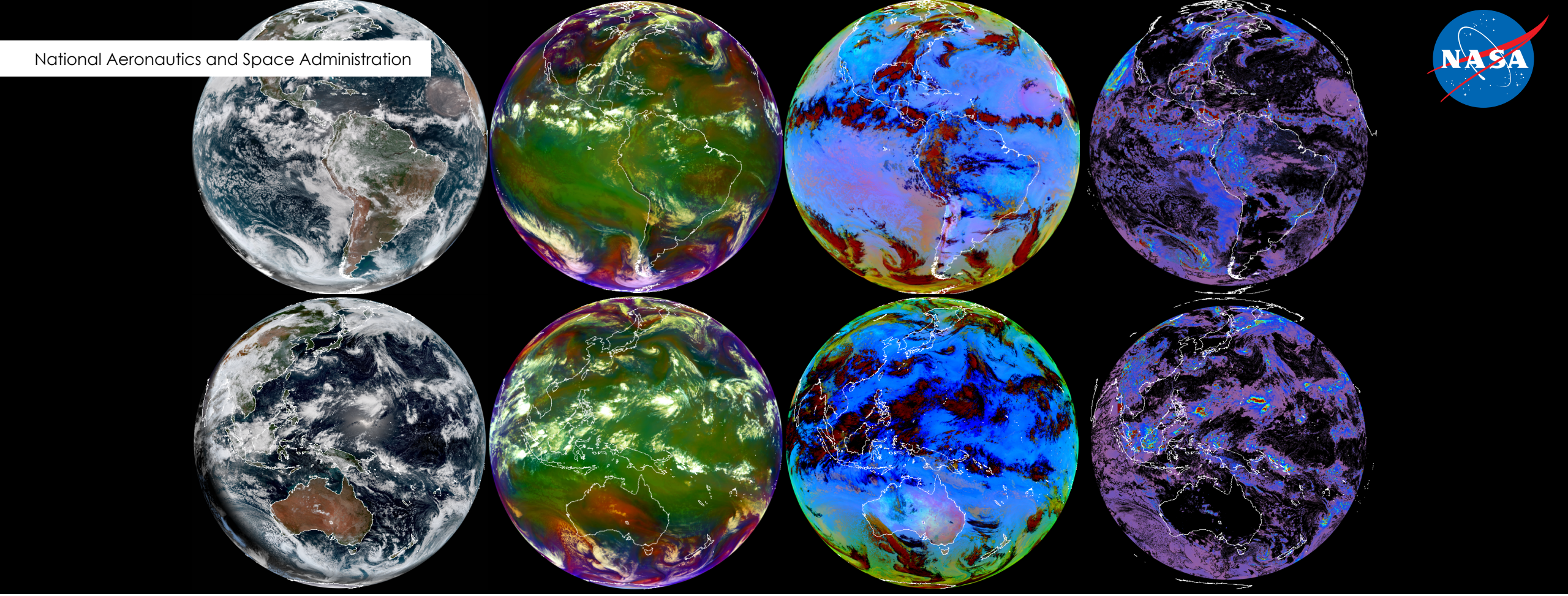
National Aeronautics and Space Administration



Aerosol Observations from the INSAT Series of Satellites Over Asia

Dr. Prakash Chauhan, Indian Institute of Remote Sensing (IIRS), Dehradun, India

High Temporal Resolution Air Quality Observations from Space, September 4-25, 2018

Learning Objectives

- By the end of the presentation you will be able to understand:
  - the advantages of high temporal resolution data for aerosol monitoring
  - the basic sensor characteristics abut the INSAT-3D imager
  - aerosol Retrieval algorithms using INSAT-3D Imager data
  - case studies using INSAT-3D for dust storms and poor air quality events over India
  - information about how to access INSAT-3D data products

What is air pollution?

- Airborne particles and gases occurring in concentrations that endanger the health and well-being of organisms or disrupt the orderly functioning of the environment
- Air pollutants are broken down into two categories:
  - Primary Pollutants
  - Secondary Pollutants

A morning in New Delhi just after Diwali, 2017

Primary Pollutants

- Primary Pollutants are airborne particles that are emitted directly from identifiable sources. These tiny structures are known collectively as Particulate matter (PM). Once suspended in either air or water, the mixture of the two becomes known as an Aerosol.

Anthropogenic

- Combustion Processes
- Chemical Processes
- Nuclear or Atomic Processes
- Roasting, Heating and Refining Processes
- Mining, Quarrying and Farming Processes

Natural

- Volcanoes
- Breaking Seas
- Pollens and Terpenes
- Fire
- Blowing Dust
- Bacteria and Viruses





Secondary Pollutants

- SMOG (smoke + fog)
- VDG (Volcanic + Smog)
- Ground Level Ozone
- SO_2
- NO_2
- CO

What are aerosols?

- Aerosols are solid or liquid particles suspended in the atmosphere: smoke, dust, sand, volcanic ash, smog, etc.

What are aerosols important?

Climate Related Effects

- Cooling produced by aerosols scattering solar radiation back to space
- Aerosol absorption of solar and longwave radiation may produce changes in atmospheric heating rates, leading to changes in atmospheric circulation

Non-Climate Related Effects

- **Air pollution:** local, regional, and global (i.e., large scale biomass burning and boreal forest fires)
- **Fertilization of the global ocean:** Iron flux from desert dust and other sources
- **Remote sensing of other geophysical parameters:** ocean color, atmospheric ozone, surface albedo, etc.

Remote Sensing

A Tool to Study Atmospheric Pollutants

- Remote sensing: obtaining information about objects or areas from a distance

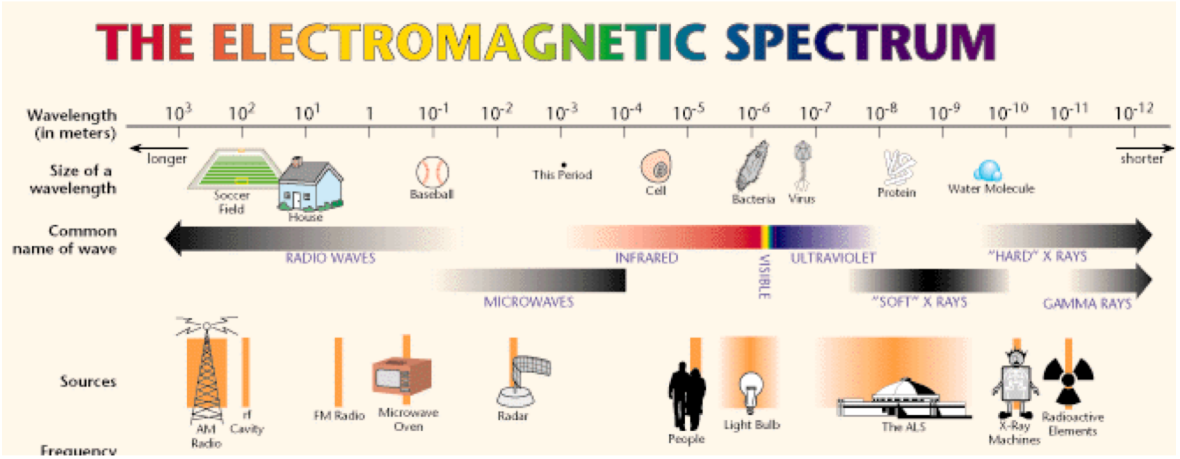


- Remote sensing measurements are typically from aircraft or satellites, but also can be from ground instruments as illustrated in the image on the left

Remote Sensing

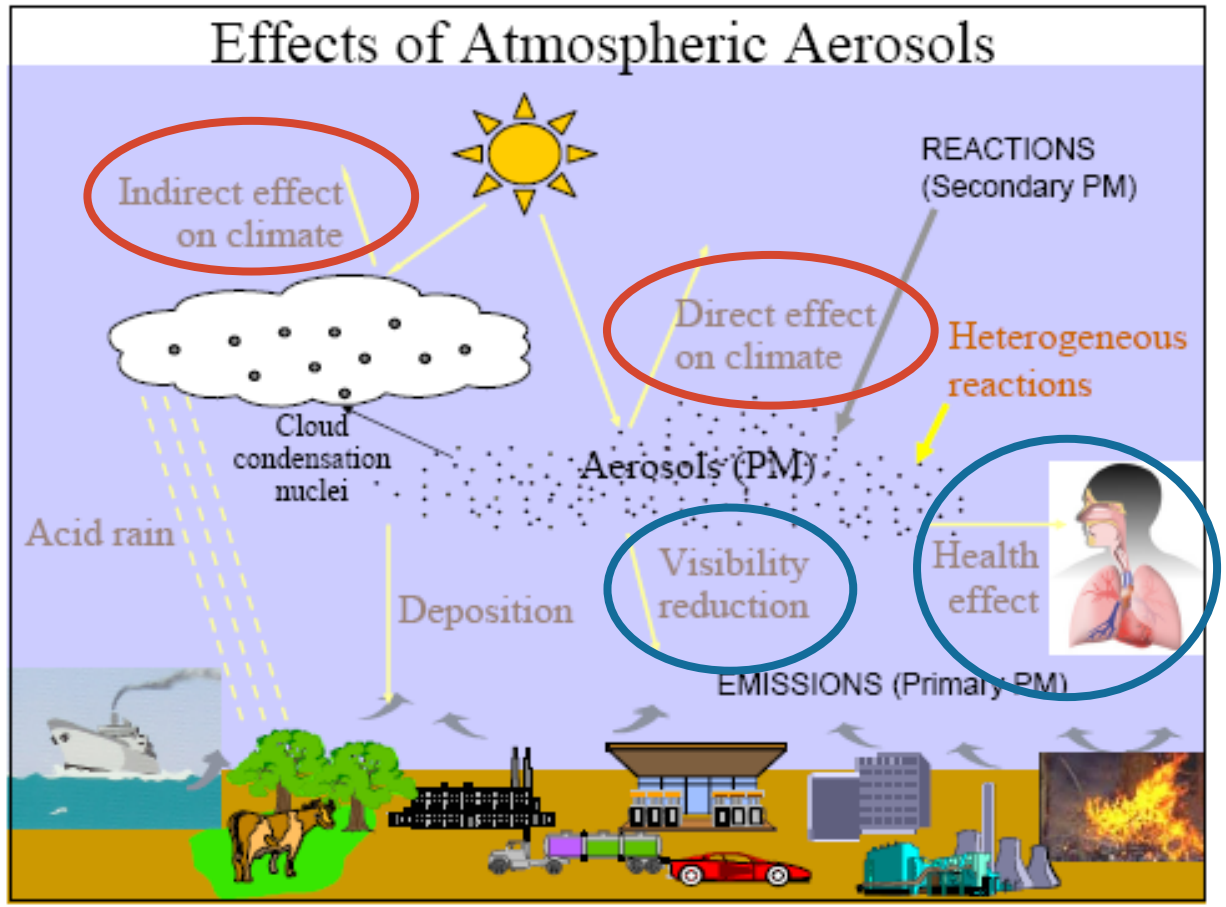
A Tool to Study Atmospheric Pollutants

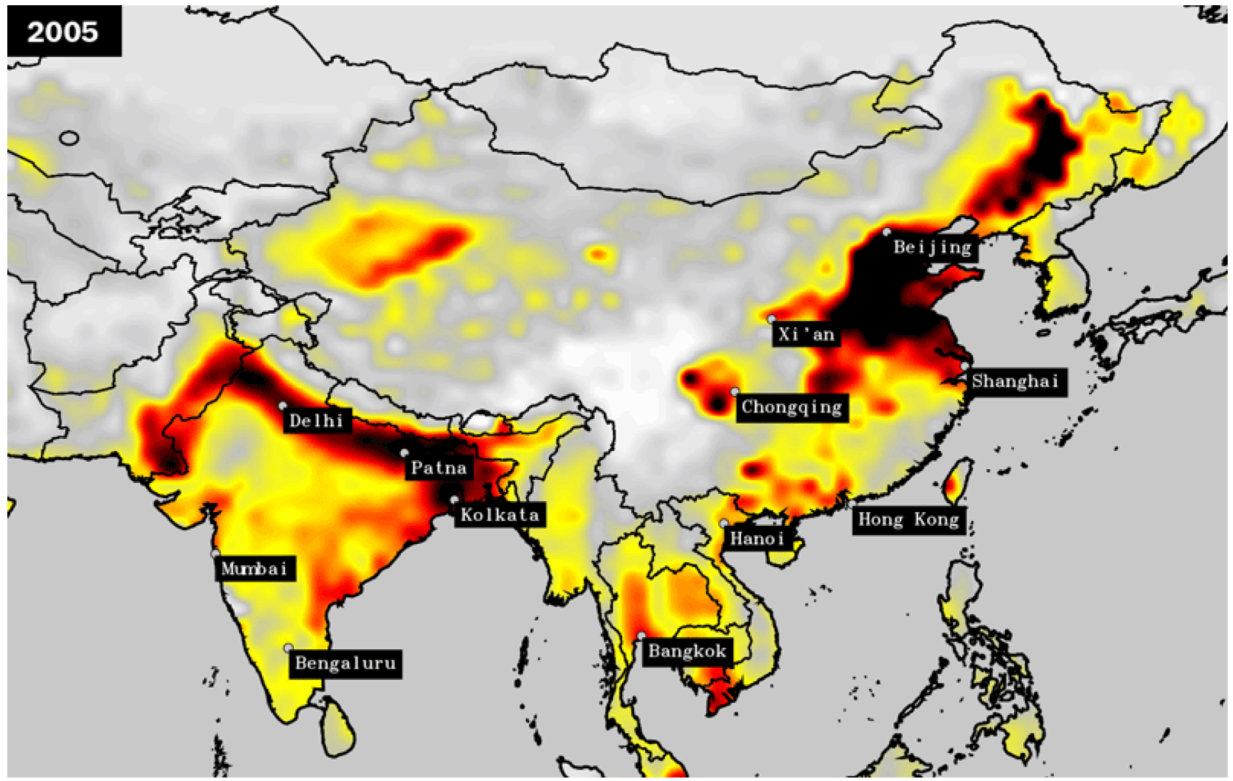
- Earth observing Satellite RS instruments typically make observations at many discrete wavelengths or wavelength bands



- Typically for Air Quality applications, we mostly use Visible for Particulate Pollution and UV for trace gas pollution
- IR channels are used to detect clouds and their properties

Aerosols: Tiny but Potent Air Pollutants

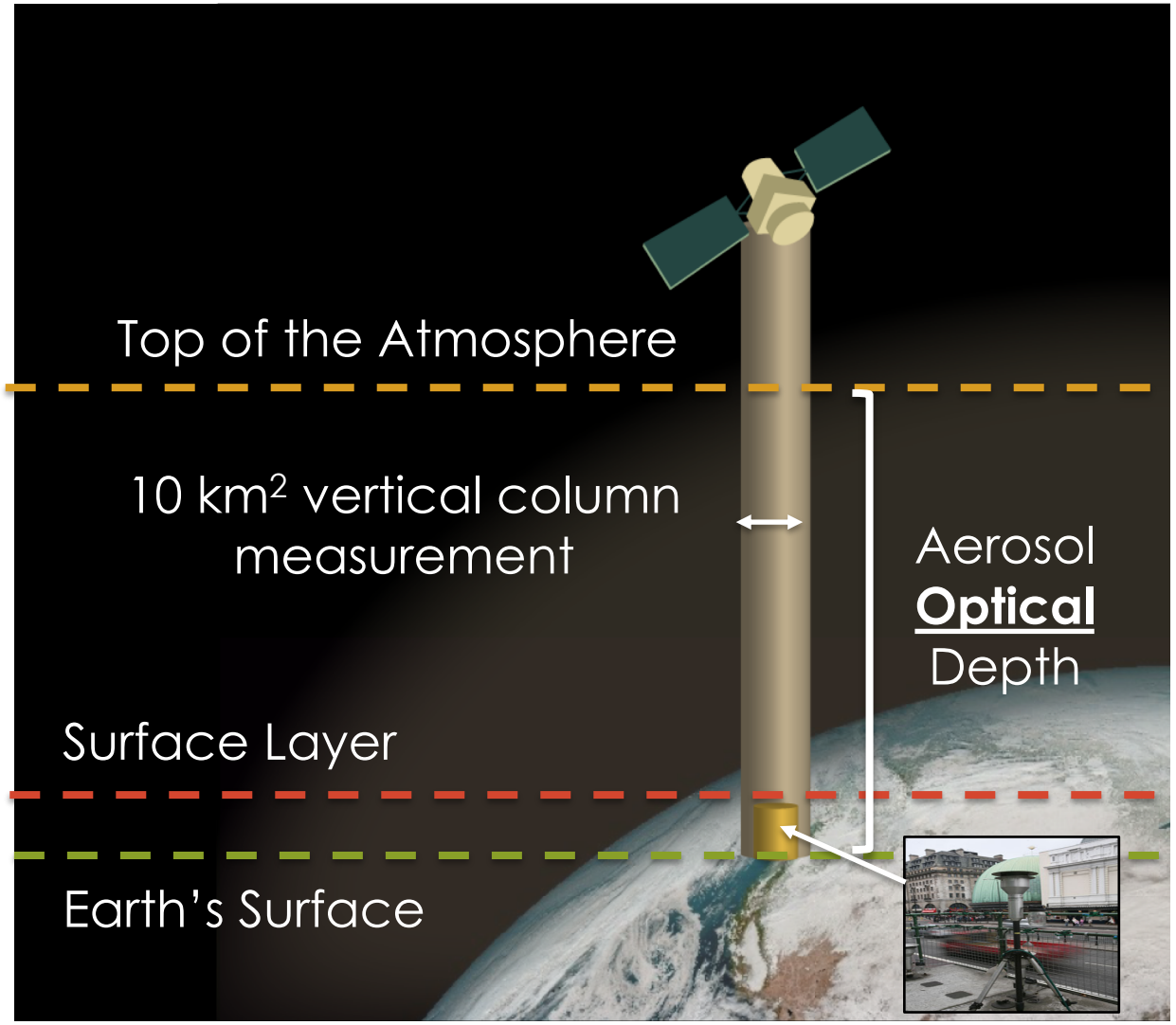




An example to show Ambient Air quality ($PM_{2.5}$) over India and China during 2005/2011/2015

Credit (Right): Washington Post

What do we get from satellites?



Aerosol Optical Depth:

- particle size
- composition
- water uptake
- vertical distribution

AOD represents the amount of aerosols in the entire column of the atmosphere

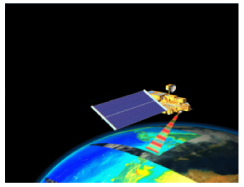
AOD is the column-integrated value from TOA to surface

Columnar aerosol optical depth correlates well with $PM_{2.5}$

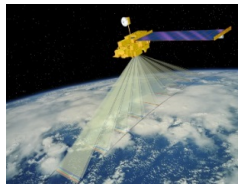
Therefore, satellite-derived AOD can be used as a surrogate to represent particulate mass at the surface

Spaceborne Sensors for Aerosol Studies

Low Earth Orbiting Satellites

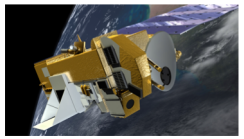


Terra/Aqua: MODIS (MODerate resolution Imaging SpectroRadiometer)
Measures: total column aerosol AOD



Terra: MISR (Multi-angle Imaging SpectroRadiometer)
Measures: AOD, particle type

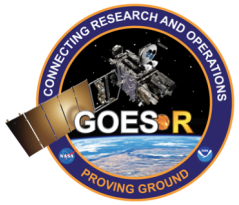
Suomi-NPP: VIIRS (Visible Infrared Imaging Radiometer Suite)
Measures: AOD, particle type



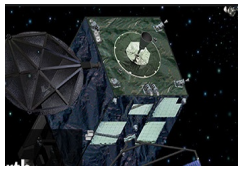
Aura: OMI (Ozone Monitoring Instrument)
Active & Passive sounders can provide vertical profiles – cloud profiling radar (CLOUDSAT), Lidar based (CALIPSO), Atmospheric Infrared Sounder (AIRS)

Geostationary Satellites

INSAT-3D/3DR: Geostationary, Indian Ocean, 30-min temporal resolution, imager-visible AOD at 10 km spatial resolution



GOES-R&S: Geostationary, Americas, 15-min temporal resolution, Advanced Baseline Imager and Multichannel Imager



Himwari-8: Geostationary, Pacific ocean, 15-min temporal resolution, sensor similar to ABI (multichannel radiometer)

Temporal Resolution: Low Earth Orbit vs. Geostationary

- Global coverage in:
  - MODIS: 1-2 days
  - MISR: 6-8 days
  - VIIRS: 1 day
  - OMI: 1 day

- Regional coverage every:
  - INSAT-3D/3DR: 30 min (15 min combined)
  - GOES-R: 15 min
  - Himawari-8: 15 min

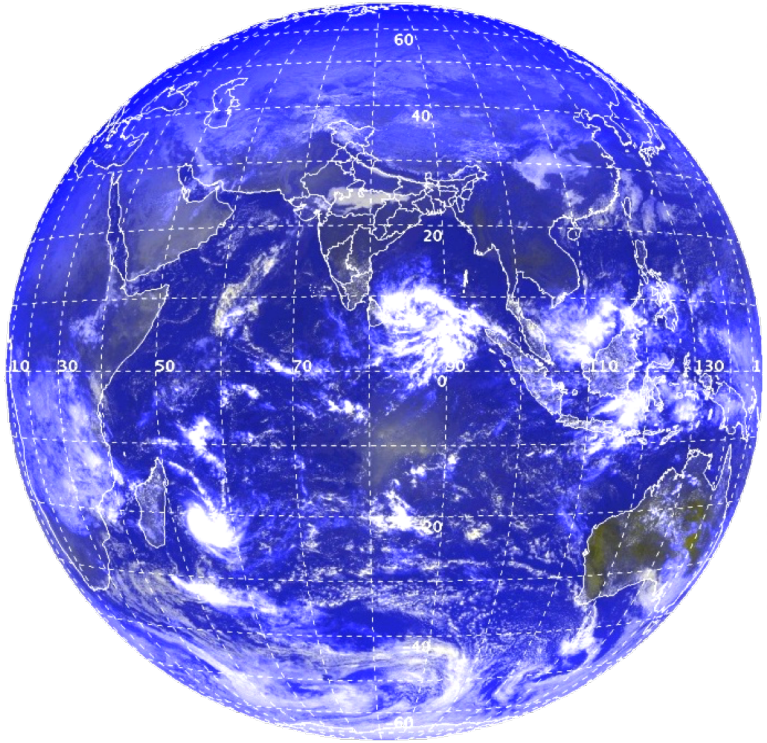
Global Geostationary Meteorological Satellites

- GOES: United States of America
- Meteosat: European Space Agency
- Himawari: Japan
- Fengyun: China
- INSAT: India

Location

INSAT-3D at 82°E

INSAT-3DR at 74 °E



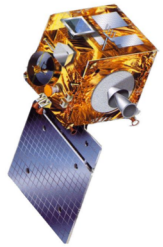
INSAT-3D image

Name of Satellite, Alternate Names	Longitude (degrees)	Launched (year)
GOCI/COMS-1 (Communication, Ocean, and Meteorological Satellite; Cheollian)	128	2010
Electro-L1 (GOMS 2 [Geostationary Operational Meteorological Satellite 2]	76	2011
Electro-L2	77.8	2015
Fengyun 2D (FY-2D)	86.51	2006
Fengyun 2E (FY-2E)	123.59	2008
Fengyun 2F (FY-2F)	105	2012
Fengyun 2G (FY 2G)	0	2014
Gaofen 4	105.5	2015
GOES 13 (Geostationary Operational Environmental Satellite, GOES-N)	−75	2006
GOES 14 (Geostationary Operational Environmental Satellite, GOES-O)	−104.41	2009
GOES 15 (Geostationary Operational Environmental Satellite, GOES-P)	−135	2010
GOES 16 (Geostationary Operational Environmental Satellite GOES-R)	−75	2016
Himawari 8	140	2014
Himawari 9	140	2016
INSAT 3A (Indian National Satellite)	93.53	2003
INSAT 3D (Indian National Satellite)	82	2013
INSAT 3DR (Indian National Satellite)	74	2016
Kalpana-1 (Metsat-1)	74.07	2002
SEVIRI/Meteosat 10 (MSGalaxy-3,MSG 3)	0	2012
SEVIRI/Meteosat 11 (MSG 4)	0	2015
SEVIRI/Meteosat 8 (MSGalaxy-1, MSG-1)	41.5	2002
SEVIRI/Meteosat 9 (MSGalaxy-2, MSG 2)	−0.02	2005
MTSAT-2 (Multi-Functional Transport Satellite)	145.06	2006

Evolution of Indian Missions for Weather & Climate Studies

Geostationary

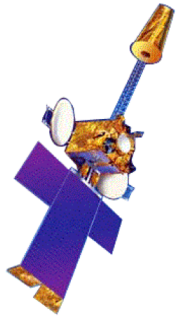
Kalpana-1 (2002)



VHRR

CMV, OLR, UTH, Rain

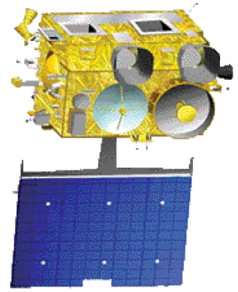
INSAT-3A (2003)



VHRR, CCD

CMV, OLR, UTH, Rain, Aerosol

INSAT-3D (2013) & 3DR (2016)



6-Ch VHRR IR Sounder

SST, CMV, OLR, UTH, Rain, T, h, Profile, Ozone

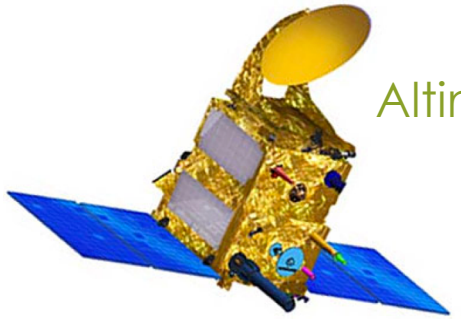
Low Earth Orbit

OCEANSAT-1/2 (1999/2009); SCATSAT (2016)

MSMR, OCM, Scatterometer ROSA (GPS)

Vector Winds, Aerosol, T&h profile

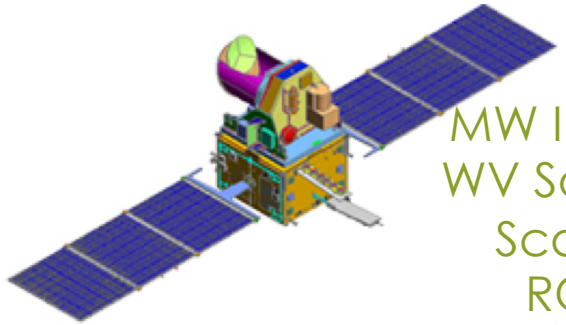
SARAL (2013)



Altimeter

SSH, Waves, Winds

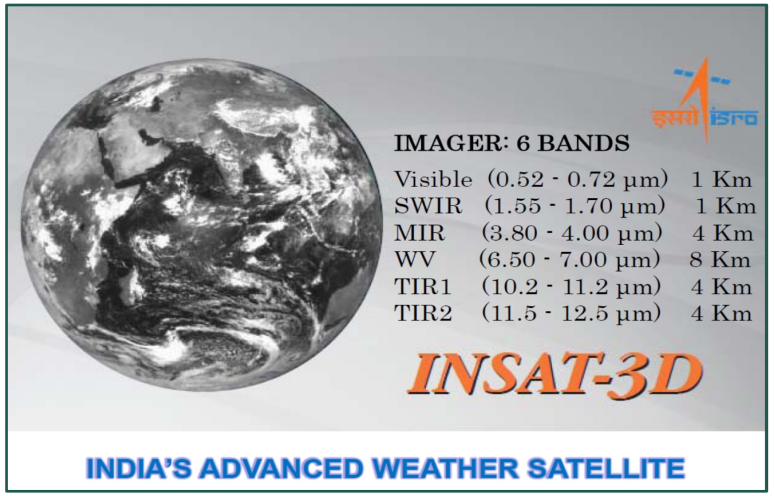
MEGHA-TROPIQES (2011)



MW Imager, WV Sounder, ScaRaB, ROSA

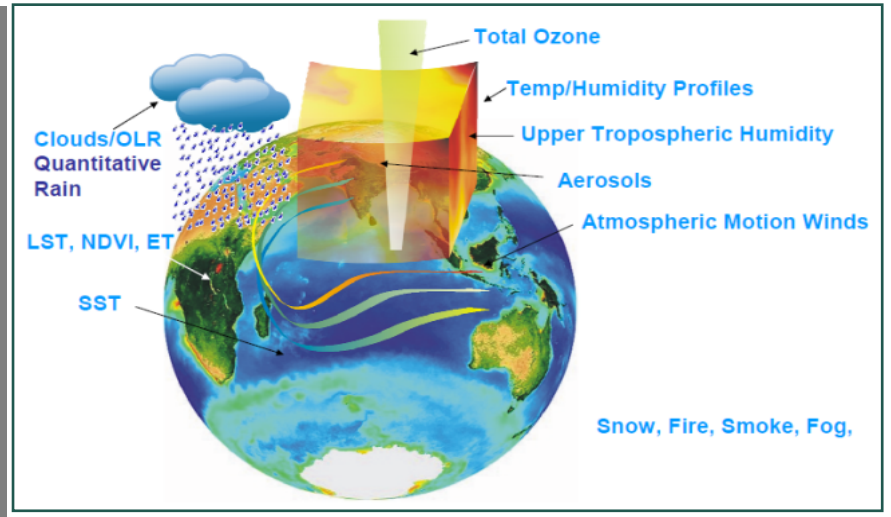
SS Wind, TWV, Rainfall, T, h Profile, Radiation Budget

INSAT-3D/3DR Meteorological Satellites

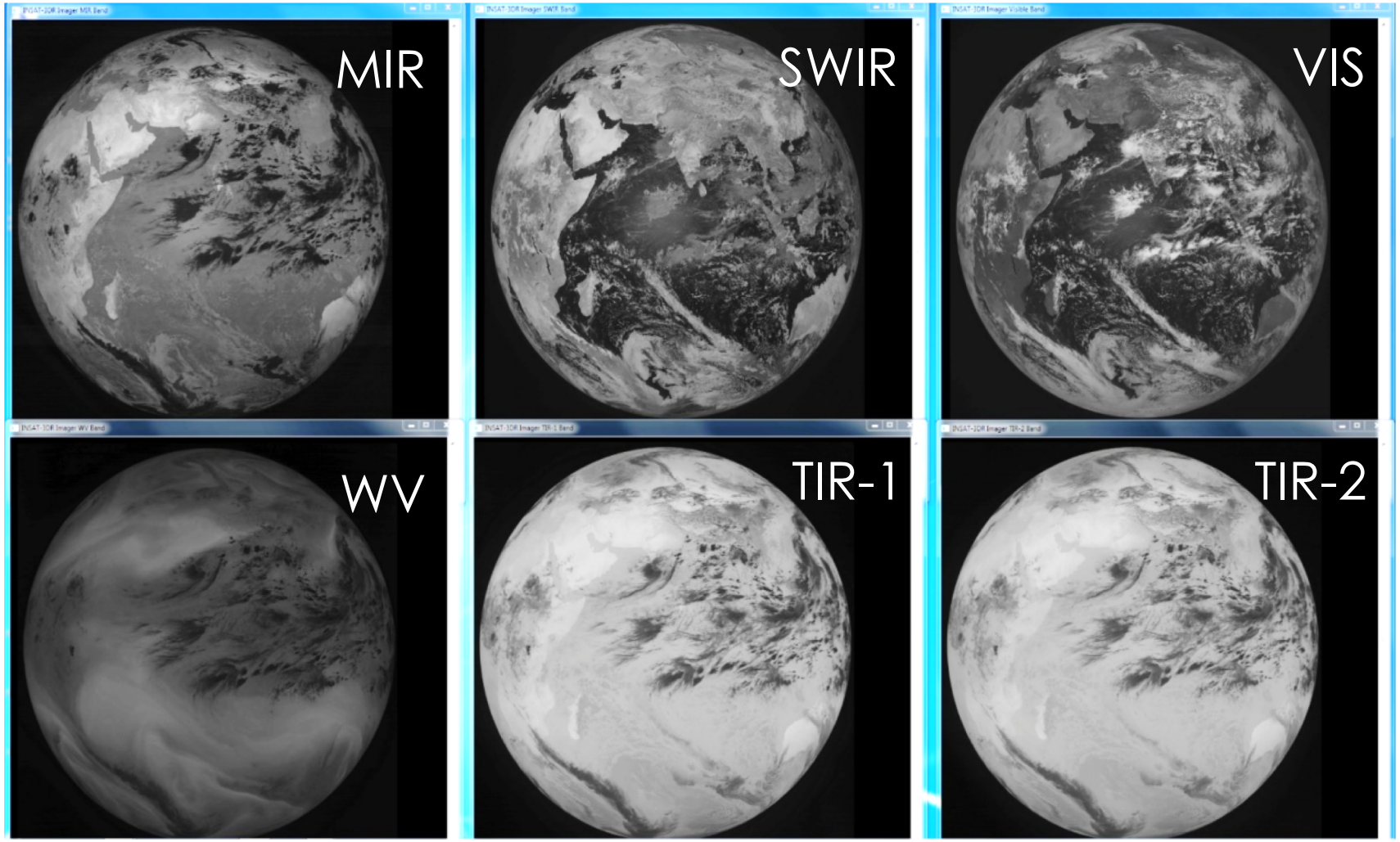


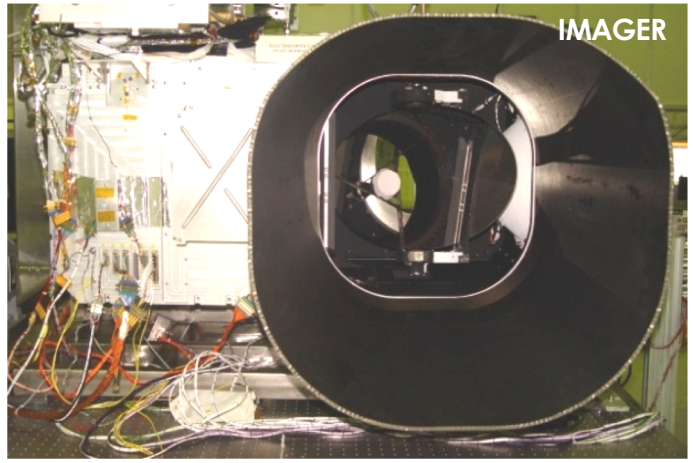
Parameter	Imager	Sounder
Telescope Aperture	310 mm	310 mm
No. of Channels	6	19 (18 infrared + 1 Visible)
IFOV	1 km (Visible and SWIR) 4 km (MIR, TIR-1 & TIR-2) 8 km (Water Vapor)	10 km
Frame Time	~27 minutes	160 minutes for 6000x 6000km area
Signal Quantization	10 bits	14 bits

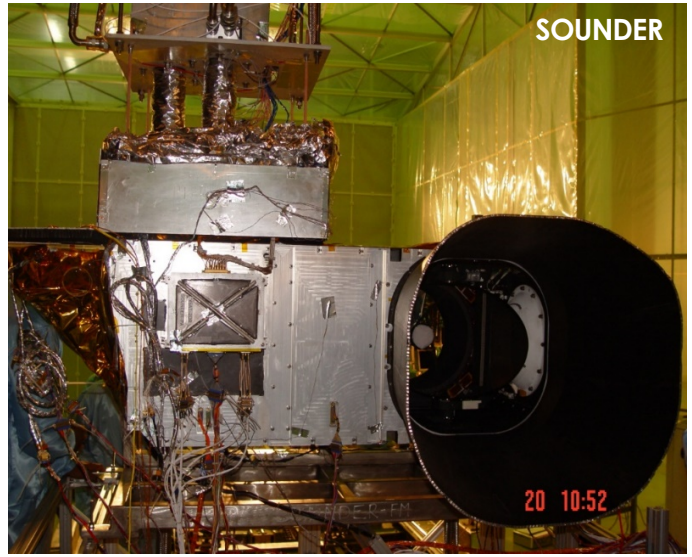
- Round-the-clock Imaging from 36000 km
- Imaging every 15 minutes with INSAT-3D and INSAT-3DR
- 6-Channel Imager and 19-channel Sounder
- Photodiodes as detector
- Filter Wheel for Sounder Channel Selection
- E-W Scanning and N-S Stepping for coverage of Earth Disk
- More than 20 Geo Physical Parameter Extraction (OLR, CMV, QPE, UTH etc.)
- Weather Monitoring and Forecasting



Earth Observation for Meteorology: INSAT-3D/3DR

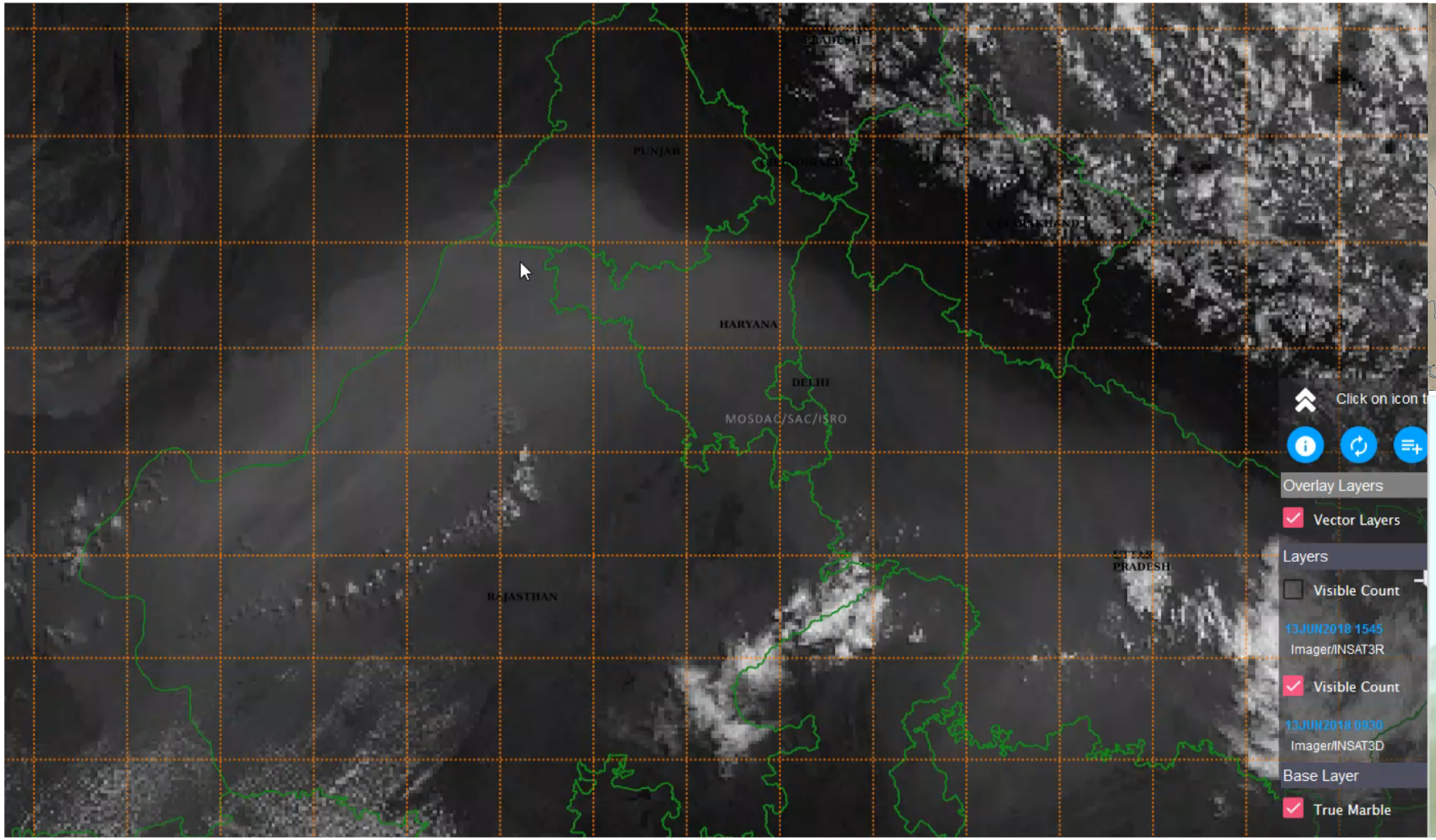


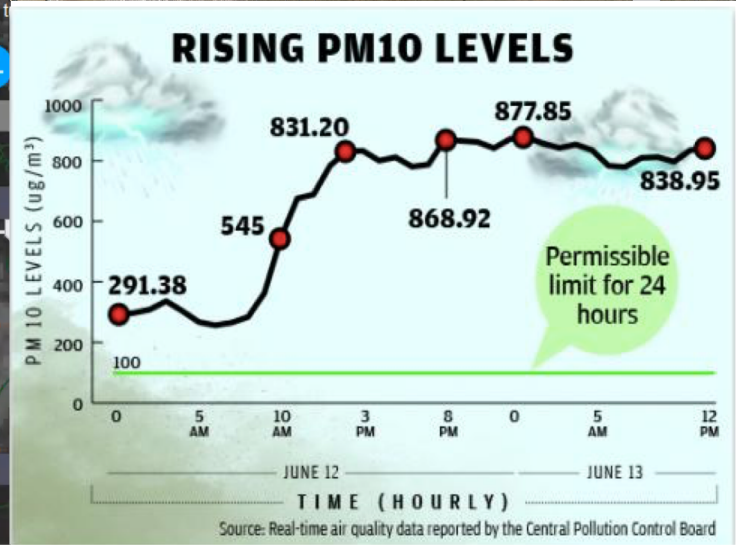




Credit : SAC-ISRO

Progression of Dust Storm in North India on June 13, 2018 by INSAT-3D Imager Data





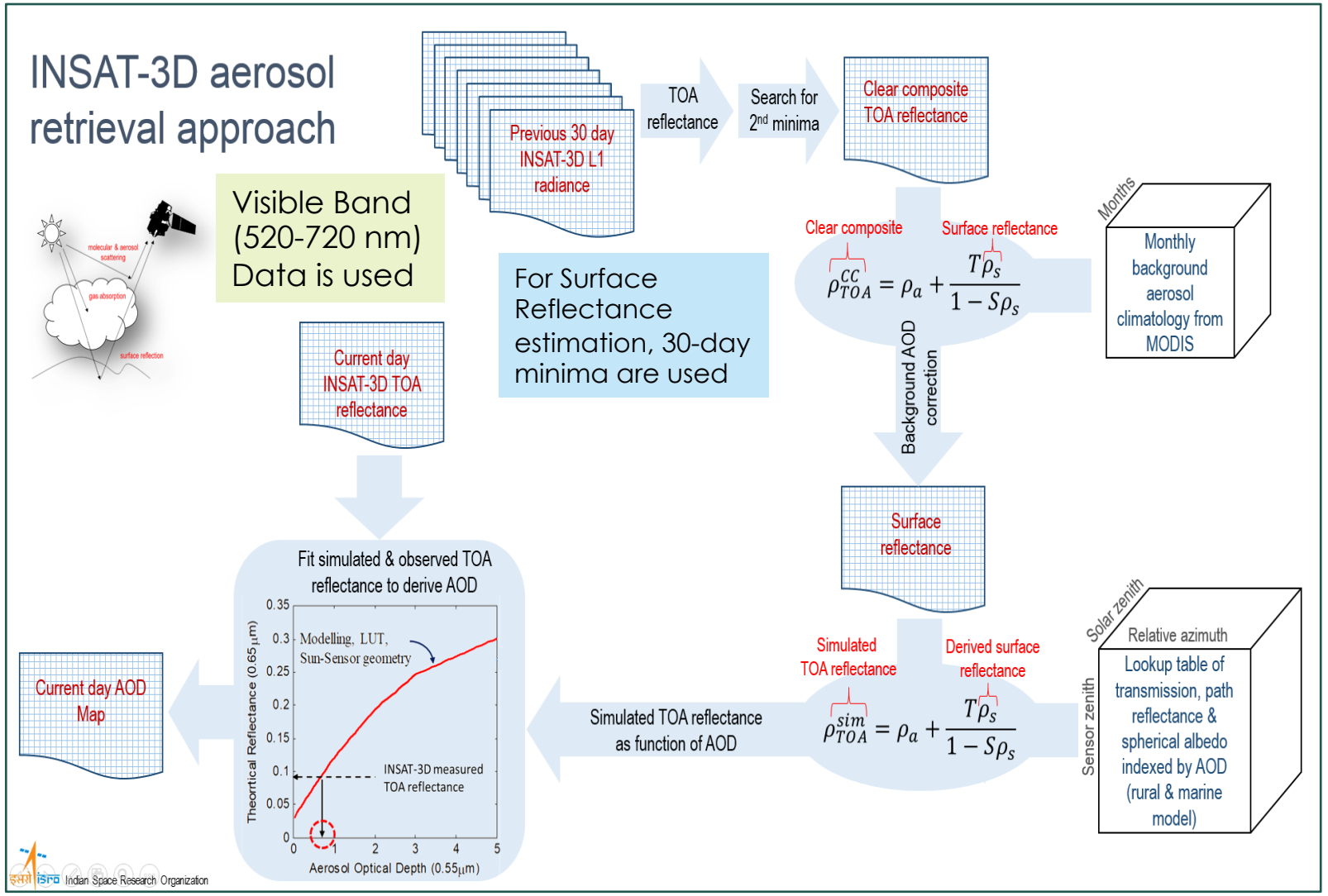
Credit : IIRS-ISRO

INSAT-3D Imager Visible Channel

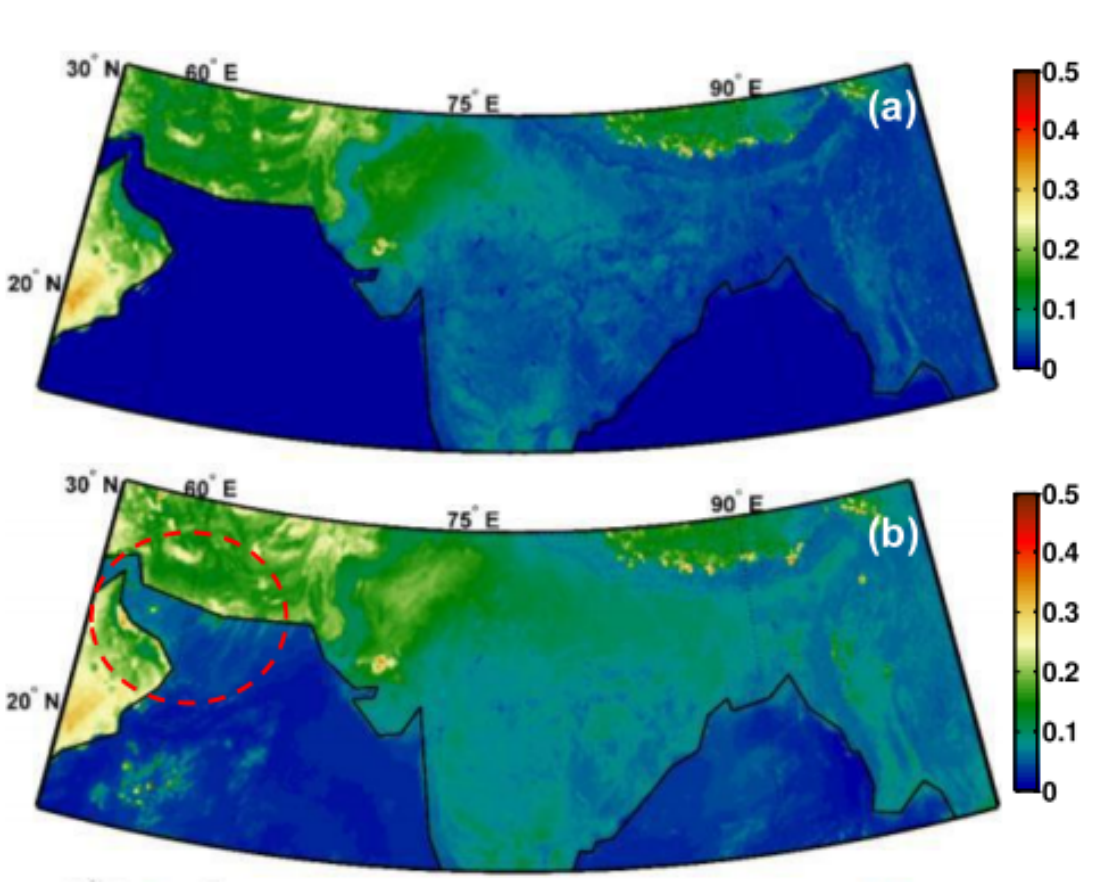
Algorithm for Aerosol Optical Depth (AOD) Estimation Using INSAT-3D Imager

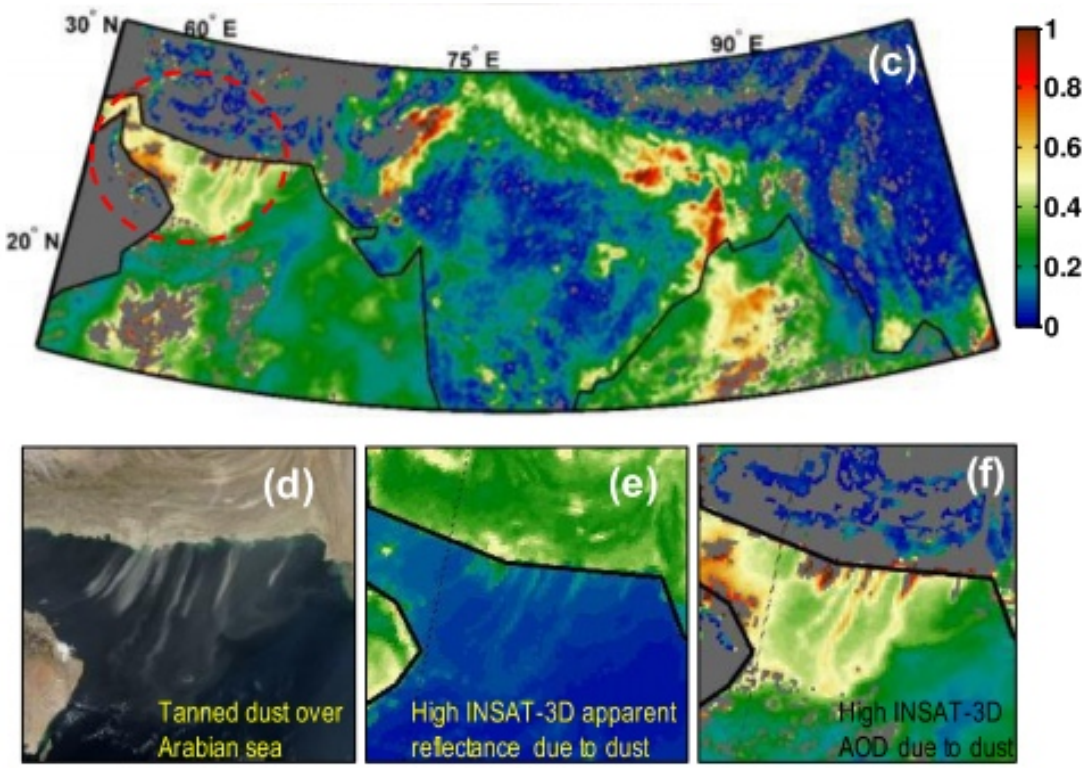
What is AOD?

- AOD is a quantitative estimate of aerosols in the atmosphere
- It is measure of scattering/absorption of visible light by particles in the air
- AOD is unitless. Ranges can be 0 to more than
- No AOD is estimated in the presence of clouds or sun glint areas over sea



Steps in Generating AOD from INSAT-3D Imager Data





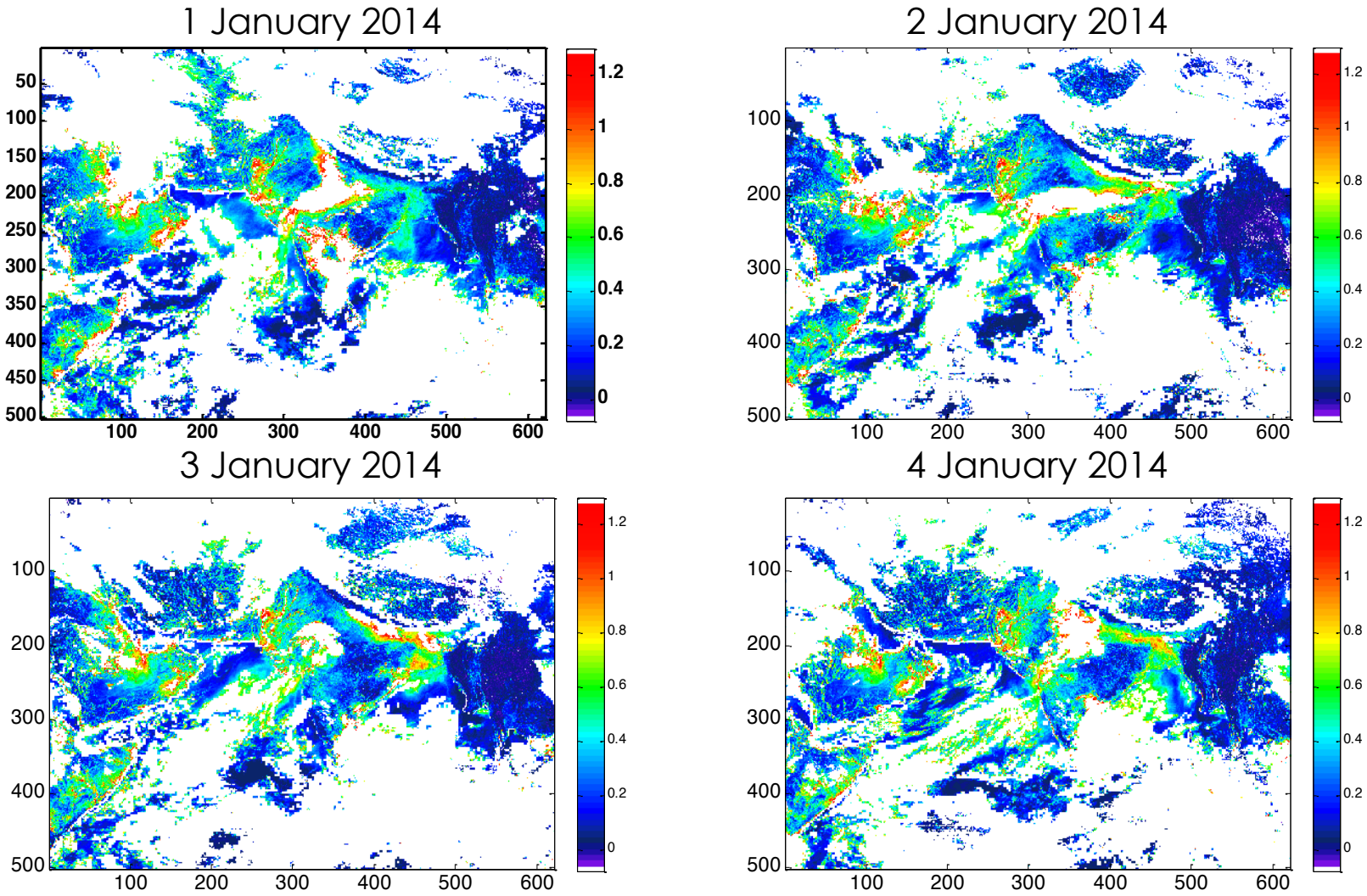
(a) Surface Reflectance using 30-day minima
(b) Top of the Atmosphere reflectance image

(c)AOD image from INSAT-3D image data
(d) MODIS Images (e) TOA reflectance (f) AOD image

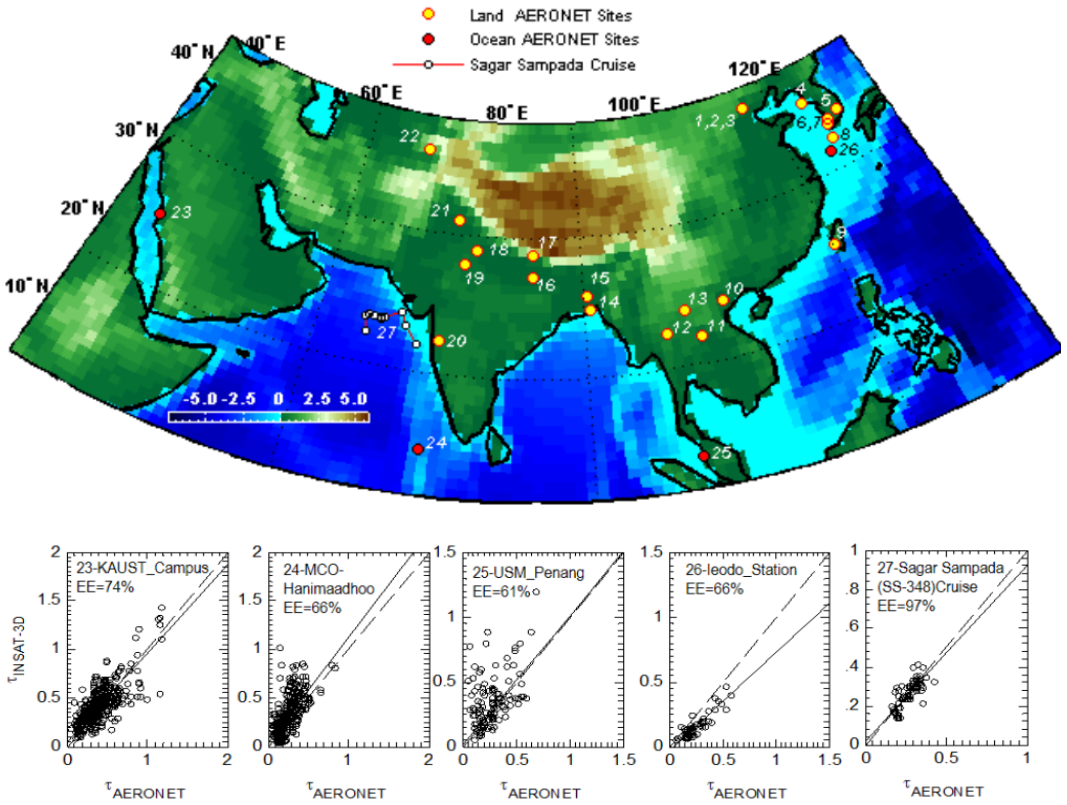
Credit : Mishra M. (2018), JGR, Atmosphere

22 Nov 2016 data set

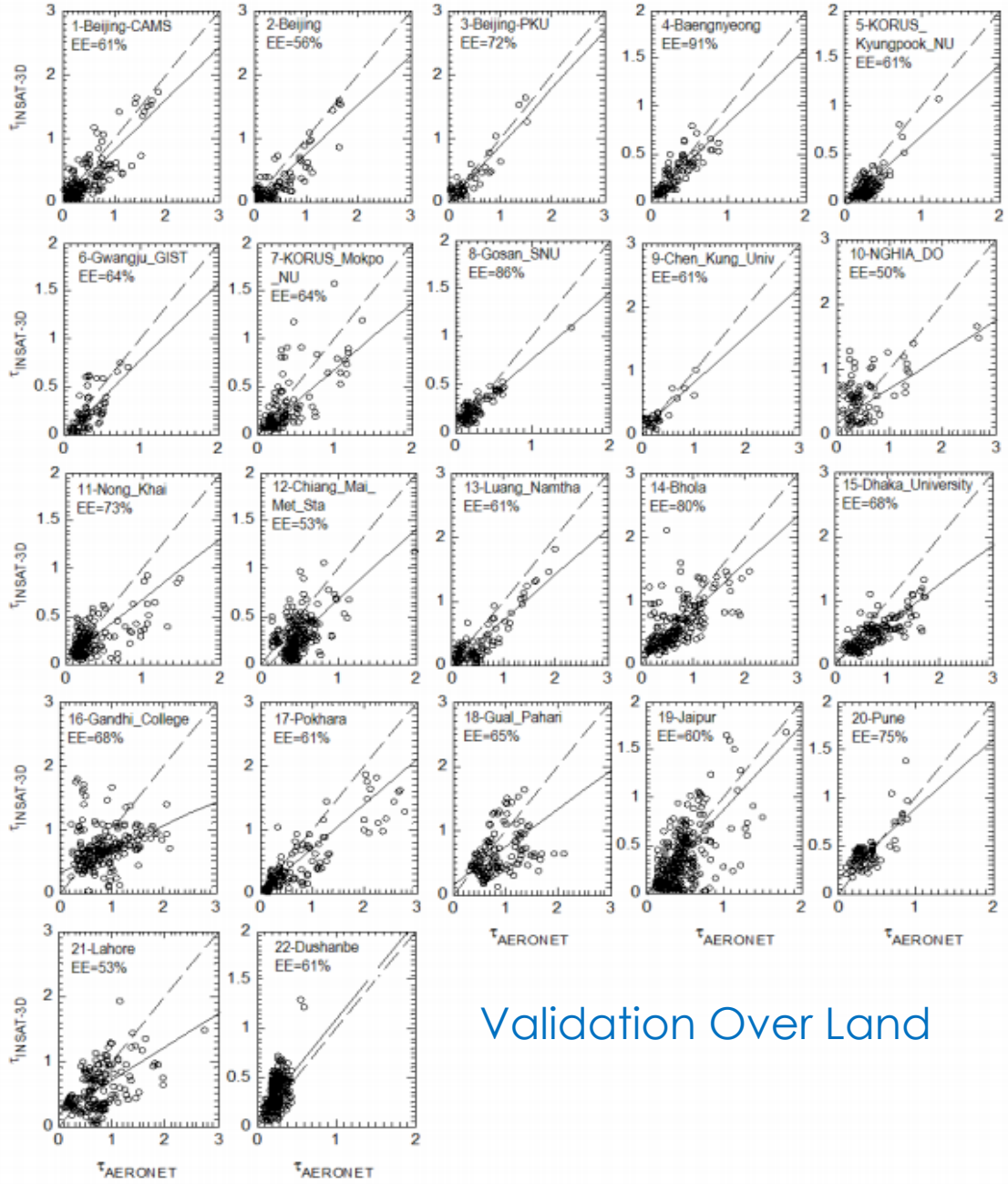
Example AOD Images from INSAT-3D



Validation of the AOD from INSAT-3D



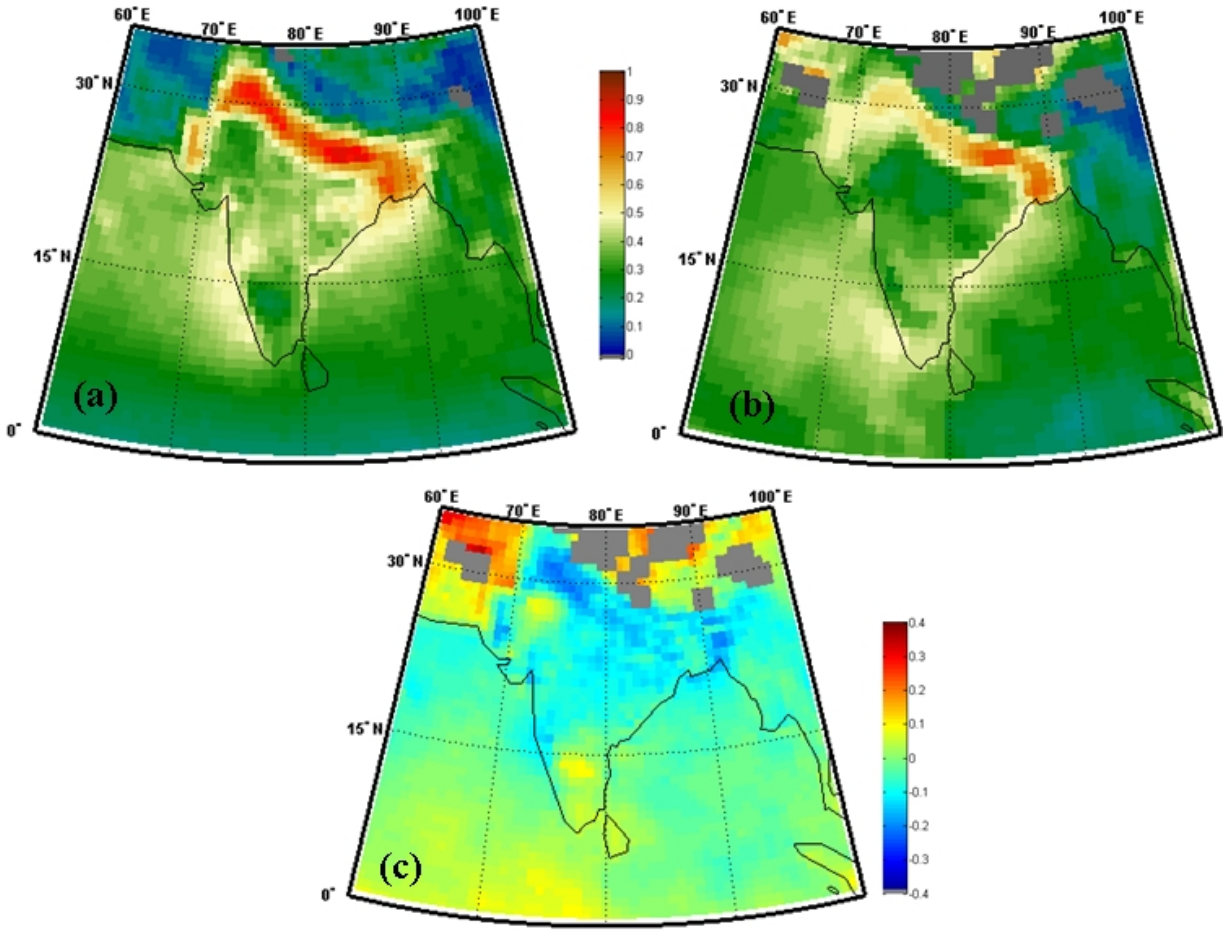
Validation Over Oceans



Validation Over Land

Credit : Mishra M. (2018)

INSAT-3D Aerosol Comparison with MODIS AOD



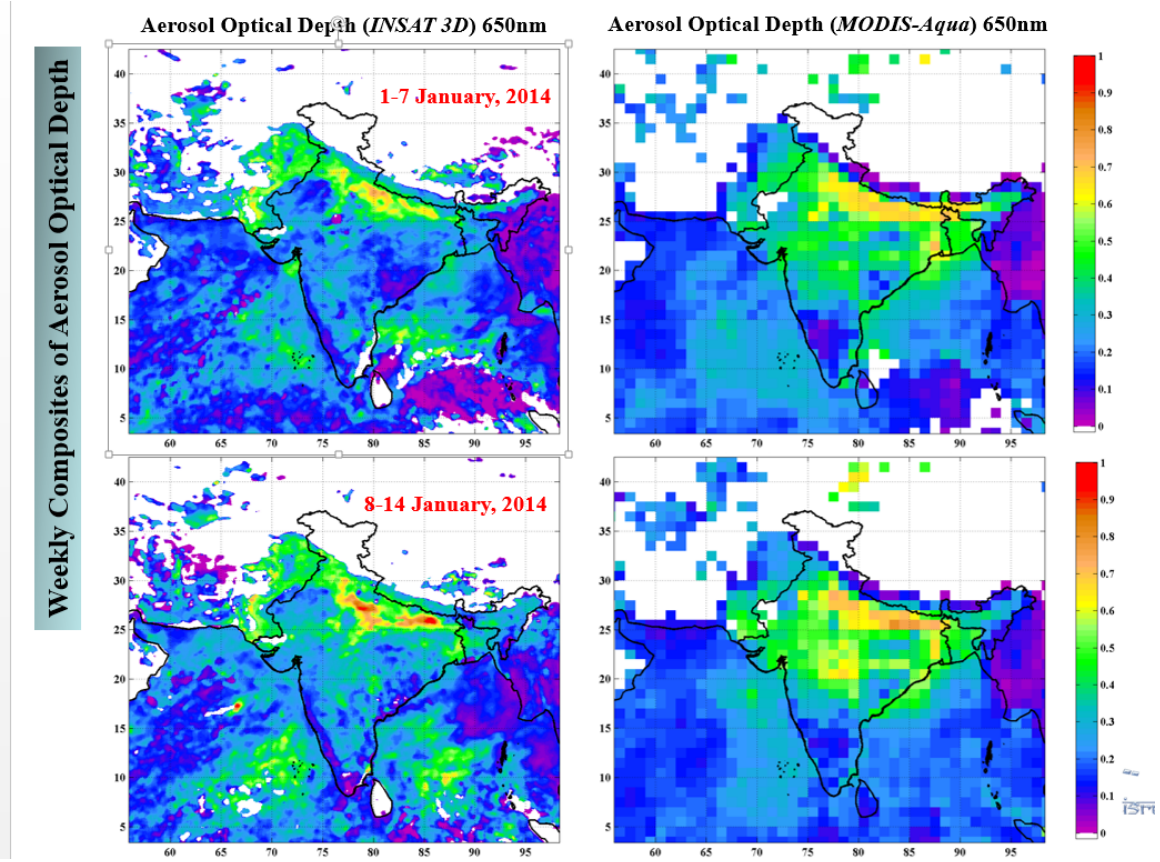
(a–c) Annual average map of MODIS-Aqua AOD, INSAT-3D AOD, and the difference (INSAT3D AOD - MODIS AOD), respectively, over Indian landmass and adjoining ocean for year 2016

MODIS = Moderate Resolution Imaging Spectro radiometer

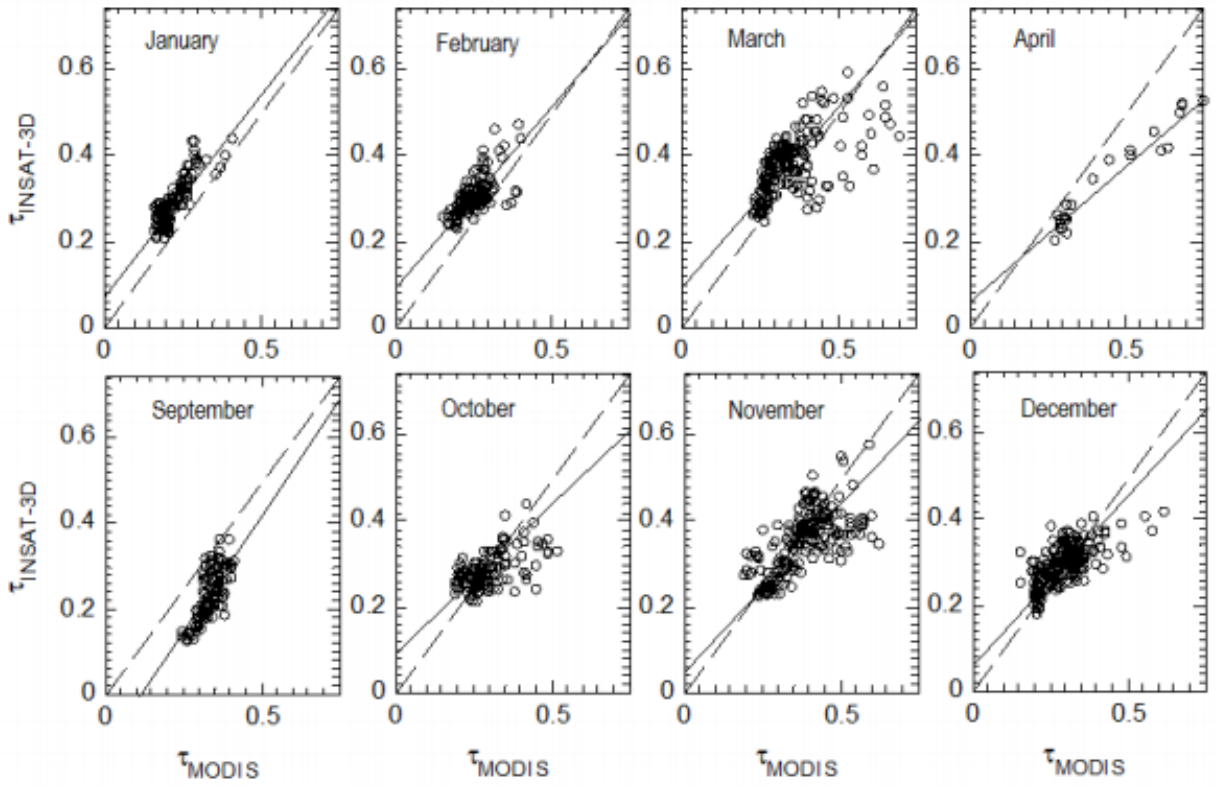
INSAT-3D = Indian National Satellite

Credit : Mishra M. , JGR, (2018)

Validation of INSAT-3D AOD with MODIS Aqua

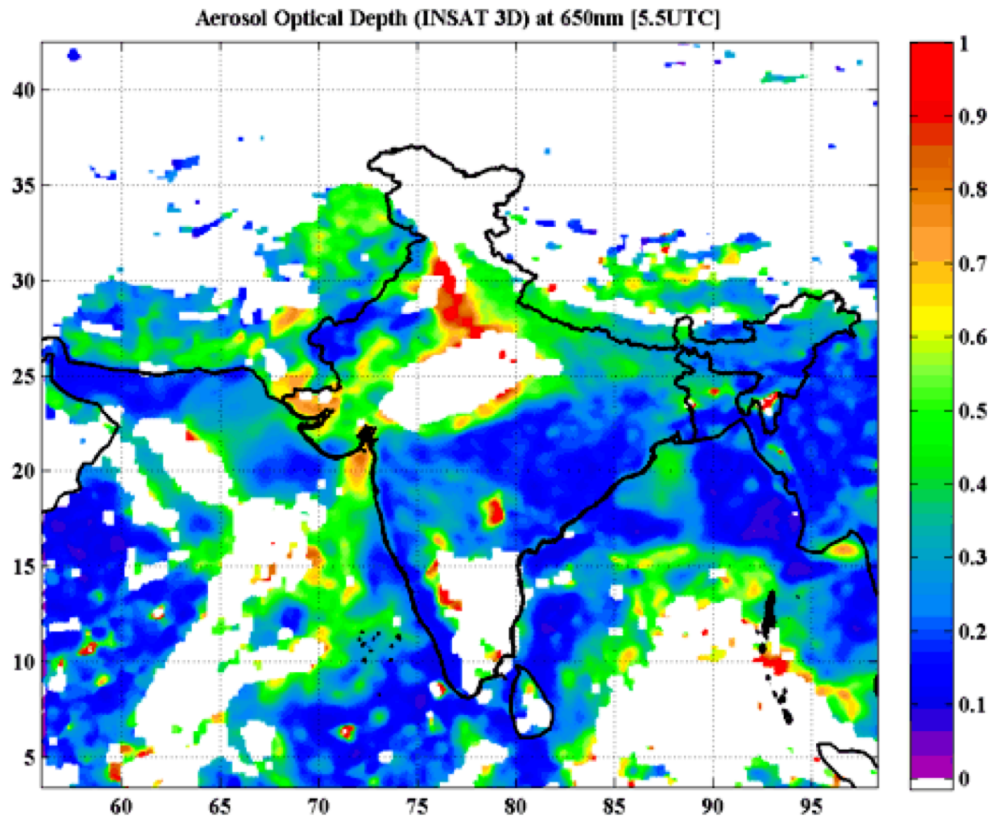


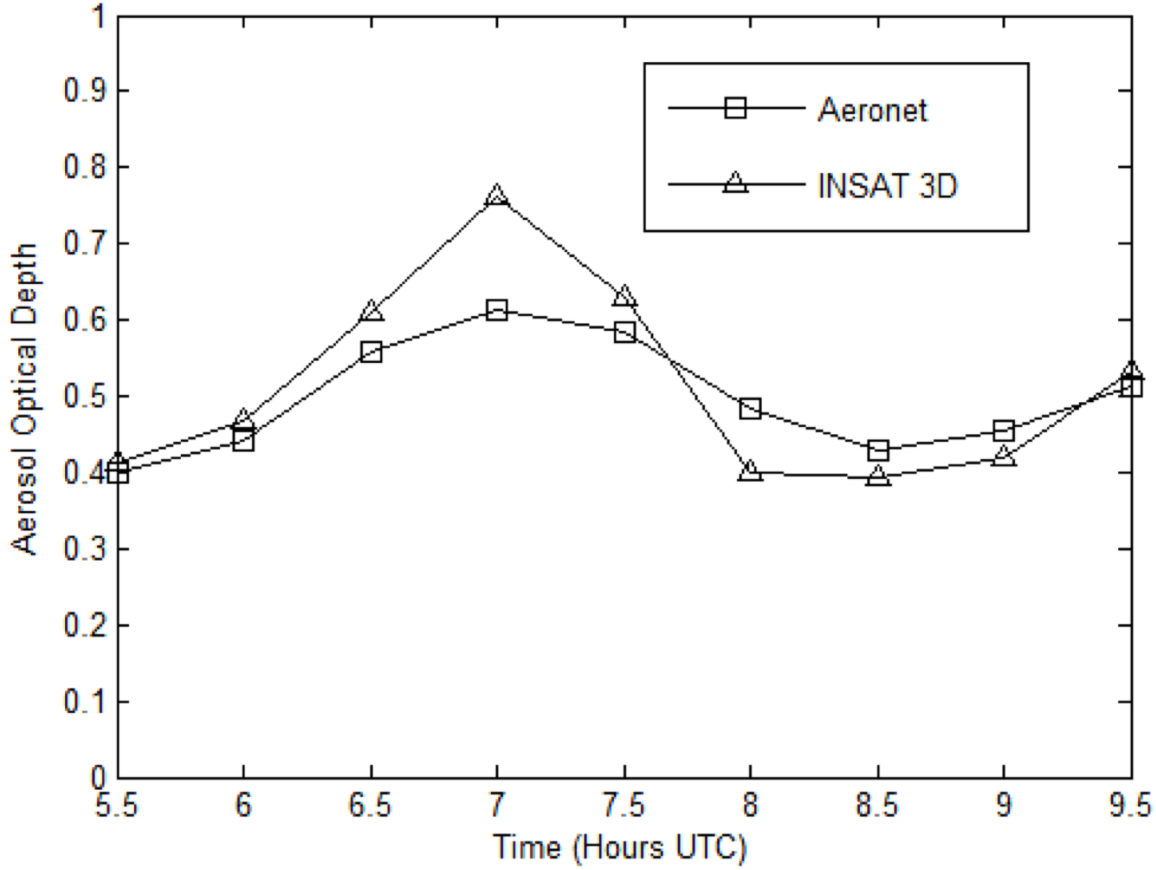
Weekly Basis



Monthly Basis

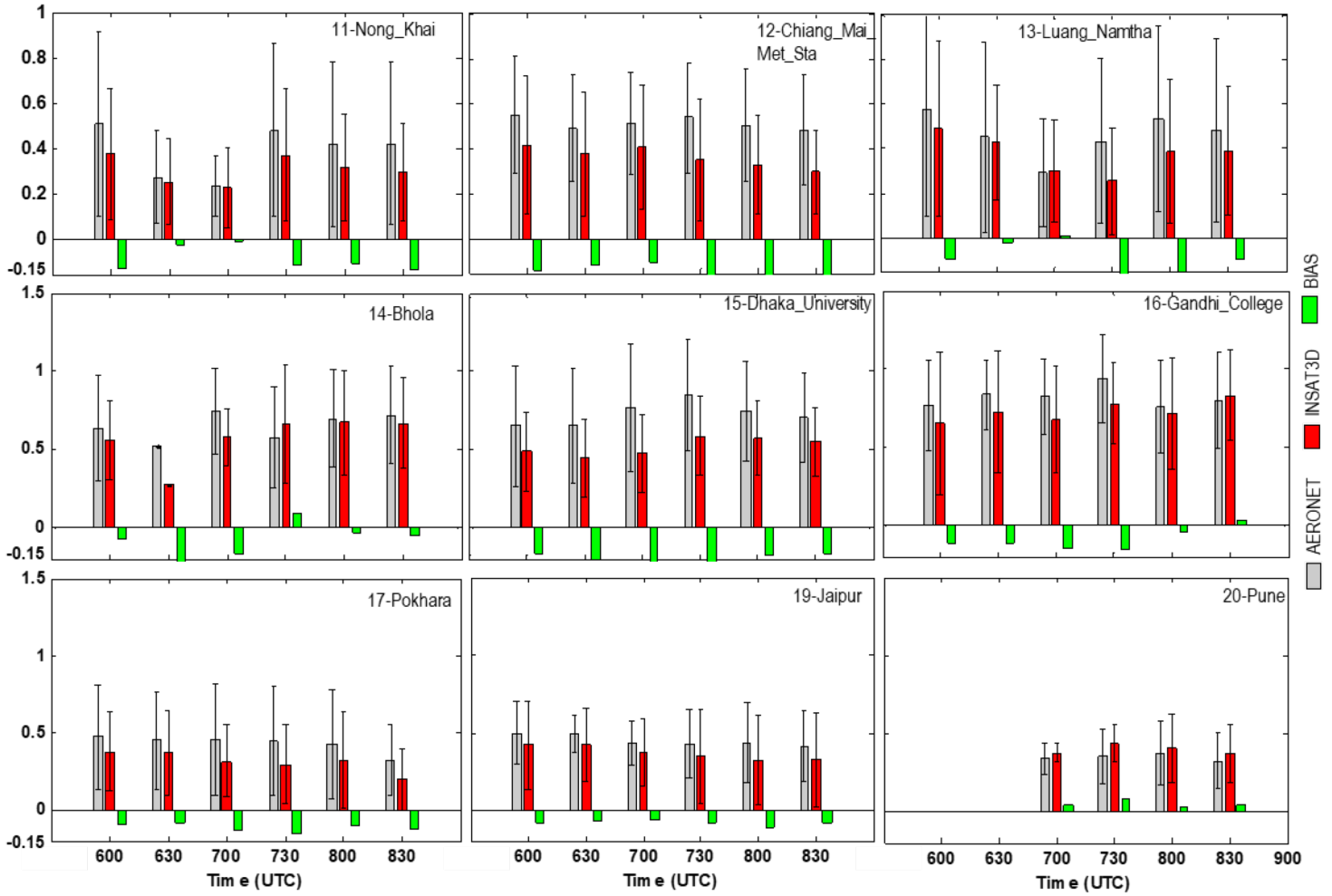
Temporal Aerosol Distribution Using INSAT-3D





Animation of INSAT 3D derived AOD from 05:30 hrs to 09:30 hrs (UTC) on 1 January 2014

Diurnal Variability in INSAT-3D and AERONET AOD



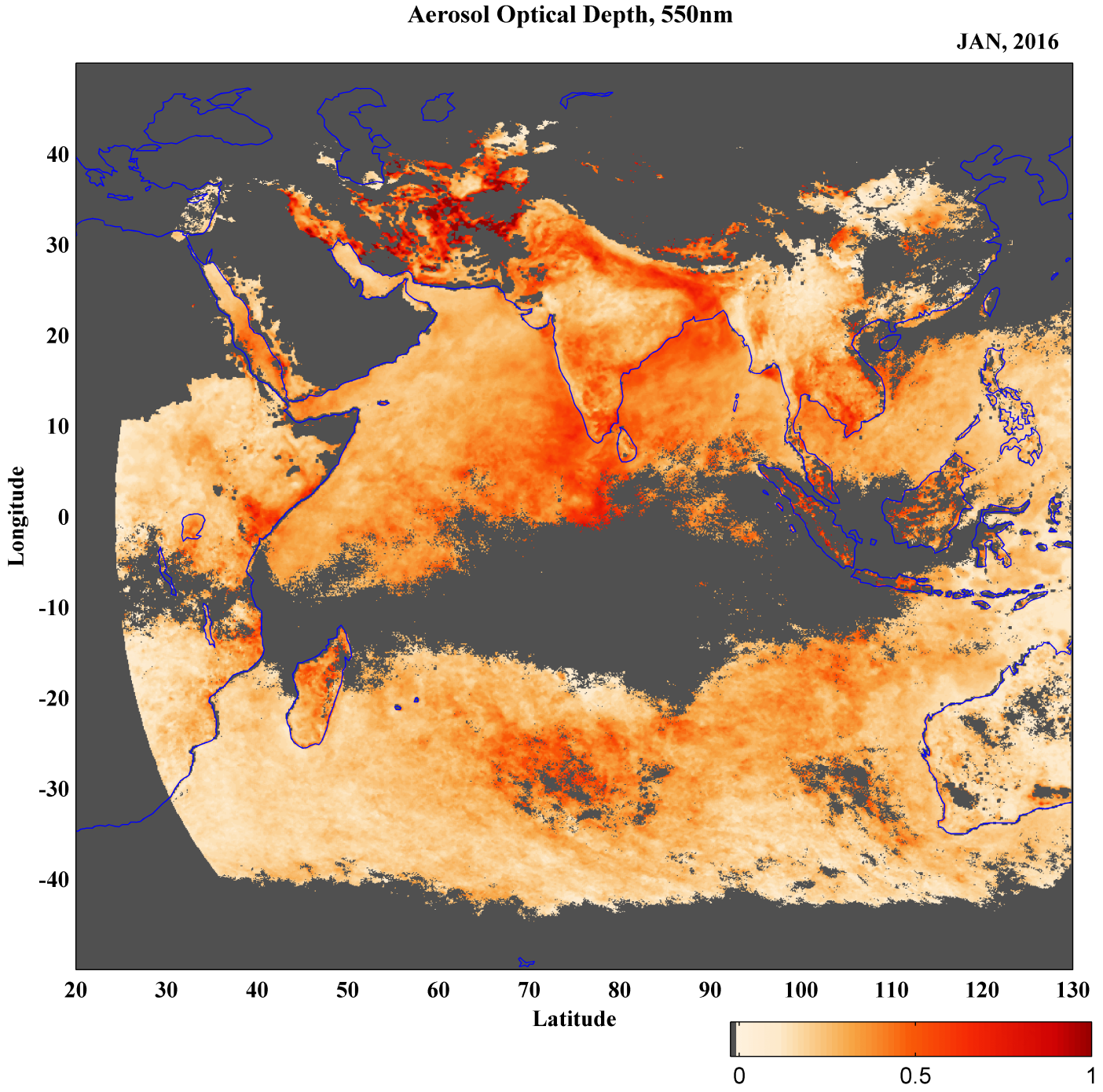
Credit : Mishra M. , JGR, (2018)

India and South-East Asian countries

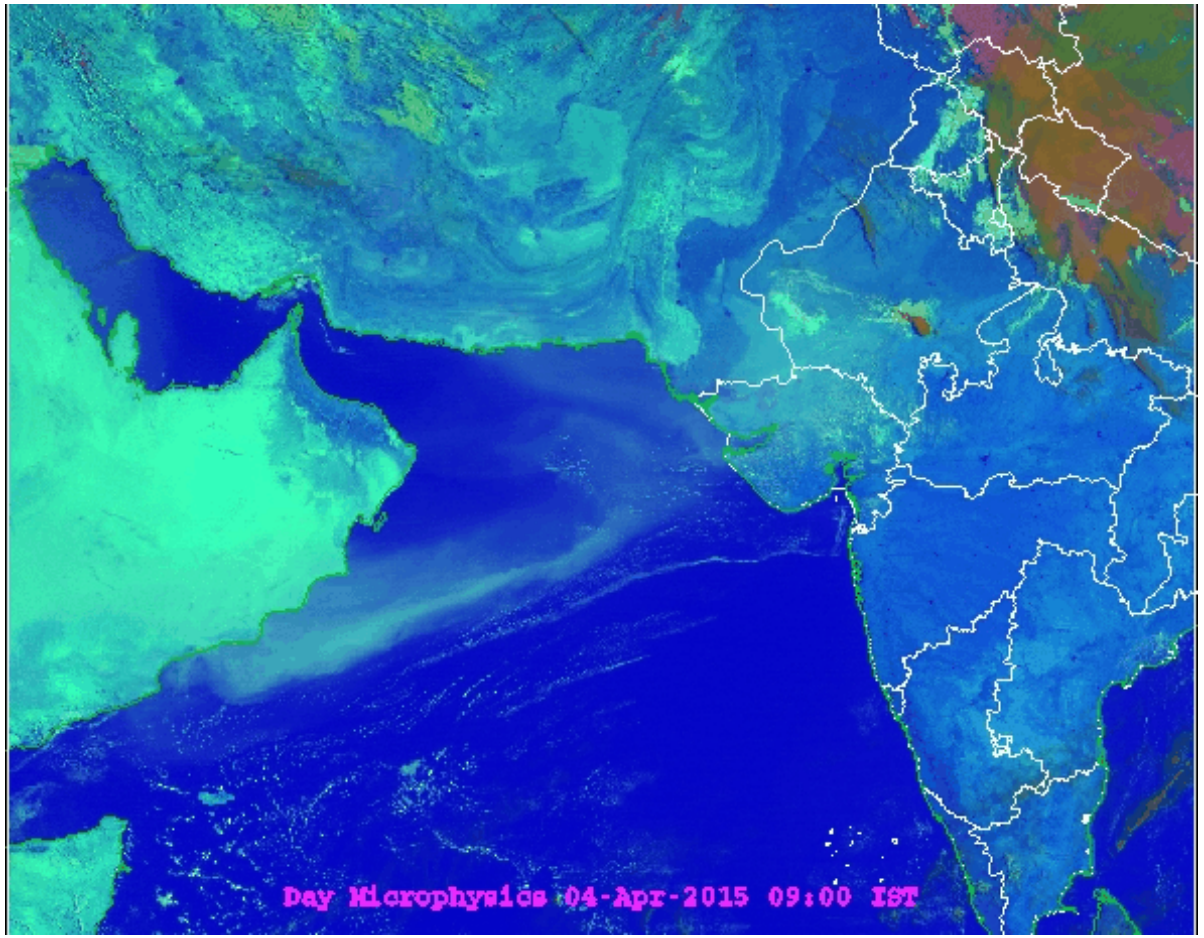
Mean Monthly of AOD Variability Over the Indian Ocean Region

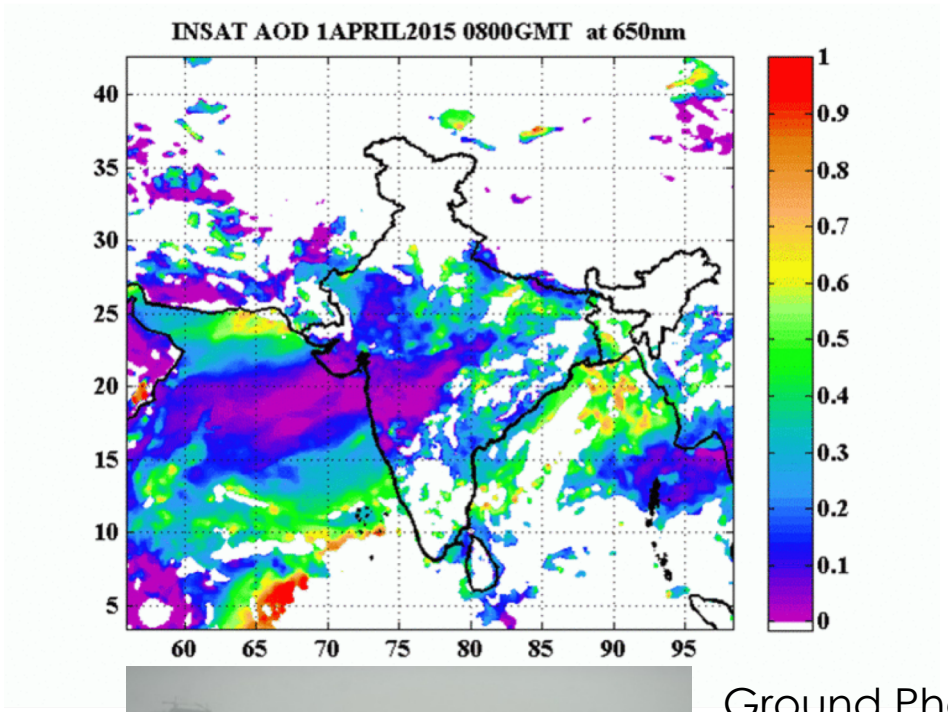
- INSAT-3D operational products available from MOSDAC
  - www.mosdac.gov.in

- Air Quality Portal of VEDAS
  - www.vedas.sac.gov.in

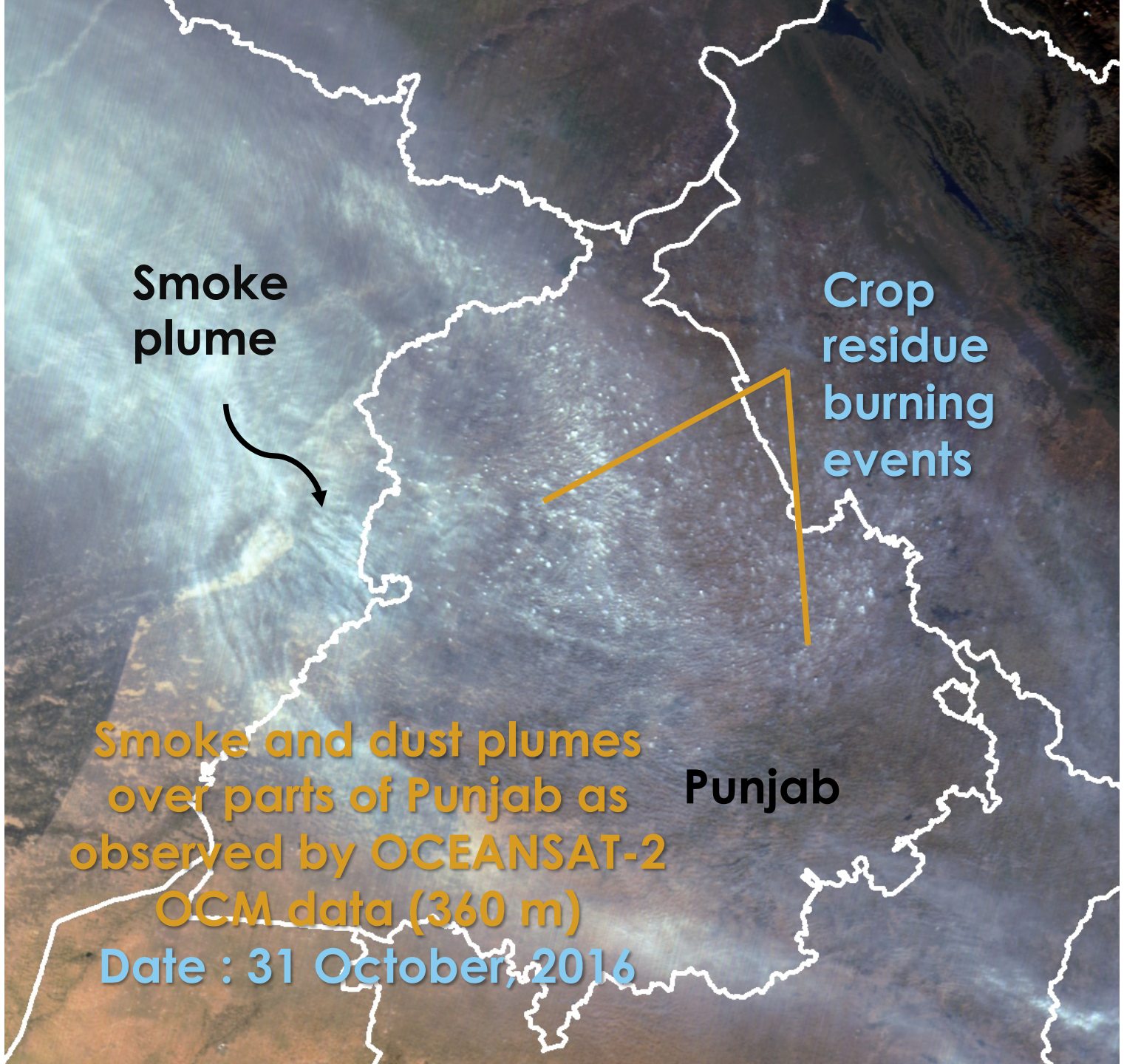


Dust Storm Monitoring Using INSAT-3D Imager on April 04, 2015





Ground Photo
Mumbai



Smoke and dust plumes over parts of Punjab as observed by OCEANSAT-2 OCM data (360 m)
Date : 31 October, 2016

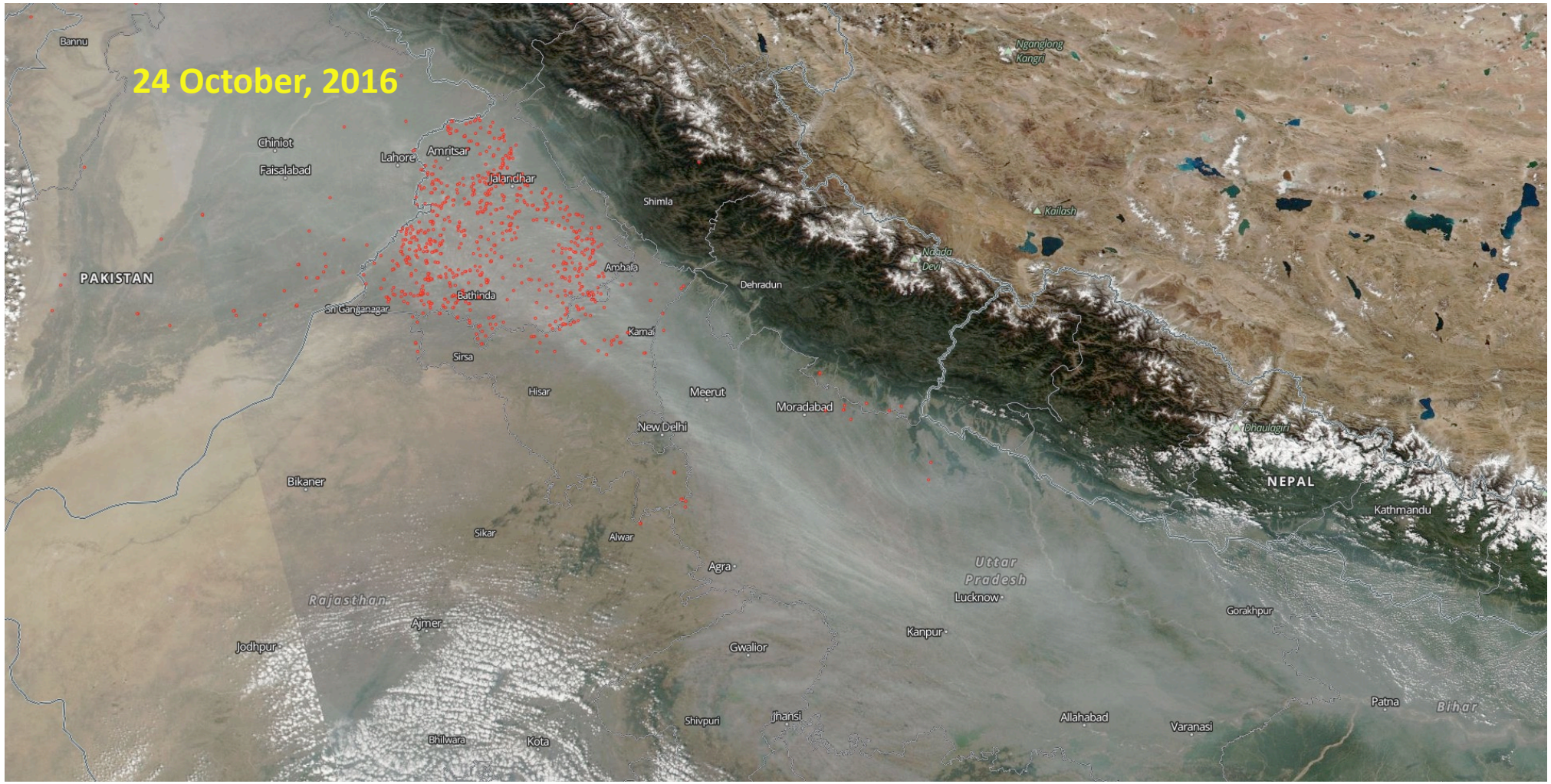
Crop Residue/Stubble Burning

1. What Is Stubble Burning?

Stubble burning is, quite simply, the act of removing paddy crop residue from the field to sow wheat. It's usually required in areas that use the 'combine harvesting' method which leaves crop residue behind. Now, what is combine harvesting?

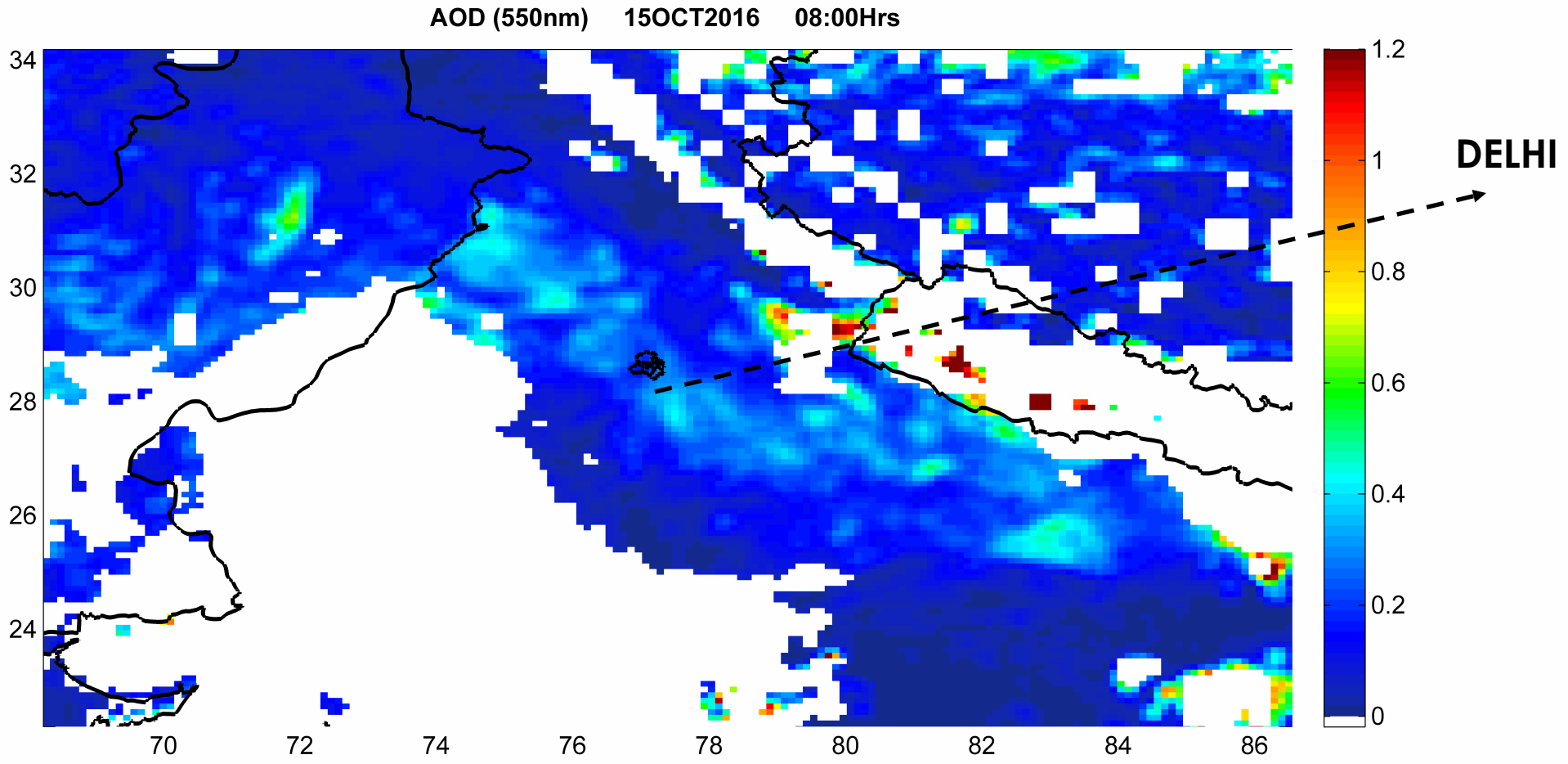
Combines are machines that harvest, thresh i.e separate the grain, and also clean the separated grain, all at once. The problem, however, is that the machine doesn't cut close enough to the ground, leaving stubble behind that the farmer has no use for. There is pressure on the farmer to sow the next crop in time for it to achieve a full yield. The quickest and cheapest solution, therefore, is to clear the field by burning the stubble.

Dispersion of Smoke in Indo-Gangetic Plains

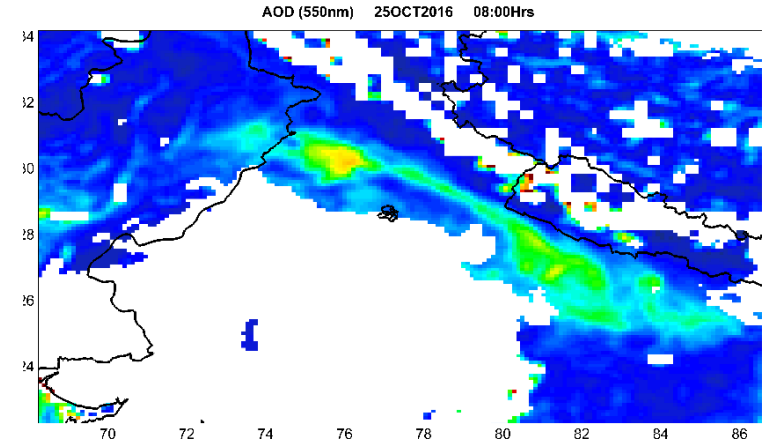


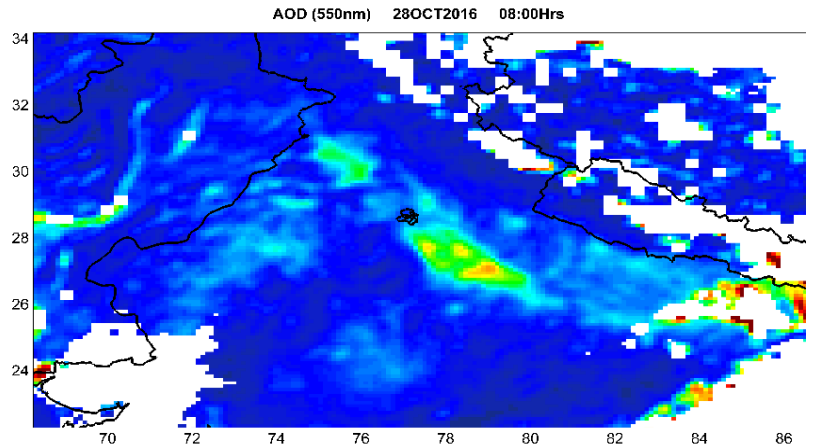
MODIS Aqua image along with active fire dots showing smoke dispersion

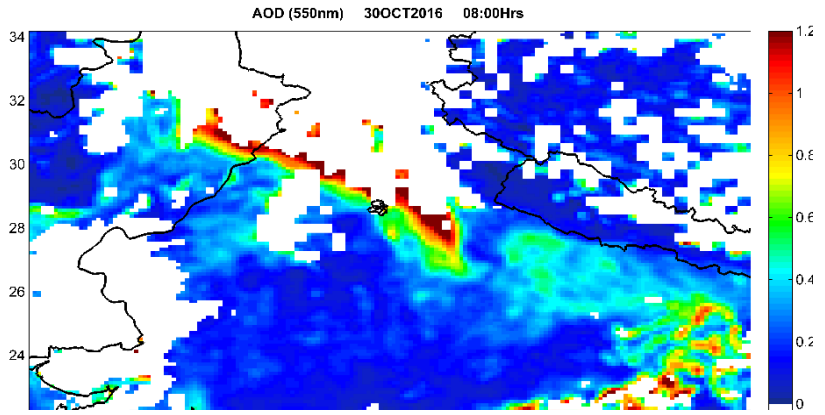
Temporal Variation of INSAT-3D AOD (550nm) : From 15 October to 06 November 2016

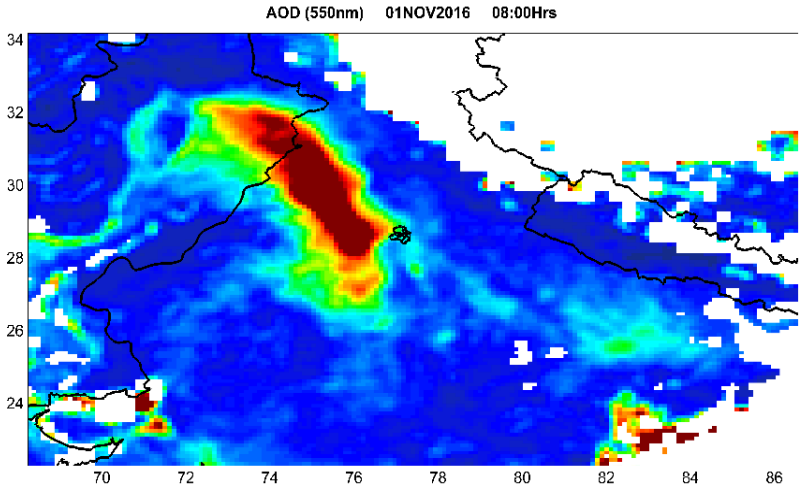


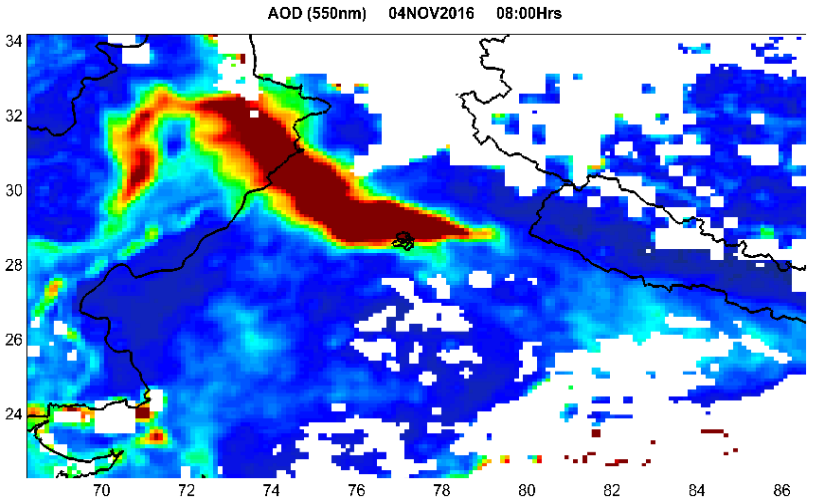
Spatial and Temporal Variations of AOD Using INSAT-3D Data Over North India

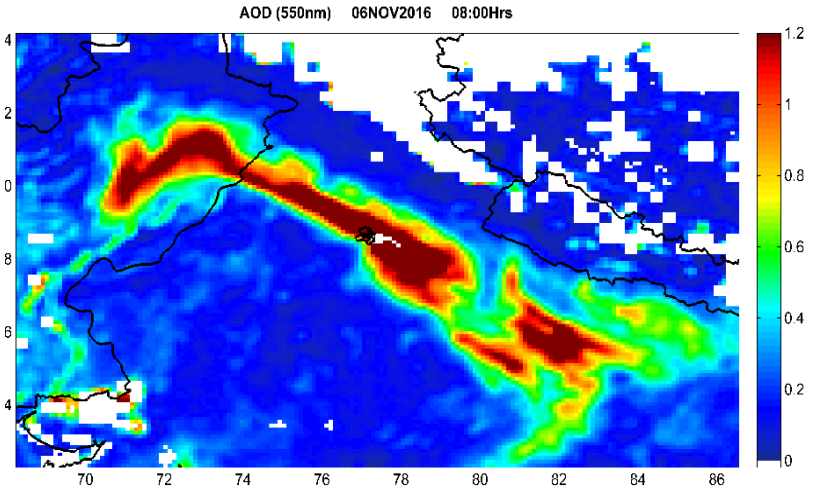






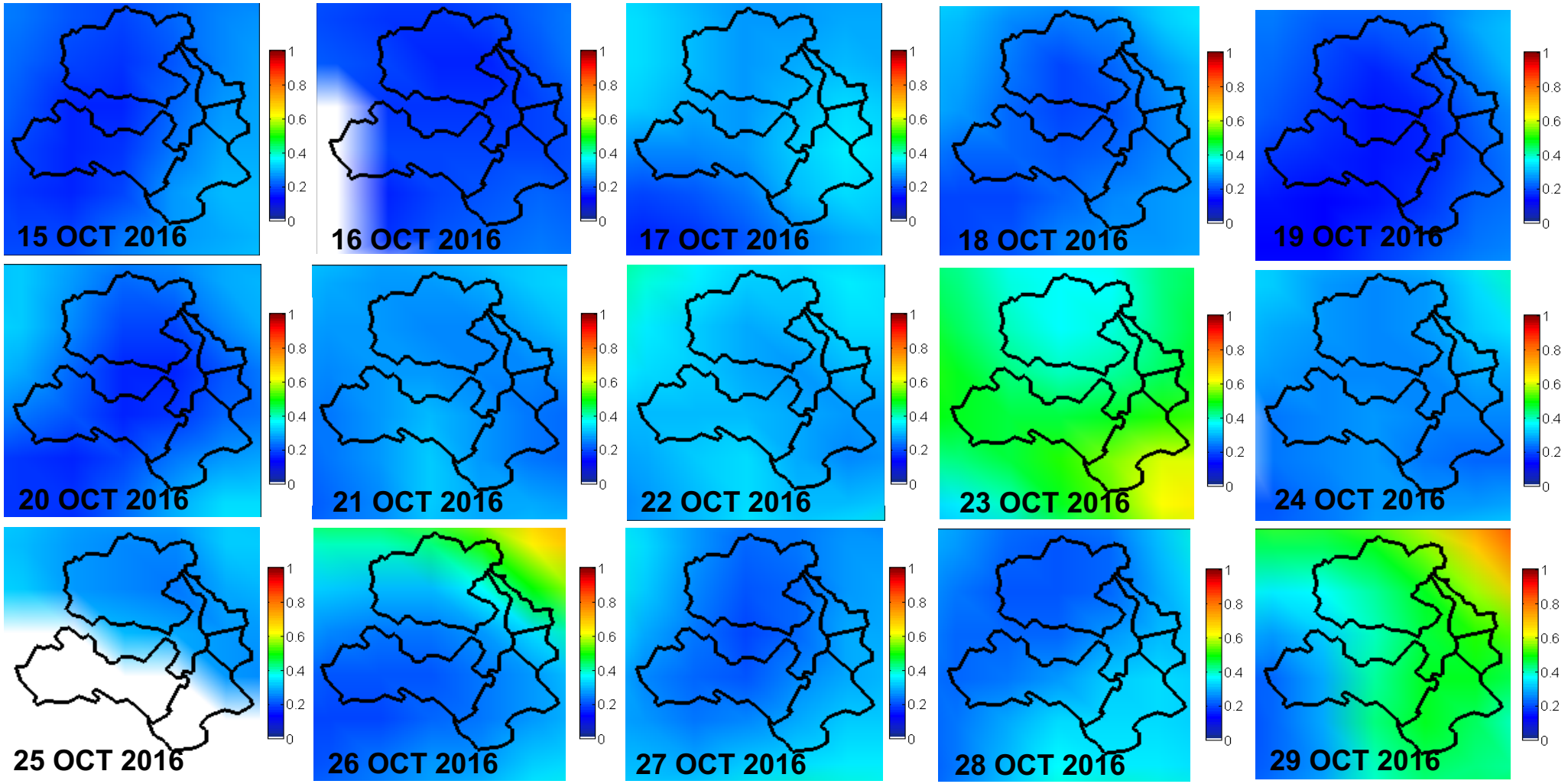






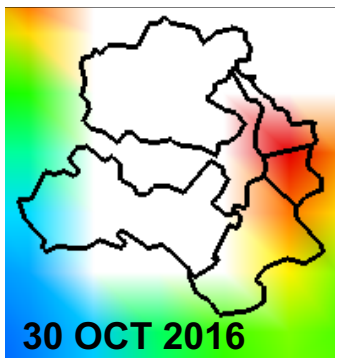
Biomass burning and dust storm activities are well captured

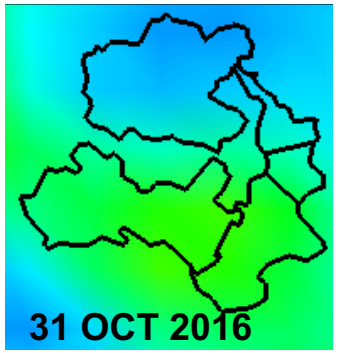
INSAT-3D AOD (550 nm) Over Delhi from 15 Oct to 6 Nov, 2016, Blended Visualization, Original Resolution ~10 km

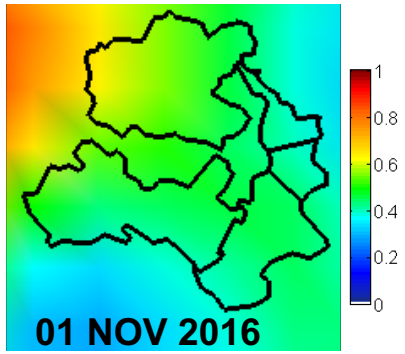


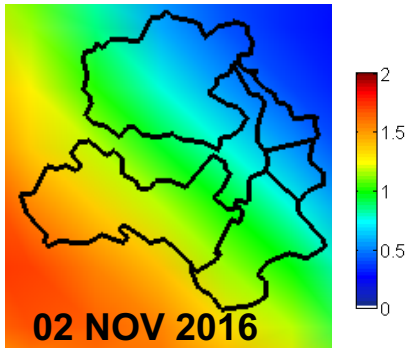
Credit : Abha Chabbra (2016)

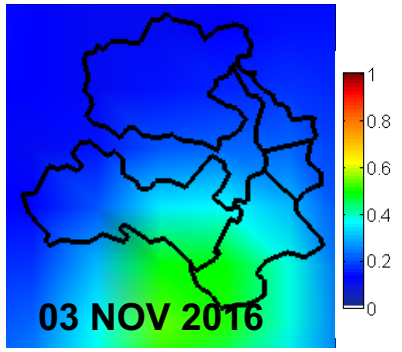
INSAT-3D AOD (550 nm) Over Delhi from 15 Oct to 6 Nov, 2016, Blended Visualization, Original Resolution ~10 km (continued)

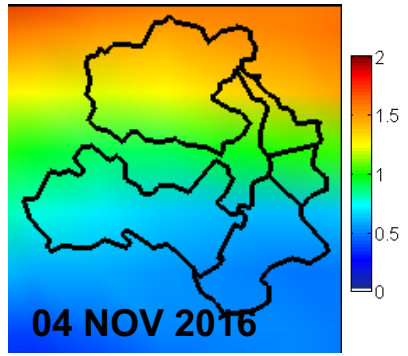


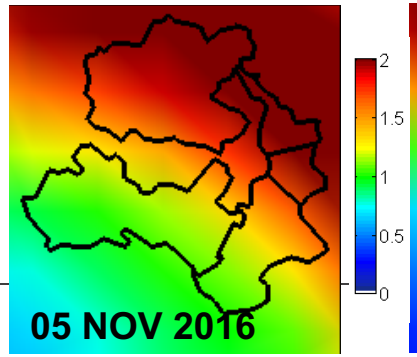


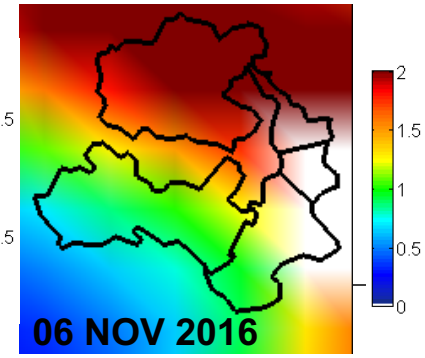


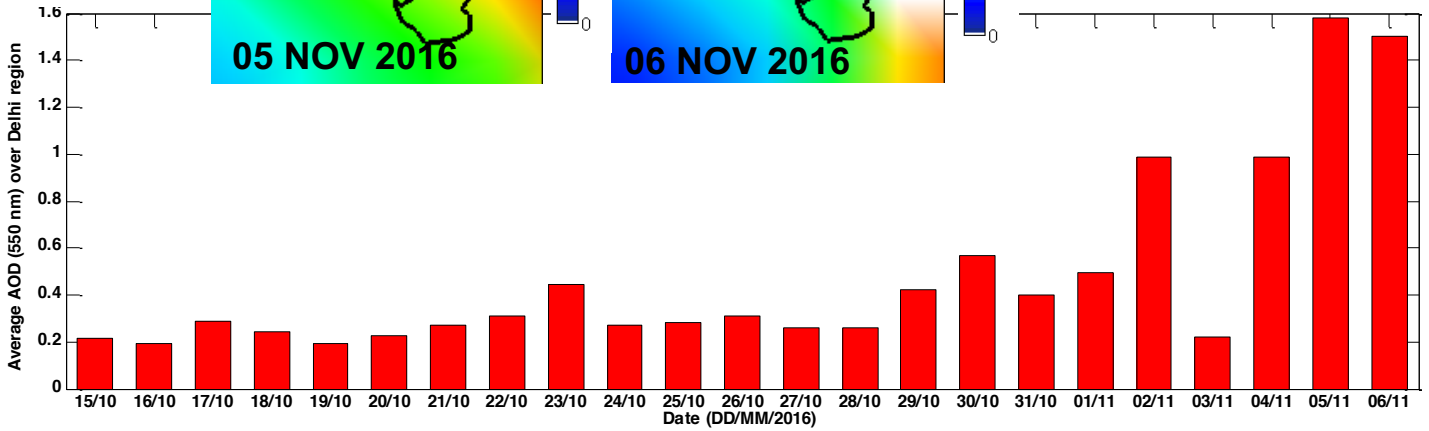








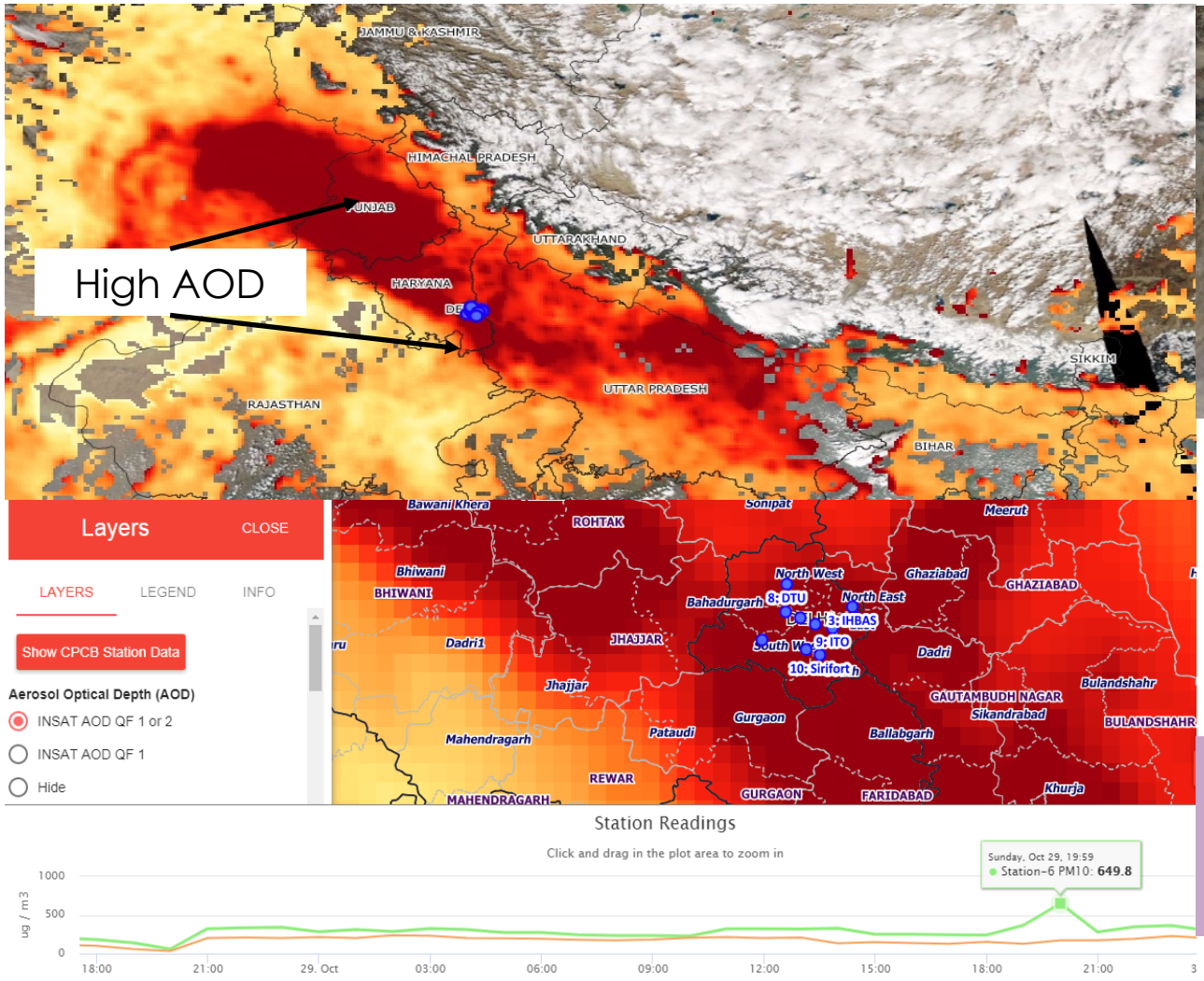




High aerosol content in the atmosphere from Oct 23, 2016 onwards due to biomass burning and very high aerosol content after Nov 2, 2016 due to dust storms caused very poor air quality over New Delhi during October-November 2016

Poor Air Quality Over North India-Pakistan During Oct-Nov 2017

Dust Storm and Biomass Burning Over North India Causing Very Poor Air Quality on Oct 19, 2017



Delhi air quality 'very poor', won't improve very soon

TNN | Updated: Oct 29, 2017, 11:02 IST

A- A+

HIGHLIGHTS

- Delhi's air quality has so far remained unaffected by stubble burning in Punjab with the region instead getting easterly winds from UP which have high moisture content
- Experts say the current meteorological conditions are likely to stay similar for the next few days which will see misty conditions in the morning

A dust storm was seen in satellite images from the INSAT-3D imager and MODIS-Aqua over north India, causing worsening of air quality over Delhi and surrounding regions. High PM_{10} values were reported by CPCB, New Delhi.

Credit : Prakash Chauhan

AOD on Nov 7, 2017, Over North India

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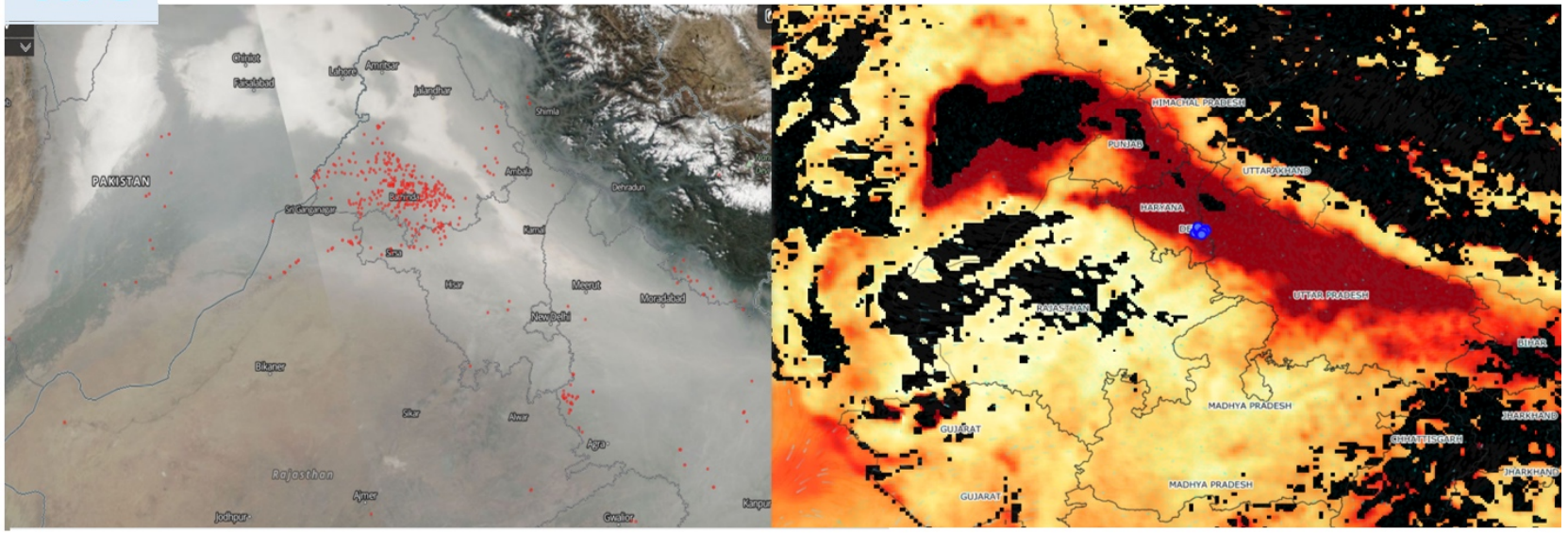
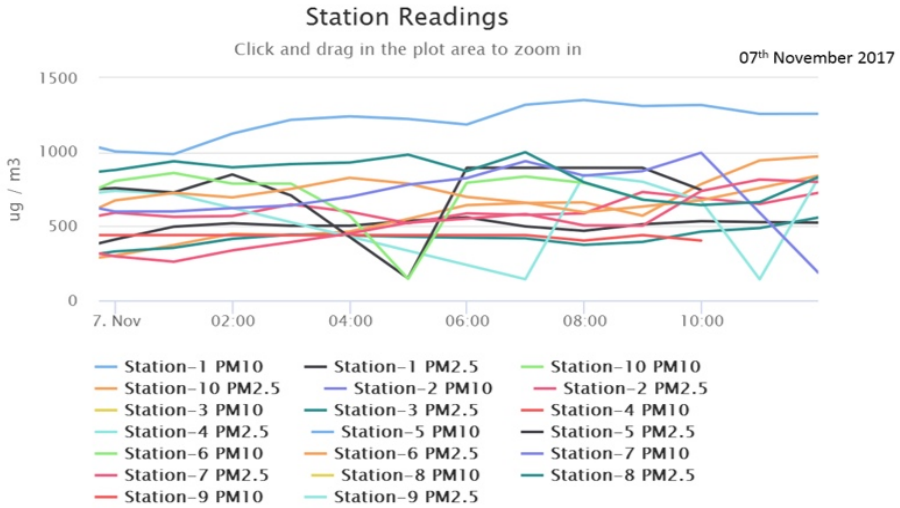
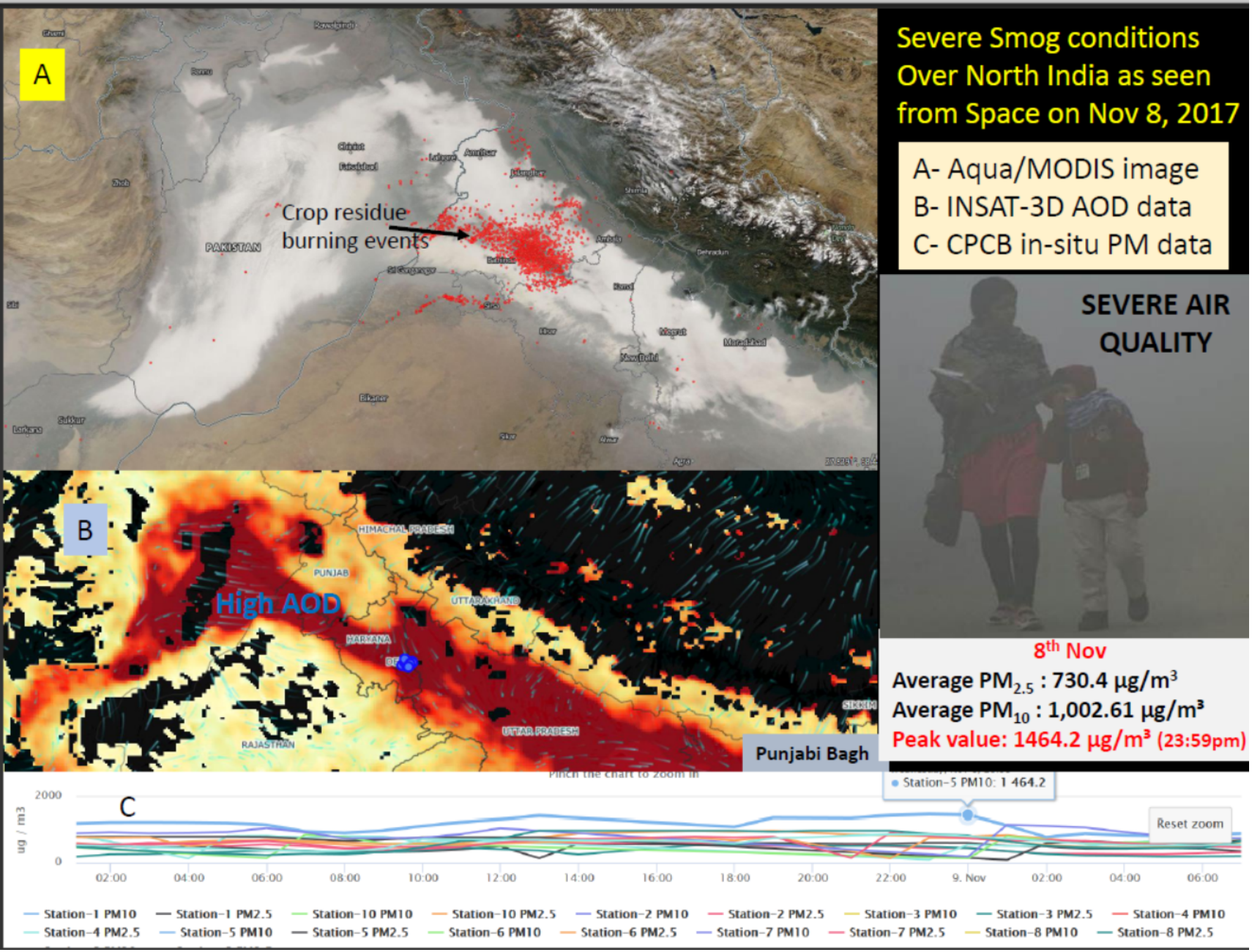




Dust and biomass burning caused a significant reduction in air quality over North India and parts of Pakistan in October-Nov 2017



Severe Smog conditions Over North India as seen from Space on Nov 8, 2017

A- Aqua/MODIS image
B- INSAT-3D AOD data
C- CPCB in-situ PM data

8th Nov
Average $PM_{2.5}$: 730.4 µg/m³
Average PM_{10} : 1,002.61 µg/m³
Peak value: 1464.2 µg/m³ (23:59pm)

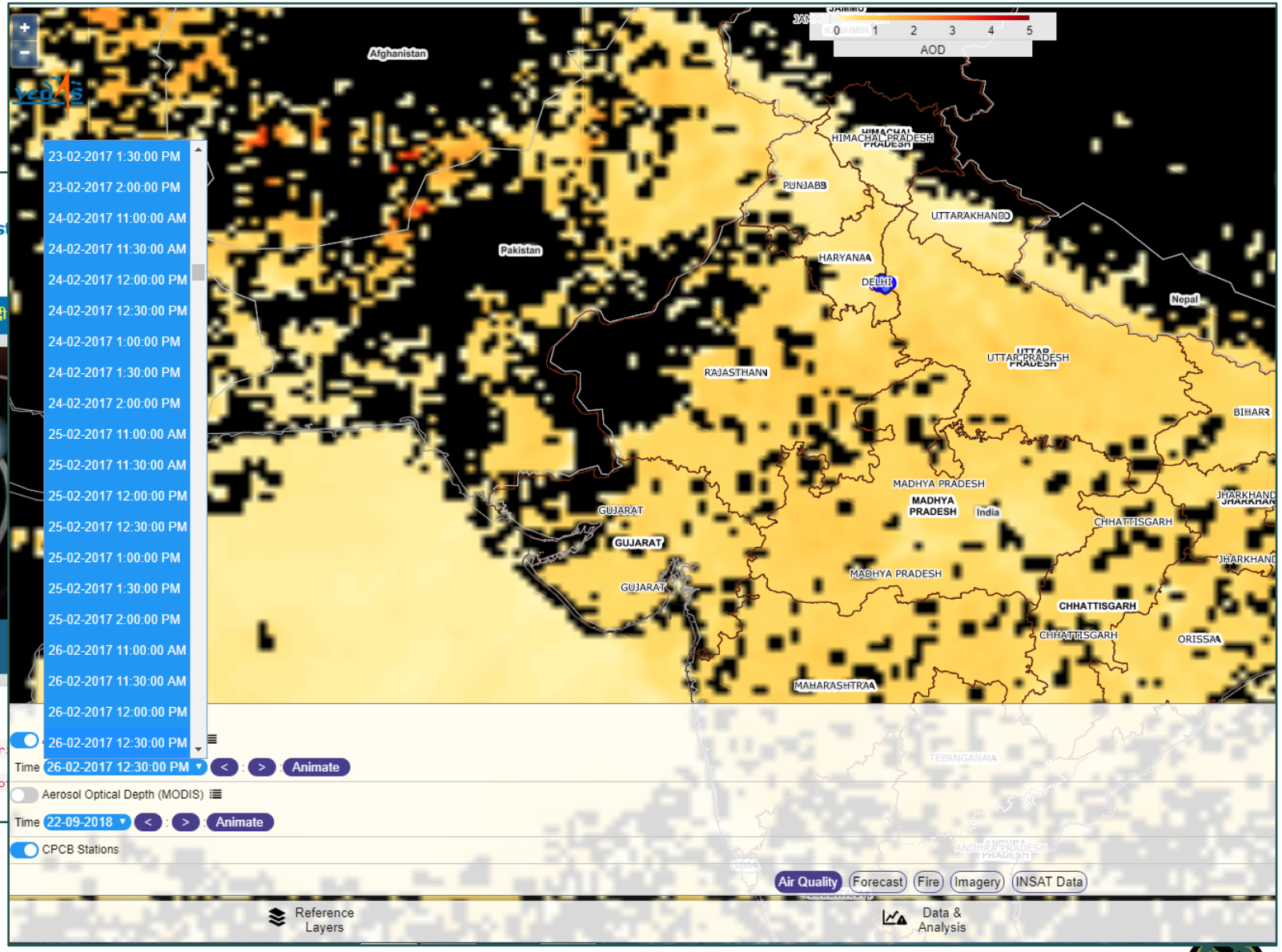
Reduction in solar insolation due to dust caused formation of fog in the month of November spreading from western Pakistan to Northeast of India covering stretches more than 2500 km long

During the months of October-November North India suffered in 2016-17 due to very poor air quality caused by a combination of factors such as biomass burning, dust events and fog conditions

Satellite data has played an important role in understanding these events

How to access the INSAT-3D AOD data

https://vedas.sac.gov.in/vedas/



Summary

- Geostationary satellites are better to study temporal variations and mesoscale atmospheric phenomena like dust transport
- INSAT-3D imager data has shown good potential to capture aerosol distribution and retrieved AOD is comparable with MODIS and in-situ measurements
- The Indo – Gangetic Plains in north India have considerable AOD loading throughout the year
- The INSAT-3D/3DR Imager has limitations for AOD estimation due to only one channel for aerosol detection
- Need to develop new algorithms for $PM_{2.5}$ & PM_{10} quantification using AOD data
- Air Quality Modelling is the key now by assimilating satellite-based AOD

Thank You