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Component-I (B) - Description of Module

Items	**Description of Module**
Subject Name	**Geography**
Paper Name	**Remote Sensing, GIS and GPS**
Module Name/Title	**Basic Principles of Remote Sensing**
Module Id	**RS/GIS-01**
Pre-requisites	
Objectives	
Keywords	Electromagnetic waves, Radiation Laws, Interactions with the Atmosphere, Interactions with the Earth's Surface, Resolutions

Basic Principles of Remote Sensing

Structure

Objectives

At the end of this unit student will be able to briefly explain:

- Energy sources and the components of the electromagnetic spectrum that collectively forms an integral part of remote sensing technology.
- Concept of surface temperature and radiation, radiation laws and terminology.
- The essential theories that describe the characteristics of electromagnetic radiation.
- Energy interactions in the atmosphere, scattering and absorption of energy in the atmosphere and ‘atmospheric windows’.
- Electromagnetic radiation interaction with Earth’s surface and various reflectance characteristics of earth’s cover types.

- Various types of resolutions that describes the utility of the spatial data forms for a variety of applications.

1.1 Introduction

Humans are closely associated with remote sensing in day to day activities by collecting and inferring useful information about the surroundings sensed through the eyes. Our eyes act as sensors which are limited to record only the visible portion of the electromagnetic energy and our brain act as a processing unit which stores the viewed information for a limited number of days. This limitation forced mankind to develop a technique capable of acquiring information about an object or phenomena covering almost the entire range of electromagnetic spectrum. The data so acquired is stored in some medium (e.g. DVDs, CDs etc.) for future interpretation and analysis. Present day sensors are installed on board satellite platforms and are capable of imaging large portions of earth and continuously transfer the digital data electronically to the ground stations.

The science of Remote Sensing has continuously evolved in the data acquisition methods as well as data processing techniques and the variety of applications it is used for. The remote sensing technology has advanced particularly towards variety of applications related to land, water and atmosphere issues e.g. water resources development and management, soil and mineral explorations, agricultural and land use practices, air quality monitoring, disaster management and mitigation, ocean studies and many more. This module attempts to provide the reader a basic understanding of the concept, capabilities and limitations of Remote Sensing technology.

> ☞ *"The simplest way of understanding the term remote sensing can be related to the reading of this sentence itself. Our eyes sense the written sentences on the page to which our brain process this information and interprets the logical meaning. This is how the remote sensing technology works".*

1.2 Definition and Scope

As discussed in the above section, our eyes are an excellent example of a remote sensing device that are capable of gathering information about the surroundings by judging the amount and nature of the reflectance of visible light energy from some external source (such as the sun or any artificial source of light) as it reflects off objects in our field of view. Gathering information where sensor and the object are not in direct contact with each other may be termed as remote sensing, for example, reading news paper, looking across window, perspective view form high terrace etc. In contrast, a thermometer, which must be in contact with the phenomenon it measures, is not a remote sensing device.

In the broadest sense, the term remote sensing can be defined as the science of acquiring information about the earth using instruments which are ant in direct contact with the earth's surface or features, usually from aircraft or satellites. Instrument aboard satellite or aircraft is usually a sensor which is capable of acquiring information in the entire region of electromagnetic spectrum (i.e. visible light, infrared or radar etc.). Remote sensing offers the ability to observe and collect data for large areas relatively quickly, and is an important source of data for Geographical Information System (GIS) interface.

Every remote sensing process involves an interaction of the incident radiation falling over the target of interest in a sense that, the radiation incident over the target is altered on account of the physical properties of the target and reflect back the incident radiation which is recorded by the sensor. This is illustrated by the use of imaging systems (referred as optical remote sensing) where the following seven elements of remote sensing are involved (Fig. 1). It should also be noted that remote sensing also involves the sensing of emitted energy and the use of non imaging sensors (referred as thermal remote sensing). The seven elements on the basis of which remote sensing technique works are enumerated as follows;

i) **Source of Illumination (I) -** The foremost requirement for any remote sensing process is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

ii) **Radiation and the Atmosphere (II)** – as the energy propagates from its source to the target, it interacts with the atmosphere as it passes through. This interaction may take place a second time as the energy travels from the target and back to the sensor.

iii) **Interaction with the Target (III)** - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the characteristics of both the target and the radiation.

iv) **Recording of Energy by the Sensor (IV)** - after the energy has been scattered or Emitted from the target, a sensor is required to collect and record the electromagnetic radiation.

v) **Transmission, Reception, and Processing (V)** - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

vi) **Interpretation and Analysis (VI)** - the processed image is interpreted, visually or digitally or electronically, to extract information about the target which was illuminated.

vii) **End users and application (VII)** - the last element of the remote sensing process is achieved when the useful information is extracted from the imagery reveal some new information, or assist in solving a particular problem.

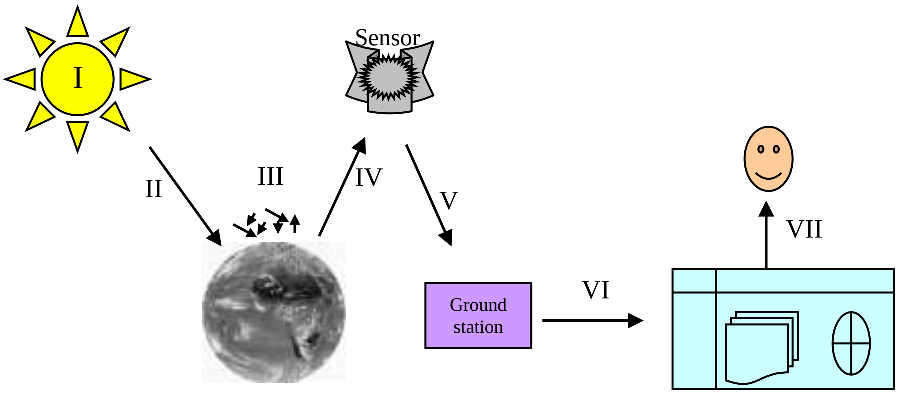


Fig. 1 Components of remote sensing.

Some of the important applications of remote sensing technology includes:

a) Environmental monitoring and assessment (global warming etc.).
b) Land use and land cover global change detection and monitoring.
c) Prediction of agricultural yield and crop health monitoring.
d) Sustainable resource exploration and management.
e) Ocean and wetland studies.
f) Weather forecasting.
g) Defence and military surveillance.
h) Broadcasting and tele-communication.

1.3 The Electromagnetic Radiation

Electromagnetic radiation (EMR), also called as electromagnetic energy, and refers to all energy that moves with the velocity of light in the form of waves. The source of EMR is the subatomic vibration of photons and is measured in terms of wavelength. Sun is the main source of EMR that travels through space in the form of waves that are either reflected or absorbed by the objects, mainly on account of the size of wavelength which is described by the distance of successive wave peaks and is represented by a Greek letter lambda (λ) (Fig. 2).

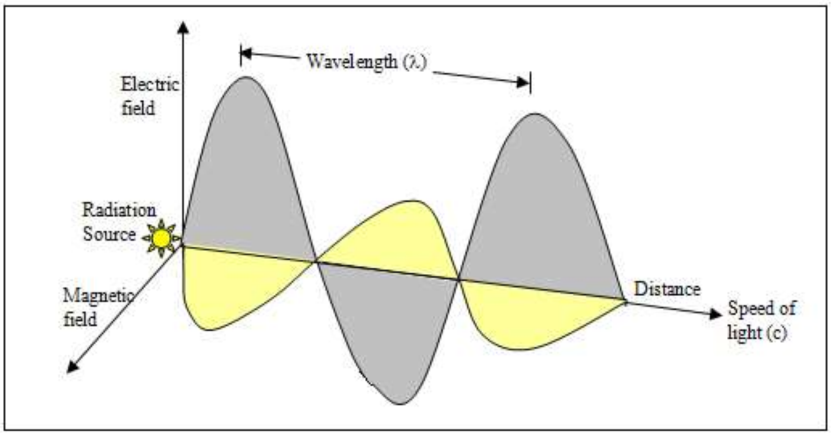


Fig. 2 Propagation of electromagnetic waves with the speed of light.

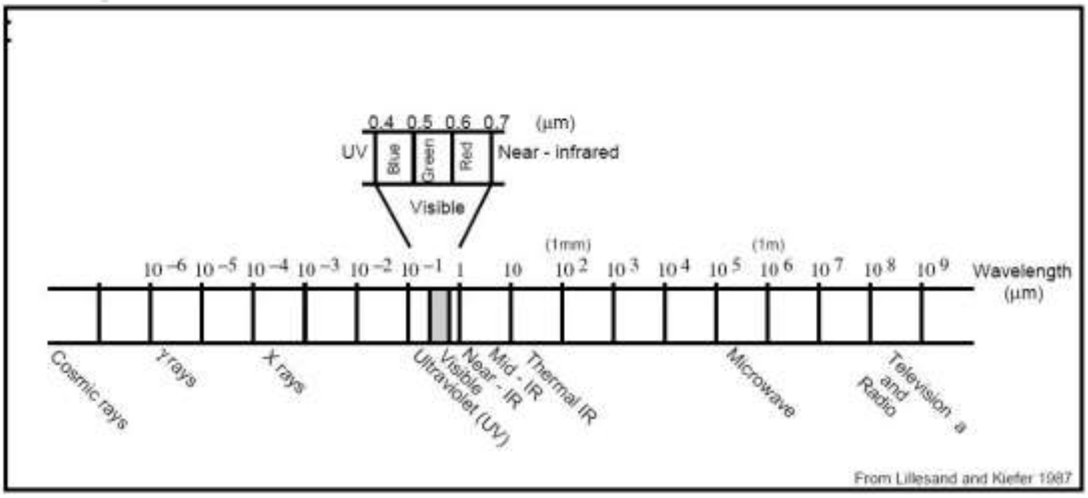
Wavelength is measured in metres (m) or some fraction of metres such as nanometres (nm, 10^{-9} metres), micrometres (μm, 10^{-6} metres) or centimetres (cm, 10^{-2} metres). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time and is normally measured in hertz (Hz). Wavelength and frequency are inversely related to one another, in other words as one increases the other decreases. This relationship is expressed as:

$$c = \lambda \times \nu \tag{1}$$

Where: c = speed of light (3×10^8 m/s), λ is the wavelength in (m, cm, μm or nm) and ν is the frequency in Hertz (cycles/second). It can be inferred from equation (1) that radiation with a small wavelength will have a high frequency whereas, radiation with a high wavelength will have a low frequency, since this frequency variation is a function of sub atomic vibration of photons. This vibration of photons in a matter releases energy which is measured in terms of temperature. To be more specific, objects releases energy above absolute zero temperature which is referred to as electromagnetic energy. Hot objects emit higher energy as compared to the cold objects that emit less amount of energy.

1.3.1 Electromagnetic spectrum

The electromagnetic spectrum covers the entire range of photon energies arranged in the increasing order of wavelengths on a logarithmic scale (See fig. 3). The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and X rays) to the longer wavelengths (including microwaves and radio waves).



From Lillesand and Kiefer 1987

Fig. 3 The electromagnetic spectrum (Lillesand Kiefer, 1987).

Almost the entire range of electromagnetic spectrum is useful for remote sensing in a way that every band provides unique information about the object of interest. Sensors on board earth resources satellites operate in visible, infrared and microwave regions of the spectrum. The spectrum regions are discussed in order of increasing wavelength and decreasing frequency.

(i) *Ultraviolet*: The ultraviolet (UV) region of electromagnetic spectrum lies just beyond the violet portion of the visible wavelengths. The UV region has short wavelengths (0.3 to 0.446 µm) and high frequency. UV wavelengths are used in geologic and atmospheric science applications. Geologic application includes material exploration since many rocks and minerals exhibit fluoresce property and emit visible light in the presence of UV radiations. Also, almost 80 to 90% of the UV light is generally absorbed by Ozone (O_3) hence becomes an integral tool related to the atmospheric studies.

(ii) *Visible light*: This is the portion of EMR to which our eyes are sensitive and is perceived as colours. The visible light covers a very small portion of the spectrum, ranging from approximately 0.4 to 0.7 µm (micrometer) and due to this small wavelength range, the visible portion of the spectrum is plotted on a linear scale so that individual colours can be discretely depicted (Fig 4). The visible light comprises of discrete colours with red at the long wavelength end and violet at the short wavelength end.

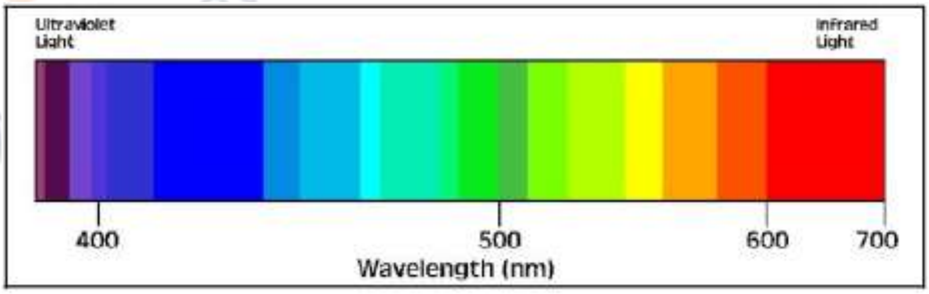


Fig. 4 The visible spectrum.

The visible colours and their corresponding wavelengths are listed below in micrometers (µm).

Violet:	0.4 to 0.446 µm
Blue:	0.446 to 0.500 µm
Green:	0.500 to 0.578 µm
Yellow:	0.578 to 0.592 µm

- Orange: 0.592 to 0.620 µm
- Red: 0.620 to 0.700 µm

(iii) *Infrared*: The infrared region (IR) which covers the wavelength range from approximately 0.7 µm to 100 µm, covering 100 times more space than the visible portion of the spectrum. The IR region is generally divided into two categories based upon their radiation characteristics i.e. (a) reflected IR and (b) the emitted or thermal IR. The reflected IR region is used for specific remote sensing applications in ways similar to the radiations in the visible portion. The reflected IR covers wavelengths approximately from 0.7 µm to 3.0 µm and is mainly employed for monitoring the status of healthy and unhealthy vegetations, as well as for distinguishing among vegetation, soil and rocks. The thermal IR differs from visible and reflected IR in a way that this energy is radiated or emitted from the earth surface or objects and characterises in the form of heat. The thermal IR covers the wavelengths from approximately 3.0 µm to 100 µm as these wavelengths are used for monitoring the temperature variations of land, water and ice.

(iv) *Microwave*: This portion of the spectrum is of recent interest to remote sensing and the wavelength ranges approximately from 1 mm to 1 meter. The shorter wavelengths have the properties similar to thermal infrared region while the longer wavelengths are used for radio broadcasts. Microwave remote sensing is used in the studies of meteorology, hydrology, oceans, geology, agriculture, forestry and soil moisture sensing.

In reference to figure 4, figure 5 illustrates the comparison between wavelength, frequency and energy of the electromagnetic spectrum.

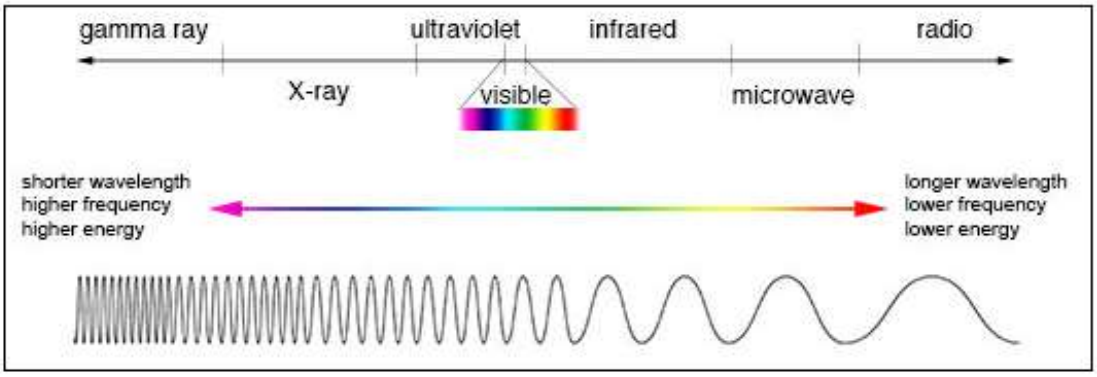


Fig. 5 Comparison between wavelength, frequency and energy of the electromagnetic spectrum (*Source: NASA's Imagine the Universe*).

1.4 Radiation Terminology

The concept of electromagnetic radiation involves various terminologies that forms the basis of many important radiation laws widely used in remote sensing based analysis and modelling. One of the important radiation term is the radiant energy which is defined as the energy carried by electromagnetic radiation and is expressed in unit of Joules. Radiant flux (Φ_e) another term is the radiant energy transmitted as a radial direction per unit time and expressed in Watt (W). In other words, the rate at which photons strike a surface is called as the radiant flux. Radiant intensity is radiant flux radiated from a point source per unit solid angle in a radiant direction and is expressed in units of W sr^{-1} (where *sr* is the spectral radiance). Irradiance (E_e) is the radiant flux incident upon a surface per unit area and expressed in a unit of Wm^{-2}. Radiant emittance (Radiant exitance 'M_e') is the radiant flux radiated from a surface per unit area and expressed in a unit of Wm^{-2}. Radiance is the radiant intensity per unit projected area in a radial direction and expressed in the unit of W sr^{-1}. Radiance is also described as the radiation field as dependent on the angle of view.

<u>Points to ponder</u>

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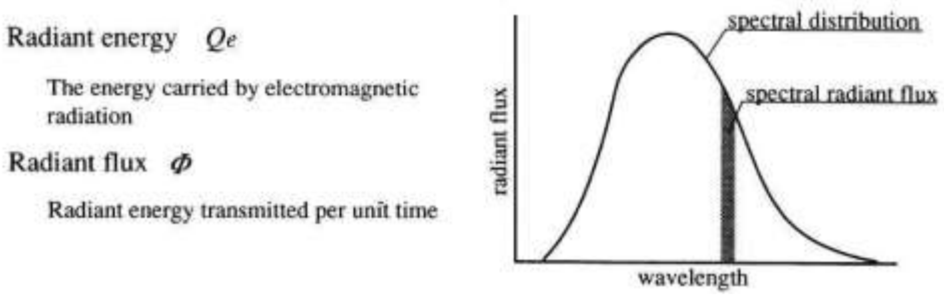

Radiant energy Q_e

The energy carried by electromagnetic radiation

Radiant flux Φ

Radiant energy transmitted per unit time

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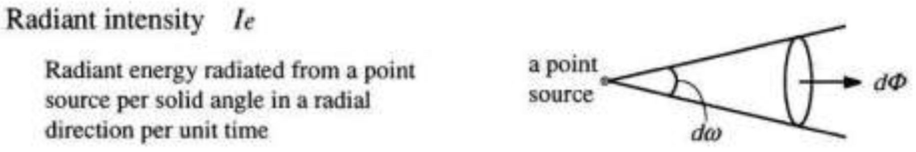

Radiant intensity I_e

Radiant energy radiated from a point source per solid angle in a radial direction per unit time

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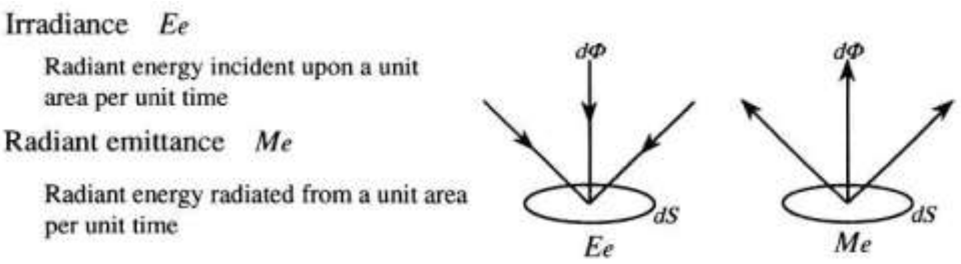

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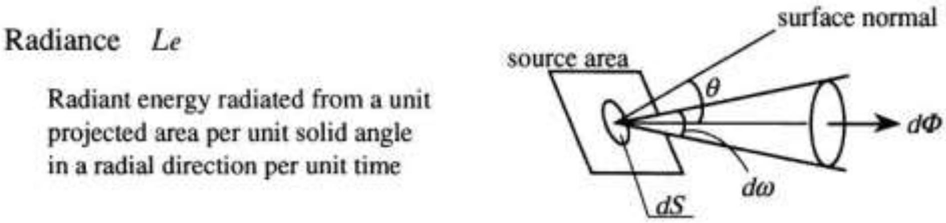
Irradiance *Ee*

Radiant energy incident upon a unit area per unit time

Radiant emittance *Me*

Radiant energy radiated from a unit area per unit time



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Radiance *Le*

Radiant energy radiated from a unit projected area per unit solid angle in a radial direction per unit time

1.5 Radiation Laws

The electromagnetic energy follows certain physical laws as it moves away from the source. Isaac Newton in his theory analysed the dual nature of light energy exhibiting both discrete and continuous phenomena associated with the stream of minuscule particles travelling in a straight line. This notion is consistent with modern theories of Max Plank (1858 – 1947) and Albert Einstein (1879 – 1955). Plank ascertained that electromagnetic energy is absorbed and emitted in discrete units called ‘photons’. The size of each unit is directly proportional to the frequency of the energy’s radiation. Therefore, Plank’s theory proposed that electromagnetic energy can be quantified by its wavelength and frequency and its intensity is expressed by ‘Q’ and is measured in Joules. The energy released by a radiating body in the form of a vibrating photon travelling at a speed of light can be quantified by relating the energy’s wavelength with its frequency. Plank defined a constant ‘h’ to relate frequency (ν) to radiant energy ‘Q’ and is expressed as follows:

$$Q = h\nu \qquad (2)$$

Since $c = \lambda\nu$ (see equation 1), therefore equation 2 can be rewritten as

$$Q = \frac{hc}{\lambda} \qquad (3)$$

where,

Q=energy of photon in Joules (J)
h=Plank’s constant (6.6×10^{-34}) Js
c=speed of light (3×10^{8} m/s)

λ=wavelength in metres
ν=frequency (cycles/second, Hz)

The above equation reveals that longer wavelengths have low energy of photons while for short wavelengths the energy will be high. For instance, blue light is on the short wavelength end of the visible spectrum (0.446 to 0.500 µm) thus has higher energy radiation in contrast to red light (0.620 to 0.700 µm) on the far end of the visible spectrum has low energy radiation.

An interesting example that proves the Plank’s theory;

Question: Using Plank’s law prove that ***blue*** light has more energy than the ***red*** light?

Solution: Using $Q = \dfrac{hc}{\lambda}$, solve for Q_{blue} (energy of blue light) and Q_{red} (energy of red light) and compare

$\lambda_{blue} = 0.475\ \mu m$, $\lambda_{red} = 0.660\ \mu m$
$H = 6.6 \times 10^{-34} 1 Js$
$c = 3 \times 10^{8}\ m/s$

$\Rightarrow$ $Q_{blue} = (6.6 \times 10^{-34} Js \times 3 \times 10^{8}\ m/s)/0.475\ \mu m$
$= 4.66 \times 10^{-31} J$

$\Rightarrow$ $Q_{red} = (6.6 \times 10^{-34} Js \times 3 \times 10^{8}\ m/s)/0.660\ \mu m$
$= 3.00 \times 10^{-31} J$

Since 4.66×10^{-31}J is greater than 3.00×10^{-31}J, therefore ***blue*** light has more energy than ***red*** light. This explains why blue portion of a fire is hotter than the red portions.

1.5.1 Black Body Radiation

All objects with temperature above absolute zero emit electromagnetic energy whereas the amount of energy and the associated wavelengths depend upon the temperature of the object. As the temperature of an object increases, the quantum of energy emitted also increases, and the corresponding wavelength of the maximum emission becomes shorter. The above hypothesis can be expressed by using the concept of blackbody. A blackbody is a hypothetical source of energy that behaves in an idealised manner such that it absorbs all or 100% of the radiation incident upon it and emits back (or radiates) the energy as a function of temperature. The Kirchhoff's, Stefan-Boltzmann and Wien's displacement laws explain the relationship between temperature, wavelength, frequency and intensity of energy.

(i) *Kirchhoff's Law*

Kirchhoff's law states that the ratio of emitted radiation to the absorbed radiation flux is same for all black bodies at the same temperature and forms the basis of the term emissivity (ε), which is defined as the ratio between the emittance of a given object (M) and that of a blackbody at the same temperature (M_b):

$$\varepsilon = M/M_b \qquad (4)$$

The emissivity of a true blackbody is 1, and that of perfect radiator (a white body) would be zero. This implies that all objects have emissivities between these two extremes. Objects that absorb high proportions of incident radiation and re-radiate this energy have high emissivities, where as those which absorb less radiation have low emissivities, i.e. they reflect more energy that reaches them.

(ii) *Stefan-Boltzmann Law*

The Stefan-Boltzmann law defines the relationship between the total emitted radiation (W) (expressed in watts cm^{-2}) and temperature (T) (absolute temperature, K):

$$W = \sigma T^4 \qquad (5)$$

The total radiation emitted from a black body is proportional to the fourth power of its absolute temperature. The constant (σ) is the Stefan-Boltzmann constant (5.6697×10^{-8}) (watts m^{-2} K^{-4}). In short, Stefan-Boltzmann law states that hot blackbodies emit more energy than cool blackbodies.

(iii) *Wien's Displacement Law*

This law specifies the relationship between the wavelength of emitted radiation and the temperature of the object:

$$\lambda = 2898/T \qquad (6)$$

Where, λ is the wavelength hat which the radiance is at a maximum and (T) is the absolute temperature in Kelvin (K). as objects become hotter, the wavelength of maximum emittance shifts to shorter wavelengths. This law is useful for determining the optimum wavelength of object having temperature (T) Kelvin.

Together, the Wien and Stefan-Boltzmann law are powerful tools. With the help of these laws, temperature and radiant energy can be determined from an object's emitted radiation. For example, temperature distribution of large water bodies can be mapped by measuring the emitted radiation, similarly, discrete temperatures over a forest canopy can be detected to plan and manage forest fires.

An example illustrating the radiation laws;

<u>Question</u>: Using the Wien's Displacement law, determine the maximum wavelength emitted by a human body.

<u>Solution</u>: The normal human body temperature measured using standard thermometer is usually
T = 98.6 F or 310 K
Applying Wien's displacement law; i.e. $\lambda = 2898/T$
We solve for corresponding wavelength λ;
$\Rightarrow \quad \lambda = 2898/310$
$\Rightarrow \quad = 9.3\ \mu m$

Therefore; humans emit radiations at a maximum wavelength of 9.3 µm, this is well beyond the capability of eyes to see but can be sensed. Since humans can see in the visible part of wavelength that ranges form 0.4 to 0.7 µm.

Self assessment exercise 1

1. Calculate the wavelength of the maximum energy emission for the Mars which has a surface temperature of approximately 150K and lava erupting from a volcano at 900K.
2. Which of the following wavelengths would you use to measure the brightness temperature of sea surfaces and why?
   a) visible,
   b) short wave infrared, or

c) thermal infrared?

1.6 Interactions with the Atmosphere

The earth's atmosphere is capable of transmitting the entire electromagnetic radiation used for a variety of remote sensing applications; however, the electromagnetic radiations get affected as these passes through different layers of atmosphere. This can be ascertained with the fact that the quality of image captured through aircraft borne sensor is less affected by atmosphere as compared to the quality of image captured by satellite borne sensor which is severely affected due to the fact that radiations passes through the entire depth of the earth's atmosphere. Hence fundamental knowledge of electromagnetic energy interaction with atmosphere forms an integral part of remote sensing based analysis of spatial data.

The incoming electromagnetic radiation gets affected by the particles of various sizes and gases (e.g. dust, smoke, haze and other atmospheric impurities) present in the atmosphere in suspended form therefore causing significant change in an acquired image in terms of brightness and colour. The electromagnetic energy passing through the earth's atmospheric layers is subjected to alterations by two important physical processes, namely: (i) scattering, and (ii) absorption.

(i) *Scattering*

Scattering of electromagnetic radiation takes place when gas molecules and particles present in the atmosphere interact with it and redirects it from its original path (Fig. 6). The amount of scattering depends on several factors including the wavelength of the radiation, the abundance and size of the particles or gases, and the distance the radiation travels through the atmosphere.

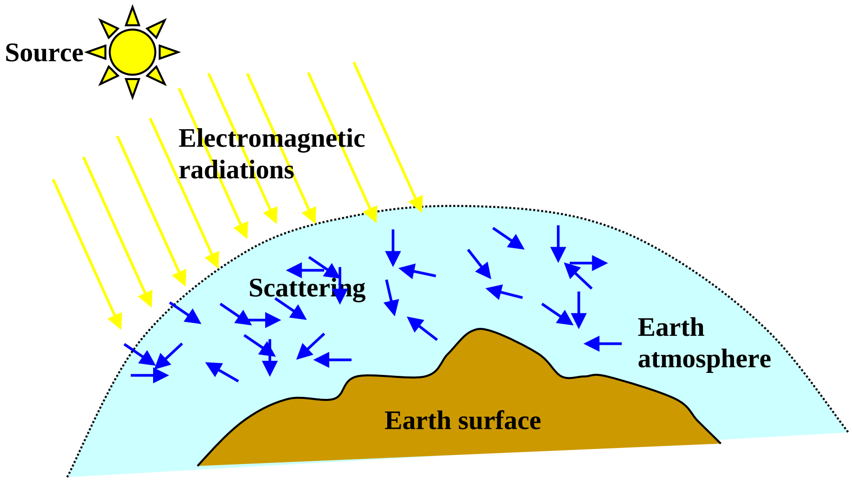


Fig. 6 The phenomena of scattering of electromagnetic energy.

Generally there are three types of scattering which take place through the earth's atmosphere, namely; Rayleigh scattering, Mie scattering and nonselective scattering.

Rayleigh scattering: Rayleigh scattering takes place when the suspended particles are very small (mainly comprising of oxygen molecules or dust particles) as compared to the wavelength of the radiation. This type of scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths and therefore the law is governed by the principle of reciprocal of fourth power of the wavelength; expressed as:

$$\text{Rayleigh scattering} = 1/\lambda^4 \qquad (7)$$

Where, λ is the wavelength in meters. This type of scattering is dominant in the upper layers of atmosphere where tiny dust particles and gas molecules predominates. Rayleigh scattering is responsible for the blue color of the sky, since blue light is scattered the most on account of the size of wavelength smaller than the size of dust particles and gas molecules. Same reasoning applies for the appearance of orange color of the sky at dusk, i.e. when sun is low in the horizon, it creates longer path length to the incoming radiations resulting in the scattering of red the light.

Mie scattering: This type of scattering occurs when the particles are just the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering wherein the longer wavelengths are scattered the most. Mie scattering is more dominant in the lower layers of atmosphere (i.e. within 0 to 8 km). In the lower layers of atmosphere larger particles are in abundance and influence a broad range of wavelengths in and near the visible spectrum.

Nonselective scattering: This scattering phenomenon occurs when the particles are much larger than the wavelength of the incoming radiation thereby leading to approximately equal scattering of all wavelengths (i.e. blue + green + red light = white light). Water droplets and large dust particles are mostly responsible for causing this type of scattering. Due to this scattering, clouds appear white in color and so as a blurry white foggy appearance to the suspended water droplets during winter seasons.

(ii) *Absorption*

There are gases namely; ozone (O_3), carbon dioxide (CO_2) and water vapor (H_2O) that are responsible for most of the absorption of electromagnetic radiations through partially preventing or strongly weakening the radiations as these passes through the atmospheric layers. Formation of ozone is the result of interaction of high energy ultraviolet radiations with oxygen molecules (O_2) present at an altitude of 20 to 30 km in the stratosphere. Presence of ozone layer forms a protective layer in the atmosphere by absorbing the harmful ultraviolet radiations that may otherwise cause skin burns or other severe skin diseases if exposed to sun light.

Carbon dioxide (CO_2) occurs in low concentrations (approximately 0.035% by volume of a dry atmosphere), mainly in the lower layers of atmosphere. CO_2 effectively absorbs radiation in the mid and far infrared regions (mostly in the range 13 to 17.5 µm) of the electromagnetic spectrum.

Lastly, water vapours (H_2O) present in the lower atmosphere (concentration normally varies from 0 to 3% by volume) are more effective in absorbing radiations as compared to other the atmospheric gases. Two important regions of spectrum ranging from 5.5 to 7.0 µm and above 27 µm, are significantly absorbed up to 75% to 80%.

1.6.1 Atmospheric Windows

The regions or bands of the electromagnetic spectrum which are not severely influenced by atmospheric absorption and thus are partially or completely transmitted through, are useful to remote sensors, are called atmospheric windows. In other words, gas molecules present in the atmosphere selectively transmit radiations of certain wavelengths and those wavelengths that are relatively easily transmitted through the atmosphere is referred to as atmospheric windows (Fig. 7).

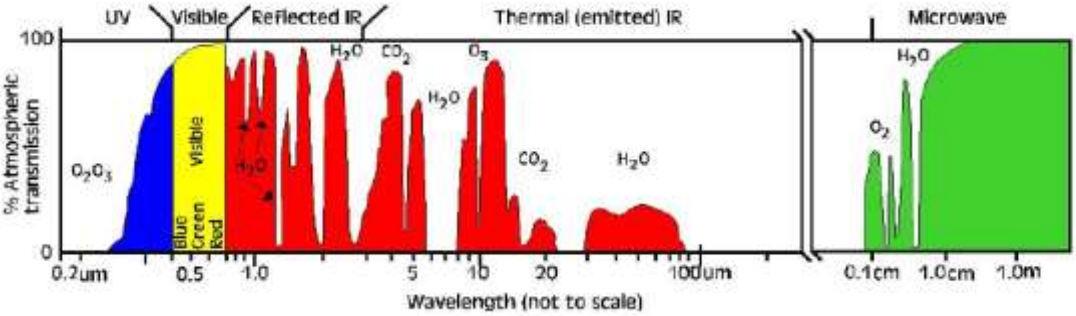


Fig. 7 Atmospheric windows with wavelength on x-axis and percent transmission measured in Hertz on y-axis. High transmission corresponds to an atmospheric window which allows radiations to penetrate electromagnetic radiation to penetrate the earth's atmosphere.

Fortunately, around 90 to 95% of the visible light passes through the atmosphere otherwise there would never be bright sunny days on earth. The atmosphere is almost 100% translucent for certain wavelengths of mid and near infrared spectrum which makes possible remote sensing analysis of satellite images in these regions possible with a minimum distortion. The thermal infrared range from 10 - 12 μm is used in measuring surface temperatures of the ground, water and clouds Ozone blocks ultraviolet radiation almost completely and almost all radiation in the range of 9.5 to 10 μm is absorbed.

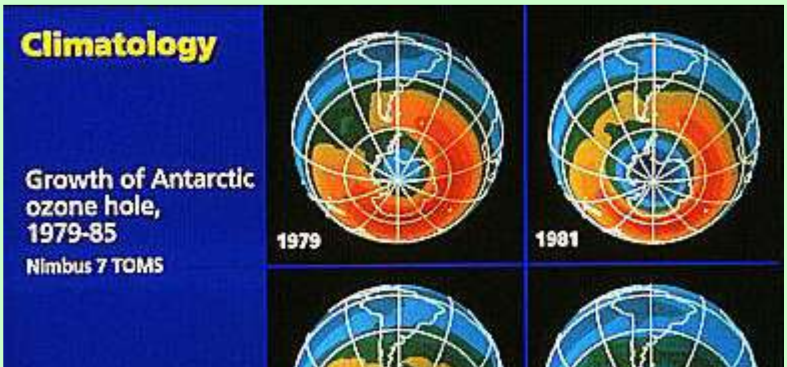
Self assessment exercise 2

1. Explain why most remote sensing sensors avoid detecting and recording wavelengths in the ultraviolet portion of the spectrum.
2. What do you think would be some of the best atmospheric conditions for remote sensing in the visible portion of the spectrum?

The Ozone hole

Whilst on the subject of atmospheric absorption, it is expected that a brief note on topical science, namely the discovery of the 'ozone hole' by satellite remote sensing would be of interest to the readers. (Figure 11 illustrates the growth of the ozone hole 1979-1985).

It is widely known that stratospheric ozone depletion due to human activities has resulted in an increase of ultraviolet radiation on the Earth's surface. Ozone depletion has been monitored by the Total Ozone Mapping Satellite (TOMS) mission based on the observation that less radiation at very short ultraviolet wavelengths (0.1 μm – 0.3 μm) was being absorbed by the atmosphere, most significantly over the arctic regions. Ozone absorbs UV radiation and so less absorption means that more UV radiation is transmitted through to the Earth's surface. This is leading to increasing concern about the possibility of skin cancers for people exposed to these higher doses.



1.7 Interactions with the Earth’s Surface

Electromagnetic radiations that are not completely absorbed or scattered in the atmosphere, travels through the entire depth of the atmosphere before finally reaching the earth’s surface. The radiations strike the surface and again redirected towards the atmosphere for the second time before being sensed or recorded by the sensor and this total distance to and fro is called as the path length. For radiations emitted from the earth’s surface the path length will be half of the path length of the radiation emitted from the sun. Generally three type of interaction takes place when the radiations strike or are incident (I) upon the surface and these include; reflection (R), absorption (A); and transmission (T). Therefore, the total energy of radiations incident upon the surface follows the law of conservation of energy or the energy balance written as:

$$E_i = E_r + E_a + E_t \tag{8}$$

Where, E_i is the incident energy, E_r is the reflected energy, E_a is the absorbed energy and E_t is the transmitted energy. The type and degree of interaction of radiations varies in accordance to the size and surface roughness for different objects as well as varying wavelengths. Figure 8 illustrates the radiations striking the earth’s surface.

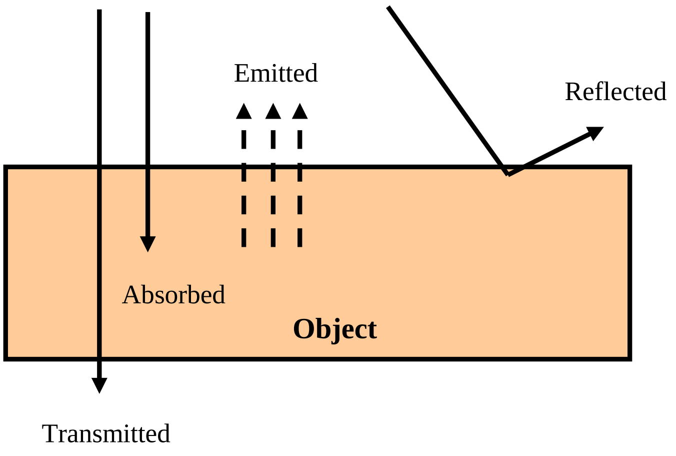
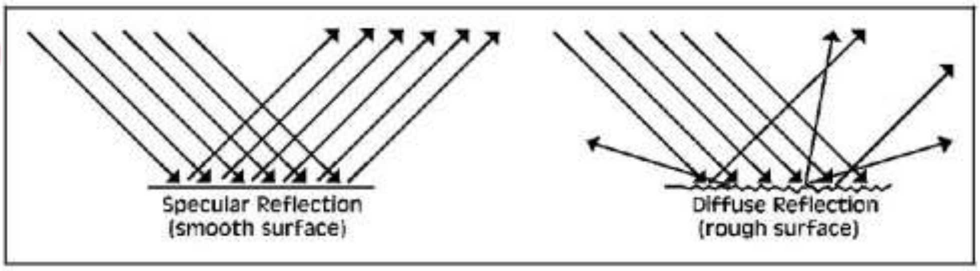


Fig. 8 Interaction of electromagnetic radiation with the surface or object.

Reflection: Reflection occurs when a radiation is re-directed as it strikes an opaque surface. The degree of re-direction depends upon the magnitude of surface roughness compared to the wavelength of the incident radiation. Reflection or re-direction of radiation occurs in two types depending upon the characteristics of the surface or feature of interest. In general there are two types of reflection, specular and defuse reflection (refer Fig. 9). If the surface is smooth relative to the wavelength, specular reflection occurs where almost all incident radiation is reflected in a single direction maintaining angle of reflection equal to the incident angle (e.g. mirror, still water body or smooth metal surface).

Diffuse reflection occurs over the rough surfaces where incident radiations are reflected almost uniformly in all directions. If the wavelengths are much smaller than the surface roughness variations, diffuse reflection will dominate (e.g. loam soil would appear fairly smooth to long wavelength microwaves in contrast to visible spectra wavelengths).



(a) (b)

Fig. 9 (a) Specular reflection over a smooth surface and (b) diffuse reflection over surface irregularities.

Transmission: Transmission of radiation takes place when radiation passes through the object or feature without any considerable fading or attenuation. For a known thickness of the object, the ability of a medium to transmit energy is measured as a transmittance (t);

$$t = \frac{Transmitted\ radiation}{Incident\ radiation} \tag{9}$$

1.8 Image Resolutions

The fundamental parameters that describes the quality and characteristics of spatial data (imagery) include; spatial resolution, temporal resolution and radiometric resolution.

1.8.1 Spatial resolution

Of the three resolutions, spatial resolution has its significance since it defines the degree of clarity of the ground features represented in a pixel. In other words, spatial resolution is defined as the area of the earth surface covered in one pixel of an image. For instance, if a satellite image has a 5 m resolution, it means that 1m x 1m area on the earth’s surface is represented in a pixel. If very large ground area, say of the order of square kilometres, the spatial resolution will be coarse and vice versa. Figure 10 illustrates spatial resolutions that an image can have.

Fig. 10 Spatial resolution of an image: (Left) nominal 1m spatial resolution (middle) 5m spatial resolution (right) 30m spatial resolution.

1.8.2 Temporal resolution

Temporal resolution is the time taken by the sensor on board space satellite to capture successive images of the same location over the earth’s surface. In other words temporal resolution is the revisit time or repeat cycle of the satellite over the same region or location over the earth’s surface. The frequency of revisit of different satellites varies from multiple times in a single day to almost about a month’s period (e.g. the temporal resolution of IRS series is 24 days, SPOT series is 26 days, IKONOS is 2.9 days etc,).

1.8.3 Radiometric resolution

Radiometric resolution refers to the finest difference in the radiation or energy levels in terms of digital numbers that a sensor can record in a single pixel and thereby imparts quality to the image in terms of finer details. The finer the radiometric resolution of a sensor, most minuscule details can be extracted in order to get more meaningful interpretation.

Any digital Image uses a binary format to store the data which is represented by a grid where each cell bears a unique number in accordance to the brightness levels recorded by the sensor and these numbers known as digital numbers. The physical value of the brightness level recorded is converted into digital numbers which are stored in the cells of an image grid. For an image, digital numbers range from 0 to a selected power of 2 which corresponds to the number of bits used for coding numbers i.e. each bit records an exponent of power 2 (e.g. 1 bit = $2^1 = 2$) and the total number of brightness levels available depends on the number of bits of energy recorded. If a sensor uses 8 bits to record the data, there would be $2^8 = 256$ digital values available (i.e. 256 shades between black and white), ranging from 0 to 255. However, if only 6 bits are used, then only $2^6 = 64$ values ranging from 0 to 63 would be available in an image. Thus, radiometric resolution would be poor for 6 or 4 bit image as compared to 8 or 16 bit image. Figure 11 depicts radiometric resolution of 11 bit image.

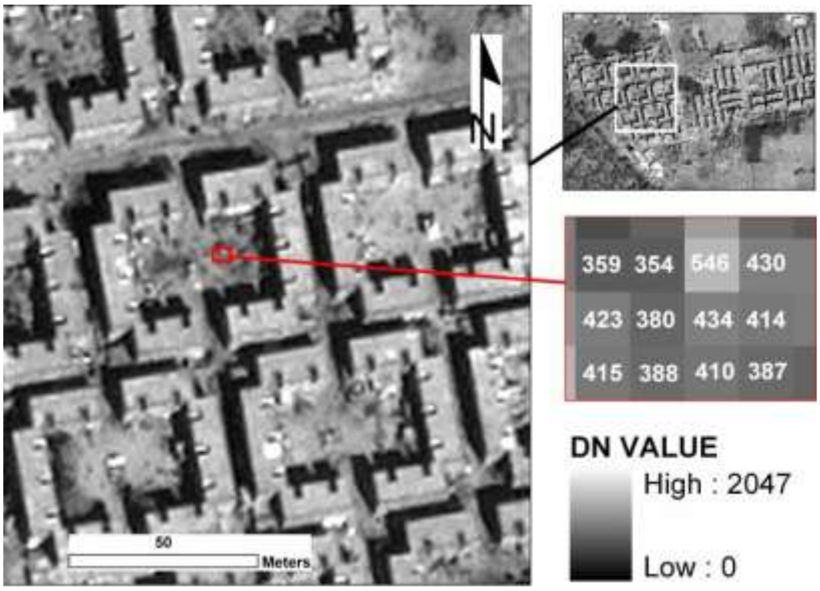


Fig. 11 An example of an 11 bit image. Each pixel contains a value between 0 and 2047 according to the strength of the EMR measured at the sensor; values termed as Digital Numbers (DN); (Lillesand Kiefer, 1987).

More the brightness levels (or DN values) in an image finer is the radiometric resolution.

1.8.4 Spectral resolution

Spectral resolution refers to the specific wavelength intervals in the electromagnetic spectrum that a sensor can record. For example, band 1 of the Landsat TM sensor records energy between 0.45 and 0.52 mm in the visible part of the spectrum. Wide intervals in the electromagnetic spectrum are referred to as coarse spectral resolution, and narrow intervals are referred to as fine spectral resolution. For example, the SPOT panchromatic sensor is considered to have coarse spectral resolution because it records EMR between 0.51 and 0.73 mm. On the other hand, band 3 of the Landsat TM sensor has fine spectral resolution because it records EMR between 0.63 and 0.69 mm (Jensen 1996). Figure 12 illustrates all four types of resolutions for Landsat TM.

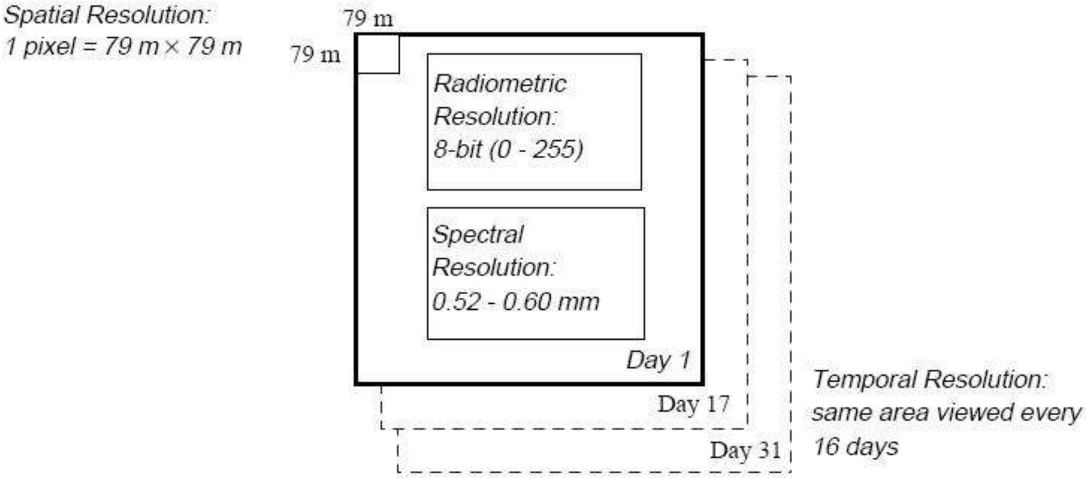


Fig. 12 Landsat TM—Band 2 (Four Types of Resolution); ***Source: EOSAT***.