Complex physical mechanisms associated with Mesoscale Convective System over South-east India using collocated high-resolution Observations

A Madhulatha[1], M Rajeevan[2], T.S Mohan[3], and S.B Thampi[4]

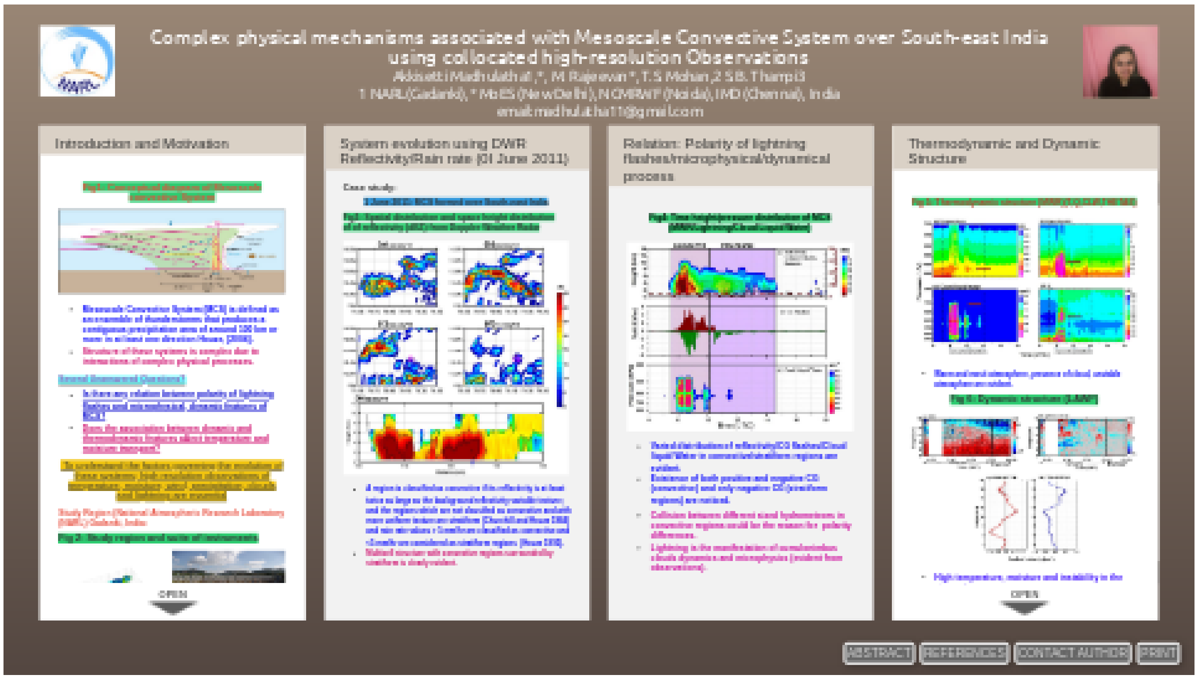
[1]National Atmospheric Research Laboratory
[2]Minsitry of Earth Sciences
[3]National Center for Medium Range Weather Forecasting
[4]India Meteorological Department

November 22, 2022

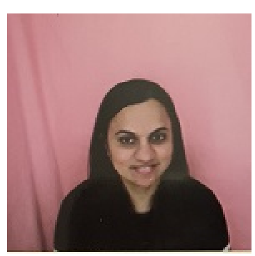
Abstract

Precise understanding of complex physical mechanisms of mesoscale process require high resolution observations of temperature, moisture, wind, precipitation, clouds. Using all collocated observations of microwave radiometer, wind profilers, electric field mill, weather radars over South-East India an observational analysis is conducted for the first time. Analysis suggests that these systems developed in warm, moist environment associated with large-scale low-level convergence. Passage of system is accompanied by convective regions with intense upward motion and towers extending up to higher levels indicating developing phase and presence of upward/downward motion comprising of heavy precipitation representing mature phase of the system followed by stratiform regions with prominent downdraft motion and less precipitation related to decay phase. Large (small) values of reflectivity and cloud liquid water values represent presence of deep (shallow)convective (stratiform) regions. Cloud to Ground (CG) lightning activity associated with storm electrification processes showed the existence of both +CG and –CG flashes in convective and dominant –CG in stratiform regions. Presence of different sized cloud liquid hydrometers in convective regions resulted in bipolar nature due to their collisions however in stratiform regions their distribution is mostly uniform and resulted in single polarity. Combination of different observations has provided the unique opportunity to examine interrelations of different physical mechanisms in storm environment. Inspection of reflectivity, CG lightning and cloud liquid water measurements have demonstrated the relationship of lightning mechanism with storm dynamics and cloud microphysics. Combined investigation of temperature, moisture and wind measurements have given considerable insight of thetae ridge formations resulting from thermal and moisture advections. Isentropic upgliding and downgliding facilitated the unique way to visualize the vertical transport of temperature and moisture through ascent and descent of air parcel. Blend of observations presented considerable insight of synoptic and complex mesoscale processes and their mutual interactions in the storm environment and provided encouraging results in explaining MCS structure.

Complex physical mechanisms associated with Mesoscale Convective System over South-east India using collocated high-resolution Observations



A. Madhulatha1,*, M. Rajeevan*, T.S. Mohan2, S.B. Thampi3
1 NARL(Gadanki),* MoES (New Delhi), NCMRWF (Noida), IMD(Chennai), India
email:madhulatha11@gmail.com

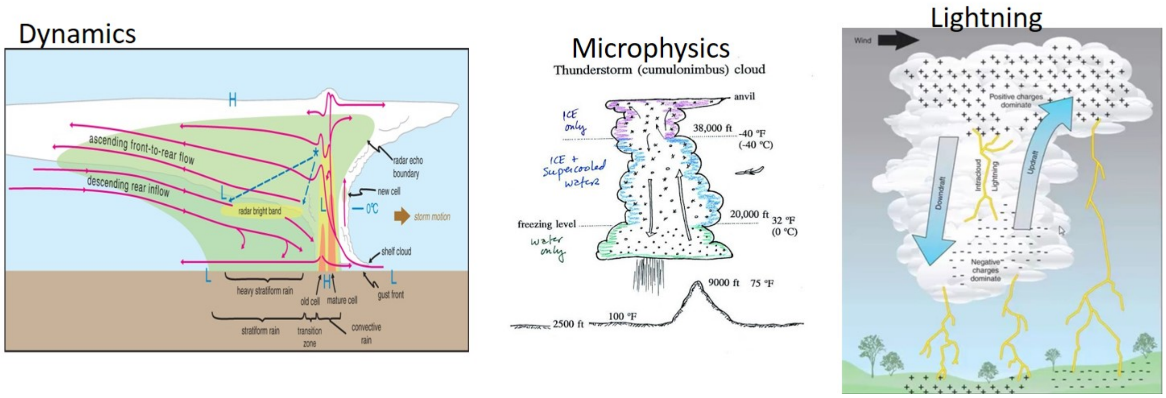


PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

INTRODUCTION AND MOTIVATION

Fig1: Conceptual diagram of Mesoscale convective System



- **Mesoscale Convective System (MCS) is defined as an ensemble of thunderstorms that produces a contiguous precipitation area of around 100 km or more in at least one direction Houze, [2004].**
- **Structure of these systems is complex (in terms of its Dynamics, Microphysics, Lightning) and also due to interactions of complex physical processes.**
- **Improve the understanding by observational and modeling approaches can help to improve forecast.**

<u>Several Unanswered Questions?</u>

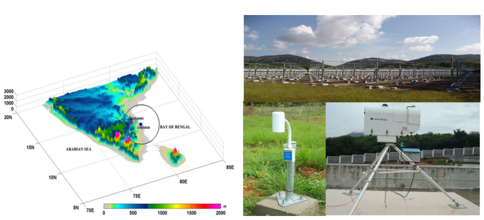
- **<u>Is there any relation between polarity of lightning flashes and microphysical, dynamic features of MCS?</u>**
- **<u>Does the association between dynamic and thermodynamic features affeect temperature and moisture transport?</u>**

<u>To understand the factors governing the evolution of these systems; high resolution observations of temperature, moisture, wind, precipitation, clouds and lightning are essential</u>

- **Study Region (National Atmospheric Research Laboratory (NARL) Gadanki, Department of Space, Gadanki, India -Super observational site in South-East India**

Doppler Weather Radar (DWR), Chennai

Fig 2: Study region and suite of instruments



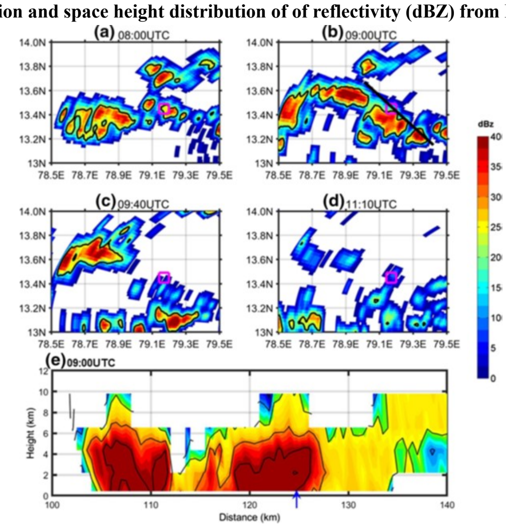
- **NARL, Gadanki has been selected in view of availability of many observational systems euipped with state of art VHF MST radar (vertical winds), UHF wind profiler (horizontal winds), AWS (surface parameters), MWR (Temp, Moisture, Winds), EFM (CG lightning flashes), 10-meter flux tower (parameters at 10m)**

SYSTEM EVOLUTION USING DWR REFLECTIVITY/RAIN RATE (0I JUNE 2011)

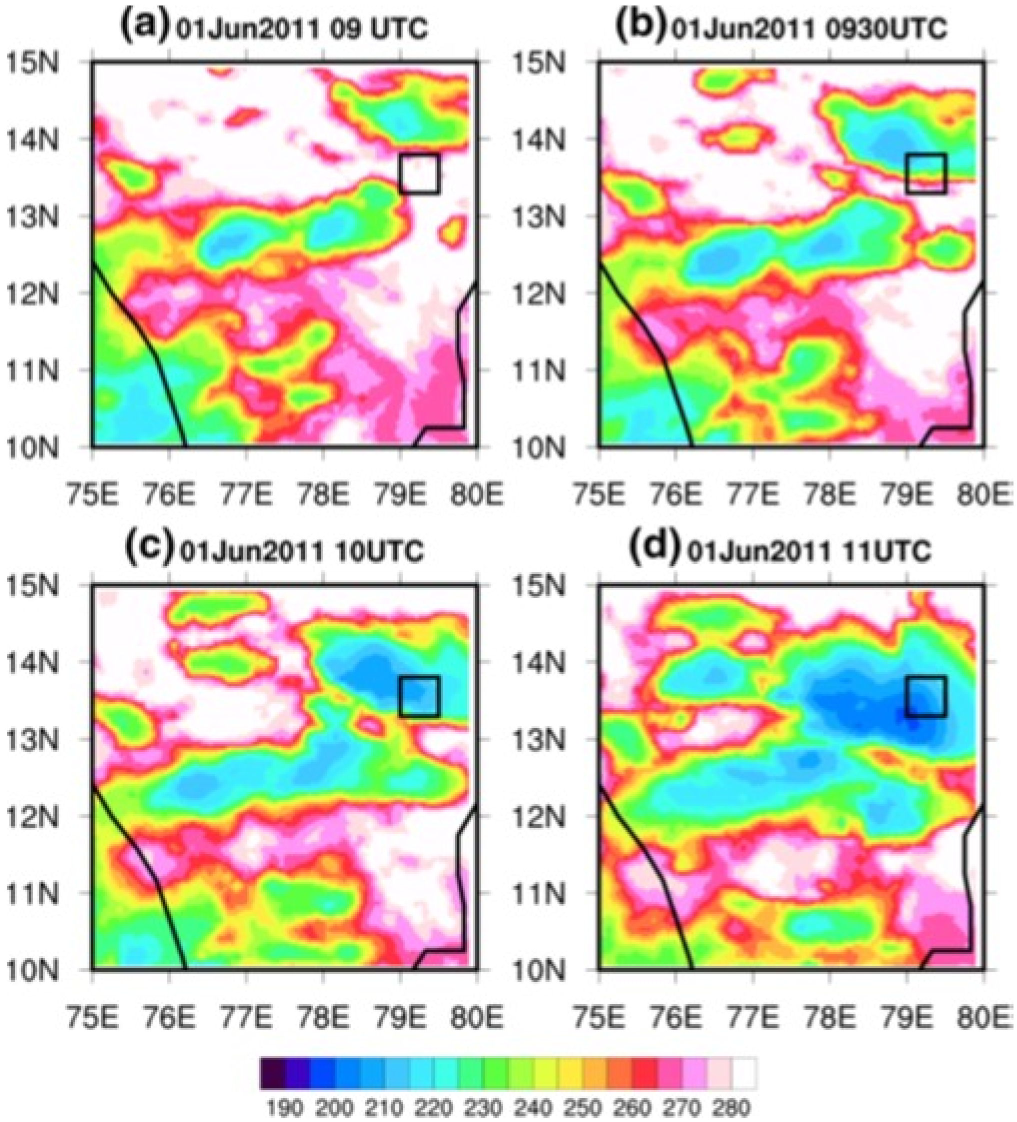
Case study:

1 June 2011: MCS formed over South-east India

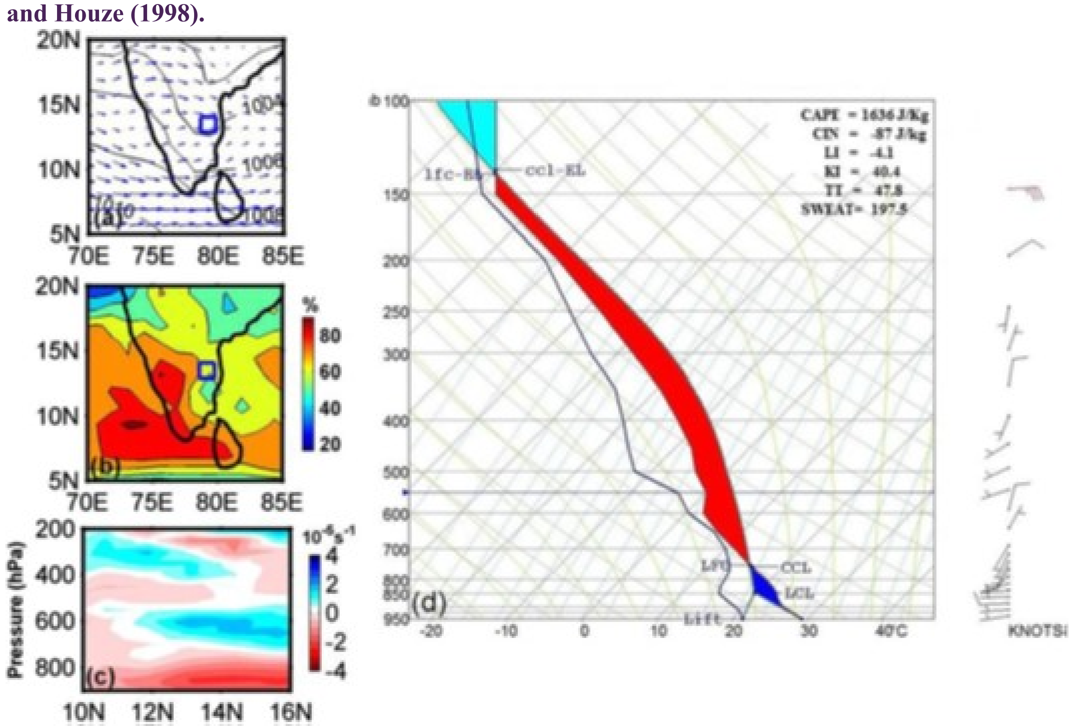
Fig3: Spatial distribution and space height distribution of of reflectivity (dBZ) from Doppler Weather Radar



- **A region is classified as convective if its reflectivity is at least twice as large as the background reflectivity variable texture; and the regions which are not classified as convective and with more uniform texture are stratiform (Churchill and Houze 1984) and rain rate values > 5 mm/hr are classified as convective and <5 mm/hr are considered as stratiform regions (Houze 1993).**
- **Multicell structure with convective regions surrounded by stratiform is clearly evident.**



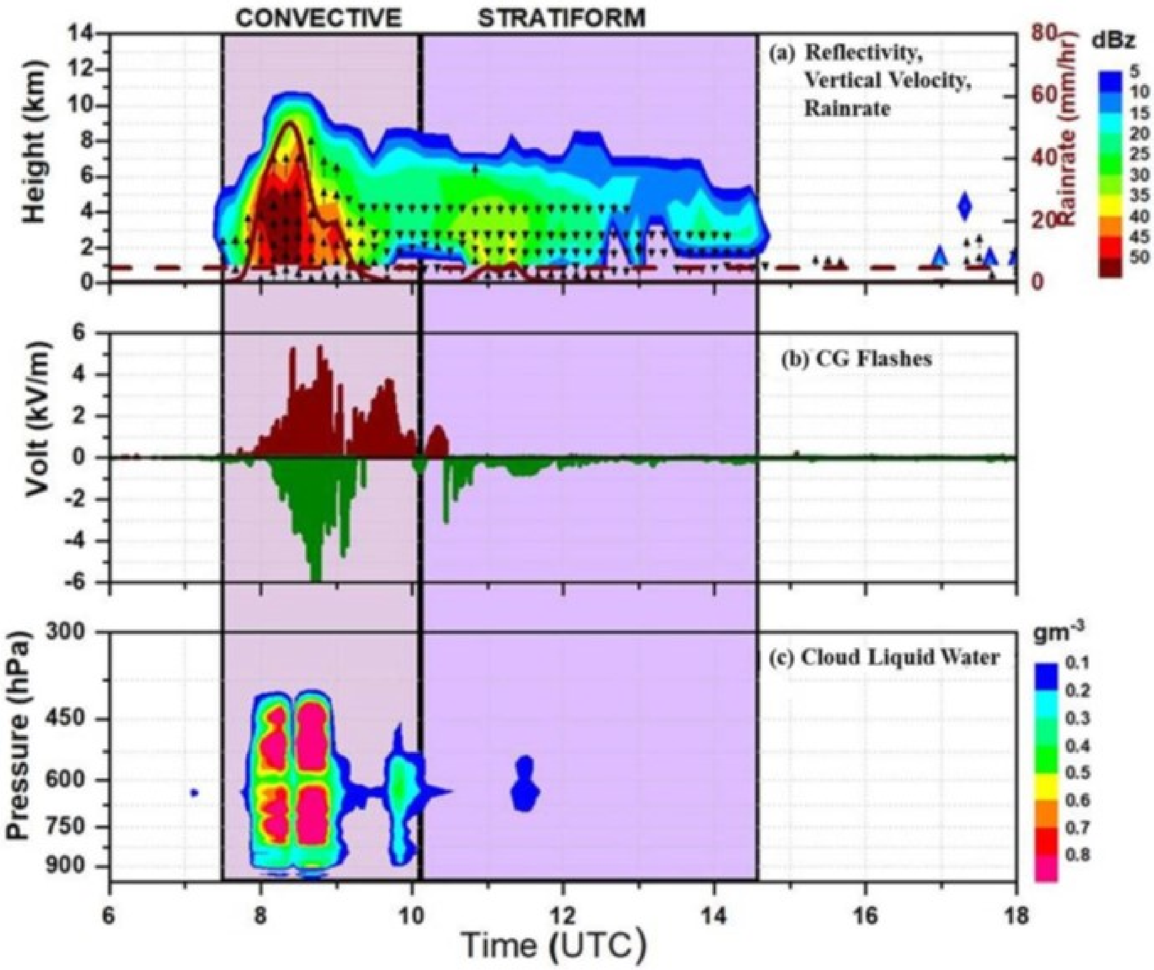
- **Tb values < 235 K related to convective surrounded by stratiform regions (>235 K) of MCS (Yuter and Houze (1998).**



- **warm temperature, high moisture, strong low-level convergence (Pre environment)**

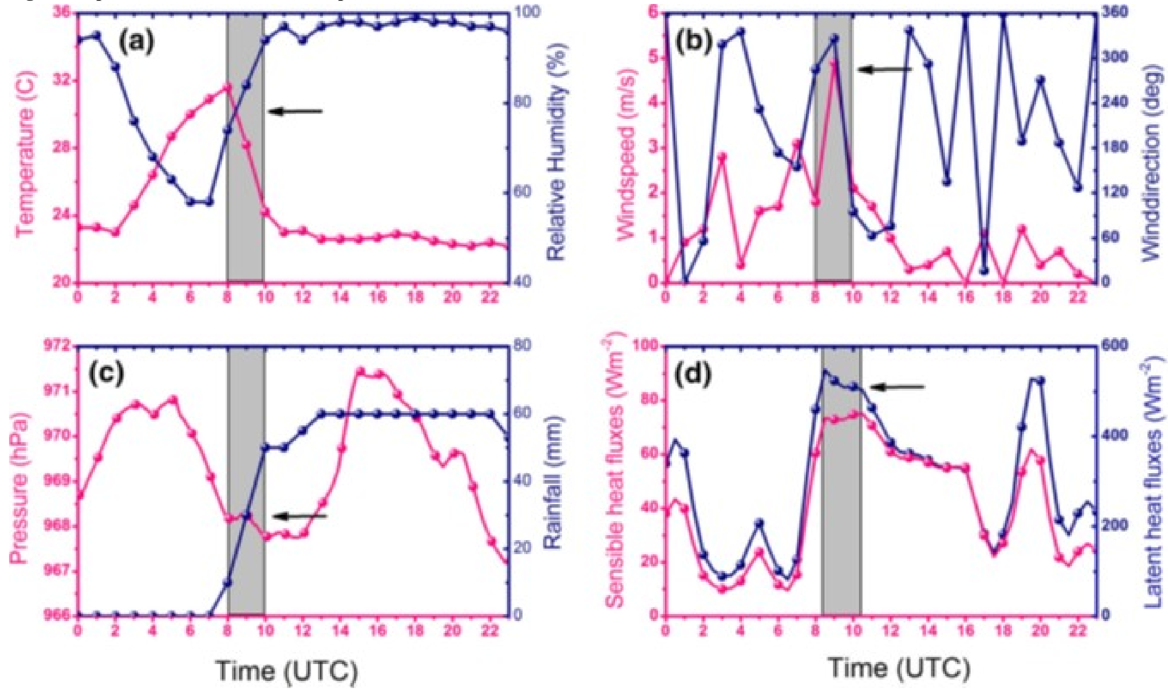
RELATION: POLARITY OF LIGHTNING FLASHES/MICROPHYSICAL/DYNAMICAL PROCESS

Fig4: Time height/pressure distribution of MCS (MWR/Lightning/Cloud Liquid Water)



- **Convective and Stratiform (DWR Reflectivity/Rain rate) MWR Liquid water content (LWC > 0.2 g/m3 (Convective and < 0.2 g/m3 (Stratiform))**
- **Varied distribution of reflectivity/CG flashes/Cloud liquid Water in convective/stratiform regions are evident.**
- **Existence of both positive and negative CG (convective) and only negative CG (stratiform regions) are noticed.**
- **Collision between different sized hydrometeors in convective regions could be the reason for polarity differences.**
- **Lightning is the manifestation of cumulonimbus clouds dynamics and microphysics (evident from observations).**

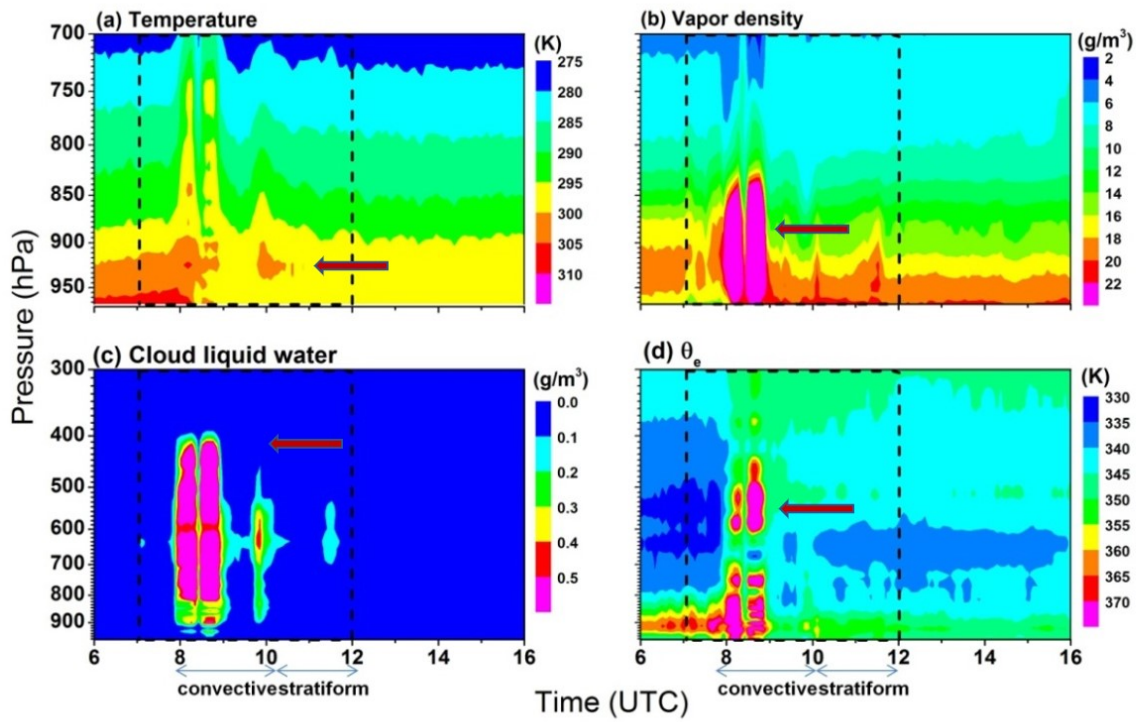
Fig 5: Temporal Distribution of Surface parameters



- **Passage of system-sudden drop in temperature**
- **-increase in wind speed, sudden change in wind speed, direction -raise in surface pressure (cold pool).**
- **Strong enhancement in surface energy fluxes represents the transport of heat, moisture and momentum in the boundary layer.**

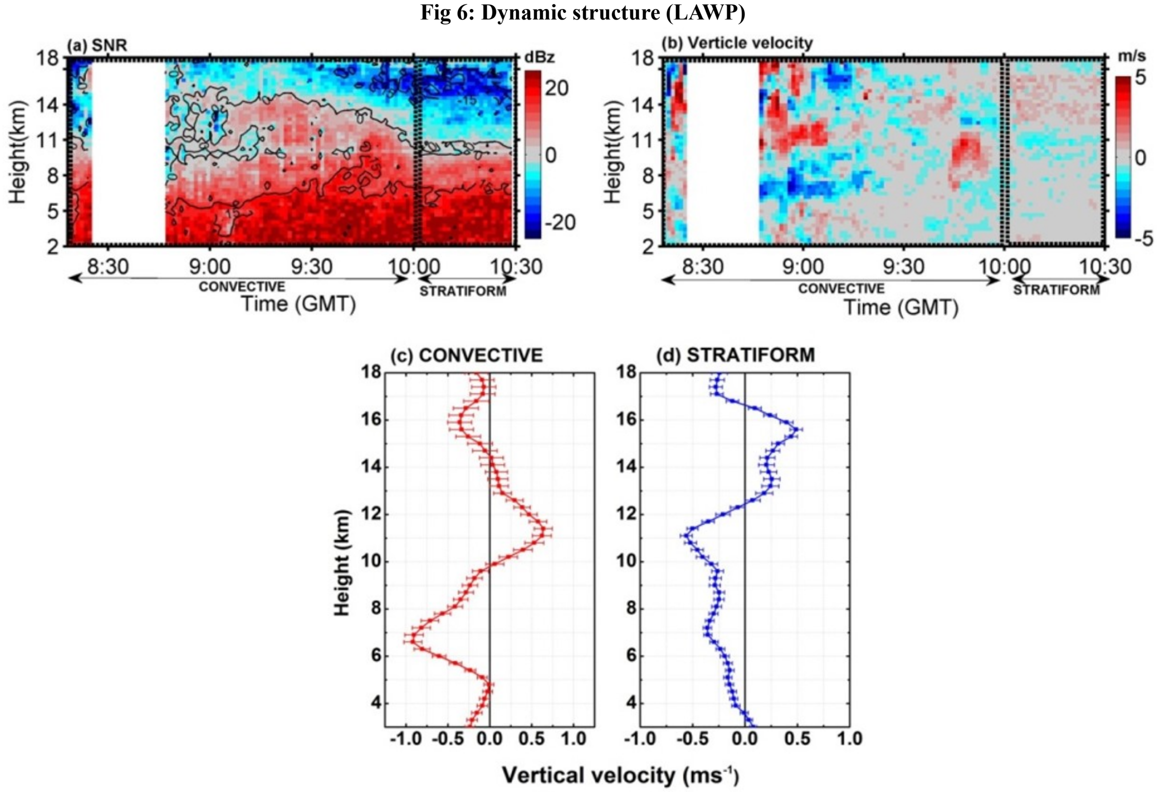
THERMODYNAMIC AND DYNAMIC STRUCTURE

Fig 5: Thermodynamic structure (MWR)(T,Q,CLW,THETAE)



- **Warm and mosit atmosphere, presence of cloud, unstable atmosphere are evident.**

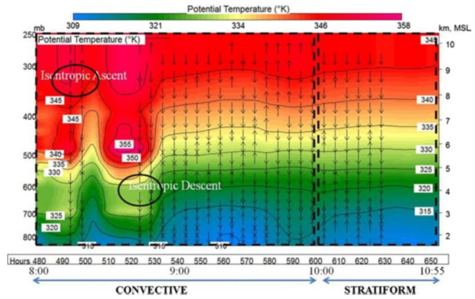
Fig 6: Dynamic structure (LAWP)



- **High temperature, moisture and instability in the atmosphere**
- **SNR=f(refractive index fluctuations- temperature, humidity variations).**

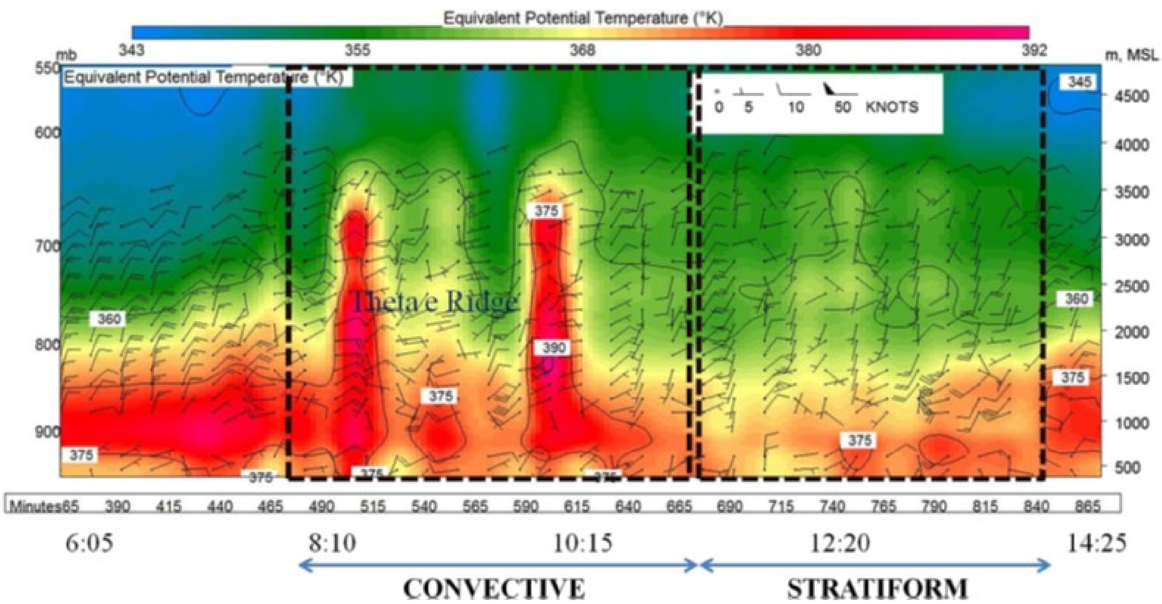
- **Dominant updraft (downdraft) motion in developing (dissipating) stages are evident.**

Fig 7: Dynamic/Thermodynamic structure (MWR/LAWP)



- **Isentropic analysis showed the existence of ascent and descent of air parcel in the storm environment.**

Fig 8: MWR derived (theta)/LAWP(hor.winds)



- **Veering (backing) of wind due to warm (cold) and moist (dry) air Advections demonstrated thetae ridge formation in the storm environment.**

Conclusions:

- **Combination of different observations provided opportunity to examine interrelations of different physical mechanisms in storm environment.**
- **Inspection of MWR,EFM,DWR demonstrated relationship of lightning with storm dynamics and microphysics (Further investigation using polarimetric radar is necessary).**
- **Simultaneous investigation of wind, temp, moisture parameters provide insight of thetae ridge formation due to temperature and moisture advections.**
- **Isentropic upgliding and downgliding facilitated unique way to visualize the vertical transport of T,Q through parcel ascent and descent**
- **Implication:Single point collocated observations provided considerable insight, to get more insight of mesoscale mechanisms there is a need of meso observation network (Rajeevan et al., 2012).**
- **To our knowledge this paper (Madhulatha et al., 2020) provides the first detailed study on thermodynamic, dynamic, kinematic, microphysical, electrical structure and life cycle of tropical MCS using suite of observations.**

Acknowledgements

- **Director, NARL, Gadanki for insitu Observations**
- **IMD Chennai (Weather Radar)**
- **Dr. Ashim Kumar Mitra, IndiaMeteorological Department (IMD), Delhi for Kalpana Satellite Data**.

In-situData avaiabliltiy:

- **Observational datasets utilized in the present study can be accessed by Blling the data request form under data dissemination https://www.narl.gov.in/.**
- **Director General of Meteorology, India MeteorologicalDWR data can be obtained by requesting Deputy**
- **Department (IMD), Chennai (http://www.imdchennai.gov.in/).**

Analysis tools: MATLAB(Mathworks),Origin (Originlab)

THANKS TO ALL VIEWERS

SPECIAL THANKS TO AGU CONVEYNERS

For More information on this poster

- **Please find the published article of this poster @https://link.springer.com/article/10.1007/s12040-019-1300-9 (https://link.springer.com/article/10.1007/s12040-019-1300-9)**
- **Madhulatha, A., M. Rajeevan, T.S. Mohan and S.B. Thampi, Observational Aspects of Tropical Mesoscale convective systems over southeast India, 2020, J. Earth Syst. Sci., 129, 65.**

References:

- **Churchill D and Houze Jr R A 1984 Development and structure of winter monsoon cloud clusters on 10 December 1978; J. Atmos. Sci. 41 933–960**
- **Rajeevan, M., Madhulatha, A., Rajasekhar, M., Bhate, J., Kesarkar, A., & Rao, B. A. (2012). Development of a perfect prognosis probabilistic model for prediction of lightning over south-east India. Journal of earth system science, 121(2), 355-371.**
- **Madhulatha, A., M. Rajeevan, T.S. Mohan and S.B. Thampi, Observational Aspects of Tropical Mesoscale convective systems over southeast India, 2020, J. Earth Syst. Sci., 129, 65.**

AUTHOR INFORMATION

madhulatha11@gmail.com

ABSTRACT

Precise understanding of complex physical mechanisms of mesoscale process require high resolution observations of temperature, moisture, wind, precipitation, clouds. Using all collocated observations of microwave radiometer, wind profilers, electric field mill, weather radars over South-East India an observational analysis is conducted for the first time. Analysis suggests that these systems developed in warm, moist environment associated with large-scale low-level convergence. Passage of system is accompanied by convective regions with intense upward motion and towers extending up to higher levels indicating developing phase and presence of upward/downward motion comprising of heavy precipitation representing mature phase of the system followed by stratiform regions with prominent downdraft motion and less precipitation related to decay phase. Large (small) values of reflectivity and cloud liquid water values represent presence of deep (shallow) convective (stratiform) regions. Cloud to Ground (CG) lightning activity associated with storm electrification processes showed the existence of both +CG and –CG flashes in convective and dominant –CG in stratiform regions. Presence of different sized cloud liquid hydrometers in convective regions resulted in bipolar nature due to their collisions however in stratiform regions their distribution is mostly uniform and resulted in single polarity.

Combination of different observations has provided the unique opportunity to examine interrelations of different physical mechanisms in storm environment. Inspection of reflectivity, CG lightning and cloud liquid water measurements have demonstrated the relationship of lightning mechanism with storm dynamics and cloud microphysics. Combined investigation of temperature, moisture and wind measurements have given considerable insight of thetae ridge formations resulting from thermal and moisture advections. Isentropic upgliding and downgliding facilitated the unique way to visualize the vertical transport of temperature and moisture through ascent and descent of air parcel. Blend of observations presented considerable insight of synoptic and complex mesoscale processes and their mutual interactions in the storm environment and provided encouraging results in explaining MCS structure.

REFERENCES

Madhulatha, A., M. Rajeevan, T.S. Mohan and S.B. Thampi, Observational Aspects of Tropical Mesoscale convective systems over southeast India, 2020, J. Earth Syst. Sci., 129, 65.