Study of Heavy rainfall over Mumbai region using X-band Radar Network, MESONET Rain-Gauge Observations and WRF-ARW Model

Presenting by

HARI KRISHNA DEVISETTY

Scientist-B

ART-Radar & Satellite Meteorology

Co-Authors: Dr. U.V. Murali Krishna, Dr. N. Nanaji Rao, Mr. Ambuj Kumar Jha, Dr. Subrata Kumar Das, Dr. Kaustav Chakravarty, Dr. Gopinath K, Mr. Manoj D, Mr. Madan M, Dr. G. Pandithurai (Project Director)

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Outline

- Introduction
- Data & Methodology
- Results & Discussions
- Conclusion
- Future Scope of work

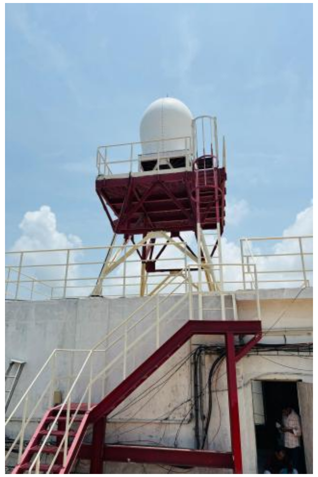
Introduction

- ➢ Extreme Rainfall Challenges in Urban Areas
- ➢ Role of Radar-Based Observations
- ➢ Significance of X-Band Radars
- ➢ Mumbai’s First Urban Radar Network
- ➢ WRF-ARW Model for heavy Rainfall Simulation

Data & Methodology

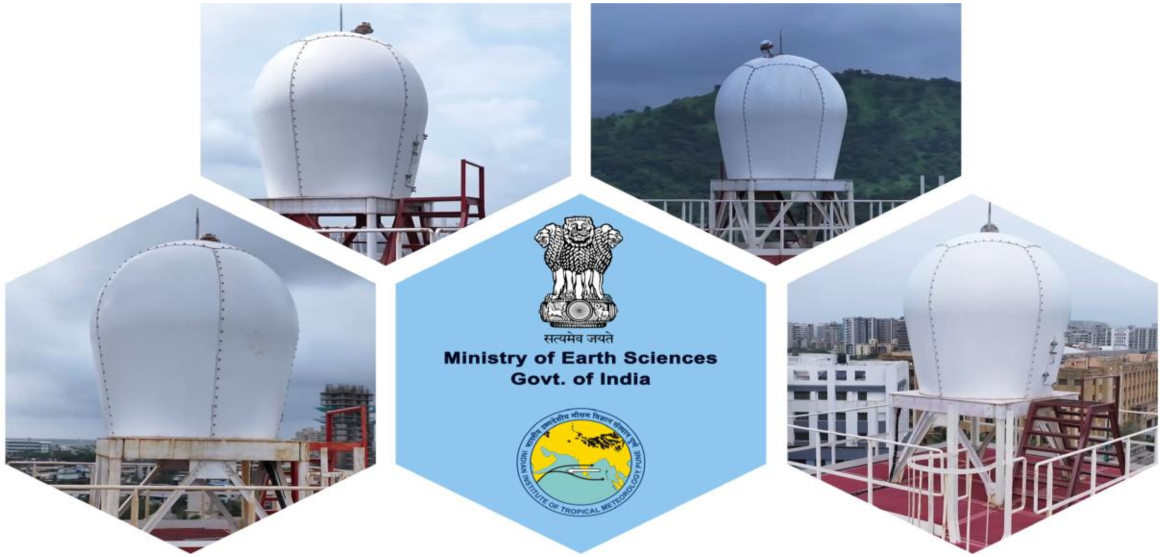
- X-band Radar Network
- MESONET Rain-gauge Network
- WRF-ARW V4.3
- ERA5 Reanalysis data
- Satellite data (GPM & EUMETSAT)
- ILLN Data
- Disdrometer data

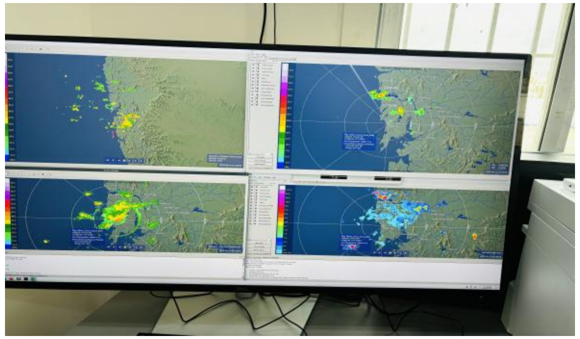


Mumbai’s First Urban Radar Network

- The Indian Institute of Tropical Meteorology (IITM), Pune, launched India's first urban radar network in Mumbai on September 14, 2024, comprising four X-band radars with a collective coverage of 60-120km each.

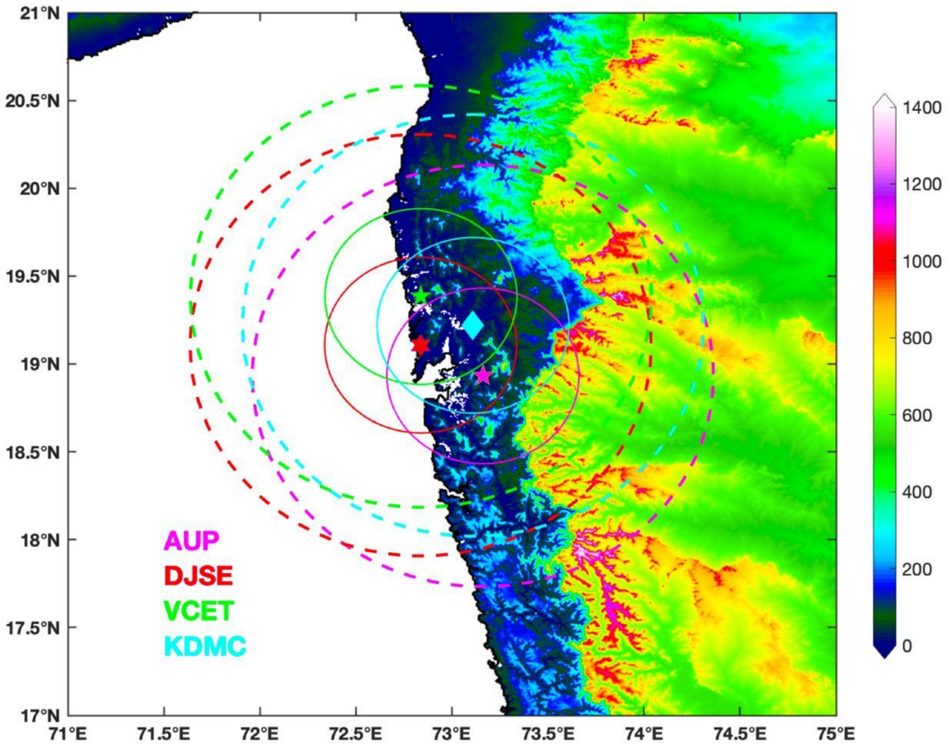




Technical Specifications and Topography

- MESO-scale rain gauge NETwork (MESONET) : This initiative integrates rainfall data from the IMD and the MCGM, offering live rainfall measurements from 139 sites across the city.

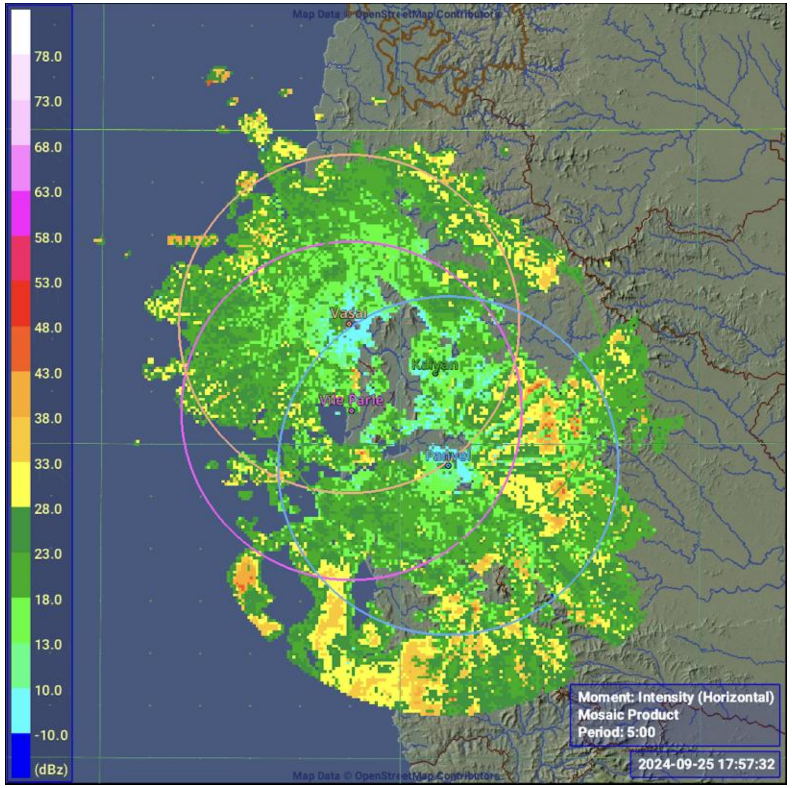
- MOSAIC (Multiple Radar and Sensor Integration for Total Coverage) for all four radars gridded at 2 Kms above MSL and generated.

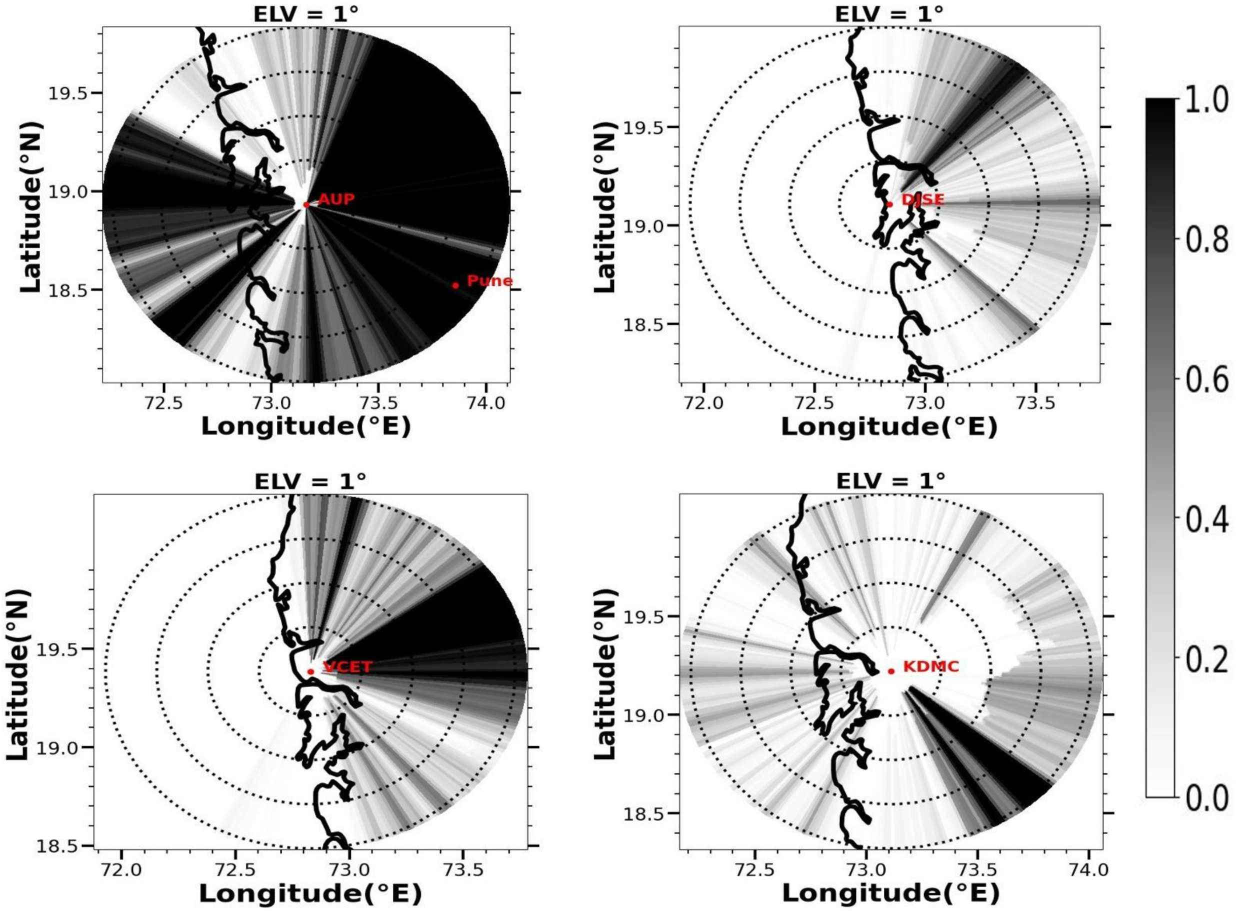


Center Frequency	9.425 GHz, 9.450 GHz, 9.475GHz, 9.5GHz
Wavelength	3.158 cm - 3.183 cm
Range	60 km max unambiguous (maximum Range 120 km)
Pulse width	Short 2μs: 0-15km Long 100μs: 15-120km
Range resolution	37.5m-50m
Pulse Repetition Frequency (PRF)	Short pulse 2μs:250Hz to 2510Hz Long pulse 100μs: 250Hz to 1500Hz
Software and data analysis	EDGE (Enterprise Doppler Graphics Environment), M/s EEC, USA.
Transmitter type	SSPA 100W-H & 100W-V. Actual measurement of Tx power ~160W per channel.
Beam width	2 degrees
Range bins	2400 with 50m resolution

Importance of Urban Radar Network and MOSAIC product

- MOSAIC (Multiple Radar and Sensor Integration for Total Coverage) : Reflectivity (dBZ).





WRF-ARW Model Initialization and Details

Enables the simulation of **mesoscale and convective weather systems**, which are critical for understanding and forecasting heavy rainfall events (Kumar et al., 2012).

Advanced physics options, improve the model's accuracy in extreme weather scenarios (Hong et al., 2006).

High-resolution configurations (e.g., 1 km, 3 km or 9 km grids) allow for **better representation of urban-induced meteorological effects**, including localized convective systems (Liu et al., 2017).

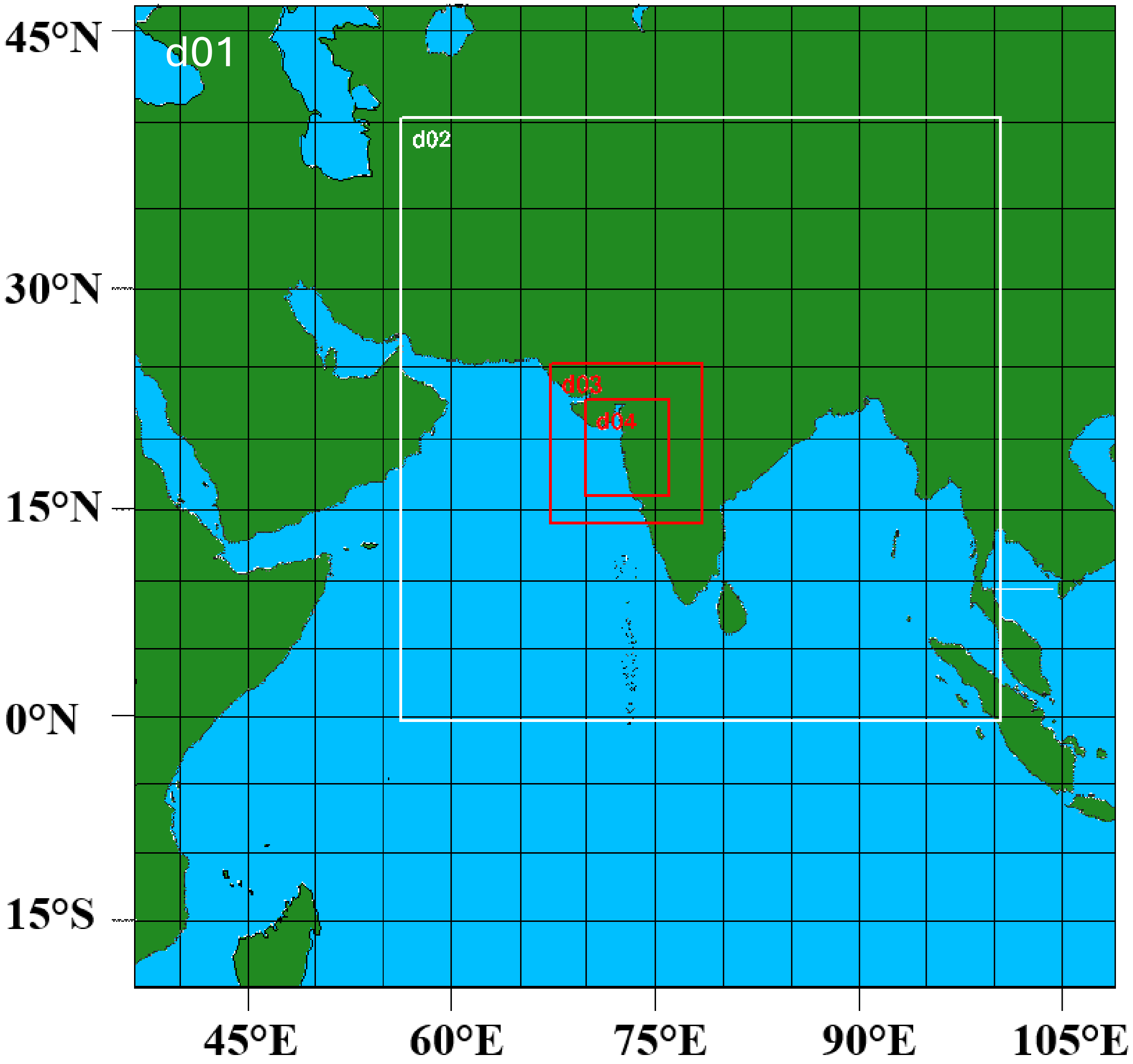
Model Configuration and Physics Schemes

S.No	Model Component	Details
1.	Version	WRF ARW V4.3
2.	Type	Non Hydrostatic
3.	Vertical Resolution	40 Vertical levels
4.	Horizontal Resolutions	27, 9, 3 and 1 km
5.	Long Wave Radiation	RRTMG
6.	Short Wave Radiation	RRTMG
7.	Cumulus Convection	Kain–Fritsch2 (KF2)
8.	Planetary Boundary Layer	Yonsei University (YSU)
9.	Micro Physics	Kessler
10.	Land Surface	Unified Noah Land Surface Model
11.	Initial and boundary conditions	NCEP-GFS at 0.25°× 0.25° horizontal resolution
12.	Model's Topography and terrain	United States Geological Survey (USGS)

WRF-ARW Model Domain Configuration

➢ WRF ARW is 1:3 Nested Domains.

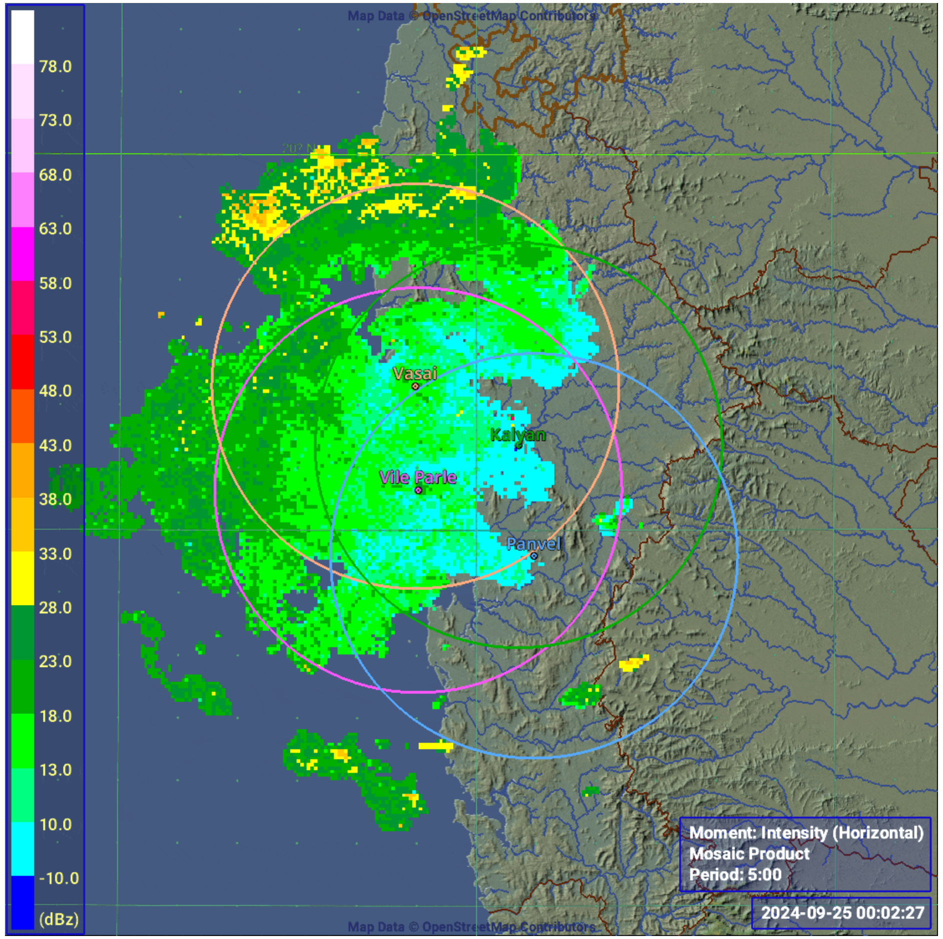
- Domain 01=27 km
- Domain 02=9 km
- Domain 03=3 km
- Domain 04=1 km

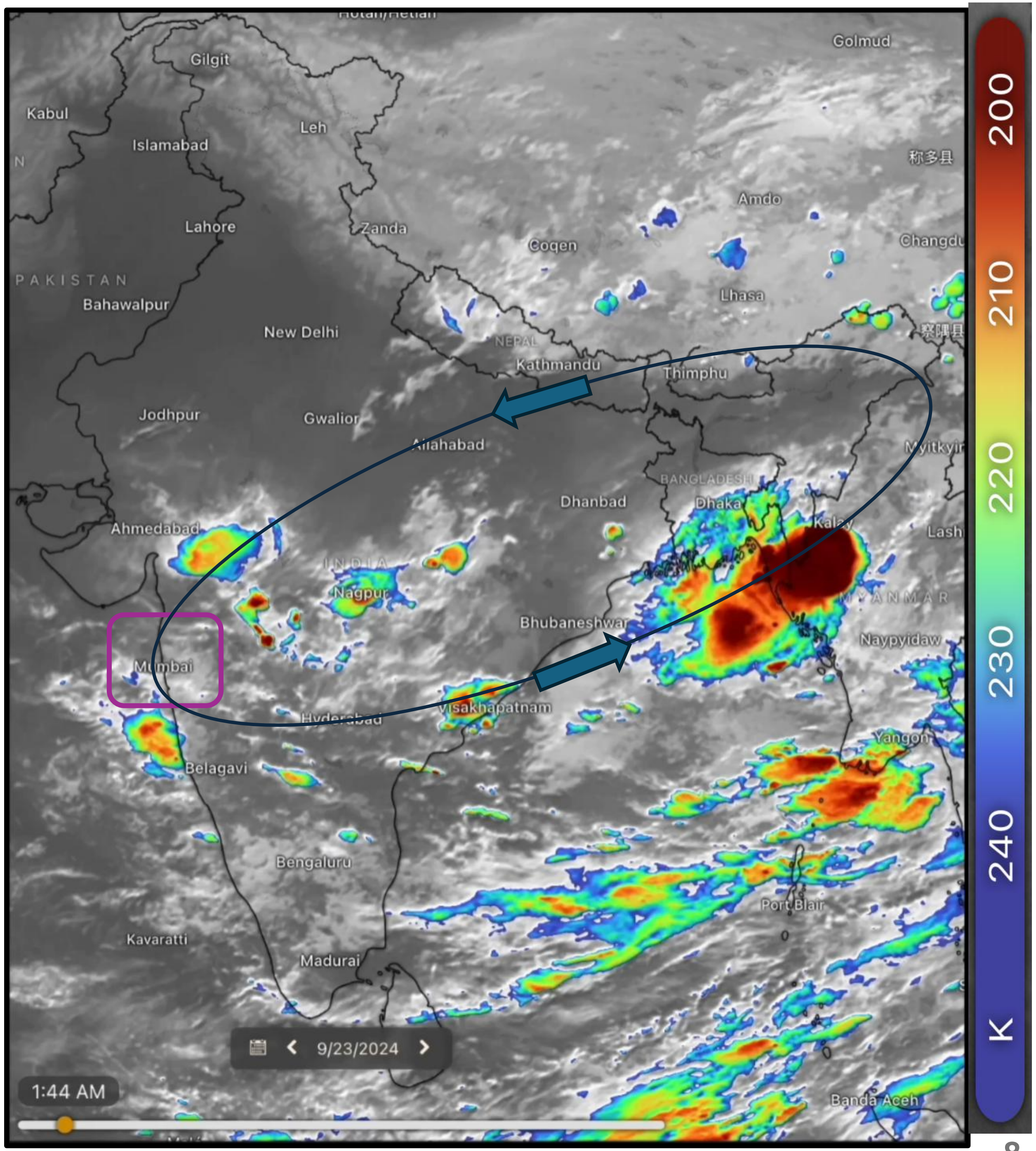


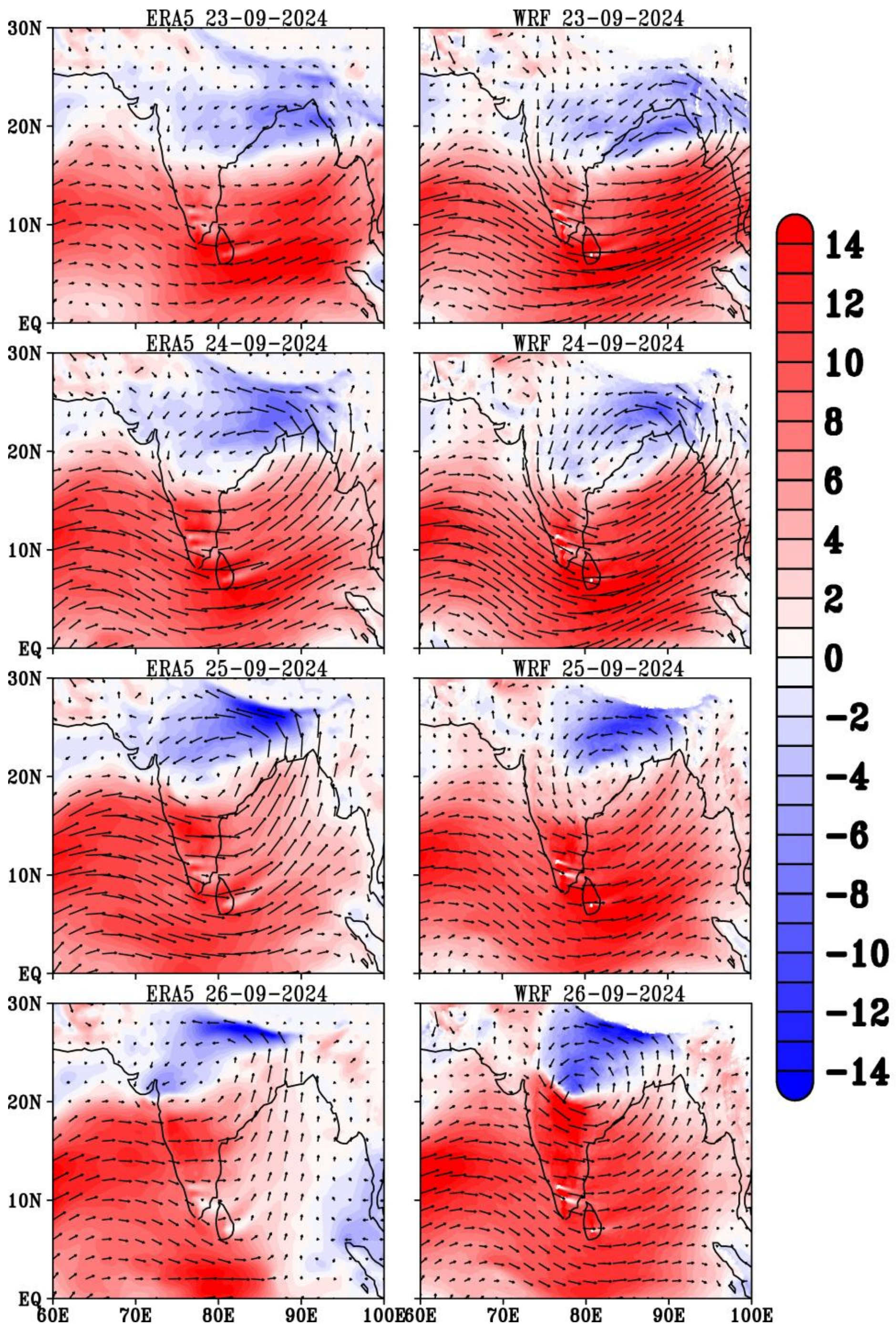
Domains for this study are used in the WRF-ARW Model.

Results & Discussions

- Heavy rainfall observed on 25th September- MOSAIC Reflectivity (Zh in dBz), 5 minutes temporal resolution and EUMETSAT Brightness Temperature in Kelvin, hourly temporal resolution.







Zonal wind speed (shading) and wind direction (vectors) from ERA5 and Model

- Low Pressure System initially formed over Bay of Bengal (N-E) region and moving towards the study region.
- Zonal winds and directions of ERA5 & ARW simulations are well matching each other during 23-26, September 2024 over the Indian region.
- Distributed rainfall observed at different places over India.

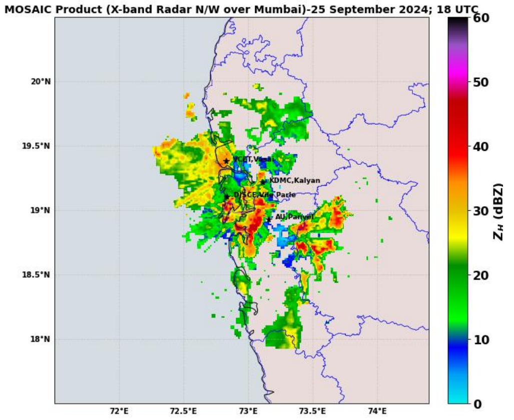
MOSAIC products of X-band Radar Network over Mumbai

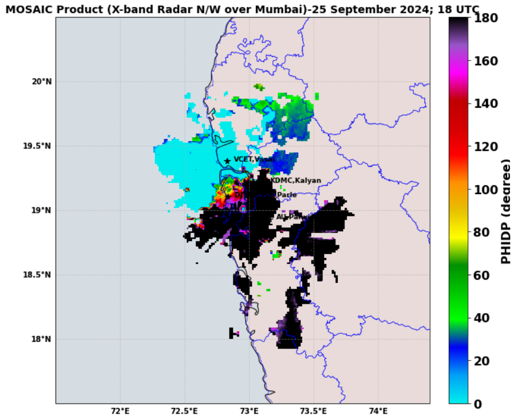
- **Reflectivity (Zh):** Good for determining precipitation intensity but does not distinguish hydrometeor type well.

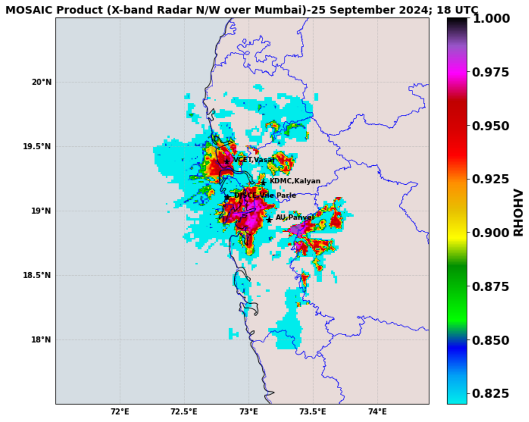
- **Differential Reflectivity (ZDR):** Useful for detecting raindrop size and shape (higher in large rain, near zero in hail).

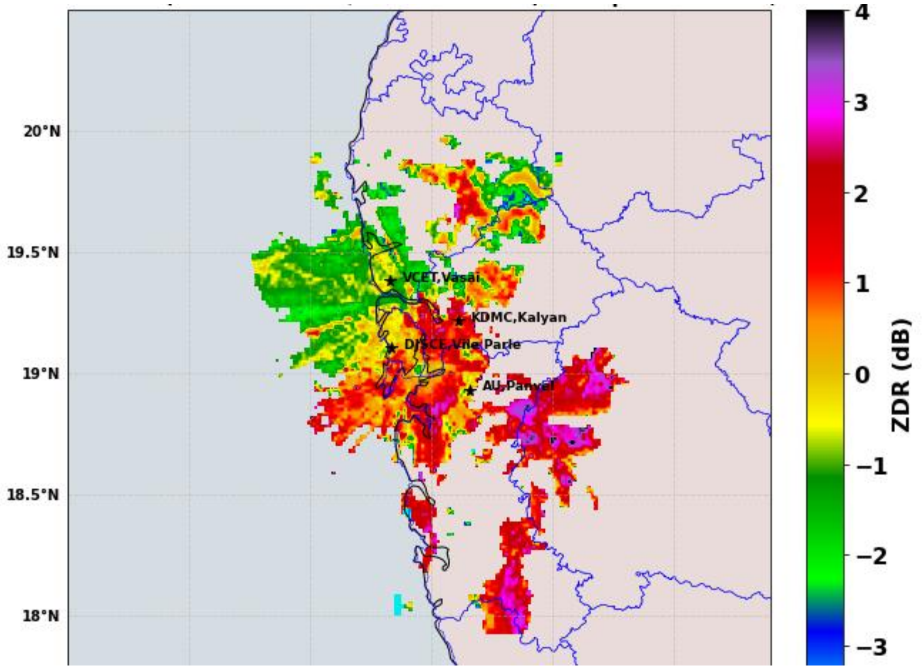
- **Correlation Coefficient (RHOHV):** Identifies mixed-phase precipitation (low in melting snow, high in dry snow and rain).

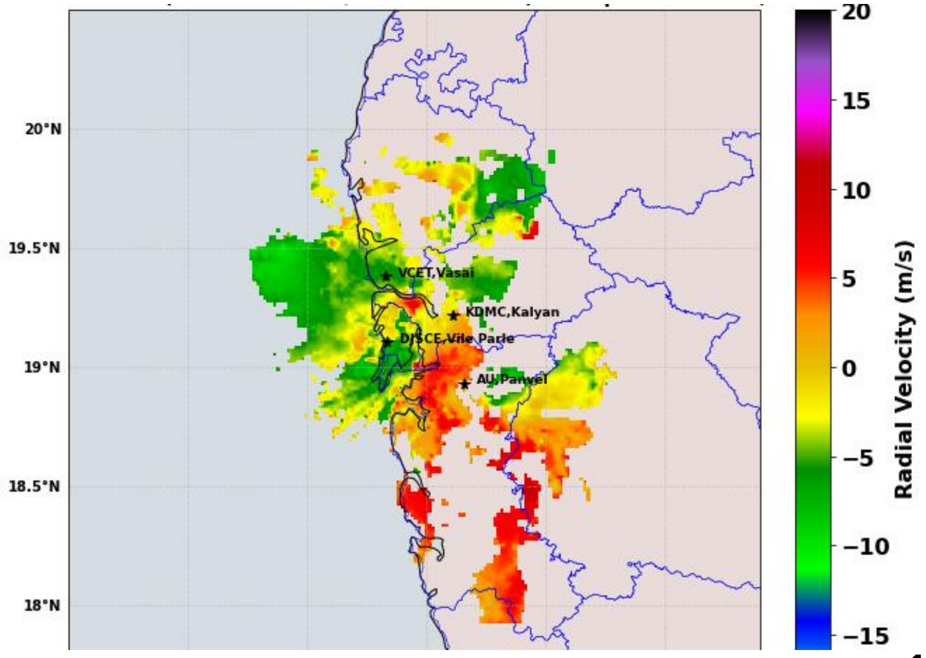
- **Differential Phase (PHIDP):** Best for estimating rain rate and detecting melting layers.



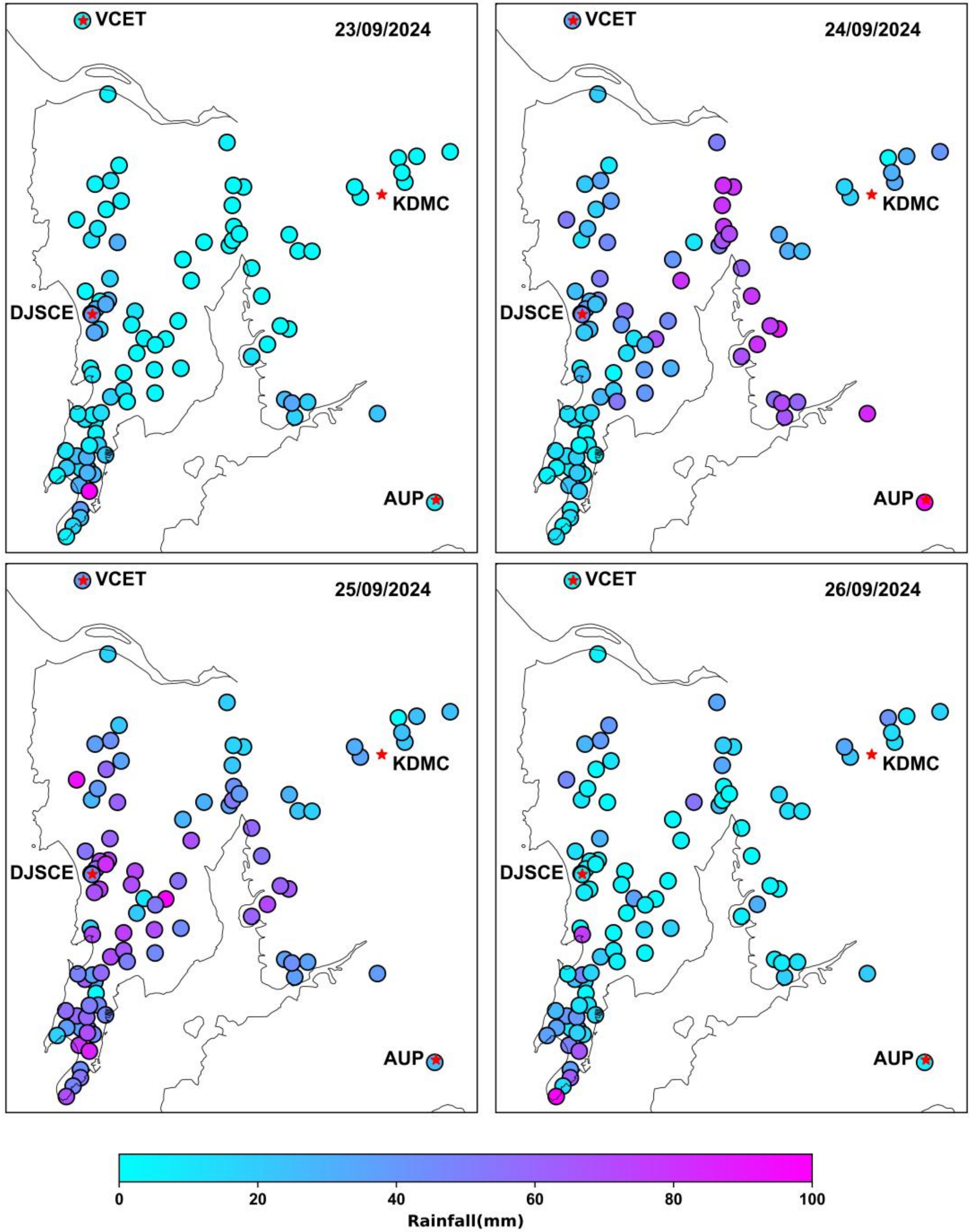




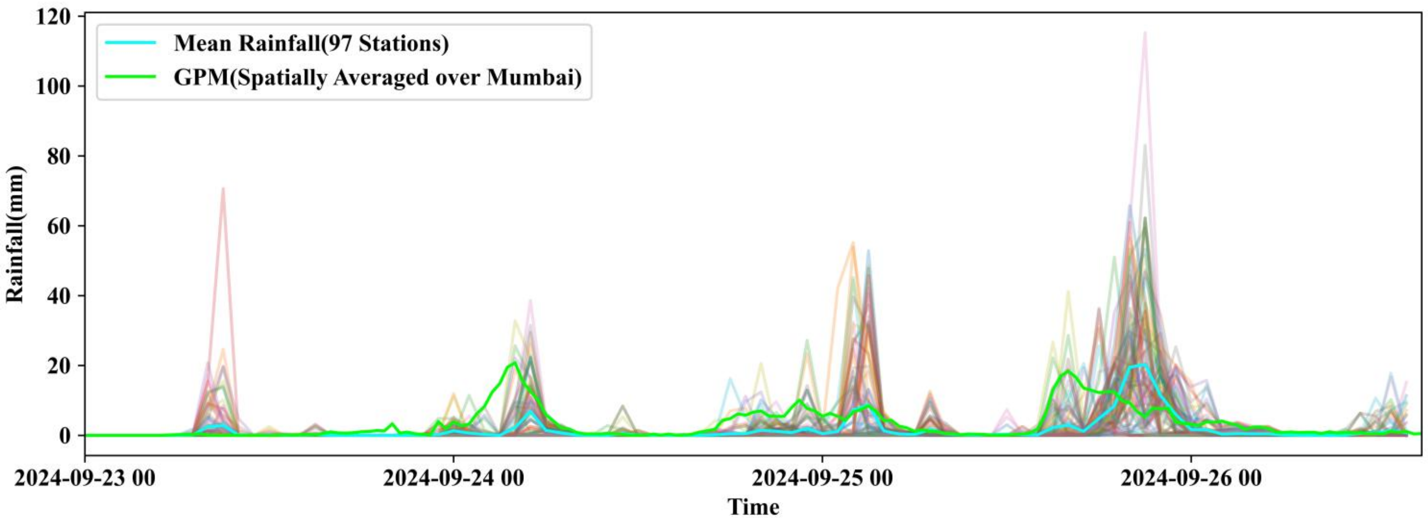




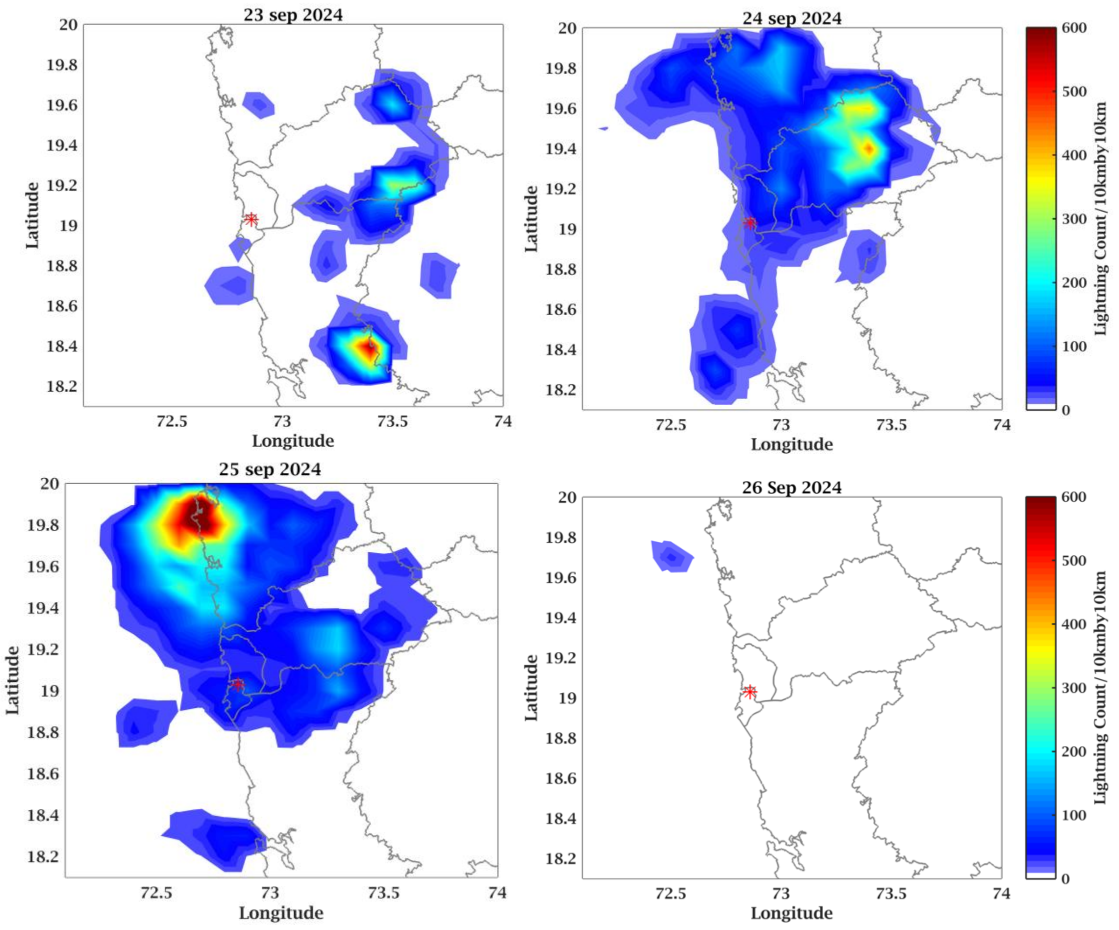
Spatial Rainfall Distribution over Mumbai-MESONET Rain-gauge N/w and GPM IMERG

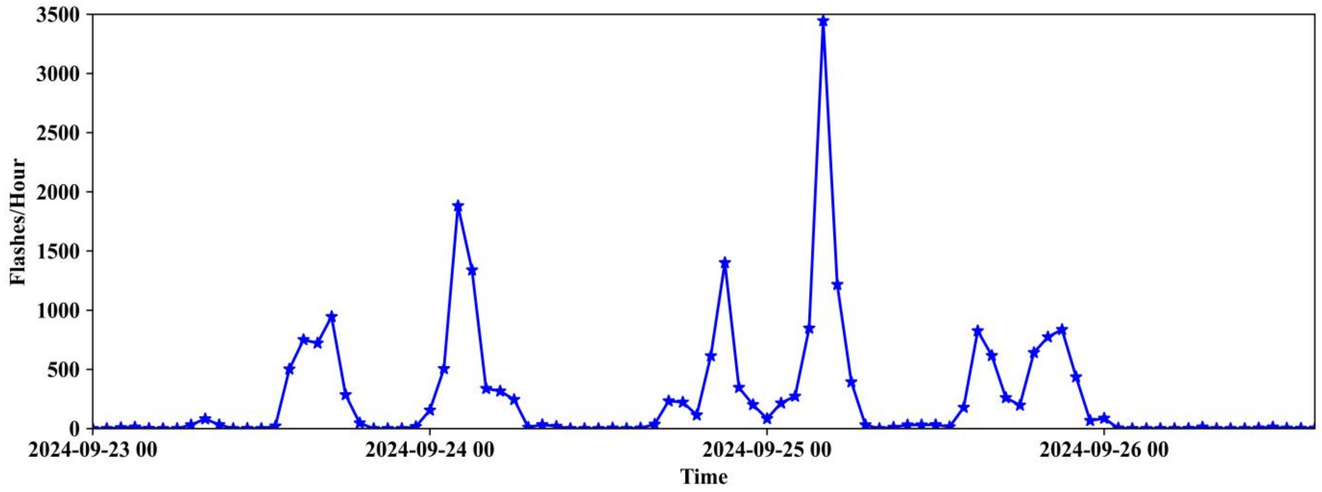


- **Ground based rainfall is well complimented by satellite based spatially averaged rainfall and both are in good agreement in pattern.**



Lightning Distribution over Study region



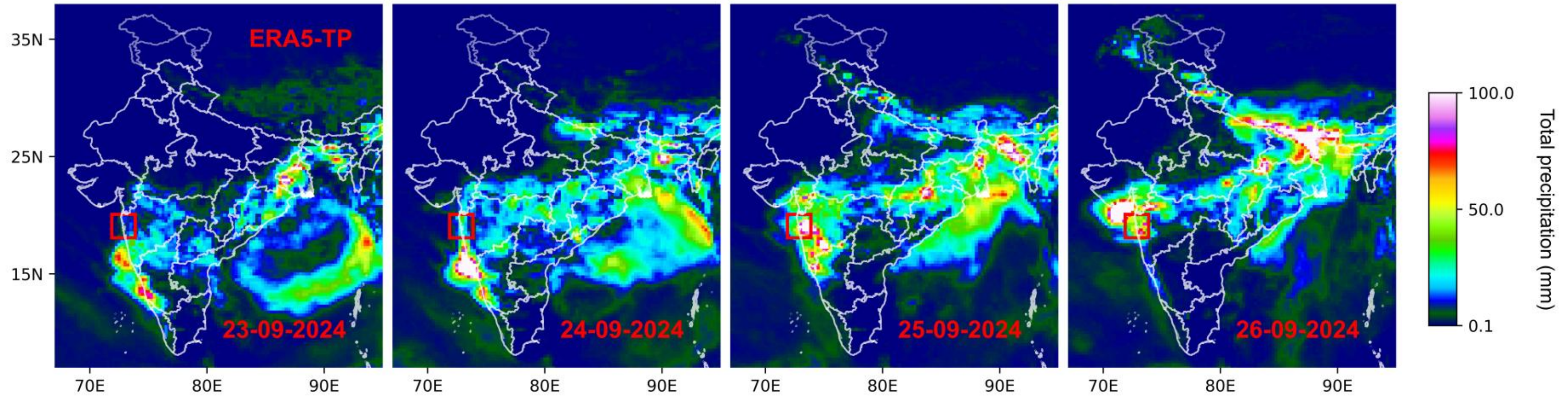


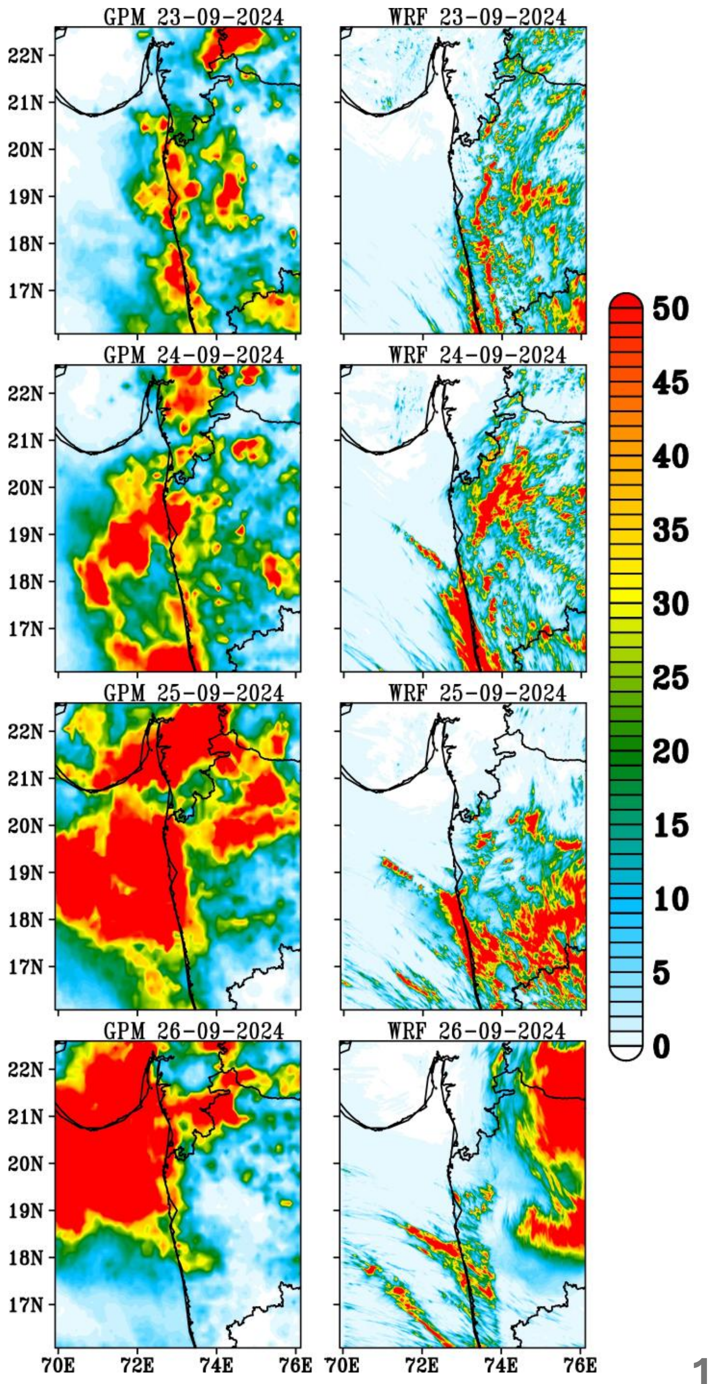
Date	Maximum Acc. Rainfall over Mumbai station (mm)	Total lightning strikes
23/09/2024	91.6 (MCGM1)	3462
24/09/2024	126 (Amity University)	8029
25/09/2024	232.35 (Nward)	11471
26/09/2024	28.93 (Pr. Thackeray Natya Mandir)	130

Rainfall Distribution : WRF-ARW Model simulations, GPM & ERA5

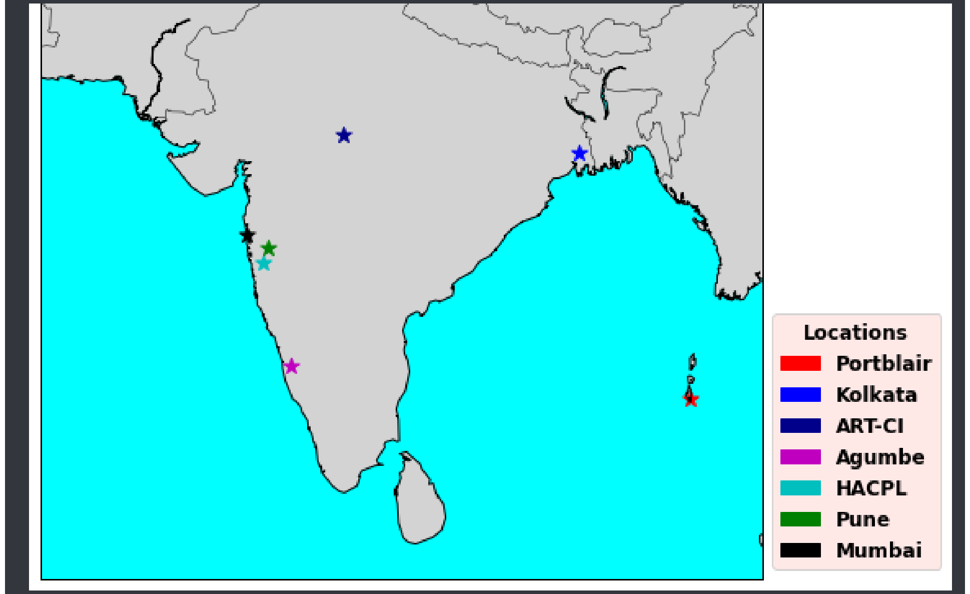
- **Model simulated accumulated rainfall (mm/day) and compared with GPM rainfall (mm/day) & ERA5 (mm/day) .**

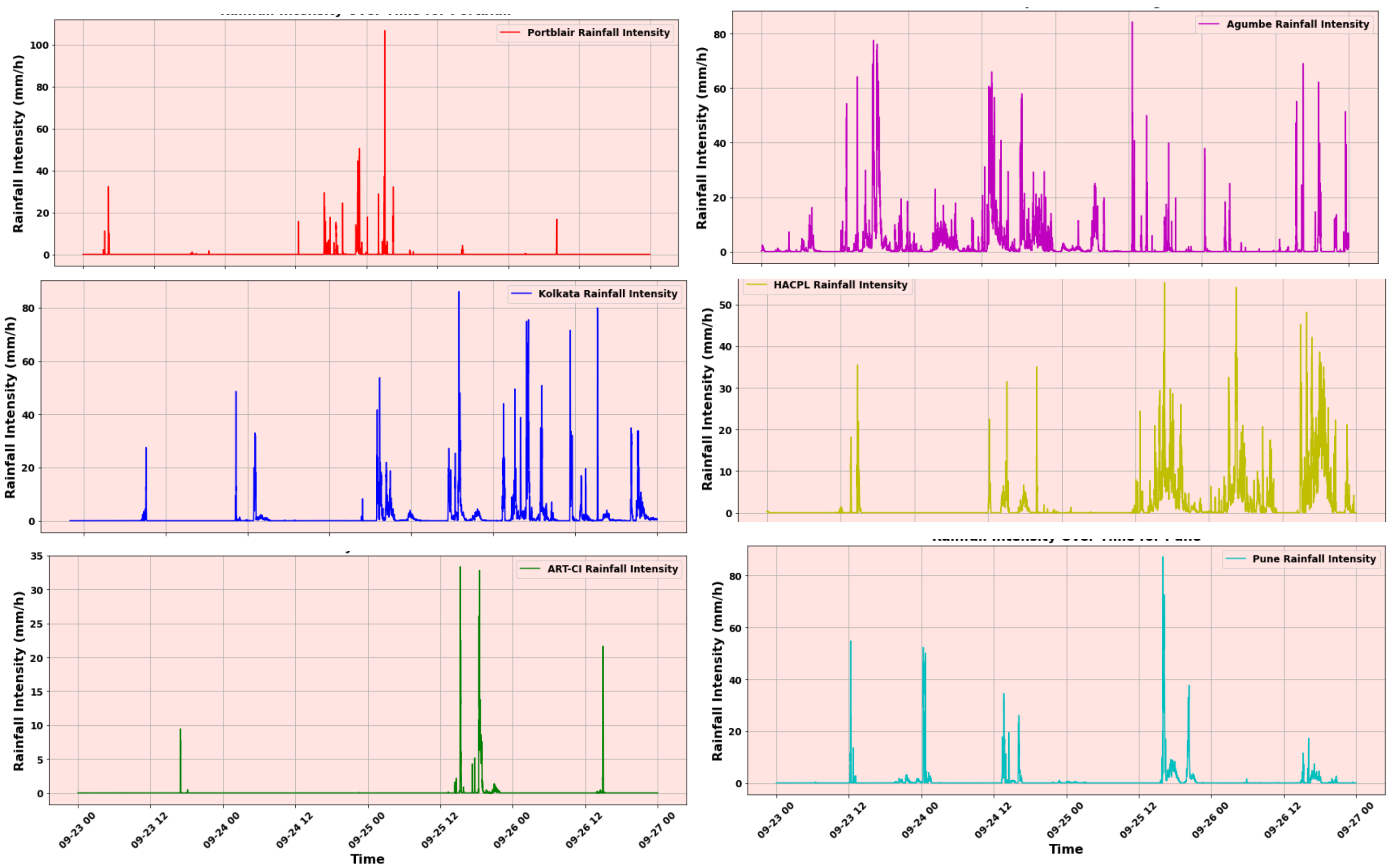
- **Model reasonably predicts the intensity of rainfall, but we have noticed that the there is a mismatch of spatial distribution of rainfall compared with GPM & ERA5.**





Distributed rainfall measurements at different sites over India using Disdrometer Network





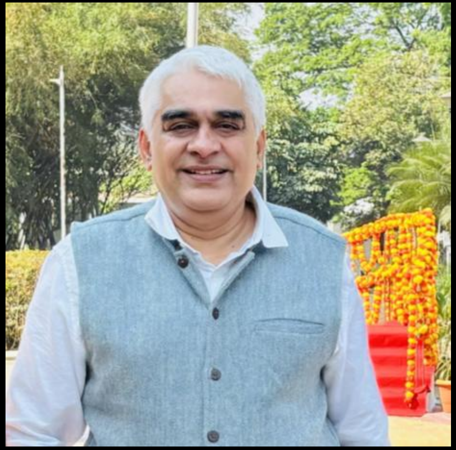
Date	Port-Blair	Kolkata	ART-CI	Agumbe	HACPL	Pune
2024-09-23	1.8	1.4	0.55	81.74	5.1	5.5
2024-09-24	15.3	7.2	0.1	115.4	13.4	19.8
2024-09-25	10.9	41.4	9.8	34.2	49.2	36.9
2024-09-26	1	76	0.75	35.1	115.2	6.6
2024-09-27	0.1	1.4	8.8	22.5	54.35	4.65

Conclusion

- The multi-radar urban network effectively eliminates blind spots caused by skyscrapers, improving the accuracy of rainfall monitoring and nowcasting in densely populated cities like Mumbai.
- Analysis of the September 23–26, 2024, event showed very heavy rainfall exceeding 200 mm/hr, ~11471 lightning strikes driven by convective cells embedded in LPS, with enhanced lightning activity closely linked to intense precipitation.
- Satellite data and ERA5 showed the influence of a LPS, contributing to widespread heavy rainfall across the region.
- WRF-ARW simulations aligned well with zonal winds and the LPS, reinforcing its role in large-scale atmospheric analysis, but we noticed that a mismatch with GPM & ERA5 rainfall.

Future Scope of Work

- This study presents preliminary findings based on model simulations and observations. Moving forward, we will conduct detailed parameterization and model configuration to identify the causes of discrepancies over the Western Ghats (WG) and the ocean.
- Real-time observations from the X-band radar network and MESONET rain-gauge network over Mumbai will be assimilated into the model.
- The macro- and microphysical characteristics of storms will be analyzed using polarimetric data from the X-band radar MOSAIC product.



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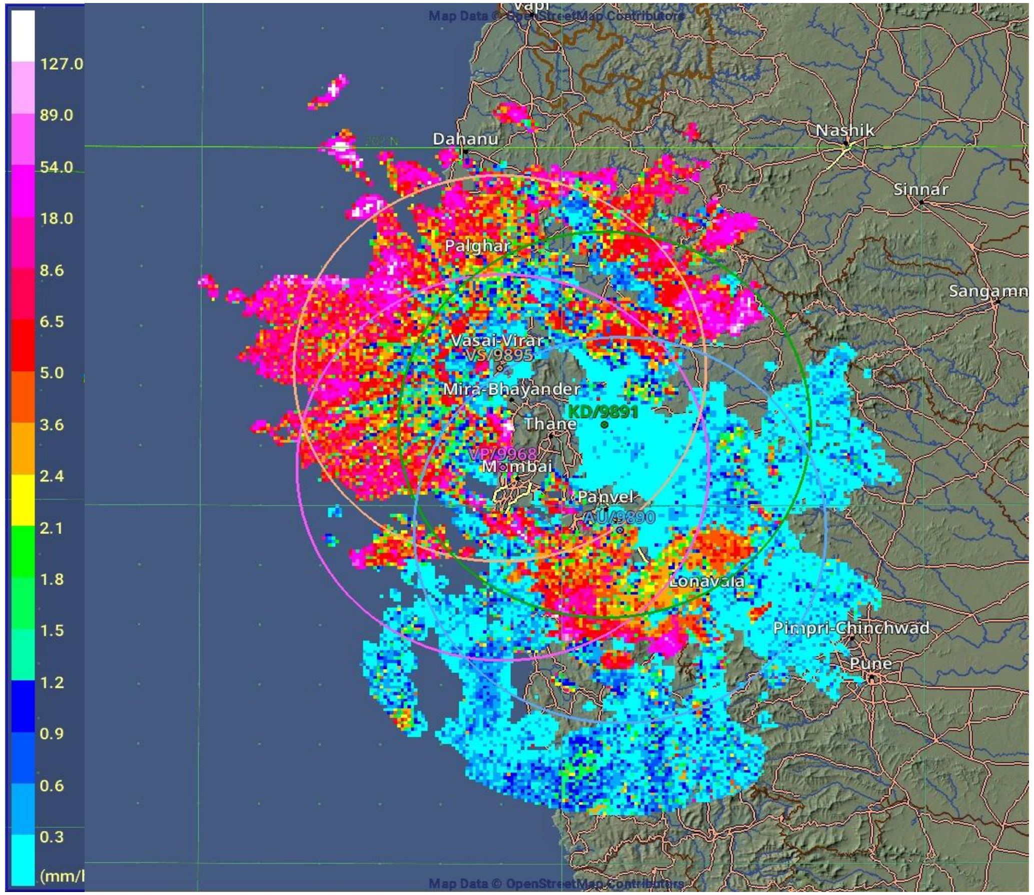
- IWM8 organizers and LOC greatly acknowledged.

Important References

- Bringi, V. N., & Chandrasekar, V. (2001). *Polarimetric Doppler Weather Radar: Principles and Applications.* Cambridge University Press.
- Ryzhkov, A., Pinsky, M., Pokrovsky, A., & Khain, A. (2011). Polarimetric radar observation operator for a cloud model with spectral microphysics. *Journal of Applied Meteorology and Climatology, 50*(4), 873-894.
- Doviak, R. J., & Zrnić, D. S. (1993). *Doppler Radar and Weather Observations.* Academic Press.
- National Severe Storms Laboratory (NSSL) - Dual-Polarization Radar Applications. https://www.nssl.noaa.gov/
- Soo on....

Rainfall retrieval using Z



$$Z = aR^b$$

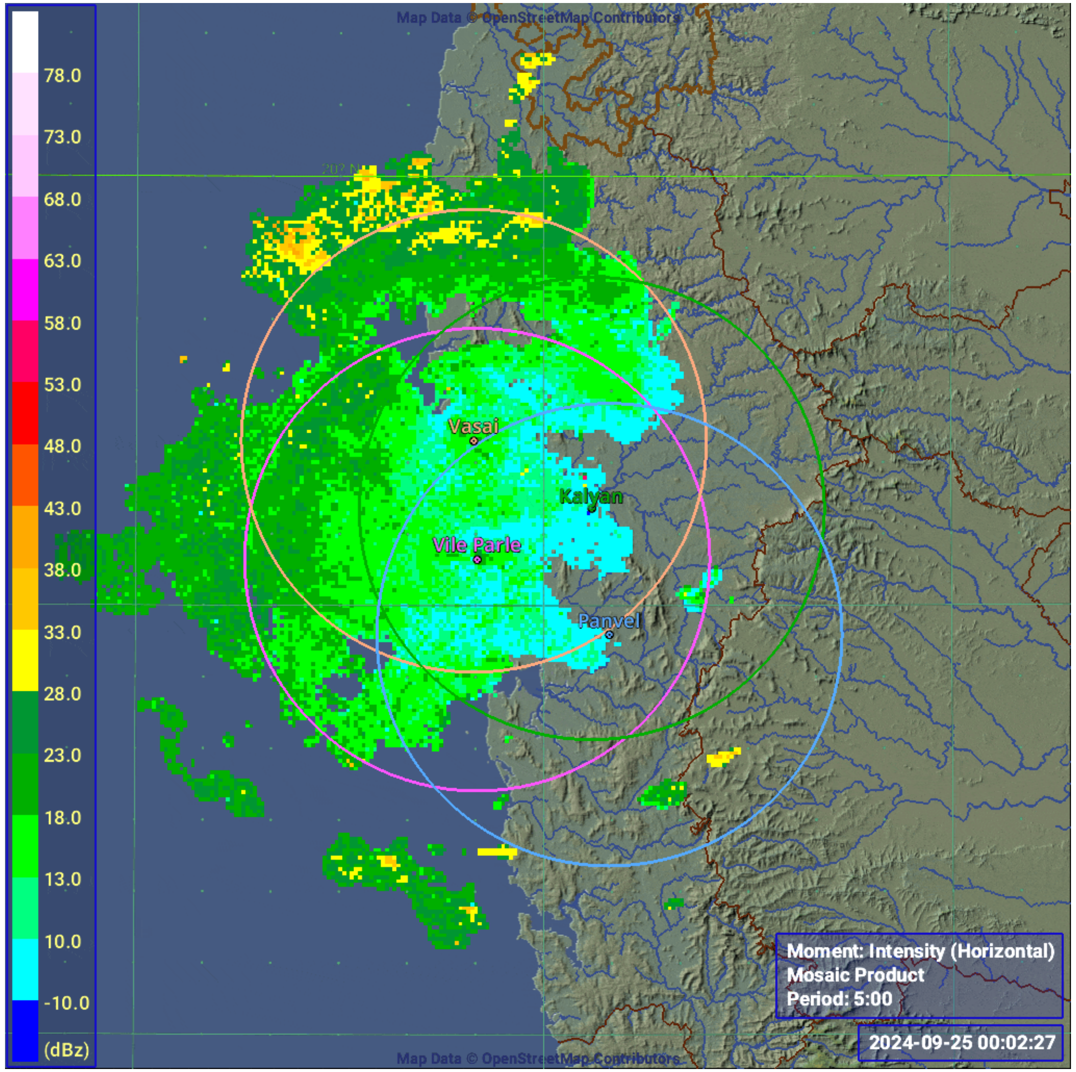
For tropical regions, the given coefficients are:

- $a = 250$
- $b = 1.6$

Thus, the equation for tropical regions becomes:

$$Z = 250R^{1.6}$$

Precipitation Type	Reflectivity (Z, dBZ)	Differential Reflectivity (ZDR, dB)	Correlation Coefficient (RHOHV)	Differential Phase (PHIDP, deg)
Light Rain	10–30 dBZ	Low (0–1 dB)	High (≥0.98)	Small increase (low PHIDP)
Heavy Rain	35–55 dBZ	Moderate to high (1–3 dB)	High (≥0.98)	High PHIDP, increases with rain rate
Dry Snow	10–35 dBZ	Near 0 dB (spherical flakes)	Very high (≥0.99)	Near zero (low phase shift)
Wet Snow	20–40 dBZ	Slightly positive (0–1 dB)	Lower (0.85–0.95) due to mixed phase	Moderate increase in PHIDP
Hail (Dry)	40–60+ dBZ	Near 0 dB (randomly oriented)	High (≥0.95)	Near zero (no significant phase shift)
Hail (Wet)	50–70+ dBZ	Near 0 dB or slightly negative (water shell effect)	Lower (0.85–0.95)	Moderate PHIDP if water-coated
Graupel (Soft Hail)	30–50 dBZ	Near 0 dB	High (≥0.98)	Near zero
Ice Pellets	20–40 dBZ	Near 0 dB	Very high (≥0.99)	Low
Rain-Snow Mix	20–40 dBZ	Variable (0–1 dB)	Moderate (0.85–0.95)	Variable PHIDP
Melting Layer	30–45 dBZ	Slightly positive (0–1 dB)	Lower (0.85–0.95)	Increased PHIDP (moderate)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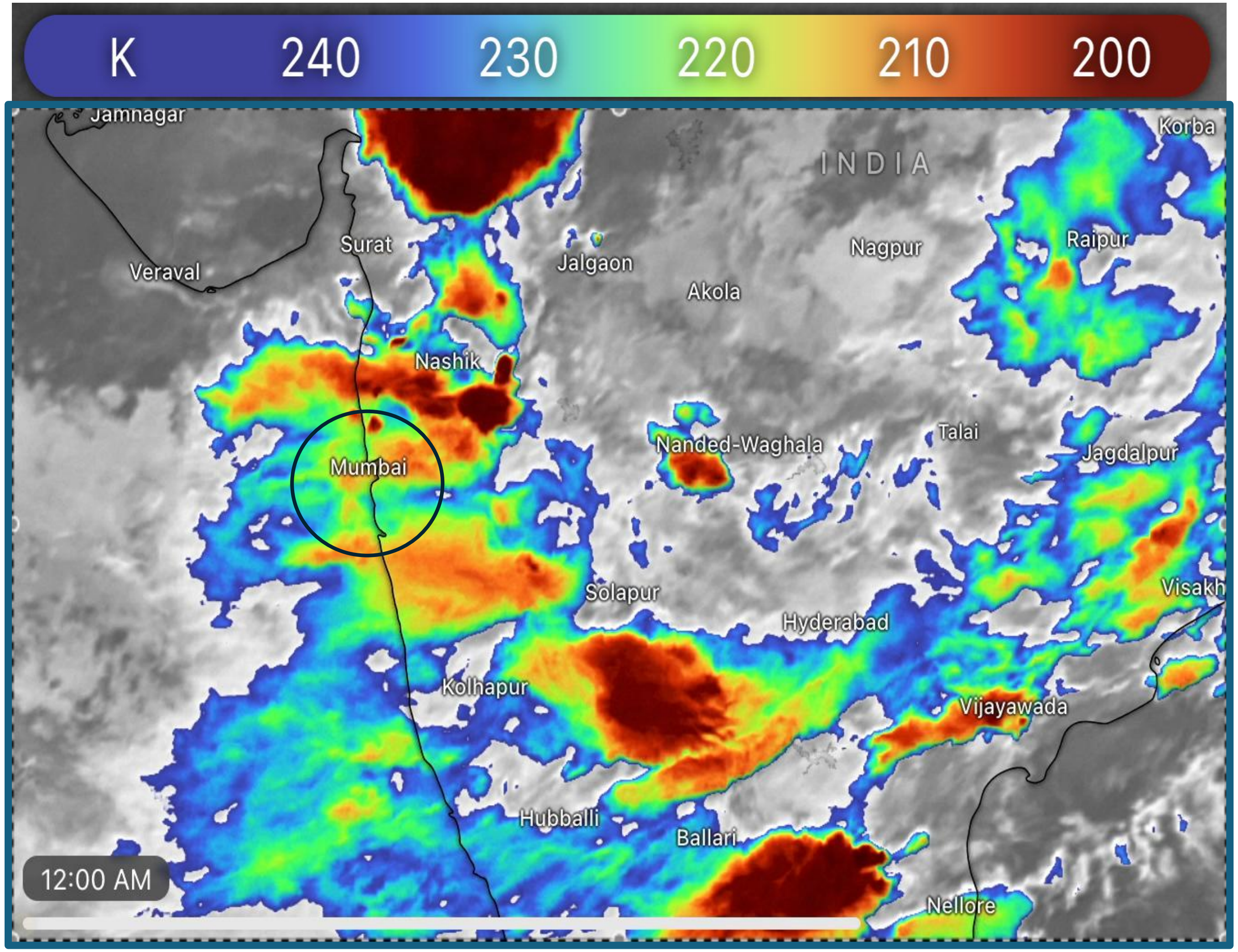
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