

Barotropic or Baroclinic: The Hybrid Genesis of Indian Summer Monsoon Low-Pressure Systems

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MOTIVATION & SCIENTIFIC GAP

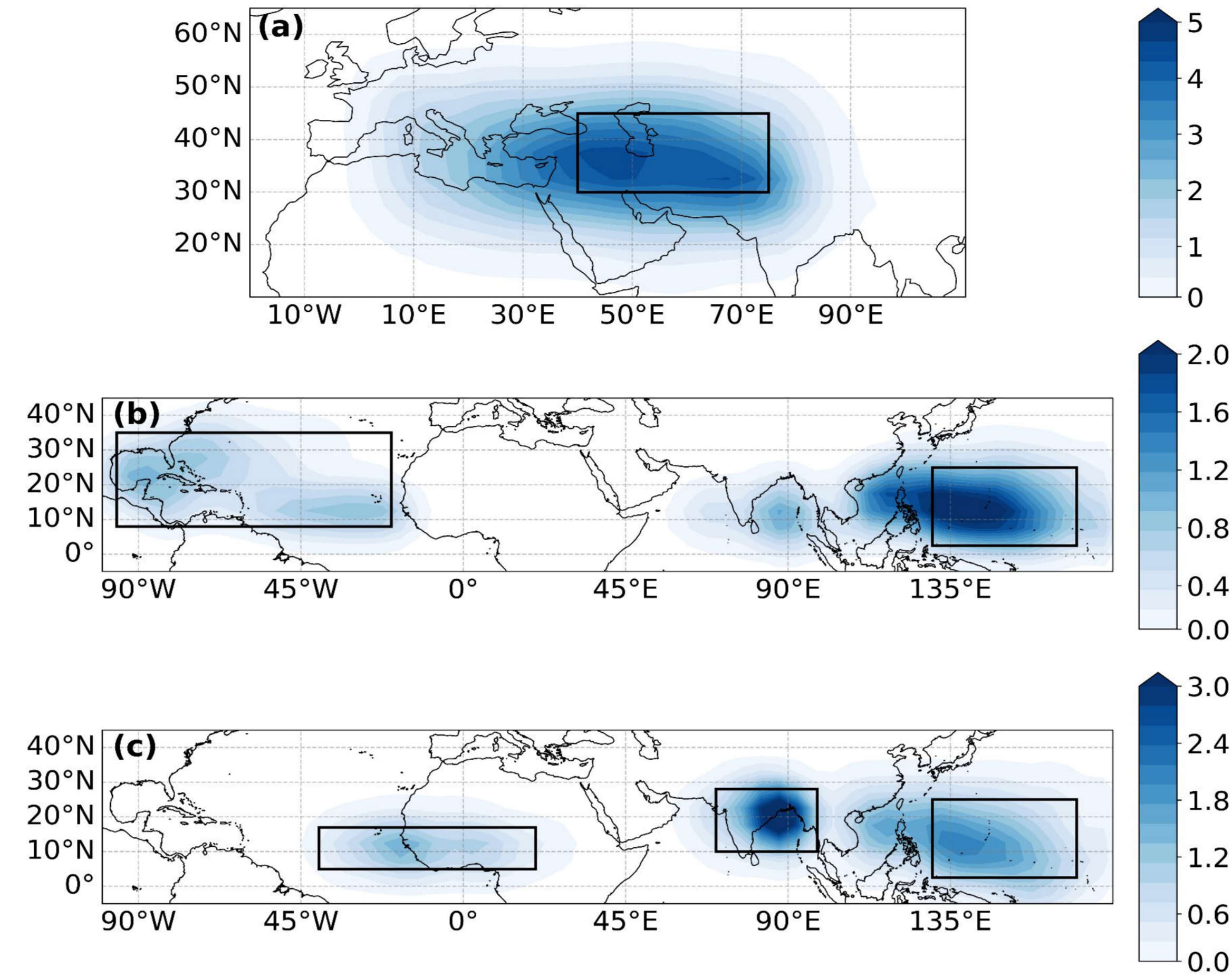
Synoptic-scale vortices in the tropical and subtropical circulation represent dynamically distinct realizations of rotating convection-circulation coupling. Despite shared spatial scales (~1000 km), they emerge under markedly different environments.

Their dynamics are governed by competing balances:

- Vertical & horizontal wind shear
- Static stability & stratification
- Column moisture distribution & transport
- Diabatic heating & convective coupling

A comprehensive framework placing these vortex classes within a unified dynamical spectrum is currently lacking.

Monsoon LPSs occupy an especially ambiguous position — they exhibit both similarities and contrasts with all other vortex classes, and their genesis mechanisms remain actively debated.



TWO COMPETING PARADIGMS

PARADIGM I — Dynamics-Dominated [Díaz & Boos (2019a,b; 2021)]

- Horizontal shear + barotropic conversion → primary growth mechanism
- Moisture acts as secondary amplifier only
- Rooted in classical hydrodynamic instability theory

PARADIGM II — Thermodynamics-Dominated [Luo & Adames et al. (2023)]

- Meridional MSE gradients → moisture-vortex instability (MVI)
- Convectively-coupled circulations sustain and drive vortex growth
- Moisture is a primary driver, not merely an amplifier

UNRESOLVED TENSION

Most frameworks rest on linear or idealized analyses. How these mechanisms operate and interact in the nonlinear, fully coupled atmosphere remains an open question.

DATA & METHODS

Datasets

- ERA5 (ECMWF), 0.25°, 1980–2020
- ISCCP, Cloud Properties (Ctp - Tau)

Vortex Identification & Tracking

- Objective tracking datasets for AEWs, WDs, LPSs, TCs.

Diagnostic Framework

- Tilt-Against-the Shear Metric
- Column MSE budget
- Cloud Morphology (HTH vs RCS Metric)
- Lorenz energy cycle — barotropic & baroclinic conversion
- Storm centered Composite life-cycle analysis along vortex tracks

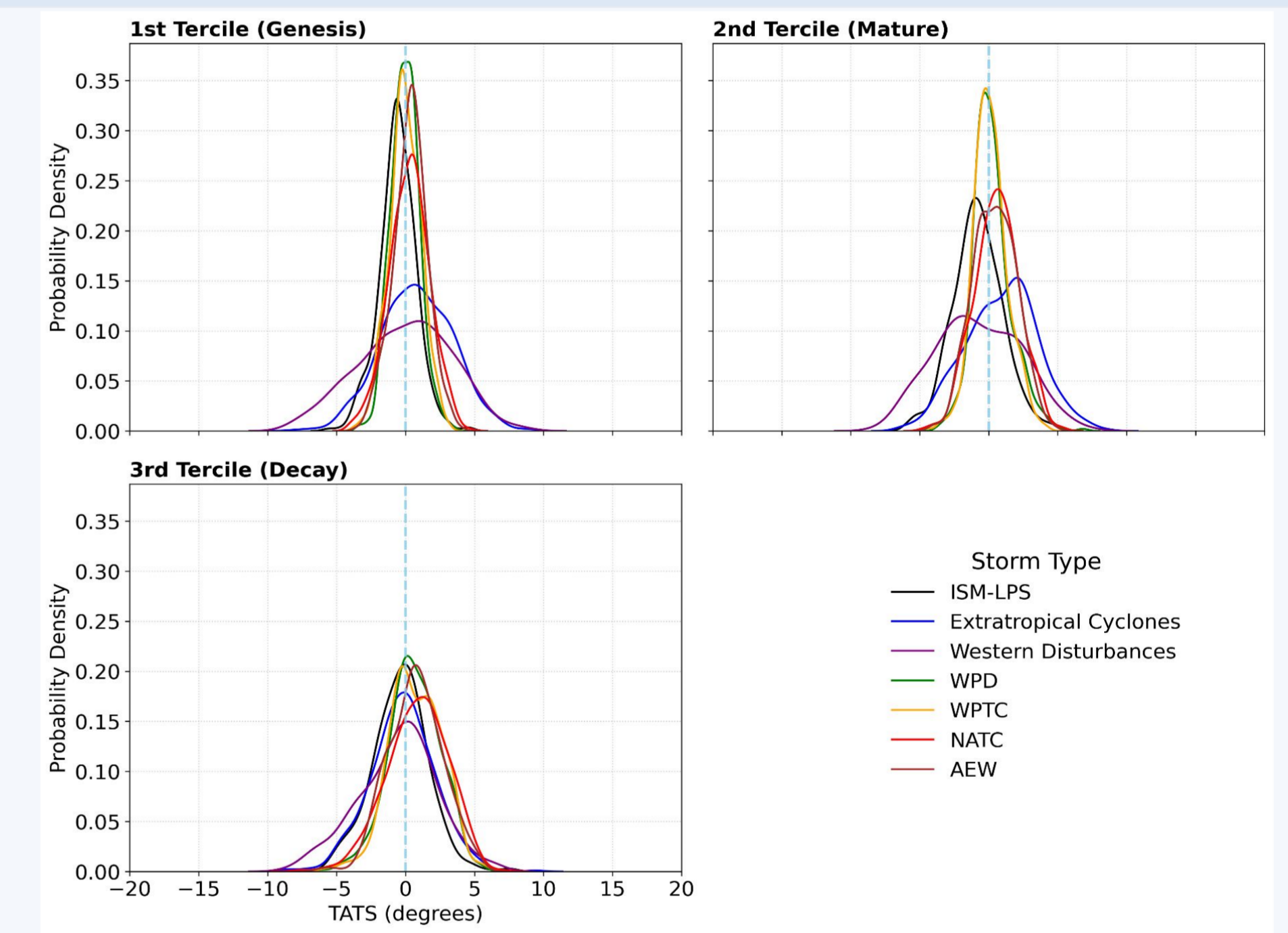
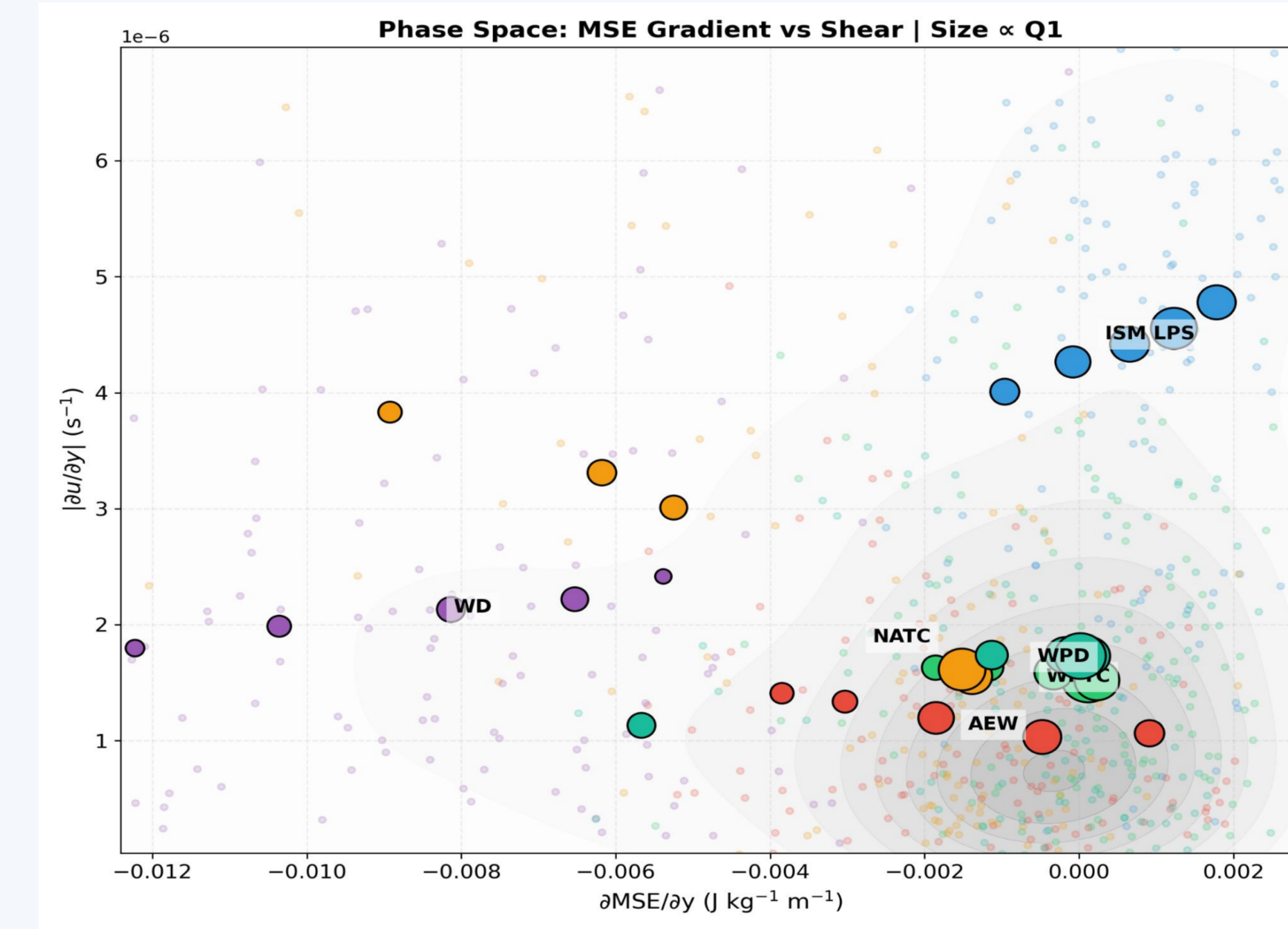
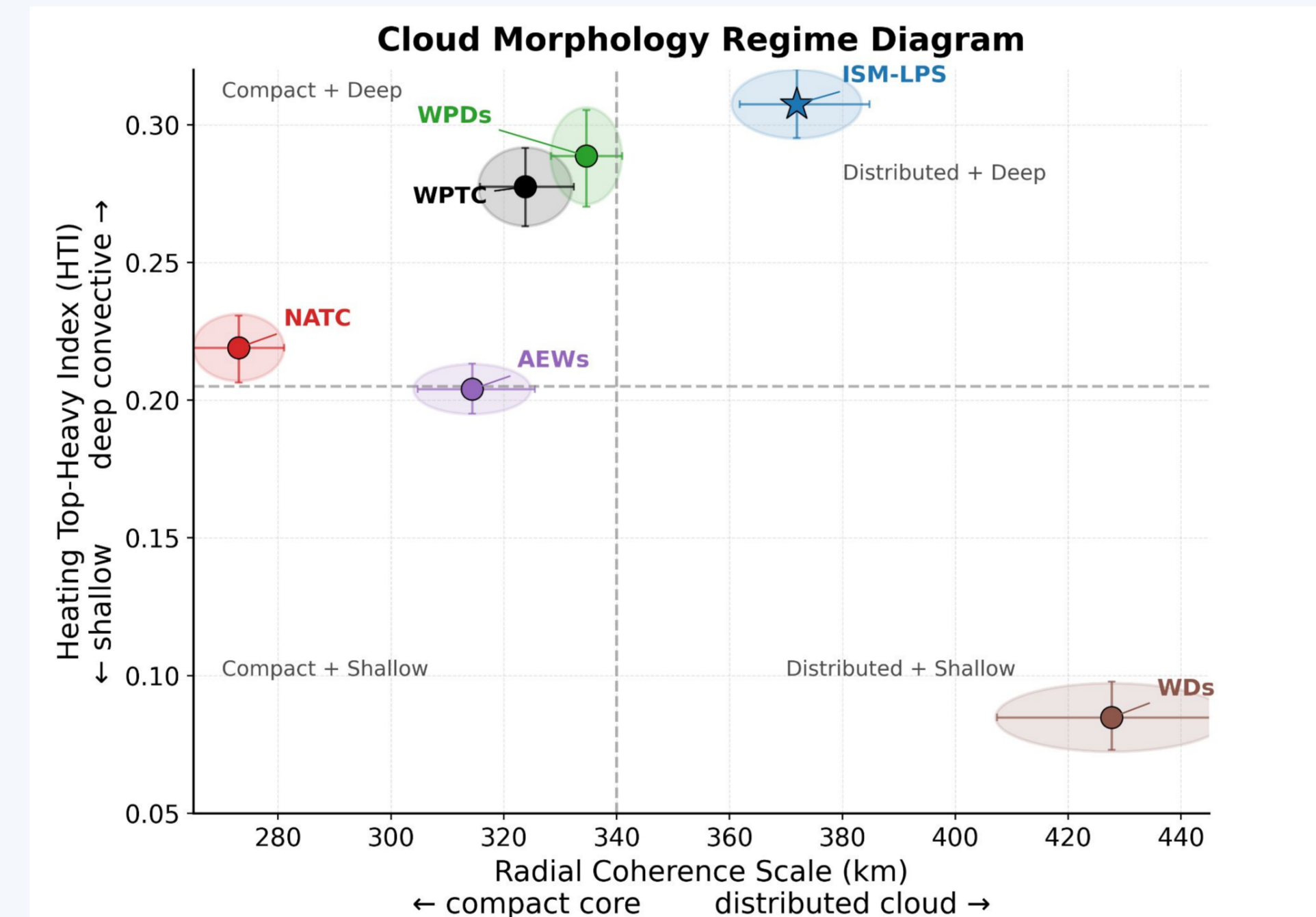
TATS is defined as the longitudinal difference between the center of mass of the upper (200-500 hPa) and lower- (600-900 hPa) level +ve PV anomalies, multiplied by the sign of climatological vertical shear.

$$TATS = -\Delta\lambda_{\text{mean}} \text{sgn}(\Delta u_{\text{mean}})$$

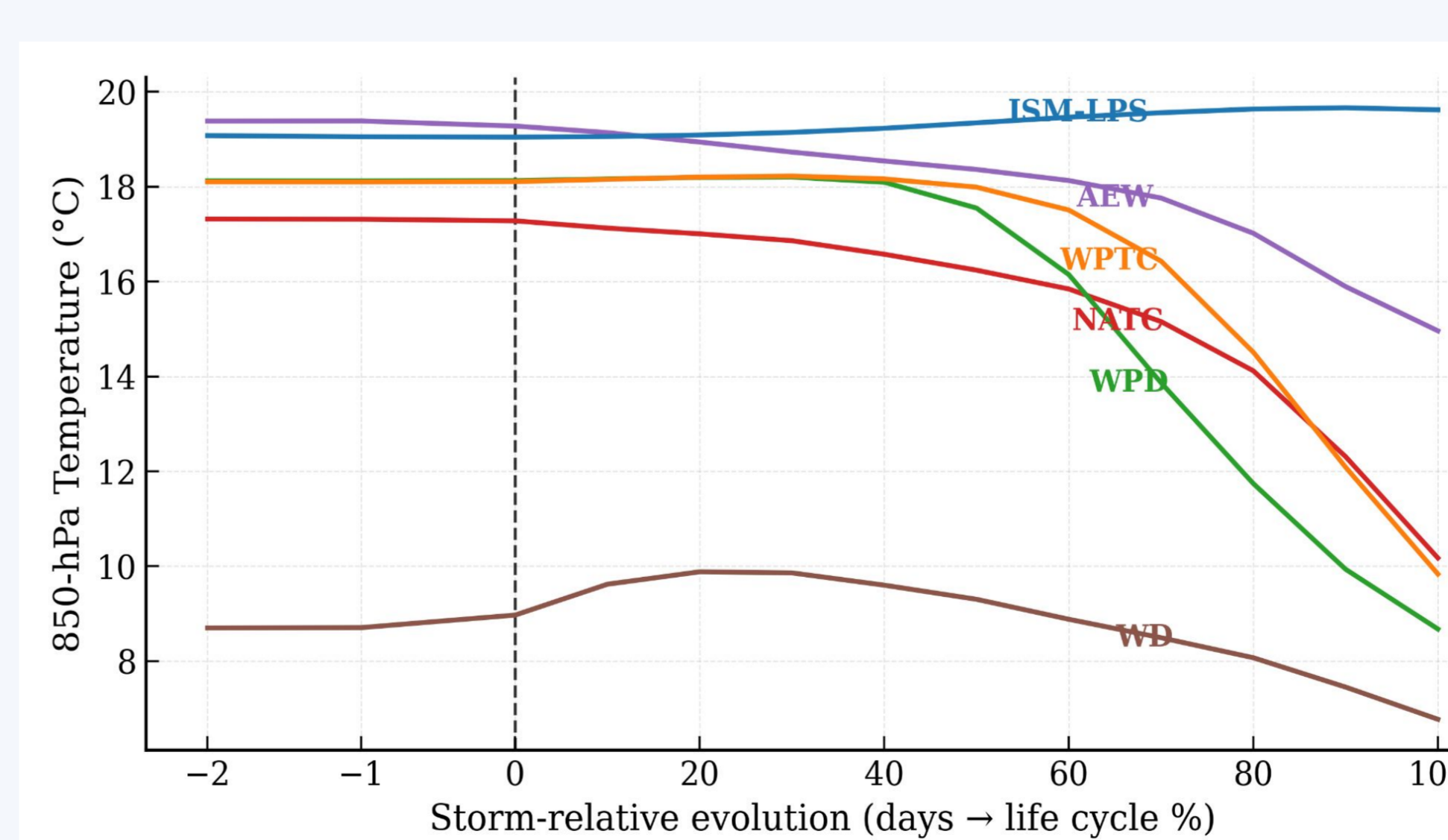
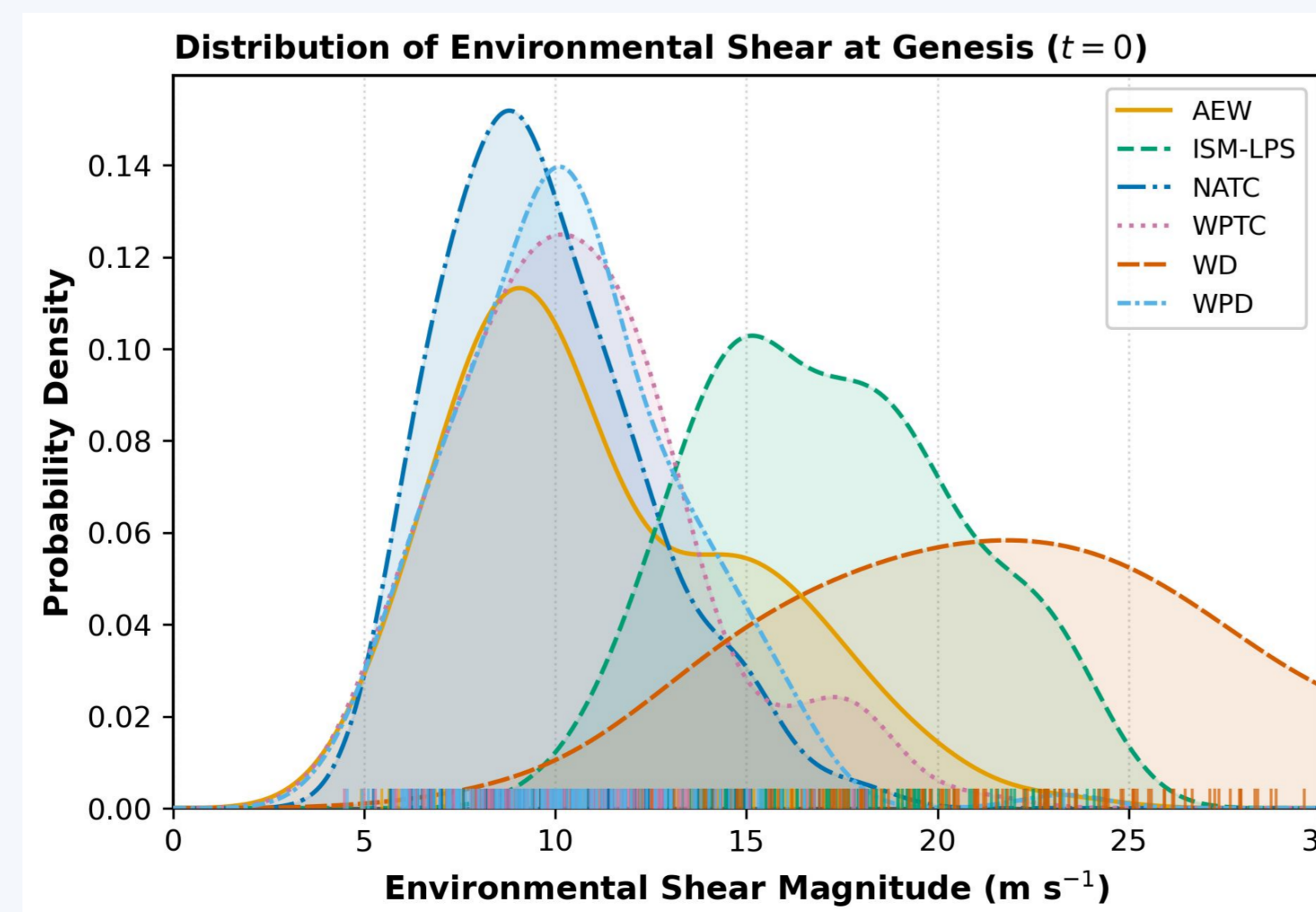
$$HTH = \sum_{\{CTP < 440, COT > 9.4\}} C(p,t) / C_{\text{tot}}$$

$$RCS = \sum_k r_k \cdot H_{\text{deep}}(r_k) / \sum_k H_{\text{deep}}(r_k)$$

STORM CHARACTERISTICS



BACKGROUND STATE



SUMMARY TABLE: DYNAMICAL SPECTRUM

	MLPS	AEW	WD	WPD	WPTC	NATC
V. Shear	~15 m/s	~6 m/s	~20 m/s	~7 m/s	~7-8 m/s	~7-8 m/s
Core	Symmetric cold	Symmetric cold	Asymmetric	Symmetric warm	Symmetric warm	Symmetric warm
TATS	Downshear	Upright	Upshear	Upright	Upright	Upright
ΔMSE_y	High	Moderate	Low	Moderate	Moderate	Moderate
ΔU_y	High	Low	Moderate	Low	Low	Moderate
HTH	0.32	0.2	0.08	0.28	0.27	0.22
RCS	372 km	315 km	428 km	335 km	325 km	270 km

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KEY REFERENCES

Díaz, M., and W. R. Boos, 2019a: Barotropic growth of monsoon depressions. Quart. J. Roy. Meteor. Soc., 145, 824–844, <https://doi.org/10.1002/qj.3467>.
 Luo, H., Á. F. Adames Corraliza, and R. B. Rood, 2023: Barotropic and Moisture-Vortex Growth of Monsoon Low Pressure Systems. J. Atmos. Sci., 80, 2823–2836, <https://doi.org/10.1175/JAS-D-22-0252.1>.

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