International Conference on Climate Change and Water (THA 2015)

Use of Multi-sensors Data Input for Improved Flood Forecasting

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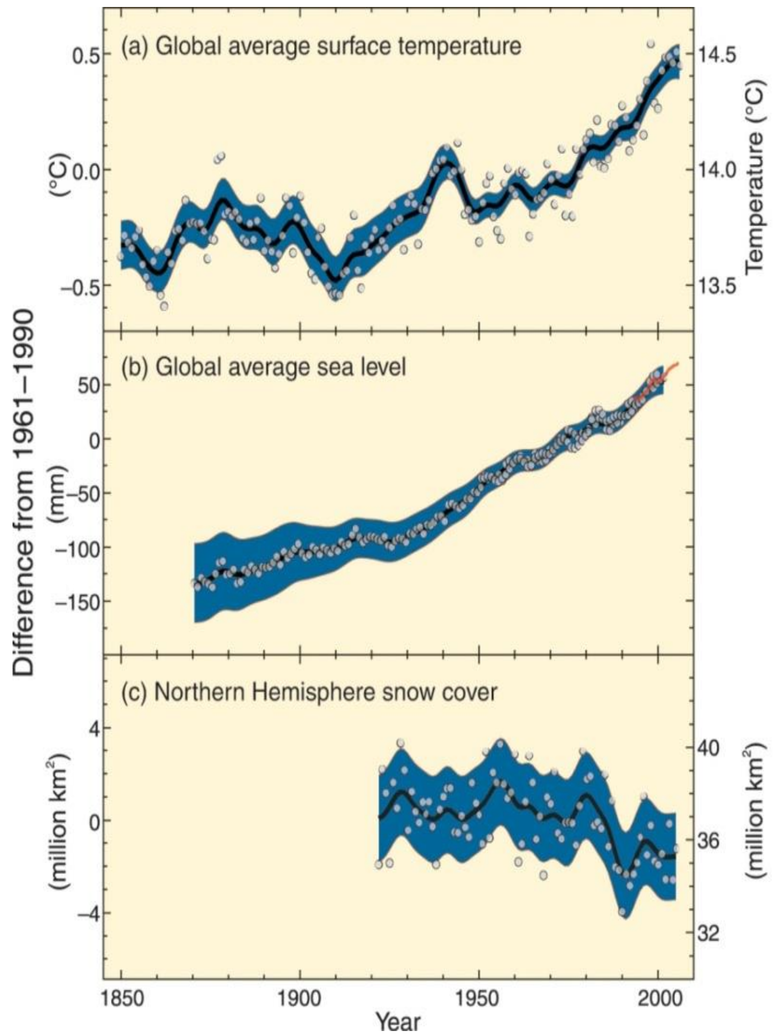
Factor Affecting Increase in Flood Disasters

Global Warming and Climate Change

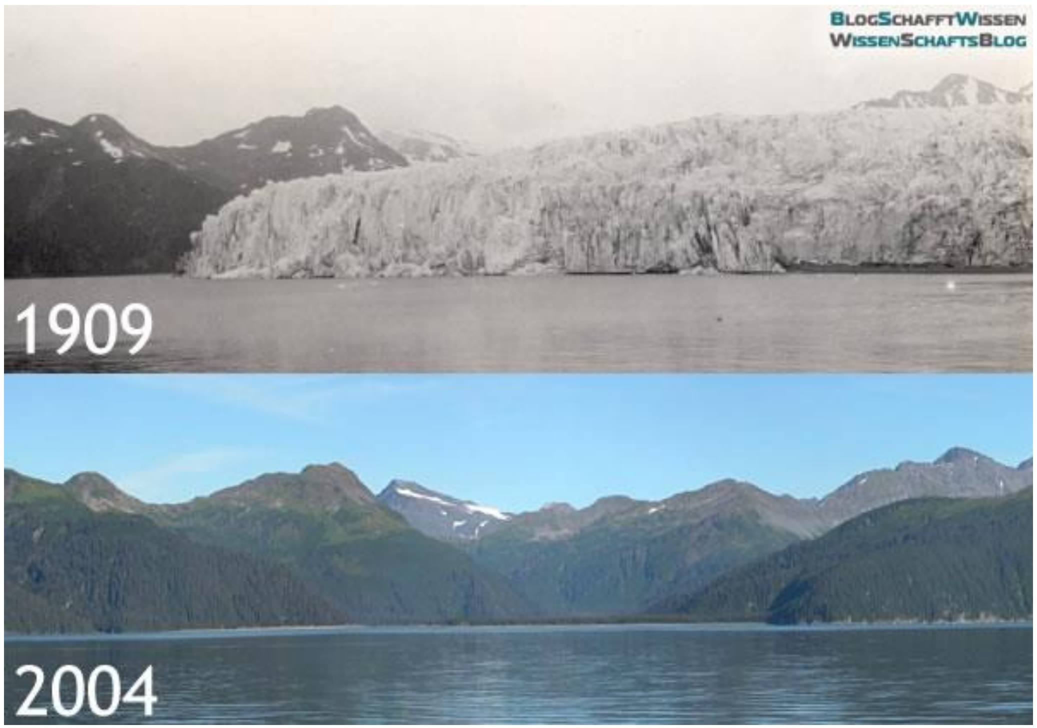
The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (2001) and Fourth Assessment Report (2007) predicted impacts from the global warming

- **More floods:** from both increased heavy precipitation events and sea level rise.
- **Increased spread of infectious diseases.**
- **Degraded water quality:** higher water temperatures will tend to degrade water quality and increased pollutant load from runoff and overflows of waste facilities.
- **More frequent and more intense heat waves, droughts, and tropical cyclones**



Source: IPCC Report, 2007

Global warming- glacier melting causing sea level rise



Swiss Glacier 1909 vs 2004

http://i186.photobucket.com/albums/x70/AnthonyMarr/glacier-melting1941-2008-1.jpg

Muir Glacier in Alaska 1941 vs 2006

Flood in Malaysia – December 2014

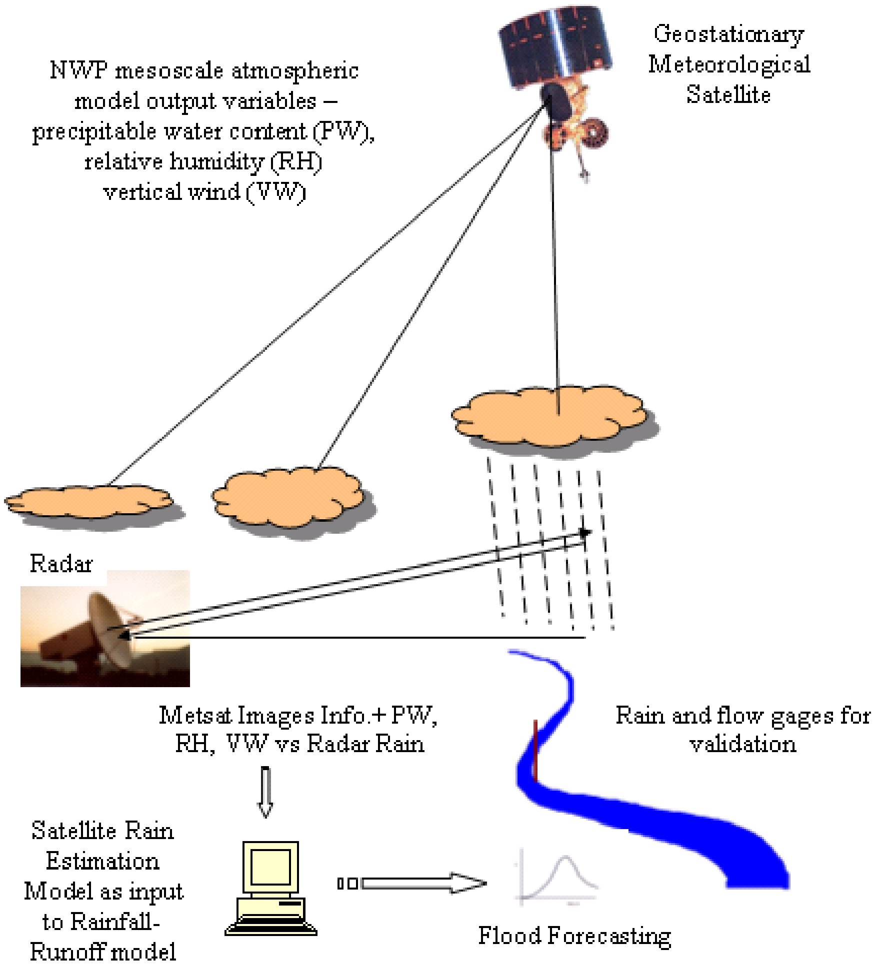
Flood at Kuantan Pahang 2013

1. Reported to be lacking in flood preparedness.
2. 7000 victims were sheltered in one school.
3. Not enough food and shelter.
4. Residents complaint of receiving no flood warning.
5. The flood warning was not effective.

Flood forecasting and warning

Flood forecasting and warning can provide longer lead times for immediate actions by the authority or the community.

However, early warning is effective if only people understand the language of early warning and be able to respond appropriately.



USE OF MULTISENSOR DATA INPUT FOR IMPROVED FLOOD FORECASTING

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

USE OF GEOSTATIONARY METEOROLOGICAL SATELLITE INFRARED IMAGES

FOR CONVECTIVE RAINFALL ESTIMATES

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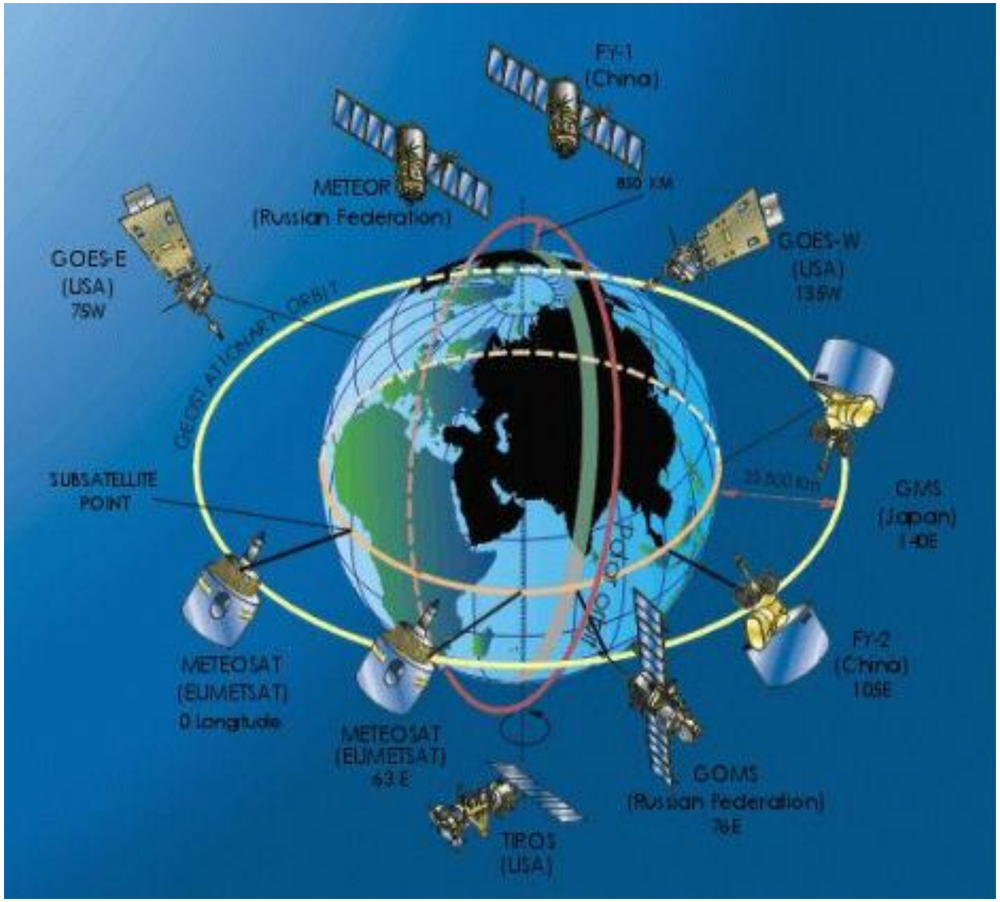

Geostationary meteorological satellites have fixed position. The satellites make observations at 20-30 minute intervals throughout each day over the same area, therefore able to monitor the raining cloud cell development over an area, thus forecast intense storm causing flood

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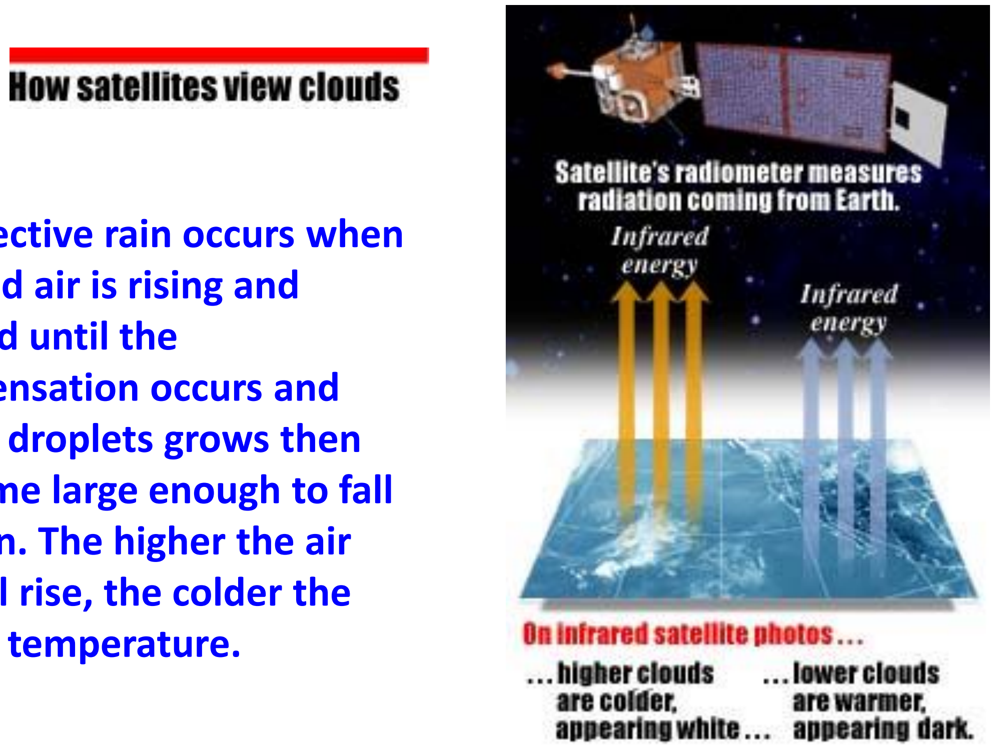
MARA

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

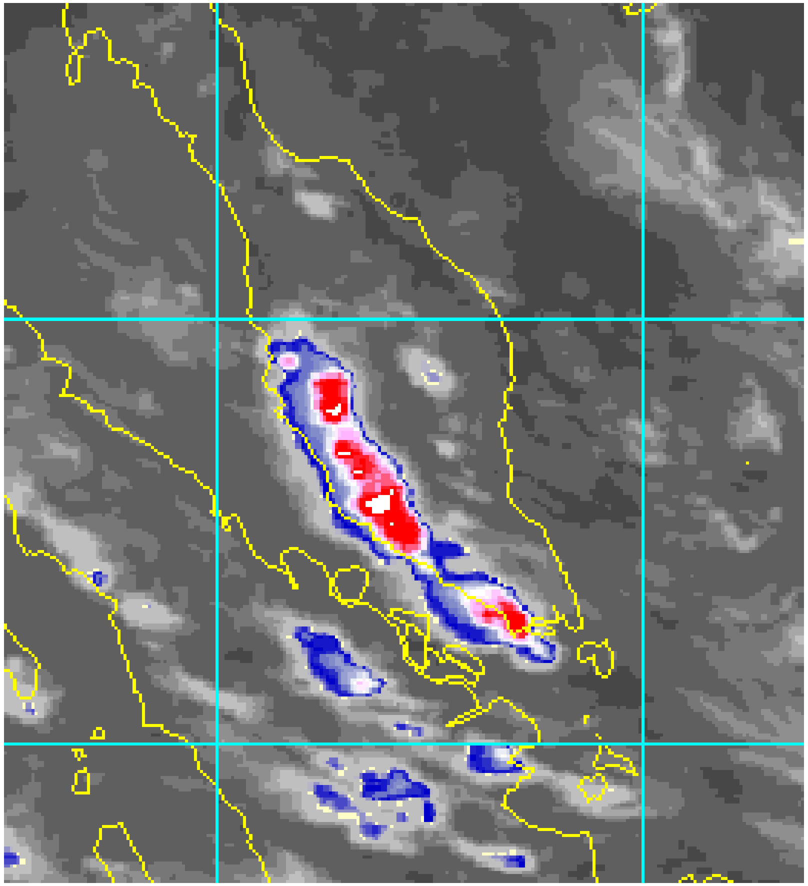
Convective rain occurs when heated air is rising and cooled until the condensation occurs and cloud droplets grows then become large enough to fall as rain. The higher the air parcel rise, the colder the cloud temperature.



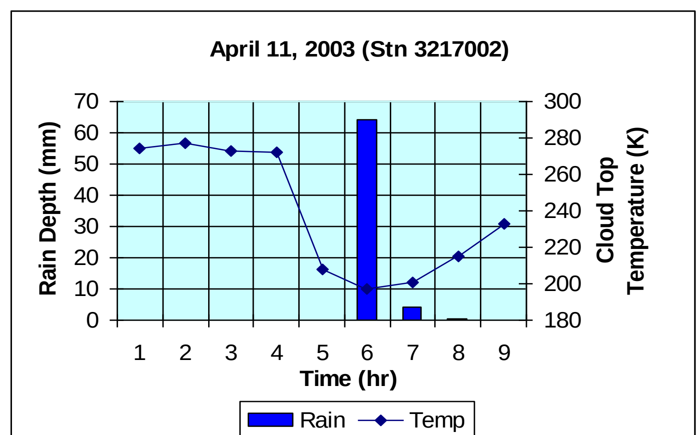
Source: USA Today

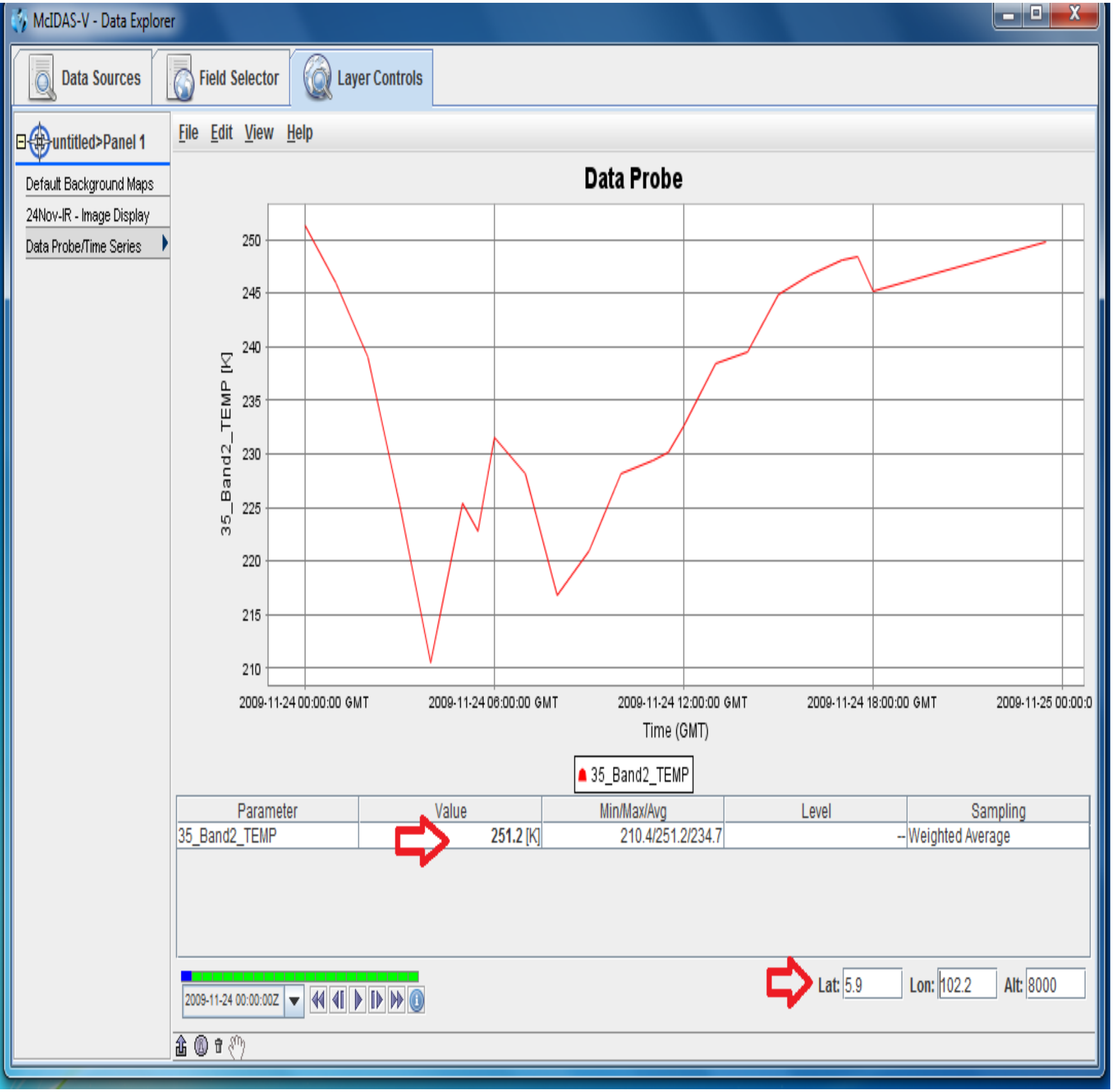
Hence, it is assumed that cloudy satellite image pixels colder than a given threshold temperature are associated with probably precipitating cumulonimbus clouds.

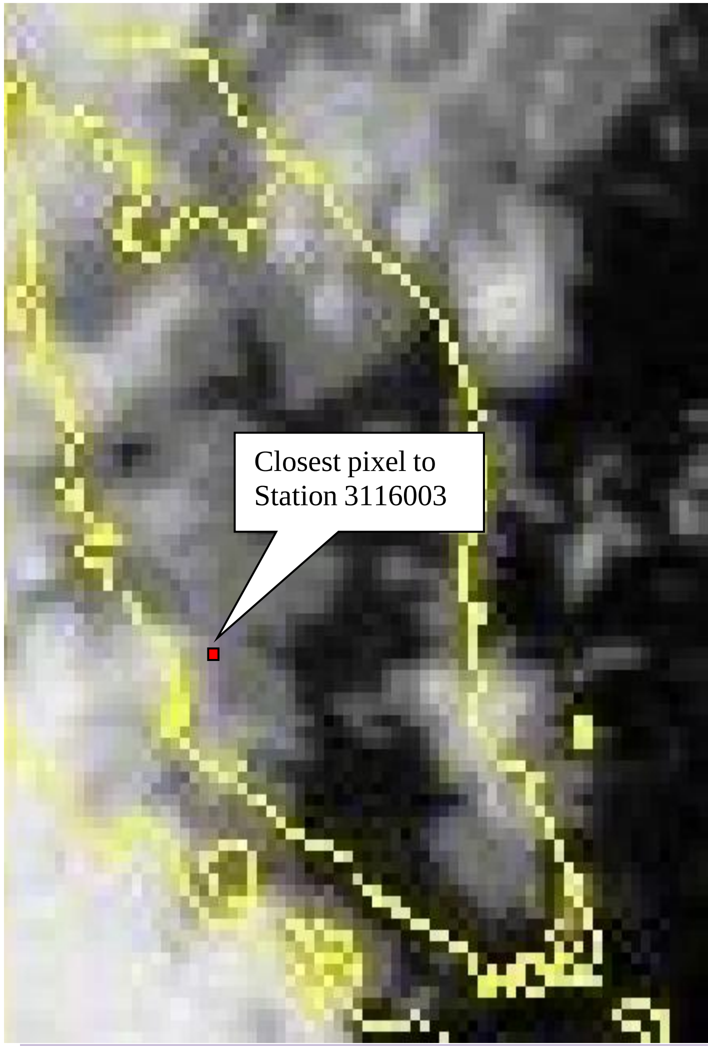
Example GMS image during a flash flood (June 10, 2003)



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



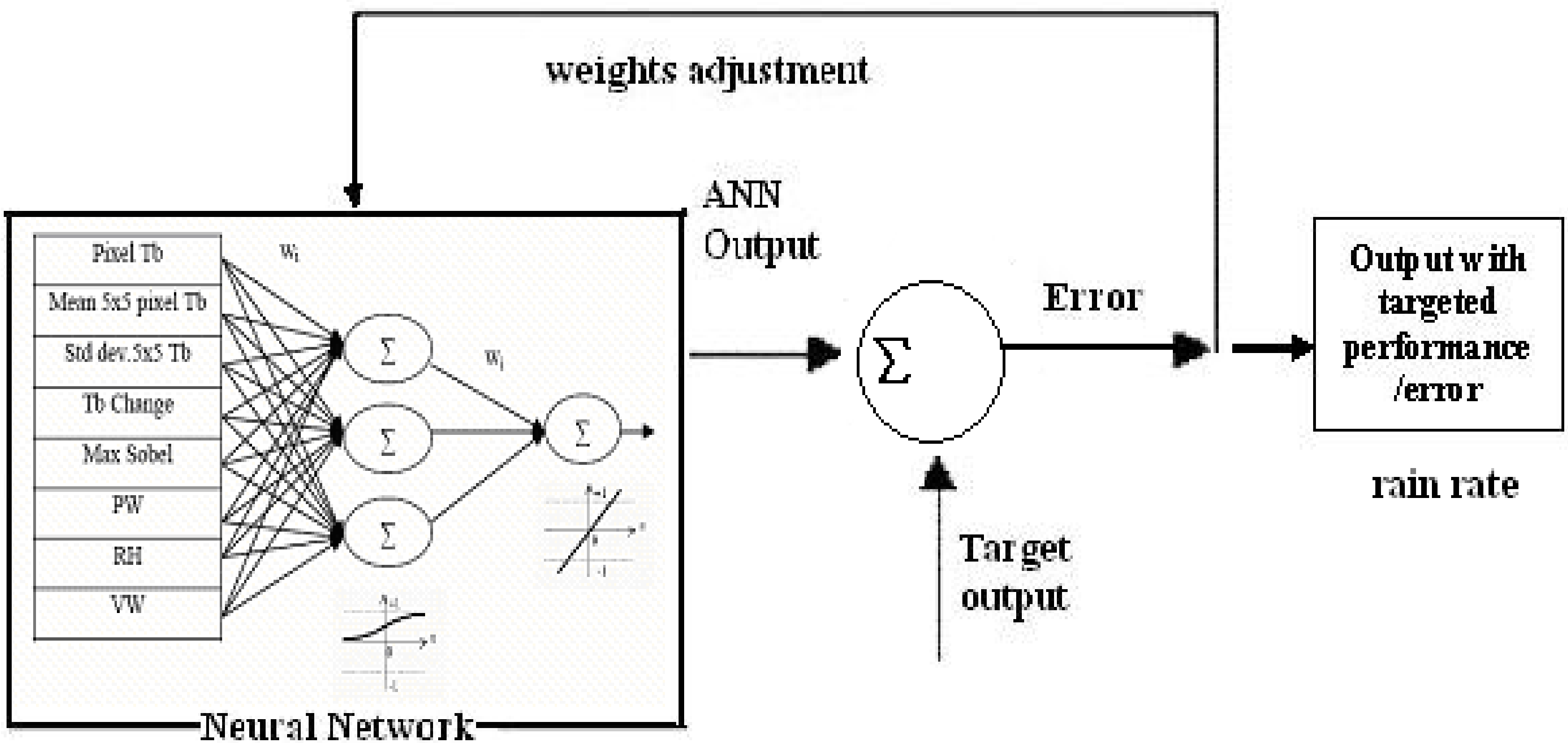




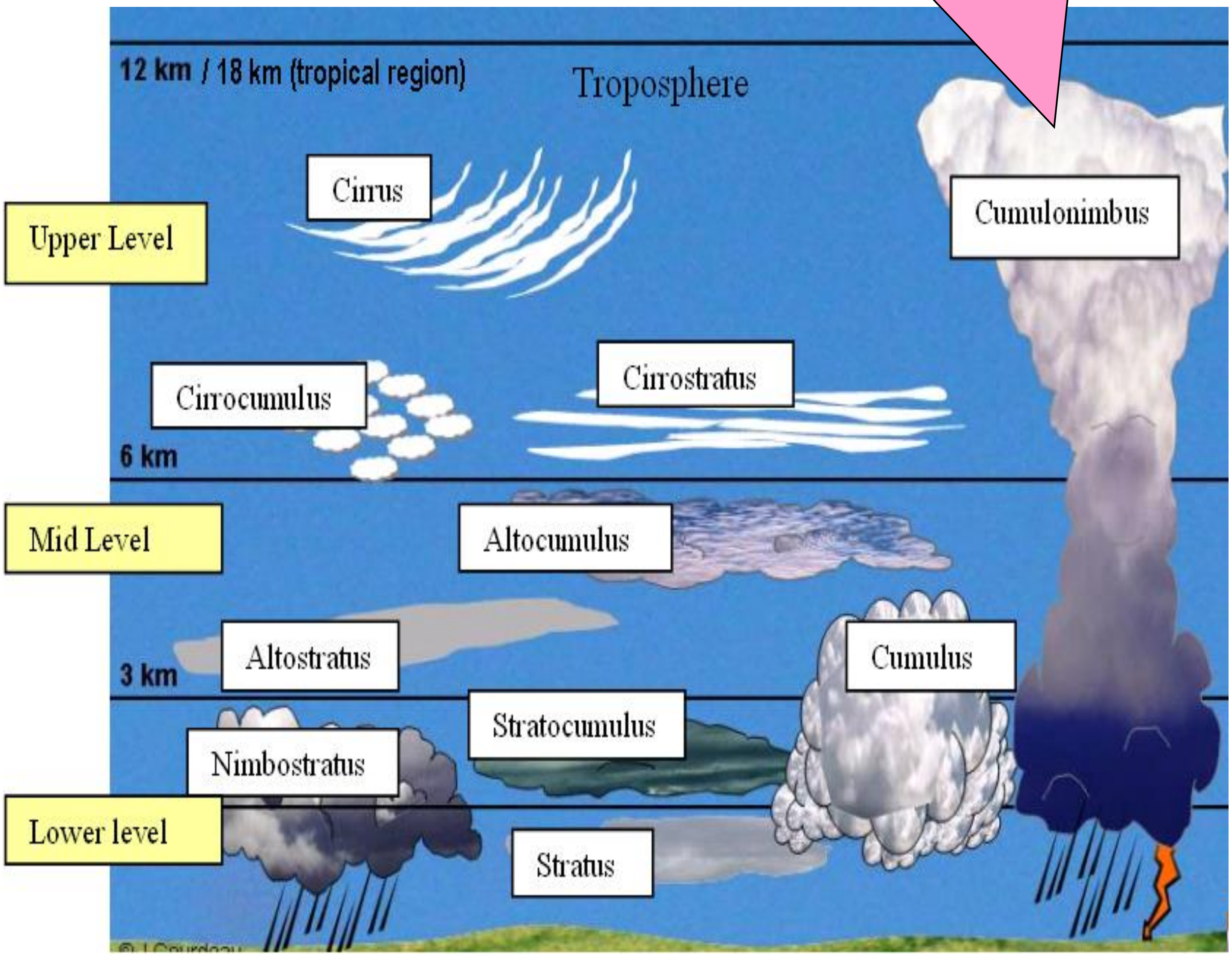
Programming/ image processing using Matlab to determine station pixel intensity value

Use McIDAS-V software to read cloud top brightness temperature

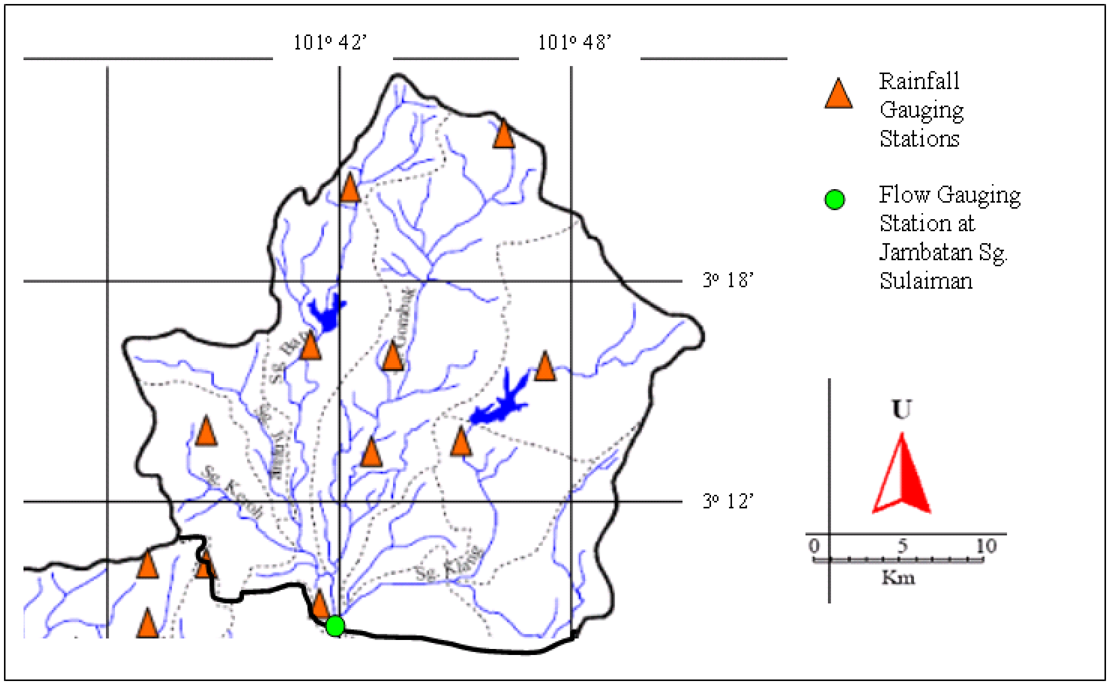
Development of Satellite Based Rainfall Estimations using Artificial Neural Network

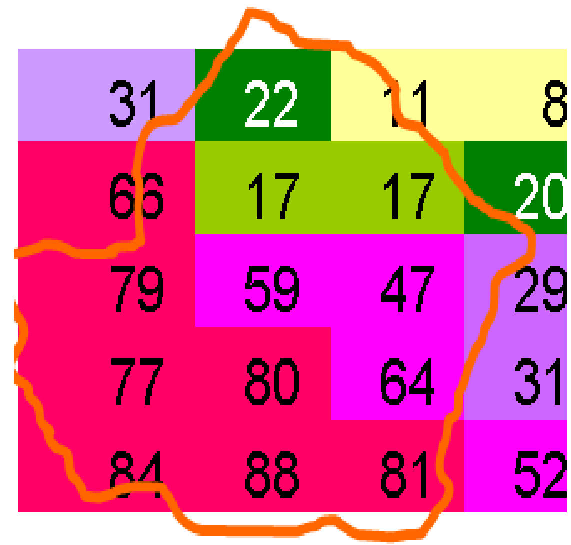


Tall overshooting convective raining cloud indicated by sobel operator



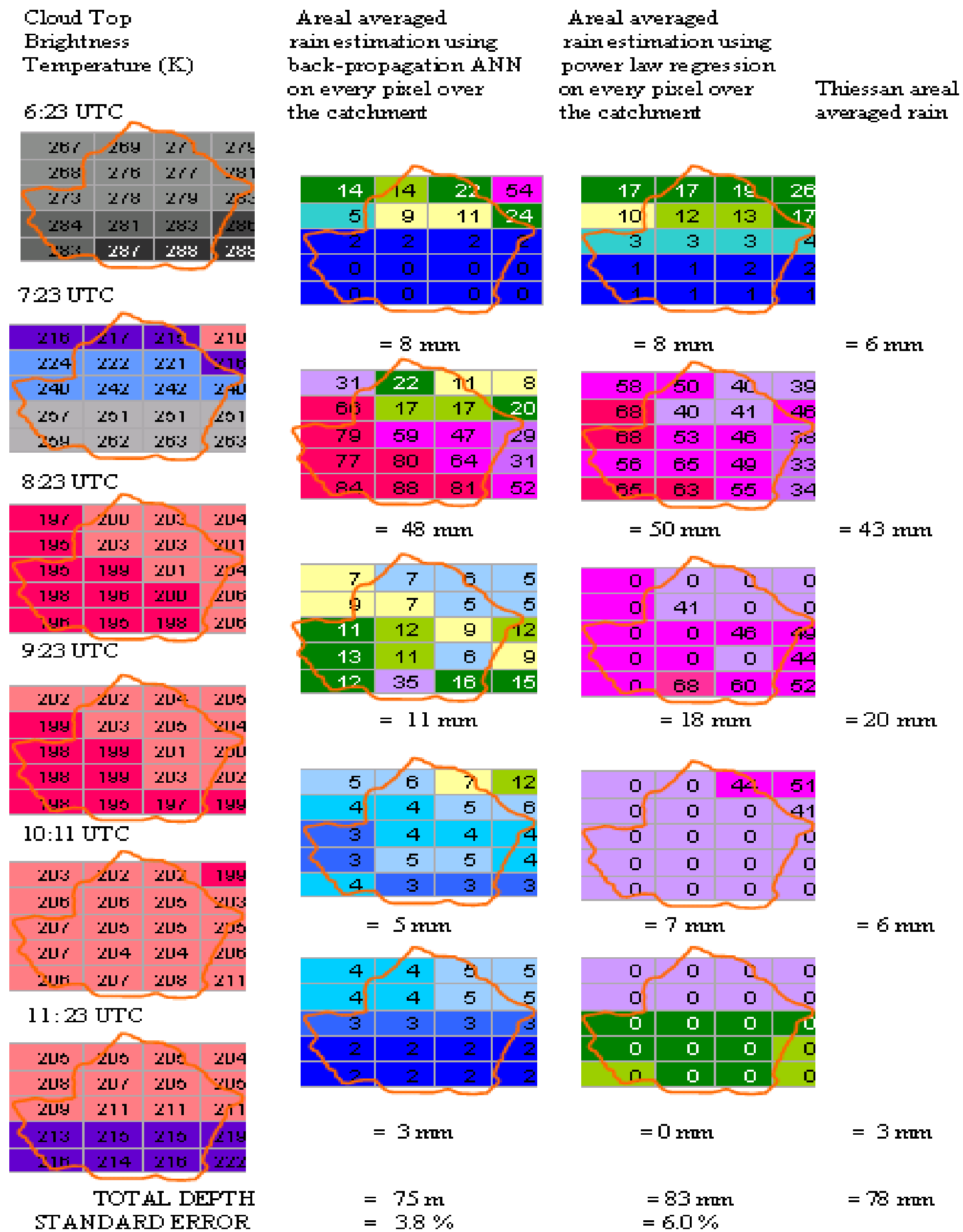
Validation with gauged- measured rain

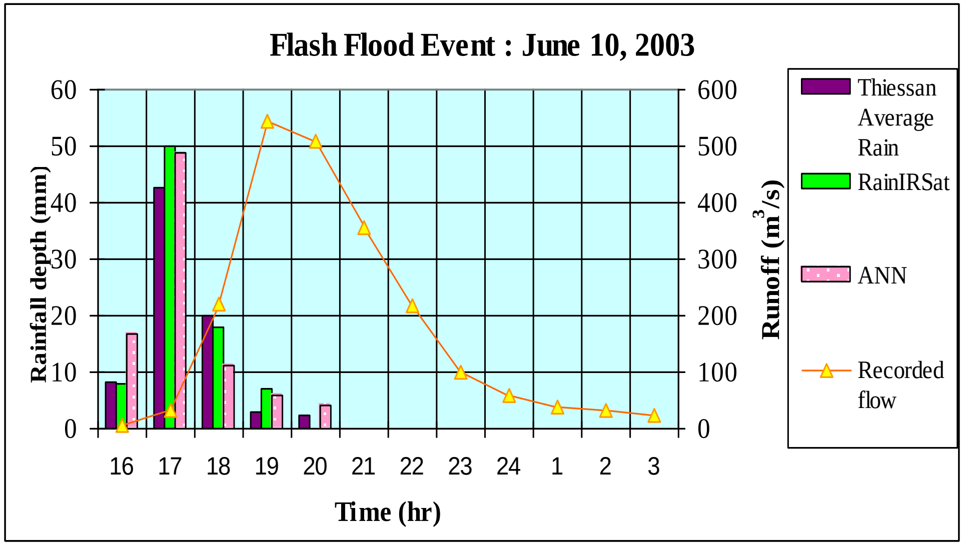




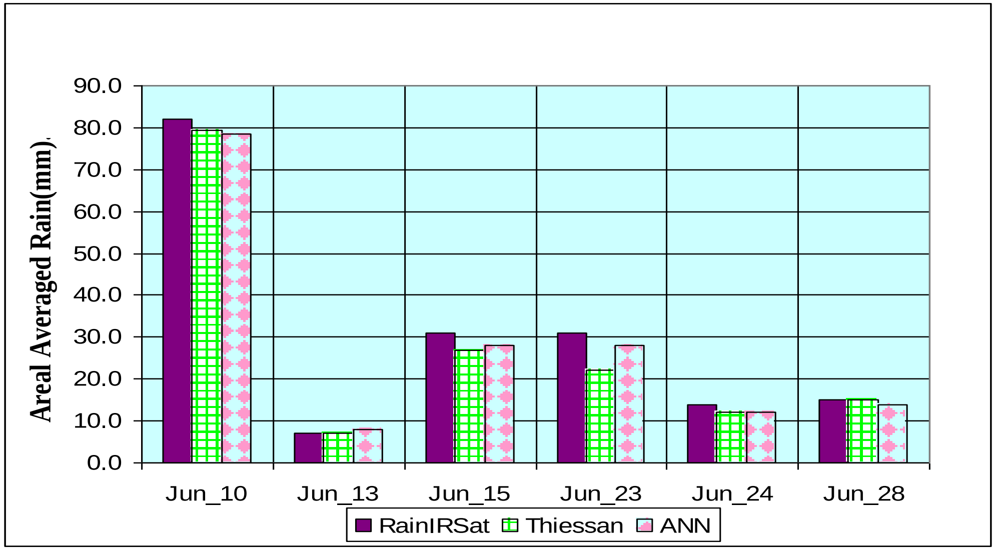
Rain Estimation over case study area of Upper Klang River Basin
(4 pm, June 10, 2003)

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

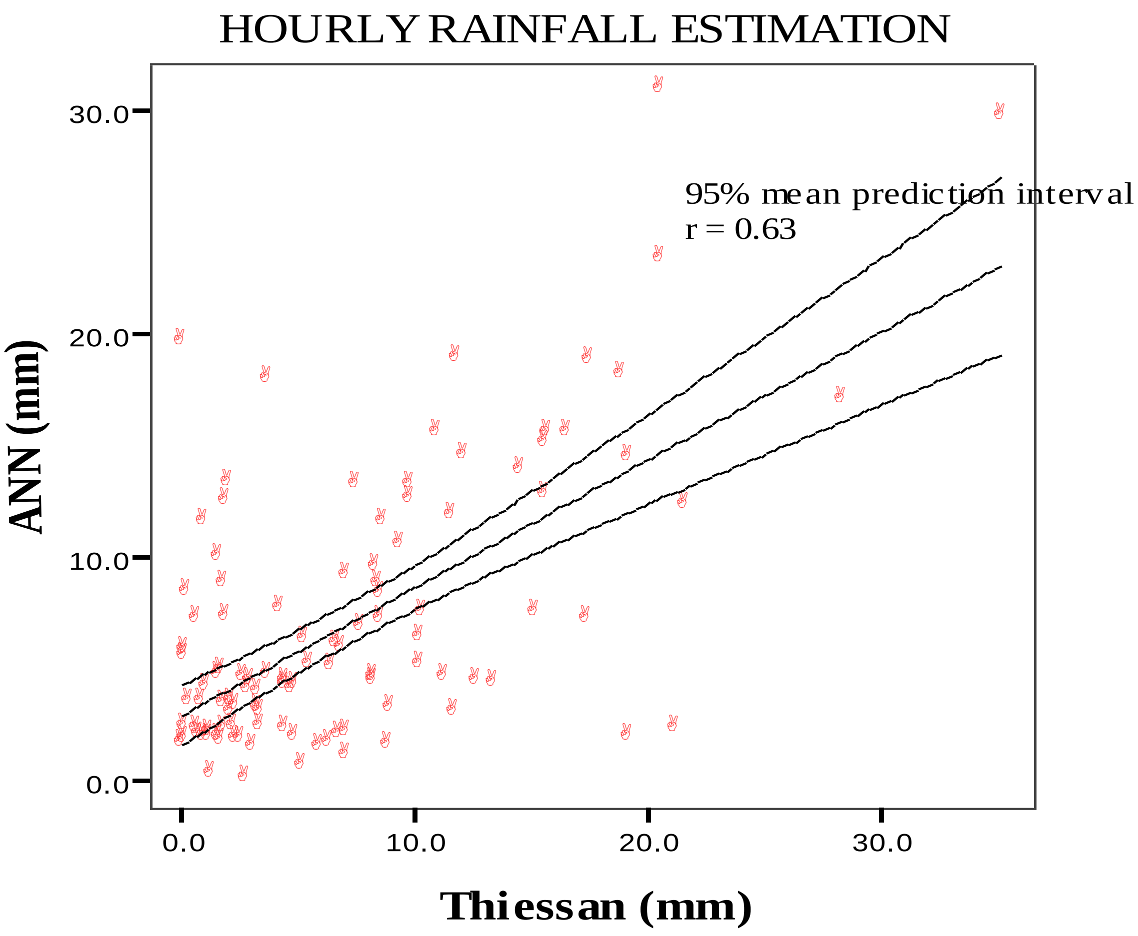




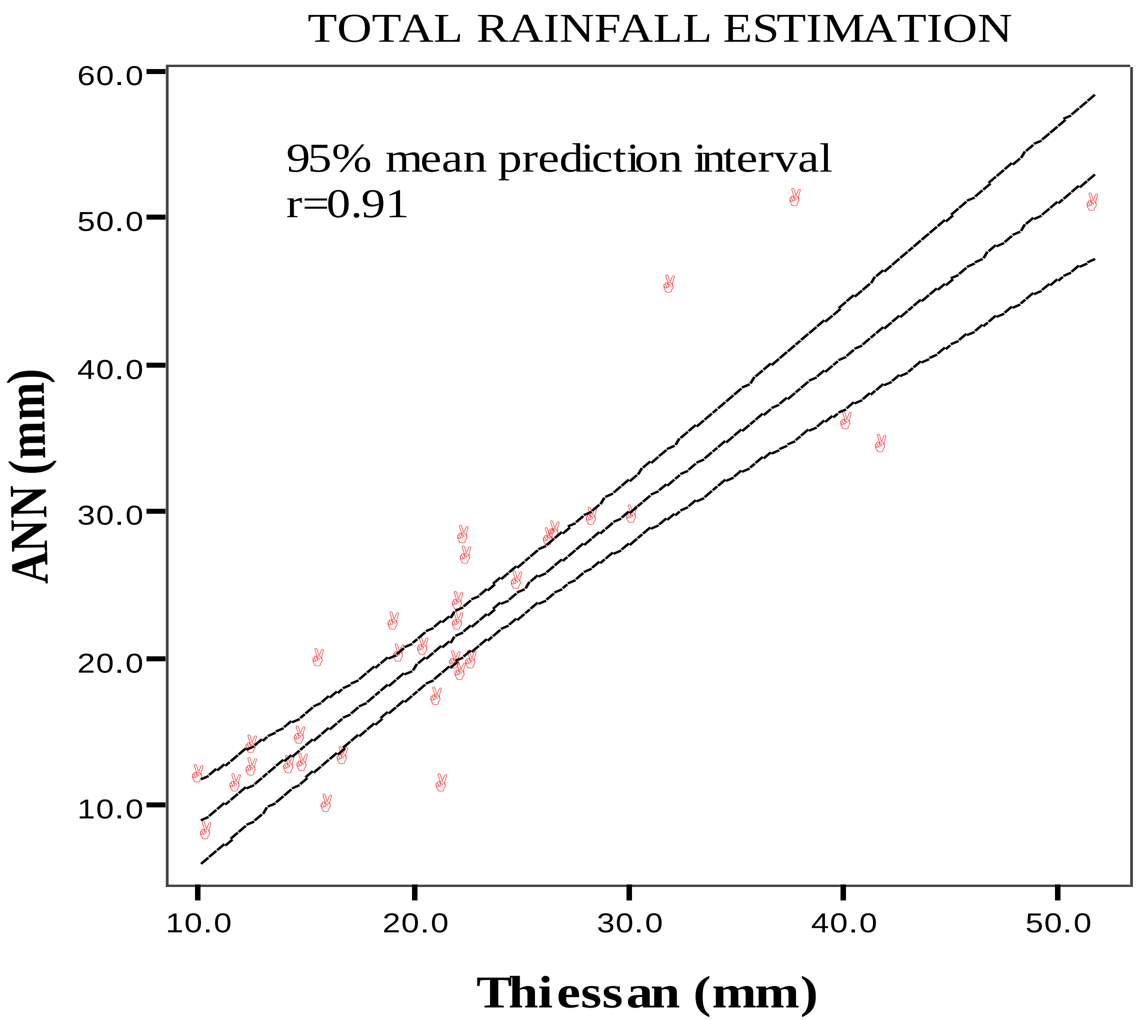
Hourly estimation of areal averaged rain depth for upper Klang River Basin on June 10, 2003 flash flood event.



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



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)



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

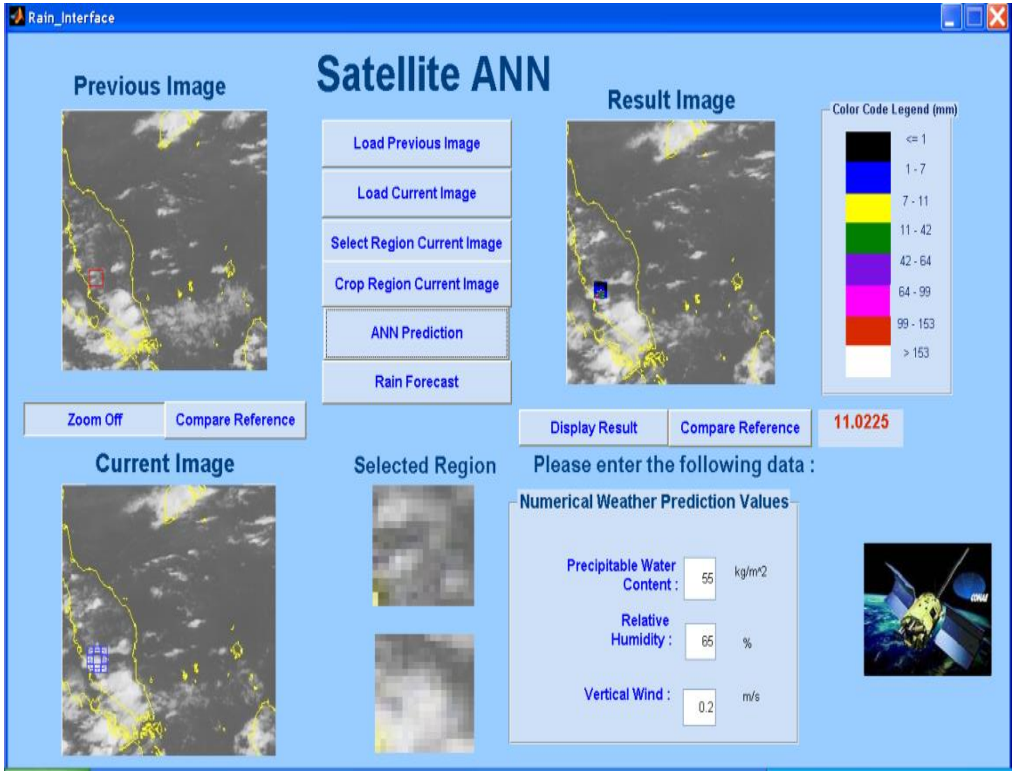
Rain-Watch Development

Rain-Watch 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

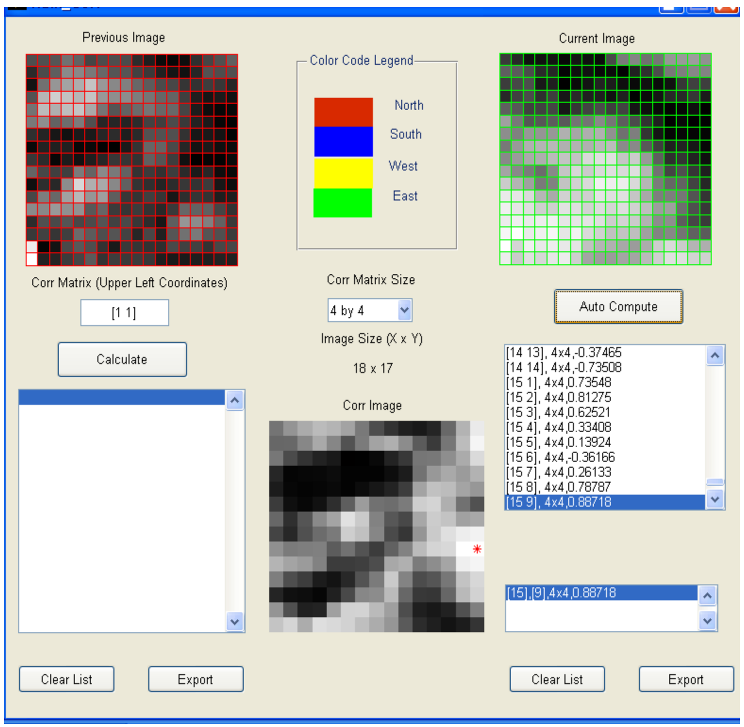


Application 2

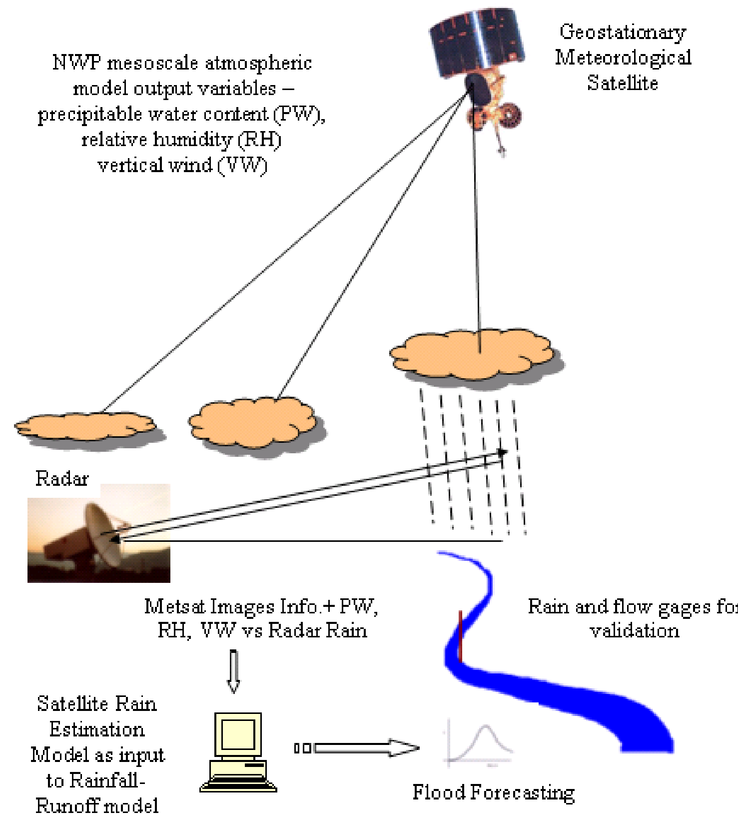
Rainfall estimation over inaccessible areas to rain-gauge or radar beam

Application 3

Flash flood forecasting for an improved lead time of flood warning

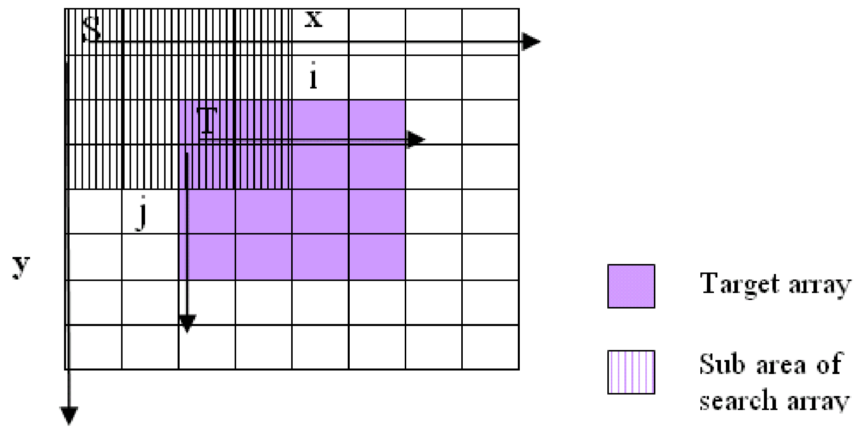


Cross-correlation option in Rain-Watch for rainfall forecast



A coupled hydro-meteorological flood forecasting system.

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

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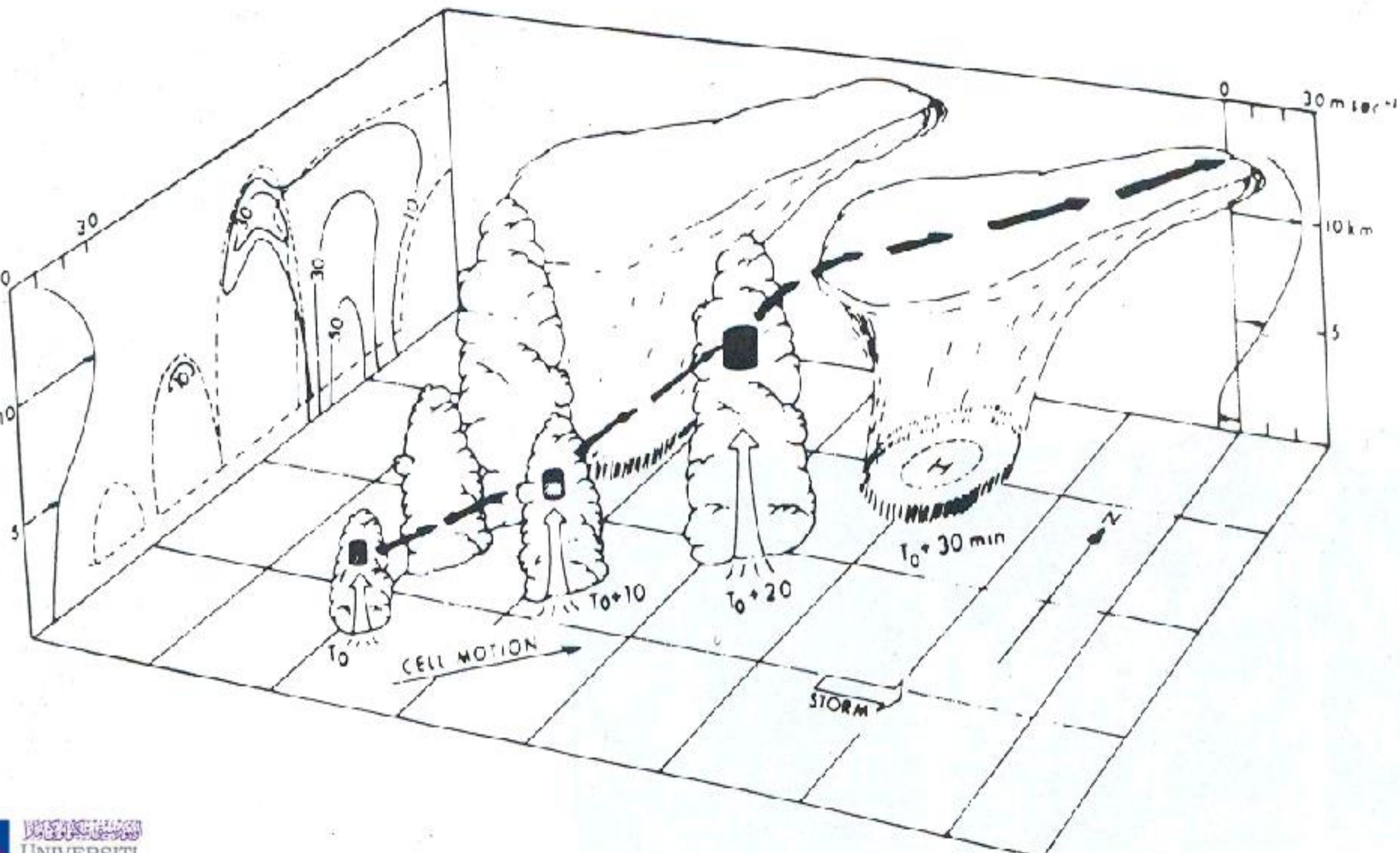
Schematic view of a multi-cell storm



(Rogers and Yau, 1996)

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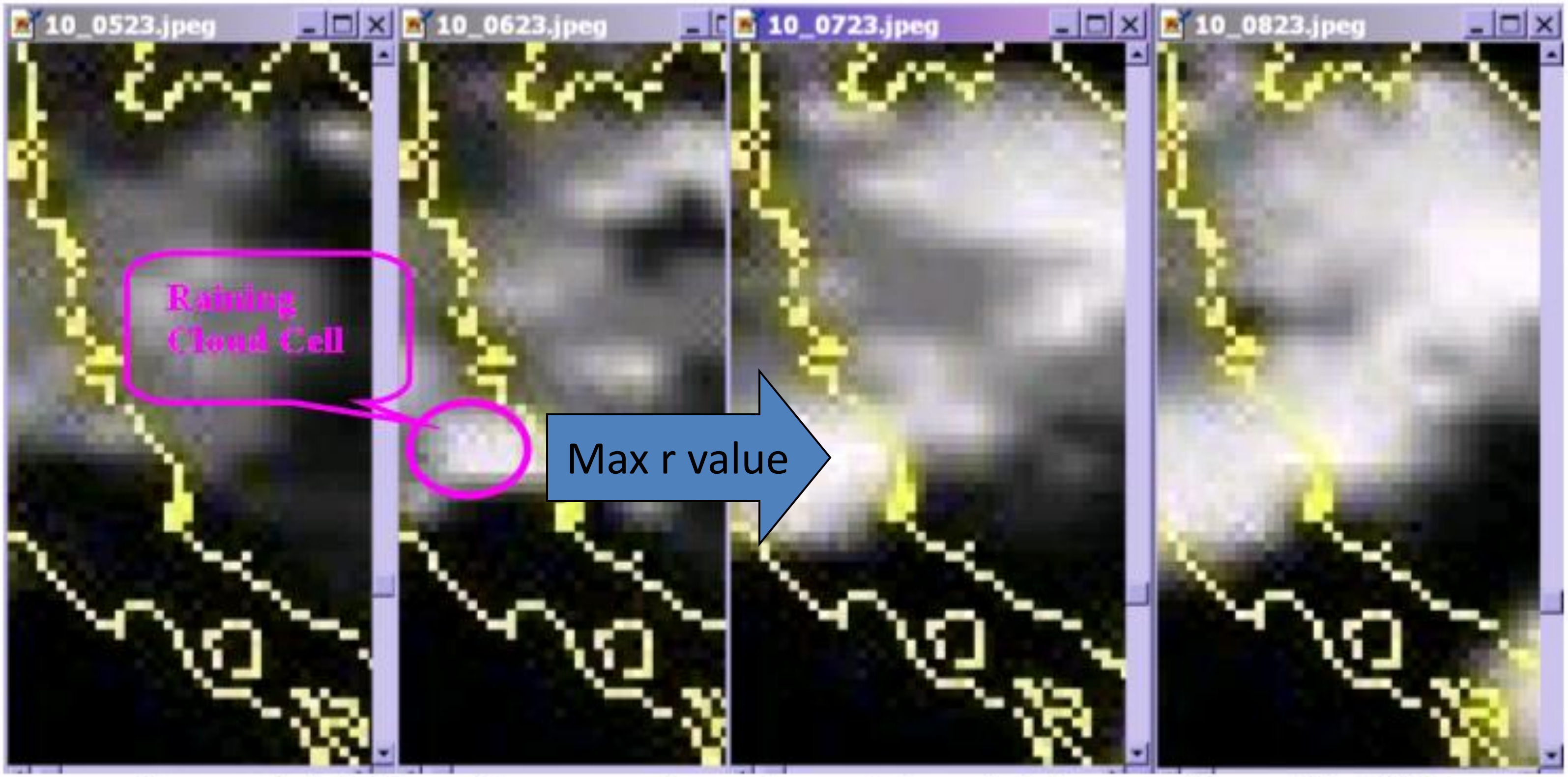
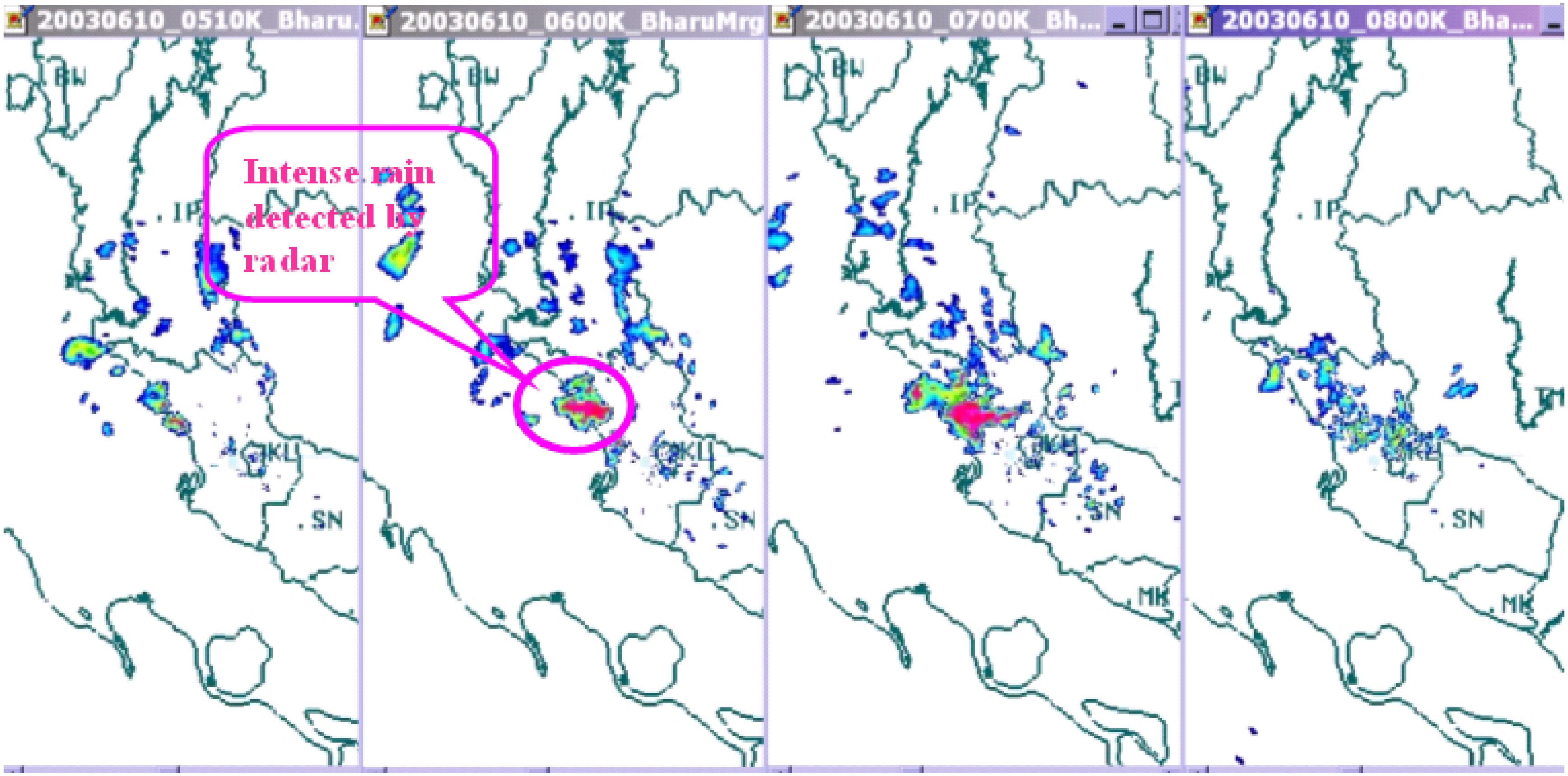


Sequential infrared images at one hour interval taken on June 10, 2003



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

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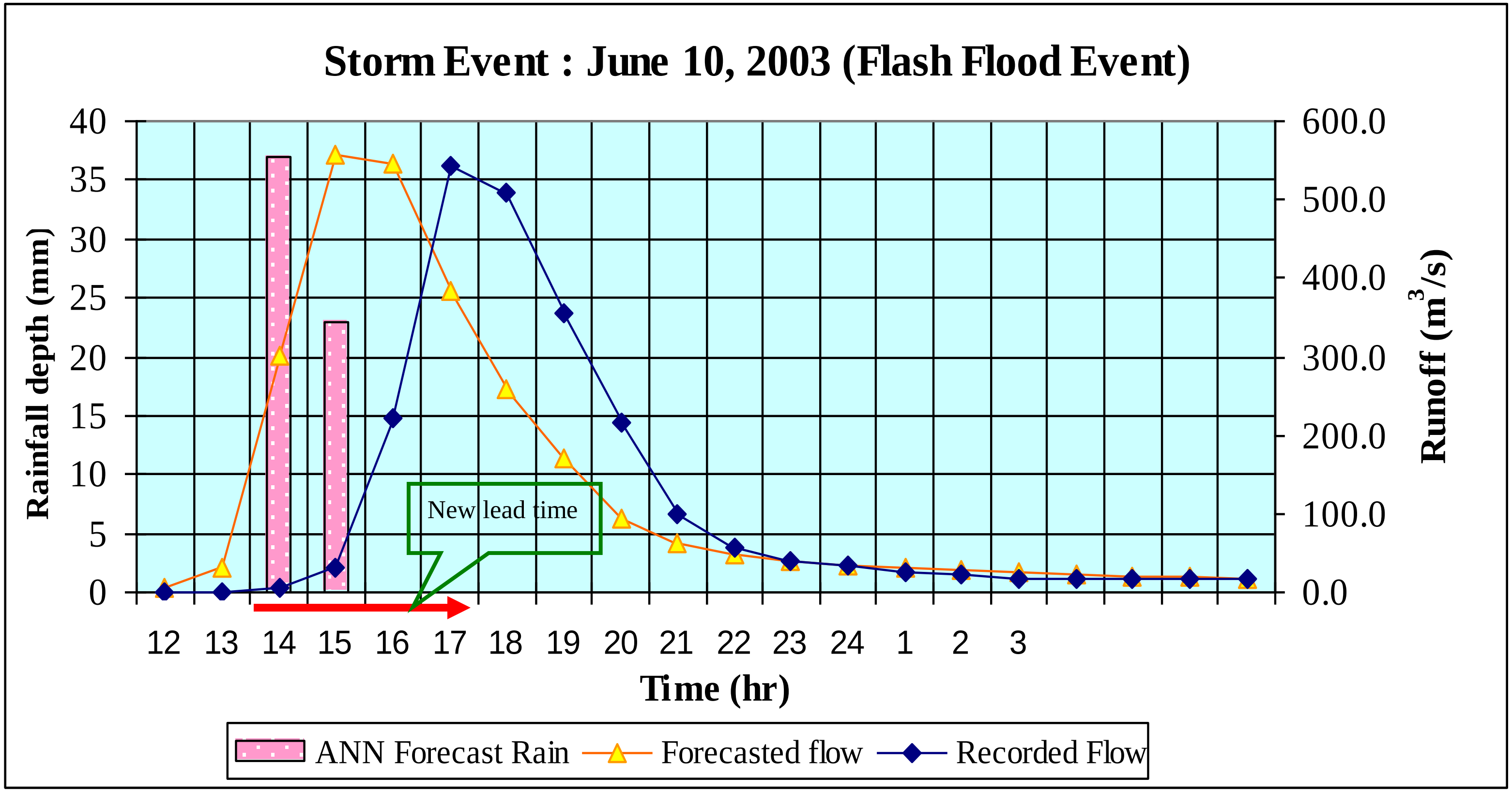
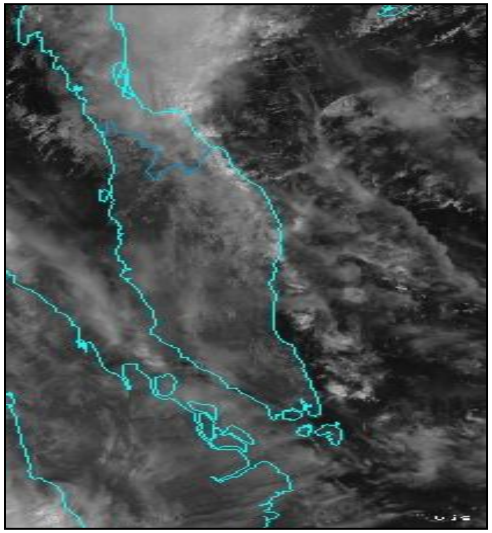


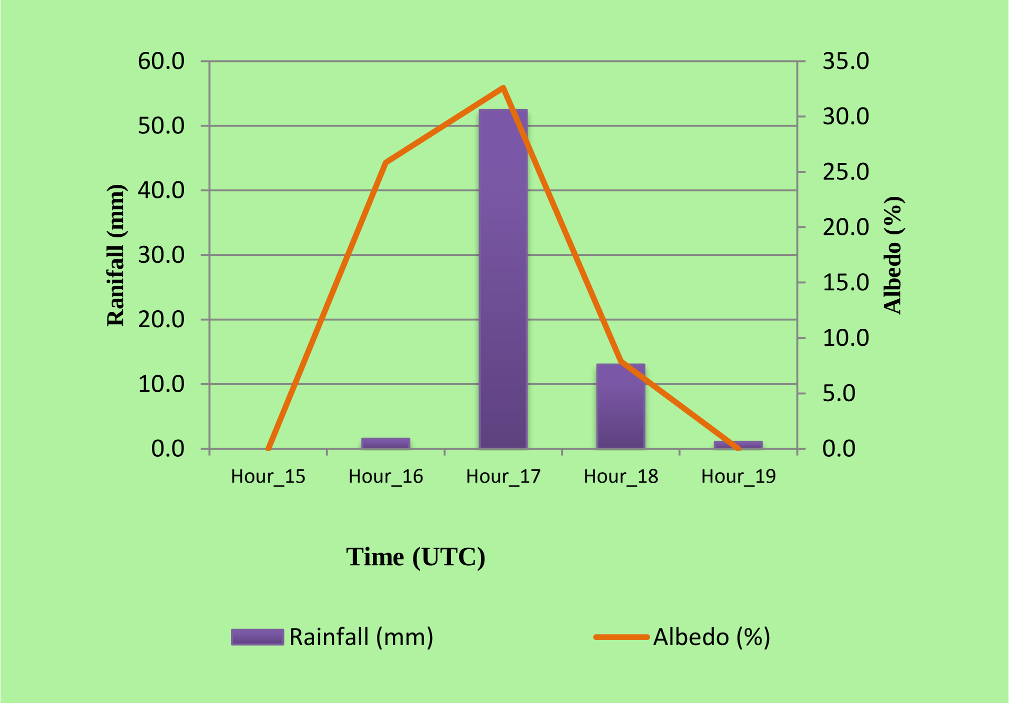
Storm Event : June 10, 2003 (Flash Flood Event)
Rainfall depth (mm)
40
35
30
25
20
15
10
5
0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Runoff (m^3/s)
New lead time
12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3
Time (hr)
ANN Forecast Rain
Forecasted flow
Recorded Flow

ON-GOING WORK

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

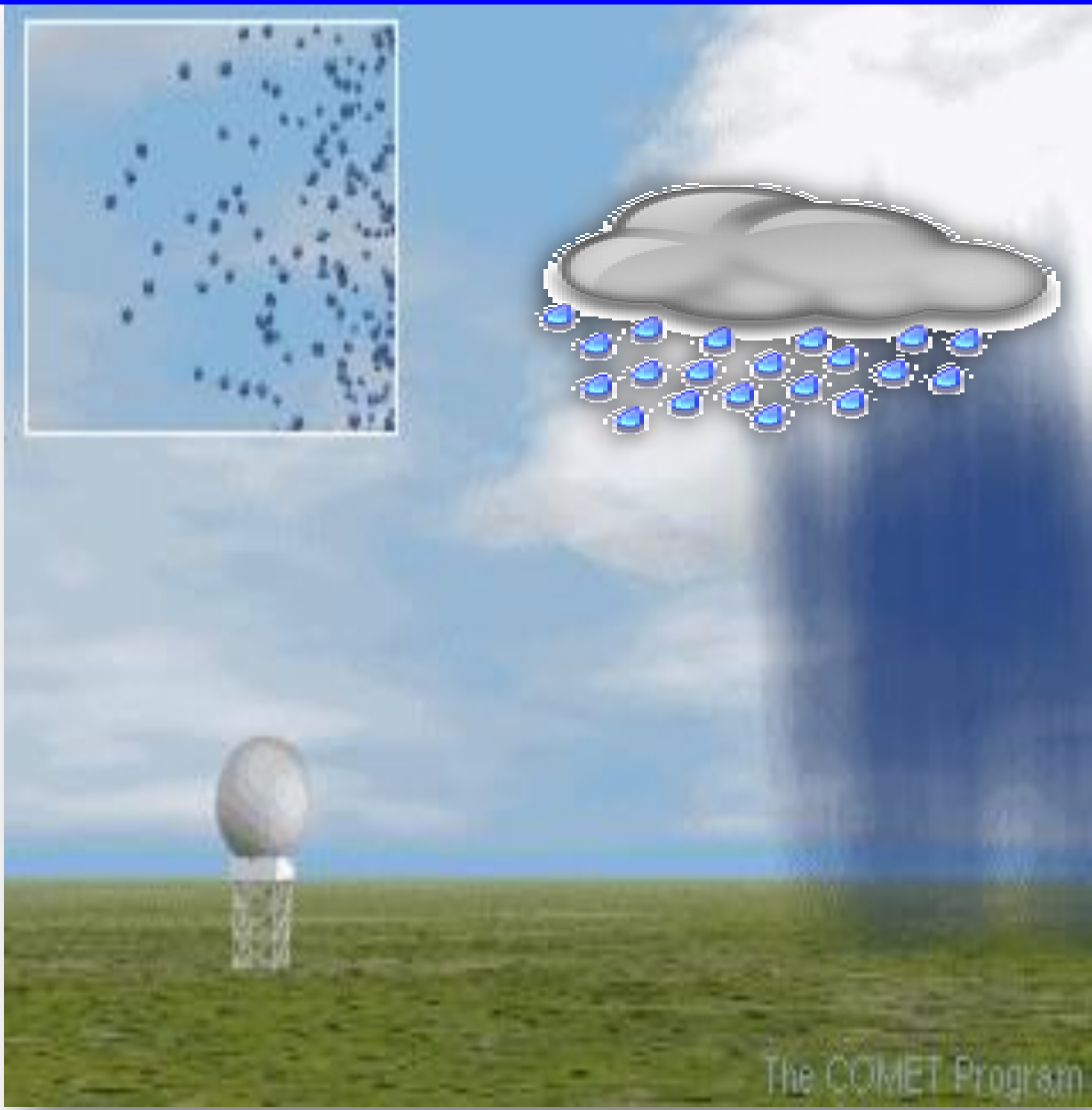


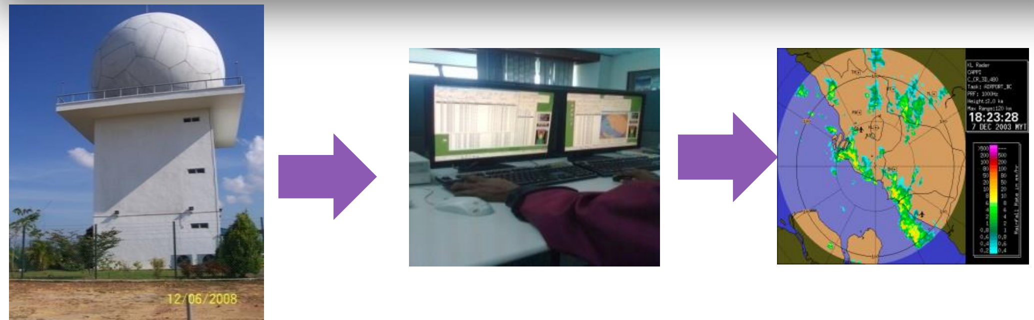
The main limitation/problem in the on-going study is the cost incurred (MMD is now charging all data)

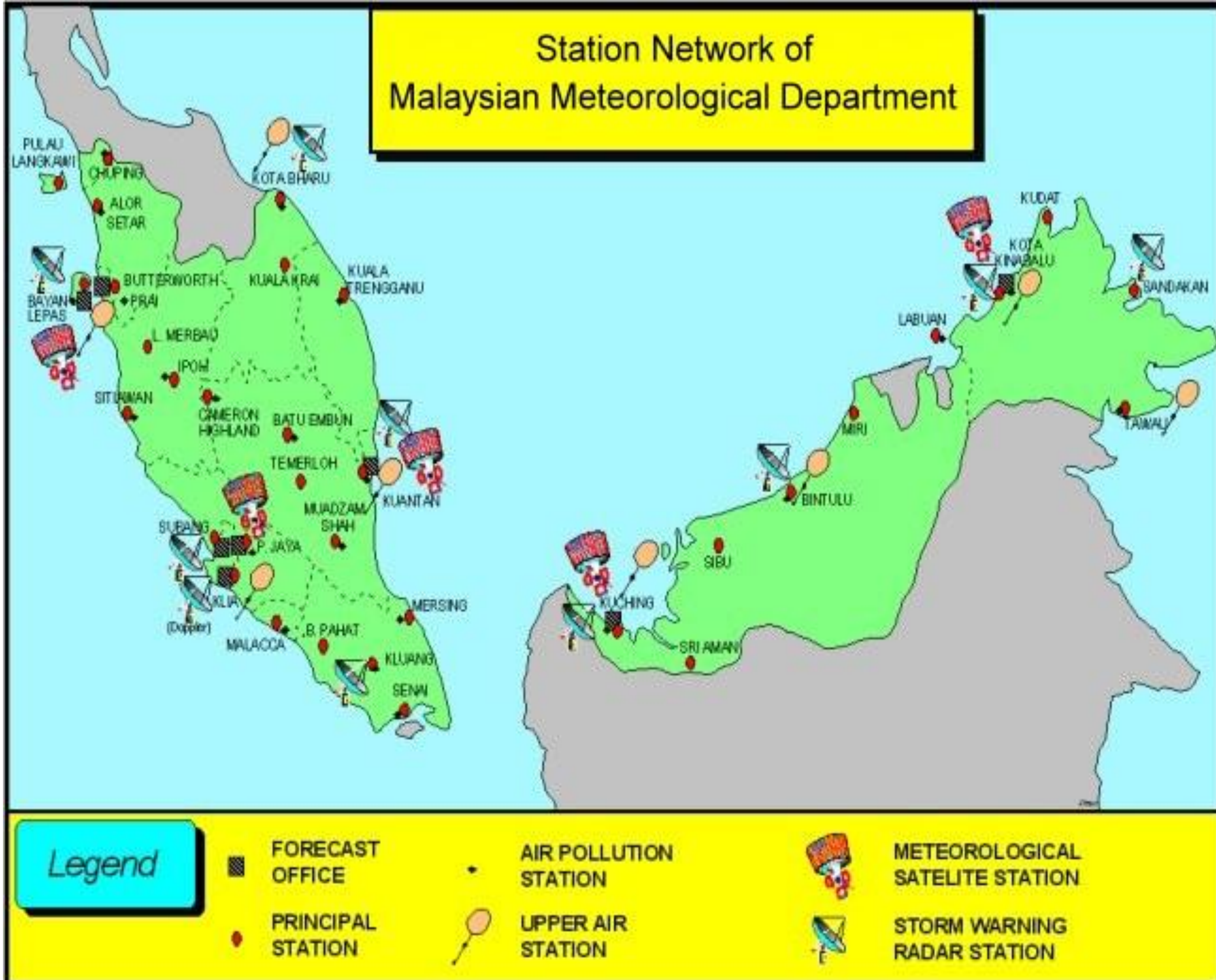


RADAR

- 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







Source : Malaysian Meteorological Department

Doppler Radar

- Development of Doppler radar starts in the era of 1970s
- Doppler radar, which is situated in Bukit Tampoi, 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.

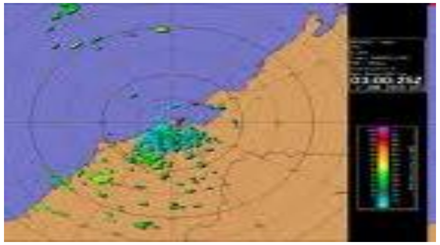
Doppler radar data acquisition process

RVP8

IRIS SOFTWARE (VAISALA)

RCP

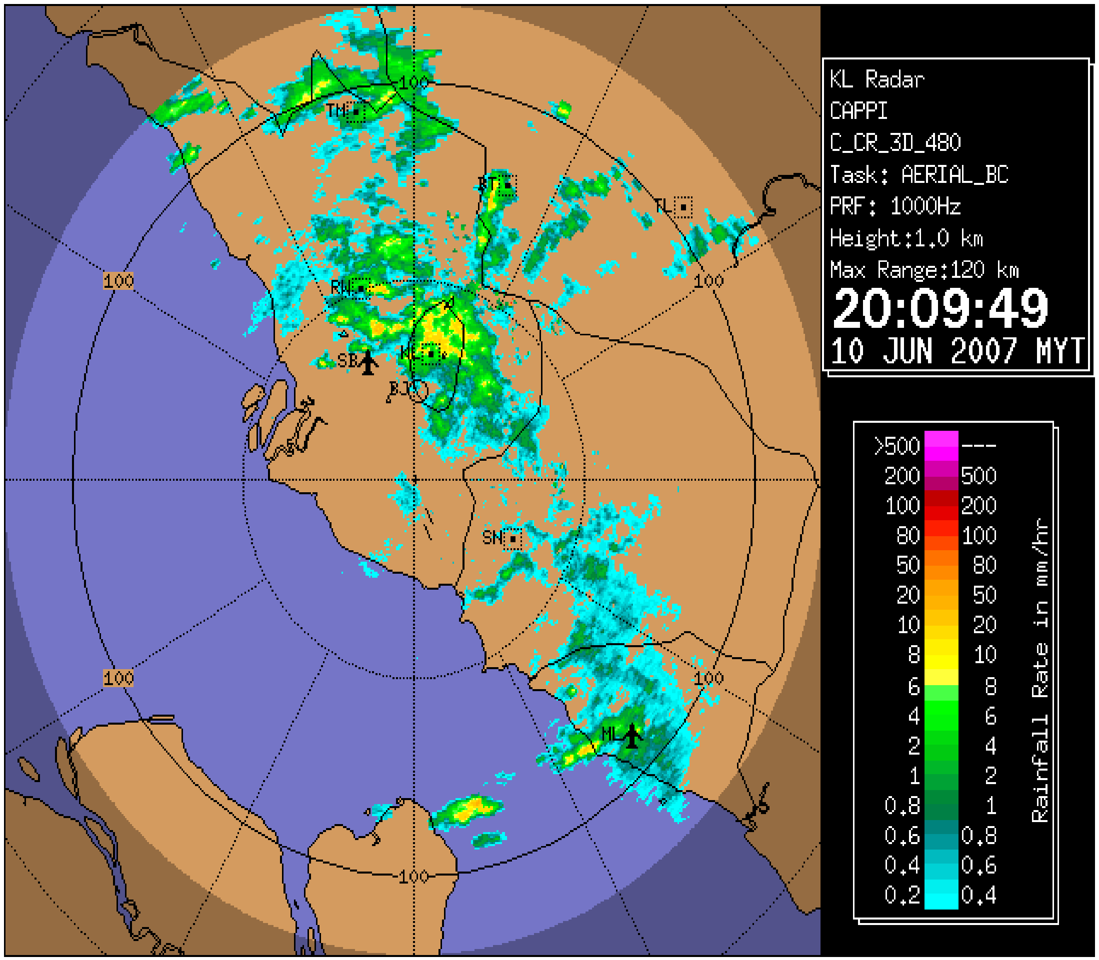
Conversion of reflectivity to rain rate using Marshal Palmer $\boldsymbol{Z=200R^{1.6}}$



RPW: Radar Product Workstation

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

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




Tiga cedera ditimpa dahan, 4 terkena cermin restoran

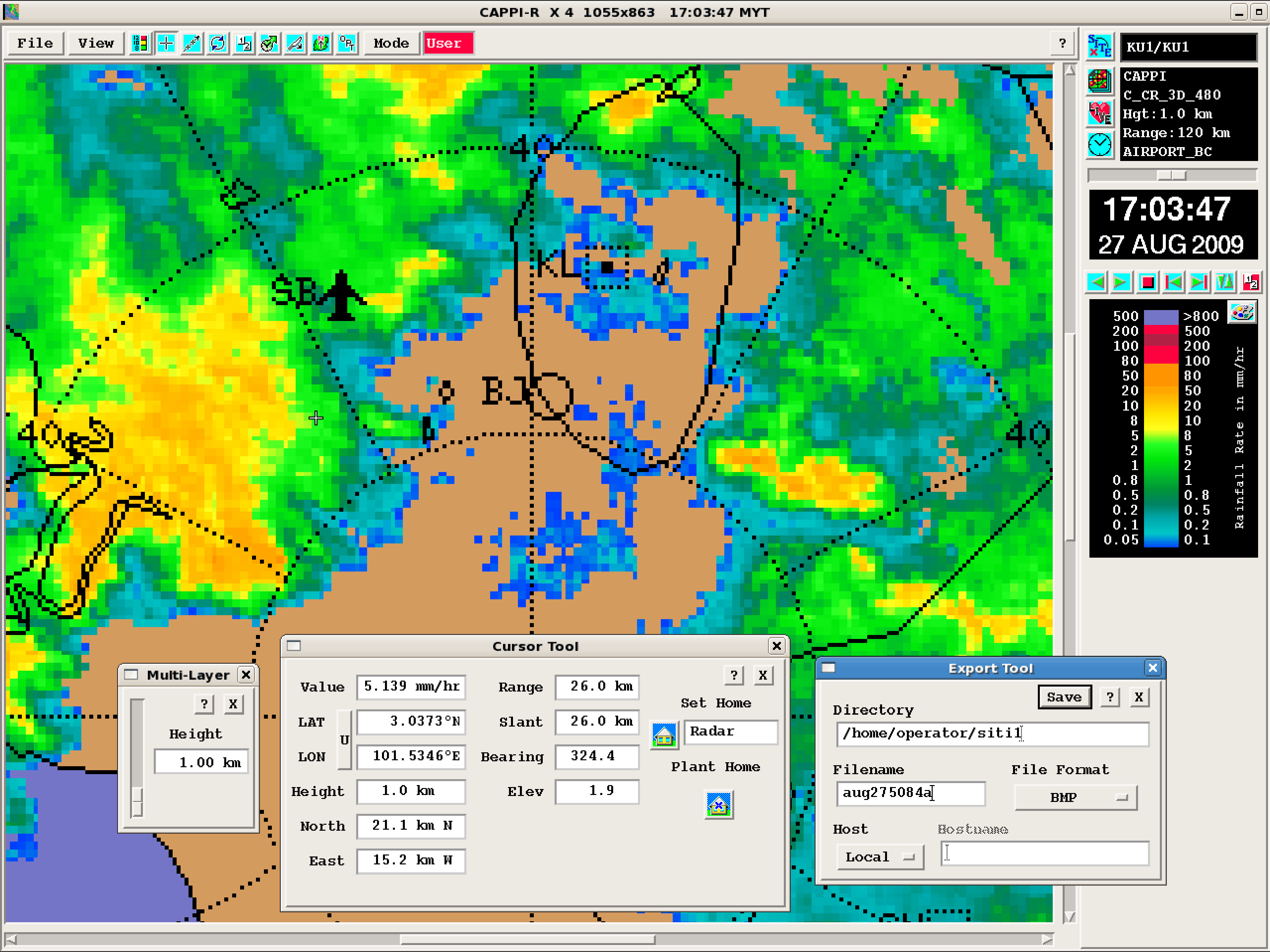
KL tenggelam

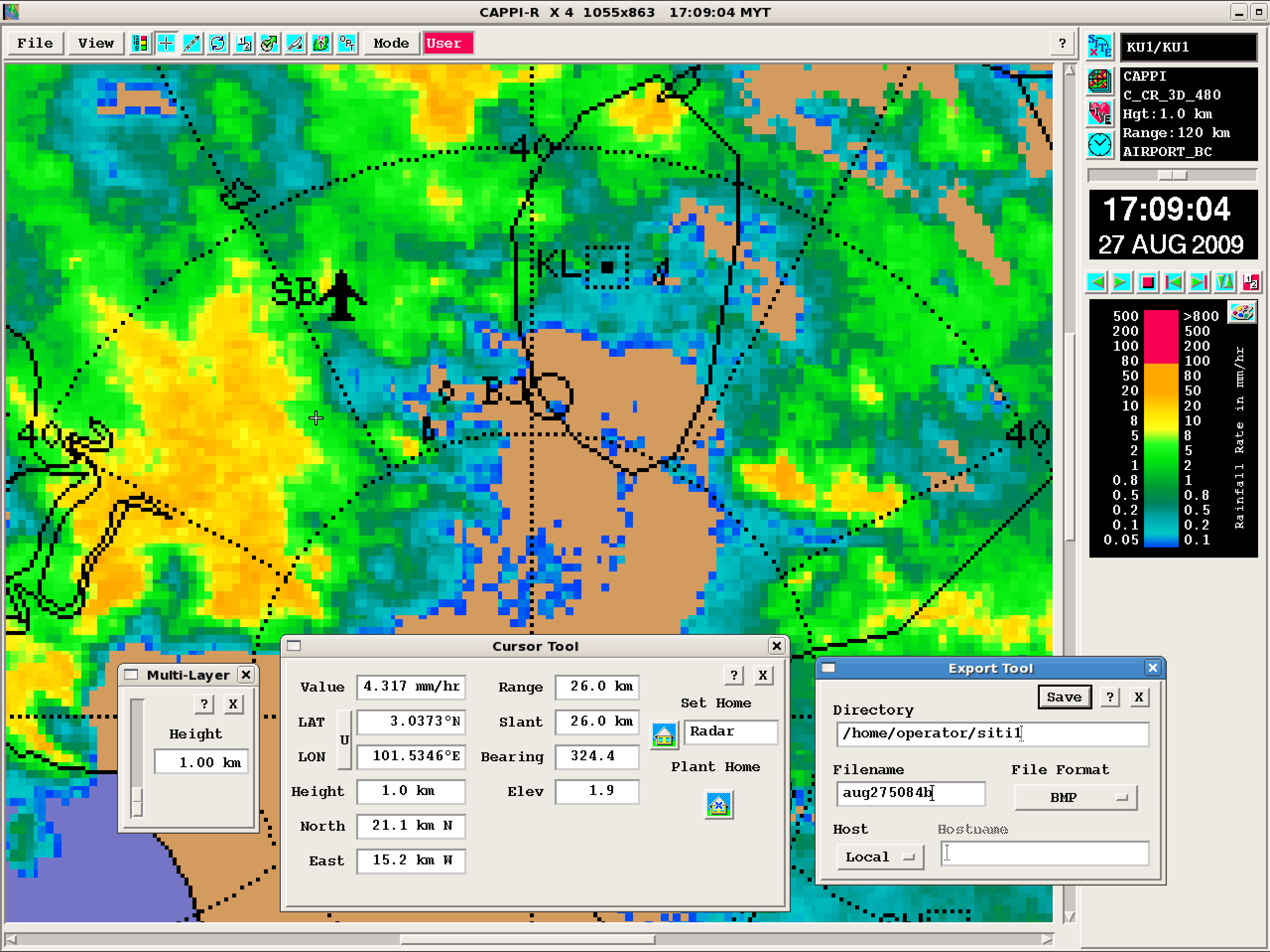
Jalan Dang Wangi

Jalan Melayu

KUALA LUMPUR: Ribuan warga kota terperangkap apabila banjir kilat terburuk sejak 2003 melanda ibu kota selepas hujan lebat hampir empat jam, lewat petang semalam. Ratusan kereta tersadai, manakala sebilangan penduduk Kampung Baru terpaksa dipindahkan, lapor Hazlihady Hasan ■ 7,8,9 & 10

TENGGELAM...warga kota meredah banjir kilat sedalam satu meter di Jalan Dooraisamy, malam tadi.


CAPPI-R X 4 1055x863 17:03:47 MYT
File
View
Mode
User
KU1/KU1
CAPPI
C_CR_3D_480
Hgt:1.0 km
Range:120 km
AIRPORT_BC
17:03:47
27 AUG 2009
500 >800
200 500
100 200
80 100
50 80
20 50
10 20
8 10
5 8
2 5
1 2
0.8 1
0.5 0.8
0.2 0.5
0.1 0.2
0.05 0.1
Rainfall Rate in mm/hr
SB
KL
BJ
40
Cursor Tool
Value 5.139 mm/hr
LAT 3.0373°N
LON 101.5346°E
Height 1.0 km
North 21.1 km N
East 15.2 km W
Range 26.0 km
Slant 26.0 km
Bearing 324.4
Elev 1.9
Set Home
Radar
Plant Home
Multi-Layer
Height
1.00 km
Export Tool
Save
Directory
/home/operator/siti1
Filename
aug275084a
File Format
BMP
Host
Local
Hostname


CAPPI-R X 4 1055x863 17:09:04 MYT
File
View
Mode
User
?
KU1/KU1
CAPPI
C_CR_3D_480
Hgt:1.0 km
Range:120 km
AIRPORT_BC
17:09:04
27 AUG 2009
500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1 0.05
>800 500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1
Rainfall Rate in mm/hr
40
KL
SB
BJ
Multi-Layer
Height
1.00 km
Cursor Tool
Value 4.317 mm/hr
LAT 3.0373°N
LON 101.5346°E
Height 1.0 km
North 21.1 km N
East 15.2 km W
Range 26.0 km
Slant 26.0 km
Bearing 324.4
Elev 1.9
Set Home
Radar
Plant Home
Export Tool
Save
Directory
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Filename
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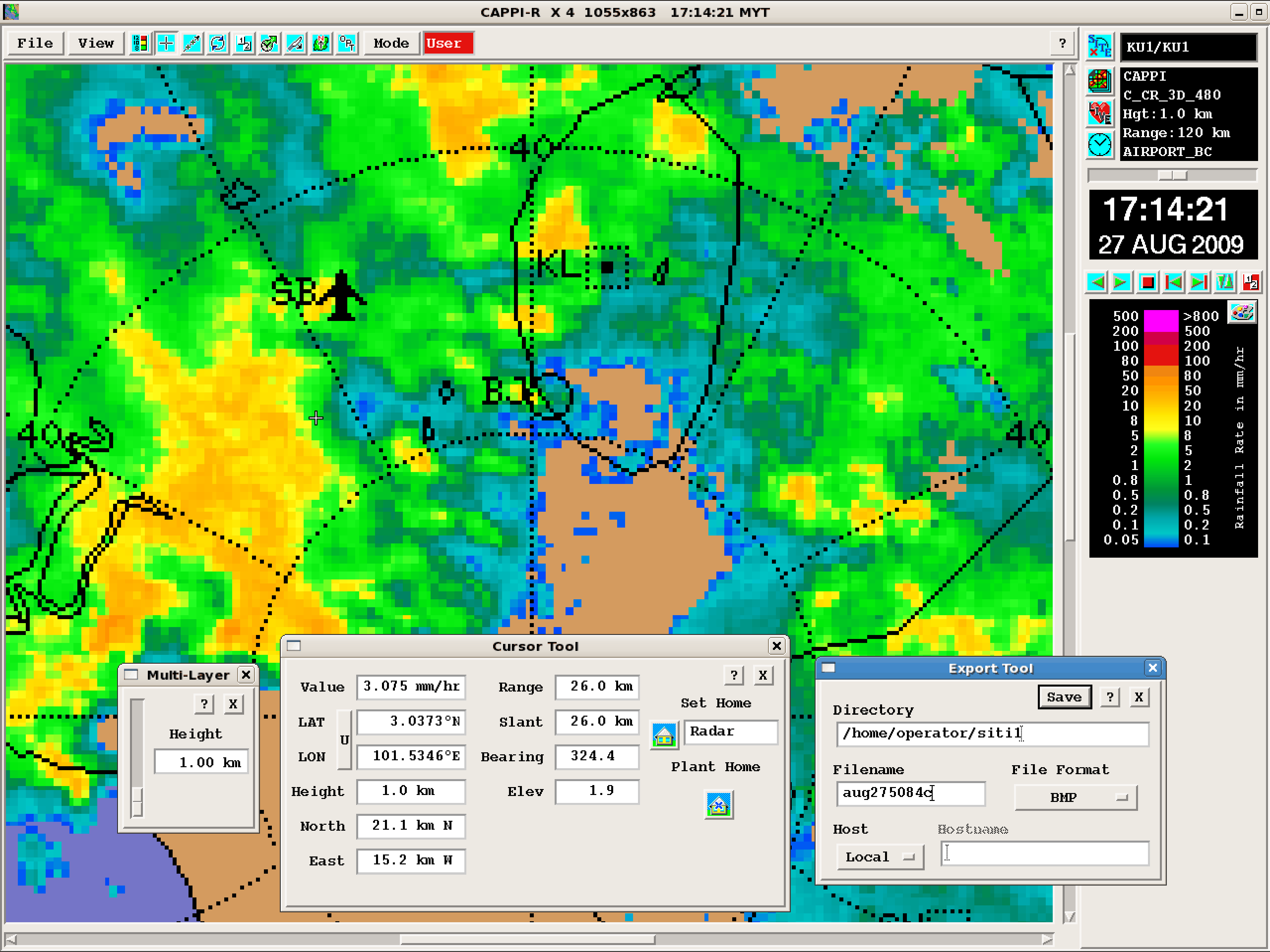
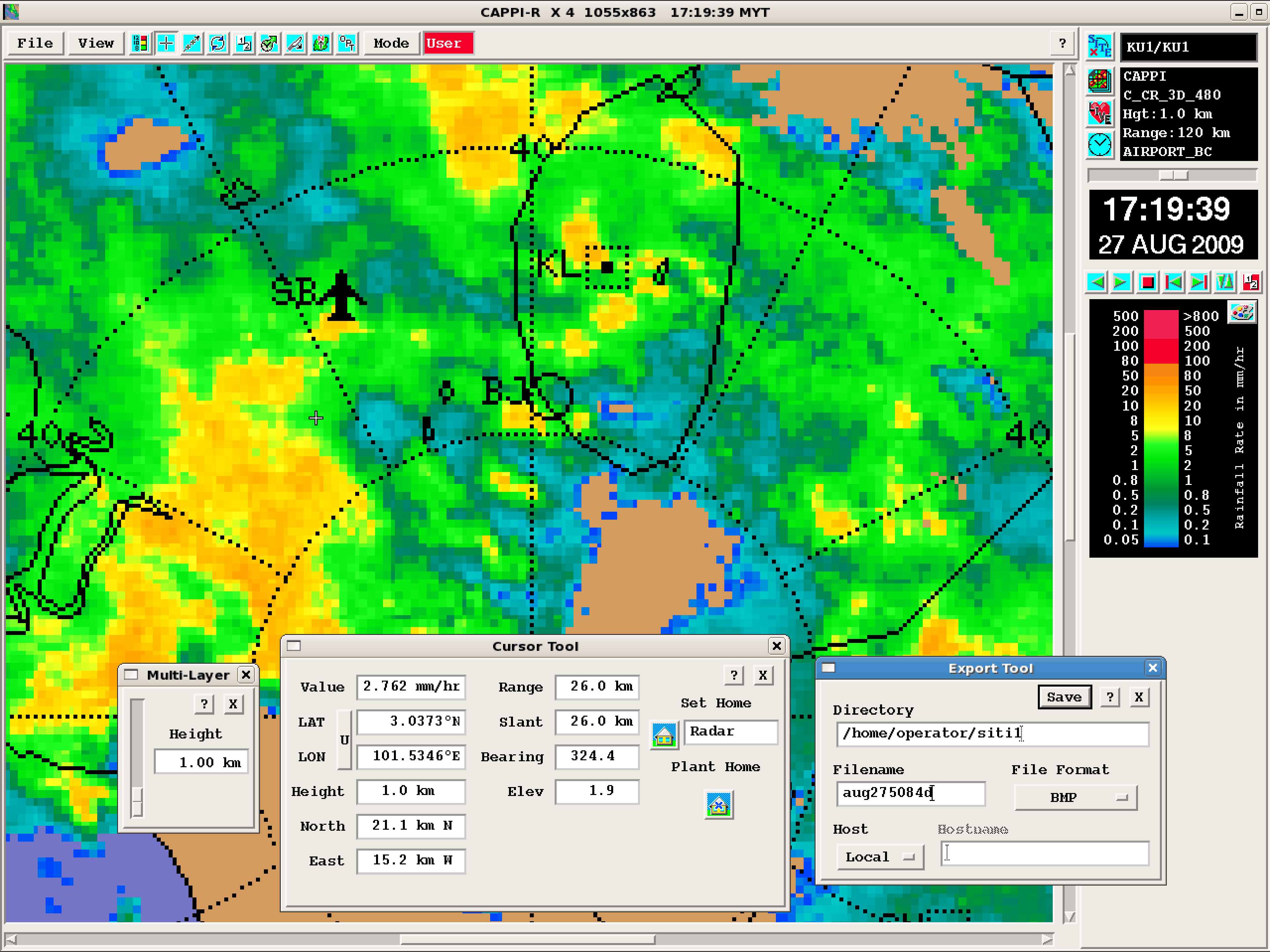
File Format
BMP
Host
Local
Hostname



CAPPI-R X 4 1055x863 17:14:21 MYT
File
View
Mode
User
?
KU1/KU1
CAPPI
C_CR_3D_480
Hgt:1.0 km
Range:120 km
AIRPORT_BC
17:14:21
27 AUG 2009
500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1 0.05
>800 500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1
Rainfall Rate in mm/hr
40
KL
SB
BJ
40
40
Multi-Layer
Height
1.00 km
Cursor Tool
Value 3.075 mm/hr
LAT 3.0373°N
LON 101.5346°E
Height 1.0 km
North 21.1 km N
East 15.2 km W
Range 26.0 km
Slant 26.0 km
Bearing 324.4
Elev 1.9
Set Home
Radar
Plant Home
Export Tool
Save
Directory
/home/operator/siti1
Filename
aug275084c
File Format
BMP
Host
Local
Hostname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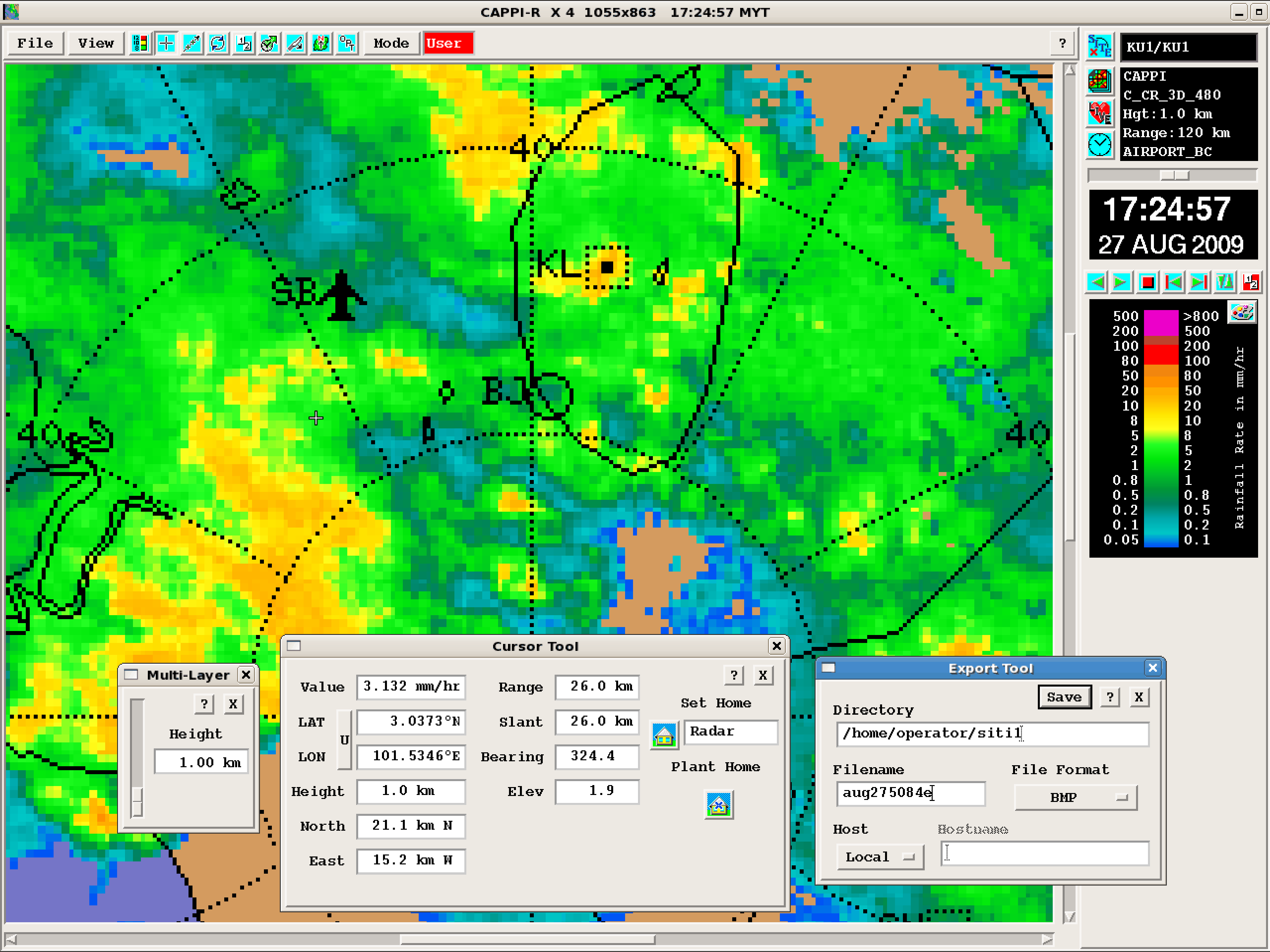
View
Mode
User
KU1/KU1
CAPPI
C_CR_3D_480
Hgt:1.0 km
Range:120 km
AIRPORT_BC
17:19:39
27 AUG 2009
500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1 0.05
>800 500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1
Rainfall Rate in mm/hr
40
KL
SB
BJ
Cursor Tool
Value 2.762 mm/hr
Range 26.0 km
LAT 3.0373°N
Slant 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
Set Home
Radar
Plant Home
Multi-Layer
Height
1.00 km
Export Tool
Save
Directory
/home/operator/siti1
Filename
aug275084d
File Format
BMP
Host
Local
Hostname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File
View
Mode
User
KU1/KU1
CAPPI
C_CR_3D_480
Hgt:1.0 km
Range:120 km
AIRPORT_BC
17:24:57
27 AUG 2009
500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1 0.05
>800 500 200 100 80 50 20 10 8 5 2 1 0.8 0.5 0.2 0.1
Rainfall Rate in mm/hr
40
KL
SB
BJ
40
40
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
Set Home
Radar
Plant Home
Multi-Layer
Height
1.00 km
Export Tool
Save
Directory
/home/operator/siti1
Filename
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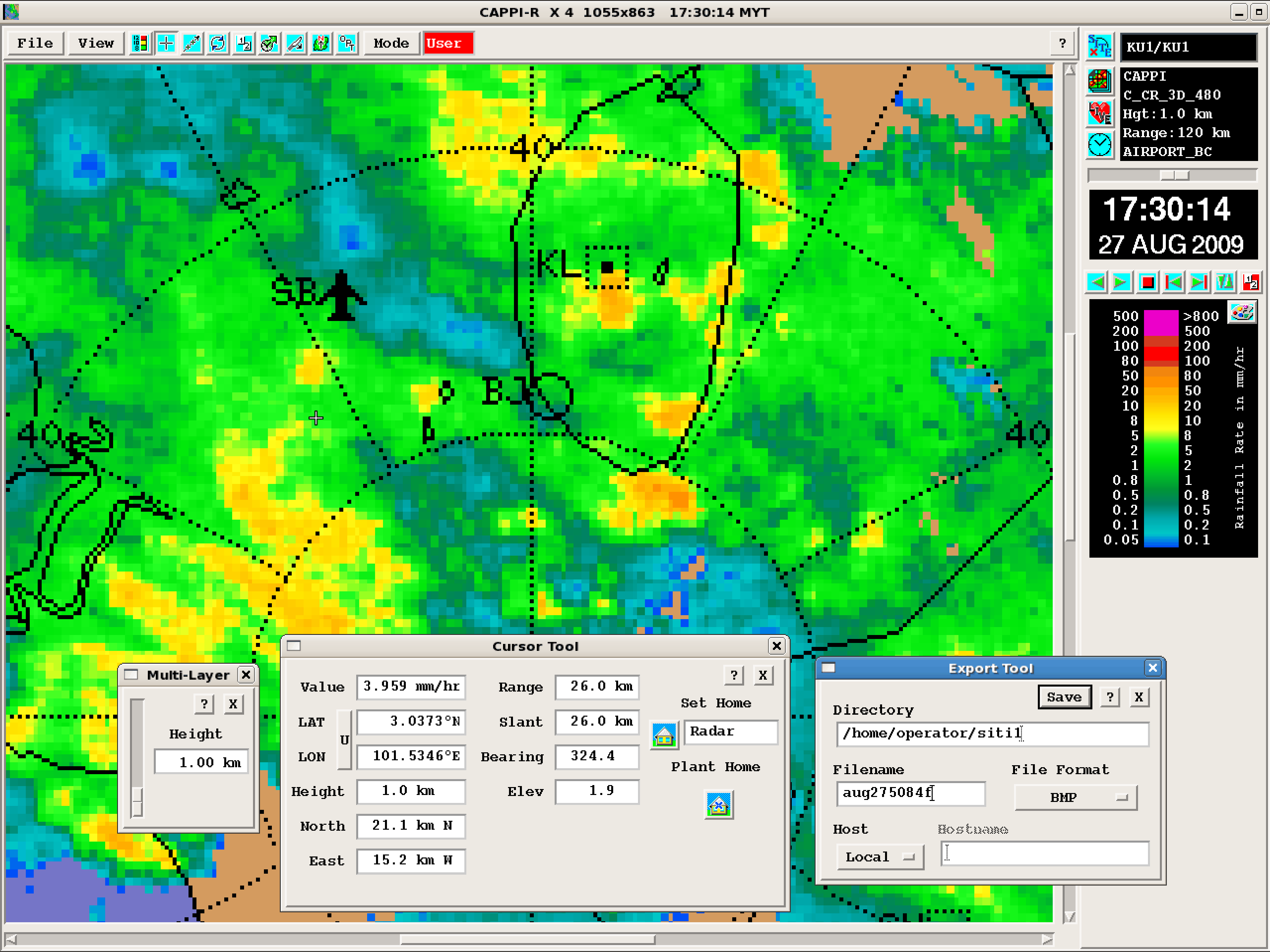
File Format
BMP
Host
Local
Hostname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File
View
Mode
User
?
KU1/KU1
CAPPI
C_CR_3D_480
Hgt:1.0 km
Range:120 km
AIRPORT_BC
17:30:14
27 AUG 2009
500 >800
200 500
100 200
80 100
50 80
20 50
10 20
8 10
5 8
2 5
1 2
0.8 1
0.5 0.8
0.2 0.5
0.1 0.2
0.05 0.1
Rainfall Rate in mm/hr
40
SB
KL
BJ
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
Set Home
Radar
Plant Home
Export Tool
Save
Directory
/home/operator/siti1
Filename
aug275084f
File Format
BMP
Host
Local
Hostname

The use of radar in quantitative precipitation estimation (QPE)

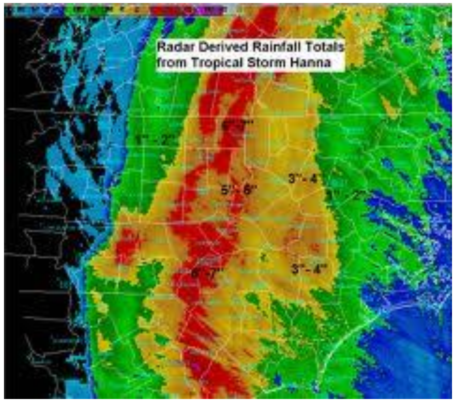
Advantages

High resolution in temporal and spatial

Disadvantages

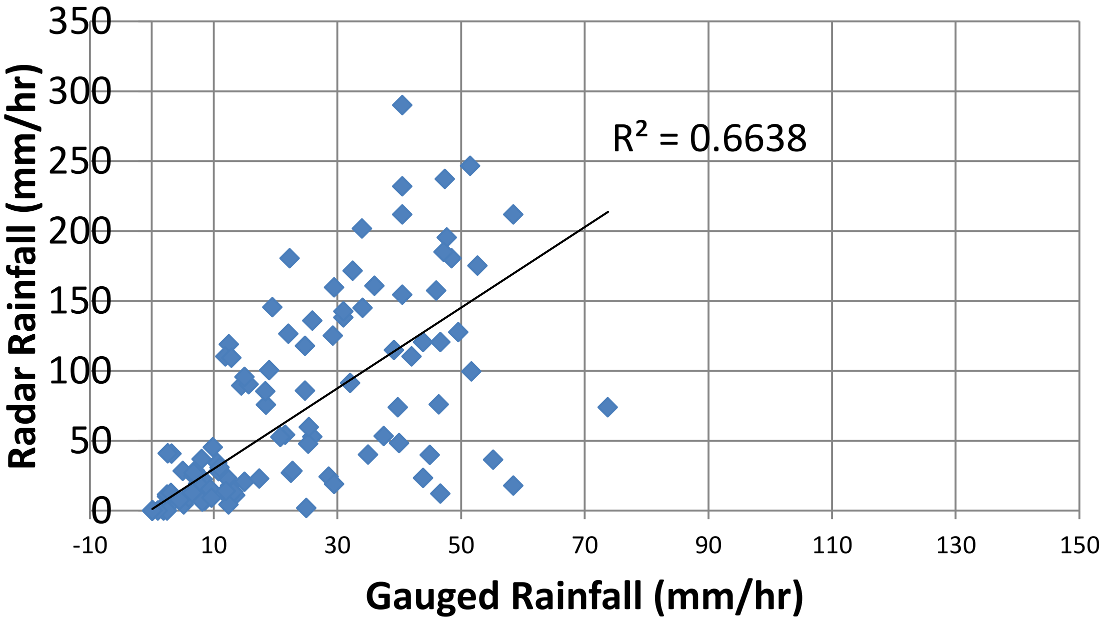
Less accuracy due to several errors (as follows):

- 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

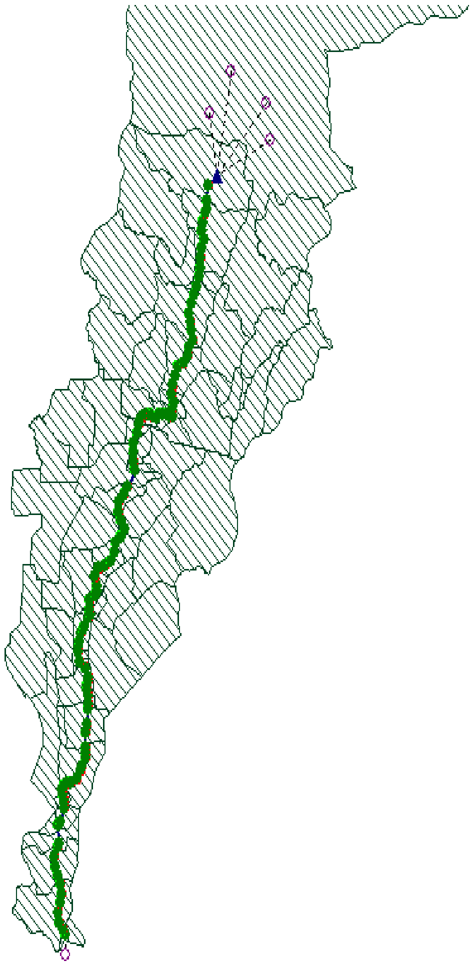
- Many studies had shown that with inappropriate use of Z/R relations, the rainfall estimates are proved to be inaccurate (Zogg, 2006).



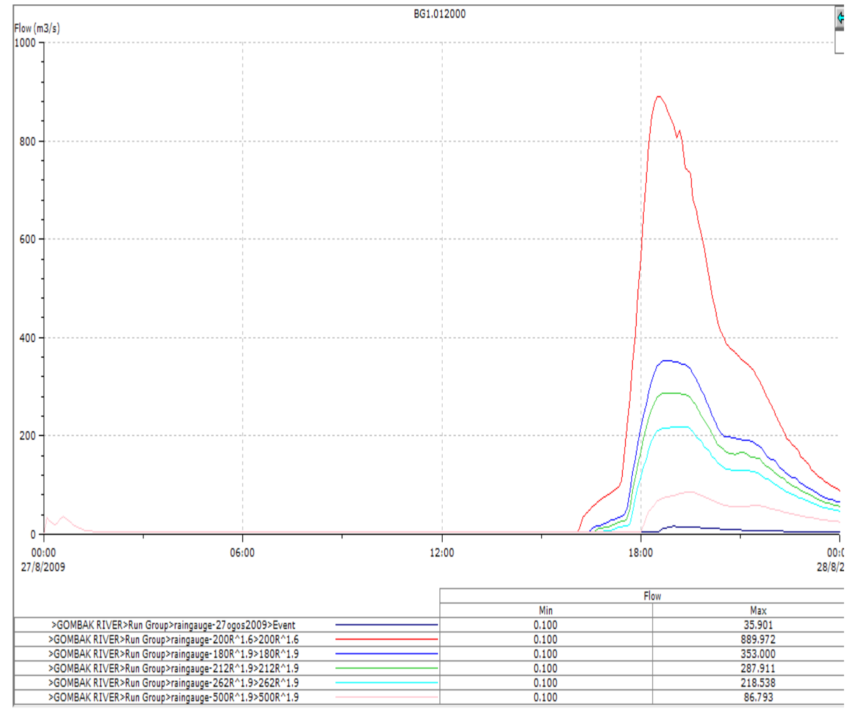
The comparison between new and current Z-R relationship categorized into monsoon and rain intensity

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



Gombak river basin model network and radar rainfall input



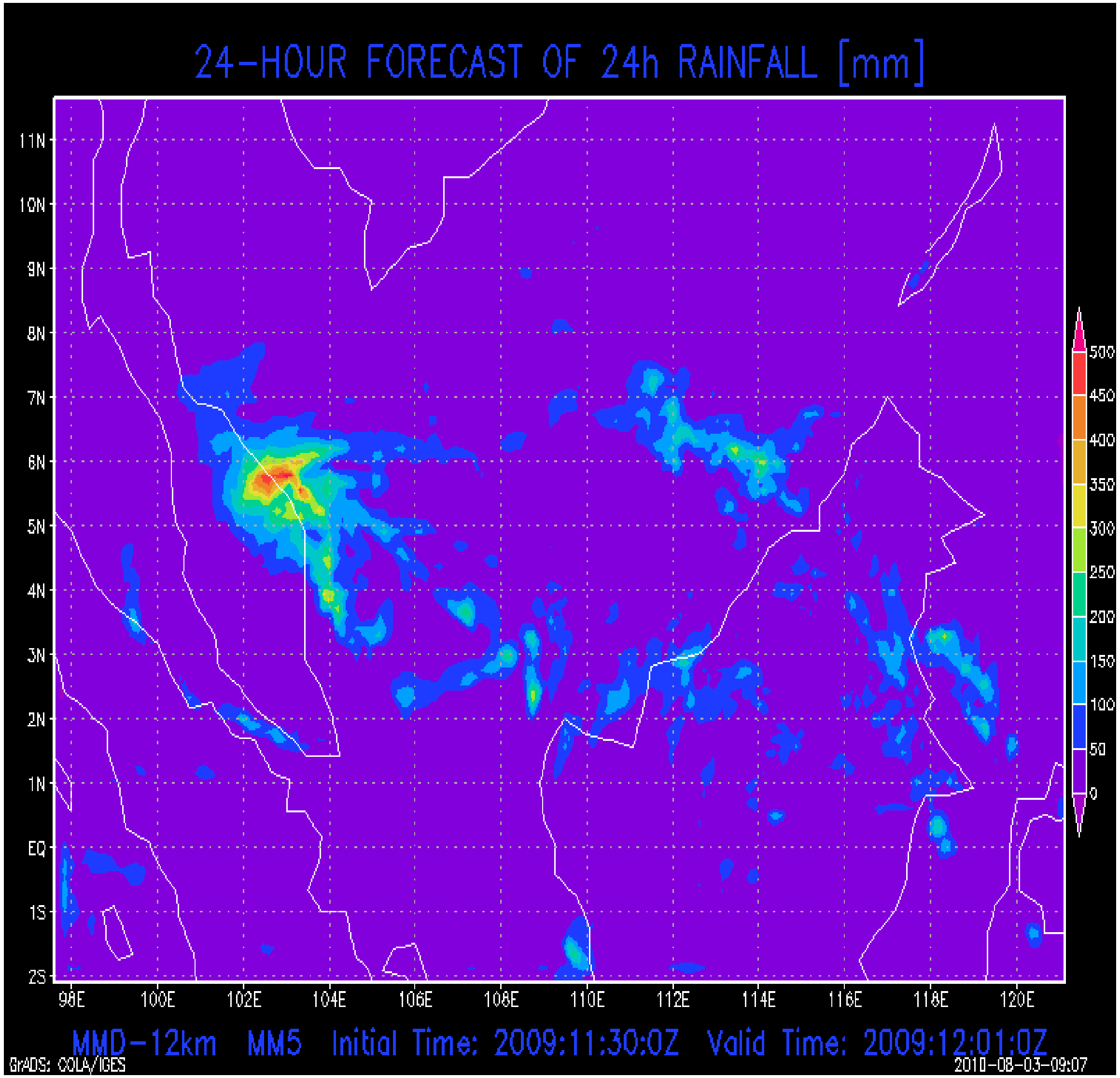
Flood hydrograph after an unsteady flow analysis using different rainfall inputs

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)

$$\frac{\partial w}{\partial t} - \frac{\rho_0}{\rho}\frac{g}{p^*}\frac{\partial p'}{\partial \sigma} + \frac{gp'}{\gamma p} = -\mathbf{V}\cdot\nabla w + g\frac{p_0}{p}\frac{T'}{T_0} - \frac{gR_d}{c_p}\frac{p'}{p} + e(u\cos\alpha - v\sin\alpha) + \frac{u^2 + v^2}{r_{earth}} + D_w$$

- 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

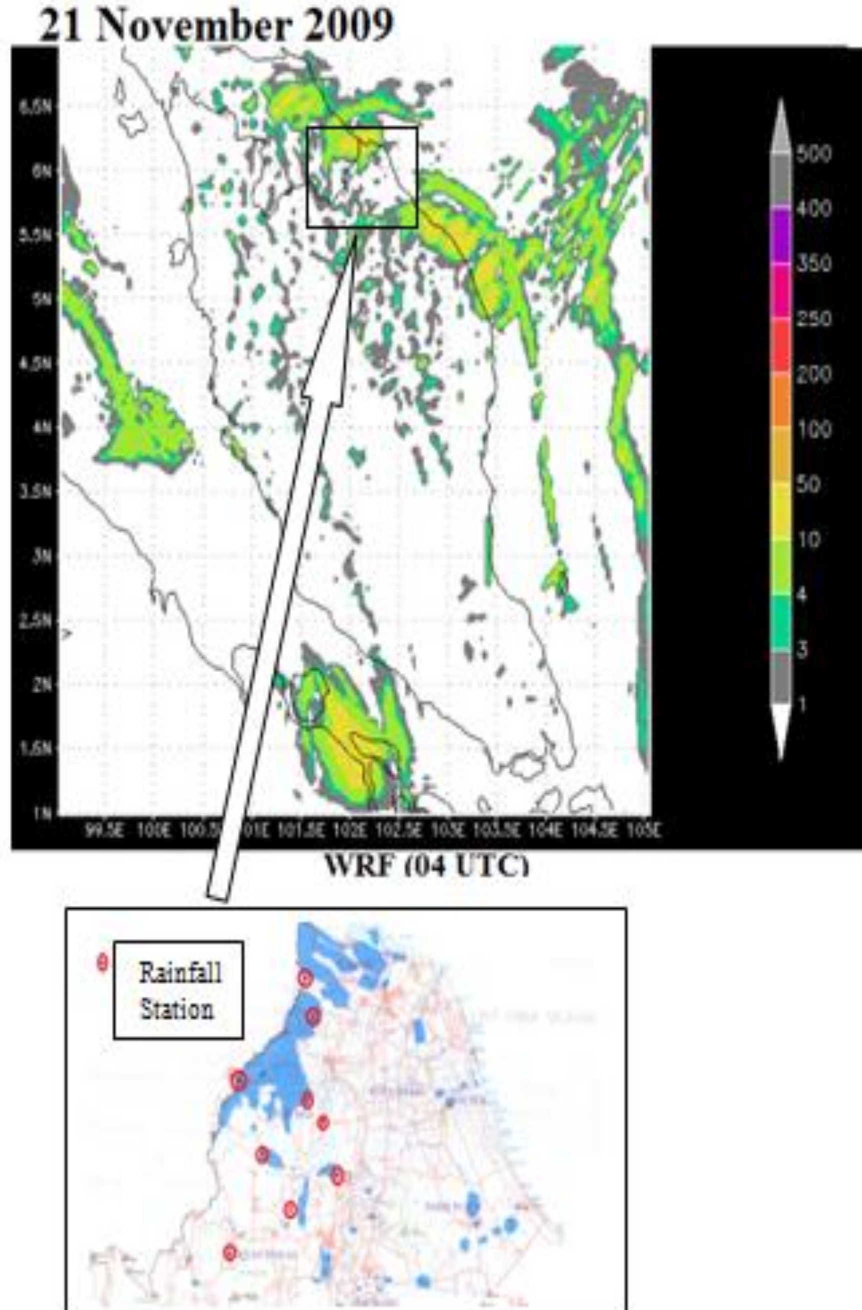
- Fifth Generation Penn State/NCAR Mesoscale (MM5)
- Weather Research and Forecasting (WRF)

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

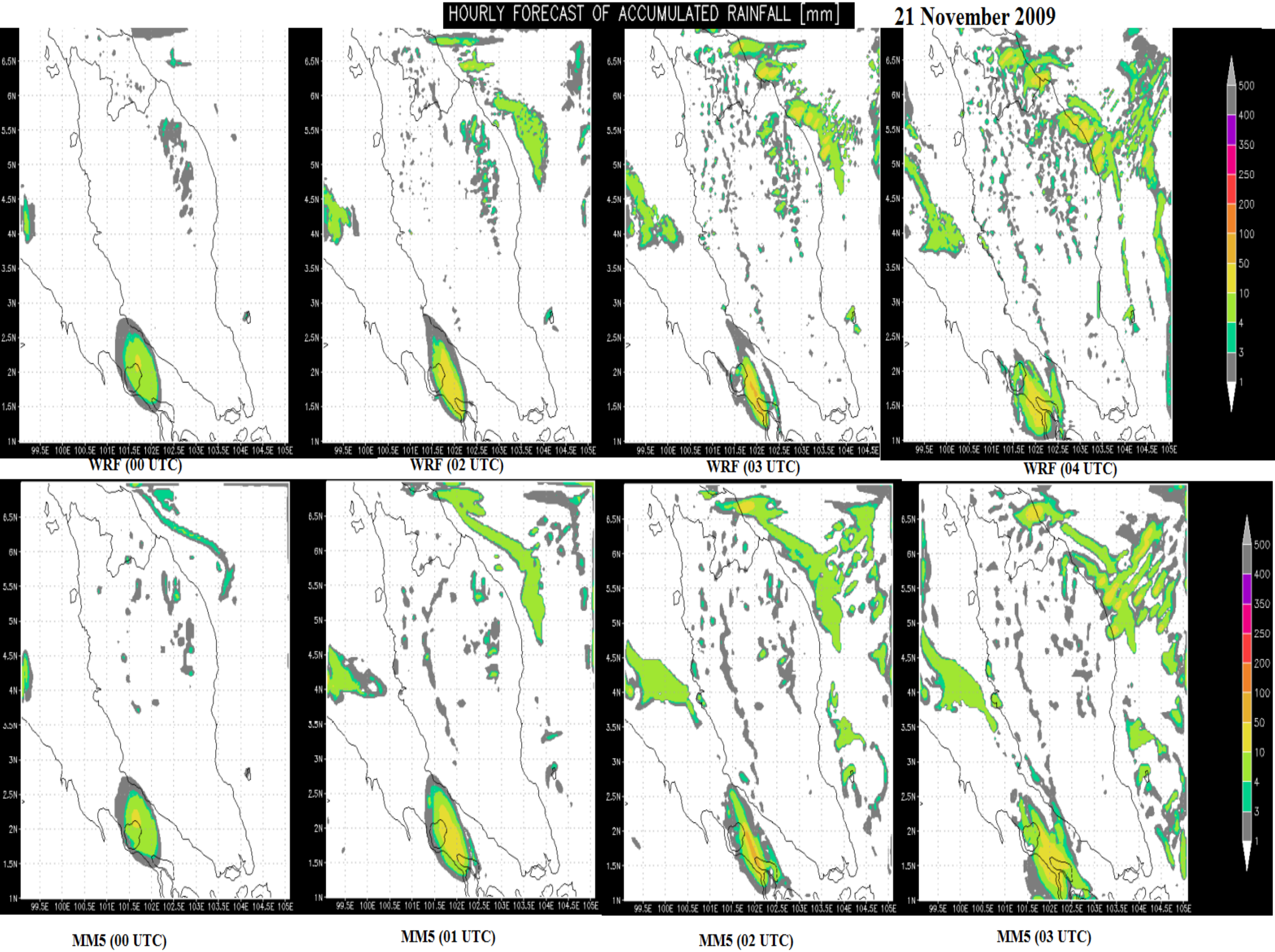
✓Model runs at 00UTC (0800 local time)
✓Forecast ranges are hourly, up to a period of 72 hours.
✓4 km resolution

Rainfall

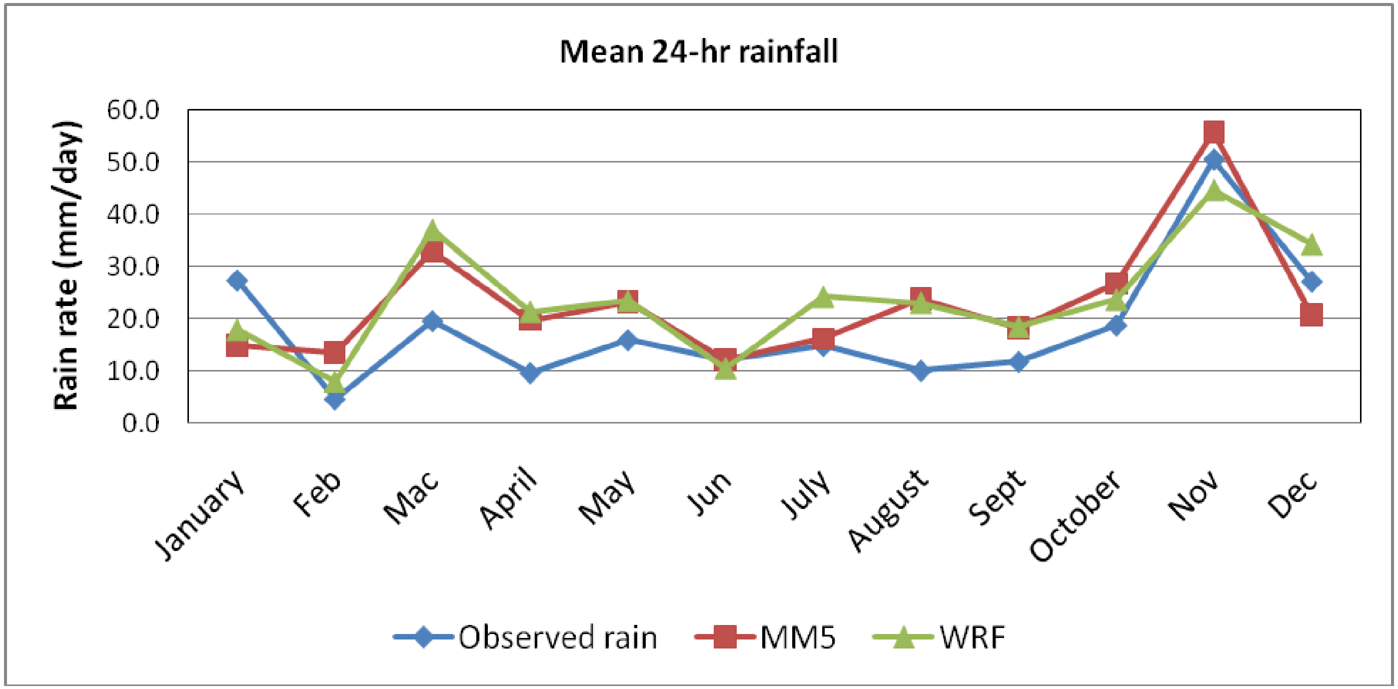
Hourly rainfall at 9 gauged stations over Kelantan River basin (DID) for year 2009



The location of Kelantan River Basin on the WRF display.

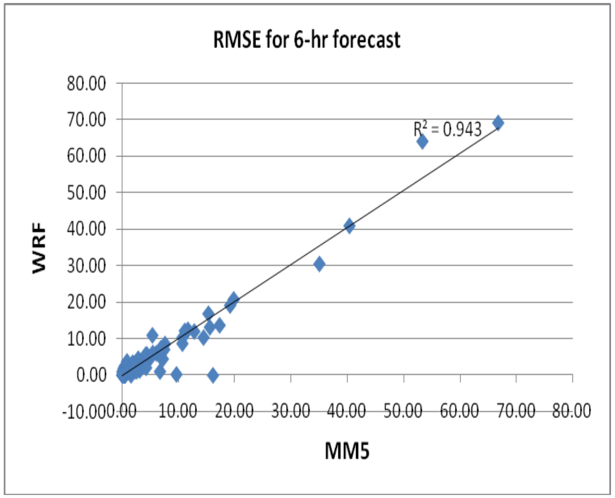

HOURLY FORECAST OF ACCUMULATED RAINFALL [mm]
21 November 2009
WRF (00 UTC)
WRF (02 UTC)
WRF (03 UTC)
WRF (04 UTC)
MM5 (00 UTC)
MM5 (01 UTC)
MM5 (02 UTC)
MM5 (03 UTC)
500
400
350
250
200
100
50
10
4
3
1

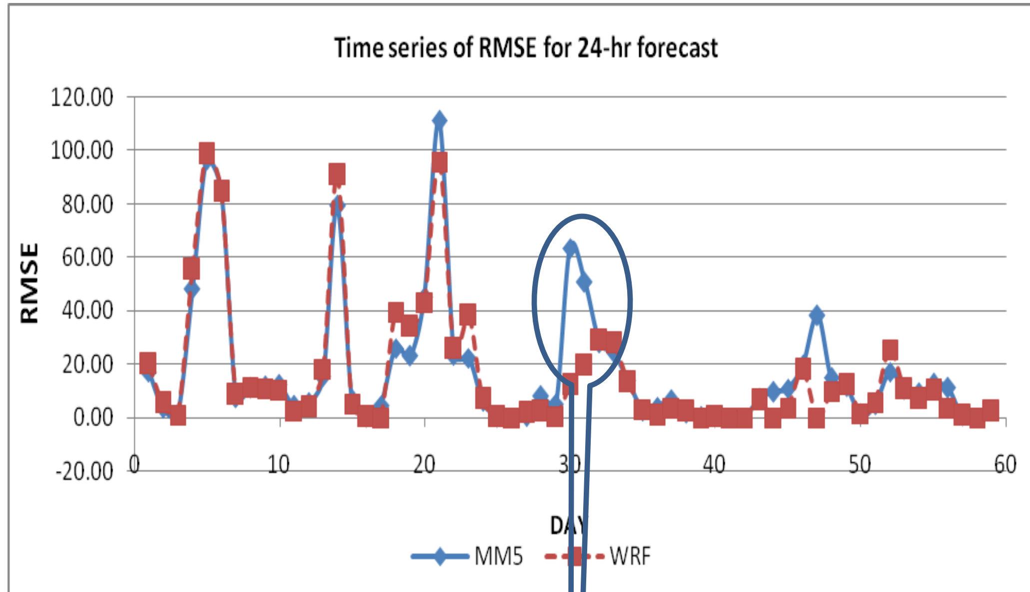
Results

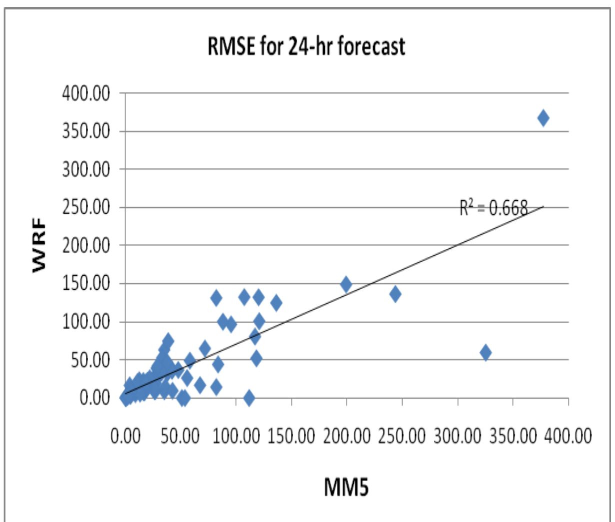


Though the model overestimates the 24-hr rainfall quite notably during Mac, April, May, August and September, they follow almost similar pattern of the mean daily rainfall amount

Results – Root Mean Square Error (RMSE)





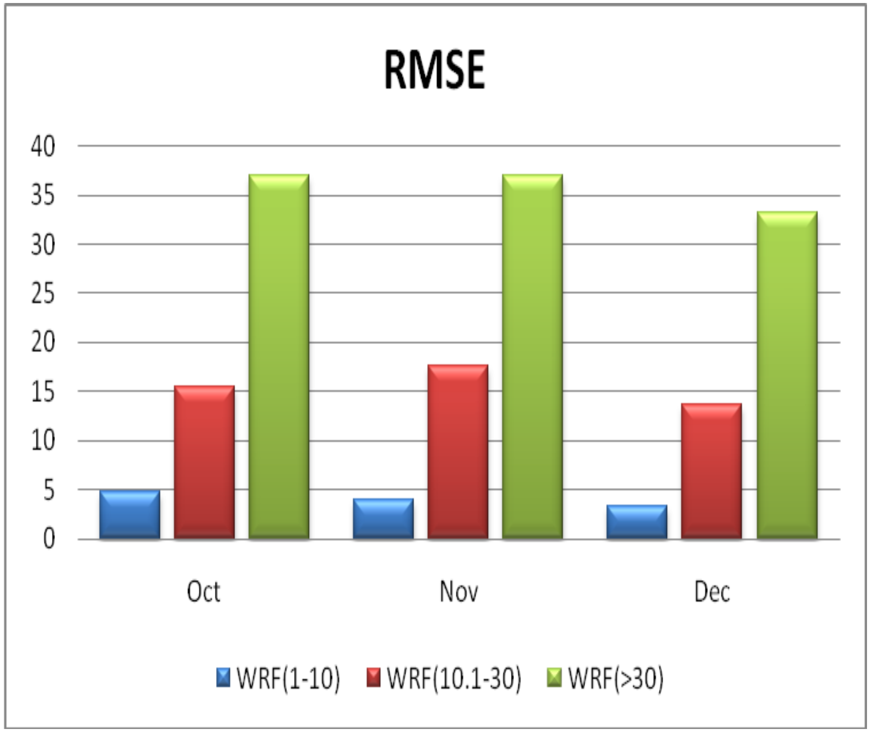


The longer forecast duration, the greater RMSE

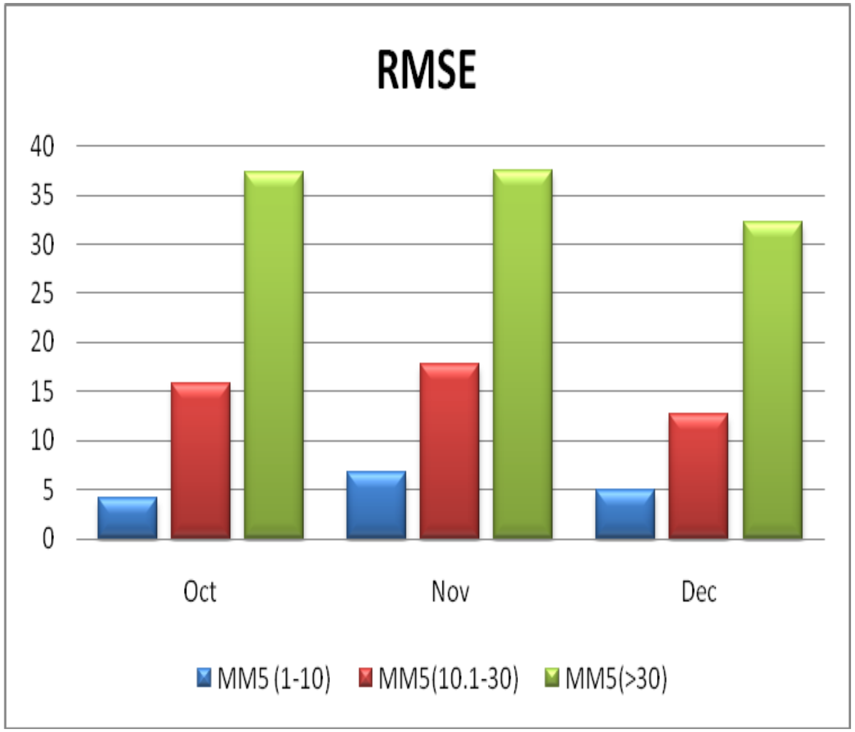
Comparison between the two models, indicate that their performance follow similar pattern

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

Results



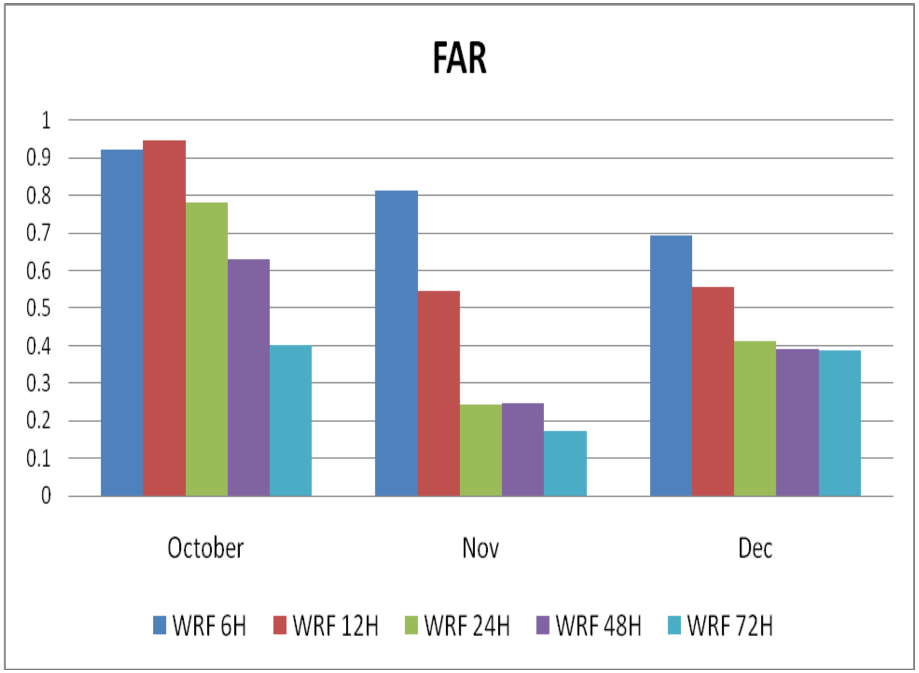
WRF



MM5

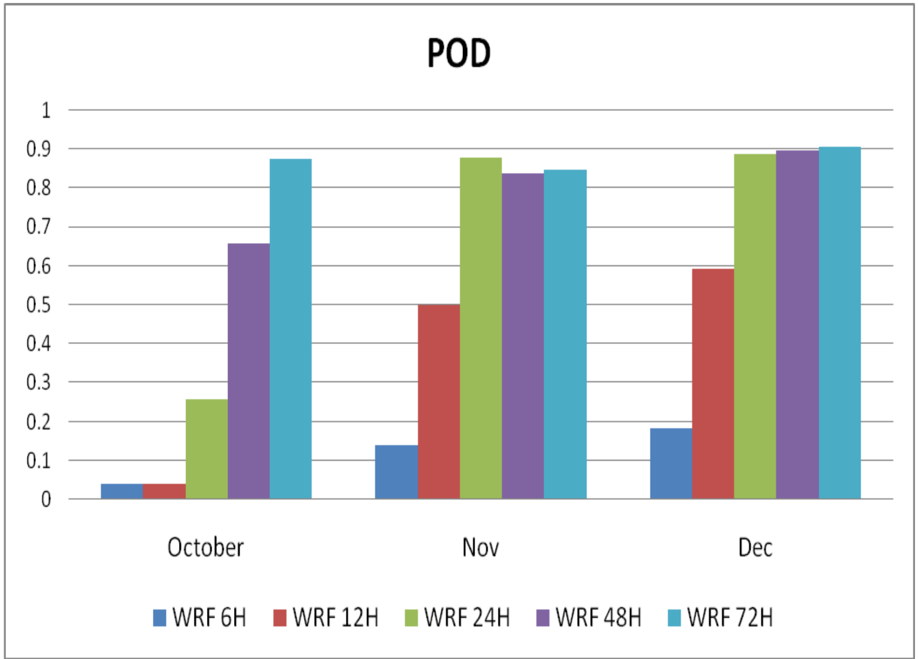
RMSE for different categories of rainfall (light, moderate, heavy)

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



POD- fraction of observed events that were correctly forecasted

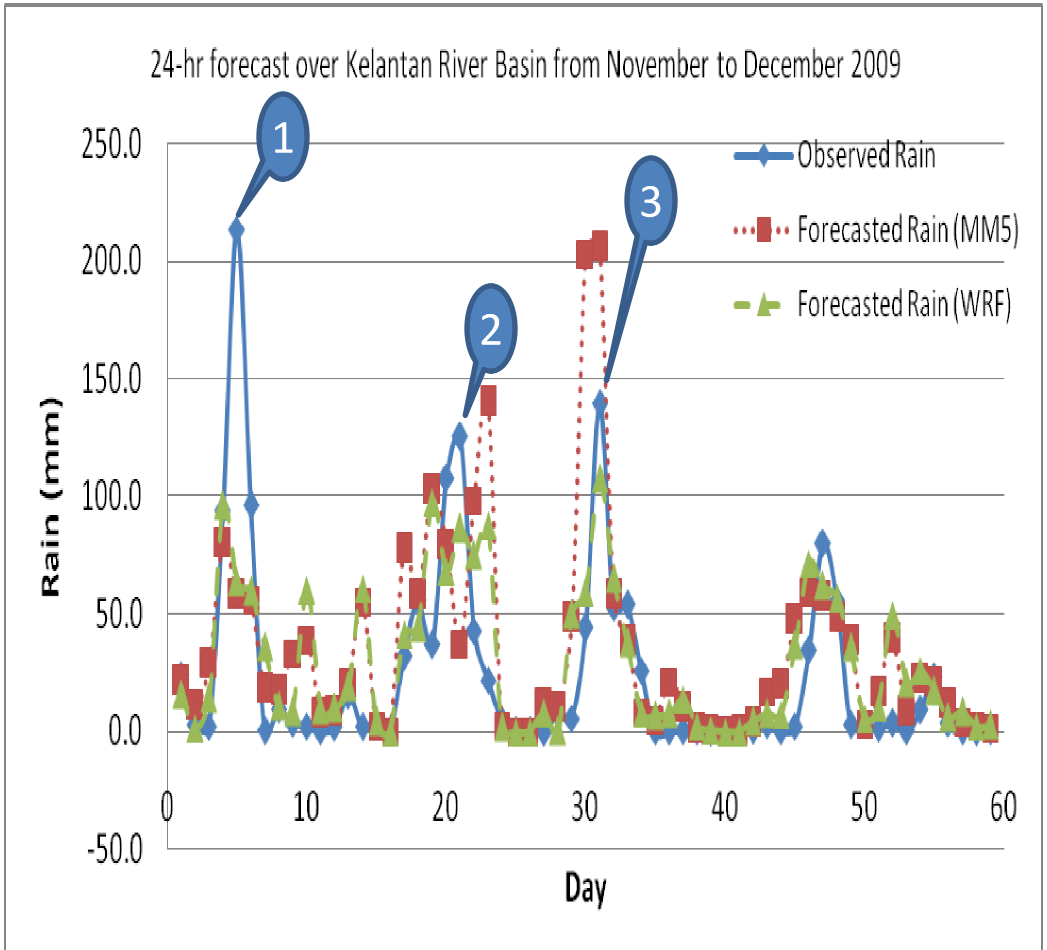
FAR - fraction of forecast events that were observed to be nonevents



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 5th November)
November 20 – 26 (areal average daily rainfall of 125 mm on 20th November)
December 2 – 6 (areal average daily rainfall of 139 mm on 2nd 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

DeFlood GS

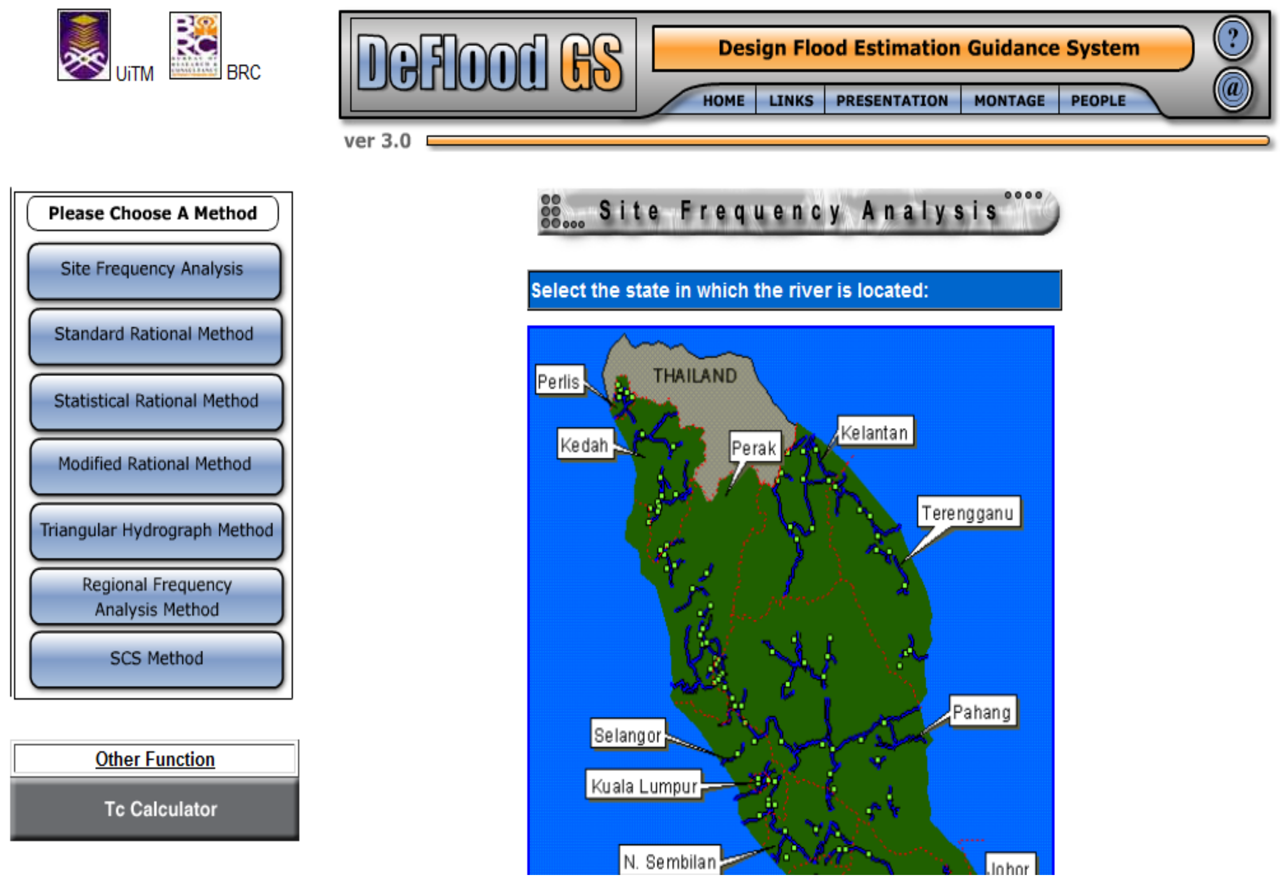
http://www.fce.uitm.edu.my/def_pro_VER3/maindeflood2.asp

Design flood estimation is crucial in the planning and design of water resources projects like the construction of culverts, bridges, reservoirs or dams.

If a water control structure is under designed, the results could be a disaster; the dam may break, the highway may flood or the bridge may collapse. On the other hand, if the structure is over designed and hence very safe, the cost involved could be unreasonably expensive.

DeFlood GS

http://www.fce.uitm.edu.my/def_pro_VER3/maindeflood2.asp



Design Flood Estimation Guidance System Version 3.0 or **DeFlood GS** provides a convenient and fast approach to compute the design flood estimation values. The techniques implemented in this application are **Site Frequency Analysis**, **Rational Method**, **Regional Flood Frequency Analysis, Triangular Hydrograph Method** and **SCS Method**

Conclusion

Flooding as one of the most devastating natural hazards has affected millions of people throughout the world. The implementation of various strategies and solutions to overcome the disasters depends on the capabilities of the regions, the authorities involved and the commitment of the government. An integrated flood management solution with participation from all stakeholders is crucial to ensure the effectiveness of the measures. At community level, all individuals can contribute to flood disaster control by reducing vulnerabilities at their sites.

Thank You

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