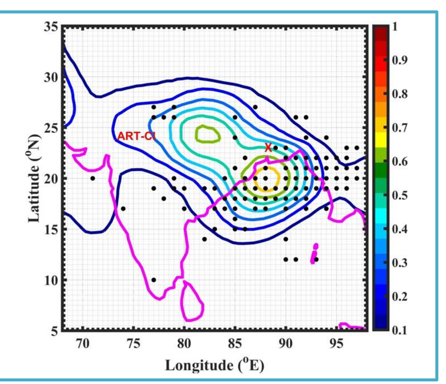
Program: Atmospheric Research Testbed

Role of Thermodynamics and Dynamics in the Diurnal Cycle, Propagation, and Progression of Convective Storms in the Eastern Flank of the Indian Monsoon Trough

Background

- Synoptically active environment during summer monsoon leads to maximum likelihood of monsoon LPSs at the eastern edge of the monsoon trough zone.
- The diurnal cycle of rainfall is one of the most fundamental modes of atmospheric variability, however, it is poorly represented by cumulus parameterization schemes in weather and climate models.
- A better understanding of the characteristics of different types of convective clouds and interrelationship can lead to the development of improved parameterization schemes for convective processes



Data and Methodology

S-band Radar

- Nine years (2009–2017) of measurements during June-September from the operational S-band (~10.43 cm) Doppler Weather Radar deployed at Kolkata (22.57°N, 88.35°E, 35m AMSL).
- Thunder-storm Identification Tracking Analysis and Nowcasting (TITAN) is used to identify the convective storms in the radar domain.
- CAPPI at 2 km with a reflectivity threshold of 35 dBZ that must be satisfied in a volume of at least 30 km^3 by TITAN are identified as storm cells.

ERA5 reanalysis

The ERA5 hourly radiation parameters (net solar radiation, latent heat flux, and sensible heat flux), mean sea level pressure, winds, specific and relative humidity are utilized to understand the mechanism for diurnal cycle of CSs and their progression.

INSAT-3D

Indian National Satellite System (INSAT-3D) measurements across a box of 20°–25°N, 85°–90°E for three monsoon seasons (JJAS, 2014–17) were utilized to estimate the convective available potential energy (CAPE).

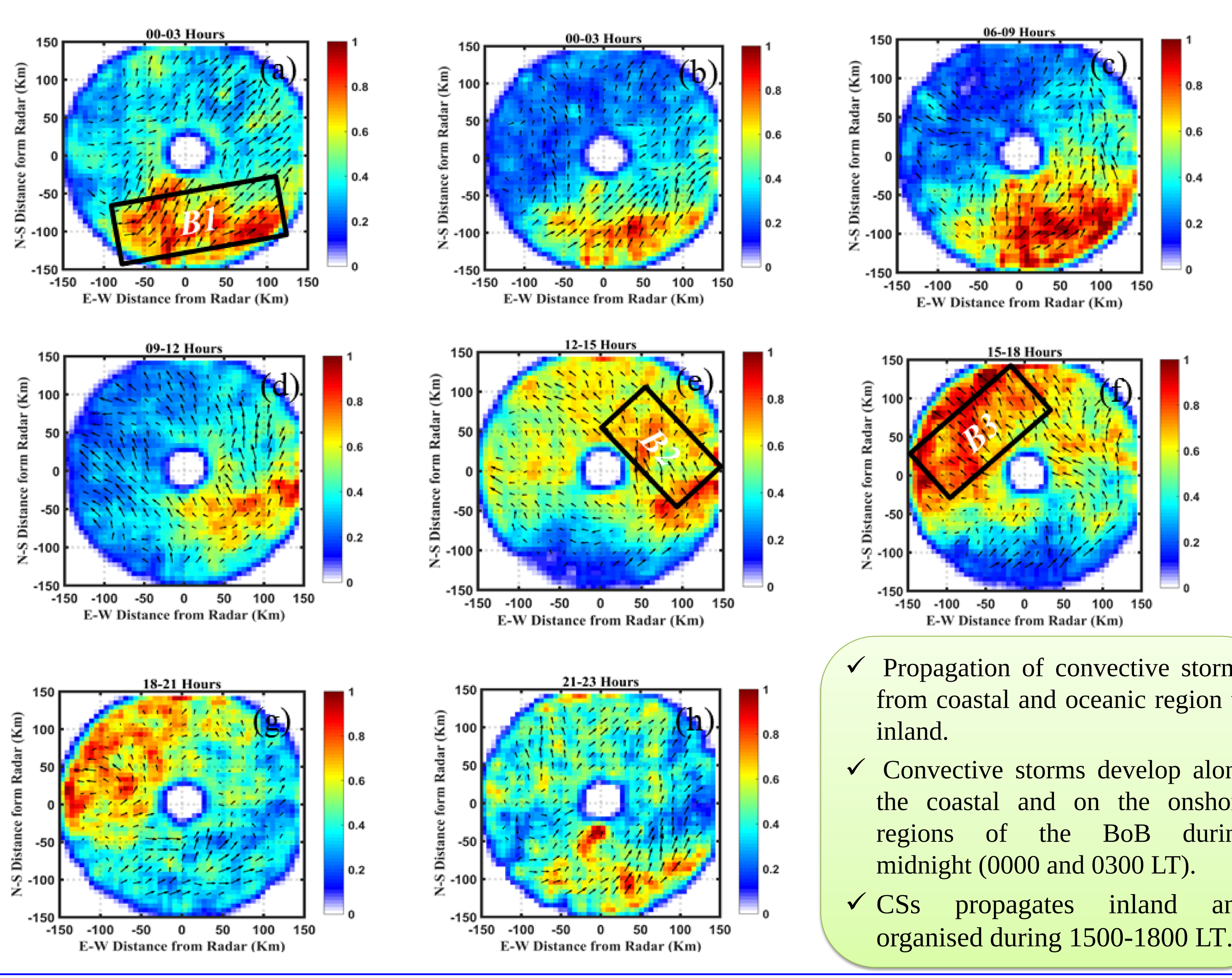
$$CAPE = \int_{LFC}^{EL} \frac{g(T_p - T_e)}{T_e} dZ$$

T_p is the virtual temperature of the air parcel
T_e is the virtual temperature of the environment
g is the acceleration due to gravity

COSMIC

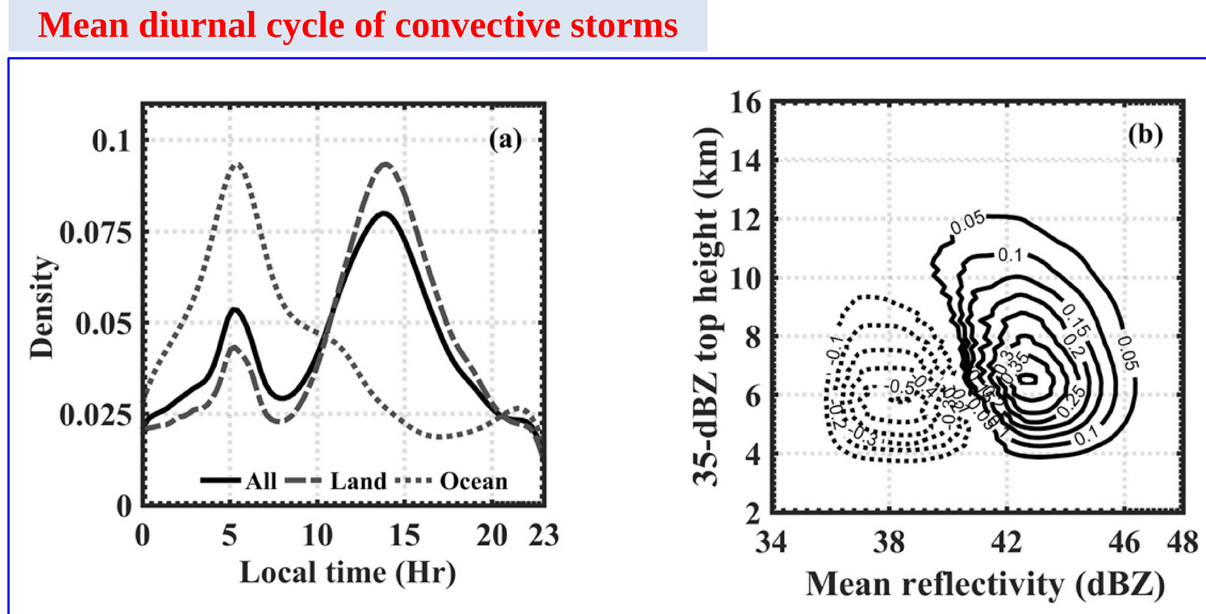
Temperature profiles collected (moist air retrieval) from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) during summer months (JJAS) from 2007 to 2017 are used to derive the 6-h temperature lapse rates.

Diurnal cycle and Propagation of Convective Storms



- Propagation of convective storms from coastal and oceanic region to inland.
- Convective storms develop along the coastal and on the onshore regions of the BoB during midnight (0000 and 0300 LT).
- CSs propagates inland and organised during 1500-1800 LT.

Mean diurnal cycle of convective storms

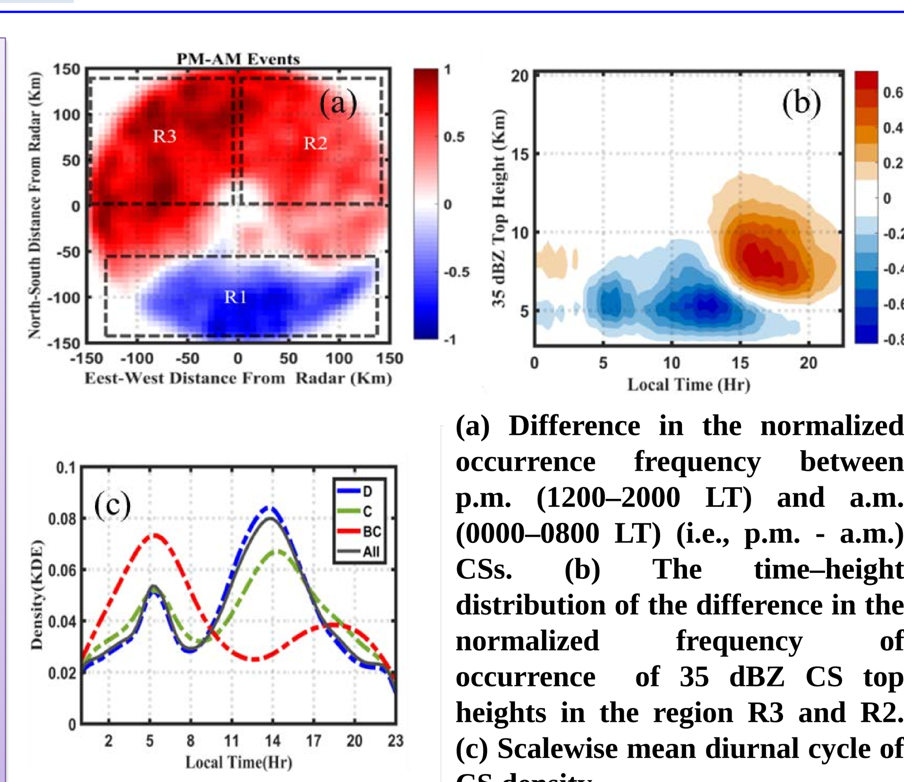


- A clear semidiurnal pattern of CSs is evident.
- CSs maxima during mid-night to morning hours over oceanic regions and afternoon hours in the land areas.
- The oceanic convection is shallower in nature with maximum occurrence at about 5-6 km and the continental convection is deeper with top height above 0° isotherm.

(a) Mean diurnal cycle (black solid line) of CSs density. (b) Difference of normalized contoured frequency by altitude diagram (CFAD) between p.m. (1200–2000 LT) and a.m. (0000–0800 LT) CSs. The black solid (dotted) contoured lines indicate relatively higher frequencies of reflectivity at that height bin during p.m. (a.m.) hours.

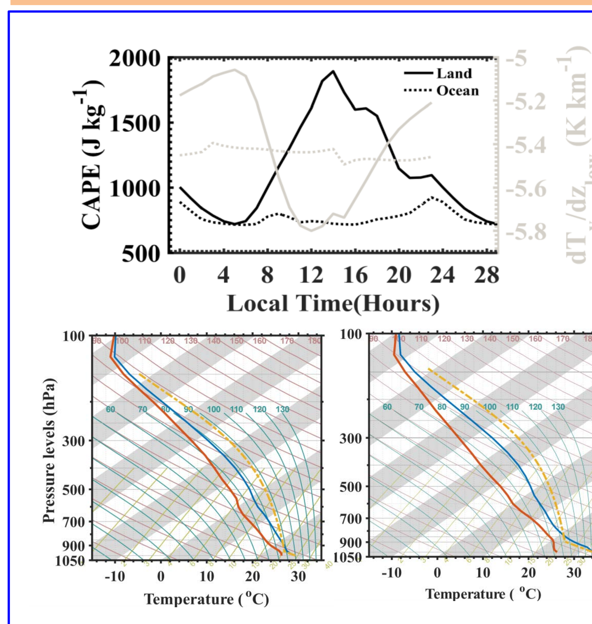
Regional and Scale-wise distribution of CSs

- CSs are categorized into AM (0000-0800 LT) and PM (1200-2000 LT) events.
- The coastal region, R1 is dominated by AM CSs, whereas PM CS's are frequent in both R2 and R3.
- The CSs are relatively shallower during morning hours in R2 and the afternoon CSs in R3 are deeper.
- The most frequent smallest CSs (D scale) has a peak in occurrence during afternoon hours (around 1400 LT), while peak occurrence hours in the case of larger CSs (C scale) is relatively skewed toward late afternoon hours (1500 LT and later).
- The largest B/C-scale CSs are frequent after evening hours (after 1800 LT) to night hours with an early morning peak.



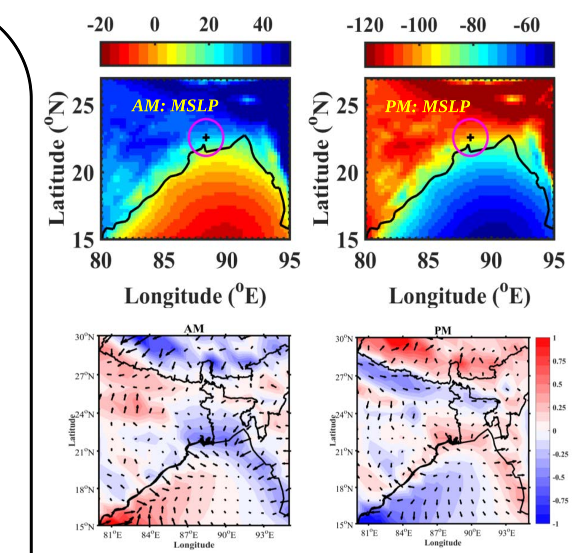
(a) Difference in the normalized occurrence frequency between p.m. (1200–2000 LT) and a.m. (0000–0800 LT) (i.e., p.m. - a.m.) CSs. (b) The time–height distribution of the difference in the normalized frequency of occurrence of 35 dBZ CS top heights in the region R3 and R2. (c) Scalewise mean diurnal cycle of CS density.

Mechanism of CS peaks and their propagation



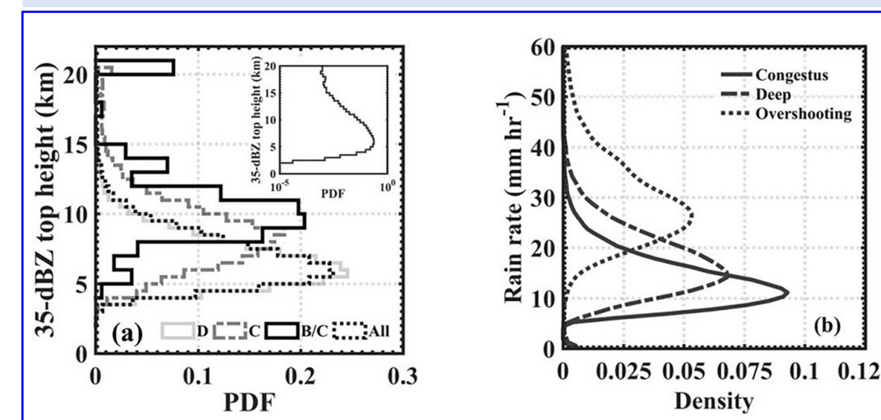
SkewT-logP Diagram over ocean (AM hours: left) and land (PM hours; right).

- Daytime surface heating and static stability are responsible for afternoon peak.
- Potentially unstable and buoyant atmosphere over land during afternoon hours help CSs to grow deeper.
- Fat (skinny) CAPE over land (oceanic) region. The parcel can attain more (less) buoyancy and thereby help CSs to grow deeper (shallower).
- The land breeze converge with the mean seasonal winds in the oceanic region, producing the nocturnal/early-morning peak.

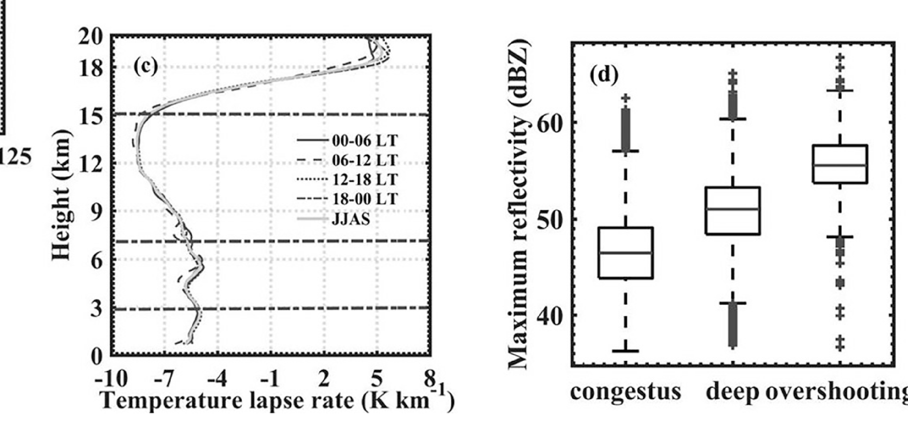


(a) MSLP anomaly (hPa) for a.m., and (b) p.m. Wind speed (shading) and wind vector (black arrows) anomaly during (c) a.m. and (d) p.m.

Four Cumulus modes

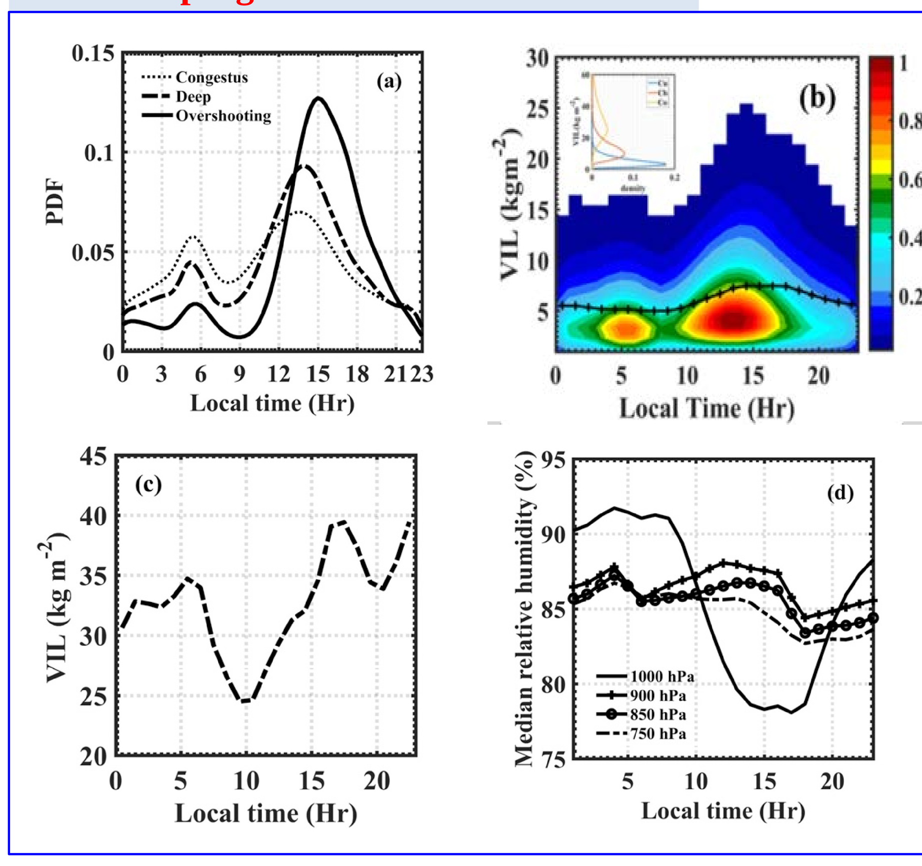


In addition to trimodal distribution, the fourth mode above 15 km (overshooting) is evidenced.



Mode 1 (M_I): Shallow Cumulus (Exempted)
Mode 2 (M_{II}): Cumulus congestus
Mode 3 (M_{III}): Deep convective
Mode 4 (M_{IV}): Overshooting

Diurnal progression of cumulus modes

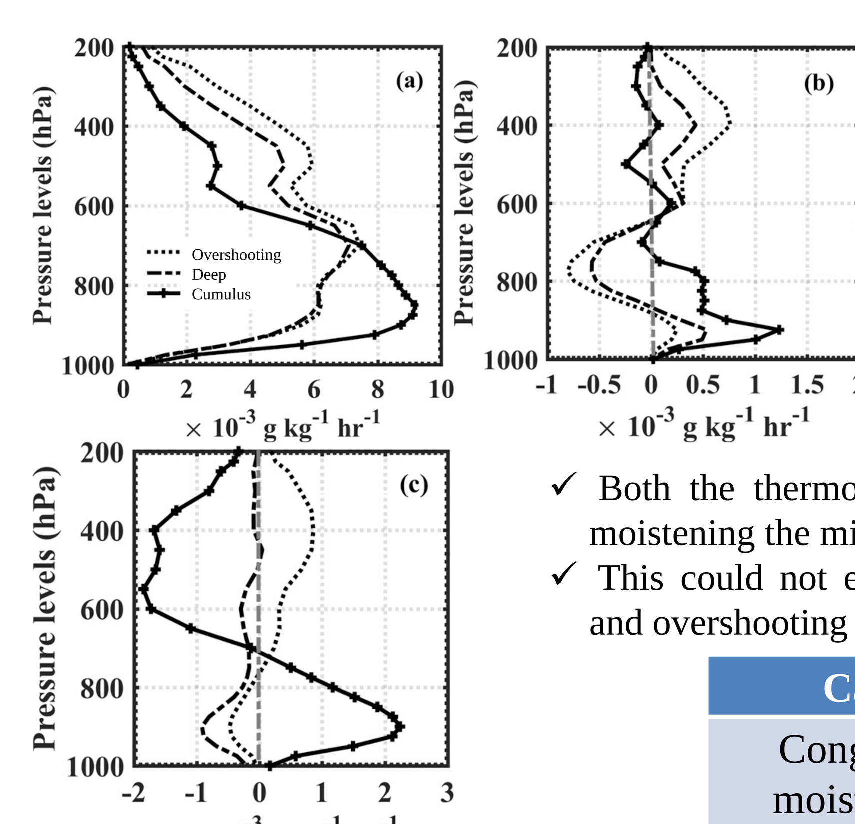


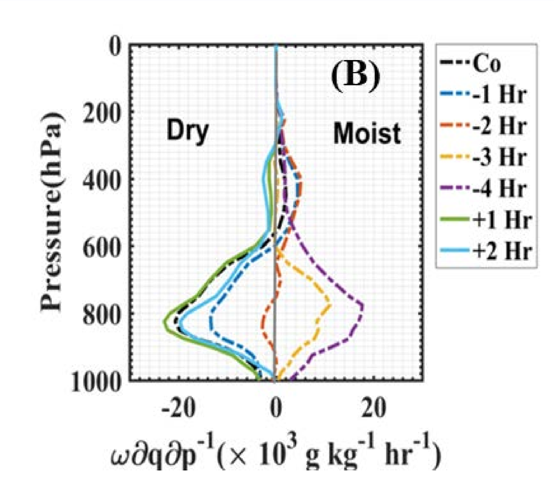
- A lead-lag of 2-4 h is observed between congestus, deep and overshooting modes, indicating the transition of congestus to deep and overshooting.
- The midtropospheric moistening processes could be responsible for deep convection.
- VIL is at its maximum during the local hours preceding the most frequent occurrence of overshooting storms (1600 and 0500 LT).
- The mid-troposphere becomes more humid 4-5 h preceding the overshooting convection.
- Two hypotheses were examined for the mid-tropospheric moistening (i) by congestus and (ii) by large-scale dynamics.

Mechanism for the transition of cumulus to deep and overshooting convection

$$\frac{\partial q}{\partial t} = v_H \cdot \nabla_H\, q + \omega \frac{\partial q}{\partial p} + Q2$$

Moistening by vertical advection can be seen 3-4 h prior to overshooting convection in the lower troposphere and 1-2 prior in mid-troposphere.





- Both the thermodynamic and dynamic processes are important for moistening the mid-troposphere prior to the deep CSs.
- This could not explain the lead-lag relation between congest, deep, and overshooting CSs.

Case	Δq_v (g / kg)	τ (h)
Congestus moistening	4	18-46
Large-scale dynamics	4	03-18

Time scale analysis is performed to understand transition from congestus to deep and/or overshooting for both the processes congestus moistening and large-scale dynamics.

$$\tau_c = \frac{\Delta q_v}{\left(\frac{dq_v}{dt}\right)_c}$$

Summary:

- The CSs exhibits a distinct semidiurnal pattern, with a prominent afternoon peak of deep convection over inland regions and a secondary peak of shallower and weaker, larger clusters corresponds to the nocturnal/early morning offshore CSs.
- The primary inland afternoon peak in CSs attributed to daytime land surface heating and associated destabilization. The secondary shallow offshore peak arises in CSs between midnight and early morning due to the convergence caused by the nocturnal land breeze and the prevailing onshore flow.
- The diurnal cycle of different CS modes (congestus, deep, and overshooting) demonstrated a lead–lag of few hours in their population, indicating a progression from congestus to deep CSs eventually growing into overshooting mode.
- The advective processes are responsible for the transition of congestus to deeper modes of convection.

Jha, A. K., Das, S. K., Murali Krishna, U. V. & Deshpande, S. M. (2022), Role of Thermodynamics and Dynamics in the Diurnal Cycle, Propagation, and Progression of Convective Storms in the Eastern Flank of the Indian Monsoon Trough. Journal of the Atmospheric Sciences, 3351–3374. https://doi.org/10.1175/JAS-D-21-0159.s1.