

**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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The slide features a central image of the Indian Institute of Technology Kharagpur building, framed by a green and blue geometric border. To the right, the NPTEL logo and course title are displayed. The text on the slide includes: 'NPTEL ONLINE CERTIFICATION COURSES', 'Machine Learning for Soil and Crop Management', 'Prof. Somsubhra Chakraborty', 'Agricultural and Food Engineering Department', 'Indian Institute of Technology Kharagpur', 'Week 9: HYPERSPECTRAL REMOTE SENSING AND ML APPLICATIONS IN AGRICULTURE', and 'LECTURE 43'.

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.

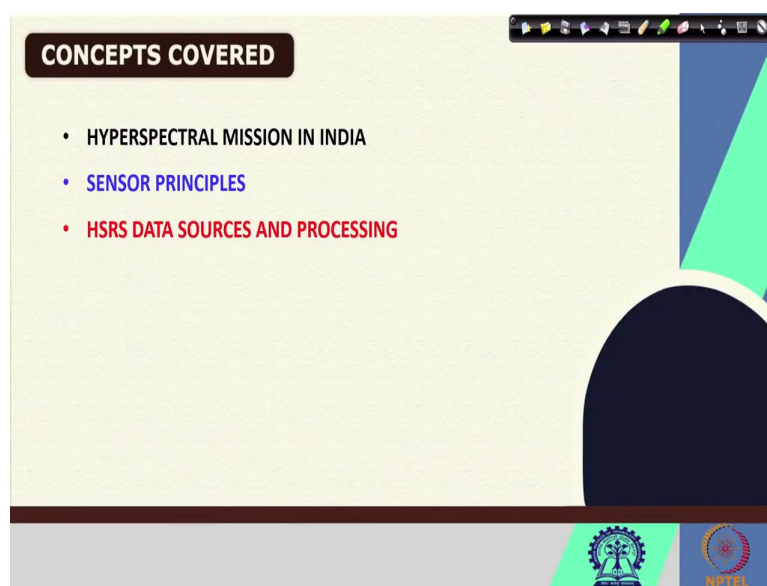
And in our previous two lectures, we have discussed the basics of hyperspectral remote sensing and how it differs from multispectral remote sensing why hyperspectral remote sensing is better than multispectral remote sensing, we have discussed and the second lecture of this week, we have discussed different 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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**KEYWORDS**

- HySI
- HySIS
- WHISKBROOM SCANNER
- PUSHBROOM SCANNER
- ATMOSPHERIC CORRECTION

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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**HYPERSPECTRAL MISSION OF INDIA**

- India's hyperspectral remote sensing (RS) journey started with development and flight testing of Aircraft Imaging Spectrometer (AIMS) with 143 bands in visible and near infrared (VNIR) spectrum in 1996
- Subsequently, a compact hyperspectral Imager (HySI) was designed and developed for Chandrayaan-1 and the same was first flown on Indian Mini satellite-1 (IMS-1) in 2008 with minor modifications

Illustration of the deployed IMS-1 microsatellite (image credit: ISRO)

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 Chandrayaan- 1, Chandrayaan- 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- 1 satellite 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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**HYPERSPECTRAL MISSION OF INDIA**

- The IMS-1 instrument provided 64 band spectrum in VisNIR region with about 505 m spatial resolution and 130 km swath
- It used a Telecentric lens, wedge filter based spectral dispersion, Active pixel area array sensor (512 × 256), highly miniaturized mechanical structure and electronics
- It was a medium resolution spectrometer with over-sampling in spectral domain

Labels in the diagram: HySI Payload, M1 Payload, 42 Sun Sensor, Diplexer, TTC Antenna, Data Antenna, Magnetometer.

Illustration of the deployed IMS-1 microsatellite (image credit: ISRO)

Logos: IIT Bombay, NPTEL

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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**Limb Viewing Hyper Spectral Imager ( LiVHySI )**

- Recorded hyper-spectral images of nighttime airglow emissions from terrestrial thermosphere and mesopause regions simultaneously over a wide range of longitudes across the globe
- An improved version of earlier developed HySI sent on moon mission Chandrayan-1

Photo of the LiVHySI instrument (image credit: ISRO/SAC)

The slide features a central photograph of the LiVHySI instrument, a complex metallic structure with various sensors and components. To the right, a circular inset shows a man in a white shirt speaking. The slide is decorated with a green and blue geometric pattern on the right side and logos for IIT Bombay and NPTEL at the bottom.

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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**HYPER SPECTRAL MISSION OF INDIA**

- The Indian Space Research Organisation (ISRO) launched the first Indian Hyperspectral Imaging Satellite (HysIS) from Sriharikota on 29 November 2018.
- The satellite is expected to be used for Earth observation in applications related to agriculture, forestry, geology, assessment of coastal zones, and environmental studies
- It was one out of 30 commercial satellites from eight different countries launched that day by the Indian PSLV C43 vehicle

The slide features a central diagram of the PSLV C43 rocket launch. The diagram shows the rocket ascending from Sriharikota, with various satellites being deployed from different stages. The satellites are labeled with their respective countries: Columbia (USA) FACSAT, Canada Repler (CSG), Australia Centauri-1, Spain (Spain) SCat-1, Netherlands HUBEX-1, and Finland Reactor Hello World. The main satellite, HysIS, is shown in a larger, detailed view. The diagram also includes a timeline for the mission, indicating the time to reach the sun orbit (00:17:19). The slide is decorated with a green and blue geometric pattern on the right side and logos for IIT Bombay and NPTEL at the bottom.

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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**HySIS**

- 2 payloads
  1. Visible Near Infrared (VisNIR) with spectral range of 0.4 to 0.95 micrometers with 60 contiguous spectral bands
  2. Shortwave Infrared Range (SWIR) with spectral range of 0.85 to 2.4 micrometers with a 10 nanometer bandwidth and 256 contiguous spectral bands
- Spatial resolution of 30 meters and a swath of 30 km from its 630 km sun-synchronous orbit

<https://www.isac.gov.in/publications/upagrah/pdf/Upagrah-July-Sept2018.pdf>

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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**CHALLENGES OF HSRS**

- Conditions are constant and well controlled in the laboratory
- Airborne/Spaceborne HSRS: significant interference
  - Lower signal-to-noise ratio (SNR) induced by the short dwell time of data acquisition over a given pixel
  - Atmospheric attenuation of gases and aerosol particles
  - Uncontrolled illumination conditions of the source and objects.
- This makes HRS a challenging technology that involves many disciplines: atmospheric science, electro-optical engineering, aviation, computer science, statistics and applied mathematics

The slide features a video inset of a man in a white shirt speaking. At the bottom, there are logos for IIT Bombay and NPTEL.

So, these HySIS has been utilized 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.

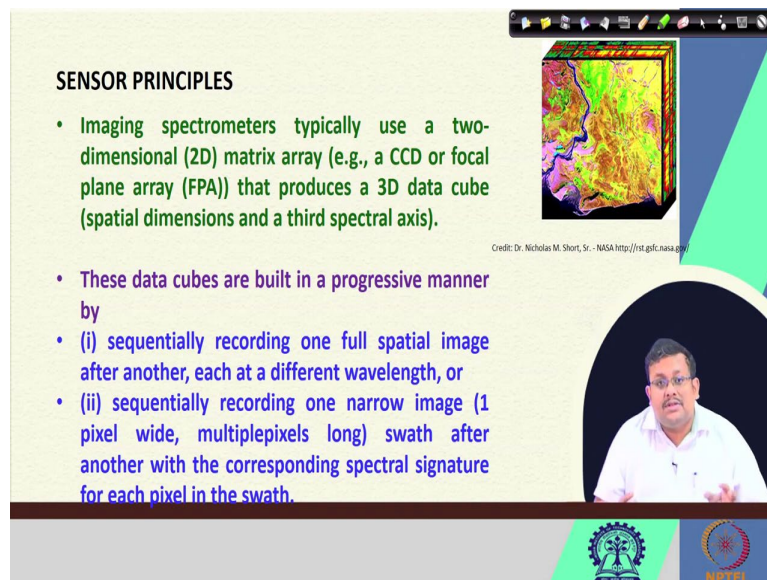
So, that it is not desirable to have lower SNR or lower signal to noise ratio in so, that creates problem in case of airborne or spaceborne hyperspectral remote sensing. The second issue is atmospheric attenuation of gases and aerosol particles. So, that is why we need to do the atmospheric correction.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

- Imaging spectrometers typically use a two-dimensional (2D) matrix array (e.g., a CCD or focal plane array (FPA)) that produces a 3D data cube (spatial dimensions and a third spectral axis).
- These data cubes are built in a progressive manner by
  - (i) sequentially recording one full spatial image after another, each at a different wavelength, or
  - (ii) sequentially recording one narrow image (1 pixel wide, multiple pixels long) swath after another with the corresponding spectral signature for each pixel in the swath.

Credit: Dr. Nicholas M. Short, Sr. - NASA <http://rst.gsfc.nasa.gov/>

The slide includes a 3D visualization of a data cube and a video inset of a speaker. Logos for IIT Bombay and NPTEL are visible at the bottom.

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.

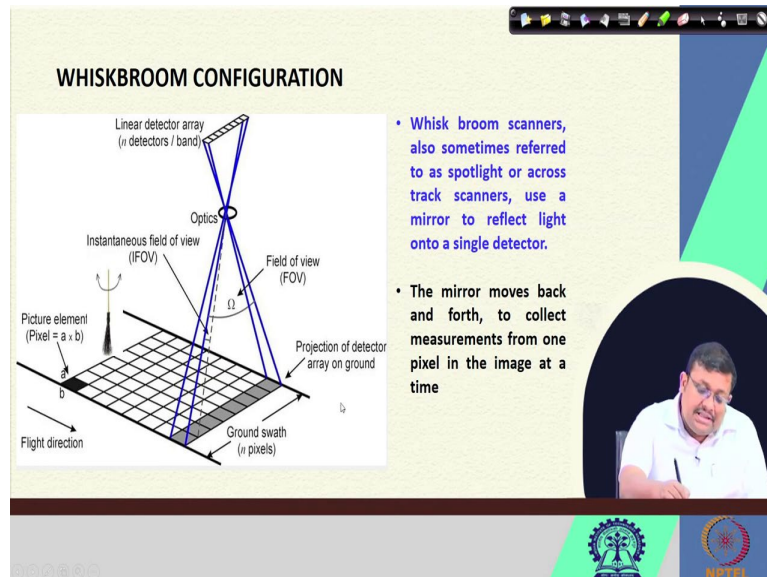
So, this data cube can be develop in a progressive manner by two ways first of all, sequentially recording one full spatial image after another, each at different wavelengths. So, we can take at each wavelength at a time and then we can take an image with individual wavelength and then cube combine them 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 back 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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**PUSHBROOM CONFIGURATION**

linear array sensor  
optics  
flight direction of platform  
scan line

- Push broom scanners, also sometimes referred to as along track scanners, use a line of detectors arranged perpendicular to the flight direction of the spacecraft
- As the spacecraft flies forward, the image is collected one line at a time, with all of the pixels in a line being measured simultaneously

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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**HOW TO ACCESS HSRS DATA?**

1. USGS EarthExplorer
2. USGS GloVis
3. NASA EarthData
4. Google Earth Engine

The screenshot shows the USGS EarthExplorer interface. It displays search results for 'EO-1 Hyperion' data. The interface includes tabs for Search Criteria, Data Sets, Additional Criteria, and Results. The Results tab is active, showing 4 search results. A note states: 'If you selected more than one data set to search, use the dropdown to see the search results for each specific data set. Note: You must be logged in to download and order scenes.' Below this, there are controls for 'Show Result Controls' and a 'Data Set' section with a link to 'Click here to export your results'. The selected data set is 'EO-1 Hyperion'. A pagination bar shows 'Displaying 1 - 100 of 83,135 (Restore Excluded Scenes)'. The entry details include: Entity ID: EO1H025028201707110K2\_SG1\_01, Acquisition Date: 2017-03-12 00:00:00-06, Target Path: 25, Target Row: 28, and Coordinates: 45.99358, -90.248548. At the bottom of the screenshot, there is a small video inset of a man speaking and logos for IIT Bombay and NPTEL.

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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**HOW TO ACCESS HSRS DATA?**

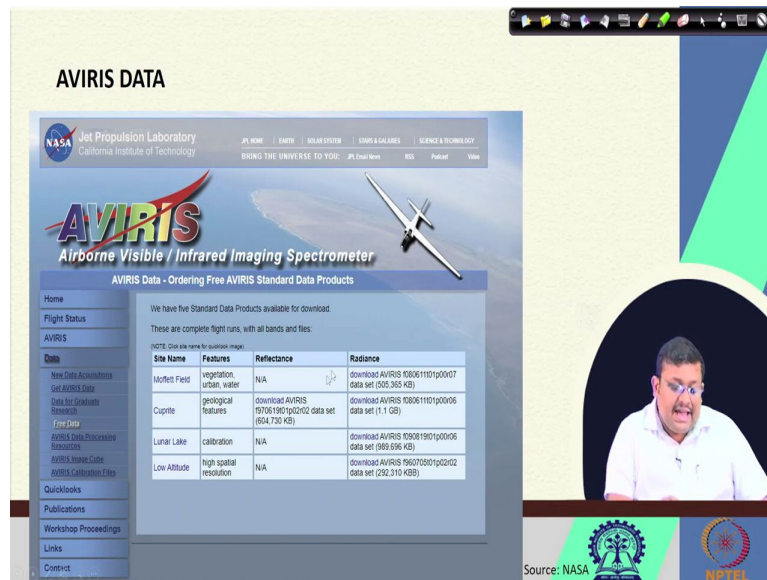
1. Data are also available through the NASA Distributed Active Archive Centers (DAACs).
  - Data is separated by application area, such as Land Processes and Ocean Biology
  - AVIRIS, HICO, CORAL and other hyperspectral datasets can be accessed through the online resources of DAACs

The screenshot shows the LP DAAC (Land Processes Distributed Active Archive Center) website. It features a satellite image of a landscape with the text 'LP DAAC' and a description: 'The Land Processes Distributed Active Archive Center (LP DAAC) is one of several discipline-specific data centers within the NASA Earth Observing System Data and Information System (EOSDIS). The LP DAAC is located at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota.' There is a 'Learn More' button. At the bottom of the screenshot, there is a small video inset of a man speaking and logos for IIT Bombay and NPTEL.

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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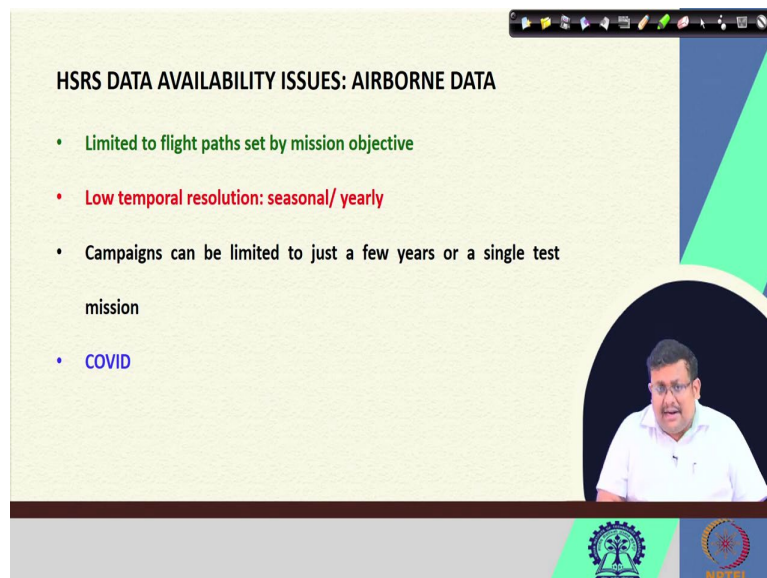


The screenshot shows the AVIRIS Data website interface. At the top, it says "AVIRIS DATA" and "NASA Jet Propulsion Laboratory California Institute of Technology". Below this is the AVIRIS logo and the text "Airborne Visible / Infrared Imaging Spectrometer". A navigation menu on the left includes Home, Flight Status, AVIRIS, Data, New Data Acquisitions, Get AVIRIS Data, Data for Calibration, Research, File Data, AVIRIS Data Processing Resources, AVIRIS Science Cube, AVIRIS Calibration Files, Quicklooks, Publications, Workshop Proceedings, Links, and Contact. The main content area is titled "AVIRIS Data - Ordering Free AVIRIS Standard Data Products" and lists five standard data products available for download. A table below provides details for each product.

Site Name	Features	Reflectance	Radiance
Moffett Field	vegetation, urban, water	N/A	download AVIRIS R0061101p0007 data set (553,363 KB)
Cuprite	geological features	download AVIRIS R17061901p0202 data set (604,730 KB)	download AVIRIS R0061101p0006 data set (1.1 GB)
Lunar Lake	calibration	N/A	download AVIRIS R0081901p0006 data set (559,366 KB)
Low Altitude	high spatial resolution	N/A	download AVIRIS R6027001p0202 data set (292,310 KBB)

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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The slide is titled "HSRS DATA AVAILABILITY ISSUES: AIRBORNE DATA" and lists several key issues:

- Limited to flight paths set by mission objective
- Low temporal resolution: seasonal/ yearly
- Campaigns can be limited to just a few years or a single test mission
- COVID

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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**HSRS DATA PROCESSING**

- Data is available at different processing levels depending on the sensor.
  - – Level 1: Radiance
  - – Level 2: Surface Reflectance
- Atmospheric correction must be applied
- Dimensionality Reduction Techniques:
  - PCA
  - Minimum Noise Fraction (MNF)

Source: USGS

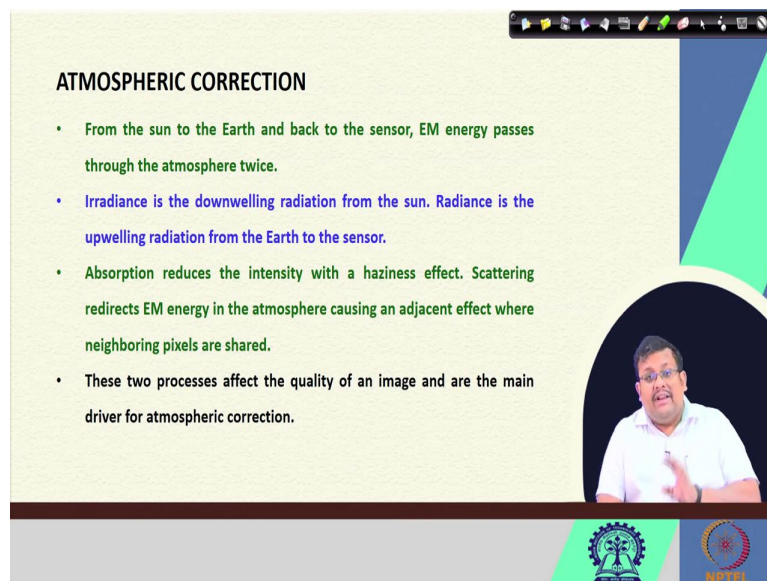
The slide features a grid of six satellite images. The top row shows three images with a color palette of reds, oranges, and yellows. The bottom row shows three images with a color palette of purples, blues, and greens. The images are arranged in a 2x3 grid. The top-left image is labeled 'ETM+4.3Z' and the bottom-left image is labeled 'Hyperspec\_095\_092\_093'.

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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**ATMOSPHERIC CORRECTION**

- From the sun to the Earth and back to the sensor, EM energy passes through the atmosphere twice.
- Irradiance is the downwelling radiation from the sun. Radiance is the upwelling radiation from the Earth to the sensor.
- Absorption reduces the intensity with a haziness effect. Scattering redirects EM energy in the atmosphere causing an adjacent effect where neighboring pixels are shared.
- These two processes affect the quality of an image and are the main driver for atmospheric correction.

The slide includes a video inset of a man speaking and logos for IIT Bombay and NPTEL at the bottom.

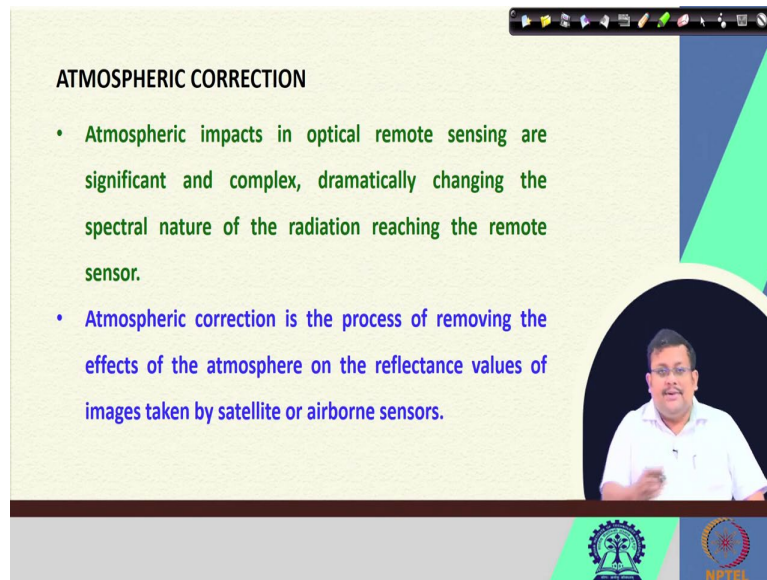
And, what is atmospheric correction? Atmospheric correction that from sun to the Earth and back to the sensor, these electromagnetic energy passes through atmosphere to twice. One during the incoming radiation and there is outgoing radiation. Now, irradiance is the downwelling radiation from the sun,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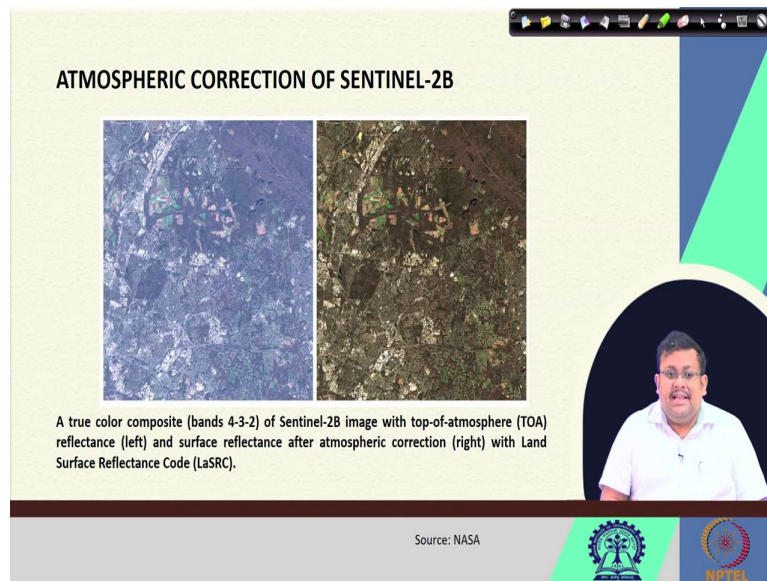


**ATMOSPHERIC CORRECTION**

- Atmospheric impacts in optical remote sensing are significant and complex, dramatically changing the spectral nature of the radiation reaching the remote sensor.
- Atmospheric correction is the process of removing the effects of the atmosphere on the reflectance values of images taken by satellite or airborne sensors.

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.

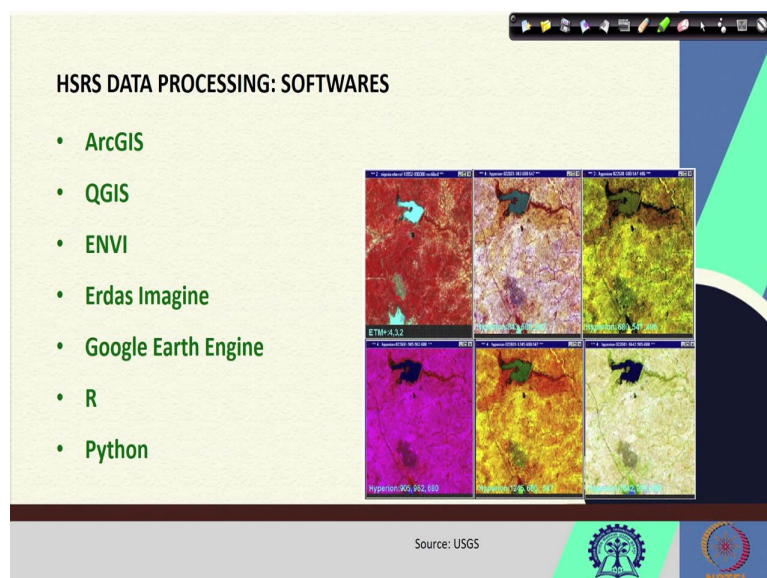
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So, here you can clearly, clearly see that an example of atmospheric correction of SENTINEL-2B, of course, this is a multispectral sensor, but you can have an idea. So, here it is a true color composite of SENTINEL-2B image with top of the atmosphere. 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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**HSRS DATA PROCESSING**

- Large data files (100-250 bands)
- High storage and processing power needed
- High correlation among bands: many bands reflects similar features (needs dimensionality reduction)
- High SNR

Noise Reduction in Hyperspectral Imagery

Classification Application

Observed H = Denoised X + Noise N

After

Rasti et al. (2018)

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.

(Refer Slide Time: 28:42)

The image displays two sequential slides from a video lecture. The top slide is titled "REFERENCES" and contains the following text: "Rasti, B.; Scheunders, P.; Ghamisi, P.; Licciardi, G.; Chanussot, J. Noise Reduction in Hyperspectral Imagery: Overview and Application. Remote Sens. 2018, 10, 482. <https://doi.org/10.3390/rs10030482>". The bottom slide features the text "Thank you" written in a cursive font on a white sticky note with a pen nib. Both slides include a video feed of the lecturer in the bottom right corner and logos for IIT Bombay and NPTEL at the bottom.

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 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.