Bottom-up Eyewall Reconstruction of Typhoon Fanapi (2010) after Encountering the Taiwan Terrain

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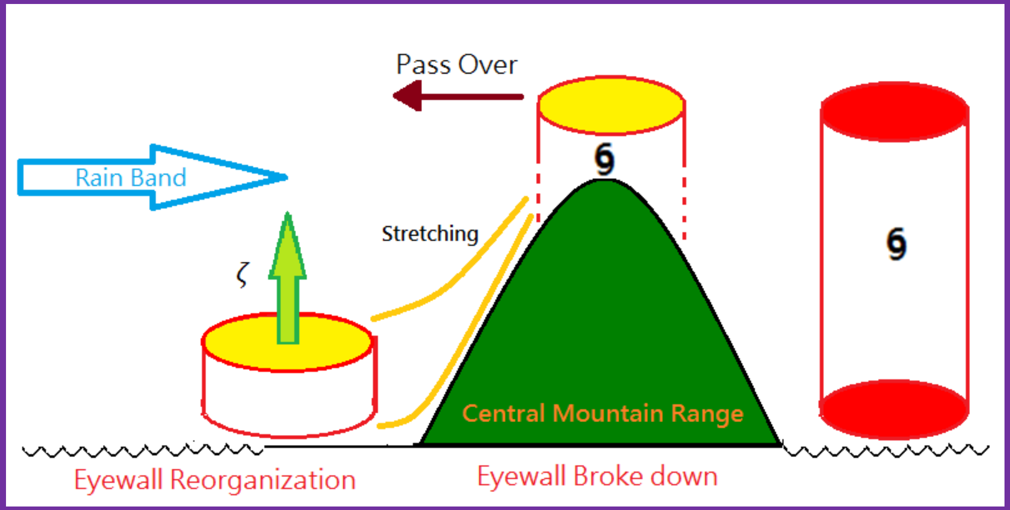
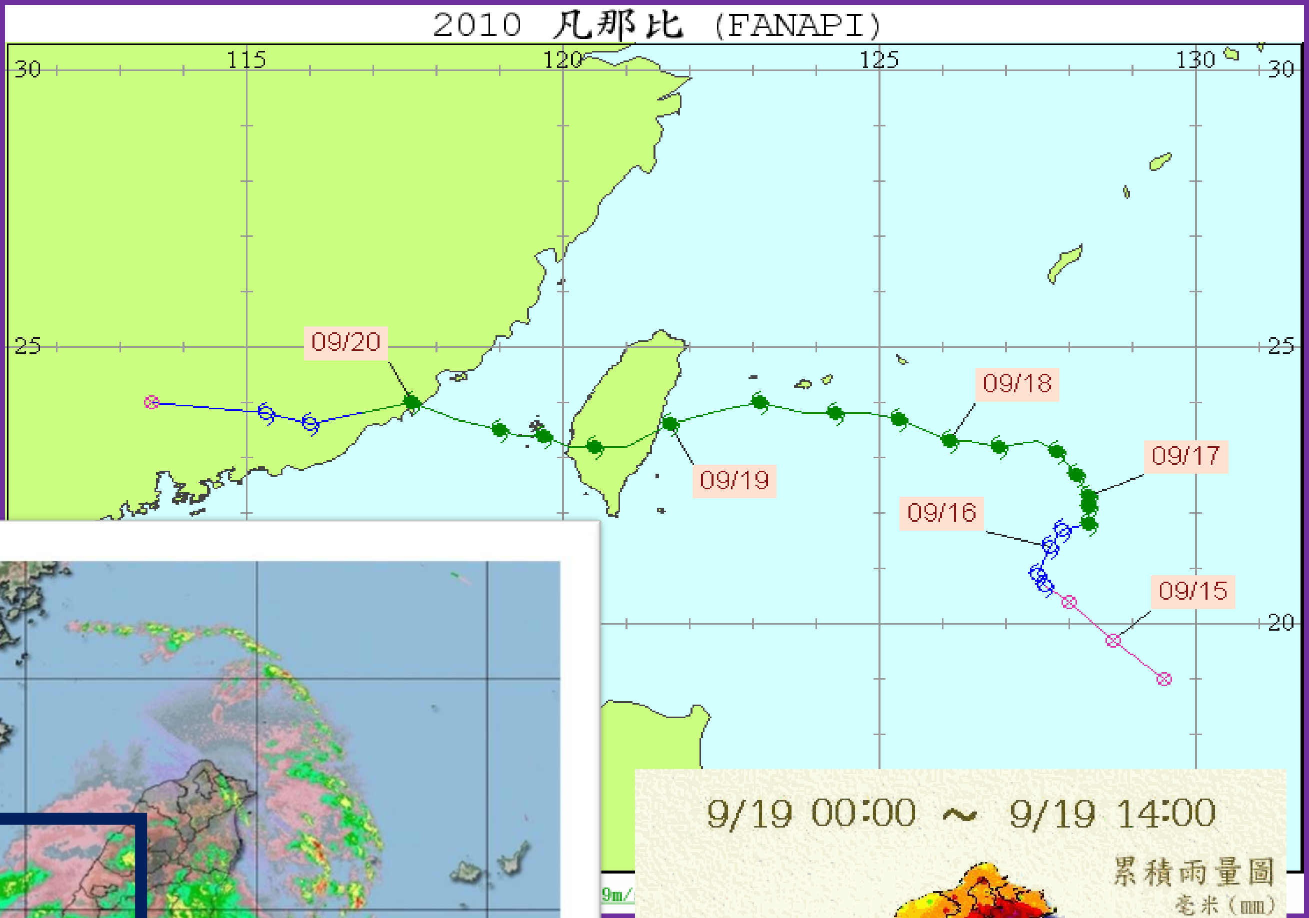


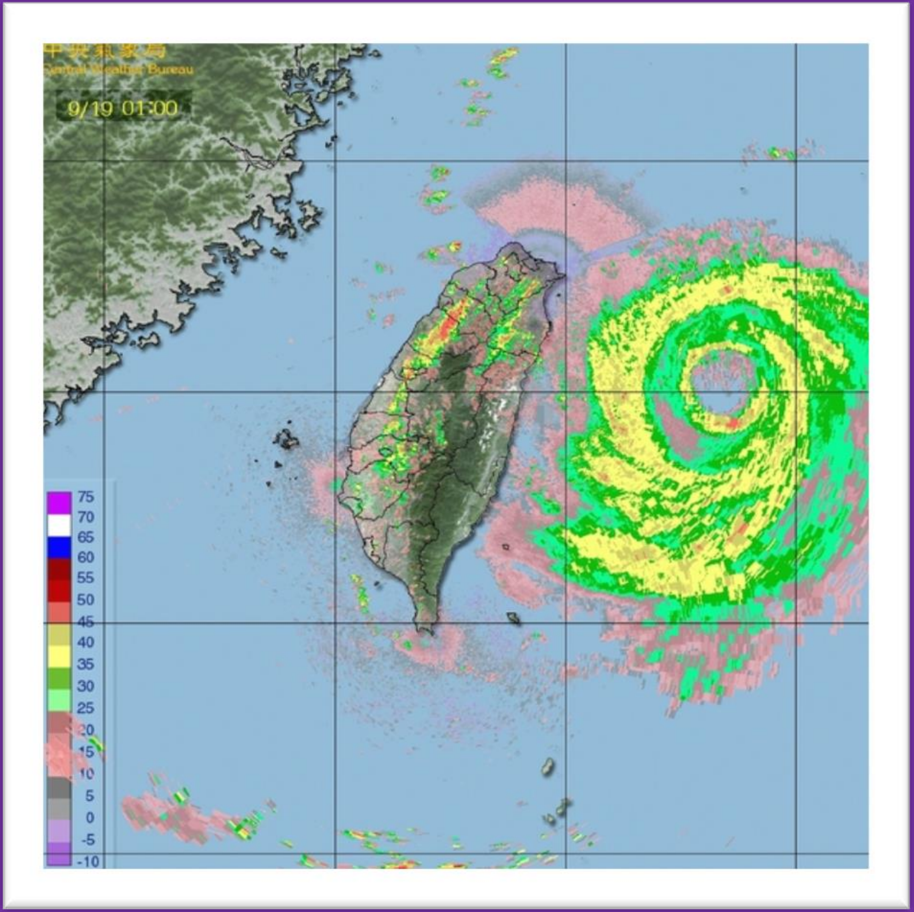
2-3 May, 2017

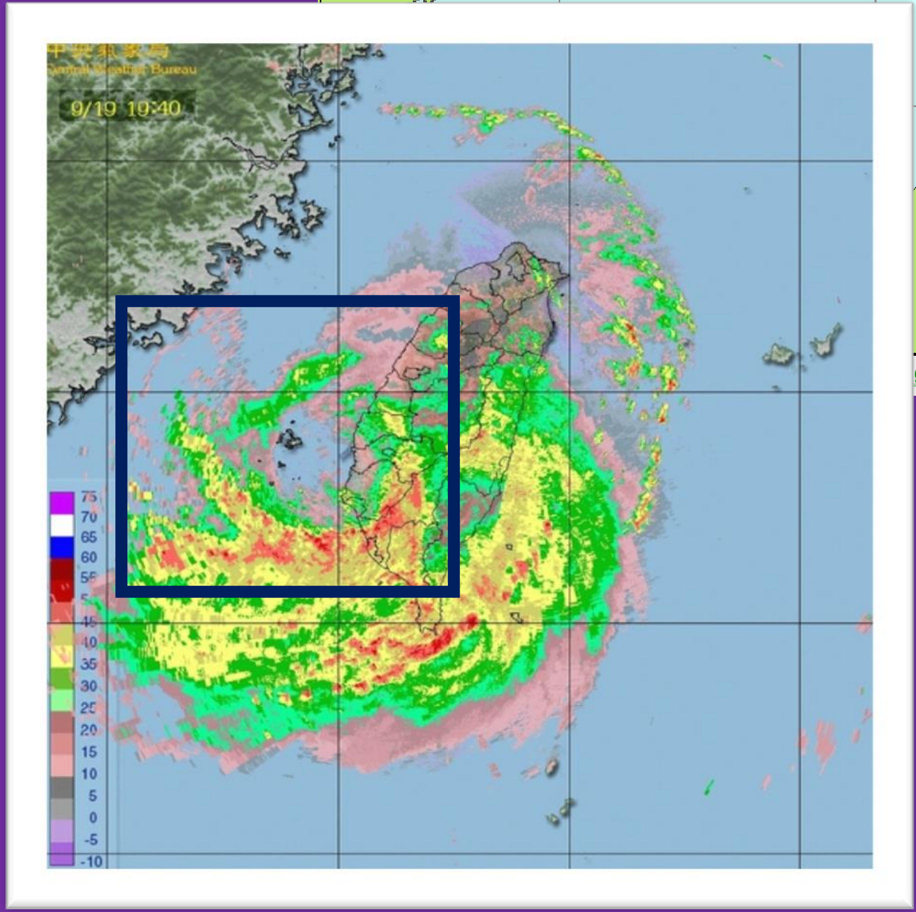
The 2017 APEC Typhoon Symposium at Taipei

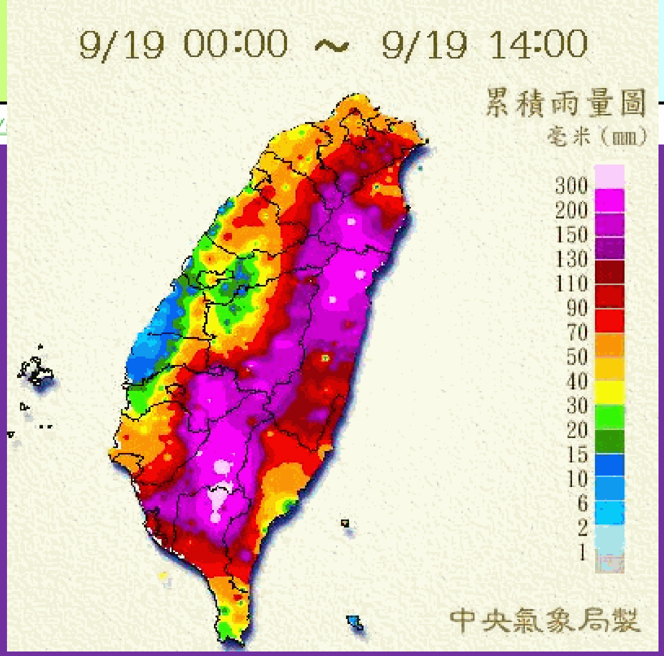
Typhoon Fanapi (2010):
Track, Radar Echo, Rainfall

Data: Central Weather Bureau (CWB), Taiwan



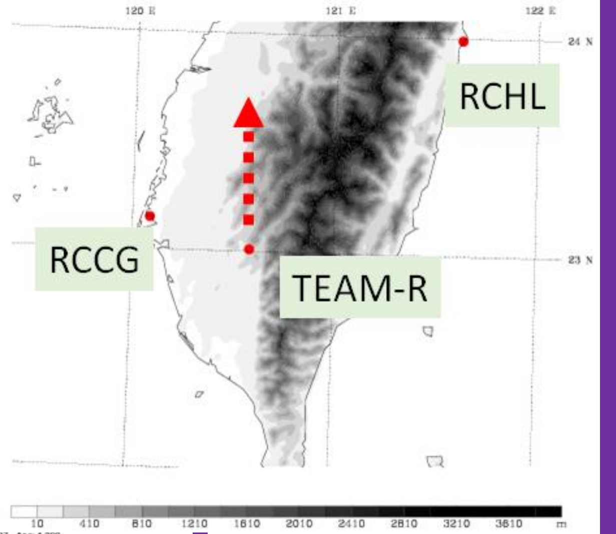




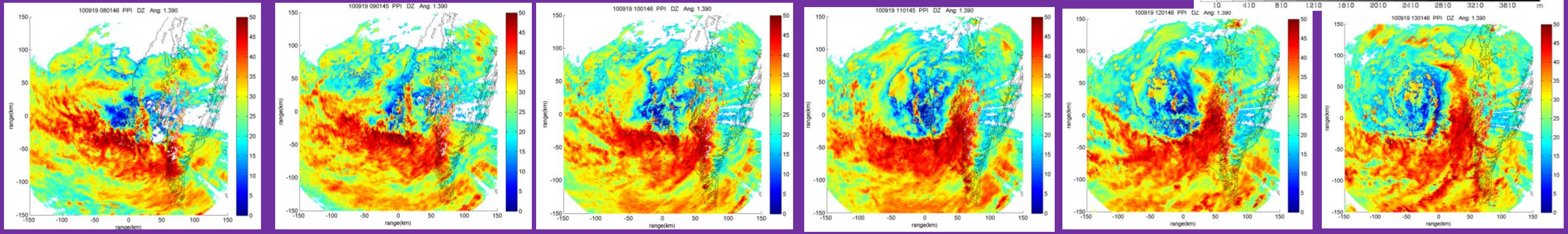


Radar Observations:

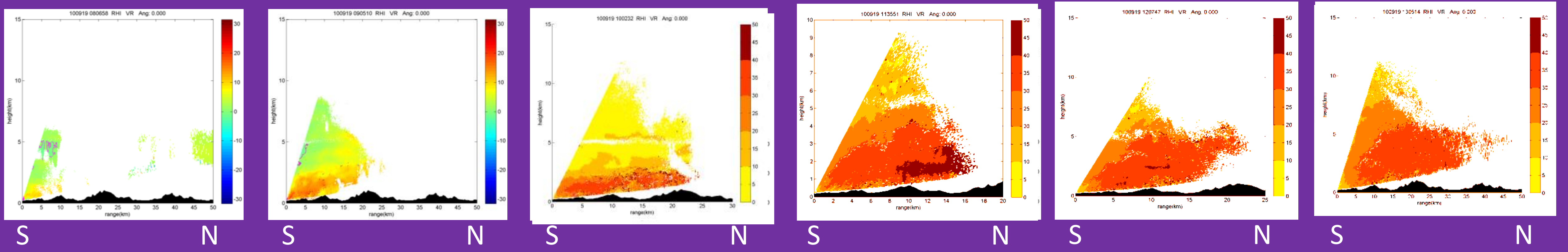
Liou, Wang, and Huang (2016; MWR)



Radar Reflectivity by RCCG (PPI 1.39^{o}) at 08-13 UTC

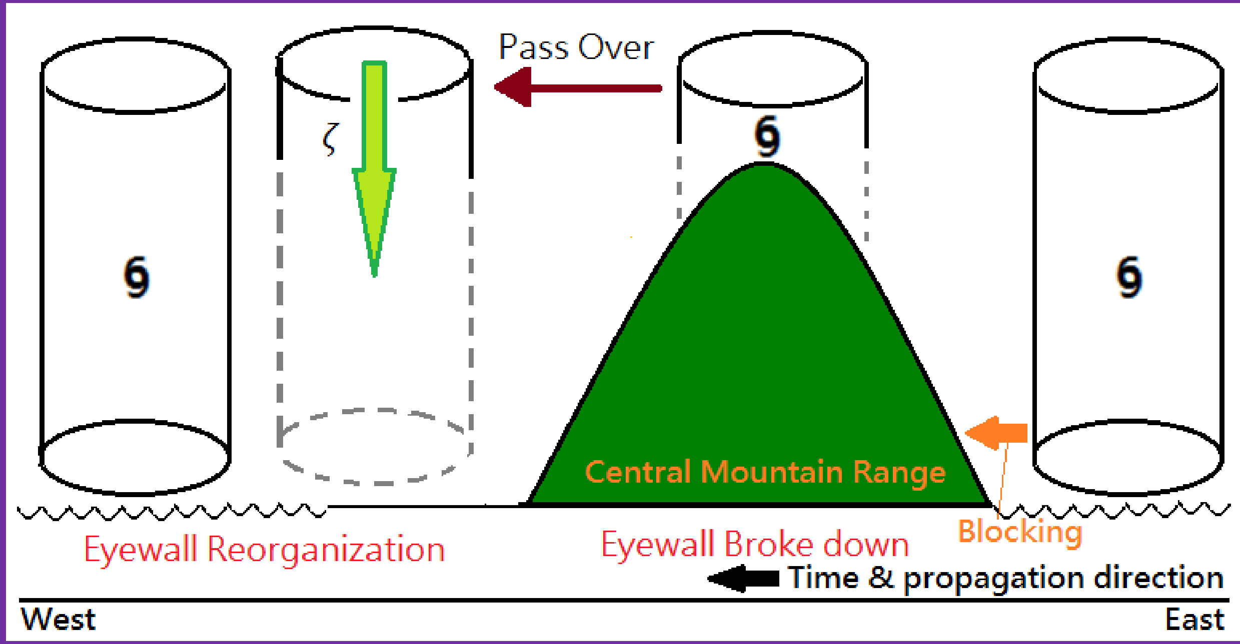


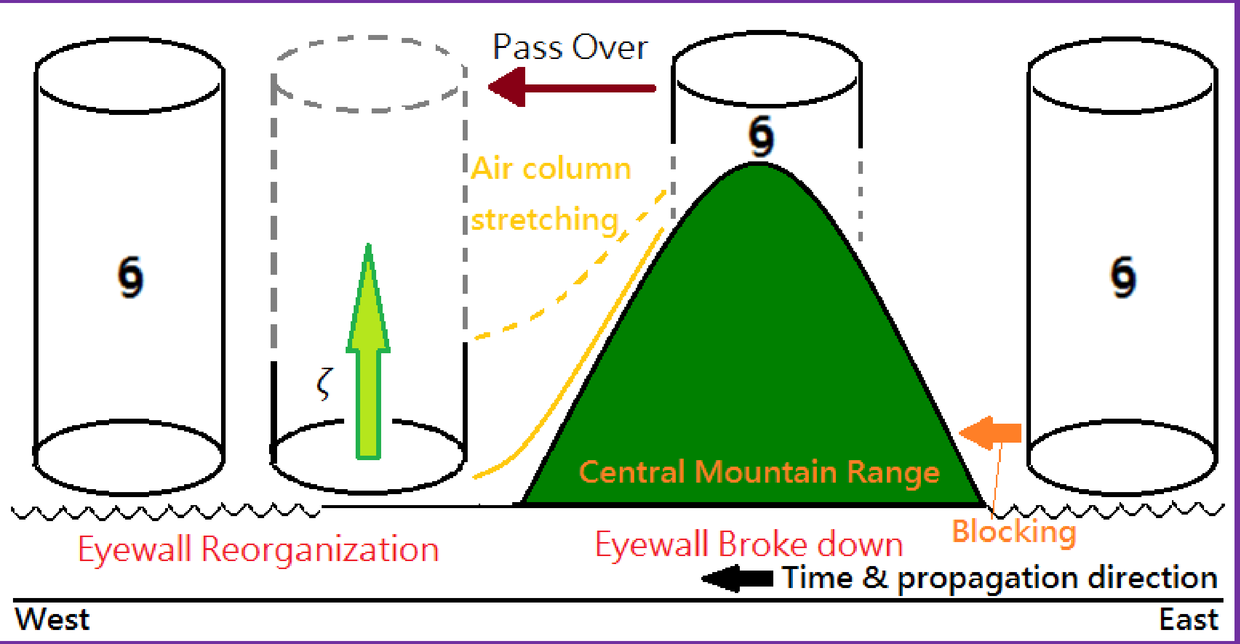
Radial Wind by TEAM-R (RHI 0^{o}) at 08-13 UTC



Scientific Question:

How did Typhoon Fanapi (2010) reorganize its eyewall after crossing terrain?

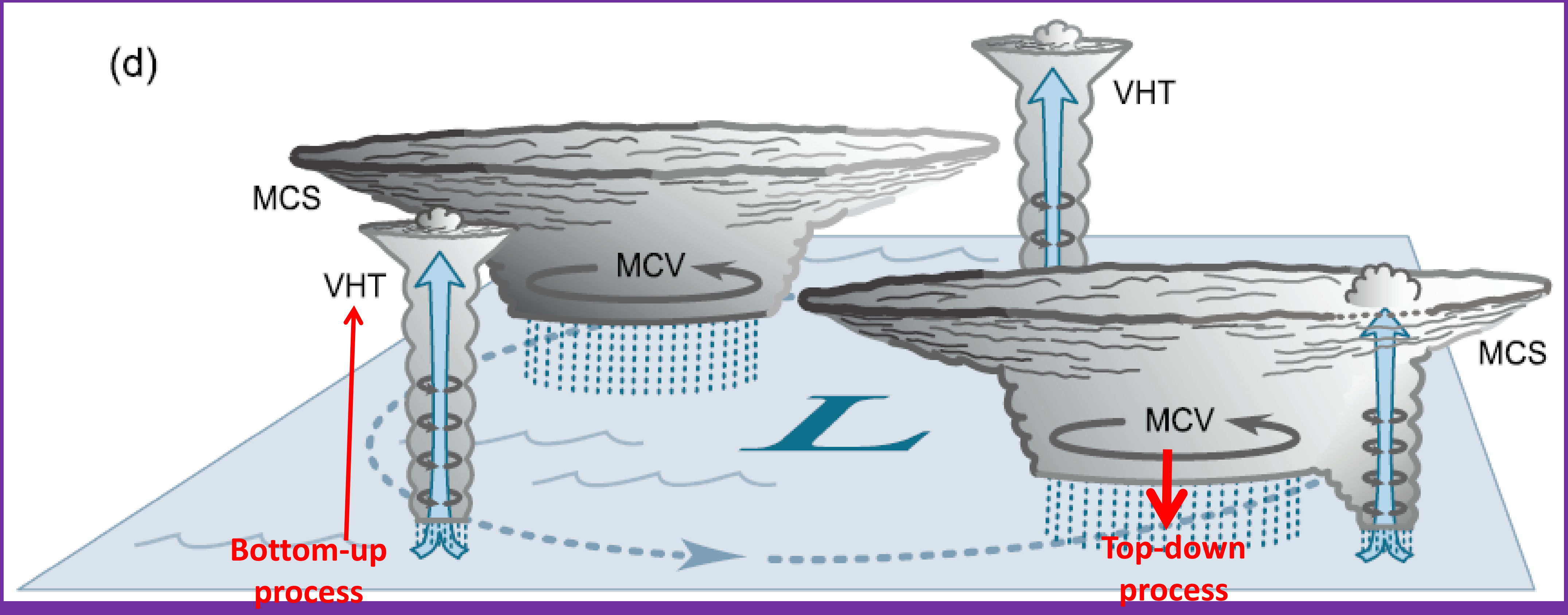




Top-down? or Bottom-up?

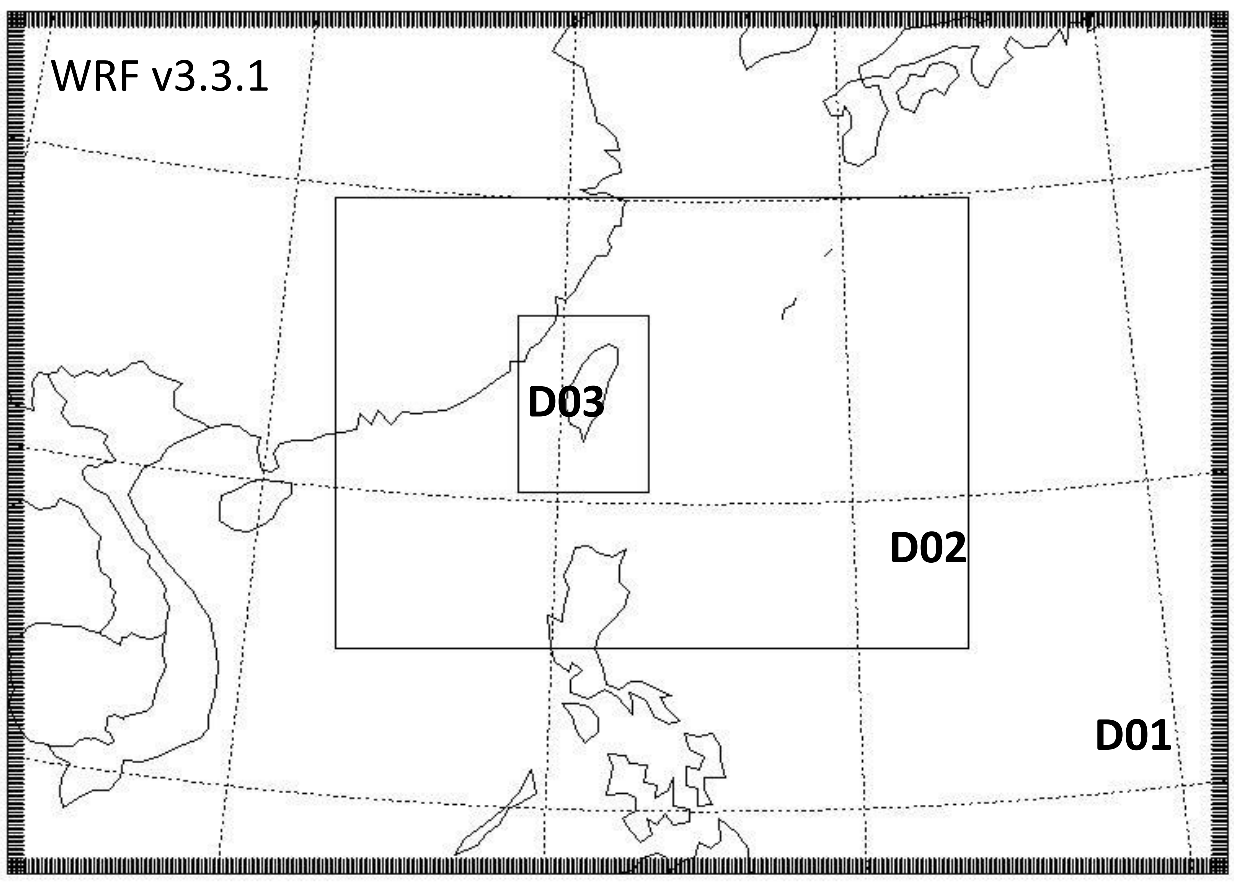
Recall the fundamental problem for TC genesis:

TC genesis over the Ocean: Top-down? or Bottom-up?



Houze et al. (2009; MWR)

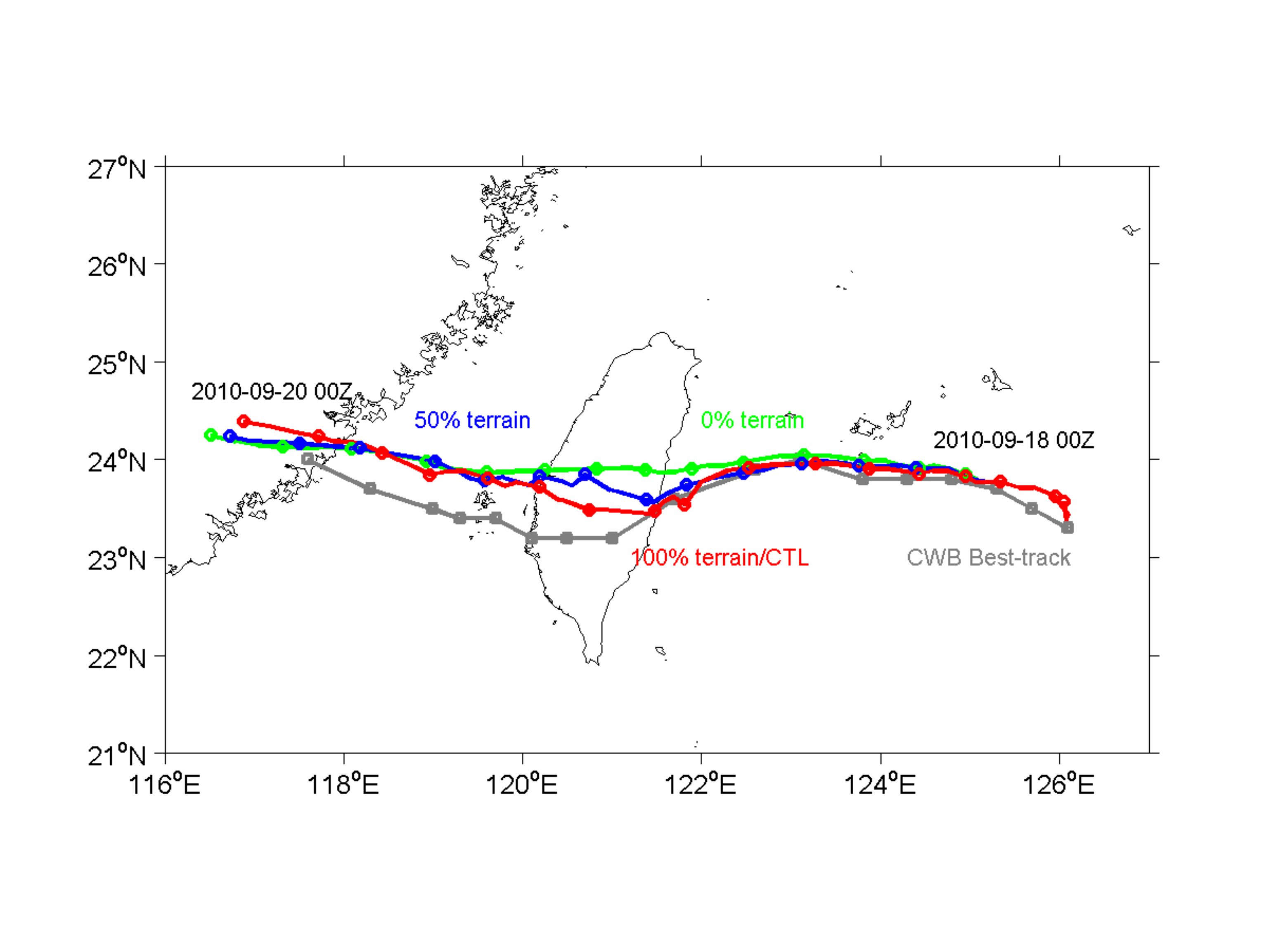
WRF Model Configuration



Numerical Experiments (Terrain-Sensitivity)		
CTL	50ter	0ter
100% Terrain	50% Terrain	0% Terrain

Domain	D01	D02	D03
Grid Size	9 km	3 km	1 km
Vertical eta layer	55		
Cumulus Parameterization	Grell-Devenyi	N/A	
Cloud Microphysics Parameterization	Double-moment Morrison scheme		
PBL Parameterization	YSU scheme		
Long-wave Radiation Parameterization	RRTM scheme		
Short-wave Radiation Parameterization	Dudhia scheme		
Initial/Boundary Condition	ECMWF 1.125 degree resolution, every 6 hours		

Observed vs. Simulated Tracks



0% terrain

50% terrain

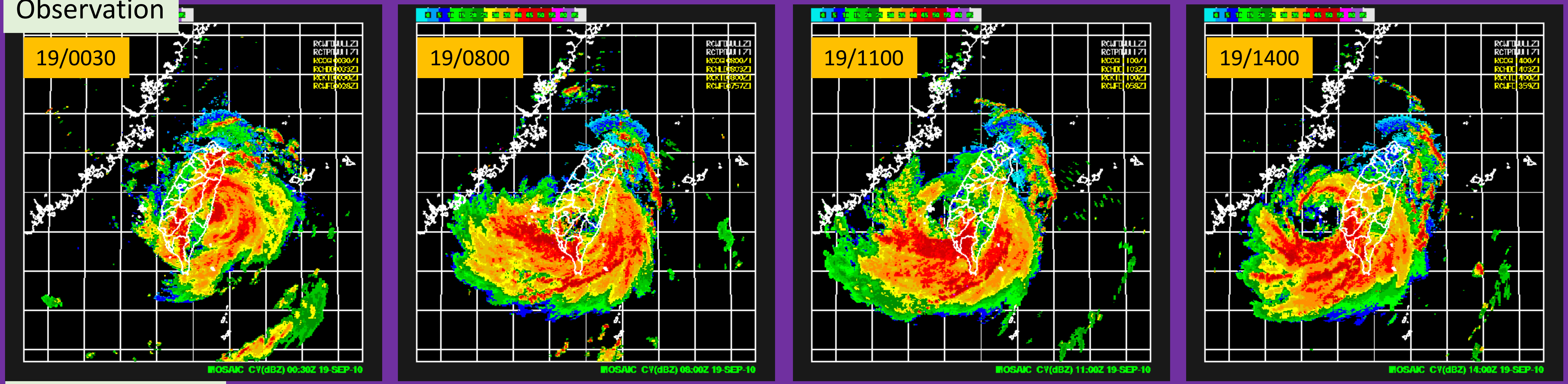
100% terrain/CTL

CWB
Best-track

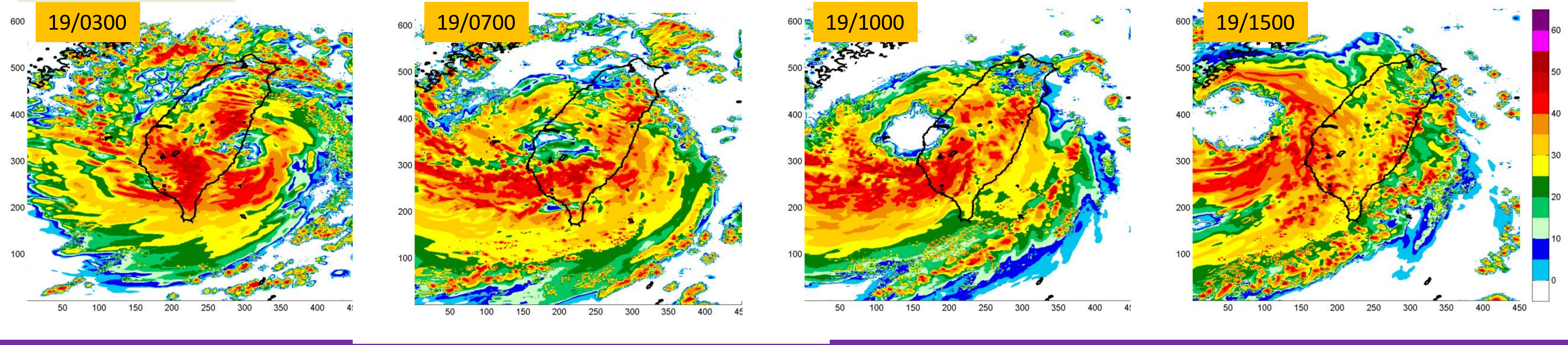
Radar Reflectivity Composite

Data: Central Weather Bureau

Observation

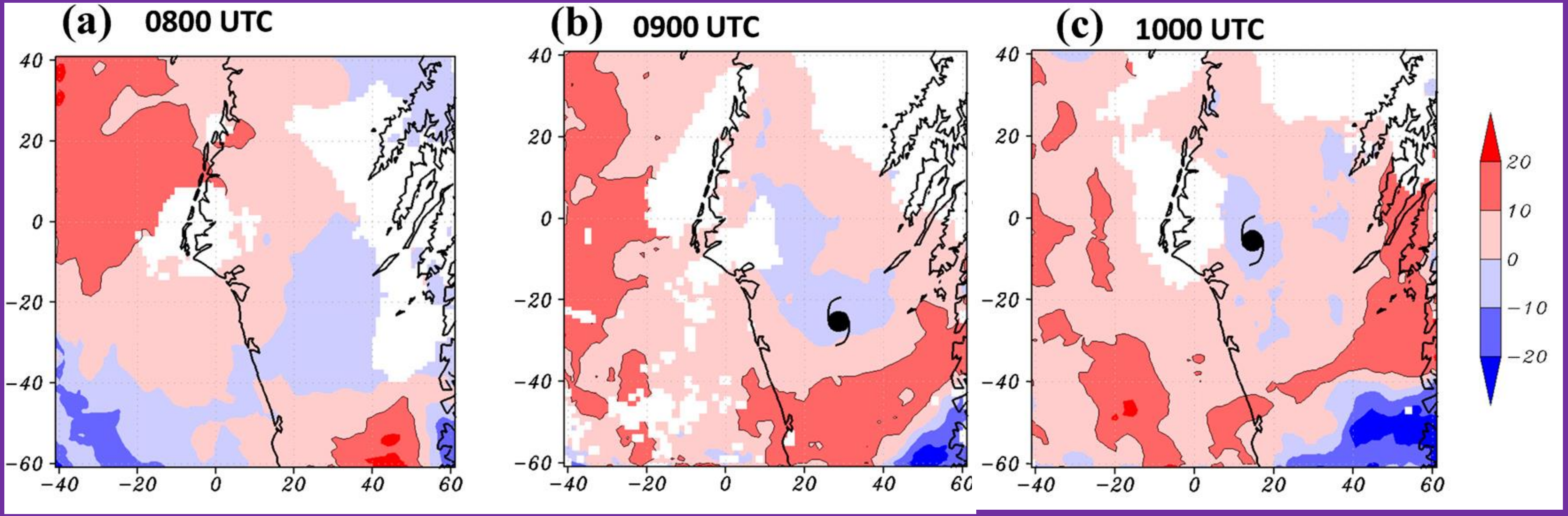


WRF Simulation

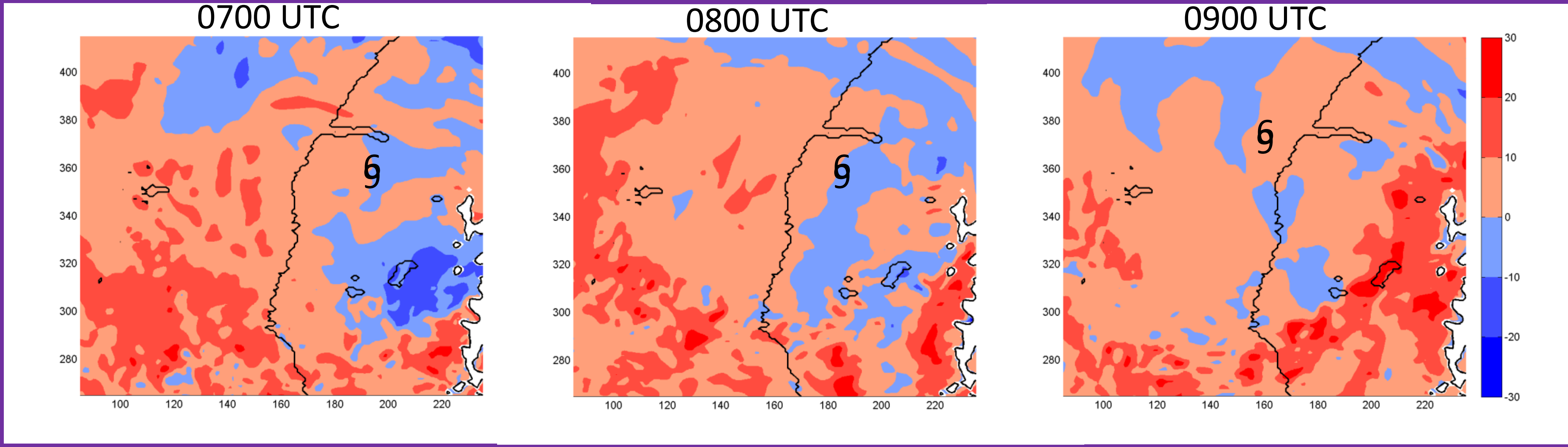


Vertical Wind Shear between Z = 2 km and Z = 5 km ($V_{2km} - V_{5km}$)

Multiple-Doppler analysis by Liou et al. (2016)

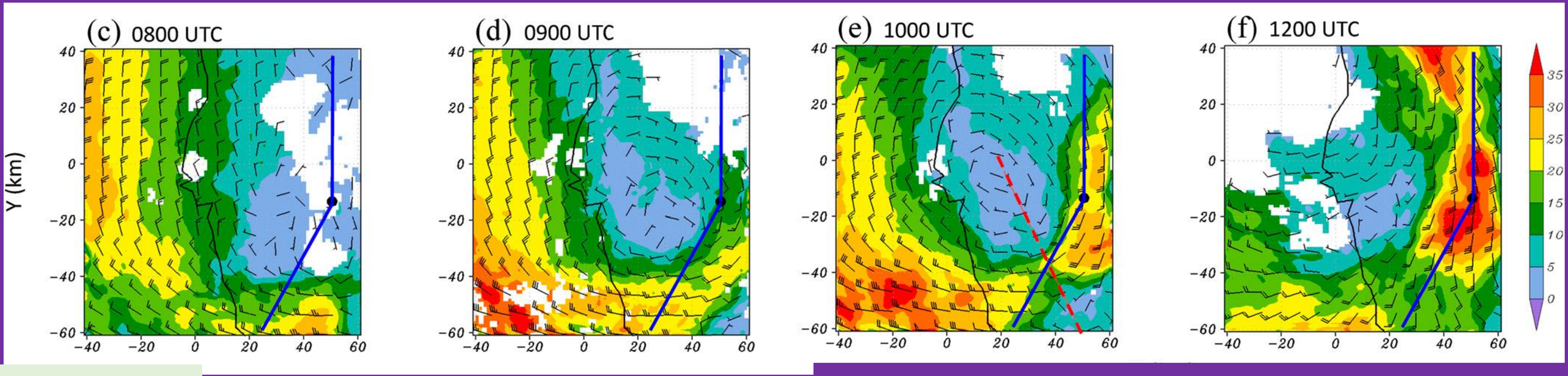


WRF Simulation

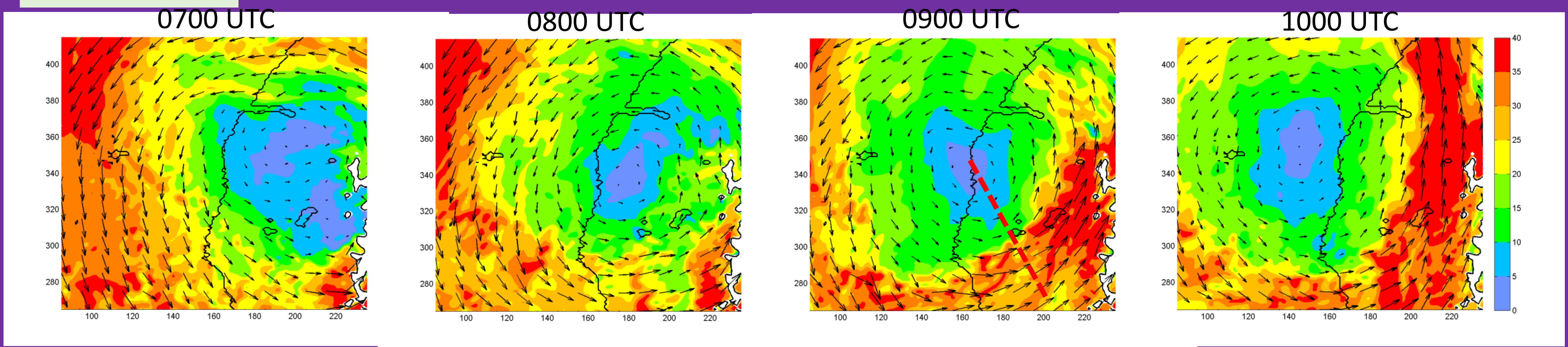


Horizontal Wind at Z = 2 km

Multiple-Doppler radar synthesis by Liou et al. (2016; MWR)



WRF simulation



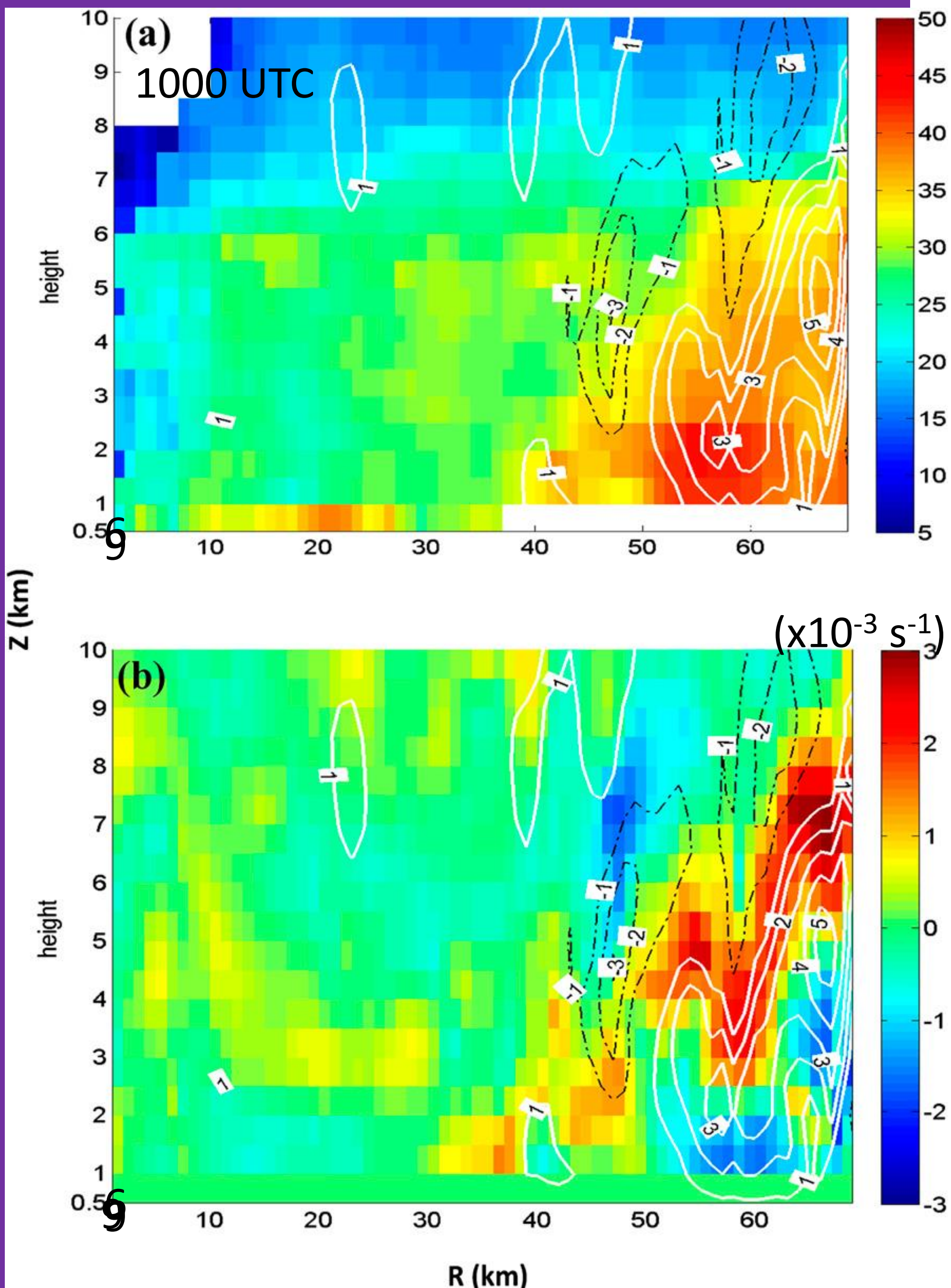
Vertical Cross Section

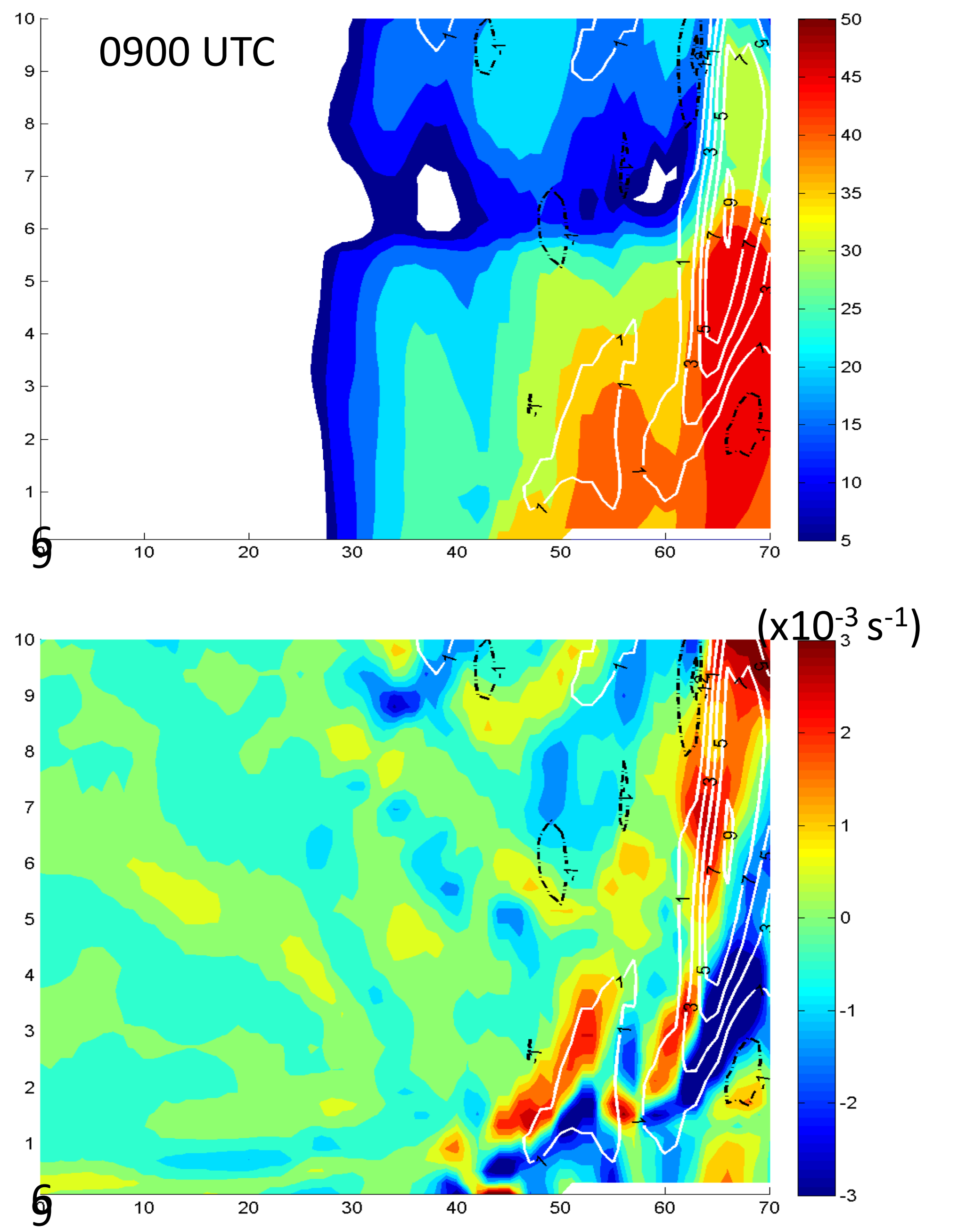
Analysis from Liou et al. (2016)

WRF simulation

Color: radar reflectivity
Contour: vertical wind

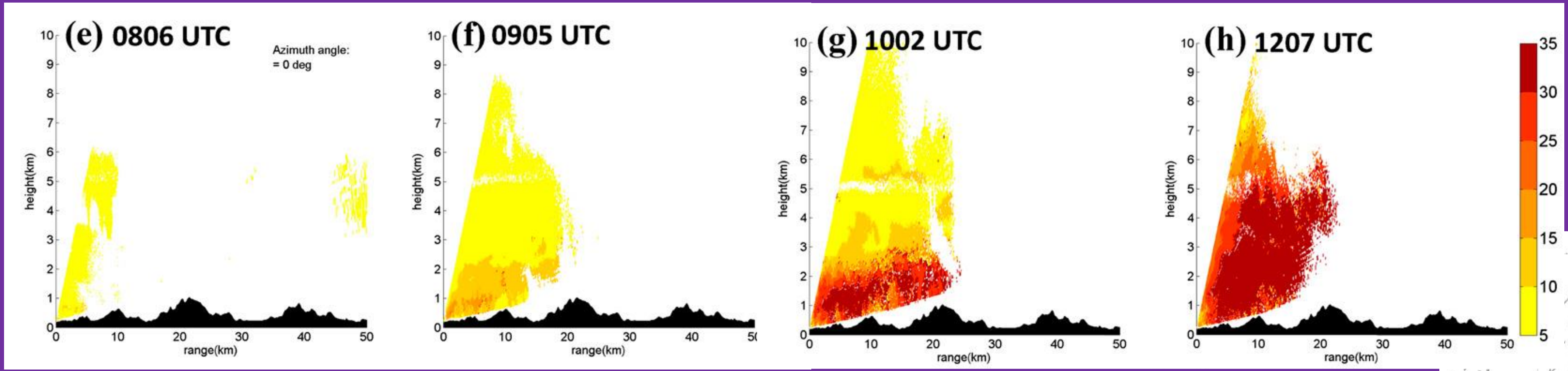
Color: divergence
Contour: vertical wind

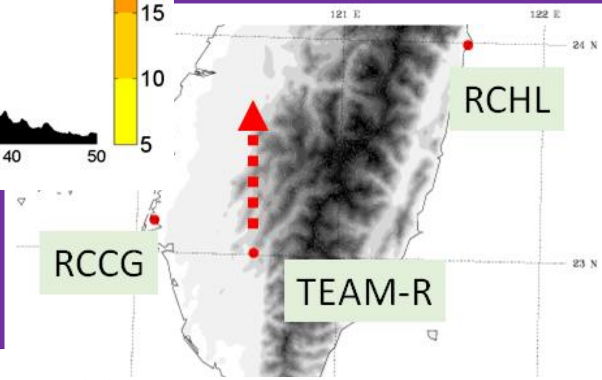




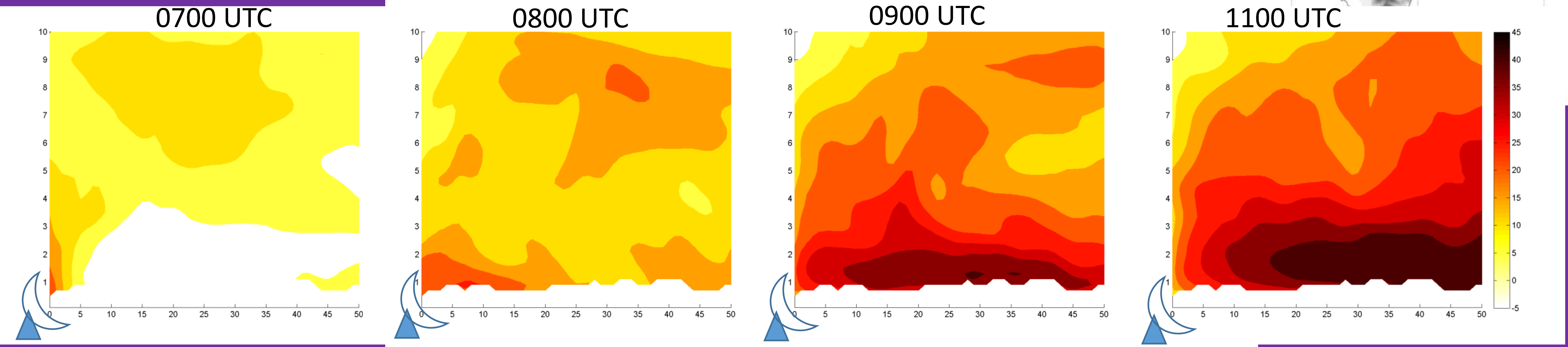
Upward transport of southerly with time

Analysis by Liou et al. (2016; MWR)



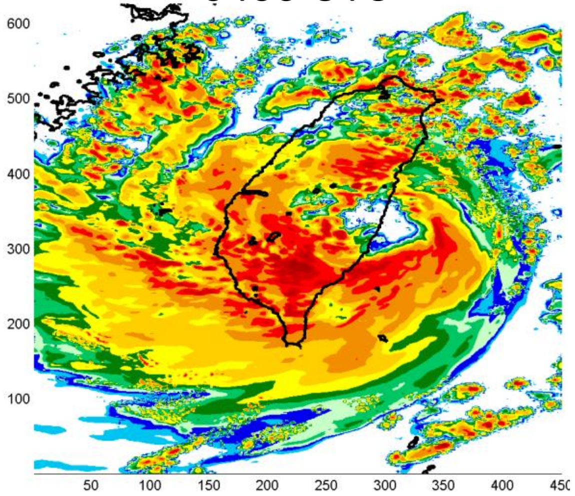


WRF Simulation

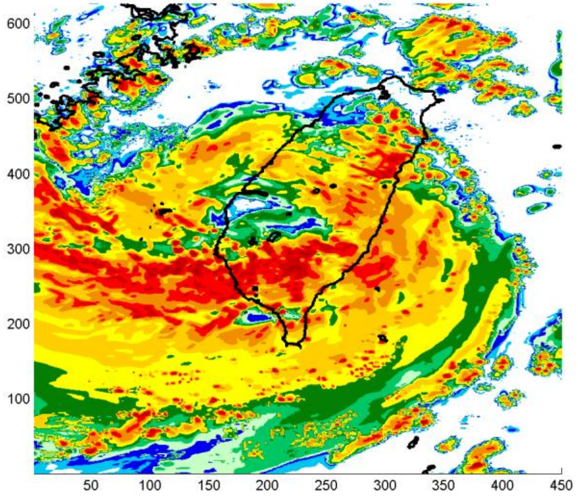


WRF/100%TERRAIN (CTL)

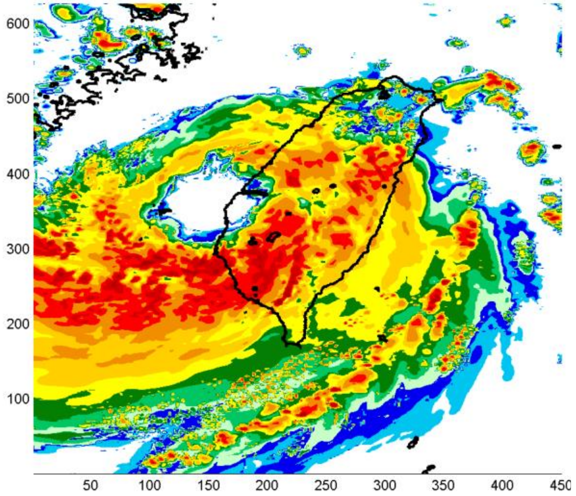
0400 UTC



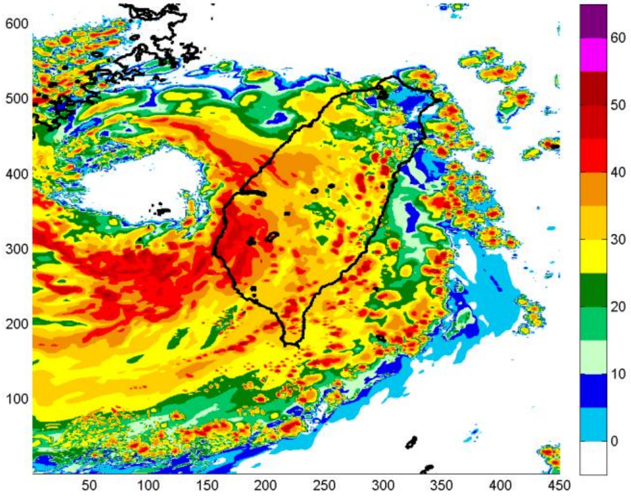
0700 UTC



1000 UTC

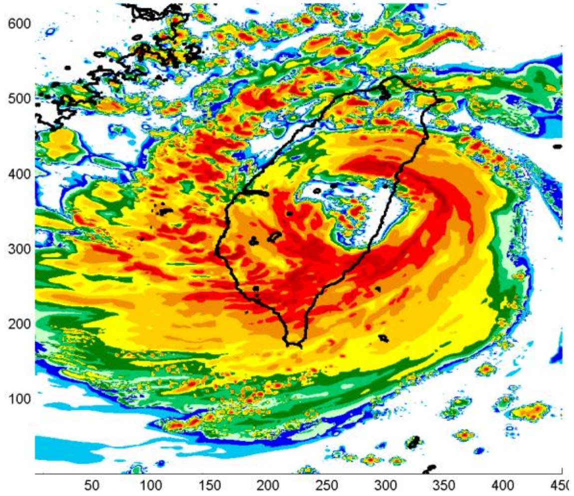


1300 UTC

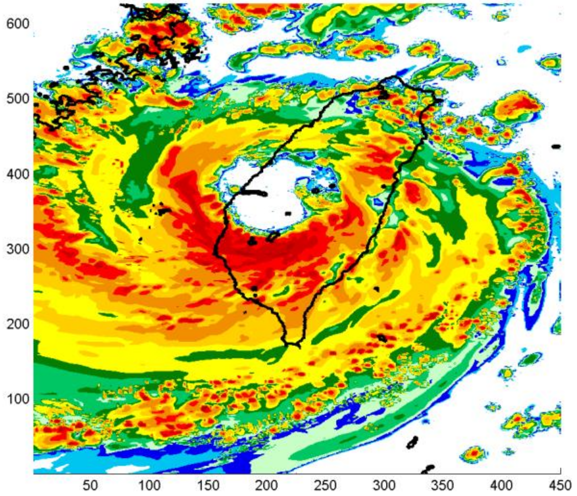


WRF/50% TERRAIN

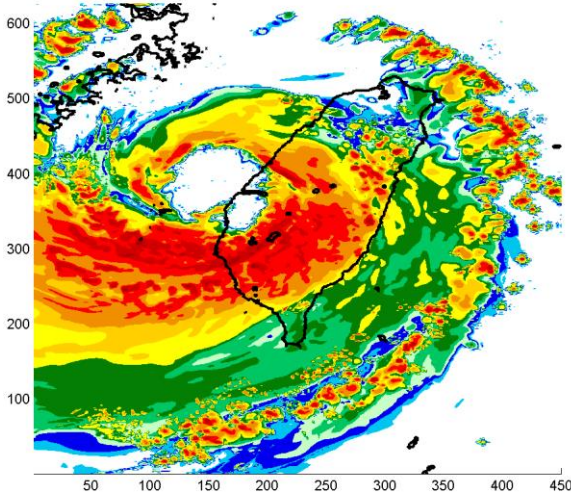
0400 UTC



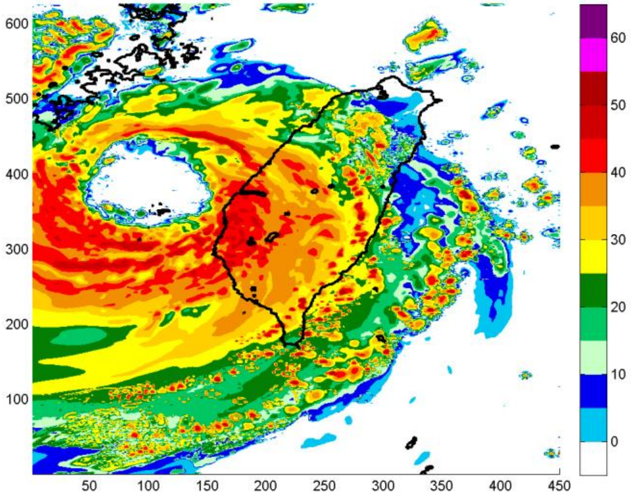
0700 UTC



1000 UTC

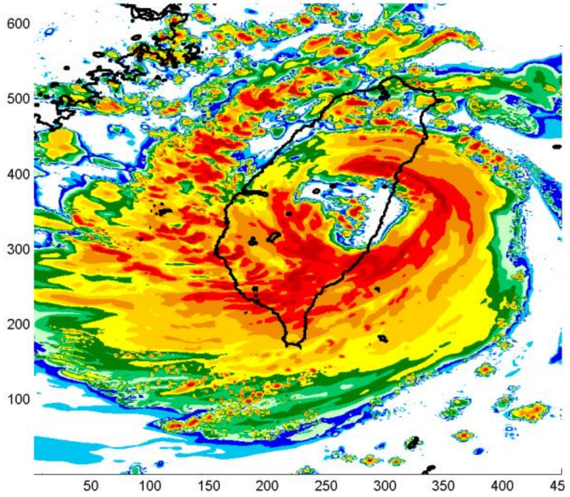


1300 UTC

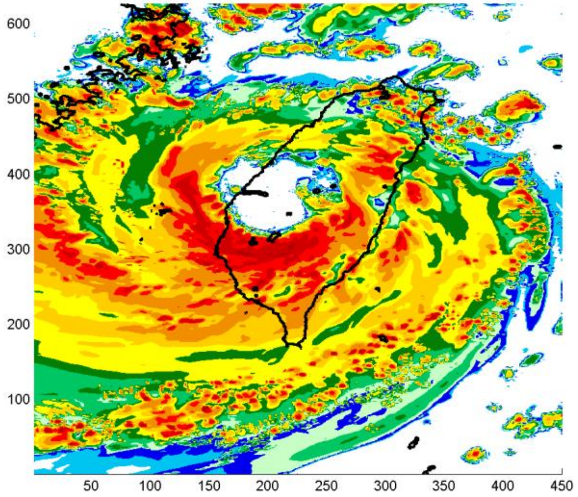


WRF/50% TERRAIN

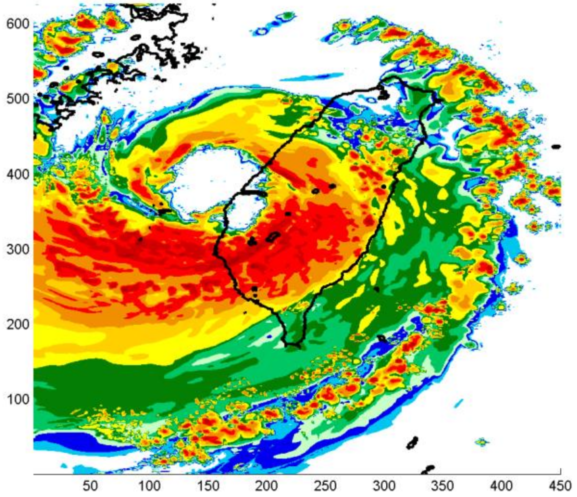
0400 UTC



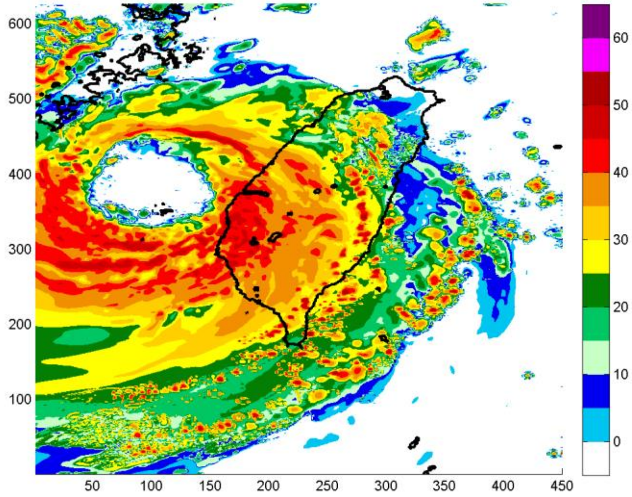
0700 UTC



1000 UTC

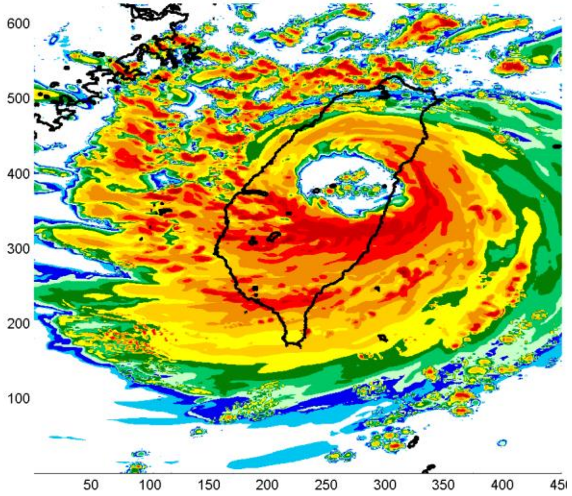


1300 UTC

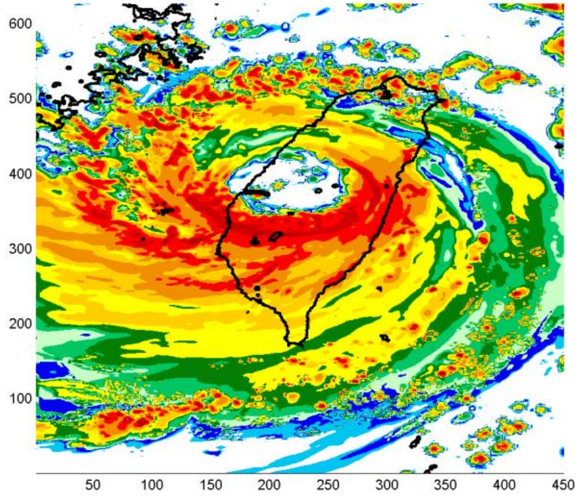


WRF/0% TERRAIN

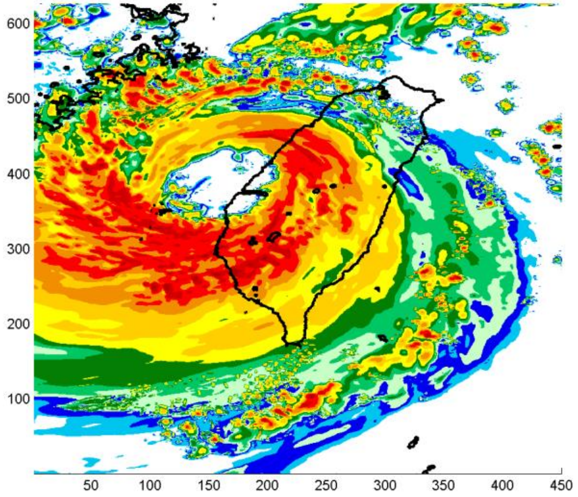
0400 UTC



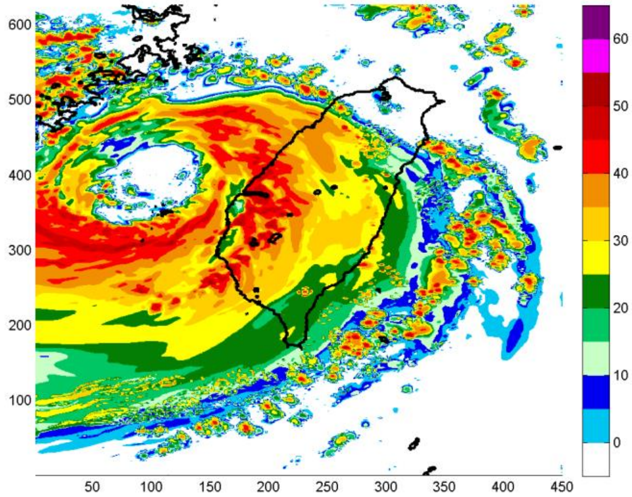
0700 UTC



1000 UTC



1300 UTC



$$\frac{\partial \eta}{\partial t_Q} = -(\overrightarrow{V_h} - \vec{C}) \cdot \nabla_h \eta - w\frac{\partial \eta}{\partial z} - \eta \nabla_h \cdot (\overrightarrow{V_h} - \vec{C}) - \hat{k} \cdot \nabla_h w \times \frac{\partial V_h}{\partial z} + \hat{k} \cdot (\nabla p \times \nabla \alpha) + R$$

TND HAD VAD STR TIL SOL RSL

z=10km

z=0.5 km

CTL (6-hr averaging, 100 km × 100 km)

[LHS]
TND= -5.02
[RHS]
HAD= 14.32
VAD= 41.11
STR=-100.00
TIL= 52.87
SOL= -0.21
RSL= -13.12

CTL

ζ

STR=-3.28*10^{-8} (s^{-2})

50% terrain (6-hr averaging, 100 km × 100 km)

[LHS]
TND= -3.02
[RHS]
HAD= -15.33
VAD= 49.55
STR=-100.00
TIL= 67.63
SOL= -0.13
RSL= -4.74

50% terrain

ζ

STR=-6.82*10^{-8} (s^{-2})

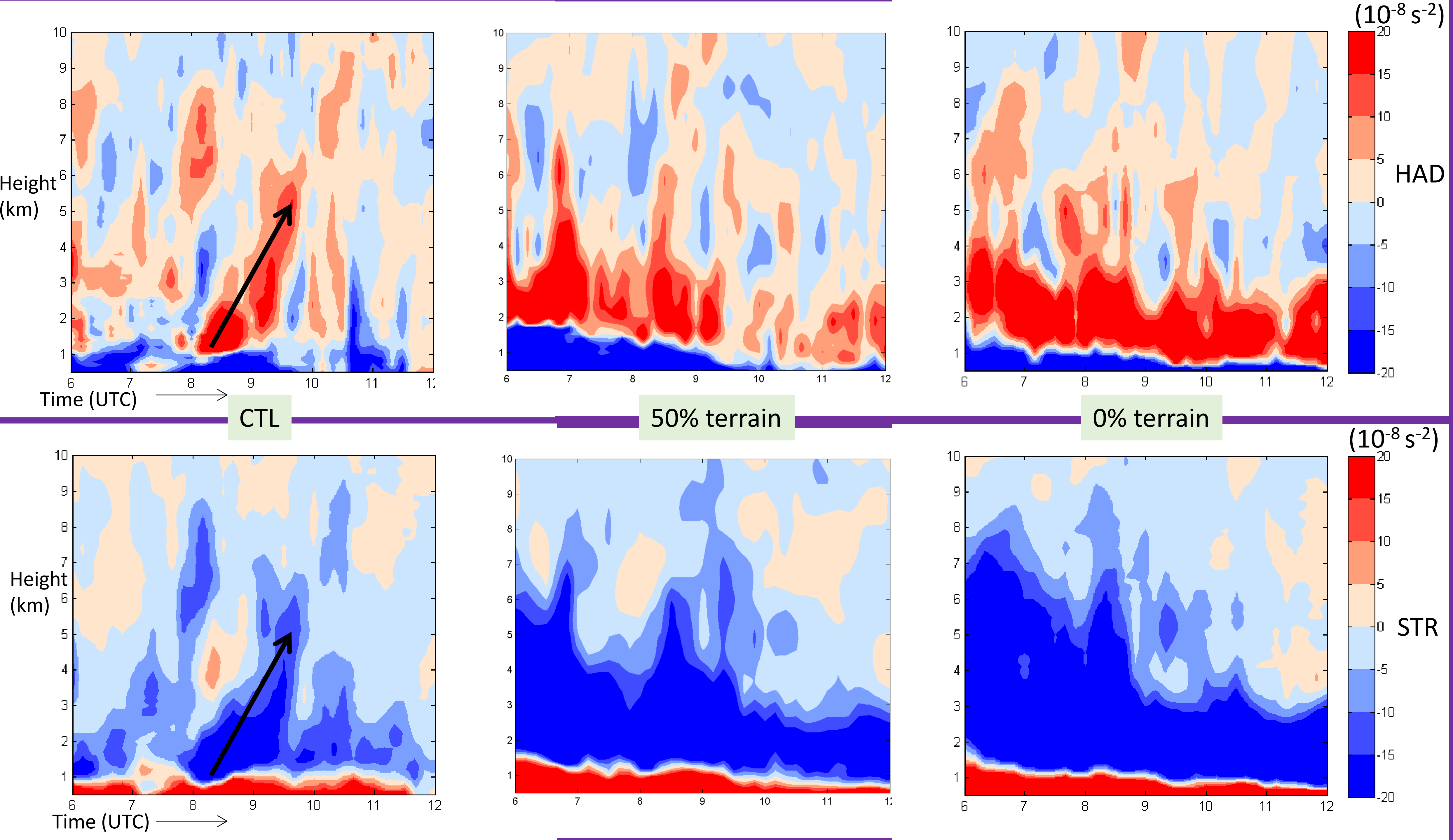
0% terrain (6-hr averaging, 100 km × 100 km)

[LHS]
TND= -9.73
[RHS]
HAD= 30.51
VAD= 17.23
STR=-100.00
TIL= 42.89
SOL= 0.18
RSL= -0.53

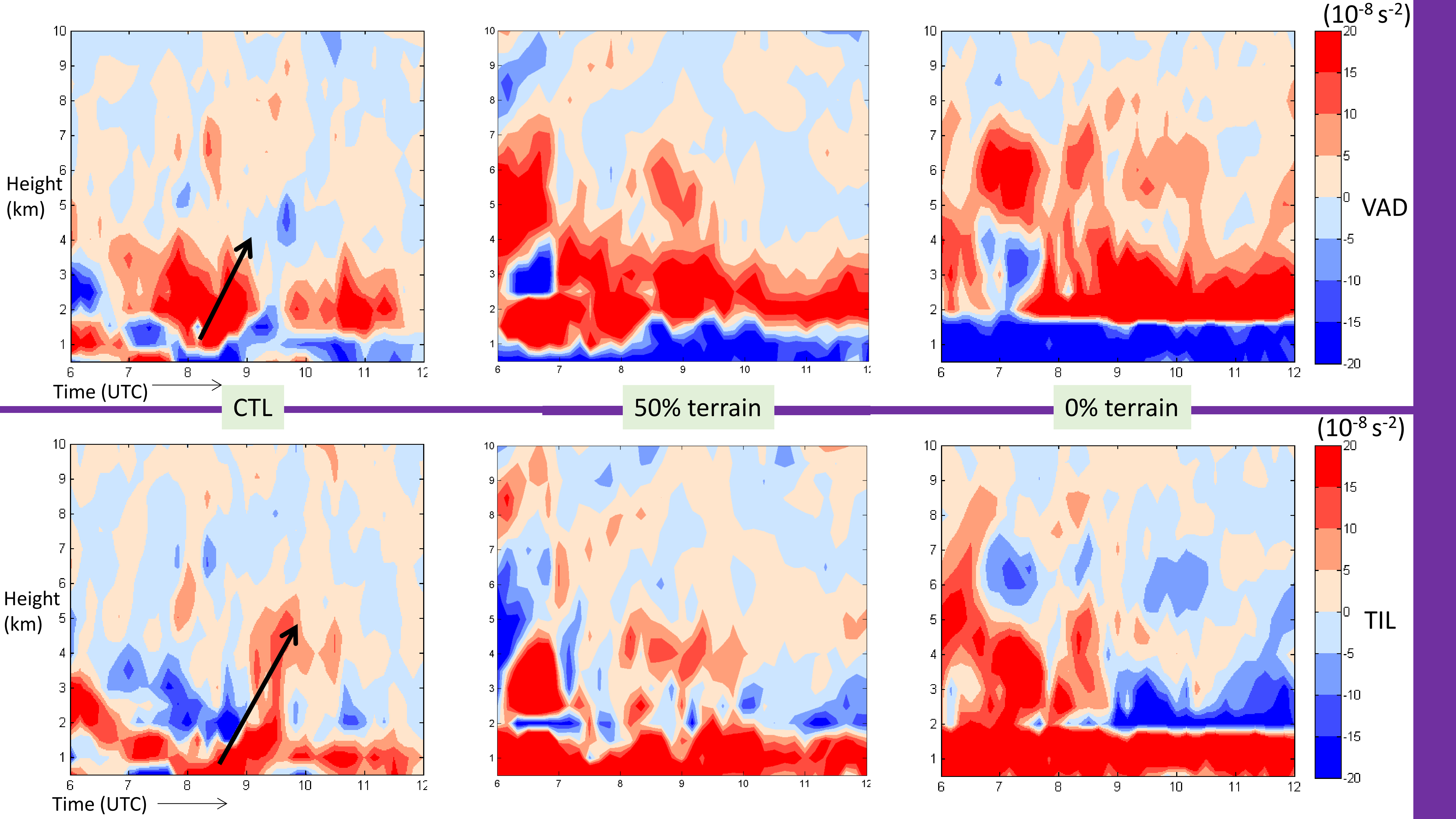
0% terrain

ζ

STR=-10.16*10^{-8} (s^{-2})

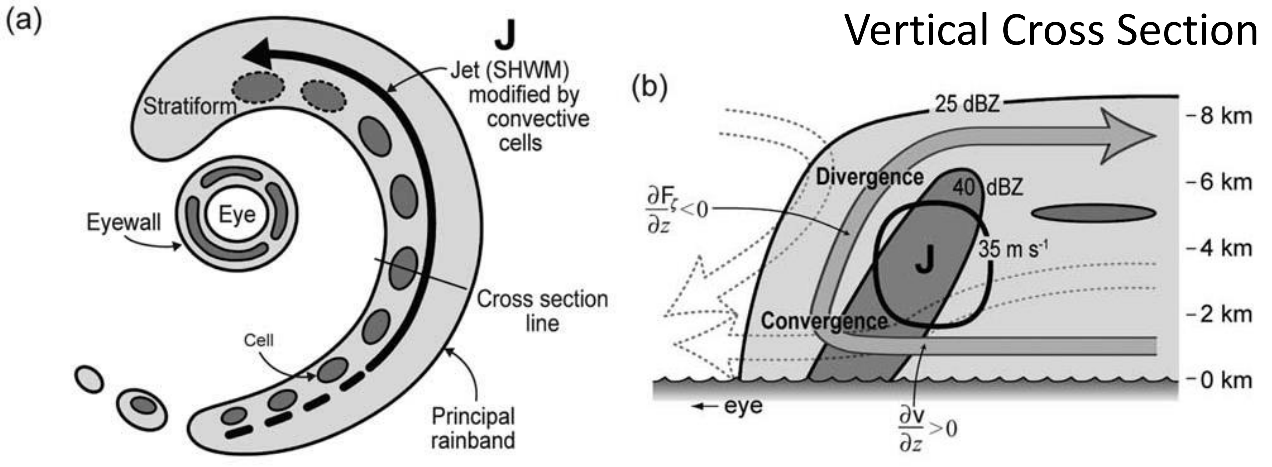


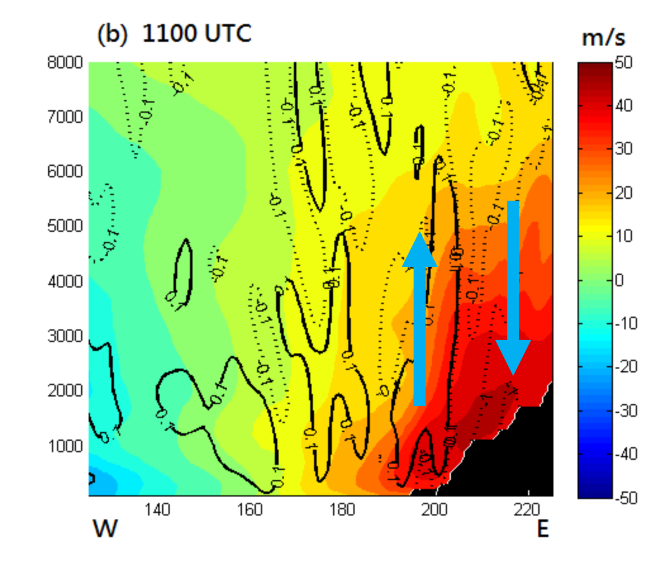
Height (km)
Time (UTC)
CTL
50% terrain
0% terrain
(10-8 s-2)
HAD
STR
20
15
10
5
0
-5
-10
-15
-20



$(10^{-8}\ s^{-2})$
VAD
Height (km)
Time (UTC)
CTL
50% terrain
0% terrain
$(10^{-8}\ s^{-2})$
TIL
Height (km)
Time (UTC)

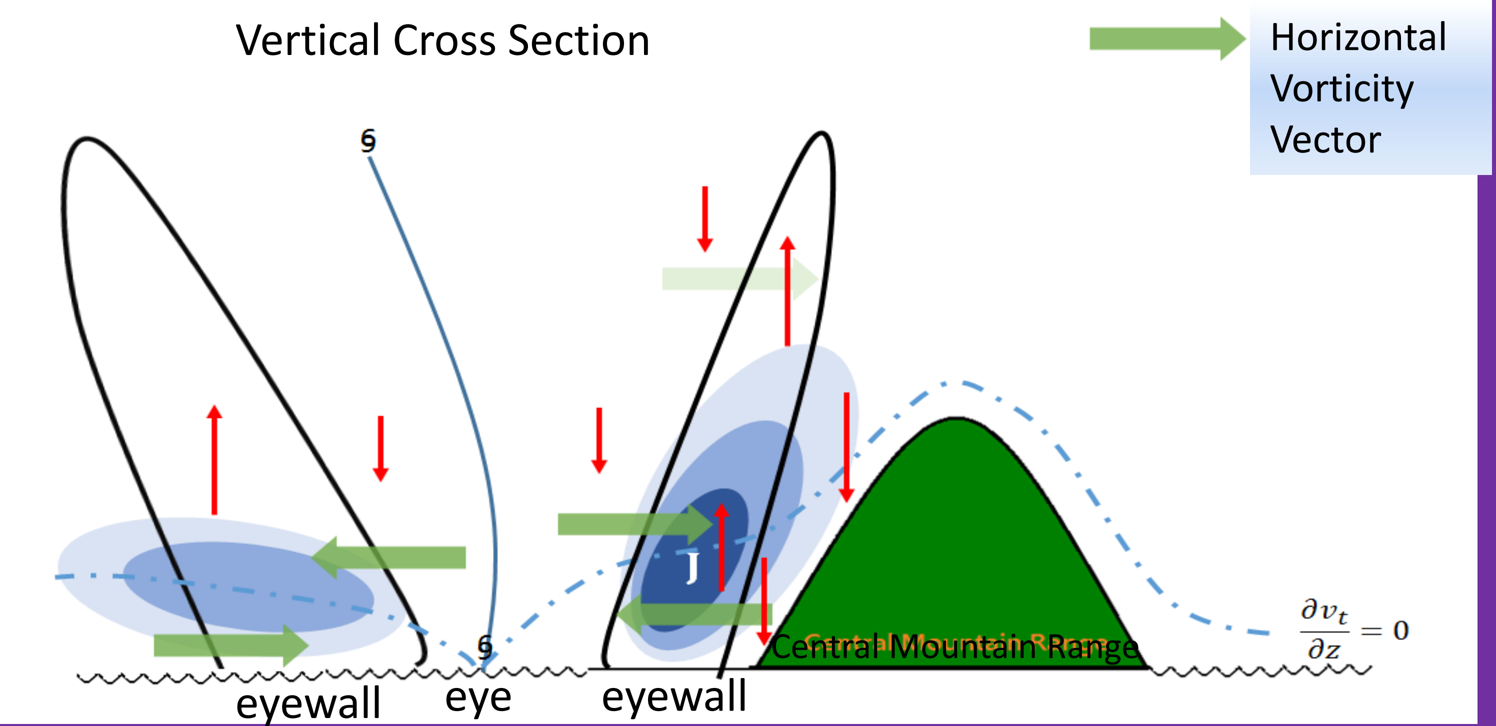
Hurricane Rita (2005)



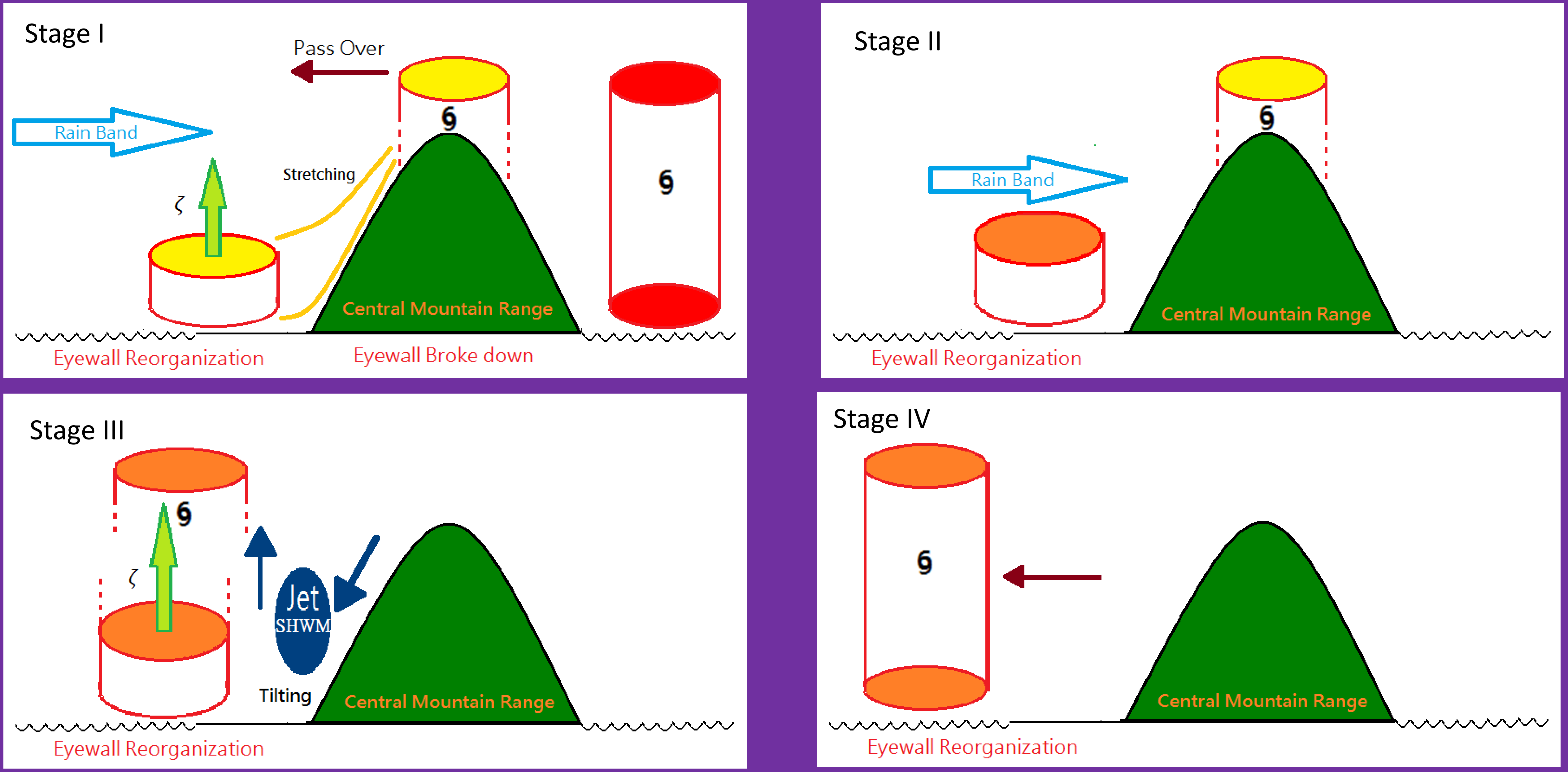


Hence and Houze (2008; JGR)

Typhoon Fanapi (2010)



Conceptual Model for the Bottom-up Eyewall Reorganization of TC Fanapi



Conclusions:

- The low-level cyclonic vorticity over the western side of CMR was formed by the vortex-tube stretching when the Fanapi vortex had not completely passed over the CMR.

- A southerly jet was formed along the western foothill of CMR as the SHWM within the principal rainband encountered the CMR. The tilting of horizontal vortex tube within the SHWM by the horizontal gradient of vertical velocity (downslope winds above the CMR and convective updrafts within the rainband) produced strong vertical vorticity in the western foothill and plane. The low-level vertical vorticity was later transported upward through vertical advection and then connected with the mid-level TC vortex circulation.

- Through the vorticity-budget analyses and terrain sensitivity experiments, it is found that the bottom-up processes is active to reorganize the eyewall when Typhoon Fanapi was over the southwestern plain of the CMR.

Thanks for your attention