

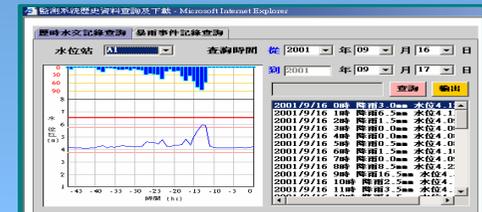
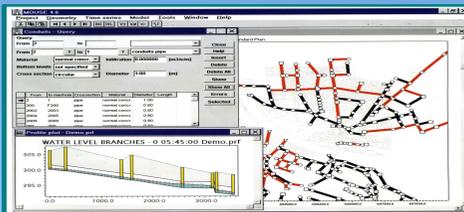
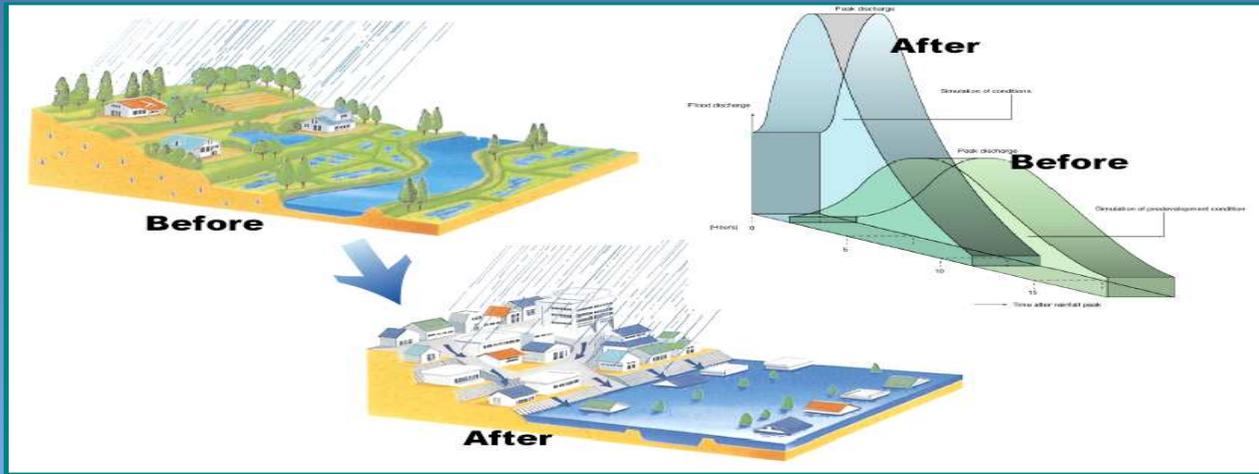


National Taiwan University

Hydropredict2012

# Multi-step-ahead inflow forecasting for reservoir operation and management in mountainous areas

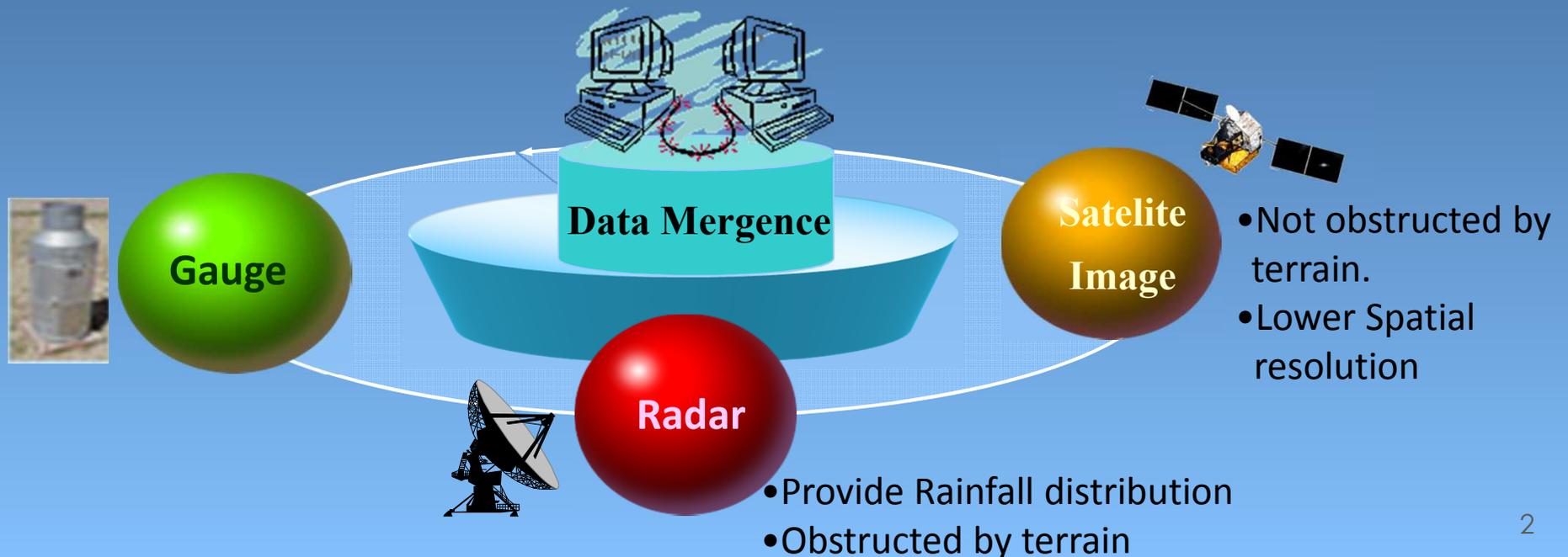
Fi-John Chang\*, MJ Tsai, LC Chang, WF Yang



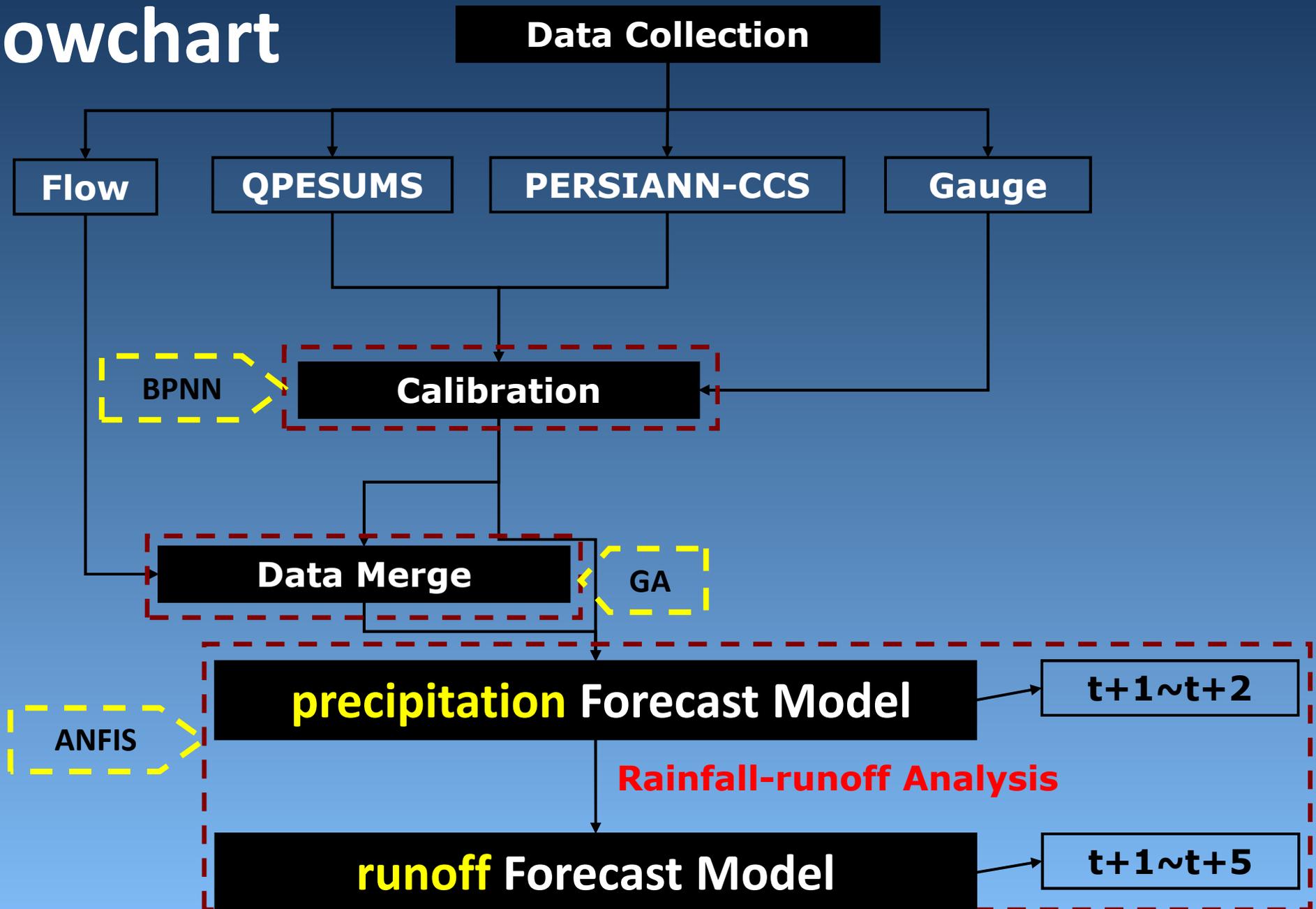
Multi-step ahead inflow forecasting has a critical role in reservoir operation during typhoons.

We develop a novel semi-distributed, data-driven, rainfall-runoff model for reservoir.

An Adaptive Network-based Fuzzy Inference System (ANFIS) is created using multiple information.



# Flowchart



# Taiwan

■ Area: 36000 km<sup>2</sup> Population: 24 M

■ Rainfall

■ Annual rainfall: 2,500 mm

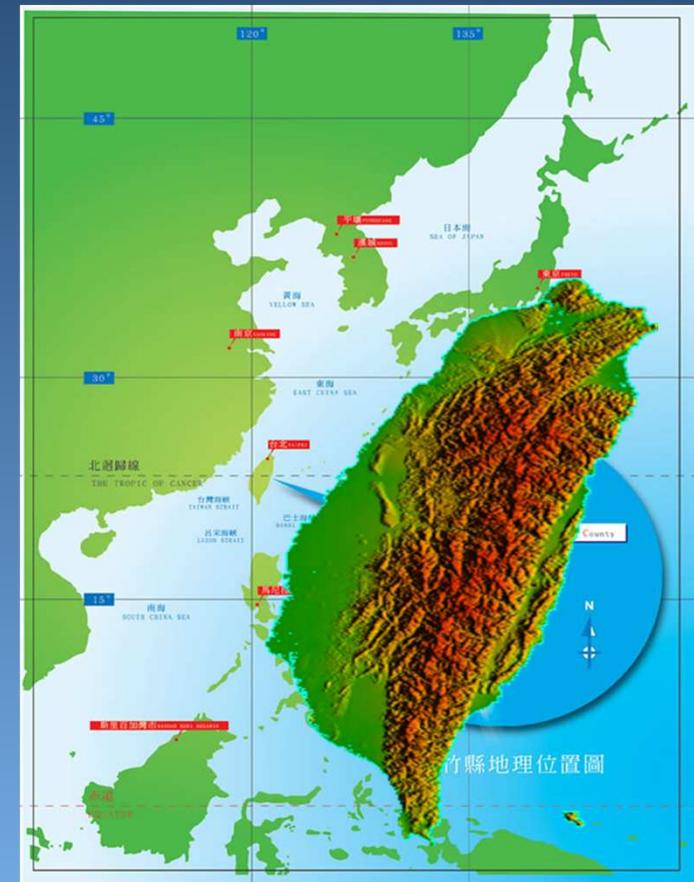
■ 2.5 times the world average

■ Runoff

■ river: short and steep

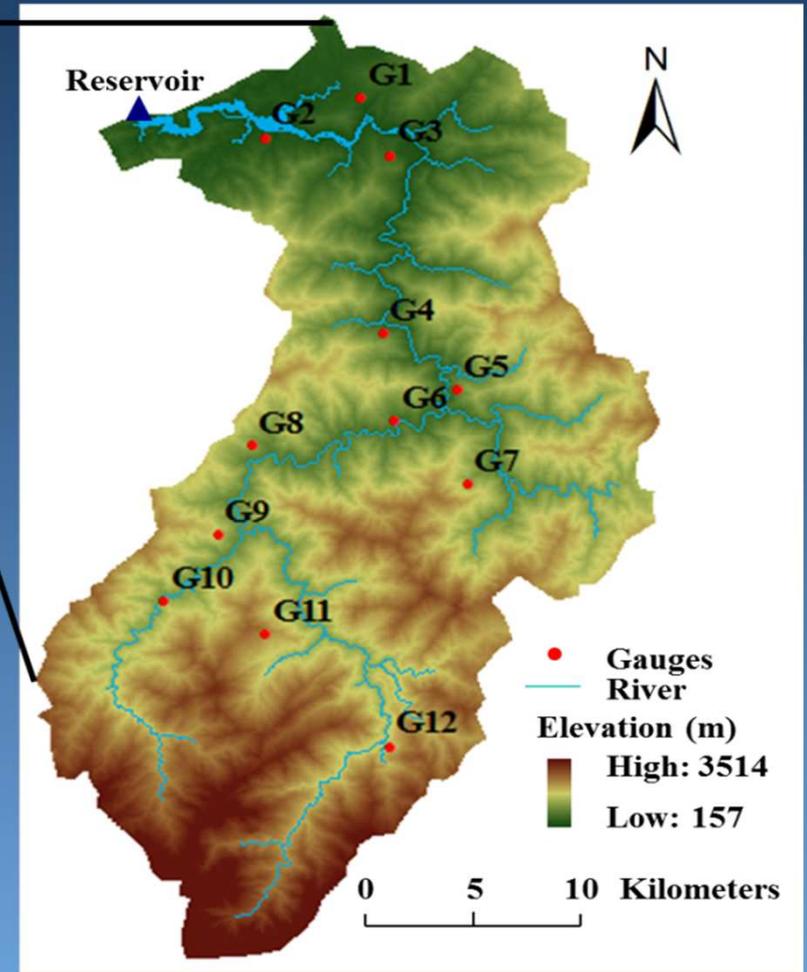
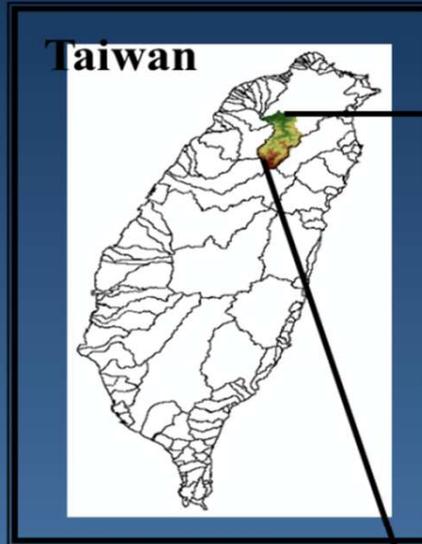
■ Typhoons

Last century about 350 Typhoons





# Study Area-- Shihmen reservoir



- Catchment area : **763.4 Km<sup>2</sup>**
- Annual average rainfall :  
**2,200 to 2,800 mm/year.**
- Most of rainfall happen in May to September **mainly contributed by Typhoons.**



# Data Collection

# Data Collection :

1. Inflow
2. Rain gauges
3. Radar Data
4. Satellite Data

Special Resolution : 1.25km

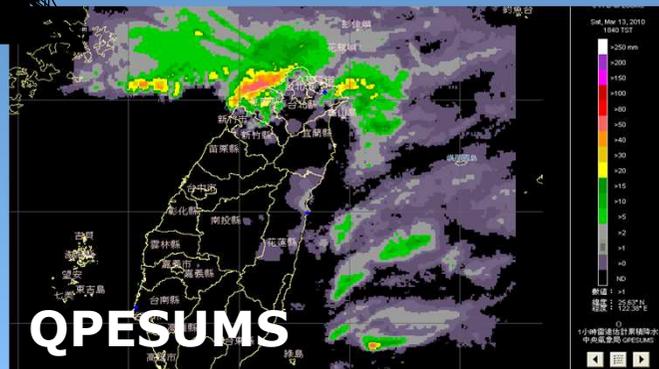
Temporal Resolution : 10 mins



Rain gauges  
Temporal Resolution : 1 hour

Shihmen Reservoir—**Inflow**

**Temporal Resolution : 1 hour**



# Quantitative Precipitation Estimation and Segregation Using Multiple Sensors (QPESUMS)

劇烈天氣監測系統  
閃電資料來源:台灣電力公司。

QPESUMS 雷達基本產品 雨量監測 閃電即時顯示 縣市雨量估計 說明 下載

台灣整合回波  
過去0-1h降水估計  
過去0-3h降水估計  
過去0-6h降水估計  
過去0-12h降水估計  
過去0-24h降水估計  
過去0-72h降水估計

新視窗 動畫 設定  
ReLoad

地理資訊  
水文資訊  
氣象資訊  
衛星影像

降雨估計

Radars

C W B QPESUMS  
Wed, Feb 22, 2012  
2220 TST

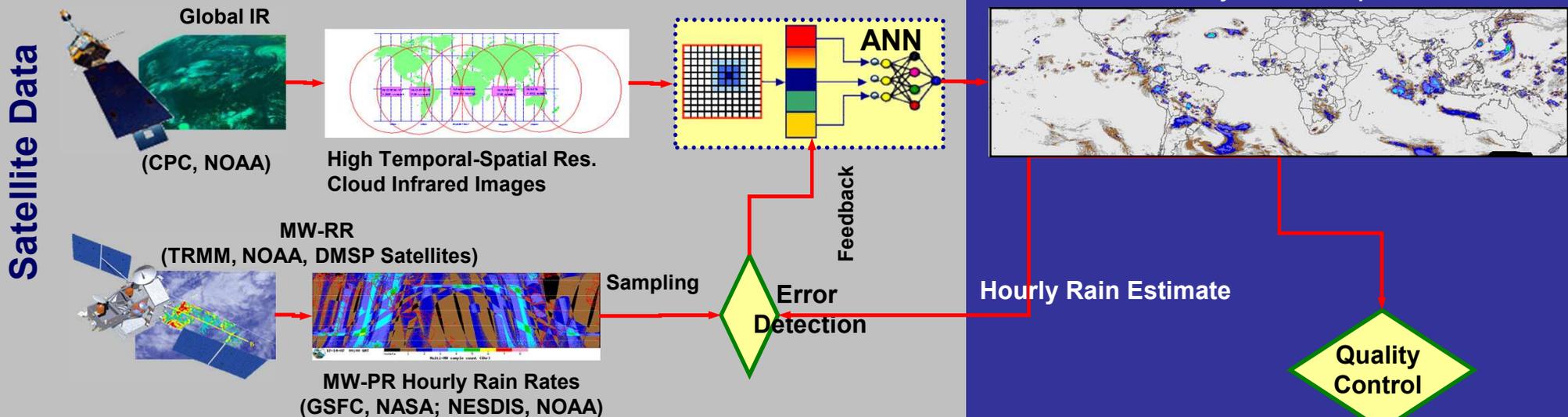
>75 dBZ  
>70  
>65  
>60  
>55  
>50  
>45  
>40  
>35  
>30  
>25  
>20  
>15  
>10  
>5  
ND

台灣整合回波  
中央氣象局 QPESUMS

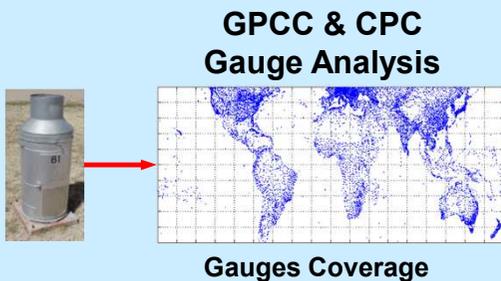
- Spatial resolution : 1.25km×1.25km
- Temporal resolution :10 mins
- Spatial Coverage : 20~27 ° N 118~123.5 ° E

# Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)

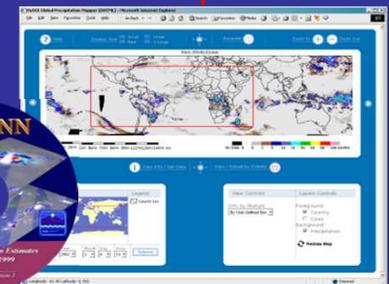
## PERSIANN System "Estimation"



## Ground Observations



- Merged Products**
- Hourly rainfall
  - 6 hourly rainfall
  - Daily rainfall
  - Monthly rainfall



# Real Time Global Data: Cooperation With UNESCO

The screenshot shows a web browser window titled "HyDIS GWADI MapServer - Windows Internet Explorer" with the URL "http://hydis.eng.uci.edu/gwadi/ss.html". The browser's address bar and menu bar are visible. The main content area displays a global map with a dark background and blue highlights representing rain data. A large, semi-transparent white box with a grid pattern is overlaid on the map, containing the text: "Many Features provided to users with Public Domain Software." in red. The left sidebar contains a "Map Layer Control" panel with "VECTOR LAYERS" (Country, Political Divisions, Urban Areas, GRDC Stations, Streams, Inland Water, Continental Basins, Major River Basins, Tributary Basins, Small Watersheds) and "PERSIANN/ NESDIS Data" (For: 04-14-2008 @ 12 Hour UT). Below this are radio buttons for "Latest Rain Totals" (3 hrs, 6 hrs, 12 hrs, 24 hrs, 48 hrs) and "Latest Heavy Rain" (3 hrs, 6 hrs, 12 hrs, 24 hrs, 48 hrs). A small world map is at the bottom left of the sidebar. The main map area includes navigation tools (Zoom in, Zoom out, Pan/Center, Query Info), a "Global View" button, and a "Show Legends" button. The map's coordinates are "Longitude: -180 to 180" and "Latitude: -90 to 90", and the date is "Mon Apr 14 06:49:49 2008". A scale bar at the bottom indicates distances from 0 to 6000 km. Logos for "CHRS" and "NASA" are in the bottom right corner.



# Calibration

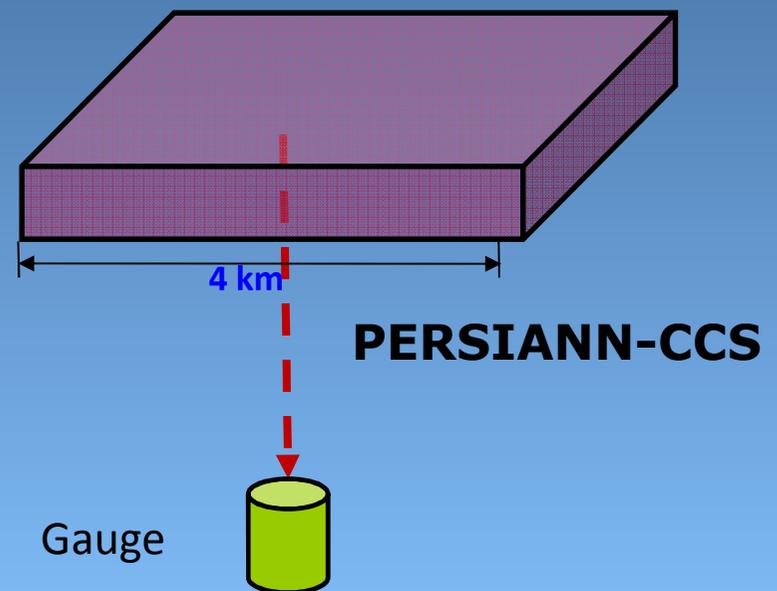
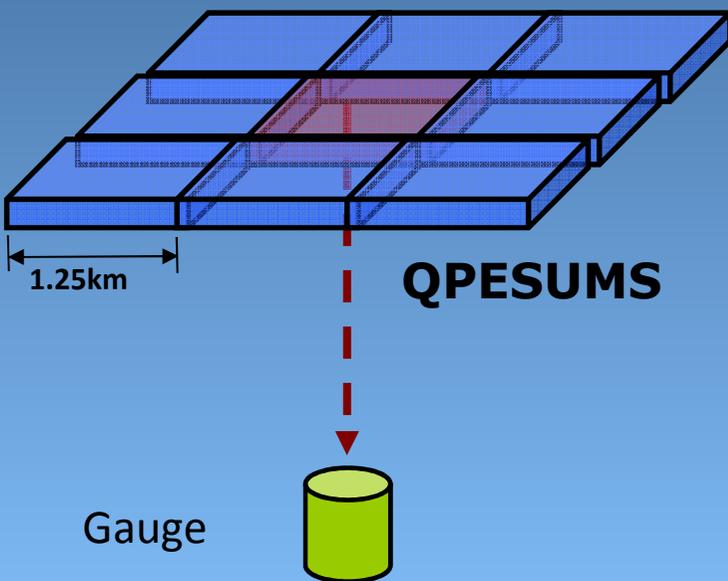
# Calibration

**QPESUMS**

Average rainfall by using  
**9 grids**

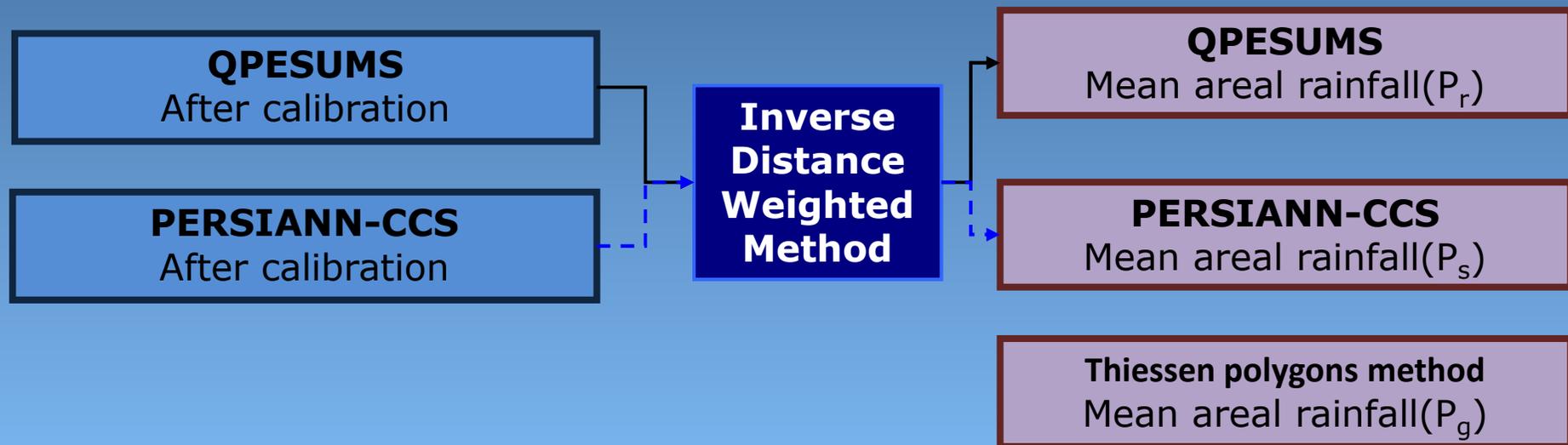
**PERSIANN-CCS**

Rainfall of **1 grid**

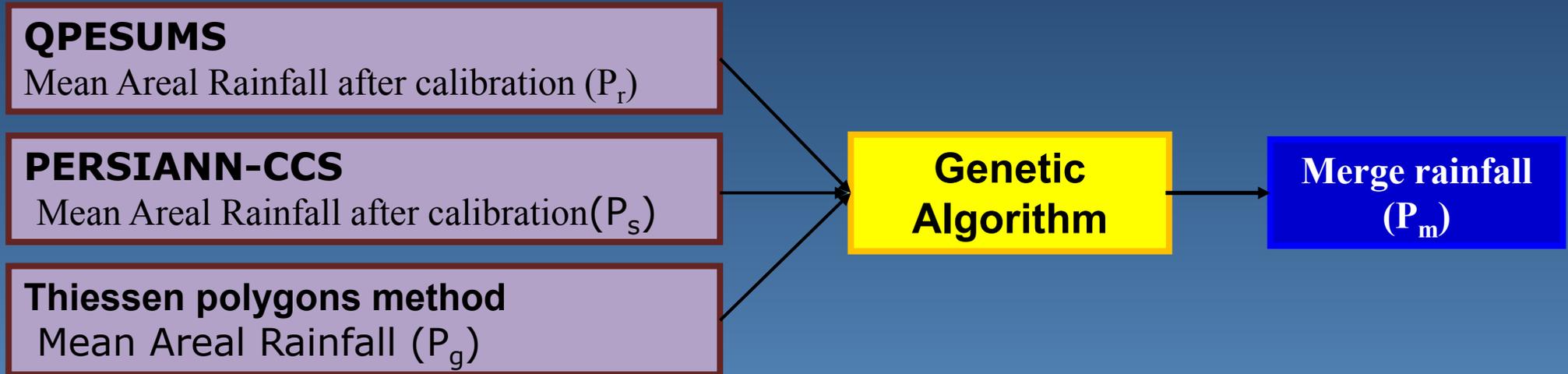


# Calibration

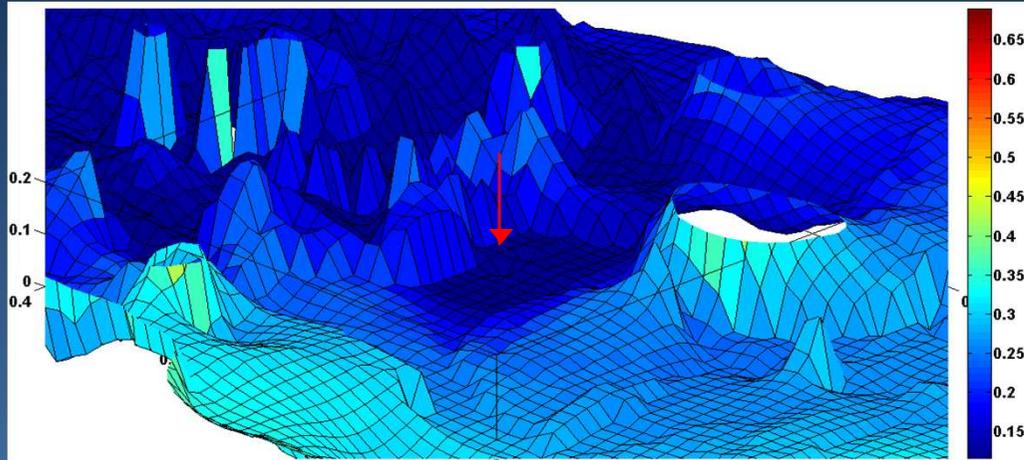
- 13 Typhoons are collected data length is 641.
  - **Train:** 7 events with data length of 350.
  - **Validation:** 3 events with data length of 153.
  - **Test:** 3 events with data length of 138.



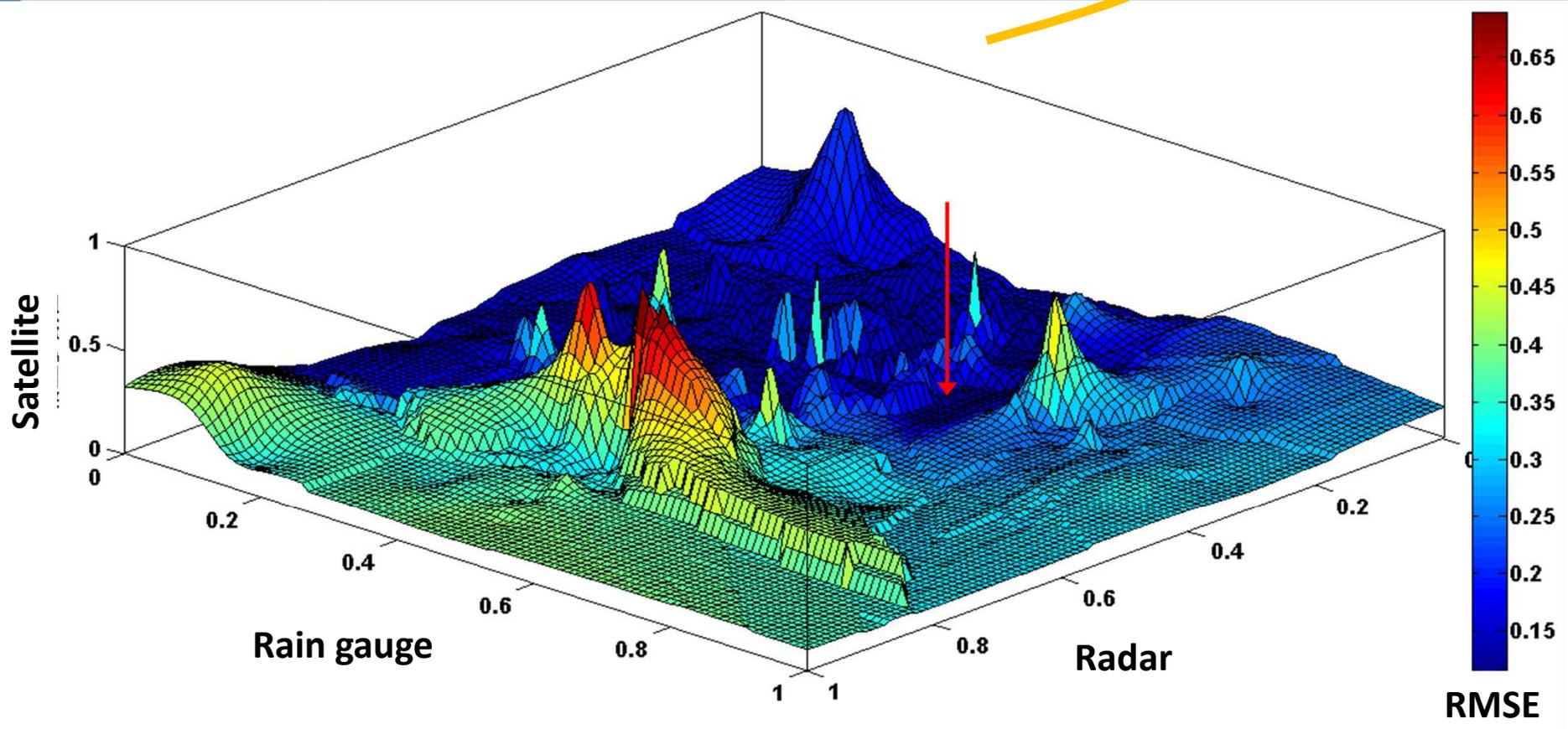
# Data merge



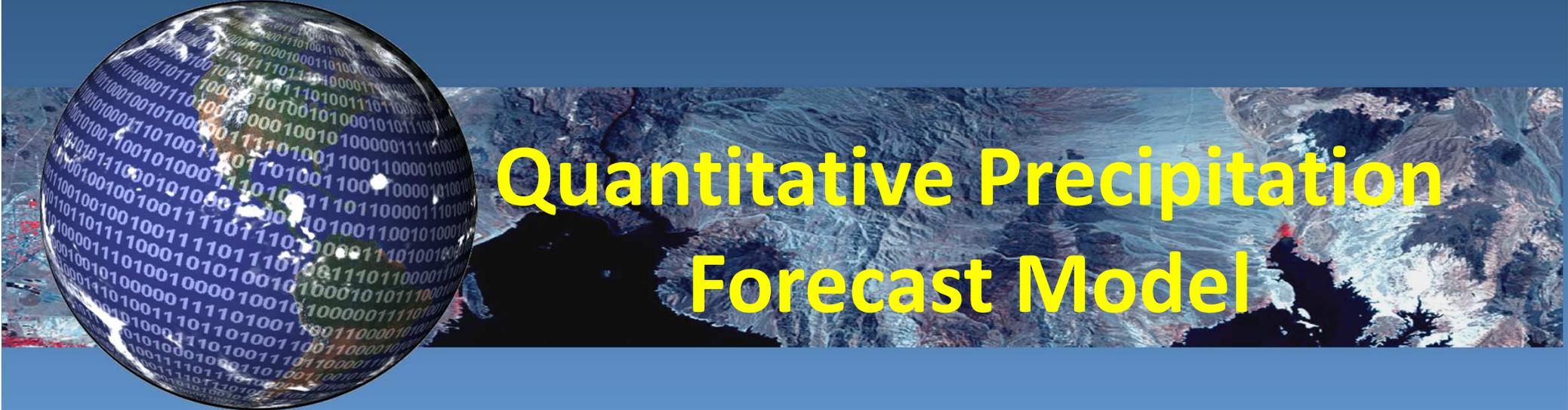
$$\text{Min}(F) = \min \{ f(X_g(t-5) \times \theta_1 + X_r'(t-5) \times \theta_2 + X_s'(t-5) \times \theta_3) - Y(t) \}$$



$\theta_1 + \theta_2 + \theta_3 \leq 1$	$\theta_1$	$\theta_2$	$\theta_3$
GA	0.56	0.30	0.06



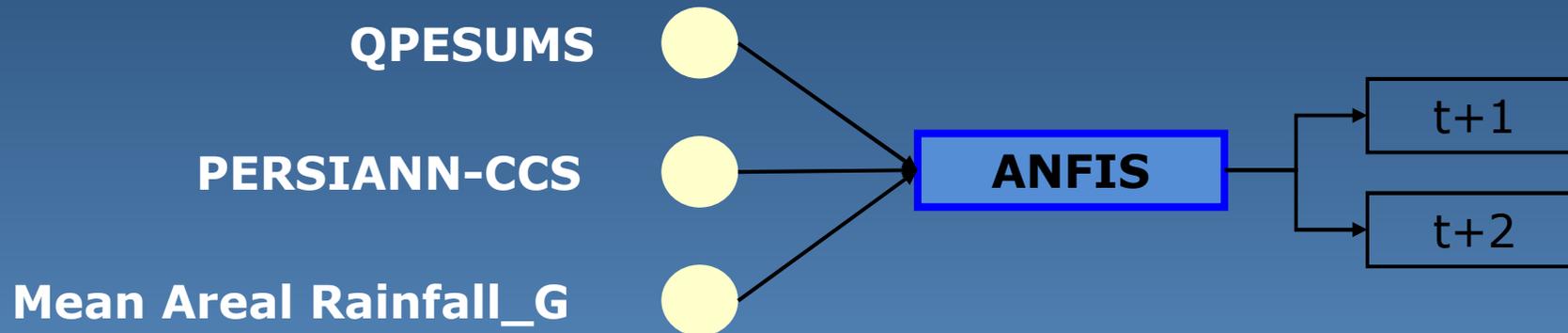
RMSE

A composite image featuring a globe on the left side, covered in binary code (0s and 1s). The globe is set against a background of a satellite-style Earth image showing terrain and clouds. The title text is overlaid on the right side of this image.

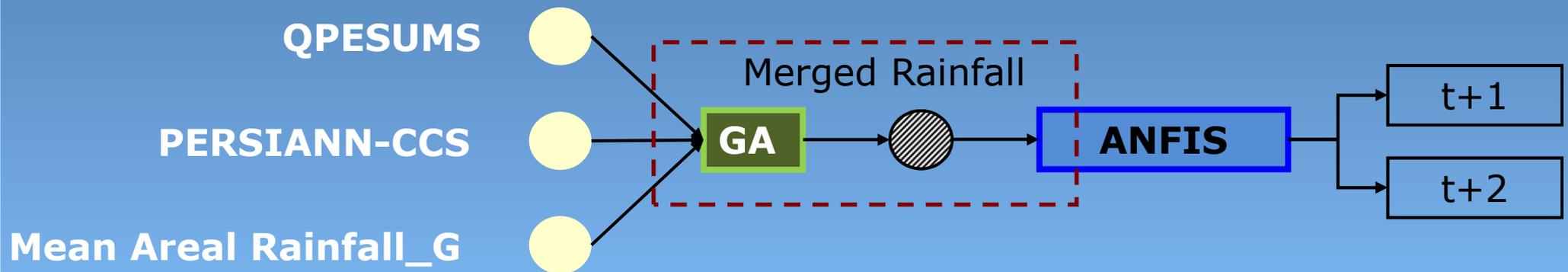
# Quantitative Precipitation Forecast Model

# Quantitative Precipitation Forecast Model

## Model P1



## Model P2

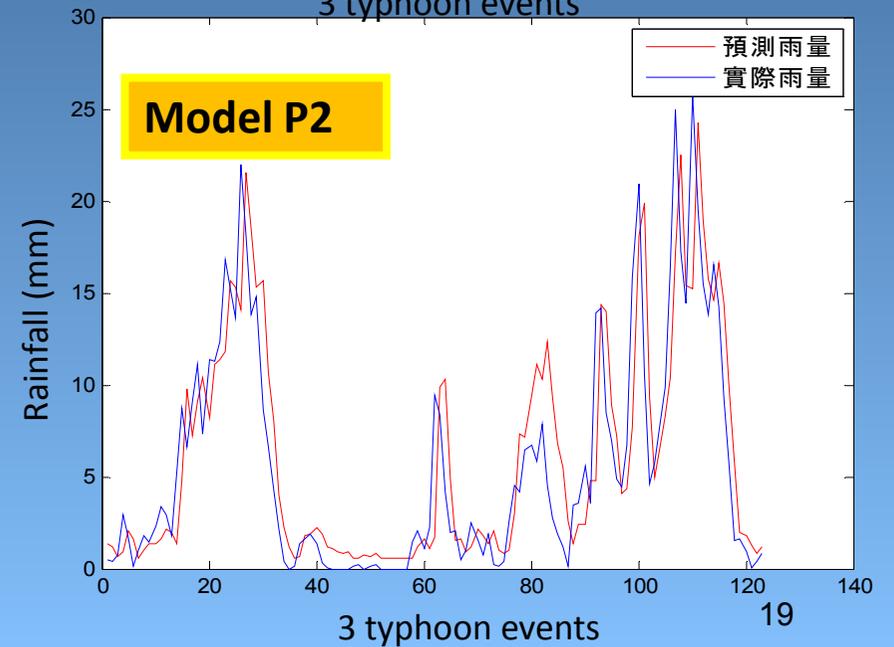
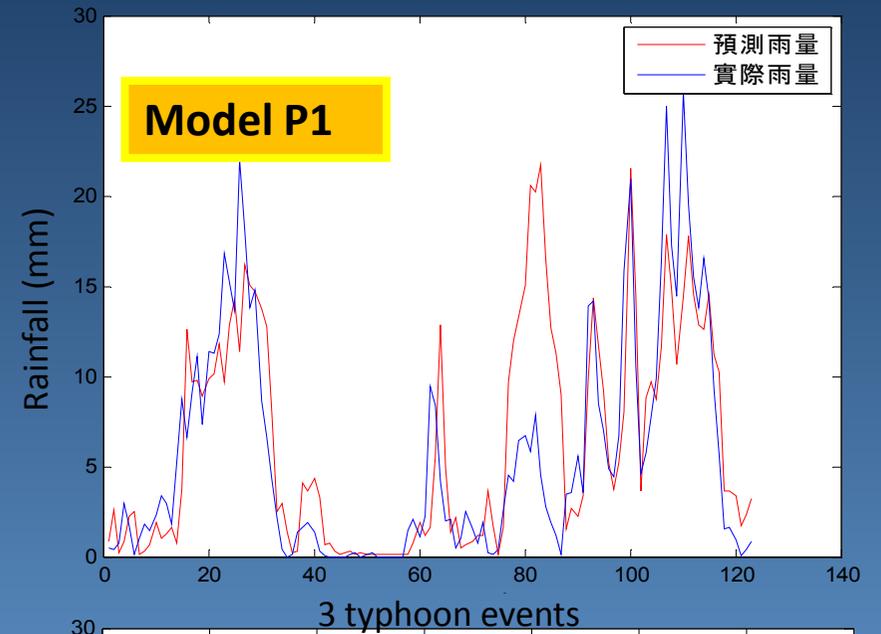
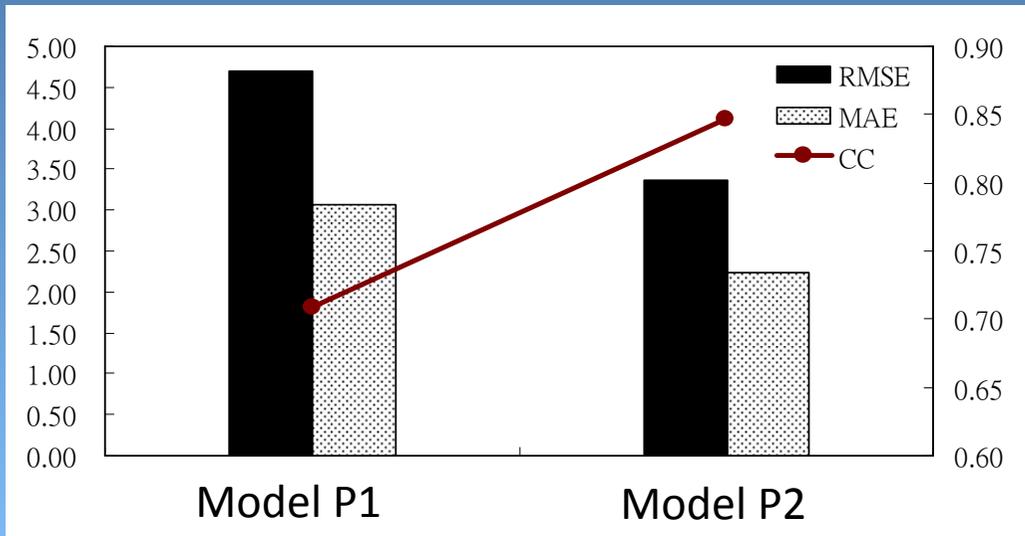


# The results of QPF Model

**t+1**

skill score (SS)

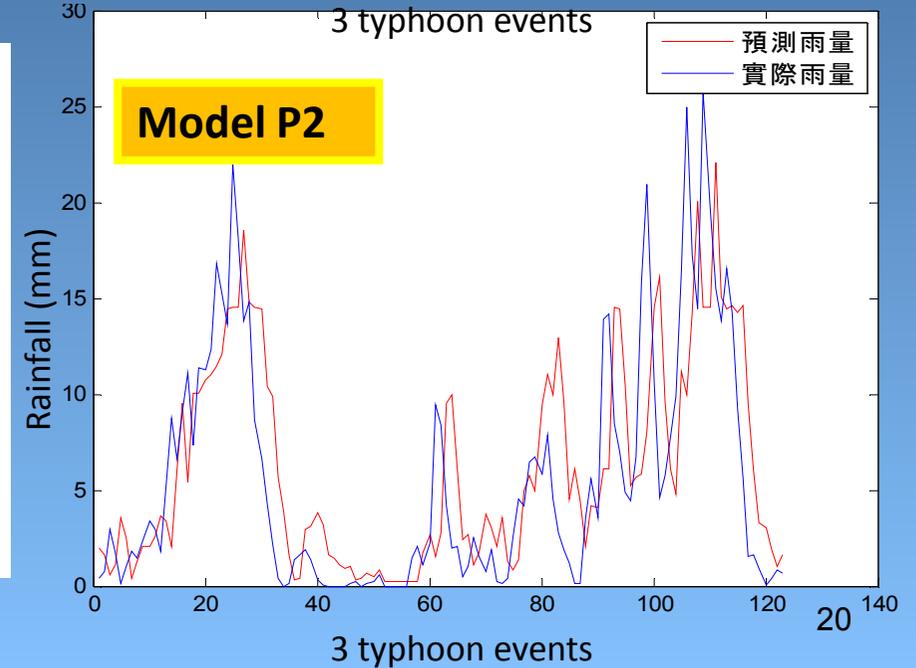
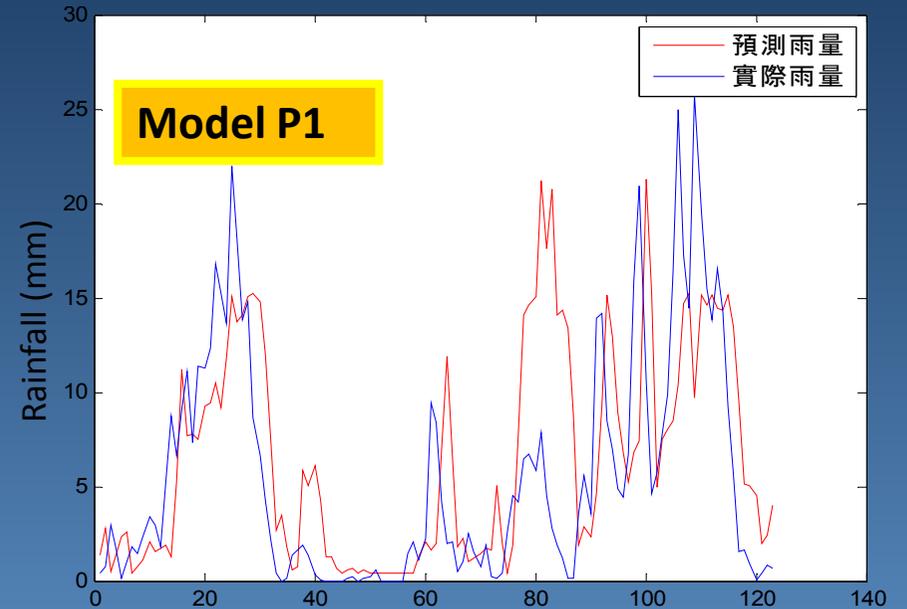
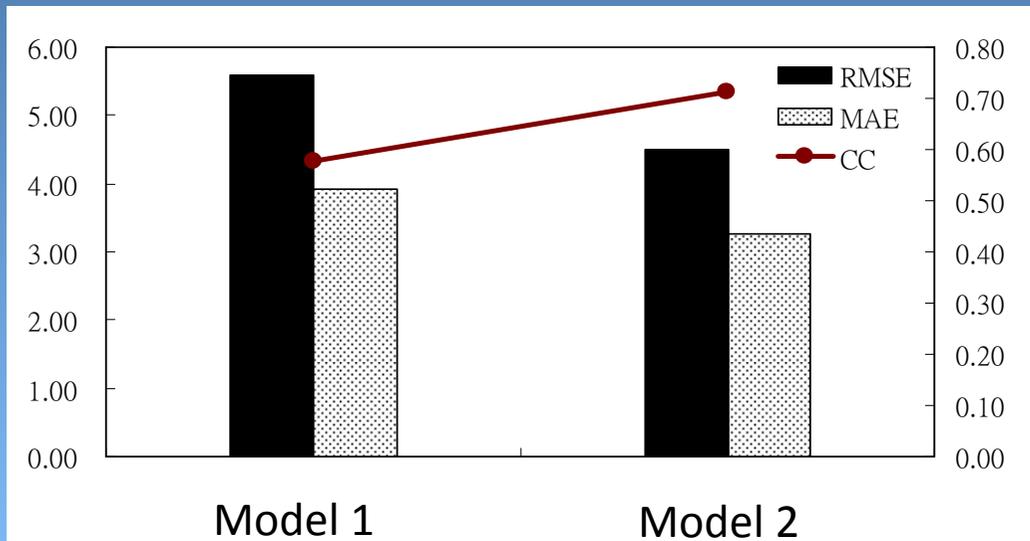
	SS
RMSE	<b>28.23%</b>
MAE	<b>27.24%</b>

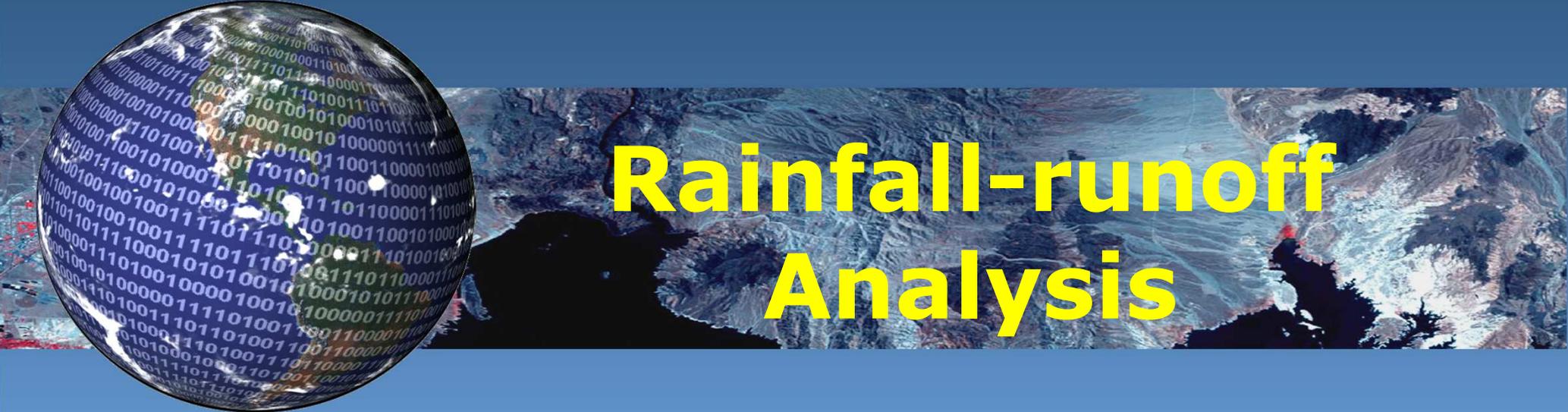


# The results of QPF Model

**t+2**

	<b>SS</b>
<b>RMSE</b>	<b>16.31%</b>
<b>MAE</b>	<b>16.60%</b>



A graphic for the 'Rainfall-runoff Analysis' section. It features a globe on the left with binary code (0s and 1s) overlaid on it. The background is a satellite-style map of a mountainous region with a river network. The title 'Rainfall-runoff Analysis' is written in large, bold, yellow letters across the center of the map.

# Rainfall-runoff Analysis

**Inclusion of spatial distribution in a data-driven, rainfall-runoff model to  
improve reservoir inflow forecasting in Taiwan  
in Hydrologic Process 2012**

# Rainfall-runoff Analysis



**Rainfall**



**Travel  
Time ?**

**Runoff**



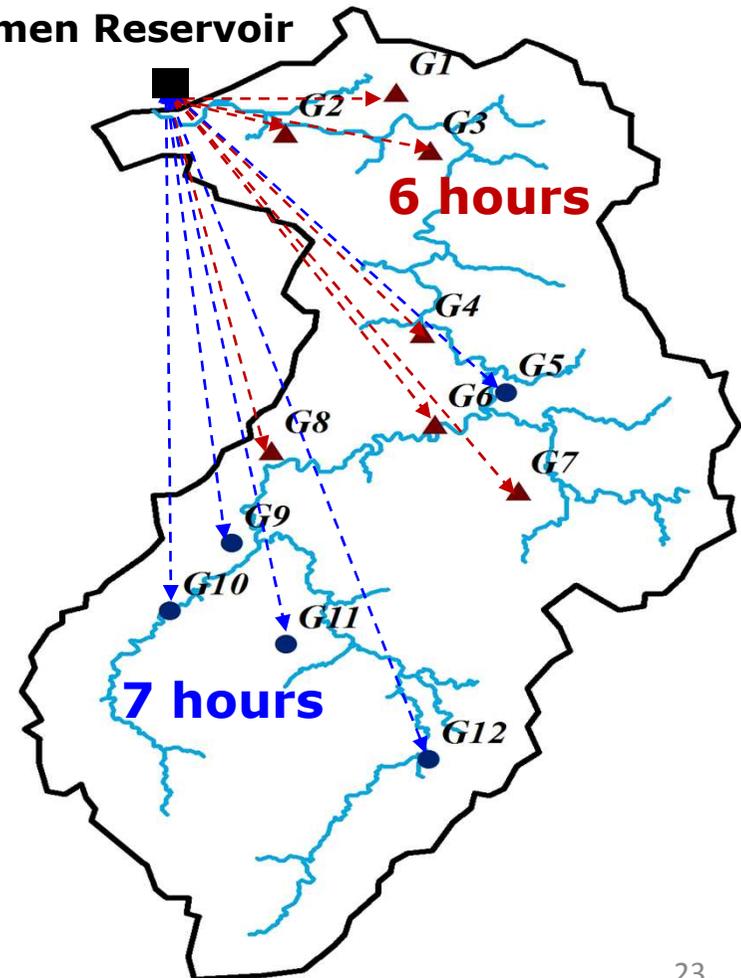
**Shihmen  
Reservoir**

# Rainfall-runoff analysis: rain gauges against reservoir inflow

## Correlation Analysis:

- a) Calculate correlation coefficient
  - 12 gauges
  - 11 inflow travel times ( $t \sim t-10$ )
  - 8 individual typhoon events
  
- b) Select the travel time based on the maximum mean correlation coefficient.

Shihmen Reservoir



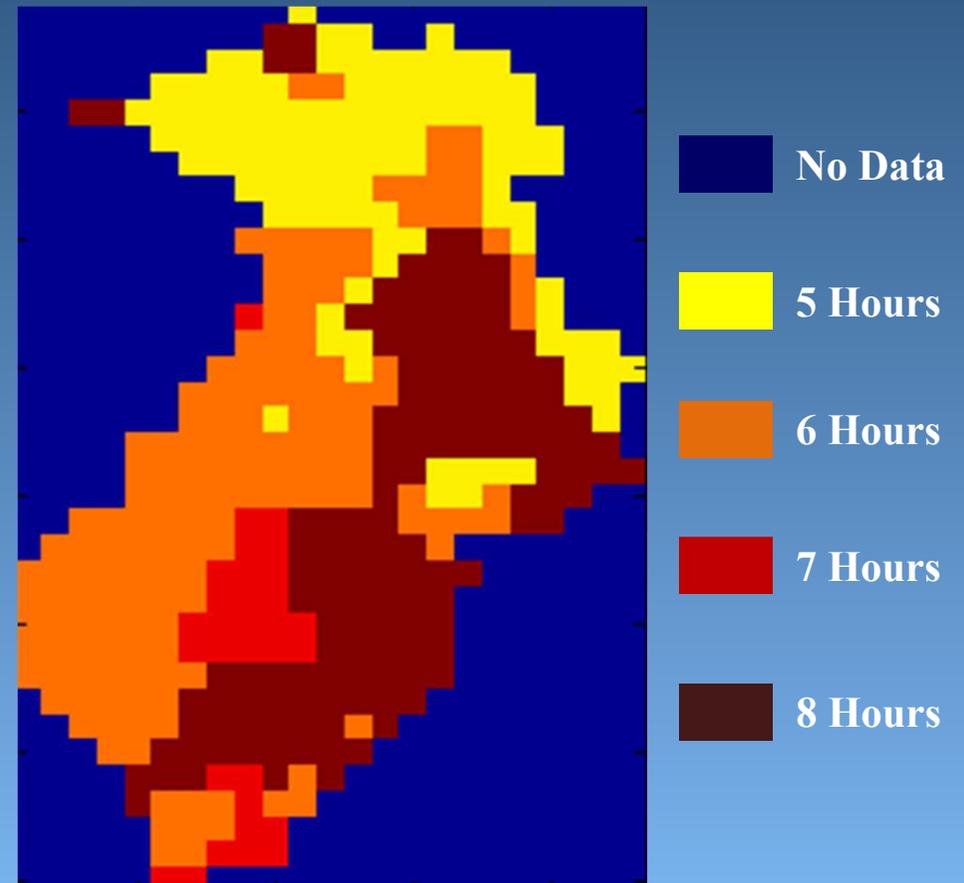
# Radar data against reservoir inflow

## Correlation Analysis:

a) Spatially-continuity of radar data.

b) 434 radar grid cells

c) To prevent the development of an excessively complex solution, **spatial lumping** was performed.



# Spatial lumping by using DEM

Catchment grid

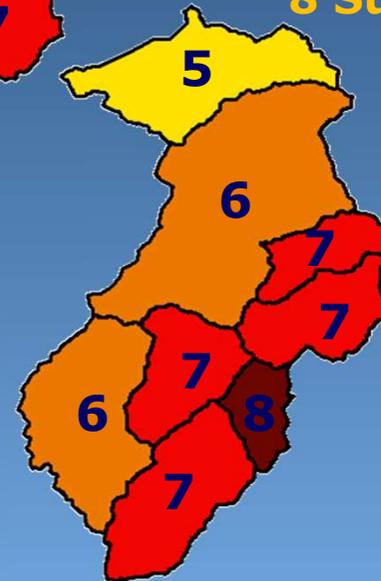
Temporal lumping



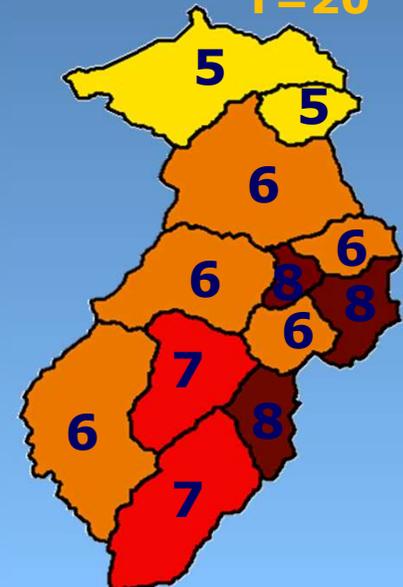
4 Sub-catchments  
T=100



8 Sub-catchments  
T=25



12 Sub-catchments  
T=20

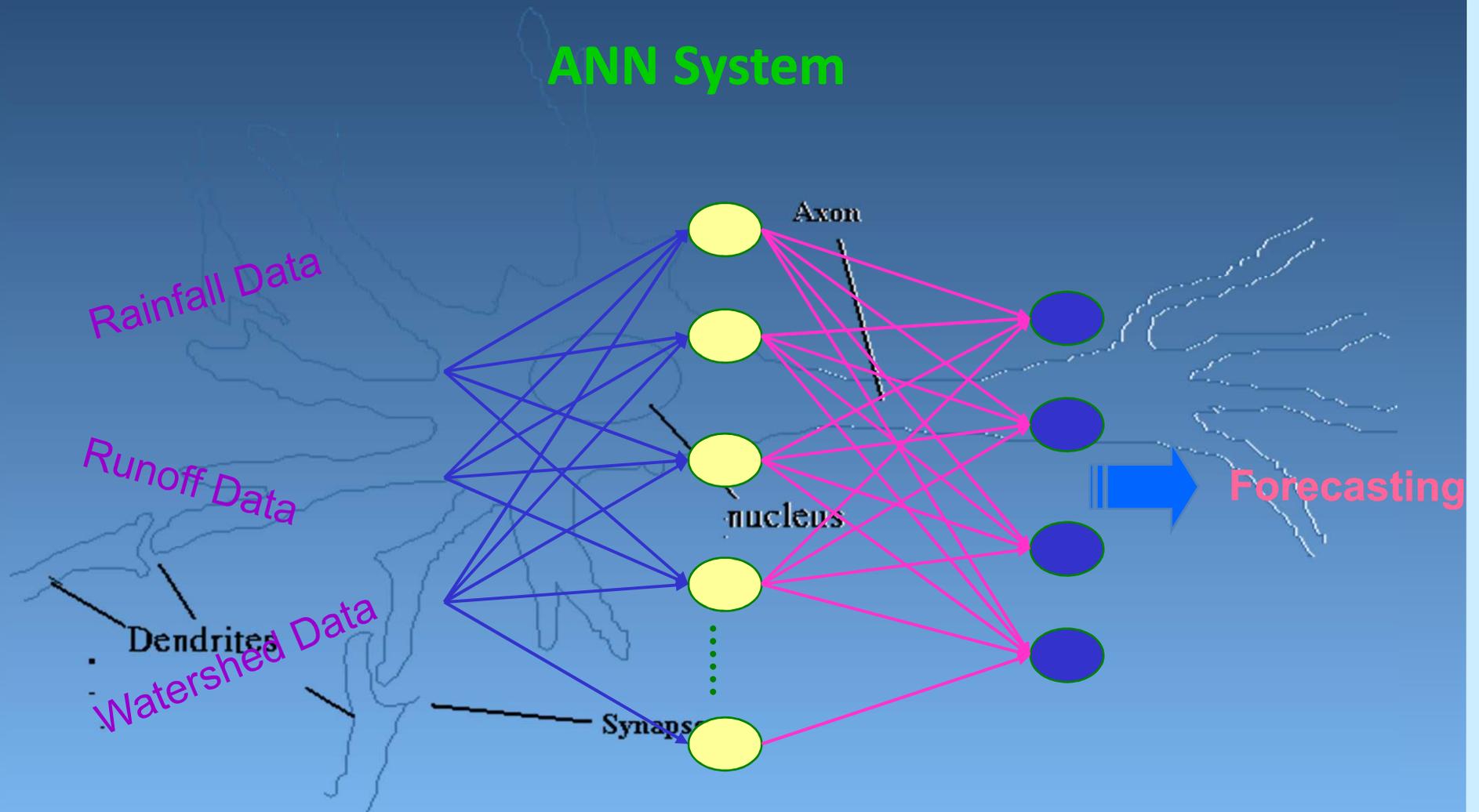


■ No Data   ■ 5 Hours   ■ 6 Hours   ■ 7 Hours   ■ 8 Hours



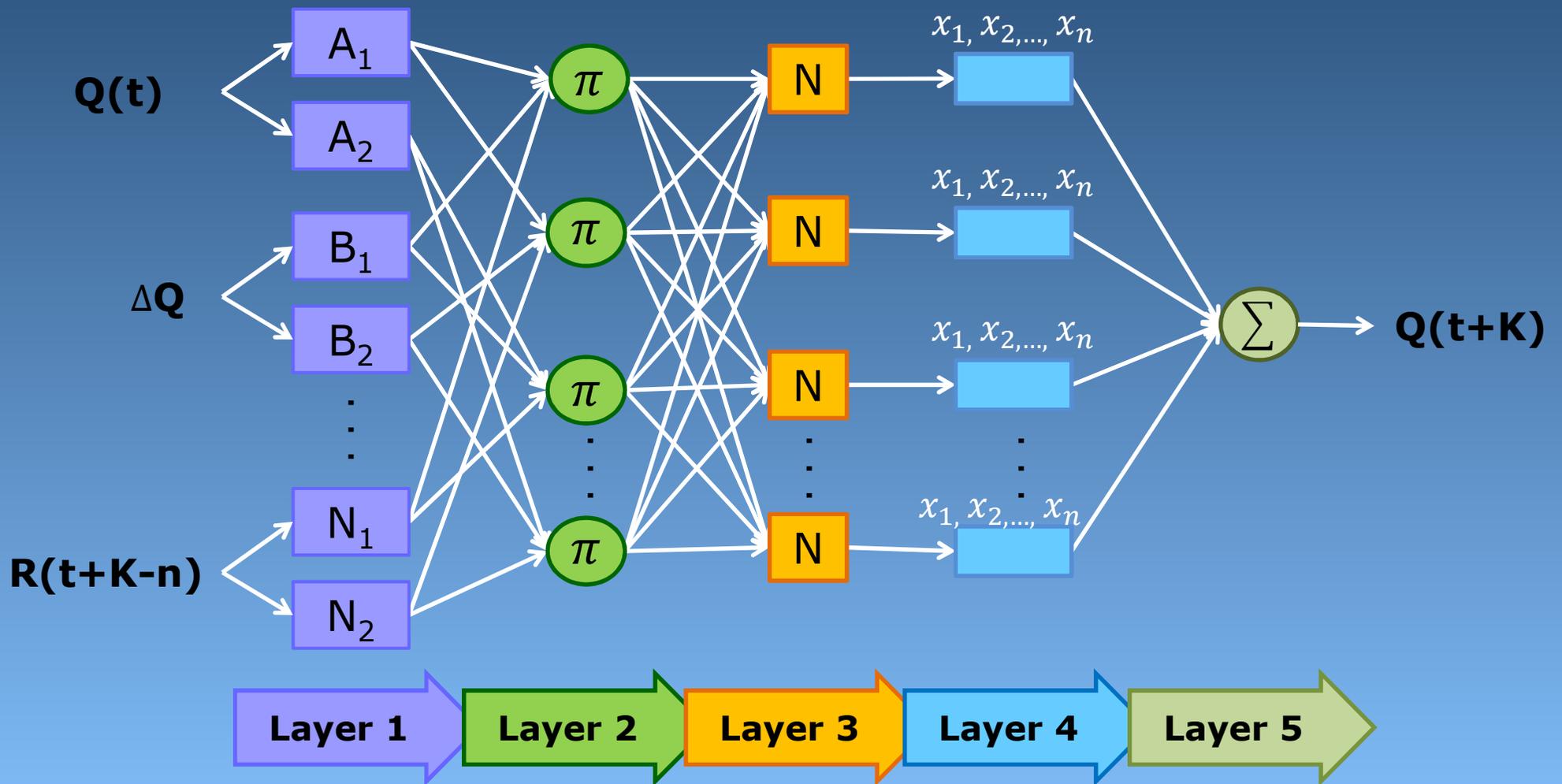
# Quantitative Inflow Forecast Model

# Artificial Neural Network



# Inflow forecasting model - ANFIS

$k = 1, 2, \dots, 5$  and  $n = \text{rainfall-runoff travel time}$

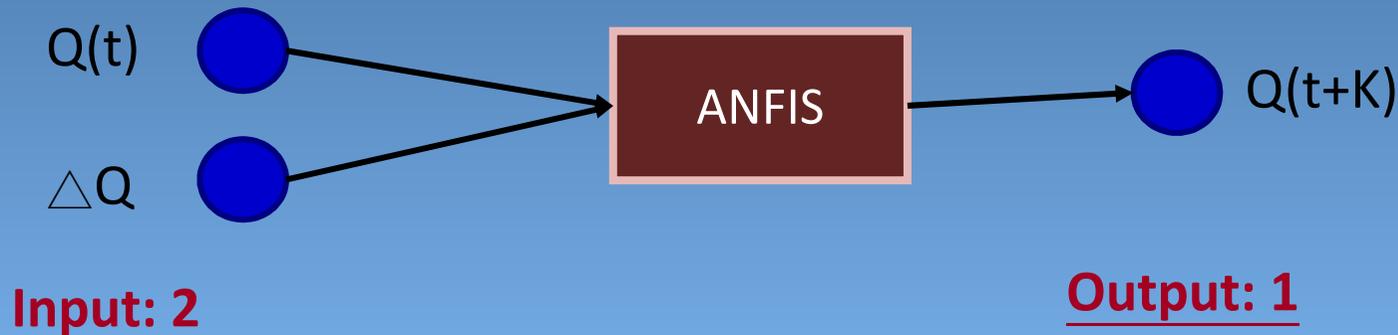


# Structure of Model Q1 – Inflow only

- **Model Q1** : Forecasting flow at  $t+K$  ( $K=1\sim 5$ ) by using Inflow( $t$ ) and  $\Delta$  Inflow

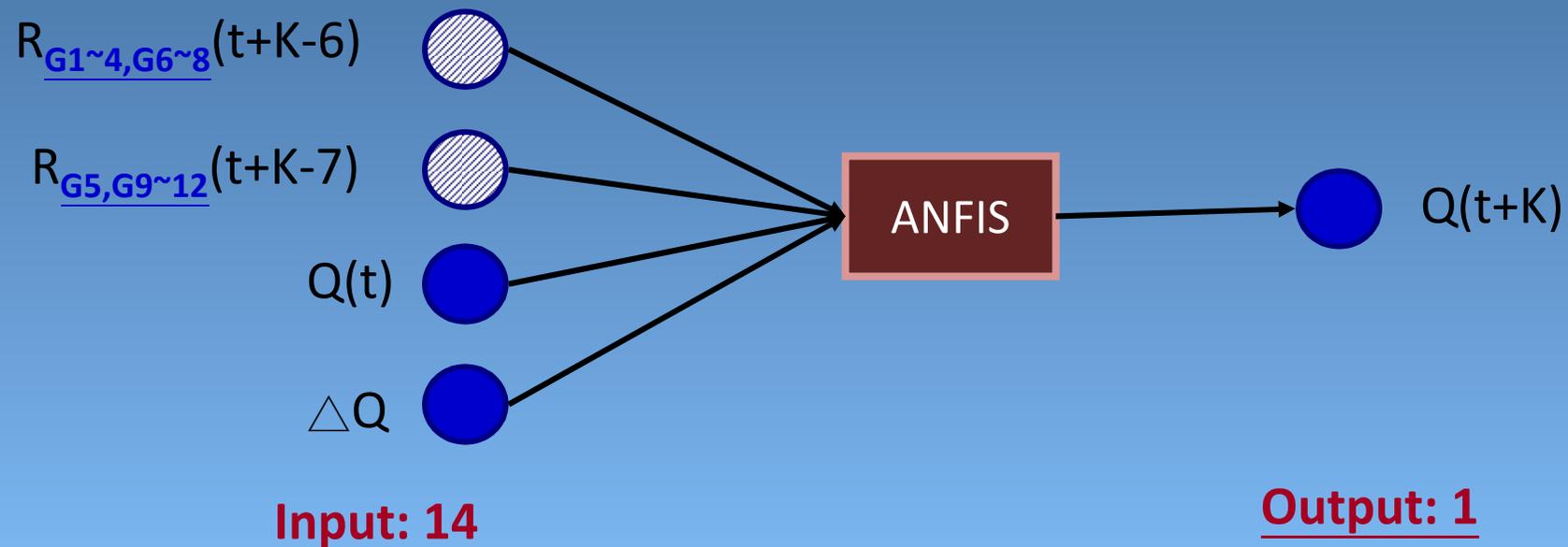
$$\Delta \text{ Inflow} = \text{Inflow}(t) - \text{Inflow}(t-1)$$

- $\Delta$  Inflow provide the trend of increase or decrease to forecasting model.



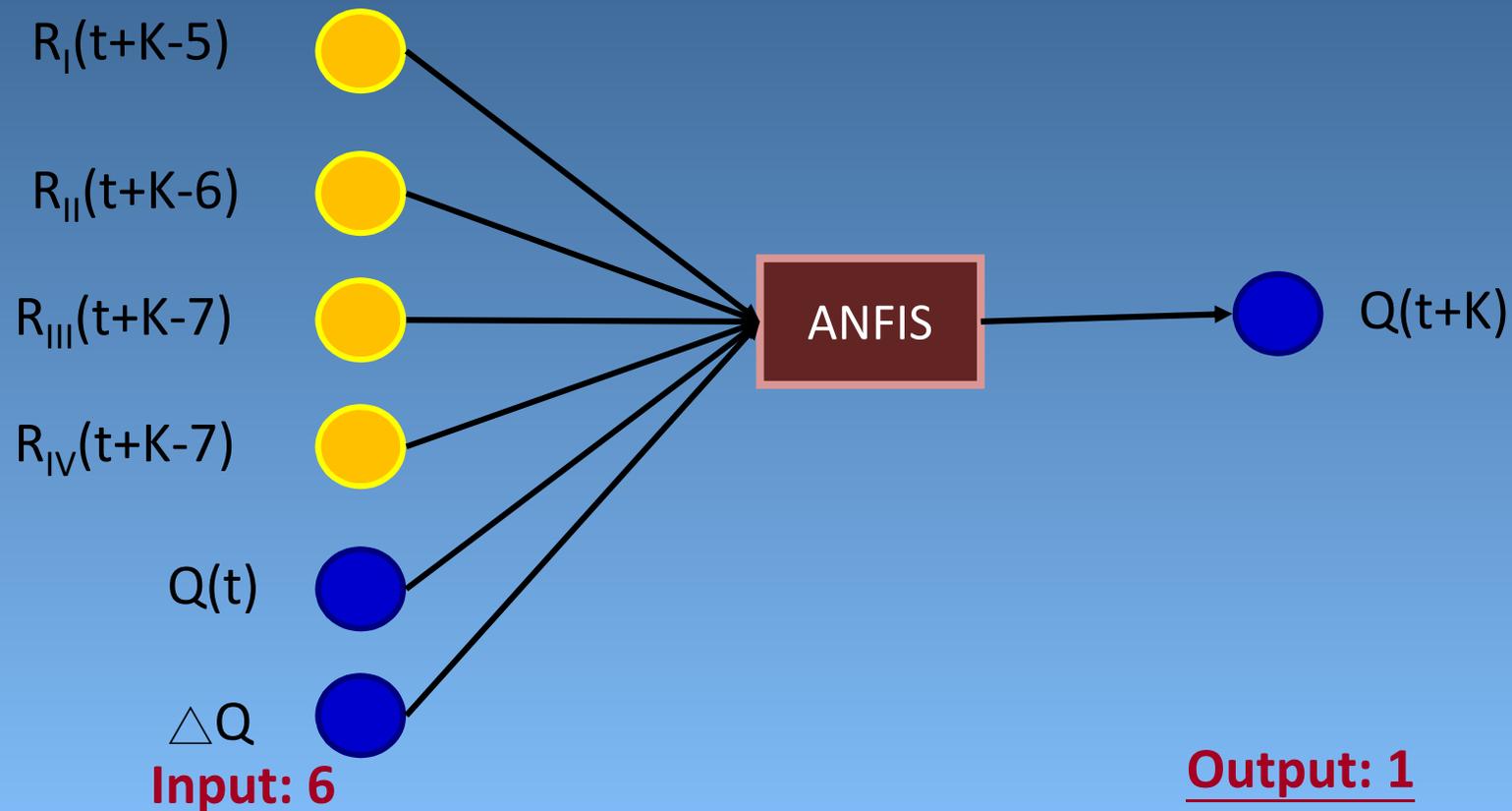
# Structure of Model Q2– Inflow and Gauge rainfall

- **Model Q2:** Forecasting inflow by using rainfall of 12 gauges with different time lag, Inflow(t) and  $\Delta$  Inflow.
- The time lag for 12 gauges were determined based on the result of correlation coefficient.



# Structure of Model Q3 – Inflow and Radar

- **Model Q3:** Forecasting inflow by using 4 sum of the rainfall with different time lag, Inflow(t) and  $\Delta$  Inflow.
- The time lag for 4 sub-catchment were determined based on the result of correlation coefficient map from Radar Rainfall.

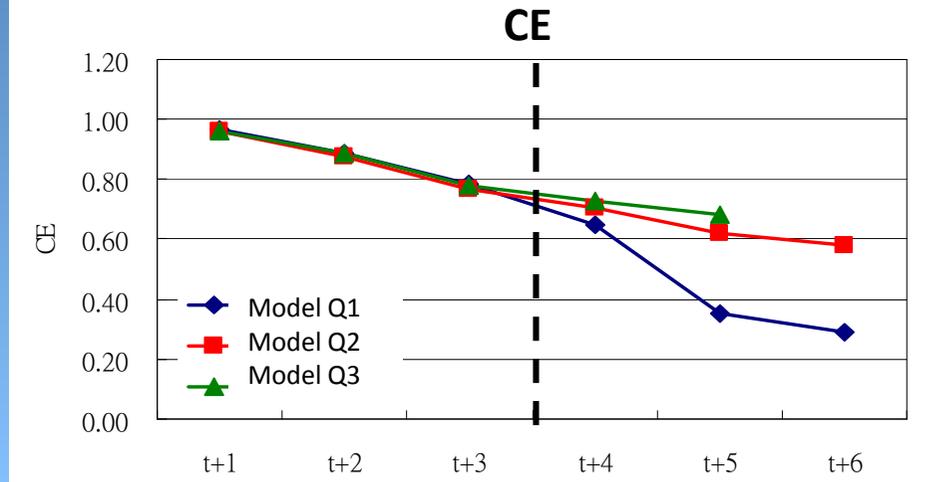
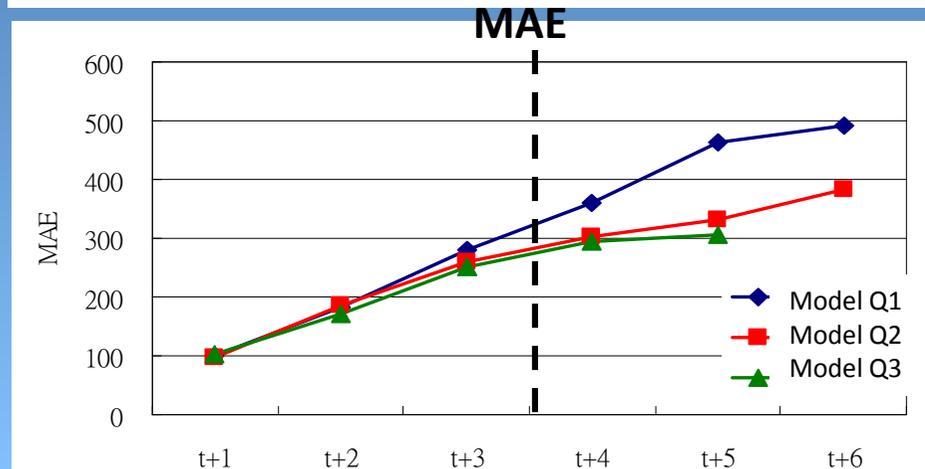
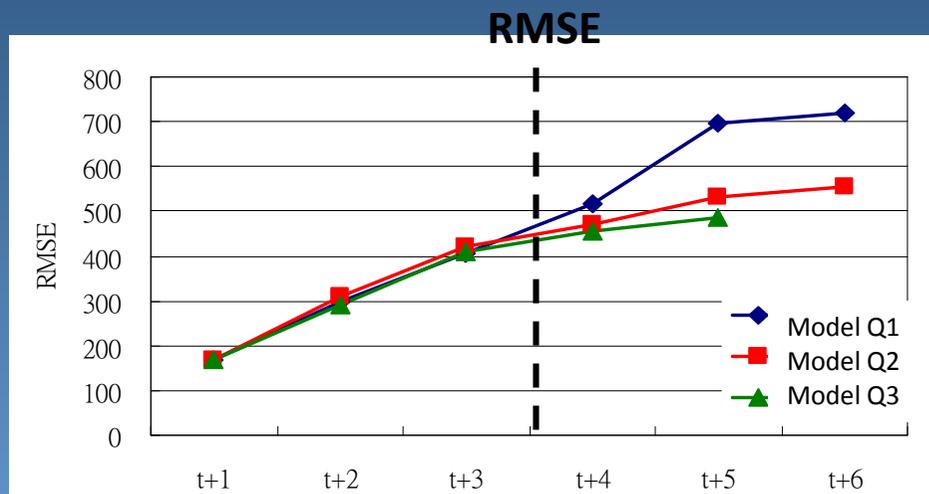
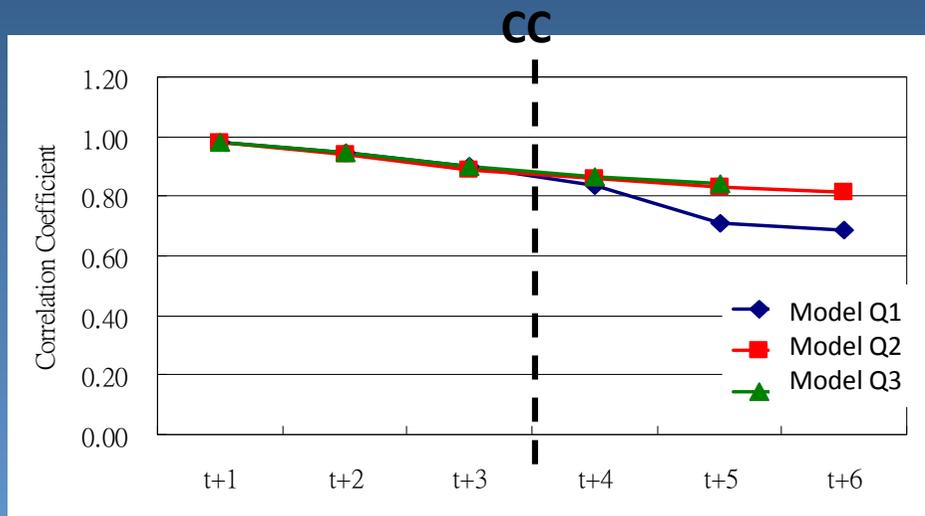


# Data set

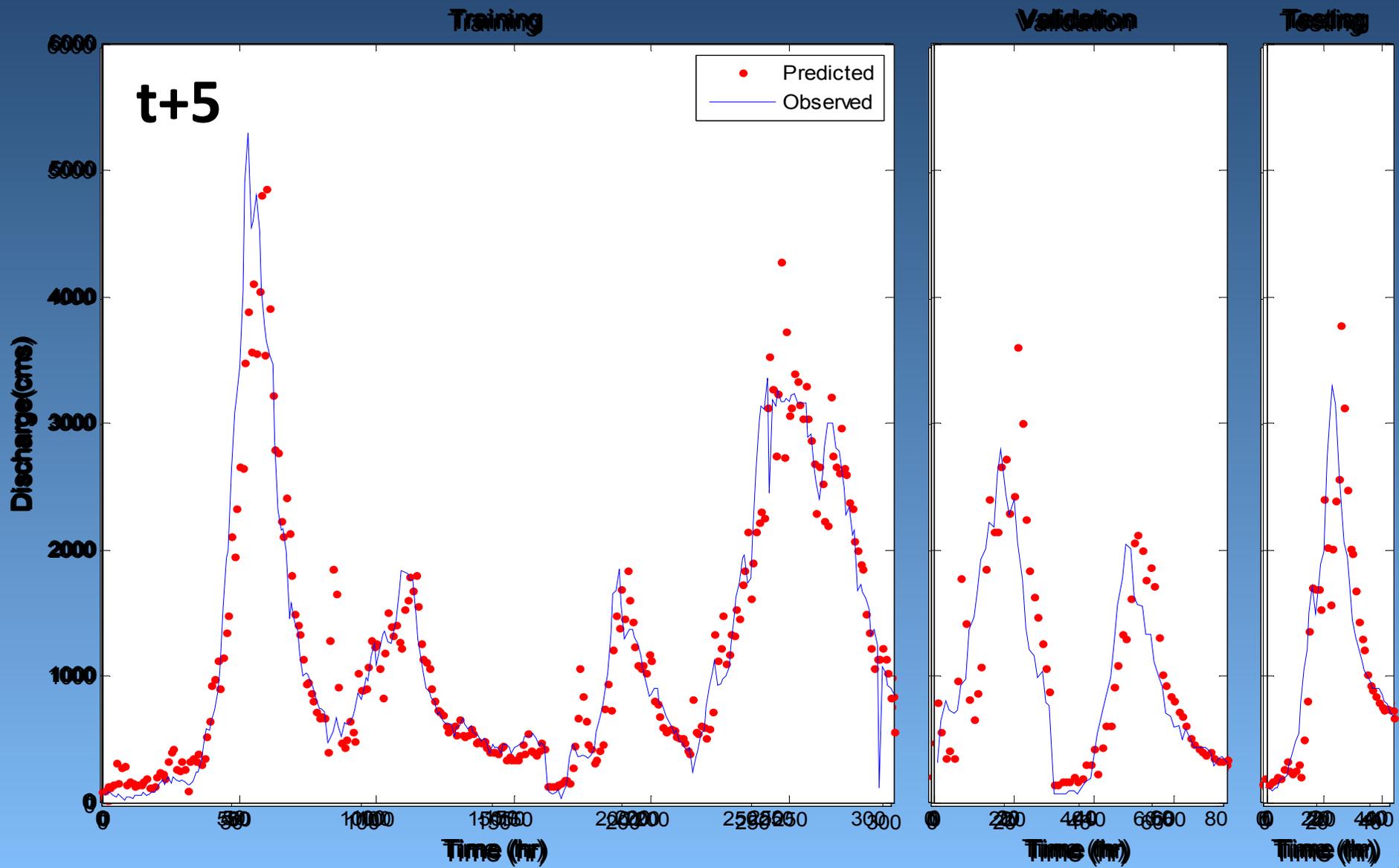
	Event	Date	Path	Peak Flow (cms)	Mean	Std.
Training	SEPAT	2007/08/16~08/19	3	1844.4	1074.09	698.22
	KROSA	2007/10/04~10/07	2	5300.39		
	KALMAEGI	2008/07/16~07/18	2	203.13		
	SINLAKU	2008/09/11~09/16	2	3351.24		
	MOROKAU	2009/08/05~08/10	3	1837.54		
Validation	WIPHA	2007/09/17~09/19	1	2788.15	1006.69	664.10
	FONG-WONG	2008/07/26~07/29	3	2039.78		
Testing	JANGMI	2008/09/26~09/29	2	3291.99	1147.78	572.91

# Testing results for different models

**Model Q3 has highest performance, especially when predict flow after t+4**

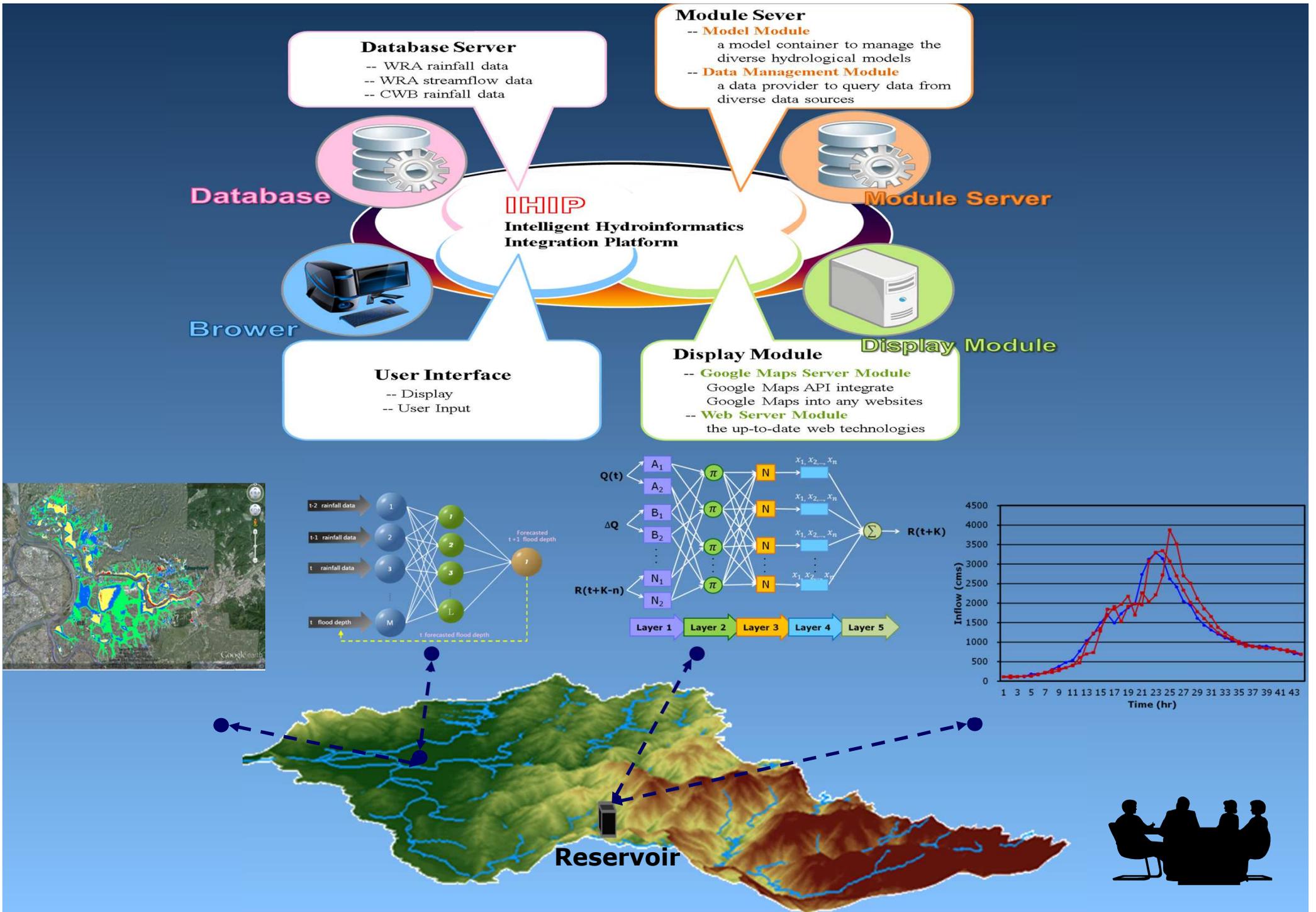


# Model Q3- time series plot





# **An early warning system to reduce disaster risk**





# Real time water level forecasting system

2012/09/11 17:00

Google map

Figures

Display legends of reservoir water level

- 小於上限(245m)
- 上限(245m) ~ 滿庫水位(245m)
- 滿庫水位(245m) ~ 超高蓄水(246m)

Catchment:  
Water level information

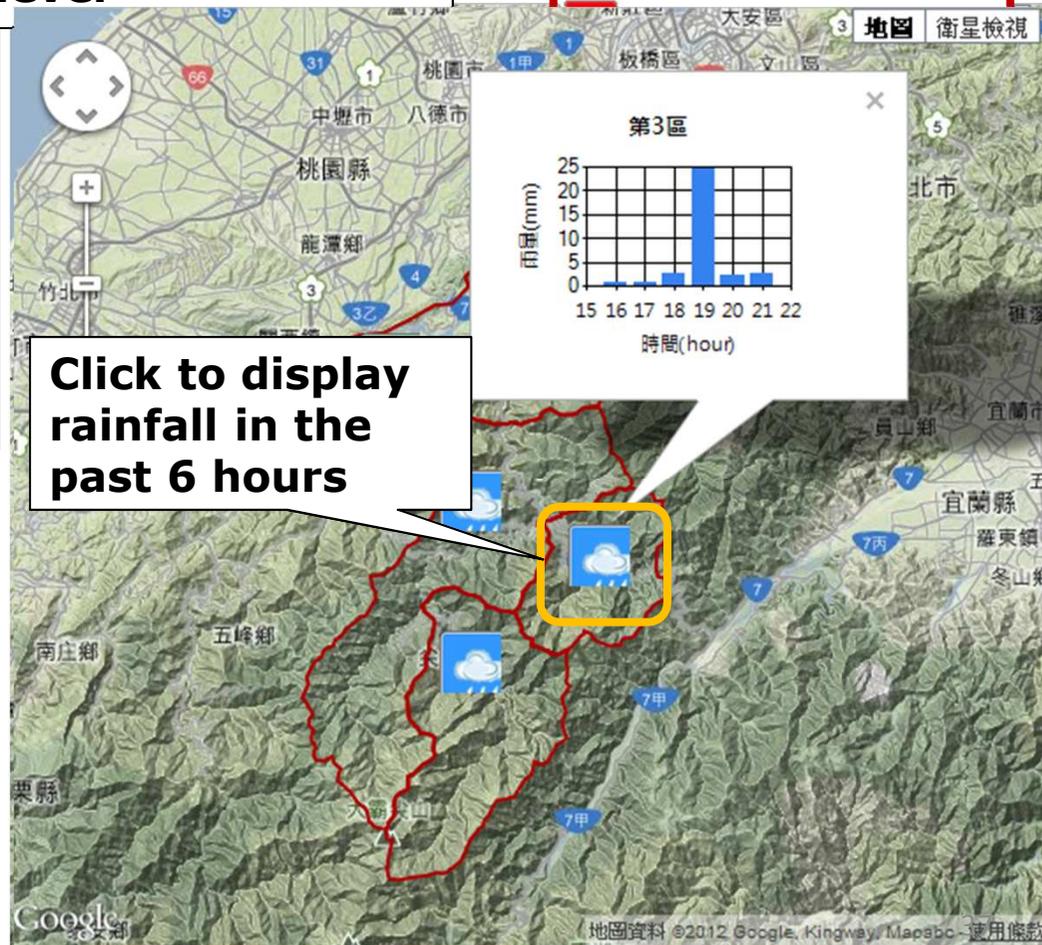
Display on Google Map

Time	Reservoir
17	243.42
18	243.37
19	243.45
20	243.31

Rainfall model:  
Rainfall information (mm):

Time	I	II	III	IV
12	0.5	0	0.8	1.6
13	0.9	1.1	2.7	0

Download file: [XML](#)



## *Conclusion*

- ❑ With more rain-gauge inputs ( in Model Q2) than four sub-catchment average inputs ( in Model Q3) did not reduce the forecasting error.
- ❑ The superior contribution arising from aggregated spatial-temporal radar rainfall on inflow forecasting is particular clear at  $t+4 \sim t+5$ .
- ❑ The radar rainfall can increase the models' performance and reduce the time shift problem.
- ❑ The on-line early warning system built in this study can be very useful for flood control and management.

<http://www.youtube.com/watch?v=jfer6mKoORo>

A composite image featuring a globe on the left with binary code (0s and 1s) overlaid on it. The globe is set against a background of a satellite-style image of a mountain range with a river valley. The text "Thanks for Your Attention" is overlaid in yellow on the right side of the image.

Thanks for Your Attention