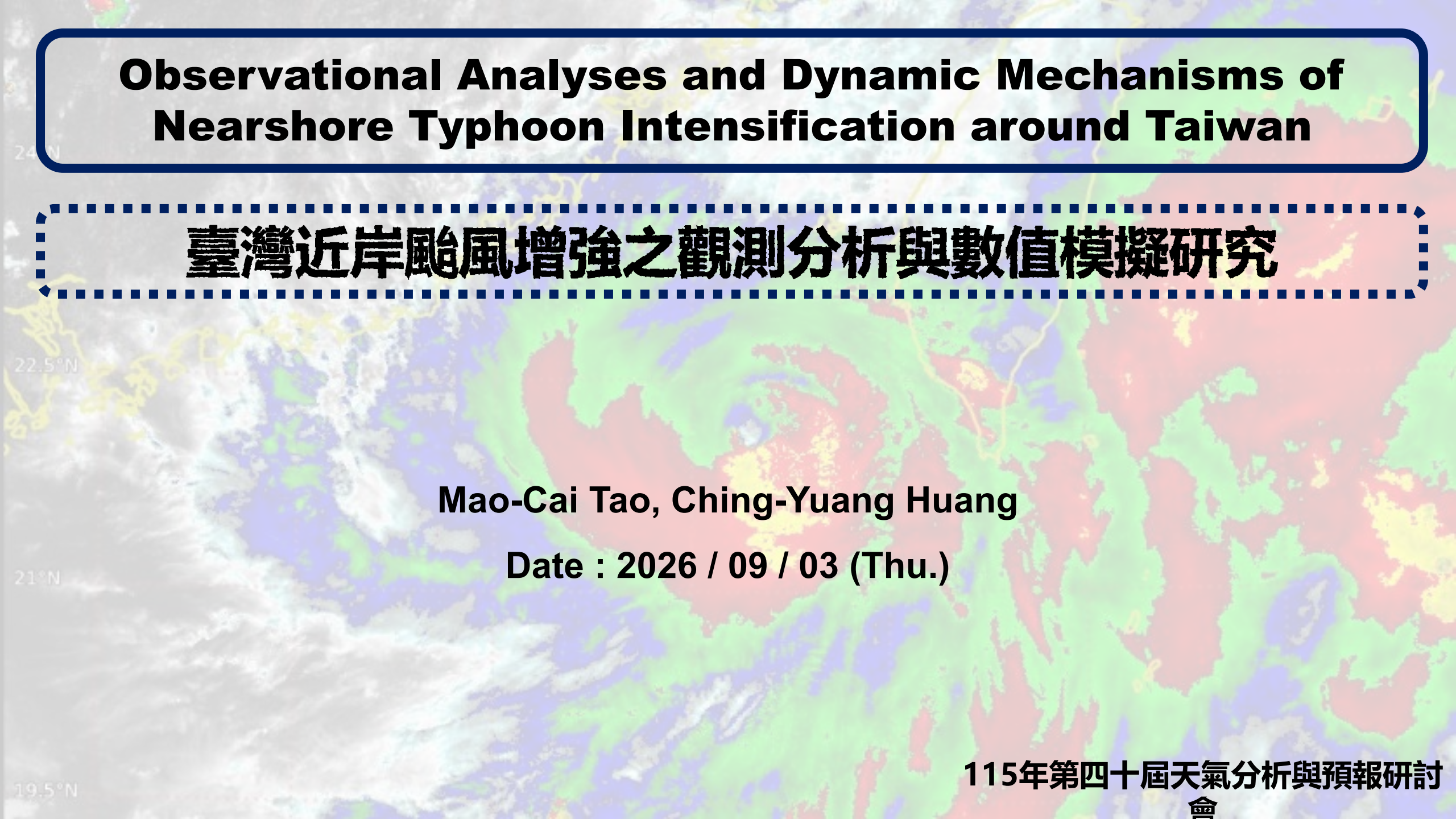




Observational Analyses and Dynamic Mechanisms of Nearshore Typhoon Intensification around Taiwan

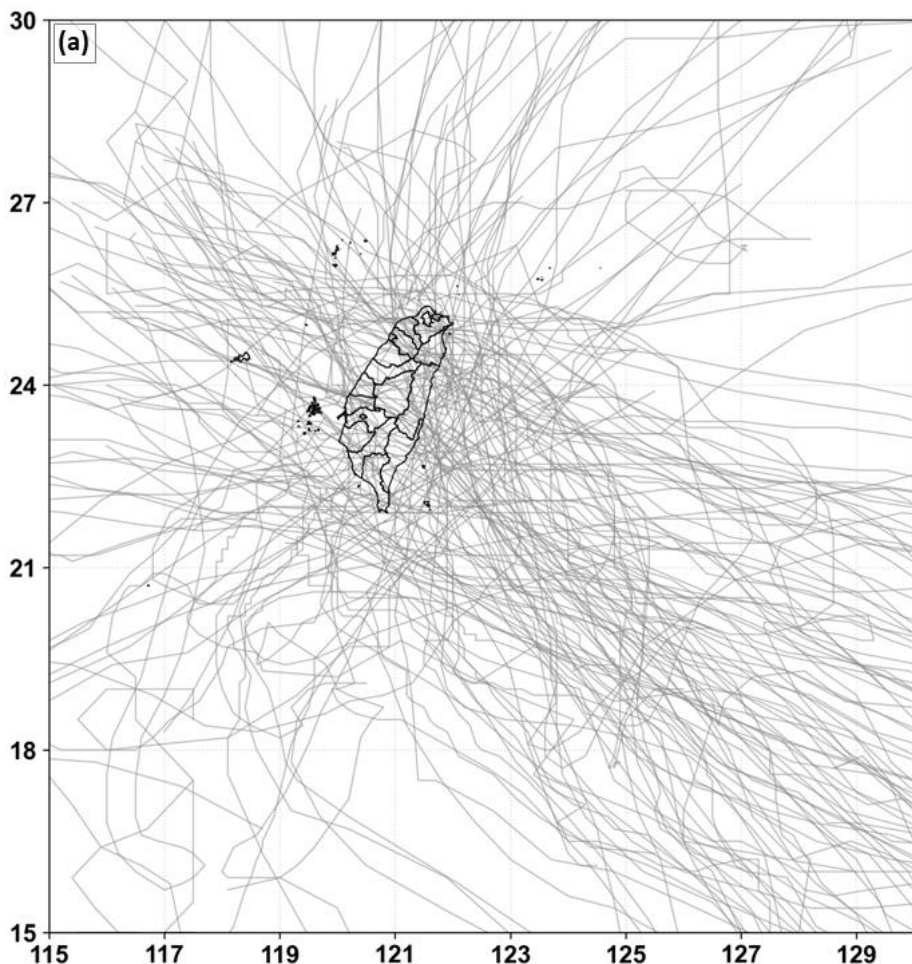
臺灣近岸颱風增強之觀測分析與數值模擬研究

Mao-Cai Tao, Ching-Yuang Huang

Date : 2026 / 09 / 03 (Thu.)

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Typhoon intensity near Taiwan is not a simple landfall-decay problem



Taiwan's ~4-km Central Mountain Range can modify TC circulation before landfall through:

- terrain blocking, recirculating, and channeling
- vortex asymmetrization and structural adjustment before the center reaches land

Wu and Kuo (1999); Jian and Wu (2008); Huang et al. (2020, 2022); Chi et al. (2024a,b)

Question

Under what storm structure and approach geometry can the Taiwan-induced adjustment temporarily strengthen the inner core?

Study strategy: first identify the signal, then isolate the mechanism



The **observational analysis** determines whether nearshore intensification has systematic storm attributes

The **WRF experiments** then test whether Taiwan provides an additional intensity contribution and how that contribution is dynamically produced

Introduction

Data & Method

Result

Summary

Reference

5

Near-Taiwan TC dataset and representative cases

129 cases (1975–2025): 89 landfalling + 40 nonlandfalling within 100 km of Taiwan coastline

Typhoon	Year	CaseType	Direction	t0	LatLon	Distance	Radius	V0	V-6	V-12	V-24	V-48	Class	V24max	V48max
PODUL	2025	Landfall	W	081304	22.6, 121.0	0	180	43	43	38	33	30	V24	10	13
DANAS	2025	Landfall	NE	070615	23.3, 120.1	0	150	40	35	33	25	15	V24	15	25
KONG-REY	2024	Landfall	NW	103105	23.1, 121.4	0	320	51	53	53	53	35	V48	0	18
GAEMI	2024	Landfall	NW	072416	24.4, 121.8	0	250	51	53	51	43	33	V24	10	20
HAIKUI	2023	Landfall	W	090307	22.9, 121.3	0	180	43	40	40	38	33	X	5	10
CHANTHU	2021	NearTaiwan	N	091205	25.0, 122.3	29.6	200	54	60	58	48	53	V24	12	12
MITAG	2019	NearTaiwan	N	093014	25.2, 122.7	76.5	180	35	35	35	30	23	X	5	12
BAILU	2019	Landfall	NW	082405	22.0, 120.9	0	150	30	30	30	25	20	X	5	10
NESAT	2017	Landfall	NW	072911	24.4, 121.8	0	180	40	38	38	30	25	V24	10	15
DUJUAN	2015	Landfall	W	092810	24.2, 121.7	0	220	51	51	51	51	40	X	0	11
FUNG-WONG	2008	Landfall	W	072722	23.5, 121.5	0	220	43	43	38	33	23	V24	10	20
KALMAEGI	2008	Landfall	NW	071713	24.4, 121.8	0	100	30	30	28	25	18	X	5	12
WIPHA	2007	NearTaiwan	NW	091807	25.7, 122.2	73.9	200	43	48	48	35	20	V24	13	28
NARI	2001	Landfall	SW	091615	24.7, 121.8	0	150	40	40	33	33	30	X	7	10
BILIS	2000	Landfall	NW	082214	22.9, 121.3	0	300	53	53	53	51	35	V48	2	18
TIM	1994	Landfall	NW	071012	23.4, 121.5	0	250	53	53	51	48	28	V48	5	25
NAT	1991	Landfall	W	092222	22.1, 120.9	0	200	51	48	45	48	28	V48	6	23
AMY	1991	NearTaiwan	NW	071818	21.5, 120.5	48	300	51	51	51	35	28	V24	16	23
DOT	1990	Landfall	NW	090715	23.3, 121.4	0	350	38	38	38	35	28	X	3	10
SARAH	1989	Landfall	NW	091116	23.1, 121.3	0	300	51	51	48	38	33	V24	13	18
GERALD	1987	NearTaiwan	NW	090917	22.4, 120.1	28	300	51	51	51	47	33	V48	4	18
ALEX	1987	Landfall	NW	072621	24.6, 121.9	0	250	42	42	42	40	30	X	2	12
NANCY	1986	Landfall	NW	062319	24.2, 121.7	0	180	30	38	38	33	15	V48	5	23
WAYNE	1983	NearTaiwan	NW	072419	21.5, 120.3	64.1	250	60	63	63	38	25	V24	25	38
PERCY	1980	Landfall	NW	091800	21.9, 120.9	0	250	60	60	55	40	28	V24	20	32
NORRIS	1980	Landfall	NW	082716	24.4, 121.8	0	250	43	43	38	30	20	V24	13	23
HOPE	1979	NearTaiwan	W	080110	21.3, 120.5	71.5	300	63	65	65	58	40	V48	7	25
VERA	1977	Landfall	W	073109	24.5, 121.8	0	200	55	55	51	51	33	V48	4	22
ELSIE	1975	NearTaiwan	NW	101218	21.1, 120.4	97.7	200	60	63	65	70	30	V48	0	40
BETTY	1975	Landfall	W	092210	22.8, 121.2	0	250	48	48	45	40	30	V48	8	18

to = landfall time or closest approach

Radius at t0 represents storm size

V24max: largest increase using −24/−12/−6/0 h

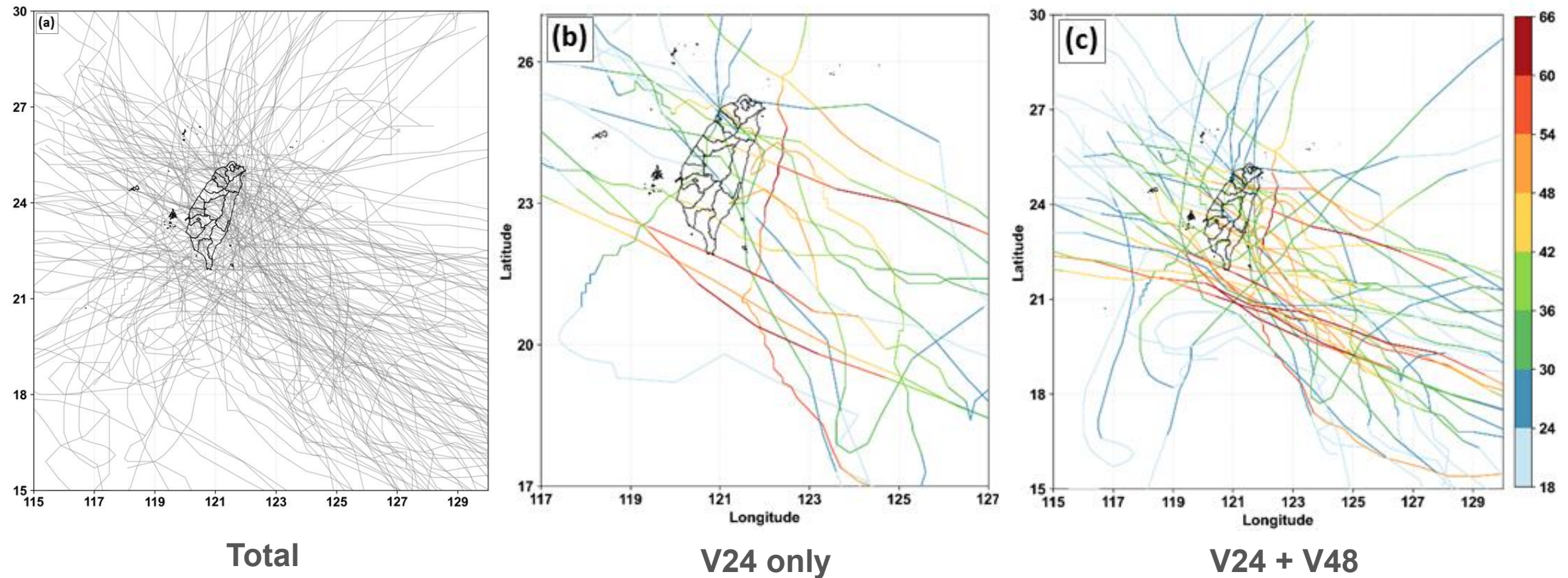
V48max: same with V24max but adds −48 h

V24 ≥10 m s^{−1} (P90) : 17 cases

V48 ≥13 m s^{−1} (P75) : 18 cases

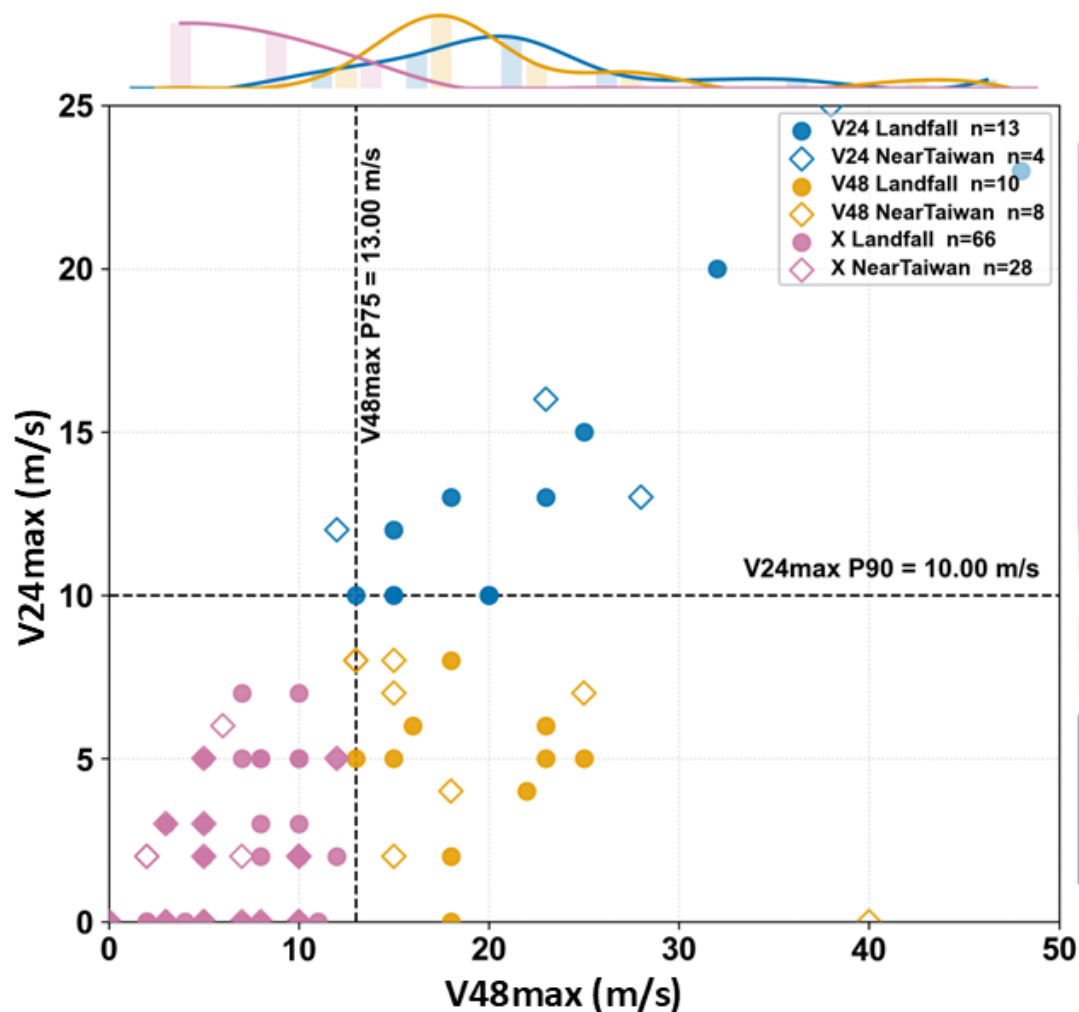
Data source:
CWA typhoon database

Observed tracks of the 129 near-Taiwan TCs



- Westward–northwestward tracks dominate the dataset and the threshold-exceeding cases
- A smaller northward family passes either west or east of the CMR

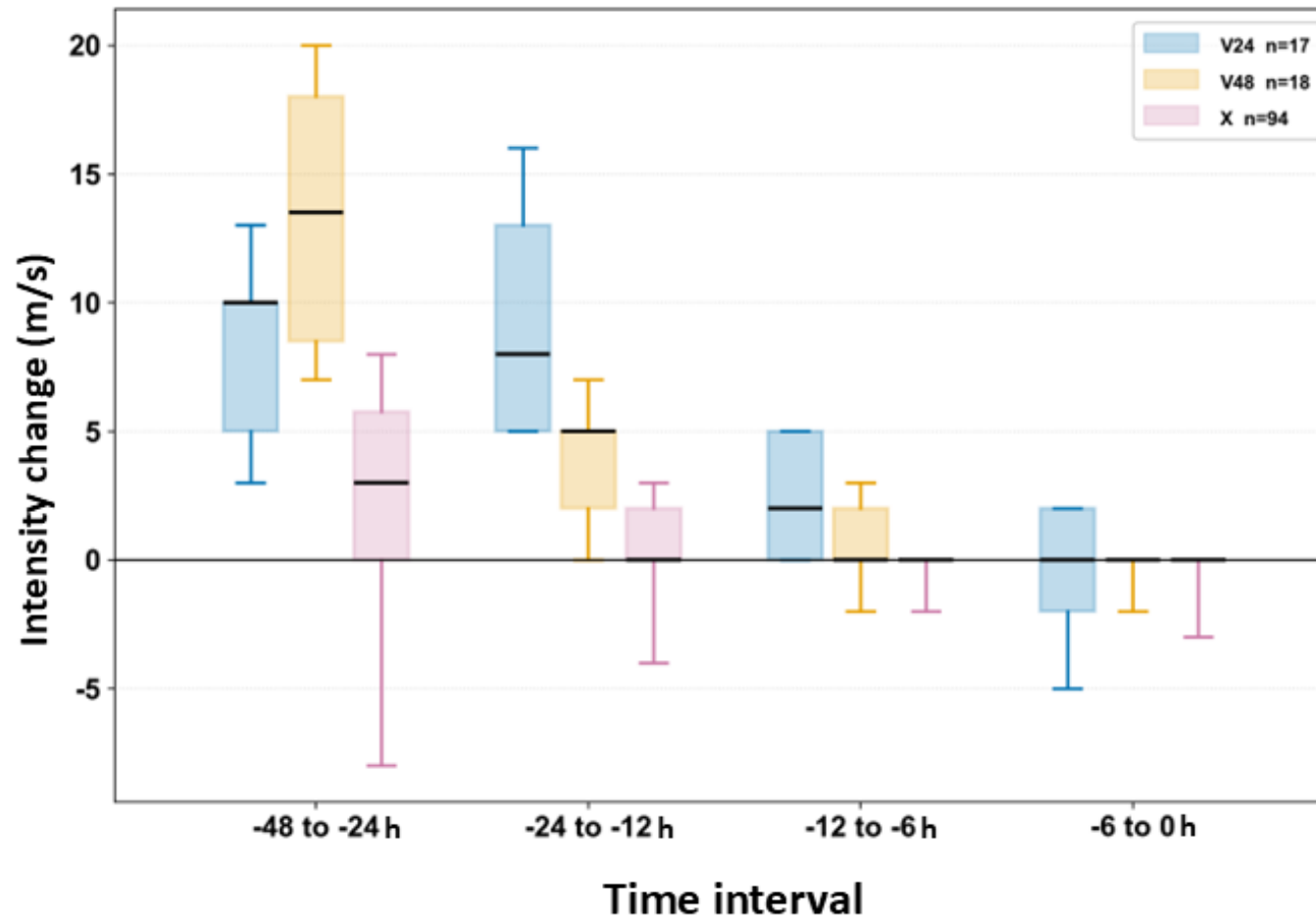
Intensity-change phase space defines V24, V48, and X



- 17 V24 cases exceed the 10 m s^{-1} V24max threshold
- 18 additional V48 cases exceed 13 m s^{-1} only after -48 h is included
- 94 cases remain below both thresholds
- Landfalling and nonlandfalling cases are well mixed

Only a small number of near-Taiwan TCs show marked nearshore intensification

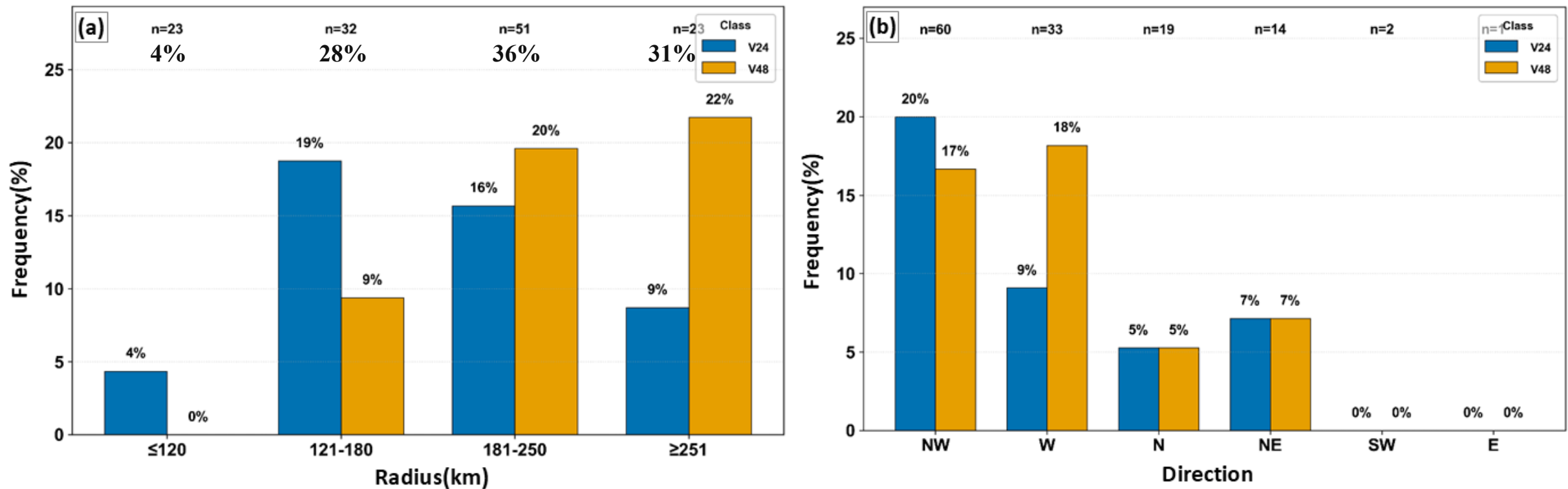
V48 strengthens earlier; V24 retains a later positive tendency



- -48 to -24 h: V48 has the largest median increase (13.5 m s^{-1}).
- -24 to -12 h: V24 retains the strongest increase (median 8 m s^{-1}).
- -6 to 0 h: all class medians are approximately zero.

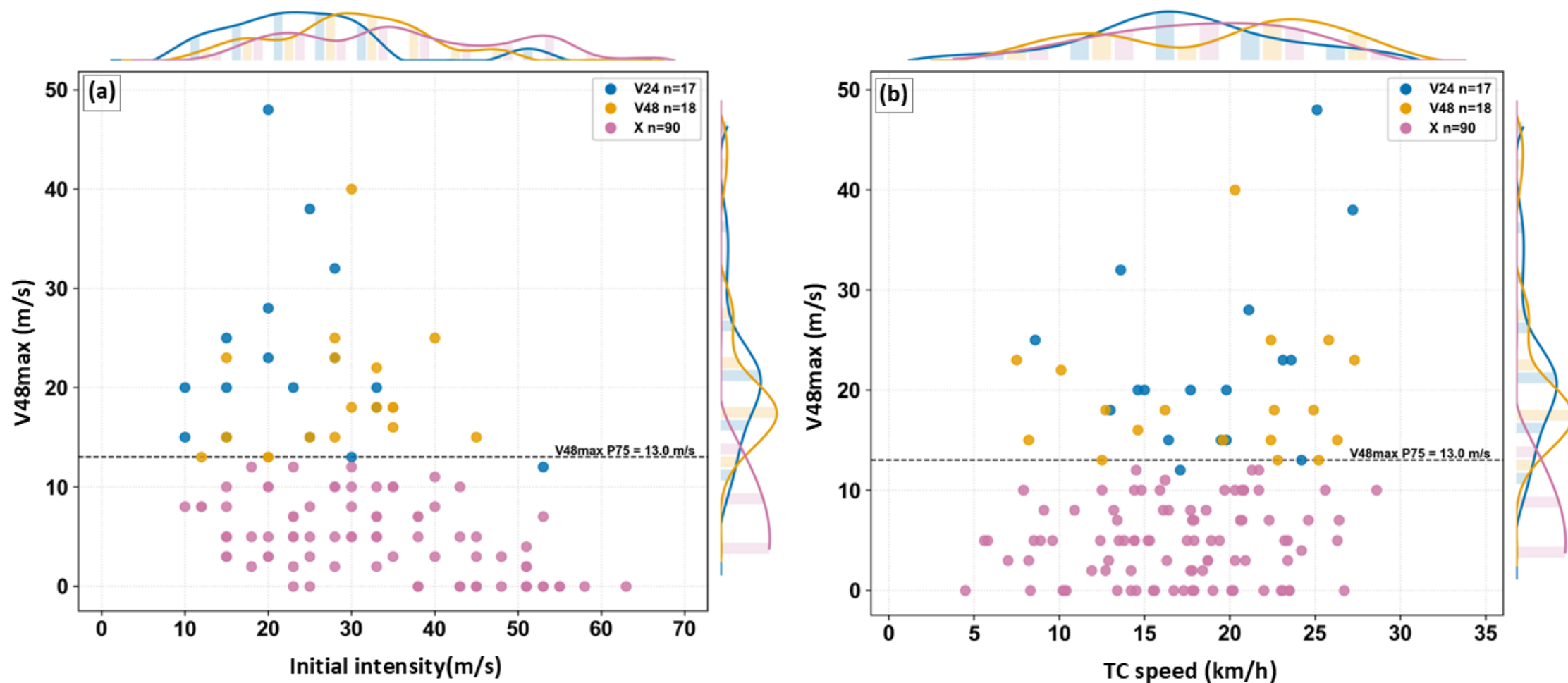
The classes separate earlier spinup from intensification that persists closer to t_0

Storm size provides the clearest statistical signal



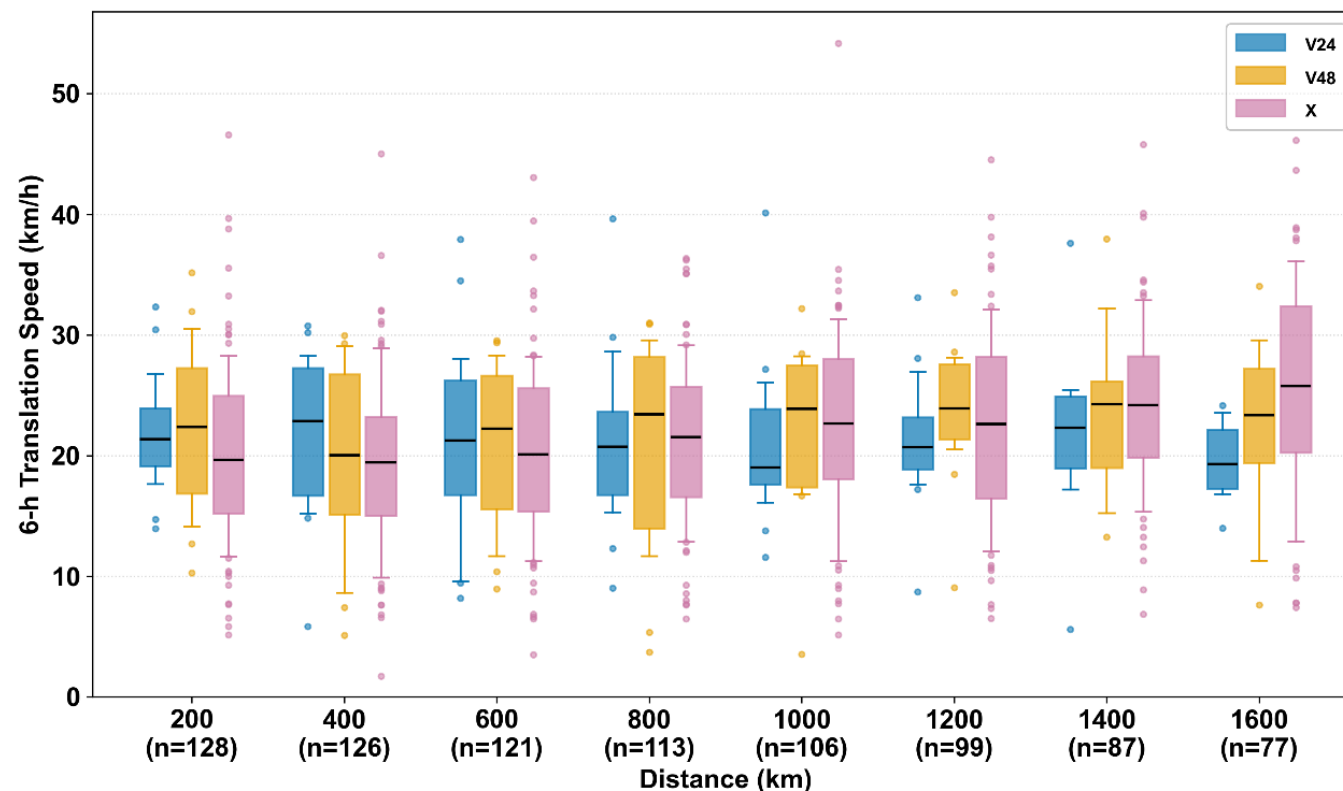
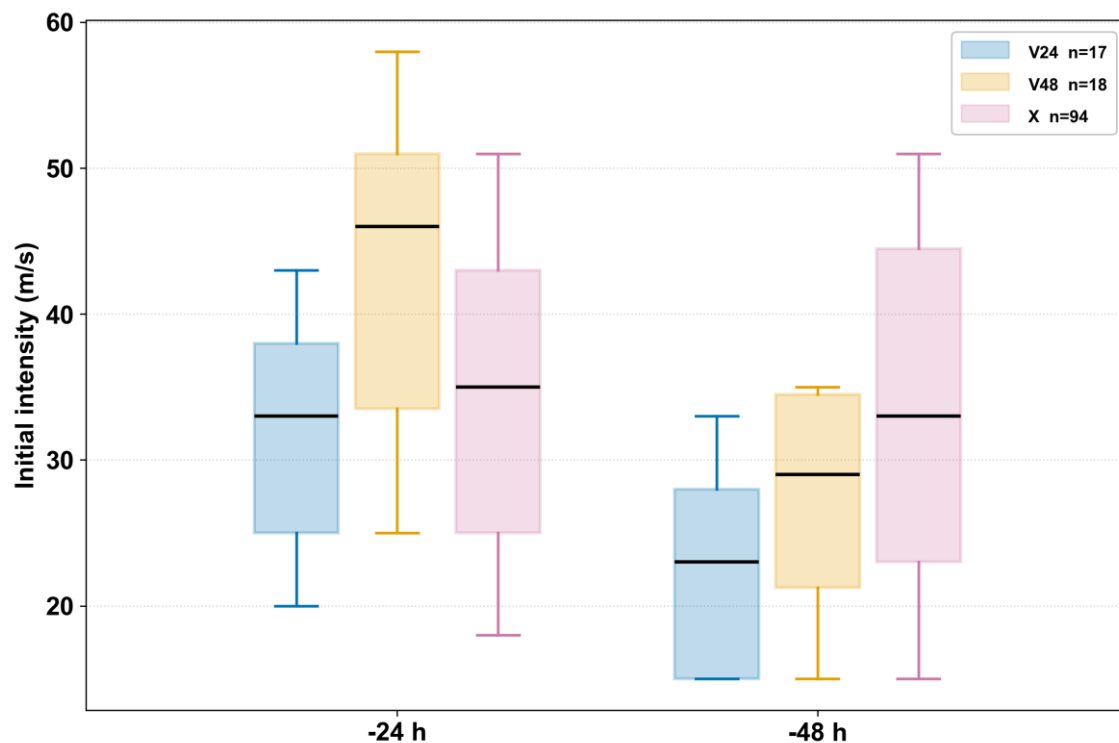
- The frequency of V24/V48 cases generally increases as radius becomes larger
- The continuous radius model gives OR = 1.39 per 50-km increase ($p = 0.023$)
- Approach direction is not a robust discriminator

Initial intensity shows a clearer pattern than translation speed



Large V48max occurs mainly from weaker-to-moderate initial storms,
while translation-speed distributions overlap broadly

Initial intensity reflects intensification timing



V24 starts weaker at -48 h, while V48 is stronger by -24 h
V24/V48 mainly occupy moderate speeds; cases below ~10 or above ~35 km h⁻¹ are mostly X

WRF model configuration

Weather Research & Forecasting Model (WRF) v4.2.2	
Resolution(time step)	D01 : 15km(60s) ; D02 : 3 km(12s)
Vertical layers	40 layers, top at 20 km
Initial conditions	NCEP GDAS/FNL 0.25°× 0.25° (6hr)
Simulations times	48hr for all cases
Physical parameterization schemes	- Convective : New Tiedtke - Microphysics : Goddard - Land surface : Noah - PBL : YSU - Surface layer : Revised MM5 - Radiation sw/lw : RRTMG

Terrain experiments

Paired terrain experiments

- CTL** Original Taiwan terrain and land surface
- noTW** Taiwan terrain and land replaced by ocean

Representative V24 cases

- Northward** Danas (2025), Chanthu (2021)
- West / NW** Gaemi (2024), Nesat (2017), Podul (2025)

Interpretation

Same initial and lateral boundary conditions;
only Taiwan is replaced by ocean in noTW

Diagnostics Tools

Axisymmetric structure

- Azimuthal-mean tangential wind
- Transverse circulation

Angular-momentum budget

Huang et al. (2020)

- Mean radial / vertical advection
- Eddy radial / vertical advection

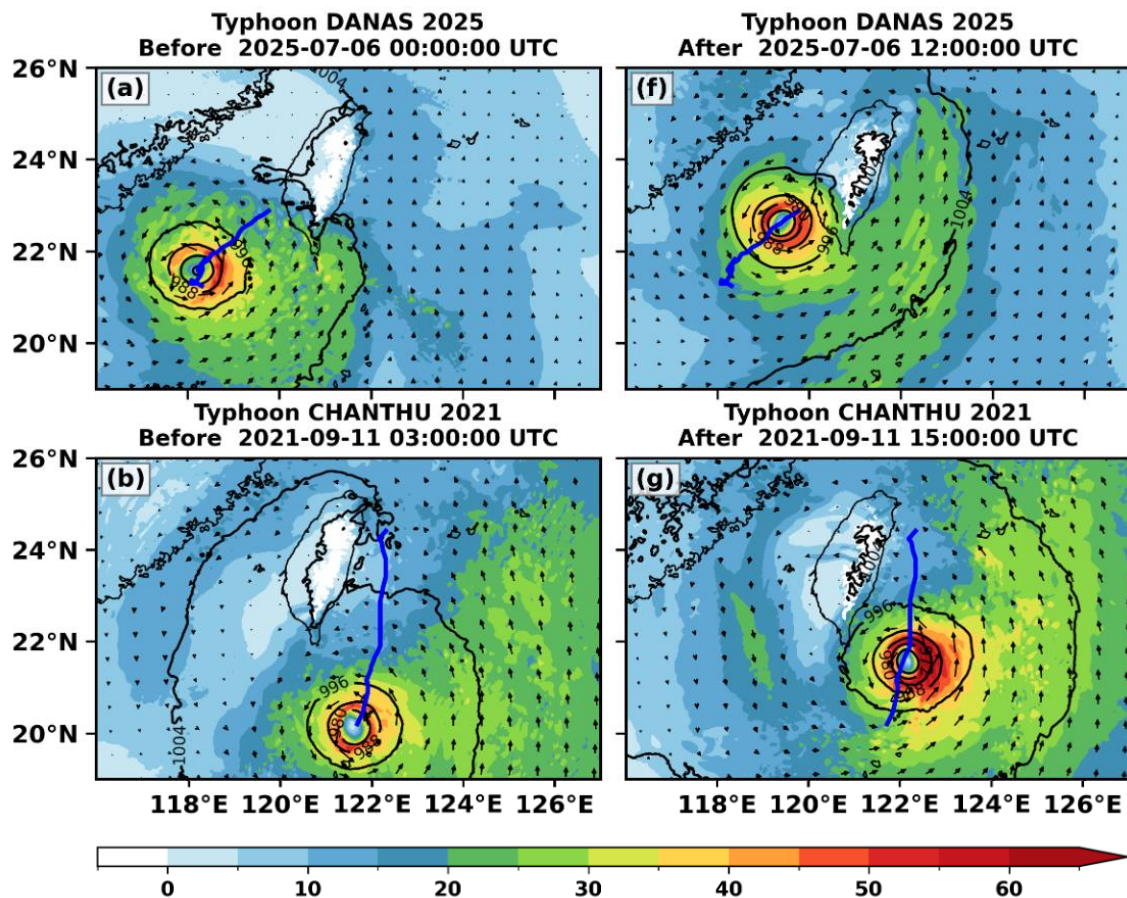
Extended Sawyer–Eliassen

Nguyen and Huang (2026)

- Diabatic heating
- Asymmetric heat / momentum forcing
- Turbulent momentum diffusion

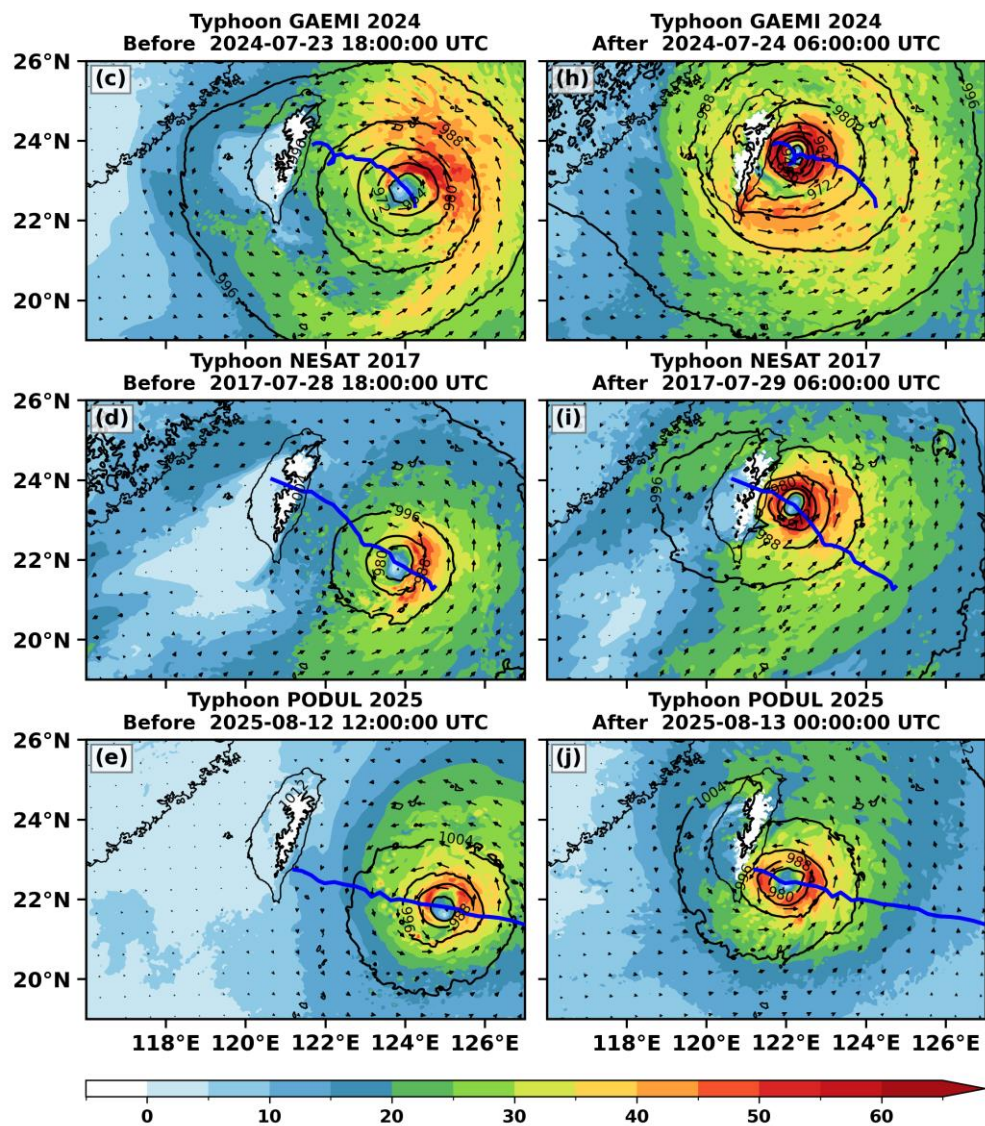
Twelve consecutive 5-min SE solutions are averaged to represent each 1-h analysis

CTL simulations result (850 hPa wind field)



- Danas, moving northward west of Taiwan develops a more consolidated inner core
- Chanthu, moving northward east of Taiwan strengthens with more prevailing flow east and south of the TC

CTL simulations result (850 hPa wind field)



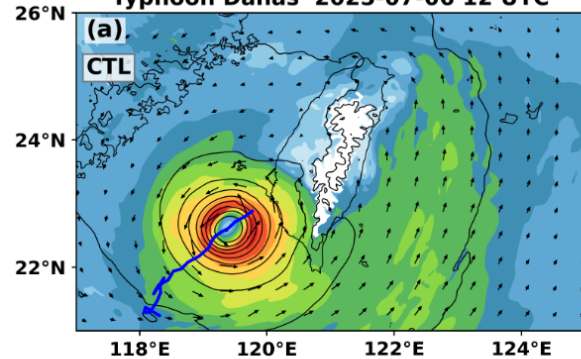
- Gaemi deepens markedly while approaching northern Taiwan
its outer circulation differs from the southern recirculation cases
- Nesat develops stronger southerly flow east and south of the center
as it approaches the central CMR
- Podul spins up while heading west toward southeastern Taiwan
with stronger flow in the southern quadrants

Effects of Taiwan terrain

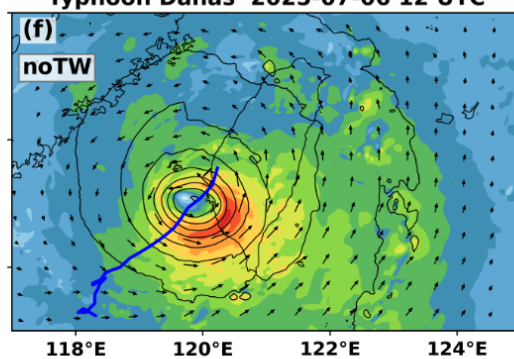
CTL

noTW

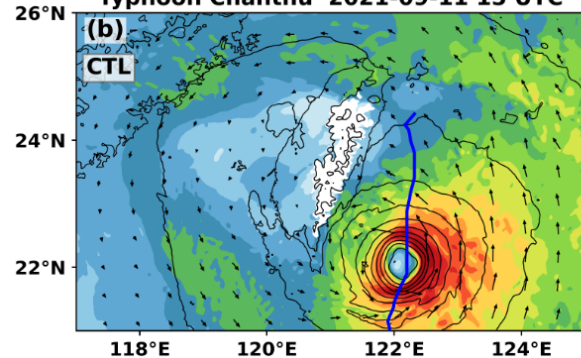
Typhoon Danas 2025-07-06 12 UTC



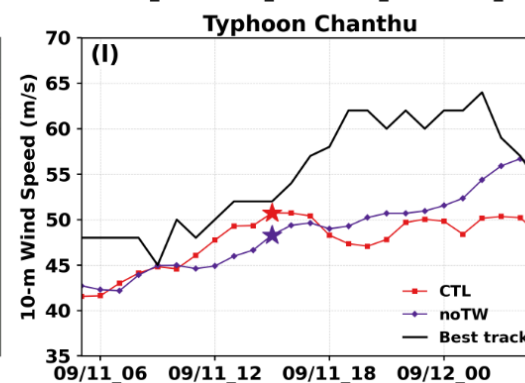
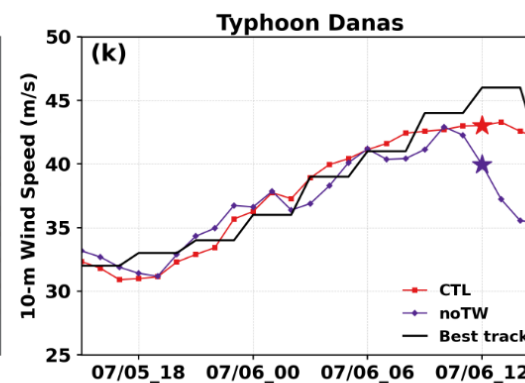
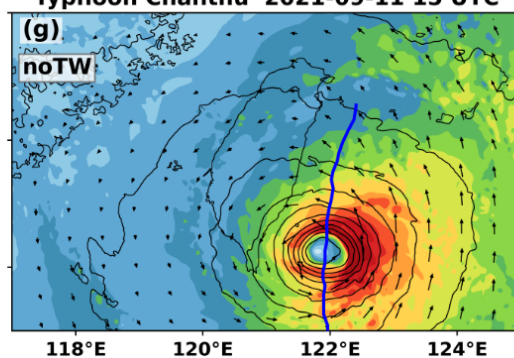
Typhoon Danas 2025-07-06 12 UTC



Typhoon Chanthu 2021-09-11 15 UTC



Typhoon Chanthu 2021-09-11 15 UTC



- At each comparison time, CTL is stronger than noTW
- The additional terrain-related increase is generally within about 5 m s^{-1}
- Danas reproduces the observed timing most closely; Chanthu does not reproduce the later observed RI Chi et al. (2024a,b)

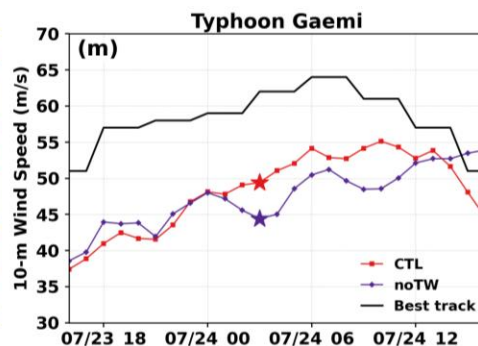
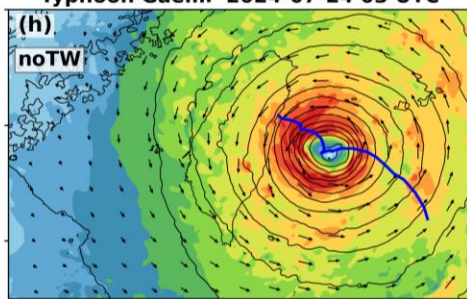
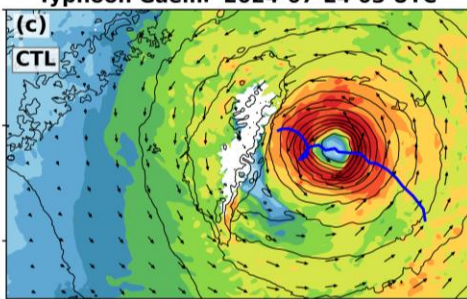
Effects of Taiwan terrain

CTL

noTW

Typhoon Gaemi 2024-07-24 03 UTC

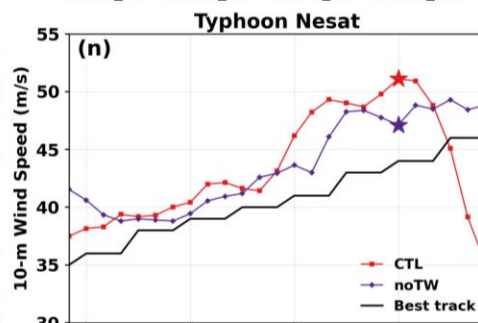
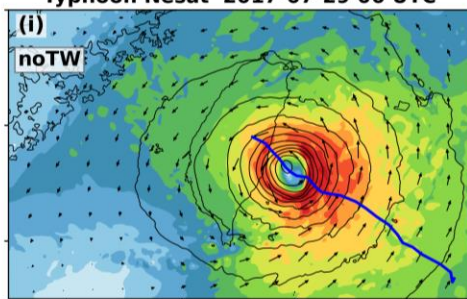
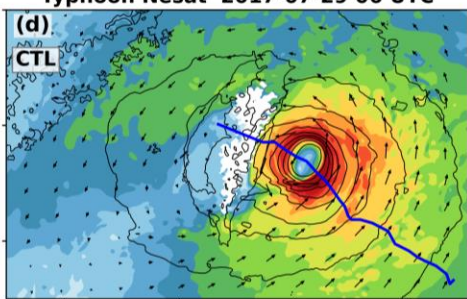
Typhoon Gaemi 2024-07-24 03 UTC



- Gaemi, Nesat and Podul also show a temporary CTL advantage before stronger terrain interaction

Typhoon Nesat 2017-07-29 06 UTC

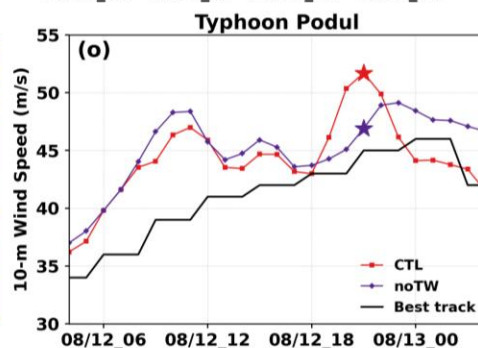
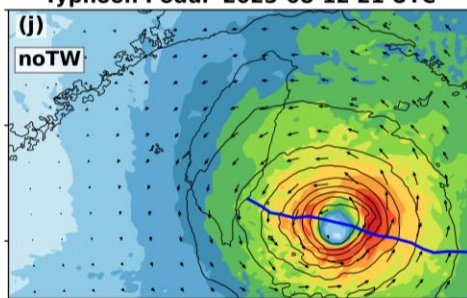
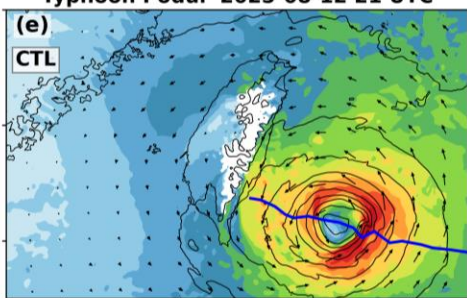
Typhoon Nesat 2017-07-29 06 UTC



- After closer overlap or landfall, CTL deforms and weakens rapidly relative to noTW

Typhoon Podul 2025-08-12 21 UTC

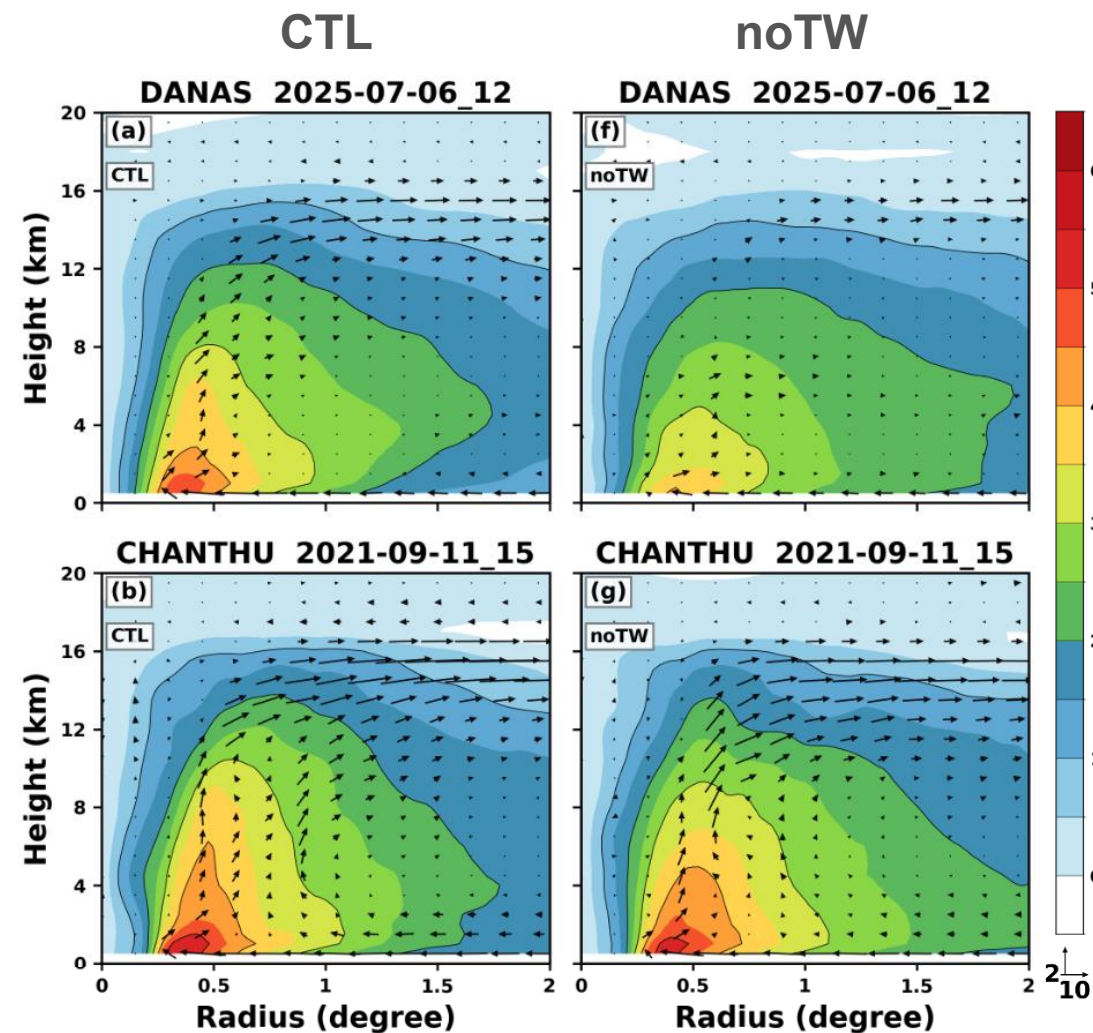
Typhoon Podul 2025-08-12 21 UTC



- noTW also intensifies at early stages, so intrinsic dynamics and the environment remain important

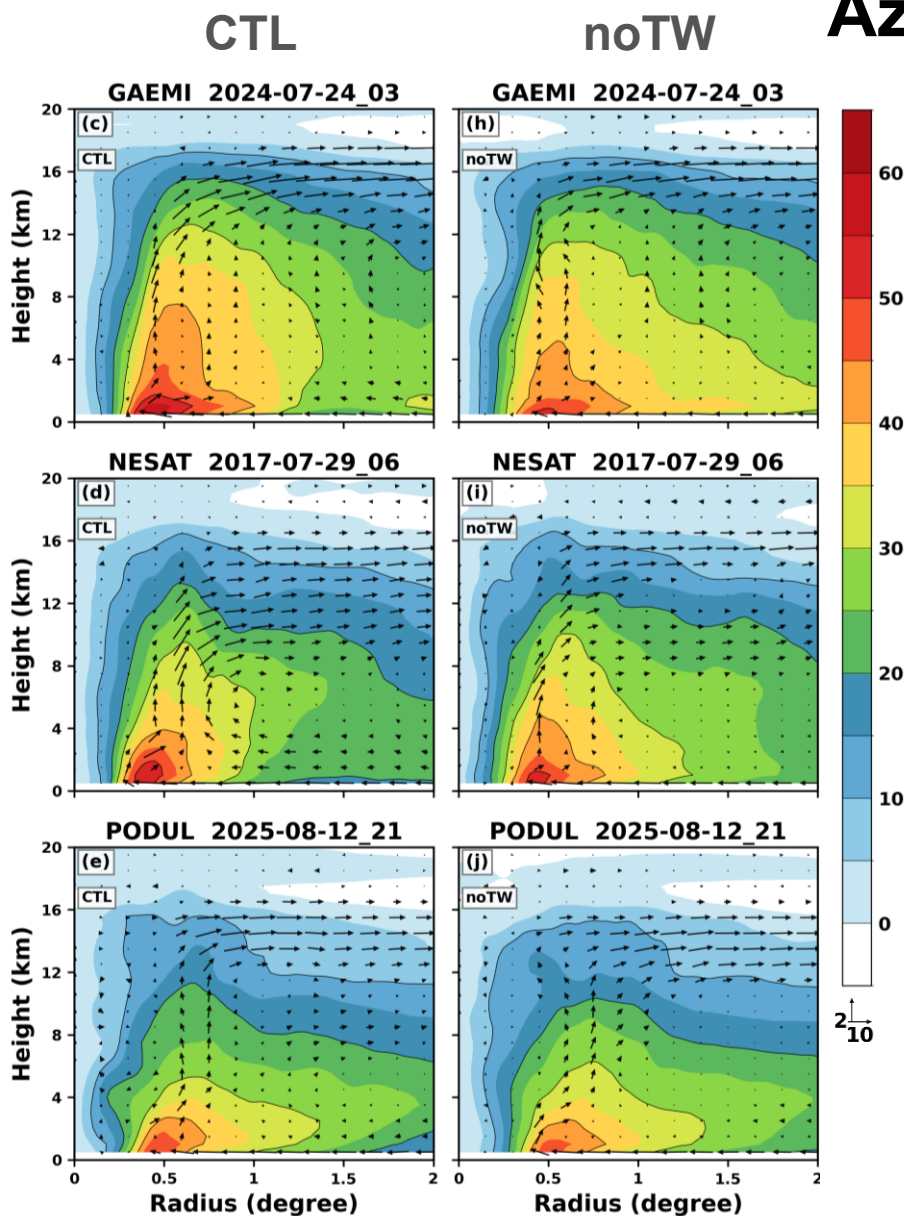


Azimuthal-mean circulation



- Danas CTL has stronger tangential wind below ~ 4 km at $\sim 0.3^\circ$ – 0.7° radius, with stronger inflow and eyewall ascent
- Chanthu shows stronger outer ascent in CTL, associated with enhanced low-level inflow convergence

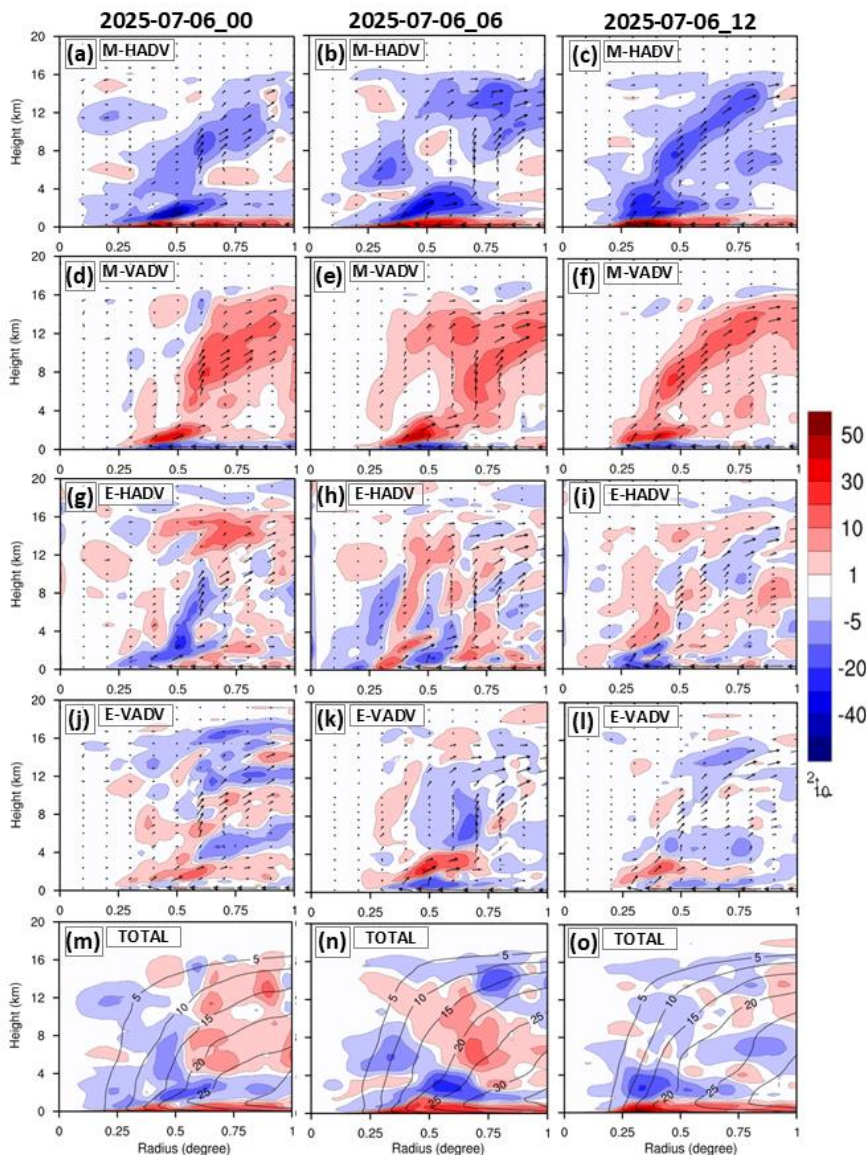
Azimuthal-mean circulation



- Gaemi CTL develops a stronger and deeper inner-eyewall wind together with stronger outer low-level inflow
- Nesat has a somewhat stronger transverse circulation in CTL, but smaller differences in mean tangential wind
- Podul shows relatively small CTL–noTW differences in both fields

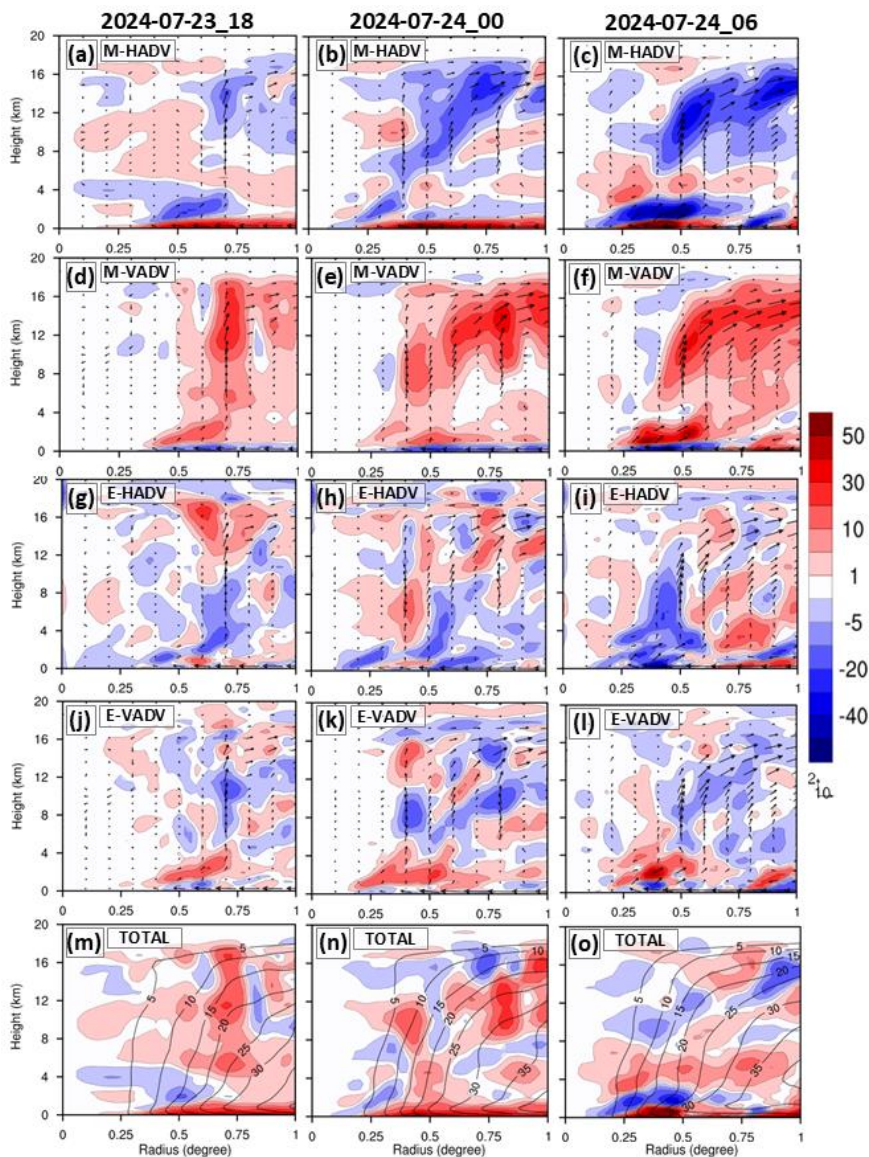
Angular momentum budget – Danas

- Mean radial advection is positive in the shallow inflow layer, indicating inward AM transport toward the inner core
- Mean vertical advection is positive along the eyewall ascent and carries AM upward through the troposphere
- TOTAL retains a pronounced positive tendency in the low-level inner core during intensification

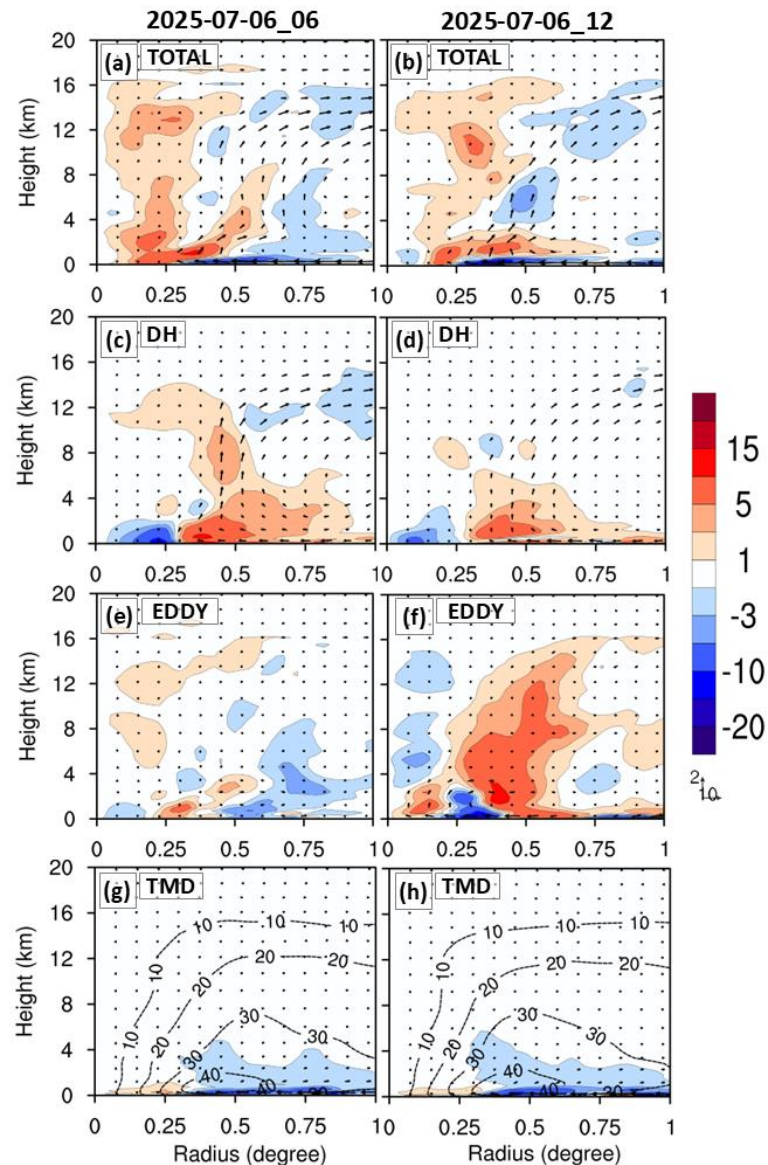


Angular momentum budget – Gaemi

- Mean radial advection imports AM through the low-level inflow layer and strengthens from 1800 to 0600 UTC
- Mean vertical advection produces a deep positive tendency through the eyewall and upper troposphere
- TOTAL is strongly positive below ~ 2 km at $\sim 0.3^\circ$ – 0.7° radius, near the strongest tangential wind



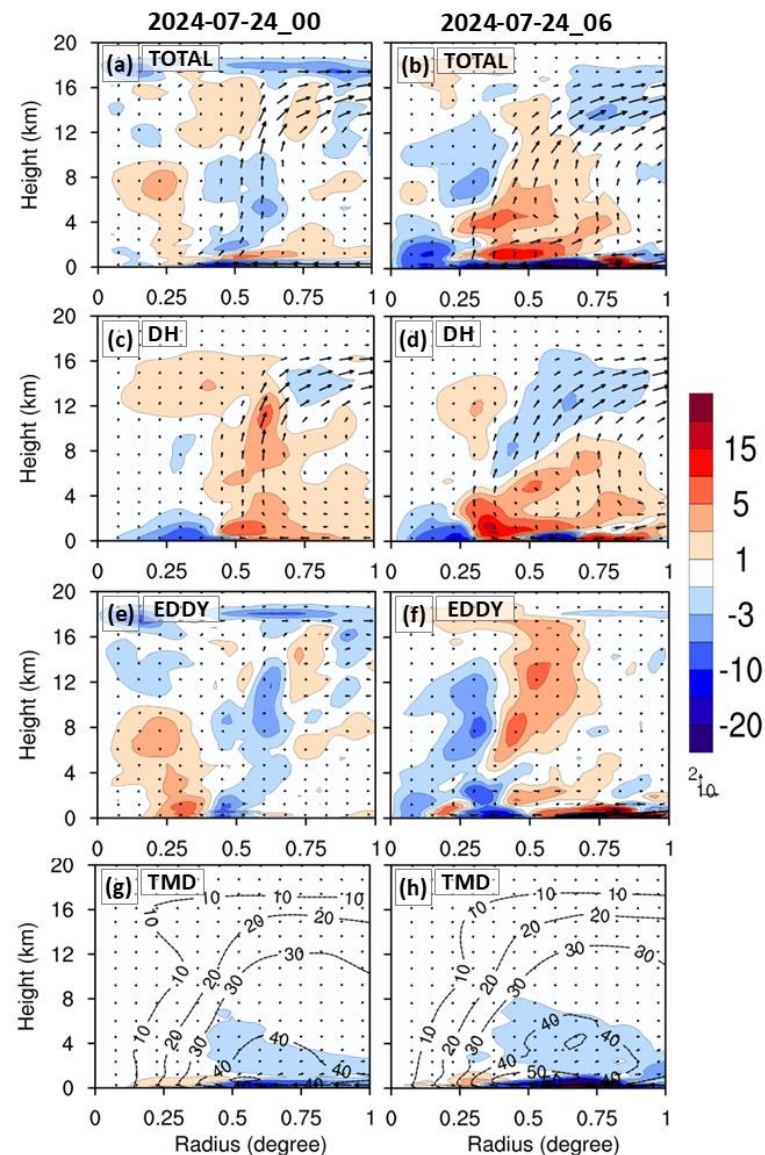
Extended SE diagnosis – Danas



- TOTAL shows strong positive tangential-wind tendency in the low-level inner core
- Diabatic heating produces the major eyewall spinup, inward flow, convergence, and ascent
- Eddy forcing become larger at 1200 UTC
- Turbulent momentum diffusion produces strong near-surface spindown and radial inflow

The organized positive response is primarily induced by diabatic heating and eddy

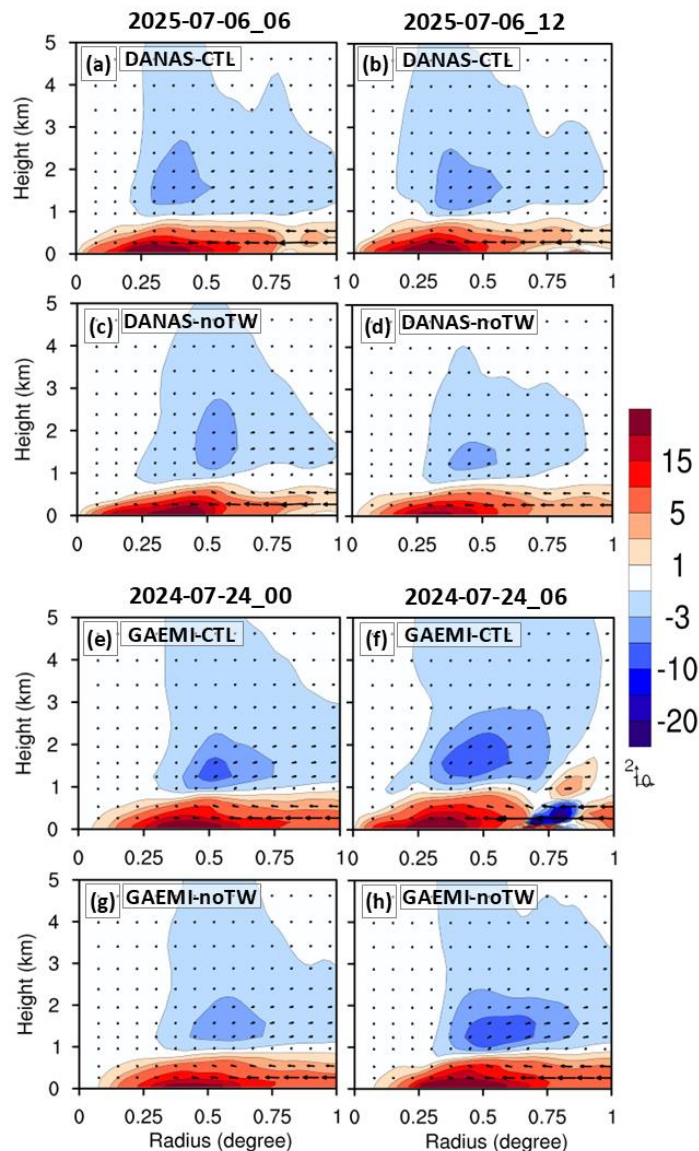
Extended SE diagnosis – Gaemi



- At 0000 UTC, Diabatic heating produces the main positive eyewall column and dominates the total circulation, eddy transport is unfavorable farther outward but can aid spinup closer to the eye
- At 0600 UTC, the positive eyewall response strengthens; diabatic heating remains dominant with complementary eddy support

Above the boundary layer, diabatic heating provides the main inflow and ascent

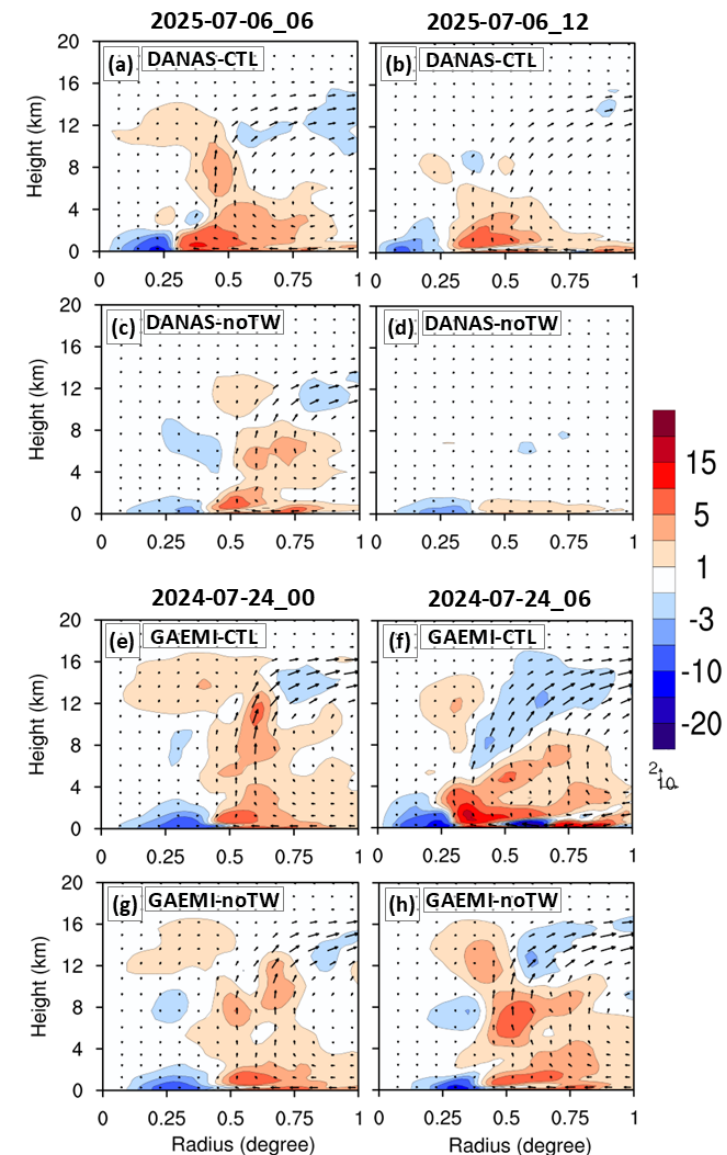
Turbulent-friction contribution



- This figure shows only the wind tendency produced by the circulation induced by turbulent momentum diffusion
- The induced radial inflow produces shallow positive tendency in both CTL and noTW; the later CTL response is slightly stronger
- The direct frictional forcing is excluded here; the full turbulent-diffusion contribution in Figs. 12–13 remains negative

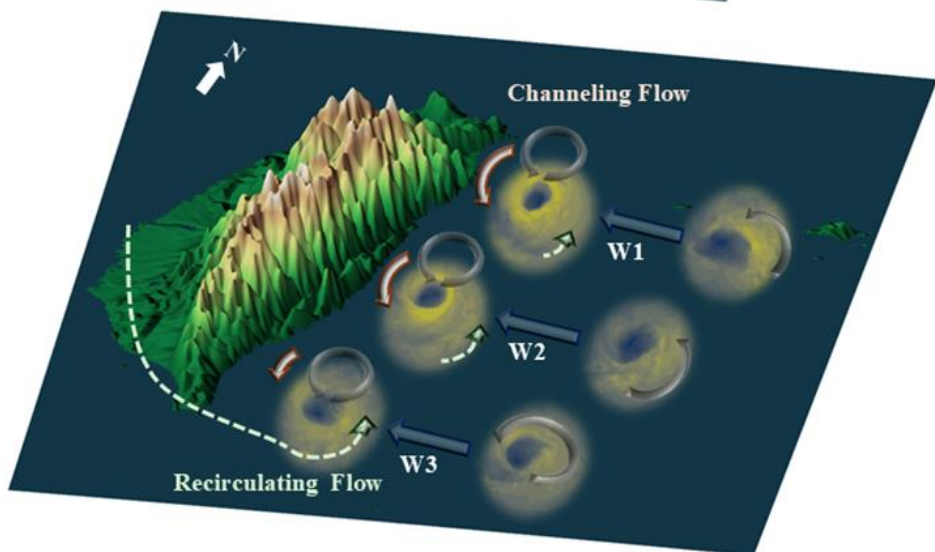
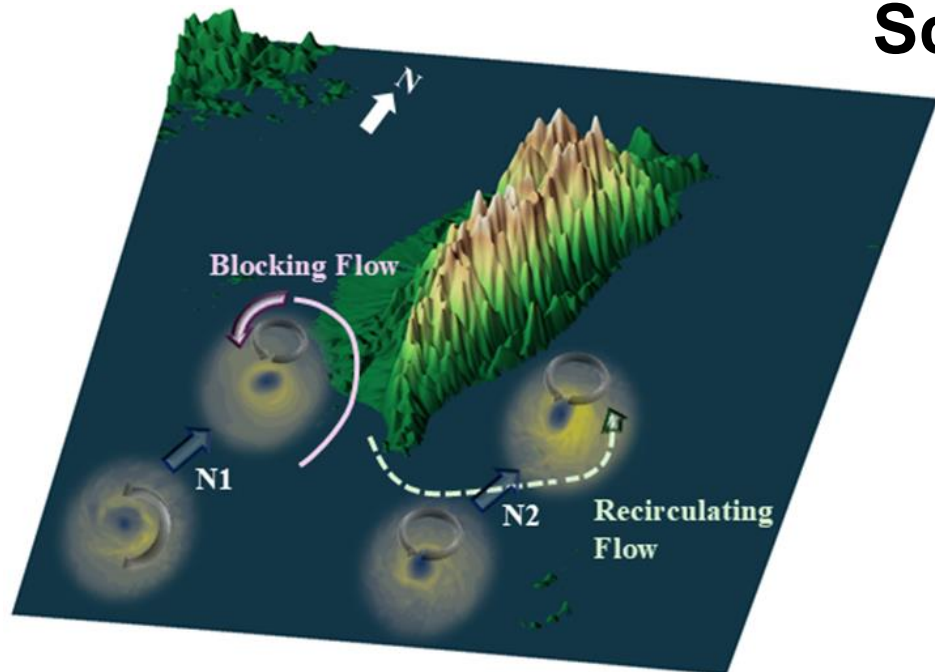
Friction-induced inflow lessens spindown but is not a net positive forcing

Diabatic-heating contribution



- Danas has much stronger heating-induced spinup in CTL than noTW, especially at 1200 UTC
- The stronger CTL response includes enhanced radial inflow and markedly stronger eyewall ascent
- Gaemi shows positive heating responses in both experiments, but the later CTL response is stronger and more organized
- The terrain-related spinup is therefore realized mainly through enhanced diabatic heating and its secondary circulation

Schematic pathways



Northward configurations

- N1: blocking flow develops west of southern Taiwan through frictional turning
- N2: flow split by the CMR turns around southern Taiwan and reconnects as cyclonic recirculation

Chi et al. (2024a)

Westward / northwestward configurations

- W1: channel flow is most prominent near northern Taiwan
- W2: channel flow and recirculation coexist
- W3: recirculation becomes more prominent farther south

Jian and Wu (2008); Huang et al. (2022); Wu et al. (2015); Wu and Liao (2026)

Spinup occurs when terrain-modified inflow reaches the RMW and remains connected to ascent

Conclusions

- 1 **Storm attribute** Larger radius is the clearest statistical signal; stronger intensification tends to begin from weaker-to-moderate intensity
- 2 **Taiwan contribution** Taiwan adds a temporary positive contribution, although noTW can also intensify
- 3 **Dynamic pathway** Inflow imports AM, ascent lifts it, and diabatic heating provides the main spinup
- 4 **Conditional response** Track geometry and interaction stage determine whether the terrain effect is favorable
- 5 **Operational implication** Nearshore terrain effects should be considered as a conditional intensity modifier rather than a deterministic predictor

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臺灣近岸颱風增強之觀測分析與數值模擬研究

**Thanks for your attention !
報告完畢，請不吝賜教**

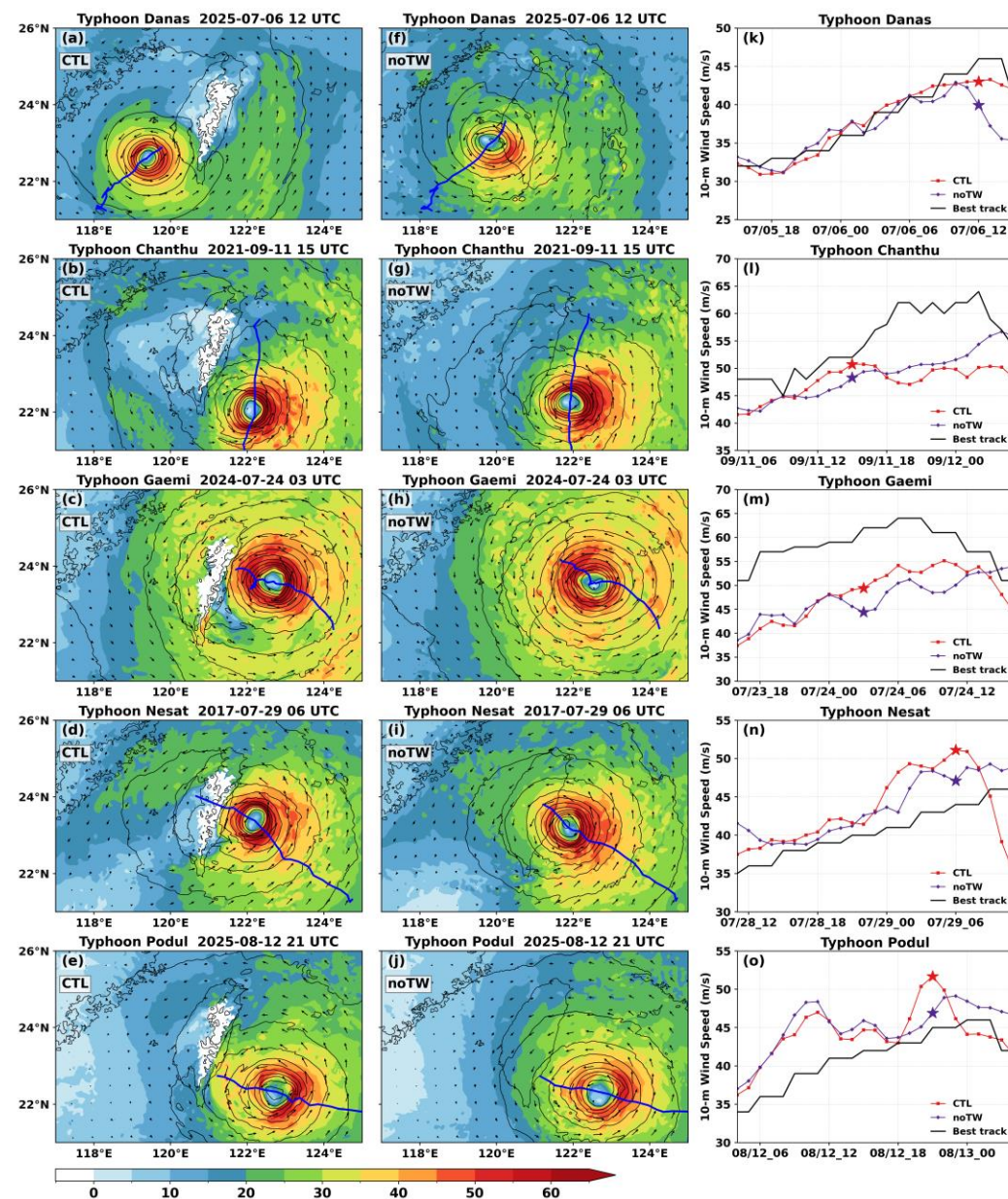
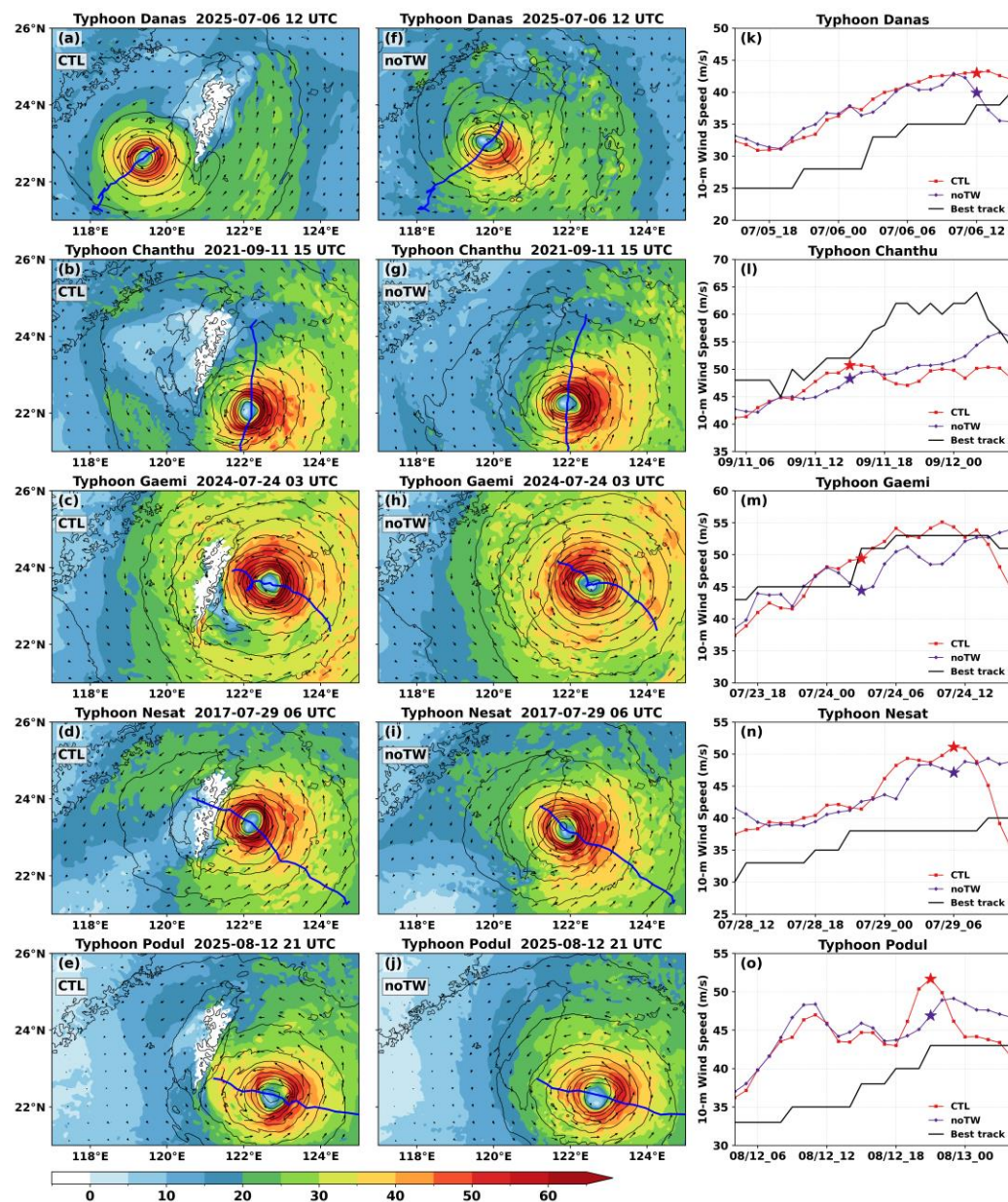
Mao-Cai Tao, Ching-Yuang Huang

Date : 2026 / 09 / 03 (Thu.)

750 **TABLE A1.** Stability of the principal statistical results across the nine threshold combinations.

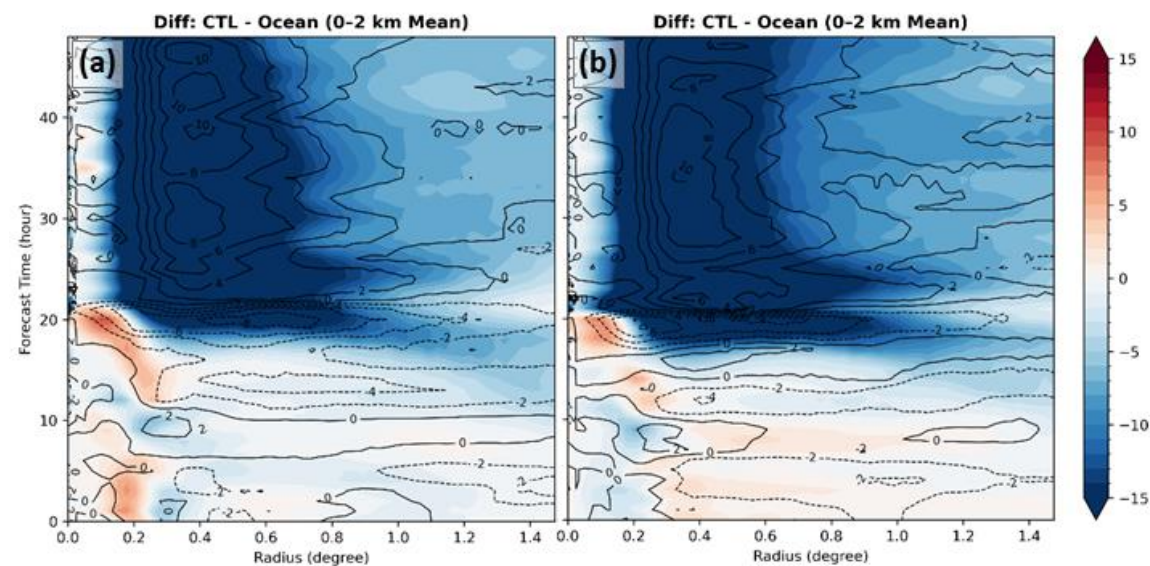
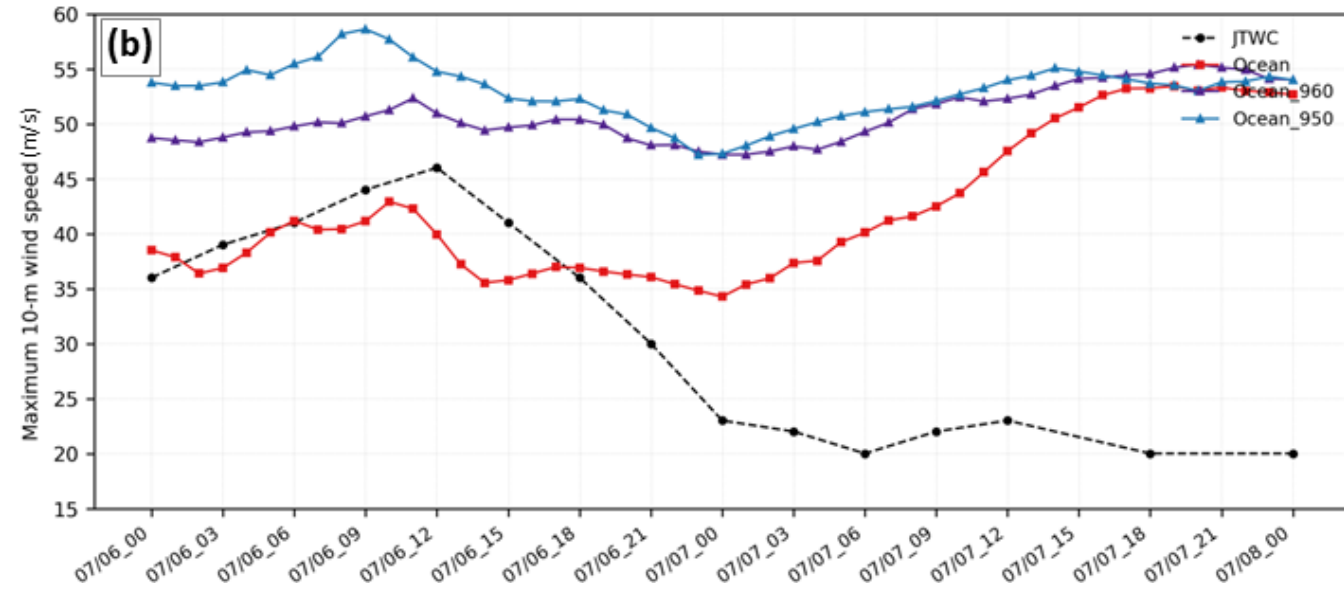
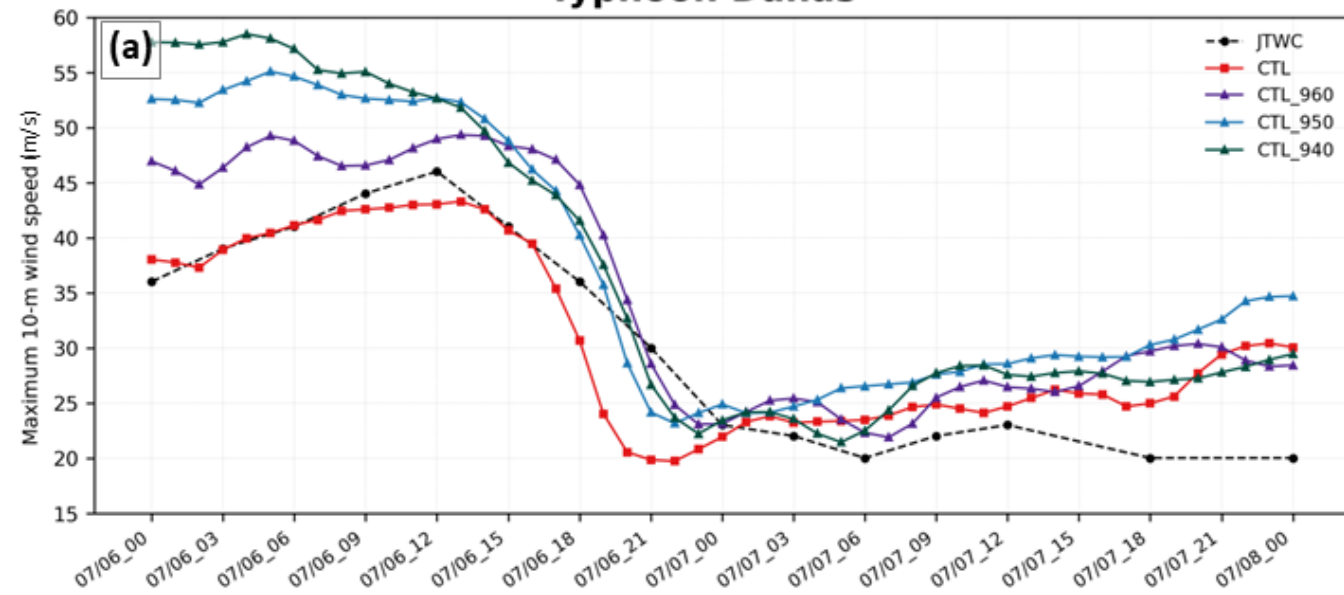
Component	Baseline result	Across threshold combinations	Consistency	Interpretation
Category membership	17 V24; 18 V48; 94 X	3–13 reassigned	90%–98% unchanged	Classification broadly retained
Case type	$p = 0.377$	$p = 0.38–0.96$	9/9 nonsignificant	No robust case-type dependence
Continuous R34 model	OR = 1.39; $p = 0.023$	OR = 1.33–1.49; $p = 0.010–0.039$	9/9 positive and significant	Positive size association retained
Any intensification × R34 bin	$p = 0.047$	$p = 0.047–0.096$	2/9 significant	Not used as primary inference
Approach direction	$p = 0.527$	$p = 0.163–0.647$	9/9 nonsignificant	No robust category dependence
Distance at –48 h	$p = 0.188$	$p = 0.127–0.279$	9/9 nonsignificant	No robust category dependence
Translation speed	$p = 0.189$	$p = 0.131–0.338$	9/9 nonsignificant	No robust category dependence

Appendix



Appendix

Typhoon Danas



Appendix

$$\frac{\partial \bar{M}}{\partial t} = -\bar{u} \frac{\partial \bar{M}}{\partial r} - \bar{w} \frac{\partial \bar{M}}{\partial z} - \overline{u' \frac{\partial M'}{\partial r}} - \overline{w' \frac{\partial M'}{\partial z}} - fr\bar{u} + r\bar{F}_v \quad (1)$$

$$\frac{\partial}{\partial r} \left(\tilde{A} \frac{\partial \psi}{\partial r} + \tilde{B}_1 \frac{\partial \psi}{\partial z} \right) + \frac{\partial}{\partial z} \left(\tilde{C} \frac{\partial \psi}{\partial z} + \tilde{B}_2 \frac{\partial \psi}{\partial r} \right) = S \quad (2)$$

$$\left. \frac{\partial \bar{v}}{\partial t} \right|_{SE} = -\bar{u} \bar{\eta} - \bar{w} \frac{\partial \bar{v}}{\partial z} + \bar{F}_V + \bar{\dot{V}} \quad (3)$$

Appendix

