Air Pollution and Control
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Lecture 25

Application of Remote Sensing/Satellite-Based Data in Air Quality Management

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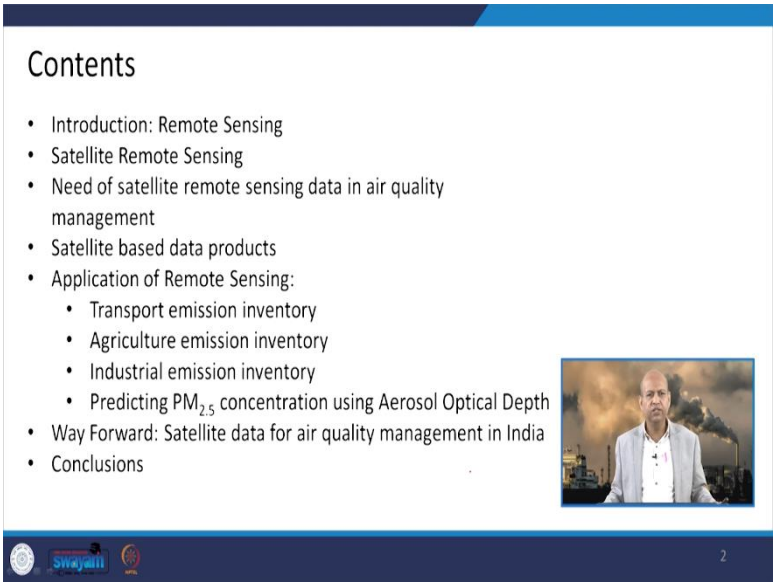

Hello friends. You may recall that we have discussed several aspects of air quality monitoring and then modelling, emission inventory development. And these days we are discussing about several kinds of emission inventories, whether for industrial sector, transportation sector, domestic sector etc.

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.

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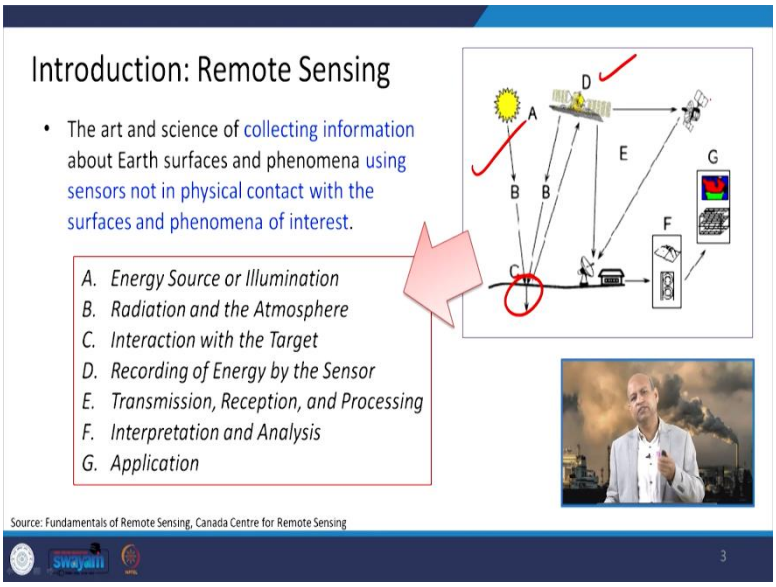

So, like when we go for the introduction of remote sensing, the remote sensing itself is an art and science of collecting information about the Earth's surfaces, there are so many features of our surface and various phenomena like, atmospheric phenomena, or watershed, airshed etc. But today's lecture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

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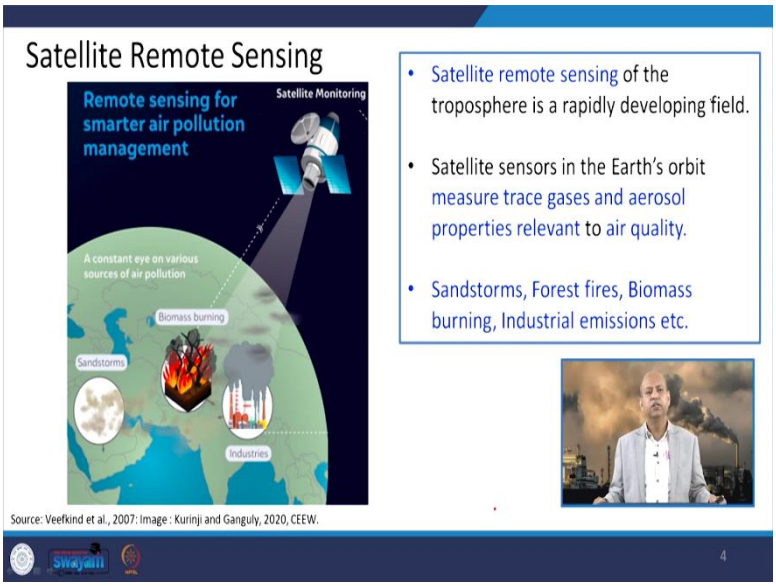

So, these satellite remote sensing of troposphere, which is the lowest layer of the atmosphere is rapidly developing in, all over the world basically, this field is very increasingly it is going on in a developing phase. So, satellite sensors in the Earth's orbit,, that can measure trash gases as well 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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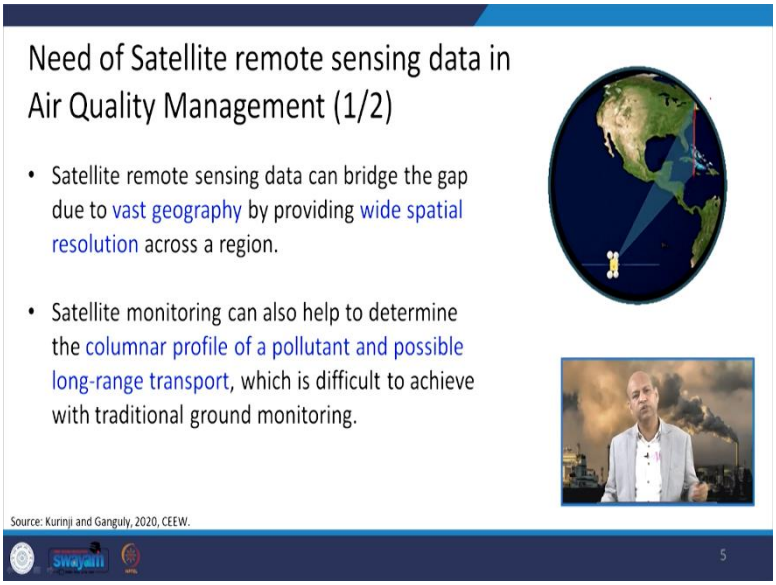

Well, when we talk about what is the need of satellite remote sensing data in air quality management. So, basically this provides a vast geographical range and the wide spatial resolution across the region, that is not possible through conventional air quality monitoring, because we have limitations 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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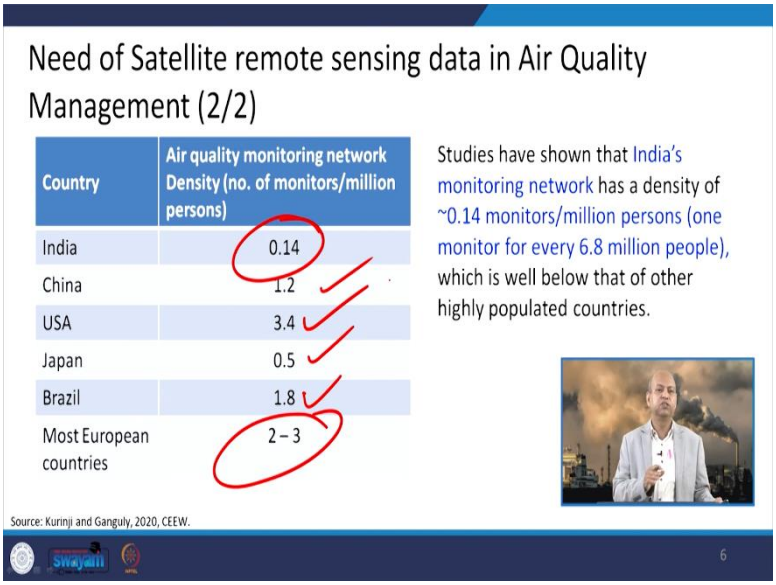

Well, then in context of India basically, if we talk about what is the air quality monitoring network density in different countries, then ours is, kind of lowest one you can see here, only 0.14, number of monitors per million of the people is there in India, whereas in China is 1.2, in USA at 3.4, in 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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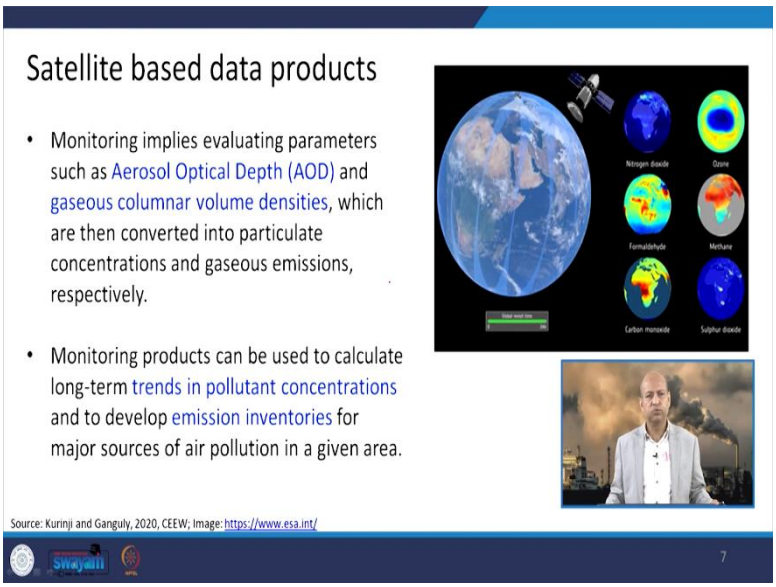

Well, when we talk about satellite based data products, so there are many like monitoring implies evaluation of different parameters such as Aerosol Optical Depth, AOD and gaseous

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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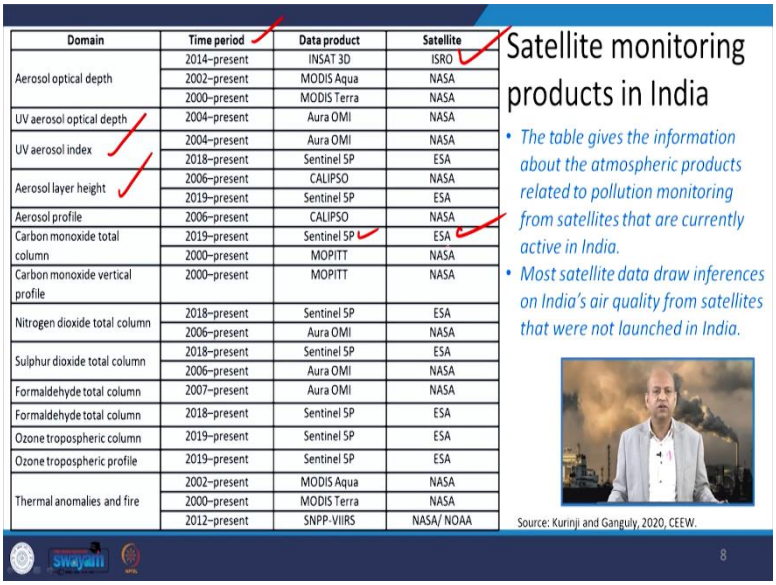

Domain	Time period	Data product	Satellite
Aerosol optical depth	2014–present	INSAT 3D	ISRO
	2002–present	MODIS Aqua	NASA
	2000–present	MODIS Terra	NASA
UV aerosol optical depth	2004–present	Aura OMI	NASA
UV aerosol index	2004–present	Aura OMI	NASA
	2018–present	Sentinel 5P	ESA
Aerosol layer height	2006–present	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

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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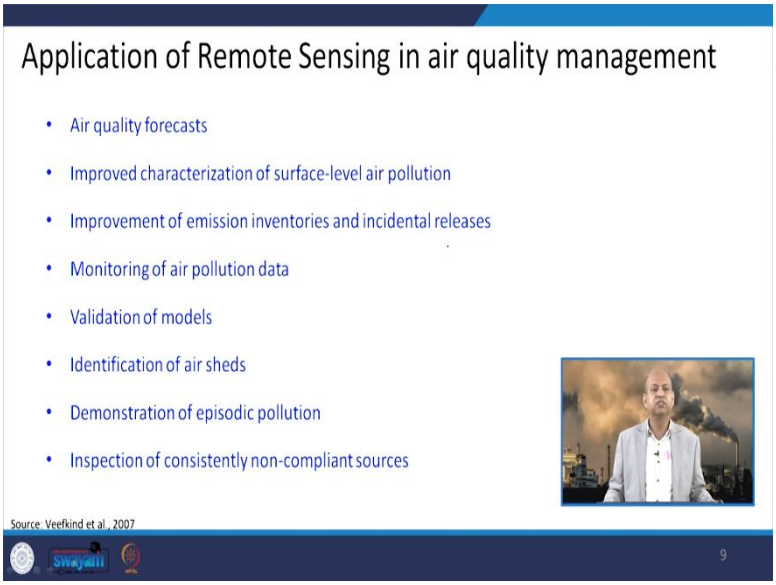

Now, when we talk about what is the application of these remote sensing data in air quality management. So, there are many like this list shows like it can help in your quality forecasts, those data can be used in that way, then it can also help in improving characterization of surface layer air pollution 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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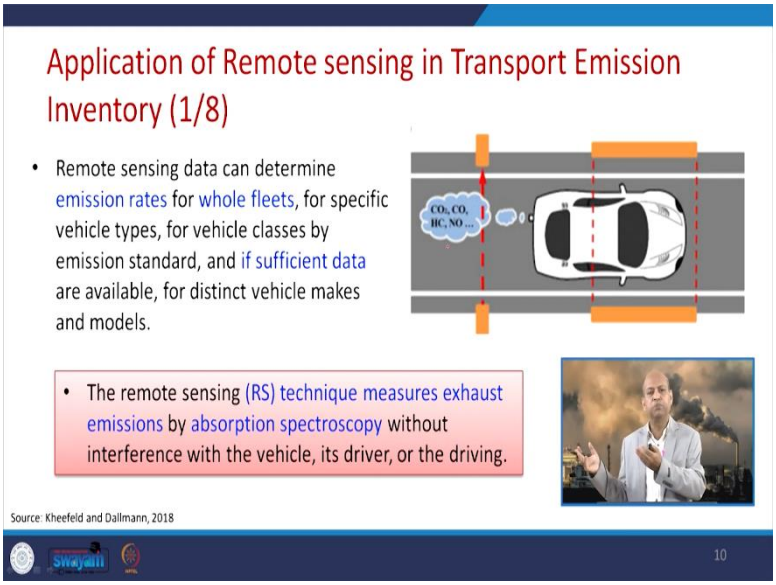

So, there are multiple applications basically. When we talk about like how to apply the remote sensing information in transport emission inventory transportation sector. So, there are some information, which are very interesting and you will find it very informative also. Basically, the remote sensing 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 absorbtion 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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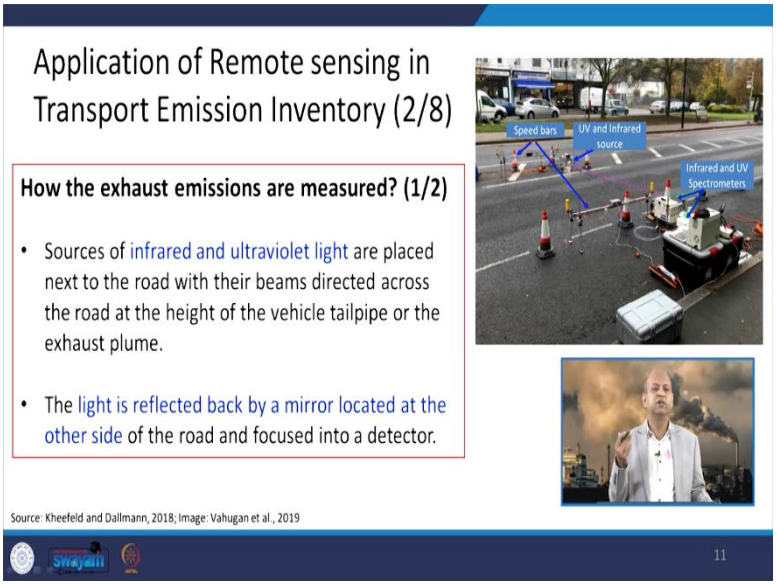

So, the sources and the how does it happens basically, how it is measured. So, the sources of infrared or ultraviolet light from a particular instruments can be put like across the road you can see here. So, this light are placed next to the road with the beam directed across the road. So, when some 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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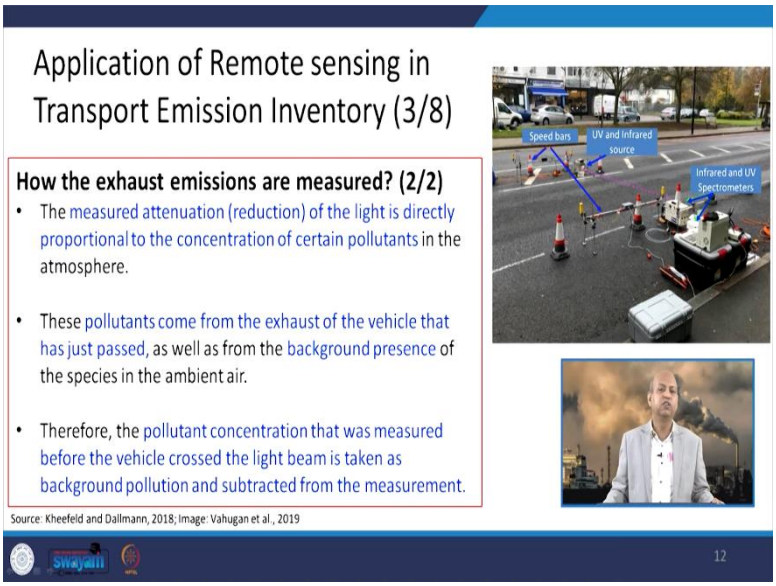

So, the measured, this reduction of the light is directly proportional to the concentration of certain pollutants in the atmosphere in that particular area. And these pollutants come from the exhaust of the vehicle that had just passed.

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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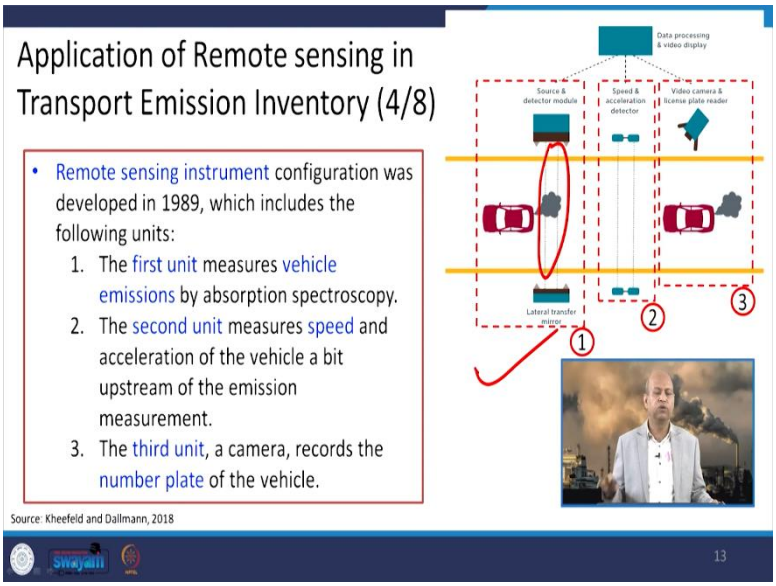

Then the remote sensing instruments, this configuration how does it take place, this is also shown in this particular figure you can see there are three units. The first unit measure the vehicle emissions by absorption spectroscopy, you can see here this one. The second unit measures the speed and acceleration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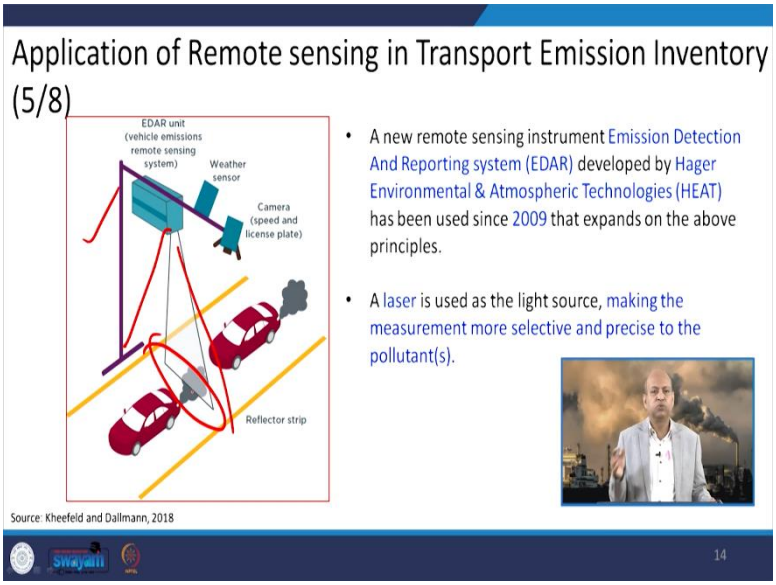

Now, if we talk about like application of remote sensing in transport emission inventory, then this technique has been further improved like rather than putting the instruments across the road, now these instruments are placed at the certain height. So, it gives this beam and the laser is used better 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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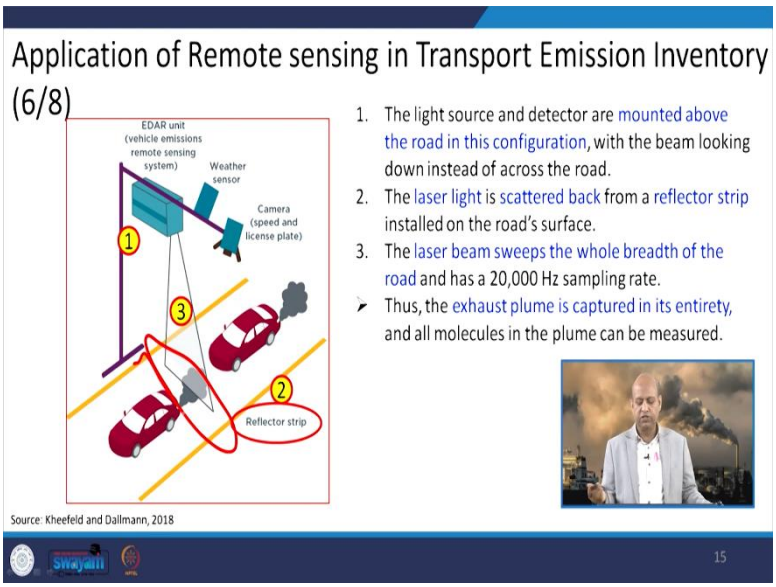

So, you can see here this the first light source and detector are mounted above the road in this particular configuration you can see, then the laser light is scattered back from the deflector strip this is reflected strip you can see on the road and then exhaust plume is captured entirely, because of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

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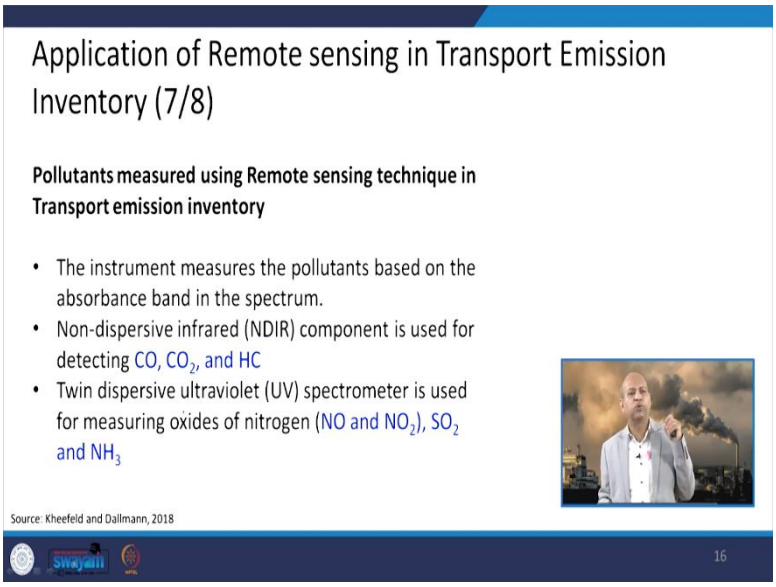

Well, when we talk about the pollutants measured using remote sensing techniques, then we see that the instruments which are measuring the pollutants are based on absorption band of a spectrum particular range is there, then Non-Dispersive Infrared NDIR component is used for detecting like carbon monoxide or CO_2 or hydrocarbons. And twin dispersive ultraviolet spectrometer is used for measuring the oxides of nitrogen like NO and NO_2 and also SO_2 and ammonia. So, that way difference is there.

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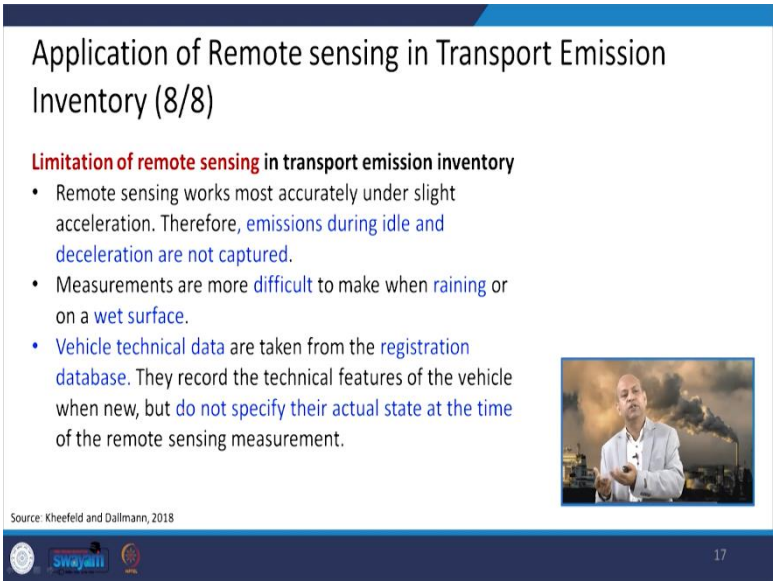

Well, there are certain limitations of remote sensing in transport emission inventory, because this remote sensing works most accurately under slight acceleration not very high acceleration and not even when this vehicle is at idle stage. So, the emissions during idle and deceleration are not captured, 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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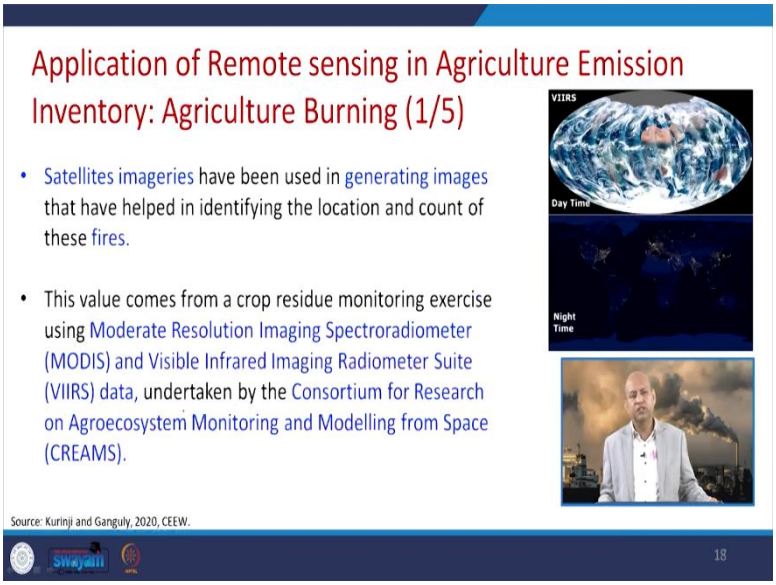

Well, now, if we come to application of remote sensing in agriculture emission inventory, because transportation is over now, we go for agriculture burning related inventory or the data. So, the satellite measurements which are generating images with the help of like identify locations and count of different 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 VIRS 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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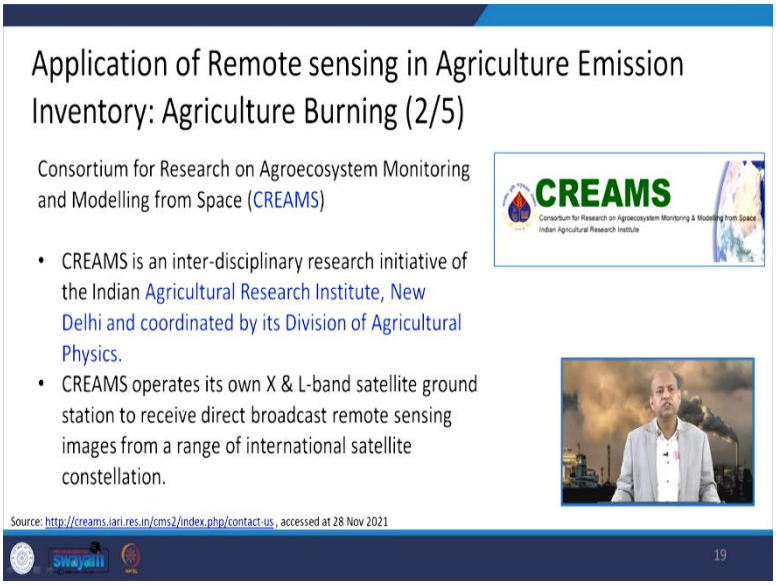

So, this is an interdisciplinary, research initiative of Indian Agriculture Research Institute, IRI in New Delhi and it is coordinated by division of agricultural physics basically. So, the CREAMS operates its own, excellent band satellite ground station and receives the direct broadcast remote sensing 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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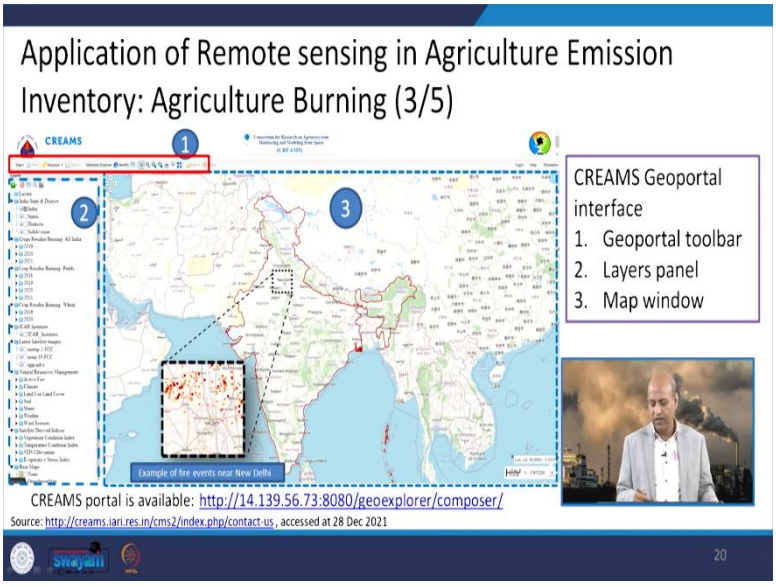

So, basically like, this has a portal, geoportal interface. So, it is shown just to give you a kind of feeling how does it work, basically, there are geoportal toolbar, layers panel and the map window you can see. So, you can select particular area, and then you can see how many points

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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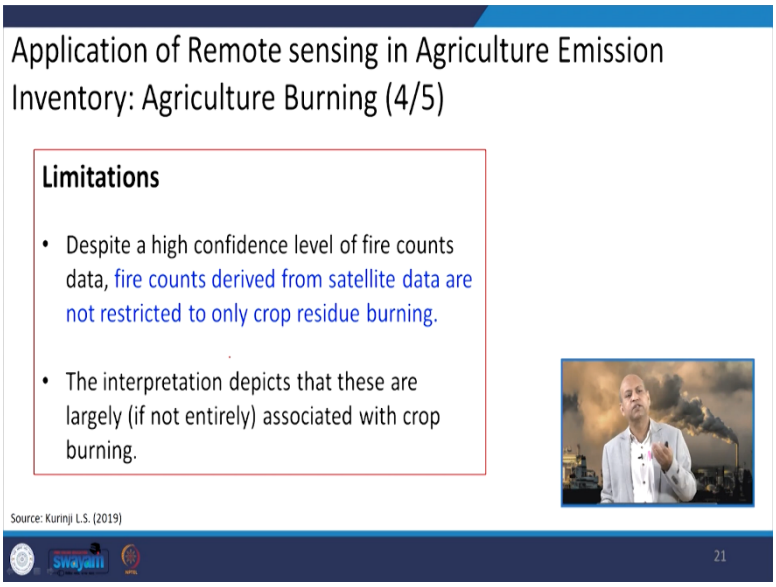

But there are limitations like despite the high confidence level of fire counts data, fire counts derived from satellites are not restricted only to crop residue burning, because even if some waste burning is there, it will count, some crop residue burning kind of thing. So, uncertainty is there and 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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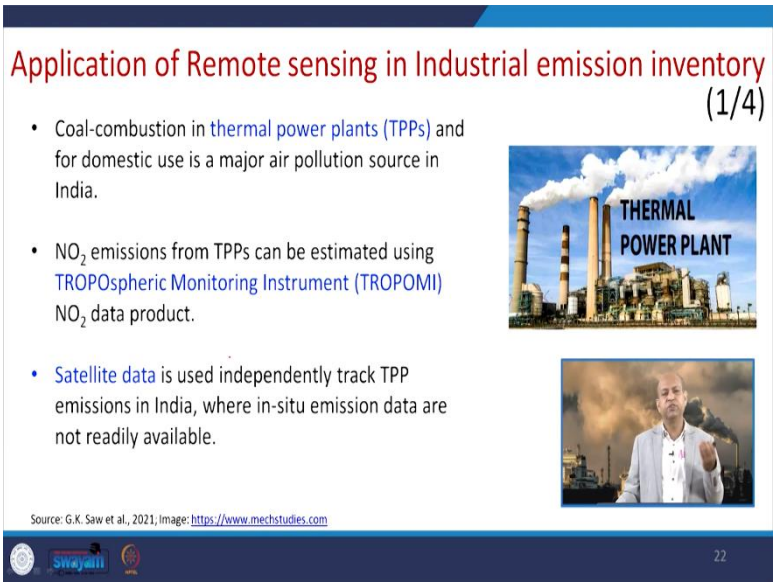

Now, next we talk about like industrial emission inventory, what is the role and application of this remote sensing. So, basically like coal combustion in Thermal Power Plants (TPP) and for domestic use in a major air pollution sources in India can be taken with satellite observations also, like NO_2 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 NO_2 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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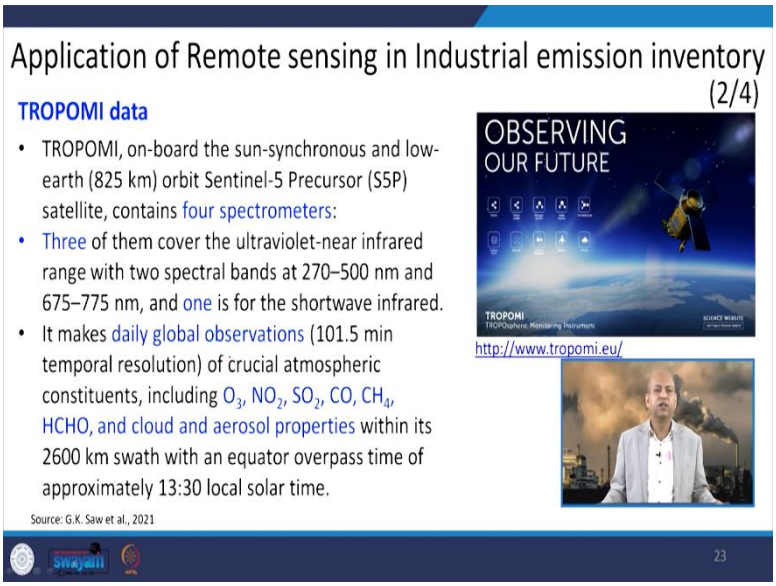

Well, the TROPOMI data, which are available on both they have this sun synchronous and low Earth orbit satellite related data, which contains four spectrometers, three of them are used for ultraviolet near infrared rains kind of thing, then the two spectral bands are there one is for the this shortwave infrared. And it makes daily global observations and it can be used for, these Ozone, NO_2, SO_2, CO, CH_4 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.

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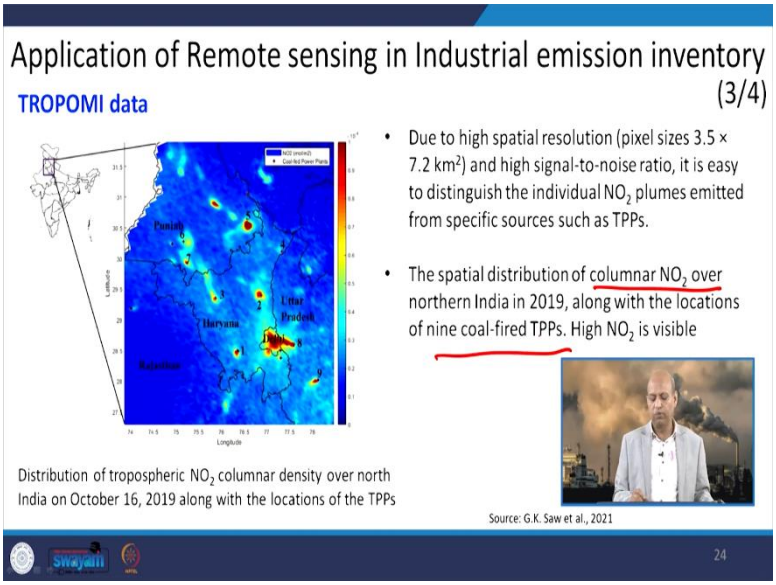

Well, you can see how it gives the data about these thermal power plant plumes. So, like due to high spatial resolution like pixel 3.5 to 7.2 square kilometer is there, high signal to noise ratio is also there, it is easy to distinguish individual NO_2 plumes like you can count here and from specific 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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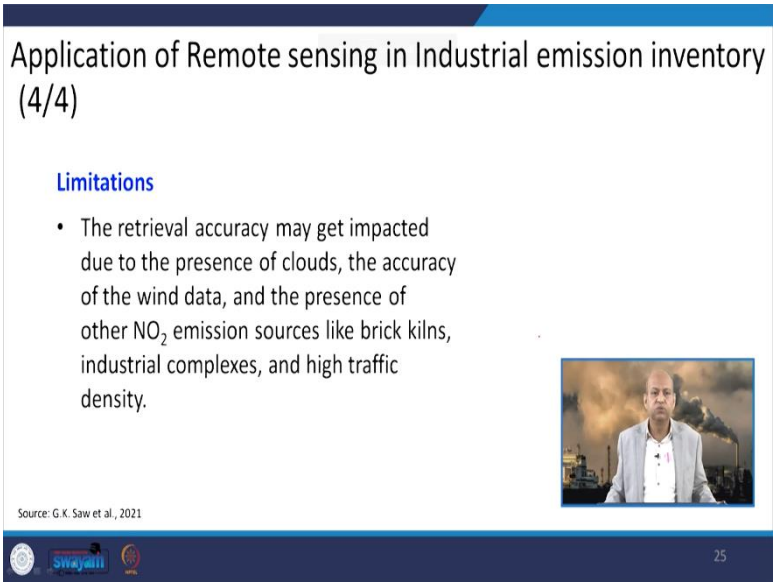

Well, there are limitations again in this case also, the retrieval accuracy may get impacted due to the presence of clouds. So, then that observation is not very accurate in that sense the

accuracy of the wind data presence of other NO_2 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 NO_2, because of these exhaust emissions from traffic. So, that kind of interference may be there which we need to remove.

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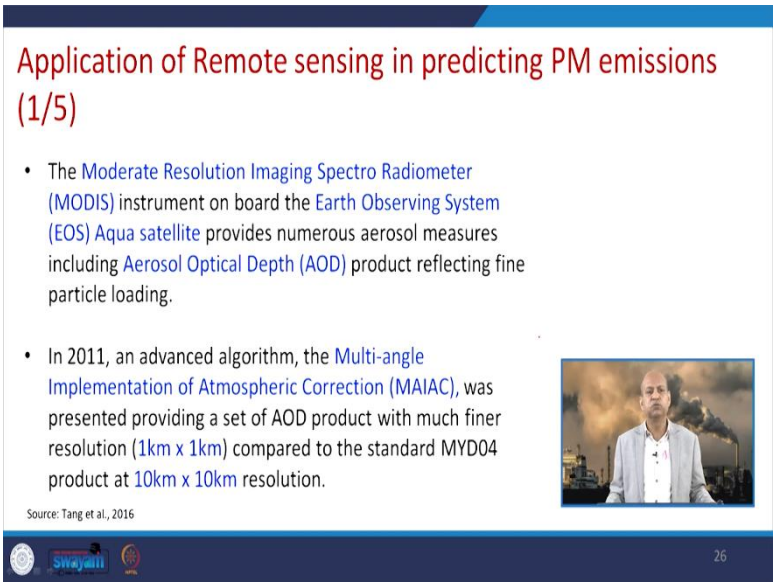

Well when we talk about like, how to apply it remote sensing for predicting particulate matter emissions? So, then again, we can go for usage of this MODIS data Moderate Resolution Imaging Spectroradiometer. And then this Earth Observing System is there US Aqua satellite, which gives the information 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.

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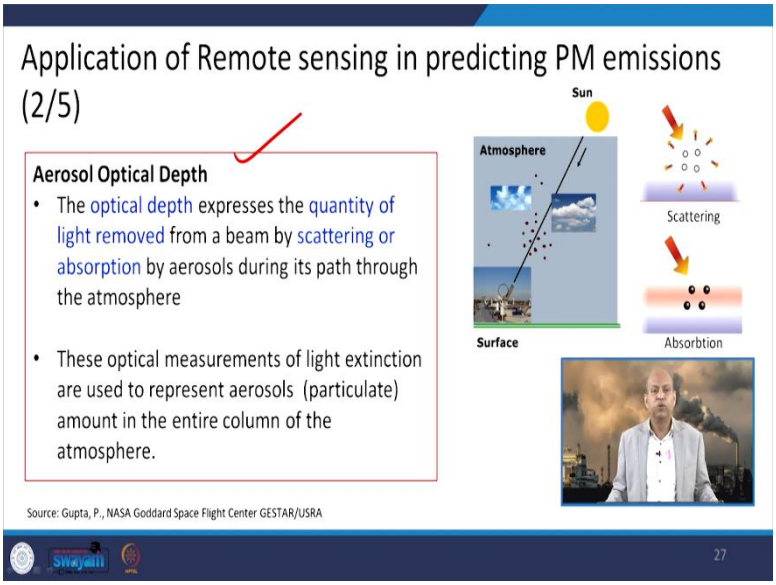

Well, when we talk about AOD or aerosol optical depth, so the optical depth expresses basically the quantity of light removed from a beam, which is being scattered or absorbed by aerosols during the, its path through the atmosphere. So, that amount gives indirectly the, aerosol optical depth related 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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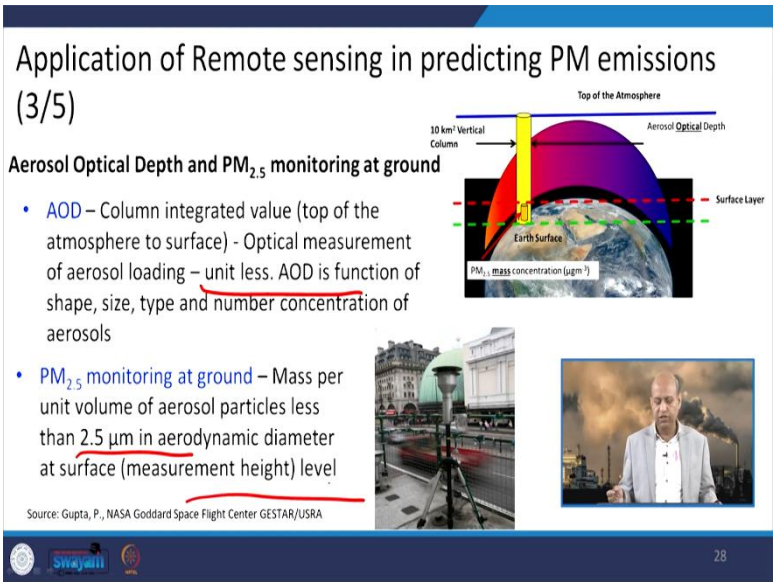

Well, so, AOD is the column integrated value basically, in the column note or the particular layer and this optical measurement of aerosol loading, AOD is function of the shape, it is unitless, shape, size and type of number of concentrations of aerosols, so that way it can vary

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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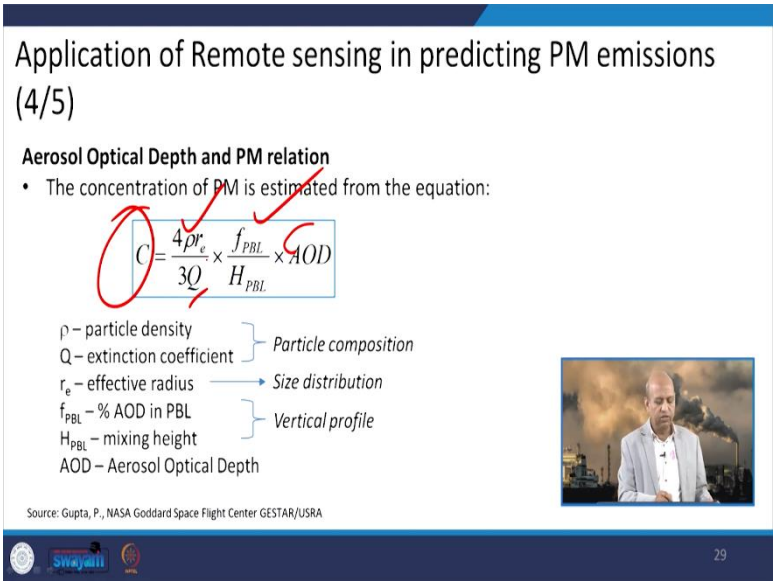

Then, there are certain like light related values, so how to convert it into concentration of particulate matter. So, this is the relationship like empirical relationship, which is used for concentration for estimating concentration of particulate matter by this AOD, which we have measured. So, the AOD 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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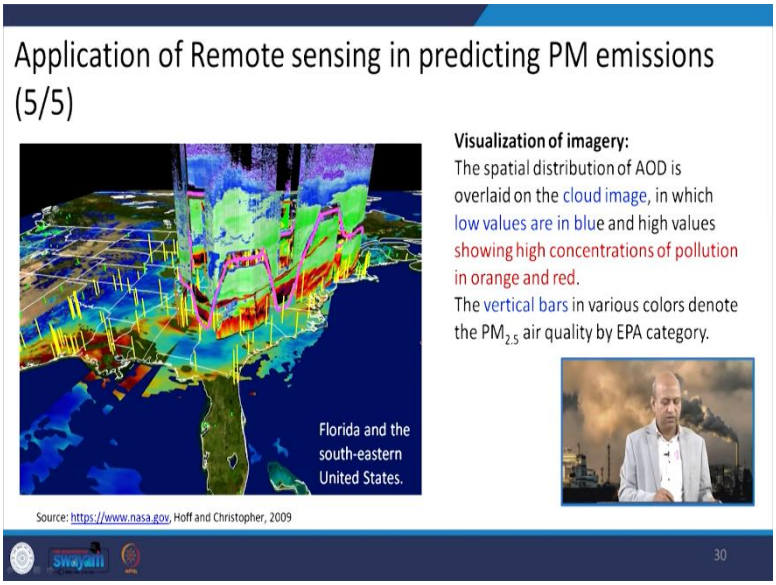

Then this kind of pictorial representation can be there which can give how much pollution is there for example, this high concentration of pollution in orange and red is shown and the cloud images are also there, then the low values of the blue, which can be seen because of this kind of pictorial representation 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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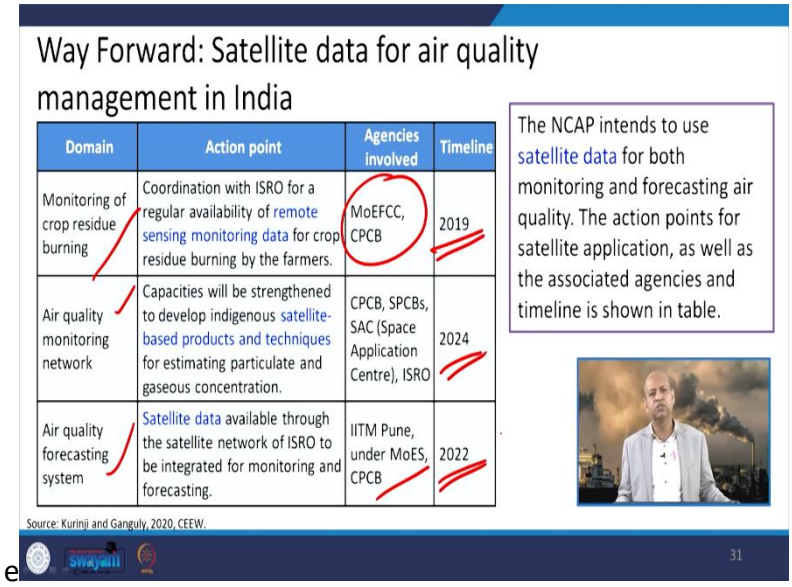

Well, so, what is the way forward of the satellite observations which are growing day by day and in different ways we can get the information. So, the NCAP, which like National Clean Air program, it has the intention or the objective to use satellite data for both monitoring as well as forecasting of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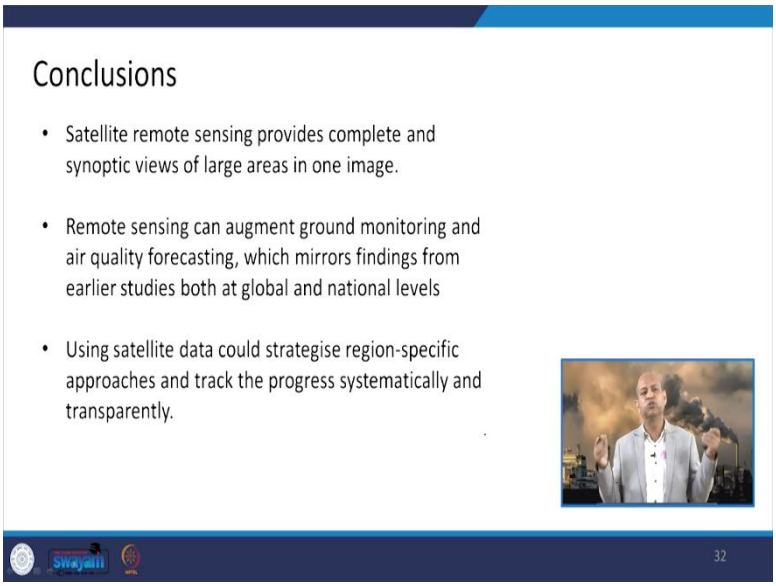

So, this is all for today we can say that this satellite remote sensing provides complete and synoptic views of large areas in one image. So, that is the beauty of the satellite observations, which is not possible by point to point air quality monitoring of the data physical monitoring of the data.

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.

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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.