Machine Learning for Soil and Crop Management
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Lecture 42
Hyperspectral Remote Sensing and ML Applications in Agriculture (Continued)

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Welcome friends to this second lecture of week 9 of NPTEL Online Certification Course of Machine Learning for Soil and Crop Management. And in this week, week 9, we are talking about Hyperspectral Remote Sensing and Machine Learning Application for Agriculture. And in this week, this is our second lecture, lecture number 42.

In our earlier lecture, that is first lecture of this week, we have described what is, what are the different areas of electromagnetic spectrum and then, what are the differences between panchromatic band then hyperspectral bands, multispectral bands and ultraspectral bands and what are the major differences between multispectral remote sensing and hyperspectral remote sensing.

We have got a brief overview of hyperspectral remote sensing. Hyperspectral remote sensing is a method, technique which utilizes hundreds of contiguous bands of narrow width, generally less than 10 nanometers less than or equal to 10 nanometers. And then we use those hyperspectral bands to get more high resolution images imagery from any surface.

And in agriculture this hyperspectral remote sensing has been utilized for getting high resolution images for analyzing both crop features as well as soil features. So, we have already got a basic overview of hyperspectral remote sensing. In this lecture, we are going to learn about different types of hyperspectral imagers.

What are the different types of satellite imagers, and hyperspectral imagers from airborne platform and different types of airborne hyperspectral imagers, we are going to learn and what are the applications we are going to learn in this lecture.

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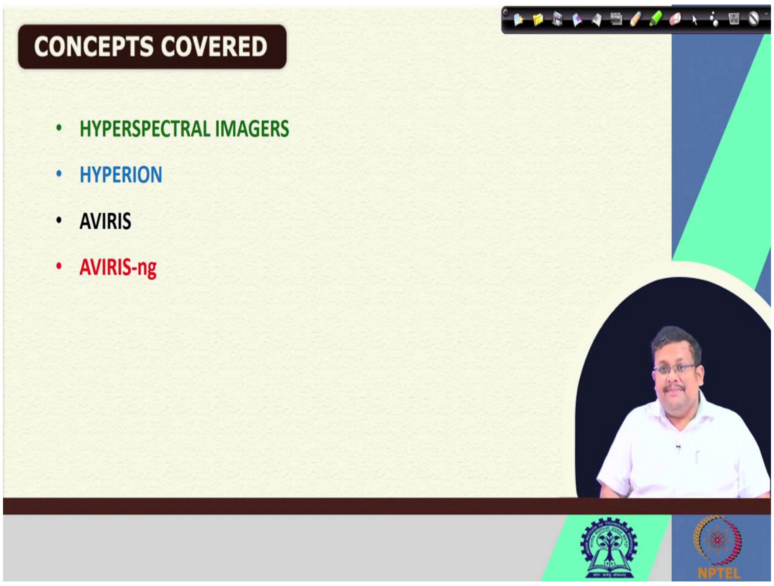

So, these are the concepts, which are topics which we are going to cover in this lecture. First of all, we are going to discuss different types of hyperspectral imagers, then, we are going to talk about Hyperion, which is an important hyperspectral imaging spectrometer and then we are going to discuss AVIRIS and AVIRIS-ng.

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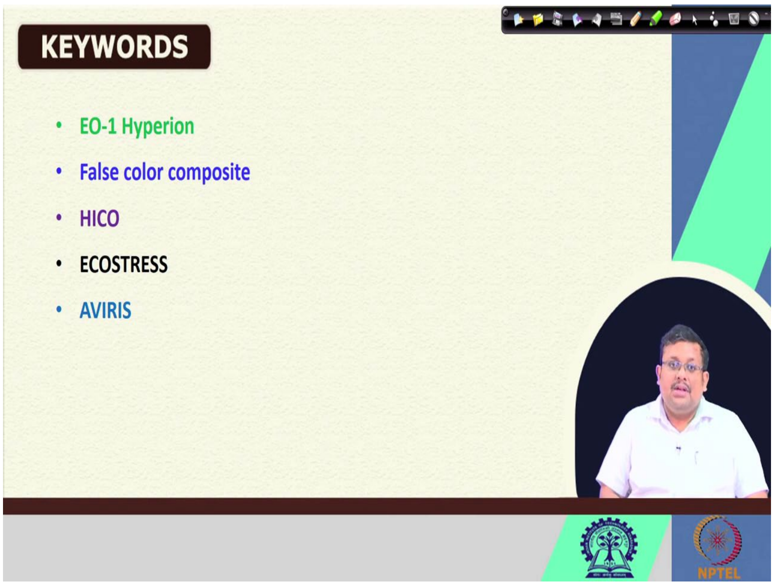

So, talking about the, the keywords of this lecture, these are a couple of keywords which we are going to use in this lecture first of all, EO-1 Hyperion, then false color composite, then HICO, ECOSTRESS and AVIRIS. We are going to discuss all of these in this lecture.

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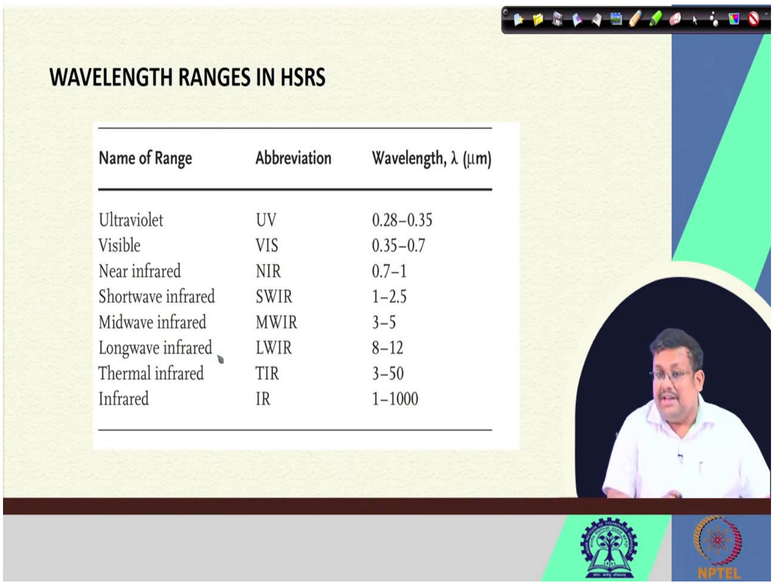

So, let us start with the wavelengths which had been used in hyperspectral remote sensing. In hyperspectral remote sensing we use different types or different ranges of wavelength or different ranges of electromagnetic spectrum and based on that, the naming is different.

For example, as you can see here, the ultraviolet range, which is having this abbreviation of which is having this abbreviation of UV generally utilizes 0.28 to 0.35 micron wavelength range. And then, as in case of visible in case of visible it utilizes from 0.35 to 0.7 micron, in case of near infrared, it generally varies from 0.7 to 1 micron.

And, in case of shortwave infrared SWIR, it varies from 1 to 2.5 micron, in case a midwave infrared or MWIR it varies from 3 to 5 micron, whereas, in case of long wave infrared, it varies from 8 to 12 micron and thermal infrared or TIR it varies from 3 to 50 microns and infrared generally, it varies from which is in the general term IR, it varies from 1 to 1000 micron. So, you can see based on the different ranges the abbreviation and wavelength ranges are different. And so, these are the wavelength ranges, which are being utilized in hyperspectral remote sensing.

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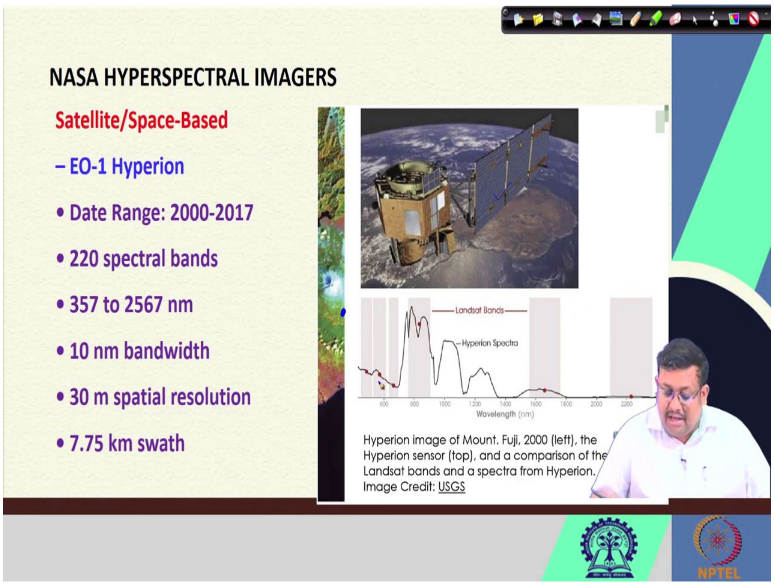

So, let us see the features of EO-1 Hyperion as I have told you that this sensor has been already decommissioned. So, these EO-1 Hyperion the date, the date range for which the data is available is from 2000 to 2017. And it has 220 spectral bands, which ranges between 357 to 2567 nanometer and it has 10 nanometer bandwidth with 30 meter spatial resolution with the 7.75 kilometers swath.

As you can see, this is the image of, Hyperion image of Mount Fuji which was taken in the year 2000. And also here you can see this is the Hyperion sensor. And also here you can clearly see the difference in the amount of information we can gather from Landsat bands as well as from the hyperspectral Hyperion spectra.

So, you can see these red dots are showing the individual bands of Landsat and these are discrete as you can see. And of course, you can also see, this continuous spectrum is from

Hyperion. So, it is clearly visible that how much information more we can gather from a hyperspectral sensor as compared to a multispectral sensor.

Of course, these hyper multispectral sensors gathers the image in discrete bands which are quite which are quite, the thick bands as you can see, but, in case of Hyperion in case of hyperspectral sensor, we can get more higher resolution images with the narrow bandwidth. And as you can see, we can get more and more information from the hyperspectral data.

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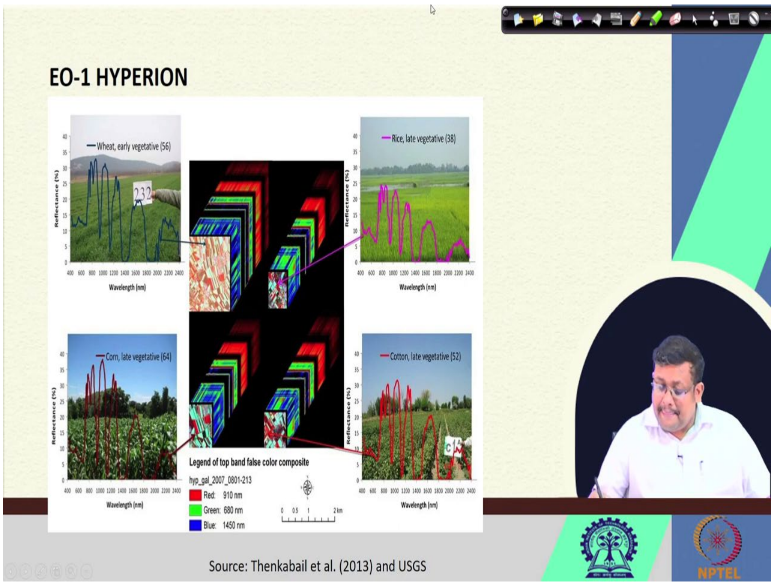

Now, these are also the hyperspectral spectra obtained from Hyperion for a given pixel. So, as we know that in case of hyperspectral remote sensing we get a data cube which is bounded by X and Y direction and in the Z direction we get the wavelengths.

So, for each of these wavelengths, we get the, the, for each of these pixel we get their spectral feature, and you can see here we can clearly see the difference of spectral features in wheat, when the early vegetative growth, here you can see the rice in the late vegetative growth, cotton in the late vegetative growth and corn in the late vegetative growth and these are showing the false color composites these legends of top band, so, showing the false color composite.

Now, the question comes what is false color composite. False color composite we are going to discuss in our next slide, but you can clearly see that using a hyperspectral sensor, how much information we can gather from any surface.

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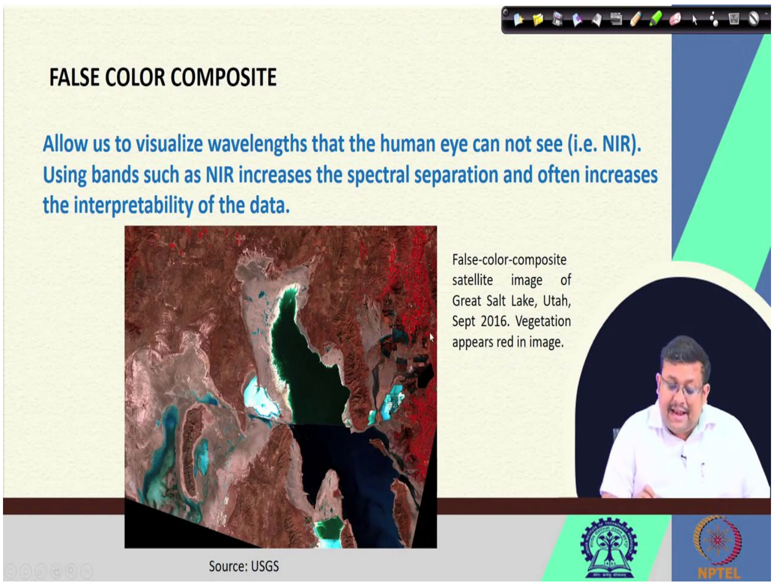

Now, if we go to the next slide and we will see that false color composite. Now, the false color composite allows us to visualize the wavelengths that human eye cannot see, of course, in the near infrared range, in the near infrared rays we cannot see by our naked eyes. So, we need some false color composite we need some color to indicate the features from the near infrared image images.

So, that is why we need to, we need to use some colors to see the features which are taken by the near infrared images. What is the reason? The reason is we need to have more spectral separation and also we need to increase the interpretability of the data as you can clearly see this is the false color composite satellite image from Great Salt Lake, Utah which was taken in 2016 and you can clearly see that these vegetations are appeared red in the images. So, this is a example of false color composite.

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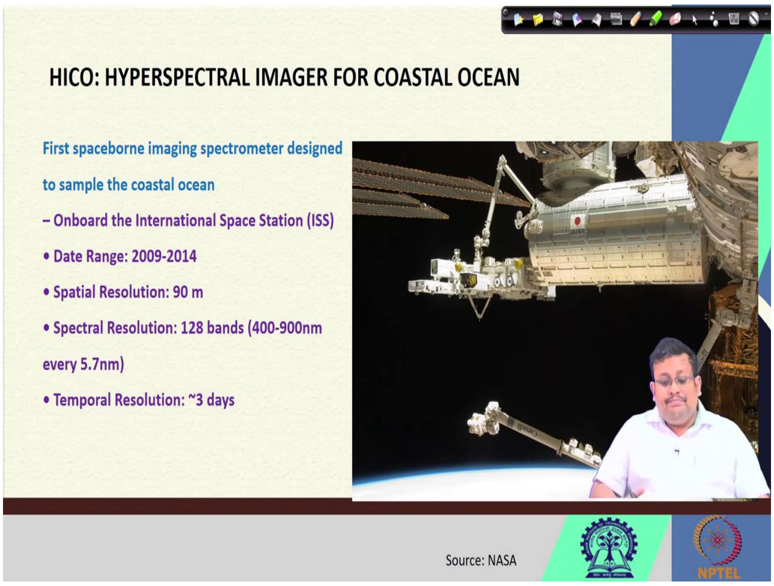

Now, another the hyperspectral sensor, spaceborne hyperspectral sensor is HICO or Hyperspectral Imager for Coastal Ocean and this is the first spaceborne imaging spectrometer designed to sample the coastal ocean and it is onboard to International Space Station and it was, the data is available from HICO from 2009 to 2014 it has a special resolution of 90 meter with a spectral resolution of 128 bands ranging between 400 to 900 nanometer with every 5.7 nanometer and temporal resolution is 3 days.

So, that means, in every 3 day we get an image from HICO. So, this is the image of the HICO sensor onboard to the International Space Station.

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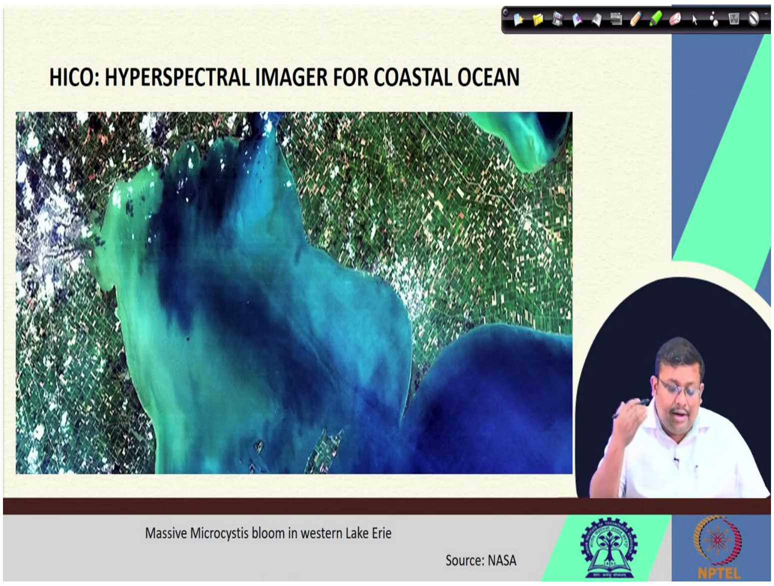

And this is an image taken by these HICO sensor you can clearly see the massive microcystis bloom in western Lake Erie and as the name suggests, in the HICO sensor is focused on coastal ocean imagery. So, you can clearly see the features which are appearing in the coastal ocean or ocean we can we can get it from the HICO hyperspectral images.

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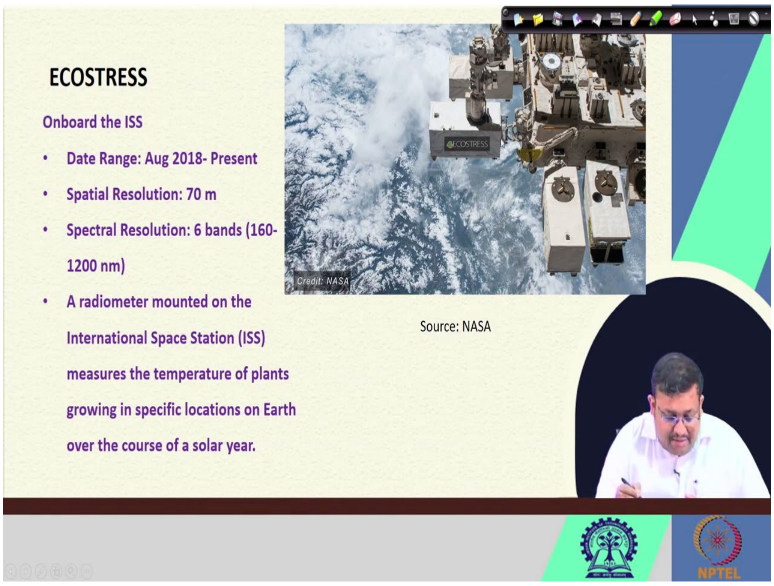

So, and also another on boards International Space Station onboard sensor is ECOSTRESS and this ECOSTRESS the data is available from August 2018 to present with a spatial resolution of 70 meter and it has a spectral resolution of 6 band ranging between 160 to 1200 nanometer it is basically a radio meter mounted in the International Space Station as you can see here, this is the ECOSTRESS sensor, it measures the temperature of the plants growing in specific location of the Earth over the course of solar year. So, these ECOSTRESS is another spaceborne hyperspectral sensor.

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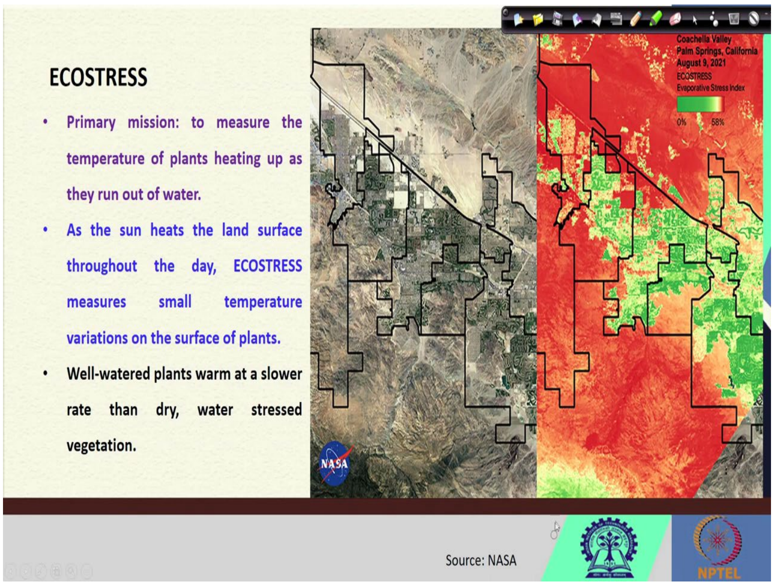

And, what is the, what is the mission of ECOSTRESS? So, mission of ECOSTRESS is to measure the temperature of the plants heating up as they run out of water. So, evaporative stress measurement is the major mission for ECOSTRESS sensor. Now, as the sun heats the land surface throughout the day, ECOSTRESS measures the small temperature variation on the surface of the plants. And remember that of course well water plants warm at a slower rate than dry, water stressed vegetation.

So, from the images, we can clearly see what are the, which portion or which areas of the images are dominated by water stressed plants. As you can see here, in this picture, we can clearly see that this red color is indicative of the image of the plants which are showing evaporative stress, high evaporative stress and these green patches are showing the plants or the areas with the plants which are suffering from low evaporative stress. So, ECOSTRESS basically shows us these features basically based on these evaporative stress index.

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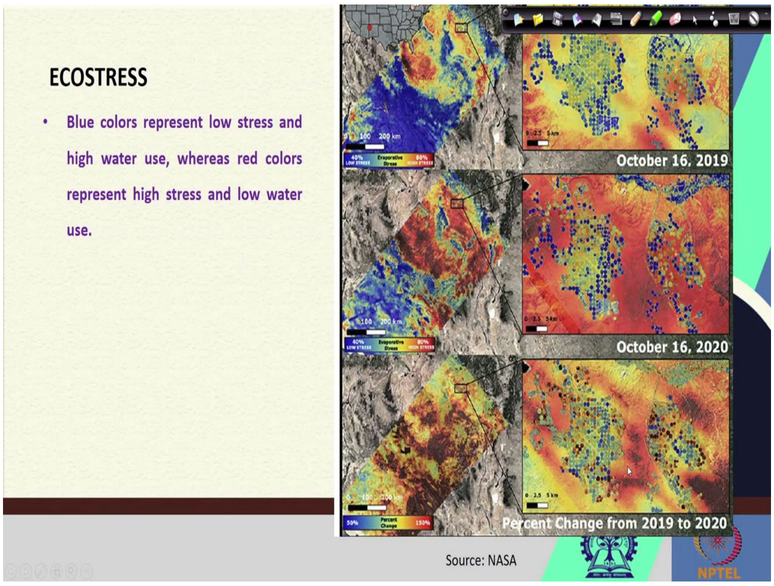

Blue color, as you can see here also in this picture, you can see there are two images one was taken at 2019 and other is 2020. And you can see the percentage changes from 2019 to 2020. And so, evaporative stress, how it changes from 19 to 20 we can clearly see so in this image is blue color represents the low stress and high water use whereas the red color represents the high stress and low water use. So this is the application of ECOSTRESS.

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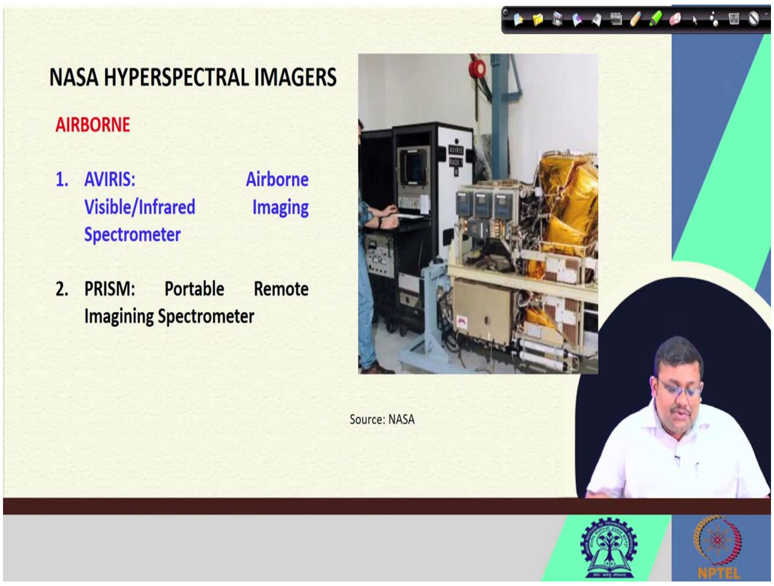

Now we have completed discussing the NASA Satellite hyperspectral imaging sensors. So, let us discuss the airborne hyperspectral imagers which are developed by NASA and utilized by NASA. So, for example AVIRIS and also PRISM. So, AVIRIS stands for Airborne

Visible/Infrared Imaging Spectrometer, whereas, PRISM stands for Portable Remote Imaging Spectrometer.

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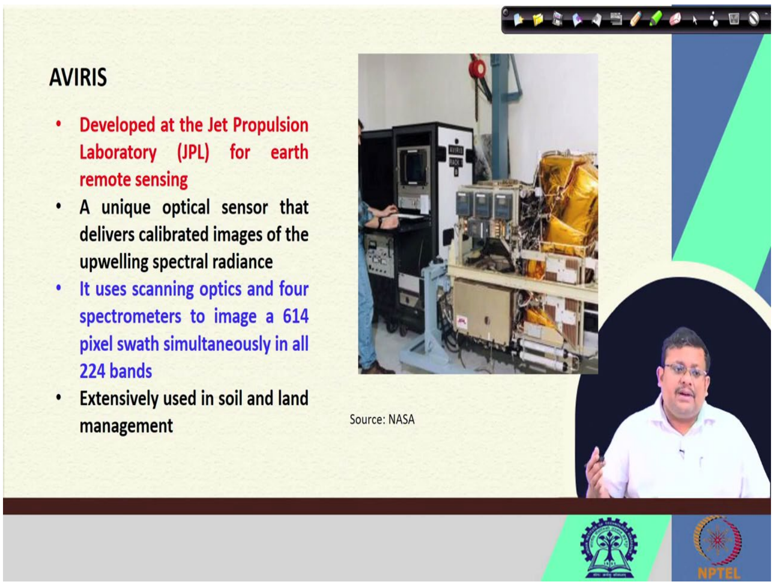

So, these AVIRIS has been lately utilized extensively for different types of agricultural purposes and land use management. So, these AVIRIS was first developed, it was actually developed in Jet Propulsion Laboratory for Earth remote sensing and this is a unique optical sensor that delivers calibrated images of the upwelling spectral radiance, it uses scanning optics and four spectrometers to image a 614 pixels worth simultaneously in all 224 bands.

So, it has 224 bands, it takes an image simultaneously using four imaging spectrometer for 600 pixel, 614 pixels swath and it has been extensively used and soil and land management as you can see these AVIRIS sensor is being calibrated before a mission in the NASA.

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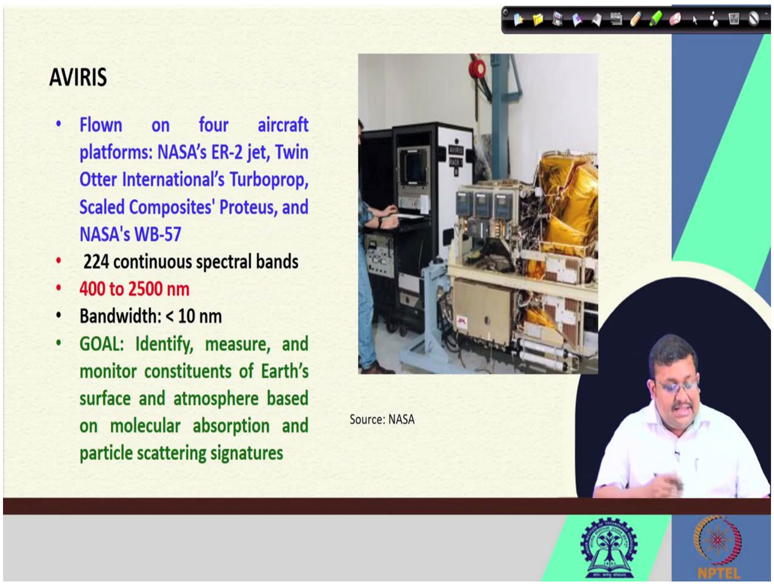

So, this AVIRIS sensor is generally being flown on four aircraft platform that is NASA's ER-2 jet, Twin Otter International Turboprop and Scaled Composites' Proteus and NASA'WB-57. So, these are the aircraft platform on which this sensor is used to capture the image of the surface.

As I have already told you, if this sensor has 224 bands, continuous spectral bands, which can ranging between 400 to 2500 nanometer with a bandwidth of less than 10 nanometer. What is the goal of AVIRIS? The goal of AVIRIS is to identify major and monitor constituents of Earth surface and atmosphere based on molecule absorption and particle scattering signatures.

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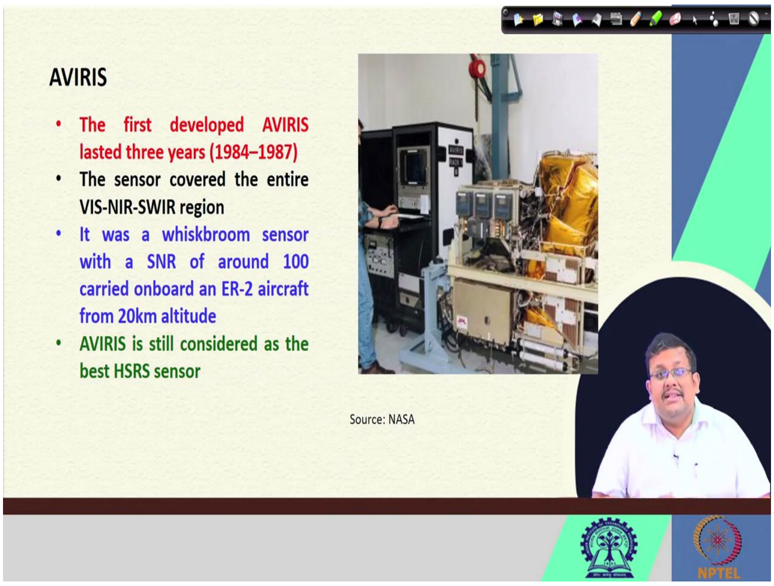

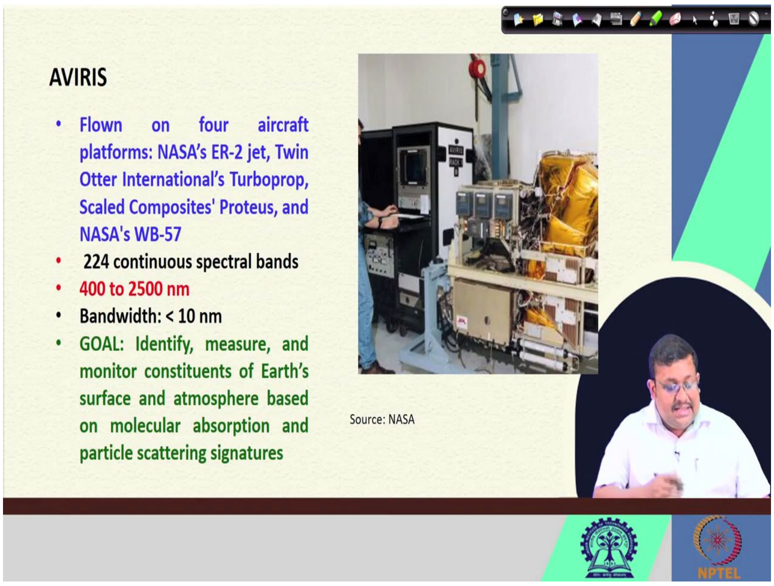

So, these sensor has been extensively utilized for identification and characterization of Earths feature. So, remember that the first every sensor was developed and it was operated it was in operation for 3 years. So, the first develop AVIRIS lasted for 3 years from 1984 to 1987. And the sensor covered the entire VIS, NIR and SWIR region. As we have discussed in the previous slide that is 400 to 2500 nanometer range and it was a whiskbroom sensor.

What is the whiskbroom sensor we are going to discuss in coming slide. So, it was a whiskbroom sensor with a signal to noise ratio of around 100 and carried onboard on ER-2 aircraft from 20 kilometer altitude. And remember that these AVIRIS is still considered as the best hyperspectral remote sensing center or hyperspectral imager I would say. From any airborne platform.

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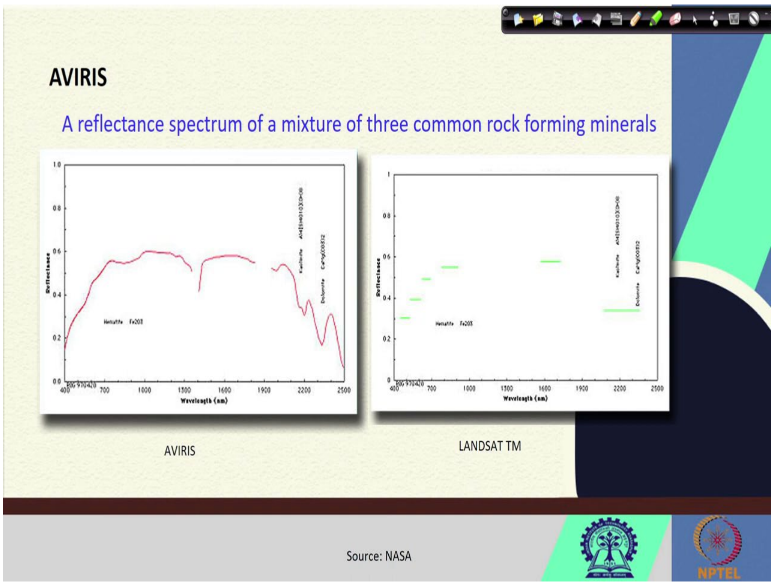

So, you can clearly see these AVIRIS reflectance spectrum of a mixture of three common rock forming mineral. Here you can see that so, this is the AVIRIS spectra and the same spectra which were taken by multispectral lens or thematic map and so, you can clearly see the difference of the information difference in information we can gather from evidence as compared to any other multispectral sensor.

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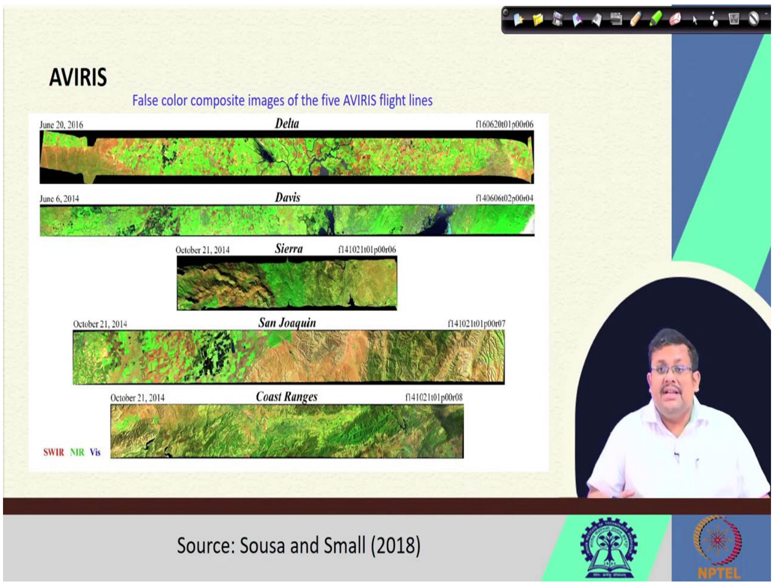

And this shows the false color composite images are five AVIRIS flight lines and you can see the and you can, you can clearly see the high resolution images showing the difference in the Earth's surface features from the AVIRIS image. So, that shows the amount of details we can gather from the AVIRIS image and that is why it has been extensively used in different application for Earth, for Earth feature characterization.

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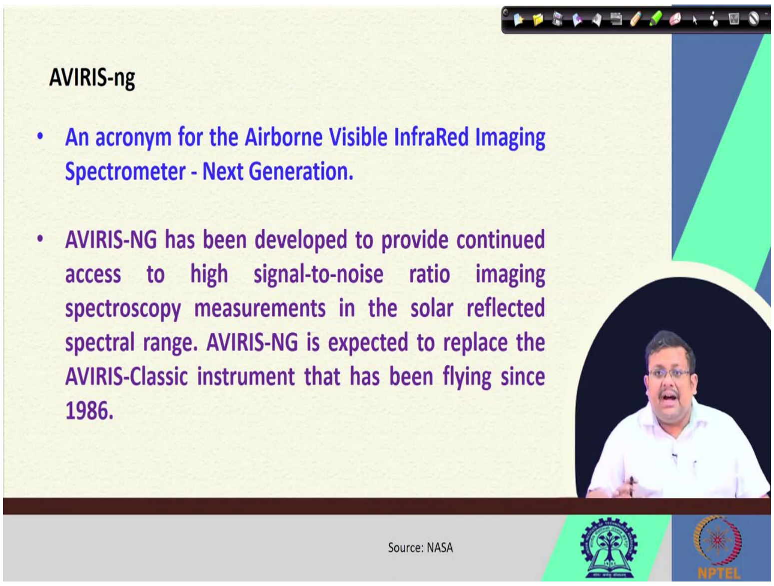

Now, AVIRIS-NG, now AVIRIS-NG, what is AVIRIS-NG. AVIRIS-NG is an acronym for the Airborne Visible InfraRed Imaging Spectrometer - Next Generation. So these AVIRIS-NG has been developed to provide the continued access to high signal to noise ratio imaging spectroscopy measurement in the solar deflected spectral range, and it is expected to replace the average classic instrument that has been flying since 1986.

So, this AVIRIS-NG has been utilized in several areas and this has been utilized to capture the high resolution images of several Earth features to to characterize them with a greater, greater accuracy.

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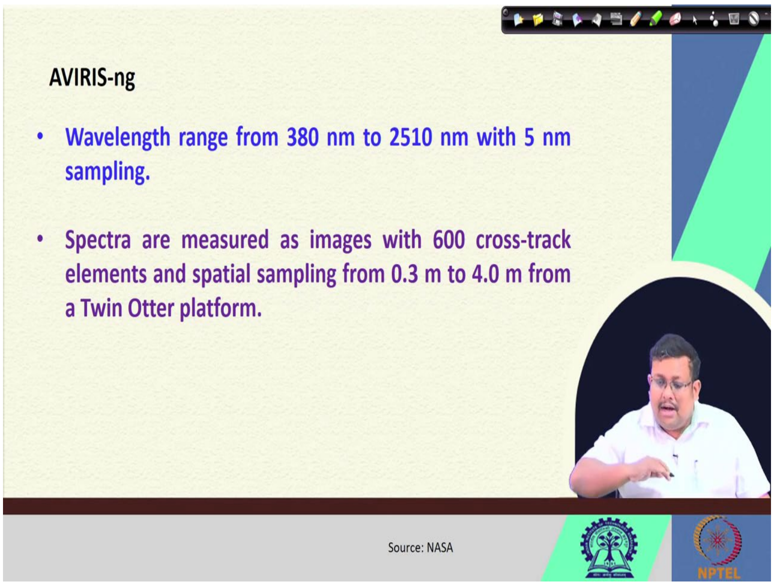

So, these wavelength range for these AVIRIS-NG generally ranges from 380 to 2510 nanometer with 5 nanometer sampling and spectra are measured as images with 600 cross-track elements and spatial sampling from 0.3 to 4 meter from a Twin Otter platform. So, this AVIRIS-NG has been flown to different areas from over the water body, over the land surface over the crop fields, over the different types of mountains and glaciers to capture their images and subsequent analyze them.

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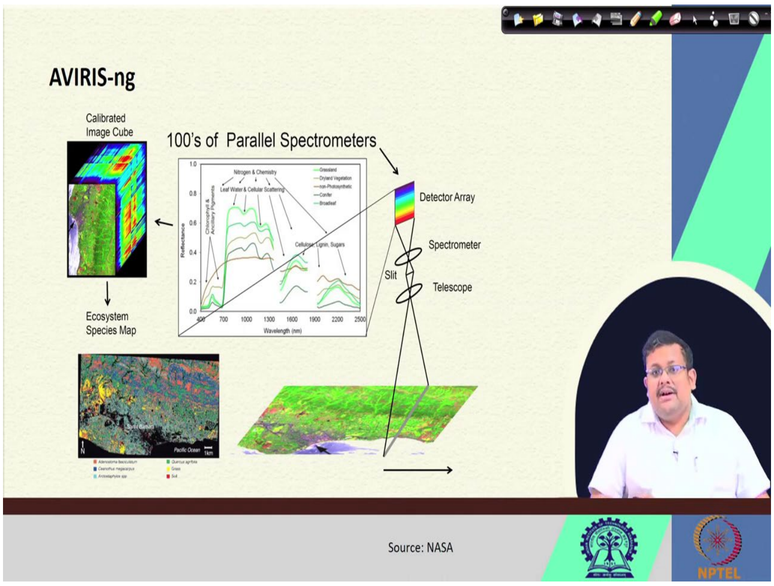

Now, you can see a simplified flowchart, how these AVIRIS-NG generally works. So, it has spectrometer which captured the images and ultimately it produces the calibrated image cube for producing the ecosystem species map, for example. So, these AVIRIS-NG has been lately utilized in different countries for producing or for capturing the high level details from the Earth features.

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Now, in India as of March 8, 2016 this AVIRIS-NG completed a three months the airborne campaign collecting imaging spectroscopic measurement for 57 sites. So, you can see here, these are the yellow points are known as the priority 1 points and the second the 57 point sites are the priority 1 sites and priority 2 sites at these yellow, yellow points.

So, these red points are the priority 1 points and the yellow points at the priority 2 points there are 25 priority 2 points. So, these AVIRIS, AVIRIS-NG India sites they collected a science and, and they collected images for different science and science and applications with the objectives which are spanning with coastal zone, then mangrove forest, then soils, forest, hydrocarbon alteration, mineralogy, agriculture, urban and, and also for calibration validation.

So, different places are utilized, a different places have been have been explored using these AVIRIS-NG images. So, as of 2016, all priority 1 sites have been acquired and these images have been utilized by different scientists group in India to explore the Earth features.

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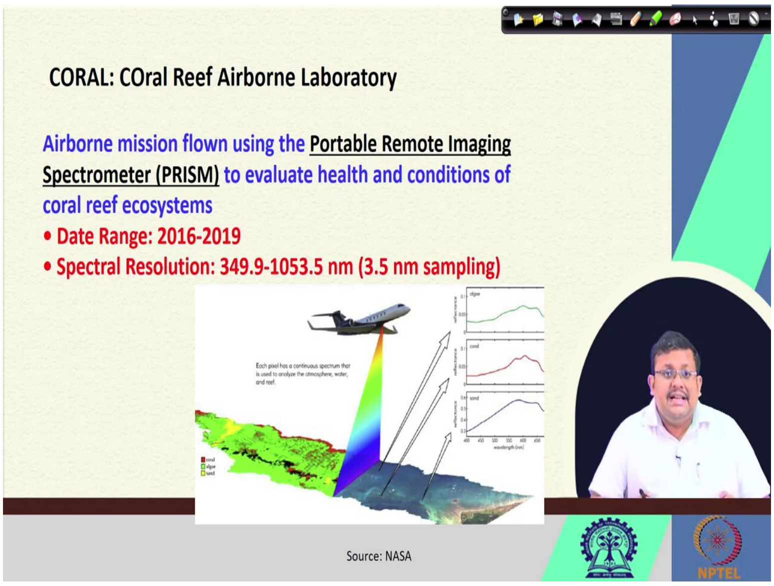

Now, another one is called the PRISM. So, PRISM stands for Portable Remote Imaging Spectrometer which is, which is there in the Coral Reef Airborne Laboratory or Coral to evaluate the health and conditions of coral reef ecosystem, it date range from 2016 to 2019 and the spectral resolution varies from 349.9 to 1053.5 nanometer with the 3.5 nanometers sampling.

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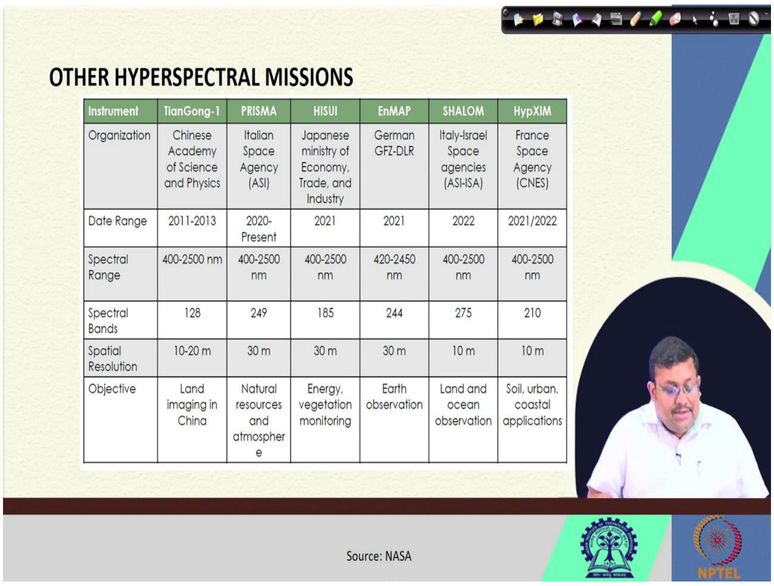

Instrument	TianGong-1	PRISMA	HISUI	EnMAP	SHALOM	HypXIM
Organization	Chinese Academy of Science and Physics	Italian Space Agency (ASI)	Japanese ministry of Economy, Trade, and Industry	German GFZ-DLR	Italy-Israel Space agencies (ASI-ISA)	France Space Agency (CNES)
Date Range	2011-2013	2020-Present	2021	2021	2022	2021/2022
Spectral Range	400-2500 nm	400-2500 nm	400-2500 nm	420-2450 nm	400-2500 nm	400-2500 nm
Spectral Bands	128	249	185	244	275	210
Spatial Resolution	10-20 m	30 m	30 m	30 m	10 m	10 m
Objective	Land imaging in China	Natural resources and atmosphere	Energy, vegetation monitoring	Earth observation	Land and ocean observation	Soil, urban, coastal applications

So, what are the other spectral, hyperspectral missions as you can see, there are different organizations like Chinese Academy of Science they have developed these TianGong- 1, then Italian Space Agency developed PRISMA, then Japanese Ministry of Economy Trade and Industry developed HISUI, German GFZ-DLR they have developed EnMAP and then Italy-

Israel Space Agency they have developed the SHALOM and HypXIM was developed by France Space Agency with different date range as well as spectral range and spectral bands spectral spatial resolution and their objectives are also different.

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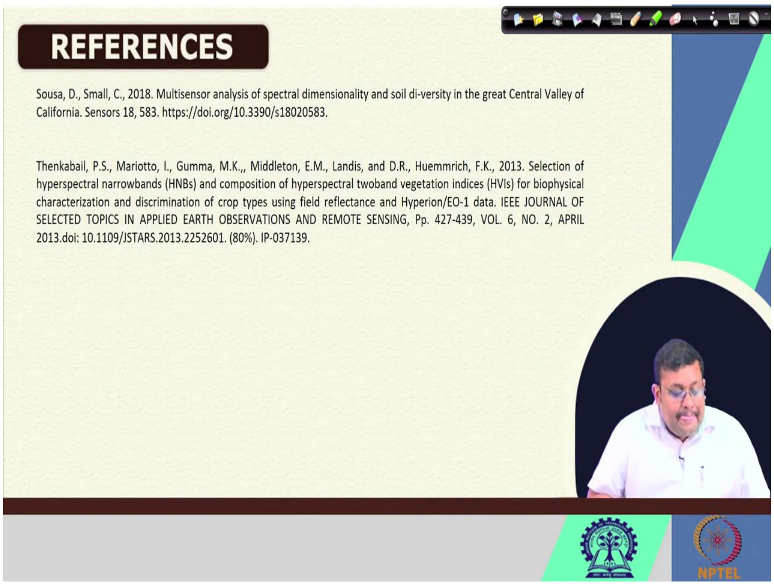

So now, guys these are the references, which I have used in this lecture and I hope that you have gathered some knowledges before we go for discussing what are the machine learning application to exploit these hyperspectral images. So, we have covered all the, the hyperspectral imagers, and both satellite as well as the airborne hyperspectral imagers and we have discussed their characteristics.

In the next lecture, we are going to discuss how we can handle the hyperspectral data and what are the sources of the hyperspectral data. And also we are going to discuss in brief about the some important features of hyperspectral sensors. So, thank you. Let us meet in our next lecture. Thank you.