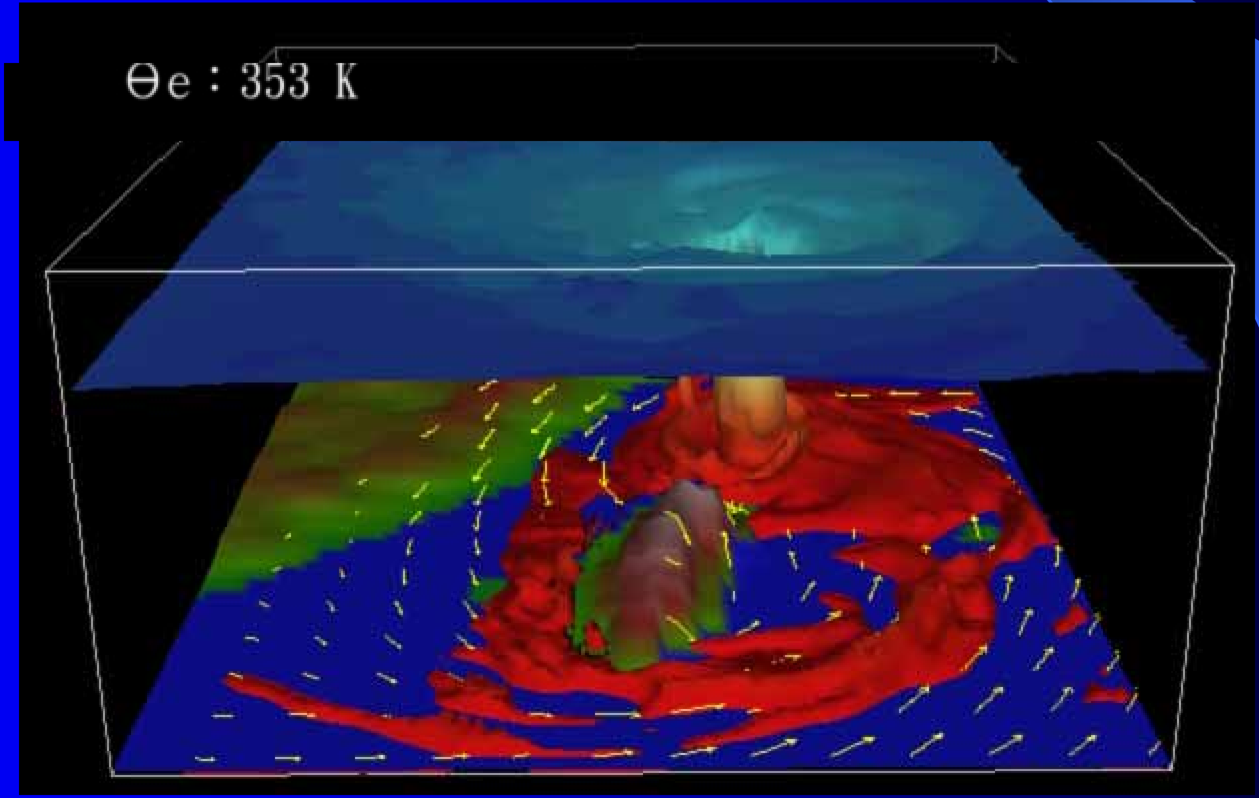
A Modeling Study on Typhoon Nari (2001): Landfall Characteristics

Ming-Jen Yang[1,2], *Hsiao-Ling Huang*[1], *Da-Lin Zhang*[2]

[1]*National Central University, Taiwan*

[2]*University of Maryland, USA*



Heavy rainfalls induced severe flooding and societal damage !

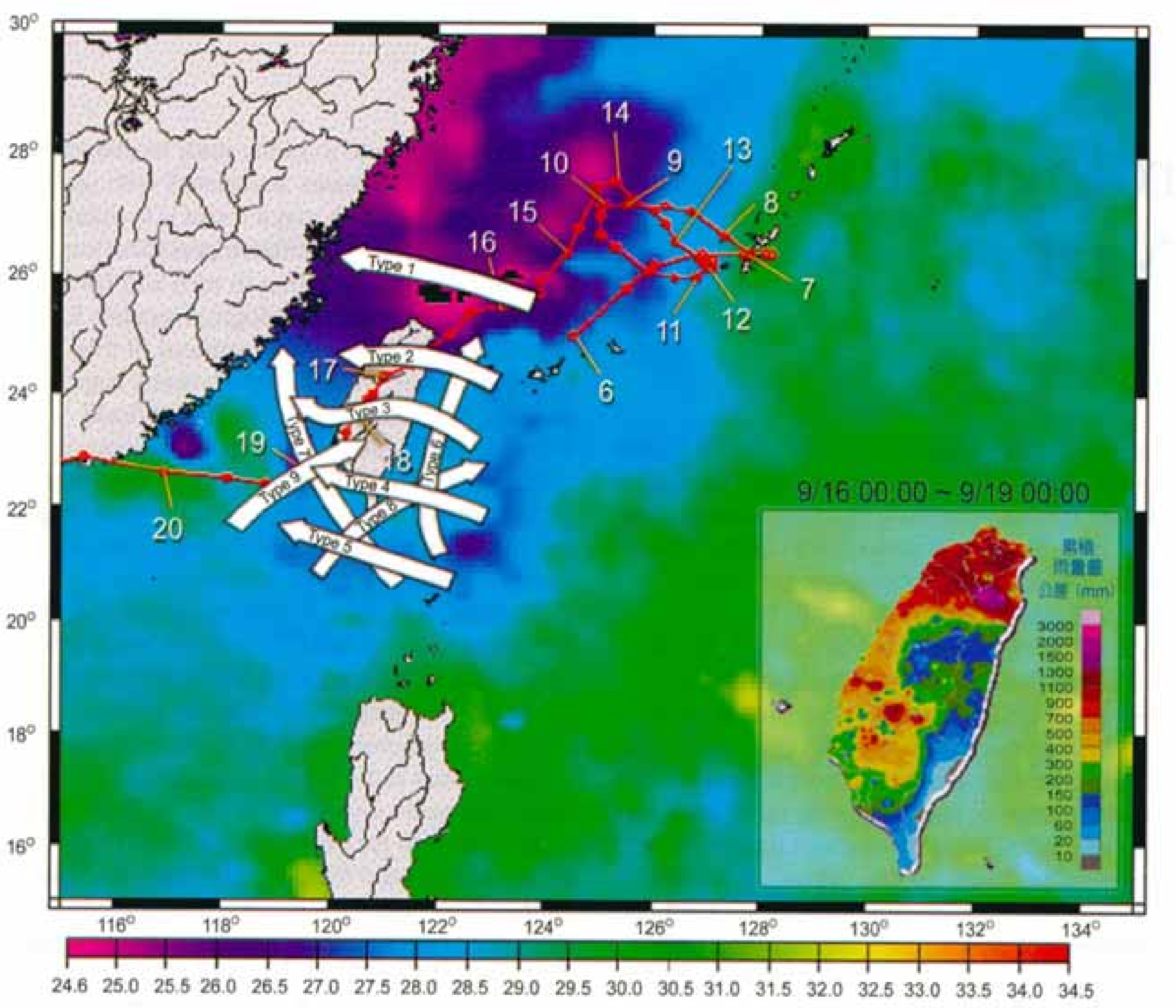
黑夜來臨、暴雨驟降，台灣
在瞬間成爲災難史上，眞實的…水世界

Even Budda cannot save you!

Water World !

Why studied Typhoon Nari (2001)?

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



Sui et al. (2002) EOS article

Content:

Part I: Model Verification
Part II: Terrain Sensitivity
Part III: Precipitation Efficiency
Part IV: Coupling with Runoff Model

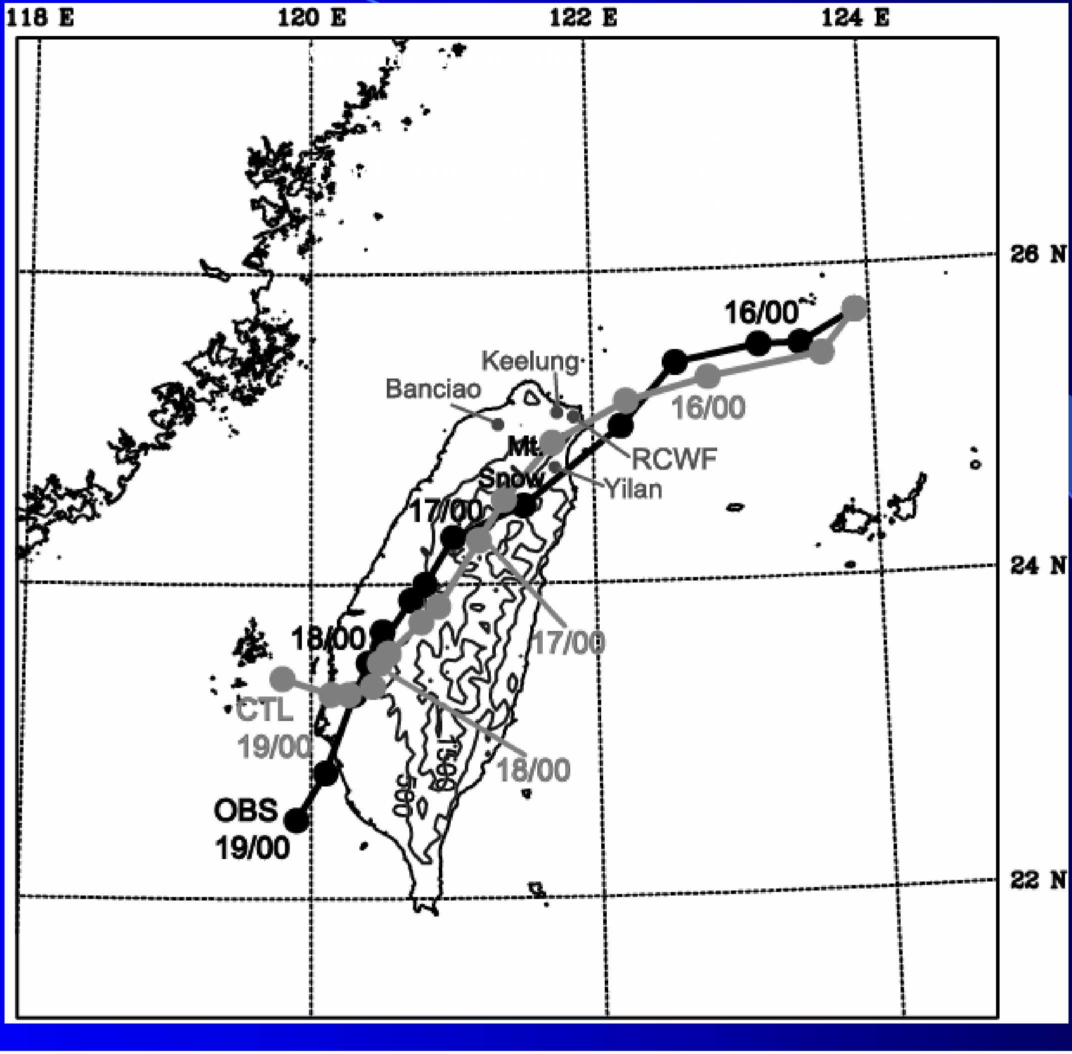
Part I: Model Verification

MM5 model physics (Control)

Grid Size	54, 18, 6, 2 km
Fcst Period	84 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

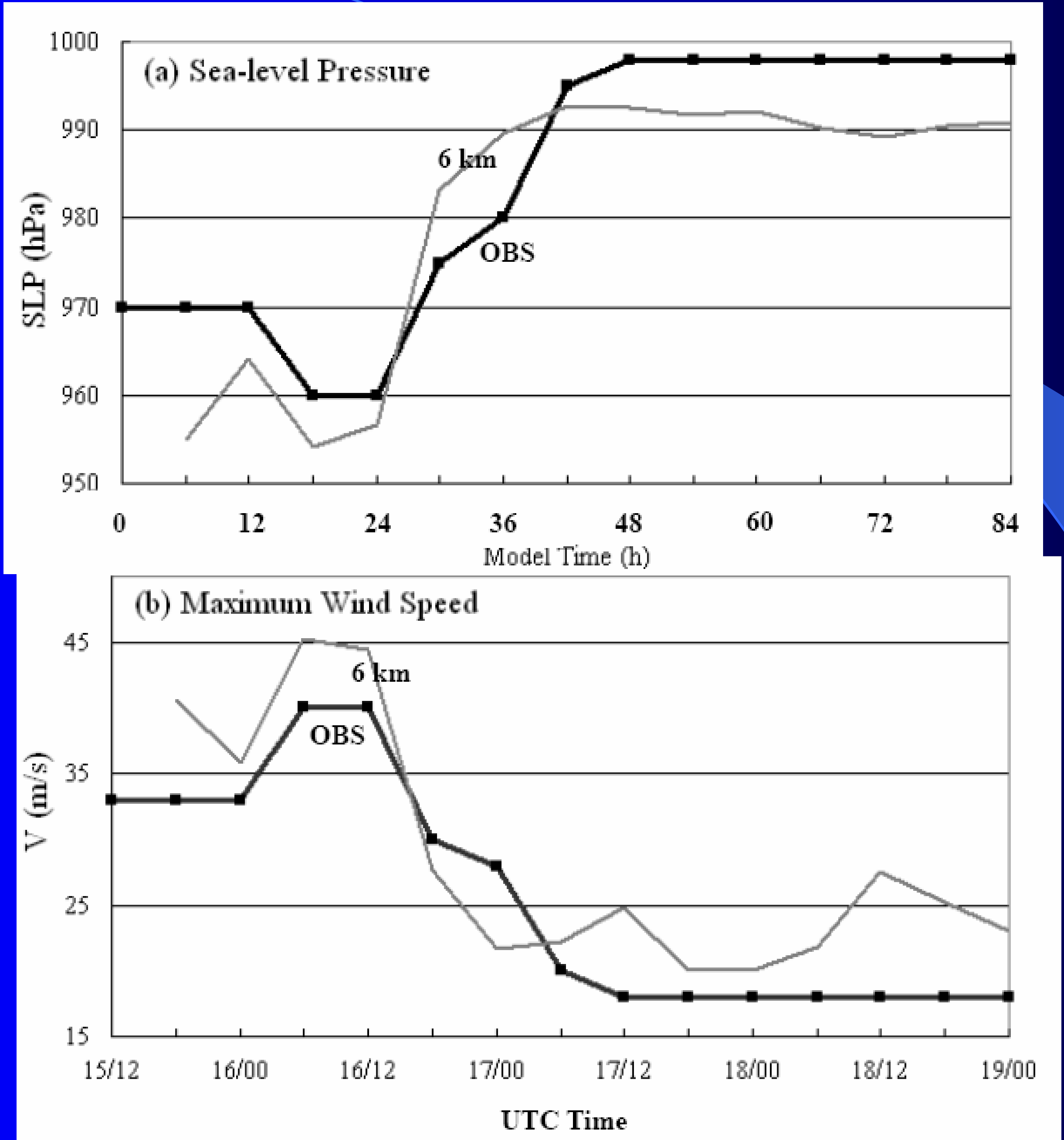
TC initialization: Davis and Low-Nam (2001)

Track Comparison



Simulation time (h)	12	24	36	48	60	72	84
Track error (km)	43.3	61.2	26.8	13.4	12.0	8.5	104.8

Time Series of SLP and Vmax

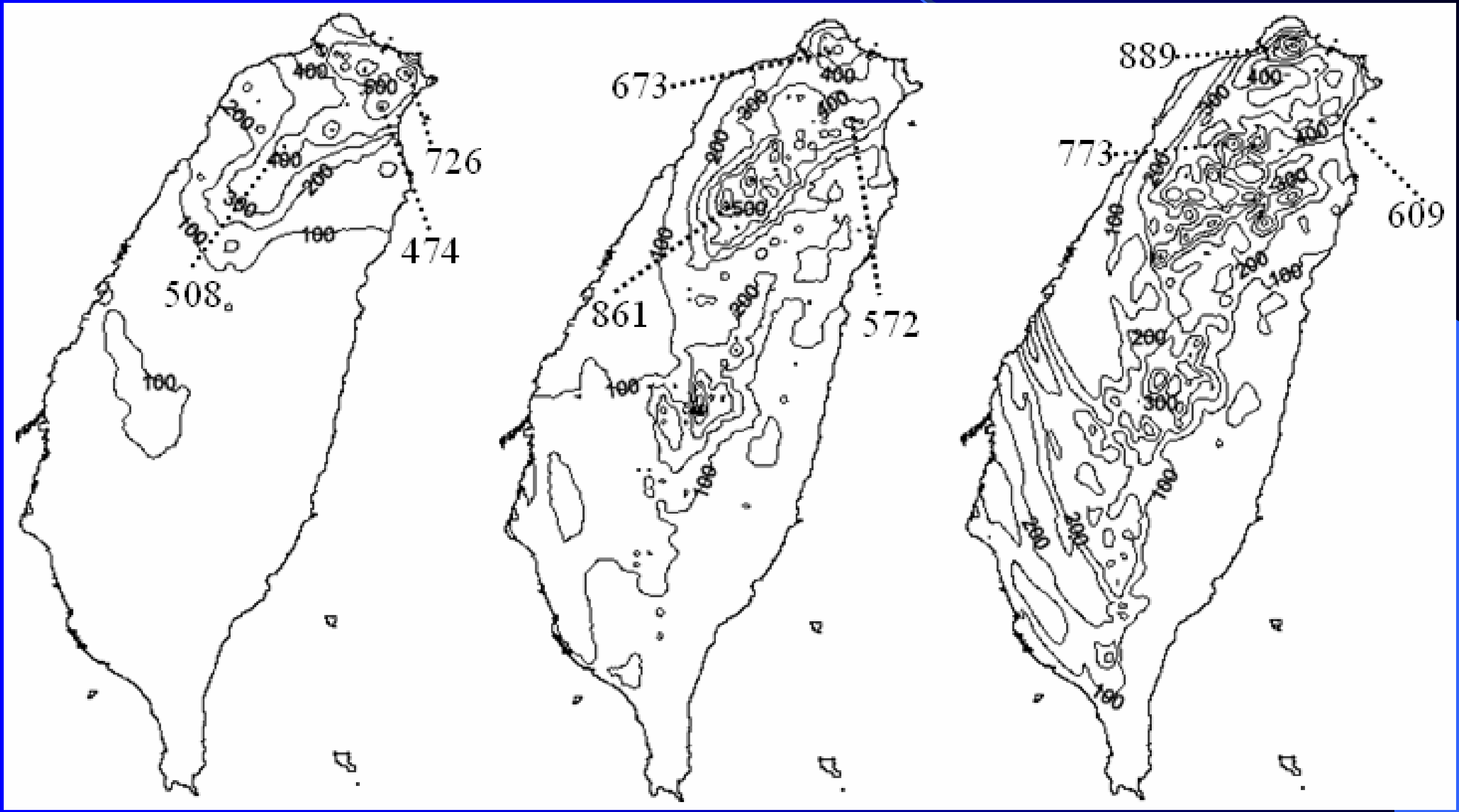


24-h rainfall on 09/16

OBS

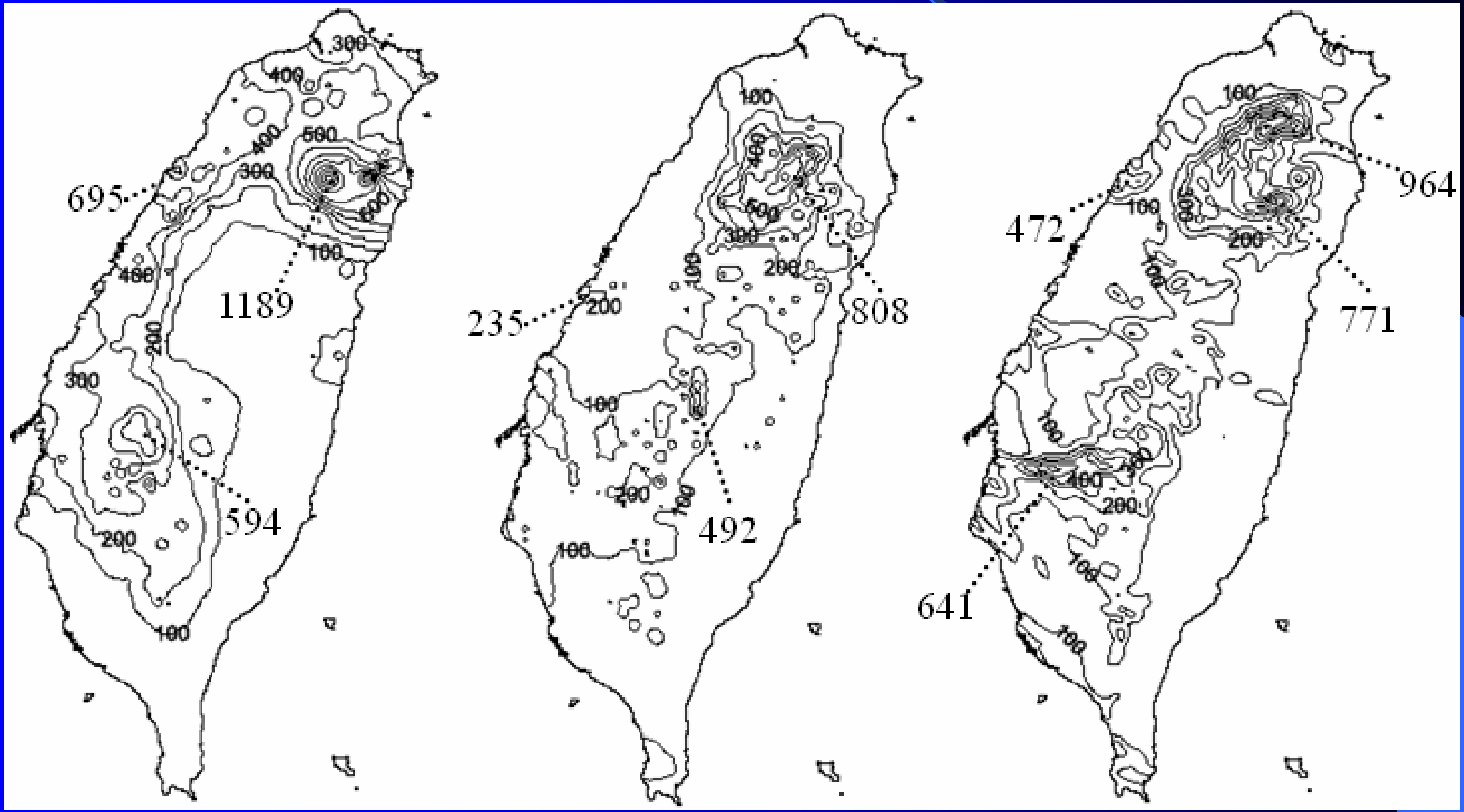
6km MM5

2km MM5



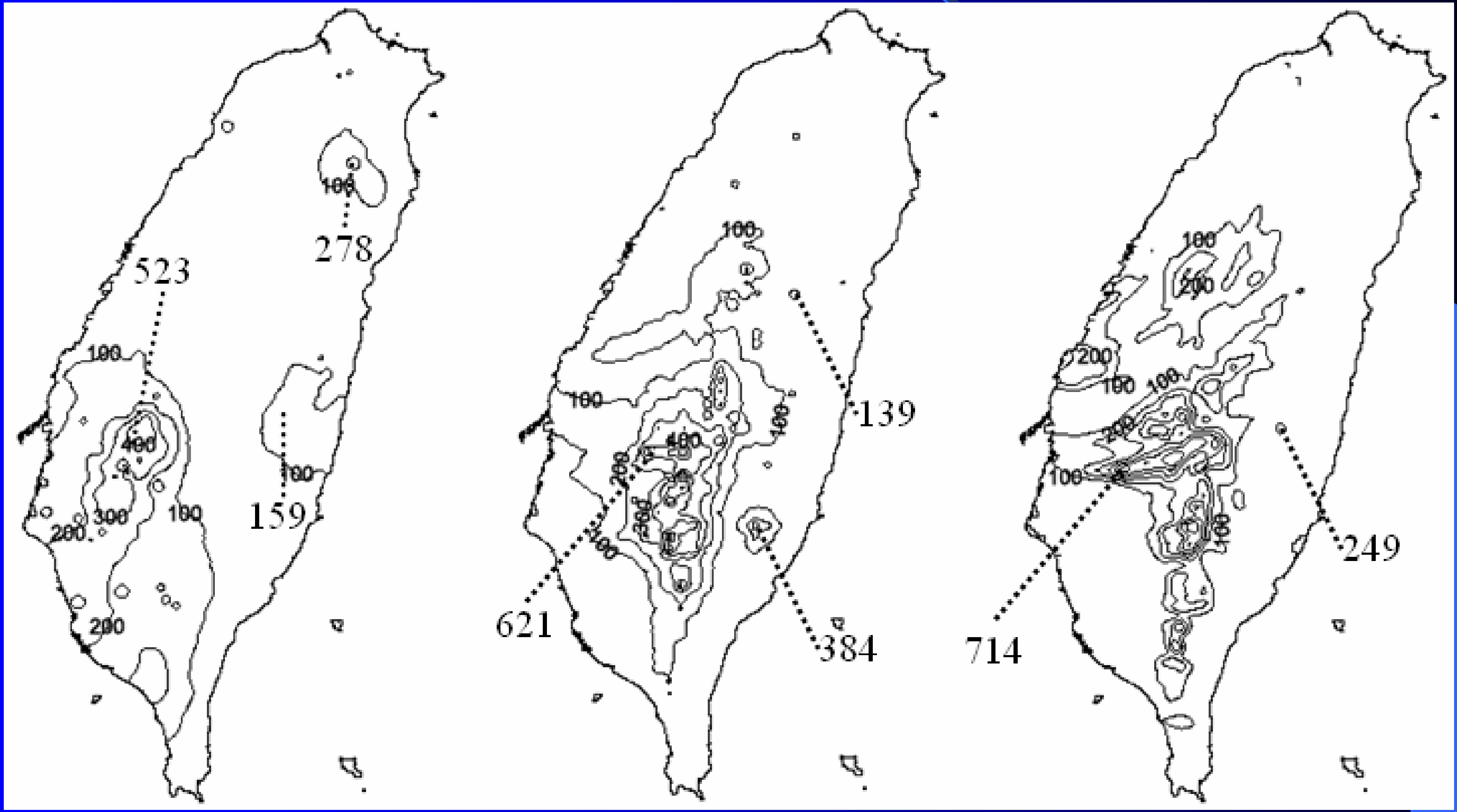
24-h rainfall on 09/17

OBS 6km MM5 2km MM5



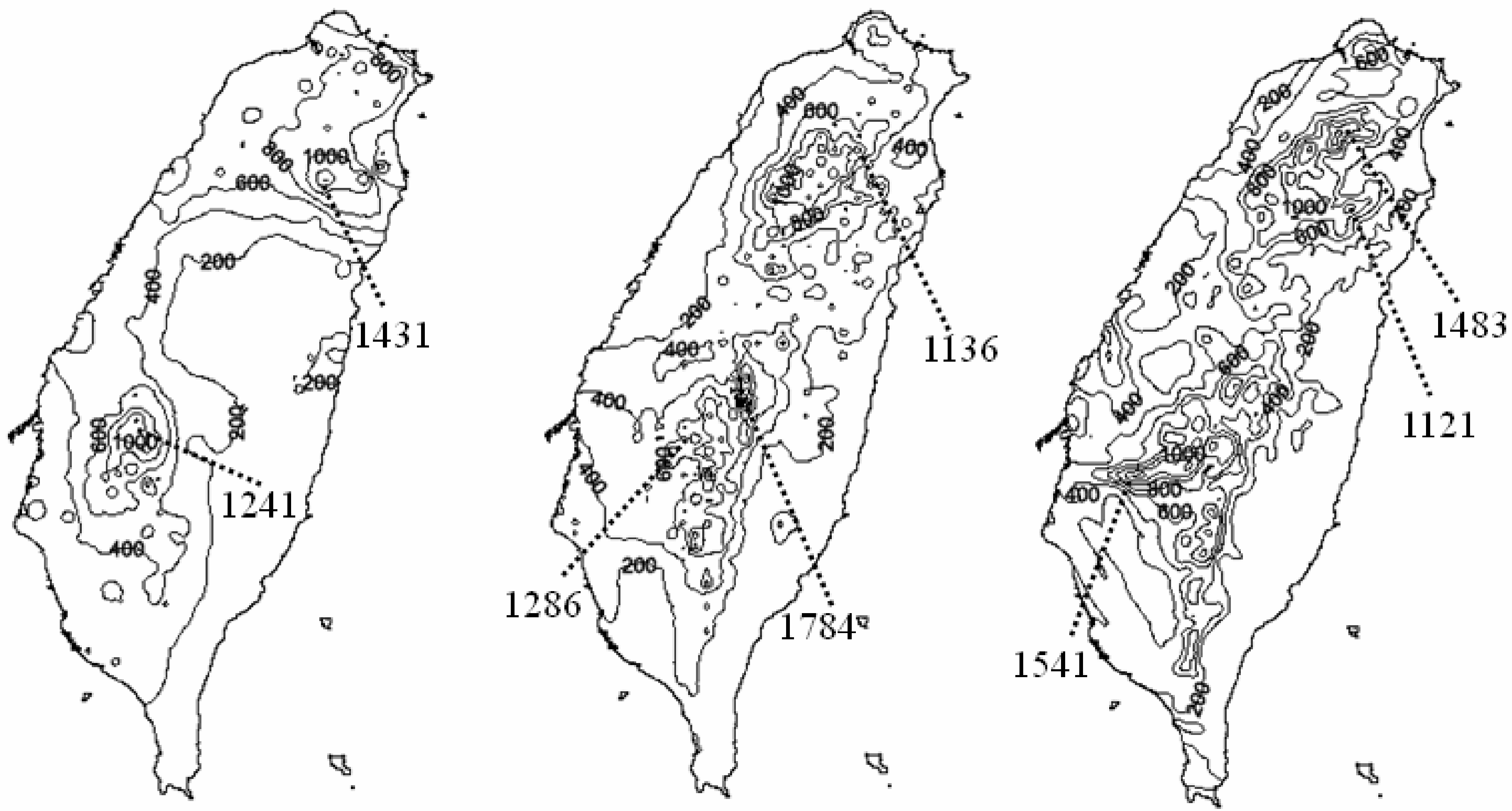
24-h rainfall on 09/18

OBS **6km MM5** **2km MM5**

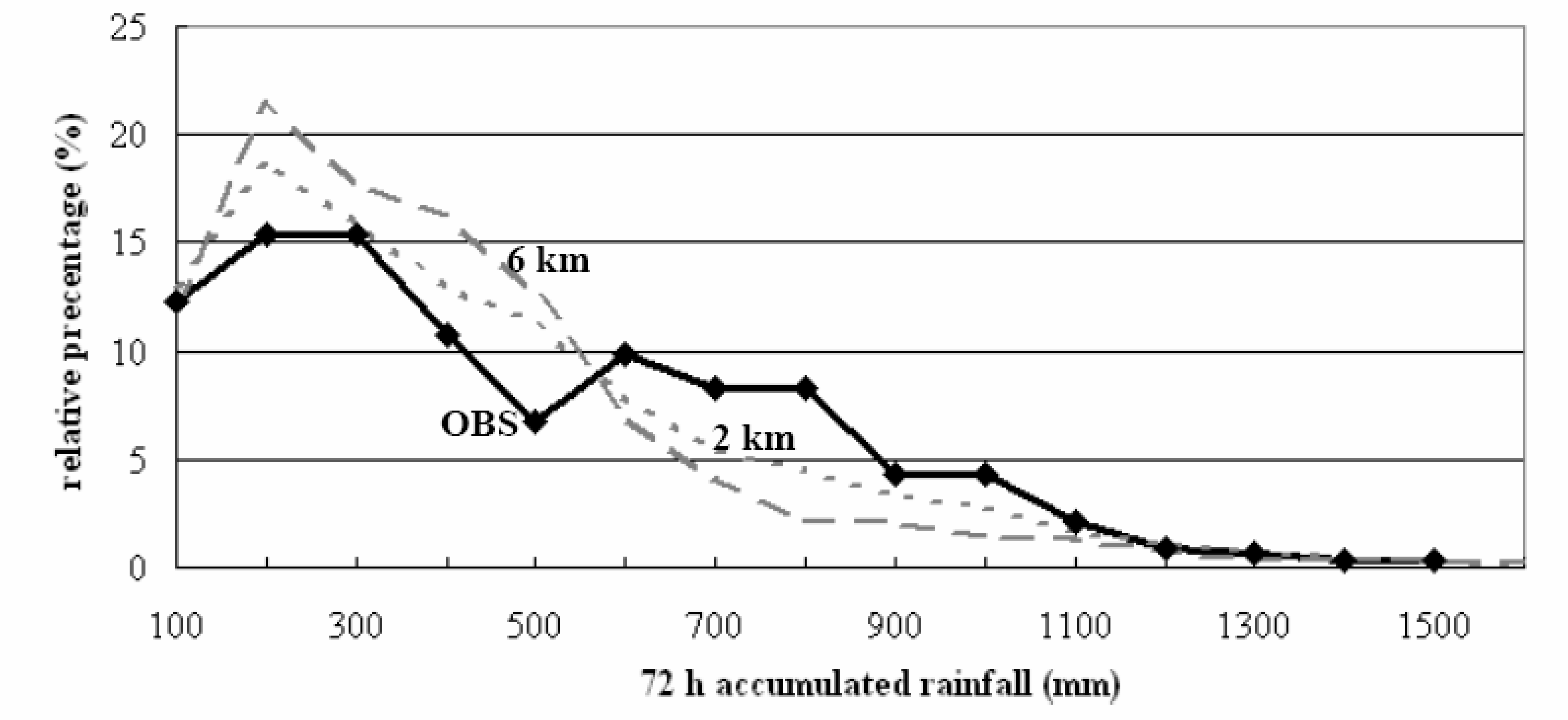


3-day rainfall on 09/16~09/18

OBS **6km MM5** **2km MM5**



Relative Percentage of 3-Day Rainfall



→MM5 overforecasts weak TC rainfall (<550mm/3day) but underestimates heavy TC rainfall (>550mm/3day)

→As resolution increases, the simulated rainfall spectrum approached the observed

Average Rainfall on Taiwan

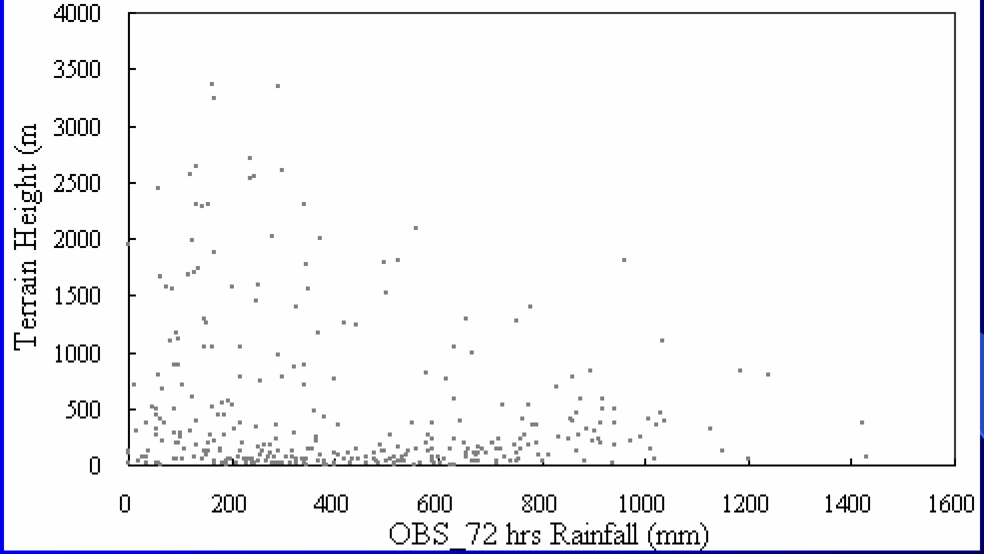
Item	N	09/16	09/17	09/18	3-Day Total
OBS (in mm)	325	132	206	97	435
6km MM5	1073	159	104	75	348
2km MM5	9602	175	133	84	383

Percentage wrt Rain Gauge OBS

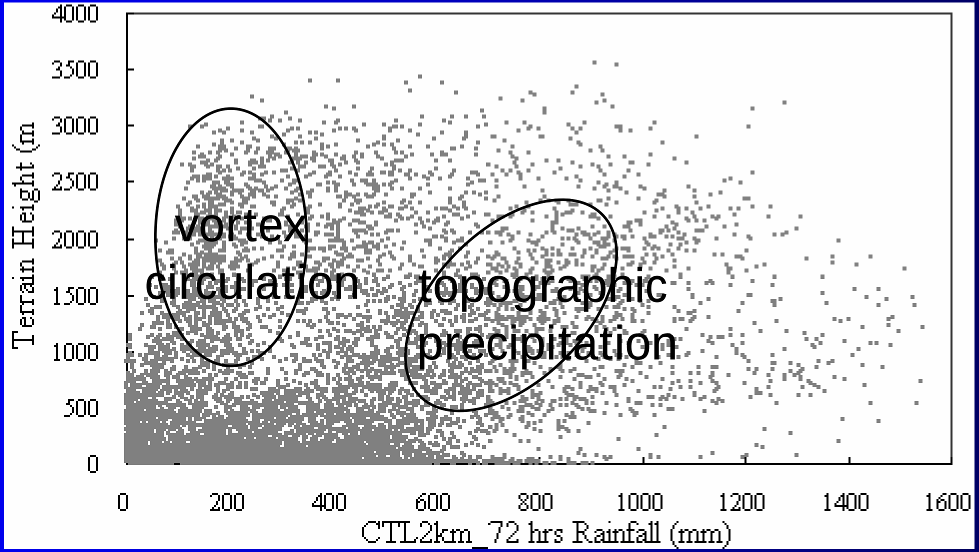
MM5/OBS	09/16	09/17	09/18	3-Day Total
6km MM5	121 %	51 %	78 %	80 %
2km MM5	133 %	65 %	87 %	88 %

3-Day Total Rainfall versus Terrain Height

Rain
Gauge
OBS



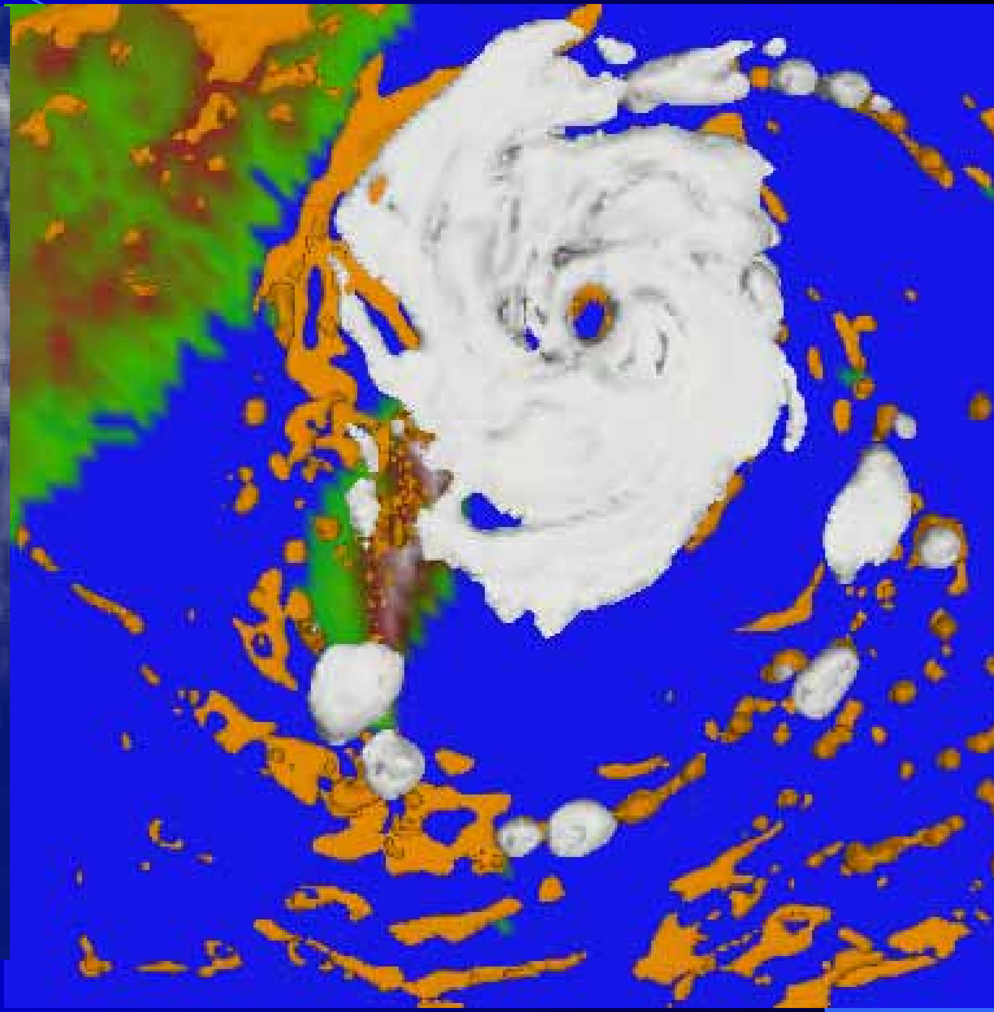
2km
MM5



Cloud Features

CWB: 0916_0100 UTC

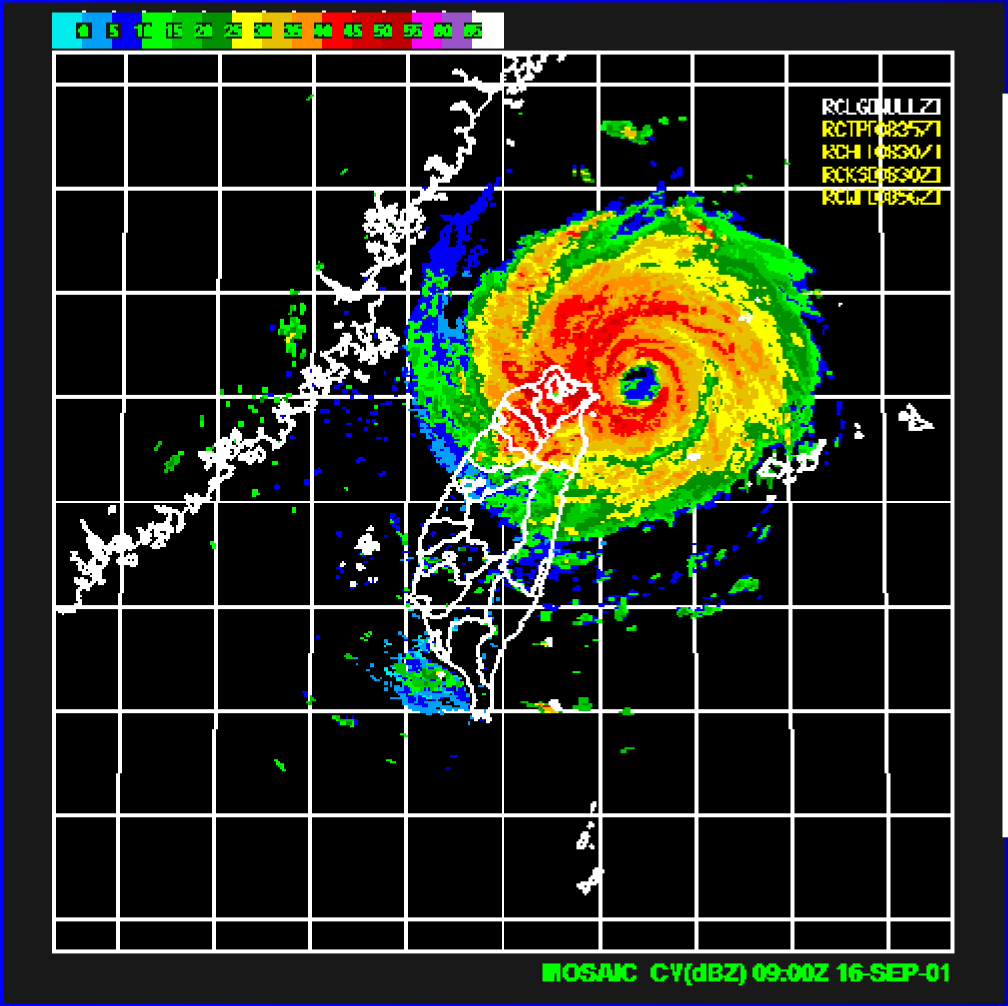
CTL: 0916_0000 UTC



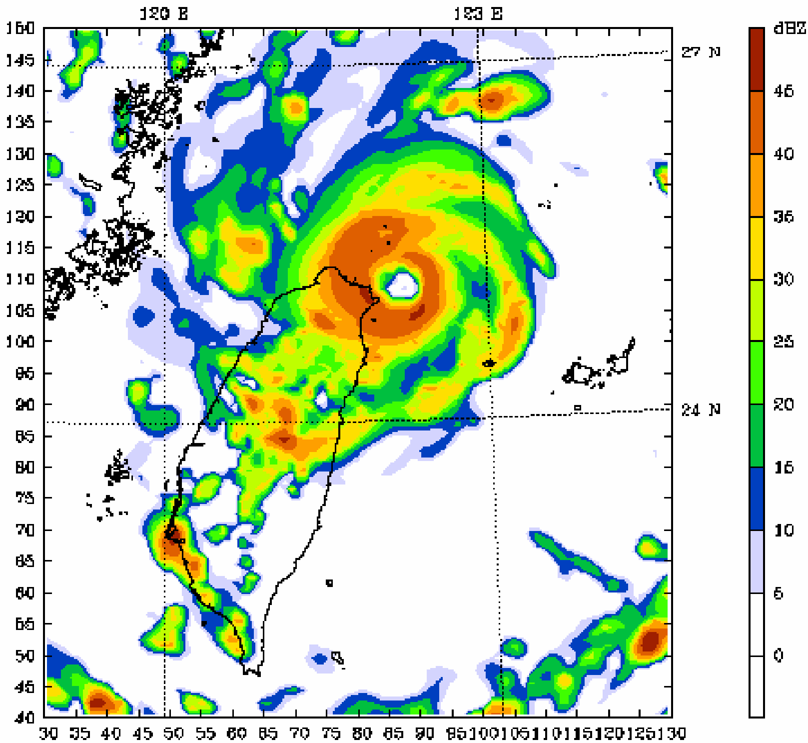
Isosurface of Snow (0.01 g/kg) and Cloud Water (0.3 g/kg)

Radar CV Composite Before Landfall

OBS

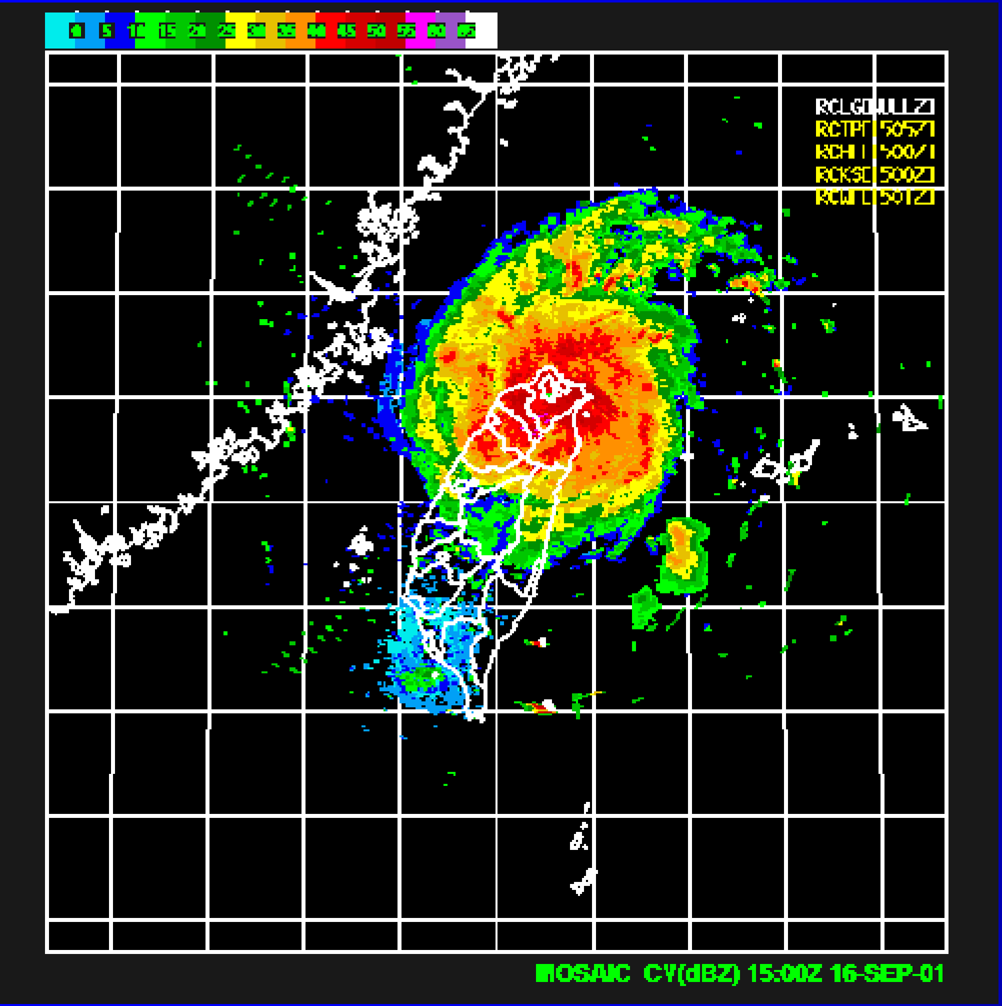


MM5

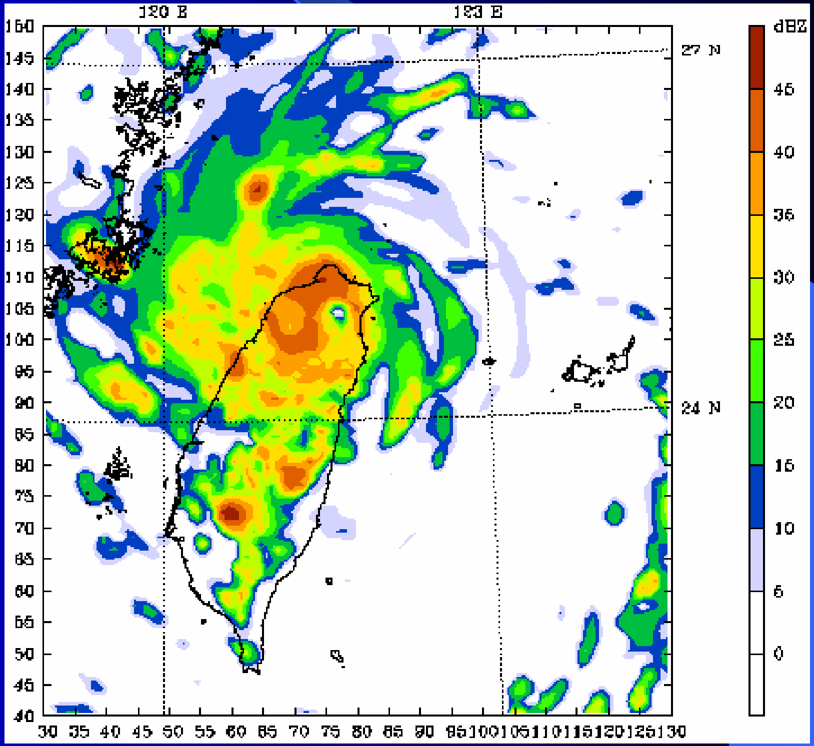


Radar CV Composite After Landfall

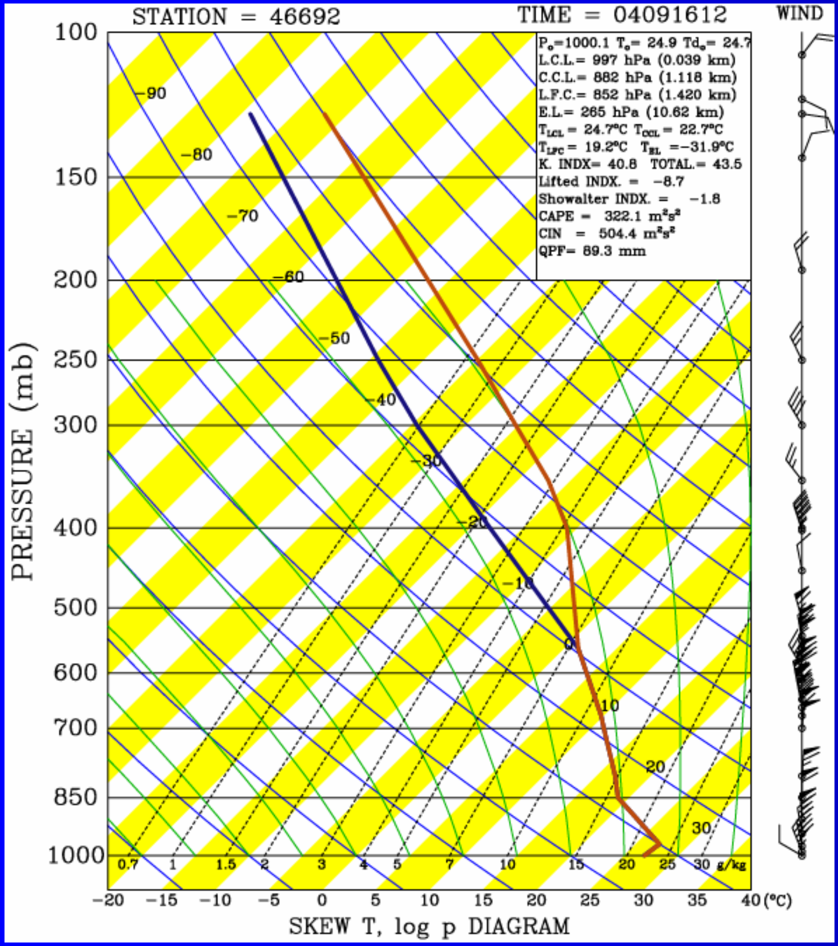
OBS



MM5

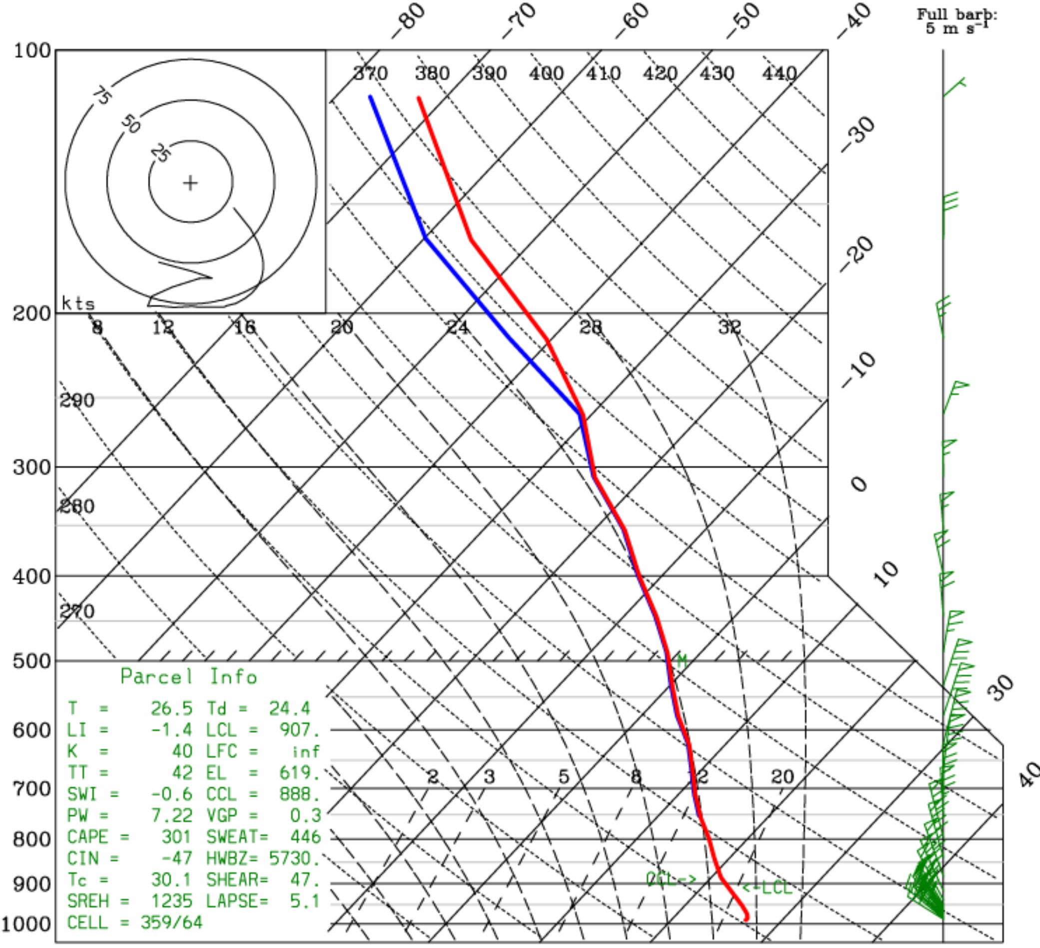


Sounding Comparison (within Eyewall)



P_o=1000.1 T_o= 24.9 Td_o= 24.7
L.C.L.= 997 hPa (0.039 km)
C.C.L.= 882 hPa (1.118 km)
L.F.C.= 852 hPa (1.420 km)
E.L.= 265 hPa (10.62 km)
T_{LCL} = 24.7°C T_{CCL} = 22.7°C
T_{LFC} = 19.2°C T_{EL} =−31.9°C
K. INDX= 40.8 TOTAL.= 43.5
Lifted INDX. = −8.7
Showalter INDX. = −1.8
CAPE = 322.1 m^2s^2
CIN = 504.4 m^2s^2
QPF= 89.3 mm

Observed Sounding

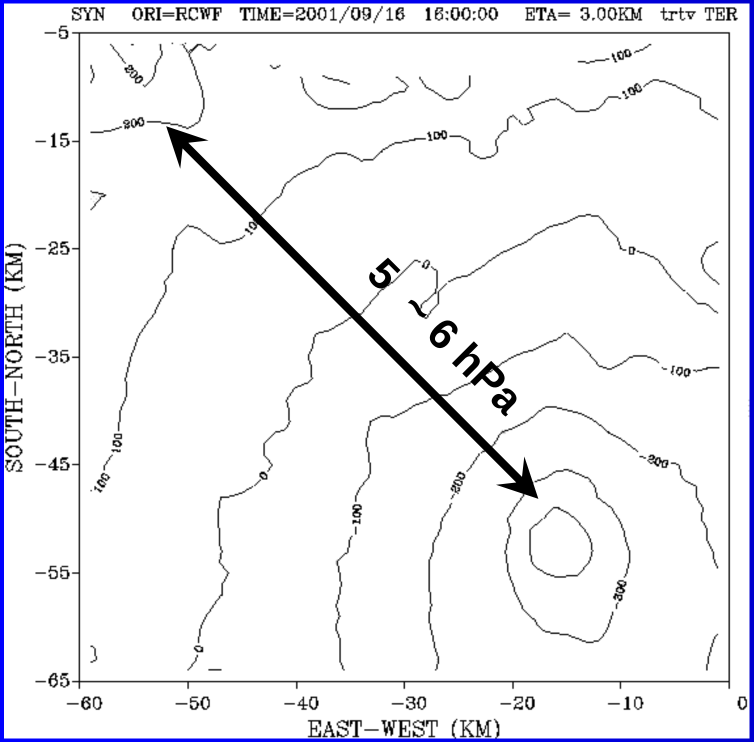


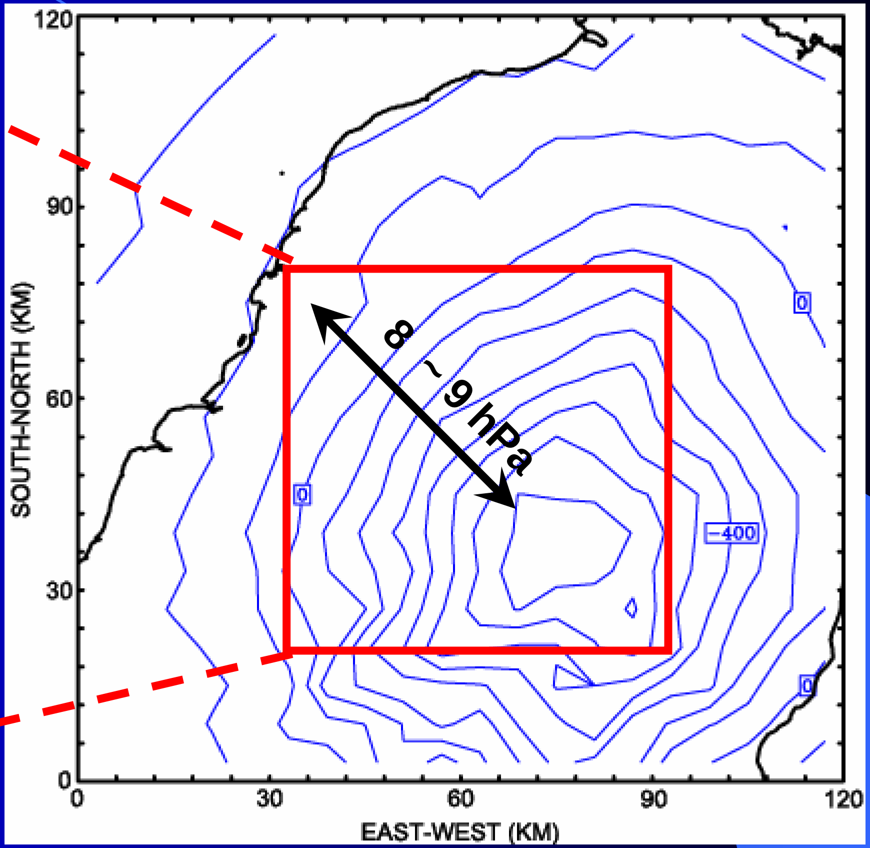
Parcel Info
T = 26.5 Td = 24.4
LI = −1.4 LCL = 907.
K = 40 LFC = inf
TT = 42 EL = 619.
SWI = −0.6 CCL = 888.
PW = 7.22 VGP = 0.3
CAPE = 301 SWEAT= 446
CIN = −47 HWBZ= 5730.
Tc = 30.1 SHEAR= 47.
SREH = 1235 LAPSE= 5.1
CELL = 359/64

MM5 Simulation

Horizontal Cross Section of Pressure Perturbations

0916_1400 UTC





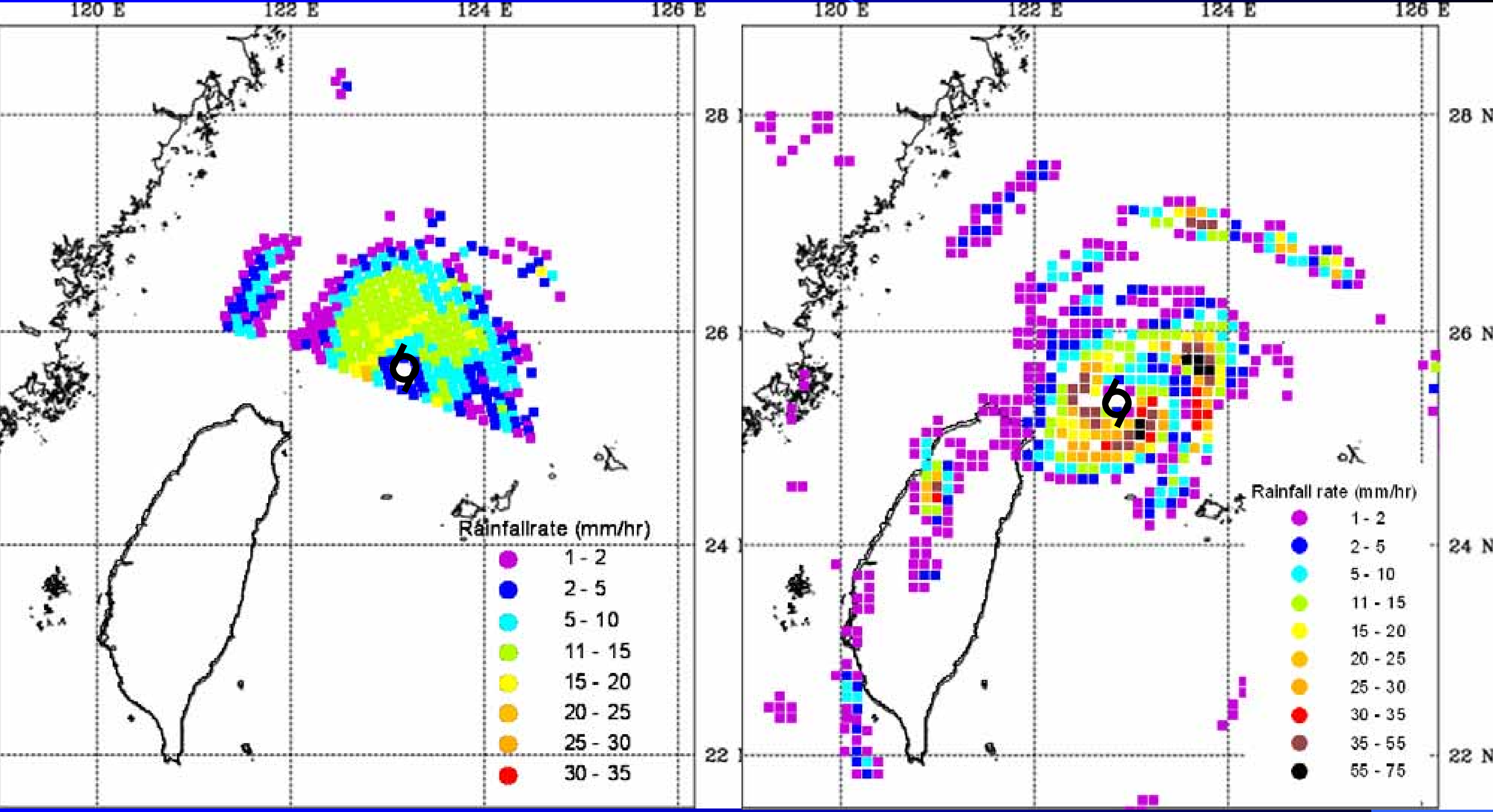
Radar Retrieval (wrt. a Station Sounding)

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

MM5 Simulation (wrt. a Horizontal Area Mean)

TRMM Rainrate Comparison

TRMM/PR: 0915/2328 UTC (10 km pixel) **MM5: 0915/2100 UTC (6 km grid)**

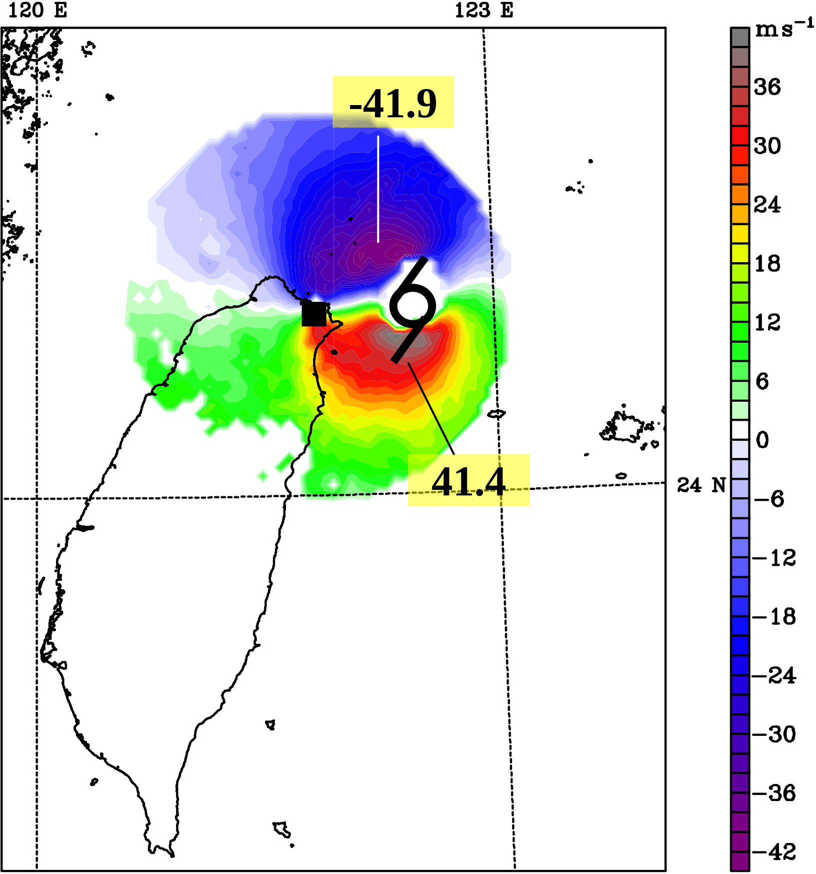


Courtesy of W.-J. Chen

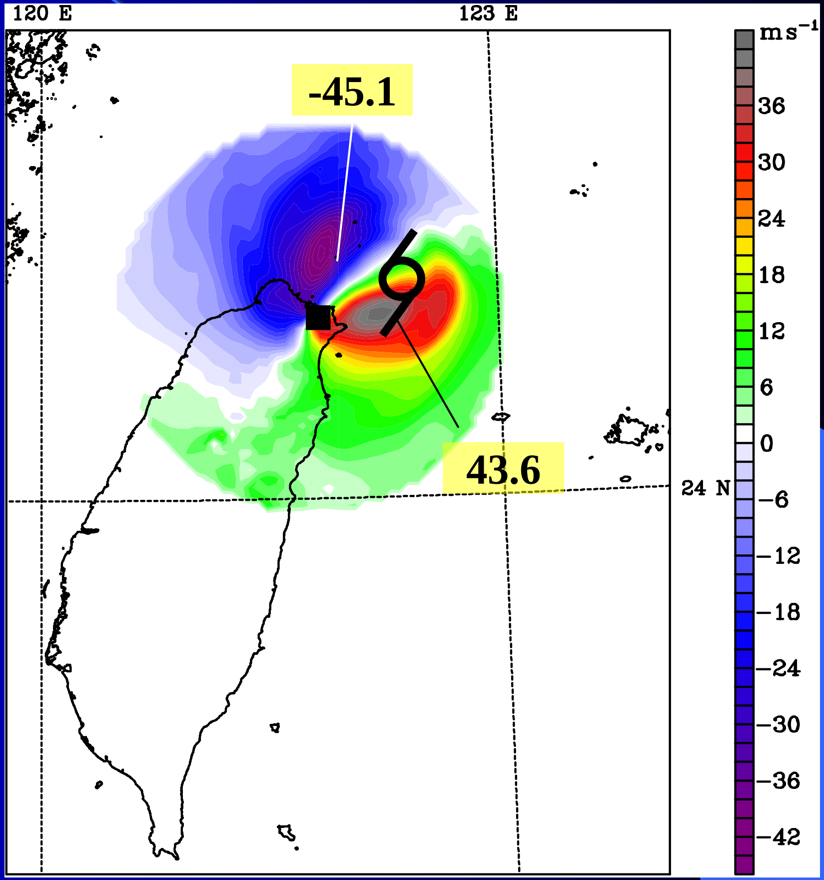
Radial Wind wrt RCWF Radar

@ 3 km Height

Obs Vr (6 km pixel)



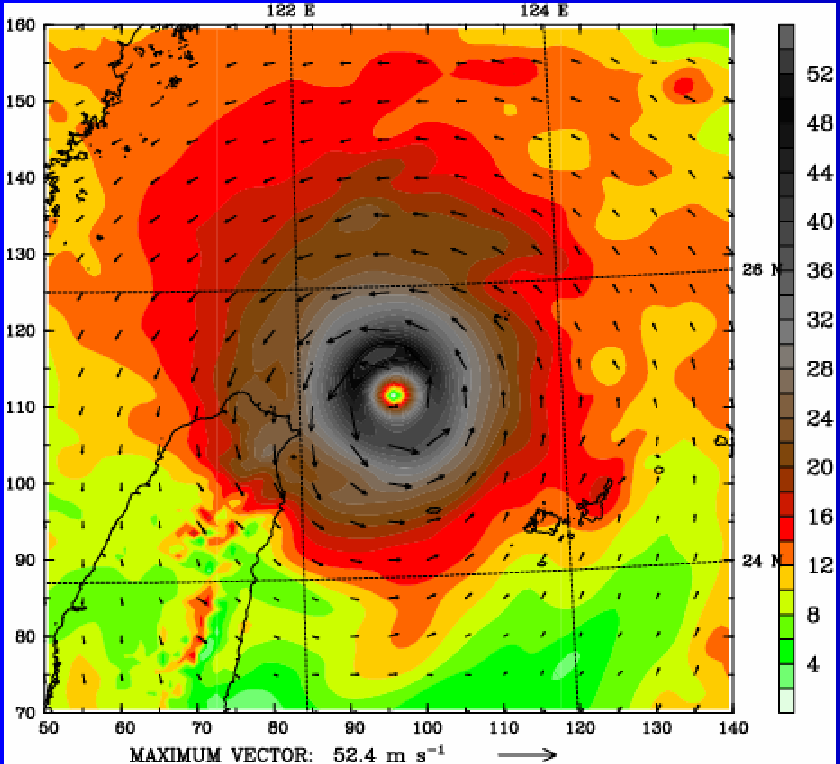
MM5 Vr (dx = 6 km)



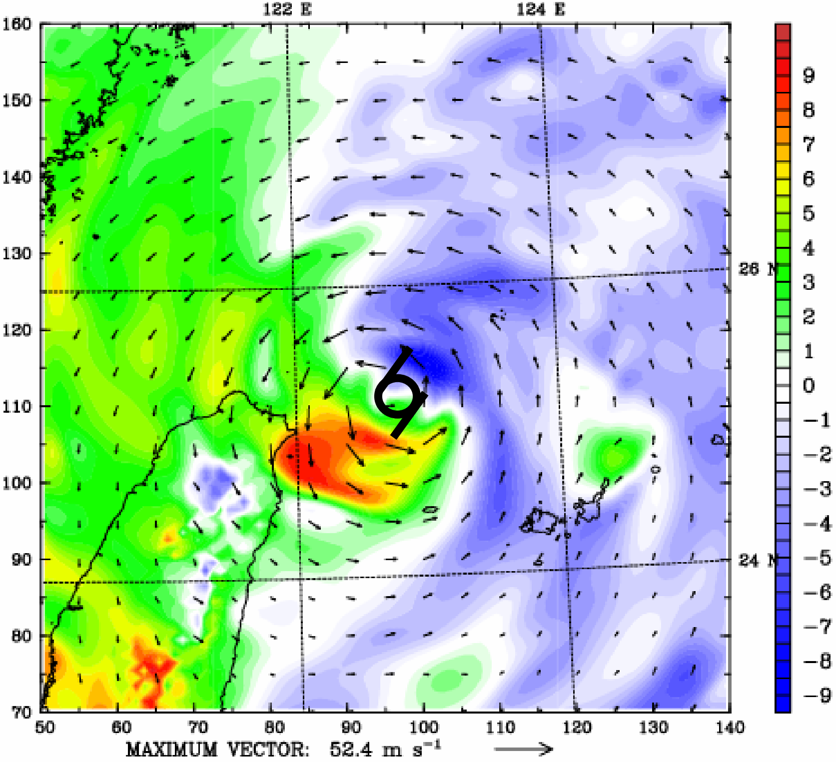
Courtesy of T.-C. Chen and Y.-C. Liou

MM5 Simulated Vr & Vt
Nari at Sea (@ 3 km Height)

Tangential Velocity



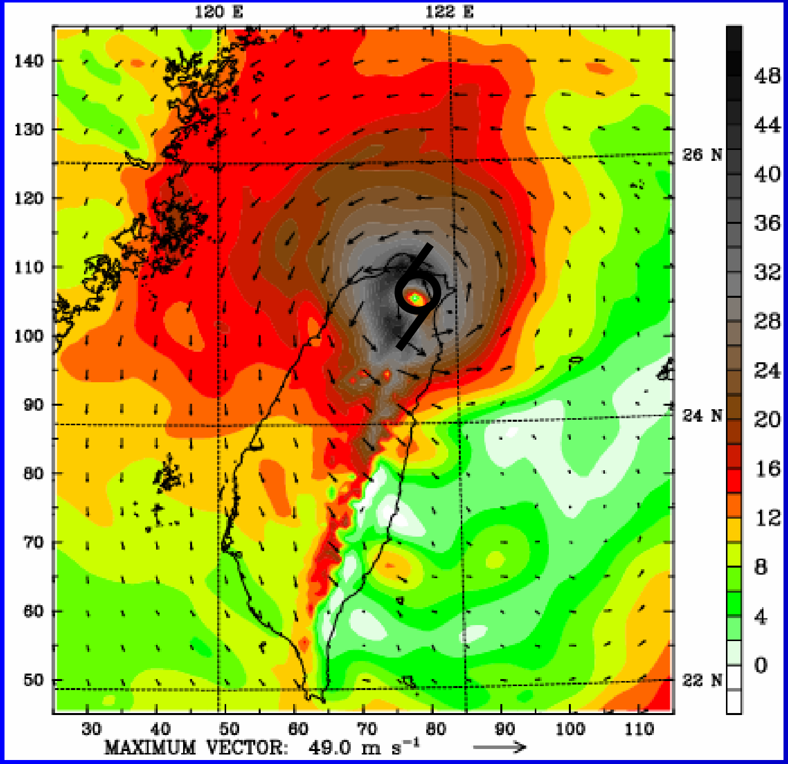
Radial Velocity



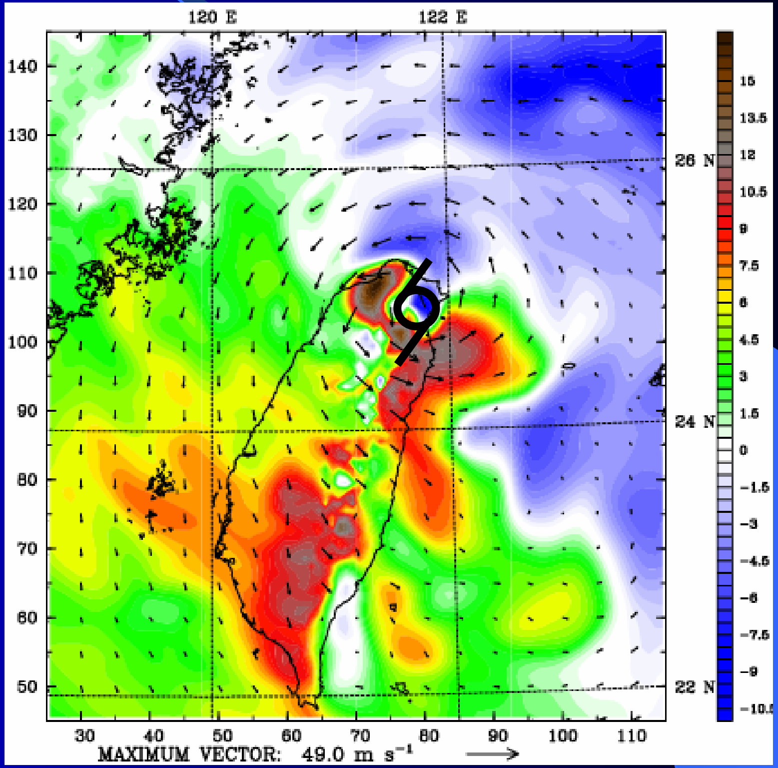
1-h time-averaged result

MM5 Simulated Vr & Vt
Nari Landfall (@ 3 km Height)

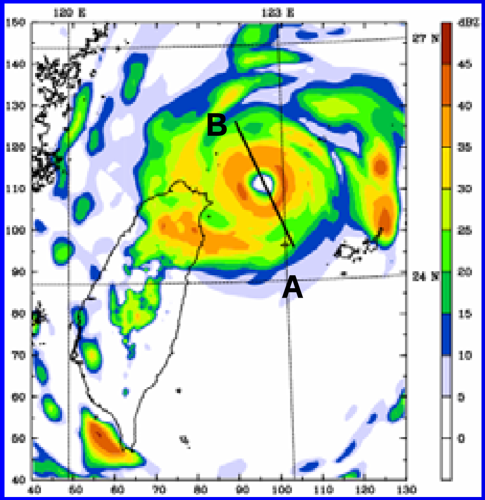
Tangential Velocity

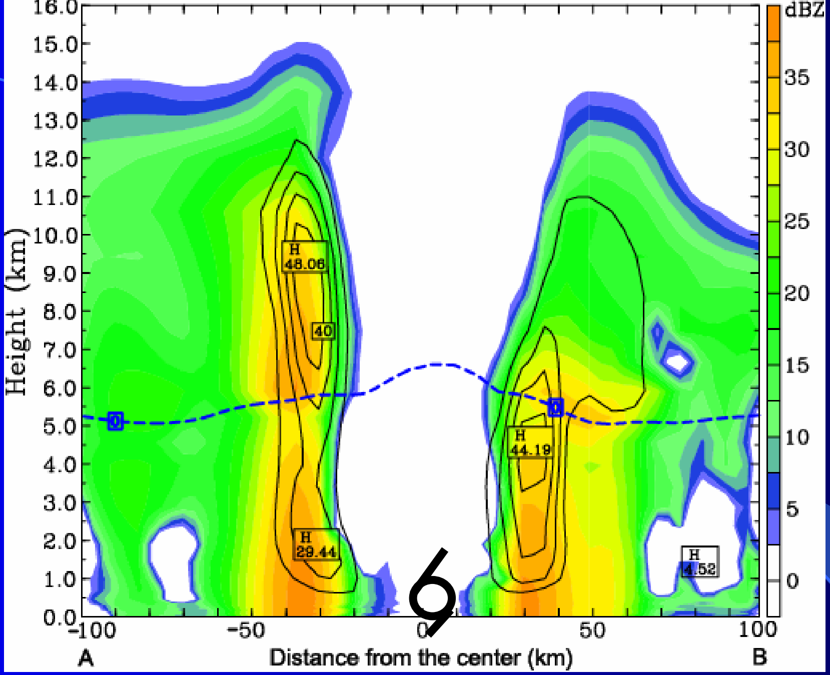


Radial Velocity



1-h time-averaged result

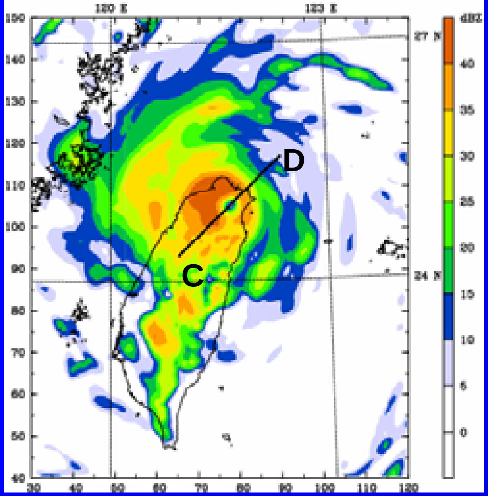


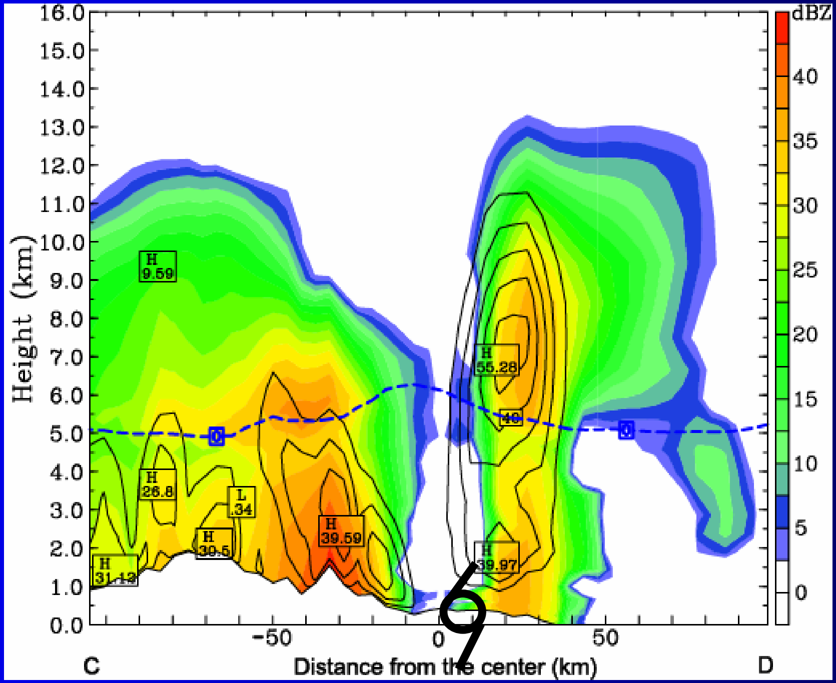


Over Ocean

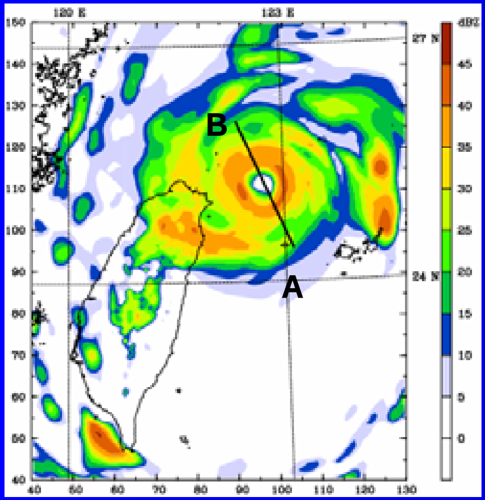
Radar Echo (color)
Condensational
Heating (contour)

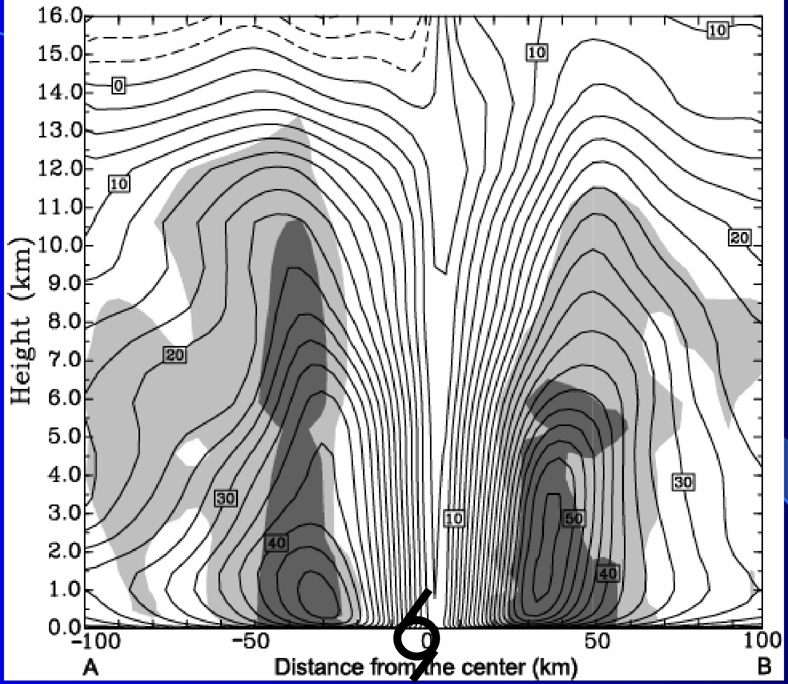
1-h averaged result





After Landfall

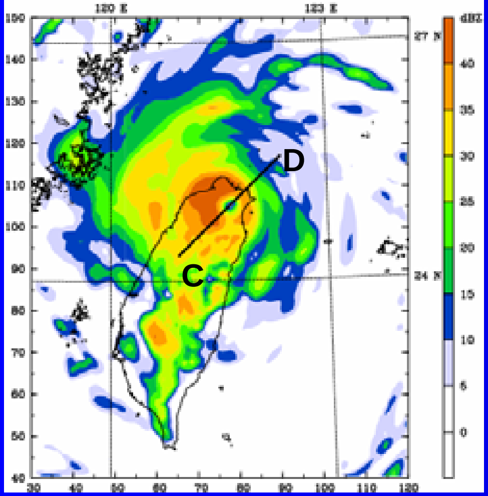


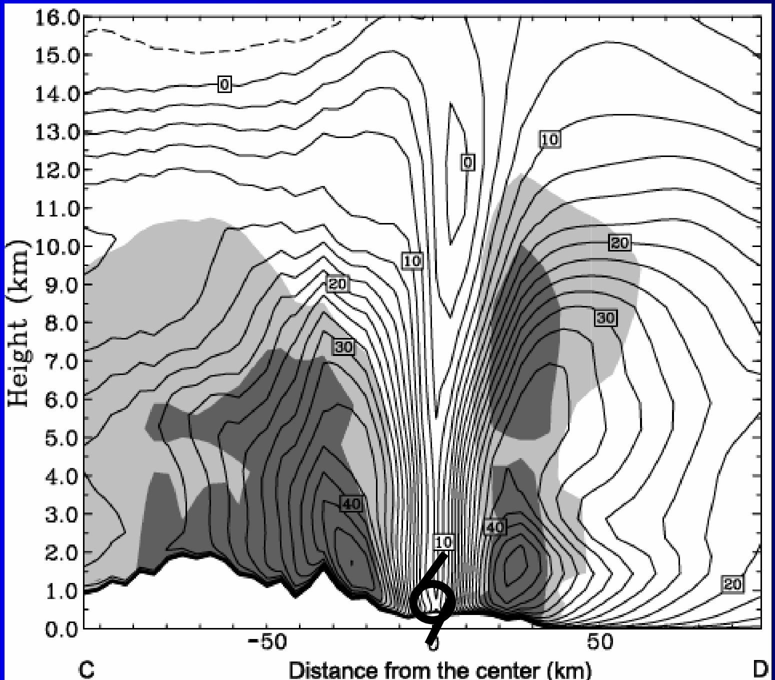


Over Ocean

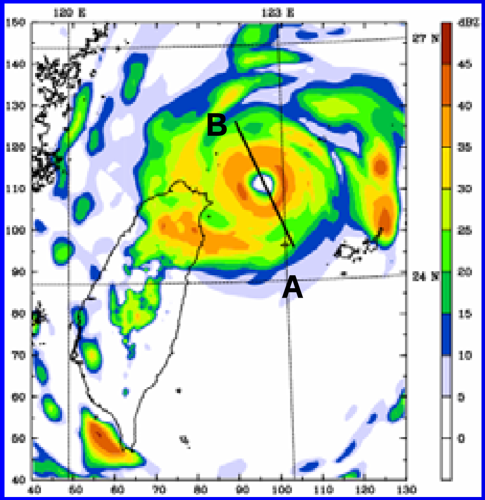
Radar Echo (gray)
Tangential
Wind (contour)

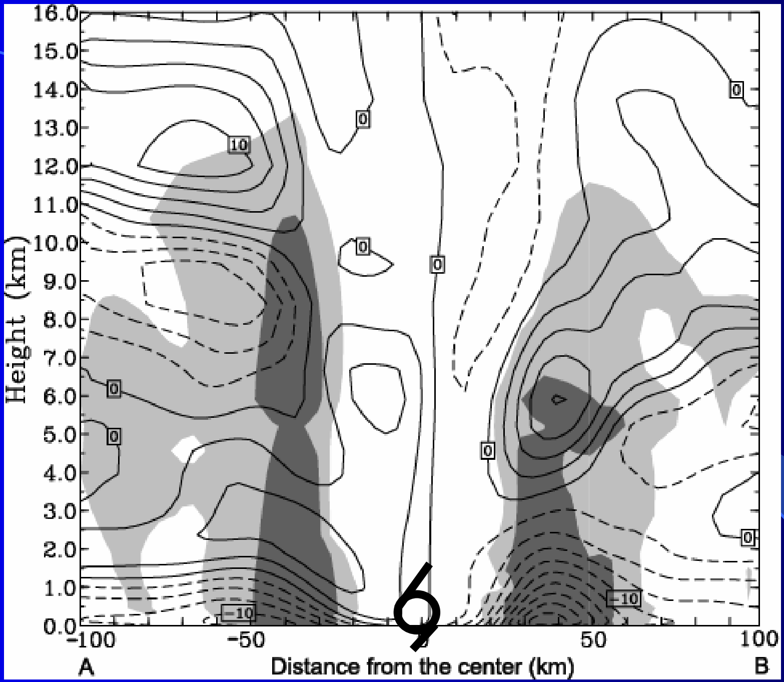
1-h averaged result





After Landfall

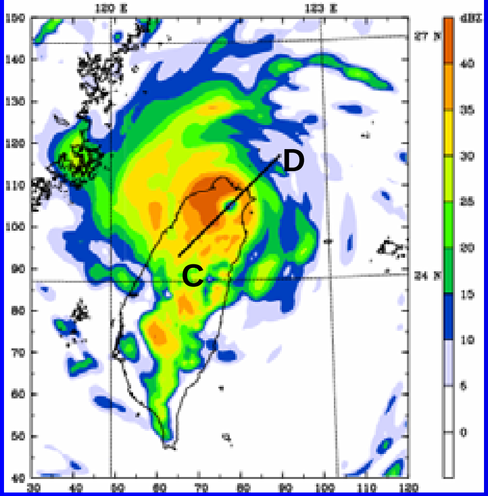


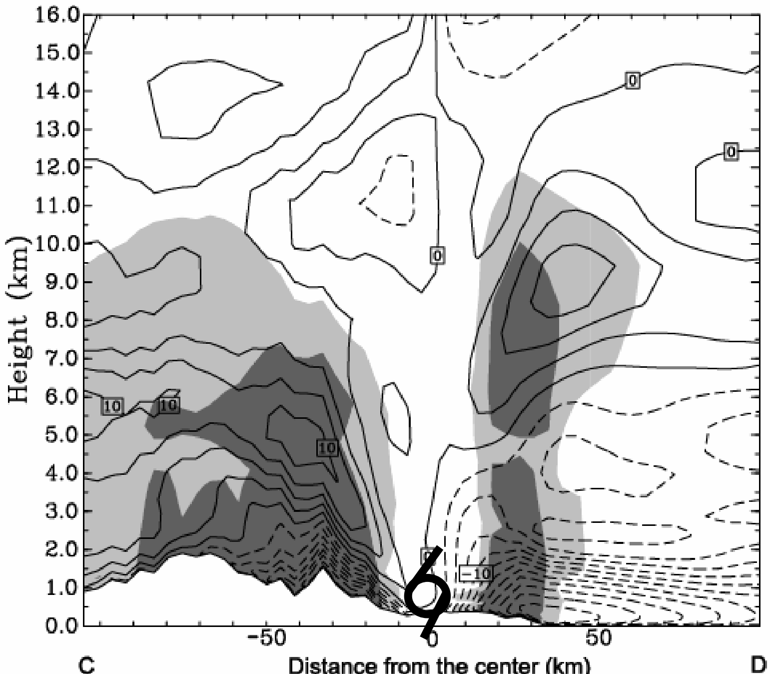


Over Ocean

Radar Echo (gray)
Radial Wind (contour)

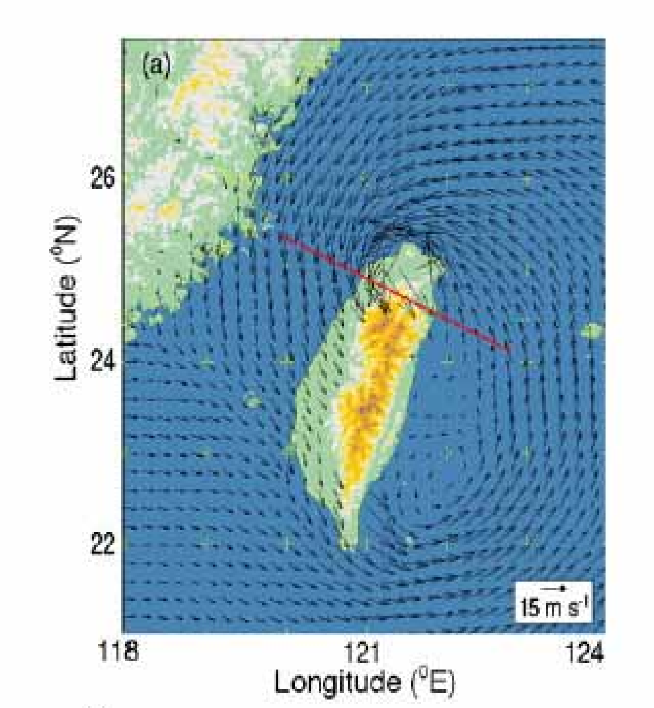
1-h averaged result



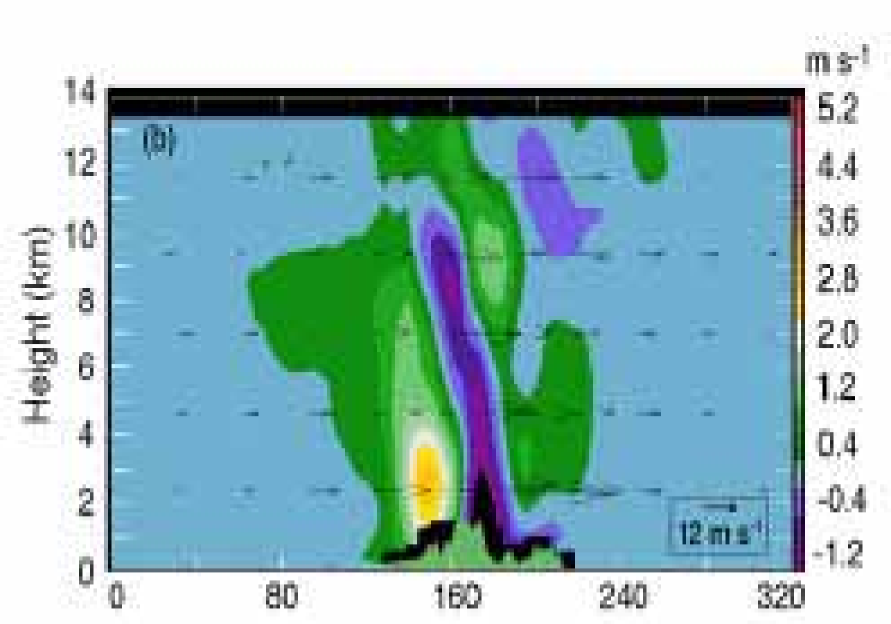


After Landfall

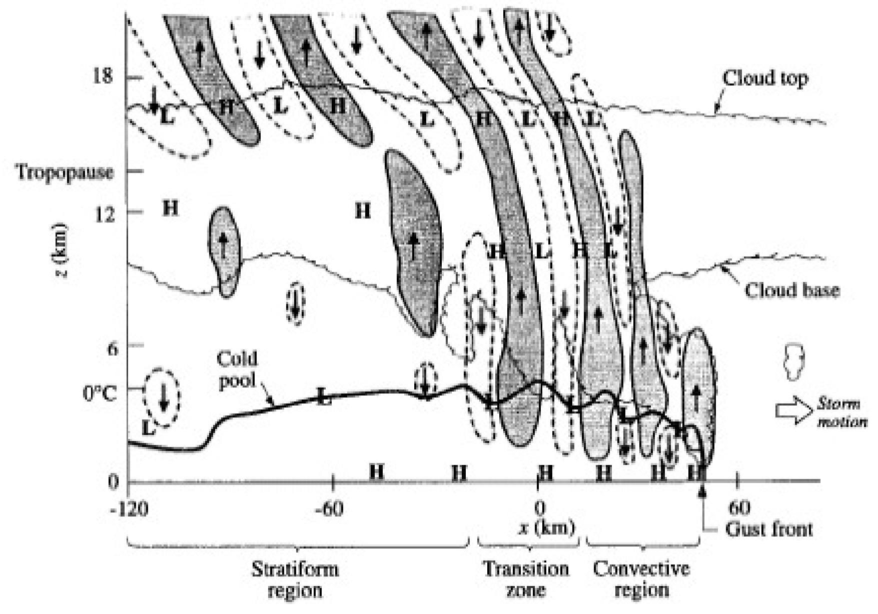
Horizontal Cross Section of low-level wind vector



Vertical Cross Session of Vertical Velocity



Gravity waves in squall lines
(Yang and Houze 1995)



Summary

- After detailed comparisons, the MM5 simulated these features of Typhoon Nari reasonably well: the storm track, the landfalling location, the intensity change and shrinking of eyewall during landfall process, pressure gradient near the inner core, and many observed precipitation and kinematic structures

- Taiwan's topography enhanced asymmetry on the kinematic structure with higher wave-number variations on the radail wind during the landfall process.

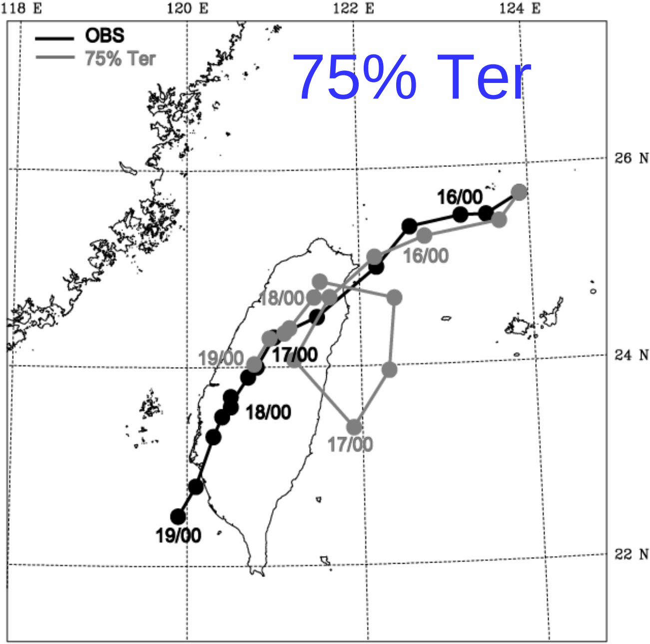
- After landfall, the vertical axis of eyewall and tangential wind tilted toward the terrain, with maximum heating located along the mountain slope.

- Two significant rainfall regimes are found: one with storm's vortex circulation, and the other with topographic precipitation.

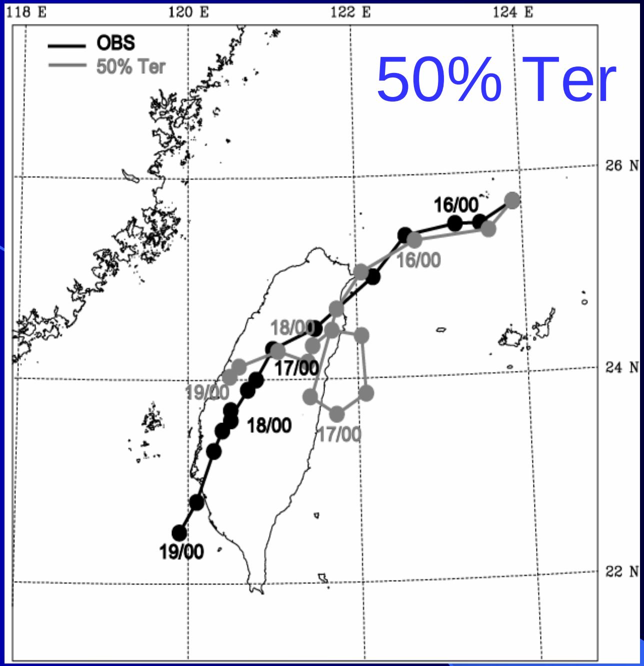
Part II: Terrain Experiments

Terrain Sensitivity Experiments

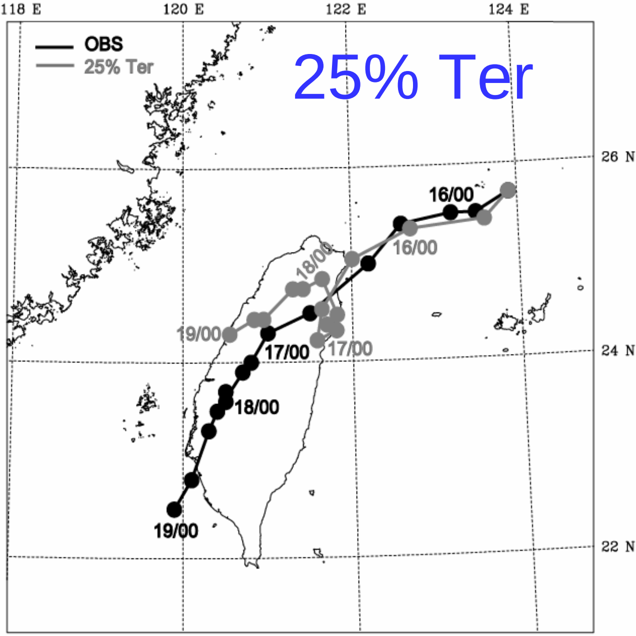
Experiment	Description
75%Ter	75% of Taiwan terrain
50%Ter	50% of Taiwan terrain
25%Ter	25% of Taiwan terrain
NoTer	Flat land on Taiwan



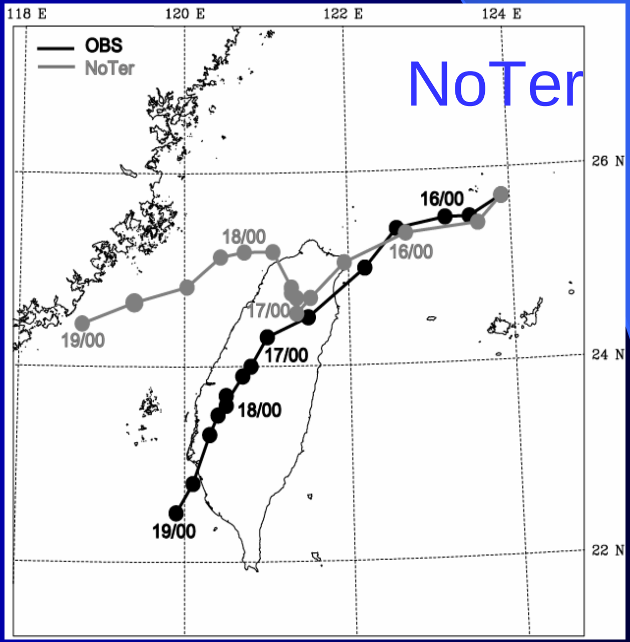
75% Ter



50% Ter

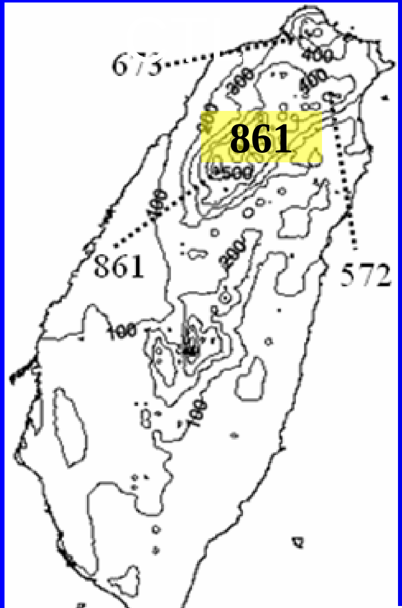


25% Ter

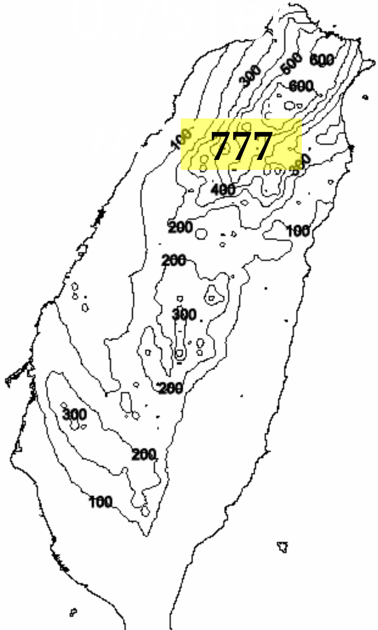


NoTer

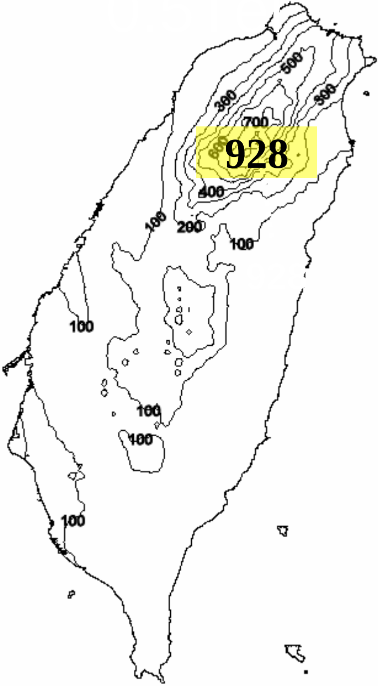
100% Terrain

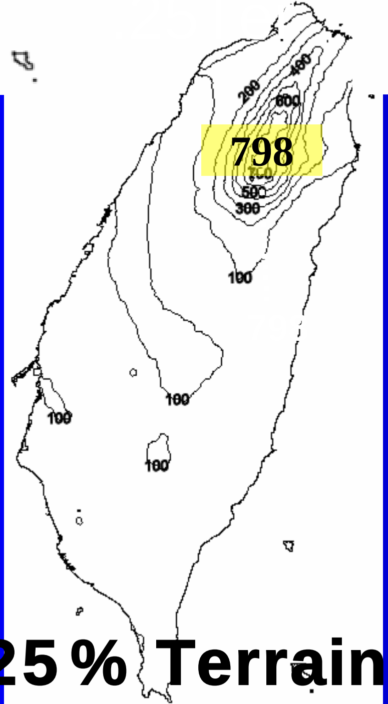


75% Terrain

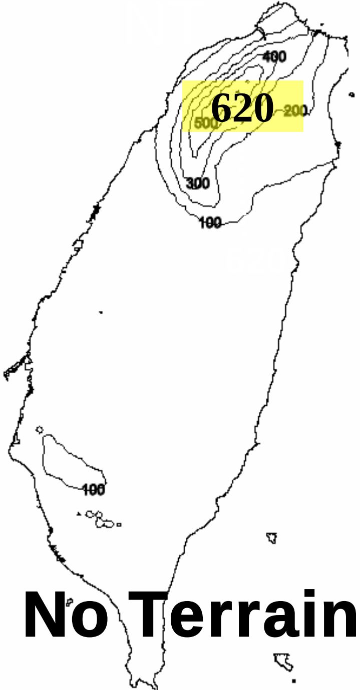


50% Terrain





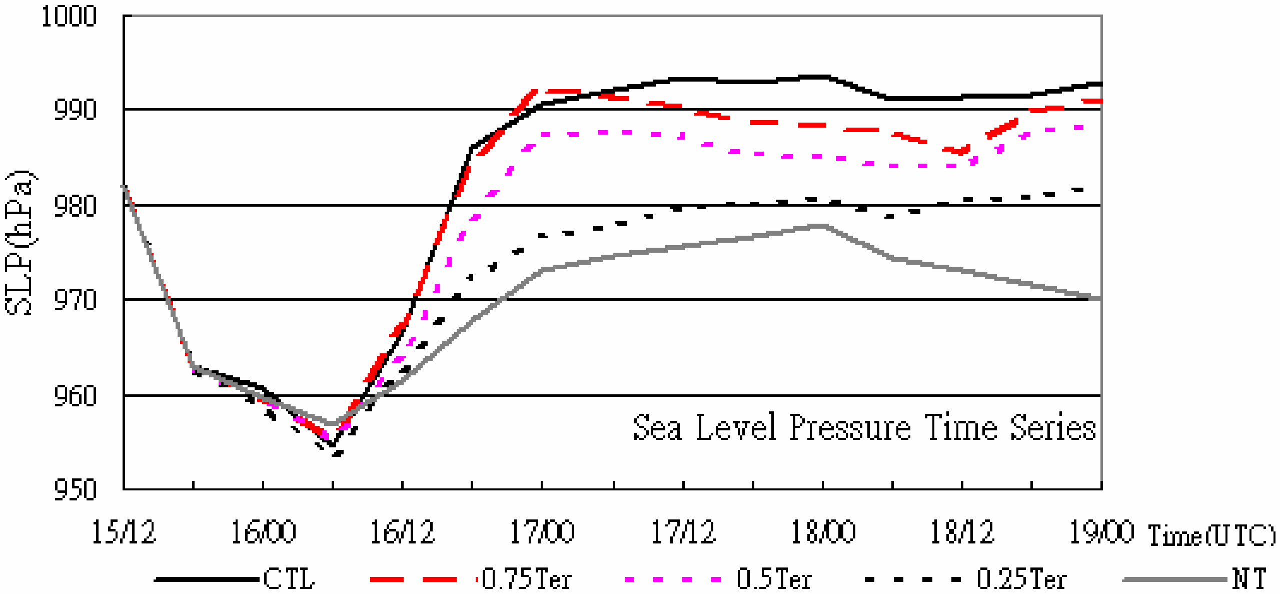
25% Terrain

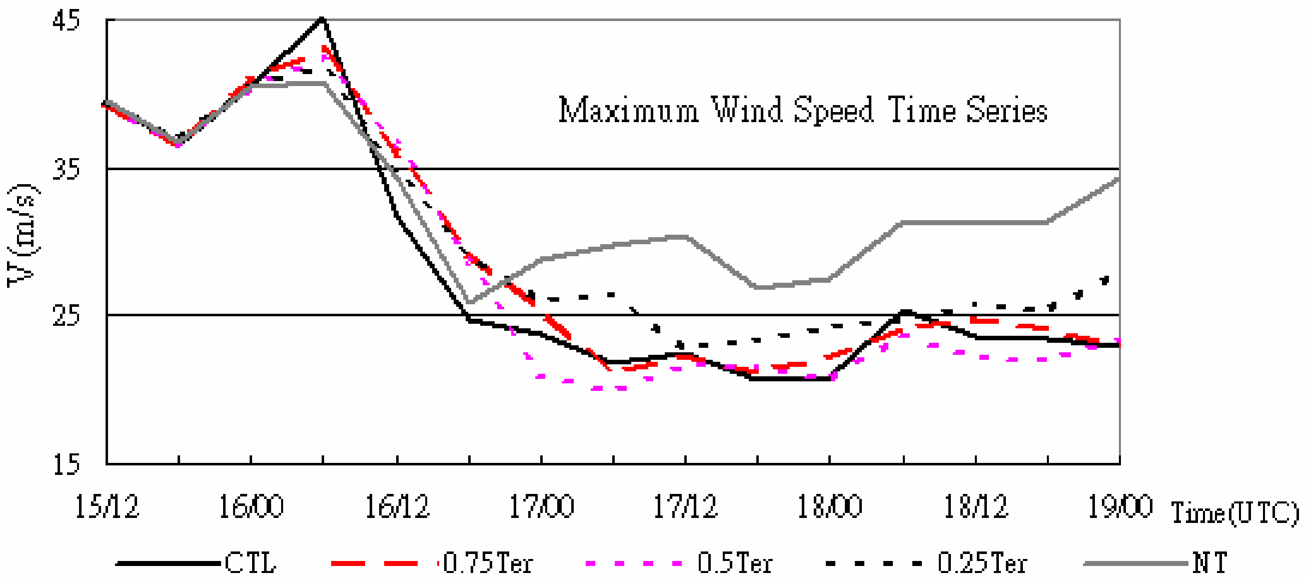


No Terrain

24-h Rainfall On 09/16

Time series of SLP and Vmax





Summary

- The terrain impact on Nari's intensity is quite linear, i.e., higher terrain producing a weaker typhoon.

- However, terrain effects on Nari's track and the accumulated rainfall on Taiwan are nonlinear.

- Nari's tracks near Taiwan result from the complicated interactions between the steering flow, Taiwan topography, and terrain-induced mesoscale forcings

Part III: 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.*, **62**, 4358–4370. .

Cloud Microphysics Precipitation Efficiency (CMPE)

$$CMPE = \frac{P_s}{[SI_{qv}]}$$

Ps **is surface precipitation**
SIqv **= [*PCND*]+ [*PDEP*]+ [*PSDEP*]+ [*PGDEP*], sinks of water vapor through condensation and deposition**

Large-Scale Precipitation Efficiencies; LSPE)

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

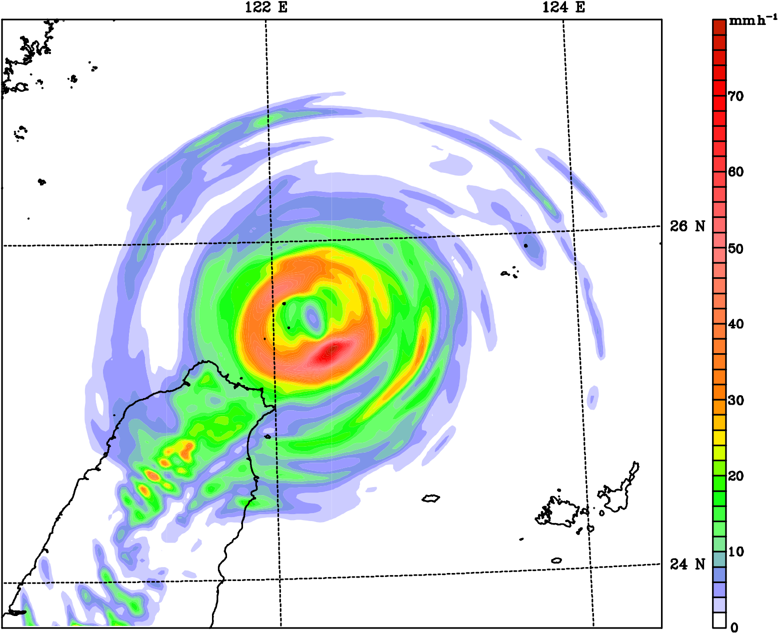
Es+[CONVqv] **is the sum of surface evaporation and water vapor convergence**

For a large-scale spatial and temporal average,

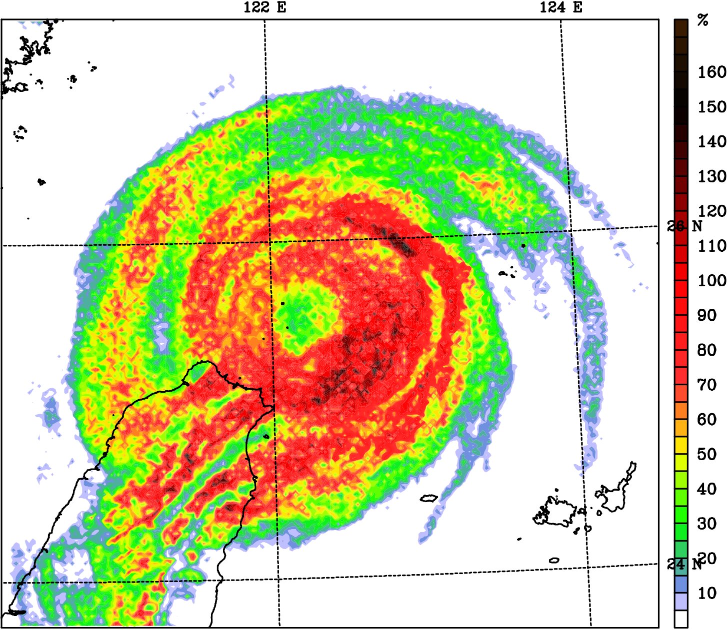
$$[P_{CND}] + [P_{DEP}] + [P_{SDEP}] + [P_{GDEP}] \approx E_s + [CONV_{qv}]$$

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

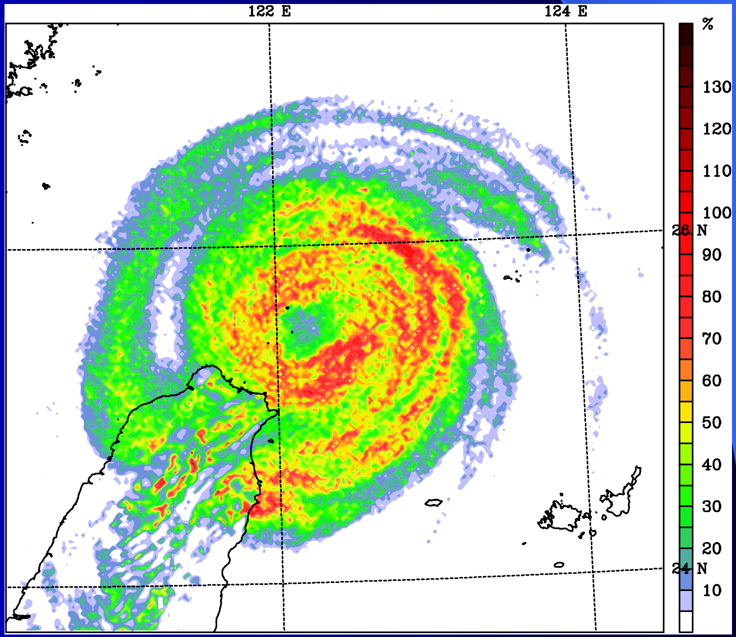
Ps (mm)



CMPE (%)



LSPE (%)

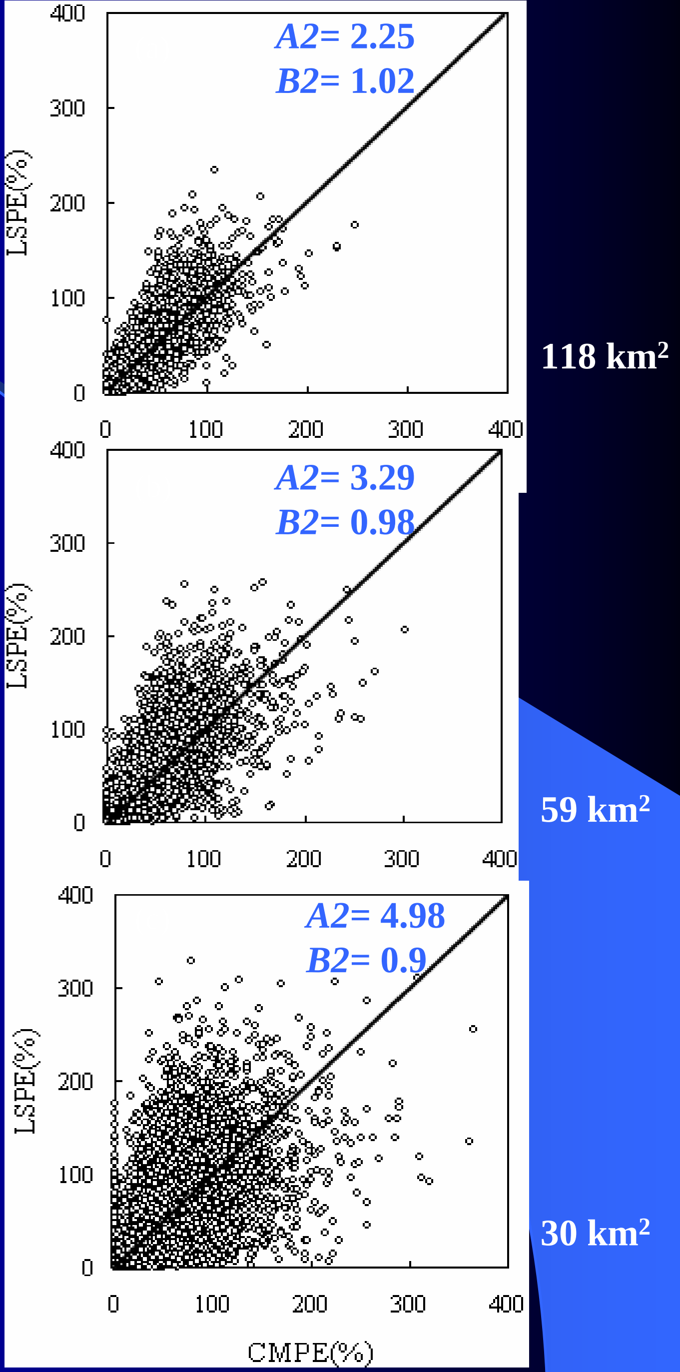


$$LSPE = A2 + B2 \times CMPE$$

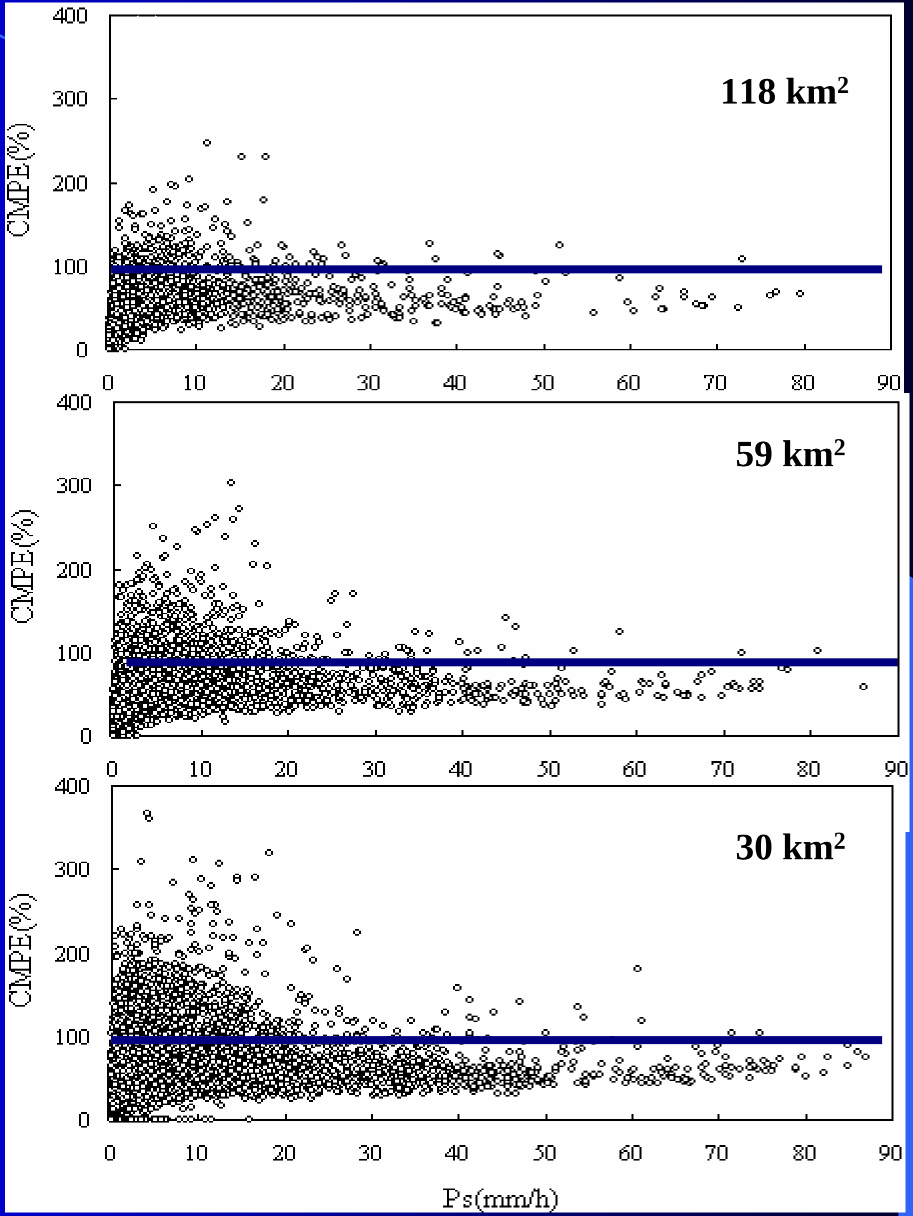
$$LSPE = Ps/SIqv$$

$$CMPE = Ps/(Es+[CONVqv])$$

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



Typhoon Nari



Typhoon Nari

Summary

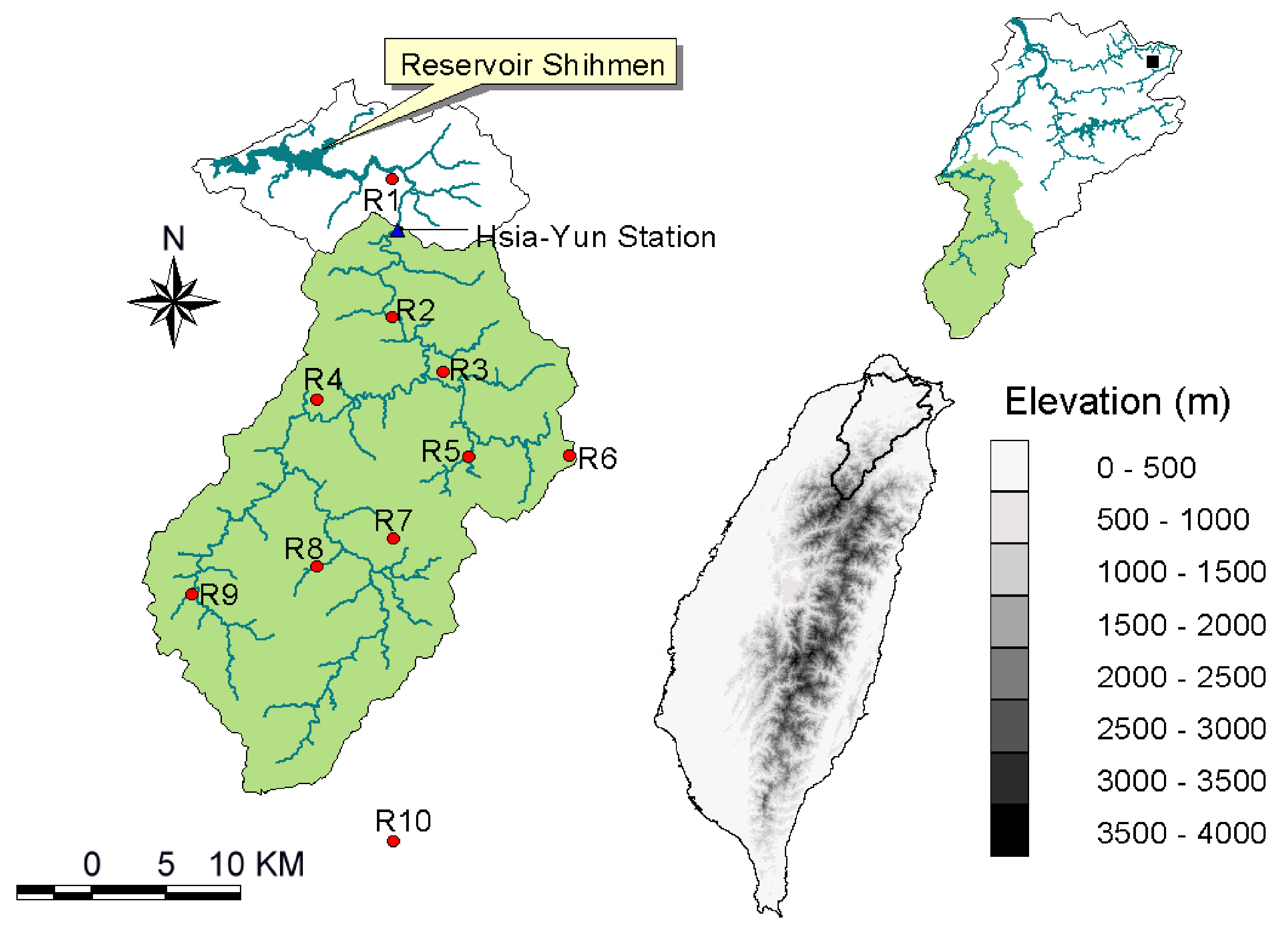
- The LSPE is equivalent to the CMPE in a statistical sense, especially after averaging over a large area (>60~100 km^2) and over several life cycles of convective cells (>3~6 h).
- The CMPE more (less) than 100% occurs in the area with positive (negative) hydrometeor convergence ([CONVc]).
- For Typhoon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

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

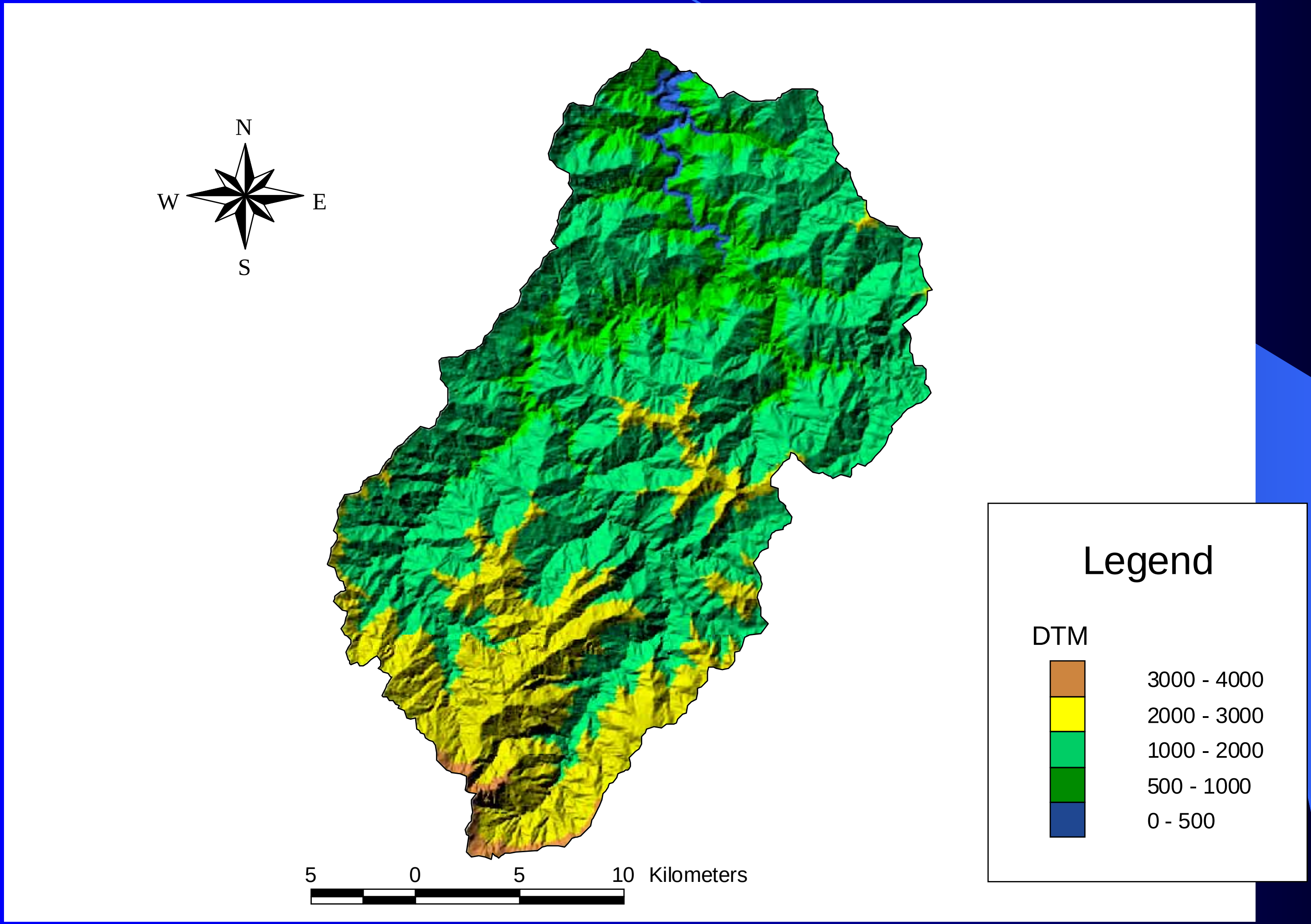
In Cooperation with Ming-Hsu Li

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.

Shihmen Basin



DTM of Shihmen Watershed



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

$$\frac{\partial h}{\partial t}+\frac{\partial hV_x}{\partial x}+\frac{\partial hV_y}{\partial y}=I_e$$

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

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

where h = river depth

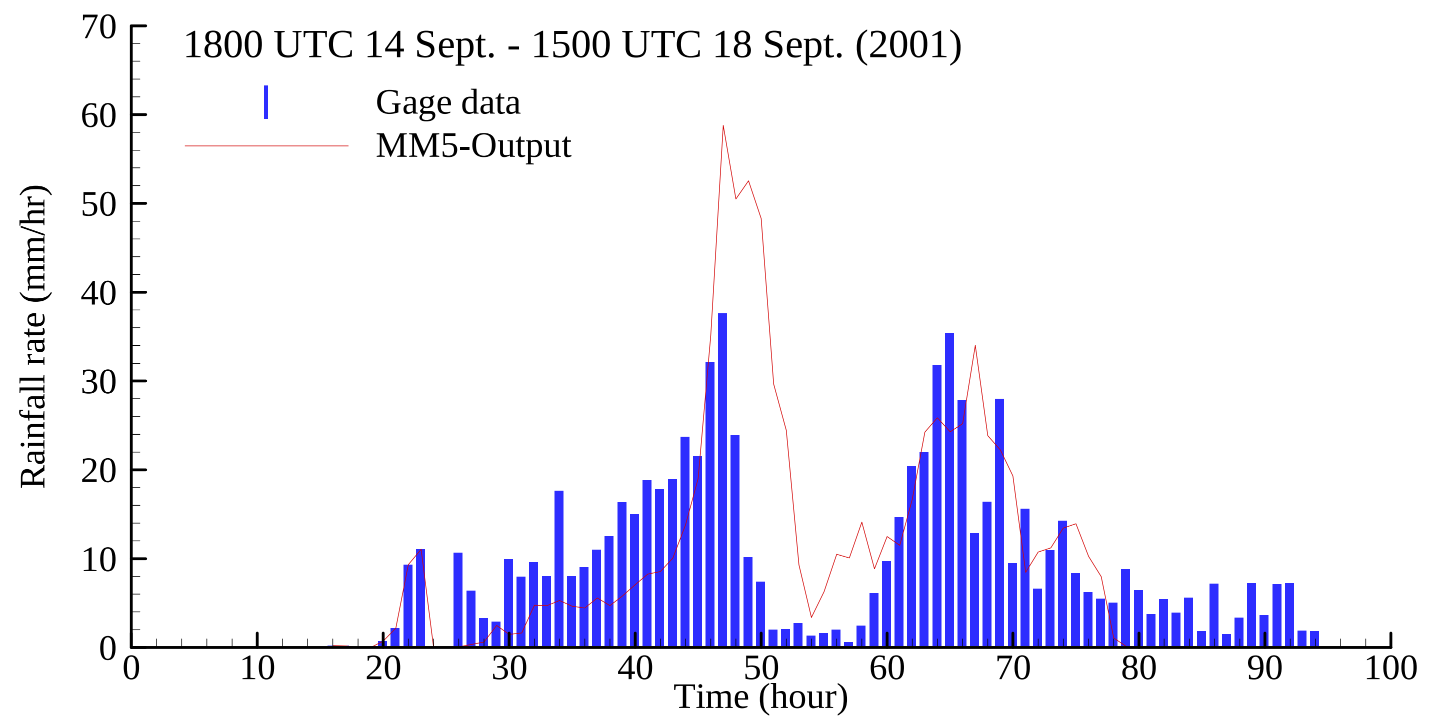
I_e = rainfall (Ps) excess over infiltration,

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

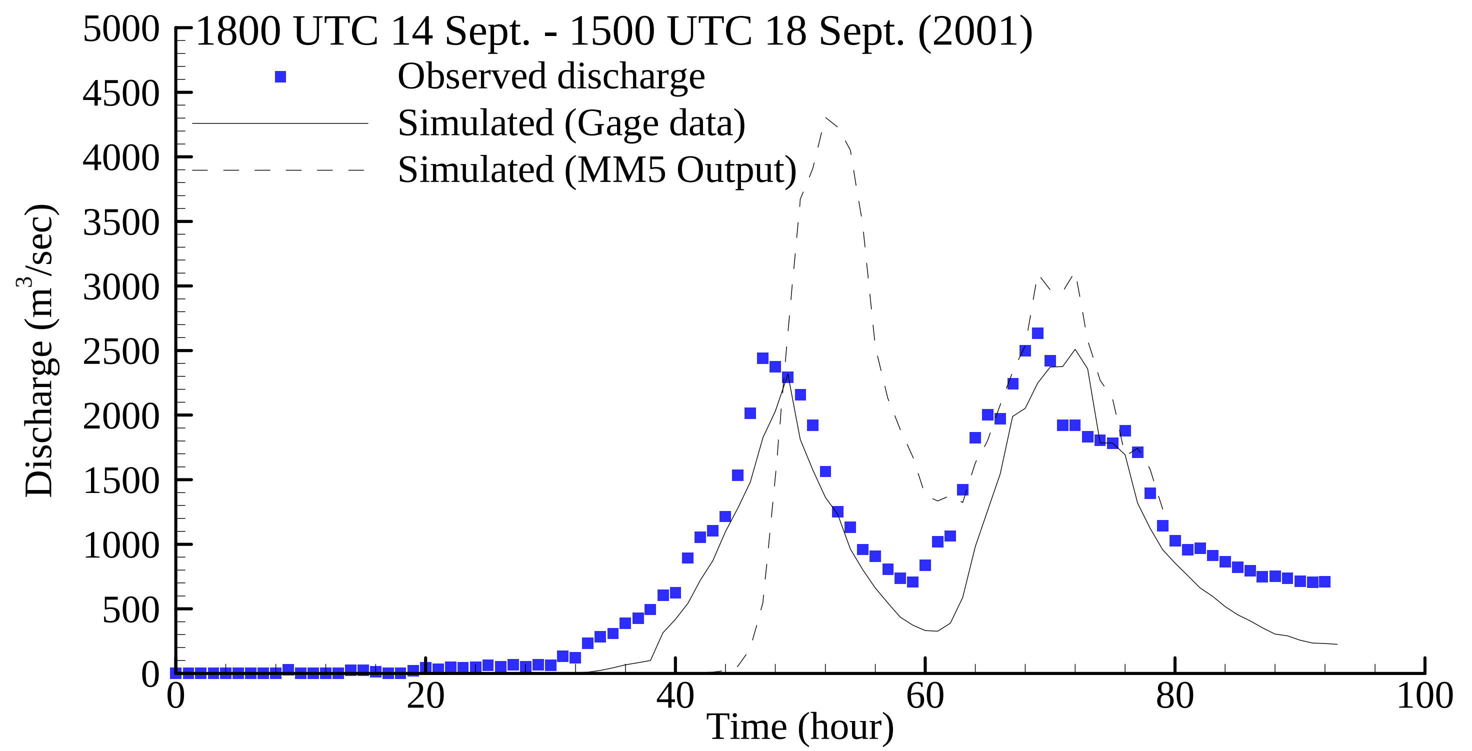
S_{ox}, S_{oy} = the bed-slope components in x- and y-dir.,

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

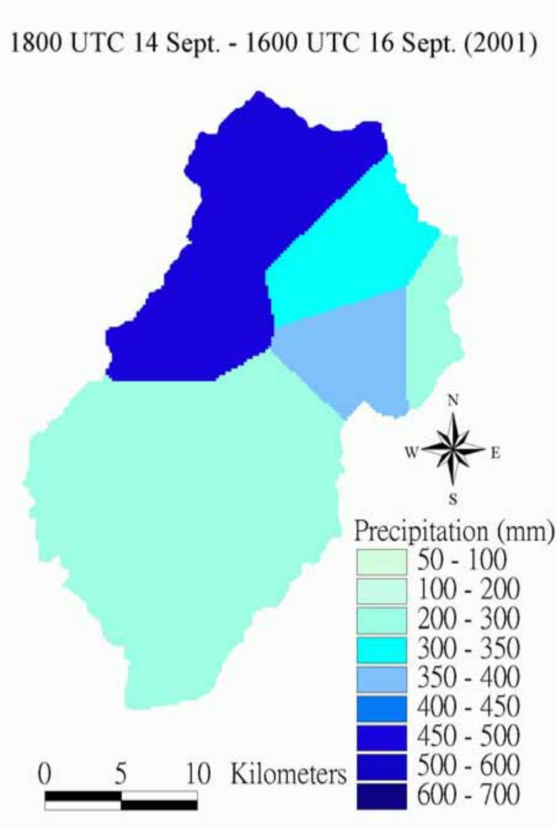
Rainfall Comparison (Basin Average)



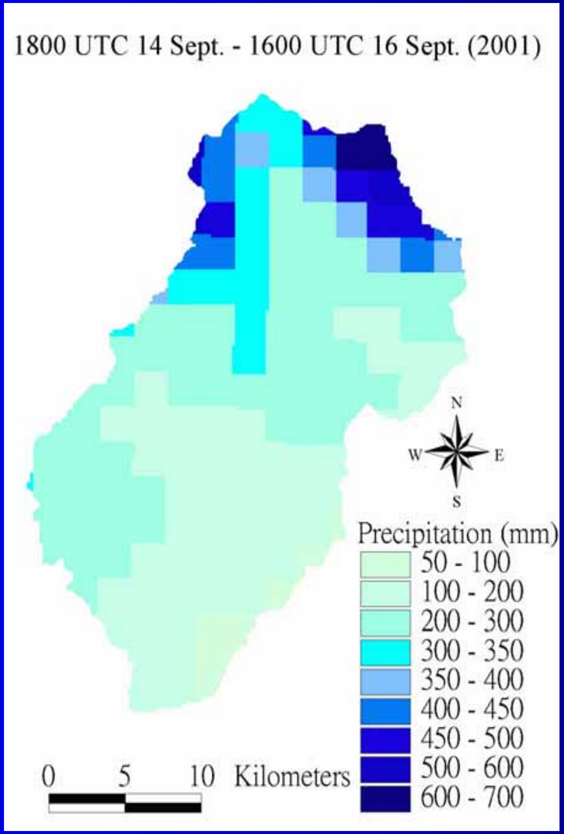
Flow Discharge Comparison (Basin Average)



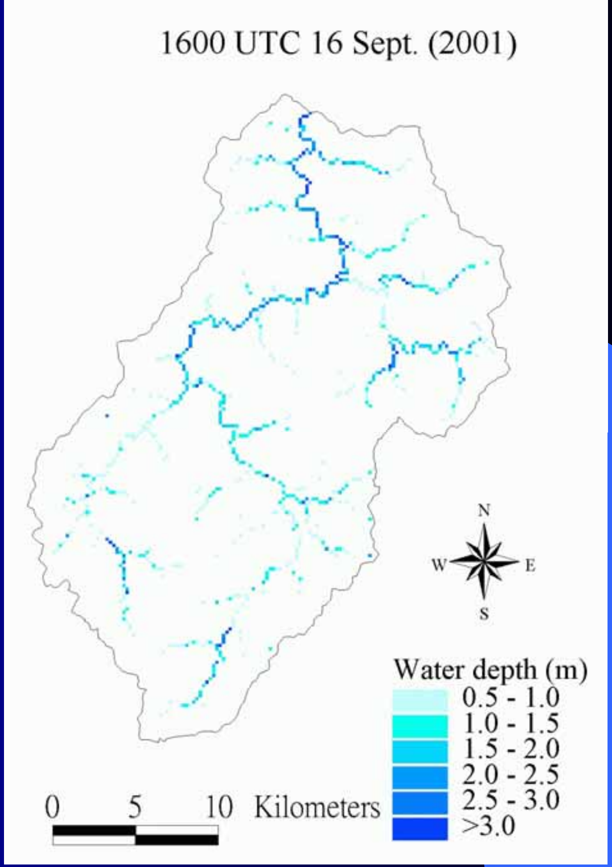
Gauge Rainfall



MM5 Rainfall



Simulated River Depths by MM5 Rainfall



Summary

- The one-way coupling of MM5 with the FLO-2D runoff model is established and verified for Typhoon Nari (2001).

- The MM5-predicted basin-averaged rainfalls are compared with those by rain gauge 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.

Thank You !