Machine Learning for Soil and Crop Management
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Lecture 43
Hyperspectral Remote Sensing and ML Applications in Agriculture (Continued)

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Welcome friends to this third lecture of week 9 of NPTEL Online Certification Course of Machine Learning for Soil and Crop Management. And in this week 9, we are discussing the Hyperspectral Remote Sensing and Machine Learning Applications in Agriculture, focusing on basically crop and soil.

And in our previous two lectures, we have discussed the basics of hyperspectral remote sensing and how it differs from multispectral remote sensing why hyperspectral remote sensing is better than multispectral remote sensing, we have discussed and the second lecture of this week, we have discussed different types of hyperspectral sensors, hyperspectral sensors, both spaceborne as well as the airborne hyperspectral sensors.

Now, these spaceborne hyperspectral, among the spaceborne hyperspectral sensors, we have, we have discussed Hyperion, then HICO then ECOSTRESS and among the spaceborne, among the, among the airborne hyperspectral sensors we have discussed AVIRIS and PRISM, we have seen the fundamental differences between the spaceborne and airborne sensors, we have discussed in details about AVIRIS and AVIRIS-NG and how these are helpful for capturing huge amount of information for Earth features.

We have seen that how AVIRIS-NG has been flown in different countries specifically in India, in the phase 1 they have flown to 57 spots and capture the images and in the phase 2, there are 25 priority points. So, we have seen and we are now in this lecture going to discuss some of the important consideration some of the important features of hyperspectral remote sensing, what are the sensor configuration what is whiskbroom sensor, what is pushbroom sensor, and also we are going to discuss in details about hyperspectral missions in India.

And finally, we are going to discuss how to get the hyperspectral data and how to handle the hyperspectral data.

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So, these are the basic concepts which we are going to discuss hyperspectral. So, first we are going to discuss the hyperspectral mission in India. Then we are going to discuss the sensor principle and then we are going to discuss hyperspectral remote sensing data sources and processing.

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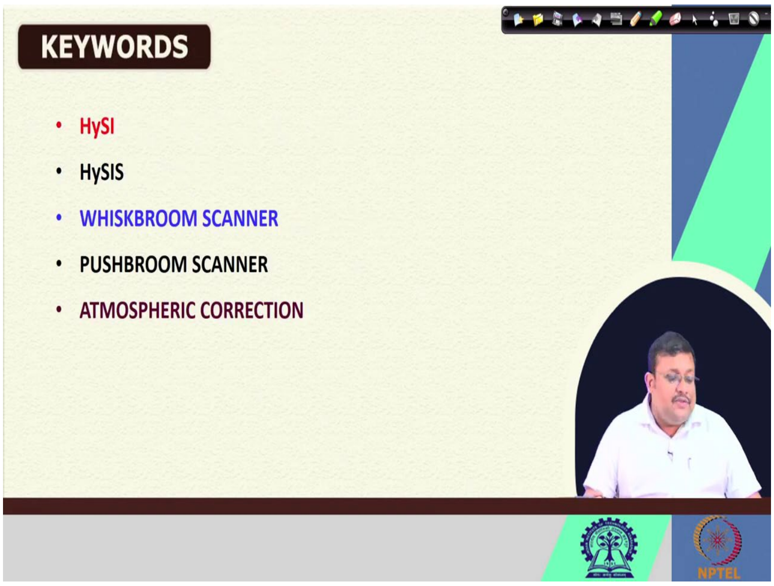

These are some of the keywords which we are going to discuss HySI, HySIS, whiskbroom scanner, pushbroom scanner and atmospheric correction.

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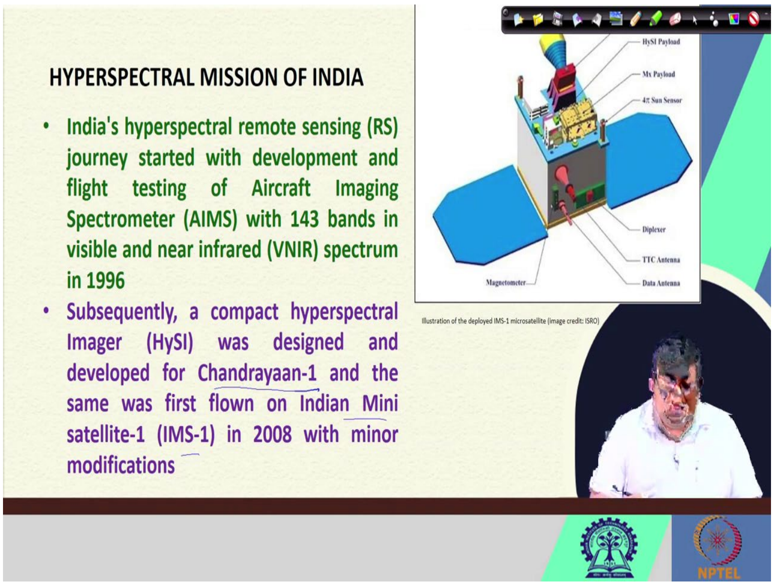

So, let us start discussing with the hyperspectral mission in India before we can get some good, before we can we can see some case studies of hyperspectral sensors, it is important to know the the history of or the timeline of hyperspectral remote sensing. So, that is why we are going to briefly cover the hyperspectral missions of India.

This hyperspectral, India's hyperspectral remote sensing journey started with the development and flight testing of Aircraft Imaging Spectrometer we call it AIMS with 143 bands in visible and near Infrared spectrum in 1996. So, and subsequently a compact hyperspectral Imager we call it HySI, this compact hyperspectral Imager or payload was designed and developed for this Chandra- 1, Chandra- 1, 1 and the same was first flown in Indian mini satellite which is called IMS- 1 in 2008.

With minor modification you can see this is an illustration of the IMS- 1satellite with the HySI payload you can see here this is the HySI payload they have indicated with different other payloads also. So, these payload HySI payload or hyperspectral Imager was basically designed and developed for this Chandrayaan- 1 mission and it was flown in this IMS-1 satellite in 2008.

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So, so, this IMS- 1 instrument provided 64 band spectrum in VisNIR region with about 505 meter spatial resolution and 130 kilometers swath and it uses different types of components like telecentric lens, wedge filter based spectral dispersion, active pixel area array sensor, highly miniaturized mechanical structure and different types of electronics. It was a medium resolution spectrometer with over sampling in spectral domain. So, this was one of the important hyperspectral Imager of India. Indian hyperspectral remote sensing missions

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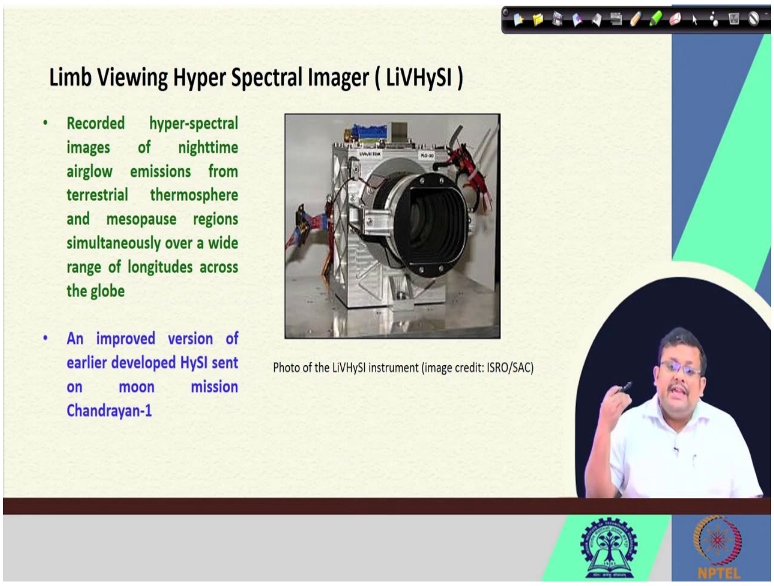

And, then come the LiVHySI the LiVHySI is the short form of Limb Viewing Hyper Spectral Imager and it was an improved version of earlier developed HySI sent in moon mission Chandrayan- 1. So, and this this LiVHySI basically recorded the hyperspectral images of nighttime airglow emissions from terrestrial thermosphere and mesopause region simultaneously over a wide range of longitude across the globe.

So, this is the image of this LiVHySI instrument. So, these HySI and LiVHySI was the important milestones of Indian hyperspectral remote sensing missions.

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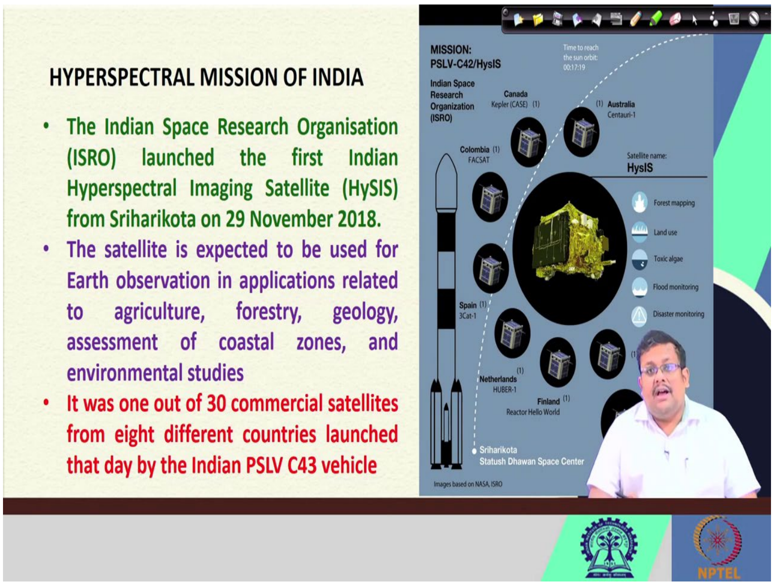

Now, in 2018, November, the ISRO, Indian Space Research Organization launched the first Indian hyperspectral imaging satellite, which is known as HySIS and this satellite is expected to be used for Earth observation, applications related to agriculture, forestry, geology, assessment of coastal zones and environmental studies.

So, these HySIS was the design to focus on agricultural operations, forestry operations, geological operations, and coastal zone explorations and environmental explorations, it was one of the 30 commercial satellite from eight different countries launched that day by Indian PSLV C43 vehicle. So, not only this payload it also this PSLV C43, C43 also carried other payloads along with HySIS on that same day, which were coming from different countries.

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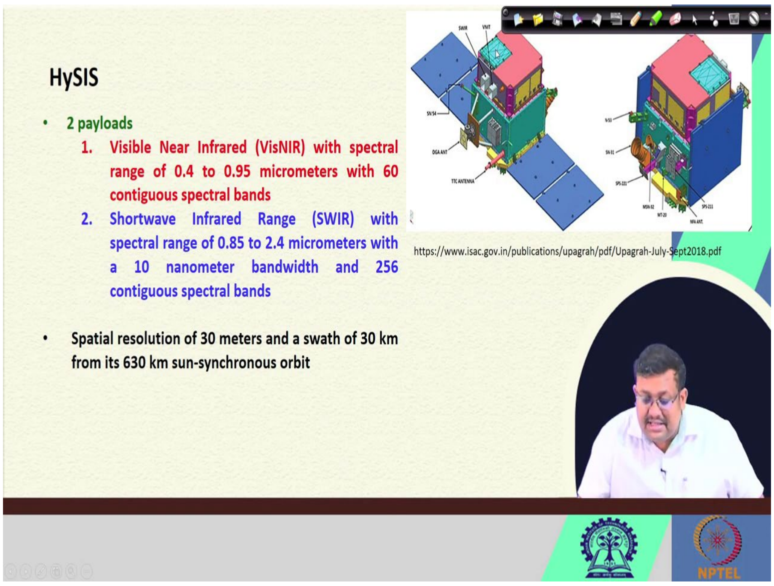

So, in this HySIS, there are two payloads. So, these two payloads are basically first one is the visible near Infrared with spectral range from 0.5, 0.4 to 0.95 micron with 60 contiguous spectral band this is the first payload, the second payload was shortwave Infrared range with spectral range of 0.85 to 2.4 micron with a 10 nanometer bandwidth and 256 contiguous spectral bands.

Spatial resolution and the HySIS had spatial resolution of 30 meters and a swath of 30 kilometer from its 630 kilometers sun-synchronous orbit. So, here you can see that these, there are different types of payloads, one is SWIR you can see payload another is VisNIR, VisNIR payload.

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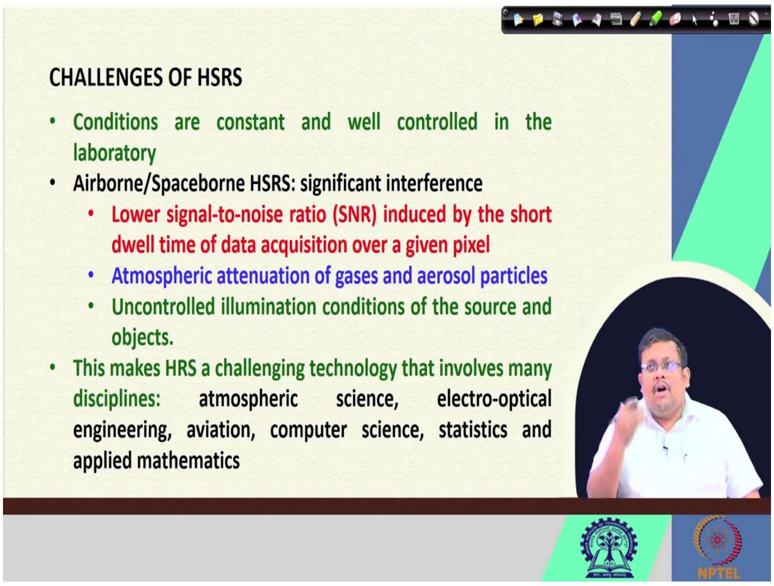

So, these HySIS was has been utilized by by ISRO for exploring different types of application as I have mentioned, for agriculture to forestry to environment and geological applications. Now, once we have covered these hyperspectral missions of India, hyperspectral missions of India.

So, let us discuss what are the challenges of hyperspectral remote sensing as a whole. Now, in the laboratory it is always easy to get the images hyperspectral images because conditions are constant and well controlled. But in case of spaceborne and airborne hyperspectral remote sensing there are some significant interferences.

First of all the lower signal to noise ratio induced by the short dwell time of data acquisition over a given pixel. Since these airborne sensors and spaceborne sensors are continuously moving. So, the dwell time of data acquisition over a given pixel is very limited and as a result there is always chance of getting higher signal to a lower signal to noise ratio.

So, that it is not desirable to have lower SNR or lower signal to noise ratio in so, that creates problem in case of airborne or spaceborne hyperspectral remote sensing. The second issue is atmospheric attenuation of gases and aerosol particles. So, that is why we need to do the atmospheric correction. What is atmospheric correction?

We are going to learn in our coming slides. So, when the image when the when the electromagnetic radiation passes through atmosphere, it is getting attenuated by gases and additional aerosol particles in the aerosol particles. And as a result, this is one of the as a result the images are highly distorted or as a result, it creates the interferences.

And, the third important issue is uncontrollable illumination condition of the source and objects which also creates the significant interference for airborne and spaceborne hyperspectral emergency. So, to to counterbalance these effects, there are different types of disciplines which are involved in dealing with hyperspectral remote sensing like atmospheric science, electro-optical engineering, aviation, computer science, statistics and applied mathematics.

So, all they are working in sync, in in a cumulative way or in synchronously, so that they can challenge, they can they can they can offset these challenges of interferences in the airborne or spaceborne hyperspectral remote sensing.

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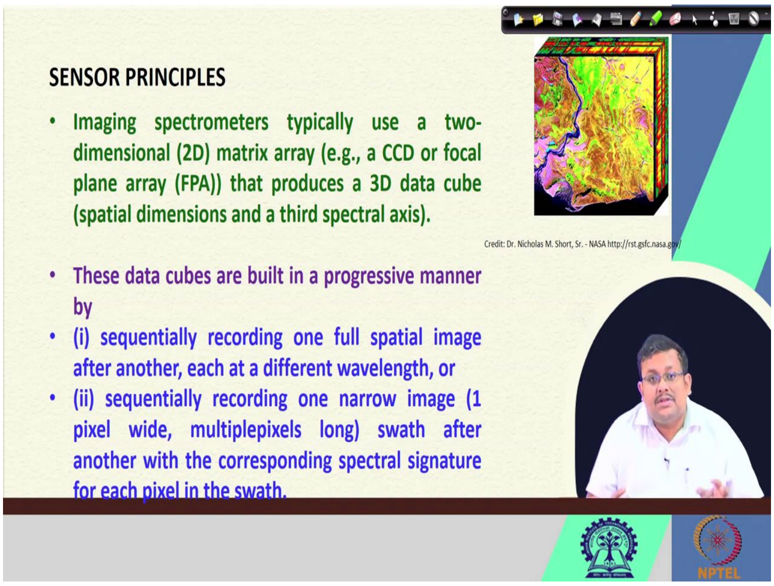

Now, if we see the sensor principal the imaging spectrometers typically uses a two-dimensional 2D matrix array, a CCD array or focal plane array that produces the 3D data cube, we already know that in case of hyperspectral remote sensing we need to have a 3D data cube. So, the output is a 3D data cube.

So, this data cube can be develop in a progressive manner by two ways first of all, sequentially recording one full spatial image after another, each at different wavelengths. So, we can take at each wavelength at a time and then we can take an image with individual wavelength and then cube combine them together to get a data cube, so this is one of the way.

The second way is, second way is sequentially recording one narrow image, one pixel wide and multi pixels long. So, one pixel wide and multi pixel long. So, these narrow image is taken, so it is called the swath.

So, one swath after another swath with the corresponding spectral signature for each pixel in the swath. So, we can take the image sequentially for each individual swath one after another with the corresponding spectral signature for each pixel in the swath. So, these are the two ways through which we can develop these data cube by these imaging spectrometers.

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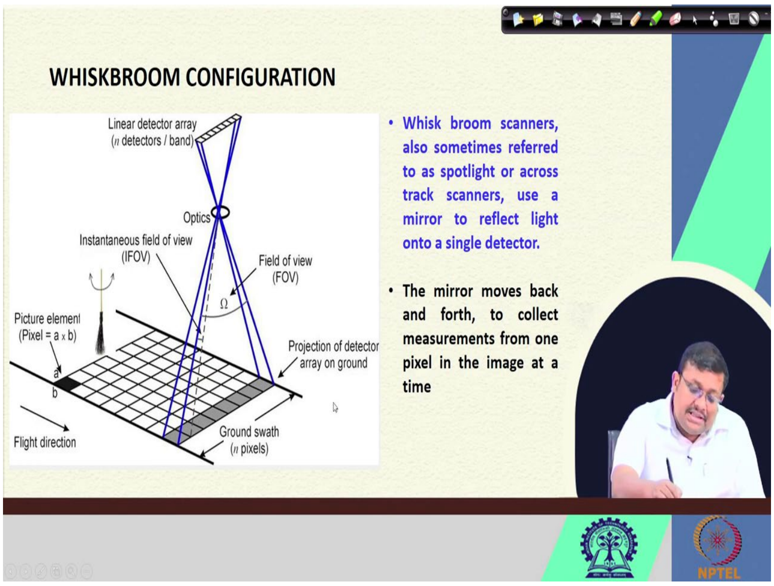

So, let us discuss, how we can generate these hyperspectral data cube? There are two types of scanner, while we talk about the hyperspectral imager, there are two types of scanner. One is whisk broom scanner another is a push broom scanner. Now, this whisk broom scanner, we can see this is a whisk broom configuration.

And in this whisk broom configuration is also known as the spotlight or across track scanners which uses a mirror to reflect the light onto a single detector. So, let us consider these a broom and this broom is moving in this direction and thereby it is moving ahead. So, ultimately by scanning the pixels in this way it is moving in the forward direction. So, this is called, this is called the whisk broom scanner.

So, in this whisk broom scanner it uses a mirror to reflect light onto the single detector and the mirror moves backs and back and forth, to collect the measurement from one pixel in the image at a time, so remember that while the scanner is moving through this swath, we can see that this is basically taking, this is basically focusing on one pixel at a time.

So, again, this whisk broom scanner utilizes a moving mirror, which moves back and forth and this is the field of view and while moving back and forth, it collects a measurement from one pixel at a time in the image and then it collects the data. So, this is the whisk broom scanner and by these motion it takes, it covers the all the pixel in this swath and thereby it moves in the in this direction. So, this is the whisk broom configuration.

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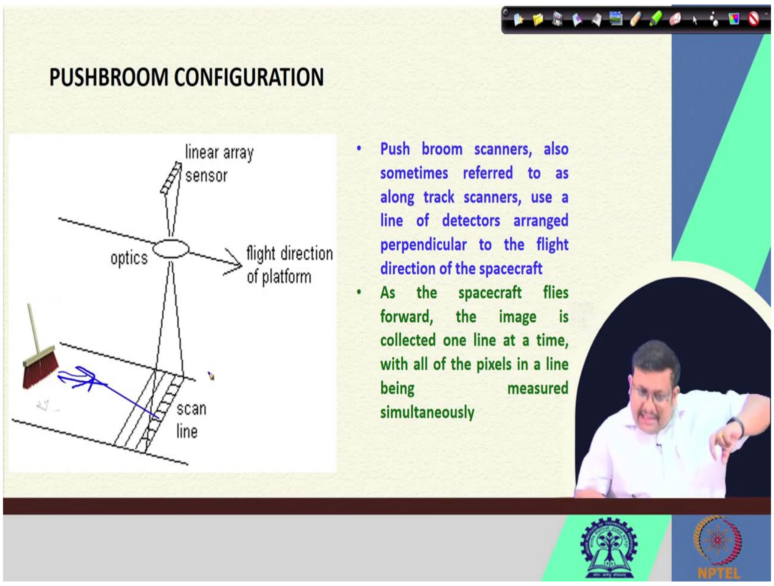

Another configuration is called a push broom configuration. So, in the push broom configuration, also sometimes referred to as the along track scanner. So, basically it utilizes a line of detectors, so, you can see here it is a line of detectors arrange perpendicular to the direction of the flight of the spacecraft.

So, suppose, the spacecraft is flying in this direction, it has a line of array, since a linear array sensor which is perpendicular and as the spacecraft is moving, these broom is continuously moving and collecting the images of the whole area.

So, as this broom is moving these images are continuously taken, so, the broom is moving in this direction and the images are taken in this swath and ultimately covering the whole region. So, the, as the spacecraft slides forward the image is collected of one line at a time with all the pixel in the line being measured simultaneously. So, this is the difference between whisk broom scanner and push broom scanner.

In case of push broom scanner, this there is this mirror is not moving and here these linear array sensor is arranged in perpendicularly from the flight path direction and it is capturing the image in lines of pixel and then covering the whole area. Whereas, in case of his broom images with broom scanner, it rotates the mirror and it capture the image of one pixel at a time and thereby complete the whole swath of pixel and then it moves. So, this is the difference between pushbroom configuration and whisk broom configuration.

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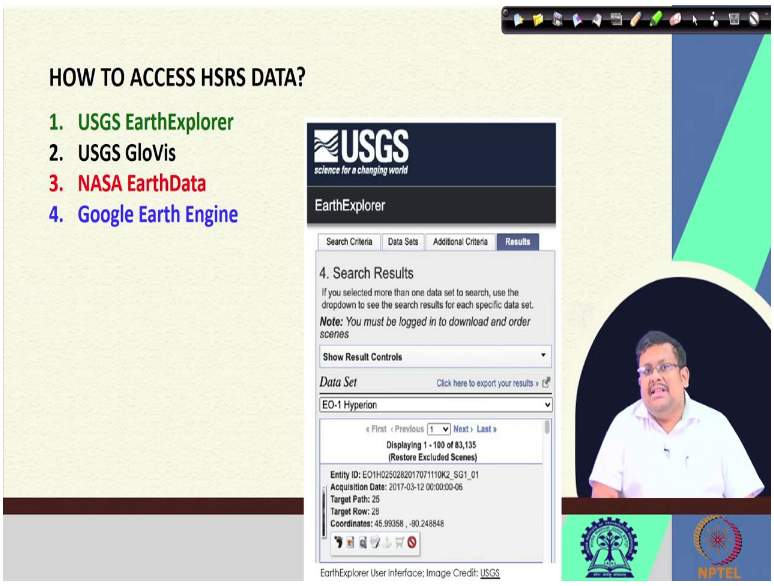

Now, the next question comes to our mind. What is the sources? What are the sources of hyperspectral remote sensing data? There are a couple of sources of hyperspectral remote sensing data. As you can see USGS Earth you can download the data from USGS EarthExplorer as you can see in this image. Also, you can download the data from USGS GloVis, NASA EarthData and Google Earth Engine. So these are a couple of sources from which you can you can this, you can download the HSRS data for hyperspectral remote sensing data.

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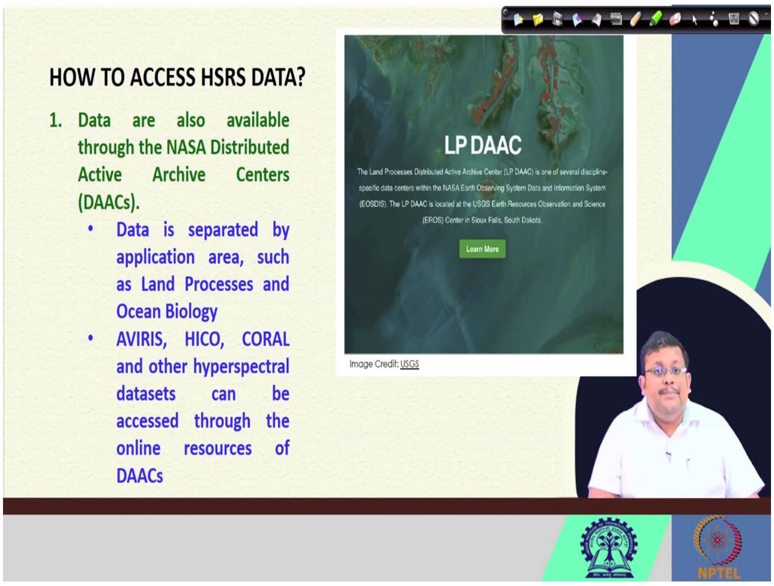

Data are also available through NASA distributed active archive centers, or DAACs. So, data is separated by application areas such as land processes and ocean biology. AVIRIS, HICO data, CORAL and other hyperspectral data set can be accessed through these online resources of DAACs.

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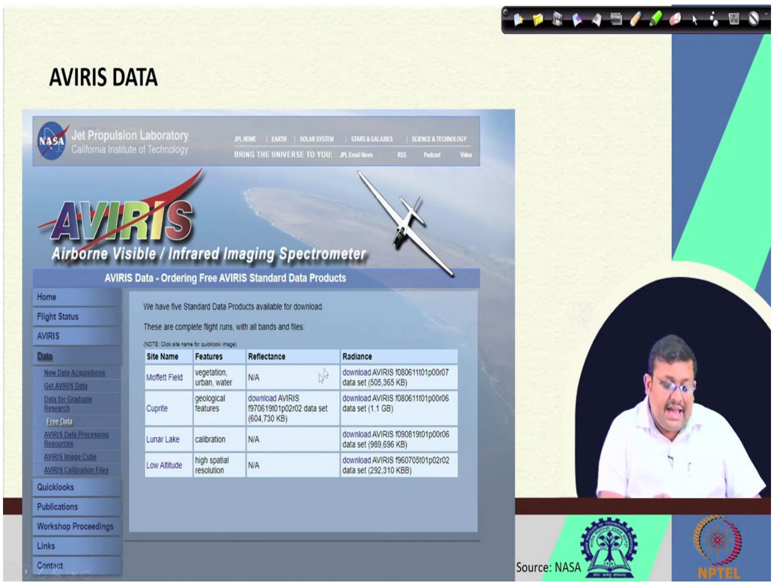

And, as you can see, AVIRIS data, you can also download from this JPL website. You can download the data both, level 1 data, which is the radiance data and level 2 data which is the reflectance data for different areas. So, these are different sources of hyperspectral data.

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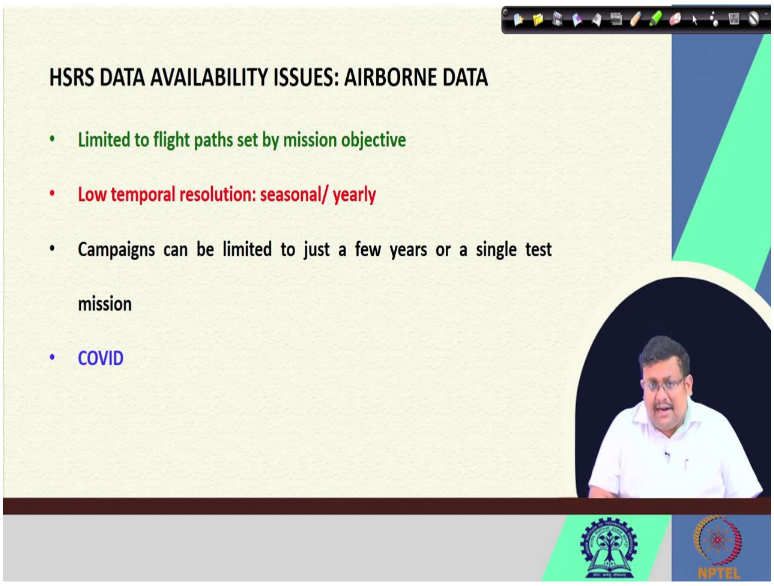

Now, what are the issues with the hyperspectral remote sensing data availability? Let us consider if, if you consider the satellite test mission data. Generally, the data access might be limited to specific geographic region. So, this is one of the issue of hyperspectral remote sensing, specifically satellite test mission data. And it is, we require some time in NASA scientists to process the raw data.

And also, it is required to make a contact with the mission program scientist to access the pre process data. So these are some of the data availability issue. Getting the hyperspectral remote sensing data is still an issue, especially for the resource poor countries. And so, but, but nowadays, more and more data are getting available from different agencies.

And in case of airborne, there are some also issues like limited to flight paths set by mission objectives, low temporal resolution. So, generally these data are available either seasonal either seasonally or yearly and also campaigns can be limited to just few years or a single test mission. So, we have seen in case of India, there are only 57 sites in the which are priority 1 and in case of priority 2 there are only 25 sites which have been explored by these airborne AVIRIS data, AVIRIS-NG data.

So, there, of course, there is the availability issues, there are availability issues, when we when we talk about the hyperspectral remote sensing data, it is not that available, it is it is not available as like as the multispectral data of course, the COVID has also affected the hyperspectral data availability. So, these are some of the major issues for hyperspectral data availability both from spaceborne platform any airborne platform.

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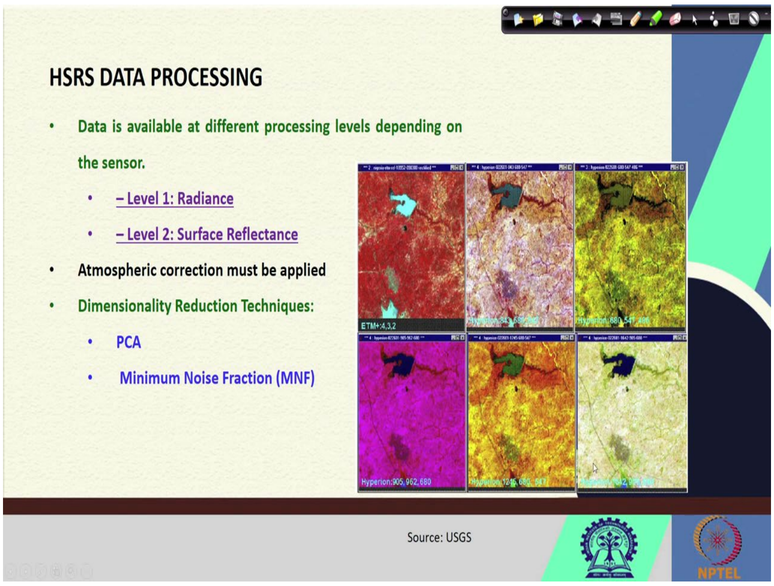

Now, data as I have showed in couple of slides earlier, that data is available in different processing levels depending on the sensor. For example, in case of AVIRIS data is available for both level 1 which is radiance data and level 2, which if we chose the surface reflectance.

So, depending on your application, we can you can get either level 1 data level 2 data, remember that the atmospheric correction is must to get the level 2 data, specifically band.

Also we need to have dimensionality reduction for example, principal component analyses or minimum noise fraction to get process data, process hyperspectral data as you can see, this is the multispectral images and these are the hyperspectral images obtained using different bands. So, of course, using different bands, the images which are available is having more and more information than that of multispectral images.

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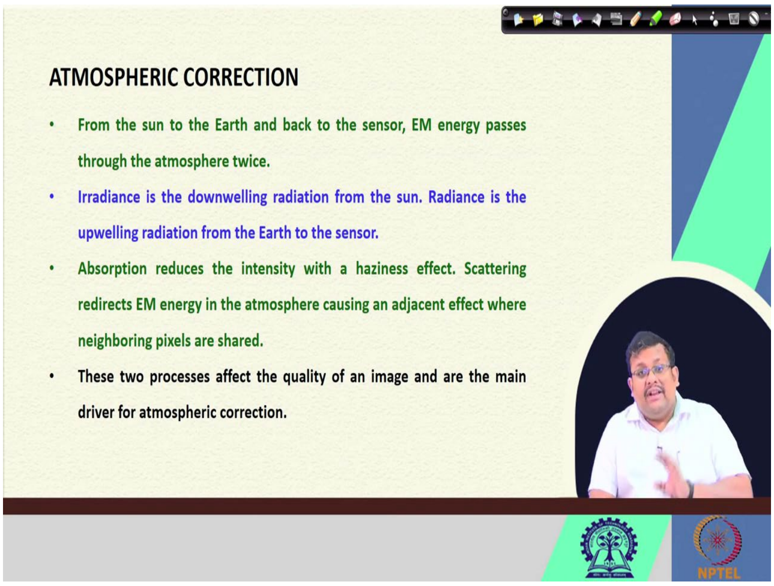

And, what is atmospheric correction? Atmospheric correction that from sun to the Earth and back to the sensor, these electromagnetic energy passes through atmosphere to twice. One during the incoming radiation and there is outgoing radiation. Now, irradiance is the down welling radiation from the sun, whereas, radiance is the upwelling radiation from the Earth to sensor.

Now, remember that during this flight of these electromagnetic radiation, there are different types of features different types of interferences for example, absorption, these absorption reduces the intensity with a haziness effect and scattering redirects the electromagnetic energy in the atmosphere causing and adjacent effect, where the neighboring pixels are shared.

So, these absorption reduces the intensity and produces the haziness and also scattering is another important aspect, which redirects the electromagnetic energy in the atmosphere causing an adjacent effect where neighboring pixels are also shared. And these two processes are the major processes that affect the quality of an image and these are the major driver of the atmospheric correction. This is why we need atmospheric correction.

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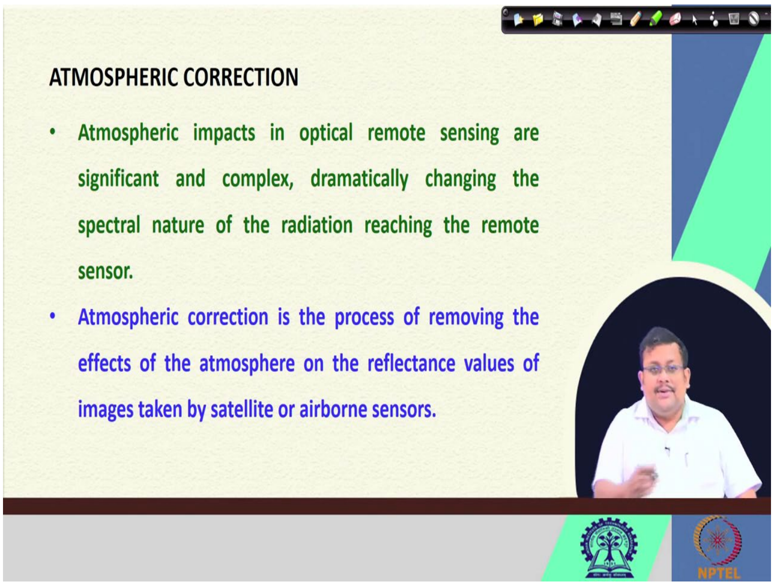

And so, atmosphere, so atmosphere impacts these hyperspectral remote sensing and these impacts are complex, dramatically changes the spectral nature of the radiation reaching the remote sensor and that is why we need to apply these atmospheric correction. So, this atmospheric correction is the process of removing the effect of the atmosphere on the reflectance values of the images taken by satellite or image airborne sensors. So, this is why these atmospheric correction is important. If we want to have the noise free images for better analysis of our features.

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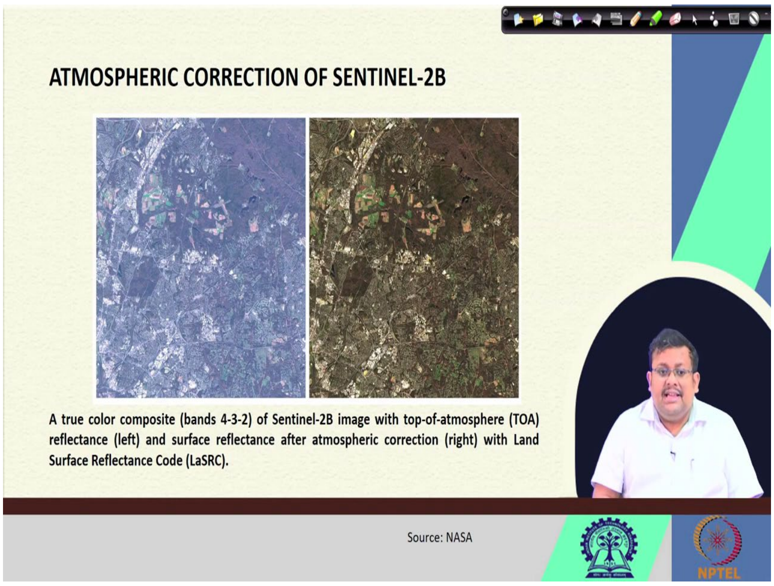

So, here you can clearly, clearly see that an example of atmospheric correction of SENTINEL-2B, of course, this is a multispectral sensor, but you can have an idea. So, here it is a true color composite of SENTINEL-2B image with top of the atmosphere. So, this is the top of the atmosphere reflectance and this is the surface reflectance after atmospheric correction with the land surface reflectance code.

So, you can clearly see the difference before and after the atmospheric correction. So, this is why we need to have atmospheric correction with the hyperspectral data to for getting the maximum and an accurate information for subsequent machine learning based characterization.

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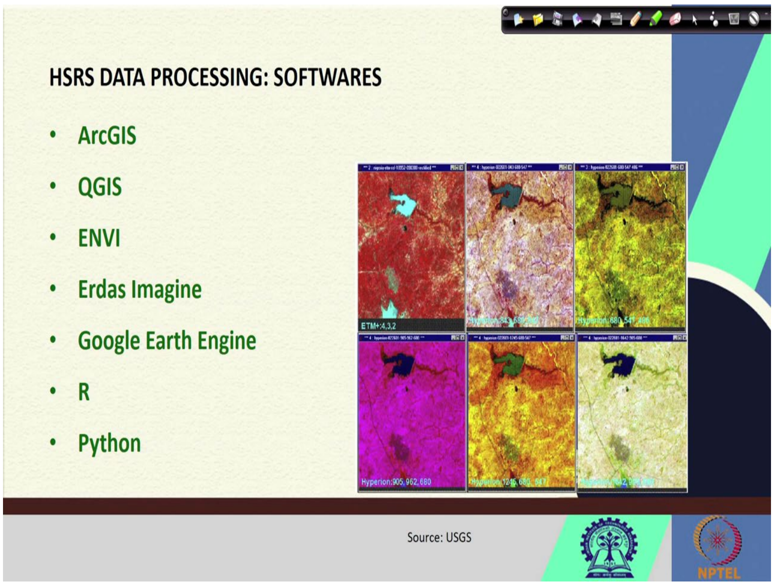

Now, what are the software's which you can use for hyperspectral data processing remote sensing data processing, you can use ArcGIS, QGIS, ENVI software, Erdas Imagine software, Google Earth Engine you can use R also you can use Python. So, these are the some of the softwares which you can extensively use for processing the hyperspectral remote sensing data.

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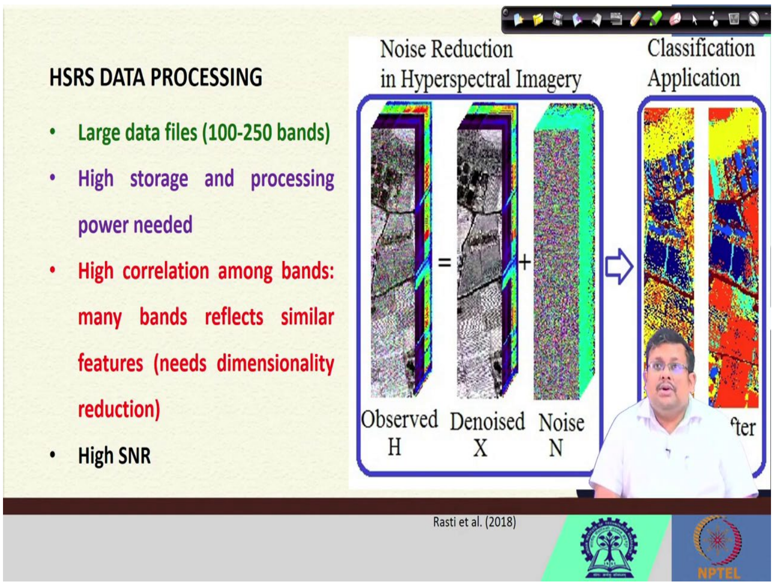

And remember, remember some of the issues that in case of hyperspectral remote sensing data processing, you have to deal with the large data files, because these data consists of 100 to 250 bands. So, these files are really large. So, of course, these files require high storage and processing power.

And sometimes we see that since they are captured in so, many bands 100 to, 100 to a couple of couple of 100 bands, we can see some time correlation among the band that means, many bands are highly correlated, and they can take the image or they can they can reflect the similar features over the Earth's surface.

So, in that condition, we need to have some kind of dimensionality reduction approach using principal component analysis or another other ways we can deco relate those bands, so, that we can get noise free images and sometime in case of hyperspectral remote sensing, we get high signal to noise ratio. So, here a good picture is given. So, here you can clearly see this noise reduction in hyperspectral imagery.

So, this is the hyperspectral imaging the original hyperspectral image and then this is the denoised image plus noise and ultimately before and classification application. So, you can see that before and after denoising the accuracy, how the accuracy for classification changes. So, before the denoising the classification accuracy was low. However, after the denoising the classification accuracy is increasing. So, this is the this is the practical benefit of noise reduction in hyperspectral imaging.

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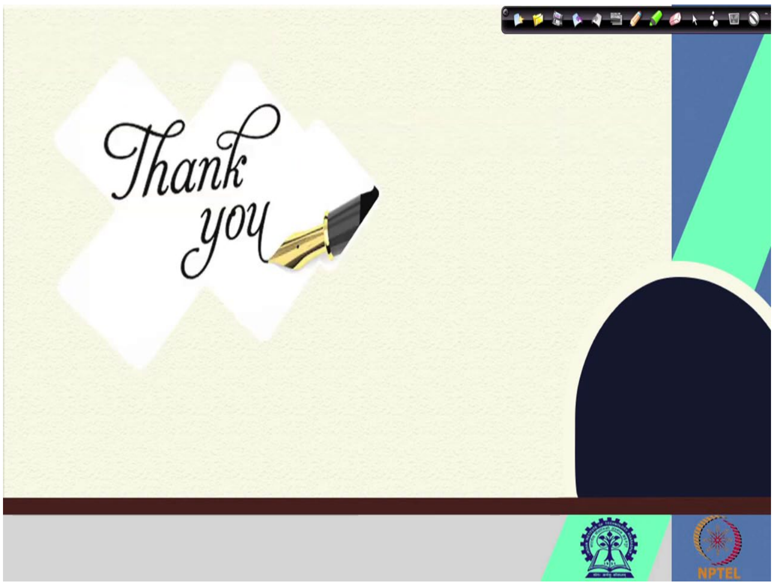

So, guys, let us wrap up this lecture and this is the reference which I have used in this lecture. This is open source and you can get a you can go ahead and read this paper for more information regarding the noise reduction in case of hyperspectral data processing.

So, guys, we have discussed some important concepts. In this lecture we have discussed the hyperspectral missions, remote sensing missions of India, we have discussed the whisk broom scanner, push broom scanners, we have also discussed some of the hyperspectral data sources some softwares which you can utilize for handling the hyperspectral data and also we have discussed that was very correction and how we and some implication of noise reduction in case of hyperspectral data processing.

Let us wrap up our lecture here in the next lecture. We will see some case studies for hyperspectral remote sensing with machine learning for characterizing both soil as well as crop features. Thank you let us meet in our next lecture.