MODULE – 1 LECTURE NOTES – 2

EMR SPECTRUM

1. Introduction

In remote sensing, some parameters of the target are measured without being in touch with it. To measure any parameters using remotely located sensors, some processes which convey those parameters to the sensor is required. A best example is the natural remote sensing by which we are able to see the objects around us and to identity their properties. We are able to see the objects around us when the solar light hits them and gets reflected and captured in our eyes. We are able to identify the properties of the objects when these signals captured in our eyes are transferred to the brain and are analysed. The whole process is analogous to the man-made remote sensing techniques.

In remote sensing techniques, electromagnetic radiations emitted / reflected by the targets are recorded at remotely located sensors and these signals are analysed to interpret the target characteristics. Characteristics of the signals recorded at the sensor depend on the characteristics of the source of radiation / energy, characteristics of the target and the atmospheric interactions.

This lecture gives details of the electromagnetic spectrum. Details of the energy sources and the radiation principles are also covered in this lecture.

2. Electromagnetic energy

Electromagnetic (EM) energy includes all energy moving in a harmonic sinusoidal wave pattern with a velocity equal to that of light. Harmonic pattern means waves occurring at frequent intervals of time.

Electromagnetic energy has both electric and magnetic components which oscillate perpendicular to each other and also perpendicular to the direction of energy propagation as shown in Fig. 1.

It can be detected only through its interaction with matter.

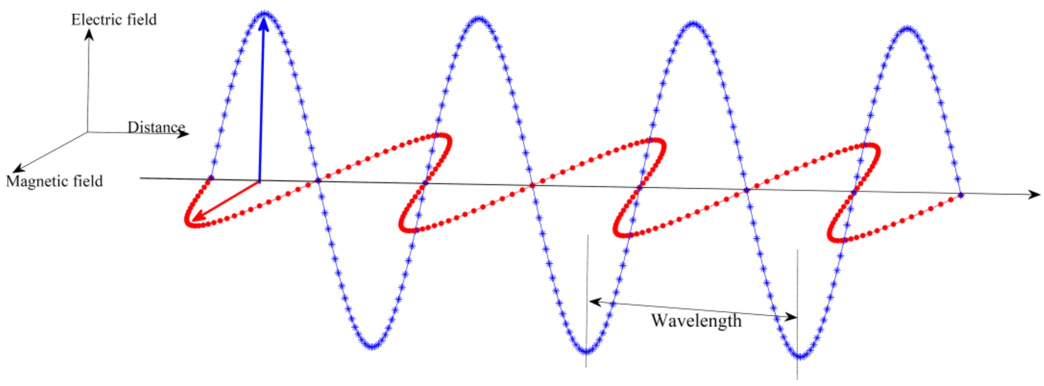


Fig.1. Electromagnetic wave

Examples of different forms of electromagnetic energy: Light, heat etc.

EM energy can be described in terms of its velocity, wavelength and frequency.

All EM waves travel at the speed of light, c, which is approximately equal to 3×10^8 m/s.

Wavelength λ of EM wave is the distance from any point on one wave to the same position on the next wave (e.g., distance between two successive peaks). The wavelengths commonly used in remote sensing are very small. It is normally expressed in micrometers (μm). 1 μm is equal to 1×10^{-6} m.

Frequency f is the number of waves passing a fixed point per unit time. It is expressed in Hertz (Hz).

The three attributes are related by

$$c = \lambda f \tag{1}$$

which implies that wavelength and frequency are inversely related since c is a constant. Longer wavelengths have smaller frequency compared to shorter wavelengths.

Engineers use frequency attribute to indicate radio and radar regions. However, in remote sensing EM waves are categorized in terms of their wavelength location in the EMR spectrum.

Another important theory about the electromagnetic radiation is the particle theory, which suggests that electromagnetic radiation is composed of discrete units called photons or quanta.

3. Electro-Magnetic Radiation (EMR) spectrum

Distribution of the continuum of radiant energy can be plotted as a function of wavelength (or frequency) and is known as the electromagnetic radiation (EMR) spectrum. EMR spectrum is divided into regions or intervals of different wavelengths and such regions are denoted by different names. However, there is no strict dividing line between one spectral region and its adjacent one. Different regions in EMR spectrum are indicated in Fig. 2.

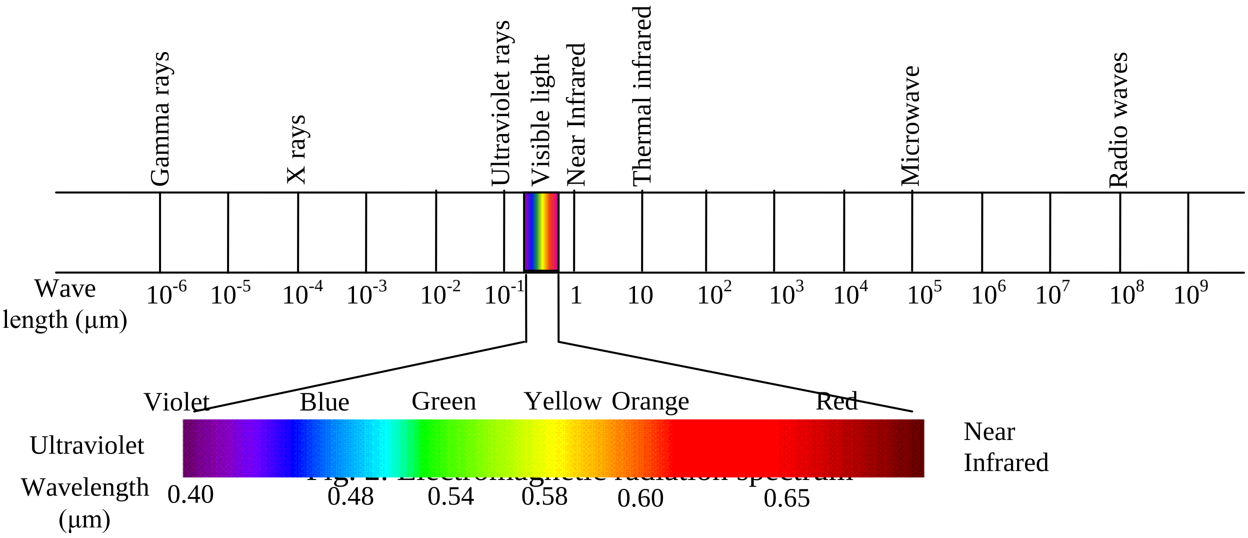


Fig. 2. Electromagnetic radiation spectrum

The EM spectrum ranges from gamma rays with very short wavelengths to radio waves with very long wavelengths. The EM spectrum is shown in a logarithmic scale in order to portray shorter wavelengths.

The visible region (human eye is sensitive to this region) occupies a very small region in the range between 0.4 and 0.7 µm. The approximate range of color “blue” is 0.4 – 0.5 µm, “green” is 0.5-0.6 µm and “red” is 0.6-0.7 µm. Ultraviolet (UV) region adjoins the blue end of the visible region and infrared (IR) region adjoins the red end.

The infrared (IR) region, spanning between 0.7 and 100 µm, has four subintervals of special interest for remote sensing:

(1) Reflected IR (0.7 - 3.0 µm)

(2) Film responsive subset, the photographic IR (0.7 - 0.9 μm)

(3) and (4) Thermal bands at (3 - 5 μm) and (8 - 14 μm).

Longer wavelength intervals beyond this region are referred in units ranging from 0.1 to 100 cm. The microwave region spreads across 0.1 to 100 cm, which includes all the intervals used by radar systems. The radar systems generate their own active radiation and direct it towards the targets of interest. The details of various regions and the corresponding wavelengths are given in Table 1.

Table 1. Spectrum of electromagnetic radiation

Region	Wavelength (μm)	Remarks
Gamma rays	$< 3\times10^{-5}$	Not available for remote sensing. Incoming radiation is absorbed by the atmosphere
X-ray	3×10^{-5} - 3×10^{-3}	Not available for remote sensing since it is absorbed by atmosphere
Ultraviolet (UV) rays	0.03 - 0.4	Wavelengths less than 0.3 are absorbed by the ozone layer in the upper atmosphere. Wavelengths between 0.3- 0.4 μm are transmitted and termed as “Photographic UV band”.
Visible	0.4 - 0.7	Detectable with film and photodetectors.
Infrared (IR)	0.7 - 100	Atmospheric windows exist which allows maximum transmission. Portion between 0.7 and 0.9 μm is called photographic IR band, since it is detectable with film. Two principal atmospheric windows exist in the thermal IR region (3 - 5 μm and 8 - 14 μm).
Microwave	10^3 - 10^6	Can penetrate rain, fog and clouds. Both active and passive remote sensing is possible. Radar uses wavelength in this range.
Radio	$> 10^6$	Have the longest wavelength. Used for remote sensing by some radars.

Energy in the gamma rays, X-rays and most of the UV rays are absorbed by the Earth’s atmosphere and hence not used in remote sensing. Most of the remote sensing systems operate in visible, infrared (IR) and microwave regions of the spectrum. Some systems use the long wave portion of the UV spectrum also.

4. Energy sources and radiation principles

4.1 Solar radiation

Primary source of energy that illuminates different features on the earth surface is the Sun. Solar radiation (also called insolation) arrives at the Earth at wavelengths determined by the photosphere temperature of the sun (peaking near 5,600 °C).

Although the Sun produces electromagnetic radiation in a wide range of wavelengths, the amount of energy it produces is not uniform across all wavelengths.

Fig.3. shows the solar irradiance (power of electromagnetic radiation per unit area incident on a surface) distribution of the Sun. Almost 99% of the solar energy is within the wavelength range of 0.28-4.96 μm. Within this range, 43% is radiated in the visible wavelength region between 0.4-0.7 μm. The maximum energy (*E*) is available at 0.48 μm wave length, which is in the visible green region.

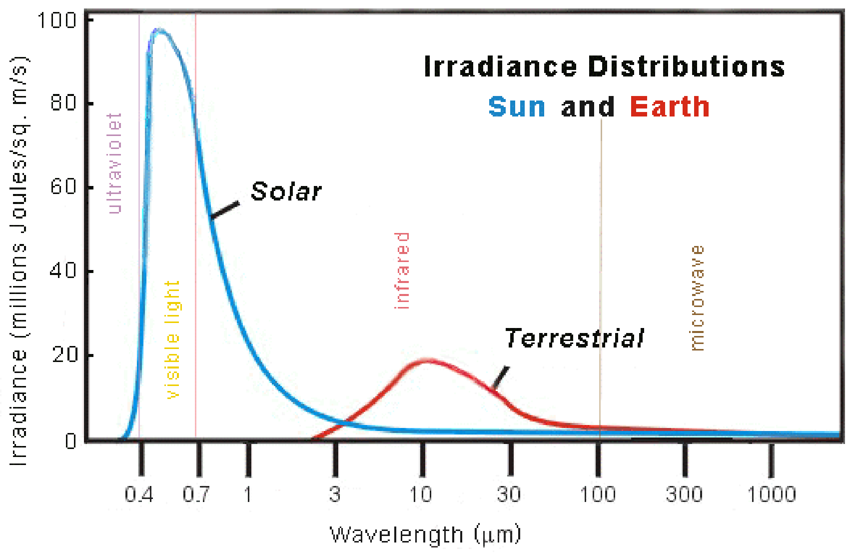


Fig.3. Irradiance distribution of the Sun and Earth (http://www.csulb.edu)

Using the particle theory, the energy of a quantum (Q) is considered to be proportional to the frequency. The relationship can be represented as shown below.

$$Q = h\, f \qquad (2)$$

where h is the Plank's constant (6.626 x 10^{-34} J Sec) and f is the frequency.

Using the relationship between c, λ and f (Eq.1), the above equation can be written as follows

$$Q = h\, c\, /\, \lambda \qquad (3)$$

The energy per unit quantum is thus inversely proportional to the wavelength. Shorter wavelengths are associated with higher energy compared to the longer wavelengths. For example, longer wavelength electromagnetic radiations like microwave radiations are associated with lower energy compared to the IR regions and are difficult to sense in remote sensing. For operating with long wavelength radiations, the coverage area should be large enough to obtain a detectable signal.

4.2 Radiation from the Earth

Other than the solar radiation, the Earth and the terrestrial objects also are the sources of electromagnetic radiation. All matter at temperature above absolute zero (0^oK or -273^oC) emits electromagnetic radiations continuously. The amount of radiation from such objects is a function of the temperature of the object as shown below.

$$M = \sigma\, T^4 \qquad (4)$$

This is known as Stefan-Boltzmann law. M is the total radiant exitance from the source (Watts / m^2), σ is the Stefan-Boltzmann constant (5.6697 x 10^{-8} Watts $m^{-2}k^{-4}$) and T is the absolute temperature of the emitting material in Kelvin.

Since the Earth's ambient temperature is about 300 K, it emits electromagnetic radiations, which is maximum in the wavelength region of 9.7 μm, as shown in Fig.3. This is considered as thermal IR radiation. This thermal IR emission from the Earth can be sensed using scanners and radiometers.

According to the Stefan-Boltzmann law, the radiant exitance increases rapidly with the temperature. However, this law is applicable for objects that behave as a blackbody.

4.3 Blackbody Radiation

A blackbody is a hypothetical, ideal radiator. It absorbs and reemits the entire energy incident upon it.

Total energy emitted by a black body varies with temperature as given in Eq. 4. The total energy is distributed over different wavelengths, which is called the spectral distribution or spectral curve here. Area under the spectral curve gives the total radiant exitance *M*.

In addition to the total energy, the spectral distribution also varies with the temperature. Fig. 4 shows the spectral distribution of the energy radiated from black bodies at different temperatures. The figure represents the Stefan-Boltzman's law graphically. As the temperature increases, area under the curve, and hence the total radiant exitance increases.

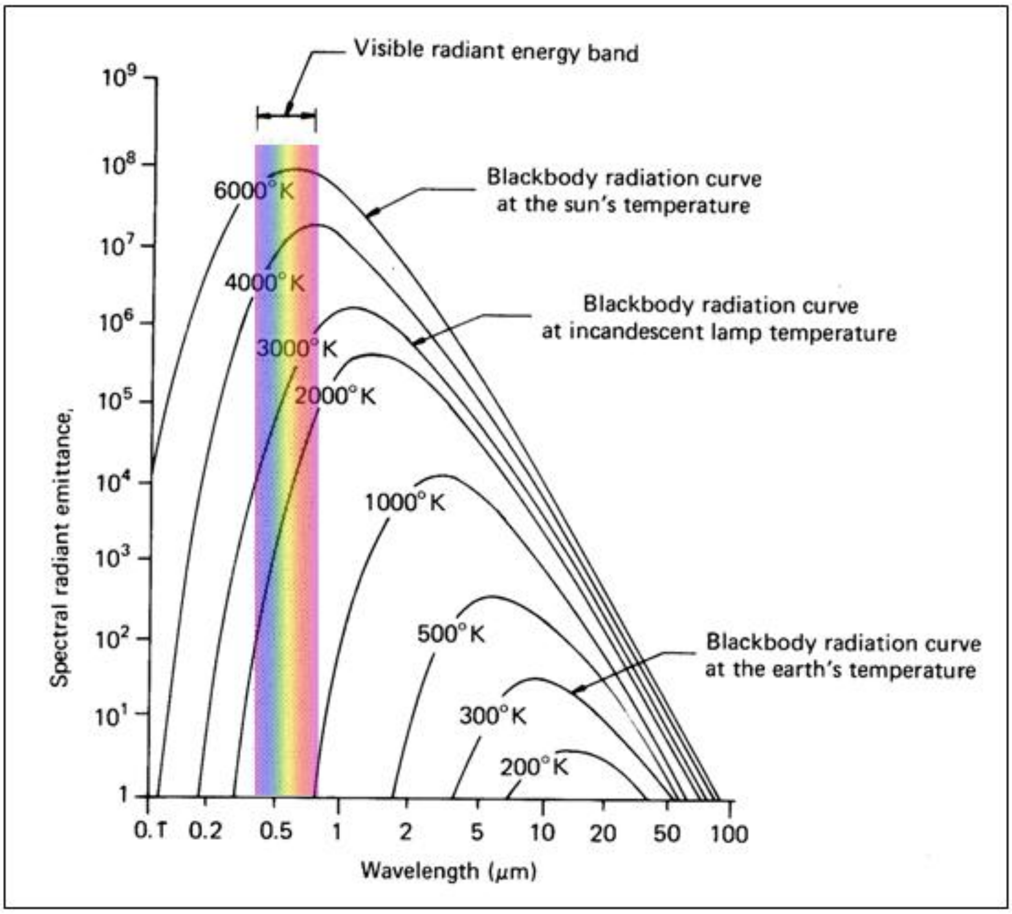


Figure 4. Spectral energy distribution of blackbody at various temperatures

From Fig. 4, it can be observed that the peak of the radiant exitance varies with wavelength. As the temperature increases, the peak shifts towards the left. This is explained by the Wien's displacement law. It states that the dominant wavelength at which a black body radiates λ_m is inversely proportional to the absolute temperature of the black body (in *K*) and is represented as given below.

$$\lambda_m = A / T \qquad (5)$$

where *A* is a constant, which is equal to 2898 μm *K*. The Sun's temperature is around 6000 K, and from the figure it can be observed that the visible part of the electromagnetic energy (0.4-0.7 μm) dominates in the radiance exitance from the Sun.

5. Remote sensing using electromagnetic radiation

As solar energy travels through atmosphere to reach the Earth, the atmosphere absorbs or backscatters a fraction of it and transmits only the remainder. Wavelength regions, through which most of the energy is transmitted through atmosphere are referred as atmospheric windows. In Fig. 5 (Short, 1999), EMR spectrum is shown identifying different regions with specific names starting from visible region to microwave regions. In the microwave region, different radar bands are also shown such as κ, X, C, L and P.

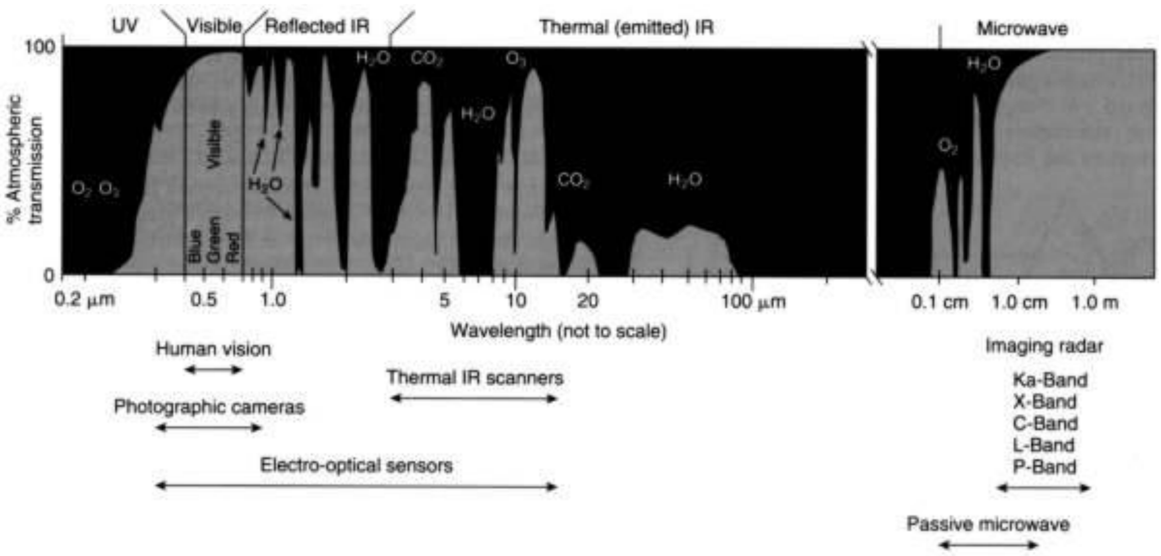


Figure 5. Atmospheric windows in the EMR spectrum

(Source: http://www.geog.ucsb.edu/~jeff/115a/remote_sensing/thermal/thermalirinfo.html)

In Fig. 5, blue (or shaded) zones mark minimal passage of incoming and/or outgoing radiation, whereas white areas denote atmospheric windows. Various constituents of atmosphere at different wavelengths are mainly responsible for atmospheric absorption or back scatter at those wavelengths.

Most remote sensing instruments on air or space platforms operate in one or more of these windows by making their measurements with detectors tuned to specific wavelengths that pass through the atmosphere.

MODULE – 1 LECTURE NOTES – 3

ENERGY INTERACTIONS IN THE ATMOSPHERE

1. INTRODUCTION

In many respects, remote sensing can be thought of as a reading process. Using various sensors, we remotely collect data that are analysed to obtain information about the objects, areas or phenomena being investigated. In most cases the sensors are electromagnetic sensors either air-borne or space-borne for inventorying. The sensors record the energy reflected or emitted by the target features. In remote sensing, all radiations traverse through the atmosphere for some distance to reach the sensor. As the radiation passes through the atmosphere, the gases and the particles in the atmosphere interact with them causing changes in the magnitude, wavelength, velocity, direction, and polarization.

In this lecture electromagnetic energy interactions in atmosphere are explained.

2. Composition of the atmosphere

In order to understand the interactions of the electromagnetic radiations with the atmospheric particles, basic knowledge about the composition of the atmosphere is essential.

Atmosphere is the gaseous envelop that surrounds the Earth's surface. Much of the gases are concentrated within the lower 100km of the atmosphere. Only $3x10^{-5}$ percent of the gases are found above 100 km (Gibbson, 2000).

Table 1 shows the gaseous composition of the Earth's atmosphere

Table.1. Gaseous composition of the Earth's atmosphere (from Gibbson, 2000)

Component	Percentage
Nitrogen (N_2)	78.08
Oxygen (O_2)	20.94
Argon	0.93
Carbon Dioxide (CO_2)	0.0314
Ozone (O_3)	0.00000004

Oxygen and Nitrogen are present in the ratio 1:4, and both together add to 99 percent of the total gaseous composition in the atmosphere. Ozone is present in very small quantities and is mostly concentrated in the atmosphere between 19 and 23km.

In addition to the above gases, the atmosphere also contains water vapor, methane, dust particles, pollen from vegetation, smoke particles etc. Dust particles and pollen from vegetation together form about 50 percent of the total particles present in the atmosphere. Size of these particles in the atmosphere varies from approximately 0.01μm to 100μm.

The gases and the particles present in the atmosphere cause scattering and absorption of the electromagnetic radiation passing through it.

3. Energy Interactions

The radiation from the energy source passes through some distance of atmosphere before being detected by the remote sensor as shown in Fig. 1.

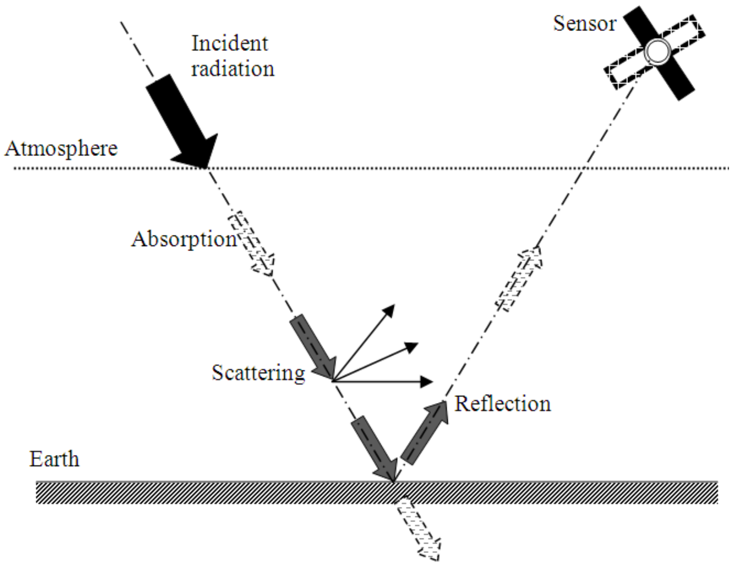


Fig. 1. Interactions in the atmosphere

The distance travelled by the radiation through the atmosphere is called the path length. The path length varies depending on the remote sensing techniques and sources.

For example, the path length is twice the thickness of the earth's atmosphere in the case of space photography which uses sunlight as its source. For airborne thermal sensors which use emitted energy from the objects on the earth, the path length is only the length of the one way distance from the Earth's surface to the sensor, and is considerably small.

The effect of atmosphere on the radiation depends on the properties of the radiation such as magnitude and wavelength, atmospheric conditions and also the path length. Intensity and spectral composition of the incident radiation are altered by the atmospheric effects. The interaction of the electromagnetic radiation with the atmospheric particles may be a surface phenomenon (e.g., scattering) or volume phenomenon (e.g., absorption). Scattering and absorption are the main processes that alter the properties of the electromagnetic radiation in the atmosphere.

4. Scattering

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.

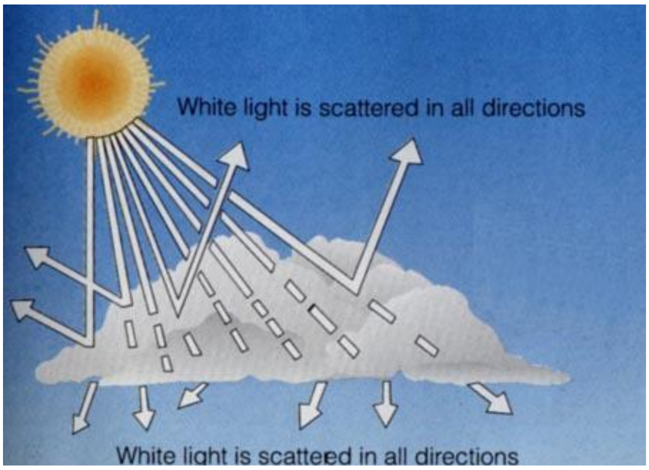


Fig. 2. Scattering of the electromagnetic radiation in the atmosphere
http://www.geog.ucsb.edu/~joel/g110_w08/lecture_notes/radiation_atmosphere/radiation_atmosphere.html

There are three different types of scattering:

- Rayleigh scattering
- Mie scattering
- Non-selective scattering

3.1 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.

Smaller particles present in the atmosphere scatter the shorter wavelengths more compared to the longer wavelengths.

The scattering effect or the intensity of the scattered light is inversely proportional to the fourth power of wavelength for Rayleigh scattering. Hence, the shorter wavelengths are scattered more than longer wavelengths.

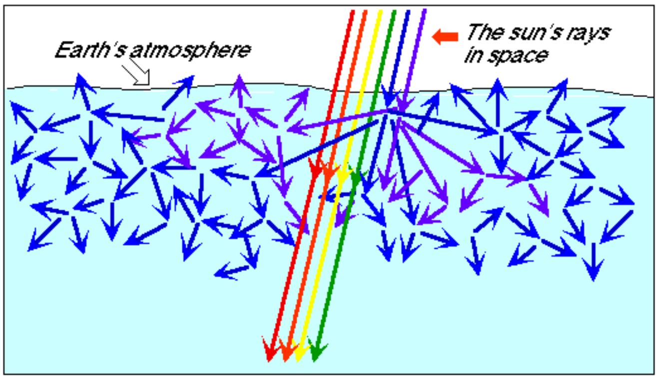


Fig. 3. Rayleigh scattering
http://home.comcast.net/~vinelandrobotics/

Rayleigh scattering is also known as selective scattering or molecular scattering.

Molecules of Oxygen and Nitrogen (which are dominant in the atmosphere) cause this type of scattering of the visible part of the electromagnetic radiation. Within the visible range, smaller wavelength blue light is scattered more compared to the green or red. A "blue" sky is thus a manifestation of Rayleigh scatter. The blue light is scattered around 4 times and UV light is scattered about 16 times as much as red light. This consequently results in a blue sky. However, at sunrise and sunset, the sun's rays have to travel a longer path, causing complete scattering (and absorption) of shorter wavelength radiations. As a result, only the longer wavelength portions (orange and red) which are less scattered will be visible.

The haze in imagery and the bluish-grey cast in a color image when taken from high altitude are mainly due to Rayleigh scatter.

3.2 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 (Fig. 4).

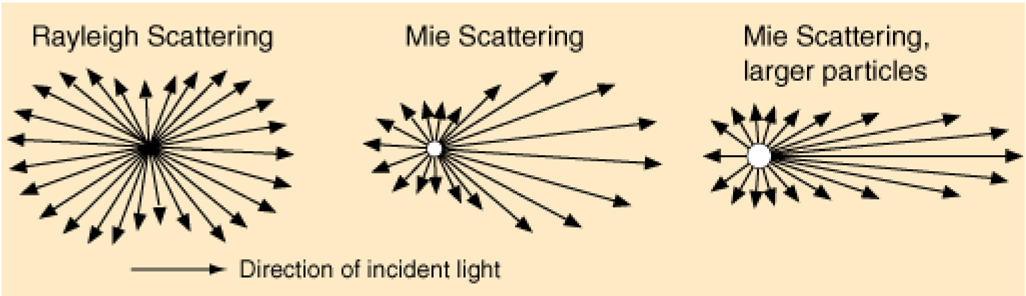


Fig.4 Rayleigh and Mie scattering

http://hyperphysics.phy-astr.gsu.edu

In Mie scattering, intensity of the scattered light varies approximately as the inverse of the wavelength.

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.

3.3 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 0.4-0.7μm), 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.

4. Absorption

Absorption is the process in which incident energy is retained by particles in the atmosphere at a given wavelength. Unlike scattering, atmospheric absorption causes an effective loss of energy to atmospheric constituents.

The absorbing medium will not only absorb a portion of the total energy, but will also reflect, refract or scatter the energy. The absorbed energy may also be transmitted back to the atmosphere.

The most efficient absorbers of solar radiation are water vapour, carbon dioxide, and ozone. Gaseous components of the atmosphere are selective absorbers of the electromagnetic radiation, i.e., these gases absorb electromagnetic energy in specific wavelength bands. Arrangement of the gaseous molecules and their energy levels determine the wavelengths that are absorbed.

Since the atmosphere contains many different gases and particles, it absorbs and transmits many different wavelengths of electromagnetic radiation. Even though all the wavelengths from the Sun reach the top of the atmosphere, due to the atmospheric absorption, only limited wavelengths can pass through the atmosphere. The ranges of wavelength that are partially or wholly transmitted through the atmosphere are known as "atmospheric windows." Remote sensing data acquisition is limited through these atmospheric windows. The atmospheric windows and the absorption characteristics are shown in Fig.5.

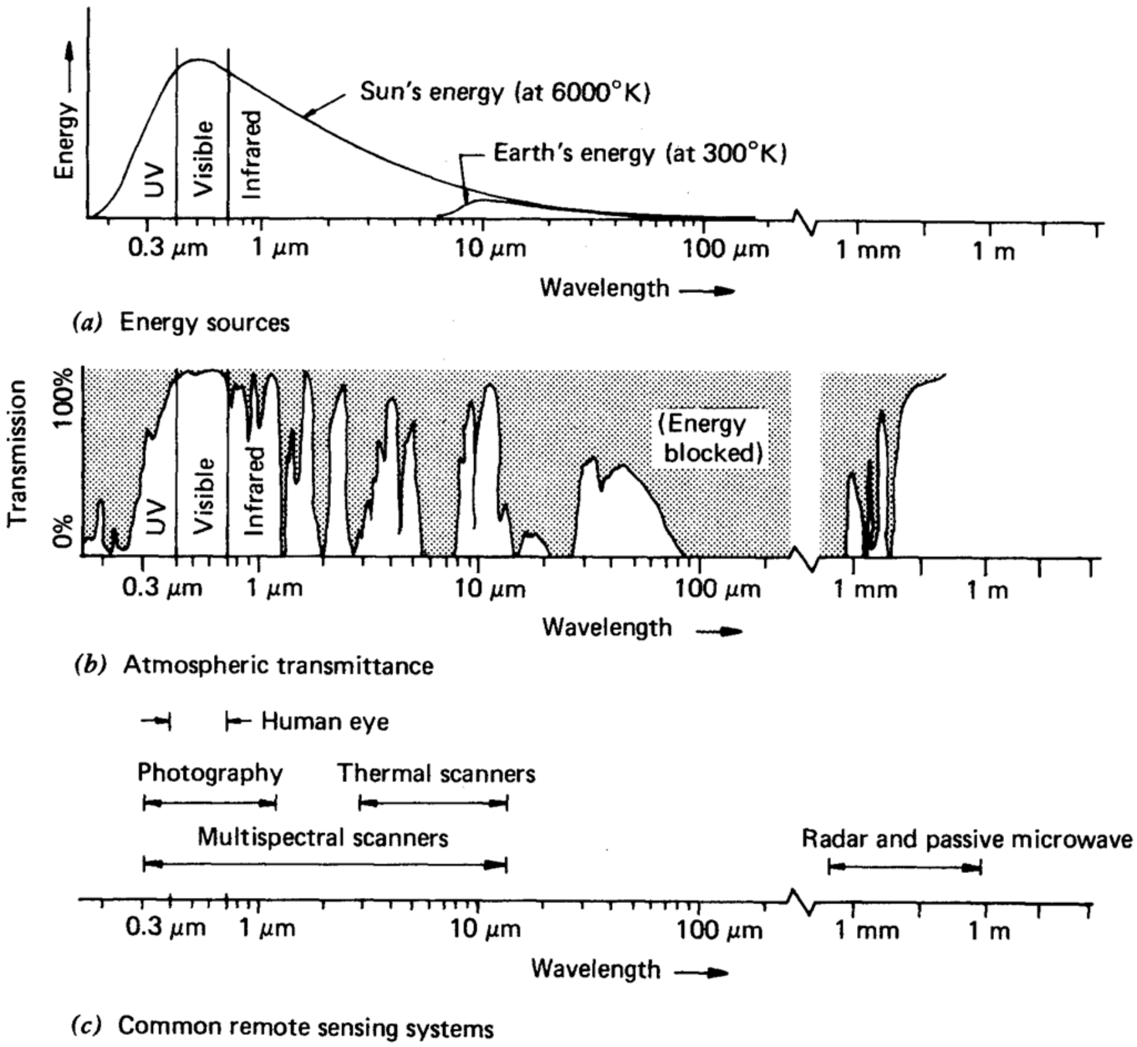


Fig. 5. (a) Spectral characteristics of main energy sources (b) Atmospheric windows and (c) Common remote sensing systems at different wavelengths (Source: Lillesand et al., 2004)

From Fig.5 it can be observed that electromagnetic radiation at different wavelengths is completely absorbed, partially absorbed or totally transmitted through the atmosphere. Nitrogen and other gaseous components in the atmosphere cause absorption of wavelengths shorter than 0.1 μm. Wavelengths shorter than 0.3μm (X-rays, Gamma rays and part of ultraviolet rays) are mostly absorbed in the atmosphere. This is caused by the ozone (O_3) present in the upper atmosphere. Oxygen in the atmosphere causes absorption centered at 6.3μm.

In the visible part of the spectrum, little absorption occurs.

Infrared (IR) radiation is mainly absorbed due to the rotational and vibrational transitions of the molecules. The main atmospheric constituents responsible for infrared absorption are water vapour (H_2O) and carbon dioxide (CO_2) molecules. Most of the radiation in the far infrared region is also absorbed by the atmosphere. However, absorption is almost nil in the microwave region.

The most common sources of energy are the incident solar energy and the radiation from the Earth. The wavelength at which the Sun's energy reaches its maximum coincides with the visible band range. The energy radiated from the Earth is sensed through the windows at 3 to 5μm and 8 to 14μm using devices like thermal scanners.

Radar and Passive microwave systems operate through a window in the 1 mm to 1 m region

Major atmospheric windows used for remote sensing are given n Table 2.

Table 2. 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

5. Sensor selection for remote sensing

While selecting a sensor the following factors should be considered:

i. The spectral sensitivity of the available sensors
ii. The available atmospheric windows in the spectral range(s) considered. The spectral range of the sensor is selected by considering the energy interactions with the features under investigation.
iii. The source, magnitude, and spectral composition of the energy available in the particular range.
iv. Multi Spectral Sensors sense simultaneously through multiple, narrow wavelength ranges that can be located at various points in visible through the thermal spectral regions

Bibliography / Further Readings

1. Gibson, P. J., 2000.Introductory Remote Sensing- Principles and Concepts, Routledge, London.
2. Lillesand, T. M., Kiefer, R. W., Chipman, J. W., 2004. Remote sensing and image interpretation. Wiley India (P). Ltd., New Delhi.

MODULE – 1 LECTURE NOTES – 4

ENERGY INTERACTIONS WITH EARTH SURFACE FEATURES

Energy incident on the Earth's surface is absorbed, transmitted or reflected depending on the wavelength and characteristics of the surface features (such as barren soil, vegetation, water body). Interaction of the electromagnetic radiation with the surface features is dependent on the characteristics of the incident radiation and the feature characteristics. After interaction with the surface features, energy that is reflected or re-emitted from the features is recorded at the sensors and are analysed to identify the target features, interpret the distance of the object, and /or its characteristics.

This lecture explains the interaction of the electromagnetic energy with the Earth's surface features.

2. Energy Interactions

The incident electromagnetic energy may interact with the earth surface features in three possible ways: Reflection, Absorption and Transmission. These three interactions are illustrated in Fig. 1.

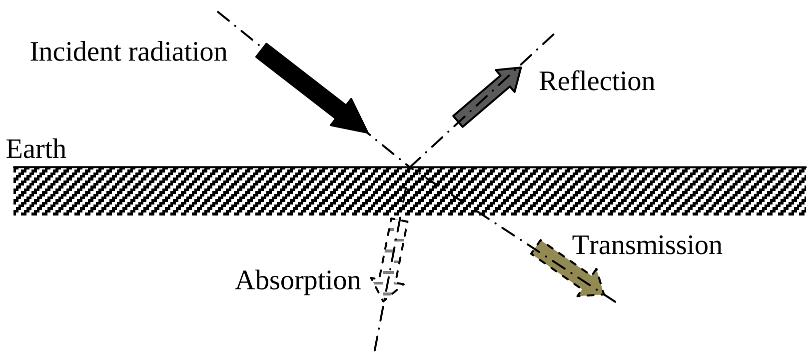


Fig. 1. Energy interactions with earth surface features

Reflection occurs when radiation is redirected after hitting the target. According to the law of reflection, the angle of incidence is equal to the angle of reflection (Fig. 2) .

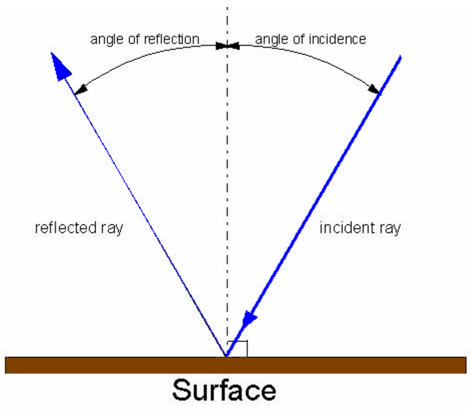


Fig. 2 Energy reflection

Absorption occurs when radiation is absorbed by the target. The portion of the EM energy which is absorbed by the Earth's surface is available for emission and as thermal radiation at longer wavelengths (Fig. 3).

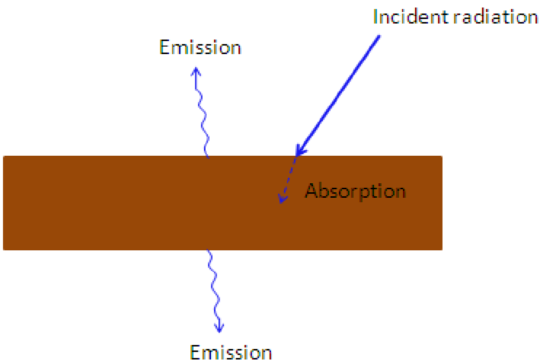


Fig. 3 Energy absorption and emission

Transmission occurs when radiation is allowed to pass through the target. Depending upon the characteristics of the medium, during the transmission velocity and wavelength of the radiation changes, whereas the frequency remains same. The transmitted energy may further get scattered and / or absorbed in the medium.

These three processes are not mutually exclusive. Energy incident on a surface may be partially reflected, absorbed or transmitted. Which process takes place on a surface depends on the following factors:

- Wavelength of the radiation
- Angle at which the radiation intersects the surface
- Composition and physical properties of the surface

The relationship between reflection, absorption and transmission can be expressed through the principle of conservation of energy. Let E_I denotes the incident energy, E_R denotes the reflected energy, E_A denotes the absorbed energy and E_T denotes the transmitted energy. Then the principle of conservation of energy (as a function of wavelength λ) can be expressed as

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda) \tag{1}$$

Since most remote sensing systems use reflected energy, the energy balance relationship can be better expressed in the form

$$E_R(\lambda) = E_I(\lambda) - E_A(\lambda) - E_T(\lambda) \tag{2}$$

The reflected energy is equal to the total energy incident on any given feature reduced by the energy absorbed or transmitted by that feature.

3. Reflection

Reflection is the process in which the incident energy is redirected in such a way that the angle of incidence is equal to the angle of reflection. The reflected radiation leaves the surface at the same angle as it approached.

Scattering is a special type of reflection wherein the incident energy is diffused in many directions and is sometimes called diffuse reflection.

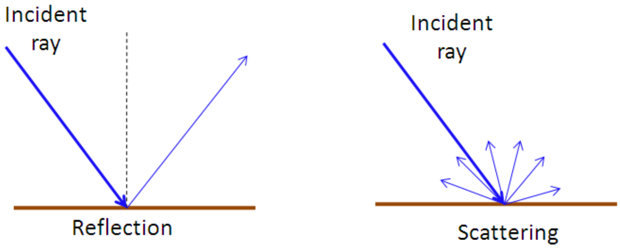


Fig.4 Reflection and scattering

When electromagnetic energy is incident on the surface, it may get reflected or scattered depending upon the roughness of the surface relative to the wavelength of the incident energy. If the roughness of the surface is less than the wavelength of the radiation or the ratio of roughness to wavelength is less than 1, the radiation is reflected. When the ratio is more than 1 or if the roughness is more than the wavelength, the radiation is scattered.

Fraction of energy that is reflected / scattered is unique for each material. This will aid in distinguishing different features on an image.

A feature class denotes distinguishing primitive characteristic or attribute of an image that have been classified to represent a particular land cover type/spectral signature. Within one feature class, the proportion of energy reflected, emitted or absorbed depends on the wavelength. Hence, in spectral range two features may be indistinguishable; but their reflectance properties may be different in another spectral band. In multi-spectral remote sensing, multiple sensors are used to record the reflectance from the surface features at different wavelength bands and hence to differentiate the target features.

Variations in the spectral reflectance within the visible spectrum give the colour effect to the features. For example, blue colour is the result of more reflection of blue light. An object appears as "green" when it reflects highly in the green portion of the visible spectrum. Leaves appear green since its chlorophyll pigment absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Similarly, water looks blue-green or blue or green if viewed through visible band because it reflects the shorter wavelengths and absorbs the longer wavelengths in the visible band. Water also absorbs the near infrared wavelengths and hence appears darker when viewed through red or near infrared wavelengths. Human eye uses reflected energy variations in the visible spectrum to discriminate between various features.

For example, Fig.5 shows a part of the Krishna River Basin as seen in different bands of the Landsat ETM$^+$ imagery. As the concepts of false color composite (FCC) have been covered in module 4, readers are advised to refer to the material in module 4 for better understanding of the color composite imageries as shown in Fig. 5. Reflectance of surface features such as water, vegetation and fallow lands are different in different wavelength bands. A combination of more than one spectral band helps to attain better differentiation of these features.

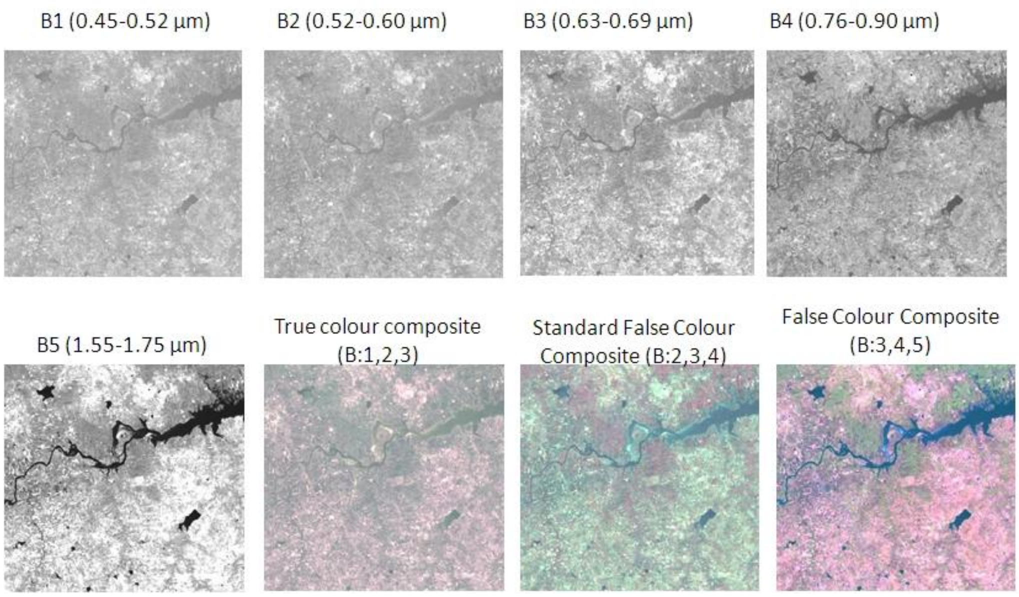


Fig. 5 A part of the Krishna River Basin as seen in different bands of the Landsat ETM$^+$ images

3. Diffuse and Specular Reflection

Energy reflection from a surface depends on the wavelength of the radiation, angle of incidence and the composition and physical properties of the surface.

Roughness of the target surface controls how the energy is reflected by the surface. Based on the roughness of the surface, reflection occurs in mainly two ways.

i. Specular reflection: It occurs when the surface is smooth and flat. A mirror-like or smooth reflection is obtained where complete or nearly complete incident energy is reflected in one direction. The angle of reflection is equal to the angle of incidence. Reflection from the surface is the maximum along the angle of reflection, whereas in any other direction it is negligible.
ii. Diffuse (Lambertian) reflection: It occurs when the surface is rough. The energy is reflected uniformly in all directions. Since all the wavelengths are reflected uniformly in all directions, diffuse reflection contains spectral information on the "colour" of the reflecting surface. Hence, in remote sensing diffuse reflectance properties of terrain features are measured. Since the reflection is uniform in all direction, sensors located at any direction record the same reflectance and hence it is easy to differentiate the features.

Based on the nature of reflection, surface features can be classified as Specular reflectors, Lambertian reflectors (Fig. 6).

An ideal specular reflector completely reflects the incident energy with angle of reflection equal to the angle incidence.

An ideal Lambertian or diffuse reflector scatters all the incident energy equally in all the directions.

The specular or diffusive characteristic of any surface is determined by the roughness of the surface in comparison to the wavelength of the incoming radiation. If the wavelengths of the incident energy are much smaller than the surface variations or the particle sizes, diffuse reflection will dominate. For example, in the relatively long wavelength radio range, rocky terrain may appear smooth to incident energy. In the visible portion of the spectrum, even a material such as fine sand appears rough while it appears fairly smooth to long wavelength microwaves.

Most surface features of the earth are neither perfectly specular nor perfectly diffuse reflectors. In near specular reflection, though the reflection is the maximum along the angle of reflection, a fraction of the energy also gets reflected in some other angles as well. In near Lambertian reflector, the reflection is not perfectly uniform in all the directions. The characteristics of different types of reflectors are shown in Fig. 6.

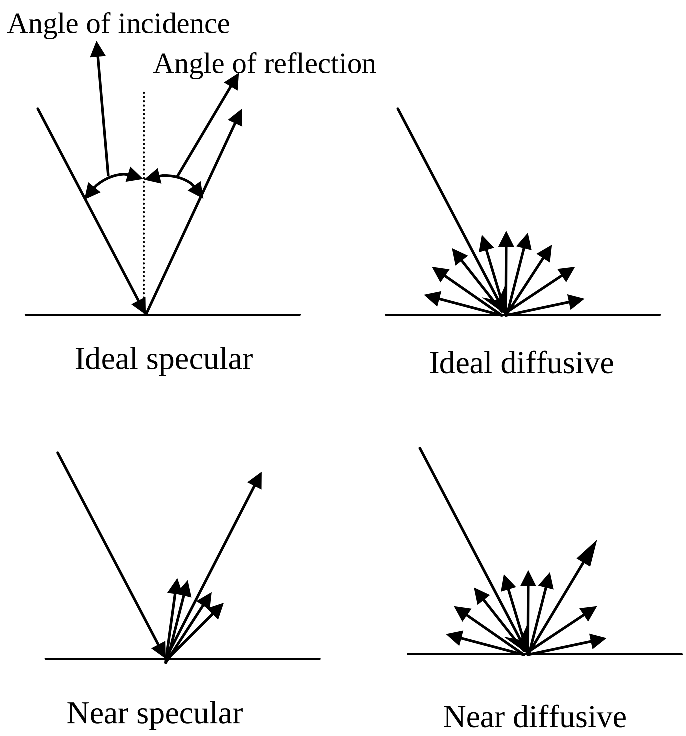


Fig. 6. Different types of reflectors

Lambertian reflectors are considered ideal for remote sensing. The reflection from an ideal Lambertian surface will be the same irrespective of the location of the sensor. On the other hand, in case of an ideal specular reflector, maximum brightness will be obtained only at one location and for the other locations dark tones will be obtained from the same target. This variation in the spectral signature for the same feature affects the interpretation of the remote sensing data.

Most natural surfaces observed using remote sensing are approximately Lambertian at visible and IR wavelengths. However, water provides specular reflection. Water generally gives a dark tone in the image. However due to the specular reflection, it gives a pale tone when the sensor is located in the direction of the reflected energy.

4. Spectral Reflectance Curves

The reflectance characteristics of earth surface features are expressed as the ratio of energy reflected by the surface to the energy incident on the surface. This is measured as a function of wavelength and is called spectral reflectance, R_λ. It is also known as albedo of the surface. Spectral reflectance or albedo can be mathematically defined as

$$R_\lambda = \frac{E_R(\lambda)}{E_I(\lambda)} = \frac{\text{Energy of wavelength } \lambda \text{ reflected from the object}}{\text{Energy of wavelength } \lambda \text{ incident on the object}} \times 100 \tag{3}$$

Albedo of various Earth surface features are given in Table 1.

Table 1. Albedo of various Earth surface features (From Gibson, 2000)

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

Albedo of fresh snow is generally very high. Dry snow reflects almost 80% of the energy incident on it. Clouds also reflect a majority of the incident energy. Dark soil and concrete generally show very low albedo. Albedo of vegetation is also generally low, but varies with the canopy density. Albedo of forest areas with good canopy cover is as low as 5-10%. Albedo of water ranges from 5 to 70 percentage, due to the specular reflection characteristics. Albedo is low at lower incidence angle and increases for higher incidence angles.

The energy that is reflected by features on the earth's surface over a variety of different wavelengths will give their spectral responses. The graphical representation of the spectral response of an object over different wavelengths of the electromagnetic spectrum is termed as spectral reflectance curve. These curves give an insight into the spectral characteristics of different objects, hence used in the selection of a particular wavelength band for remote sensing data acquisition.

For example, Fig. 7 shows the generalized spectral reflectance curves for deciduous (broad-leaved) and coniferous (needle-bearing) trees. Spectral reflectances varies within a given material i.e., spectral reflectance of one decisuous tree will not be identical with another. Hence the generalized curves are shown as a "ribbon" and not as a single line. These curves help in the selection of proper sensor system in order to differentiate deciduous and coniferous trees.

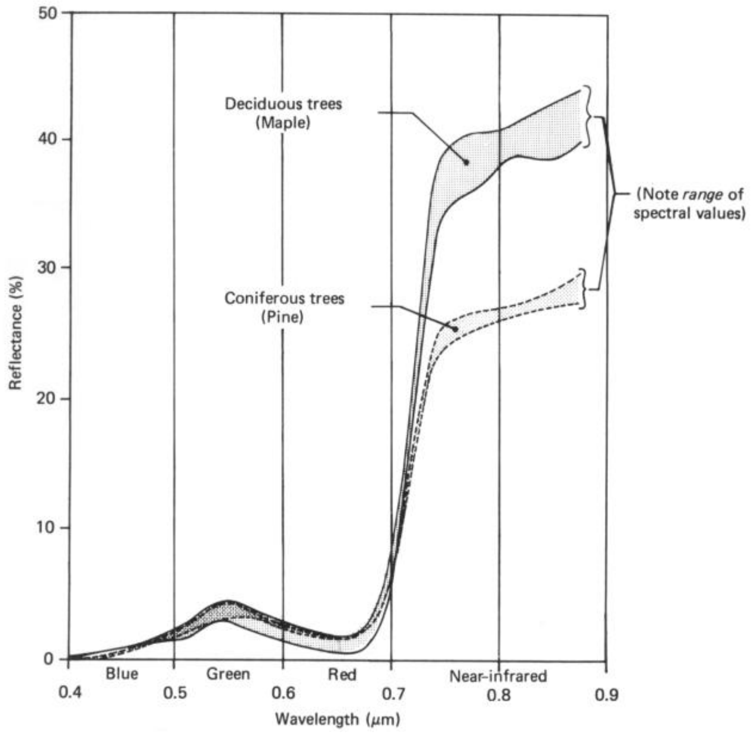
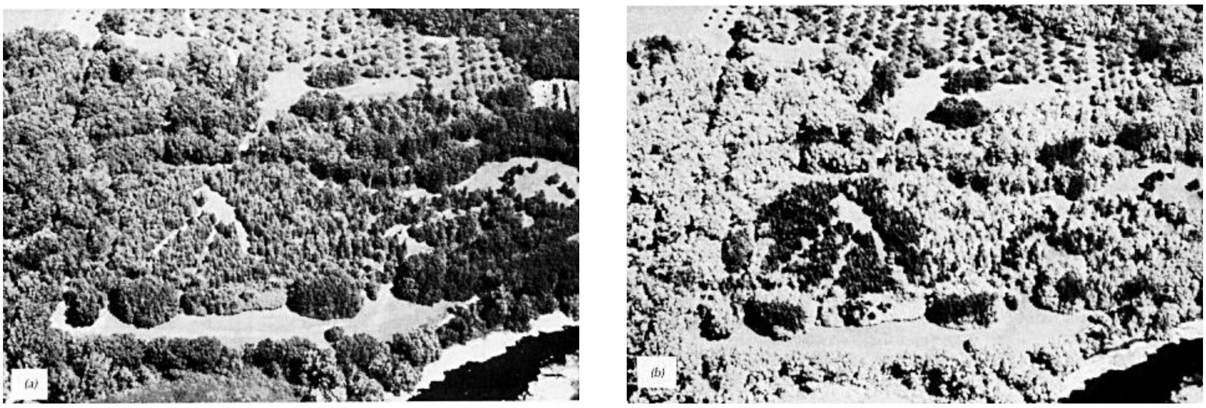


Fig. 7. Spectral reflectance curves for deciduous and coniferous trees (Lillesand et al., 2004)

As seen from Fig. 7, spectral reflectance curves for each tree type are overlapping in most of the visible portion. A choice of visible spectrum is not a feasible option for differentiation since both the deciduous and coniferous trees will essentially be seen in shades of green. However, in the near infra red (NIR) they are quite different and distinguishable. Within the electromagnetic spectrum, the NIR represents a wavelength range from (0.7-1) to 5 microns.

A comparison of photographs taken in visible band and NIR band is shown in Fig. 8. It should be noted that panchromatic refers to black and white imagery that is exposed by all visible light. In visible band, the tone is same for both trees. However, on infrared photographs, deciduous trees show a much lighter tone due to its higher infrared reflectance than conifers.



(a) (b)

Fig. 8. (a) Panchromatic photograph using reflected sunlight over the visible wavelength band 0.4 to 0.7 mm and (b) Black and white infrared photograph using reflected sunlight over 0.7 to 0.9 mm wavelength band (Lillesand et al., 2004)

In remote sensing, the spectral reflectance characteristics of the surface features have been used to identify the surface features and to study their characteristics. This requires basic understanding of the general reflectance characteristics of different feature, which is covered in the next lecture.

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MODULE – 1 LECTURE NOTES – 5

SPECTRAL REFLECTANCE CURVES

Electromagnetic energy incident on the surface features are partially reflected, absorbed or transmitted through it. The fractions that are reflected absorbed or transmitted vary with material type and the condition of the feature. It also varies with the wavelength of the incident energy. Majority of the remote sensing systems operate in the region in which the surface features mostly reflect the incident energy. The reflectance characteristics of the surface features are represented using spectral reflectance curves.

This lecture covers the spectral reflectance characteristics of some of the important surface features.

Understanding spectral reflectance curves for different features at different wavelengths is essential to interpret and analyze an image obtained in any one or multiple wavelengths.

1. Spectral Reflectance Curve for Vegetation

Spectral reflectance curve for healthy green vegetation exhibits the "peak-and-valley" configuration as illustrated in Fig. 1. The peaks indicate strong reflection and the valleys indicate predominant absorption of the energy in the corresponding wavelength bands.

In general, healthy vegetations are very good absorbers of electromagnetic energy in the visible region. The absorption greatly reduces and reflection increases in the red/infrared boundary near 0.7 μm. The reflectance is nearly constant from 0.7-1.3 μm and then decreases for the longer wavelengths.

Spectral response of vegetation depends on the structure of the plant leaves. Fig. 1 shows the cell structure of a green leaf and the interaction with the electromagnetic radiation (Gibson 2000).

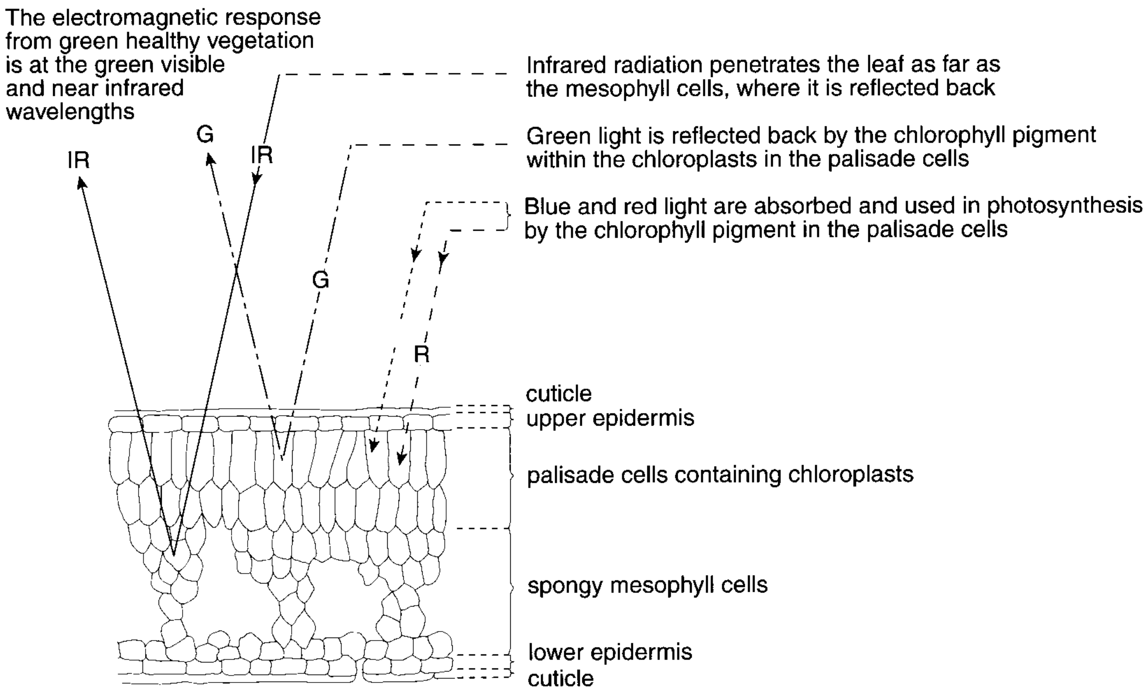

Fig.1. Cell structure of a green leaf and interactions with the electromagnetic radiation (Gibson, 2000)

The valleys in the visible portion of the spectrum are due to the pigments in plant leaves. The palisade cells containing sacs of green pigment (chlorophyll) strongly absorb energy in the wavelength bands centered at 0.45 and 0.67 μm within visible region (corresponds to blue and red), as shown in Fig.2. On the other hand, reflection peaks for the green colour in the visible region, which makes our eyes perceive healthy vegetation as green in colour. However, only 10-15% of the incident energy is reflected in the green band.

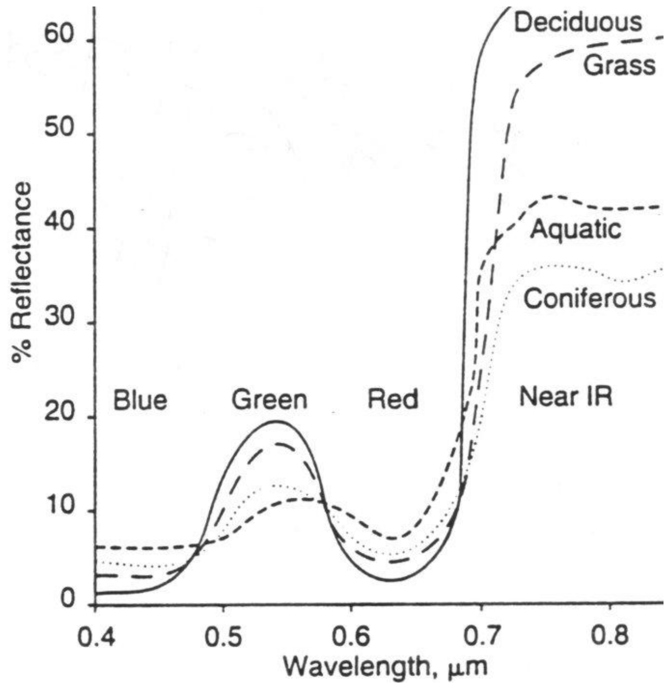

Fig. 2. Spectral reflectance of healthy vegetation in the visible and NIR wavelength bands
http://www.geog.ucsb.edu/

In the reflected infrared portion (or near infrared, NIR) of the spectrum, at 0.7 µm, the reflectance of healthy vegetation increases dramatically. In the range from 0.7 to 1.3 µm, a plant leaf reflects about 50 percent of the energy incident upon it. The infrared radiation penetrates the palisade cells and reaches the irregularly packed mesophyll cells which make up the body of the leaf. Mesophyll cells reflect almost 60% of the NIR radiation reaching this layer. Most of the remaining energy is transmitted, since absorption in this spectral region is minimal. Healthy vegetation therefore shows brighter response in the NIR region compared to the green region. As the leaf structure is highly variable between plant species, reflectance measurements in this range often permit discrimination between species, even if they look same in visible wavelengths as seen in Fig. 3.

If a plant is subjected to some form of stress that interrupts its normal growth and productivity, it may decrease or cease chlorophyll production. The result is less absorption in the blue and red bands in the palisade. Hence, red and blue bands also get reflected along with the green band, giving yellow or brown colour to the stressed vegetation. Also in stressed vegetation, the NIR bands are no longer reflected by the mesophyll cells, instead they are absorbed by the stressed or dead cells causing dark tones in the image (Fig. 3)

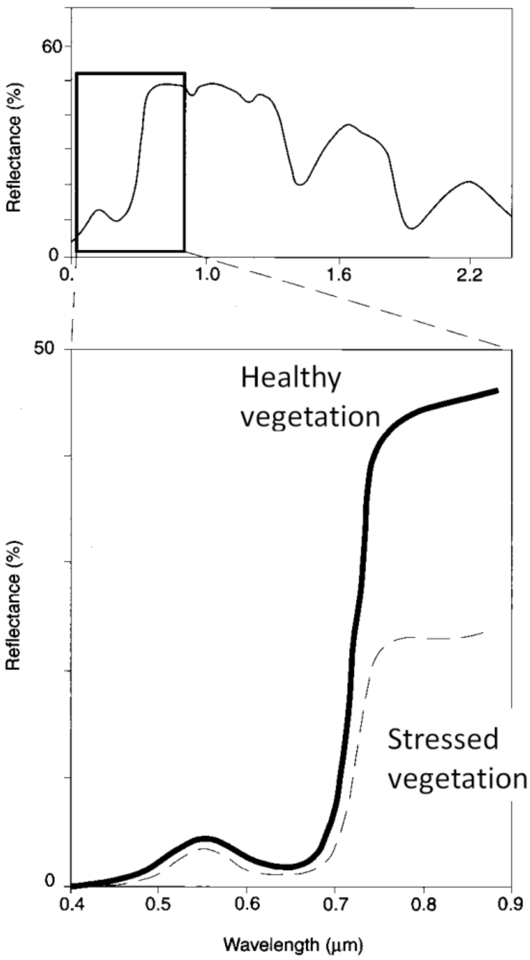

Fig. 3 Spectral reflectance curve for healthy and stressed vegetations (Gibson, 2000)

Beyond 1.3 μm, energy incident upon the plants is essentially absorbed or reflected, with little to no transmittance of energy. Dips in reflectance occur at 1.4, 1.9, and 2.7 μm as water in the leaf strongly absorbs the energy at these wavelengths. So, wavelengths in these spectral regions are referred to as water absorption bands. Reflectance peaks occur at 1.6 and 2.2 μm, between the absorption bands. At wavelengths beyond 1.3 μm, leaf reflectance is approximately inversely related to the total water present in a leaf. This total water is a function of both the moisture content and the thickness of the leaf.

Similar to the reflection and absorption, transmittance of the electromagnetic radiation by the vegetation also varies with wavelength. Transmittance of electromagnetic radiation is less in the visible region and it increases in the infrared region. Vegetation canopies generally display a layered structure. Therefore, the energy transmitted by one layer is available for reflection or absorption by the layers below it (Fig. 4). Due to this multi-layer reflection, total infrared reflection from thicker canopies will be more compared to thin canopy cover. From the reflected NIR, the density of the vegetation canopy can thus be interpreted.

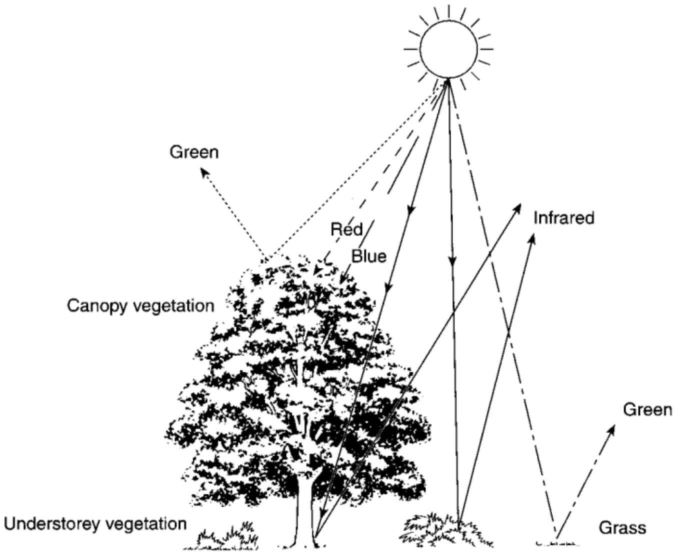

Fig. 4. Reflectance from dense forest and thin vegetation canopies (Gibson, 2000)

As the reflectance in the IR bands of the EMR spectrum varies with the leaf structure and the canopy density, measurements in the IR region can be used to discriminate the tree or vegetation species. For example, spectral reflectance of deciduous and coniferous trees may be similar in the green band. However, the coniferous trees show higher reflection in the NIR band, and can be easily differentiated (Fig.5). Similarly, for a densely grown agricultural area, the NIR signature will be more.

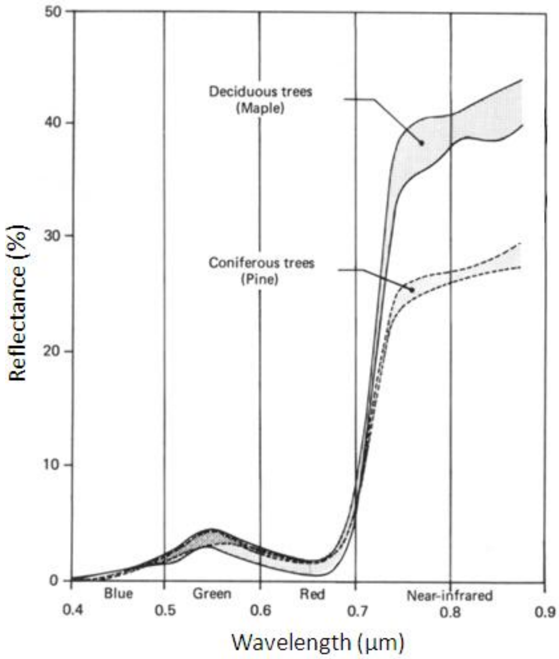

Fig. 5 Spectral reflectance curves for deciduous and coniferous trees (Lillesand et al., 2004)

2. Spectral Reflectance of Soil

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Some of the factors effecting soil reflectance are moisture content, soil texture (proportion of sand, silt, and clay), surface roughness, presence of iron oxide and organic matter content. These factors are complex, variable, and interrelated.

For example, the presence of moisture in soil decreases its reflectance. As with vegetation, this effect is greatest in the water absorption bands at 1.4, 1.9, and 2.7 μm. On the other hand, similar absorption characteristics are displayed by the clay soils. Clay soils have hydroxyl ion absorption bands at 1.4 and 2.2 μm.

Soil moisture content is strongly related to the soil texture. For example, coarse, sandy soils are usually well drained, resulting in low moisture content and relatively high reflectance. On the other hand, poorly drained fine textured soils generally have lower reflectance. In the absence of water, however, the soil itself exhibits the reverse tendency i.e., coarse textured soils appear darker than fine textured soils.

Two other factors that reduce soil reflectance are surface roughness and the content of organic matter. Presence of iron oxide in a soil also significantly decreases reflectance, at least in the visible region of wavelengths.

3. Spectral Reflectance for Water

Water provides a semi-transparent medium for the electromagnetic radiation. Thus the electromagnetic radiations get reflected, transmitted or absorbed in water. The spectral responses vary with the wavelength of the radiation and the physical and chemical characteristics of the water.

Spectral reflectance of water varies with its physical condition. In the solid phase (ice or snow) water give good reflection at all visible wavelengths. On the other hand, reflection in the visible region is poor in case of water in liquid stage. This difference in reflectance is due to the difference in the atomic bond in the liquid and solid states.

Water in the liquid form shows high reflectance in the visible region between 0.4μm and 0.6μm. Wavelengths beyond 0.7μm are completely absorbed. Thus clear water appears in darker tone in the NIR image. Locating and delineating water bodies with remote sensing data is done more easily in reflected infrared wavelengths because of this absorption property.

For example, Fig. 6 shows a part of the Krishna River Basin in different bands of the Landsat ETM+ imagery. The water body appears in dark colour in all bands and displays sharp contrast in the IR bands.

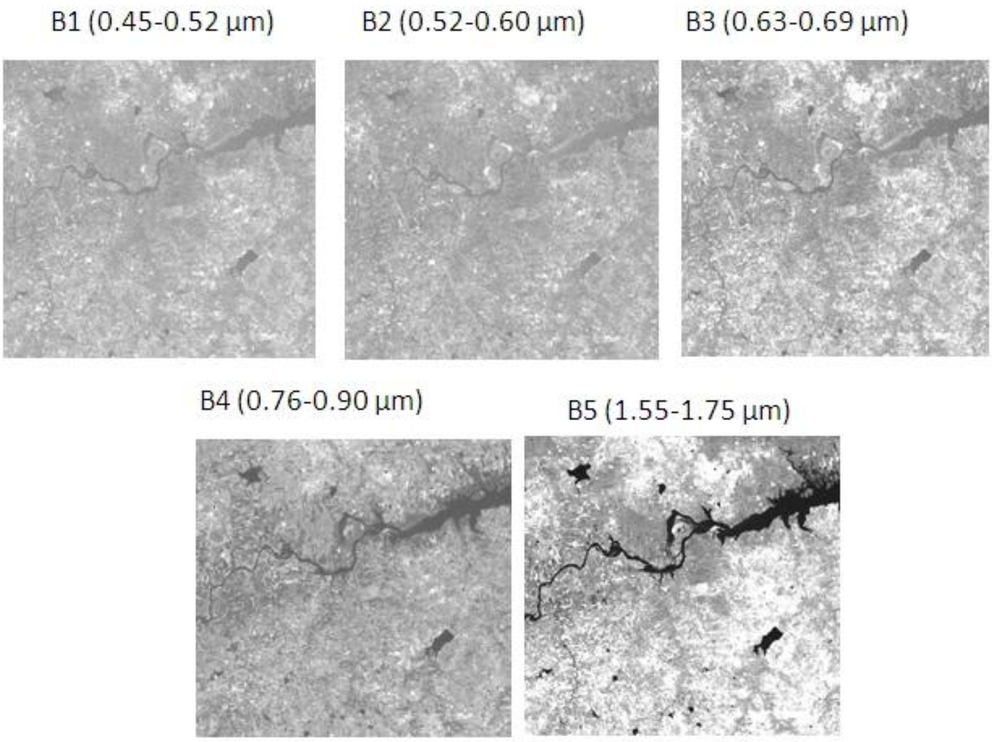


Fig. 6 Landsat ETM+ images of a part of the Krishna river basin in different spectral bands

(Modified from Nagesh Kumar and Reshmidevi, 2013)

However, various conditions of water bodies manifest themselves primarily in visible wavelengths. The energy/matter interactions at these wavelengths are very complex and depend on a number of interrelated factors (Fig. 7). For example, the reflectance from a water body can stem from an interaction with the water's surface (specular reflection), with material suspended in the water, or with the bottom surface of the water body. Even in deep water, where bottom effects are negligible, the reflectance properties of a water body are not only a function of the water, but also of the material in the water.

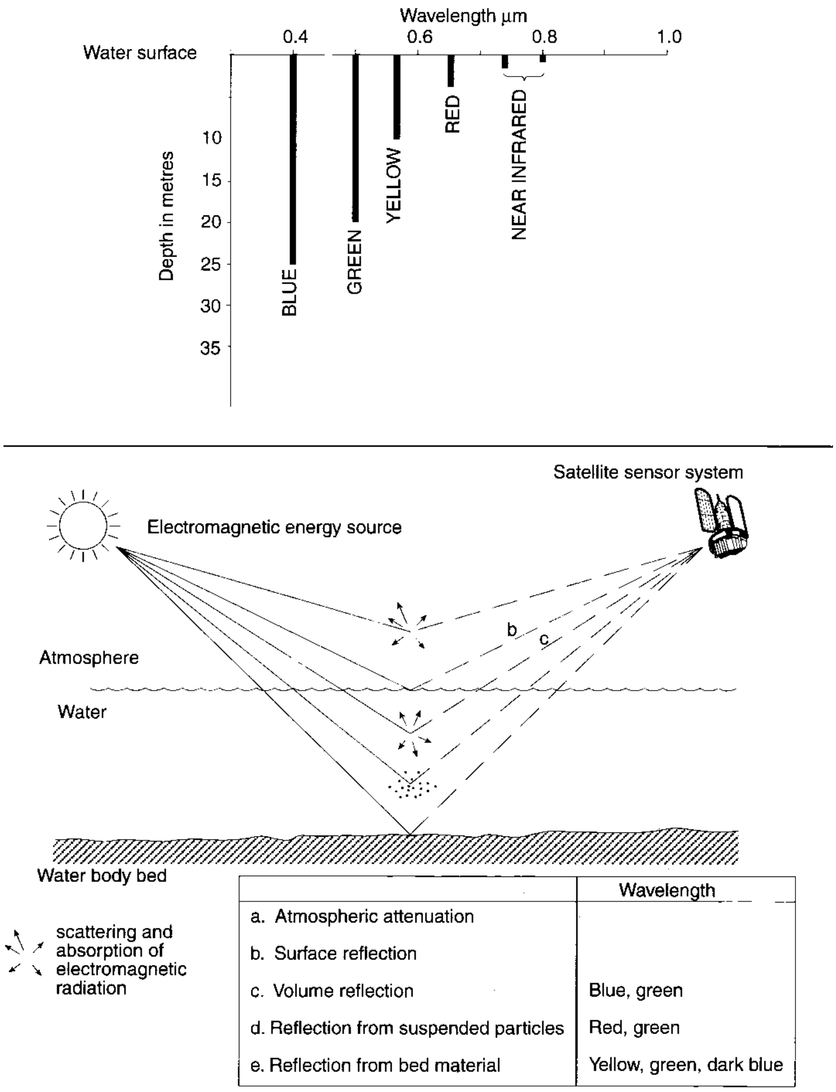


Fig. 7. Complex spectral response from a water body (Gibson, 2000)

Clear water absorbs relatively less energy having wavelengths shorter than 0.6 μm. High transmittance typifies these wavelengths with a maximum in the blue-green portion of the spectrum. However, as the turbidity of water changes (because of the presence of organic or inorganic materials), transmittance and therefore reflectance change dramatically. For example, water bodies containing large quantities of suspended sediments normally have much higher visible reflectance than clear water. Likewise, the reflectance of water changes with the chlorophyll concentration involved. Increase in chlorophyll concentration tends to decrease reflectance in blue wavelengths and increase reflectance in green wavelengths. These changes have been used in remote sensing to monitor the presence and to estimate the concentration of algae. Reflectance data have also been used to determine the presence or absence of tannin dyes from bog vegetation in lowland areas, and to detect a number of pollutants, such as oil and certain industrial wastes.

Many important characteristics of water such as dissolved oxygen concentration, pH, and salt concentration cannot be observed directly through changes in water reflectance. However, such parameters sometimes correlate with observed reflectance. Thus, there are many complex interrelationships between the spectral reflectance of water and particular characteristics.

Variation in the spectral reflectance in the visible region can be used to differentiate shallow and deep waters, clear and turbid waters, as well as rough and smooth water bodies. Reflectance in the NIR range is generally used for delineating the water bodies and also to study the algal boom and phytoplankton concentration in water. More details on the remote sensing applications for monitoring water quality parameters can be found in Nagesh Kumar and Reshmidevi (2013).

Further details on the spectral characteristics of vegetation, soil, and water can be found in Swain and Davis (1978).

4. Spectral Reflectance of Some Natural Features

Sample spectral reflectance curves of some of the natural features like snow, healthy vegetation, stressed vegetation, dry soil, turbid water and clear water are given in Fig. 8.

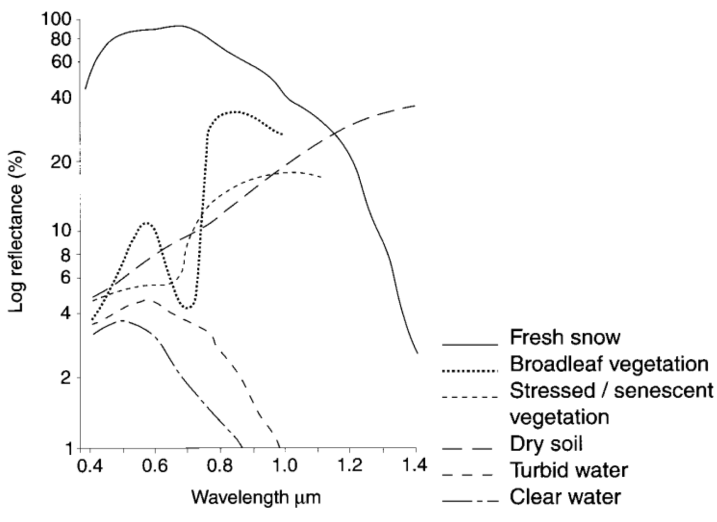
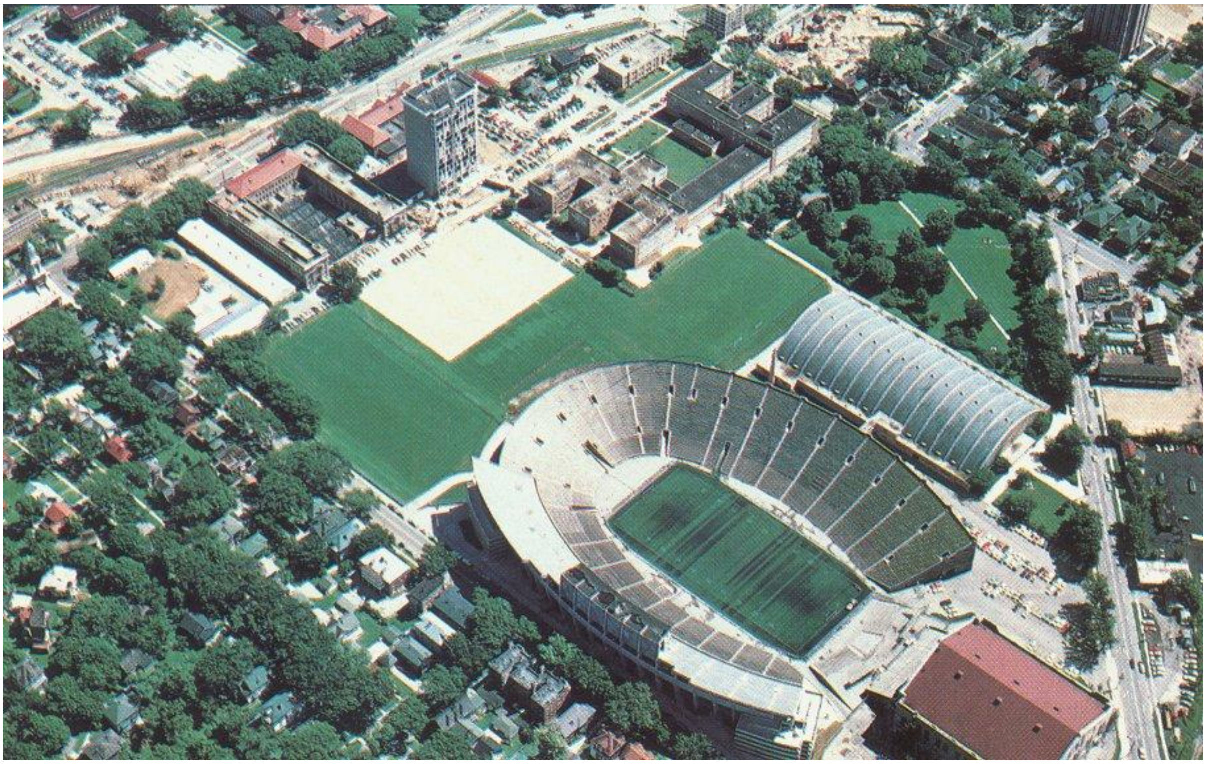


Fig. 8 Sample spectral reflectance curves for natural features

In a multispectral image, multiple sensors are used to sense the reflectance in different wavelength bands. Reflectance recorded in multiple bands are analysed to find how the spectral reflectance varies with wavelength. Using the average spectral reflectance curves as the basic information, the spectral reflectance variation is used to identify the target features.

For example, in Fig.9 aerial photographs of a stadium in normal colour and colour IR are shown. In normal colour photograph, the artificial turf inside the stadium and the natural vegetation outside the stadium appear in the same colour. On the other hand, the IR colour photograph helps to differentiate both very clearly. The artificial turf appears dark in tone, whereas the natural vegetation shows high reflectance in the IR region. Spectral reflectance curves of the natural vegetation and the artificial turf are shown in Fig. 10. (Images are taken from Lillesand et al., 2004).

(a)



(b)

Fig. 9 Aerial photograph of a football stadium with artificial turf (a) normal colour photograph (b) colour IR photograph (from Lillesand et al., 2004)

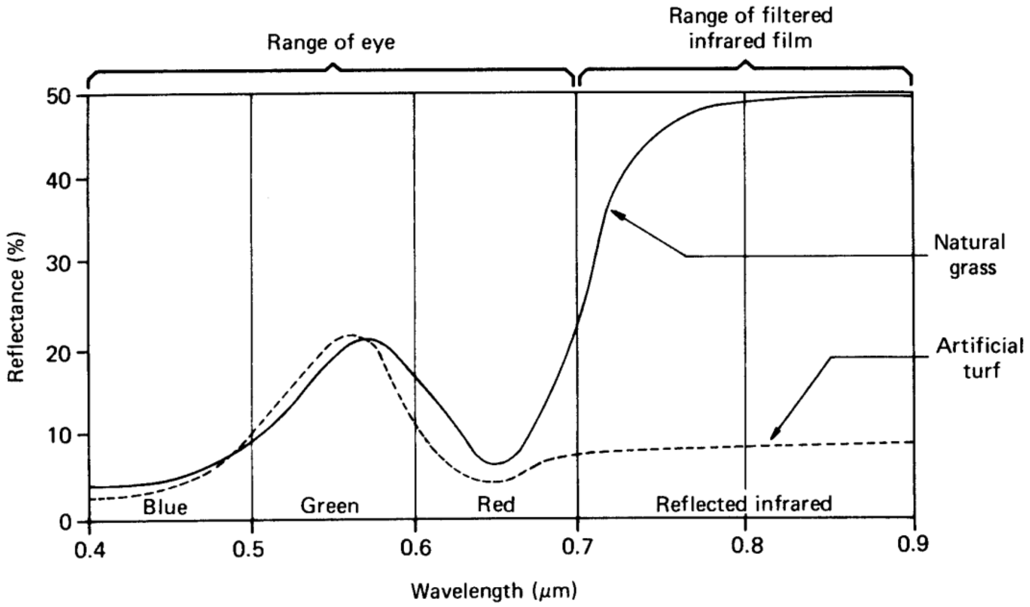


Fig. 10 Spectral reflectance curves of the natural vegetation and the artificial turf (From Lillesand et al., 2004)

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