QPF techniques and development

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Contents

- QPF techniques : Radar-based nowcasting
- Operational and research development systems
- QPF accuracy assessment
- Cases study: Bangkok rainfall forecasting system

__Reference__ *: Quantitative Precipitation Forecasts based on radar observations: Principle, algorithms and operation system by dr. Maarten Reyniers (2008)*

QPF techniques: Radar-based nowcasting

The worldwide variety of QPF systems currently available is three systems :

- Systems based on " *Cell tracking* " or " *Centroid tracking* "
- Systems based on " *Area tracking* "
- Systems based on "*Spectral algorithms*"

“*Cell tracking*” or “*Centroid tracking*”

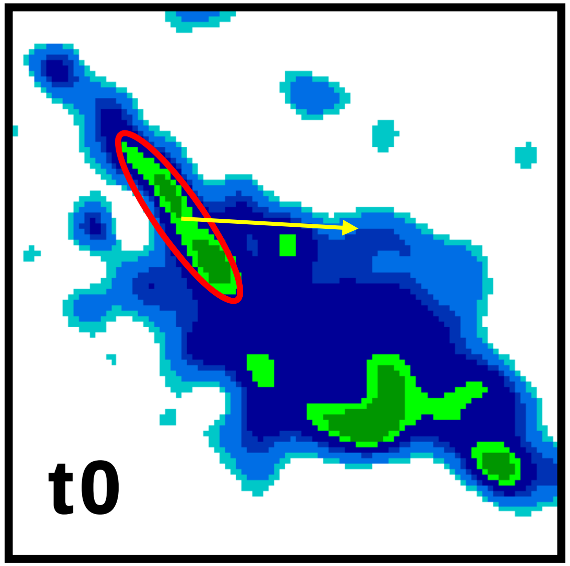
***1st* : Detection algorithm**

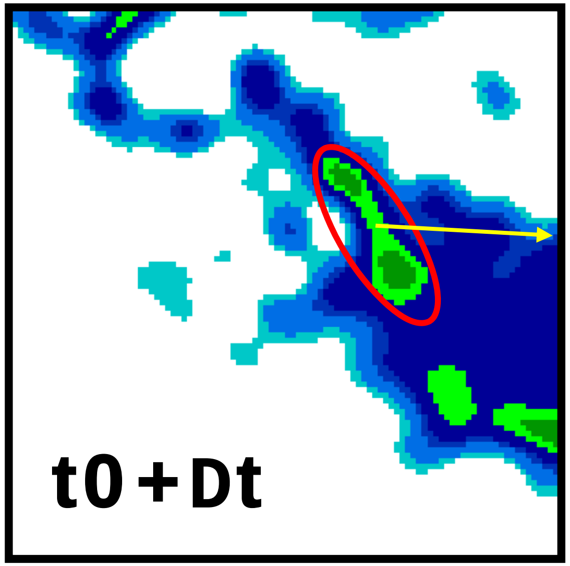
- Discrete objects (which normally contiguous regions of high reflectivity) are identified on the scans.

***2nd* : Matching algorithm**

- Identify identical cells on consecutive images by characteristics (area, echo-tops, VIL, etc…)
- Defined a searching area for identify identical cell, base on previous cell velocities

Cell-centroid tracking method





- identification of rainfields
- characterisation of rainfields
- recognition of rainfields
- analysis of past rainfield dynamics
- extrapolation of dynamics into the future
- assessment of forecast accuracy

Advantage of "*Cell tracking*"

- Cell statistics can be derived from cell trackers
- Statistical studies of precipitating cells become feasible
- Cell tracking is situated for convective storms

Cell Tracking Algorithms

- **TITAN** (**T**hunderstorm **I**dentification **T**racking **A**nd **A**nalysis)
- **SCIT** (**S**torm **C**ell **I**dentification **T**racking)
- **TRACE3D**
- **CELLTRACK**
- **TRT** (**T**hunderstorm **R**adar **T**racking algorithm)

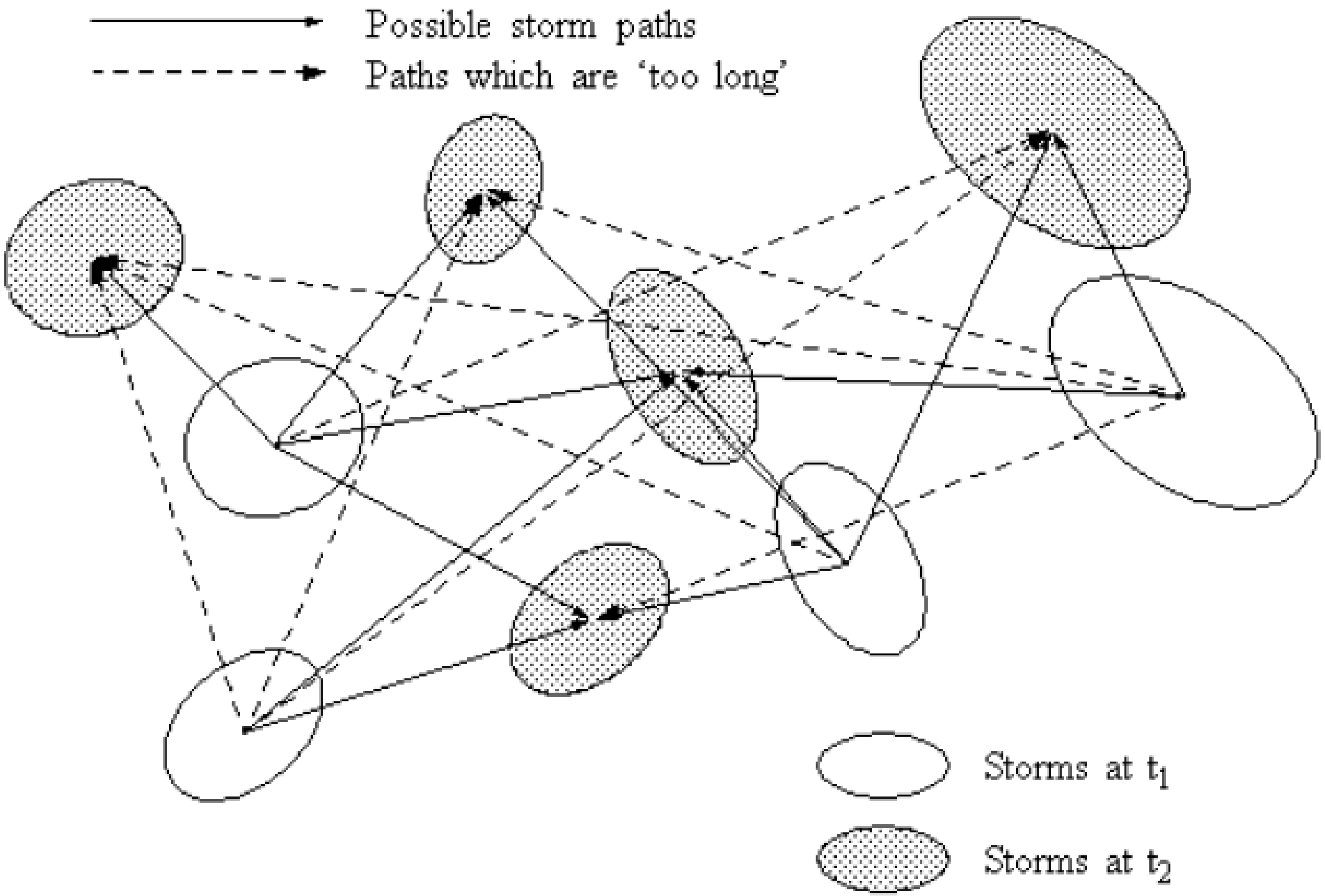
“*TITAN*” (3D)

Thunderstorm **I**dentification **T**racking **A**nd a**N**alysis

- A storm is defined as a contiguous region of enhanced reflectivity exceeding a certain threshold in both reflectivity and volume (*35 dBZ and 50 km*^{3})
- Storm tracking in TITAN is done through an optimization evaluating every possible track between the storms.
- A track is favoured as a “*true one*” if it is shorter and if it connects storm cells with similar properties.
- Previously shape is approximated by an ellipse, now it is replaced by a polygon.
- It is handling of merge and splits.

Developed by Dixon and Wiener, 1993

Storm Tracking in "TITAN"



Dixon and Wiener (1993)

“*SCIT* ” (3D)

Storm **C**ell **I**dentification and **T**racking

- It works with several reflectivity thresholds for cell detection. (default is 7)
- Cell tracking is done solely upon a distance criterion.
- It performs very well as a tracker for convective cells, but largely fails in tracking mesoscale stratiform precipitation area.
- It is not freely downloadable, but it integrated in WDSS-II system.

Developed by Johnson et al. (1998)

“*TRACED3D* ”(3D) Handwerker (2002)

- It contains some innovative features in both the identification and the tracking of storm cells.
- The tracking procedure resembles the one in SCIT, but has some importance differences in that way it handles cell splitting and merging. (“*Parent and Children*” cells)
- The performance of TRACE3D has been evaluated against test persons. It turned out that TRACED3D performed slightly worse than the human eyes, especially in situations with a complex cell pattern.
- Source code is available for free, upon request to the author.

“*CELLTRACK* ”(2D MAX field)

- It has been integrated into the operational QPF system at the Czech hydrometeorological Institute (CHMI)

- ***Cell identification***: CELLTRACK uses a single threshold, with a default of 44 dBZ on the maximum reflectivity field

- ***Cell tracking*** *: using more complex algorithm. All potential parent-child cells are grouped into cell clusters.*

Developed by Kyznarova and Novak, 2005, 2007

“*TRT* ”(2D MAX field)

Thunderstorm **R**adar **T**racking Algorithm

- It is operational nowcasting system tool of MeteoSwiss
- *<u>Cell detection and tracking part</u>* : similar to TRACE3D. It uses an adaptive thresholding scheme, allowing cells to be detected and tracked in different stages of their evolution.
- Cell detection works on the maximum reflectivity field not the volumetric data.
- Account for cell spitting and merging.
- Satisfactory performance, but it fails in cases of a frontal passage and slowly moving cells.

Developed by Hering et al. (2004, 2005, 2006)

“ Area tracking”

- Divides a rain rate image into a grid boxes. For each box, a corresponding box (maximum correlation) is search in the next image.

- The collection of vectors realising the translation between the corresponding boxes, forms the velocity field.

Originally developed by Hilst and Russo (1960)

Area Tracking Algorithms

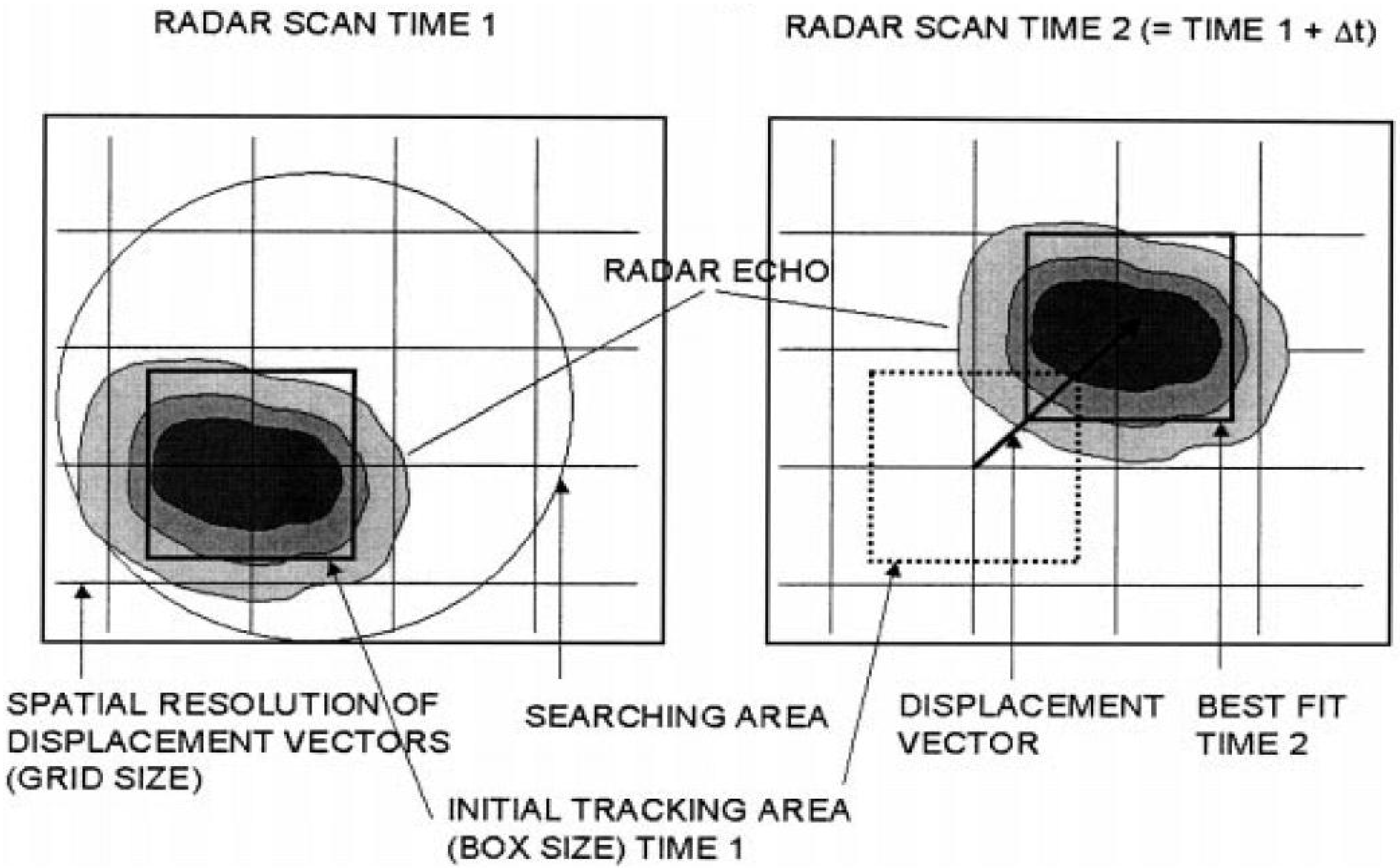
- **TREC**
- **COTREC**
- **VET (MAPLE)**

“TREC”

- Determines the spatial resolution for displacement vectors.
- Around each grid point a tracking area is defined, called “*box size*”
- This box is compared to similar boxes within the searching range of the second image.
- The size of searching range is defined by choosing a maximum velocity and the time lag between 1st and 2nd images.
- For each pair of boxes of the 1st and 2nd images, the correlation coefficient is computed.
- The translation vector between a pair of boxes realising the maximum correlation coefficient is taken as a valid velocity vector.

First implemented by Rinehart and Garvey (1978)

“ TREC”



(Mecklenburg et al. 2008)

Problem of "*TREC*"

- The procedure leads to "*noisy velocity field* " which often containing wrong vectors or divergent feature.

- Several schemes are developed to smooth and/or correct these shortcomings such as COTREC (Li et al.1995)

"COTREC"

- It consists of reprocessing the raw *TREC* velocity field through a minimisation of $\partial u / \partial x + \partial v / \partial y$
- In *COTREC* scheme, a very rudimentary echo growth and decay estimate is made by comparing the total reflectivity of a box with the corresponding box in the previous image.
- COTREC has a commercial version called ***RainCast*** (Schmid et al., 2000)

Developed by Li et al. (1995)

“*VET (MAPLE)* ”

Variational **E**cho **T**racking

- It is a part of the McGill Algorithm for Precipitation Nowcasting Using Semi-Lagrangian Extrapolation (MAPLE)

- The algorithm was originally developed by Laroche and Zawadzki (1994) to retrieve three-dimensional wind fields from single-Doppler clear air echos.

- Germann and Zawadzki (2002) adapted it to determine the velocity field of continental-scale radar composites.

Originally developed by Laroche and Zawadzki (1994)

“Spectral algorithms”

- A reflectivity image of dimension *L x L* pixels is spatially decomposed into an additive cascade of *n* levels.

$$dBZ_{i,j}(t) = \sum_{k=1}^{n} X_{k,i,j}(t), \qquad i = 1,\dots, L, \qquad j = 1,\dots, L \qquad L = 2^n$$

where dBZ = reflectivity in dB at pixel (i,j) at time t, X_k *in the cascade represents the variability of the original field with structures of scales between* $2^{-(k+1)}L$ *and* $2^{-k}L$ *pixels*

- Rainfall intensity **R** has a multiplicative structure, i.e. rainfields can be approximated by multiplying independent component processes at different scale.
- This multiplicative structure converts into a summation when taking logarithm.

Developed by Seed (2003)

“Spectral algorithms” *(Continued)*

- After decomposition, the evolution of the levels is considered separately.

- A feature rain rate image is then composed by the summation of the different levels, taking account their predict lifetime as weight.

- The levels with larger structures will have high correlation values with previous levels, and thus will dominate for large lead times.

“ Spectral algorithms”*(Continued)*

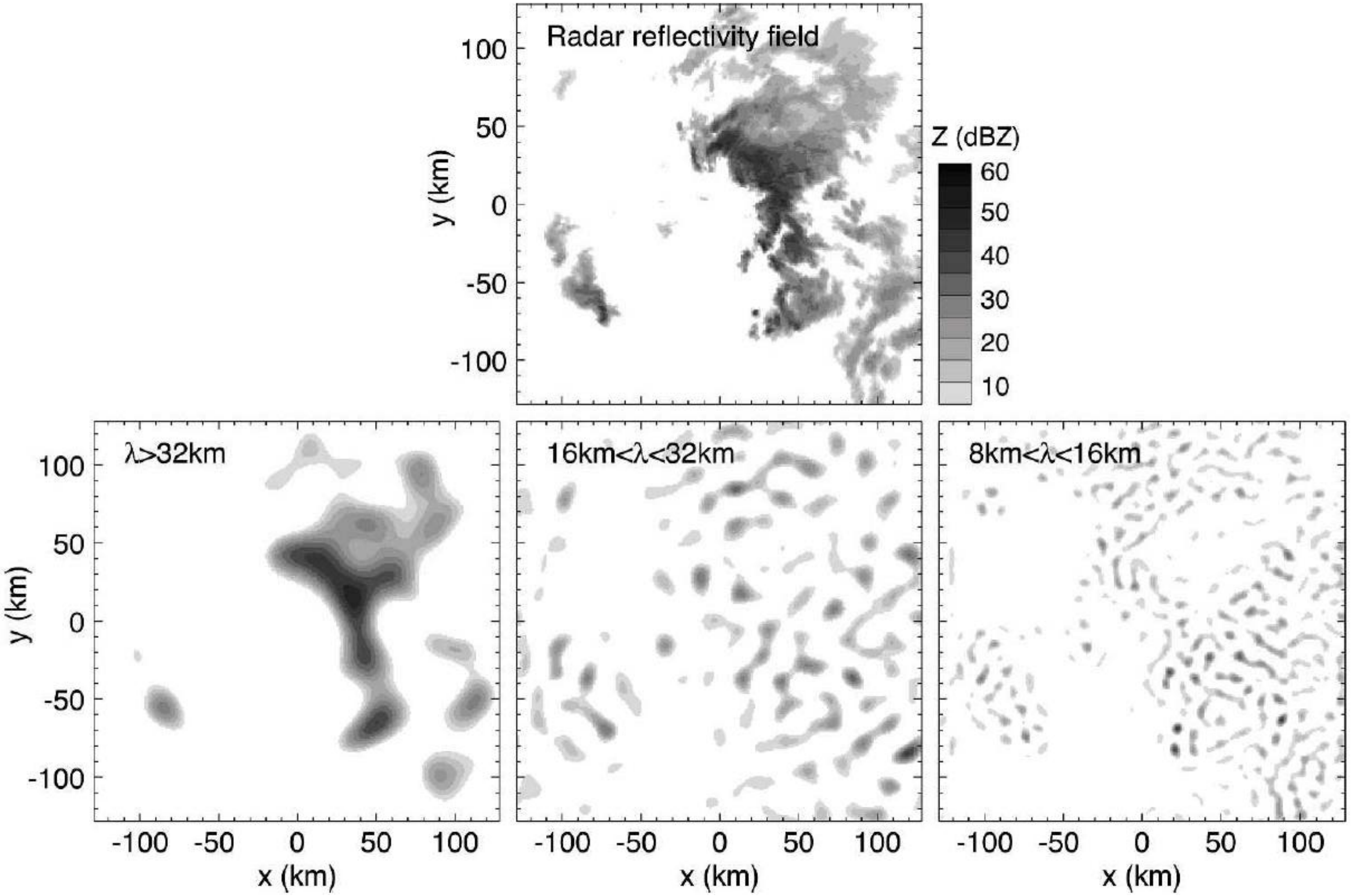


Illustration of the decomposition of a reflectivity field into a cascade of structures of different scales.

(Berenguer et al. 2008)

Problem of “*Spectral Algorithms*”

- Presence of periodic structures in the smallest scale, “ *Gibbs effect* ”. Avoid by using local spectral decompositions such as “*wavelets*”.

- Spectral algorithms do not provide an advection procedure on their own. Different levels of the cascade have to be advected by an additional procedure, i.e., *STEPS* uses the spectral decomposition of *S-PROG* and uses area tracker *COTRAC* as the advection scheme.

Operational and Research QPF systems

- AMV – Finland
- ANC – U.S. (most complex nowcasting system)
- CARDS – Canada
- Czech system
- GANDOLF – UK
- INCA and GaliMet – Austria
- MAPLE – Canada
- NIMROD – U.K.
- RadViL – France

- S-PROG – Australia
- S-PROG – Spain
- STEPS – U.K., Australia (Probabilistic QPF scheme)
- SWIRLS – Hong Kong (concentrate on heavy precipitation event)
- TRT - Switzerland

Recent developments and experiments

- ANN approach
- Multiple regression models
- K-Means clustering for segmentation
- Kalman filtering for smoothing
- WSDD-II

QPF Accuracy assessment

QPF Verification Statistics

		Observed	
		yes	no
Forecast	yes	hits	false alarms
	no	misses	correct negatives

Several verification statistics can be calculated with such a table, e.g.

$$\text{POD} = \text{probability of detection} = \frac{\text{hits}}{\text{hits} + \text{misses}}$$

$$\text{FAR} = \text{false alarm ratio} = \frac{\text{false alarms}}{\text{hits} + \text{false alarms}}$$

$$\text{CSI} = \text{critical success index} = \frac{\text{hits}}{\text{hits} + \text{misses} + \text{false alarms}}$$

An example of a more advanced score is the Heidke skill score (HSS):

$$\text{HSS} = \frac{(\text{hits + correct negatives}) - (\text{expected correct})_{\text{random}}}{N - (\text{expected correct})_{\text{random}}}$$

where

$$(\text{expected correct})_{\text{random}} = \frac{1}{N}\left[(\text{hits + misses})(\text{hits + false alarms}) + (\text{correct negatives} + \text{misses})(\text{correct negatives + false alarm})\right]$$

Bangkok rainfall forecasting system : An operational radar and RTC application

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hydro & meteo GmbH & Co. KG, Germany

Kannika Pahonepipat
Asdecon Corporation Co., Ltd., Thailand

einfalt & hydrotec GbR
Wetter + Wasser

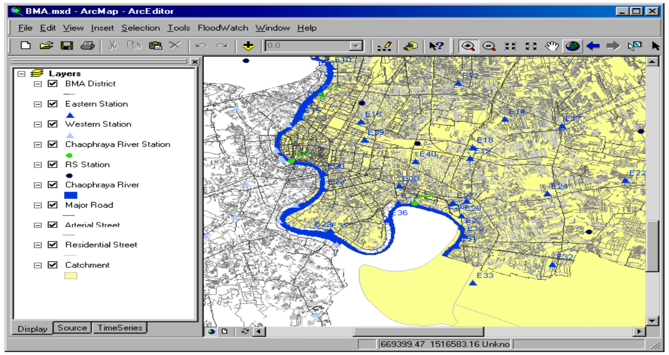
Outline

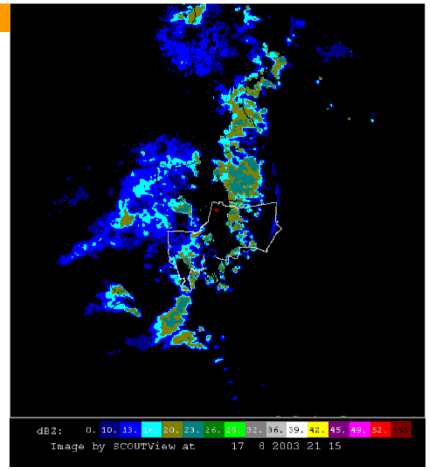
- Bangkok flood forecasting system
- Bangkok rainfall forecasting system
- Data availability and data quality
- Radar rainfall measurement
- Radar rainfall forecasting : What you can expect and what you can not expect?
- Conclusion

Department of Drainage and Sewerage (DDS)
Bangkok Metropolitan Administration (BMA)

FLOOD FORECASTING AND MANAGEMENT SYSTEM

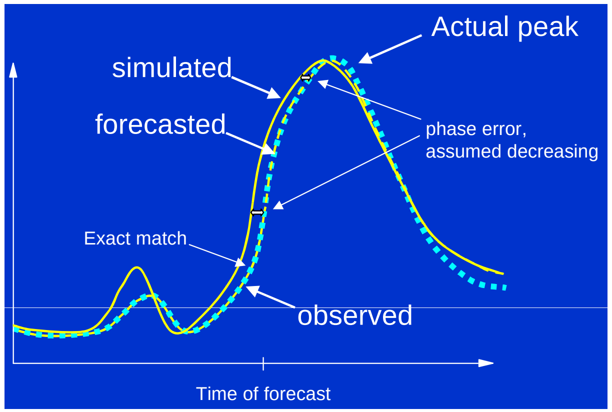
REAL TIME TELEMETRY





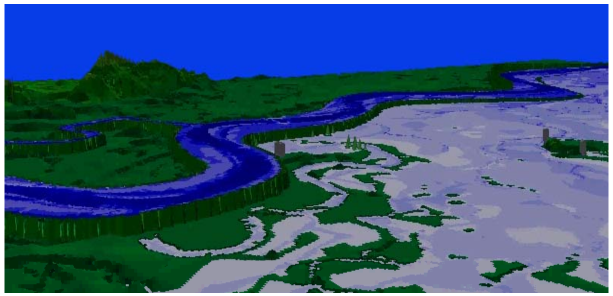
SCOUT RAINFALL FORECAST

FLOODWATCH



MIKE 11

DISSEMINATION

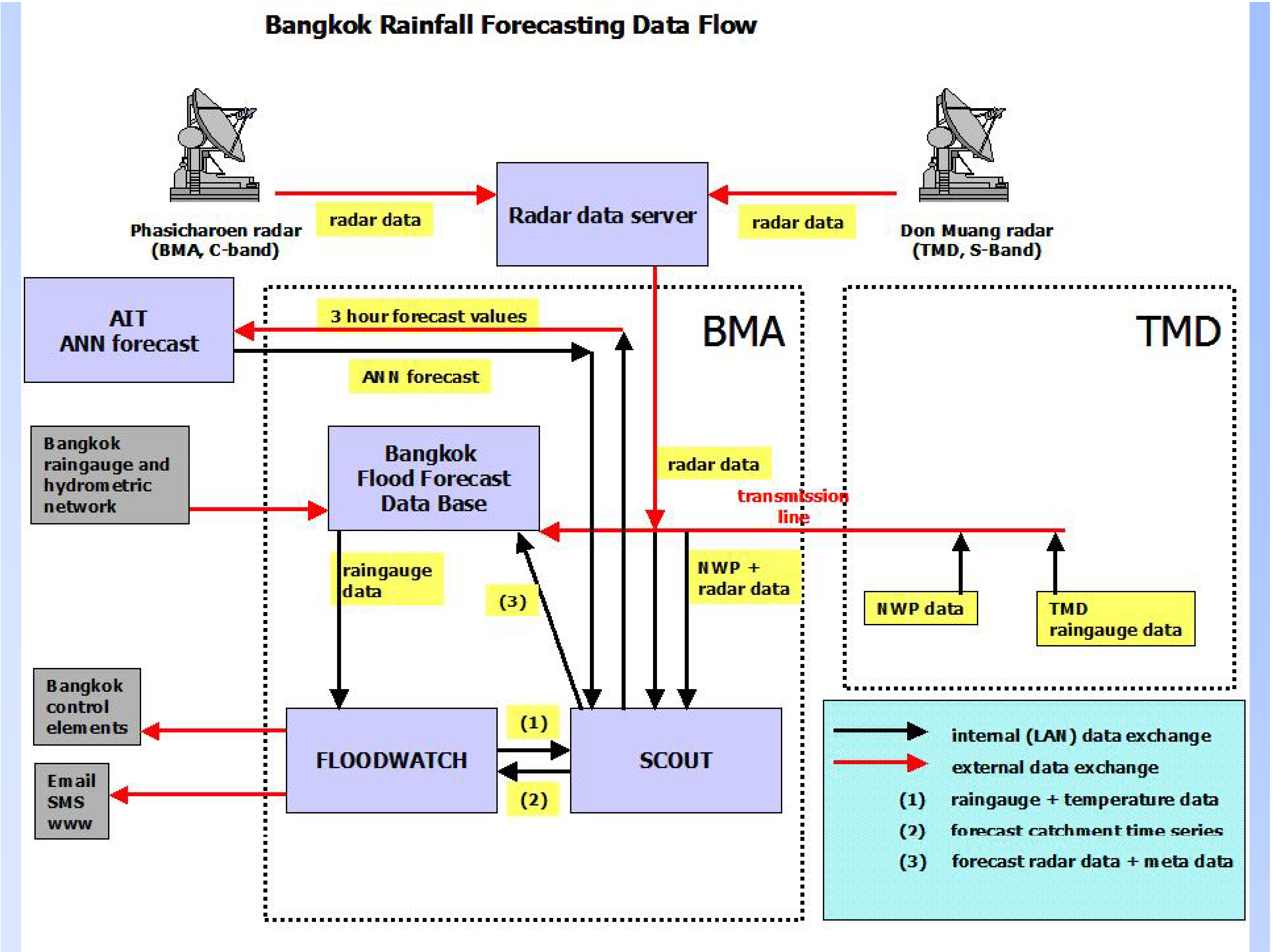


MIKE 11 GIS FLOOD MAPPING

BKK rainfall forecasting system

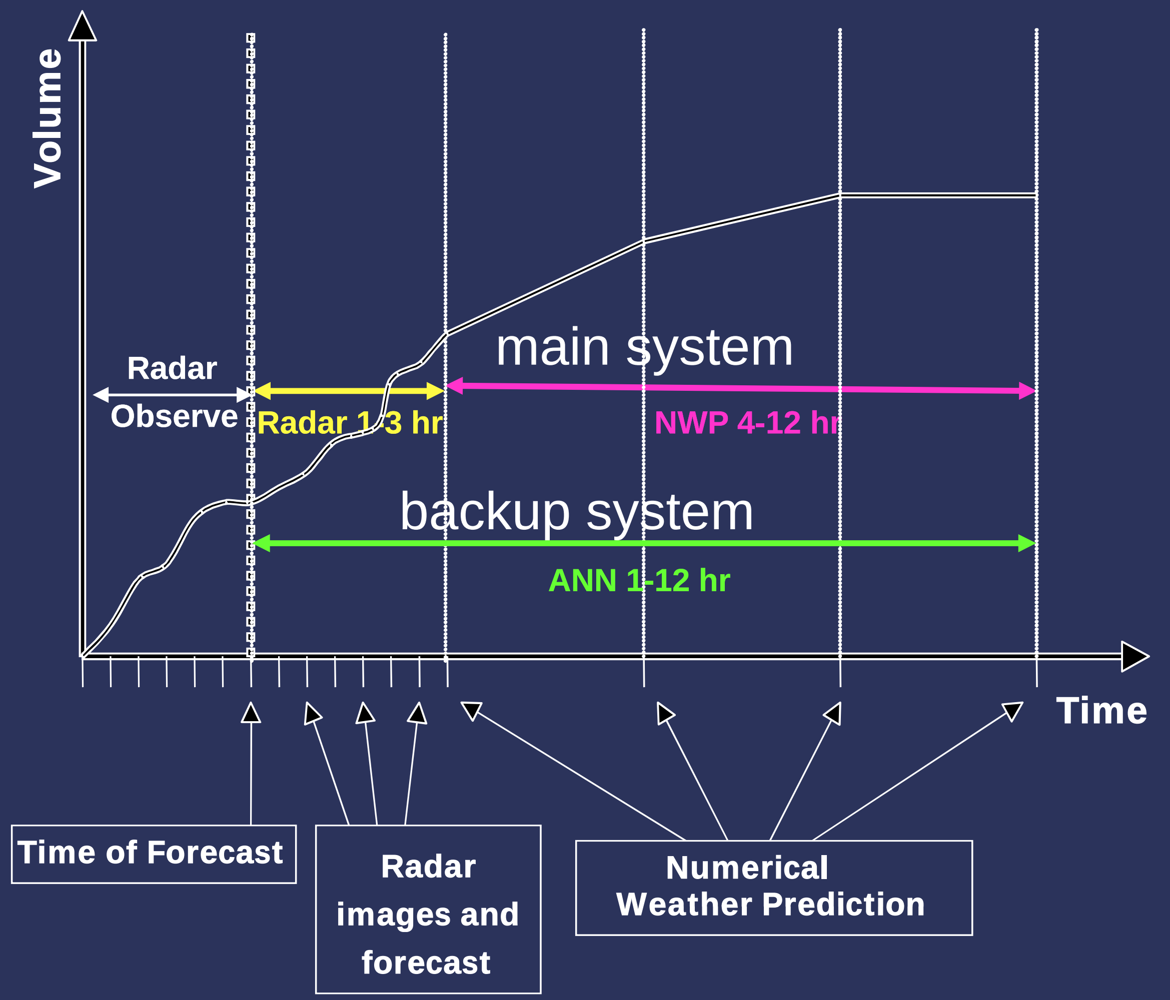
Objectives:

- Prepare rainfall information for the FLOODWATCH water level forecast
- Prepare rainfall information for the web
- Provide warning information in real time



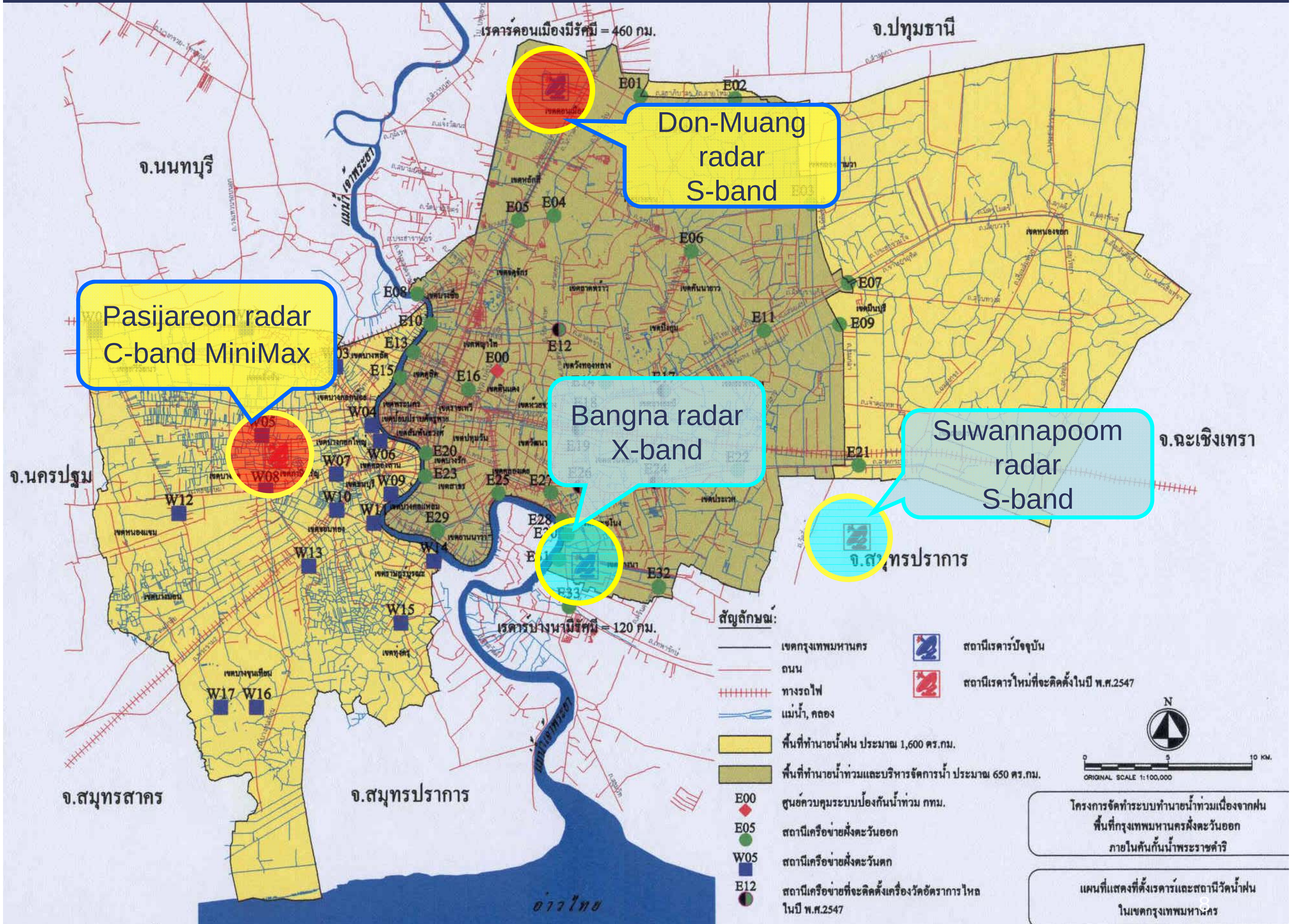
Bangkok Rainfall Forecasting Data Flow
Phasicharoen radar (BMA, C-band)
radar data
Radar data server
radar data
Don Muang radar (TMD, S-Band)
AIT ANN forecast
3 hour forecast values
ANN forecast
BMA
TMD
Bangkok raingauge and hydrometric network
Bangkok Flood Forecast Data Base
radar data
transmission line
raingauge data
(3)
NWP + radar data
NWP data
TMD raingauge data
Bangkok control elements
Email SMS www
FLOODWATCH
(1)
(2)
SCOUT
internal (LAN) data exchange
external data exchange
(1) raingauge + temperature data
(2) forecast catchment time series
(3) forecast radar data + meta data

Forecast combination



Data availability

- Raingauges
  - 61 from BMA
  - 50 from TMD
- Radar
  - Don Muang S-Band radar
  - Phasicharoen C-Band radar
- Numerical Weather prediction
  - From TMD
- ANN forecast (AIT)

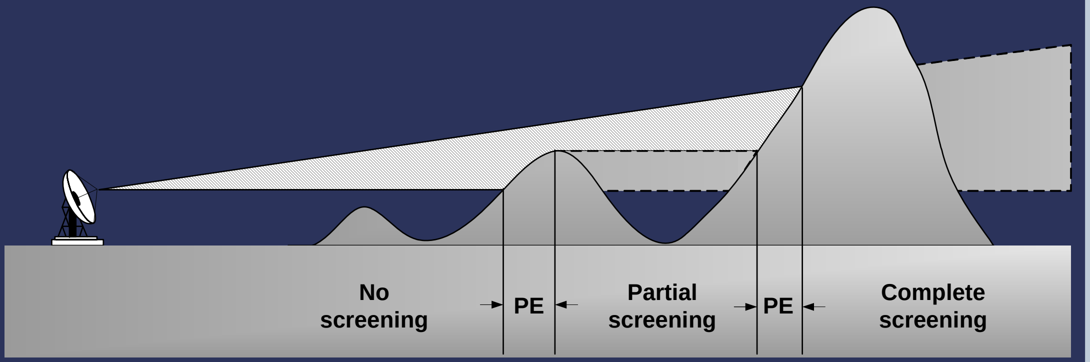


Don-Muang radar S-band
Pasijareon radar C-band MiniMax
Bangna radar X-band
Suwannapoom radar S-band
เรดาร์ดอนเมืองมีรัศมี = 460 กม.
เรดาร์บางนามีรัศมี = 120 กม.
จ.ปทุมธานี
จ.นนทบุรี
จ.นครปฐม
จ.ฉะเชิงเทรา
จ.สมุทรปราการ
จ.สมุทรสาคร
อ่าวไทย
สัญลักษณ์:
เขตกรุงเทพมหานคร
ถนน
ทางรถไฟ
แม่น้ำ, คลอง
พื้นที่ทำนายน้ำฝน ประมาณ 1,600 ตร.กม.
พื้นที่ทำนายน้ำท่วมและบริหารจัดการน้ำ ประมาณ 650 ตร.กม.
E00 ศูนย์ควบคุมระบบป้องกันน้ำท่วม กทม.
E05 สถานีเครือข่ายฝั่งตะวันออก
W05 สถานีเครือข่ายฝั่งตะวันตก
E12 สถานีเครือข่ายที่จะติดตั้งเครื่องวัดอัตราการไหล ในปี พ.ศ.2547
สถานีเรดาร์ปัจจุบัน
สถานีเรดาร์ใหม่ที่จะติดตั้งในปี พ.ศ.2547
ORIGINAL SCALE 1:100,000
โครงการจัดทำระบบทำนายน้ำท่วมเนื่องจากฝน พื้นที่กรุงเทพมหานครฝั่งตะวันออก ภายในคันกั้นน้ำพระราชดำริ
แผนที่แสดงที่ตั้งเรดาร์และสถานีวัดน้ำฝน ในเขตกรุงเทพมหานคร

Radar rainfall estimation

1. Reflectivity measurement error

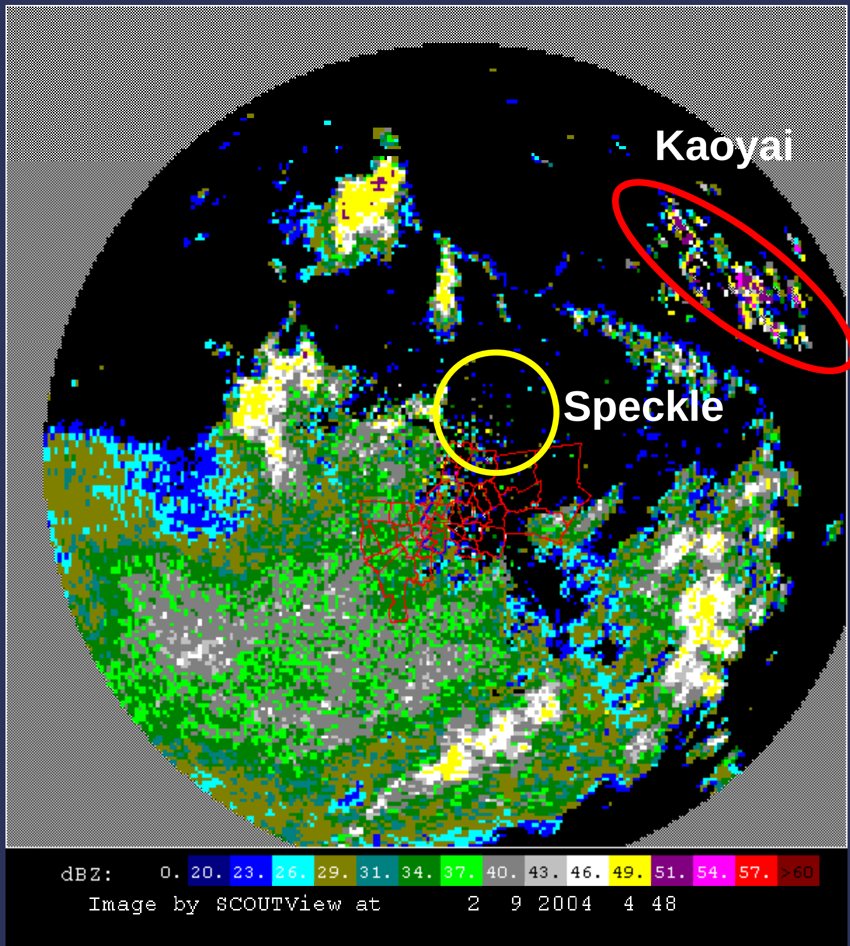
- ground clutter
- attenuation
- vertical reflectivity profile
- beam geometry



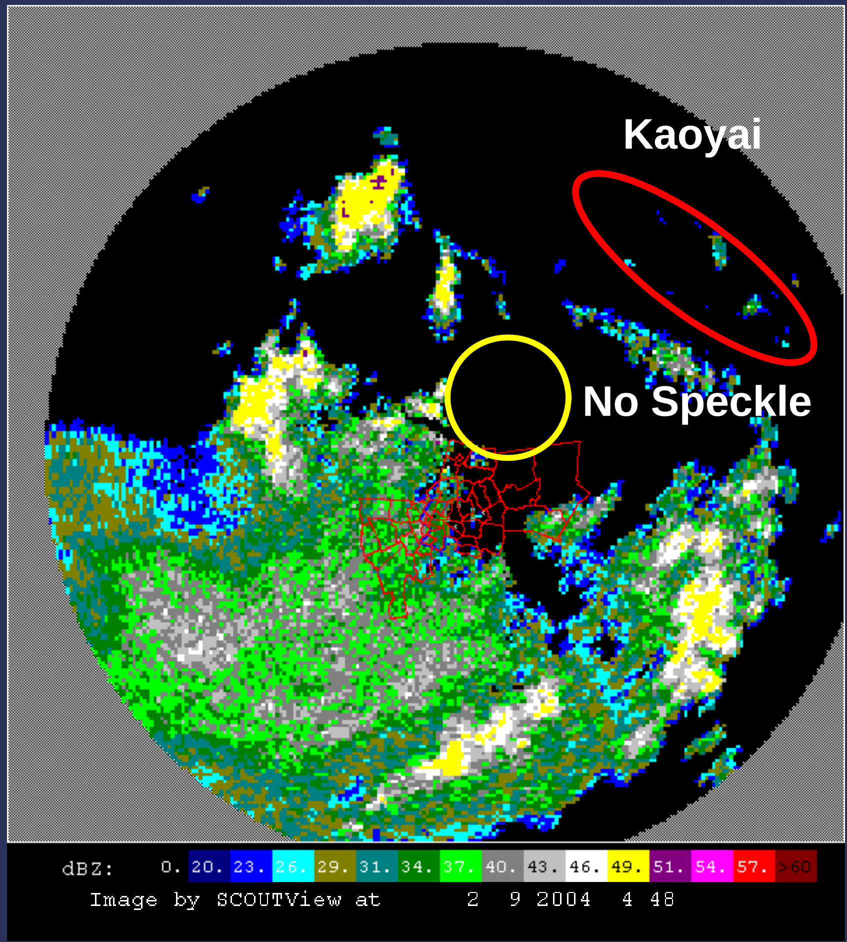
2. Z-R conversion error

3. Residual errors when compared with raingauges

Data correction

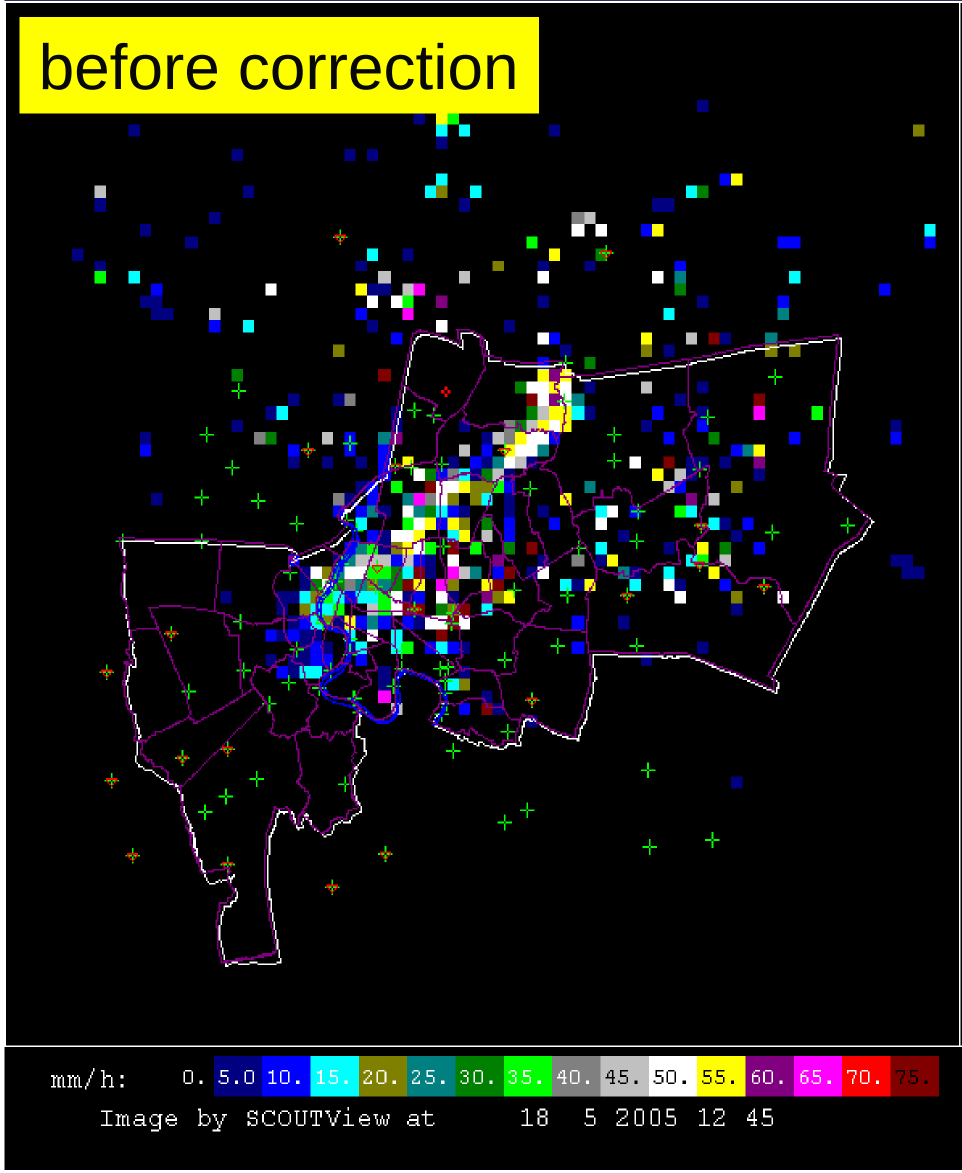


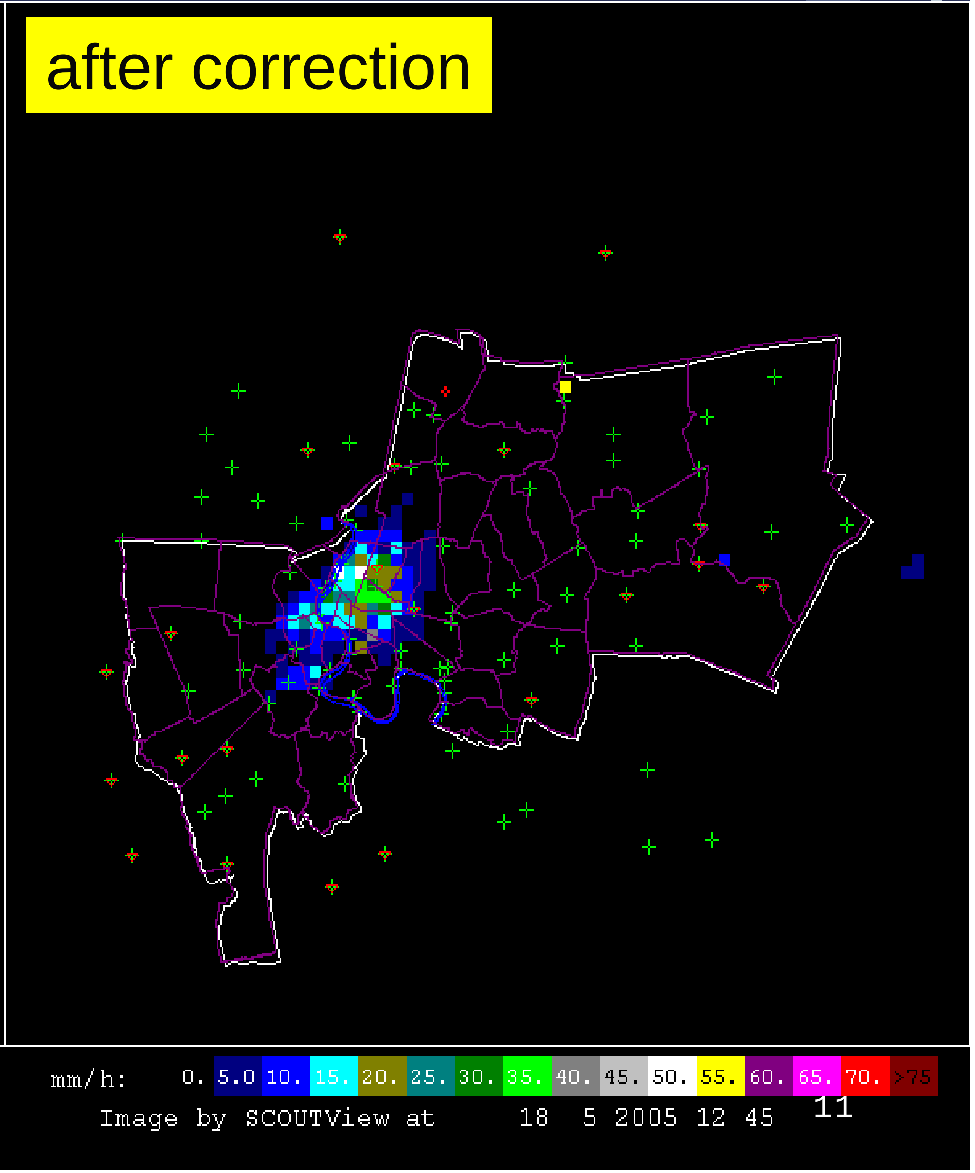
before



after

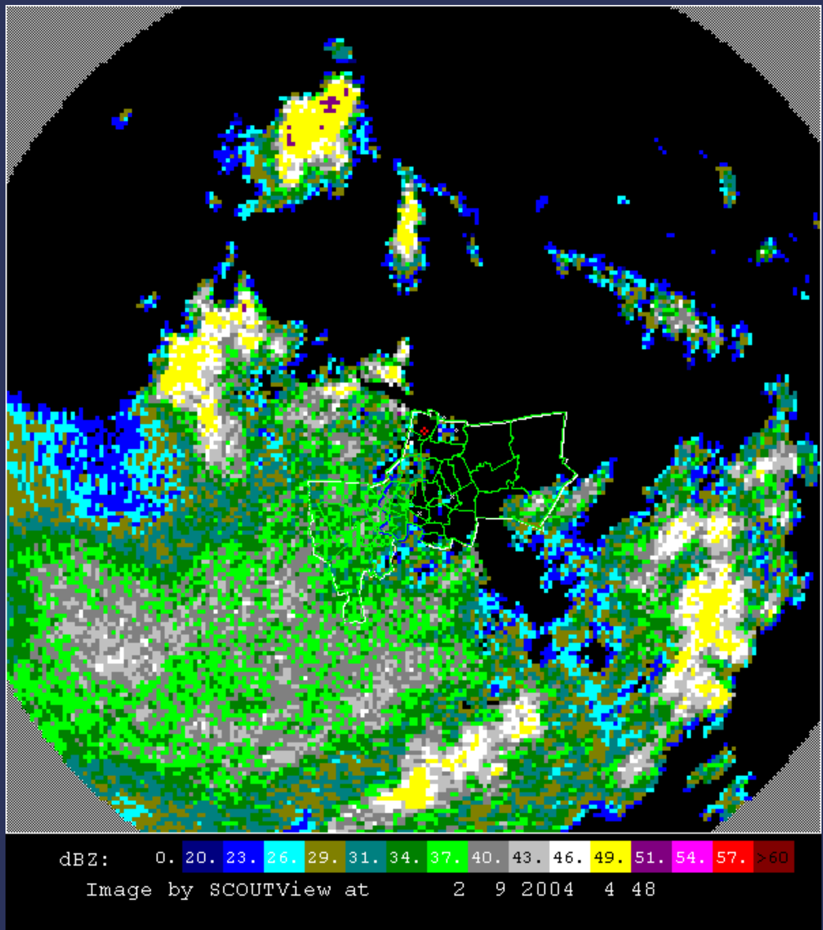
Data correction



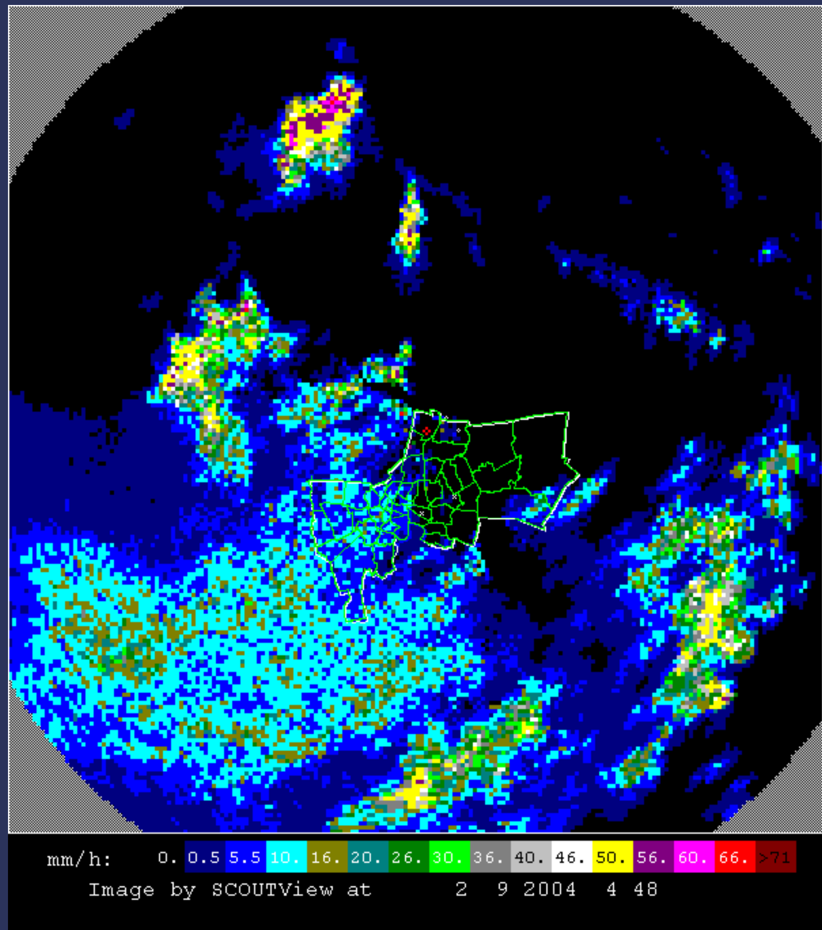


Z-R conversion

Radar reflectivity

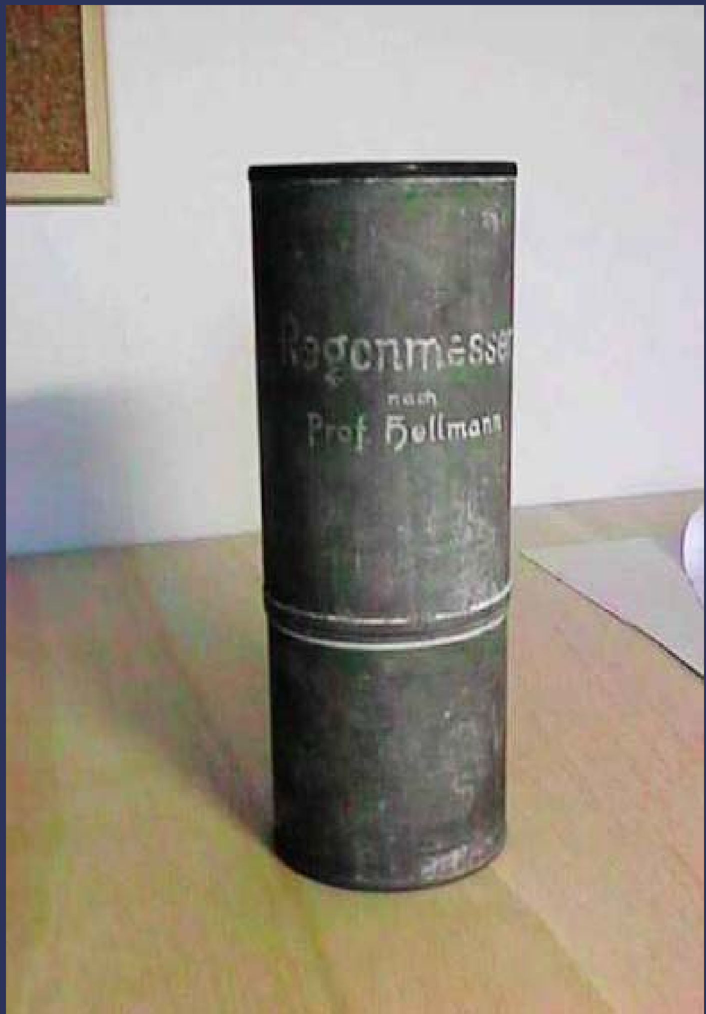


Rainfall rate



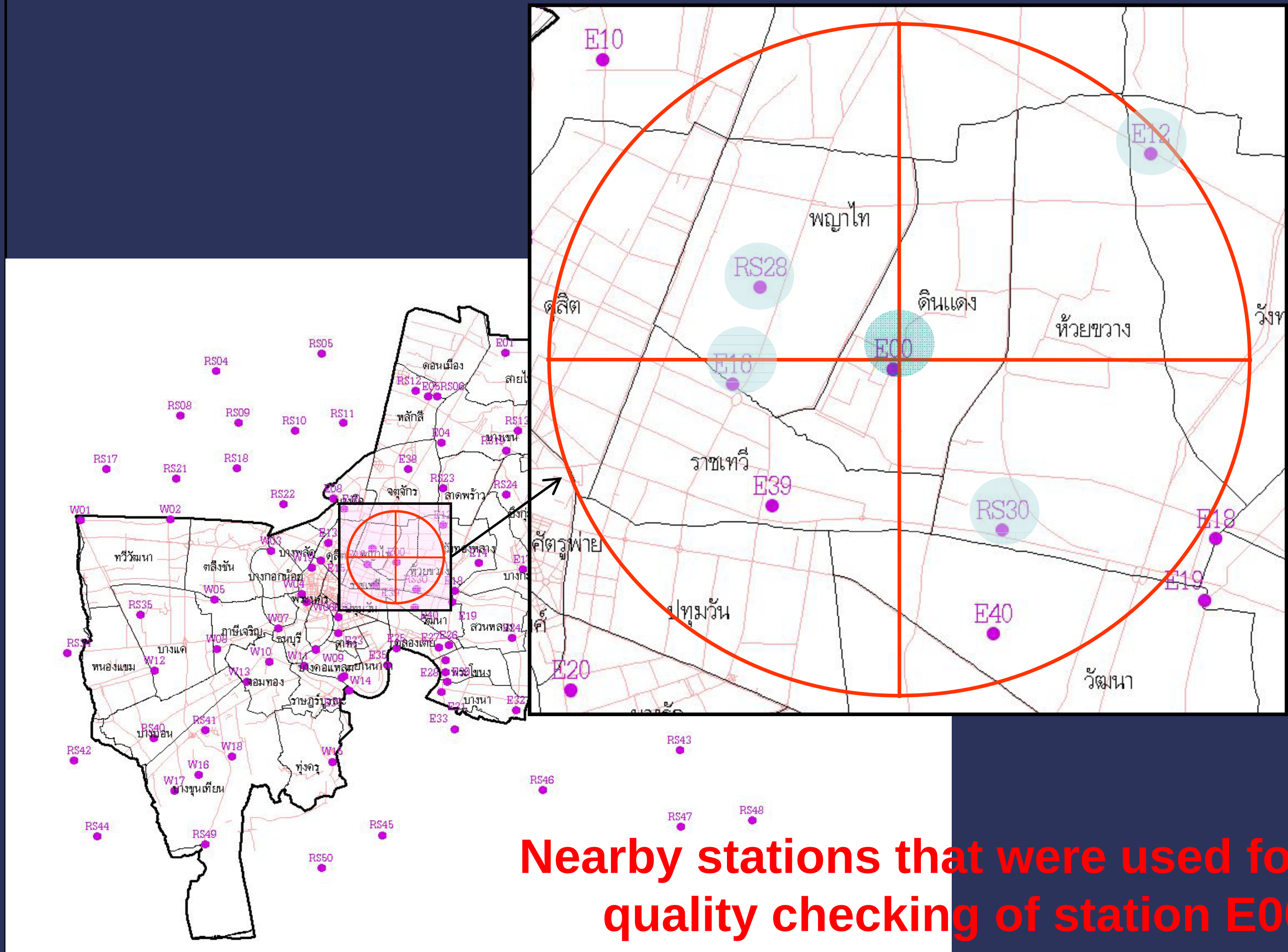
$$Z = 200R^{1.6}$$

Bias adjustment



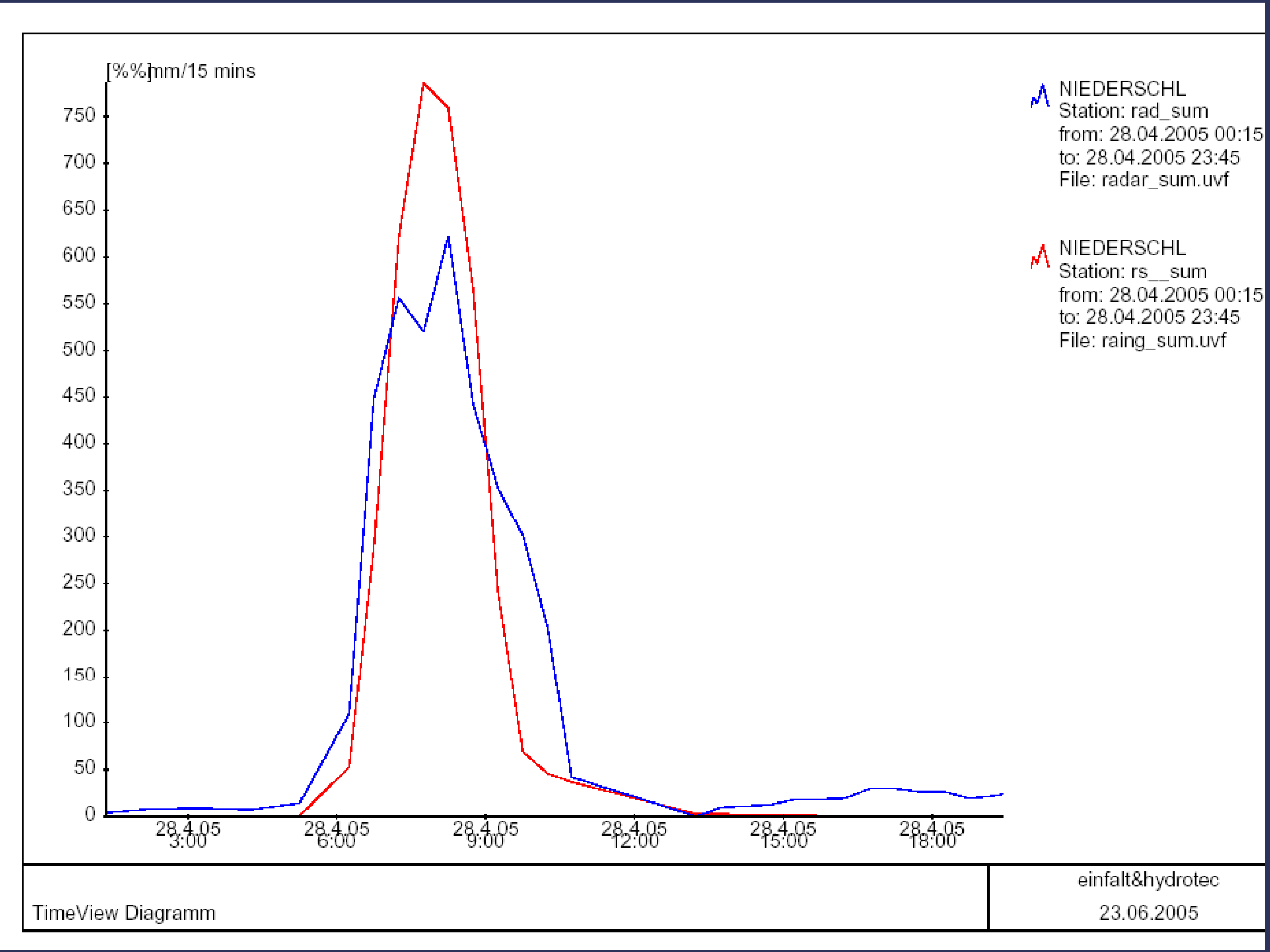
? =

Rain gauge quality control (NASS)



Nearby stations that were used for quality checking of station E00

Radar Vs rain gauge



Bias adjustment factors

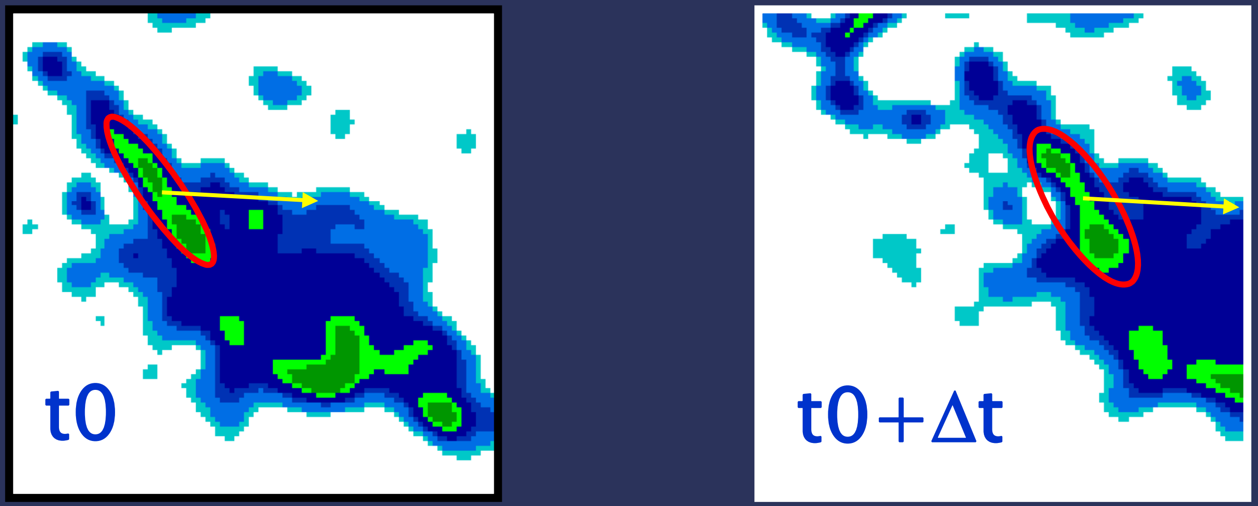
- **Don Muang Radar**

Radar rainfall = 1.3 x initial radar rainfall estimates

- **Pasijareon Radar**

Radar rainfall = 4 x initial radar rainfall estimates

SCOUT[1] forecasting scheme



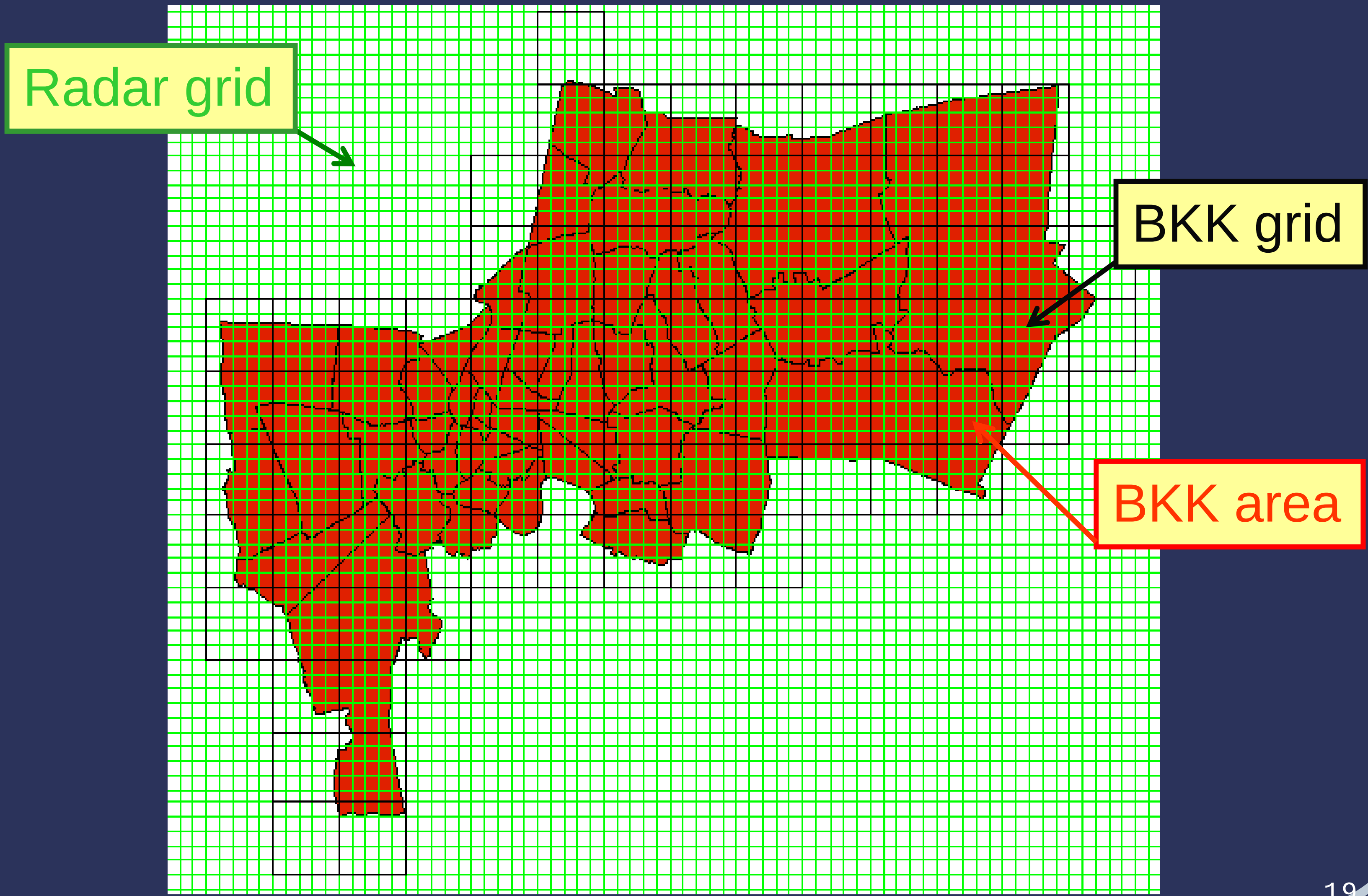
- identification of rainfields
- characterisation of rainfields
- recognition of rainfields
- analysis of past rainfield dynamics
- extrapolation of dynamics into the future
- assessment of forecast accuracy

[1]Developed by hydro & meteo GmbH & Co. KG

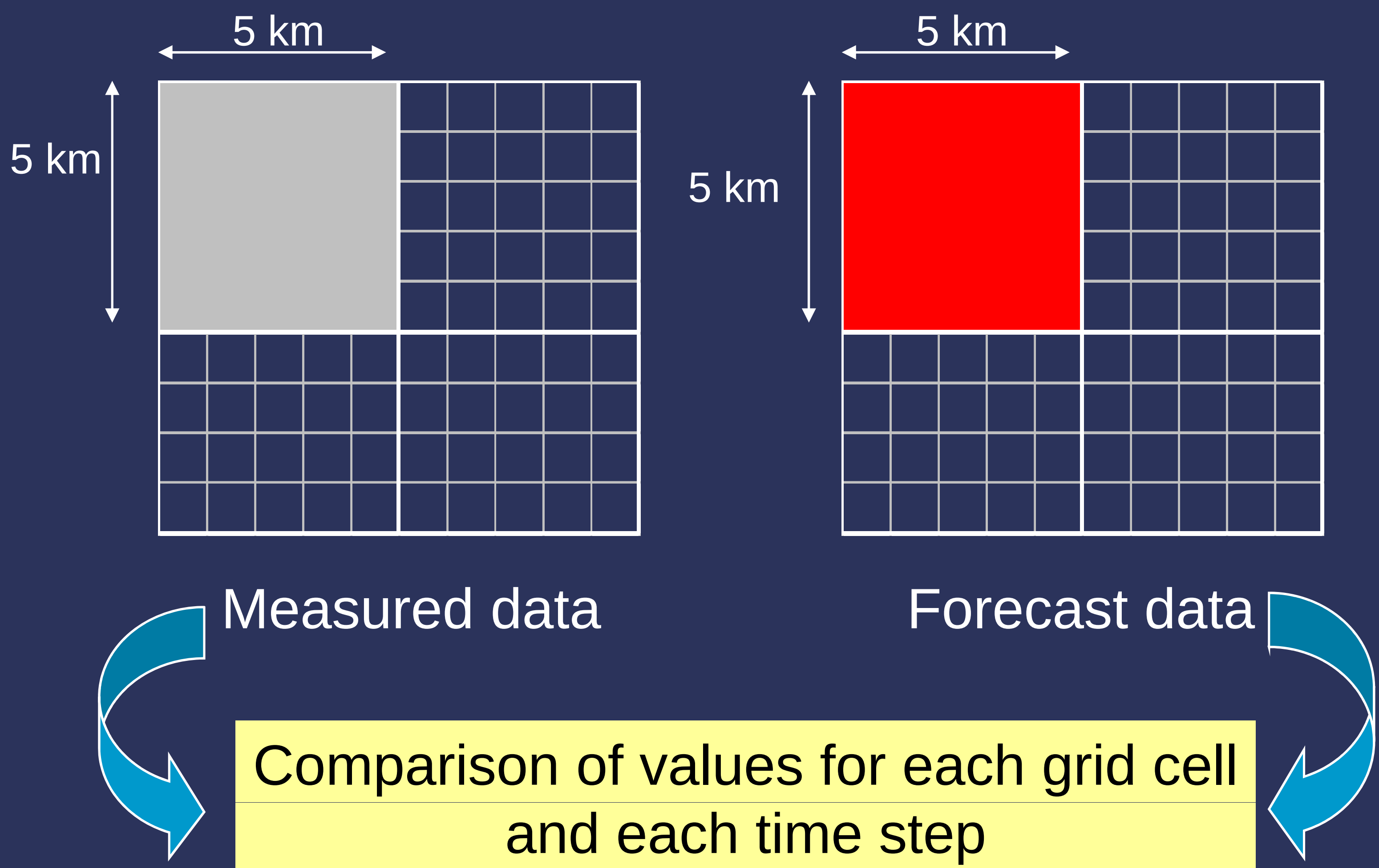
Forecast Quality

- Check on values (mm or intensities)
- Check on location
- Check on correct timing

Forecast accuracy



Accuracy measurement



Comparison of values for each grid cell and each time step

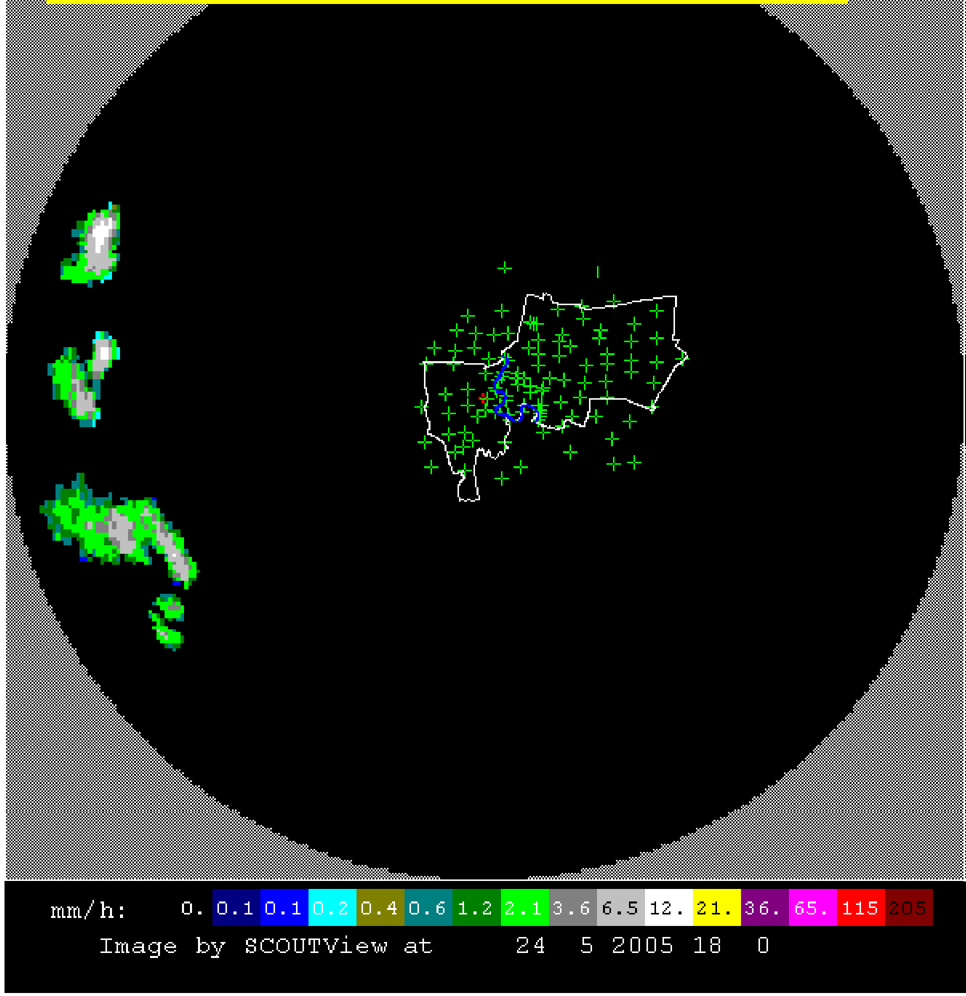
Radar based forecast

- Example 1:

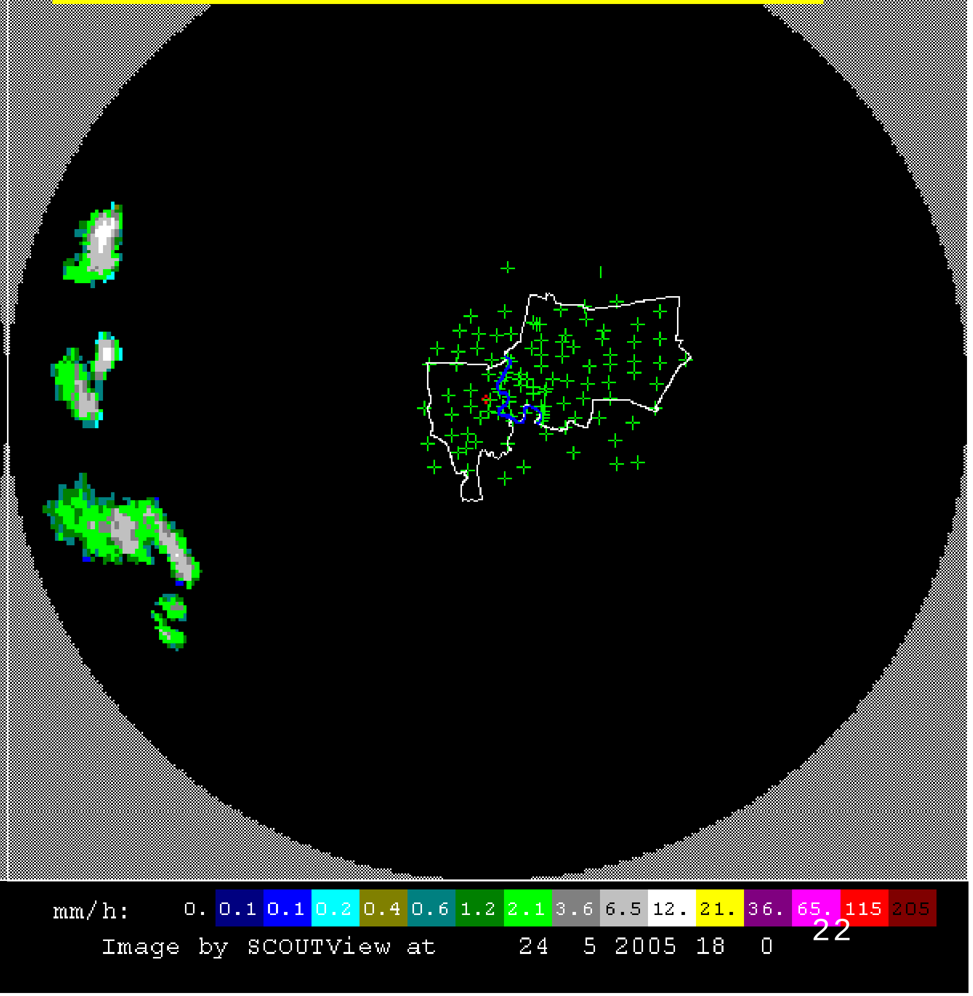
  (5 minute time step)

Forecast 0 hours ahead

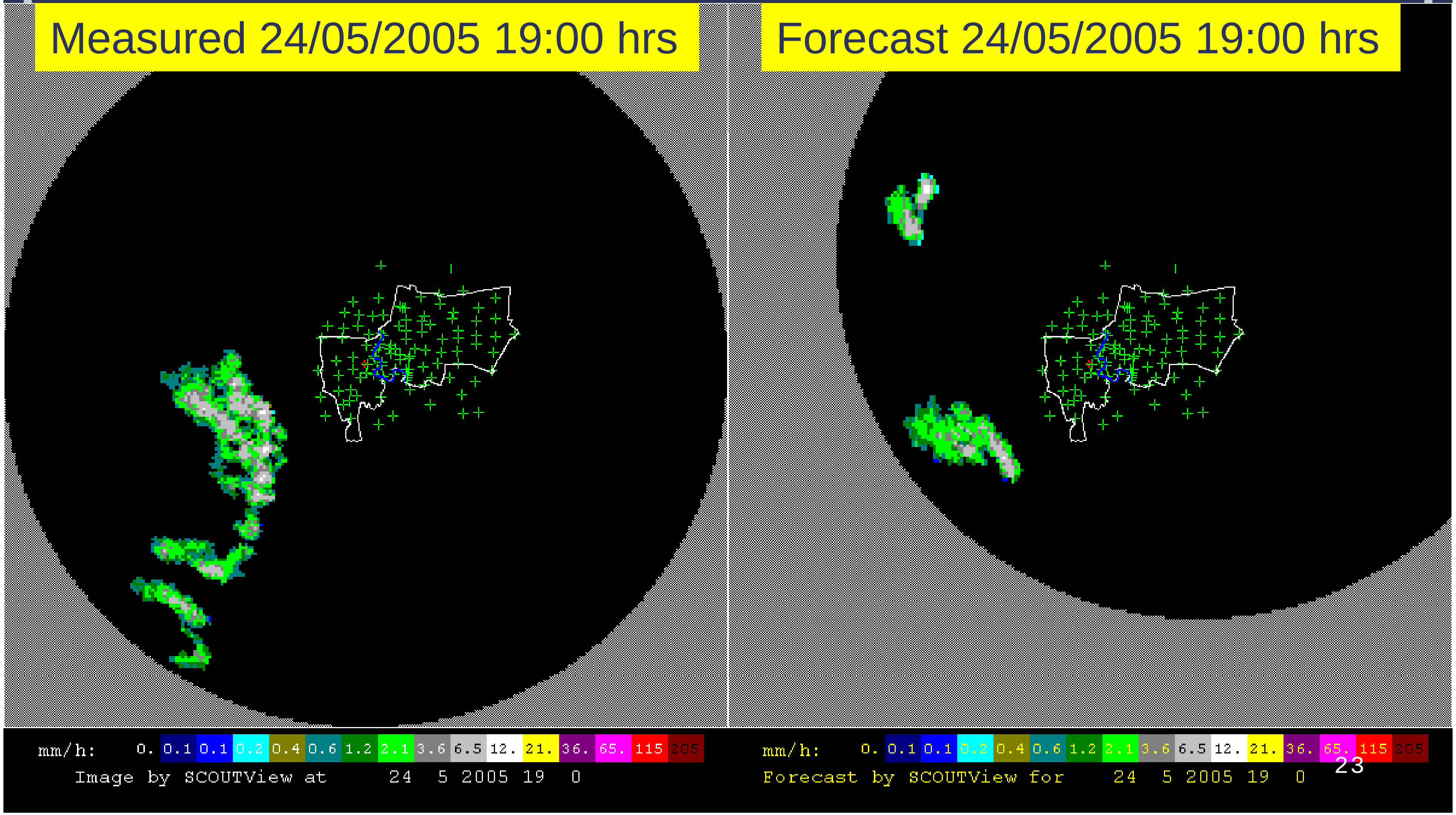
Measured 24/05/2005 18:00 hrs



Forecast 24/05/2005 18:00 hrs

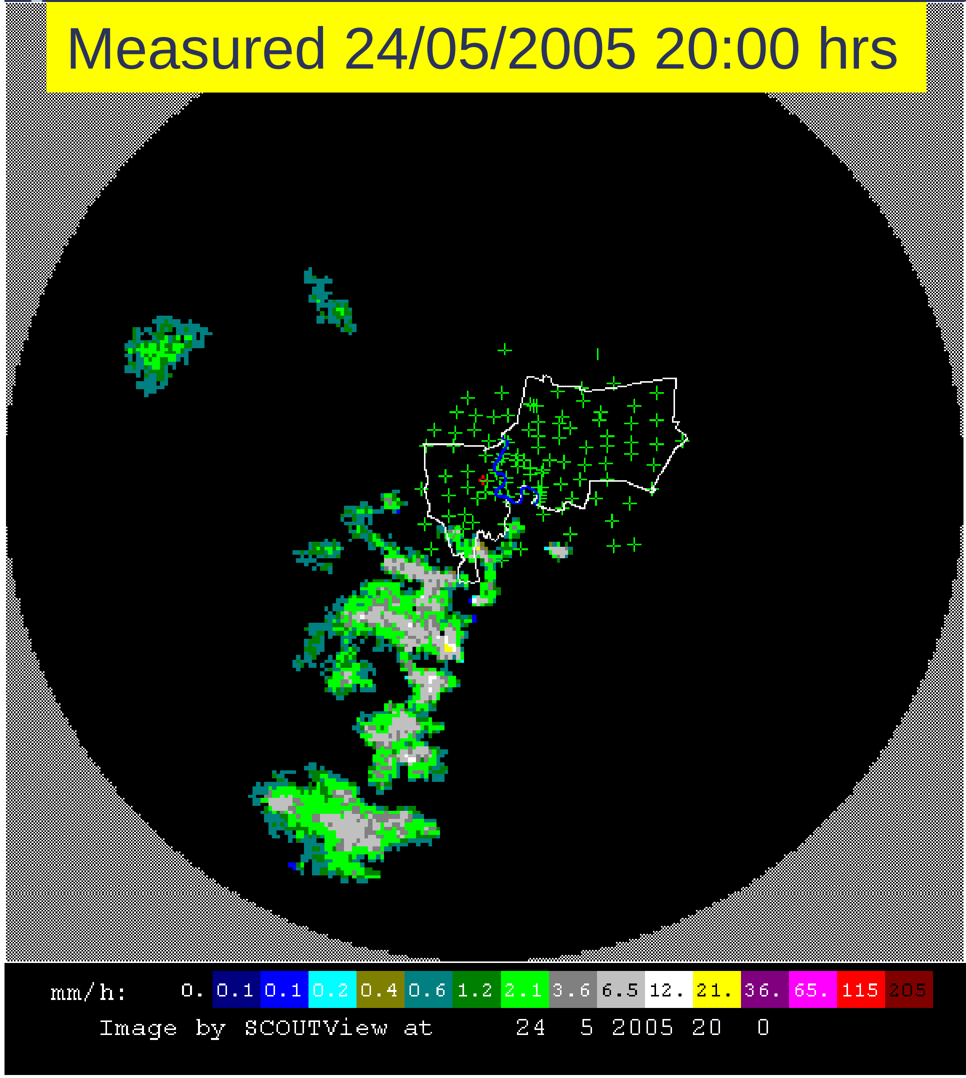


Forecast 1 hour ahead

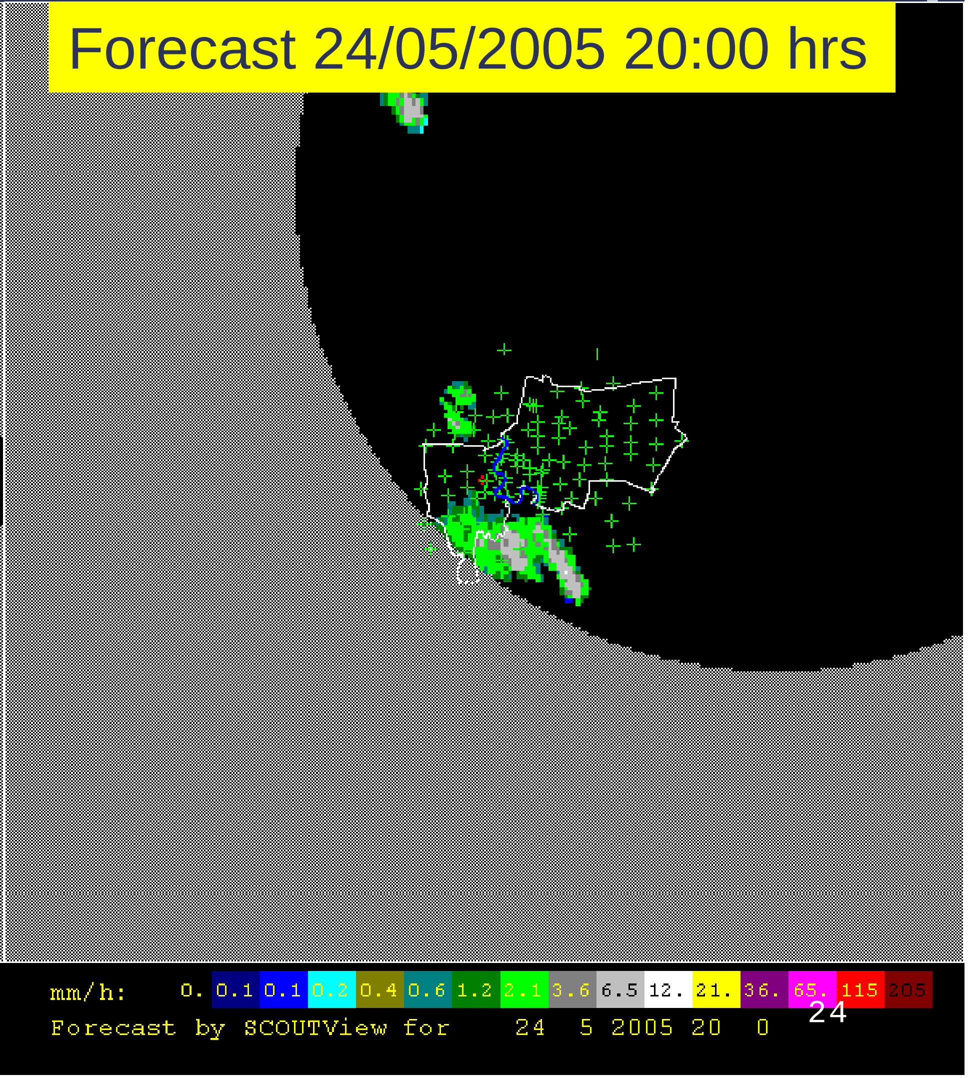


Forecast 2 hours ahead

Measured 24/05/2005 20:00 hrs

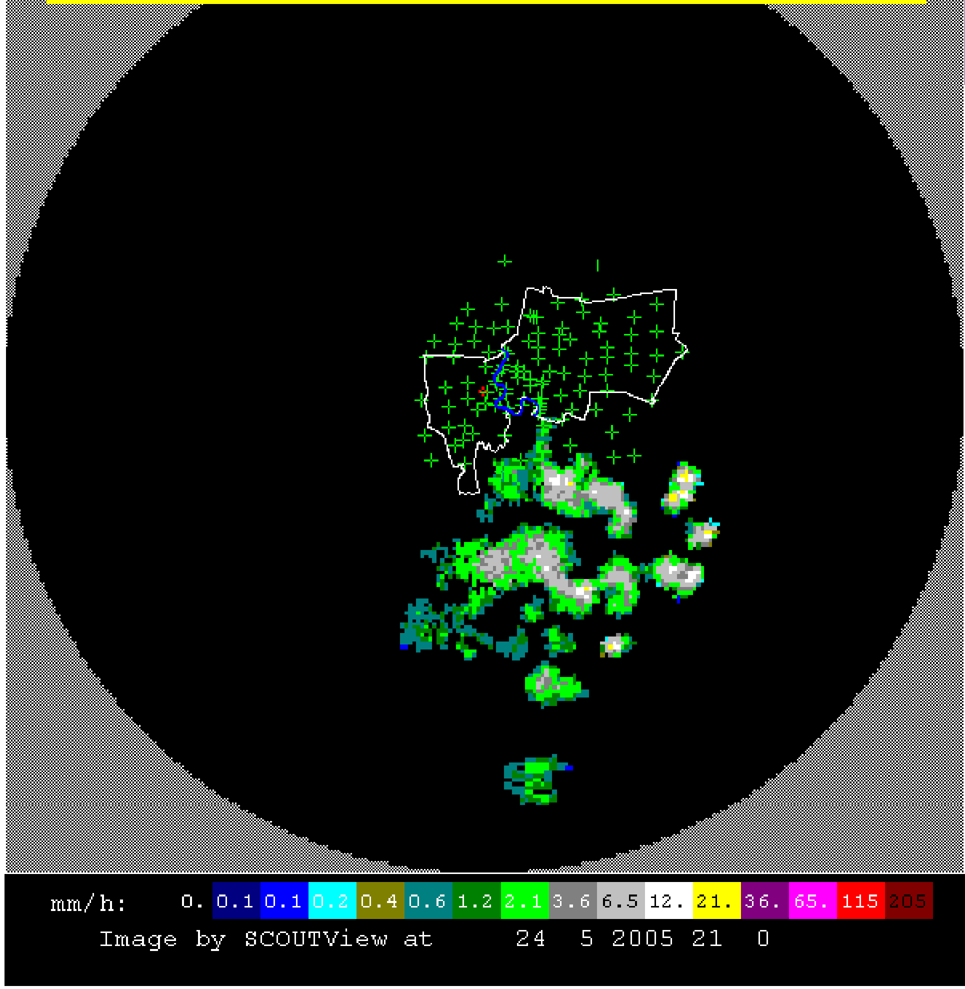


Forecast 24/05/2005 20:00 hrs

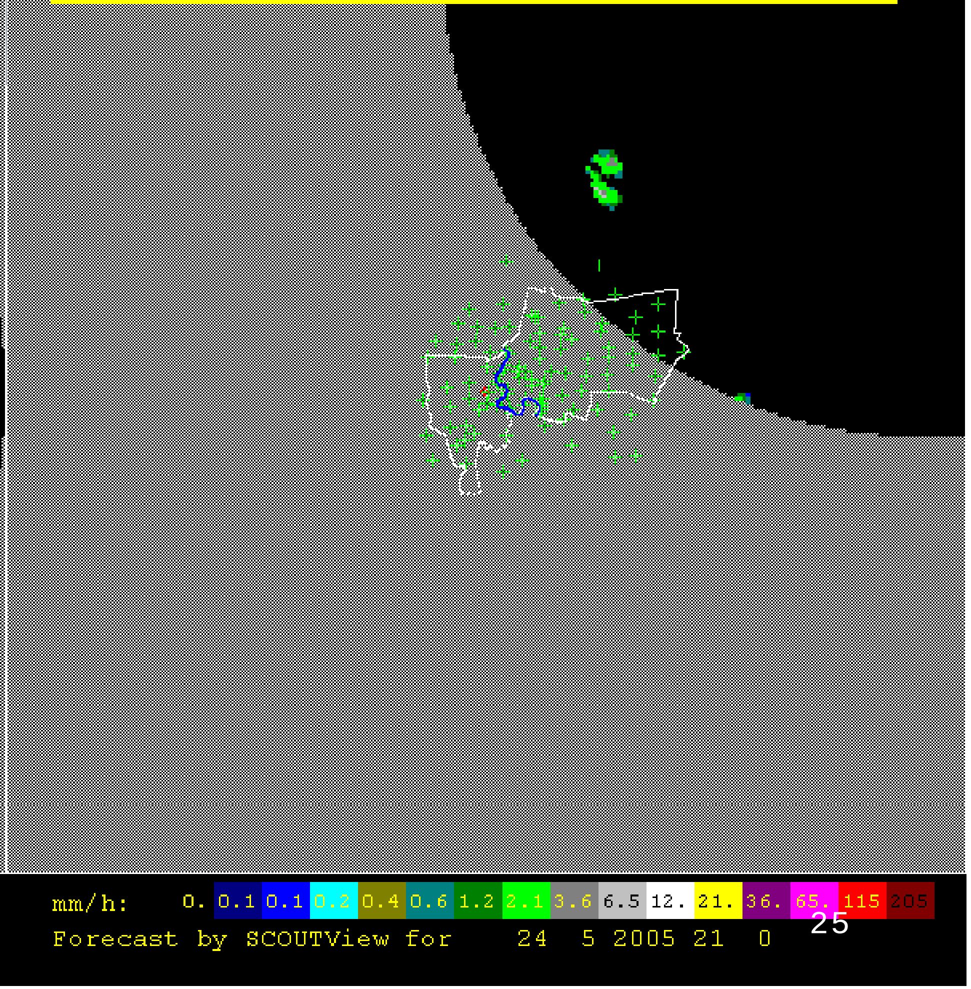


Forecast 3 hours ahead

Measured 24/05/2005 21:00 hrs



Forecast 24/05/2005 21:00 hrs



Radar based nowcast

What can we see?

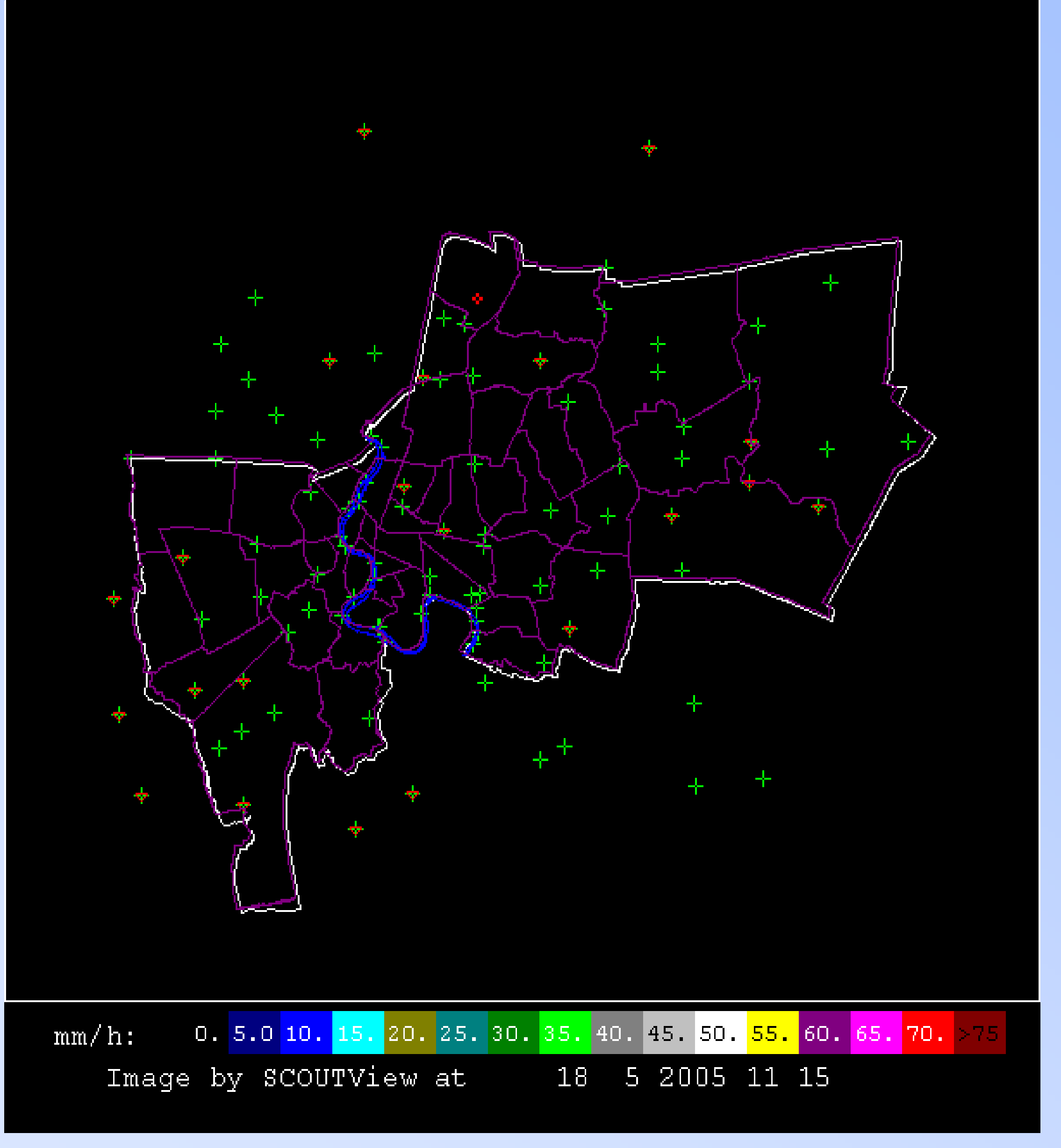
- A short time step between images shows well the rainfall behaviour
- The speed and direction of the rainfields can be well estimated with these images
- The estimation of the development of rainfields is much more difficult

Radar based forecast

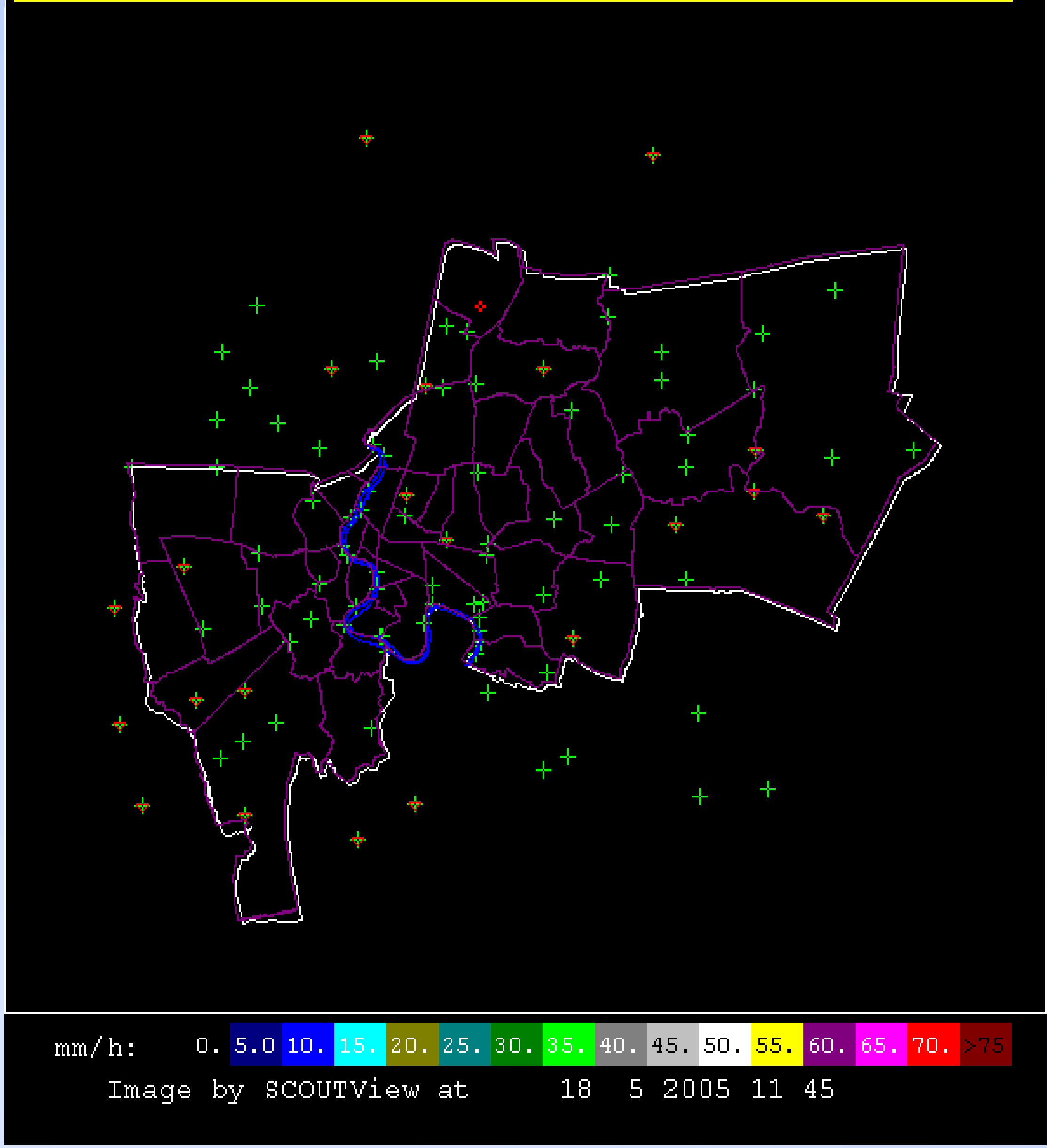
- Example 2:

  (30 minute time step)

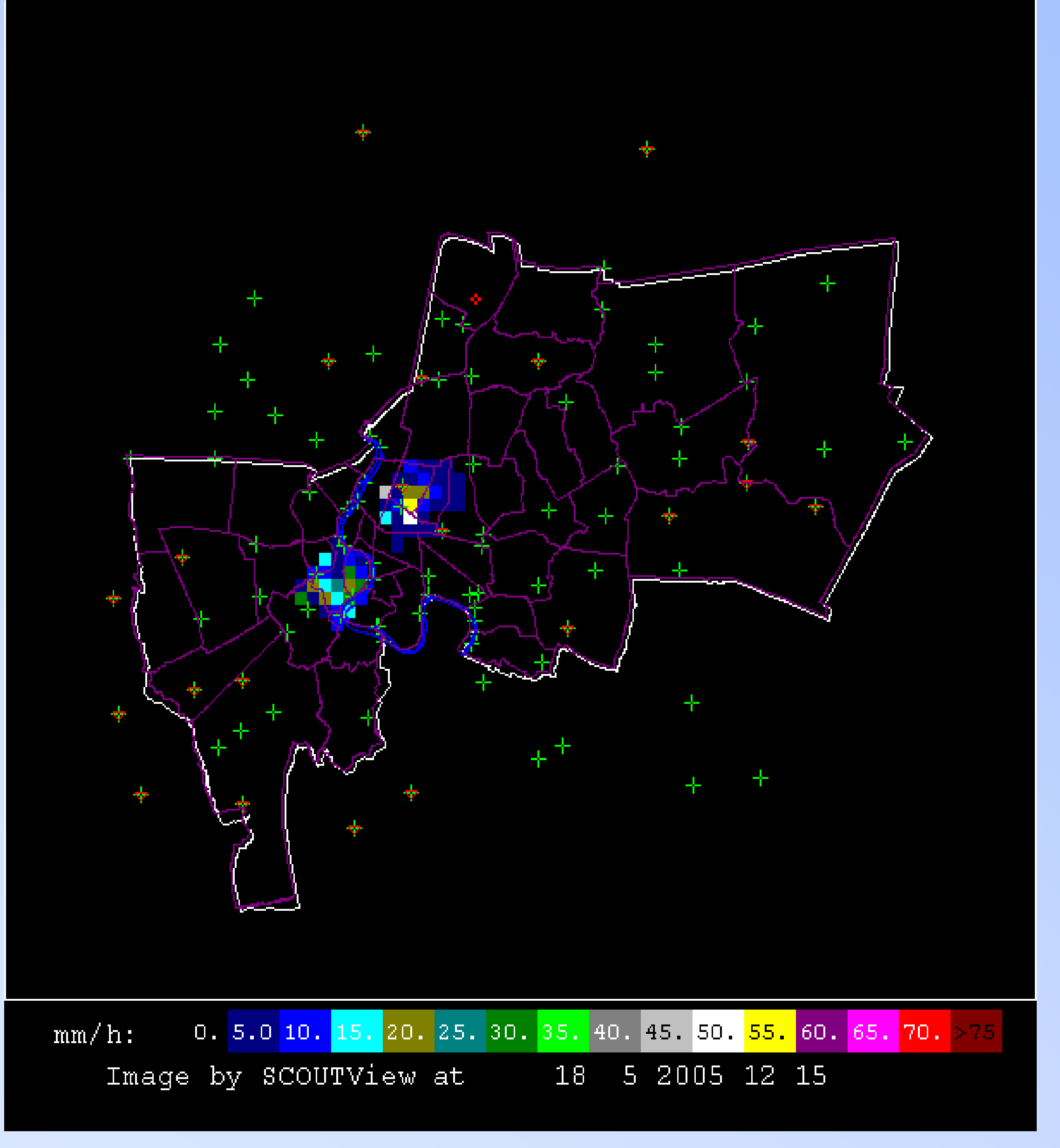
Example 18/05/2005 11:15 hrs



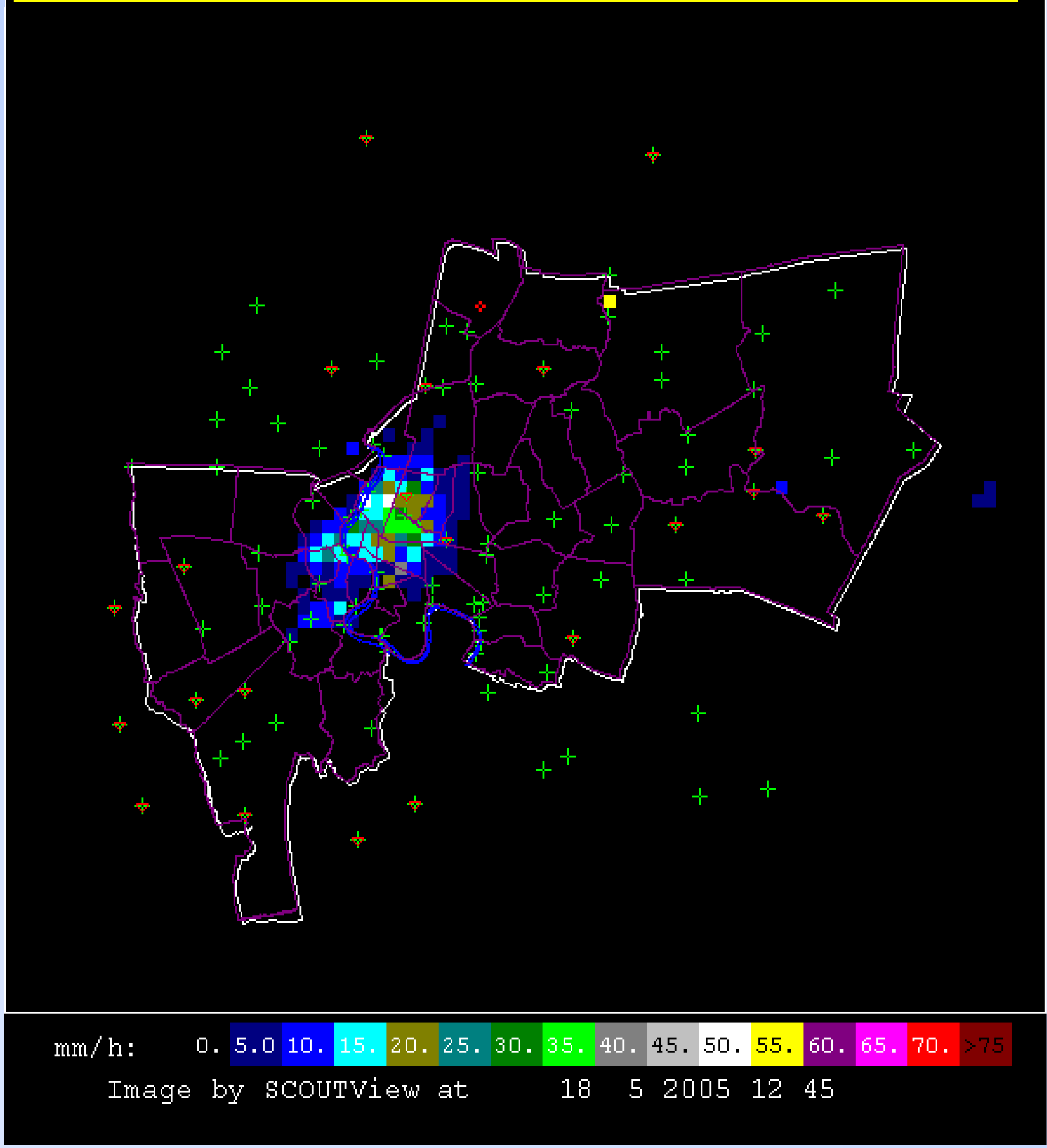
Example 18/05/2005 11:45 hrs



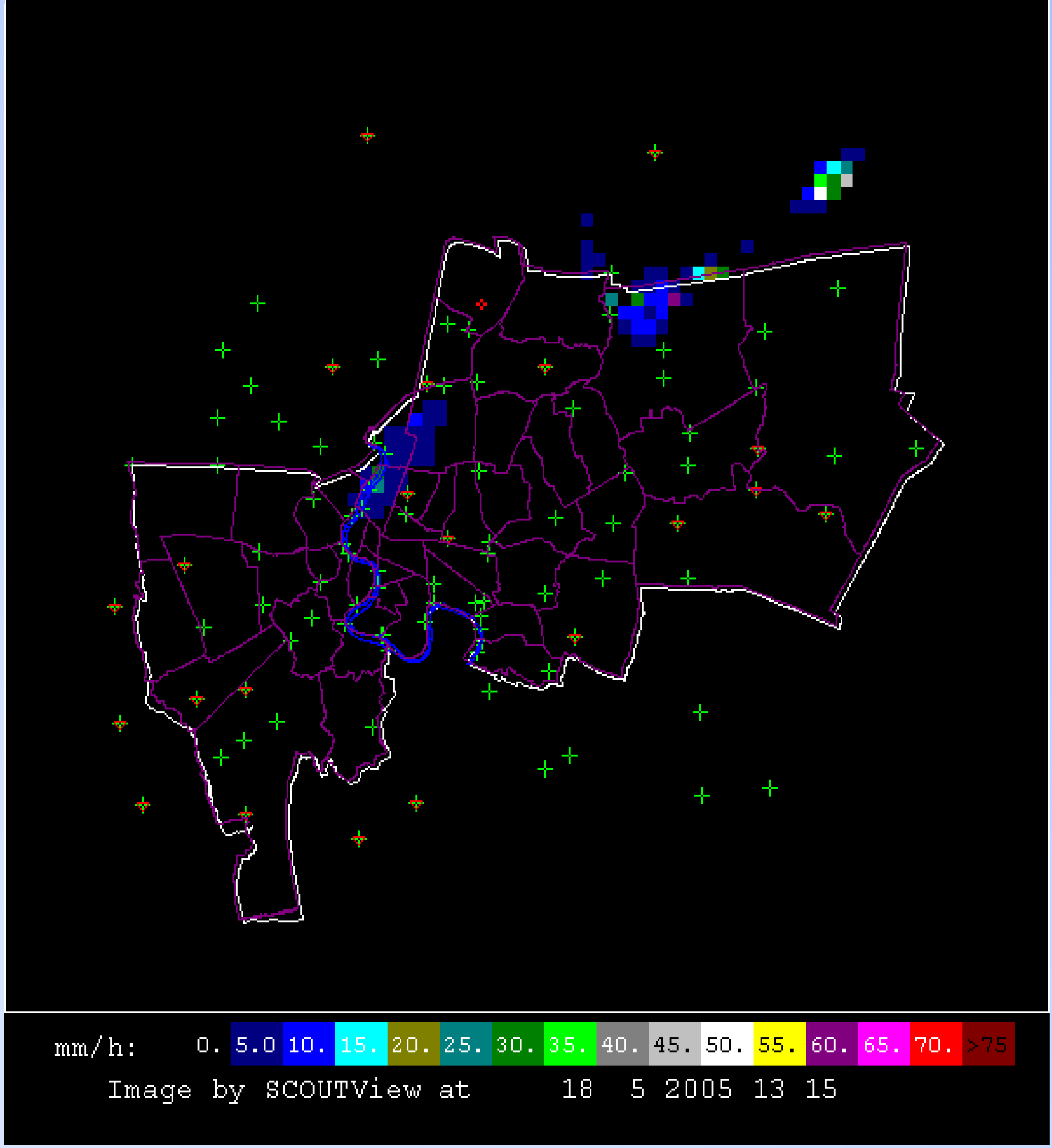
Example 18/05/2005 12:15 hrs



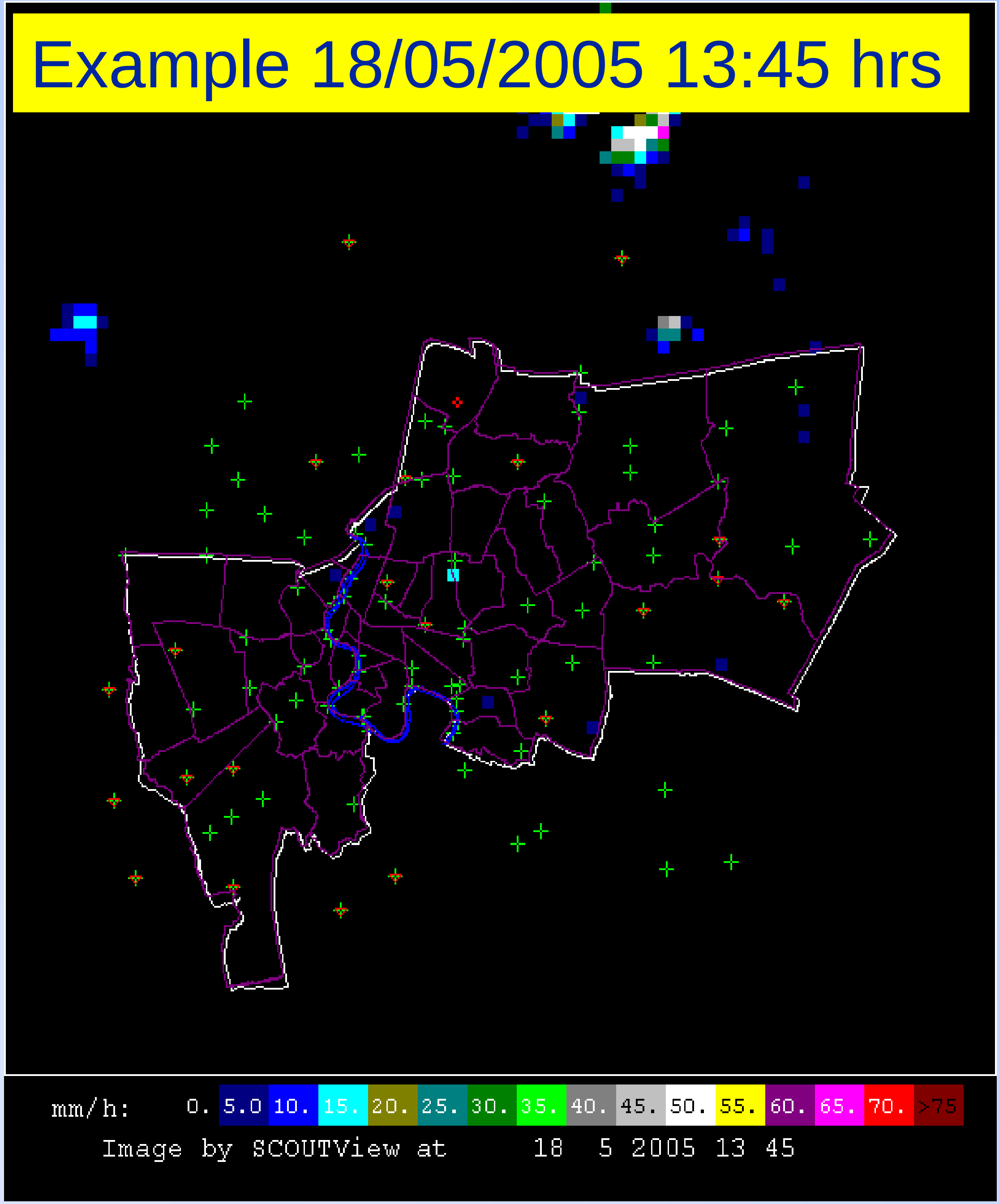
Example 18/05/2005 12:45 hrs



Example 18/05/2005 13:15 hrs



Example 18/05/2005 13:45 hrs

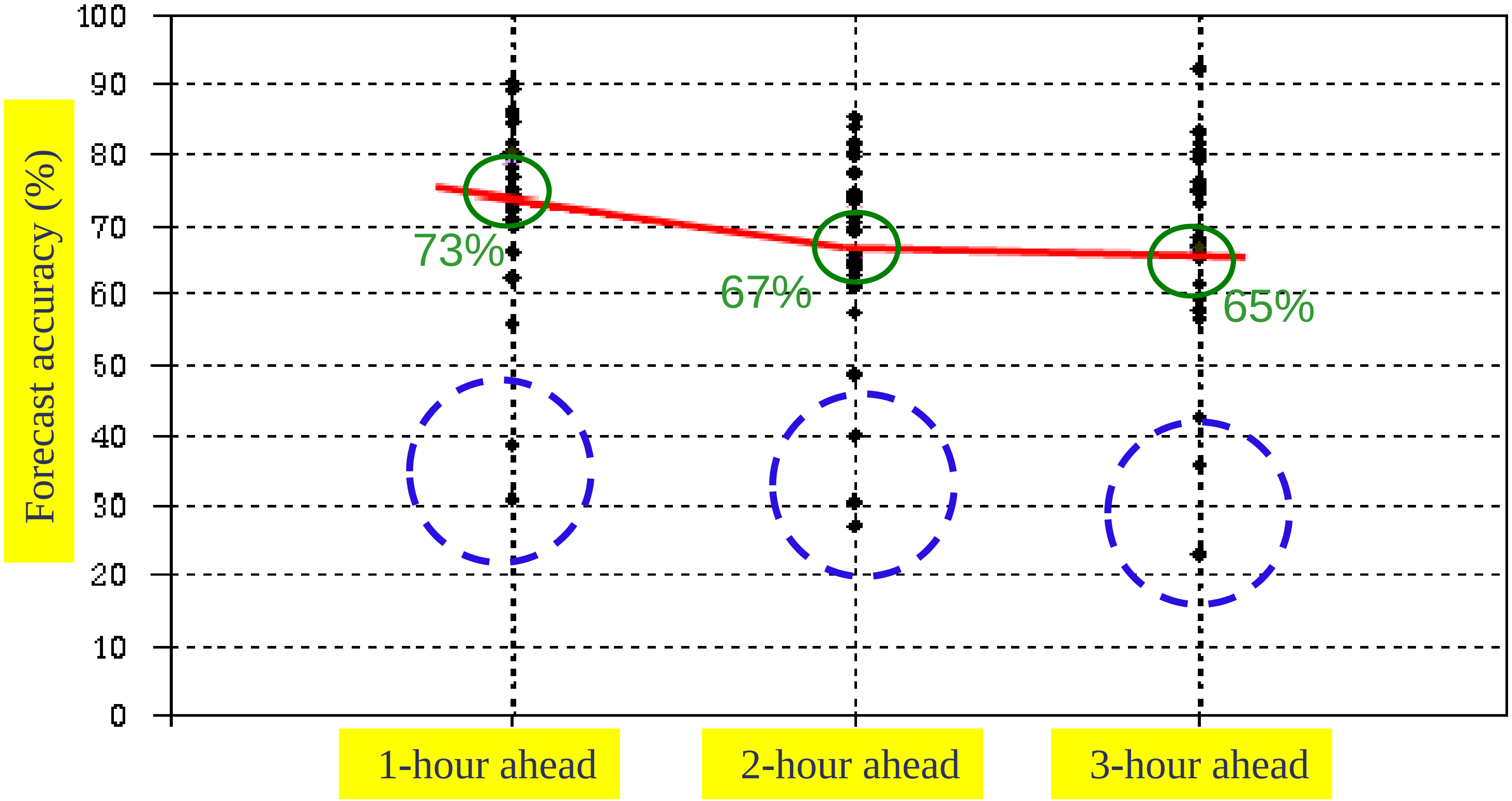


Radar based nowcast

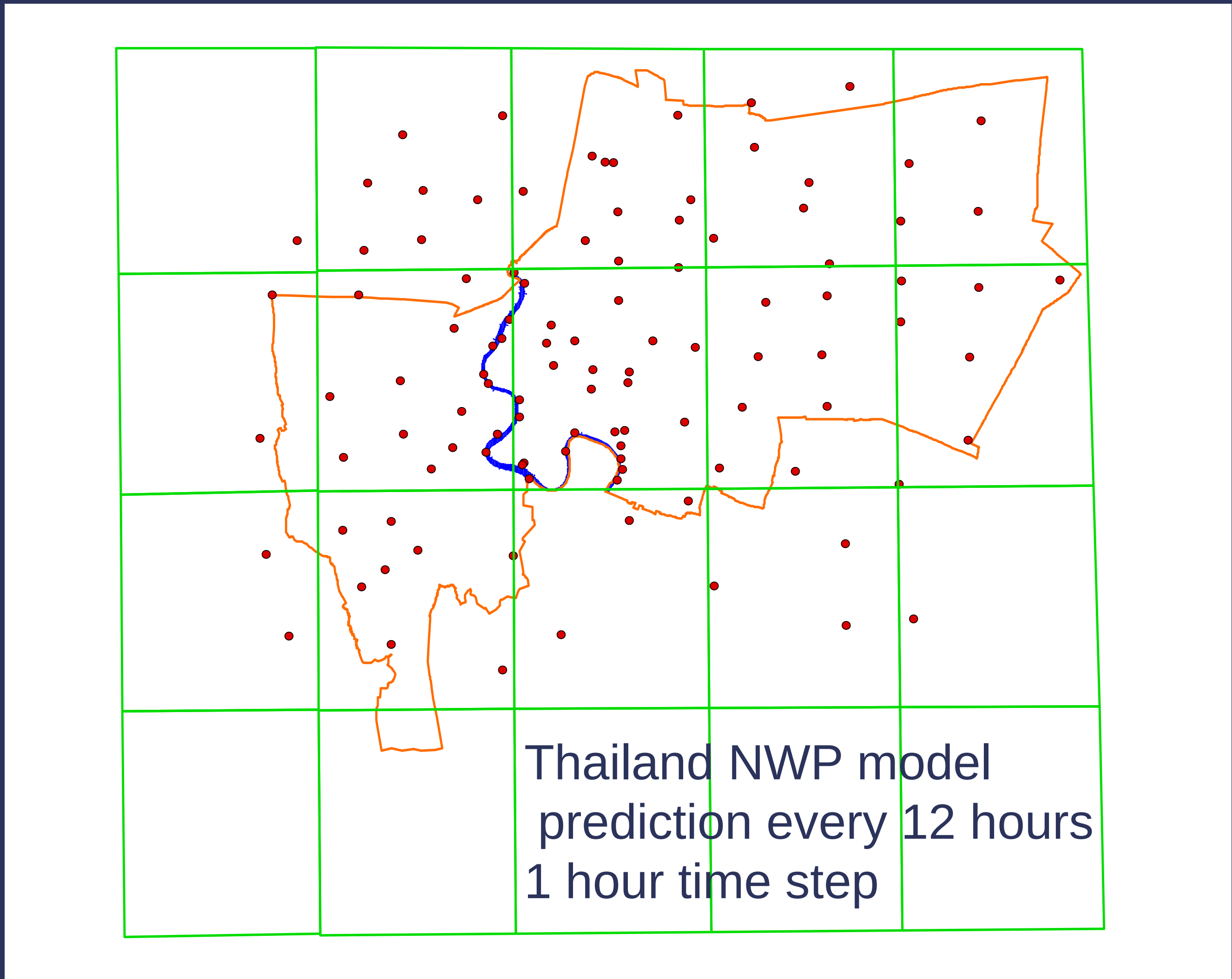
What can we see?

- Radar alone cannot guess where rainfall is going to create
- Rain cells with a short life time are difficult to forecast, even when they are already existing
- Rain can only be forecasted if detected by radar, rainfields outside the radar range cannot be used

Results (30 events)



Rainfall forecast for 4-12 hr using NWP result



Backup rainfall forecasting system (ANN)

Developed by Asian Institute of Technology (AIT)

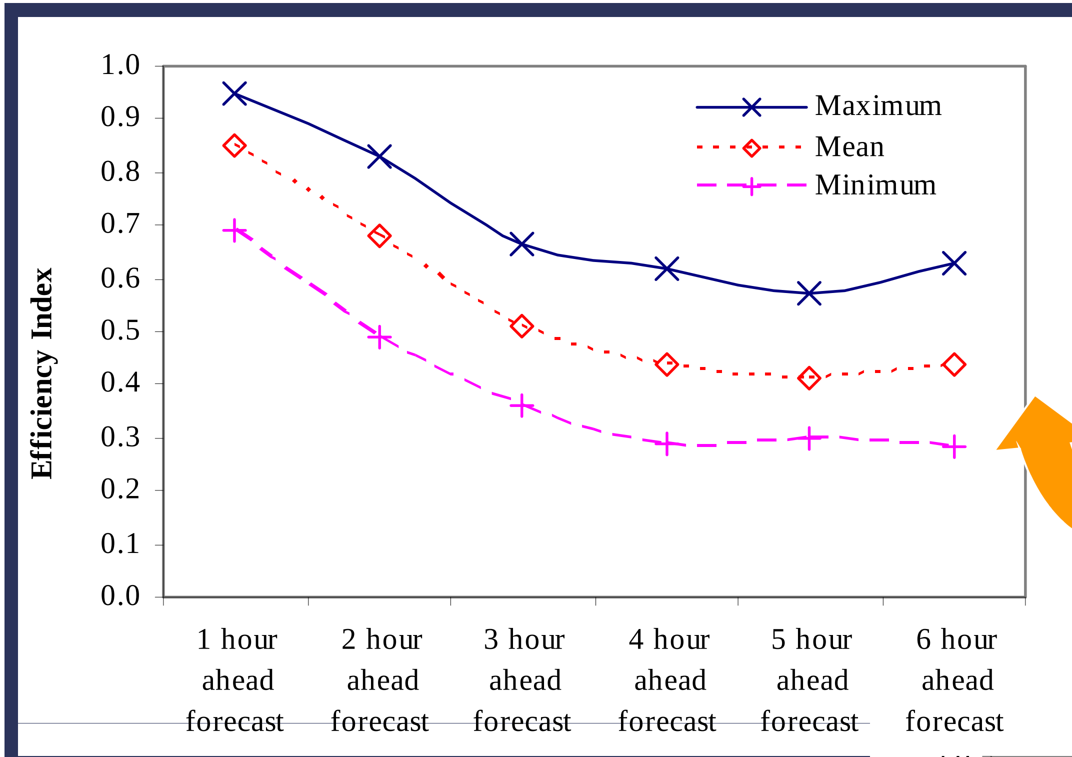
Function of ANN rainfall forecasting

$$R_p(t+1) = f\,[\,C(t), P(t), RH(t), T(t), R(t), R_{s1}(t), R_{s2}(t), R_{s3}(t), R_p(t)\,]$$

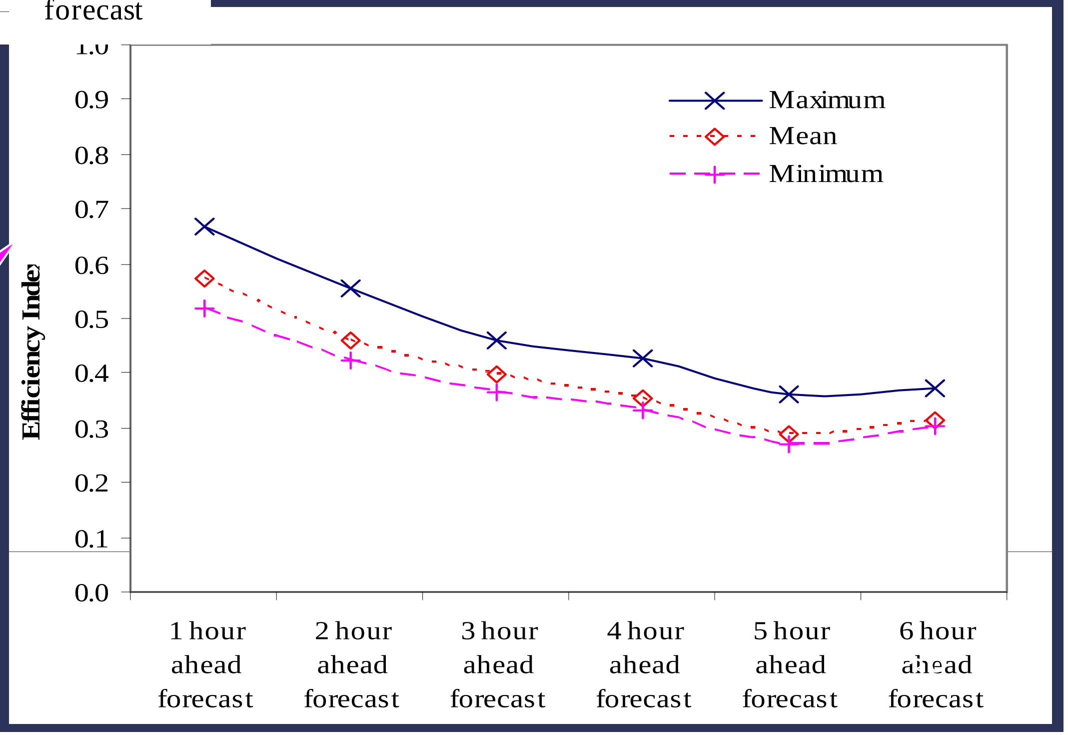
when

$R_p(t+1)$	=	forecast rainfall at station P at time t+1
$C(t)$	=	cloud data at the TMD station time t
$P(t)$	=	air pressure at time t
$RH(t)$	=	relative humidity at time t
$T(t)$	=	temperature at time t
$R(t)$	=	measured rainfall at the TMD station at time t
$R_{s1}(t)$	=	measured rainfall at station S1 (nearby station) at time t
$R_{s2}(t)$	=	measured rainfall at station S2 (nearby station) at time t
$R_{s3}(t)$	=	measured rainfall at station S3 (nearby station) at time t
$R_p(t)$	=	measured rainfall at the forecast station (p) at time t

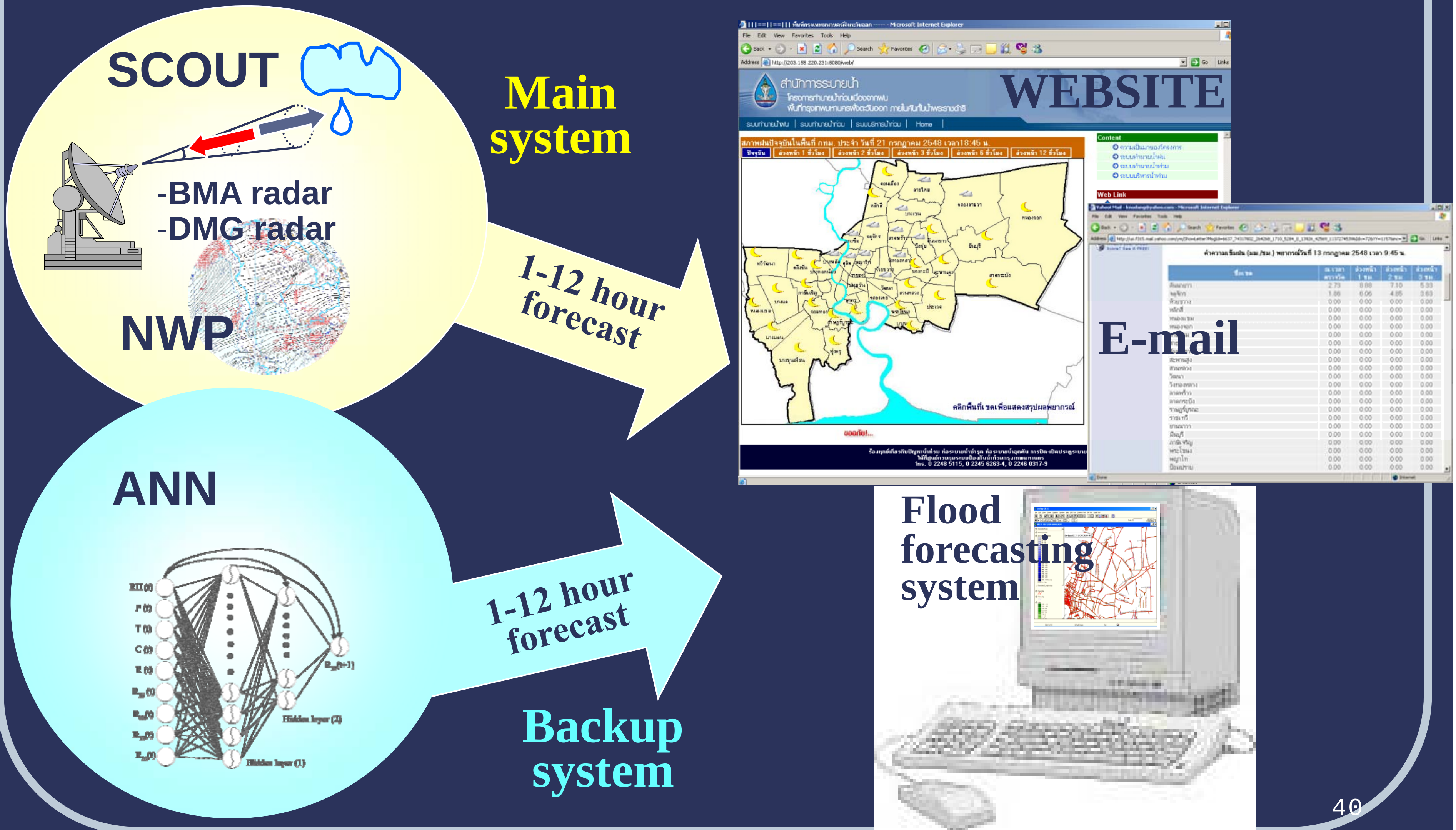
Efficiency Indexes for 1-6 hour forecast leadtime (Aug, Sep, Oct)



Efficiency Indexes for 1-6 hour forecast lead time (May, June)



Conclusion


SCOUT
-BMA radar
-DMG radar
NWP
Main system
1-12 hour forecast
WEBSITE
E-mail
ANN
1-12 hour forecast
Backup system
Flood forecasting system

Acknowledgement

- Department of Drainage and Sewerage (DDS)
  Bangkok Metropolitan Administration (BMA)

- The Thai Meteorological Department (TMD)