

# **Roles of Steering Flow, Latent Heating, and Taiwan Topography on the track of Typhoon Morakot (2009)**

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# 1. Research Background

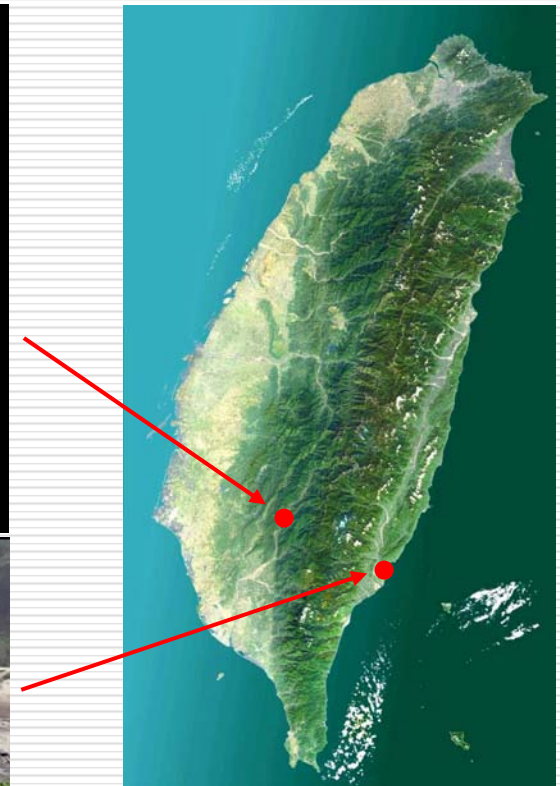
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- Morakot (2009): Most devastating typhoon to hit Taiwan during the past 50 years (some may argue 100 years)

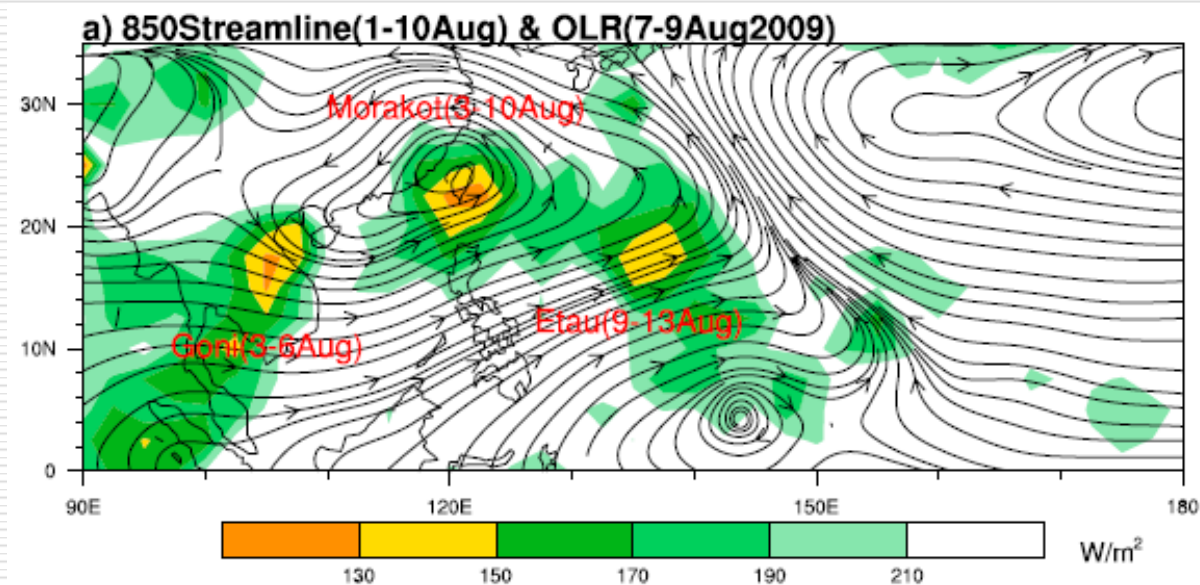
**Shiao-Lin village buried by catastrophic mudslide, causing nearly 500 deaths**



**Collapse of a 6-story hotel in Taitung**

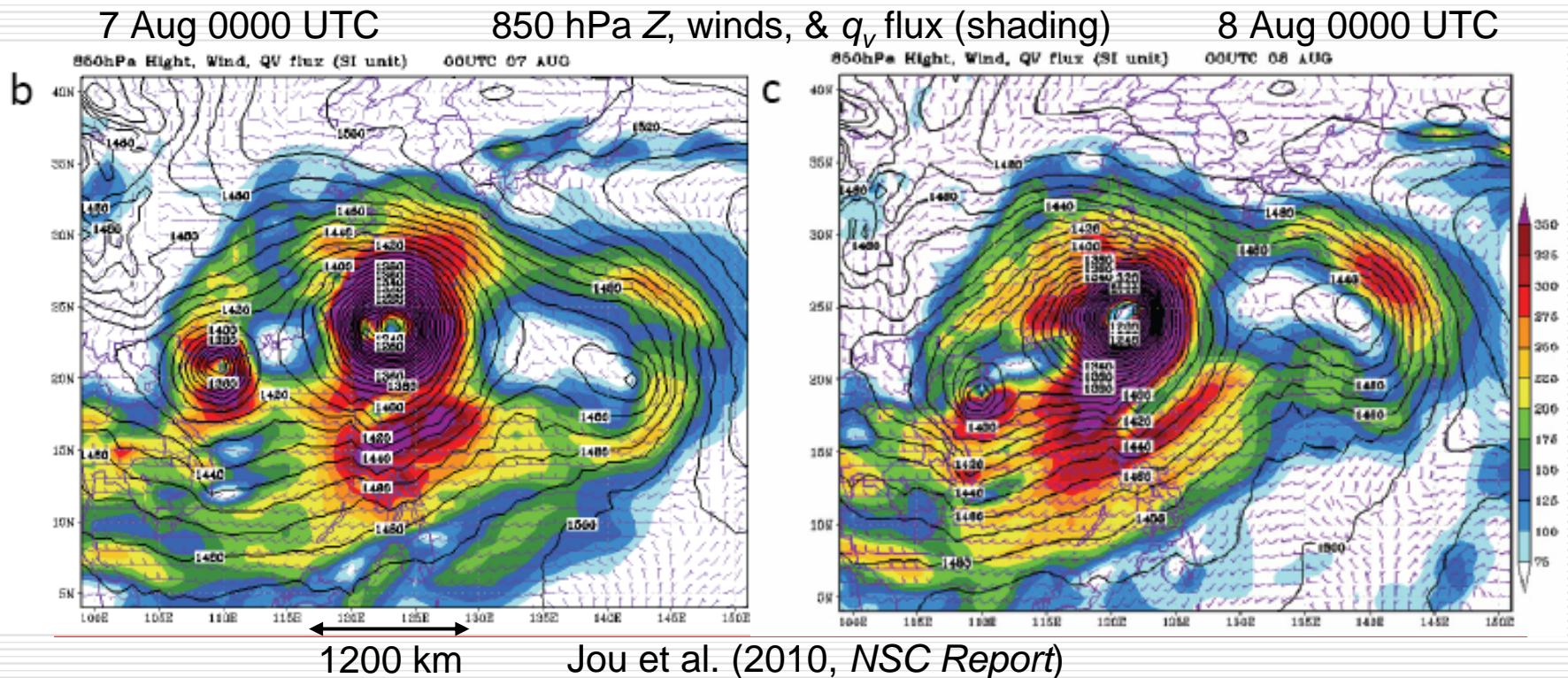


- Preliminary NSC report released on March earlier this year
- Unique features of Morakot (2009) related to its record-breaking rainfall of nearly 3000 mm:
  - Multi-scale background, embedded within a large-scale monsoon gyre (~ 4000 km) with three vortices

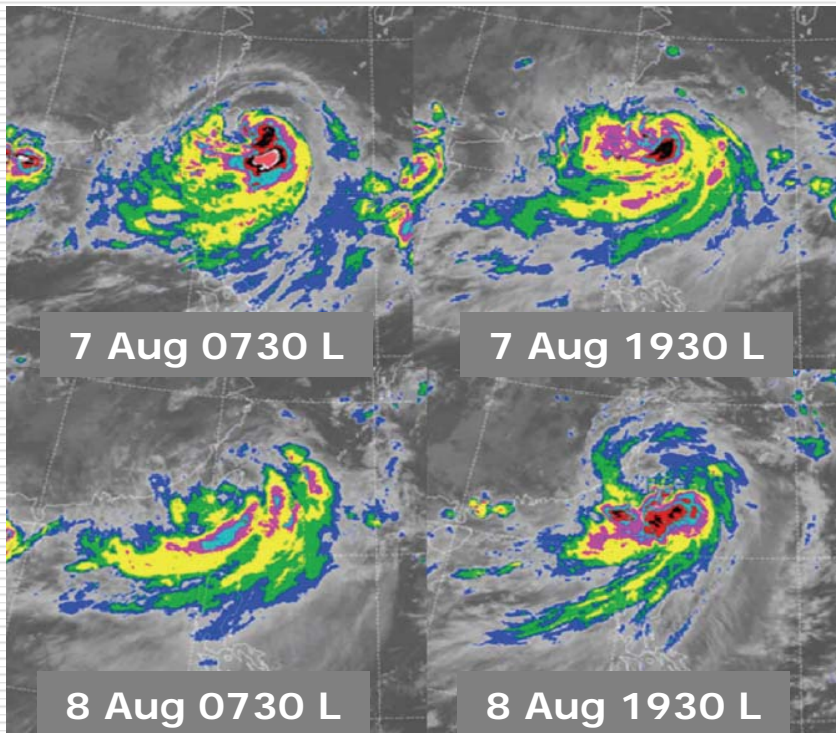


Hong et al. (2010, *GRL*)

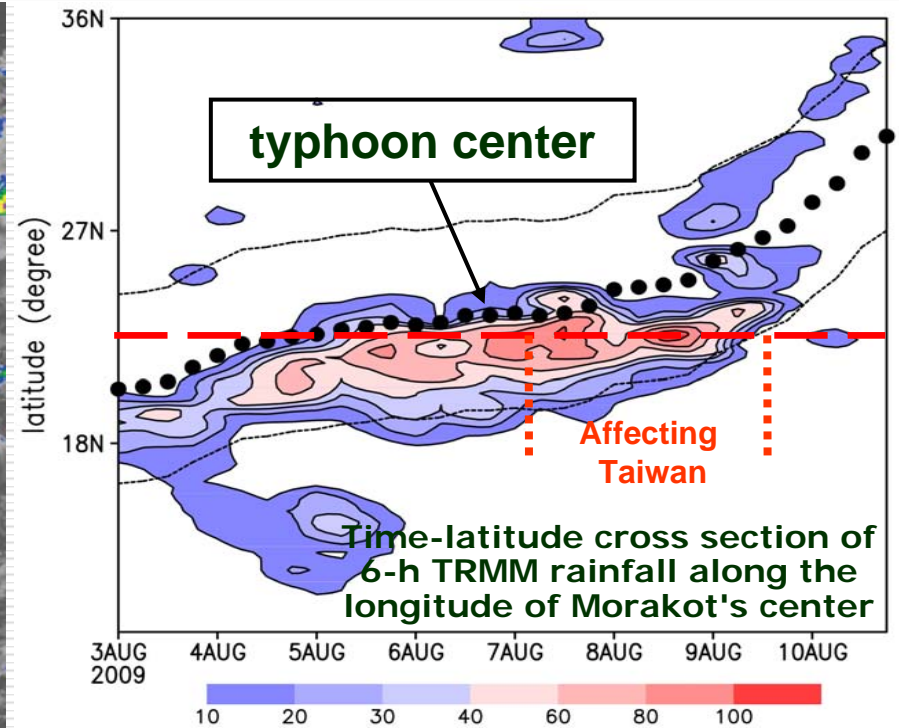
- Unusually strong outer circulation with large gale-wind radius
- Rainfall enhanced by Taiwan topography (Ge et al. 2010) but already known by scientists here



- Highly asymmetric rainfall distribution linked to strong low-level moisture fluxes from the southwest (originated from BOB)
- Repeated rain-band formation upstream from Taiwan topography

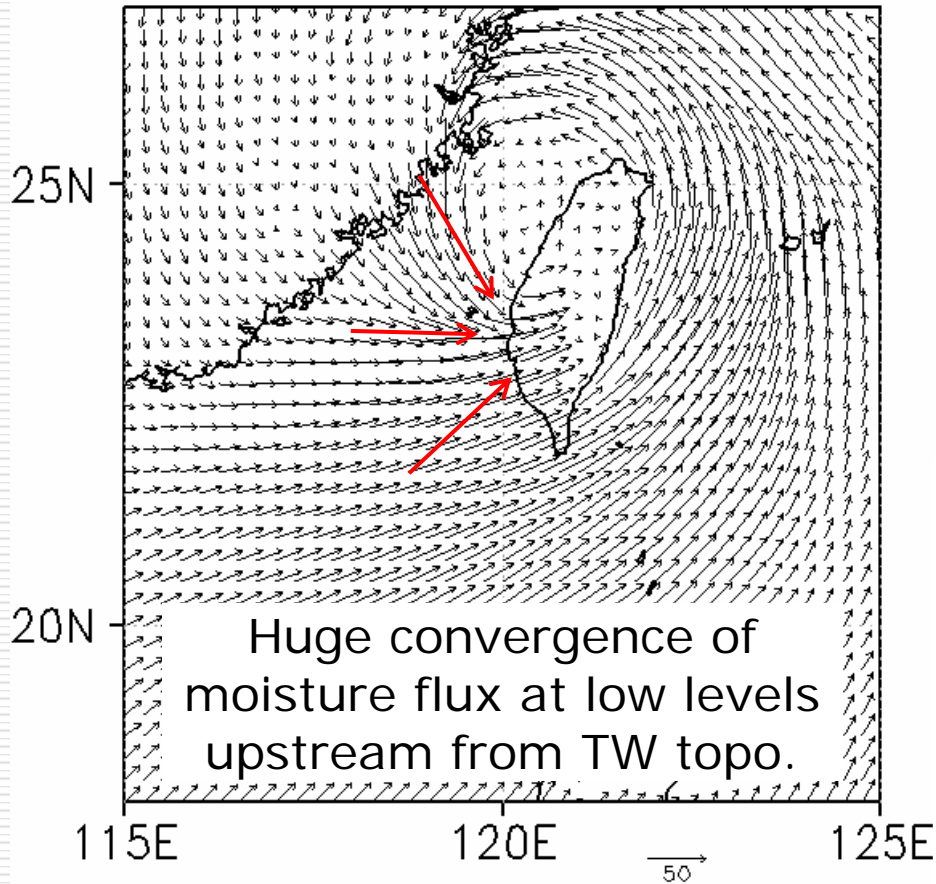


Chen et al. (2010, NSC Report)

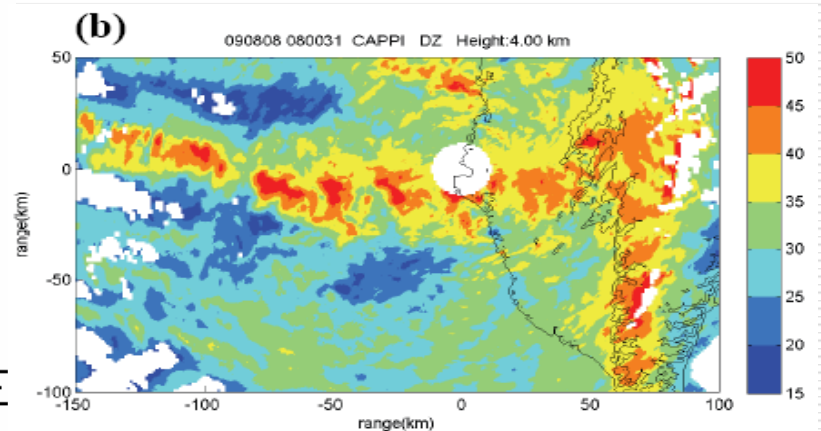
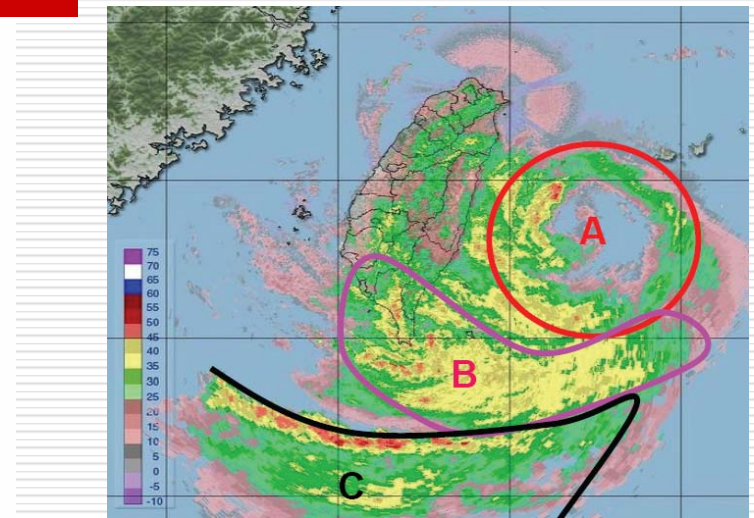


Wu et al. (2010, WPGM)

2009080812Z\_925mb\_wind\_vector

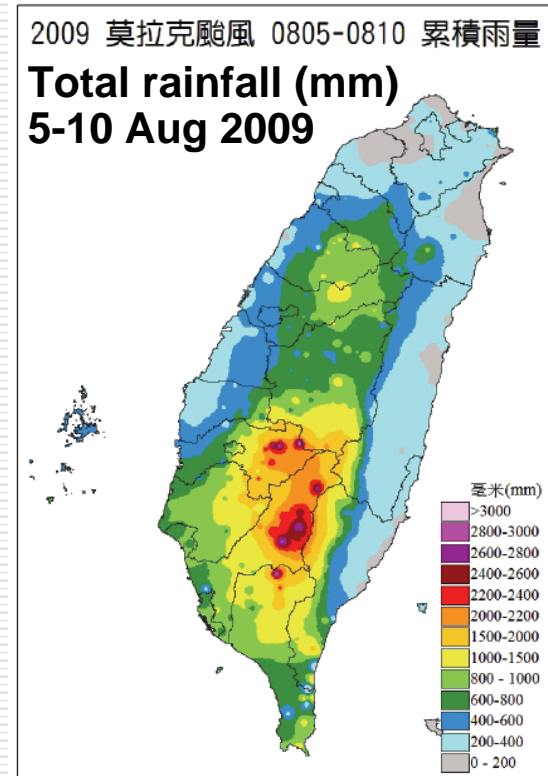
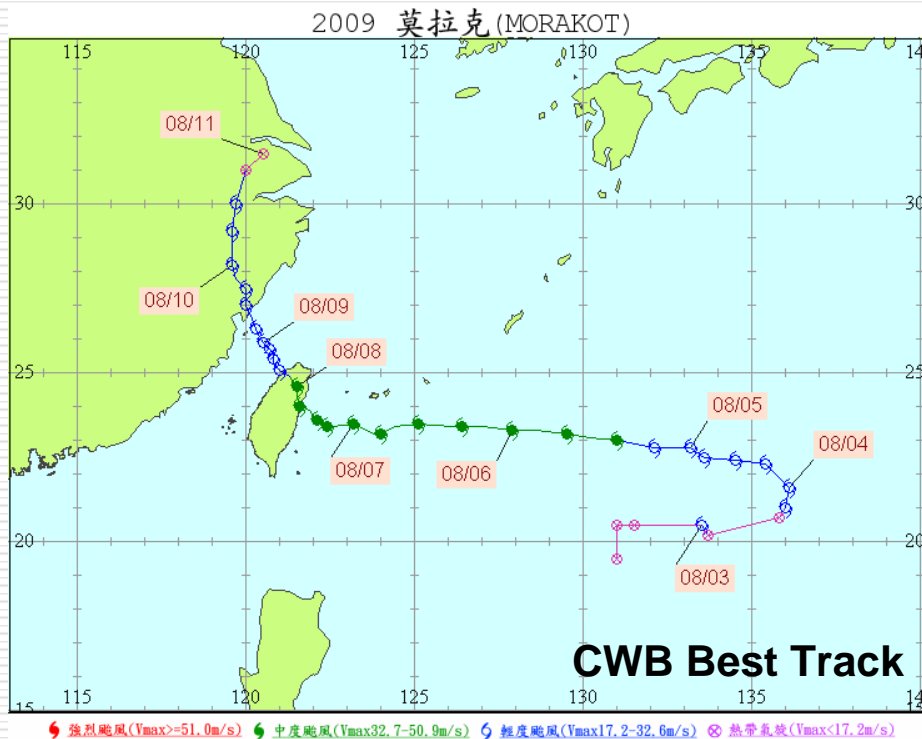


Kuo et al. (2010, *Morakot Conf.*)



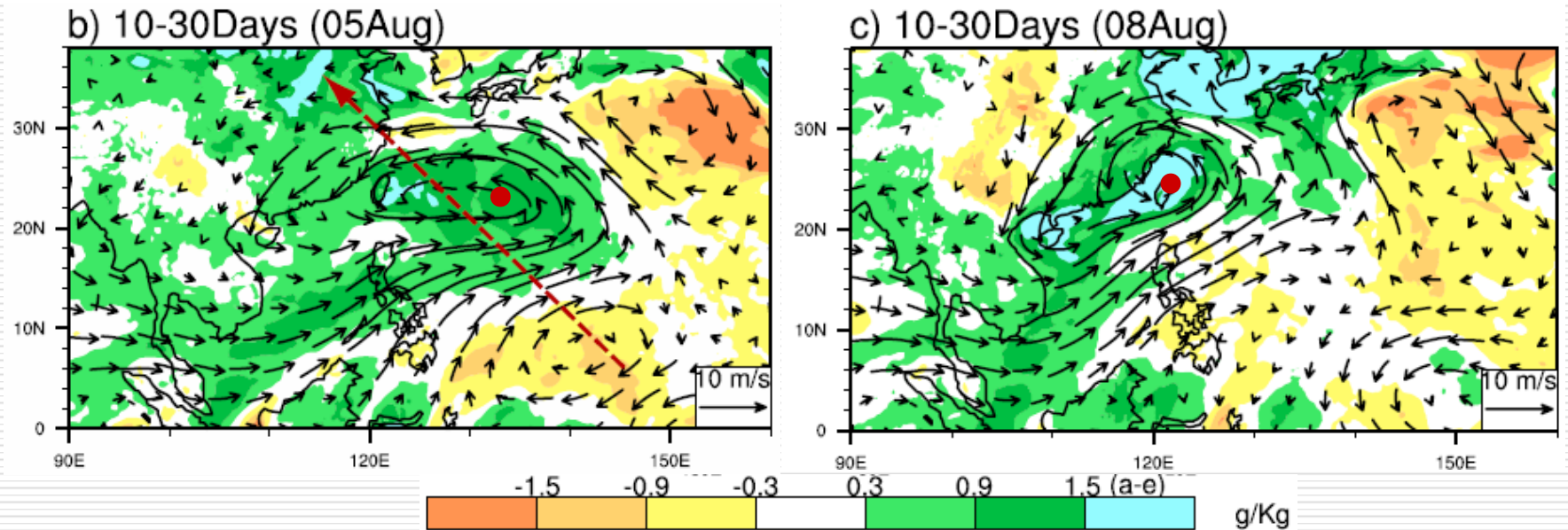
Chen et al. (2010, *NSC Report*)

- Slow translation speed linked to the weakening of steering flow
- Record-breaking rainfall caused by continuous heavy rain for a lengthy period



Jou et al. (2010, NSC Report)

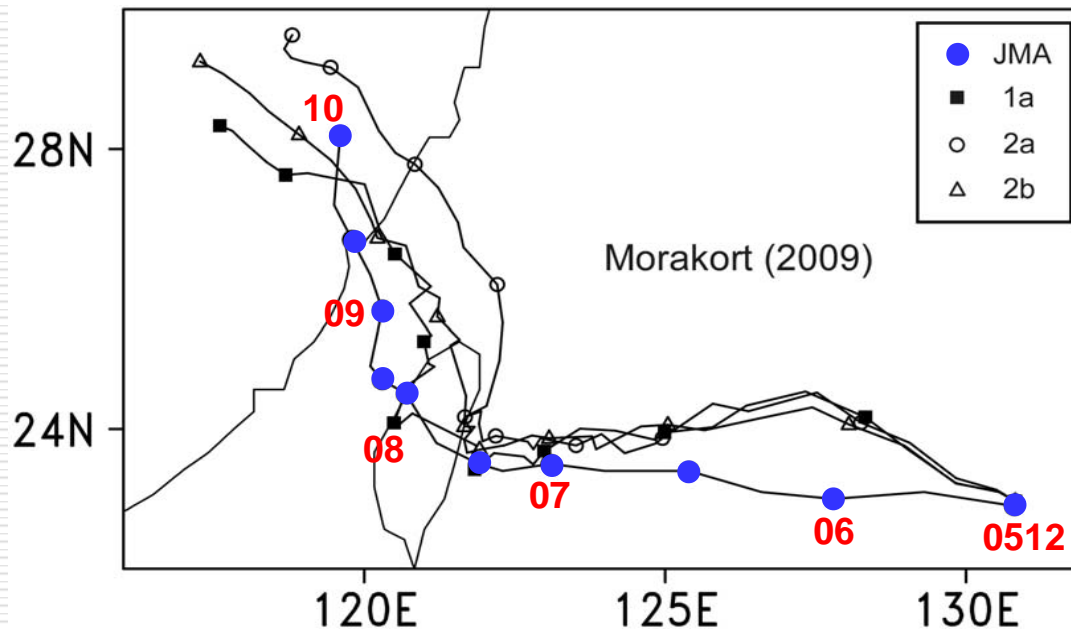
- What we have learned so far about the slow translation speed of Typhoon Morakot (2009):
  - Low-frequency circulation (monsoon gyre) propagated from SE toward NW, leaving TC subjected to weakening easterly ambient flow, causing it to slow down when approaching Taiwan



Hong et al. (2010, *GRL*)

■ Sensitivity test of Wu et al. (2010, *WPGM*) from NUIST

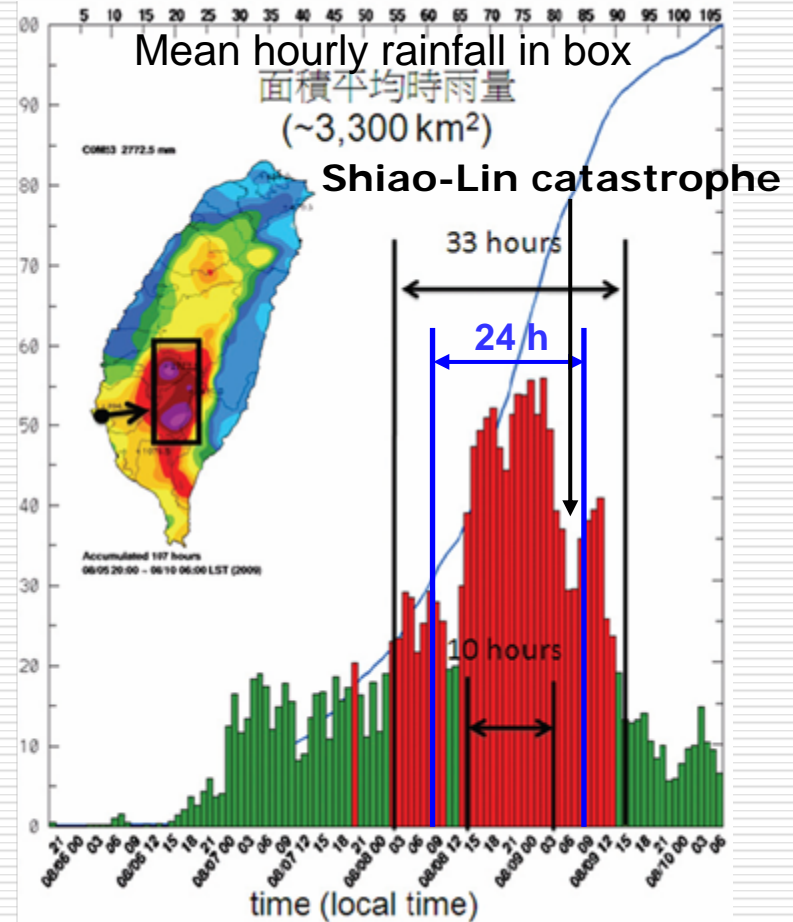
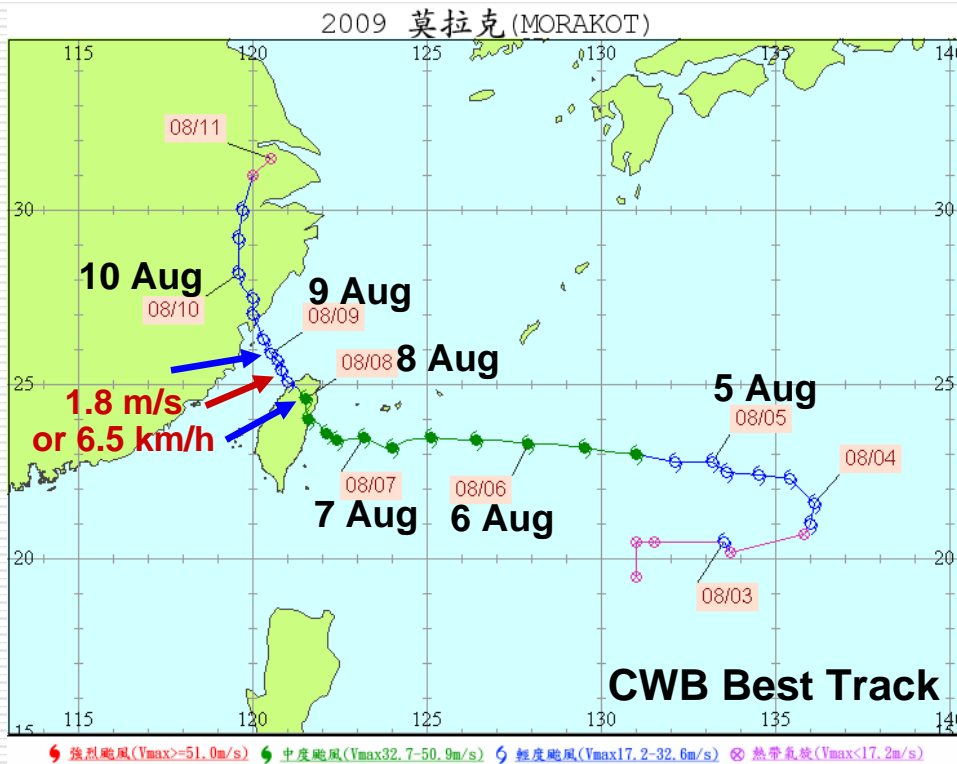
Exps.	Description
1a	Real terrain, observed FNL fields and a bogus vortex
2a	As in 1a, but the terrain is reduced to 100 m
2b	As in 1a, but Taiwan Island becomes ocean surface



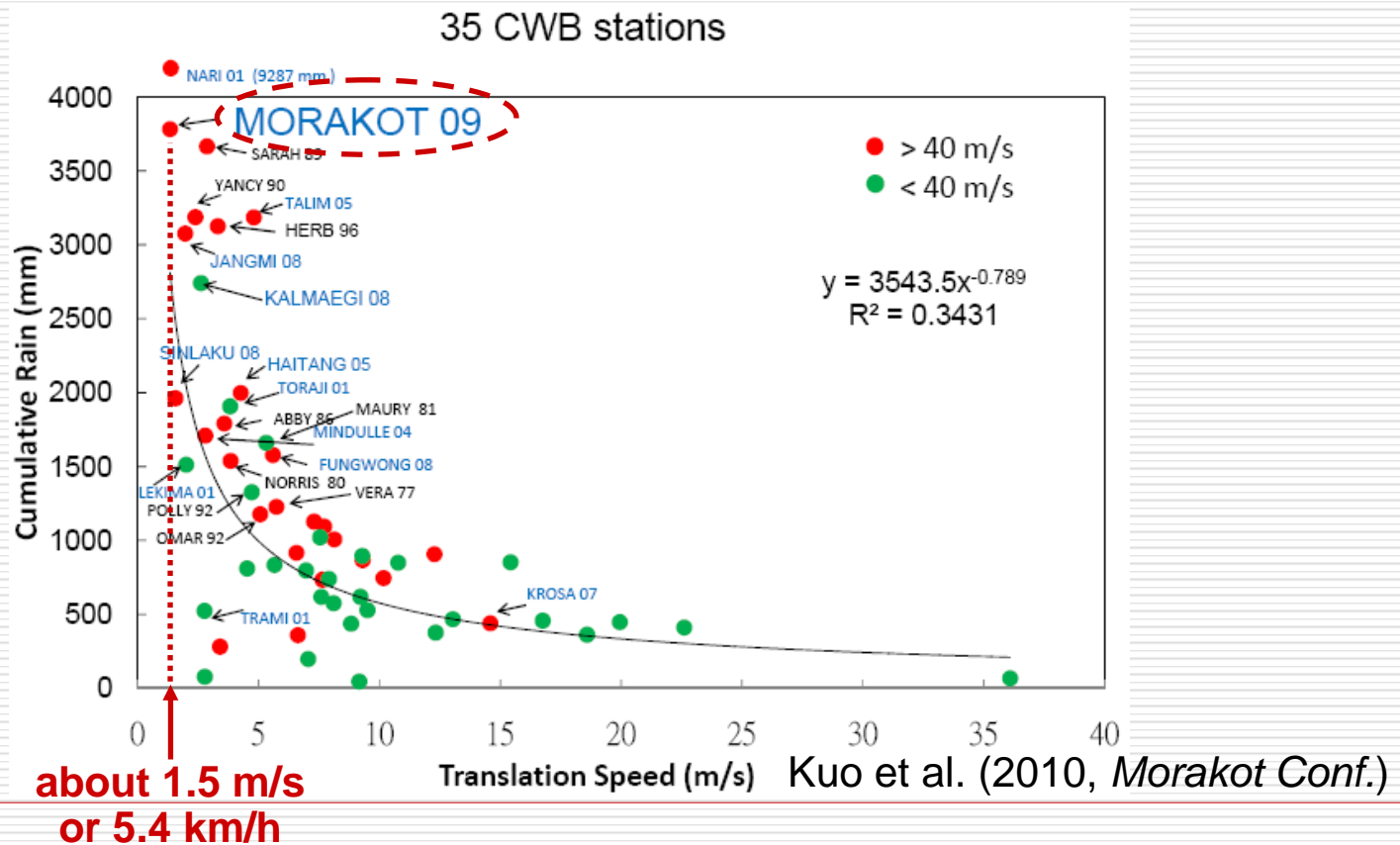
The overall sudden track change is not due to the Taiwan terrain, which may slightly modify the track

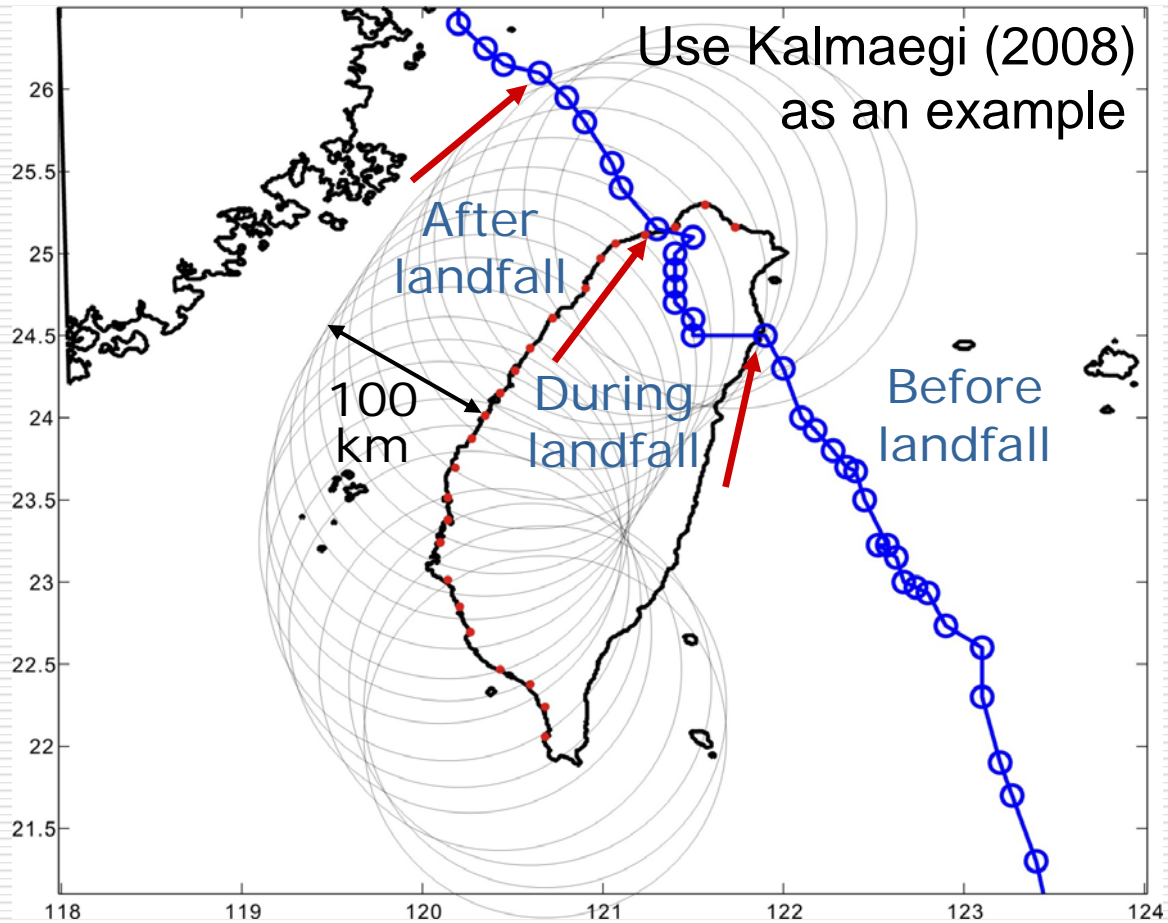
Wu et al. (2010, *WPGM*)

- The speed was extremely slow on 8 Aug, when the rain was heaviest

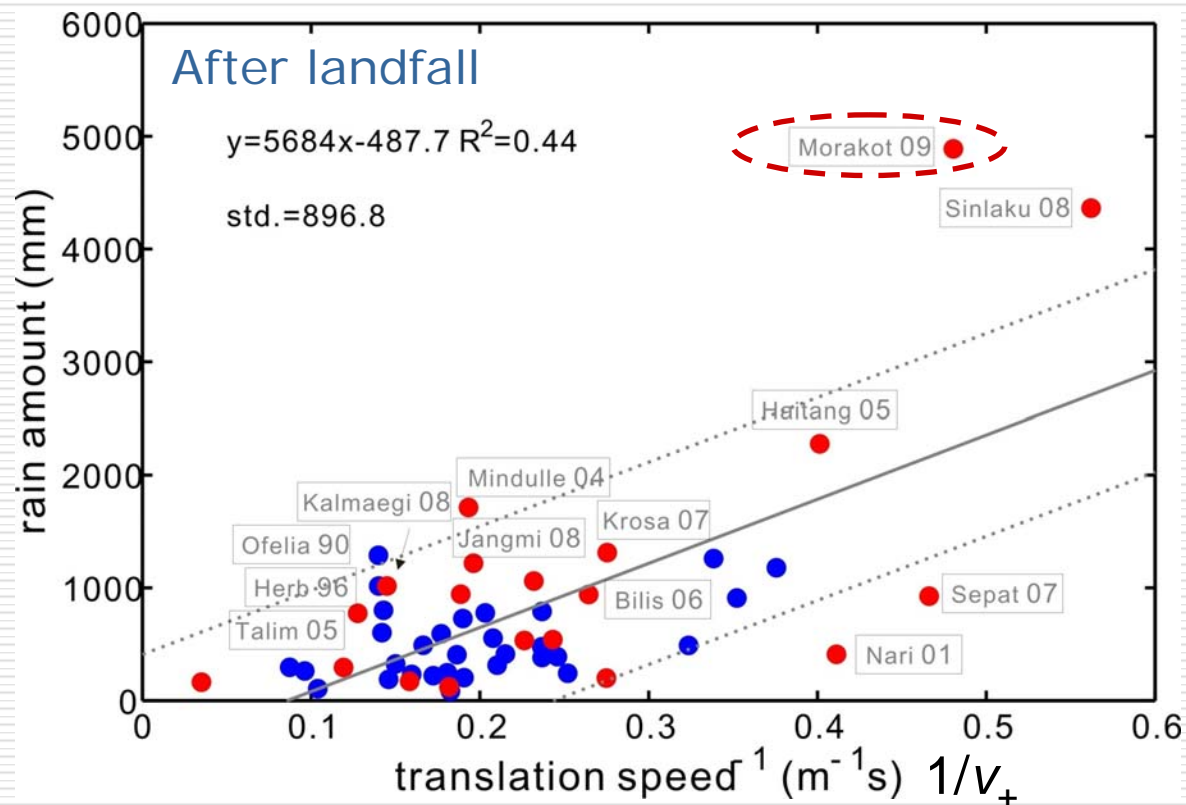


- Rainfall amount roughly inversely proportional to translation speed, similar to many other previous typhoons

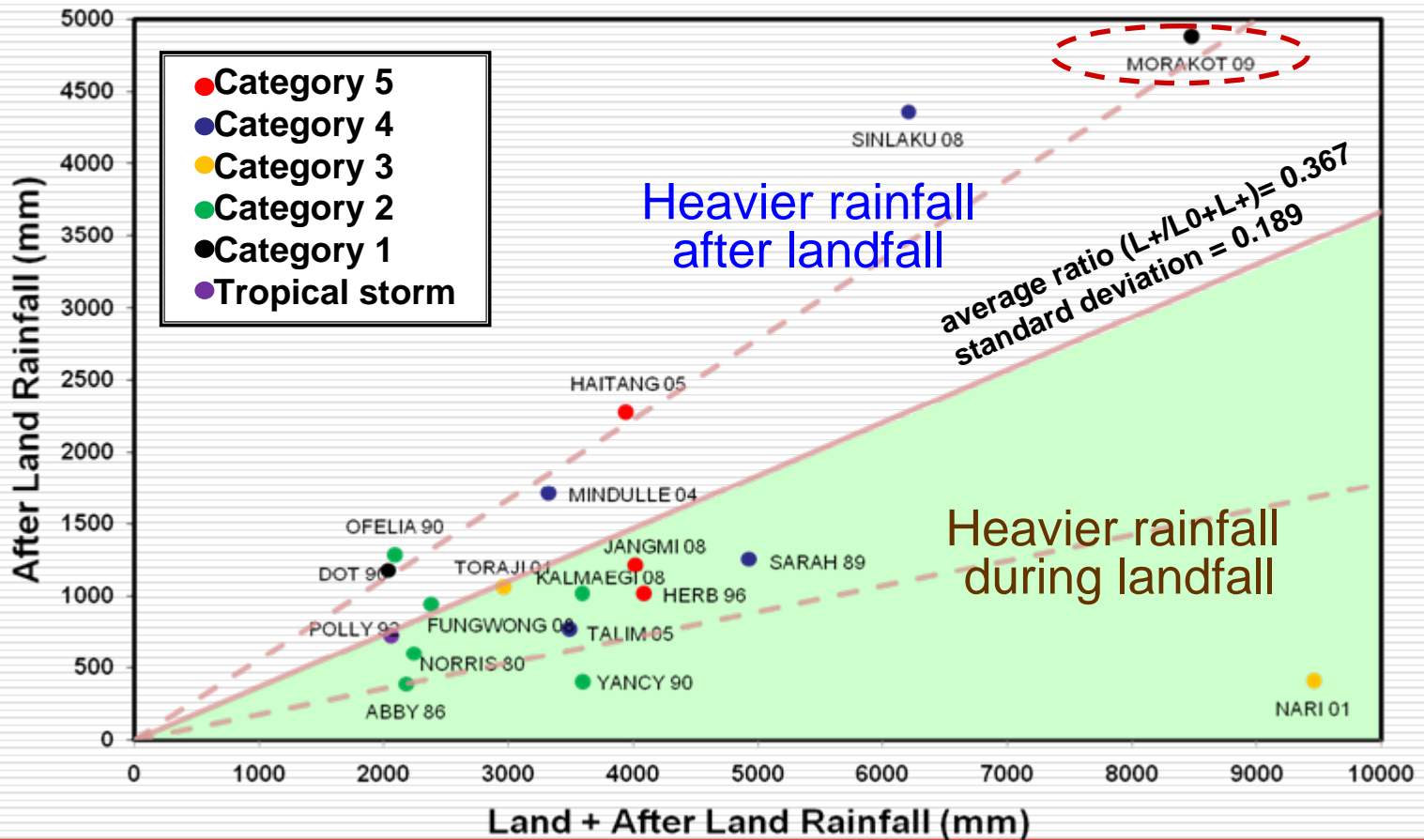




- Slowest moving typhoon after landfall, together with Sinlaku (08)
- Rainfall amount after landfall far exceeding 1 SD

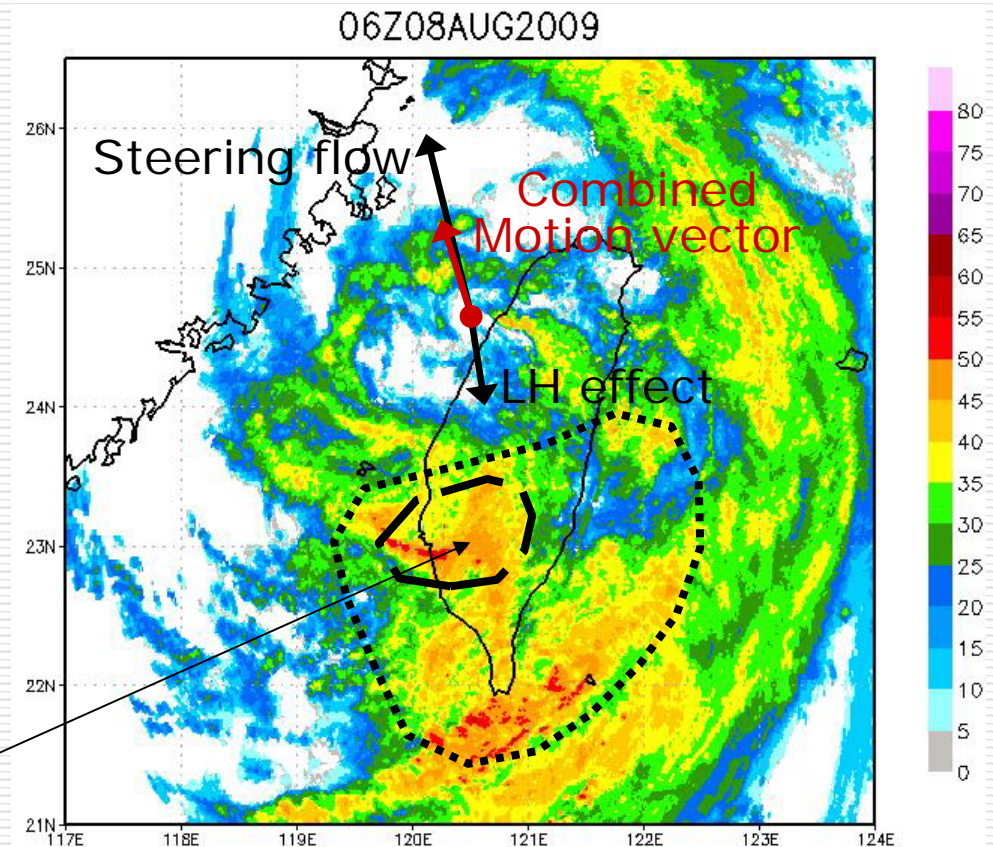


## Strong Precipitation Typhoon Cases Since 1977 (>2000 mm)



- Question: Why did Morakot move so slowly? Was it really just the steering flow?
- Hypothesis: Latent heating effect associated with the **asymmetric rainfall** (and enhanced by terrain) also contributed to the further slow down of Morakot upon leaving Taiwan on 8 August?

Strongest rainfall



## 2. Data and Model Experiments

### □ Model used: Cloud-Revolving Storm Simulator (CReSS) v.2.3

	Model domain
Domain size (km)	1728 × 1440 × 25 (centered at 25.5°N, 122.0°E)
Grid size (km) and number	3 × 3, 100-745 m stretched (576 × 480 × 50)
Projection	Lambert Conformal, 120°E, secant at 10°N, 40°N
Initial and boundary conditions	ECMWF-YOTC (0.25° × 0.25°, 16 levels, 6 h)
Topography and SST data	Real at (1/120)° and weekly SST at 1° resolution
Initial time and forecast length	0000 UTC 6 August 2009, for 96 h (4 days)
Data output frequency	Every 30 min (193 output times, $t_0$ included)
	Model physics
Advection and diffusion	Forth order in H/V, forth order in H/V
Cloud microphysics	Bulk cold rain scheme (6 species: $q_v, q_c, q_r, q_i, q_s, q_g$ )
Cumulus parameterization	None
PBL parameterization	1.5-order closure with TKE prediction
Surface processes	Energy and momentum fluxes, and shortwave and longwave radiation (no cloud radiation)
Soil (substrate) model	41 levels, every 5 cm to 2 m deep
	Numerical methods
Time steps (large/small)	$\Delta t = 5$ s, $\Delta \tau = 2.5$ s (time splitting)
Time integration	Filtered leapfrog for $\Delta t$ (HE-VE), and leapfrog and Crank-Nicolson for $\Delta \tau$ (HE-VI)
Number of PEs	32 CPUs (4 nodes)

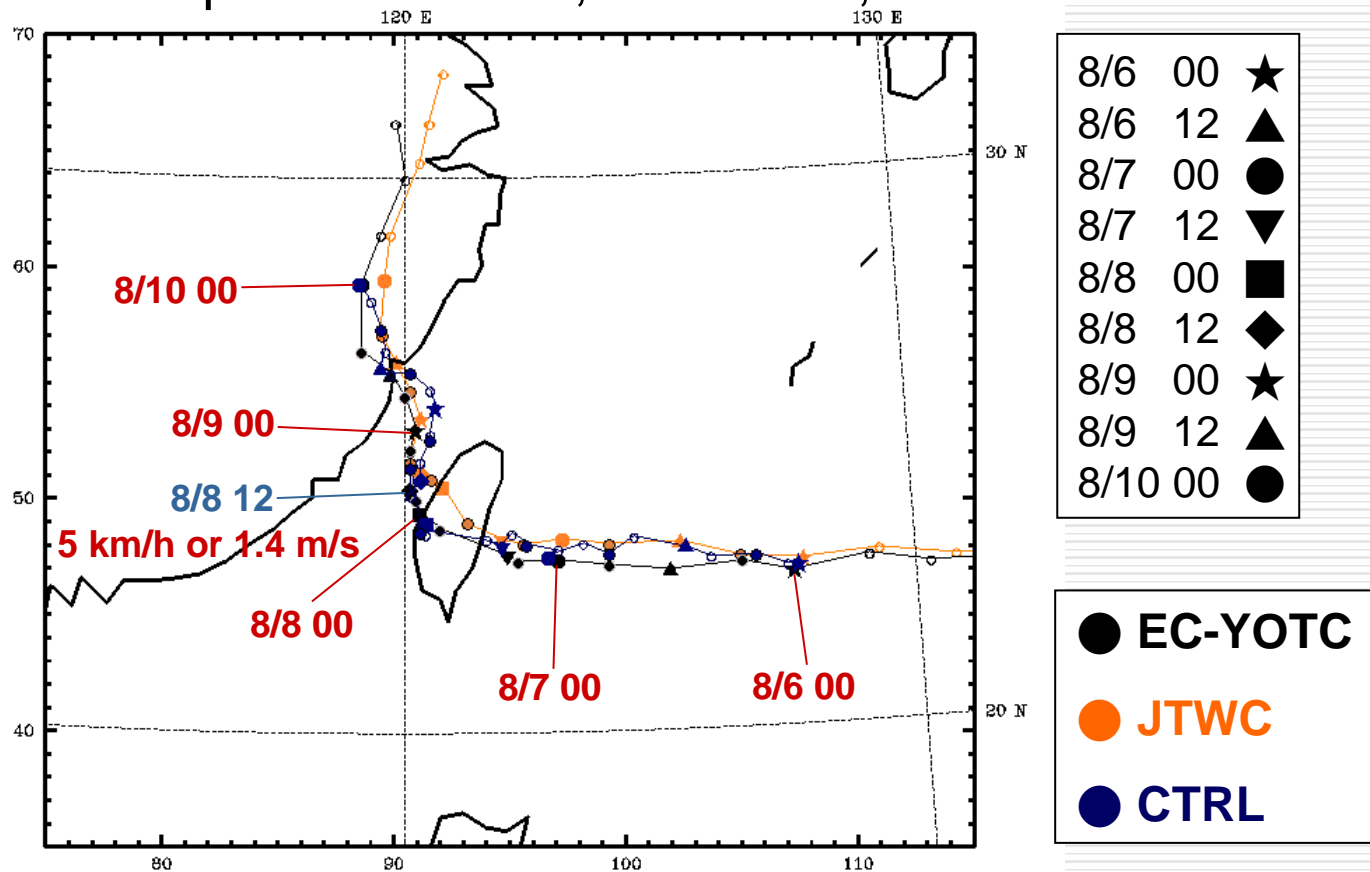
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- Sensitivity test: A set of 12 runs to test the effect of latent heating (by adjusting water vapor amount in IC/LBC) and terrain height of Taiwan
    - Water vapor amount in IC/LBC: 100, 50, 25, and 0 % (Q4, Q2, Q1, and Q0)
    - Terrain height of Taiwan: 100, 50, and 0 % (T4, T2, and T0)

Water vapor amount Terrain height	100 %	50 %	25 %	0 %
100 %	● CTRL [1]	● Q2T4 [2]	● Q1T4 [3]	● Q0T4 [4]
50 %	● Q4T2 [5]	● Q2T2 [6]	● Q1T2 [7]	● Q0T2 [8]
0 % (1 m)	● Q4T0 [9]	● Q2T0 [10]	● Q1T0 [11]	● Q0T0 [12]

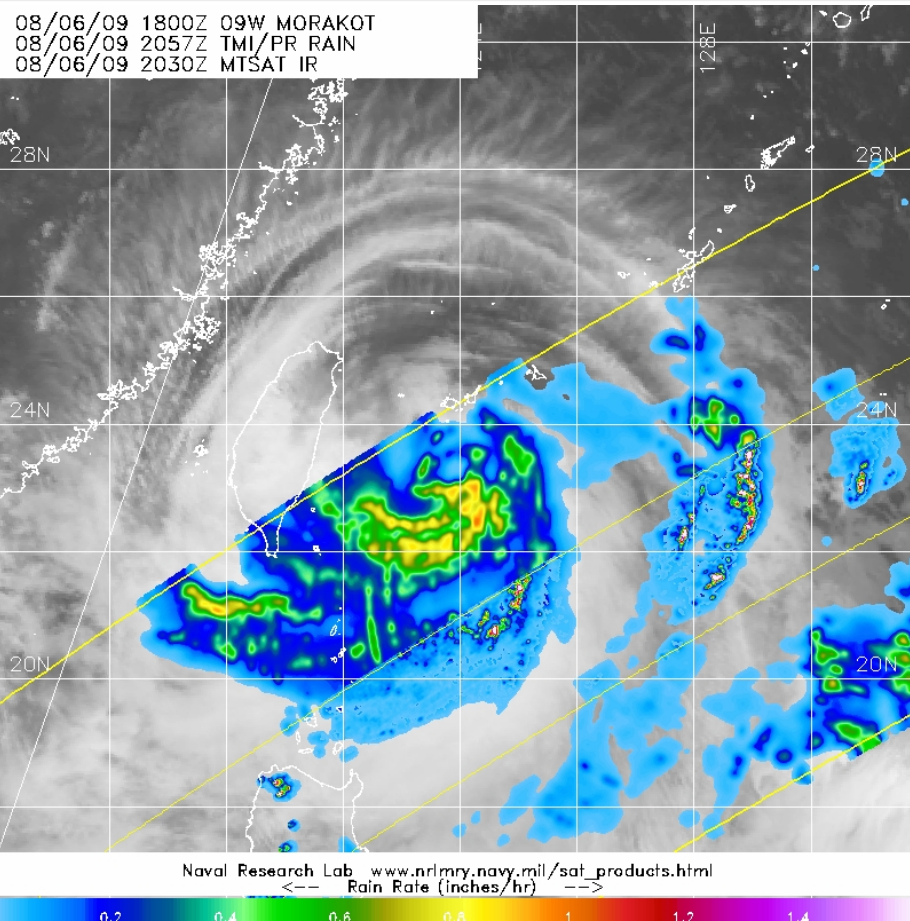
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### 3. Results of First-Set Experiment

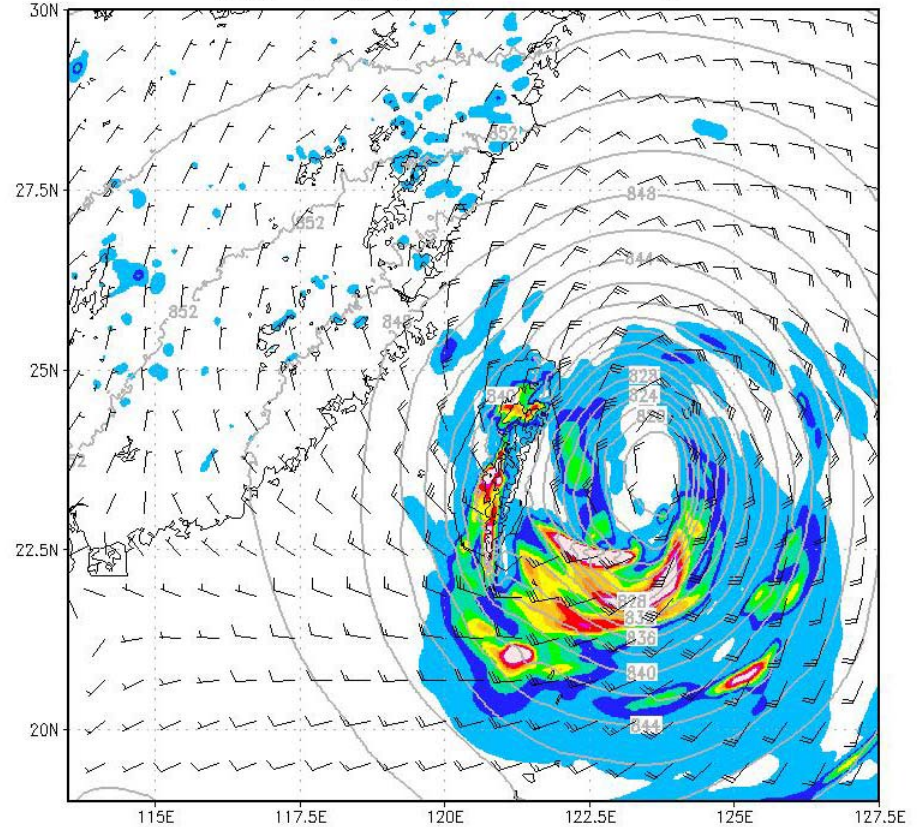
□ Track comparison: JTWC, EC-YOTC, and CTRL run



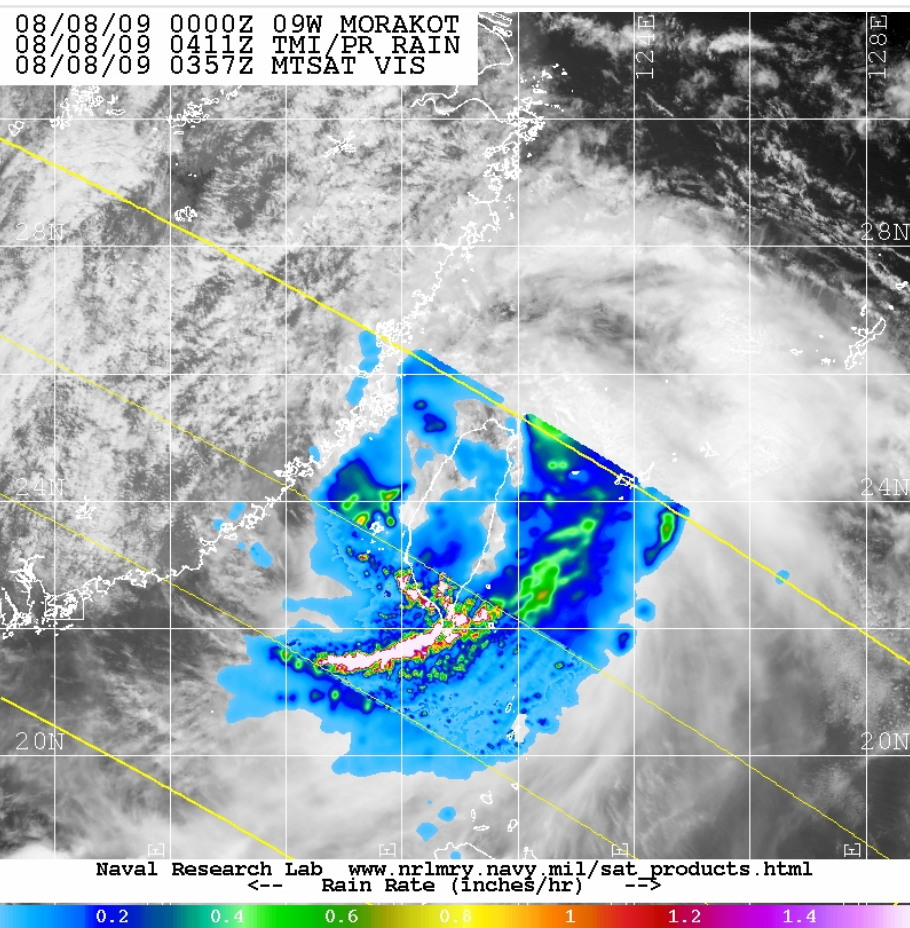
# □ Snap shots showing asymmetric structure at selected times



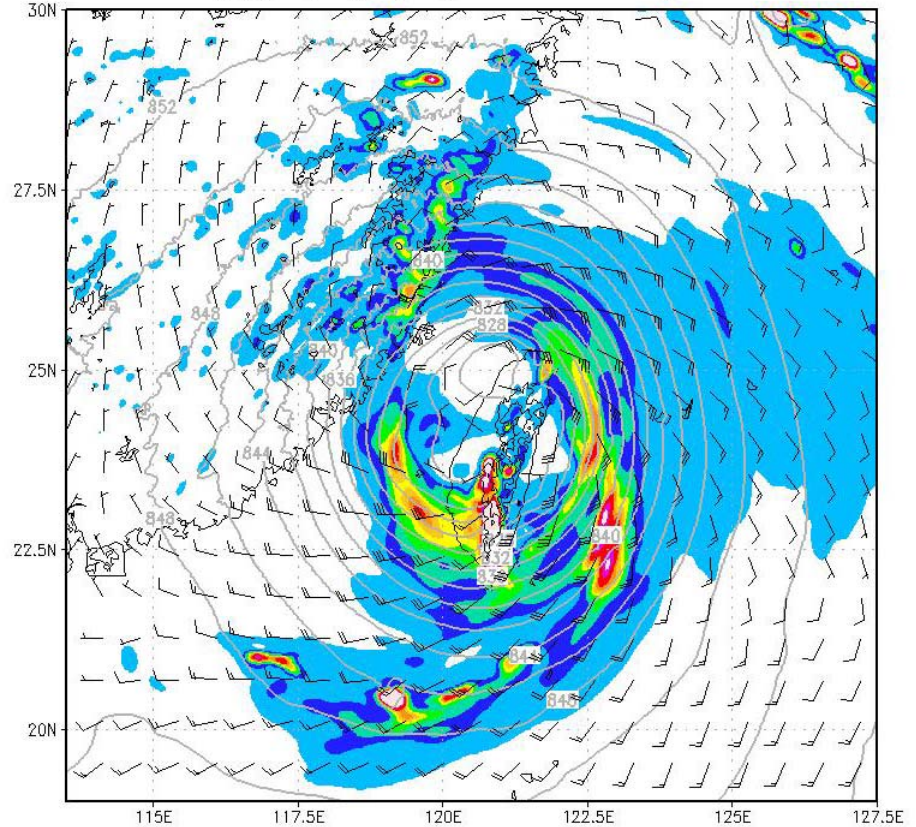
30min-rain/p/u/v(m/s) 2009 08/06 2030 UTC



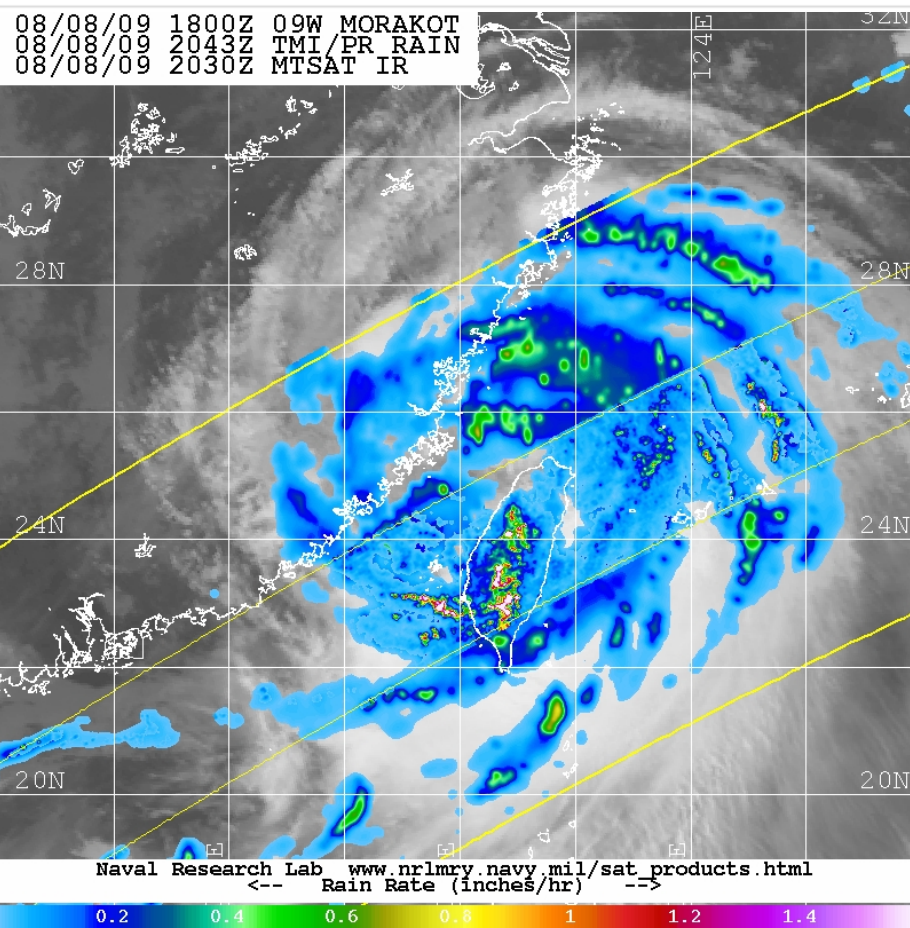
# □ Snap shots showing asymmetric structure at selected times



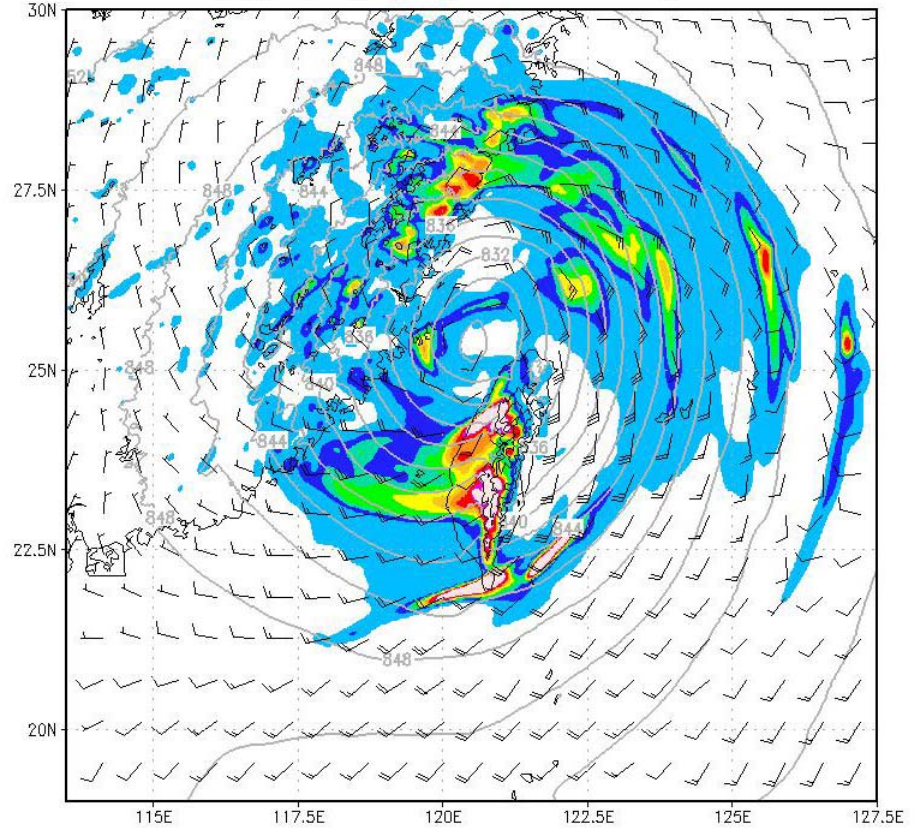
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# Snap shots showing asymmetric structure at selected times



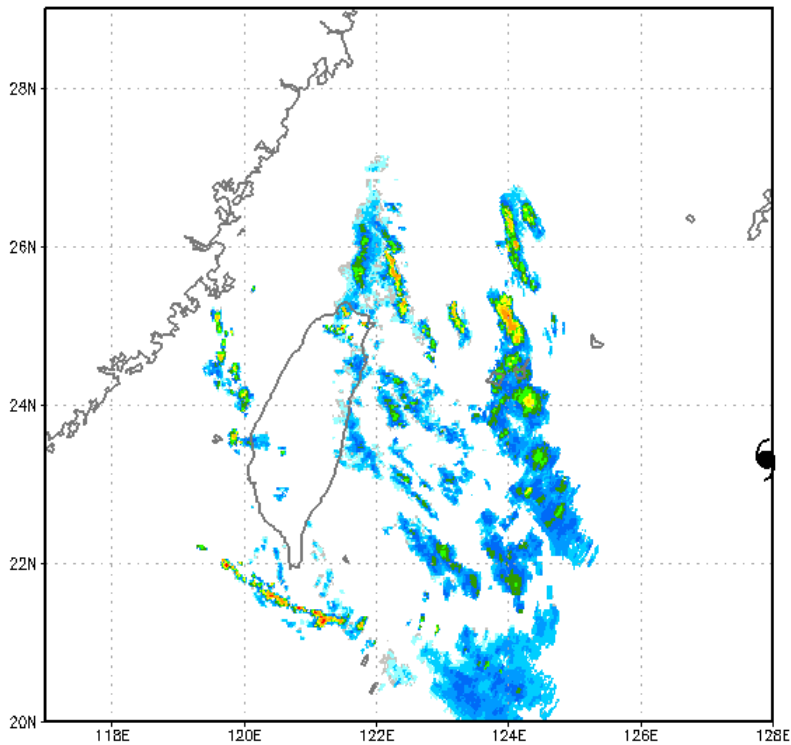
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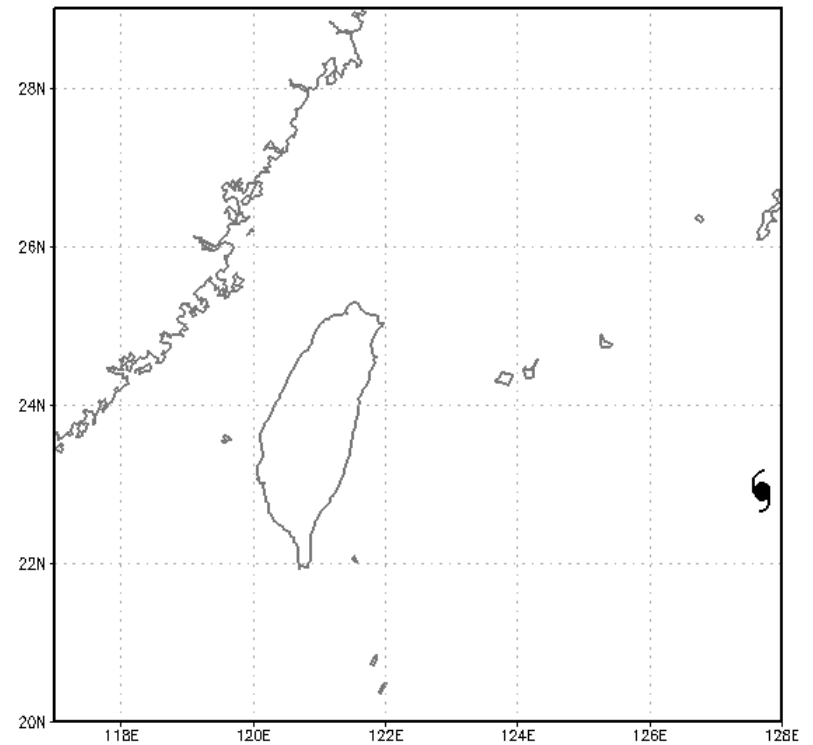
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□ Evolution of Morakot near Taiwan: Radar reflectivity vs.  $q_3\text{max}$

00Z06AUG2009

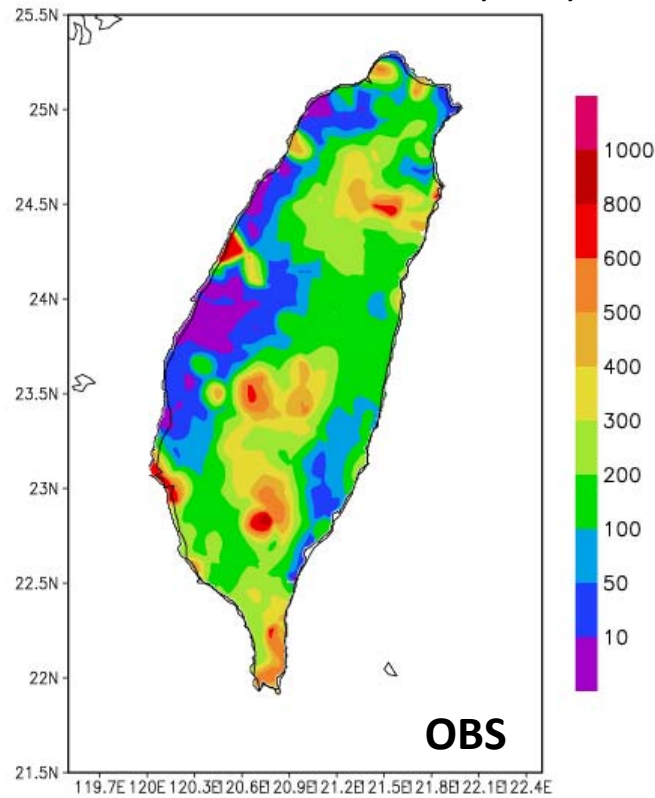


$q_3\text{max}$  ( $q_r+q_g+q_s$ ) 2009 08/06 0000 UTC

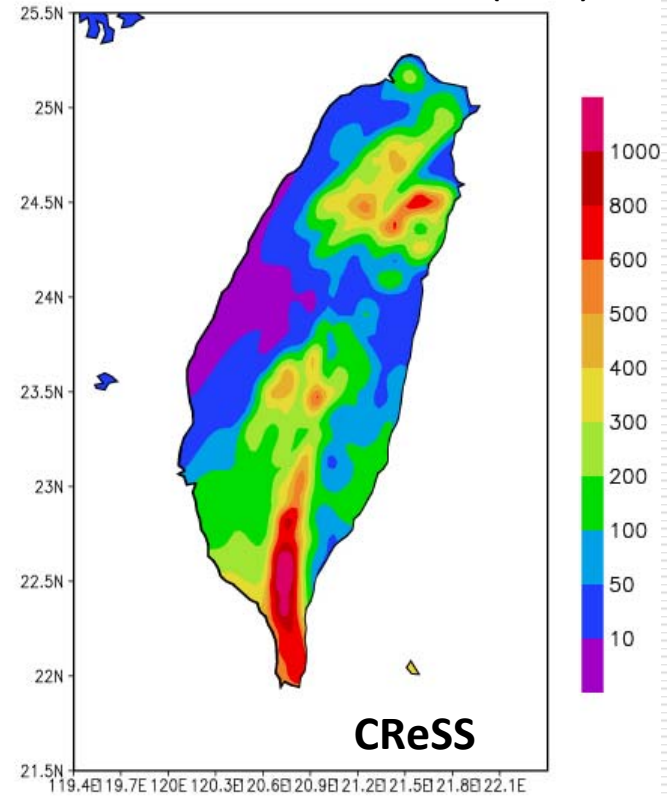


## □ Daily accumulative rainfall over Taiwan (7-9 Aug)

2009/08/07 00-24 LST (mm)

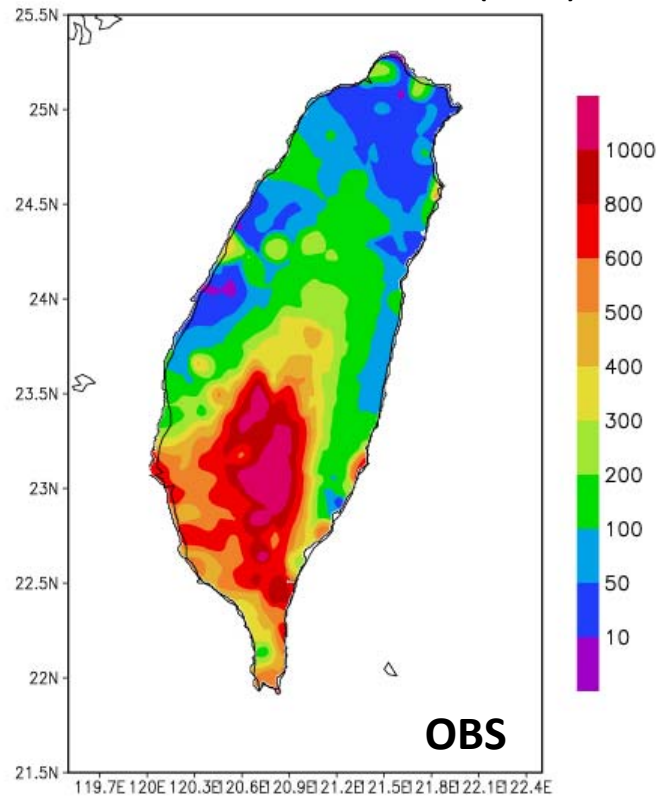


2009/08/07 00-24 LST (mm)

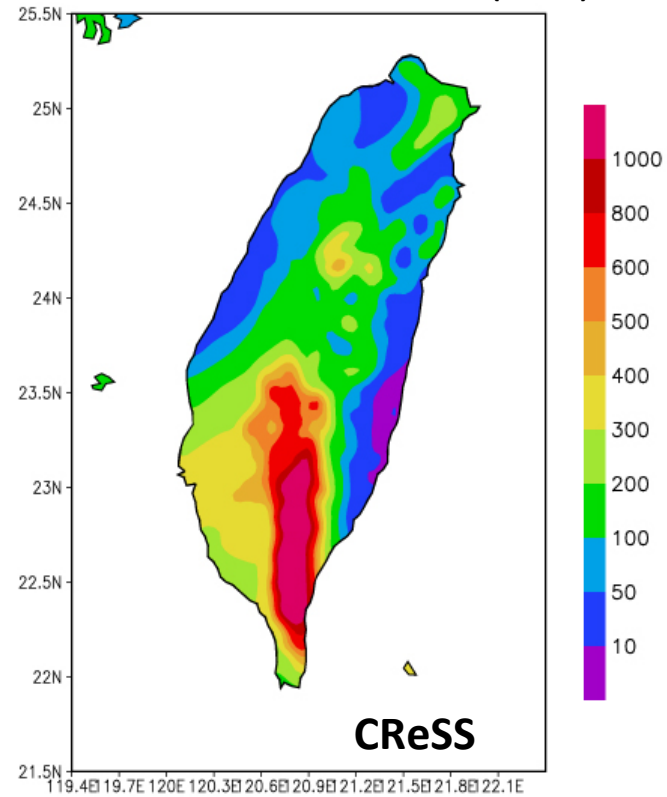


## □ Daily accumulative rainfall over Taiwan (7-9 Aug)

2009/08/08 00-24 LST (mm)

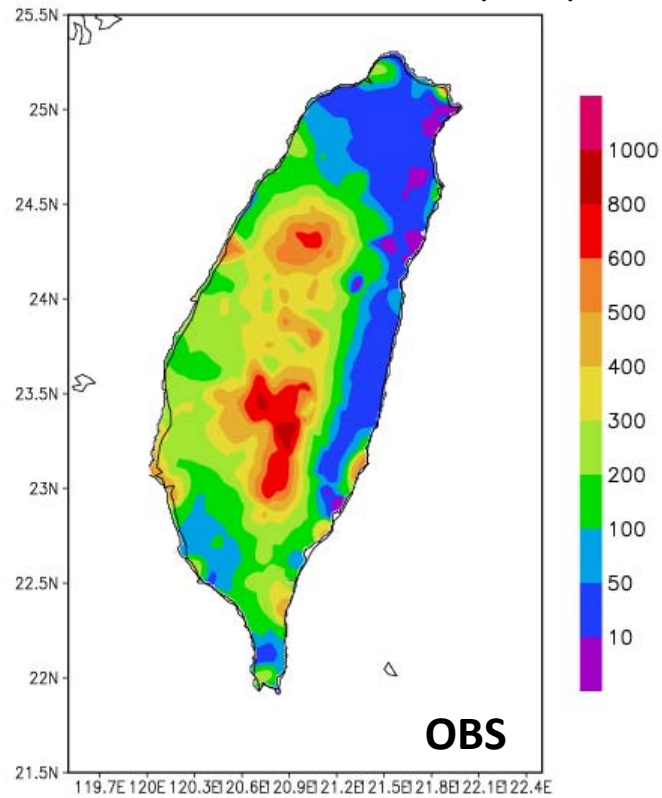


2009/08/08 00-24 LST (mm)

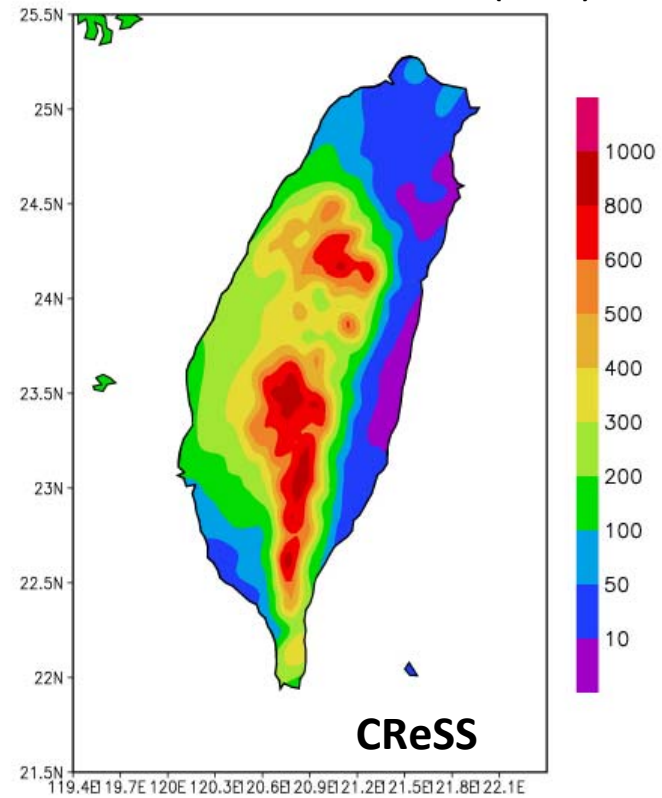


## □ Daily accumulative rainfall over Taiwan (7-9 Aug)

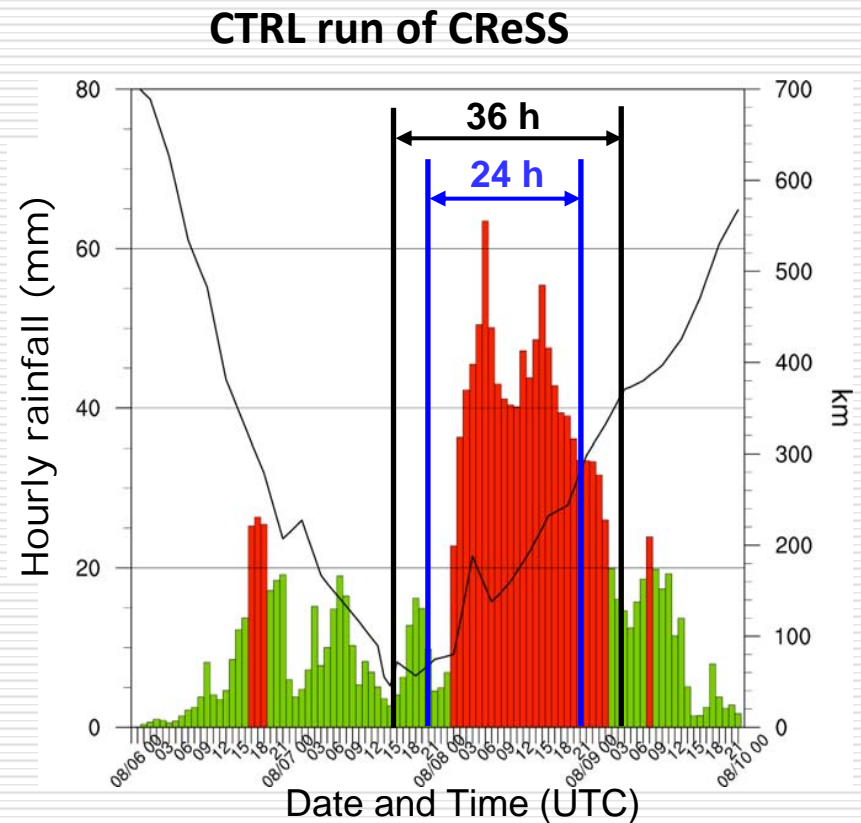
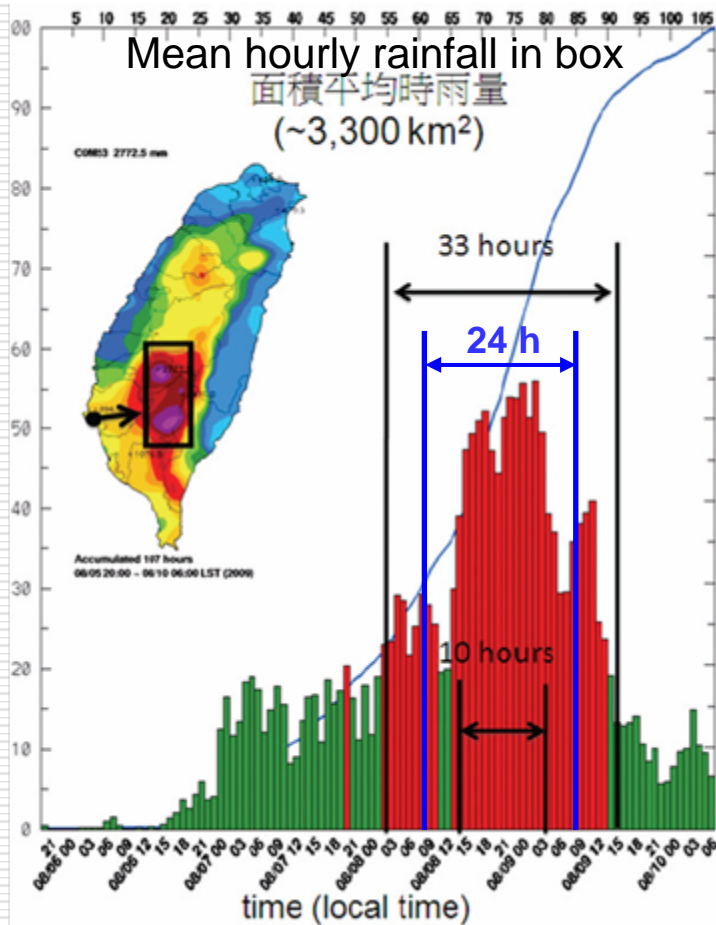
2009/08/09 00-24 LST (mm)



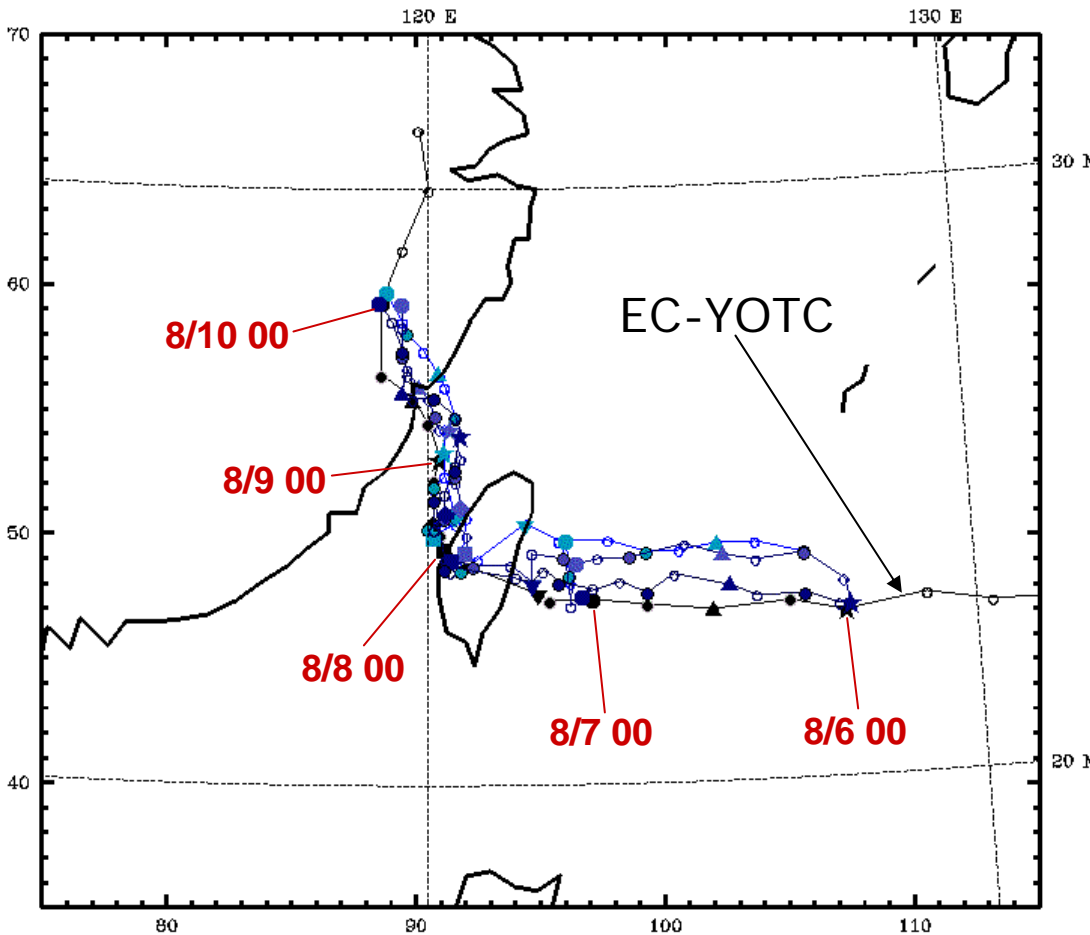
2009/08/09 00-24 LST (mm)



□ Rainfall histogram (inside box) during the simulation period



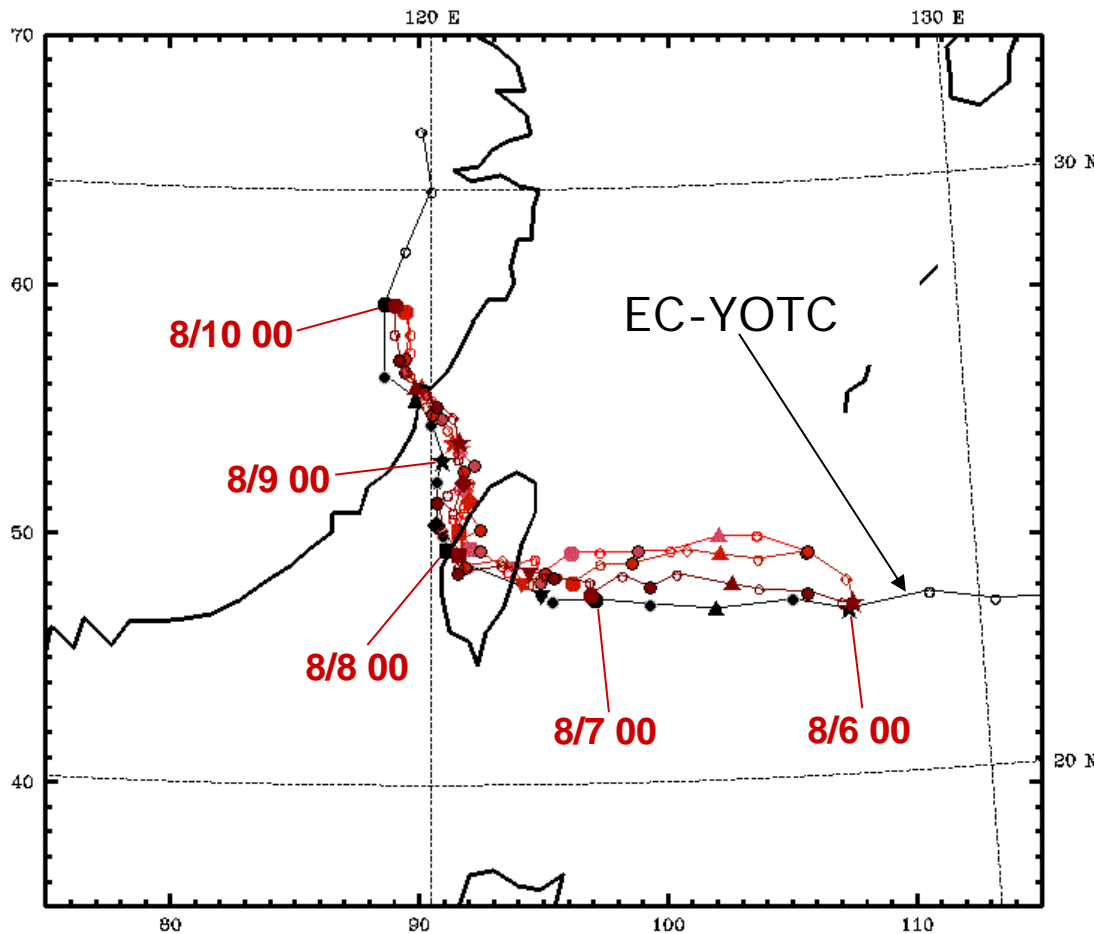
# Comparison of TC tracks in tests using 100% terrain height



- 8/6 00 ★
- 8/6 12 ▲
- 8/7 00 ●
- 8/7 12 ▼
- 8/8 00 ■
- 8/8 12 ◆
- 8/9 00 ★
- 8/9 12 ▲
- 8/10 00 ●

		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %	●	●	●	
	50 %				
	0 %				

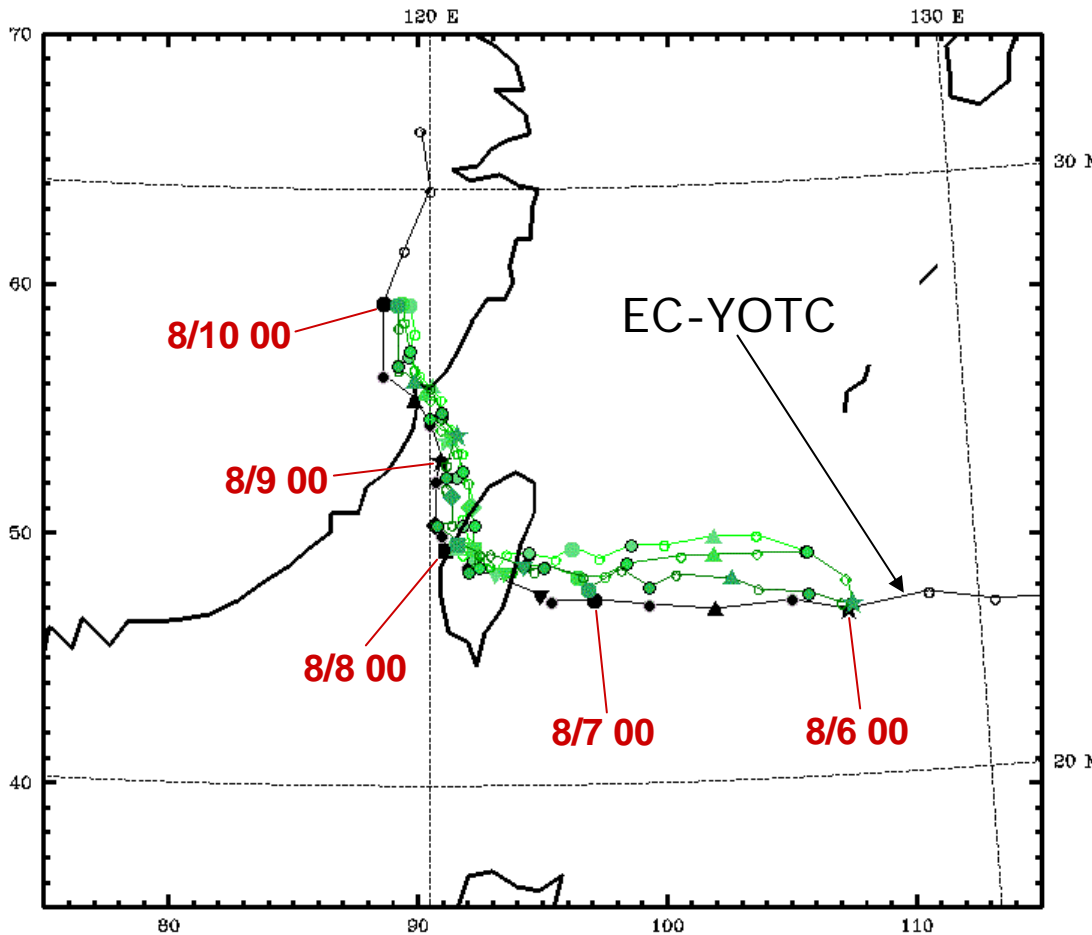
# Comparison of TC tracks in tests using 50% terrain height



- 8/6 00 ★
- 8/6 12 ▲
- 8/7 00 ●
- 8/7 12 ▼
- 8/8 00 ■
- 8/8 12 ◆
- 8/9 00 ★
- 8/9 12 ▲
- 8/10 00 ●

		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %				
	50 %	●	●	●	
	0 %				

# Comparison of TC tracks in tests using 0% (1 m) terrain height

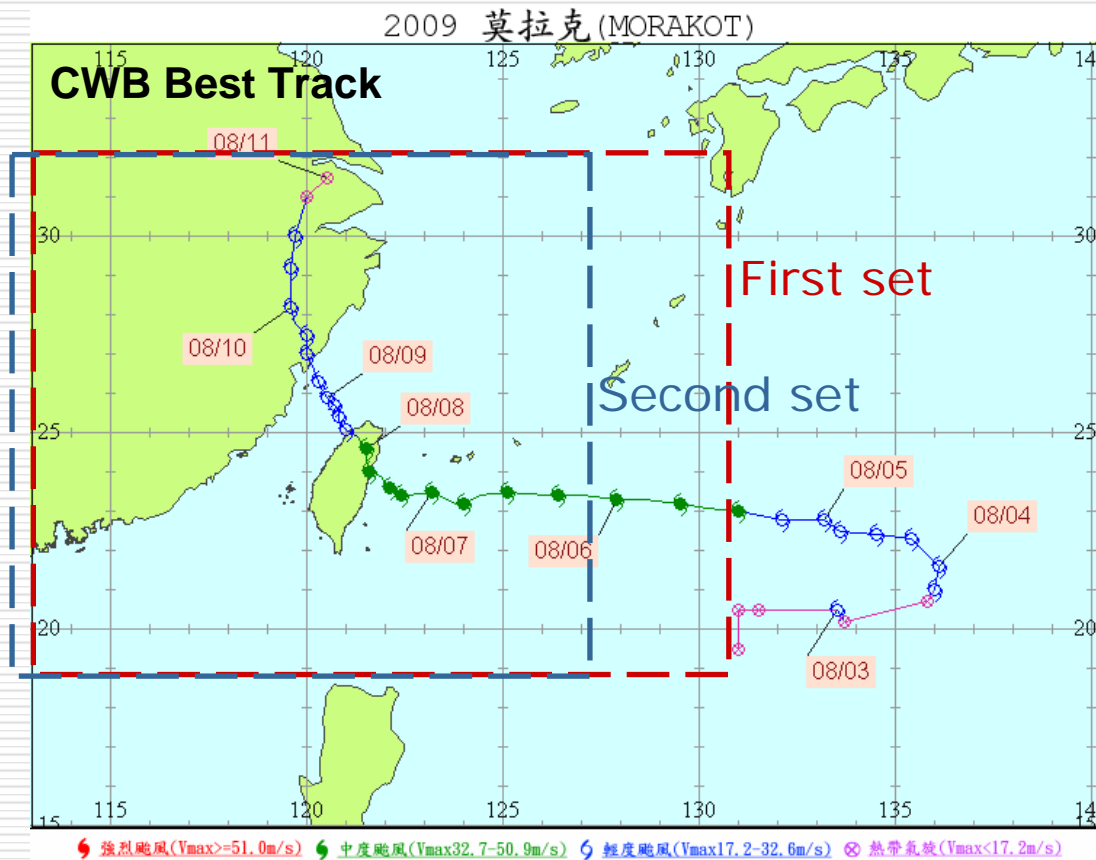


- 8/6 00 ★
- 8/6 12 ▲
- 8/7 00 ●
- 8/7 12 ▼
- 8/8 00 ■
- 8/8 12 ◆
- 8/9 00 ★
- 8/9 12 ▲
- 8/10 00 ●

		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %				
	50 %				
	0 %	●	●	●	

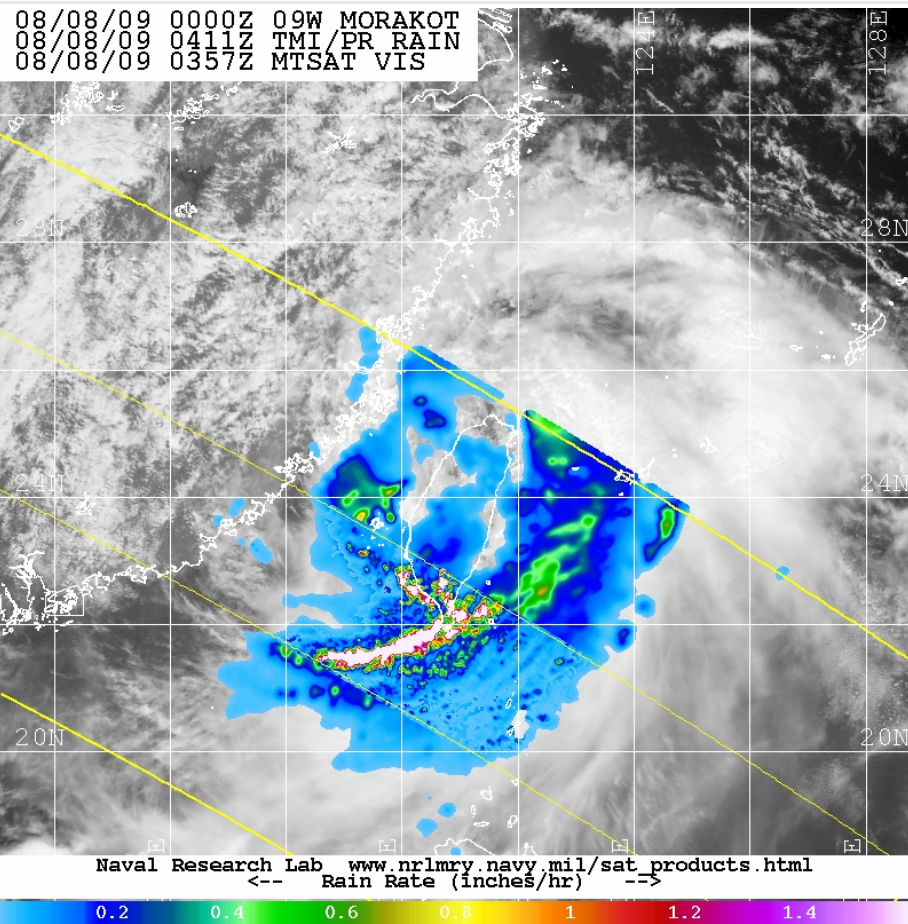
□ A second set of 12 runs performed from 0000 UTC 8 Aug 2009, so that all TCs in model experience nearly identical steering flow

■ Same resolution but square domain (480 x 480)

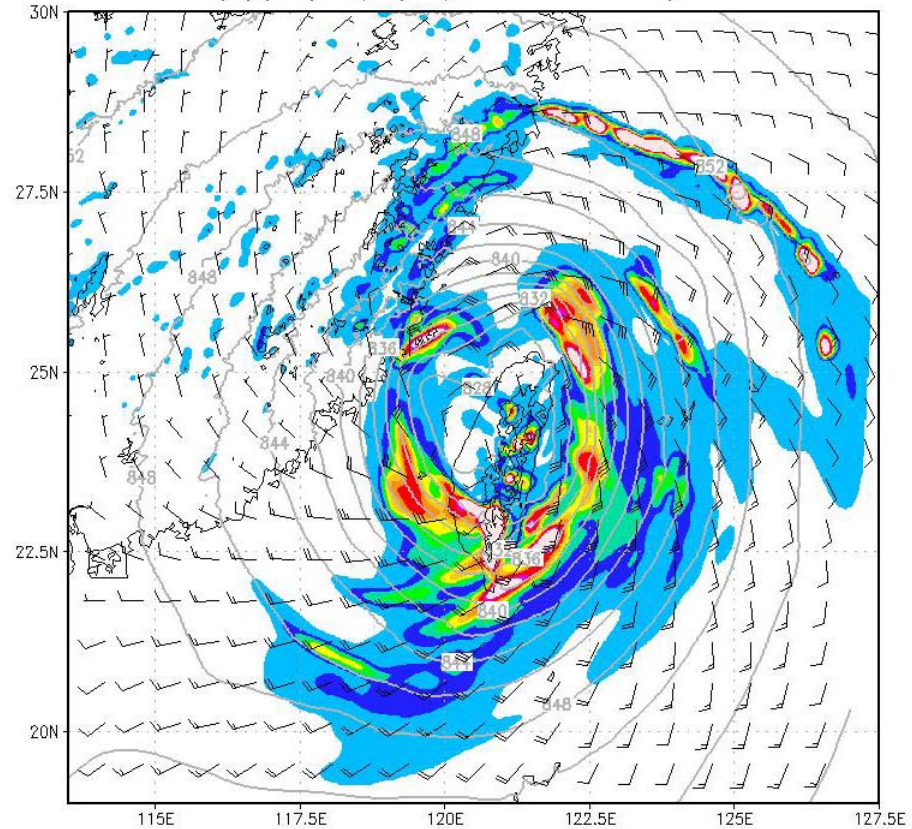


## 4. Results of Second-Set Experiment

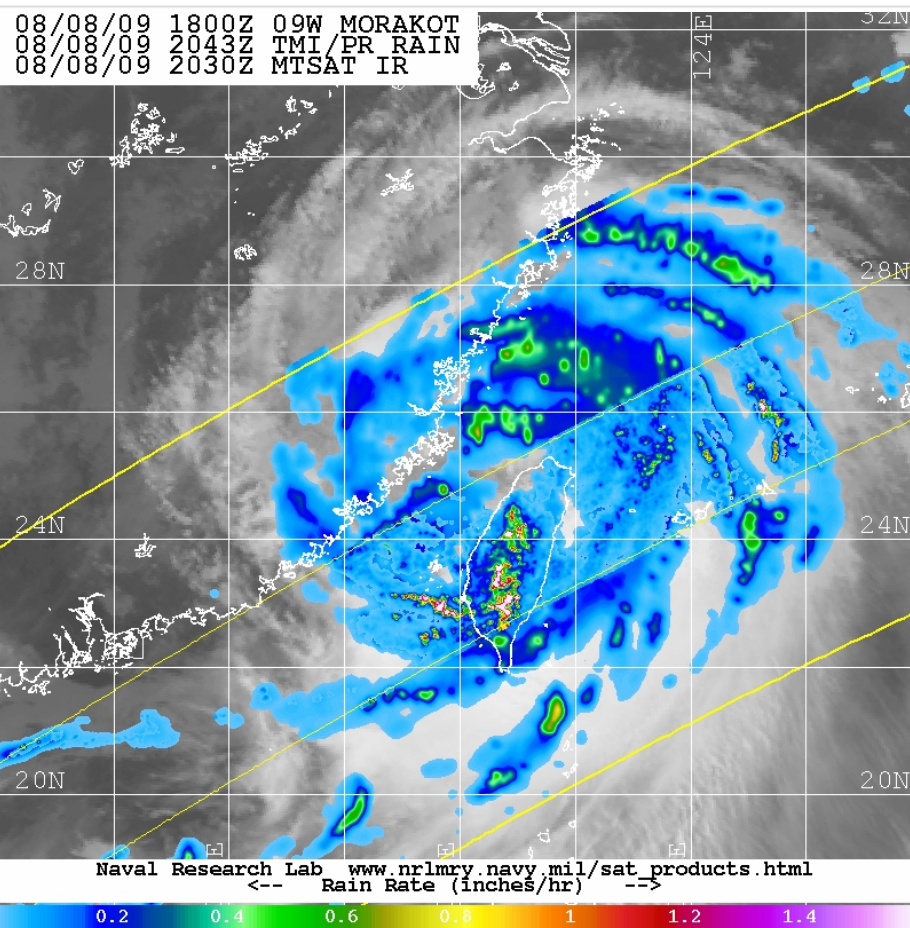
- Snap shots showing asymmetric structure at selected times



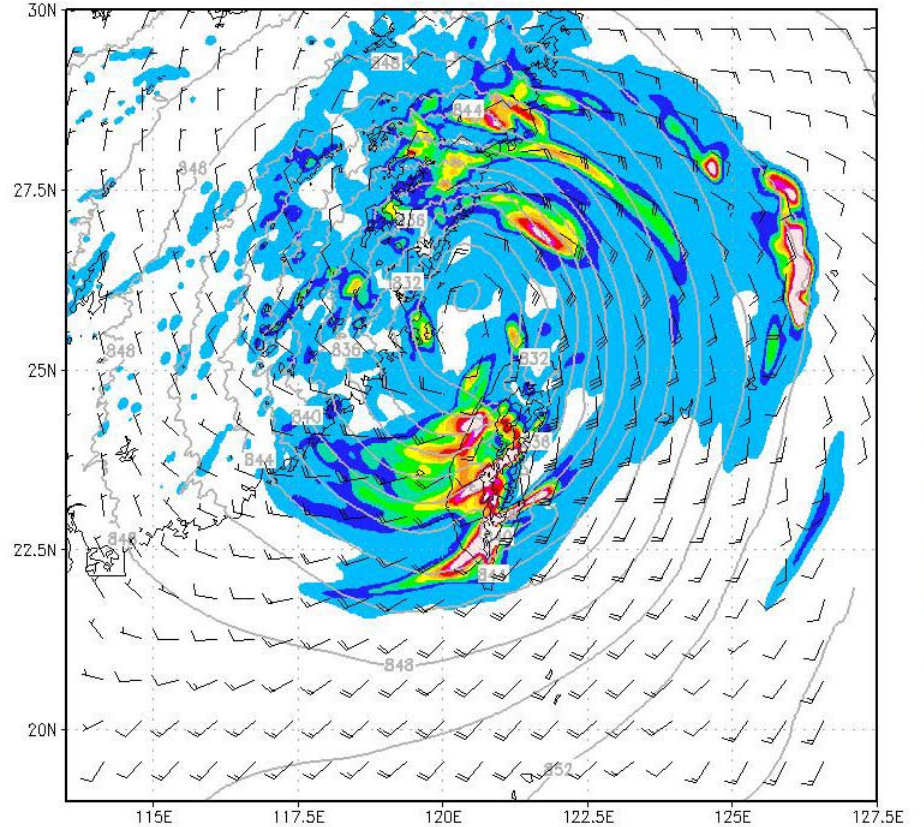
30min-rain/p/u/v(m/s) 2009 08/08 0400 UTC



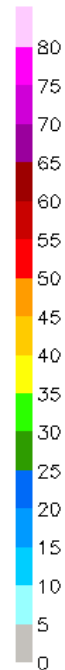
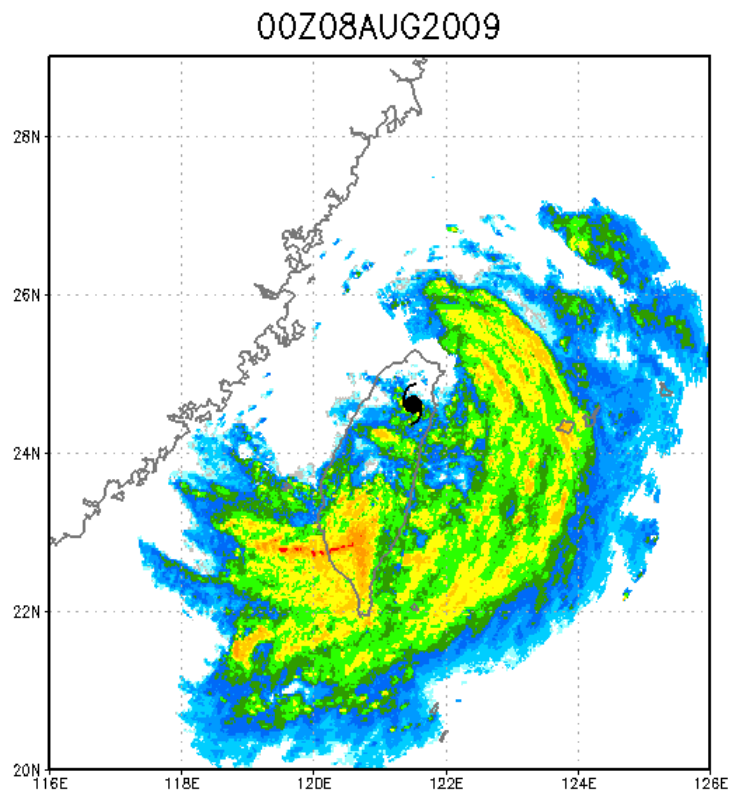
# Snap shots showing asymmetric structure at selected times



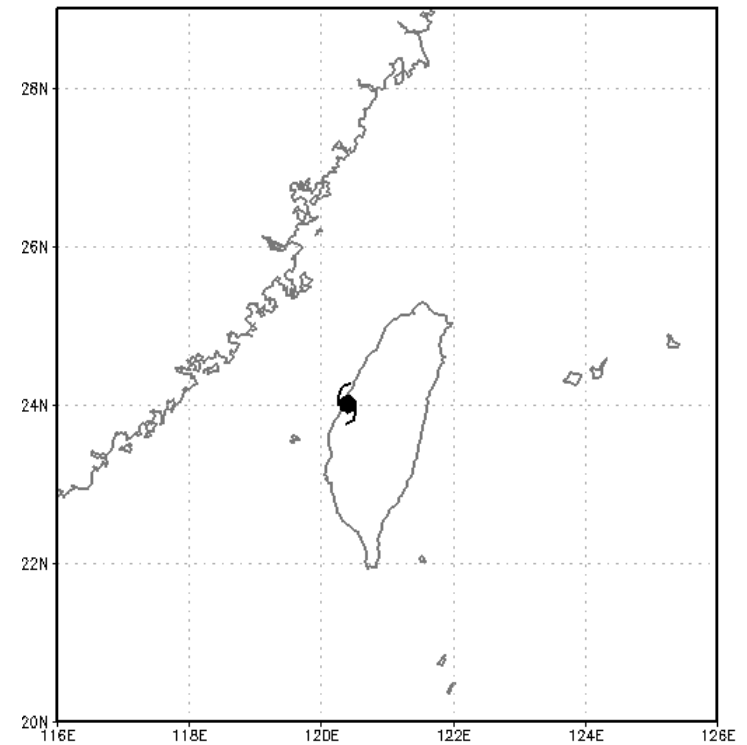
30min-rain/p/u/v(m/s) 2009 08/08 2030 UTC



## □ Evolution of Morakot near Taiwan: Radar reflectivity vs. q3max

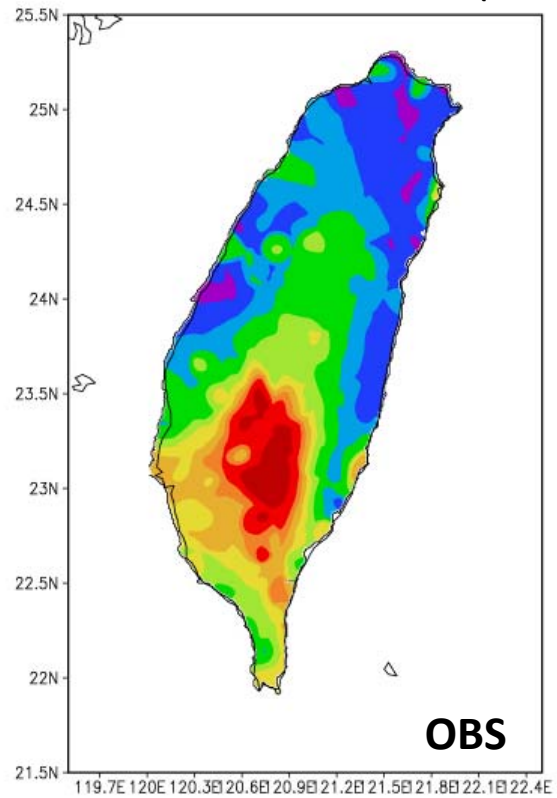


q3max (qr+qg+qs) 2009 08/08 0000 UTC

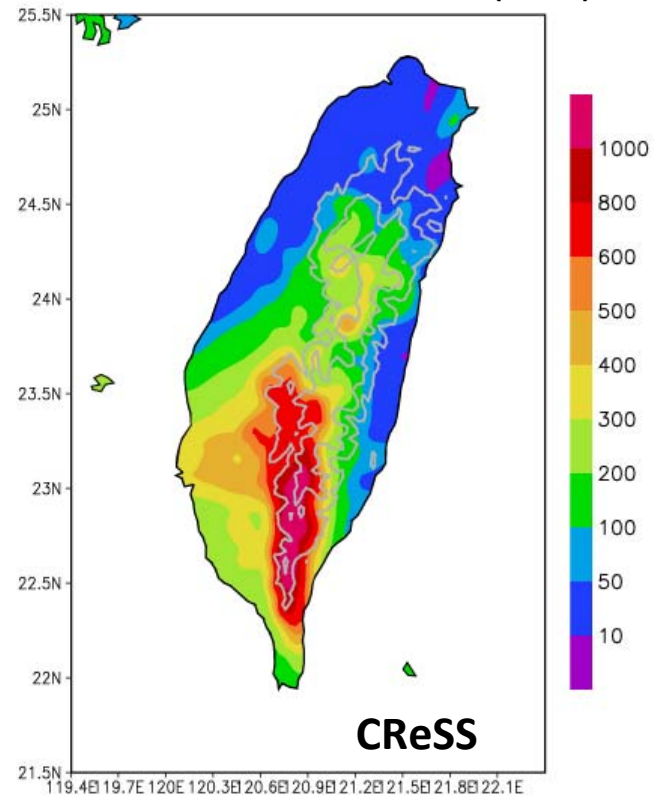


## □ Daily accumulative rainfall over Taiwan (8-9 Aug)

2009/08/08 08-24 LST (mm)

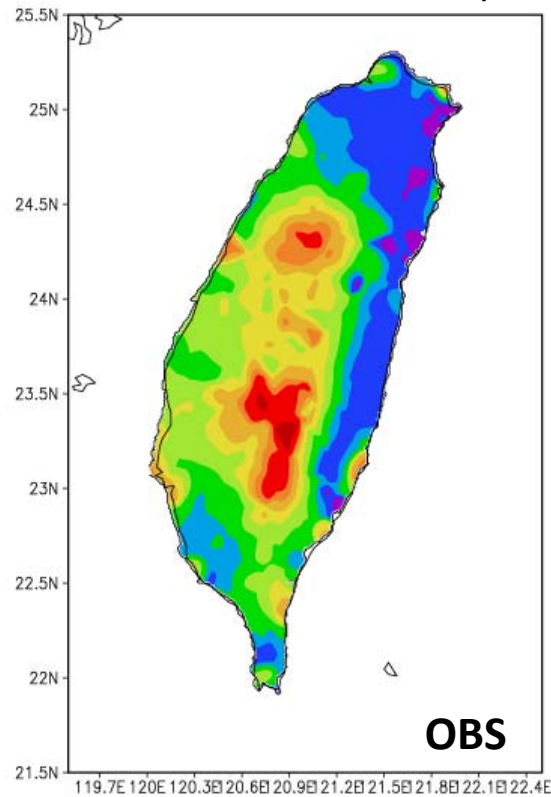


2009/08/08 08-24 LST (mm)

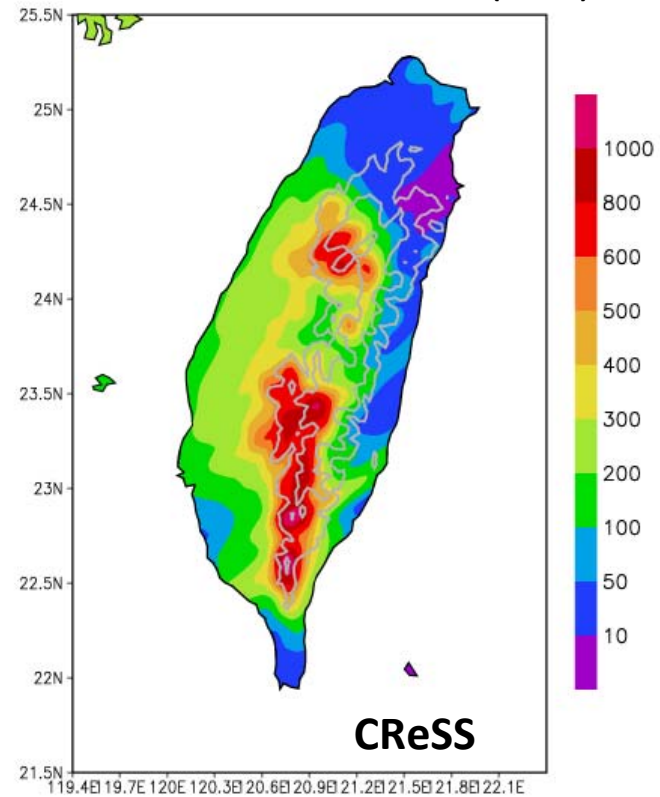


## □ Daily accumulative rainfall over Taiwan (8-9 Aug)

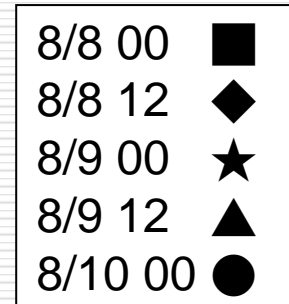
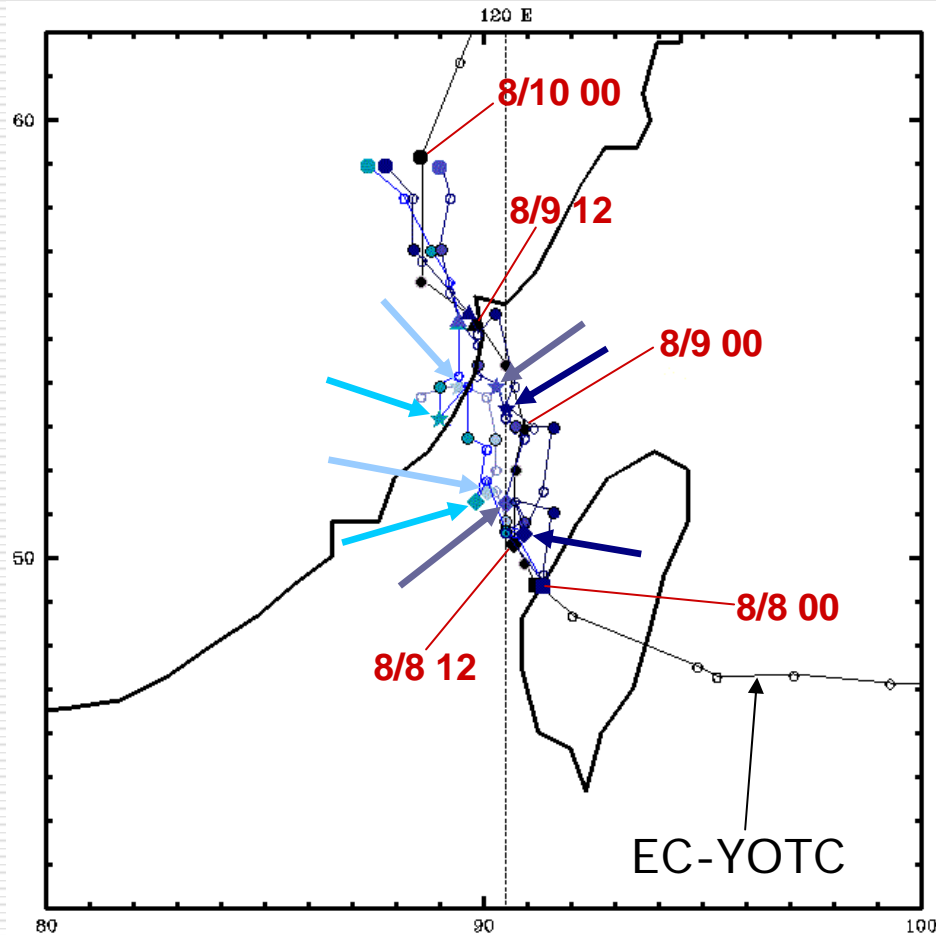
2009/08/09 00-24 LST (mm)



2009/08/09 00-24 LST (mm)



# Comparison of TC tracks in tests using 100% terrain height

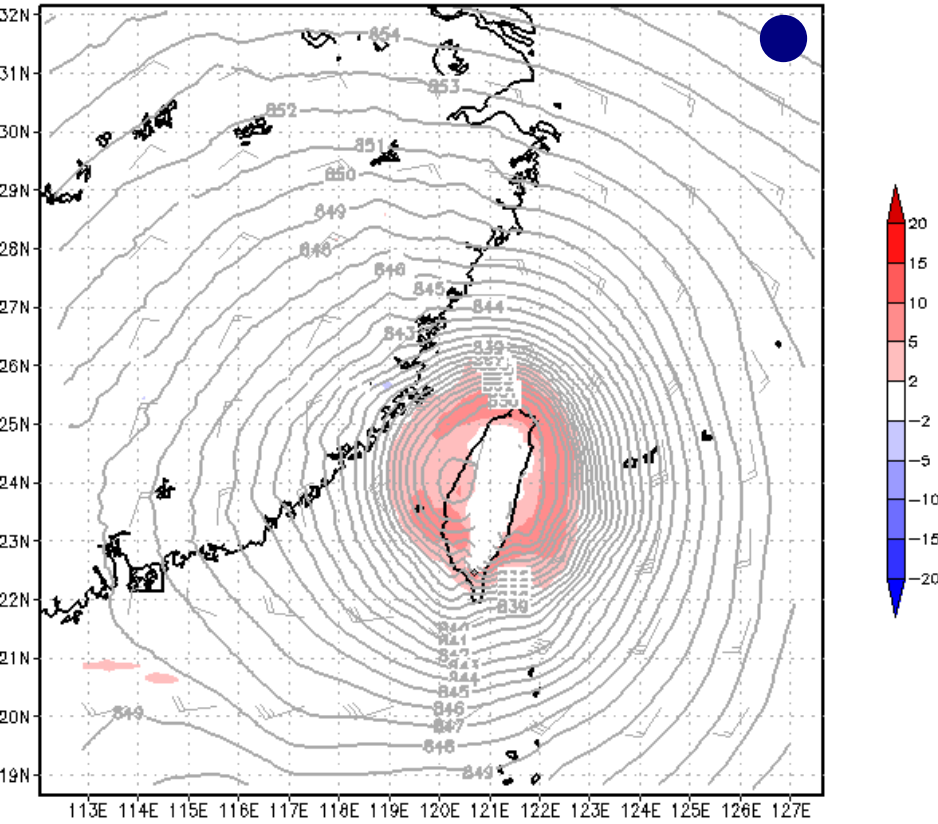


		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %				
	50 %				
	0 %				

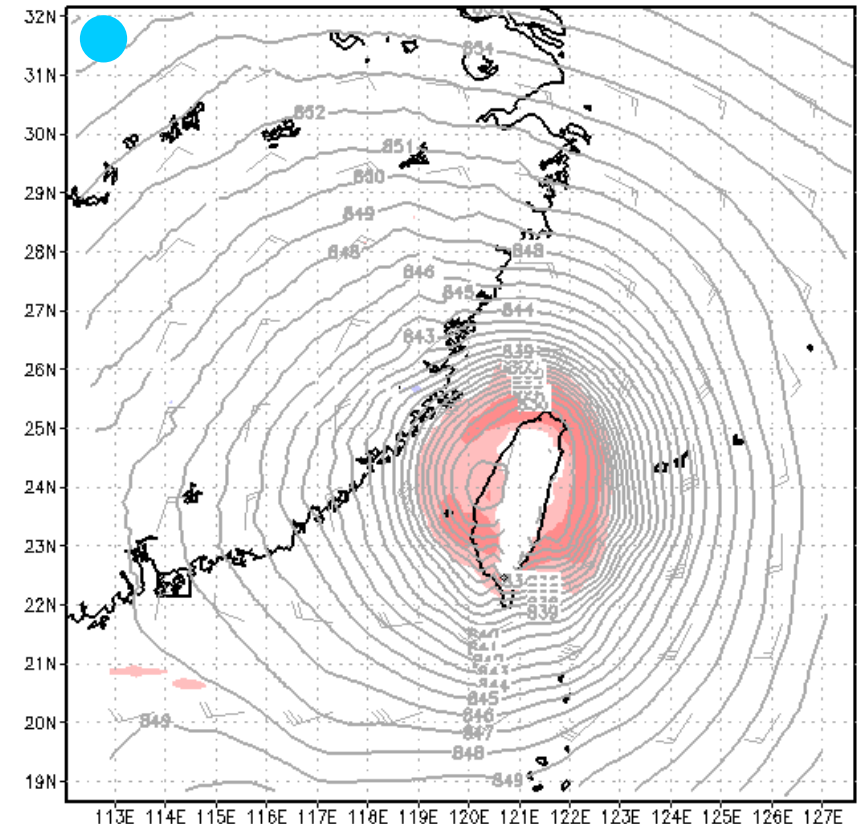
# TC evolution at 1500 m: [1] vs [3]

		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %	●		●	
	50 %				
	0 %				

0m vort(-4)/u/v/w(m/s) 2009 08/08 0000 UTC

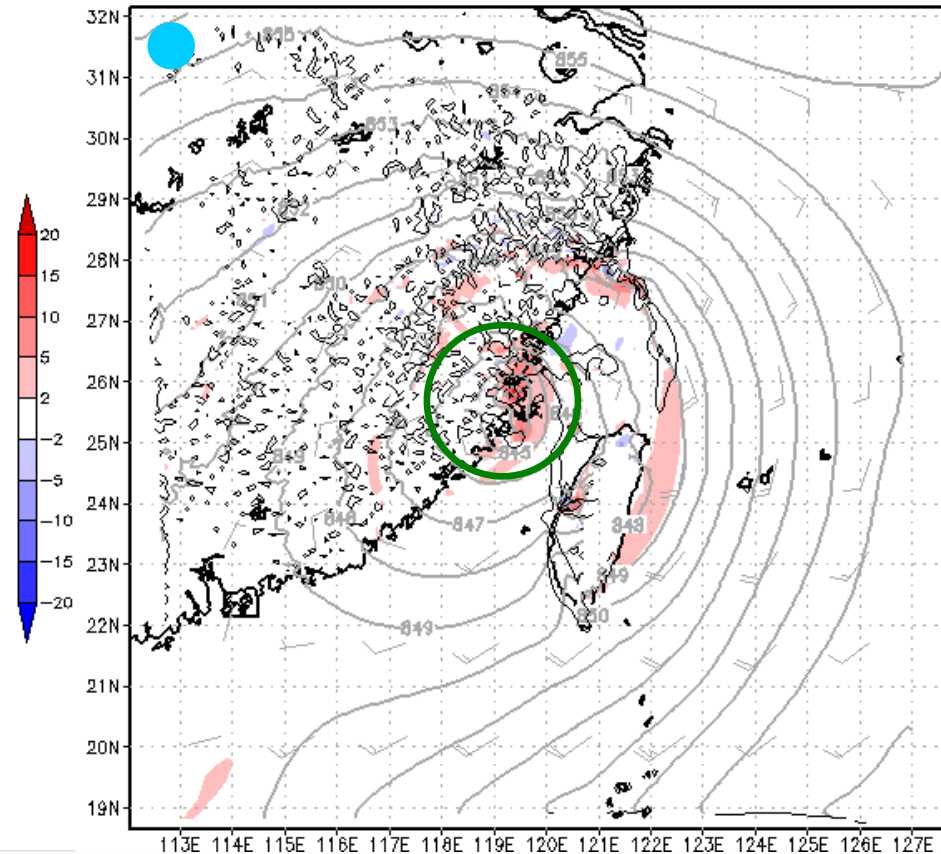
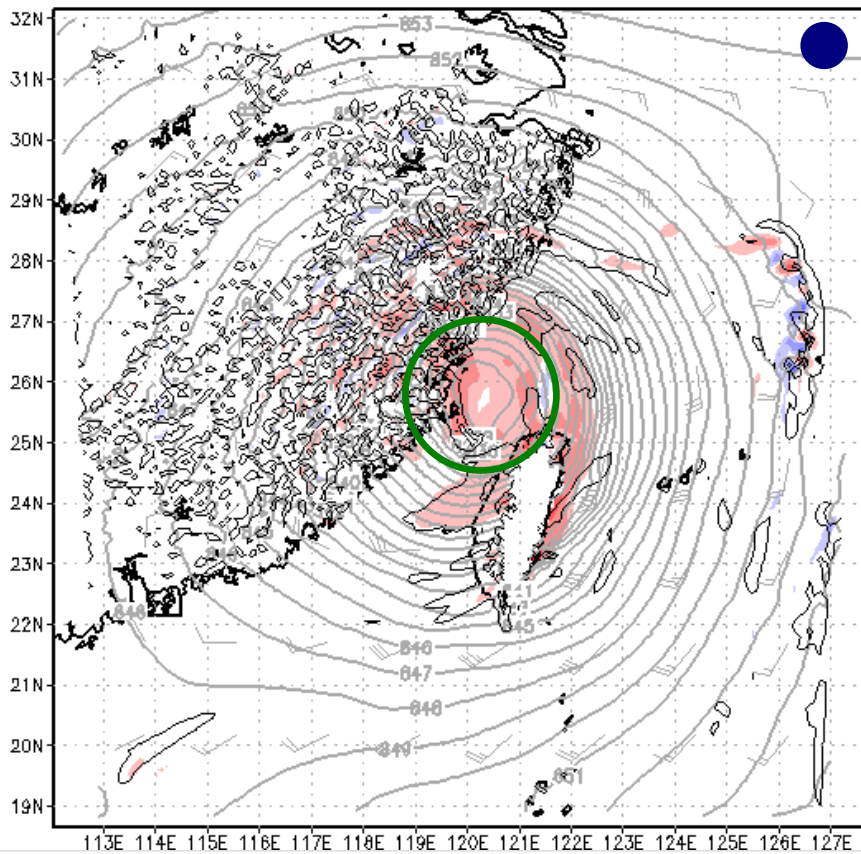


500m vort(-4)/u/v/w(m/s) 2009 08/08 0000 UTC

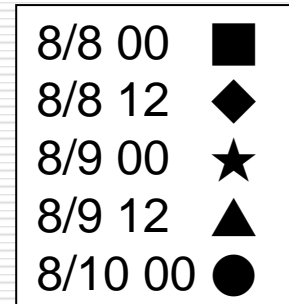
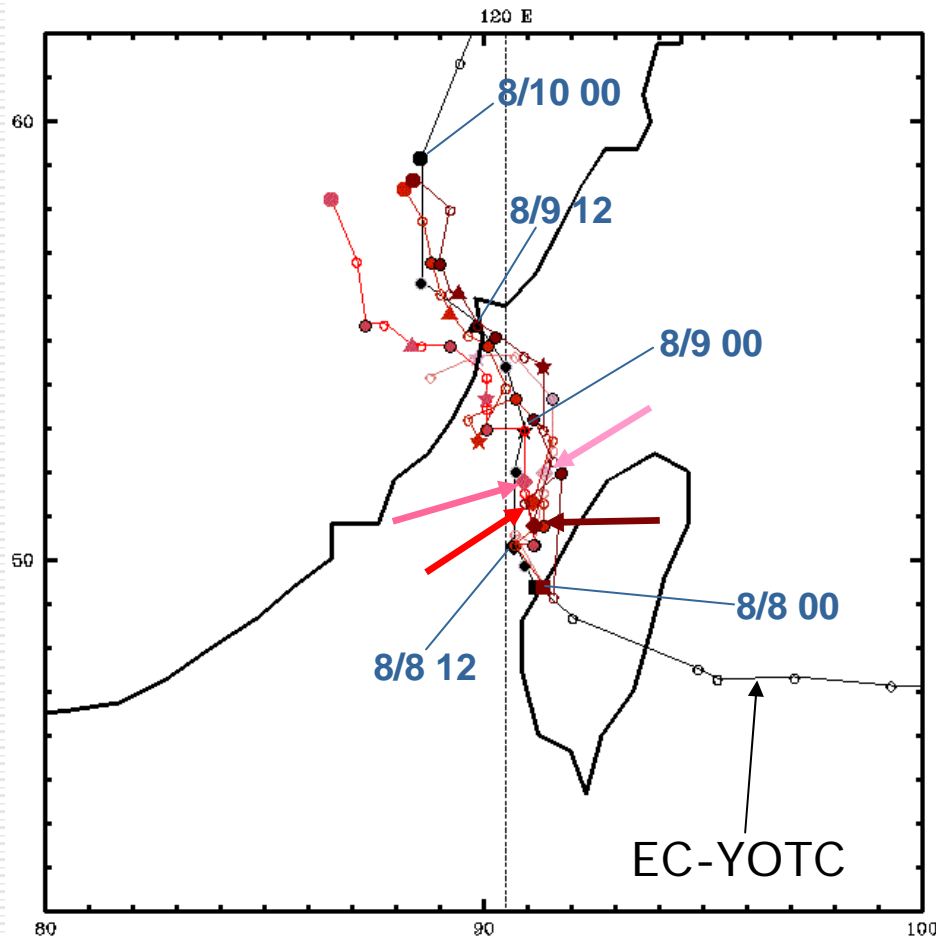


Plotted: Z, winds, w,  $\zeta$  ( $10^{-4} \text{ s}^{-1}$ , shading)

■ Comparison of TC center at 2200 UTC 8 Aug 2009 (z = 1.5 km)

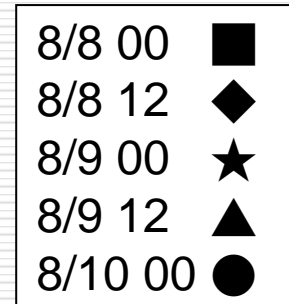
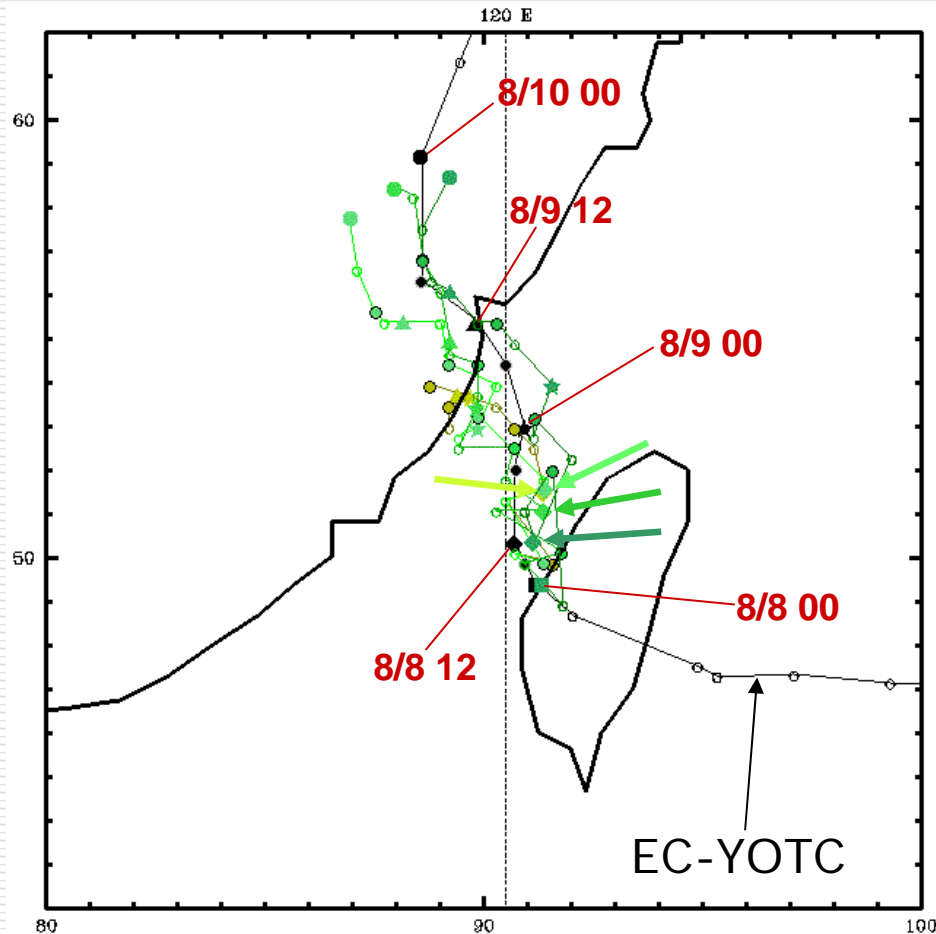


# Comparison of TC tracks in tests using 50% terrain height



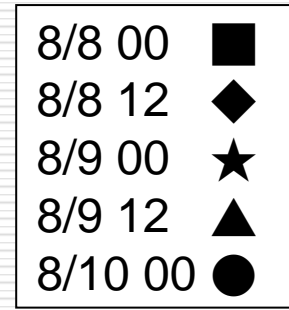
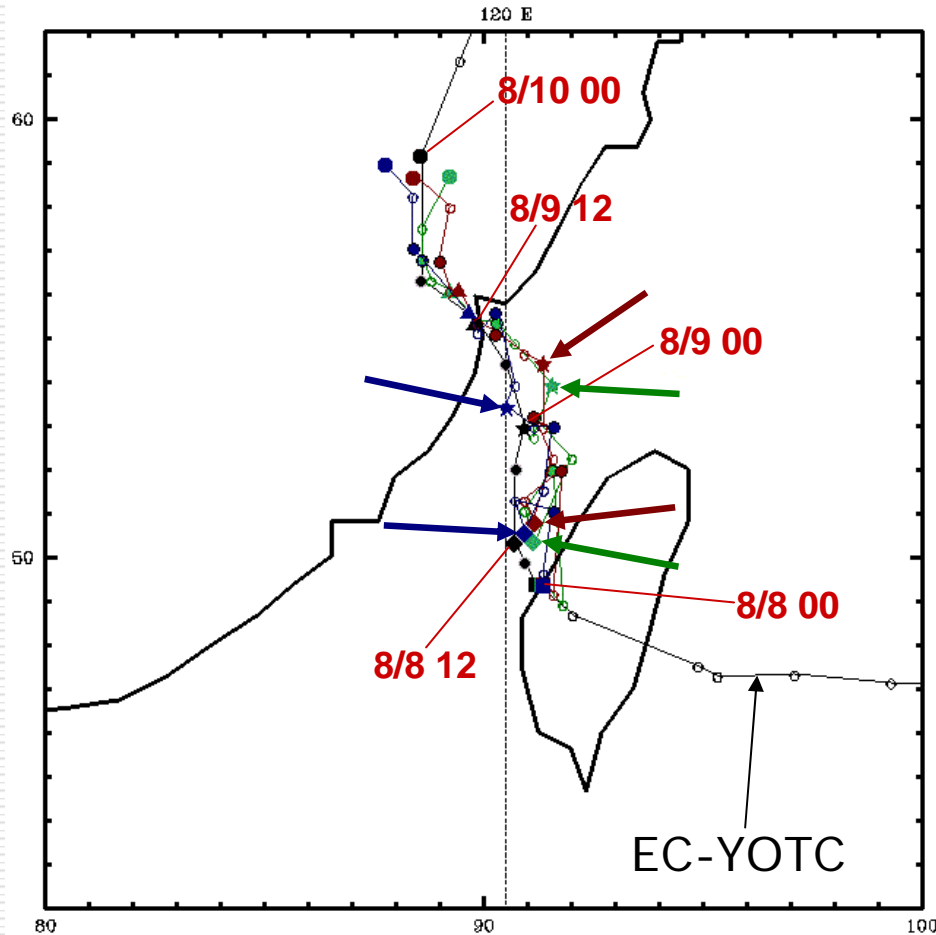
		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %				
	50 %				
	0 %				

Comparison of TC tracks in tests using 0% (1 m) terrain height



		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %				
	50 %				
	0 %	●	●	●	●

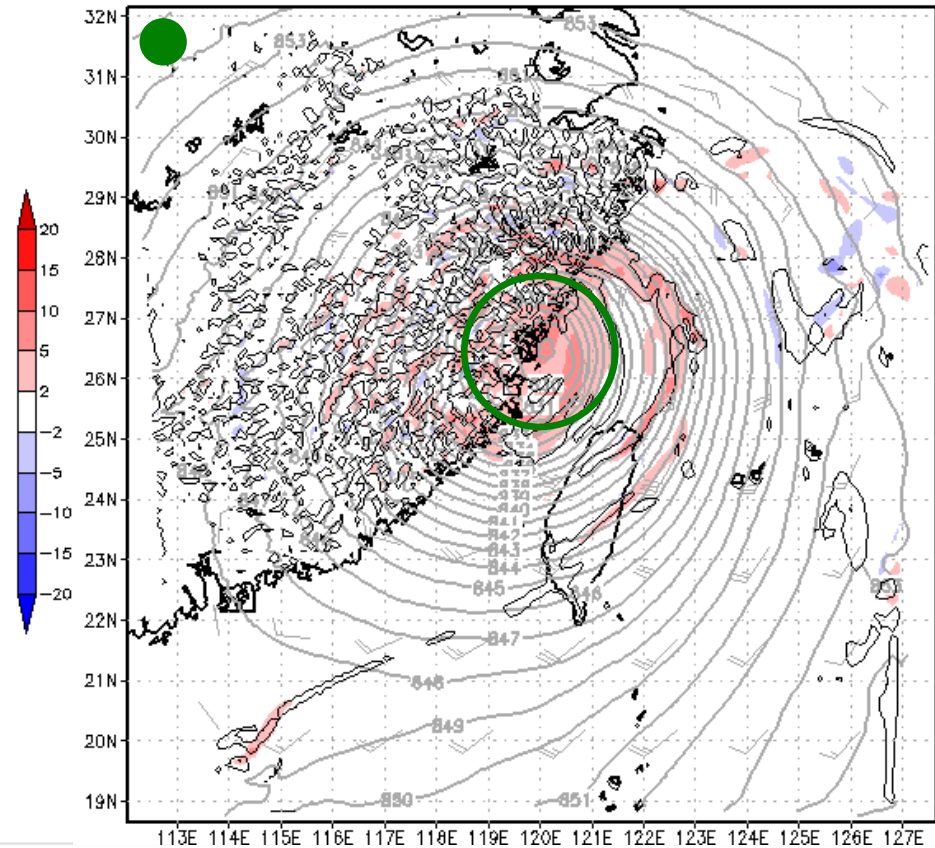
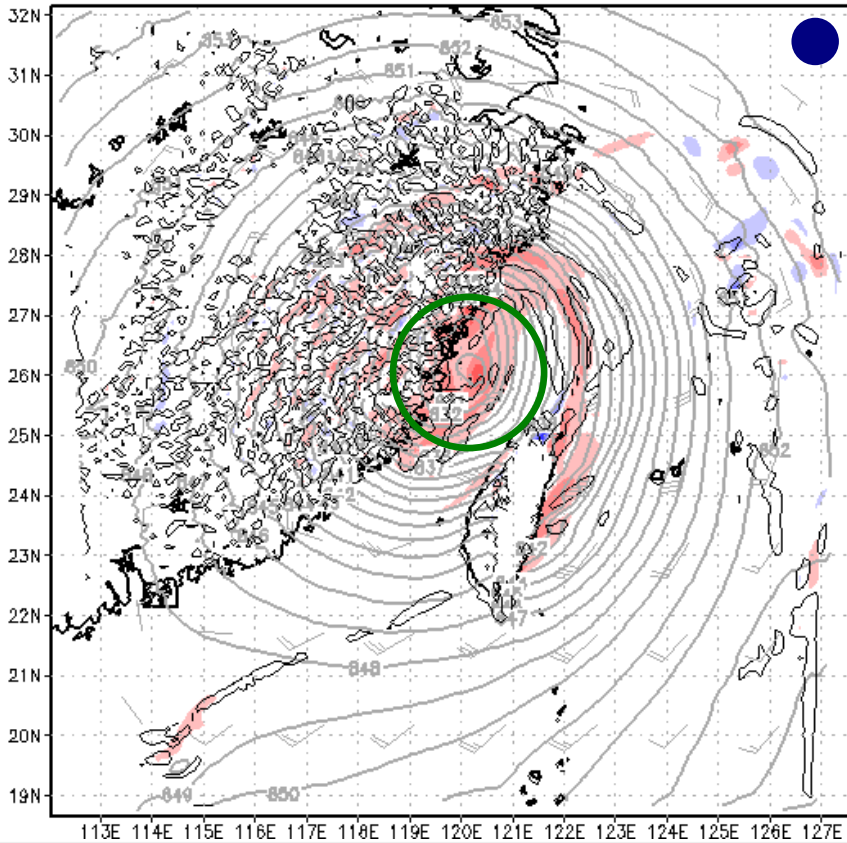
Comparison of TC tracks using different terrain height (100%  $q_v$ )







		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %	●			
	50 %	●			
	0 %	●			

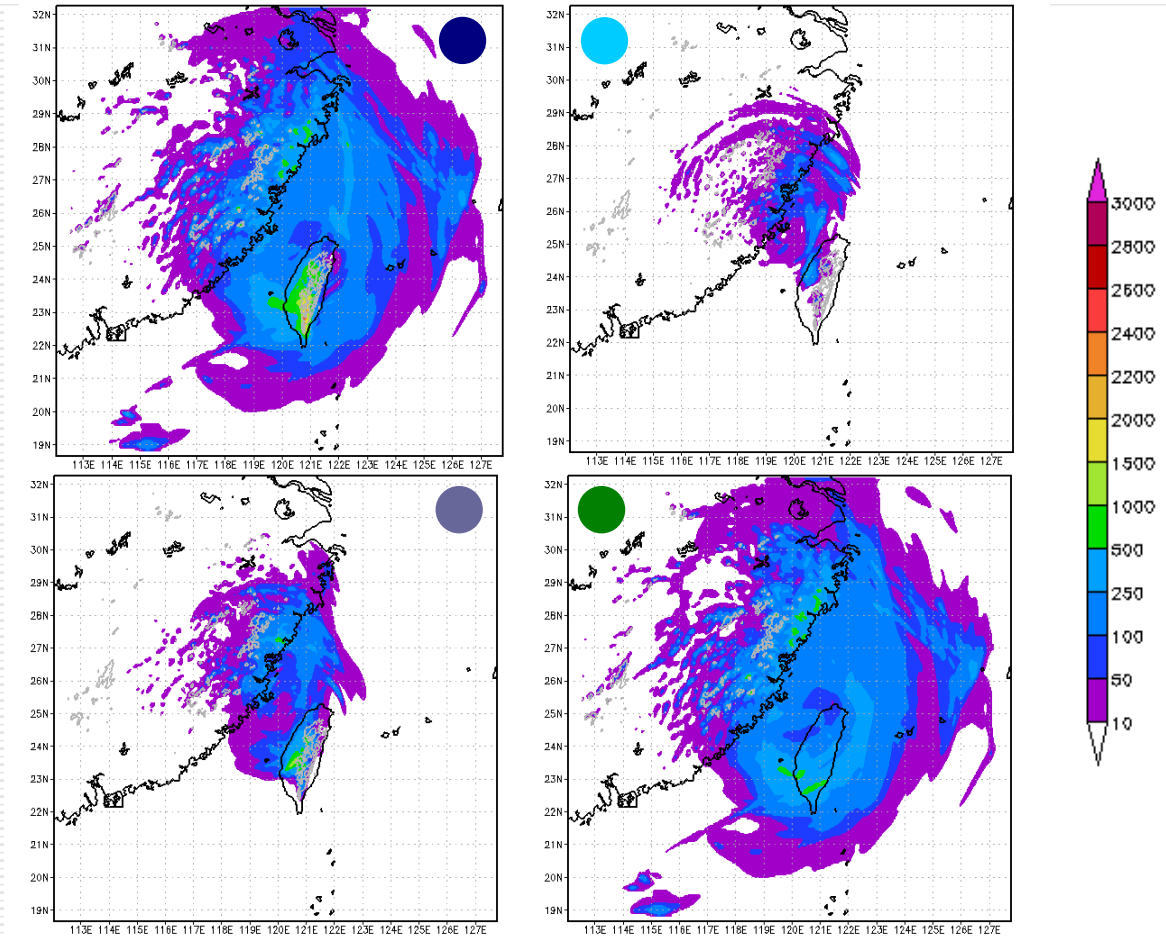
		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %	●			
	50 %				
	0 %	●			

■ Comparison of TC center at 0330 UTC 9 Aug 2009 (z = 1.5 km)

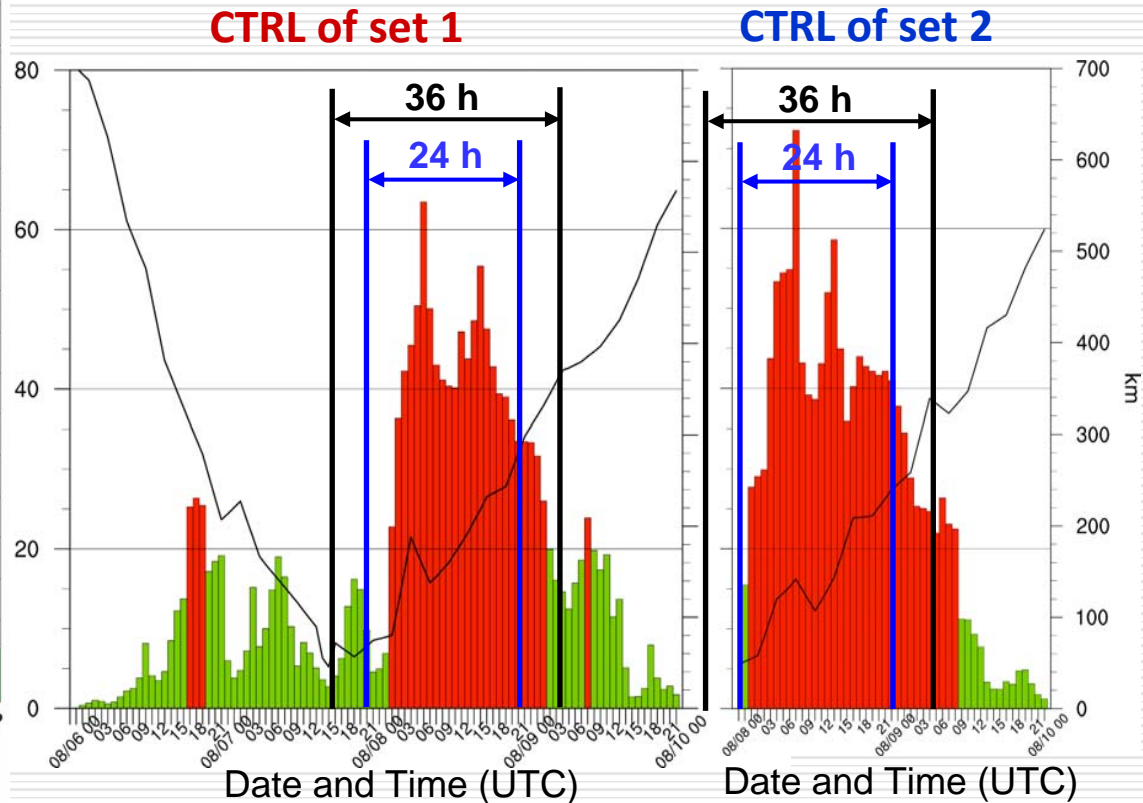
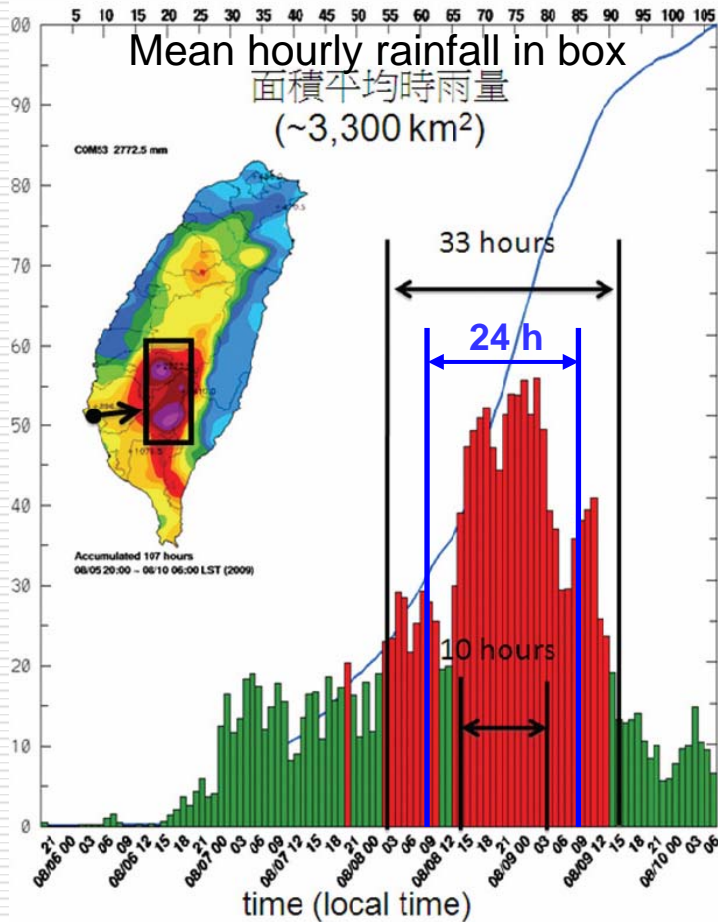


■ Comparison of 2-day total rainfall:

		Water vapor amount			
		100 %	50 %	25 %	0 %
Terrain height	100 %				
	50 %				
	0 %				

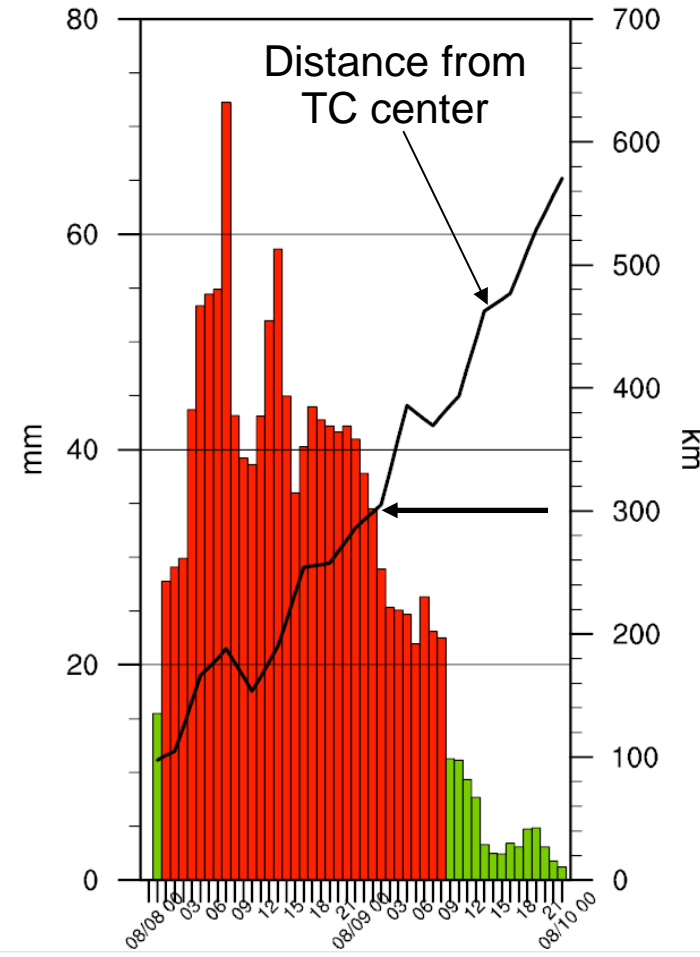
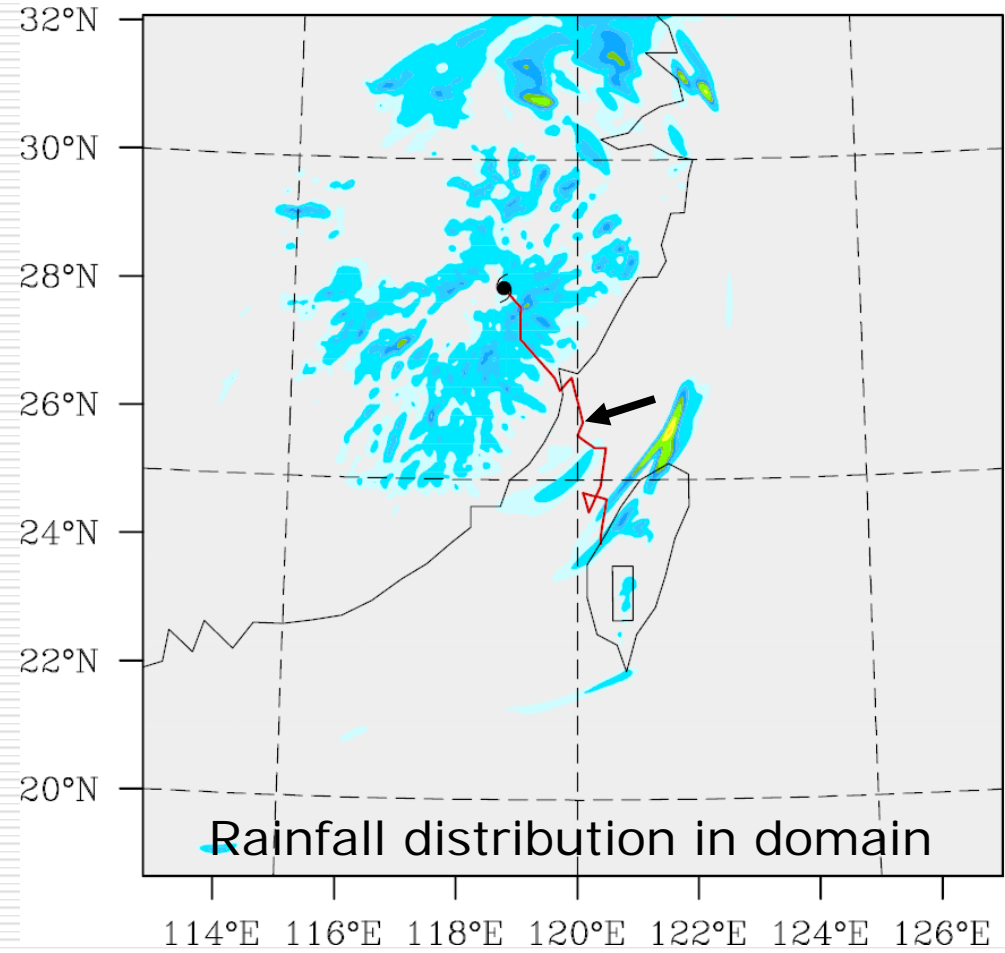


# ☐ Rainfall histogram (inside box) during the simulation period



08/10 00UTC

6.24 mm

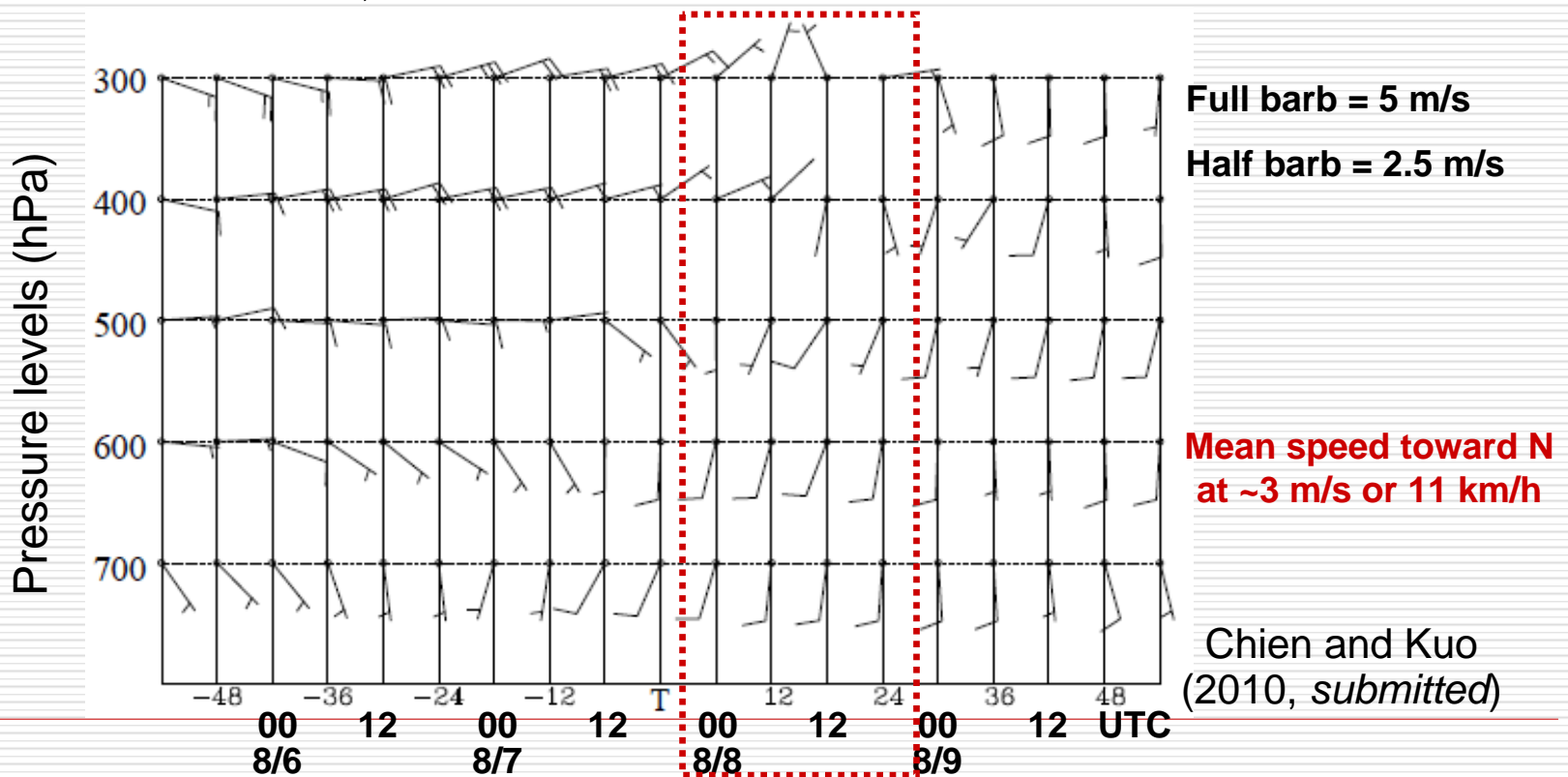


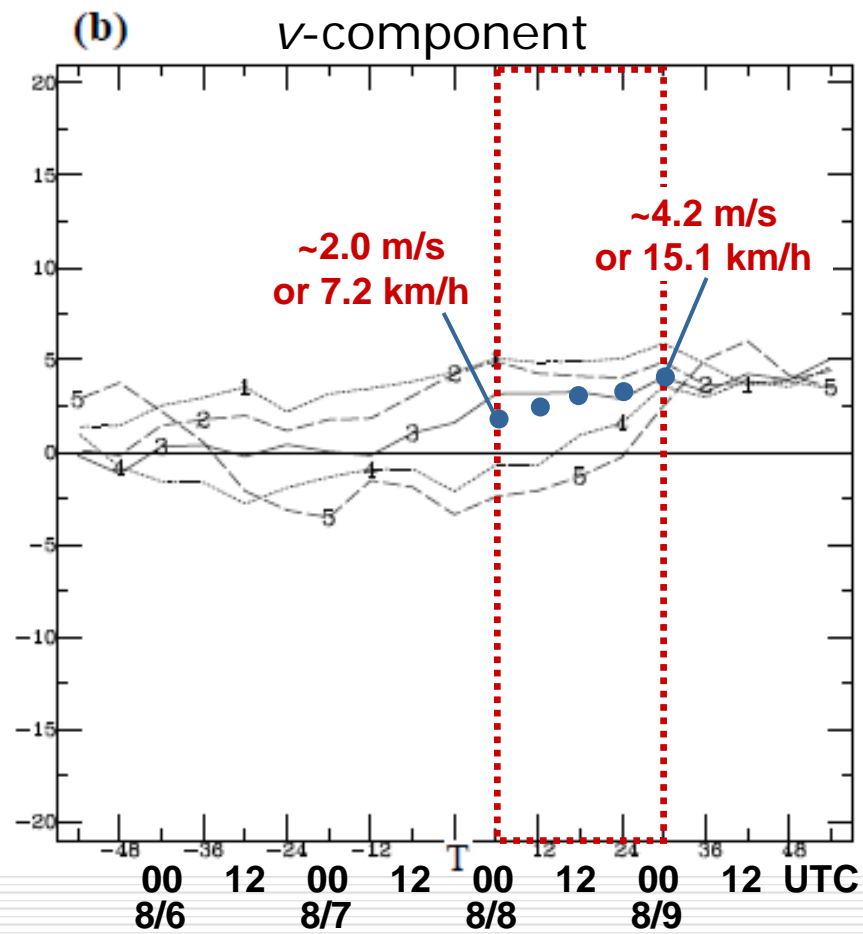
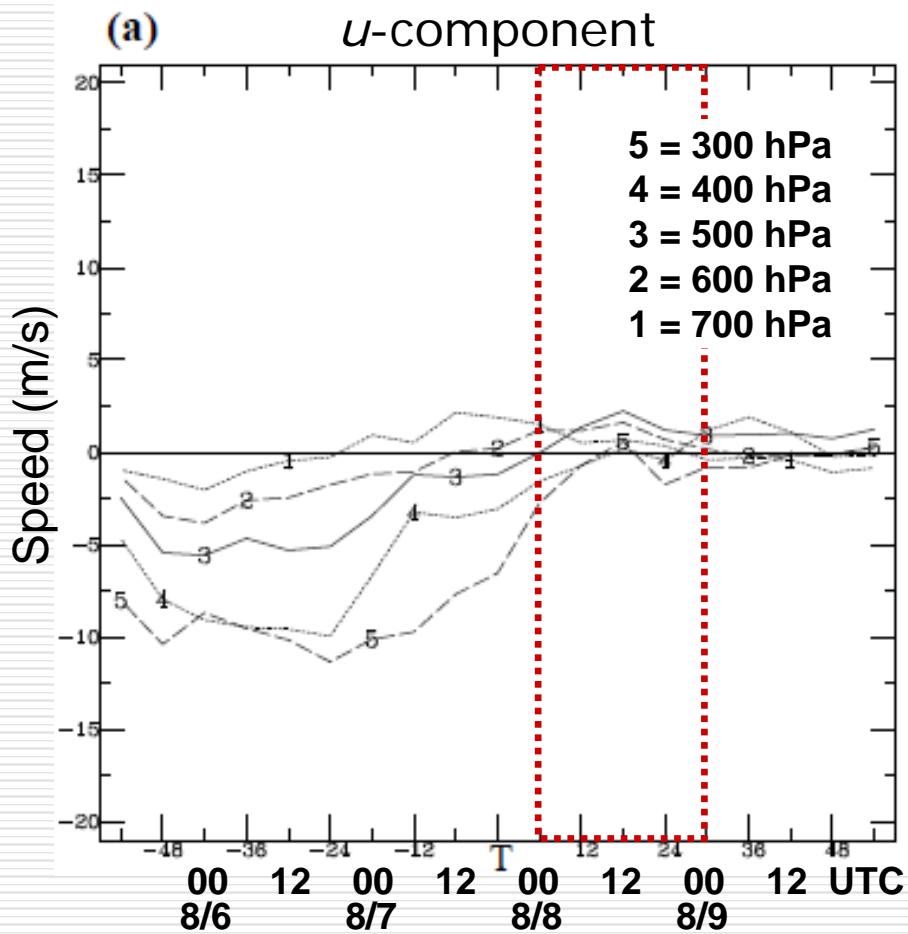
## 5. Discussion

### □ Summary of TC motion in 2nd-set runs (0000 UTC, 8-10 Aug)

Period	8/8 00-12 UTC			8/8 12-24 UTC			8/9 00-24 UTC		
	Speed		Dir.	Speed		Dir.	Speed		Dir.
Exp.	km/h	m/s	deg.	km/h	m/s	deg.	km/h	m/s	deg.
[1] ●	4.92	1.37	340	11.22	3.12	351	11.98	3.33	333
[2] ●	8.14	2.26	335	10.20	2.83	355	10.04	2.79	345
[3] ●	9.48	2.63	324	8.14	2.26	332	11.60	3.22	343
[4] ●	9.75	2.71	329	9.59	2.66	345	n/a	n/a	n/a
[5] ●	5.61	1.56	351	13.89	3.86	4	10.22	2.84	324
[6] ●	7.44	2.07	353	7.53	2.09	317	10.72	2.98	342
[7] ●	9.40	2.61	350	8.14	2.26	335	11.36	3.16	321
[8] ●	10.17	2.83	360	11.78	3.27	330	n/a	n/a	n/a
[9] ●	3.79	1.05	347	13.97	3.88	7	10.36	2.88	333
[10] ●	6.47	1.80	360	10.99	3.05	327	10.43	2.90	339
[11] ●	8.32	2.31	360	8.13	2.26	313	10.99	3.05	327
[12] ●	8.32	2.31	360	10.74	2.98	321	n/a	n/a	n/a

- Recent analysis on steering flow by Chien and Kuo (2010)
  - EC-YOTC, within 300-700 km radii, weighted by distance from TC center, at five different levels from 700 to 300 hPa





Chien and Kuo (2010, *submitted*)

## 6. Conclusion

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- Using the CReSS model at 3 km resolution and the EC-YOTC analysis data, the event of Morakot (2009) was reproduced, including the unusually slow speed and record-breaking rainfall
  - For typhoons approaching Taiwan from the east with an asymmetric rainfall pattern (similar to Morakot), model will likely tend to predict a track too far north (more toward the NW) if the effect of LH is not adequately represented
  - The slow translation speed of Morakot over the Taiwan Strait after landfall (within about 100 km from the coast) was due not only to the weakening of the steering flow but also the LH effect favoring intensification to the rear (contributed about 1/2)
  - Watch out for typhoons with a similar configuration---it may slow down and lengthen the duration of influence
  - Effect of Taiwan topography on track of Morakot was small compared to that of LH associated with asymmetric rainfall
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**--- The End ---**

**Thank you for your attention**

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