Atmospheric Research Testbed:
A unique facility in the tropical core monsoon zone of India for process studies

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Acknowledgments: IITM-ARTs Team

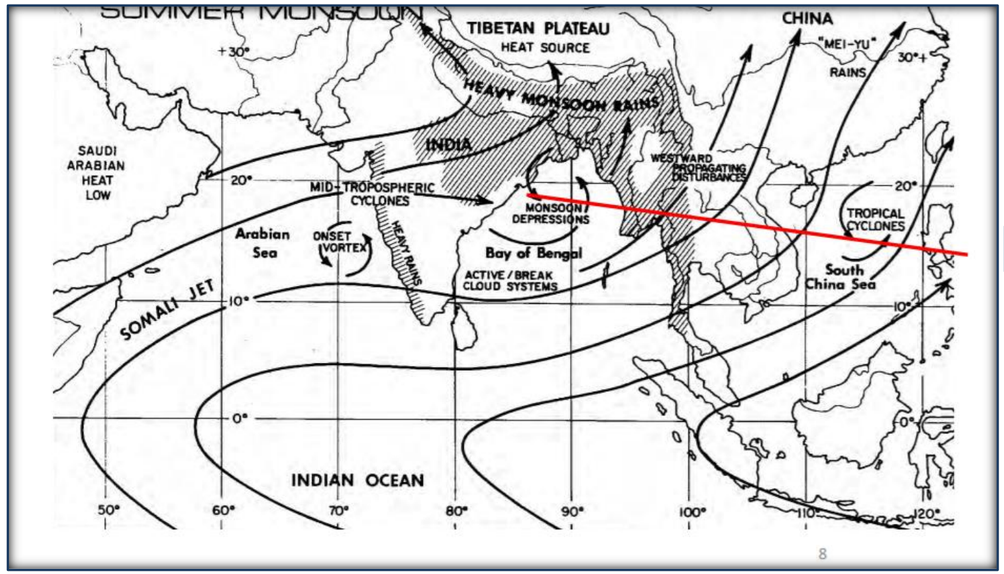
8th International Workshop on Monsoons

Outline

- Importance of core monsoon zone
- Need for Atmospheric Research Testbed for Process studies
- Observational glimpses from Monsoon campaigns
- Summary

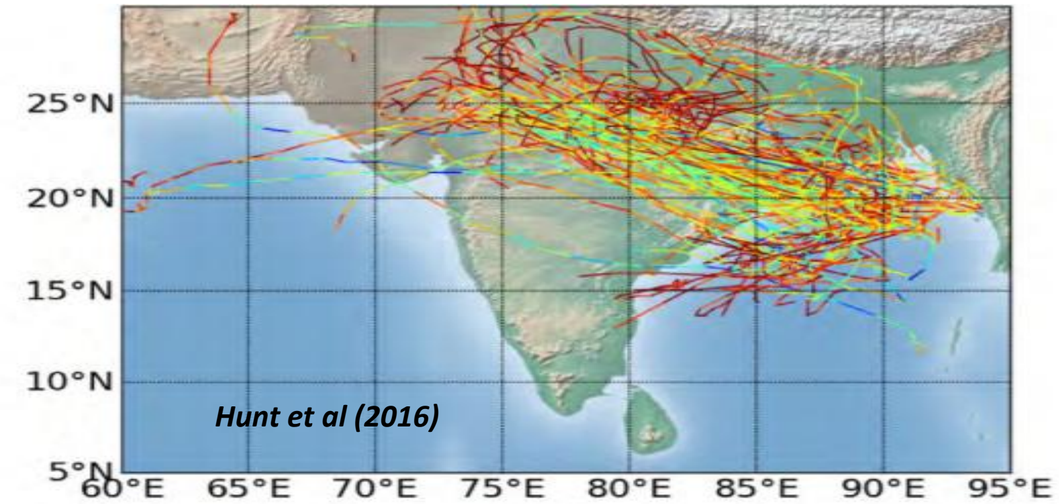
Importance of Core Monsoon Zone

Summer Monsoon

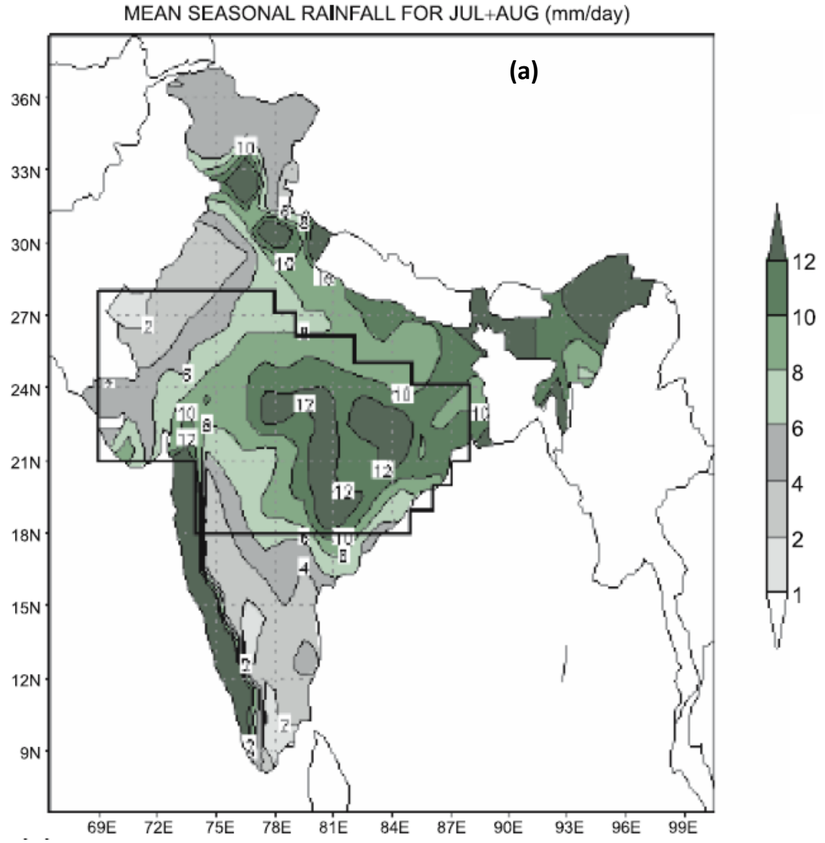


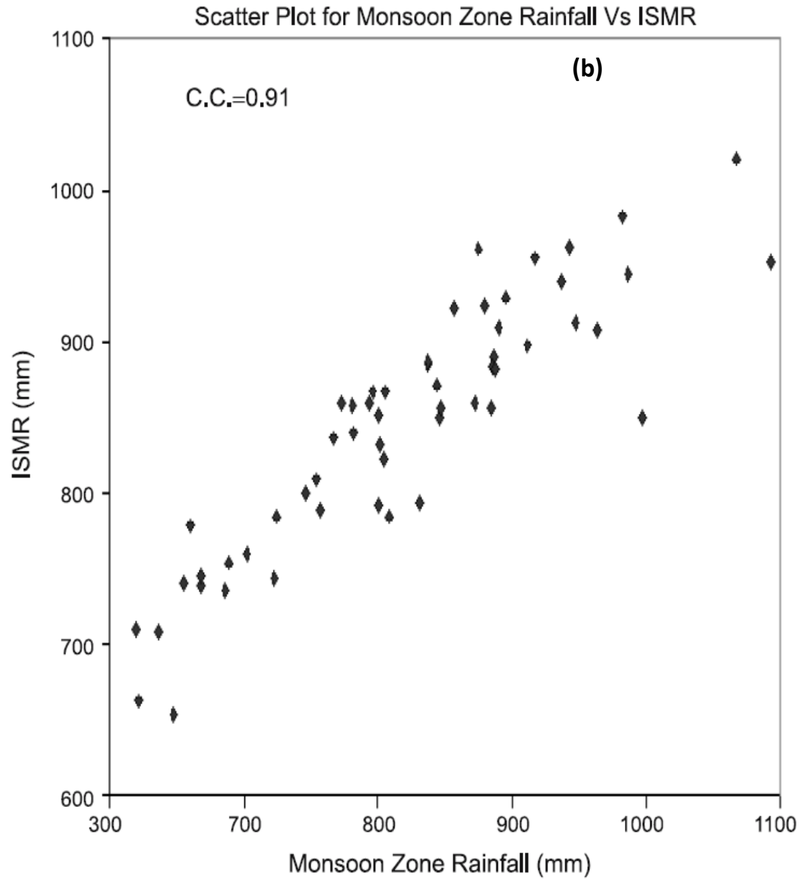
- The monsoon trough over Central India, which comprises the **monsoon core zone (MCZ),** is one of the important semi-permanent systems of the regional monsoon system.
- **Detailed atmospheric measurements in MCZ** wherein synoptic-scale disturbances (monsoon lows and depressions) frequently pass during the monsoon season **were overdue**.

Tracks of monsoon depressions



(a) Monsoon core zone considered to identify the active and break events. Spatial variation of mean (1951-2007) rainfall (mm/day) during the period July and August is also shown. (b) Scatter plot between the average rainfall over the monsoon core zone (June to September) and ISMR. Period: 1951–2007 (***Rajeevan et al., 2010***).





- It is known that **<u>variability in all-India summer monsoon rainfall</u>** is highly correlated with that of summer monsoon rainfall over central India (**Gadgil, 2003**).
- So an **<u>improved prediction of variability in central India</u>** should also project onto larger-scale predictability.

Need for Atmospheric Research Testbed in Central India

- Considering this importance, an **Atmospheric Research Testbed (ART) Facility in Central India** was established by IITM-MoES at Silkheda (50 km NW of Bhopal) for better understanding of processes governing monsoon convection.

- **ART is a permanent observation facility** and have a wide set of remote-sensing and in-situ instruments that will provide continuous observations of convection, clouds, cloud microphysics, aerosols, radiation, precipitation, land surface properties (& many more)

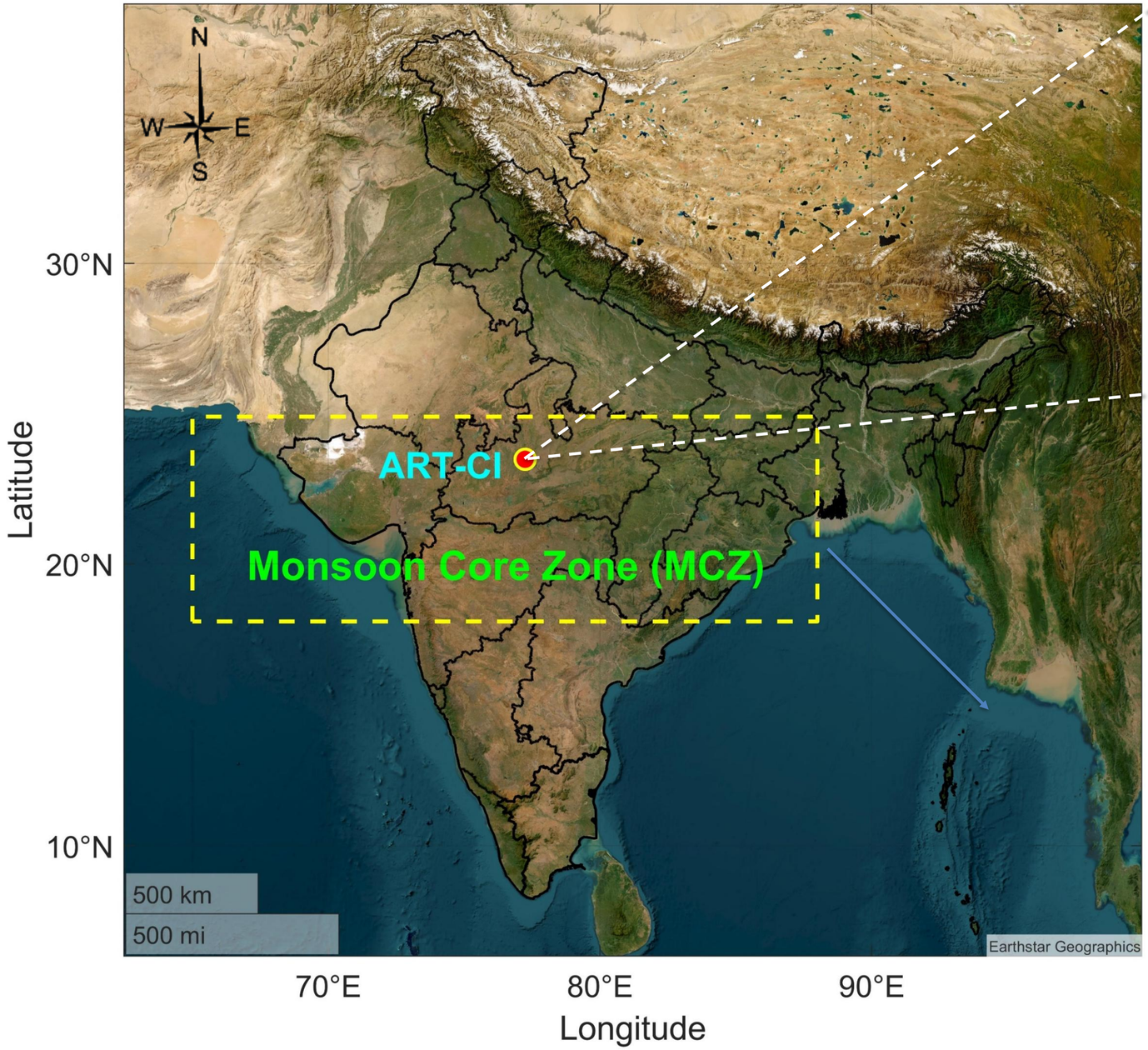
- ART datasets will provide **key resources for validating CRM & GCMs** using both statistical & process-oriented approaches.

Objectives of the ART Project

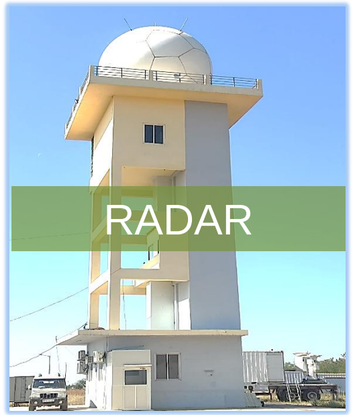
1. **To establish an Atmospheric Research Testbed in Central India (ART-CI)** for a better understanding of processes governing monsoon convection including its diurnal variation and land-atmosphere interactions over the monsoon core region using state-of-the-art observational systems.

2. **To organize intense observational campaigns along with weather prediction model runs** for testing hypotheses and to improve physical parameterizations in models related to convection and land surface processes.

3. **Outreach, Training, and Dissemination of ART-CI data sets.** The testbed will be made into an international facility for intense observational campaigns and testing physical parameterization schemes including sensitivity runs. Data will be used to test/validate/constrain numerical models in improving predictions of intense convective storms, and high-impact mesoscale weather events.



Geographical location of ART-CI site



ART-CI

C-Band RADAR

Ka-Band RADAR

Radiosonde

Instr. Laboratory

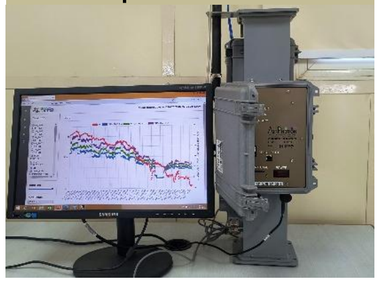
CCN Counter

TCA

SP2

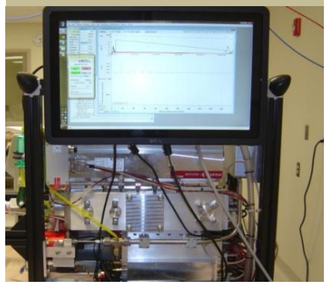
SMPS

Nephelometer



Ceilometer

ACSM



Athalometer

Radiometric Profiler

Impact Disdrometer

Micro Rain Radar

Radiation Observatory

Sensors on sun tracker

Sun Photometer

Whole sky imager

Progress History.....

2021

1. C-Band RADAR
2. Micro Rain Radar
3. Impact Disdrometer
4. Microwave Radiometric Profiler
5. Ceilometer

2022

1. C-Band RADAR
2. Micro Rain Radar
3. Impact Disdrometer
4. Microwave Radiometric Profiler
5. Ceilometer
6. CCN Counter
7. Aethalometer
8. Total Carbon Analyser

2023

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3. Impact Disdrometer
4. Microwave Radiometric Profiler
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7. Aethalometer
8. Total Carbon Analyser
9. SMPS
10. MRR
11. Radiation Sensors
12. WSI
13. GHG 72m flux tower
14. Radiosonde
15. Lightning Location Network

Present

1. Dual Pol C-Band RADAR
2. Micro Rain Radar
3. Impact Disdrometer
4. Microwave Radiometric Profiler
5. Ceilometer
6. CCN Counter
7. Aethalometer
8. Total Carbon Analyser
9. SMPS
10. Radiation Sensors
11. WSI
12. GHG 72m flux tower
13. Radiosonde
14. Lightning Location Network
15. ACSM
16. Sunphotometer
17. SP2

Timeline

Progress History.....

2025-26
SODAR: Boundary layer wind measurements
205 MHZ wind profiler: continuous vertical profile of winds including vertical winds
LIDAR: vertical profiles of aerosol and water vapor
W-band radar (94 GHz): non-precipitating clouds
ARG network: rain measurements
5 mesonet sites (25 km radius from a central facility; Met and Soil parameters)

2021

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2. Micro Rain Radar
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2022

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Timeline

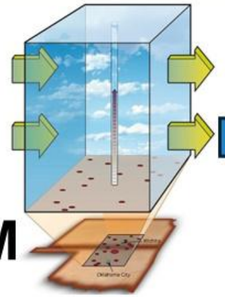
Application of ART data to initialize single column model to improve 3-D model

Use of Observation data in Model

In situ data from ART-CI

Field campaigns to generate the cloud scale/mesoscale data time series

Forcing from field campaign/ANL to run 1D GFS Single Column Model (SCM)



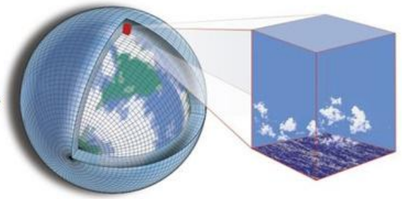
SCM

Validation/Test/ Modification of cloud process of SCM

Modelling Objective

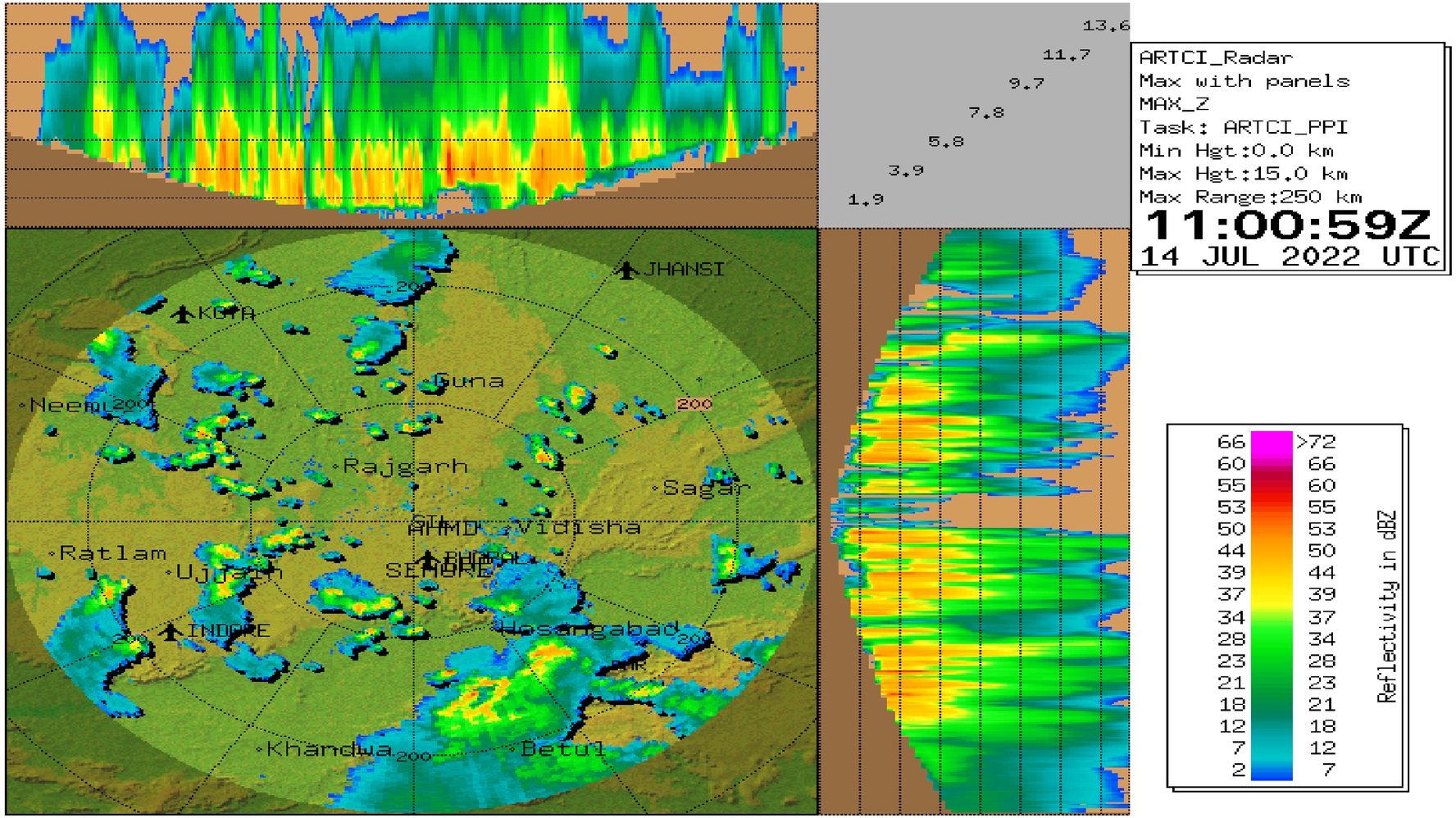
Running of CFS/GFS to identify biases in capturing cloud / convective processes associated during the organized convection at different spatio-temporal scale (Diurnal, Daily, Weekly, Seasonal)

Improved 3D NWP Model (CFS/GFS)

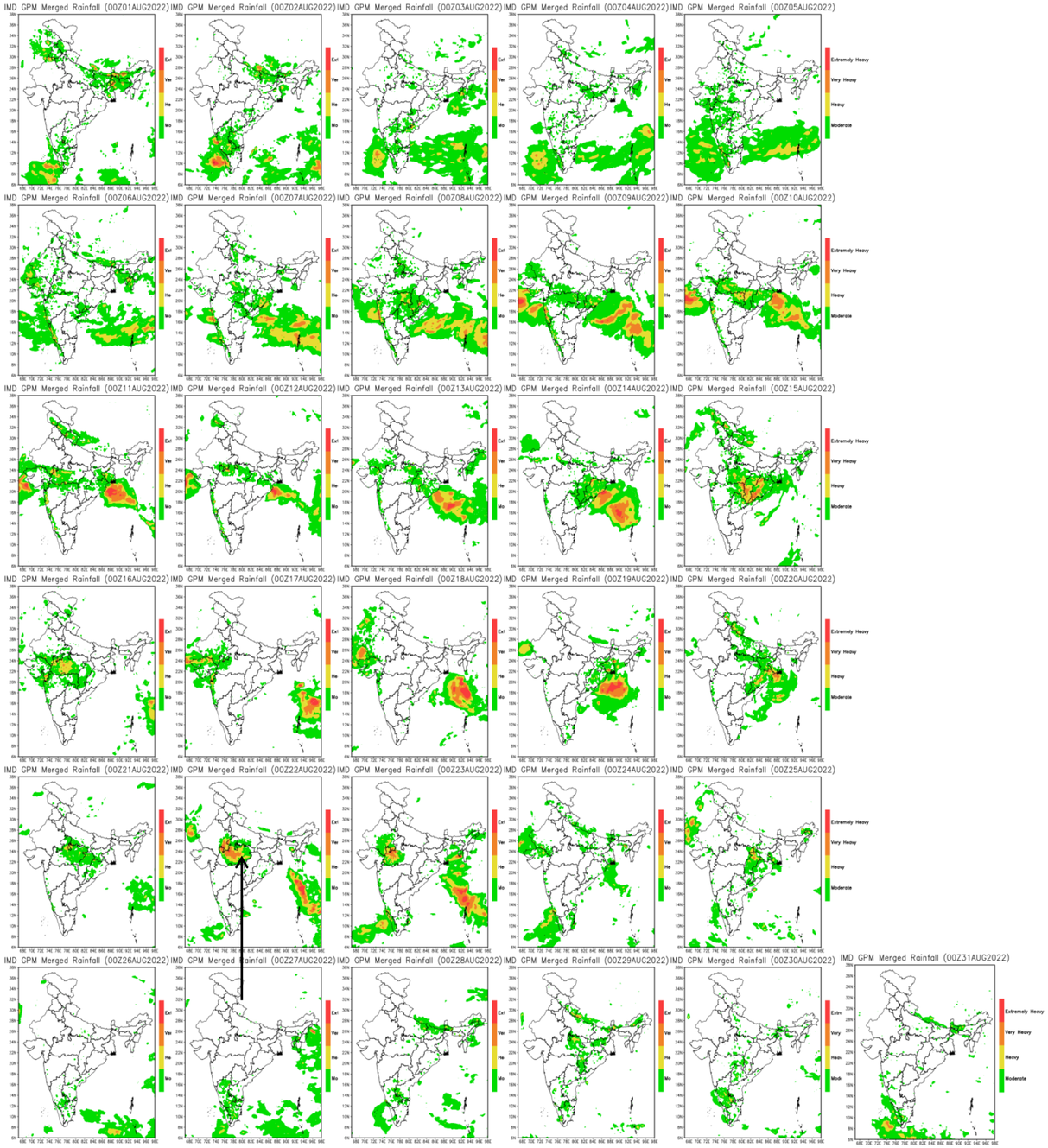


Courtesy: Mukhopadhyay

Passage of a typical convective storm: Radar's view



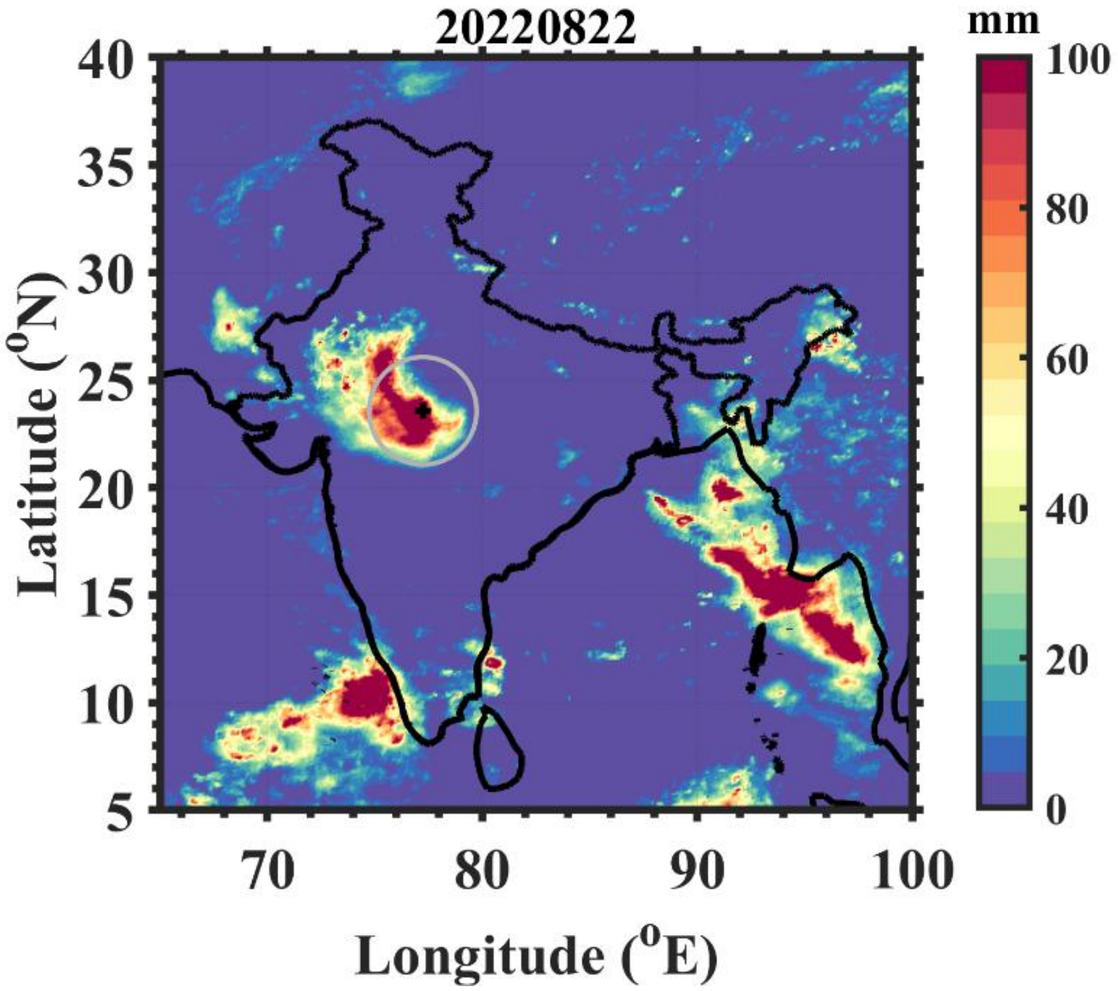
IMD GPM Merged Rainfall –Aug 2022



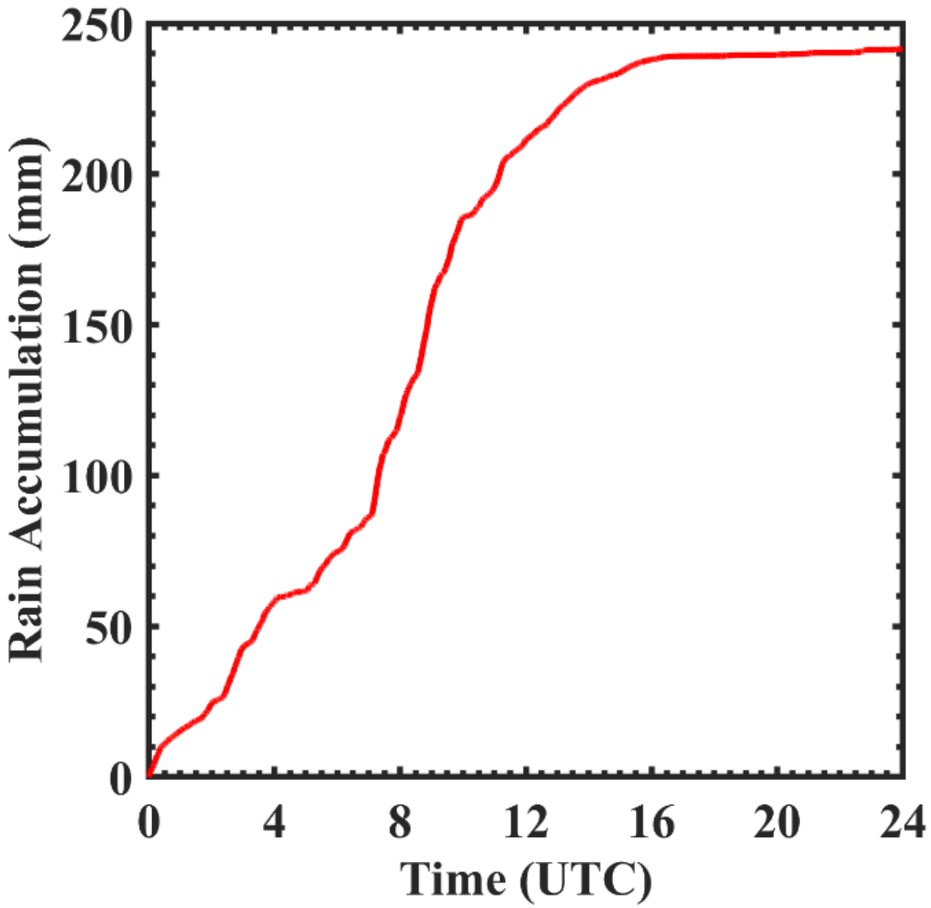
Category	24h rainfall (mm)	Colour in colorbar
Very light	Trace - 2.4	
Light	2.5 – 15.5	
Moderate	15.6 – 64.4	Green
Heavy	64.5 – 115.5	Yellow
Very heavy	115.6 – 204.4	Orange
Extremely heavy	> 204.5	Red

Fig: Spatial distribution of IMD-GPM merged rainfall during August 2022.

GPM-IMERG

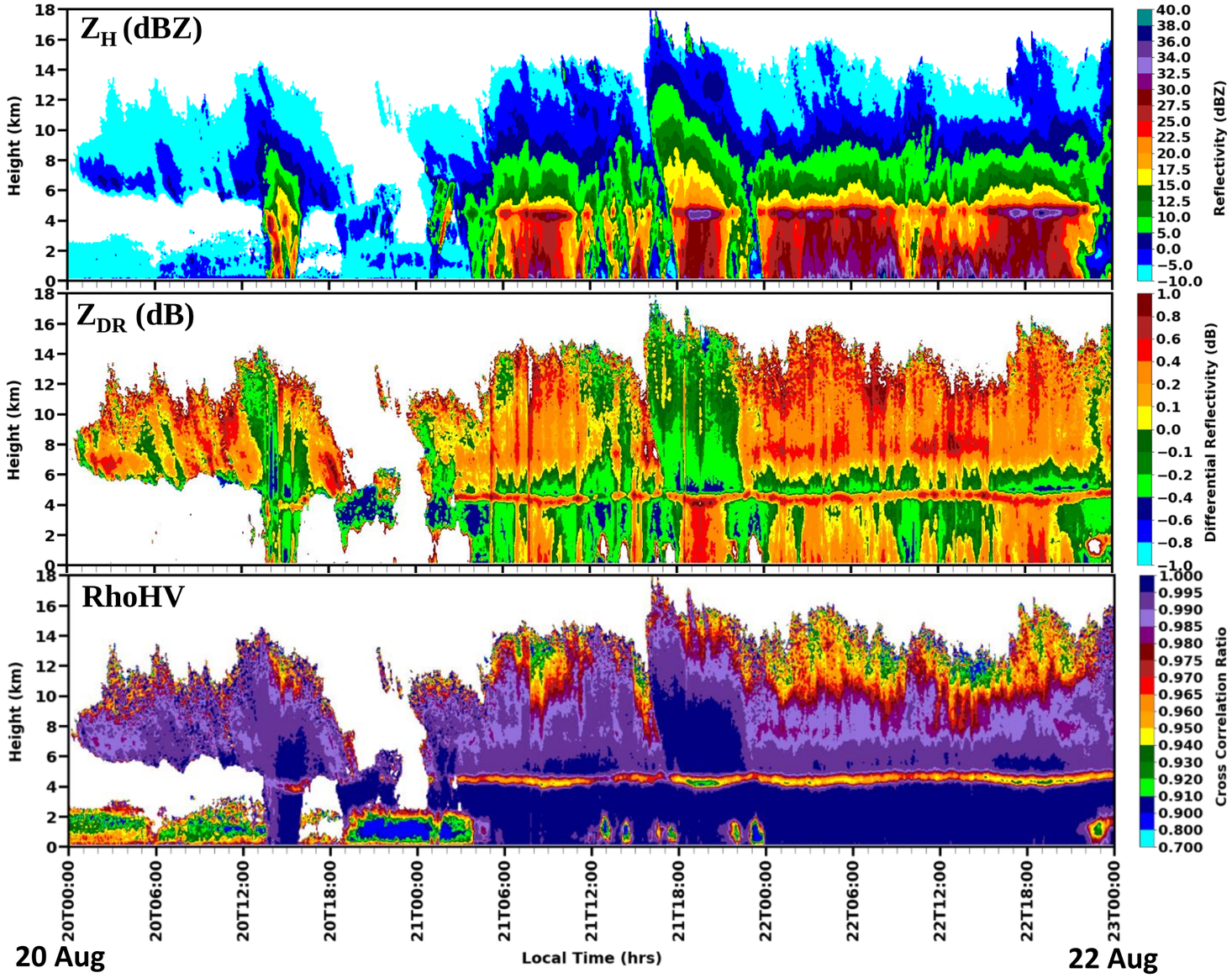


JWD



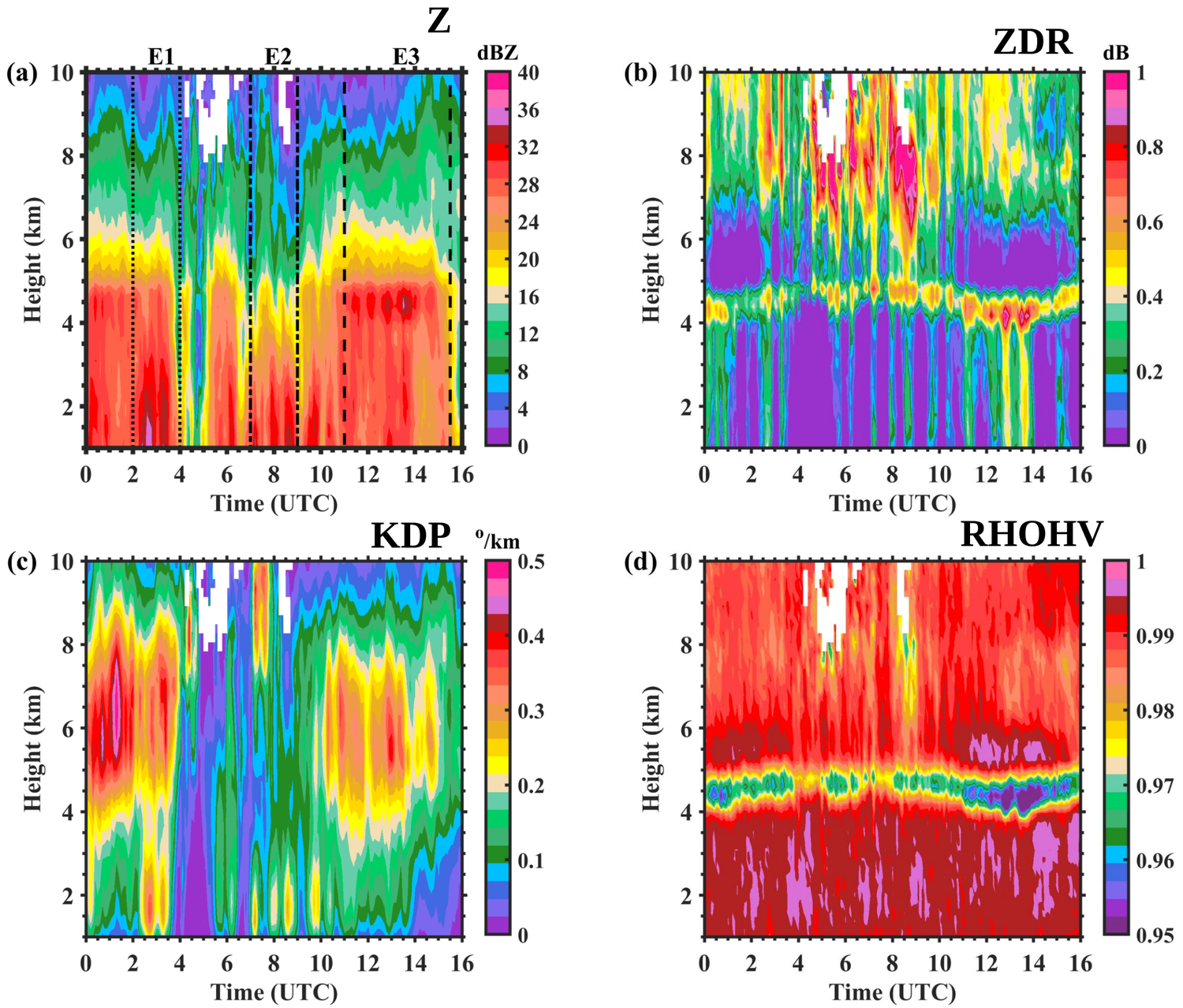
Here, difference in rain accumulation is due to point measurement and gridded averaging

Quasi Vertical Profiles (QVPs) of Polarimetric Data Revealing Temporal Dynamics of Microphysical Processes



- Each figure shows **time-height evolution of QVPs during 72 h (432 profiles)**.
- Well defined **signature of melting layer** (at ~ 5 km) in stratiform cloud is characterized by **elevated Z_H, Z_{DR}, and depressed RhoHV.**
- High-resolution representations of the melting-layer with some undulations is seen.

Understanding precipitation microphysics from dual-pol. Radar observations

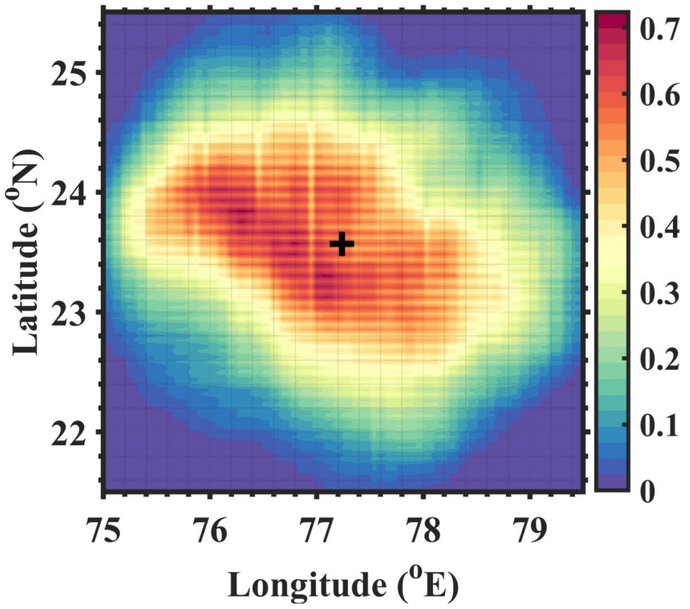


- Radar polarimetric signature can be used to understand the microphysics in rain- and ice-phase.
- Sagging of the melting layer (thickness ~1 km) can be observed between 12 and 14 UTC.
- Dominance of riming above 5 km during 11-16 UTC.
- Aggregation plays a major role in hydrometeor growth between 5 and 8 km during 00-02 UTC.
- Collision-coalescence process is found to associate with the raindrop growth below melting layer
- Presence of warm/shallow rain also evident between 6 and 9 UTC.

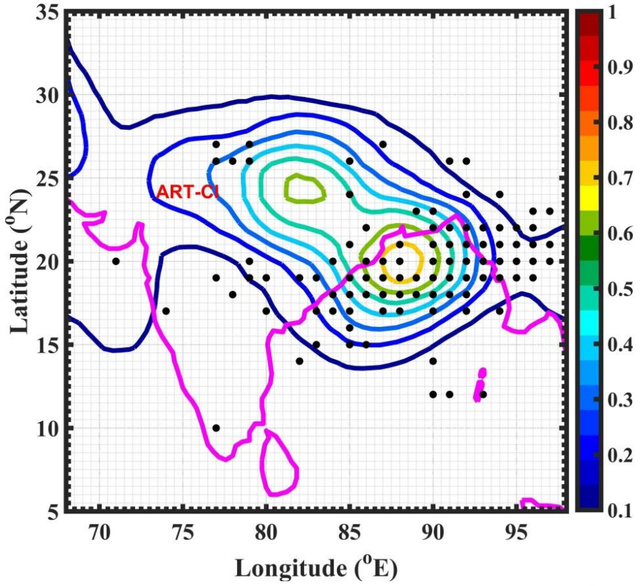
Fig: Quasi-vertical profiles (QVPs) of Z, ZDR, KDP and RHOHV during a typical heavy rainfall event on 22 Aug 2022

Radar observations of Extreme/Heavy rainfall events during Monsoon-2022

Frequency of Extreme Rainfall Events



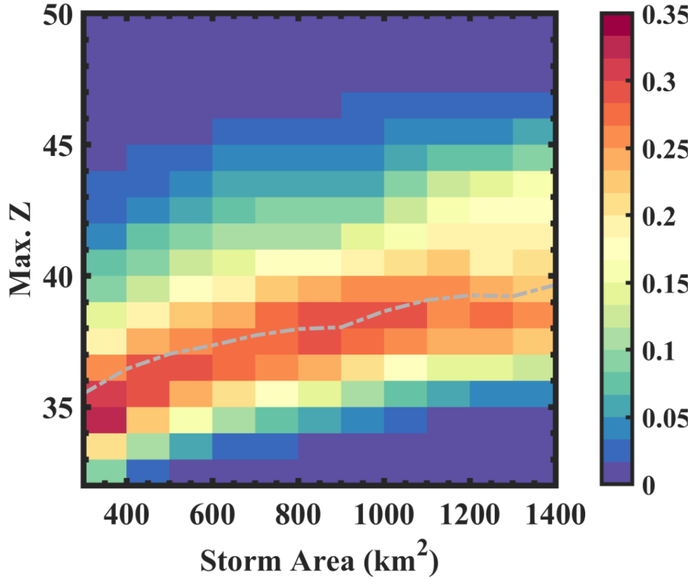
Spatial climatology of monsoon LPSs



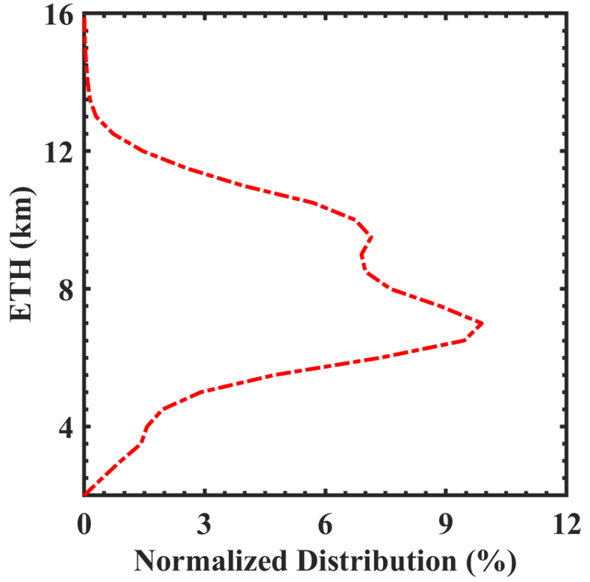
- Higher frequency of extreme rainfall events are observed in the **Southeast to Northwest** direction in the radar domain.
- Frequency of extreme rainfall aligned parallel to monsoon trough region (from southeast to northwest).

- Storms are MCS-scale in the radar domain. The storm area increases with its intensity.
- The vertical extent of the EREs is limited to 12 km over central India.
- Bimodal distribution of EREs: Primary peak at ~7 km (cumulus) and a secondary peak at ~ 10 km (deeper storms)

Storm area vs max. Z

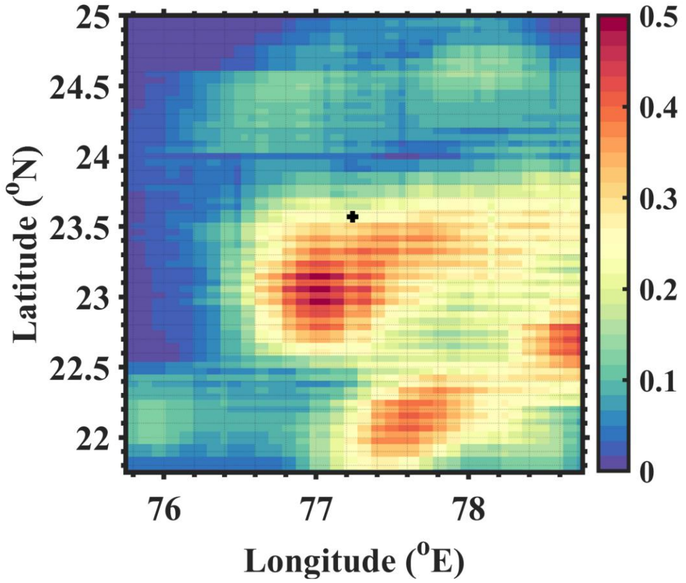


Histogram of storm top height

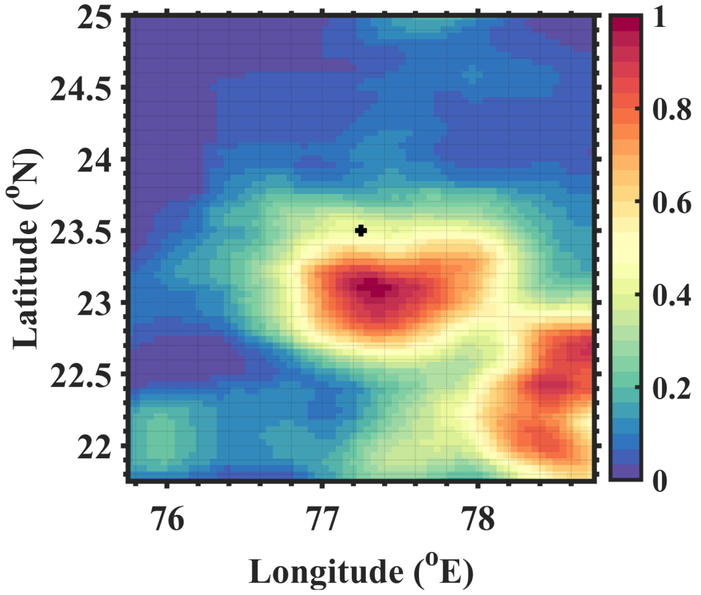


Pre-monsoon convective storms and their association with lightning

Radar-observed storm frequency

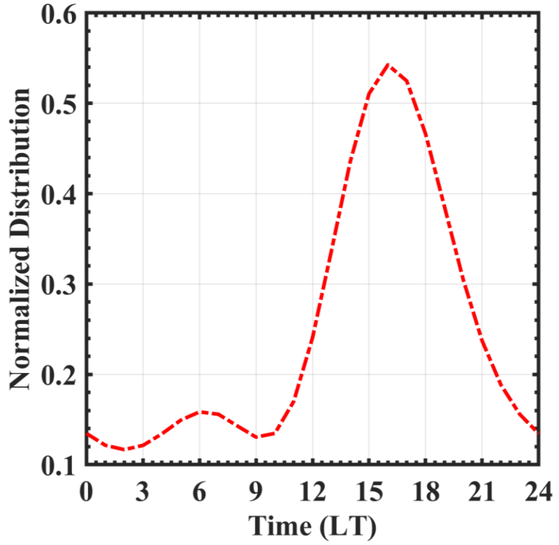


Lightning stroke density over ART-CI

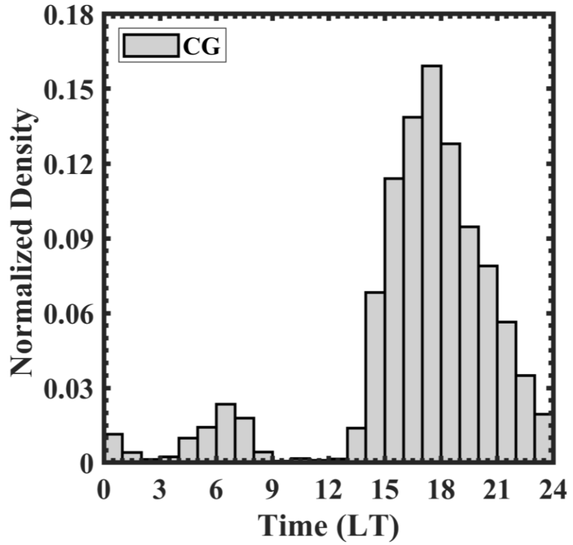


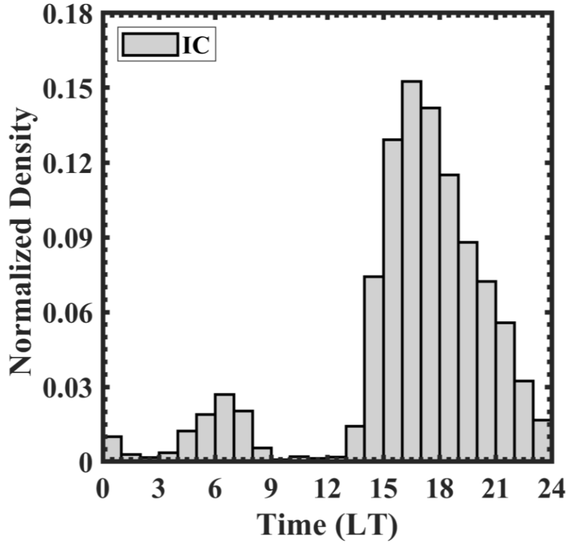
- ✓ High frequency of lightning and storms occur along topographic regions in the SE sector of the radar.
- ✓ The pre-monsoon storms occurs during afternoon hours in the radar domain, associated with surface heating.
- ✓ The diurnal storm occurrence matches with the lightning flash density, indicating the association of pre-monsoon storms with lightning.

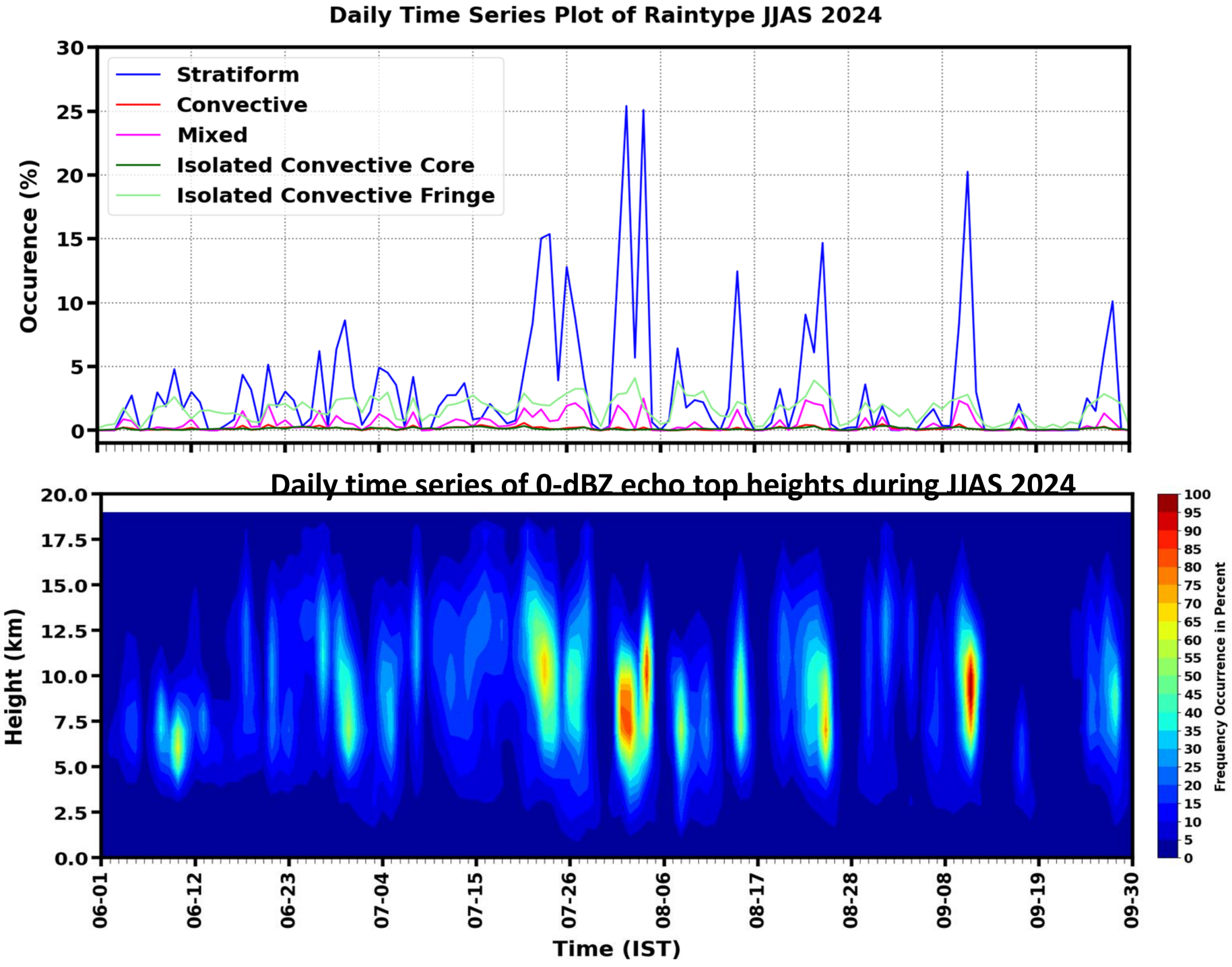
Diurnal cycle of storm frequency



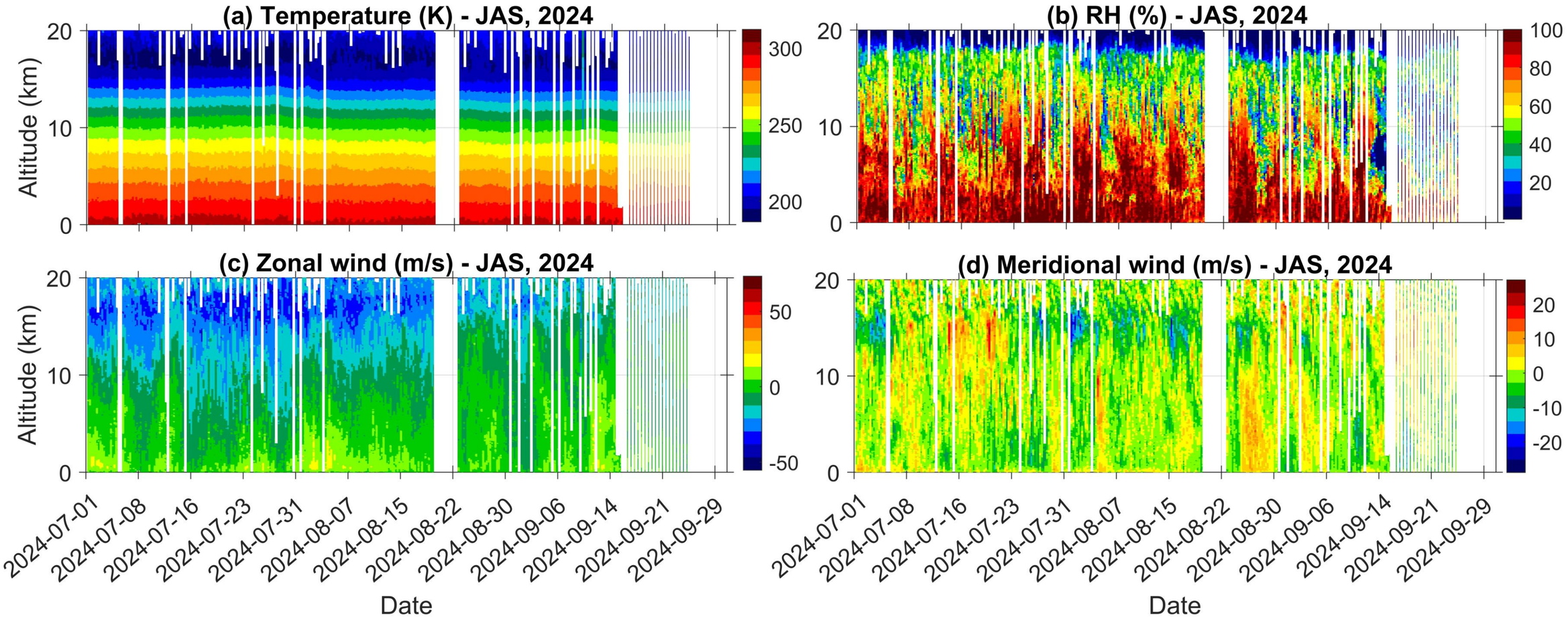
Diurnal variability of cloud-to-ground and intra-cloud lightning





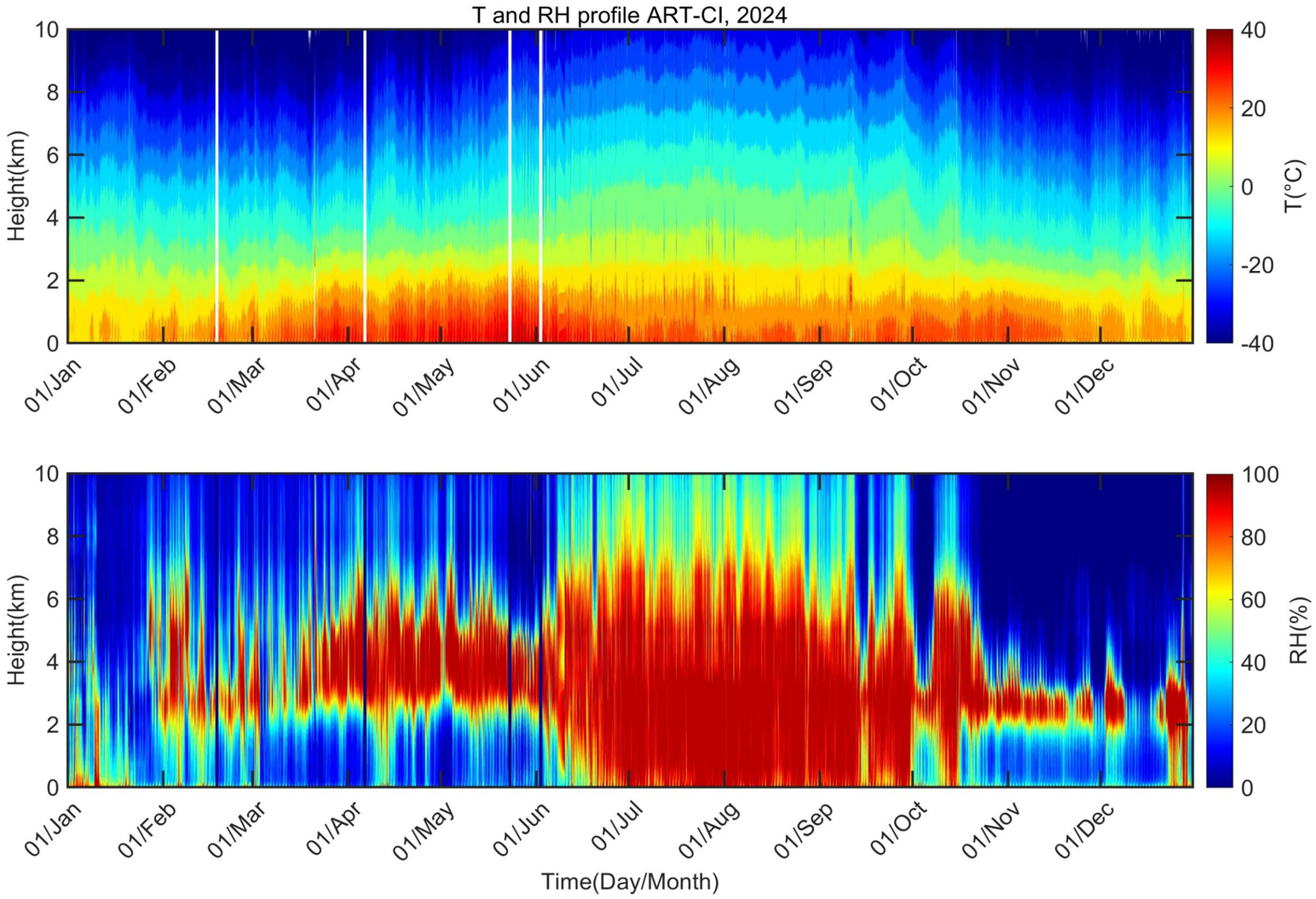

Daily Time Series Plot of Raintype JJAS 2024
Stratiform
Convective
Mixed
Isolated Convective Core
Isolated Convective Fringe
Occurence (%)
30
25
20
15
10
5
0
Daily time series of 0-dBZ echo top heights during JJAS 2024
Height (km)
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
06-01
06-12
06-23
07-04
07-15
07-26
08-06
08-17
08-28
09-08
09-19
09-30
Time (IST)
Frequency Occurrence in Percent
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Time series of upper air data from GPS Radiosonde during Monsoon 2024



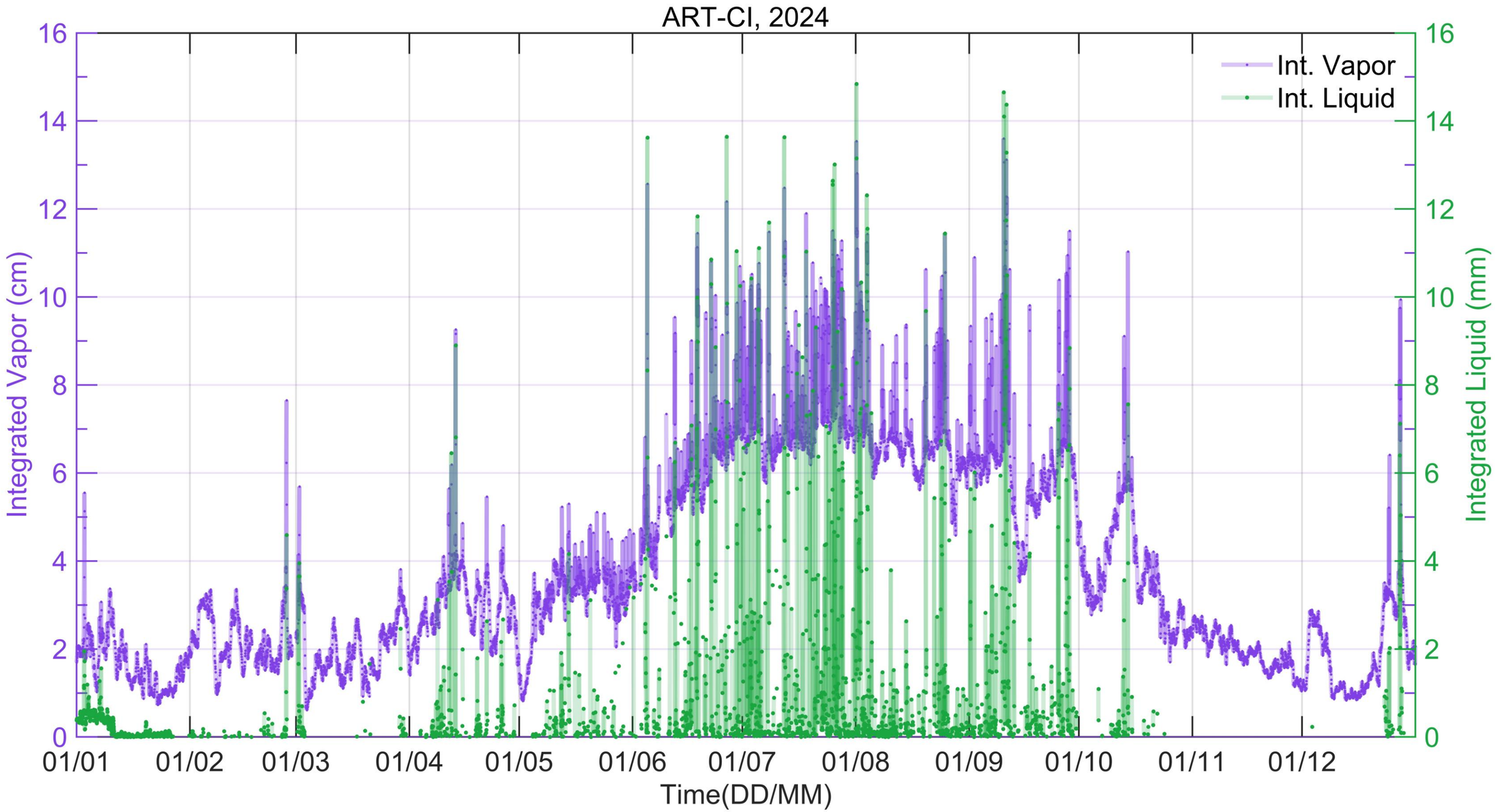
The figure shows the daily observations of (a) temperature, (b) Relative humidity, (c) Zonal wind, and Meridional wind during the monsoon Campaign in 2024. Here, the data was shown daily with four timings (00, 06, 12, and 18 UTC) to follow the time consistency in the plots.

Vertical Profiles of T and RH from Microwave Radiometric Profiler



The figure shows the daily observations of vertical profiles of temperature and Relative humidity from MWR during 2024

Variation of Integrated water vapor and liquid water derived from Microwave Radiometric Profiler



Atmospheric Research Testbeds (ARTs) Project of IITM, MoES

1

Monsoon Core Zone Testbed (3 yrs. OBS)

Established an Atmospheric Research Testbed in Central India for better understanding on processes governing monsoon convection including its diurnal variation and land-atmosphere interactions.

Measure relevant meteorological parameters using state-of-the-art observational systems.

2

Orographic Testbed (~10 yrs. OBS)

Established high altitude cloud physics laboratory (HACPL) for cloud, aerosol, rain microphysics using in-situ and radars over Western Ghats .

Better understand orographic convection and precipitation processes; aerosol-cloud-precipitation interaction processes.

3

Urban Testbed (OBS began Aug 2024)

Establishing a small Radar network in Mumbai to provide high-resolution rainfall (both temporal and spatial) to enable flood warning and nowcasting.

Utilize radar data sets to better understand heavy precipitation processes and to validate satellite retrievals.

Summary

- Atmospheric Research Testbed (ART) facility in core monsoon zone can provide observations for atmospheric process studies
- Advanced observing systems are being added further based on requirements from user community
- Coordinated Monsoon campaigns are planned in collaboration with other Institutions/projects.
- Precipitation process data sets can contribute to WCSSP India, GEWEX/GPEX/AsiaPEX efforts.

Thank you.

Scientific Film on ART Facility

Short English version
https://youtu.be/5qNyvL5NT9A
Long English version
https://youtu.be/GjT4tx1aX5Y