Genesis, structure and propagation of synoptic systems over the Indian Ocean during the Northeast Monsoon

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Objective

Establish a systematic understanding of synoptic systems during the Northeast Monsoon, including their background state, genesis conditions and dynamics.

Data and Methodology

- ERA5 data from 1998 – 2019 in 40°E-120°E, 24°N-24°S domain is used.
- The synoptic systems are identified using a tracking algorithm.[1]

Genesis regions: relation to vorticity and moist static energy

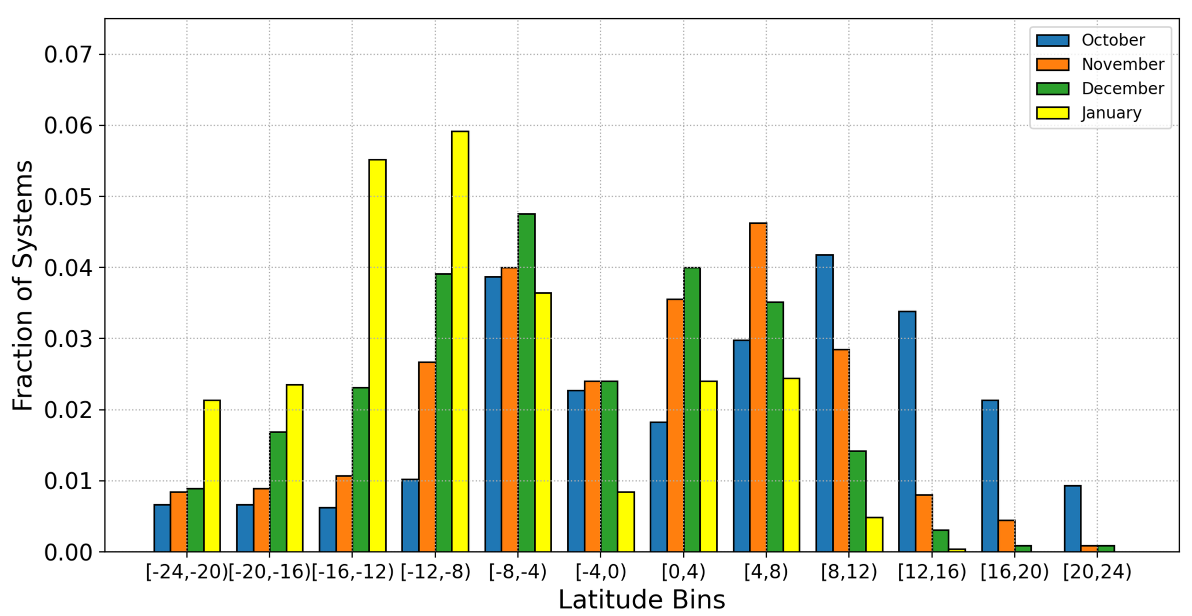


Figure 1. Fraction of systems with genesis in different latitude bins across various months.

- Evolving latitude dependence of genesis locations.
- Bimodal distribution of genesis locations that shifts southwards and becomes more meridionally confined as the season progresses.

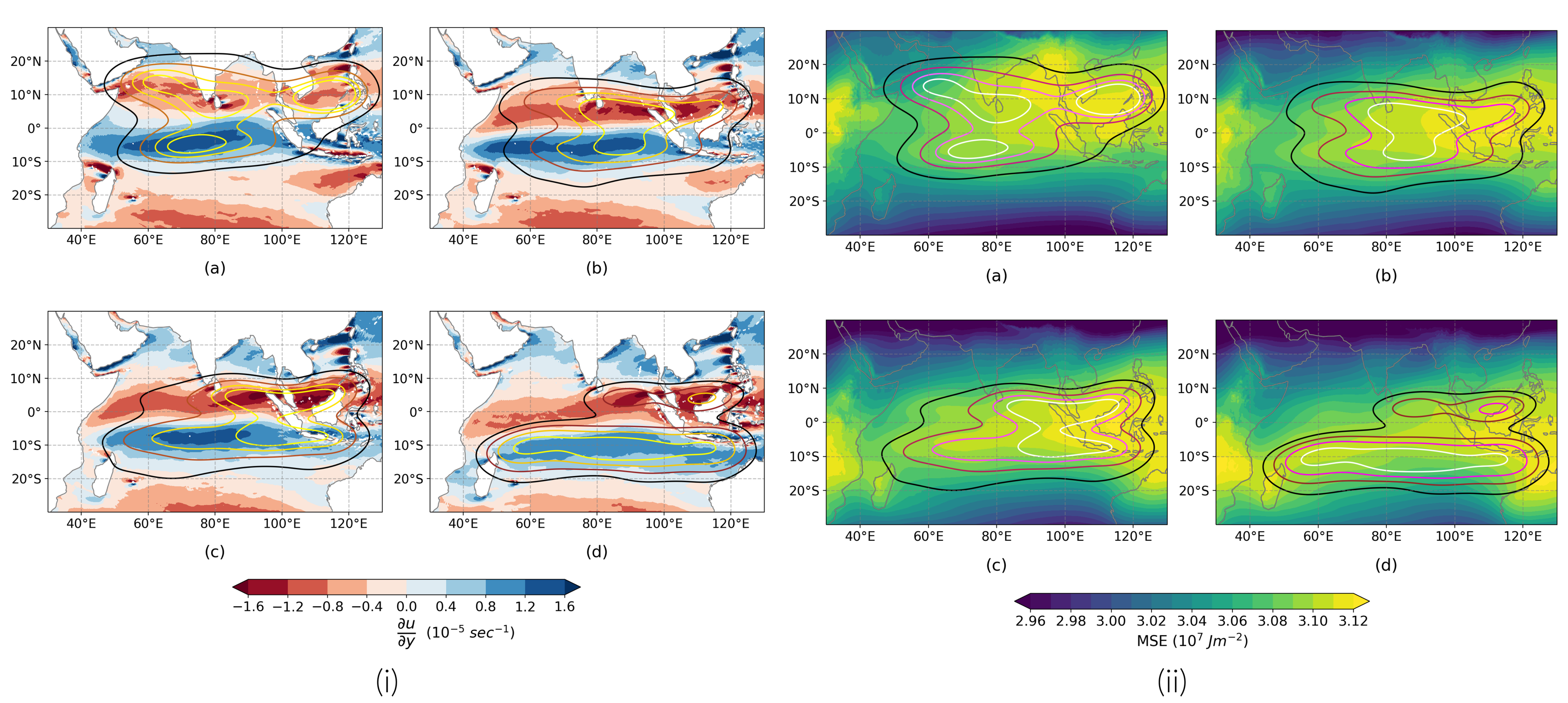
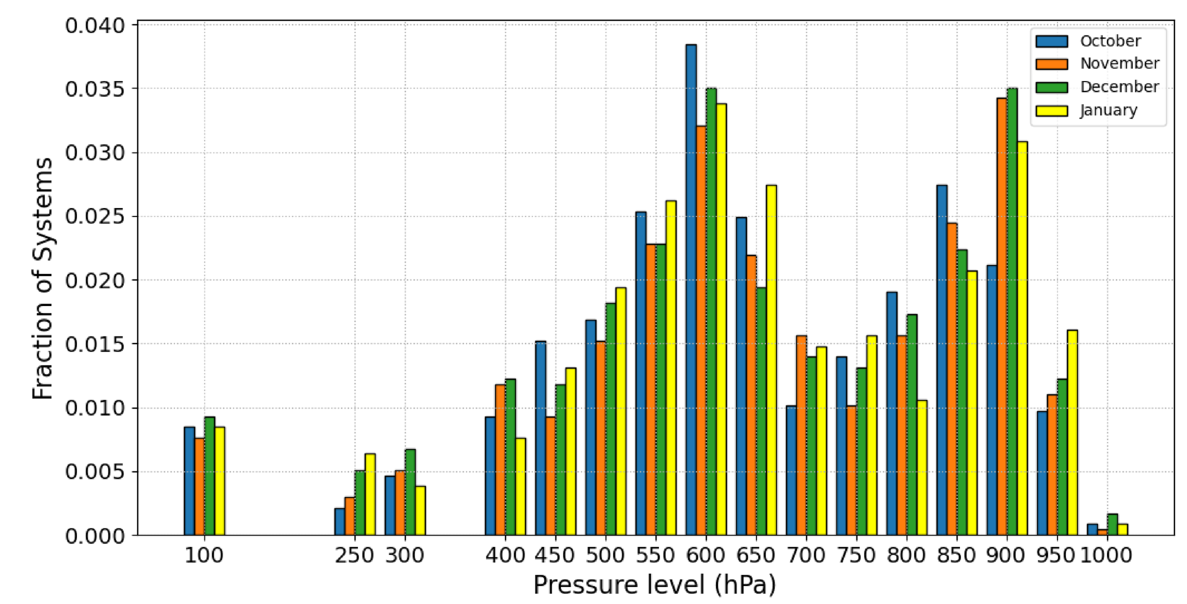


Figure 2. Climatology of (i) meridional gradient of zonal wind, (ii) column-integrated Moist Static Energy (MSE) overlaid with Kernel Density Estimate (KDE) of genesis location for (a) October, (b) November, (c) December and (d) January.

- A southward and eastward shift of the genesis distribution and MSE values.
- Peaks in KDE are associated with regions of high vorticity in all months.

System (UTC, MTC and LTC) Classification and Characteristics



(a)

Northern Hemisphere	Mean	Standard Deviation
Upper Troposphere Systems	6.1	2.2
Mid Troposphere Systems	20.4	6.2
Lower Troposphere Systems	19.2	4.1
Total	45.5	12.4
Southern Hemisphere	**Mean**	**Standard Deviation**
Upper Troposphere Systems	6.6	2.3
Mid Troposphere Systems	26.6	8.0
Lower Troposphere Systems	21.2	6.4
Total	57.8	14.1

(b)

Figure 3. (a) Systems formed during October, November, December and January as a function of level of maximum vorticity observed during genesis and (b) mean and standard deviation of system frequency.

- Two large peaks observed - one centred around 900 mb and another centred around 600 mb.
- Systems with maximum vorticity below 700 mb are classified as Lower Tropospheric Cyclones (LTCs), between 500–700 mb as Mid Tropospheric Cyclones (MTCs), and above 500 mb as Upper Tropospheric Cyclones (UTCs).
- Majority of systems observed are MTCs and LTCs with very few UTCs.

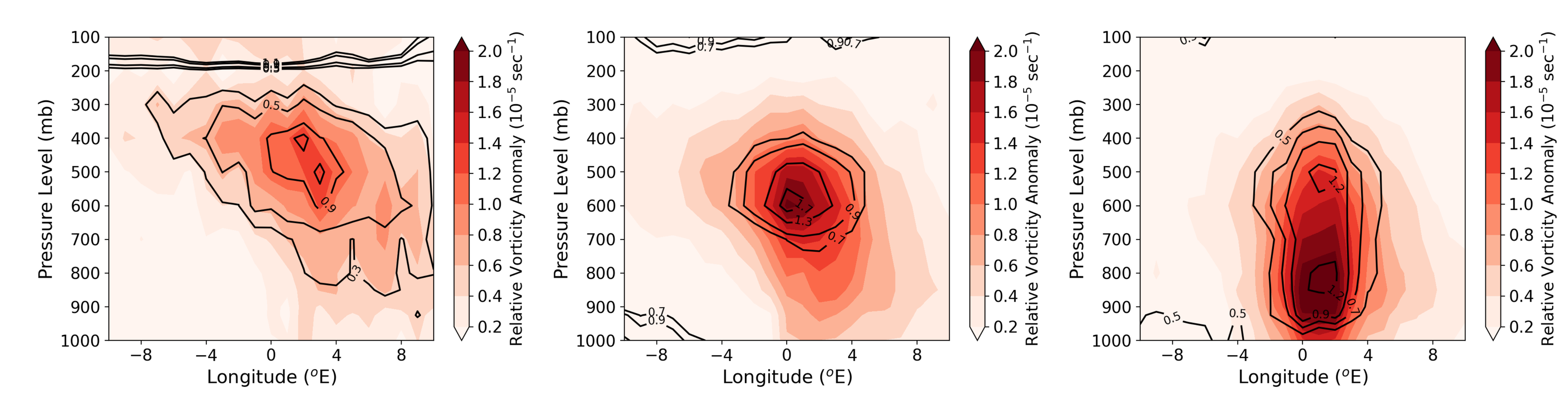


Figure 4. Vertical structure of Relative Vorticity (shaded) and PV anomaly (10^{-1} PVU) during genesis (0 is the reference longitude) for (a) UTC, (b) MTC and (c) LTC in NH.

- UTCs and MTCs exhibit westward tilt with height, with vorticity maxima near 400 and 600 mb respectively.
- LTCs exhibit upright structure with vorticity maximum around 800 mb.

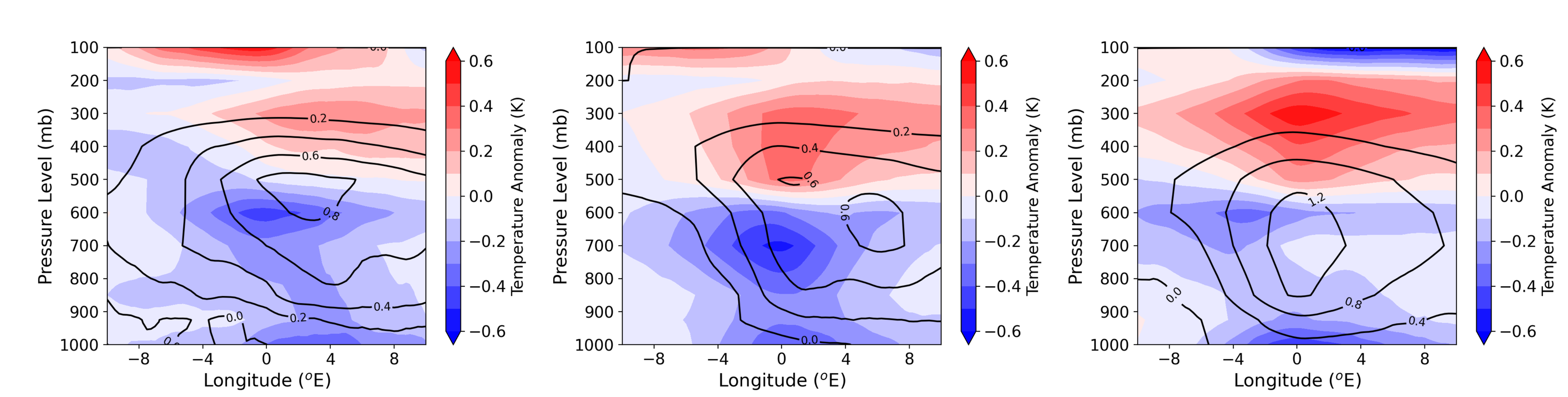


Figure 5. Vertical structure of temperature anomaly (shaded) and specific humidity anomalies (g/kg) during genesis (0 is the reference longitude) for (a) UTC, (b) MTCS and (c) LTC in NH.

- UTCs and MTCs feature a cold core below and a warm core above the UTC and MTC center respectively.
- LTCs show strong warm anomalies at 500 mb and above, with a weak cold anomaly below.

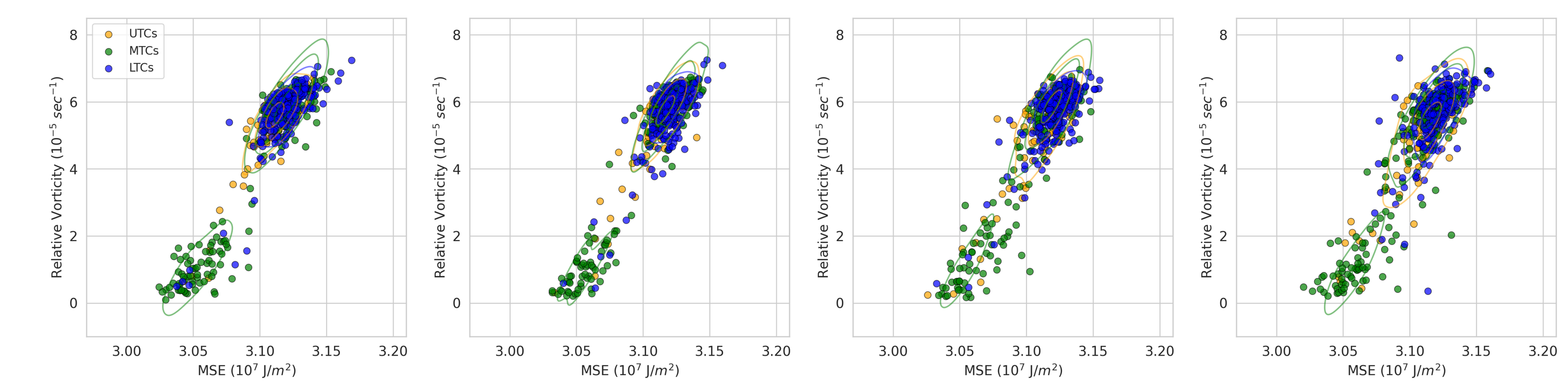


Figure 6. Joint Distribution of Relative Vorticity and column-integrated MSE of genesis points for (a) October, (b) November, (c) December, (d) January.

- Systems strengthen with moisture - strong systems (i.e., high relative vorticity) tend to be associated with high MSE.
- LTCs typically exhibit high vorticity and MSE, while UTCs and MTCs are found in two distinct regimes: one with high MSE and vorticity, and another with low values.

Propagation and Precipitation

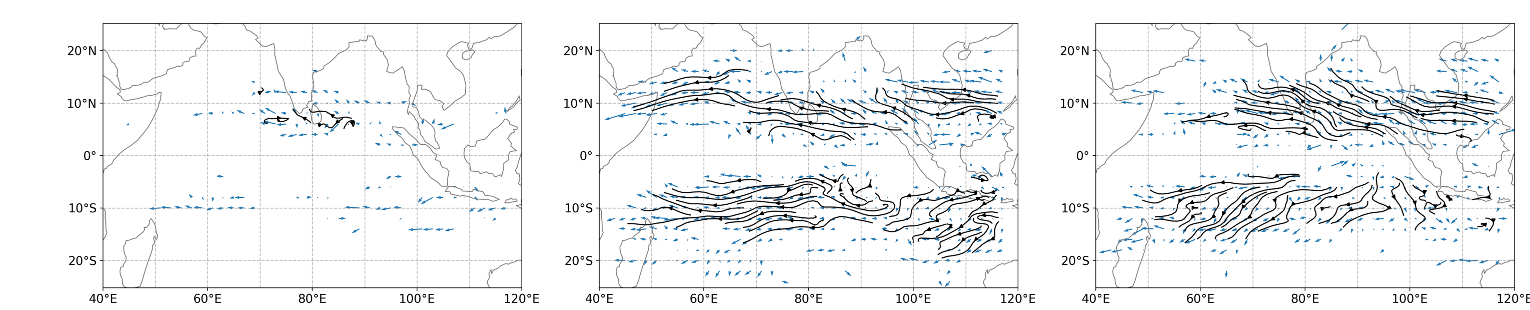


Figure 7. Motion vectors (blue) and streamlines (black) associated with (a)UTC, (b) MTC, and (c) LTC.

- MTC trajectories are more zonal, while LTCs tend to have a significant meridional component.

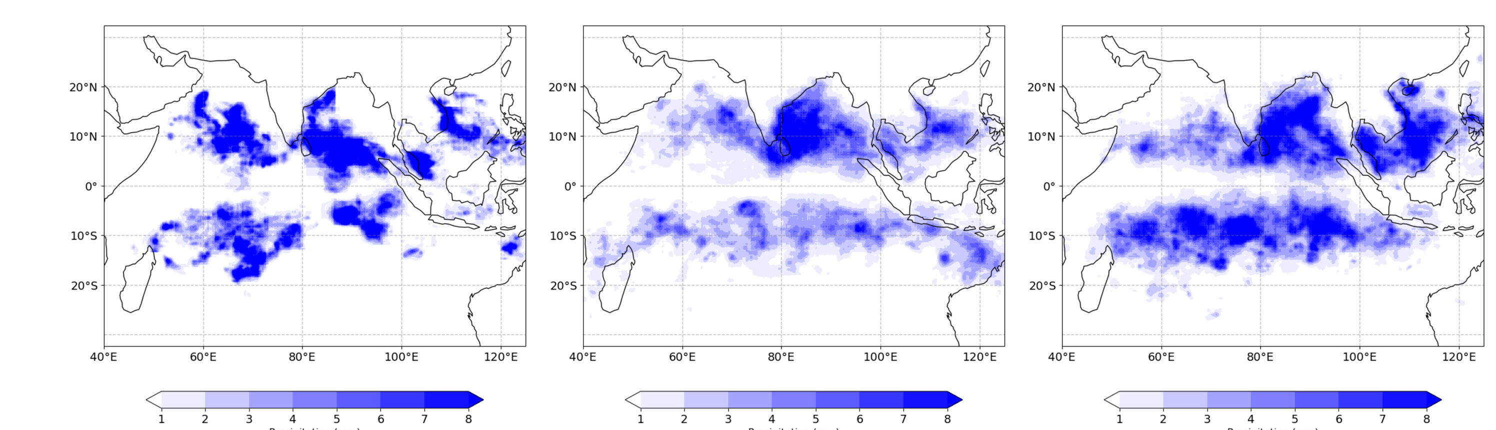


Figure 8. Precipitation associated with (a) UTCs, (b) MTCs and (c) LTCs.

- UTCs generate localised precipitation mainly over the Arabian Sea (AS), Bay of Bengal (BoB), and the southwest and northeast Tropical South Indian Ocean (TSIO), while MTCs produce significant rainfall over the AS, BoB, South China Sea (SCS), and TSIO.
- LTCs produce the most rainfall, mainly over the BoB, SCS, and the TSIO.

Summary

- Genesis locations exhibit strong latitude dependence, coinciding with regions of high relative vorticity and column-integrated Moist Static Energy (MSE).
- Near the equator, UTCs and MTCs display similar structures, distinct from LTCs. This suggests that UTCs and MTCs may have different formation mechanisms compared to LTCs.
- A coupling exists between system strength and moisture, with stronger systems associated with higher MSE values.
- Different trajectories lead to different precipitation patterns, highlighting the importance of understanding the underlying dynamics.

[1] Pradeep Kushwaha, Jai Sukhatme, and Ravi Nanjundiah. A global tropical survey of midtropospheric cyclones. *Monthly Weather Review*, 149(8):2737 – 2753, 2021.