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ON

APPLICATIONS OF REMOTE SENSING AND GIS IN WATER RESOURCES MANAGEMENT

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LECTURE NOTE

INTRODUCTION AND PRINCIPLES OF REMOTE SENSING

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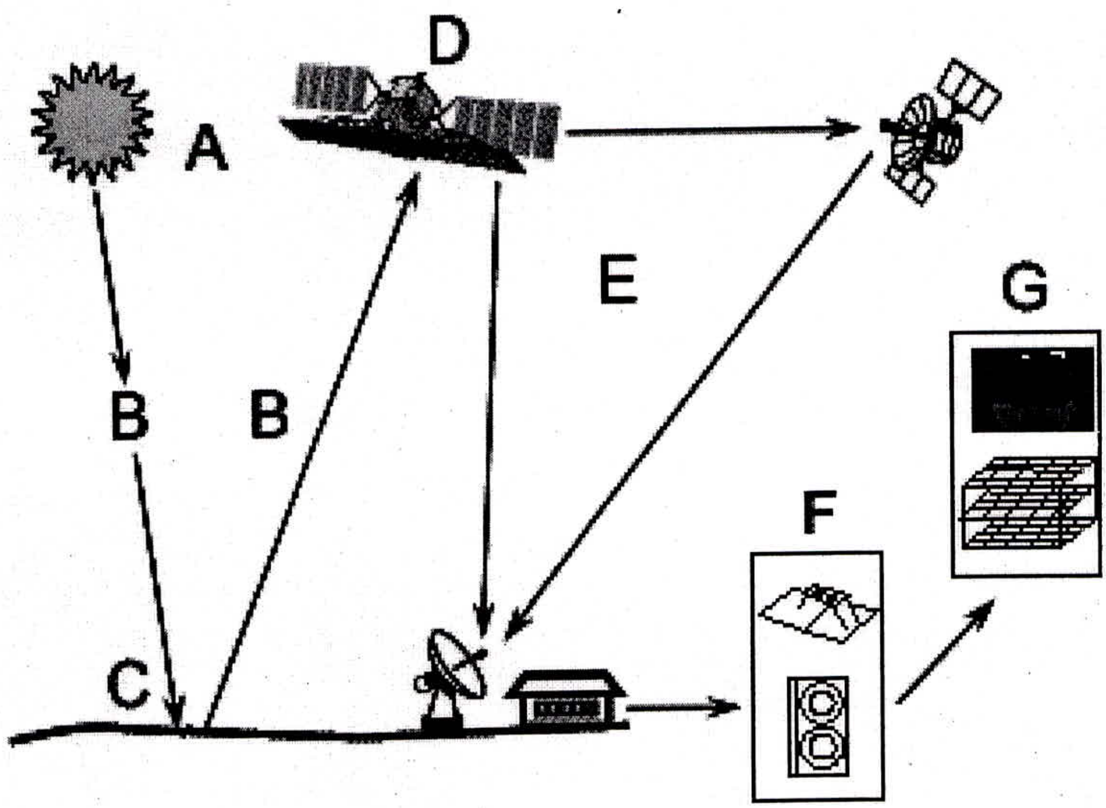
INTRODUCTION AND PRINCIPLES OF REMOTE SENSING

Remote sensing refers to techniques used for collecting information about an object and its surroundings from a distance without physically contacting them. Normally, this gives rise to some form of imagery which is further processed and interpreted to produce useful data for application in agriculture, archaeology, forestry, geography, geology, planning and other fields. Information about the object concerned is obtained by a sensor system located on a satellite or aircraft, which receives electromagnetic radiation which has been either emitted by the object or has interacted with the object. Here we will consider the latter case, in which the source of radiation is not the object.

Basic components of remote sensing

The overall process of remote sensing can be broken down into five components. These components are: 1) an energy source; 2) the interaction of this energy with particles in the atmosphere; 3) subsequent interaction with the ground target; 4) energy recorded by a sensor as data; and 5) data displayed digitally for visual and numerical interpretation. Figure 1 illustrates the basic elements of airborne and satellite remote sensing systems.

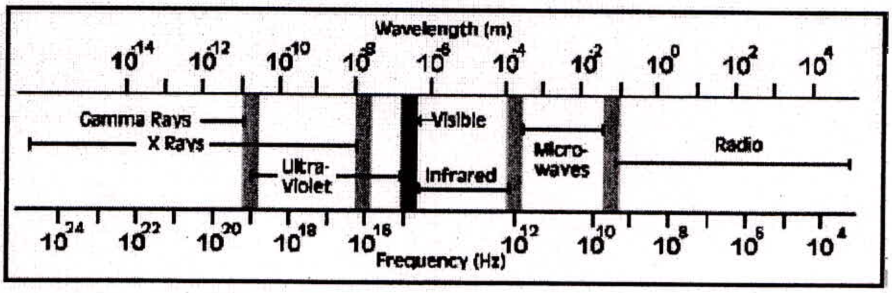


- Energy Source or Illumination (A) - fundamental requirement for remote sensing system

- ➢ Radiation and the Atmosphere (B) - energy will come in contact with and interact with the atmosphere it passes through - may take place a second time as the energy travels from the target to the sensor.
- ➢ Interaction with the Target (C) - once the energy makes its way to the target through the atmosphere, it interacts with the target in a manner depending on the properties of both the target and the radiation.
- ➢ Recording of Energy by the Sensor (D) - after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.
- ➢ Transmission, Reception, and Processing (E) - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hard copy and/or digital).
- ➢ Interpretation and Analysis (F) - the processed image is interpreted, visually and/or digitally, to extract information about the target
- ➢ Application (G) - the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

3. Physical properties of electromagnetic energy

As was noted in the previous section, the first requirement for remote sensing is to have an energy source (unless the sensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation. According to its wave properties, the electromagnetic energy is seen to travel through space as a wave at the velocity of light, i.e., 3x1010 cm/s. Wavelength is measured in meters (m) or in fractions of meters such as nanometers (nm, 10^{-9} meters), micrometers (μm 10^{-6} meters) or centimeters (cm, 10^{-2} meters). The electromagnetic spectrum, as shown in figure below, ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). There are several regions of the electromagnetic spectrum that are useful for remote sensing.



The ultraviolet (UV) portion of the spectrum has the shortest wavelengths that are practical for remote sensing. This radiation is just beyond the violet portion of the visible wavelengths. Some Earth surface materials, primarily rocks and minerals, fluoresce or emit visible light when illuminated by UV radiation.

The light, which our eyes can detect, is part of the visible spectrum. It is important to recognize how small the visible portion is relative to the rest of the spectrum. There is a lot of radiation around us that is "invisible" to our eyes, but can be detected by other remote sensing instruments. The visible wavelengths cover a range from approximately 0.4 to 0.7 μm . The longest visible wavelength is red and the shortest is violet. Common wavelengths of what we perceive as particular colors from the visible portion of the spectrum are listed below. It is important to note that this is the only portion of the spectrum we can associate with the concept of colors.

- **Violet**: 0.4 - 0.446 μm
- **Blue**: 0.446 - 0.500 μm
- **Green**: 0.500 - 0.578 μm
- **Yellow**: 0.578 - 0.592 μm
- **Orange**: 0.592 - 0.620 μm
- **Red**: 0.620 - 0.7 μm

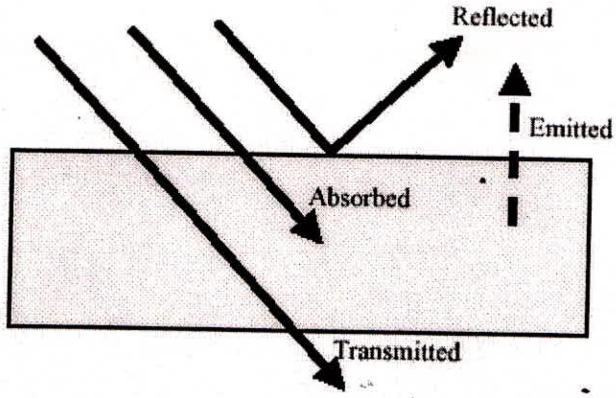
Blue, green, and red are the primary colors or wavelengths of the visible spectrum. They are defined as such because all other colors can be formed by combining blue, green, and red in various proportions. Sunlight is actually composed of various wavelengths of radiation in primarily the ultraviolet, visible and infrared portions of the spectrum.

The infrared (IR) region covers the wavelength range from approximately 0.7 mm to 100 mm. The infrared region can be divided into two categories based on their radiation properties - the reflected IR, and the emitted or thermal IR. Radiation in the reflected IR region is used for remote sensing purposes in ways very similar to radiation in the visible portion. The reflected IR covers wavelengths from approximately 0.7 μm to 3.0 μm . The thermal IR region is different from the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from approximately 3.0 μm to 100 μm .

The electromagnetic radiation (EM) is the source of all signals collected by most remote sensing instruments. The source of this energy varies depending on the sensor characteristics. Most systems rely on the sun to generate all the EM energy needed to image terrestrial surfaces. These systems are called ***passive sensors***. Other sensors generate their own energy, called ***active sensors***, transmit that energy in a certain direction and records the portion reflected back by features within the signal path. Electromagnetic energy can be generated by changes in the energy levels of electrons, acceleration of electrical charges, decay of radioactive substances, and the thermal motion of atoms and molecules. Table 1 lists some representative applications for different spectral bands available from existing satellites.

Electromagnetic energy interacts with surface and near surface objects

Electromagnetic energy that reaches a target will be absorbed, transmitted, and reflected. The proportion of each depends on the composition and texture of the target's surface. The following figure illustrates these three interactions. Much of the remote sensing is concerned with reflected energy.



(i)Absorption: Absorption occurs when radiation penetrates a surface and is incorporated into the molecular structure of the object. All objects absorb incoming incident radiation to some degree. Absorbed radiation can later be emitted back to the atmosphere. Emitted radiation is useful in thermal studies.
(ii) Transmission. Transmission occurs when radiation passes through material and exits the other side of the object. Transmission plays a minor role in the energy's interaction with the target. This is attributable to the tendency for radiation to be absorbed before it is entirely transmitted. Transmission is a function of the properties of the object.
(iii) Reflection. Reflection occurs when radiation is neither absorbed nor transmitted.
The reflection of the energy depends on the properties of the object and surface roughness relative to the wavelength of the incident radiation. Differences in surface properties allow the distinction of one object from another.
Absorption, transmission, and reflection are related to one another by
$E_I = E_A + E_T + E_R$ (2-6)
where

E_I = incident energy striking an object
E_A = absorbed radiation
E_T = transmitted energy
E_R = reflected energy.

(iv) Reflectance of Radiation. Reflectance is simply a measurement of the percentage of incoming or incident energy that a surface reflects Reflectance = Reflected energy/Incident energy where incident energy is the amount of incoming radiant energy and reflected energy is the amount of energy bouncing off the object.
Reflectance is a fixed characteristic of an object. Surface features can be distinguished by comparing the reflectance of different objects at each wavelength. Reflectance comparisons rely on the unchanging proportion of reflected energy relative to the sum of incoming energy. This permits the distinction of objects regardless of the amount of incident energy. Unique objects reflect differently, while similar objects only reflect differently if there has been a physical or chemical change.
Note: reflectance is not the same as reflection.

Energy is Detected and Recorded by the Sensor.

Earlier paragraphs of this lecture explored the nature of emitted and reflected energy and the interactions that influence the resultant radiation as it traverses from source to target to sensor. This paragraph will examine the steps necessary to transfer radiation data from the satellite to the ground and the subsequent conversion of the data to a useable form.

Data collected at a sensor are converted from a continuous analog to a digital number. This is a necessary conversion, as electromagnetic waves arrive at the sensor as a continuous stream of radiation. The incoming radiation is sampled at regular time intervals and assigned a value. The value given to the data is based on the use of a 6-, 7-, 8-, 9-, or 10-bit binary computer coding scale; powers of 2 play an important role in this system. Using this coding allows a computer to store and display the data. The computer translates the sequence of binary numbers, given as ones and zeros, into a set of instructions with only two possible outcomes (1 or 0, meaning "on" or "off"). The binary scale that is chosen (i.e., 8 bit data) will depend on the level of brightness that the radiation exhibits.

Satellite receiving stations are positioned throughout the world. Each satellite program has its own fleet of receiving stations with a limited range from which it can pick up the satellite signal. Satellites can only transmit data when in range of a receiving station. When outside of a receiving range, satellites will store data until they fly within range of the next receiving station.

Once transmitted the carrier signal is filtered from the data, which are decoded and recorded onto a high-density digital tape (HDDT) or a CDROM, and in some cases transferred via file transfer protocol (FTP). The data can then undergo geometric and radiometric preprocessing, generally by the vendor. The data are subsequently recorded onto tape or CD compatible for a computer.

REFLECTANCE CHARACTERISTICS OF DIFFERENT OBJECTS

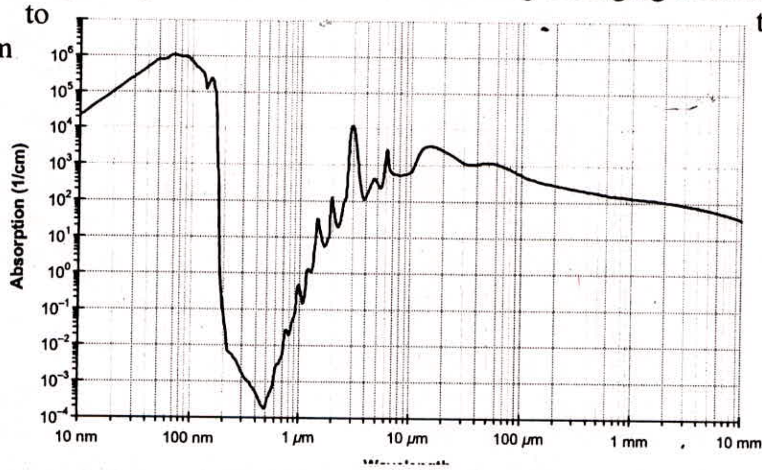
Spectral Reflectance Curves.

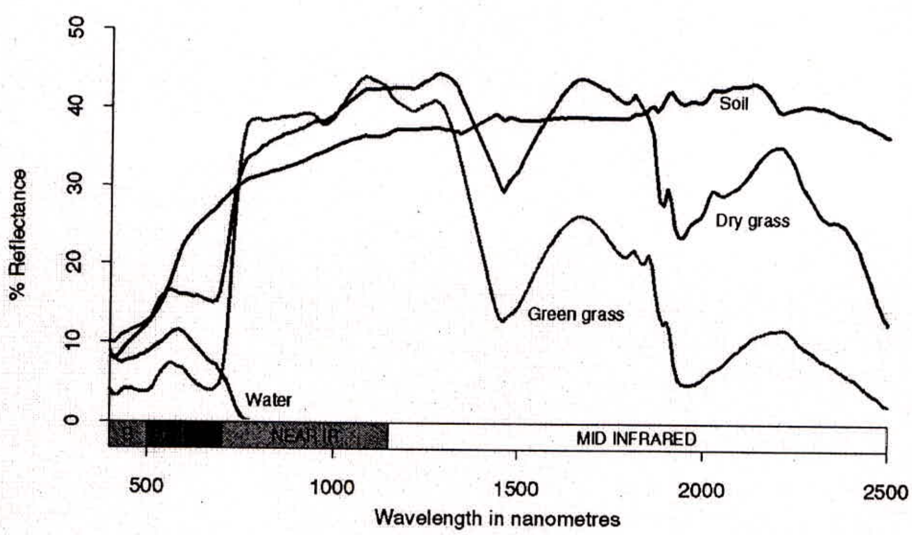
A surface feature's color can be characterized by the *percentage* of incoming
electromagnetic energy (illumination) it reflects at each wavelength across the electromagnetic spectrum. This is its spectral reflectance curve or "spectral signature"; it is an unchanging property of the material. For example, an object such as a leaf may reflect 3% of incoming blue light, 10% of green light and 3% of red light. The amount of light it reflects depends on the amount and wavelength of incoming illumination, but the percents are constant. Unfortunately, remote sensing instruments do not record reflectance directly, rather radiance, which is the *amount* (not the percent) of electromagnetic energy received in selected wavelength bands. A change in illumination, more or less intense sun for instance, will change the radiance. Spectral signatures are often represented as plots or graphs, with wavelength on the horizontal axis, and the reflectance on the vertical axis

Important Reflectance Curves and Critical Spectral Regions. While there are too many surface types to memorize all their spectral signatures, it is helpful to be familiar with the basic spectral characteristics of green vegetation, soil, and water. This in turn helps determine which regions of the spectrum are most important for distinguishing these surface types.

Spectral Reflectance of Water. Spectral reflectance of clear water is low in all portions of the spectrum. Reflectance increases in the visible portion when materials are suspended in the water. Water absorption is a phenomenon in the transmission of electromagnetic radiation through a medium containing water molecules. Water molecules are excited by radiation at certain wavelengths and tend to selectively absorb portions of the spectrum while allowing the balance of the spectrum to be transmitted with minimal effect.

Strong water vapor absorption bands occur at wavelengths around 2500, 1950 and 1450 nanometers (nm), with weaker absorption around 1200 and 970 nm, and three additional sets of water-vapor absorption lines near 930, 820, and 730 nm, all in the infrared spectrum. Water has a complex absorption spectrum — the 2007 HITRAN spectroscopy database update lists more than 64,000 spectral lines corresponding to significant transitions of water vapor ranging from the microwave region to the visible spectrum





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Tł EM spectrum to which a sensor is sensitive. There are many possible bands that can be used by a remote sensing system. Some are ideal for one set of applications, while others are good for a different set.

<u>Spatial Resolution</u>

The resolution of an image can be described as the closest that two objects can be together and still be reliably distinguished. The spatial resolution of images acquired by satellite sensor systems is usually expressed in meters. A 30-meter resolution means that two objects, 30 meters long or wide sitting side by side can be separated on the image. High resolution allows distinguishing relatively small objects or those that are closely spaced. In imagery taken at 3-meter resolution, for example, cars can be distinguished from trucks, while in imagery taken at 10-meter resolution neither cars nor trucks can be identified. High spatial resolution implies imaging a small area. For an image of 1000 pixels square, at 20m resolution the area viewed is 20x20km, but at 1km resolution this increases to 1000x1000km (actually rather more, due to the variation in viewing angle over a large area). The latter is therefore suitable for large-scale studies.

Radiometric Resolution

Quantization level, sensitivity of a sensor to differences in signal strength (e.g., number of bits, integer or floating point)

Temporal Resolution

How often the sensor records imagery of a particular area

REMOTE SENSING PLATFORMS

Platform is a stage to mount the camera or sensor to acquire the information about a target under investigation. Based on its altitude above earth surface, platforms may be classified as

Ground borne

Air borne

Space borne

Ground based platforms

The ground based remote sensing systems for earth resources studies are mainly used for collecting the ground truth or for laboratory simulation studies.

Air borne platforms

Aircrafts are generally used to acquire aerial photographs for photo-interpretation and photogrammetric purposes. Scanners are tested against their utility and performance from these platforms before these are flown onboard satellite missions.

Space-borne platforms

Platforms in space are not affected by the earth's atmosphere. These platforms are freely moving in their orbits around the earth, and entire earth or any part of the earth can be covered at specified intervals. The coverage mainly depends on the orbit of the satellite. It is through these space borne platforms, we get the enormous amount of remote sensing data and as such the remote sensing has gained international popularity.

Depending on their altitudes and orbit these platforms may be divided in two categories:

Geostationary

Polar orbiting or Sun-synchronous

Geostationary satellites

An equatorial west to east satellite orbiting the earth at an altitude of 35000 km. The altitude at which it makes one revolution in 24 hours, synchronous with earth's rotation. These platforms are covering the same place and give continuous near hemispheric coverage over the same area day and night. Its coverage is limited to 70 N to 70 Latitudes and one satellite can view one third of the globe. These are mainly used for communication and meteorological applications viz GEOS, METOSAT, INTELSAT and INSAT satellites.

Sun-Synchronous satellites

An earth satellite orbit in which the orbital plane is near polar and the altitude is such that the satellite passes over all places on earth having the same latitude twice in each orbit at the same local sun-time.

Through these satellites the entire globe is covered on regular basis and gives repetitive coverage on periodic basis. All the remote sensing resources satellites may be grouped in this category. Few of these satellites are Landsat series, SPOT series, IRS series, NOAA, SEASAT, TIROS etc.

SATELLITE PROGRAMS

LANDSAT Programme: Till date, the Landsat programme has provided the most extensively used remote sensing data, the world over. Its chief plank has been in delivering unrestricted global data of good geometric accuracy. Under the Landsat programme till date six satellites (Landsat - 1,2,3,4,5 & 6) have been launched (Landsat-6 having failed). These satellites have been placed in near-polar, near-circular, sun-synchronous orbit. In this configuration, as the satellite orbits in the north-south plane, the Earth below spins around its axis, from west to east. Thus, different parts of the globe are `seen' by the satellite during different north-south passes. The remote sensing data are acquired in the descending node, i.e. as the satellite moves from the North Pole to South Pole. The L - 1,2,3 were placed at an altitude of 918 km with a repeat cycle of 18 days, and L-4,5 at an altitude of 705 km with a repeat cycle of 16 days.

The Landsat have carried on-board two main sensors, Multispectral Scanning System (MSS) and Thematic Mapper (TM), both being OM-line scanners and producing ground scenes of nominally 185*185 km size. The MSS sensor has been a regular payload of the Landsat and has made this programme a tremendous success. The TM is an advanced multispectral scanner used in Landsat 4 & 5 missions. TM operates in seven wavelength bands, out of which six are in the solar reflection region and one in thermal-IR region.

SPOT Programme: The French satellite system SPOT is a typical second generation earth resources satellite. These satellites have been placed in near-polar sun-synchronous 830 km high orbit with a repeat cycle of 26 days. The sensor here is called HRV (High Resolution Visible), which is a CCD-line scanner. The HRV's acquire data in two interesting modes: (a) panchromatic mode in a swath of 60 km with ground resolution of 10*10 m and (b) multispectral mode, in three channels (green, red and infrared) with a ground resolution of 20*20 m in a swath width of 60 km. Further, the HRV's can be tilted to acquire data in off-nadir viewing mode, for more frequent repetitive coverage, and for stereoscopy.

INDIAN SPACE PROGRAMME

Till date ISRO has launched eleven Indian Remote Sensing Satellites (IRS) starting with IRS-1A in March 1988 to IRS P-5 (CARTOSAT-1) launched in May 2005. In the area of Satellite based remote sensing in the past, the first generation satellite IRS-1A and 1B were designed, developed and launched successfully during 1988 and 1991 with multi-spectral cameras with spatial resolution of 72.5 m and 36 m. respectively. Subsequently, the second generation remote sensing satellites IRS-1C and 1D with improved spatial resolutions of 70 m in multi-spectral and 5.8 m. in Panchromatic bands and a wide field sensor with 188m resolution and 800 Km. swath, have been developed and successfully launched in 1995 and 1997 respectively. In this series recently in May 2005 CARTOSAT-1 was launched. These satellites and sensors have been described briefly in the following section.

- **IRS-1A and IRS-1B**

  These were the operational first generation remote sensing satellites.

- Launched on March 1988 and August 1991,
- Altitude of 904 km,
- Placed in near-polar, sun-synchronous orbit,
- Ground Resolution of 72.5 mt and 36.25 mt respectively,
- Repetitive Time of 22 days,
- Life of 3 years, (IRS-1B still working) and
- Sensors with two linear Imaging Scanning Sensors (LISS-I and LISS-II) for providing data in four spectral bands: Visible, Infra Red (IR) and Near Infra Red (NIR).

- **IRS-P2**

The satellite was launched in October 1994, on the indigenously developed Polar Satellite Launch Vehicle (PSLV-D2). It carried a modified LISS camera.

- **IRS-1C and IRS-1D**

These were the first of the second generation, operational, multi-sensor satellite missions with better resolution.

- Launched on 1995 and 29 September 1997 from Sriharikota,
- Altitude of 817 km and 780 km,
- Placed in near-polar, sun-synchronous orbit, whereas there have been some problems with the orbit of IRS-1D,
- Resolution of 5.2-5.8 mt and 188 mt respectively.
- Repetitive time of 22 days,
- Life of 3 years,
- Sensors with Panchromatic (PAN) and LISS-III cameras.

- **IRS-P3**

Launched on April 1996 on PSLV-D3, had two imaging sensing sensors and one non- imaging sensors i.e. WiFs, with a resolution of 188 mt and swath of 810 km.

- **IRS- P4**

Most of the existing missions cater to land applications. IRS-P4 satellite, which is also called as Oceansat, will primarily cater to oceanographic applications. The indigenous Polar Satellite Launch Vehicle (PSLV) launched this satellite on 26th May, 1999, into polar Sun-synchronous orbit at an altitude of 720 km. The satellite has a high receptivity of 2 days. The payload include a Ocean Colour Monitor (OCM), a Multi frequency Scanning Microwave Radiometer (MSMR) and solid state memory for recording data outside the visibility of a ground station.

- **IRS- P6 (RESOURCESAT-1)**

IRS-P6 (RESOURCESAT-1) is launched in to the polar sun synchronous orbit on October 17, 2003. It is a state-of-art satellite mainly for agriculture applications and have a 3-band multispectral LISS-IV camera with a spatial resolution better than 6 m and a swath of around 25 km with across track steerability for selected area monitoring. An improved version of LISS-III with four bands (red, green, near IR and SWIR), all at 23 m resolution and 140 km swath will provide the essential continuity to LISS-III. Together with an advanced Wide Field Sensor (WiFS) with 80 m resolution and 1400 km swath, the payloads will greatly aid crop/vegetation and integrated land and water resources related applications.

- **IRS-P5 (CARTOSAT-1/2)**

This satellite was launched on May 05, 2005. It has an improved sensor system that provides 2.5 m resolution with fore-aft stereo capability. This mission caters to the needs of cartographers and terrain modelling applications. The satellite will provide cadastral level information up to 1:5000 scale and will be useful for making 2.5 m contour maps. IRS Cartosat-2 has been successfully launched in January 10, 2007 by the PSLV-C7 from Satish Dhawan Space Centre, Sriharikota. The spatial resolution of the satellite is less than 1 m. The swath width is 9.6 km and radiometric resolution is10 bit.

Radar Remote Sensing

RADAR stands for "Radio Detection And Ranging". By virtue of sending out pulses of microwave electromagnetic radiation this type of instrument can be classified as an "active sensor" - it measures the time between pulses and their reflected components to determine distance. Different pulse intervals, different wavelengths, different geometry and polarizations can be combined to roughness characteristics of the earth surface. Radar uses relative long wavelengths which allow these systems to "see" through clouds, smoke, and some vegetation. Also, being an active system, it can be operated day or night. There are disadvantages, such as the non-unique spectral properties of the returned radar signal. Unlike infrared data that help us to identify different minerals or vegetation types from reflected sunlight, radar only shows the difference in the surface roughness and geometry and moisture content of the ground (the complex dielectric constant). Radar and infrared sensors are complimentary instruments and are often used together to study the same types of earth surfaces.

Types of Imaging Radar

SLAR (Side-Looking Airborne Radar)

- develop by guess who in the 1950's
  - airborne, fixed antenna width, sends one pulse at a time and measures what gets scattered back
  - resolution determined by wavelength and antenna size (narrow antenna width = higher resolution)

- **SAR (Synthetic Aperture Radar)**

- also developed by those responsible for SLAR, but this configuration is not dependent on the physical antenna size although to achieve higher resolution the receiving antenna components and transmitter components need to be separated.
- "synthesizes" a very broad antenna by sending multiple pulses

Radar resolution has two components; the "range" resolution and the "azimuth" resolution. These are determined by, among other factors, the width of the synthesized antenna (which is dictated by the pulse interval) and the wavelength.

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Table 1 Remote Sensing Applications for different Spectral bands

Spectral band m	**Applications**
Blue (0.45 -0.50) Green (0.50- 0.60) Red (0.60- 0.70	Water penetration, land use, vegetation characteristics, sediment Green reflectance of healthy vegetation Vegetation discrimination because of red chlorophyll absorption
Panchromatic (0.50 - 0.75) Reflective Infrared (0.75 -0.90)	Mapping, land use, stereo pairs Biomass, crop identification, soil-crop, land-water boundaries
Mid-infrared (1.5 -.1.75) Mid-infrared (2.0- 2.35)	Plant turgidity, droughts, clouds, snow-ice discrimination Geology, rock formations
Thermal infrared (10 - 12.5)	Relative temperature, thermal discharges, vegetation classification, moisture studies, thermal inertia
Microwave- Short wave (0.1- 5 cm)	Snow cover, depth, vegetation water content
Microwave-Long wave (5- 24 cm)	Melting snow, soil moisture, water-land boundaries, penetrate Vegetation .