

Remote sensing: It is the science of deriving information about an object without actually coming in contact with it.

“It is the practice of deriving information about the Earth’s land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the Earth Surface.”

Milestones in the history of remote sensing:

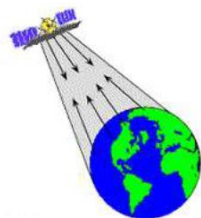
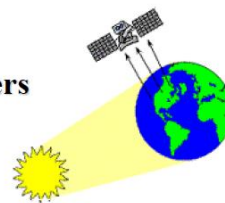
- 1800 Discovery of infrared by Sir William Herschel
- 1839 Beginning of practice of photography
- 1847 Infrared spectrum shown by A.H.L. Fizeau and J.B.L. Foucault to share properties with visible light
- 1850-1860 Photography from balloons
- 1873 Theory of electromagnetic energy developed by James Clerk Maxwell
- 1909 Photography from airplanes
- 1914-1918 World War I: aerial reconnaissance
- 1920-1930 Development and initial applications of aerial photography and photogrammetry
- 1929-1939 Economic depression generates environmental crises that lead to governmental applications of aerial photography
- 1930-1940 Development of radars in Germany, United States and United Kingdom
- 1939-1945 World War II: application of nonvisible portion of electromagnetic spectrum, training of persons in acquisition and interpretation of airphotos
- 1950-1960 Military research and development
- 1956 Colwell’s research on plant disease detection with infrared photography
- 1960-1970 First use of term remote sensing
 - TIROS weather satellite
 - Skylab remote sensing observation from space
- 1972 Launch of Landsat 1
- 1970-1980 Rapid advances in digital image processing
- 1980-1990 Landsat 4: new generation of Landsat sensors
- 1986 SPOT French Earth observation satellite
- 1980s Development of hyperspectral sensors
- 1990s Global remote sensing system, Lidars

Remote sensing sensors

REMOTE SENSORS

Passive Sensors

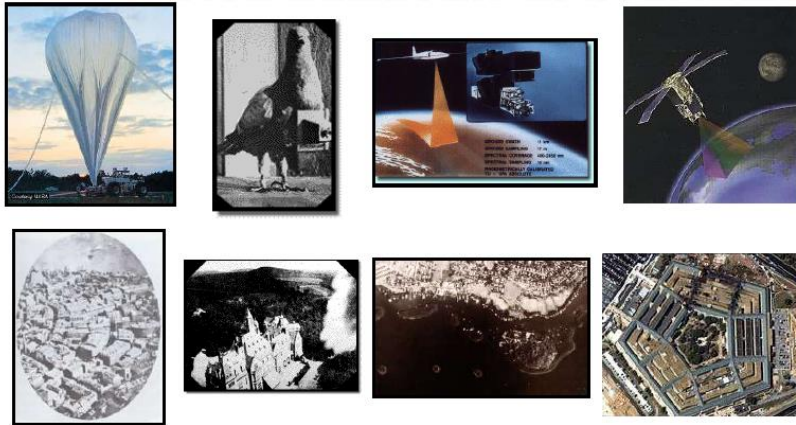
- Aerial Cameras
- Visible and IR Scanners
- Thermal



Active Sensors

- Acoustic Sensors
 - Microwave (Radar)
 - Lidar
-

Remote sensing platforms:



Balloons → Pigeons → Airplanes → Satellites

1859 - Gaspard Felix Tournachon (also known as Nadar) used balloons as platforms to take the first aerial photographs.

1880 - M. A. Batut took aerial photos in France using kites.

1903 - Bavarian Pigeons are used with the first light camera. This camera took photos every 30 seconds during the bird flight. They were faster than balloons and much smaller.

1908 - Wilbur Wright was a very important pilot for remote sensing. The first photograph from an airplane was taken by L. P. Bonvillain in France during a demo flight.

World wars 1910-1950

- The planes replaced the balloons and pigeons in observing the enemy lines.
- Aerial photography was strongly developed.
- Photos were used by world nations for aerial reconnaissance.
- At the end of the wars this new technology was very much appreciated.

Interwar Years 1919-1939

The science of photogrammetry was applied to aerial photography.

Photogrammetry is the practice of making accurate measurements from photographs.

Satellite remote sensing 1970s

- In July 1972 NASA launched the first “Earth Resources Technology Satellite” (ERTS-1).
- These multispectral data provided a better understanding of our planet, including land used and land cover, urban development, and Earth global processes.
- The name was later changed to LANDSAT and it has been a very successful long-term mission.

Meteorological sensor

- In the 70’s other sensors were developed to acquire images in other regions of the electromagnetic spectrum besides the visible, like the mid infrared and the thermal infrared.
- They had large field of view (in hundreds of kilometers).
- Such large-scale cover was valuable for meteorology.

Earth observing system 1990s

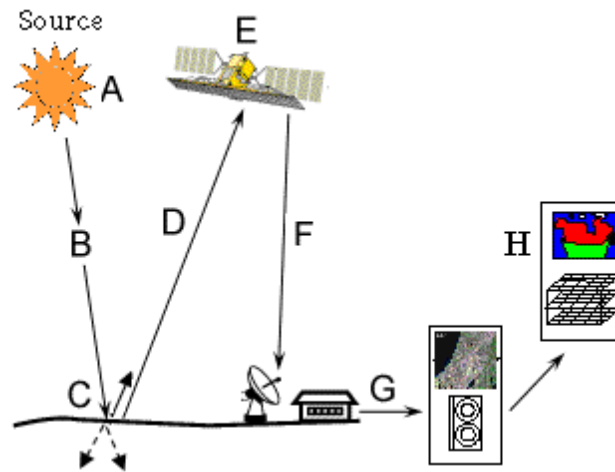
Stages of remote sensing

Main stages in remote sensing are the following:

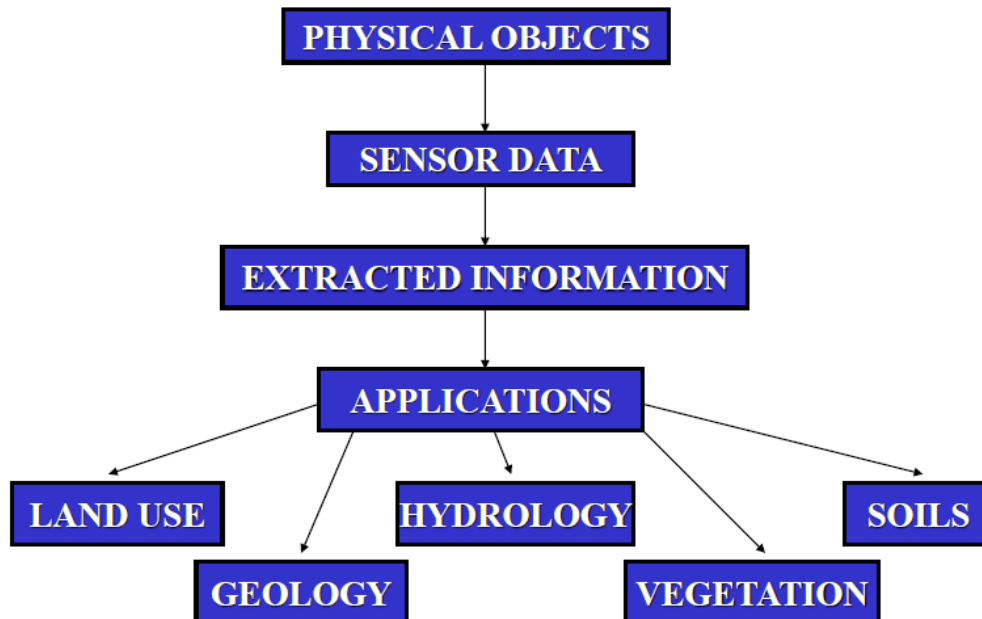
A. Emission of electromagnetic radiation

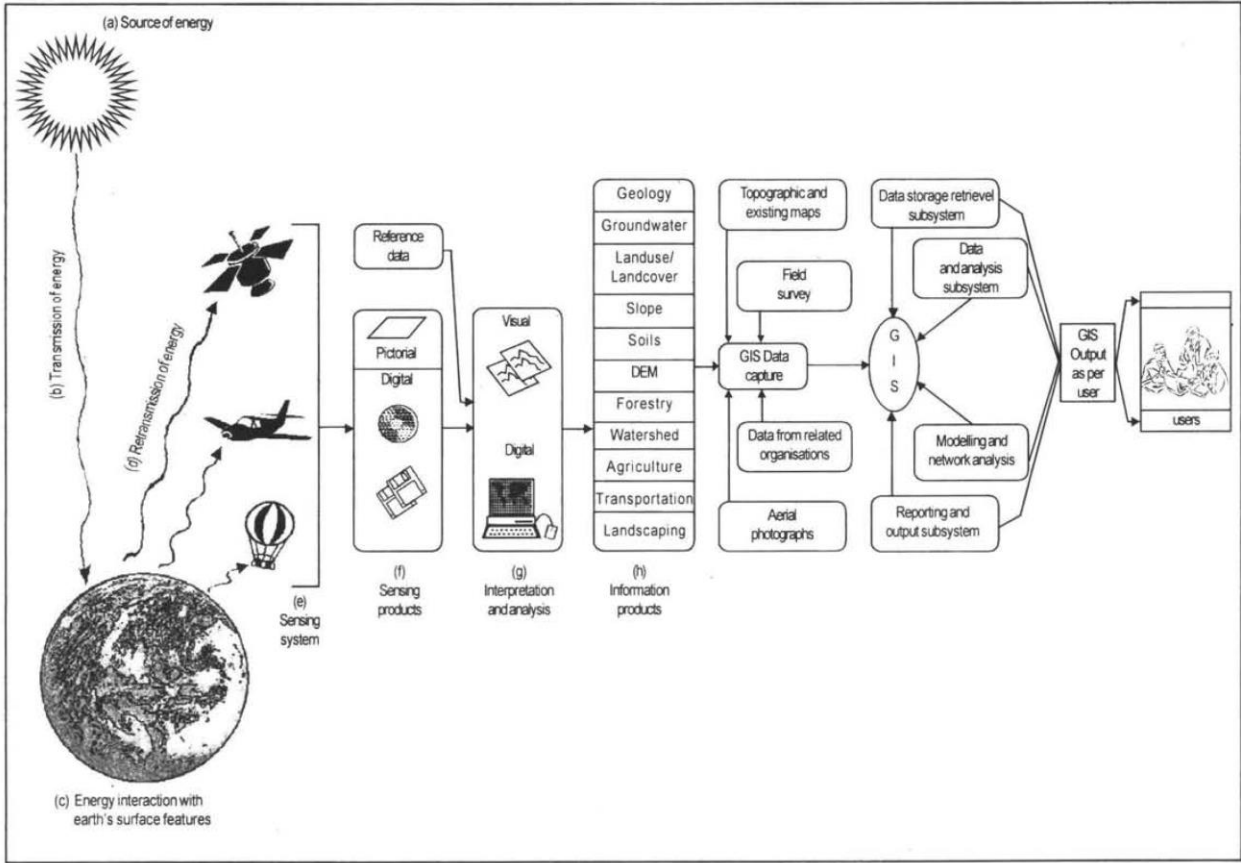
- The Sun or an EMR source located on the platform

- B. Transmission of energy from the source to the object
 - Absorption and scattering of the EMR while transmission
- C. Interaction of EMR with the object and subsequent reflection and emission
- D. Transmission of energy from the object to the sensor
- E. Recording of energy by the sensor
 - Photographic or non-photographic sensors
- F. Transmission of the recorded information to the ground station
- G. Processing of the data into digital or hard copy image
- H. Analysis of data



OVERVIEW OF REMOTE SENSING PROCESS





Electromagnetic Remote Sensing Process with overview on GIS

Resolution refers to the ability of a remote sensing system to record and display fine details. The types of resolutions are:

SPECTRAL DIFFERENTIATION - Remote sensing depends on observed spectral differences in the energy reflected or emitted from features of interest.

Spectral Resolution: This refers to the number of bands in the spectrum in which the instrument can take measurements.

- Human Eye = 3 channels (RGB) + 1 Pan.

Pan indicating that the visible spectrum is represented as a single channel (without distinguishing between the three primary colors)

- Landsat TM = 7 channels
- SeaWiFS = 8 channels
- AVIRIS = 224 channels.

This refers to the number of bands in the spectrum in which the instrument can take measurements. Eg. **Landsat TM = 7 channels**

RADIOMETRIC DIFFERENTIATION – Examination of any image acquired by remote sensing ultimately depends on detection of differences in the brightness of objects and the features.

Radiometric Resolution: This is the sensitivity to small differences in the radiation of an observed object.

- Landsat TM = 8 bits
- MODIS = 12 bits
- ERS SAR = 16 bits

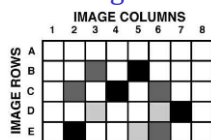
This is the sensitivity to small differences in the radiation of an observed object.

Eg. **Landsat TM = 8 bit**

SPATIAL DIFFERENTIATION - Every sensor is limited in respect to the size of the smallest area that can be separately recorded as an entity on an image.

Spatial Resolution: This represents the ability of the sensor to detect and distinguish small objects and fine detail in larger objects. Depends on the instrument's sensitivity and distance from the object, and defines the **pixel size** of a digital image.

- Landsat TM = 30 m
- AVHRR = 1 km
- Meteosat = 7 Km
- IKONOS = 1 m



This represents the ability of the sensor to detect and distinguish small objects and fine detail in larger objects. Depends on the instrument's sensitivity and distance from the object, and defines the pixel size of a digital image. Eg. **Landsat TM = 30m**

TEMPORAL DIMENSIONS- Although a single image can easily demonstrate the value of remotely sensed imagery, its effectiveness is best demonstrated through the use of many images of the same region acquired over time.

TEMPORAL RESOLUTION: Represents the frequency with which a sensor can revisit an area of interest and acquire a new image. Depends on the instrument's field of vision, and the platform (i.e. satellite vs. airplane).

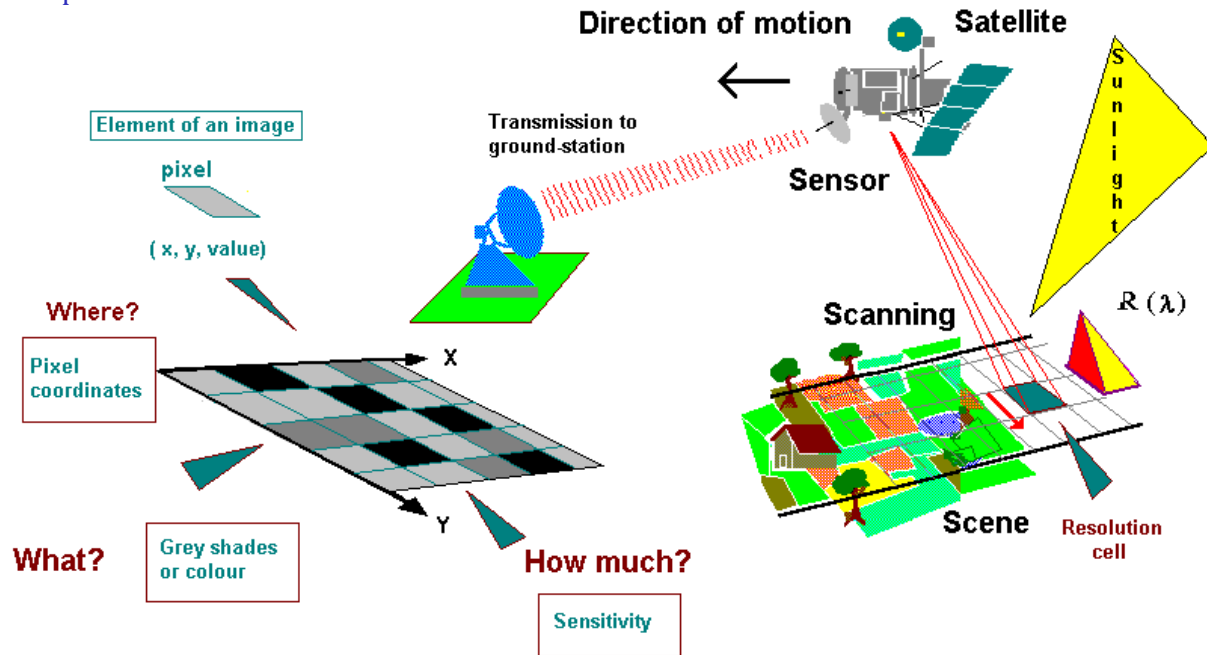
Represents the frequency with which a satellite can re-visit an area of interest and acquire a new image. Depends on the instrument's field of vision, and the satellite's orbit. Eg. **Landsat TM 16 days**

GEOMETRIC TRANSFORMATION – Every remotely sensed image represents a landscape in a specific geometric relationship determined by the design of the remote sensing instrument, specific operating conditions, terrain relief, and other factors.

Each image includes positional errors caused by the perspective of the sensor optics, the motion of scanning optics, terrain relief, and Earth curvature.

REMOTE SENSING INSTRUMENTATION ACTS AS A SYSTEM - The image analyst must always be conscious of the fact that the many components of the remote sensing process *act as a system* and therefore cannot be isolated from one another.

This means that the interpreter must know the remote sensing system and the subject of the interpretation.



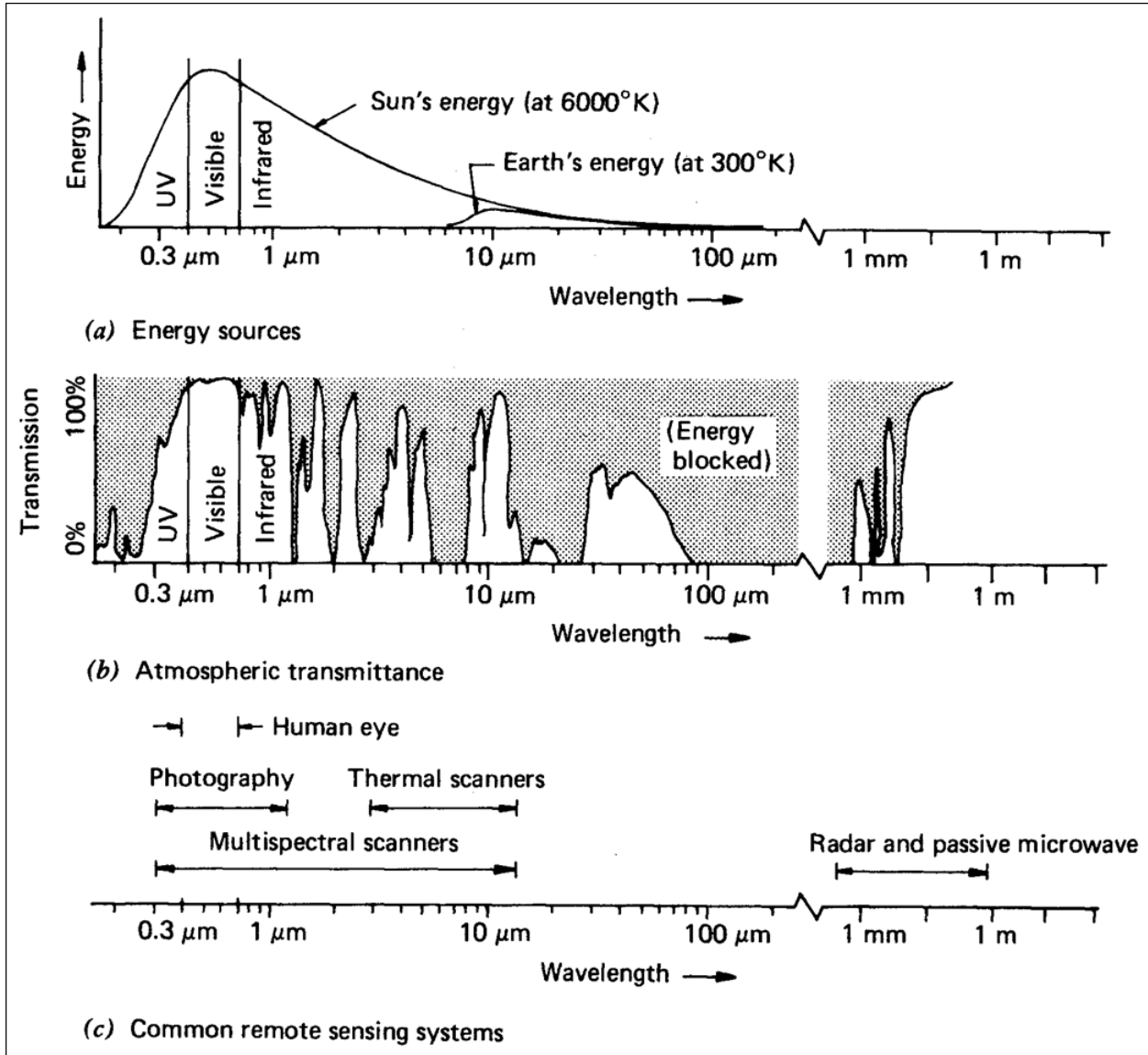
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ROLE OF THE ATMOSPHERE - All energy reaching the remote sensing instrument must pass through a portion of the Earth's atmosphere. The Sun's energy is altered in intensity and wavelength by particles and gases in the Earth's atmosphere.

These changes appear on the image in ways that degrade image quality or influence the accuracy of interpretation.

In satellite images the Atmosphere is 90% of the total signal.

Atmospheric window

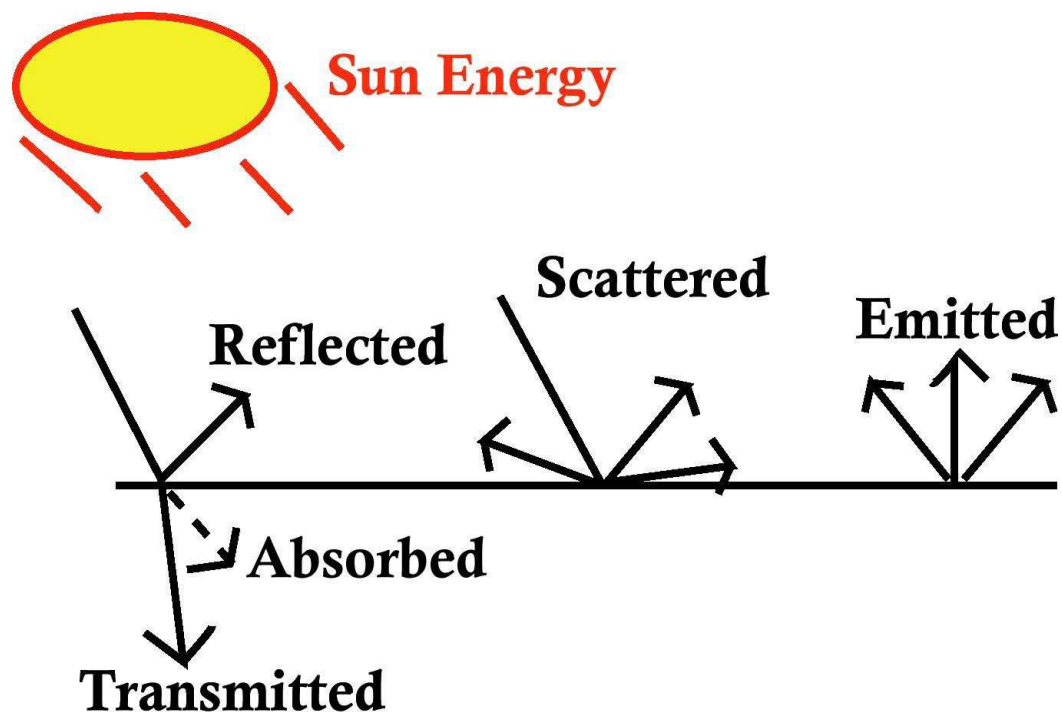


Major atmospheric windows used in remote sensing and their characteristics

Atmospheric window	Wavelength band μm	Characteristics
Upper ultraviolet, Visible and photographic IR	0.3-1 apprx.	95% transmission
Reflected infrared	1.3, 1.6, 2.2	Three narrow bands
Thermal infrared	3.0-5.0 8.0-14.0	Two broad bands
Microwave	> 5000	Atmosphere is mostly transparent

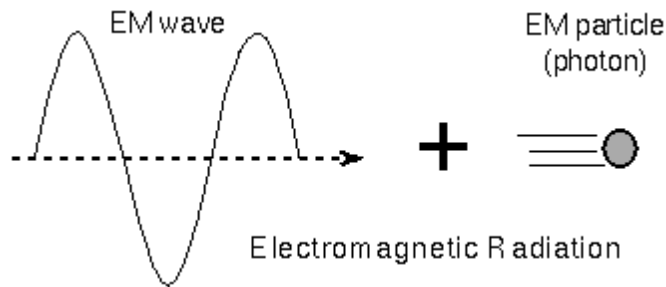
Electromagnetic radiation

- With the exception of objects at absolute zero, all objects **emit** electromagnetic radiation (EMR).
- Objects also **reflect** radiation that has been emitted by other objects.
- Electromagnetic energy is generated by several mechanisms.
- Remote sensing imagery is interpreted based on the interaction of the EMR with the Earth's objects and the atmosphere.



•It is a way to transfer energy through space, which has properties of wave and particle.

- **Every object with a temperature higher than 0 K (-273.15 oC / -459.67 oF) emits electromagnetic radiation.**



Sources of Sun's energy

The fusion process: Nuclear reactions where lightweight chemical elements (like hydrogen) form heavier elements (such as helium and carbon). This process converts matter (i.e. mass of an atom) to energy.

Albert Einstein in 1905 showed that: $E = mc^2$

Where, E= Energy

m= mass

c=speed of light in a vacuum (3.0×10^8 m/s)

The Sun produces its energy by two fusion reactions:

1. Proton-Proton (PP) – 88%
2. Carbon-Nitrogen-Oxygen (CNO) – 12%

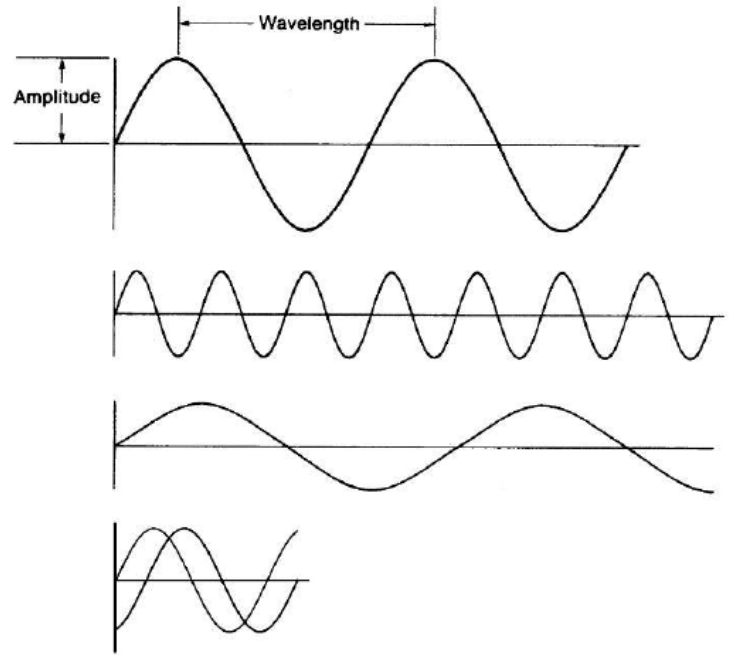
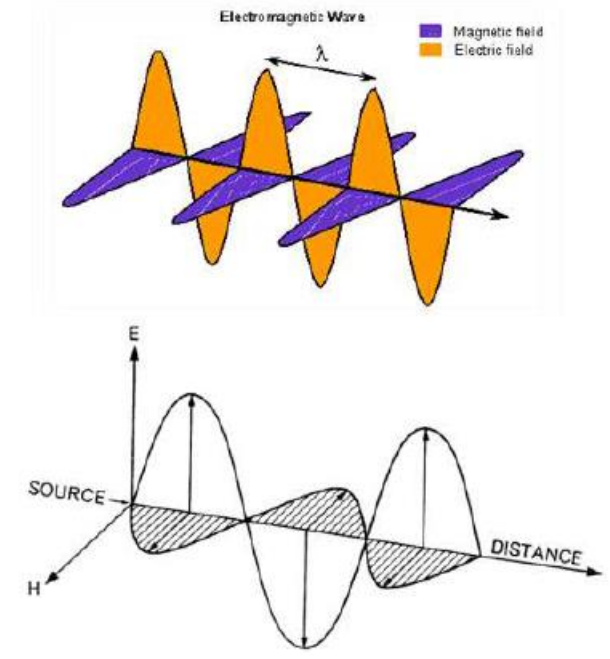
Wave properties

James Clerk Maxwell (1864): Theory of Electromagnetic Radiation

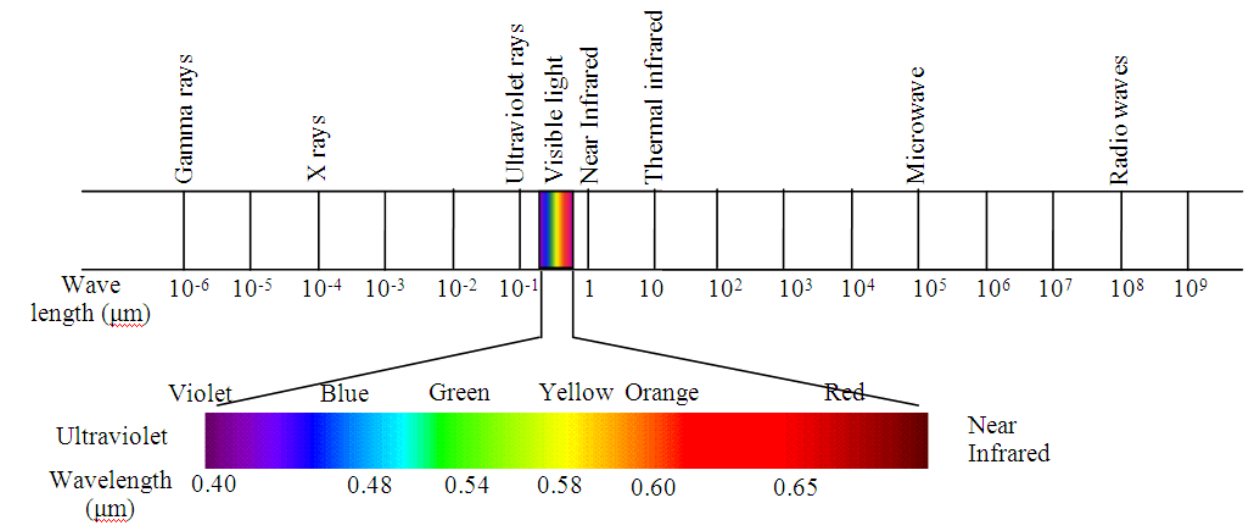
- This radiation is made of the **electric and magnetic fields**, that travel perpendicular to each other along the wave propagation.
- These waves can be described with **wavelength and frequency**.
- They vary proportional inverse and are related by the following equation:

$$f = c/\lambda$$

where c = velocity of light (constant)



Electromagnetic spectrum



Division	Limits
Gamma rays	< 0.03 nm
X-rays	0.03–300 nm
Ultraviolet radiation	0.30–0.38 μm
Visible light	0.38–0.72 μm
Infrared radiation	
Near infrared	0.72–1.30 μm
Mid infrared	1.30–3.00 μm
Far infrared	7.0–1,000 μm (1 mm)
Microwave radiation	1 mm–30 cm
Radio	\geq 30 cm

Particles properties

This radiation can be described equally well in terms of waves or in terms of packets of radiant energy called **quanta** or **photons**. The relationship between these two "forms" of electromagnetic radiation is:

$$E = hf$$

Where,

E = Energy of a photon (joules)

h = Planck's constant (joules * s)

f = frequency (hertz)

1 hertz=cycle/second

Therefore, the energy of a photon is directly proportional to the frequency but indirectly proportional to the wavelength.

Q. What is the energy of a photon with a wavelength of 400 nm?

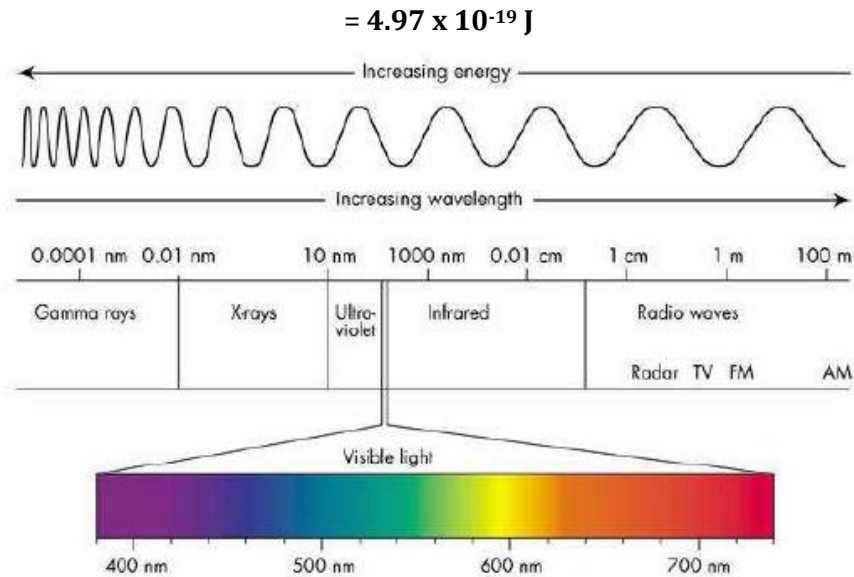
1. Get wavelength (λ) in meters:

$$1 \text{ nm} = 10^{-9} \text{ meters}$$

$$? \text{ meters} = 400 \text{ nm} (10^{-9} \text{ m}) / 1 \text{ nm} = 4 \times 10^{-7} \text{ meters}$$

2. Get the frequency: $f = c/\lambda = (3 \times 10^8 \text{ m})/\text{s} / (4 \times 10^{-7} \text{ m}) = 7.5 \times 10^{14} \text{ cycles/second (or Hz)}$

3. Get the energy: $E = hf = (6.63 \times 10^{-34} \text{ J*s}) (7.5 \times 10^{14} / \text{s})$



At 400 nm **At 500 nm** **At 700 nm**
 $E=4.97 \times 10^{-19} \text{ J}$ **$E=3.98 \times 10^{-19} \text{ J}$** **$E=2.84 \times 10^{-19} \text{ J}$**

Scattering of the electromagnetic radiation in the atmosphere

Atmospheric scattering is the process by which small particles in the atmosphere diffuse a portion of the incident radiation in all directions. There is no energy transformation while scattering. But the spatial distribution of the energy is altered during scattering.

There are three different types of scattering:

- Rayleigh scattering
- Mie scattering
- Non-selective scattering

Rayleigh scattering

Rayleigh scattering mainly consists of scattering caused by atmospheric molecules and other tiny particles. This occurs when the particles causing the scattering are much smaller in diameter (less than one tenth) than the wavelengths of radiation interacting with them.

Mie Scattering

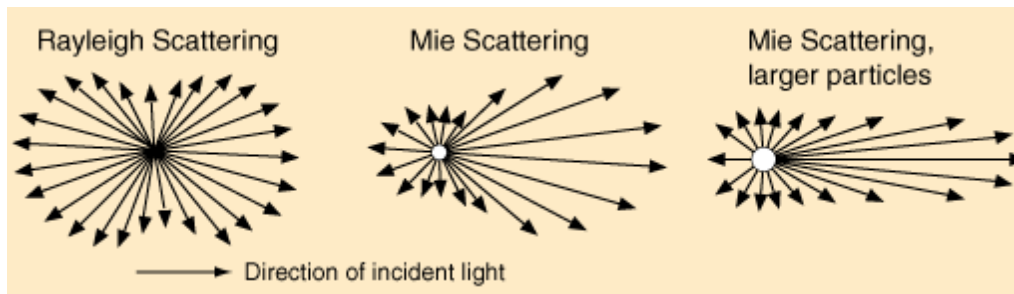
Another type of scattering is Mie scattering, which occurs when the wavelengths of the energy is almost equal to the diameter of the atmospheric particles. In this type of scattering longer wavelengths also get scattered compared to Rayleigh scatter.

Mie scattering is usually caused by the aerosol particles such as dust, smoke and pollen. Gas molecules in the atmosphere are too small to cause Mie scattering of the radiation commonly used for remote sensing.

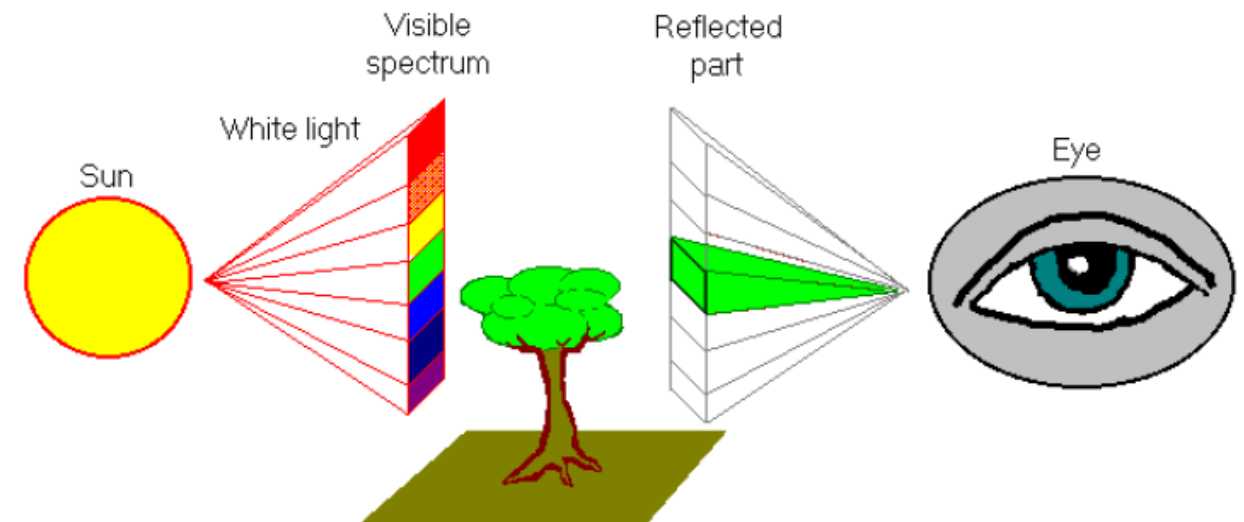
Non-selective scattering

A third type of scattering is nonselective scatter, which occurs when the diameters of the atmospheric particles are much larger (approximately 10 times) than the wavelengths being sensed. Particles such as pollen, cloud droplets, ice crystals and raindrops can cause non-selective scattering of the visible light.

For visible light (of wavelength 0.4-0.7 μm), non-selective scattering is generally caused by water droplets which is having diameter commonly in the range of 5 to 100 μm . This scattering is nonselective with respect to wavelength since all visible and IR wavelengths get scattered equally giving white or even grey color to the clouds.



Visible spectrum



Energy interactions with Earth's surface materials

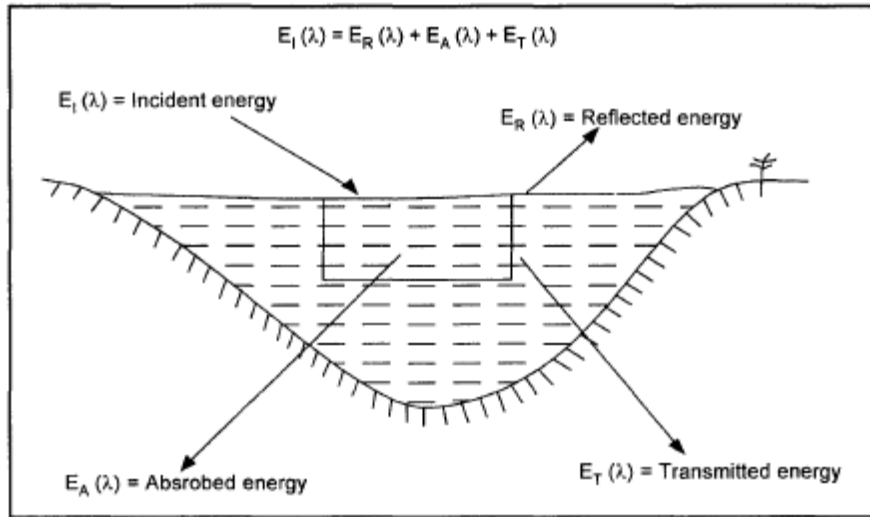
When electromagnetic energy is incident on any feature of earth's surface, such as a water body, various fractions of energy get reflected, absorbed, and transmitted. Applying the principle of conservation of energy, the relationship can be expressed as:

$$E_i(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$$

E_i = Incident energy

E_R = Reflected energy

E_A = Absorbed energy
 E_T = Transmitted energy



In remote sensing, the amount of reflected energy $E_R(\lambda)$ is more important than the absorbed and transmitted energies. Therefore, it is more convenient to rearrange these terms like:

$$E_R(\lambda) = E_i(\lambda) - [E_A(\lambda) + E_T(\lambda)]$$

This equation is called balance equation. From this mathematical equation, two important points can be drawn. Firstly,

$$\frac{E_R(\lambda)}{E_i(\lambda)} = \frac{E_i(\lambda) - [E_A(\lambda) + E_T(\lambda)]}{E_i(\lambda)}$$

$\frac{E_R(\lambda)}{E_i(\lambda)}$, $\frac{E_A(\lambda)}{E_i(\lambda)}$ and $\frac{E_T(\lambda)}{E_i(\lambda)}$ are called Reflectance, Emittance and Transmittance and can denoted as: $\rho(\lambda)$, $\alpha(\lambda)$ and $\gamma(\lambda)$

Simply, it can be understood that, the measure of how much electromagnetic radiation is reflected off a surface is called its reflectance. The reflectance range lies between 0 and 1. A measure of 1.0 means that 100% of the incident radiation is reflected off the surface, and a measure '0' means that 0% is reflected. The reflectance characteristics are quantified by "spectral reflectance, $\rho(\lambda)$ which is expressed as the following ratio:

$$\rho(\lambda) = \frac{E_R(\lambda)}{E_i(\lambda)} = \frac{\text{Energy of the wavelength } \lambda \text{ reflected from the object}}{\text{Energy of the wavelength } \lambda \text{ incident upon the object}}$$

can be written as:

$$\rho(\lambda) = 1 - [\alpha(\lambda) + \gamma(\lambda)]$$

Since, almost all earth surface features are very opaque in nature, the transmittance $\gamma(\lambda)$ can be neglected. According to Kirchoff's law of physics, the absorbance is taken as emissivity (ξ).

$$\text{Therefore, } \rho(\lambda) = 1 - \xi(\lambda)$$

This is the fundamental equation by which the conceptual design of remote sensing technology is built. If $\xi(\lambda)$ is a zero, then $\rho(\lambda)$, that is, the reflectance is one, which means, the total energy incident on the object is reflected and recorded by sensing systems. The classical example of this type of object is snow (white object). If $\xi(\lambda)$ is one, then $\rho(\lambda)$ is a zero indicating that whatever the energy incident on the object, is completely absorbed by that object. Black body such as lamp

smoke is an example of this type of object. Therefore, it can be seen that the reflectance varies from 0 (black body) to 1 (white body).

When we divide the incident energy on both sides of the balance equation, we get the proportions of energy reflected, absorbed and transmitted which vary for different features of the earth depending on the material type. These differences provide a clue to differentiate between features of an image. Secondly, from the wavelength dependency of the energy components, it is evident that even within a given feature type, the proportion of reflected, absorbed, and transmitted energies may vary at different wavelengths. Therefore, two features which are indistinguishable in one spectral range, may exhibit a marked contrast in another wavelength band. Because many remote sensing systems operate in the wavelength regions in which reflected energy predominates, the reflectance properties of terrestrial features are very important.

Spectral reflectance

A basic assumption made in remote sensing is that a specific target has an individual and characteristic manner of interacting with incident radiation. The manner of interaction is described by the spectral response of the target.

- Represents the reflectance characteristics of earth surface features
- Ratio of energy reflected by the surface to the energy incident on the surface
- Measured as a function of wavelength
- Also known as Albedo
- Mathematical representation of spectral reflectance or albedo

$$R_{\lambda} = \frac{E_R(\lambda)}{E_I(\lambda)}$$

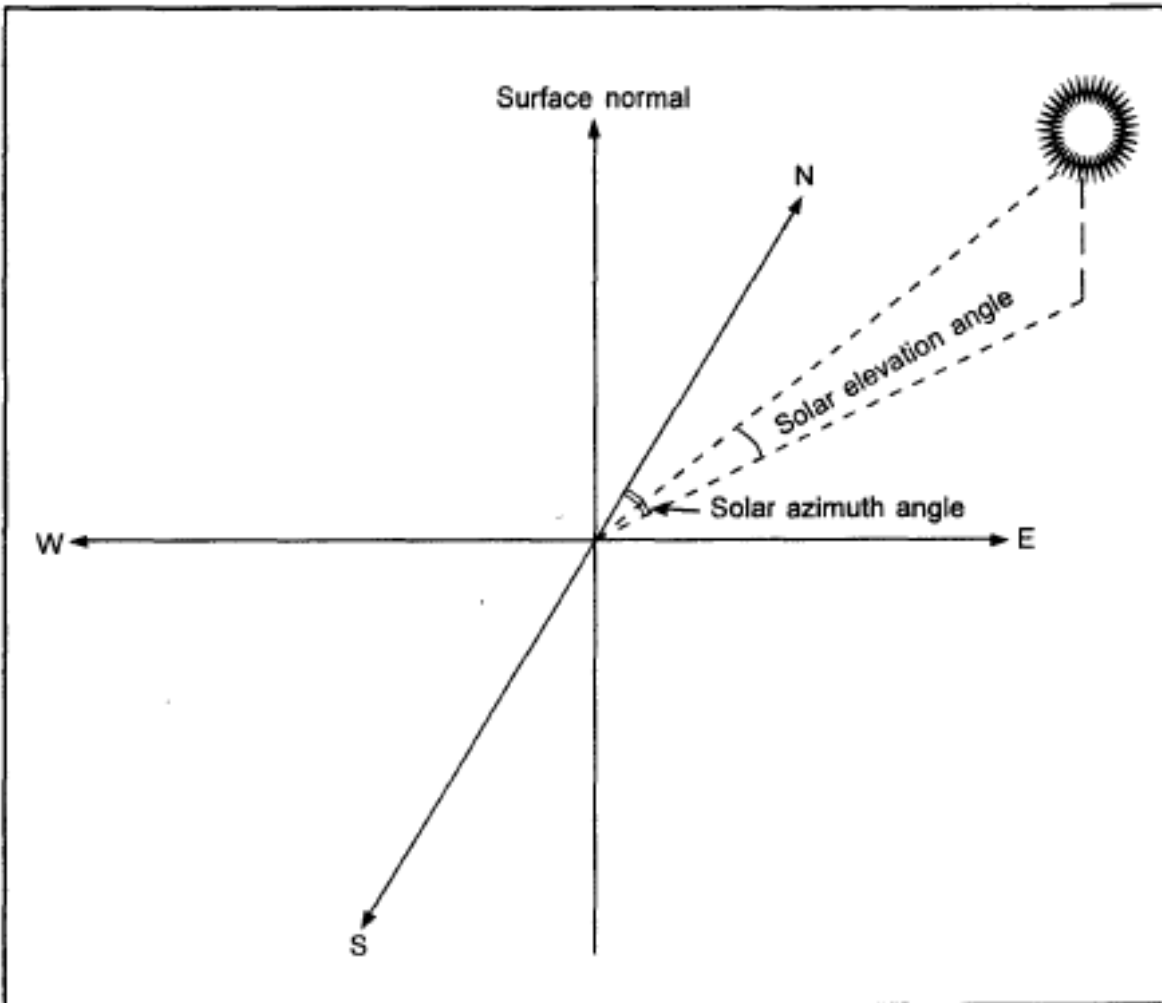
$$= \frac{\text{Energy of wavelength } \lambda \text{ reflected from the object}}{\text{Energy of wavelength } \lambda \text{ incident on the object}} \times 100$$

Albedo of the earth surface features:

Surface type	Albedo %
Grass	25
Concrete	20
Water	5-70
Fresh snow	80
Forest	5-10
Thick cloud	75
Dark soil	5-10

Spectral reflectance curve

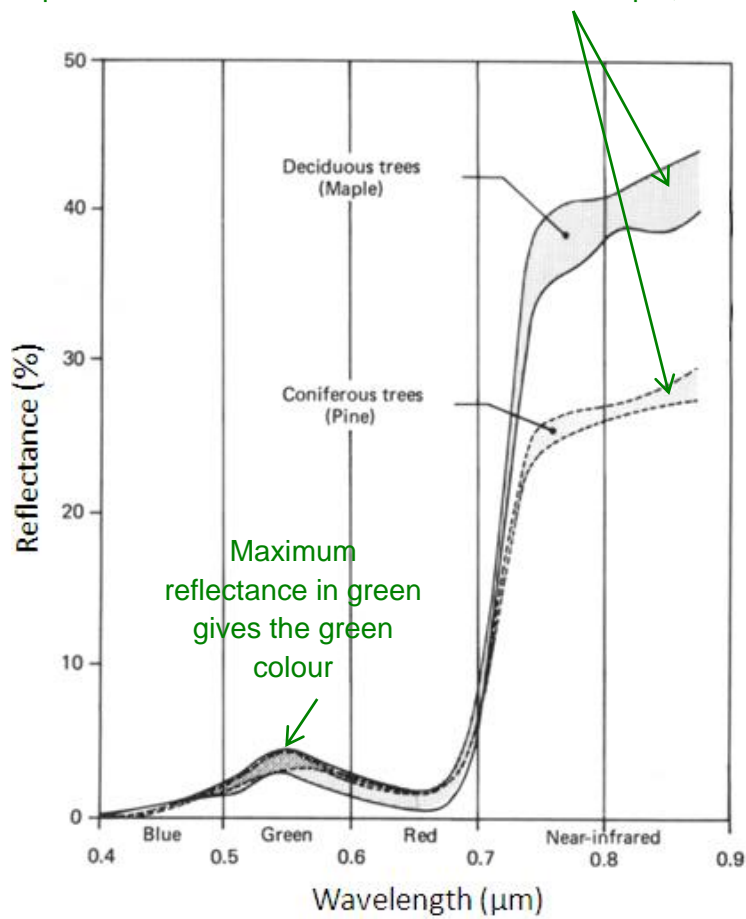
The spectral reflectance curves describe the spectral response of a target in a particular wavelength region of electromagnetic spectrum, which, in turn depends upon certain factors, namely, orientation of the sun (solar azimuth), the height of the Sun in the sky (solar elevation angle), the direction in which the sensor is pointing relative to nadir (the look angle), and nature of the target, that is, state of health of vegetation.



- Graphical representation of the spectral response over different wavelengths of the electromagnetic spectrum
 - Give an insight into the spectral characteristics of different objects
 - Used for the selection of a particular wavelength band for remote sensing data acquisition
- Energy reflected from the surface is recorded in remote sensing
- Fraction of energy that is reflected / scattered is unique for each material
 - Used for distinguishing different features on an image

- Within a feature class, energy reflected / emitted / absorbed depends on the wavelength
 - Features may be similar and hence indistinguishable using single spectral band
 - Their reflectance properties may be different in another spectral band
 - Use of multiple wavelength bands helps to further differentiate the features within one class
 - Reflected energy from multiple wavelength bands are recorded in multi-spectral remote sensing

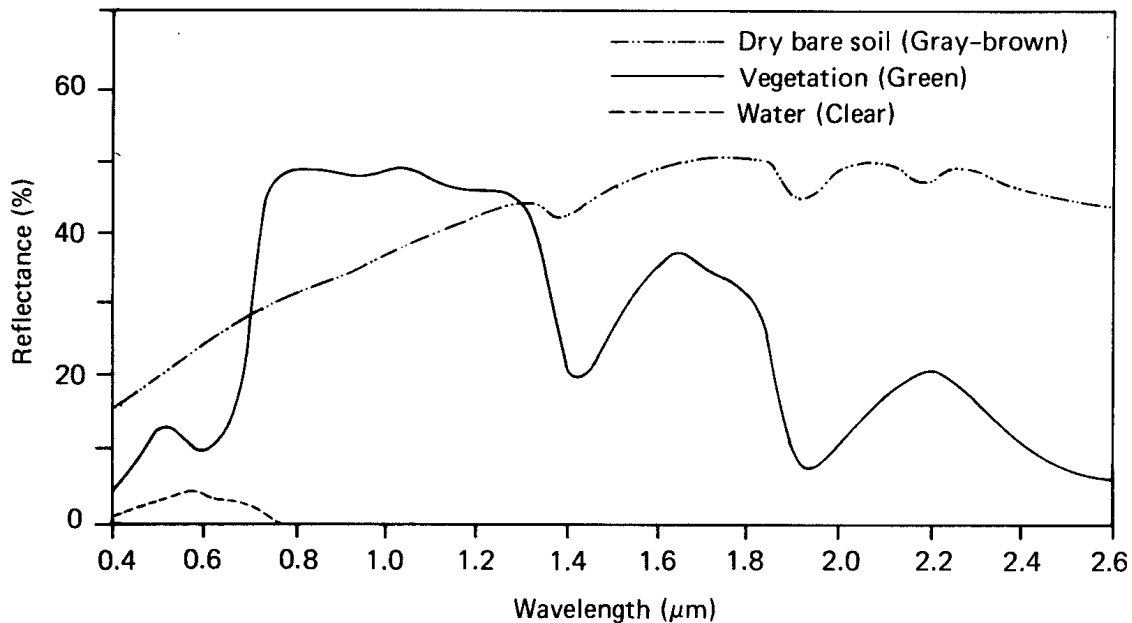
Spectral reflectance within one class is not unique, and hence the ranges are shown



Example:

Generalized spectral reflectance curves for deciduous and coniferous trees. Sensor selection to differentiate deciduous and coniferous trees. Curves overlap in the visible portion. Deciduous and coniferous trees cannot be differentiated through visible spectrum. Spectral reflectance are quite different in NIR. Deciduous and coniferous trees can be differentiated through NIR spectrum.

- Spectral reflectance curve of some of the important earth surface features
 - Vegetation
 - Bare soil
 - Water



Typical spectral reflectance curves for vegetation, soil and water (Lillesand et al., 2004)

- Average reflectance curves of healthy vegetation, dry barren soil and clear water bodies
 - Reflectance of individual features varies considerably above and below the average
 - The average curves demonstrate some fundamental points concerning spectral reflectance
- Spectral reflectance curve for **healthy green vegetation** exhibits the "peak-and-valley" configuration
 - Peaks indicate strong reflection in the wavelength bands

- Valleys indicate predominant absorption of the energy in the wavelength band
- Good absorption in visible region (0.4-0.7 μm)
- Absorption reduces and reflection increases in the red/infrared boundary near 0.7 μm
- Reflectance is nearly constant from 0.7-1.3 μm
- Reflectance decreases for longer wavelengths
- Spectral reflectance curve for **soil** shows considerably less peak-and-valley variation compared to that for vegetation
 - The factors that influence soil reflectance act over less specific spectral bands
- Factors affecting soil reflectance
 - Moisture content
 - Soil texture (proportion of sand, silt, and clay)
 - Surface roughness
 - Presence of iron oxide and organic matter
- These factors are complex, variable, and interrelated
- Dry soil
 - Coarse texture → Less reflectance → Dark tone
 - Fine texture → more reflectance → Light tone
- Wet soils display reverse tendency
 - Moisture content reduces the reflectance
 - Coarse texture → better drainage → less moisture content → good reflectance
 - Fine texture → poor drainage → more moisture content → poor reflectance
 - Water absorption bands are at 1.4, 1.9, and 2.2 μm wavelengths
 - Clay soils have hydroxyl ion absorption bands at 1.4 and 2.2 μm .
 - Surface roughness reduces the reflectance
 - Presence of organic matter reduces the soil reflectance

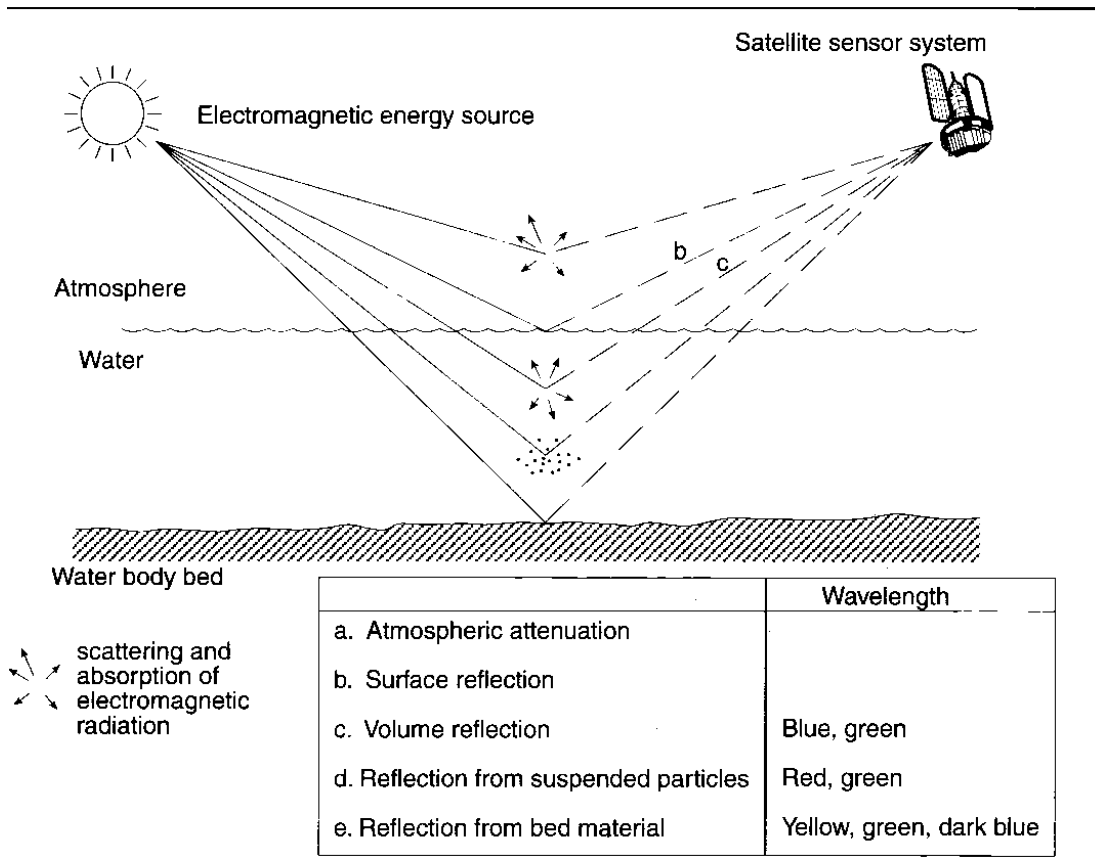
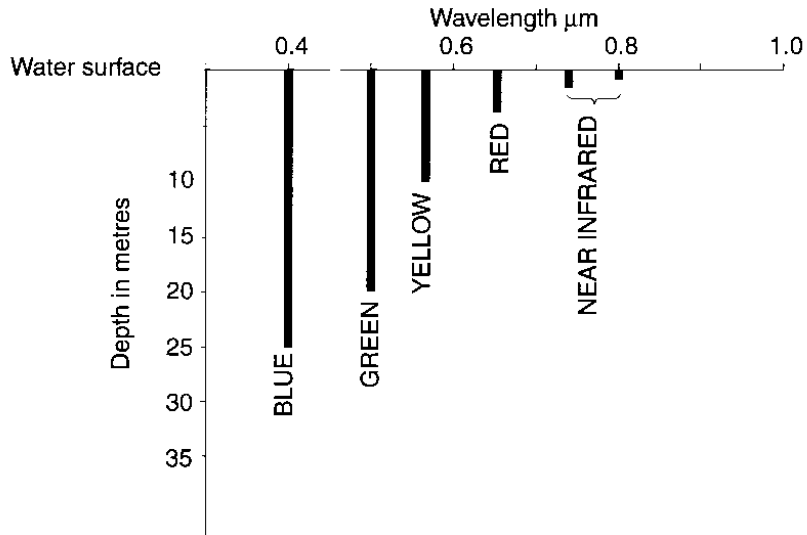
- Presence of iron oxide significantly decreases soil reflectance, at least in the visible region

Water provides a semi-transparent medium for the electromagnetic radiation

- Electromagnetic radiations get reflected, transmitted or absorbed in water
- Spectral responses varies with
 - Wavelength of the radiation
 - Physical and chemical characteristics of the water
- Water in liquid phase
 - High reflectance in the visible region between 0.4 μ m and 0.6 μ m
 - Wavelengths beyond 0.7 μ m are completely absorbed.
- Water in solid phase (ice or snow)
 - Good reflection at all visible wavelengths
- Liquid water
 - High reflectance in the visible region between 0.4 μ m and 0.6 μ m
 - Wavelengths beyond 0.7 μ m are completely absorbed.
- ✓ Clear water appears darker in tone in the NIR image
- ✓ Mapping of water bodies with remote sensing data is done in reflected infrared wavelengths
- ✓ The water body appears in dark colour in all bands and displays sharp contrast in the IR bands

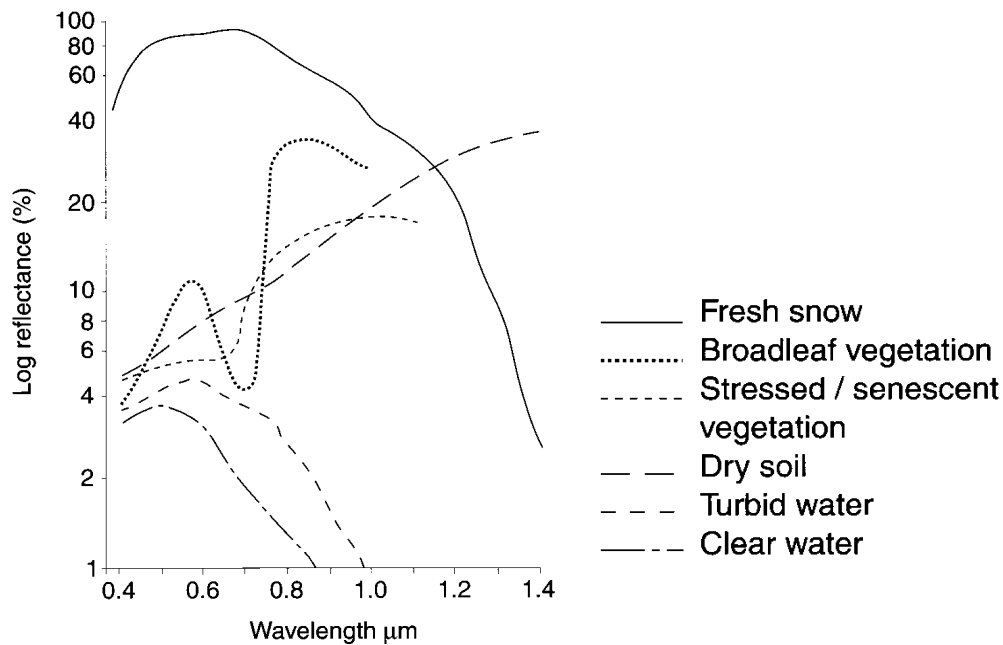
Reflectance from a water body can be from

- An interaction with the water's surface (specular reflection)
- An interaction with material suspended in the water
- An interaction with the bottom surface of the water body



- Reflectance properties of a water body also depends on the materials present in water
- Clear water
 - Absorbs relatively little energy having wavelengths shorter than 0.6 μm.

- High transmittance typifies these wavelengths with a maximum in the blue-green portion of the spectrum.
- Turbidity : Presence of suspended sediments increases visible reflectance
- Chlorophyll : Decrease blue wavelength reflection and increase green wavelength reflection
- Dissolved oxygen concentration, pH, and salt concentration
 - Cannot be observed directly through changes in water reflectance
 - Correlation between these parameters and observed reflectance is used
- Variation in the spectral reflectance in the visible region can be used to differentiate
 - Shallow and deep waters
 - Clear and turbid waters
 - Rough and smooth water bodies
- Reflectance in the NIR ranges are generally used to
 - Delineate the water bodies
 - To study the algal boom and phytoplankton concentration in water

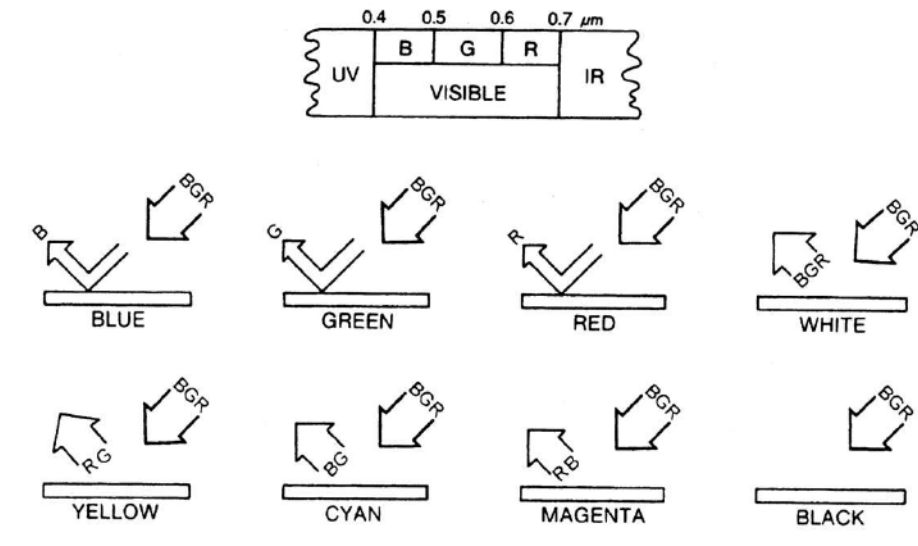


Spectral reflectance of some natural features

Multi spectral remote sensing

- Multiple sensors are used to sense the reflectance in different wavelength bands
- Reflectance recorded in multiple bands are analysed to find spectral reflectance variation with wavelength
- Using the average spectral reflectance curves as the basic information, the spectral reflectance variation is used to identify the target features.

Reflection of the colour



RADIATION LAWS

- **Planck Law: Energy and Frequency**
- **Kirchhoff Law: Energy, Wavelength, and Temperature**
- **Stefan-Boltzmann Law: Emitted radiation and temperature**
- **Wien Displacement Law: Wavelength and temperature**

Planck Law

Planck discovered that electromagnetic energy is absorbed and emitted in discrete units now called **quanta** or **photons**.

The size of each unit is directly proportional to the frequency of the energy's radiation.

$$Q = h\nu$$

Where,

Q = Energy of a photon (joules)

h = Planck's constant (joules * s)

ν = frequency (hertz)

1 hertz=cycle/second

His model explains the **photoelectric effect**, the generation of electric currents by the exposure of certain substances to light.

Kirchhoff Law

This law states that the ratio of emitted radiation to absorbed radiation flux is the same for all blackbodies at the same temperature.

It forms the basis for the definition of **emissivity (ϵ)**:

$$\epsilon = M/M_b$$

Where,

M = the emittance of a given object

M_b = the emittance of a blackbody at the same temperature

The emissivity of a true blackbody is 1, and that of a perfect reflector (a white body) would be 0. In nature, all objects have emissivities that fall between these extremes (graybodies).

Stefan-Boltzmann Law

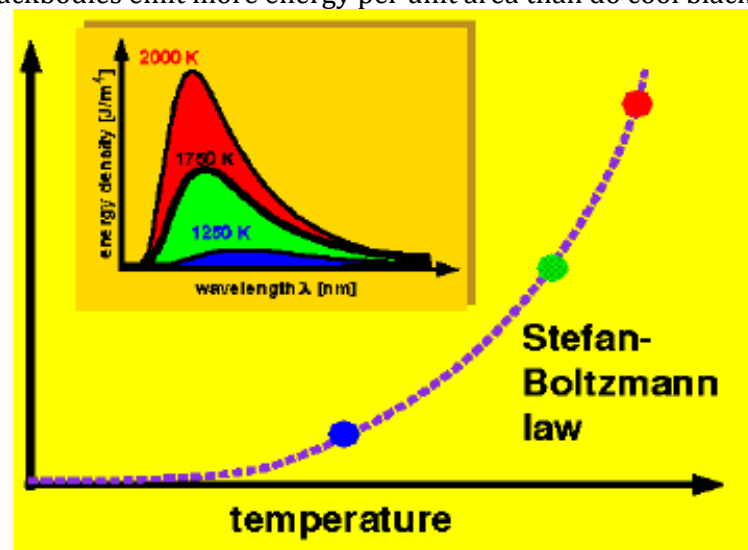
Defines the relationship between the total emitted radiation (W) and temperature (T).

It states that total radiation emitted from a blackbody is proportional to the fourth power of its absolute temperature.

$$W = \sigma T^4$$

where σ is the Stefan-Boltzmann constant, $5.6697 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$.

It states that hot blackbodies emit more energy per unit area than do cool blackbodies.



Wien Displacement Law

This law specifies the relationship between the wavelength of radiation emitted and the temperature of a blackbody.

$$\lambda = k / T$$

where k is a constant equaling $2898 \mu\text{m K}$, and T is the absolute temperature in kelvin.

Therefore, as the Sun approximates a 6000 K blackbody, its dominant wavelength (λ_{max}) is:

$$2898 \mu\text{m K} / 6000\text{K} = 0.483 \mu\text{m}$$

Decrease of λ_{peak}
with increase in
temperature

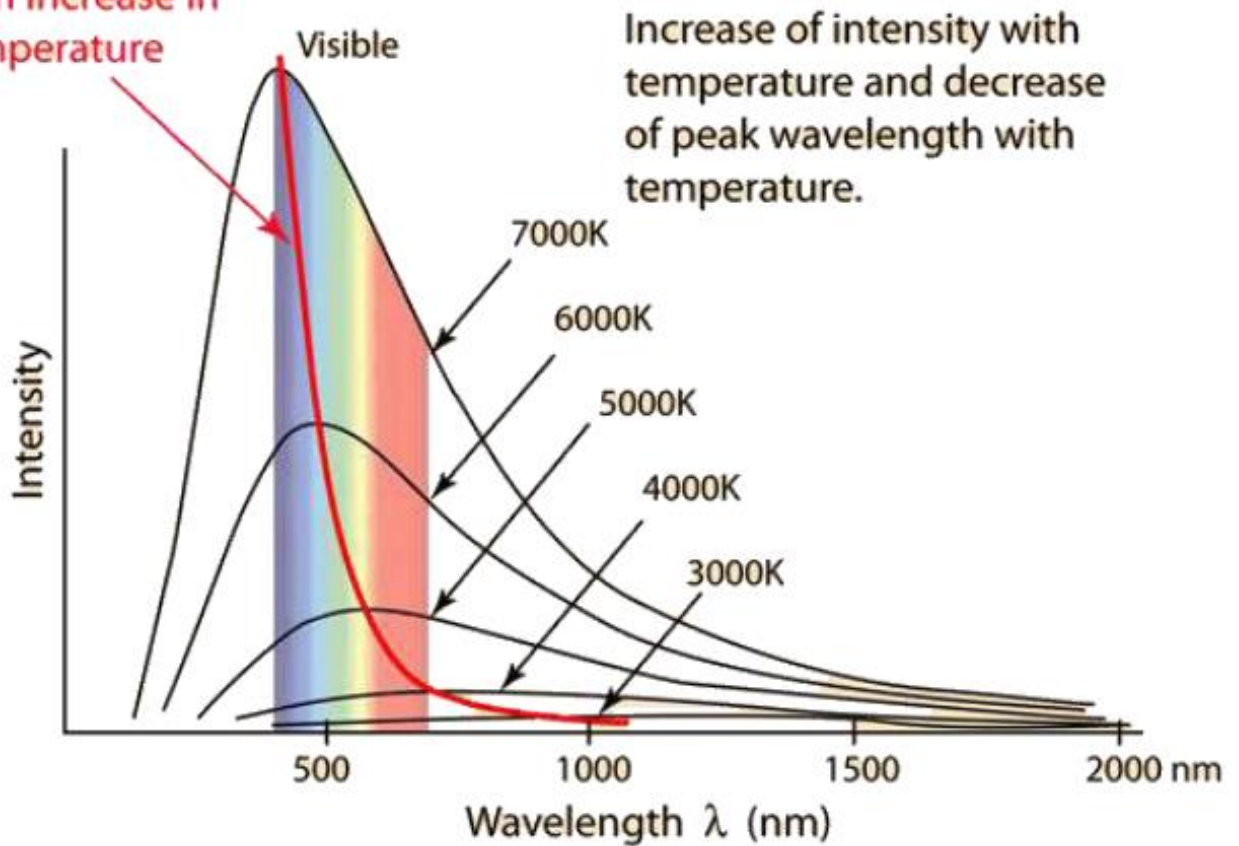
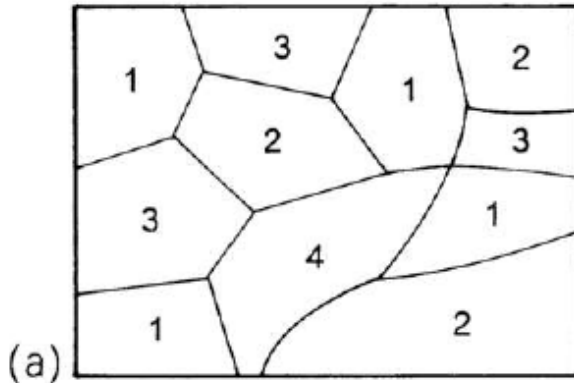


Image Interpretation

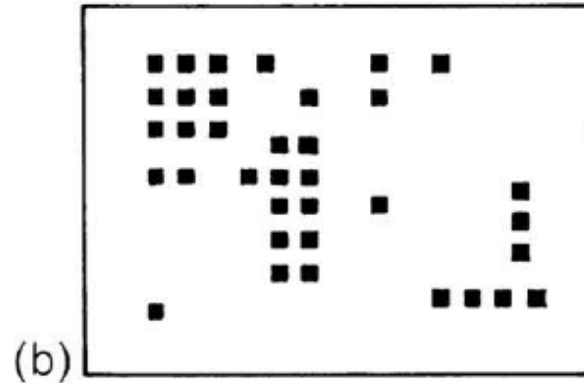
Kinds of knowledge needed for image interpretation

- **Subject:** the kind of information that motivates us to examine the image.
- **Geographic Region:** the unique characteristics that influence the patterns recorded on an image.
- **Remote Sensing System:** the variables that influences the image to be interpreted and how to evaluate them.

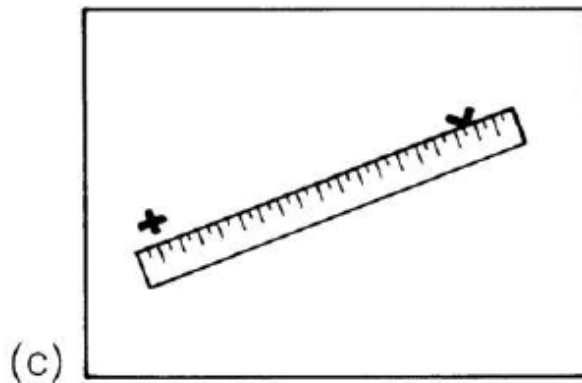
Classification



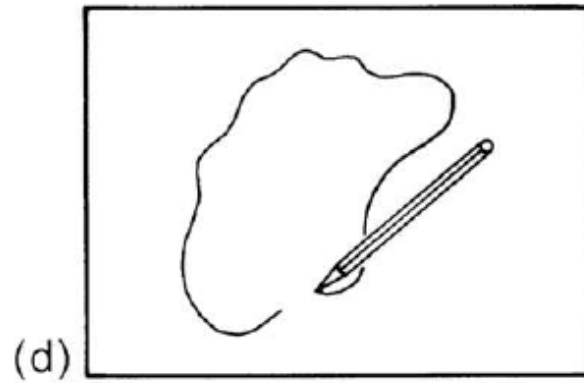
Enumeration



Mensuration



Delineation



Elements of image interpretation

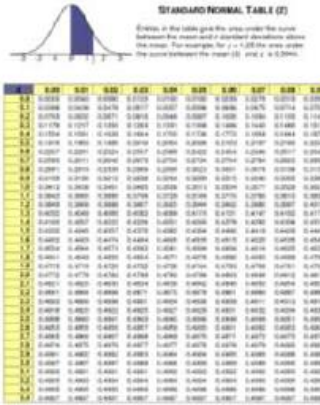
- **Image Tone**-Denotes the lightness or darkness of a region within an image.
- **Image Texture**-Refers to the apparent roughness or smoothness on an image region.
- **Shadow**-An especially important clue in the interpretation of objects.
- **Pattern**-The arrangement of individual objects into distinctive recurring forms the facilitate their recognition on imagery.
- **Association**-The occurrence of certain objects or features, usually without the strict spatial arrangement implied by pattern.
- **Shape**-Are obvious clues to their identities.

- **Size**-Provides an intuitive notion of objects scale and resolution and helps identification based on other factors .
- **Site**-Refers to topographic position.

For example, sewage treatment facilities are positioned at low topographic sites near streams or rivers to collect waste flowing through the system from higher locations.

Collateral information

Or ancillary information refers to nonimage information used to assist in the interpretation of an image. Ex: Books, Maps, Statistical tables, field observations, others.



Interpretative overlays

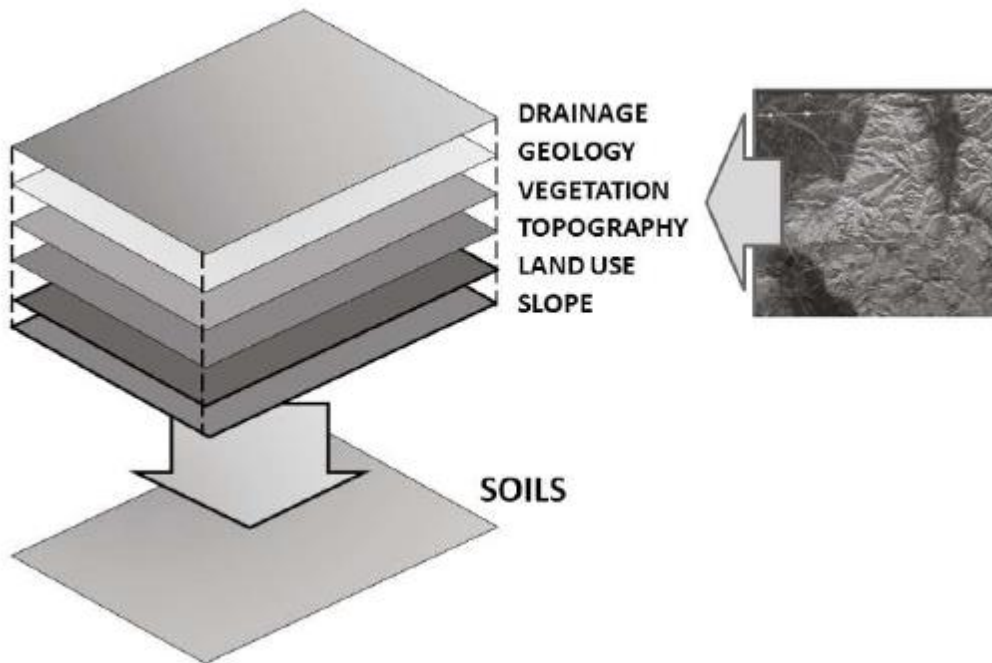
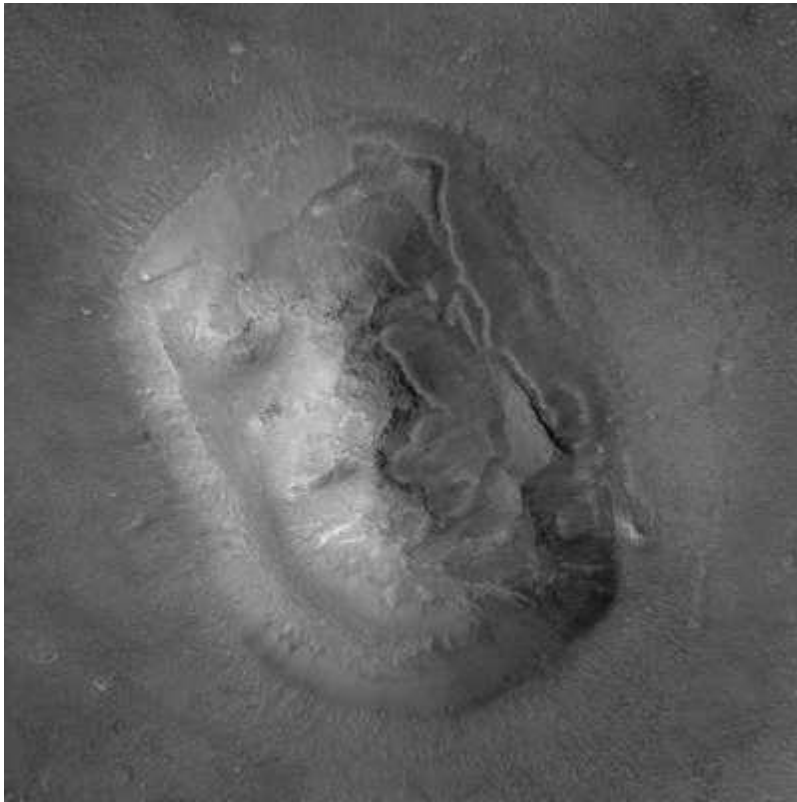


Image interpretation produces several separate overlays that can combine to permit interpretation of another feature that is not directly visible on the image.



orbiter and released by NASA
on July 25, 1976

Mars Reconnaissance Orbiter image by its HiRISE camera
of the "Face on Mars".

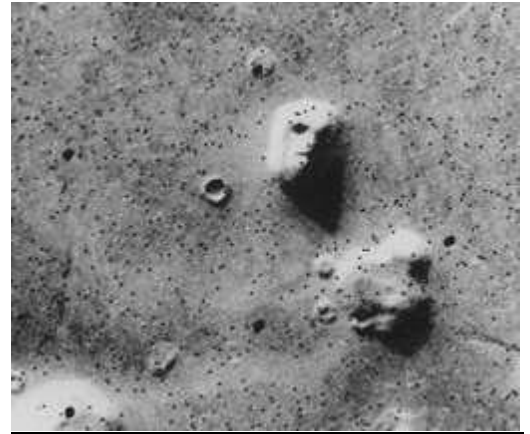
Stereovision

Stereoscopy is the ability to derive distance information (or height in aerial photos) from two images from the same scene.



Significance of context

A visual understanding of an image does not necessarily lead to an understanding of its underlying meaning.

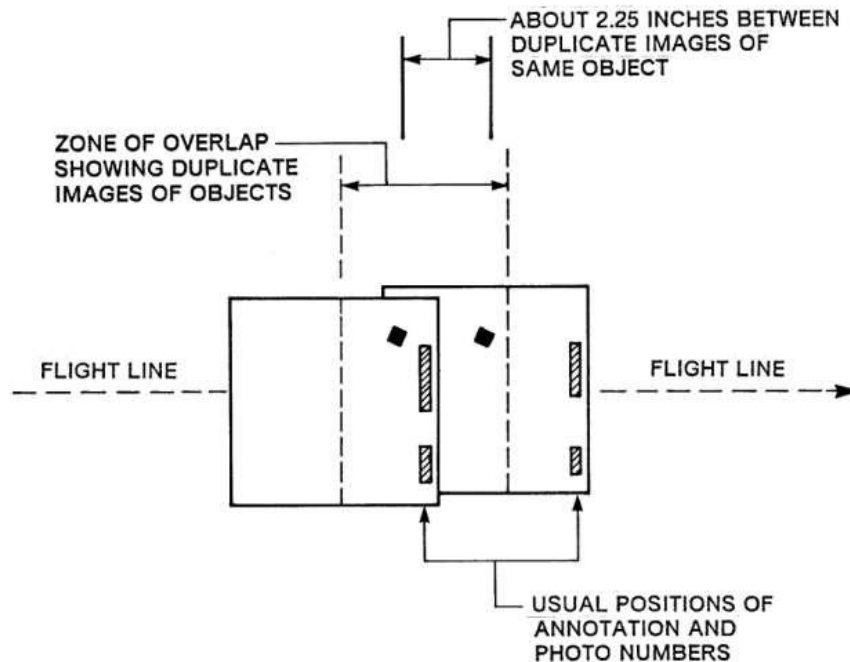


Small part of the Cydonia
region, taken by the Viking 1

Stereoscope



“Stereoscopic aerial photographs are acquired in sequences designed to provide overlapping views of the same terrain—that is, they provide two separate perspectives of the same landscape, just as our eyes provide two separate images of a scene.”



Positioning aerial photographs for stereoscopic viewing. The flight line must be oriented laterally in front of the viewer.

Digital photo interpretation

“Analyses that previously were conducted by visual examination of photographic prints or transparencies can now be completed by examination of digital images viewed on computer screens.”



A digital record of image interpretation, showing the outlines as traced by the analyst using onscreen digitization (left), the outlines without the image backdrop (center), and a detail of the raster structure of the digitized outlines (right).

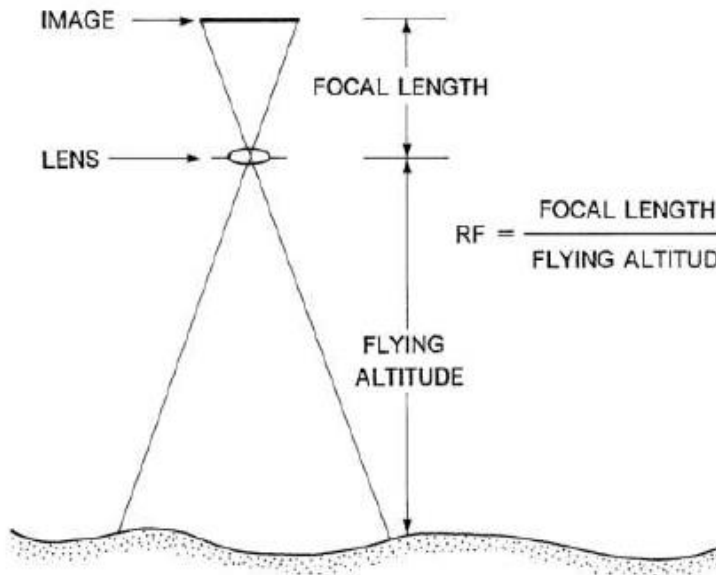
Image scale calculation

“Scale is an expression of the relationship of the image distance between two points and

the actual distance between the two corresponding points on the ground. This relationship can be expressed in several ways.”

Image scale from flying information

$$\text{Representative Fraction (RF)} = \frac{\text{Focal length}}{\text{Altitude}}$$

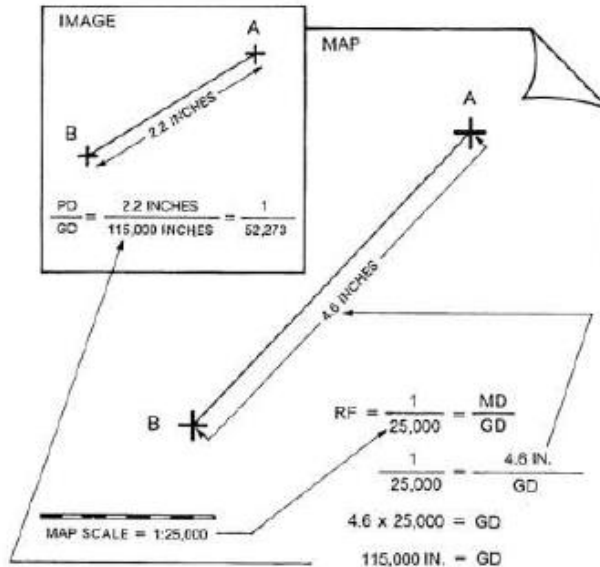


EXAMPLE:
If a camera with a 6-in. focal length is flown at 10,000 ft., the scale is $0.5/10,000 = 1:20,000$.

Estimating image scale by focal length and altitude.

Image scale from a map

$$RF = \frac{\text{Focal length}}{\text{Ground distance}} = \frac{2.2 \text{ in.}}{1.82 \text{ mi.}} = \frac{2.2 \text{ in.}}{115,000 \text{ in.}} = \frac{1}{52,273}$$

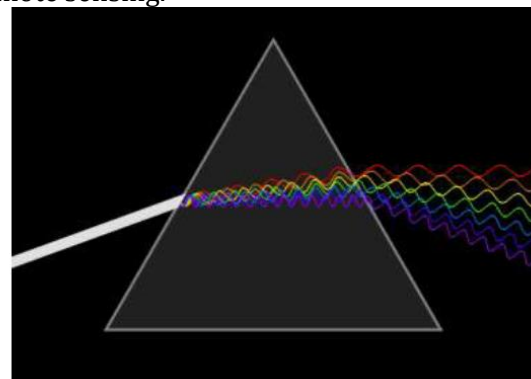
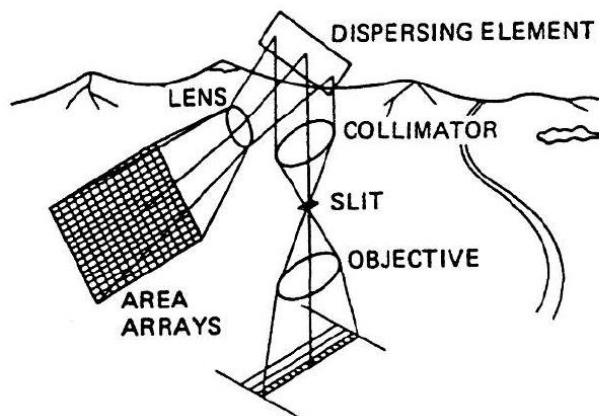


Note: 1 MI. = 63,360 IN. $\frac{115,000}{63,360} = 1.82 \text{ MI.} = \text{GD}$

. Measurement of image scale using a map to derive ground distance.

Hyperspectral Remote Sensing

Hyperspectral remote sensing is based on examination of many narrowly defined spectral channels. The hyperspectral sensors described here can provide 200 or more channels, each only 10 nm wide. Hyperspectral data have detail and accuracy that permit investigation of phenomena and concepts that greatly extend the scope of traditional remote sensing.



Imaging spectrometer. NASA

diagram.

Wavelet analysis

It decomposes images, sounds, or spectra into wavelets of varying duration. A **wavelet** can be defined as a wave-like oscillation of a fixed duration, characterized by an amplitude that has a value of zero, then increases, then declines again to zero -analogous perhaps to oscillations such as those that we encounter on seismographs or heart monitors.

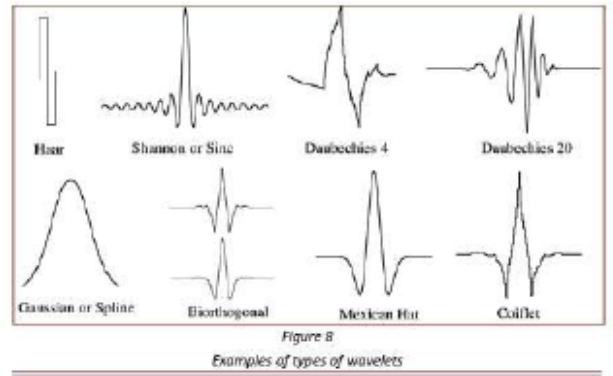
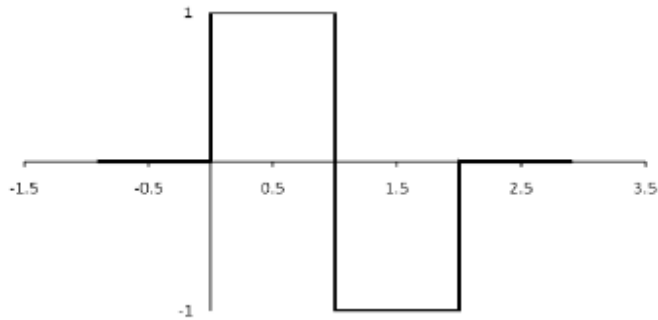


Illustration of a Haar wavelet.

Remote Sensing Application in Mineral Exploration

Definition: Features which suggest the probability of ore deposition in the area under investigation are referred to as guide. There are five types of guides.

1.) **Geologic guide:**- Aerial photographic studies provides geologic feature which act as localizer.

2.) **Regional guide:**- Useful in relation to their formation, deposition.

- a) Primary ores (Magnetite and pegmatite ore) E.g. Chromite, Magnetite
- b) Content metamorphic and igneous metamorphic appears an intrusions and plutons. E.g. Asbestos, Barite
- c) Hydrothermal ore: Igneous plutons are such source of minerals and ores. E.g. BHA, BHQ

3.) **Physiographic guide:** - Some mineral deposits have a direct topographic expression that give a clue to geologic structure.

Indirect inference from an understanding of a geomorphic studies.

- (i) Surface expression of ores
 - a) Domal structure. Example: mineralized quartzite, Fe, Mn, Al
 - b) Subsidence feature. Example: Calcite.
- (ii) Placer deposit: Have distinct physiographic expression on alluvium. E.g. Gold, Diamond.
 - Placer occur where steep gradient are very gentle.
 - Buried channels may also be inferred from isopach measurement.

4.) **Structural guide:**-

- i. **Fracture:** The study of shape of fracture patterns and lineament studies by aerial photograph provides the key to structure of main types of deposit.
- ii. **Vein Pattern:** An understanding of origin and mechanism of vein pattern permit prediction. It could be intersecting, branching etc.
- iii. **Contact cones:** Contact between igneous masses and intruded host rocks are especially favorable to ore occurrence even when ore is not genetically related to intrusive deposits of contact metamorphic are commonly form in the general vicinity.
- iv. **Folds:** Found in specific part of folds such as crest or troughs or in the interlimbs.
- v. **Faults:** Readily interpreted by aerial photo. Gold bearing quartz veins are associated with fault and shear zone.

5.) **Stratigraphic and lithologic guide:**- Ore occurs in a given sedimentary basin constituent the ideal guide.

- i. Coal deposits in Gondwana and tertiary rocks.
- ii. Gold deposits in Dharwar rocks.
- iii. Petroleum deposits in Dharwar rocks.
- iv. Iron ore deposits in general in Cryogenic Singhbhum.

- v. Basic intrusive. E.g. Platinum, Chromium, Nickel.

In general, rock alteration as a guide for mineral exploration.

- a) On color photograph, different zones of alteration can be identified.
- b) Oxidation zone: Red, green, brown, yellow and blue zone are identifiable on aerial photograph such as Bauxites, Pyrite, Copper, Zinc etc.
- c) Distinctive type of gases as reflecting upper proportion deposits can be seen in color photograph.
- d) Aerial photography in geo-botanical indicator guide
 - i. Aero-geo-botanical survey to detect mineralization by means of indicator plant and morphological changes.
 - ii. Aero-geo-botanical survey technique for identified plant suffering from Gigantism, Dwarfism etc.

Mineral Exploration in India

In India in August 1997, minerals exploration was started in the form of LANDSAT exploration of Himalayan and Peninsular region. The six projects areas related are scattered throughout India and lie in areas of known mineralization.

- 1.) Dhanpur-Pokhir and adjacent areas of U.P. (Kumaon-Garhwal Himalaya): Integrated map of area is prepared with the help of LANDSAT imageries. In these major lineaments, structural elements, broad lithological groups and mineral occurrences are shown together. In location, there are two sets of curvilinear or linear features interred represent potential area for mineral exploration.
- 2.) Indus suture and adjoining areas:
 - Interpretation from four bands of LANDSAT imageries reveals a number of linear and curvilinear in the area.
 - Great potential for porphyry copper in the major NW-SE trending lineaments.
- 3.) Mailaram copper belt:- Interpretation of LANDSAT imageries show four major lineaments and a no. of minor lineaments. Three of them are NW-SE trending and the fourth one has NE-SW trend.
- 4.) Bastar mineralization belt:- Three major lineament group are observed on LANDSAT imageries.
 - N-Central and NW zone
 - E & SE zone.
 - S central and SW zone.
- 5.) Panna diamond belt: photographic studies revealed circular depressions parallel in appearance to Majhgawan and Hinota depressions. LANDSAT imageries of Northern Vindhyan Basin revealed two intersecting major lineaments.
 - One is ENE-WSW
 - NE-SW direction

- Two major lineaments observed in Narmada-Son valley have NE-SW and ENE_WSW trends. A number of base metal occurrences reposted from these areas are confined between these two major lineaments.
- 6.) ASBESTOS MINERAL exploration in Cuddapah basin (A.P.):
- Airborne MSS imageries in the photo format of SW margins of Cuddapah basin was analysed in conjugations with air photo and LANDSAT imageries.
 - EW trending fractures in the sills are potential areas.

Remote Sensing Application in Oil & Gas Exploration

Petroleum occurs at considerable depth below the surface in sedimentary basin and is formed in specific geological environment represented by source rock for the formation of oil from organic debris under particular pressure and temperature condition, ultimately migrated, entrapped and accumulated. A petroleum bearing basin must exhibit several important characteristics. These include:

- (i) Source rock from which petroleum is generated.
- (ii) Rocks with adequate porosity and permeability to allow migration and cap rock to seal further migration.
- (iii) Structural and stratigraphic traps in which petroleum can accumulate.
- (iv) Timing factor, which bring all geological and geochemical factors together at the right time in such a way that generate hydrocarbons and entrap them under pressure.

There are generally four basic steps in a typical petroleum exploration, which are as follows:

- a) Remote sensing interpretation: Digital and visual interpretation to identify regional geologic, geomorphic and structural features.
- b) Reconnaissance geophysical survey: Detailed geologic surface and sub-surface mapping.
- c) Ground geophysical exploration: Seismic maps and cross-sections show details of sub-surface geologic structure.
- d) Drilling: Test wells are drilled to test the subsurface targets defined by preceding steps.

Remote sensing takes a minimum time & effort at steps (a), (b) and also aid to step (c)

Application of remote sensing techniques plays a major role in regional geological mapping. It helps in identifying. The following four basic areas of interest in oil exploration are:

- 1) Structural mapping: Folds, faults, fractures and joints.
- 2) Rock type mapping: It can be recognized on the basis of color, texture, landform, patterns, thermal interaction etc.
- 3) Geometric analysis: Drainage pattern, land forms, fracture patterns and tonal or color anomaly are valuable clues in this analysis.
- 4) Surface indication of hydrocarbons:- The hydrocarbons escaping from the traps can alter surface rock type to produce color, mineralogical and vegetation anomalies which can be detected by remote sensing techniques. Some of anomalies which manifest a remote sensing data are:

- High heat flow associated with hydrocarbon bearing structures. (Thermal IR data)
- Vegetation or soil anomalies and subtle total anomalies (SWIR)
- Chemical alteration zones caused by vertical migration (Thermal inertia mapping)

Various remote sensing techniques:

- (i) Thermal infrared imageries: Structures which are observed or concealed on visual bands can be detected on thermal IR images. Oil and gas fields are associated with high heat flows. Thermal inertia mapping using day and night images are also very important from the aspect of geological and hydrological study. These images can't only be used to differentiate rock type but also to detect the surface alterations caused by hydrocarbon micro seepages.
- (ii) Radar imageries:- Useful for emphasis in topographic relief because of the strong shadowing effect that can be obtained. Side looking airborne radar can be powerful tool for structural geologic mapping especially in heavily vegetated areas. Aid to lithologic discrimination in heavily vegetated areas.
- (iii) Satellite Altimetry:- Gravity anomalies derived from altimeter data of SeaSat and GeoSat. Sea bottom topography derived from SAR data constitute important new data set that can be used in regional tectonics and sedimentary basin as a part of deep water prospect.
- (iv) MagSat data:-
 - Provide information with uniform coverage in all parts of ocean.
 - Used to global tectonic studies and more particularly over offshore areas.
- (v) Using various airborne geophysical surveys.
 - a) **Magnetic surveys:-** It is a potential reconnaissance tool in mapping the regional surface and subsurface structures. Measurement of anomalous variation in the Earth's magnetic field is used to determine the configuration of crystalline basement rocks that are commonly influences the development of hydrocarbon. Hydrocarbon migrating towards the surface causes a variety of chemical reaction in the materials overlying. The reaction products result in magnetic anomalies which may be detected by low level airborne magnetic measurements.
 - b) **Gamma Ray Spectrometer surveys:-** Process of mineral fixation are known to be influenced by oil & gas habitat and therefore can represent surface manifestation of possible hydrocarbon occurrence at depth. A low activity area characterized by gamma field sink and rimmed by 10-15% increased activity is observed generally over oil/gas bearing structures.
 - c) **Geochemical data:-** Geochemical maps are used for interpreting various kinds of chemical analysis of rocks, soil and their fluid content. Such maps may show the surface distribution of hydrocarbon or of the bacteria that utilizes hydrocarbon.
 - d) **Earthquake data analysis:-** Records at seismographic stations are used to estimate broad regional oceanic and continental crustal structure. Thickness of sediments can also be calculated from observed higher mode waves.

Application of remote sensing in Hydrology

Definition: - The source which deals with the occurrence and distribution of water of the Earth, including their physical and chemical properties and their interaction with environment.

For convenience, hydrology can be subdivided into.

- Hydrometeorology: Concerned primarily with the exchange process in hydrological cycles
- Surface hydrology: Focus on water near the surface of land.
- Hydrogeology: Concerned with water at or below surface of rock and regolith
- Oceanography: Dealing with the nature and behavior of world's largest water bodies.

I.) **Hydrometeorology:** Hydrological cycle comprised of three types of components namely storage, transport and exchange processes. Apart from ocean, significant amount of water are retained temporarily within the rocks, ice caps and snow field on the surface of the Earth. Water is transported by circulation in the atmosphere and oceans, and by movement over or near surface. The exchange process causes transformation of water from one physical state another (Solid, liquid, gas). These include precipitation, evaporation and evapo-transpiration. The above written process is monitored through remote sensing as:

- a) Precipitation: - Microwave and radar has been used for rainfall monitoring.
 - Radar system can provide real time estimation of rainfall intensity over selected area for following processes as;
 - River management
 - Control of soil erosion
 - Short term rainfall intensity
- b) Radar system can give estimates of total rainfall, which is useful in prediction of likely flows of streams and rivers.
- c) Coherent Doppler radar system can give information on the movement and development of rain cells within clouds.
- d) Radar is capable of observing the location and areal extent of rainfall storms.

The radar equation basis to most rainfall studies may be written as:

$$\bar{\rho}_\lambda = CZ/r^2$$

Where, $\bar{\rho}_\lambda$ = mean received signal

C = Constant (Speed of light)

Z = Reflecting factor relating to type of precipitation in target area

r = Range (or distance) between the radar and the reflecting surface of rain.

In mid-latitude: $Z = a R^b$

Where; R= Quantitative estimates of rainfall.

a & b are constants.

Thus, $\bar{\rho}_\lambda = \text{Constant} * (R^b / r^2)$

- e) Ice & snow monitoring: Knowledge of distribution of snow fields and their volumes in terms of water equivalents is required so that we can improve forecast of stream flow and water

storages. Several nations are now developing methods for utilizing LANDSAT imageries to supplement or even replace surface or aircraft observations of ice and snow accumulation.

- i. Northern hemisphere snow and ice charts: Polar stereographic maps of snowfield and ice field boundaries and their relative reflectivity are used by US Navy & various secondary uses.
 - ii. Basin snow cover observations: Percent snow cover messages sent via teletype and maps sent via telecopy for selected river basin in USA for use by US office of Hydrology.
 - iii. Great lakes and Alaskan ice charts:- Detailed analysis of boundaries and type of age of ice, revealing ice fast and ice free areas as well as ice concentration and loads. The primary use include US Navy, Coast Guard, Marine fishery services and commercial transportation
- f) Evaporation & evapo-trnspiration estimation:

Evaporation monitoring from satellites exploits thermal inertia properties of soil as they are expressed through diurnal changes of surface temperatures. These changes are governed by:

- Radiation budget (related to external environment of the soil)
- Thermal inertial (related to internal characteristics of the soil)

The first can be evaluated with or without remote sensing. The second can be accessed from infrared imageries. The thermal inertia of unsaturated soil is influenced greatly by soil-porosity.

The greatest separation between thermal inertia cycles of different soil is found about the local solar maxima and minima. The TELL-US model has been developed to yield following parameters from twice daily aircraft or satellite observations.

$$P = \frac{1}{\sqrt{KC\rho}}$$

Where, P = Thermal inertia, K= 0.0007, C= 0.4 and $\rho = .207$

A comprehensive estimation model designed to exploit satellite data has been developed from a resistance form of energy balance equation in which:

$$L_{\varepsilon} = R_n - G - Q \cdot C_p (T_c - T_a) / r_H$$

Where, L_{ε} = Latent heat flux

R_n = Net radiation

G = Soil heat flux

Q = Air density

C_p = Specific heat of air

T_c = Plant canopy temperature

T_a = Air temperature

r_H = Thermal diffusion resistance.

Key variable monitored by satellite include R_n , T_c , & T_a .

It is recognized that evapo-transpiration performance of a crop or vegetation area changes through growing season.

Leaf area indices evaluated from LANDSAT reflectance data are being invoked in attempts to such method for these seasonal effects.

LAI = Relating the leaf areas of a crop to the area of the ground on which it grows.

II.) Surface Hydrology: Remote sensing is used to study

- ❖ Rainfall
- ❖ Infiltration
- ❖ Standing surface water

- a) Watershed parameter: - Recognizes and maps the recurring landscape feature.
 - i. Deforestation and urbanization: Increases the rate & volume of basin runoff.
 - ii. Areas which are heavily clouded.
 - iii. The surface draining pattern: Variation in draining pattern depict the nature and depth of soil cover, lithology, morphology and prevailing structural and tectonic influences.
- b) Drainage network feature: - Stream network analysis, invokes mapping, measurement and classification if active drainage lines. MSS bands are used for this purpose.
 - i. Band 5: - Flood plain feature. E.g. Channels, sandy islands, shoals etc.
 - 1.....0.45 μ m to 0.52 μ m
 - 2.....0.52 μ m to 0.60 μ m
 - 3.....0.63 μ m to 0.69 μ m
 - 4.....0.76 μ m to 0.9 μ m
 - 5.....1.55 μ m to 1.75 μ m
 - 610.4 μ m to 12.5 μ m
 - 7.....2.08 μ m to 2.35 μ m
 - ii. Band 7: Active river courses (water is dark in near Infrared)
 - iii. Band 4, 5 and 7: False color composite, alluvial areas and classes of vegetation.
- c) Flood plain mapping and monitoring of floods: - MeteoSat, visible and infrared imagery have been used for monitoring of change in large lakes and swamps. Passive microwave system has the advantage of cloud penetration (all weather) and could be useful in synoptic scale mapping of major flood events.
- d) Wetland monitoring:- Surface water is prominent in LANDSAT Band-7 imagery. Successful estimates of water quality have been made through regression of a quantitative "brightness parameter"
- e) Hydrology basin modeling:
 - i. Physical (laboratory) model based on hydrologic process.
 - ii. Representative basin model, based on response.

In every case, aim is the same namely to transform the inputs to a basin into outputs with best possible representation of reality.

- f) Mathematical modeling for flood hydrograph prediction:- On the flood flow scale. Three processes are of particular importance.
- Infiltration into soil surface
 - Surface runoff
 - Channel flow

Five steps have been proposed for basin modeling and thus predict flood peaks.

- Determine the physical extent of basin:- Using air or LANDSAT visible imagery,. A low angle of solar illumination is best for the evidence of shadow is especially useful in watershed determination.
- Idealize the basin topography:- Stereoscopic air photographs or multi-frequency radar images are analyzed for rectangular slope elements.
- Idealized stream channel geometry:- Near IR imagery may be used for both high water level determination and the analysis of stream patterns into rectangular line segments.
- Differentiate and delineate areas of impermeable surfaces and saturated soils.
 - Impermeable surfaces may be identified and assessed in IR imagery on account of their low thermal inertia.
 - Wet lands are dark in visible images.

Application of remote sensing in 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:

- crop type classification
- crop condition assessment
- crop yield estimation
- mapping of soil characteristics
- mapping of soil management practices
- compliance monitoring (farming practices)

Application of remote sensing in Forestry

Forests are a valuable resource providing food, shelter, wildlife habitat, fuel, and daily supplies such as medicinal ingredients and paper. Forests play an important role in balancing the Earth's CO₂ supply and exchange, acting as a key link between the atmosphere, geosphere, and hydrosphere. Tropical rainforests, in particular, house an immense diversity of species, more capable of adapting to, and therefore surviving, changing environmental conditions than monoculture forests. This diversity also provides habitat for numerous animal species and is an important source of medicinal ingredients. The main issues concerning forest management are depletion due to natural causes (fires and infestations) or human activity (clear-cutting, burning, land conversion), and monitoring of health and growth for effective commercial exploitation and conservation.

Humans generally consider the products of forests useful, rather than the forests themselves, and so extracting wood is a wide-spread and historical practice, virtually global in scale. Depletion of forest resources has long term effects on climate, soil conservation, biodiversity, and hydrological regimes, and thus is a vital concern of environmental monitoring activities. Commercial forestry is an important industry throughout the world. Forests are cropped and re-harvested, and the new areas continually sought for providing a new source of lumber. With increasing pressure to conserve native and virgin forest areas, and unsustainable forestry practices limiting the remaining areas of potential cutting, the companies involved in extracting wood supplies need to be more efficient, economical, and aware of sustainable forestry practices. Ensuring that there is a healthy regeneration of trees where forests are extracted will ensure a future for the commercial forestry firms, as well as adequate wood supplies to meet the demands of a growing population.

Non-commercial sources of forest depletion include removal for agriculture (pasture and crops), urban development, droughts, desert encroachment, loss of ground water, insect damage, fire and other natural phenomena (disease, typhoons). In some areas of the world, particularly in the tropics, (rain) forests, are covering what might be considered the most valuable commodity - viable agricultural land. Forests are burned or clear-cut to facilitate access to, and use of, the land. This practice often occurs when the perceived need for long term sustainability is overwhelmed by short-term sustenance goals. Not only are the depletion of species-rich forests a problem, affecting the local and regional hydrological regime, the smoke caused by the burning trees pollutes the atmosphere, adding more CO₂, and furthering the greenhouse effect.

Radar is more useful for applications in the humid tropics because its all-weather imaging capability is valuable for monitoring all types of depletion, including clear cuts, in areas prone to cloudy conditions. Cuts can be defined on radar images because clear cuts produce less backscatter than the forest canopy, and forest edges are enhanced by shadow and bright backscatter. However, regenerating cuts are typically difficult to detect, as advanced regeneration and mature forest canopy are not separable. Mangrove forests generally occur in tropical coastal areas, which are prone to cloudy conditions, therefore a reliable monitoring tool is required to successively measure the rate of forest depletion. Radar has been proven to differentiate mangrove from other land covers, and some bands have long wavelengths capable of penetrating cloud and rain. The only limitation is in differentiating different mangrove species.

Remote sensing can be used to detect and monitor forest fires and the regrowth following a fire. As a surveillance tool, routine sensing facilitates observing remote and inaccessible areas, alerting monitoring agencies to the presence and extent of a fire. NOAA AVHRR thermal data and GOES meteorological data can be used to delineate active fires and remaining "hot-spots" when optical sensors are hindered by smoke, haze, and /or darkness. Comparing burned areas to active fire areas provides information as to the rate and direction of movement of the fire. Remote sensing data can also facilitate route planning for both access to, and escape from, a fire, and supports logistics planning for firefighting and identifying areas not successfully recovering following a burn.

Application of remote sensing in Geology

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 earth quakes, and is thus a critical factor for geotechnical studies relating to construction and engineering.

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 lithology 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.

Structural geology plays an important role in mineral and hydrocarbon exploration, and potential hazard identification and monitoring.

Structural mapping is the identification and characterization of structural expressions. Structures include faults, folds, synclines and anticlines and lineaments. Understanding structures is the key to interpreting crustal movements that have shaped the present terrain. Structures can indicate potential locations of oil and gas reserves.

Geological applications of remote sensing include the following:

- surficial deposit / bedrock mapping
- lithological mapping
- structural mapping
- sand and gravel (aggregate) exploration/ exploitation
- mineral exploration · hydrocarbon exploration
- environmental geology
- geobotany
- baseline infrastructure
- sedimentation mapping and monitoring

- event mapping and monitoring
- geo-hazard mapping
- planetary mapping

Application of remote sensing in Hydrology

Hydrology is the study of water on the Earth's surface, whether flowing above ground, frozen in ice or snow, or retained by soil. Hydrology is inherently related to many other applications of remote sensing, particularly forestry, agriculture and land cover, since water is a vital component in each of these disciplines. Most hydrological processes are dynamic, not only between years, but also within and between seasons, and therefore require frequent observations. Remote sensing offers a synoptic view of the spatial distribution and dynamics of hydrological phenomena, often unattainable by traditional ground surveys. Radar has brought a new dimension to hydrological studies with its active sensing capabilities, allowing the time window of image acquisition to include inclement (extrem) weather conditions or seasonal or diurnal darkness.

As an example, remote sensing techniques are used to measure and monitor the areal extent of the flooded areas, to efficiently target rescue efforts and to provide quantifiable estimates of the amount of land and infrastructure affected. Incorporating remotely sensed data into a GIS allows for quick calculations and assessments of water levels, damage, and areas facing potential flood danger. Users of this type of data include flood forecast agencies, hydropower companies, conservation authorities, city planning and emergency response departments, and insurance companies (for flood compensation). The identification and mapping of floodplains, abandoned river channels, and meanders are important for planning and transportation routing.

RADARSAT provided some excellent views of the flood, because of its ability to image in darkness or cloudy weather conditions, and its sensitivity to the land/water differences. In RADARSAT image, the flood water completely surrounds the town, visible as a bright patch within the dark flood water. The flooded areas appear dark on radar imagery because very little of the incident microwave energy directed toward the smooth water surface returns back to the sensor. The town however, has many angular (corner) reflectors primarily in the form of buildings, which cause the incident energy to "bounce" back to the sensor.

Hydrology is the study of water on the Earth's surface, whether flowing above ground, frozen in ice or snow, or retained by soil. Examples of hydrological applications include:

- wetlands mapping and monitoring,
- soil moisture estimation,
- snow pack monitoring / delineation of extent,
- measuring snow thickness,
- determining snow-water equivalent,
- river and lake ice monitoring,
- flood mapping and monitoring,
- glacier dynamics monitoring (surges, ablation)
- river /delta change detection

- drainage basin mapping and watershed modelling
- irrigation canal leakage detection
- irrigation scheduling

Application of remote sensing in Land-Use-Land -Cover

Although the terms land cover and land use are often used interchangeably, their actual meanings are quite distinct.

Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other.

Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture.

It is important to distinguish this difference between land cover and land use, and the information that can be ascertained from each. The properties measured with remote sensing techniques relate to land cover, from which land use can be inferred, particularly with ancillary data or a priori knowledge.

Throughout the world, requirements for rural/urban delineation will differ according to the prevalent atmospheric conditions. Areas with frequently cloudy skies may require the penetrating ability of radar, while areas with clear conditions can use air photo, optical satellite or radar data. While the land use practices for both rural and urban areas will be significantly different in various parts of the world, the requirement for remote sensing techniques to be applied (other than the cloud-cover issue) will be primarily the need for fine spatial detail.

Although the terms land cover and land use are often used interchangeably, their actual meanings are quite distinct. Land cover refers to the surface cover on the ground, while Land use refers to the purpose the land serves. The properties measured with remote sensing techniques relate to land cover, from which land use can be inferred, particularly with ancillary data or a priori knowledge. Land use applications of remote sensing include the following:

- Natural resource management
- Wildlife habitat protection
- Baseline mapping for GIS input
- Urban expansion / encroachment
- Routing and logistics planning for seismic / exploration / resource extraction activities
- Damage delineation (tornadoes, flooding, volcanic, seismic, fire)
- Legal boundaries for tax and property evaluation
- Target detection - identification of landing strips, roads, clearings, bridges, land/water interface

Application of remote sensing in Mapping

Mapping constitutes an integral component of the process of managing land resources, and mapped information is the common product of analysis of remotely sensed data. Natural features and manufactured infrastructures, such as transportation networks, urban areas, and administrative boundaries can be presented spatially with respect to referenced co-ordinate systems, which may

then be combined with thematic information. Baseline, thematic, and topographic maps are essential for planning, evaluating, and monitoring, for military or civilian reconnaissance, or land use management, particularly if digitally integrated into a geographic information system as an information base. Integrating elevation information is crucial to many applications and is often the key to the potential success of present day mapping programs.

For cloud covered areas, radar is the obvious choice for providing planimetric data.

The availability of digital elevation models (DEMs) is critical for performing geometric and radiometric corrections for terrain on remotely sensed imagery, and allows the generation of contour lines and terrain models, thus providing another source of information for analysis. Generating DEMs from remotely sensed data can be cost effective and efficient. A variety of sensors and methodologies to generate such models are available and proven for mapping applications. Two primary methods of generating elevation data are

1. Stereogrammetry techniques using airphotos (photogrammetry) or radar data (radargrammetry)
2. Radar interferometry.

Baseline thematic mapping / topographic mapping: As a base map, imagery provides ancillary information to the extracted planimetric or thematic detail. Sensitivity to surface expression makes radar a useful tool for creating base maps and providing reconnaissance abilities for hydrocarbon and mineralogical companies involved in exploration activities. This is particularly true in remote northern regions, where vegetation cover does not mask the microtopography and generally, information may be sparse. Multispectral imagery is excellent for providing ancillary land cover information, such as forest cover. Supplementing the optical data with the topographic relief and textural nuance inherent in radar imagery can create an extremely useful image composite product for interpretation. From elevation models, contour lines can be generated for topographic maps, slope and aspect models can be created for integration into (land cover) thematic classification datasets or used as a sole data source.

Remote sensing application in Oceans & Coastal Monitoring

The oceans not only provide valuable food and biophysical resources, they also serve as transportation routes, are crucially important in weather system formation and CO₂ storage, and are an important link in the earth's hydrological balance. Coastlines are environmentally sensitive interfaces between the ocean and land and respond to changes brought about by economic development and changing land-use patterns. Often coastlines are also biologically diverse intertidal zones, and can also be highly urbanized. Ocean applications of remote sensing include the following:

- Ocean pattern identification: • currents, regional circulation patterns, shears frontal zones, internal waves, gravity waves, eddies, upwelling zones, shallow water bathymetry
- Storm forecasting
- wind and wave retrieval
- Fish stock and marine mammal assessment
- water temperature monitoring
- water quality
- ocean productivity, phytoplankton concentration and drift

- aquaculture inventory and monitoring
- Oil spill
- mapping and predicting oil spill extent and drift
- strategic support for oil spill emergency response decisions
- identification of natural oil seepage areas for exploration
- Shipping
- navigation routing
- traffic density studies
- operational fisheries surveillance
- near-shore bathymetry mapping
- Intertidal zone
- tidal and storm effects
- delineation of the land /water interface
- mapping shoreline features / beach dynamics
- coastal vegetation mapping
- human activity / impact

Remote sensing application in Sea Ice

Ice covers a substantial part of the Earth's surface and is a major factor in commercial shipping and fishing industries, Coast Guard and construction operations, and global climate change studies.

Examples of sea ice information and applications include:

- Ice concentration · ice type / age /motion
- Iceberg detection and tracking · surface topography
- Tactical identification of leads: navigation: safe shipping routes/rescue
- Ice condition (state of decay)
- Historical ice and iceberg conditions and dynamics for planning purposes · wildlife habitat · pollution monitoring · meteorological / global change research

OTHER APPLICATIONS IN CIVIL ENGINEERING

Introduction: With the availability of high spatial and spectral resolution data, remote sensing technology finds wide variety of applications in civil engineering. This lecture gives a very brief overview of a few such applications, viz.,

1. Urban and regional planning
 2. Identification of geothermal energy sources
 3. Assessment of snow cover and water equivalent
 4. Groundwater studies
 5. Earthquake and Tsunami studies
1. **Urban and Regional Planning:** Our urban areas are expanding at a rapid rate mainly due to the population growth and the large scale migration from the rural areas. This urban area expansion creates additional pressure on the land, water and infrastructural resources. Regular monitoring of the urban growth scenario, as well as appropriate planning is

essential to ensure the accessibility to basic amenities in all areas. However the rapid growth rate and the unregulated growth are the major problems in field level monitoring of the urban areas. Continuous planning is required to meet the demands of growing urban areas. Detailed information about land distribution and its use in and around the urban area is essential in this regard.

Satellite remote sensing finds potential application in urban planning owing to its capability to capture very fine resolution images of the urban areas and feasibility to achieve frequent temporal imaging. Data can be acquired in minimum time with less effort. With satellites such as IKONOS and IRS Cartosat, capable of providing less than 1m spatial resolution, it is now possible to identify features as small as 1m from the satellite images.

Venugopala Rao et al. (2010) listed a few potential applications of remote sensing and GIS in urban planning, under three broad classes:

Perspectives plan/ development plan preparation

- Present land use and regional level landscape
- Infrastructure network (Roads, Railways, and Settlements)
- Hydrological features (River/Stream, lakes)
- Updation of base maps
- Urban sprawl, land use change and population growth, and
- Master plan/ Regional plan proposals

Infrastructure planning involving

- Road network and connectivity planning
- Road alignment
- Utility planning (Sewage treatment plant, garbage dump site selection, water works)
- Growth centre locations

Environmental planning that require:

- Mapping of environmental parameters like green cover, surface water bodies and drainage network.
- Urban land use indicators and Impact assessment
- Development of Decision Support Systems like Urban Information System (UIS), Urban Indicator Observatory (UIO), Municipal Information System (MIS) etc.

2. Geo-thermal Energy: Geo-thermal energy has been gaining wide attention recently. Geo-thermal energy is produced from underground reservoirs of steam or hot water. Being the most reliable, and sustainable source of energy, several studies have been ongoing to develop technologies to tap these geo-thermal energy resources for human use. Following are some essential conditions required to be met by a good geo-thermal reservoir (Sabbins, 1973).

- A large high-temperature heat source must be present at a relatively shallow depth

- Porous and permeable reservoir rocks to hold steam or water must be present near the heat source
- There must be a natural recharge system to produce the steam or hot water

An impermeable zone above the reservoir is necessary to prevent the escape of steam to the surface. All these being the features below ground surface, it is difficult to locate geo-thermal reservoirs from surface observations.

However, many geothermal reservoirs have some sort of surface expressions in the form of minute increase in the surface temperature. Such phenomenon can be monitored with the aid of thermal remote sensing data. Moreover, the thermal energy reservoirs are generally associated with faults and fractures. Remote sensing data can also be used to identify the faults and fractures to a large extent.

3. Snow cover and water equivalent: Periodic snow cover depth and extent are some of the essential informations required for snow-melt runoff forecasting. Field-based surveys for periodic monitoring of Snow covered areas (SCA) are not easy due to the difficulties in the physical access to the snow covered areas. Satellite remote sensing techniques, being operational from space-borne platforms, help to overcome the accessibility issues. With the capability to provide images of fine spatial resolution and frequent temporal sampling, satellite remote sensing is becoming a vital tool for the near-real time monitoring of the SCA with good accuracy. Both optical and microwave (both passive and active) remote sensing techniques have been used for SCA mapping.

Optical remote sensing:

- Uses VIS and NIR bands. Example: Landsat TM, MODIS
- The most commonly used approach for SCA mapping
- Finer spatial resolution of the images is the major advantage
- Advantageous for mapping dry snow cover
 - Cloud cover commonly observed over SCA is generally one of the major hindrances in optical remote sensing. Active microwave remote sensing (e.g., Synthetic Aperture radar, SAR):
 - Backscattering of the microwave signals by SCA is different from that by the bare ground. Difference is maximum in case of wet snow and hence can be easily identified. Difference is insignificant in case of dry snow and hence is difficult to differentiate from bare ground
 - Capable of collecting data even under cloud cover Passive microwave imaging:
 - Microwave signals reflected from the surface are used to estimate the brightness temperature of the surface, which in turn are used to estimate snow depth, snow extent and snow water equivalent. For example, Schmugge et al (2002) used the following equation to relate snow water equivalent (SWE) to the brightness temperature. where A and B are the regression coefficients, TB is the brightness temperature and f1 and f2 are the frequencies of the low scattering and high scattering microwave channels, respectively.

- Advantageous over optical remote sensing due to their capability to penetrate through the cloud cover.
- Reduced cost involved and availability of global coverage are the advantages of passive microwave imaging over the radar remote sensing for snow mapping.
- Poor spatial resolution is a major limitation of the passive microwave image application in SCA mapping.

4. Groundwater Studies: Another important application of remote sensing is in groundwater assessment and management. Remote sensing application in the groundwater studies are generally classified into three broad areas:

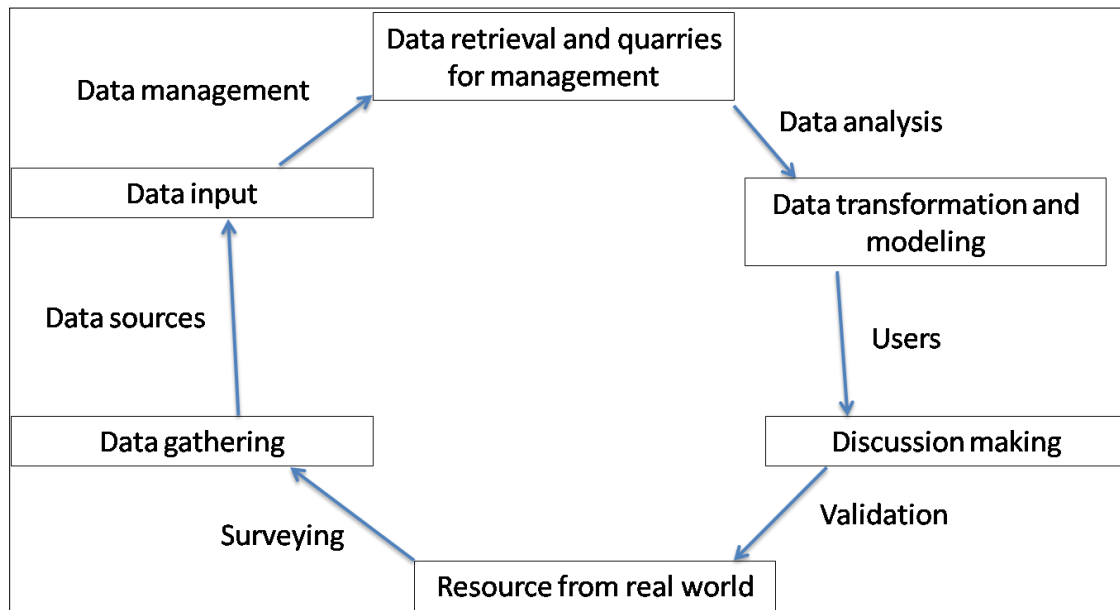
- Estimation of the geomorphologic parameters essential for the groundwater modeling
- Estimation of the groundwater potential
- Estimation of the groundwater storage.

Estimation of the geomorphologic parameters Remote sensing techniques have been widely used to extract information about the geological and surface features (eg., dykes and lineaments, changes in the lithology, terrain characteristics) that are closely associated with the occurrence of groundwater. Optical sensors such as Landsat TM, IRS LISS have been commonly used for such studies.

5. Earthquake and Tsunami studies: Remote sensing techniques have been successfully employed for assessing the damage caused during natural calamities like earthquake and tsunami. Very high-resolution remote sensing data can be used to identify the structural damage and the extent of affected areas. Manmade structures possess more or less regular shape and pattern. Any structural damage generally causes visible changes to this shape, and this concept is used in damage assessment with the aid of remote sensing data (Dell'Acqua and Gamba, 2012). Comparison of images obtained before and after the earthquake helps to identify the affected areas and the spatial extent of the damage. Remote sensing images also find applications in assessing the inundation (flood) and damage caused due to tsunami. Remote sensing images in the visible and thermal bands, and the radar images have been widely used for identifying the inundation areas and to identify the surface features hampering the propagation of tsunami waves (Stramondo, 2013).

Geographic Information System

Definition: It means the amalgamation of integrated or cross-referenced data sets and necessary software to manipulate and analyse these data sets into products. They may be in raster, vector or point form. GIS is rapidly becoming a useful tool for management of resources. The management and analysis of such large volumes of spatial data requires a computer-based system called GIS, which can be used for solving complex geological, geographical and hydrological problem.

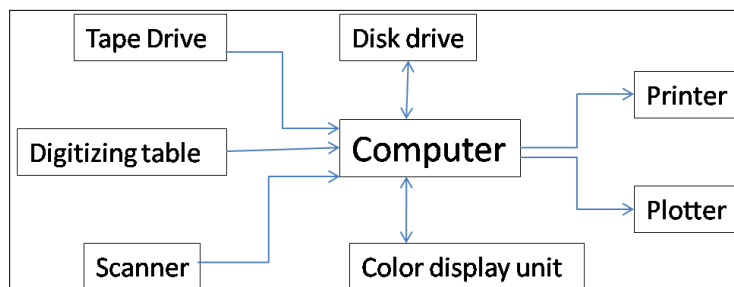


Schematic diagram showing GIS development process.

The major advantage of GIS is that it is an information system, therefore the digital database which has been developed at any stage can also be used in future. Remote sensing is a powerful tool for the collection of spatial data and GIS is a powerful tool for management and analysis of data required for any land developmental activity.

Essential elements of GIS: GIS consists of two major elements: **Hardware** and **Software**.

a) **Hardware:** The major hardware components of GIS are shown in figure.



Schematic diagram showing parts of GIS hardware

Processing unit (CPU):

- Spatial data entry system comprises of digitizer, scanner etc.
- Graphic display system facilitates viewing of data while entering, editing and analysing. This serves as interface between user and processing unit.
- Plotter/printer is useful in taking output
- Tape or CD drive is also a part of hardware for data backup.

b) Software: Software component of GIS enables data input, storage, transformation, processing and output. There are number of software packages available in the market.

- Key Indicator Data System (KIDS):** It is developed by world agricultural information centre (WAICENT) of food and agriculture organization of United Nations. It is an open-source software frame work, collects, reference, visualize, exchange and disseminate statistical, survey and indicator data. Visualization is possible through maps, raster images, tables, graphs etc.
- Map maker:** Powerful map, making GIS software for Windows. If it is used in a wide range of environmental work including forestry and fisheries. It supports raster, vector and DTM data and can import & export a wide range of formats.
- GRASS GIS:** Used for geo-spatial data management and analysis, image processing, graphics, maps production, spatial modeling and visualization used in academic and commercial setting around the world.
- Basin:** It is a multi-purpose environmental analysis system integrated with GIS. It combines National water shed data and state an art of environmental assessment into a convenient package.
- HUGO:** Hugo is moving map software for UNIX. It can view maps in simple raster, vector and TIFF formats.
- Geo Tools:** It is a free JAVA based mapping toolkit that allows maps to be viewed interactively on web browser without the need of dedicated server-side support.

These modules of GIS can be classified into four categories.

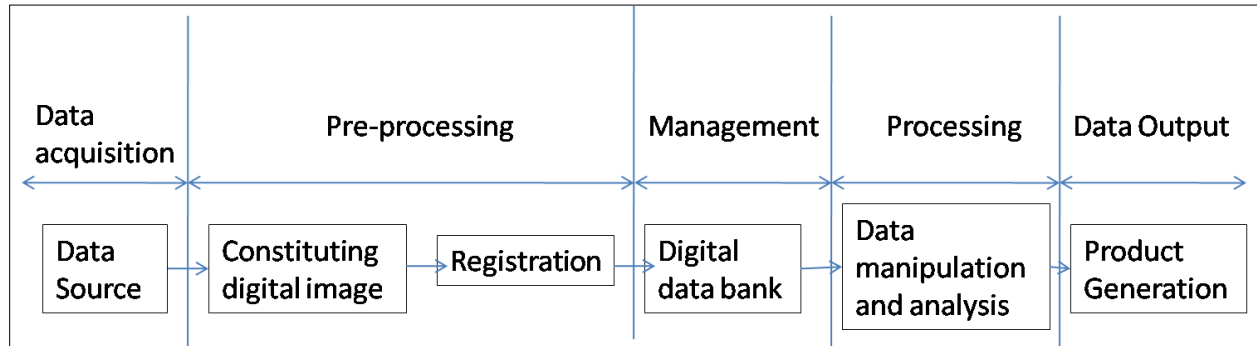
- Data input and editing
- Database management
- Data analysis/transformation /manipulation.
- Data display and O/P.

Basic data structure in GIS

- 1) Vector data structure: - A simple vector map using each of vector elements
 - Points for wells
 - Lines for rivers & roads
 - Polygon for lakes etc.
- 2) Raster data structure: - Raster data type consists of row and column of cells where in each cell a single value is stored. It can be image as with each fixed containing a color value.

Additional values recorded for each cell may be discrete as land use, continues such as temperature or null value if no data is available while a raster cell store a single value, it can be extended by using raster bands to represent RGB color, color maps etc. The resolution of raster data set is its cell width in ground units.

➤ Main steps of GIS are:



Schematic diagram showing main steps of GIS.

a) Data Acquisition: GIS requires various types of Geodata from different platforms as an input source of Geodata in GIS.

- 1) Remote sensing spectral data.
- 2) Geophysical survey data
 - i. Magnetic data
 - ii. Seismic data
 - iii. Electromagnetic data
 - iv. Electric data
- 3) Geochemical data
- 4) Geological data
 - i. Structural data
 - ii. Lithologic data
- 5) Topographic data
- 6) Other thematic data
 - i. Vegetation/forestry
 - ii. Land use
 - iii. Soil
 - iv. Hydrological
 - v. Meteorological

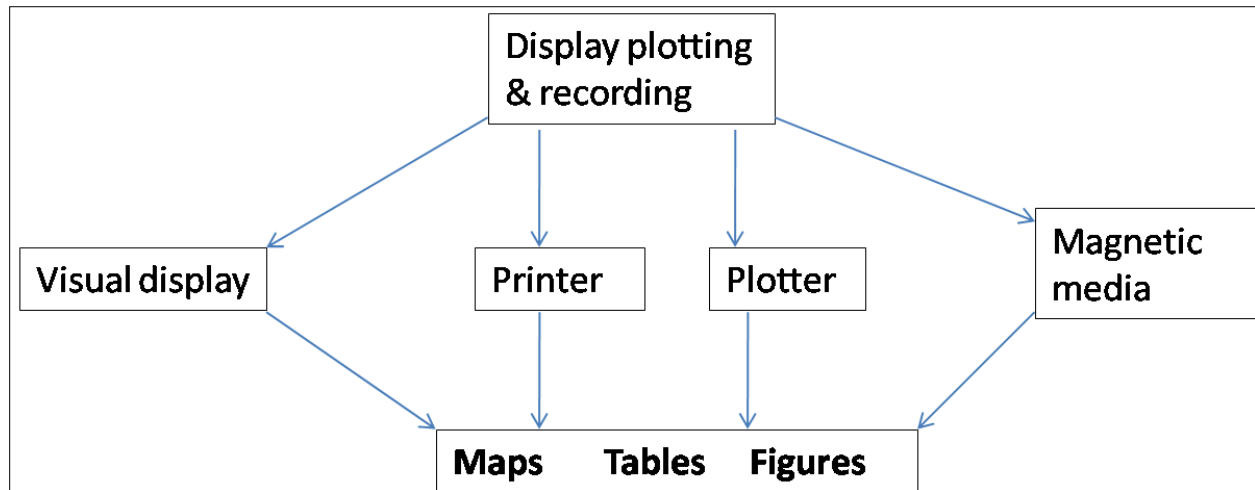
b) Pre-processing: It is almost invariably required to convert the collected data set into suitable form for storage in GIS data bank and for analysis.

c) Data management: Data Base Management System (DBMS) comprises a set of programs to manipulate and maintain data in a data base. DBMS act as a controller to provide interaction between the data base and the application program.

d) Data Manipulation & Analysis: Taking into consideration the pattern of most commercially available software packages their manipulation and analysis are divided into three parts.

- i. Image processing operation
- ii. Classification
- iii. GIS Analysis

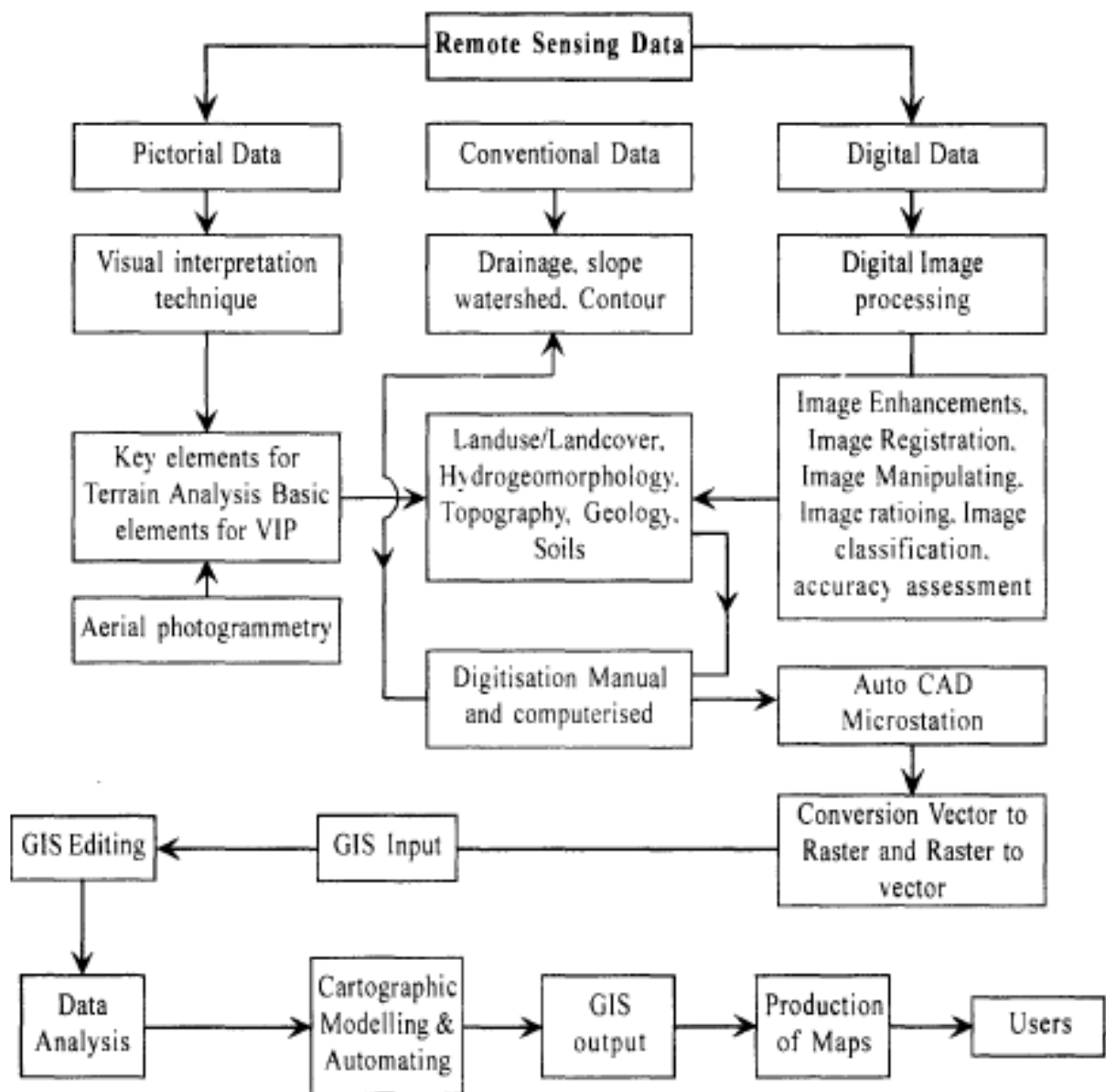
e) Data Output: The processed output data from GIS can be taken in several forms; soft copy, hard copy or in electronic form.



Schematic diagram showing steps of data output.

Advantages:

- i. Powerful tool for handling spatial data collected from variety of sources at different scale & resolution.
- ii. Large quantity of data can be stored, maintained and retrieved at greater speed & low cost.
- iii. Able to manipulate and integrate different types of data.
- iv. Perform complex spatial analysis providing both qualitative and quantitative results.



Overview of the linkage of remote sensing and GIS