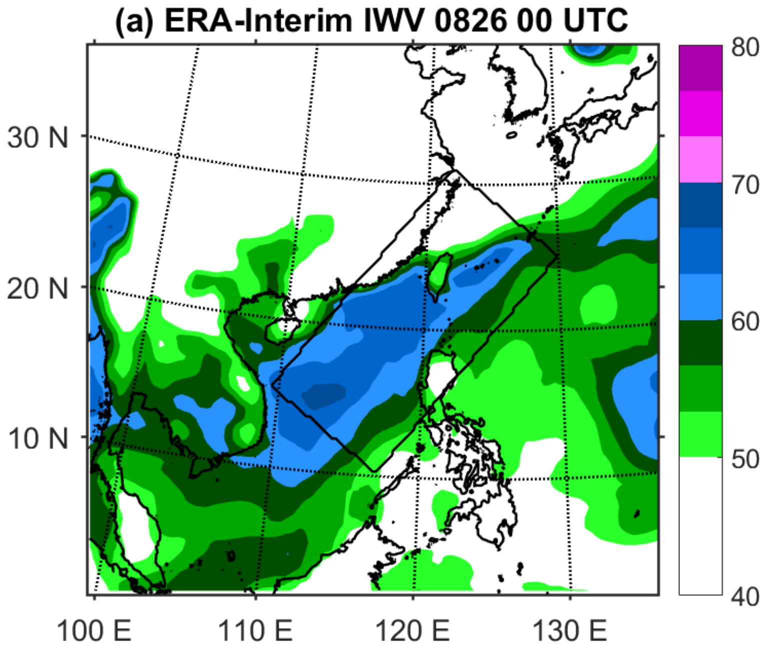
Evolution of Water Budget and Precipitation Efficiency of Mesoscale Convective Systems associated with Southwesterly Monsoon Flows over the South China Sea



Ming-Jen Yang

Pacific Science Association

The 7th WMO International Workshop on Monsoon (IWM-7)

hosted by India Meteorological Department, Ministry of Earth Science, India

22-26 March 2022

Motivation:

The abundant **moisture transport** along the **Southwesterly Monsoon Flow** frequently produces **heavy rainfall** and **severe flooding** over the East Asia. Thus, an improved understanding and better forecast of the moisture transport is needed.

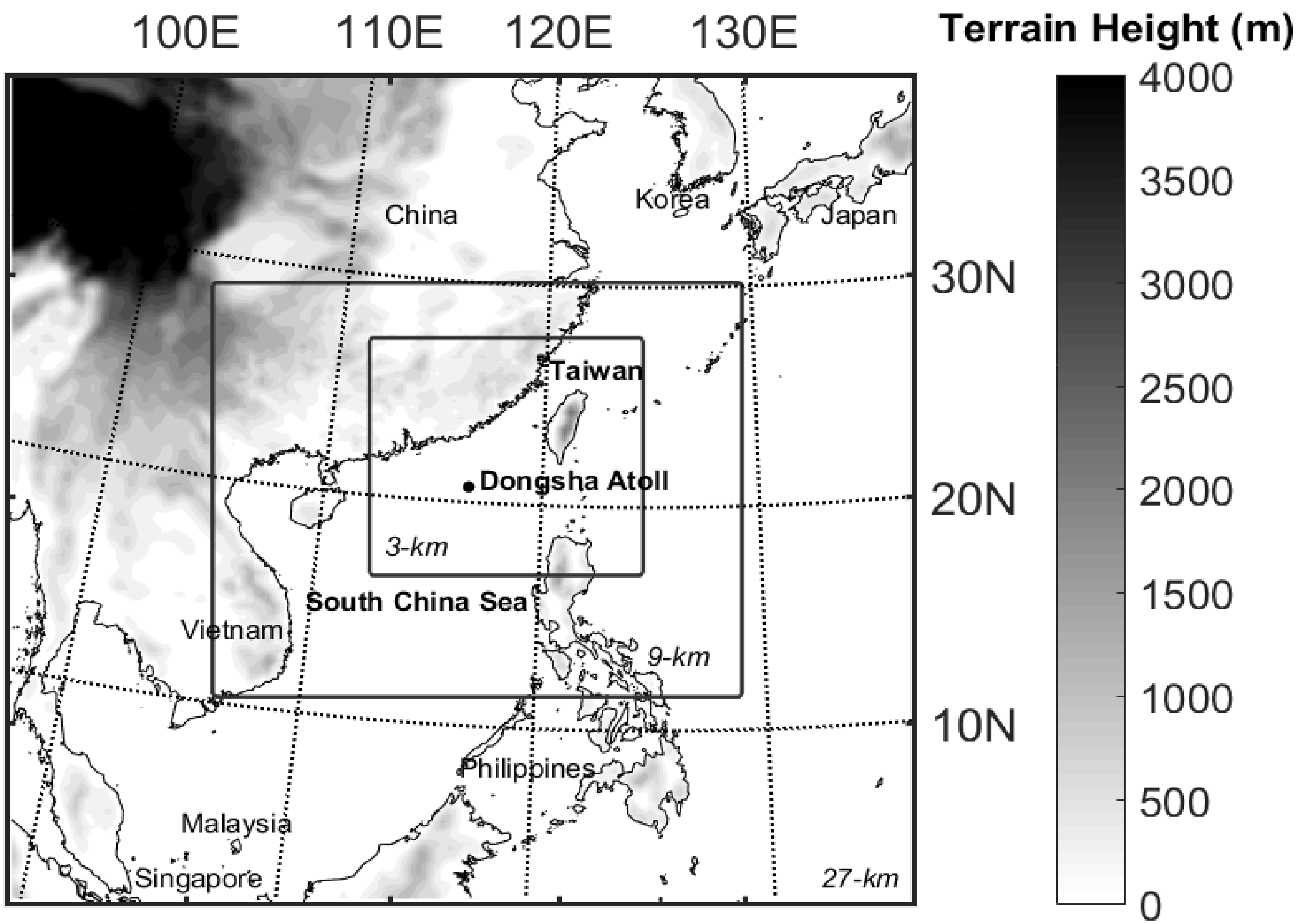
Scientific Questions:

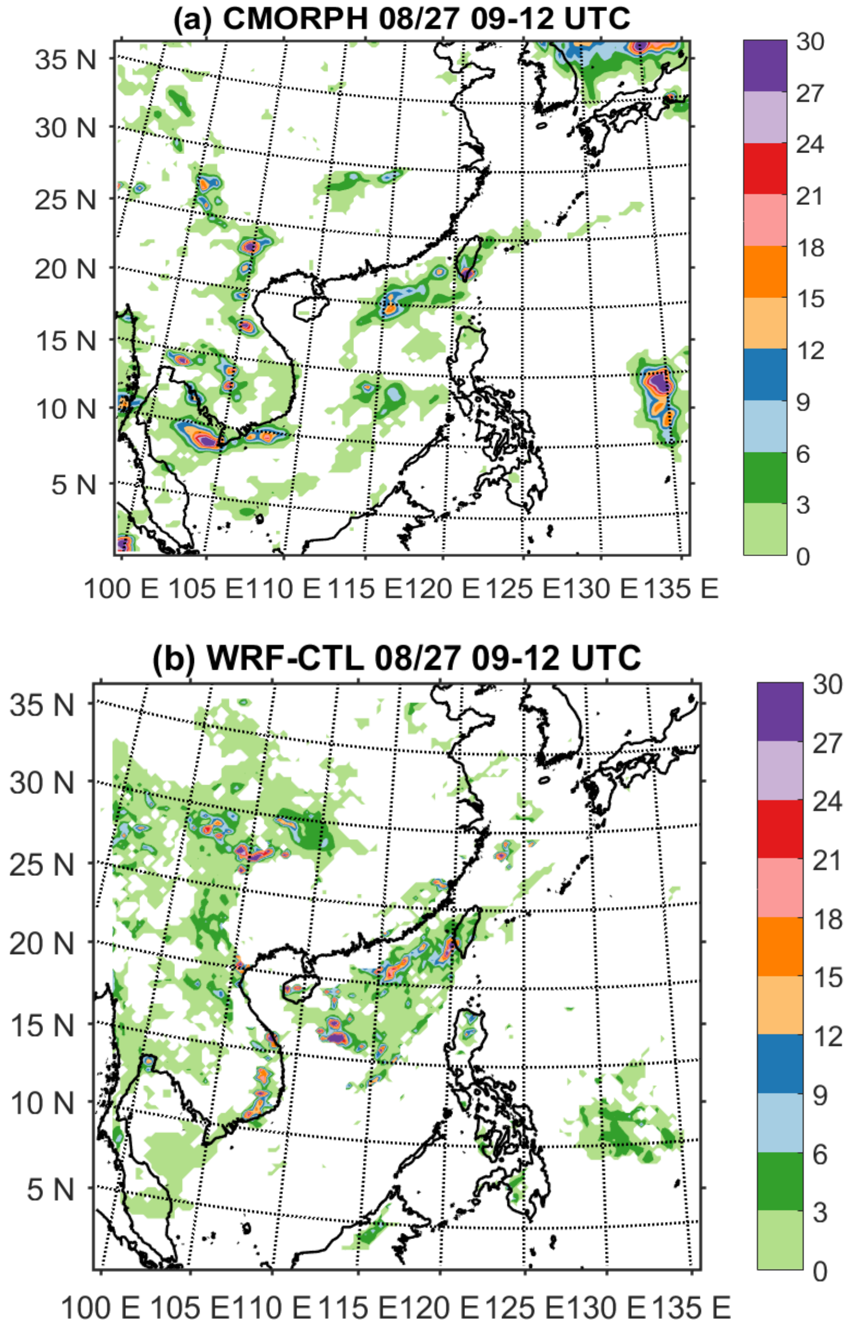
1) How does **water vapor transport** along the Southwesterly Monsoon Flows across the South China Sea change with the **increase/decrease** of **low-level water vapor** and **wind speed**?

2) Does **wind convergence** or **water vapor advection** play a more important role in the change of **horizontal vapor flux convergence** associated with the Southwesterly Monsoon Flows?

WRF model configuration

- **ARW-WRF v3.9**
- Simulation period
  - 00Z 25 Aug - 18Z 28 Aug 2015 (90h)
- Spatial grid size
  - **27/9/3-km on the triply-nested grid**
  - **55 η levels**
- IC/BC
  - ECMWF ERA-Interim (0.75 degree)
- Parameterization scheme
  - Microphysics: **Morrison two-moment**
  - Longwave radiation: RRTM
  - Shortwave radiation: Dudhia
  - PBL: YSU
  - **Cumulus: Grell 3D (Domain 1)**
- **Sensitivity experiments on IC & BC:**
  - **W10/D10 (RH: ±10% @ Surface – 700 hPa)**
  - **F10/S10 (Speed ±10% @ Surface – 700 hPa)**





3-h Accumulated Rainfall (mm)
From **CMORPH** Global Precipitation Analysis
(09–12 UTC 27 August 2015)
0.25 degree

3-h Accumulated Rainfall (mm)
From **WRF CTL Simulation**
(09–12 UTC 27 August 2015)
27-km grid

IWV: integrated water vapor

$$IWV = \frac{1}{g}\int_{sfc}^{200mb} q_v dp$$

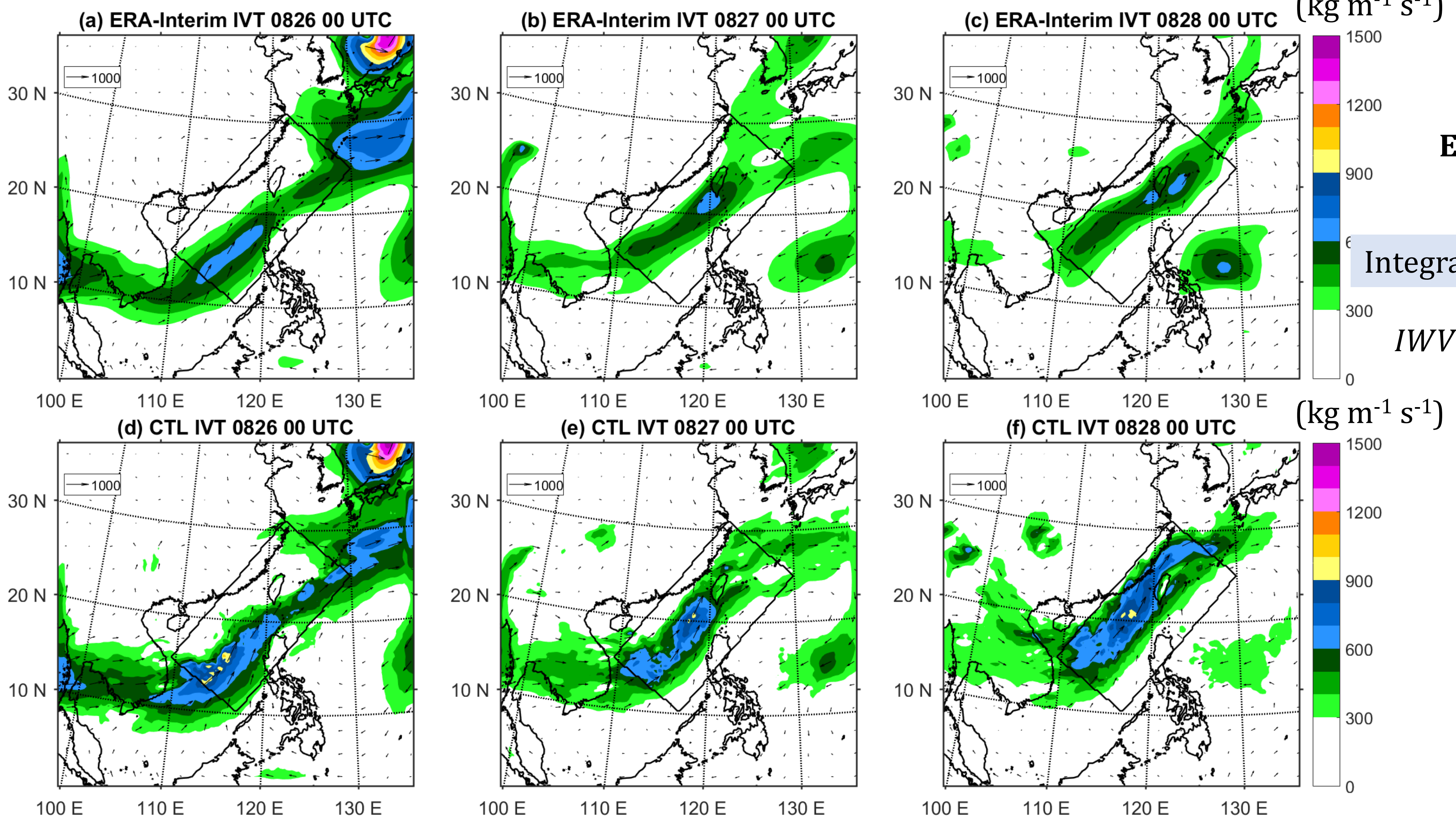
IMT: integrated mass transport

$$IMT = \frac{1}{g}\int_{sfc}^{200mb} \vec{U} dp$$

IVT: integrated water vapor transport

$$IVT = \frac{1}{g}\int_{sfc}^{200mb} q_v \vec{U} dp$$

Reference:
Zhu and Newell (1998)
Ralph, Neiman, and Rotunno (2005)
Mundhenk, Barnes, and Maloney (2016)



ERA-Interim

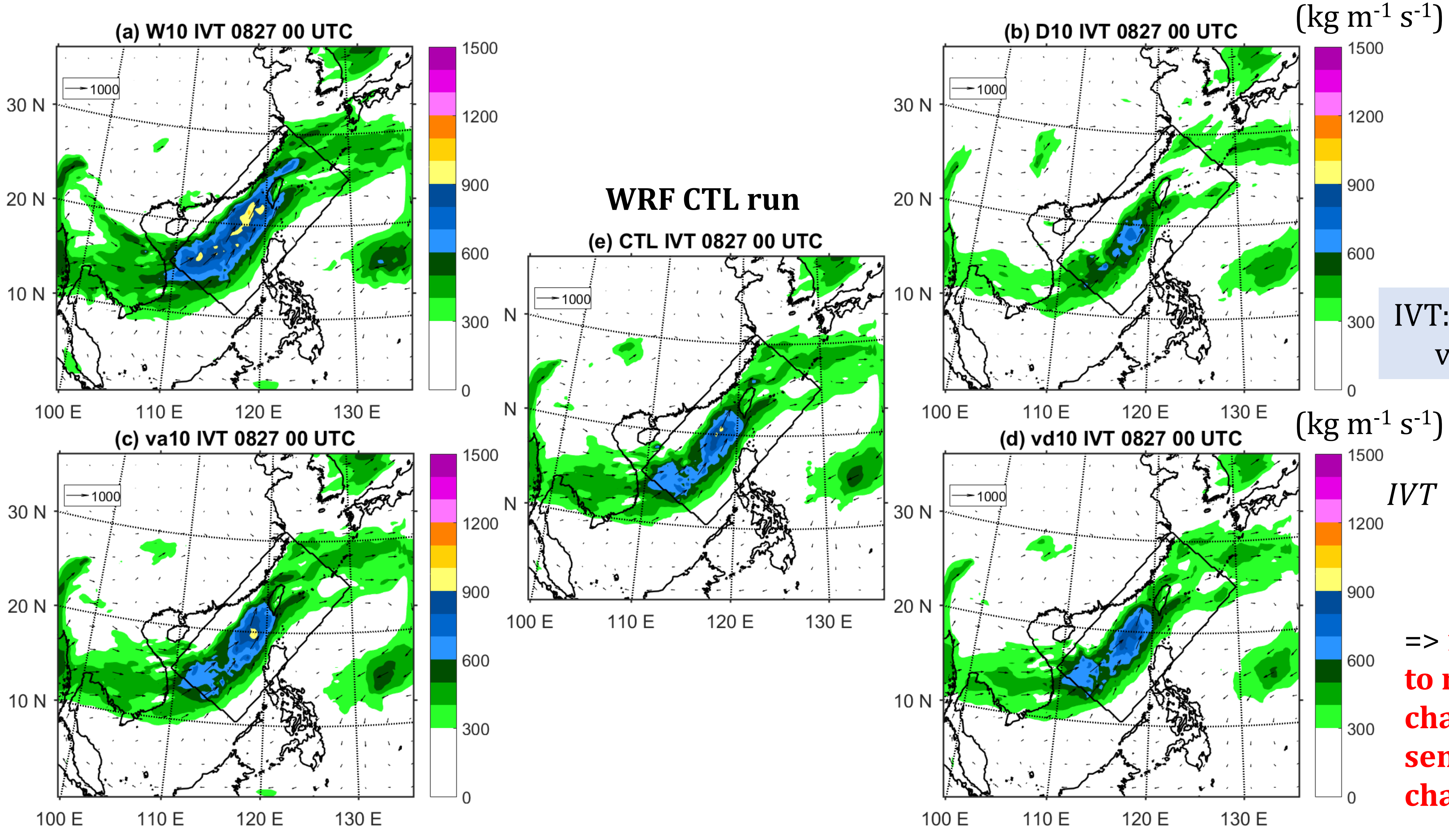
WRF CTL run

Integrated Water Vapor

$$IWV = \frac{1}{g}\int_{sfc}^{200mb} q_v dp$$

W10 Experiment: RH+10%

D10 Experiment: RH-10%



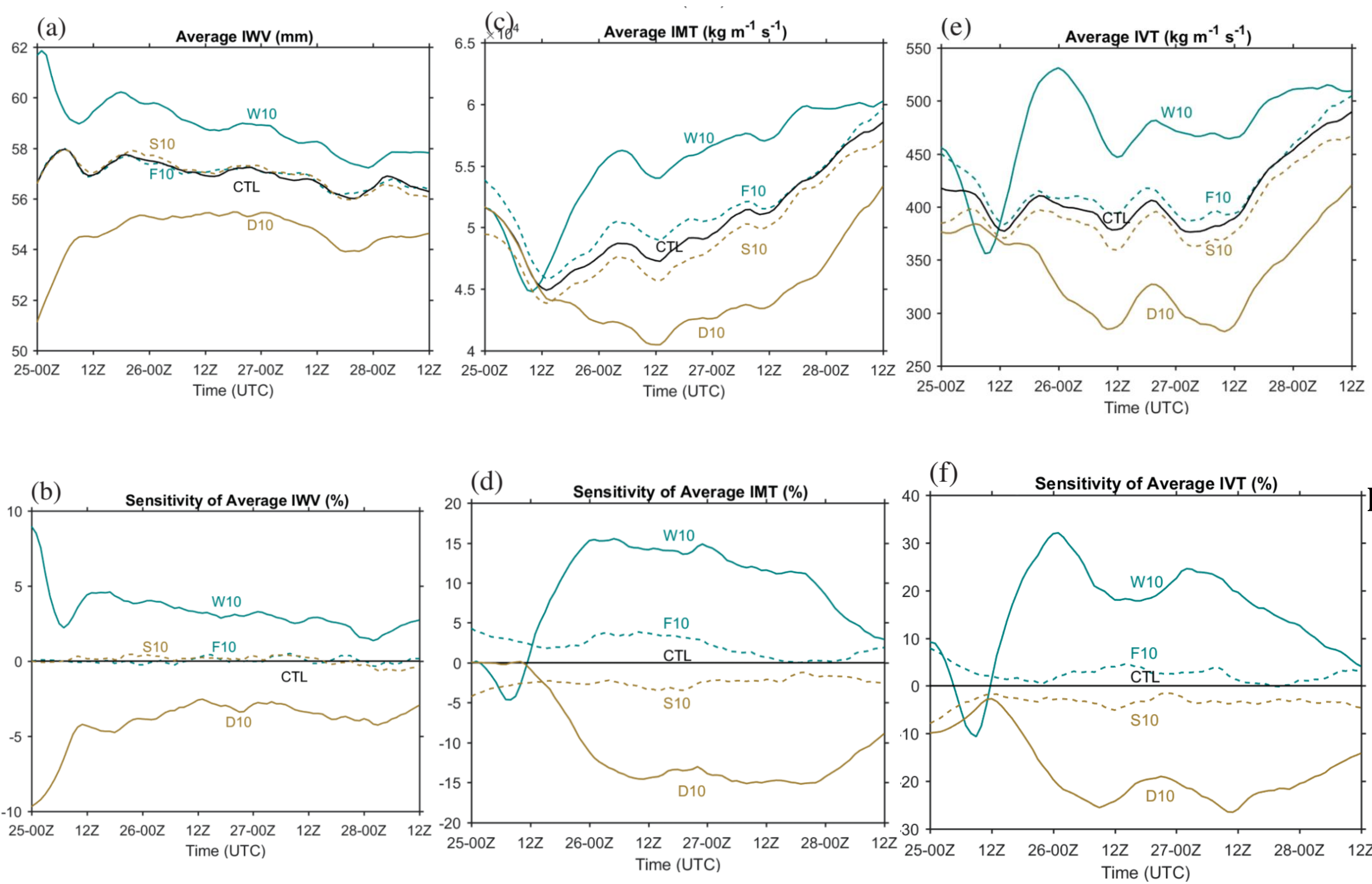
IVT: integrated water vapor transport

$$IVT = \frac{1}{g}\int_{sfc}^{200mb} q_v \vec{U} dp$$

=> **more sensitive to moisture change and less sensitive to speed change!**

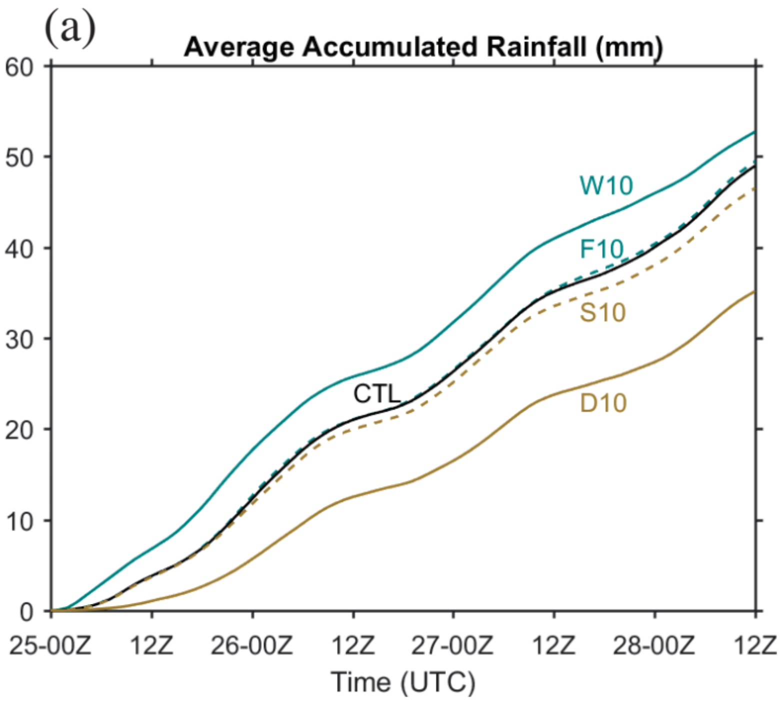
F10 Experiment: Speed+10%

S10 Experiment: Speed-10%

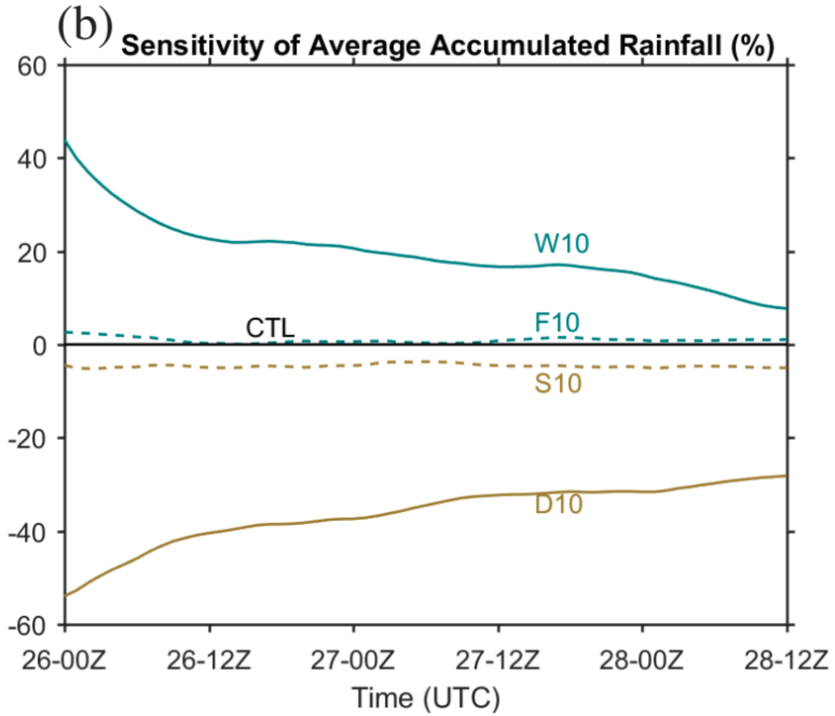


84-h Evolution of Area-Averaged IWV, IMT, and IVT within the Monsoon Flow for CTL/Sensitivity Experiments

Relative Change of Area-Averaged IWV, IMT, and IVT within the Monsoon Flow of Sensitivity Experiments wrt. the CTL run



System Total Evolution along Monsoon Flows



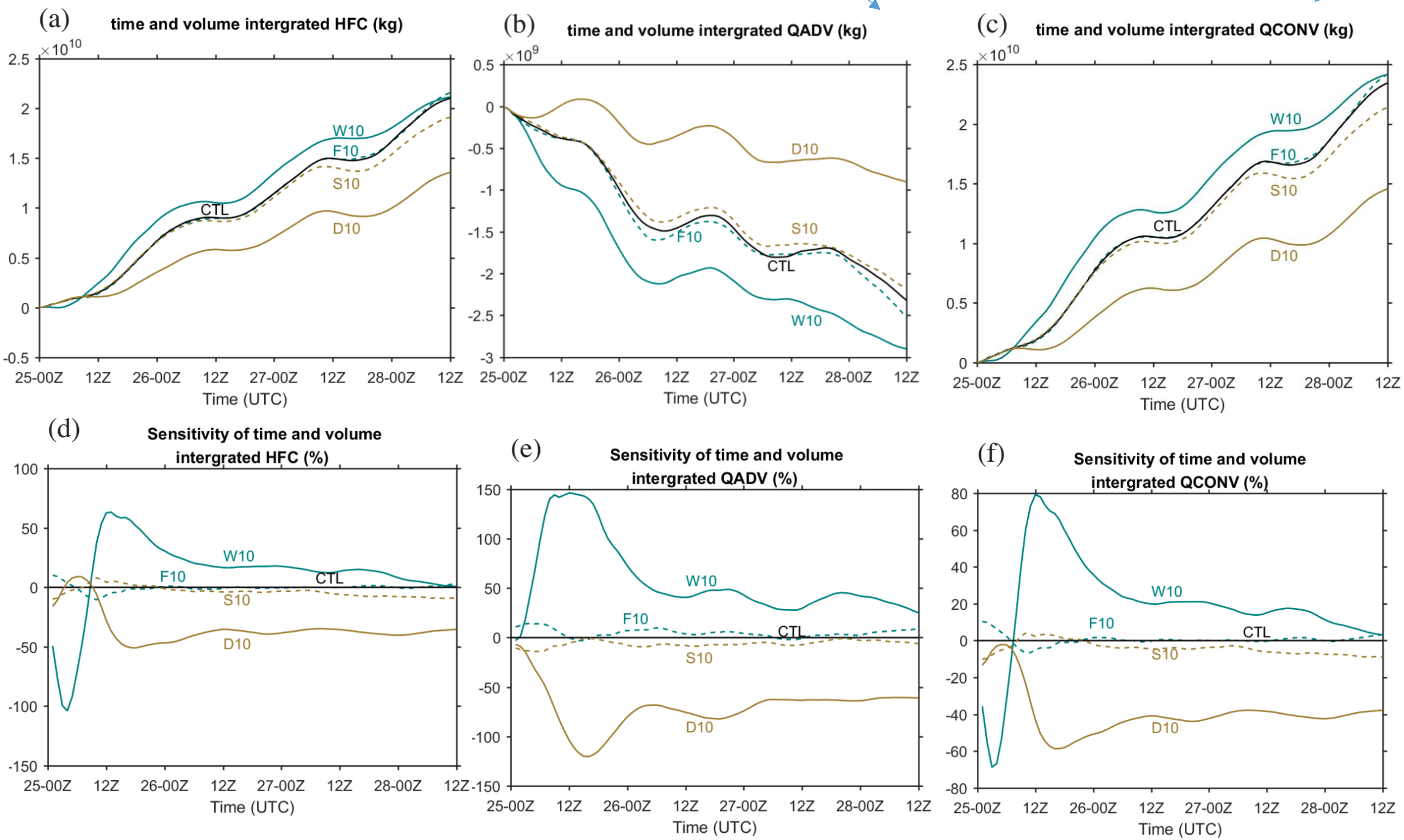
Relative Change wrt. CTL

1) **10% increase in RH** can produce **20% increase in rainfall.**
2) **10% decrease in RH** can produce **40% decrease in rainfall.**
3) 10% increase or decrease in wind speed produce has minor change in rainfall

$$\{F\} = \int_{t_0}^{t_1} \int_V \rho F dV dt$$

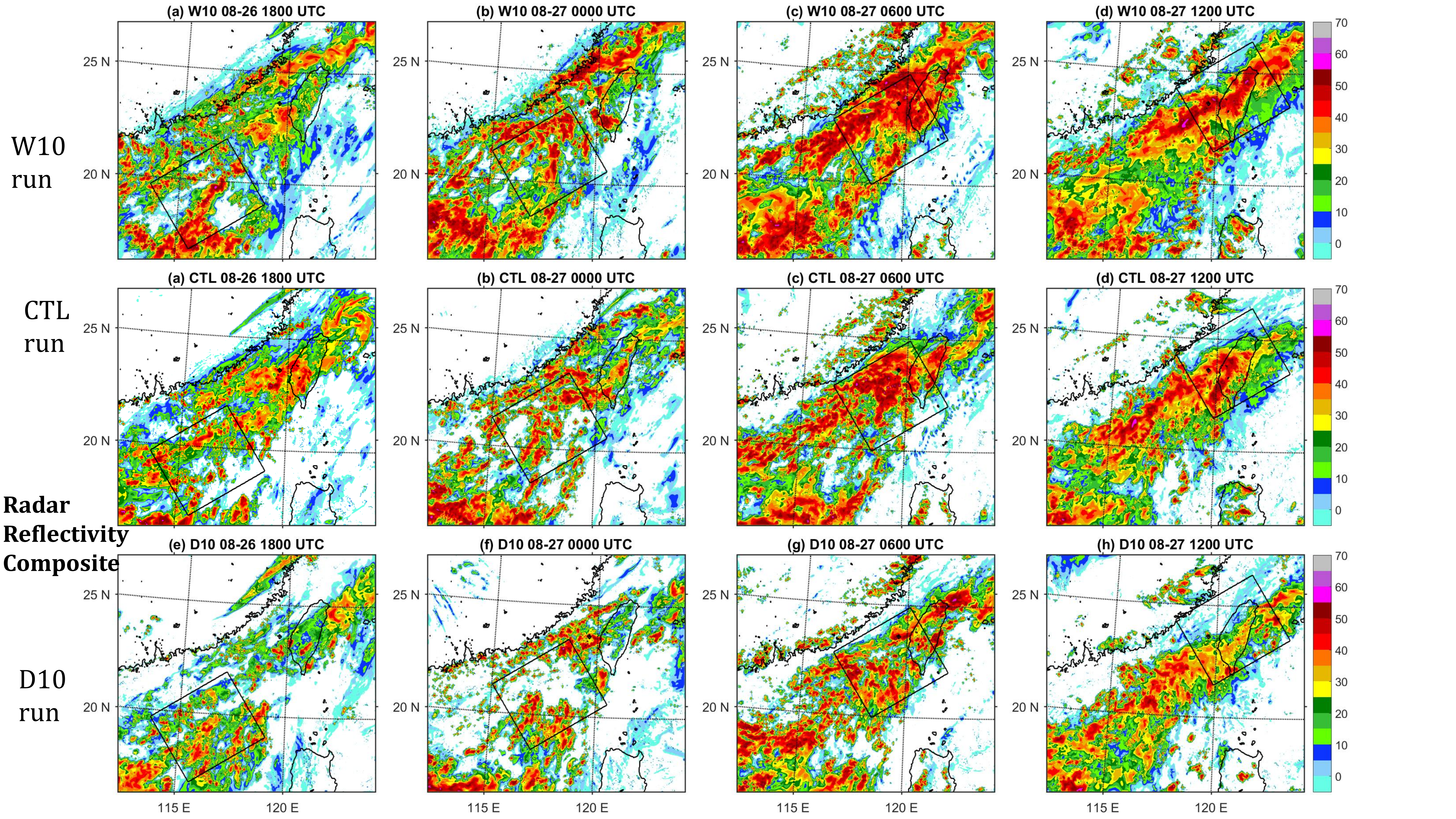
$$-\nabla \cdot (q_v \vec{V}) = -\vec{V} \cdot \nabla q_v - q_v (\nabla \cdot \vec{V})$$

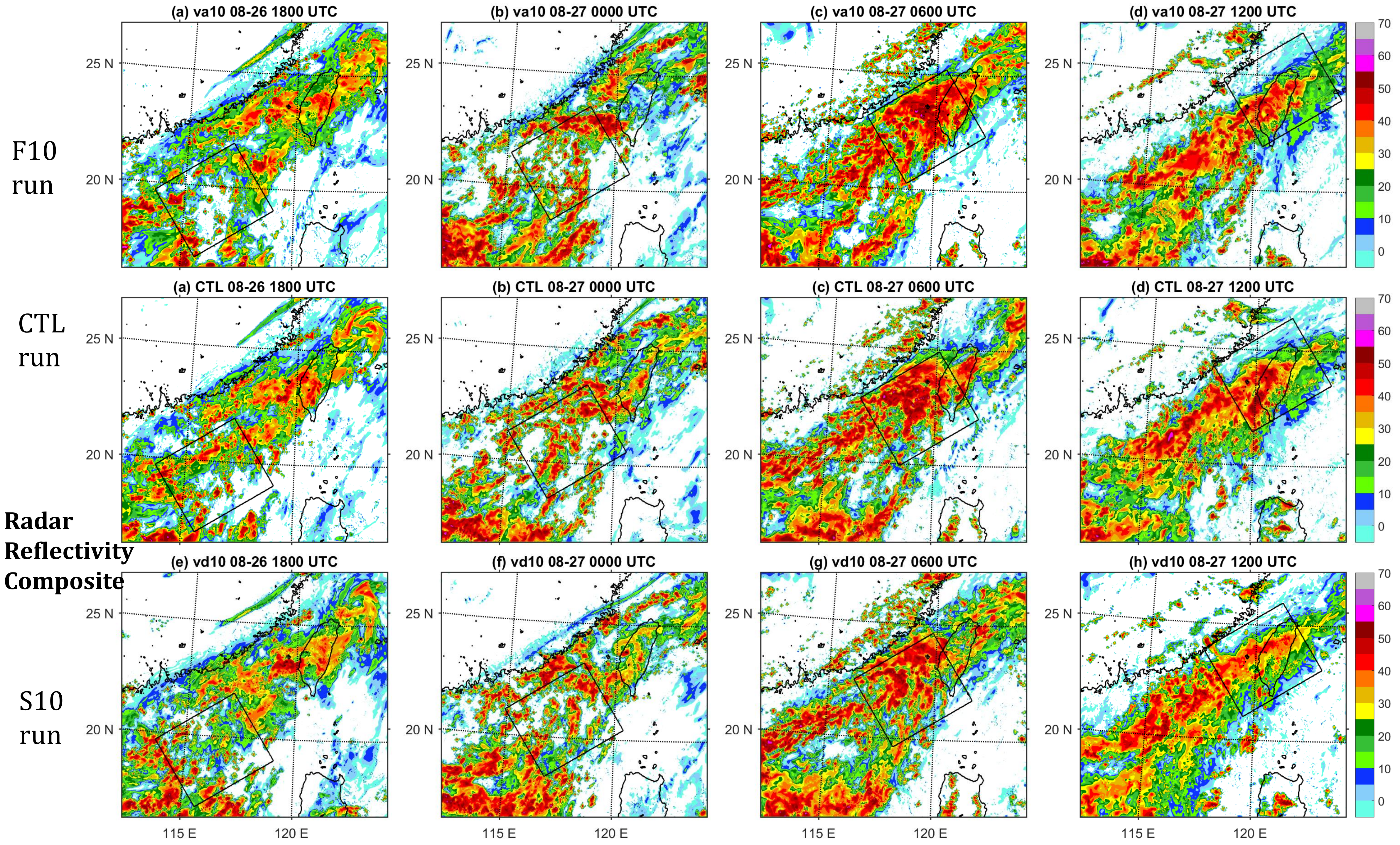
$$\{HFC\} = \{QADV\} + \{QCONV\}$$



System Total Evolution

Relative Change wrt CTL


W10 run
CTL run
D10 run
Radar Reflectivity Composite
(a) W10 08-26 1800 UTC
(b) W10 08-27 0000 UTC
(c) W10 08-27 0600 UTC
(d) W10 08-27 1200 UTC
(a) CTL 08-26 1800 UTC
(b) CTL 08-27 0000 UTC
(c) CTL 08-27 0600 UTC
(d) CTL 08-27 1200 UTC
(e) D10 08-26 1800 UTC
(f) D10 08-27 0000 UTC
(g) D10 08-27 0600 UTC
(h) D10 08-27 1200 UTC
25 N
20 N
115 E
120 E
70
60
50
40
30
20
10
0


F10
run
CTL
run
Radar
Reflectivity
Composite
S10
run
(a) va10 08-26 1800 UTC
(b) va10 08-27 0000 UTC
(c) va10 08-27 0600 UTC
(d) va10 08-27 1200 UTC
(a) CTL 08-26 1800 UTC
(b) CTL 08-27 0000 UTC
(c) CTL 08-27 0600 UTC
(d) CTL 08-27 1200 UTC
(e) vd10 08-26 1800 UTC
(f) vd10 08-27 0000 UTC
(g) vd10 08-27 0600 UTC
(h) vd10 08-27 1200 UTC
25 N
20 N
115 E
120 E
70
60
50
40
30
20
10
0

Water vapor budget: q_v

$$Tend_v = HFC_v + VFC_v + Div_v + Diff_v + PBL_v - Cond + Evap + Resd_v$$

Hydrometeors budget: $q_h = q_c + q_r + q_i + q_s + q_g$

$$Tend_h = HFC_h + VFC_h + Div_h + Diff_h + PBL_h + Cond - Evap + P + Resd_h$$

Reference:
Braun (2006; JAS)
Yang et al. (2011; MWR)
Huang et al. (2014; JAS)

				W10		D10		F10		S10	
		CTL		W10		D10		va10		vd10	
	Cond (10^{12} kg)	8.09		8.57		4.69		7.68		6.49	
		WV	HY	WV	HY	WV	HY	WV	HY	WV	HY
Total condensation	Cond	-100.00	100.00	-100.00	100.00	-100.00	100.00	-100.00	100.00	-100.00	100.00
Total evaporation	Evap	43.76	-43.76	43.96	-43.96	49.53	-49.53	43.08	-43.08	45.44	-45.44
Horizontal flux convergence	HFC	48.30	0.05	42.63	0.03	37.68	1.10	50.55	-0.15	47.19	0.09
Vertical flux convergence	VFC	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00
Divergence	Div	1.90	0.43	1.76	0.35	1.49	0.43	1.89	0.39	1.73	0.41
Diffusion	Diff	0.00	-0.01	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.01
PBL	PBL	7.44	0.00	7.25	0.00	10.81	0.00	8.41	0.00	9.62	0.00
Tendency	Tend	-0.41	1.92	-6.27	0.53	-1.78	1.15	2.14	1.68	2.40	1.43
Residuals	Resd	-1.82	-2.50	-1.88	-0.99	-1.29	-1.81	-1.80	-2.15	-1.59	-1.97
Precipitation flux	P		-54.21		-55.43		-50.18		-55.01		-53.10

Large-Scale Precipitation Efficiency (Sui et al, 2007; Huang et al. 2014; Xu et al, 2017)

$$LSPE = \frac{P}{\sum_{i=1}^{4} sgn(Q_i) Q_i}$$

$$Q_i = (Q_{WVT}, Q_{WVF}, Q_{WVE}, Q_{CM})$$

$$\begin{cases} Q_{WVT} = [-\partial q_v / \partial t] & \text{local water vapor change} \\ Q_{WVF} = [-\nabla \cdot (q_v \vec{U})] & \text{water vapor convergence} \\ Q_{CM} = [-\partial q_t / \partial t] + [-\nabla \cdot (q_t \vec{U})] & \text{local hydrometeors change and convergence} \end{cases}$$

Q_{WVE} → surface evaporation rate

Cloud-Microphysics Precipitation Efficiency (Sui et al, 2007; Huang et al, 2014; Xu et al, 2017)

$$CMPE = \frac{P}{Cond + sgn(Q_{CM}) Q_{CM}}$$

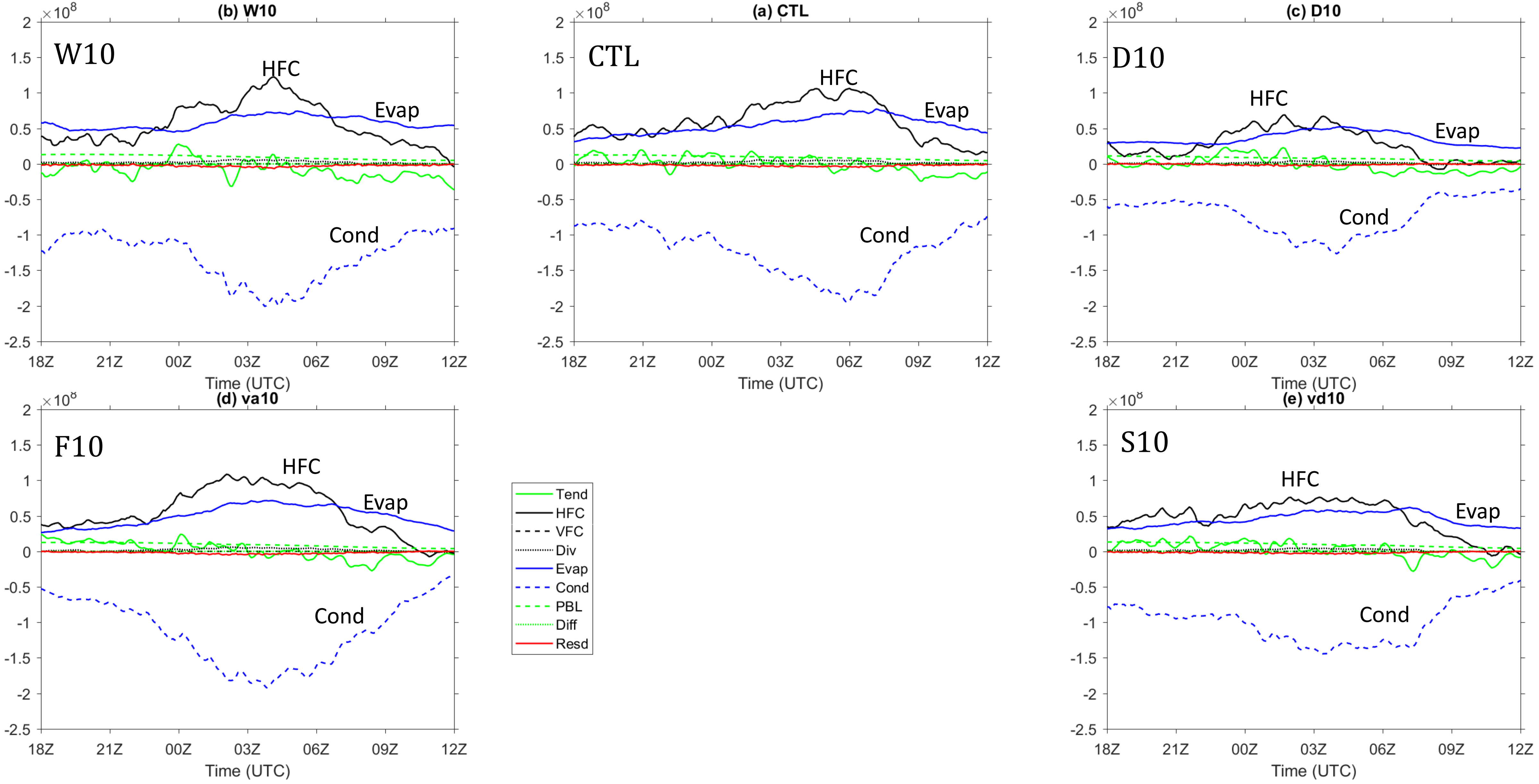
Condensation Ratio $CR = \frac{Cond_l}{Cond + sgn(Q_{CM}) Q_{CM}}$ — $Cond_l$ → Liquid-phase condensation

Deposition Ratio $DR = \frac{Cond_s}{Cond + sgn(Q_{CM}) Q_{CM}}$ — $Cond_s$ → Ice-phase deposition

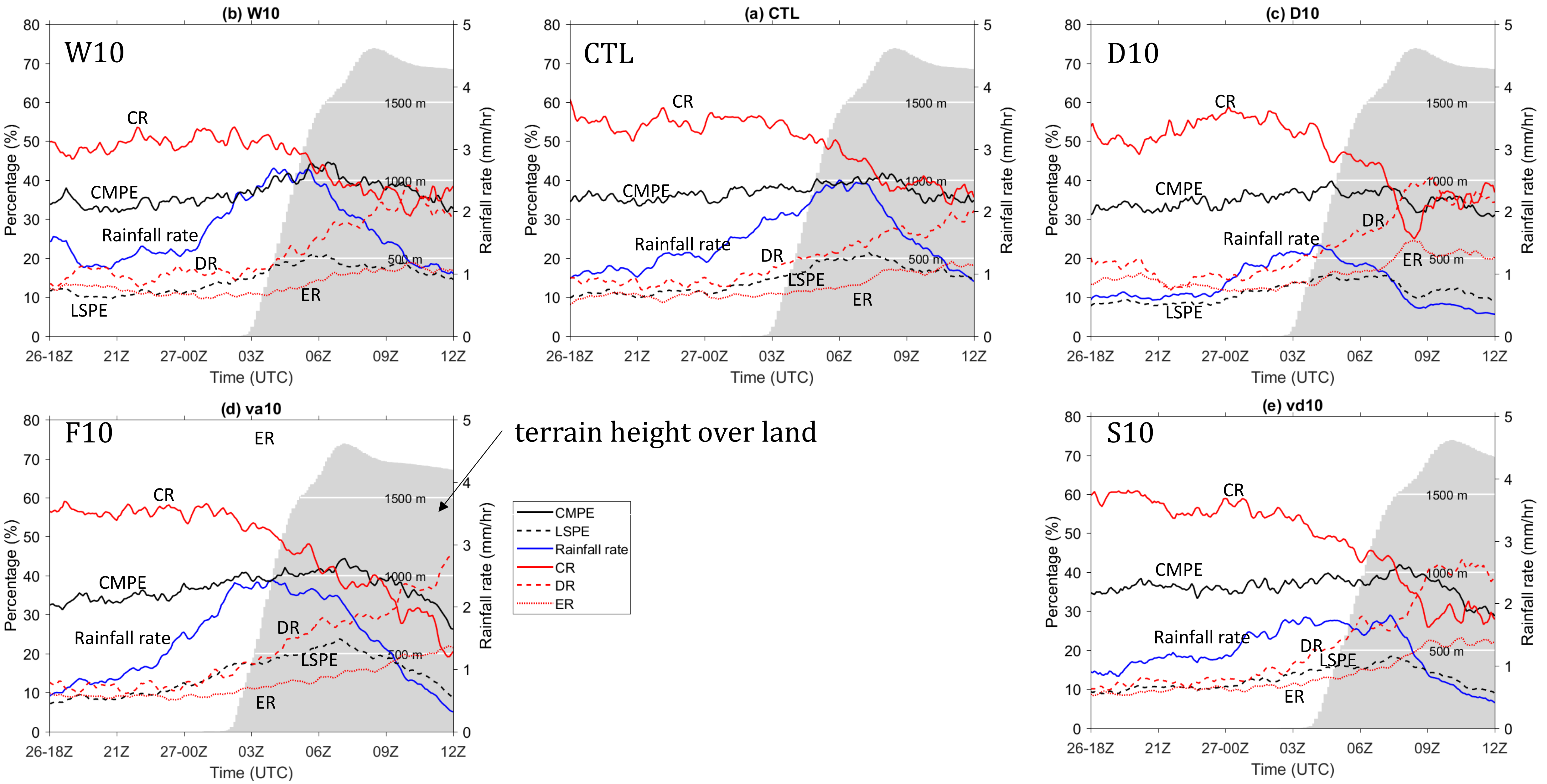
Evaporation Ratio $ER = \frac{Evap_r}{Cond + sgn(Q_{CM}) Q_{CM}}$ — $Evap_r$ → Raindrop evaporation

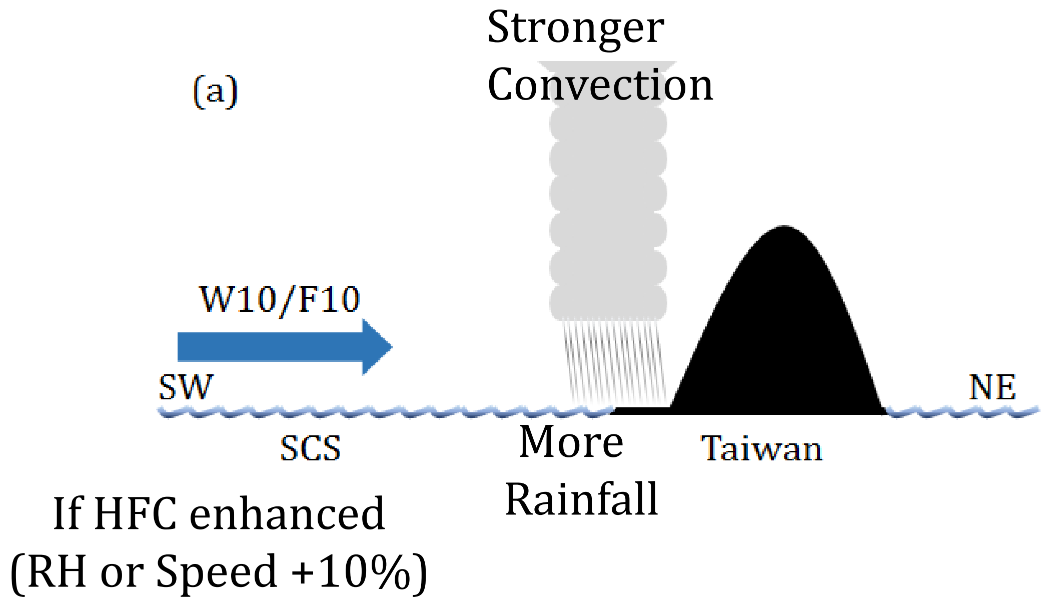
(Huang et al. 2014)

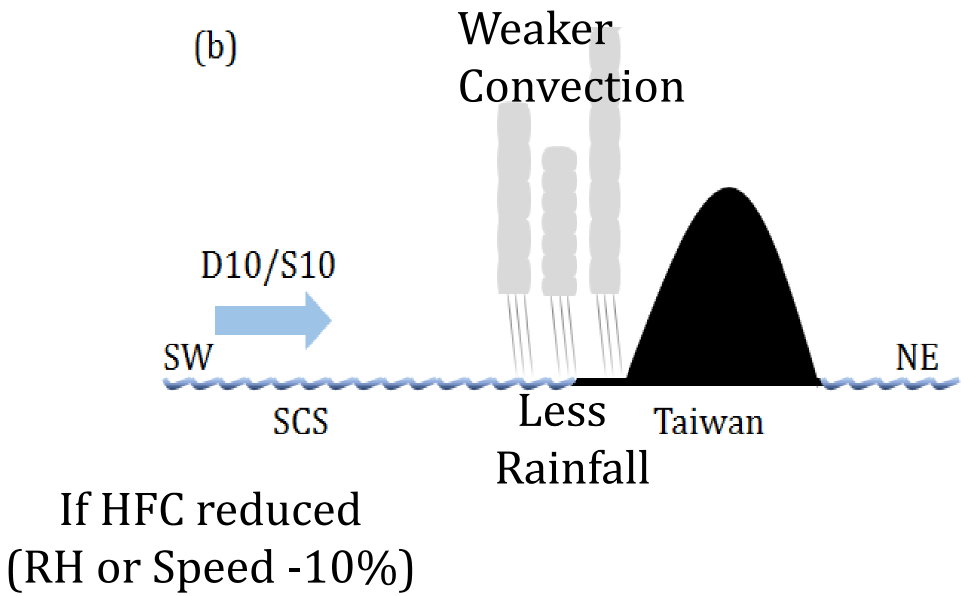
Quasi-Lagrangian Change of Water vapor budget within MCS



Quasi-Lagrangian Change of Microphysics Ratios within MCS







Relative change of Sensitivity Experiment wrt. CTL

	IWV	IMT	IVT	HFC	P
W10	↑5%	↑15%	↑20%	↑15%	↑20%
F10	—	↑5%	↑5%	↑<1%	↑<5%
S10	—	↓5%	↓5%	↓5%	↓5%
D10	↓5%	↓15%	↓20%	↓40%	↓40%

Conclusions:

1) The integrated water vapor transport (IVT) and integrated mass transport (IMT) within the SW monsoon flow over the SCS **are more (less) sensitive to water vapor (wind speed)**; a 10% decrease of low-level RH may lead to 15% decrease of IMT, 20% decrease of IVT, and 40% decrease of total precipitation (P).

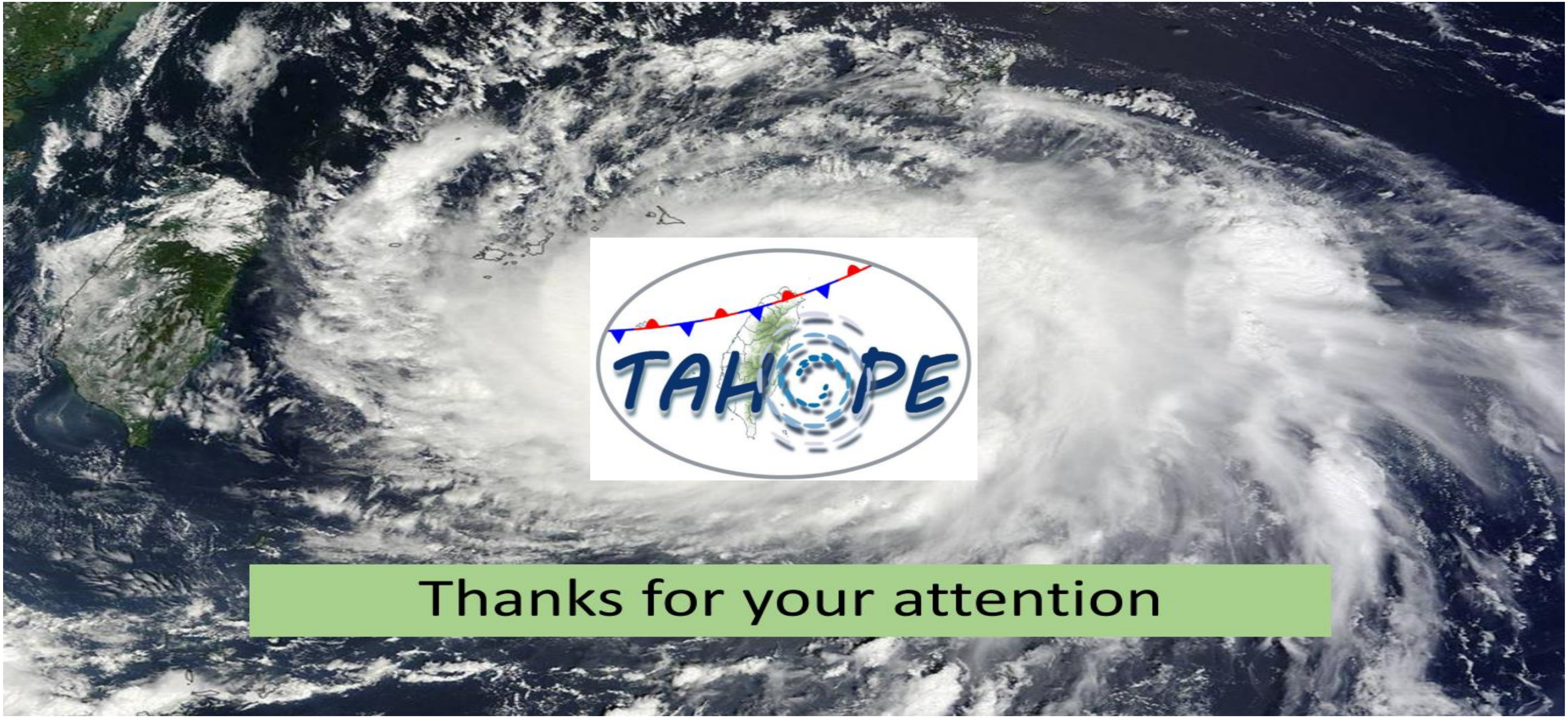
2) **Water vapor in the boundary layer plays a more important role in determining horizontal flux convergence (HFC) and resultant precipitation (P) rather than the horizontal wind speed**.

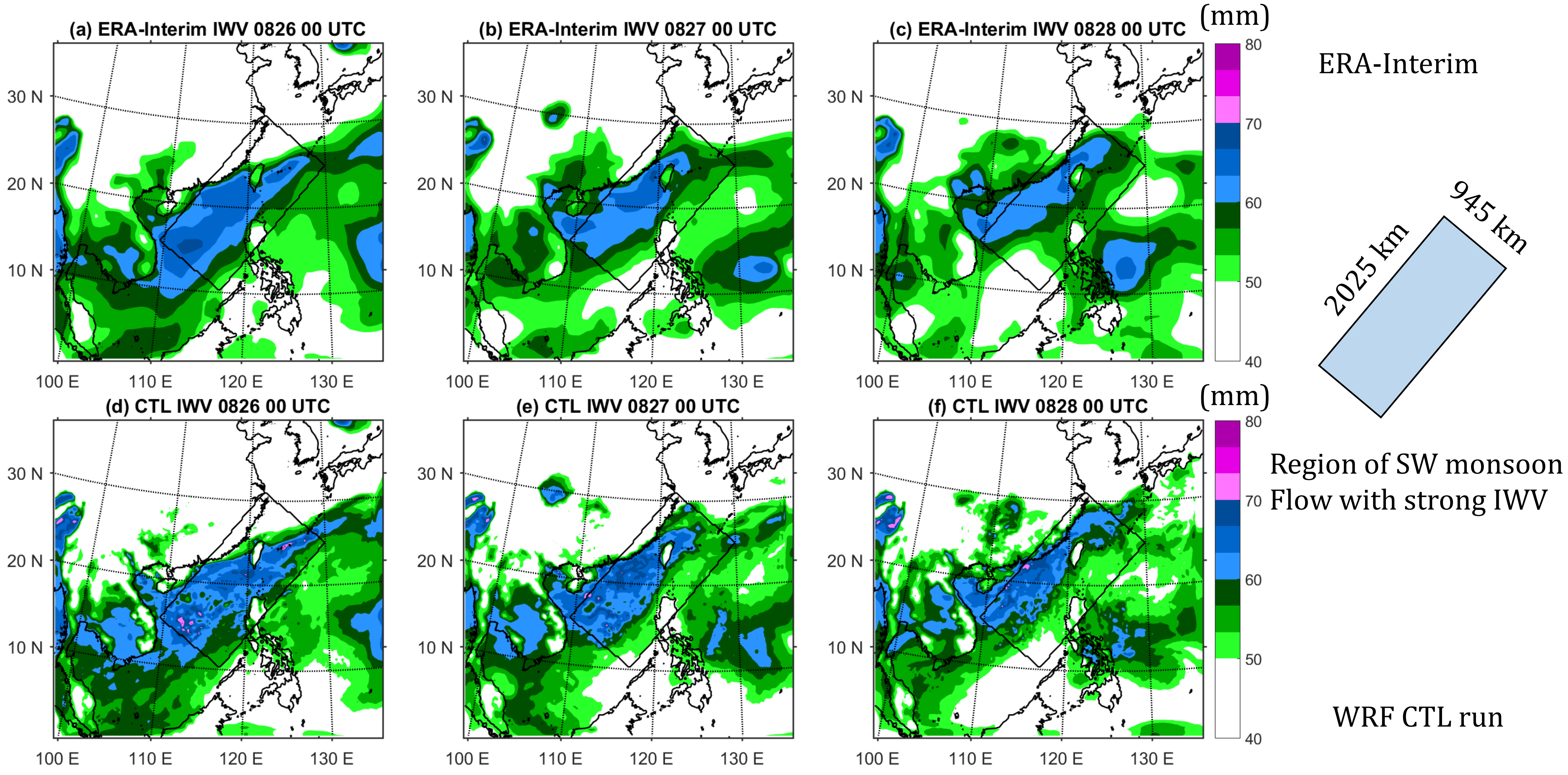
3) Along the SW monsoon flow, the horizontal moisture flux convergence (**HFC**) is mainly determined by the **wind convergence**; however, compared to wind convergence, water vapor advection has the **minor but opposite** contribution to the HFC.

4) Following the movement of a targeted MCS, its precipitation efficiency (**PE**) is increased about **10%** while encountering Taiwan topography from ocean (**LSPE: 10%→20%; CMPE: 30%→40%**).

Field Experiment:

Taiwan Area Heavy rain Observation and Prediction Experiment (TAHOPE) in May- August 2022


TAHOPE
Thanks for your attention


(a) ERA-Interim IWV 0826 00 UTC
(b) ERA-Interim IWV 0827 00 UTC
(c) ERA-Interim IWV 0828 00 UTC
(d) CTL IWV 0826 00 UTC
(e) CTL IWV 0827 00 UTC
(f) CTL IWV 0828 00 UTC
30 N
20 N
10 N
100 E
110 E
120 E
130 E
(mm)
80
70
60
50
40
ERA-Interim
2025 km
945 km
Region of SW monsoon
Flow with strong IWV
WRF CTL run