A Modeling Study of Typhoon Nari (2001) at Landfall: Topographic Effects

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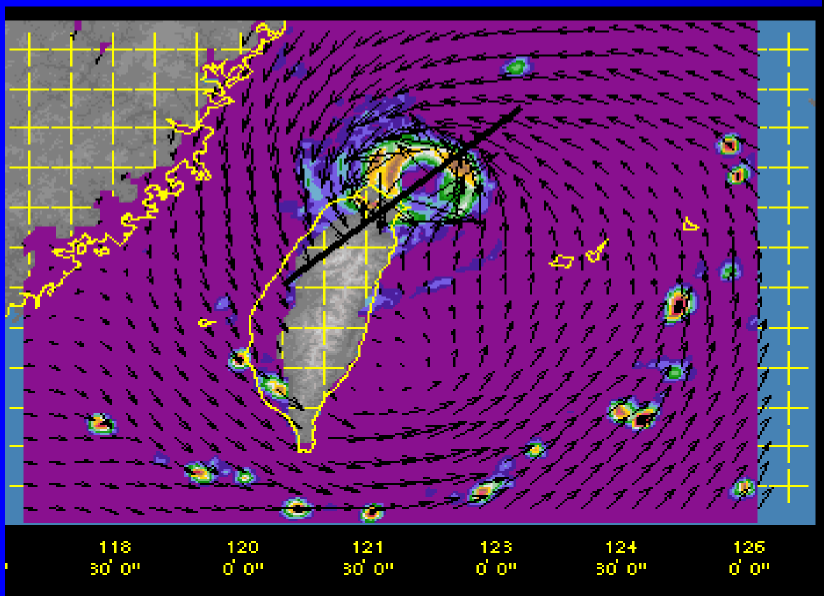
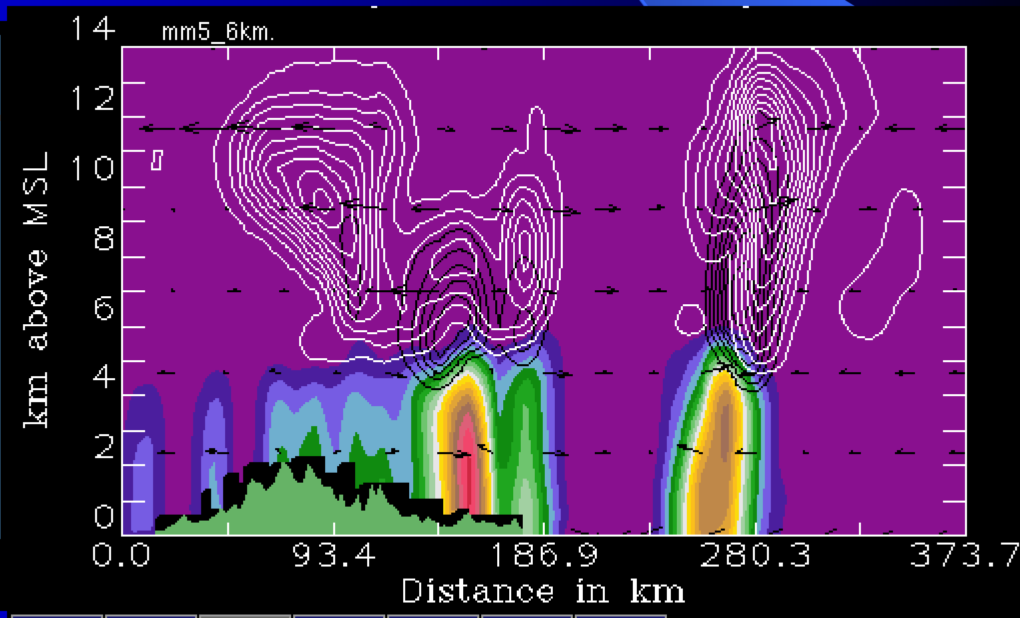
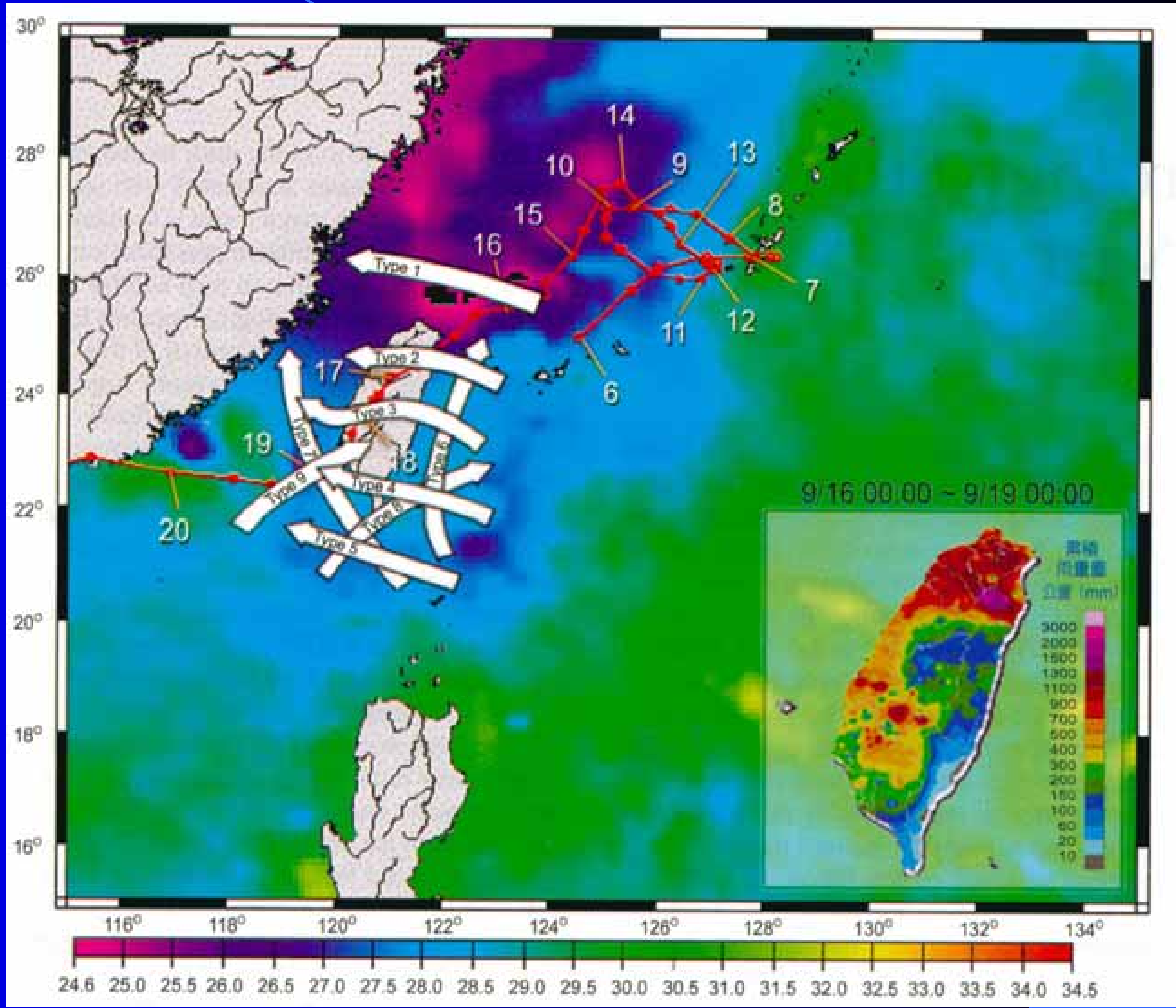




Unique Characteristics of Typhoon Nari (2001)

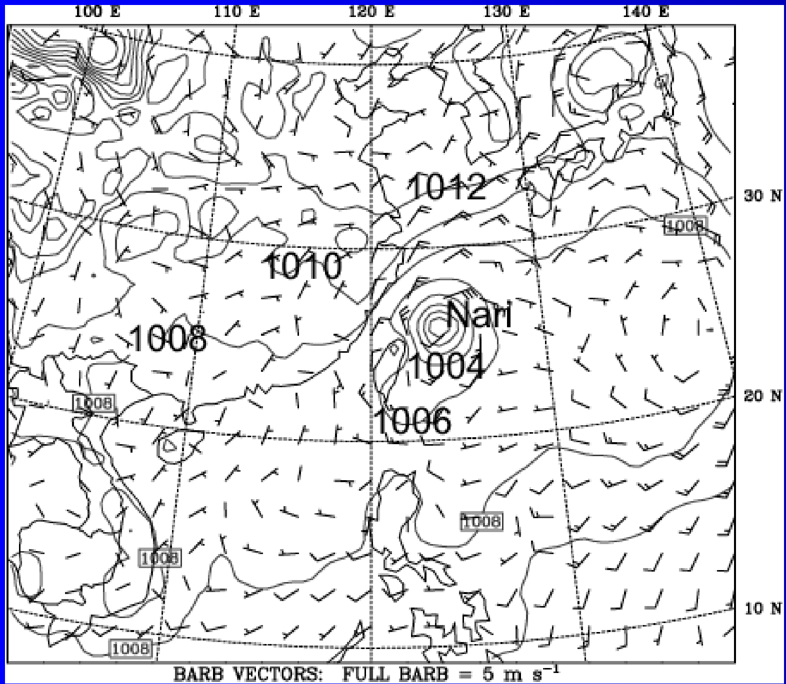
- Unique track
- Slow motion
- Long duration
- Heavy rainfall
- Severe flooding



Sui et al. (2002) EOS article

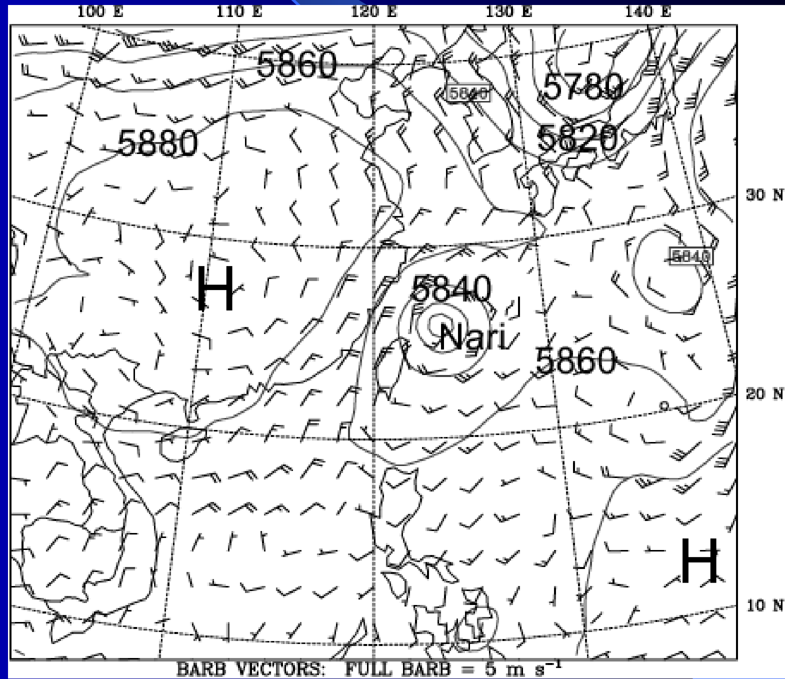
Synoptic Environment

(a)

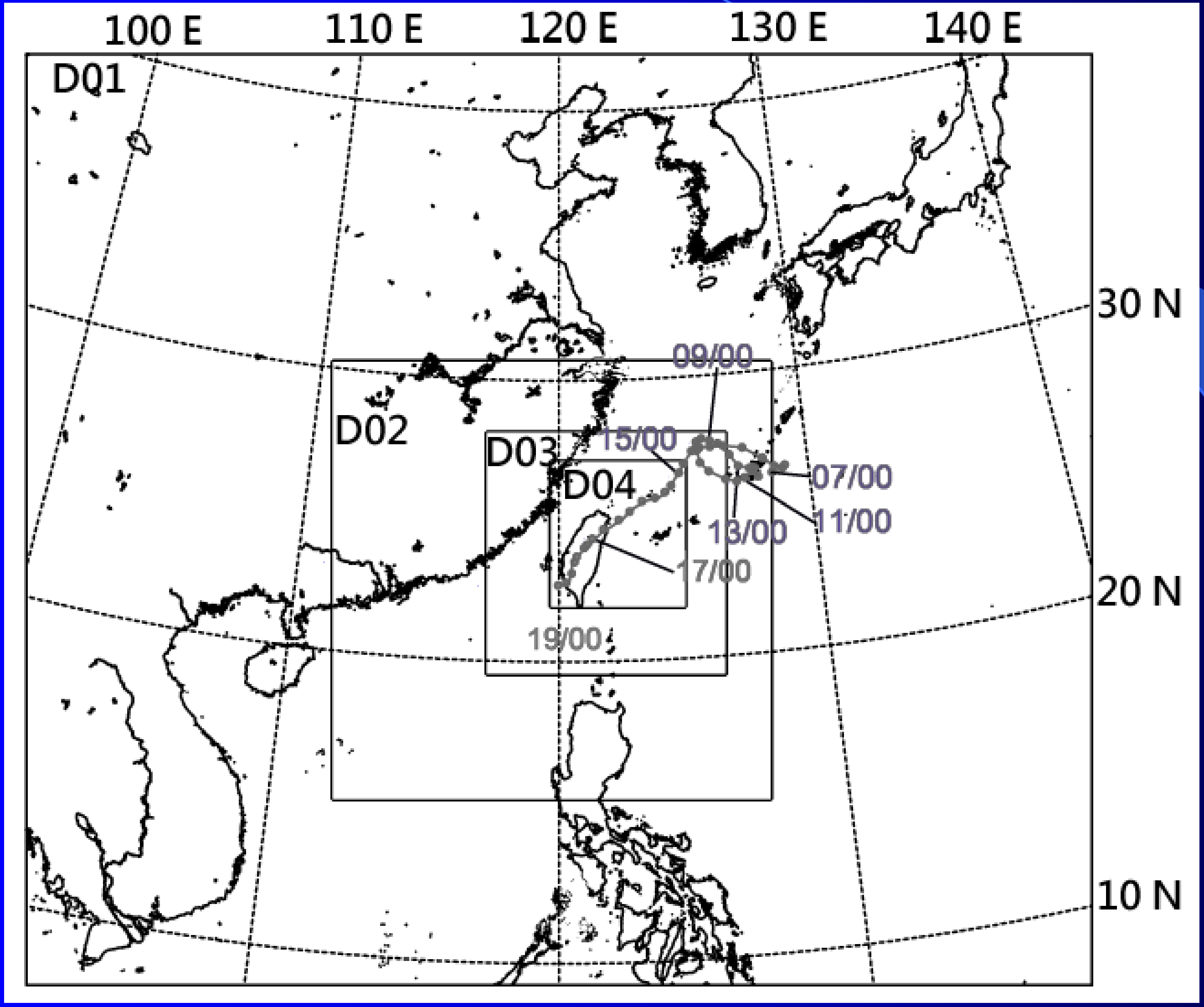


SFC Map

(b)



500-hPa Map



MM5
Domains

D1: 54 km
D2: 18 km
D3: 6 km
D4: 2 km

31 levels
In vertical

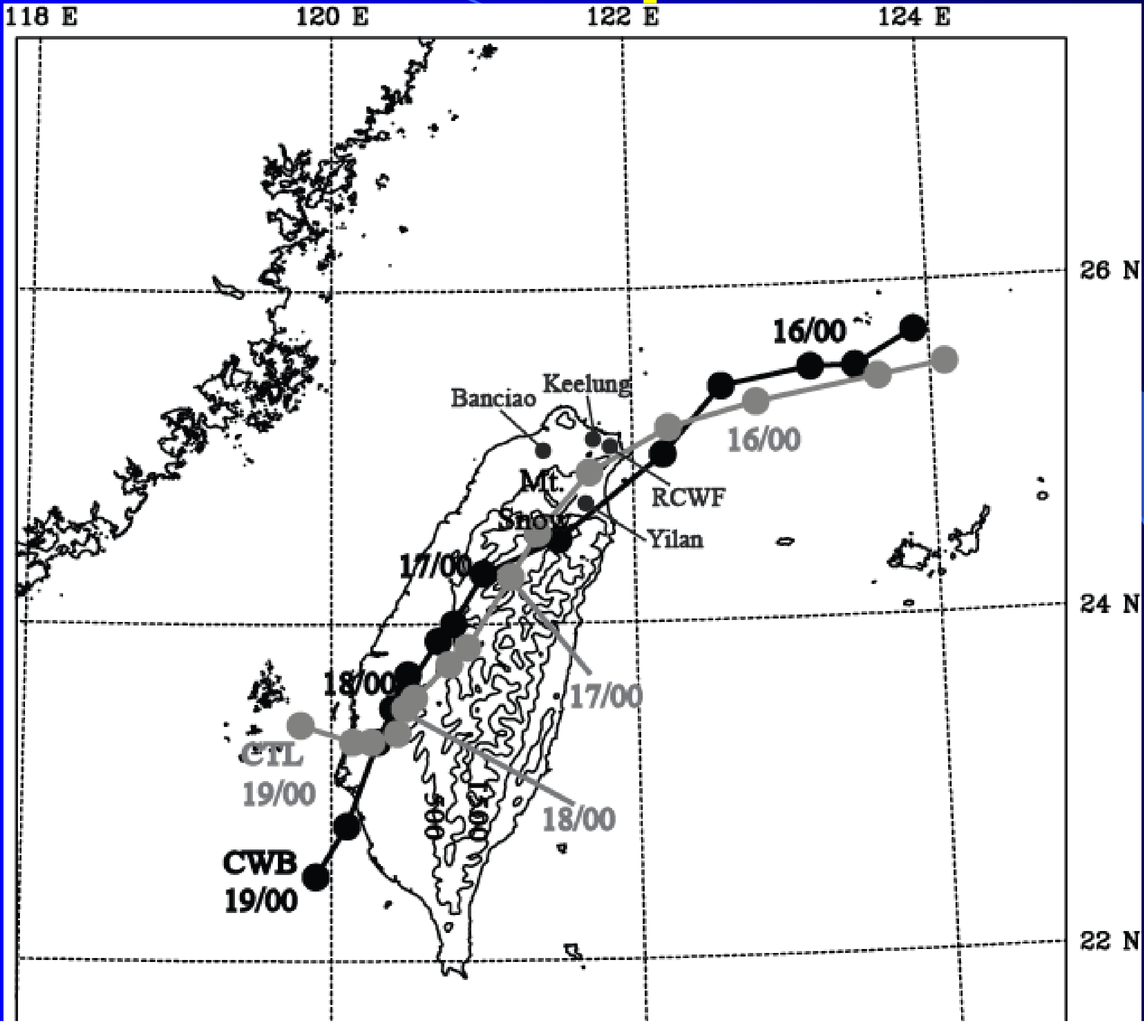
MM5 model physics (Control)

Version	V 3.5
Fcst Period	84 h
Cumulus	Grell (1993)
Microphysics	Reisner et al. (1998) with graupel
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)

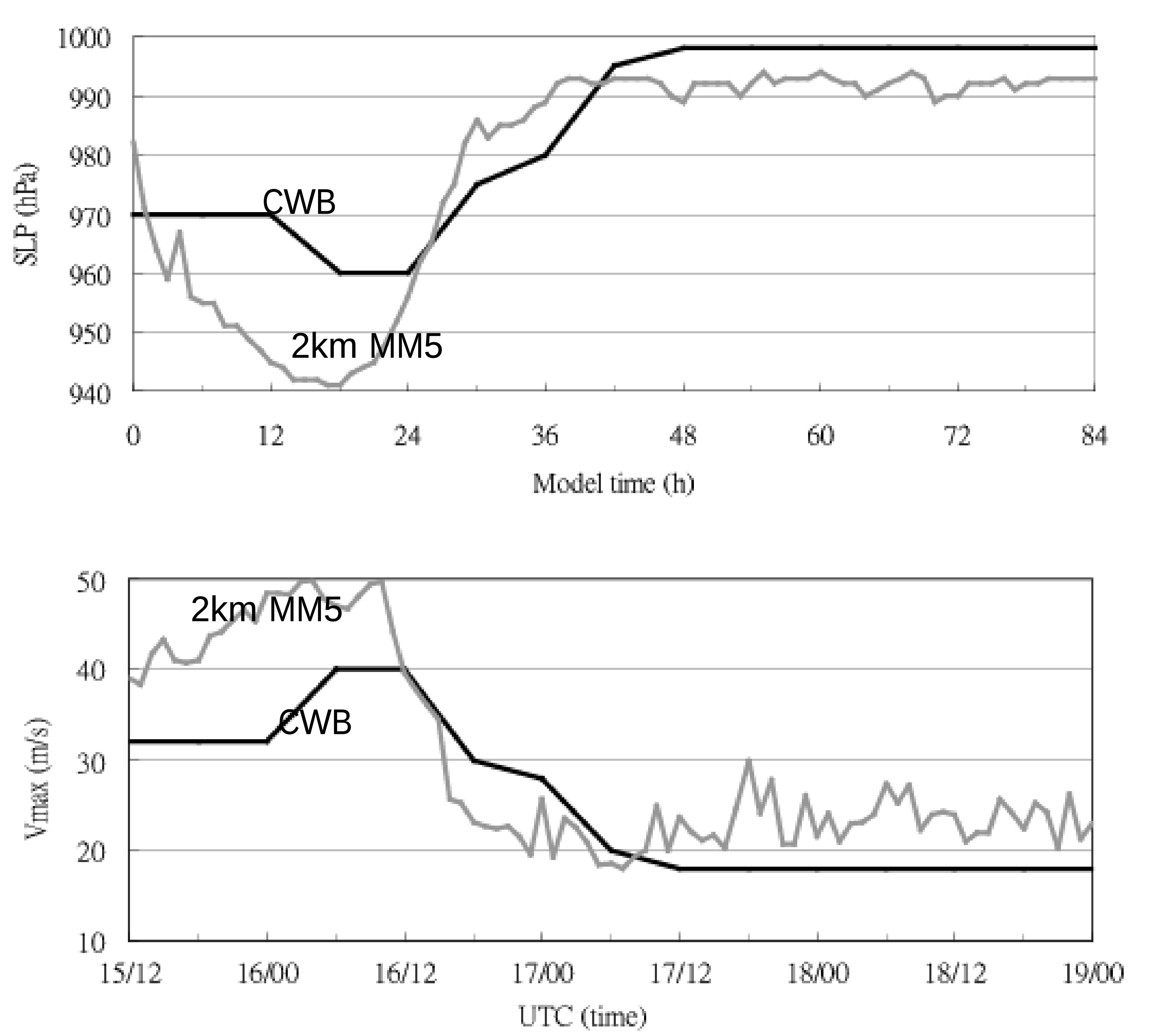
Part I: Control Simulation & Verification

Track Comparison



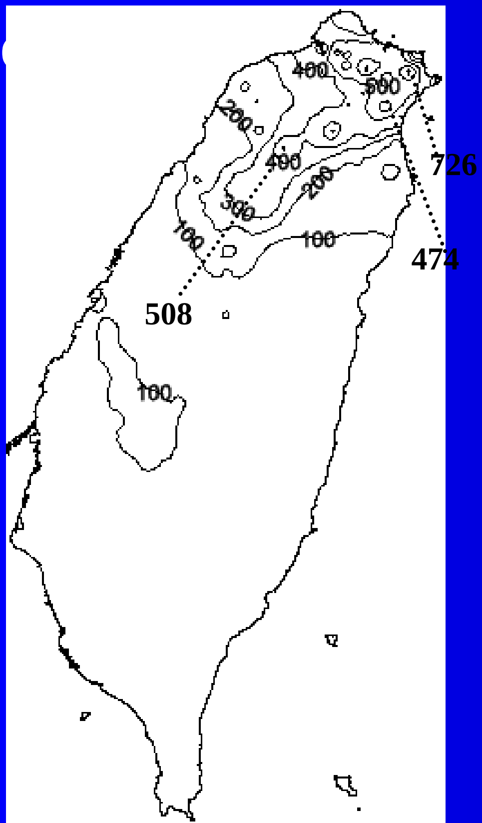
Simulation time (hr)	12	24	36	48	60	72	84
Track error (km)	43.3	61.2	26.8	13.4	12	8.5	104.8

Time Series of SLP and Vmax

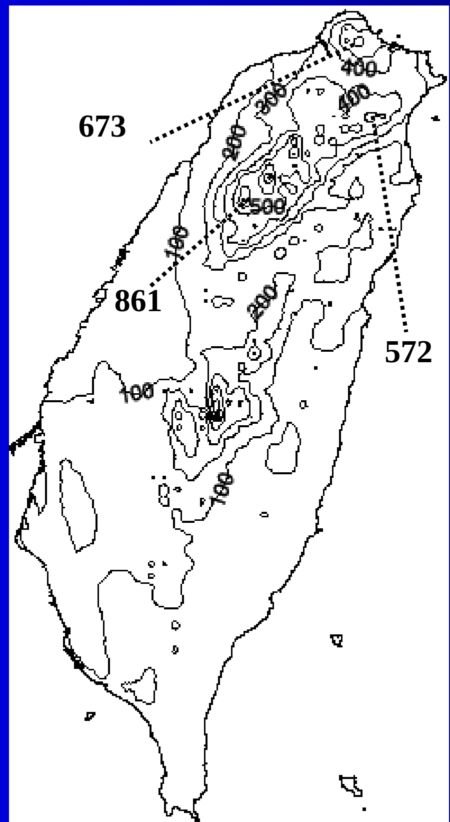


24-h Accumulated Rainfall on 09/16

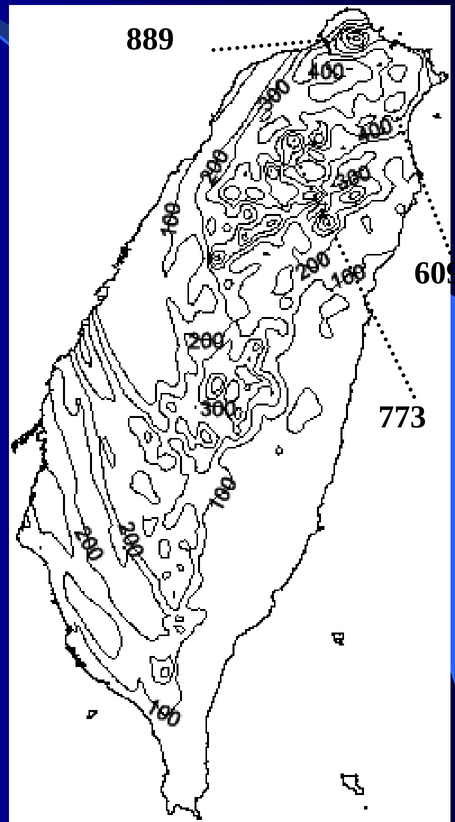
OBS



6km MM5

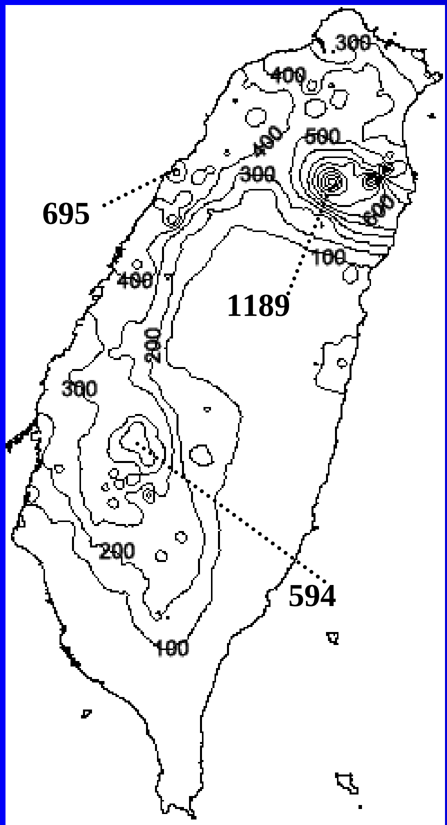


2km MM5

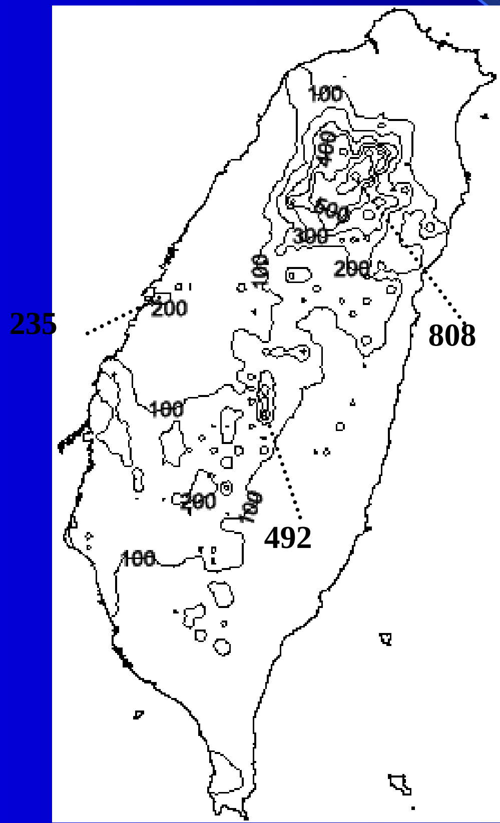


24-h Accumulated Rainfall on 09/17

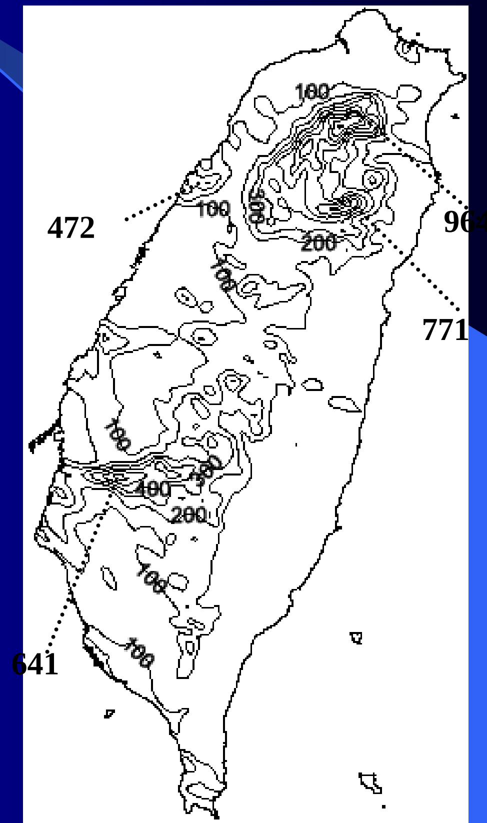
OBS

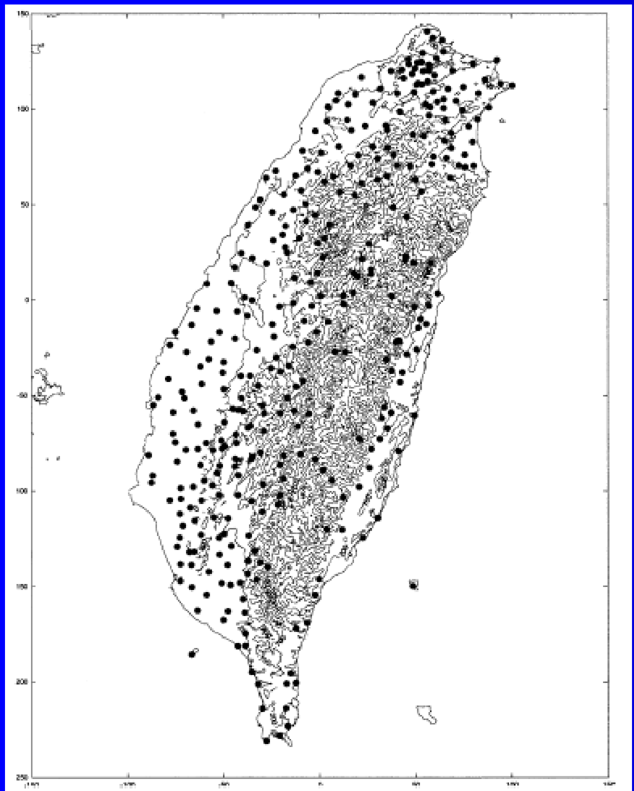


6km MM5

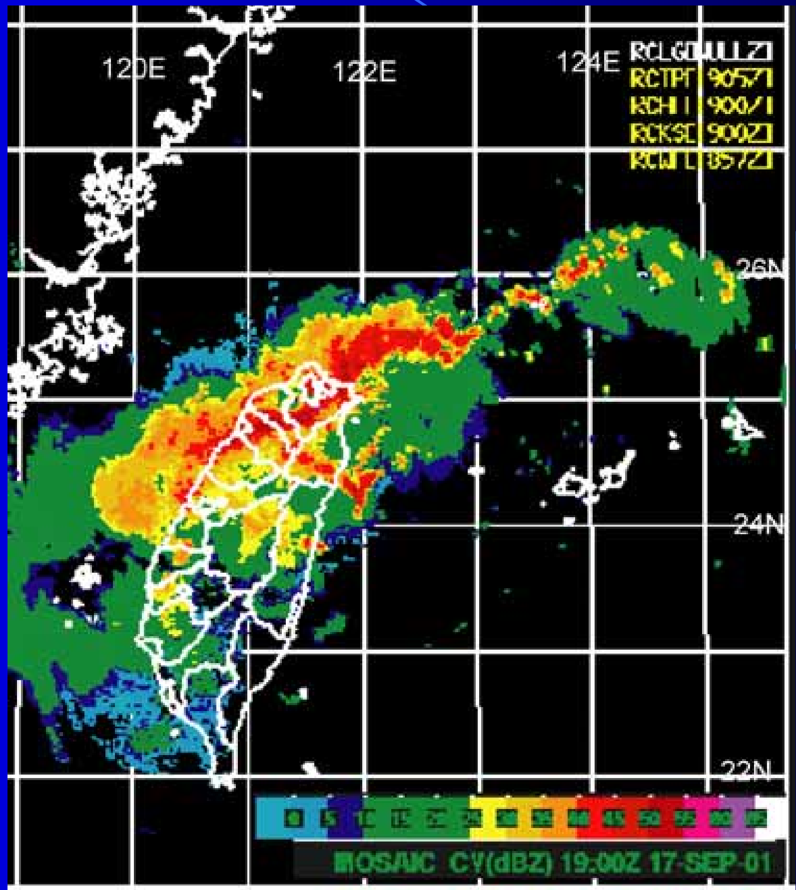


2km MM5





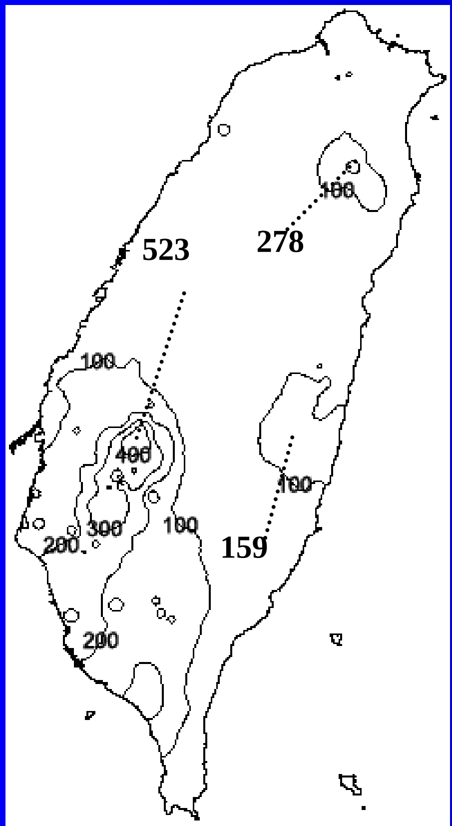
Raingauge Stations



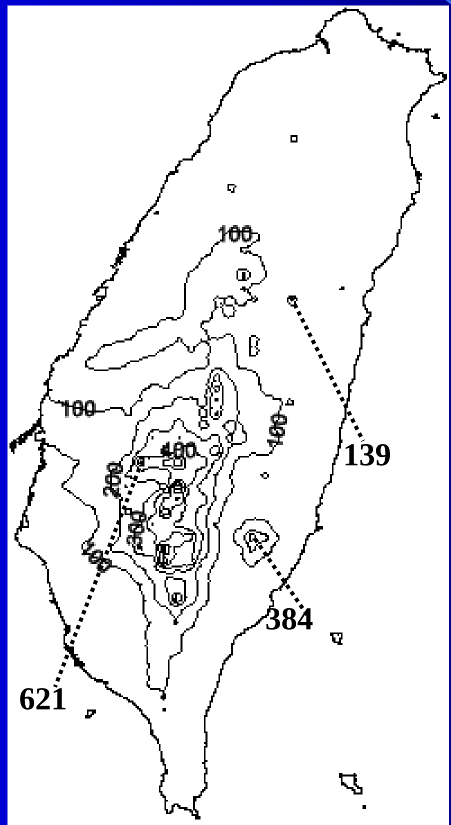
Radar CV @ 9/17 19 UTC

24-h Accumulated Rainfall on 09/18

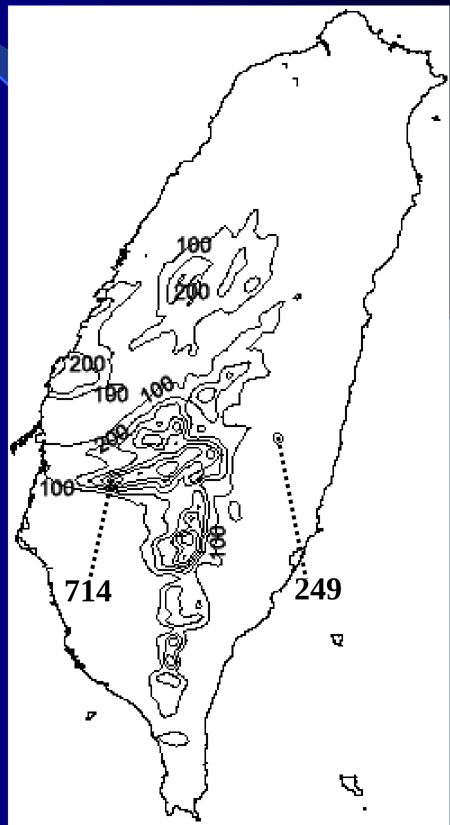
OBS



6km MM5



2km MM5

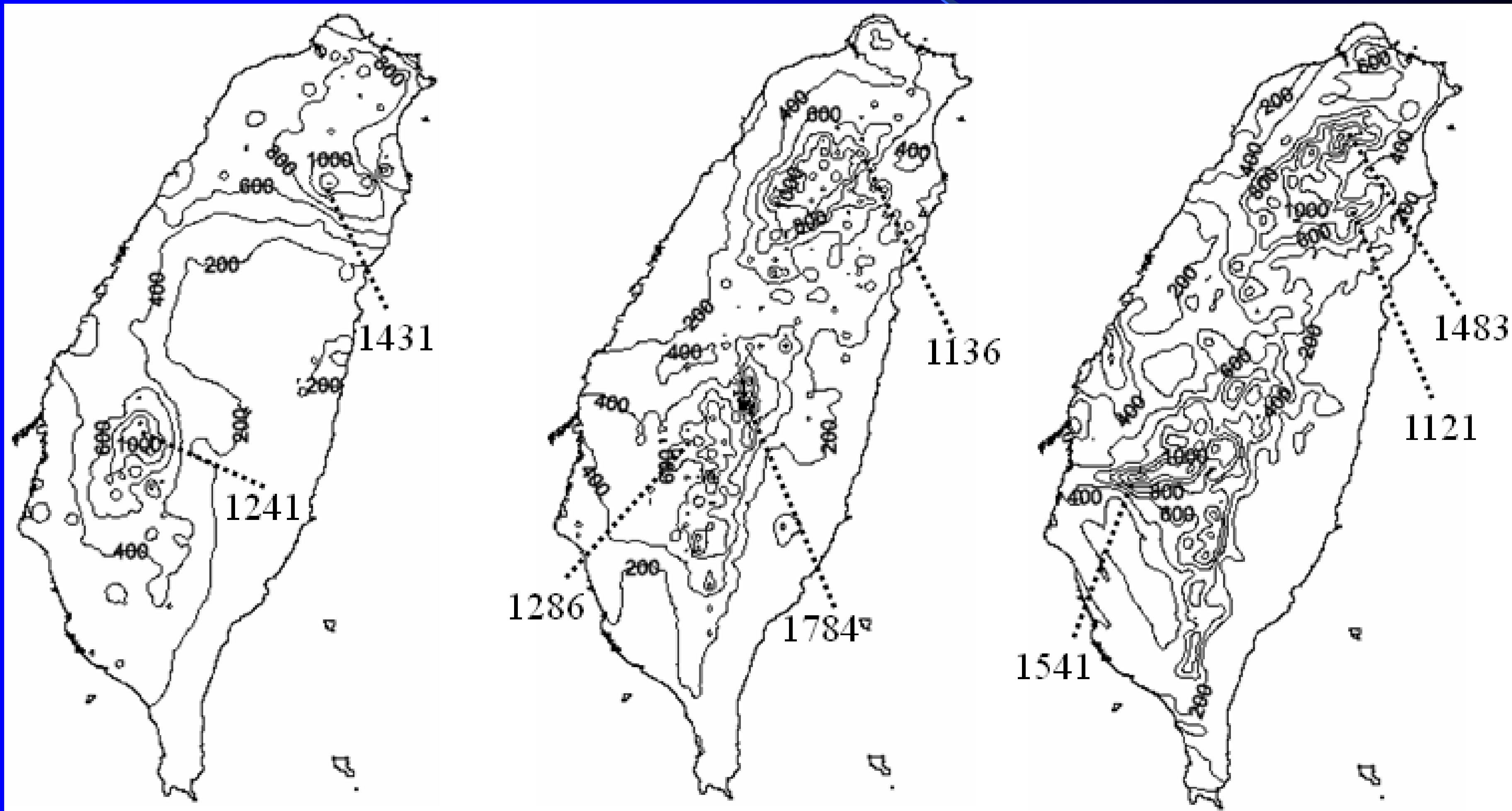


3-day rainfall (09/16~09/18)

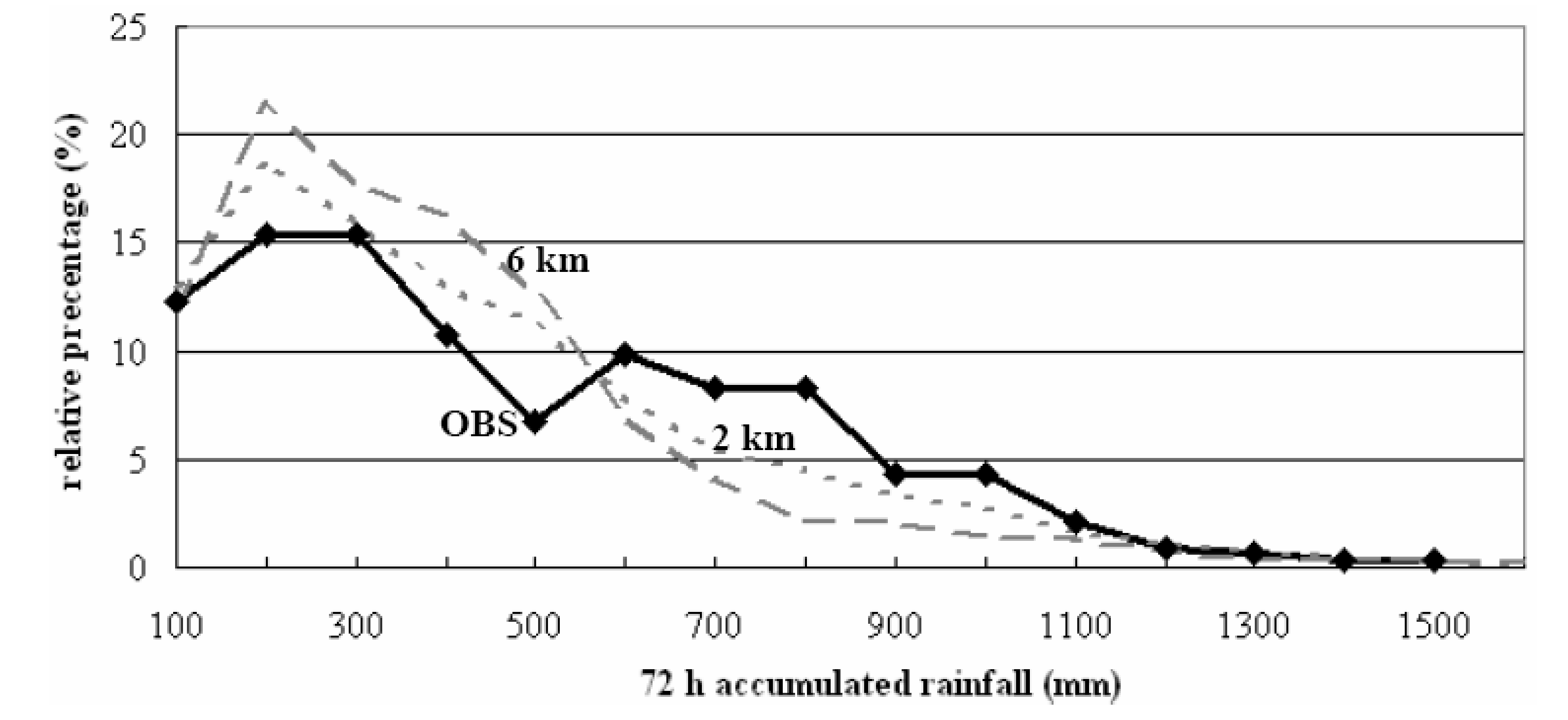
OBS

6km MM5

2km MM5



Relative Percentage of 3-Day Rainfall



→MM5 overforecasts weak TC rainfall (<550mm/3day) but underestimates heavy TC rainfall (>550mm/3day) (consistent with Chien et al. 2002;Yang et al. 2004)

→As model resolution increases, the simulated rainfall spectrum approaches the observed (consistent with Wu et al. 2002)

Average Rainfall on Taiwan

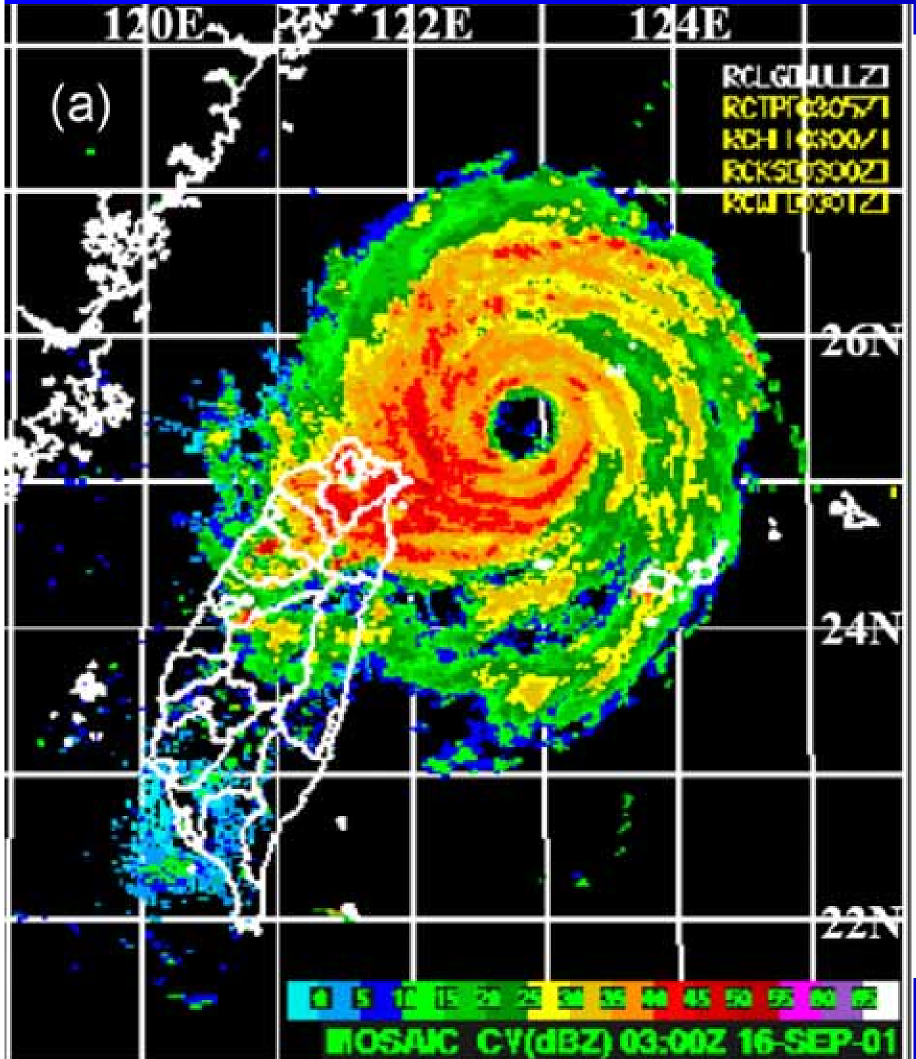
Item	N	09/16	09/17	09/18	3-Day Total
OBS (in mm)	325	132	206	97	435
6km MM5	1073	159	104	75	348
2km MM5	9602	175	133	84	383

Percentage wrt Rain Gauge OBS

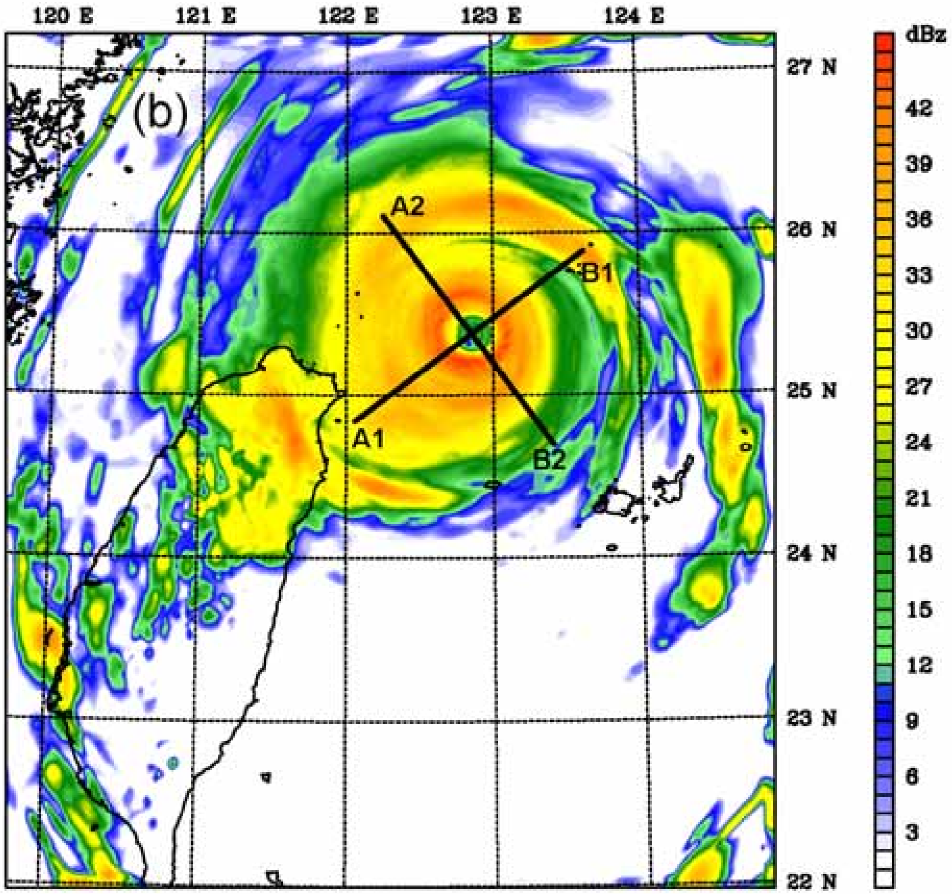
MM5/OBS	09/16	09/17	09/18	3-Day Total
6km MM5	121 %	51 %	78 %	80 %
2km MM5	133 %	65 %	87 %	88 %

Radar Composite Before Landfall

OBS



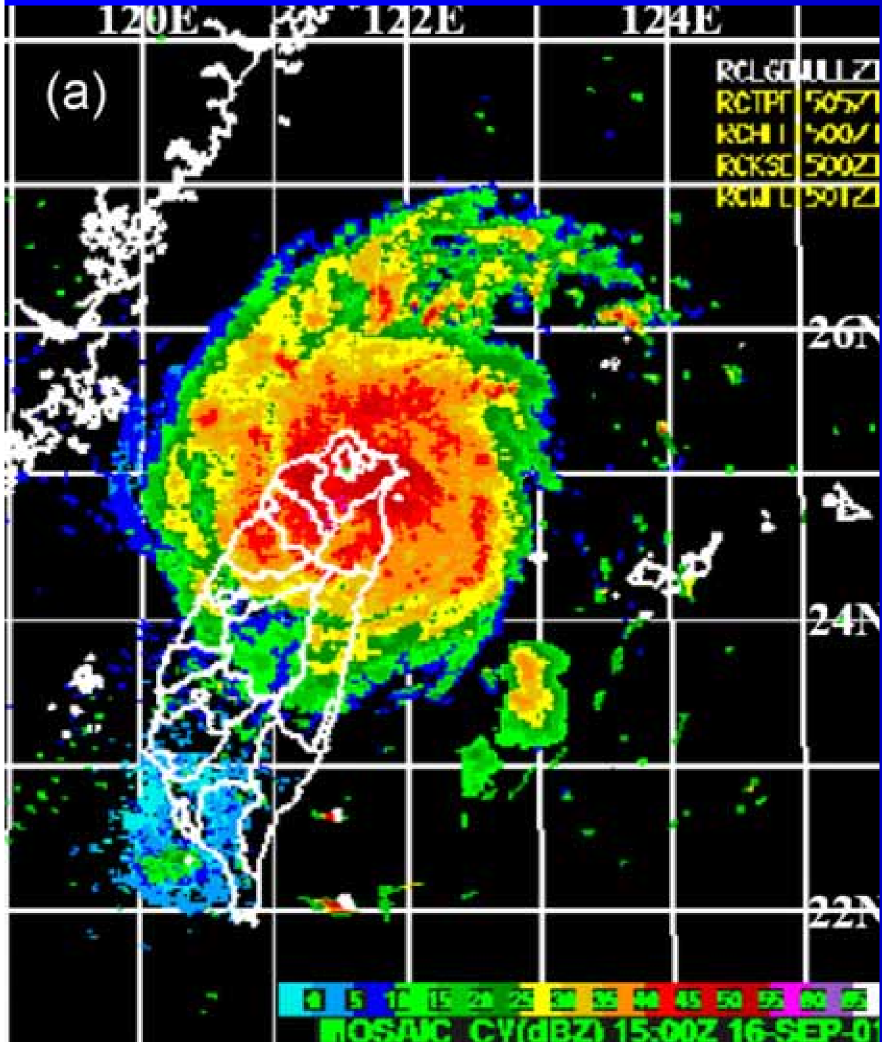
2-km MM5



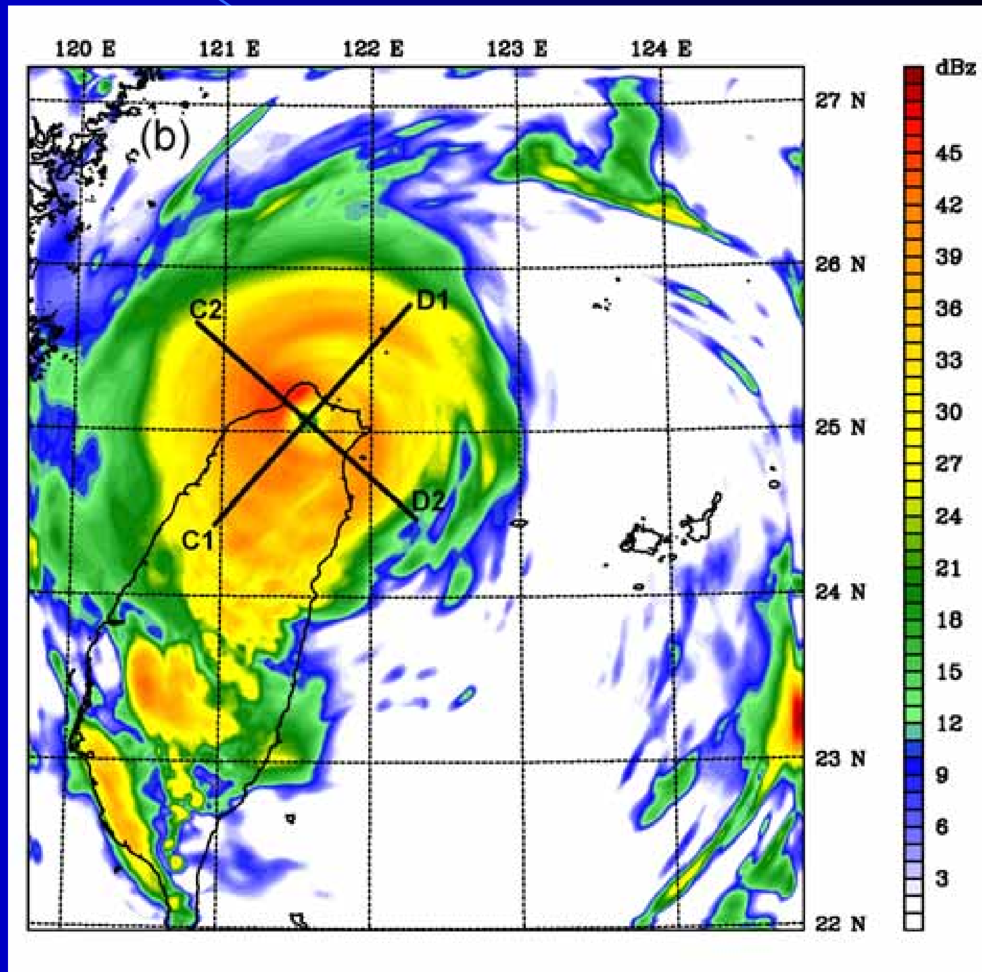
MM5 Radar CV @ 9/16 0130Z (1-h time averaged)

Radar Composite After Landfall

OBS

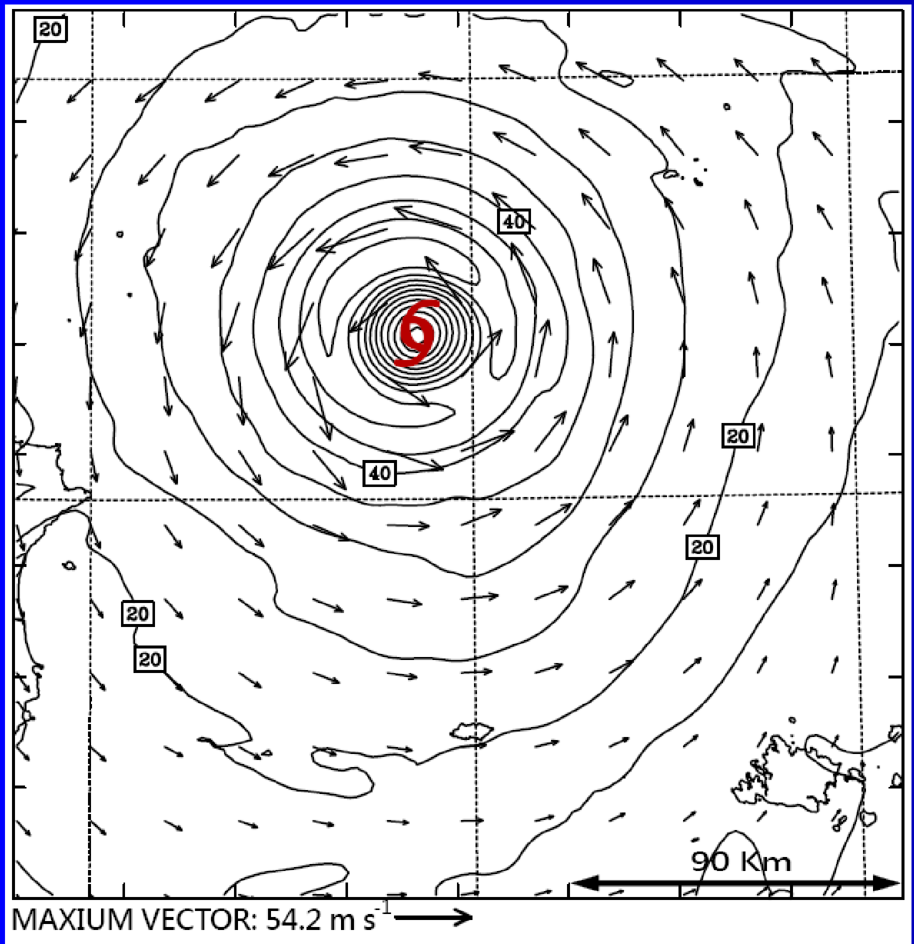


2-km MM5

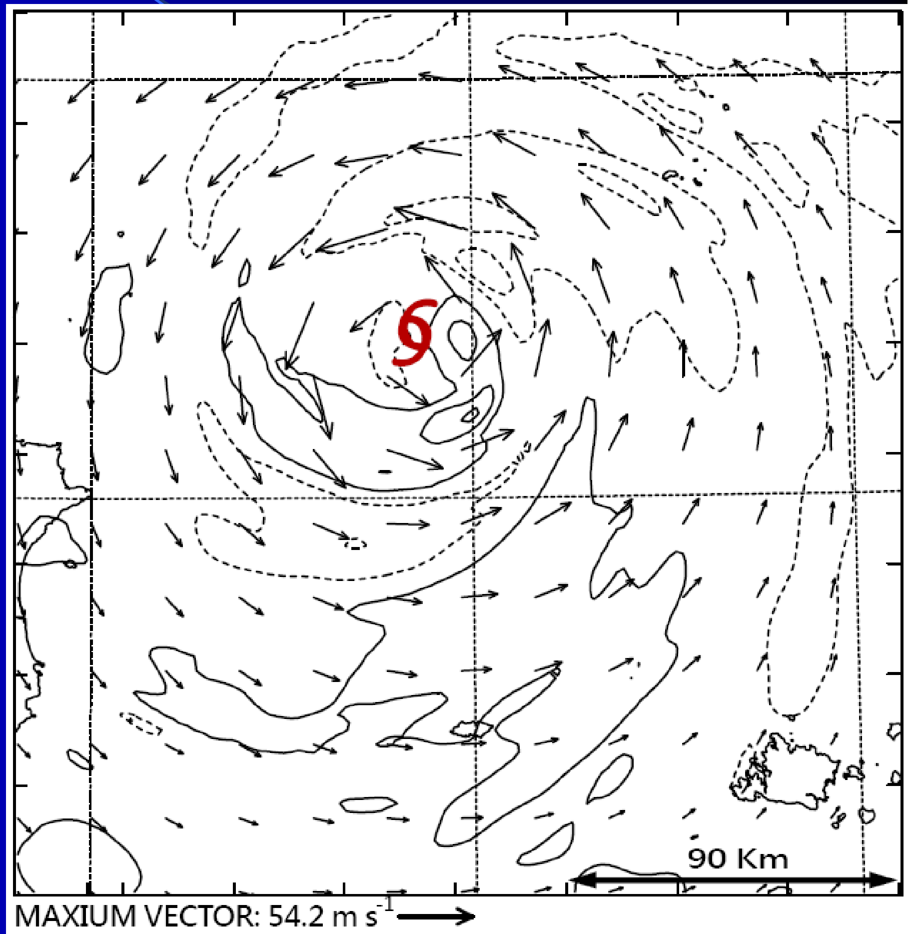


MM5 Radar CV @ 9/16 1200Z (1-h time averaged)

Storm-Relative Vt & Vr @ 3km AGL
(1-h time average centered @ 9/16 0130Z)

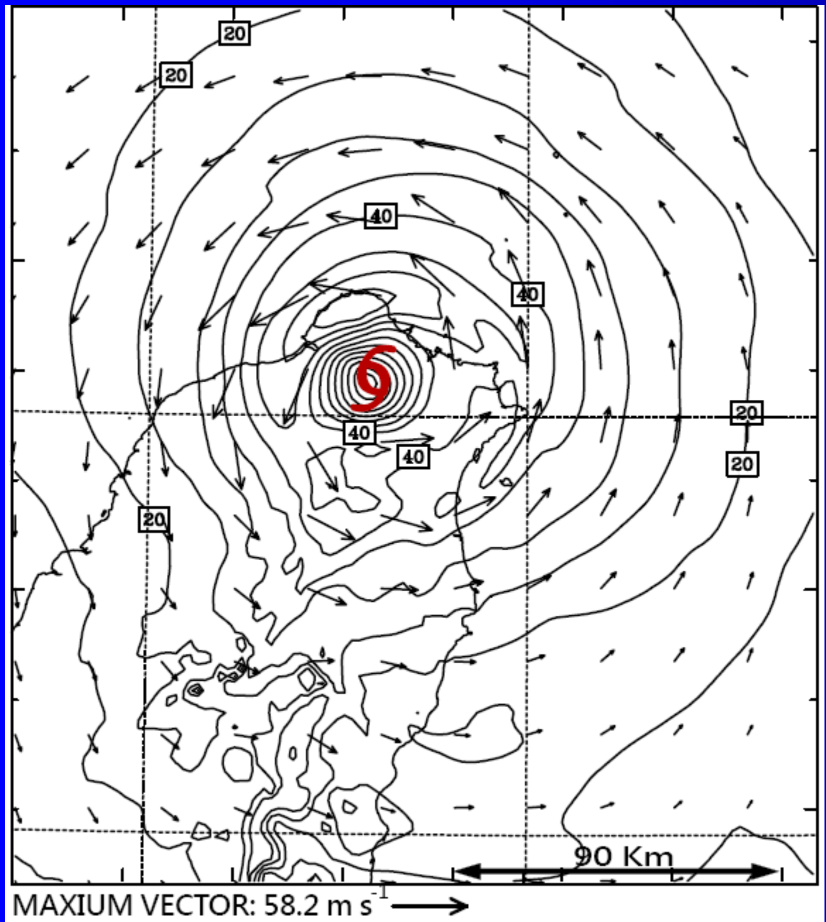


Tangential velocity

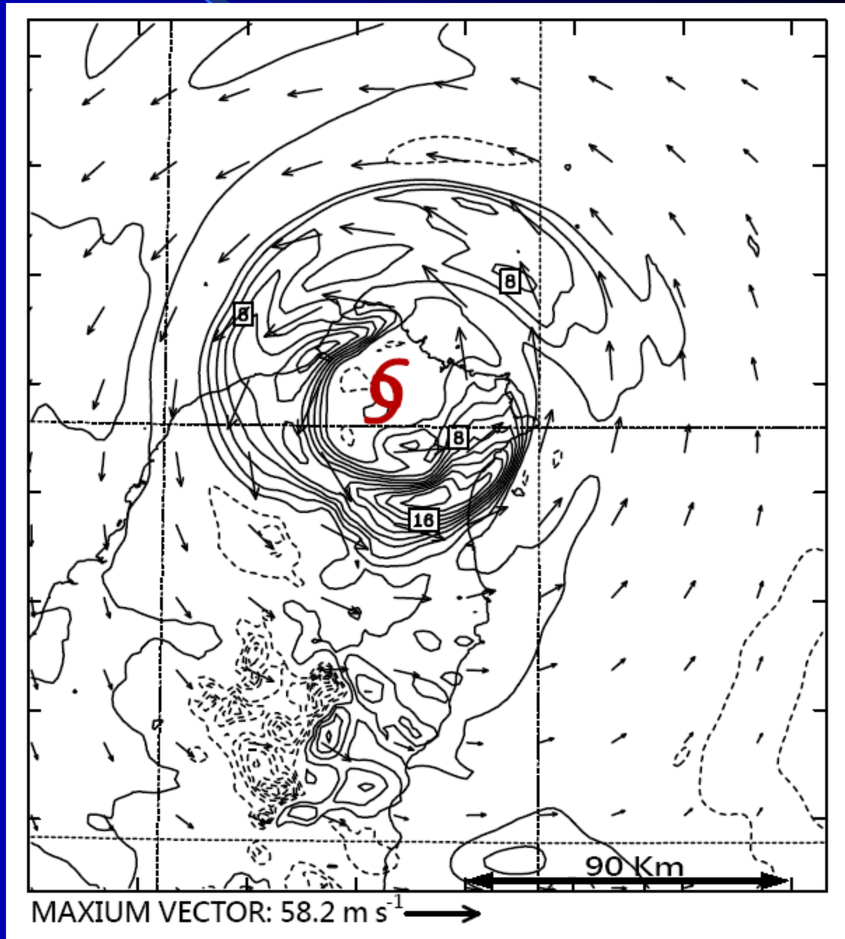


Radial Velocity

Storm-Relative Vt & Vr @ 3km AGL
(1-h time average centered @ 9/16 1200Z)

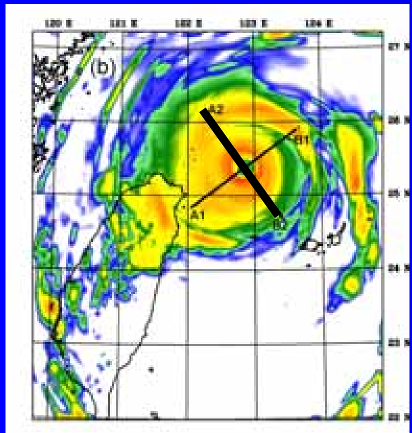


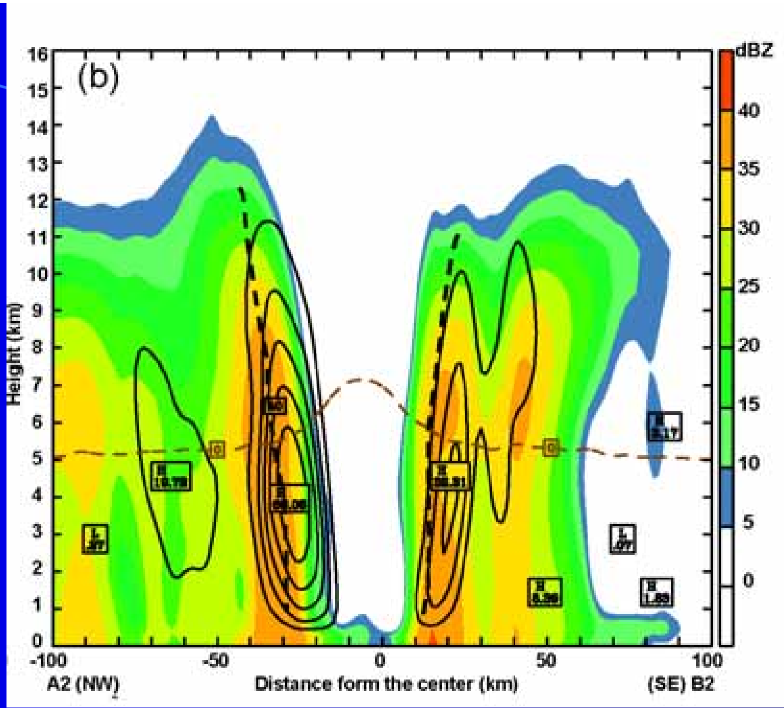
Tangential Velocity



Radial Velocity

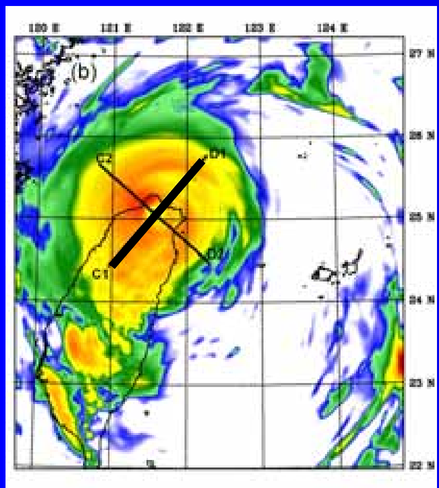
Part II: Storm Structure Changes After Landfall

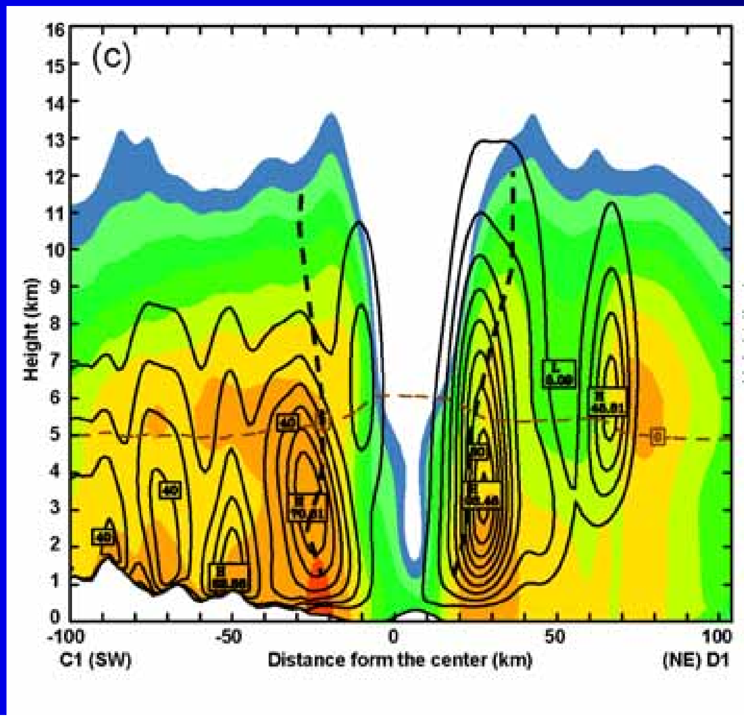




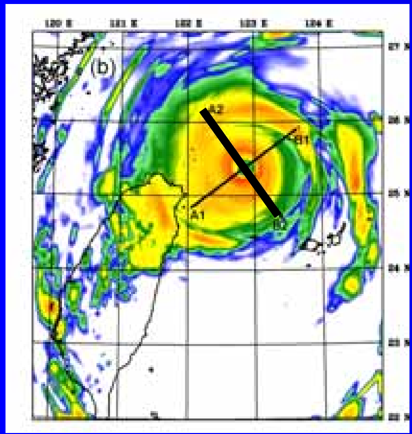
Before Landfall

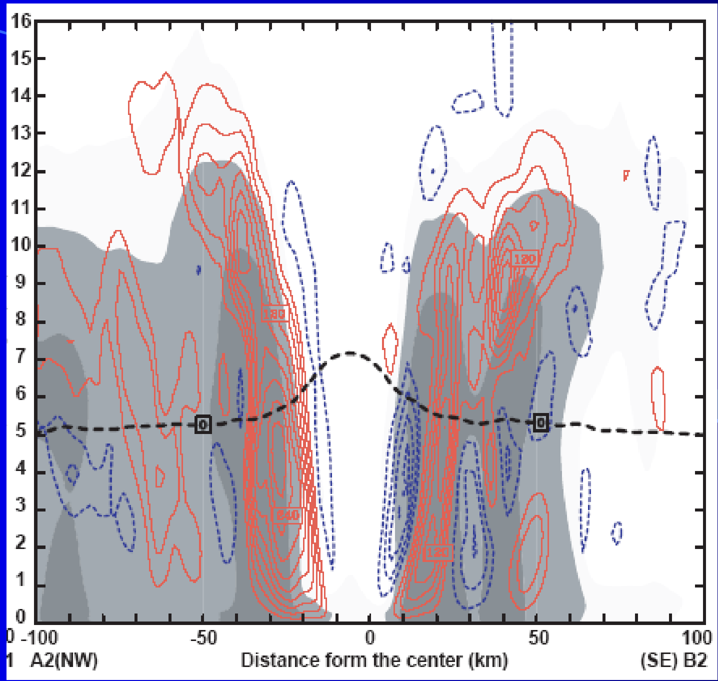
Radar Echo (color)
Condensational Heating (contour)





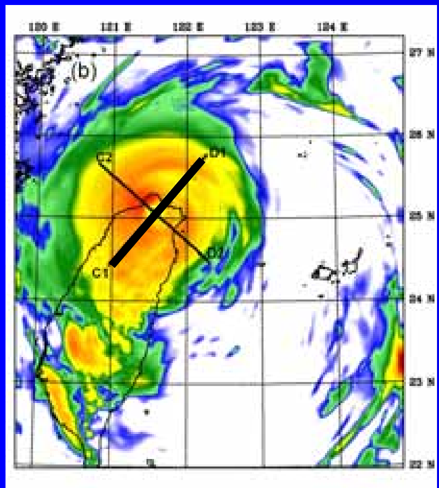
After Landfall

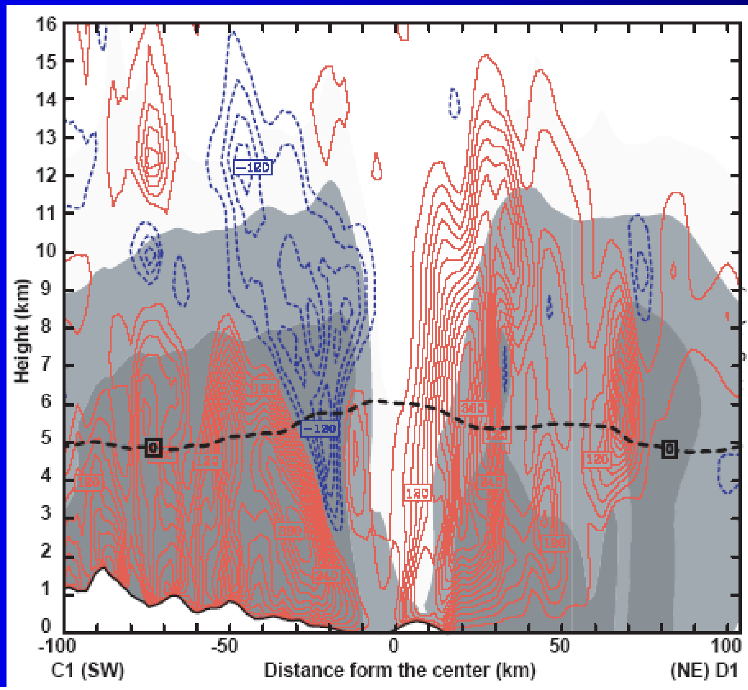




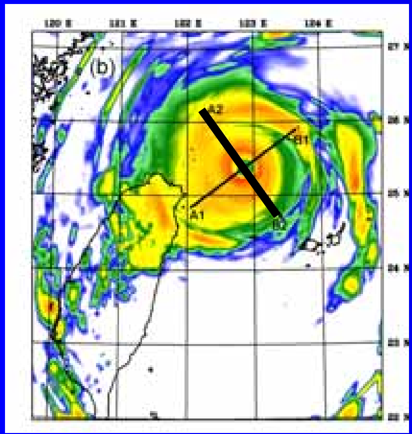
Before Landfall

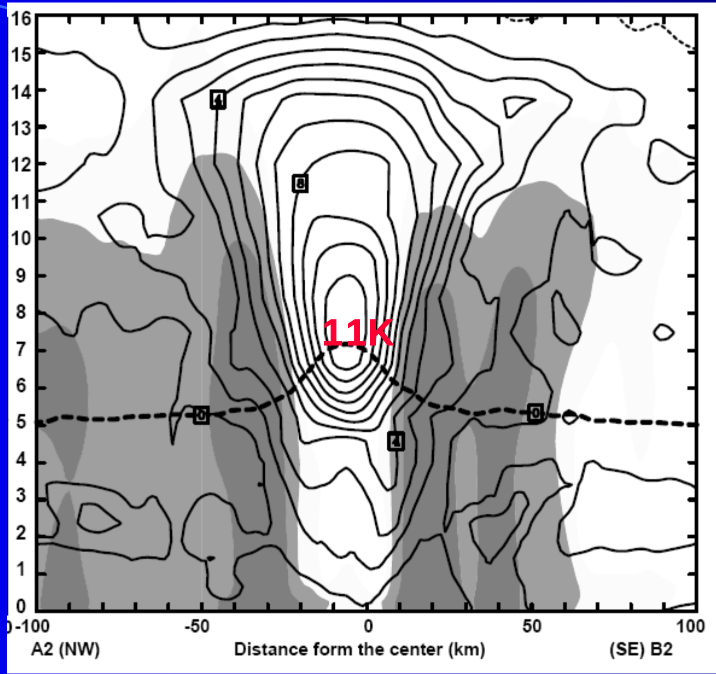
Radar Echo (shading)
Updraft (red)
Downdraft (blue)





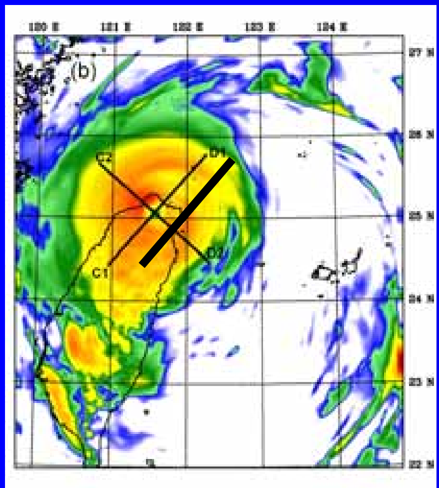
After Landfall

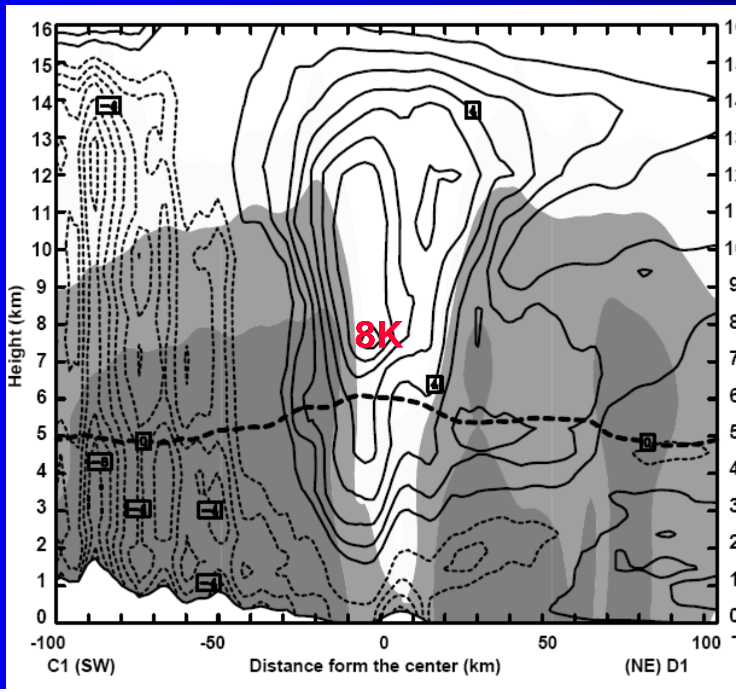




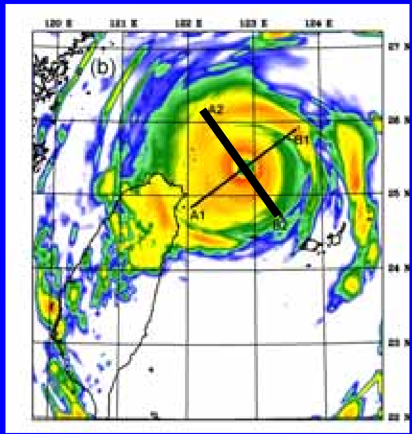
Before Landfall

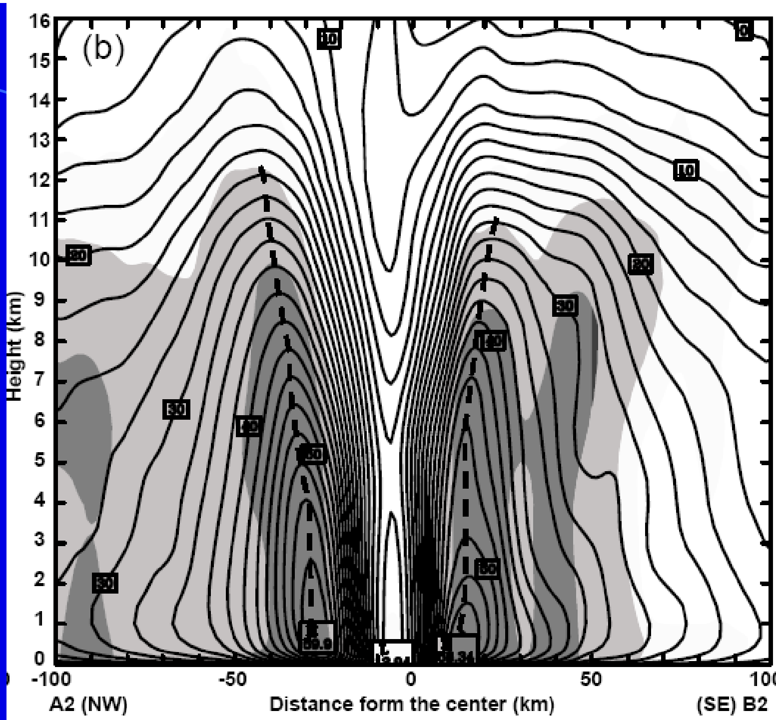
Radar Echo (shading)
Temperature Perturbation
Warming (solid)
Cooling (dashed)





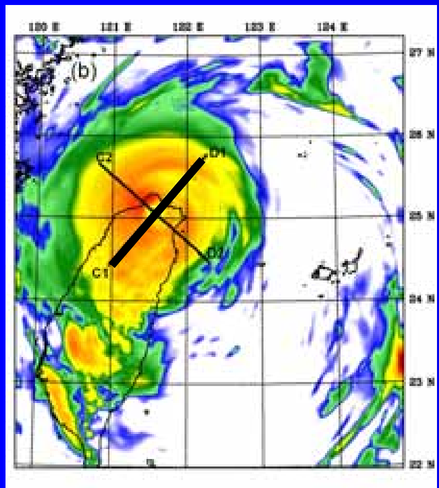
After Landfall

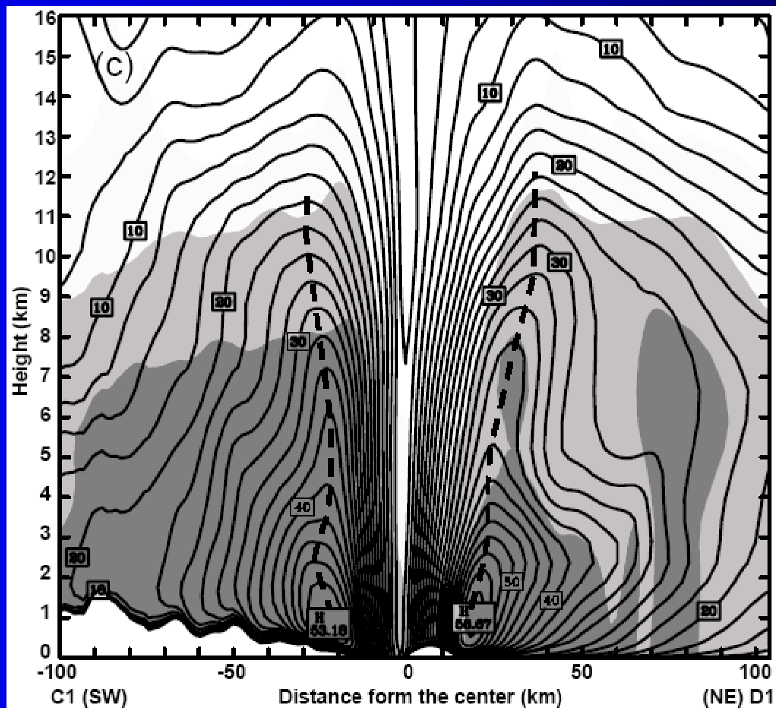




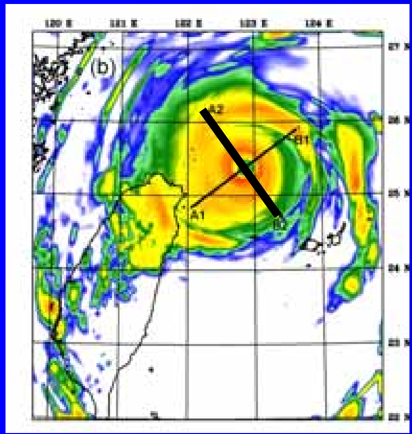
Before Landfall

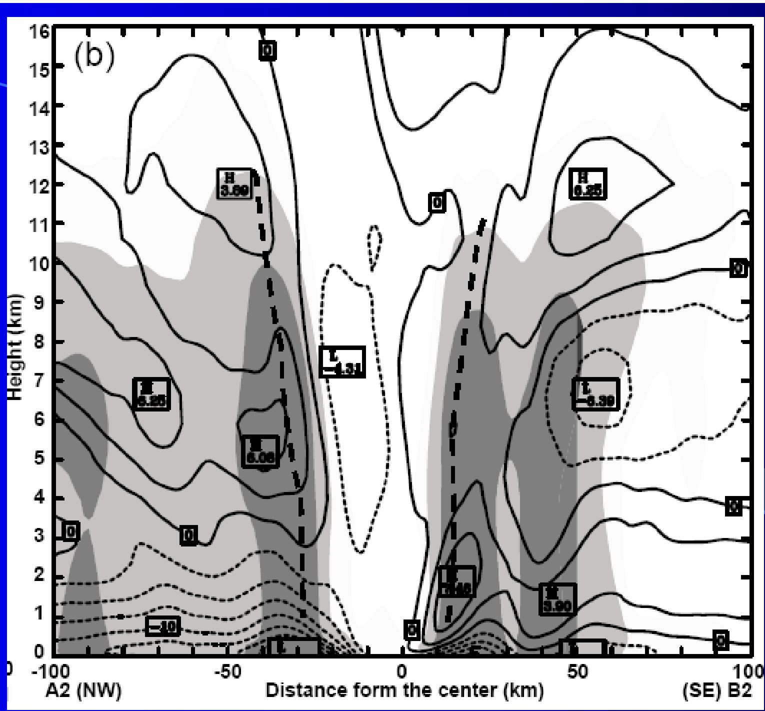
Radar Echo (shading)
Tangential Velocity (contour)





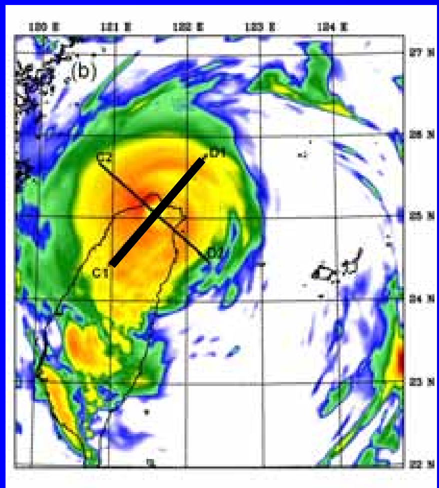
After Landfall

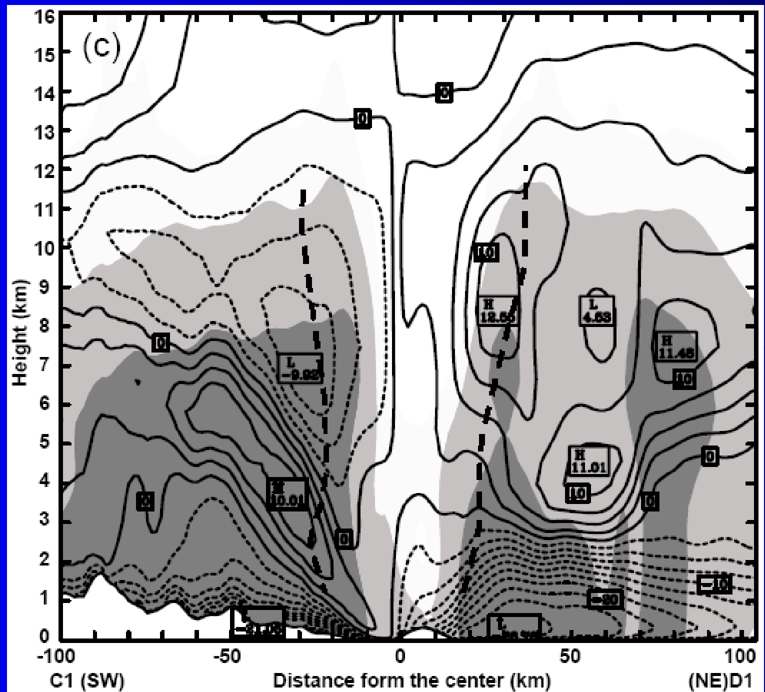




Before Landfall

Radar Echo (shading)
Radial Velocity (contour)





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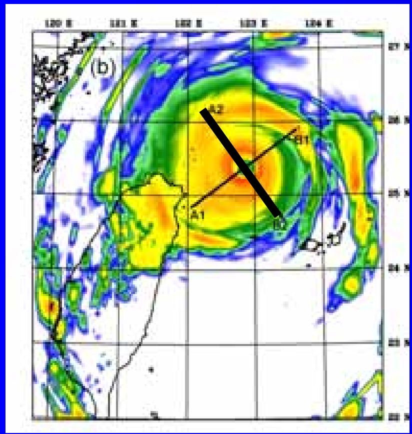
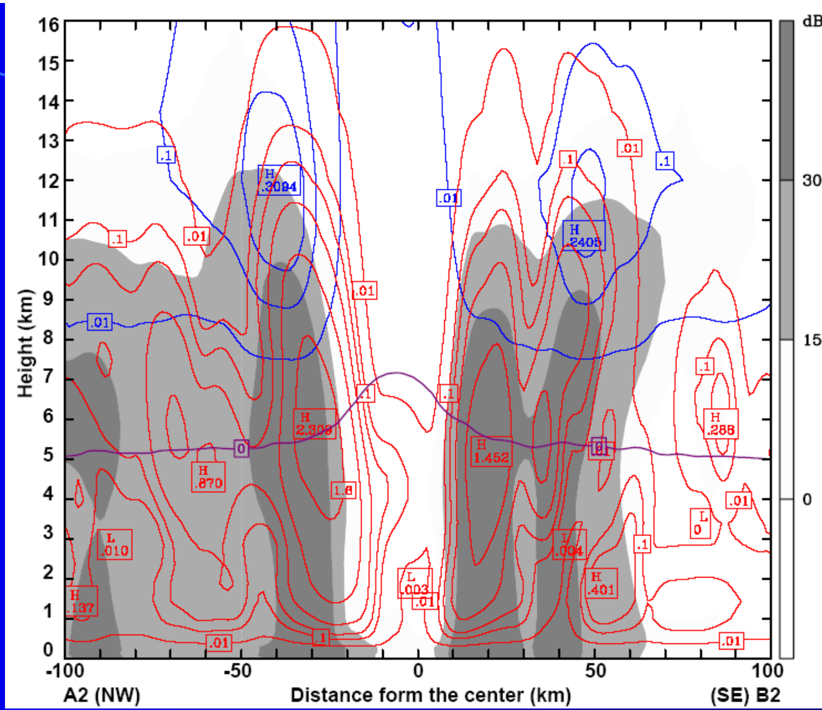
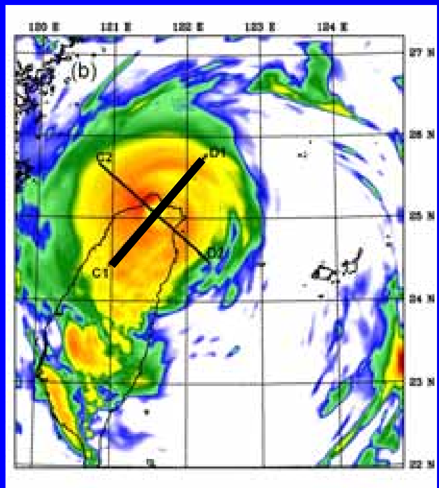
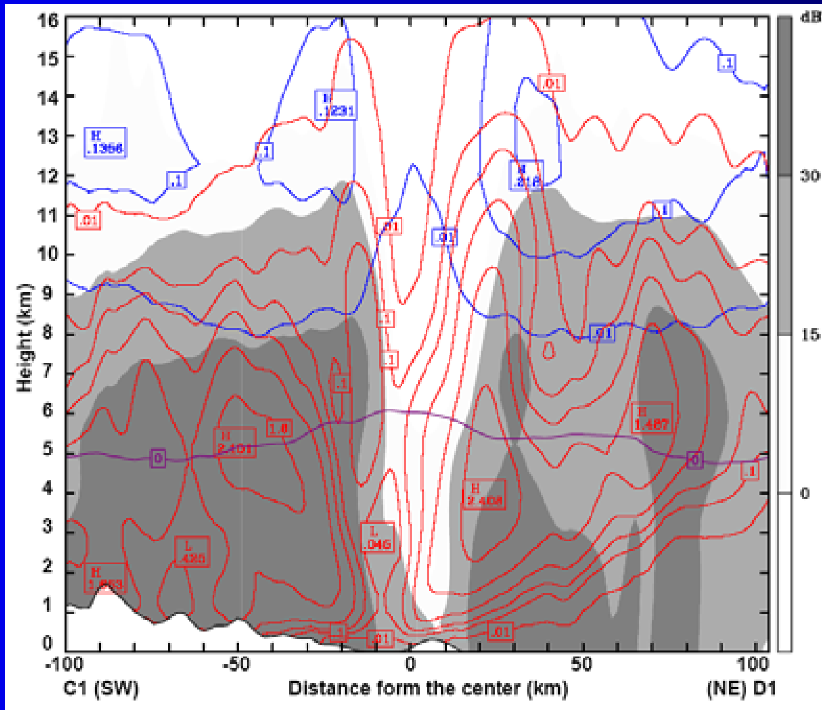




Before Landfall

Radar Echo (shading)
Cloud Ice (blue)
Cloud Water (red)





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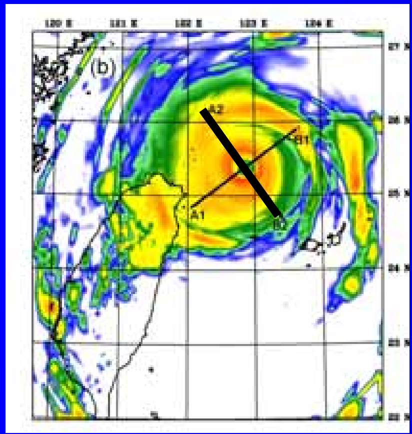
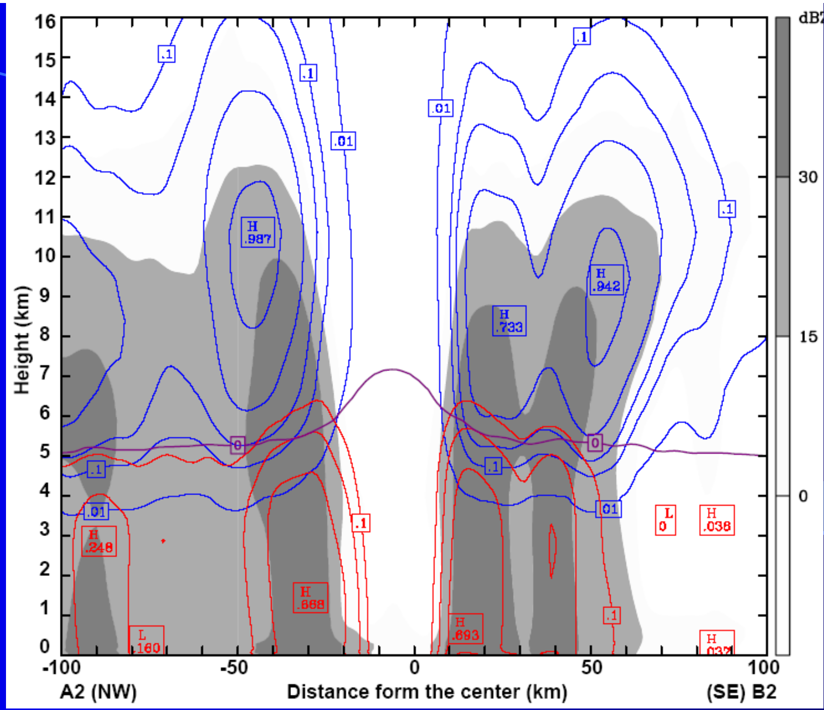
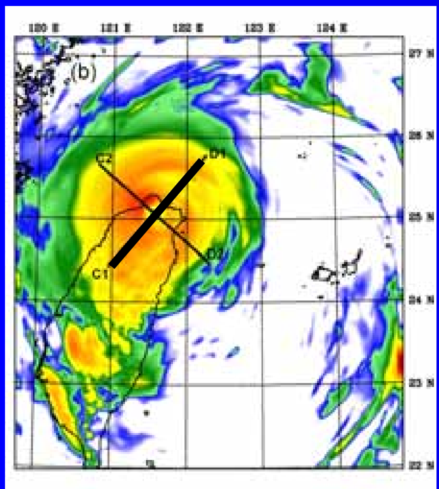
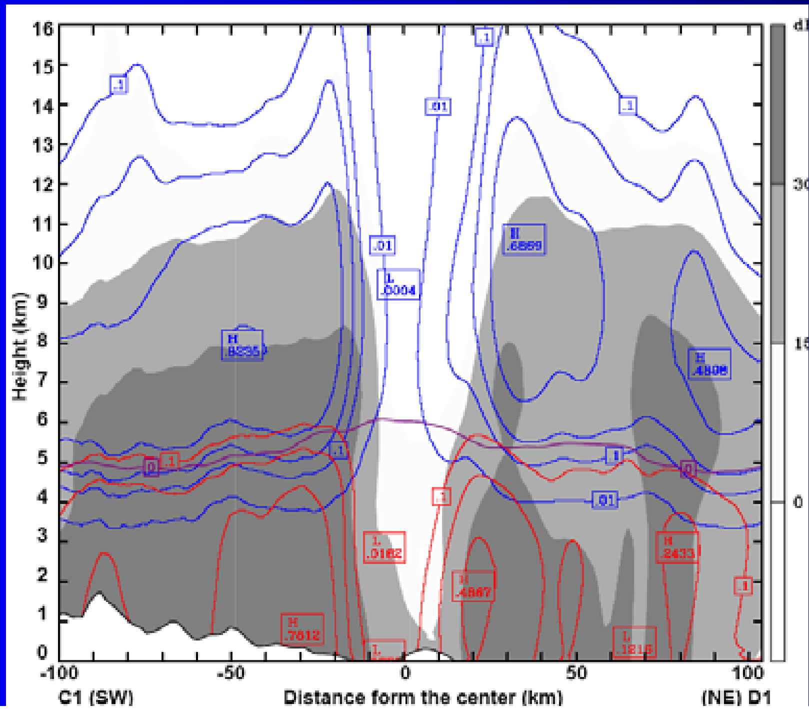




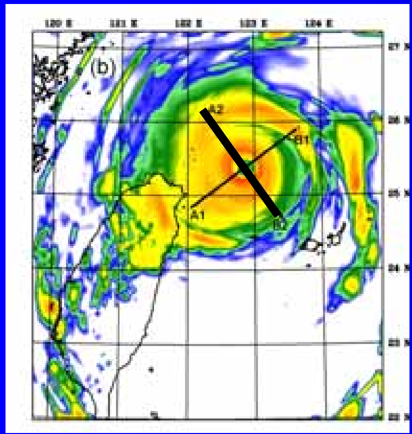
Before Landfall

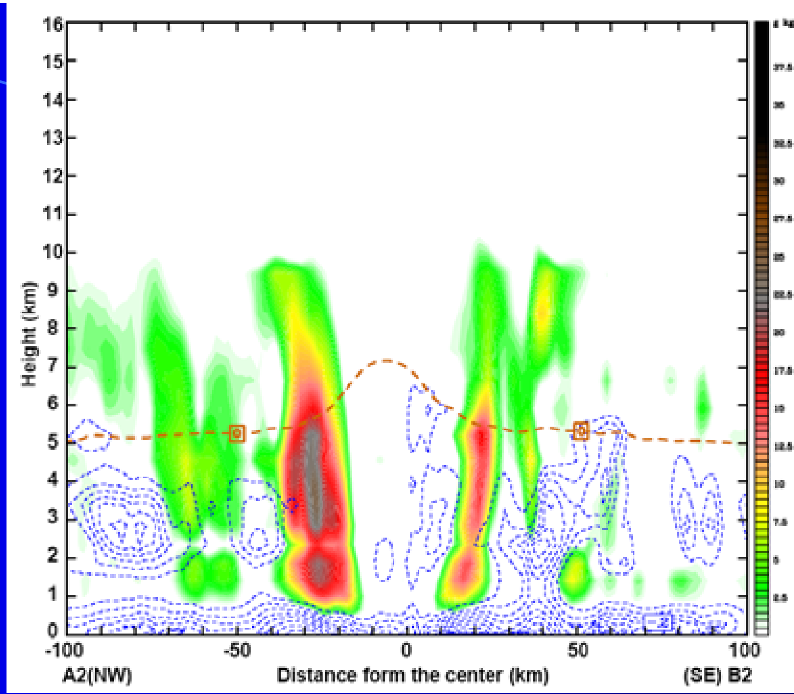
Radar Echo (shading)
Snow (blue)
Rain (red)





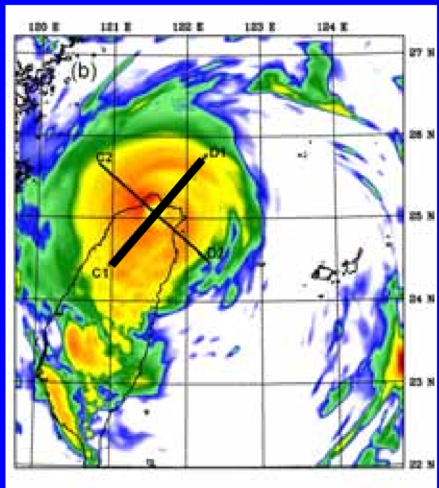
After Landfall

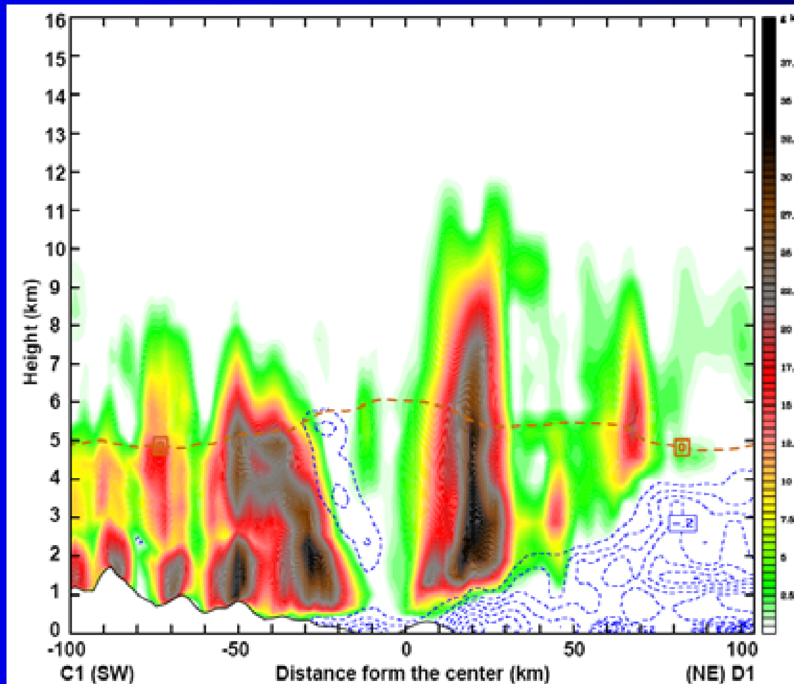




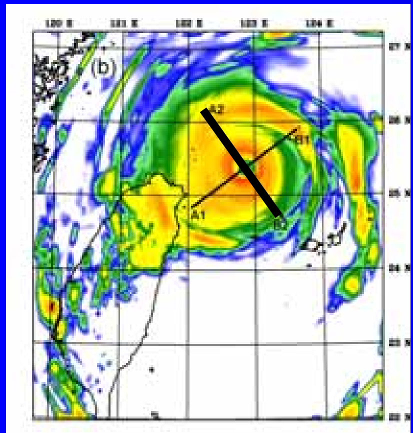
Before Landfall

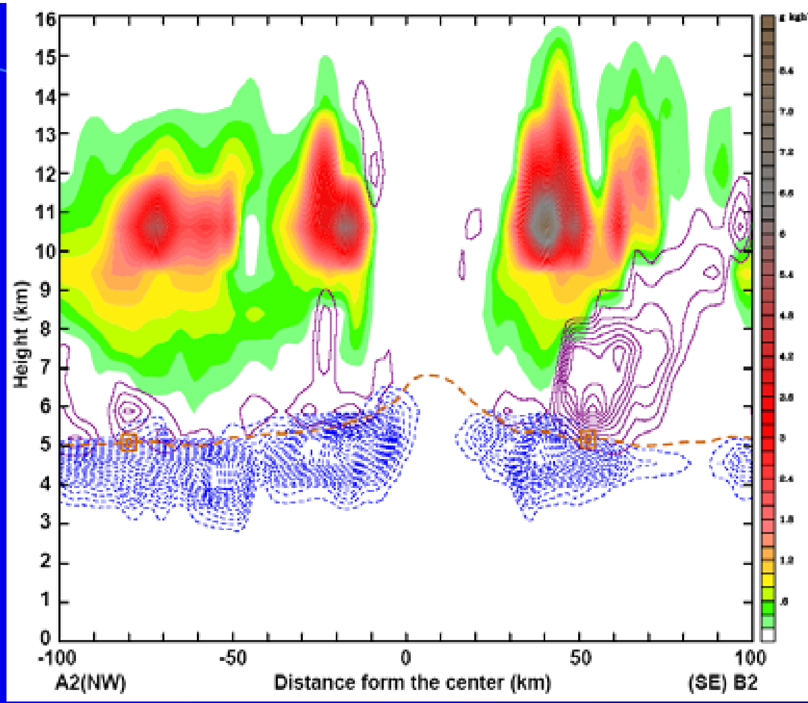
Condensation (color)
Evaporation (dashed)





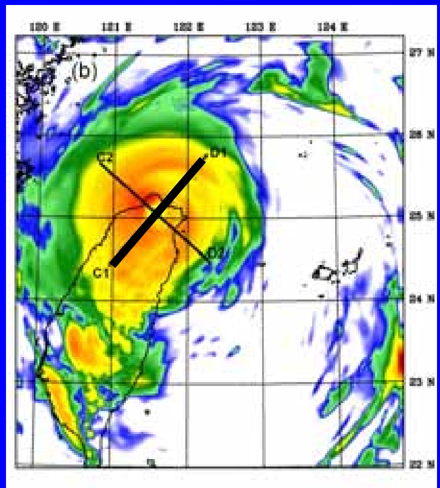
After Landfall

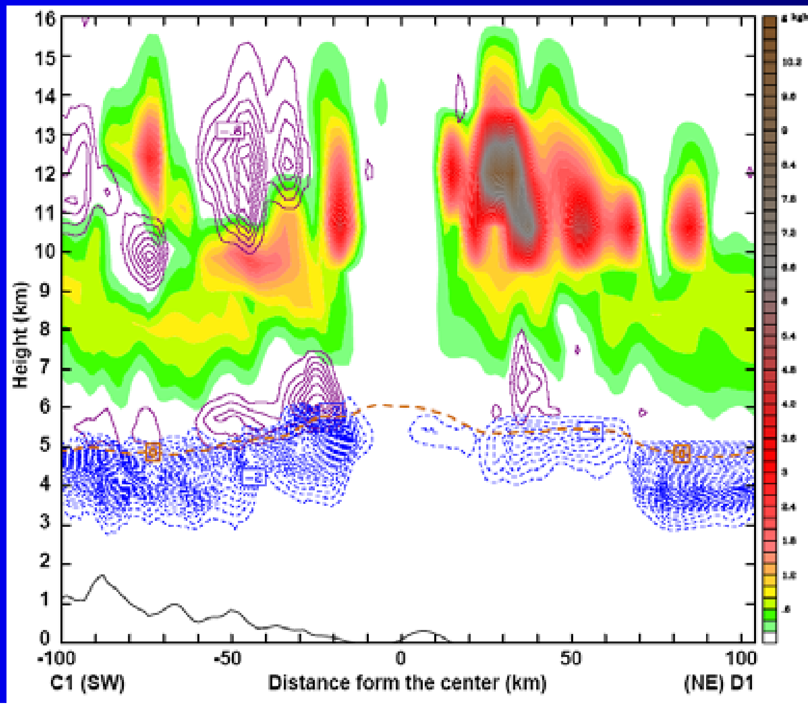




Before Landfall

Deposition (color)
Sublimation (solid)
Melting (dashed)





After Landfall

Conclusions (I)

- The model reasonably simulates Nari's track, slow motion, the eye, the eyewall, the spiral rainbands, the basic rainfall pattern and local maxima over Taiwan during the various landfall stages.

- In particular, the model captures well Nari's landfall location at 22 h into the integration, with 3-h timing error and 30-km further north.

- The model reproduces the rapid filling of central pressure (~1.67 hPa/h) and weakening of the maximum surface wind (~1 m/s/h) during the 24-h landfalling period.

- The simulated 3-day rainfall totals capture 88% of the observed amount on Taiwan, and some local maxima over Mt. Snow and the foothills of the Central Mountain Range in south-central Taiwan.

Conclusions (I I)

- Prior to landfall, Nari's eyewall and RMW are upright with a larger eye size, and the maximum latent heating is located at the mid-to-upper troposphere. After landfall, the eye shrinks with more clouds filled inward from the eyewall.

- While tangential flows are more axisymmetric, radial flows and leatent heating profiles are more asymmetric with pronounced radial outflows above the Central Mountain Range.

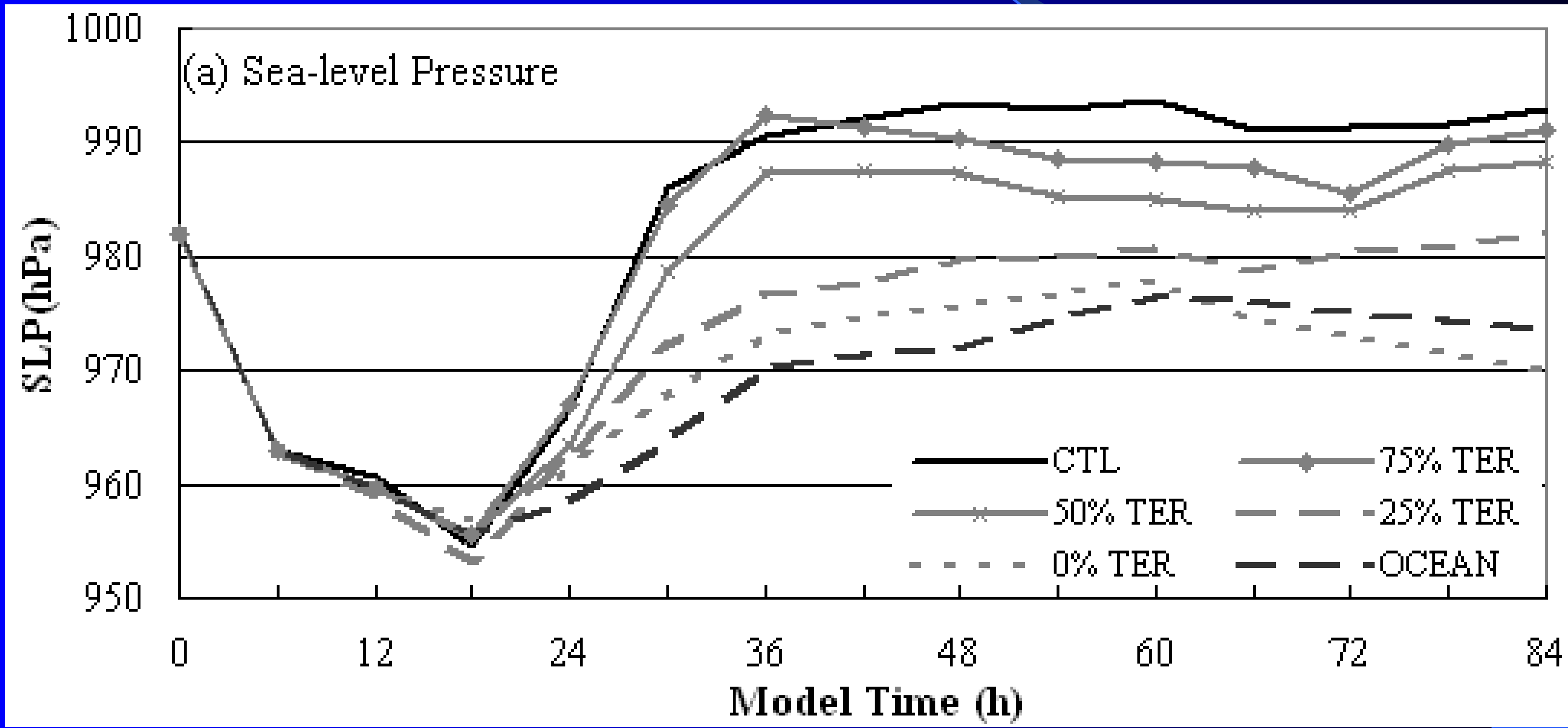
- Nari's storm intensity remains nearly constant for 36 h after crossing Taiwan's terrain, indicating that the damping effects by the terrain-induced radial outflows may be balanced with the intensifying effects of strong latent heating associated with the torrential rainfall.

Part III: Terrain Effects

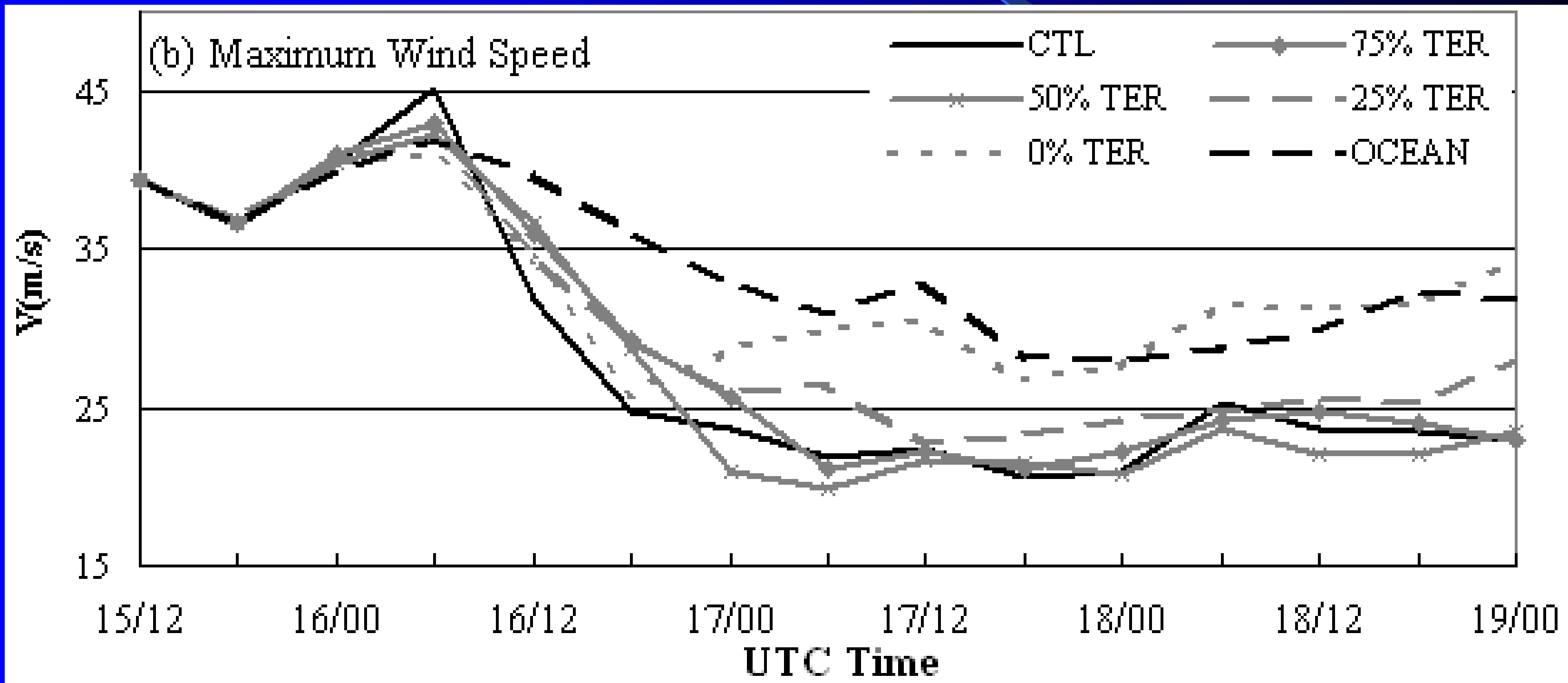
Terrain Sensitivity Experiments

Experiment	Description
75%Ter	75% of Taiwan terrain
50%Ter	50% of Taiwan terrain
25%Ter	25% of Taiwan terrain
0%Ter	Flat land on Taiwan
OCEAN	Ocean condition on Taiwan

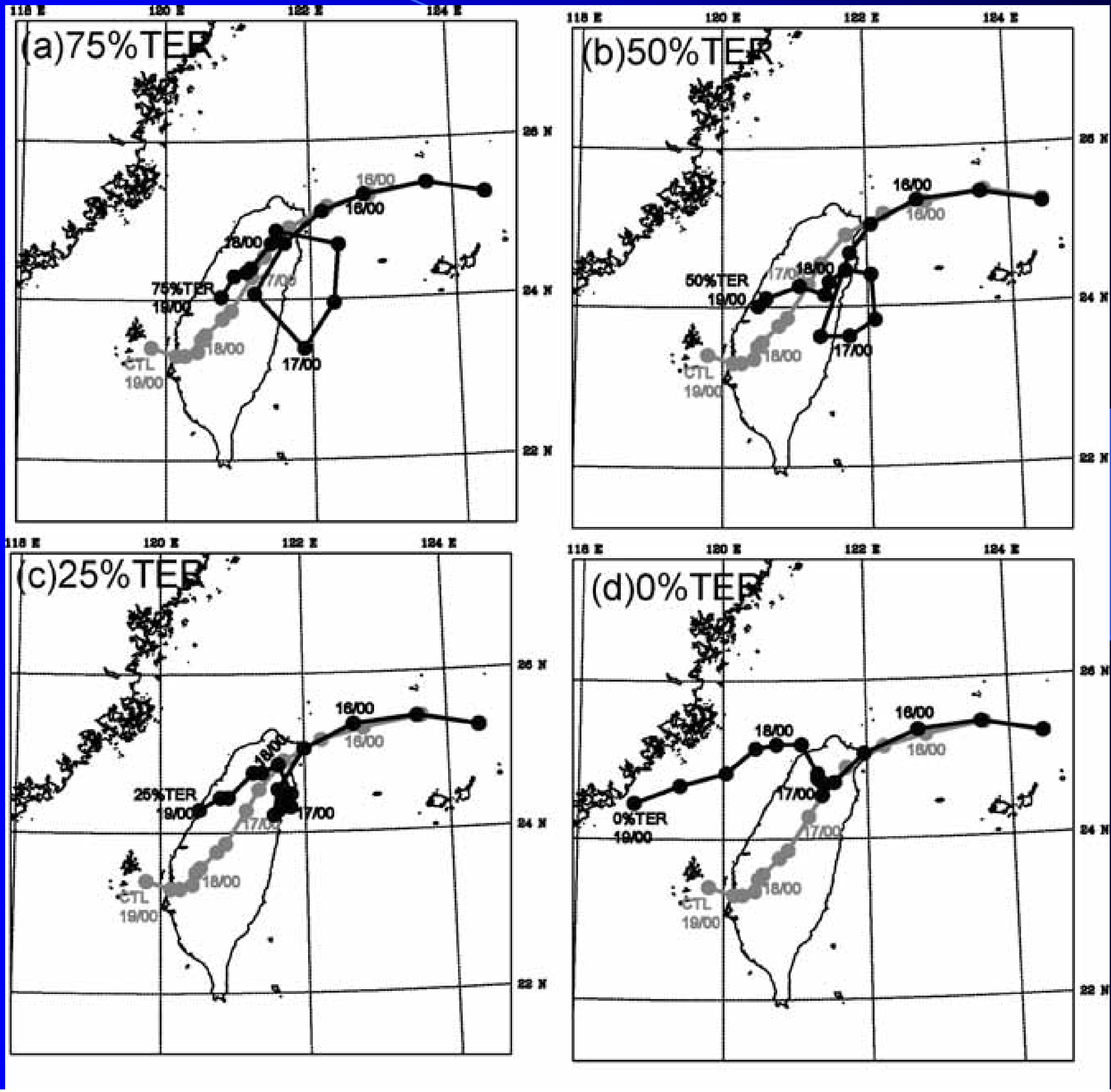
Time Series of SLP



Time Series of Vmax



Simulated Tracks of Terrain Experiments

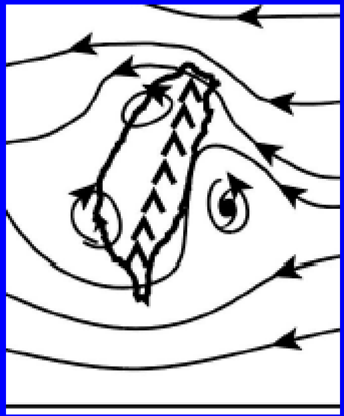


Froude Number Analysis

Temporally-averaged parameters of terrain-sensitivity experiments during the landfall period (0900–2100 UTC 16 September 2001). *H* is the mountain height, *U* is the deep-layer across-CMR mean flow, and *N* is the Brunt-Väisälä frequency

Experiment	*H* (m)	*U* (m s^{-1})	*U/NH*
CTL	3500	2.10	0.06
75%Ter	2625	1.76	0.07
50%Ter	1750	1.74	0.10
25%Ter	875	0.95	0.11

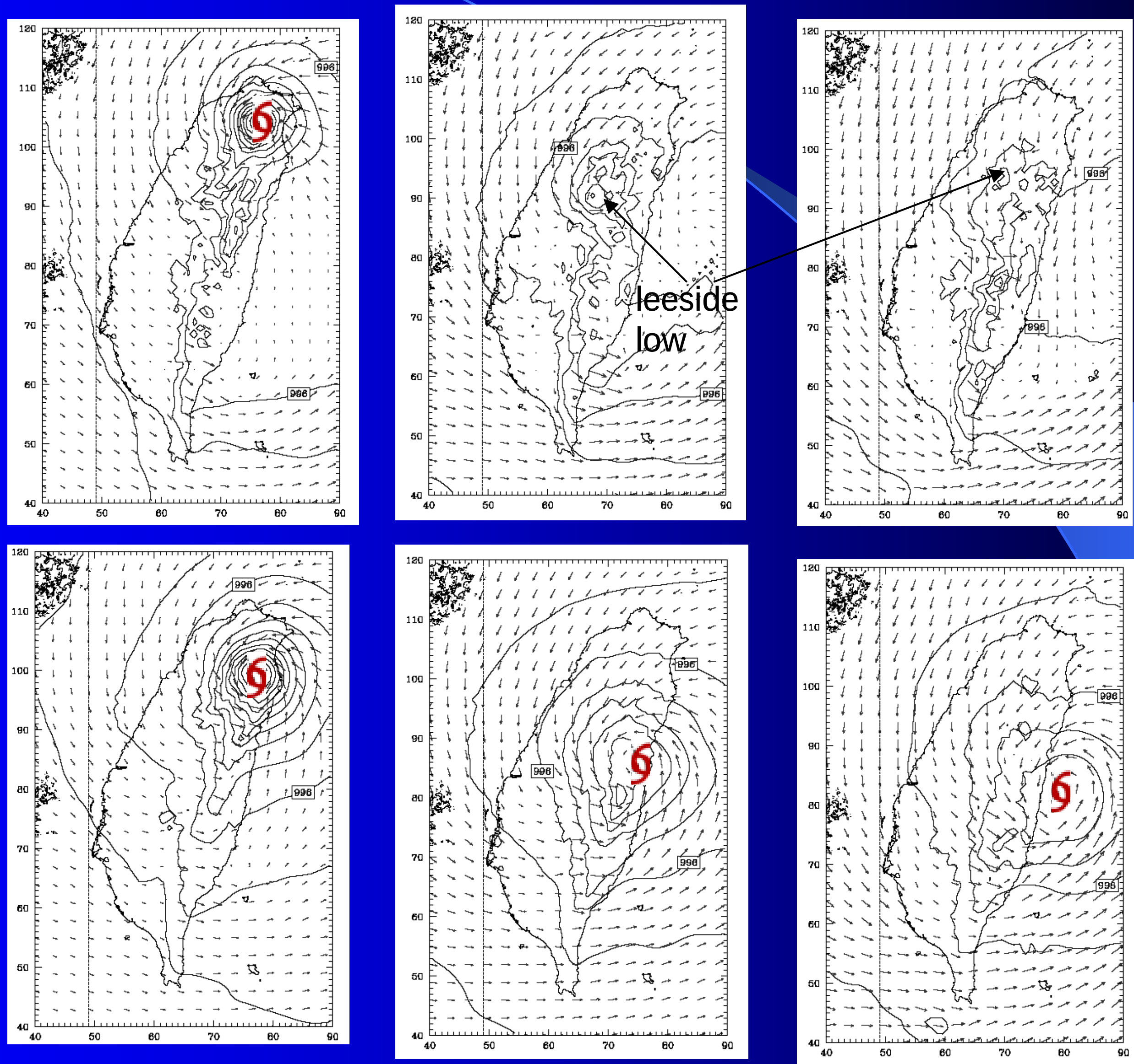
Lin et al. (2005; 2006) indicates that: When $U/NH < 0.5$, then the TC track is discontinuous. Otherwise, the TC track is continuous.



9/16 12Z | 9/16 18Z | 9/17 00Z

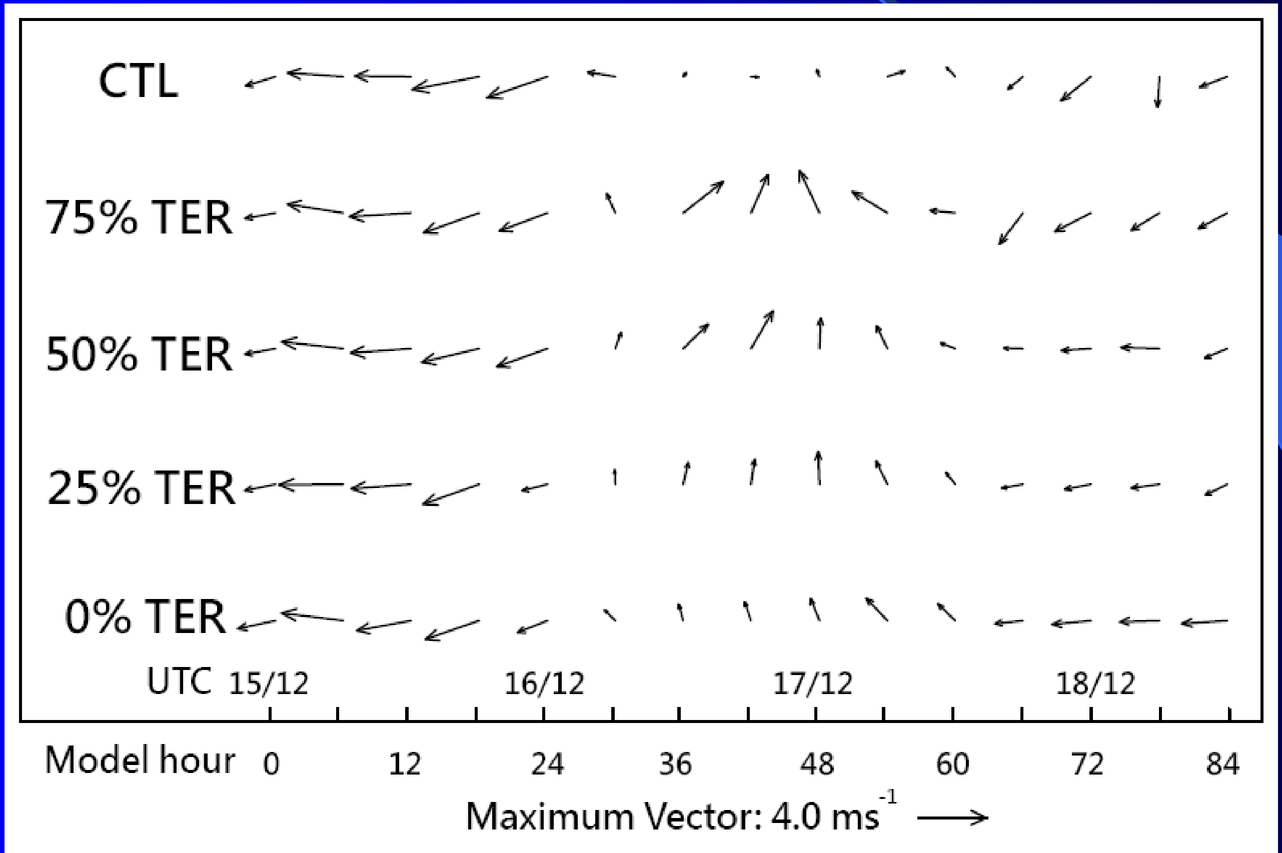
CTL

50%TER



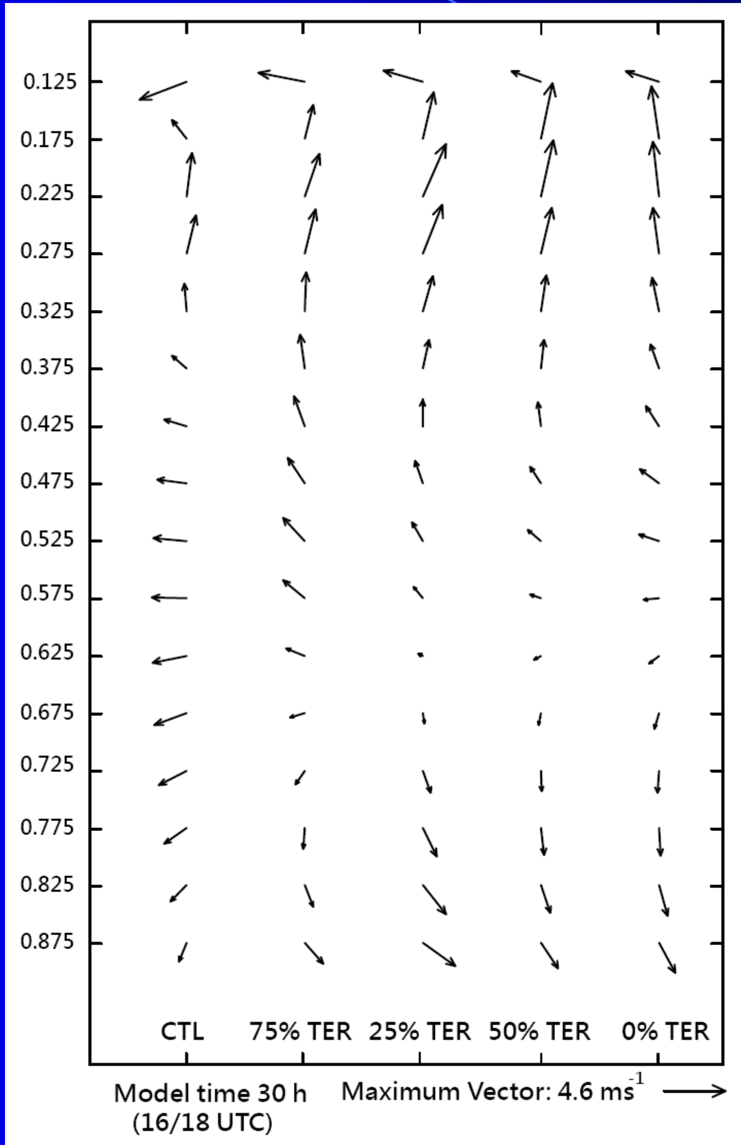
SLP & SFC Wind

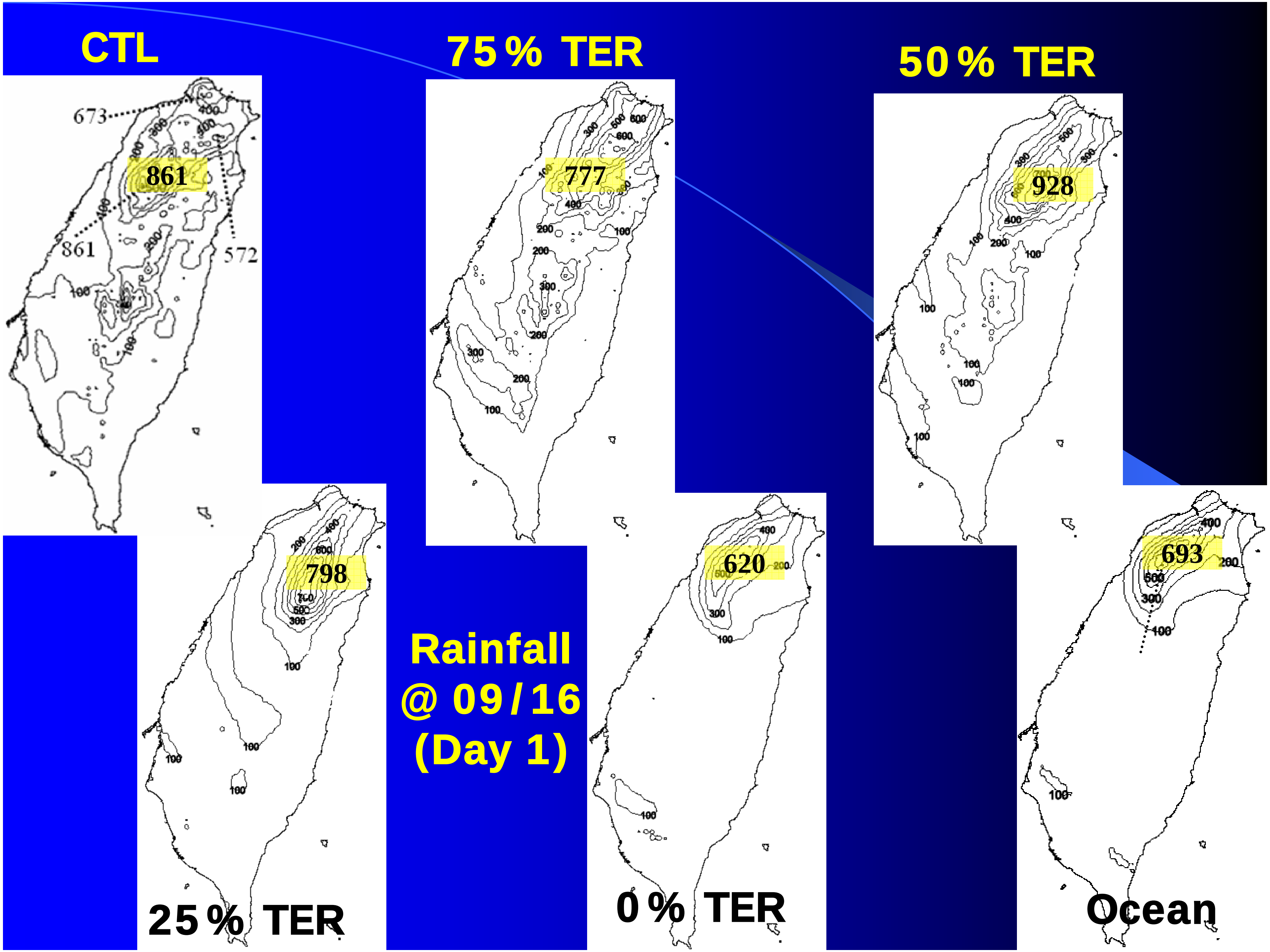
Evolution of Environmental Steering Vector



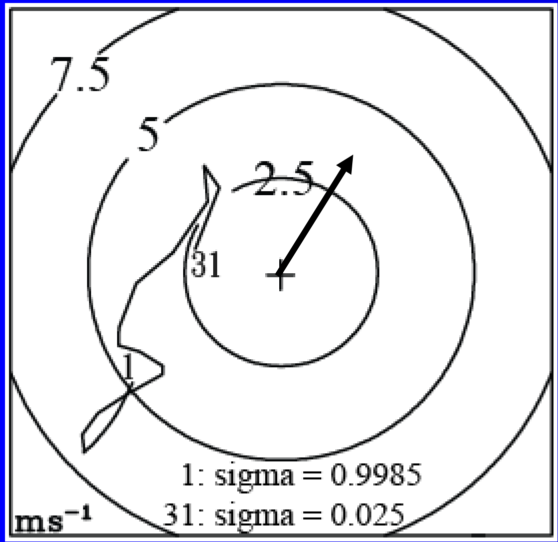
Environmental steering flow vectors calculated by averaging horizontally within the 360-km radius from simulated Nari center and vertically between sigma levels of 0.9 and 0.1

Vertical Structure of Steering Flow at the Time of Landfall

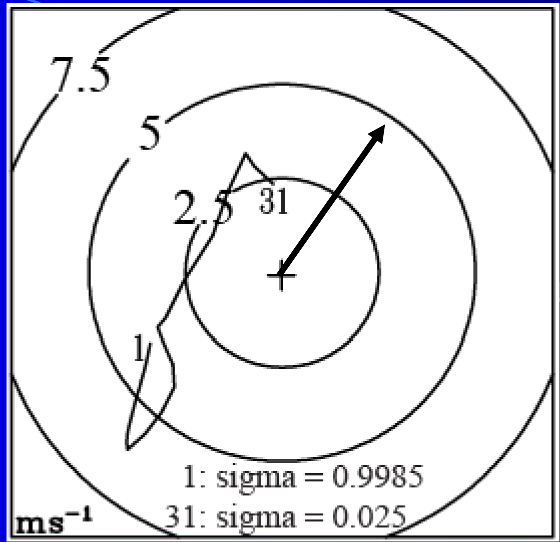



CTL
861
673
861
572
75 % TER
777
50 % TER
928
25 % TER
798
Rainfall
@ 09/16
(Day 1)
0 % TER
620
Ocean
693

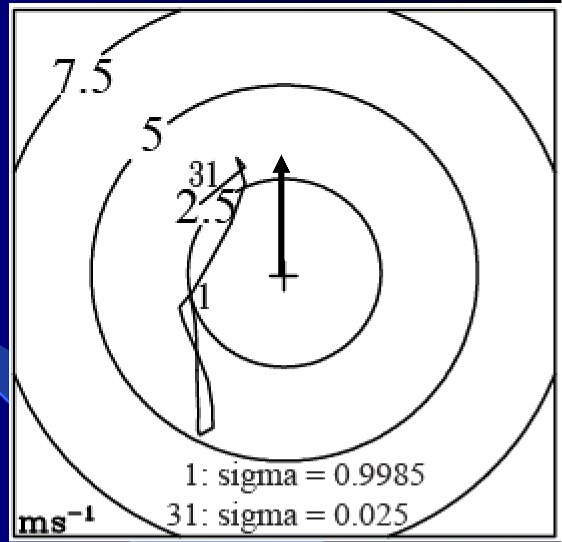
CTL



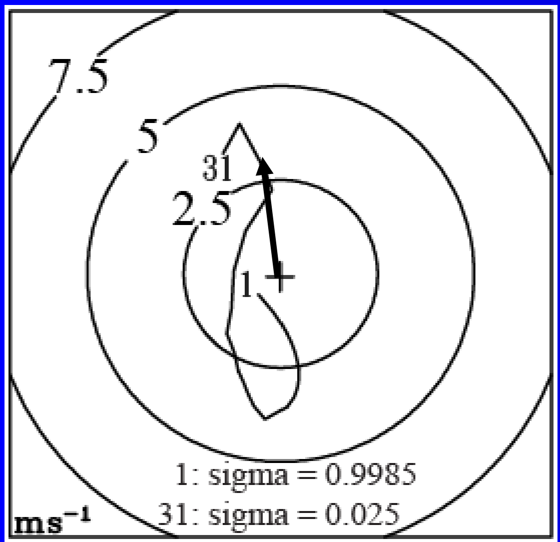
75 % TER



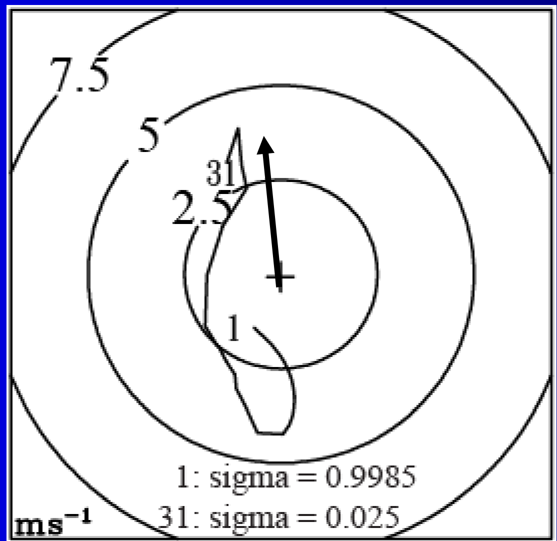
50 % TER



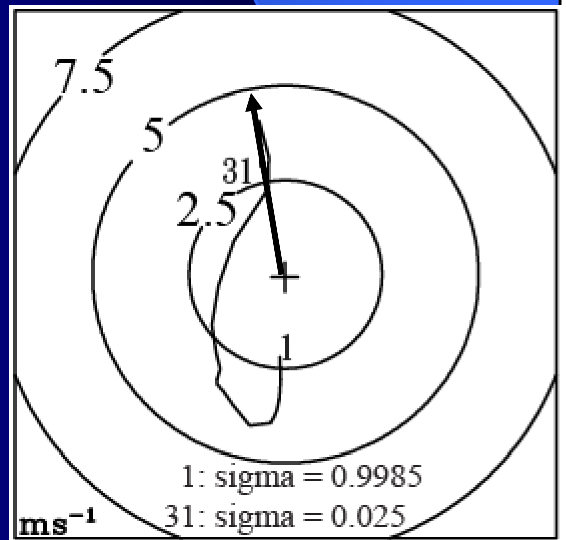
25 % TER



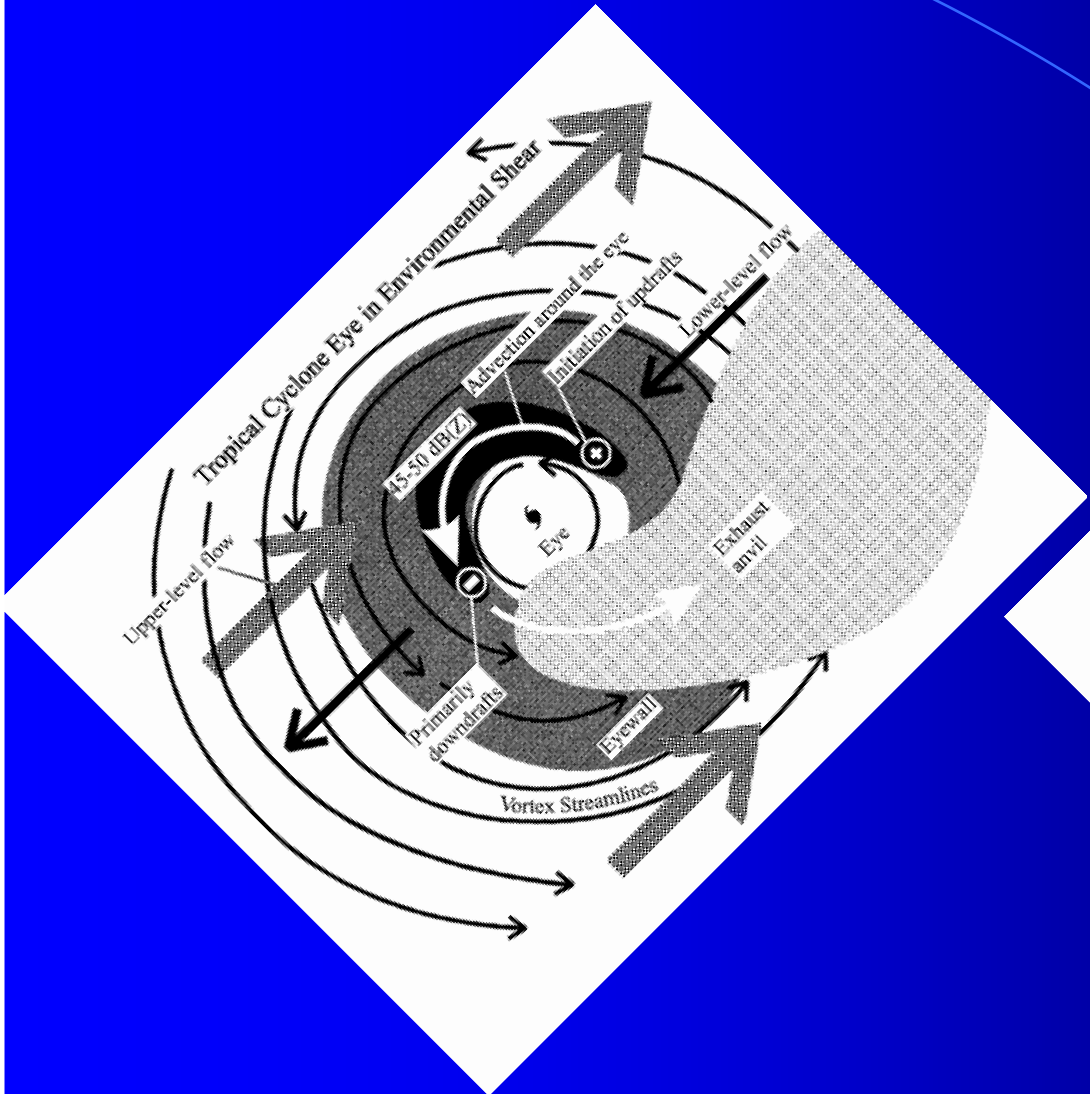
0 % TER



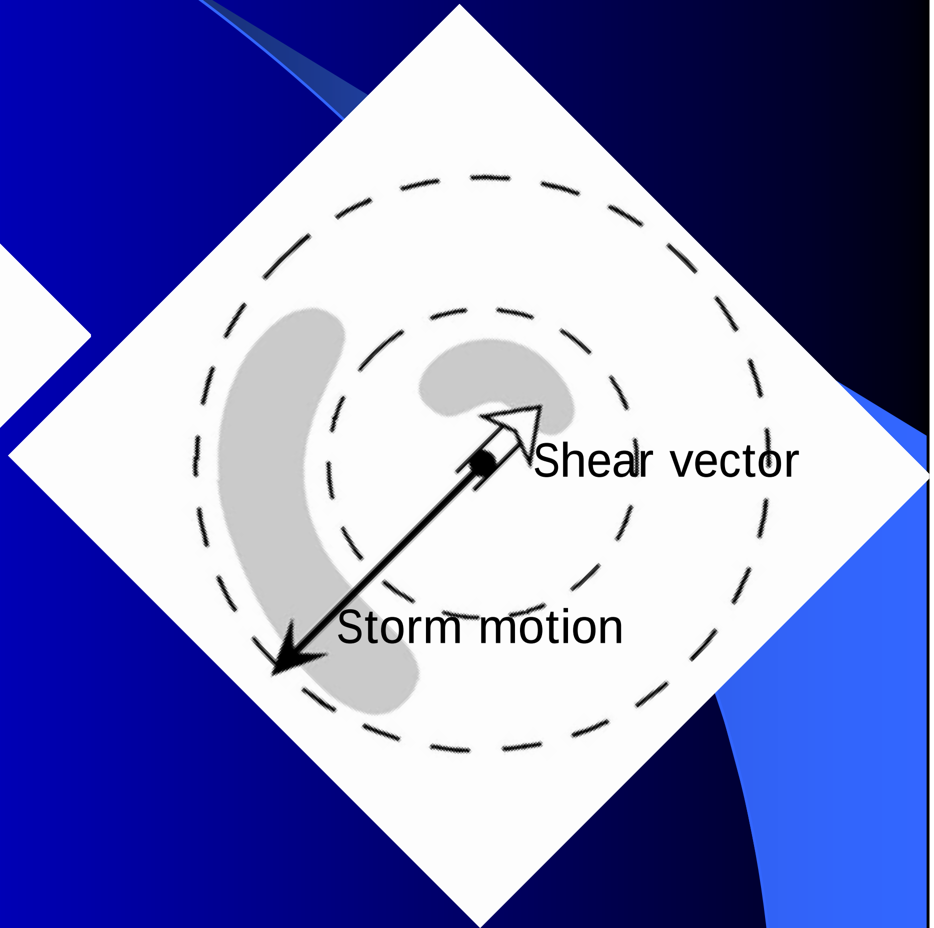
Ocean



Heavy rainfall occurs on the downshear left side of eyewall !



Black et al. (2002; Fig. 17)



Chen et al. (2006; Fig. 14e)

Percentage wrt CTL for Day-1 Rainfall on Taiwan

Variable	CTL	75%Ter	50%Ter	25%Ter	0%Ter	Ocean
Percent wrt. CTL (%)	100.0	102.9	88.2	70.0	51.9	52.3

Percentage of Day-1 Rainfall wrt. CTL within the 100km,150km, 200km radii from typhoon center

Radius	Number of points	CTL	75%Ter	50%Ter	25%Ter	0%Ter	Ocean
100 km	877	100	97.3	84.2	64.7	62.2	61.5
150 km	1961	100	94.1	85.1	68.5	64.9	64.1
200 km	3503	100	95.4	84.0	71.8	66.3	68.3

Conclusions (I I)

- 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.
- Stronger storms of reduced terrain experience more a deeper steering layer, compared to the weaker storms over higher terrain.
- For Day 1, the environmental wind shear determines the max. rainfall location (downshear left). For Day 2 and Day 3, the rainfall distribution is mainly decided by Taiwan's CMR.
- Foir Day 1, The CMR-induced lifting contributes about half of the observed rainfall for Typhoon Nari.