The Hydrometeorological Issues Associated with Typhoon Nari (2001)

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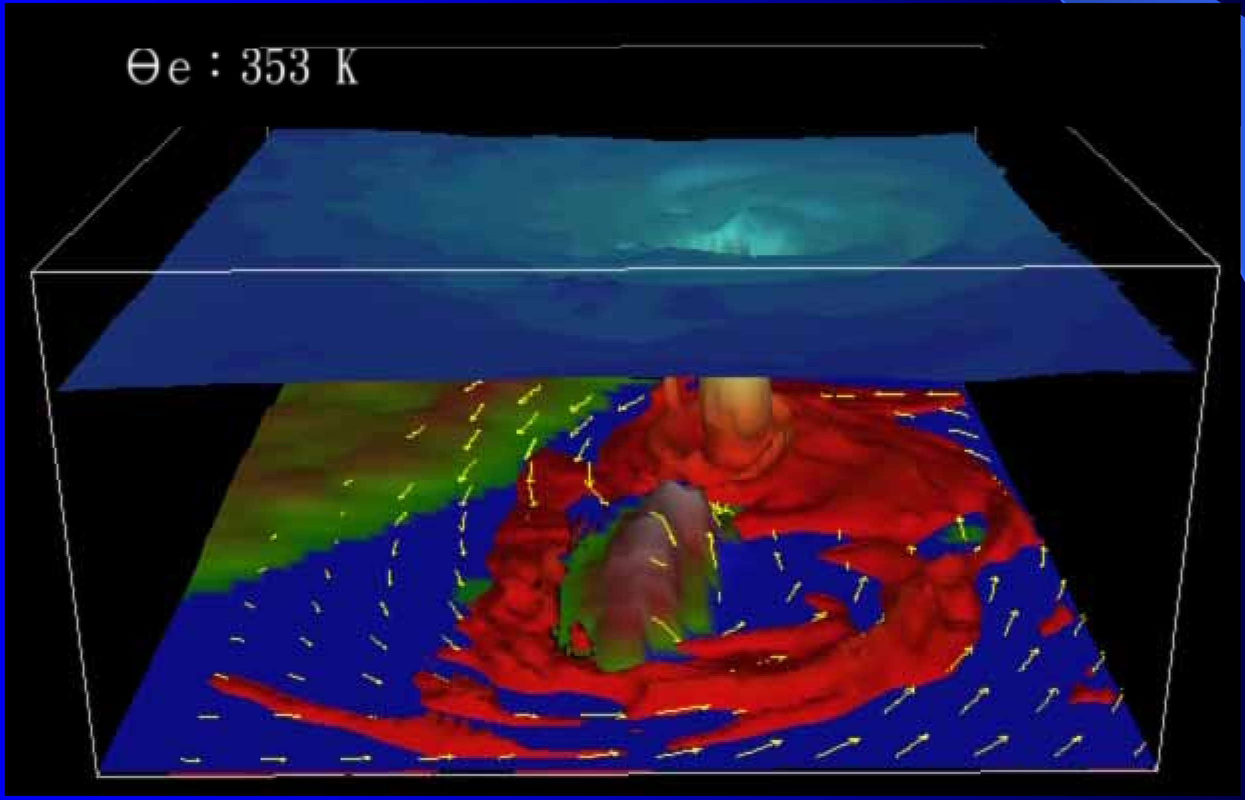


Heavy rainfalls induced severe flooding and societal damage !

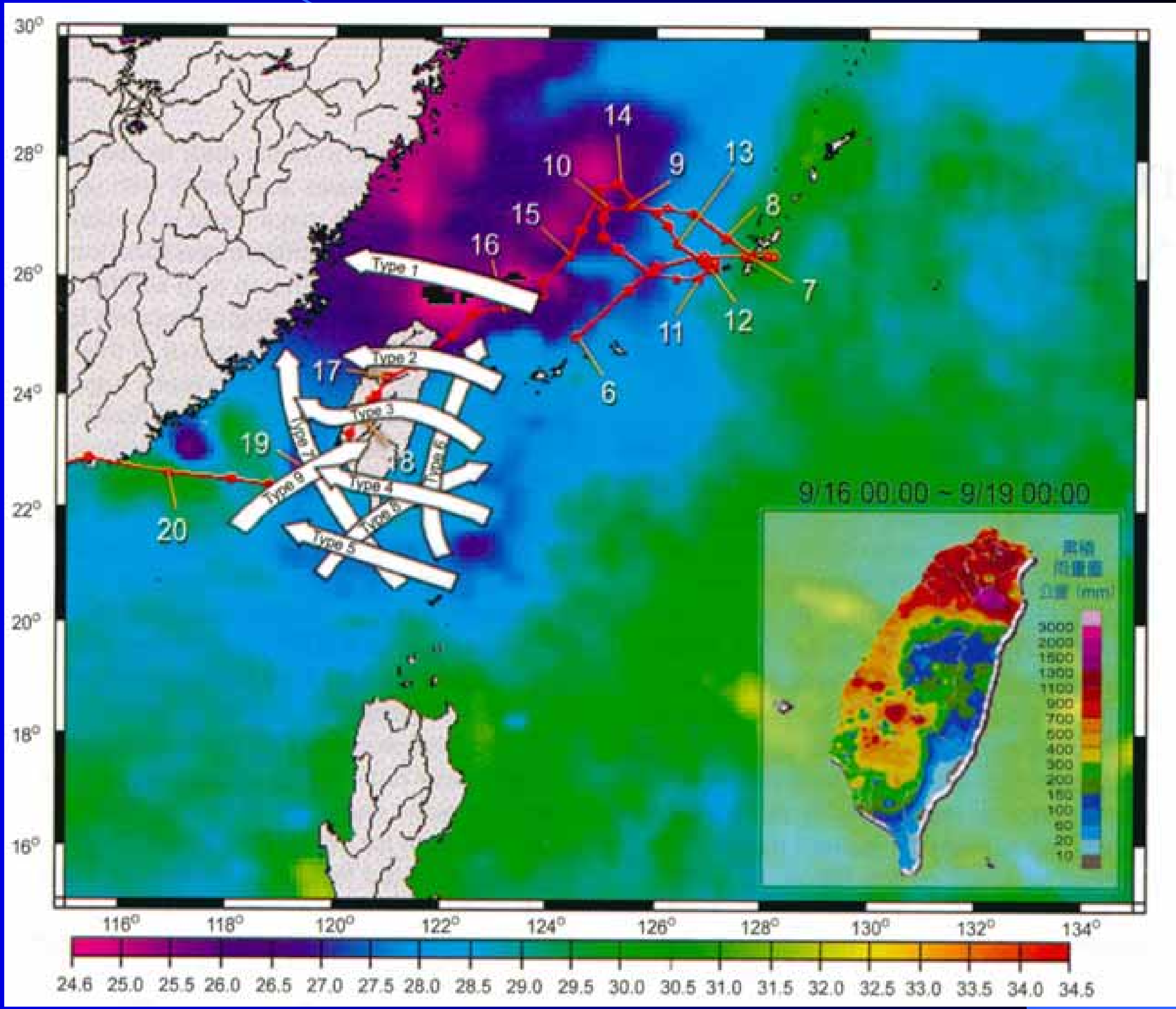
Even Budda cannot save you!

Water World !

Flooding over the Parking Lot

Why studied Typhoon Nari (2001)?

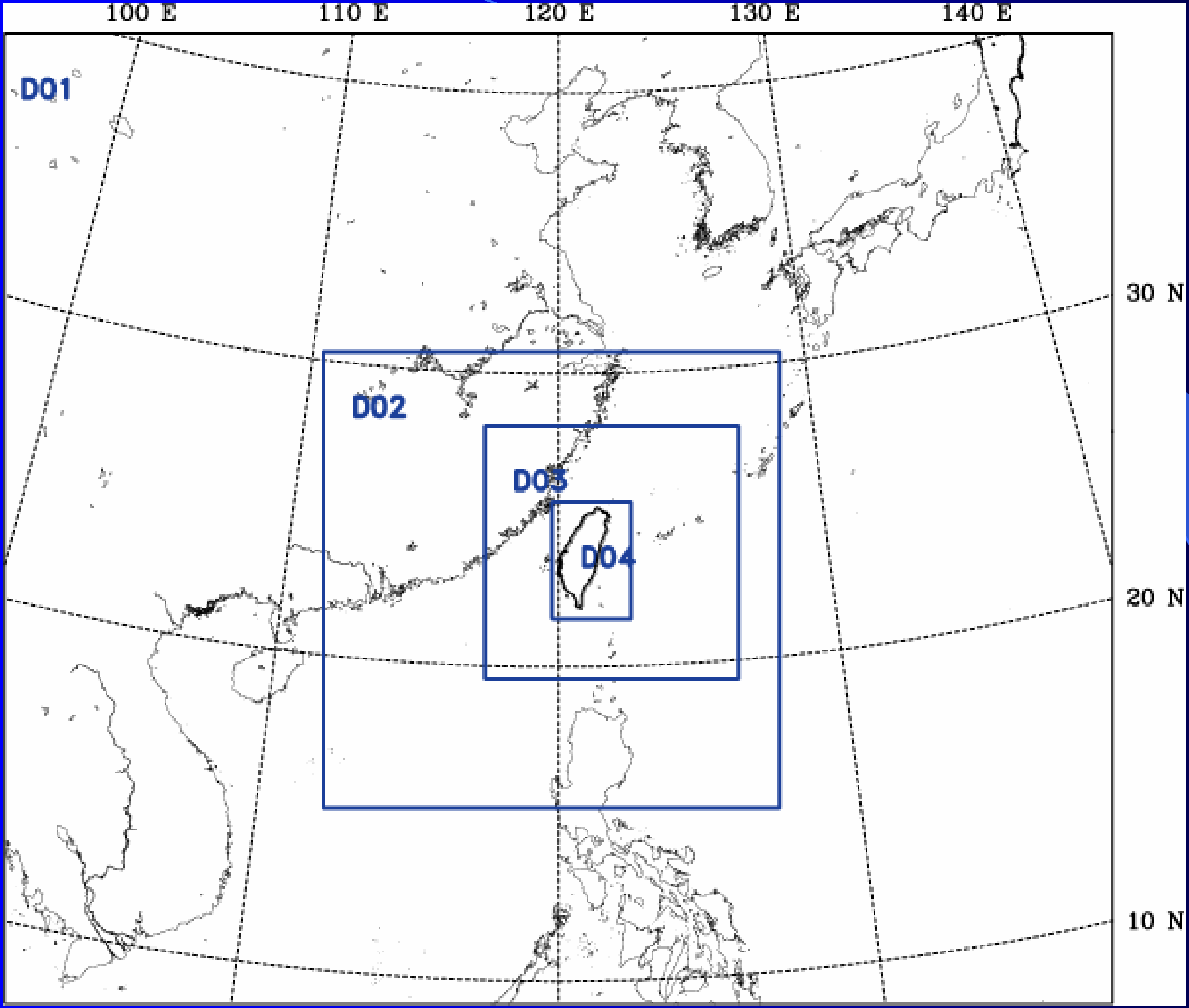
- Unique track
- Slowly moving
- Long duration
- Warm ocean
- Heavy rainfall
- Severe flooding



Sui et al. (2002) EOS article

Part I: Precipitation and Kinematic Structures (Model Verification)

In cooperation with Tai-Chi Chen, Yu-Chieng Liou, Jen-Hsin Teng, and Wann-Jin Chen



MM5 Domains

D1: 54 km

D2: 18 km

D3: 6 km

D4: 2 km

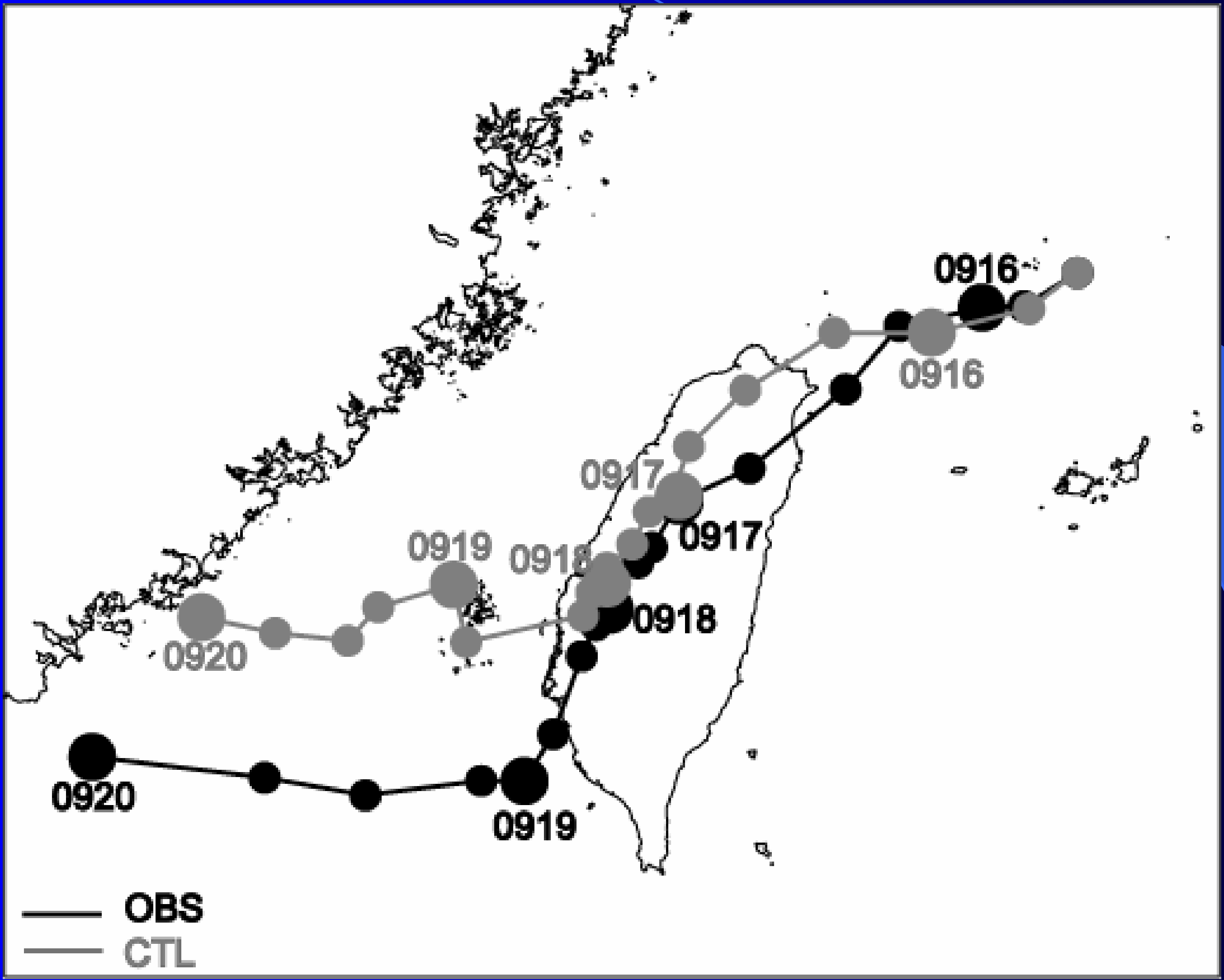
31 levels
In vertical

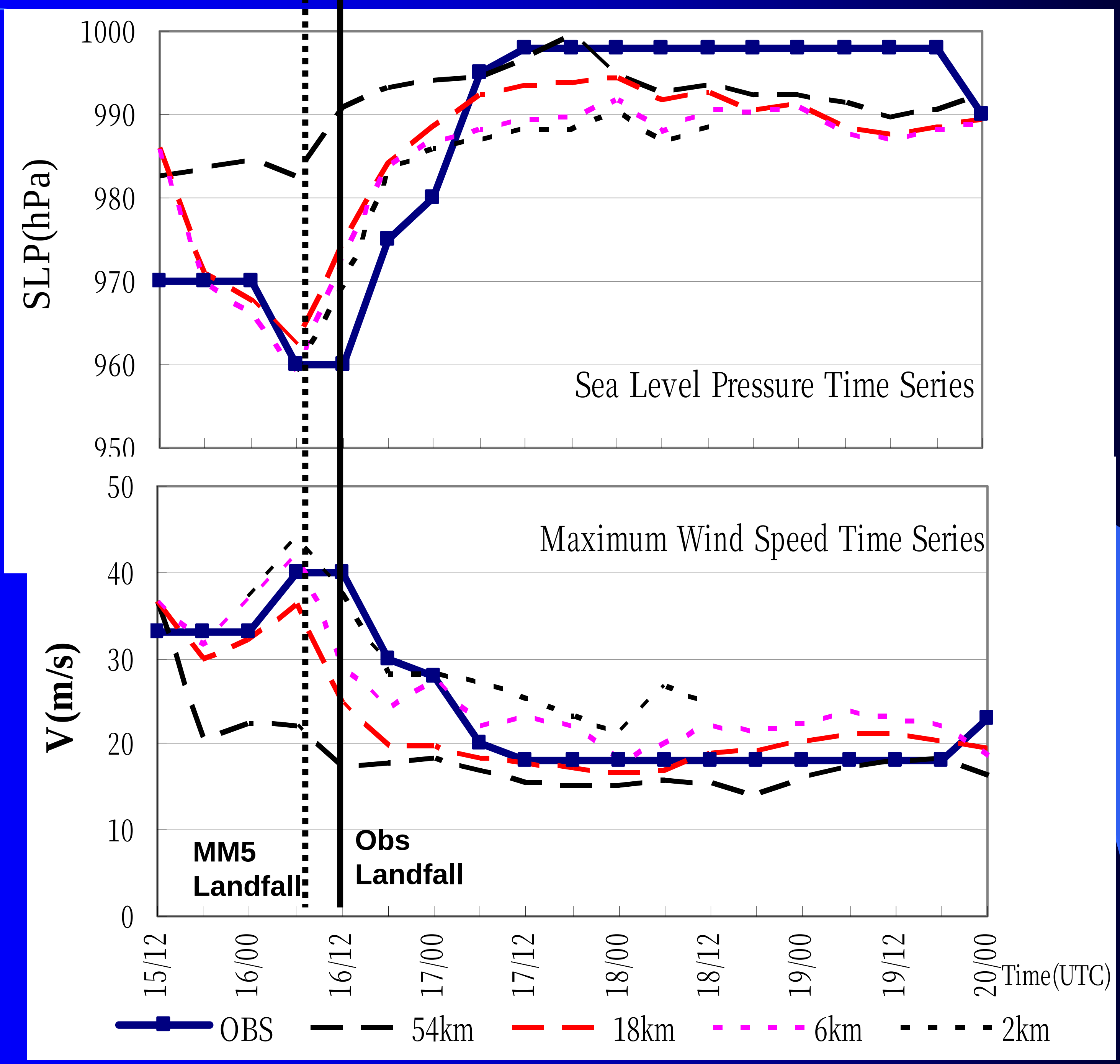
MM5 model physics (Control)

Version	V 3.5
Fcst Period	108 h
Cumulus	Grell (1993)
Microphysics	Reisner et al. (1998)
PBL	MRF (Hong and Pan 1996)
Radiation	Dudhia (1989）
I.C.	ECMWF advanced analysis (2001/09/15 1200 UTC)
B.C.	ECMWF advanced analysis

TC initialization: Davis and Low-Nam (2001)

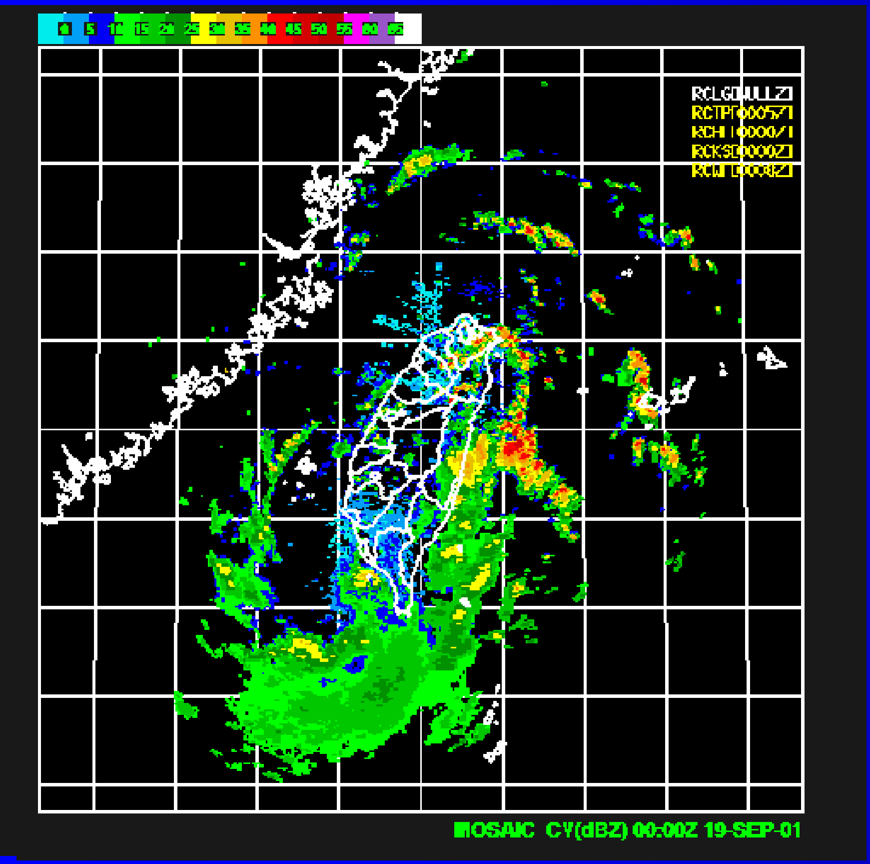
Track Comparison



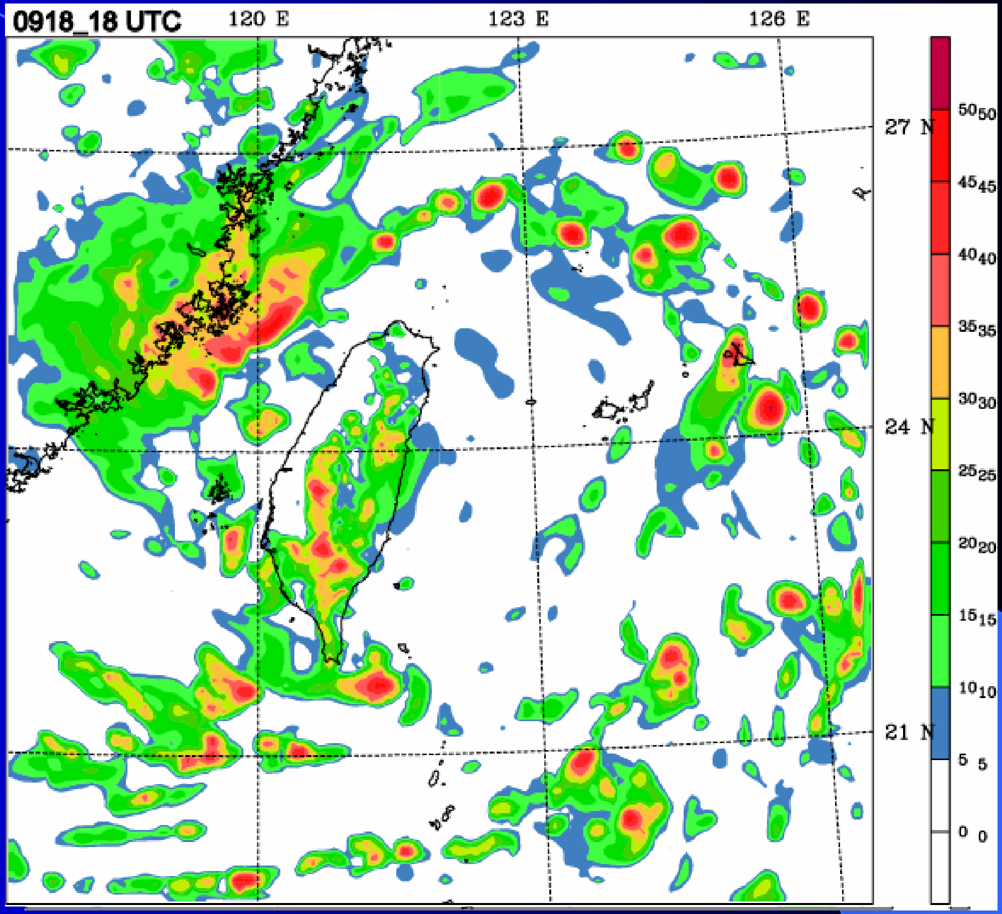


SLP(hPa)
1000
990
980
970
960
950
Sea Level Pressure Time Series
50
40
30
20
10
0
V(m/s)
Maximum Wind Speed Time Series
MM5
Landfall
Obs
Landfall
15/12
16/00
16/12
17/00
17/12
18/00
18/12
19/00
19/12
20/00
Time(UTC)
OBS
54km
18km
6km
2km

Obs dBZ (CV composite)

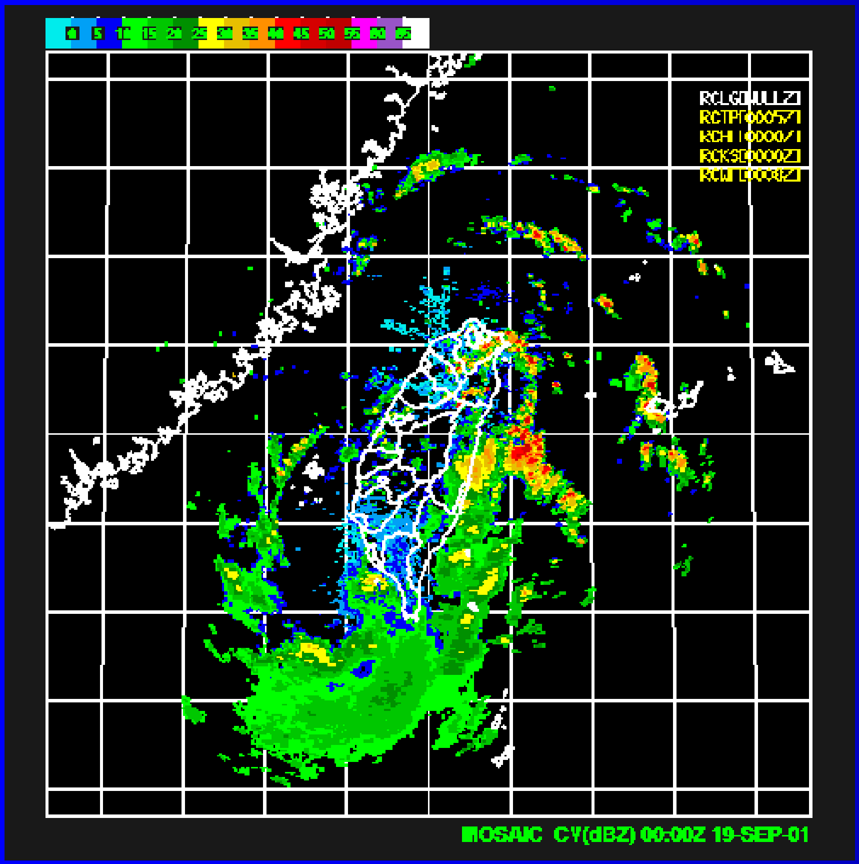


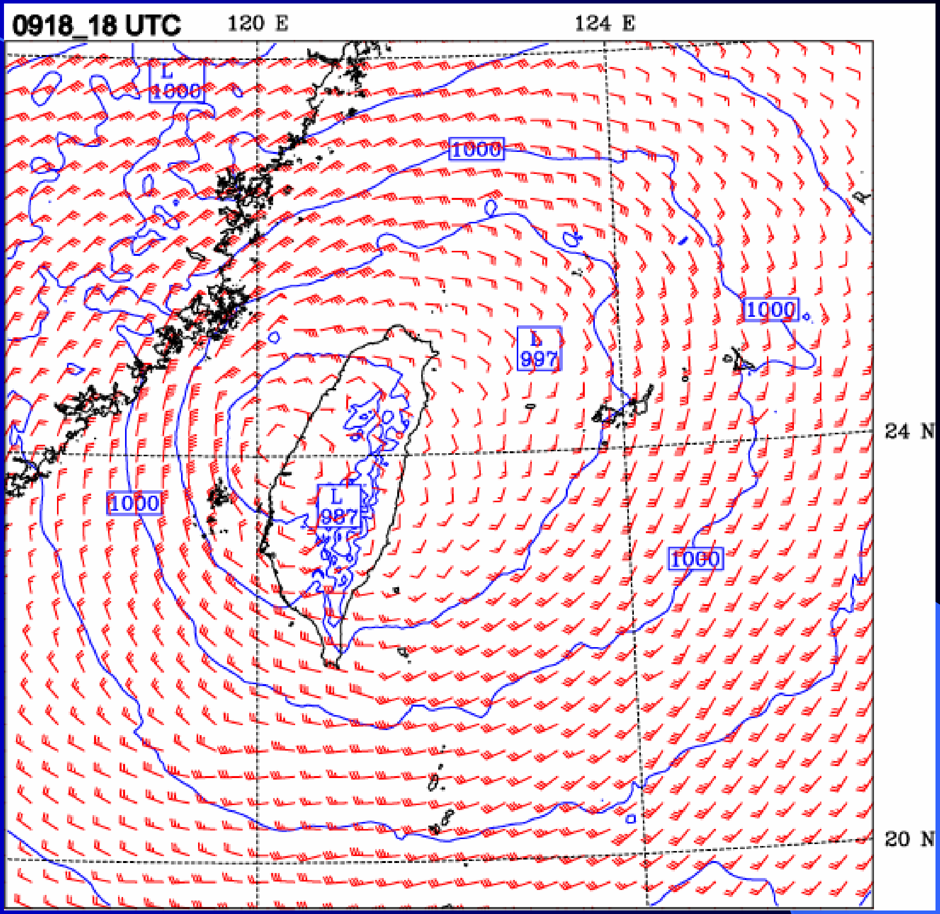
MM5 dBZ CV composite (6 km grid)



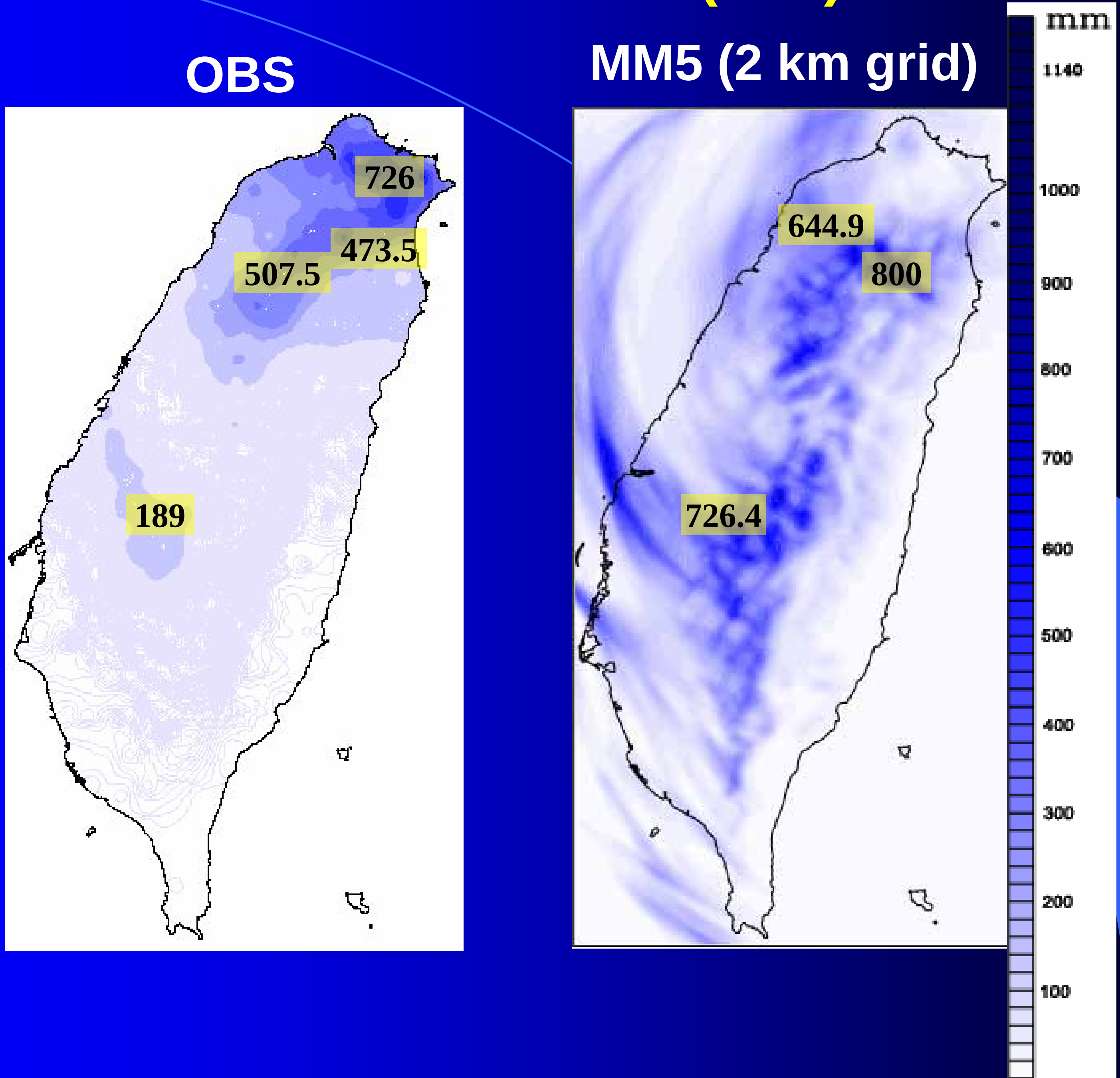
Obs dBZ (Composite)

MM5 SLP (6 km grid)

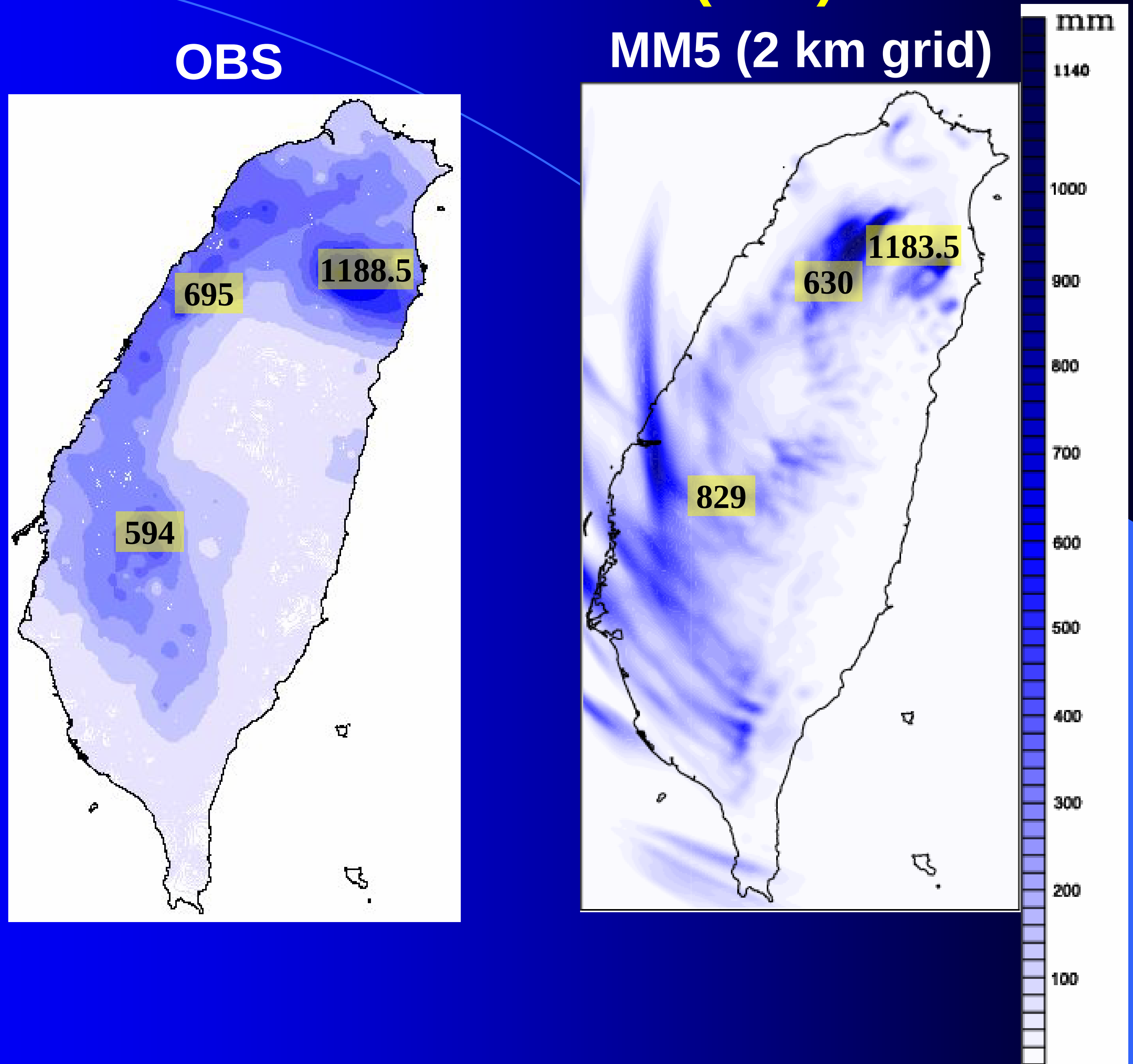




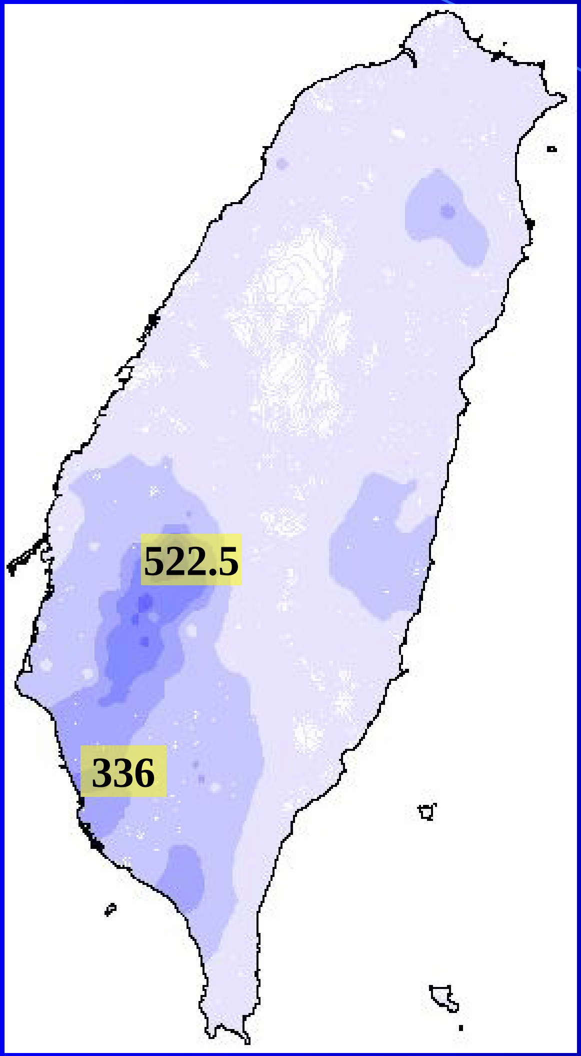
9/16 24h Rainfall (mm)

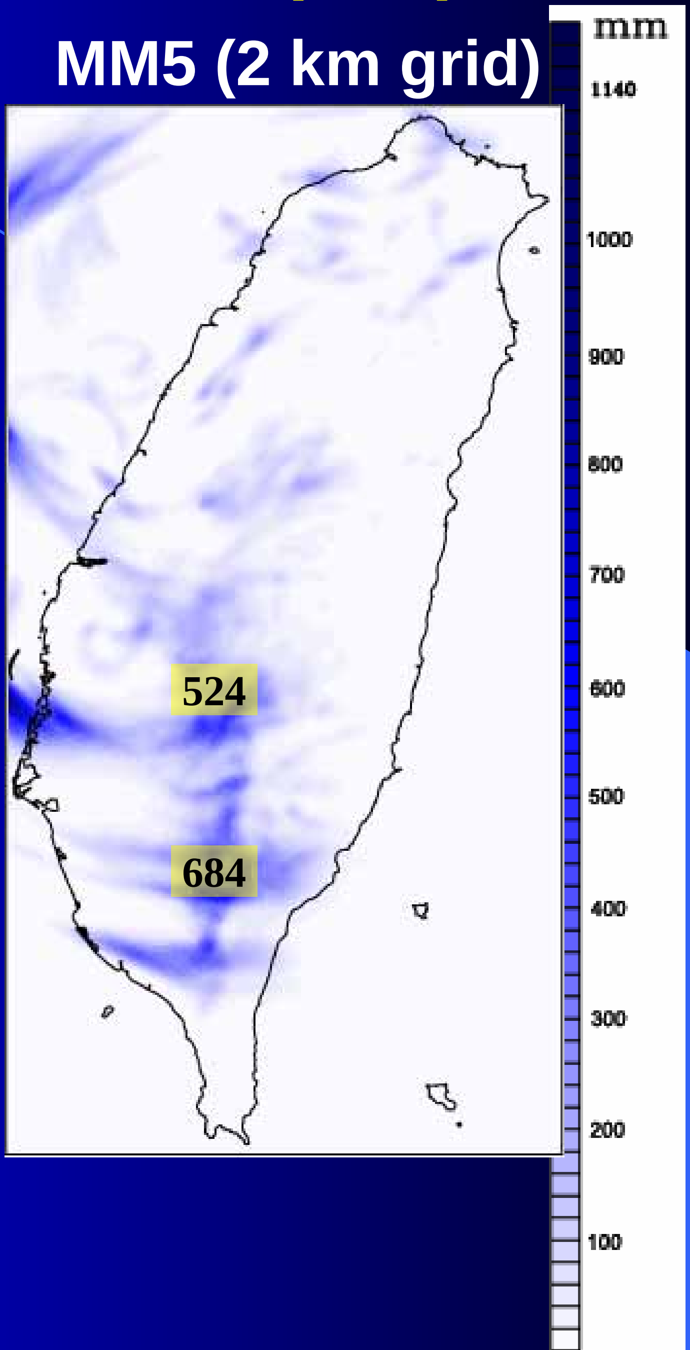


9/17 24h Rainfall (mm)



09/18 24h Rainfall (mm)

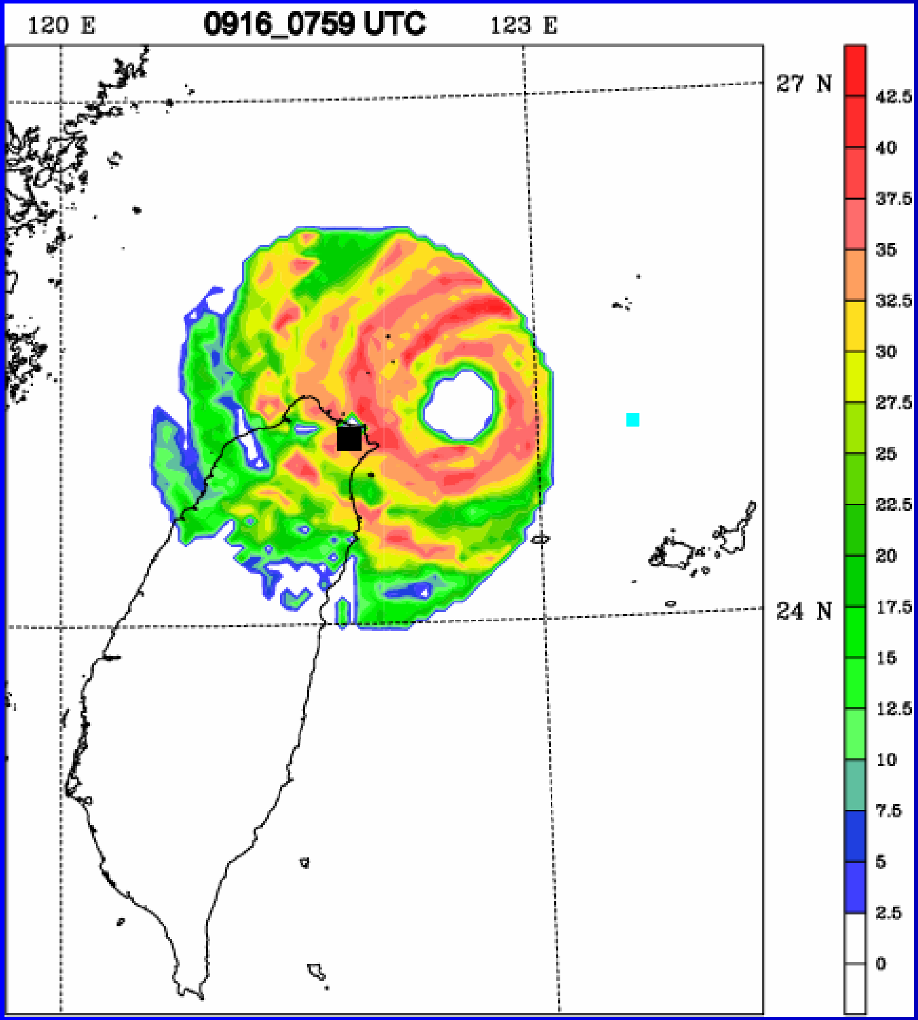


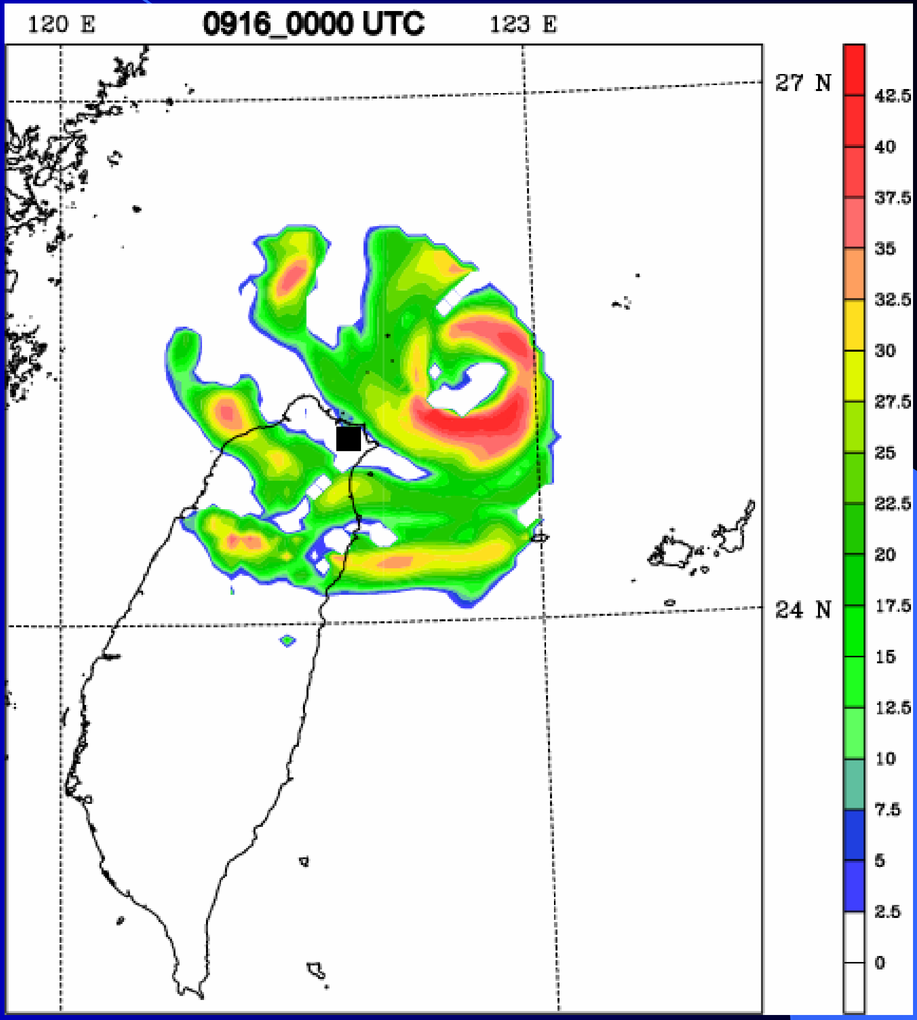


Radar Reflectivity Comparison

Height = 3 km

RCWF dBZ (6 km pixel) **MM5 dBZ (dx = 6 km)**



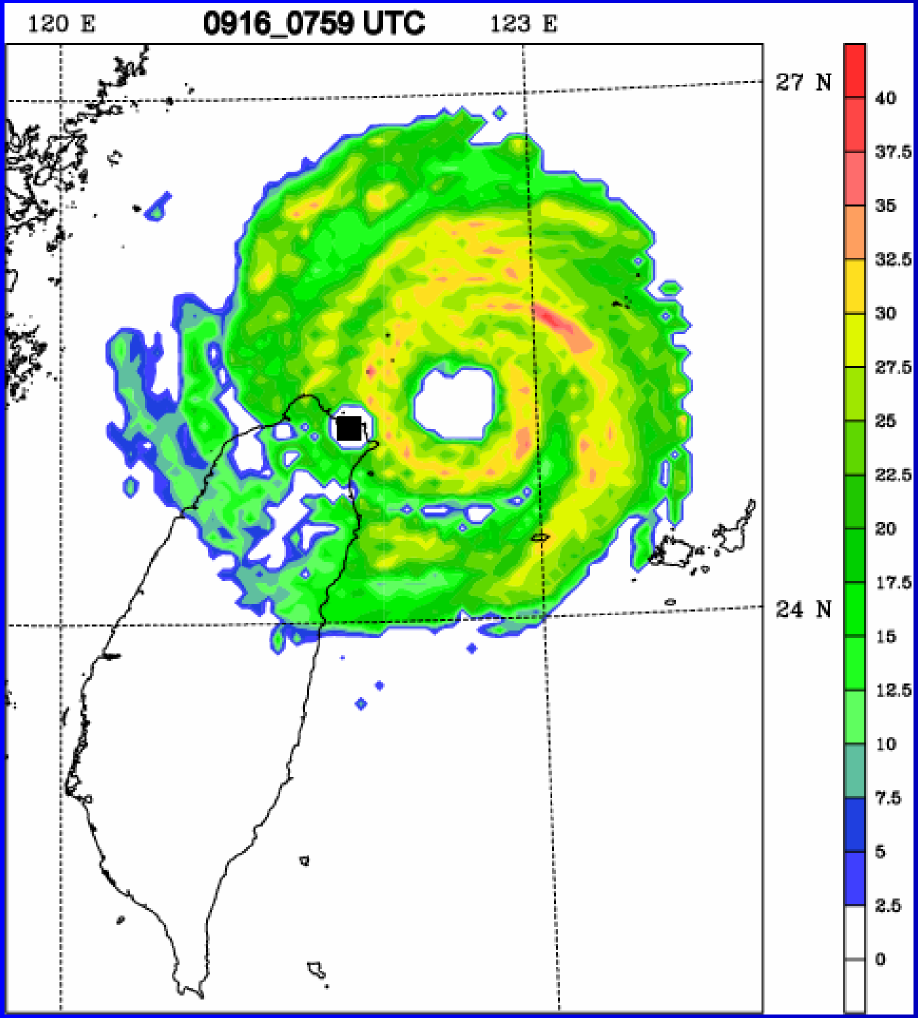


Courtesy of T.-C. Chen and Y.-C. Liou

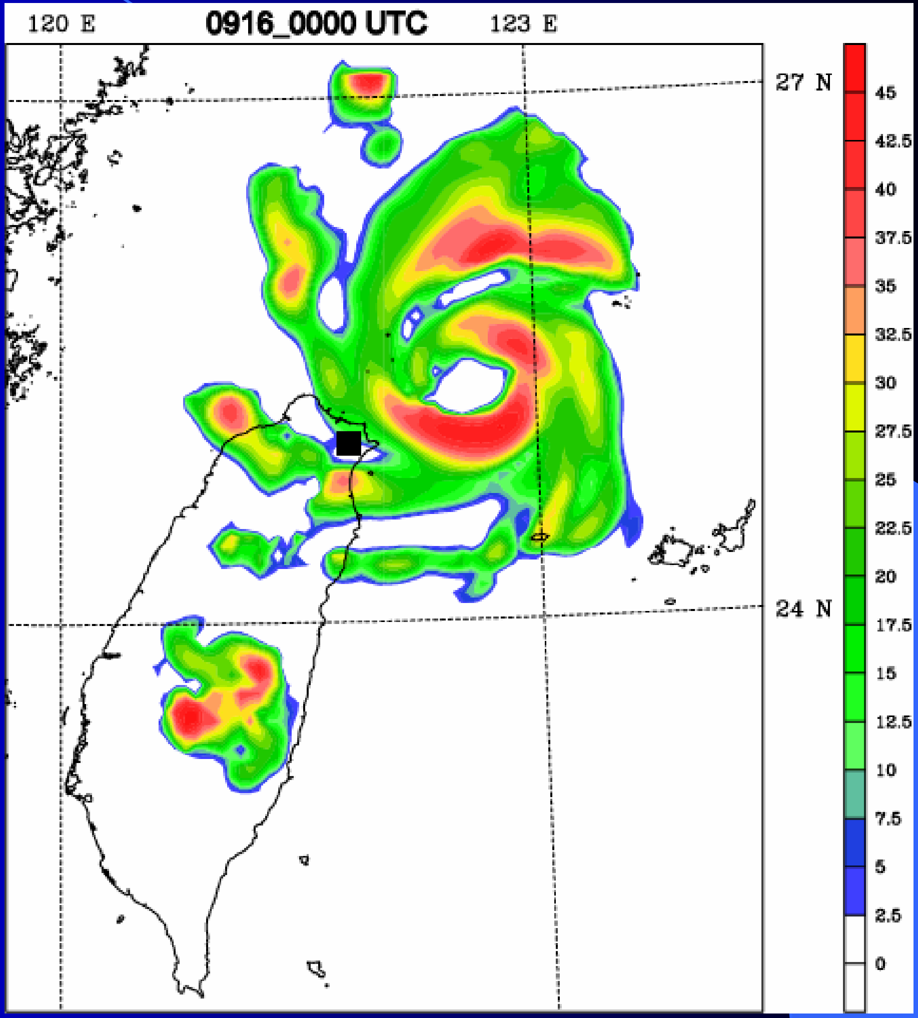
Radar Reflectivity Comparison

Height = 6 km

RCWF dBZ (6 km pixel)



MM5 dBZ (dx = 6 km)

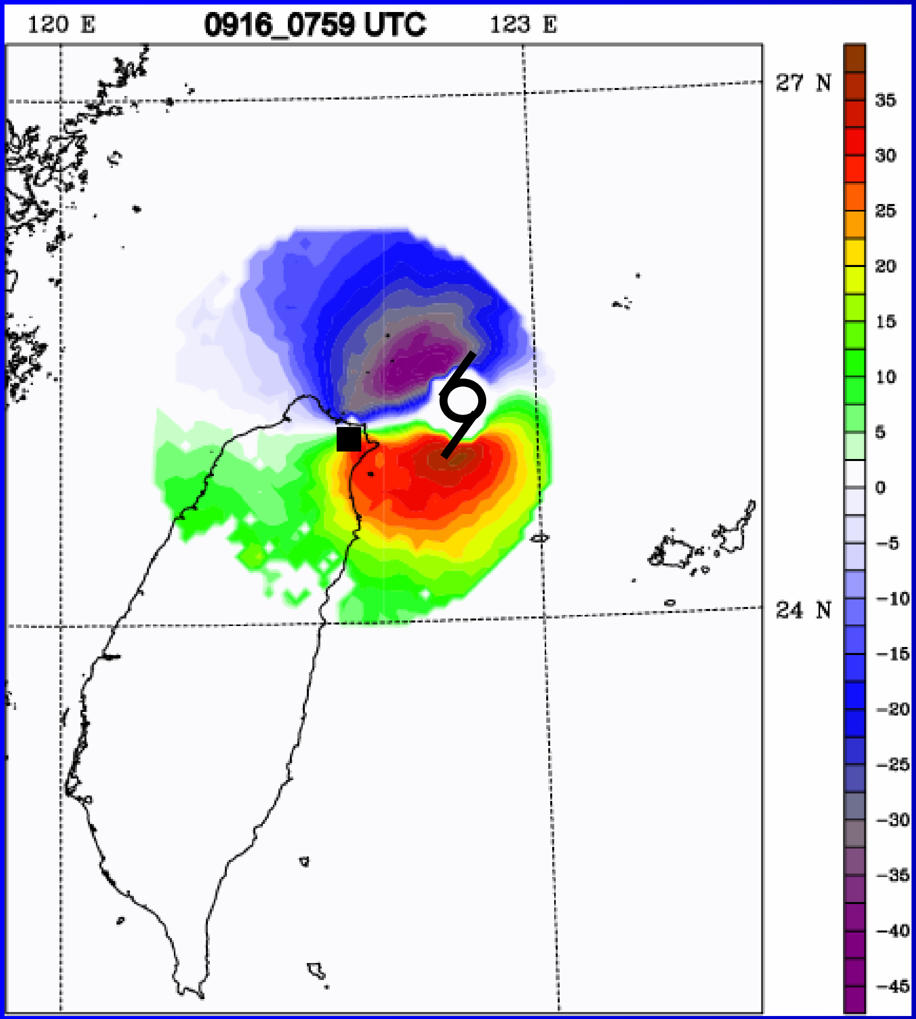


Courtesy of T.-C. Chen and Y.-C. Liou

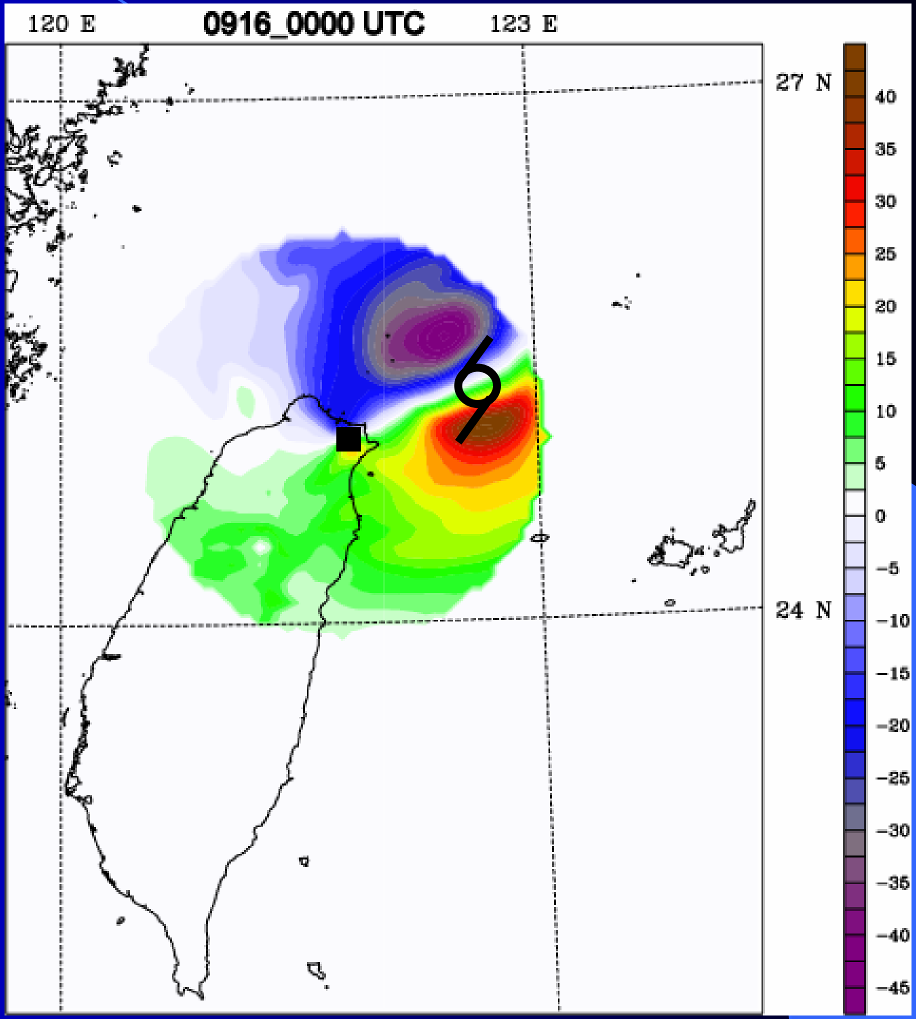
Radial Wind wrt RCWF Radar

Height = 3 km

Obs Vr (6 km pixel)



MM5 Vr (dx = 6 km)

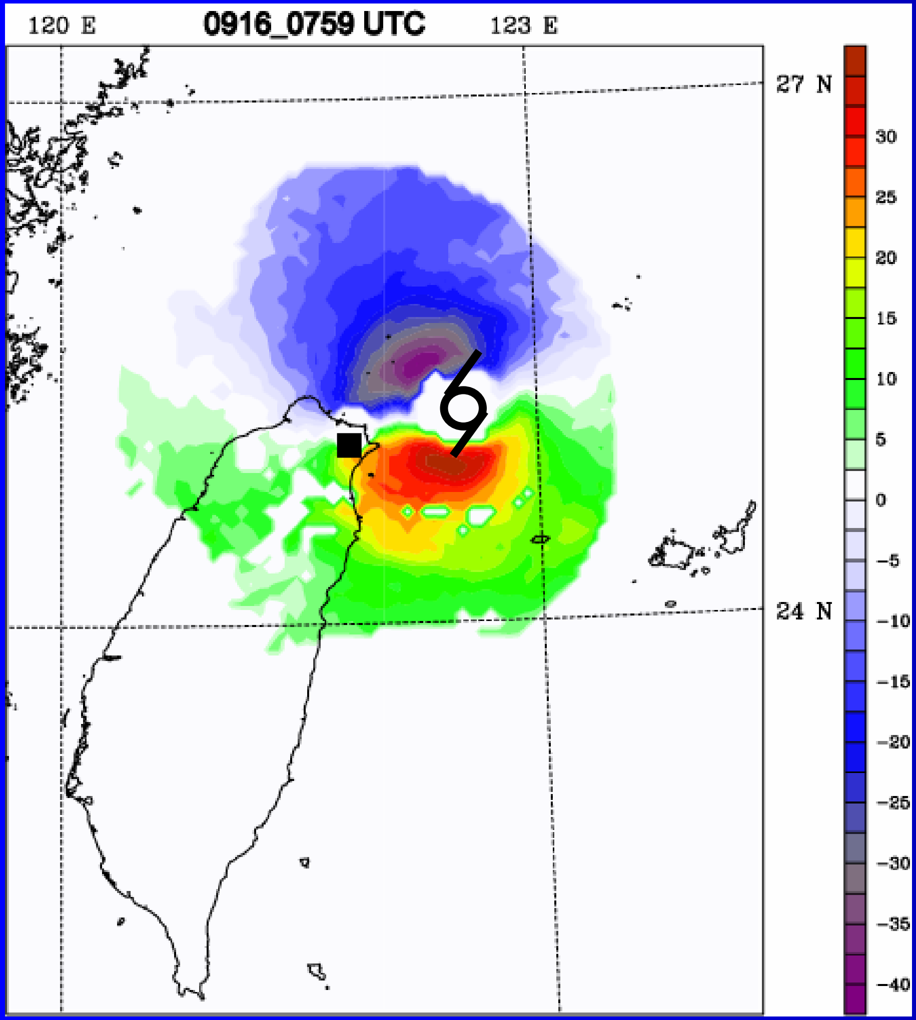


Courtesy of T.-C. Chen and Y.-C. Liou

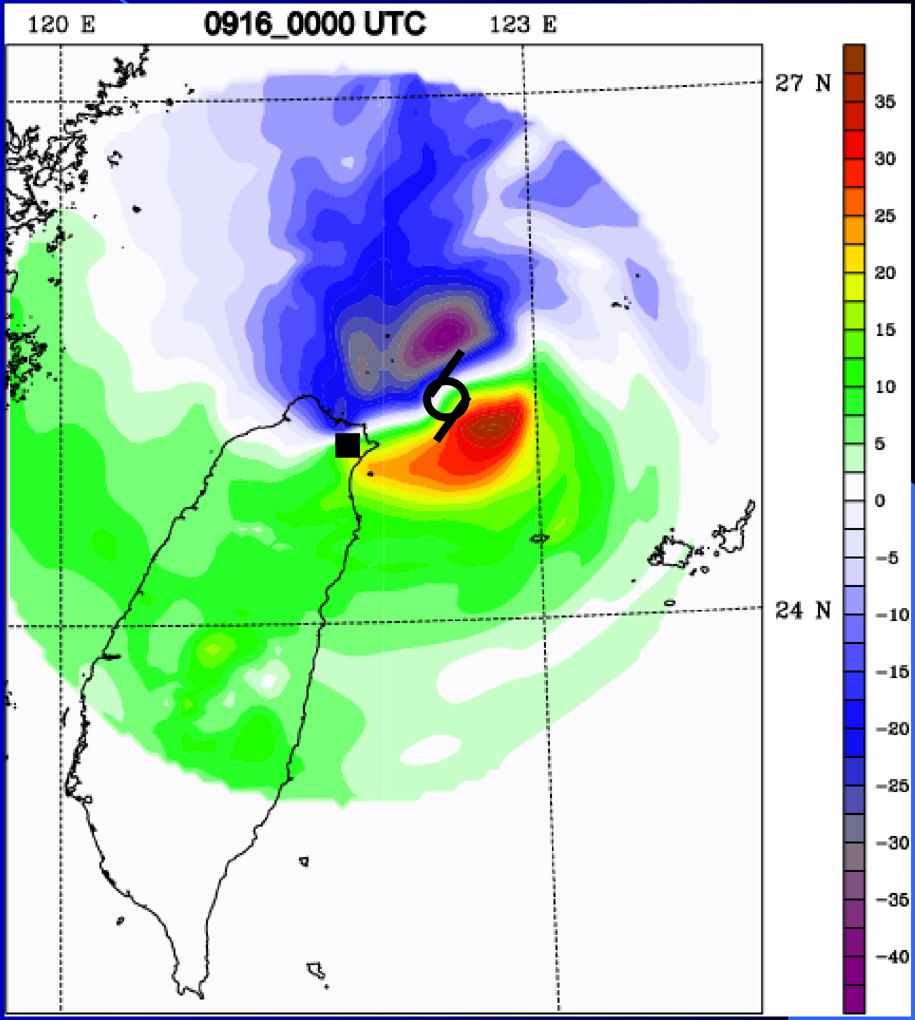
Radial Wind wrt RCWF Radar

Height = 6 km

Obs Vr (6 km pixel)



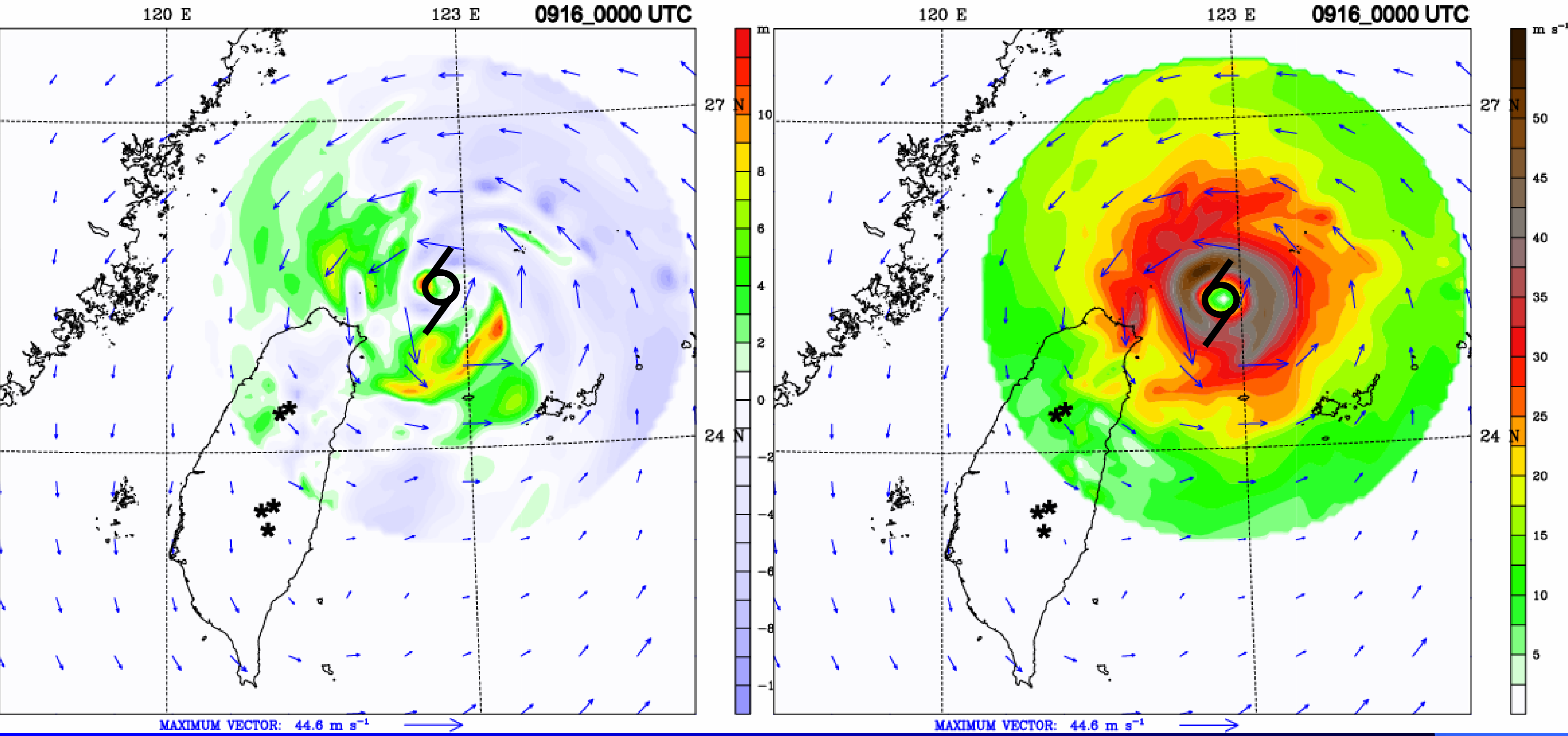
MM5 Vr (dx = 6 km)



Courtesy of T.-C. Chen and Y.-C. Liou

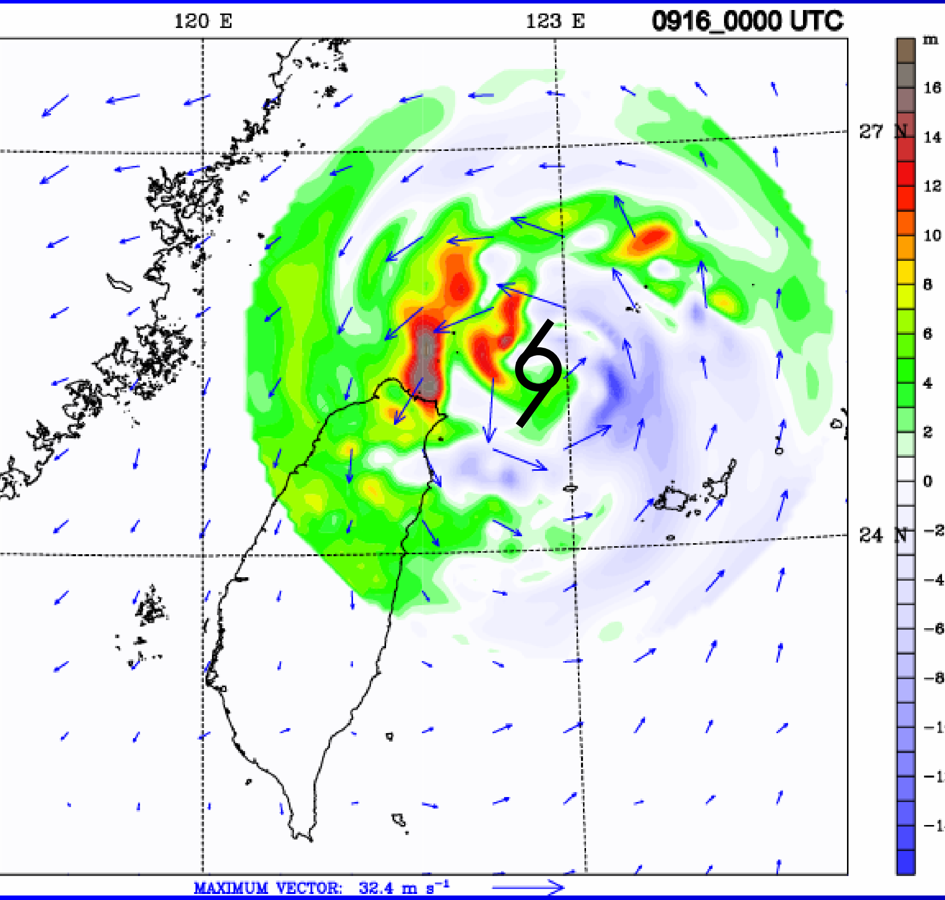
MM5 Simulated Vr & Vt
Nari at Sea (H = 3 km)

Radial Velocity | Tangential Velocity

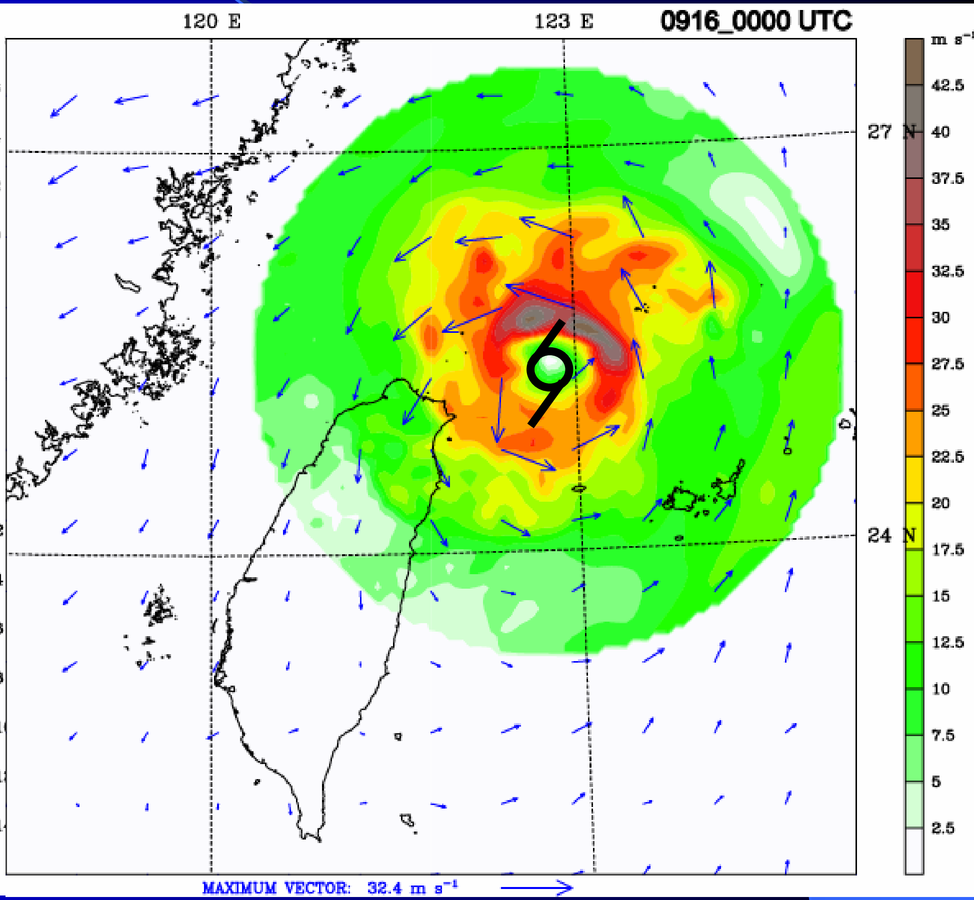


MM5 Simulated Vr & Vt
Nari at Sea (H = 9 km)

Radial Velocity

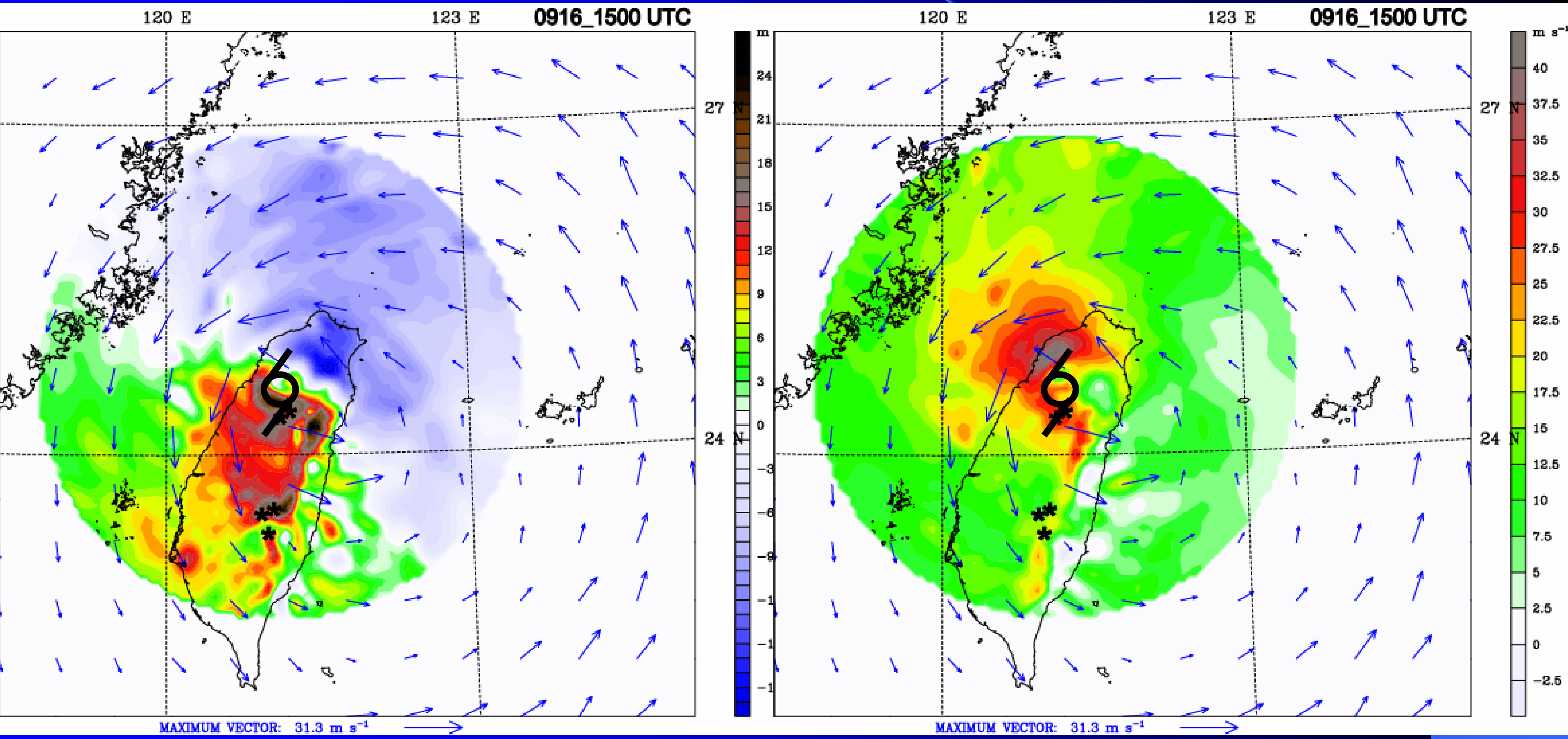


Tagential Velocity



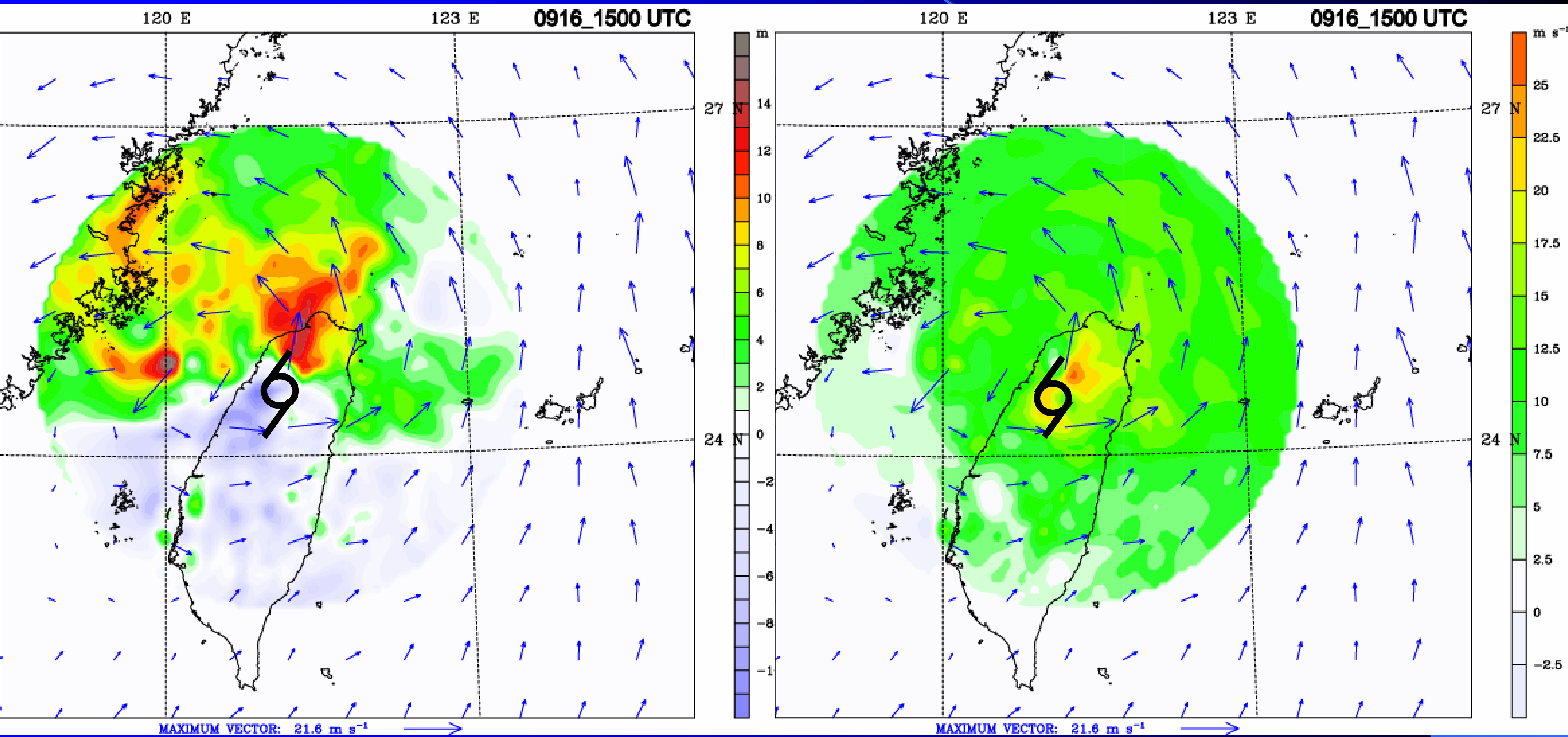
MM5 Simulated Vr & Vt
Nari Landfall (H = 3 km)

Radial Velocity **Tagential Velocity**

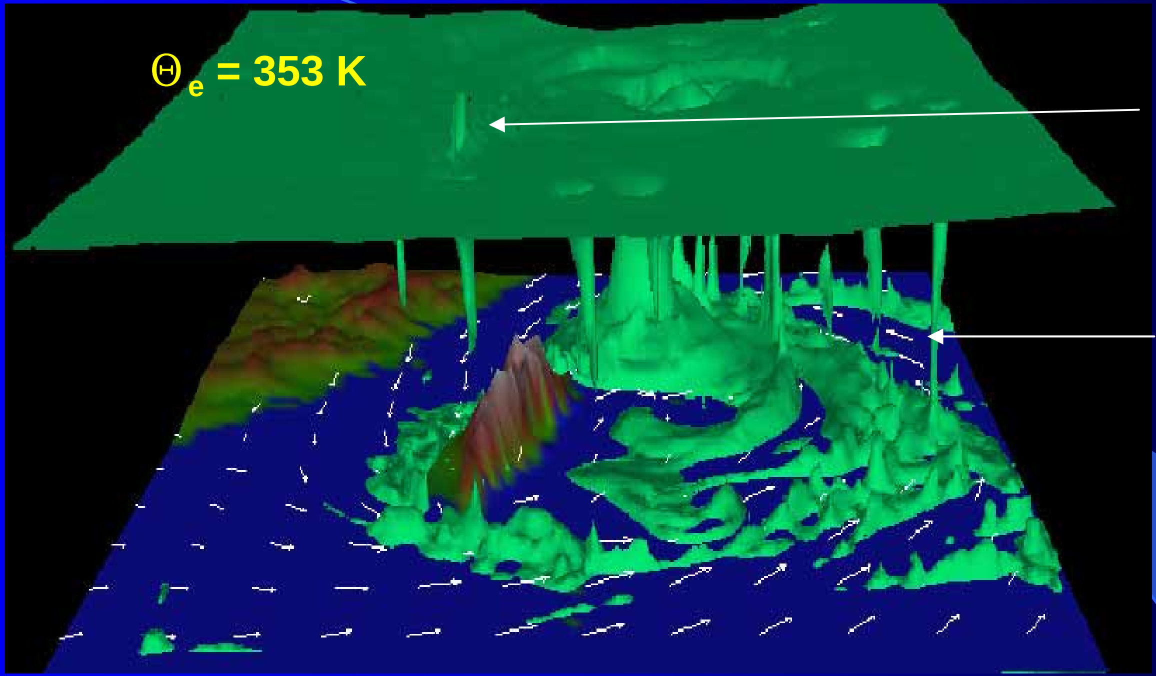


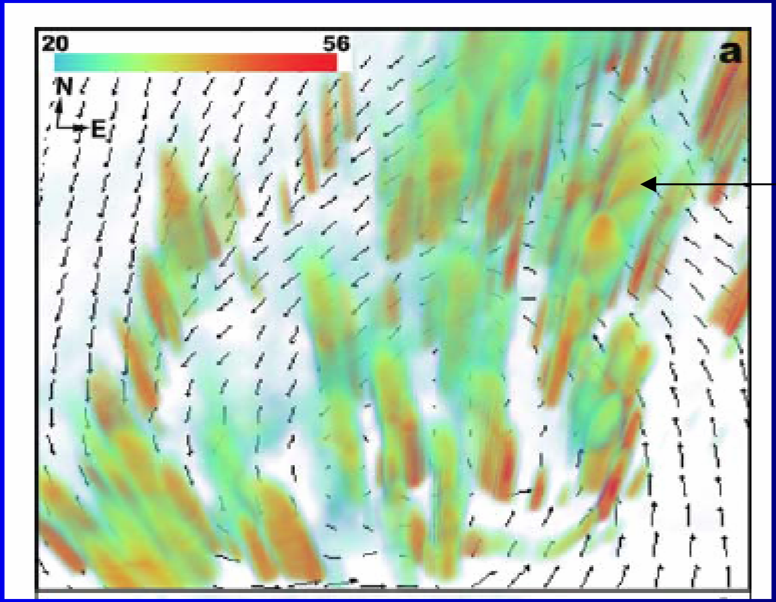
MM5 Simulated Vr & Vt
Nari Landfall (H = 9 km)

Radial Velocity **Tagential Velocity**



Vis5D plot of 353K Θ e isosurface



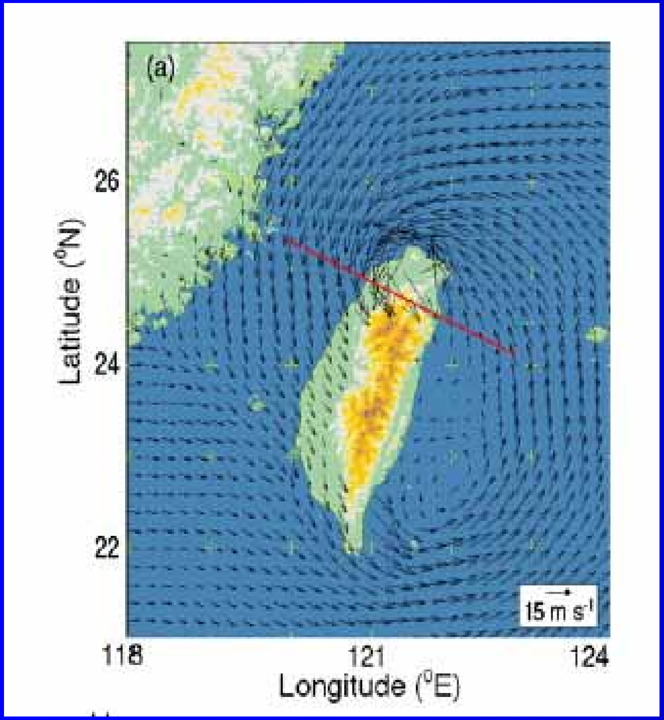


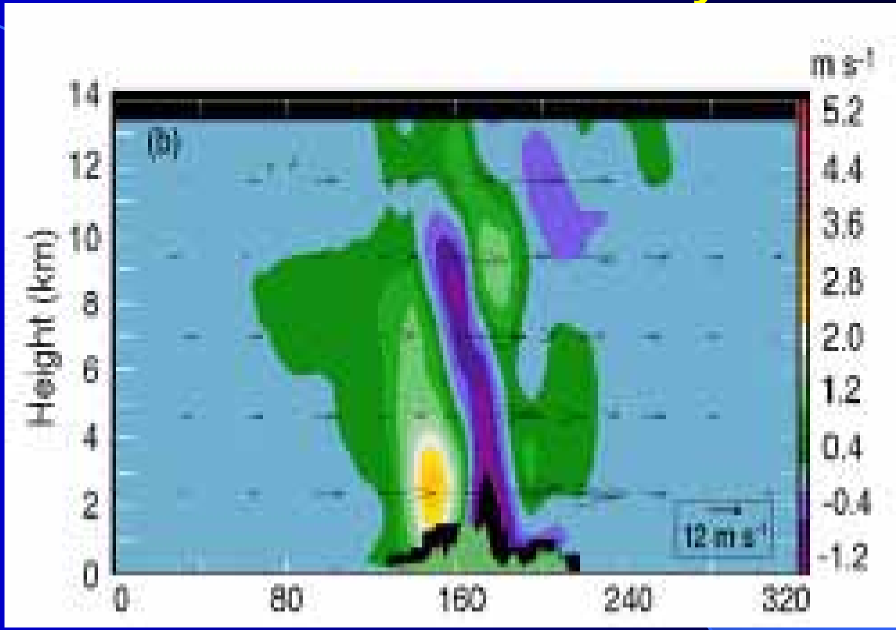
Vis5D plot of Nari's radar echo (color)

Courtesy of D.-L. Zhang

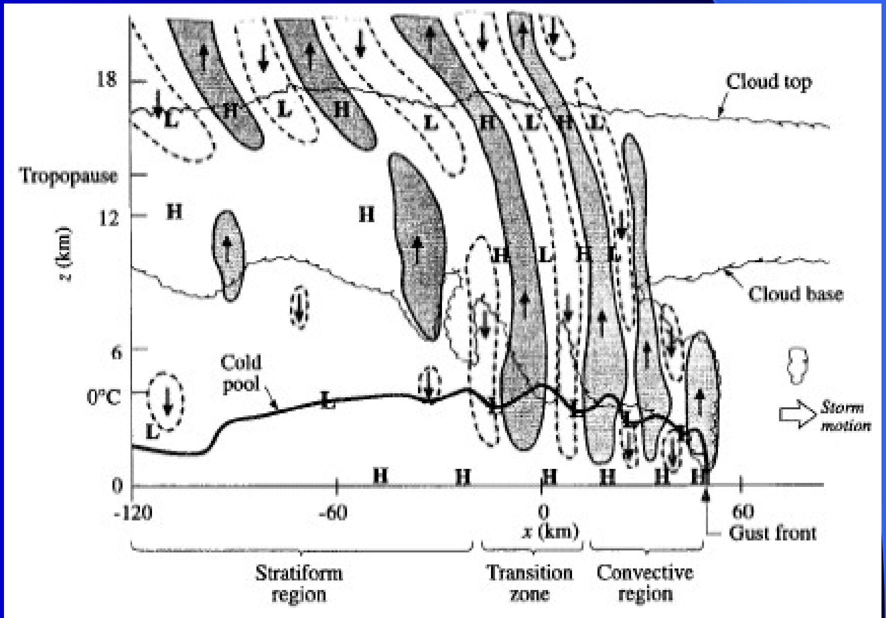
Horizontal Cross Section

Vertical Cross Session of Vertical Velocity

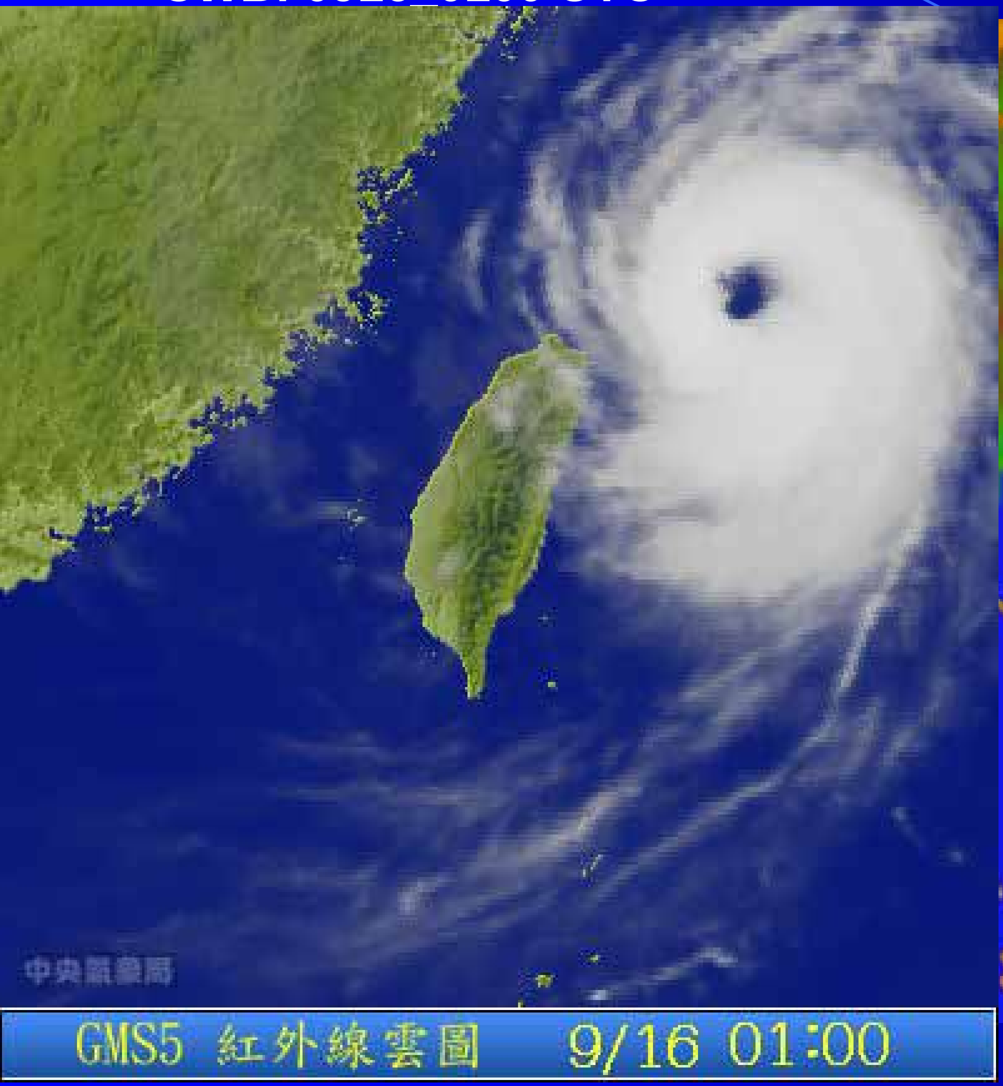




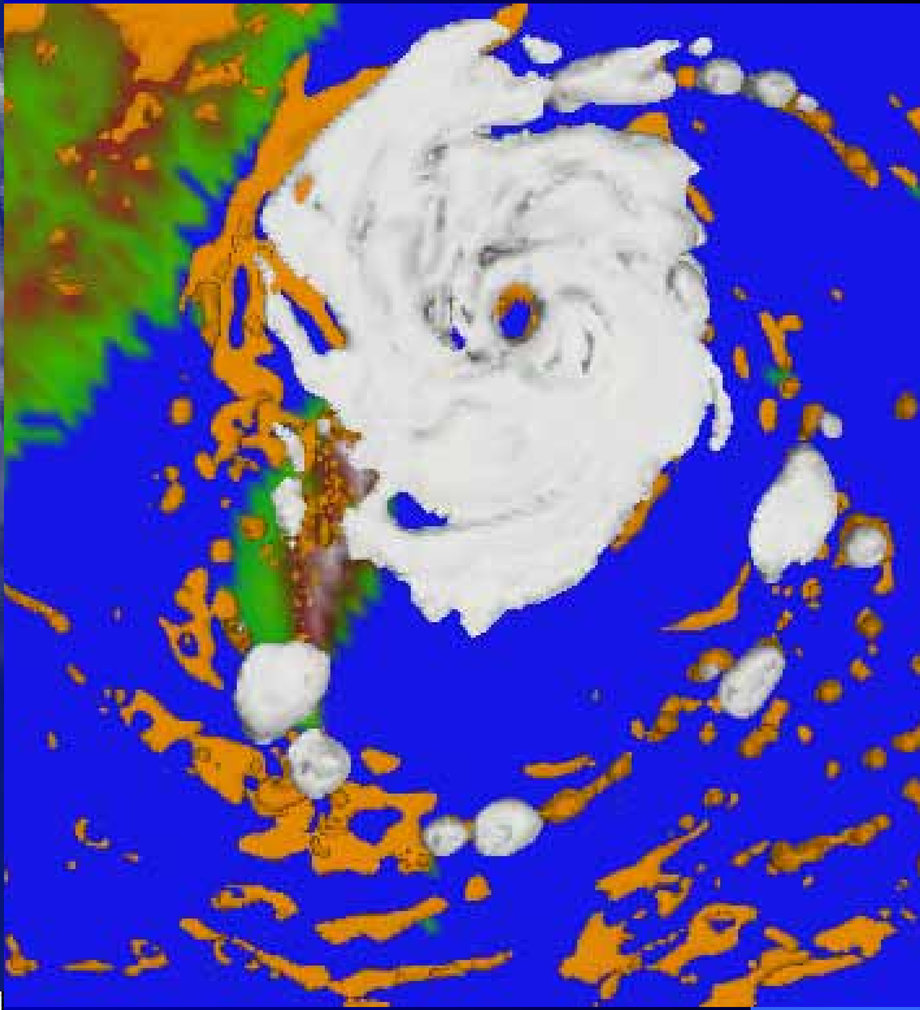
Gravity waves in squall lines (Yang and Houze 1995)



CWB: 0916_0100 UTC



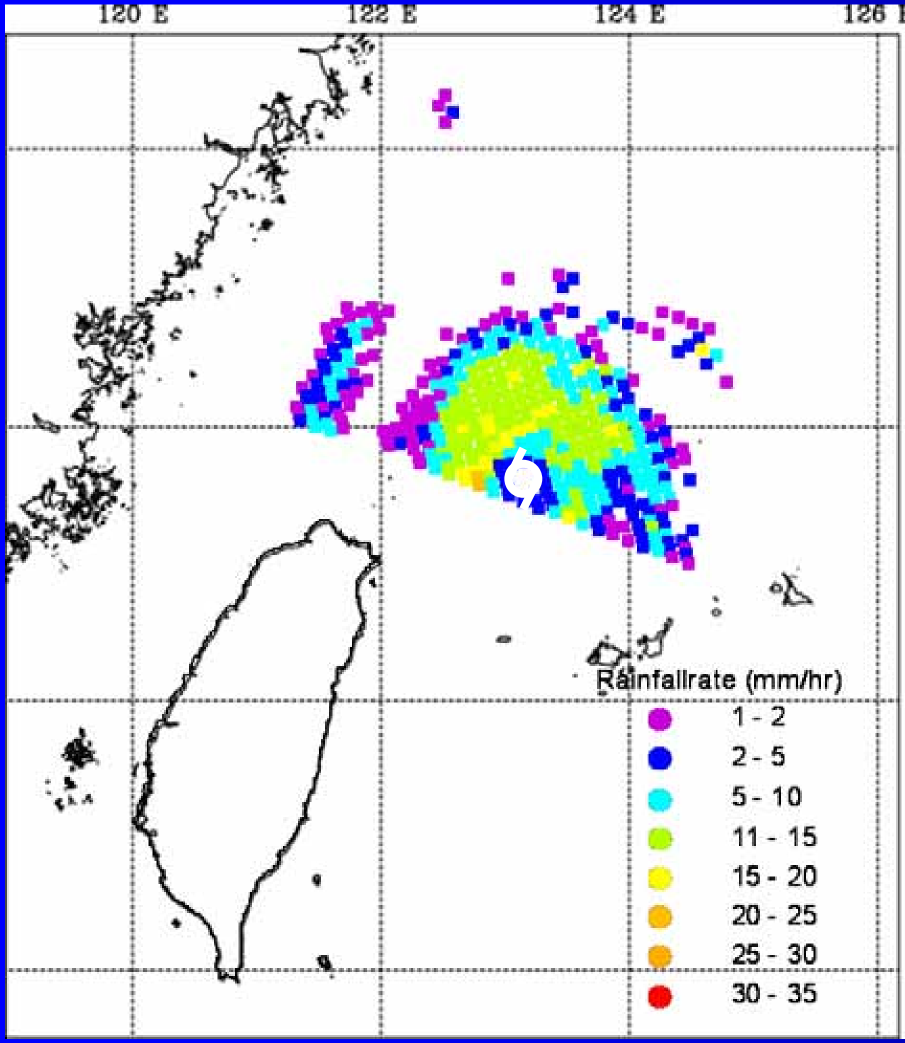
CTL: 0916_0000 UTC



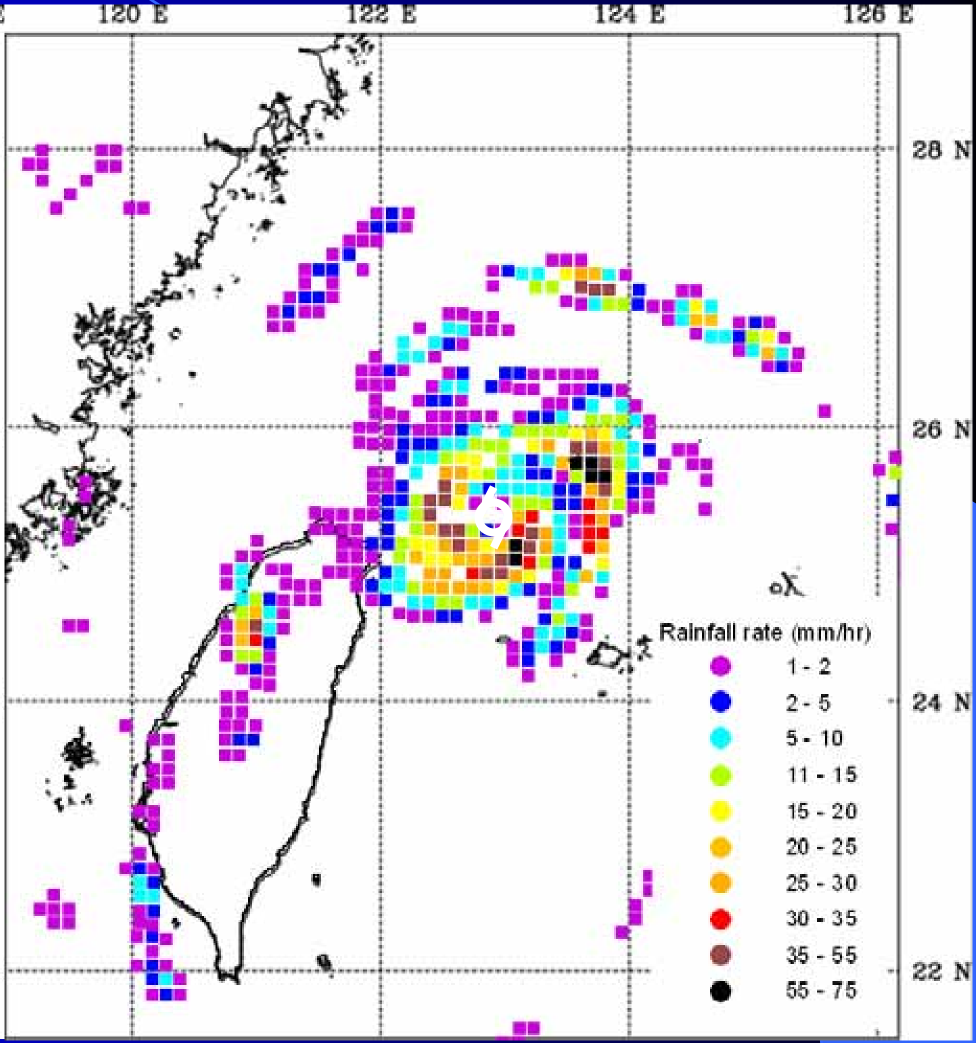
Isosurface of Snow and Cloud Water

Rainrate Comparison

TRMM/PR: 0915/2328 UTC (10 km pixel)



MM5: 0915/2100 UTC (12 km grid)

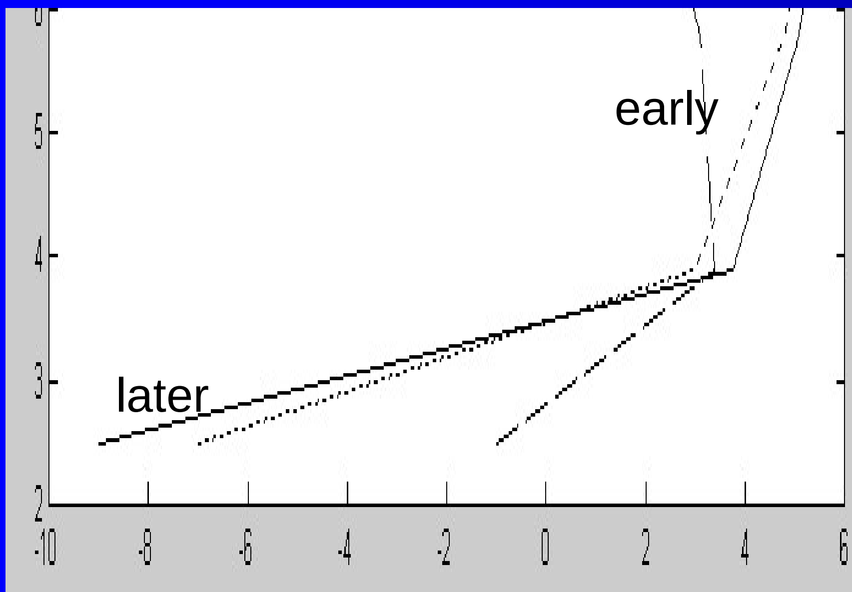


Courtesy of W.-J. Chen

Vertical Profile of Horizontal Divergence

Radar VAD Analysis

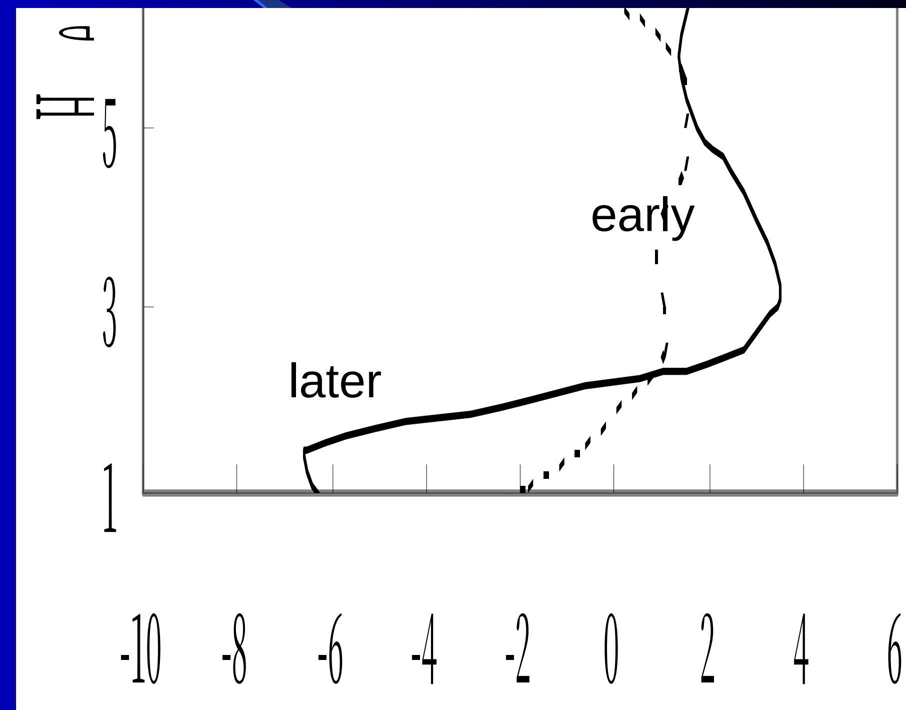
Height (km)



Divergence (1E-4 /s)

Courtesy of T.-C. Chen
and Y.-C. Liou

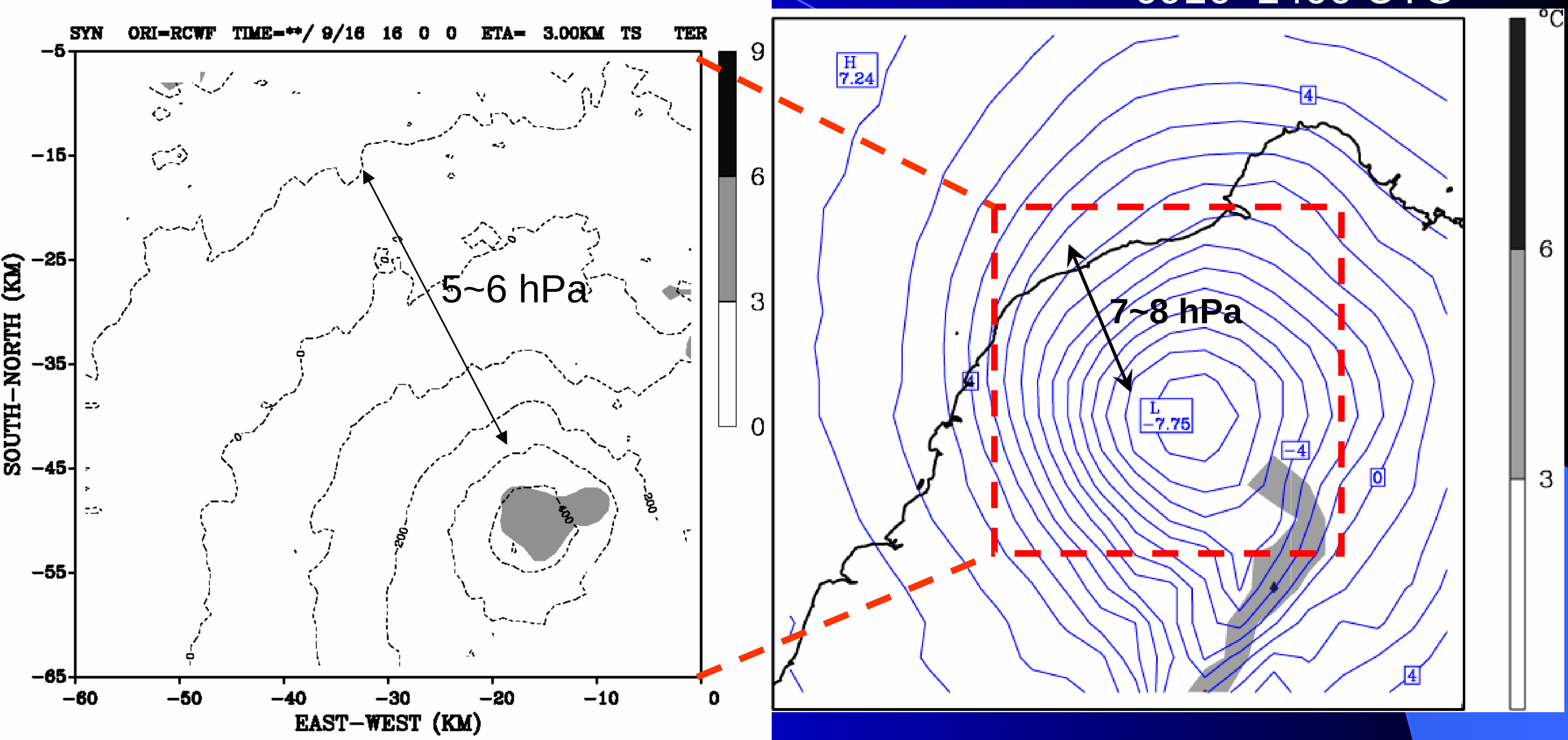
MM5 Divergence Profile



Divergence (1E-4 /s)

Horizontal Cross Section of Pressure and Temperature Perturbations

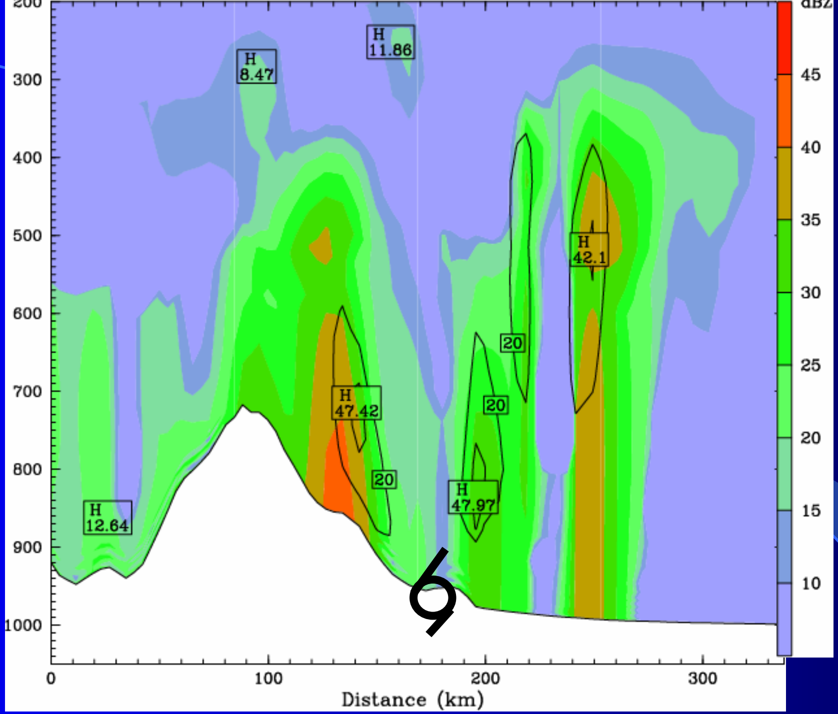
0916 1400 UTC



Radar Retrieval (wrt. a Station Sounding)

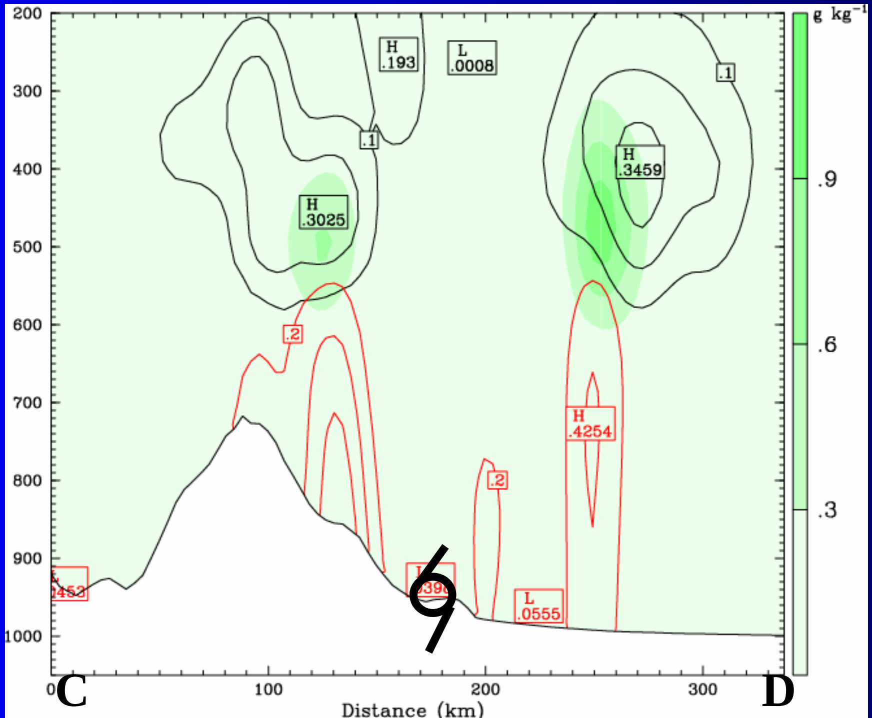
Courtesy of T.-C. Chen and Y.-C. Liou

MM5 Simulation (wrt. a Horizontal Area Mean)

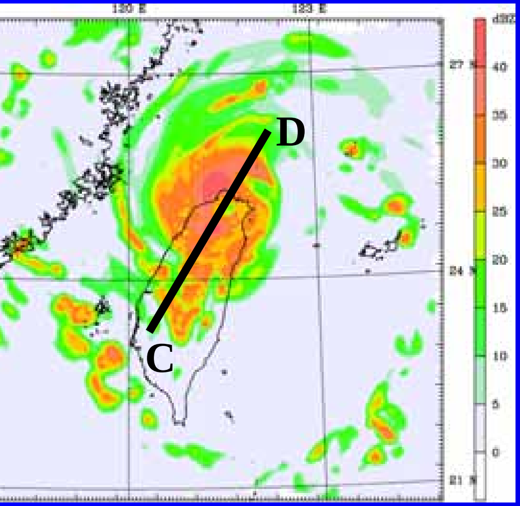


Radar echo (color)
Condensational Heating (contour)

Vertical Cross Section after Landfall



Snow (black contour)
Rain (red contour)
Graupel (color)



Summary

- After detailed comparisons, the MM5 simulated the following features reasonably well:

  the track of Typhoon Nari,

  landfall over northeast Taiwan and intensity change,

  many observed precipitation and kinematic features

- Simulated temperature and pressure perturbations are in good agreement with radar retrieval results. Simulated vertical divergence profile compares fairly with that by radar data.

- After landfall, Taiwan’s topography enhances asymmetry on the kinematic structure with stronger response on the radail wind, and its impacts are stronger at lower levels and weaker at upper levels

Part II: Precipitation Efficiency

In cooperation with Chung-Hsiung Sui, and Xiaofan Li

Ref: Sui, C.-H., X. Li, M.-J. Yang, and H.-L. Huang, 2005: Estimation of oceanic precipitation efficiency in cloud models. *J. Atmos. Sci.*, in press.

Effects of hydrometeor convergence on precipitation efficiency

$$\frac{\partial[q_v]}{\partial t} = [CONV_{qv}] + E_s - [S_{qv}]$$

$$\frac{\partial[C]}{\partial t} = [CONV_C] - P_s + [S_C]$$

Ps **is surface precipitation；**
Sqv = SIqv + SOqv
SIqv **= [*PCND*]+ [*PDEP*]+ [*PSDEP*]+ [*PGDEP*], sinks of water vapor through condensation and deposition (via cloud ice, snow, and graupel)；**
SOqv = [PREVP]+ [PMLTG]+ [PMLTS], **sources of water vapor through evaporation of cloud water, melting snow, and melting graupel；**
[CONVc] **is convergence of all hydrometeors (C)；**
C = qc + qr + qi + qs + qg

Cloud Microphysics Precipitation Efficiency (CMPE)

$$\boldsymbol{CMPE} = \frac{P_s}{[SI_{qv}]} = 1 - \frac{[SO_{qv}]}{[SI_{qv}]} + \frac{[CONV_C]}{[SI_{qv}]}$$

Ps **is surface precipitation**
SIqv **= [*PCND*]+ [*PDEP*]+ [*PSDEP*]+ [*PGDEP*], sinks of water vapor through condensation and deposition (cloud ice, snow, and graupel)**

Large-Scale Precipitation Efficiencies; LSPE)

$$\boldsymbol{LSPE} = \frac{P_s}{[CONV_{qv}] + E_s}$$

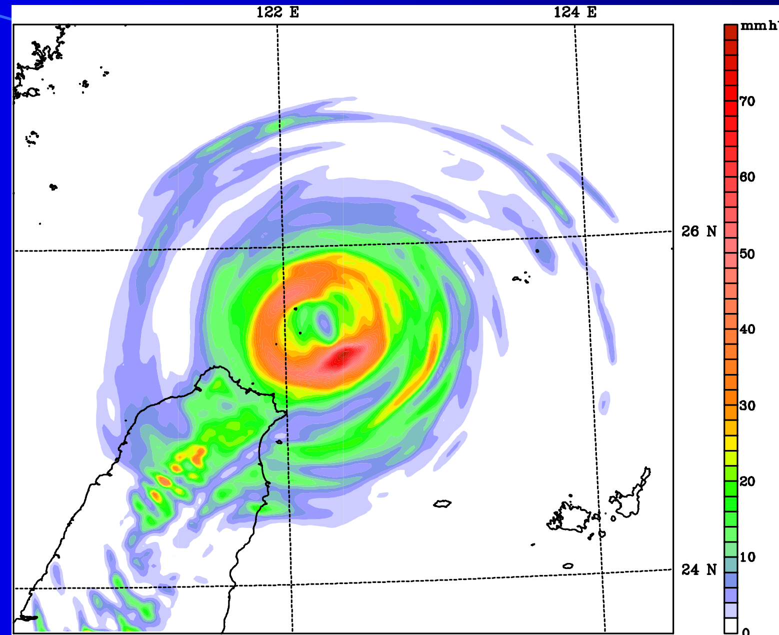
Es+[CONVqv] **is the sum of surface evaporation and water vapor convergence**

For a large-scale spatial and temporal average,

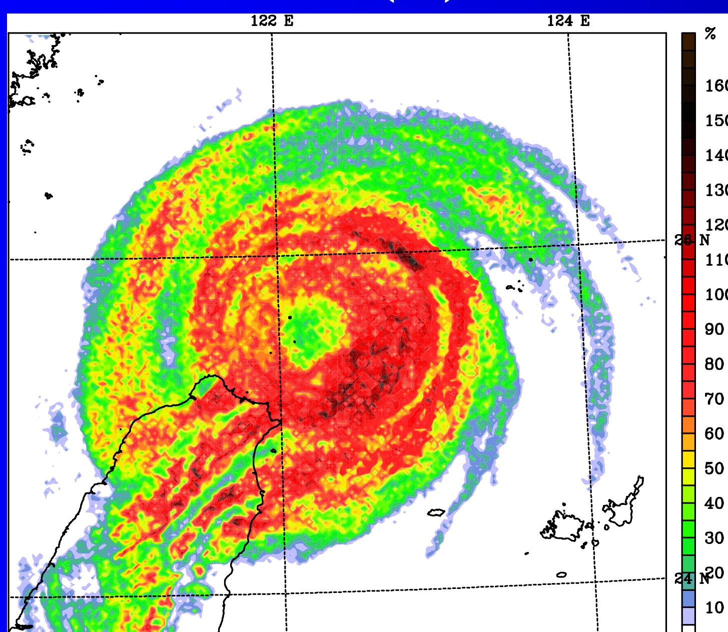
$$[P_{CND}] + [P_{DEP}] + [P_{SDEP}] + [P_{GDEP}] \approx E_s + [CONV_{qv}]$$

Note that [*F*]= $\int_0^{z_t} \overline{\rho}\, F dz$ **, the vertical integral of F weighted by density.**

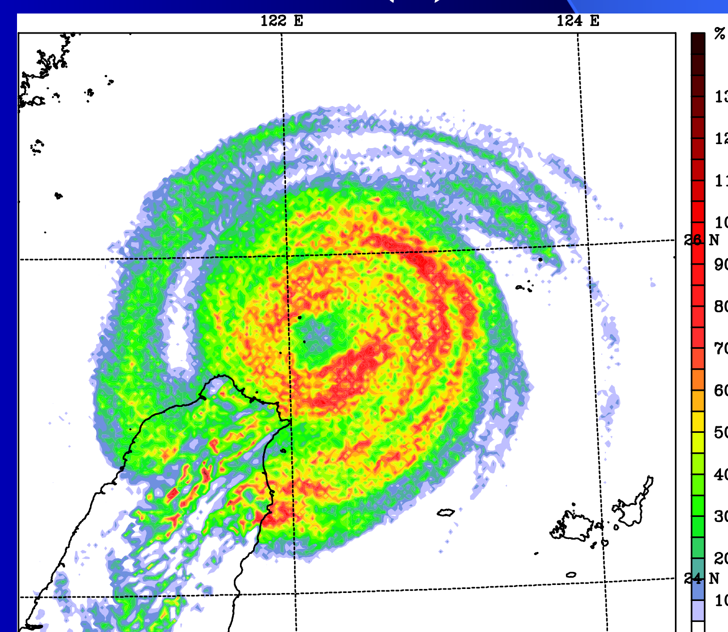
Ps (mm)



CMPE (%)



LSPE (%)

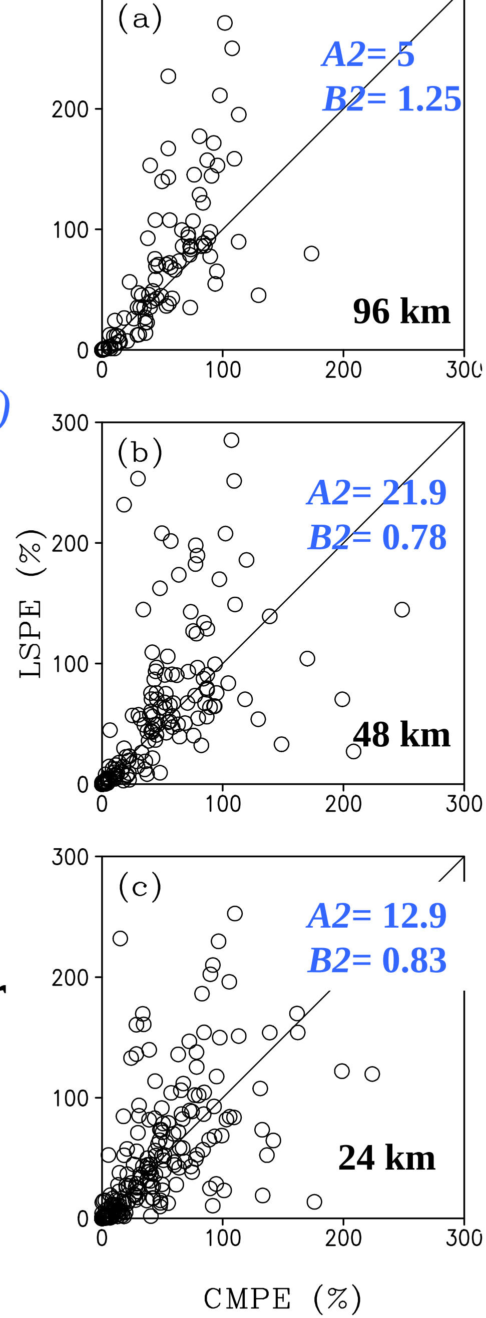


LSPE = A2 + B2 × CMPE

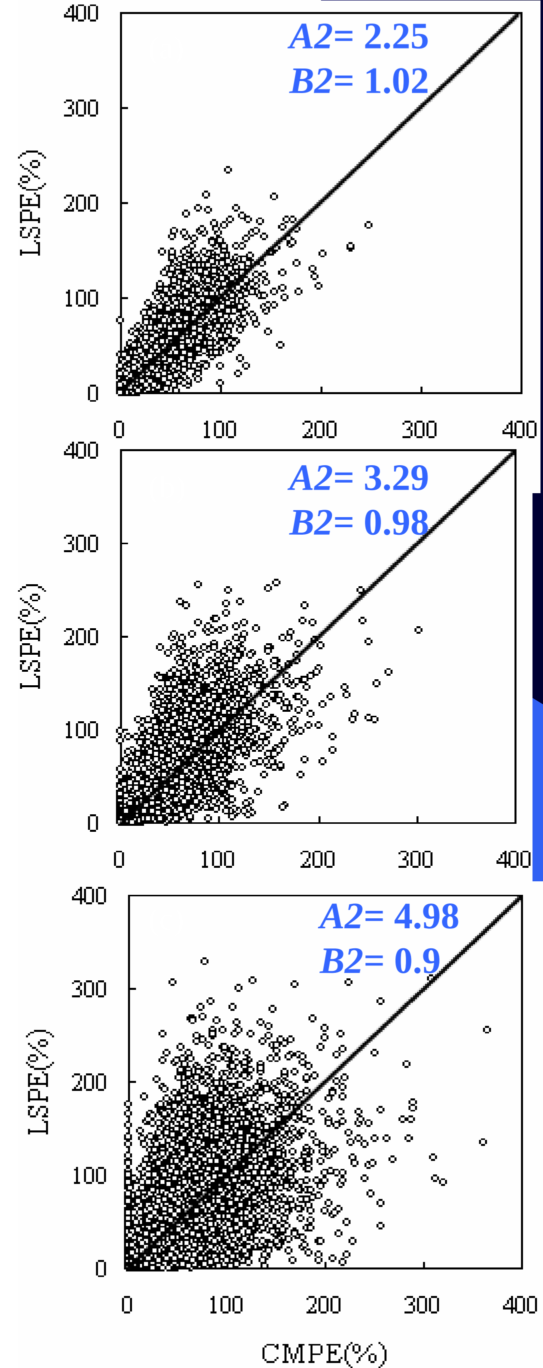
LSPE = Ps/SIqv

CMPE = Ps/(Es+[CONVqv])

All panels show the statistical equivalence CMPE =LSPE, specially when averaging over a larger area



TOGA COARE (2D)

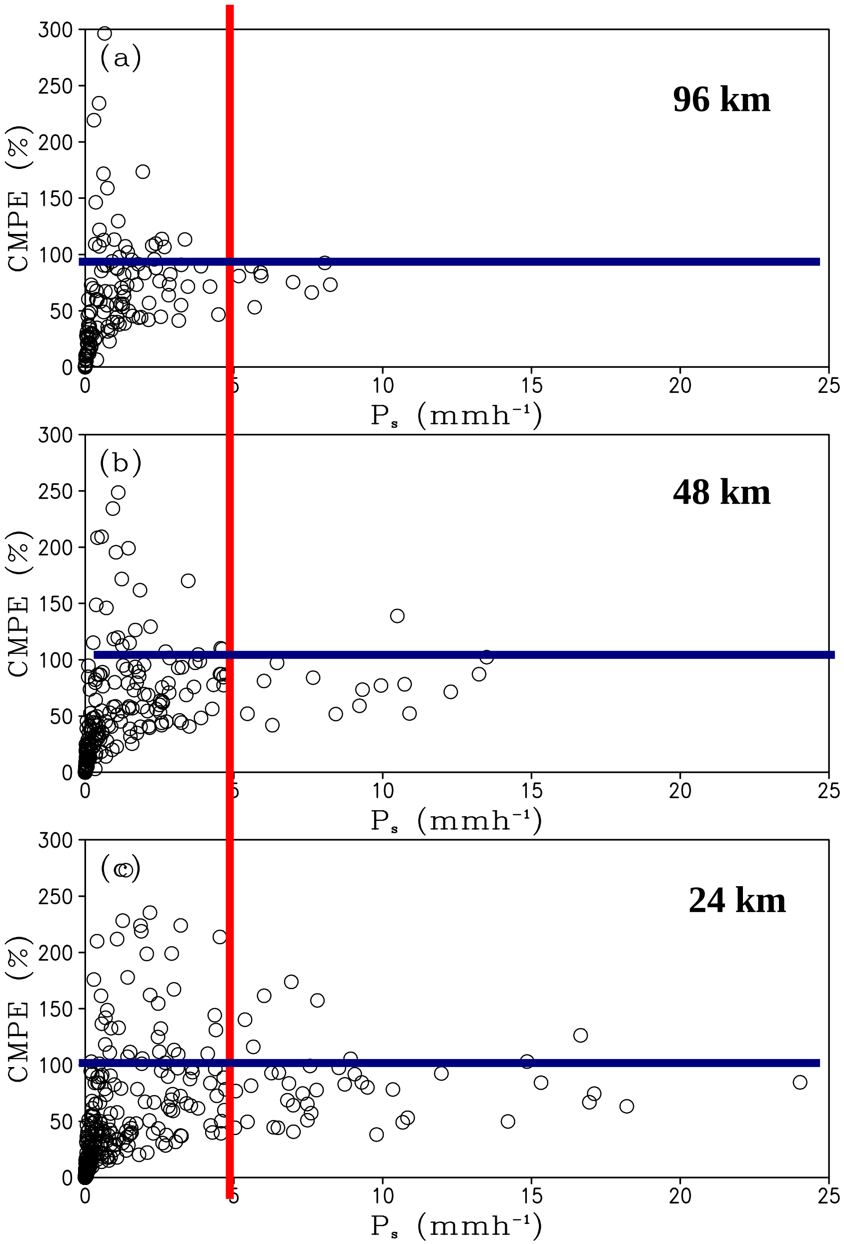


118 km²

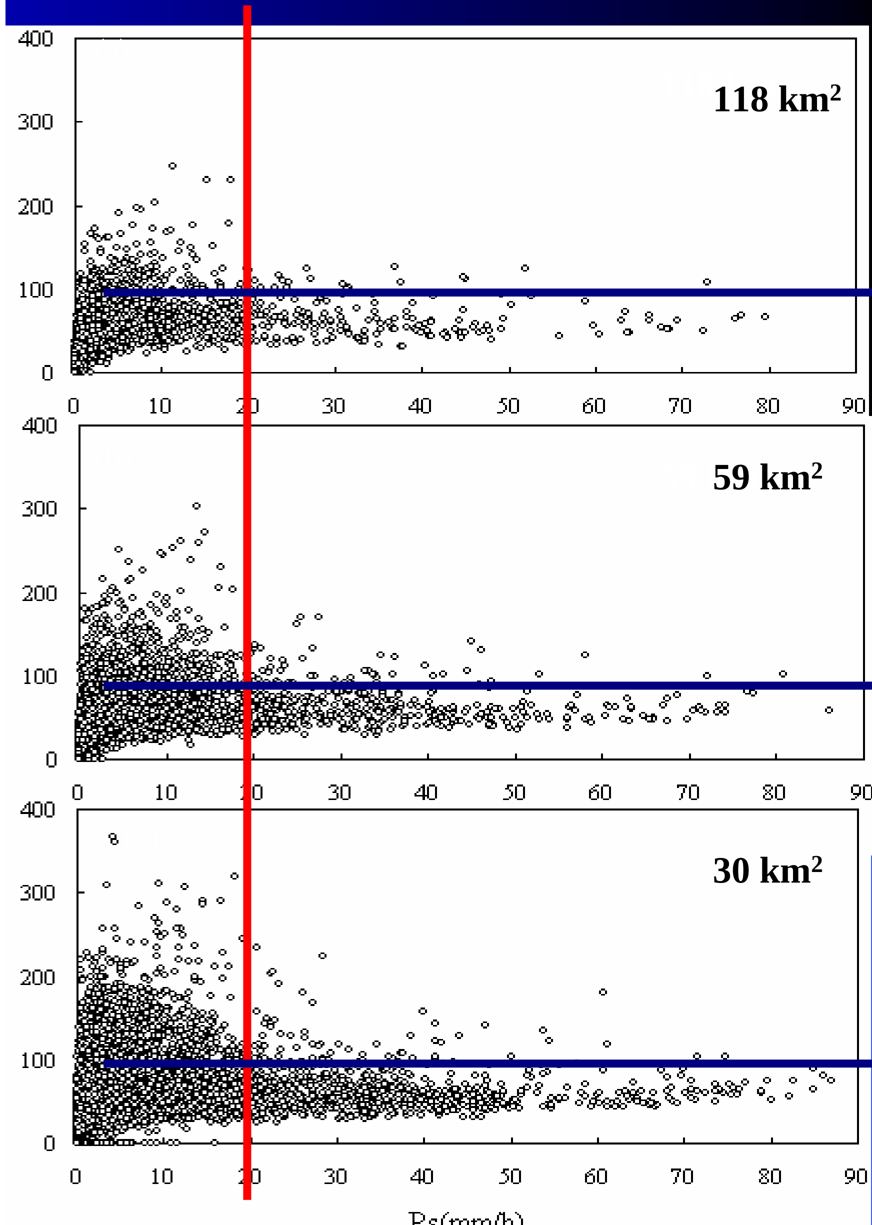
59 km²

30 km²

Typhoon Nari (MM5)



TOGA COARE (2D)



Typhoon Nari (MM5)

Summary

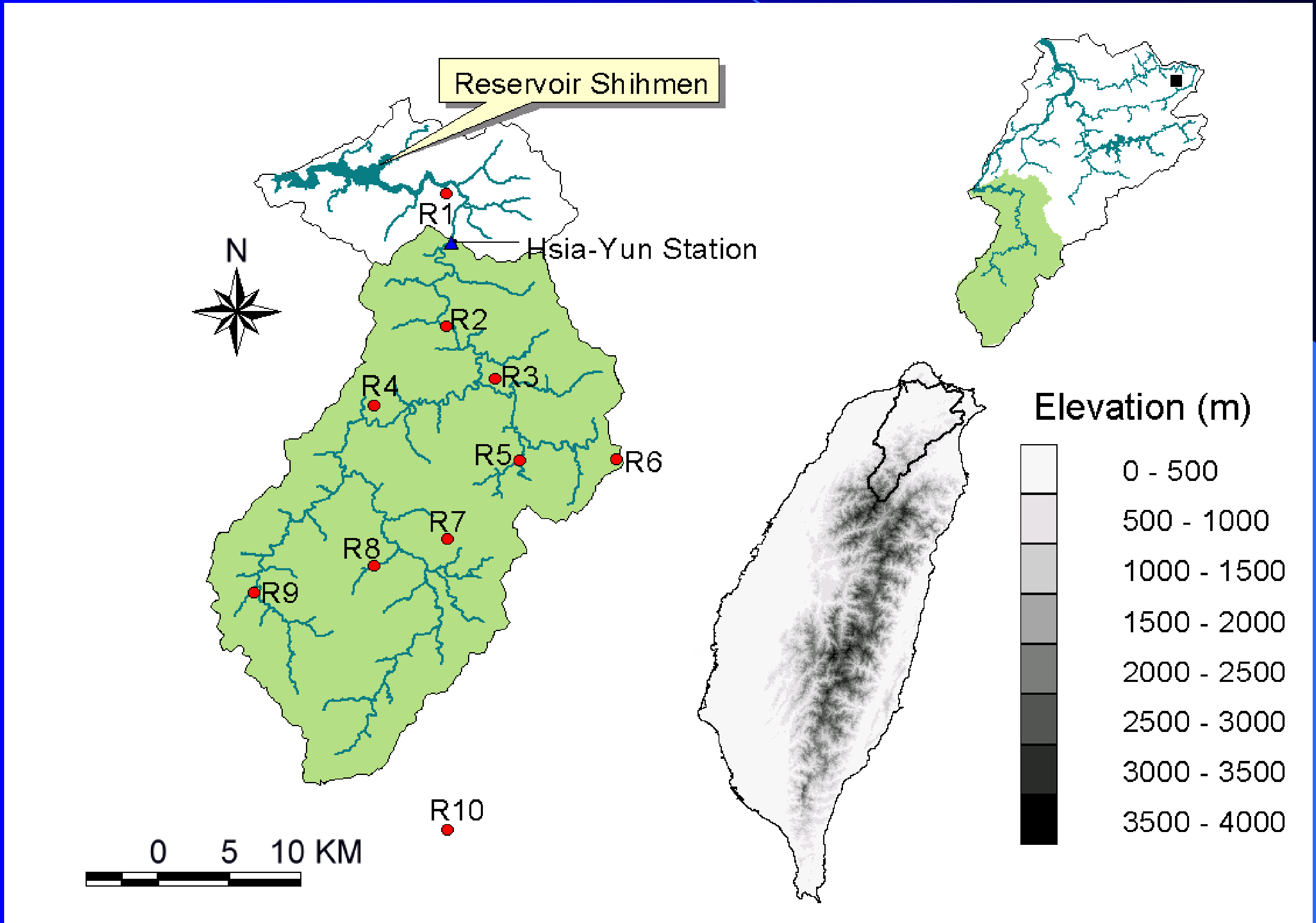
- The LSPE is equivalent to the CMPE in a statistical sense, especially after averaging over a large area (>60~100 km^2) and over several life cycles of convective cells (>3~6 h).
- The CMPE more (less) than 100% occurs in the area with positive (negative) hydrometeor convergence ([CONVc]).
- For Typhoon Nari’s heavy rainfall regime (Ps > 20~40 mm/h), the CMPE approaches to a threshold value of 60~80 %.

Part III: River Runoff Simulation (Coupling MM5 with FLO-2D)

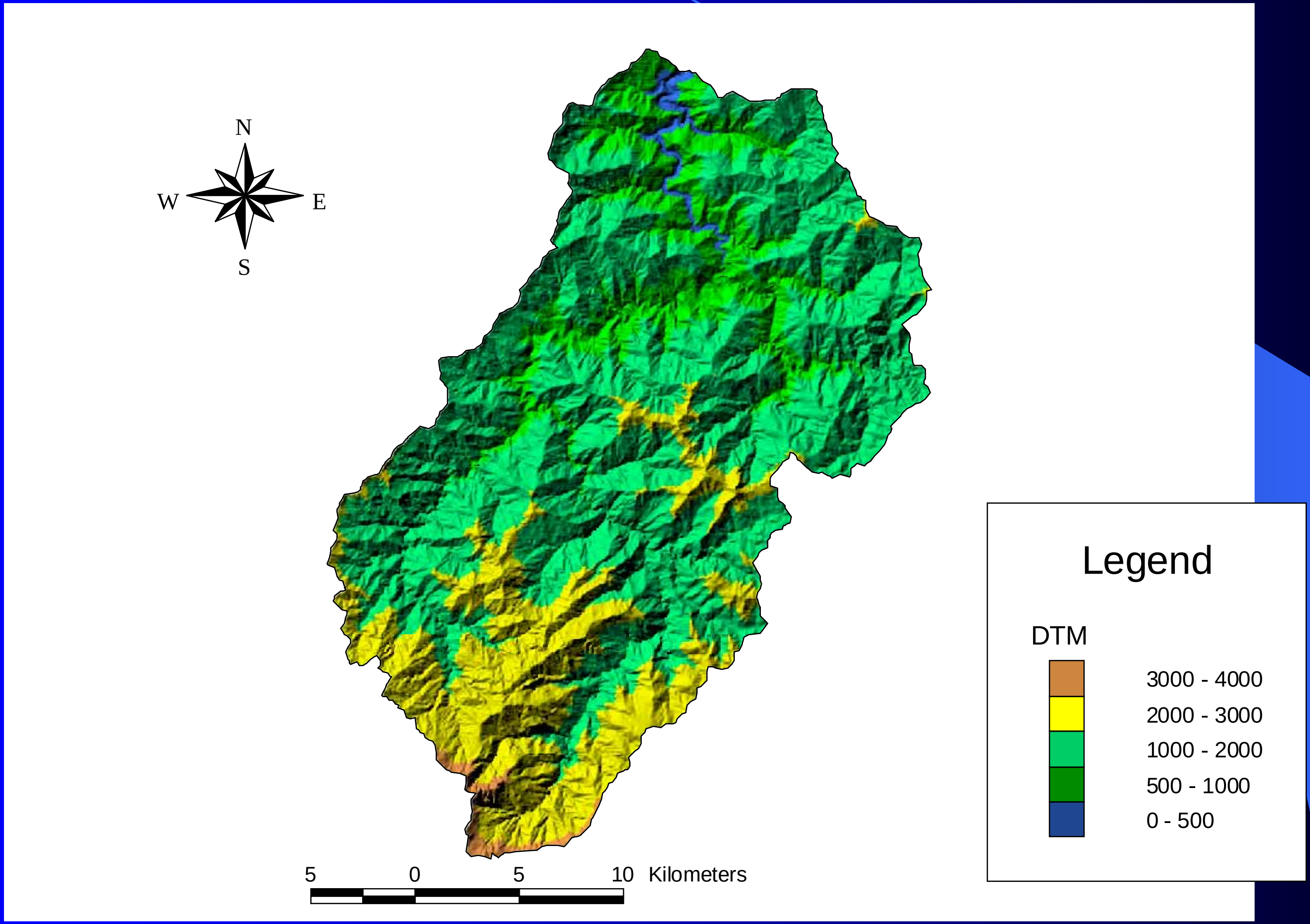
In Cooperation with Ming-Hsu Li

Ref: Li, M.-H., M.-J. Yang, R. Soong, and H.-L. Huang**,** 2005: Simulating typhoon floods with gauge data and mesoscale modeled rainfall in a mountainous watershed. *J. Hydrometeor.*, **6**, 306–323.

Shiehmen Basin



DTM of Shihmen Watershed



The continuity and depth-averaged momentum equations in the FLO-2D runoff model are:

$$\frac{\partial h}{\partial t} + \frac{\partial h V_x}{\partial x} + \frac{\partial h V_y}{\partial y} = I_e$$

$$\frac{\partial V_x}{\partial t} = -V_x \frac{\partial V_x}{\partial x} - V_y \frac{\partial V_x}{\partial y} - g \frac{\partial h}{\partial x} + g\left(S_{ox} - S_{fx}\right)$$

$$\frac{\partial V_y}{\partial t} = -V_x \frac{\partial V_y}{\partial x} - V_y \frac{\partial V_y}{\partial y} - g \frac{\partial h}{\partial y} + g\left(S_{oy} - S_{fy}\right)$$

where h = river depth

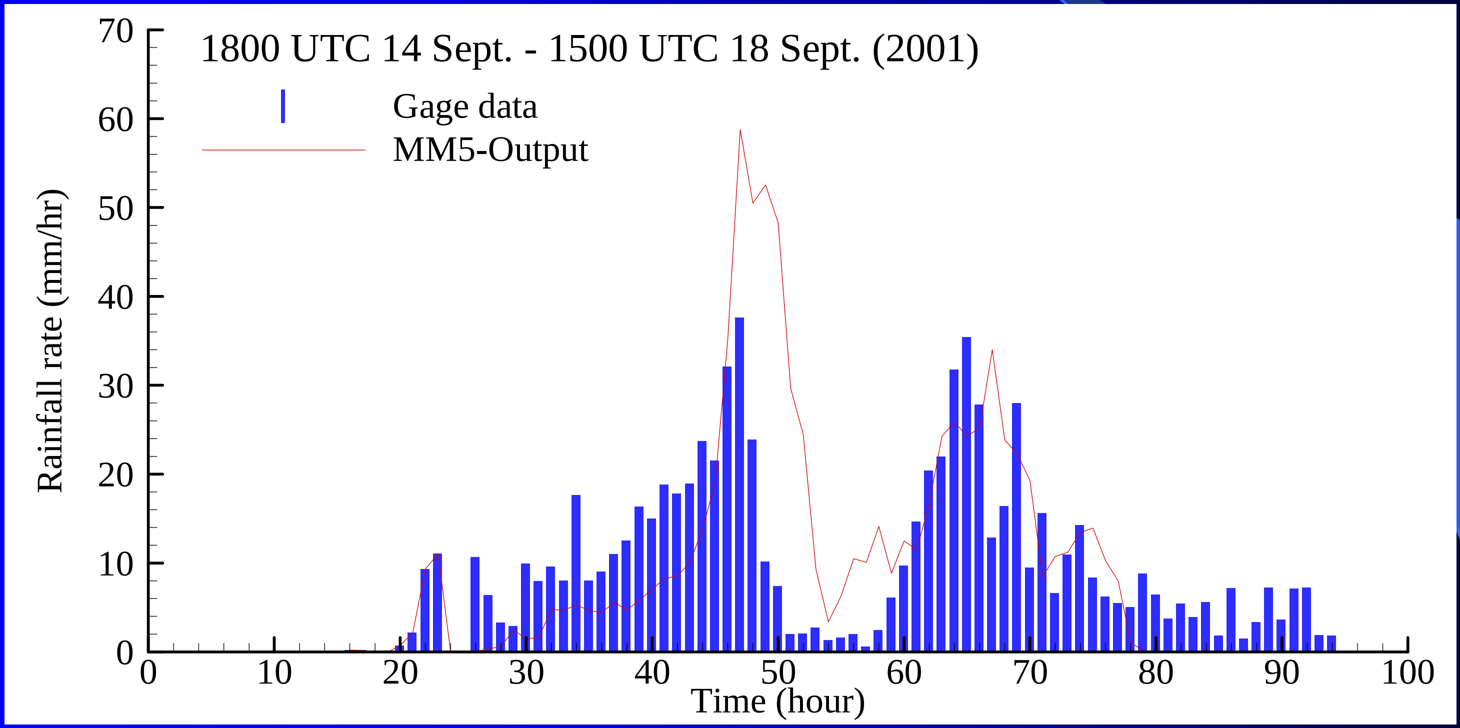
I_e = rainfall (Ps) excess over infiltration,

V_x, V_y = the depth-averaged velocity in x- and y-dir.,

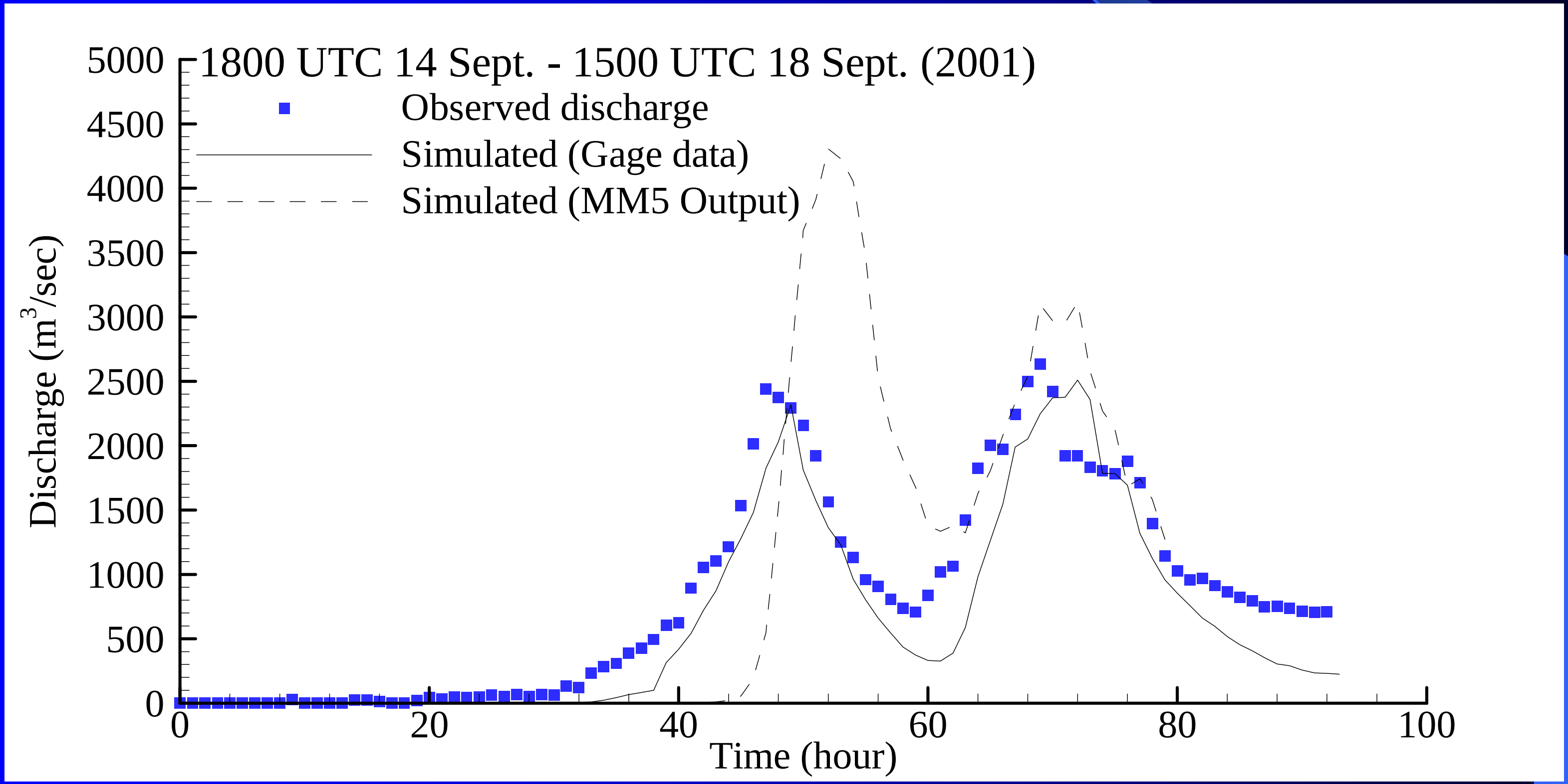
S_{ox}, S_{oy} = the bed-slope components in x- and y-dir.,

S_{fx}, S_{fy} = the friction-slope components in x- and y-dir.

Rainfall Comparison (Basin Average)

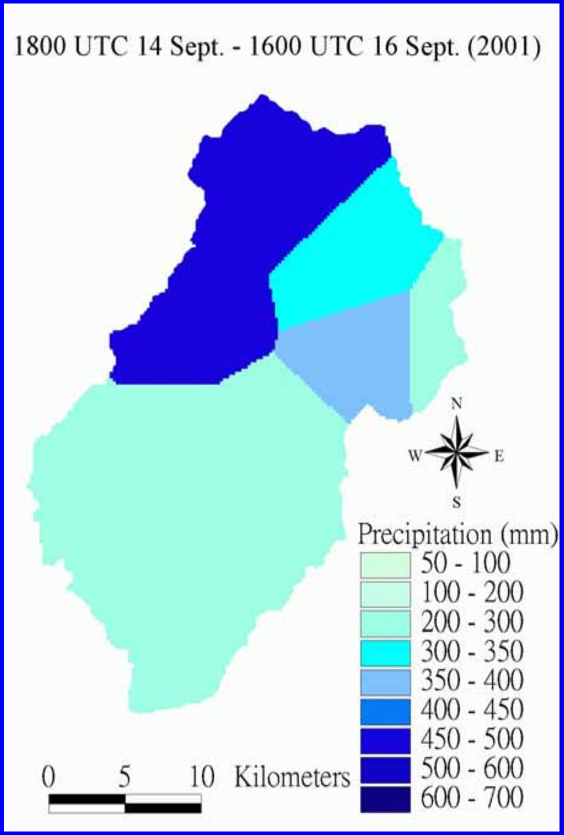


Flow Discharge Comparison (Basin Average)

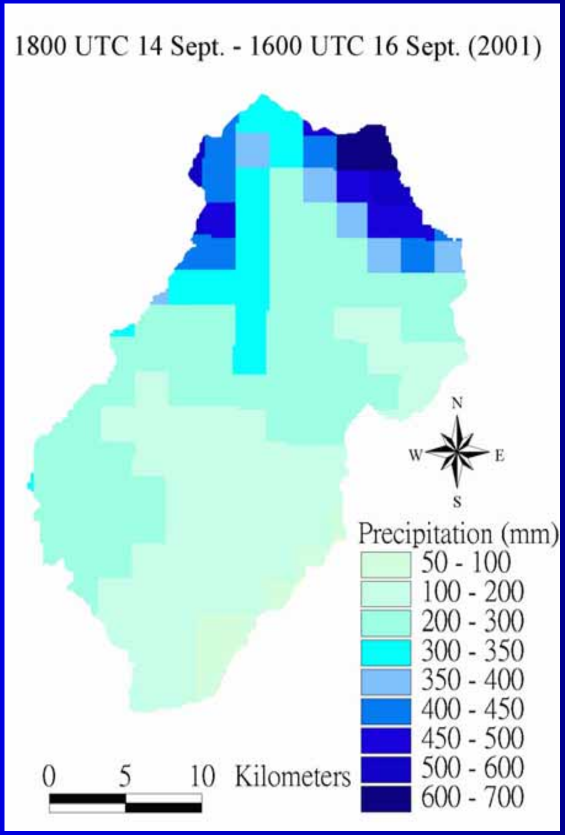


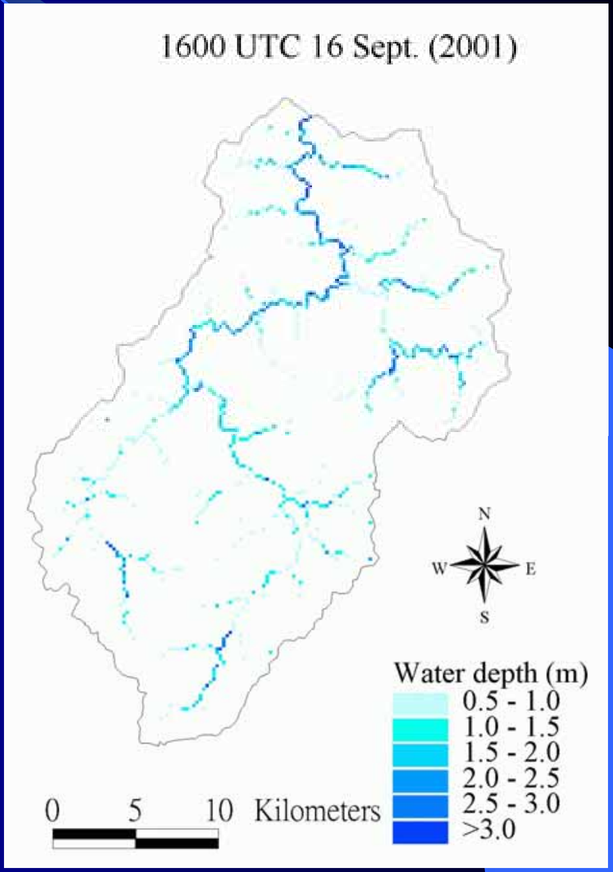
Simulated River Depths by MM5 Rainfall

Gauge Rainfall



MM5 Rainfall





Summary

- The one-way coupling of MM5 with the FLO-2D runoff model is established and verified with three typhoon cases [Herb(1996), Zeb(1998), and Nari(2001)].

- The MM5-predicted basin-averaged rainfalls are compared with those by raingauge data. This comparisons in rainfall peak amounts and time lags are used to investigate the effect of rainfall forecast error on runoff prediction.

- The error of flood prediction with the MM5 rainfall is mainly caused by the rainfall peak and timing differences, as a result of inherent uncertainties in the simulated rainfalls over a mountainous watershed during typhoon landfall periods.