Aerosol Observations from the INSAT Series of Satellites Over Asia

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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 about 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
• SO₂
• NO₂
• 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

Effects of Atmospheric Aerosols

- Indirect effect on climate
- Direct effect on climate
- Heterogeneous reactions
- REACTIONS (Secondary PM)
- EMISSIONS (Primary PM)
- Acid rain
- Deposition
- Visibility reduction
- Health effect

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

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**Table:**

<table>
<thead>
<tr>
<th>Name of Satellite, Alternate Names</th>
<th>Longitude (degrees)</th>
<th>Launched (year)</th>
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<td>GOCI/COMS-1 (Communication, Ocean, and Meteorological Satellite; Cheollian)</td>
<td>128</td>
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<td>Electro-L1 (GOMS 2 [Geostationary Operational Meteorological Satellite 2])</td>
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<td>Electro-L2</td>
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<tr>
<td>Fengyun 2E (FY-2E)</td>
<td>123.59</td>
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<td>Fengyun 2F (FY-2F)</td>
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<td>2014</td>
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<td>Gudan 4</td>
<td>105.5</td>
<td>2015</td>
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<td>GOES 13 (Geostationary Operational Environmental Satellite, GOES-N)</td>
<td>−104.41</td>
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<td>GOES 14 (Geostationary Operational Environmental Satellite, GOES-O)</td>
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<td>GOES 15 (Geostationary Operational Environmental Satellite, GOES-P)</td>
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<td>GOES 16 (Geostationary Operational Environmental Satellite GOES-R)</td>
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<td>2016</td>
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<tr>
<td>Himawari 8</td>
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<tr>
<td>Himawari 9</td>
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<td>2016</td>
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<td>INSAT 3A (Indian National Satellite)</td>
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<td>INSAT 3D (Indian National Satellite)</td>
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<td>2013</td>
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<td>INSAT 3DR (Indian National Satellite)</td>
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<td>Kalpaka-1 (Metsat-1)</td>
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<td>SEVIRI/Meteosat 11 (MSG 4)</td>
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<td>2015</td>
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<tr>
<td>METSATS-2 (Multi-Functional Transport Satellite)</td>
<td>145.06</td>
<td>2006</td>
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Evolution of Indian Missions for Weather & Climate Studies

Kaplana-1 (2002)
- VHRR
- CMV, OLR, UTH, Rain

OCEANSAT-1/2 (1999/2009); SCATSAT (2016)
- MSMR, OCM, Scatterometer
- ROSA (GPS)
- Vector Winds, Aerosol, T&h profile

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
- MEGHA-TROPIQES (2011)
- MW Imager, WV Sounder, ScaRaB, ROSA
- SS Wind, TWV, Rainfall, T, h Profile, Radiation Budget

Low Earth Orbit

Geostationary
INSAT-3D/3DR Meteorological Satellites

- 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Imager</th>
<th>Sounder</th>
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<tbody>
<tr>
<td>Telescope Aperture</td>
<td>310 mm</td>
<td>310 mm</td>
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<tr>
<td>No. of Channels</td>
<td>6</td>
<td>19 (18 infrared + 1 Visible)</td>
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<tr>
<td>IFOV</td>
<td>1 km (Visible and SWIR)</td>
<td>4 km (MIR, TIR-1 &amp; TIR-2)</td>
</tr>
<tr>
<td></td>
<td>4 km (MIR, TIR-1 &amp; TIR-2)</td>
<td>8 km (Water Vapor)</td>
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<tr>
<td>Frame Time</td>
<td>~27 minutes</td>
<td>160 minutes for 6000x 6000km area</td>
</tr>
<tr>
<td>Signal Quantization</td>
<td>10 bits</td>
<td>14 bits</td>
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</table>
Earth Observation for Meteorology: INSAT-3D/3DR

Credit: SAC-ISRO

NASA's Applied Remote Sensing Training Program
Progression of Dust Storm in North India on June 13, 2018 by INSAT-3D Imager Data

Credit: IRS-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)

NASA’s Applied Remote Sensing Training Program
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

India and South-East Asian countries

Credit: Mishra M., JGR, (2018)
Mean Monthly of AOD Variability Over the Indian Ocean Region

- INSAT-3D operational products available from MOSDAC
  - [www.mosdac.gov.in](http://www.mosdac.gov.in)

- Air Quality Portal of VEDAS
  - [www.vedas.sac.gov.in](http://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

24 October, 2016

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

AOD (550nm) 15OCT2016 08:00Hrs

DELHI
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

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