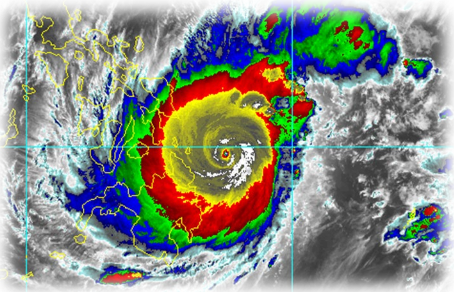
Effects of Surface Layer Physics Schemes on the Simulated Intensity and Structure of Typhoon Rai (2021)



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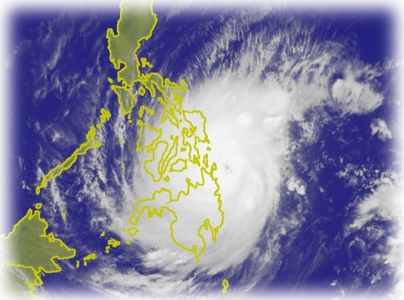
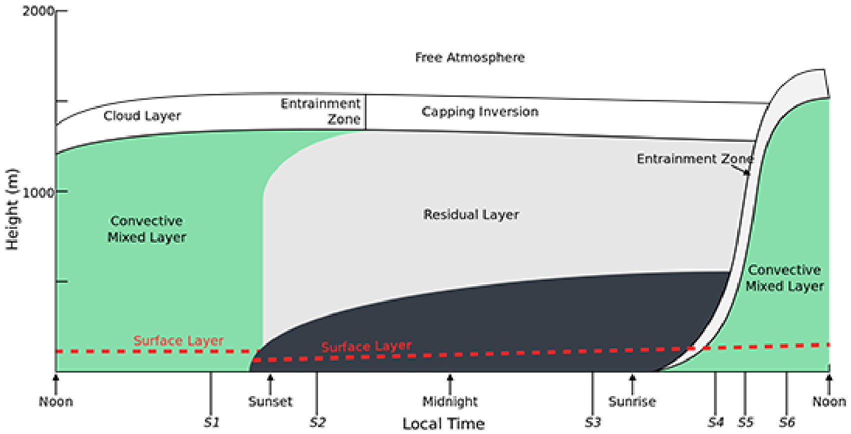


Introduction

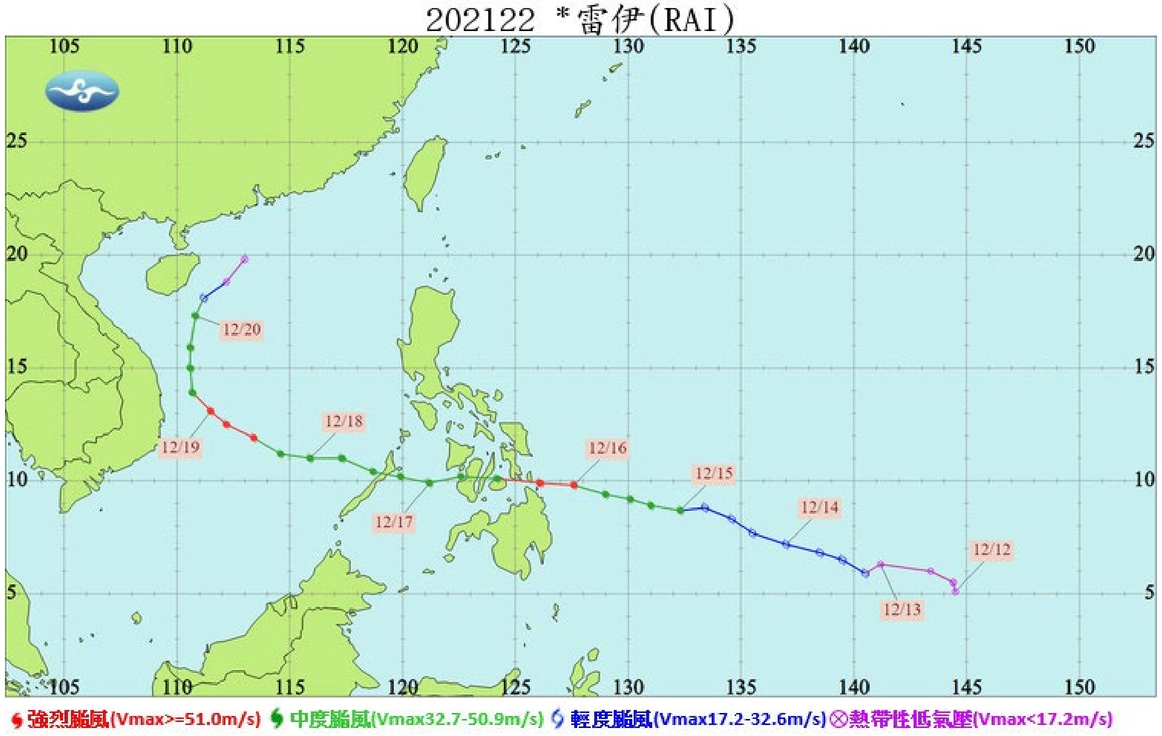
- Numerical simulation depends on many factors: initial condition, initial time, **physical processes** …
- Influence of microphysics scheme, cumulus parameterization, and PBL parameterization on TC track and intensity (Kanase et al. 2015; Miglietta et al. 2015)
- But few studies have discussed the impact of **surface layer (SL) physics schemes** on TC simulation

- SL physics scheme: determine the exchange of momentum, heat, and moisture (Skamarock et al., 2021)
- Crucial for the formation, development, and maintenance of tropical cyclones (Byers 1944; Riehl 1954; Malkus and Riehl 1960; Emanuel 1986; Gao et al. 2019)



SL physics schemes impact on TC intensity and structure

Typhoon Rai (2021)



Source: CWA

Typhoon Rai (Odette)

- Powerful and destructive TC hit the Philippines
- Peak intensity: 105 kt (54 m/s), 915 hPa off the Philipines coast (06 UTC on December 16)
- Extreme rain, strong wind, and storm surge: over 400 lives, over $1.02 billion U.S. dollars in damages

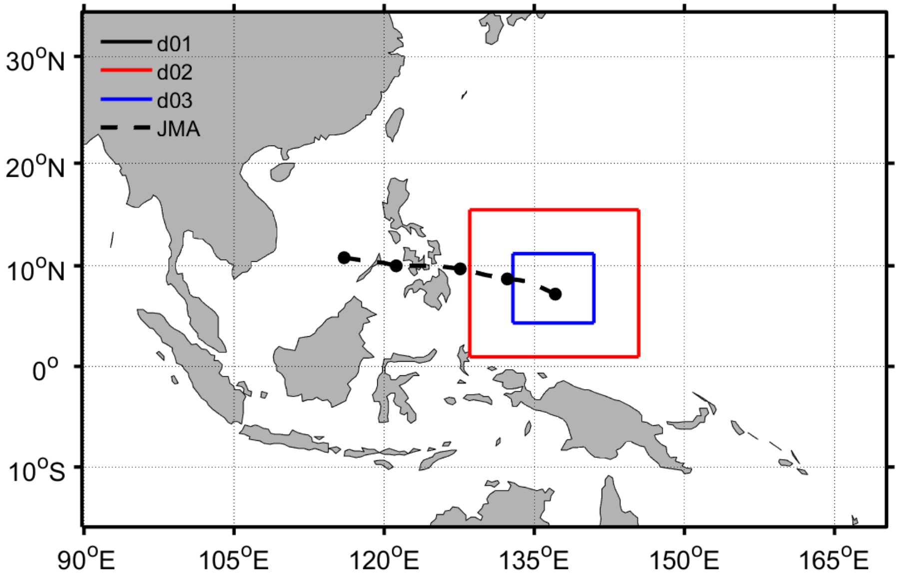
→ The big tropical cyclone impact highlighted the need for improved forecasting of track and intensity

Experimental Design

Model	WRF-ARW model (version 4.5.1)
Domains	Domain 1: 18 km (fixed) Domain 2: 6 km (moving) Domain 3: 2 km (moving)
Vertical levels	51 levels
Time runs	96 hours
Data	NCEP FNL

Cumulus prameterization	KF
Microphysics	Lin
PBL parameterization	MYNN
Land surface model	Noah
Shortwave radiation	Dudhia
Longwave radiation	RRTM

Rai (2021)



SL physics schemes: **MO**, **MM5**, **MYNN**

parameterization of **surface fluxes** plays key role in the simulation

Momentum τ — C_D

Heat HFX — C_H

Moisture QFX — C_Q

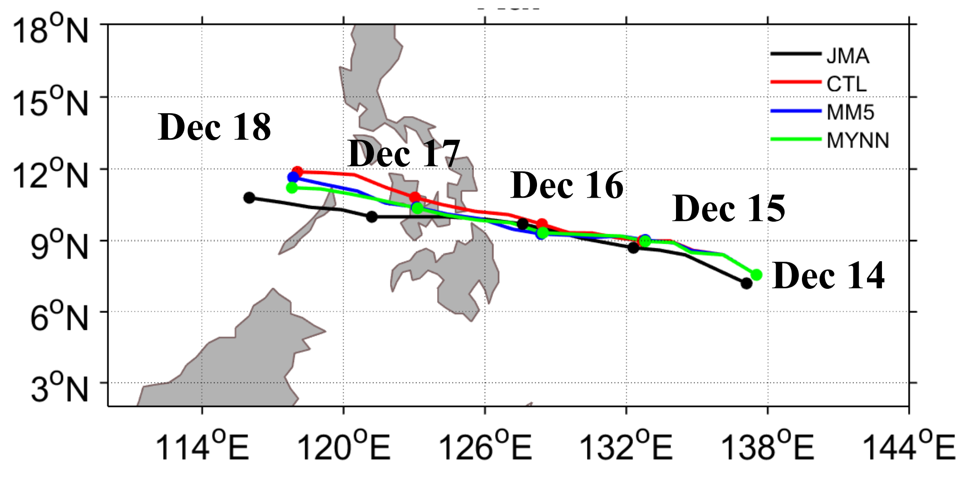
$C_H \dashrightarrow C_K \dashleftarrow C_Q$

Results

- ✓ Simulated Track and Intensity
- ✓ Characteristics of Surface Layer
- ✓ Characteristics of Planetary Boundary Layer
- ✓ Typhoon Structure
- ✓ Solution of Sawyer-Eliassen Equation

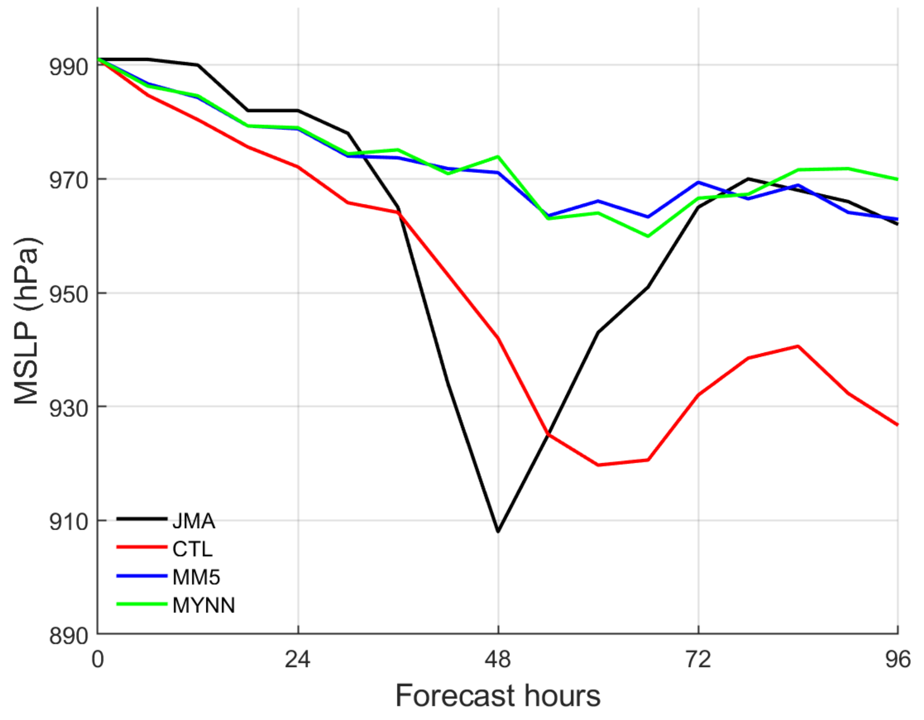
Simulated Track and Intensity

00 UTC 15 Dec to 06 UTC 16 Dec 2021
Compare with JMA
R: correlation coefficient
BIAS: the bias
RMSE: Root mean square error



Assessment statistics of simulated maximum wind speed

	R	BIAS (m s^{-1})	RMSE (m s^{-1})
CTL	0.995	-0.412	0.849
MM5	0.930	-4.270	5.378
MYNN	0.932	-5.359	5.745

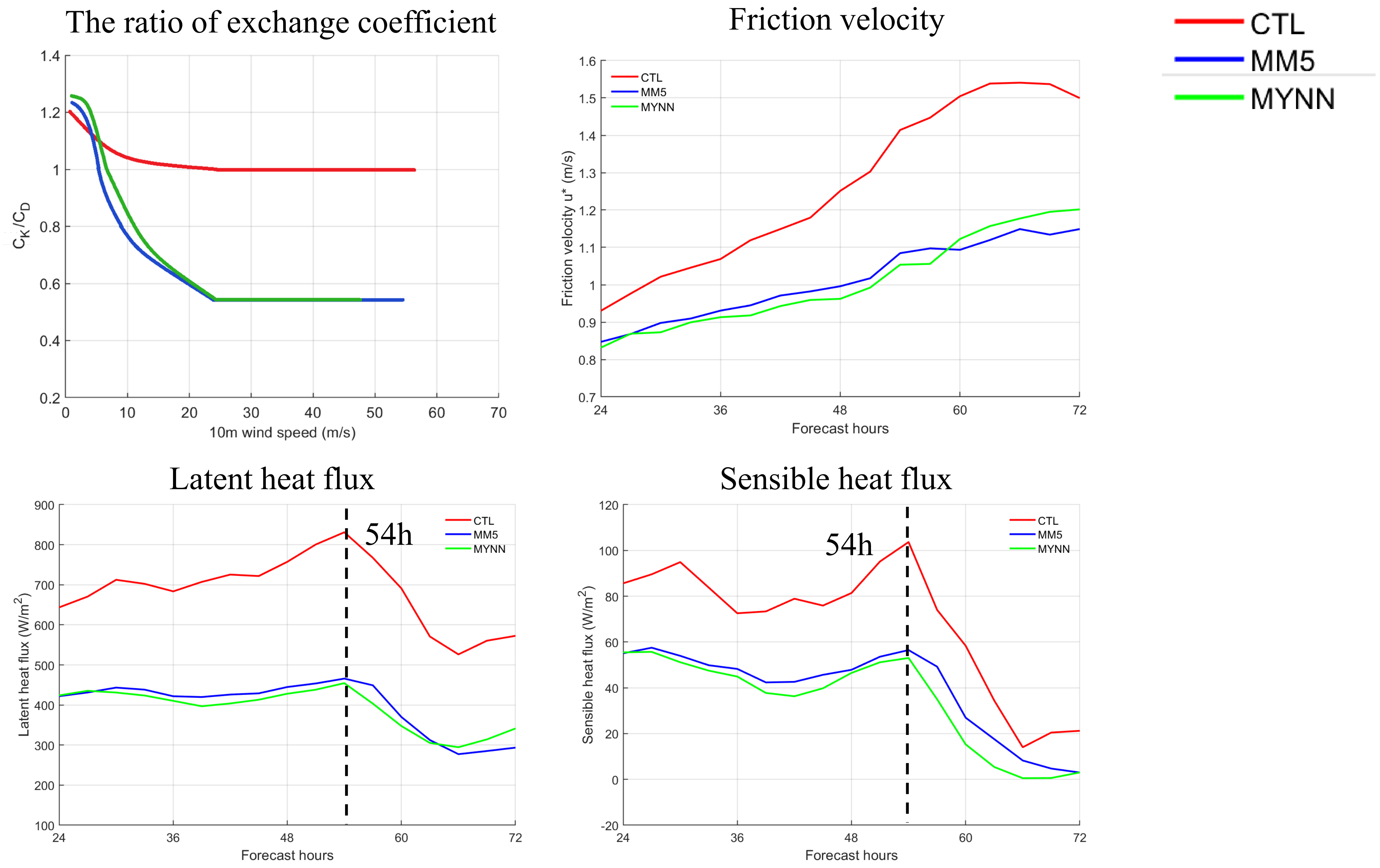


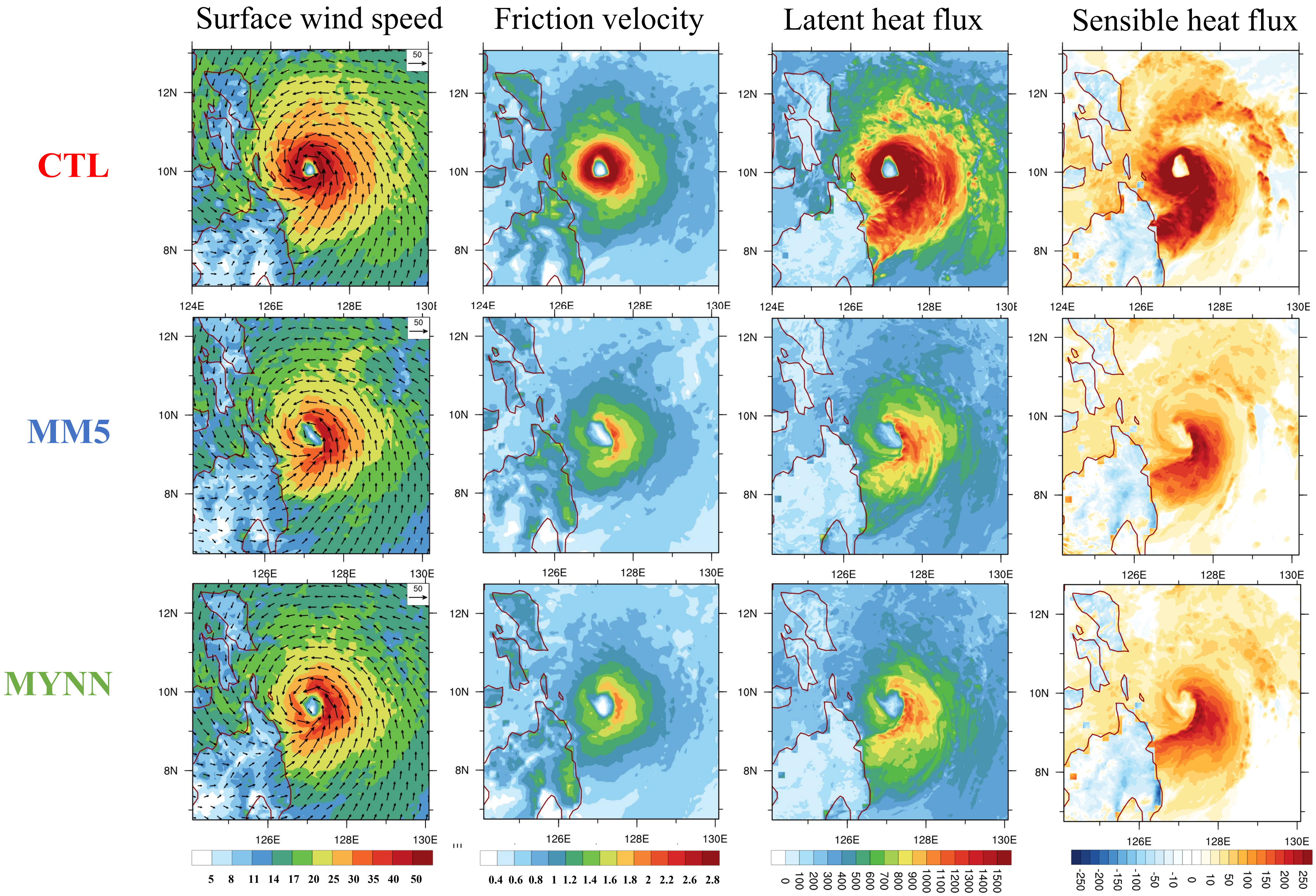
SL physics schemes barely affect TC track but strongly affect TC intensity

CTL good produce the Typhoon Rai intensity

→ TC intensity is **sensitive to** the selection of different SL physics schemes

Characteristics of Surface Layer



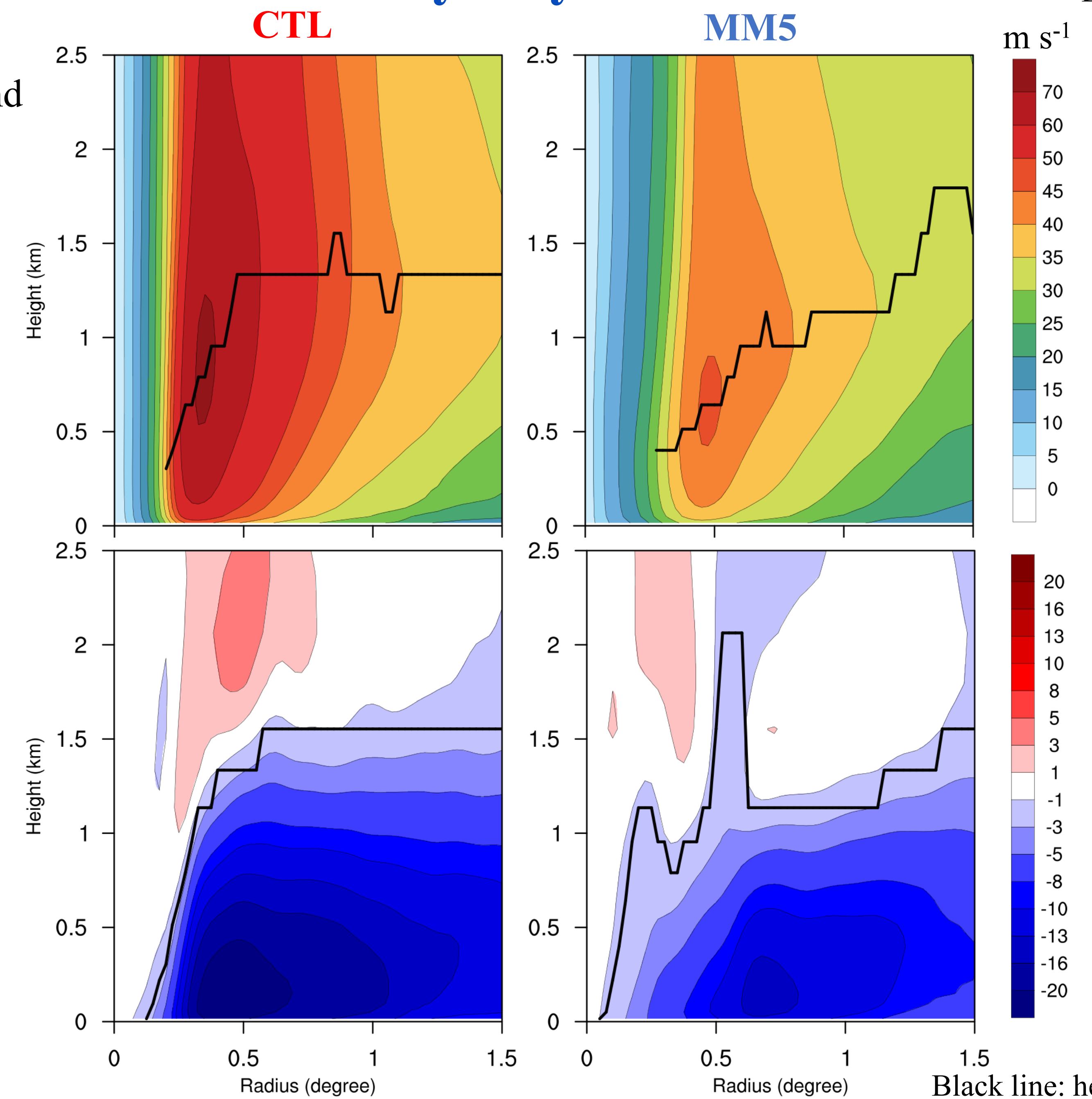

Surface wind speed
Friction velocity
Latent heat flux
Sensible heat flux
CTL
MM5
MYNN
12N
10N
8N
124E
126E
128E
130E
50
5 8 11 14 17 20 25 30 35 40 50
0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.6 2.8
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
-250 -200 -150 -100 -50 -10 0 10 50 100 150 200 250

Characteristics of Boundary Layer

Black line: height of maximum wind speed

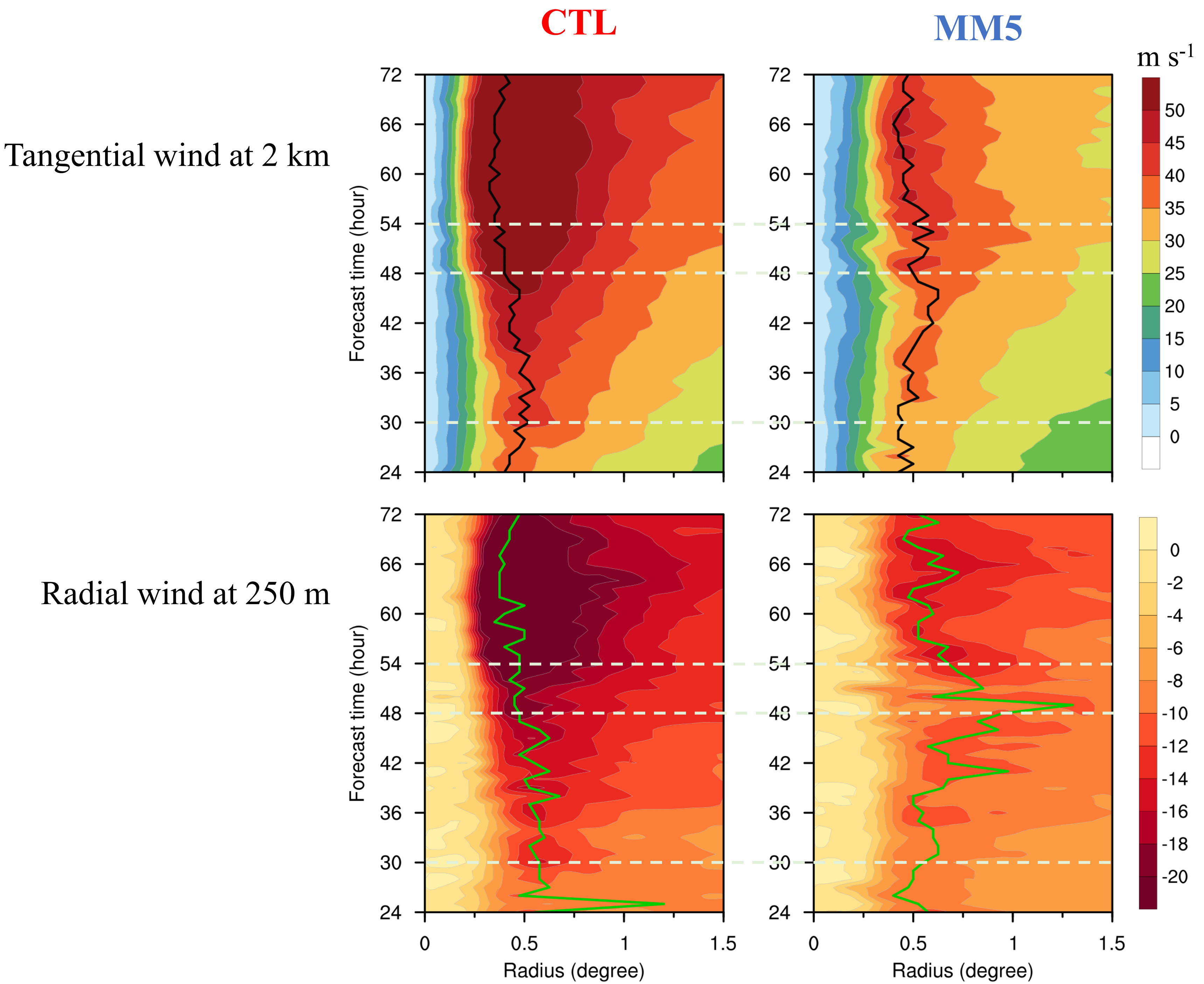
Tangential wind

Radial wind



Black line: height where radial wind speed is 10% of peak inflow

- Locations of maximum V_t and V_r are in different regions
- Kinematic boundary layer height decreases with decreasing radius to the TC center
- h V_r > h V_t
- **CTL**: larger circulation and PBL height



Black line: radius of maximum wind speed at 2 km

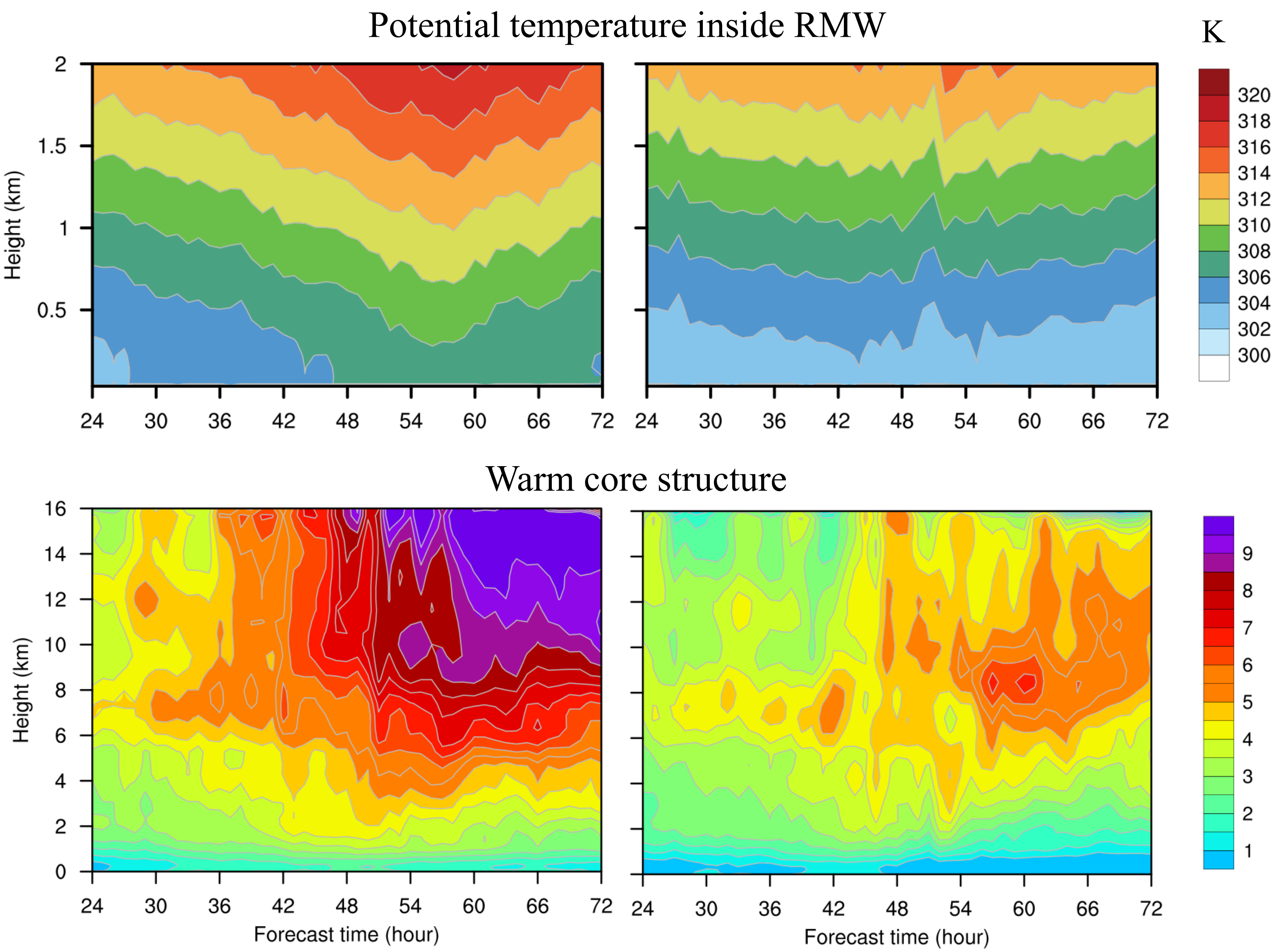
Green line: maximum inflow at 0.25 km

CTL: always much greater

RWM has a contraction

- **CTL**: 46 h
- **MM5**: 50 h

CTL **MM5**



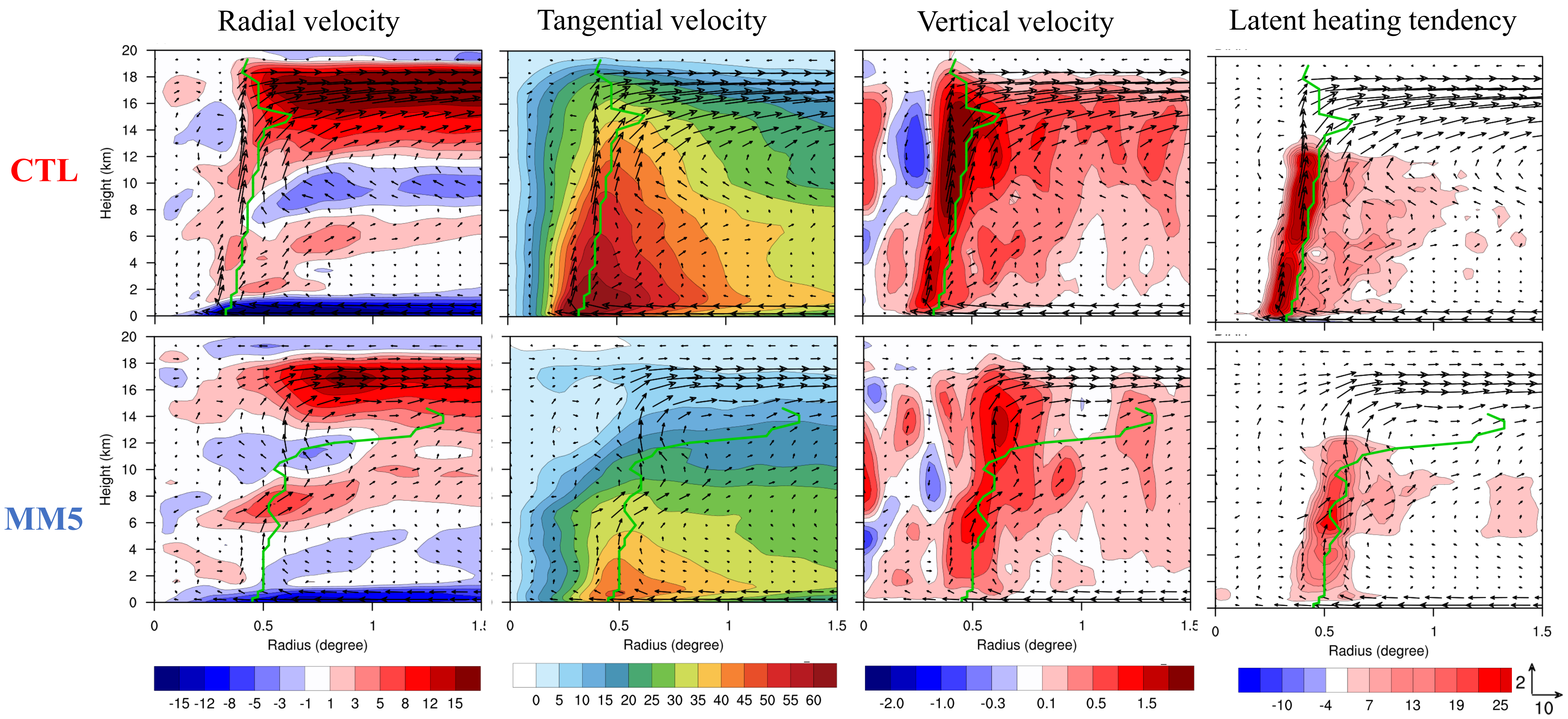
CTL: higher

- Potential temperature
- Warm core strength
- Warm core height

SL parameterization affects the vertical structure of TC above the surface layer

Typhoon Structure

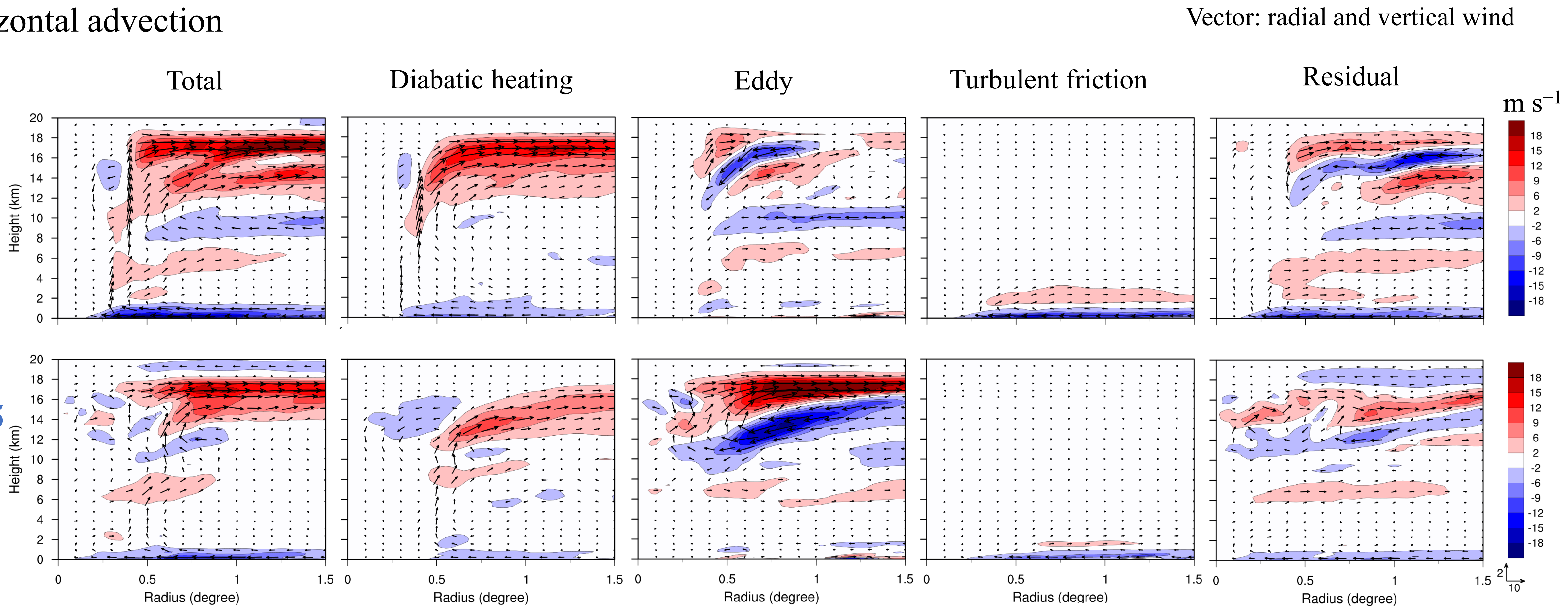
Vector: radial and vertical wind
Green line: radius of maximum wind speed



CTL: stronger inflow, upward, and diabatic heating

Solution of Sawyer-Eliassen Equation

Horizontal advection

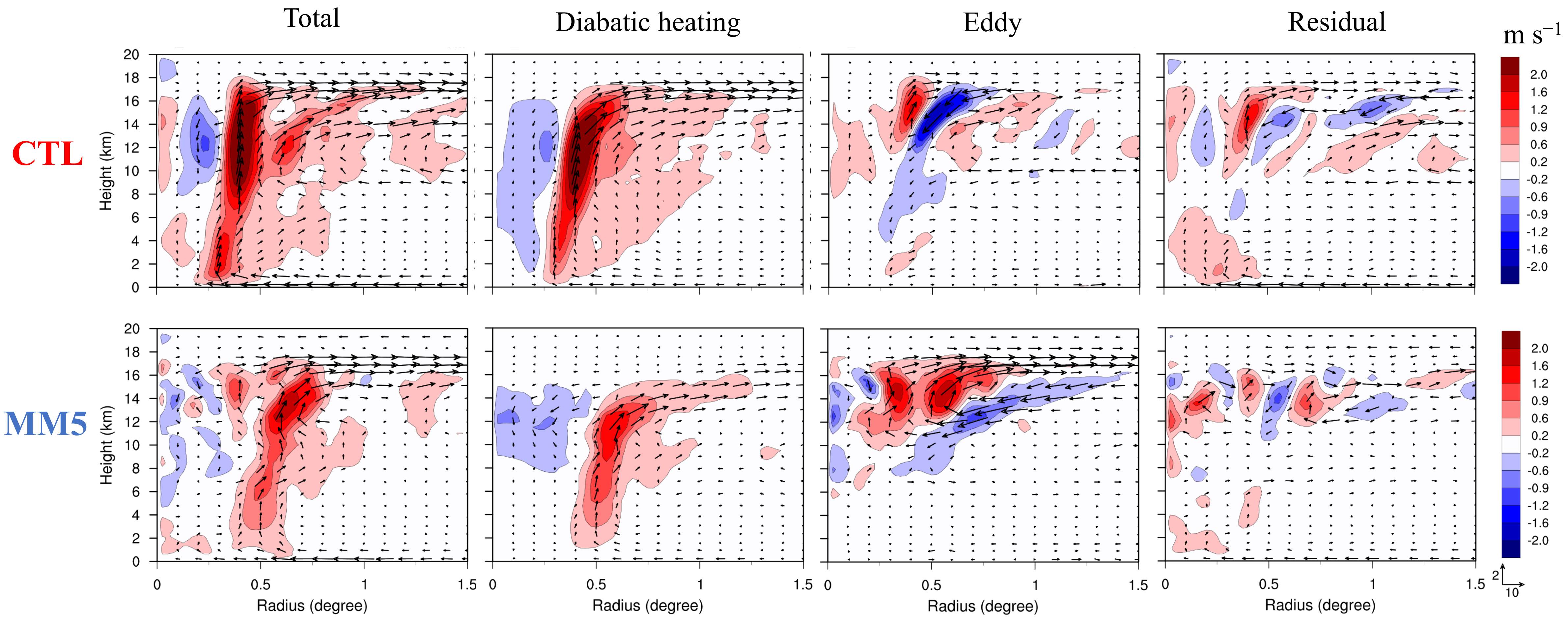


- Turbulent friction: important in the low-level
- Diabatic heating: important in the low-level and upper level

Solution of Sawyer-Eliassen Equation

Vertical advection

Vector: radial and vertical wind



Diabatic heating dominant the vertical advection

Conclusions

- Key findings
  - SL layer physics schemes: minimal affect TC track but strongly affect TC intensity.
  - The highest correlation coefficient and smallest bias and root mean square error between the best track is in **CTL** compared to **MM5** and **MYNN**
  - The **CTL** produces good Typhoon Rai intensity ➔ good option for SL physics scheme.

  - Relatively higher surface wind speed, friction velocity, ratio of exchange coefficient, surface fluxes of heat and moisture are found in **CTL**, followed by **MM5** and **MYNN**
  - TC structures: primary and secondary circulation, potential temperature, boundary layer heights, warm-core strength and height are substantially impacted by surface layer physics schemes.
  - Using the SE equation to analyze the contributing components, diabatic heating and turbulent friction play a major role in the secondary circulation.

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Thanks for your attention

Sawyer-Eliassen Equation

Sawyer–Eliassen (SE) equation: derived as a linear partial differential equation applied to investigate the responses of a primary mean vortex, different force sources, and the intensification of the TC (Nguyen and Huang, 2023)

$$S = -\frac{\partial}{\partial z}(\chi\xi \boldsymbol{G_v}) + \frac{\partial}{\partial r}[g\chi^2(1+\epsilon q_v)\boldsymbol{H_\theta}] + \frac{\partial}{\partial z}[C\chi^2(1+\epsilon q_v)\boldsymbol{H_\theta}] - \frac{\partial}{\partial z}(\chi\xi\dot{\boldsymbol{V}}) + \frac{\partial}{\partial t}\left(\frac{\partial\chi\dot{\boldsymbol{U}}}{\partial z}\right) - \frac{\partial}{\partial t}\left(\frac{\partial\chi\dot{\boldsymbol{W}}}{\partial r}\right)$$

(momentum)

$$G_v = \underbrace{-\overline{u'\eta'} - \overline{w'\frac{\partial v'}{\partial z}} + \overline{\frac{\rho'}{\bar{\rho}^2}\frac{1}{r}\frac{\partial p'}{\partial\lambda}}}_{(1)} + \underbrace{\bar{F}_v}_{(2)}$$

(thermodynamic heat)

$$H_\theta = \underbrace{-\overline{u'\frac{\partial\theta'}{\partial r}} - \overline{v'\frac{\partial\theta'}{r\partial\lambda}} - \overline{w'\frac{\partial\theta'}{\partial z}}}_{(3)} + \underbrace{\bar{F}_\theta}_{(4)} + \underbrace{\frac{1}{\bar{\Pi}}\bar{\dot{Q}}}_{(5)}$$

(1) Eddy transport

(2) Turbulent momentum diffusion

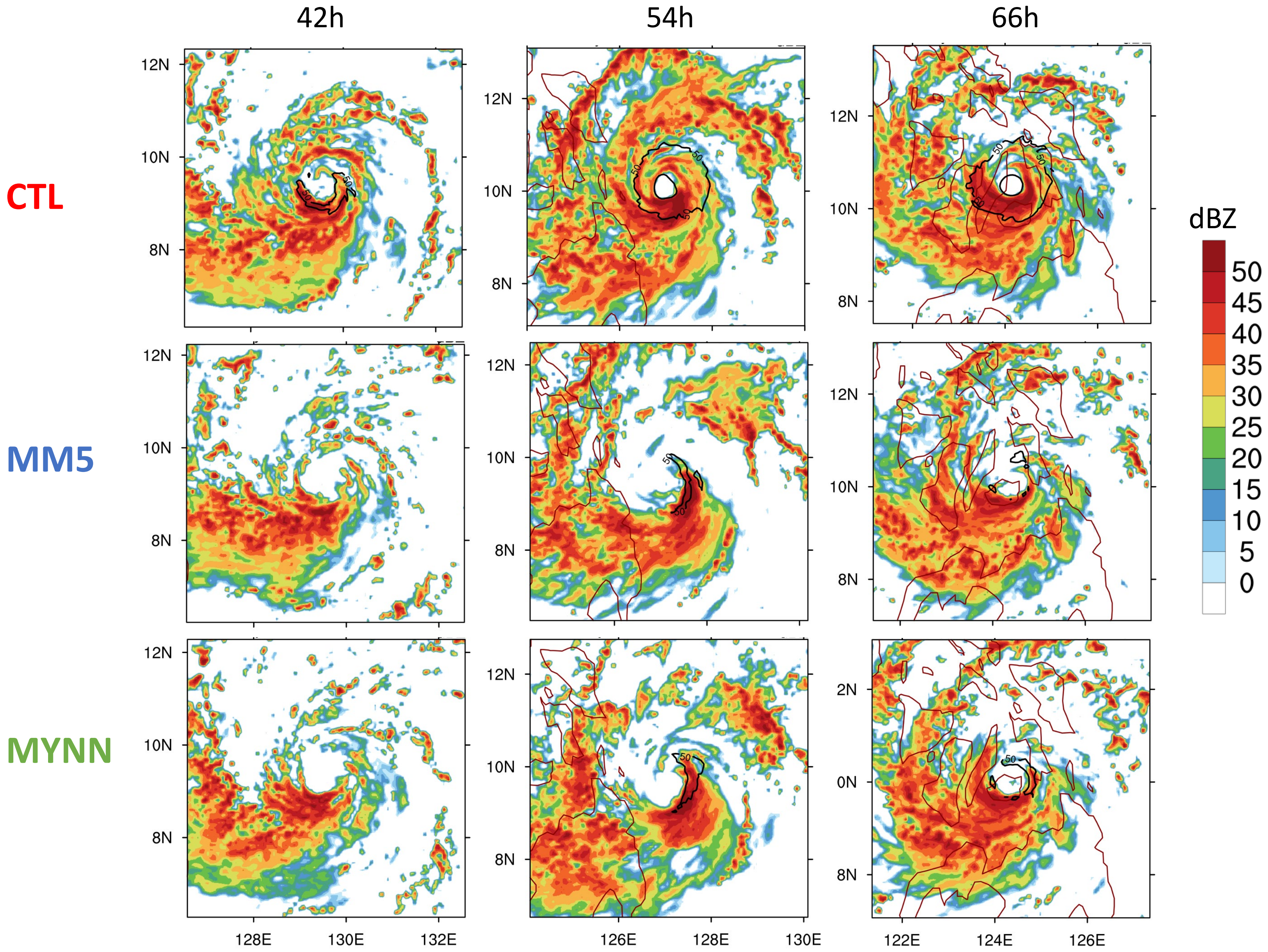
(3) Eddy temperature

(4) Turbulent heat diffusion

(5) Diabatic heating

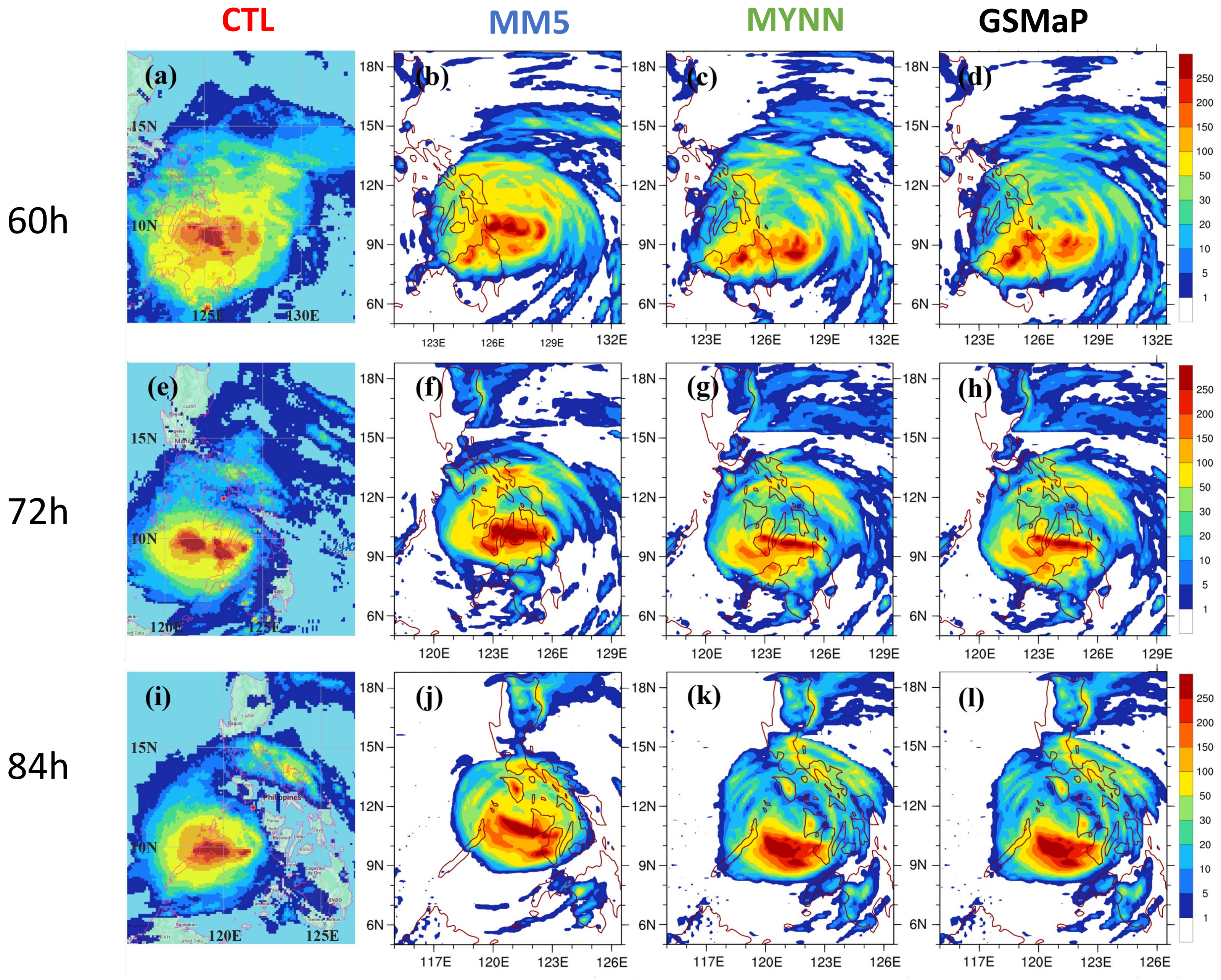
Residual terms $\dot{\boldsymbol{V}}, \dot{\boldsymbol{U}}, \dot{\boldsymbol{W}}$ and (4) are not significant compared to others, are not shown

Radar Reflectivity



- **CTL** more symmetric than **MM5** and **MYNN,** strongest and widest in **CTL**
- 42h: highly concentrated in the southern
- 54h: south-eastern
- 66h: south to south-western

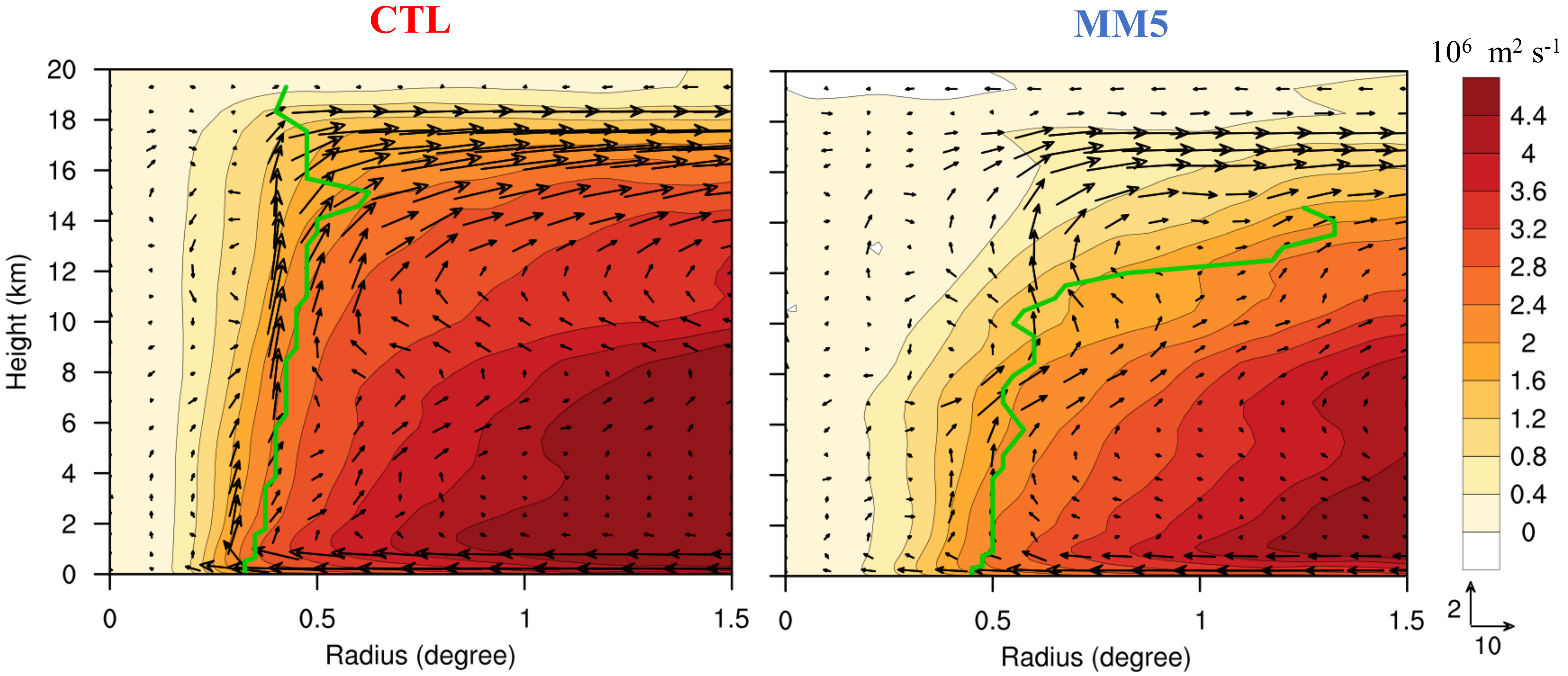
12h Accumulated Precipitation



- Rainfall: concentrate along the path of TC
- First and second stage: **CTL** is strongest and widest
- Third stage: **MM5** and **MYNN** are higher

Azimuthal-mean Angular Momentum $\boxed{M = r\bar{v}}$

Vector: radial and vertical wind
Shaded: azimuthal-mean angular momentum
Green line: radius of maximum wind speed



The AM decreases inward and upward with the TC center

CTL > MM5