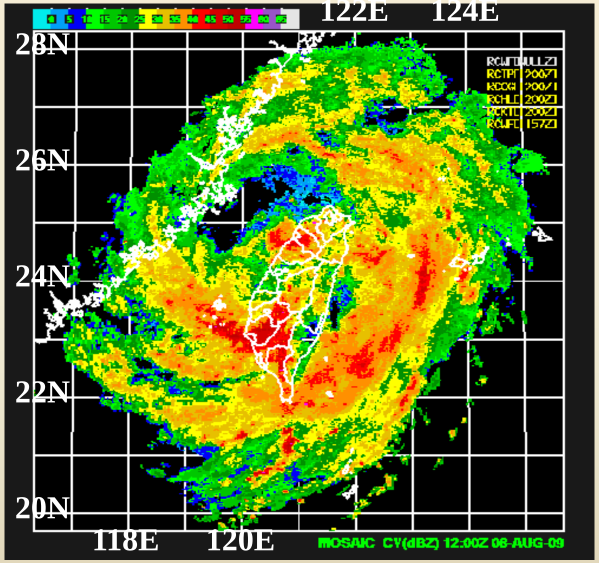
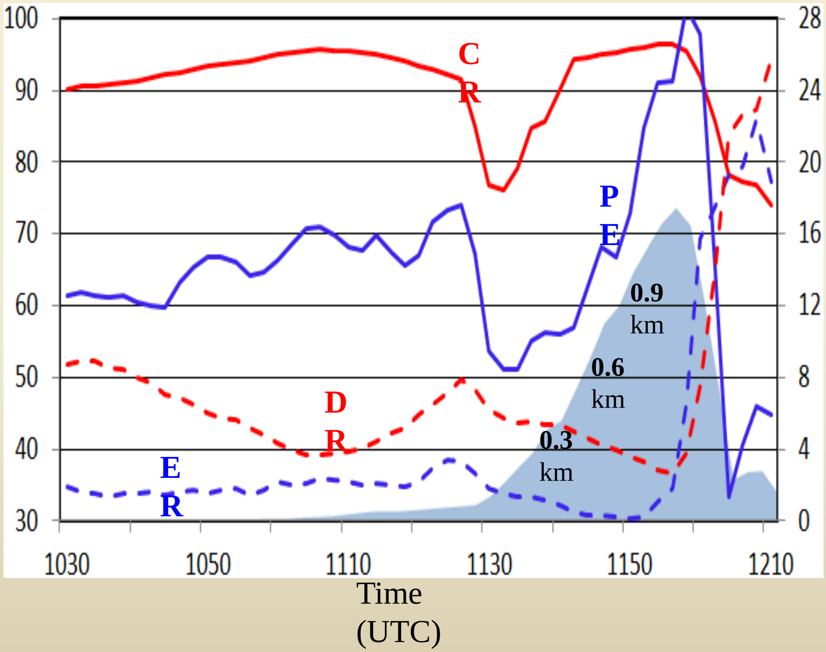
Water Budget and Precipitation Efficiency of Typhoon Morakot (2009)

Ming-Jen Yang

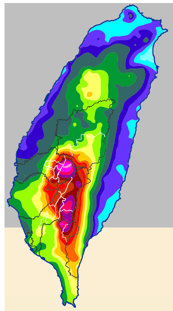
National Central University, Taiwan



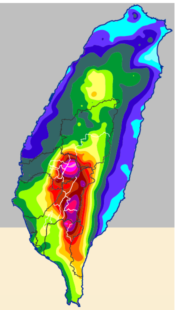


Acknowledgement: Hsiao-Ling Huang, Chung-Hsiung Sui

UW Dept. of Atmos. Sci. Colloquium @ 2014/01/31



Uniqueness of Typhoon Morakot



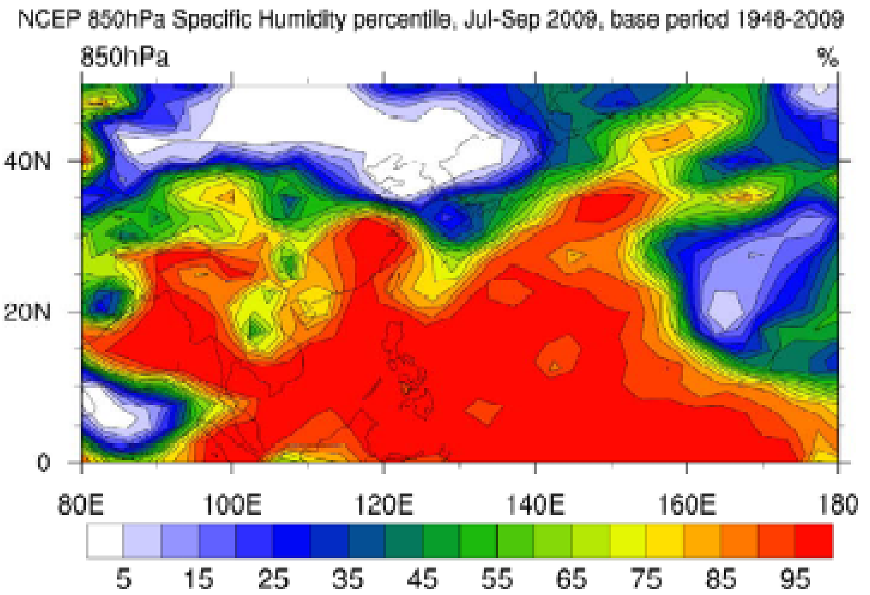
1. Morakot occurred in a dry monsoon season
2. Long duration and record-breaking rainfall (> 3 m)
3. Weakening steering flow; small translation speed; long influencing time (> 64 hours)
4. Asymmetric precipitation structure embedded in large-scale convection zone
5. Coexistence of southwesterly monsoon and typhoon
6. Continuous formation of outer rainbands
7. Mountain lifting effect

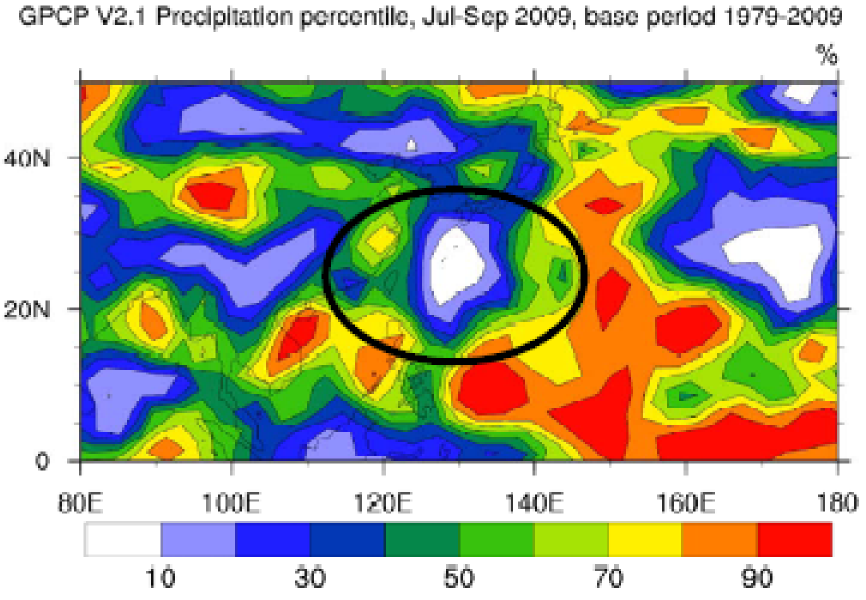
SST and Precipitation

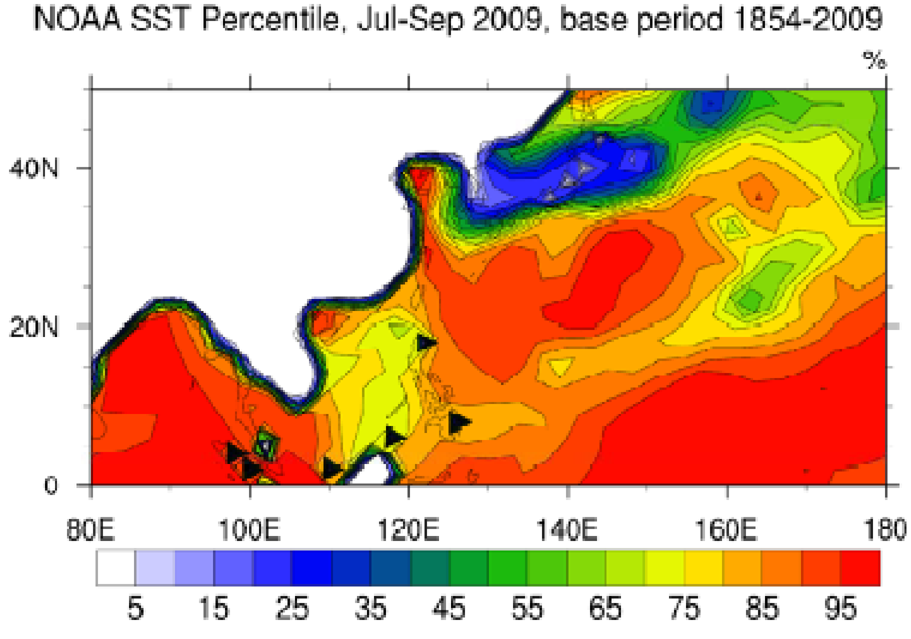
How anomalous was the 2009 typhoon season?

- **humid, high SST > PR95**
- **but less precipitation < PR10**

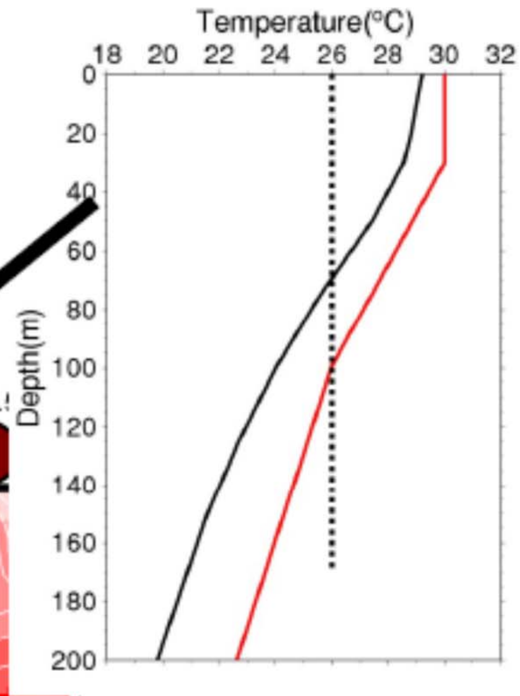
C.-H. Wong

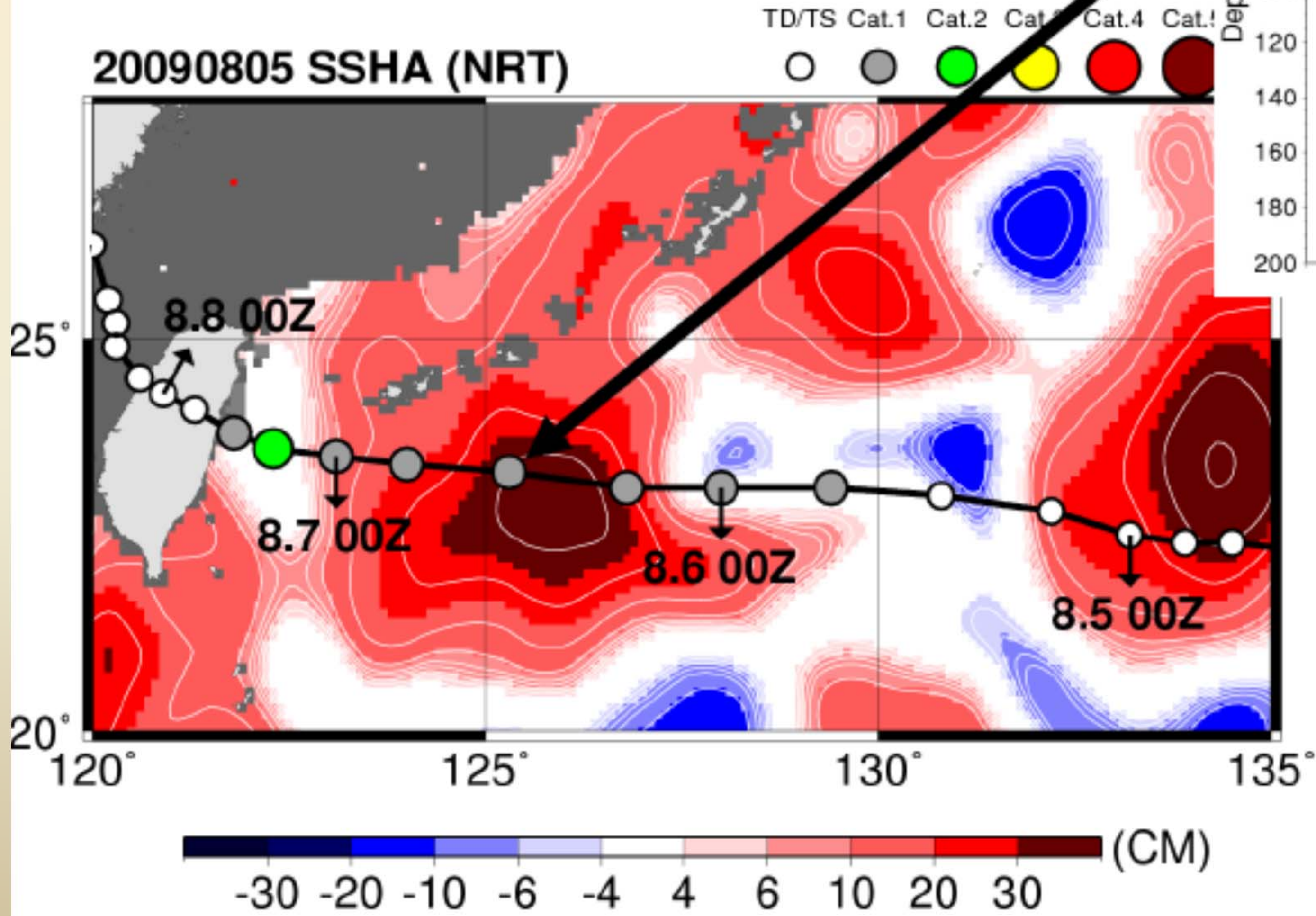






Warm eddy provides favourable pre-condition for precipitation development before landfall

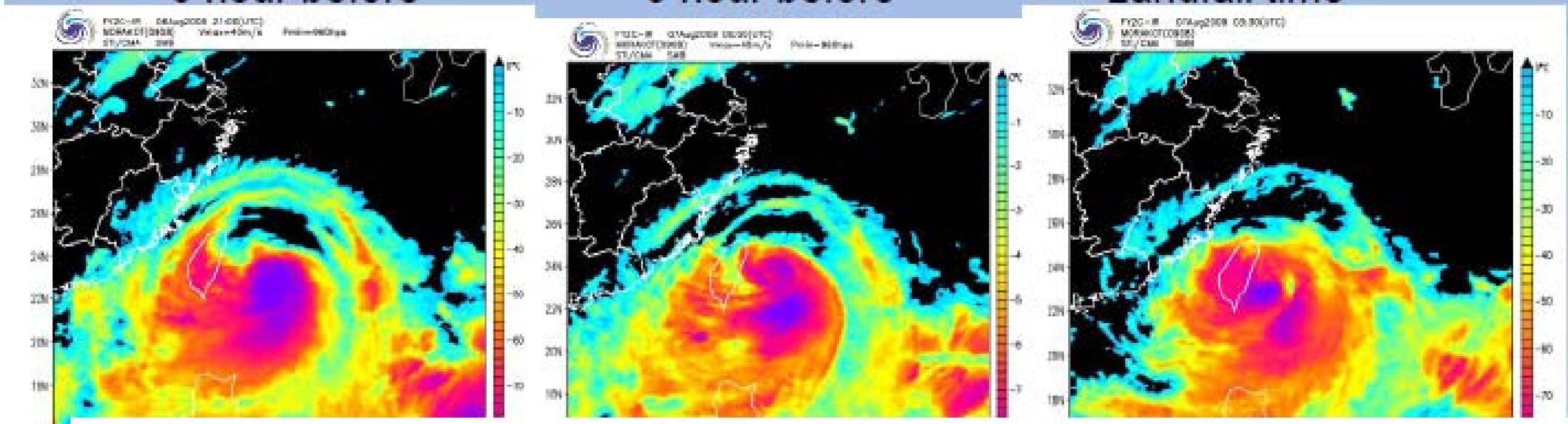




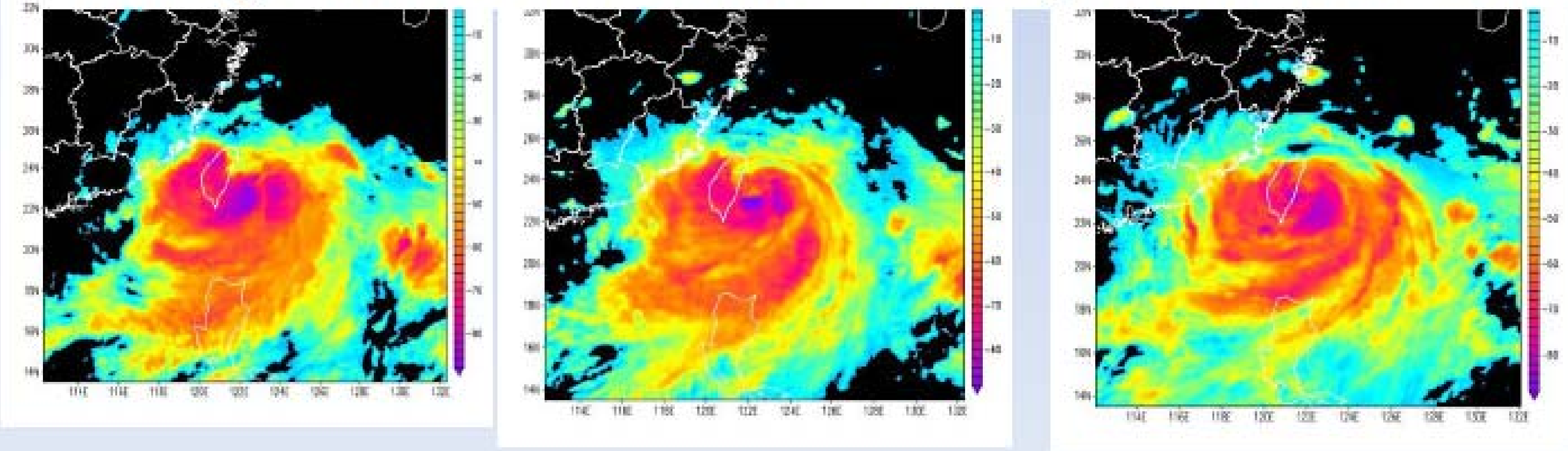
I.-I. Lin

Structure of Morakot while landfalling Taiwan

-6 hour before | -3 hour before | Landfall time

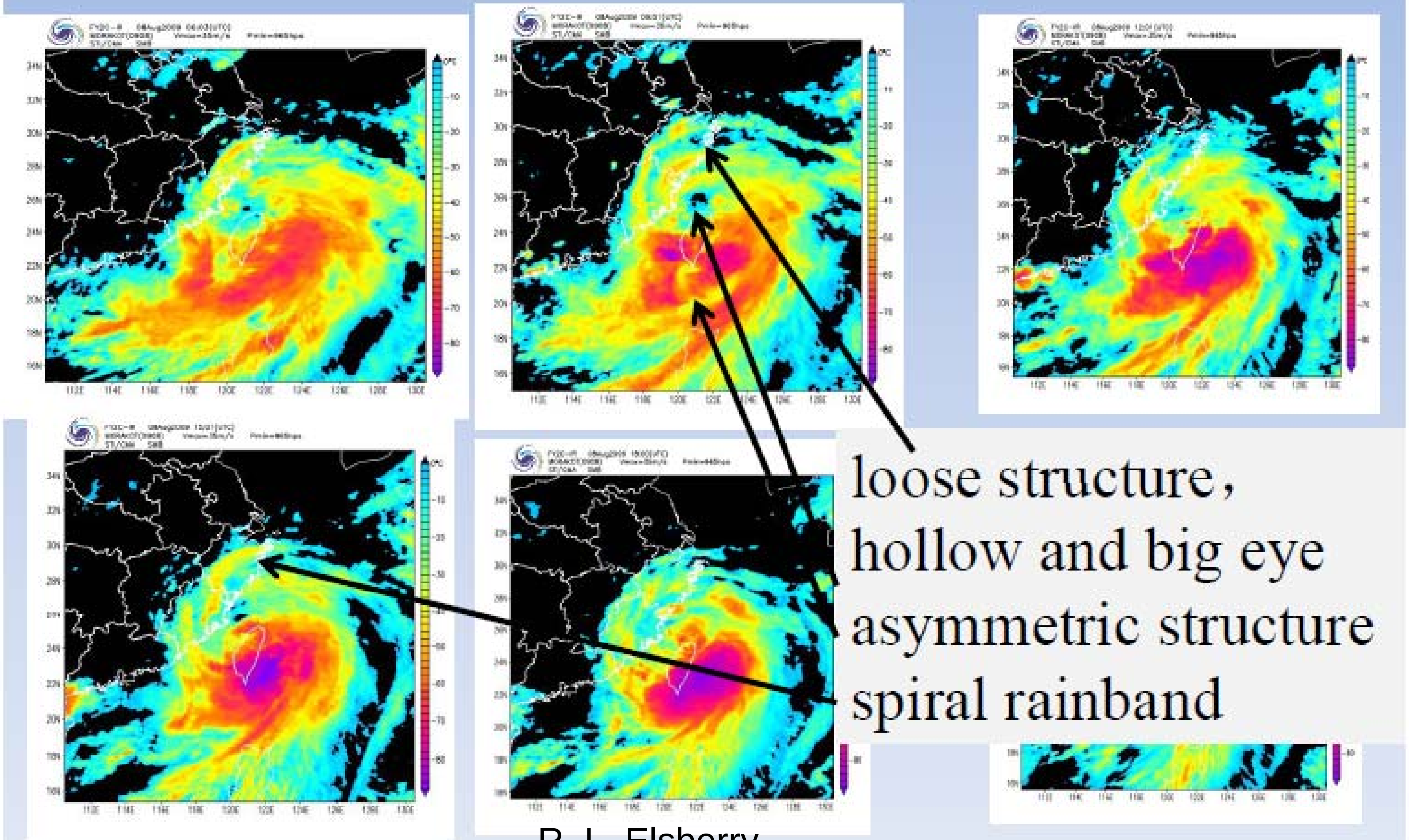


Asymmetric structure,
strong convective in the south part of Morakot



R. L. Elsberry

Structure of Morakot in the Taiwan strait

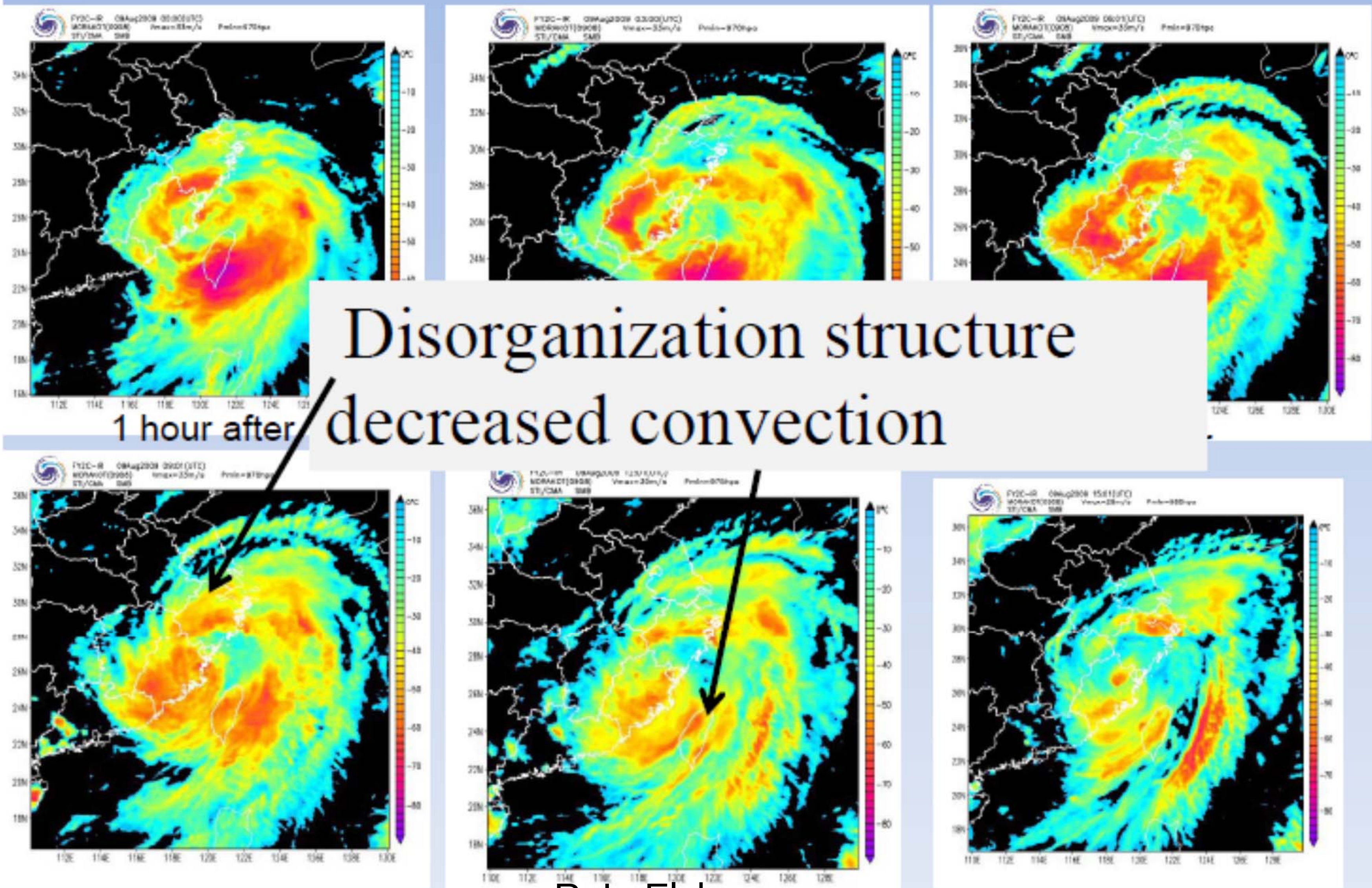


R. L. Elsberry

Structure of Morakot while landfalling China mainland

-8 hour before | -6 hour before | 2 hour before

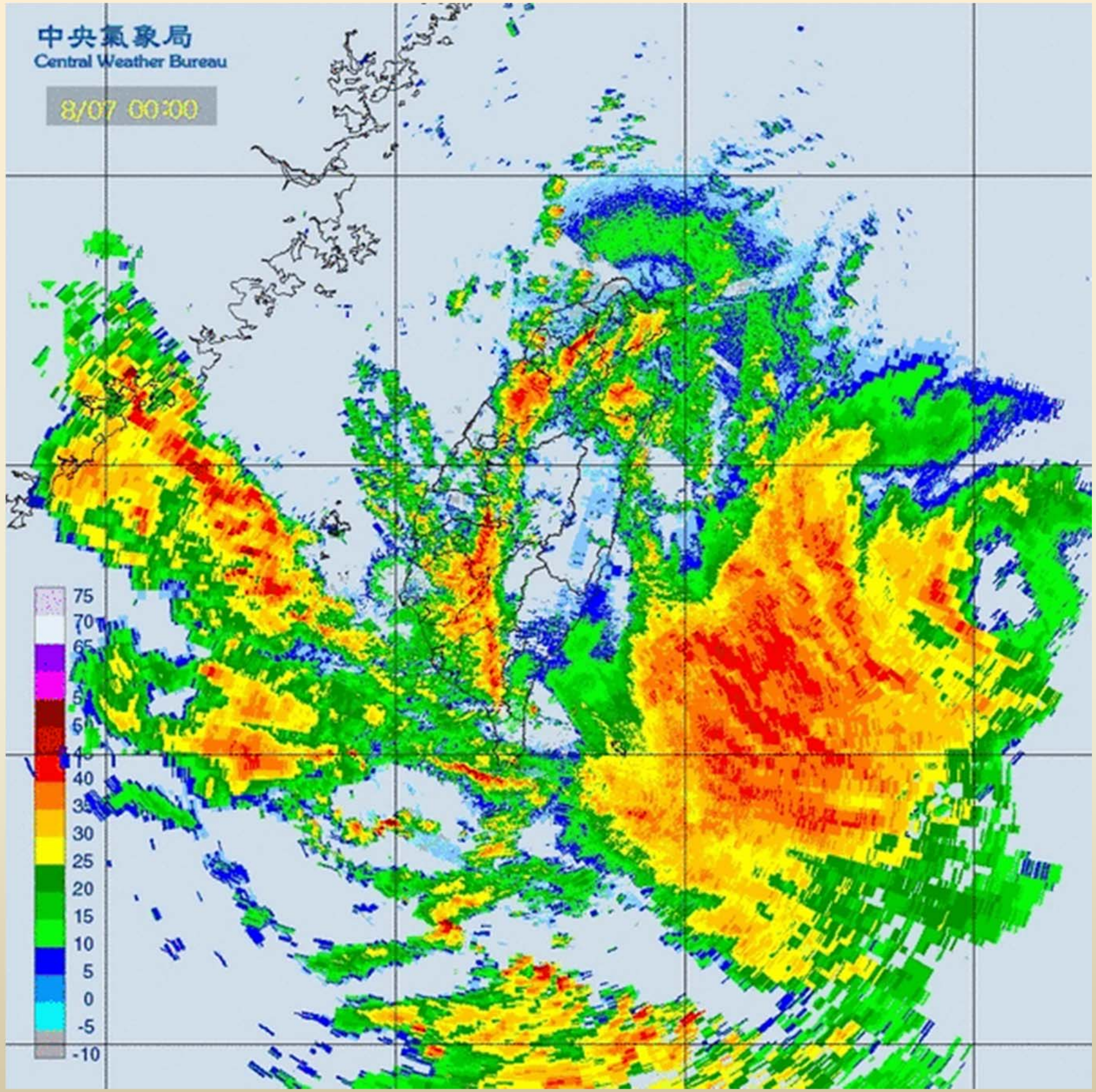
1 hour after



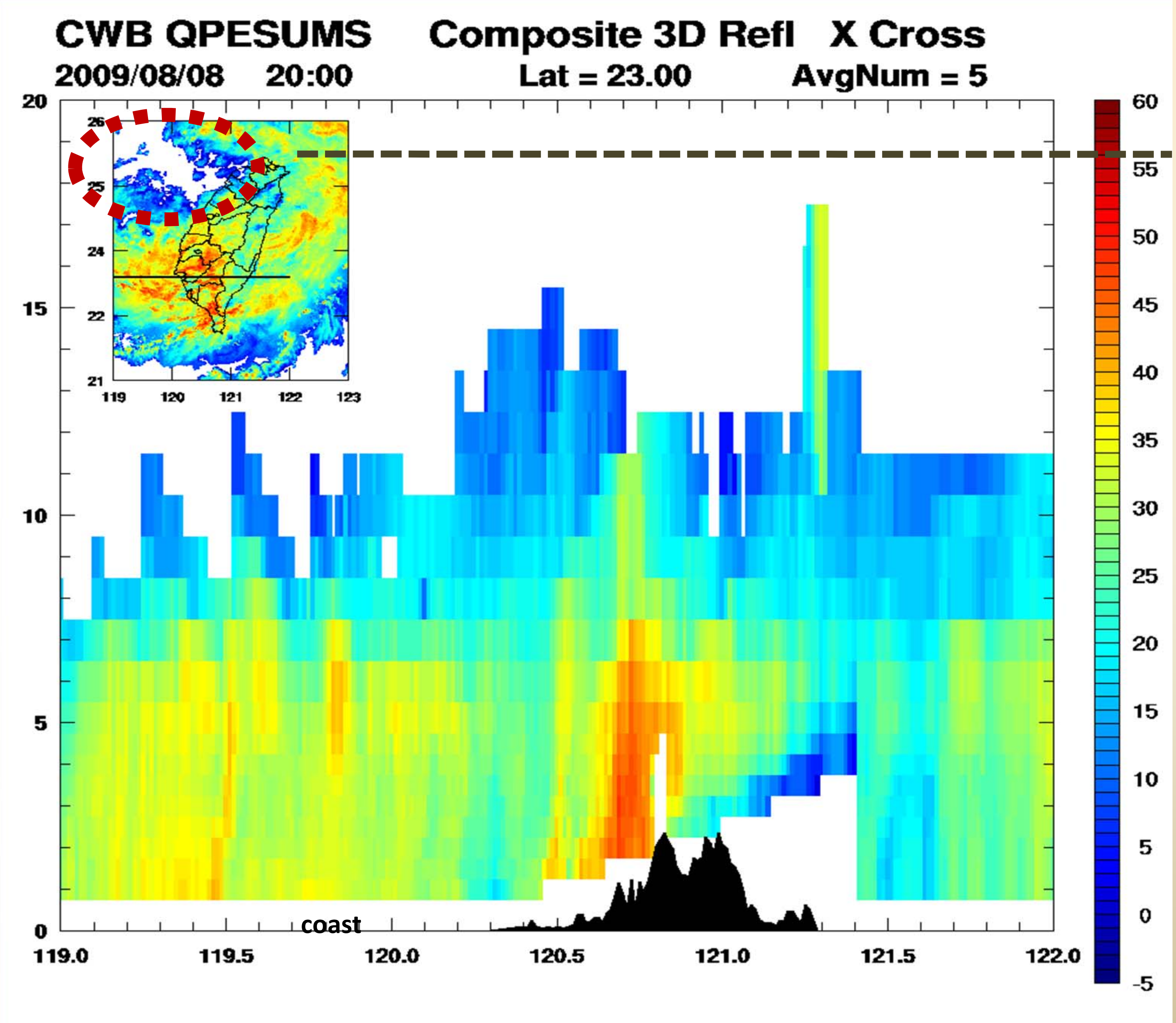
Disorganization structure
decreased convection

R. L. Elsberry

Radar Reflectivity Loop of Morakot (2009)



Continuous formation of the outer rainbands over the Taiwan Strait



Ben Jou

65kt

Typhoon Morakot (2009)

before

after

http://daveslandslideblog.blogspot.com/

More than 100 houses affected

Over all in Taiwan: Life losses close to 700.

Morakot

- 614 deaths confirmed, 92 still reported as missing.
- More than 1.6 million people evacuated.
- Direct economic loss estimated at US$ 5.3 billion.

(UN OCHA report) (over Taiwan and mainland China)

http://itasa2010.files.wordpress.com/2009/08/typhoon_morakot.jpg

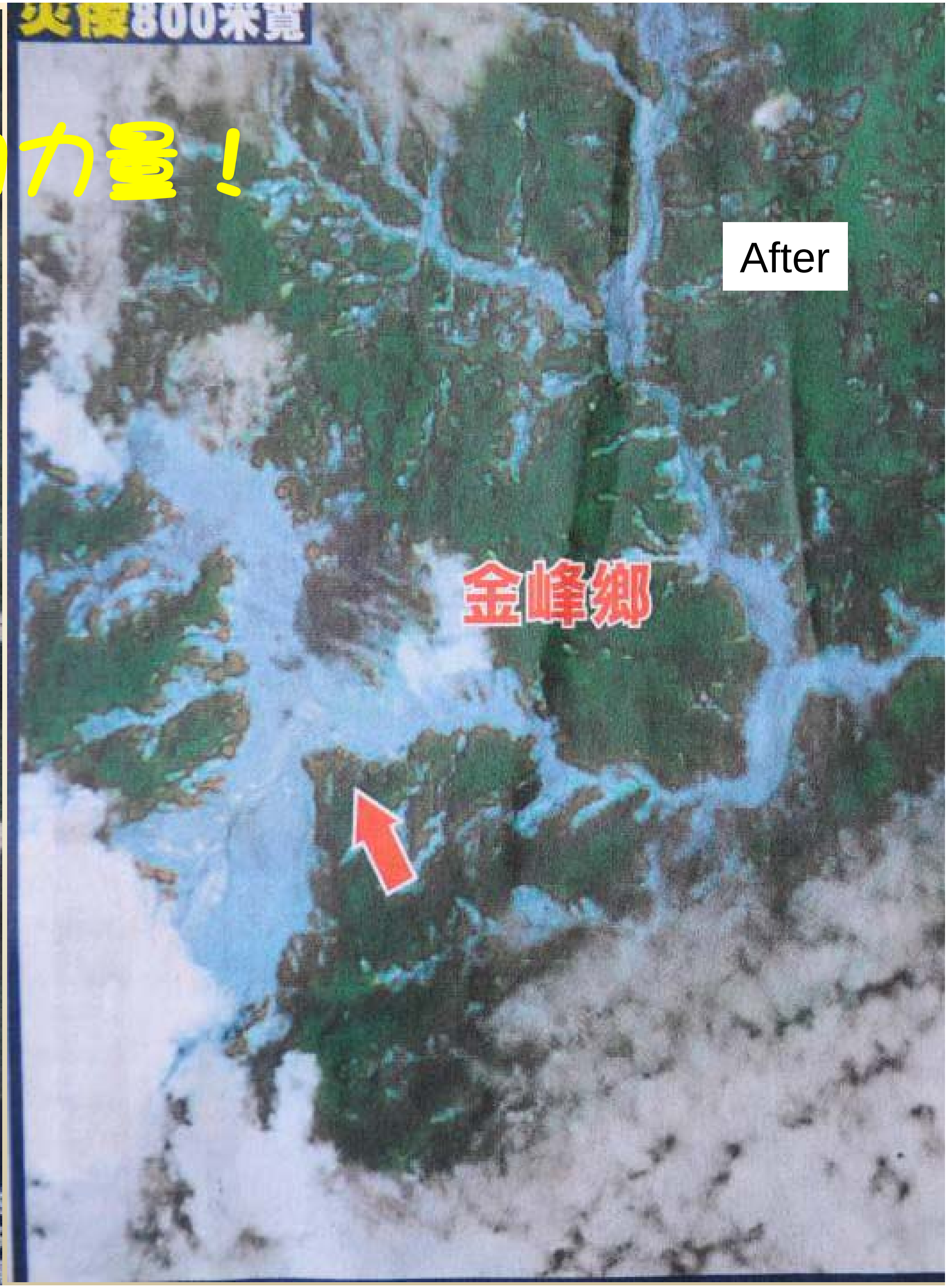



HOTEL

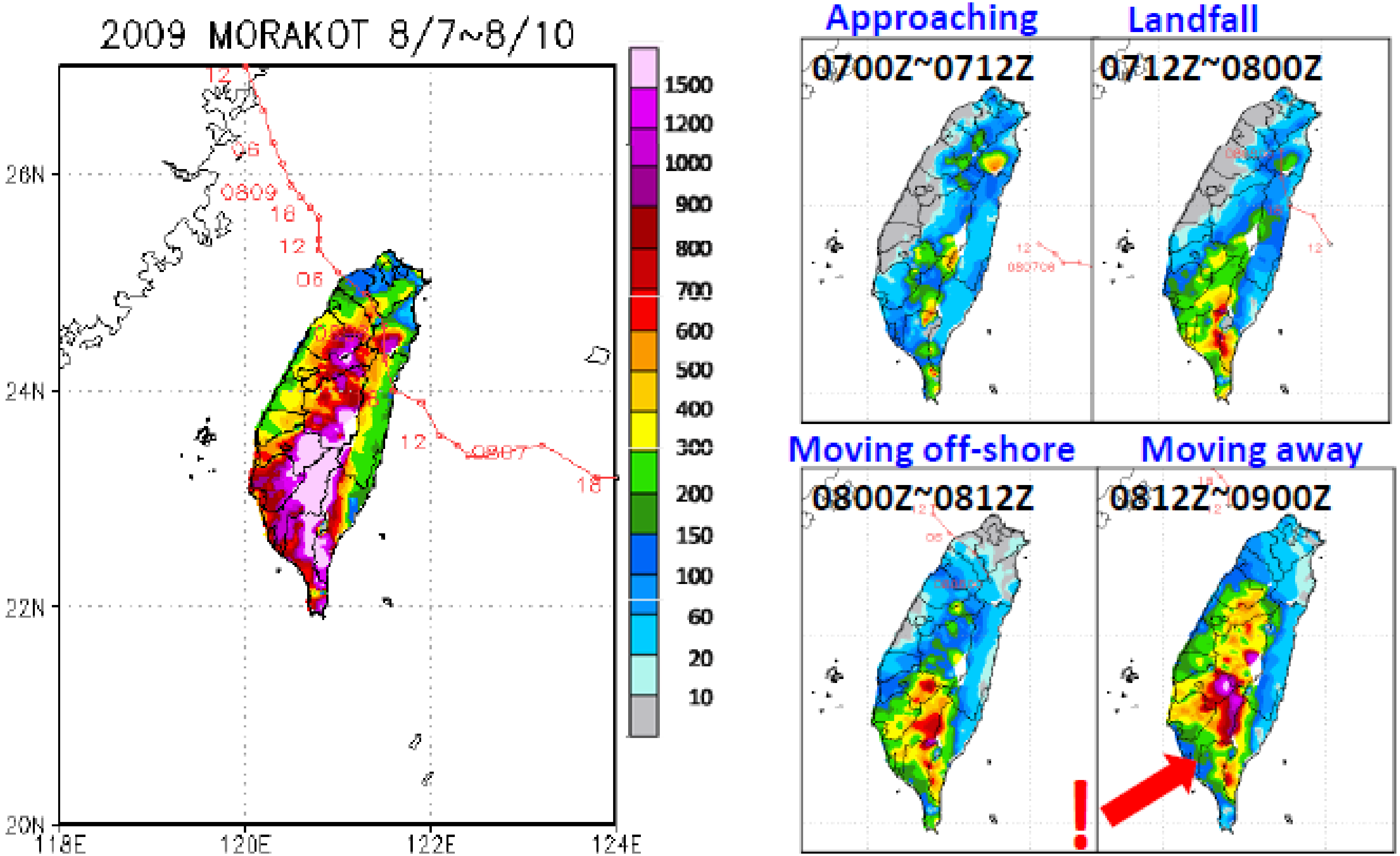

千萬別小看大自然的力量！

Before

After



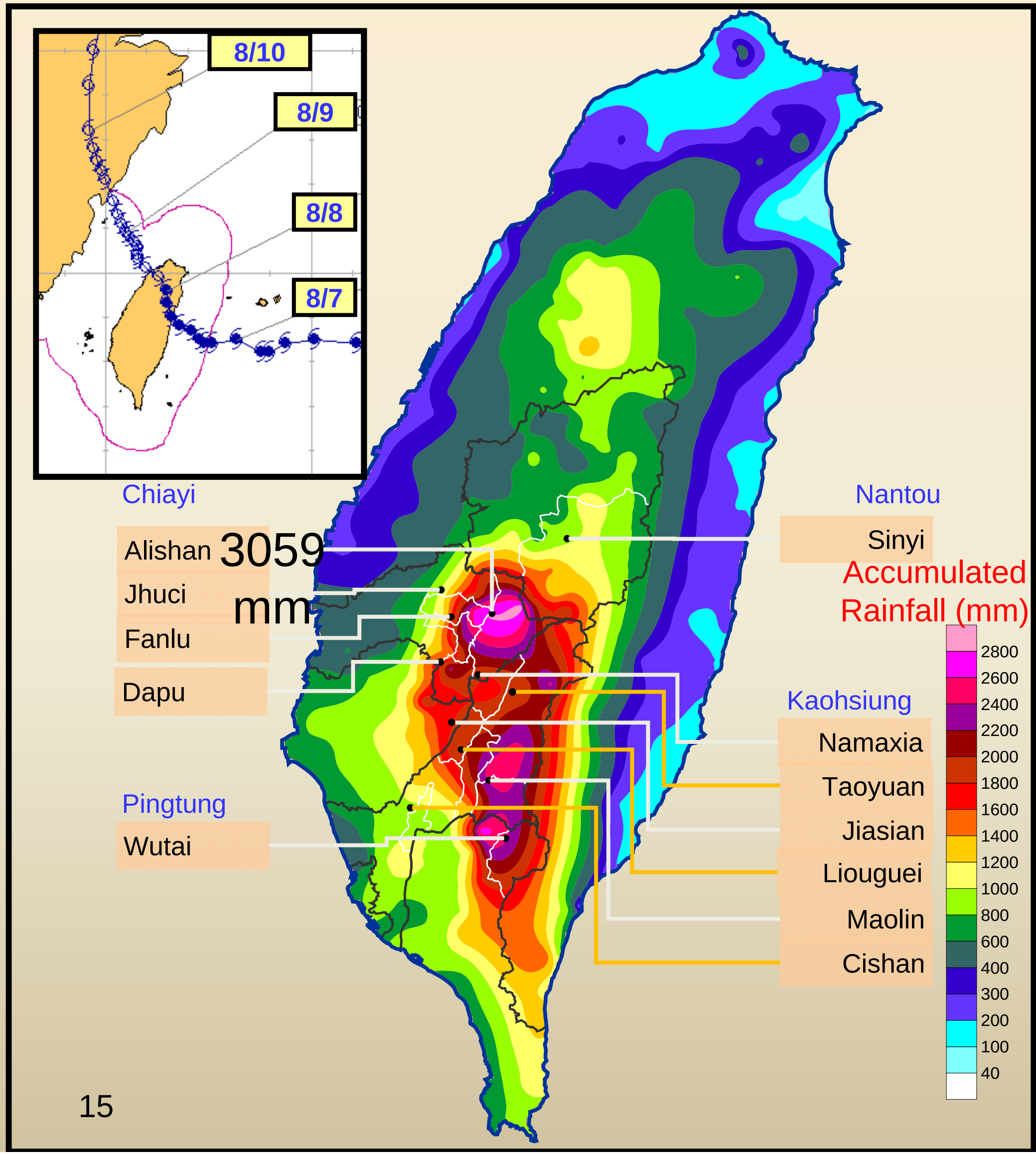
Rainfall during the Morakot period



Heaviest rainfall occurred when Morakot was leaving Taiwan.

C.-S. Lee

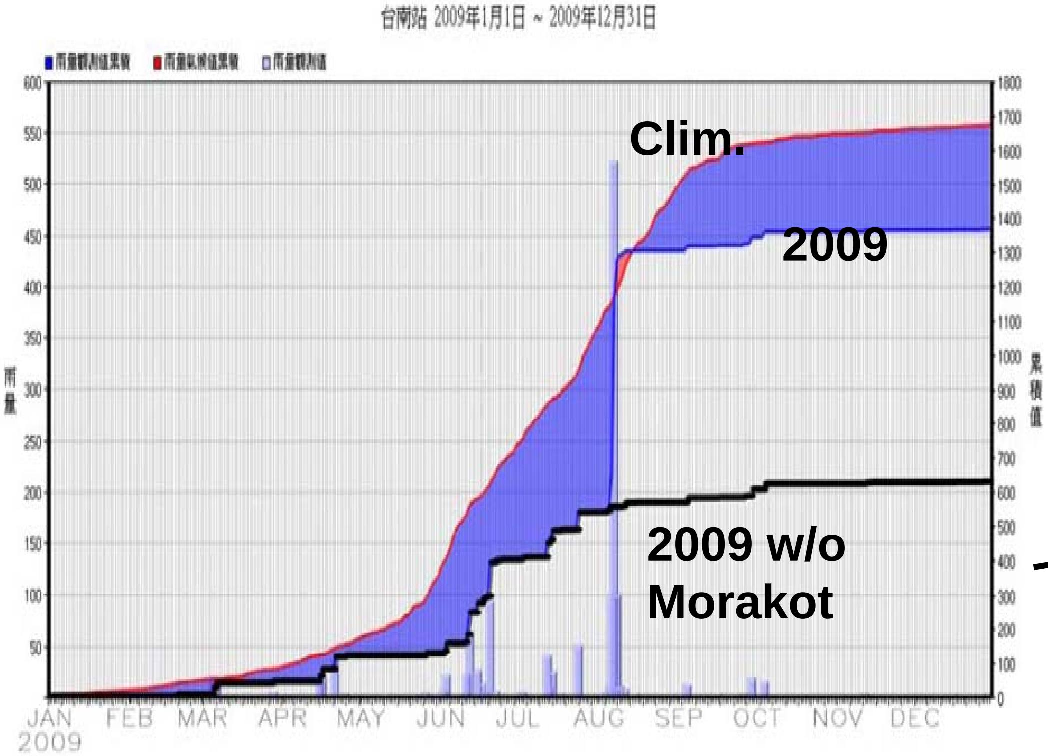
Long duration
Record-breaking rainfall

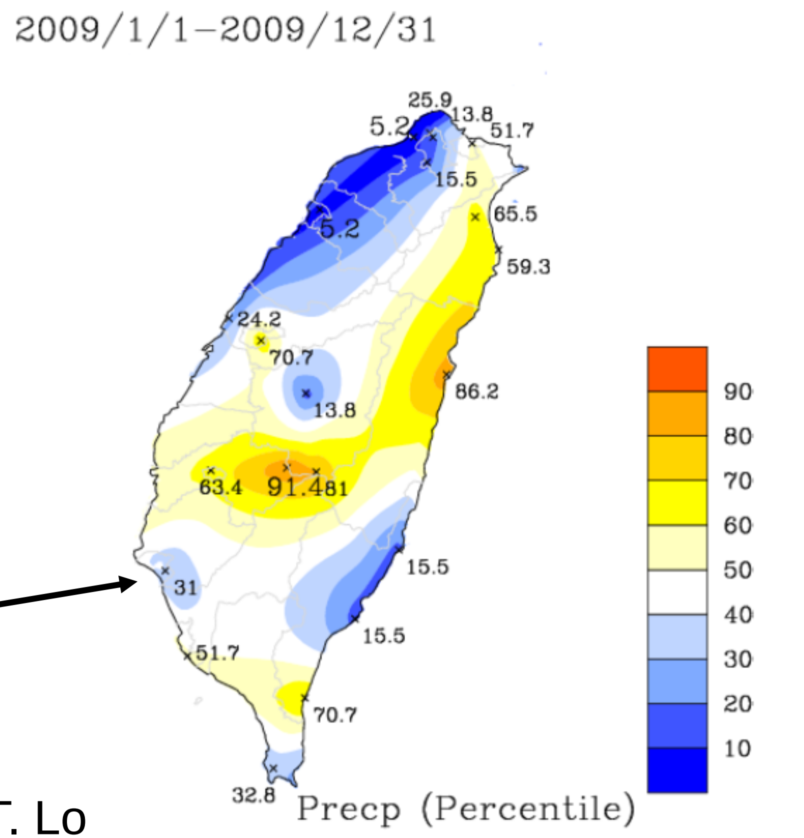


CWB

Even with the record-breaking rainfall, 2009 annual rainfall is still below average

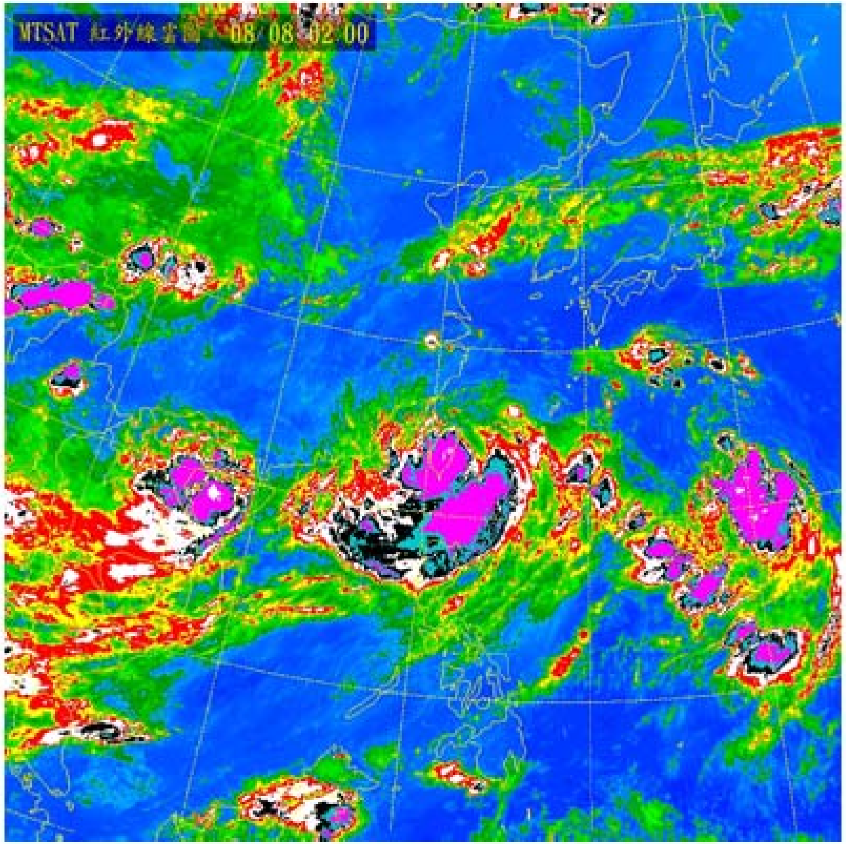
Tainan

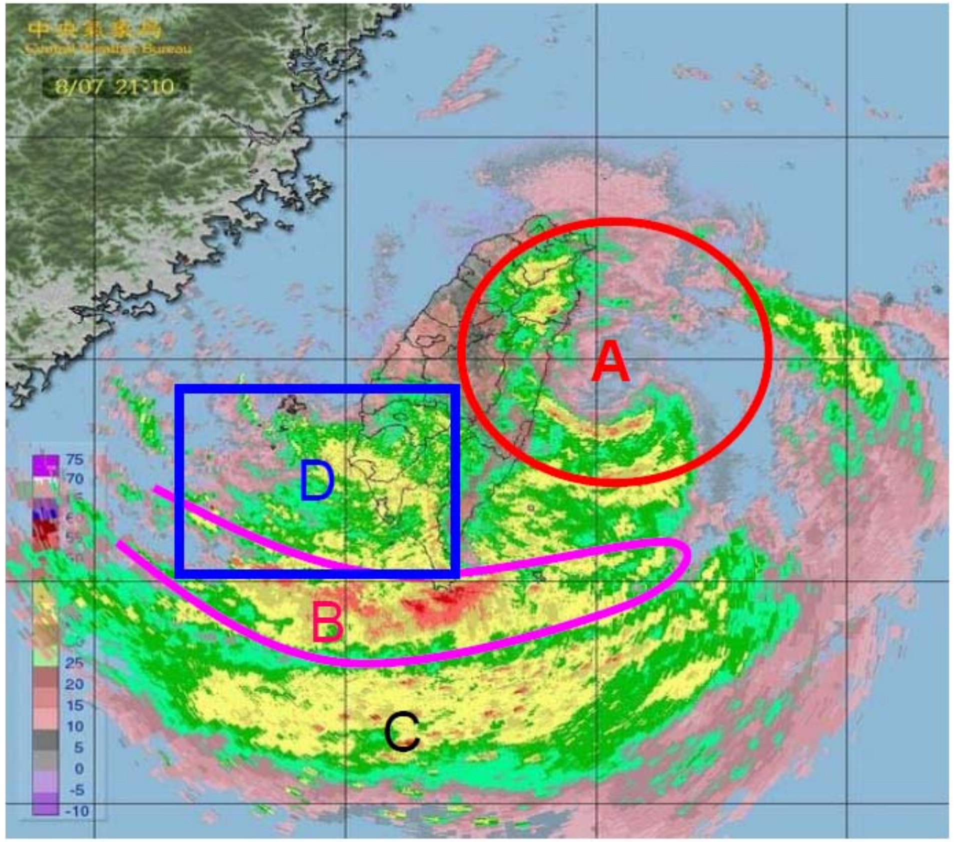




T.-T. Lo

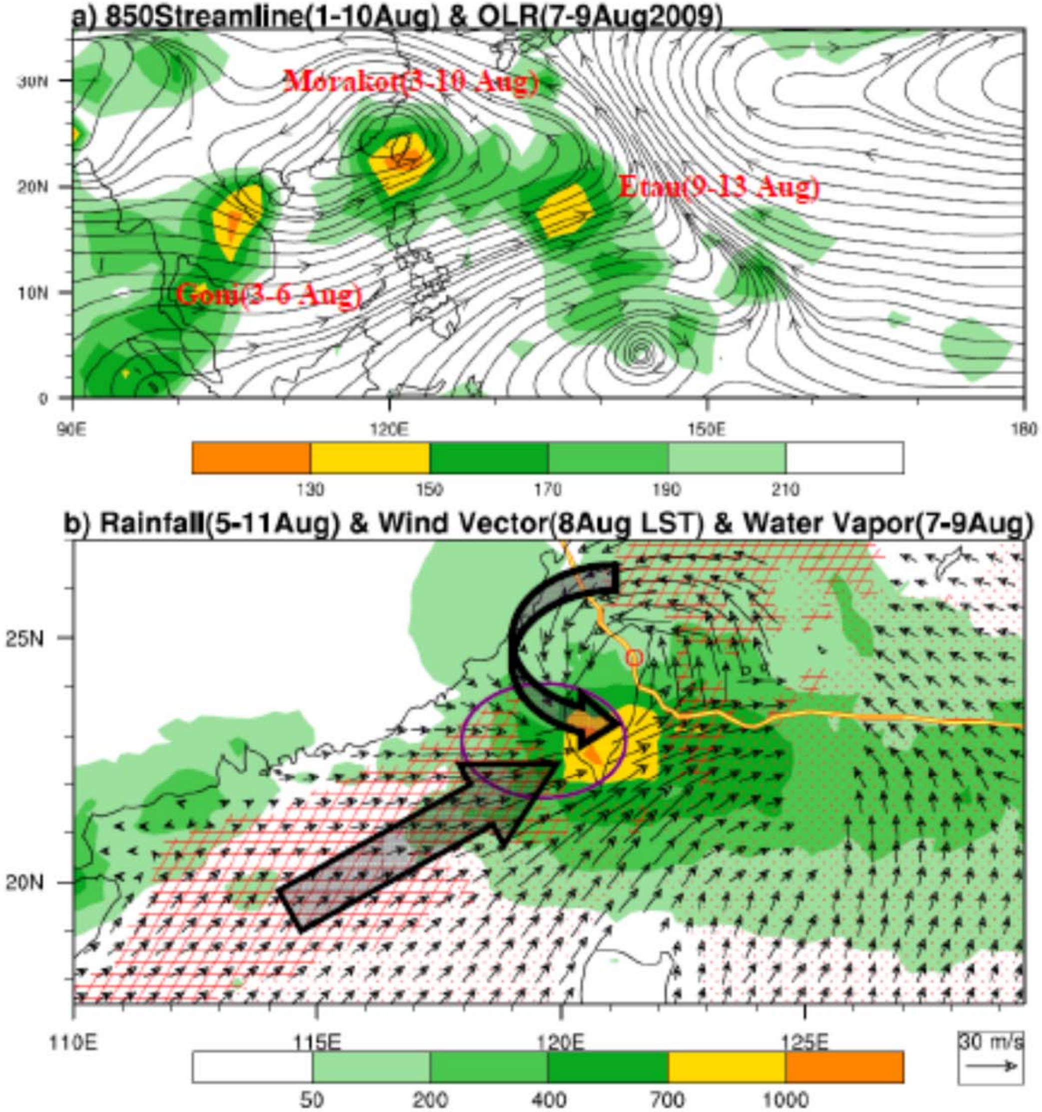
Asymmetric structure embedded with Large-scale convection zone



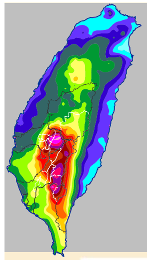


T.-C. Chen

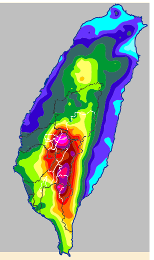
Typhoon Goni, Morakot, and Etau in a Monsoon Gyre, Moist Southwesterly

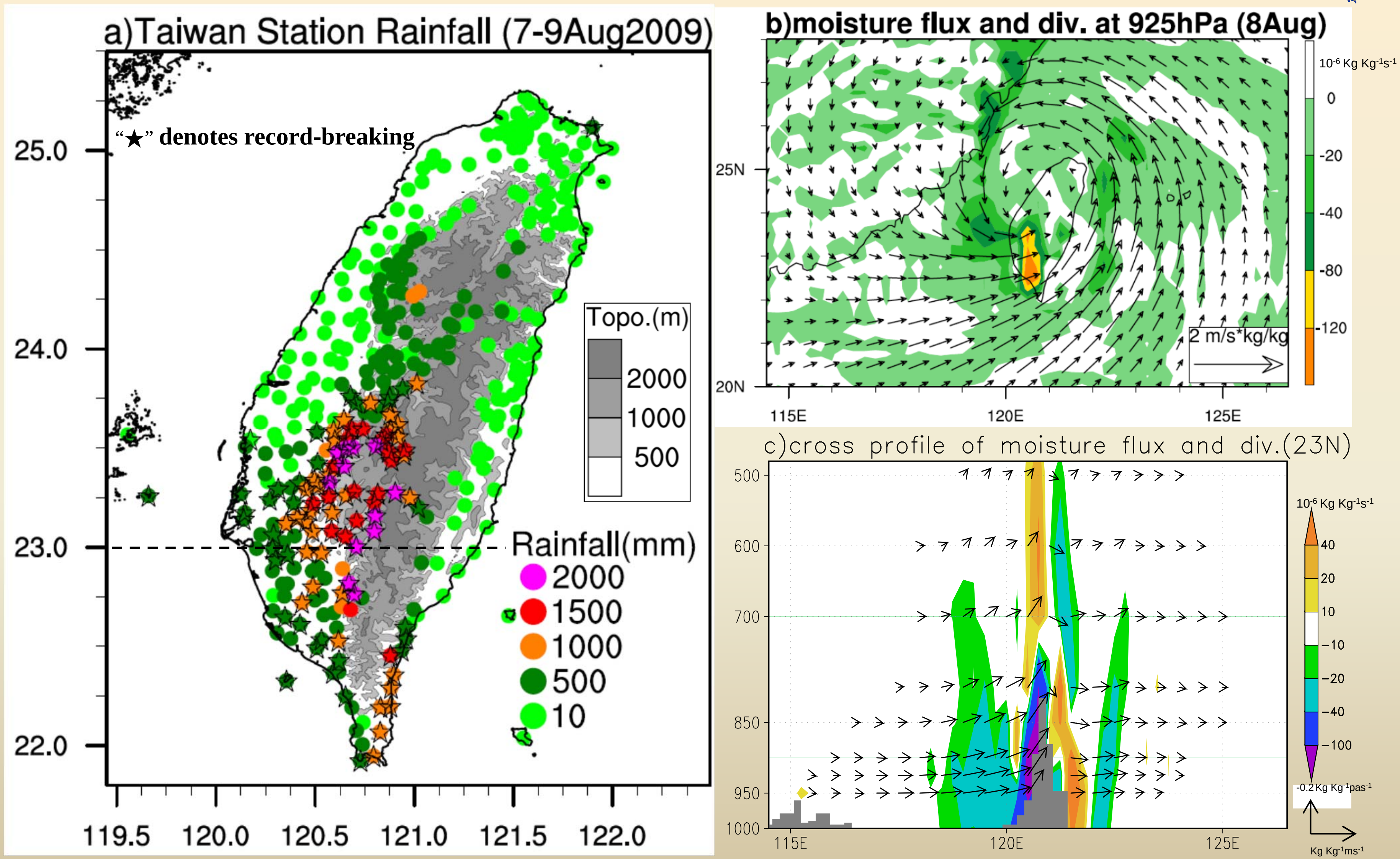


Hong et al., 2010:
Accepted by
Geophys. Res. Lett.



Convergence between the NW-ly typhoon flow and SW-ly monsoon flow
Monsoon & Terrain Effect





H.-H. Hsu

Multiscale: 40-50 day ISO
10-30 day perturbation, and typhoon

2009/7/20~2009/8/18 850hPa UV (vector) & q (shaded)

Wavelet analysis

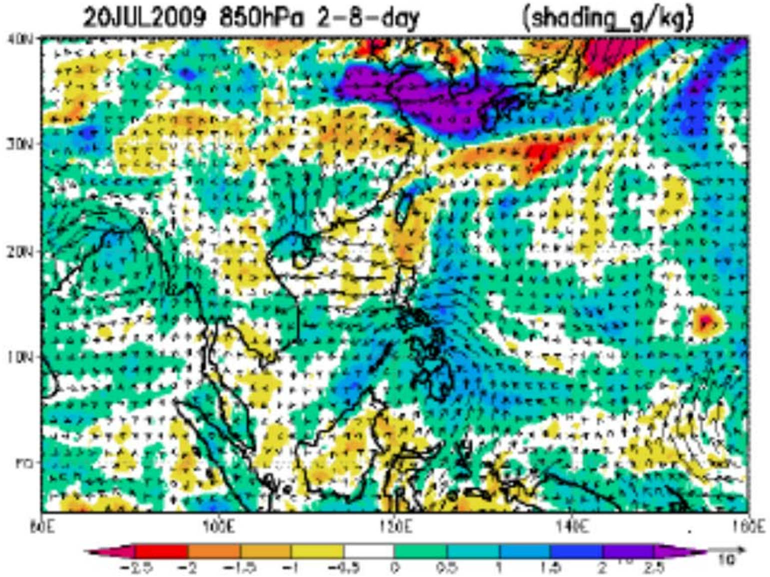
2-8 days → TC

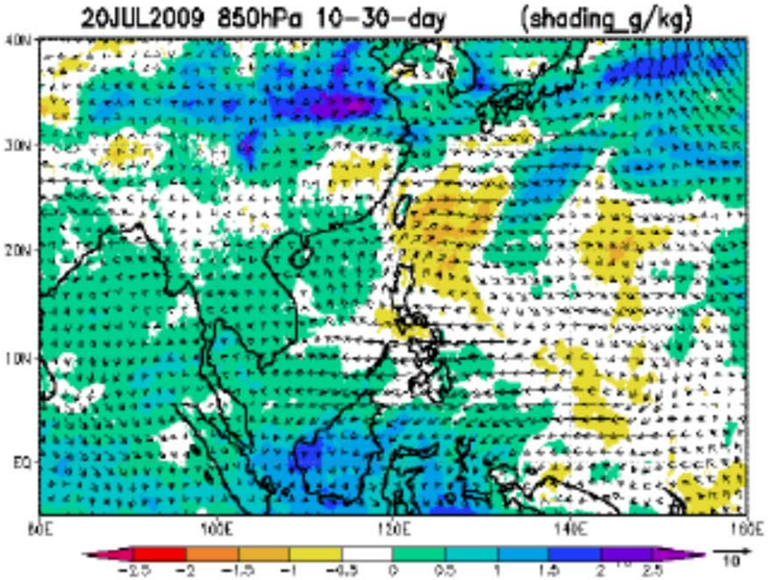
10-30 days → submonthly wave

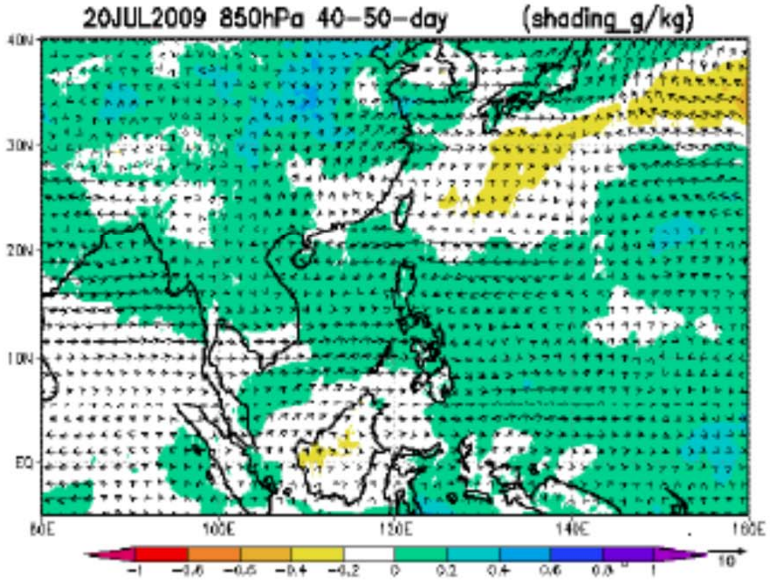
40-50 days → ISO

- **10-30 days : contributes the largest amount of moisture**

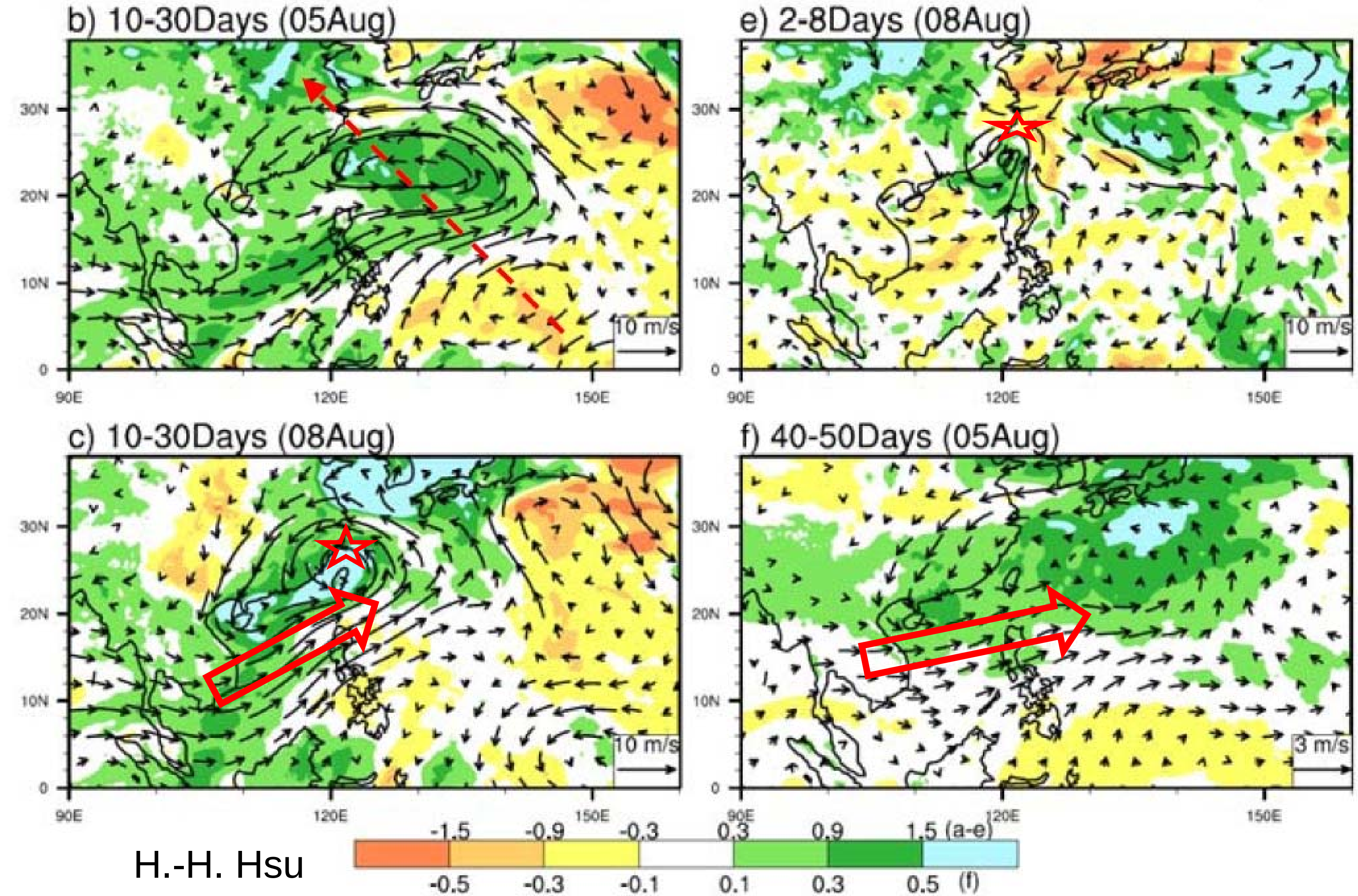
Hong et al. 2010







40-50 day ISO provides water vapor channel from the Indian Ocean/South China Sea, transporting moisture into Typhoon Morakot



H.-H. Hsu

Background Summary

- Morakot's landfall on Taiwan occurred concurrently with the southwesterly monsoonal flow, very slow TC movement and the continuous formation of mesoscale convection. (Chien and Kuo 2011; JGR)
- The terrain of Taiwan strongly determines the Morridakot rainfall distribution at the time of landfall. (Fang et al. 2011 in WAF; Huang et al. 2011 and Yen et al. 2011 in TAO)
- PE (Precipitation Efficiency) was used to predict rainfall from grid-scale vapor convergence in operational model forecasts (Doswell et al. 1996; Auer and Marwitz 1968; Heymsfield and Schotz 1985; Chong and Hauser 1989; Li et al. 2002a; Tao et al. 2004; Sui et al. 2005).
- Yang et al. (2011; MWR) investigates the evolution of the water vapor, cloud, and precipitation budgets of Nari (2001) prio to and after landfall on Taiwan.
- The water budget study may help us to understand the basic physical mechanisms producing the heavy rainfall on Taiwan for Morakot, and improve the microphysical parameterization for TCs in the future.

Budget Equations

[Gamache et al. (1992), Braun (2006), Yang et al. (2011)]

Water vapor budget: q_v

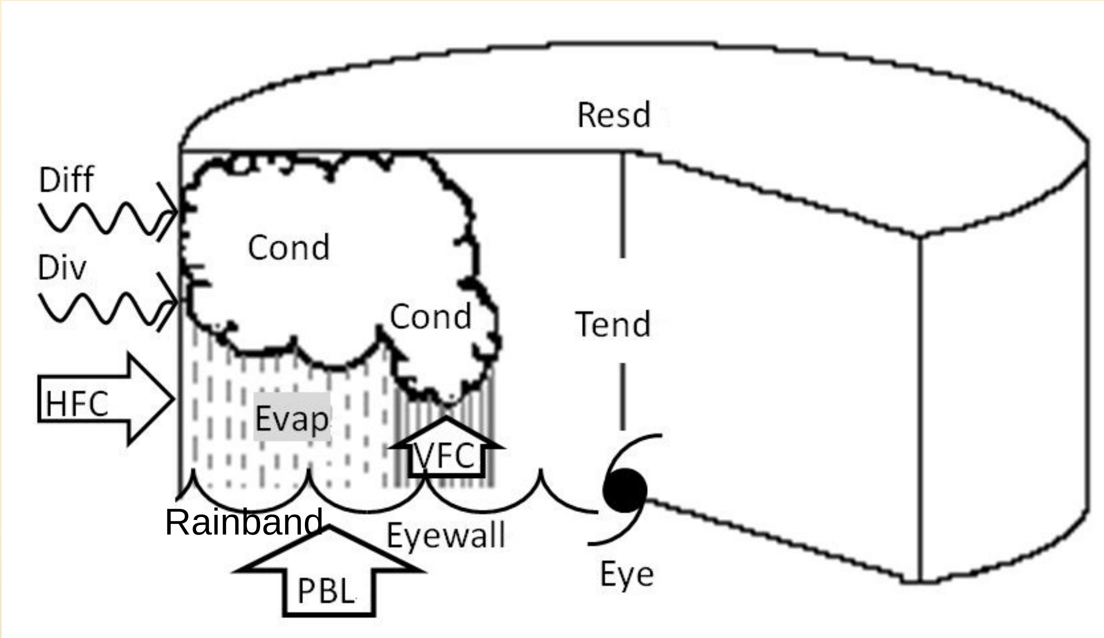
$$\mathrm{Tend} = \mathrm{HFC} + \mathrm{VFC} + \mathrm{Div} + \mathrm{Diff} + \mathrm{Cond_T} + \mathrm{Evap} + \mathrm{PBL} + \mathrm{Resd.}$$

Cloud budget: $q_c = q_w + q_i$

$$\mathrm{Tend} = \mathrm{HFC} + \mathrm{VFC} + \mathrm{Div} + \mathrm{Diff} + \mathrm{P} - \mathrm{Cond_T} - \mathrm{Evap} + \mathrm{PBL} + \mathrm{Resd.}$$

where $\mathrm{Cond_T}$ is the total condensation and deposition;
Evap is the evaporation and sublimation;
HFC is the net horizontal flux convergence;
VFC is the vertical flux convergence;
Div is the divergence term
Diff is the numerical diffusion
PBL is the boundary layer source and vertical (turbulent) diffusion
P is the precipitation flux
Resd is the residual term

Conceptual Model for TC Water Budget

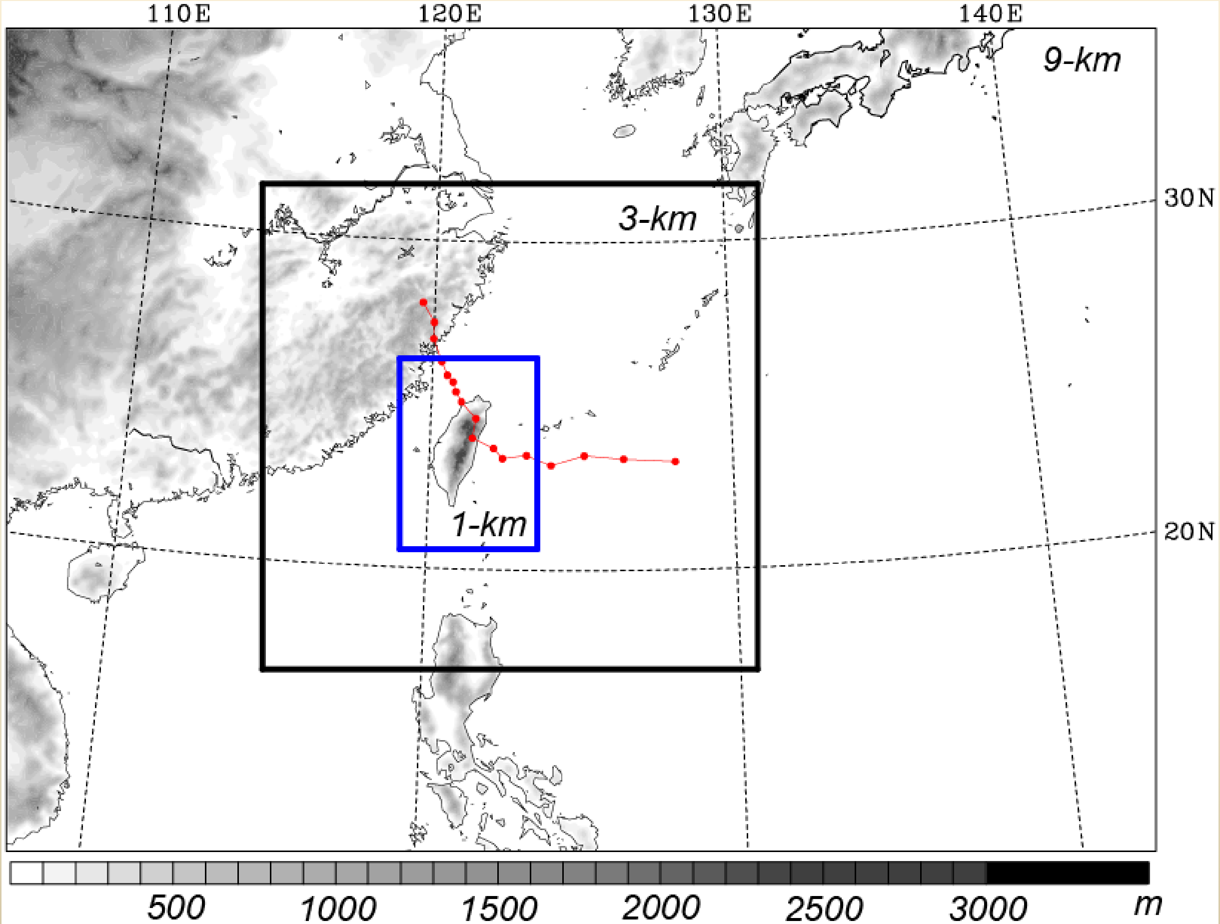


CMPE (Cloud Microphysics Precipitation Efficiency; CMPE2, Sui et al. 2007):

$$PE = P/Cond_T = P/[SI_{qv} + sgn(Q_{CM})Q_{CM}]$$

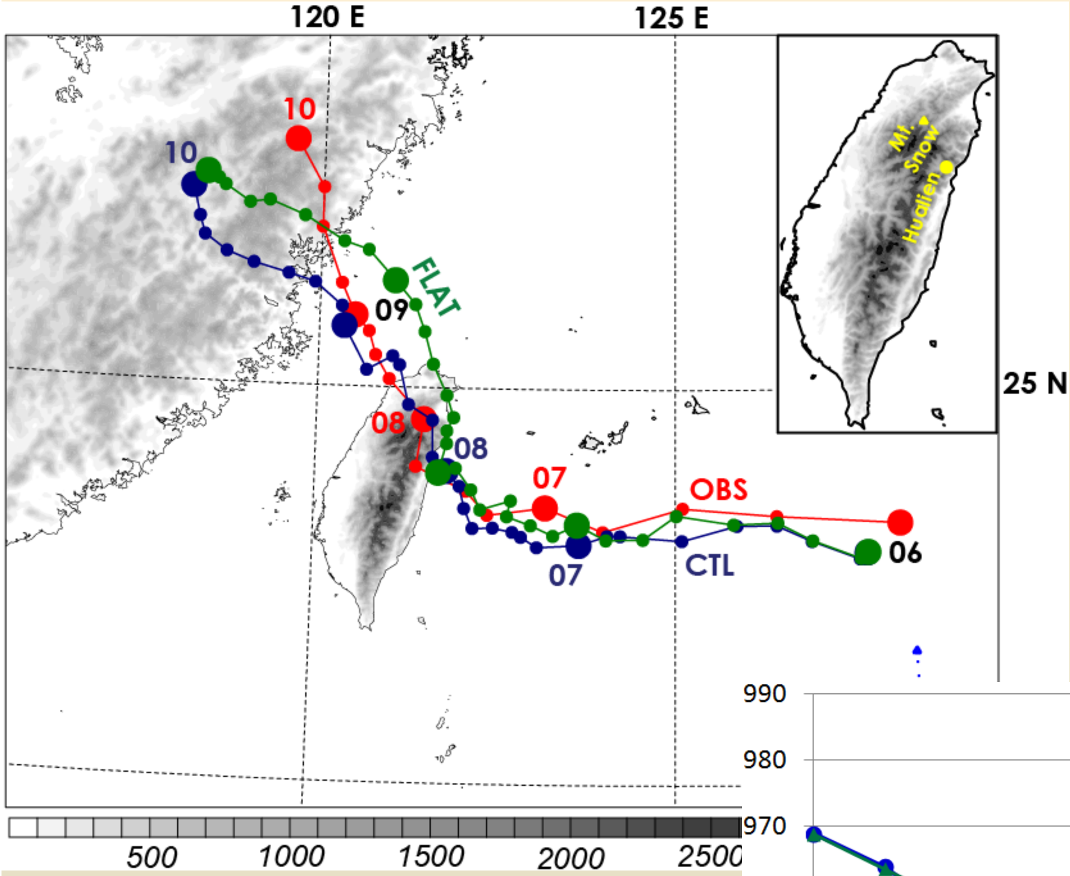
WRF domain and physics for Morakot Simulation

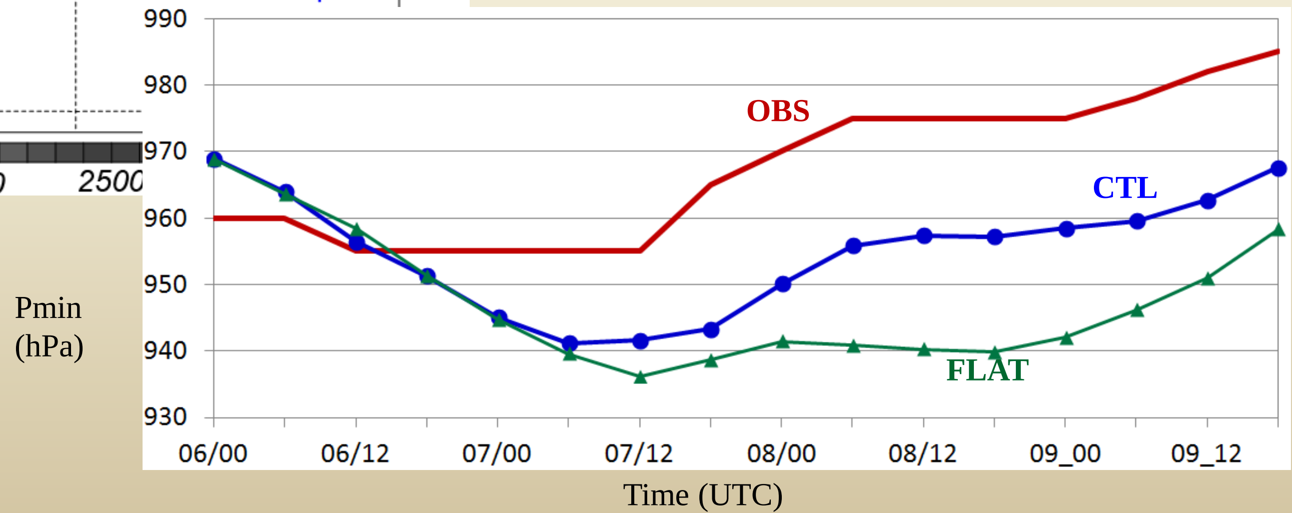
- 9/3/1 km (416x301 / 541x535/ 451x628)



- ✓ 31 sigma (σ) levels
- ✓ Two-way feedbacks
- ✓ **No CPS is used**
- ✓ WRF Single-Moment 6-class scheme (WSM6)
- ✓ YSU PBL scheme
- ✓ IC/BC: ECMWF 1.125^{o} lat/lon
- ✓ Initial time: 0000 UTC, 6 Aug 2009
- ✓ Integration length: 96 h

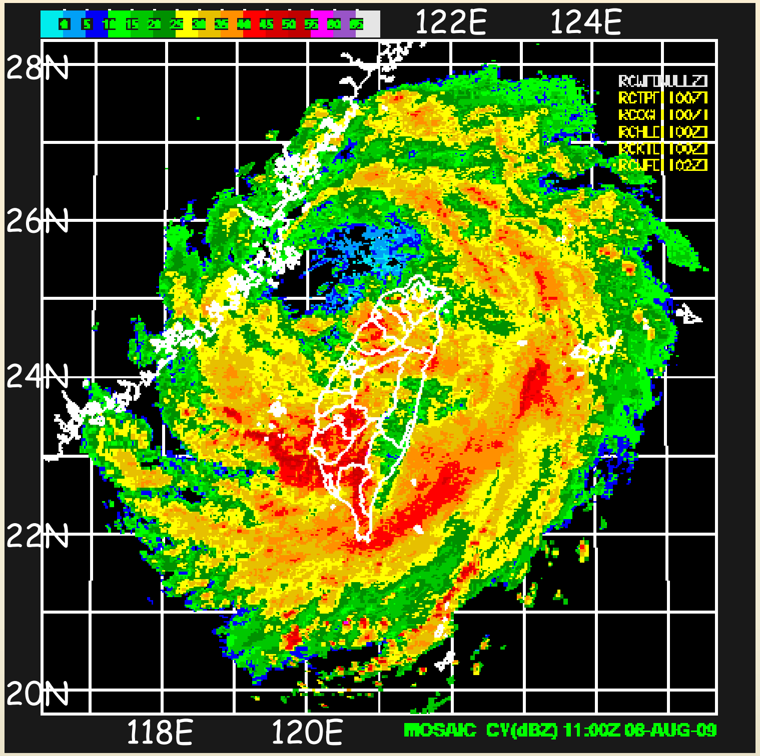
Tracks from the CWB (OBS) and WRF (CTL/FLAT)

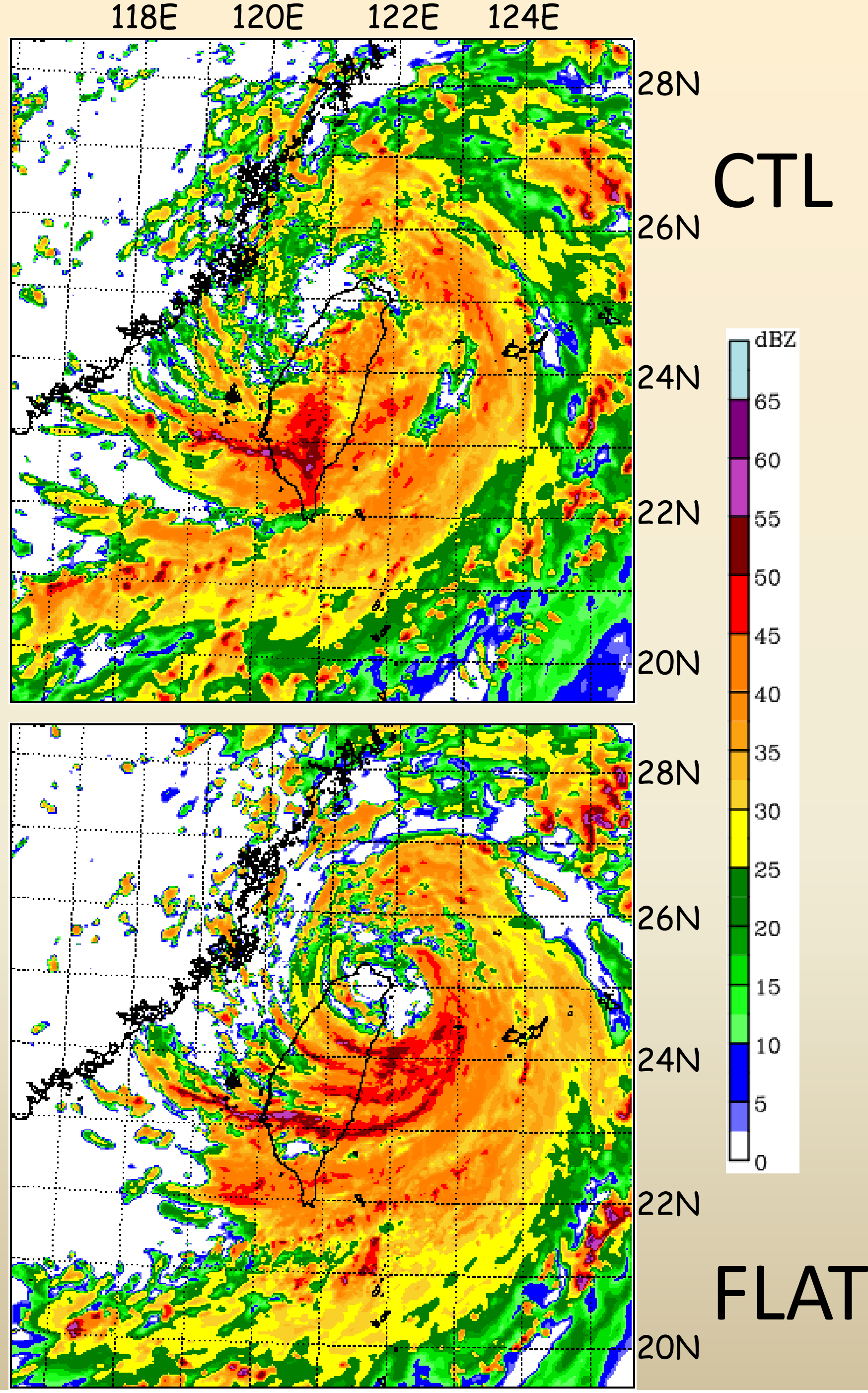




08/08/11 UTC

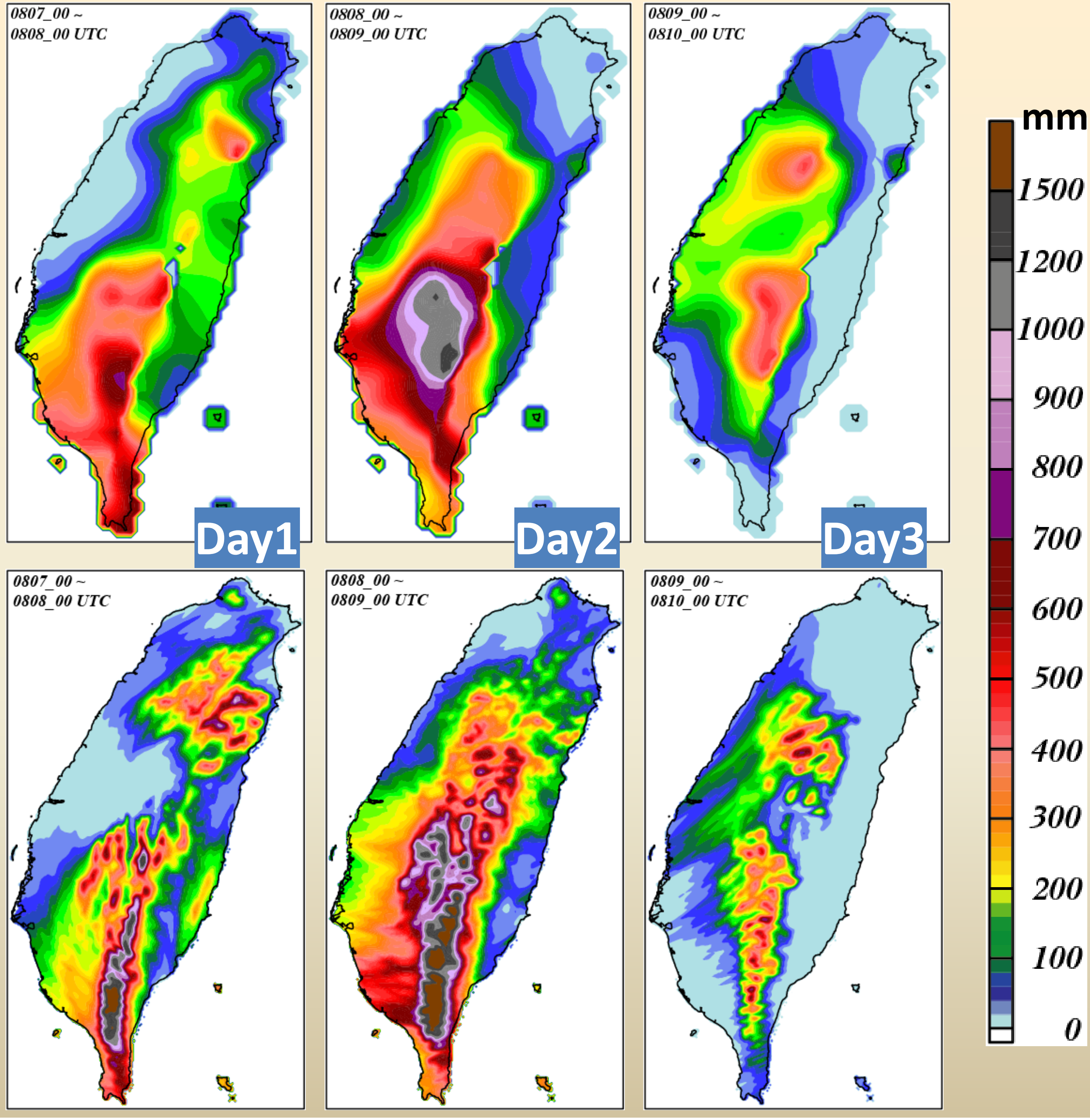
OBS @ CWB





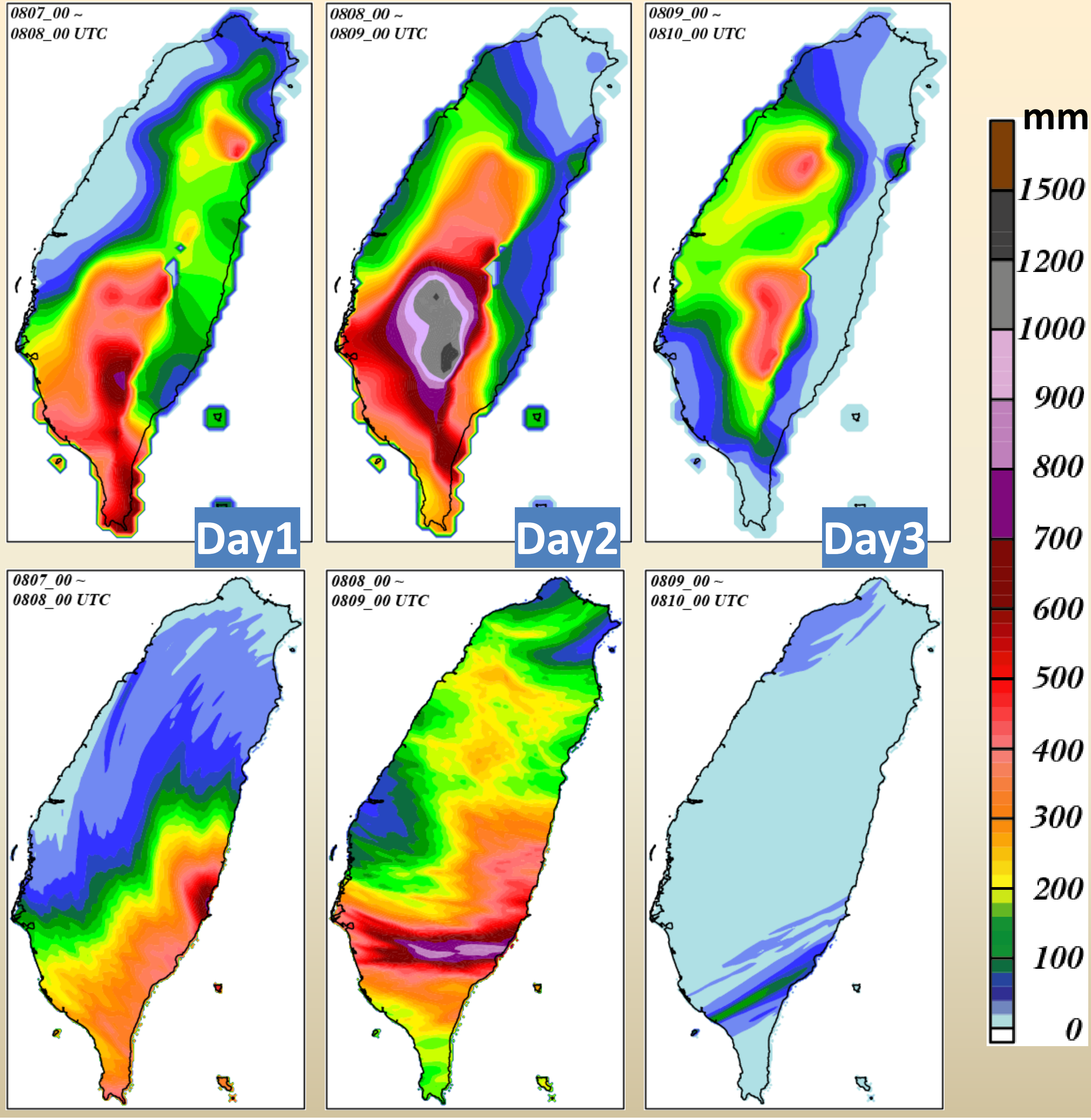
CWB:
OBS

WRF:
CTL

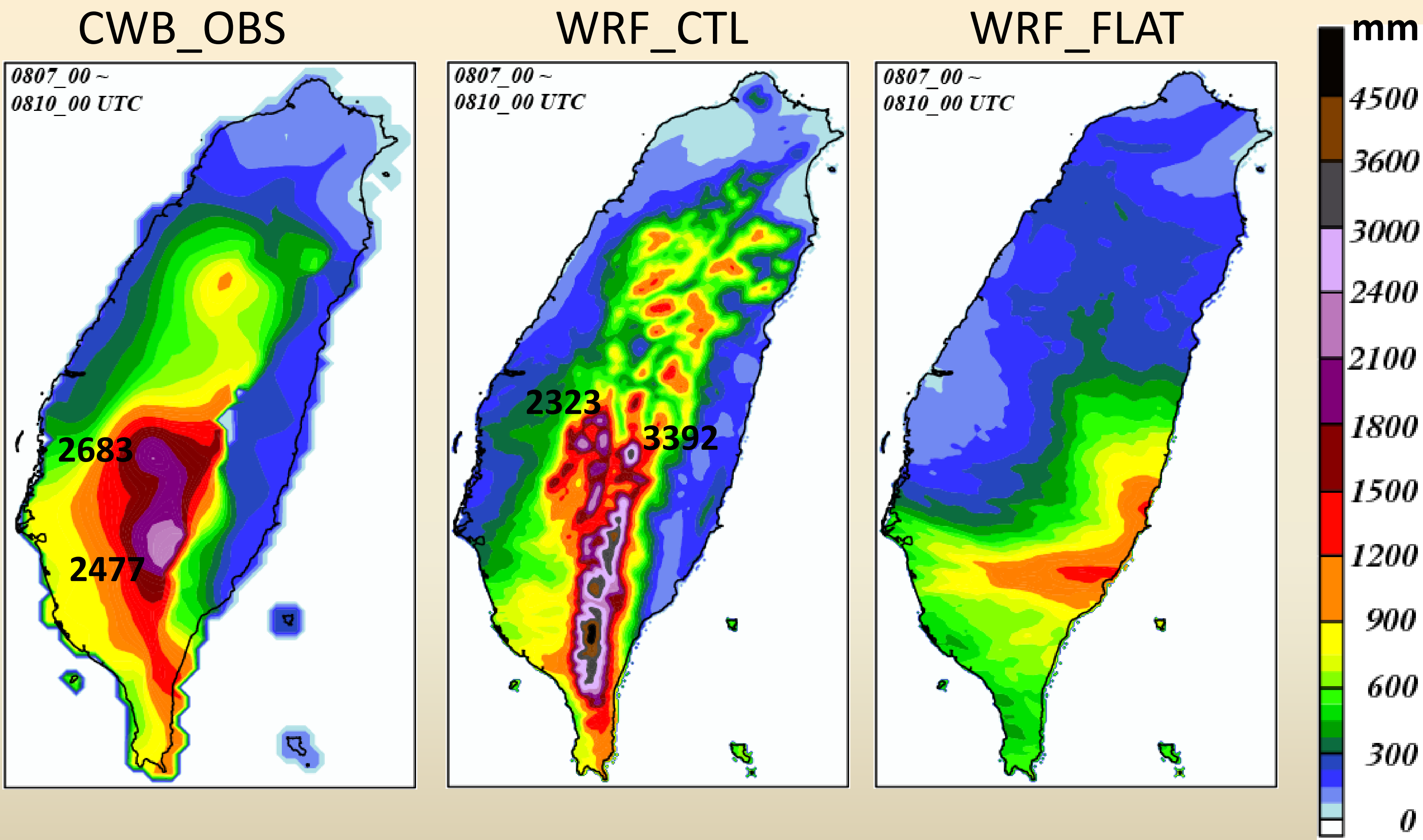


CWB: OBS

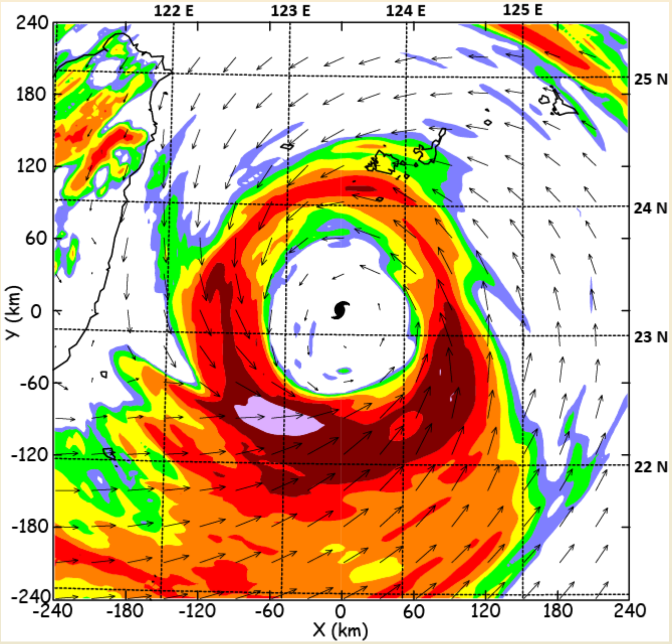
WRF: FLAT

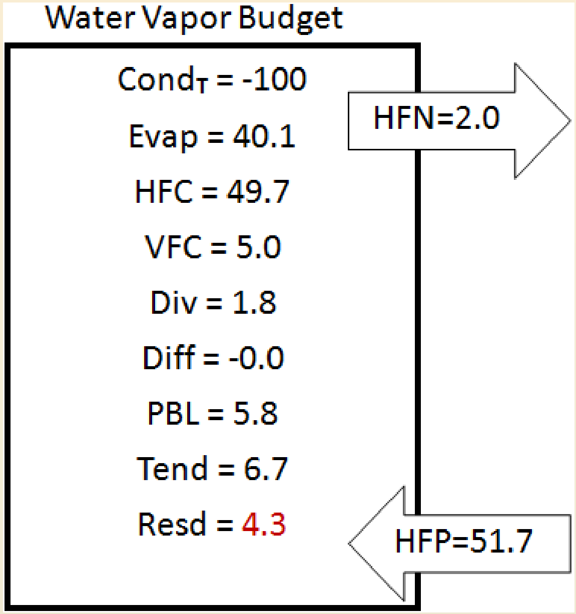


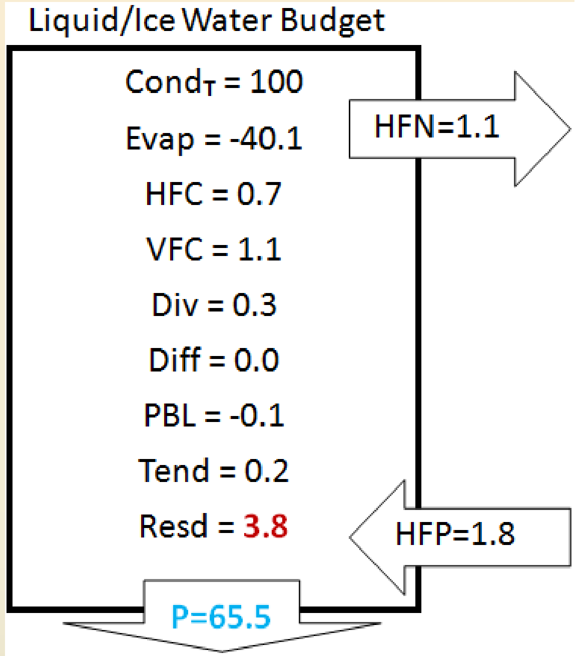
72-h Rainfall (08/07/00 ~ 08/10/00 UTC)

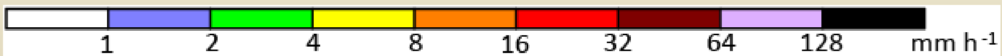


Oceanic Stage (0000 ~ 0100 UTC 7 August 2009) within the TC vortex circulation









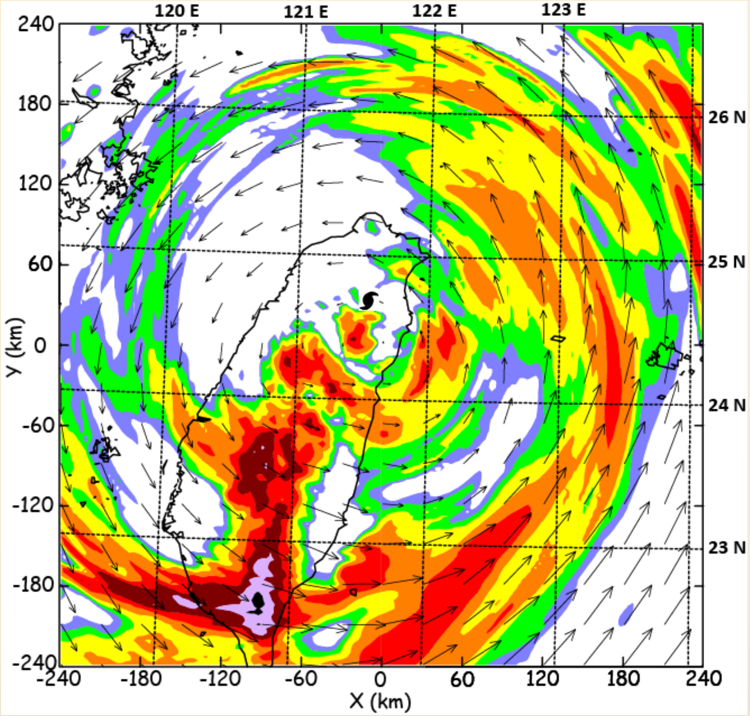
Water Vapor Budget:

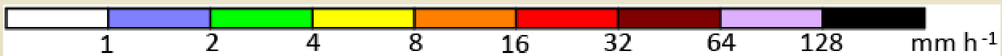
$$\mathrm{Tend} = \mathrm{HFC} + \mathrm{VFC} + \mathrm{Div} + \mathrm{Diff} + \mathrm{Cond}_T + \mathrm{Evap} + \mathrm{PBL} + \mathrm{Resd.}$$

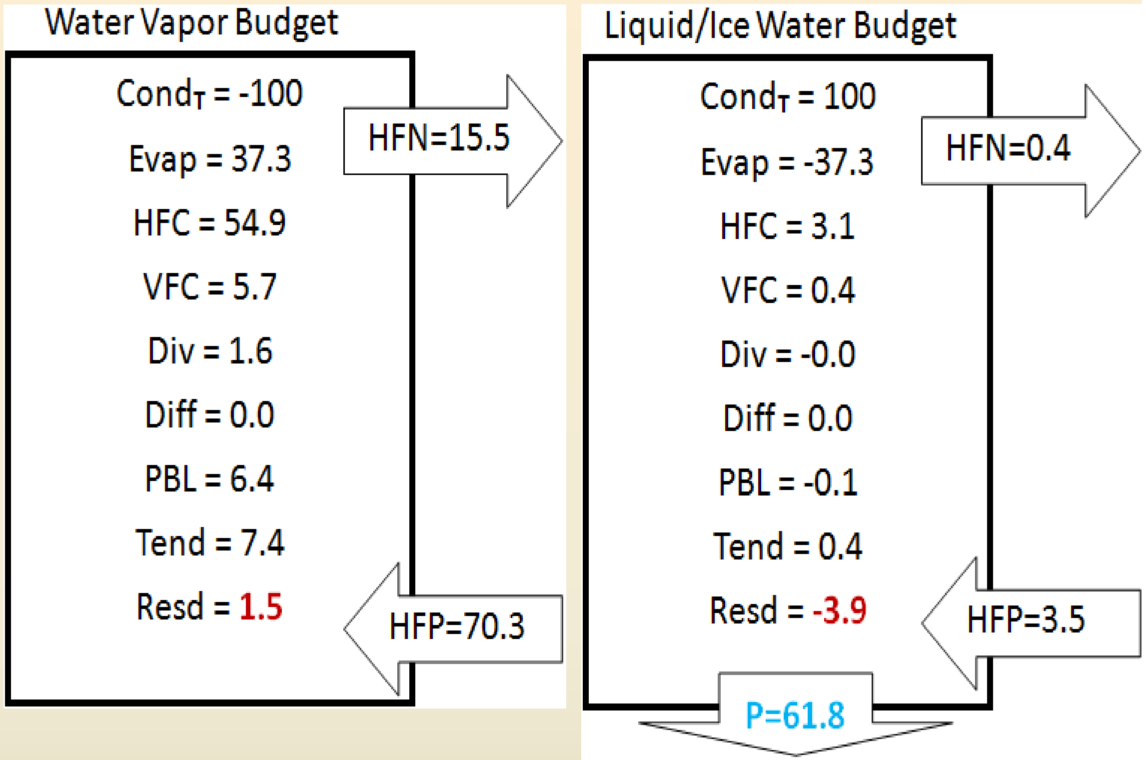
Liquid/Ice Water Budget:

$$\mathrm{Tend} = \mathrm{HFC} + \mathrm{VFC} + \mathrm{Div} + \mathrm{Diff} + \mathrm{P} - \mathrm{Cond}_T - \mathrm{Evap} + \mathrm{PBL} + \mathrm{Resd.}$$

Landfall Stage (00730 ~ 0830 UTC 8 August 2009) within the TC vortex circulation

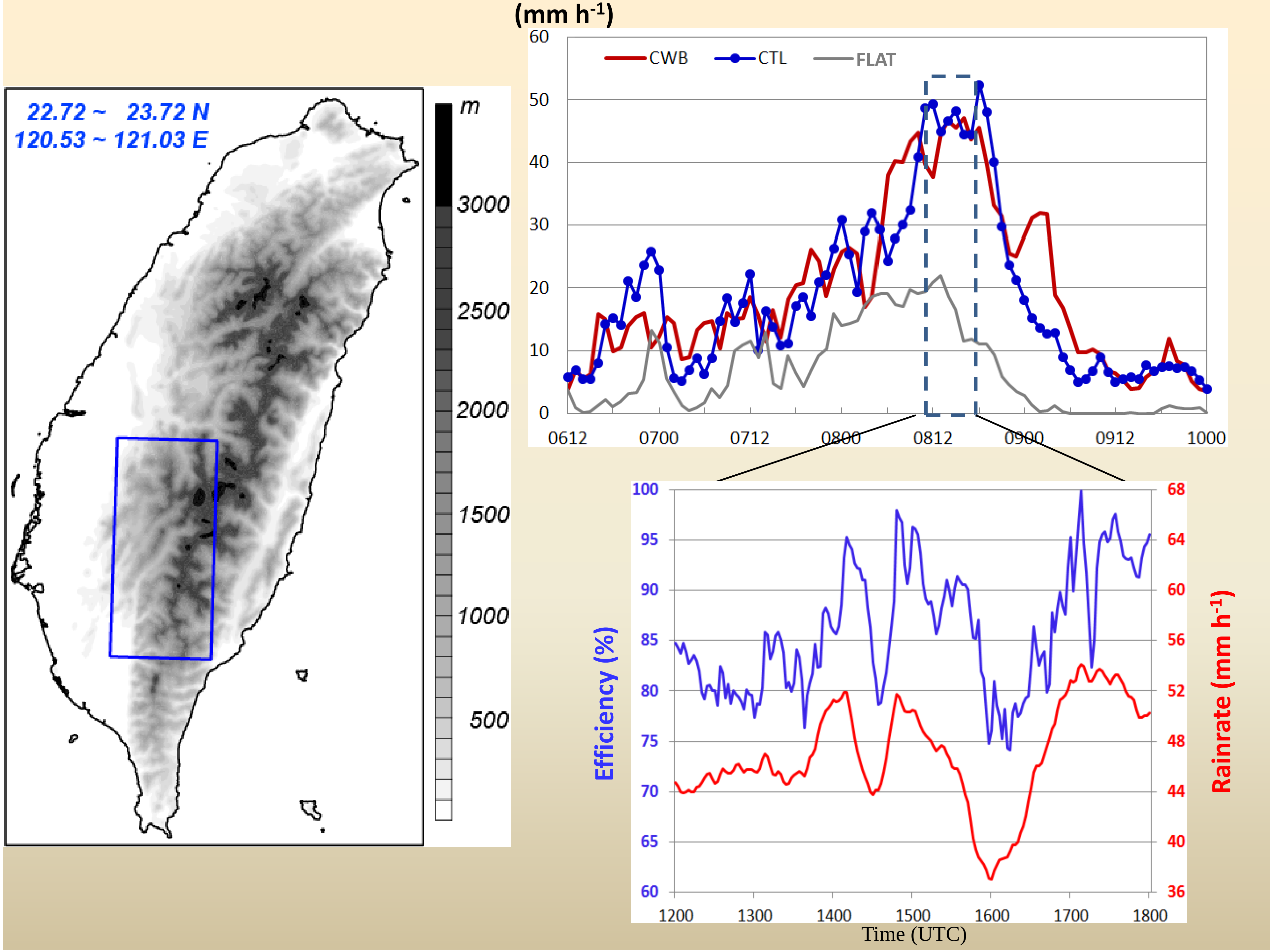






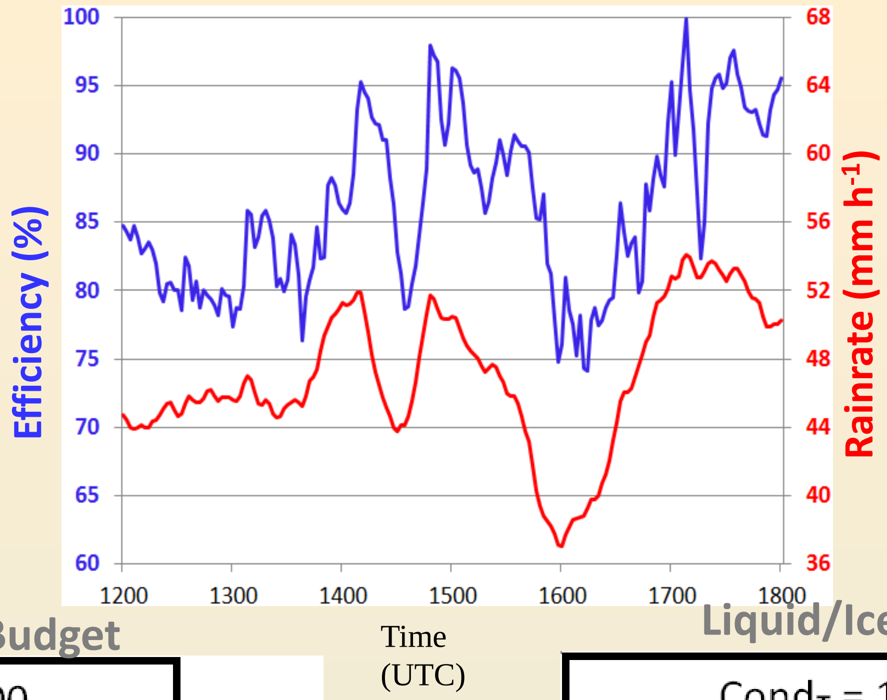
Water Vapor Budget: $\text{Tend} = \text{HFC} + \text{VFC} + \text{Div} + \text{Diff} + \text{Cond}_T + \text{Evap} + \text{PBL} + \text{Resd.}$

Liquid/Ice Water Budget: $\text{Tend} = \text{HFC} + \text{VFC} + \text{Div} + \text{Diff} + \text{P} - \text{Cond}_T - \text{Evap} + \text{PBL} + \text{Resd.}$

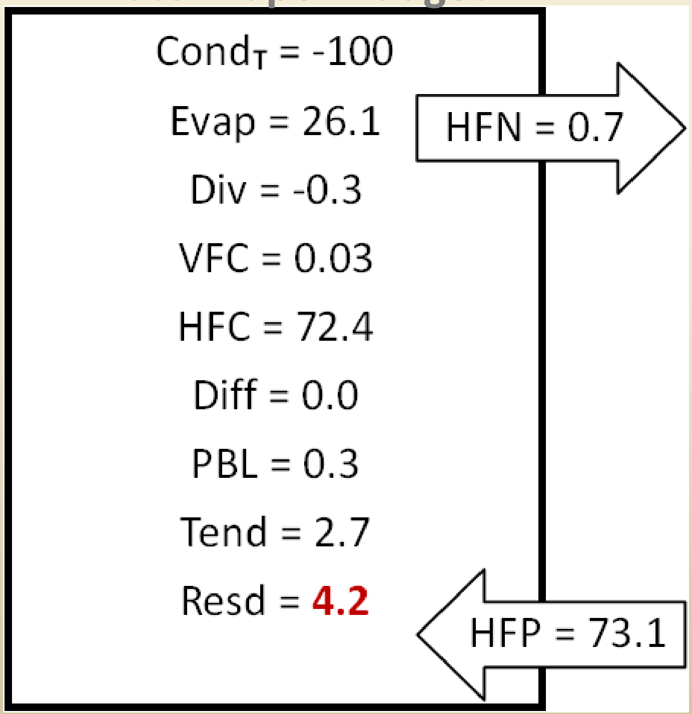


22.72 ~ 23.72 N
120.53 ~ 121.03 E
m
3000
2500
2000
1500
1000
500
(mm h-1)
CWB
CTL
FLAT
60
50
40
30
20
10
0
0612
0700
0712
0800
0812
0900
0912
1000
Efficiency (%)
100
95
90
85
80
75
70
65
60
Rainrate (mm h-1)
68
64
60
56
52
48
44
40
36
1200
1300
1400
1500
1600
1700
1800
Time (UTC)

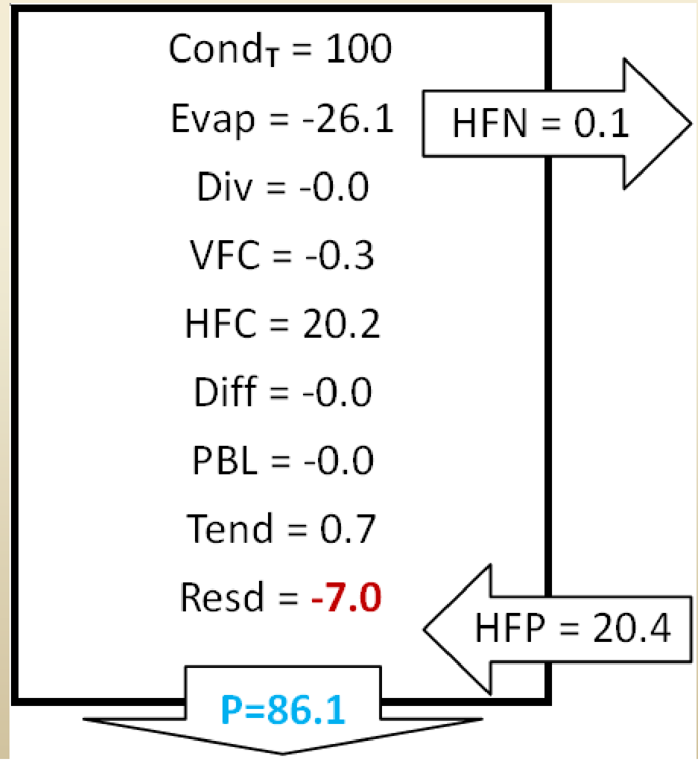
Within the box area over the mountains



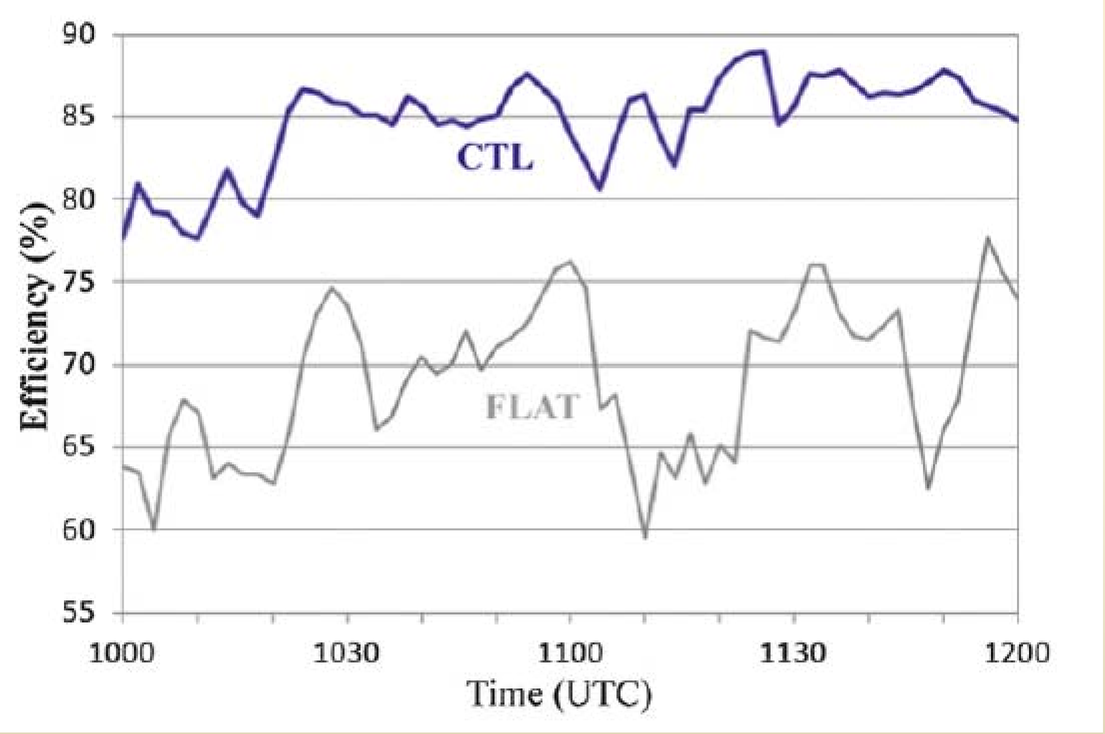
Water Vapor Budget



Liquid/Ice Water Budget



PEs of the CTL and FLAT run over the box area



Further decomposition of microphysical parameters into three components

Condensation Ratio:

$$CR = Cond_C/Cond_T.$$

Deposition Ratio:

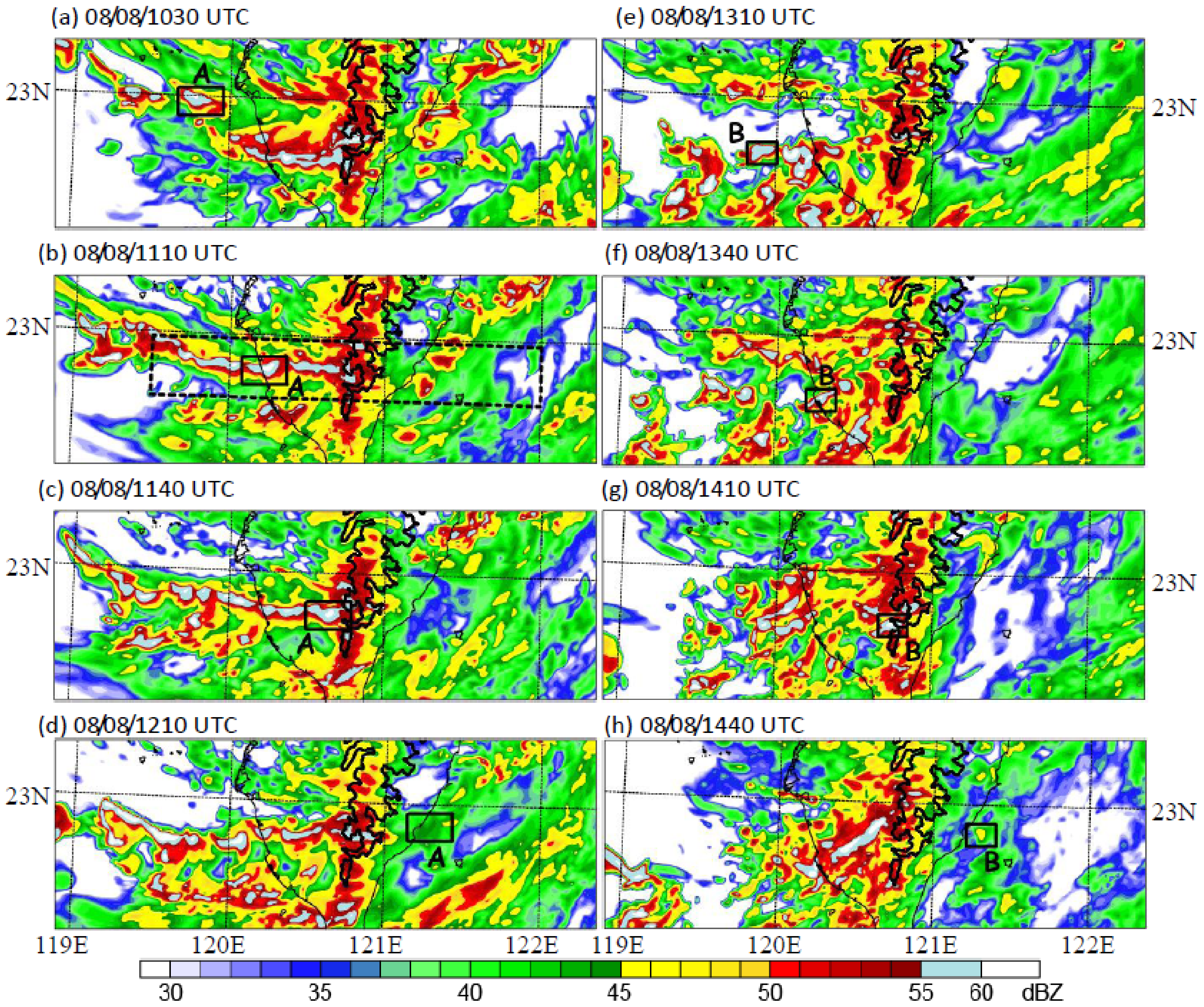
$$DR = (Dep_S + Dep_G + Dep_I)/Cond_T$$

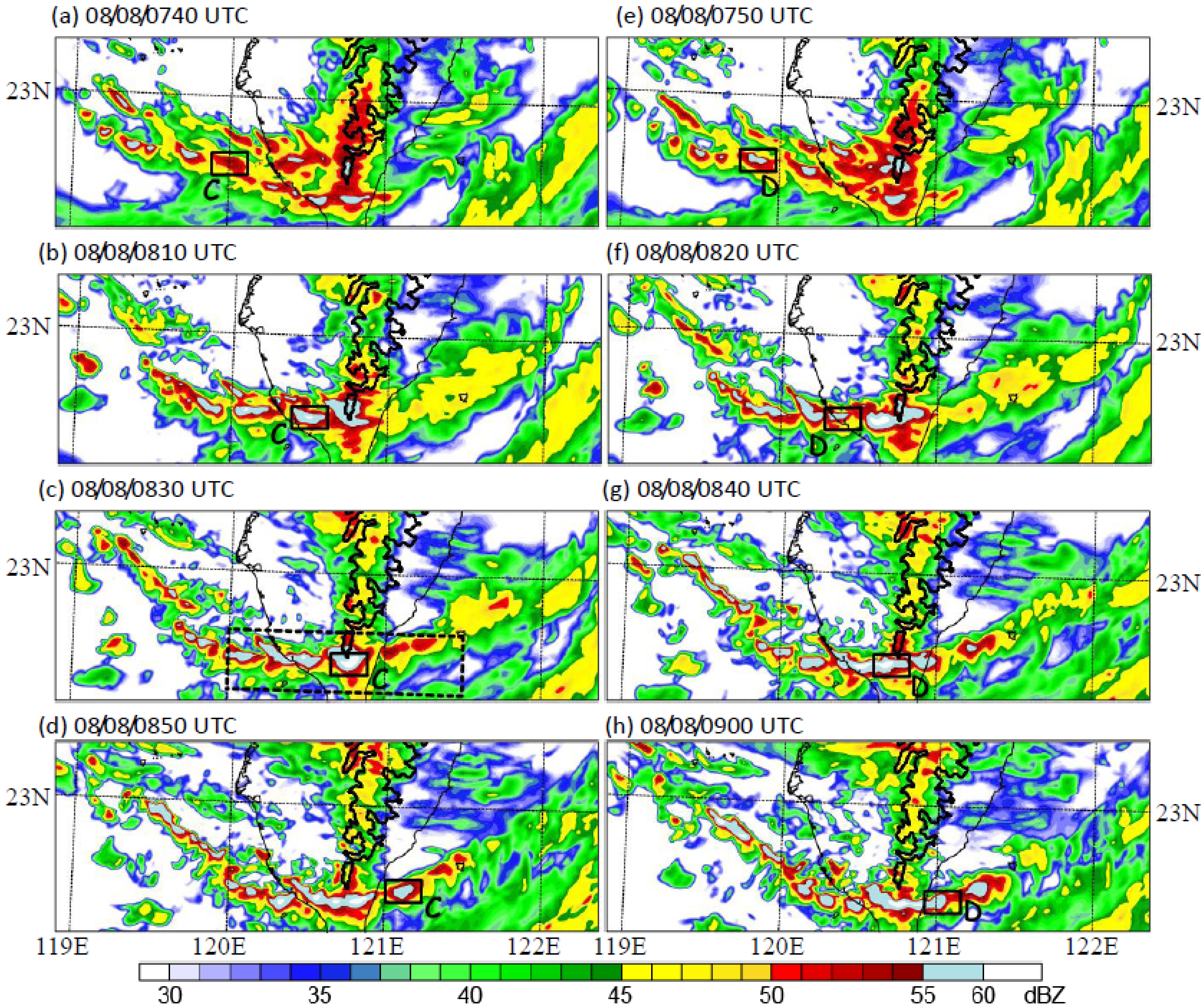
Evaporation Ratio:

$$ER = Evap_R/Cond_T$$

where $Cond_T$ is the total condensation and deposition;
$Cond_C$ is the cloud water condensation;
Dep_S is the snow deposition;
Dep_G is the graupel deposition;
Dep_I is the cloud ice deposition;

$Evap_R$ is the raindrop evaporation

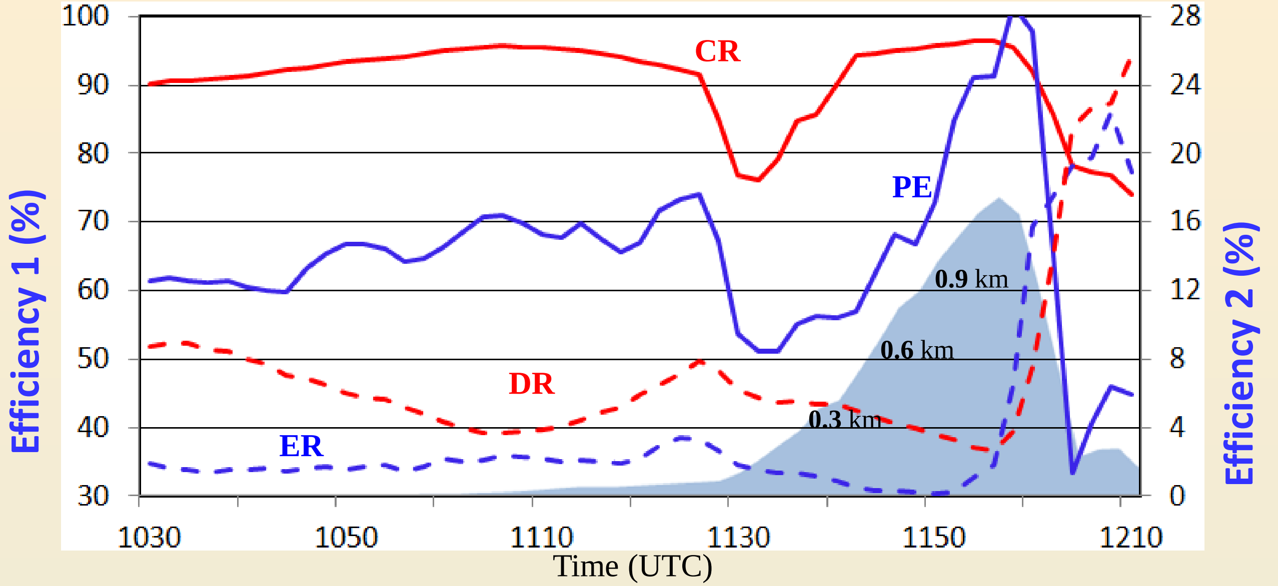

(a) 08/08/1030 UTC
(b) 08/08/1110 UTC
(c) 08/08/1140 UTC
(d) 08/08/1210 UTC
(e) 08/08/1310 UTC
(f) 08/08/1340 UTC
(g) 08/08/1410 UTC
(h) 08/08/1440 UTC
A
B
23N
119E
120E
121E
122E
30
35
40
45
50
55
60
dBZ



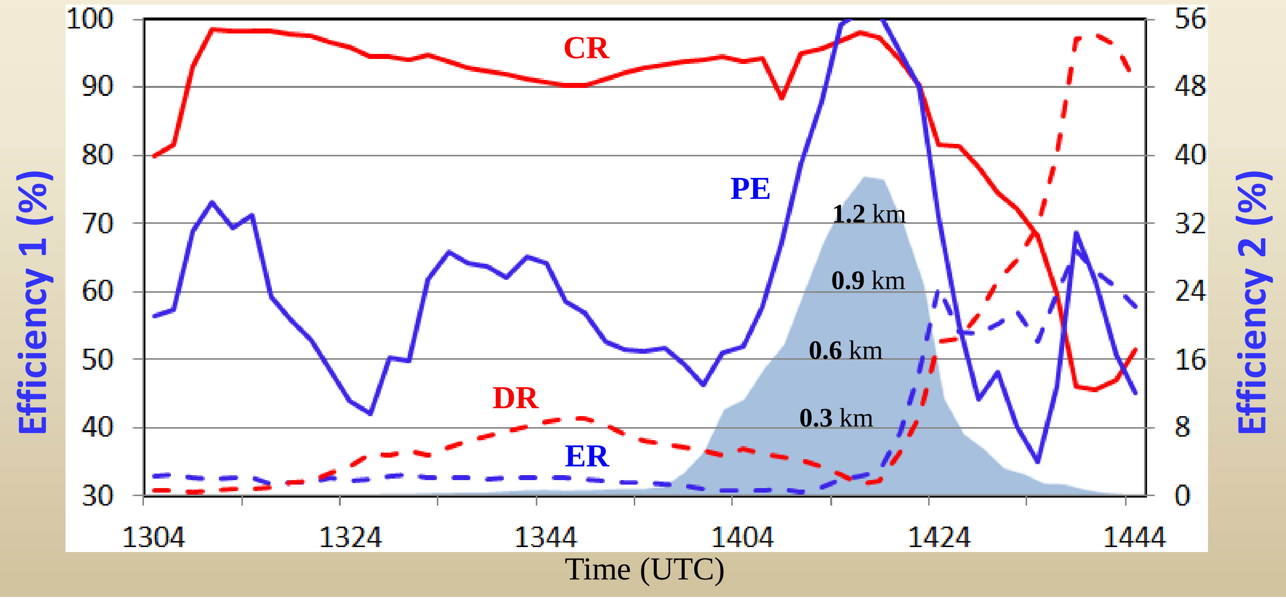
(a) 08/08/0740 UTC
(b) 08/08/0810 UTC
(c) 08/08/0830 UTC
(d) 08/08/0850 UTC
(e) 08/08/0750 UTC
(f) 08/08/0820 UTC
(g) 08/08/0840 UTC
(h) 08/08/0900 UTC
C
D
23N
119E
120E
121E
122E
30
35
40
45
50
55
60
dBZ

Lagrangian evolution of microphysical parameters

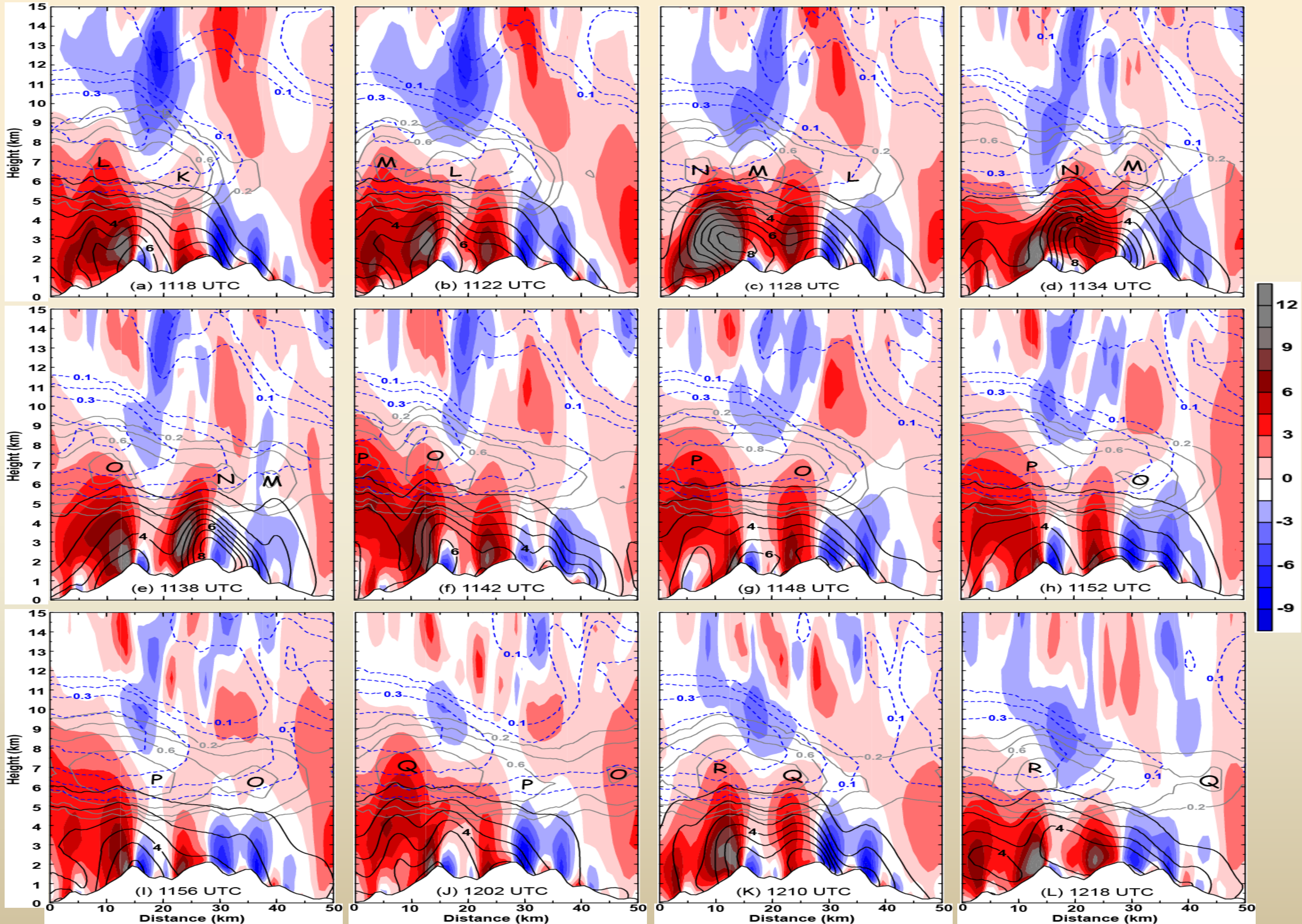
Cell A



Cell B

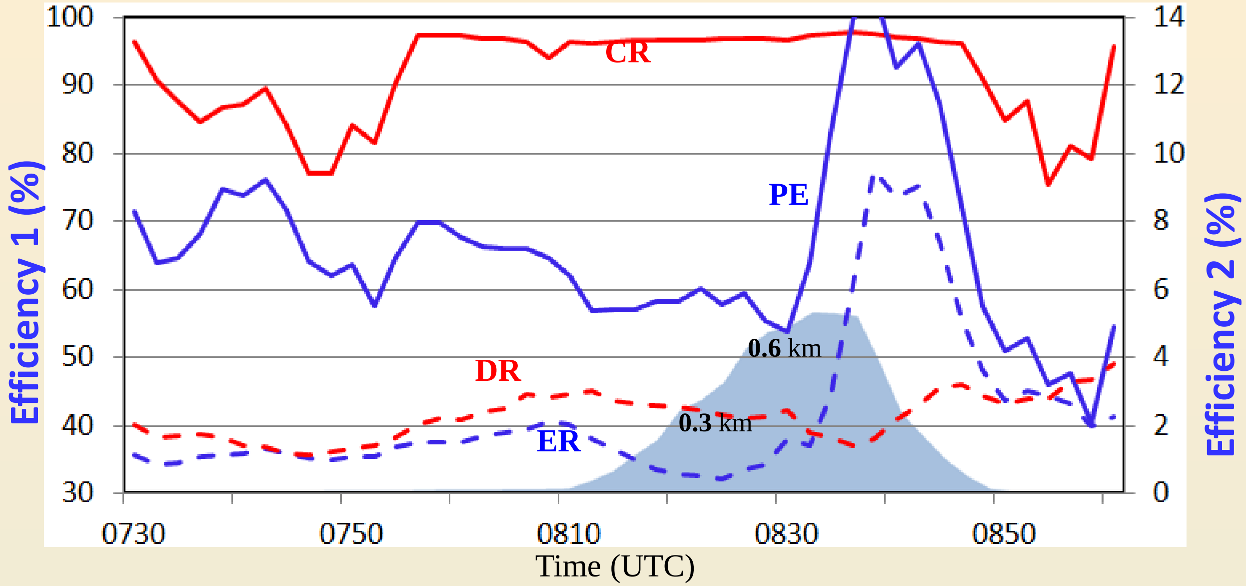


Gravity Waves on the Lee Side (vertical velocity, colored; hydrometeor mixing ratio, contoured)

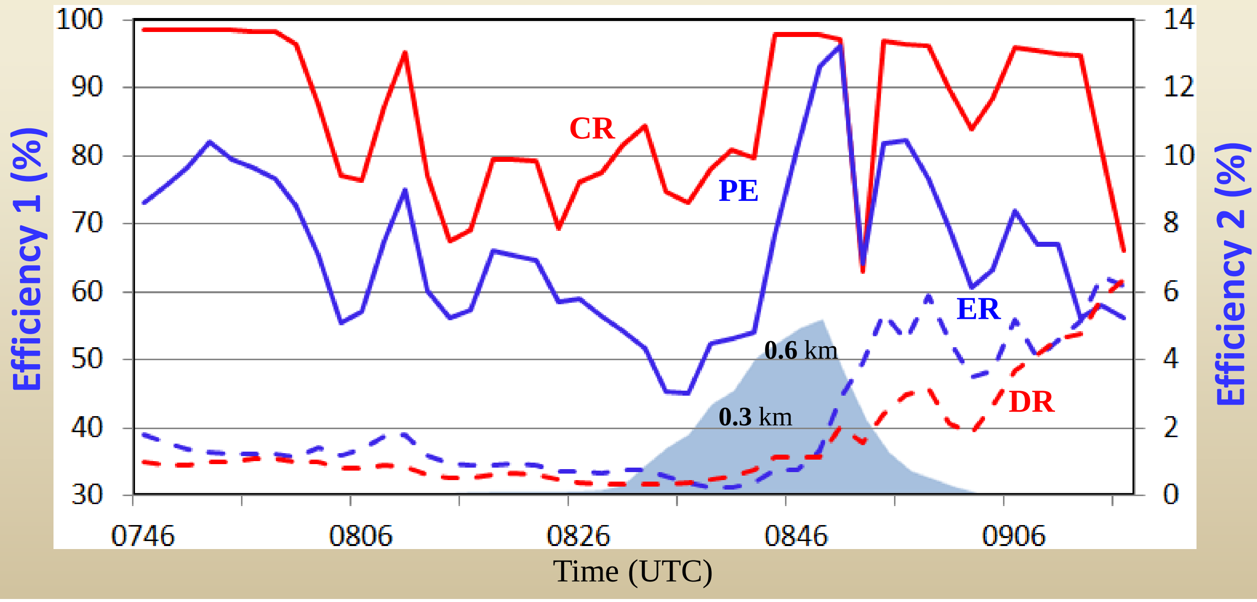


Lagrangian evolution of microphysical parameters

Cell C

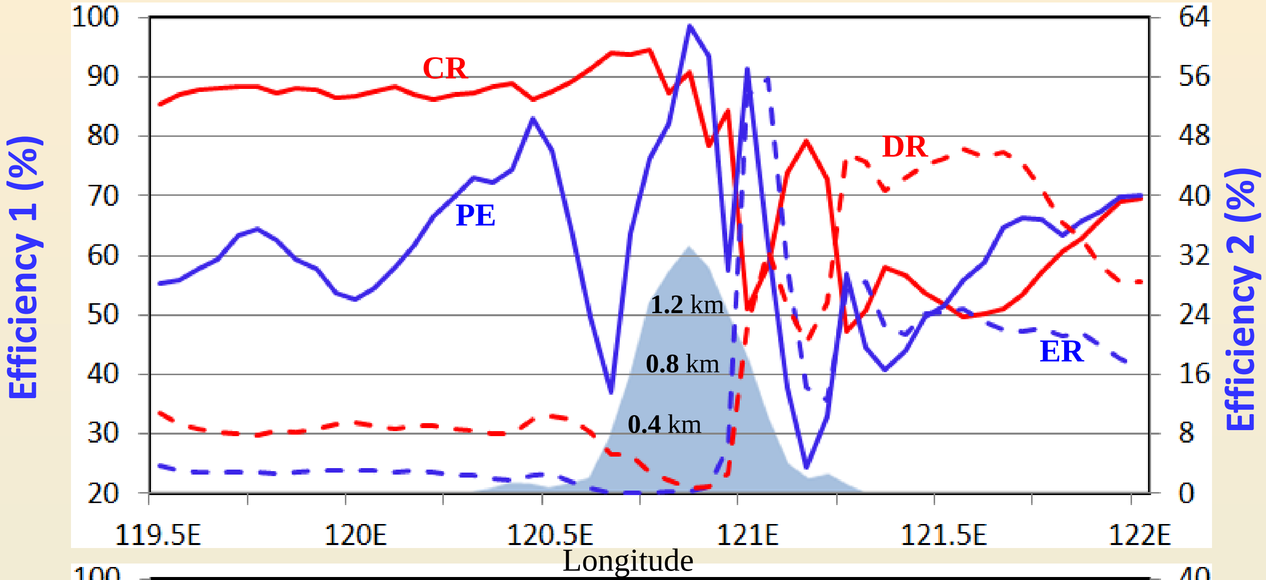


Cell D

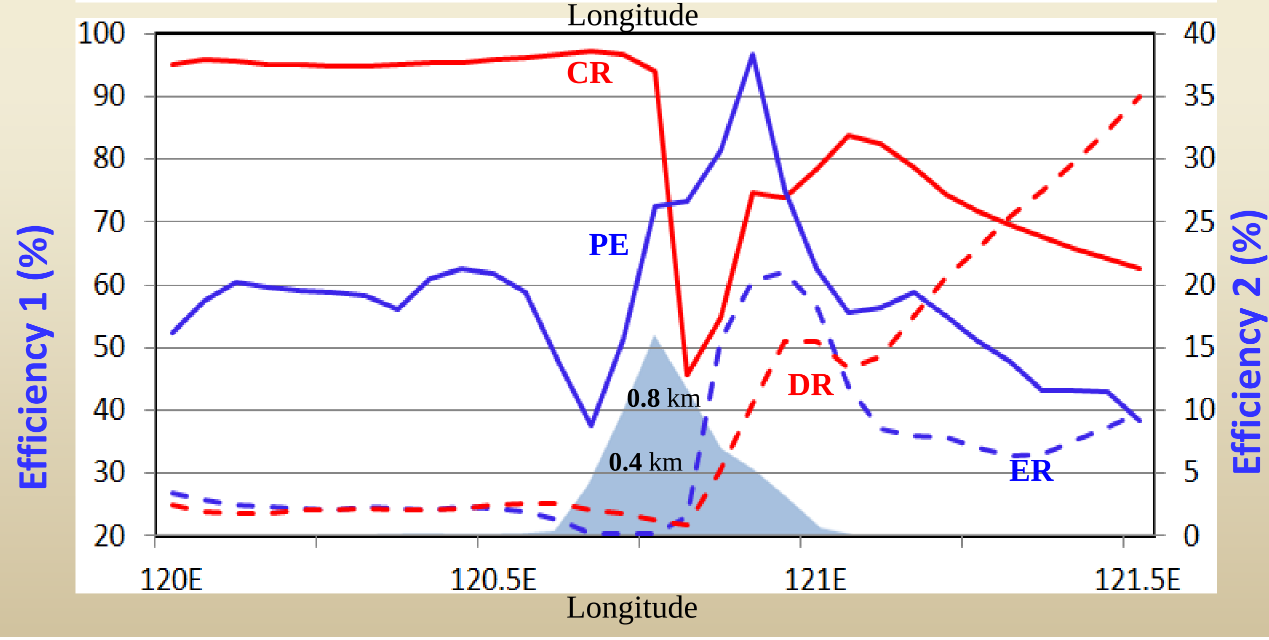


Eulerian evolution of microphysical parameters In two time-and-space-averaged cross sections

Cross Section A



Cross Section B



Conclusions

- The 1-km WRF simulation reproduced resonably well the Morakot track, the organization, the sizes of eye and eyewall, major convective cells on outer rainbands, and rainfall maxima on southwest Taiwan.
- The surface rainrate (36-54 mm/h) and PE (75-100%) over southwest Taiwan are highly correlated.
- The surface rainrate of the no-terrain run are 50% of the full-terrain run; and the PE of no-terrain run are 15-20% less than the full-terrain run.
- By following the movement of major convective cells, PEs are 60-75% over ocean and > 95% above terrain, which may account for the record-breaking heavy rainfall over Taiwan.
- The Lagrangian evolution of major cells shows that PE and CR are increased on the windward slope but decreased on the lee side; the reverse trend is found for the DR and ER.
- The Lagrangian evolution is confirmed by the changes of microphysical parameters across the mountains in two time-and-space-averaged cross sections in an Eulerian framework.

Reference: Huang, H.-L., M.-J. Yang*****, and C.-H. Sui, 2014: Water budget and precipitation efficiency of Typhoon Morakot (2009). *J. Atmos. Sci.*, **71**, 112–129, doi:10.1175/JAS-D-13-053.1. (January issue)


Thank you !