Numerical Simulations of Typhoon Nari (2001)

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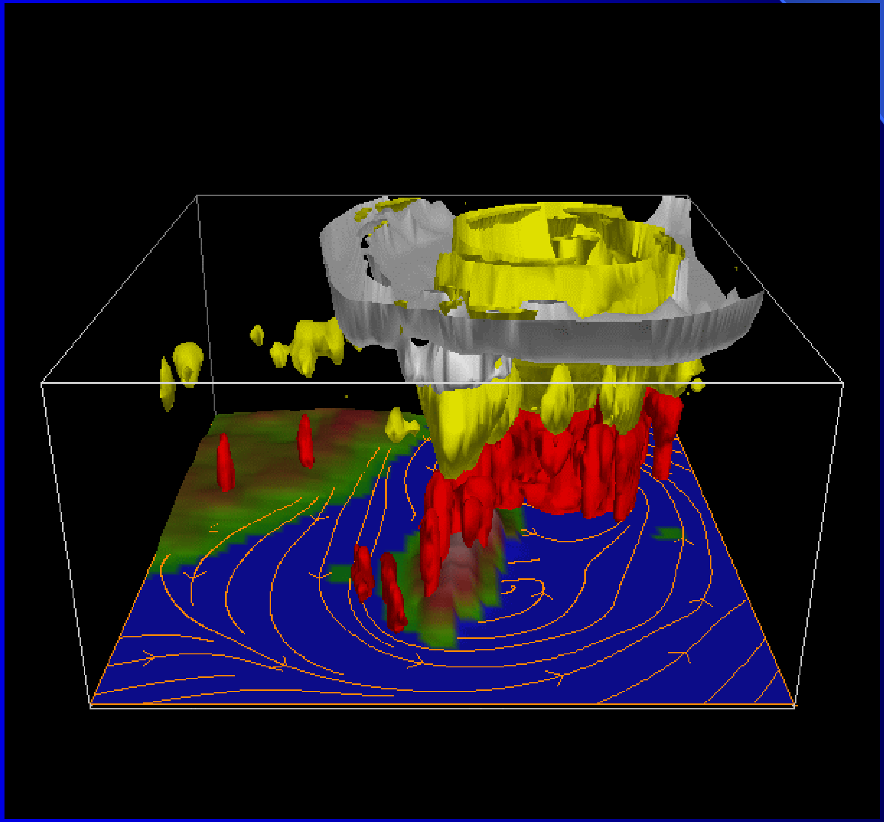


Part I

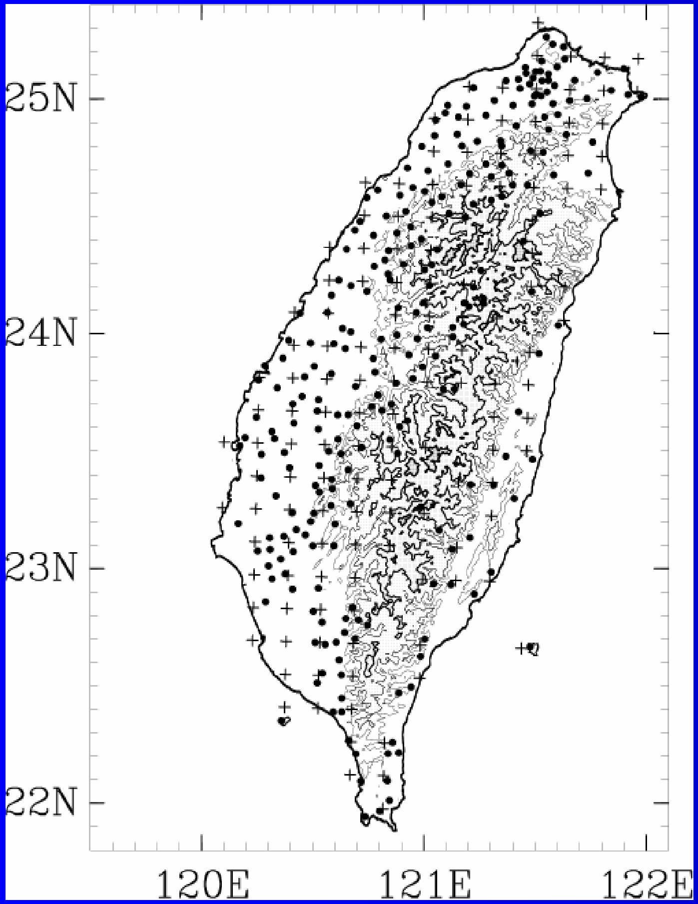
Ensemble Forecast of Rainfall over the Taiwan Area during the 2000-2002 Mei-Yu Seasons

A Cooperation between the National Central University,
National Taiwan University,
National Taiwan Normal University,
Chinese Culture University,
Central Weather Bureau,
and Civil Aeronautics Administration

Precipitation Physics Combination of Six Ensemble Members

Member	Cumulus	Microphysics	Site
BM-R1	Betts-Miller	Reisner 1	NCU
KF-SI	Kain-Fritsch	Simple Ice	NTNU
KF-GD	Kain-Fritsch	Goddard	CCU
AK-SI	Anthes-Kuo	Simple Ice	CWB
GR-R1	Grell	Reisner 1	NTU
KF-R1	Kain-Fritsch	Reisner 1	CAA

Grid-Point Rainfall Analysis



- Arithmetic Averaging:

$$A_k^a = \frac{\sum_{i=1}^{N}(A_i^o)}{N}$$

N is number of raingauge stations inside a 15-km MM5 grid;

A_k^a is the analyzed rainfall on a MM5 grd;

A_i^o is the observed rainfall by raingauge.

•Raingauge (dot): 343 points

•MM5 grid (cross): 140 points on Taiwan

51 points for verification

(after data screening)

Ensemble rainfall forecast using a multiple linear regression (MLR) method:

Assume observed rainfall (O) can be expressed as a linear combination of MM5-forecasted rainfalls (M) as:

$$\begin{bmatrix} O_1 \\ O_2 \\ O_3 \\ \vdots \\ O_N \end{bmatrix} = \alpha \begin{bmatrix} (m_1)_1 \\ (m_1)_2 \\ (m_1)_3 \\ \vdots \\ (m_1)_N \end{bmatrix} + \beta \begin{bmatrix} (m_2)_1 \\ (m_2)_2 \\ (m_2)_3 \\ \vdots \\ (m_2)_N \end{bmatrix} + \gamma \begin{bmatrix} (m_3)_1 \\ (m_3)_2 \\ (m_3)_3 \\ \vdots \\ (m_3)_N \end{bmatrix} + \kappa \begin{bmatrix} (m_4)_1 \\ (m_4)_2 \\ (m_4)_3 \\ \vdots \\ (m_4)_N \end{bmatrix} + \delta \begin{bmatrix} (m_5)_1 \\ (m_5)_2 \\ (m_5)_3 \\ \vdots \\ (m_5)_N \end{bmatrix} + \varepsilon \begin{bmatrix} (m_6)_1 \\ (m_6)_2 \\ (m_6)_3 \\ \vdots \\ (m_6)_N \end{bmatrix} - \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ \vdots \\ r_N \end{bmatrix} \quad (1)$$

where m_1 is the first ensemble member, m_2 is the second ensemble member, and so on. N is the total number of forecast rainfall events during a Mei-Yu season.

The above equation can be written in a vector form as:

$$\vec{O} = \alpha \vec{m}_1 + \beta \vec{m}_2 + \gamma \vec{m}_3 + \kappa \vec{m}_4 + \delta \vec{m}_5 + \varepsilon \vec{m}_6 - \vec{r} \quad (2)$$

Then the rainfall forecast error is

$$\vec{r} = \alpha\vec{m}_1 + \beta\vec{m}_2 + \gamma\vec{m}_3 + \kappa\vec{m}_4 + \delta\vec{m}_5 + \varepsilon\vec{m}_6 - \vec{O} \qquad (3)$$

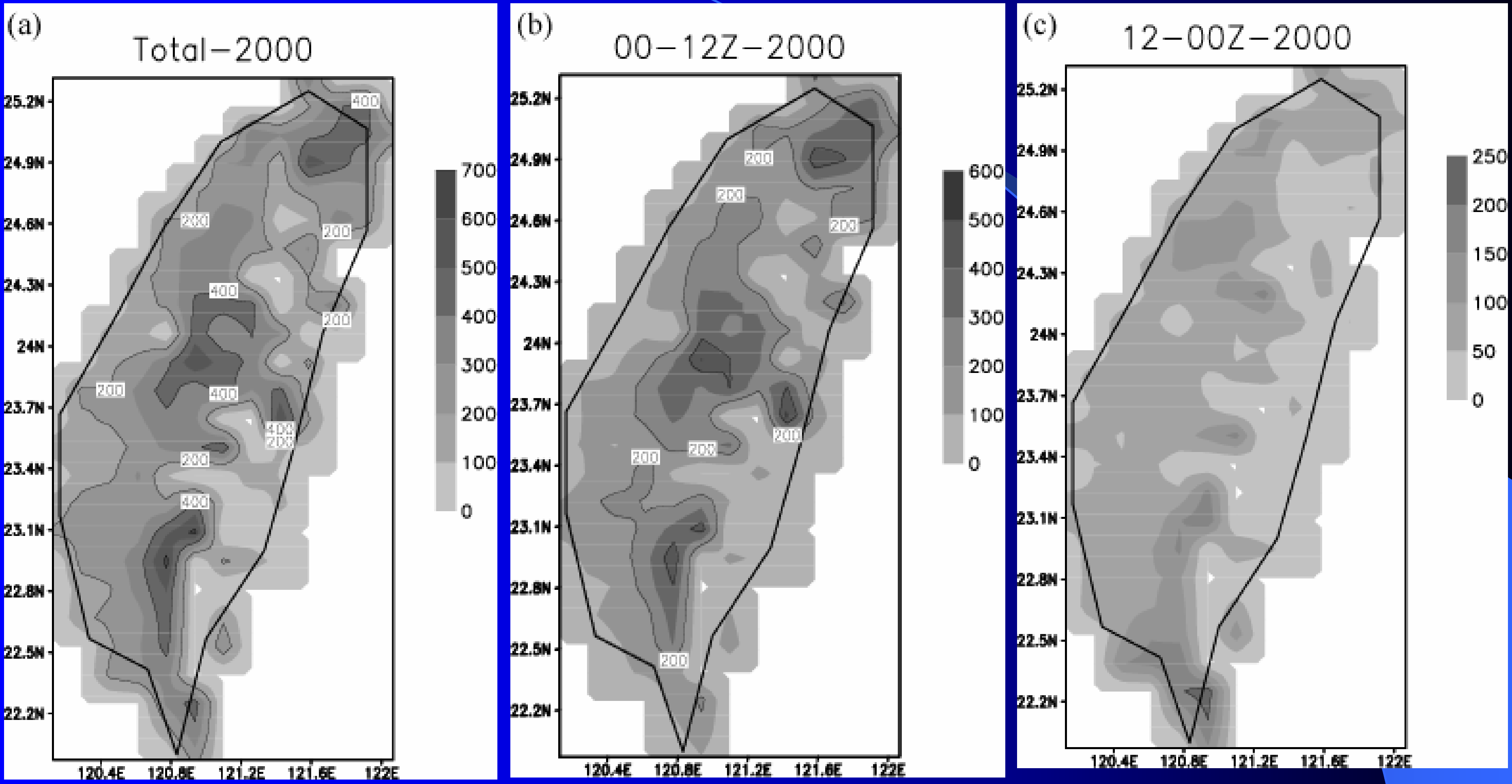
where $\alpha, \beta, \gamma, \kappa, \delta, \varepsilon$ is the weighting coefficient for each member.

The square of forecast rainfall error is

$$r^2 = \vec{r} \cdot \vec{r} = (\alpha\vec{m}_1 + \beta\vec{m}_2 + \gamma\vec{m}_3 + \kappa\vec{m}_4 + \delta\vec{m}_5 + \varepsilon\vec{m}_6 - \vec{O})^2 \qquad (4)$$

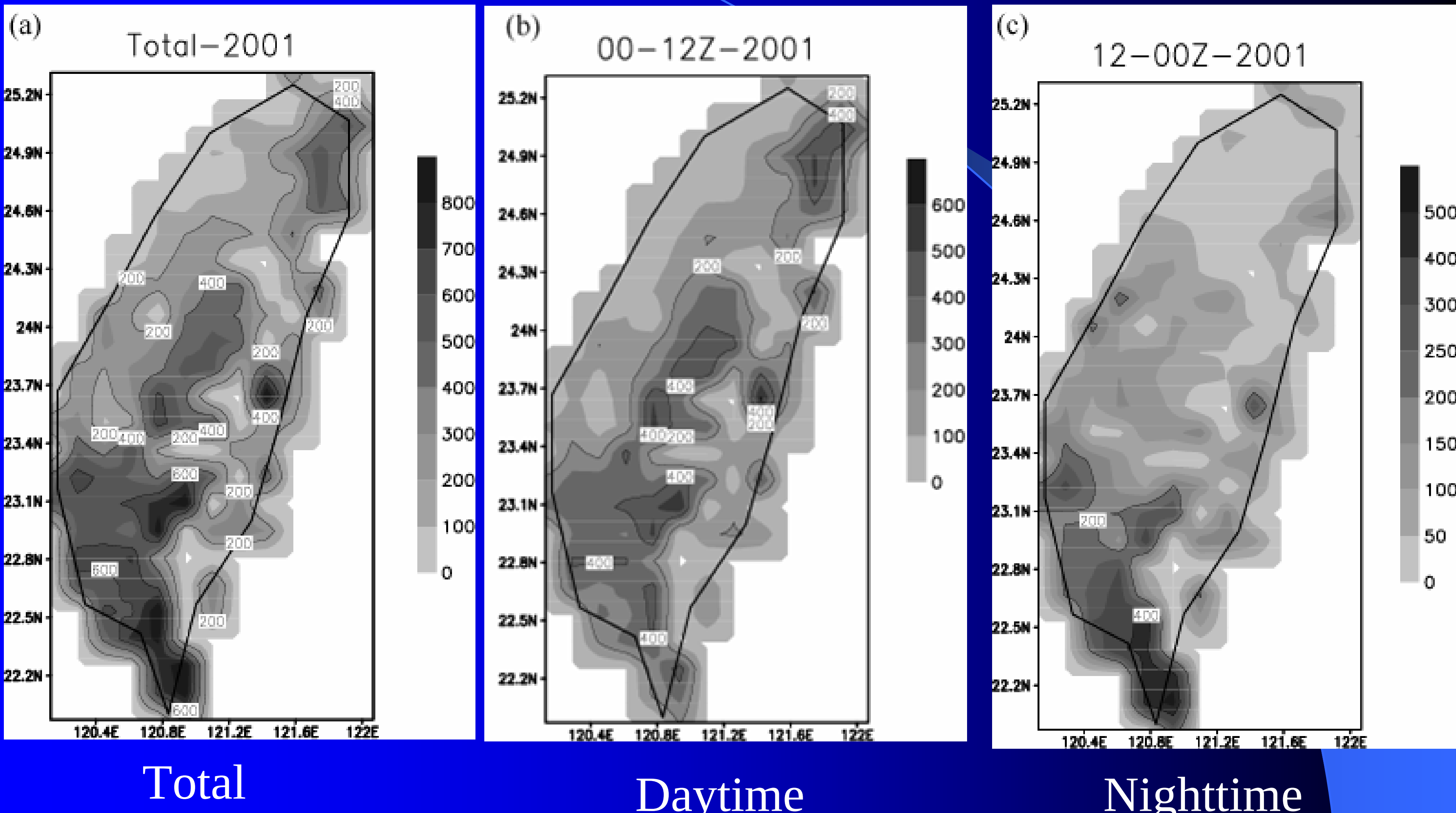
Then the weighting coefficients $(\alpha, \beta, \gamma, \kappa, \delta, \varepsilon)$ can be determined by the minimization of rainfall forecast error in a least square sense.

Rainfall Distribution during the 2000 Mei-Yu Season

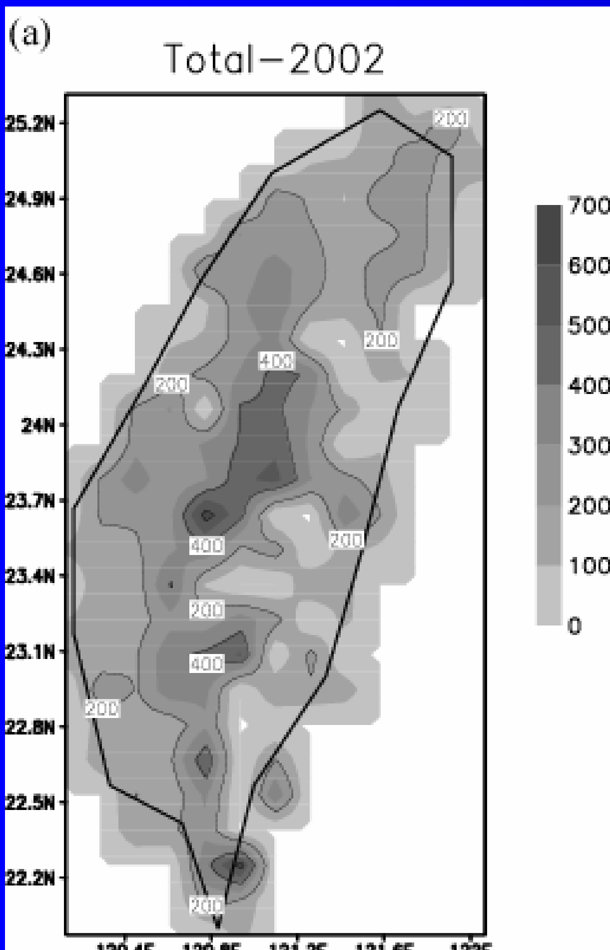


Total Daytime Nighttime

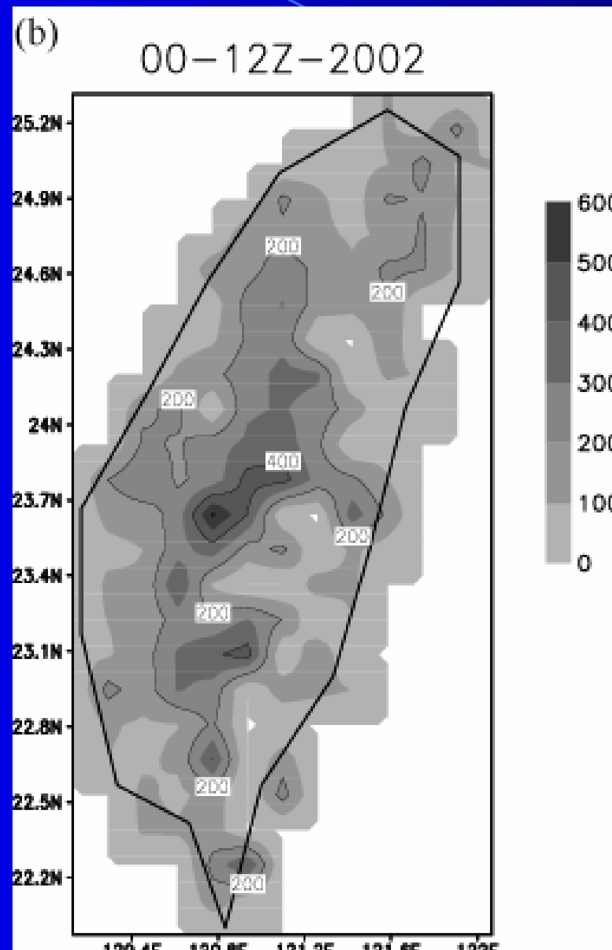
Rainfall Distribution during the 2001 Mei-Yu Season



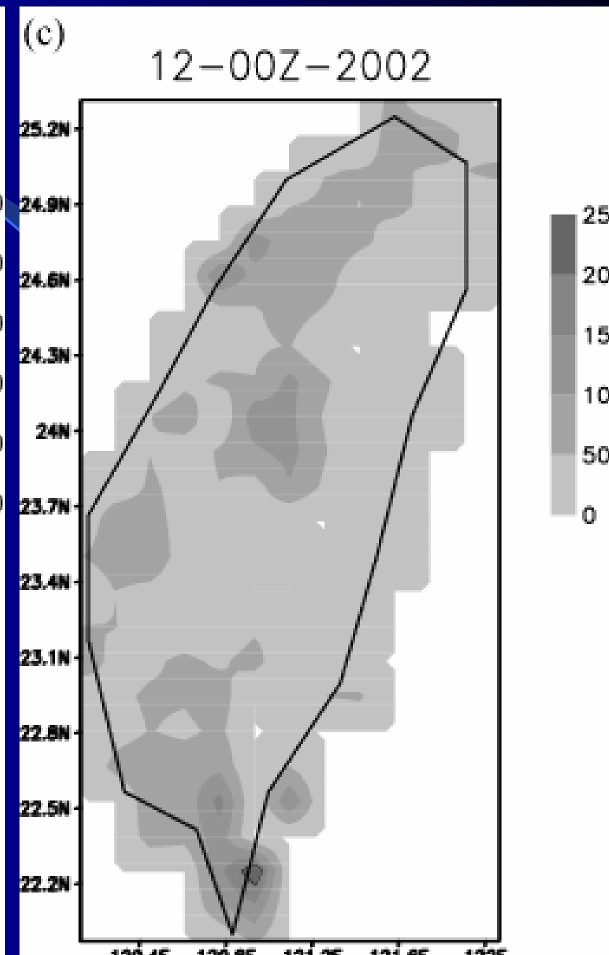
Rainfall Distribution during the 2002 Mei-Yu Season



Total



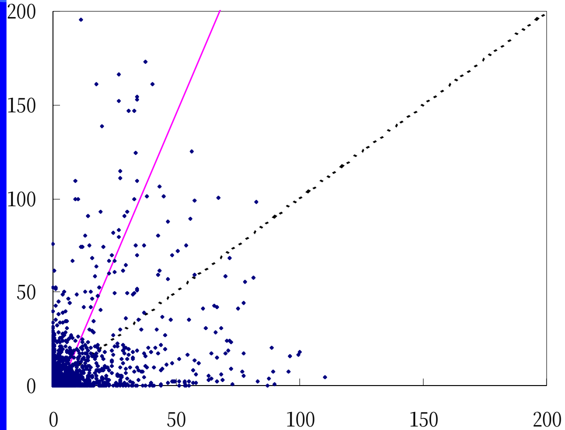
Daytime



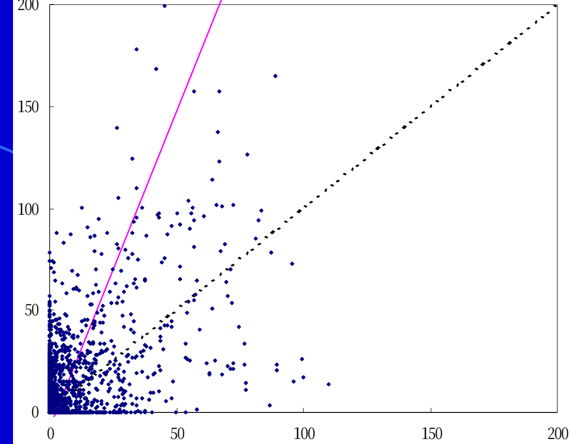
Nighttime

Observed vs. Forecasted Rainfall Amount for the 12-24 h Forecast during the 2000 Mei-Yu Season

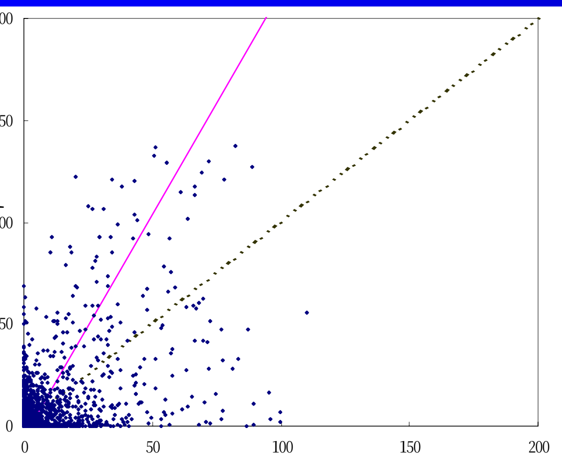
AK-SI



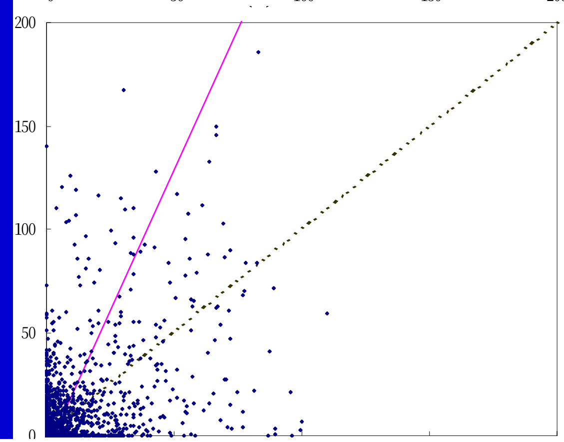
BM-R1



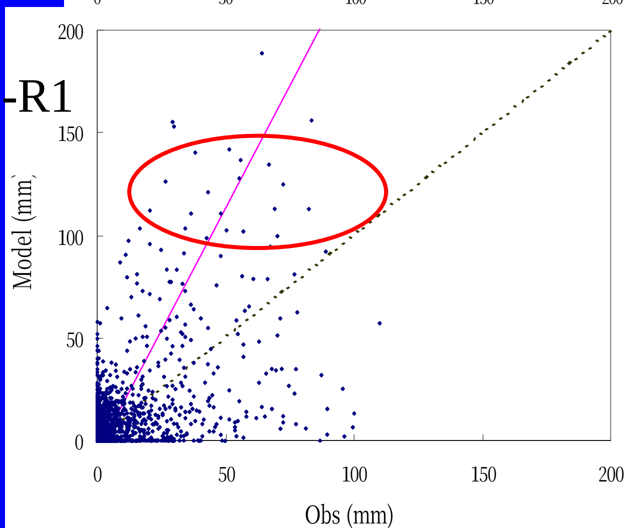
GR-R1



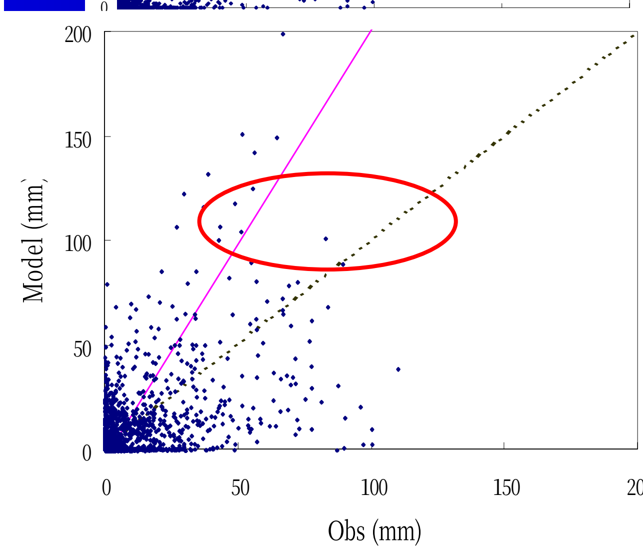
KF-GD



KF-R1

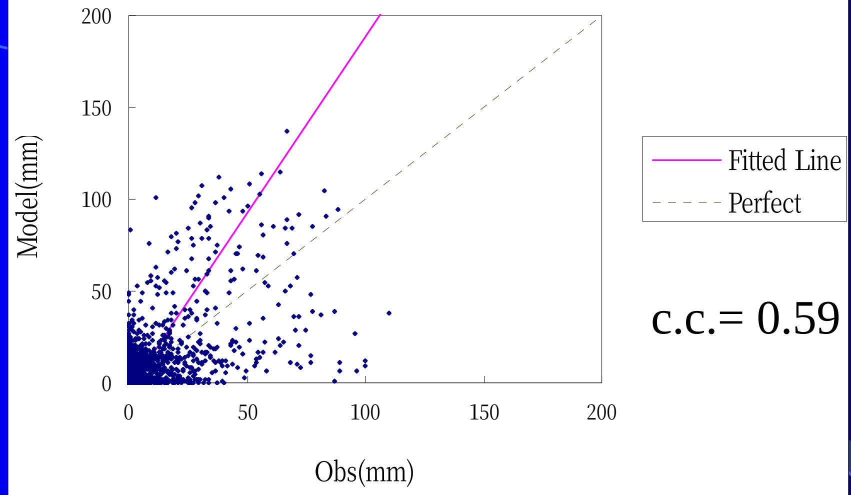


KF-SI

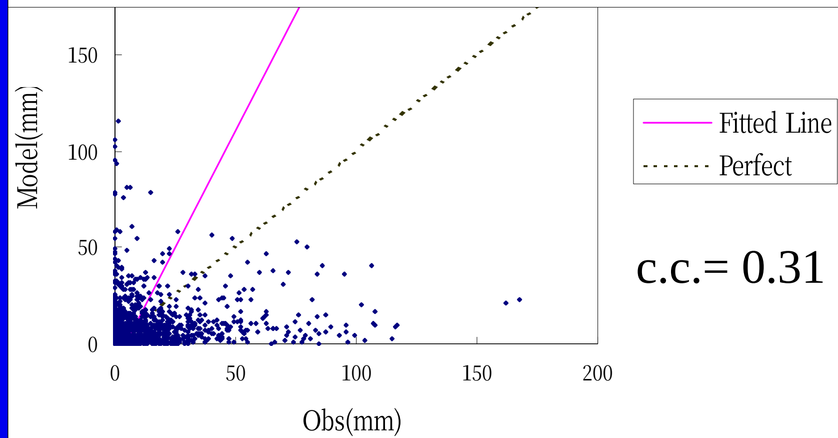


Observed vs. MLR Ensemble Forecasted Rainfall Amount for the 12-24 h Forecast during three Mei-Yu Seasons

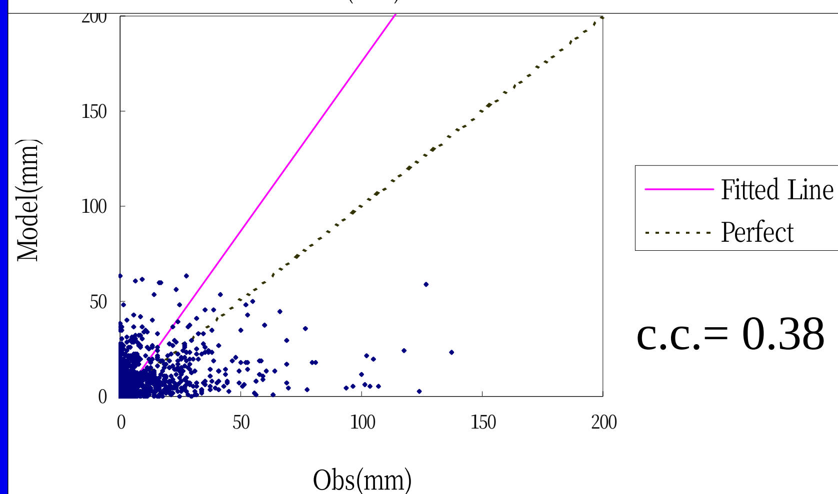
2000

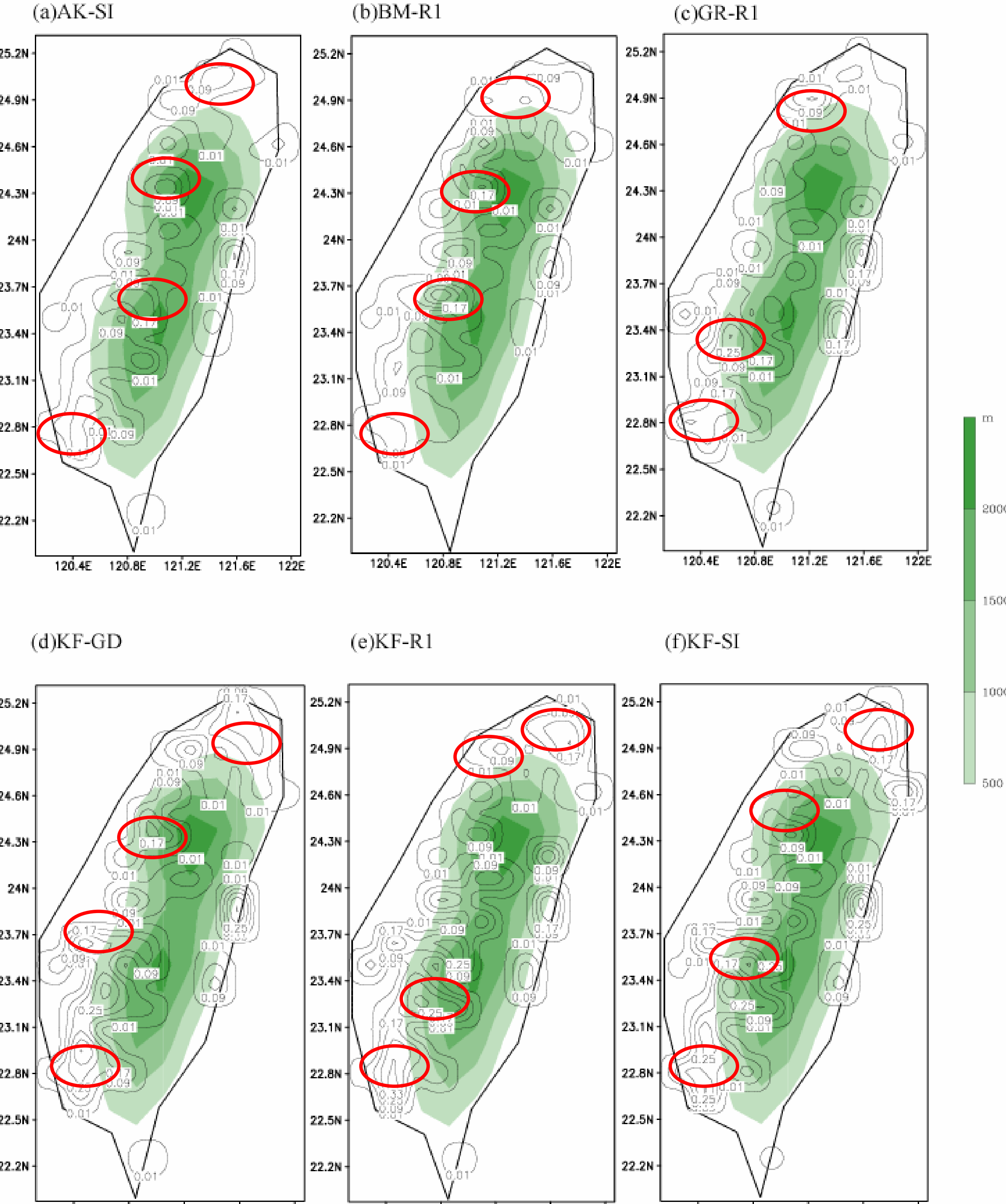


2001



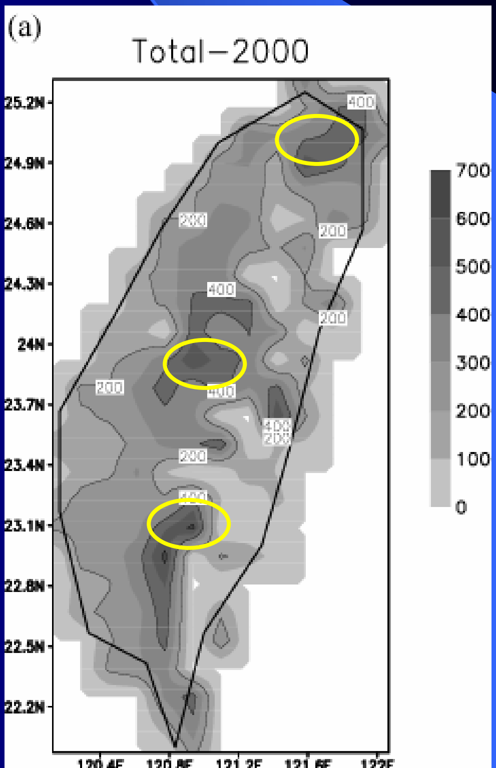
2002





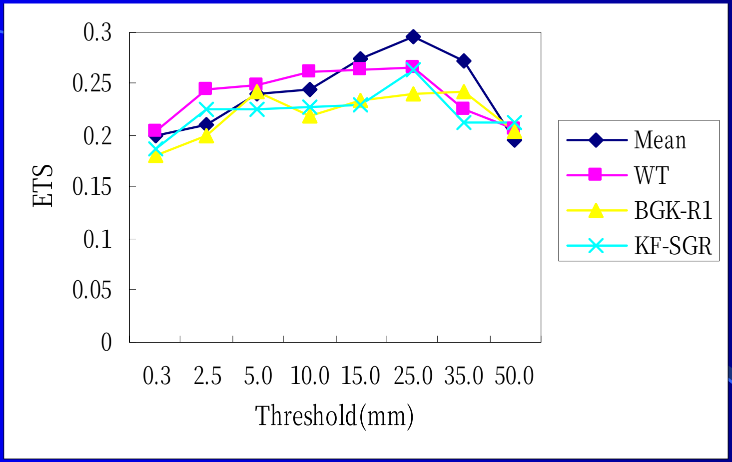
Horizontal ETS Distribution For 12-24 h fcst of Rainfall Chance

Observed Rainfall Distribution in 2000

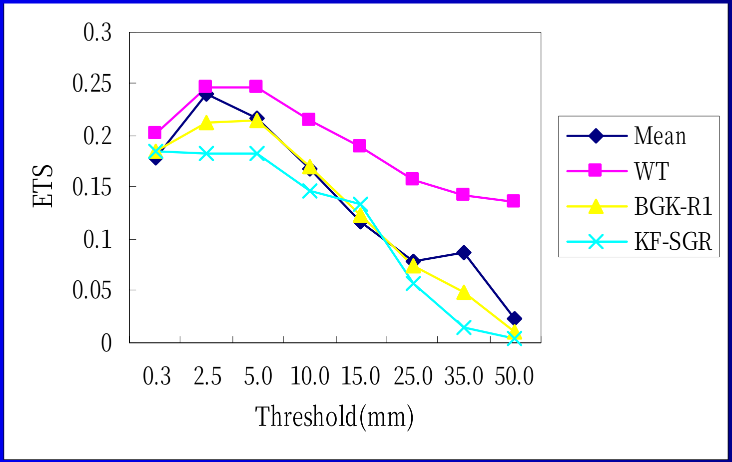


ETS Scores for Four Ensemble 12-24 h Forecasts

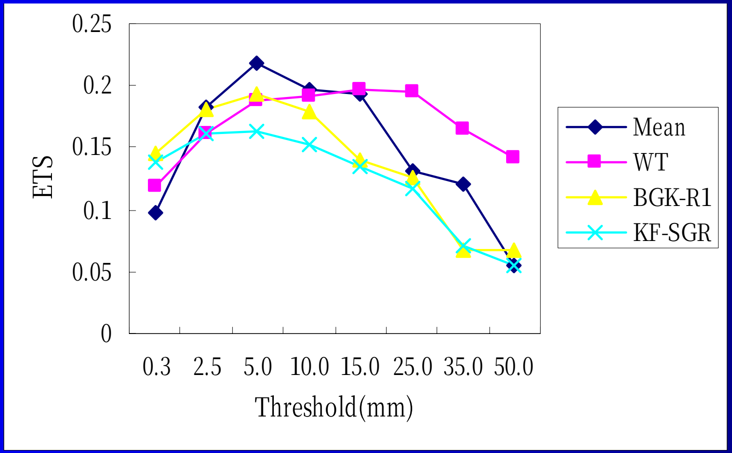
2000



2001



2002

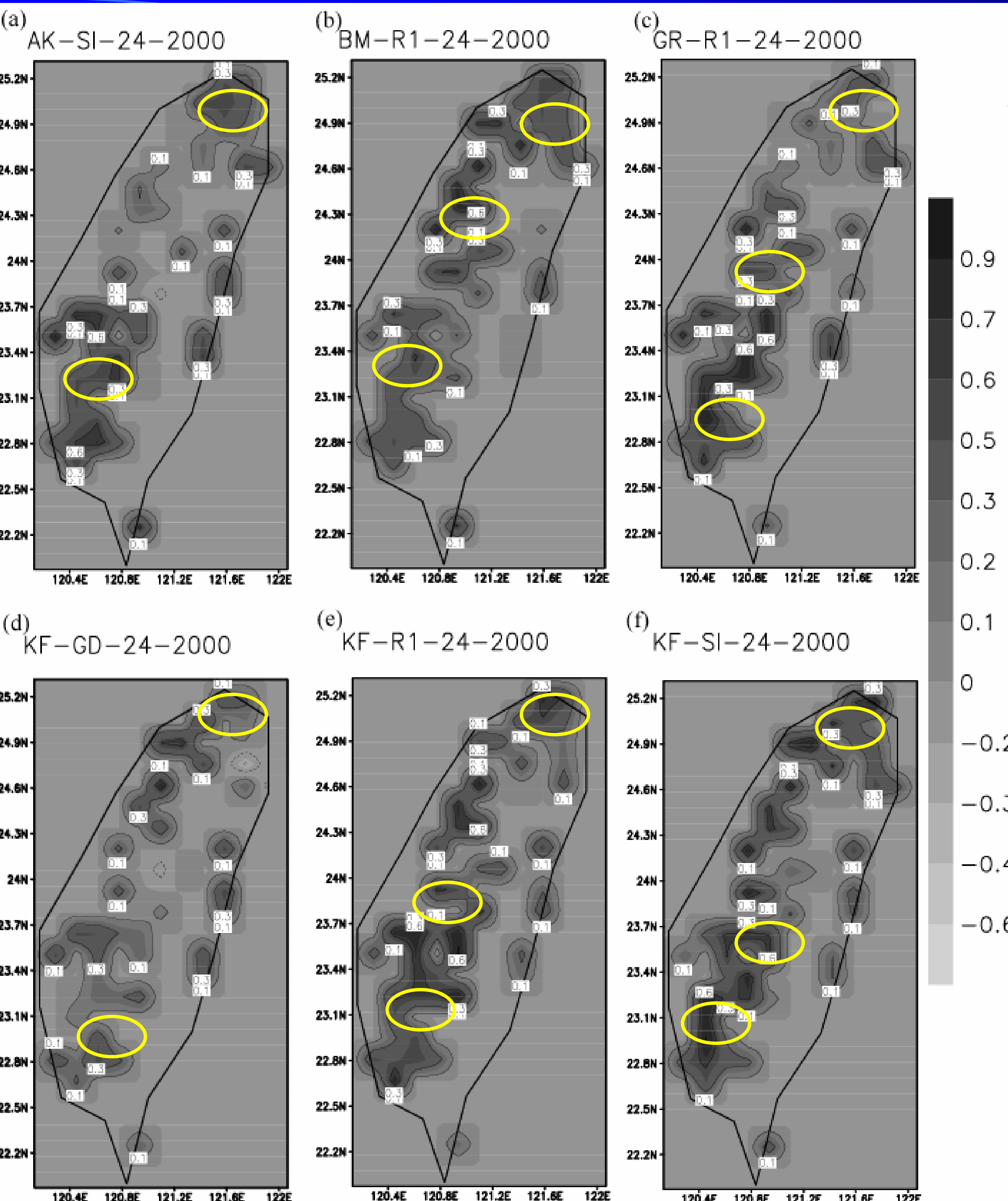


Mean: Same weighting for Six members (used in real time)

WT: multiple linear regression (MLR) method

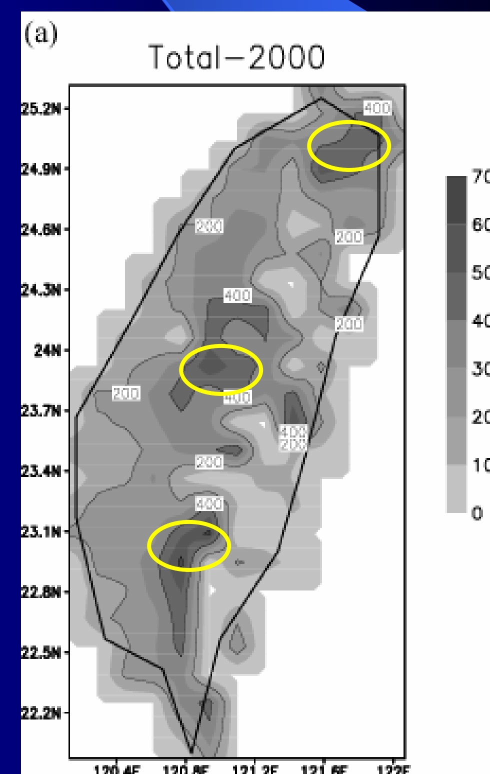
BKG-R1: Same weighting for Three CPS members

KF-SGR: Same weighting for Three Microphysics members



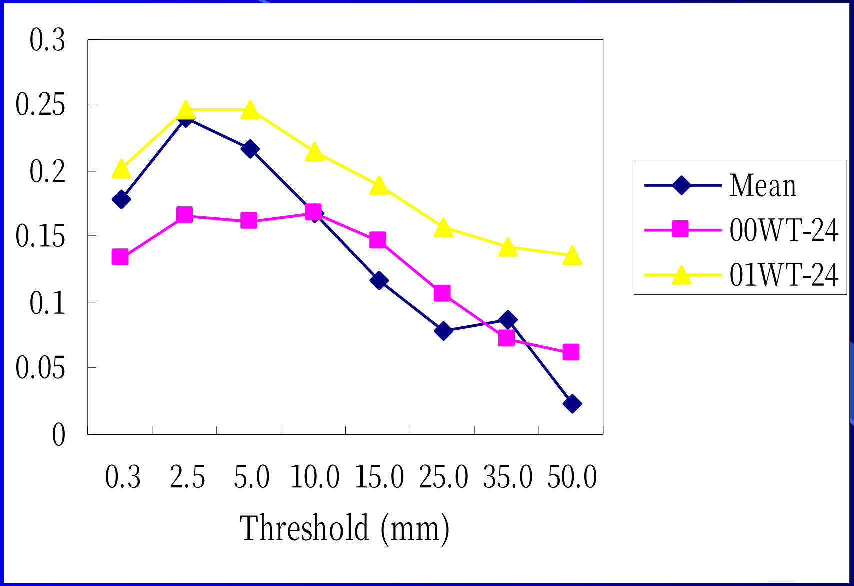
Distribution of Weighting Coefficients for 12-24 h fcst

Observed Rainfall Distribution in 2000



12-24 h 2001

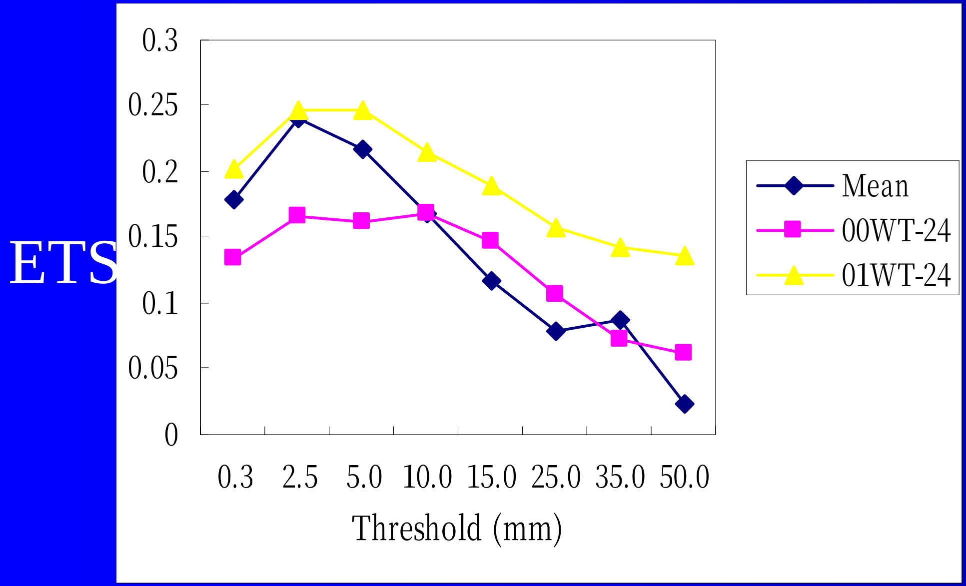
ETS



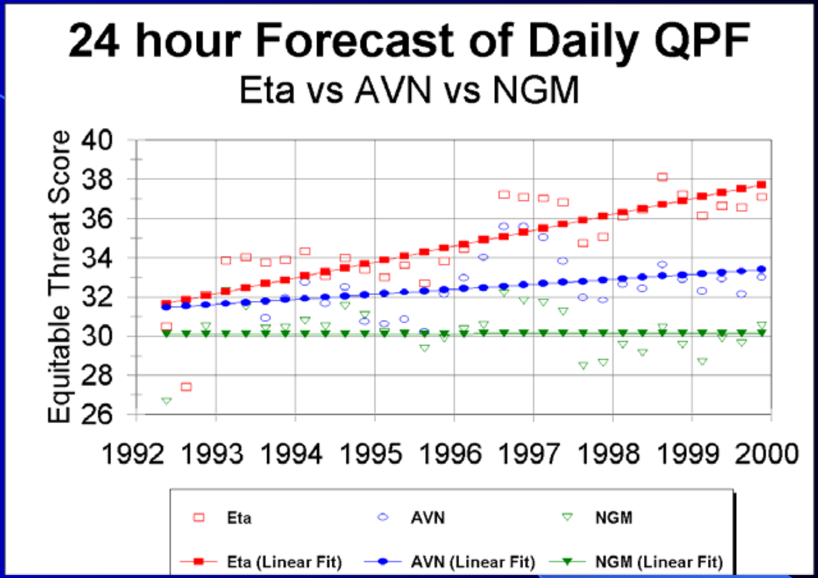
Mean: Same Weighting for Six Members
00WT: Use the MLR Weighting from Year 2000
01WT: Use the MLR Weighting from Year 2001 (Current Year)

Taiwan's Mei-Yu Season MLR Ensemble Forecasting

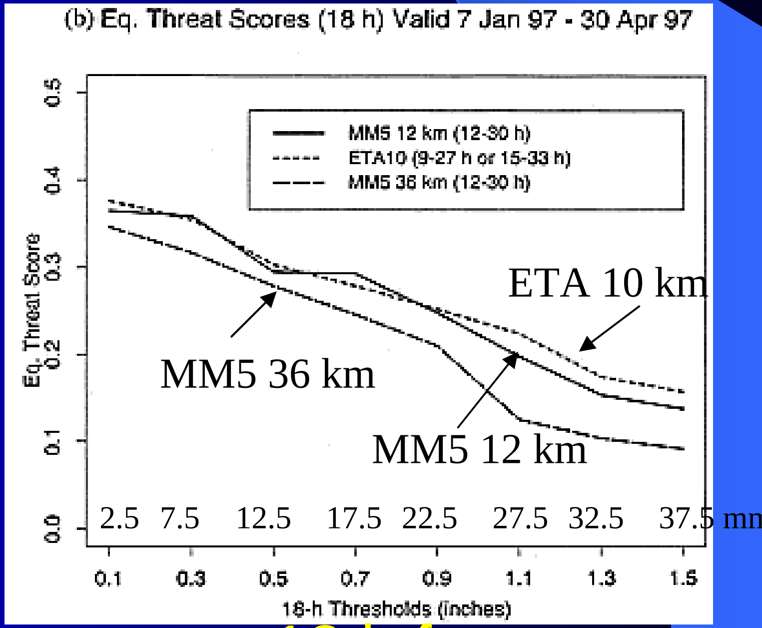
12-24 h 2001 (MM5 15 km)



NCEP Model Forecast for Threshold = 0.25 mm



Washington's Cold Season (Colle et al. 1999)



18 h fcst

Summary

(1) For rainfall occurrence forecast, most members had better skill over the NE mountain area, NW coastal plan, central mountain slope, SW coastal plain, and SW mountain area. These areas were also regions of more accumulated rainfalls during three Mei-Yu seasons.

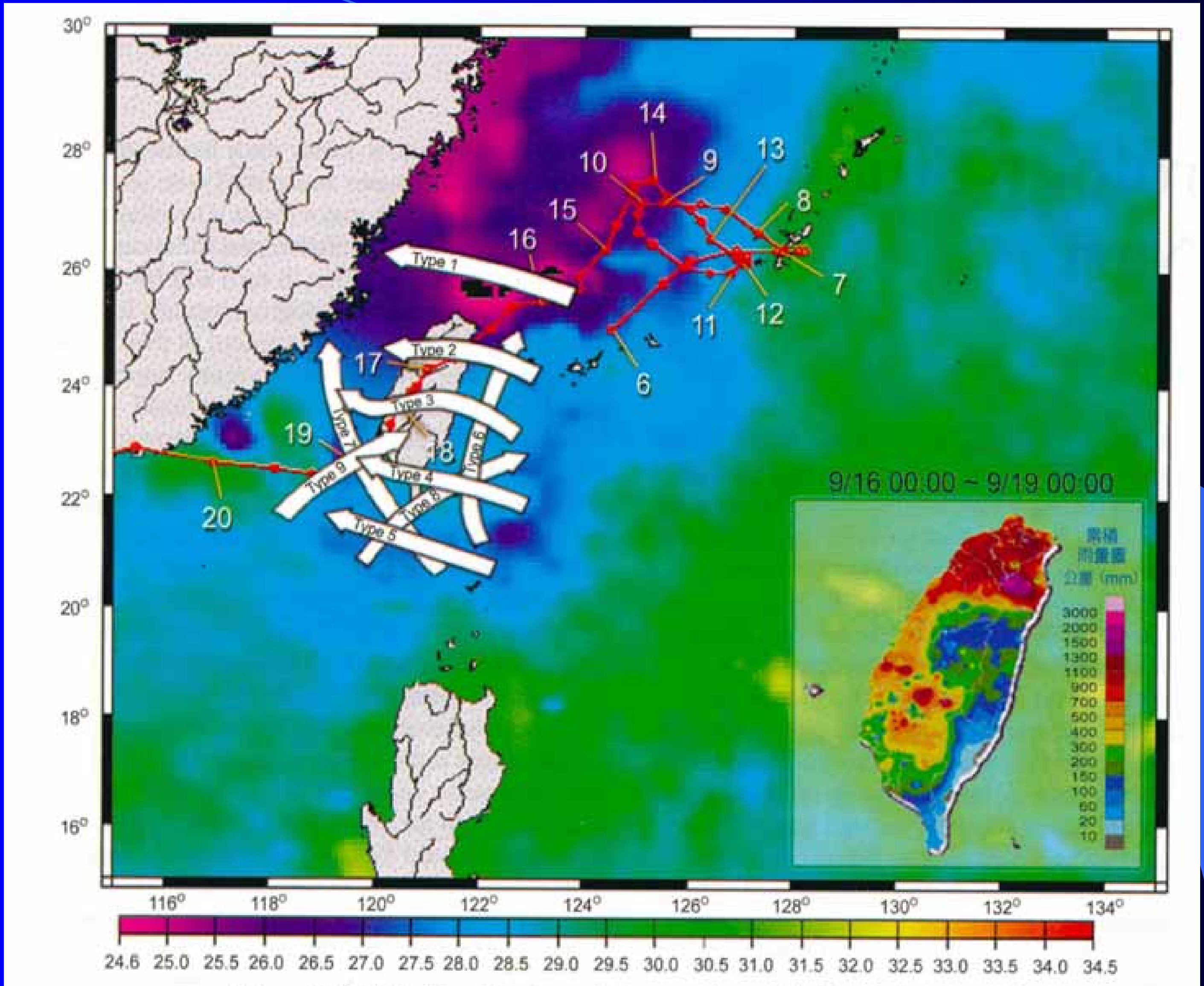
(2) An ensemble forecast of rainfall using the MLR method had the best ETS performance for all rainfall thresholds, and it persistently outperformed the MEAN forecast with 6 members having the same weighting.

(3) The MLR ensemble forecasting applies more weighting over regions of higher ETS scores, thus producing a better predictive skill for all (particularly for high) precipitation thresholds.

(4) The MLR ensemble forecasting with weighting from previous years still had similar ETS trend to that determined from current-year weighting, albeit with less skill.

Part II:
Precipitation Processes of the Landfalling Typhoon Nari

Track and SST



Sep. 18 2001 Sea Surface Temperature (3 Days Average)

Sui et al. (2002) EOS article

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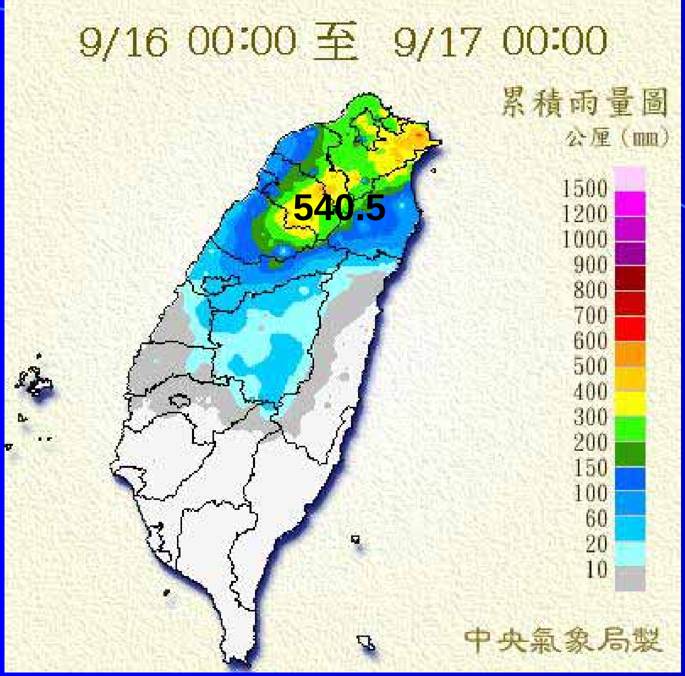

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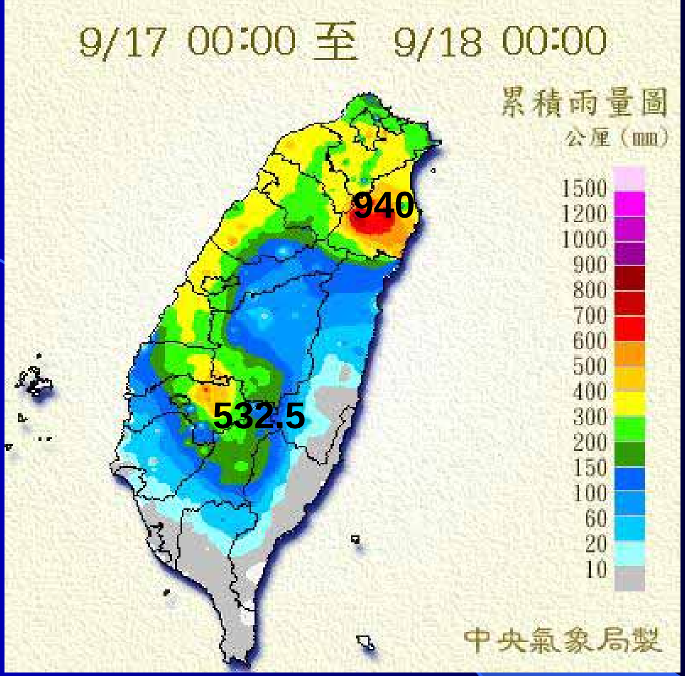

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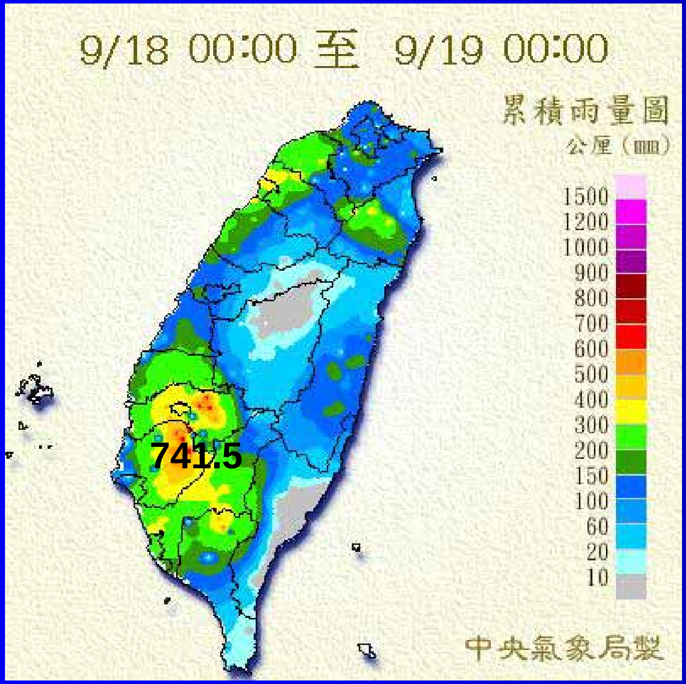

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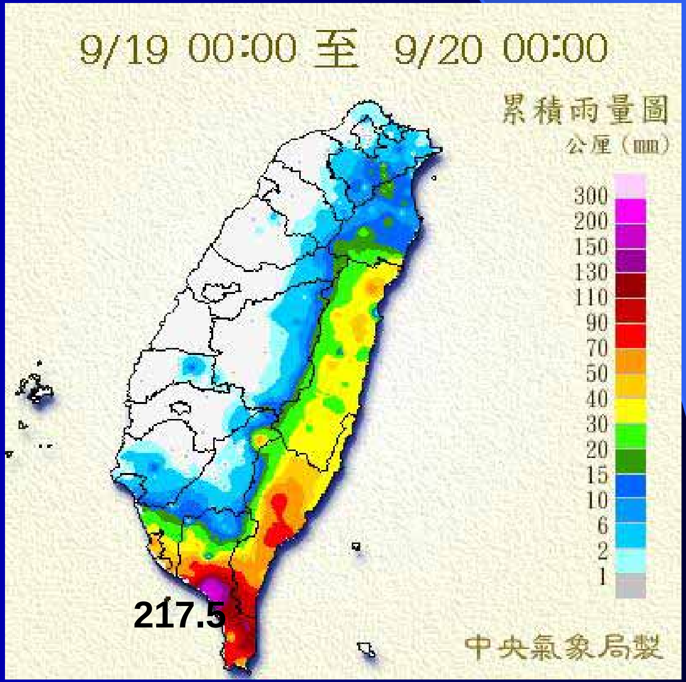
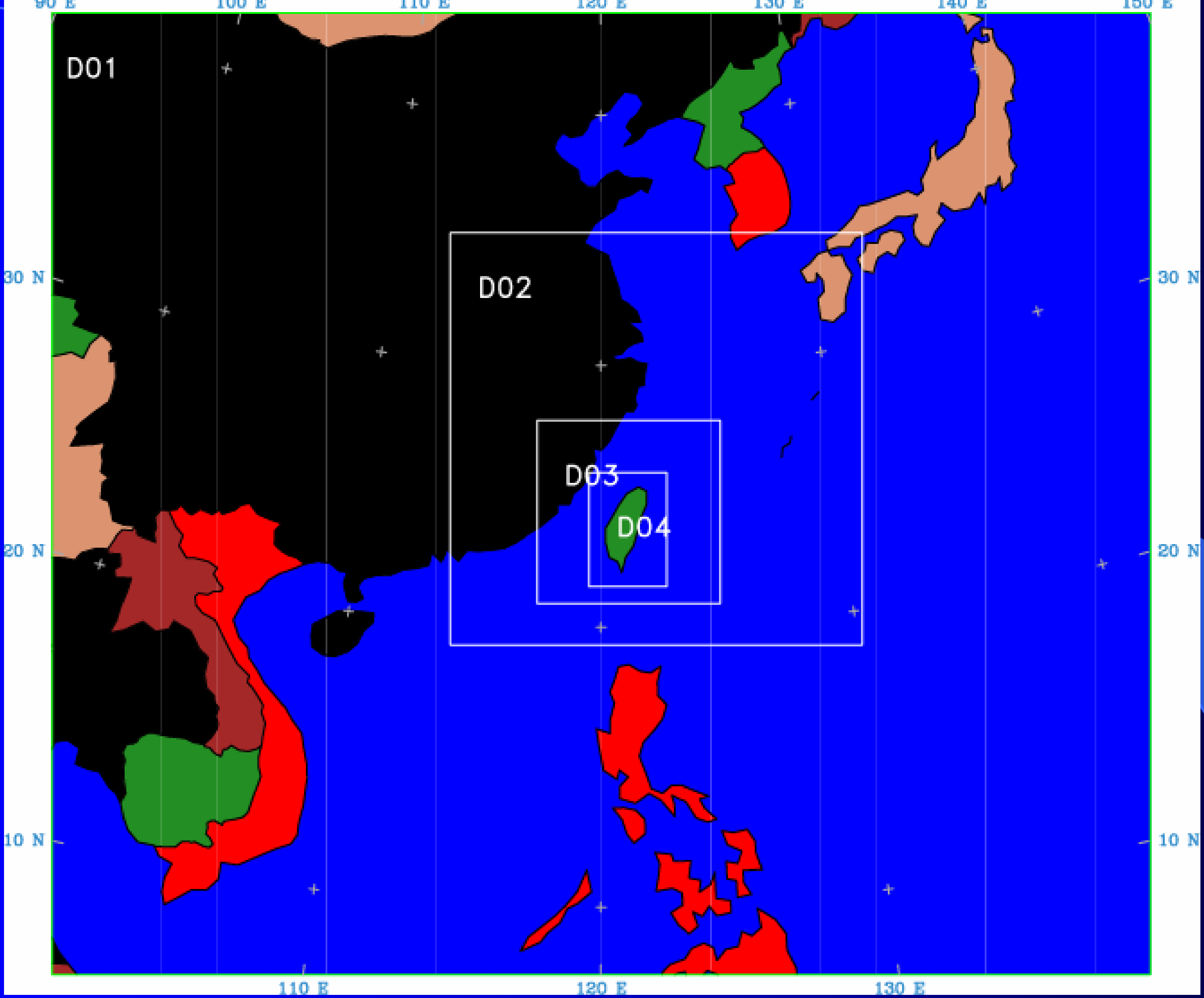




D1: 60 km (81x 71x 31) in x-, y-, z-directions

D2: 20 km (91x 91x 31)

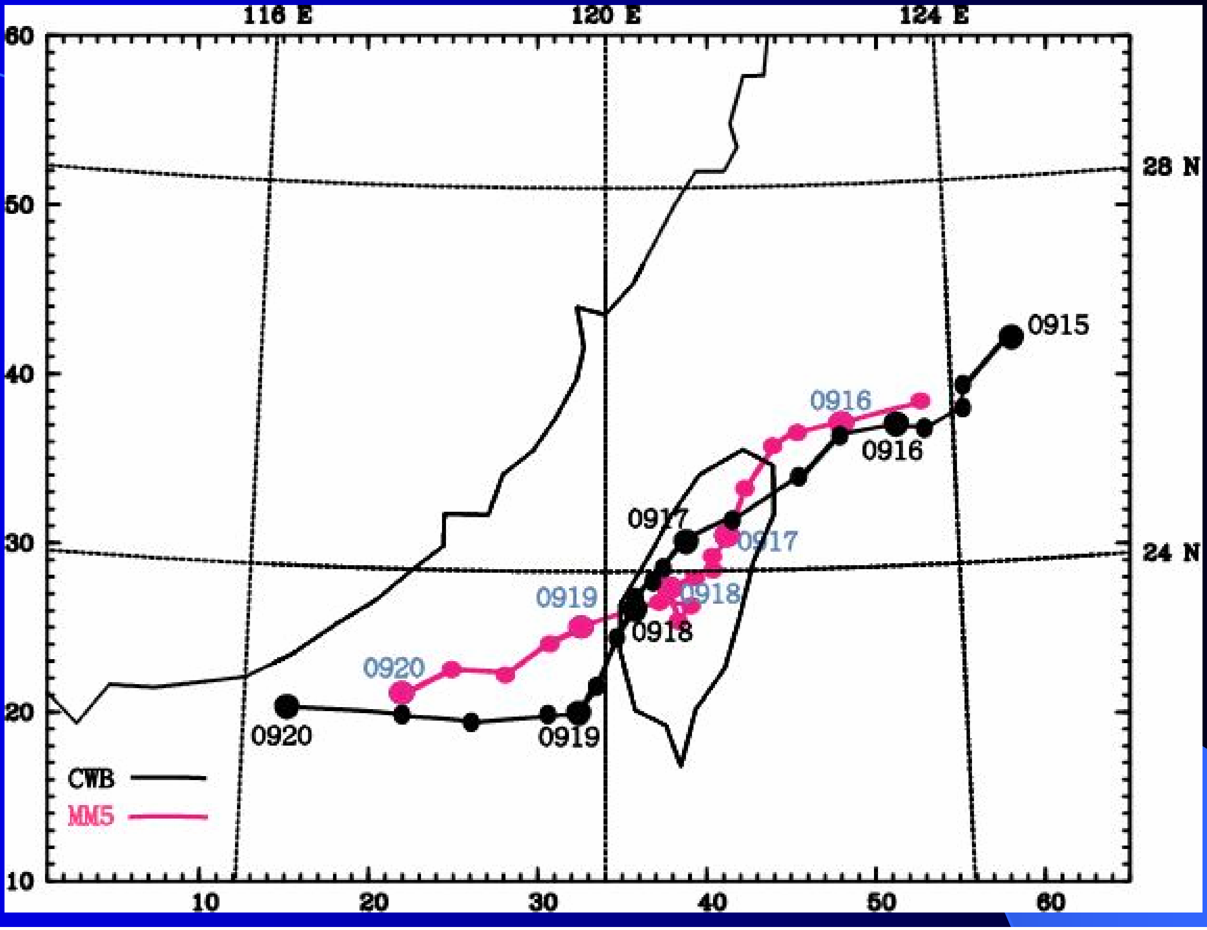
D3: 6.67 km (121x 121x 31)

D4: 2.22 km (154x 226x 31)

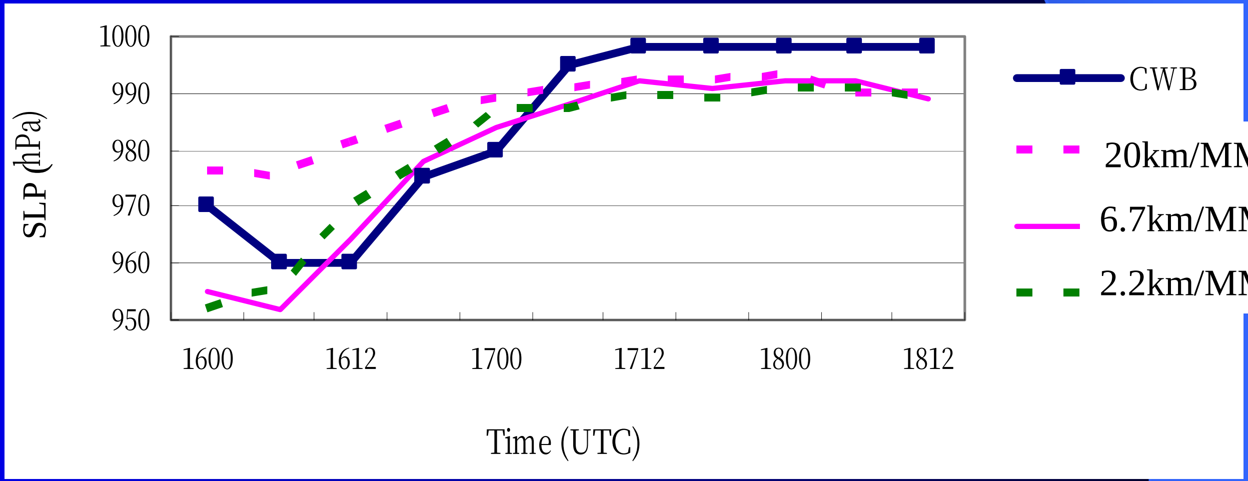
MM5 model physics (Control)

Item	Description
Version	Version 3.5
Cumulus	Grell (1993)
Microphysics	Reisner et al. 1998
PBL	MRF (Hong and Pan 1996)
Radiation	Dudhia (1989）
I.C.	ECMWF advanced analysis
B.C.	ECMWF advanced analysis

Simulated Track
vs.
Observed Track

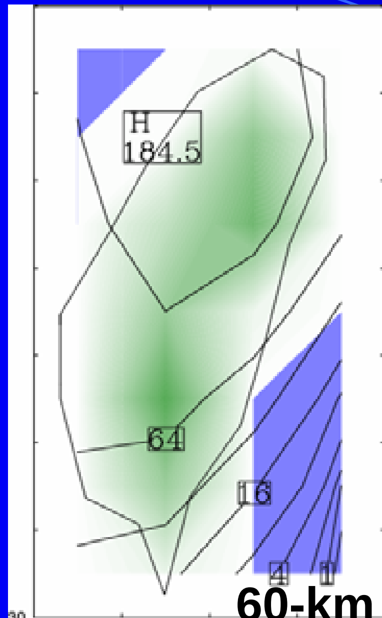


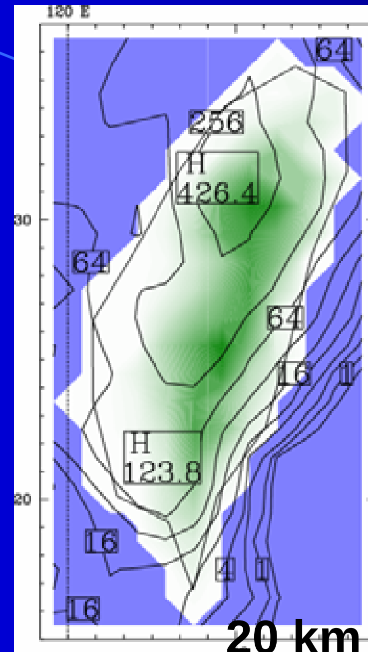
Simulated Intensity
vs.
Observed Intensity

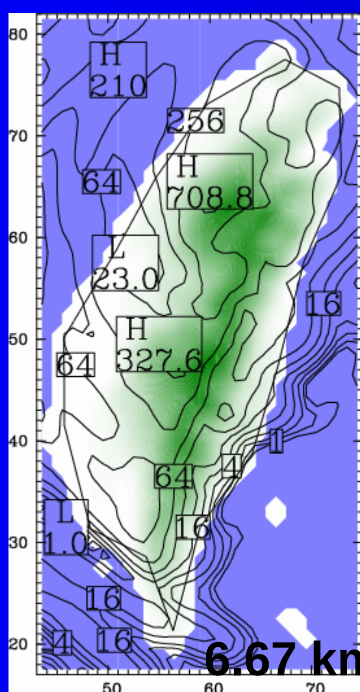


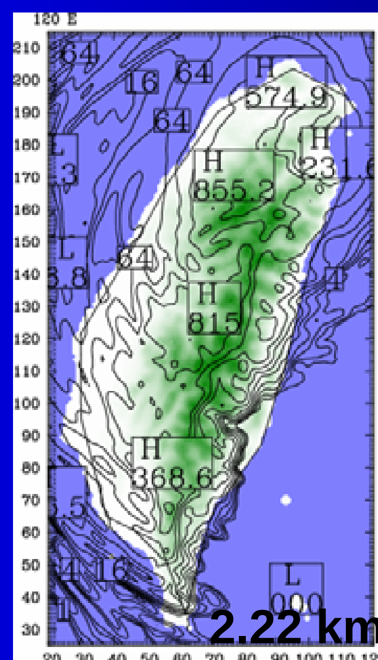
Resolution Dependence

Simulated 24-h Rainfall

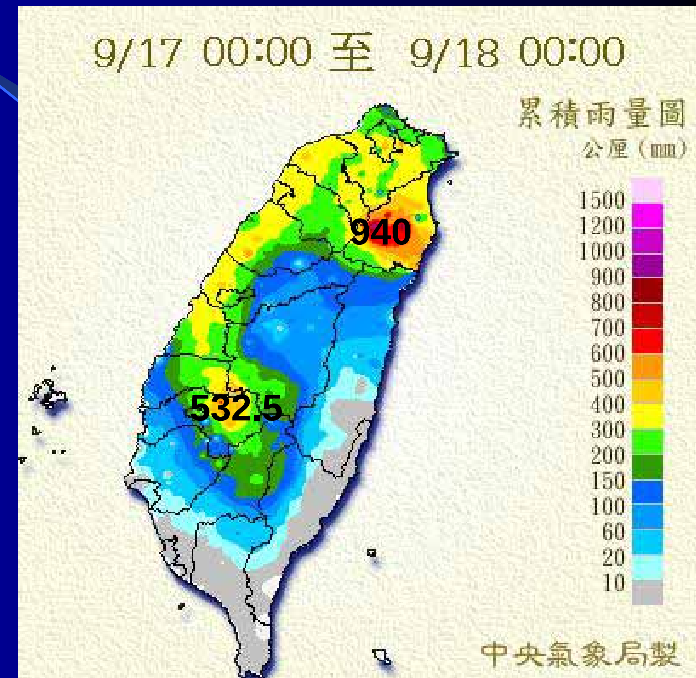






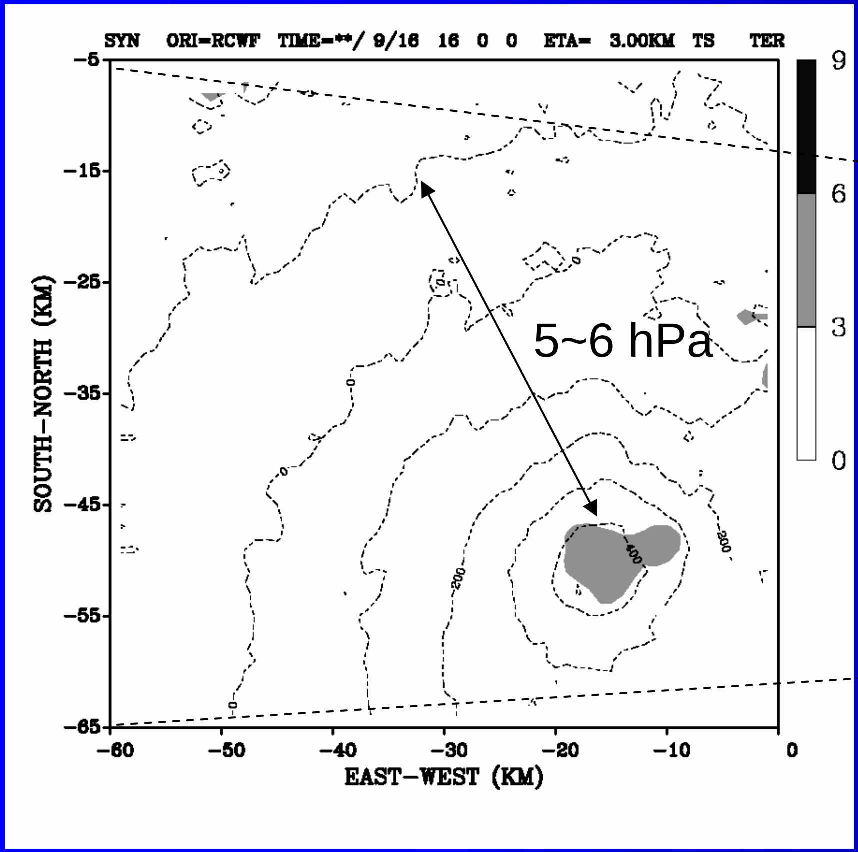


Observed 24-h Rainfall

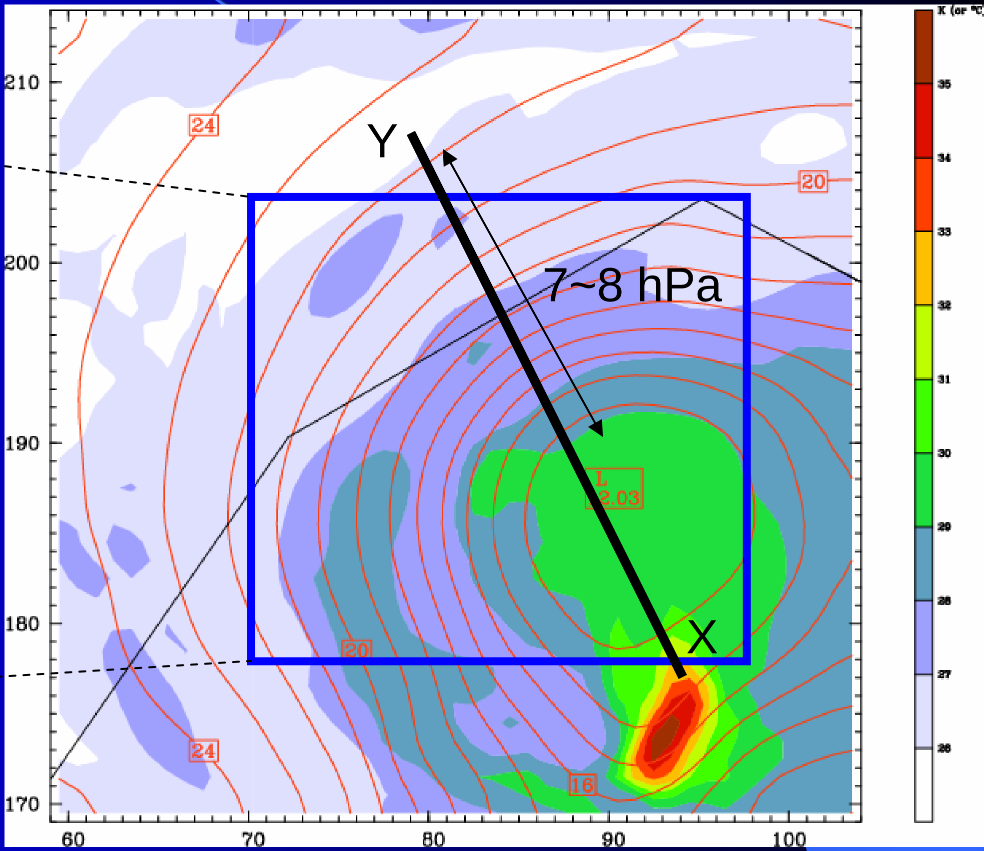


Horizontal Cross Section of Pressure and Temperature Perturbations

Radar Retrieval (wrt. a Station Sounding)



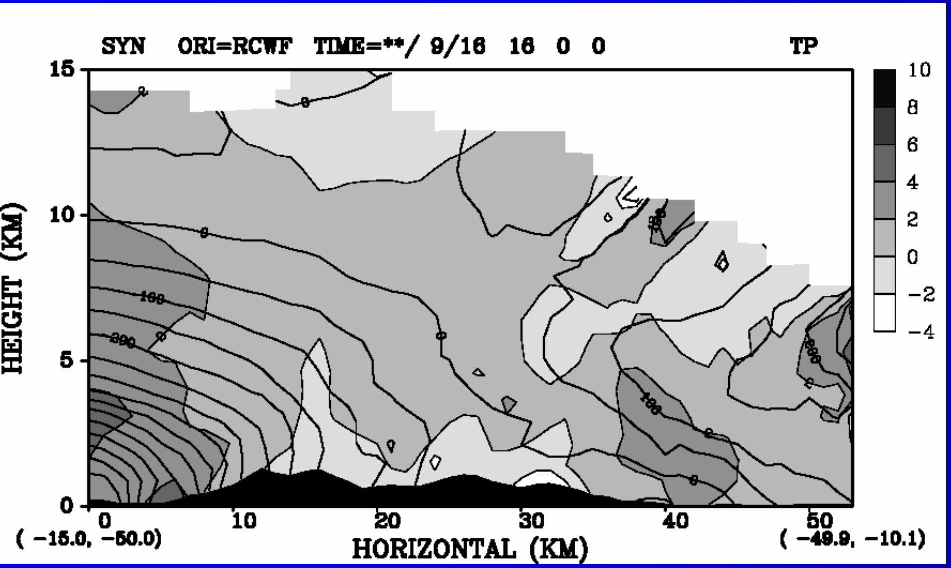
MM5 Simulation (wrt. a Hydrostatic Basic State)



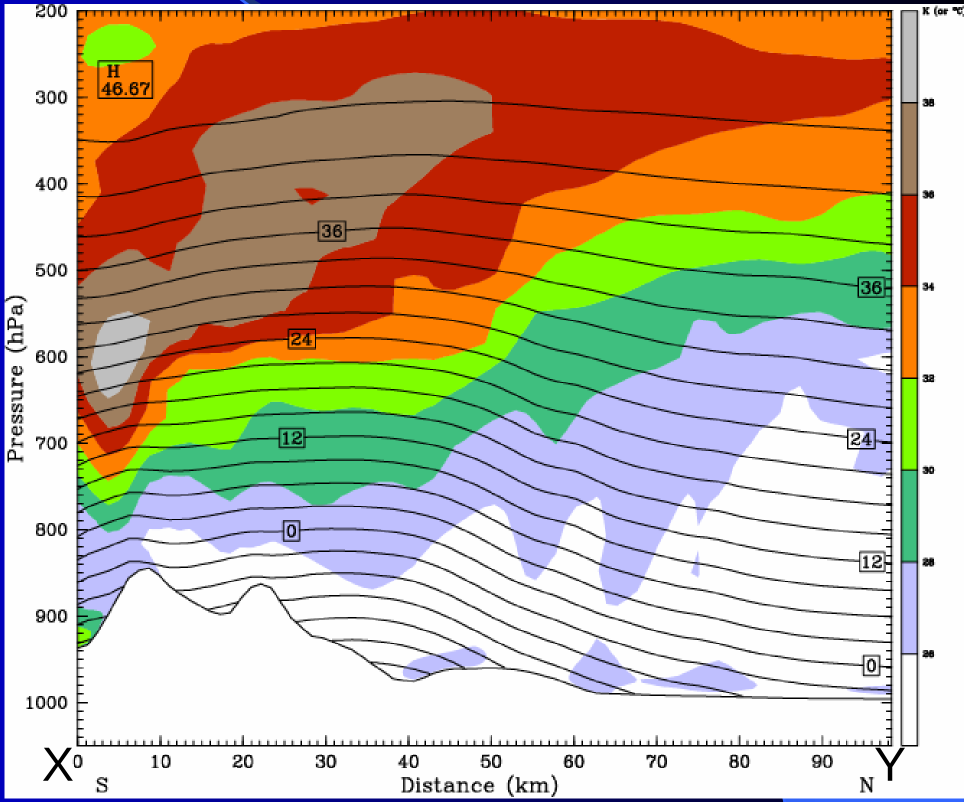
Courtesy of T.-C. Chen Wang and Y.-C. Liou

Vertical Cross Section of Pressure and Temperature Perturbations

Radar Retrieval (wrt. a Stational Sounding)



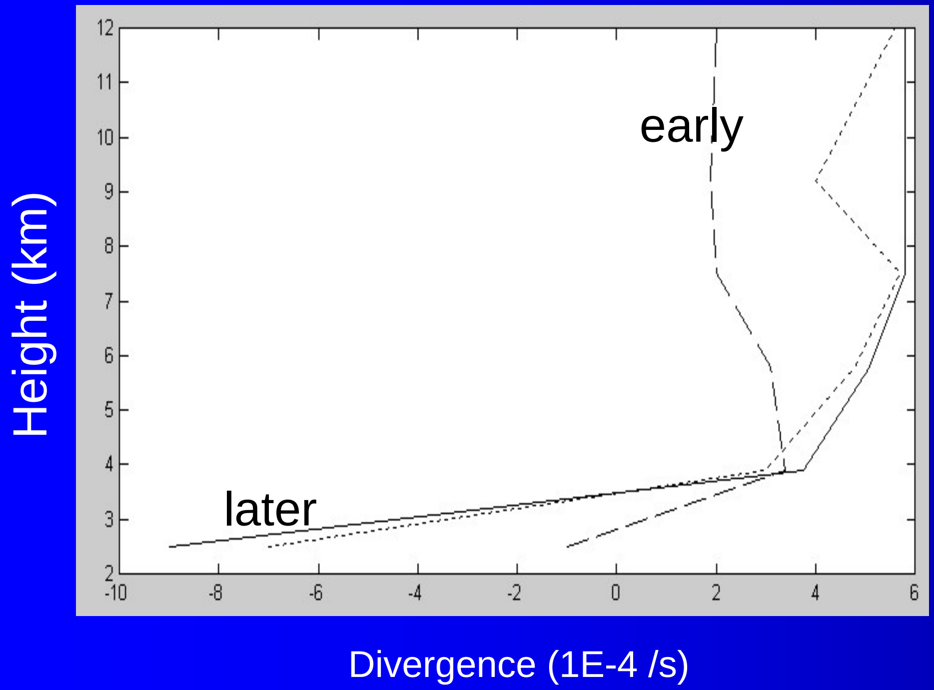
MM5 Simulation (wrt. a Hydrostatic Basic State)



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

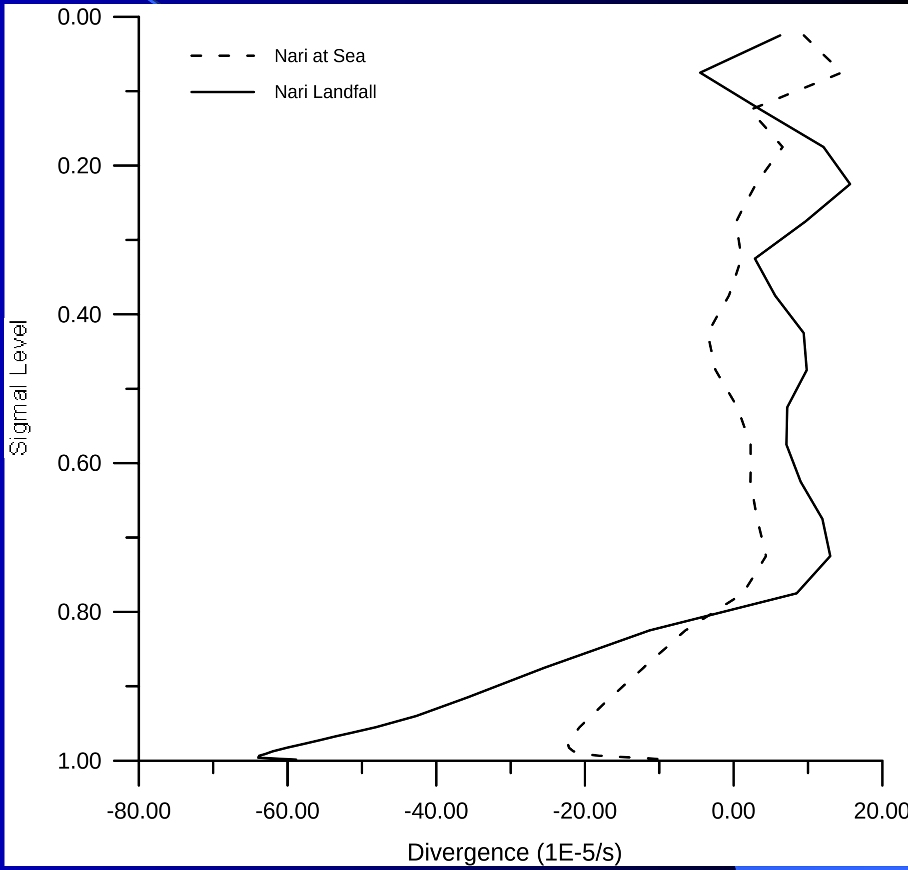
Vertical Profile of Horizontal Divergence

Radar VAD Analysis

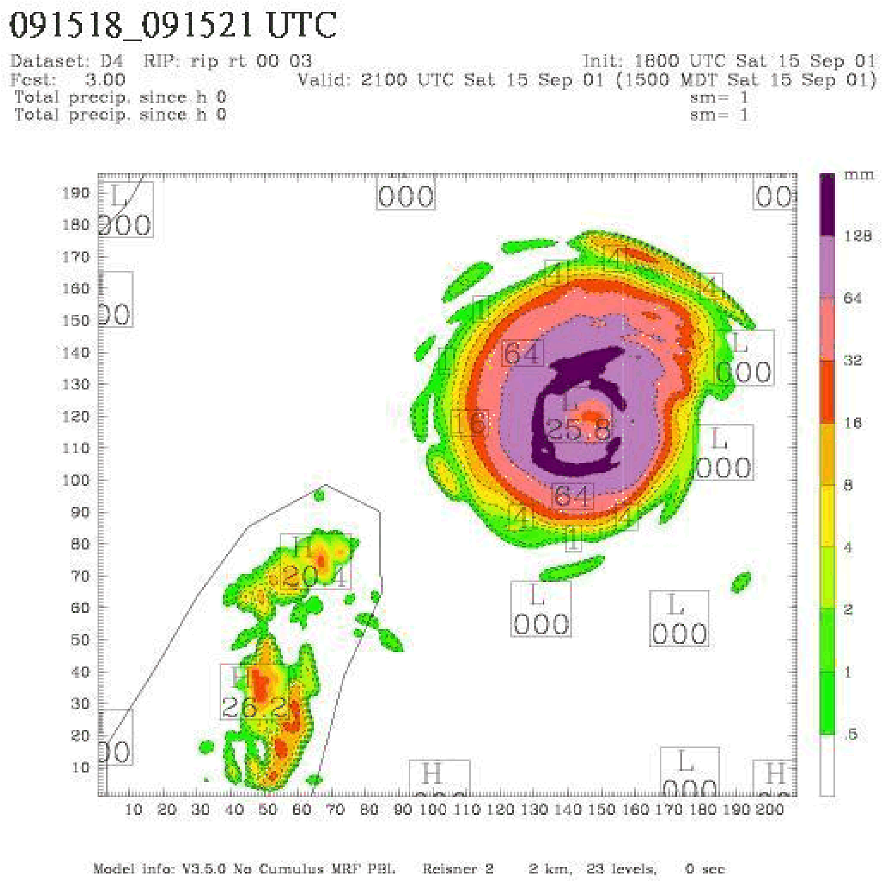


Courtesy of T.-C. Chen Wang and Y.-C. Liou

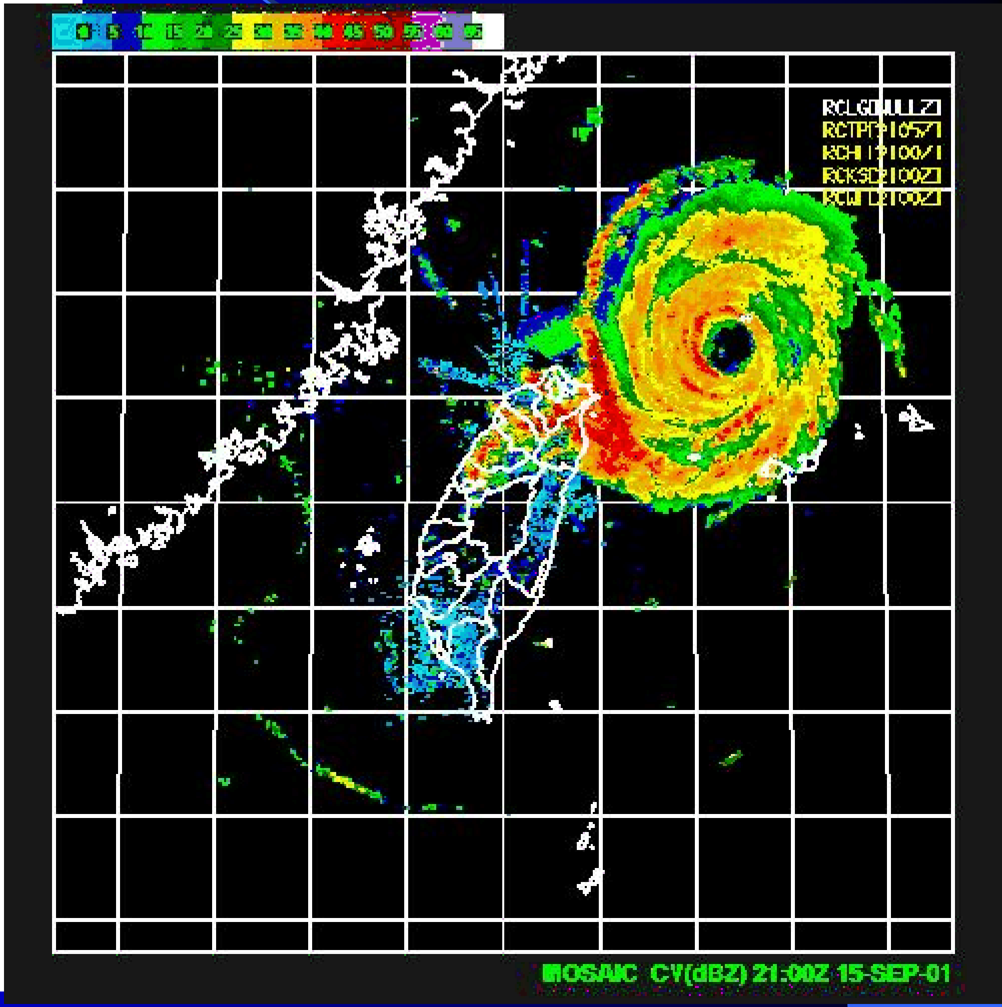
MM5 Simulation



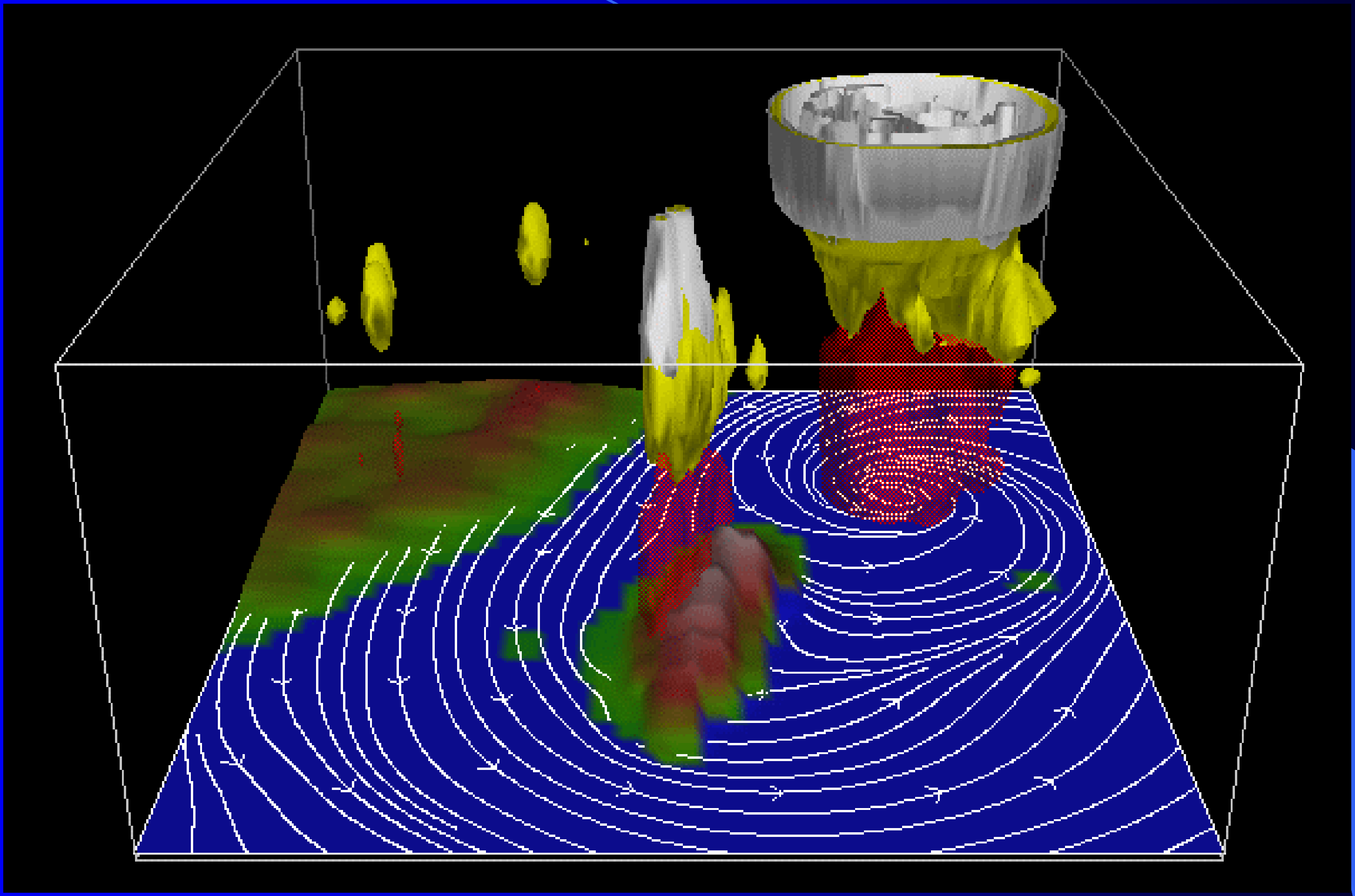
Simulated 3-h Rainfall



Observed Radar Echo (CV)

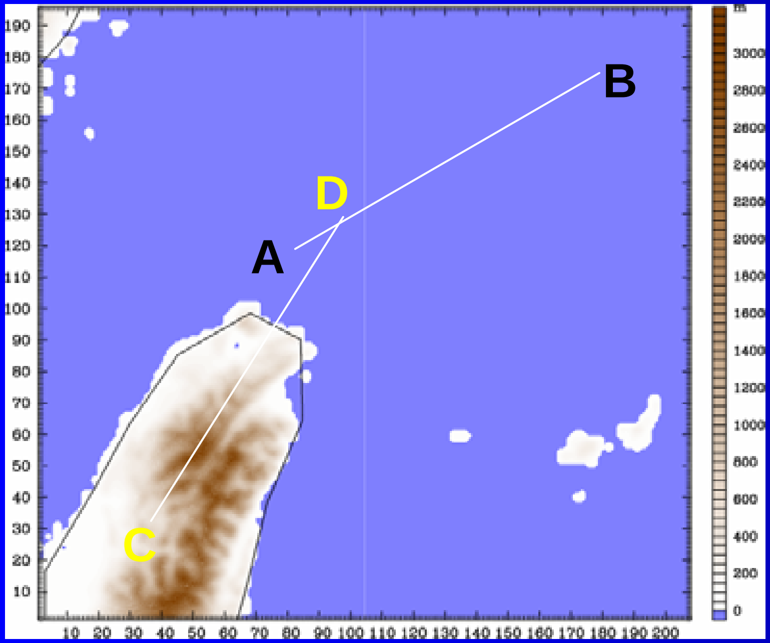


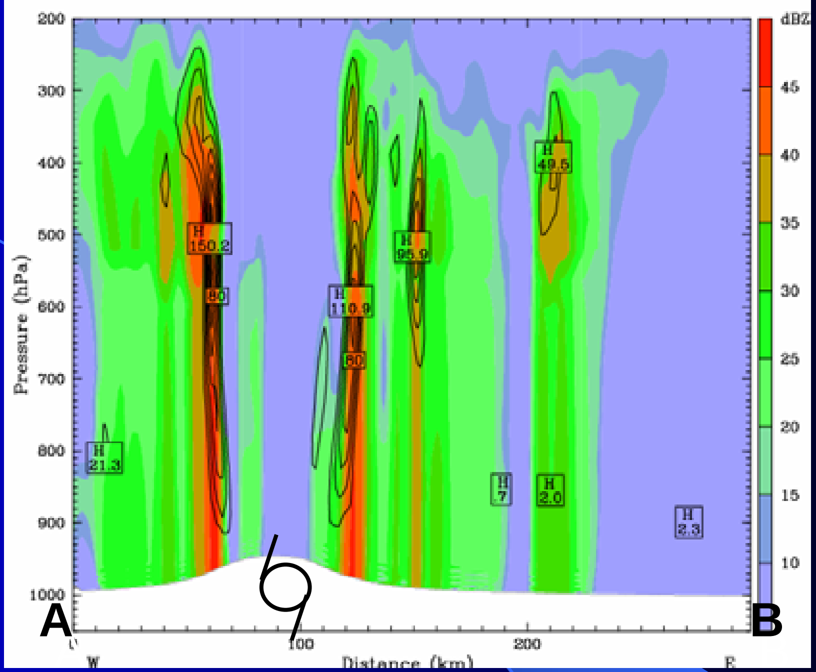
6.67-km MM5 Grid

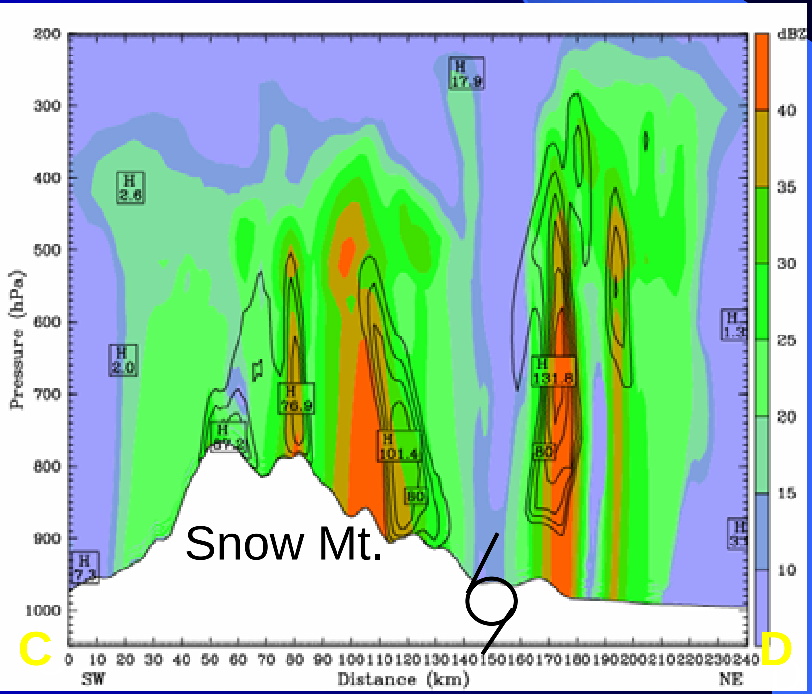


Gray: Ice Yellow: Snow Light Red: Rain

Vertical Cross Section of Radar Echo and Condensational Heating

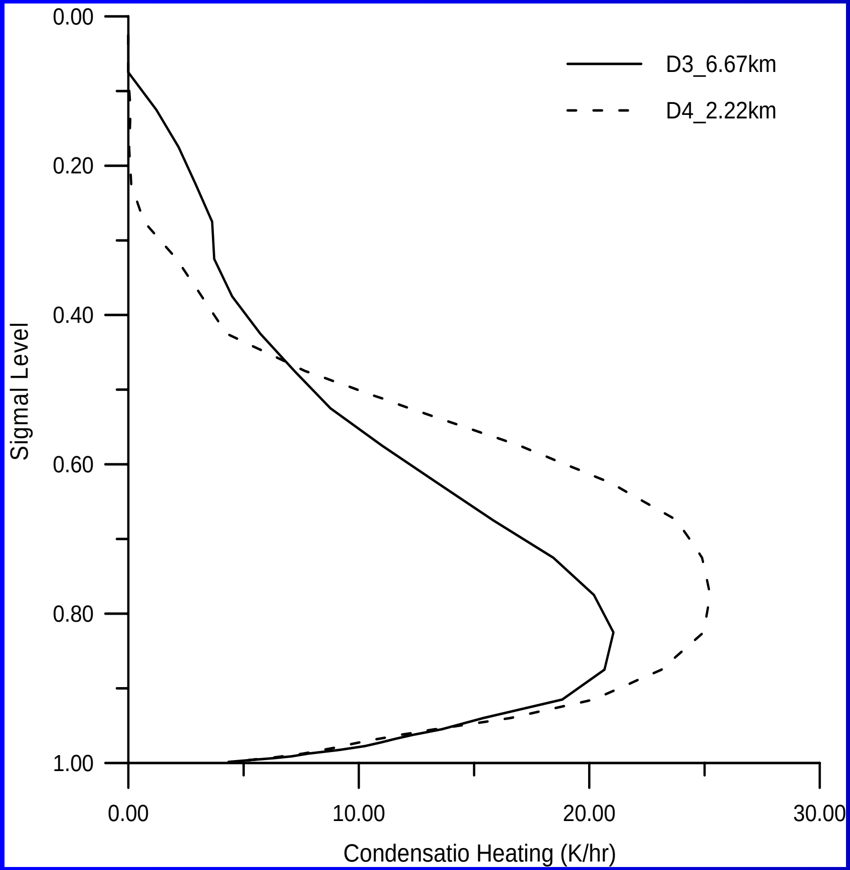






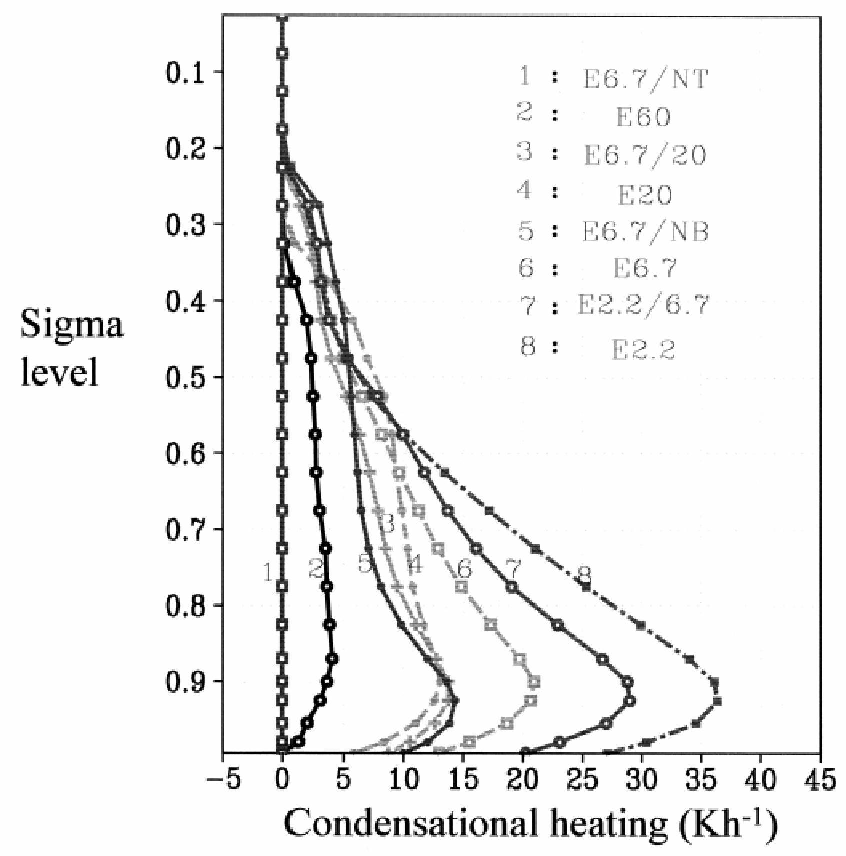
Vertical Profile of Condensational Heating

Nari (2001)



40 km x 40 km area avg.

Herb (1996)



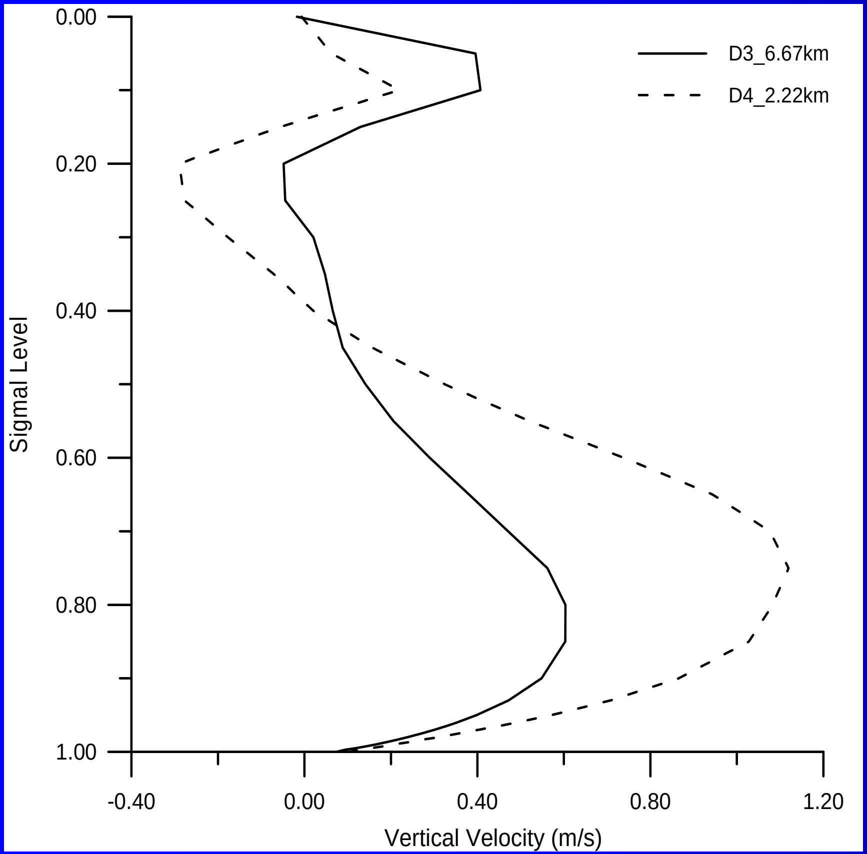
Wu et al. (2002)

40 km x 40 km area avg.

24-h time avg.

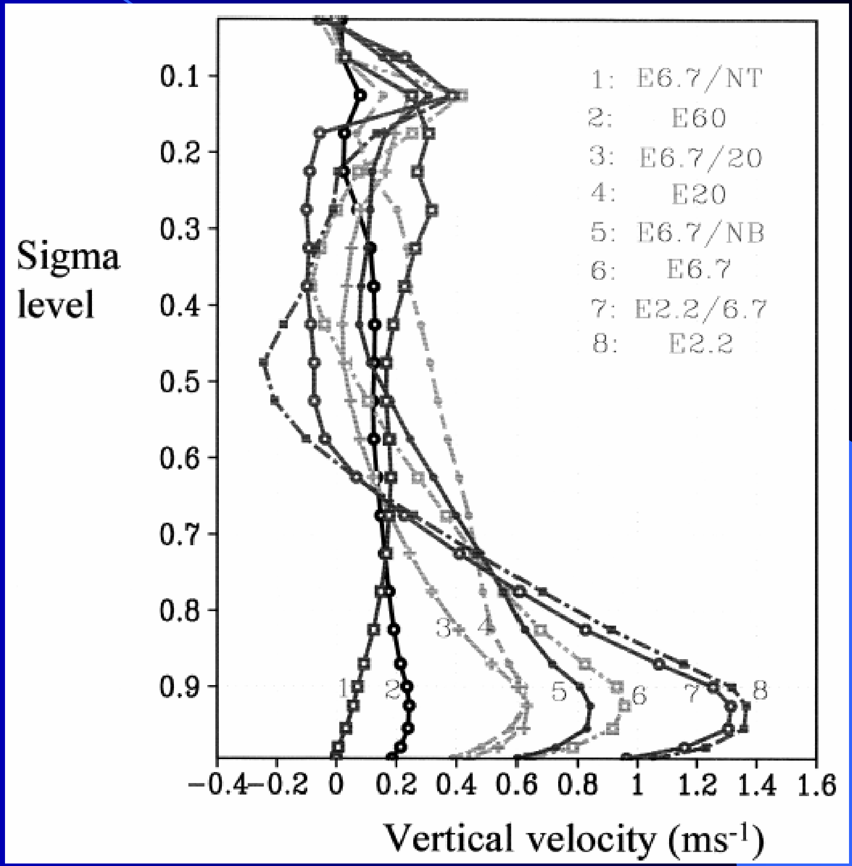
Vertical Profile of Vertical Velocity

Nari (2001)



40 km x 40 km area avg.

Herb (1996)



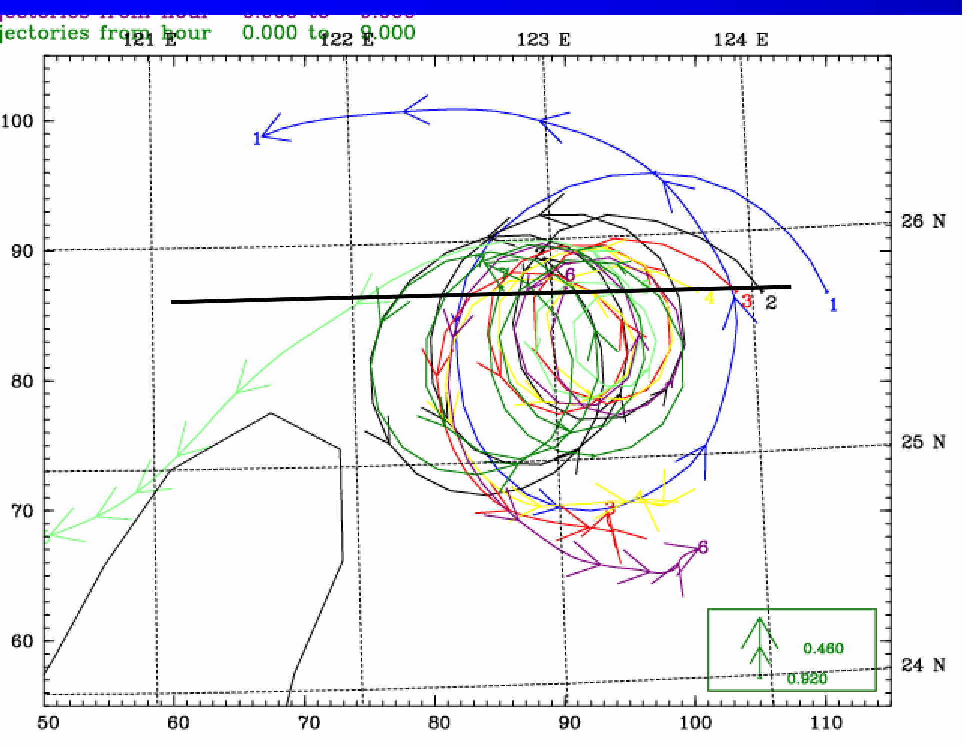
Wu et al. (2002)

40 km x 40 km area avg.

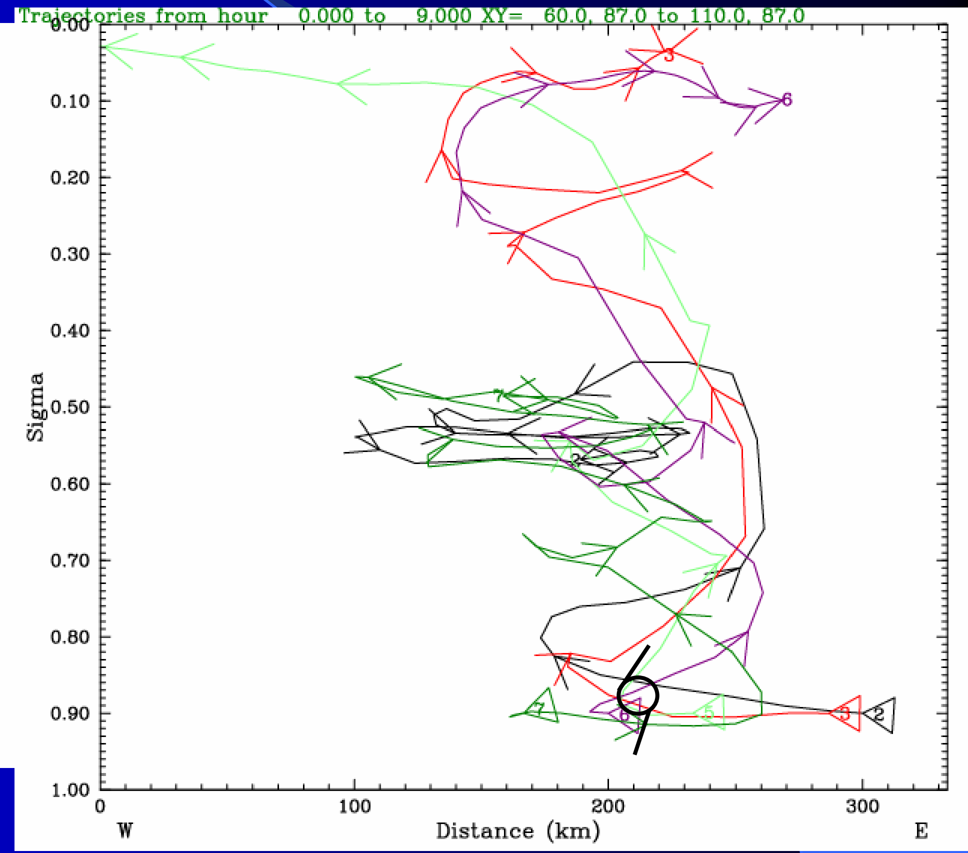
24-h time avg.

Nine-Hour Air-Parcel Trajectories when Nari is over Sea

Horizontal Cross Section



Vertical Cross Section



Anthes (1969)

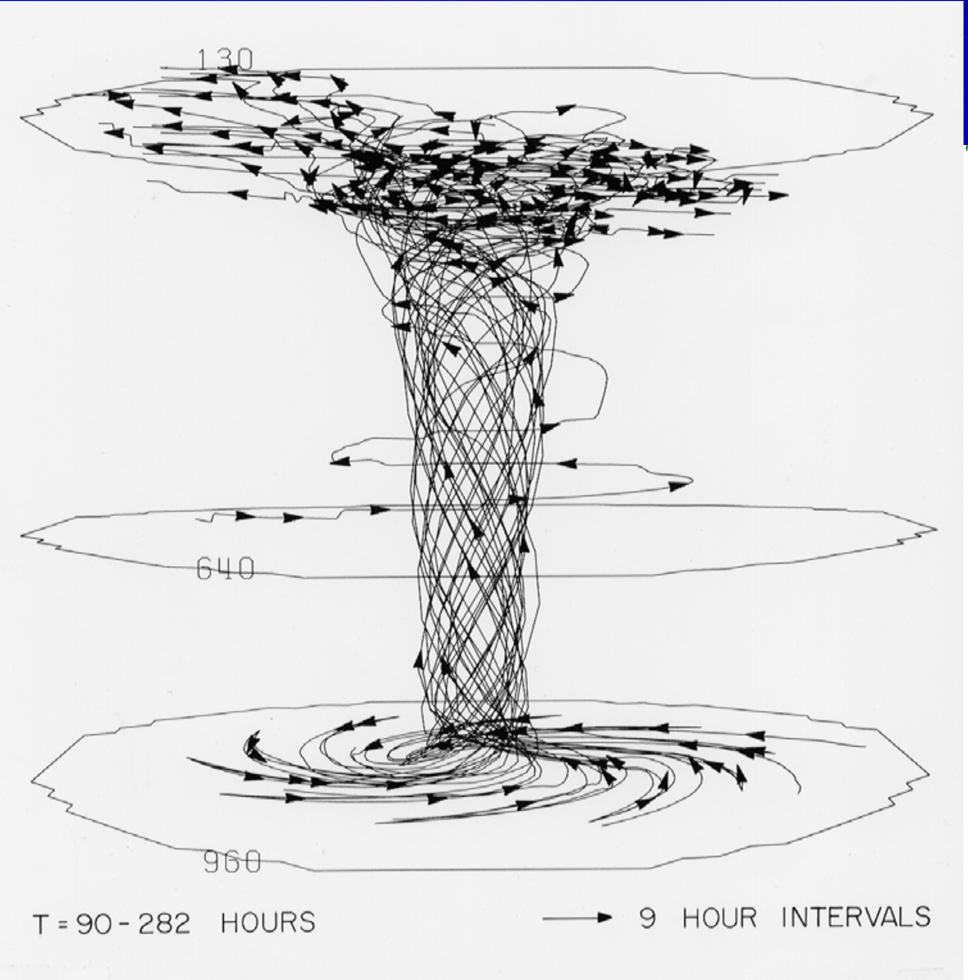
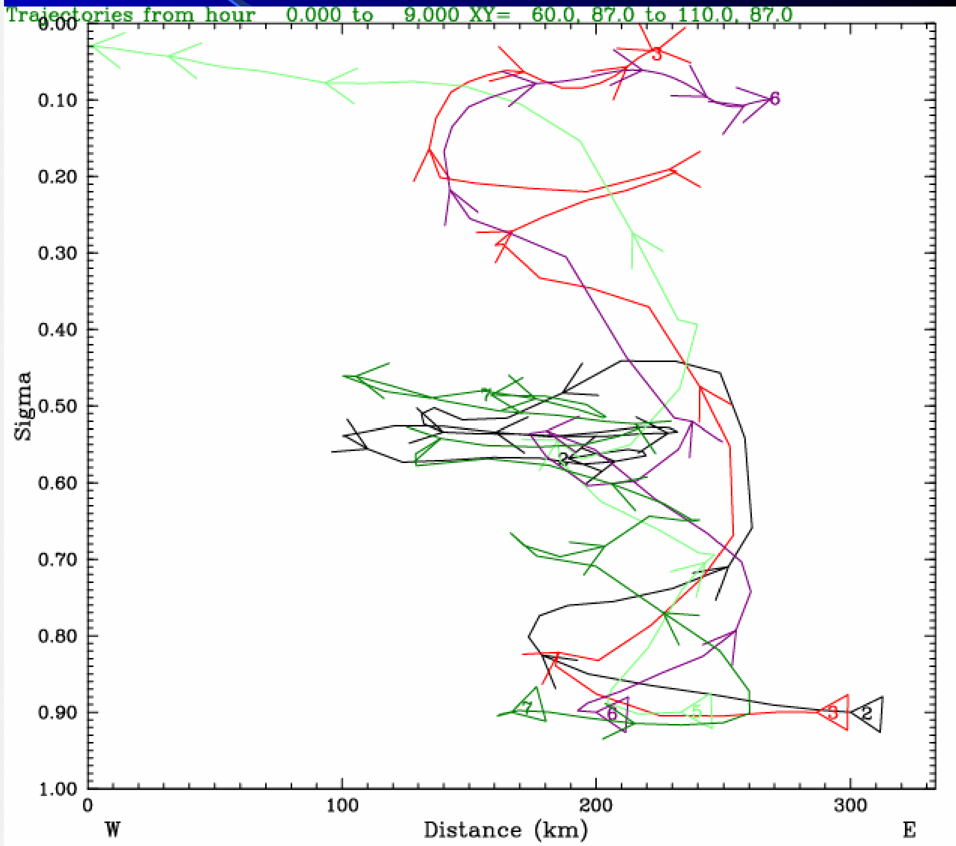


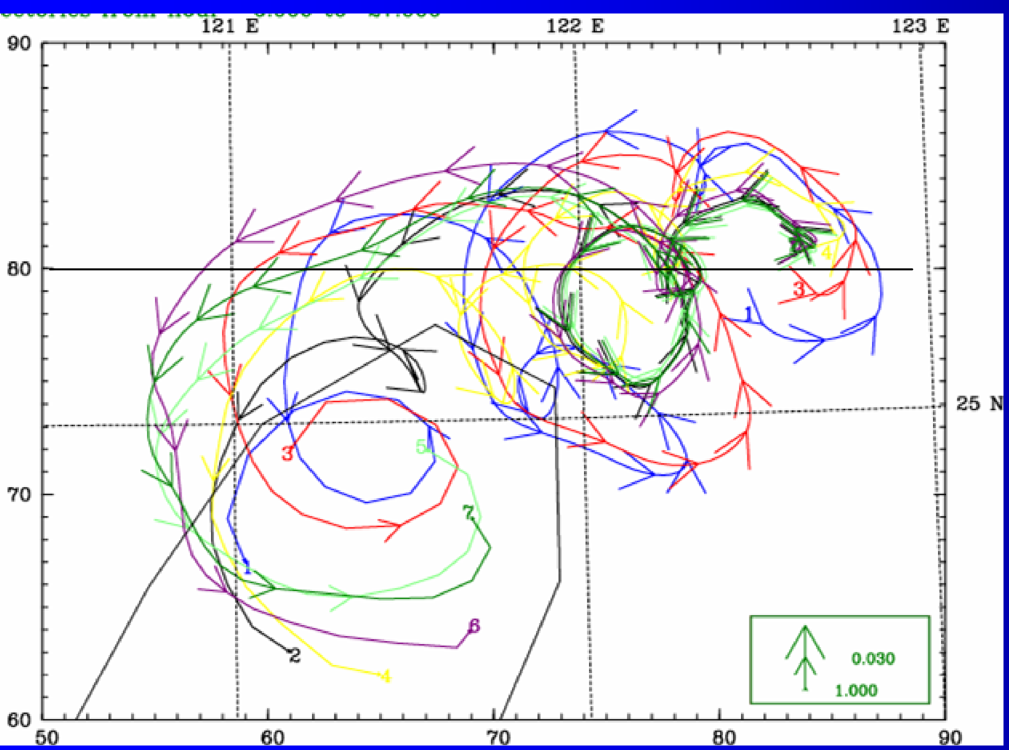
Figure 1: Particle trajectories calculated from a numerical model of an asymmetric hurricane. Labels of 3 levels in mb.

Nine-Hour Air-Parcel Trajectories for Typhoon Nari

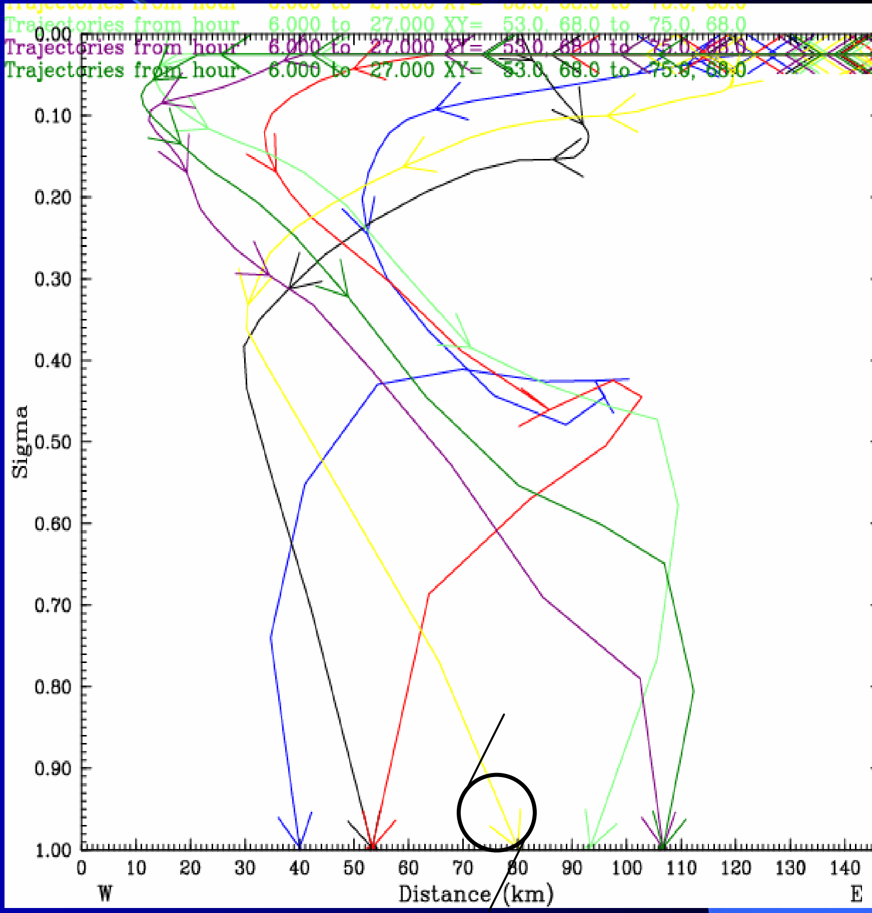


Twenty-One-Hour Backward Hydrometeor Trajectories

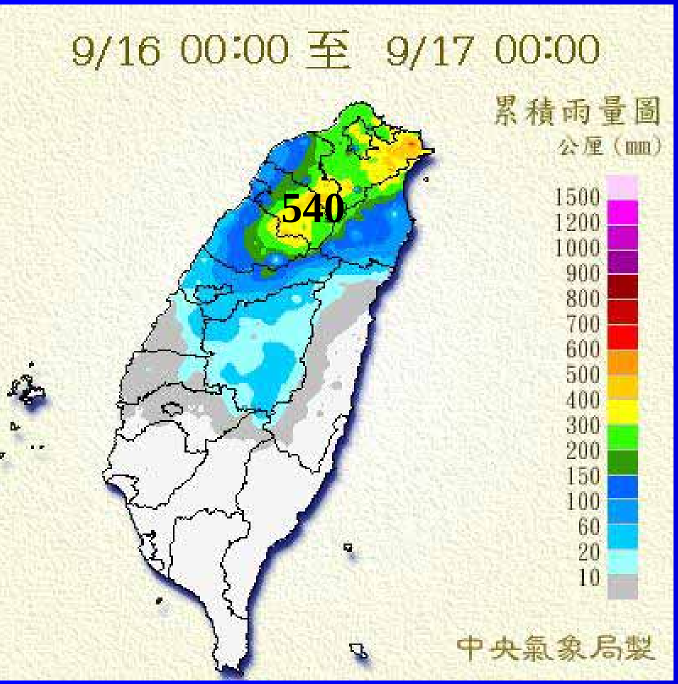
Horizontal Cross Section

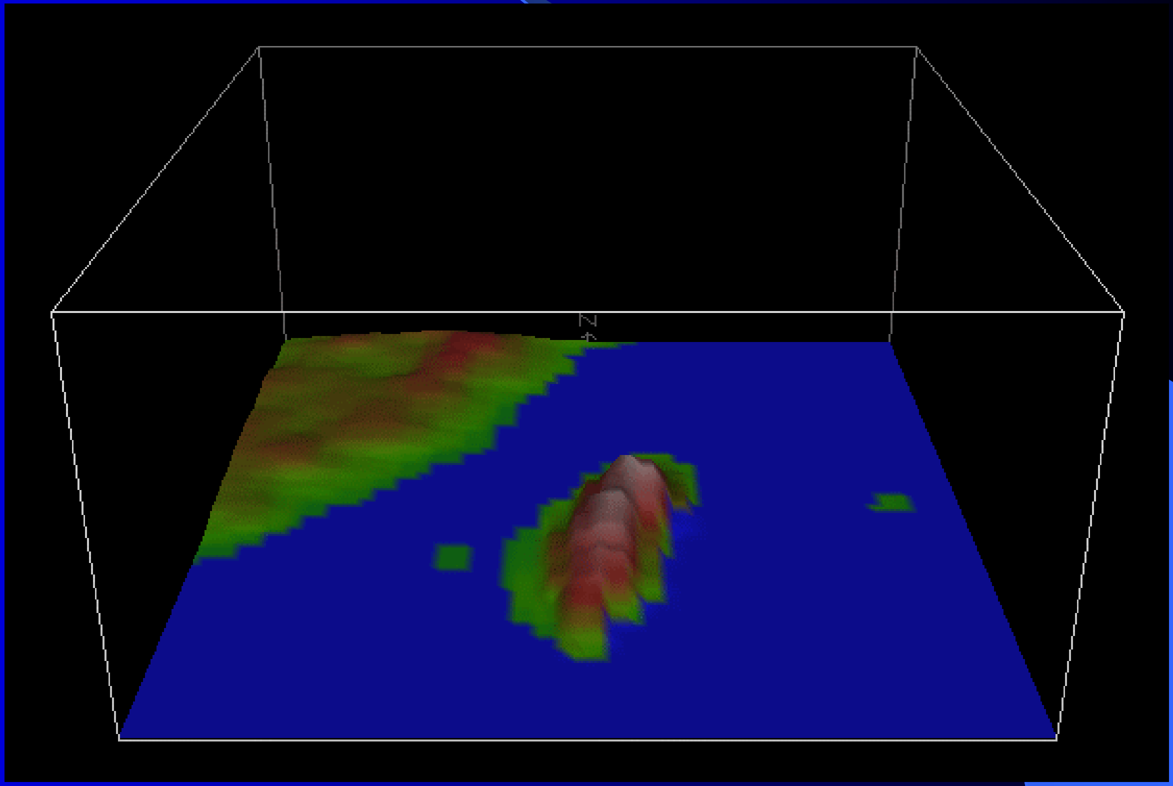


Vertical Cross Section



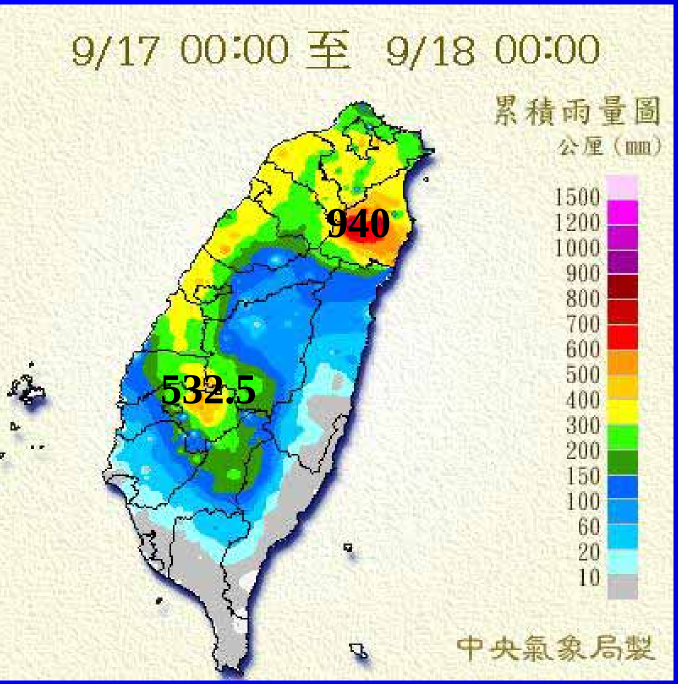
24-h Air-Parcel Trajectory ending over Mt. Snow

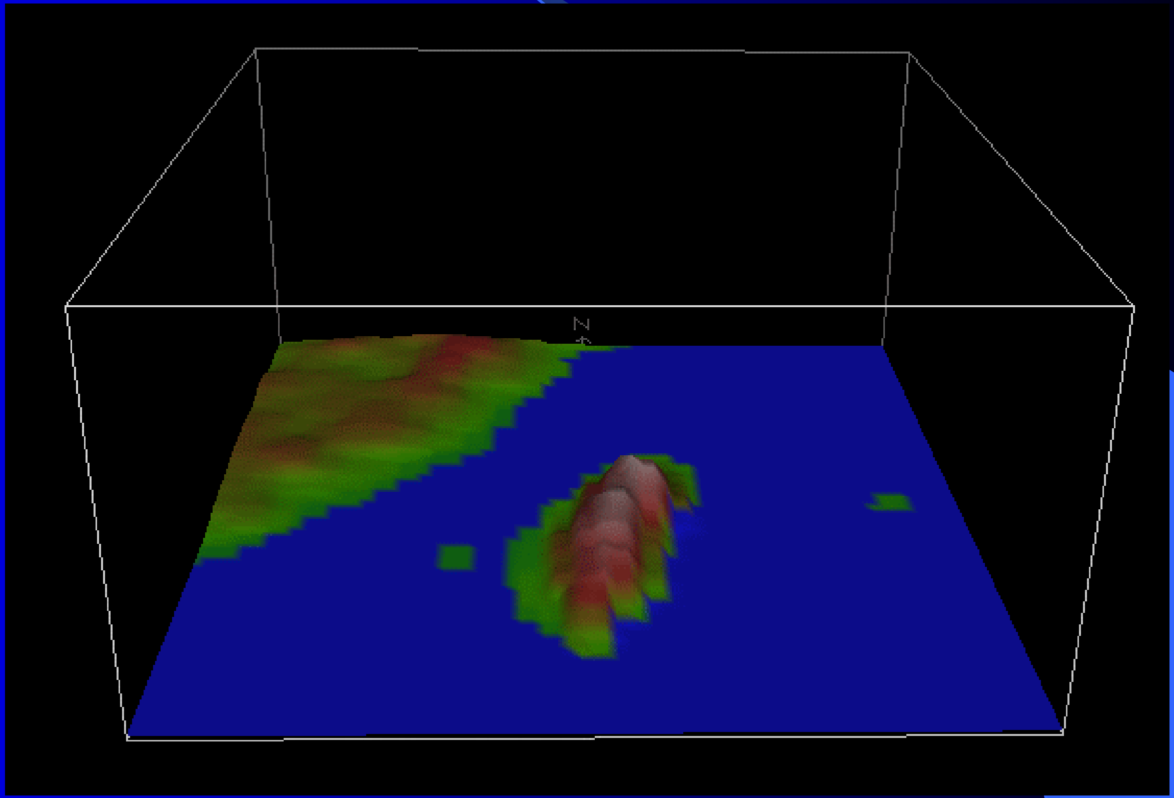




6.67-km MM5 Grid

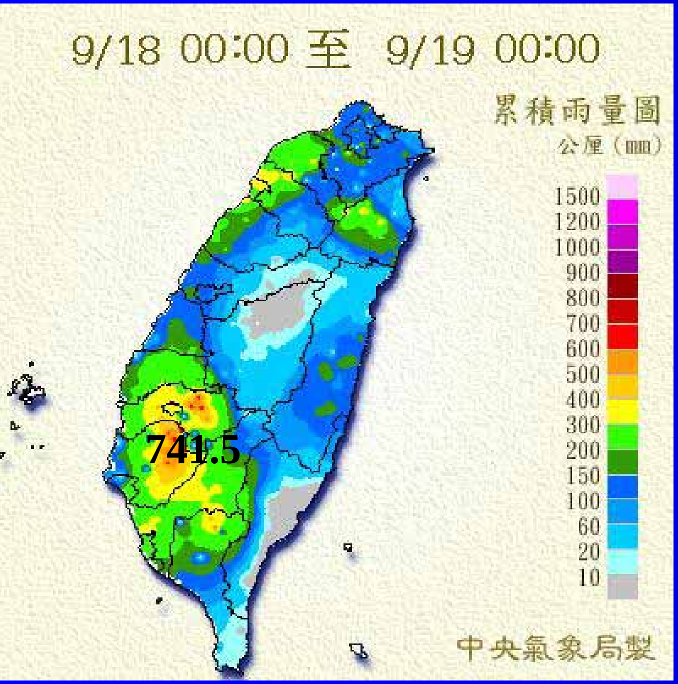
48-h Air-Parcel Trajectory ending over I-Lan County

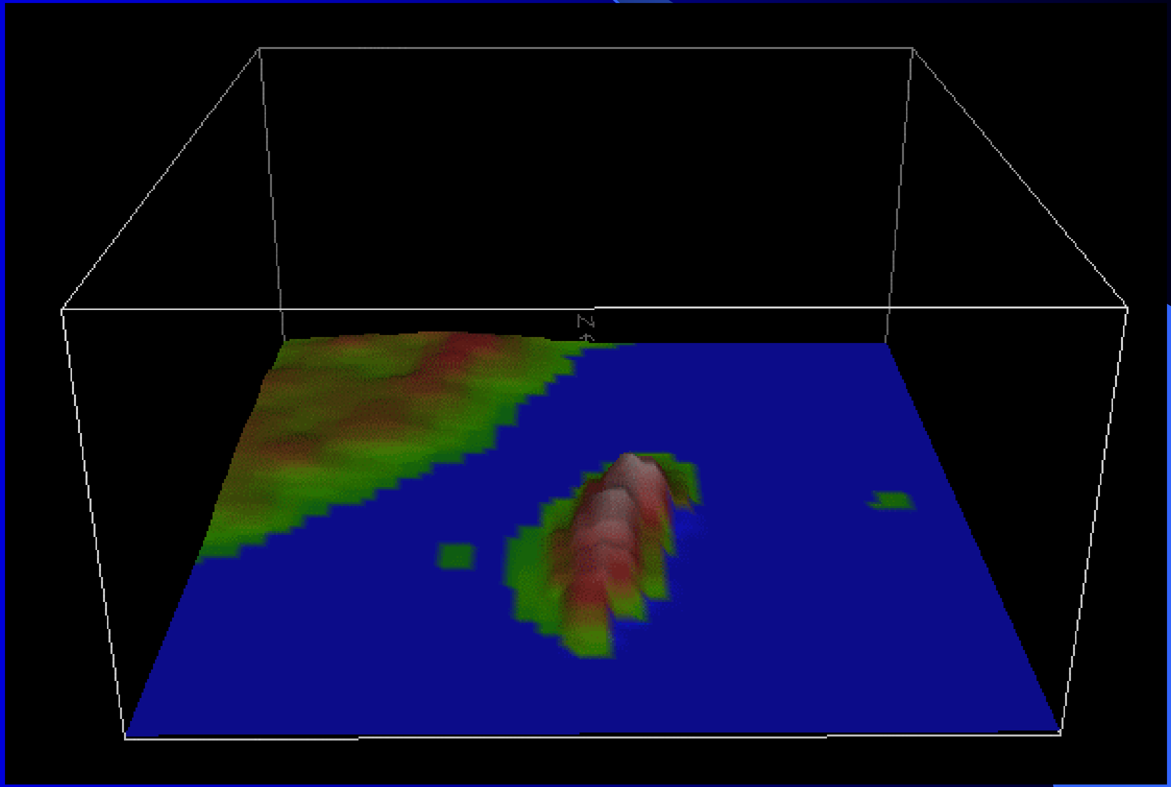




6.67-km MM5 Grid

72-h Air-Parcel Trajectory ending over Cha-I County





6.67-km MM5 Grid

Summary

(1) The ability of the model to successfully predict the observed rainfall maximum is increased with the refinement of grid size, consistent with Wu et. al (2002).

(2) Hydrometeor trajectory analysis may shed some lights on the high precipitation efficiency over Mt. Snow.

(3) Liquid-phase precipitation mainly occurs within eyewall and mountain slopes, and ice-phase precipitation occurs mostly in spiral rainbands.

(4) Simulated temperature and pressure perturbations are in good agreement with those retrieved by radar data. Simulated vertical divergence profile also compares fairly with that estimated by radar observations.

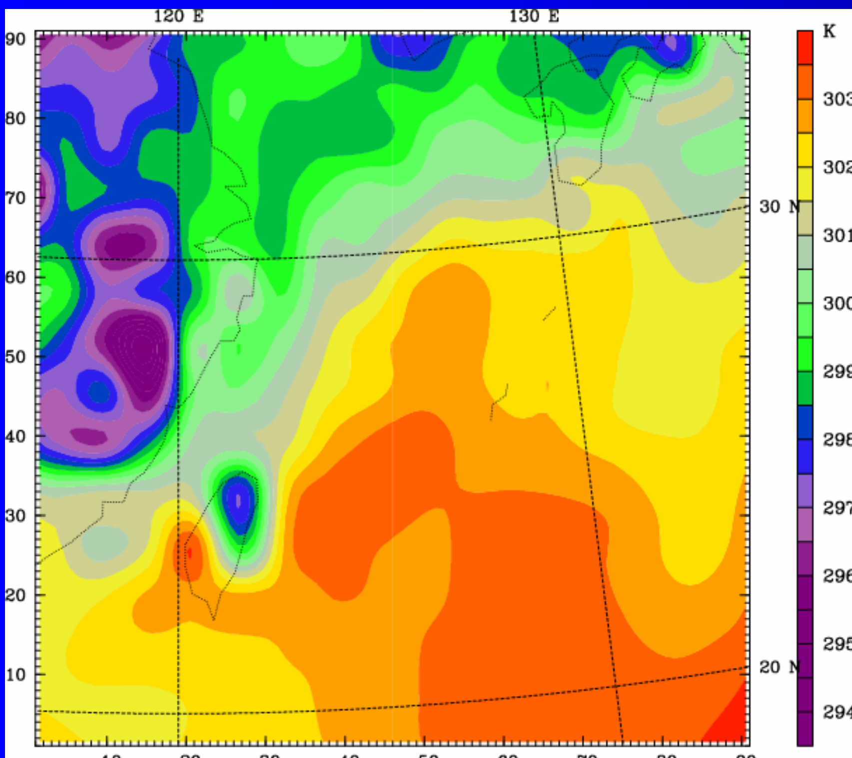
(5) Typhoon Nari (2001) has similar but weaker vertical profiles of vertical velocity and condensational heating compared to those of Herb (1996).

Part III:
SST impact on oceanic Typhoon Nari

In Cooperation with Prof. C.-H. Sui (NCU/IHS)

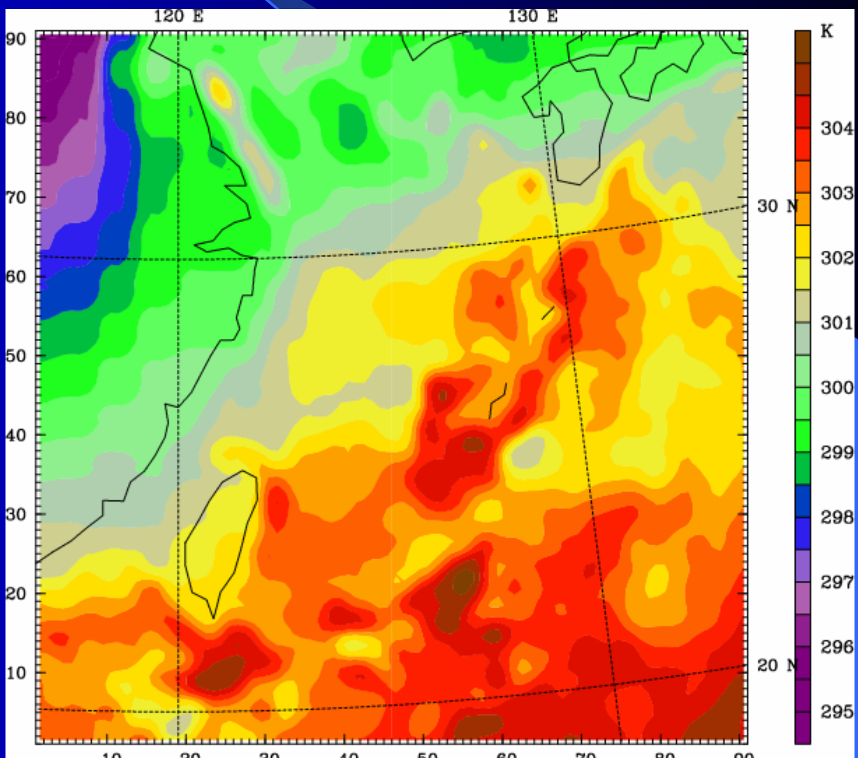
Default Setup

MM5 SST from ECMWF analysis (1.125º x 1.125º; weekly)

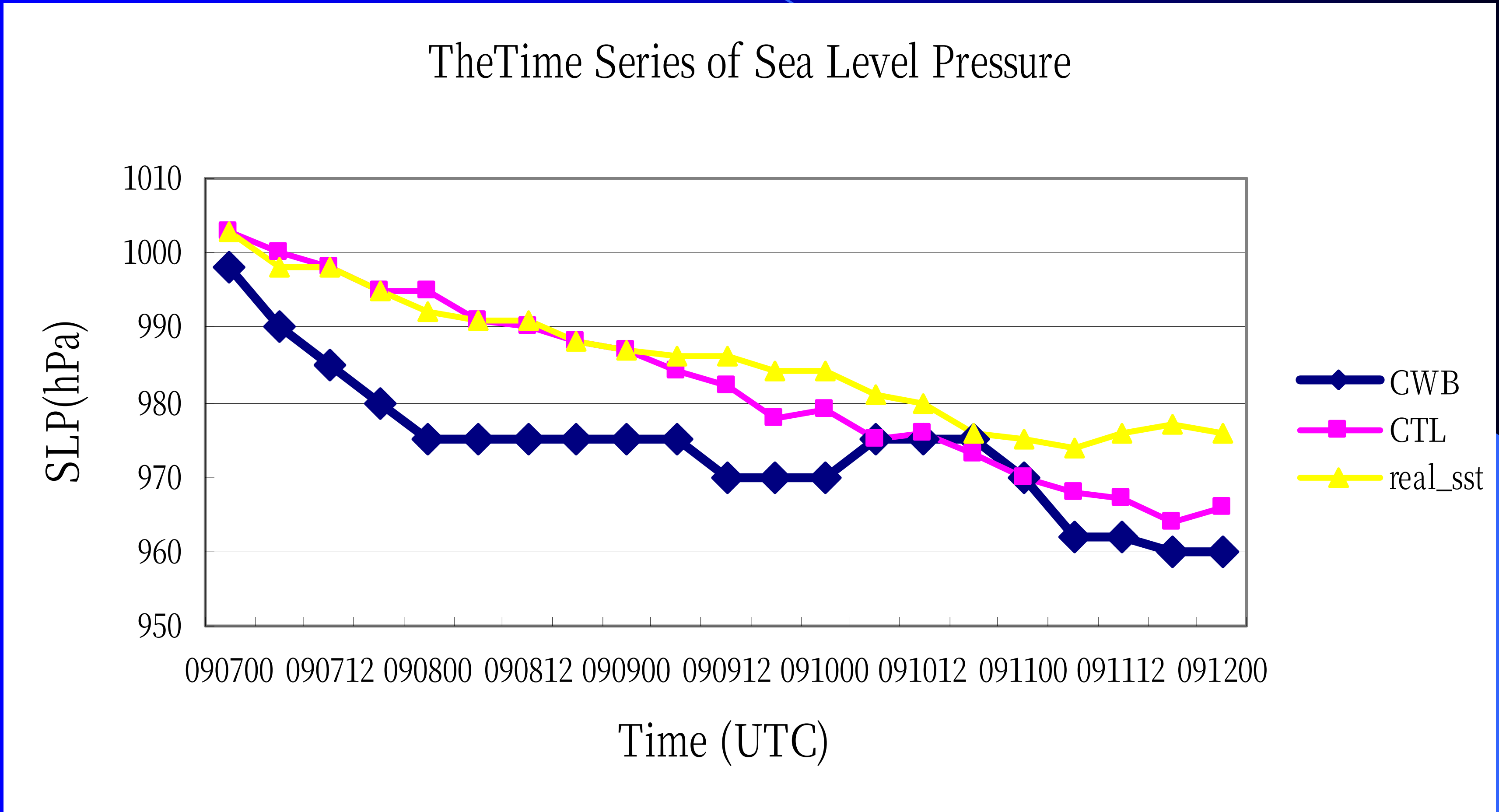


High-resolution data

MM5 SST from TRMM obs. (0.25º x 0.25º; daily)



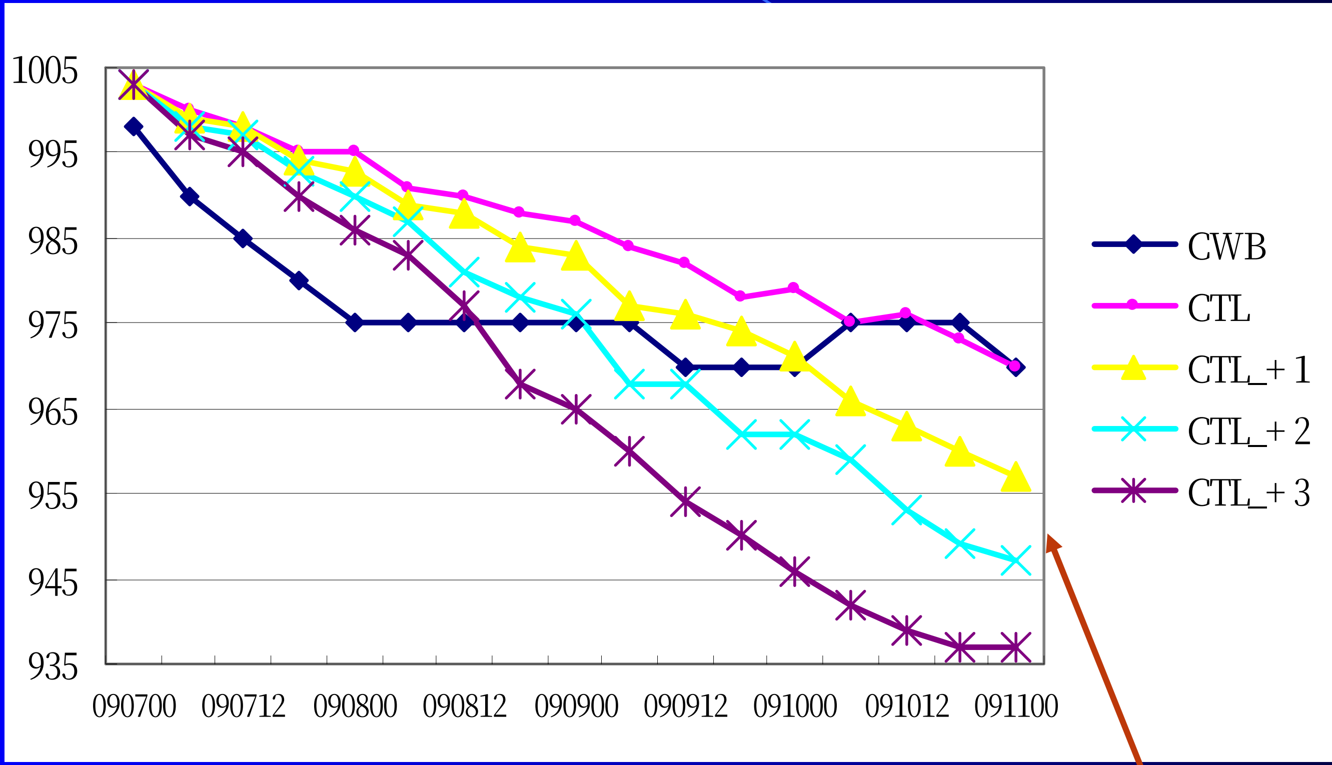
20-km MM5 Grid



20-km MM5 Grid

Impact on MPI by increasing SST

Time Series of Central Sea Level Pressure (SLP)



Time (UTC)

dSLP/dSST ~ 30 hPa/3K
consistent with Emanuel (1999)
and Holland (1997)

Part IV:
Preliminary result of the MM5 coupled with an intermediate ocean model

In Cooperation with Prof. Bin Wang (U. Hawaii),
and Prof. Xiaolei Zou (FSU)

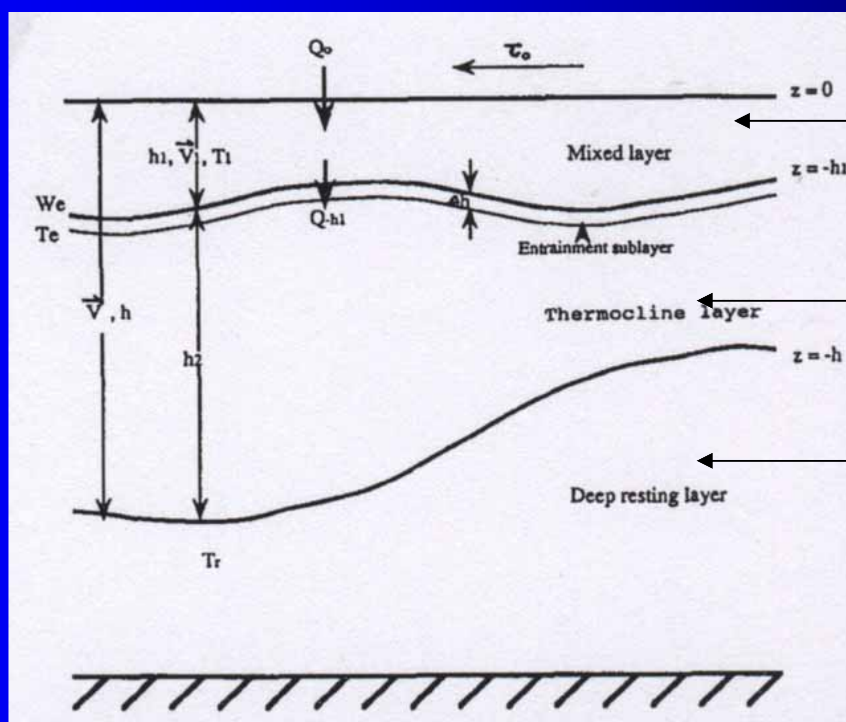
Typhoon-ocean coupling

MM5 + an intermediate ocean model (Wang et al. 1995)

wind stress & heat fluxes

MM5 ⇄ Ocean model

SST

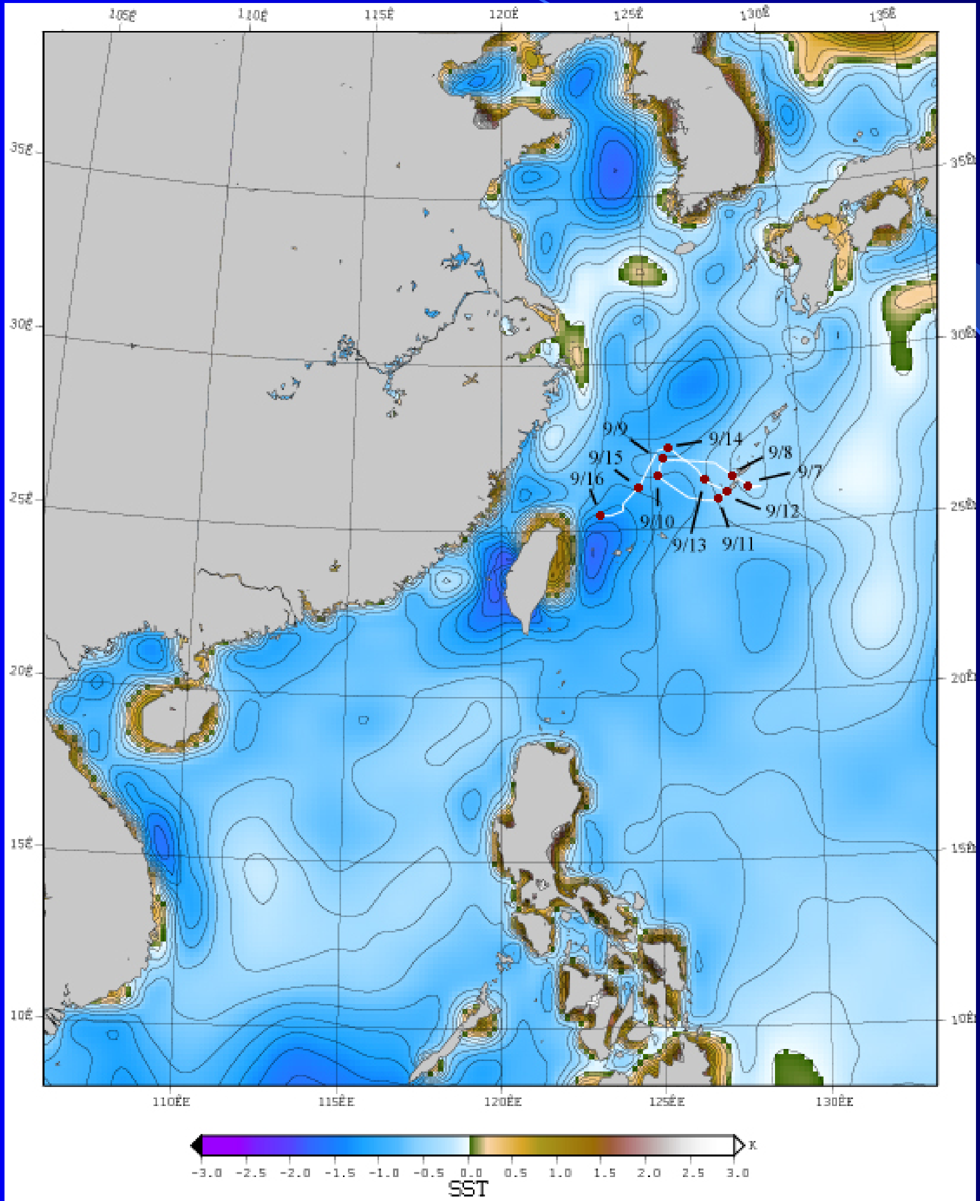


Mixed layer

Thermocline layer

Deep resting layer

SST cooling induced by the typhoon-ocean coupling



60-km MM5 Grid