Deficiencies in Flash Flood Nowcasting and the Risk of Catastrophic Flooding for Metropolitan Taipei

Tim Hau Lee

Civil Engineering, NTU

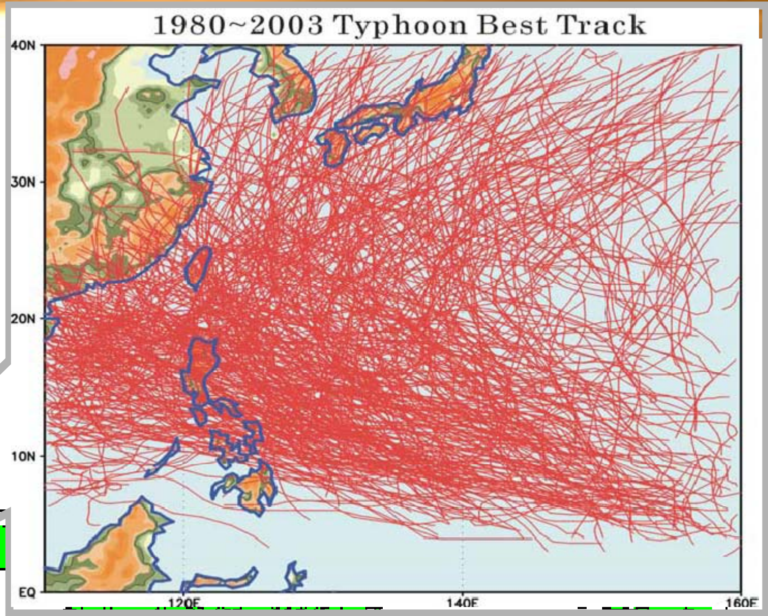
Content

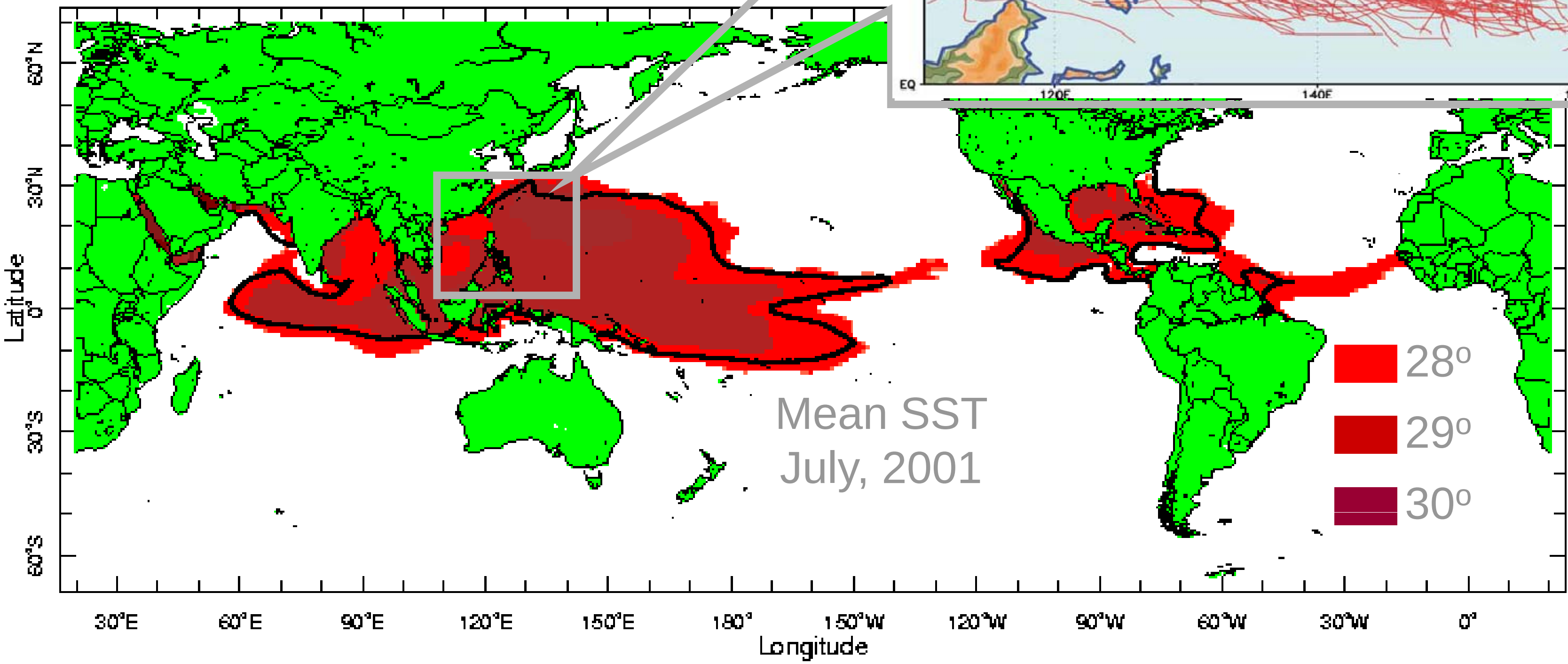
- Some facts about the floods at Taiwan
- Distributed Runoff And Inundation Nowcast System (DRAINS)
- Typhoon Nari induced flood, responses and mitigation measures
- Deficiencies and Ideas for Improvement
- Relocating Morakot Rain to Danshui River
- Future Prospects

Hydrometeorology Challenges

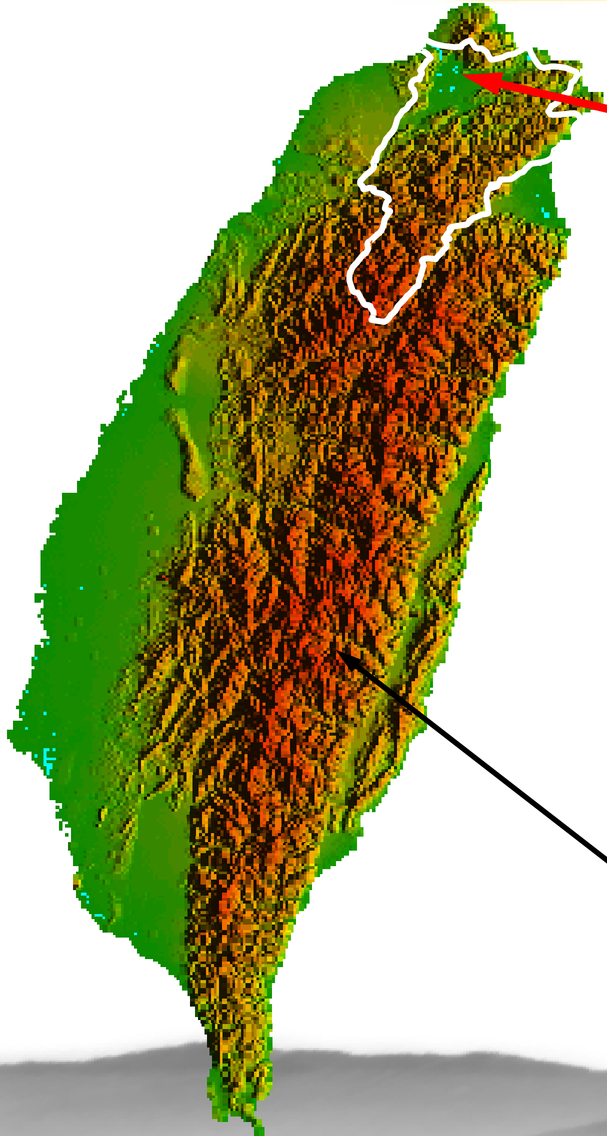
On the average, Taiwan is struck by 3.5 typhoons/year

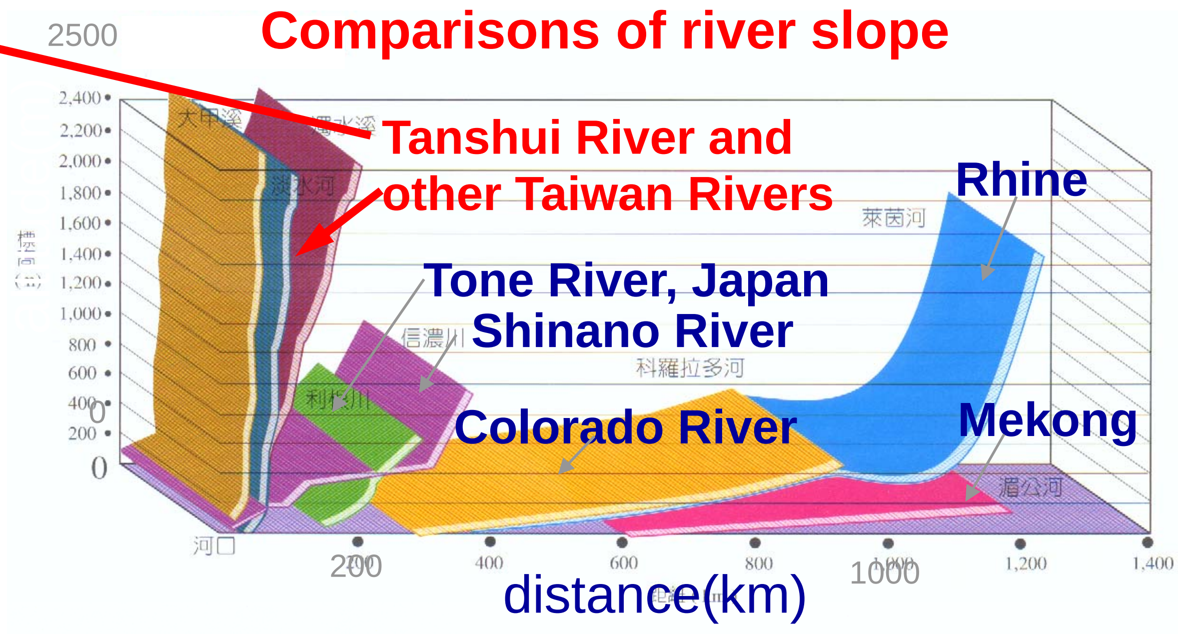
Warm NW Pacific sea surface temperature produces the highest Typhoon Maximum Potential Intensity on earth.





Topography and River Slope



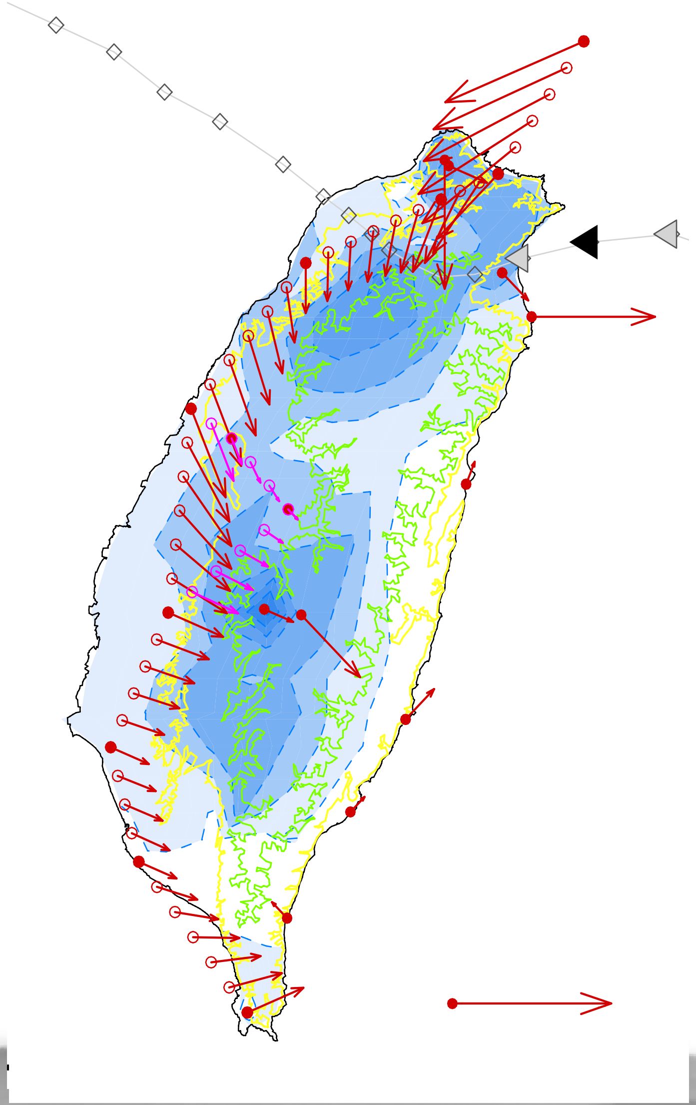


Island length : ~ 400 km

Island width : < 150 km

Highest mountain : 3950 m

Orographic Enhanced Typhoon Rainfall



Strong wind/high Froude number over-mountain airflow induces heavy rainfall on the windward side

Without orographic enhancement, typhoon rainfall intensity:

i ~ 20 mm/hr e.g. over ocean

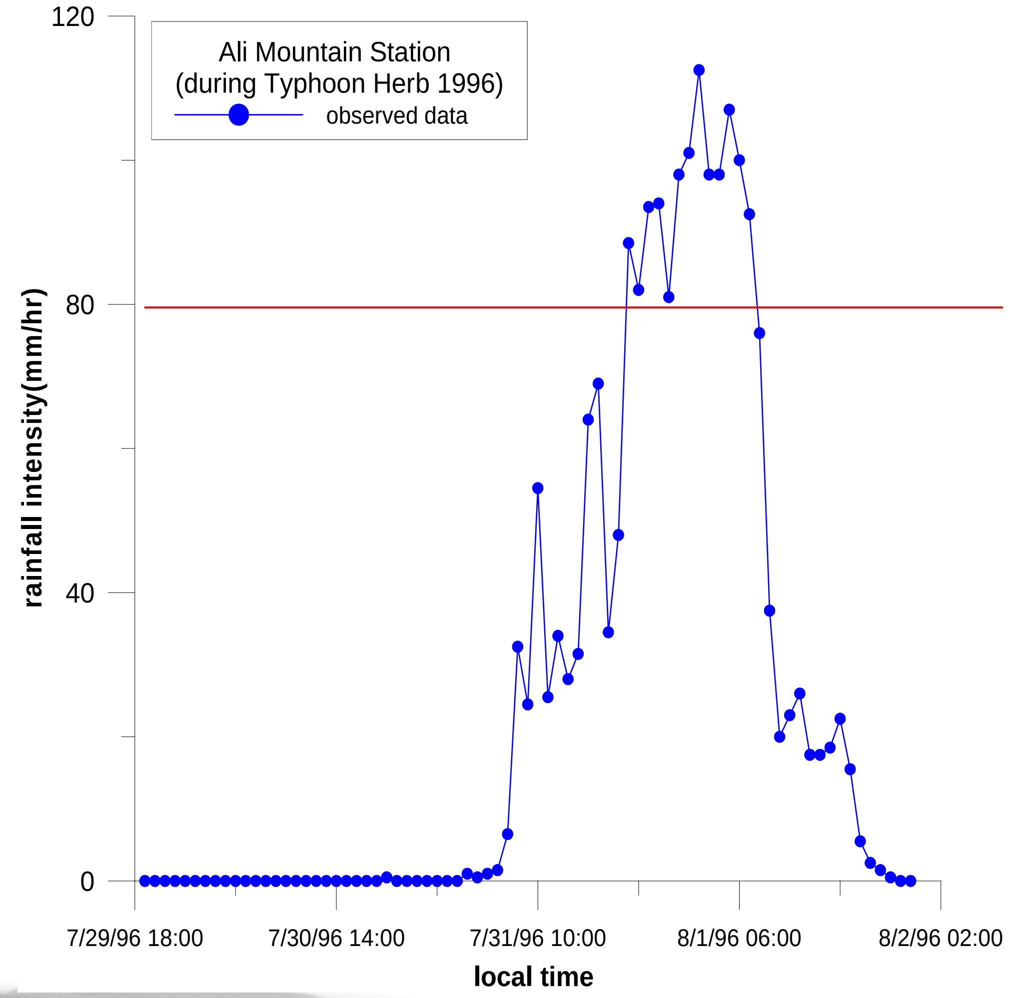
With orographic enhancement :

i ~ 50 mm/hr

Heavy rainfall and steep terrain causes flash flood and debris flow in the upstream valleys as well as inundation in the alluvial plain.

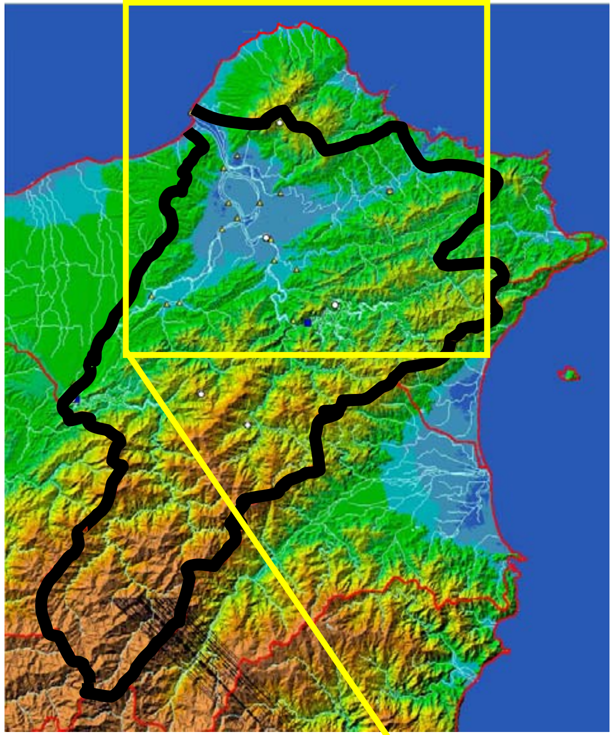
Orographic Enhanced Typhoon Rainfall

- During Typhoon Herb 1996, Ali Mountain Station recorded hourly rainfall intensity was continuously greater than 80 mm/hr for 13 hours.
- Maximum 24-hour rainfall is 1748mm, which is about 94% of the world record.



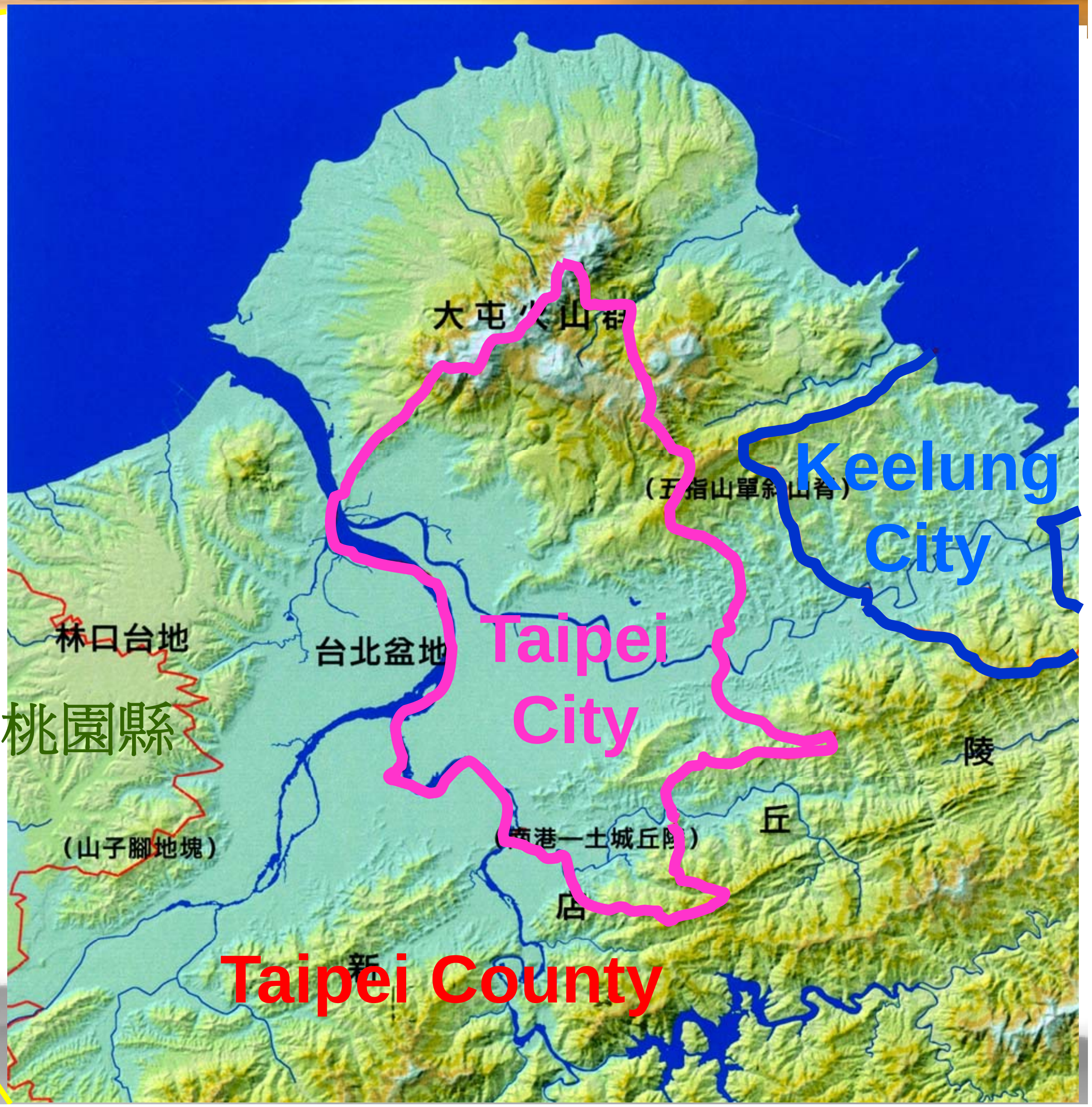
Challenge: Extreme flood passes through

Taipei Metro



Basin area = 2726 km2

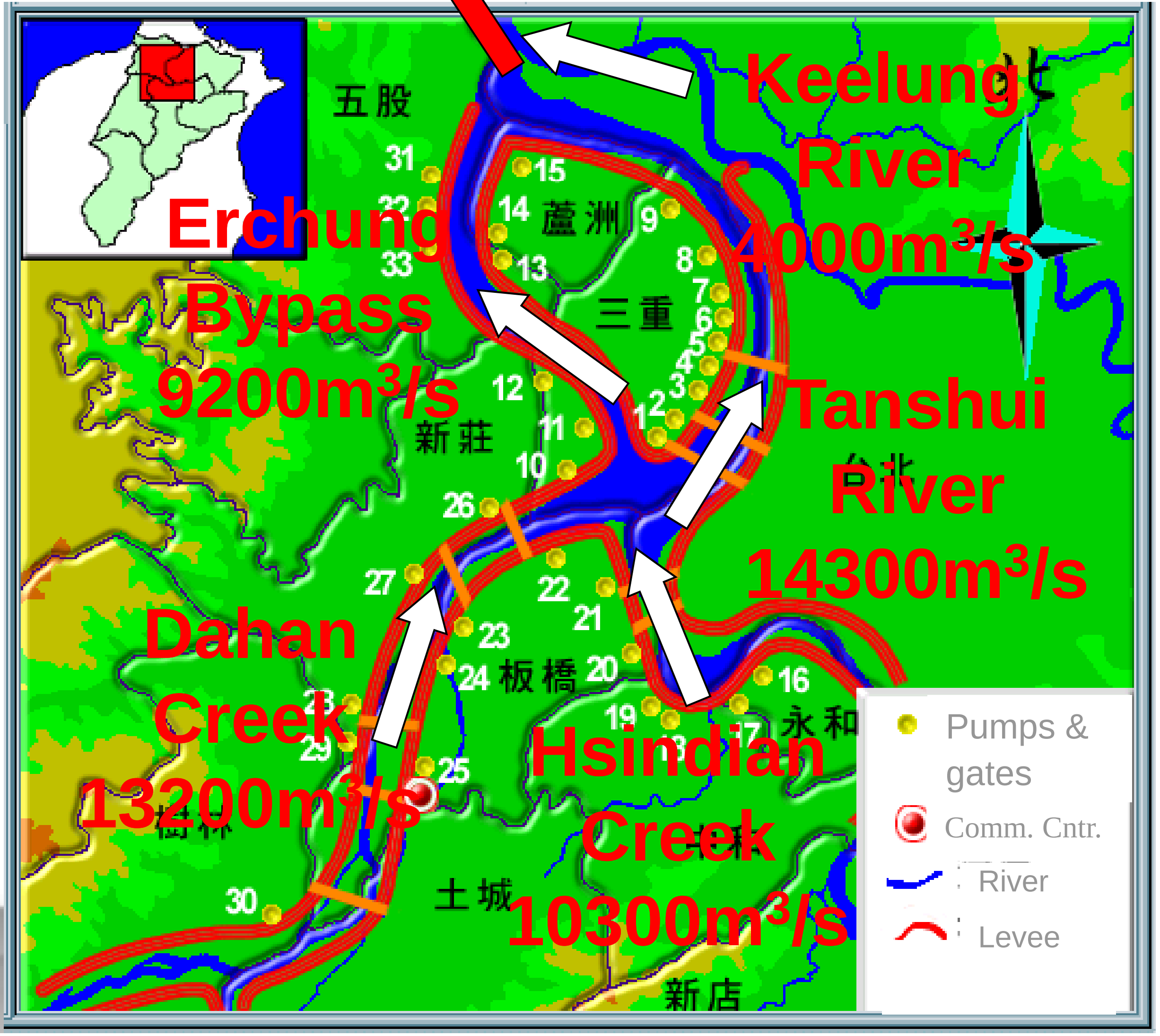
0-20m a.m.s.l. : 9%



Huge Flood Discharge

200 Year Return Period **25000 m^3/s**

- 200-year return period flood : 25,000 m^3/s equivalent to 33mm/hr*basin area 2726km^2
- Levee height: >10m a.m.s.l.
- Urban drainage: pumped into stream



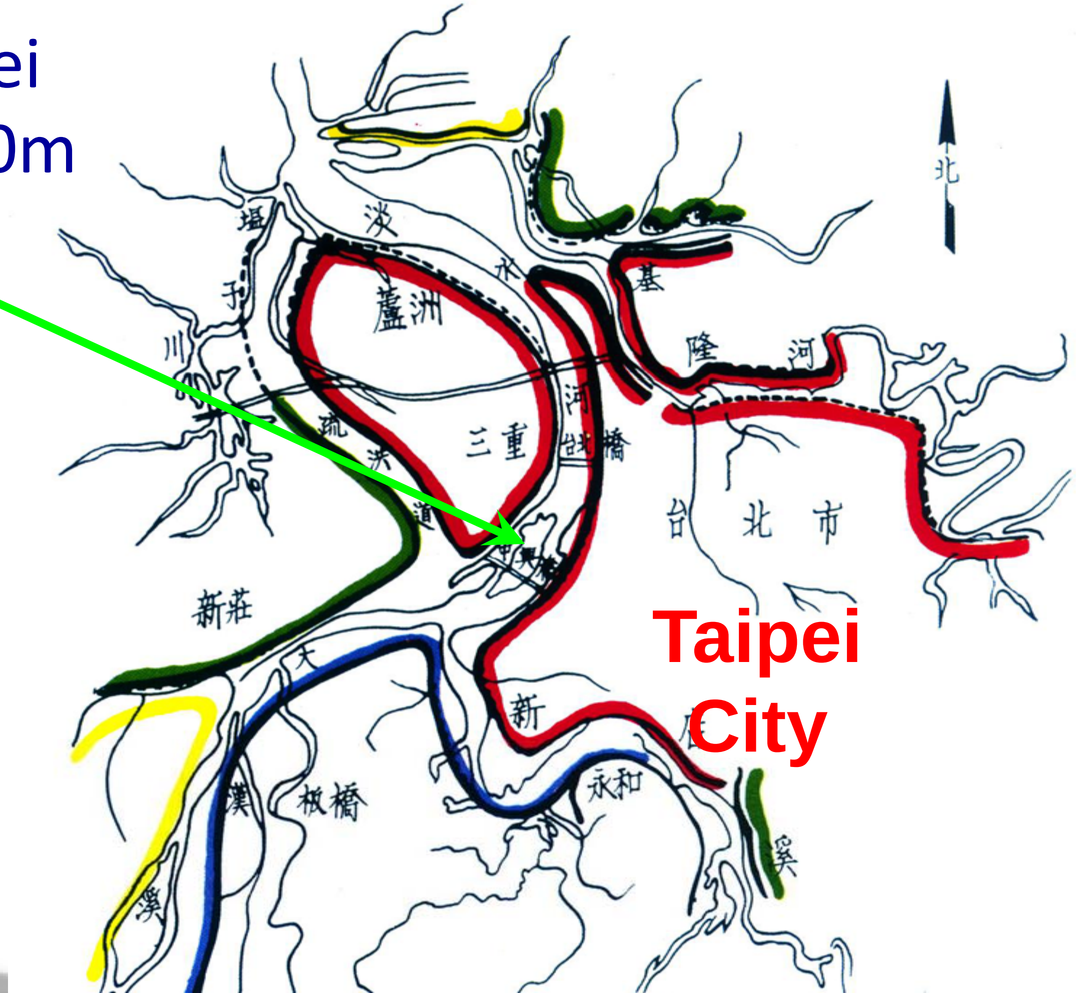
Flood Mitigation Project for Taipei

Raise Embankments

- Levee height at Taipei Bridge is raised to 10m above m.s.l.

Length of newly built or raised:

- Taipei City 98 km
- Taipei County 96km

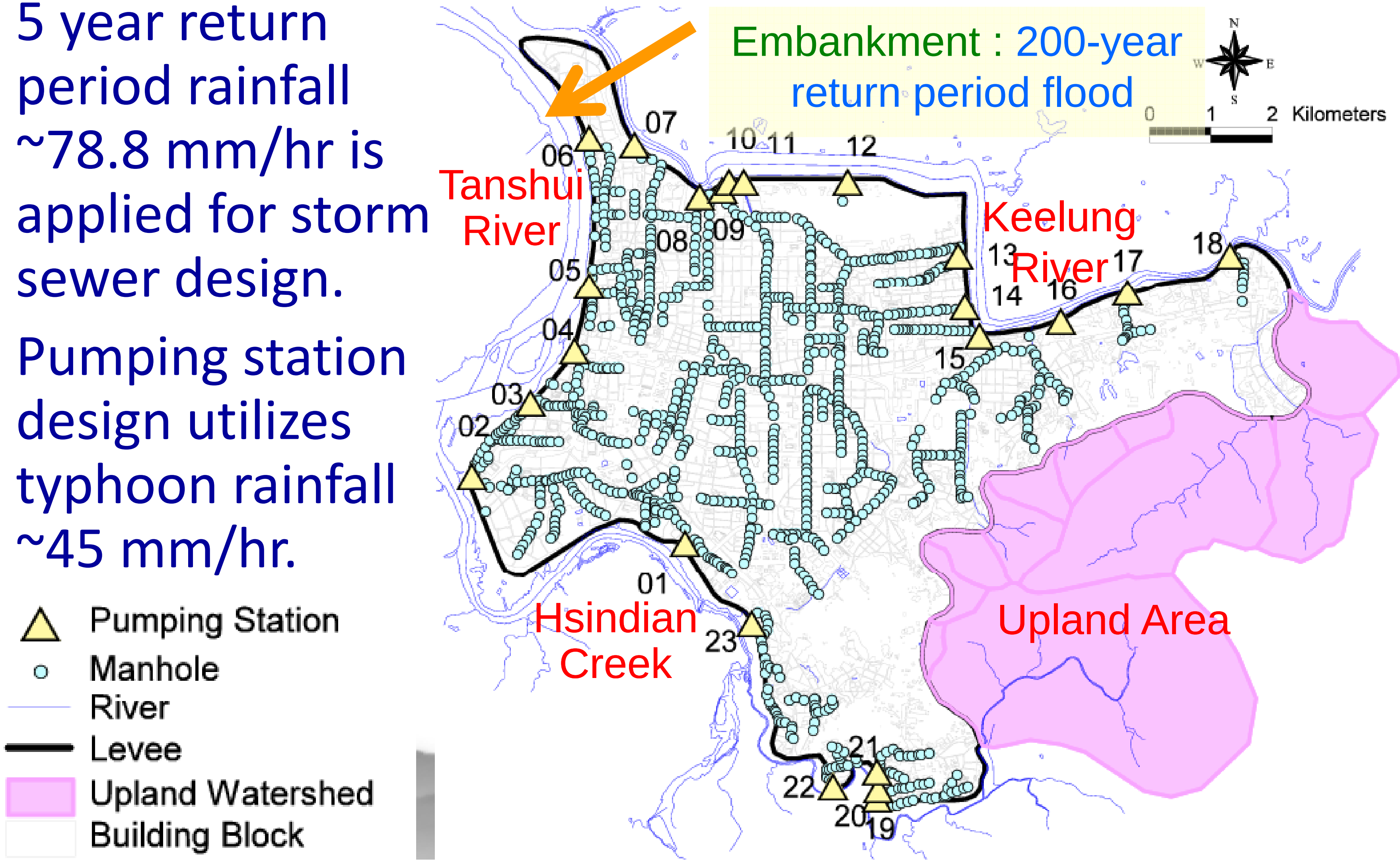


Birdseye View of Taipei City

Flood Mitigation Project for Taipei

Develop Urban Drainage System

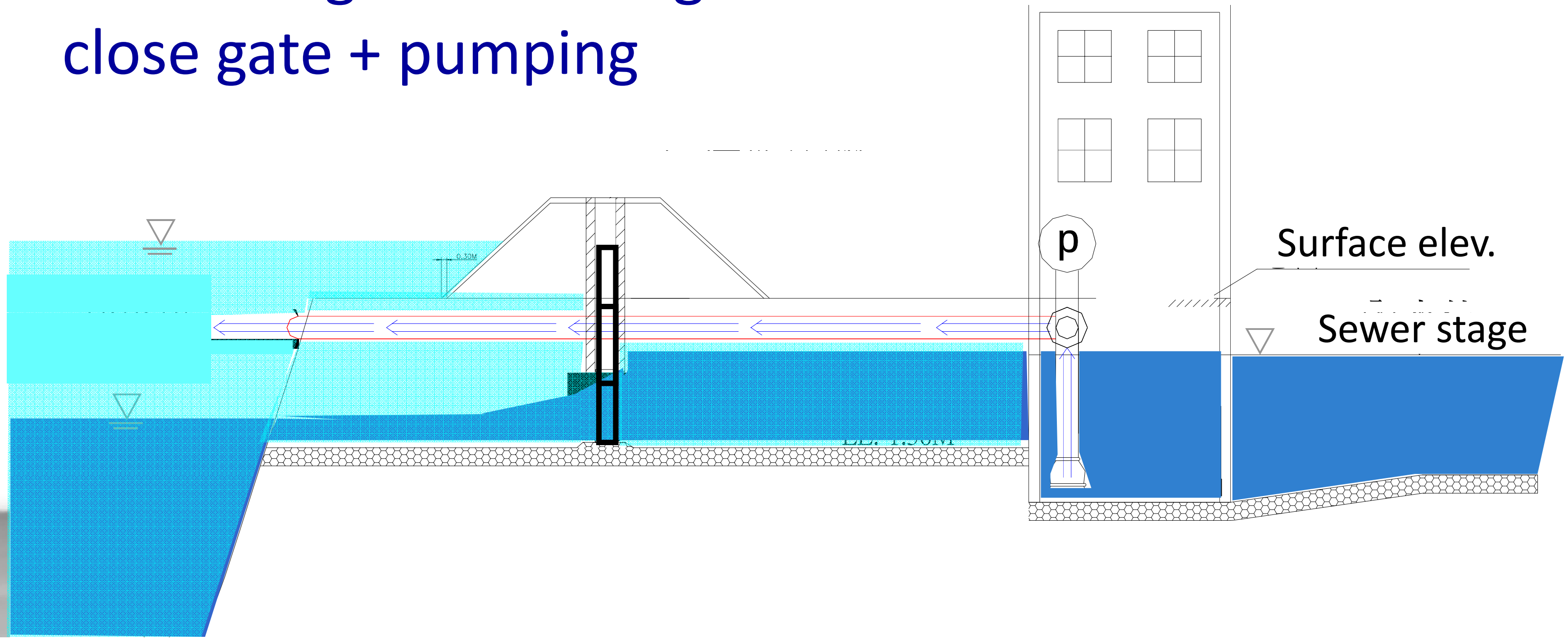
- 5 year return period rainfall ~78.8 mm/hr is applied for storm sewer design.
- Pumping station design utilizes typhoon rainfall ~45 mm/hr.



Flood Mitigation Project for Taipei

Operation Rules of Pumps and Gates

- Pumps are operated locally with the help of Danshui River Flood Forecast Center to lower river stage by reducing reservoir discharge.
- Sewer stage > river stage : open gate (+ pumping)
- Sewer stage < river stage :
  close gate + pumping



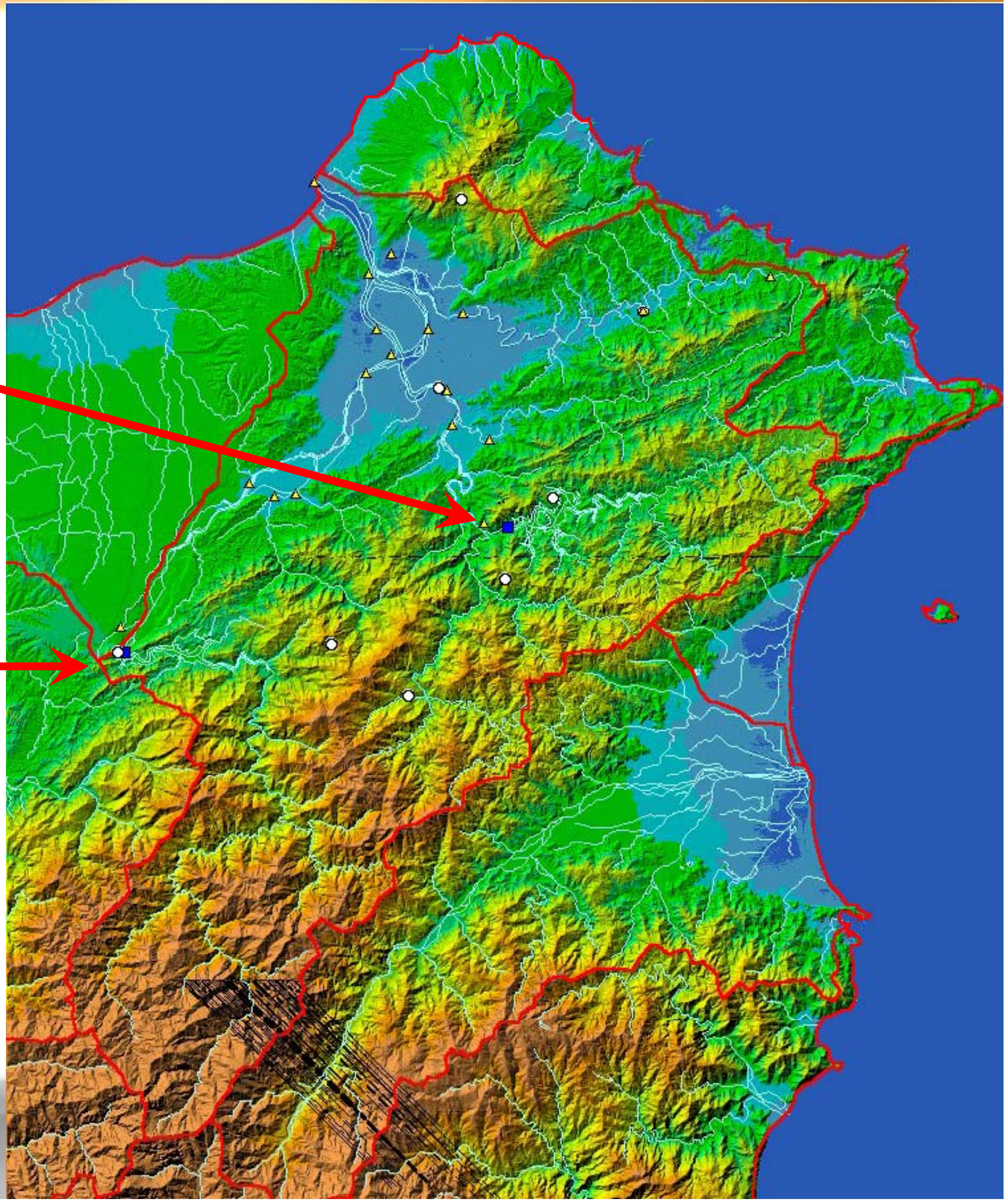
Yu-chen Pumping Station at Keelung River

Largest Pumping Station, Max. Capacity 184 m^3/s (8 *23)

Flood Mitigation Project for Taipei

Optimize Reservoir Operation for Flood Peak Reduction

- Feitsui Reservoir : storage 4×10^8 m^3, flood peak travel time to Taipei Bridge ~1.5hr,
- Shihmen Reservoir : storage 2.3×10^8 m^3, flood peak travel time to Taipei Bridge ~ 3.0hr



Types of Flooding at Taipei

- **Major Flooding:**
  - Caused by flood stage topping levee or major levee failure.
  - Large area, max. depth > 1.5m inundation.
  - Most underground streets, subway, basements and 1st floor near dike are submerged.
  - Events: 2000 Xangsane, 2001 Nari typhoons at Keelung River.
  - 3- to 6-hr leadtime river stage nowcast using DRAINS.

Types of Flooding at Taipei

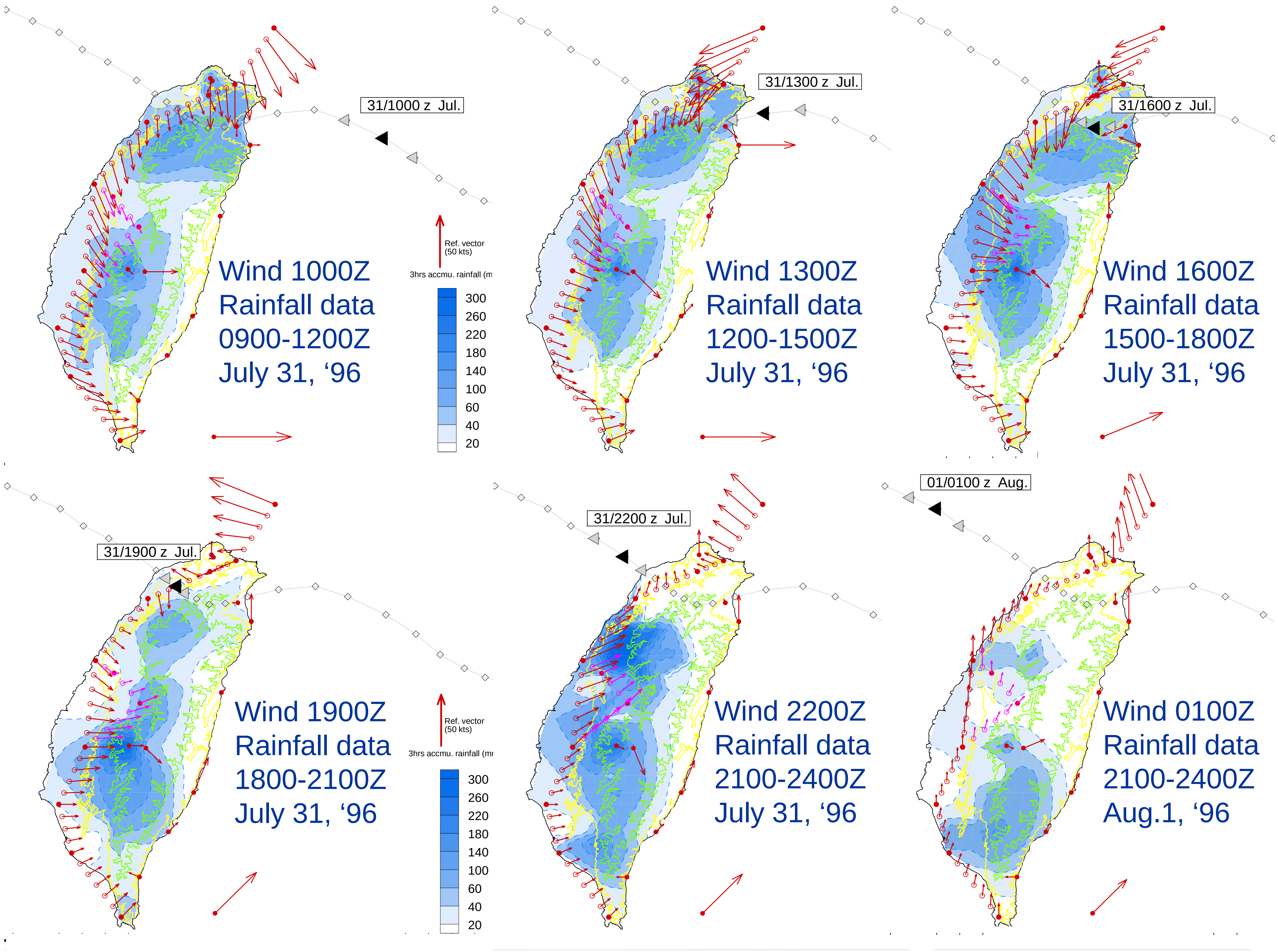
- **Minor Flooding:**
  - Caused by rainfall intensity exceeding sewer/pumping capacity only for a short period.
  - Inundation depth <0.5m
  - Some basements are submerged and buildings inundated.
  - Gone in a few hours.
  - Happens a few times a year.
  - A radar-based urban flash flood nowcast system is needed.

Types of Flooding at Taipei

- **Moderate Flooding:**
  - Caused by minor levee failure, flood gate, pumping station failure or a combination of the 3.
  - 0.5m < max. inundation depth < 1.5m.
  - Many underground space are submerged
  - 2004 Typhoon Aere. Flood stage (6.8m amsl) is 6.5m higher than the adjacent ground surface (0.3m) near Taipei Bridge
  - A system with video monitoring + river stage + urban flash flood nowcasting is needed

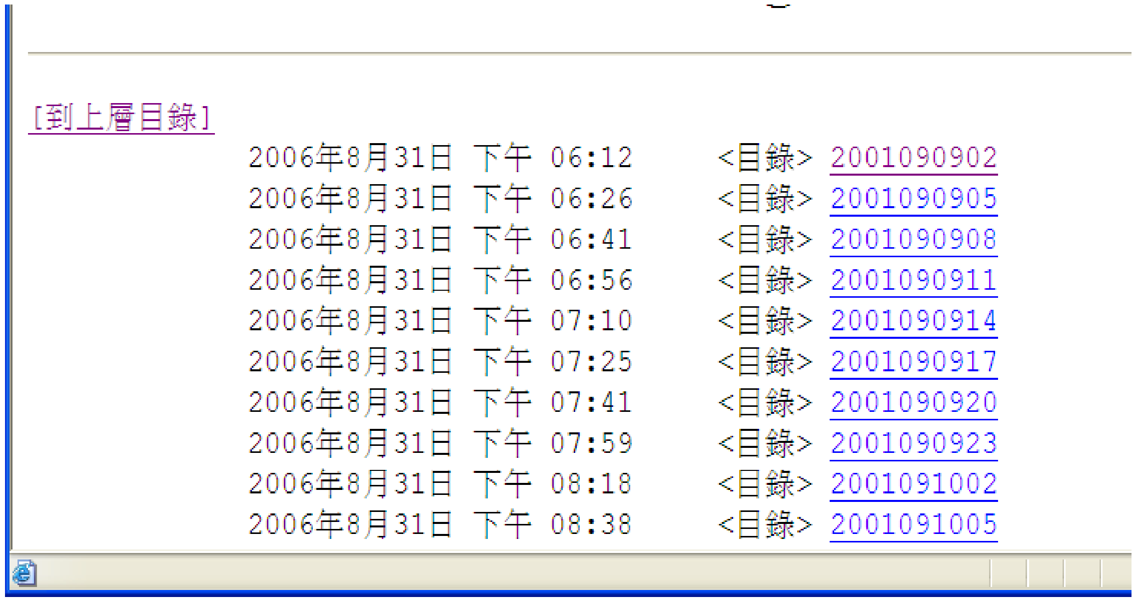
Climatology Typhoon QPF Module

- CTQPF bases on the climatology relationship among typhoon centers, maximum wind speed and station rainfall mined from historical events data.
- Utilize the typhoon track and maximum wind speed forecasts by Central Weather Bureau (CWB), Japan Meteorological Agency (JMA) and Joint Typhoon Warning Center (JTWC) as predictors.
- Supplies data for flood forecasting as well as for decision support GUI display


31/1000 z Jul.
Wind 1000Z
Rainfall data
0900-1200Z
July 31, '96
Ref. vector
(50 kts)
3hrs accmu. rainfall (m
300
260
220
180
140
100
60
40
20
31/1300 z Jul.
Wind 1300Z
Rainfall data
1200-1500Z
July 31, '96
31/1600 z Jul.
Wind 1600Z
Rainfall data
1500-1800Z
July 31, '96
31/1900 z Jul.
Wind 1900Z
Rainfall data
1800-2100Z
July 31, '96
Ref. vector
(50 kts)
3hrs accmu. rainfall (m
300
260
220
180
140
100
60
40
20
31/2200 z Jul.
Wind 2200Z
Rainfall data
2100-2400Z
July 31, '96
01/0100 z Aug.
Wind 0100Z
Rainfall data
2100-2400Z
Aug.1, '96

Climatologic Typhoon QPF Products

- Covers the Island at 0.0125 deg. Lat-Lon resolution, and divides into watersheds.
- Provides 24-120 hr lead-time at 1-hr resolution.

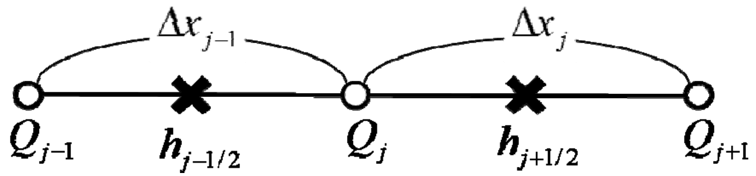


[到上層目錄]

2006年8月31日	下午 06:12	<目錄>	2001090902
2006年8月31日	下午 06:26	<目錄>	2001090905
2006年8月31日	下午 06:41	<目錄>	2001090908
2006年8月31日	下午 06:56	<目錄>	2001090911
2006年8月31日	下午 07:10	<目錄>	2001090914
2006年8月31日	下午 07:25	<目錄>	2001090917
2006年8月31日	下午 07:41	<目錄>	2001090920
2006年8月31日	下午 07:59	<目錄>	2001090923
2006年8月31日	下午 08:18	<目錄>	2001091002
2006年8月31日	下午 08:38	<目錄>	2001091005

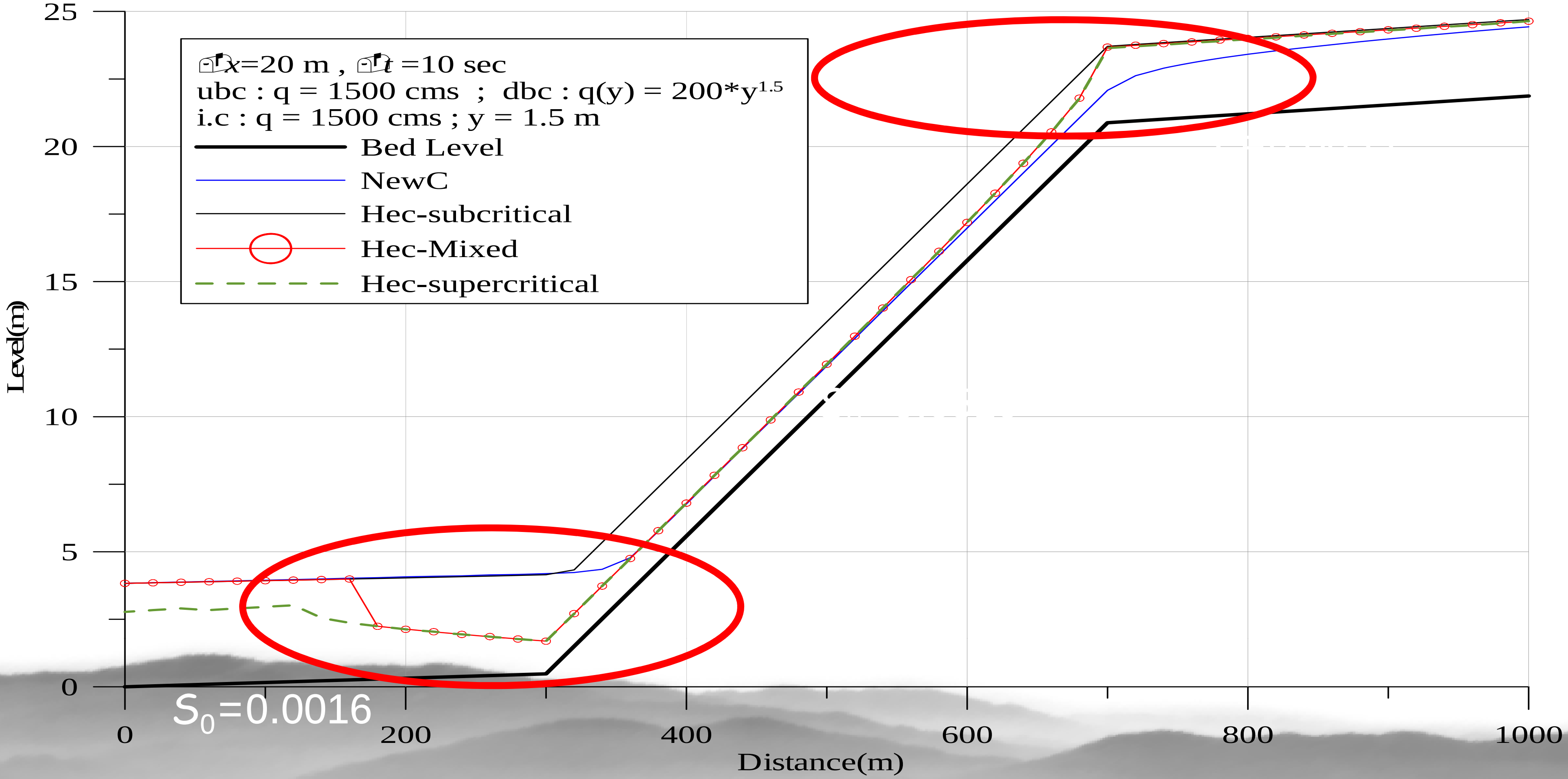
NewC Channel Routing Module

- Adopts NewC Scheme by Kutija(2002) for flood routing
- Use staggered grid, eliminate stage and reduce to tri-diagonal coefficient matrix of discharge, similar to Abbott-Ionescu technique
- Simplify the convective acceleration of momentum term to enable stability for trans-critical flow simulation.

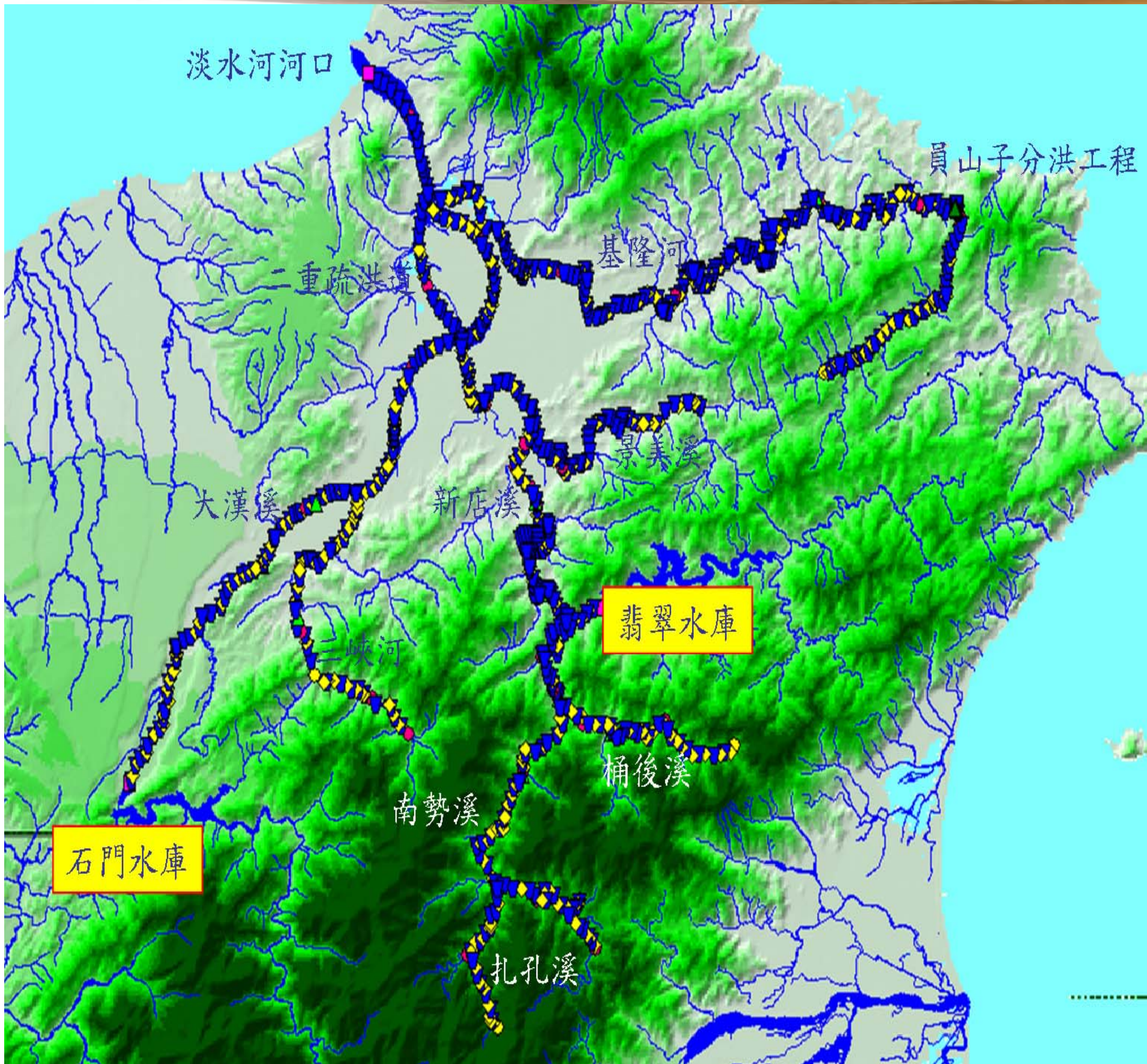


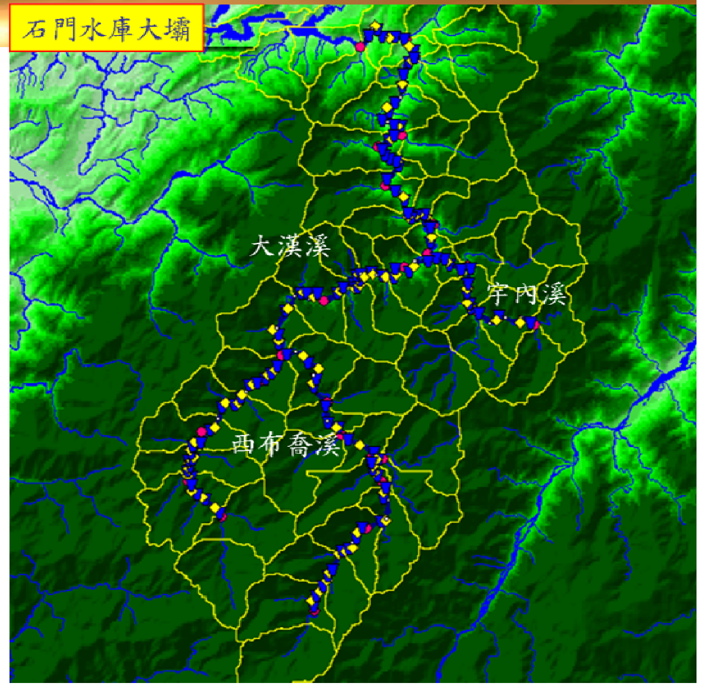
NewC Scheme, Pros and Cons

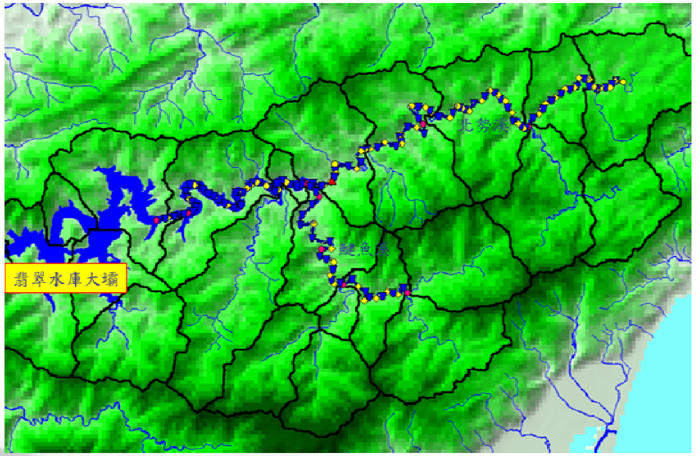
- Pros: Continuous trans-critical simulation enabling future data assimilation with Adjoin State Method.
- Cons: Stage is not correct where depth variation is large



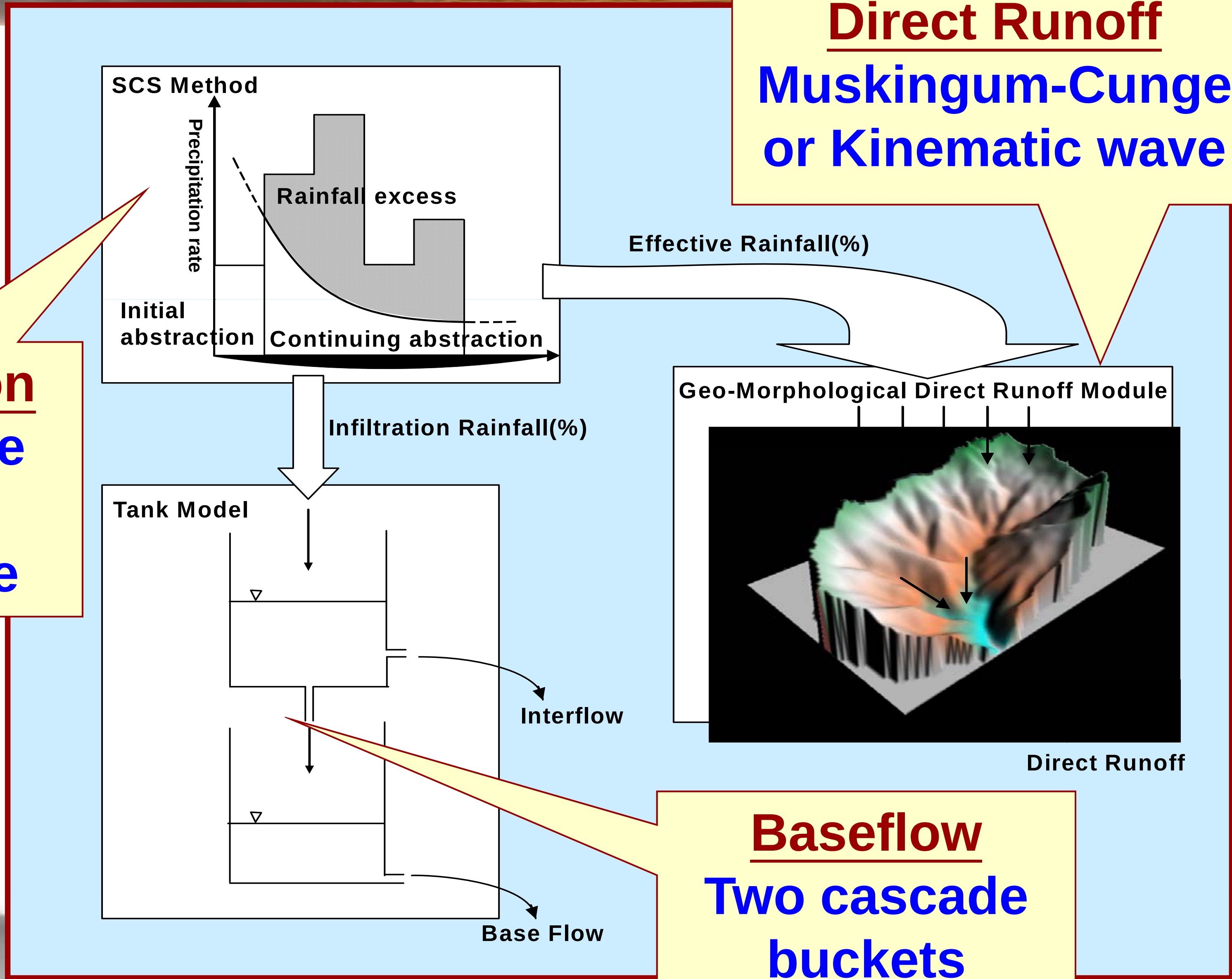
Tanshui River Channel/Catchment Layout







Geo-Morphological Runoff Module



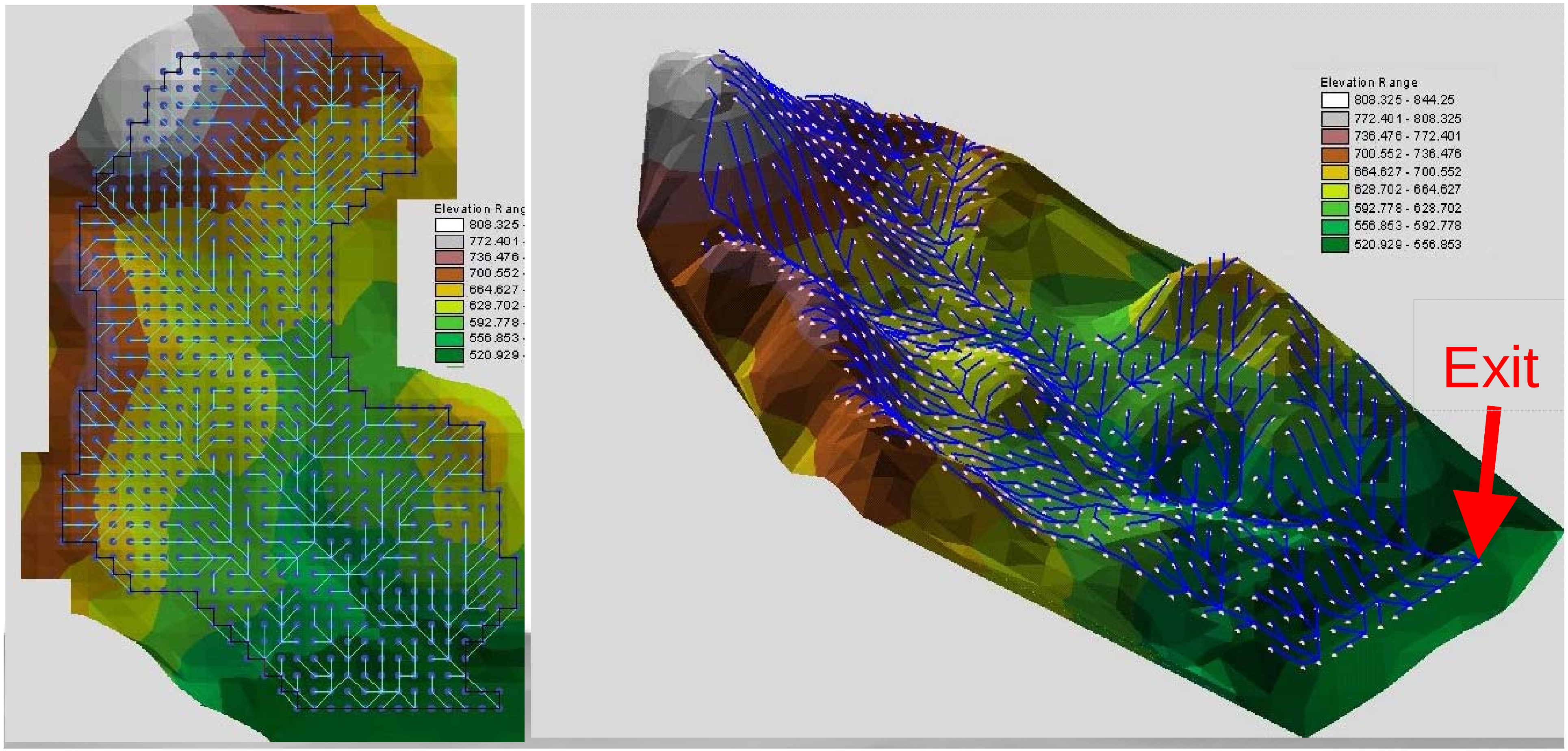
Direct Runoff
Muskingum-Cunge or Kinematic wave

Abstraction
SCS Curve Number Technique

Baseflow
Two cascade buckets

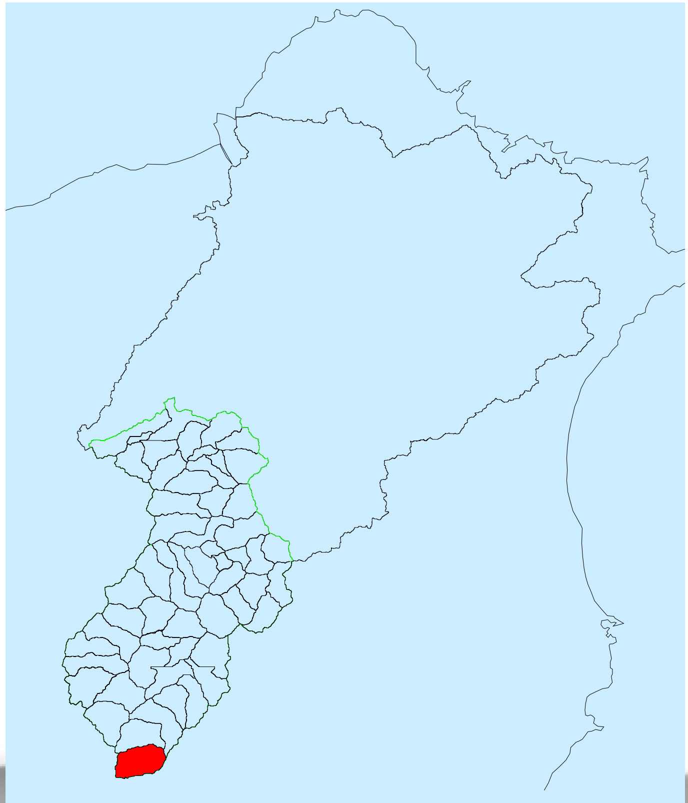
Direct Runoff Module

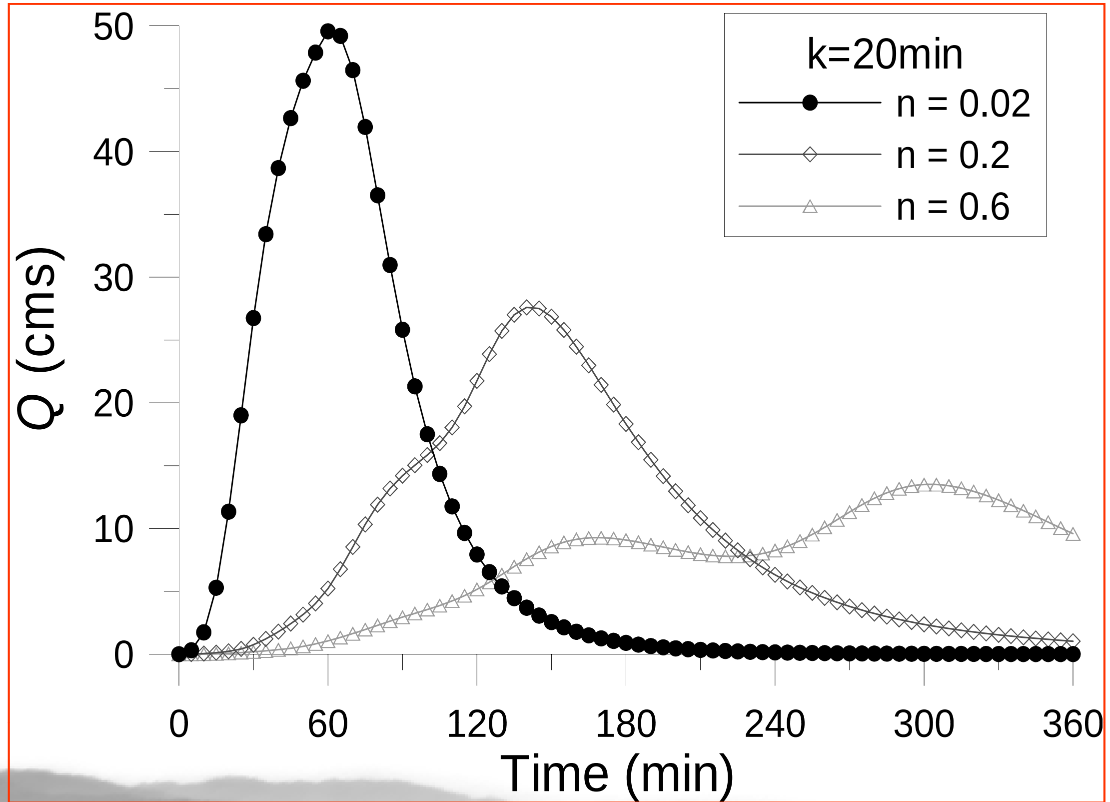
- Without linear assumption. Real-time computation.
- Save the final state variables in all the gullies and to be retrieved as the initial condition for next nowcast.



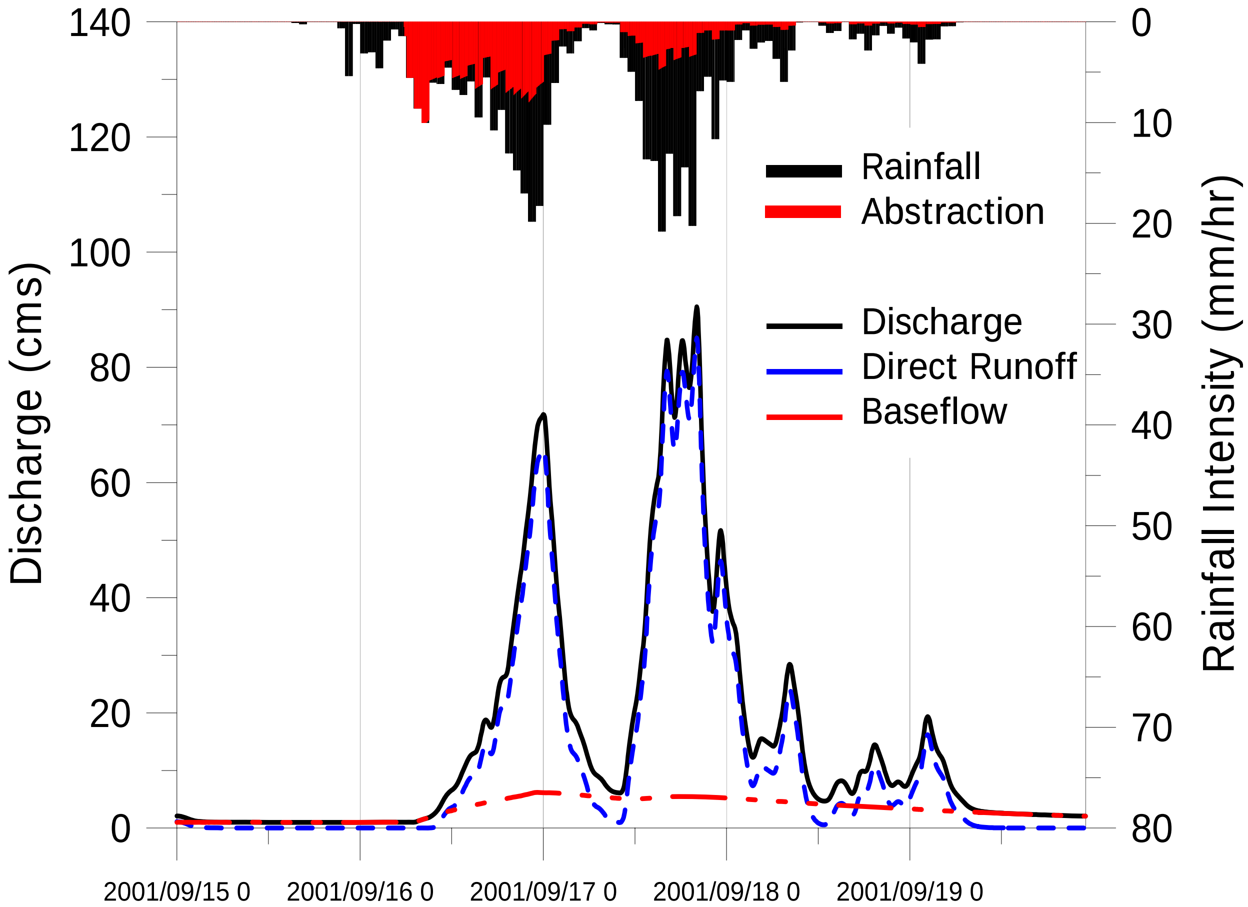
Direct Runoff Hydrographs

- Direct runoff hydrograph from 10mm/1hr-duration excess rainfall with different Manning's roughness coef.
- Surface runoff through a linear reservoir with k=20min.





Runoff for Typhoon Nari Rainfall



Area=19.9km^2

Simulation Parameters

CN=55

K= 40min

Manning's n=0.04

Upper Tank Orifice Height= 0.04 m

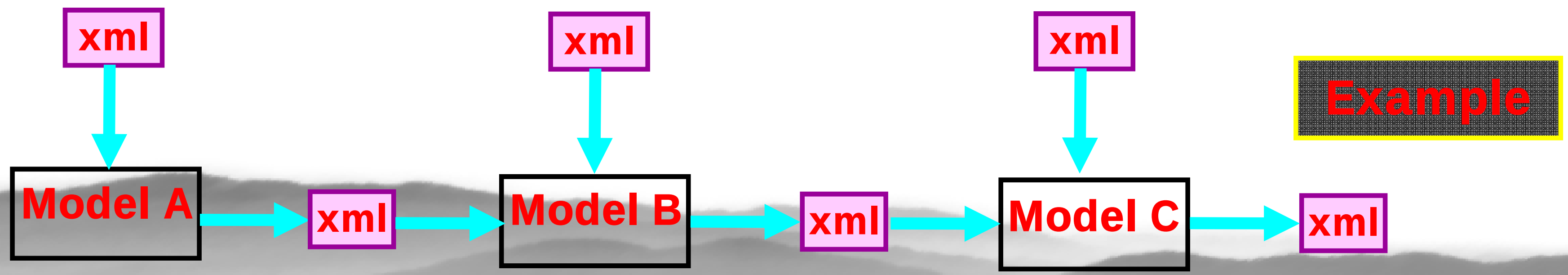
Upper Tank Orifice 1 Time Constant=3 day

Upper Tank Orifice 2 Time Constant=3 day

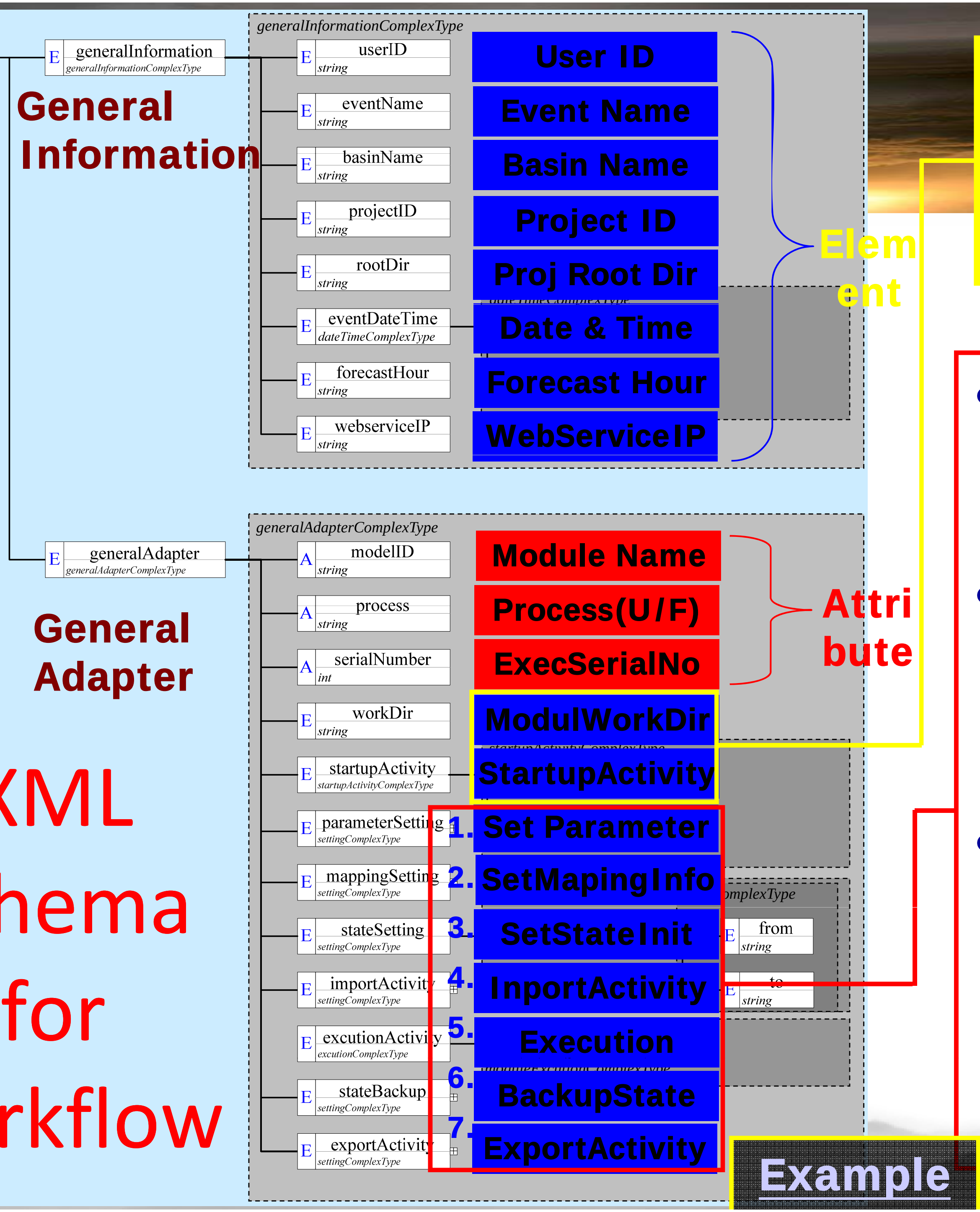
Lower Tank Orifice Time Constant=14 day

XML-Based I/O files, Adapters & Workflows

- Define XML I/O files for all hydrologic models. Time-series and map-stack types.
- Use pre- and post adapters to modulize hydrologic models.
  - Pre Adapter ：transform time series xml into hydrologic model input format (java)
  - Hydrologic simulation model (any language)
  - Post Adapter ：transform hydrologic model output format into time series xml (java)

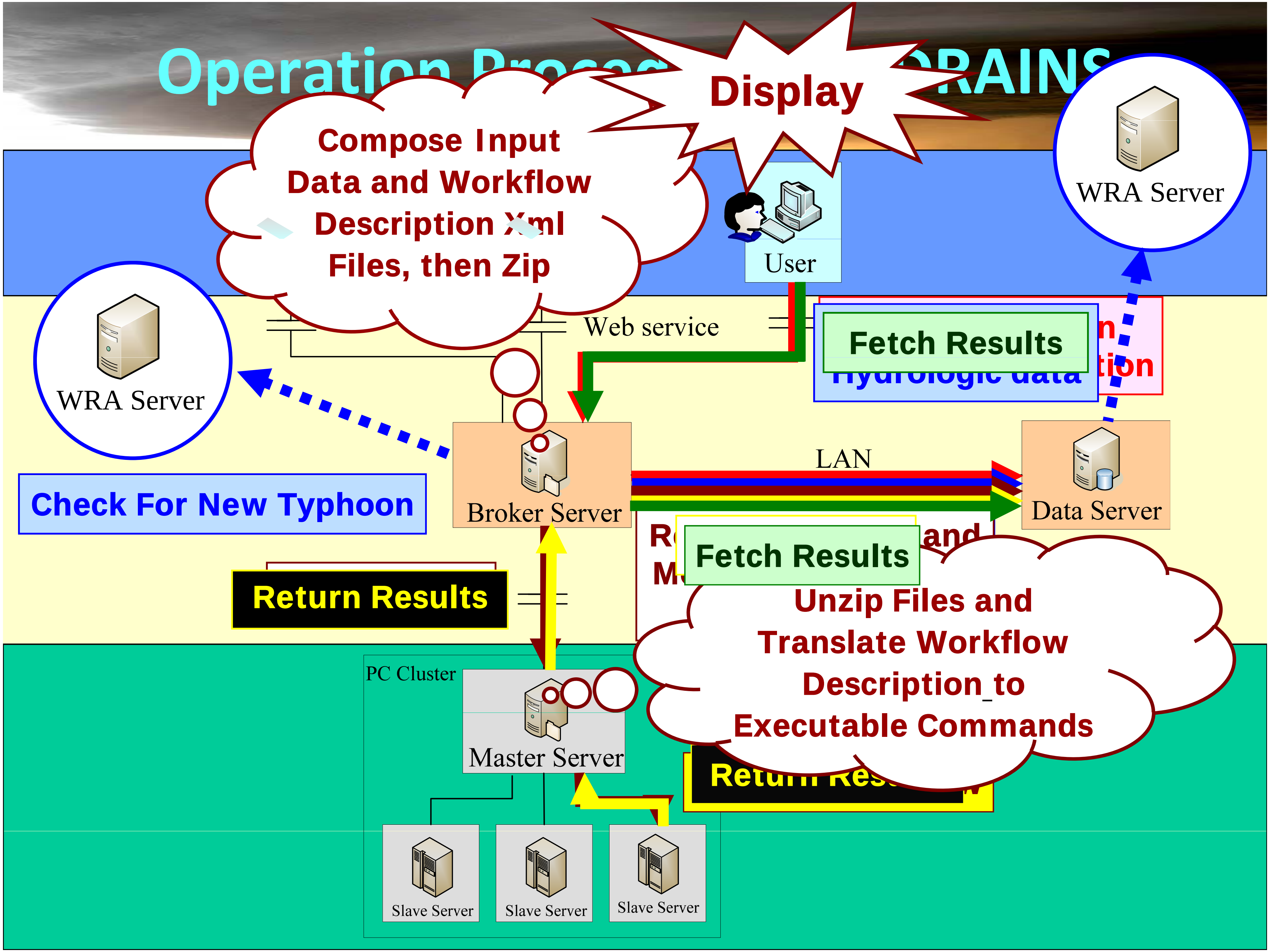


XML schema for workflow



- Delete old XML files
- Make new directory according to event date/time

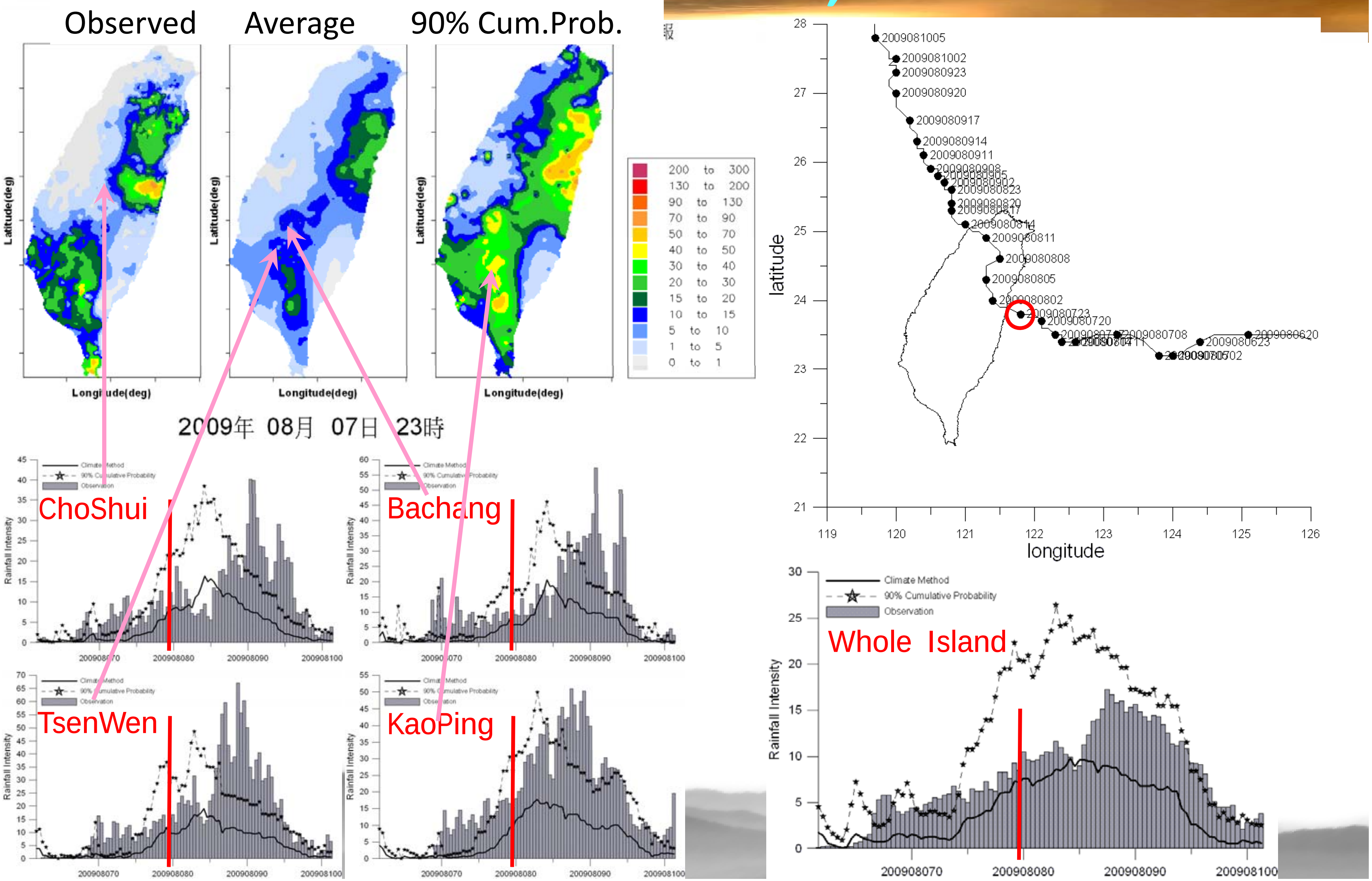
- 7 standardized steps to execute hydrologic modules.
- Step 5:
  - Execute PreAdapter
  - Execute Model
  - Execute PostAdapter
- Others:
  - Prepare execution environment
  - Prepare all model input data
  - Backup and output


Display
Compose Input Data and Workflow Description Xml Files, then Zip
User
WRA Server
Web service
Fetch Results
WRA Server
Broker Server
LAN
Data Server
Check For New Typhoon
Fetch Results
Return Results
Unzip Files and Translate Workflow Description to Executable Commands
PC Cluster
Master Server
Slave Server
Slave Server
Slave Server

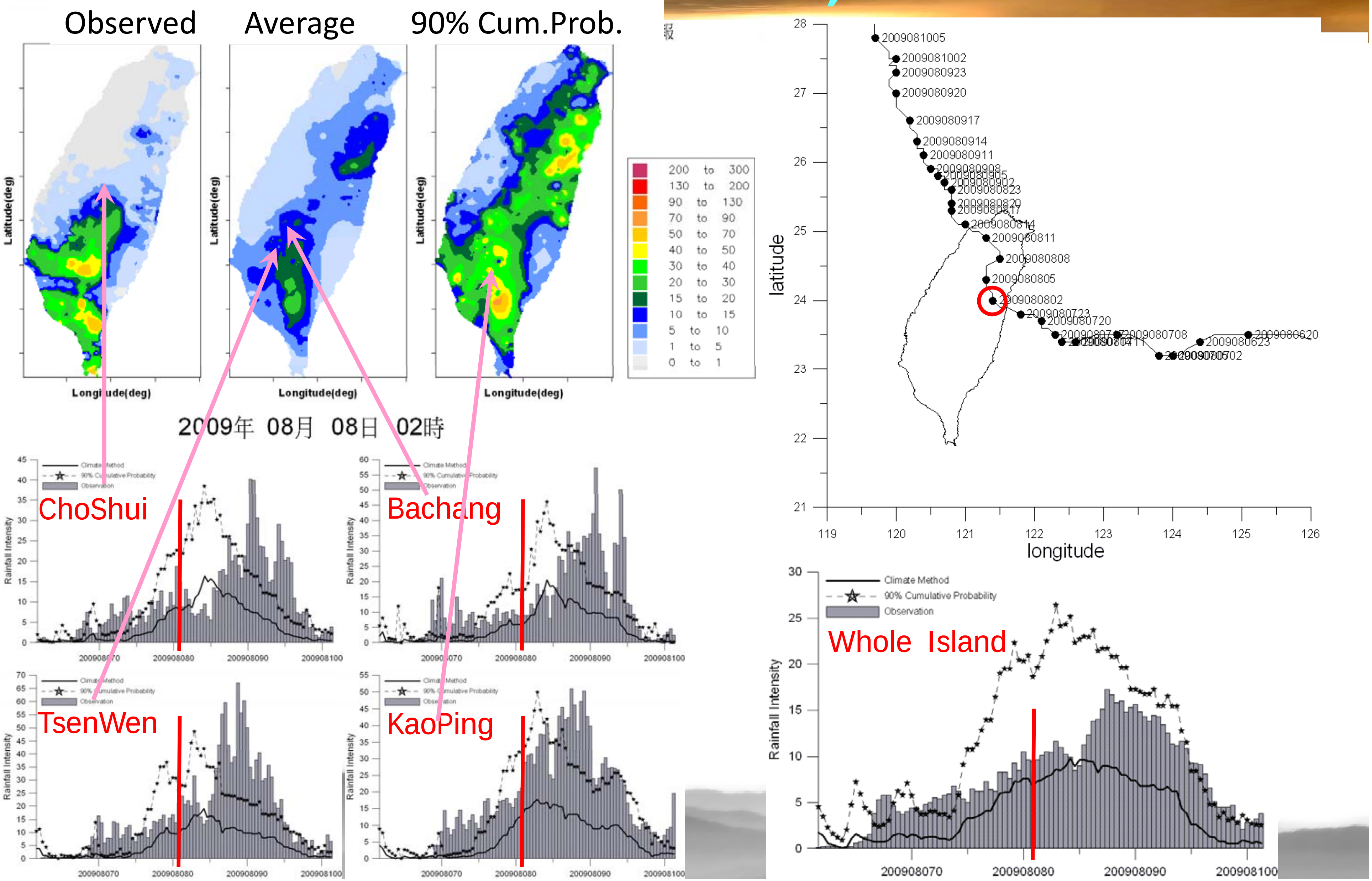
Deficiencies–Typhoon Climatology QPF

- The trend is OK, good for reservoir operation, but not the spikes induced by rainbands.
- Works for normal typhoons, not for extremes.
- Does not work if accompanied by strong Asian monsoon flow (south-westerly flow in early to mid-summer, north-easterly flow in autumn)
- Does not work when typhoon is nearly stagnant where the eye-wall and rain-bands are altered by the topography.

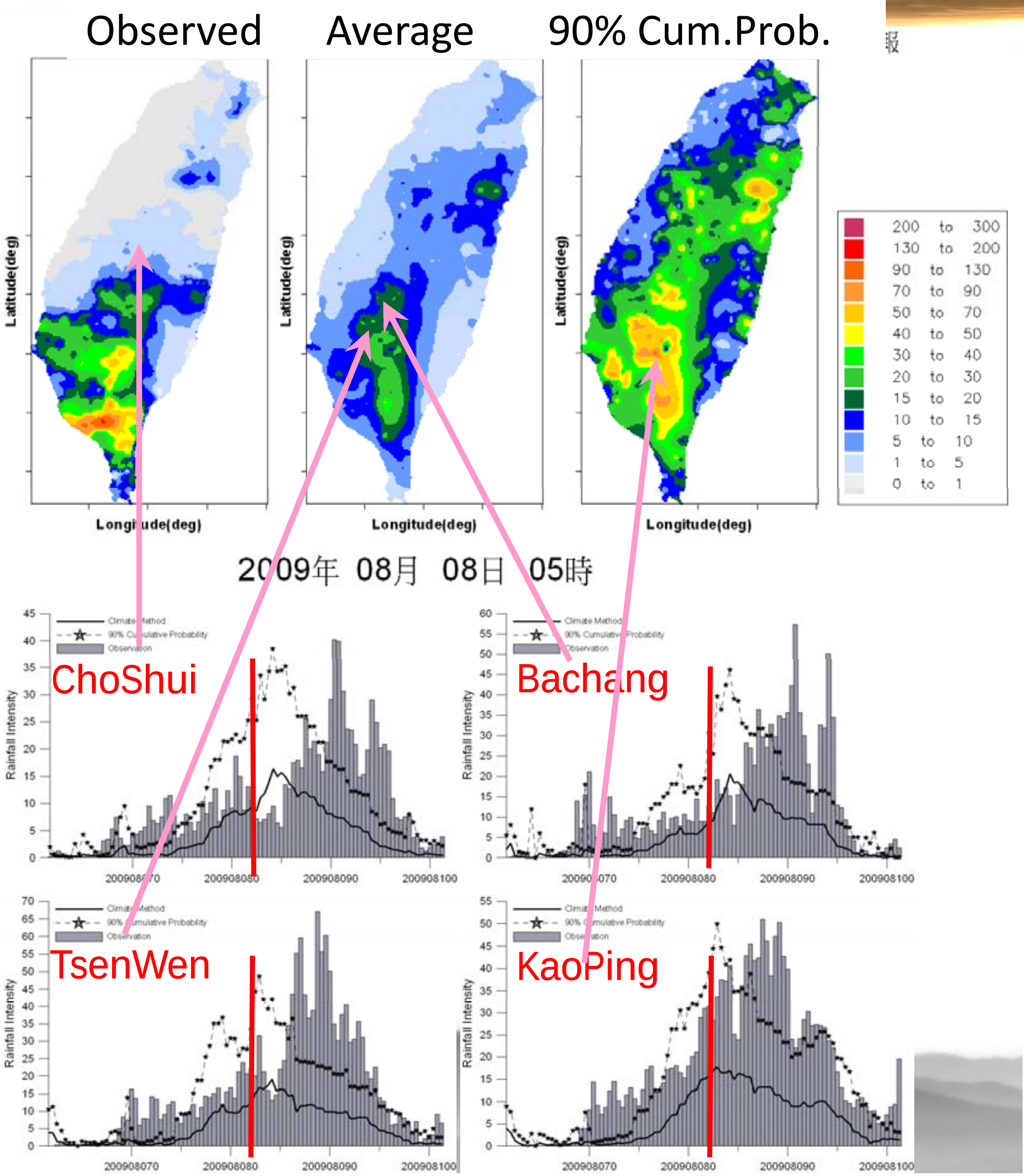
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

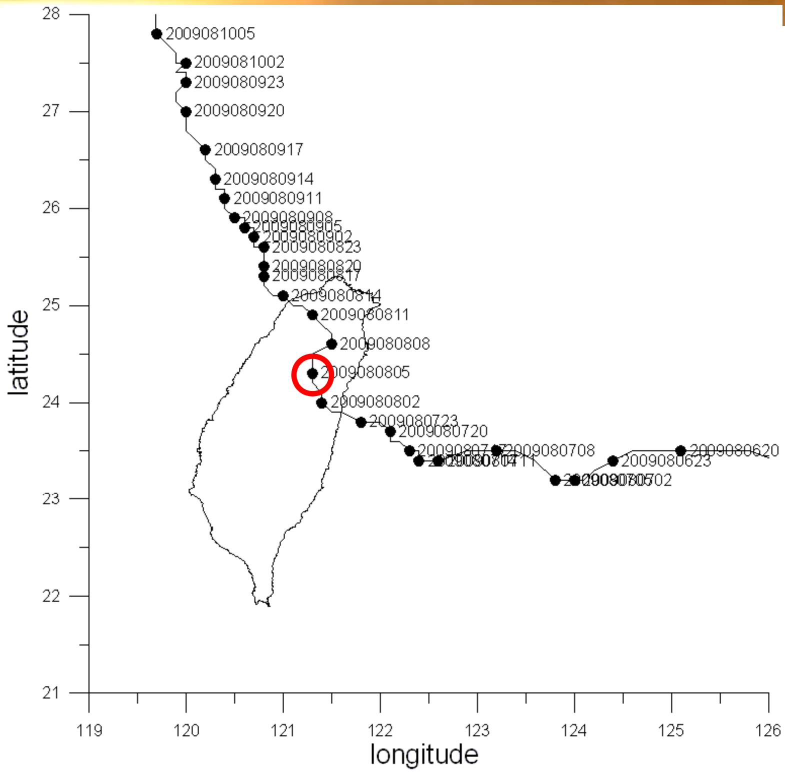


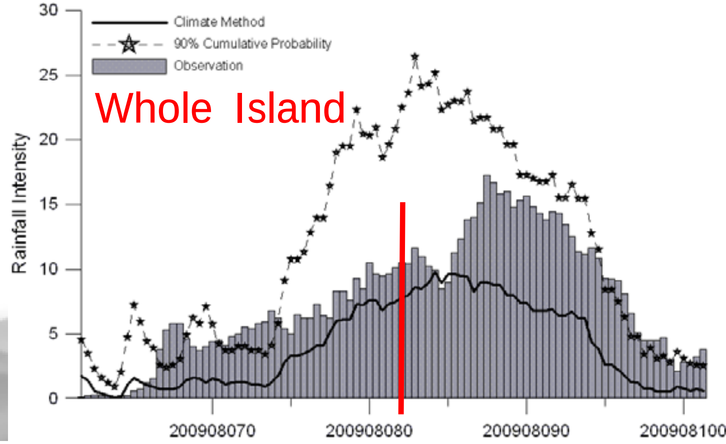
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009



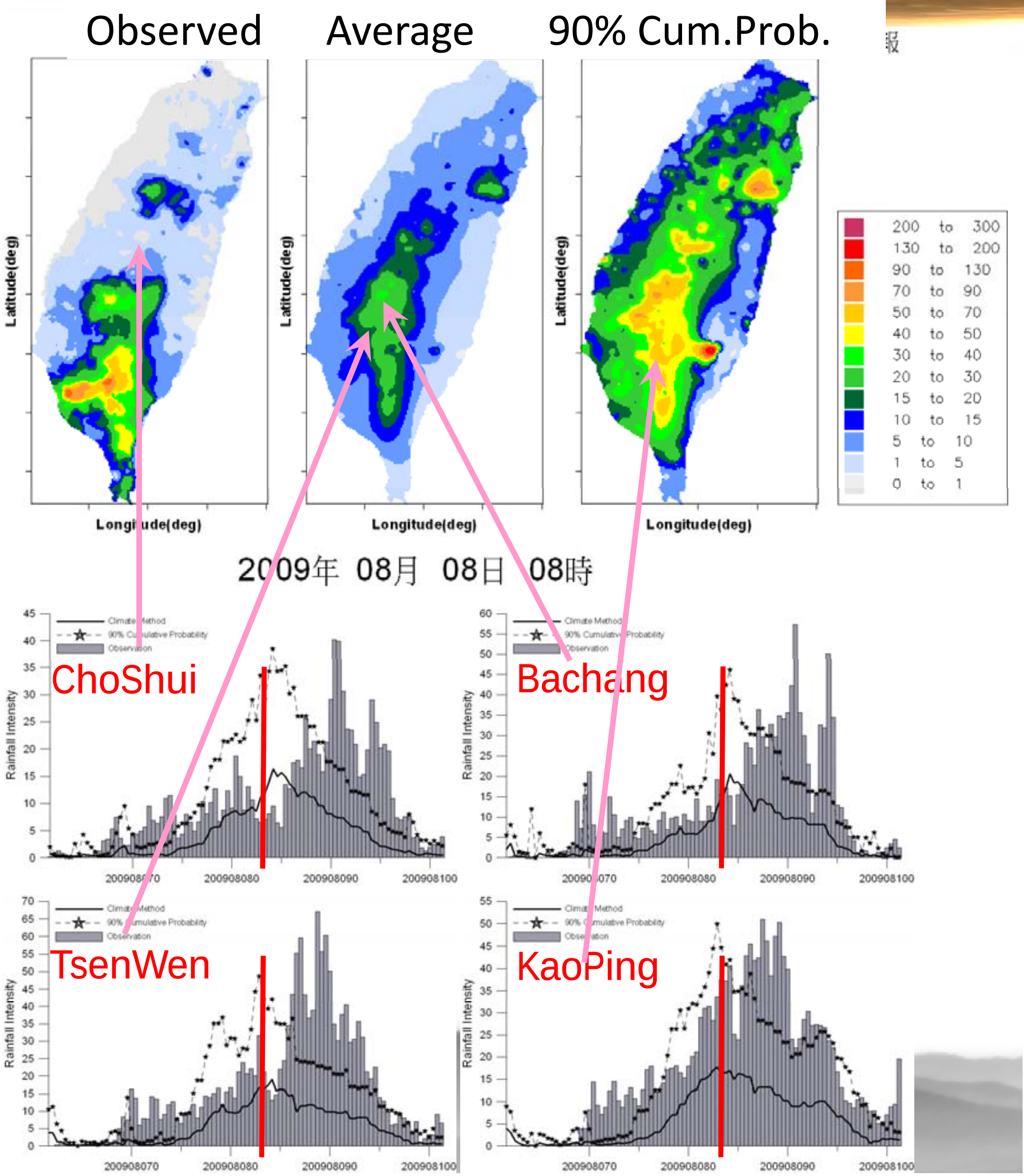
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

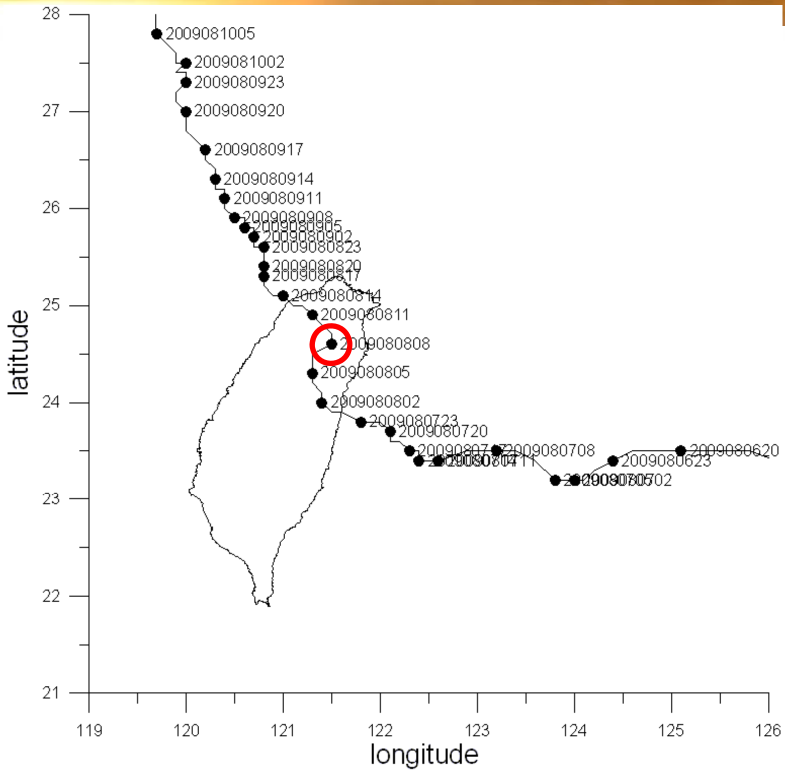


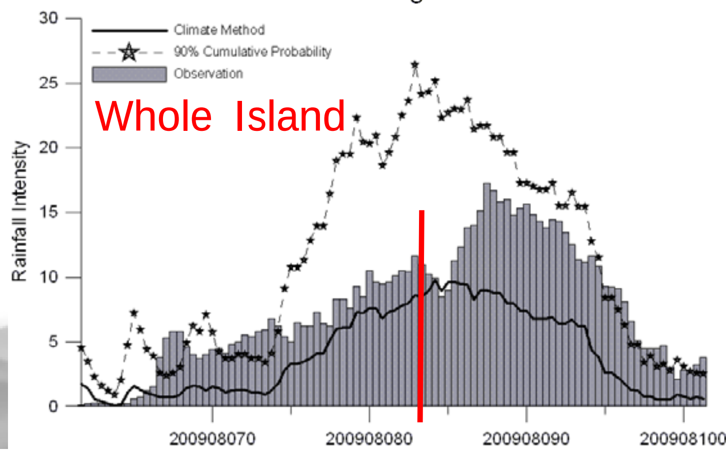




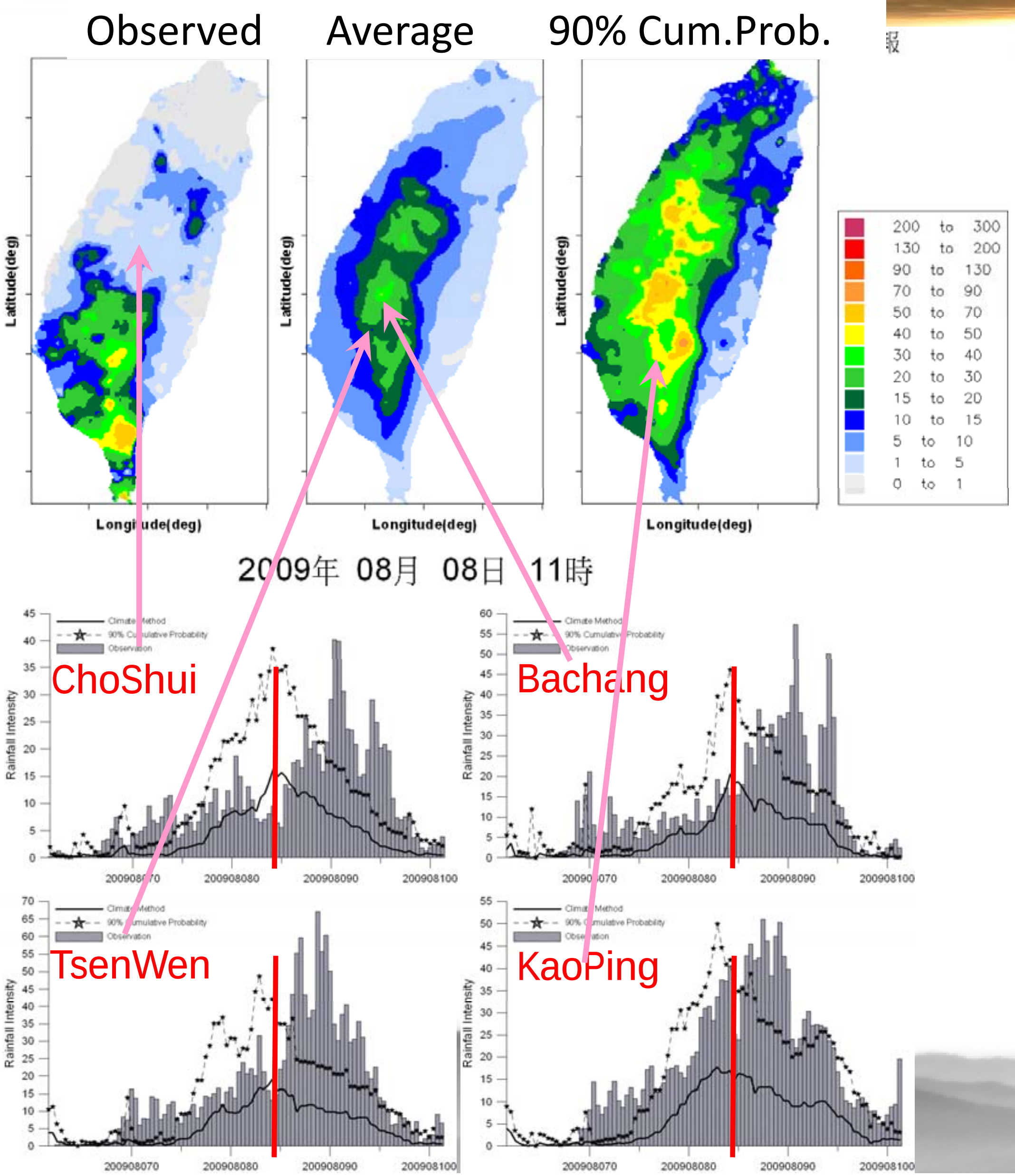
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

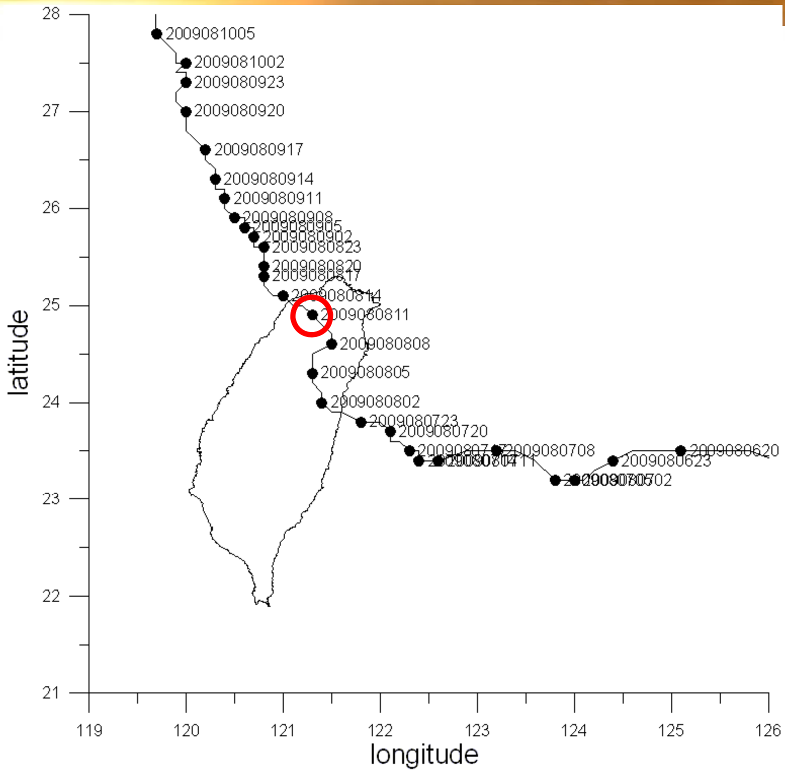


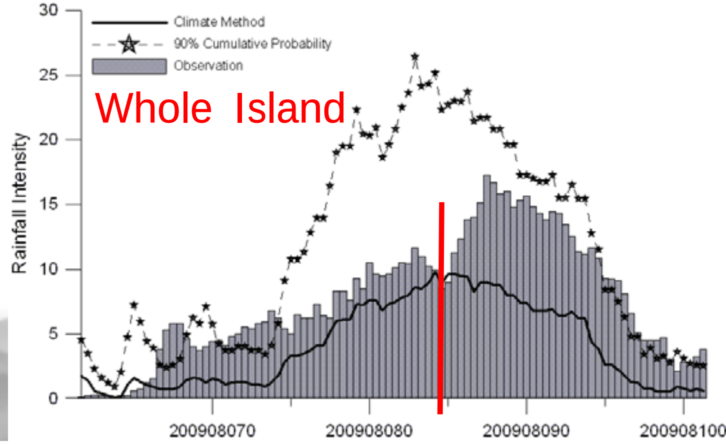




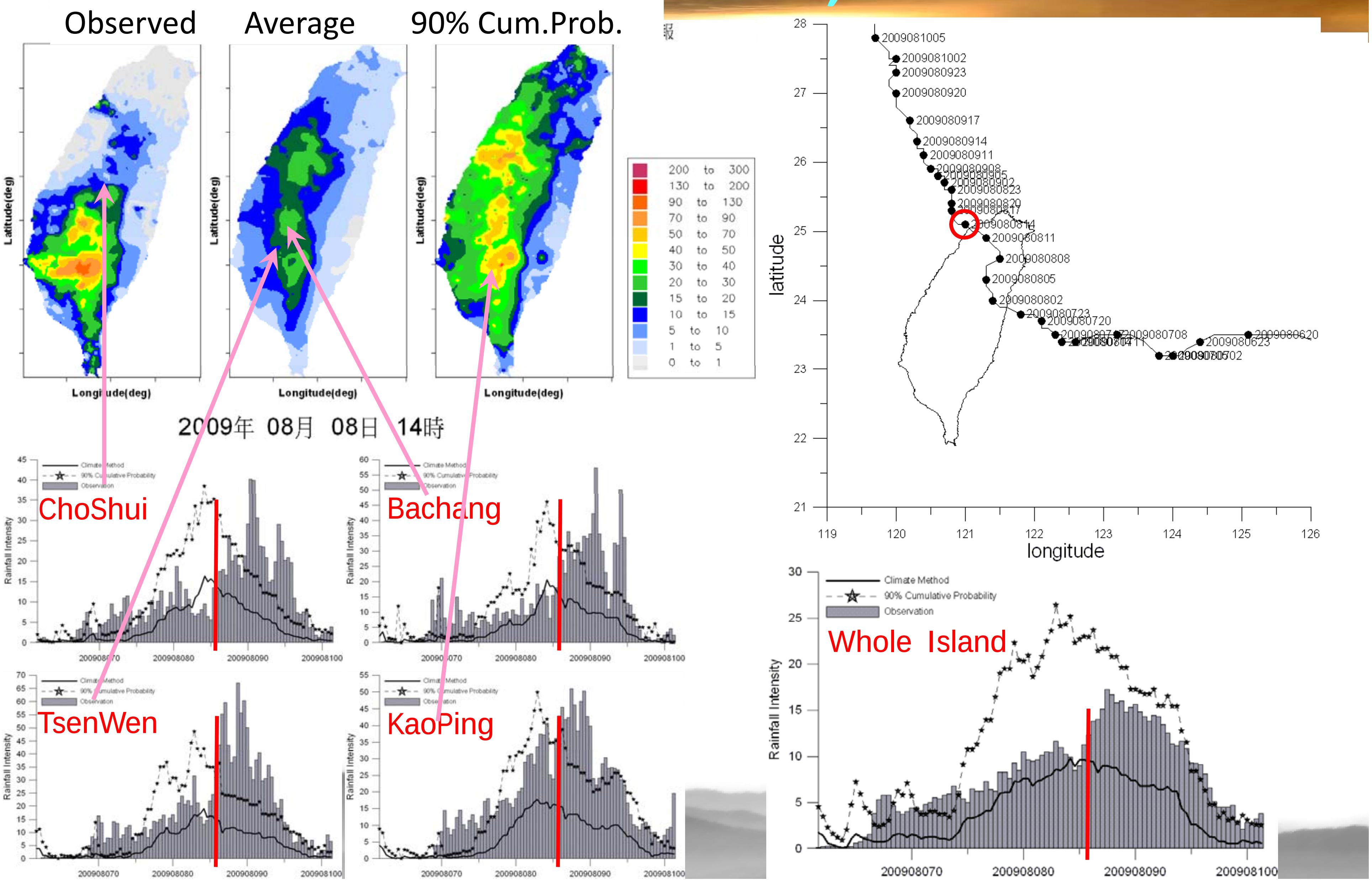
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009



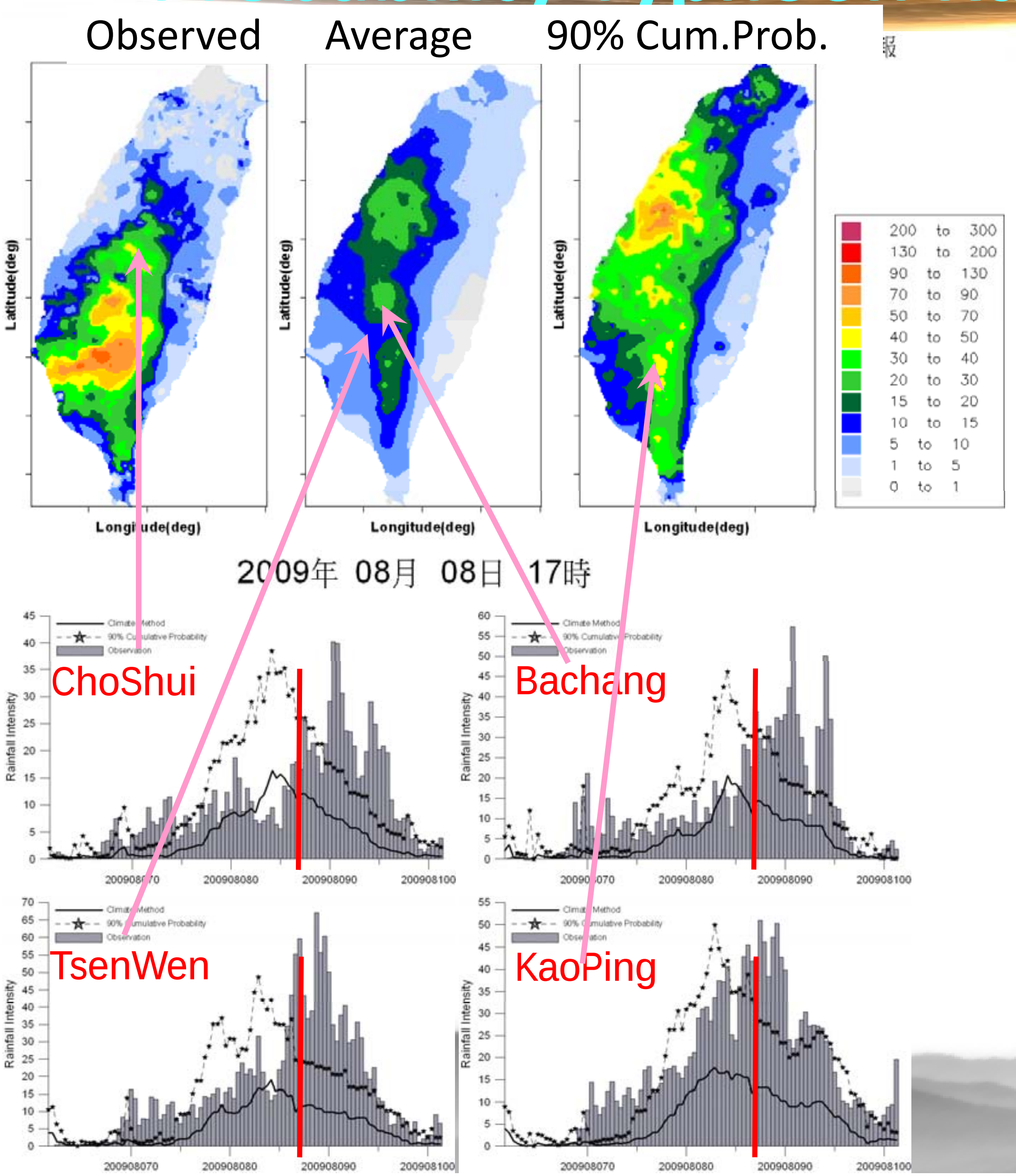


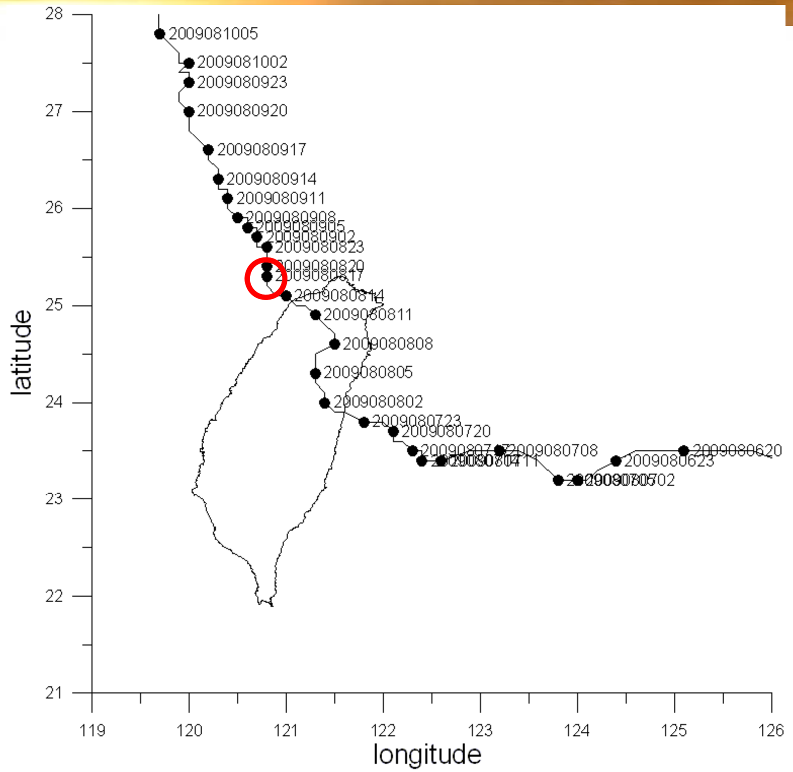


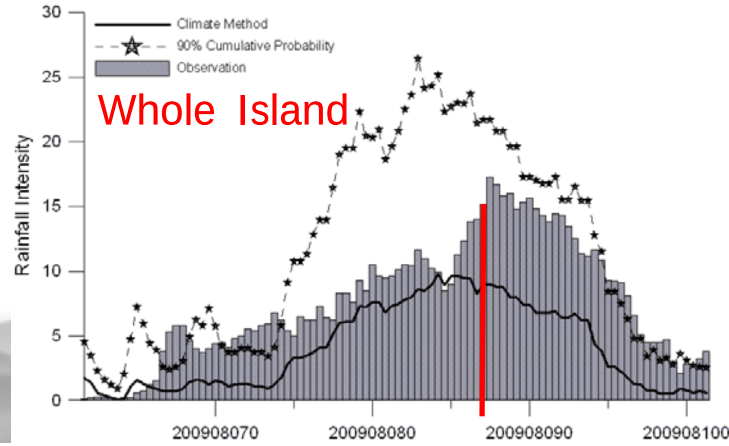
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009



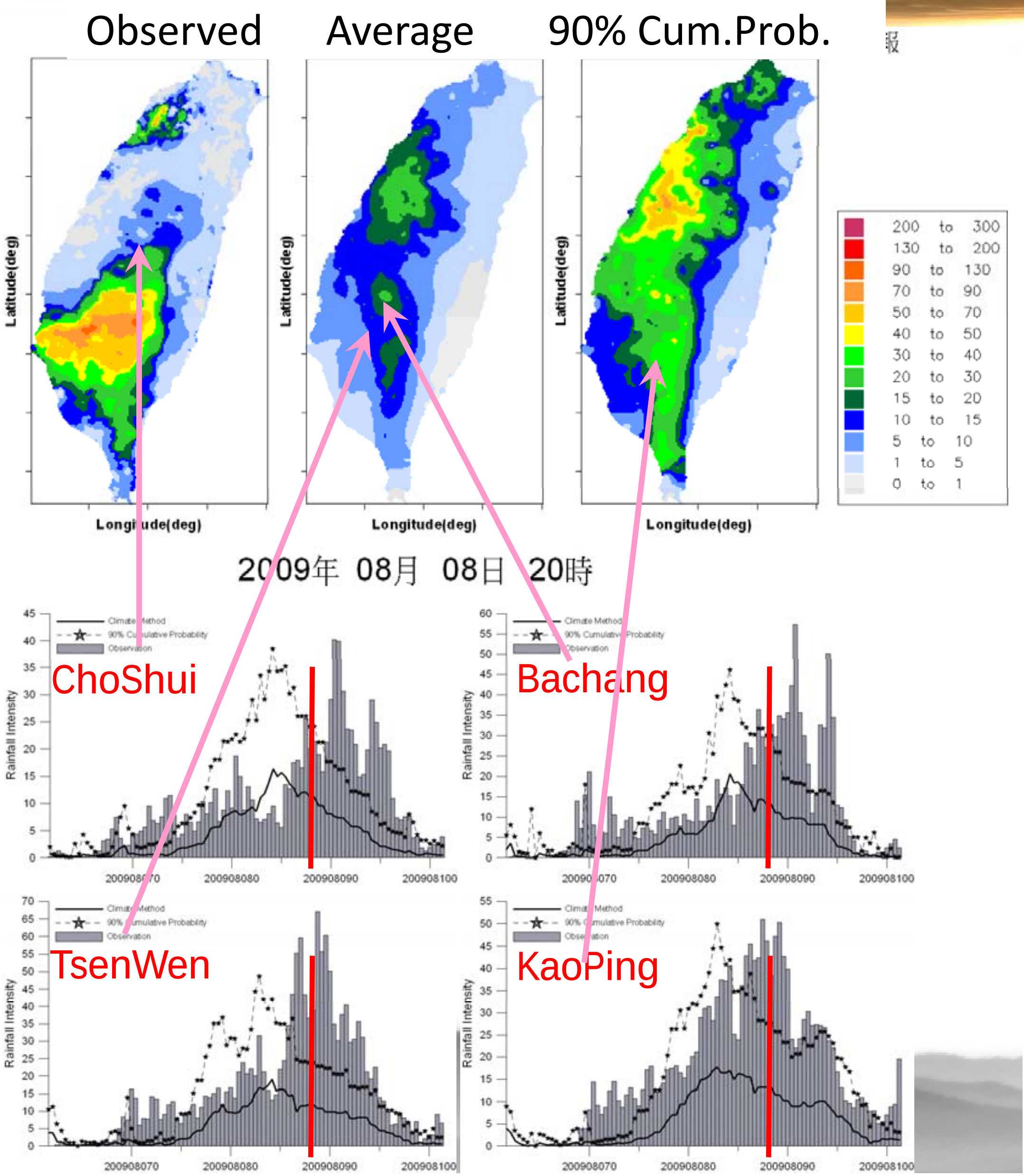
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

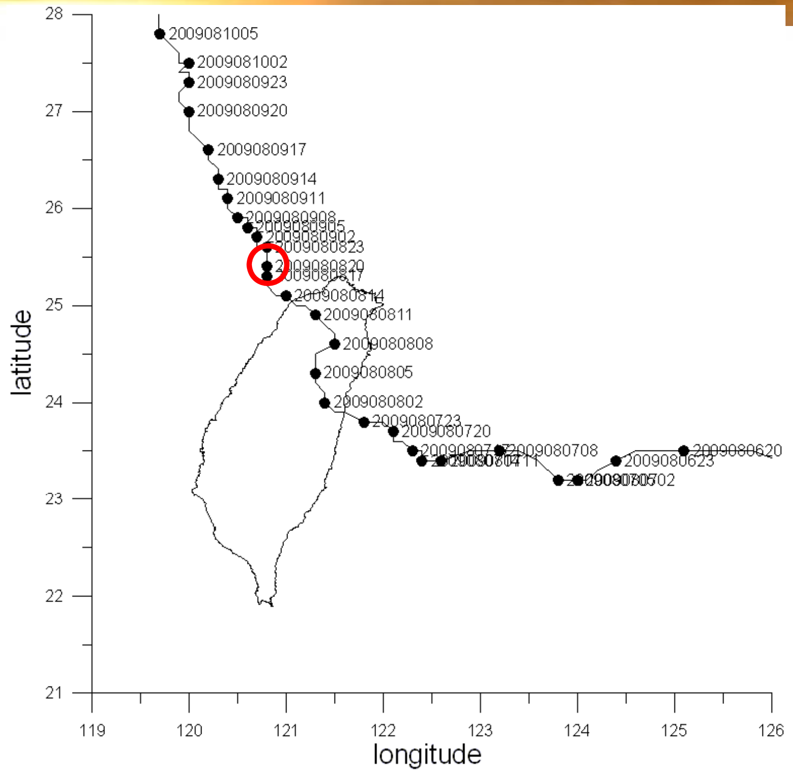


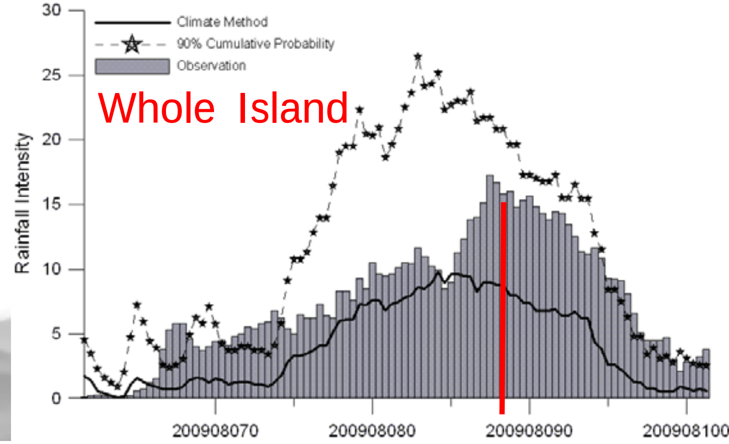




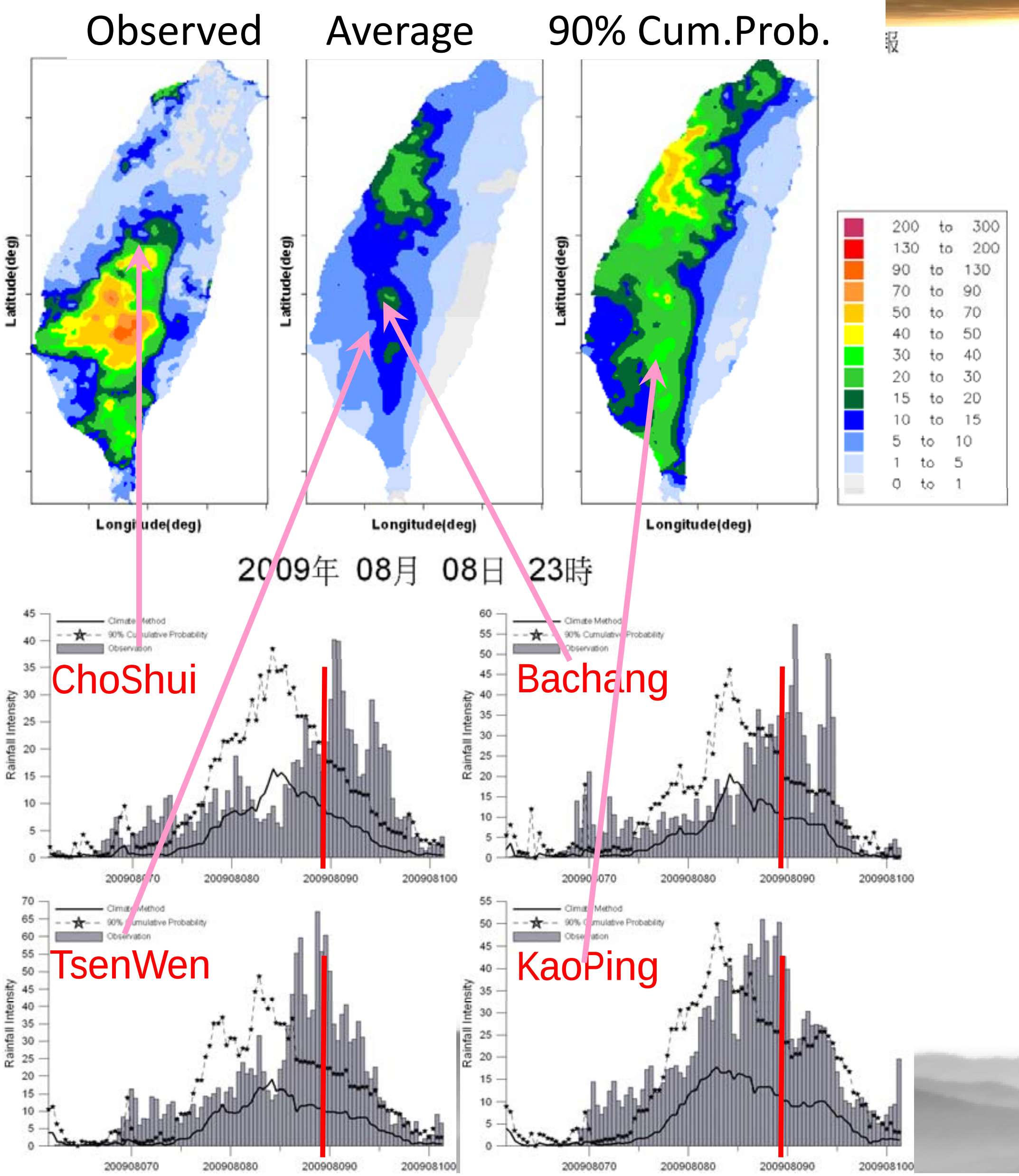
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

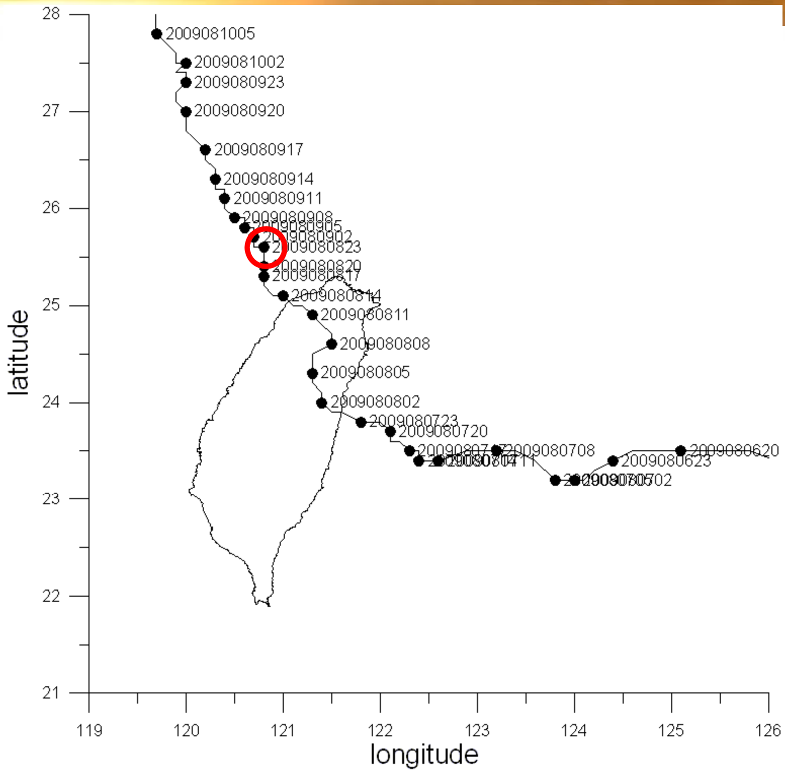


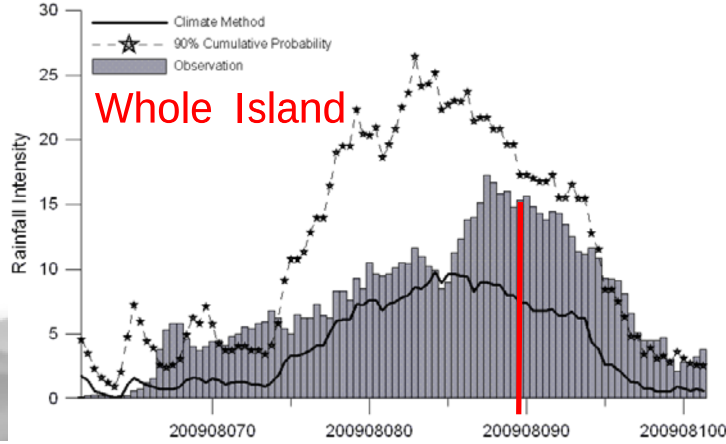




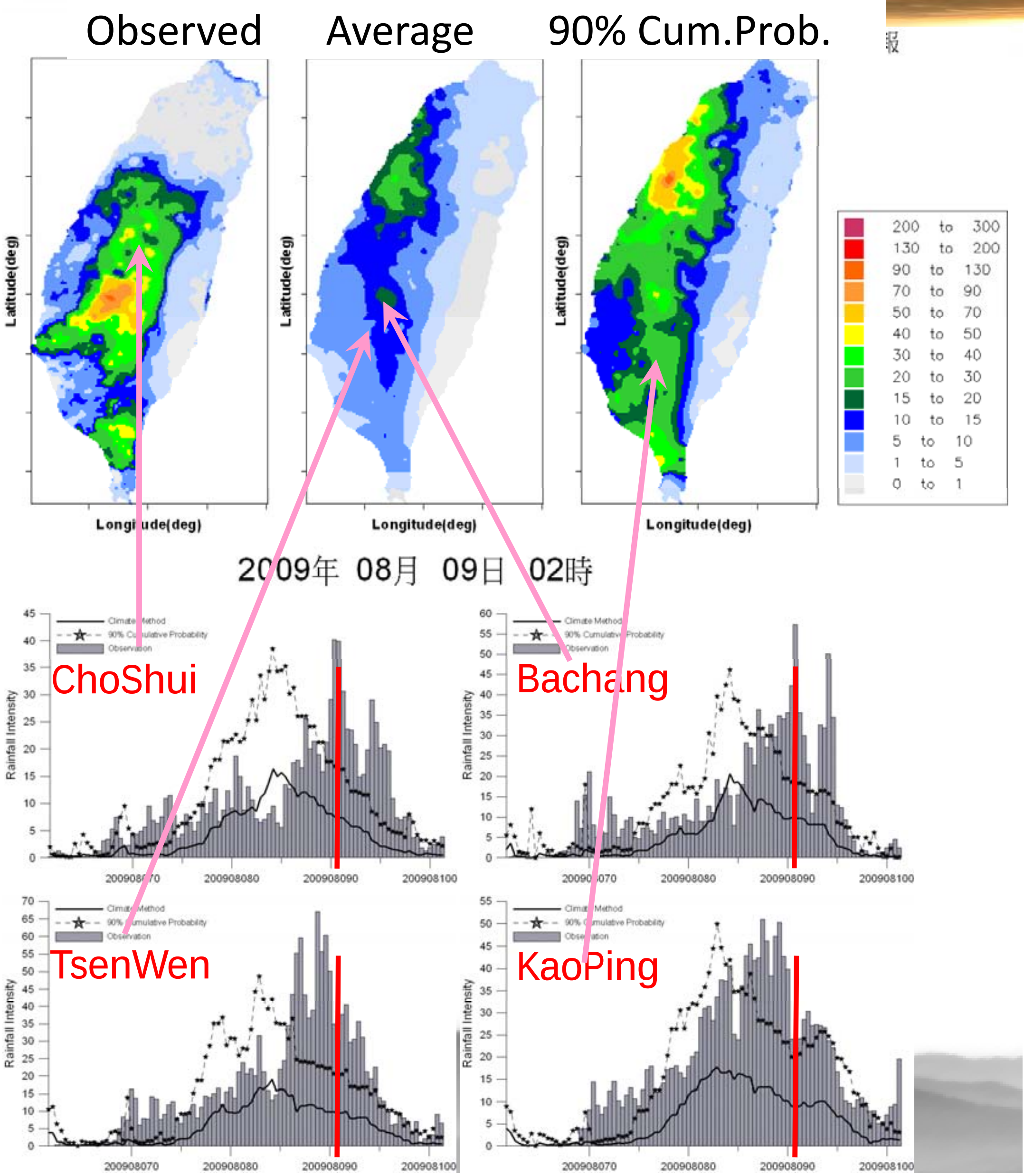
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

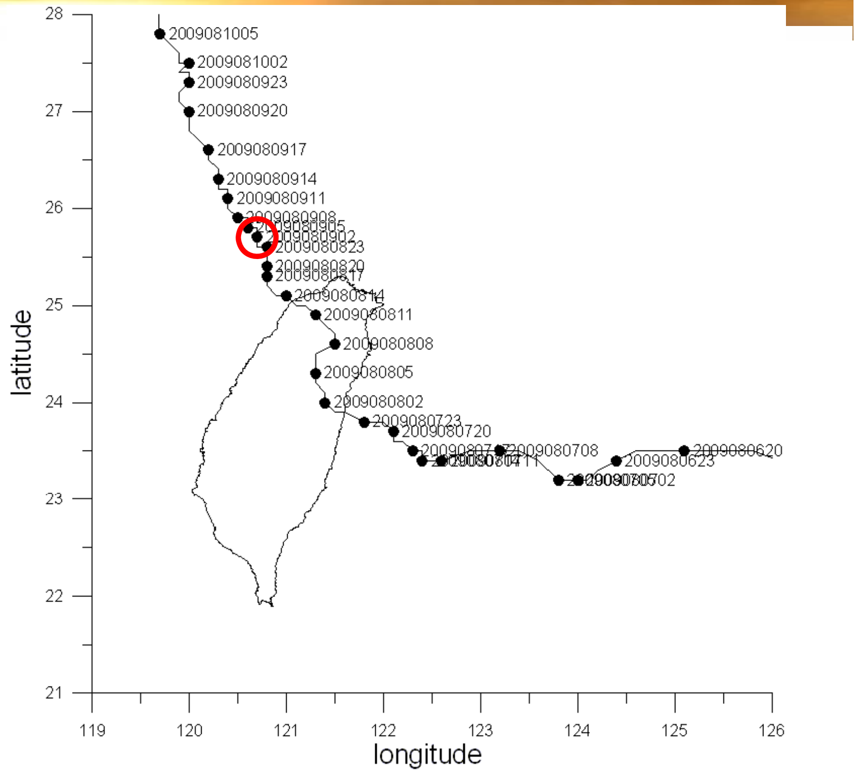


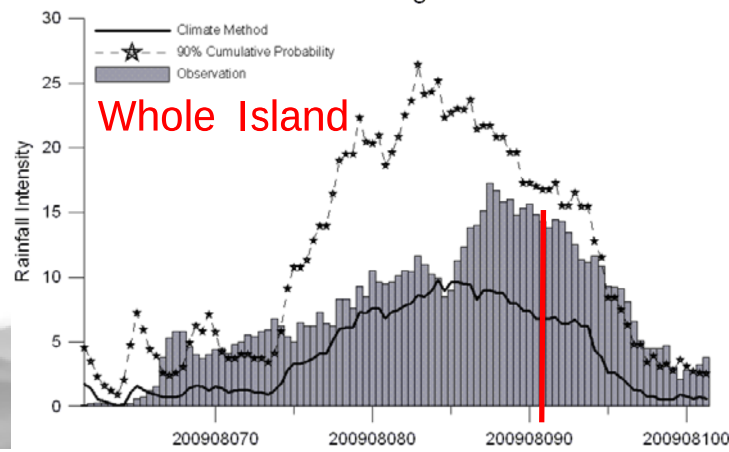




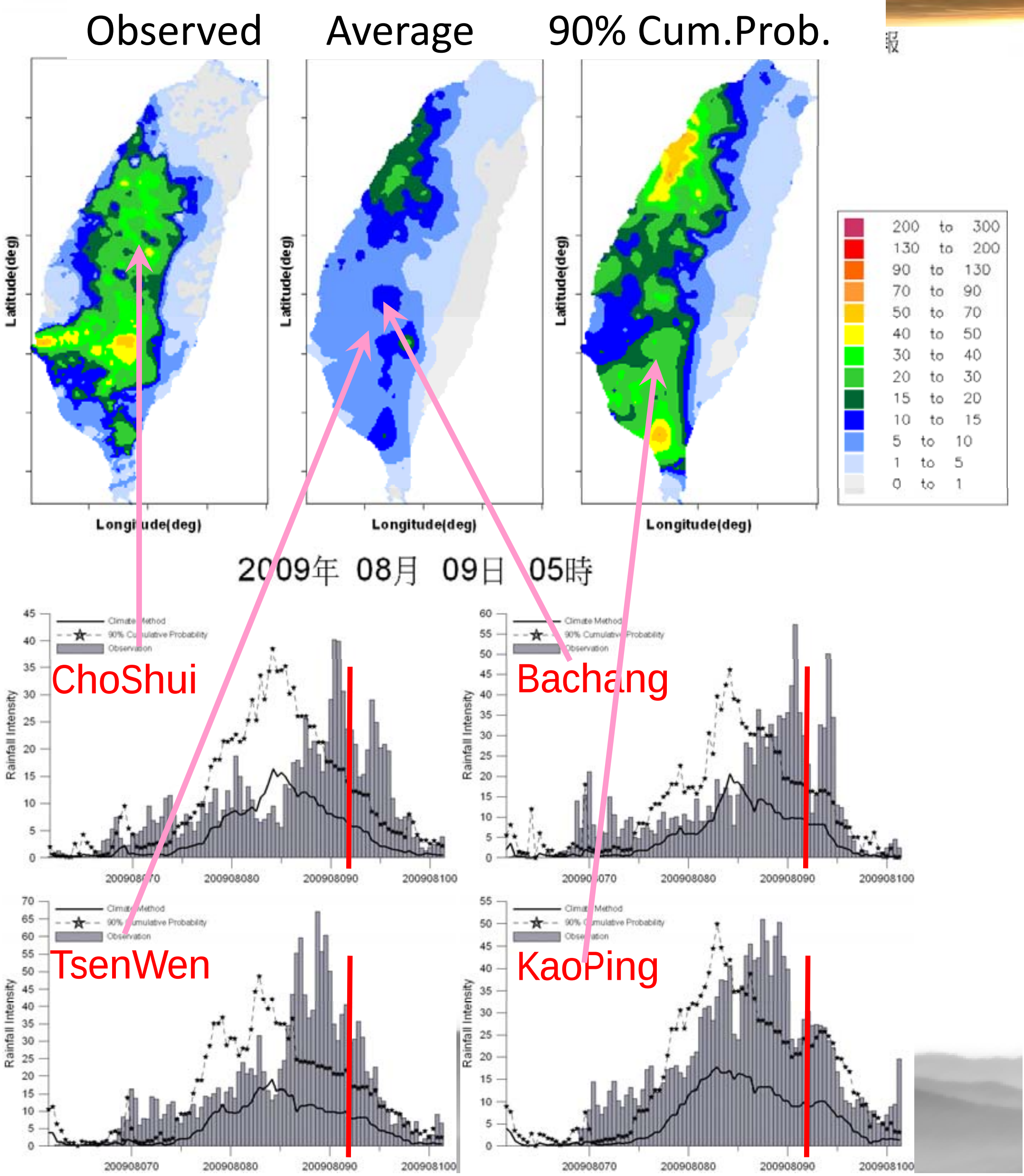
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

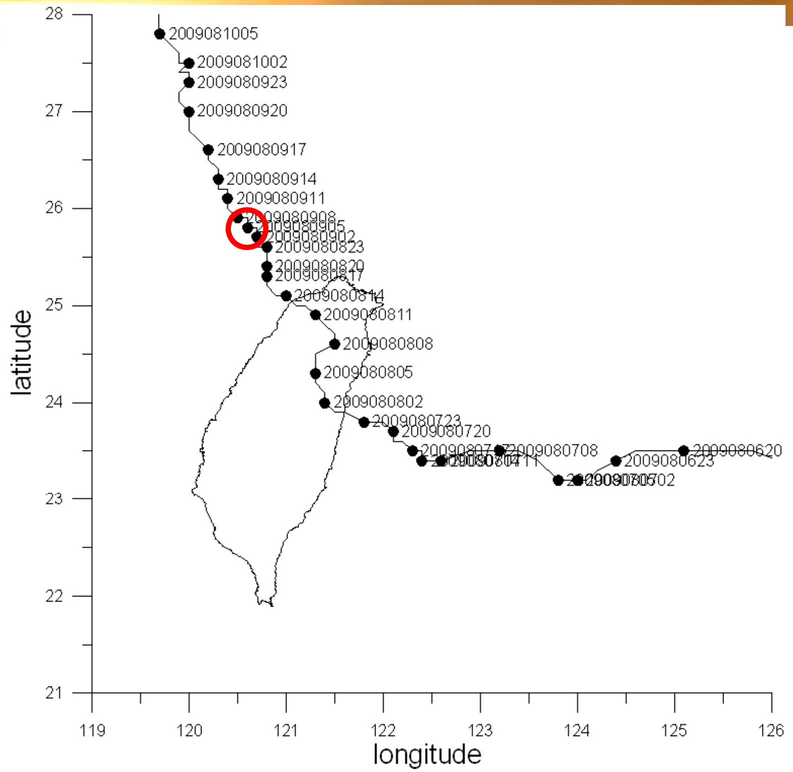


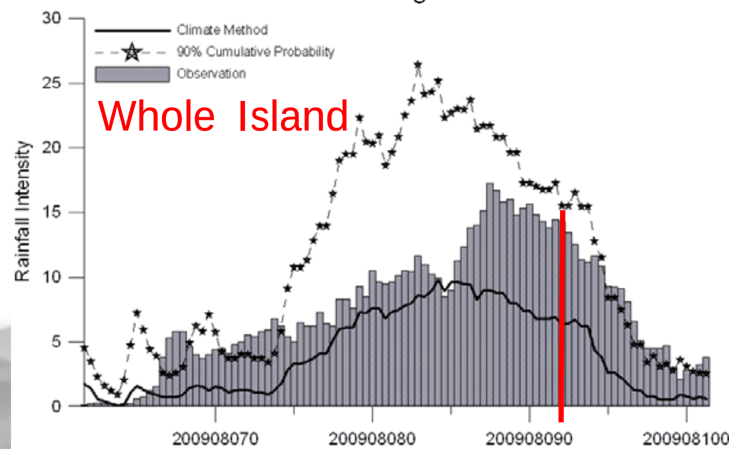




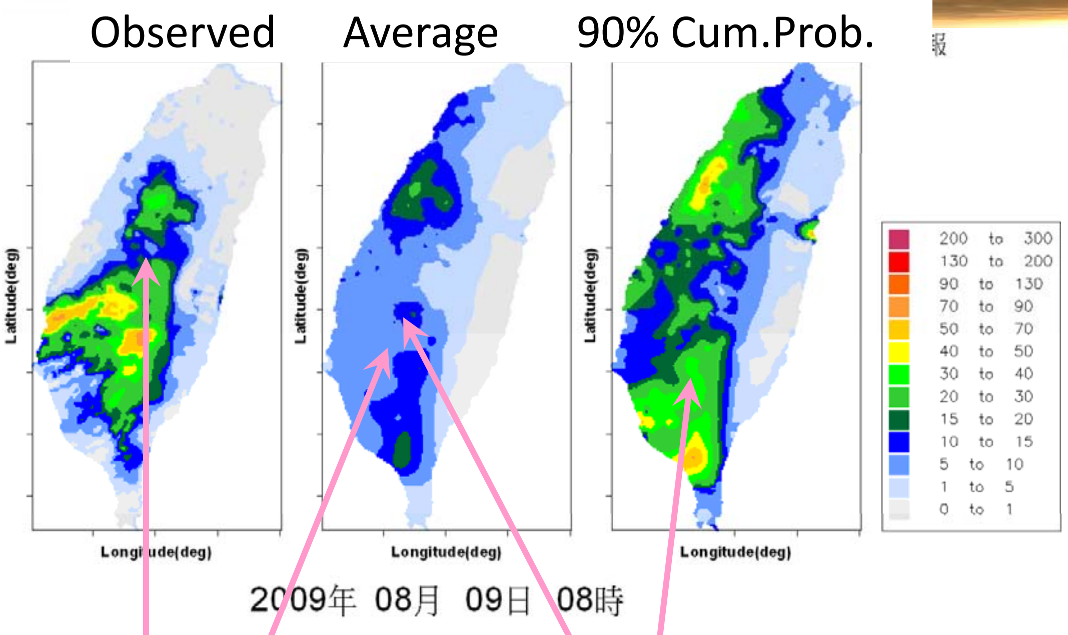
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

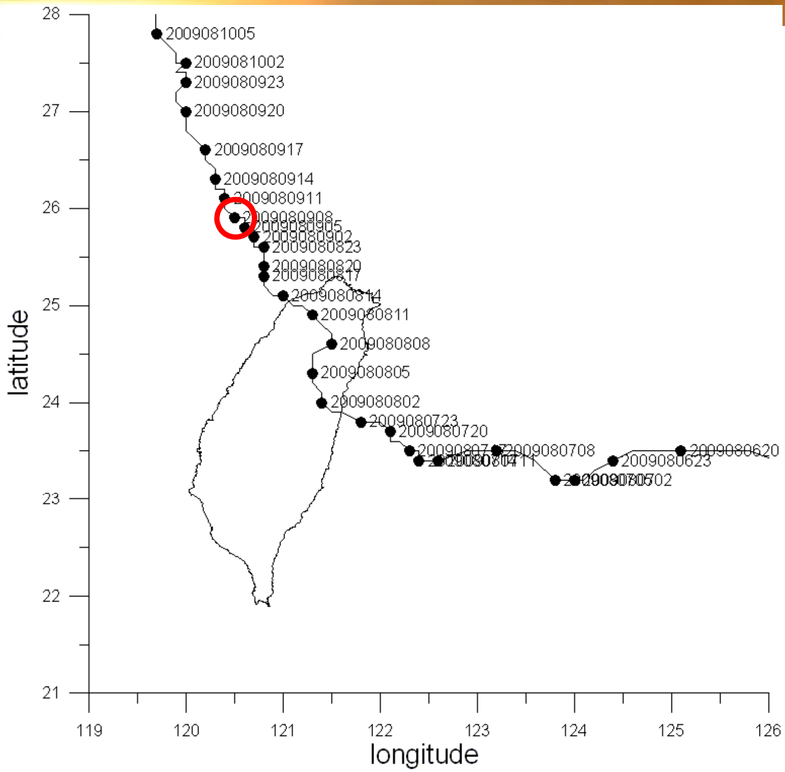


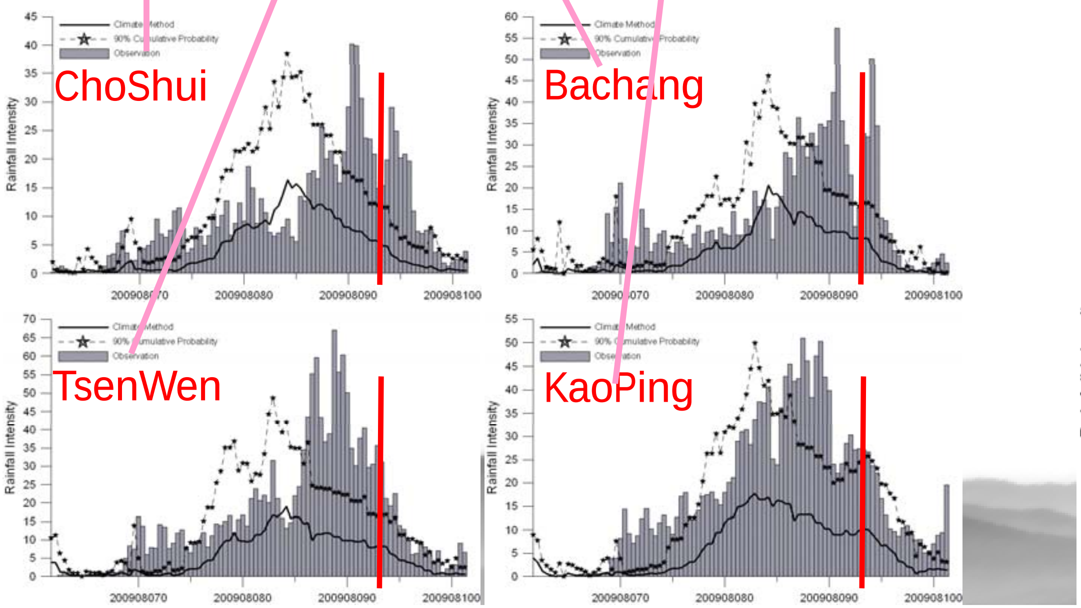


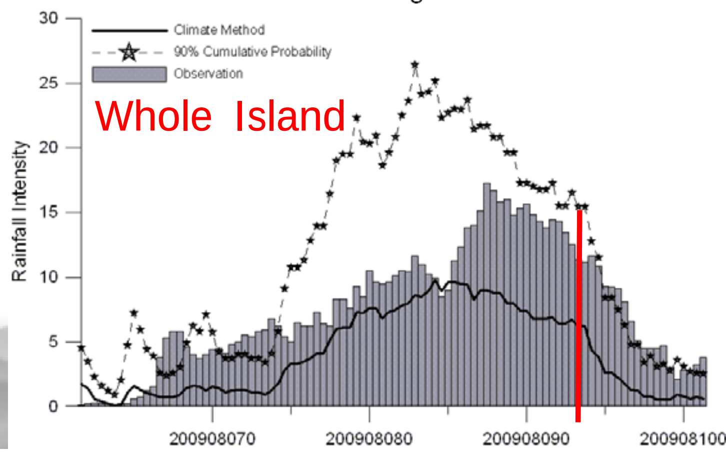


Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009

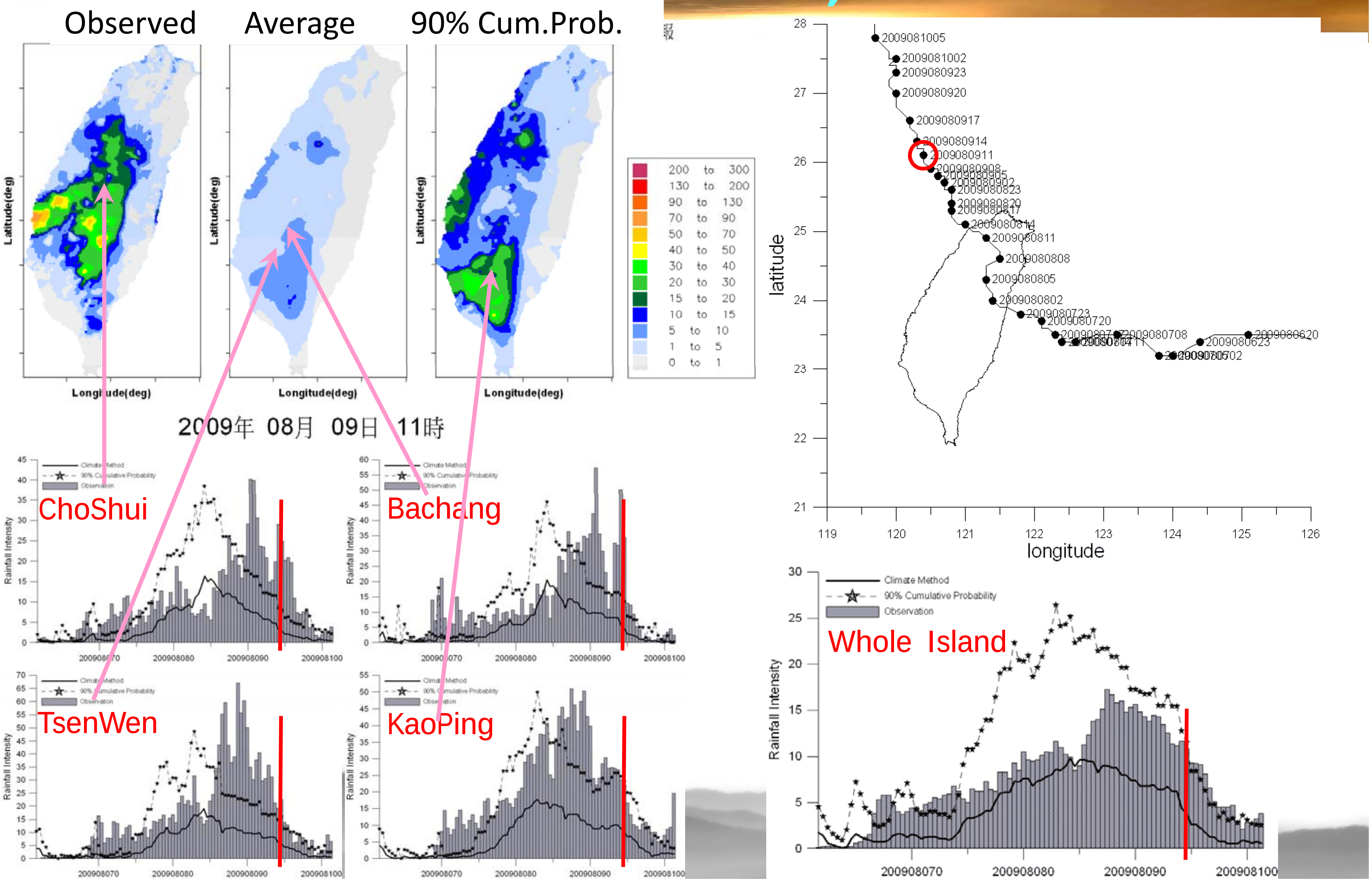




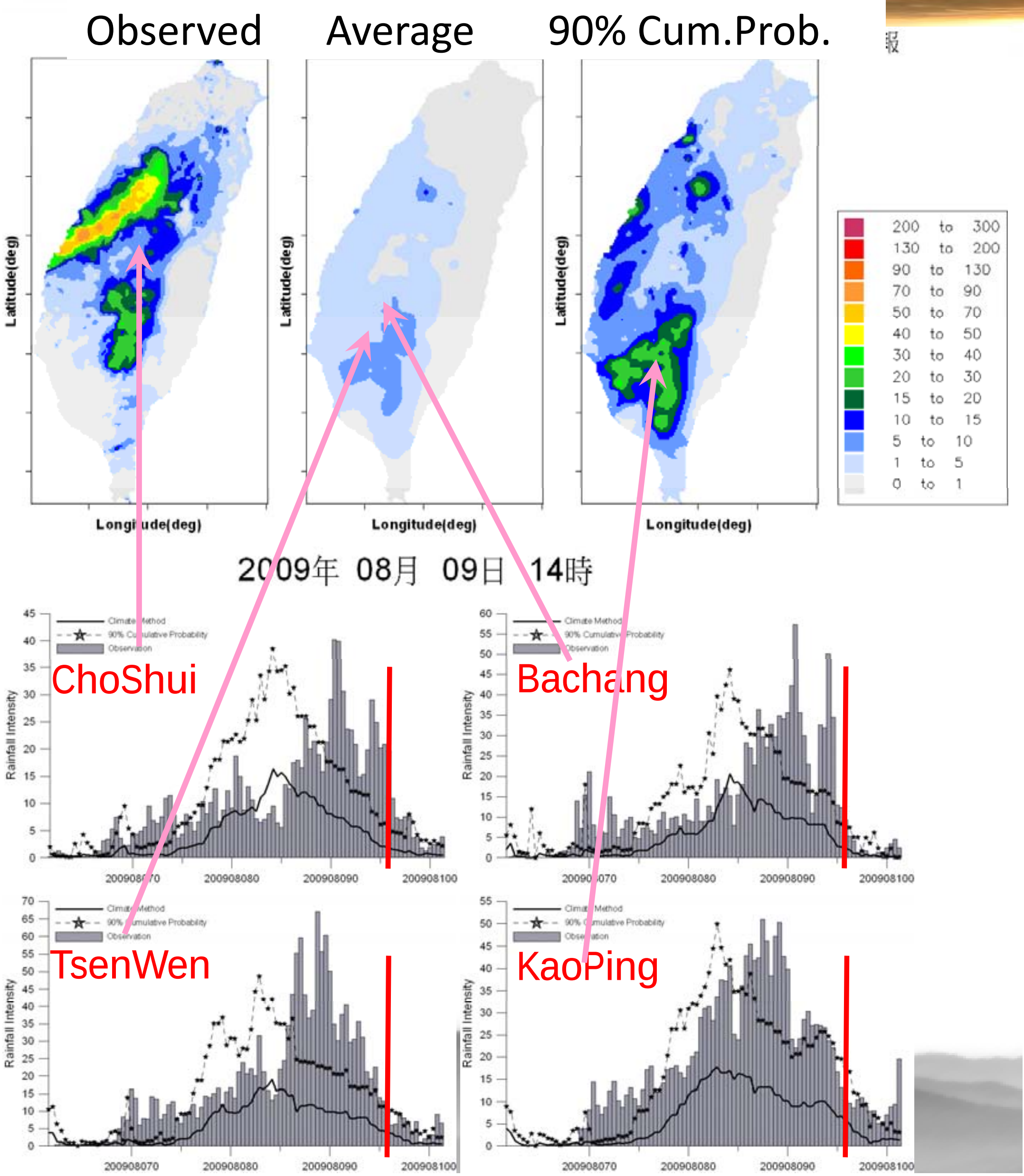


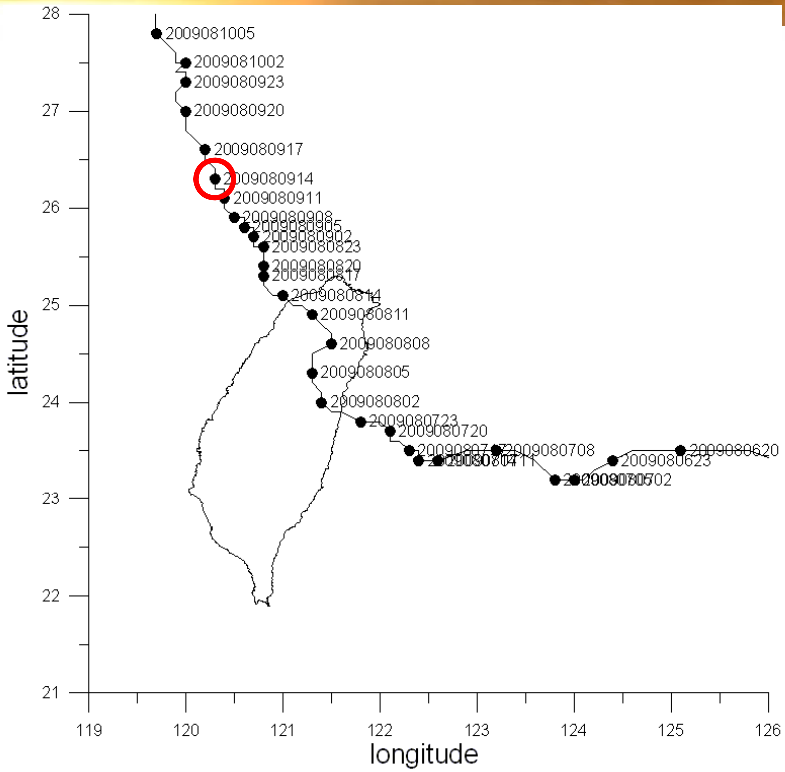


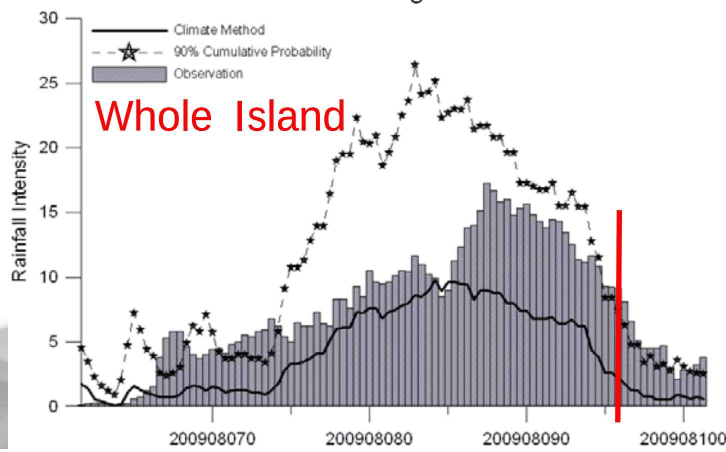
Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009



Observed, Average and 90% Cumulative Probability Typhoon Rain, Morakot 2009





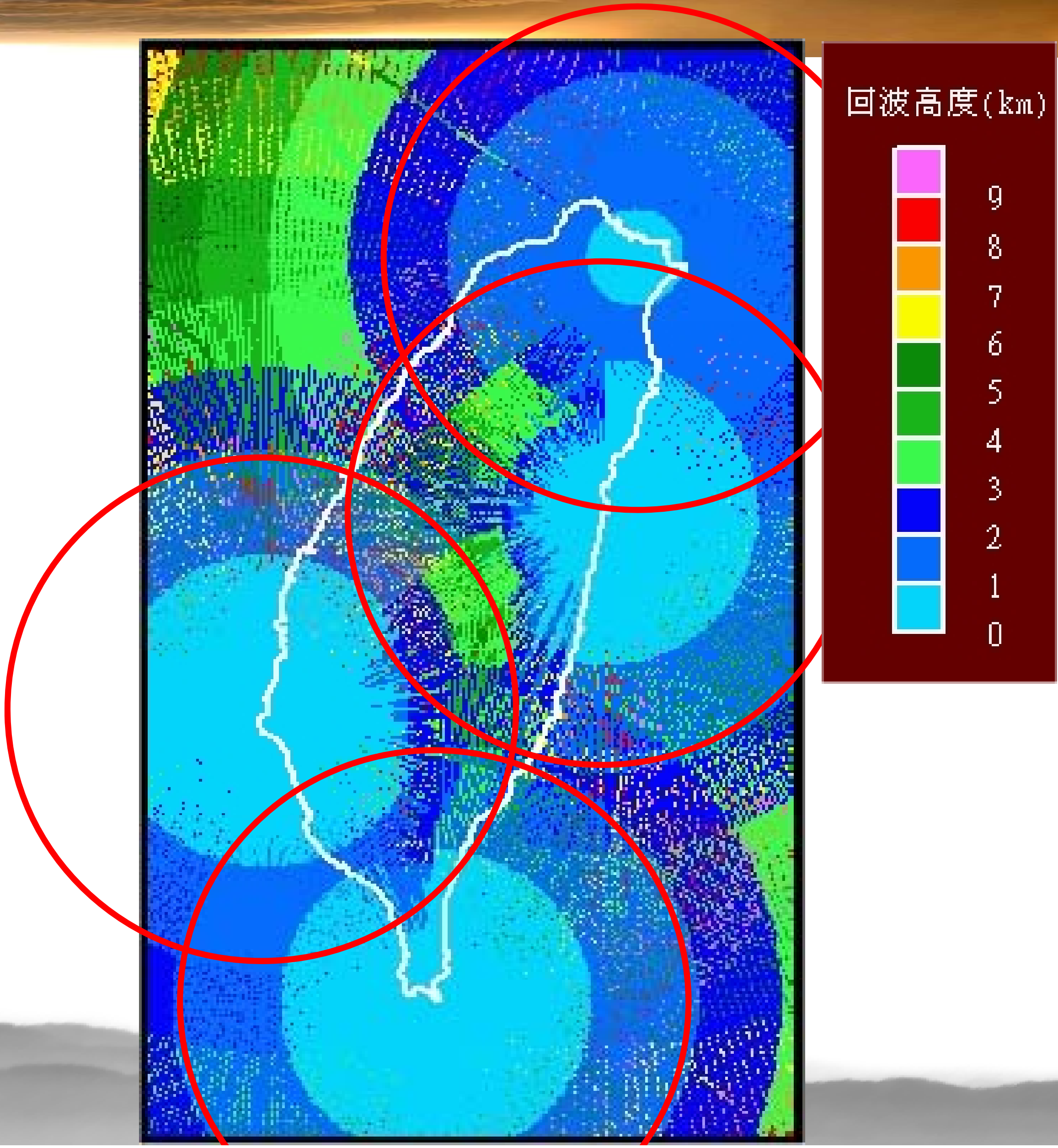


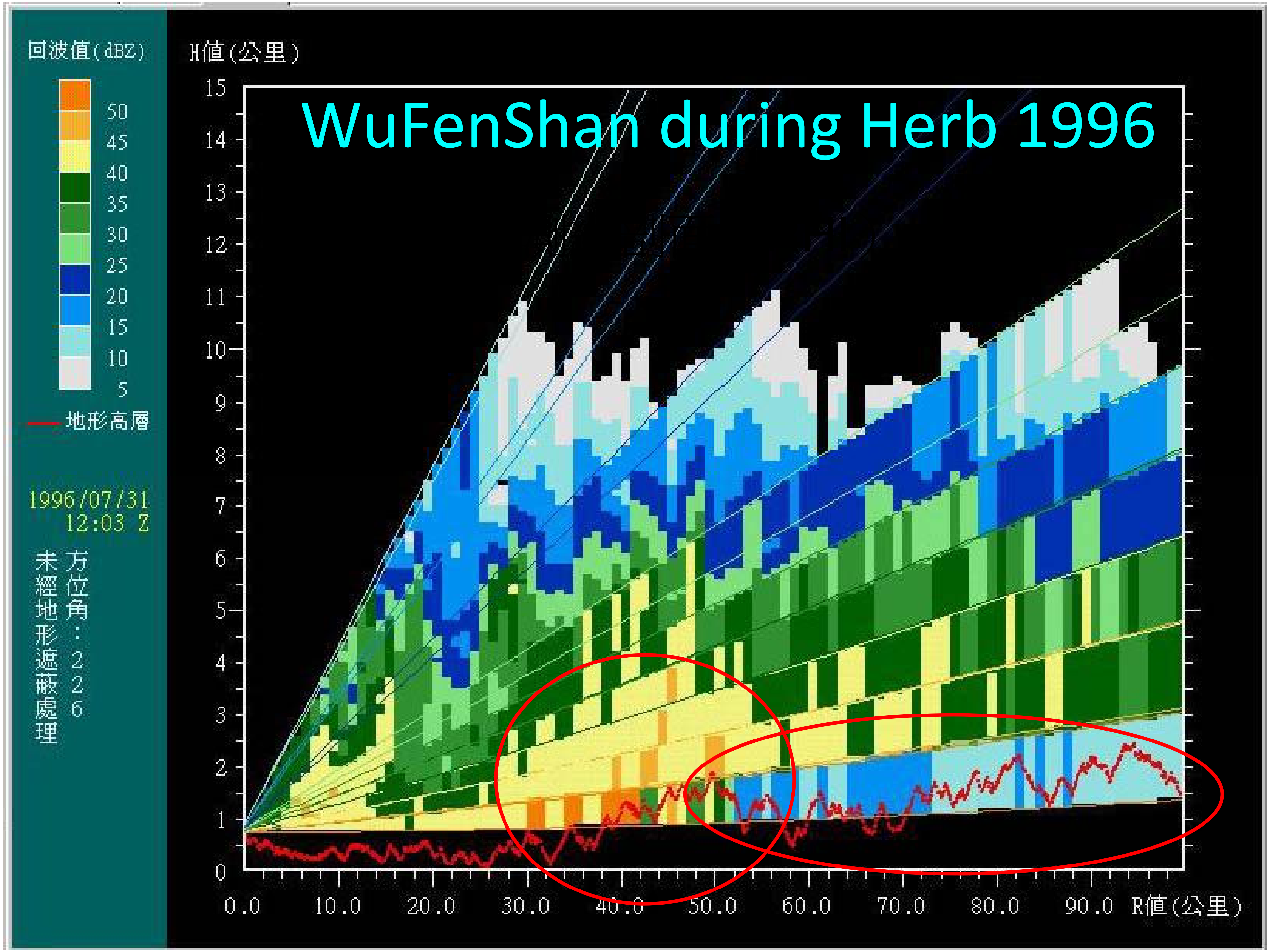
Deficiencies–QPE in mountainous region

- 2/3 area of Taiwan is mountainous. Raingauge station installation and maintenance is difficult and thus sparse.
- 4 CWB radars have difficulties to accurately estimate high intensity rain in the valleys or near-surface orographic rain.
- The into-reservoir volume is 1.4 times the rainfall observed at TsenWen Reservoir.

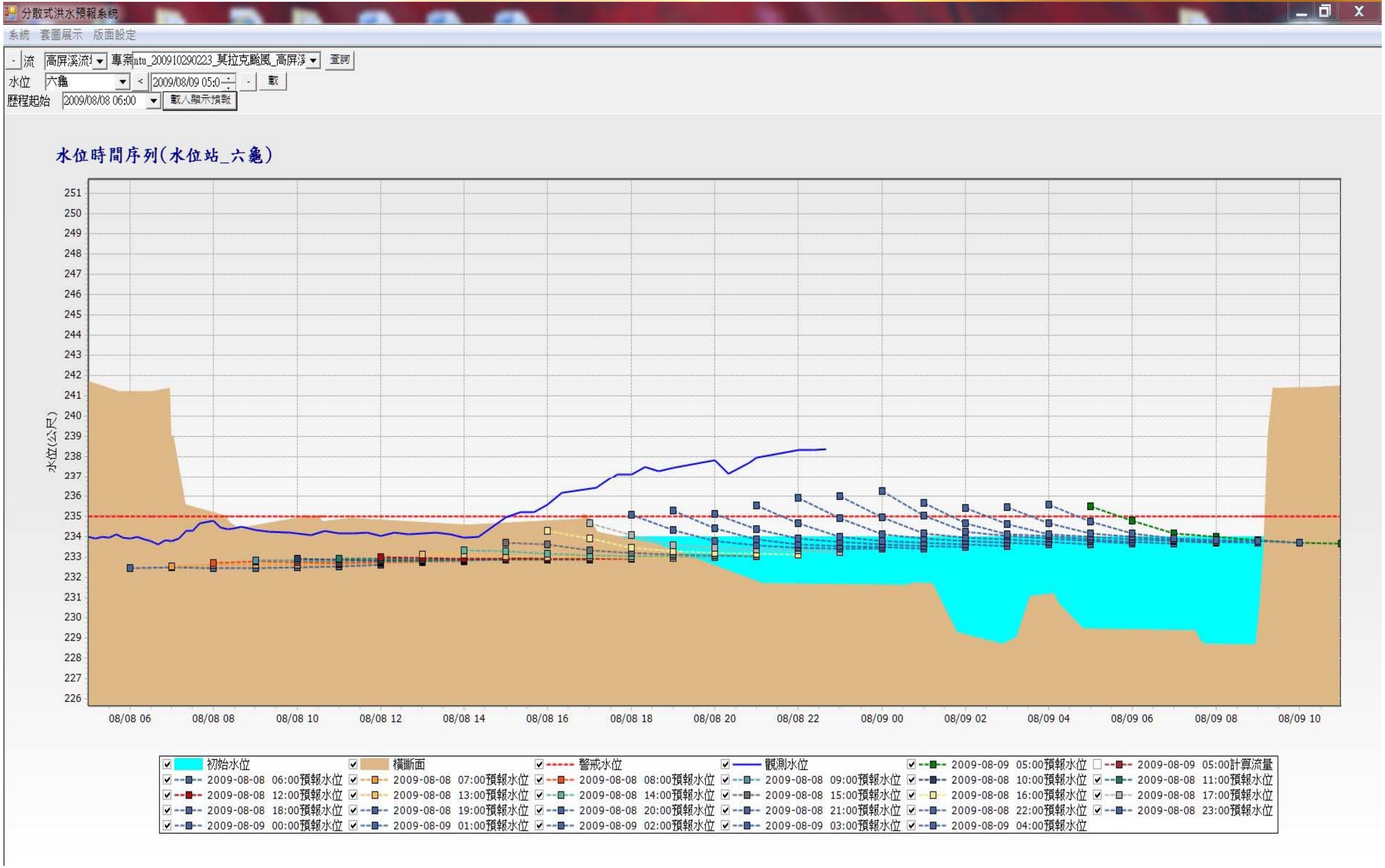
4 Dopplar Radars of CWB

- Terrain unaffected radar mosaic
- Range =120km

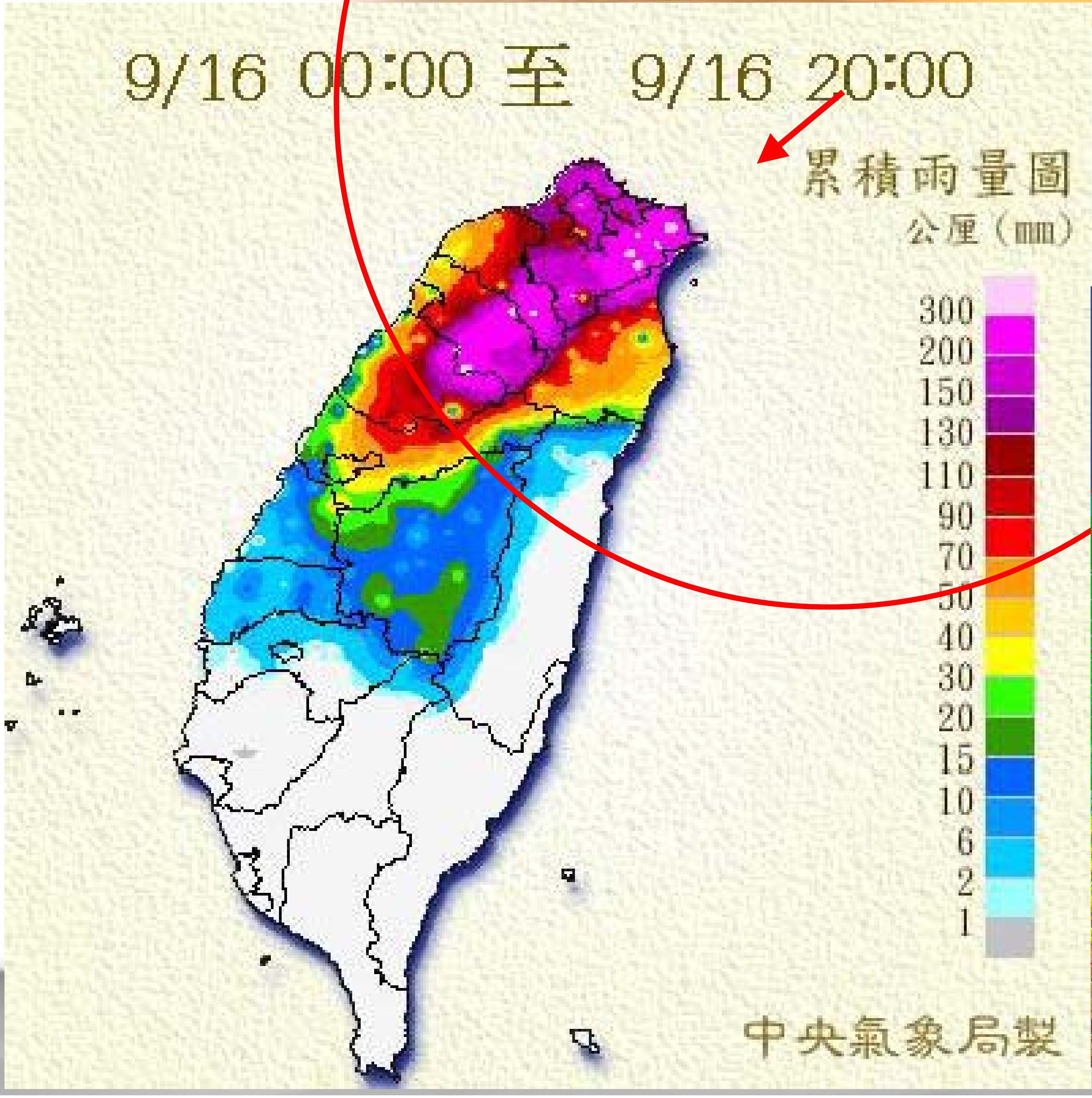



WuFenShan during Herb 1996
回波值(dBZ)
50
45
40
35
30
25
20
15
10
5
地形高層
1996/07/31
12:03 Z
未經地形遮蔽處理
方位角：226
H值(公里)
R值(公里)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0

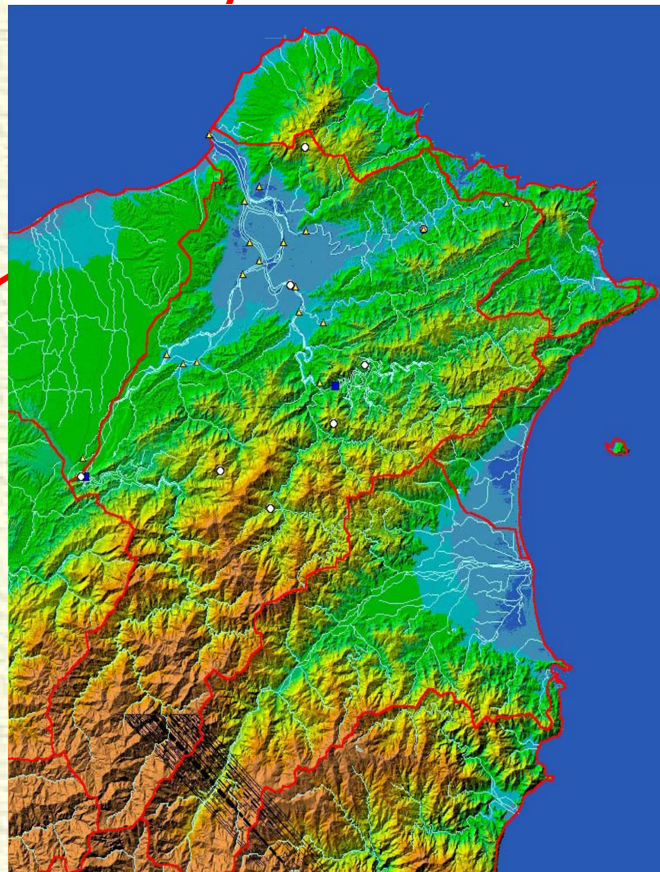
Erroneous Stage Nowcast at U/S KaoPing



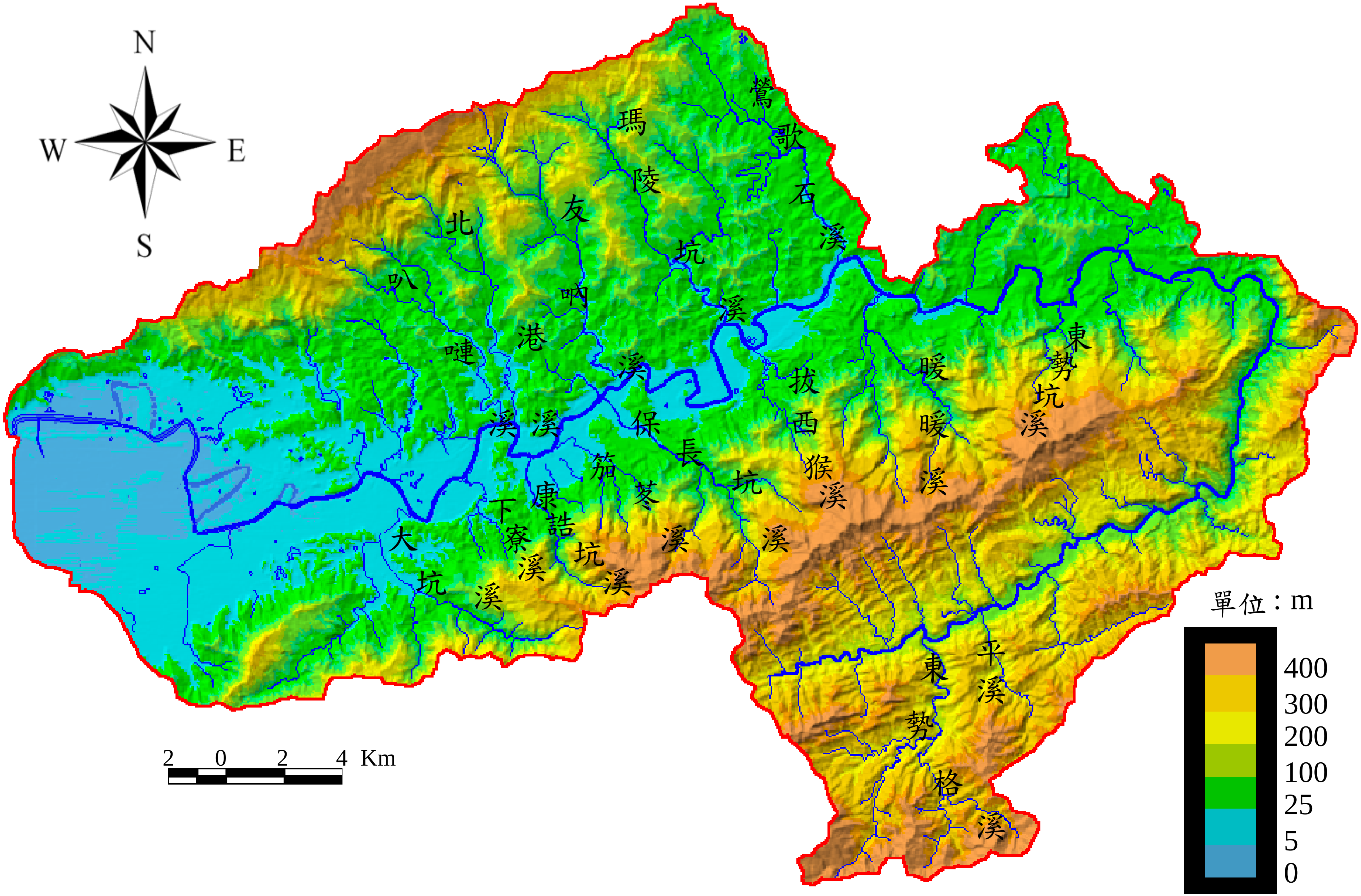
Rainfall Pattern of Typhoon Nari

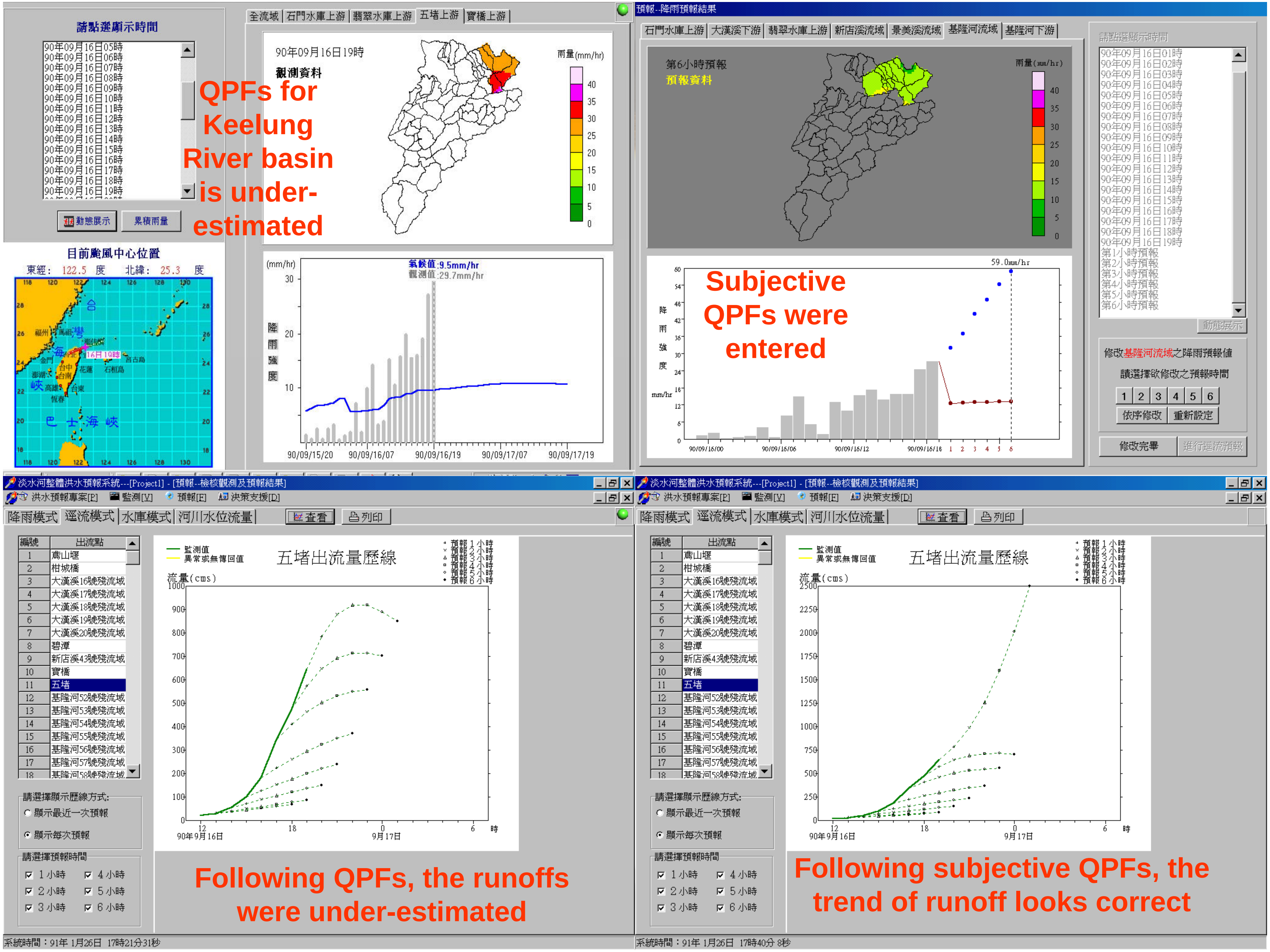


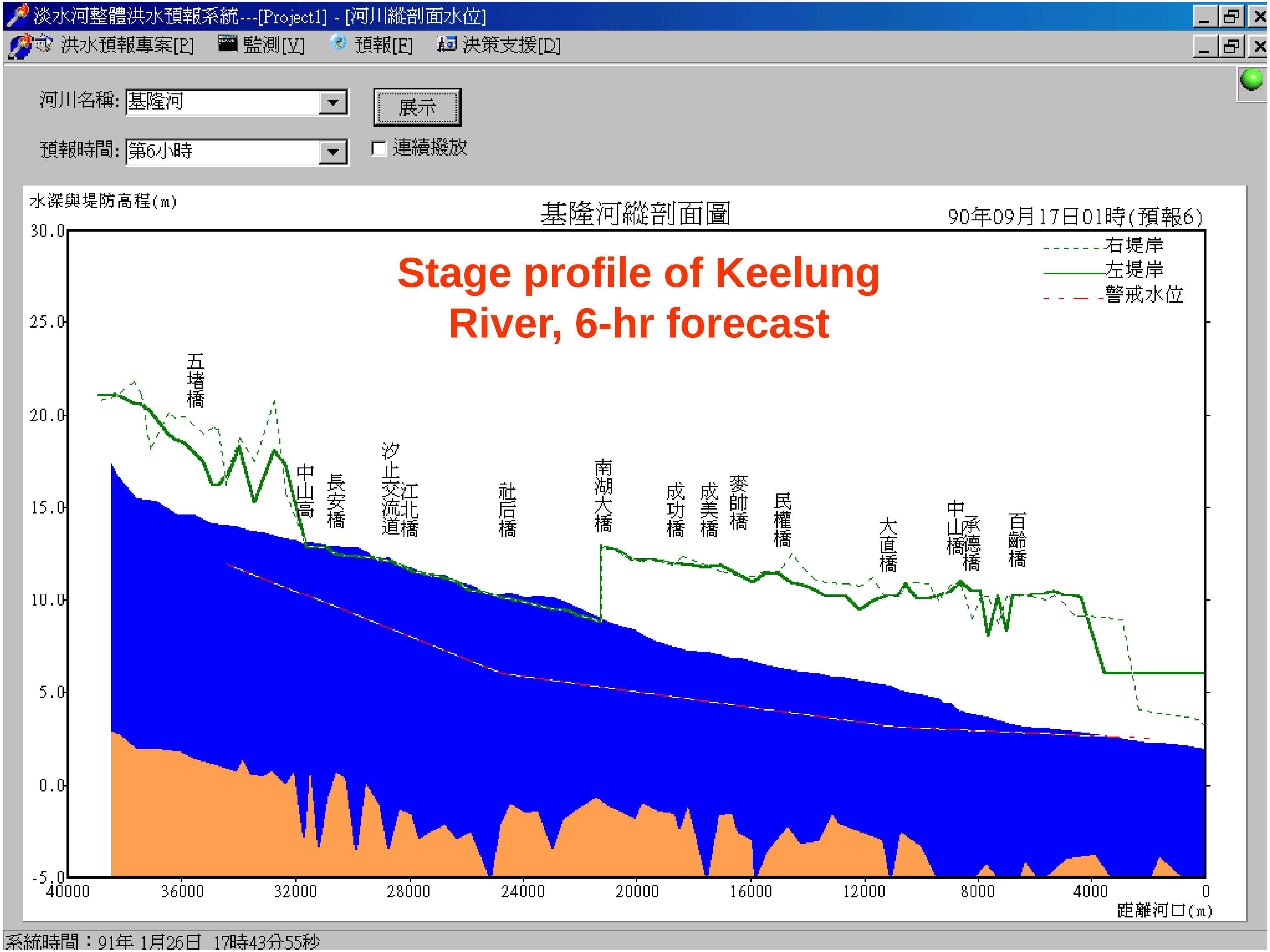
Rainfall amount
0:00~20:00 LST
Sep.16, 2001



Keelung River Basin




請點選顯示時間
全流域
石門水庫上游
翡翠水庫上游
五堵上游
寶橋上游
90年09月16日19時
觀測資料
雨量(mm/hr)
QPFs for Keelung River basin is under-estimated
動態展示
累積雨量
目前颱風中心位置
預報--降雨預報結果
石門水庫上游
大漢溪下游
翡翠水庫上游
新店溪流域
景美溪流域
基隆河流域
基隆河下游
第6小時預報
預報資料
雨量(mm/hr)
Subjective QPFs were entered
修改基隆河流域之降雨預報值
請選擇欲修改之預報時間
依序修改
重新設定
修改完畢
進行逕流預報
淡水河整體洪水預報系統---[Project1] - [預報--檢核觀測及預報結果]
降雨模式
逕流模式
水庫模式
河川水位流量
查看
列印
五堵出流量歷線
流量(cms)
請選擇顯示歷線方式:
顯示最近一次預報
顯示每次預報
請選擇預報時間
Following QPFs, the runoffs were under-estimated
Following subjective QPFs, the trend of runoff looks correct
系統時間：91年 1月26日 17時21分31秒
系統時間：91年 1月26日 17時40分 8秒

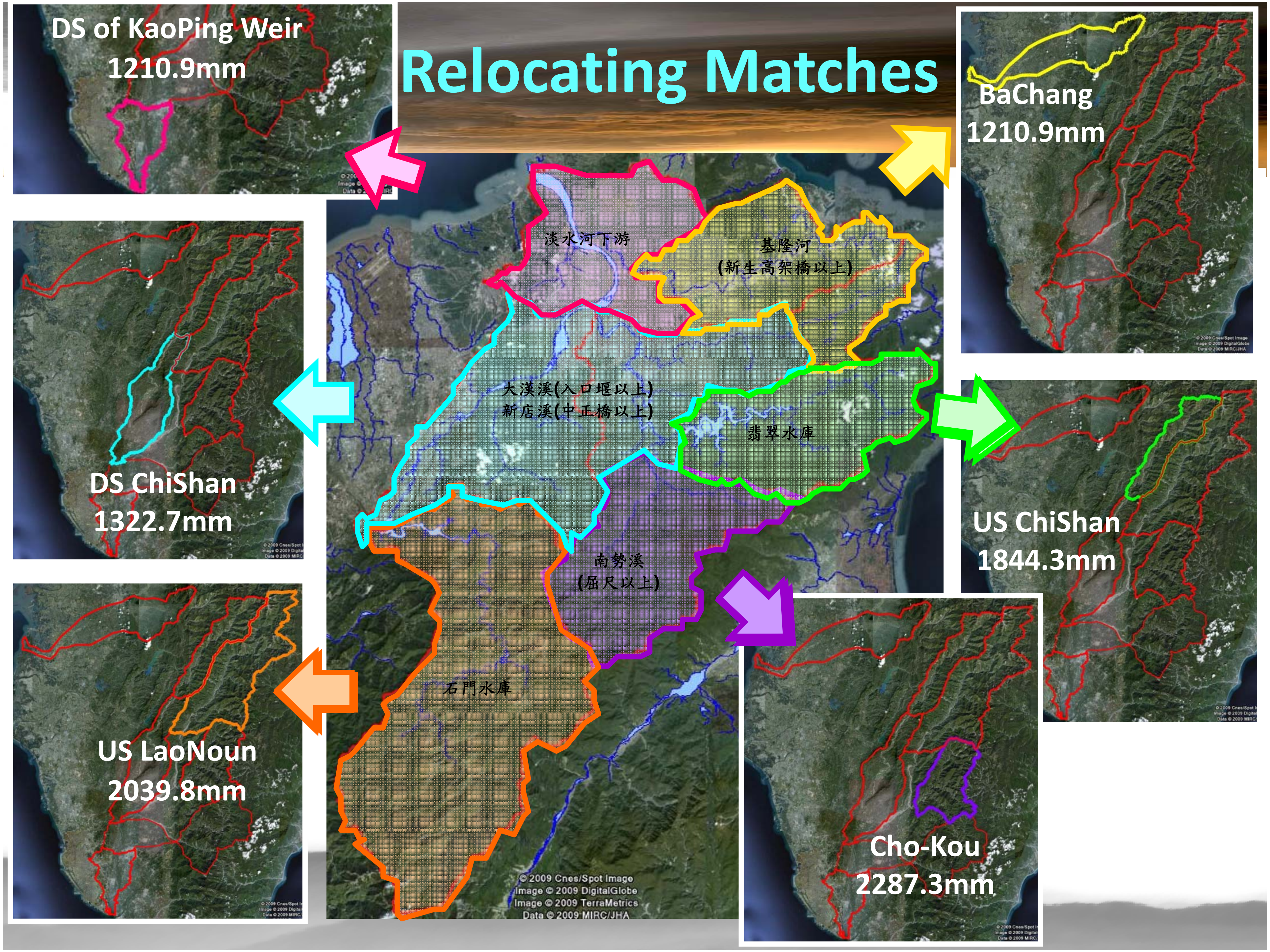


淡水河整體洪水預報系統---[Project1] - [河川縱剖面水位]
洪水預報專案[P]
監測[V]
預報[F]
決策支援[D]
河川名稱: 基隆河
展示
預報時間: 第6小時
連續撥放
水深與堤防高程(m)
基隆河縱剖面圖
90年09月17日01時(預報6)
Stage profile of Keelung River, 6-hr forecast
右堤岸
左堤岸
警戒水位
五堵橋
中山高
長安橋
汐止交流道
江北橋
社后橋
南湖大橋
成功橋
成美橋
麥帥橋
民權橋
大直橋
中山橋
承德橋
百齡橋
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
40000
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
距離河口(m)
系統時間：91年 1月26日 17時43分55秒

Data Assimilation

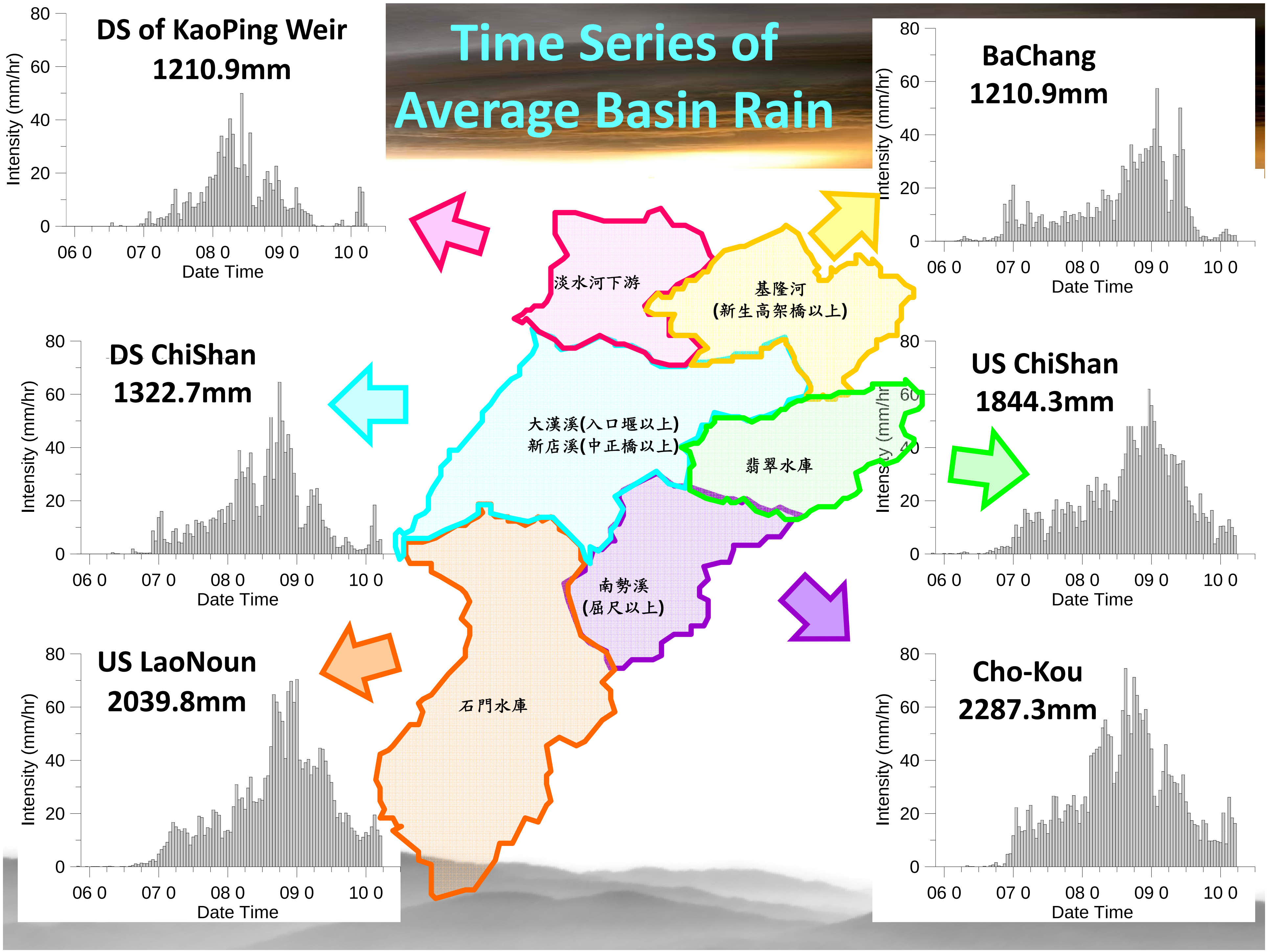
- River Stage DA uncertainties :
  - QPE and runoff uncertainties contribute to channel lateral inflow uncertainty
  - Scouring and sedimentation leads to river bathymetry uncertainty
- Changes in runoff hydrograph induces a need to assimilate Direct Runoff and Base-flow (tank model)
- Kalman Filter, which assimilates the states only, does not work for bathymetry uncertainty

Relocating Matches

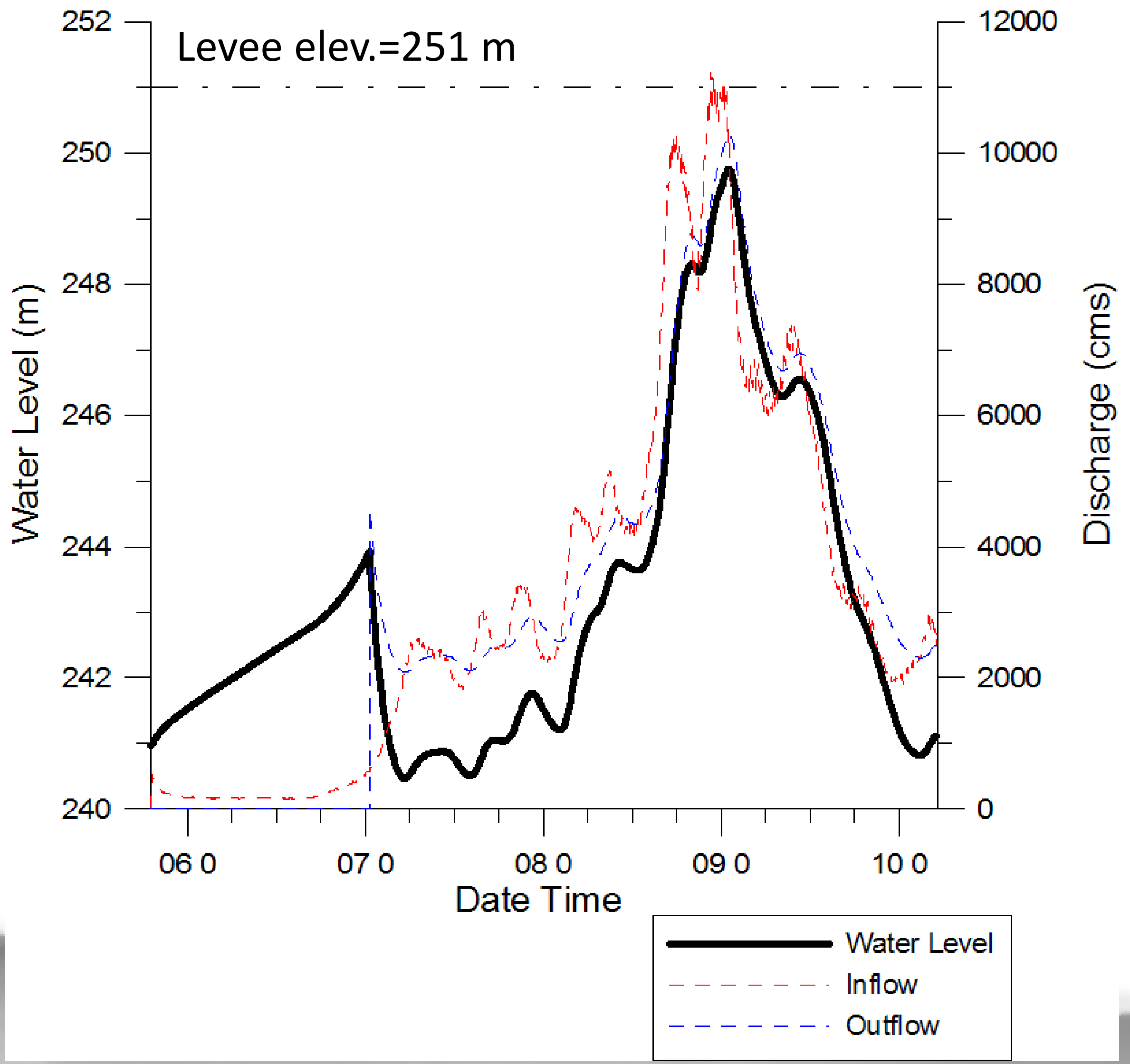


Relocating

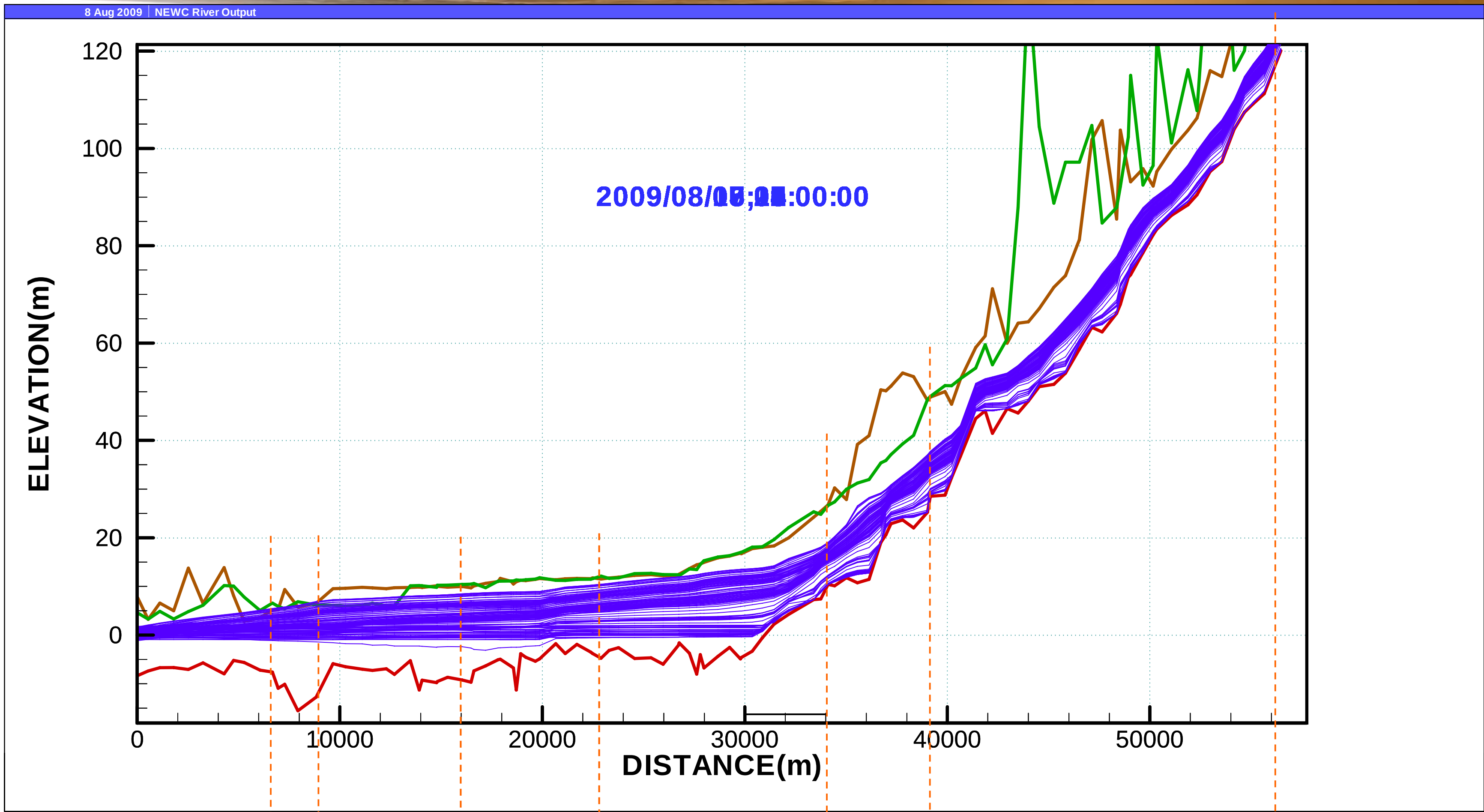
DanShui River	面積 (Km^2)	對照區域	面積 (Km^2)	累積雨量 (mm)
基隆河(員山子上游)	90	八掌溪流域	475	1210.9
基隆河(員山子-新生高架橋)	266			
南勢溪(上龜山橋以上)	330	濁口溪	368	2287.3
FeiTsuei Reservoir	301	旗山溪上游(楠峰橋以上)	335	1844.3
新店溪(中正橋以上)	278	旗山溪下游(楠峰橋-里嶺大橋)	478	1322.7
大漢溪(入口堰以上)	412			
ShihMen Reservoir	756	荖濃溪上游(荖濃站以上)	812	2038.9
台北盆地	287	高屏溪下游(攔河堰-河口)	195	834.0


Time Series of
Average Basin Rain
DS of KaoPing Weir
1210.9mm
BaChang
1210.9mm
DS ChiShan
1322.7mm
US ChiShan
1844.3mm
US LaoNoun
2039.8mm
Cho-Kou
2287.3mm
Intensity (mm/hr)
Date Time
06 0
07 0
08 0
09 0
10 0
0
20
40
60
80
淡水河下游
基隆河
(新生高架橋以上)
大漢溪(入口堰以上)
新店溪(中正橋以上)
翡翠水庫
南勢溪
(屈尺以上)
石門水庫

ShihMen Reservoir Hydrographs



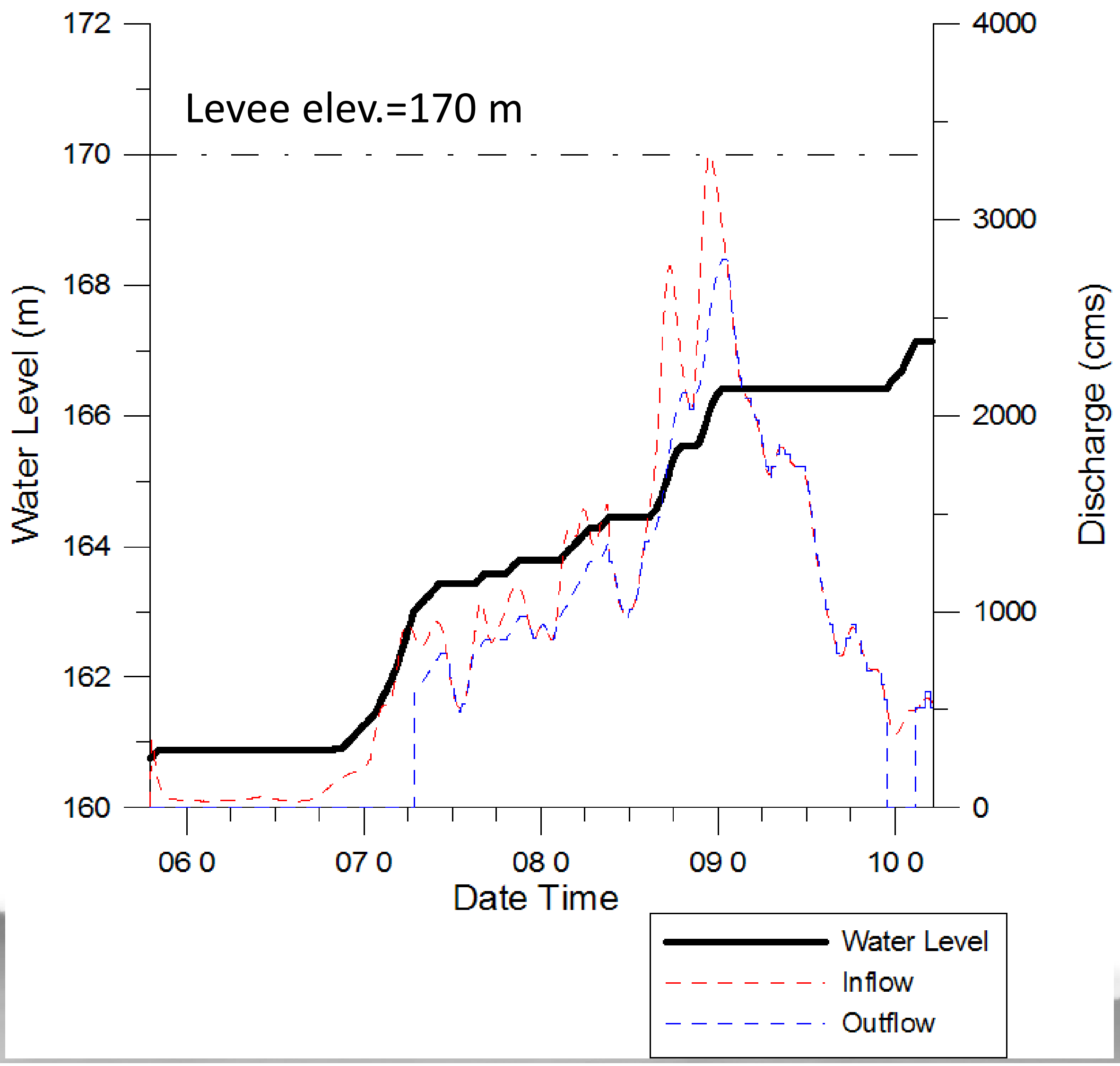
DaHan and DanShui River



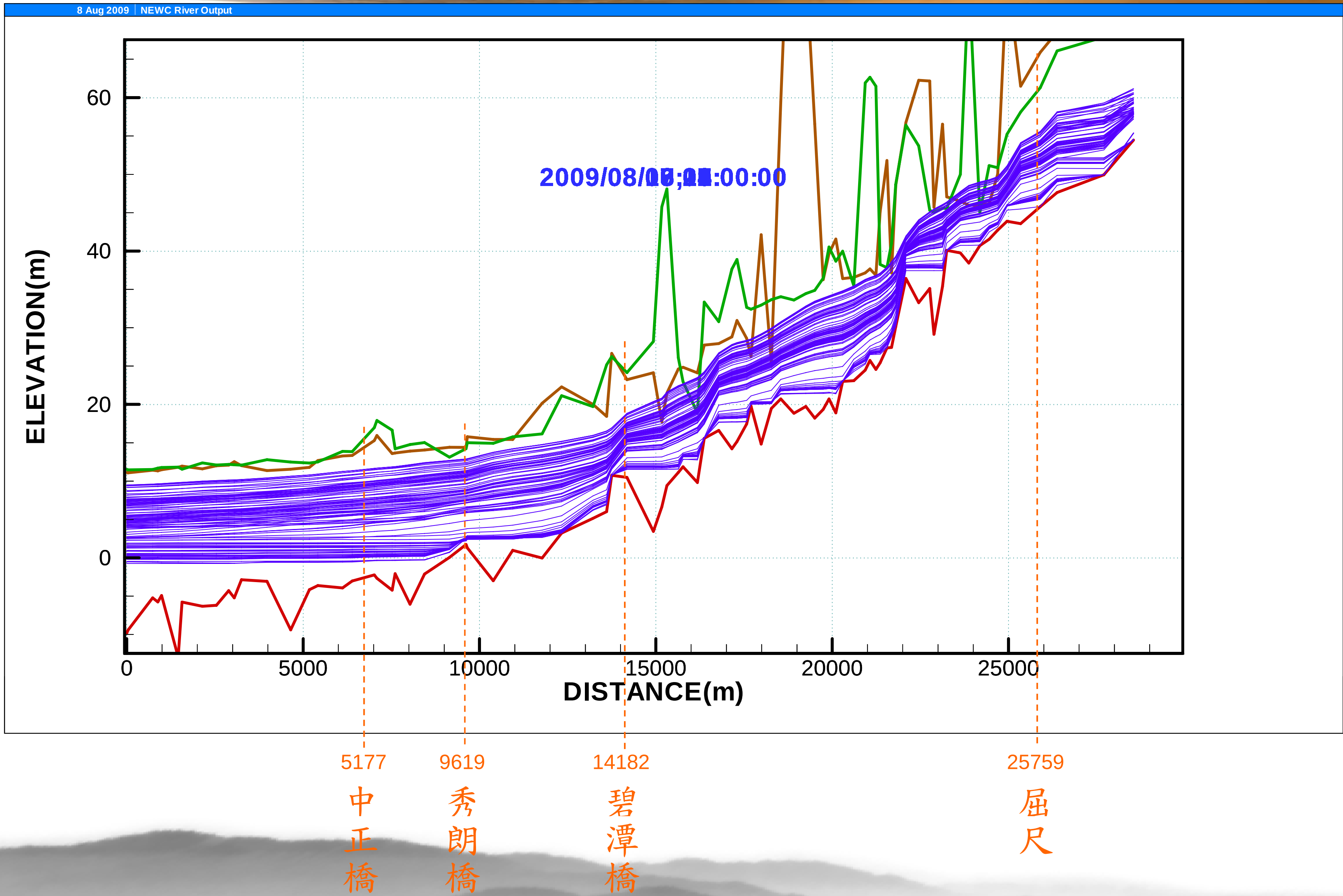
6672 8835 16048 22900 34116 39020 56475

土地公鼻 獅子頭 台北橋 新海橋 柑園橋 三鶯橋 石門後池

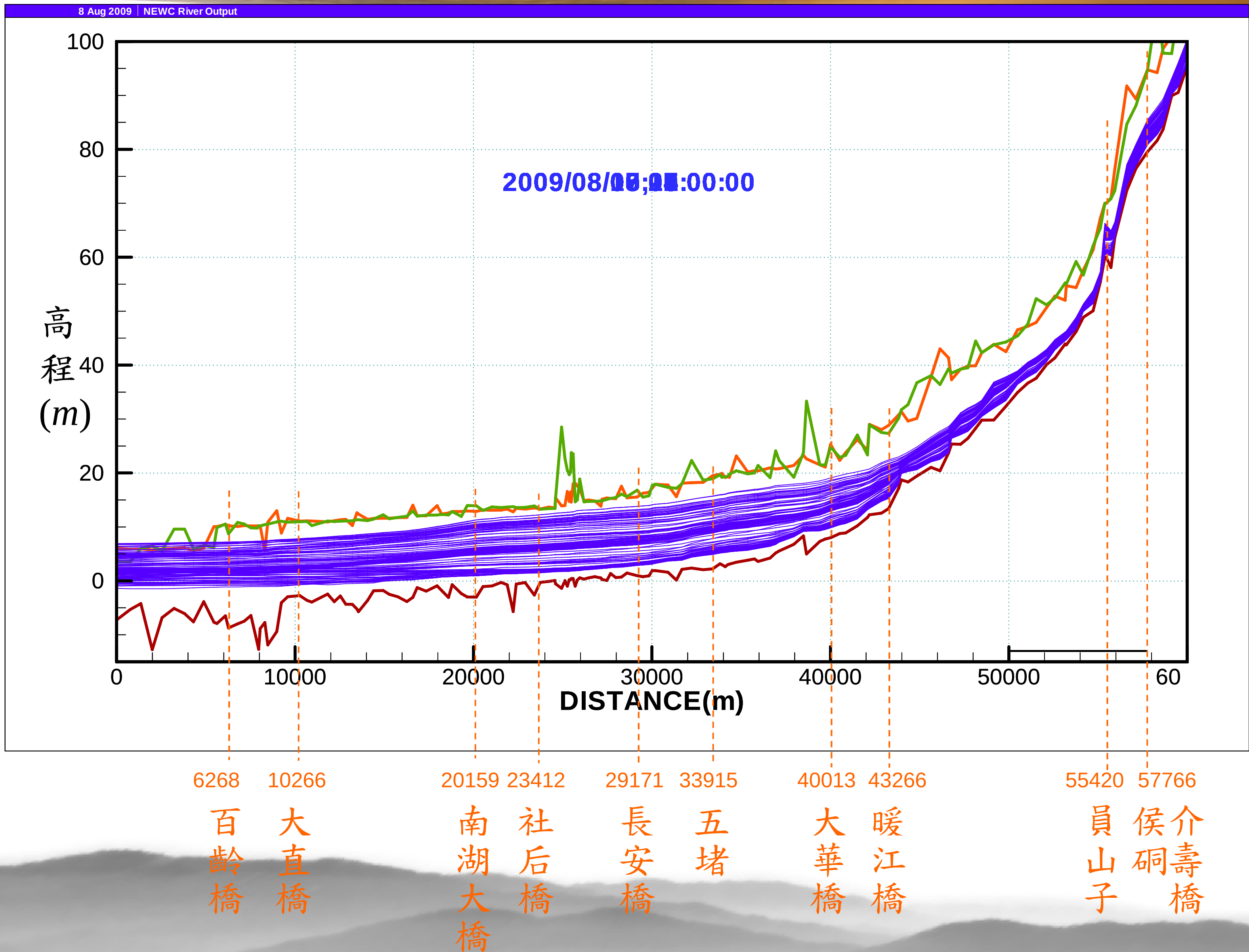
FeiTsuei Reservoir Hydrographs



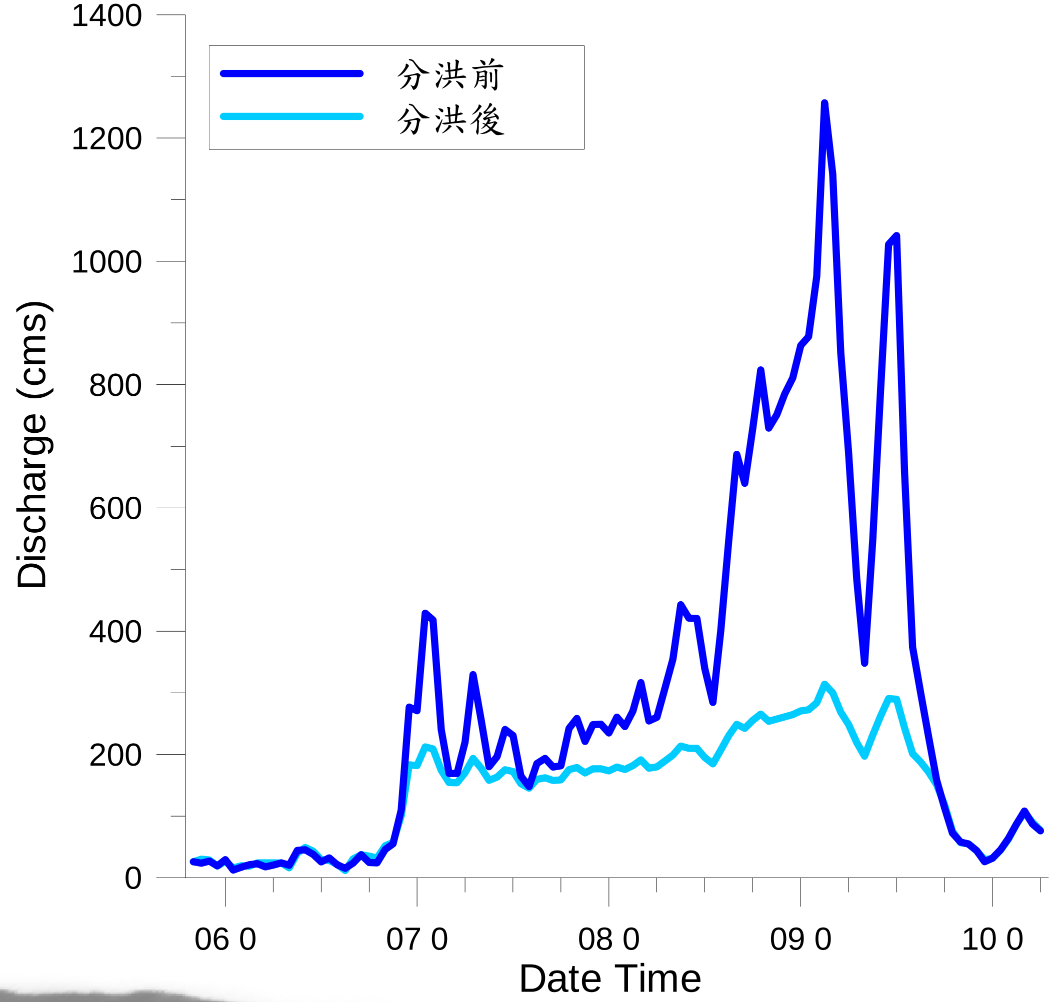
HsinDian Creek



Keelung River



With or W/O YuanShanTse Diversion



Summary

- The river stage nowcast system still needs some major improvements.
- The clean water simulation is not a complete story.
- Catastrophic flooding is possible in Taipei Metropolitan Area.


Thank you for
Your Attention