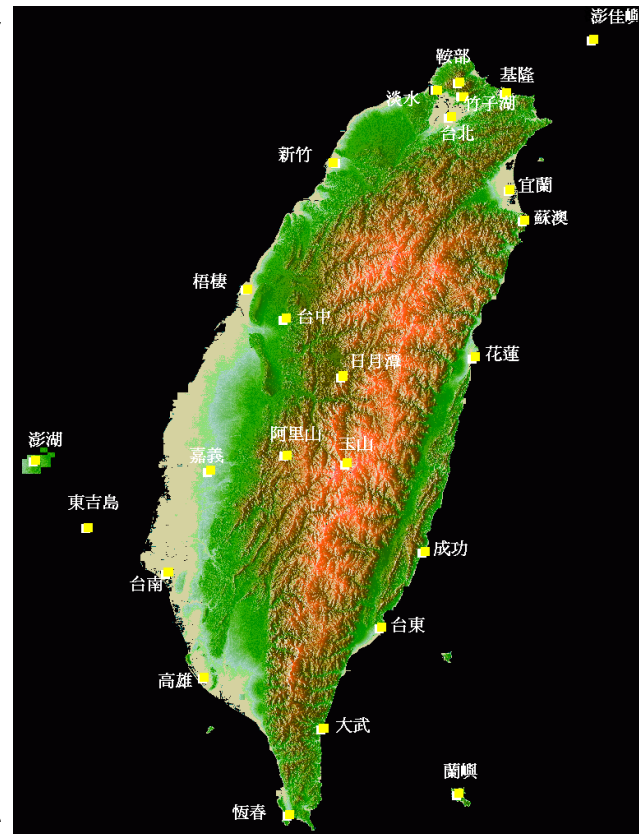
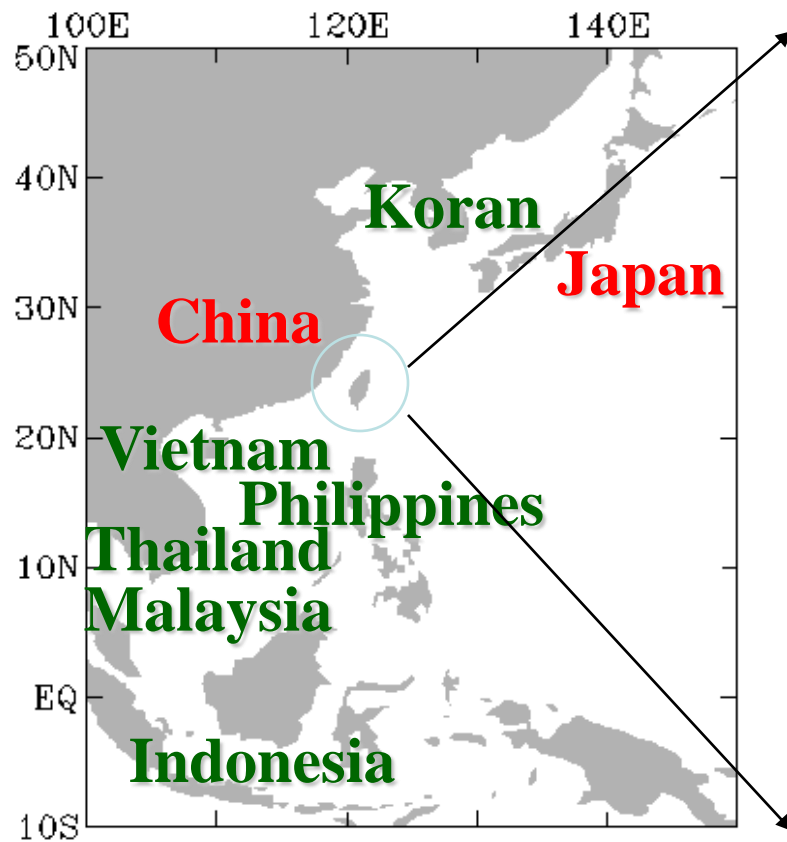




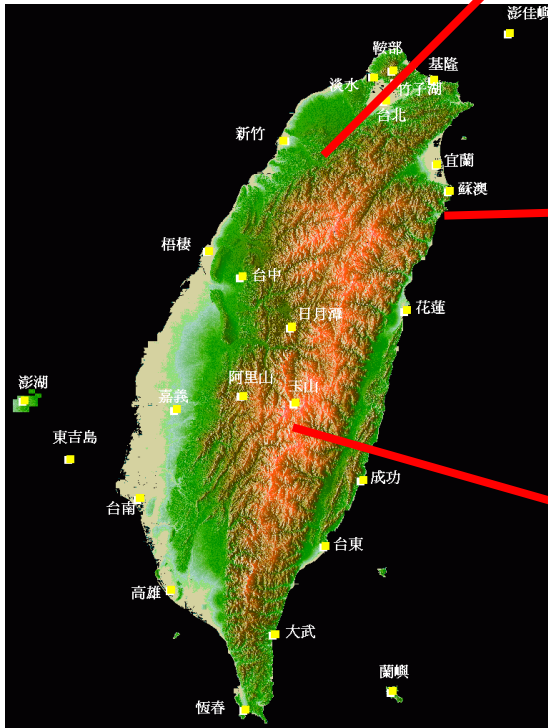
Disaster Weather Systems in Taiwan and the Weather Service of the Central Weather Bureau

T.-C. Yeh
Central Weather Bureau, MOTC
May 6, 2008

Taiwan



36,000 km²



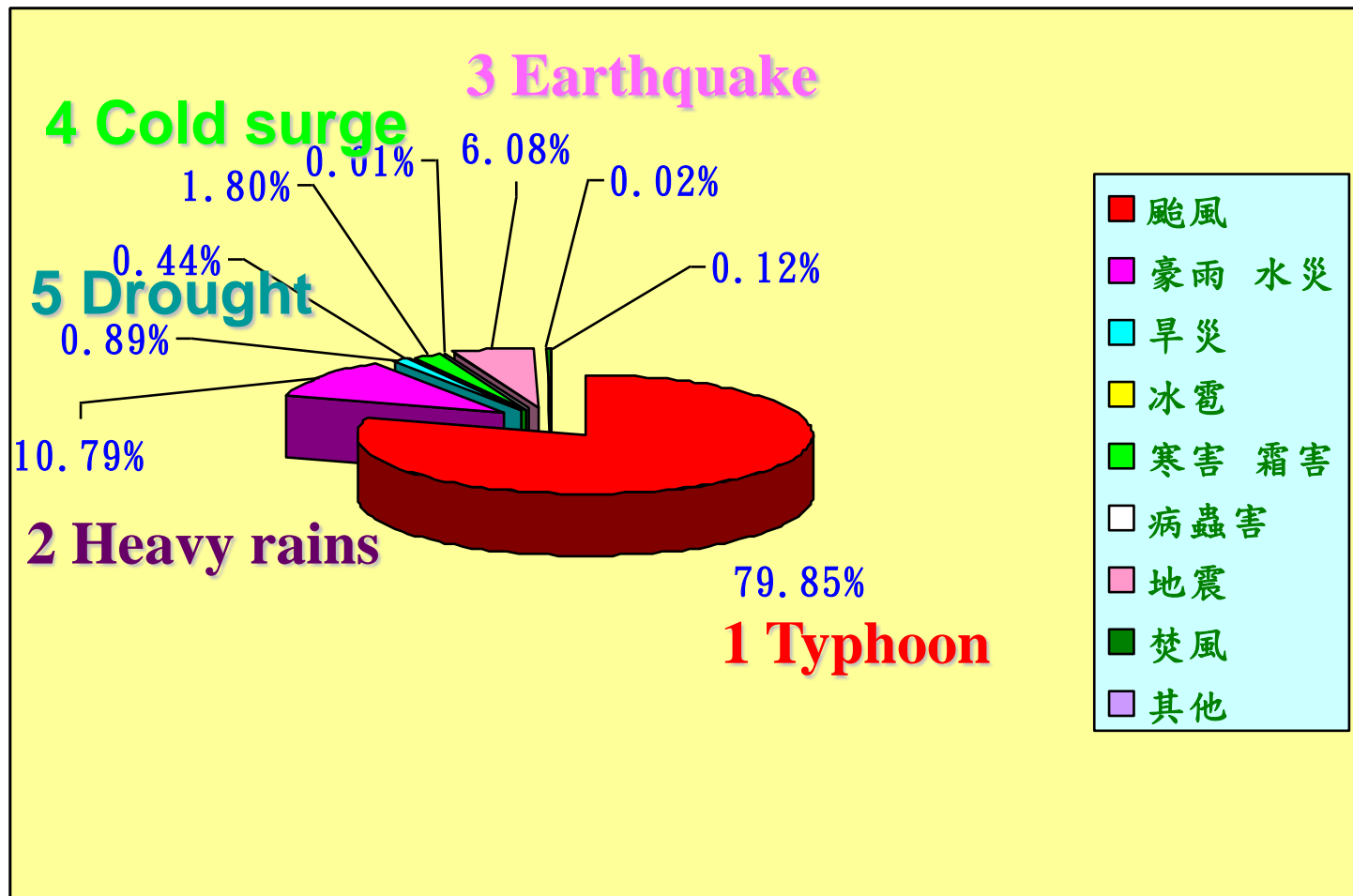


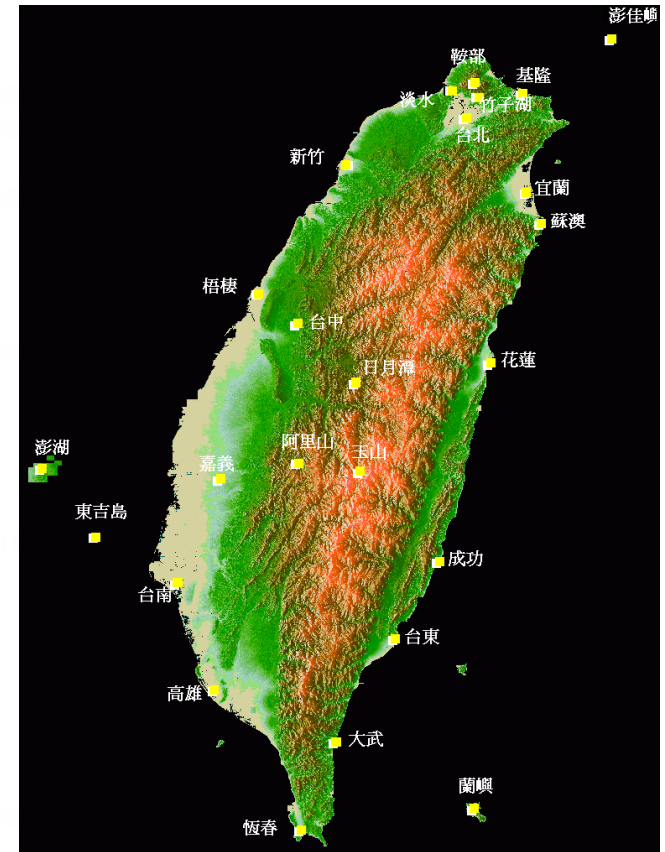
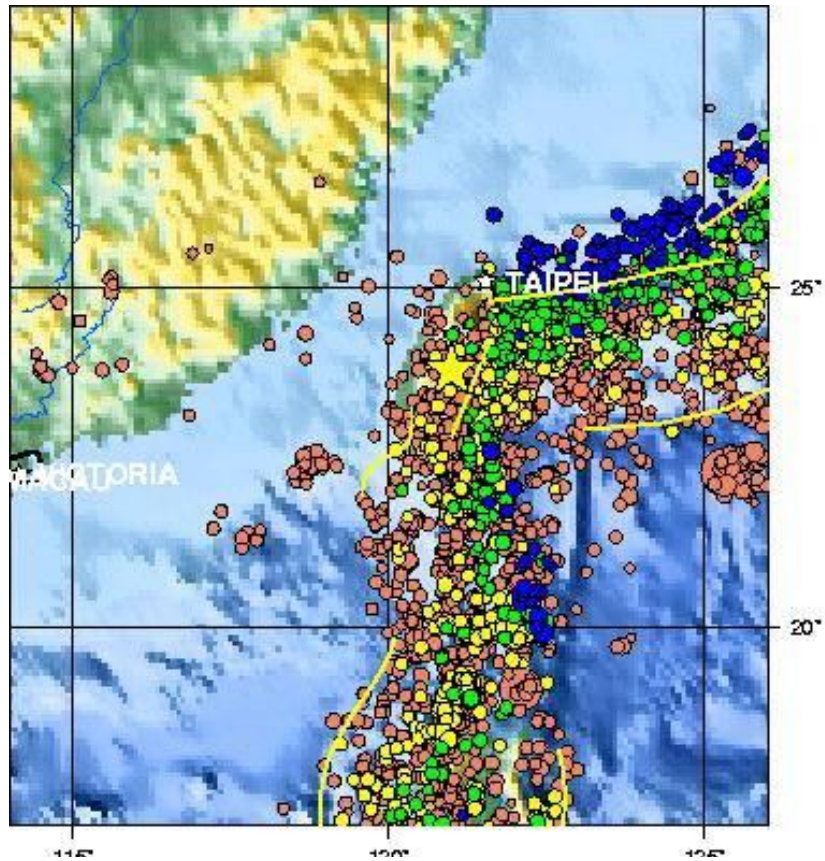




Percentage Distribution Among Natural Disaster Losses

Total direct losses due to the
Weather and earthquake related disasters from 1985 to 2005
is about NT\$ 332 B. (US\$ 0.5 B per year)

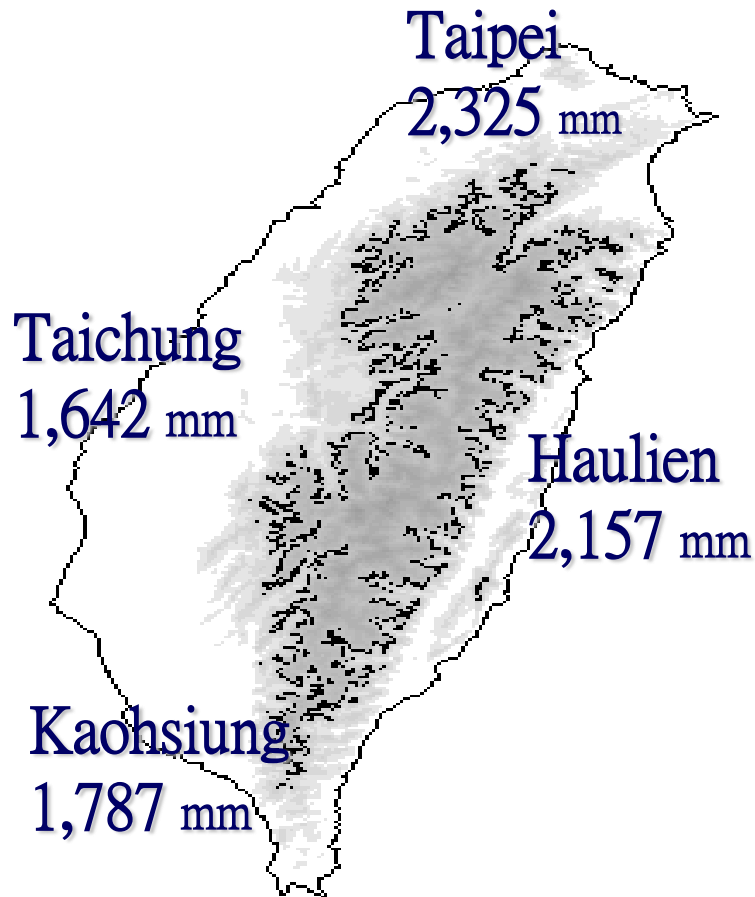




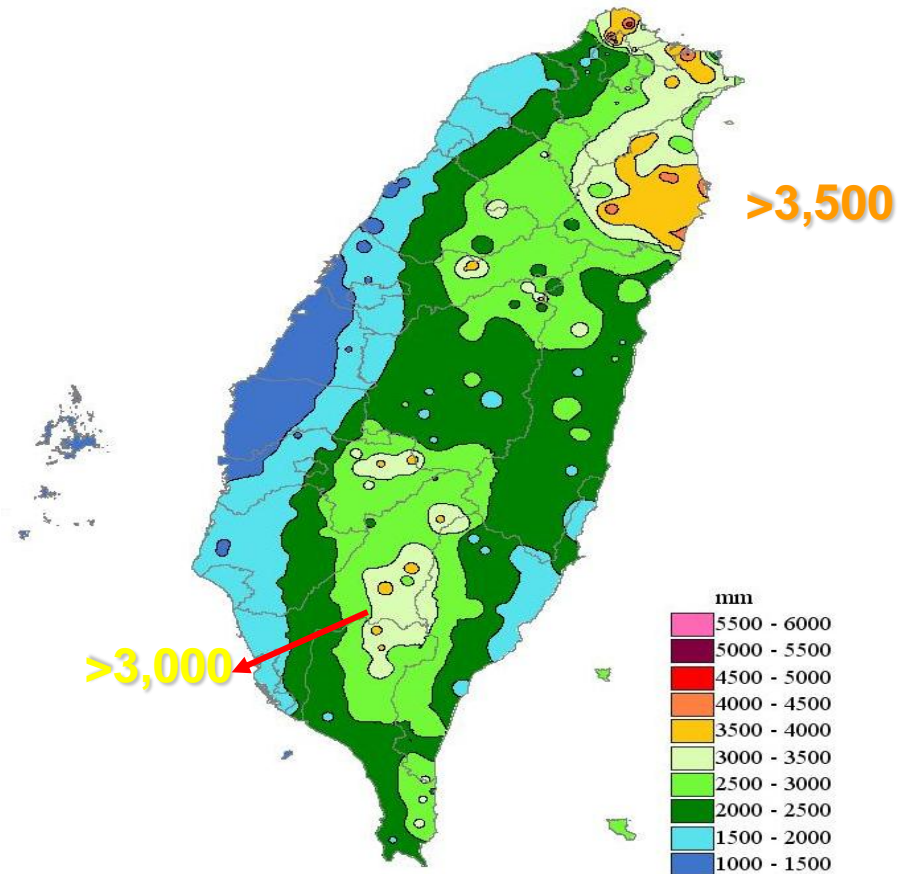
Located on the circum-Pacific seismic belt

32% of the area with elevation higher than 1,000 m

Annual Rainfall



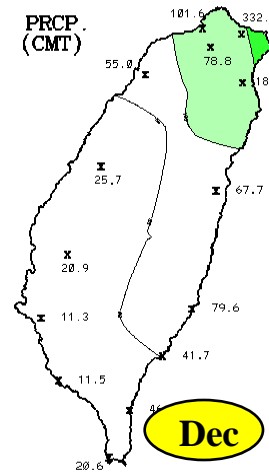
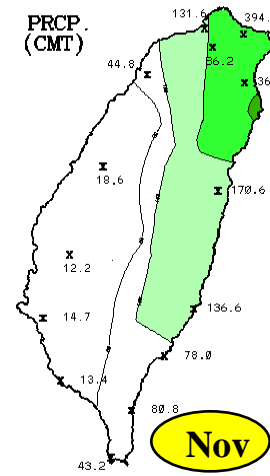
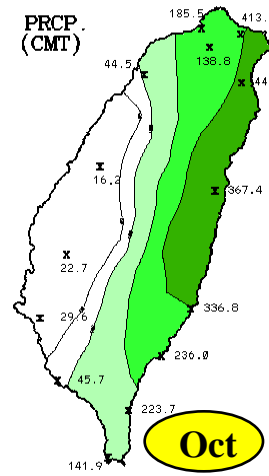
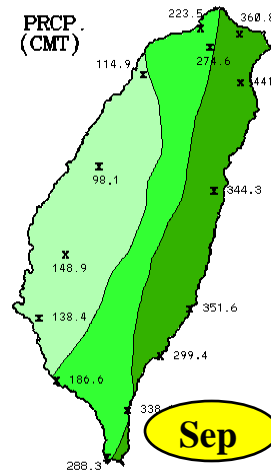
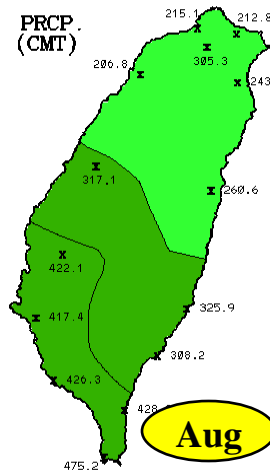
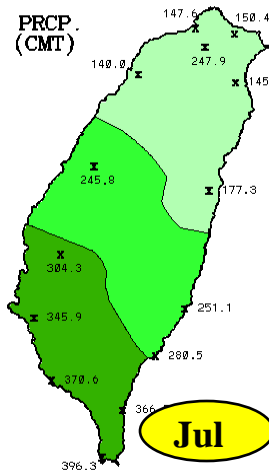
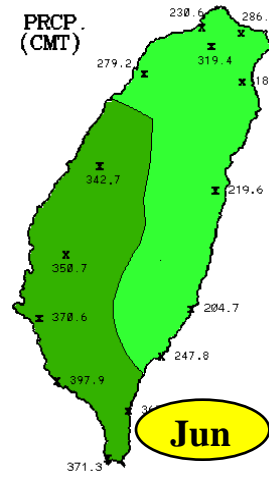
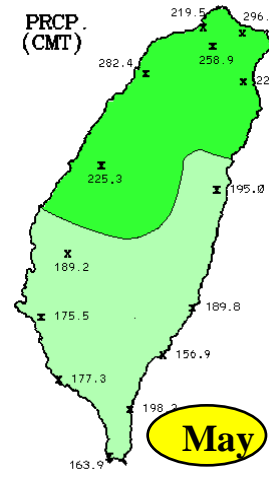
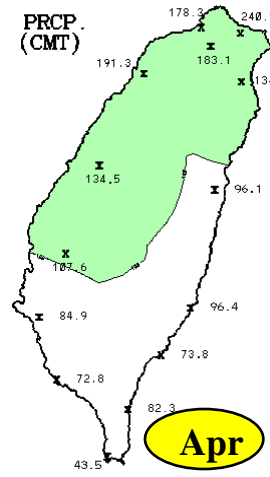
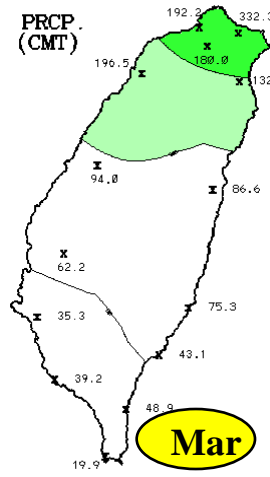
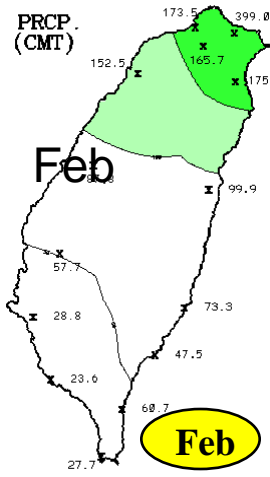
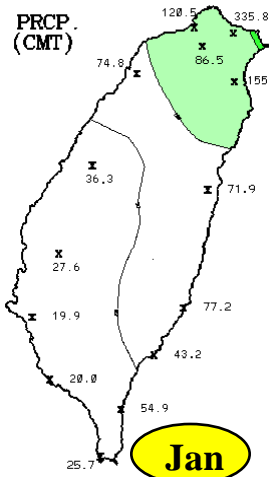
(data period 1971-2000)



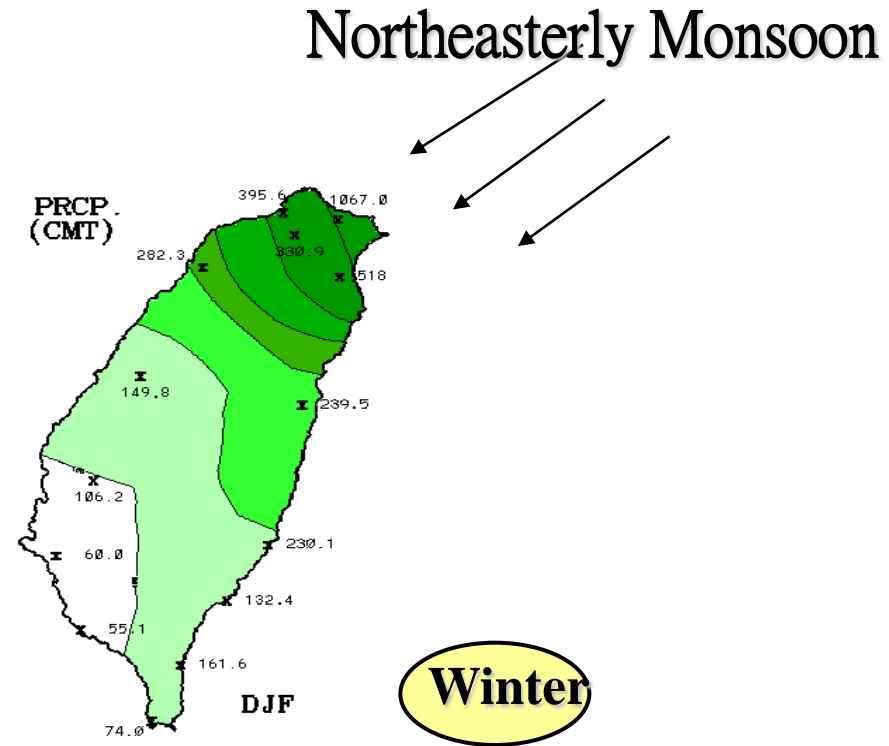
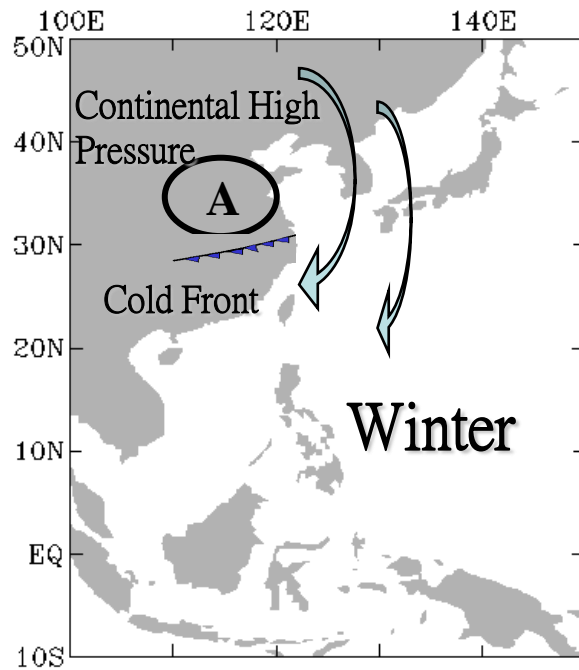
(data period 1992-2006)

Monthly Rainfall (data period 1971-2000)

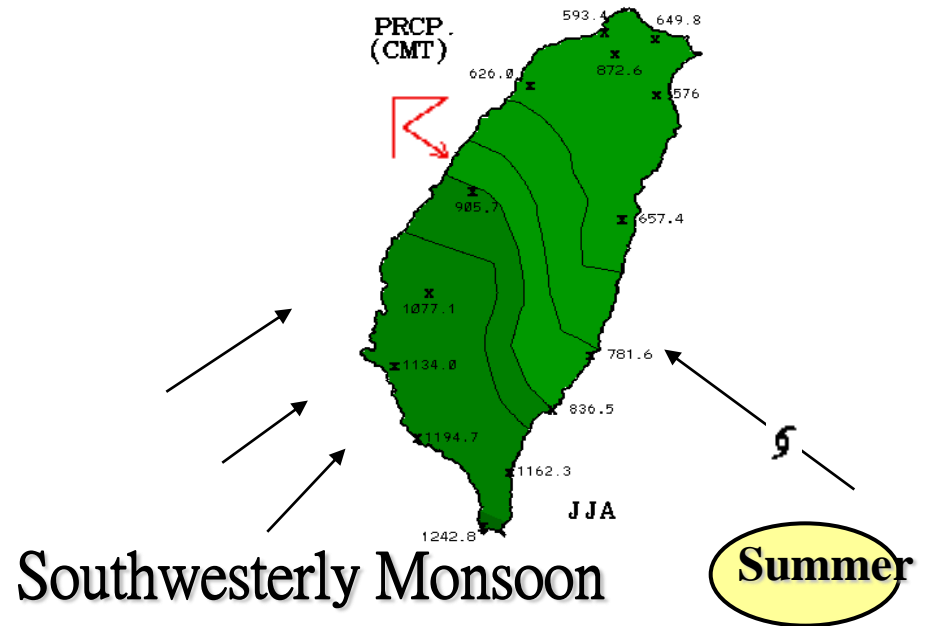
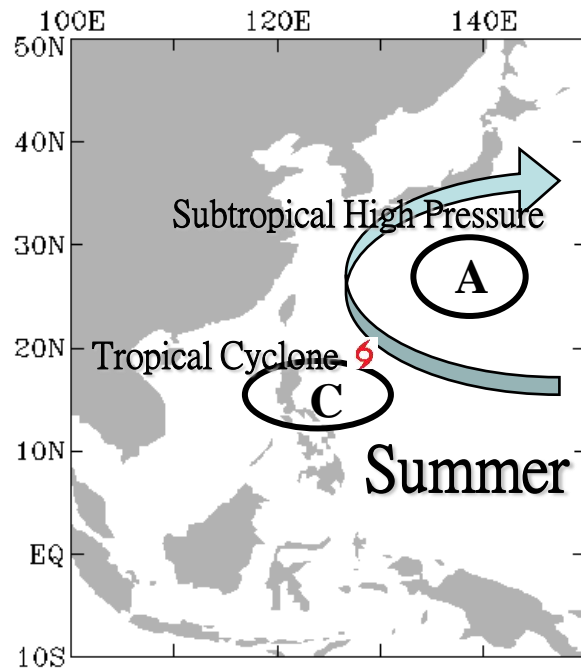
Jan



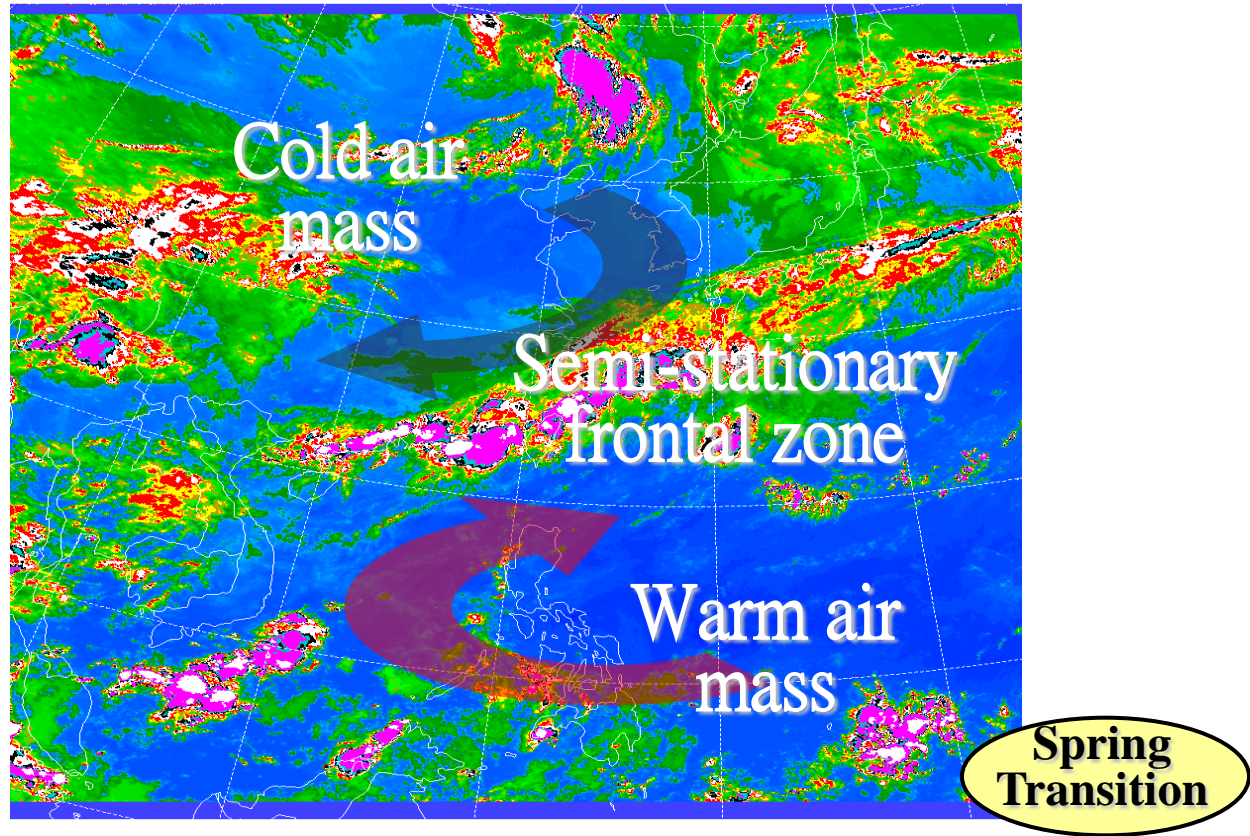
Climate in Taiwan



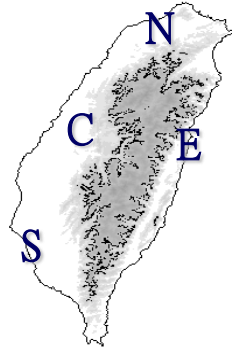
Climate in Taiwan



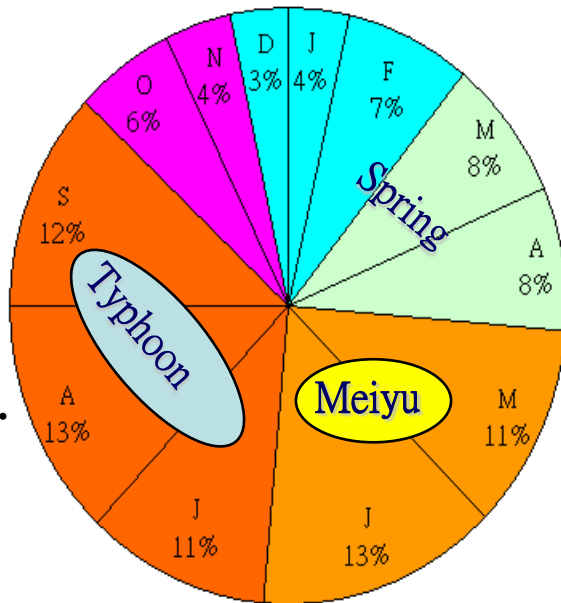
Climate in Taiwan



Rainfall Distribution

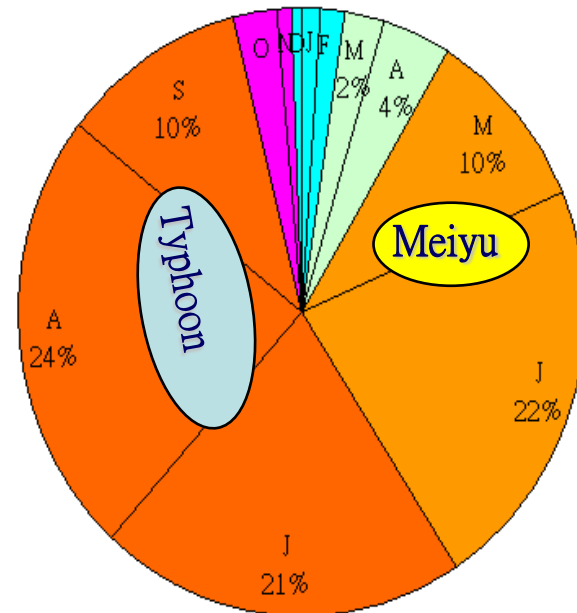


North of Taiwan(Taipei)



Taipei
May-Sep.
60%

South of Taiwan(744)



Kaohsiung
May-Sep.
87%

Rainfall Warning or Alert

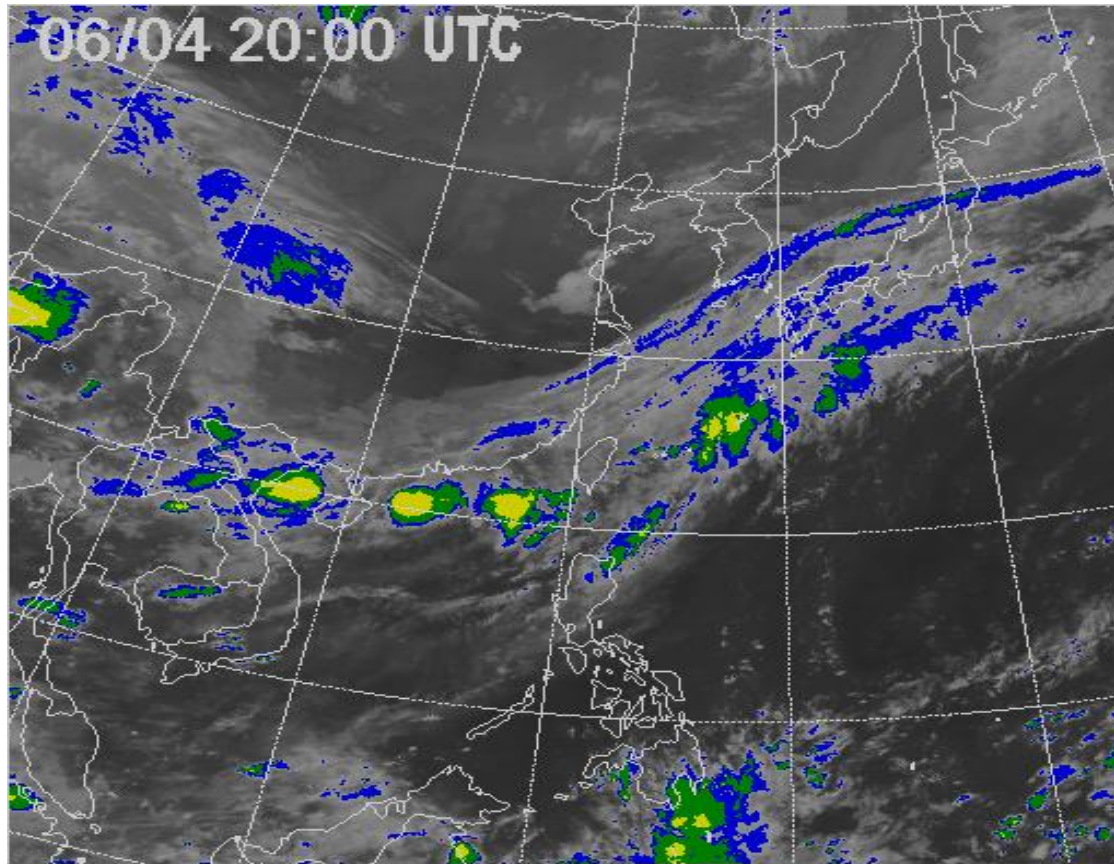
Heavy Rain $> 50 \text{ mm}/24\text{h}$ and $> 15 \text{ mm}/\text{h}$

Extremely Heavy Rain $> 130 \text{ mm}/24\text{h}$

Torrential Rain $> 200 \text{ mm}/24\text{h}$

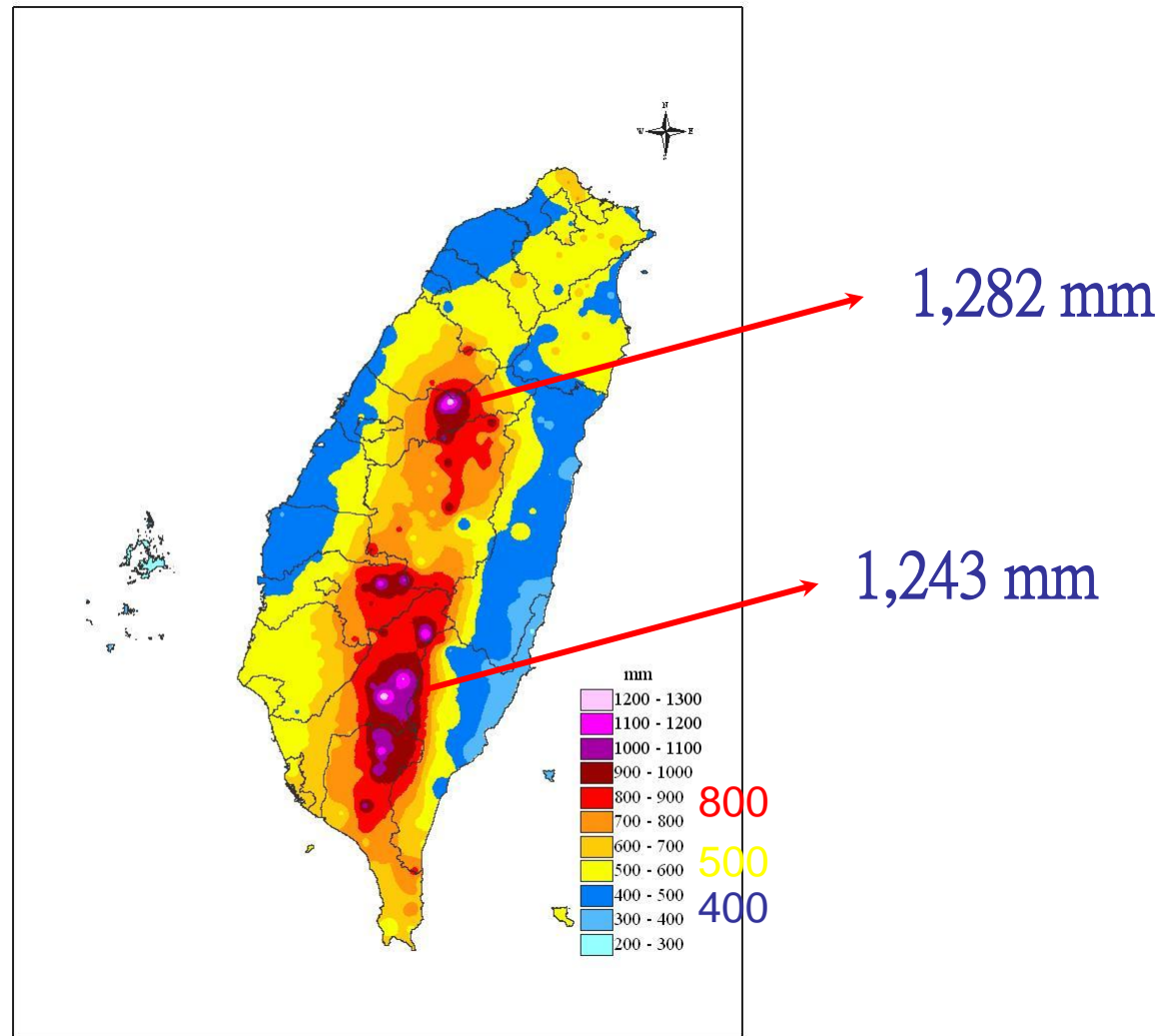
Extremely Torrential Rain $> 350 \text{ mm}/24\text{h}$

Meiyu



Frequent Mesoscale Convergence Systems (MCSs) occur along the Meiyu front

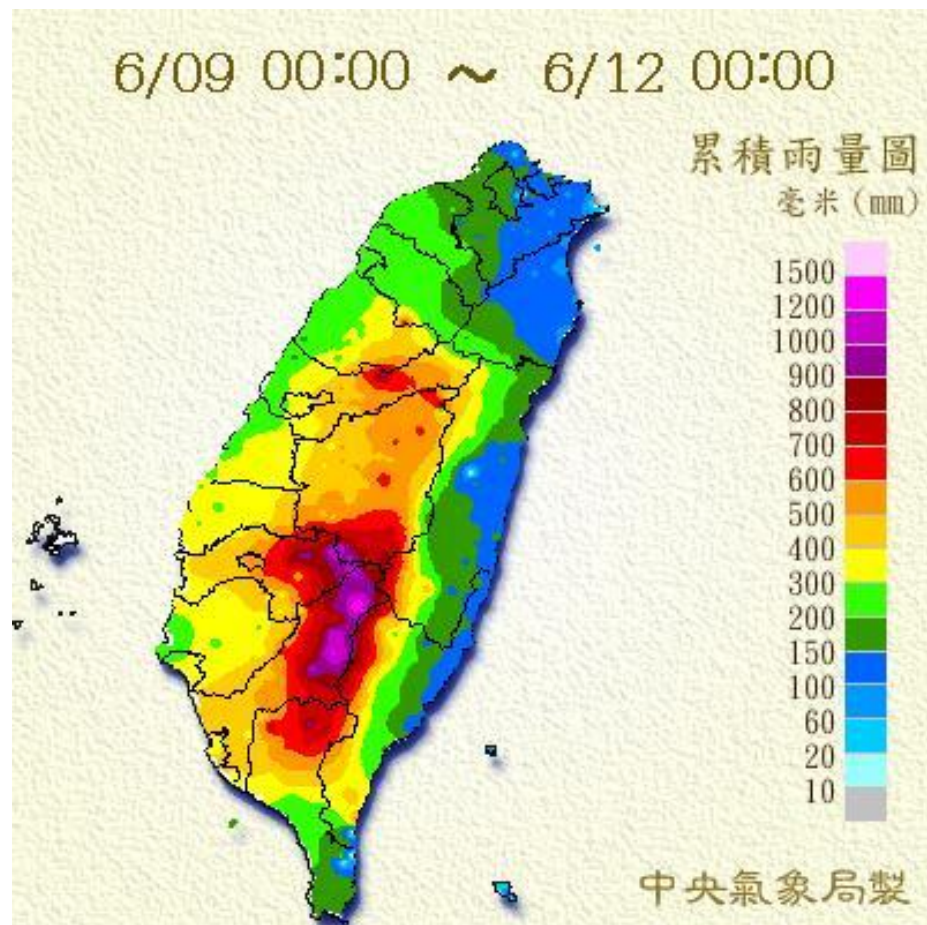
Averaged Rainfall In May-June



(data period 1992-2006)

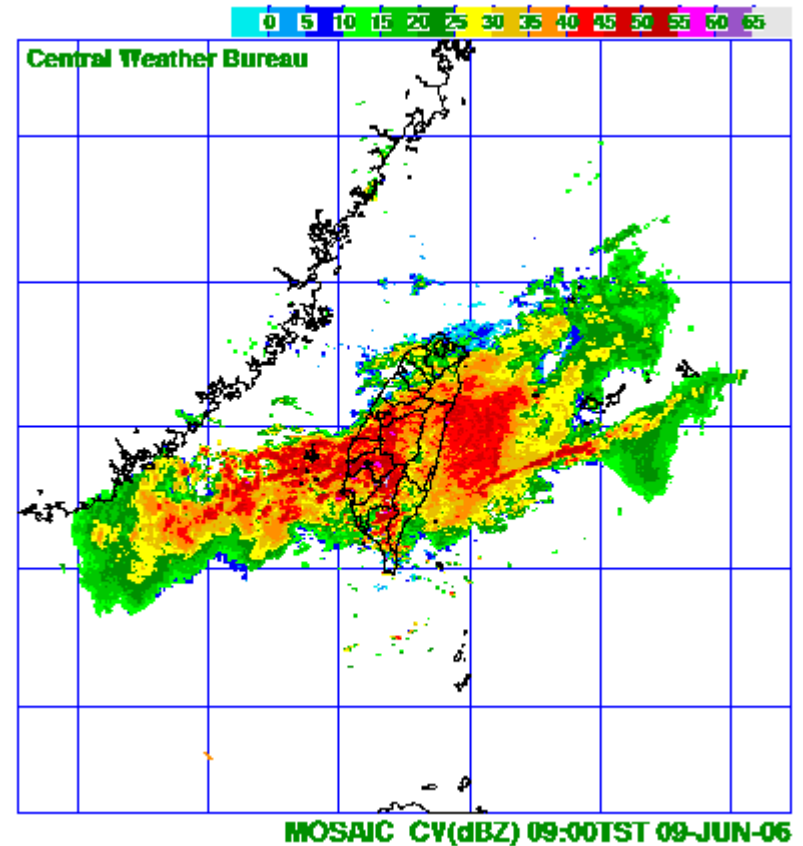
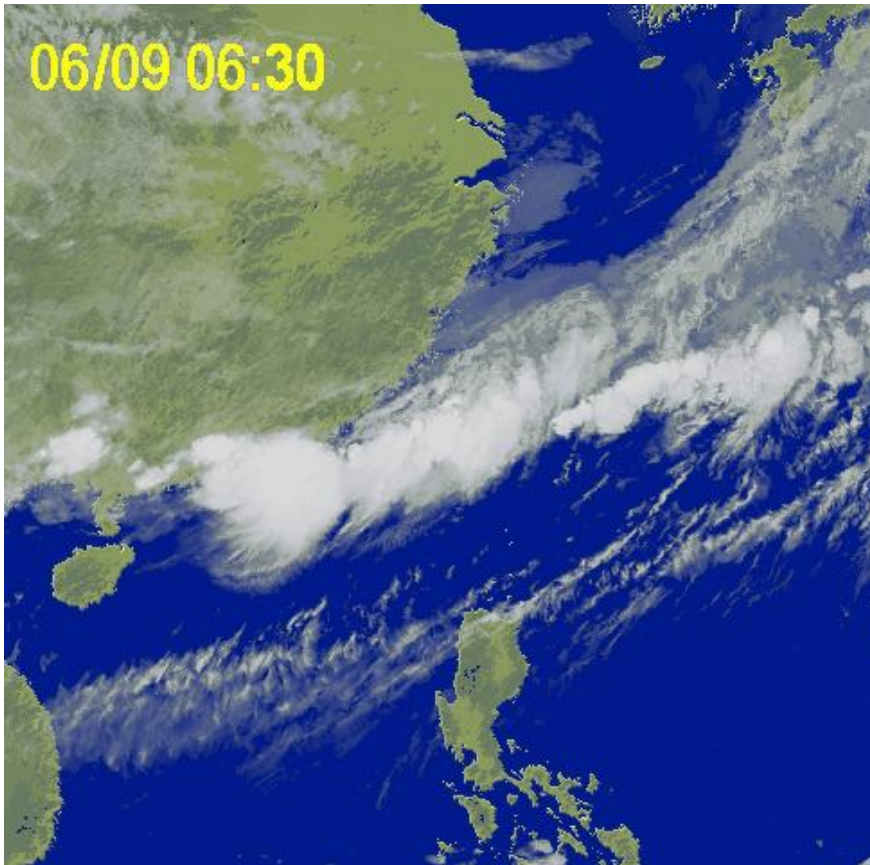
A Case

72-hour accumulated rainfall from June 9 to 11, 2006

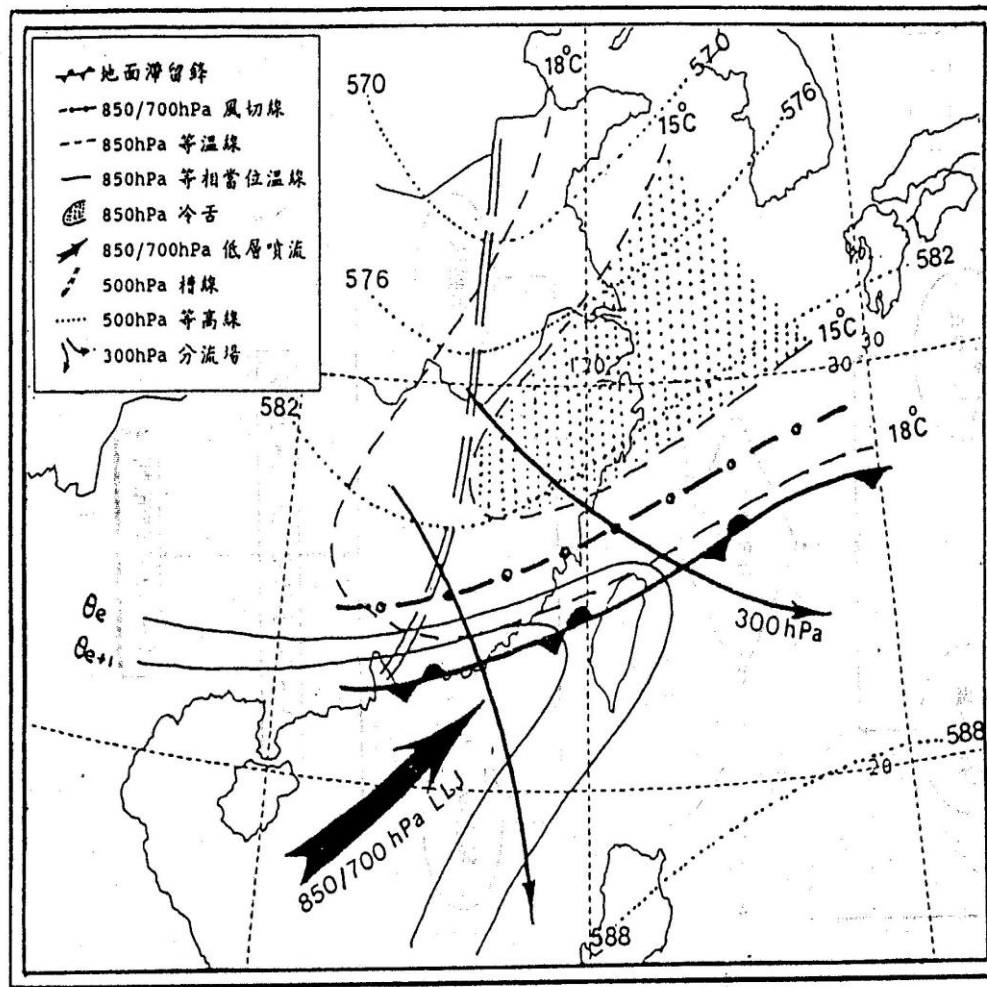


- 1 1373.0 南天池 高雄縣桃源鄉
- 2 1242.0 阿里山 嘉義縣阿里山鄉
- 3 1223.0 溪南 高雄縣桃源鄉
- 4 1132.0 楠溪 高雄縣桃源鄉
- 5 1131.5 小關山 高雄縣桃源鄉
- 6 1068.0 神木村 南投縣信義鄉
- 7 1031.5 御油山 高雄縣桃源鄉
- 8 1031.0 新高口 嘉義縣阿里山鄉
- 9 978.5 奮起湖 嘉義縣竹崎鄉
- 10 976.5 石磐龍 嘉義縣竹崎鄉

The weather system viewed from satellite and radar imageries



Conceptual models have been developed for heavy rainfall prediction in Meiyu period



Features:
Stationary front
Low level jet
Upper level defluence
Middle level trough
Cold tongue

Checklist (favorable conditions) is applied in CWB for heavy rainfall forecast

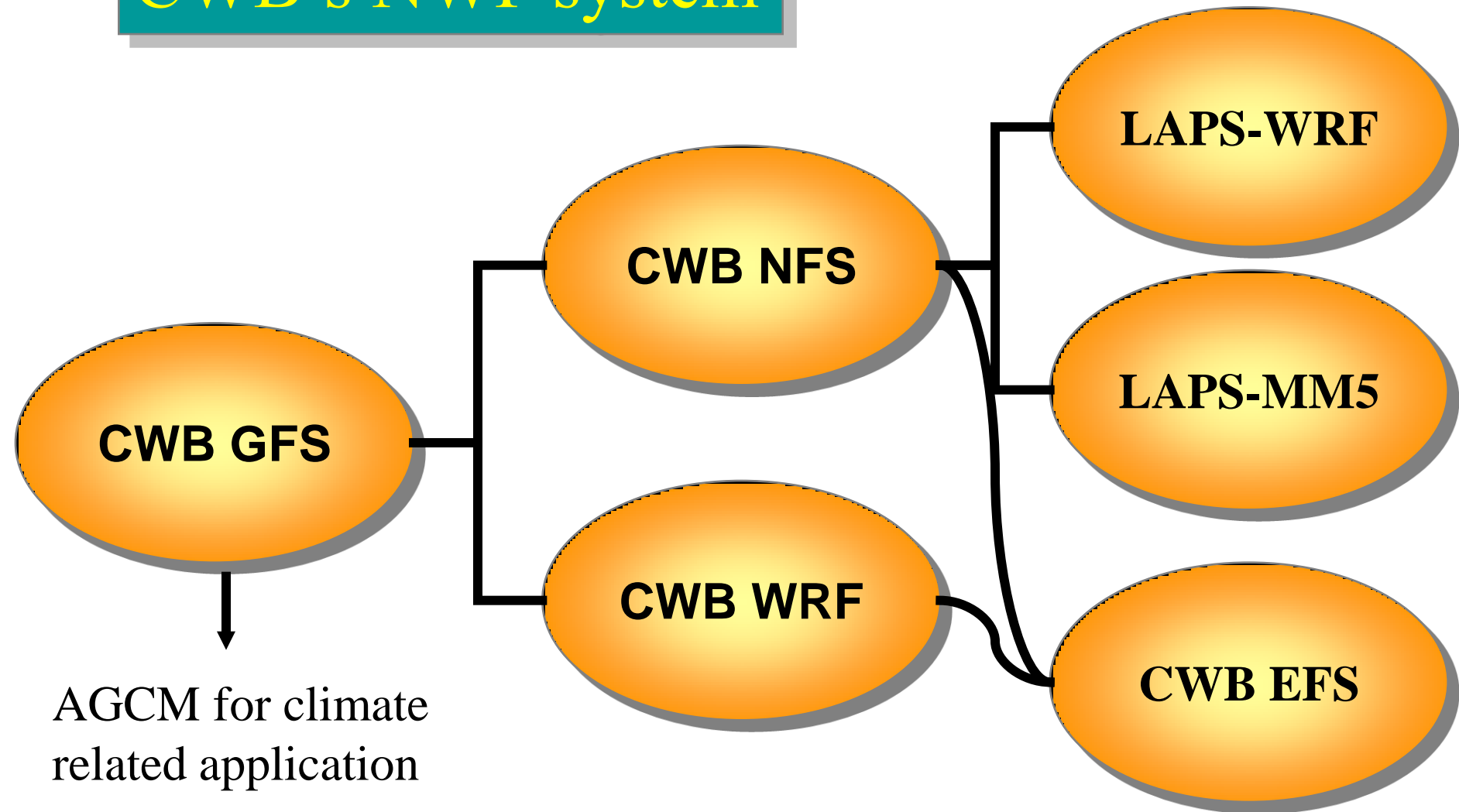
台灣地區梅雨季12~48小時豪(大)雨預報檢查表

(涵蓋範圍: 15N~30N, 110E~127E)

分析圖時間: 2004年5月20日00Z

檢 查 項 目	OBJ	12H	24H	36H	48H
一、梅雨鋒面存在於: 20N~28N, 118E~124E間 台北位於鋒後100Km或鋒前200Km內 高雄位於鋒前200km內	() () ()	(✓) (✓) (✓)	(✓) (✓) (✓)	(✓) (✓) (✓)	(✓) (✓) (✓)
二、濕度分佈 850hPa Td≥15℃ 850hPa θe主軸指向台灣 700hPa T-Td≤3℃	() (✓) (✓)	(✓) (✓) (✓)	(✓) (✓) (✓)	(✓) () (✓)	(✓) (✓) (✓)
三、低層噴流(18N~26N, 115E~125E間) 地面有10~20kts西南風 850hPa有>25kts西南風 700hPa有>30kts西南風 850hPa有≥10kts南風~西南風(南海15N以北)	(✓) (✓) (✓) (✓)	(✓) (✓) (✓) (✓)	(✓) (✓) (✓) (✓)	(✓) (✓) (✓) (✓)	(✓) (✓) (✓) (✓)
四、溫度場 850/700hPa風切線北側有冷舌 台灣位於500-1000hPa厚度場分流區	() ()	() ()	() ()	() ()	() ()
五、風切線(22N~28N, 114E~127E間) 有850/700hPa風切線存在	()	()	()	(✓)	(✓)
六、次系統(華南沿海或南海北部, 114E以東) 地面/850hPa有中尺度低壓 700/500hPa有短波槽	(✓) (✓)	(✓) (✓)	(✓) (✓)	(✓) (✓)	(✓) (✓)
七、氣壓(台灣附近) 台灣位於低壓帶內 地面氣壓<1005hPa	(✓) (✓)	(✓) (✓)	(✓) (✓)	(✓) (✓)	(✓) (✓)
八、高層風場 300/200hPa風場分流角度>45° 台灣位於300/200hPa噴流條入區右側	() ()	() ()	() ()	() ()	() ()
九、穩定度 K指數(K Index)>35	()	()	(✓)	(✓)	(✓)
統 計 結 果	$\frac{9}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{14}{20}$	$\frac{15}{20}$

CWB's NWP system



New CWB HPC System :

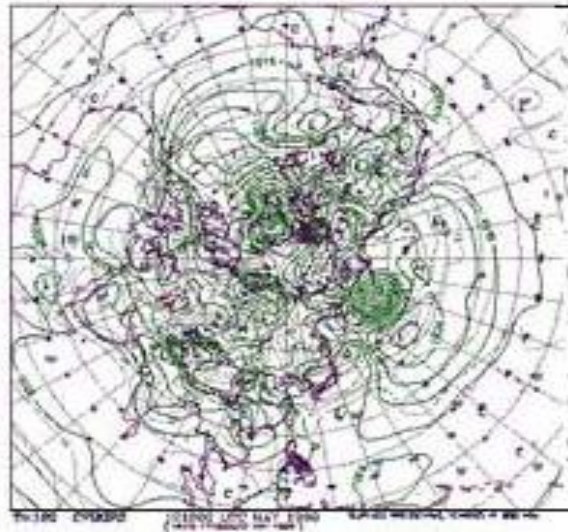
IBM P5-575 Cluster 1600

- **IBM Power5 1.5 GHz SMT Dual core, Superscalar Architecture, peak of 6 GFlops**
- **13 frames total, 12 nodes per frames, 156 nodes total, 8 dual cores (16 CPUs) per node, 2496 CPUs total**
- **4 GB Memory/CPU 36 Nodes
2 GB Memory/CPU 120 Nodes**
- **4 nodes for data input/output servers,
12 nodes for GPFS servers
138 nodes for computational**
- **14 TB RAID10 disk storage system for operation
18 TB RAID5 disk storage system for research**



The numerical weather prediction system

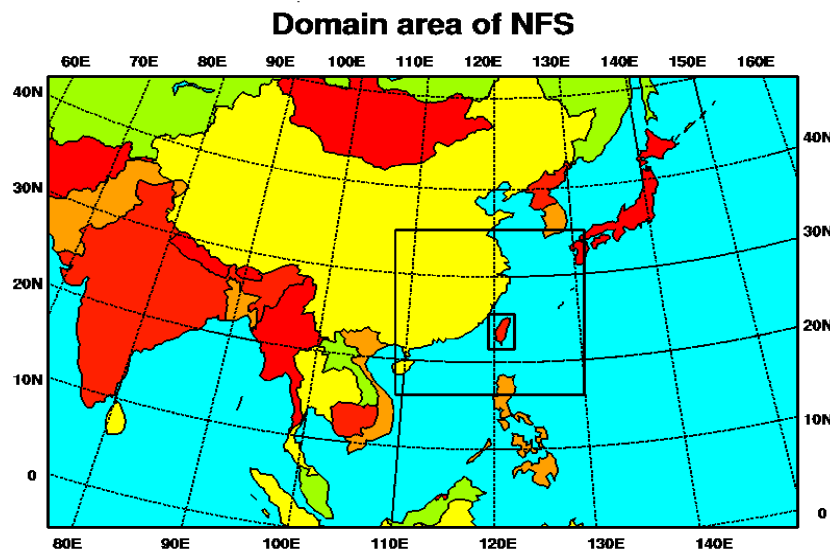
-- Global model



Objective analysis	3D variation
Initialization	Non-linear normal mode
Horizontal resolution	Triangle truncation T213
Vertical resolution	δ coordinate 30 layers
Time integration scheme	Semi-implicit time step 600 sec
Cumulus parameterization scheme	Modified Arakawa-Schubert
PBL parameterization scheme	TKE-ϵ
Radiation parameterization scheme	Harshvarden et al. (1987)
Horizontal Diffusion	4-order horizontal diffusion

The numerical weather prediction system

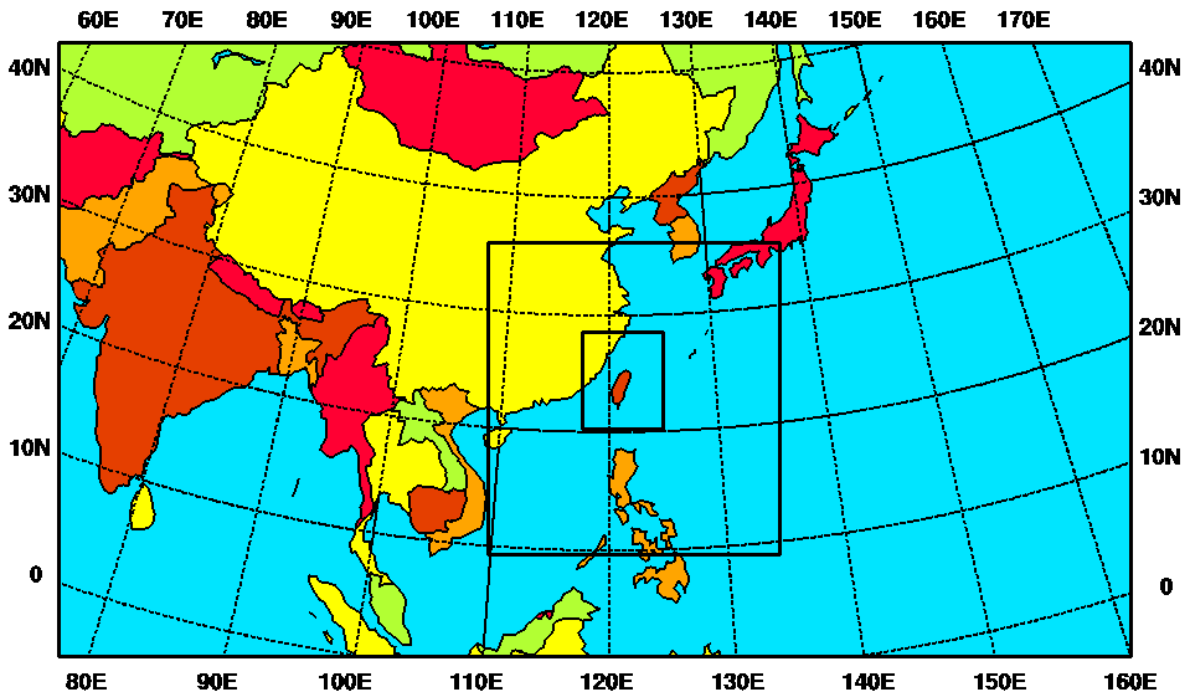
-- Limited area model



Horizontal resolution	45 km /15 km/5 km triply nested, Lambert conformal mapping
Vertical coordinate and layers	δ coordinate 30 layers
Lateral boundaries	From the global model
Objective analysis	Optimal interpolation
Time integration scheme	Leap-frog & split-explicit methods
Cumulus parameterization scheme	Kuo Scheme/ Modified Arakawa-Schubert
PBL parameterization scheme	TKE-ϵ
Radiation parameterization scheme	Harshvardhen et al. (1987)

CWBWRF Domains

Domain of CWB WRF



D1: 45-km resolution

222X128

dt=180 s

D2: 15-km resolution

184X196

dt=90 s

D3: 5-km resolution

151X181

dt=30 s

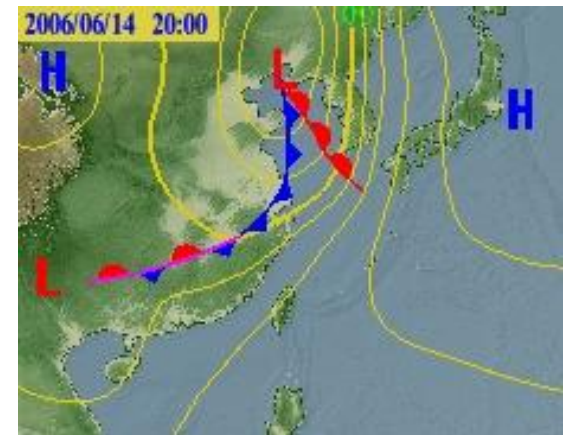
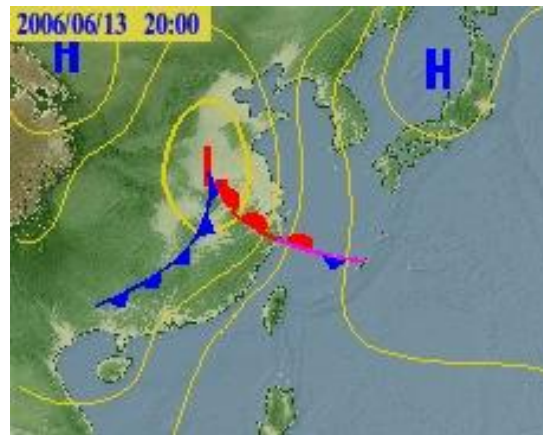
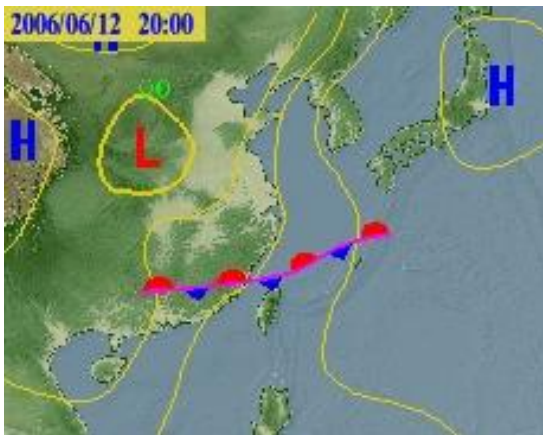
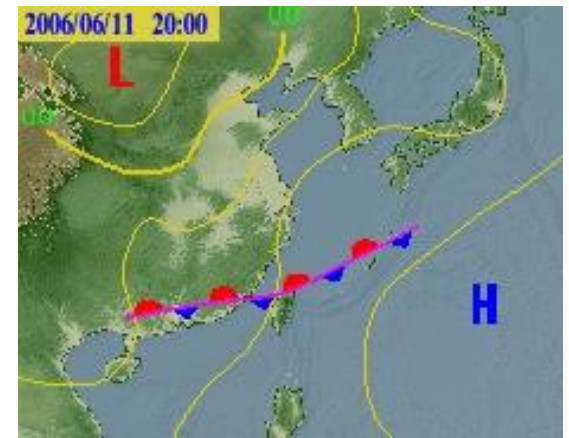
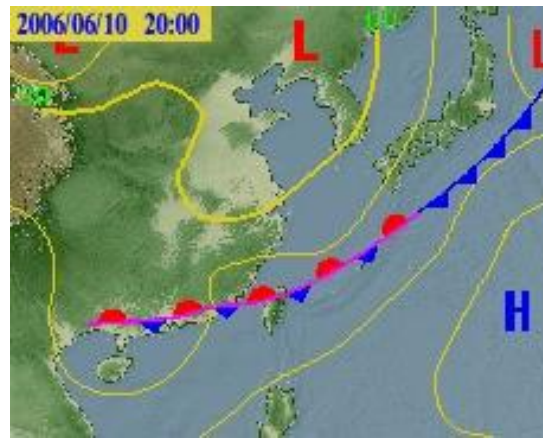
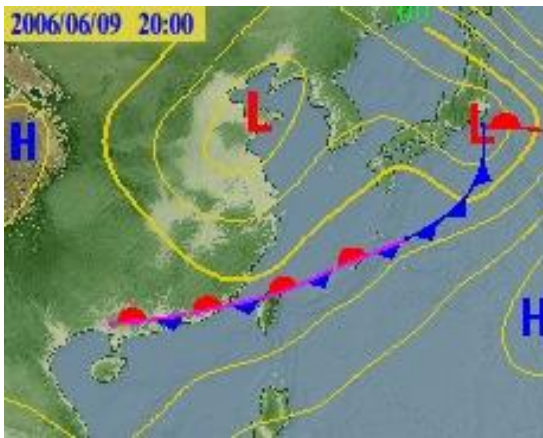
Physical process

Component	Schemes
PBL	YSU
CUP	Old KF
MPS	WSM 5
LSM	Thermal diffusion
Long wave	RRTM
Short wave	Goddard

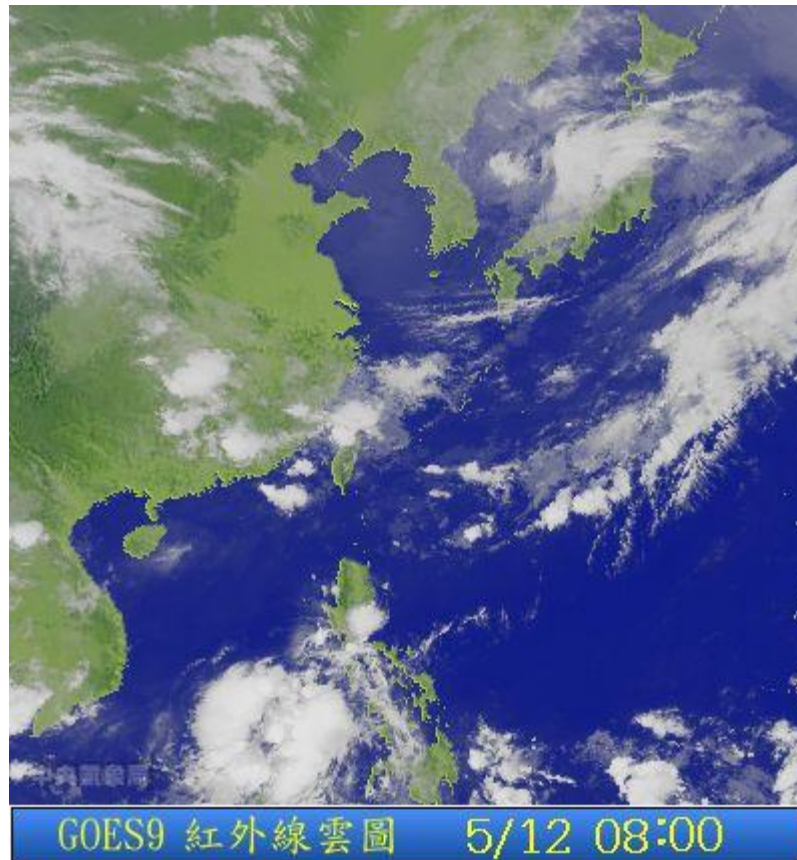
WRF 3D VAR

- Operation starts from July/2007
- 6h Data window
 - -3h~+3h
- Cv3 option, Cold start (background CWB)
- Background error
 - CV3 WrfVar default (NCEP GFS)
- Observation Used
 - Sonde, Synop, Ships, Metar, Buoy, Airep, Pilot, Satem, Ge
oamv, drop sonde, drift sonde
 - Typhoon Bogus

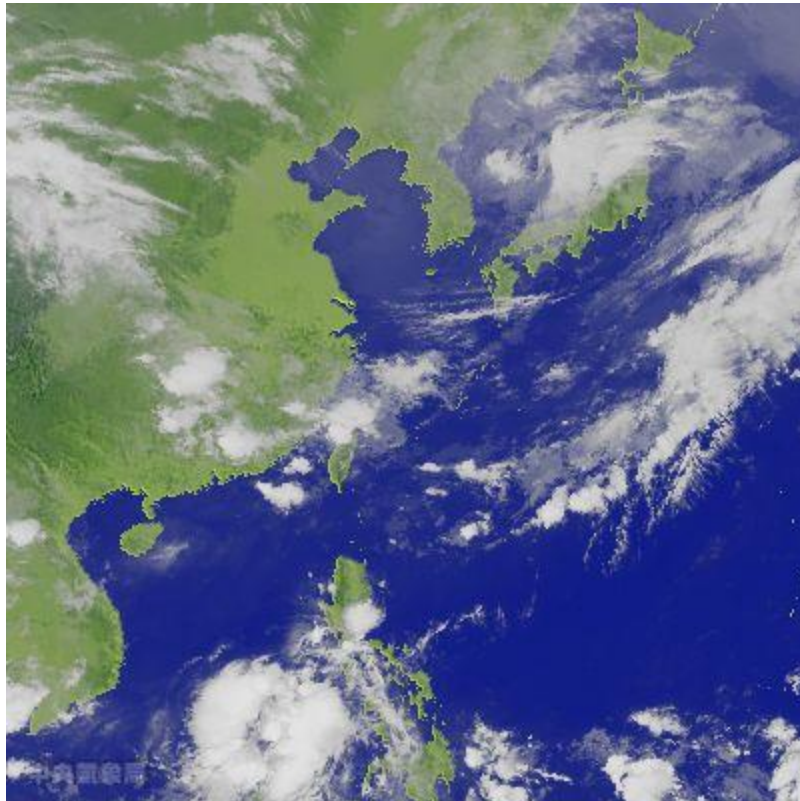
CWB 5 days forecast for June 9-14, 2006.
Based on numerical model and the conceptual model



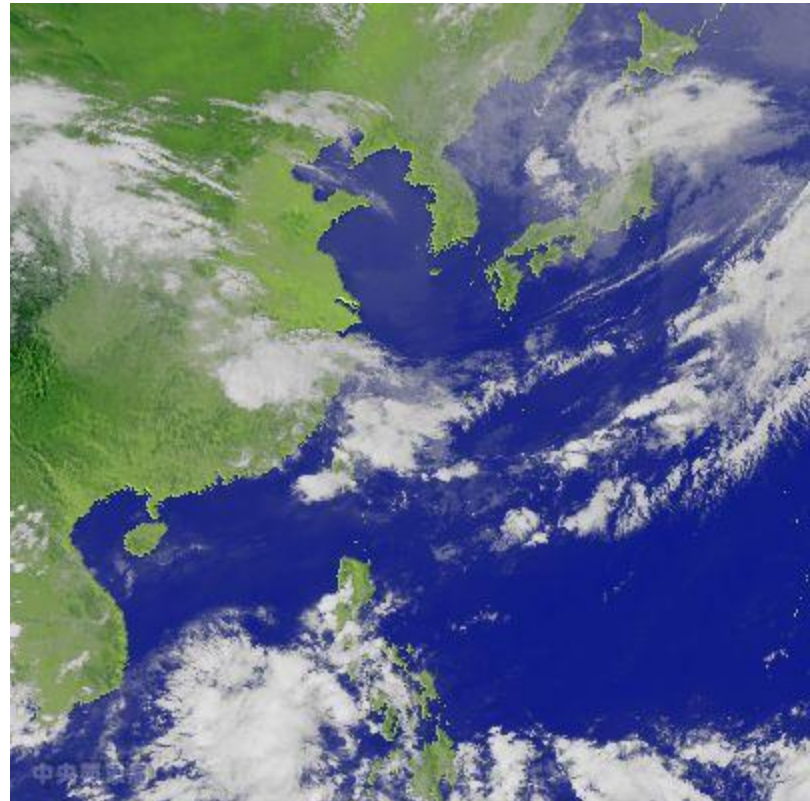
Another case: May 12, 2005
The frontal zone is not well organized



Another case: May 12, 2005



GOES9 紅外線雲圖 5/12 08:00

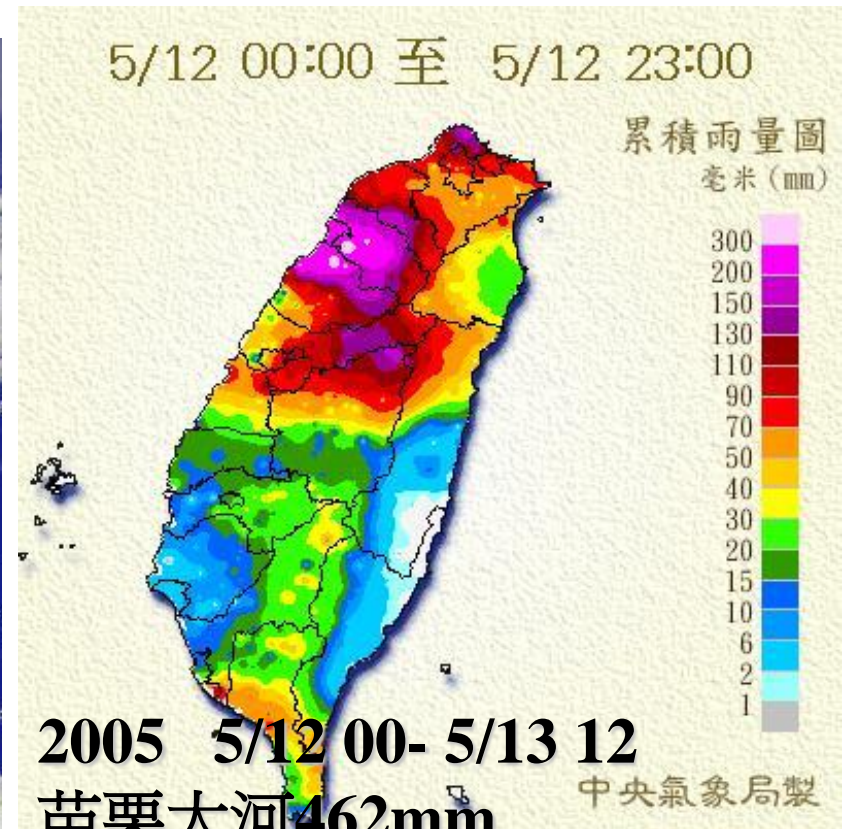
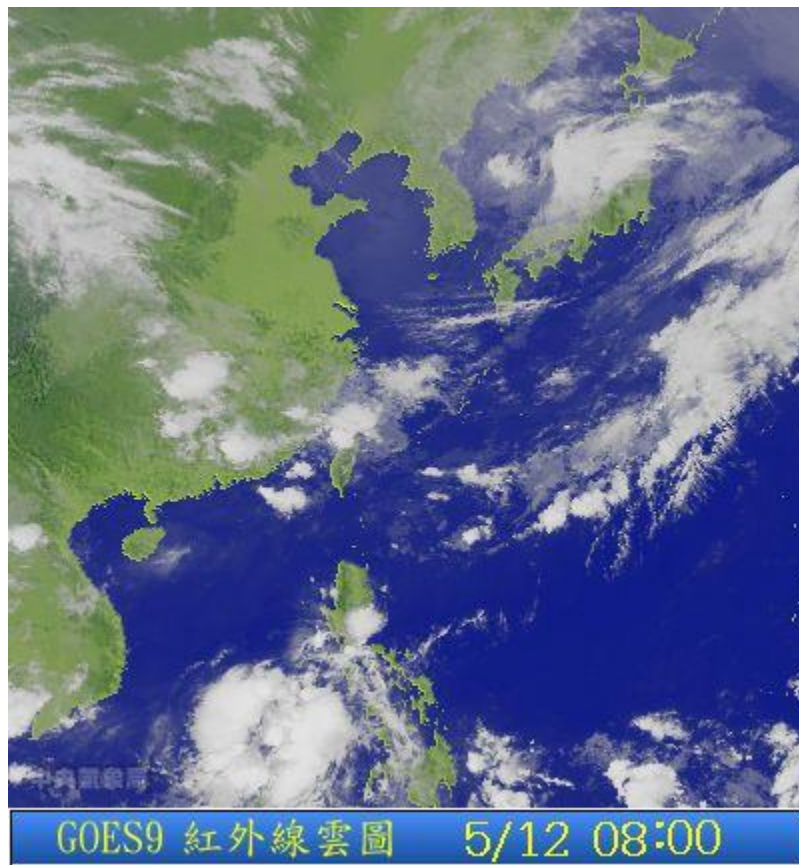


GOES9 紅外線雲圖 5/12 14:00

Challenge - - Thermal driven /smaller scale

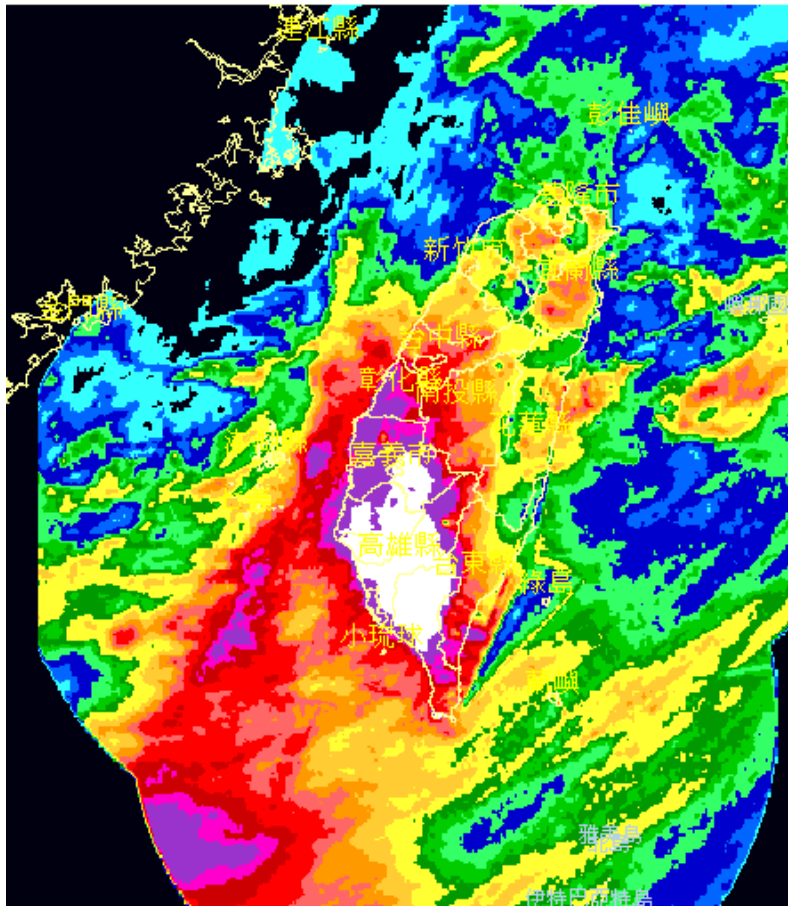
23-hour accumulated rainfall

for May 12, 2005

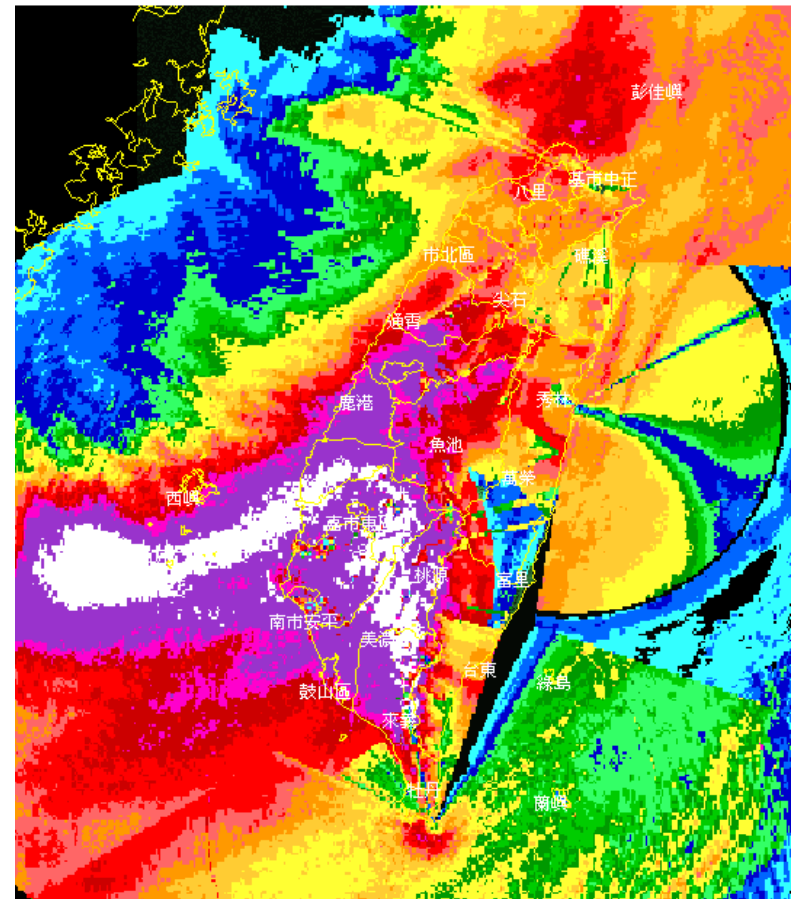


Challenge – quantitative forecast – Where and how much

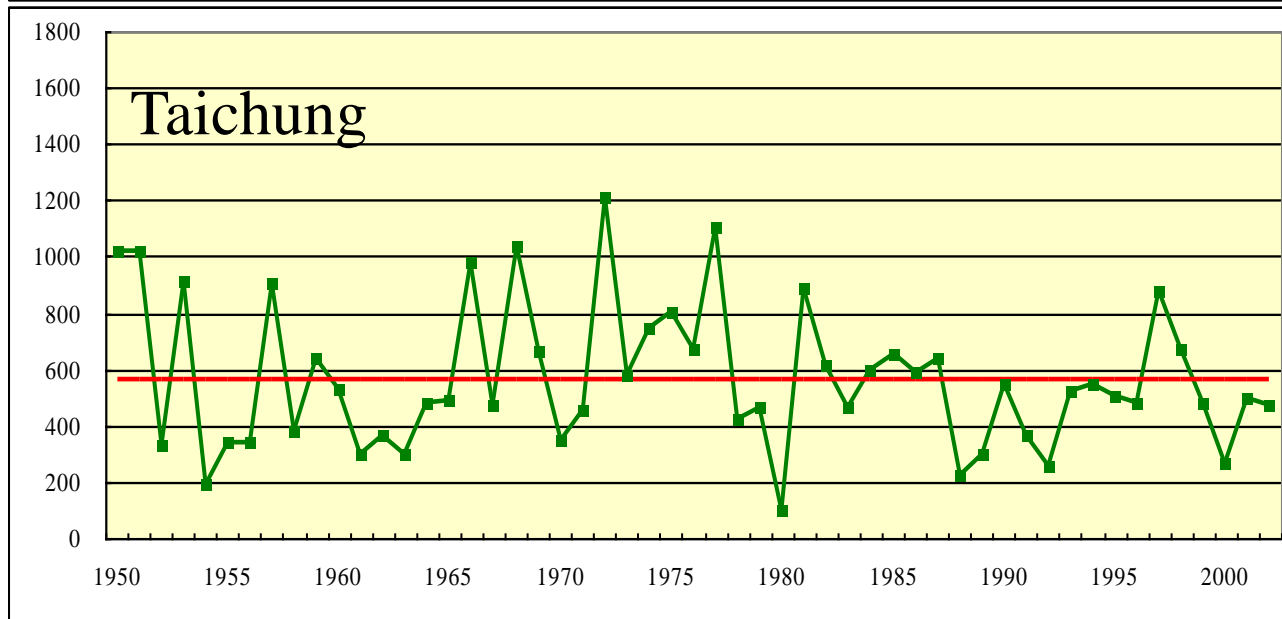
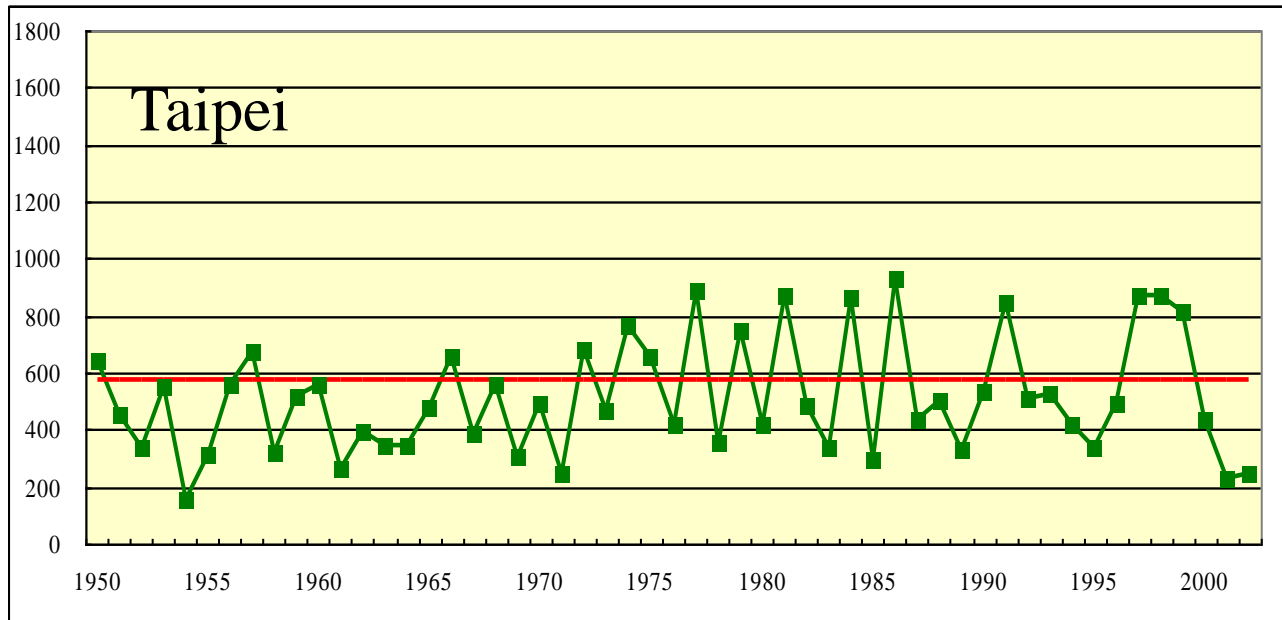
72 hrs QPE (June 12~14, 2005),
Maximum = 1,758mm
Rains at plane



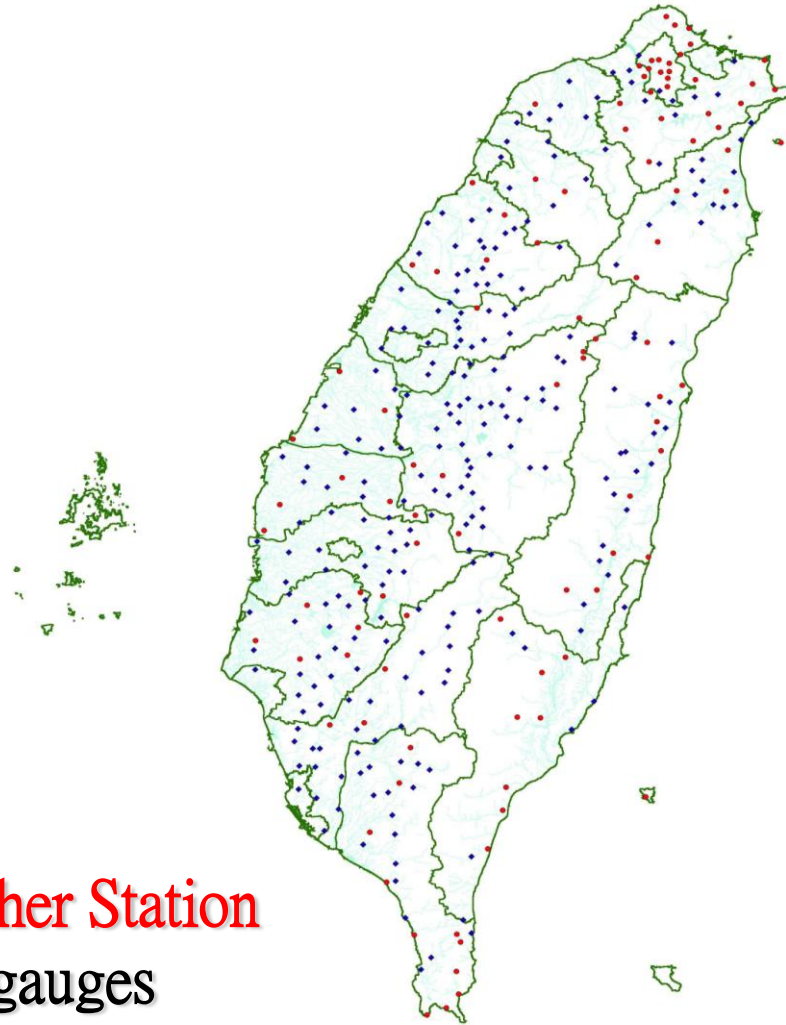
72 hrs QPE (July 2~4, 2004),
Maximum = 1,375mm
Rains at high mountains



Annual variation of Meiyu rainfall

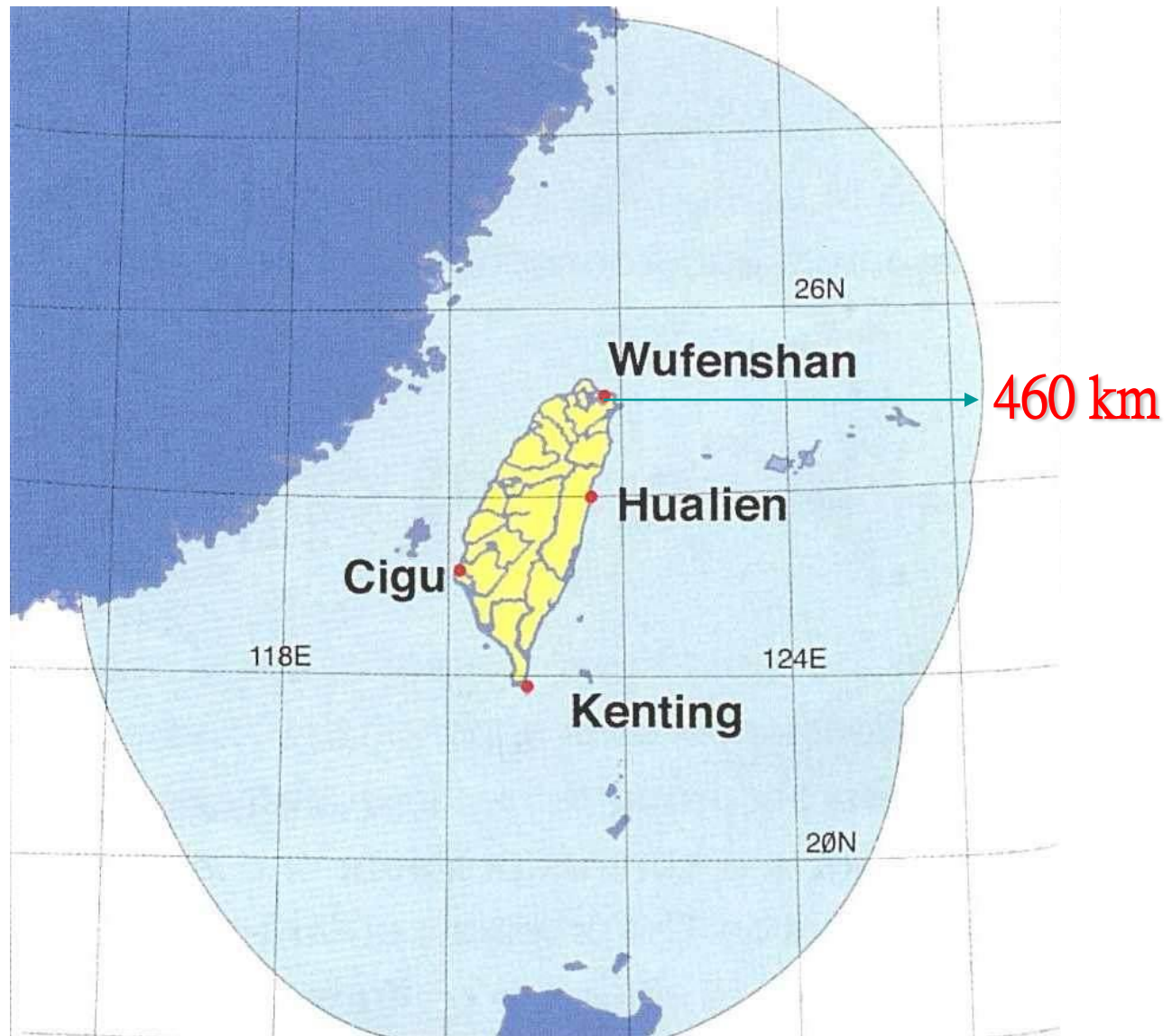


Automatic stations

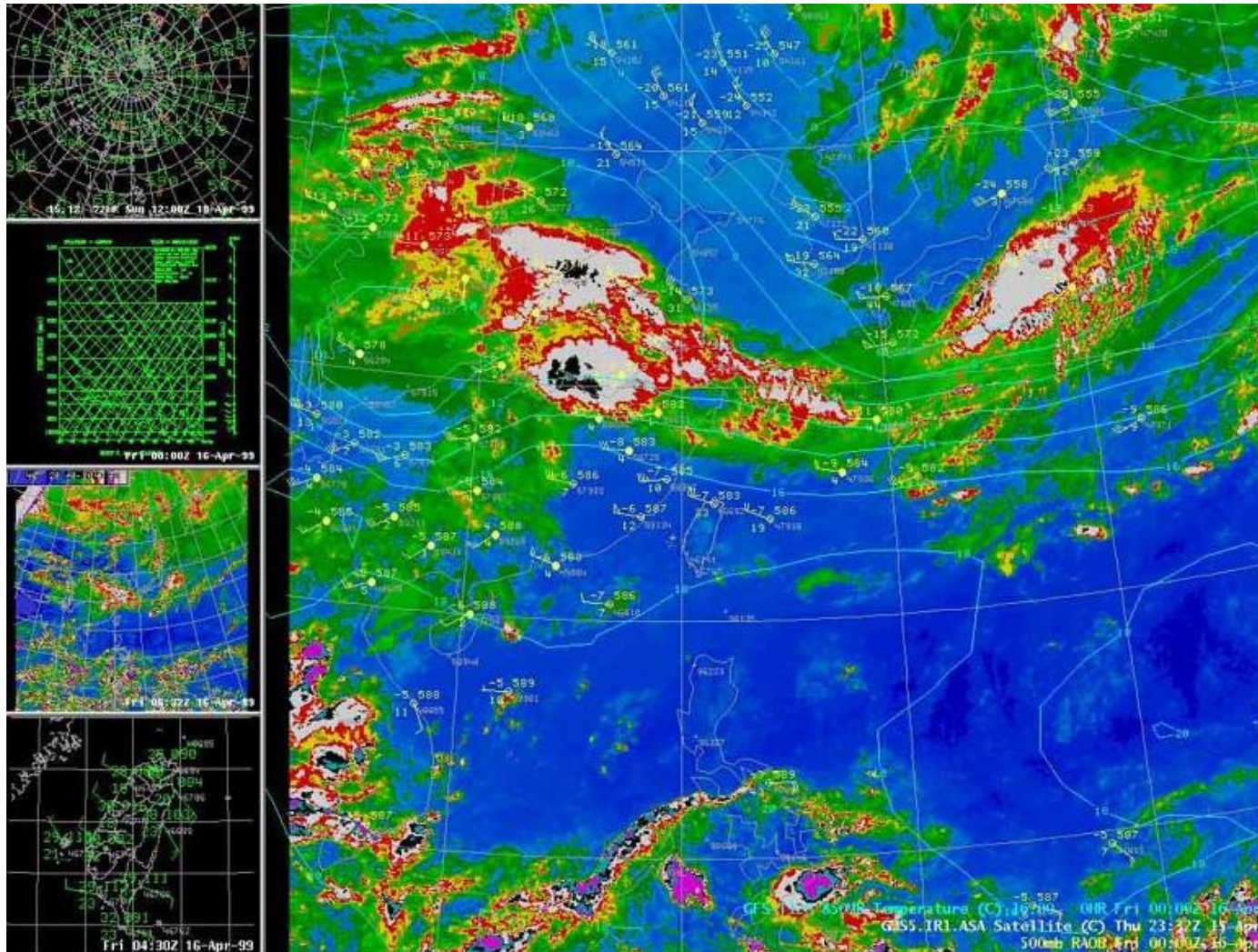


115 Weather Station
259 rain gauges

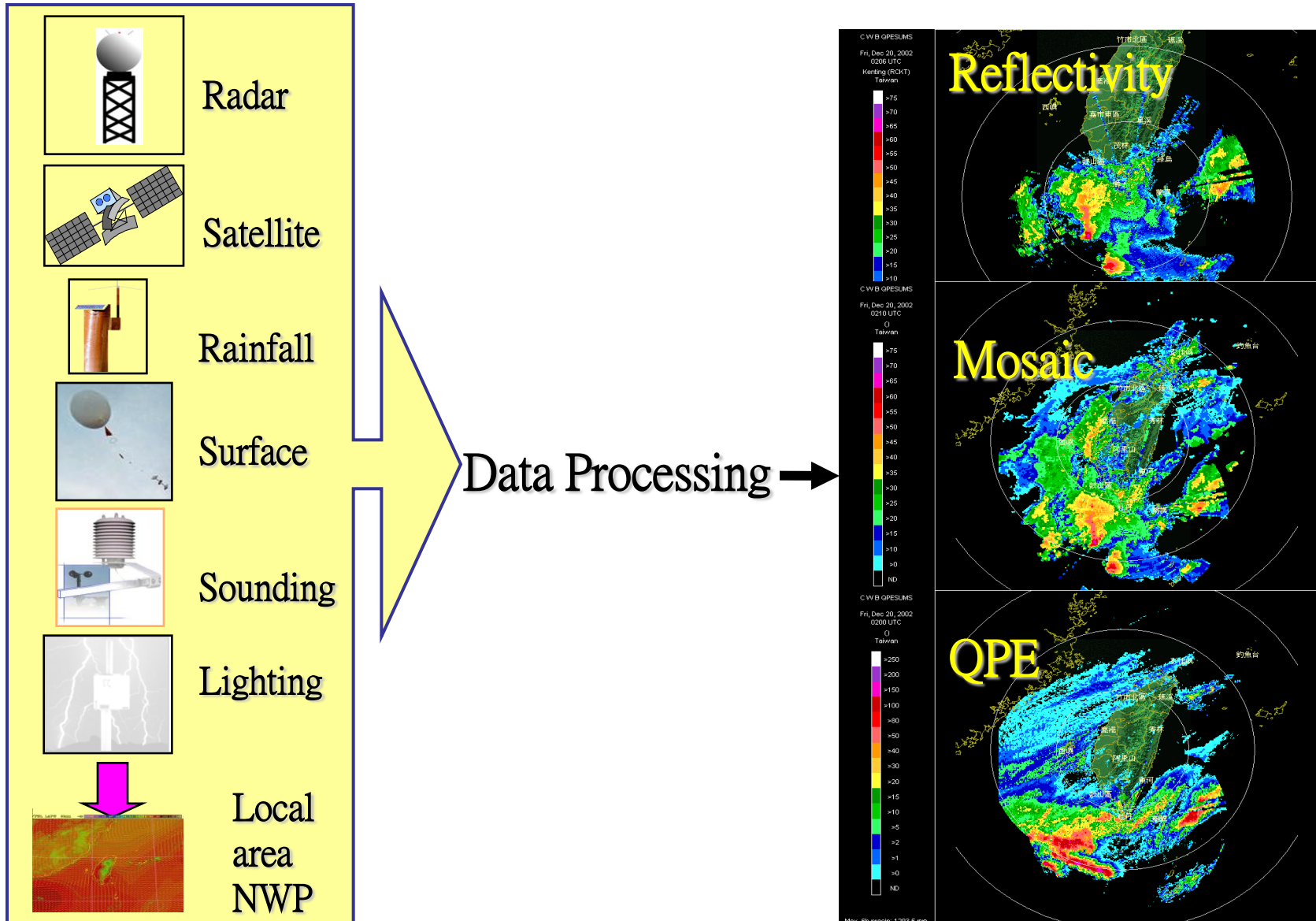
Radar network



Weather Integration and Nowcasting System (WINS)

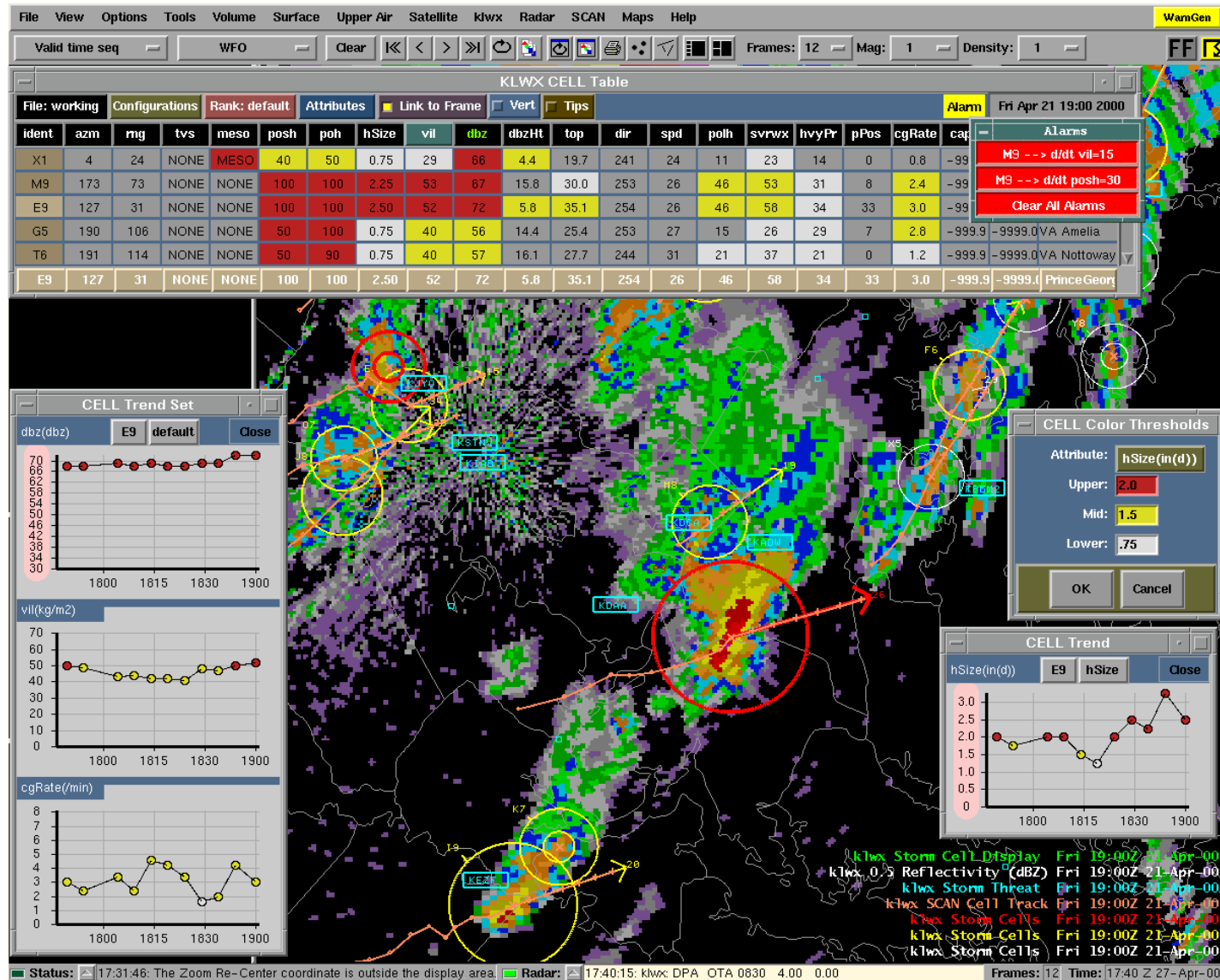


QPESUMS (Quantitative Precipitation Estimation)



SCAN

System for Convective Analysis and Nowcasting



Channels of Services

Cell Phone Short Message

Press Conference/Interview

Telephone Interview

FAX

WWW

Press

Cell Phone Short Message

FAX

Point To Point System

Phone

WWW

EMO

Cell Phone Short Message

FAX

P T O P

Phone

WWW

Government

Newspaper 、 166/167

FOD 、 WWW

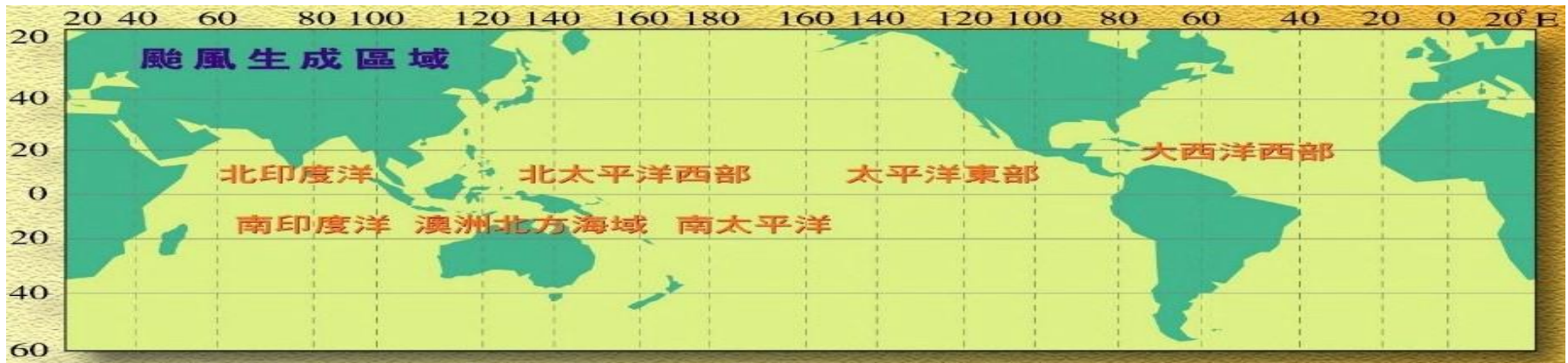
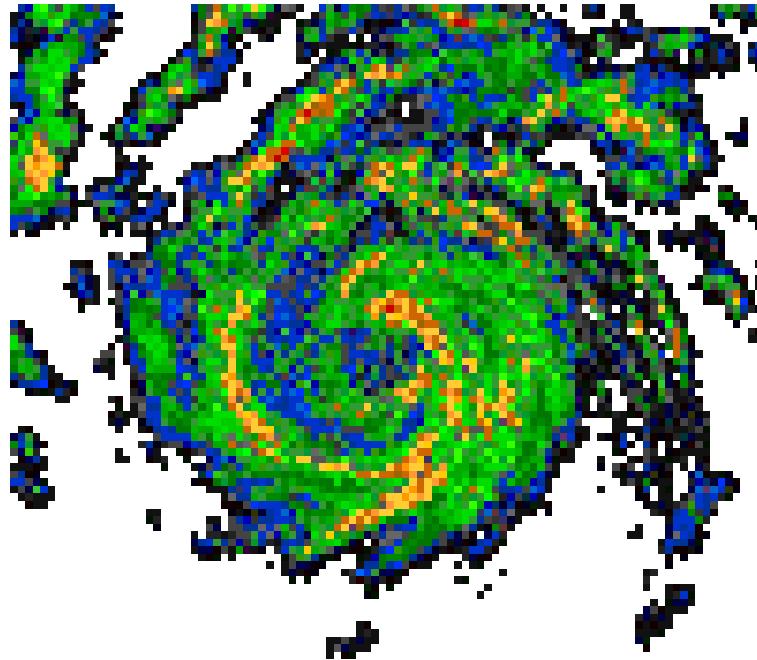
email 、 SSB

Consultation Phone

Television & Radio

Public

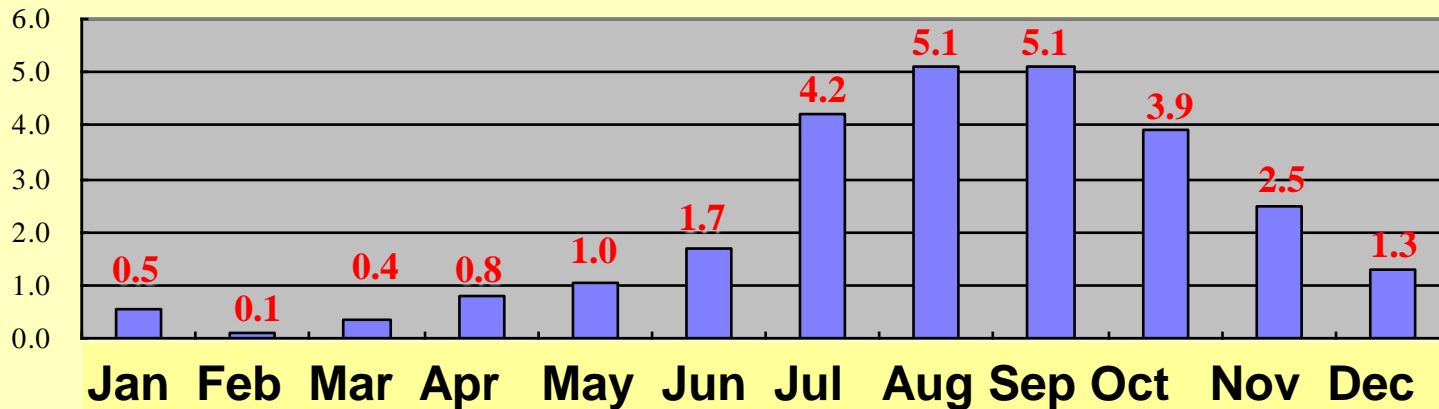
Tropical cyclones (typhoons)



Number of tropical cyclones in NW Pacific ocean from 1971 to 2000

每月颱風發生氣候平均數(1971~2000年)

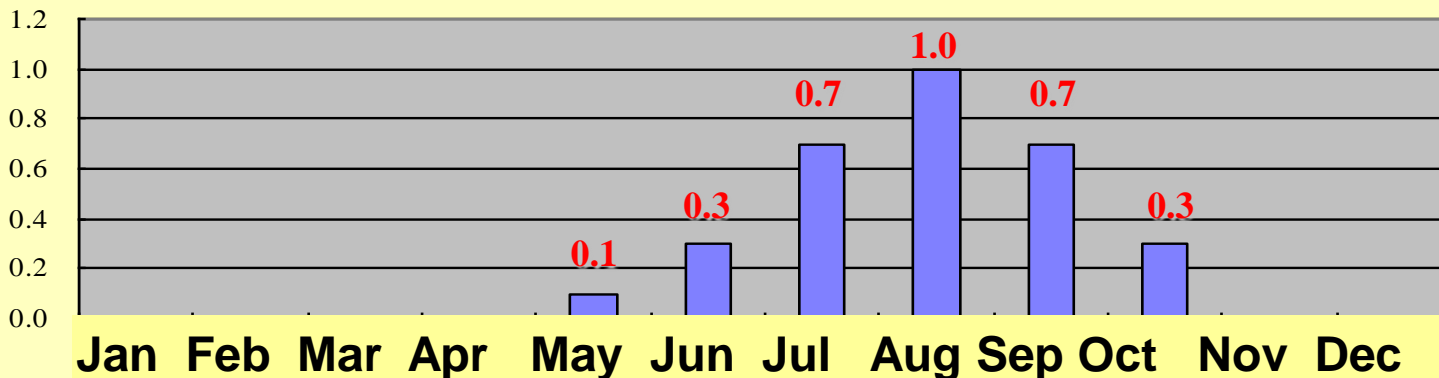
Formation



26.6

侵襲台灣的颱風氣候平均數(1971~2000年)

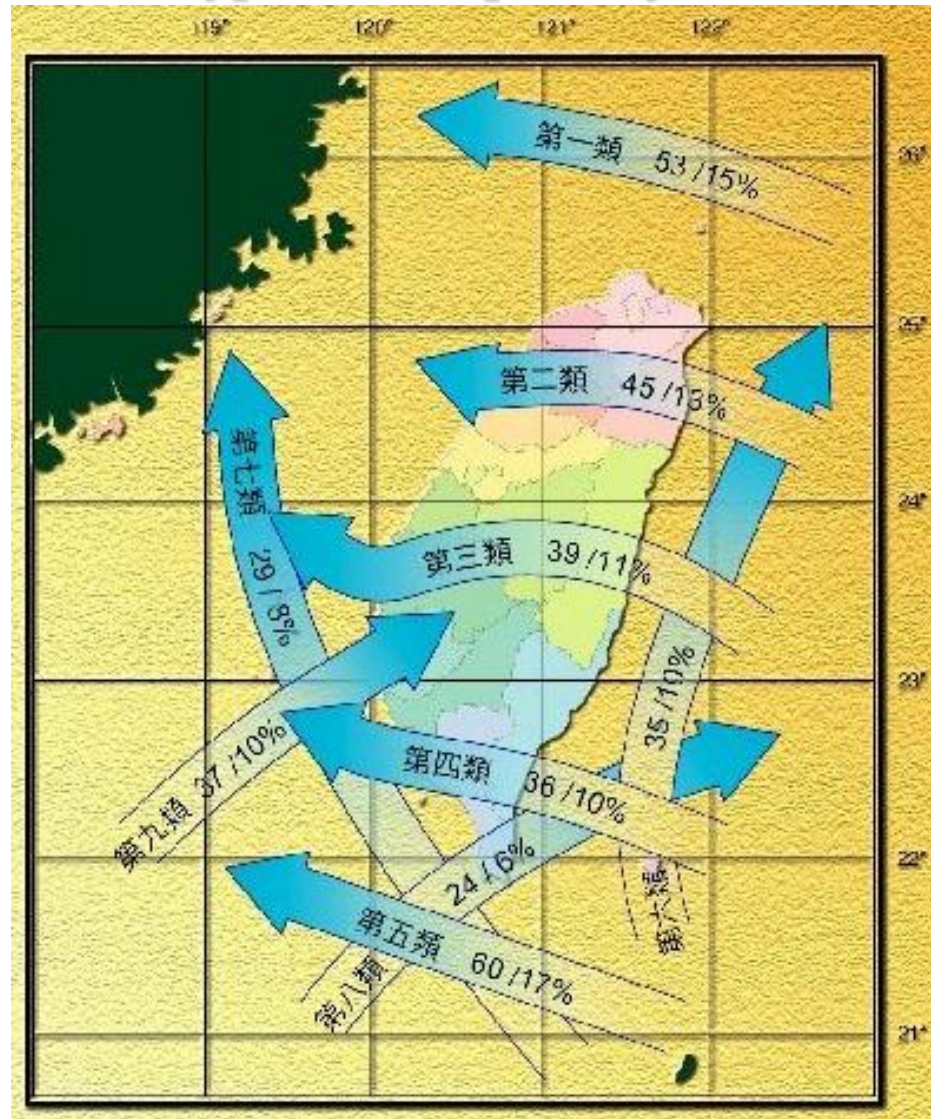
Invaded Taiwan



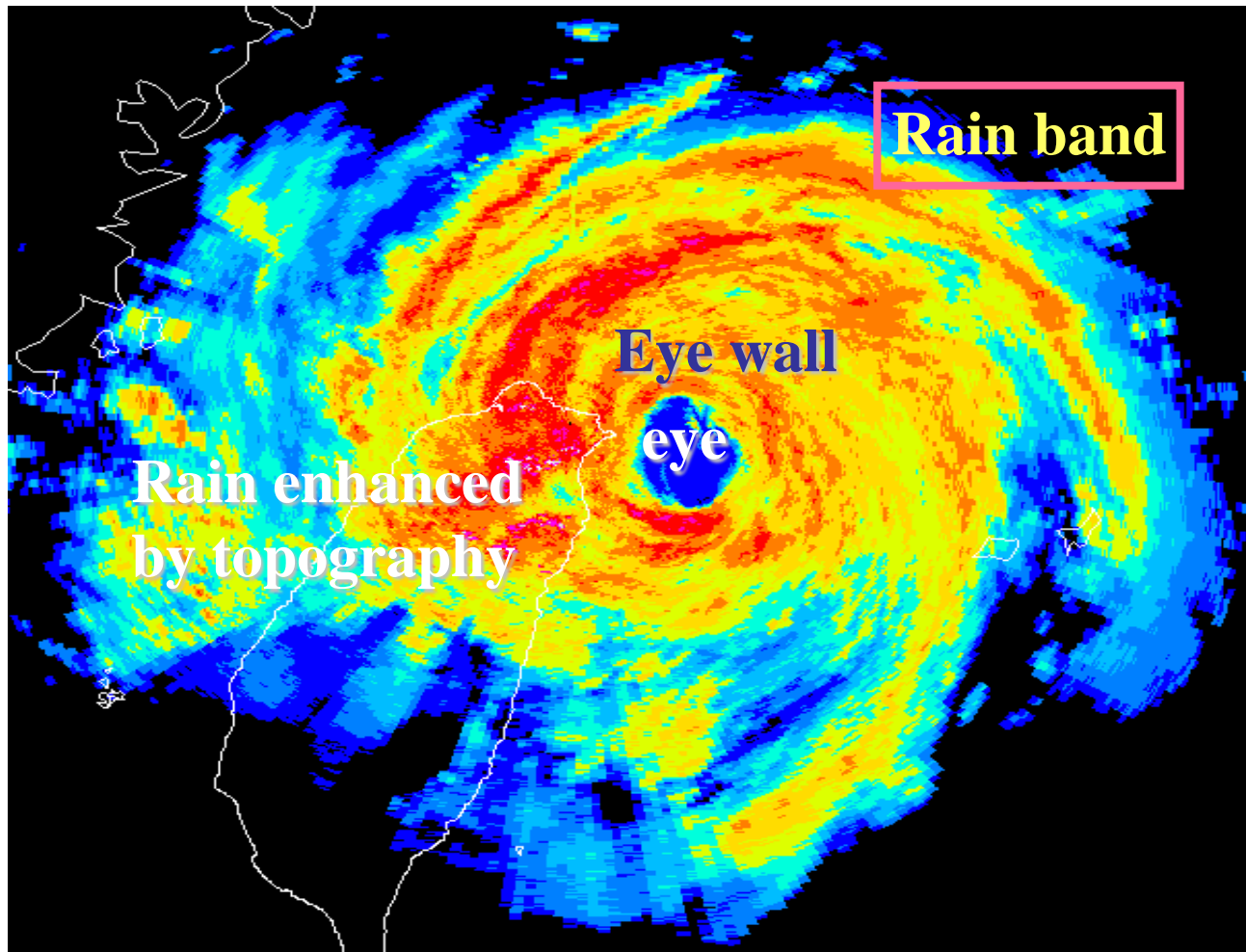
3.1

Major track types of typhoons invaded Taiwan

Typhoon=tropical cyclone



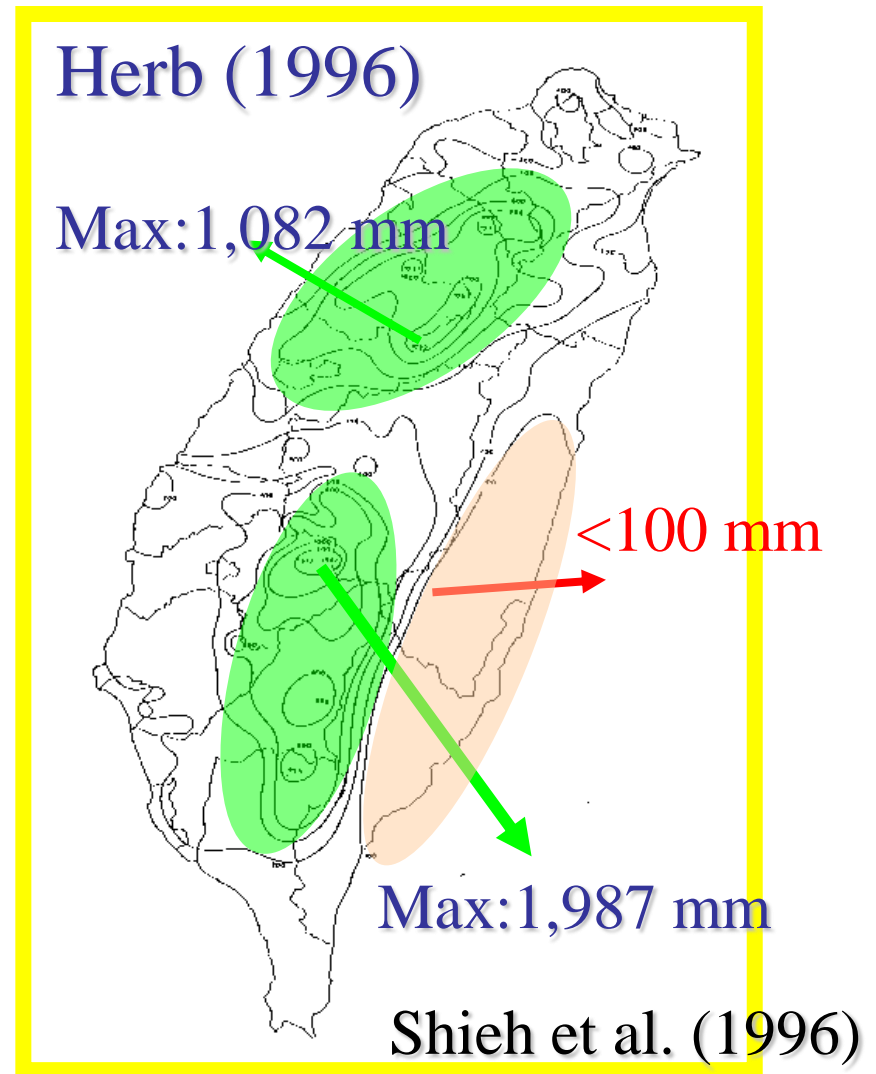
Typhoon Herb (1996) encounters Taiwan



Torrential rains associated with tropical cyclones

Liao (1960) showed that there were more than 20 tropical cyclones that brought more than 700 mm rainfall in Taiwan from 1911 to 1959.

-- experienced a very heavy rainfall event per 2-year.



Damages caused by torrential rains associated with typhoons

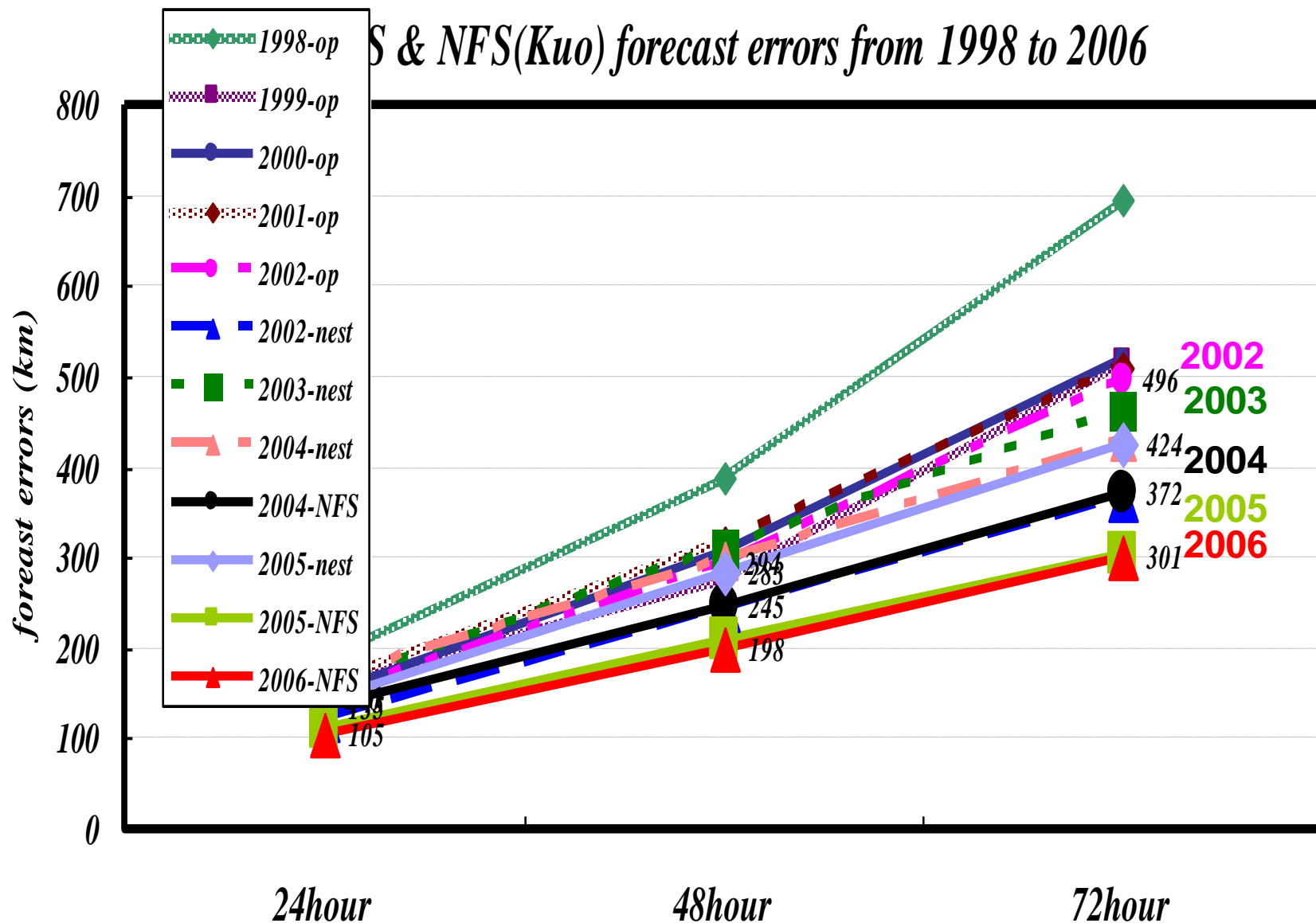


Damages caused by strong winds



(Typhoon Longwang 2005)

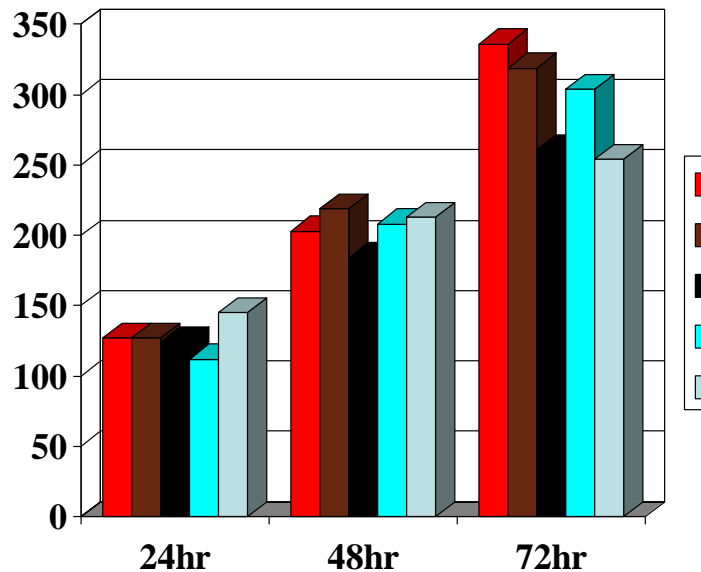
NFS typhoon track forecasting errors



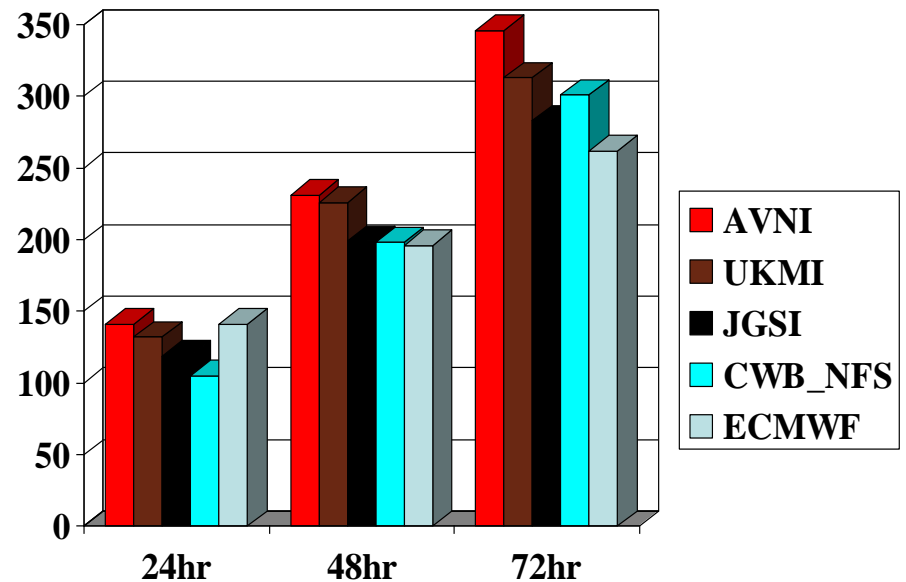
2005/2006 other models' errors

Non-homogeneous comparisons
Model datum are read from GTS or FTP

**2005 Western North Pacific
Non-Homogeneous TC Forecast Er**



**2006 Western North Pacific
Non-Homogeneous TC Forecast Error (km)**

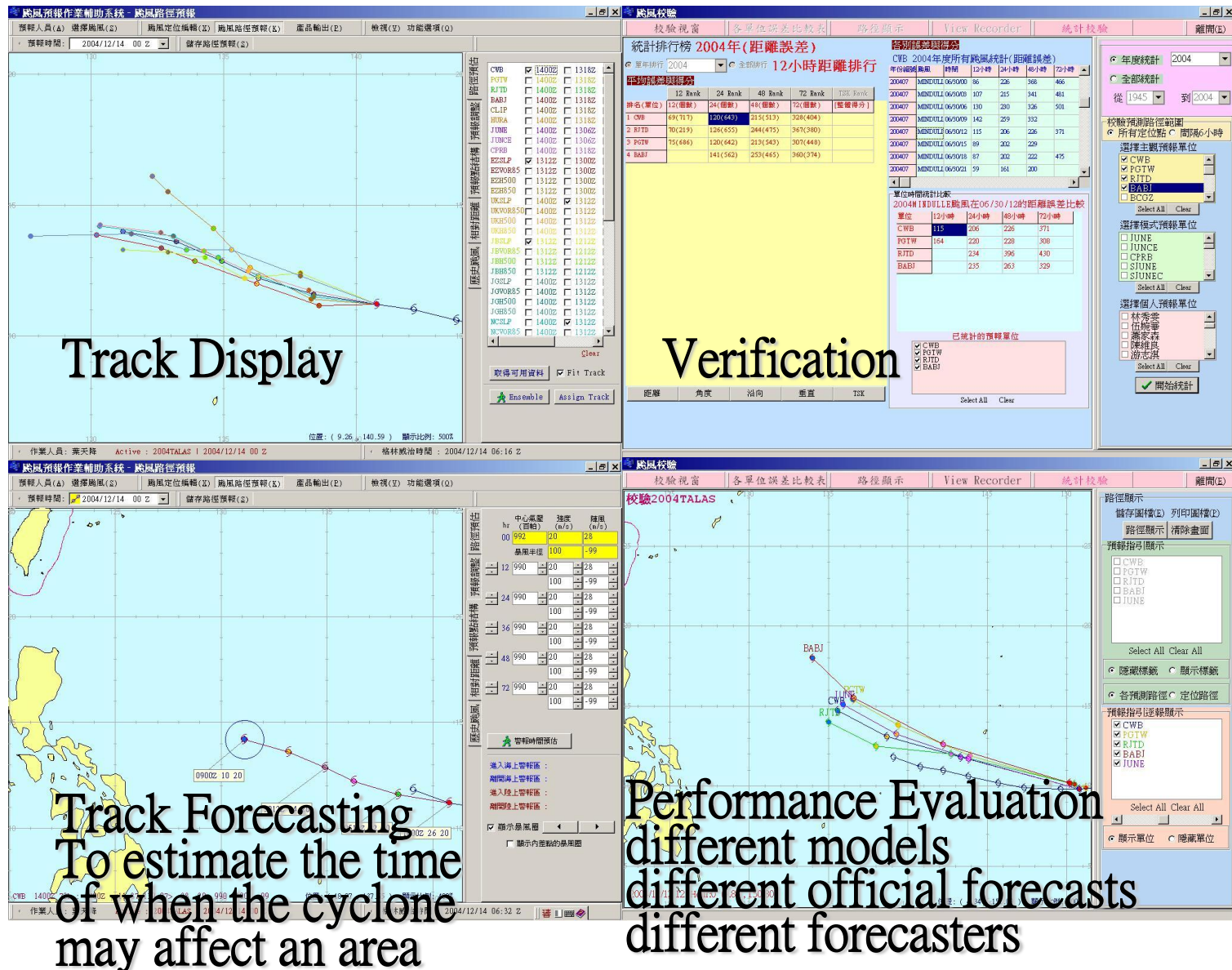


AVNI, UKMI, JGSI, ECMWF are global models; CWBNFS is a regional model

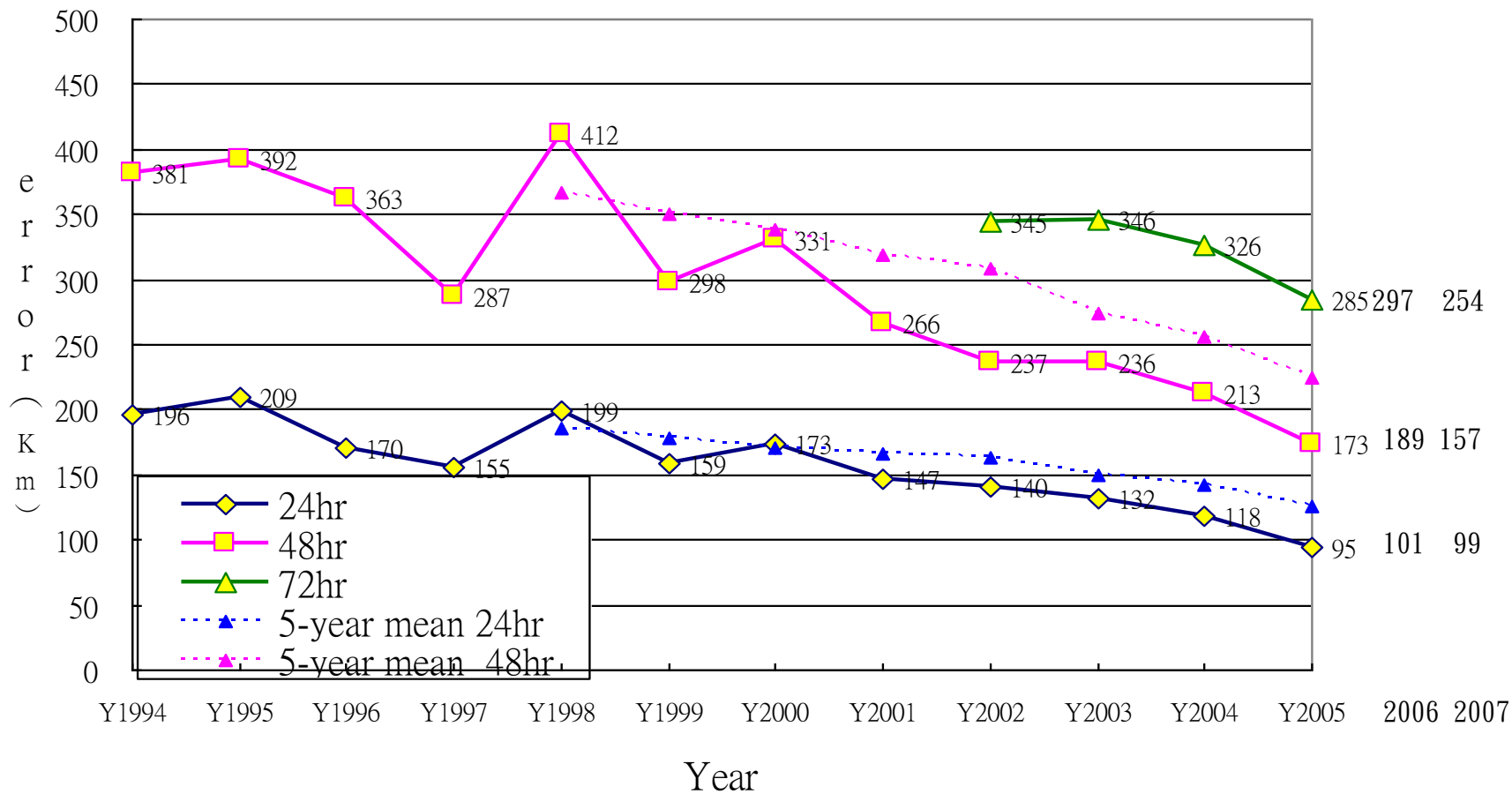
TAFIS (Typhoon Analysis and Forecasting Information System)



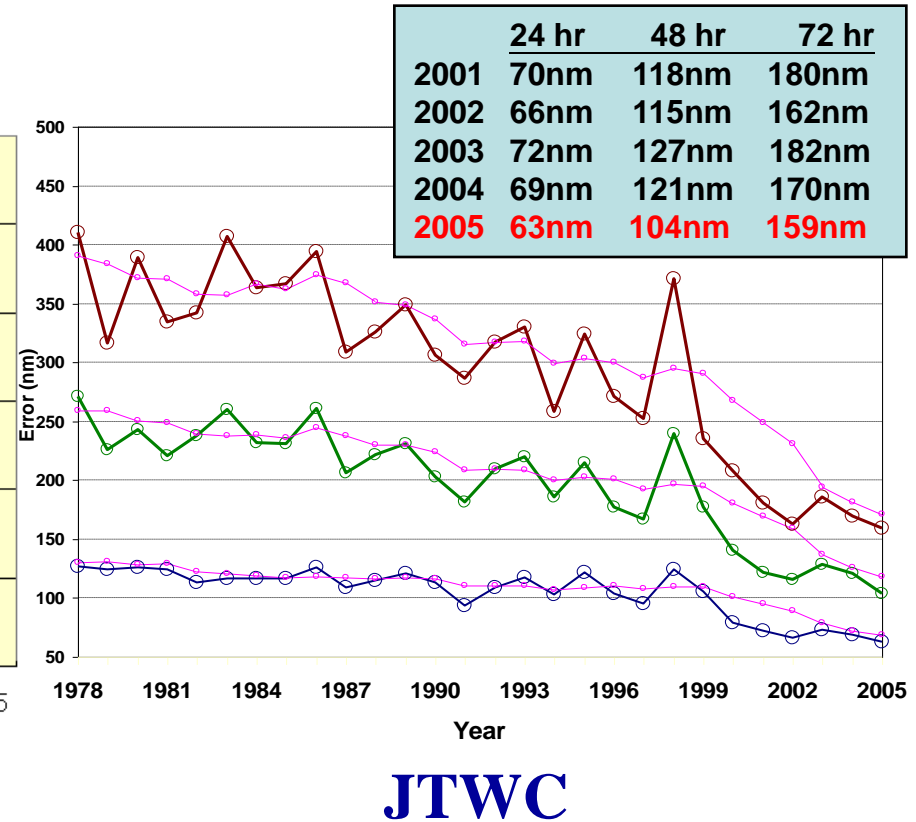
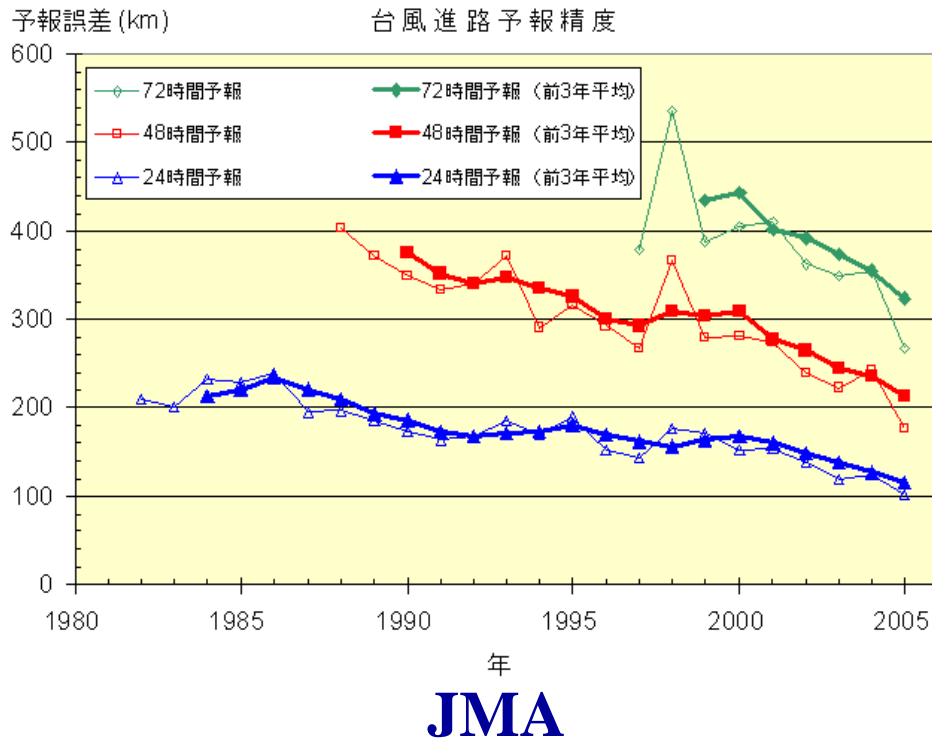
TAFIS (Typhoon Analysis and Forecast Information System)



CWB typhoon track forecast errors (1994~2007)

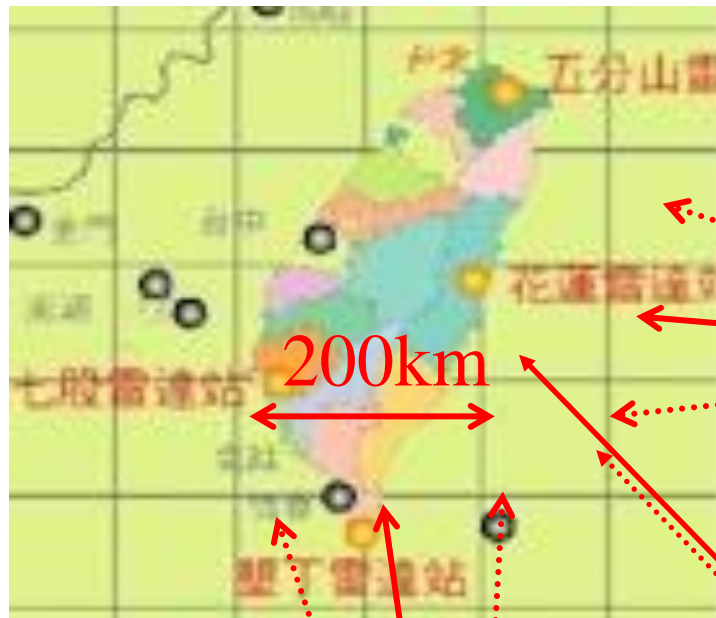


Similar forecast errors are found from other centers



Challenge

- Small track forecasting error maybe result in completely different scenarios

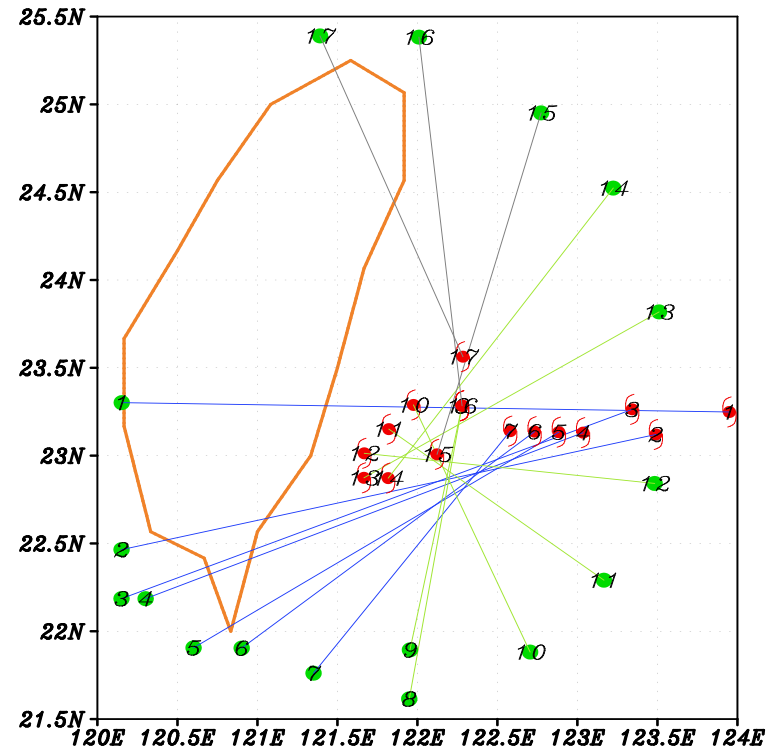
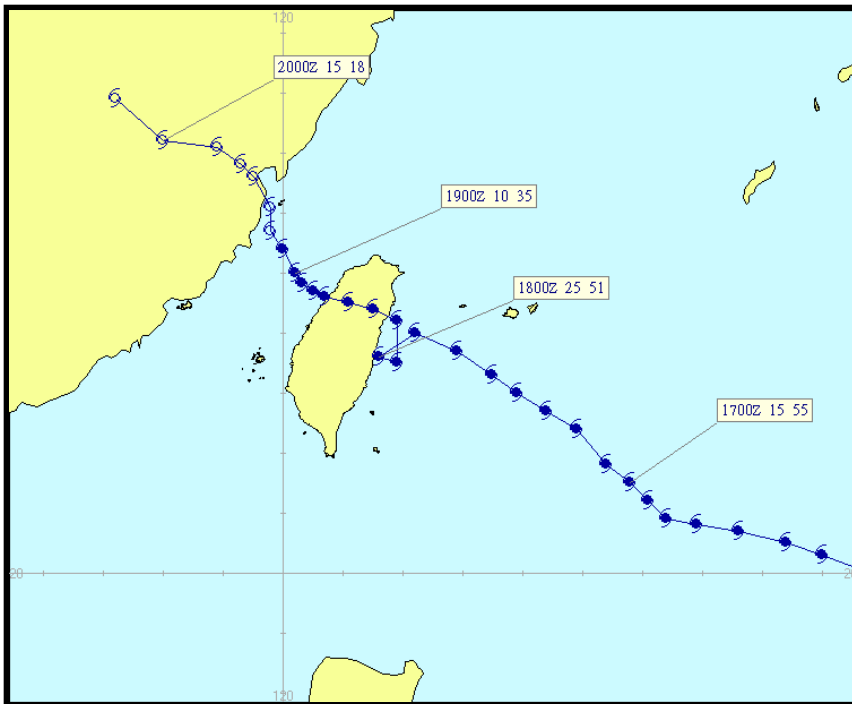


Pass by different sides of CMR

Time can be few hours
different even track is correct

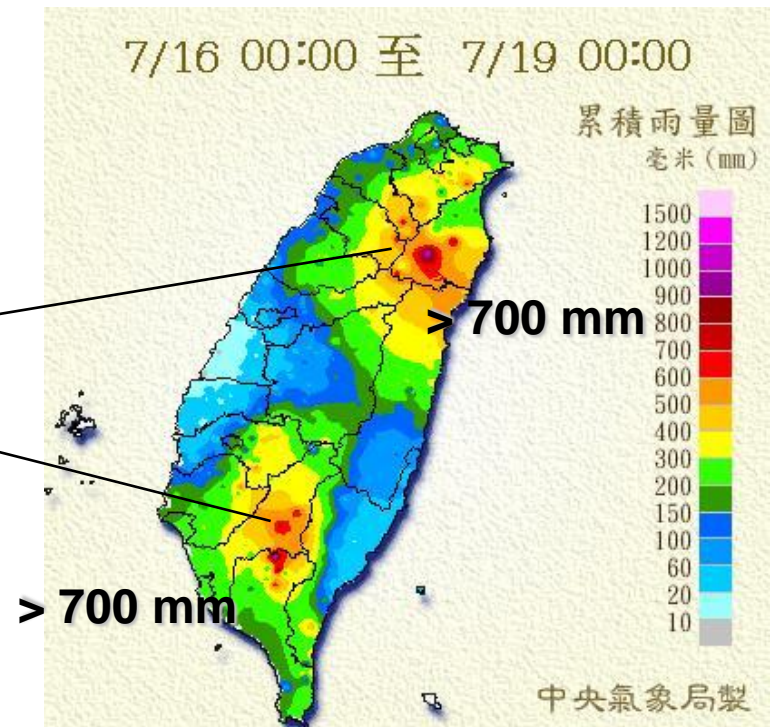
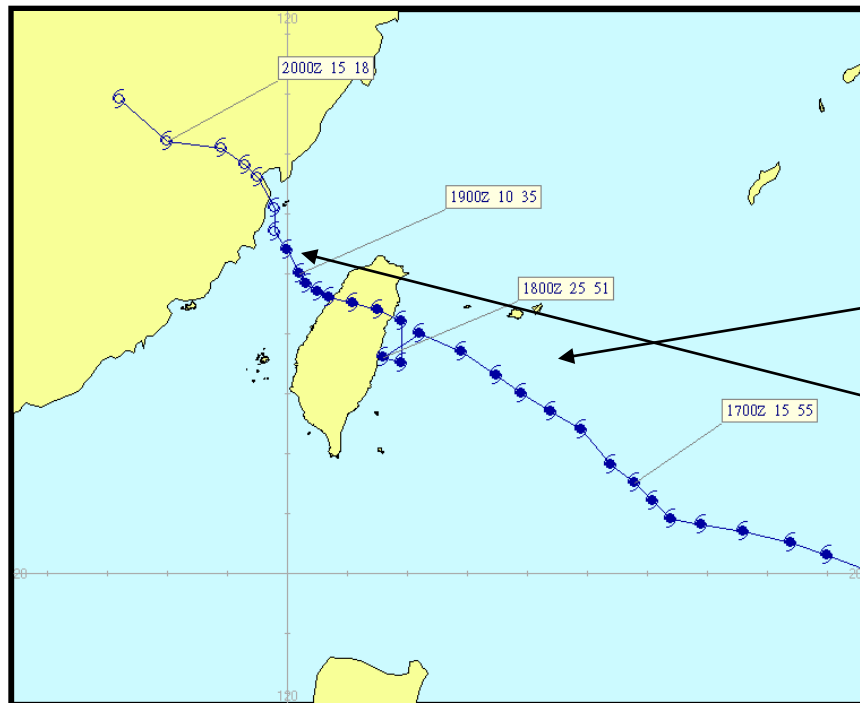
Challenge

- Topography effect on tropical cyclones



Typhoon Haitang 2005

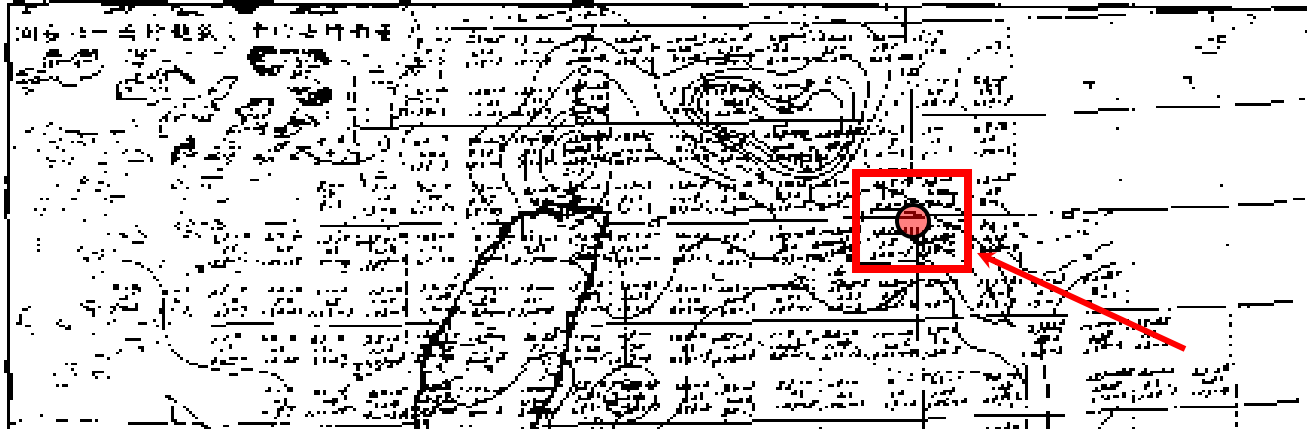
Typhoon rainfall



Typhoon Haitang 2005

Typhoon rainfall forecast

Climate data shows that the rainfall at a station has high correlation with the typhoon center location



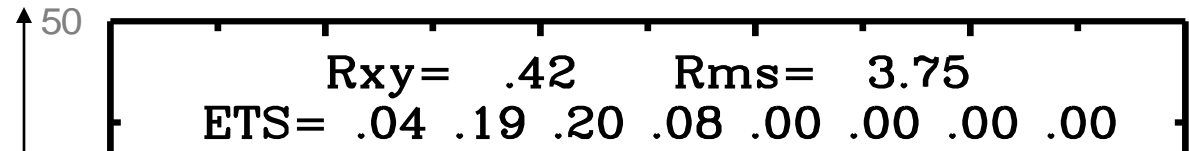
Rainfall at a station (time)

= Mean rainfall of that station of
all cases of TYs centered in the grid box
of which is the forecasted location of the
coming storm

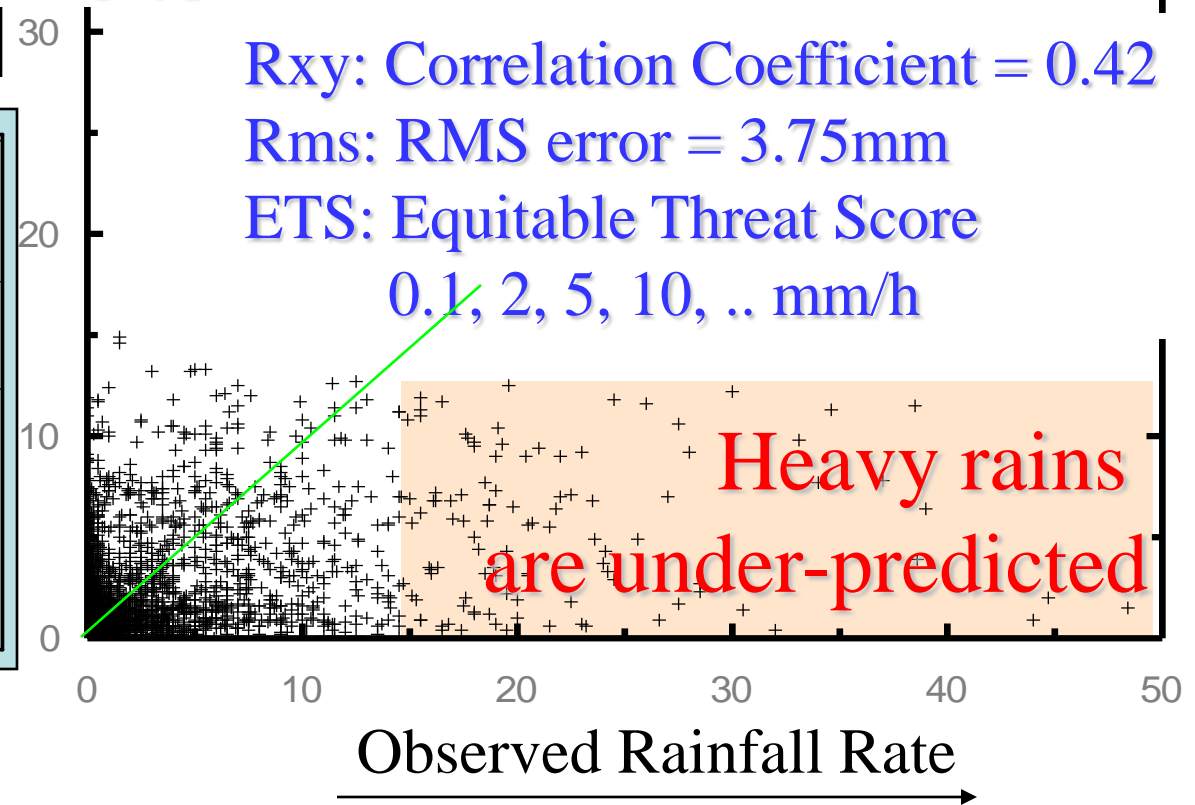
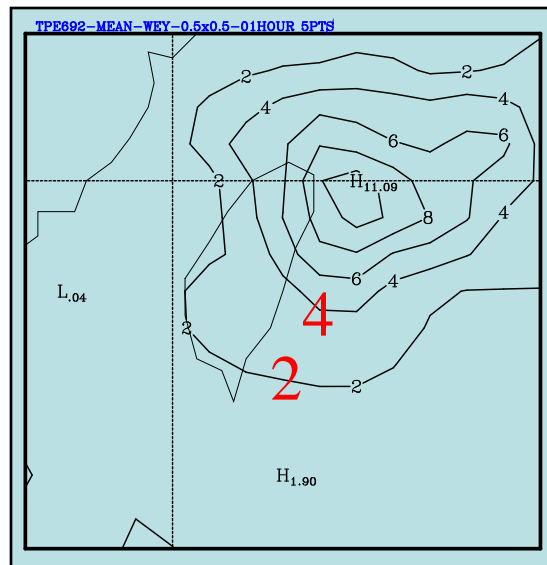
Wang et al. (1986)

TPE692CLMN

No=W5077



Taipei rainfall rate predicted
by the Climatologic Average Method
for the westward moving typhoons



Mean rainfall rate
Data : 1961-1996

Climatologic Average (Wang et al. 1986)

$$R(t+h)=M(L_t)$$

Deviation Persistence or Bias Correction

(Yeh et al. 1999)

Deviation=Difference From The Average

$$D(L_t) = R(t) - M(L_{t-h})$$

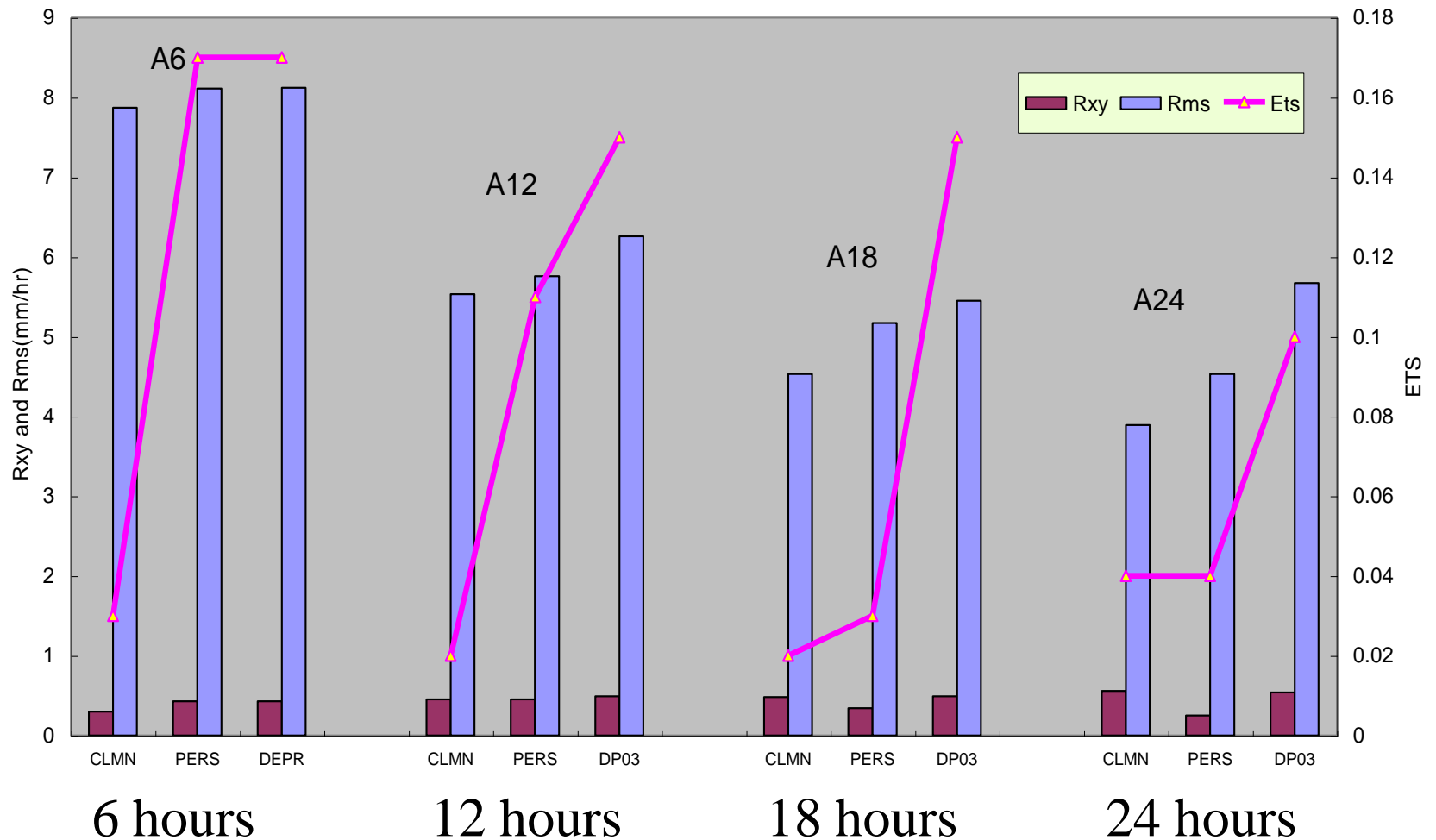
Persistence: $D(L_{t+h}) = D(L_t)$

$$R(t+h) - M(L_t) = R(t) - M(L_{t-h})$$

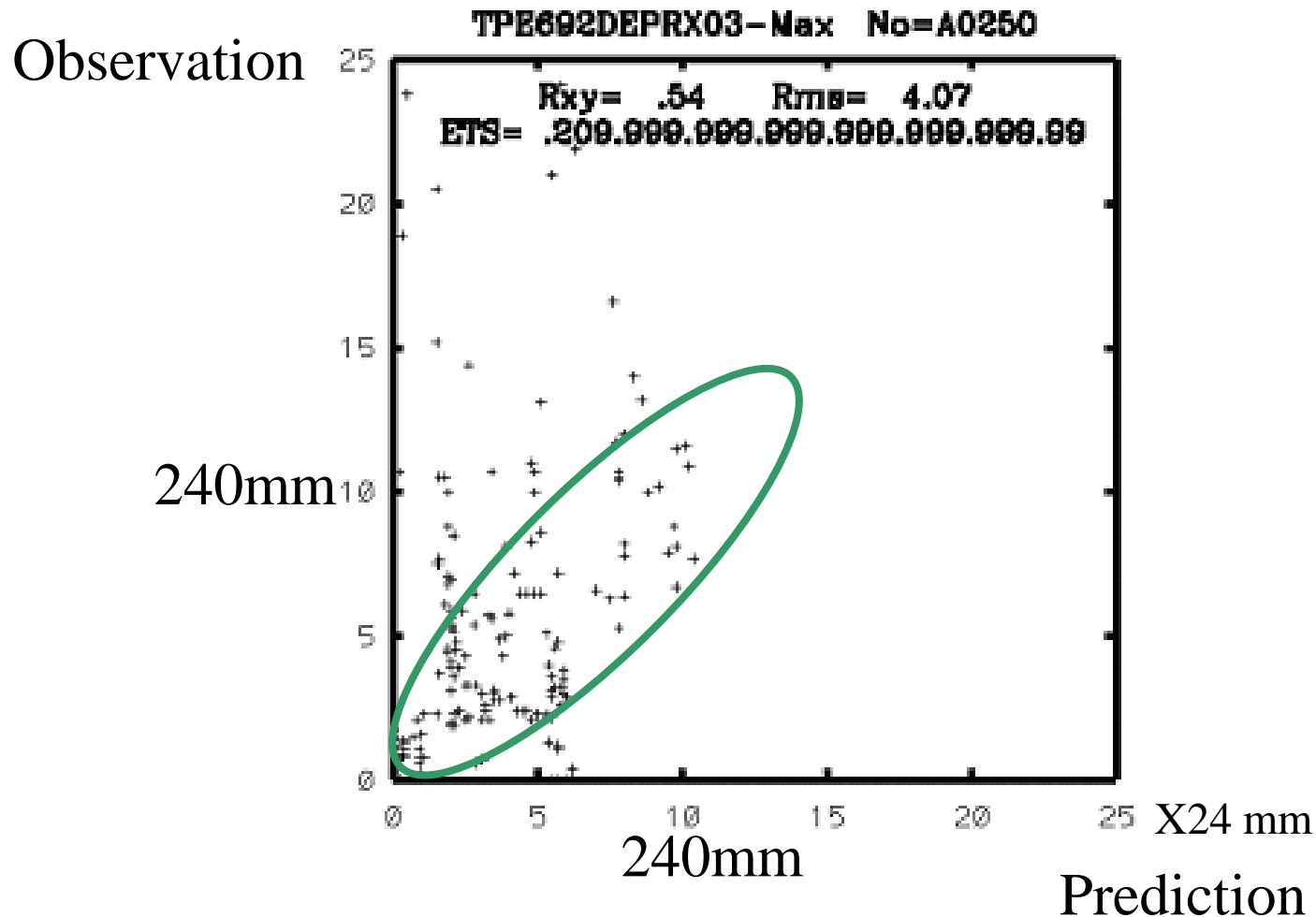
$$R(t+h) = M(L_t) + D(L_t)$$

Scores of the accumulated rainfall forecast

CLMN: Climatological Mean PERS: Persistence DP03: Bias Correction

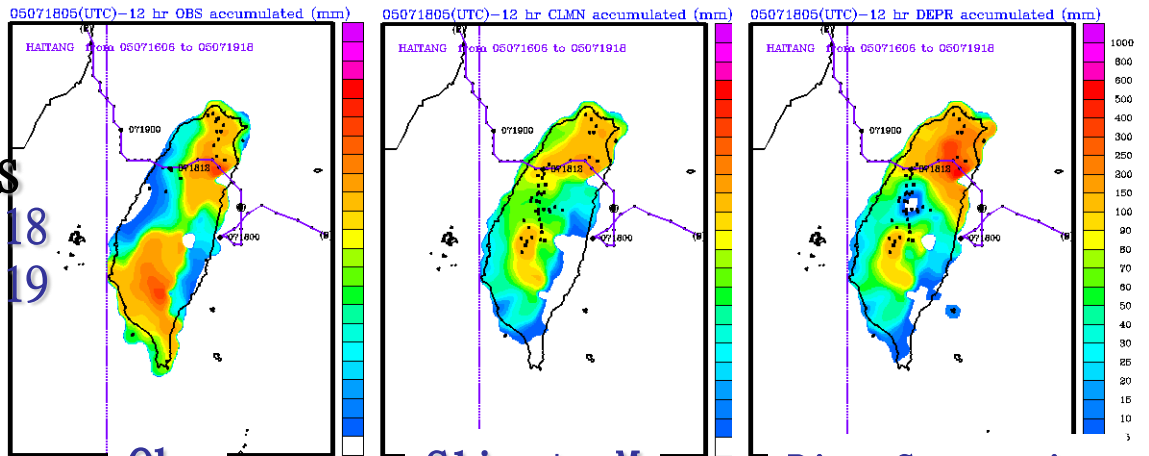


Scattering diagram of the observed and predicted 24h accumulated rainfall at Taipei



12h accumulated rainfall forecasts

Fm 12 LST 18
to 00 LST 19

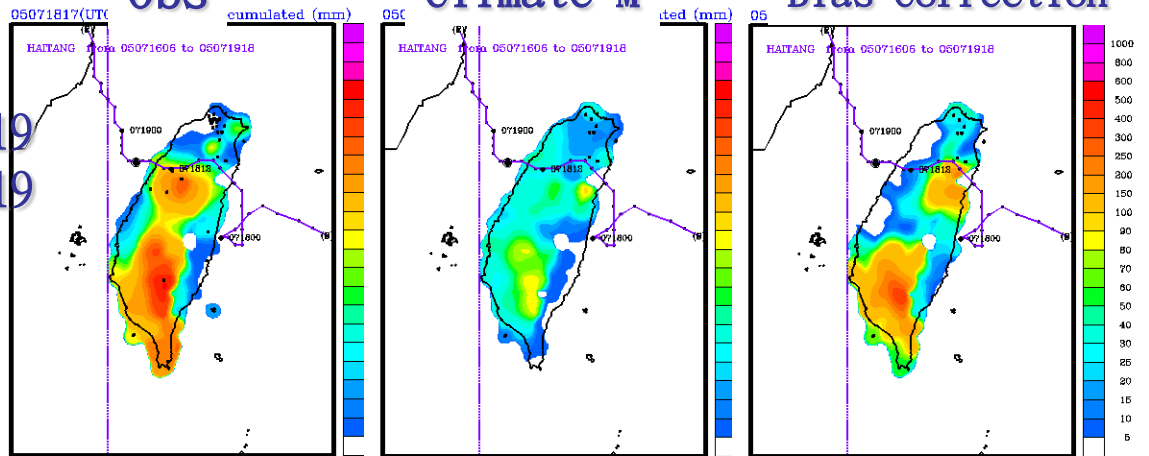


Obs

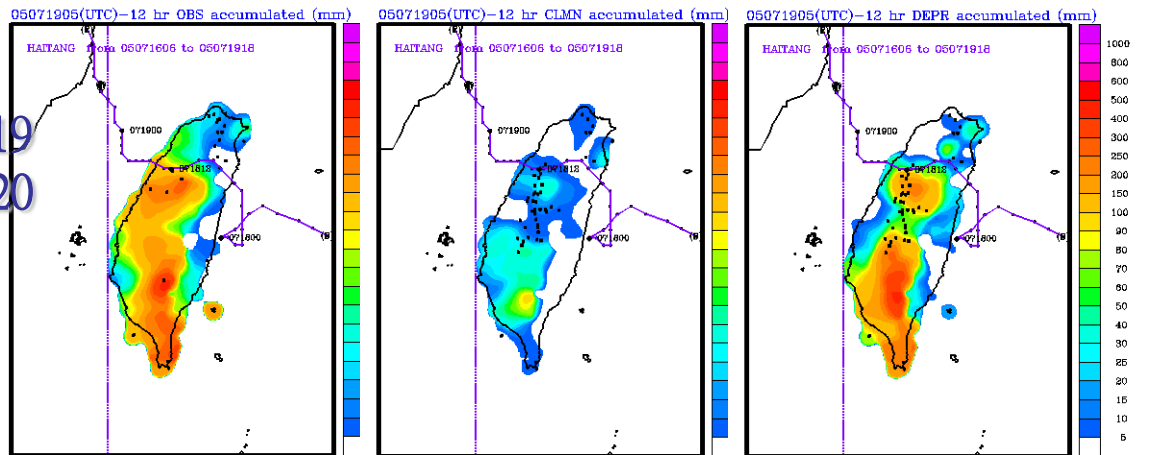
Climate M

Bias Correction

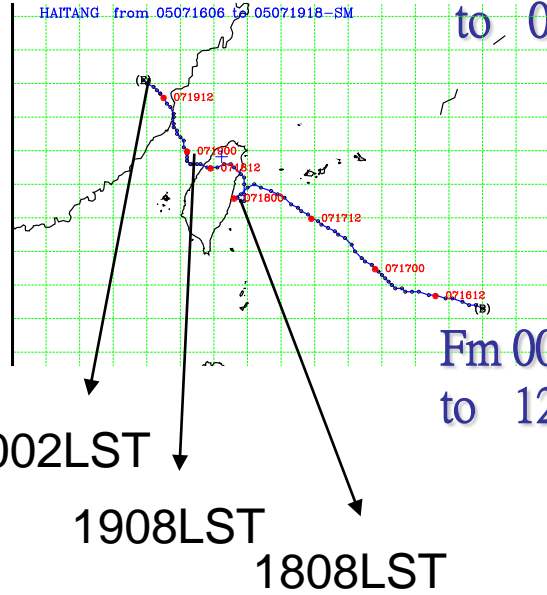
Fm 00 LST 19
to 12 LST 19



Fm 12 LST 19
to 00 LST 20



HAITANG from 05071606 to 05071918-SW



2002LST

1908LST

1808LST

Haitang (Aug 2005)

Typhoon rainfall estimation for major watersheds

Peng et al. (1967) Wang et al. (1977) Wu et al. (1981)

Rainfall due to convergent $P_c = 2M (r_2 V_{r2} - r_1 V_{r1}) / (r_2^2 - r_1^2)$

Rainfall due to terrain effect $P_i = -\rho \, dq/dz \, V \cdot \nabla H \, \Delta Z_i$

M precipitable water vapor

V_{r1}, V_{r2} inward flow speed at r_1, r_2

ρ air density

q mixing ratio

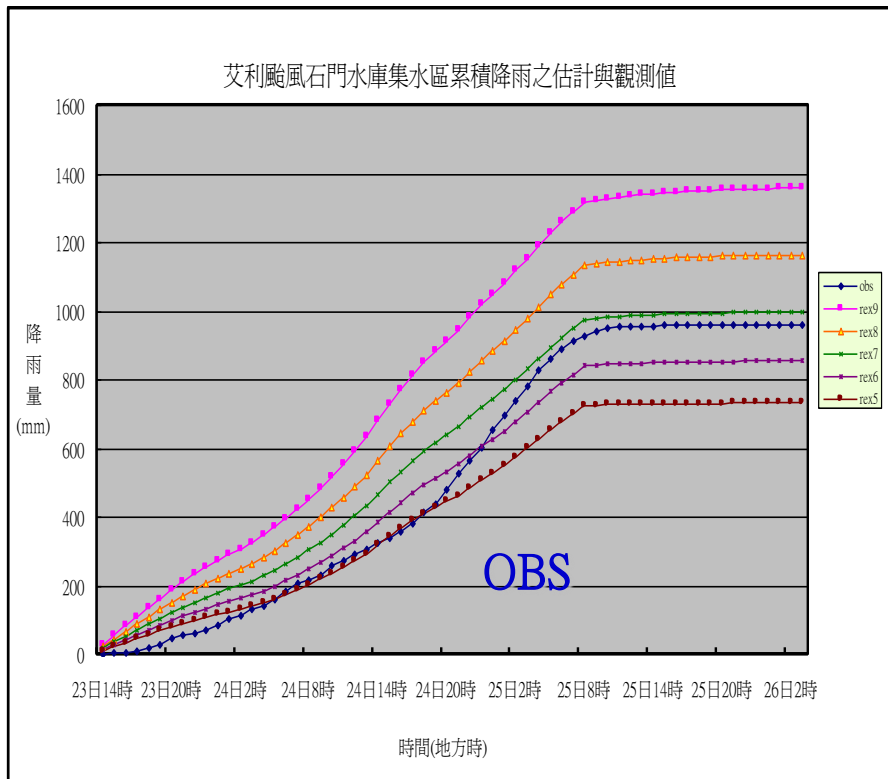
H terrain height

V wind speed

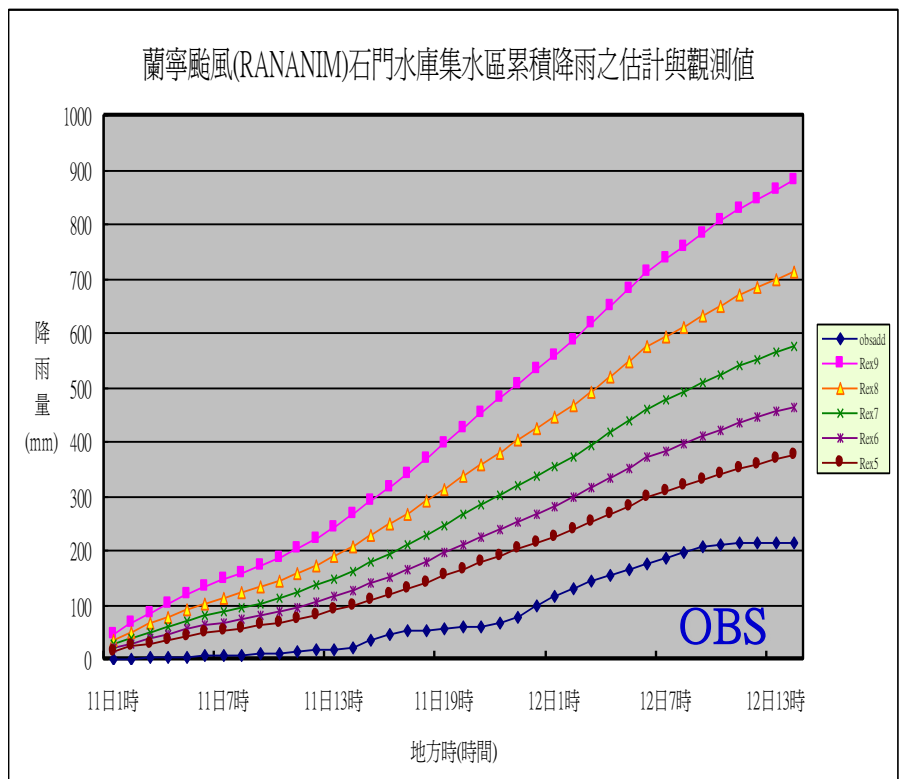
Z_i depth of the air

Rainfall estimation for the watersheds of Shiman Reservoir

Rainfall of Typhoon Aere

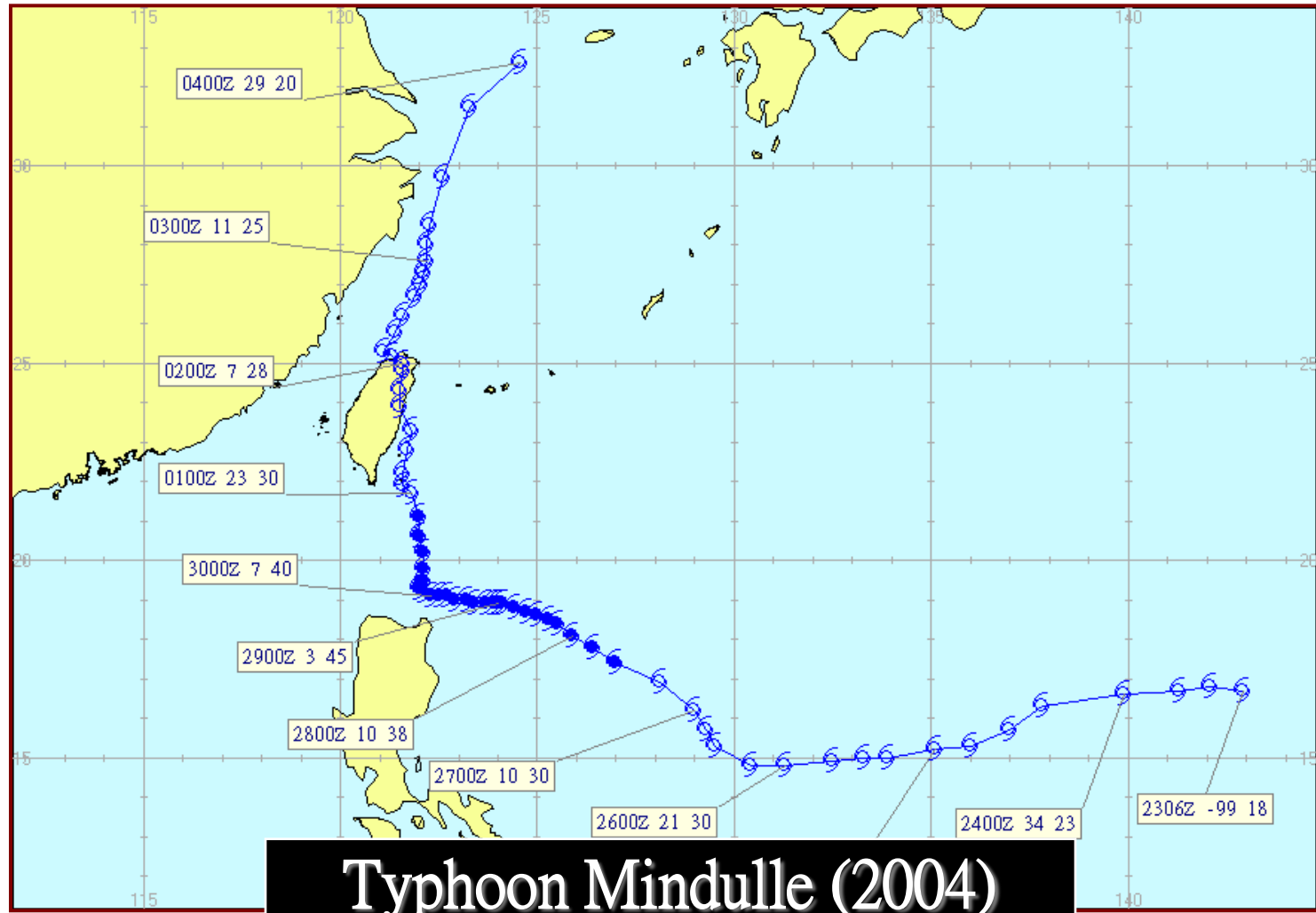


Rainfall of Typhoon Rananim

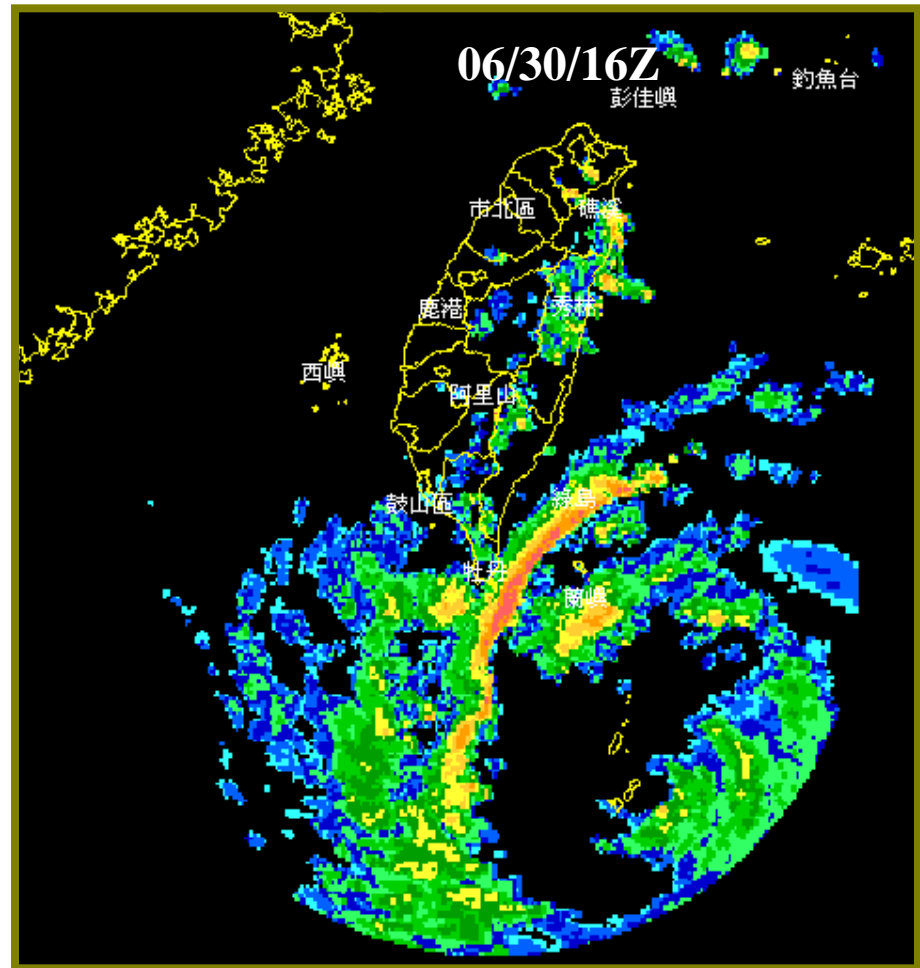
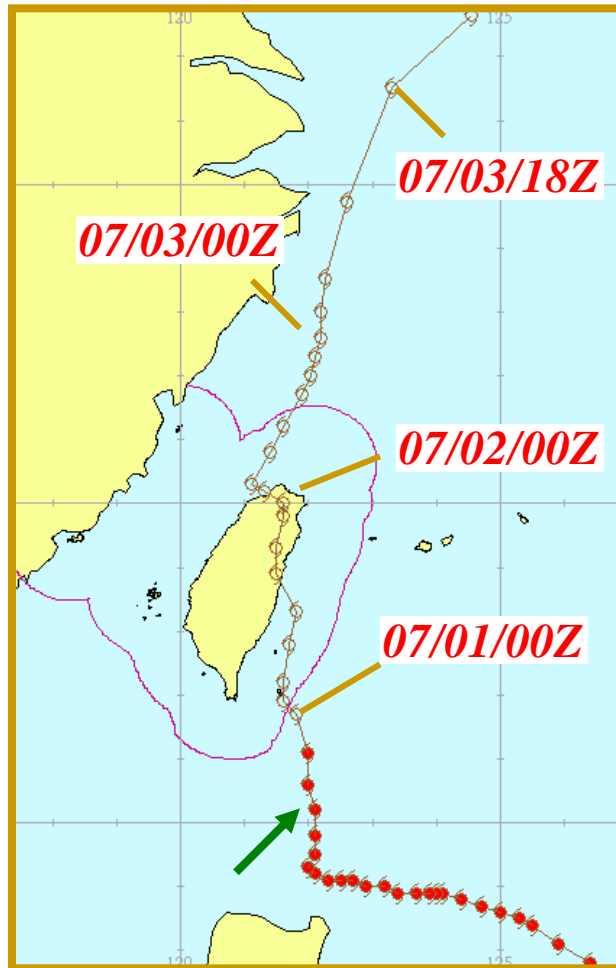


Challenge

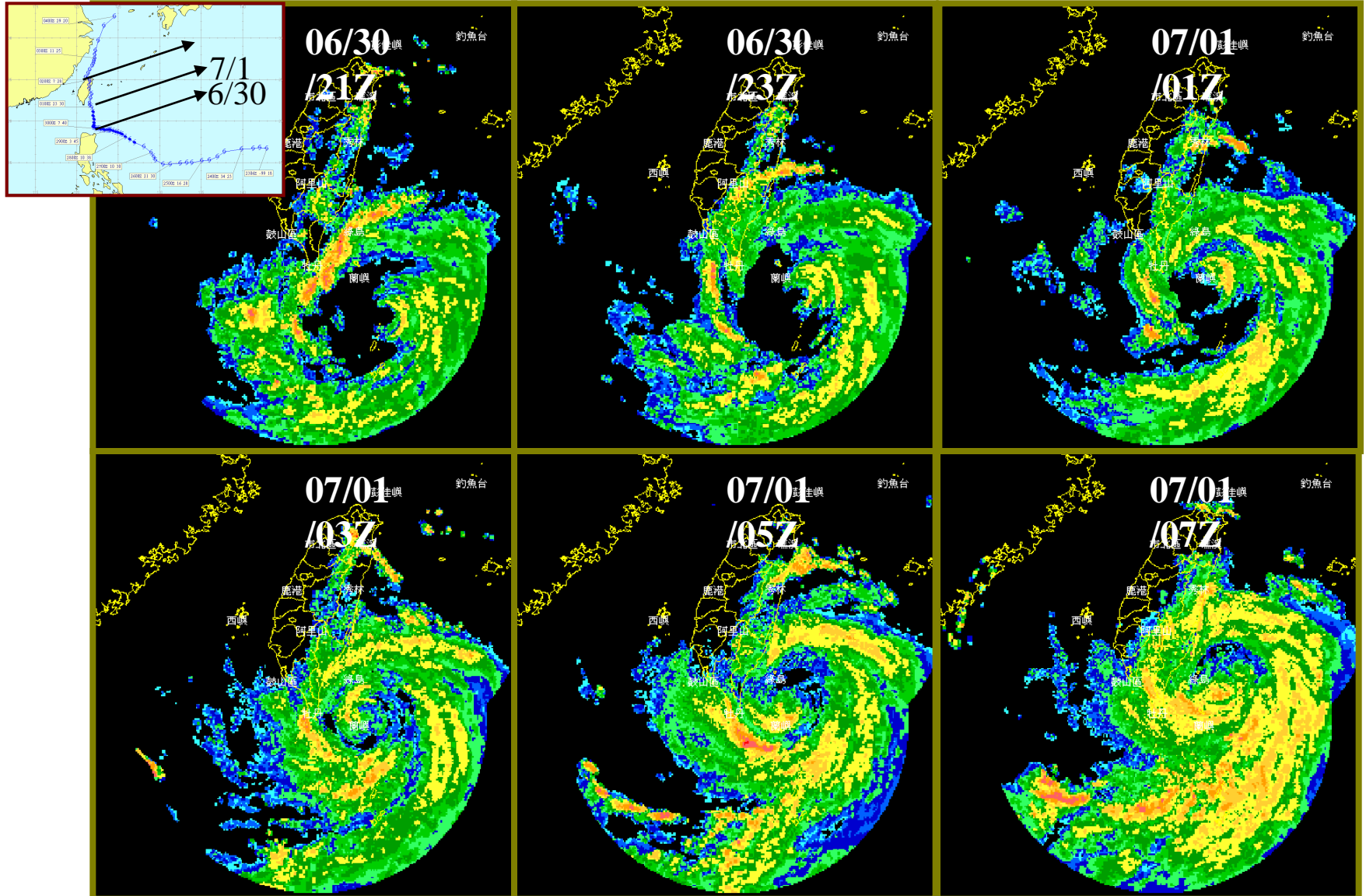
- Not fully understand the mechanism of the typhoon motion and structure change



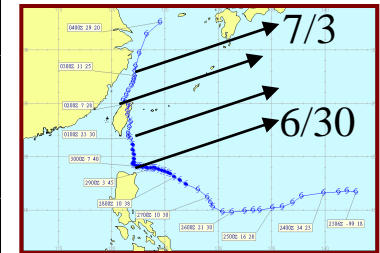
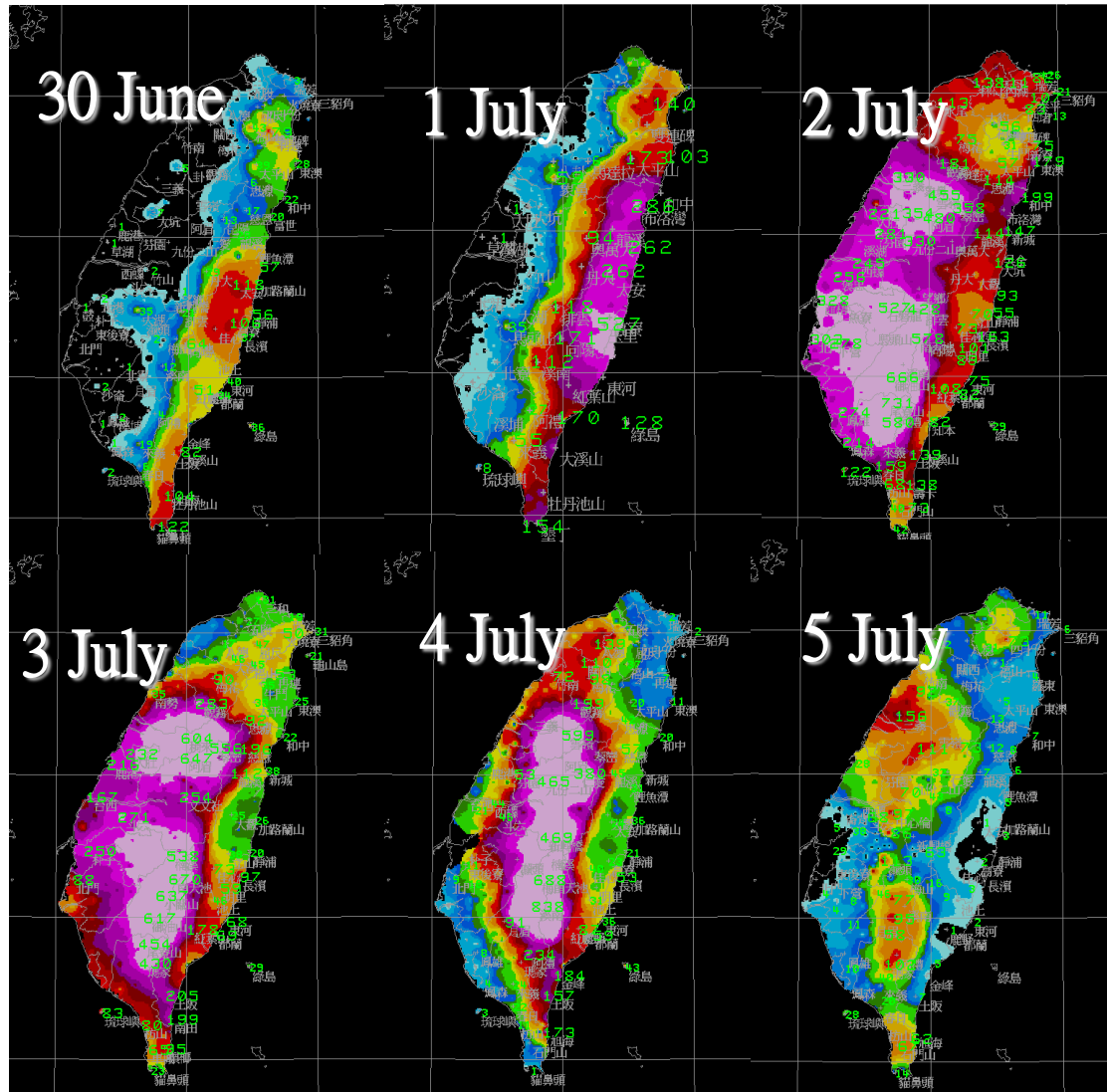
Structure of Mindulle Observed from CWB Radars



Structure of Mindulle Observed from CWB Radars

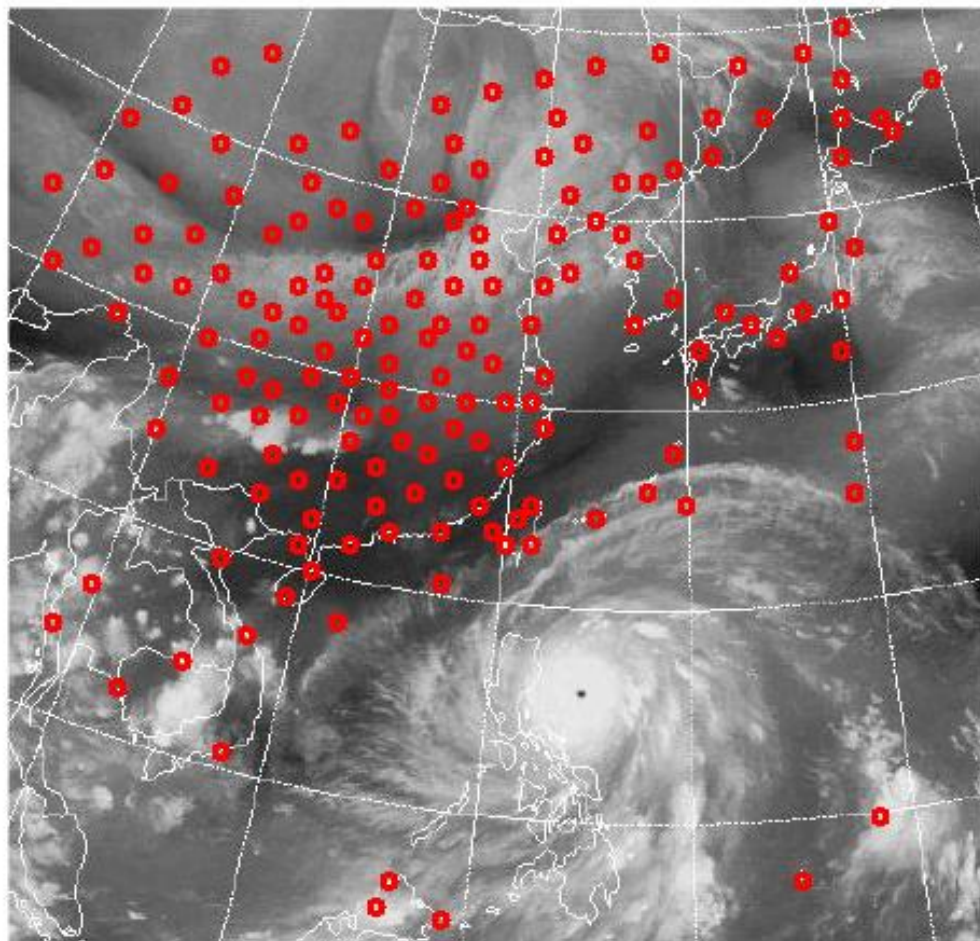


Rainfall on 30 June to 5 July (under the influence of Typhoon Mindulle)



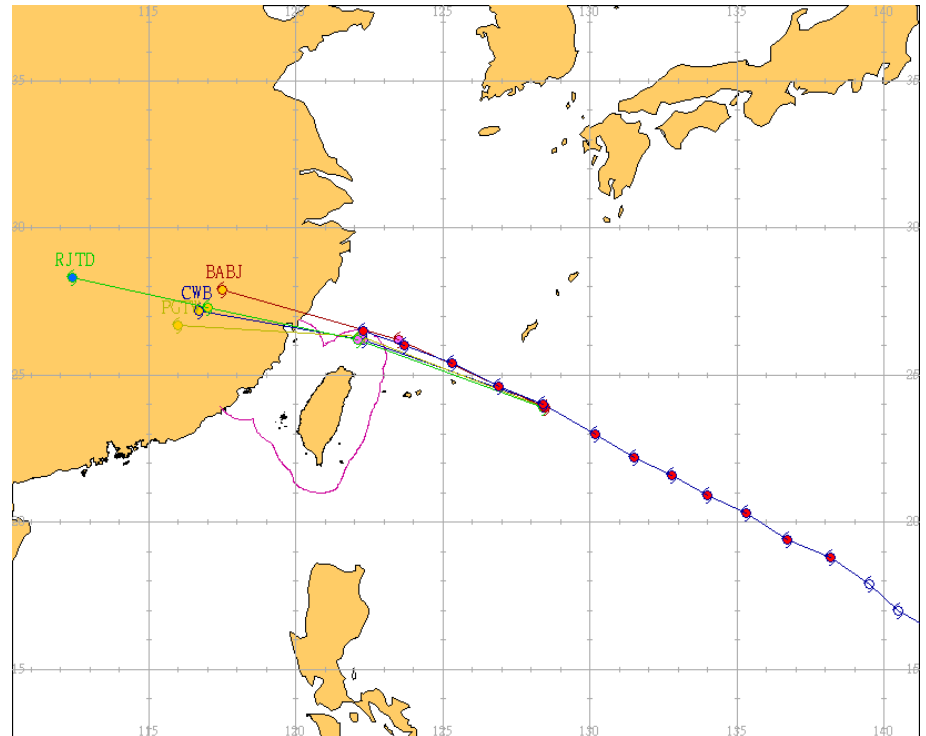
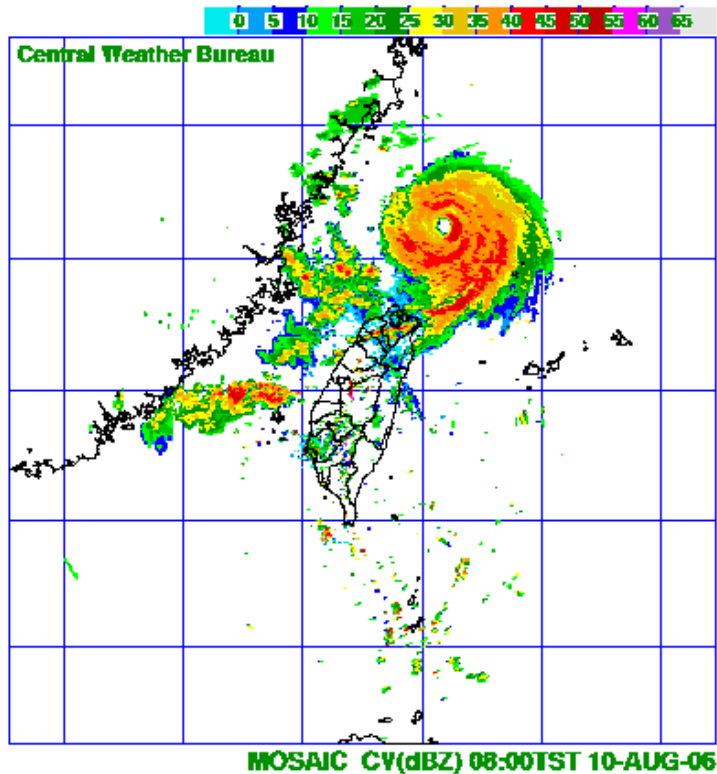
Challenge

- Poor data coverage



Challenge

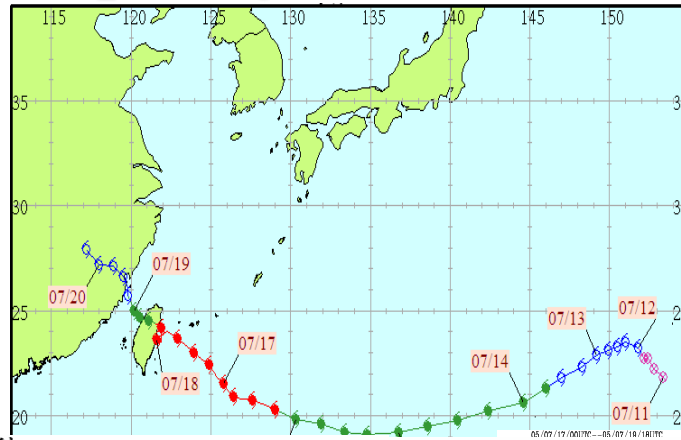
- Small track different results in completely different scenarios



Songmei passes by Taiwan and caused many casualties in China

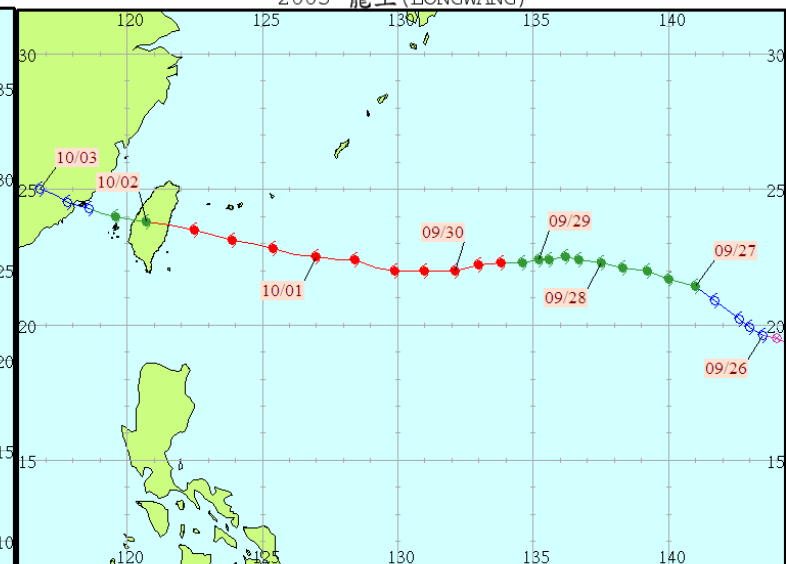
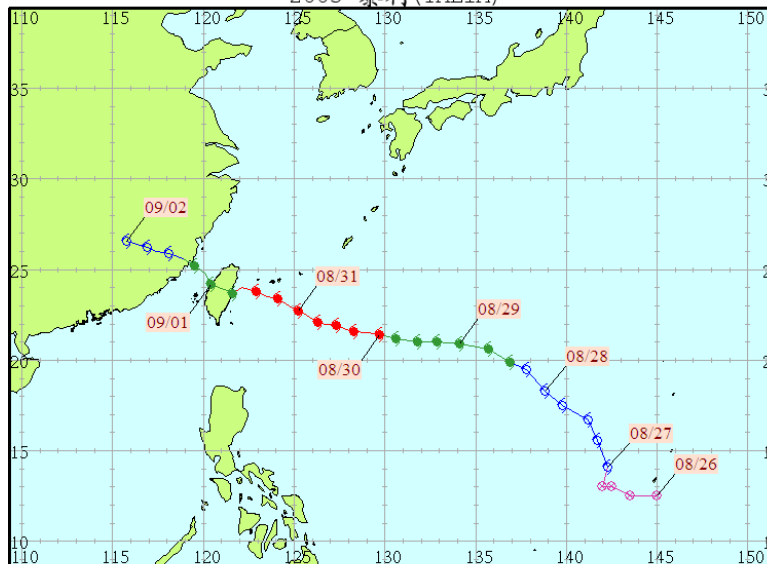
Challenge

- Environment and cyclone structure different results in completely different scenarios



2005 泰利 (TALIM)

2005 龍王 (LONGWANG)

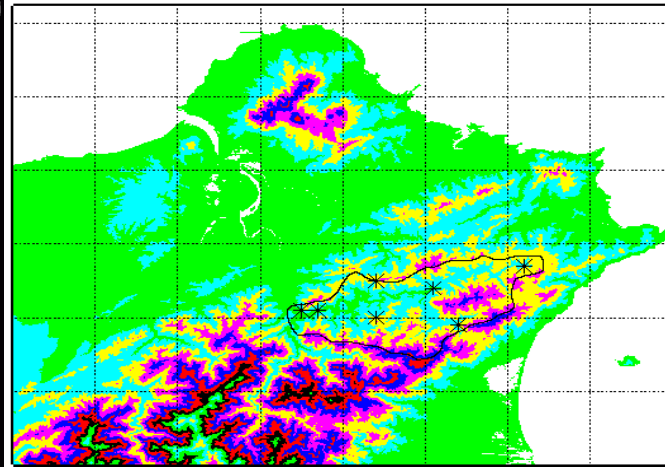
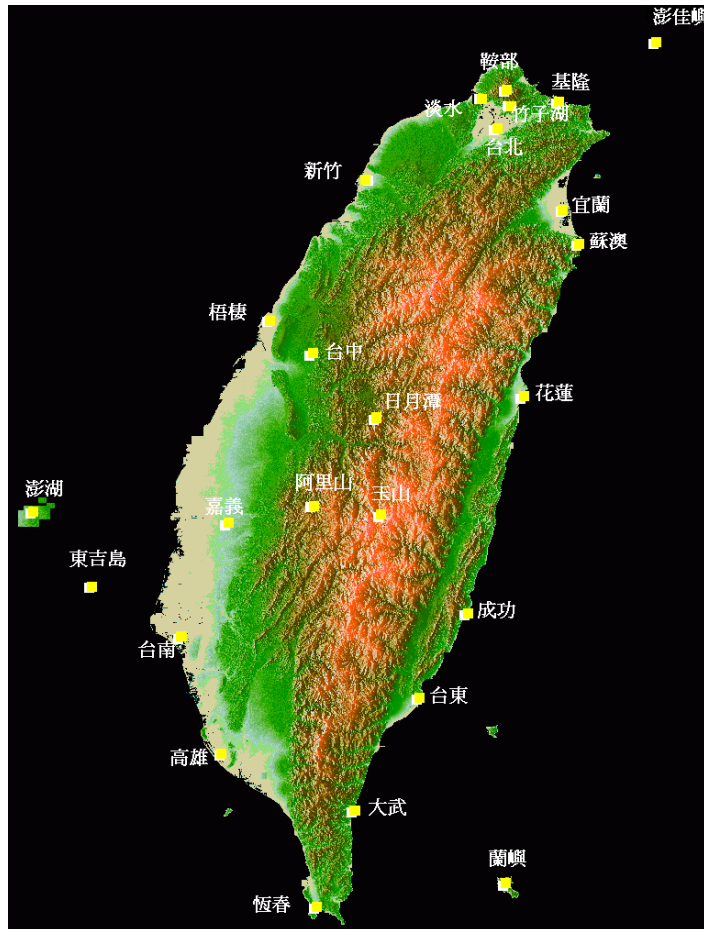


● 強烈颱風($V_{max} \geq 51.0 \text{ m/s}$) ● 中度颱風($V_{max} 32.7-50.9 \text{ m/s}$) ● 輕度颱風($V_{max} 17.2-32.6 \text{ m/s}$) ● 熱帶氣旋($V_{max} < 17.2 \text{ m/s}$)

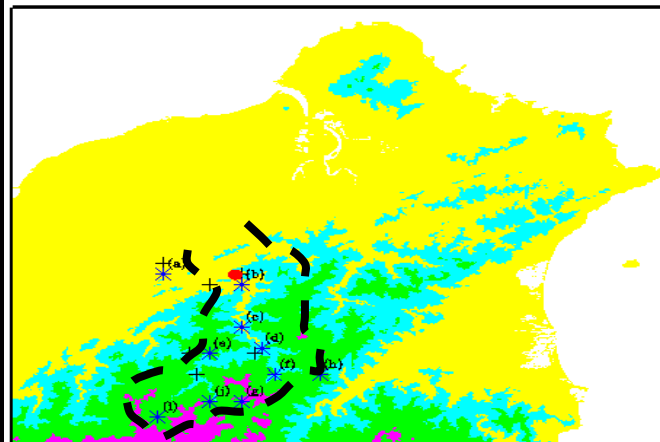
● 強烈颱風($V_{max} \geq 51.0 \text{ m/s}$) ● 中度颱風($V_{max} 32.7-50.9 \text{ m/s}$) ● 輕度颱風($V_{max} 17.2-32.6 \text{ m/s}$) ● 熱帶氣旋($V_{max} < 17.2 \text{ m/s}$)

Challenge

- Steep slope, small reservoirs, small watersheds with high water demand result in great challenge of water management in Taiwan



303 km²
10 km²
400 M m³



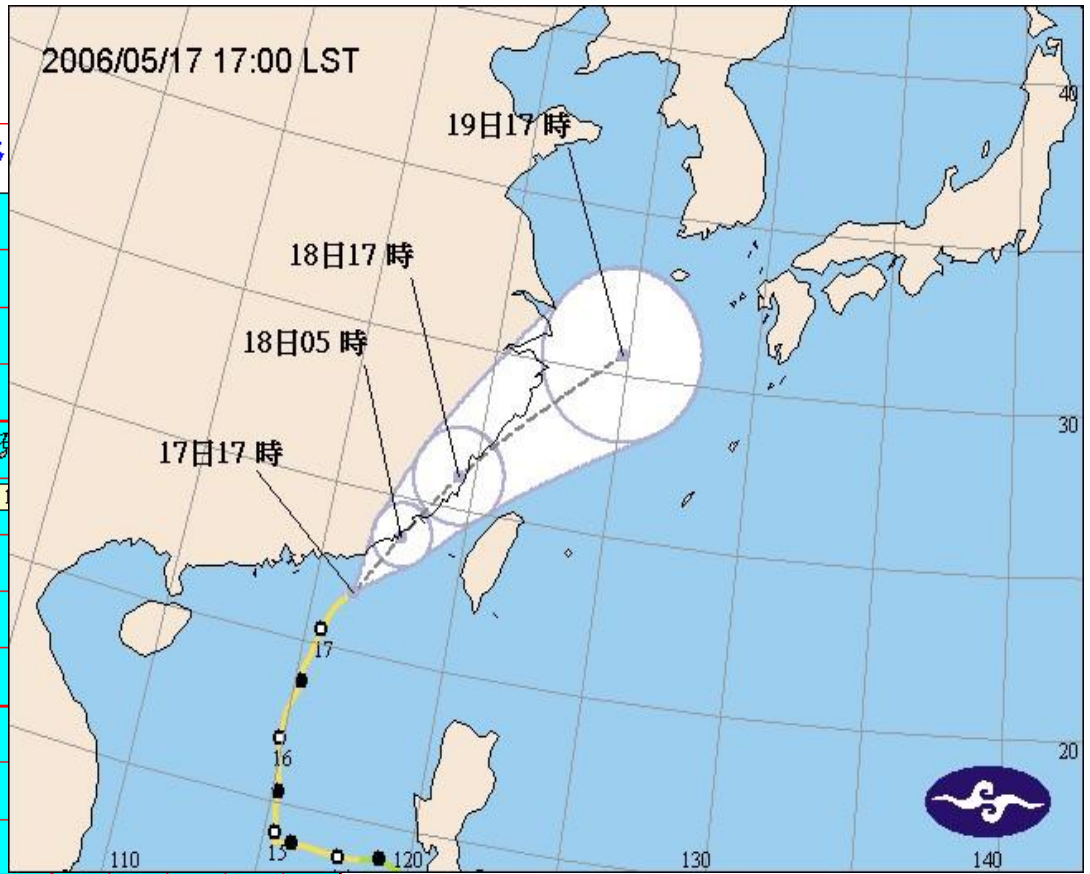
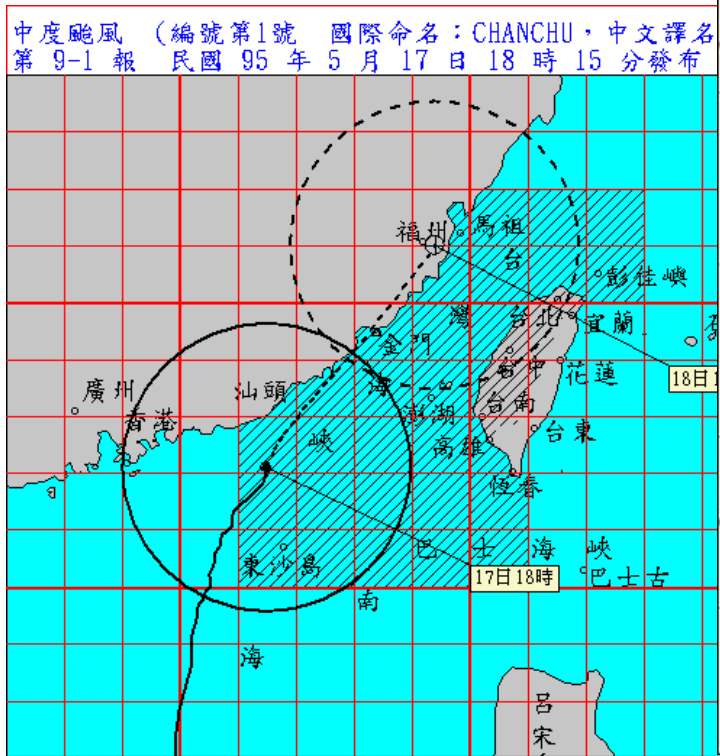
Tropical Cyclone Warnings

Provided every 3-hour

Update center location every hour during
inland warnings

Includes current location, intensity, rainfall,
24-hour forecasted center location,
trend of intensity change, probability
track forecast, warning area,
and remarks.

An example of the warning diagram shows the forecasted track and warning areas



Rainfall forecasts

Rainfall forecasts are provided at 5 am, 10 am, 5 pm, and 10 pm LST.

The rainfall forecasts include the total accumulation rainfall for the whole period of typhoon invasion and the next 24-h accumulation rainfall for each county.

An example of the rainfall forecast table shows the total accumulation rainfall forecasts

九十年第十六號颱風警報區域雨量預測

中央氣象局發布

發布時間：90年9月16日10時00分

分 區 雨 量		台北 桃園 地區	基隆 地區	宜蘭 地區	花蓮 地區	新竹 苗栗 地區	台中 彰化 地區	南投 地區	台東 地區
總 雨 量 （公厘）	平 地	200 300	200 300	200 300	200 300	200 300	150 200	150 200	50 100
		山 區	400 600	300 500	400 600	250 350	400 600	250 350	350 500

下次預定發布時間：90年9月16日17時00分

Channels of Services

Cell Phone Short Message

Press Conference/Interview

Telephone Interview

FAX

WWW

Press

Cell Phone Short Message

FAX

Point To Point System

Phone

WWW

EMO

Cell Phone Short Message

FAX

P T O P

Phone

WWW

Government

Newspaper 、 166/167

FOD 、 WWW

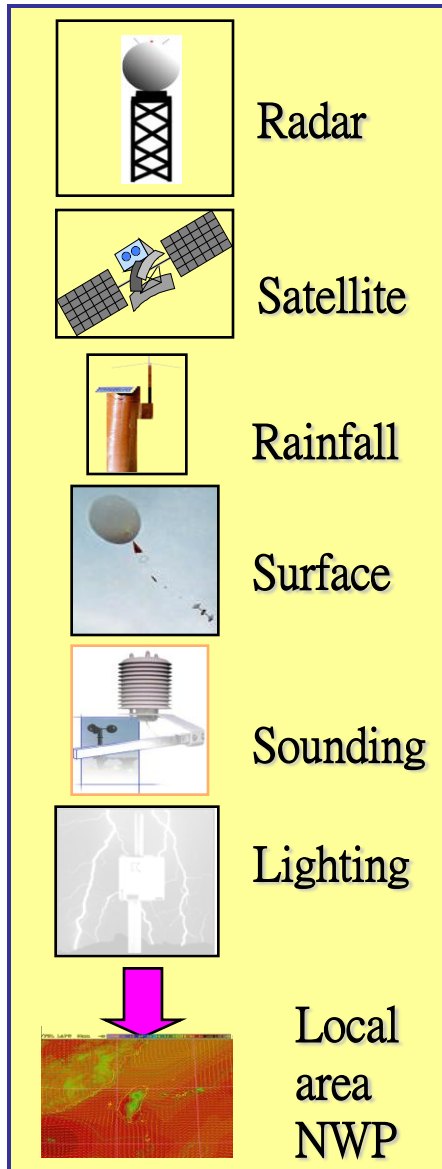
email 、 SSB

Consultation Phone

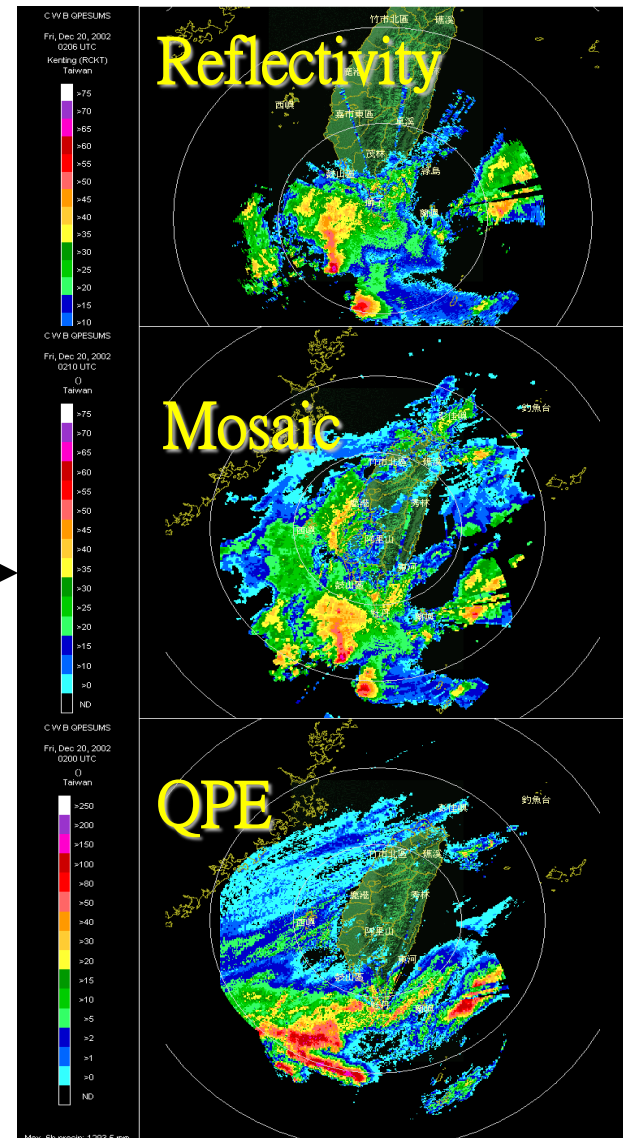
Television & Radio

Public

QPESUMS (Quantitative Precipitation Estimation)

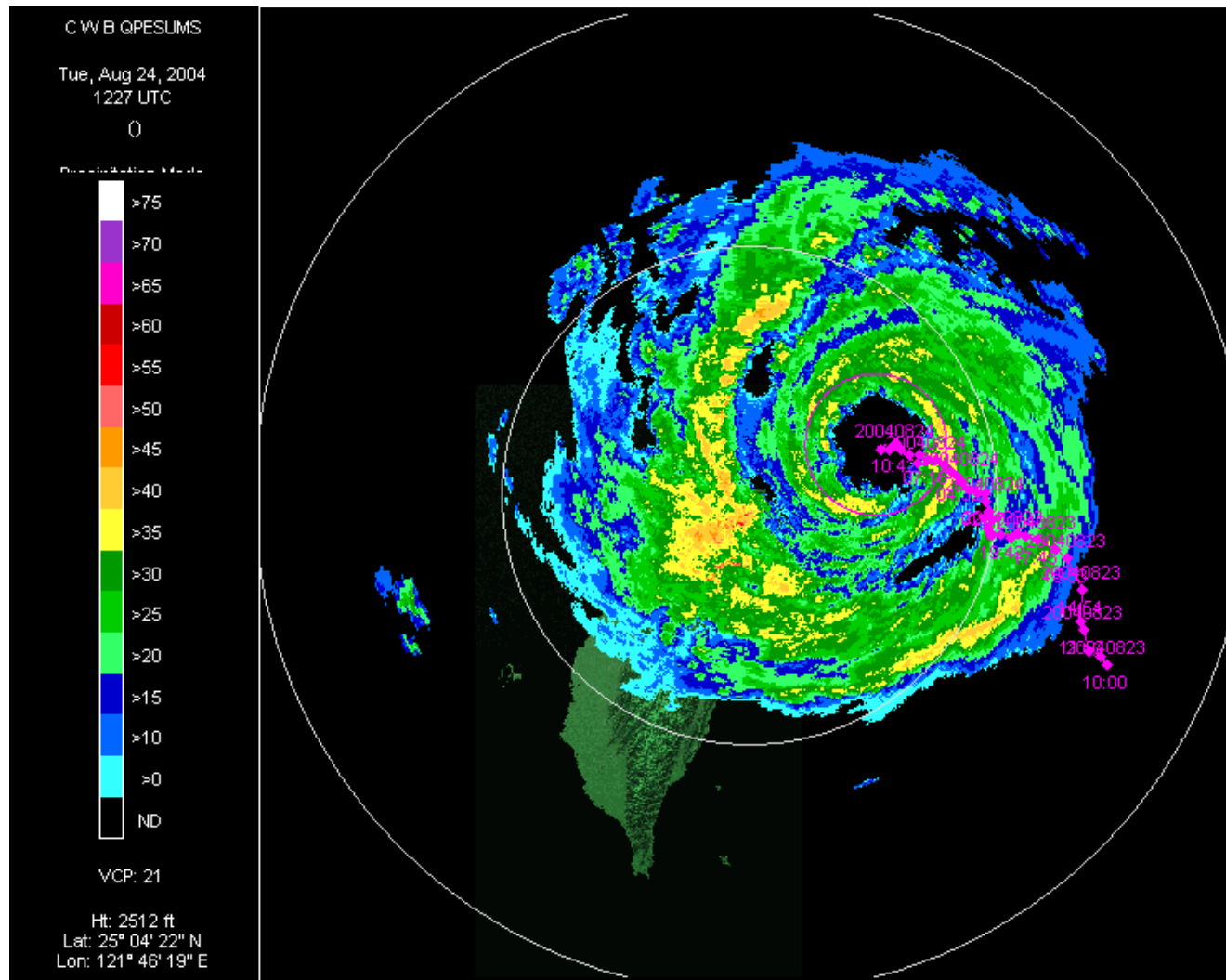


Data Processing →



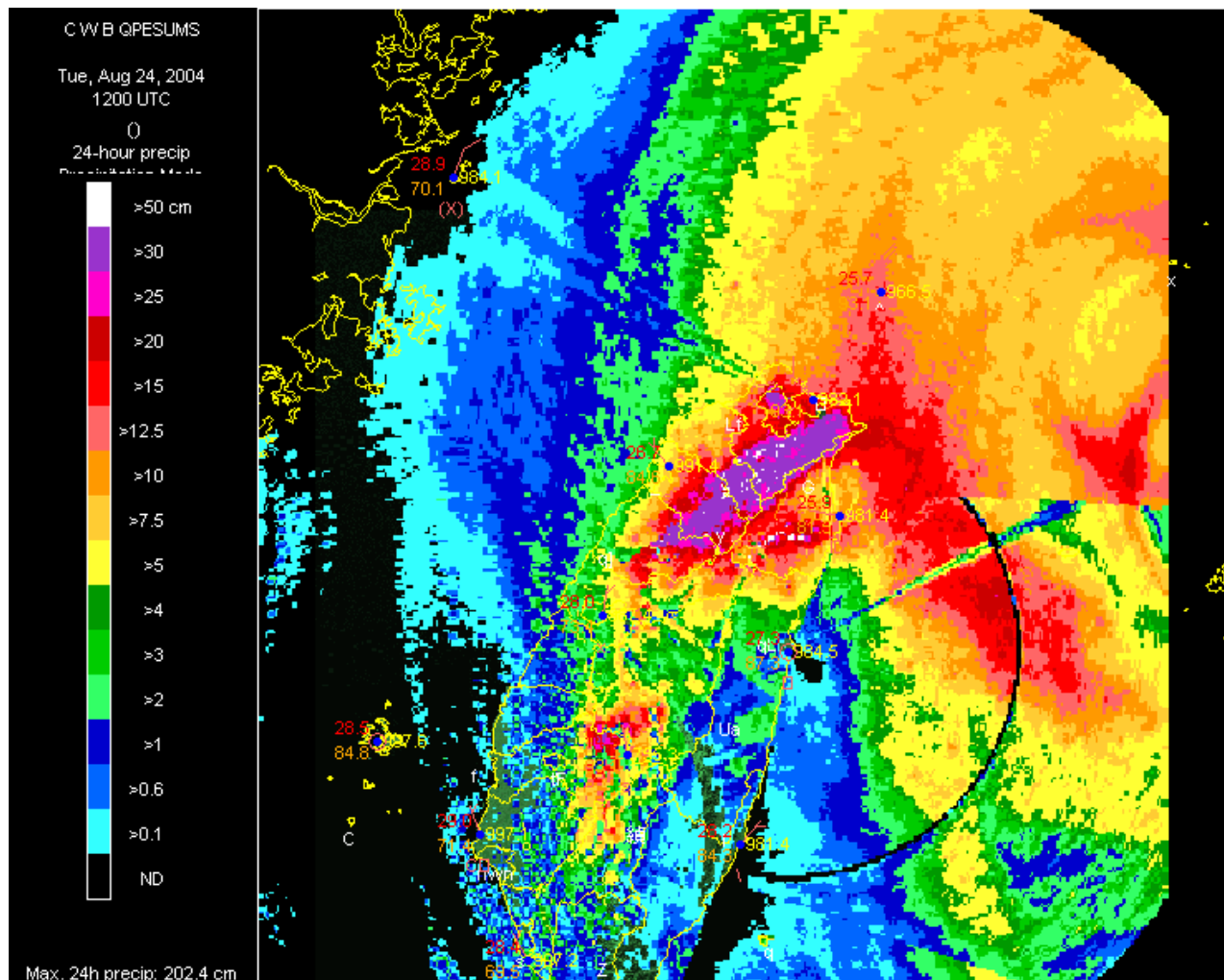
Typhoon Forecasting

Determining the Center Location



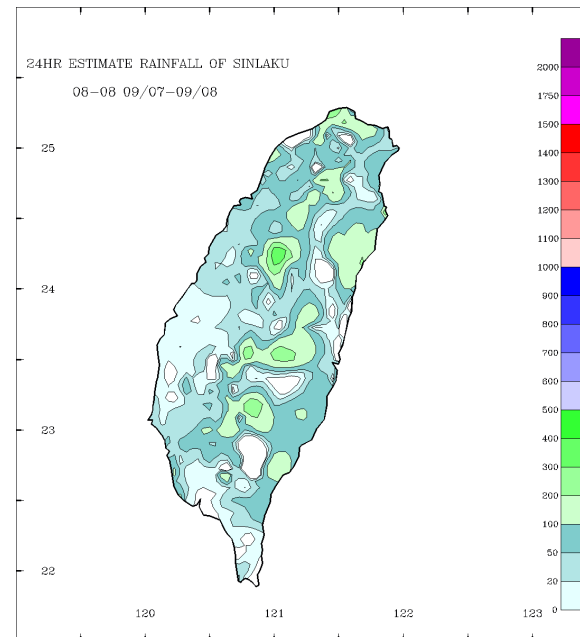
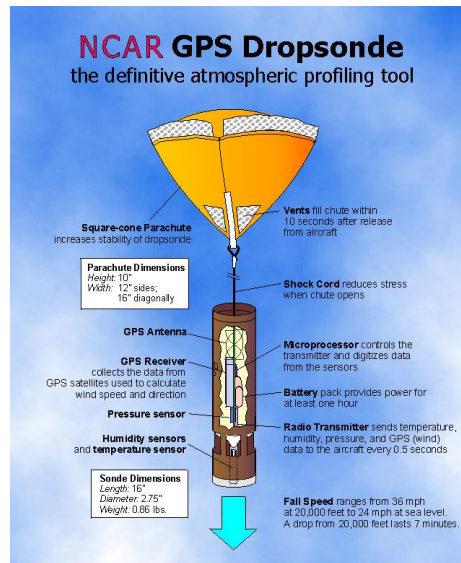
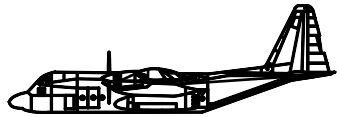
Typhoon Forecasting

Rainfall Estimation



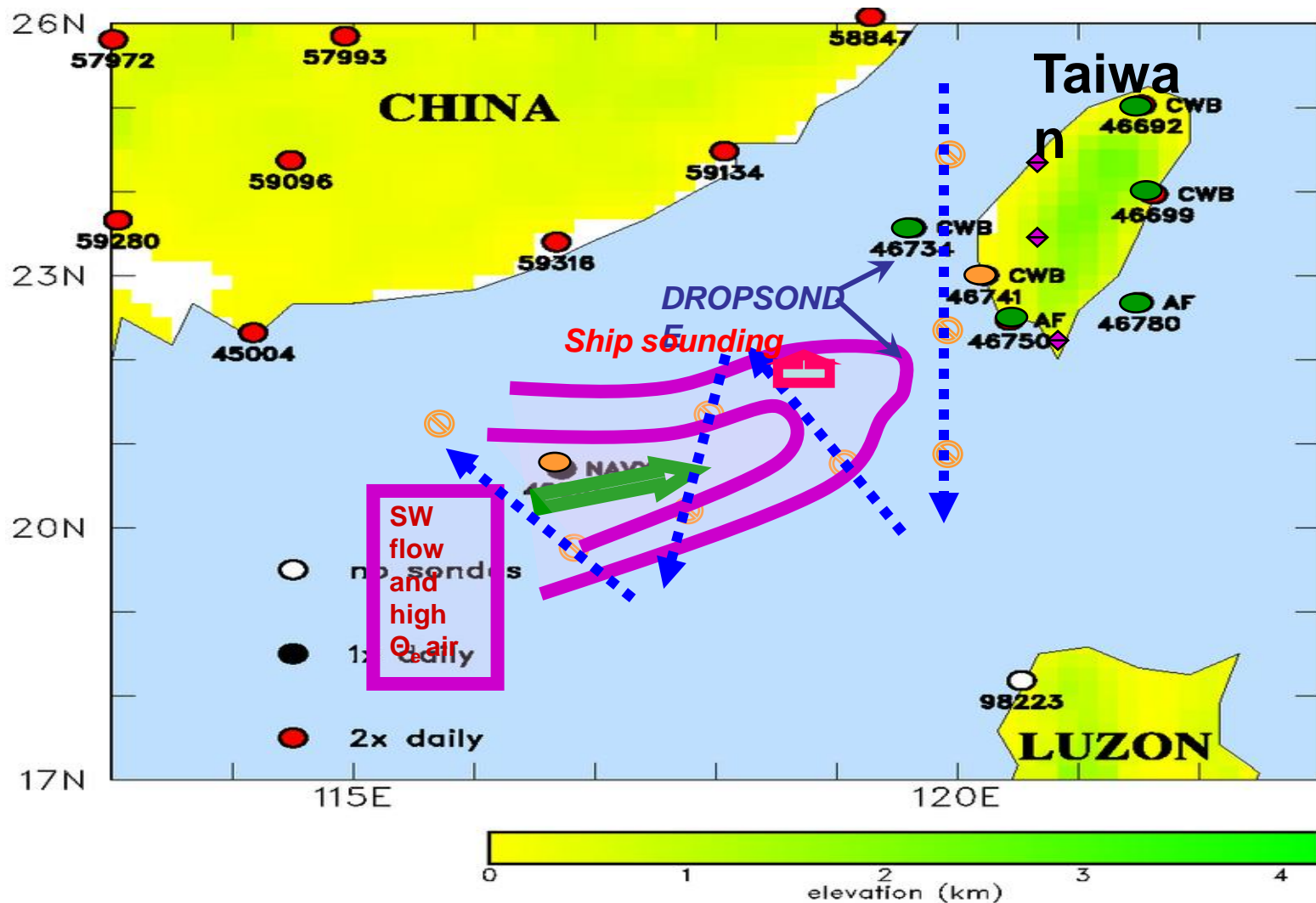
Future Work

-- Typhoon dropsonde observation experiment

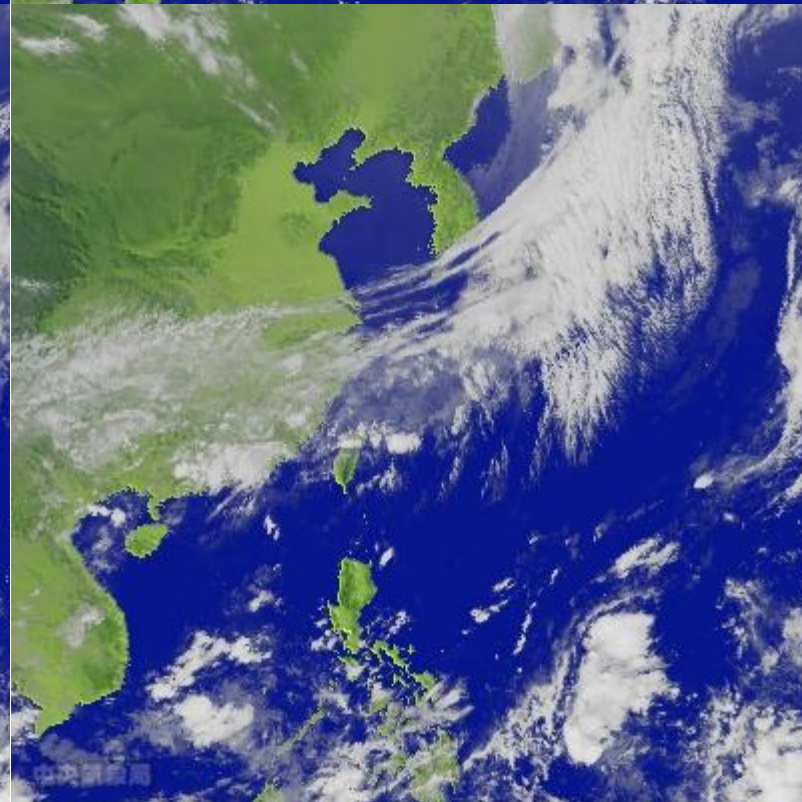
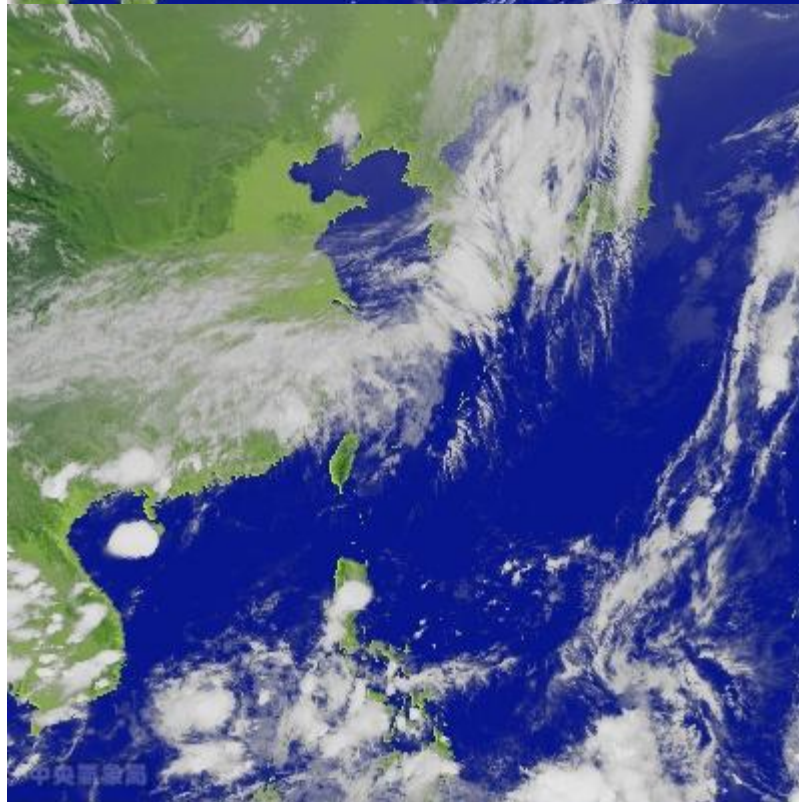
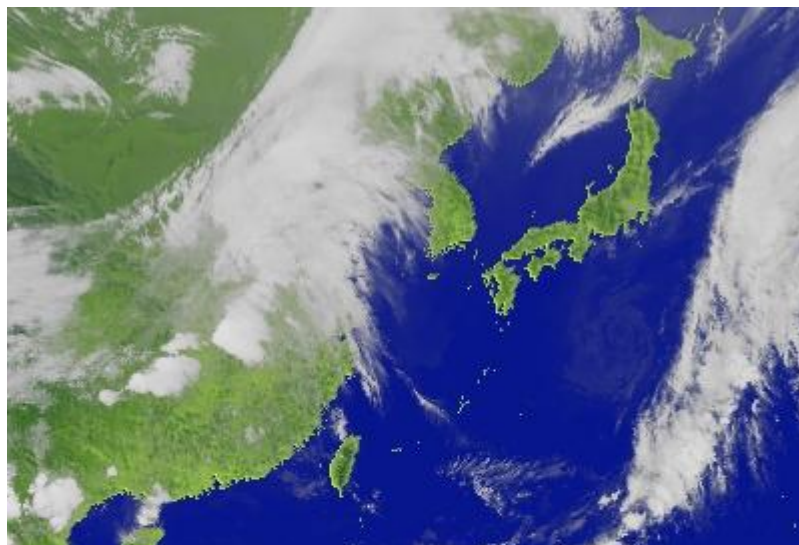


Future Work

-- 2008 Southwesterly monsoon field experiment



Thank you for your attention



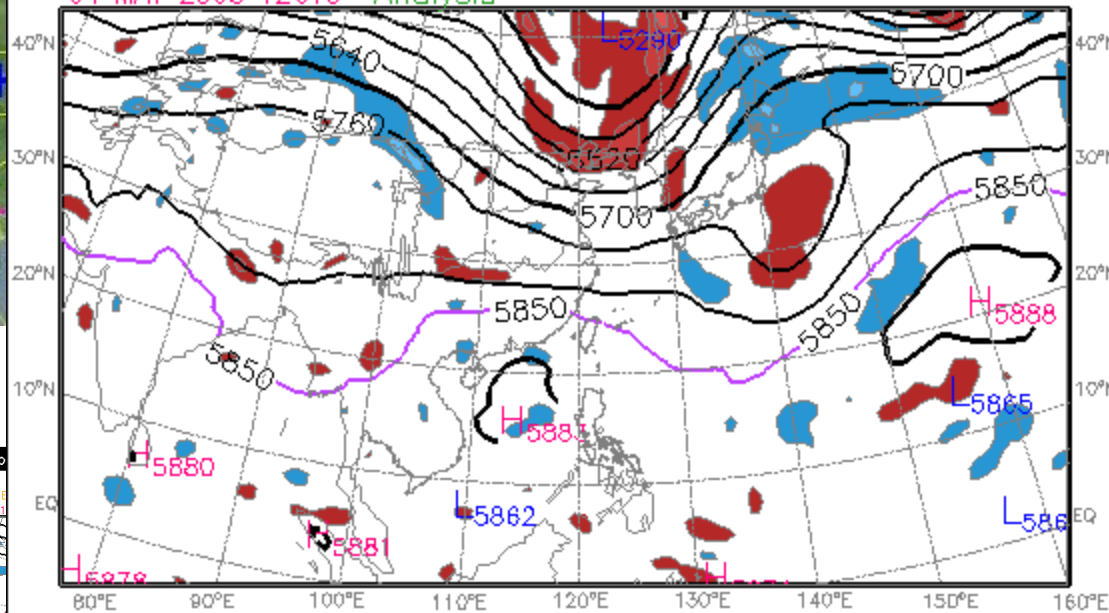
MTSAT 紅外線雲圖 5/04 20:00

MTSAT 紅外線雲圖 5/05 08:00

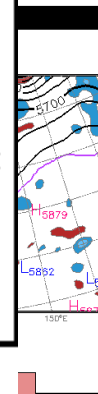
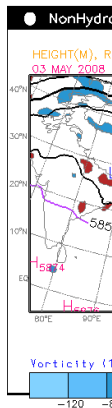
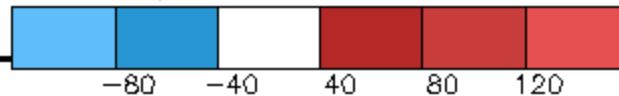
● NonHydrostatic Forecast System(45km)

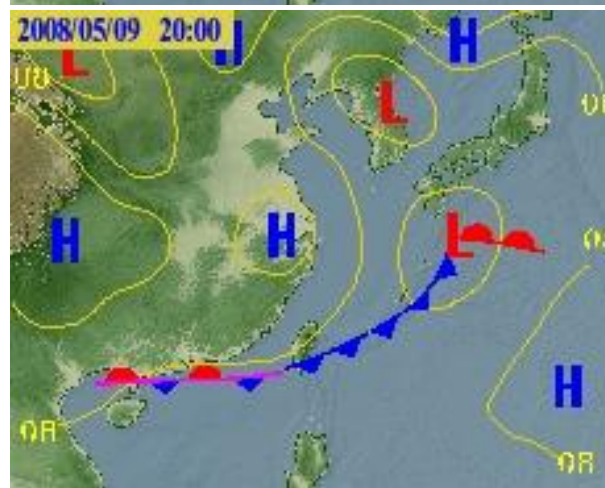
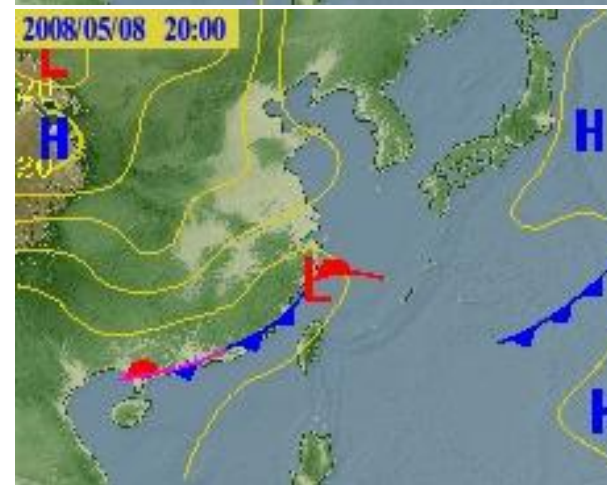
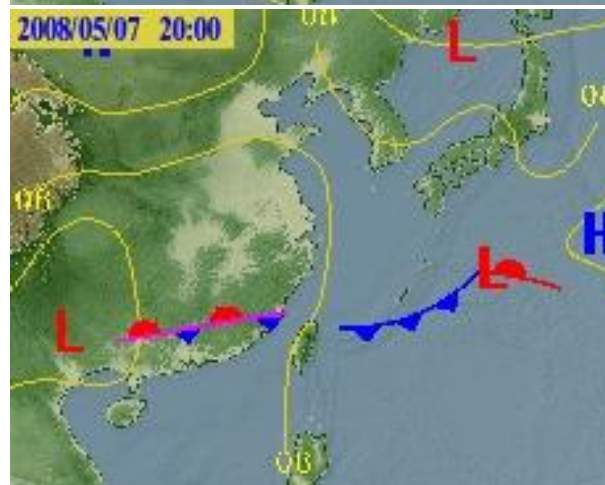
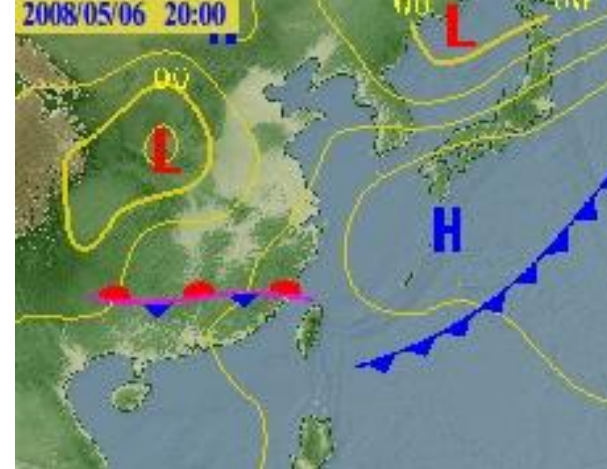
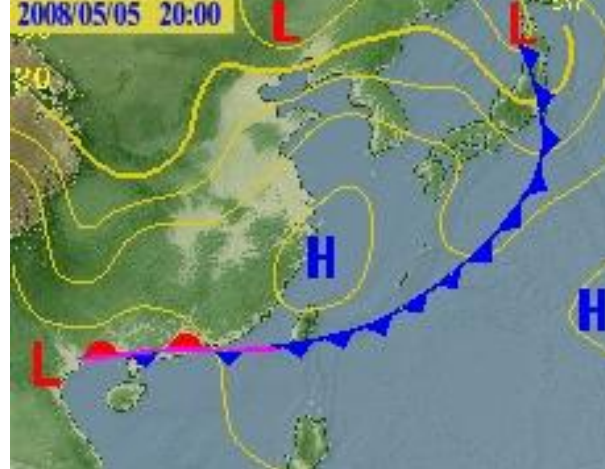
HEIGHT(M), RELATIVE VORTICITY(E-6/s) AT 500 hPa

04 MAY 2008 12UTC Analysis



Vorticity (10**-6/sec)





Outreach Program 2008 – CWB hosted 4 Workshops in April

