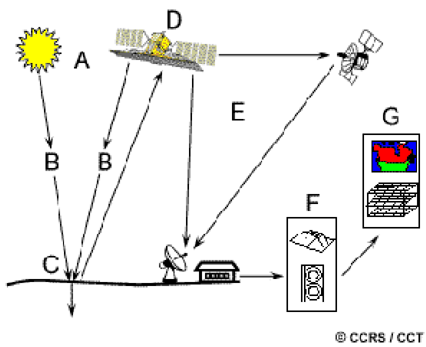
# Chapter 5. Introduction to Remote Sensing

## 5.1 What is Remote Sensing

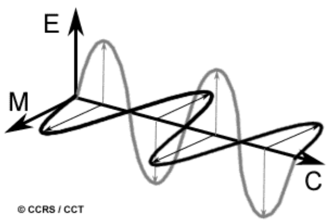
Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information.

In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. Note, however that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.



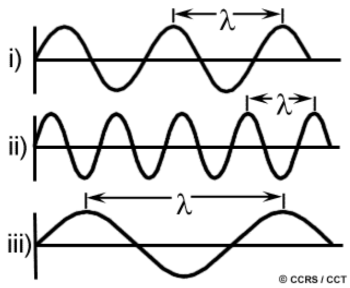

1. **Energy Source or Illumination (A)** - the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2. **Radiation and the Atmosphere (B)** - as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.
3. **Interaction with the Target (C)** - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4. **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.
5. **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 (hardcopy and/or digital).
6. **Interpretation and Analysis (F)** - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
7. **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

## 5.2 Electromagnetic Radiation



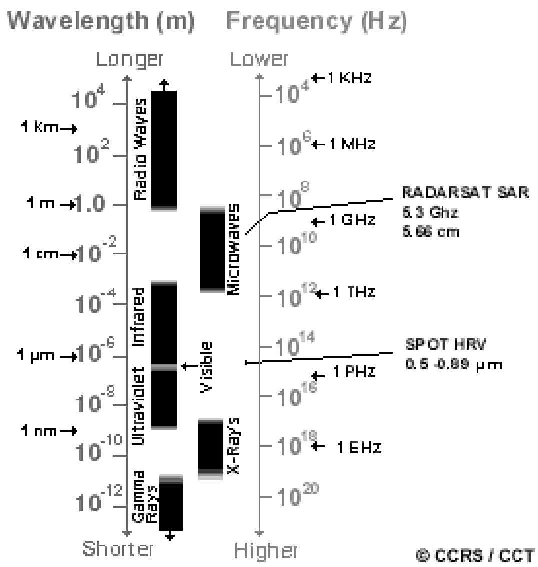

The first requirement for remote sensing is to have an **energy source to illuminate the target** (unless the sensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation. All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory. Electromagnetic radiation consists of an electrical field(E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c).

The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in metres (m) or some factor of metres such as **nanometres** (nm, $10^{-9}$ metres), **micrometres** (μm, $10^{-6}$ metres) or centimetres (cm, $10^{-2}$ metres). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in **hertz** (Hz), equivalent to one cycle per second, and various multiples of hertz. *The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency.*

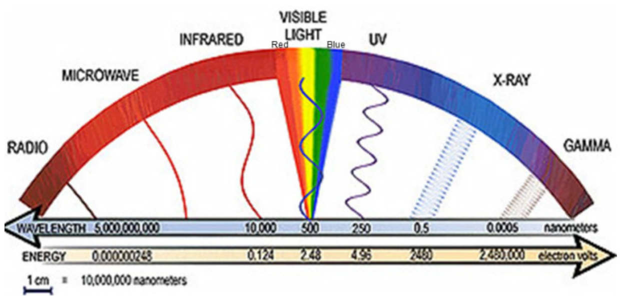



## 5.3 The Electromagnetic Spectrum

The electromagnetic spectrum 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 which are useful for remote sensing. For most purposes, the ultraviolet or UV portion of the spectrum has the shortest wavelengths which are practical for remote sensing. This is a small visible portion relative to the rest of the spectrum. There is a lot of radiation around us which is "invisible" to our eyes, but can be detected by other remote sensing instruments and used to our advantage. 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. Some of common colors have the wavelength in following ranges:



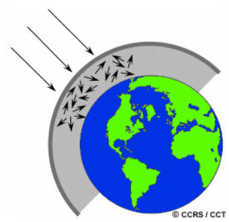
| | |
|---|---|
| Violet: | 0.4 - 0.446 µm |
| Blue: | 0.446 - 0.500 µm |
| Green: | 0.500 - 0.578 µm |
| Yellow: | 0.578 - 0.592 µm |
| Orange: | 0.592 - 0.620 µm |
| Red: | 0.620 - 0.7 µm |




## 5.4 Interactions with the Atmosphere

Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of scattering and absorption

**A. SCATTERING** occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path. There are three types of scattering which take place.




**Rayleigh scattering** occurs when particles are very small compared to the wavelength of the radiation. These could be particles such as small specks of dust or nitrogen and oxygen molecules. Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere. The fact that the sky appears "blue" during the day is because of this phenomenon. As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths. At sunrise and sunset the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere.

**Mie scattering** occurs when the particles are just about the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering. Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.

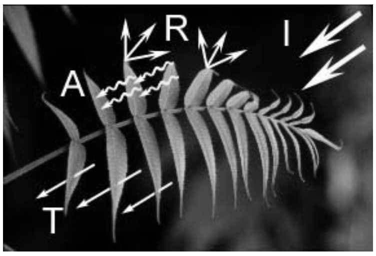

**Non-selective scattering** occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering. Nonselective scattering gets its name from the fact that all wavelengths are scattered about equally. This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities (blue + green + red light = white light).

**B. ABSORPTION** is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation. Ozone serves to absorb the harmful (to most living things) ultraviolet radiation from the sun. Without this protective layer in the atmosphere our skin would burn when exposed to sunlight.

The reason carbon dioxide is referred to as a greenhouse gas because it tends to absorb radiation strongly in the far infrared portion of the spectrum - that area associated with thermal heating - which serves to trap this heat inside the atmosphere. Water vapour in the atmosphere absorbs much of the incoming longwave infrared and shortwave microwave radiation (between 22µm and 1m). Because these gases absorb electromagnetic energy in very specific regions of the spectrum, they influence where (in the spectrum) we can "look" for remote sensing purposes.

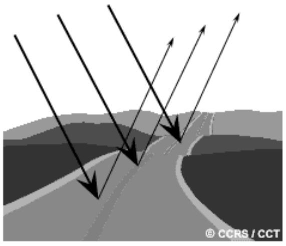
***Those areas of the spectrum which are not severely influenced by atmospheric absorption and thus, are useful to remote sensors, are called atmospheric windows.***

## 5.5 Radiation - Target Interactions

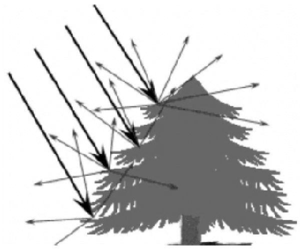



Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface. There are three (3) forms of interaction that can take place when energy strikes, or is incident (I) upon the surface. These are: absorption (A); transmission (T); and reflection (R). The total incident energy will interact with the surface in one or more of these three ways. The proportions of each will depend on the wavelength of the energy and the material and condition of the feature.

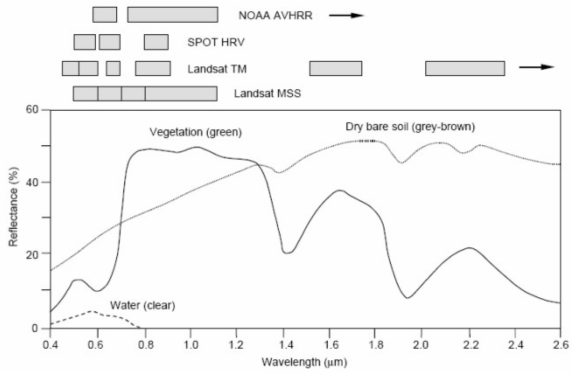
Absorption (A) occurs when radiation (energy) is absorbed into the target while transmission (T) occurs when radiation passes through a target. Reflection (R) occurs when radiation "bounces" off the target and is redirected. In remote sensing, we are most interested in measuring the radiation reflected from targets.




We refer to two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target: ***specular reflection*** and ***diffuse reflection***.



When a surface is smooth we get specular or mirror-like reflection where all (or almost all) of the energy is directed away from the surface in a single direction. Diffuse reflection occurs when the surface is rough and the energy is reflected almost uniformly in all directions.




The different target objects on earth behave with radiation as:

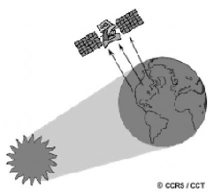
**Vegetation(Green)**: A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Leaves appear "greenest" to us in the summer, when chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths).

**Water**: Longer wavelength visible and near infrared radiation is absorbed more by water than shorter visible wavelengths. Thus water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or near infrared wavelengths.

By measuring the energy that is reflected (or emitted) by targets on the Earth's surface over a variety of different wavelengths, we can build up a ***spectral response*** for that object. By comparing the response patterns of different features we may be able to distinguish between them, where we might not be able to, if we only compared them at one wavelength. *For example, water and vegetation may reflect somewhat similarly in the visible wavelengths but are almost always separable in the infrared.*

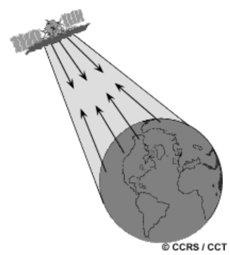
## 5.6 Passive vs. Active Sensing

Remote sensing systems which measure energy that is naturally available are called **passive sensors**. Passive sensors can only be used to detect energy when the naturally occurring energy is available. For all reflected energy, this can only take



place during the time when the sun is illuminating the Earth. There is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded

**Active sensors**, on the other hand, provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets. Synthetic aperture radar (SAR) is an example of active sensor.

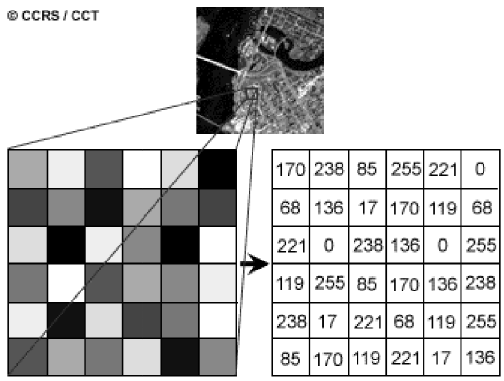



## 5.7 Characteristics of Images

Electromagnetic energy may be detected either photographically or electronically. The photographic process uses chemical reactions on the surface of light-sensitive film to detect and record energy variations. It is important to distinguish between the terms images and photographs in remote sensing. An image refers to any pictorial representation, regardless of what wavelengths or remote sensing device has been used to detect and record the electromagnetic energy.

*A photograph refers specifically to images that have been detected as well as recorded on photographic film*. The black and white photo here was taken in the visible part of the spectrum. Photos are normally recorded over the wavelength range from 0.3 µm to 0.9 µm - the visible and reflected infrared. Based on these definitions, we can say that *all photographs are images, but not all images are photographs*. Therefore, unless we are talking specifically about an image recorded photographically, we use the term image.

A photograph could also be represented and displayed in a digital format by subdividing the image into small equal-sized and shaped areas, called picture elements or pixels, and representing the brightness of each area with a numeric value or digital



number. Indeed, that is exactly what has been done to the photo to the left. In fact, using the definitions we have just discussed, this is actually a digital image of the original photograph! The photograph was scanned and subdivided into pixels with each pixel assigned a digital number representing its relative brightness. The computer displays each digital value as different brightness levels

The information from a narrow wavelength range is gathered and stored in a channel, also sometimes referred to as a band. This information is combined and displayed digitally using the three primary colours (blue, green, and red). The data from each channel is represented as one of the primary colours and, depending on the relative brightness (i.e. the digital value) of each pixel in each channel, the primary colours combine in different proportions to represent different colours. When we use this method to display a single channel or range of wavelengths, we are actually displaying that channel through all three primary colours.

## 5.8 Satellites and Sensors

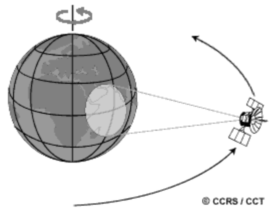
### 5.8.1 Sensor Platform

In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable platform removed from the target or surface being observed. Platforms for remote sensors may be situated on the ground, on an aircraft or balloon (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside of the Earth's atmosphere. Ground-based sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors. Aerial platforms are primarily stable wing aircraft, although helicopters are occasionally used. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.

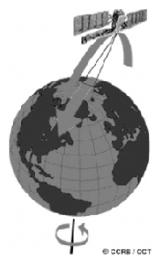
In space, remote sensing is sometimes conducted from the space shuttle or, more commonly, from satellites. Satellites are objects which revolve around another object - in this case, the Earth. For example, the moon is a natural satellite, whereas man-made satellites include those platforms launched for remote sensing, communication, and telemetry (location and navigation) purposes. Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis. Cost is often a significant factor in choosing among the various platform options.

## 5.8.2 Satellite Characteristics: Orbits and Swaths

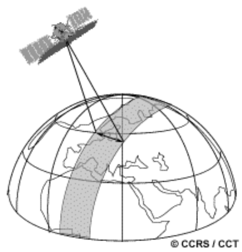
Although ground-based and aircraft platforms may be used, satellites provide a great deal of the remote sensing imagery commonly used today. Satellites have several unique characteristics which make them particularly useful for remote sensing of the Earth's surface.




The path followed by a satellite is referred to as its **orbit**. Satellite orbits are matched to the capability and objective of the sensor(s) they carry. Orbit selection can vary in terms of altitude (their height above the Earth's surface) and their orientation and rotation relative to the Earth. Satellites at very high altitudes, which view the same portion of the Earth's surface at all times have geostationary orbits. These geostationary satellites, at altitudes of approximately 36,000 kilometers, revolve at speeds which match the rotation of the Earth so they seem stationary, relative to the Earth's surface. This allows the satellites to observe and collect information continuously over specific areas. Weather and communications satellites commonly have these types of orbits. Due to their high altitude, some geostationary weather satellites can monitor weather and cloud patterns covering an entire hemisphere of the Earth.



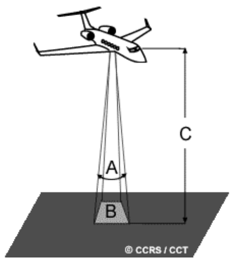
Many remote sensing platforms are designed to follow an orbit (basically north-south) which, in conjunction with the Earth's rotation (west-east), allows them to cover most of the Earth's surface over a certain period of time. These are near- polar orbits, so named for the inclination of the orbit relative to a line running between the North and South poles. Many of these satellite orbits are also ***sun-synchronous*** such that they cover each area of the world at a constant local time of day called local sun time. At any given latitude, the position of the sun in the sky as the satellite passes overhead will be the same within the same season. This ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days. This is an important factor for monitoring changes between images or for mosaicking adjacent images together, as they do not have to be corrected for different illumination conditions.




As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the swath. Imaging swaths for space borne sensors generally vary between tens and hundreds of kilometers wide. As the satellite orbits the Earth from pole to pole, its east-west position wouldn't change if the Earth didn't rotate. However, as seen from the Earth, it seems that the satellite is shifting westward because the Earth is rotating (from west to east) beneath it. This apparent movement allows the satellite swath to cover a new area with each consecutive pass. The satellite's orbit and the rotation of the Earth work together to allow complete coverage of the Earth's surface, after it has completed one complete cycle of orbits.

Starting with any randomly selected pass in a satellite's orbit, an orbit cycle will be completed when the satellite retraces its path, passing over the same point on the Earth's surface directly below the satellite (called the nadir point) for a second time. The exact length of time of the orbital cycle will vary with each satellite. The interval of time required for the satellite to complete its orbit cycle is not the same as the "revisit period". Using steerable sensors, an satellite-borne instrument can view an area (off-nadir) before and after the orbit passes over a target, thus making the 'revisit' time less than the orbit cycle time. The revisit period is an important consideration for a number of monitoring applications, especially when frequent imaging is required (for example, to monitor the spread of an oil spill, or the extent of flooding). In near-polar orbits, areas at high latitudes will be imaged more frequently than the equatorial zone due to the increasing overlap in adjacent swaths as the orbit paths come closer together near the poles.

### 5.8.3 Spatial Resolution, Pixel Size, and Scale




Sensors onboard platforms far away from their targets, typically view a larger area, but cannot provide great detail. The detail discernible in an image is dependent on the spatial resolution of the sensor and refers to the size of the smallest possible feature that can be detected. Spatial resolution of passive sensors depends primarily on their Instantaneous Field of View (IFOV).

The IFOV is the angular cone of visibility of the sensor (A) and determines the area on the Earth's surface which is "seen" from a given altitude at one particular moment in time (B). The size of the area viewed is determined by multiplying the IFOV by the distance from the ground to the sensor (C). This area on the ground is called the resolution cell and determines a sensor's maximum spatial resolution.

Most remote sensing images are composed of a matrix of picture elements, or pixels, which are the smallest units of an image. Image pixels are normally square and represent a certain area on an image. It is important to distinguish between pixel size and spatial resolution - they are not interchangeable. If a sensor has a spatial resolution of 20 meters and an image from that sensor is displayed at full resolution, each pixel represents an area of 20m x 20m on the ground. In this case the pixel size and resolution are the same. However, it is possible to display an image with a pixel size different than the resolution. Images where only large features are visible are said to have coarse or low resolution. In fine or high resolution images, small objects can be detected.

The ratio of distance on an image or map, to actual ground distance is referred to as scale. If you had a map with a scale of 1:100,000, an object of 1cm length on the map would actually be an object 100,000cm (1km) long on the ground. Maps or images with small "map-to-ground ratios" are referred to as small scale (e.g. 1:100,000), and those with larger ratios (e.g. 1:5,000) are called large scale

### 5.8.4 Spectral Resolution

Different classes of features and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges. Broad classes, such as water and vegetation, can usually be separated using very broad wavelength ranges - the visible and near infrared. Spectral resolution describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as multi-spectral sensors.

Advanced multi-spectral sensors called hyperspectral sensors, detect hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. Their very high spectral resolution facilitates fine discrimination between different targets based on their spectral response in each of the narrow bands

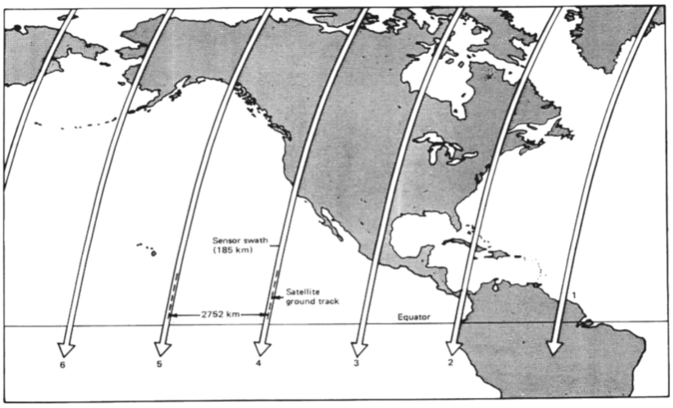
### 5.8.5 Radiometric Resolution


While the arrangement of pixels describes the spatial structure of an image, the radiometric characteristics describe the actual information content in an image. Every time an image is acquired on film or by a sensor, its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution. The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

Imagery data are represented by positive digital numbers which vary from 0 to (one less than) a selected power of 2. This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of power 2 (e.g. 1 bit=2 1=2). The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be $2^8$=256 digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only $2^4$=16 values ranging from 0 to 15 would be available. Thus, the radiometric resolution would be much less. Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data). By comparing a 2-bit image with an 8-bit image, we can see that there is a large difference in the level of detail depending on their radiometric resolutions.

### 5.8.6 Temporal Resolution

The revisit period of a satellite sensor is usually several days. Therefore the absolute temporal resolution of a remote sensing system to image the exact same area at the same viewing angle a second time is equal to this period. However, because of some degree of overlap in the imaging swaths of adjacent orbits for most satellites and the increase in this overlap with increasing latitude, some areas of the Earth tend to be re-imaged more frequently. Also, some satellite systems are able to point their sensors to image the same area between different satellite passes separated by periods from one to




Spacing between adjacent Landsat-4 or -5 orbit tracks at the equator. The earth revolves 2752 km to the east at the equator between passes. (Adapted from NASA diagram.)

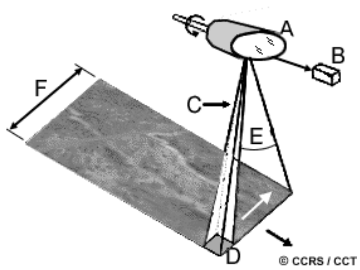
five days. Thus, the actual temporal resolution of a sensor depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap, and latitude.

Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing multi-temporal imagery. By imaging on a continuing basis at different times we are able to monitor the changes that take place on the Earth's surface, whether they are naturally occurring (such as changes in natural vegetation cover or flooding) or induced by humans (such as urban development or deforestation). The time factor in imaging is important when:

- persistent clouds offer limited clear views of the Earth's surface (often in the tropics)
- short-lived phenomena (floods, oil slicks, etc.) need to be imaged
- multi-temporal comparisons are required (e.g. the spread of a forest disease from one year to the next)
- the changing appearance of a feature over time can be used to distinguish it from near- similar features (wheat / maize)

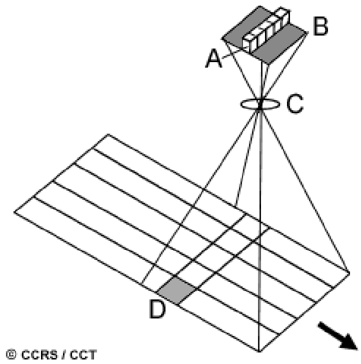
## 5.9 Multispectral Scanning

Many electronic remote sensors acquire data using scanning systems, which employ a sensor with a narrow field of view (i.e. IFOV) that sweeps over the terrain to build up and produce a two-dimensional image of the surface. Scanning systems can be used on both aircraft and satellite platforms and have essentially the same operating principles. A scanning system used to collect data over a variety of different wavelength ranges is called a multispectral scanner (MSS), and is the most commonly used scanning system. There are two main modes or methods of scanning employed to acquire multispectral image data - across-track scanning, and along-track scanning.




**Across-track (whiskbroom) scanners** scan the Earth in a series of lines. The lines are oriented perpendicular to the direction of motion of the sensor platform (i.e. across the swath). Each line is scanned from one side of the sensor to the other, using a rotating mirror (A). As the platform moves forward over the Earth, successive scans build up a two-dimensional image of the Earth´s surface. The incoming reflected or emitted radiation is separated into several spectral components that are detected independently. The UV, visible, near-infrared, and thermal radiation are dispersed into their constituent wavelengths. A bank of internal detectors (B), each sensitive to a specific range of wavelengths, detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing

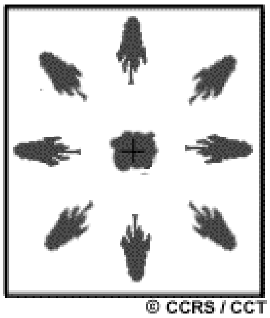
The IFOV (C) of the sensor and the altitude of the platform determine the ground resolution cell viewed (D), and thus the spatial resolution. The angular field of view (E) is the sweep of the mirror, measured in degrees, used to record a scan line, and determines the width of the imaged swath (F). Airborne scanners typically sweep large angles (between 90º and 120º), while satellites, because of their higher altitude need only to sweep fairly small angles (10-20º) to cover a broad region. Because the distance from the sensor to the target increases towards the edges of the swath, the ground resolution cells also become larger and introduce geometric distortions to the images. Also, the length of time the IFOV "sees" a ground resolution cell as the rotating mirror scans (called the dwell time), is generally quite short and influences the design of the spatial, spectral, and radiometric resolution of the sensor.




**Along-track (pushbroom) scanners** also use the forward motion of the platform to record successive scan lines and build up a two-dimensional image, perpendicular to the flight direction. However, instead of a scanning mirror, they use a linear array of detectors (A) located at the focal plane of the image (B) formed by lens systems (C), which are "pushed" along in the flight track direction (i.e. along track). These systems are also referred to as pushbroom scanners, as the motion of the detector array is analogous to the bristles of a broom being pushed along a floor. Each individual detector measures the energy for a single ground resolution cell (D) and thus the size and IFOV of the detectors determines the spatial resolution of the system. A separate linear array is required to measure each spectral band or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded.

Along-track scanners with linear arrays have several advantages over across-track mirror scanners. The array of detectors combined with the pushbroom motion allows each detector to "see" and measure the energy from each ground resolution cell for a longer period of time (dwell time). This allows more energy to be detected and improves the radiometric resolution. The increased dwell time also facilitates smaller IFOVs and narrower bandwidths for each detector. Thus, finer spatial and spectral resolution can be achieved without impacting radiometric resolution. Because detectors are usually solid-state microelectronic devices, they are generally smaller, lighter, require less power, and are more reliable and last longer because they have no moving parts. On the other hand, cross-calibrating thousands of detectors to achieve uniform sensitivity across the array is necessary and complicated

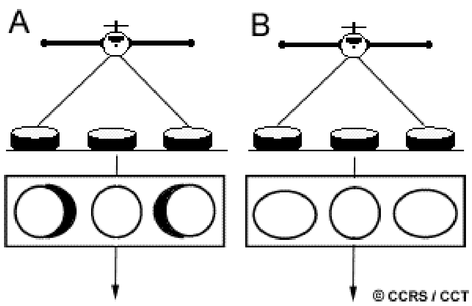
## 5.10 Geometric Distortion in Imagery




Any remote sensing image, regardless of whether it is acquired by a multispectral scanner on board a satellite, a photographic system in an aircraft, or any other platform/sensor combination, will have various geometric distortions. *This problem is inherent in remote sensing, as we attempt to accurately represent the three-dimensional surface of the Earth as a two-dimensional image*. All remote sensing images are subject to some form of geometric distortions, depending on the manner in which the data are acquired. These errors may be due to a variety of factors, including one or more of the following, to name only a few:

- the perspective of the sensor optics,
- the motion of the scanning system,
- the motion and (in)stability of the platform,
- the platform altitude, attitude, and velocity,
- the terrain relief, and
- the curvature and rotation of the Earth.

Along-track scanner, provide an instantaneous "snapshot" view of the Earth from directly overhead. The primary geometric distortion is due to relief displacement. Objects directly below the centre of the sensor(i.e. at the nadir) will have only their tops visible, while all other objects will appear to lean away from the centre of the image such that their tops and sides are visible. If the objects are tall or are far away from the centre of the photo, the distortion and positional error will be larger.




Images from across-track scanning systems exhibit two main types of **geometric distortion**. They too exhibit relief displacement (A), similar to aerial photographs, but in only one direction parallel to the direction of scan. There is no displacement directly below the sensor, at nadir. As the sensor scans across the swath, the top and side of objects are imaged and appear to lean away from the nadir point in each scan line. Again, the displacement increases, moving towards the edges of the swath. Another distortion (B) occurs due to the rotation of the scanning optics. As the sensor scans across each line, the distance from the sensor to the ground increases further away from the centre of the swath. Although the scanning mirror rotates at a constant speed, the IFOV of the sensor moves faster (relative to the ground) and scans a larger area as it moves closer to the edges. This effect results in the compression of image features at points away from the nadir and is called **tangential scale distortion**.

All images are susceptible to geometric distortions caused by variations in platform stability including changes in their speed, altitude, and attitude (angular orientation with respect to the ground) during data acquisition. These effects are most pronounced when using aircraft platforms and are alleviated to a large degree with the use of satellite platforms, as their orbits are relatively stable, particularly in relation to their distance from the Earth. However, the eastward rotation of the Earth, during a satellite orbit causes the sweep of scanning systems to cover an area slightly to the west of each previous scan. The resultant imagery is thus skewed across the image. This is known as **skew distortion** and is common in imagery obtained from satellite multispectral scanners

## 5.11 Land Observation Satellites/Sensors

**LANDSAT**

The first satellite designed specifically to monitor the Earth's surface, Landsat-1, was launched by NASA in 1972. Initially referred to as ERTS-1, (Earth Resources Technology Satellite), Landsat was designed as an experiment to test the feasibility of collecting multi-spectral Earth observation data from an unmanned satellite platform.

Landsat's success is due to several factors, including: a combination of sensors with spectral bands tailored to Earth observation; functional spatial resolution; and good areal coverage (swath width and revisit period). The long lifespan of the program has provided a voluminous archive of Earth resource data facilitating long term monitoring and historical records and research. All Landsat satellites are placed in near-polar, sun-synchronous orbits. The first three satellites (Landsat 1-3) are at altitudes around 900 km and have revisit periods of 18 days while the later satellites are at around 700 km and have revisit periods of 16 days. All Landsat satellites have equator crossing times in the morning to optimize illumination conditions.

The most popular instrument in the early days of Landsat was the MultiSpectral Scanner (MSS) and later the Thematic Mapper (TM). Each of these sensors collected data over a swath width of 185 km, with a full scene being defined as 185 km x 185 km.

Routine collection of MSS data ceased in 1992, as the use of TM data, starting on Landsat 4, superseded the MSS. The TM sensor provides several improvements over the MSS sensor including: higher spatial and radiometric resolution; finer spectral bands; seven as opposed to four spectral bands; and an increase in the number of detectors per band (16 for the non- thermal channels versus six for MSS). Sixteen scan lines are captured simultaneously for each non-thermal spectral band (four for thermal band), using an oscillating mirror which scans during both the forward (west-to-east) and reverse (east-to-west) sweeps of the scanning mirror. This difference from the MSS increases the dwell time and improves the geometric and radiometric integrity of the data. Spatial resolution of TM is 30 m for all but the thermal infrared band which is 120 m. All channels are recorded over a range of 256 digital numbers (8 bits). The accompanying table outlines the spectral resolution of the individual TM bands and some useful applications of each.

| Band No. | Wavelength Interval (µm) | Spectral Response | Resolution (m) | Principal Applications |
|---|---|---|---|---|
| 1 | 0.45 - 0.52 | Blue-Green | 30 | Coastal Water Mapping, Soil Vegetation differentiation, deciduous/coniferous differentiation |
| 2 | 0.52 - 0.60 | Green | 30 | Green reflectance by healthy vegetation |
| 3 | 0.63 - 0.69 | Red | 30 | Chlorophyll absorption for plant specifies differentiation |
| 4 | 0.76 - 0.90 | Near IR | 30 | Biomass surveys, water body delineation |
| 5 | 1.55 - 1.75 | Mid-IR | 30 | Vegetation moisture measurement, snow cloud differentiation |
| 6 | 10.40 - 12.50 | Thermal IR | 120 | Plant heat stress measurement, other thermal mapping |
| 7 | 2.08 - 2.35 | Mid-IR | 30 | Hydrothermal mapping |

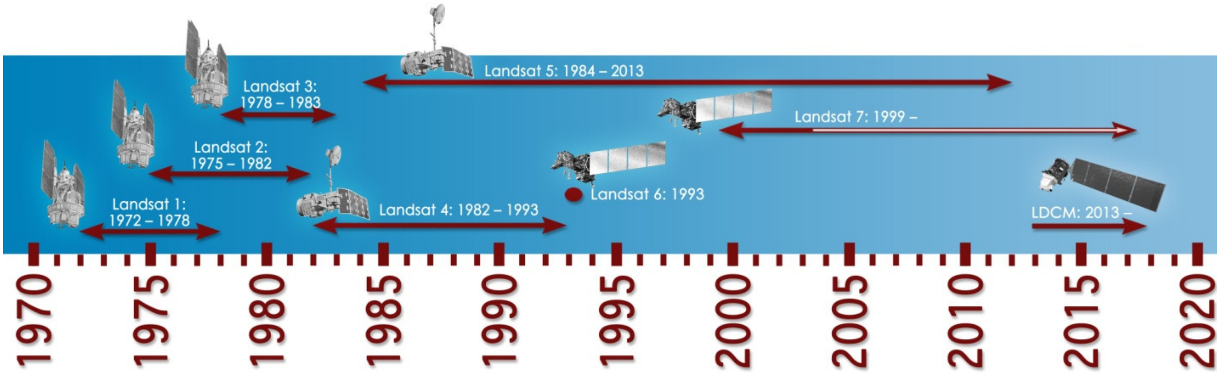



Fig. The Landsat Satellite programme timeline.

Landsat 7 is the most accurately calibrated Earth-observing satellite, i.e., its measurements are extremely accurate when compared to the same measurements made on the ground. Landsat 7's sensor has been called "the most stable, best characterized Earth observation instrument ever placed in orbit." Landsat 7's rigorous calibration standards have made it the validation choice for many coarse-resolution sensors.

The excellent data quality, consistent global archiving scheme, and reduced pricing ($600) of Landsat 7 led to a large increase of Landsat data users. In October 2008 USGS made all Landsat 7 data free to the public (all Landsat data were made free in January 2009 leading to a 60-fold increase of data downloads).

**Orbit**

The orbit of Landsat 7 is repetitive, circular, Sun-synchronous, and near polar at a nominal altitude of 705 km (438 miles) at the Equator. The spacecraft crosses the Equator from north to south on a descending orbital node from between 10:00 AM and 10:15 AM on each pass. Circling the Earth at 7.5 km/sec, each orbit takes nearly 99 minutes. The spacecraft completes just over 14 orbits per day, covering the entire Earth between 81 degrees north and south latitude every 16 days. The Figure illustrates Landsat's orbit characteristics.

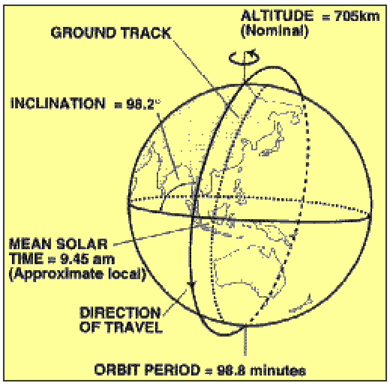



Fig. Landsat Orbit

## Swathing Pattern

Landsat 7 orbits the Earth in a preplanned ground track as illustrated in the Figure . The ETM+ sensor onboard the spacecraft obtains data along the ground track at a fixed width or swath as depicted in Figure. The 16-day Earth coverage cycle for Landsat 7 is known as the swathing pattern of the satellite. for daytime acquisitions, the adjacent swath to the west of a previous swath is traveled by Landsat 7 one week later (and the adjacent swath to the east occurred one week earlier and will recur nine days later). After familiarization with the data acquisition cycle or swathing pattern, it becomes quite straight forward to select Landsat 7 scenes or subintervals required for a specific project.

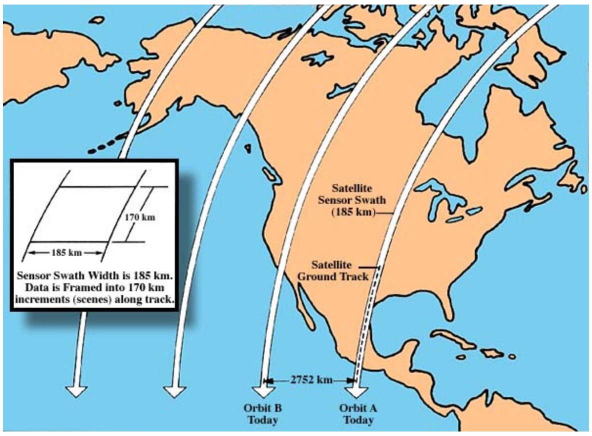



Fig. ETM+ Swath

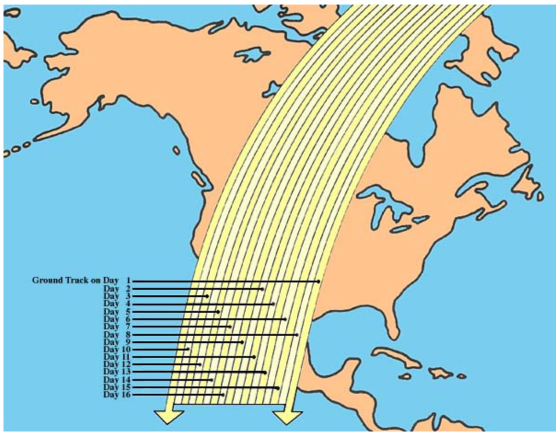



Fig. ETM+ Swath Pattern

Table shows the amount of sidelap from 0 to 80 degrees latitude in 10 degree increments. At the Equator, adjacent swaths overlap at the edges by 7.3 percent. Moving from the Equator toward either pole, this sidelap increases because the fixed 185 km swath width. The following table shows the amount of sidelap from 0 to 80 degrees latitude in 10 degree increments.

**Table: Image Sidelap of Adjacent Swaths**

| Latitude (degrees) | Image Sidelap (%) |
|---|---|
| 0 | 7.3 |
| 10 | 8.7 |
| 20 | 12.9 |
| 30 | 19.7 |
| 40 | 29.0 |
| 50 | 40.4 |

| | |
|---|---|
| 60 | 53.6 |
| 70 | 68.3 |
| 80 | 83.9 |

At the Equator, adjacent swaths overlap at the edges by 7.3 percent. Moving from the Equator toward either pole, this sidelap increases because the fixed 185 km swath width.

**The Worldwide Reference System**

The standard worldwide reference system as defined for Landsat 4 and 5 was preserved for Landsat 7. The WRS indexes orbits (paths) and scene centers (rows) into a global grid system (daytime and night time) comprising 233 paths by 248 rows.

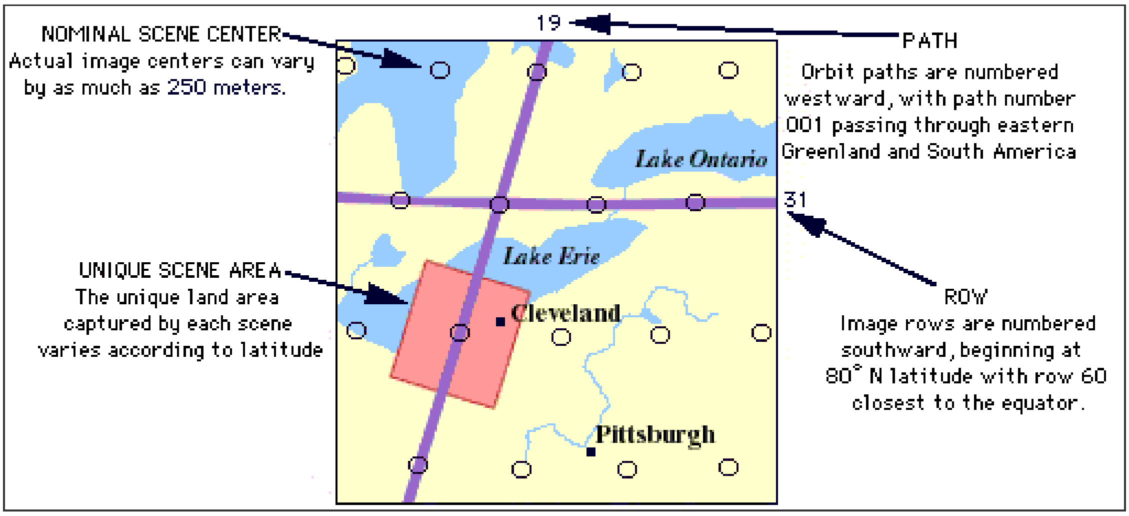



Fig. WRS Path/Row Numbering Scheme

The term row refers to the latitudinal center line across a frame of imagery along any given path. As the spacecraft moves along a path, the ETM+ scans the terrain below. During ground processing, the continuous data stream or subinterval is framed into individual scenes each 23.92 seconds of spacecraft to create 248 rows per complete orbit. The rows have been assigned in such a way the row 60 coincides with the Equator (descending node). Row one of each path starts at 80° 47' N and the numbering increases southward to latitude 81° 51' S (row 122). Then, beginning with row 123, the row numbers ascend northward, cross the Equator (row 184) and continue to latitude 81° 51' N (row 246). Row 248 is located at latitude 81° 22' N, whereupon the next path begins. The Landsat satellites are not placed in a true polar orbit but rather a near polar orbit which means the path/row numbers do not coincide with latitudes 90° north and south.

Successive orbits and spacecraft attitude are controlled to assure minimal variation to either side from the intended ground track and framing of scene centers is controlled through LPS processing so that successive images of a specific scene or scenes can be registered for comparison purposes.

Landsat 7 and Terra were launched and injected into identical 705 kilometer, sun-synchronous orbits in 1999. This same day orbit configuration will space the satellites ideally 15 minutes apart (i.e. equatorial crossing times of 10:00 to 10:15 AM for Landsat 7 and 10:30 for Terra). A multispectral data set having both high (30 meter) and medium to coarse (250 to 1000 meter) spatial resolution will thus be acquired on a global basis repetitively and under nearly identical atmospheric and plant physiological conditions.

**Scientific Theory of Measurements**

The Landsat-7 system is designed to collect 7 bands or channels of reflected energy and one channel of emitted energy. A well calibrated ETM+ enables one to convert the raw solar energy collected by the sensor to absolute units of radiance. Radiance refers to the flux of energy (primarily irradiant or incident energy) per solid angle leaving a unit surface area in a given direction. Radiance corresponds to brightness in a given direction toward the sensor, and is often confused with reflectance, which is the ratio of reflected versus total power energy. Radiance is what is measured at the sensor and is somewhat dependent on reflectance.

The eight bands of ETM+ data are used to discriminate between Earth surface materials through the development of spectral signatures. For any given material, the amount of emitted and reflected radiation varies by wavelength. These variations are used to establish the signature reflectance fingerprint for that material. The basic premise of using spectral signatures is that similar objects or classes of objects will have similar interactive properties with electrmagnetic radiation at any given wavelength. Conversely, different objects will have different interactive properties. A plot of the collective interactive mechanisms (scattering, emittance, reflectance, and absorption) at wavelengths on the electromagnetic spectrum should, according to the basic premise, result in a unique curve, or spectral signature, that is diagnostic of the object or class of objects. A signature on such a graph can be defined as reflectance as a function of wavelength. Four such signatures are illustrated in Figure below.

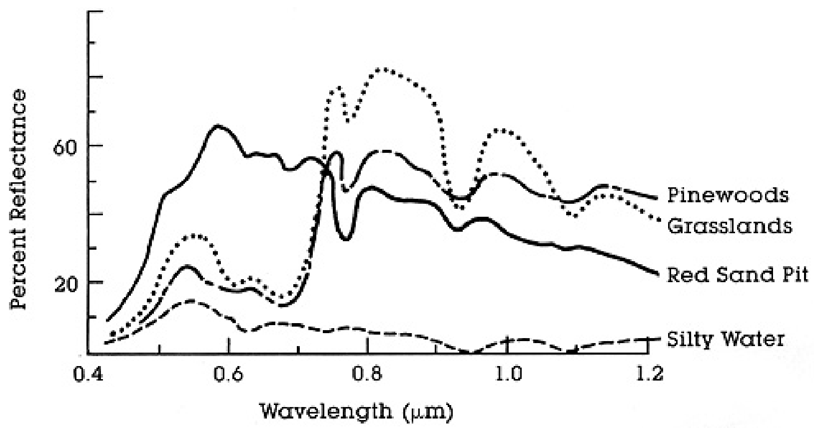



Fig. Spectral Reflectance Curves of Four Different Targets

ETM+ data can be used to plot spectral signatures although the data are limited to eight data points within the spectral range of .45 to 12.5 µm. More useful is plotting the ETM+ spectral signatures in multi-dimensional feature space. The four surface materials shown in above are plotted below using just two of the ETM+ spectral bands. (GL representing grasslands, PW representing pinewoods, RS representing red sand, and SW representing silty water) may be characterized as distinct.

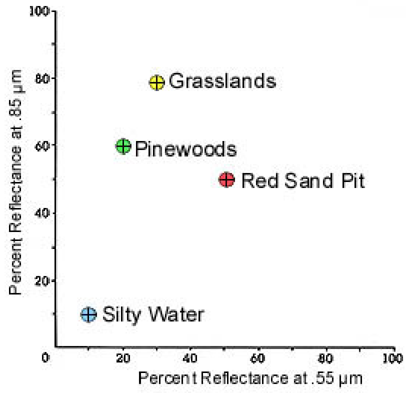



Fig. Spectral Separability with two Bands.

Each of the materials has been plotted according to its percent reflectance for two of the wavelengths or spectral bands. When more than two wavelengths are involved, the plots in multi-dimensional space tend to increase the separability among different materials. This spectral separation forms the basis for multispectral analysis where the goal is to define the bounds of accurately identified data point clusters.

**Spatial Characteristics**

Spatial resolution is the resolving power of an instrument needed for the discrimination of features and is based on detector size, focal length, and sensor altitude. More commonly used descriptive terms for spatial resolution are ground sample distance (GSD) and instantaneous field of view (IFOV). The IFOV, or pixel size, is the area of terrain or ocean covered by the field of view of a single detector. The ETM+ ground samples at three different resolutions; 30 meters for bands 1-5, and 7, 60 meters for band 6, and 15 meters for band 8.

A standard WRS scene covers a land area approximately 185 kilomenters (across-track) by 180 kilometers (along-track). A more precise estimate for actual scene size can be calculated from the 0R product image dimensions.

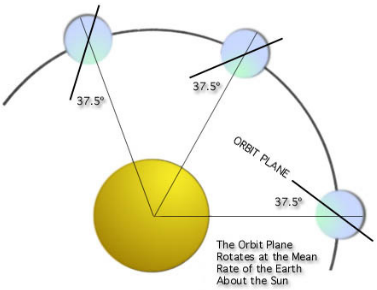
| **Image Dimensions for a Landsat 7 0.R. Product** | | | |
|---|---|---|---|
| Band Number | Resolution (meters) | Samples (columns) | Data Lines (rows) |
| 1-5, 7 | 30 | 6,600 | 6000 |
| 6 | 60 | 3,300 | 3,000 |
| 8 | 15 | 13,200 | 12,000 |

**Temporal Characteristics**

**Orbit Times**

The Landsat 7 orbit is sun synchronous. Consequently, the geometric relationship between the orbit's descending, or southbound, track and the mean projection of the sun onto the equatorial plane will remain nearly constant throughout the mission. As a result, the mean sun time at each individual point in the orbit will remain fixed, and in fact, all points at a given latitude on descending passes will have the same mean sun time. For Landsat 7, the nominal mean sun time of the descending node at the Equator is 10:00 AM.

A fixed mean sun time does not mean that local clock time will remain fixed for all points at a given latitude, since discrete time zones are used to determine local time throughout the world. The local time that the satellite crosses over a given point at latitudes other than at the equator also varies due to the time the satellite takes to reach the given point (nearly 99 minutes are required for one complete orbit), and the time zones crossed by the satellite relative to its equatorial crossing point.




While the orbit of Landsat 7 allows the spacecraft to pass over the same point on the Earth at essentially the same local time every 16 days, changes in sun elevation angle, cause variations in the illumination conditions under which imagery is obtained. These changes are due primarily to the north-south seasonal position of the sun relative to the Earth.

The actual effects of variations in sun elevation angle on a given scene are very dependent on the scene area itself. The reflectance of sand, for example, is significantly more sensitive to variations in sun elevation angle than most types of vegetation. Atmospheric effects also affect the amount of radiant energy reaching the Landsat sensor, and these too can vary with time of year. Because of such factors, each general type of scene area must be evaluated individually to determine the range of sun elevation angles over which useful imagery can be realized.

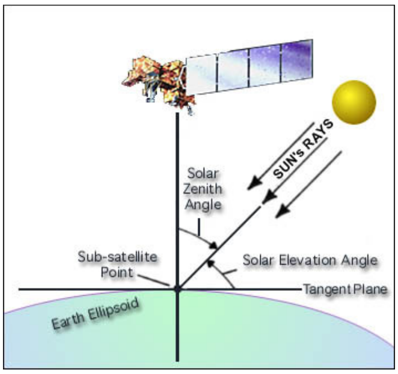



Fig. Sun Elevation Angle

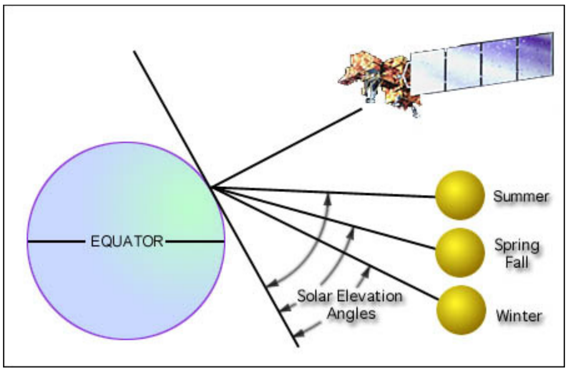



Fig. Effects of Seasonal Changes on Solar Elevation Angle

Depending on the scene area, it may or may not be possible to obtain useful imagery at lower sun elevation angles. At sun elevation angles greater than 30 degrees, one should expect that all image data can be fully exploited. A sun elevation angle of 15 degrees, below which no imagery is acquired, has been established for the Landsat 7 mission.

Repeat imaging opportunities for a given scene occur every 16 days. This does not mean every scene is collected every 16 days. Duty cycle constraints, limited onboard recorder storage, the use of cloud cover predictions make this impossible. The goal, however, is to collect as much imagery as possible over dynamically changing landscapes. Deserts do not qualify and thus are imaged once or twice per year. Temperate forests and agricultural regions qualify as dynamic and are imaged more frequently.

**IRS**

Indian Remote Sensing (IRS) satellite system was commissioned with the launch of IRS-1A, in 1988. With ten satellites in operation, IRS is the largest civilian remote sensing satellite constellation in the world providing imageries in a variety of spatial resolutions, spectral bands and swaths. The data is used for several applications covering agriculture, water resources, urban development, mineral prospecting, environment, forestry, drought and flood forecasting, ocean resources and disaster management.

The Indian Remote Sensing (IRS) satellite series, combines features from both the Landsat MSS/TM sensors and the SPOT HRV sensor. Some popular IRS sensors are listed in the following table:

| Sensor | Resolution (m) | Swath Width (km) | Sensor Channels | Spectral Bands (µm) |
|---|---|---|---|---|
| Linear Imaging Self-Scanning System I (LISS-I) | 72 | 148 | LISS-I-1<br>LISS-I-2<br>LISS-I-3<br>LISS-I-4 | 0.45-0.52 (blue)<br>0.52-0.59 (green)<br>0.62-0.68 (red)<br>0.77-0.86 (near IR) |
| Linear Imaging Self-Scanning System II (LISS-II) | 36 | 74 | LISS-II-1<br>LISS-II-2<br>LISS-II-3<br>LISS-II-4 | 0.45-0.52 (blue)<br>0.52-0.59 (green)<br>0.62-0.68 (red)<br>0.77-0.86 (near IR) |
| Linear Imaging Self-Scanning System III (LISS-III) | 23 | 142 | LISS- III-1<br>LISS- III-2<br>LISS- III -3<br>LISS- III-4 | 0.45-0.52 (blue)<br>0.52-0.59 (green)<br>0.62-0.68 (red)<br>0.77-0.86 (near IR) |
| | 50 | 148 | LISS-III-5 | 1.55-1.70 (mid-IR) |
| | 6 | 70 | PAN | 0.5-0.75 |
| High Resolution Linear Imaging Self-Scanning System IV (LISS-IV) | 5.8 | 24 - 70 | LISS-IV-2<br>LISS-IV-3<br>LISS-IV-4 | 0.52-0.59 (green)<br>0.62-0.68 (red)<br>0.77-0.86 (near IR) |
| Wide Field Sensor (WiFS) | 188 | 774 | WiFS-1<br>WiFS-2 | 0.62-0.68 (red)<br>0.77-0.86 (near IR) |
| Advanced Wide Field Sensor (AWiFS) | 56-70 | 370-740 | AWiFS-1<br>AWiFS-2<br>AWiFS-3<br>AWiFS-4 | 0.52-0.59 (green)<br>0.62-0.68 (red)<br>0.77-0.86 (near IR)<br>1.55-1.70 (mid-IR) |

| | | | | |
|---|---|---|---|---|
| *Source: http://uregina.ca/piwowarj/Satellites/IRS.html* | | | | |
| CARTOSAT-1 | 2.5 | 30 | Two PAN cameras | 0.5-0.85 |
| CARTOSAT-2 | <1m | 9.6 | PAN camera | 0.5-0.85 |
| *Source: NRSC/Antrix Corporation Information Brochure* | | | | |

## 5.12 Image Classification

Classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, then the pixel is assigned to the class that corresponds to those criteria.

For the first part of the classification process, the computer system must be trained to recognize patterns in the data. Training is the process of defining the criteria by which these patterns are recognized. The result of training is a set of signatures, which are criteria for a set of proposed classes. There are two ways of classify pixels into different categories:

- Unsupervised
- Supervised

## 5.13 The Classification Process

i. **Pattern Recognition** In a computer system, while performing spectral pattern recognition, statistics are derived from the spectral characteristics of all pixels in an image. Then, the pixels are sorted based on mathematical criteria. The classification process breaks down into two parts: training and classifying (using a decision rule).

ii. **Training** First, the computer system must be trained to recognize patterns in the data. Training is the process of defining the criteria by which these patterns are recognized (Hord, 1982). Training can be performed with either a supervised or an unsupervised method, as explained below.

- **Supervised Training**

Supervised training is closely controlled by the analyst. In this process, you select pixels that represent patterns or land cover features that you recognize, or that you can identify with help from other sources, such as aerial photos, ground truth data, or maps. Knowledge of the data, and of the classes desired, is required before classification. By identifying patterns, you can instruct the computer system to identify pixels with similar characteristics.

- **Unsupervised Training**

Unsupervised training is more computer-automated. It enables you to specify some parameters that the computer uses to uncover statistical patterns that are inherent in the data. These patterns are simply clusters of pixels with similar spectral characteristics.

iii. **Signatures** The result of training is a set of signatures that defines a training sample or cluster. Each signature corresponds to a class, and is used with a decision rule to assign the pixels in the image file to a class. Signatures can be parametric (based on statistics parameter) or non-parametric (based on feature space i.e. polygon or rectangles).

iv. **Decision Rule** After the signatures are defined, the pixels of the image are sorted into classes based on the signatures by use of a classification decision rule. The decision rule is a mathematical algorithm that, using data contained in the signature, performs the actual sorting of pixels into distinct class values.

- **Parametric Decision Rule**

A parametric decision rule is trained by the parametric signatures. These signatures are defined by the mean vector and covariance matrix for the data file values of the pixels in the signatures. When a parametric decision rule is used, every pixel is assigned to a class since the parametric decision space is continuous.

- **Nonparametric Decision Rule**

If a pixel is located within the boundary of a nonparametric signature, then this decision rule assigns the pixel to the signature's class. Basically, a nonparametric decision rule determines whether or not the pixel is located inside of nonparametric signature boundary.

**v. Output File**

When classifying an image file, the output file is an image file with a thematic raster layer. This file automatically contains class values, class names, color table, statistics, histogram.