REMOTE SENSING

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Course Goals

The course will consist of lectures and laboratory components. The lectures will provide the theoretical foundation that will enable you to understand what does it means by remote sensing and GIS applications, processes and interpretations. Understanding these topics will be stressed throughout, such as the importance environmental investigations. The labs will provide hands-on training in remote sensing data, processes and analysis, aided by the use of software.

A. Principles of Remote Sensing

1. Introduction

1.1 What is Remote Sensing (Definitions)?

"Remote Sensing is the science and art of acquiring information (spectral, spatial, temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. Without direct contact, some means of transferring information through space must be utilized".

"The acquisition and measurement of data/information on some property(ies) of a phenomenon, object, or material by a recording device not in physical intimate contact with the feature(s) under surveillance; techniques involve amassing knowledge pertinent to environments by measuring force fields, electromagnetic radiation or acoustic energy employing cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, seismographs, magnetometers, gravimeters, scintillometers, and other instruments."

"Remote sensing is the collection of information about an object or system without coming into direct physical contact with it".

- That information is nearly always carried by electromagnetic radiation (EMR)
- The detection and recording instruments for this technology are known as ***remote sensors***. The object being monitored is called ***target***.

The concept of remote sensing:

When you view the screen of your computer monitor, you are actively engaged in remote sensing.

A physical quantity (light) emanates from that screen, which is a source of radiation. The radiated light passes over a distance, and thus is "remote" to some extent, until it encounters and is captured by a sensor (your eyes). Each eye sends a signal to a processor (your brain) which records the data and interprets this into information. Several of the human senses gather their awareness of the external world almost entirely by perceiving a variety of signals, either emitted or reflected, actively or passively, from objects that transmit this information in waves or pulses. Thus, one hears disturbances in the atmosphere carried as ***sound waves***, experiences sensations such as heat (either through direct contact or as radiant energy), reacts to ***chemical signals*** from food through taste and smell, is cognizant of certain with the feature(s) under surveillance; techniques involve amassing knowledge pertinent to environments by measuring force fields, electromagnetic radiation, or acoustic energy employing cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, seismographs, magnetometers, gravimeters, scintillometers, and other instruments.

In remote sensing, information transfer is accomplished by use of electromagnetic radiation (EMR). EMR is a form of energy that reveals its presence by the observable effects it produces when it strikes the matter. EMR is considered to span the spectrum of wavelengths from 10^{-10} mm to cosmic rays up to 10^{10} mm, the broadcast wavelengths, which extend from 0.30-15 mm. 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.

1.3 *Why we need remote sensing?*

Unobtrusive, Automated, Useful for extreme conditions, Offers excellent spatial and temporal coverage, Extends our senses, Near Real-time, No “Political” Boundary, Often cost effective

a- Unobtrusive

- No physical contact
- Passive remote sensing does not disturb the object

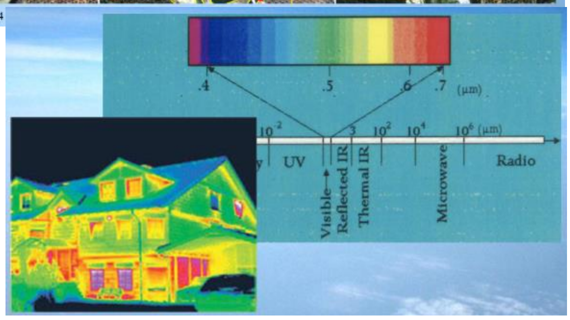
b- Automated

c- Useful for extreme conditions

d- Difficult and dangerous access

e- Offers excellent spatial and temporal coverage

f- Extends our senses



g- Near Real-time

Real-time transmission of data the ground receiving station and the end user

h- No “Political” Boundary

i- Often cost effective

1.4 *Components of remote sensing system:*

Energy Source or Illumination - the first requirement for remote sensing is to have an energy source which provides electromagnetic energy to the target of interest.
Radiation and the Atmosphere - 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.
Interaction with the Target - as the energy travels from its source to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
Recording of Energy by the Sensor - after the energy has been emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation. 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. Sensors may be placed on a ladder, scaffolding, tall building, cherry picker, crane, etc. Aerial platforms are primarily stable wing aircraft, although helicopters

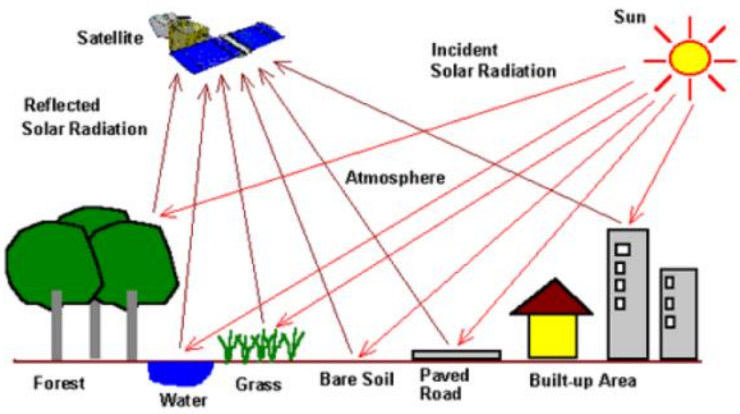
are occasionally used. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.

Transmission, Reception, and Processing - 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).

Interpretation and Analysis - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target, which was illuminated.

Application - 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.

These seven elements comprise the remote sensing process from beginning to end.



1.5 Classification of Remote Sensing Systems

1.5.1 WITH RESPECT TO THE TYPE OF ENERGY RESOURCES

a) Passive Remote Sensing:

Makes use of sensors that detect the reflected or emitted electro-magnetic radiation from natural sources. The sun provides a very convenient source of energy for remote sensing. The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then re-emitted, as it is for thermal infrared wavelengths. *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.

• **Passive sensor** - uses naturally emitted radiation from the sun or the object being observed . In passive remote sensing, the sensor does not emit any signal. It simply measures the ambient signal in the surrounding medium (air, water, ...).

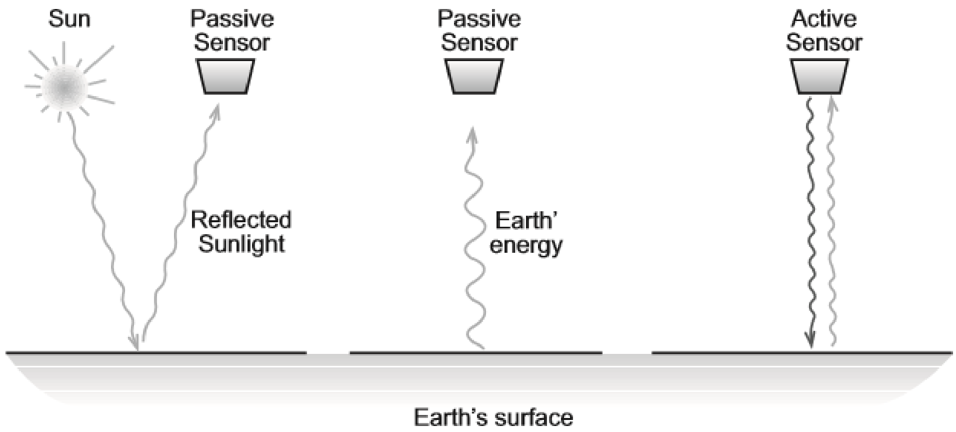
b) Active remote Sensing:

Makes use of sensors that detect reflected responses from objects that are irradiated from artificially generated energy sources, such as radar. Active sensors 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. Some examples of active sensors are a laser fluorosensor and a synthetic aperture radar (SAR).

• **Active Sensor** – illuminates subject from an artificial (on-board) energy source. In active remote sensing, the sensor emits a signal (electromagnetic, sonar, laser ...) and measures the signal returned by the target.

Note:

• Imaging sensor – creates a "picture" by scanning across a linear array of detectors while the array moves through space • Non-imaging sensors = measures along a transect or at a point.



A remote sensing sensor measures reflected or emitted energy. An active sensor has its own source of energy.

1.5.2 WITH RESPECT TO WAVELENGTH REGIONS

Remote Sensing is classified into three types in respect to the wavelength regions

a)Visible and Reflective Infrared Remote Sensing:

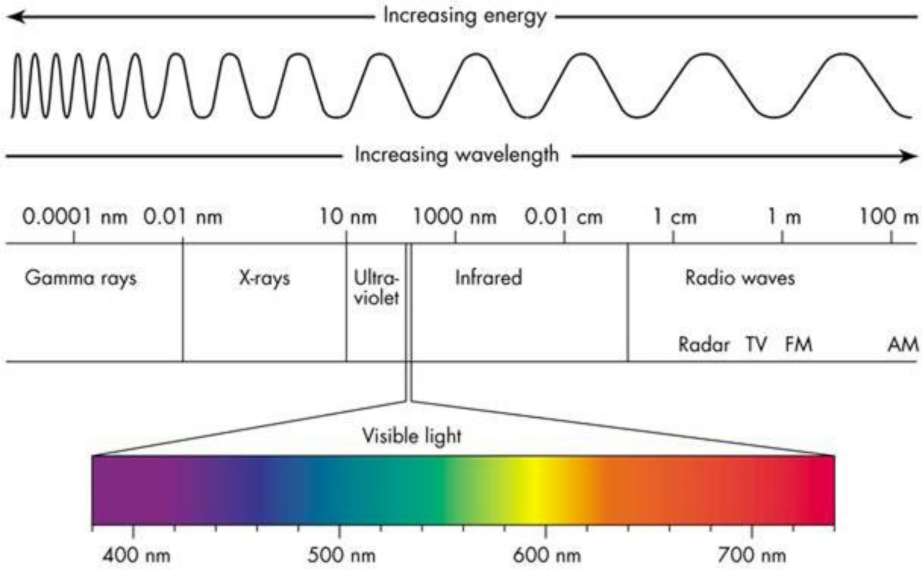
The **energy source** used in the visible and reflective infrared remote sensing is the sun. The sun radiates electro-magnetic energy with a peak wavelength of 0.5 μm. Remote sensing data obtained in the visible and reflective infrared regions mainly depends on the **reflectance** of objects on the ground surface. Therefore, information about objects can be obtained from the spectral reflectance. However laser radar is exceptional because it does not use the solar energy but the laser energy of the sensor.

b)Thermal Infrared Remote Sensing:

The source of radiant energy used in thermal infrared remote sensing is the object itself, because any object with a normal temperature will emit electro-magnetic radiation with a peak at about 10 μm .

c) Microwave remote sensing:

There is two types of microwave remote sensing, passive microwave remote sensing and active remote sensing. In passive microwave remote sensing, the microwave radiation emitted from an object is detected, while the back scattering coefficient is detected in active microwave remote sensing. Active microwave sensors are generally divided into two distinct categories: imaging and non-imaging. The most common form of imaging active microwave sensors is RADAR. RADAR is an acronym for Radio Detection And Ranging, which essentially characterizes the function and operation of a radar sensor. The sensor transmits a microwave (radio) signal towards the target and detects the backscattered portion of the signal. The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or range) to the target.



1.6 Remote Sensing Data Types

Most common types are visible, infrared, thermal, and microwave

- There are many different sensor designs as far as the spatial, spectral resolutions, coverage area and orbits concerned.
- The best type of RS data is determined according the special needs of the project.
- The trade-off between the possible spatial and spectral resolution and temporal coverage. configurations must be considered before choosing a sensor/RS platform.
-

Analog vs. Digital

Analog: Medium is film

- **Benefits: (1)** Easy to view **(2)** High spatial resolution **(3)** Sometimes cost-effective **(4)** Compact
- **Drawbacks (1)** Difficult to transmit remotely **(2)** Difficult to edit after acquisition **(3)** Limited response to light (visible and near infrared wavelengths only) **(4)** Degradation over time can limit archive capabilities

Digital

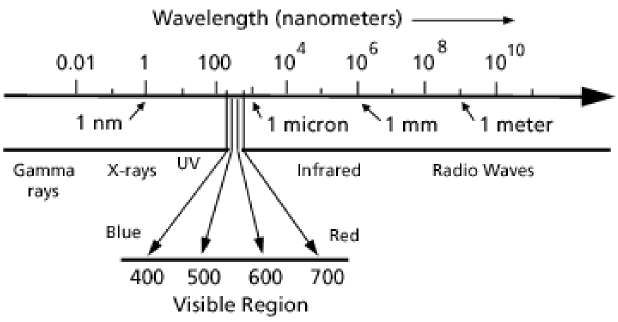
- **Benefits:** (1) Wide variety of detectors (2) Electromagnetic and other types (3) Large amplitude range (4) Data easily transmitted remotely (5) Data easily edited/manipulated/enhanced after acquisition (6) Long-term archive
- **Drawbacks** (1) Storage requirements can be large (2) Reduced spatial resolution in many cases (3) Requires sophisticated equipment and analysis techniques to use

2. Electromagnetic energy and remote sensing

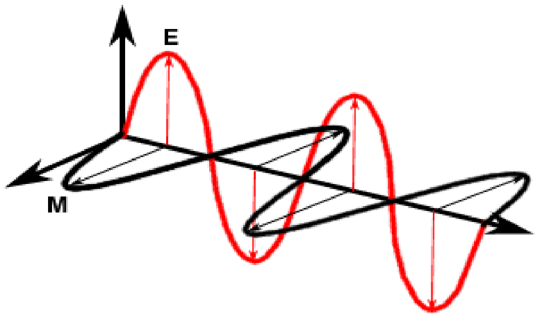
The electromagnetic energy

Definition of electromagnetic radiation

Electromagnetic radiation (EMR) describes the way in which high-frequency energy (visible light, radio waves, heat, ultraviolet rays and X-rays) is transferred from one object to another through space. All this energy radiates in accordance with the wave theory (Maxwell's equations).



Electromagnetic Spectrum



Waves and photons

Electromagnetic (EM) energy can be modelled in two ways: by waves or by energy bearing particles called photons. In the wave model, electromagnetic energy is considered to propagate through space in the form of sine waves. These waves are characterized by electrical (E) and magnetic (M) fields, which are perpendicular to each other. For this reason, the term electromagnetic energy is used.

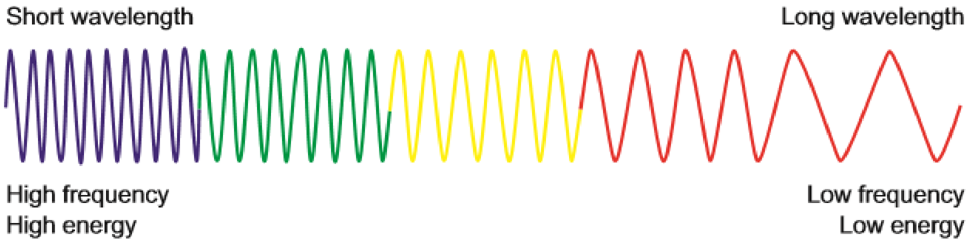
The vibration of both fields is perpendicular to the direction of travel of the wave. Both fields propagate through space at the speed of light c, which is approximately 299,790,000 m/s and can be rounded off to 3·108 m/s.

One characteristic of electromagnetic waves is particularly important for understanding remote sensing. This is the wavelength, λ, that is defined as the distance between successive wave crests (Figure 2.2). Wavelength is measured in metres (m), nanometres (nm = 10−9 m) or micrometres (μm = 10−6 m). (For an explanation of units and prefixes refer to Appendix 1). The frequency, v, is the number of cycles of a wave passing a fixed point over a specific period of time. Frequency is normally measured in hertz (Hz), which is equivalent to one cycle per second. Since the speed of light is constant, wavelength and frequency are inversely related to each other:

$$c = \lambda \times v.$$

In this equation, c is the speed of light (3·108 m/s), λ is the wavelength (m),and v is the frequency (cycles per second, Hz). The shorter the wavelength, the higher the frequency. Conversely, the longer the wavelength, the lower the frequency

Relationship between wavelength, frequency and energy.



Most characteristics of EM energy can be described using the ‘wave’ model as described above. For some purposes, however, EM energy is more conveniently modelled by the particle theory, in which EM energy is composed of discrete units called ‘photons’. This approach is taken when quantifying the amount of energy measured by a multispectral sensor (Section 5.2.1). The amount of energy held by a photon of a specific wavelength is then given by

$Q = h \times \nu = h \times$

c λ

where Q is the energy of a photon (J), h is Planck’s constant (6.6262·10−34 J s), and v the frequency (Hz). From the aforementioned equations it follows that the longer the wavelength, the lower its energy content. Gamma rays (around 10−9 m) are the most energetic, and radio waves (> 1 m) the least energetic. An important consequence for remote sensing is that it is more difficult to measure the energy emitted in longer wavelengths than in shorter wavelengths.

Electromagnetic Wave Properties

- Electric and magnetic fields are orthogonal each other
- Wave travel through space at the velocity of light

Frequencies and wavelengths

$c = \nu\ \lambda$

λ = distance of separation between two wave peaks

ν = number of wave peaks passing in a given time

c = speed of light

Properties of Electromagnetic Radiation EMR

The orientation of the electric field is termed polarization and is important in discussing the operation of remote sensing system

<u>Polarization</u>

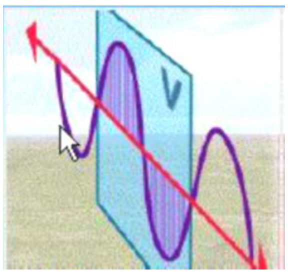
Vertical Polarization (V):

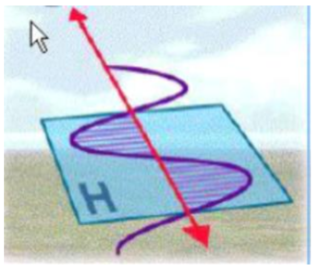
electric vector is perpendicular to the plane of incidence

Horizontal polarization (H):

electric vector is parallel to the plane of incidence

- Radiation from the Sun is unpolarized (at random)
- Man made sources (laser, radar) have polarized radiation





EM Particle Properties

- EM energy is transferred in discrete units (Photons)
- Radiant energy (Q of 1 photon) is proportional to the frequency (ν)

$Q = h\nu$ Joule (J)

h = Plank’s constant = 6.626 x 10-34 Js

1 μm = 10^{-6} m

1 nm = 10^{-9} m

Classification of EM waves

1 µm = 10^{-6} m   1 nm = 10^{-9} m   1 Å = 10^{-10} m

<u>Properties of Electromagnetic Radiation</u>

- Electromagnetic Radiation (EMR): form of energy transport in free space

<u>Generation of EMR</u>

EMR is generated by transformation of energy from other forms, such as:
1. Kinetic heat (friction)
2. Chemical visible (molecular excitation)
3. Electrical radio frequency (dipole antenna)
4. Magnetic microwave (electron tube)

<u>The Electromagnetic Spectrum</u>

All matter with a temperature above absolute zero (K) radiates electromagnetic waves of various wavelengths. The total range of wavelengths is commonly referred to as the electromagnetic spectrum. It extends from gamma rays to radio waves.

Remote sensing operates in several regions of the electromagnetic spectrum. The optical part of the EM spectrum refers to that part of the EM spectrum in which optical phenomena of reflection and refraction can be used to focus the radiation. The optical range extends from X-rays (0.02 µm) through the visible part of the EM spectrum up to and including far-infrared (1000 µm). The ultraviolet (UV) portion of the spectrum has the shortest wavelengths that are of practical use for remote sensing. This radiation is beyond the violet portion of the visible wavelengths. Some of the Earth's surface materials, in particular rocks and minerals, emit or fluoresce visible light when illuminated with UV radiation. The microwave range covers wavelengths from 1 mm to 1 m. The visible region of the spectrum is commonly called 'light'. It occupies a relatively small portion in the EM spectrum. It is important to note that this is the only portion of the spectrum that we can associate with the concept of color. Blue, green and red are known as the primary colors or wavelengths of the visible spectrum. Section 10.2 gives more information on 'light' and perception of 'color'.

The longer wavelengths used for remote sensing are in the thermal infrared and microwave regions. Thermal infrared gives information about surface temperature. Surface temperature can be related, for example, to the mineral composition of rocks or the condition of vegetation. Microwaves can provide information on surface roughness and the properties of the surface such as water content.

- The EMR varies along a frequency spectrum with infinite bounds;
- The frequency range measurable and usable by remote sensors vary within more than 9 orders of magnitude ~[0.1 mm – 100 m];
- The physical principles of interaction of the EMR with targets are different over each spectral range.

<u>The visible spectral domain</u>

- The spectral range over which the EMR is perceptible to the human naked eye is only a tiny portion of the usable overall range;
- The human eye is generally sensitive between the [0.4-0.8] µm range.

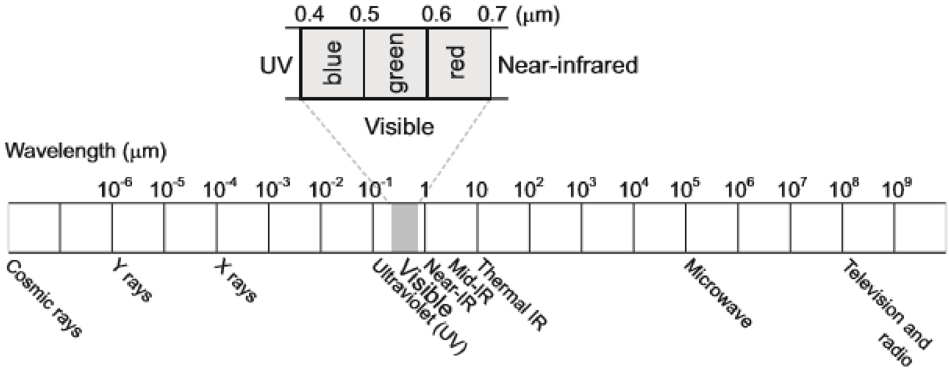
<u>ultraviolet</u>

- **The ultraviolet** zone is mostly opaque due to the atmosphere (for the protection of life on earth), hence is generally unusable for the RS applications;

- **<u>In RS</u>**, it is common practice to use the visible domain with the near-infrared domain since the underlying physical interactions are similar. The EMR in NIR which is not perceptible by the human eye : The VNIR region.

- **EMR used in remote sensing**

Diagram shows those of the EM spectrum which is important in remote sensing

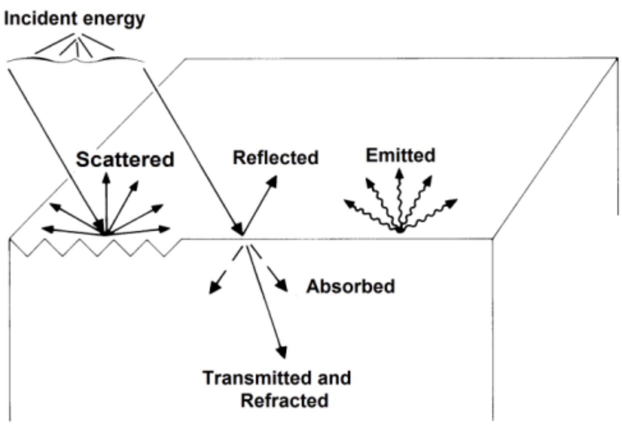


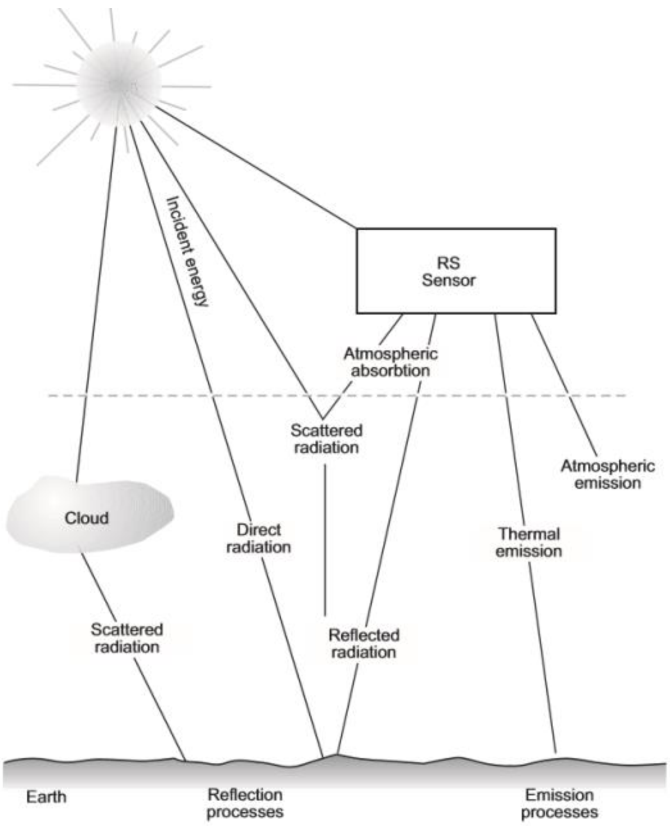
The electro-magnetic spectrum, after

__3- The interaction of the EMR with the target__

The EMR reaching the target enters in some physical interactions with it. The most common processes are the absorption, scattering, reflection, transmission, refraction and reemission. Many other more uncommon processes also exist. The occurrence of these events depend on the type of the target, the physical geometry and the wavelengths involved.

The most important source of energy is theSun. Before the Sun's energy reaches the Earth's surface, three fundamental interactions in the atmosphere are possible: absorption, transmission and scattering. The energy transmitted is then reflected or absorbed by the surface material



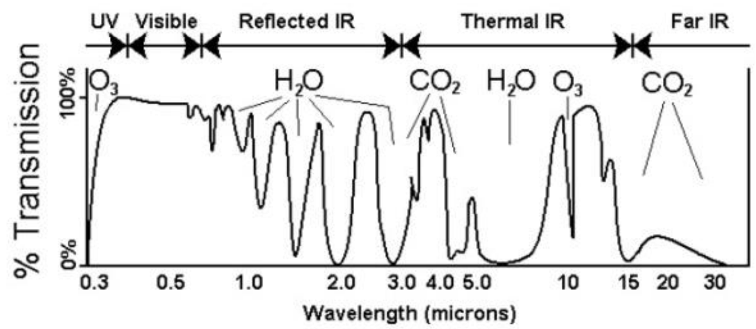


Absorption and transmission

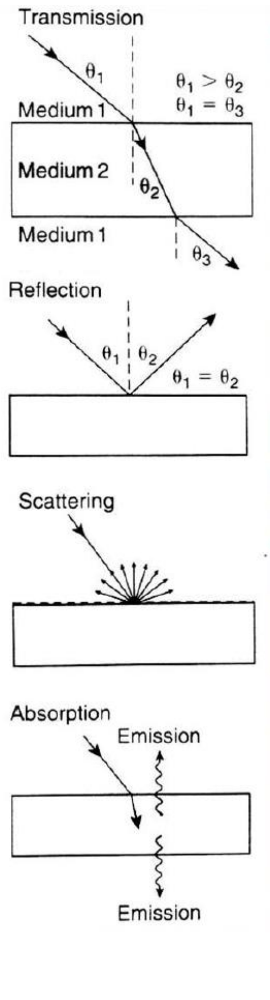
Electromagnetic energy travelling through the atmosphere is partly absorbed by various molecules. The most efficient absorbers of solar radiation in the atmosphere are ozone (O3), water vapour (H2O) and carbon dioxide (CO2). The following figure gives a schematic representation of the atmospheric transmission in the 0–22 µm wavelength region. From this figure it may be seen that about half of the spectrum between 0–22 µm is not useful for remote sensing of the Earth's surface, simply because none of the corresponding energy can penetrate the atmosphere. Only the wavelength regions outside the main absorption bands of the atmospheric gases can be used for remote sensing. These regions are referred to as the atmospheric transmission windows and include:

- A window in the visible and reflected infrared region, between 0.4–2 µm. This is the window where the optical remote sensors operate.
- Three windows in the thermal infrared region, namely two narrow windows around 3 and 5 µm, and at hird, relatively broad,window extending from approximately 8 to 14 µm.

Because of the presence of atmospheric moisture, strong absorption bands are found at longer wavelengths. There is hardly any transmission of energy in the region from 22 µm to 1 mm. The more or less transparent region beyond 1 mm is the microwave region. The solar spectrum as observed both with and without the influence of the Earth's atmosphere is shown in Figure2.8. First of all,look at the radiation curve of the Sun (measured outside the influence of the Earth's atmosphere), which resembles a black body curve at 6000 K. Secondly, compare this curve with the radiation curve as measured at the Earth's surface. The relative dipsinthis curve indicate the absorption by different gases in the atmosphere



Atmospheric windows for power transmission in the micron range. Notice the narrow bands of high transmissivity near one micron.



- ➢ The primary RS windows are depending on the atmospheric molecules.
- ➢ Absorption by these molecules make the atmosphere opaque;
- ➢ Even at the atmospheric windows, the opacity still exist at some d

Effect of the absorption on transmission

- ➢ The absorption of light has an influence on the percentage of light that can be transmitted through a medium;
- ➢ Absorption and transmission are inversely proportional;
    - o Absorbed photons are not able to travel anymore
    - o In case of seawater, the higher the light absorption by dissolved organic matter in the blue (shown by increasing Jerlov water types), the the lower the transmittance of the water.

Atmospheric scattering

Atmospheric scattering occurs when the particles or gaseous molecules present in the atmosphere cause the EM waves to be redirected from their original path. The amount of scattering depends on several factors including the wavelength of the radiation, the amount of particles and gases, and the distance the radiation travels through the atmosphere. For the visible wavelengths, 100% (in case of cloud cover) to 5% (in case of a clear atmosphere) of the energy received by the sensor is directly contributed by the atmosphere. Three types of scattering take place: ***Rayleigh scattering, Mie Scattering and Non-selective scattering.***

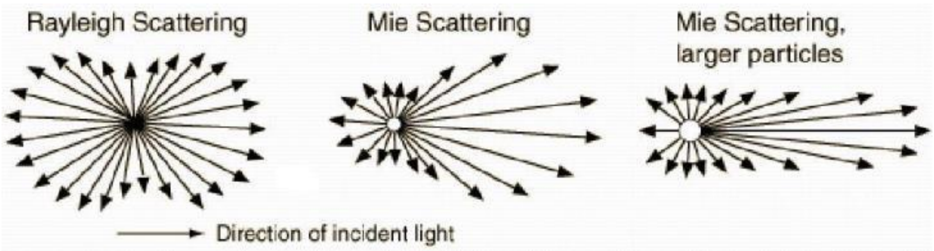
<u>Types of scattering</u>

- Type of scattering is determined according to the wavelength relative to the mean particle particle size of the medium.
- Decrease with increase in radiation wavelenght

Types of scattering encountered in the atmosphere depending on:

<u>1) wavelength</u>, 2) <u>size of the gas molecule</u>, dust particle, and/or water vapor droplet encountered

1- ***<u>Rayleigh</u>*** <u>scattering</u> (particle diameter << wavelength)
2- ***<u>MIE</u>*** <u>scattering</u> (particle diameter ~ wavelength)
3-***<u>Non-selective</u>*** <u>scattering</u> (particle diameter >> wavelength)



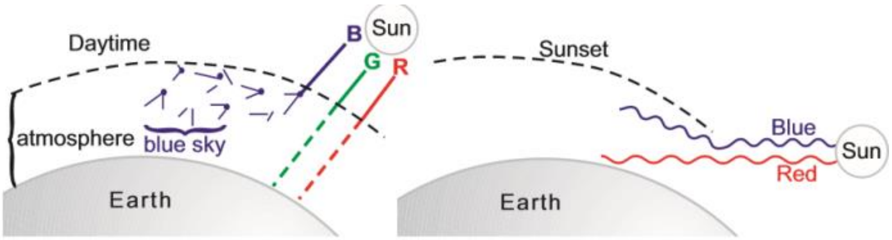
<u>Rayleigh scattering</u>

Rayleigh scattering predominates where electromagnetic radiation interacts with particles that are smaller than the wavelength of the incoming light. Examples of these particles are tiny specks of dust, and nitrogen (NO_2) and oxygen (O_2) molecules. The effect of Rayleigh scattering is inversely proportional to the 4th power of the wavelength: shorter wavelengths are scattered more than longer wavelengths

Rayleigh scattering is caused by particles smaller than the wavelength and is maximal for small wavelengths.

In the absence of particles and scattering, the sky would appear black. At daytime, the Sun rays travel the shortest distance through the atmosphere. In that situation, Rayleigh scattering causes a clear sky to be observed as blue because this is the shortest wavelength the human eye can observe. At sun rise and sunset, however, the Sun rays travel a longer distance through the Earth’s atmosphere before they reach the surface. All the shorter wavelengths are scattered after some distance and only the longer wavelengths reach the Earth’s surface. As a result, the sky appears orange or red

Rayleigh scattering causes us to perceive a blue sky during daytime and a red sky at sunset.



In the context of satellite remote sensing, Rayleigh scattering is the most important type of scattering. It causes a distortion of spectral characteristics of the reflected light when compared to measurements taken on the ground: due to the Rayleigh effect the shorter wavelengths are overestimated. In colour photos taken from high altitudes it accounts for the blueness of these pictures. In general, the Rayleigh scattering diminishes the 'contrast' in photos, and thus has a negative effect on the possibilities for interpretation. When dealing with digital image data (as provided by multispectral scanners) the distortion of the spectral characteristics of the surface may limit the possibilities for image classification.

- Dominant at elevations of 9 to 10 km above the surface;
- Follows a wavelength dependency of ~
- It is the Rayleigh scattering that causes the blue color of the sky and the red color at sunset.
- **<u>I</u>**ntensity is proportional to $1/\lambda^4$
- **<u>Example:</u>**
  <u>UV radiation</u> (0.3μm) is scattered 16 times as readily as red wavelength at 0.6 μm as $(0.6/0.3)^4 = 16$
  Blue radiation (λ= 0.46 μm)   Red radiation (λ= 0.66 μm)
  $(0.66\ \mu m/0.46\ \mu m)^4 = 4.24$
- Scattering increases as the wavelength becomes shorter;
- Blue light is scattered about four times as much as red light and UV light about 16 times as red light;
- Very well known and easily modelable (not dependent on particle size);

<u>MIE scattering</u>

Mie scattering occurs when the wavelength of the incoming radiation is similar in size to the atmospheric particles. The most important cause of Mie scattering are aerosols: a mixture of gases, water vapour and dust. Mie scattering is generally restricted to the lower atmosphere where larger particles are more abundant, and dominates under overcast cloud conditions. Mie scattering influences the entire spectral region from the near-ultraviolet up to and including the near-infrared, and has a greater effect on the larger wavelengths than Rayleigh scattering.

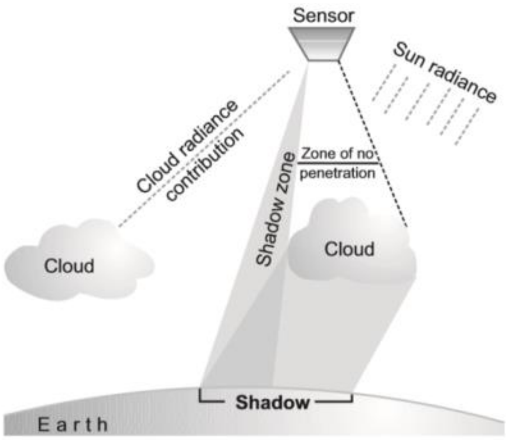
- This type of scattering occurs when (average) the particle diameter is on the same order of magnitude as the wavelength;
- water vapor, smoke particles, salt crystal
- Intensity is proportional to λ^{-4} and λ^{0}
- In some applications, the naturally available particle size ranges are divided into small and large particle categories. Although it helps, this is only an approximation.

Clear atmosphere is a medium for both Raleigh and Mie scattering-their combined influence is between λ^{-7} and λ^{-2}

- Sunset shorter wavelenghts scattered away (blue and green), leaving only red wavelenghts to reach our eyes.

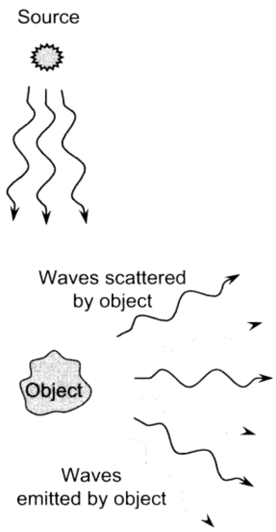
Non-selective scattering

Non-selective scattering occurs when the particle size is much larger than the radiation wavelength. Typical particles responsible for this effect are waterdroplets and larger dust particles. Non-selective scattering is independent of wavelength, with all wavelengths scattered about equally. The most prominent example of non-selective scattering includes the effect of clouds (clouds consist of water droplets). Since all wavelengths are scattered equally, a cloud appears white. Optical remote sensing, therefore, cannot penetrate clouds. Clouds also have a secondary effect: shadowed regions on the Earth's surface.



Direct and indirect effects of clouds in optical remote sensing.

- Non-selective Scattering happends when the diameters of the particles are much larger than the wavelength;
- This type of scattering is not wavelength dependent;
- For example, water droplets (5-to-100 µm in diameter) causes equal scattering at all visible, NIR and mid-IR wavelengths → non-selective;
- Non-selective scattering is the primary cause of atmospheric haze;
- Thanks to its non-selective nature, it is considerably easier to model this type of scattering using mathematical functions.
- Clouds, smog and fog will cause the color of the sky to go from blue to grayish white.



Red Sky at Night

At sunset, solar radiation must traverse a longer through the atmosphere. Viewing a setting sun, the energy reaching the observer is largely depleted of blue radiation, leaving mostly red wavelenghts (Raleigh). Dust and smoke and additional scattering with a wavelenght dependence that increase the red-sky effect (Mie)

Reemission

- Reemission of EMR by objects (targets) is dependent on the level of vibration of the molecules making up that object;
- All objects always emit some EMR;
- Reemission in the thermal infrared is dependent on the internal temperature of the object;

Thermal Radiation

Every object with a positive temperature (T > -273.15^{O}C) emits radiation. The thermal energy contained within the molecules is converted to radiant energy which is emitted. This radiation is available in nature and is measurable by remote sensors.

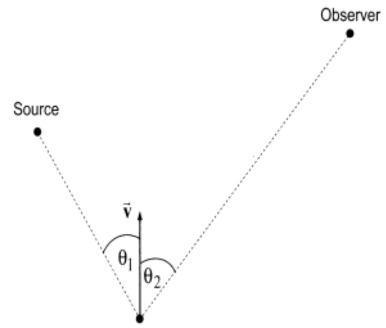
Black-body

A black-body in thermal equilibrium absorbs all radiation it receives from the surrounding media and emits exactly the same energy it absorbs. Moreover, it emits exactly the same wavelengths it absorbs. It is thus said to be a “perfect emitter” of thermal energy as radiation.

The radiation emitted by a perfect black-body depends only of its temperature and is independent of the molecules making up the object

Reflection

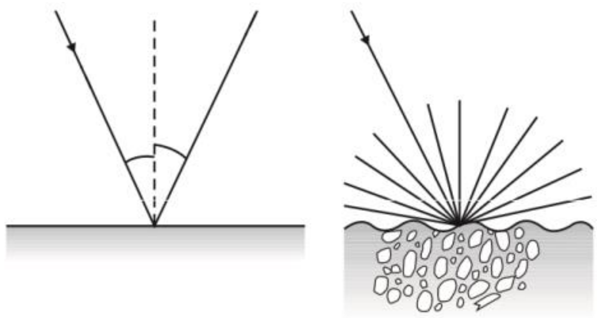
- Reflected light does not enter the medium.
- In theory, the intensity of the reflected light is equal to the intensity of the incident beam;
- The zenith angle of the reflected beam is equal to that of incident beam :
- Light reflection usually happens when the reflecting surface can optically be considered as flat (as compared with the wavelength of the light beam);



Energy interactions with the Earth’s surface

In land and water applications of remote sensing we are most interested in the reflected radiation because this tells us something about surface characteristics. Reflection occurs when radiation ‘bounces’ off the target and is then redirected. Absorption occurs when radiation is absorbed by the target. Transmission occurs when radiation passes through a target. Two types of reflection, which represent the two extremes of the way in which energy is reflected by a target, are specular reflection and diffuse reflection. In the real world, usually a combination of both types is found.

Specular reflection, or mirror-like reflection, typically occurs when a surface is smooth and all (or almost all) of the energy is directed away from the surface in a single direction. It is most likely to occur when the Sun is high in the sky. Specular reflection can be caused, for example, by a water surface or a glass house roof. It results in a very bright spot (also called ‘hot spot’) in the image.



Schematic diagrams showing (a) specular and (b) diffuse reflection.

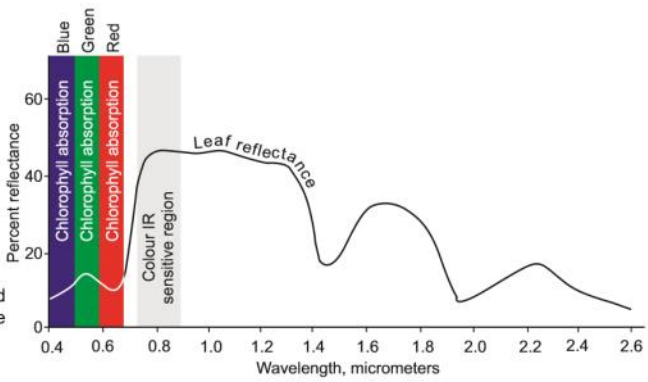
Diffuse reflection occurs in situations where the surface is rough and the energyisreflectedalmostuniformlyinalldirections. Whether a particular target reflects specularly or diffusely, or somewhere in between, depends on the surface roughness of the feature in comparison to the wavelength of the incoming radiation.

Spectral reflectance curves

Consider a surface composed of a certain material. The energy reaching this surface is called irradiance. The energy reflected by the surface is called radiance. Irradiance and radiance are expressed in W m−2 sr−1. For each material, a specific reflectance curve can be established. Such curves show the fraction of the incident radiation that is reflected as a function of wavelength. From such curve you can find the degree of reflection for each wavelength (e.g. at 0.4 µm, 0.41 µm, 0.42 µm, ...). Most remote sensing sensors are sensitive to broader wavelength bands, for example from 0.4–0.8 µm, and the curve can be used to estimate the overall reflectance in such bands. Reflectancecurves,whichareveryspecificfordifferentmaterials(seeSection14.1, and are typically collected in the optical part of the electromagnetic spectrum (up to 2.5 µm). Large efforts are made to store collections of typical curves in spectral libraries. Reflectance measurements can be carried out in a laboratory or in the field using a field spectrometer. In the following subsections the reflectance characteristics of some common land cover types are discussed.

Vegetation

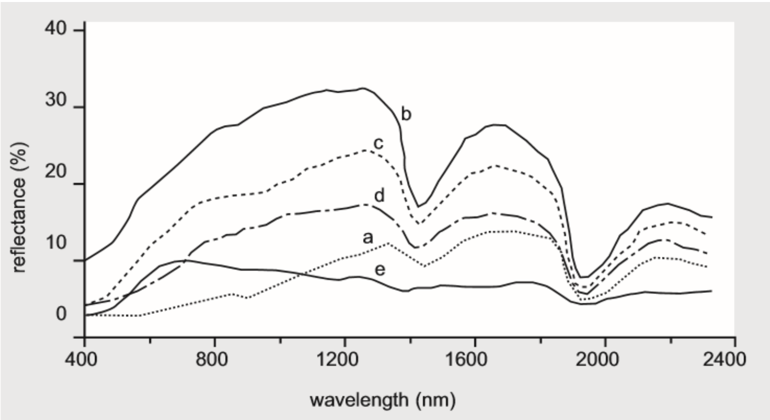
The reflectance characteristics of vegetation depend on the properties of the leafs, including the orientation and the structure of the leaf canopy. The proportion of the radiation reflected in the different parts of the spectrum depends on leaf pigmentation, leaf thickness and composition (cell structure), and on the amount of water in the leaf tissue. Figure 2.13 shows an ideal reflectance curve of healthy vegetation. In the visible portion of the spectrum, the reflection from the blue and red light is comparatively low, since these portions are absorbed by the plant (mainly by chlorophyll) for photosynthesis, and the vegetation reflects relatively more green light. The reflectance in the near-infrared is highest, but the amount depends on leaf development and cell structure. In the middle infrared, the reflectance is mainly determined by the free water in the leaf tissue; more free water results in less reflectance. They are therefore called water absorption bands. When the leafs dry out, for example during the harvest time of the crops, theplant may change colour (for example, to yellow). At this stage there is no photo synthesis, causing reflectance in the red portion of the spectrum to be higher. Also, the leafs will dry out, resulting in higher reflectance in the middle infrared, whereas the reflectance in the near-infrared may decrease. Asa result, optical remote sensing data provide information about the type of plant and also about its health condition.



An idealized spectral reflectance curve of a healthy vegetation.

Bare soil

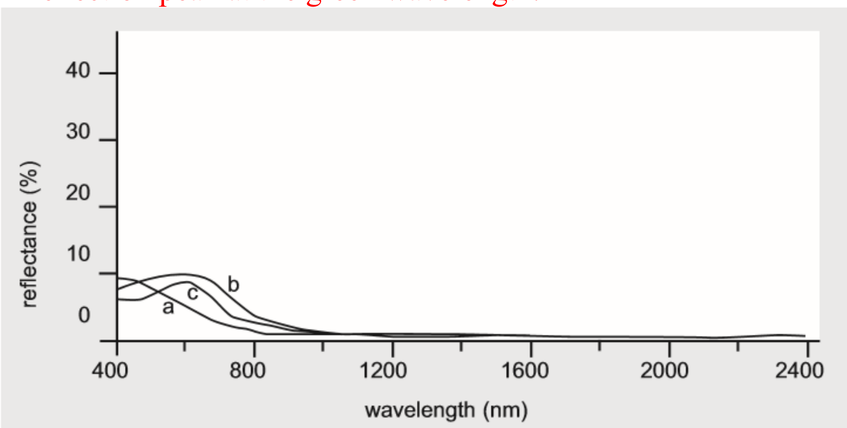
Surface reflectance from bare soil is dependent on so many factors that it is difficult to give one typical soil reflectance curve. The main factors influencing the reflectance are soil color, moisture content, the presence of carbonates, and iron oxide content. The figure gives some reflectance curves for the five main types of soil occurring in the USA. Note the typical shapes of most of the curves, which show a convex shape between 0.5–1.3 µm and dips at 1.45–1.95µm. These dips are so-called water absorbtion bands and are caused by the presence of soil moisture. Theiron-dominated soil(e) has quite a different reflectance curve that can be explained by the iron absorbtion dominating at longer wavelengths.



Reflectance spectra of surface samples of five mineral soils, (a) organic dominated, (b) minimally altered, (c) iron altered, (d) organic affected and (e) iron dominated

Water

Compared to vegetation and soils, water has the lower reflectance. Vegetation may reflect up to 50%, soils up to 30–40%, while water reflects at most 10% of the incoming radiation. Water reflects EM energy in the visible up to the nearinfrared. Beyond 1.2 µm all energy is absorbed. Some curves of different types of water are given in Figure 2.15. The highest reflectance is given by turbid (silt loaded) water, and by wate rcontaining plants with a chlorophyll reflection peak at the green wavelength.



Typical effects of chlorophyll and sediments on water reflectance: (a) ocean water, (b) turbid water, (c) water with chlorophyll

Summary

Remote sensing is based on the measurement of Electromagnetic (EM) energy. EM energy propagates through space in the form of sine waves characterized by electrical (E) and magnetic (M) fields,which are perpendicular to each other. EM can be modelled either by waves or by energy bearing particles called photons. One property of EM waves that is particularly important for understanding remote sensing is the wavelength (λ), defined as the distance between successive wave crests measured in metres (m), micrometres (μm, 10^{-6} m)or nanometres (nm, 10^{-9} m). The frequency is the number of cycles of a wave passing a fixed point in a specific period of time and is measured in hertz (Hz). Since the speed oflightisconstant,wavelength and frequency are inversely related to each other. The shorter the wavelength, the higher the frequency and vice versa. All matter with a temperature above the absolute zero (0 K) radiates EM energy due to molecular agitation. Matter that is capable of absorbing and reemitting all EM energy received is known as a blackbody. All matter with a certain temperature radiates electromagnetic waves of various wavelengths depending on its temperature. The total range of wavelengths is commonly referred to as the electromagnetic spectrum. It extends from gamma rays to radio waves. The amount of energy detected by a remote sensing system is a function of the interactions on the way to the object, the object itself and the interactions on the way returning to the sensor. The interactions of the Sun's energy with physical materials, both in the atmosphere and at the Earth's surface,cause this energy to bereflected, absorbed, transmitted or scattered. Electromagnetic energy travelling through the atmosphere is partly absorbed by molecules. The most efficient absorbers of solar radiation in the atmosphere are ozone (O_3), water vapour (H_2O) and carbon dioxide (CO_2). Atmospheric scattering occurs when the particles or gaseous molecules present in the atmosphere interact with the electromagnetic radiation and cause it to be redirected from its original path. Three types of scattering take place: Rayleigh scattering, Mie Scattering and Non-selective scattering. When electromagnetic energy from the Sun hits the Earth's surface, three fundamental energy interactions are possible: absorption, transmission, and reflectance. Specular reflection occurs when a surface is smooth and 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.

Questions

1. What is the electromagnetic spectrum?
2. List and define the three types of atmospheric scattering
3. What specific energy interactions take place when EM energy from the Sun hits the Earth's surface?
4. Indicate True or False: Only the wavelength region outside the main absorption bands of the atmospheric gases can be used for remote sensing.
5. Indicate True or False: The amount of energy detected by a remote sensing sensor is a function of how energy is partitioned between its source and the materials with which it interacts on its way to the detector.

3. Platforms

Introduction

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.

Since the early 1960s, numerous satellite sensors have been launched into orbit to observe and monitor the Earth and its environment

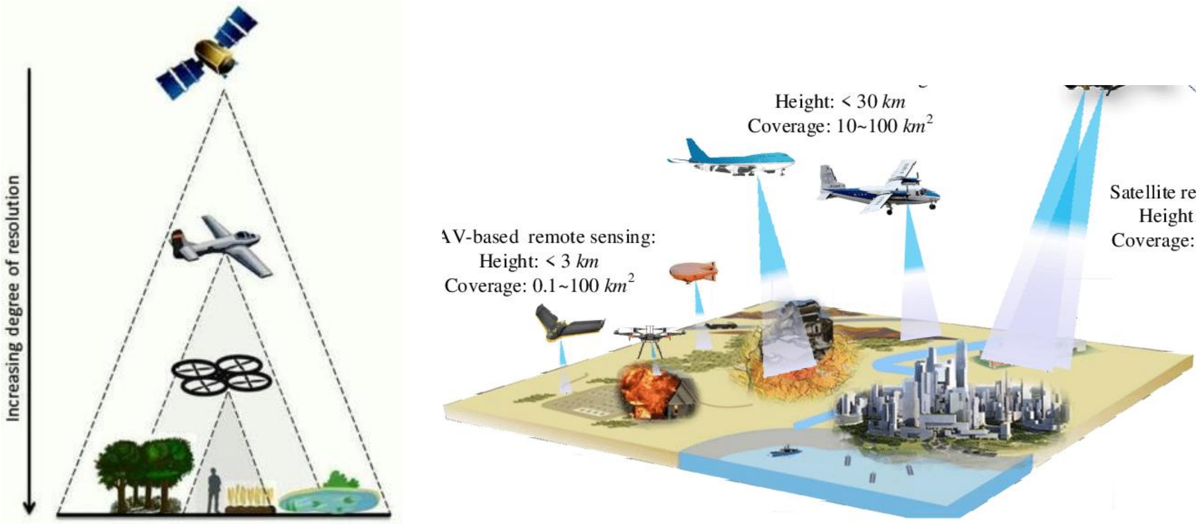


Figure ….. shows the different platforms of remote sensing

Development of remote sensing systems

- The modern discipline of remote sensing arose with the development of flight. The balloonist G. Tournachon (alias Nadar) made photographs of Paris from his balloon in 1858.
Messenger pigeons, kites, rockets and unmanned balloons were also used for early images.
- Systematic aerial photography was developed for military surveillance and reconnaissance purposes beginning in World War I and reaching a climax during the Cold War with the use of modified combat aircraft.

- The advent of earth resources satellite sensors (those with a primary objective of mapping and monitoring land cover) occurred when the first Landsat satellite was launched in July 1972.
- A more recent development is that of increasingly smaller sensor pods such as those used by law enforcement and the military, in both manned and unmanned platforms. The development of artificial satellites in the latter half of the 20th century allowed remote sensing to progress to a global scale as of the end of the Cold War.

The main platforms for remote sensing are Aircraft and Satellites. Other useful platforms are – Towers, Balloons , Kites

Type of platforms

Ground-based sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors.

- Sensors may be placed on a ladder, scaffolding, tall building, cherry-picker, crane, etc.
- 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.

<table>
<tr>
<td colspan="2">1- Aircrafts

Features

- Very convenient
- On-board repairs possible
- Range of altitudes from meters to a kilometers
- Speed: 0 – 300 m/s
- Height determines scale, coverage, and resolution
- Speed determines linear sampling rate</td>
<td colspan="2">• Navigation

Electronic navigation system give the aircraft’s true position

–Position

• Loran: Ground based radio transmitter
• GPS: Satellite based radio transmitter</td>
<td colspan="2">• Ground control points

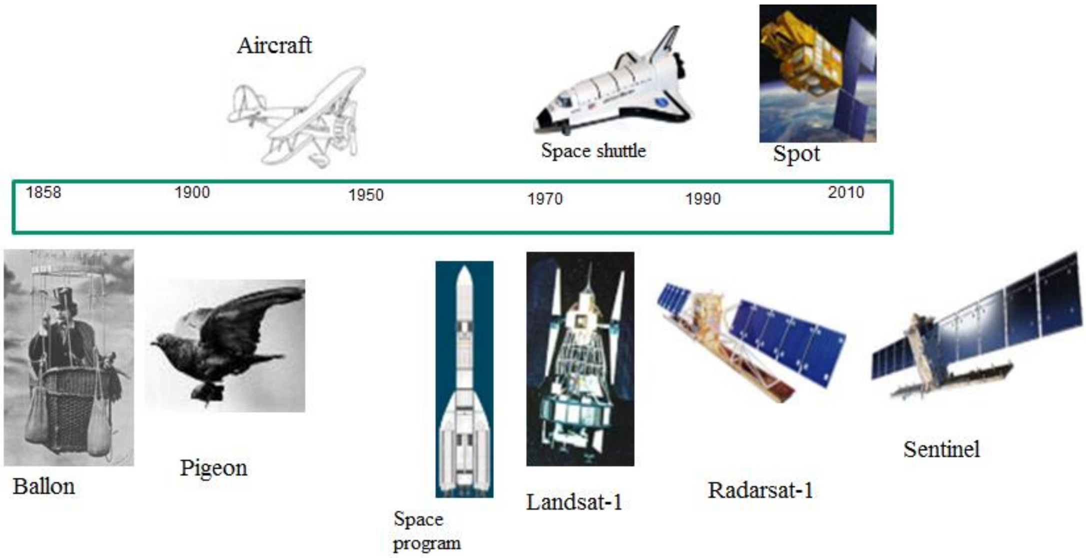
–Natural features of know location

–GCPs should not have a tendency to change over time, examples for ideal GCPs are: road intersections and airport runways

–Marker on the ground.</td>
</tr>
<tr>
<td colspan="6">2- Satelites</td>
</tr>
<tr>
<td colspan="3">• Advantages

- Increased platform speed
- Continuity of missions
- Better data coverage
- Homogeneous data collection
- No political boundary issues</td>
<td colspan="3">• Disadvantages

- –On-board repairs difficult or impossible
- –Sampling constrained by orbital geometry</td>
</tr>
</table>



Satellite Orbit geometry

Launch and Maneuver of Satellites

Velocity of a satellite in low-earth orbit: 7 km/s

•A rocket capable of reaching this orbit consists of 97% fuel

• Single-stage rockets only capable of placing small satellites into orbit

• Multiple-stage rockets can put a few tons into orbit

• The space shuttle can place 30 tons into 400 km orbit or 6 tons into a geostationary orbit.

Fundamentals of Orbital Mechanics

V *orbit* Orbital velocity is describes the speed of a satellite in orbit around a planet

$$V_{orbit} = \sqrt{\frac{GM_p}{R_p + H}}$$

Where: V orbit = orbital velocity in m/seconds;

G = Gravitational Constant (6.67300 × 10-11 m3 kg-1 s-2);

M_p = the mass of the Earth (5.9742 × 1024 kilograms)

R_p = planet radius (earth 6380 km) H = orbit altitude (km)

Orbital time

• Time required for a satellite to complete one revolution about the Earth

$$T_0 = 2\pi(R_p + H)\sqrt{\frac{R_p + H}{g_s R_P^2}}$$

• For a stable orbit around Earth, the orbital time depends only on the height of the satellite

T_0 = orbital time in seconds

R_p = planet radius (6380 km for Earth)

H = orbit altitude (km)

g_s = gravitational acceleration at the surface 9.81 m s-2

Description of orbits

Eccentricity (e)

The extent to which an orbit is elliptical or circular is defined as its *eccentricity (e)*

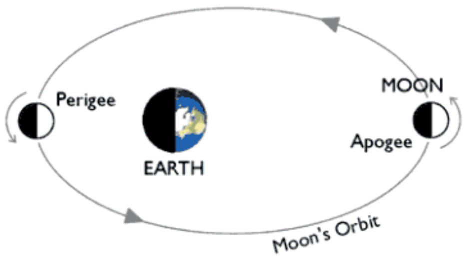
Often the orbit is close to a circle with an *eccentricity (e)* of 0

Apogee is the farthest point from the earth

Perigee is the closest point to the earth and it is in this stage that the moon appears larger.

$$e = \frac{r_a - r_p}{r_a + r_p}$$

r_p = radius at perigee
r_a = radius at apogee



Ascending (Descending) pass

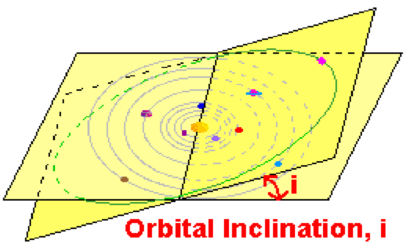
–Path followed by the satellite as it moves from south to north (north to south) in its orbital trajectory

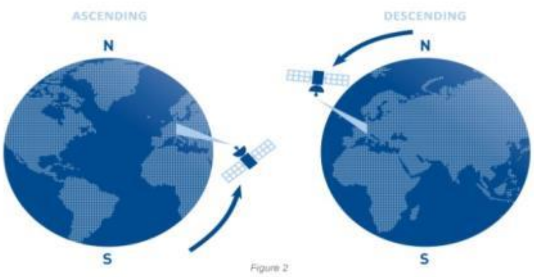
Inclination

–Angle made by the ground track of the satellite in relation to the Equator on its ascending pass

–Less than 90 degrees is a prograde orbit (in direction of rotational motion)

–Greater than 90 degrees is a retrograde orbit (opposite rotational motion)





Types of orbits

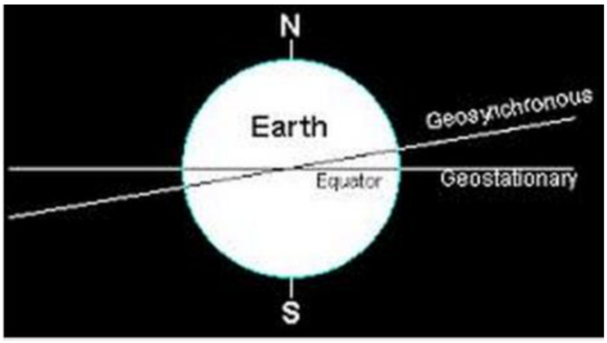
(a) Geostationary

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 kilometres, 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.

(Orbital inclination = zero)

The orbital period = 23 hrs 56 min. 4 sec

Geosynchronous and Geostationary Orbits

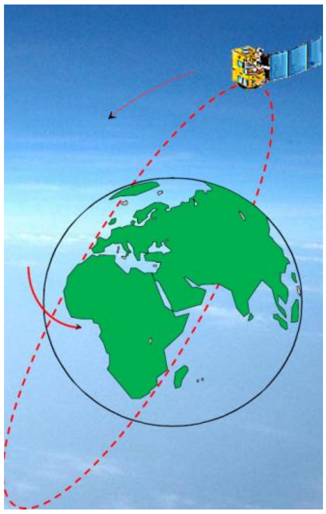


(b) Geosyncronous

A Geosynchronous satellite is a satellite in geosynchronous orbit, with an orbital period the same as the Earth's rotation period.

- Orbital period = earth's rotation = 24 hrs
- Orbital inclination ≠ zero

(c) Sun Synchronous



• The satellite crosses a given latitude at the same solar time every day

• The orbital plane rotates about the polar axis

• Orbital height about 1000 km

• Orbital inclination is greater than 96°

• Landsat, SPOT, NOAA, DMSP, RADARSAT, ERS-1/2

• Earth monitoring – global coverage

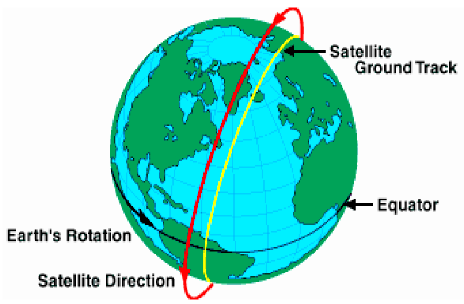
• Orbital altitude typically between 600 and 1000 km

– good spatial resolution

•Ascending and descending orbits should cross at 90°

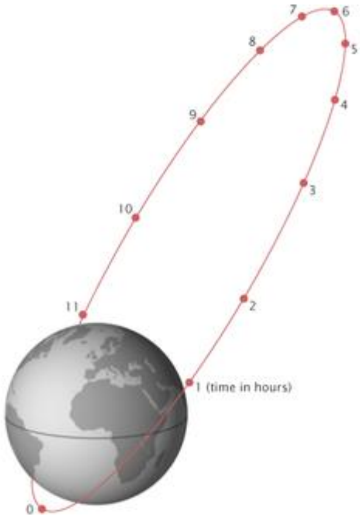
- Designed so that orthogonal components of surface
- slope will have equal accuracy

•Orbital inclination depends on location of alttimetric needs.



(d) Molniya Orbit

A satellite in a highly eccentric orbit spends most of its time in the neighborhood of Apogee which for a Molniya orbit is over the northern hemisphere, the sub-satellite point at apogee having a latitude of 63.4 degrees North.



Scanner Sensor System

Multispectral scanners measure reflected electromagnetic energy by scanning the Earth's surface. This results in digital image data, of which the elementary unit is a picture element, a pixel. As the name multispectral suggests, the measurements are made for different ranges of the EM spectrum. Multispectral scanners have been used in remote sensing since 1972 when the first Landsat satellite was launched. After the aerial camera it is the most commonly used sensor. Applications of multispectral scanner data are mainly in the mapping of land cover, vegetation, surface mineralogy and surface water. Two types of multispectral scanners can be distinguished, the whiskbroom scanner and the pushbroom sensor.

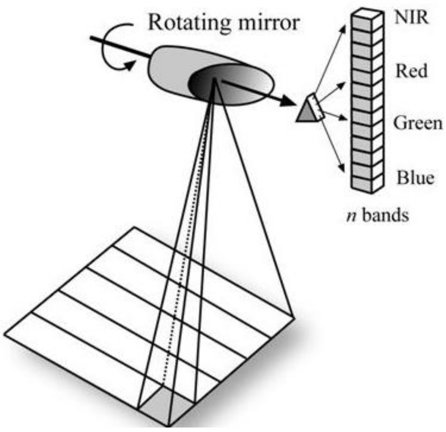
One type of scanner is called a ***whiskbroom*** scanner also referred to as across-track scanners (e.g. on LANDSAT). It uses rotating mirrors to scan the landscape below from side to side perpendicular to the direction of the sensor platform, like a whiskbroom. The width of the sweep is referred to as the sensor swath. The rotating mirrors redirect the reflected light to a point where a single or just a few sensor detectors are grouped together. Whiskbroom scanners with their moving mirrors tend to be large and complex to build. The moving mirrors create spatial distortions that must be corrected with preprocessing by the data provider before image data is delivered to the user. An advantage of whiskbroom scanners is that they have fewer sensor detectors to keep calibrated as compared to other types of sensors.

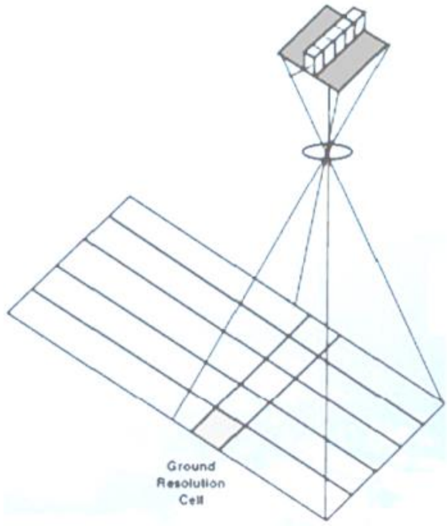
Another type of scanner, which does not use rotating mirrors, is the ***pushbroom*** scanner also referred to as an along-track scanner (e.g. on SPOT). The sensor detectors in a pushbroom scanner are lined up in a row called a linear array. Instead of sweeping from side to side as the sensor system moves forward, the one dimensional sensor array captures the entire scan line at once like a pushbroom would. Some recent scanners referred to as step stare scanners contain two-dimensional arrays in rows and columns for each band. Pushbroom scanners are lighter, smaller and less complex because of fewer moving parts than whiskbroom scanners. Also they have better radiometric and spatial resolution. A major disadvantage of pushbroom scanners is the calibration required for a large number of detectors that make up the sensor system.

Number of detectors is equivalent to the scanned cells

Number of detectors = Swath/size of ground resolution cell (pixel)

Whiskbroom	Pushbroom
- Wide swath width - Complex mechanical system - Simple optical system - Shorter dwell time - Pixel distortion - filters/sensors - Satellite: LANDSAT	- Narrow swath width - Simple mechanical system - Complex optical system - Longer dwell time - Less pixel distortion - solid state detectors CCD - Satellite: SPOT

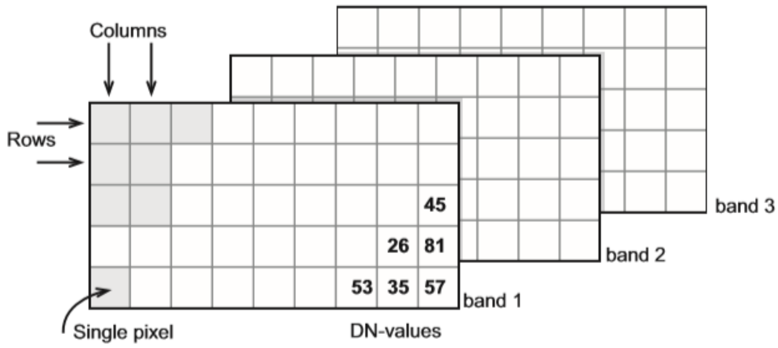




Resolution of Remote Sensing sensors

The quality of image data is primarily determined by the characteristics of the sensor-platform system. The image characteristics are usually referred to as: Spatial resolution, Spectral resolution, Radiometric resolution, and Temporal resolution.

Remote sensing image data are more than a picture, they are measurements of EM energy. Image data are stored in a regular grid format (rows and columns). A single image element is called a pixel, a contraction of 'picture element'. For each pixel, the measurements are stored as Digital Numbers, or DN-values. Typically, for each measured wavelength range a separate data set is stored, which is called a band or a channel, and sometimes a layer



Spatial Resolution, Pixel Size, and Scale

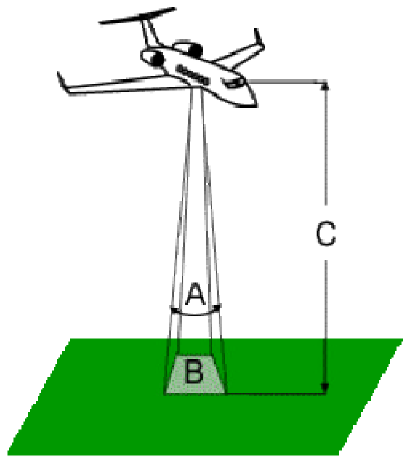
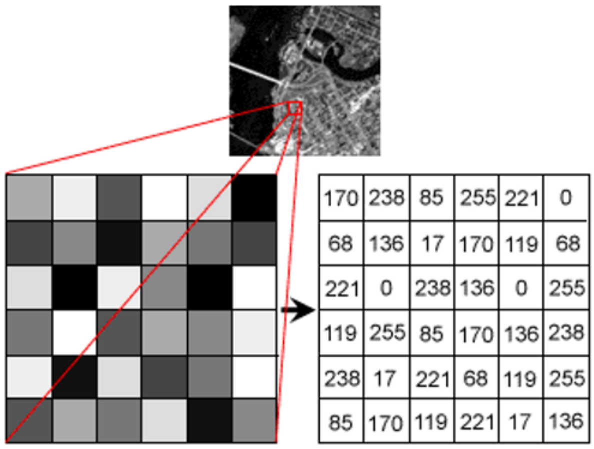


Figure: Instanteneous Field Of View

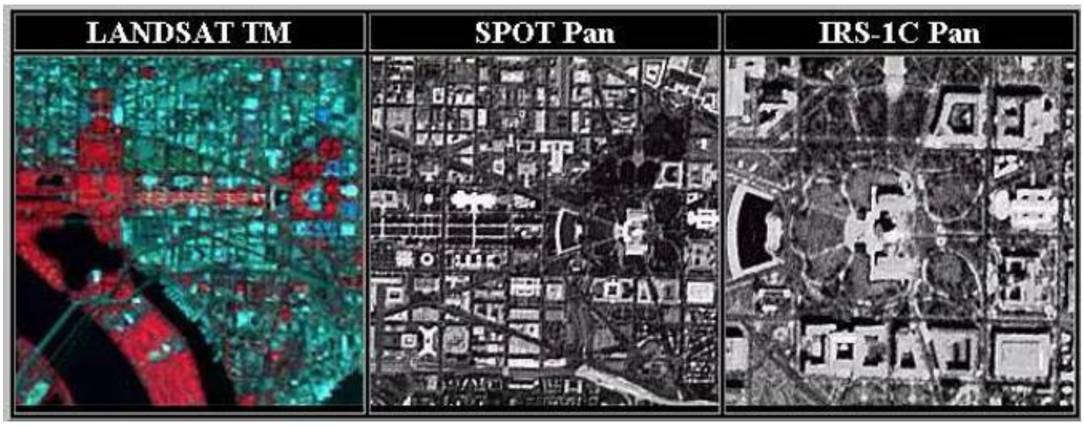
For some remote sensing instruments, the distance between the target being imaged and the platform, plays a large role in determining the detail of information obtained and the total area imaged by the sensor. Sensors onboard platforms far away from their targets, typically view a larger area, but cannot provide great detail. Compare what an astronaut onboard the space shuttle sees of the Earth to what you can see from an airplane. The astronaut might see your whole province or country in one glance, but couldn't distinguish individual houses. Flying over a city or town, you would be able to see individual buildings and cars, but you would be viewing a much smaller area than the astronaut. There is a similar difference between satellite images and airphotos.

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 (we will look at the special case of active microwave sensors later) 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. For a homogeneous feature to be detected, its size generally has to be equal to or larger than the resolution cell. If the feature is smaller than this, it may not be detectable as the average brightness of all features in that resolution cell will be recorded. However, smaller features may sometimes be detectable if their reflectance dominates within a particular resolution cell allowing sub-pixel or resolution cell detection.



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 metres 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. Many posters of satellite images of the Earth have their pixels averaged to represent larger areas, although the original spatial resolution of the sensor that collected the imagery remains the same.

A photograph can 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.



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. Military sensors for example, are designed to view as much detail as possible, and therefore have very fine resolution. Commercial satellites provide imagery with resolutions varying from a few metres to several kilometres. Generally speaking, the finer the resolution, the less total ground area can be seen.

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.

Spectral characteristics

Spectral characteristics, which refer to the spectral wavelengths that the sensor is sensitive to. Spectral range is important to cover enough diagnostic spectral absorption to solve a desired problem. There are general spectral ranges that are in common use, each to first order controlled by detector technology: a) ultraviolet (UV): 0.001 to 0.4 µm, b) visible: 0.4 to 0.7 µm, c) near-infrared (NIR): 0.7 to 3.0 µm, d) the mid-infrared (MIR): 3.0 to 30 µm, and d) the far infrared (FIR): 30 µm to 1 mm (e.g. see The Photonics Design and Applications Handbook, 1996 and The Handbook of Chemistry and Physics, any recent year). The ~0.4 to 1.0-µm wavelength range is sometimes referred to in the remote sensing literature as the VNIR (visible-near-infrared) and the 1.0 to 2.5-µm range is sometimes referred to as the SWIR (short-wave infrared). It should be noted that these terms are not recognized standard terms in other fields except remote sensing, and because the NIR in VNIR conflicts with the accepted NIR range, the VNIR and SWIR terms probably should be avoided. The mid-infrared covers thermally emitted energy, which for the Earth starts at about 2.5 to 3 µm, peaking near 10 µm, decreasing beyond the peak, with a shape controlled by greybody emission.

Spectral bandwidth is the width of an individual spectral channel in the spectrometer. The narrower the spectral bandwidth, the narrower the absorption feature the spectrometer will accurately measure, if enough adjacent spectral samples are obtained. Some systems have a few broad channels, not contiguously spaced and, thus, are not considered spectrometers (Figure 1a). Examples include the Landsat Thematic Mapper (TM) system and the MODerate Resolution Imaging Spectroradiometer (MODIS), which can't resolve narrow absorption features. Others, like the NASA JPL Airborne Visual and Infra-Red Imaging Spectrometer (AVIRIS) system have many narrow bandwidths, contiguously spaced (Figure 1b). Figure 1 shows spectra for the mineral alunite that could be obtained by some example broadband and spectrometer systems. Note the loss in subtle spectral detail in the lower resolution systems compared to the laboratory spectrum. Bandwidths and sampling greater than 25 nm rapidly lose the ability to resolve important mineral absorption features. All the spectra in Figure 1b are sampled at half Nyquist (critical sampling) except the Near Infrared Mapping Spectrometer (NIMS), which is at Nyquist sampling (named after H. Nyquist, that in his work published in 1928, stated that there must be at least to samplings per wavelength of the highest frequency, in order to appropriately sample the waveform). Note, however, that the fine details of the absorption features are lost at the ~25 nm bandpass of NIMS. For example, the shoulder in the 2.2-µm absorption band is lost at 25-nm bandpass. The Visual and Infrared Mapping Spectrometer (VIMS) and NIMS systems measure out to 5 µm, thus can see absorption bands not obtainable by the other systems.

Radiometric resolution

Radiometric resolution, which refers to the smallest differences in levels of energy that can be distinguished by the sensor.

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.

Digital resolution is the number of bits comprising each digital sample. 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 = 21 = 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 28 = 256 digital values available, ranging from 0 to 255 – termed also as the dynamic range of the system. However, if only 4 bits were used, then only 24 = 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 2bit image with an 8-bit image, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions. The range of energy values expected from a system must “fit” within the range of values possible of the data format type, and yet the value must represent accurately the energy value of the signal relative to others. The cost of more bits per data point is longer acquisition times, the requirement of larger storage capacity and longer processing time. Any signal outside the range is “clipped” and thus unrecoverable. On the other hand, if the dynamic range of the signal is widened too much as to allow the recording of extremely high or low energy values, the true variability within the signal will be lost.

Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions. These are referred to as multi-spectral sensors and will be described in some detail in following sections. 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.

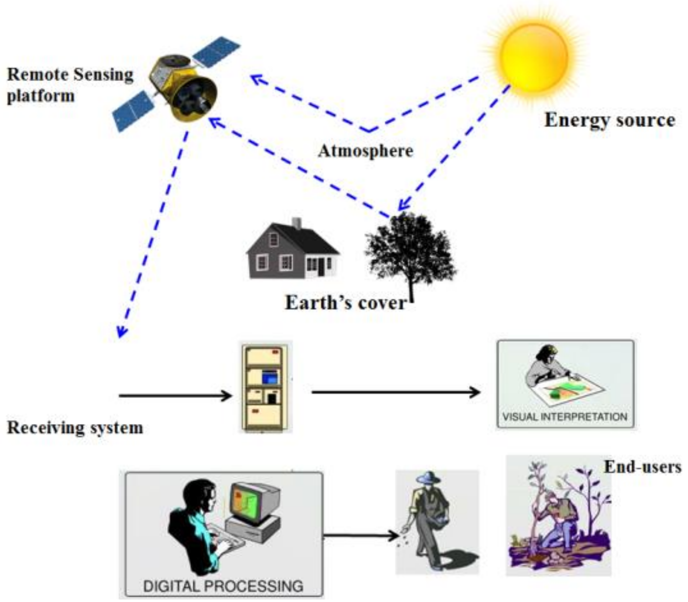
There are 4 general parameters that describe the capability of a spectrometer: 1) spectral range, 2) spectral bandwidth, 3) spectral sampling, and 4) signal-to-noise ratio (S/N).

Temporal Resolution

In addition to spatial, spectral, and radiometric resolution, the concept of temporal resolution is also important to consider in a remote sensing system. 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, the actual temporal resolution of a sensor depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap, and latitude. The ability to collect imagery of the same area of the Earth's surface at different periods of time is one of the most important elements for applying remote sensing data. Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing multi-temporal imagery. For example, during the growing season, most species of vegetation are in a continual state of change and our ability to monitor those subtle changes using remote sensing is dependent on when and how frequently we collect 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).

4. Remote Sensing Applications

In principle, remote sensing provides information about the upper few millimetres of the Earth's surface. Some techniques, specifically in the microwave domain, relate to greater depths. The fact that measurements only refer to the surface is a limitation of remote sensing. Additional 'models' or assumptions are required to estimate subsurface characteristics. In the case of SST, the temperature derived from RS only tells something about the temperature of the actual surface of the ocean. No information can be derived about subsurface currents (which is possible when using buoys).



Mapping the sea floor (bathymetry)

Many parts of the world's sea floor are charted only in a general fashion or the charts are inaccurate (being out of date, etc). Accurate charts are especially needed for shallow shelf areas where submarine deposition, erosion, and growth of coral reefs can change the bottom topography within a few years after a bathymetric survey is completed.

Remote Sensing of the sea floor from aircraft or satellites is restricted by the fact that water absorbs or reflects most wavelengths or electromagnetic energy. IR energy is absorbed by waterm, and only visible wavelengths penetrate water. The depth of penetration is influenced by the turbidity of the water and the wavelength of the light. A 10-m layer of clear ocean water transmits almost 50 percent of the incident radiation from 0.4 to 0.6 mm in wavelength, but transmits less than 10 percent of radiation from 0.6 to 0.7 mm wavelength. The increased turbidity results in a decrease of light transmittance and a shift in the wavelength of maximum transmittance to the 0.5 to 0.6 mm region.

Ice motion and monitoring

Ice moves quickly and sometimes unpredictably in response to ocean currents and wind. Vessels can be trapped or damaged by the pressure resulting from these moving ice floes. Even offshore structures can be damaged by the strength and momentum of moving ice. For these reasons it is important to understand the ice dynamics in areas of construction or in the vicinity of a shipping/fishing route.

Remote sensing gives a tangible measure of direction and rate of ice movement through mapping and change detection techniques. Ice floes actually have individual morphological characteristics (shape, structures) that allow them to be distinguished from one another. The floes can be mapped and their movement monitored to facilitate in planning optimum shipping routes, to predict the effect of ice movement on standing structures (bridges, platforms).Users of this type of information include the shipping, fishing, and tourism industries, as well as engineers involved in offshore platform and bridge design and maintenance.

Monitoring of ice movement requires frequent and reliable imaging. The revisit interval must be frequent enough to follow identifiable features before tracking becomes difficult due to excessive movement or change in appearance. Active microwave sensing (radar) provides a reliable source of imaging under all weather and illumination conditions. RADARSAT provides this type of sensor and is a spaceborne platform, which is advantageous for routine imaging operations. The orbital path ensures that Arctic areas are covered daily which meets the requirement for frequent imaging.

Oil Spill Detection

Oil spills can destroy marine life as well as damage habitat for land animals and humans. To limit the areas affected by the spill and facilitate containment and cleanup efforts, a number of factors have to be identified: • Spill location • Size and extent of the spill • Direction and magnitude of oil movement • Wind, current and wave information for predicting future oil movement

Remote sensing offers the advantage of being able to observe events in remote and often inaccessible areas. For example, oil spills from ruptured pipelines, may go unchecked for a period of time because of uncertainty of the exact location of the spill, and limited knowledge of the extent of the spill. Remote sensing can be used to both detect and monitor spills. Detecting oil seeps can be also used in exploration programs.

For ocean spills, remote sensing data can provide information on the rate and direction of oil movement through multi-temporal imaging, and input to drift prediction modelling and may facilitate in targeting clean-up and control efforts. Remote sensing devices used include the use of infrared video and photography from airborne platforms, thermal infrared imaging, airborne laser fluourosensors, airborne and space-borne optical sensors, as well as airborne and spaceborne SAR. SAR sensors have an advantage over optical sensors in that they can provide data under poor weather conditions and during darkness. Users of remotely sensed data for oil spill applications include the Coast Guard, national environmental protection agencies and departments, oil companies, shipping industry, insurance industry, fishing industry, national departments of fisheries and oceans, and departments of defence.

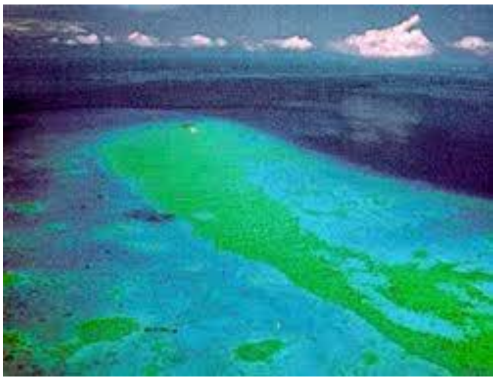
The key operational data requirements are fast turnaround time and frequent imaging of the site to monitor the dynamics of the spill. For spill identification, high resolution sensors are generally required, although wide area coverage is very important for initial monitoring and detection. Airborne sensors have the advantage of frequent site specific coverage on demand, however, they can be costly. Spills often occur in inclement weather, which can hinder airborne surveillance.

On daytime and nighttime IR images both refined and crude oils have cooler signatures than the adjacent clean water. The oil and water have the same kinetic temperature beacause the two liquids are in direct contact. However, the emissivity of pure water is 0.993, and a thin film of petroleum reduces the emissivity to 0.972. For a kinetic emperature of 18ºC, the radiant temperature of pure water will be 17.5ºC, while that of the oil film will be just 15.9ºC. IR images have the advantage of being available both for day and night operations. However, rain and fog preven temperature image acquisition, and the interpreter must be careful to avoid confusing cold water currents with oil slicks.

SAR sensors can image oilspills through the localized suppression of Bragg scale waves. Oilspills are visible on a radar image as circular or curvilinear features with a darker tone than the surrounding ocean (the small waves that cause backscatter on radar images of the sea are dampened by a thin film of oil). The detection of an oilspill is strongly dependent upon the wind speed. At wind speeds greater than 10 m/s, the slick will be broken up and dispersed, making it difficult to detect. Another factor that can play a role in the successful detection of an oilspill is the difficulty in distinguishing between a natural surfactant and an oilspill. Multi-temporal data and ancillary information can help to discriminate between these two phenomena.

Oceans & Coastal Monitoring

Ocean applications of remote sensing include the following:



• Currents, regional circulation patterns, shears

• Frontal zones, internal waves, gravity waves, eddies, upwelling zones, shallow water bathymetry ,

• Wind and wave retrieval

• Water temperature monitoring

• Water quality

• Ocean productivity, phytoplankton concentration and drift

• Aquaculture inventory and monitoring

Geological applications of remote sensing include the following:

➢ Surficial deposit / bedrock mapping

➢ Lithological mapping

➢ Structural mapping

➢ Sand and gravel (aggregate) exploration/ exploitation

➢ Mineral exploration

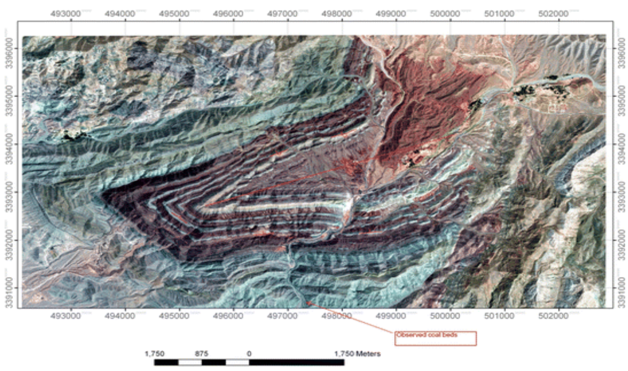
➢ Environmental geology

➢ Sedimentation mapping and monitoring

➢ Event mapping and monitoring

➢ Geo-hazard mapping

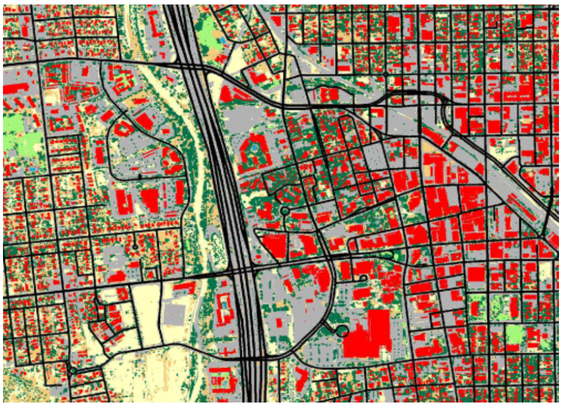
➢ Planetary mapping



Geology involves the study of landforms, structures, and the subsurface, to understand physical processes creating and modifying the earth's crust. It is most commonly understood as the exploration and exploitation of mineral and hydrocarbon resources, generally to improve the conditions and standard of living in society. Petroleum provides gas and oil for vehicle transportation, aggregate and limestone quarrying (sand and gravel) provides ingredients for concrete for paving and construction, potash mines contribute to fertilizer, coal to energy production, precious metals and gems for jewelry, diamonds for drill bits, and copper, zinc and assorted minerals for a variety of uses. Geology also includes the study of potential hazards such as volcanoes, landslides, and earthquakes, and is thus a critical factor for geotechnical studies relating to construction and engineering. Geological studies are not limited to Earth - remote sensing has been used to examine the composition and structure of other planets and moons. Remote sensing is used as a tool to extract information about the land surface structure, composition or subsurface, but is often combined with other data sources providing complementary measurements. Multispectral data can provide information on litho logy or rock composition based on spectral reflectance. Radar provides an expression of surface topography and roughness, and thus is extremely valuable, especially when integrated with another data source to provide detailed relief. Remote sensing is not limited to direct geology applications - it is also used to support logistics, such as route planning for access into a mining area, reclamation monitoring, and generating base maps upon which geological data can be referenced or superimposed.

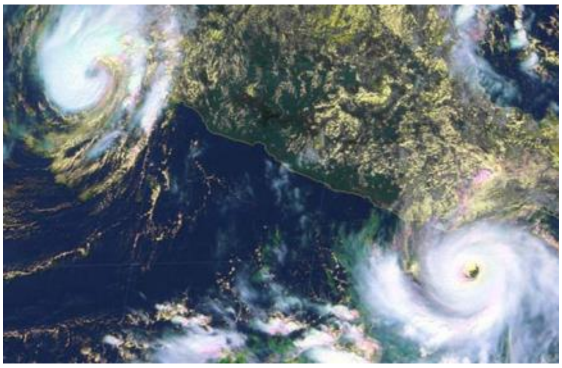
Land use applications of remote sensing include the following:

Land cover refers to the surface cover on the ground, while Land use refers to the purpose the land serves.



- Natural resource management
- wildlife habitat protection
- Urban expansion / encroachment
- Exploration / resource extraction activities
- Damage delineation (tornadoes, flooding, volcanic, seismic, fire)
- Target detection - identification of landing strips, roads, clearings, bridges, land/water interface

Weather Forecasting



NASA's constellation of current missions provide several opportunities to apply satellite remote sensing observations to weather forecasting and disaster response applications. Examples include: Using NASA's Terra and Aqua MODIS, and the NASA/NOAA Suomi-NPP VIIRS missions to prepare weather forecasters for capabilities of GOES-R; Incorporating other NASA remote sensing assets for improving aspects of numerical weather prediction; Using NASA, NOAA, and international partner resources (e.g. ESA/Sentinel Series); and commercial platforms (high-res, or UAV) to support disaster mapping.

Agriculture

Agriculture plays a dominant role in economies of both developed and undeveloped countries. Whether agriculture represents a substantial trading industry for an economically strong country or simply sustenance for a hungry, overpopulated one, it plays a significant role in almost every nation. The production of food is important to everyone and producing food in a cost-effective manner is the goal of every farmer, large-scale farm manager and regional agricultural agency. A farmer needs to be informed to be efficient, and that includes having the knowledge and information products to forge a viable strategy for farming operations. These tools will help him understand the health of his crop, extent of infestation or stress damage, or potential yield and soil conditions. Commodity brokers are also very interested in how well farms are producing, as yield (both quantity and quality) estimates for all products control price and worldwide trading. Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability, and monitor farming practices. Agricultural applications of remote sensing include the following:

1. Crop type classification
2. Crop condition assessment
3. Crop yield estimation
4. Mapping of soil characteristics
5. Mapping of soil management practices
6. Compliance monitoring (farming practices)
7. Monitoring extent and type of vegetation
8. Mapping soil types
9. Estimating vegetation biomass
10. Estimating

Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability, and monitor farming practices. Agricultural applications of remote sensing include the following:

Crop type classification

Crop condition assessment

Crop yield estimation

Mapping of soil characteristics

Use of remote sensing in forestry:

- Forestry applications of remote sensing include the following:
a) Reconnaissance mapping:
Objectives to be met by national forest/environment agencies include forest cover updating, depletion monitoring, and measuring biophysical properties of forest stands.

1. Forest cover type discrimination
2. Agro forestry mapping

b) Commercial forestry:
Of importance to commercial forestry companies and to resource management agencies are inventory and mapping applications: collecting harvest information, updating of inventory information for timber supply, broad forest type, vegetation density, and biomass measurements.

1. Clear cut mapping / regeneration assessment
2. Burn delineation

3. Infrastructure mapping / operations support
4. Forest inventory
5. Biomass estimation
6. Species inventory

c) Environmental monitoring

Conservation authorities are concerned with monitoring the quantity, health, and diversity of the Earth's forests.

1. Deforestation (rainforest, mangrove colonies)
2. Species inventory
3. Watershed protection (riparian strips)
4. Coastal protection (mangrove forests)
5. Forest health and vigor

Planetary Remote Sensing

Planetary Remote Sensing usually refers only to remote sensing of planets other than Earth in our Solar System. Data used from planetary remote sensing has been used to gather such information as:

- Planetary topography, including surface roughness and surface characteristics,
- Surface, atmosphere and radiant temperatures,
- Surface and atmospheric mineral and chemical compositions,
- And even gravity, atmospheric pressure and atmospheric density information

Remote sensing application in search and rescue

Search and Rescue (SAR) is one of the many applications that can benefit from remote sensing. Real-time data, collected over wide areas, reduce the uncertainty that is always present in maritime emergencies. Specifically, improvements in trajectory prediction, target detection, and survival estimation can be expected through the availability of remotely sensed data Remote sensing can help determine the wind and surface current velocities required to predict the trajectory of a SAR target. Remote sensing can also give clues to estimate the variability in the wind and surface currents. For trajectory prediction, the SAR needs is essentially the same as applied physical oceanography and meteorology. A multiple sensor approach will likely be required, with the results blended by a numerical model. Sea consult Marine Research Limited recommended the blending of real data into models for oil spill operations after trials on the west coast using ground based HF radar to detect surface currents.

5. Image processing

As a result of solid state multispectral scanners and other raster input devices, we now have available digital raster images of spectral reflectance data. The chief advantage of having these data in digital form is that they allow us to apply computer analysis techniques to the image data—a field of study called *Digital Image Processing*.

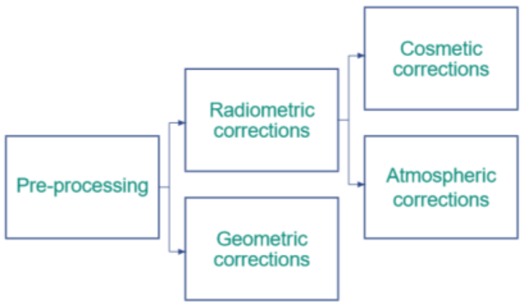
Digital Image Processing is largely concerned with four basic operations: ***image restoration***, ***image enhancement***, ***image classification***, ***image transformation***. *Image restoration* is concerned with the correction and calibration of images in order to achieve as faithful a representation of the earth surface as possible—a fundamental consideration for all applications. *Image enhancement* is predominantly concerned with the modification of images to optimize their appearance to the visual system. Visual analysis is a key element, even in digital image processing, and the effects of these techniques can be dramatic. *Image classification* refers to the computer-assisted interpretation of images—an operation that is vital to GIS. Finally, *image transformation* refers to the derivation of new imagery as a result of some mathematical treatment of the raw image bands.
In order to undertake the operations listed in this section, it is necessary to have access to Image Processing software.

5.1 Image restoration

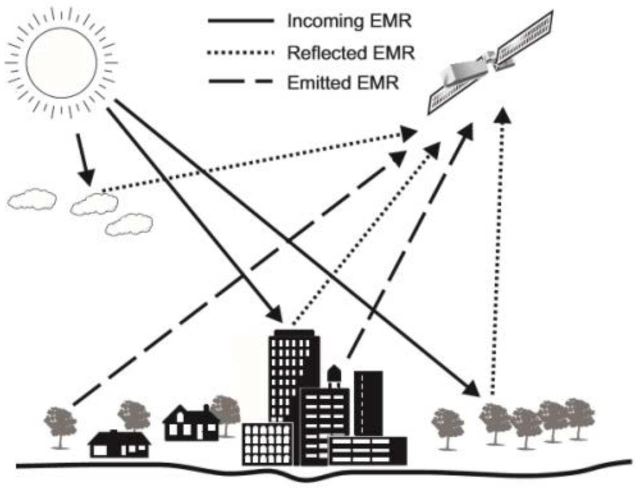
5. 1.1 Radiometric correction

Three groups of radiometric corrections are identified:

- 'Cosmetic' rectification to compensate for data errors,
- Relative atmospheric correction based on ground reflectance properties, and
- Absolute atmospheric correction based on atmospheric process information.
-



The radiance values of reflected polychromatic solar radiation and/or the emitted thermal radiance from a certain specific target (pixel) at the Earth surface are for researchers the most valuable information obtainable from a RS scanner. In the absence of an atmosphere, these radiances leaving the ground will reach the orbiting sensor practically unaltered in any wavelength, in others words, what is recorded by the satellite directly corresponds to the radiance leaving the target on Earth in the wavelength range (band) underconsideration



5.1.1.1 From satellite to ground radiances: the atmospheric correction

The presence of a heterogeneous, dense and layered terrestrial atmosphere composed of water vapour, aerosols and gases disturbs the signal reaching the sensor in many ways. Therefore, methods of atmospheric corrections (AC) are needed to ‘clean’ the images from these disturbances, in order to allow the retrieval of pure ground radiances from the target. The physics behind the AC techniques in the visible and in the thermal range is essentially the same, meaning that the same AC procedures applicable in one also apply to the other. However, there are a number of reasons and facts that allow a distinction between techniques applicable to visible and thermal data:

• Incident and reflected solar radiation and terrestrial thermal emission fall into very different parts of the spectrum.

• Solar emission and reflection depends on the position of the sun and the satellite at the moment of image acquisition. Thermal emission is theoretically less dependent on this geometry**.**

5.1.1.2 Atmospheric correction in the visible part of the spectrum

As mentioned earlier, the signal correction methods in the visible part of the spectrum (solar radiation) can be grouped according to the rigour of the final product required by the application. In increasing order of difficulty, the following methods are discussed below:

• Cosmetic corrections;

• Relative AC methods based on ground reflectance properties;

• Absolute AC methods based on atmospheric process information.

Cosmetic correction

These procedures are not true AC techniques. Their objective is to correct visible errors and noise in the image data. No atmospheric model of any kind is involved at all in these correction processes; instead, corrections are achieved using especially designed filters and image stretching and enhancement procedures. Nowadays these corrections are typically executed (if required) at the satellite data receiving stations or image pre-processing centres, before reaching the final user. All applications require this form of correction. True AC methods, if required, follow these cosmetic modifications. Typical problems requiring cosmetic corrections are:

- Periodic line dropouts;
- Line striping;
- Random noise or spike corrections.

These effects can be identified visually and automatically, and are here illustrated on a Landsat Enhanced Thematic Mapper (ETM) image of Enschede.

(a)

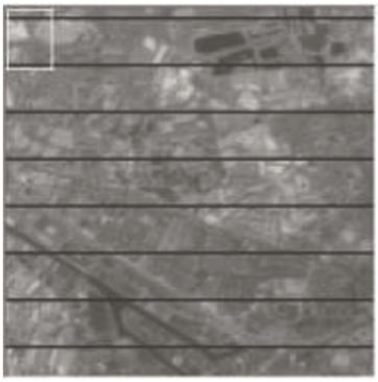

(b)

96	87	83	94	114	109	107	104	94	83	81	96	90	110	109
89	89	96	94	98	108	111	110	94	80	88	79	73	107	121
104	108	93	92	97	94	86	81	75	83	91	75	75	110	131
114	97	93	86	96	100	92	88	88	92	93	92	105	110	106
131	143	107	101	122	127	88	86	87	90	90	92	124	122	116
122	155	147	115	145	155	101	91	92	95	102	119	131	128	132
112	127	148	151	159	155	134	91	92	91	106	126	121	112	126
137	152	162	164	161	157	150	98	86	96	118	127	104	121	122
138	149	155	159	168	162	154	123	87	97	126	123	108	125	121
131	137	139	141	148	158	159	137	96	92	122	117	114	121	121
108	132	136	134	135	124	115	106	96	88	90	96	113	120	116
88	101	113	100	94	93	90	84	89	79	82	91	88	102	114
78	68	81	88	73	76	76	78	79	72	76	83	86	86	91
70	85	111	118	100	89	86	85	84	81	73	68	73	79	85
87	114	128	127	119	96	87	86	80	74	69	72	76	80	81
106	126	125	127	108	88	92	87	80	80	71	75	77	84	68
106	116	123	119	89	95	99	95	82	76	79	79	79	71	69
99	116	123	119	89	95	99	93	85	74	69	66	70	71	78
88	95	99	96	112	76	104	93	85	74	69	66	70	71	85
91	91	85	87	80	97	115	105	94	87	78	70	73	65	85

Original Landsat ETM image of Enschede and environs (a), and corresponding Digital Numbers (DN) of the the indicated subset (b).

Periodic line dropouts

Periodic line dropouts occur due to recording problems when one of the detectors of the sensor in question either gives wrong data or stops functioning. The Landsat ETM, for example, has 16 detectors in all its bands, except the thermal band. A loss of one of the

(a)


(b)

96	87	83	94	114	109	107	104	94	83	81	96	90	110	109
89	89	96	94	98	108	111	110	94	80	88	79	73	107	121
104	108	93	92	97	94	86	81	75	83	91	75	75	110	131
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
131	143	107	101	122	127	88	86	87	90	90	92	124	122	116
122	155	147	115	145	155	101	91	92	95	102	119	131	128	132
112	127	148	151	159	155	134	91	92	91	106	126	121	112	126
137	152	162	164	161	157	150	98	86	96	118	127	104	121	122
138	149	155	159	168	162	154	123	87	97	126	123	108	125	121
131	137	139	141	148	158	159	137	96	92	122	117	114	121	121
108	132	136	134	135	124	115	106	96	88	90	96	113	120	116
88	101	113	100	94	93	90	84	89	79	82	91	88	102	114
78	68	81	88	73	76	76	78	79	72	76	83	86	86	91
70	85	111	118	100	89	86	85	84	81	73	68	73	79	85
87	114	128	127	119	96	87	86	80	74	69	72	76	80	81
106	126	125	127	108	88	92	87	80	80	71	75	77	84	68
106	116	123	119	89	95	99	95	82	76	79	79	79	71	69
99	116	123	119	89	95	99	93	85	74	69	66	70	71	78
88	95	99	96	112	76	104	93	85	74	69	66	70	71	85
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

The image with periodic line dropouts (a) and the DN-values (b). All erroneous DN-values in these examples are shown in bold.

(a)


(b)

96	87	83	94	114	109	107	104	94	83	81	96	90	110	109
89	89	96	94	98	108	111	110	94	80	88	79	73	107	121
104	108	93	92	97	94	86	81	75	83	91	75	75	110	131
118	**126**	**100**	**97**	**110**	**111**	**87**	**84**	**81**	**87**	**91**	**84**	**100**	**116**	**124**
131	143	107	101	122	127	88	86	87	90	90	92	124	122	116
122	155	147	115	145	155	101	91	92	95	102	119	131	128	132
112	127	148	151	159	155	134	91	92	91	106	126	121	112	126
137	152	162	164	161	157	150	98	86	96	118	127	104	121	122
138	149	155	159	168	162	154	123	87	97	126	123	108	125	121
131	137	139	141	148	158	159	137	96	92	122	117	114	121	121
108	132	136	134	135	124	115	106	96	88	90	96	113	120	116
88	101	113	100	94	93	90	84	89	79	82	91	88	102	114
78	68	81	88	73	76	76	78	79	72	76	83	86	86	91
70	85	111	118	100	89	86	85	84	81	73	68	73	79	85
87	114	128	127	119	96	87	86	80	74	69	72	76	80	81
106	126	125	127	108	88	92	87	80	80	71	75	77	84	68
106	116	123	119	89	95	99	95	82	76	79	79	79	71	69
99	116	123	119	89	95	99	93	85	74	69	66	70	71	78
88	95	99	96	112	76	104	93	85	74	69	66	70	71	85
90	**93**	**93**	**90**	**102**	**95**	**110**	**101**	**87**	**81**	**77**	**74**	**74**	**81**	**95**

The image after correction for line dropouts (a) and the DN-values (b).

Line striping

Line striping is far more common than line dropouts. Line striping often occurs due to non-identical detector response. Although the detectors for all satellite sensors are carefully calibrated and matched before the launch of the satellite, with time the response of some detectors may drift to higher or lower levels. As a result, every scan line recorded by that detector is brighter or darker than the other lines (see Figure 8.6). It is important to understand that valid data are present in the defective lines, but these must be corrected to match the overall scene.

The image with line striping (a) and the DN-values (b). Note that the destriped image would look similar to the original image.

(a)

96	87	83	94	114	109	107	104	94	83	81	96	90	110	109
89	89	96	94	98	108	111	110	94	80	88	79	73	107	121
104	108	93	92	97	94	86	81	75	83	91	75	75	110	131
150	**127**	**121**	**113**	**129**	**130**	**121**	**116**	**115**	**120**	**127**	**124**	**143**	**148**	**142**
131	143	107	101	122	127	88	86	87	90	90	92	124	122	116
122	155	147	115	145	155	101	91	92	95	102	119	131	128	132
112	127	148	151	159	155	134	91	92	91	106	126	121	112	126
137	152	162	164	161	157	150	98	86	96	118	127	104	121	122
138	149	155	159	168	162	154	123	87	97	126	123	108	125	121
131	137	139	141	148	158	159	137	96	92	122	117	114	121	121
108	132	136	134	135	124	115	106	96	88	90	96	113	120	116
88	101	113	100	94	93	90	84	89	79	82	91	88	102	114
78	68	81	88	73	76	76	78	79	72	76	83	86	86	91
70	85	111	118	100	89	86	85	84	81	73	68	73	79	85
87	114	128	127	119	96	87	86	80	74	69	72	76	80	81
106	126	125	127	108	88	92	87	80	80	71	75	77	84	68
106	116	123	119	89	95	99	95	82	76	79	79	79	71	69
99	116	123	119	89	95	99	93	85	74	69	66	70	71	78
88	95	99	96	112	76	104	93	85	74	69	66	70	71	85
125	**121**	**111**	**119**	**107**	**132**	**160**	**139**	**128**	**121**	**104**	**93**	**99**	**90**	**113**

(b)

Though several procedures can be adopted to correct this effect, the most popular is the histogram matching. Separate histograms corresponding to each detector unit are constructed and matched. Taking one response as standard, the gain (rate of increase of DN) and offset (relative shift of mean) for all other detector units are suitably adjusted, and new DN-values are computed and assigned. This yields a destriped image in which all DN-values conform to the reference level and scale.

Random noise or spike noise

The periodic line dropouts and striping are forms of non-random noise that may be recognized and restored by simple means. Random noise, on the other hand, requires a more sophisticated restoration method such as digital filtering. Random noise or spike noise may be due to errors during transmission of data or to a temporary disturbance. Here, individual pixels acquire DN-values that are much higher or lower than the surrounding pixels. In the image these pixels produce bright and dark spots that interfere within formation extraction procedures. A spike noise can be detected by mutually comparing neighboring pixel values. If neighboring pixel values differ by more than a specific threshold margin, it is designated as a spike noise and the DN is replaced by an interpolated DN-value (based on the values of the surrounding pixels).

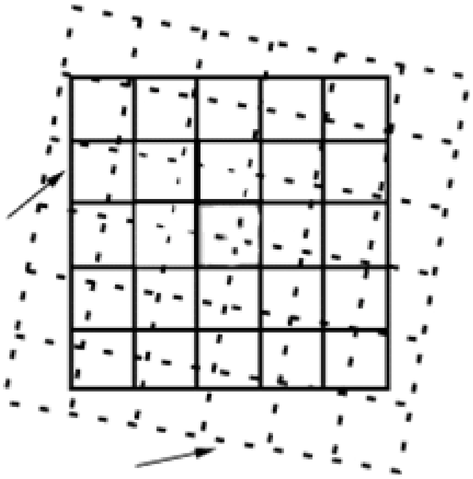
(a) 

96	87	83	94	114	109	107	104	94	83	81	96	90	110	109
89	89	96	94	98	108	111	110	94	80	88	79	73	107	121
104	108	93	92	97	94	86	81	75	**255**	91	75	75	110	131
114	97	93	86	96	100	92	88	88	92	93	92	105	110	106
131	143	107	101	122	127	88	86	87	90	90	92	124	122	116
122	155	147	115	145	155	101	91	92	95	102	119	131	128	132
112	127	148	151	159	155	134	91	92	91	106	126	121	112	126
137	152	162	**0**	161	157	150	98	86	96	118	127	104	121	122
138	149	155	159	168	162	154	123	87	97	126	123	108	125	121
131	137	139	141	148	158	159	137	96	92	122	117	114	121	121
108	132	136	134	135	124	115	106	96	88	90	96	113	120	116
88	101	113	100	94	93	90	84	89	79	82	91	88	102	114
78	68	81	88	73	76	76	78	79	72	76	83	86	86	91
70	85	111	118	100	89	86	85	84	81	73	68	73	79	85
87	114	128	127	119	96	87	86	80	74	69	72	76	80	81
106	126	125	127	108	88	92	87	**255**	80	71	75	77	84	68
106	116	123	119	89	95	99	95	82	76	79	79	79	71	69
99	116	123	119	89	95	99	93	85	74	69	66	70	71	78
88	95	99	96	112	76	104	93	85	74	69	66	70	71	85
91	91	85	87	80	97	115	105	94	87	78	70	73	65	85

(b)

The image with spike errors (a) and the DN-values (b).

5.1.2 Geometric Restoration



For mapping purposes, it is essential that any form of remotely sensed imagery be accurately registered to the proposed map base. With satellite imagery, the very high altitude of the sensing platform results in minimal image displacements due to relief. As a result, registration can usually be achieved through the use of a systematic rubber sheet transformation process that gently warps an image (through the use of polynomial equations) based on the known positions of a set of widely dispersed control points.

With aerial photographs, however, the process is more complex. Not only are there systematic distortions related to tilt and varying altitude, but variable topographic relief leads to very irregular distortions (differential parallax) that cannot be removed through a rubber sheet transformation procedure. In these instances, it is necessary to use photogrammetric rectification to remove these distortions and provide accurate map measurements. Failing this, the central portions of high altitude photographs can be resampled with some success.

RESAMPLE is a module of major importance, and it is essential that one learn to use it effectively. Doing so also requires a thorough understanding of reference systems and their associated parameters such as datums and projections.

5.2. Image Enhancement

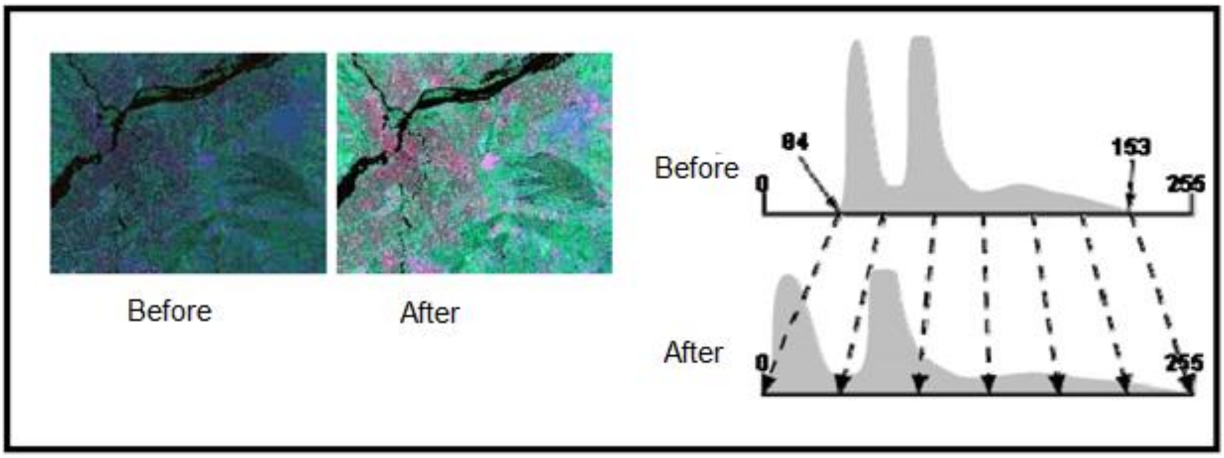
Image enhancement is concerned with the modification of images to make them more suited to the capabilities of human vision. Regardless of the extent of digital intervention, visual analysis invariably plays a very strong role in all aspects of remote sensing. While the range of image enhancement techniques is broad, the following fundamental issues form the backbone of this area:

5.2.1 Contrast Stretch

Digital sensors have a wide range of output values to accommodate the strongly varying reflectance values that can be found in different environments. However, in any single environment, it is often the case that only a narrow range of values will occur over most areas. Grey level distributions thus tend to be very skewed. Contrast manipulation procedures are thus essential to most visual analyses. Figure 1 shows TM Band 3 (visible red) and its histogram.

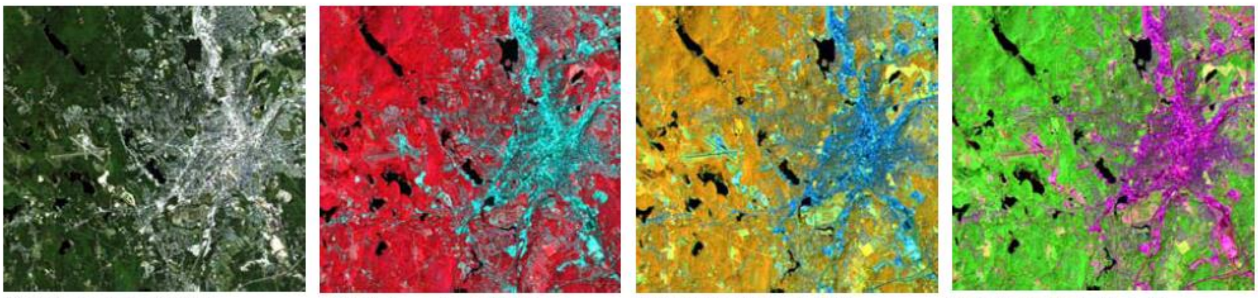
Note that the values of the image are quite skewed. The right image of the figure shows the same image band after a linear stretch between values 12 and 60 has been applied.

This type of contrast is normally used for visual analysis only—original data values are used in numeric analyses. New images with stretched values are produced with the module STRETCH.



5.2.2 Composite Generation

For visual analysis, color composites make fullest use of the capabilities of the human eye. Depending upon the graphics system in use, composite generation ranges from simply selecting the bands to use, to more involved procedures of band combination and associated contrast stretch. Figure shows several composites made with different band combinations from the same set of TM images.



RGB=bands 3,2,1 RGB=bands 4,3,2 RGB=bands 4,5,3 RGB=bands 7,4,2

5.2.3 Digital Filtering

One of the most intriguing capabilities of digital analysis is the ability to apply digital filters. Filters can be used to provide edge enhancement (sometimes called *crispening*), to remove image blur, and to isolate lineaments and directional trends, to mention just a few.

5.3. Image Classification

Image classification refers to the computer-assisted interpretation of remotely sensed images. Although some procedures are able to incorporate information about such image characteristics as texture and context, the majority of image classification is based solely on the detection of the spectral signatures (i.e., spectral response patterns) of land cover classes. The success with which this can be done will depend on two things: 1) the presence of distinctive signatures for the land cover classes of interest in the band set being used; and 2) the ability to reliably distinguish these signatures from other spectral response patterns that may be present.

There are two general approaches to image classification: supervised and unsupervised. They differ in how the classification is performed. In the case of supervised classification, the software system delineates specific landcover types based on statistical characterization data drawn from known examples in the image (known as training sites). With unsupervised classification, however, clustering software is used to uncover the commonly occurring landcover types, with the analyst providing interpretations of those cover types at a later stage.

5.3.1 Supervised Classification

The first step in supervised classification is to identify examples of the information classes (i.e., land cover types) of interest in the image. These are called training sites. The software system is then used to develop a statistical characterization of the reflectances for each information class. This stage is often called signature analysis and may involve developing a characterization as simple as the mean or the range of reflectances on each band, or as complex as detailed analyses of the mean, variances and covariances over all bands.
Once a statistical characterization has been achieved for each information class, the image is then classified by examining the reflectances for each pixel and making a decision about which of the signatures it resembles most. There are several techniques for making these decisions, called classifiers. Most Image Processing software will offer several, based on varying decision rules.

5.3.2 Unsupervised Classification

In contrast to supervised classification, where we tell the system about the character (i.e., signature) of the information classes we are looking for, unsupervised classification requires no advance information about the classes of interest. Rather, it examines the data and breaks it into the most prevalent natural spectral groupings, or clusters, present in the data. The analyst then identifies these clusters as landcover classes through a combination of familiarity with the region and ground truth visits.
The logic by which unsupervised classification works is known as *cluster analysis*. CLUSTER performs classification of composite images (created with COMPOSITE) that combine the most useful information bands. It is important to recognize, however, that the clusters unsupervised classification produces are not information classes, but spectral classes (i.e., they group together features (pixels) with similar reflectance patterns). It is thus usually the case that the analyst needs to reclassify spectral classes into information classes. For example, the system might identify classes for asphalt and cement which the analyst might later group together, creating an information class called pavement.

Accuracy Assessment

A vital step in the classification process, whether supervised or unsupervised, is the assessment of the accuracy of the final images produced. This involves identifying a set of sample locations (such as with the SAMPLE module) that are visited in the field. The land cover found in the field is then compared to that which was mapped in the image for the same location. Statistical assessments of accuracy may then be derived for the entire study area, as well as for individual classes (using ERRMAT). In an iterative approach, the error matrix produced (sometimes referred to as a *confusion matrix*), may be used to identify particular cover types for which errors are in excess of that desired. The information in the matrix about which covers are being mistakenly included in a particular class (*errors of commission*) and those that are being mistakenly excluded (*errors of omission*) from that class can be used to refine the classification approach.

5.4. Image Transformation

Digital Image Processing offers a limitless range of possible transformations on remotely sensed data. Two are mentioned here specifically, because of their special significance in environmental monitoring applications.

5.4.1 Band ratio (e.g., Vegetation Indices)

here are a variety of vegetation indices that have been developed to help in the monitoring of vegetation. Most are based on the very different interactions between vegetation and electromagnetic energy in the red and near-infrared wavelengths. Refer back to Figure 3-4, which includes a generalized spectral response pattern for green broad leaf vegetation. As can be seen, reflectance in the red region (about 0.6 - 0.7_) is low because of absorption by leaf pigments (principally chlorophyll). The infrared region (about 0.8 - 0.9 __, however, characteristically shows high reflectance because of scattering by the cell structure of the leaves. A very simple vegetation index can thus be achieved by comparing the measure of infrared reflectance to that of the red reflectance.

Although a number of variants of this basic logic have been developed, the one which has received the most attention is the *normalized difference vegetation index* (NDVI). It is calculated in the following manner:

NDVI = (NIR - R) / (NIR + R)

where NIR = Near Infrared

and R = Red

This kind of calculation is quite simple for a raster GIS or Image Processing software system, and the result has been shown to correlate well with ground measurements of biomass. Although NDVI needs specific calibration to be used as an actual measure of biomass, many agencies have found the index to be useful as a relative measure for monitoring purposes. For example, the United Nations Food and Agricultural Organization (FAO) Africa Real Time Information System (ARTEMIS) and the USAID Famine Early Warning System (FEWS) programs both use continental scale NDVI images derived from the NOAA-AVHRR system to produce vegetation index images for the entire continent of Africa every ten days. While the NDVI measure has proven to be useful in a variety of contexts, a large number of alternative indices have been proposed to deal with special environments, such as arid lands.

5.4.2 Principal Components Analysis

Principal Components Analysis (PCA) is a linear transformation technique related to Factor Analysis. Given a set of image bands, PCA produces a new set of images, known as components, that are uncorrelated with one another and are ordered in terms of the amount of variance they explain from the original band set. PCA has traditionally been used in remote sensing as a means of data compaction. For a typical multispectral image band set, it is common to find that the first two or three components are able to explain virtually all of the original variability in reflectance values. Later components thus tend to be dominated by noise effects. By rejecting these later components, the volume of data is reduced with no appreciable loss of information. Given that the later components are dominated by noise, it is also possible to use PCA as a noise removal technique. By zeroing out the coefficients of the noise components in the reverse transformation, a new version of the original bands can be produced with these noise elements removed.

Recently, PCA has also been shown to have special application in environmental monitoring. In cases where multispectral images are available for two dates, the bands from both images are submitted to a PCA as if they all came from the same image. In these cases, changes between the two dates tend to emerge in the later components. More dramatically, if a time series of NDVI images (or a similar single-band index) is submitted to the analysis, a very detailed analysis of environmental changes and trends can be achieved. In this case, the first component will show the typical NDVI over the entire series while each successive component illustrates change events in an ordered sequence of importance. By examining these images, along with graphs of their correlation with the individual bands in the original series, important insights can be gained into the nature of changes and trends over the time series.