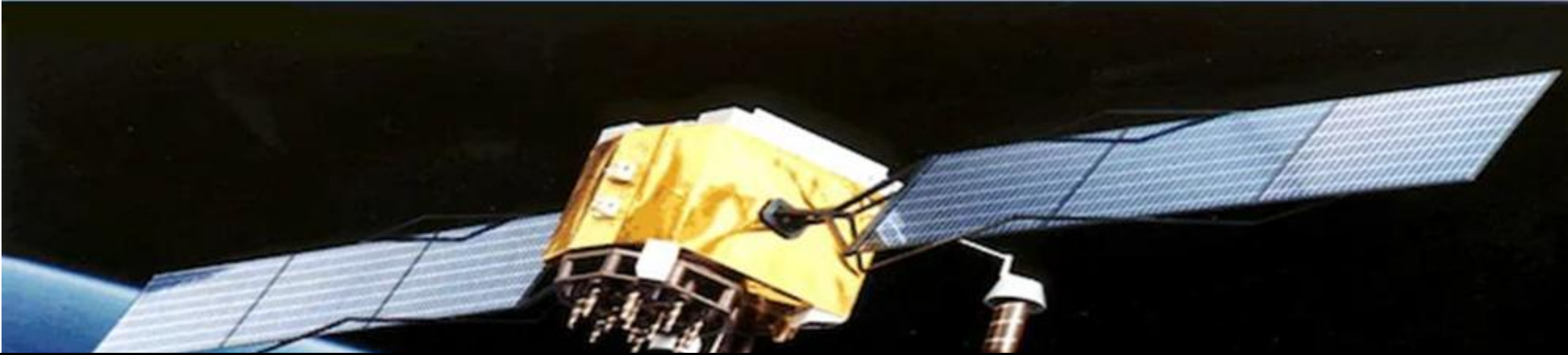


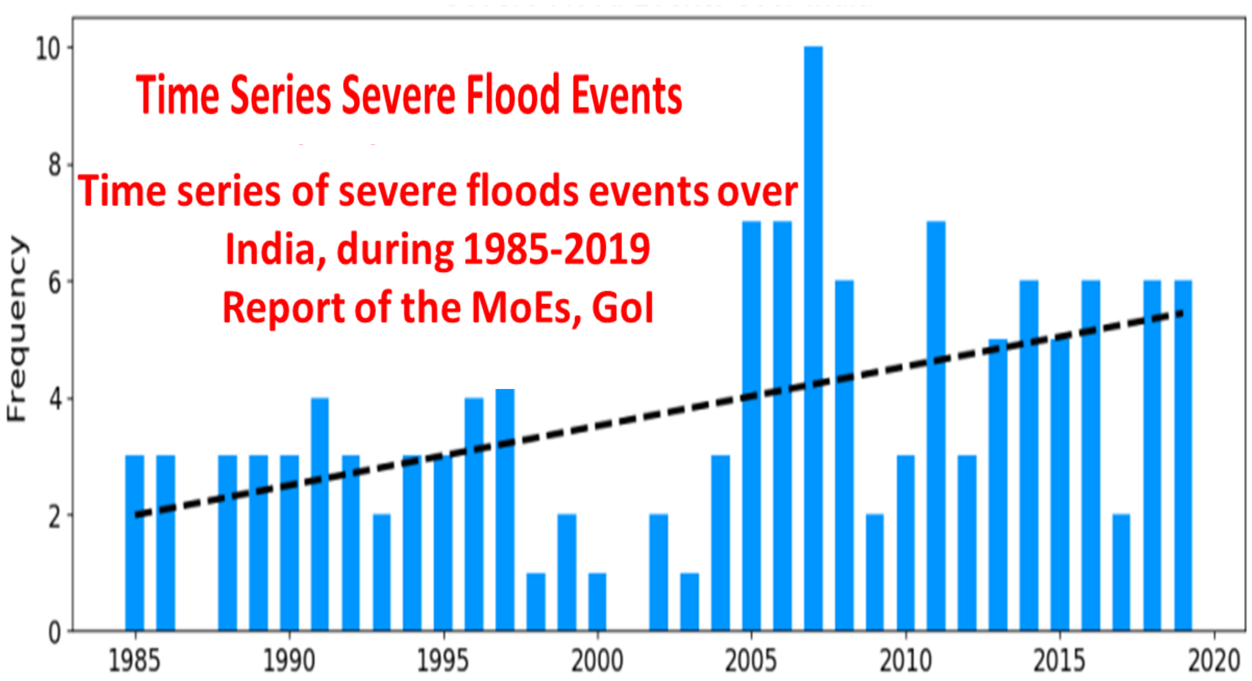
Space-Based Rainfall Measurements: Present Capabilities & Gaps

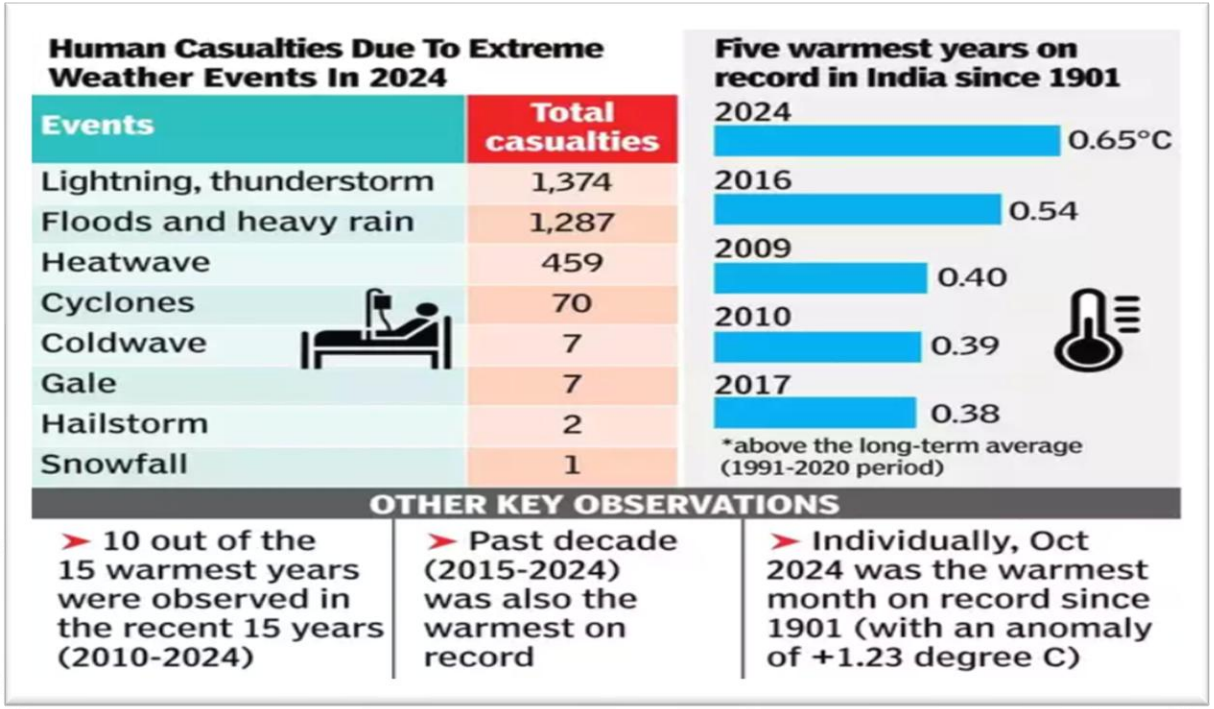
Randhir Singh

Space Applications Centre (SAC), ISRO, Ahmedabad

Extreme Weather and Climate Change

- **Under global warming heavy rainfall events across India are increasing, resulting in regular floods**
- **Floods cause major loss of life in India, especially during the monsoon season**
- **Rainfall monitoring with high spatial and temporal resolution from space platforms has become vital**





Human Casualties Due To Extreme Weather Events In 2024

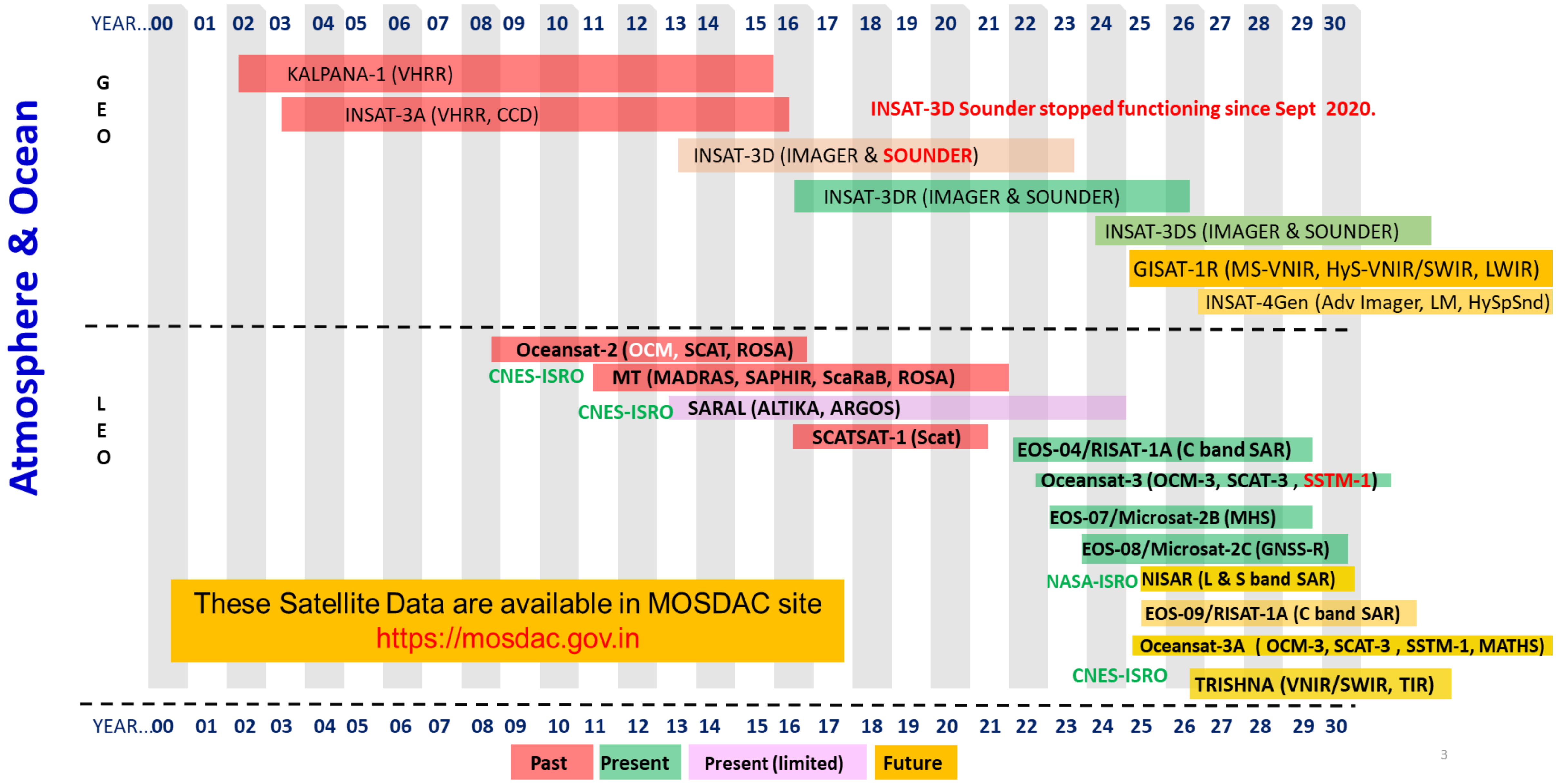
Events	Total casualties
Lightning, thunderstorm	1,374
Floods and heavy rain	1,287
Heatwave	459
Cyclones	70
Coldwave	7
Gale	7
Hailstorm	2
Snowfall	1

OTHER KEY OBSERVATIONS

- 10 out of the 15 warmest years were observed in the recent 15 years (2010-2024)
- Past decade (2015-2024) was also the warmest on record
- Individually, Oct 2024 was the warmest month on record since 1901 (with an anomaly of +1.23 degree C)

Courtesy: IMD

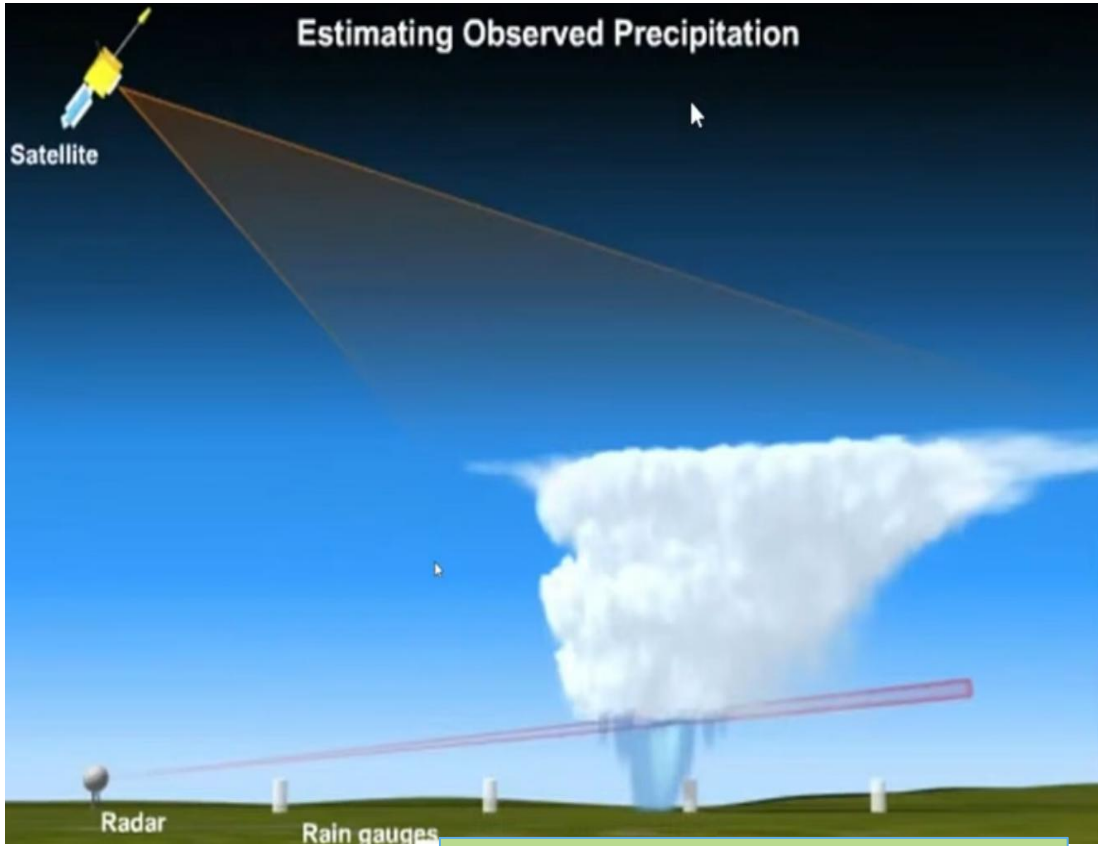
ISRO's Earth Observation Satellite Missions



Why is it necessary to use space based rainfall measurements?

Limitations of conventional methods: Radars and Rain gauges

- **Rain gauges are not evenly distributed, and cover a very limited portion of the Earth**
- **Radar networks are generally deployed by limited countries and cover limited area**
- **Maintenance issue**
- **Difficult to get observations in hilly and polar regions**
- **Instrument calibration**
- **Oceans are not fully covered, apart from scattered ship observations, buoys, and radars**



https://www.comet.ucar.edu/

Space-based rainfall measurement

Platforms

- Geostationary
- Polar
- Low inclination

Frequency

- Visible (0.4-0.7 µm)
- Thermal Infra-Red (10.6 -12.6 µm)
- Microwave(10-200 GHZ (0.15-3 cm)

Technique

- Active
- Passive

Modes

- Imaging
- Sounding

Space-based rainfall measurement

Rainfall measurement: Satellite Orbit

Geostationary Orbit

Advantages:

- Uninterrupted high Spatial and temporal monitoring
- Near real time tracking of weather events

Limitations:

- Till date no microwave payload (imager & sounder)
- Region specific

Polar Orbit

Advantages:

- Global
- Microwave imager, sounder & radars

Limitations:

- Limited passes
- Non-continuous measurement
- Tracking of weather events is not possible

Low inclinations

Advantages:

- Dense observations over tropics
- Microwave imager, sounder & radars

Limitations:

- Not global
- Continuous tracking of weather event is not possible

Rainfall monitoring satellites

Geostationary (Infrared sensors)

- **Present capabilities include rainfall data with a spatial resolution of 1 to 5 km and a temporal resolution of 15-30 minutes.**

INSAT-3D/3DR/3DS (INDIA)

METEOSAT-3 Gen (EUMETSAT)

HIMAWARI (JAPAN)

GOES (USA)

FENGYUN-4 (CHINA)

Rainfall monitoring satellites

Polar/Low Inclinations (Microwave sensors)

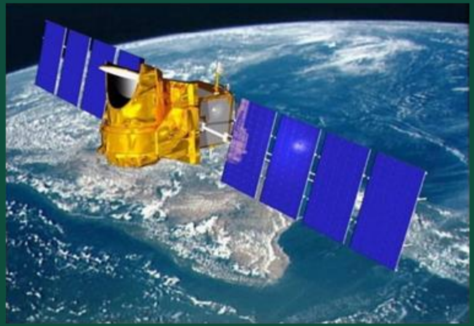
- Present capabilities include rainfall data with a spatial resolution of 5 to 25 km and a temporal resolution of 3 hours.

AMSU-A, MHS /NOAA

ATMS/NPP

AMSRE/GCOM

MADRAS, SAPHIR / Megha-Tropiques



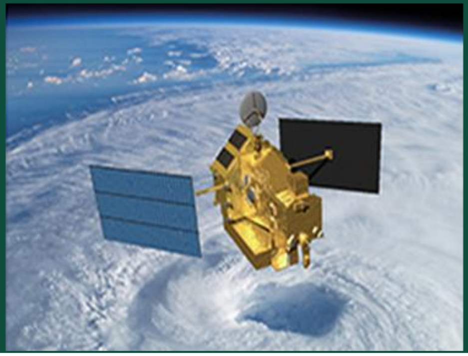
DPR/GPM

SSMI/DMSP

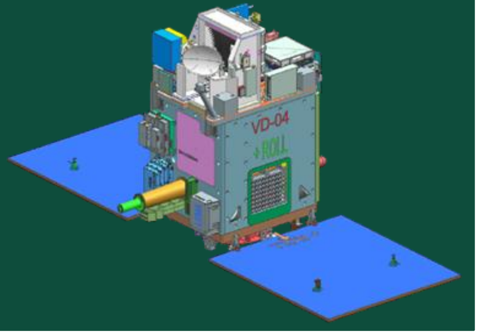
AMSU-A,MHS/Metop

MWRI/FY-3 Series

TMI, PR/TRMM



MHS/EOS-07

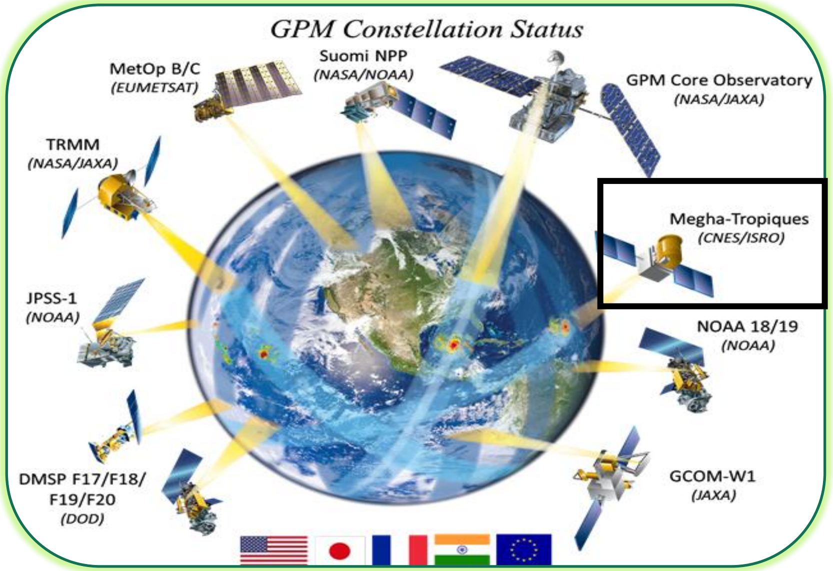


Space-based rainfall monitoring satellites
Polar/ Low Inclination – Synergy & Constellation

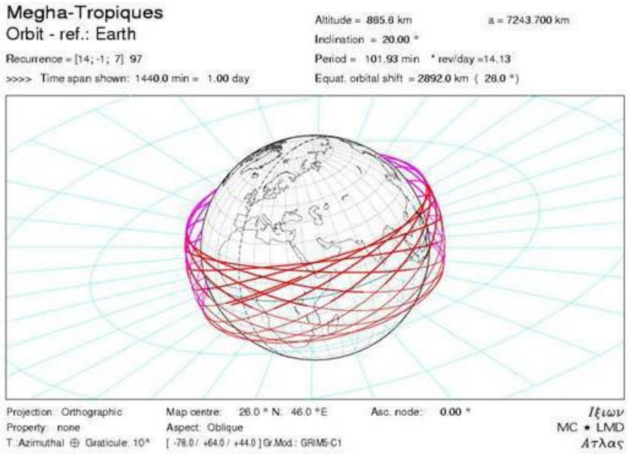
Global Precipitation Measuring Mission (GPM)

GPM utilizes globally available satellite sensors (active/passive, polar/geostationary) to monitor precipitation and hydrological cycle.

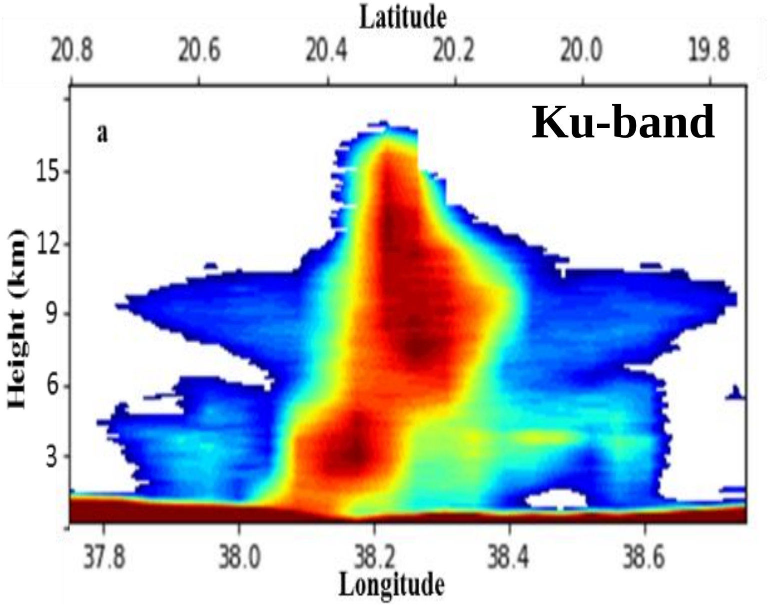
Core observatory consists Imager and Dual frequency precipitation Radar



India also contributed in GPM through MEGHA-TROPIQUES: Indo-French joint mission

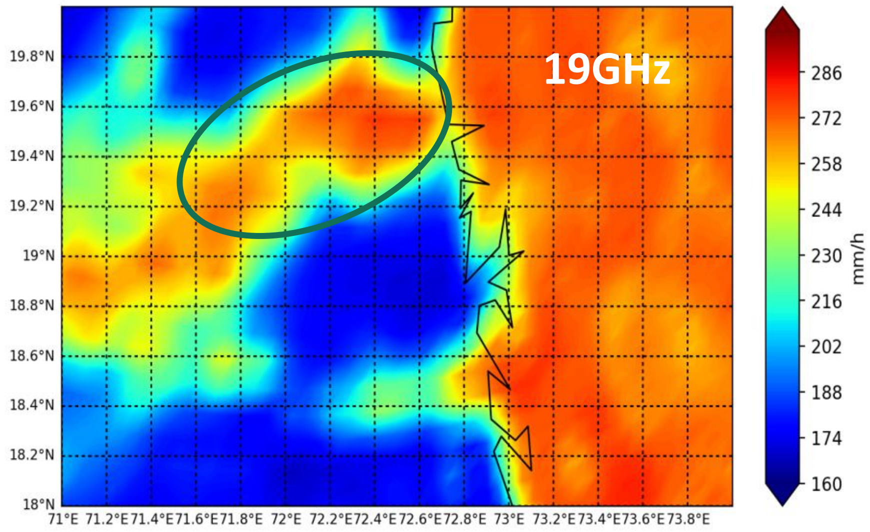


Dual Frequency Radar provides vertical profile of reflectivity at two frequencies (Ku & Ka) to understand 3-dimensional structure of rain



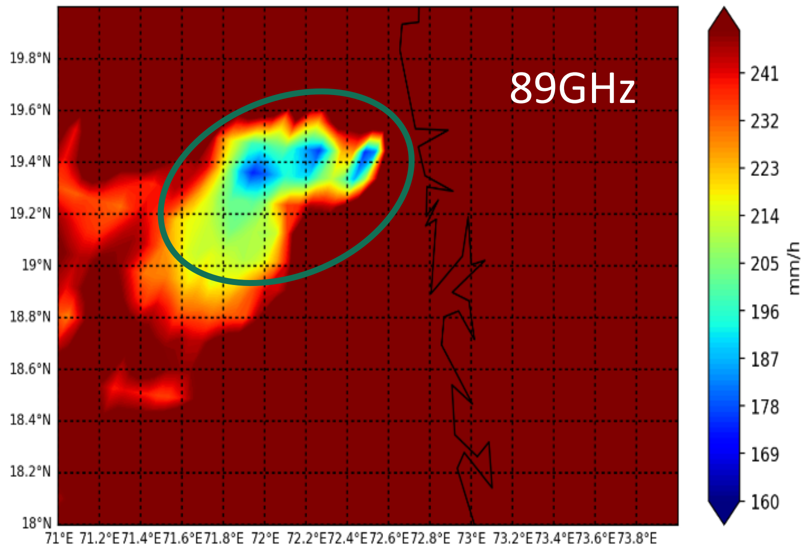
Rainfall signatures in different frequencies

Low frequencies microwave emissive signatures



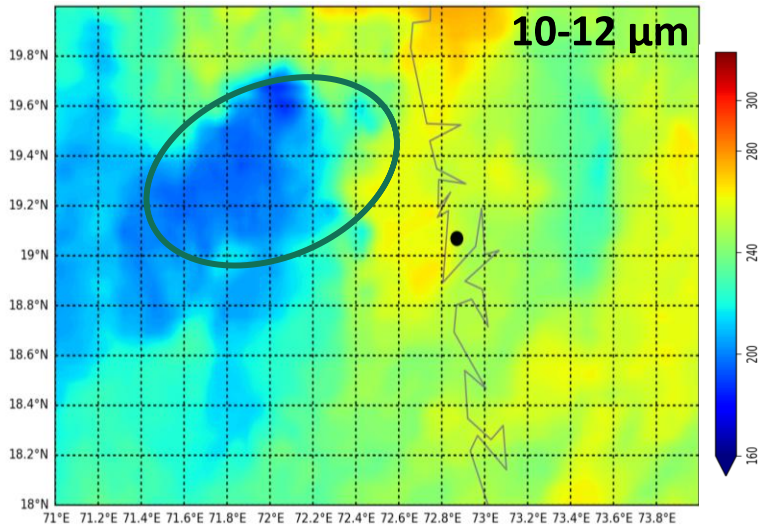
Due to emission signals from liquid water present in the cloud, brightness temperature of low frequency (19 GHz) microwave signals show high value over rainy pixels.

High frequencies microwave scattering signatures



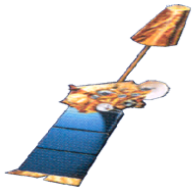
Due to scattering signals from ice/snow/hail present in the cloud, brightness temperature of high frequency (>=37 GHz) microwave signals show low value over rainy pixels.

Drop in TIR BT-INSAT-3D

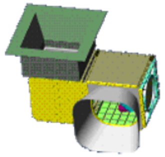


TIR frequency senses only cloud top temperature. Cloud top temperature decreases with the growth of cloud. Thus, rainy pixel shows low TIR BT.

Present series: INSAT-3D/3DR/3DS



INSAT-3DS Instruments



Six Channels Imager

- Spectral Bands (µm)

Visible	: 0.55 - 0.75
Short Wave Infra Red	: 1.55 - 1.70
Mid Wave Infra Red	: 3.80 - 4.00
Water Vapour	: 6.50 - 7.00
Thermal Infra Red – 1	: 10.2 - 11.3
Thermal Infra Red – 2	: 11.5 - 12.5

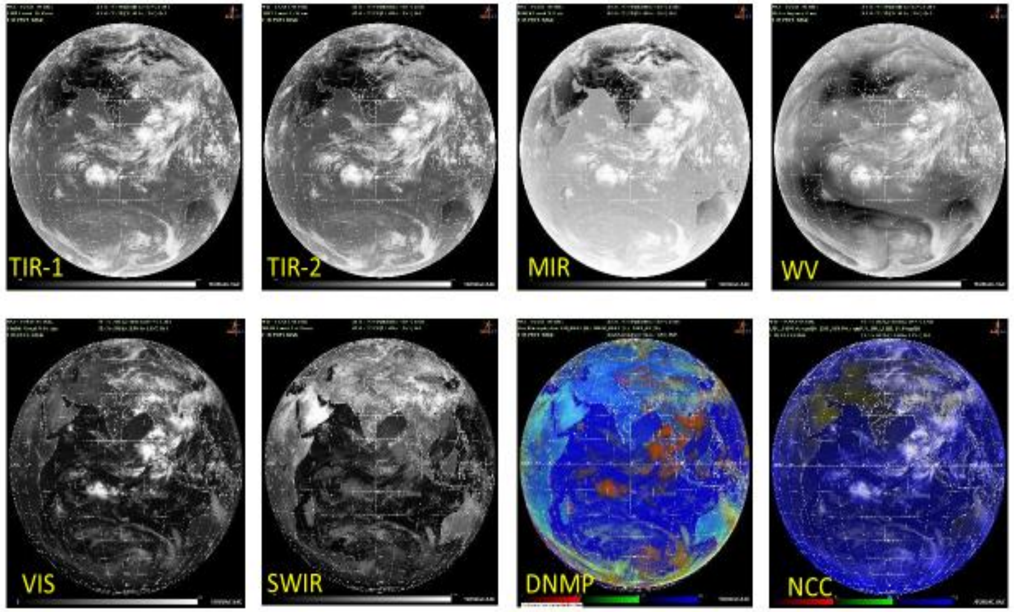
- Resolution : 1 km for Vis, SWIR
  4 km for MIR, TIR
  8 km for WV

18 Channels Sounder

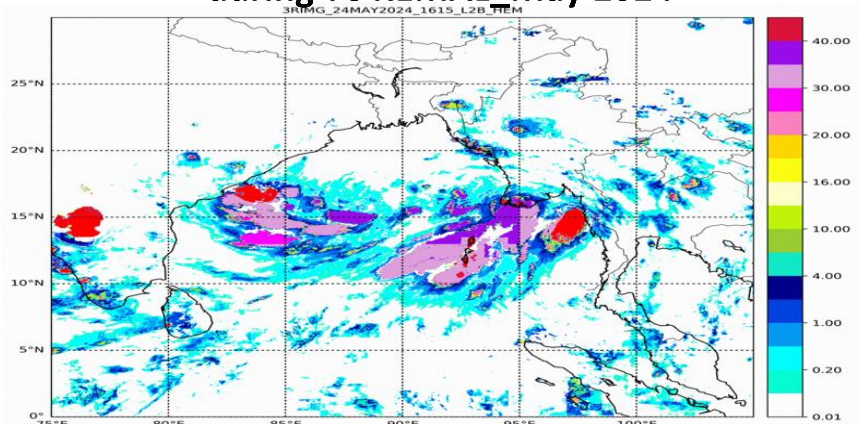
- Spectral Bands (µm)

Short Wave Infra Red	: Six bands
Mid Wave Infra Red	: Five Bands
Long Wave Infra Red	: Seven Bands
Visible	: One Band

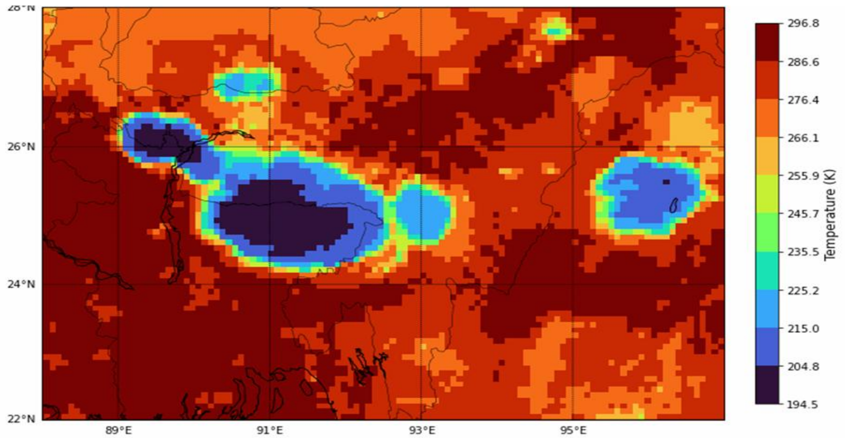
- Resolution (km) : 10 X 10 for all bands



Hydro-Estimator rainfall from INSAT-3DR during TC REMAL_May 2024



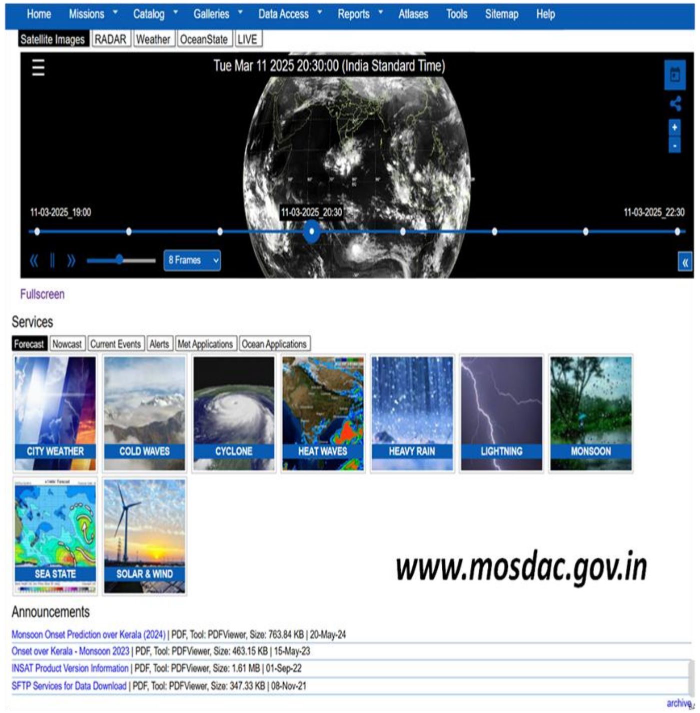
Rapidly developing overshooting cloud identified by INSAT-3DS, on 8 June 2024



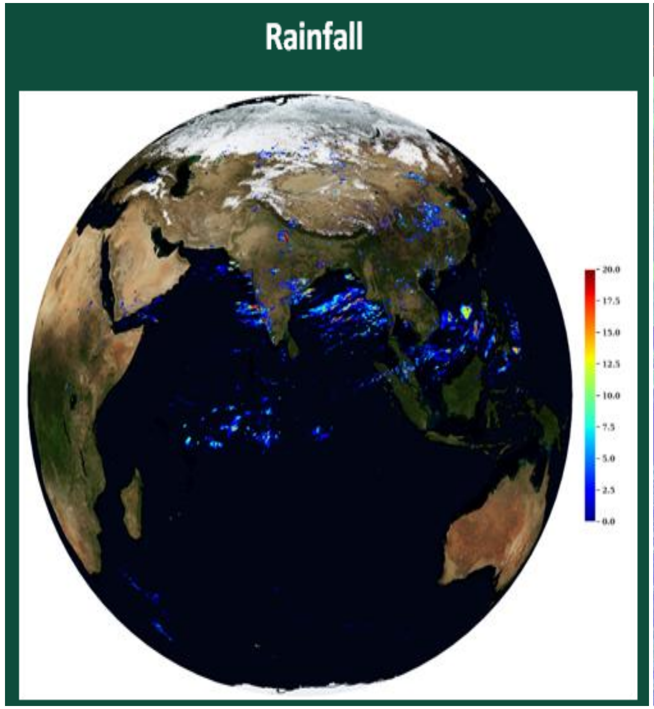
INSAT-3DS Products

A few samples from INSAT-3DS satellite

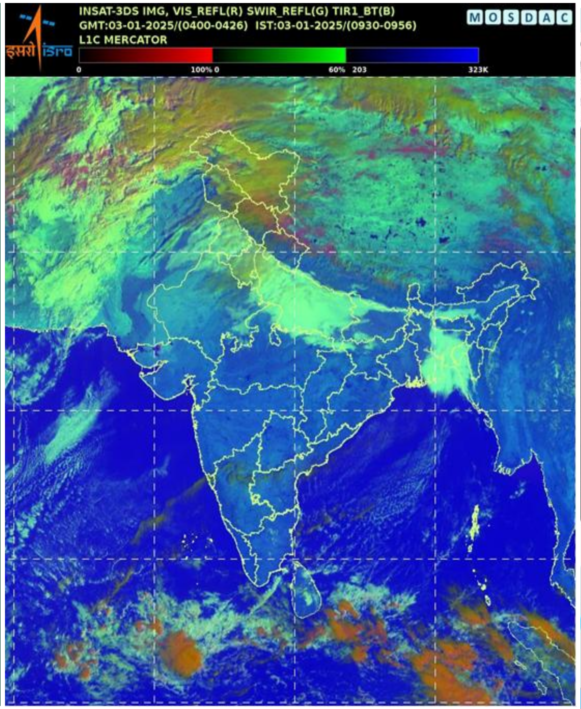
@MOSDAC



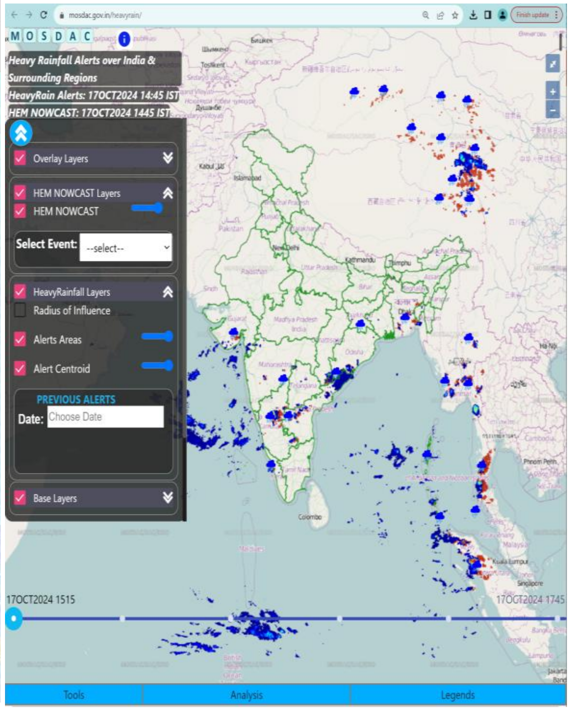
Hydro-Estimator rainfall



Day time cloud microphysics



Hydro-Estimator NOWCAST



Space-based rainfall monitoring satellites
Polar/ Low Inclination

MT Payloads:

Microwave Analysis and Detection of Rain and Atmospheric Structure (MADRAS) : Precipitation and cloud properties
89 & 157 GHz: ice particles at cloud top
18 & 37GHz: cloud liquid water and precipitation
23GHz:Integrated water vapour.

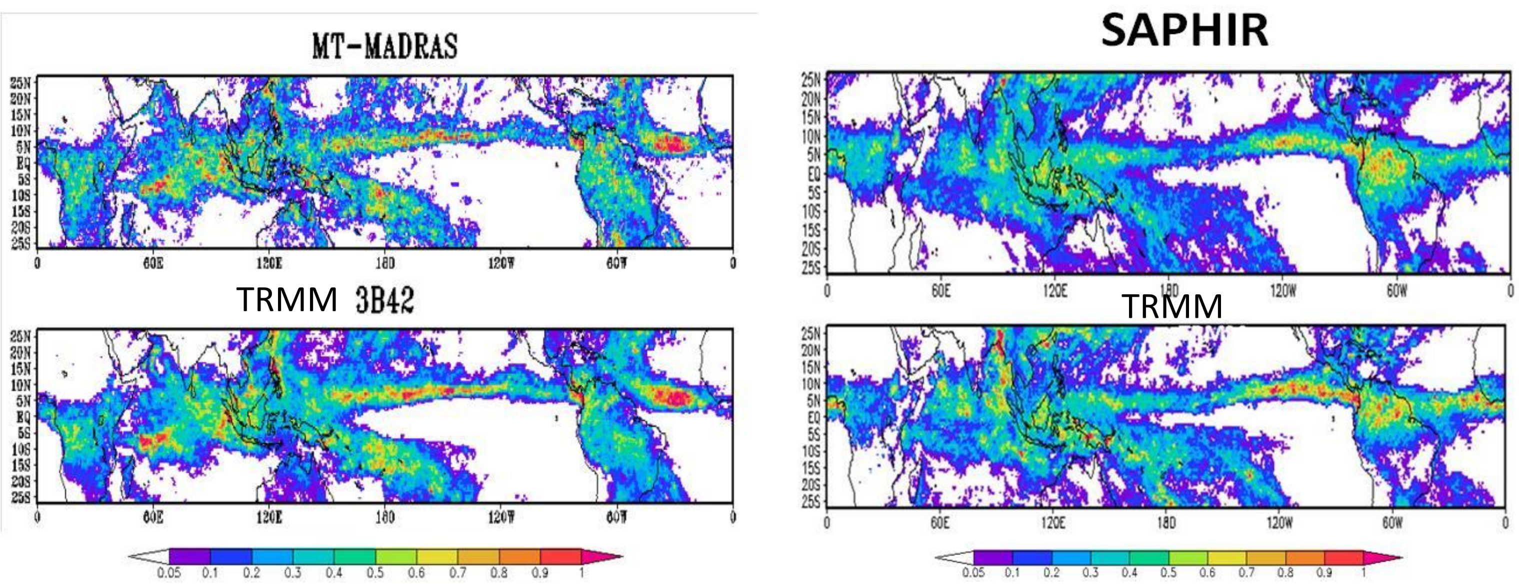
SAPHIR: 6 channel sounder near to 183 GHz: sounding upto 12km height
Resolution:10km, Swath:2200km

ScaRaB: Outgoing fluxes at TOA
Resolution: 40km
Swath: 2200km

ROSA: Temperature and humidity profiles.

Megha-Tropiques (MT-1) satellite, a successful collaborative effort between ISRO and CNES, for studying water cycle and energy exchanges in the tropical belt.

Rainfall monitoring from Megha-Tropiques



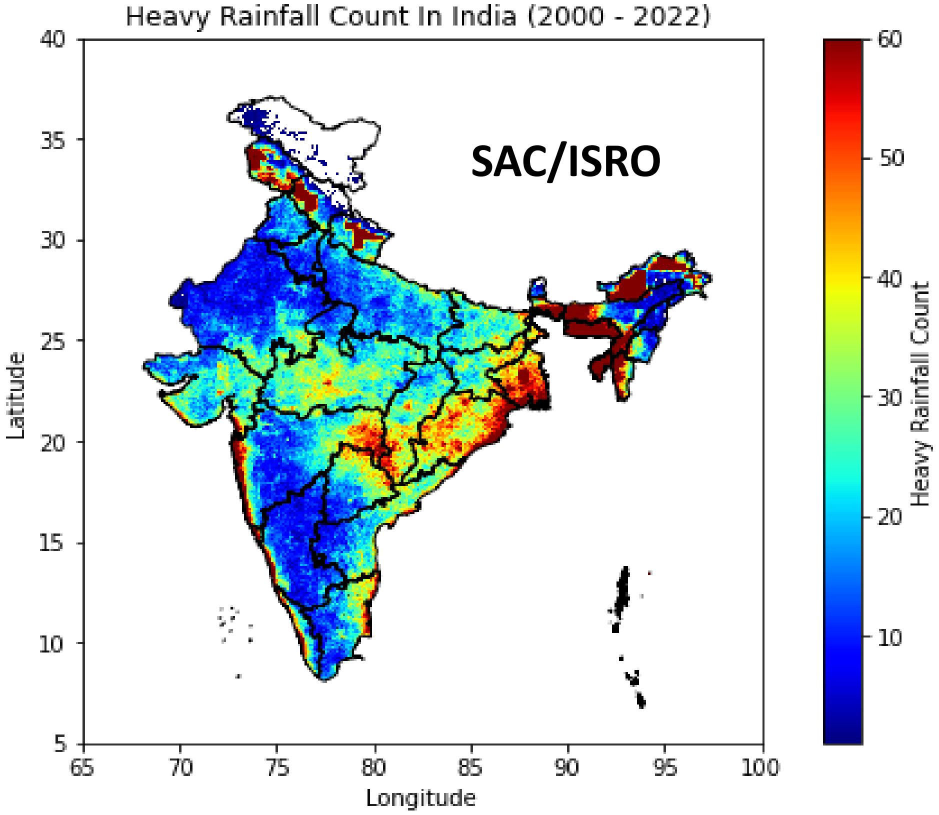
The performance of Megha-tropiques is comparable to other contemporary sensors.

Applications of rainfall data from multi sensors and satellites

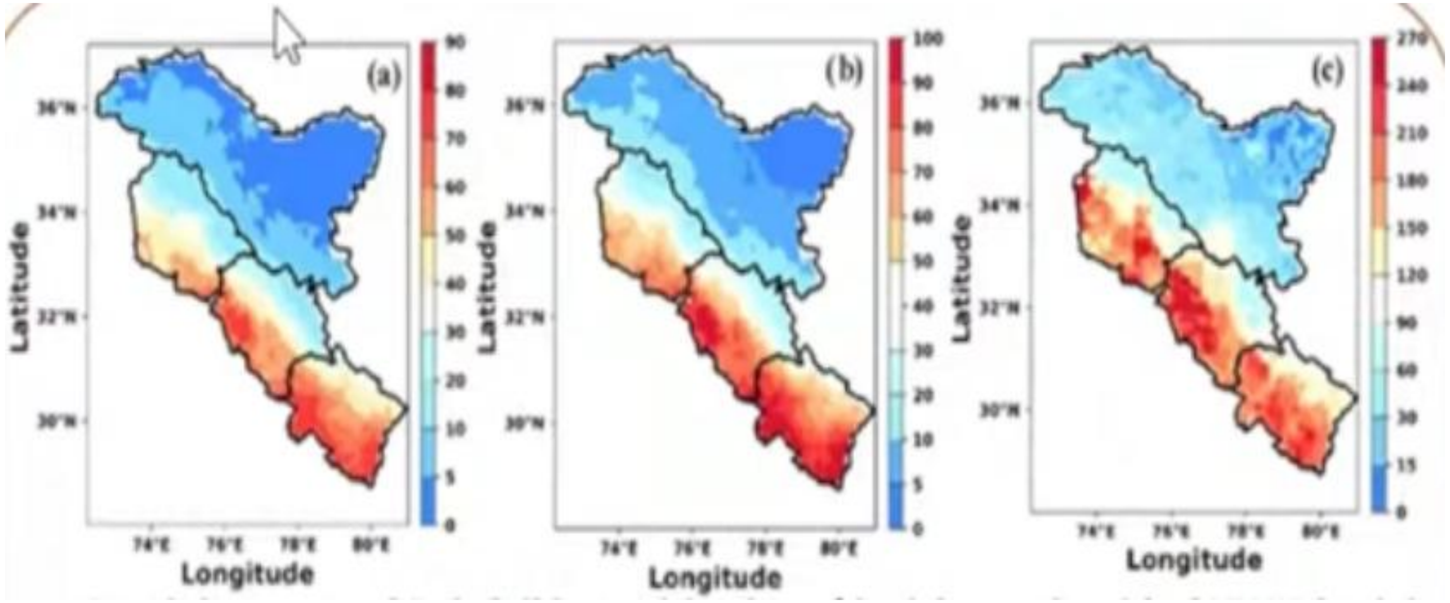
IMERG: Integrated Multi-satellitE Retrievals for GPM

NASA IMERG algorithm combines GPM Satellites to estimate global precipitation

Heavy rainfall trend using GPM-IMERG during 2000-2022



Rainfall intensities (mm/day) over north west Himalayas (a) 98th, (b) 99th and (c) 99.99th percentiles during the monsoon season for the period 1998-2014



https://www.sciencedirect.com/science/article/abs/pii/S0022169425001611

Gap-areas & Way Forward

Synergistic approach (Dynamics and sampling) → **Constellation (Multi-frequency measurement active/passive)** → **Small satellites with imaging/sounding/radar capabilities**

VIS/IR/MICROWAVE

➢ **VIS**

- Only in day time
- Difficult to differentiate warm clouds

➢ **IR**

- Cloud top information
- Indirect way of estimation
- Weak BT relationship with rainfall

➢ **Microwave:**

- Poor spatial & temporal resolution
- Low energy & large antenna, not in geostationary orbit.
- Problem in coastal areas & land

➢ **Way Forward:**

1. Advanced Imager (more spectral channels) & sounder
2. Microwave sensor on geostationary orbit
3. Synergistic approach of estimation.

ACTIVE/PASSIVE

➢ **ACTIVE:**

- Limited precipitation (TRMM & GPM) and cloud (CloudSAT) radars.
- No Doppler capability

➢ **Way Forward:**

- 1. Multi frequency radars
- 2. Doppler capability to measure vertical velocity

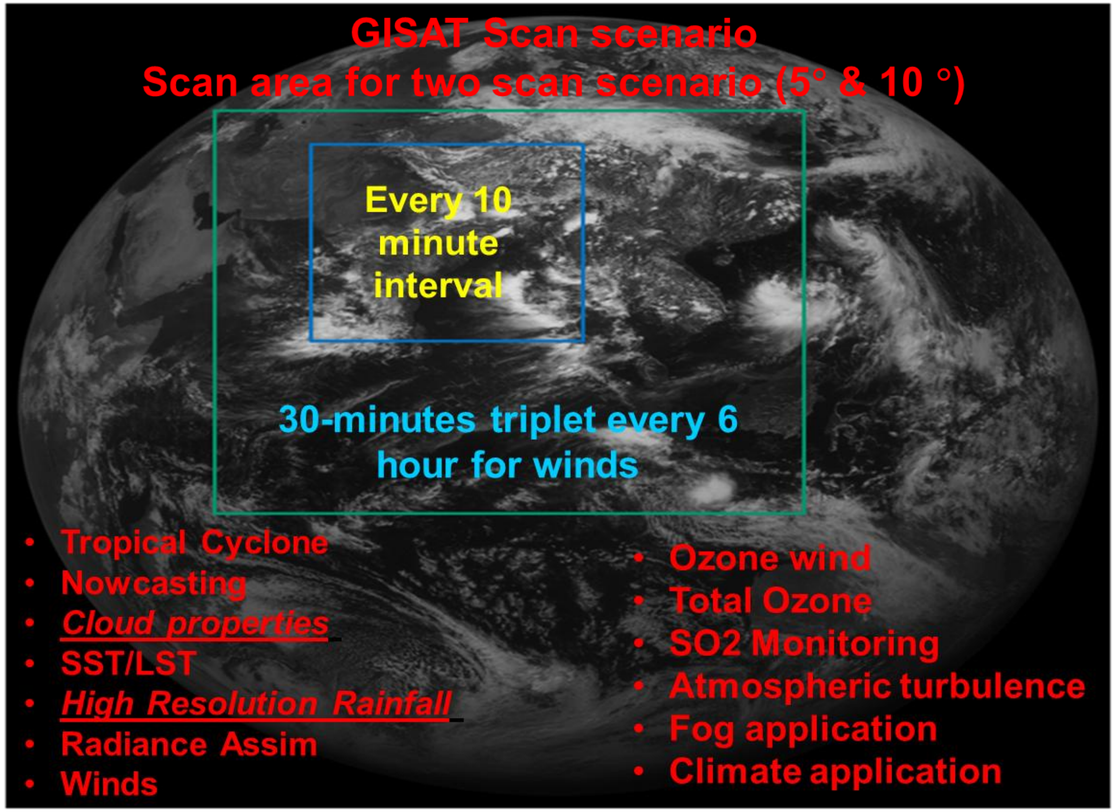
ISRO’s Missions

GEO satellites (GISAT-1R)

GISAT Strengths: **(i)** High spatial (1.2 km) and temporal resolution (10 minutes) from LWIR

MX-VNIR: Multispectral - Visible Near Infrared, HySI-VNIR: Hyperspectral Imager - Visible Near Infrared, HySI-SWIR: Hyperspectral Imager - Short Wave Infrared, MX-LWIR: Multispectral - Long Wave Infrared.

Band	Ch	SNR/ NEdT @300K	IFOV (m)	Range (µm)	Channels bandwidth (µm)
MX-VNIR	6	> 200	42	0.45 - 0.875	0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86 0.71-0.74 0.845-0.875
HyS-VNIR	158	> 400	320	0.375 - 1.0	Δλ : 4 nm
HyS-SWIR	256	> 400	190	0.9 - 2.5	Δλ : 7 nm
MX-LWIR	6	< 0.15K	1200	7.0 – 13.5	7.1-7.6 8.3-8.7 9.4-9.8 10.3-11.3 11.5-12.5 13.0-13.5



ISRO’s Missions

Future ISRO’s GEO and LLEO satellites

Rainfall with very high spatial and temporal resolution

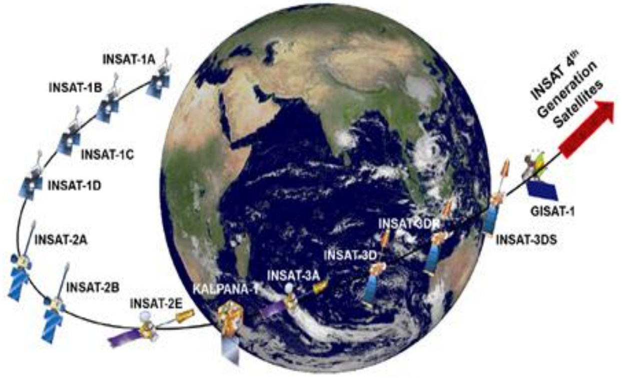
GEO: INSAT-4th Generation Satellite

a) Advanced Imager (legacy: GOES-R/ABI)
- 16 bands from 0.5 – 13.5 µm with spatial resolution 500m for VIS and 2 km for IR
- Faster scanning for Nowcasting applications
- FD (Full Disk), Indian Landmass (3000 km x 3000 km) and Mesoscale (1000 km x 1000 km)
- Capability to provide simultaneously, one Full Disk Image every 5 minutes, Indian Landmass every 2 minutes and Mesoscale Images every 30 seconds.

b) Lightning Mapper

c) Hyperspectral Infrared Sounder

- Cloud Properties (CTT/CTP)
- Cloud Microphysics (CER/COT)
- Rainfall
- Aerosol Optical Depth



LEO:

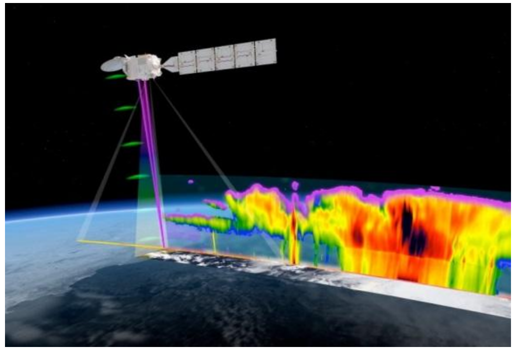
a) MW Temperature & Humidity Sounder
b) Hyper spectral Microwave and Infrared Sounder
c) 1.4-89 GHz MW Radiometer
d) Dual Frequency Scatterometer, C/Ku
e) GNSS-R/RO

International Missions for Rainfall

Recently launched or to be launched International satellites

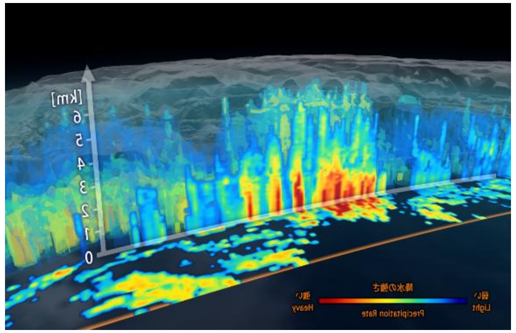
- **Earth Cloud Aerosol and Radiation Explorer (EarthCARE): ESA**

  -Cloud profiling radar with Doppler capabilities (launched, May 2024)



- **Doppler Precipitation Radar (DPR): NASA+JAXA**

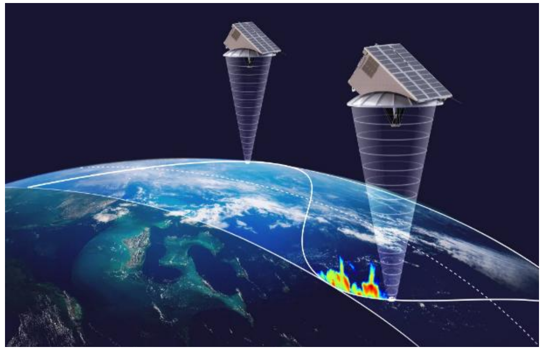
  -First Doppler precipitation measuring capability (planned)



- **Full operations of MTG (launched) and EPS-SG (planned): EUMETSAT Advanced imaging/sounding payloads in geostationary & polar orbits**

- **Constellations of small satellites: Tomorrows-R (radar)/(sounder) (launched 2023/2024)**

  -3-dimensional mapping of rain



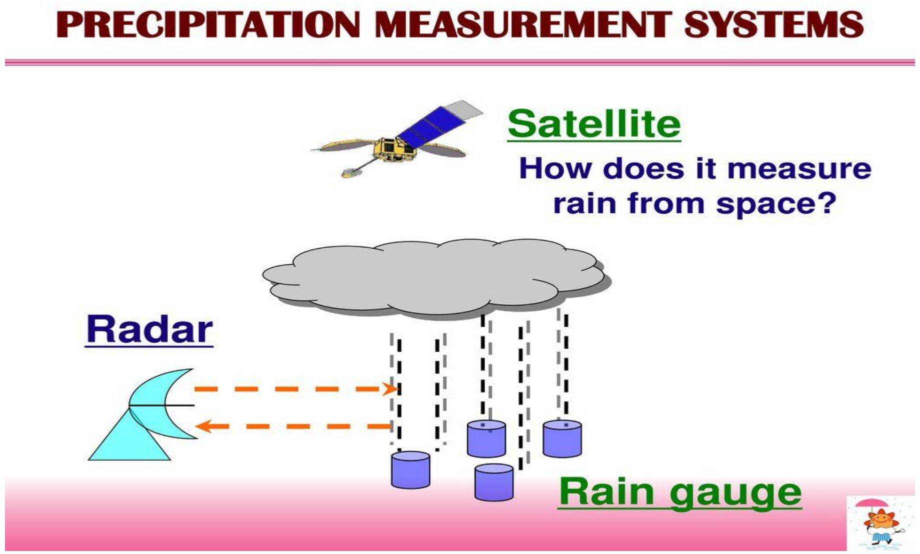
Synergy of ground and space-based rainfall observations

Issues :

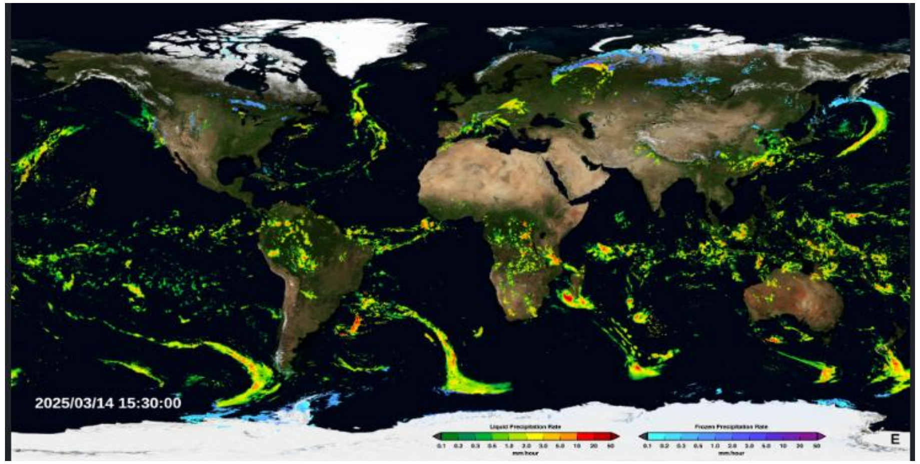
- **Rain Gauge : Representativeness error in rain gauge**
- **Ground Based Radar : Cost, Complexity, difficulty in measuring light rain, Limited range etc**
- **Satellite : Satellite beam filling problem (non-uniform distribution of rain in satellite FOV)**

Answer :

- **Satellite and ground-based measurements complement each other**
- **Combining satellite and ground-based rainfall measurements is the answer !**



Multiple satellite and multiplatform rainfall data



https://svs.gsfc.nasa.gov/4285

An Example of Space & Ground-based development of Rain Product

(GSMaP_ISRO under ISRO-JAXA Implementation of Agreement)

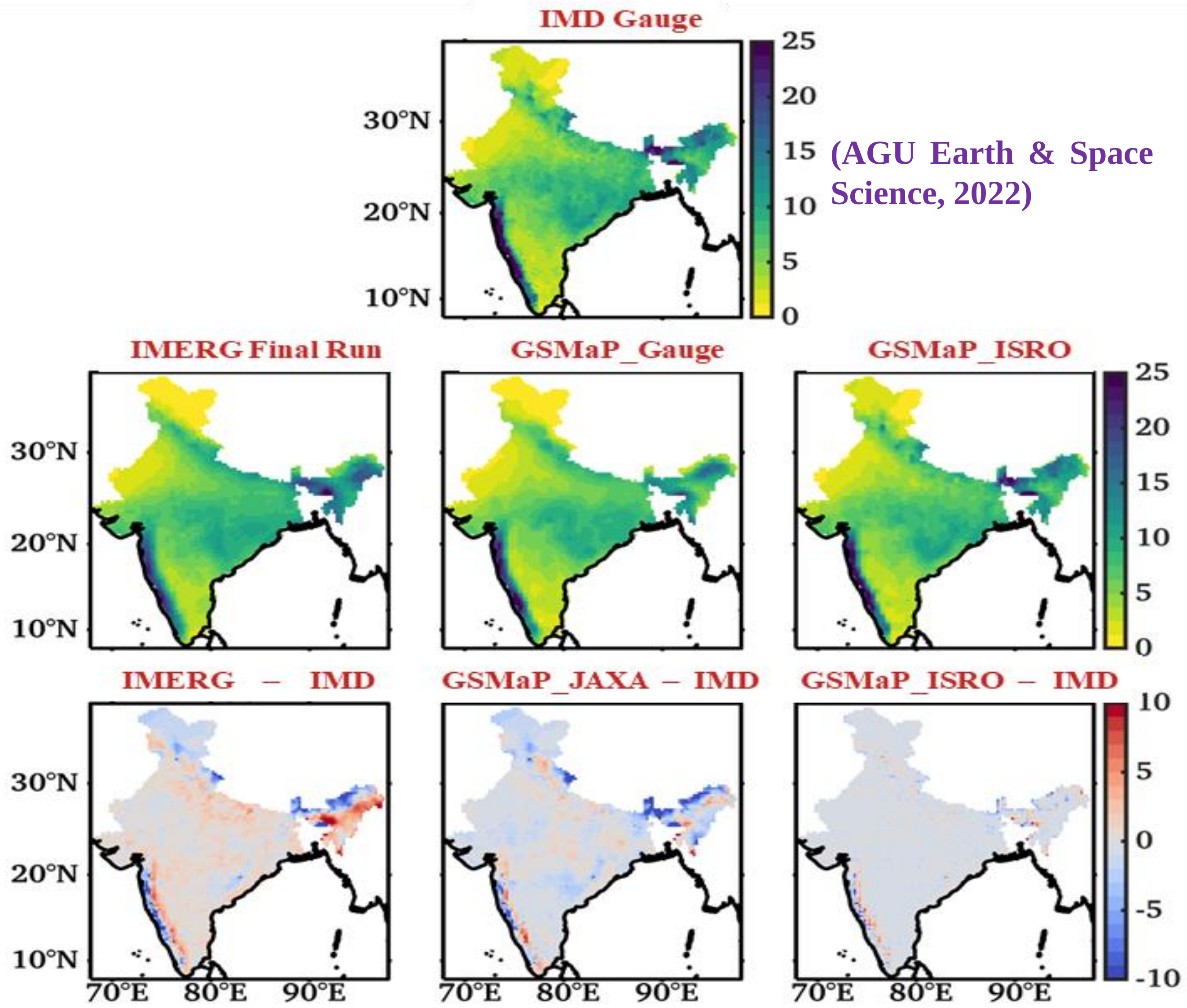
The GSMaP_ISRO rainfall product is a long-term high spatio-temporal resolution rainfall product, adjusted using IMD gauges.

- **The temporal resolution is houly, and the sptial resolution is 0.1°.**
- **Available from March 2000: https://mosdac.gov.in/**

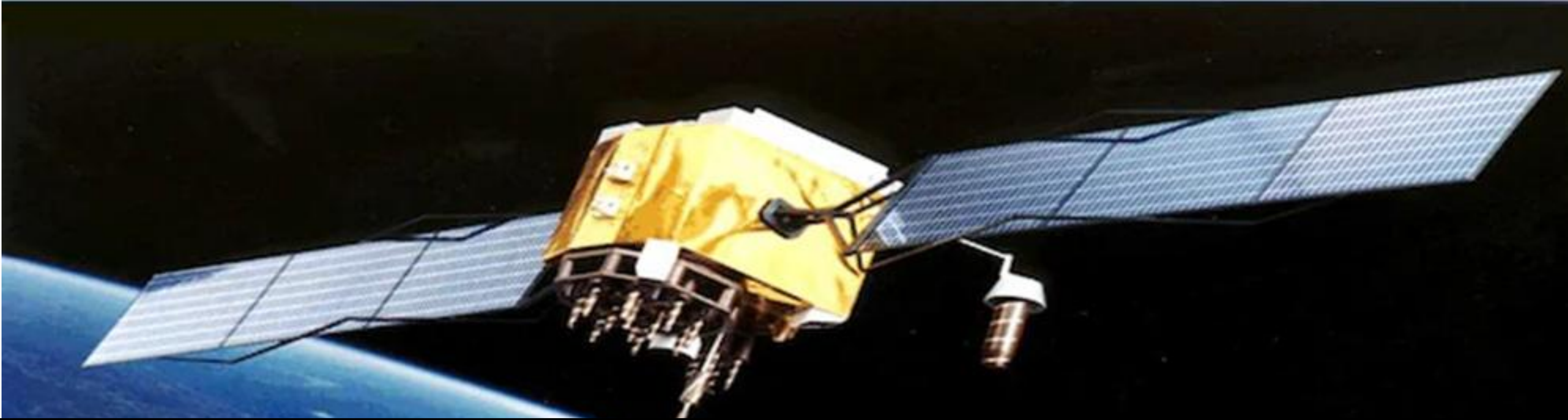
Improvements are very significant over the high rainfall regions mainly Western Ghats and NE India.

<u>Way Ahead</u>

Development of High Resolution (~1 km) rainfall over India using high resolution satellite Imagery, Ground Radar (e.g. DWR), and Gauge.



(AGU Earth & Space Science, 2022)



Thank You