Vertical Structure of Convection during the Dry and Wet spells of Monsoon over the Western Ghats of India

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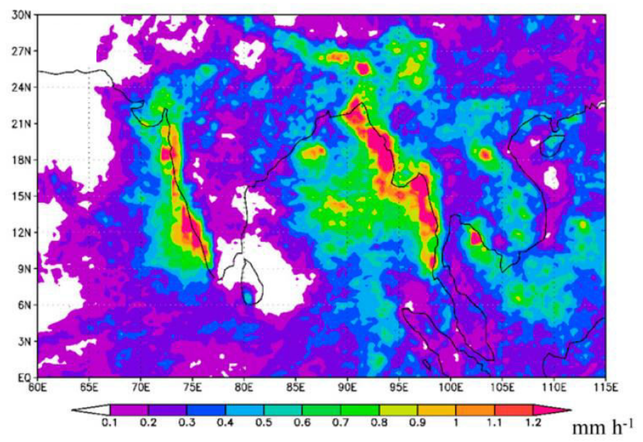
Background, data, and methodology

Within ISM domain, some of the highest & most spatially variable rainfall rates are found along & upstream of the Western Ghats (WG), which acts as anchors for generating convective centers of monsoon [Xie et al. 2006].



Mesoscale precipitation pattern: steep west-to-east gradient of precipitation across WG.

Figure 1 : TRMM monsoon precipitation climatology [Shige et al., 2017]

Within season, rainfall over WG fluctuates between dry and wet spells usually occurring during active & break spells of large-scale rainfall over monsoon zone

NWP models: continuing efforts to improve simulation of organization of clouds and precipitation in the monsoon ISO scale; but suffers owing to limited observations of mesoscale convective features under different ISO settings.

Past studies on orographic precipitation & intra-seasonal variability over the WG, were mainly based on satellite and reanalysis data sets.

In present study, time-continuous X-band radar observations are used to characterize the vertical structure and evolution of convective cloud fields during the dry and wet epochs of monsoon & relate small-scale convective features (as obtained form radar data) to the large-scale atmospheric state. Auxiliary data from satellites, reanalysis and Lightning Location Network are used.

Spell identification & large scale features

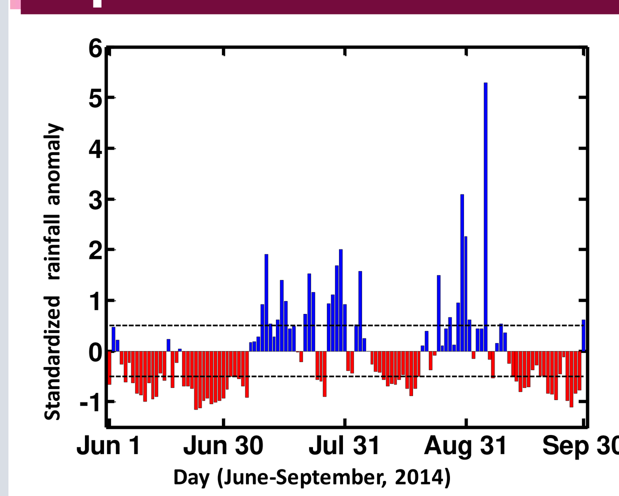


Figure 2 : Identification of dry and wet spells of Monsoon 2014 (JJAS) using gridded IMD rainfall (0.25°x 0.25°) over radar domain.

A period is marked as wet (dry) if the standardized rainfall anomaly is above (below) 0.5 (-0.5) for 3 consecutive days

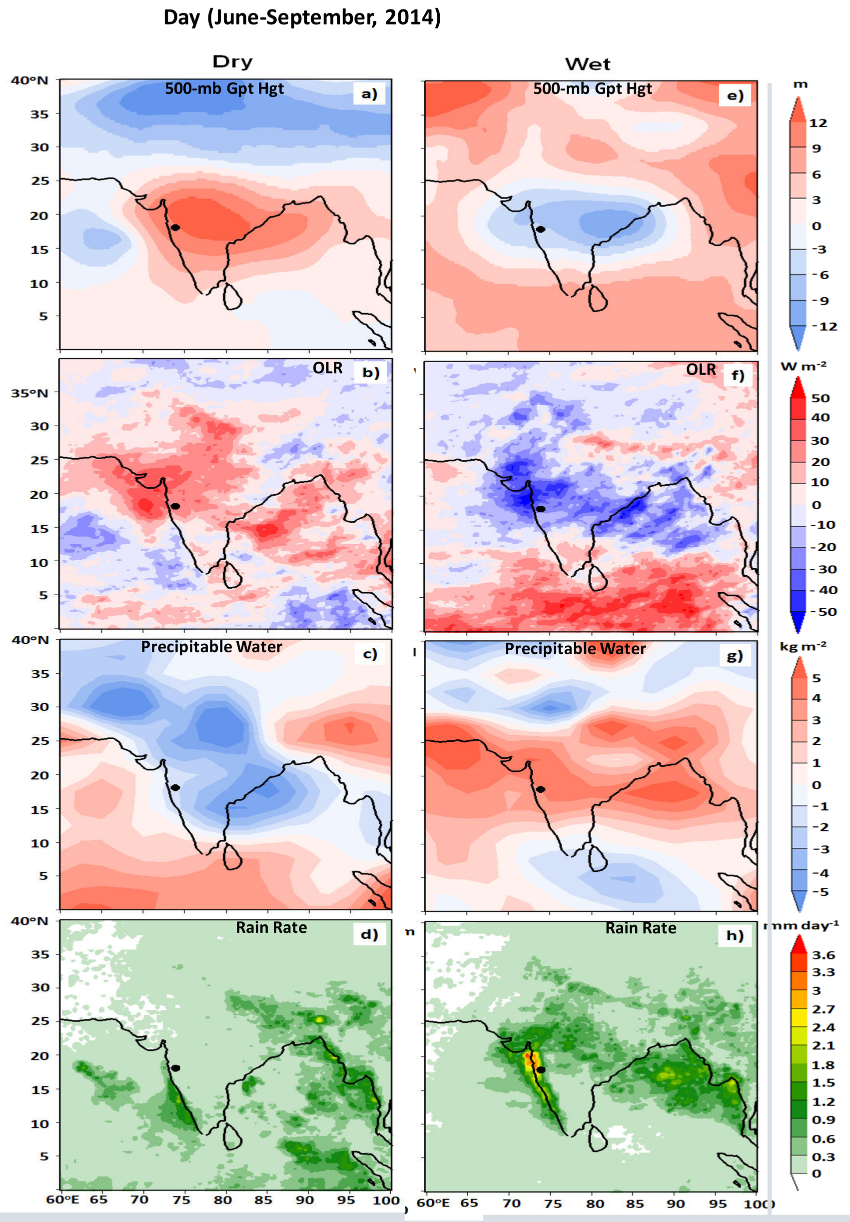


Figure 3: Anomalies of geopotential height at 500hPa (a & e); OLR (b & f); Precip. water (c & g) and rain rate (d & h) during dry & wet spells of monsoon.

Dry composites

- +ve GPH : anticyclonic circulation: fewer precipitation systems.
- +ve OLR & -ve precip water
- weak rain belt along coast

Wet composites

- Negative GPH anomaly: cyclonic circulation; anomalous south-west flow; many precipitation systems
- Anomalies of -ve OLR & positive precipitable water
- Rainfall maxima along WG, extending over Arabian Sea

Echo top heights relationship with LH profiles & low-level stability

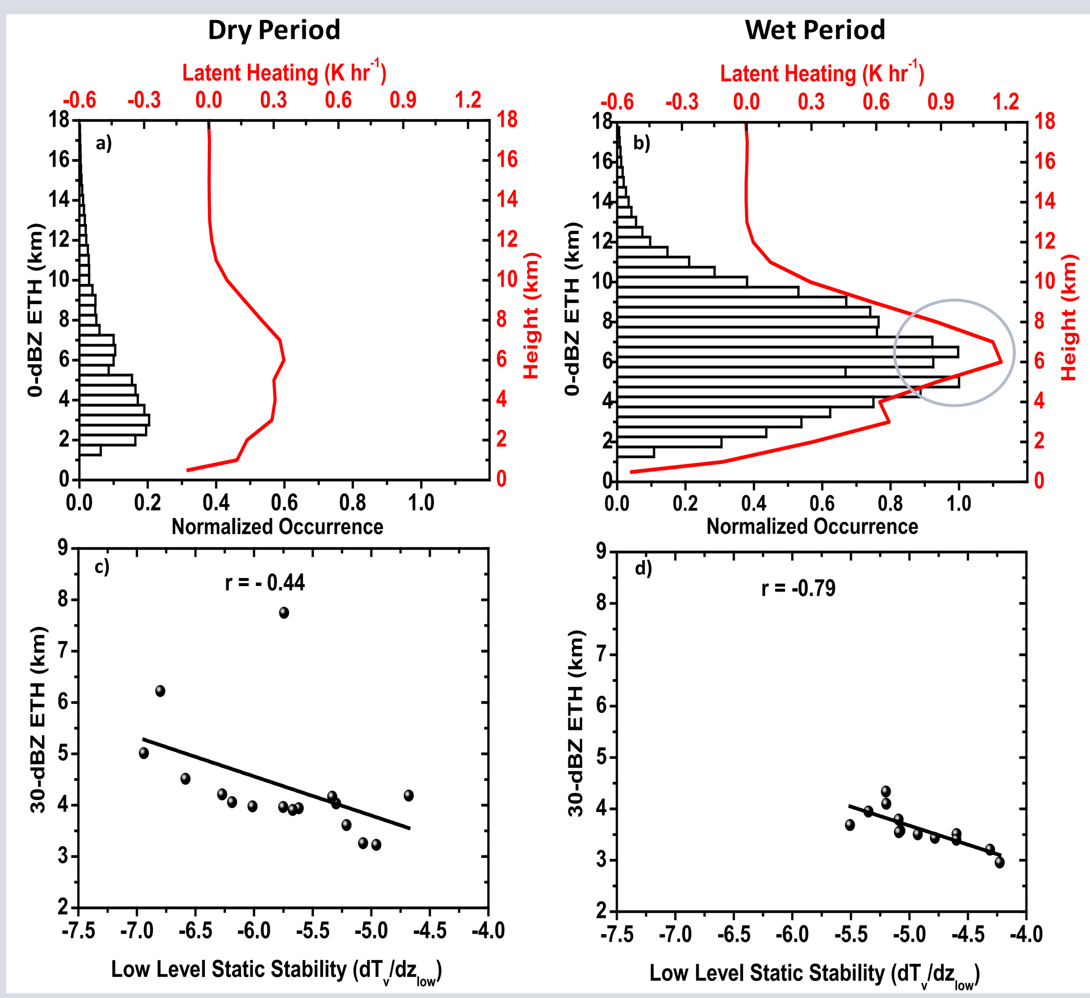


Figure 4: Top Panel: Vertical profiles of 0 dBZ ETH distribution and TRMM 3G31 LH profiles for a) dry and b) wet period.. Bottom Panel: Scatter plot of 30 dBZ ETH and low level static stability (1.5-4.5km) for c)dry and d) wet periods.

Dry: Suppressed heating and sharp decline in 0-dBZ ETH occurrence

Wet: Enhanced 0-dBZ ETH occurrence :cooling below 2 km & increased heating aloft with maxima at 6 km.

Similar variations in ETH and LH profiles implying that heating profiles has a distinct signature for different distribution of cloud tops

ETH of precipitating convection decreases with increasing low level stability. Low-level static stability inhibits cloud growth beyond freezing level, promote cloud detrainment; important factor in determining top heights of precipitation.

Positive feedback between low-level heating and low-level static stability maintains shallow nature of convection over Western Ghats.

Diurnal cycle of convection and its control by upstream winds

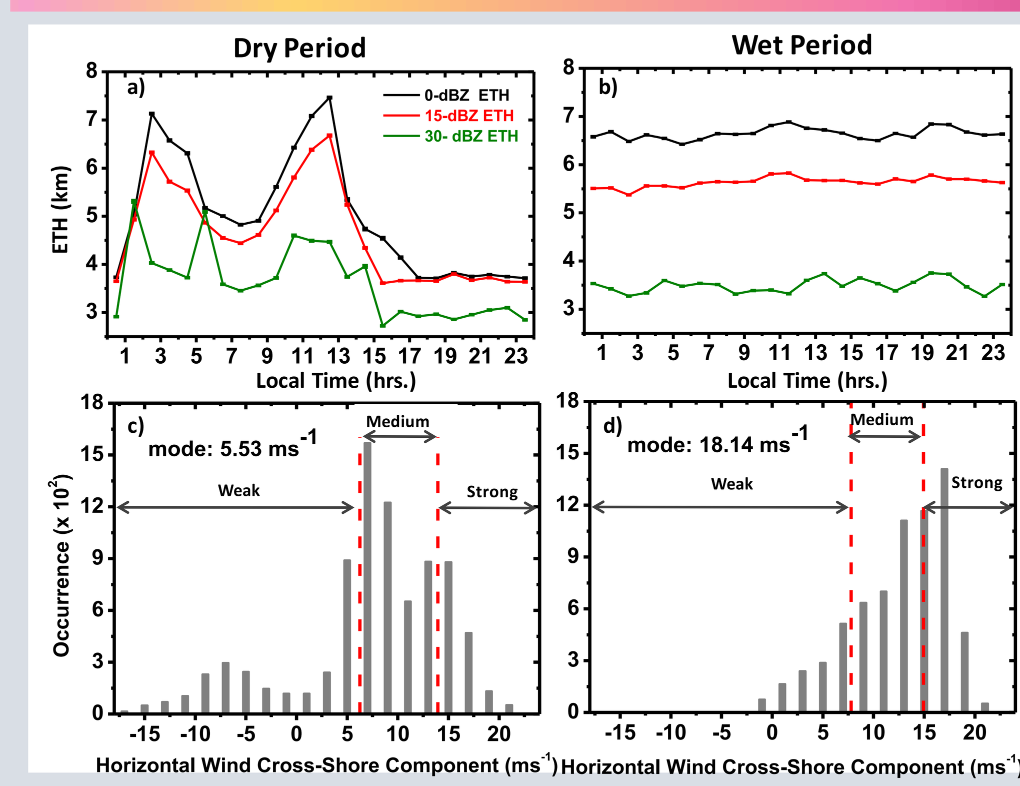


Figure 5: Top panel: Diurnal cycle of 0, 15 and 30 dBZ during a) dry & b) wet period. Bottom panel: Histogram of cross shore horizontal wind at 850 hPa during c) dry & d) wet days.

Dry period : associated with strong diurnal cycle and weak upstream winds

Wet Period: associated with weak diurnal cycle and strong upstream winds

Inferred that the observed convective features during dry (wet) periods are associated with the thermally (mechanically) induced circulations.

Upstream wind at 850 hPa: 16.75° N-19.25° N, 69° E-75° E over the Arabian Sea [Shige et. al 2017]

Three wind regimes defined: weak ($U \le \bar{U} - \sigma$), medium ($\bar{U} - \sigma < U < \bar{U} + \sigma$), strong ($U \ge \bar{U} + \sigma$)

Reduced dimension analysis

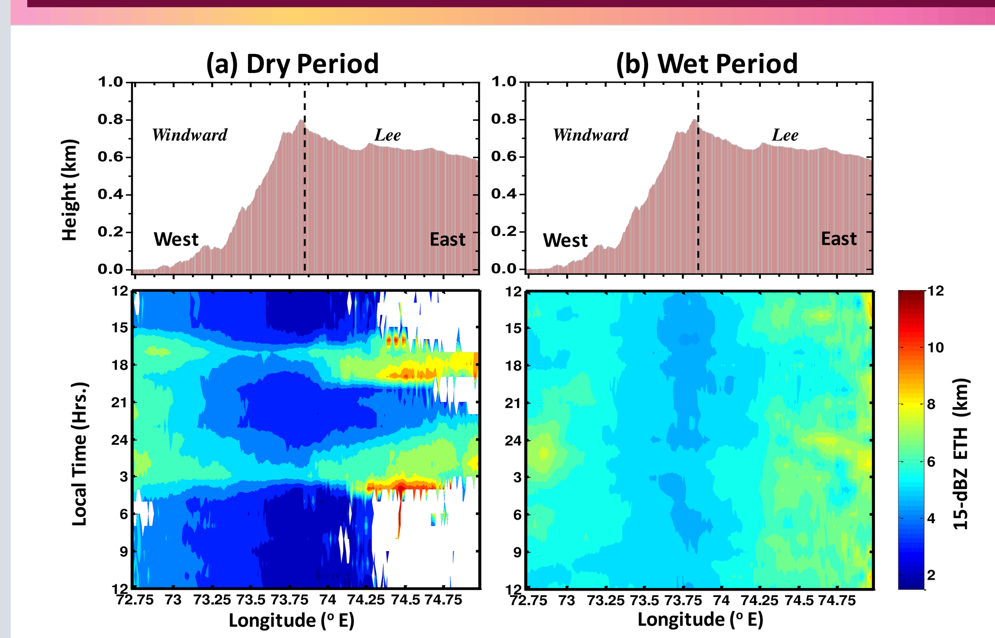


Figure 6: Time zonal sections of composite diurnal 15-dBZ ETH cycle (latitudinal average over radar domain) during (a) dry & (b) wet periods. Mean elevation profile of topography above the plots is shown in gray

Dry period : Strong diurnal amplitude; two broad maxima due to deep convection of lee

Wet Period: Small diurnal amplitude on both windward & leeward sides. Shallow ETHs over upslope

Total lightning & 30-dBZ ETH

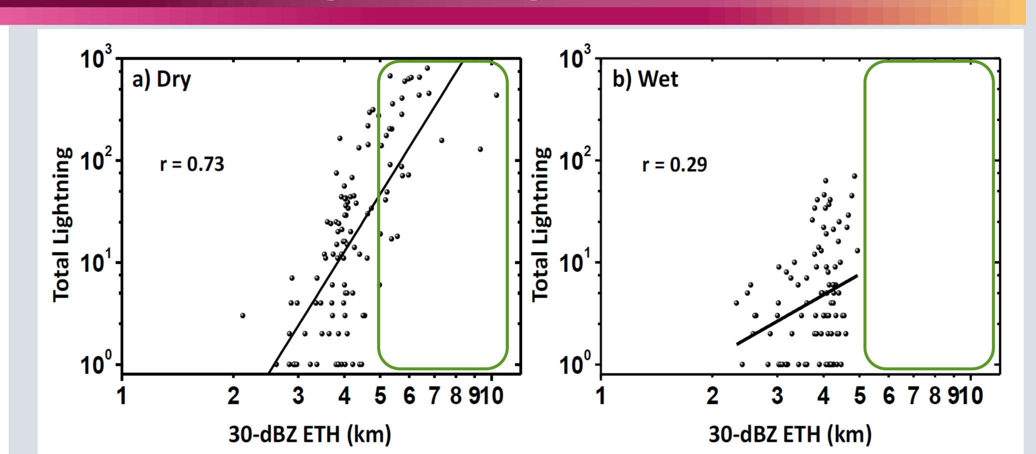


Figure 7: Scatter plot of total lightning as a function of 30-dBZ echo-top height (ETH) for (a) dry and (b) wet periods. Radar volumes with zero flashes have been excluded in this analysis.

Dry period: Penetration of 30-dBZ ETH above the 0°C isotherm : indicator of the existence of large particles in mixed phase region of the cloud, supported by updrafts well correlated with increased lightning occurrence

Wet period: Seldom electrical activity, which may be related to insufficient updraft speeds within convective core to produce lightning.

Lightning, convective tops & area fractions

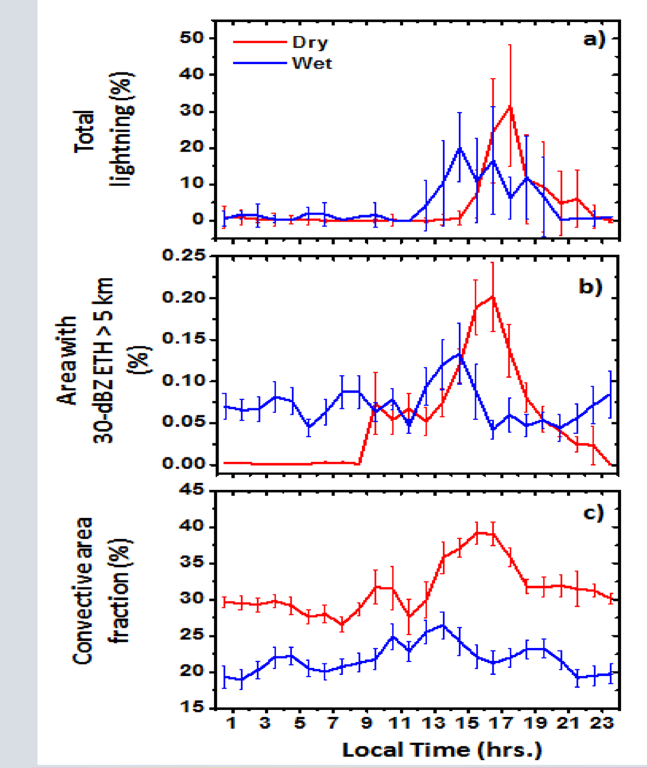


Figure 8: Diurnal variations of (a) total lightning, (b) fractional area with 30-dBZ echo-top heights (ETHs) >5 km, and (c) convective area fraction with their standard errors for dry period (red line) and for wet period (blue line).

Dry: An afternoon peak in lightning production is observed accompanied by increased penetration of 30-dBZ ETH > 0°C isotherm, increased convective area fractions, favouring strong electrification within convection.

Wet: Overall lightning activity is reduced by almost 50%; with subdued Convective area fraction

Convection relative to precipitation maxima

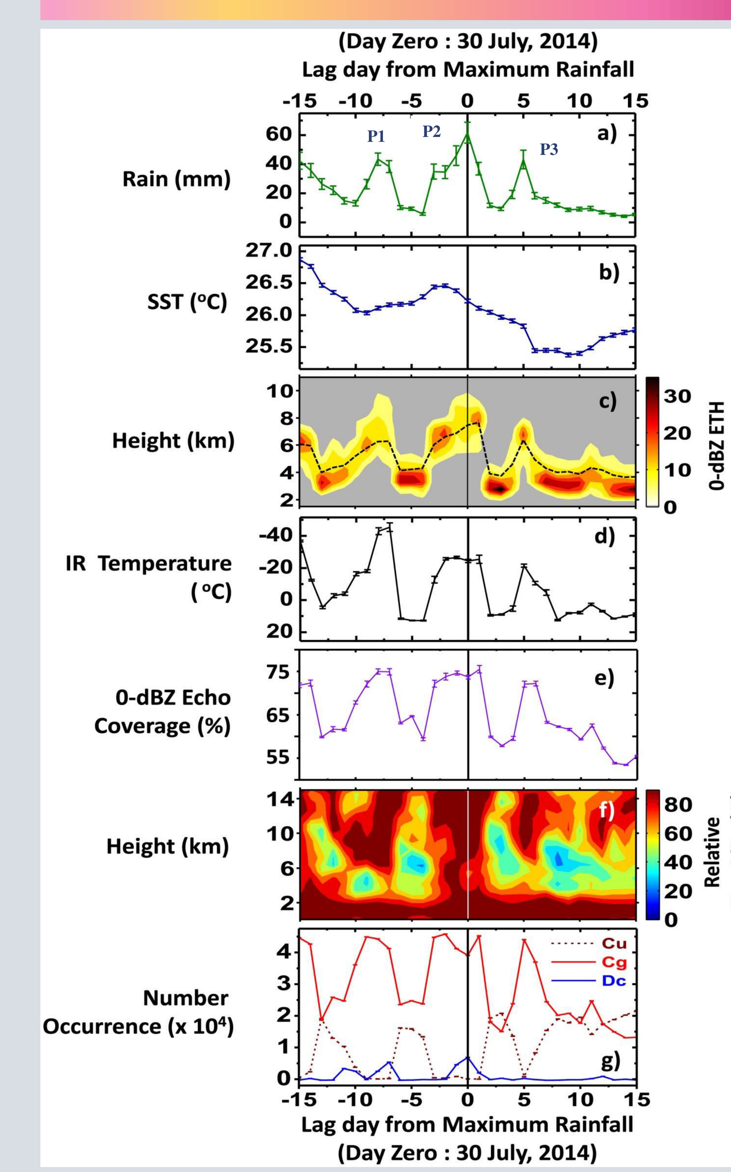


Figure 9: Daily evolution of a)Rainfall b)SST c)0 dBZ ETH Occurrence d) IR T_B e) 0-dBZ echo coverage f) Relative Humidity & g) evolution of cumulus, congestrus and Deep clouds from 0 dBZ ETH

Three episodes of high rainfall (P1,P2, P3), 3-5 day periodicity

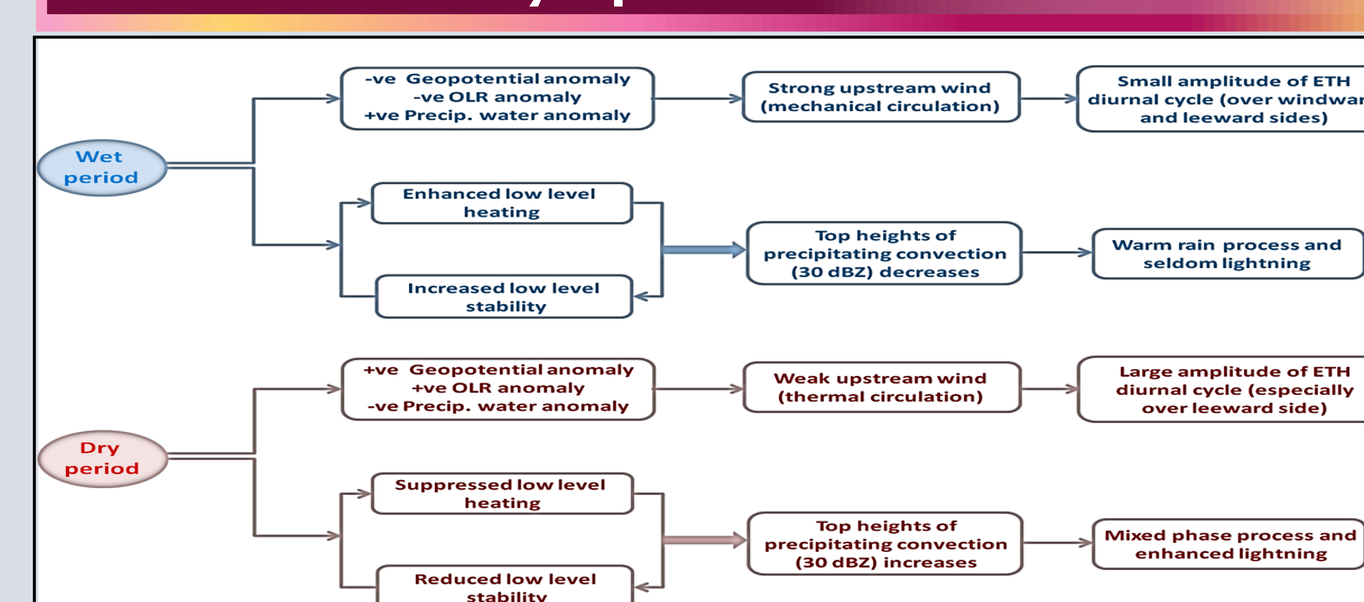
Cloud top heights increase steadily at about same rate for 1 week prior to rainfall event.

Mid-tropospheric moisture rapidly increased over a period of 2 to 3 days ahead of the increase in cloud top heights and their areal coverage near the high precipitation events.

Atmosphere is always moist below 3 km Maximum moisture variations found above 3 km

Midtroposphere moistening & drying occurs during peak occurrence of congestus & shallow convection modes.

Summary : pictorial flowchart



Acknowledgements

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