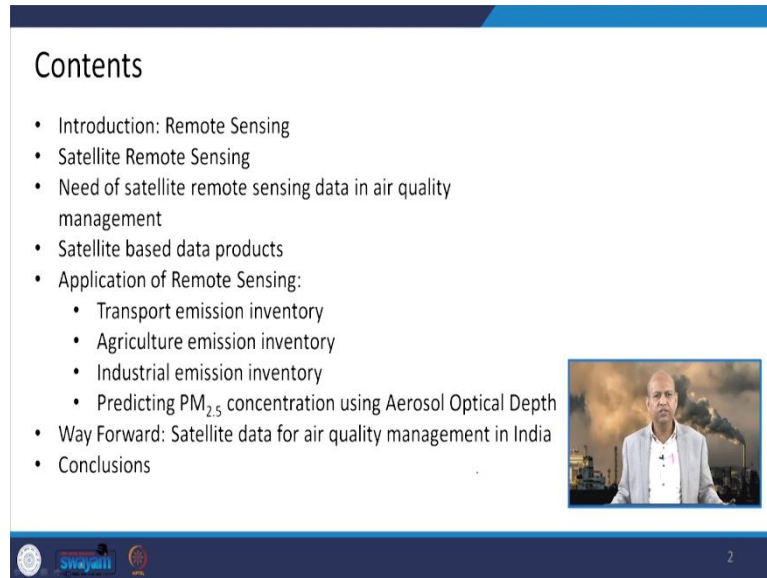



Air Pollution and Control
Professor Bhola Ram Gurjar
Department of Civil Engineering
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Lecture 25


Application of Remote Sensing/Satellite-Based Data in Air Quality Management
(Refer Slide Time: 01:02)



Contents

- Introduction: Remote Sensing
- Satellite Remote Sensing
- Need of satellite remote sensing data in air quality management
- Satellite based data products
- Application of Remote Sensing:
 - Transport emission inventory
 - Agriculture emission inventory
 - Industrial emission inventory
 - Predicting PM_{2.5} concentration using Aerosol Optical Depth
- Way Forward: Satellite data for air quality management in India
- Conclusions



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Hello friends. You may recall that we have discussed several aspects of air quality monitoring and then modelling, emission inventory development. And these days we are discussing about several kinds of emission inventories, whether for industrial sector, transportation sector, domestic sector etc.

Today, we will discuss about the application of remote sensing or satellite-based data in air quality management. So, in air quality management means, this can also help in developing like emission inventories or other issues. So, this lecture will constitute of these particular classifications or content list like, we will discuss first of all what is remote sensing.

And then satellite remote sensing. What is the need of satellite based remote sensing data in air quality management? And what are different products of satellite-based remote sensing observations? And then how do we apply these remote sensing data in transport emission inventory or agriculture emission inventory or industrial sector emission inventory?

Then we will also see that how these remote sensing based data can be used for predicting PM_{2.5} concentration, that is particulate matter of 2.5 micrometer size and using this Aerosol Optical Depth, which is a technique AOD aerosol optical depth, then we will see what is the

way forward that means what are new things which we can do with the help of satellite data for better air quality management.

(Refer Slide Time: 01:57)

Introduction: Remote Sensing

- The art and science of collecting information about Earth surfaces and phenomena using sensors not in physical contact with the surfaces and phenomena of interest.

A. Energy Source or Illumination
B. Radiation and the Atmosphere
C. Interaction with the Target
D. Recording of Energy by the Sensor
E. Transmission, Reception, and Processing
F. Interpretation and Analysis
G. Application

Source: Fundamentals of Remote Sensing, Canada Centre for Remote Sensing

So, like when we go for the introduction of remote sensing, the remote sensing itself is an art and science of collecting information about the Earth's surfaces, there are so many features of our surface and various phenomena like, atmospheric phenomena, or watershed, airshed etc. But today's lecture is basically concentrated on atmospheric constituents based on remote sensing data.

So, we will focus on these particular aspects of the atmosphere, which is monitored using some sensors without physical contact with the surface of the earth or with the phenomena whether like air pollution plumes are there. So, without any contact with that like a physical monitoring system has some sort of instrument, which has physical contact, then they measure, but in remote sensing only sensor based data observations are there without physical contact.

So, if you want to understand how does it go like what do we do in remote sensing basically, the fundamental concept can be understood with this pictorial representation where this illumination or the energy source is from this sun and the solar radiation comes and the surface absorbs some part of it, then it reflects some part of it. So, you can see at the point C, this is the interaction target of the solar installation, then it reflects then it goes up to the satellite.

So, the recording of the energy by the sensors are there in the at this place and then transmission of the reception of processing these data can be through several other instruments, which are part of this. At last, we interpret or analyze these data with the help of computers and

techniques, maybe some statistical tools plotting the graph tabulations etc, so that we apply and use that information for whatever purpose we are getting this data like this lecture is for air quality management. So, we will see how do we use these products of remote sensing or satellite for air quality management.

(Refer Slide Time: 03:58)

The slide is titled "Satellite Remote Sensing". On the left, there is a diagram showing a satellite in orbit labeled "Satellite Monitoring" with a beam of light directed at Earth. Below the satellite, a globe is shown with several icons representing pollution sources: "Sandstorms", "Biomass burning", and "Industries". The text "Remote sensing for smarter air pollution management" is written in blue, and "A constant eye on various sources of air pollution" is written in white. On the right side of the slide, there is a blue-bordered box containing three bullet points. Below the box is a small video inset showing a man speaking in front of a background of industrial smokestacks. At the bottom left of the slide, there is a source citation: "Source: Veeffkind et al., 2007; Image: Kurinji and Ganguly, 2020, CEEW." The bottom of the slide features logos for "Swayam" and "CEEW" and a small number "4" in the bottom right corner.

Satellite Remote Sensing

Remote sensing for smarter air pollution management

Satellite Monitoring

A constant eye on various sources of air pollution

- Satellite remote sensing of the troposphere is a rapidly developing field.
- Satellite sensors in the Earth's orbit measure trace gases and aerosol properties relevant to air quality.
- Sandstorms, Forest fires, Biomass burning, Industrial emissions etc.

Source: Veeffkind et al., 2007; Image: Kurinji and Ganguly, 2020, CEEW.


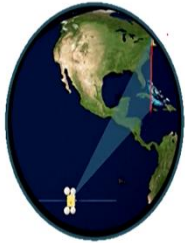
So, these satellite remote sensing of troposphere, which is the lowest layer of the atmosphere is rapidly developing in, all over the world basically, this field is very increasingly it is going on in a developing phase. So, satellite sensors in the Earth's orbit,, that can measure trash gases as well as particulate matter or aerosols and their property is relevant to air quality, whether their concentration and their other aspects.

So, also like sand storms or forest fires, biomass burning, industrial emissions, all those plumes can also be traced by satellite observations. So, this is, several uses of the satellite products.

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Need of Satellite remote sensing data in Air Quality Management (1/2)

- Satellite remote sensing data can bridge the gap due to **vast geography** by providing **wide spatial resolution** across a region.
- Satellite monitoring can also help to determine the **columnar profile of a pollutant** and **possible long-range transport**, which is difficult to achieve with traditional ground monitoring.



Source: Kurinji and Ganguly, 2020, CEEW.

Swajathi

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Well, when we talk about what is the need of satellite remote sensing data in air quality management. So, basically this provides a vast geographical range and the wide spatial resolution across the region, that is not possible through conventional air quality monitoring, because we have limitations in terms of resources in terms of, human resources, advisors, financial resources, because it needs a lot of instrumentation etc. But this way it can, cover a lot of geographical region which requires a lot of investment, if we go surface monitoring kind of network.


So, the satellite monitoring can also help in determining like columnar profile of a pollutant like CO profile in a column or ozone or other like, and then also possible long range transportation of plumes like when forest fire is there or from thermal power plants, plumes are going, because of some atmospheric phenomena it can go up and then go transfer that can transport it in downwind direction. So, it can trace this satellite observation can easily trace and it can give a good spatial distribution of those plumes. And these air pollution concentrations.

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Need of Satellite remote sensing data in Air Quality Management (2/2)

Country	Air quality monitoring network Density (no. of monitors/million persons)
India	0.14
China	1.2
USA	3.4
Japan	0.5
Brazil	1.8
Most European countries	2-3

Studies have shown that India's monitoring network has a density of ~0.14 monitors/million persons (one monitor for every 6.8 million people), which is well below that of other highly populated countries.



Source: Kurinji and Ganguly, 2020, CEEW.

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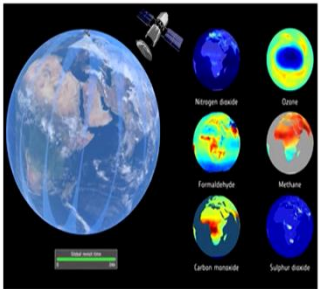
Well, then in context of India basically, if we talk about what is the air quality monitoring network density in different countries, then ours is, kind of lowest one you can see here, only 0.14, number of monitors per million of the people is there in India, whereas in China is 1.2, in USA at 3.4, in European countries it is two to three and Brazil 1.8, Japan point five, so, we are the lowest one in that case.

So, we need a lot of other ways of information and satellite information can really fill this gap which is because of limitations through surface monitoring.

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Satellite based data products

- Monitoring implies evaluating parameters such as **Aerosol Optical Depth (AOD)** and **gaseous columnar volume densities**, which are then converted into particulate concentrations and gaseous emissions, respectively.
- Monitoring products can be used to calculate long-term **trends in pollutant concentrations** and to develop **emission inventories** for major sources of air pollution in a given area.



Source: Kurinji and Ganguly, 2020, CEEW, Image: <https://www.esa.int/>

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Well, when we talk about satellite based data products, so there are many like monitoring implies evaluation of different parameters such as Aerosol Optical Depth, AOD and gaseous


columnar volume densities, which are then converted into some particulate concentration values and gaseous emissions values in that form. And the monitoring products can be used to calculate or estimate long range trends in pollutant concentrations and to develop emission inventories also for major sources of air pollution in a particular given area. So, these are the uses of these basic products.

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Domain	Time period	Data product	Satellite
Aerosol optical depth	2014-present	INSAT 3D	ISRO
	2002-present	MODIS Aqua	NASA
	2000-present	MODIS Terra	NASA
UV aerosol optical depth	2004-present	Aura OMI	NASA
UV aerosol index	2004-present	Aura OMI	NASA
	2018-present	Sentinel 5P	ESA
Aerosol layer height	2006-present	CALIPSO	NASA
	2019-present	Sentinel 5P	ESA
Aerosol profile	2006-present	CALIPSO	NASA
Carbon monoxide total column	2019-present	Sentinel 5P	ESA
	2000-present	MOPITT	NASA
Carbon monoxide vertical profile	2000-present	MOPITT	NASA
Nitrogen dioxide total column	2018-present	Sentinel 5P	ESA
	2006-present	Aura OMI	NASA
Sulphur dioxide total column	2018-present	Sentinel 5P	ESA
	2006-present	Aura OMI	NASA
Formaldehyde total column	2007-present	Aura OMI	NASA
Formaldehyde total column	2018-present	Sentinel 5P	ESA
Ozone tropospheric column	2019-present	Sentinel 5P	ESA
Ozone tropospheric profile	2019-present	Sentinel 5P	ESA
Thermal anomalies and fire	2002-present	MODIS Aqua	NASA
	2000-present	MODIS Terra	NASA
	2012-present	SNPP-VIIRS	NASA/ NOAA

Satellite monitoring products in India

- The table gives the information about the atmospheric products related to pollution monitoring from satellites that are currently active in India.
- Most satellite data draw inferences on India's air quality from satellites that were not launched in India.



Source: Kurinji and Ganguly, 2020, CEEW.


And when we talk about, these satellite monitoring products which are available to India, these are like you can see for different periods and the domain like aerosol optical depth, ultraviolet aerosol optical depth, aerosol index, aerosol layer height, aerosol profile, these different, products or parameters are there which are available for different periods from 2000 onwards a lot of information is available, some are latest one like 2019 to present, carbon monoxide total column which is from, the satellite 5P of European Space Agency.

So, different agencies are there like ISRO from India, then NASA from USA and European Space Agency is there. So, several data are available or products are available in Indian context we can use all these kinds of parameters basically. So, this table gives the information about these atmospheric products, which are related to pollution monitoring in Indian context. And these most satellite data, basically draw inferences on India's air quality from satellites which are not, launched in India like from USA from European Space Agency, but we have collaborations and we can get those data.

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Application of Remote Sensing in air quality management

- Air quality forecasts
- Improved characterization of surface-level air pollution
- Improvement of emission inventories and incidental releases
- Monitoring of air pollution data
- Validation of models
- Identification of air sheds
- Demonstration of episodic pollution
- Inspection of consistently non-compliant sources



Source: Veeffind et al., 2007

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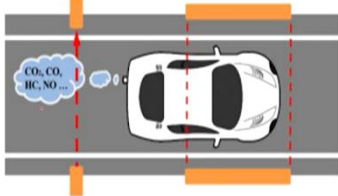
Now, when we talk about what is the application of these remote sensing data in air quality management. So, there are many like this list shows like it can help in your quality forecasts, those data can be used in that way, then it can also help in improving characterization of surface layer air pollution information, it can also improve the emission inventories and incidental releases from particular sources of some pollutants, monitoring of air pollution data validation of models like, because it will give additional information. So, the validation which we do from generally from these physical monitoring sites available data, this can also help in validation.

Then identification of air sheds in different ways like this air shed is more polluted, this is less particular pollutant is there in a particular air sheds. So, this can help in that way also, it can also help in demonstration of episodic pollution, which happens, once a while not always, then inspection of, consistency or consistently these non-compliant sources we can have with these kind of data.

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Application of Remote sensing in Transport Emission Inventory (1/8)

- Remote sensing data can determine emission rates for whole fleets, for specific vehicle types, for vehicle classes by emission standard, and if sufficient data are available, for distinct vehicle makes and models.
- The remote sensing (RS) technique measures exhaust emissions by absorption spectroscopy without interference with the vehicle, its driver, or the driving.



Source: Kheefeld and Dallmann, 2018

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So, there are multiple applications basically. When we talk about like how to apply the remote sensing information in transport emission inventory transportation sector. So, there are some information, which are very interesting and you will find it very informative also. Basically, the remote sensing data can determine emission rates for whole fleets and even for a specific vehicle types and vehicle classes with some emission instruments like Euro 1, Euro 2 or Bharat Stage 1, Bharat Stage 2 like that,, if sufficient data are available, then distinct vehicle mix and those models those related emission profiles can also be created with the help of these remote sensing data.

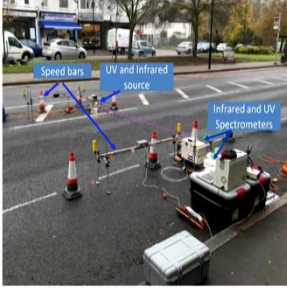
So, the remote sensing or RS technique, which measures exhaust emissions from the tailpipe by absorption spectroscopy with the absorption spectroscopic technique without interference with the vehicle means vehicle is moving and without coming in contact with any other thing, so without talking to the driver or without interfering in driving, the driver is taking its vehicle without talking to any other person and the remote sensing technique is capturing that information what is the pollutant stream from the tailpipe.

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Application of Remote sensing in Transport Emission Inventory (2/8)

How the exhaust emissions are measured? (1/2)

- Sources of **infrared and ultraviolet light** are placed next to the road with their beams directed across the road at the height of the vehicle tailpipe or the exhaust plume.
- The **light is reflected back by a mirror located at the other side of the road and focused into a detector.**



The diagram shows a road with a vehicle passing. A 'UV and Infrared source' is positioned on the left side of the road, with a beam directed across the road. A 'Speed bars' are also shown. On the right side, 'Infrared and UV Spectrometers' are positioned to receive the reflected light. A small inset image shows a man speaking, likely the presenter.

Source: Kheefeld and Dallmann, 2018; Image: Vahugan et al., 2019

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So, the sources and the how does it happens basically, how it is measured. So, the sources of infrared or ultraviolet light from a particular instruments can be put like across the road you can see here. So, this light are placed next to the road with the beam directed across the road. So, when some vehicle will pass it can penetrate through those plumes or the emission streams at the height of the vehicle it is kept, so that the pollution capture is proper at the tailpipe or exhaust plume.

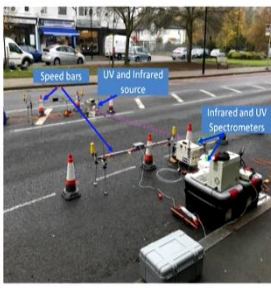
The light is reflected back by a mirror located at the other side of the road and focused into a detector. So, that way this light intends to give the indirect information of the pollution.

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Application of Remote sensing in Transport Emission Inventory (3/8)

How the exhaust emissions are measured? (2/2)

- The measured **attenuation (reduction) of the light is directly proportional to the concentration of certain pollutants in the atmosphere.**
- These pollutants come from the **exhaust of the vehicle that has just passed**, as well as from the **background presence** of the species in the ambient air.
- Therefore, the **pollutant concentration that was measured before the vehicle crossed the light beam is taken as background pollution and subtracted from the measurement.**



The diagram shows a road with a vehicle passing. A 'UV and Infrared source' is positioned on the left side of the road, with a beam directed across the road. A 'Speed bars' are also shown. On the right side, 'Infrared and UV Spectrometers' are positioned to receive the reflected light. A small inset image shows a man speaking, likely the presenter.

Source: Kheefeld and Dallmann, 2018; Image: Vahugan et al., 2019

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So, the measured, this reduction of the light is directly proportional to the concentration of certain pollutants in the atmosphere in that particular area. And these pollutants come from the exhaust of the vehicle that had just passed.

So, as well as from the background presence of the species of the air pollutants in the ambient air. So, therefore, the pollutant concentration that was measured before the vehicle crosses that particular light beam and then taken after the vehicle courses. So, the difference is given the difference of that particular concentration gives how much pollution has been released by the particular vehicle.

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Application of Remote sensing in Transport Emission Inventory (4/8)

- Remote sensing instrument configuration was developed in 1989, which includes the following units:
 - The first unit measures vehicle emissions by absorption spectroscopy.
 - The second unit measures speed and acceleration of the vehicle a bit upstream of the emission measurement.
 - The third unit, a camera, records the number plate of the vehicle.

Source: Kheefeld and Dallmann, 2018

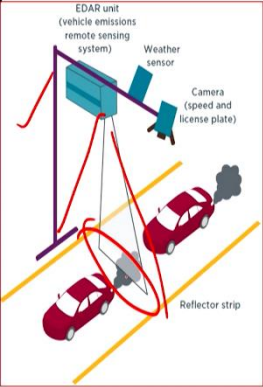
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Then the remote sensing instruments, this configuration how does it take place, this is also shown in this particular figure you can see there are three units. The first unit measure the vehicle emissions by absorption spectroscopy, you can see here this one. The second unit measures the speed and acceleration of the vehicle and the third unit reads the number plate of the vehicle.


So, with the help of number plate of the vehicle, we know how much how many years old this vehicle is and there are many other information which can be taken from that particular repository which is available through this RTO office.

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Application of Remote sensing in Transport Emission Inventory (5/8)



- A new remote sensing instrument **Emission Detection And Reporting system (EDAR)** developed by Hager Environmental & Atmospheric Technologies (HEAT) has been used since 2009 that expands on the above principles.
- A **laser** is used as the light source, making the measurement more selective and precise to the pollutant(s).



Source: Kheefeld and Dallmann, 2018

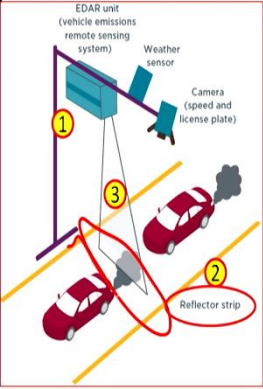
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Now, if we talk about like application of remote sensing in transport emission inventory, then this technique has been further improved like rather than putting the instruments across the road, now these instruments are placed at the certain height. So, it gives this beam and the laser is used better for better capture of information. So, that can have this particular information across the road plus there is a stripe, which can reflect this light of the laser light.

So, the laser beam is used and the information is captured for the whole plume which is being emitted by the vehicle. So, that way accuracy is better in comparison to the other technique. So, the laser is used as a source and making the measurement more selective and precise to the pollutants in that way.


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Application of Remote sensing in Transport Emission Inventory (6/8)



1. The light source and detector are **mounted above the road** in this configuration, with the beam looking down instead of across the road.
2. The **laser light** is scattered back from a **reflector strip** installed on the road's surface.
3. The **laser beam** sweeps the whole breadth of the road and has a 20,000 Hz sampling rate.

➤ Thus, the **exhaust plume** is captured in its entirety, and all molecules in the plume can be measured.



Source: Kheefeld and Dallmann, 2018

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So, you can see here this the first light source and detector are mounted above the road in this particular configuration you can see, then the laser light is scattered back from the deflector strip this is reflected strip you can see on the road and then exhaust plume is captured entirely, because of that particular this arrangement.

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Application of Remote sensing in Transport Emission Inventory (7/8)

Pollutants measured using Remote sensing technique in Transport emission inventory

- The instrument measures the pollutants based on the absorbance band in the spectrum.
- Non-dispersive infrared (NDIR) component is used for detecting CO, CO₂, and HC
- Twin dispersive ultraviolet (UV) spectrometer is used for measuring oxides of nitrogen (NO and NO₂), SO₂ and NH₃



Source: Kheefeld and Dallmann, 2018

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Well, when we talk about the pollutants measured using remote sensing techniques, then we see that the instruments which are measuring the pollutants are based on absorption band of a spectrum particular range is there, then Non-Dispersive Infrared NDIR component is used for detecting like carbon monoxide or CO₂ or hydrocarbons. And twin dispersive ultraviolet spectrometer is used for measuring the oxides of nitrogen like NO and NO₂ and also SO₂ and ammonia. So, that way difference is there.

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Application of Remote sensing in Transport Emission Inventory (8/8)

Limitation of remote sensing in transport emission inventory

- Remote sensing works most accurately under slight acceleration. Therefore, emissions during idle and deceleration are not captured.
- Measurements are more difficult to make when raining or on a wet surface.
- Vehicle technical data are taken from the registration database. They record the technical features of the vehicle when new, but do not specify their actual state at the time of the remote sensing measurement.



Source: Kheefeld and Dallmann, 2018

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Well, there are certain limitations of remote sensing in transport emission inventory, because this remote sensing works most accurately under slight acceleration not very high acceleration and not even when this vehicle is at idle stage. So, the emissions during idle and deceleration are not captured, so little till the acceleration must be there then it gives the good reading. Measurements are more difficult when raining is there or surfaces the wet, again then accuracy is not good.

Then vehicle technique data, technical data taken from the registration database as I said when this number plate is captured them from that repository from the RTO office we get the information. So, the record the technical features of the vehicle, when it is new and but there is no data that how much it is being repaired, how many times or the what is the stage of its maintenance, those kinds of things are not available. So, some uncertainty maybe they are in that particular data.

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Application of Remote sensing in Agriculture Emission Inventory: Agriculture Burning (1/5)

- Satellites imageries have been used in generating images that have helped in identifying the location and count of these fires.
- This value comes from a crop residue monitoring exercise using Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) data, undertaken by the Consortium for Research on Agroecosystem Monitoring and Modelling from Space (CREAMS).



Source: Kurinji and Ganguly, 2020, CEEW.

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Well, now, if we come to application of remote sensing in agriculture emission inventory, because transportation is over now, we go for agriculture burning related inventory or the data. So, the satellite measurements which are generating images with the help of like identify locations and count of different fires, which are taking place at the forest level or even agricultural fields and the values which come from a crop residue monitoring exercise using this Moderate Resolution Imaging Spectroradiometer MODIS and Visible Infrared Imaging Radiometer Suite like VIIRS data.

So, these undertake by the Consortium for Research on Agro Ecosystem Monitoring and Modelling from Space this is known as CREAMS. So, that way, it is a well-established well managed program through this CREAMS agency consortium.


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Application of Remote sensing in Agriculture Emission Inventory: Agriculture Burning (2/5)

Consortium for Research on Agroecosystem Monitoring and Modelling from Space (CREAMS)



- CREAMS is an inter-disciplinary research initiative of the Indian Agricultural Research Institute, New Delhi and coordinated by its Division of Agricultural Physics.
- CREAMS operates its own X & L-band satellite ground station to receive direct broadcast remote sensing images from a range of international satellite constellation.



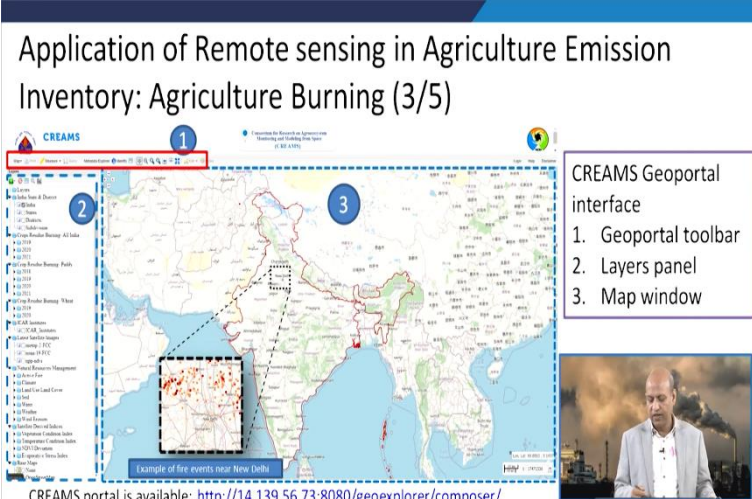
Source: <http://creams.iari.res.in/cms2/index.php/contact-us>, accessed at 28 Nov 2021

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So, this is an interdisciplinary, research initiative of Indian Agriculture Research Institute, IRI in New Delhi and it is coordinated by division of agricultural physics basically. So, the CREAMS operates its own, excellent band satellite ground station and receives the direct broadcast remote sensing images and a range of international site these satellite these constellations are also there. So, a lot of information inflow is there.

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Application of Remote sensing in Agriculture Emission Inventory: Agriculture Burning (3/5)



CREAMS Geoportal interface

1. Geoportol toolbar
2. Layers panel
3. Map window

Example of fire events near New Delhi

CREAMS portal is available: <http://14.139.56.73:8080/geoexplorer/composer/>

Source: <http://creams.iari.res.in/cms2/index.php/contact-us>, accessed at 28 Dec 2021

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So, basically like, this has a portal, geoportal interface. So, it is shown just to give you a kind of feeling how does it work, basically, there are geoportal toolbar, layers panel and the map window you can see. So, you can select particular area, and then you can see how many points


are there of the fire burning events or agriculture burning, so you can count them and that information can be drawn.

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Application of Remote sensing in Agriculture Emission Inventory: Agriculture Burning (4/5)

Limitations

- Despite a high confidence level of fire counts data, **fire counts derived from satellite data are not restricted to only crop residue burning.**
- The interpretation depicts that these are largely (if not entirely) associated with crop burning.



Source: Kurinji L.S. (2019)



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But there are limitations like despite the high confidence level of fire counts data, fire counts derived from satellites are not restricted only to crop residue burning, because even if some waste burning is there, it will count, some crop residue burning kind of thing. So, uncertainty is there and the interpretation depicts largely if not entirely associated with the crop burning, so that way as I said, because it will also count other kind of burning which is not the real crop residue burning, so that we have to be a little bit careful.

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Application of Remote sensing in Industrial emission inventory (1/4)

- Coal-combustion in **thermal power plants (TPPs)** and for domestic use is a major air pollution source in India.
- NO₂ emissions from TPPs can be estimated using **TROPOspheric Monitoring Instrument (TROPOMI)** NO₂ data product.
- **Satellite data** is used independently track TPP emissions in India, where in-situ emission data are not readily available.



Source: G.K. Saw et al., 2021, Image: <https://www.mechstudies.com>

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Now, next we talk about like industrial emission inventory, what is the role and application of this remote sensing. So, basically like coal combustion in Thermal Power Plants (TPP) and for domestic use in a major air pollution sources in India can be taken with satellite observations also, like NO₂ emissions from thermal power plants can easily be estimated using this particular TROPOMI. This is nothing about tropospheric monitoring instrument.

So, this can be used for NO₂ data product and the satellite data, which is used independently to track TPP emissions in India, where in situ emission data are not readily available. So, that way it can again bridge the gap or fill the gap.


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Application of Remote sensing in Industrial emission inventory (2/4)

TROPOMI data

- TROPOMI, on-board the sun-synchronous and low-earth (825 km) orbit Sentinel-5 Precursor (S5P) satellite, contains **four spectrometers**:
- **Three** of them cover the ultraviolet-near infrared range with two spectral bands at 270–500 nm and 675–775 nm, and **one** is for the shortwave infrared.
- It makes **daily global observations** (101.5 min temporal resolution) of crucial atmospheric constituents, including O₃, NO₂, SO₂, CO, CH₄, HCHO, and cloud and aerosol properties within its 2600 km swath with an equator overpass time of approximately 13:30 local solar time.

Source: G.K. Saw et al., 2021



<http://www.tropomi.eu/>

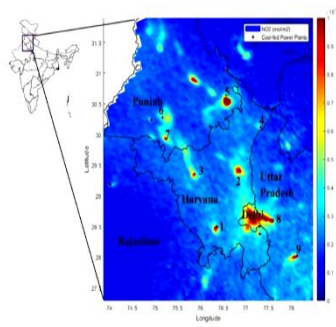
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Well, the TROPOMI data, which are available on both they have this sun synchronous and low Earth orbit satellite related data, which contains four spectrometers, three of them are used for ultraviolet near infrared rains kind of thing, then the two spectral bands are there one is for the this shortwave infrared. And it makes daily global observations and it can be used for, these Ozone, NO₂, SO₂, CO, CH₄ and then HCHO cloud and aerosol properties with 2600 kilometer, that kind of area it can easily cover overlapping this equator and approximately around 13:30 local solar time is there when it gives the data basically.

(Refer Slide Time: 19:47)


Application of Remote sensing in Industrial emission inventory (3/4)

TROPOMI data



- Due to high spatial resolution (pixel sizes $3.5 \times 7.2 \text{ km}^2$) and high signal-to-noise ratio, it is easy to distinguish the individual NO_2 plumes emitted from specific sources such as TPPs.
- The spatial distribution of columnar NO_2 over northern India in 2019, along with the locations of nine coal-fired TPPs. High NO_2 is visible

Distribution of tropospheric NO_2 columnar density over north India on October 16, 2019 along with the locations of the TPPs



Source: G.K. Saw et al., 2021

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Well, you can see how it gives the data about these thermal power plant plumes. So, like due to high spatial resolution like pixel 3.5 to 7.2 square kilometer is there, high signal to noise ratio is also there, it is easy to distinguish individual NO_2 plumes like you can count here and from specific sources such as thermal power plants. So, in that particular picture basically the spatial distribution of this columnar NO_2 over northern India in 2019 was observed along with the locations of nine coal fired thermal power plants. So, this high NO_2 is visible in these particular locations.

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Application of Remote sensing in Industrial emission inventory (4/4)

Limitations

- The retrieval accuracy may get impacted due to the presence of clouds, the accuracy of the wind data, and the presence of other NO_2 emission sources like brick kilns, industrial complexes, and high traffic density.



Source: G.K. Saw et al., 2021

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Well, there are limitations again in this case also, the retrieval accuracy may get impacted due to the presence of clouds. So, then that observation is not very accurate in that sense the


accuracy of the wind data presence of other NO₂ emission sources like brick kilns which can be mistakenly taken from the stack as the thermal power plants, industrial complexes and high traffic density there can also be source of NO₂, because of these exhaust emissions from traffic. So, that kind of interference may be there which we need to remove.

(Refer Slide Time: 21:00)

Application of Remote sensing in predicting PM emissions (1/5)

- The **Moderate Resolution Imaging Spectro Radiometer (MODIS)** instrument on board the **Earth Observing System (EOS) Aqua satellite** provides numerous aerosol measures including **Aerosol Optical Depth (AOD)** product reflecting fine particle loading.
- In 2011, an advanced algorithm, the **Multi-angle Implementation of Atmospheric Correction (MAIAC)**, was presented providing a set of AOD product with much finer resolution (**1km x 1km**) compared to the standard MYD04 product at **10km x 10km** resolution.

Source: Tang et al., 2016



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Well when we talk about like, how to apply it remote sensing for predicting particulate matter emissions? So, then again, we can go for usage of this MODIS data Moderate Resolution Imaging Spectroradiometer. And then this Earth Observing System is there US Aqua satellite, which gives the information about that and it provides numerous aerosol measurements including aerosol optical depth AOD, which can be used for reflecting fine particulates loading etc.


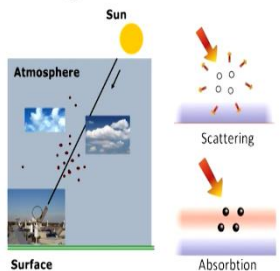
In 2011, an advanced algorithm was developed, this is known as Multi-Angle Implementation of Atmospheric Correction, that is MAIAC which was presented providing a set of AOD aerosol optical depth product with finer resolutions one by 1 kilometer x 1 kilometer. Earlier it was 10 kilometer x 10 kilometers. So, that way this resolution related preciseness has been enhanced over the years.

(Refer Slide Time: 22:00)

Application of Remote sensing in predicting PM emissions (2/5)

Aerosol Optical Depth

- The **optical depth** expresses the quantity of light removed from a beam by scattering or absorption by aerosols during its path through the atmosphere
- These optical measurements of light extinction are used to represent aerosols (particulate) amount in the entire column of the atmosphere.



Source: Gupta, P., NASA Goddard Space Flight Center GESTAR/USRA

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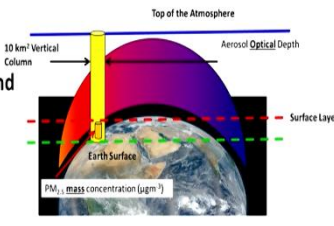
Well, when we talk about AOD or aerosol optical depth, so the optical depth expresses basically the quantity of light removed from a beam, which is being scattered or absorbed by aerosols during the, its path through the atmosphere. So, that amount gives indirectly the, aerosol optical depth related quantity, and these optical measurements of light extinction are used to represent aerosols particulate matters amount in the entire column of the atmosphere. So, that is why we call it columnar values.

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Application of Remote sensing in predicting PM emissions (3/5)

Aerosol Optical Depth and PM_{2.5} monitoring at ground

- AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unit less. AOD is function of shape, size, type and number concentration of aerosols
- PM_{2.5} monitoring at ground – Mass per unit volume of aerosol particles less than 2.5 μm in aerodynamic diameter at surface (measurement height) level



Source: Gupta, P., NASA Goddard Space Flight Center GESTAR/USRA

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Well, so, AOD is the column integrated value basically, in the column note or the particular layer and this optical measurement of aerosol loading, AOD is function of the shape, it is unitless, shape, size and type of number of concentrations of aerosols, so that way it can vary

from place to place. Now, PM_{2.5} monitoring at the ground mass per unit of volume of aerosol particles less than 2.5 micrometer and diameter surface. So, measurement can be done with the help of these satellite-based observations also.

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Application of Remote sensing in predicting PM emissions
(4/5)


Aerosol Optical Depth and PM relation

- The concentration of PM is estimated from the equation:

$$C = \frac{4\rho r_e}{3Q} \times \frac{f_{PBL}}{H_{PBL}} \times AOD$$

ρ – particle density } Particle composition
 Q – extinction coefficient }
 r_e – effective radius } Size distribution
 f_{PBL} – % AOD in PBL } Vertical profile
 H_{PBL} – mixing height }
 AOD – Aerosol Optical Depth

Source: Gupta, P., NASA Goddard Space Flight Center GESTAR/USRA



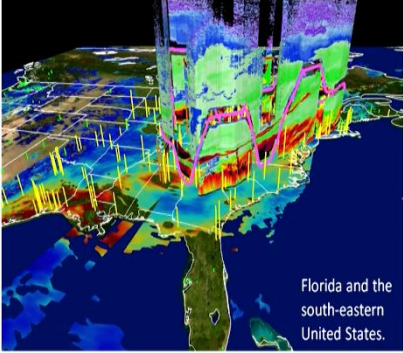
Then, there are certain like light related values, so how to convert it into concentration of particulate matter. So, this is the relationship like empirical relationship, which is used for concentration for estimating concentration of particulate matter by this AOD, which we have measured. So, the AOD is multiplied by this f_{PBL} and H_{PBL} this is nothing but percentage of AOD in planetary boundary layer and the mixing height and we also have this particle density and the effective radius of the particles and this extinction coefficient Q is there.

$$C = \frac{4\rho r_e}{3Q} \times \frac{f_{PBL}}{H_{PBL}} \times AOD$$

So, then this concentration can be calculated by this relationship. So, according to this r_e , effective radius size distribution we can get calculation for different kinds of sizes of the pollutants.

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Application of Remote sensing in predicting PM emissions (5/5)



Florida and the south-eastern United States.

Source: <https://www.nasa.gov>, Hoff and Christopher, 2009

Visualization of imagery:
The spatial distribution of AOD is overlaid on the cloud image, in which low values are in blue and high values showing high concentrations of pollution in orange and red.
The vertical bars in various colors denote the PM_{2.5} air quality by EPA category.



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Then this kind of pictorial representation can be there which can give how much pollution is there for example, this high concentration of pollution in orange and red is shown and the cloud images are also there, then the low values of the blue, which can be seen because of this kind of pictorial representation and the vertical bars in various colour denote the PM_{2.5} air quality by the EPA category, different columns you can see these are the PM_{2.5} concentrations.

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Way Forward: Satellite data for air quality management in India

Domain	Action point	Agencies Involved	Timeline
Monitoring of crop residue burning	Coordination with ISRO for a regular availability of remote sensing monitoring data for crop residue burning by the farmers.	MoEFCC, CPCB	2019
Air quality monitoring network	Capacities will be strengthened to develop indigenous satellite-based products and techniques for estimating particulate and gaseous concentration.	CPCB, SPCBs, SAC (Space Application Centre), ISRO	2024
Air quality forecasting system	Satellite data available through the satellite network of ISRO to be integrated for monitoring and forecasting.	IITM Pune, under MoES, CPCB	2022

The NCAP intends to use satellite data for both monitoring and forecasting air quality. The action points for satellite application, as well as the associated agencies and timeline is shown in table.



Source: Kurinji and Ganguly, 2020, CEEW.

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Well, so, what is the way forward of the satellite observations which are growing day by day and in different ways we can get the information. So, the NCAP, which like National Clean Air program, it has the intention or the objective to use satellite data for both monitoring as well as forecasting of air quality. The action points for satellite applications as well as the

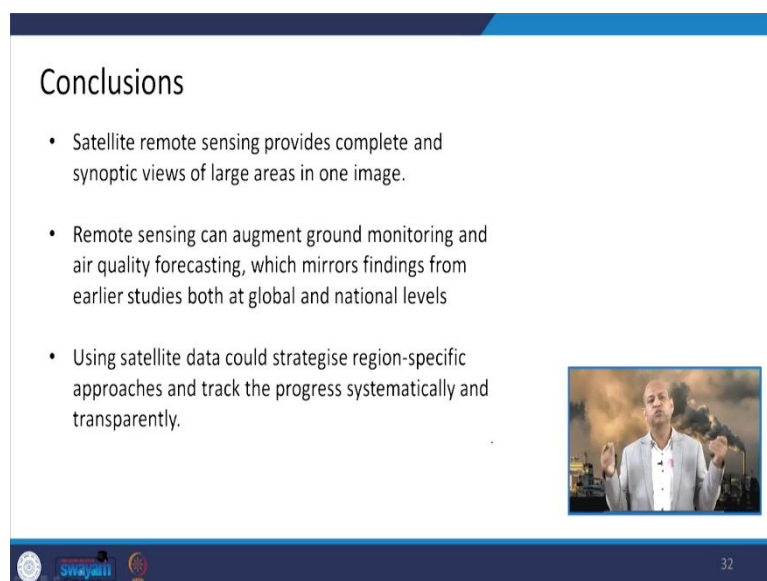
associated agencies and timeline are shown in this particular table like domains, monitoring of the crop residue burning, air quality monitoring network, air quality forecasting system.

So, up to 2019, this was placed into action point like coordination with ISRO, remote sensing monitoring data for crop burning by the farmers this Ministry of Environment Forests and Climate Change and Central Pollution Control Board, they made possible for that particular air quality monitoring network up to 2024 target is there all these state pollution control boards, central pollution control board ISRO and the space application centre they are joining hands to develop the capacities for strengthening the efforts for development of indigenous satellite based products and techniques for estimating particulates and gaseous concentrations in the atmosphere.

And then when we talk about air quality forecasting system, then the satellite data available through the satellite network of ISRO to be integrated for monitoring and forecasting and IITM Pune, that is Indian Institute of Tropical Metrology Pune and under this Ministry of our Sciences and the Central Pollution Control Board, they are collaborating and by 2022 this will be taken into account and it will be properly implemented.


So, we can see that these satellite observations or remote sensing kind of things are integrating into the real air quality management efforts, which are being made by different government agencies in India. And I look forward that because of these integrations, more efficient air quality management will be able to be accomplished.


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Conclusions

- Satellite remote sensing provides complete and synoptic views of large areas in one image.
- Remote sensing can augment ground monitoring and air quality forecasting, which mirrors findings from earlier studies both at global and national levels
- Using satellite data could strategise region-specific approaches and track the progress systematically and transparently.





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So, this is all for today we can say that this satellite remote sensing provides complete and synoptic views of large areas in one image. So, that is the beauty of the satellite observations, which is not possible by point to point air quality monitoring of the data physical monitoring of the data.

Then remote sensing can also augment or increase the ground monitoring and air quality forecasting, which mirrors findings from earlier studies both at the global and national levels. So, that way it can strengthen those kind of efforts and using satellite data, it can be used for strategies like region specific approaches or it can track the progress systematically and transparently. So, that there is no more big chances of big errors, that kind of things can be done by the application of remote sensing data and satellite based products.

(Refer Slide Time: 27:37)

References

- Veeffkind, P., van Oss, R. F., Eskes, H., Borowiak, A., Dentner, F., & Wilson, J. (2007). The Applicability of Remote Sensing in the Field of Air Pollution. Institute of Environment and Sustainability, Italy, 1–54.
- Kurinji, L. S., & Ganguly, T. (2020). Managing India's Air Quality Through an Eye in the Sky. January.
- Kurinji, L. S. (2019). Alternative Methods to Monitor Air Pollution A Study of Crop Residue Burning in Punjab. March.
- Hoff, R. M., & Christopher, S. A. (2009). Remote sensing of particulate pollution from space: Have we reached the promised land? *Journal of the Air and Waste Management Association*, 59(6), 645–675. <https://doi.org/10.3155/1047-3289.59.6.645>
- Borken-Kleeefeld, Jens, Dallmann, T. (2018). Remote Sensing of vehicle exhaust emissions. In *The International Council of Clean Transportation*. <https://doi.org/10.1021/es00055a001>
- Fundamentals of Remote Sensing. Canada Centre for Remote Sensing. <https://doi.org/10.1175/amsmonographs-d-16-0015.1>
- Tang, C.-H. (2016). Development of Satellite-Based Emission Inventories and Indoor Exposure Prediction Models for PM_{2.5}.
- Gupta, P. Satellite Remote Sensing of Surface Air Quality. NASA Goddard Space Flight Center GESTAR/USRA, ARSET Applied Remote Sensing Training.
- Saw, G. K., Dey, S., Kaushal, H., & Lal, K. (2021). Tracking NO₂ emission from thermal power plants in North India using TROPOMI data. *Atmospheric Environment*, 259(2), 118514. <https://doi.org/10.1016/j.atmosenv.2021.118514>

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So, this is all for today and these are the references for additional information. So, that way we have completed the Emission Inventory related lectures and now we will see other things through case studies etc. So, thank you for your kind attention and see you in the next lecture. Thanks again.