

REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lecture 1: Introduction to Remote Sensing

Remote Sensing for Natural Hazard Studies is a 12-week course with 10 modules, and here you can find the details of all the modules that are in this table.

MODULE	MODULE NAME	WEEK
1	Basics of Remote Sensing	1
2	Concept of Remote Sensing	2
3	Data Processing	3
4	Potential of Remote Sensing in Hazard Studies	4
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8	Landslides	10
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The course begins with the fundamentals of remote sensing and gradually progresses through key concepts, data processing techniques, and related topics, culminating in applications for drought assessment. Each module is followed by an assignment designed to reinforce your understanding of the material covered in class. Details regarding assignments and submission deadlines will be available through your NPTEL login. You can also use the platform to post queries and seek clarification. Additionally, a few live sessions will be conducted during the course to help address doubts and facilitate interactive discussions. Since this course does not require any prerequisites, it is open to students at all academic levels as well as working professionals. It is suitable for B.Tech, MS, MSR, M.Sc., M.Tech, and Ph.D. students. In the context of increasing climate variability and intensified human activities, natural disasters are becoming more frequent. This course introduces geospatial techniques as a vital tool for studying and

understanding natural hazards. It is structured around two key aspects first one is remote sensing; the second one is the natural hazard, which will be explored in detail throughout the modules. This course begins with the basics of remote sensing, which are essential for understanding its wide-ranging applications. It will cover various types of natural hazards, including floods, cryospheric events, avalanches, glacial lake outburst hazards, landslides, liquefaction, and drought. As part of exploring the application potential of remote sensing in hazard studies, selected case studies from reputed journals will be discussed to illustrate key concepts and demonstrate real-world relevance. These examples will help clarify how remote sensing techniques are used in analyzing and managing natural hazards. With this foundation, we begin the journey into this course.

Module 1: Basics of Remote Sensing

Lecture 1: Introduction to Remote Sensing

In this lecture, we begin by addressing some fundamental questions that often arise when we talk about remote sensing:

- What is remote sensing?
- What do we measure?
- What kind of output do we get?

To answer these, we start with the basics.

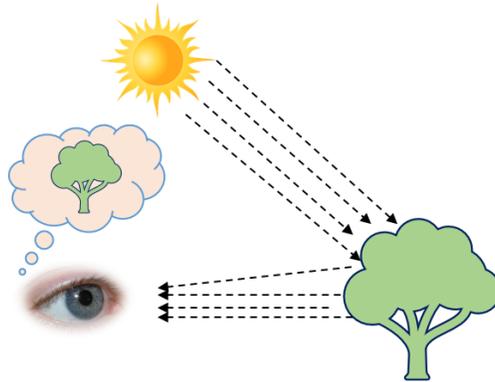
Remote sensing is defined as the art and science of acquiring information about an object or environment without being in direct physical contact with it. This definition highlights two key aspects:

Art and Science: Remote sensing involves both technical precision and interpretive skill. It is not a complete solution in itself, but it serves as a powerful tool for gathering data that supports broader analysis or problem-solving.

Non-contact Measurement: The data is collected without touching the object, typically using electromagnetic radiation (light) as the medium.

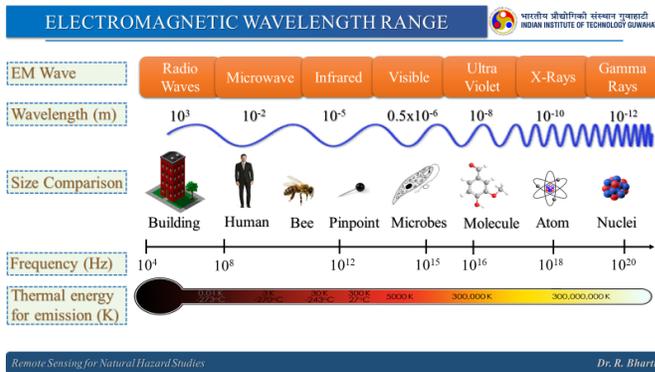
The information is usually captured in the form of images, which are then processed and analyzed to extract meaningful insights. By the end of this lecture, you should have a clear understanding of what remote sensing is, what it measures, and the types of outputs it generates. So, in remote sensing, there are two key elements to consider: (1) the object (the specific feature or target we want to observe), and (2) the environment (the surrounding conditions that also influence the data we collect). Remote sensing is not just about capturing the object itself, but also about gathering meaningful information related

to it. To understand how this works, let's begin with a very basic example: how our eyes perceive an object.



First, the Sun illuminates the object. This incoming light interacts with the surface of the object. Then, the object reflects a portion of that light. This reflected light travels through the atmosphere and reaches our eyes (or a sensor, in the case of remote sensing). The sensor then captures this reflected energy and converts it into an image or other data format. This process, illumination, reflection, and detection, is fundamental to remote sensing. The medium here is electromagnetic radiation, primarily light, and the output is typically in the form of images, which can be analyzed to extract useful information.

Once light is reflected from an object, our eyes receive that reflected energy, and the retina captures it. The brain then processes this information, allowing us to recognize and interpret the object. This is how we perceive our surroundings visually. In remote sensing, instruments perform a similar function. For example, a satellite sensor continuously observes a specific location on Earth, collecting reflected, emitted, or backscattered energy from the surface. This energy is then processed to generate images, which can be analyzed to extract meaningful information. Just as our eyes are sensitive to a limited portion of the electromagnetic spectrum, specifically the visible range from 400 to 700 nanometers, remote sensing instruments can detect a much broader range of wavelengths. This allows us to observe features and phenomena that are invisible to the naked eye. Interestingly, as you view your computer screen right now, you are also engaging in a form of remote sensing. However, in scientific terms, remote sensing typically refers to instrument-based measurements that utilize electromagnetic radiation to gather data from a distance. To understand this better, let's now explore the concept of the electromagnetic wave, which is the foundation of remote sensing technology. Now, let's look at the electromagnetic spectrum, which is fundamental to remote sensing.



On the slide, you can see the spectrum ranging from radio waves (with the longest wavelengths and lowest energy) to gamma rays (with the shortest wavelengths and highest energy). This progression is important because:

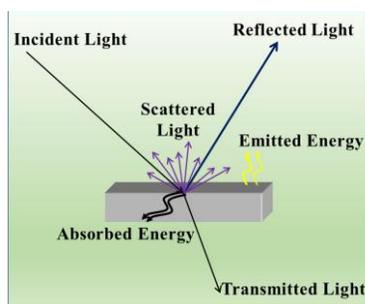
- **Gamma rays**, with extremely short wavelengths, carry the highest energy and can provide information at the nuclear level.
- **X-rays** have slightly lower energy and are useful for studying atomic structures.
- **Ultraviolet (UV)** radiation relates to molecular-level interactions.
- **Visible light** (400–700 nanometers) is what our eyes can detect and is useful for observing microbial and surface-level features.
- **Infrared and microwave regions** allow us to detect larger objects, such as vegetation, soil moisture, and terrain features.
- **Radio waves**, with the longest wavelengths, are used for observing very large-scale phenomena and penetrate through clouds and vegetation.

The wavelength and frequency of electromagnetic waves are inversely related:

Shorter wavelengths = higher frequency = higher energy

Longer wavelengths = lower frequency = lower energy

Understanding these properties—wavelength, frequency, energy, and object size sensitivity—is essential for grasping how different remote sensing instruments work and what kind of data they can capture. Let’s consider solar energy falling on a surface. When this energy interacts with the object, it undergoes three primary processes:

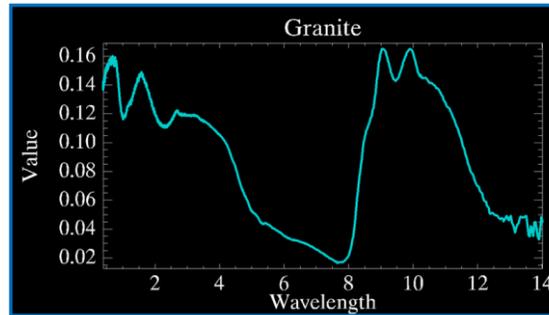


Reflection – A portion of the energy is reflected off the surface.

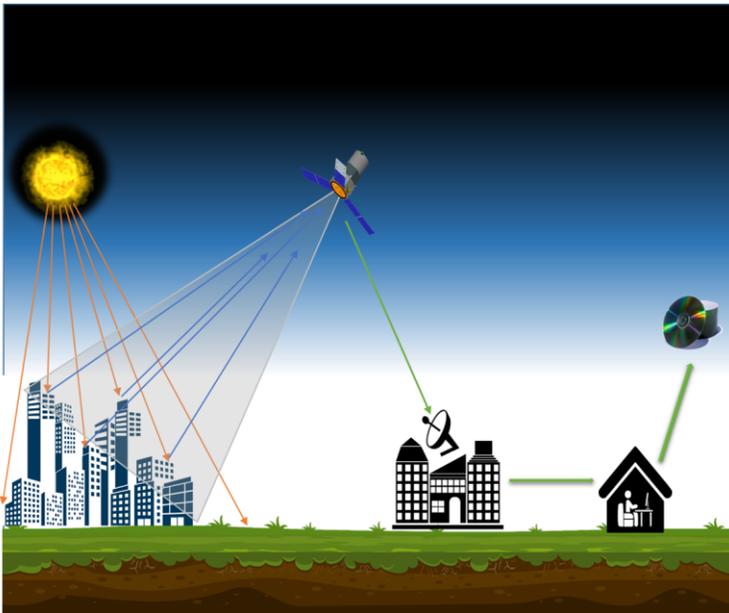
Transmission – Some energy passes through the material.

Absorption – The remaining energy is absorbed by the object.

To maintain thermal equilibrium with its surroundings, the object then emits part of the absorbed energy. This emitted energy is what we measure in thermal remote sensing. As discussed earlier, thermal emission is a volumetric property; it originates from within the material, not just the surface. This is because the entire volume absorbs energy and contributes to the emission. Using this emitted energy, we can generate spectral signatures. The nature of this interaction, how much energy is reflected, transmitted, or emitted, is governed by the internal atomic structure and composition of the material. These characteristics produce a unique spectral response for each material.

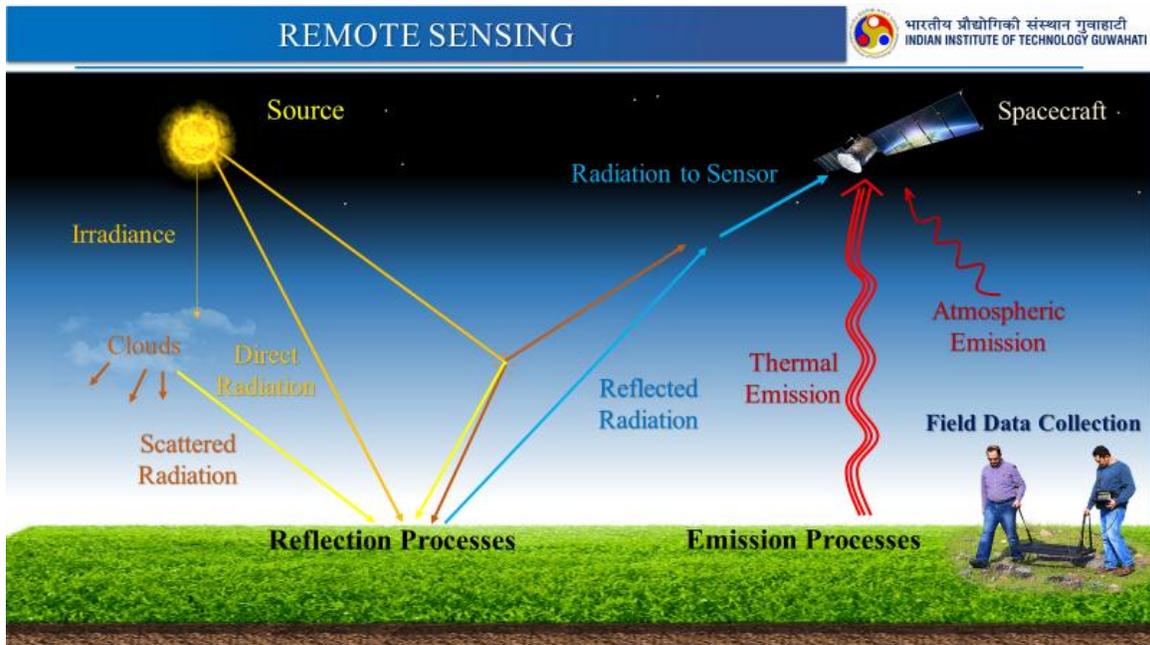


For example, in the case of granite, its spectral curve shows distinct peaks and troughs. In remote sensing, we focus particularly on the troughs, as they represent wavelengths where energy is reflected by the target. These features help us identify and differentiate materials based on their spectral behavior.



When the Sun illuminates the Earth's surface, energy in the reflective domain (e.g., 0.7 to 2.5 micrometers) is reflected by the surface and captured by satellite sensors. These sensors generate images based on the reflected energy. Once the satellite passes near a

ground station, the data is transmitted and then distributed to users for analysis. However, this process is not straightforward. The Earth's atmosphere contains various constituents; gases, aerosols, dust particles, and clouds, which interact with incoming solar radiation. These interactions cause scattering, diverting some of the energy before it reaches the surface. After scattering, the remaining energy reaches the surface, gets reflected, and is then captured by the sensor. But the sensor also receives additional signals from the atmosphere. This unwanted signal is known as path radiance; it's the atmospheric contribution that mixes with the actual ground signal, affecting the accuracy of the data. Understanding and correcting for path radiance is crucial in remote sensing to ensure that the information extracted truly represents the surface characteristics.



When solar energy reaches the Earth, it is referred to as **irradiance**, the incoming energy from the Sun. As this energy interacts with the Earth's surface and atmosphere, it undergoes several transformations:

Radiance is the energy that is reflected from the Earth's surface and captured by remote sensing instruments.

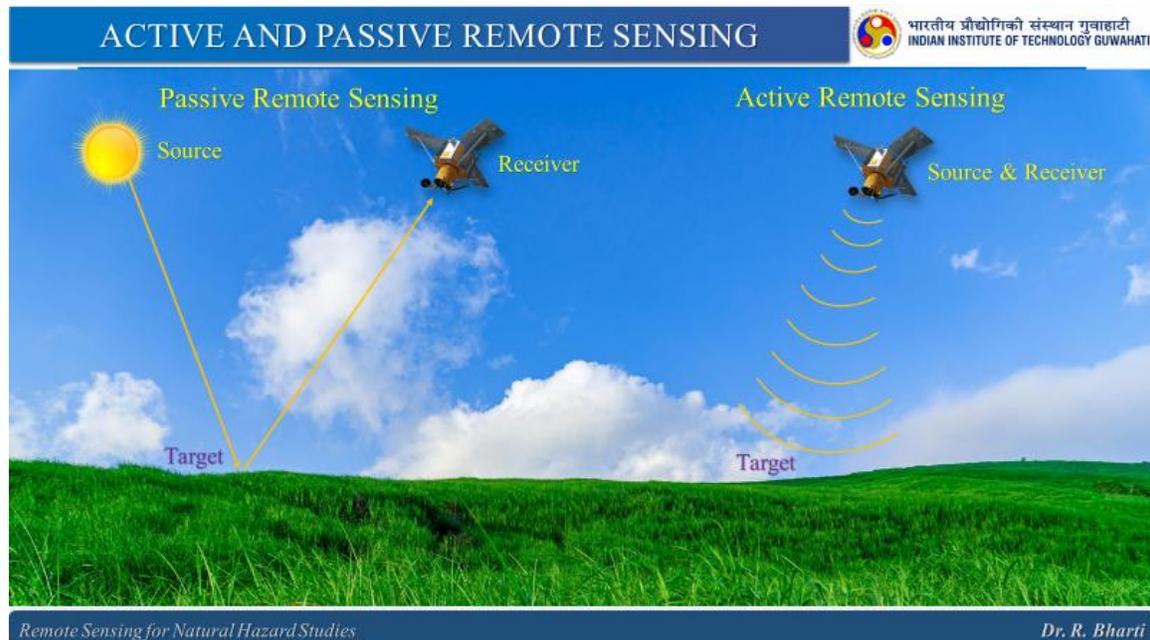
Path Radiance refers to the additional energy introduced by the atmosphere. As solar irradiance passes through the atmosphere, it interacts with gases, aerosols, dust particles, and clouds, causing scattering. This scattered energy adds unwanted signals to the satellite image, which are not part of the actual surface reflection.

These three terms, irradiance, radiance, and path radiance, are fundamental to understanding how remote sensing data is acquired and interpreted. Please keep these concepts in mind, as we will revisit them throughout the course.

In the emissive domain, which relates to thermal remote sensing, the emitted energy from the Earth's surface also passes through the atmosphere. During this journey, atmospheric constituents such as gases, dust, and aerosols absorb some of the thermal energy. When these particles absorb energy, they eventually re-emit it at longer wavelengths to maintain thermal equilibrium. This re-emitted energy from the atmosphere is known as atmospheric emission, and it becomes part of the signal detected by the sensor. Therefore, the final measurement includes both the true surface emission and the atmospheric contribution, which must be accounted for during data analysis.

The next important aspect of remote sensing is field data collection. In this process, we use ground-based sensors that are designed to match or closely resemble the specifications of satellite sensors. These instruments are deployed in the field to collect data directly from the Earth's surface. By correlating this ground data with satellite imagery, we can scale up local observations to a broader spatial context. This process is known as upscaling, and it plays a vital role in validating satellite-based analyses, improving the accuracy of remote sensing products, and supporting calibration and correction efforts. Ground-based measurements are essential for ensuring the reliability of remote sensing data and have numerous applications across environmental monitoring, agriculture, disaster assessment, and more.

Passive vs. Active Remote Sensing



In remote sensing, the source of energy used to illuminate the target determines whether the system is passive or active:

Passive Remote Sensing: Relies on natural sources of energy, typically the Sun. The Sun illuminates the Earth's surface, and the reflected energy is captured by the sensor. This configuration is common in optical and thermal remote sensing.

Active Remote Sensing: The sensor itself emits energy toward the target. It then measures the reflected, emitted, or backscattered energy. Examples include radar and LiDAR, which can operate independently of sunlight and are effective in all weather conditions and during nighttime.

Understanding the distinction between passive and active systems is crucial for selecting the appropriate remote sensing technique based on the application and environmental conditions.

Space-borne vs. Airborne Remote Sensing Platforms:

In remote sensing, data is often collected using platforms located either in space or within the Earth's atmosphere. You may have come across terms like space-borne, airborne, and UAVs (Unmanned Aerial Vehicles).

Space-borne Platforms

These are sensors mounted on satellites orbiting the Earth. Typically operate at altitudes ranging from 700 to 900 kilometers, and in some cases between 185 to 575 kilometers. These platforms provide large-scale coverage and are ideal for global or regional monitoring.

Airborne Platforms

These sensors are mounted on aircraft, helicopters, or UAVs flying within the atmosphere. Examples include Aerial photography, Airborne Synthetic Aperture Radar (SAR), Aerial television systems, UAV-based sensors. These platforms offer high-resolution data and are suitable for localized studies.

Understanding the distinction between these platforms helps in selecting the appropriate data source based on the scale, resolution, and application of your study.



This slide shows a series of photographs captured using everyday devices such as mobile phones, DSLR cameras, or other consumer-grade cameras. These types of images are familiar and easy to generate using commonly available equipment. However, the key difference between these images lies in the distance between the object and the data acquisition system. As the distance increases (such as when using airborne or satellite platforms) the area covered by the image also increases, providing broader aerial coverage. So, while a mobile phone or DSLR captures detailed, close-range images, a satellite sensor captures large-scale imagery from hundreds of kilometers above the Earth's surface. This difference in scale and perspective significantly affects the type and utility of the information captured.

All the images shown are digital images, meaning they are produced by electro-optical sensors. These sensors convert light into electronic signals, which are then processed into images. Unlike hand-drawn sketches or scanned documents, digital images are composed of tiny, uniformly sized units called pixels (short for picture elements). Each pixel represents a specific area on the ground and contains information about the reflectance or intensity of light at that location. In remote sensing, the term pixel is fundamental. It's used to describe the smallest unit of a digital image, and understanding pixel-level data is essential for image analysis and interpretation.



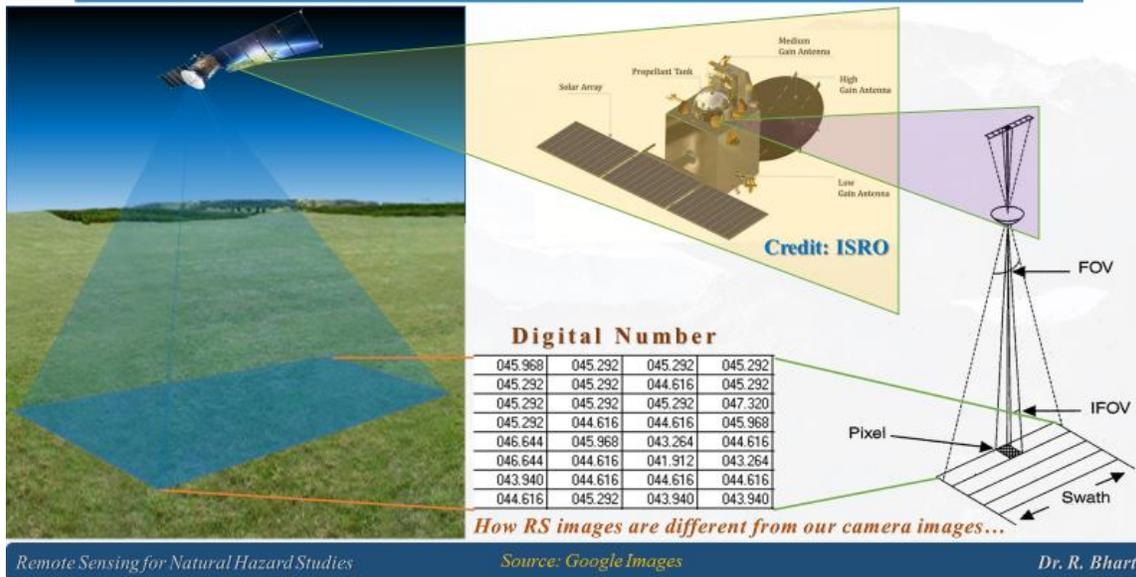
- Produced by Electro-Optical Sensors,
- Composed of tiny equal areas, or picture elements abbreviated as pixels or pels arranged in a rectangular array,
- With each pixel, a value is associated, known as Digital Number (DN)/ Brightness Value (BV)/ Gray Level, which is a record of variation in radiant energy in discrete form,
- An object reflecting more energy records a higher number for itself on the digital image and vice versa.

045.968	045.292	045.292	045.292
045.292	045.292	044.616	045.292
045.292	045.292	045.292	047.320
045.292	044.616	044.616	045.968
046.644	045.968	043.264	044.616
046.644	044.616	041.912	043.264
043.940	044.616	044.616	044.616
044.616	045.292	043.940	043.940
045.968	044.616	043.940	043.264
044.616	043.264	042.588	043.264
043.264	043.940	044.616	043.940
043.940	043.940	044.616	045.292
045.968	045.292	045.968	044.616
045.292	045.968	045.968	043.940
044.616	045.292	045.292	042.588
043.264	043.940	043.940	043.264
043.264	045.968	044.616	043.264
044.616	044.616	044.616	045.292
043.940	042.588	043.940	045.292
043.940	042.588	043.264	044.616
043.940	043.940	043.940	043.940
043.940	043.264	042.588	043.940
043.940	042.588	043.264	044.616

When you zoom into an image on your screen, you may notice that beyond a certain level, the image begins to appear pixelated. This pixelation reveals the individual square units that make up the image, which are called pixels. Each pixel represents a small, uniform area of the image and corresponds to the energy captured by the sensor's detectors. These detectors record the radiant energy from the surface and arrange it in a regular grid to form a complete image. Associated with each pixel is a numerical value that reflects the intensity of the captured energy. This value is commonly referred to as: Digital Number (DN), Brightness Value, or Gray Level. These values represent the variation in radiant energy in a discrete form, allowing us to analyze and interpret the image quantitatively. Understanding pixels and their associated values is fundamental to remote sensing and image processing.

Before I move further, let's understand the concept of a spacecraft and a sensor. A spacecraft acts as a carrier platform for multiple sensors, each designed with specific technical specifications. These sensors contain detectors arranged in a way that allows them to observe the Earth's surface. Each detector has a defined field of view (FOV), and the altitude of the sensor determines how much area on the ground is covered.

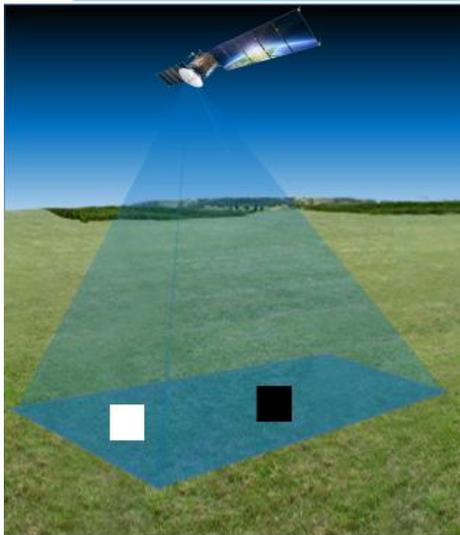
REMOTE SENSING



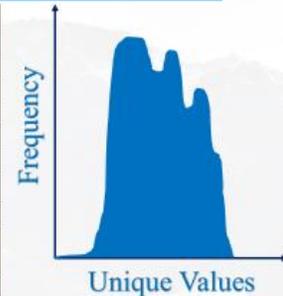
For example, if a sensor is positioned at an altitude of 100 kilometers and is designed to observe a $1 \text{ km} \times 1 \text{ km}$ area, you can calculate the FOV or, conversely, determine the altitude if the FOV is known. This relationship is governed by basic principles of physics and geometry. Each detector is responsible for capturing energy, whether reflected, emitted, or backscattered, from the surface. This energy is recorded as a digital number (DN), which becomes the value associated with a pixel in the final image. The output from these sensors is typically a digital image, composed of a grid of pixels. Each pixel represents a small area on the ground and contains a DN that reflects the intensity of the captured energy.

Before moving forward, it's important to understand how light interacts with materials and how this interaction is recorded in remote sensing images. Once an image is imported into a programming environment, we can begin analyzing it. The key principle is that objects reflecting more energy will appear brighter in the image and will have higher digital number (DN) values. Conversely, objects that absorb more energy will appear darker and have lower DN values. This variation is influenced by the field of view of the sensor, the chemical composition of the material, and the surface characteristics that determine how much energy is reflected, absorbed, or emitted.

DIGITAL IMAGE



63	61	61	62	62	60	60	63	64	55	50	53
62	63	70	65	56	51	44	45	48	47	46	47
64	69	68	51	43	49	59	62	60	57	54	53
65	65	56	43	53	57	61	66	64	66	68	66
63	58	47	48	58	58	65	67	61	61	67	64
60	50	50	57	57	57	66	70	62	60	62	58
56	47	62	59	56	56	61	66	61	61	64	62
44	56	66	61	56	55	57	60	59	60	61	57
62	74	66	64	56	57	56	58	65	62	63	55
75	71	63	65	58	58	58	56	62	59	60	55
69	63	61	65	60	59	62	59	58	54	55	56
62	59	59	61	62	62	59	59	61	58	59	60



An object reflecting more energy records a higher number for itself on the digital image and vice versa.

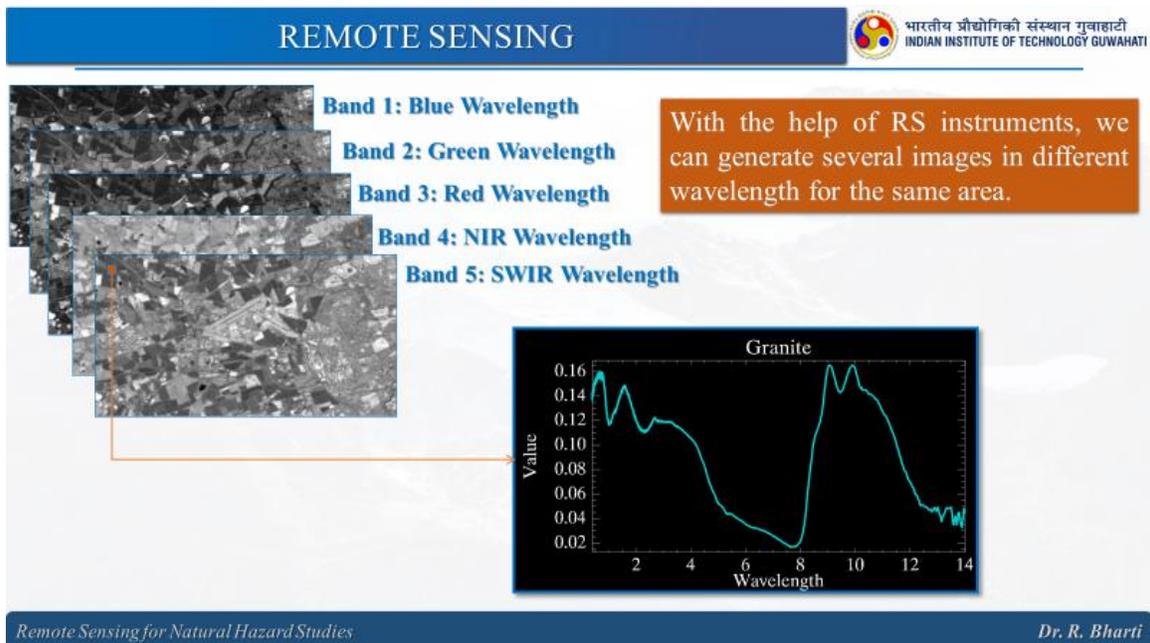
In the slide, we see a satellite observing a section of the Earth's surface. Within this area, there are both bright and dark objects. The bright object reflects more energy, resulting in higher DN values, while the dark object reflects less, resulting in lower DN values. When this image is converted into a matrix of pixel values, each pixel contains a DN that represents the amount of energy received from that specific location. By analyzing this matrix, we can distinguish between different surface features based on their reflectance properties. Once the image matrix is available, we can generate a histogram, a graphical representation of the distribution of pixel values. In remote sensing, histograms are used to identify unique DN values in the image, understand the brightness distribution, detect contrast levels and image quality, support classification, and enhancement techniques. This basic analysis helps in interpreting remote sensing data and extracting meaningful information from digital images. To generate a histogram, on the X-axis, we plot the digital number (DN) values, typically ranging from 0 to 255 for 8-bit images, and on the Y-axis, we plot the frequency (how many pixels in the image have each DN value). This histogram helps us understand the distribution of brightness across the image. If the histogram is skewed to the left (towards lower DN values), the image will appear dark, and if it is skewed to the right (towards higher DN values), the image will appear bright. A Gaussian (bell-shaped) distribution indicates a well-balanced image with appropriate contrast and brightness, which is ideal for analysis. However, since remote sensing data is collected under natural conditions, histograms often show uneven distributions. This is where digital image enhancement techniques become necessary to improve visual quality and analytical accuracy.

In remote sensing, the satellite acts as a carrier platform for multiple sensors. Each sensor contains an array of detectors, and each detector has a specific field of view (FOV). As

the satellite passes over the Earth's surface, each detector captures energy (reflected, emitted, or backscattered) from a specific ground area. This energy is converted into a digital number, which becomes a pixel in the final image. Thus, every pixel in a remote sensing image corresponds to a specific location on the ground and contains valuable information about the surface characteristics.

In remote sensing, each pixel in an image is generated by a detector within a sensor mounted on a satellite. These detectors are arranged in a linear or matrix configuration, each with a specific field of view (FOV). As the satellite moves, each detector captures energy (reflected, emitted, or backscattered) from a specific portion of the Earth's surface. This energy is then converted into a digital number (DN) using an Analog-to-Digital Converter (ADC). The bit depth of the ADC (e.g., 2-bit, 6-bit, 8-bit, 10-bit, or 12-bit) determines the range of DN values that can be recorded. These DNs are stored in the image matrix, where each pixel represents a discrete measurement of surface energy.

Unlike regular cameras (e.g., mobile phones or DSLRs), which typically operate within the visible spectrum (400–700 nm) or slightly into the near-infrared (up to ~1000 nm), remote sensing instruments are designed to capture data across a much broader range of wavelengths, including visible, NIR, SWIR, thermal infrared, and microwave. This allows remote sensing systems to capture multiple images of the same area simultaneously across different spectral bands and analyze how materials behave across wavelengths, revealing their chemical composition and internal atomic structure.



For example, a remote sensing satellite may capture one image in the blue band (400–500 nm), another in green (500–600 nm), another in red (600–700 nm), one in NIR (700–800 nm), and another in SWIR (800–900 nm). Each image contains the same spatial footprint,

so a single pixel across all bands corresponds to the same ground location. By comparing the DN values across these bands, we can construct a spectral profile for that pixel, which acts as a fingerprint for identifying materials. The absorption features observed in the spectral profile are directly linked to the material's chemical composition and atomic structure. These features allow us to identify natural and manmade materials and allow us to perform classification and thematic mapping. For instance, if a material shows distinct absorption features in the SWIR region, and those features match known patterns for granite, we can confidently identify the material as granite. This process, using multi-spectral or hyperspectral data to analyze material behavior across wavelengths, is the foundation of remote sensing-based material identification.

To effectively understand remote sensing, it's essential to grasp the concept of resolution, as it plays a critical role in selecting the most suitable images, satellites, or sensors for your study. There are four key types of resolution to consider:

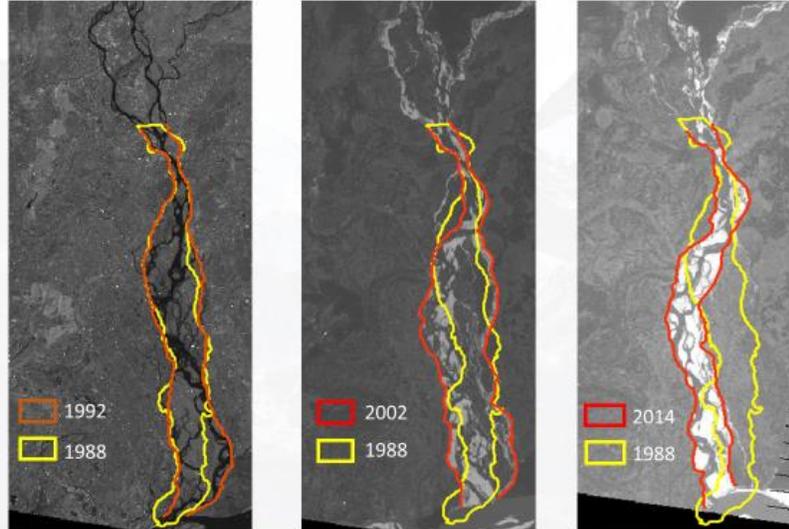
- Temporal Resolution – how frequently a satellite revisits and captures data for the same location.
- Radiometric Resolution – the sensitivity of a sensor to detect slight differences in energy levels.
- Spectral Resolution – the ability of a sensor to distinguish between different wavelengths of electromagnetic radiation.
- Spatial Resolution – the size of the smallest object that can be detected, typically defined by pixel size.

We'll explore each of these resolutions in detail to understand how they influence data quality and help you choose the appropriate sensor or satellite for your specific research needs.

Temporal Resolution:

Temporal resolution depends on the revisit time of a satellite—how often it passes over the same location. This is influenced by the satellite's orbit and altitude. Satellites at lower altitudes (e.g., 1000 km) complete orbits faster and revisit locations more frequently. Satellites at higher altitudes (e.g., 1800 km) take longer to orbit the Earth, resulting in longer revisit intervals. Additionally, some satellites are equipped with tiltable sensors, allowing them to capture images of areas outside their direct path. This tilting capability enhances revisit frequency by enabling off-nadir observations, capturing data before the satellite's orbit directly aligns with the target area.

TEMPORAL RESOLUTION



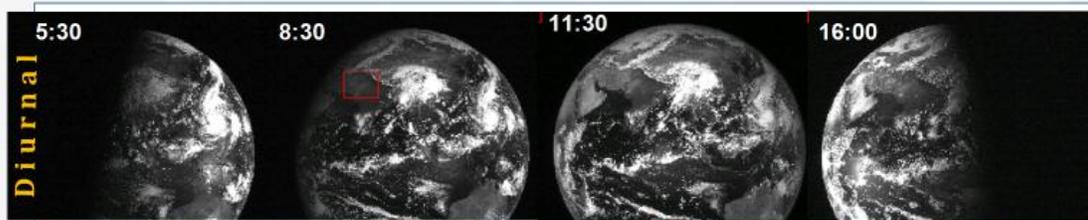
Remote Sensing for Natural Hazard Studies

Dr. R. Bharti

Comparing images from 1988, 1992, and 2002 reveals how a river's path has shifted over time. Such temporal analysis is valuable for studying geomorphological changes, floodplain dynamics, and environmental impacts.

TEMPORAL RESOLUTION

- This depends on the return time of the Satellite,
- Return time is a function of the altitude at which the satellite is launched,
- Higher the altitude, more circumference of orbit, longer to orbit the earth,
- With the ability to tilt the camera system (view direction), revisit capability can be increased.



Remote Sensing for Natural Hazard Studies

Credit: Dr. R. R. Navalgund, Former Director, SAC

Dr. R. Bharti

Images captured at different times of the day (e.g., 5:30 AM, 8:30 AM, 11:30 AM, and 4:00 PM) show cloud movement. This time-series data is crucial for predicting weather conditions, with remote sensing imagery serving as a primary input for forecasting models.

Spatial Resolution:

Spatial resolution refers to the size of the smallest object that can be detected by a sensor. In simple terms, spatial resolution defines how much ground area is represented by a single pixel in an image. Remote sensing images are composed of a grid of pixels, each carrying a digital number (DN) that represents the energy reflected, emitted, or backscattered from the Earth's surface. The physical area that each pixel covers (e.g., $15 \times 15\text{m}$, $1 \times 1\text{m}$, or $1 \times 1\text{ km}$) is what we call spatial resolution.

- Higher spatial resolution means smaller pixel size, allowing finer details to be captured.
- Lower spatial resolution (or coarse resolution) means larger pixel size, which may miss smaller features.

CONCEPT OF IFOV AND FOV

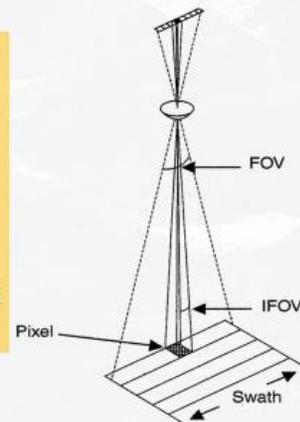


Spatial resolution is the projection of the detector element onto the ground through optics.

Instantaneous Field of View (IFOV) and Field of View (FOV):

IFOV specifies the sensor as independent of the altitude.

“Data can be generated by sampling at certain specified ground distances, which are smaller than IFOV”.



Spatial resolution is also influenced by the Instantaneous Field of View (IFOV) and Field of View (FOV). IFOV refers to the ground area viewed by a single detector at any instant. It determines the pixel size and is independent of altitude, whether the sensor is airborne or spaceborne. Whereas FOV is the total area covered by the entire sensor system, combining all detectors. Each detector in a sensor captures energy from a specific portion of the ground, and the size of this footprint defines the spatial resolution. For example, if one detector observes a $10 \times 10\text{m}$ area, then each pixel in the image will represent that $10 \times 10\text{m}$ section.

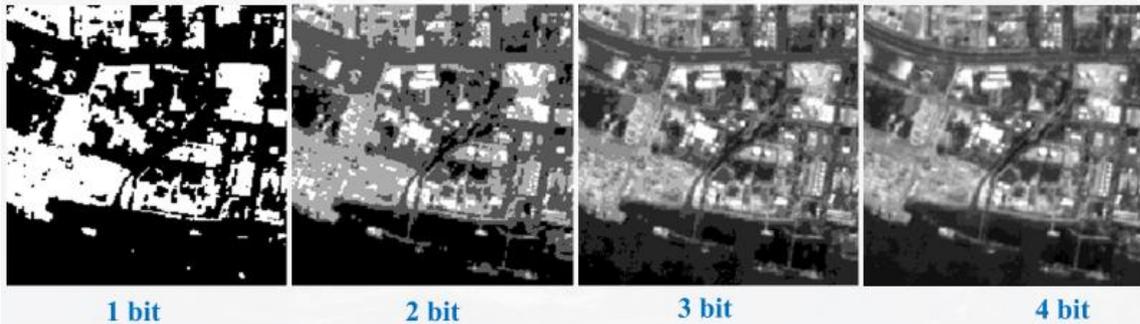
Radiometric Resolution:

Radiometric resolution refers to a sensor's ability to detect and differentiate subtle variations in the intensity of electromagnetic energy reflected or emitted from the Earth's surface. In simple terms, it defines how finely a sensor can measure the incoming radiation and how many distinct levels of brightness it can record. This sensitivity is determined by the Analog-to-Digital Converter (ADC) used in the sensor. The ADC converts the continuous analog signal into discrete digital values, known as digital numbers (DNs).

RADIOMETRIC RESOLUTION



It defines the sensitivity of a detector to differences in signal strength as it records the radiant flux reflected or emitted from the object...



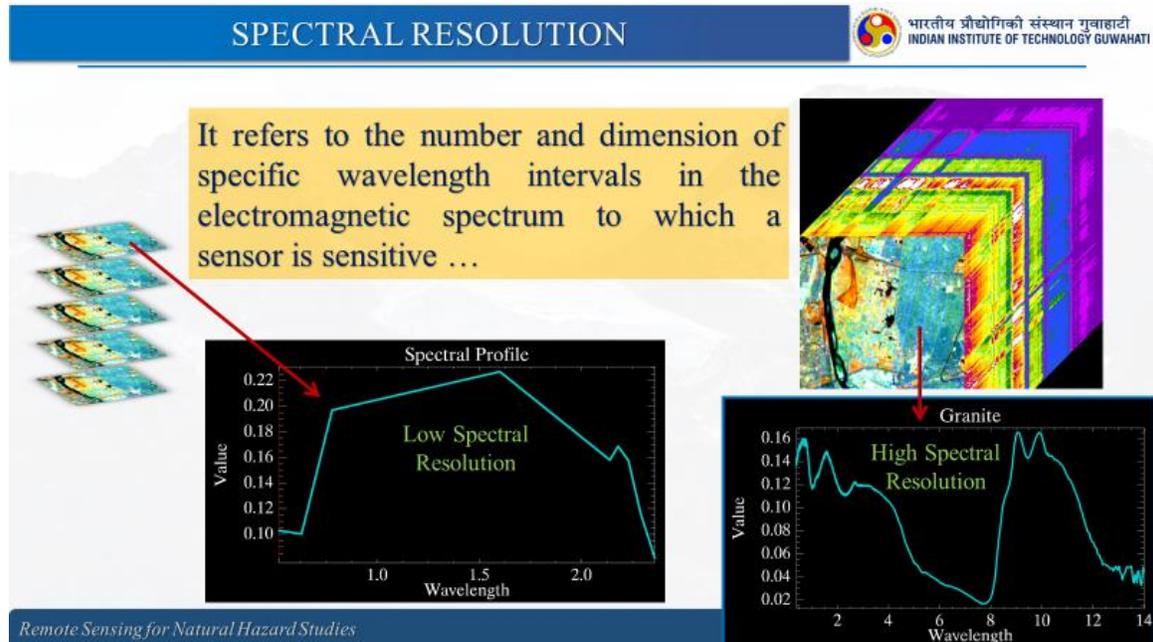
Understanding Bit Depth:

- A 1-bit ADC can record only 2 levels: 0 and 1. This means the sensor can only distinguish between two states—dark and bright—with no intermediate values.
- A 2-bit ADC provides 4 levels (2^2), allowing slightly more detail.
- A 3-bit ADC gives 8 levels, and so on.
- An 8-bit ADC can record 256 levels (2^8), offering much finer detail and contrast.

As the radiometric resolution increases, the image contains more detailed information about the surface. For example, a 3-bit image may appear flat or lacking in detail, whereas an 8-bit image of the same area will reveal subtle variations in brightness, texture, and material properties. This enhanced detail is crucial for applications like vegetation analysis, water quality assessment, and land cover classification, where small differences in reflectance can indicate significant changes.

Spectral Resolution:

Spectral resolution refers to the number and width of specific wavelength intervals in the electromagnetic spectrum that a sensor can detect. It determines how finely a sensor can distinguish between different wavelengths of light, which is crucial for identifying material properties and surface features.



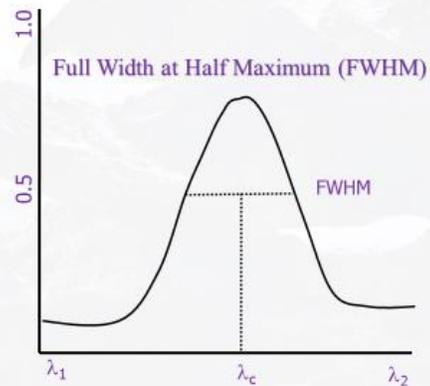
Key Concepts:

Wavelength Range: Consider a sensor sensitive to wavelengths from 400 nm to 2500 nm. This is the total spectral range within which the sensor operates.

- Number of Bands (Images): Within this range, the sensor may generate multiple images—each corresponding to a specific wavelength interval. For example:
 - Band 1: 450–550 nm
 - Band 2: 575–675 nm
 - Band 3: 700–800 nm
- The number of bands and their individual wavelength ranges define the spectral resolution.
- Band Characteristics: Each band has a central wavelength (e.g., 500 nm) and a bandwidth (e.g., 100 nm). A sensitivity curve, often resembling a Gaussian distribution, meaning the detector is most sensitive at the center and less so at the edges.

SPECTRAL RESOLUTION

- A spectral band is defined in terms of
 - ✓ Central Wavelength λ_c and
 - ✓ Band width ($\Delta\lambda$).
- The bandwidth is defined by a lower (λ_1) and an upper (λ_2) cut off wavelengths.
- Spectral resolution is $\lambda_2 - \lambda_1$, which describes the wavelength interval in which the observation is made.
- $\Delta\lambda$ is full width at half maximum (FWHM).
- Selection of bandwidth is a trade-off between the energy to be collected and spectra shape of the feature to be observed.



The Full Width at Half Maximum (FWHM) is used to describe the effective bandwidth where the detector is most responsive.

The selection of bandwidth in remote sensing is a trade-off between two key factors (1) the amount of energy that can be collected by the sensor, and (2) the spectral detail required to observe specific features. When designing a sensor, the choice of detector configuration depends on the mission objective, whether the goal is to detect subtle material differences, monitor land cover, or observe atmospheric phenomena. Higher spectral resolution allows us to detect minor variations in material composition, which are often missed in multispectral data due to broader and fewer bands.

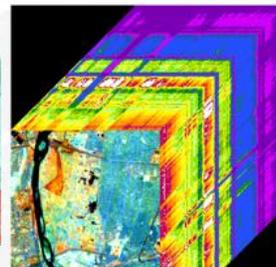
PANCHROMATIC, MULTISPECTRAL AND HYPERSPECTRAL



PANCHROMATIC



MULTISPECTRAL



HYPERSPECTRAL

Types of Remote Sensing Based on Spectral Resolution:

1. Panchromatic Imaging:

- Uses a broad wavelength range (e.g., 400–1500 nm) to generate a single grayscale image.
- Captures high-energy shorter wavelengths, which allow for higher spatial resolution.
- Ideal for detecting fine spatial details such as buildings, roads, and individual trees.

2. Multispectral Imaging:

- Divides the same wavelength range (e.g., 400–1500 nm) into a few distinct bands (typically 3–10).
- Each band covers a specific portion of the spectrum (e.g., 450–550 nm, 575–675 nm, etc.).
- Offers moderate spatial resolution and is suitable for land cover classification, vegetation monitoring, and water body analysis.
- May have gaps between bands, limiting the ability to detect fine spectral features.

3. Hyperspectral Imaging

- Captures hundreds or thousands of narrow, contiguous bands within the same wavelength range.
- Bandwidths are typically 10–20 nm, with no gaps between adjacent bands.
- Provides high spectral resolution, enabling detailed analysis of material composition and chemical properties.
- Ideal for applications like mineral mapping, crop health assessment, and environmental monitoring.

Spectral Band Characteristics: Each spectral band is defined by:

- Central Wavelength – the midpoint of the band (e.g., 500 nm)
- Bandwidth – the range of wavelengths covered (e.g., 400–500 nm)
- Sensitivity Curve – typically a Gaussian distribution, where the detector is most sensitive at the center and less so at the edges

The Full Width at Half Maximum (FWHM) is used to describe the effective bandwidth where the detector collects meaningful data. For example, a band labeled 400–500 nm may have an FWHM of 425 – 475 nm, indicating the range where the detector is most responsive.

Type	Spatial Resolution	Spectral Resolution	Best For
Panchromatic	High	Low	Detailed spatial analysis (e.g., urban mapping)
Multispectral	Moderate	Moderate	Land cover classification, vegetation studies
Hyperspectral	Lower	High	Material identification, chemical composition analysis

Sensor Technologies in Remote Sensing:

Remote sensing images are generated using different sensor technologies, each with its own method of scanning the Earth's surface:

Whisk Broom Scanning: Uses an oscillating mirror to sweep across the Earth's surface, much like a broom sweeping a floor. The mirror deflects upwelling radiation onto wavelength-sensitive photodetectors, capturing one pixel at a time across the swath. This method is dynamic but involves mechanical movement, which can affect stability.

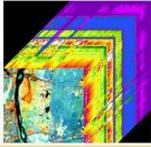
Push Broom Scanning: Employs a linear array of detectors, each aligned with a pixel in a row of the image. Captures an entire line of pixels simultaneously as the satellite moves forward. More stable than whisk broom systems since it avoids moving parts.

Frame Scanning: Captures the entire image frame at once. The number of detectors equals the total number of pixels in the image. Commonly used in aerial photography and high-resolution imaging systems.

Advantages of Remote Sensing:

ADVANTAGES OF REMOTE SENSING


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INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI



IMAGES GENERATED BEYOND THE VISIBLE SPECTRUM



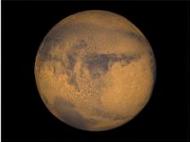
LARGE AERIAL COVERAGE



TEMPORAL IMAGES



ACCESS TO INACCESSIBLE AREAS



PLANETARY EXPLORATION

Remote Sensing for Natural Hazard Studies
Dr. R. Bharti

- **Beyond Visible Spectrum:** While human eyes are sensitive to wavelengths between 400–700 nm, remote sensing instruments can capture data in the thermal infrared and microwave domains, revealing information invisible to the naked eye.
- **Large Aerial Coverage:** Enables the study of large-scale features such as river morphology, lake shapes, and urban sprawl.
- **Temporal Monitoring:** Time-series images allow us to observe changes over time, such as glacier movement, seasonal vegetation cycles, or urban expansion.
- **Access to Remote Areas:** Remote sensing is invaluable for monitoring inaccessible or hazardous regions, including those relevant to military and defense operations.
- **Planetary Exploration:** Remote sensing is the primary tool for studying other planets. Missions like Chandrayaan and Mangalyaan use satellite sensors to gather data on lunar and Martian surfaces, helping scientists analyze material properties and surface characteristics from afar.
