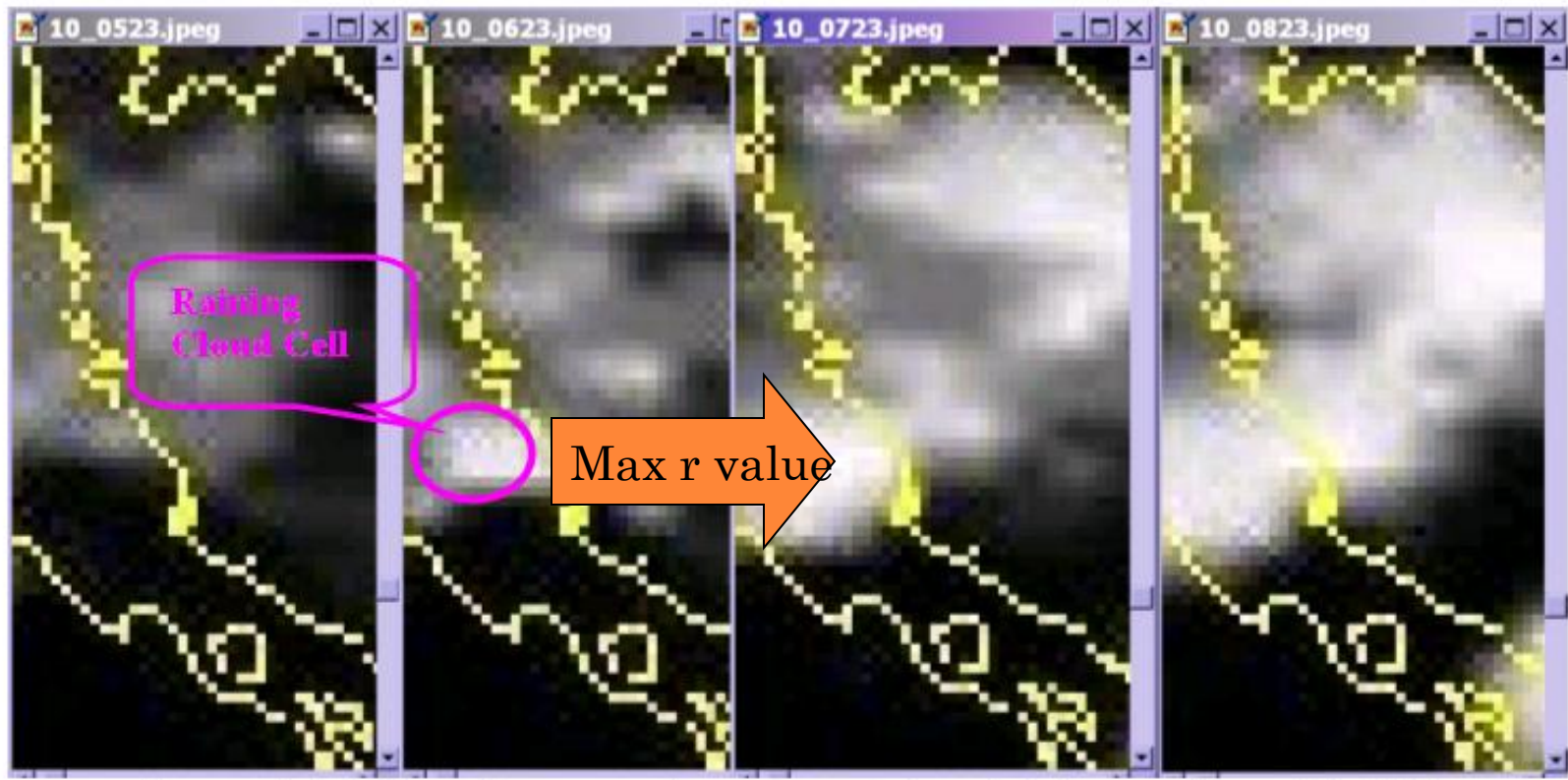
$$r_{x,y} = \frac{\sum_{i=1}^4 \sum_{j=1}^4 [S_{i+x+2, j+y+2} - \bar{S}(x, y)][T_{i,j} - \bar{T}]}{\left\{ \sum_{i=1}^4 \sum_{j=1}^4 [S_{i+x+2, j+y+2} - \bar{S}(x, y)]^2 \sum_{i=1}^4 \sum_{j=1}^4 (T_{i,j} - \bar{T})^2 \right\}^{1/2}}$$

## CROSS CORRELATION TECHNIQUE TO TRACK THE DIRECTION OF CLOUD MOVEMENT



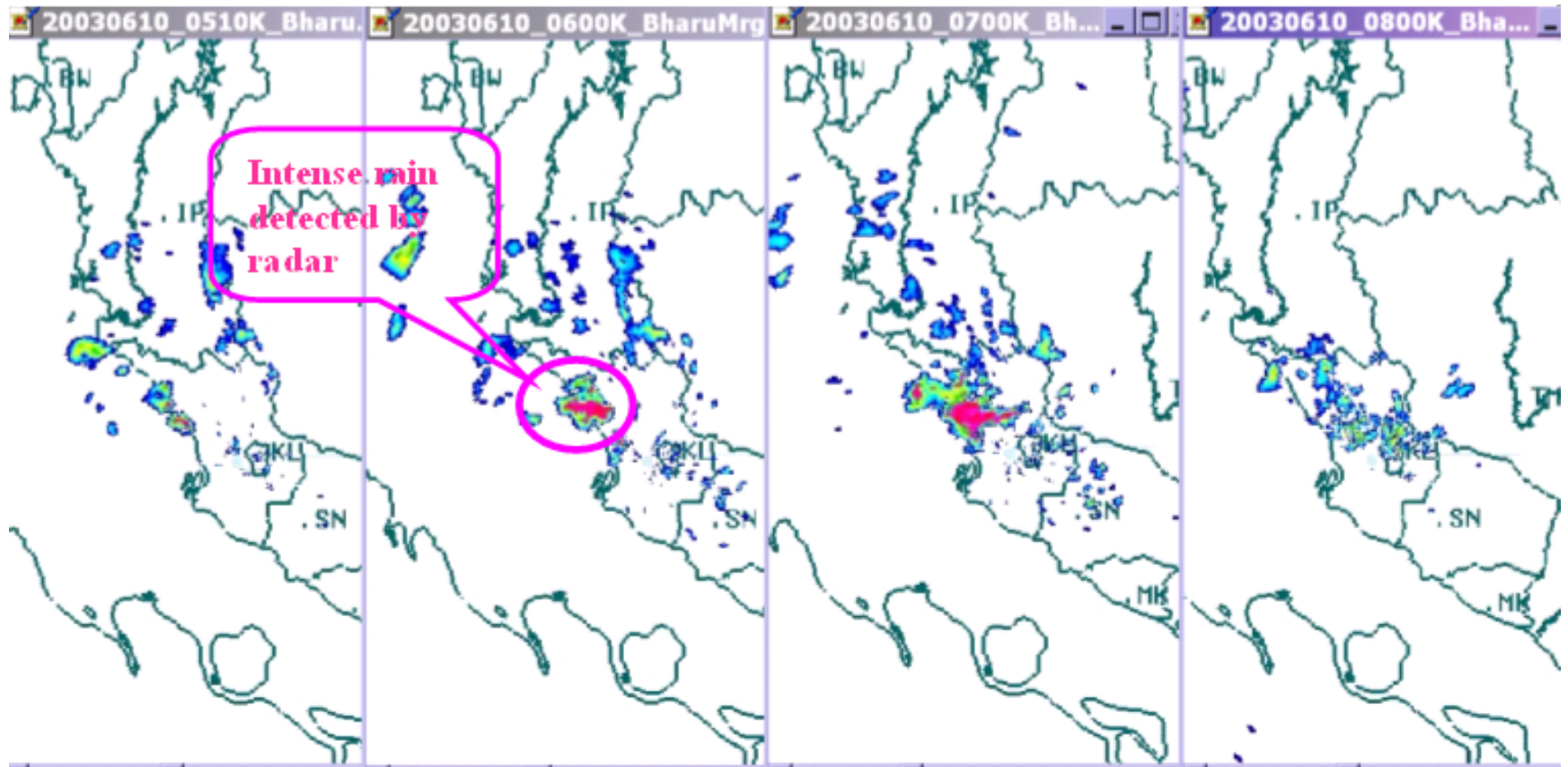
# Schematic view of a multi-cell storm





Sequential infrared images at one hour interval taken on June 10, 2003

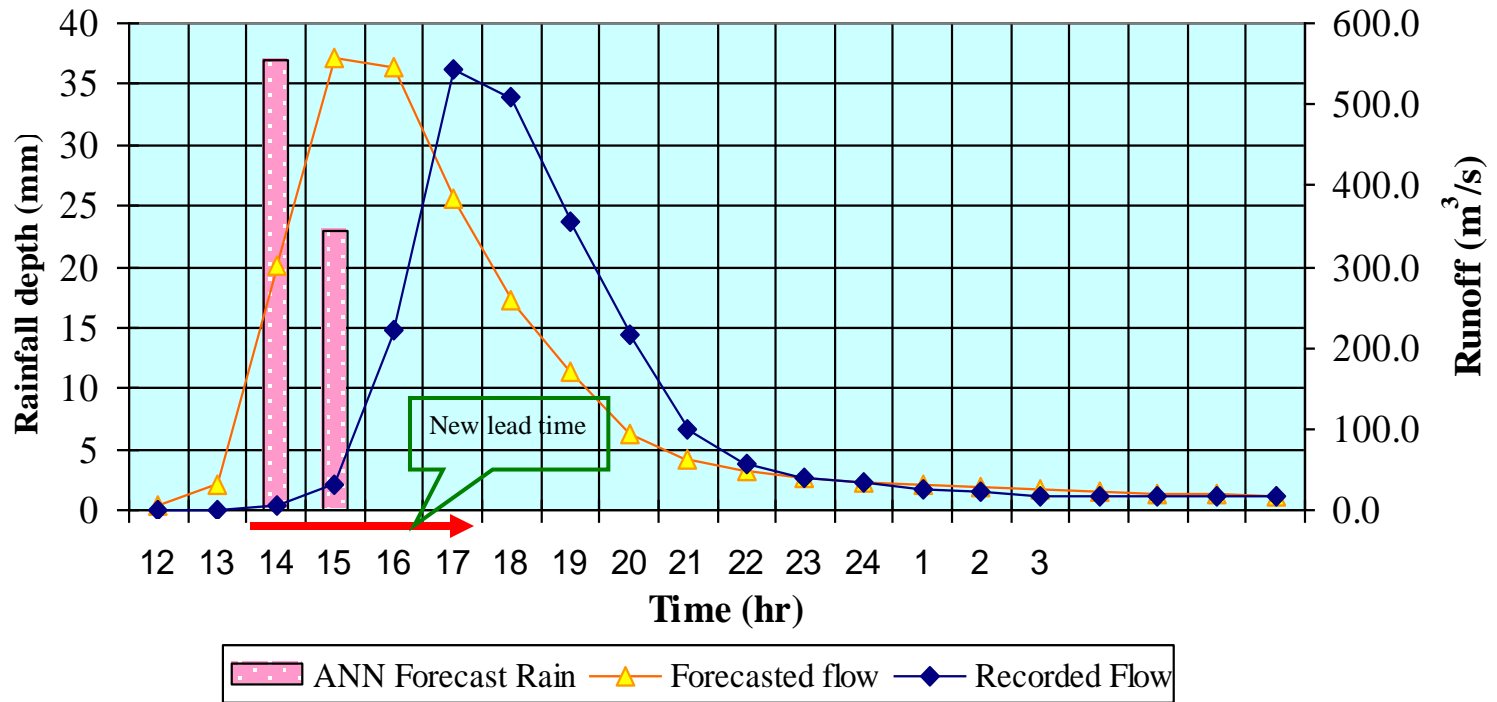




Sequential radar displays at one hour interval taken on June 10, 2003

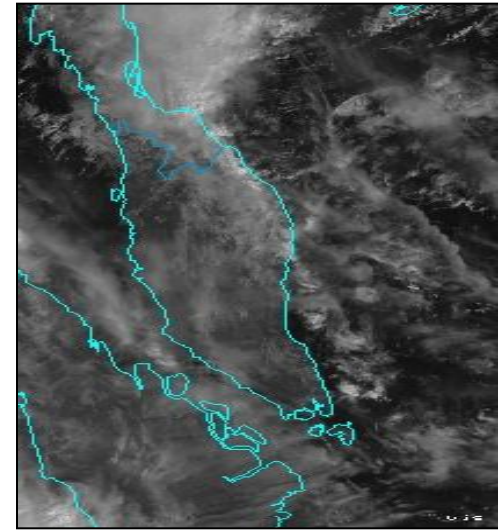


### Storm Event : June 10, 2003 (Flash Flood Event)

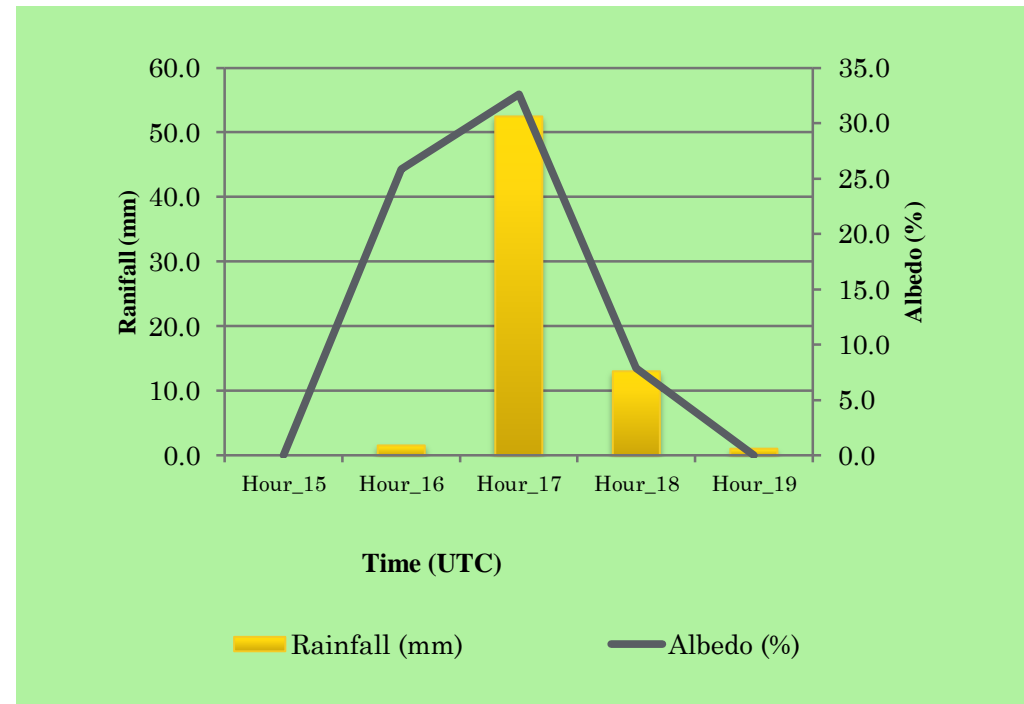


# ON-GOING WORK

- ❑ Further validation and application (Kelantan River basin, Pahang River basin, Sg Muda River basin)
- ❑ Use of other satellite images (VISIBLE, Vapor)

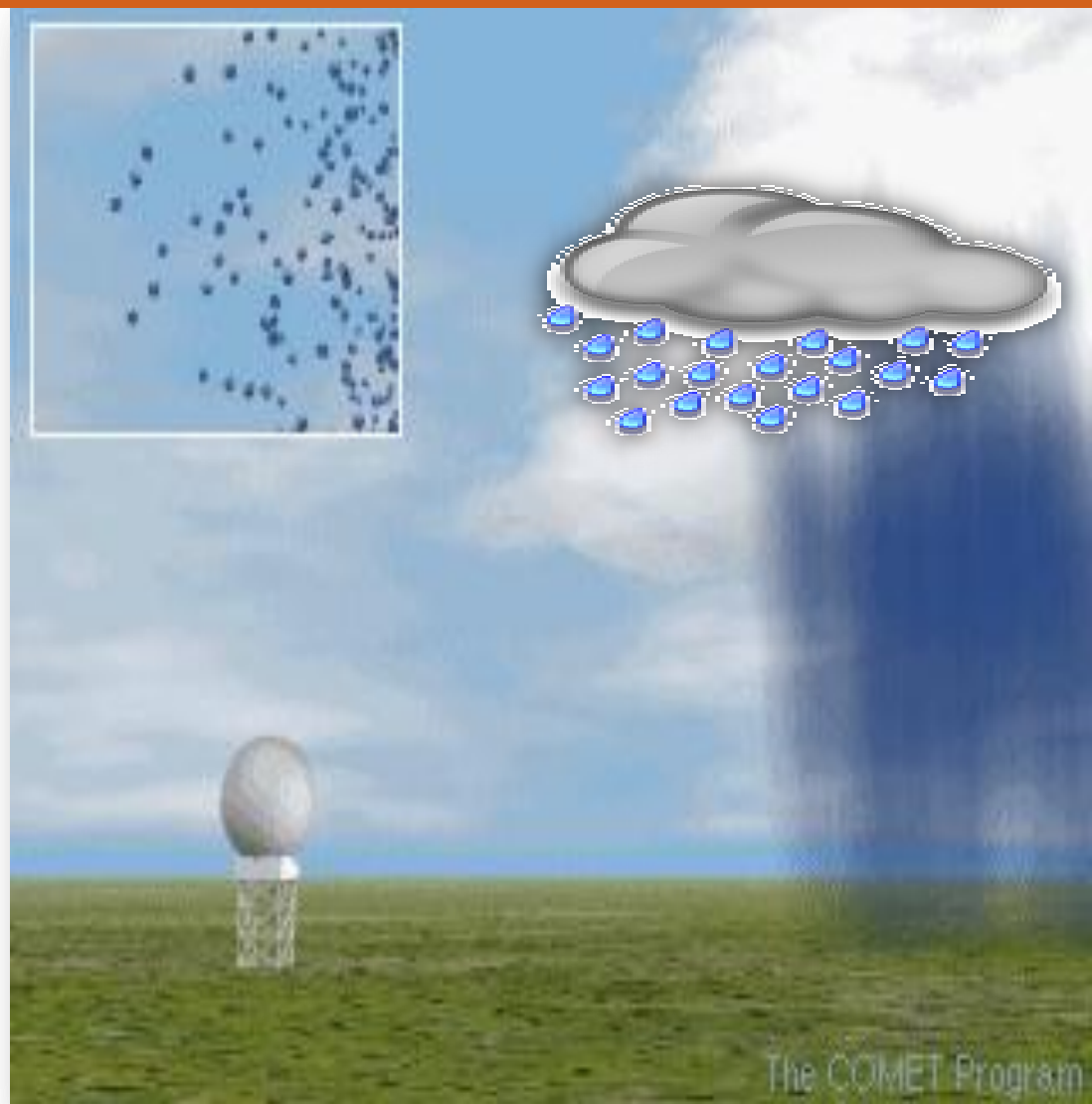
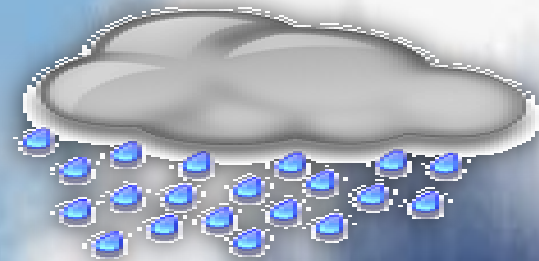


**The main limitation/problem in the on-going study is the cost incurred (MMD is now charging all data)**



# RADAR

- Radar stands for Radio Detection and Ranging.
- It detects the position, velocity and characteristics of targets.
- Weather radar sends directional pulse of microwave
- The energy of each pulse will bounce off the small particles (droplets) back in the direction of the radar station.
- The signal in reflectivity will then be converted into rain rate.
- The relationship between reflectivity,  $Z$  and rainfall rate,  $R$  is established empirically and it is known as  $Z$ - $R$  relationships



# Station Network of Malaysian Meteorological Department



## Legend

■ FORECAST OFFICE

● PRINCIPAL STATION

● AIR POLLUTION STATION

● UPPER AIR STATION



METEOROLOGICAL SATELITE STATION



STORM WARNING RADAR STATION

# DOPPLER RADAR

- Development of Doppler radar starts in the era of 1970s
- Doppler radar, which is situated in Bukit Tampo, Dengkil, about 10 km to North KLIA was first introduced in 1998.
- The prime function of TDR is to detect and to alert KLIA on the wind shear problem and also microburst scenario. Both conventional and Doppler radars can detect rainfall intensity through its signal reflectivity.



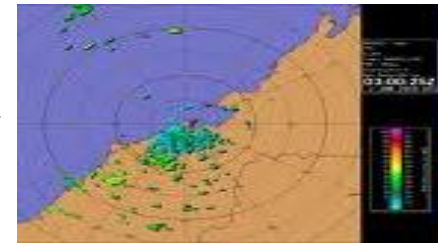
# DOPPLER RADAR DATA ACQUISITION PROCESS



RVP8

→ IRIS SOFTWARE  
(VAISALA) →

RCP



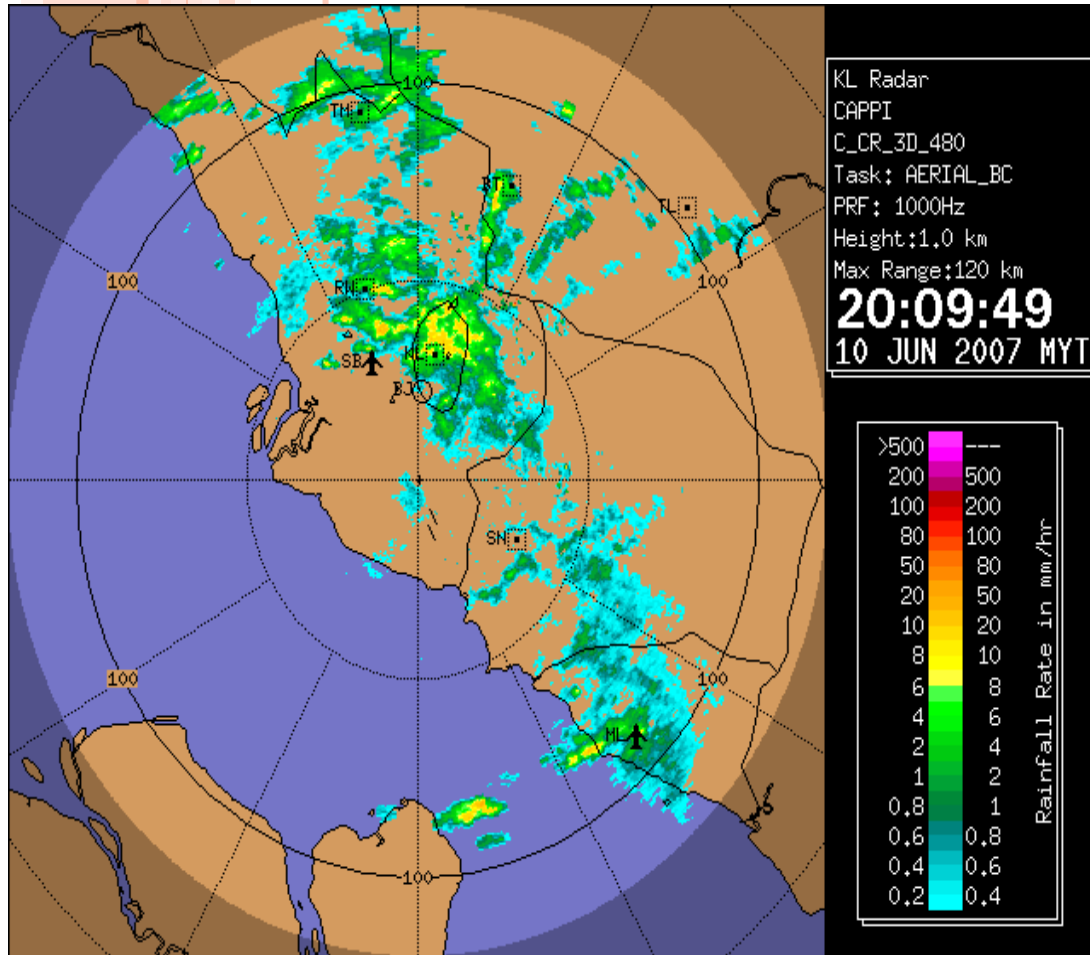
RPW: Radar Product  
Workstation

Products:  
PPI-raw data rain rate  
CAPPI- image data  
Wind speed data  
microburst

Conversion of  
reflectivity to  
rain rate using  
Marshal Palmer  
 $Z=200R^{1.6}$



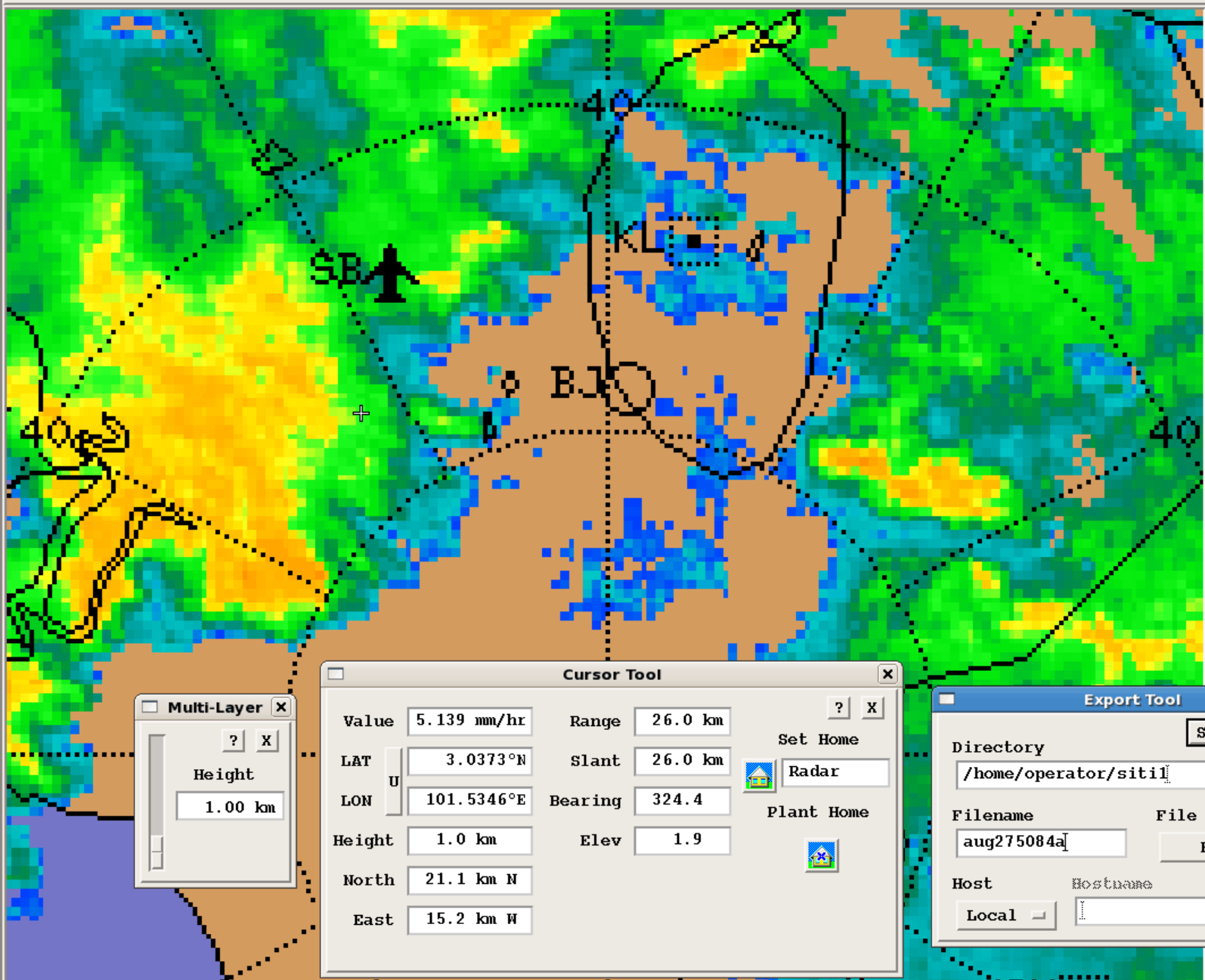
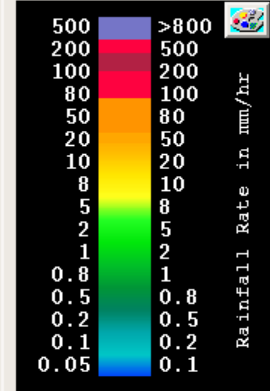
# An example of a Doppler radar image during a flash flood (June 10, 2007)



**KU1/KU1**

**CAPPI**  
 C\_CR\_3D\_480  
 Hgt: 1.0 km  
 Range: 120 km  
 AIRPORT\_BC

**17:03:47**  
**27 AUG 2009**



**Multi-Layer**  **X**

? X

Height

1.00 km

**Cursor Tool**  **X**

Value  Range  ? X

LAT  Slant  Set Home

LON  Bearing  Radar

Height  Elev  Plant Home

North

East

**Export Tool**  **X**

Save ? X

Directory

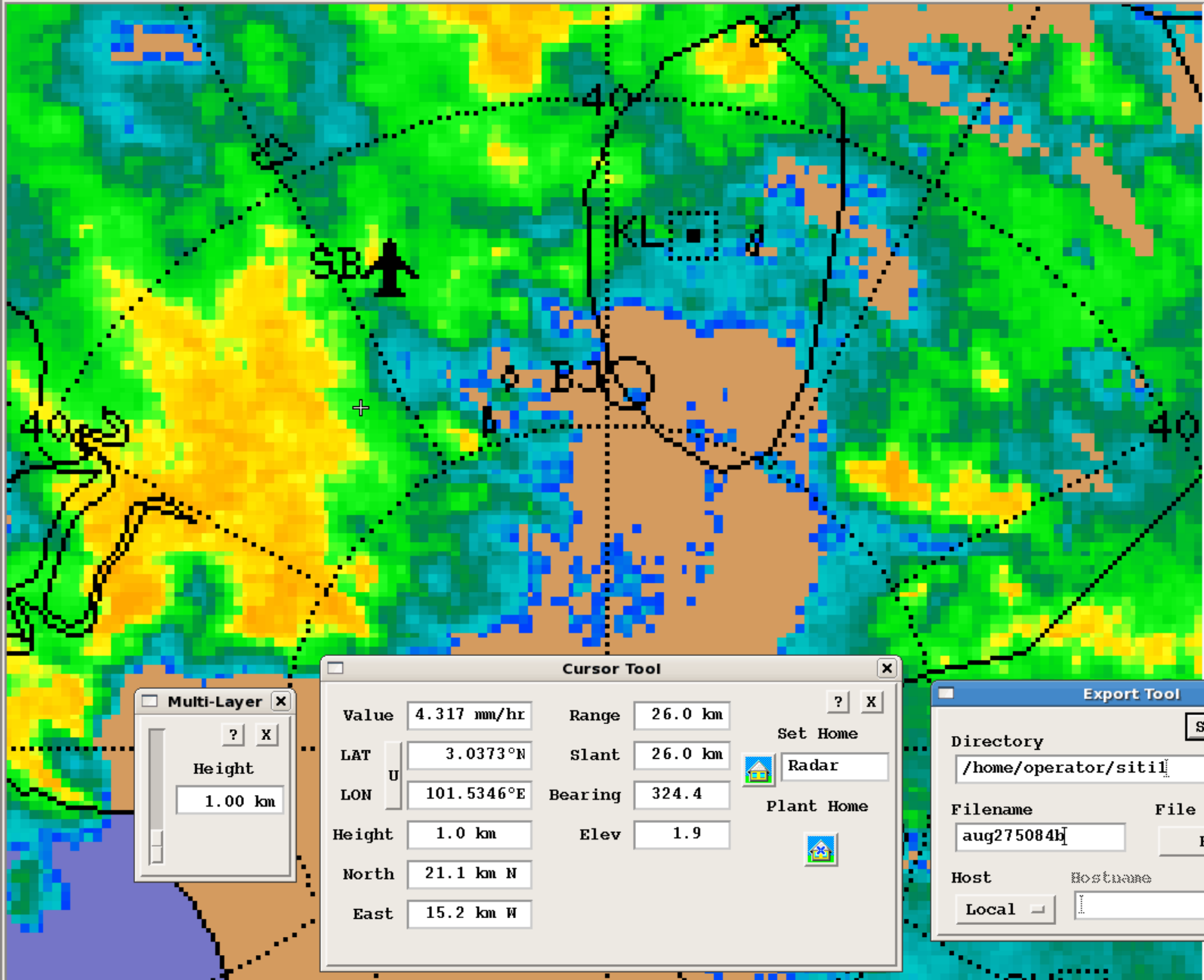
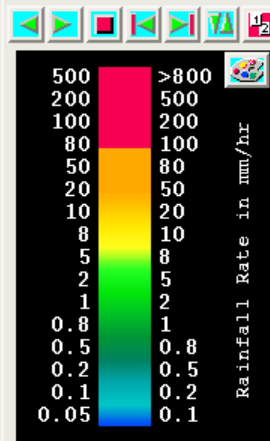
Filename  File Format

Host  Hostname

**KU1/KU1**

**CAPPI**  
 C\_CR\_3D\_480  
 Hgt: 1.0 km  
 Range: 120 km  
 AIRPORT\_BC

**17:09:04**  
**27 AUG 2009**



**Multi-Layer**

Height  
 1.00 km

**Cursor Tool**

Value: 4.317 mm/hr    Range: 26.0 km

LAT: 3.0373°N    Slant: 26.0 km

LON: 101.5346°E    Bearing: 324.4

Height: 1.0 km    Elev: 1.9

North: 21.1 km N

East: 15.2 km W

Buttons: Set Home, Radar, Plant Home

**Export Tool**

Directory: /home/operator/siti

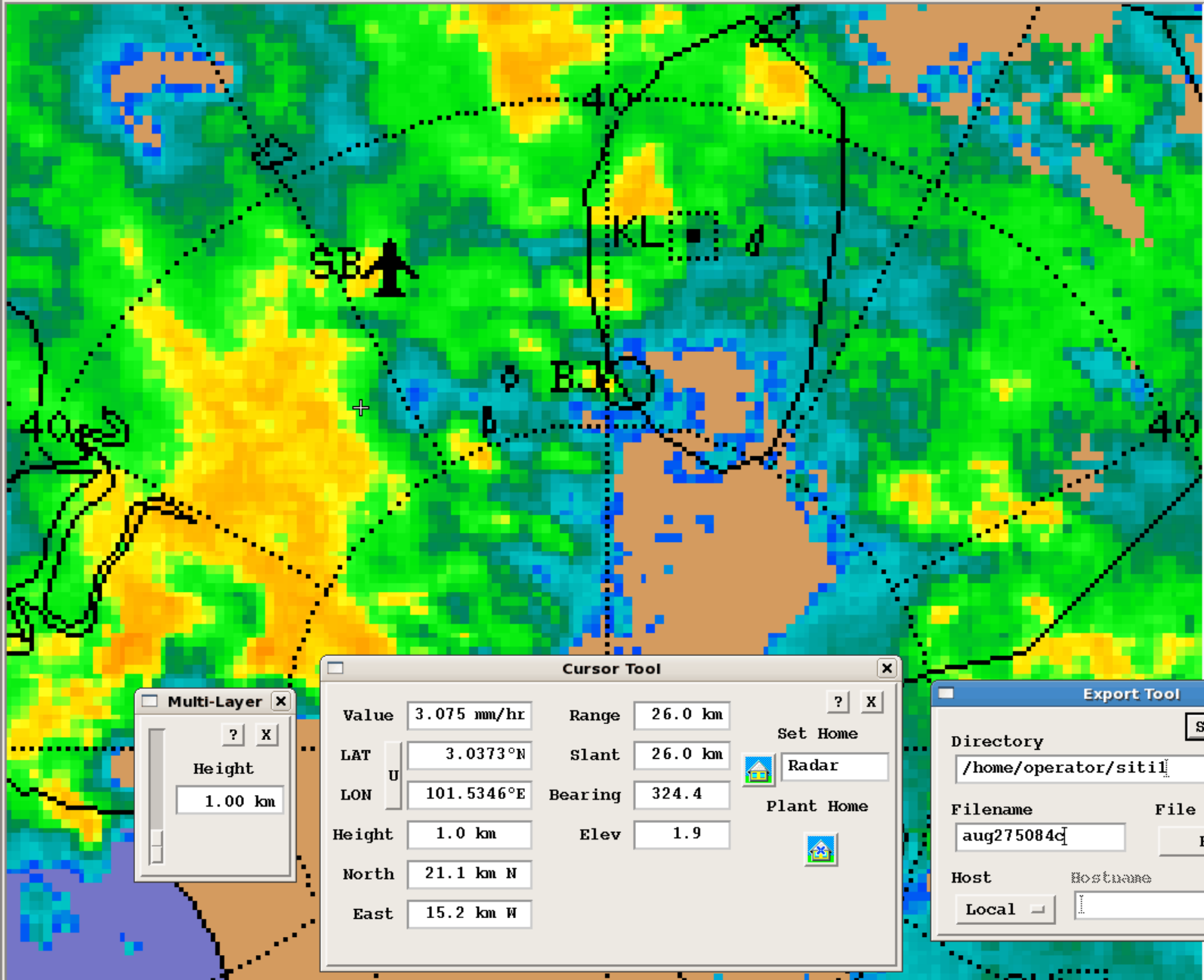
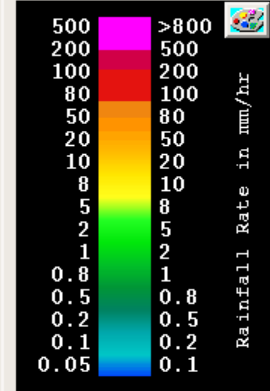
Filename: aug275084h    File Format: BMP

Host: Local

**KU1/KU1**

**CAPPI**  
 C\_CR\_3D\_480  
 Hgt: 1.0 km  
 Range: 120 km  
 AIRPORT\_BC

**17:14:21**  
**27 AUG 2009**



**Multi-Layer**

Height  
 1.00 km

**Cursor Tool**

Value 3.075 mm/hr Range 26.0 km  
 LAT 3.0373°N Slant 26.0 km  
 LON 101.5346°E Bearing 324.4  
 Height 1.0 km Elev 1.9  
 North 21.1 km N  
 East 15.2 km W

Set Home  
 Radar  
 Plant Home

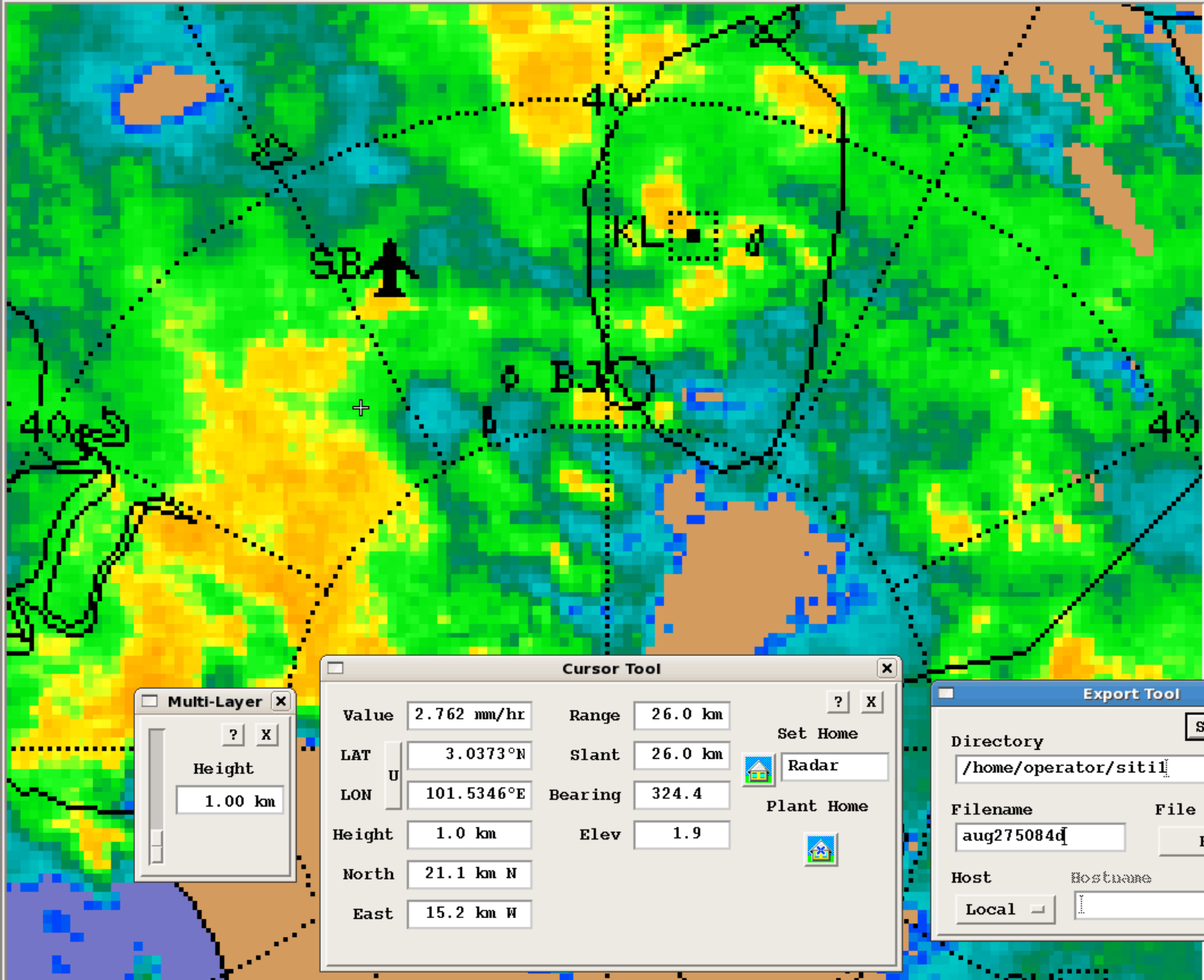
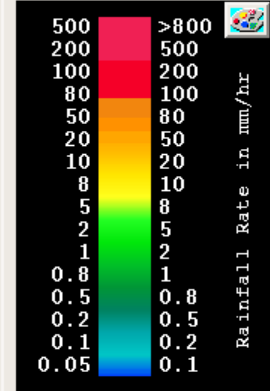
**Export Tool**

Directory /home/operator/siti  
 Filename aug275084c File Format BMP  
 Host Local Hostname

**KU1/KU1**

**CAPPI**  
 C\_CR\_3D\_480  
 Hgt: 1.0 km  
 Range: 120 km  
 AIRPORT\_BC

**17:19:39**  
**27 AUG 2009**



**Cursor Tool**

Value: 2.762 mm/hr    Range: 26.0 km

LAT: 3.0373°N    Slant: 26.0 km

LON: 101.5346°E    Bearing: 324.4

Height: 1.0 km    Elev: 1.9

North: 21.1 km N

East: 15.2 km W

Buttons: Set Home, Radar, Plant Home

**Multi-Layer**

Height: 1.00 km

**Export Tool**

Directory: /home/operator/siti

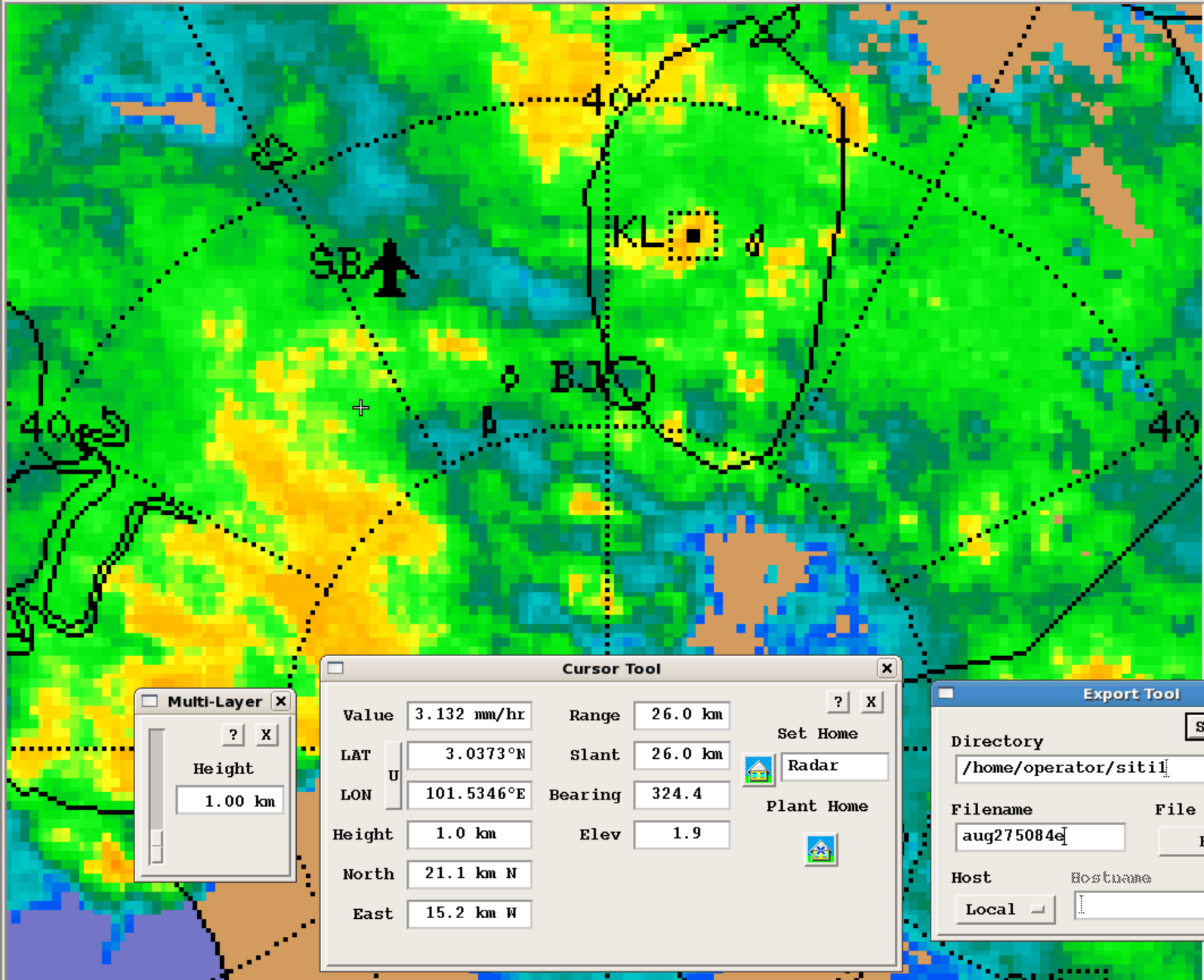
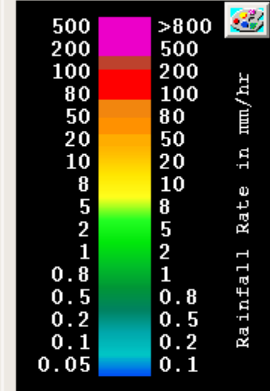
Filename: aug275084d    File Format: BMP

Host: Local

**KU1/KU1**

**CAPPI**  
 C\_CR\_3D\_480  
 Hgt: 1.0 km  
 Range: 120 km  
 AIRPORT\_BC

**17:24:57**  
**27 AUG 2009**



**Cursor Tool**

Value: 3.132 mm/hr    Range: 26.0 km

LAT: 3.0373°N    Slant: 26.0 km

LON: 101.5346°E    Bearing: 324.4

Height: 1.0 km    Elev: 1.9

North: 21.1 km N

East: 15.2 km W

Buttons: Set Home, Radar, Plant Home

**Multi-Layer**

Height: 1.00 km

**Export Tool**

Directory: /home/operator/siti

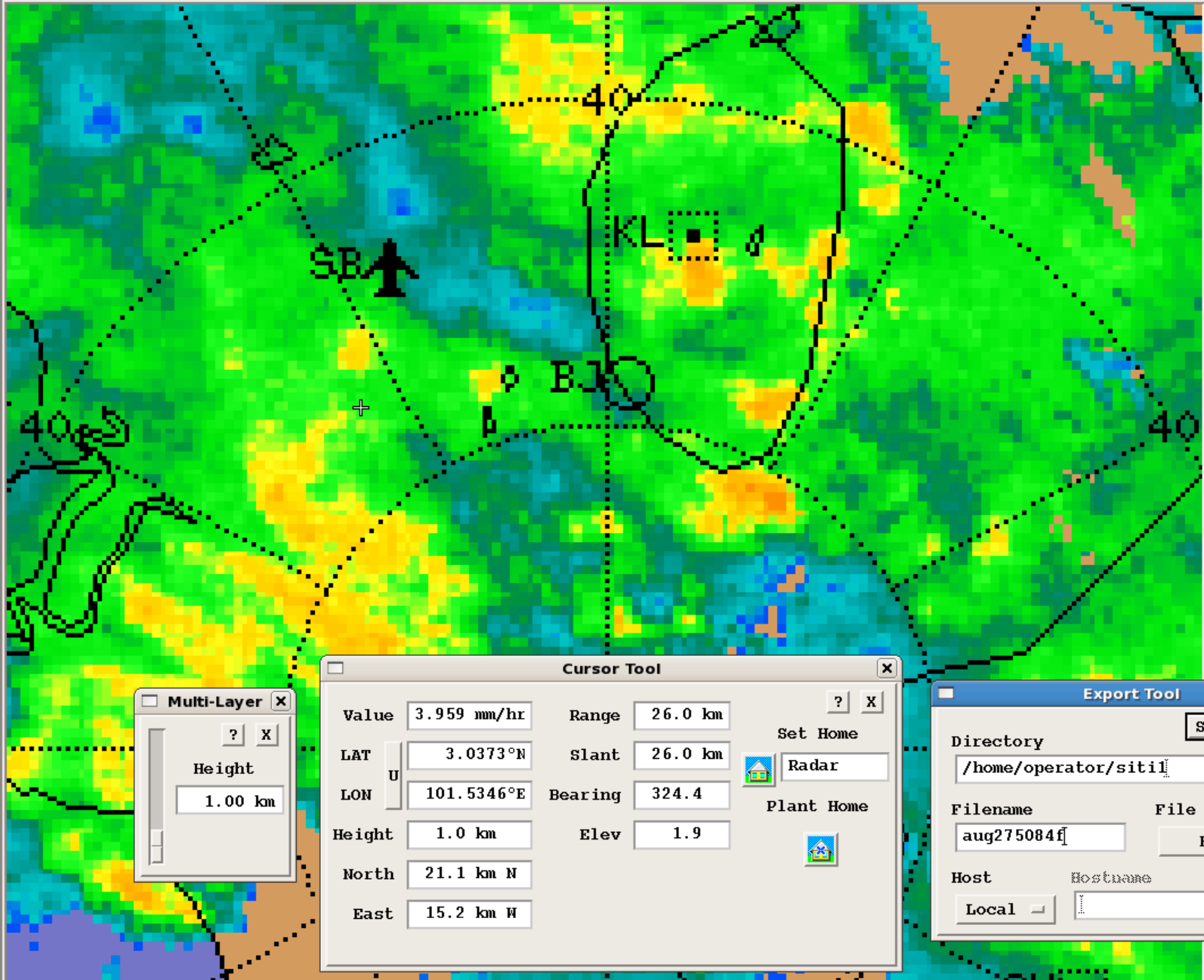
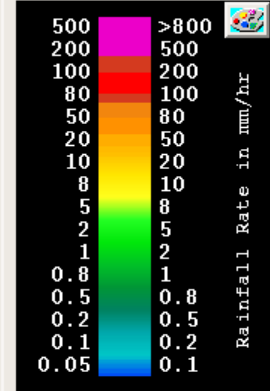
Filename: aug275084e    File Format: BMP

Host: Local    Hostname:

**KU1/KU1**

**CAPPI**  
 C\_CR\_3D\_480  
 Hgt: 1.0 km  
 Range: 120 km  
 AIRPORT\_BC

**17:30:14**  
**27 AUG 2009**



**Multi-Layer**

Height  
 1.00 km

**Cursor Tool**

Value: 3.959 mm/hr    Range: 26.0 km

LAT: 3.0373°N    Slant: 26.0 km

LON: 101.5346°E    Bearing: 324.4

Height: 1.0 km    Elev: 1.9

North: 21.1 km N

East: 15.2 km W

Buttons: Set Home, Radar, Plant Home

**Export Tool**

Directory: /home/operator/siti

Filename: aug275084f    File Format: BMP

Host: Local

# The use of radar in quantitative precipitation estimation (QPE)

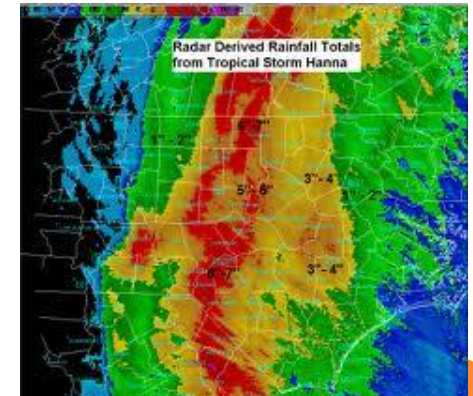
## Advantages

High resolution in temporal and spatial

## Disadvantages

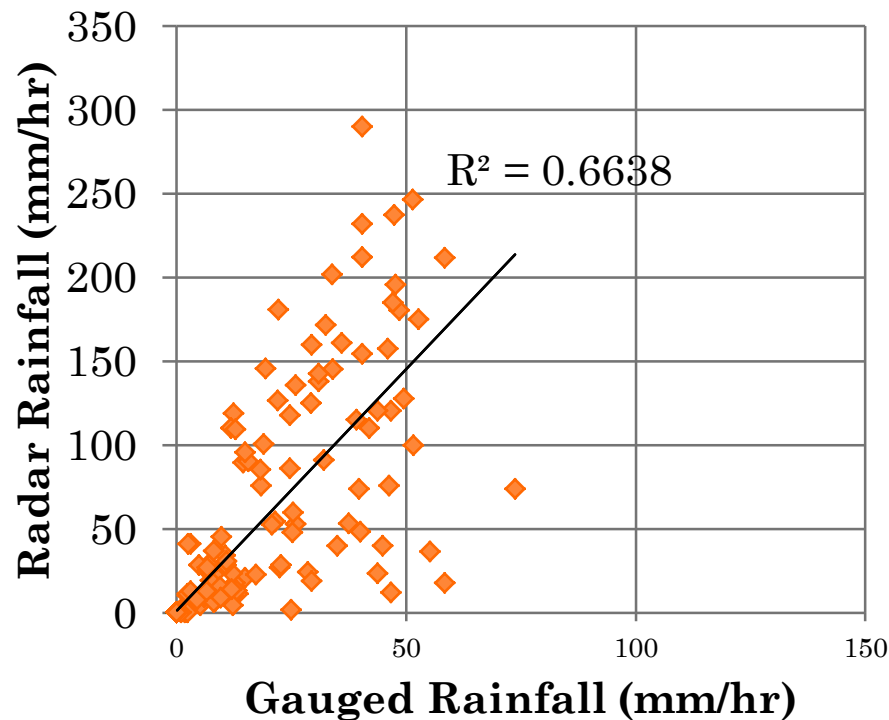
Less accuracy due to several errors (as follows):

- Z-R variability
- Ground clutter contamination
- Bright band effects
- Beam attenuation
- Vertical profile reflectivity
- Rain gauge representativeness
- Miscellaneous (poor maintenance and radar calibration)



# OUR STUDY : IMPROVING Z/R RELATIONSHIP

- Many studies had shown that with inappropriate use of Z/R relations, the rainfall estimates are proved to be inaccurate (Zogg, 2006).

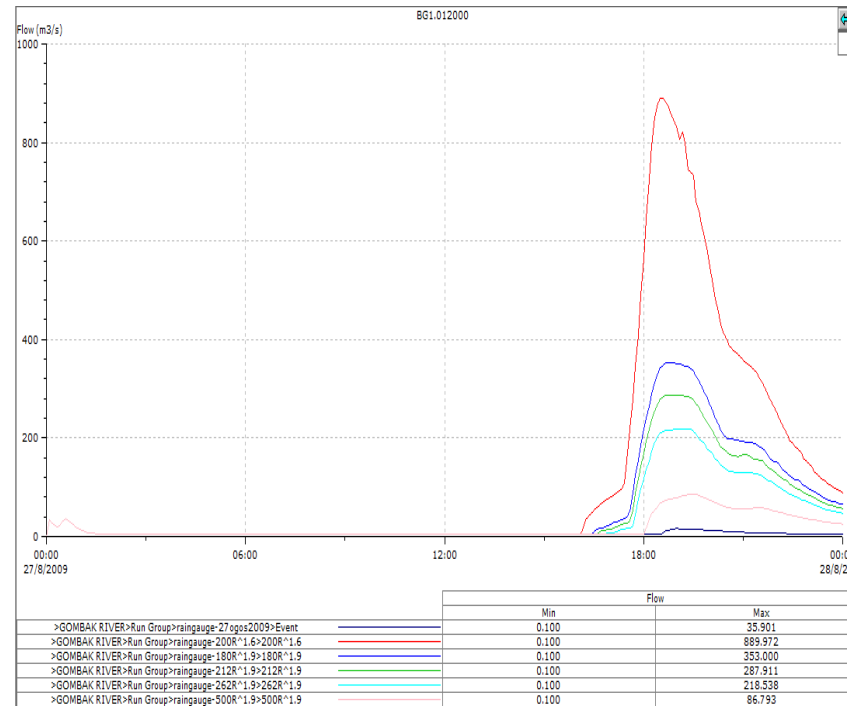
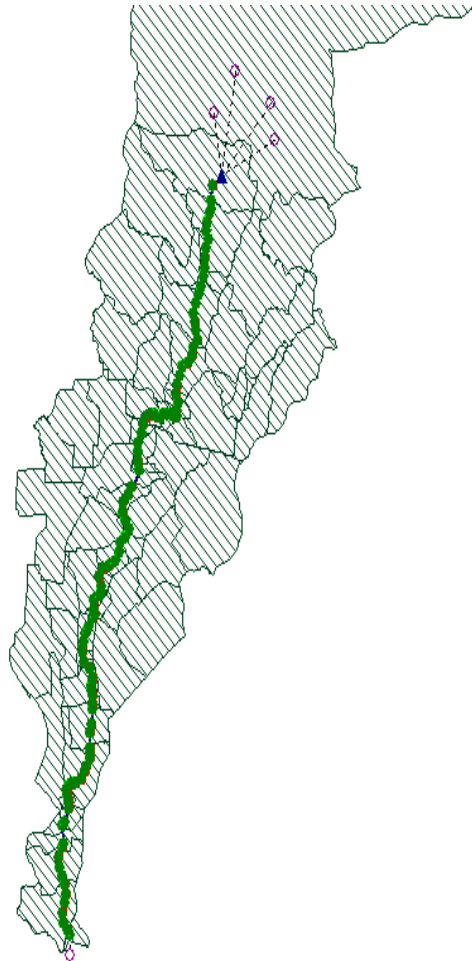


The comparison between new and current Z-R relationship categorized into monsoon and rain intensity

CATEGORY OF RAIN		Z-R Equations	Mean Absolute Error
LOW	New	$Z=180R^{1.9}$	3.08
	Current	$Z=200R^{1.6}$	4.58
MODERATE	New	$Z=212R^{1.9}$	7.18
	Current	$Z=200R^{1.6}$	15.86
HEAVY	New	$Z=262R^{1.9}$	15.04
	Current	$Z=200R^{1.6}$	67.48
SOUTHWEST MONSOON	New	$Z=500R^{1.9}$	8.66
	Current	$Z=200R^{1.6}$	56.25
NORTHEAST MONSOON	New	$Z=166R^{1.9}$	13.03
	Current	$Z=200R^{1.6}$	32.78
INTERSWM	New	$Z=367R^{1.9}$	11.54
	Current	$Z=200R^{1.6}$	99.44
INTERNEM	New	$Z=260R^{1.9}$	32.04
	Current	$Z=200R^{1.6}$	97.58



# APPLICATION OF RADAR RAINFALL INPUT



Flood hydrograph after an unsteady flow analysis using different rainfall inputs

Gombak river basin model network and radar rainfall input

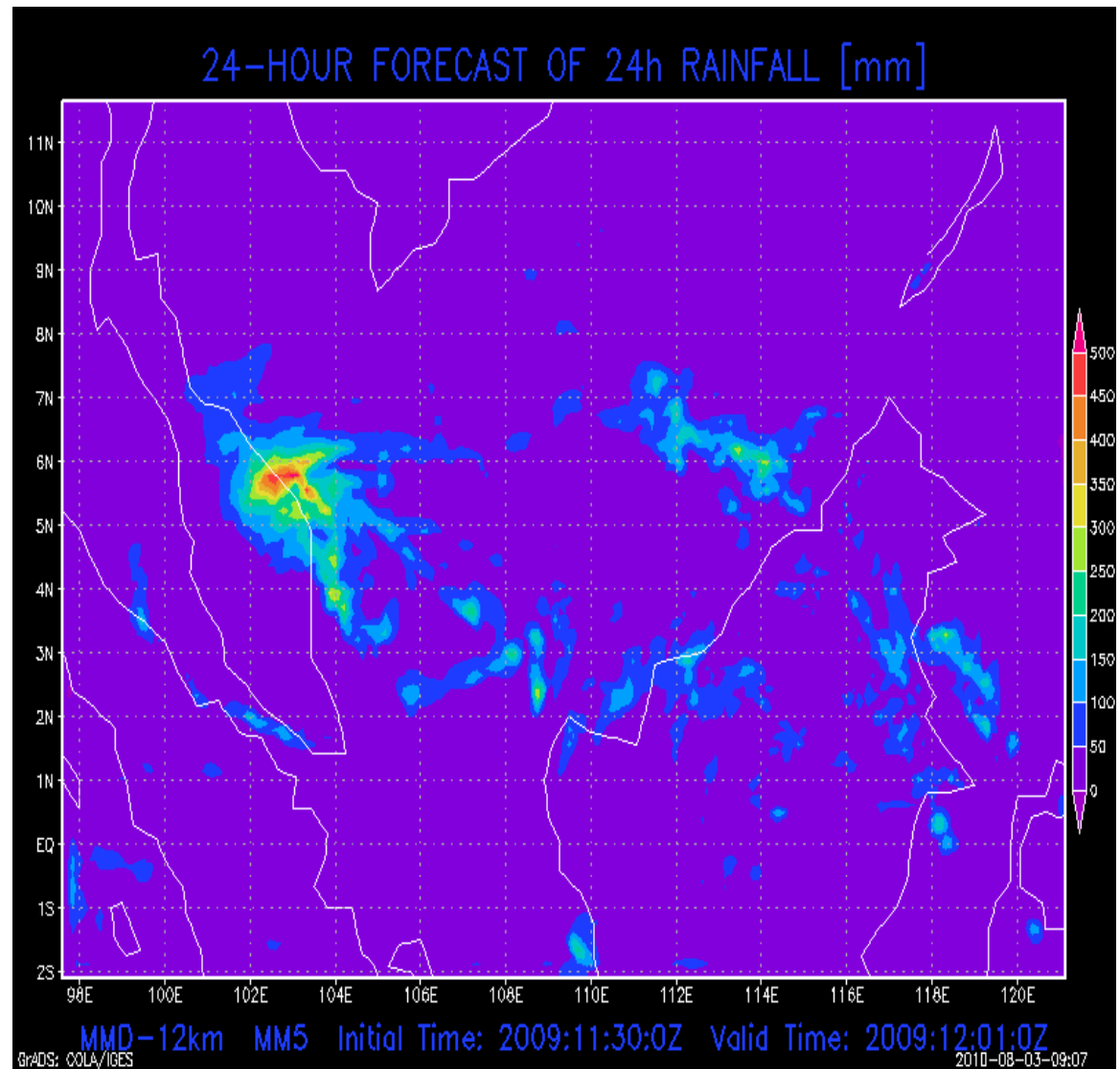


## ON-GOING WORK

- Further improvement in radar rainfall estimation, reducing error by Kalman filter
- Radar rainfall input into grid-based rainfall-runoff model

# NUMERICAL WEATHER PRODUCTS (NWP)

High-resolution  
Numerical weather  
prediction (NWP)  
models with grid cell  
sizes between 2 and  
14 km have great  
potential in  
contributing towards  
reasonably accurate  
QPF.



24-hour Accumulated Rainfall data (30.11-1.12.2009)  
using MM5

## WHAT IS

# NUMERICAL WEATHER PREDICTION (NWP) ?

Objective weather forecasts by solving a set of governing equations that describe the evolution of the present state of the atmosphere (e.g: conservation of momentum, conservation of mass, moisture, and gas law) . The process involves initial variables that describes the current state of the atmosphere such as: humidity, temperature, wind velocity, pressure. Fundamental equations of physics represent these variables and through integration over time a forecast or an estimation of the variables at the future state is made.

Example NWP equations:

**Momentum (x-component)**

$$\frac{\partial u}{\partial t} + \frac{m}{\rho} \left( \frac{\partial p'}{\partial x} - \frac{\sigma}{p^*} \frac{\partial p^*}{\partial x} \frac{\partial p'}{\partial \sigma} \right) = -\mathbf{V} \cdot \nabla u + v \left( f + u \frac{\partial m}{\partial y} - v \frac{\partial m}{\partial x} \right) - ew \cos \alpha - \frac{uw}{r_{earth}} + D_u$$

**Momentum (y-component)**

$$\frac{\partial v}{\partial t} + \frac{m}{\rho} \left( \frac{\partial p'}{\partial y} - \frac{\sigma}{p^*} \frac{\partial p^*}{\partial y} \frac{\partial p'}{\partial \sigma} \right) = -\mathbf{V} \cdot \nabla v - u \left( f + u \frac{\partial m}{\partial y} - v \frac{\partial m}{\partial x} \right) + ew \sin \alpha - \frac{vw}{r_{earth}} + D_v$$

**Momentum (z-component)**

$$\frac{\partial w}{\partial t} - \frac{\rho_0}{\rho} \frac{g}{p^*} \frac{\partial p'}{\partial \sigma} + \frac{gp'}{\gamma p} = -\mathbf{V} \cdot \nabla w + g \frac{\rho_0 T'}{p T_0} - \frac{g R_d p'}{c_p p} + e(u \cos \alpha - v \sin \alpha) + \frac{u^2 + v^2}{r_{earth}} + D_w$$

- During the 1970's several NWP modelling systems were implemented, global, hemispheric or as limited area models (LAMs).
- LAMs ran with a higher resolution over a smaller area and took boundary conditions from a larger hemispheric or global model.
- During the last decades, several regional LAMs have been developed such as the Fourth Generation Penn State/NCAR Mesoscale (MM4) and later the MM5 (Grell *et al.* 1994) and the new Weather Research and Forecasting (WRF) model (NCAR/UCAR, 2005).
- Today, NWP is the most widely used prediction system, and can predict future states for up to 10 days.



# NWP USED BY THE MALAYSIAN METEOROLOGICAL DEPARTMENT

- Malaysian Meteorological Department (MMD) currently uses the MM5 and the WRF for the weather forecasting purposes. NWP model outputs include forecasts for rainfall, humidity, wind speed and a range of other derived variables which may be useful for flood forecasting.
- With advances in NWP in the recent years as well as an increase in computing power, it is now possible to generate very high resolution rainfall forecast at the catchment scale.



## OUR STUDY :

- Statistical verification of two NWP models namely MM5 and WRF against gauged rain over Kelantan River Basin and Klang River Basin.
- Comparison of MM5 and WRF performance against gauged rain over Kelantan River Basin.

# Datasets used

NWP model used in Malaysia

- Fifth Generation Penn State/NCAR Mesoscale (MM5)
- Weather Research and Forecasting (WRF)

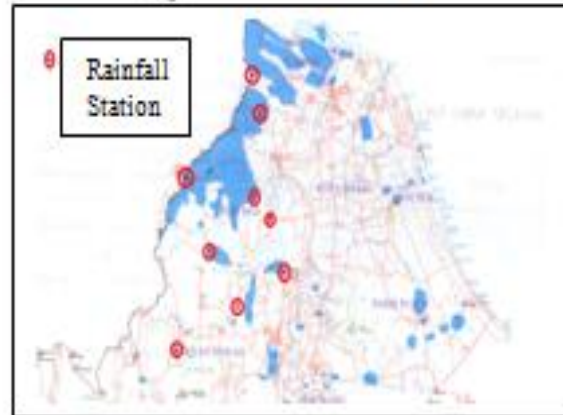
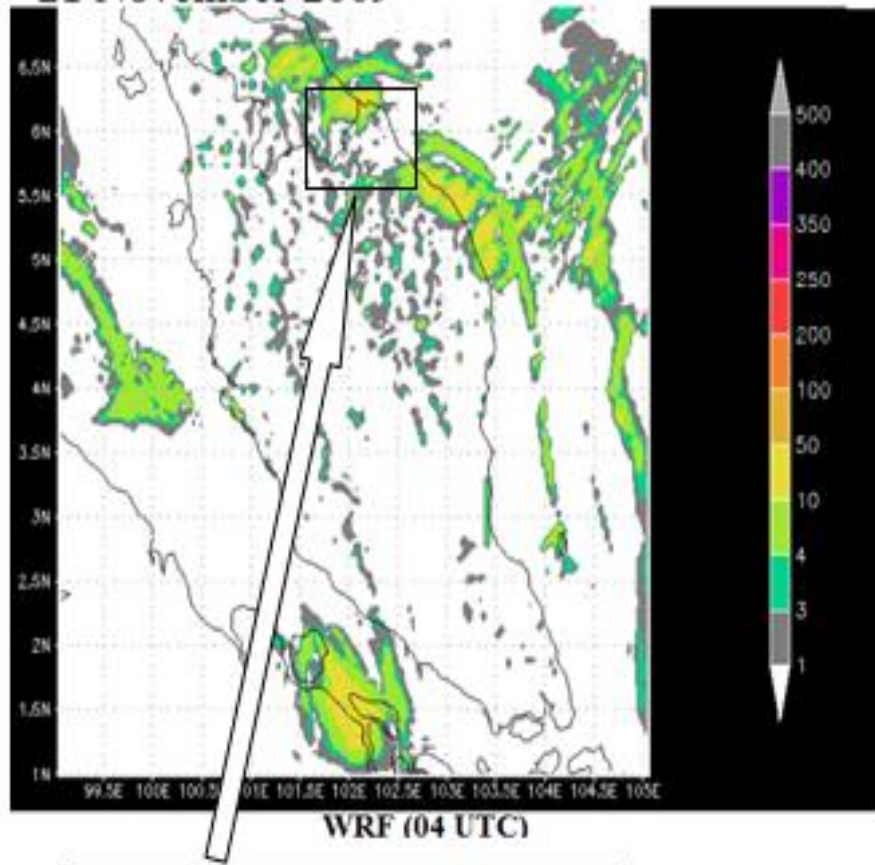
Use software Grid Analysis and Display System (GrADS) for processing NWP data

- ✓ Model runs at 00UTC (0800 local time)
- ✓ Forecast ranges are hourly, up to a period of 72 hours.
- ✓ 4 km resolution

## Rainfall

Hourly rainfall at 9 gauged stations over Kelantan River basin (DID) for year 2009

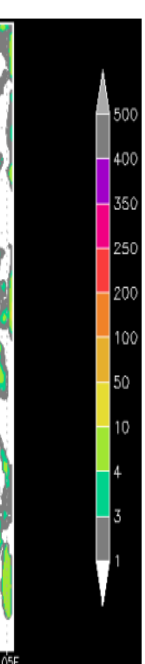
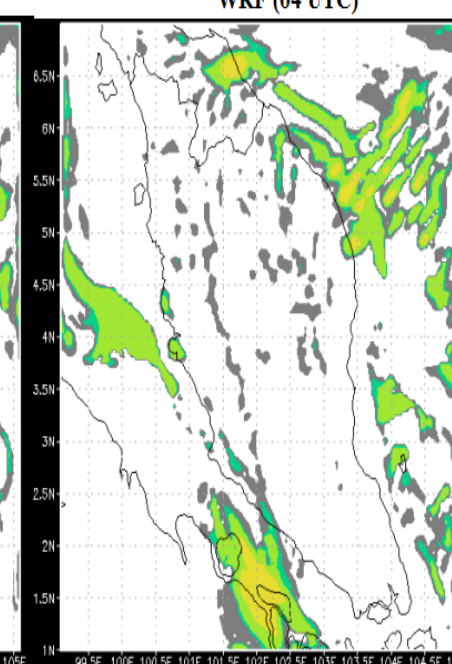
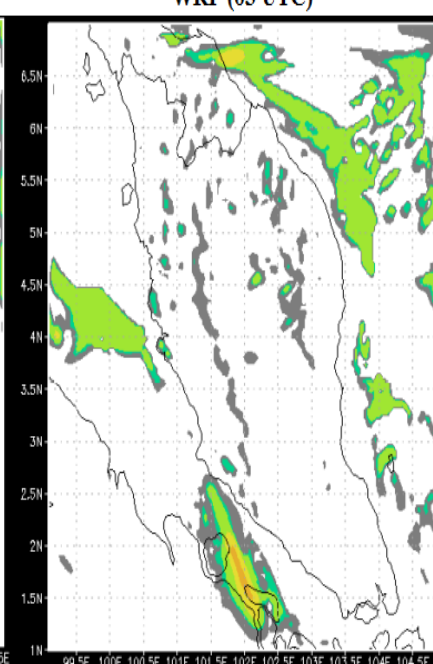
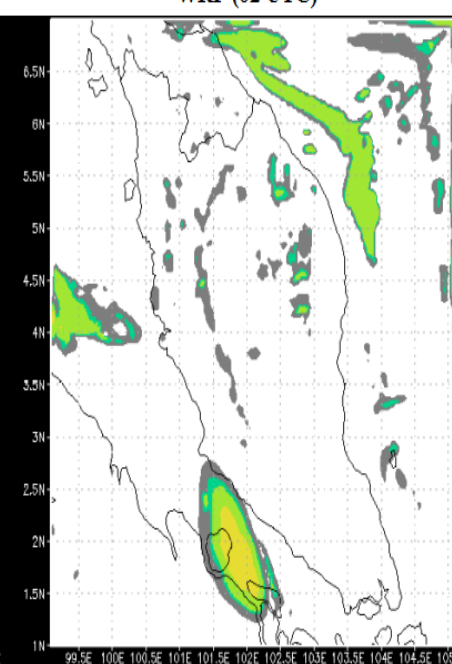
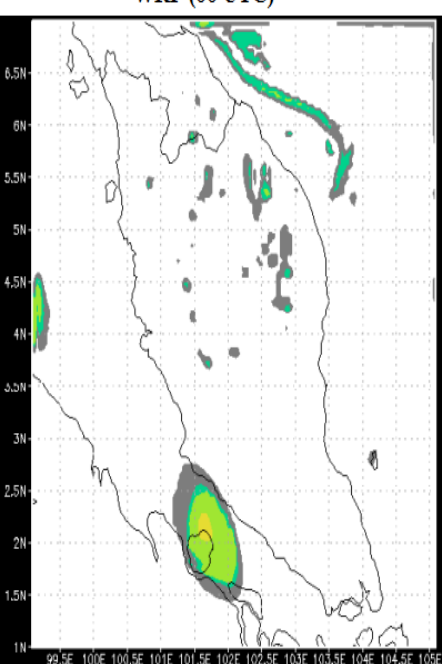
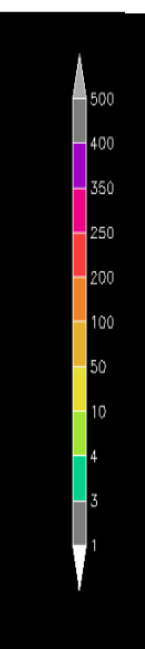
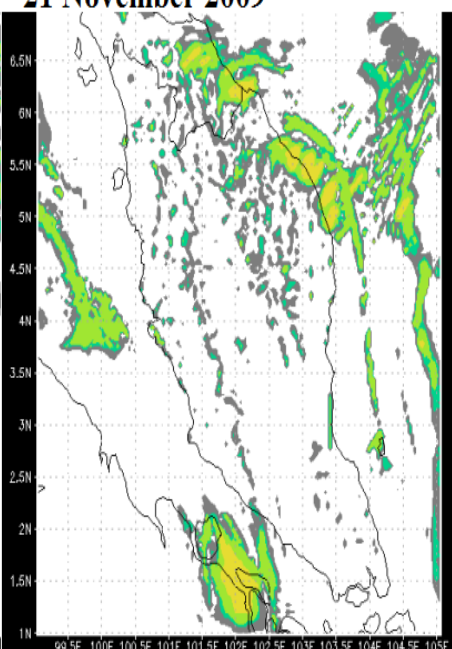
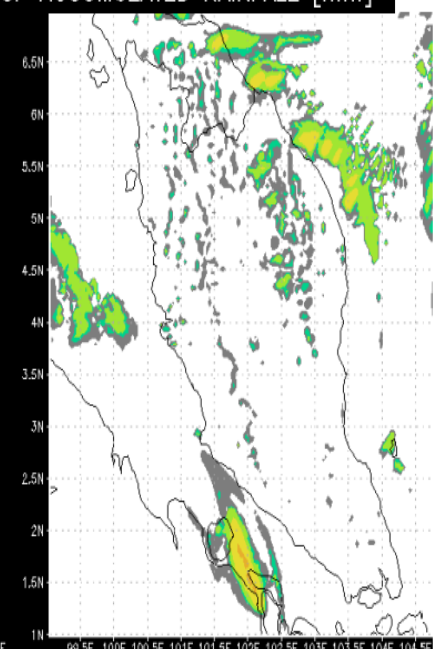
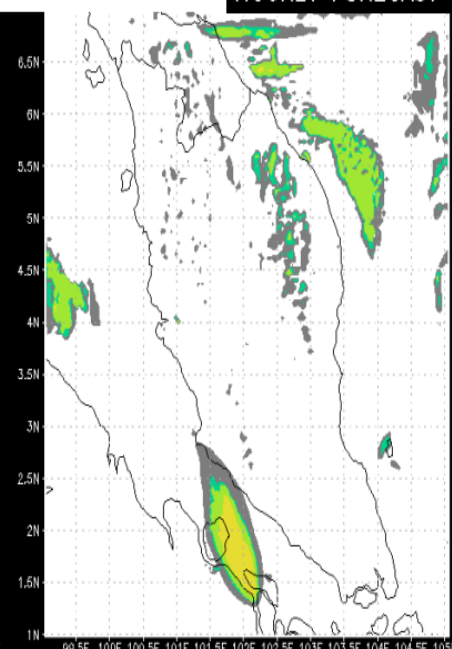
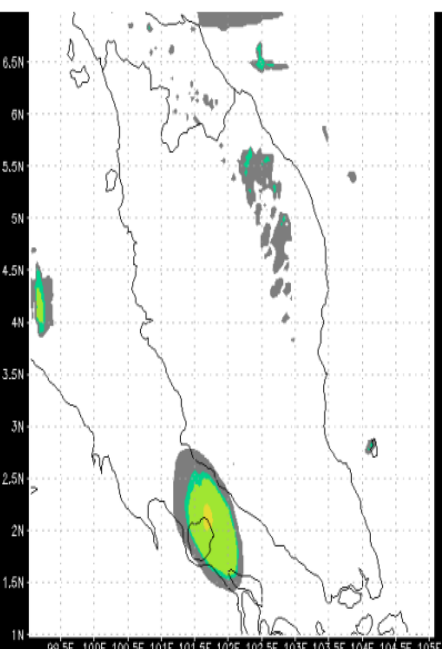
21 November 2009



The location of Kelantan River Basin on the WRF display.

# HOURLY FORECAST OF ACCUMULATED RAINFALL [mm]

## 21 November 2009



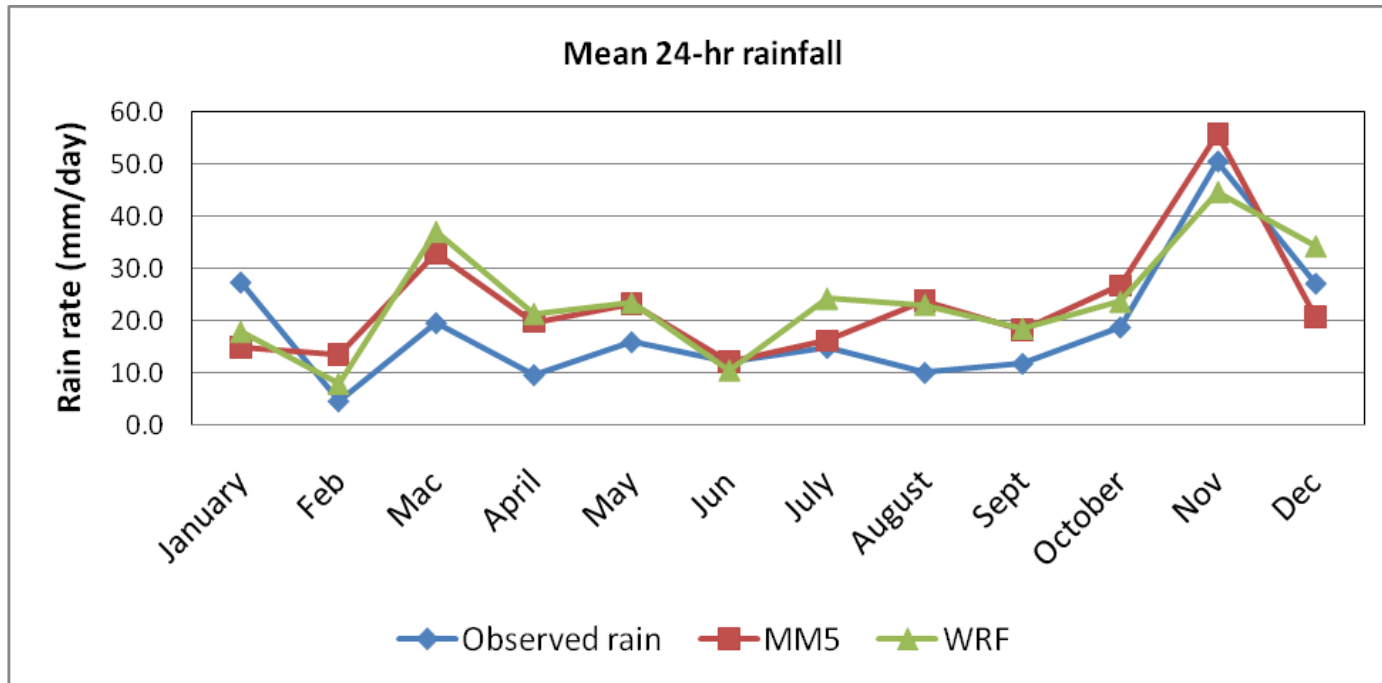
MM5 (00 UTC)

MM5 (01 UTC)

MM5 (02 UTC)

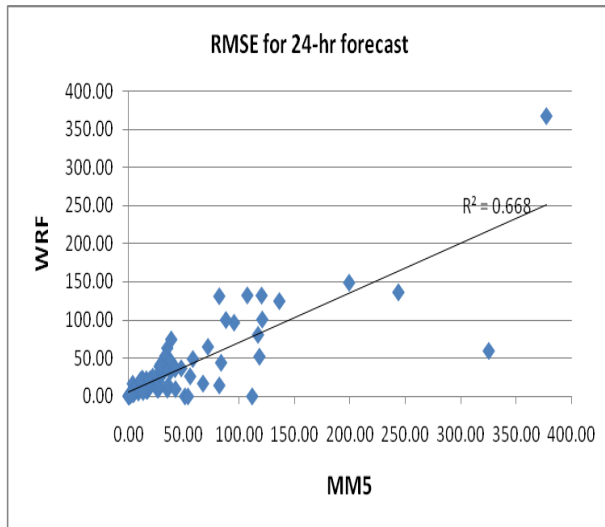
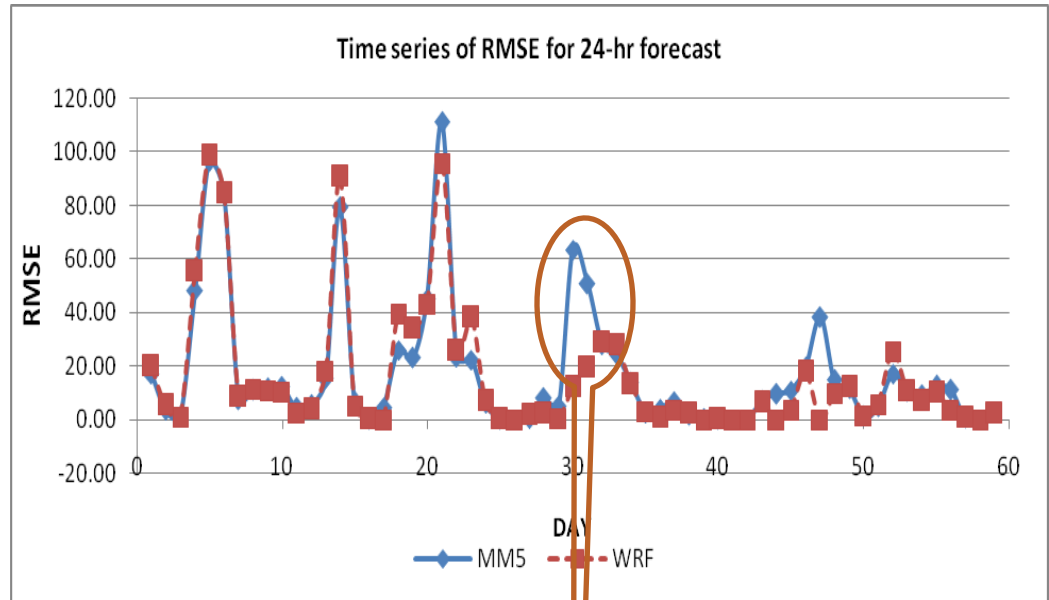
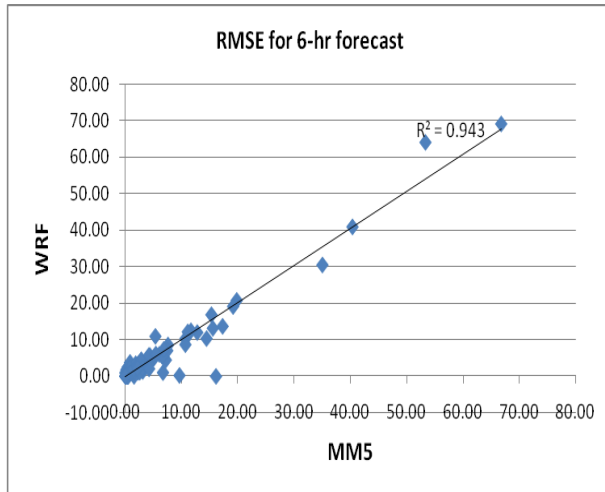
MM5 (03 UTC)

# Results



Though the model overestimates the 24-hr rainfall quite notably during Mac, April, May, August and September, they follow almost similar pattern of the mean daily rainfall amount

# Results – Root Mean Square Error (RMSE)



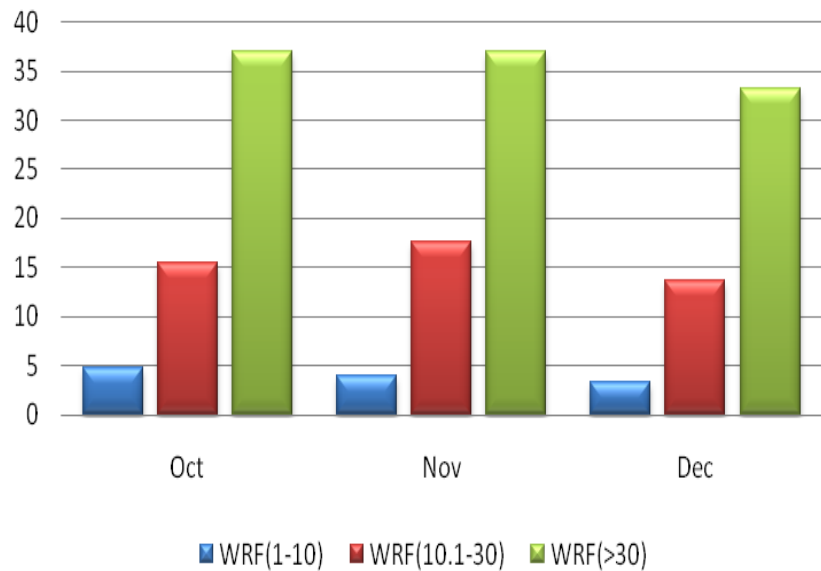
The longer forecast duration, the greater RMSE

Comparison between the two models, indicate that their performance follow similar pattern

It is observed that WRF performed slightly better than MM5 especially for 24-hr forecast.

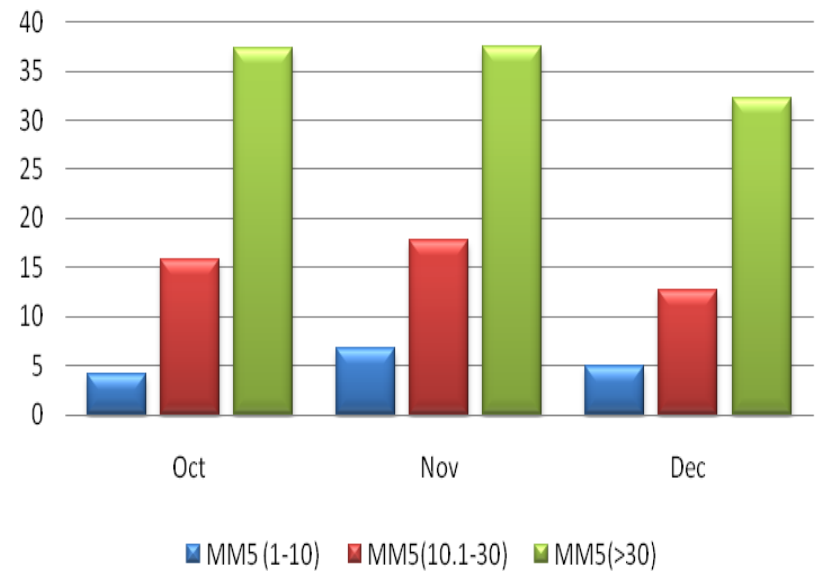
# Results

## RMSE



## WRF

## RMSE



## MM5

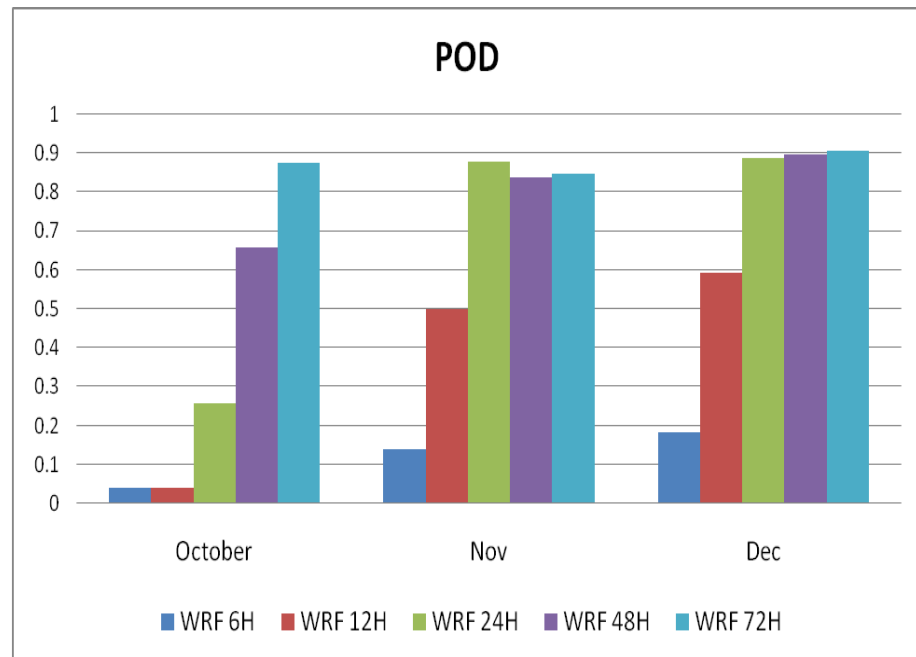
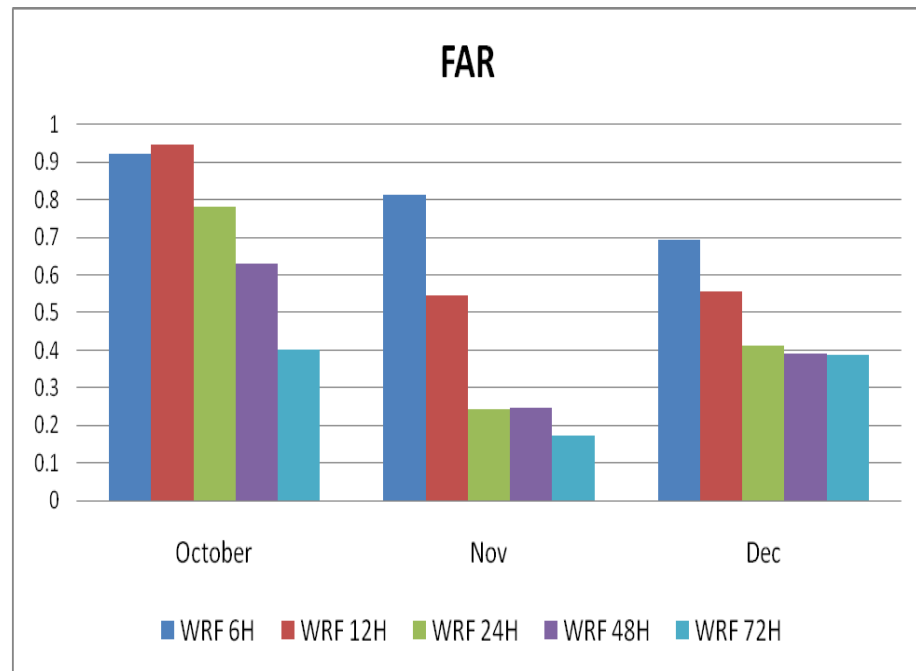
RMSE for different categories of rainfall (light, moderate, heavy)

# Probability of Detection (POD) and False Alarm Ratio (FAR)

**POD- fraction of observed events that were correctly forecasted**

**FAR - fraction of forecast events that were observed to be nonevents**

**The longer rainfall forecast duration, the higher the POD and the lesser FAR**

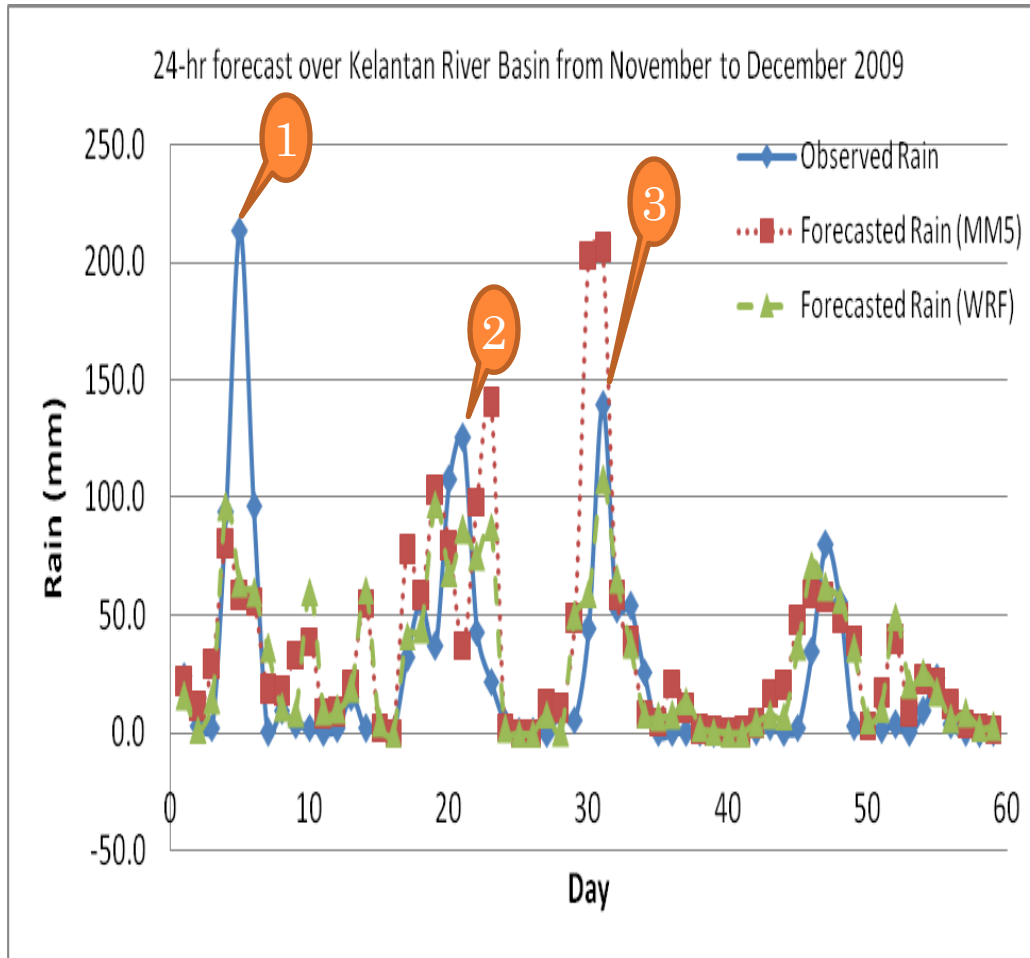


# Prediction of Rainfall causing Flood Events

November 5 - 11 (areal average daily rainfall of 234 mm on 5<sup>th</sup> November)

November 20 – 26 (areal average daily rainfall of 125 mm on 20<sup>th</sup> November)

December 2 – 6 (areal average daily rainfall of 139 mm on 2<sup>nd</sup> December)



For the first event, both models forecast well before the flood event, but miss the very heavy rainfall on November 5

During the second flood event, both models produce 24-hr forecast which are closed to the rainfall that had caused the flood with WRF performed slightly better.

The third event indicates that the QPF produced by the WRF forecast is much closer than the overestimated value from the MM5

# ON-GOING WORK

- Further statistical verification
- Ensembles with weather satellite and radar rainfall estimation and forecasting.

# CONCLUSION

- ❑ **Geostationary meteorological satellite, radar and numerical weather prediction model are very promising tools to be used to improve our flood forecasting.**
- ❑ **More work should be done; support and collaborative work should be strengthened for the technological advancement of our nation**



**Thank You**  
**for your attention**