UNIT-5

Remote Sensing

Unit Specifics

Through this unit, we have discussed the following aspects:

- Remote sensing components
- Various parts of electro-magnetic spectrum (EMS)
- Interaction of EMS with the atmosphere
- Scattering process and Spectral signature of objects
- Various types of resolutions and their need
- Types of sensors and their salient features
- Types of satellite platforms and their characteristics
- Properties of digital remote sensing data
- Geometric and radiometric correction of satellite images
- Enhancement procedure to improve the quality of remote sensing images
- Image transformations and their utility
- Image classification methods
- Accuracy assessment of thematic maps

In addition to the basic principle of remote sensing data analysis, the characteristics of sensors for different types of data collection has been explained. The practical utility of optical, thermal, microwave, and hyperspectral images is presented for various applications. The unit mainly focusses on the charactrisristics and utilisation of optical remote sensing images for the preparation of various kinds of thematic maps. Questions of short and long answer types are given following lower and higher order of Bloom's taxonomy, and a list of references and suggested readings is given at the end so that the students can go through them for acquiring more knowledge.

Rationale

This unit provides details of various types of remote sensing data and their resolutions. Each of the data has a specific application required for creating the thematic maps, but this unit specifically covers the characteristiscs and analysis of optical remote sensing images. It is important to understand the interactions of EMS with the atmosphere, which is also given in this unit. Since satellite images contain radiometric and geometric errors, so students will learn to apply these corrections to satellite images. Several images have poor contrast due to unfavourable atmospheric conditions, so these image are to be enhanced using various methods as explained here. Image transformations, as explained here, also play an important role for the identification of several features from satellite images. Classification from images become an important activity, so two broad approaches of classifications are discussed here along with their advantages and disadvantages to provide a deeper understanding. At last, a thematic map without accuracy has no meaning, so accuracy assessment method has been described.

Pre-Requisites

Mathematics: geometry and trigonometry, Earth surface, Computer, Software.

Unit Outcomes

List of outcomes of this unit is as follows:

U5-O1: Describe various components of EMS and their utility in remote sensing

U5-O2: Explain the interactions of EMS with the atmosphere and their impact on satellite images.
U5-O3: Realize the role of sensors and data products available from them at various resolutions.
U5-O4: Describe various pre-processing methods to improve the geometry and quality of satellite images.
U5-O5: Apply the reflectance characteristics and other properties of objects for classification of satellite images using supervised and unsupervised classification techniques, including their accuracy assessment.

Unit-5 Outcomes	**Expected Mapping with Programme Outcomes** *(1- Weak correlation; 2- Medium correlation; 3- Strong correlation)*					
	CO-1	**CO-2**	**CO-3**	**CO-4**	**CO-5**	**CO-6**
U5-O1	3	1	2	3	2	1
U5-O2	2	2	3	1	2	2
U5-O3	2	2	3	3	-	3
U5-O4	3	3	2	2	3	-
U5-O5	2	3	2	3	1	3

5.1 Introduction

The word "remote" means "from a distance", and "sensing" in this case means "to record." So remote sensing can be defined as the collection of information about an object, area, or phenomenon and subsequent analysis of data acquired by a device from a remote distance (Lillesand and Kiefer, 1996). More precisely, it can be defined as the "*art of science & technology of obtaining reliable information about the physical objects and environment through the process of recording, measuring & interpreting images/data obtained from remotely distant sensor systems*". For example, with eyes it is possible to gather information about the surroundings from a distance. Reading newspaper, watching TV, listening a lecture during classes, are all are the examples of remote sensing. The human eyes capture the light reflected by these objects and the brain interprets the colour, shape, pattern, etc., and translates this data into useful information. The human eye however is limited to a small part of the total electromagnetic spectrum (EMS), i.e., visible light.

Remote sensing involves an interaction between the incident radiation (EMS) and the targets/objects. It also involves the sensing of reflected /emitted energy from the objects with the help of sensors. The sensors on-board satellites detect the of radiations from the objects/targets. In remote sensing, various kinds of devices and sensors are used to record the electromagnetic radiation outside the visible range, especially the near infrared, middle infrared, thermal infrared and microwaves. Detection and discrimination of objects/features are done through recording of radiant energy reflected or emitted by objects or surface material in various wavelength regions of EMS.

The amount of radiations, emitted and reflected from the Earth's features/objects, depends on the physical and chemical properties of the objects or material. It also depends on the surface roughness, angle of incidence, intensity and wavelength of radiant energy. The variation in energy helps in identification of various objects on the Earth surface. So, the sensors play an important role in data capture and dissemination of objects/targets.

Remote sensing systems provide spatio-temporal information on Earth surface processes from local to global scale. The images from these systems help in a wide range of disciplines, such as surveying and mapping, geography, geology, computer science, zoology, agriculture, forestry, botany, meteorology, soil science, urban planning, military, oceanography and civil engineering. Information, such as land use, vegetation types, urbanisation, soils, water, geology, forest, surface elevation and snow, can be derived from remote sensing images. Temporal remote sensing images are helpful in monitoring the land use change, flood, water pollution, deforestation, forest fire, snow cover, urban sprawl, crop damage, disaster monitoring, etc.

Today, remote sensing images have become an integral part of many national level government schemes or projects. With the availability of very high resolution images from CARTOSAT-3, SPOT-7, Sentinel, IKONOS, WorldView, QuickBird, GeoEye, AMSR, TRMM, SSM/I, RADAR, SAR, etc., remote sensing applications are growing rapidly. Integration of remote sensing data with other thematic layers in a Geographic Information System (GIS) provides additional benefits and flexibility to be used in a variety of applications requiring spatial modelling. In addition, the remotely sensed data and software available on open source platforms have popularized it to be used in various disciplines. Today remote sensing has become an interdisciplinary tool, and is being applied in various disciplines.

This chapter specifically provides the details of data from optical sensors, their characteristics and methods of classification. However, a small description is also given about microwave data and images.

5.2 Advantages and Disadvantages of Remote Sensing

The remote sensing technology has some advantages and disadvantages. These are summarized below:

Advantages:

1. Provides data of large areas, giving bird's eye view
2. Provides global data, including data of remote and inaccessible regions
3. Easy and rapid collection of data
4. Provides permanent record of the ground
5. All weather, and day & night data collection
6. Temporal images can be used for monitoring of the area
7. Multispectral data allows identification of features which otherwise may not be seen by human eyes.
8. Digital data can be integrated directly with other digital data in GIS.
9. Relatively economical production of various thematic maps
10. Accurate and fast determination of information
11. Rapid analysis using image processing software

Disadvantages:

1. The interpretation of imagery requires specialized skill
2. The data from high resolution sensors may be expensive
3. Field visit is a must as the analysis needs ground verification
4. Data from multiple sources is difficult to integrate and requires accurate georeferencing
5. Objects can be misclassified if sufficient reference data is not available
6. Requires complete infrastructure of hardware and software

5.3 Applications of Remote Sensing

In the present day world, here are large number of application of remote sensing. For more applications, refer to Garg (2022). Some of the applications are given below:

1. Mapping

Mapping from remote sensing image is the most important application. Mapping applications of remote sensing include: land surveying techniques accompanied by the use of a GPS, generating DEMs from remotely sensed data, baseline topographic mapping, water resources mapping, road map, damage delineation (tornadoes, flooding, volcanic, seismic, fire), mapping boundaries for tax/property evaluation, target detection, etc. This is particularly useful in remote and inaccessible areas.

2. Land Cover and Land Use

Land use applications of remote sensing include natural resource mapping, soils, water, urban, wasteland mapping. The temporal data is very useful to determine the changes in the land use and land cover which is useful in planning and management of resources and infrastructure.

3. Agriculture

Satellite images can be used as mapping tools to classify crops, examine their health and viability, and monitor the farming practices. The remote sensing data provides field-based information including crop identification, crop area determination and crop condition monitoring (health and viability). These data are employed in precision agriculture to manage and monitor the farming practices at individual field level, including crop optimization and management of technical operations. The images can help determine the location and extent of crop stress, and develop a treatment plan that optimizes the use of agricultural chemicals. Remote sensing technology can be used to prepare maps of crop types and their extent, needed for agricultural agencies. This information can be used to predict crop yield, derive crop production statistics, facilitate crop rotation records, assess soil productivity, identification of factors influencing crop stress, assessment of crop damage and monitoring the farming activity.

The spectral reflectance of vegetation depends on stage type, changes in the phenology (growth), and crop health, and thus can be measured and monitored by multi-spectral sensors. The observation of vegetation phenology requires multi-temporal images (data at frequent intervals throughout the growing season). Remote sensing can aid in identifying crops affected by conditions that are too dry or wet, affected by insect, weed or fungal infestations or weather related damage. The infrared wavelength is highly sensitive to crop vigour, crop stress and crop damage. Detecting damage and monitoring crop health requires high-resolution, multi-spectral and multi-temporal images.

4. Environmental Study

Coastlines are environmentally sensitive interfaces between the ocean and land, and respond to changes brought about by economic development and changing land use patterns. To determine the impact of human activities in coastal region, there is a need to monitor changes, such as coastal erosion, loss of natural habitat, urbanization, effluents and offshore pollution. The dynamics of the ocean and changes in the coastal region can be mapped and monitored using remote sensing techniques. Remote sensing can be used to study the deforestation, degradation of fertile lands, pollution in atmosphere, desertification, eutrophication of large water bodies and oil spillage from oil tankers. Remote sensing satellites, like MODIS, have helped to study the climate and environment. Retrievals of the Sea Surface Temperature (SST) and Land Surface Temperature (LST) from space provide information for interactions between ocean/land and atmosphere, such as evaporation processes and boundary layer dynamics. Remote sensing images are extensively used for weather forecasting as well as to warn people about the impending cyclones.

5. Forest mapping

Forest types inventories require detailed measurements of stand contents and characteristics (tree type, height, density). Using remote sensing data, various forest types can be identified and delineated. For mapping differences in forest cover (canopy texture, leaf density), multi-spectral images are required, and to get detailed species identification high resolution images are needed. Multi-temporal images datasets offer phenology information of seasonal changes of different species. Stereo-images would help in the delineation and assessment of density, tree height and species. Hyperspectral imagery can be used to generate signatures of vegetation species and certain stresses (e.g., infestations) on trees. The RADAR data is valuable for monitoring the forest in the humid tropics because its all-weather imaging capability. The LiDAR data allows capturing 3-dimensional structure of the forest. The multiple return systems of LiDAR are capable of detecting the elevation of land and objects on it. The LiDAR data helps estimate a tree height, a crown area and number of trees per unit area.

6. Geology

Geology involves the study of landforms, structures, and the subsurface to understand physical processes that create and modify the Earth's crust. Geological applications of remote sensing include: bedrock mapping, lithological mapping, structural mapping, mineral exploration, hydrocarbon exploration, environmental geology, sedimentation monitoring, and geo-hazard mapping.

7. Risk mapping

One of the essential tools for risk assessment is remote sensing data of the area. Remote sensing images can provide valuable data for mapping different types of disasters and mapping the parameters associate with risk. The high-resolution imagery has opened new possibilities in the process of risk estimation, mitigation, and management. This data is useful for both effective damage estimation as well as emergency management. The post-disaster images of event, like volcanic eruptions, tsunamis, fires, floods, hurricanes, and earthquakes have been used globally for saving lives.

8. Hydrology

Hydrology is the study of water on the Earth's surface, whether flowing above ground, frozen in ice or snow, or retained by soil. Examples of hydrological applications include: wetlands monitoring, soil moisture estimation, snow pack monitoring, measuring snow thickness, determining the snow-water equivalent, ice monitoring, flood monitoring, glacier dynamics monitoring, river/delta change detection, drainage basin mapping, watershed modelling, irrigation canal leakage detection, and irrigation scheduling.

9. Oceans and coastal monitoring

The oceans provide valuable food-biophysical resources, and are an important link in the Earth's hydrological balance. Coastlines are environmentally sensitive interfaces between the ocean and land, and they respond to changes brought about by economic development and changing land-use patterns. Ocean applications of remote sensing include; ocean pattern identification, storm forecasting, fish stock assessment, sea surface temperature, oil spill, and shipping.

10. Urban growth
Remote sensing images have been found as one of the most effective tools for monitoring and mapping the environmental changes and urban growth. The advantage of remotely sensed data is the synoptic and repetitive coverage that can help study the growth in urban areas. It helps create a base for urban environmental impact assessment, monitor urban growth, detect the urban change, land cover distribution, and land use.

5.4 Components of a Passive Remote Sensing System

A complete passive remote sensing system has various components, as discussed below, and shown in Figure 5.1:

A. Source of illumination (Sun)
B. Atmosphere through which signals travel
C. Emitted or reflected signals (from an object or phenomenon)
D. Atmosphere
E. Sensor (from a satellite platform), and
F. Ground receiving station
G. Archive centre and the data products
H. Data interpretation, analysis, and applications

First and foremost, requirement in remote sensing is that we need to illuminate the object in order to collect the images. Sun (A) is the best source of energy illuminating the objects/targets on the Earth surface. Electromagnetic radiation (EMR) from the Sun interacts with the atmosphere (B) and gets absorbed, scattered or transmitted, due to molecules, dust gas particles present in the atmosphere. The radiations reach the Earth surface and interact with the objects/targets (C) where scattering, transmittance, absorption and reflection processes will take place. These process will depend upon the physical and chemical characteristics of the objects/targets. The reflected energy from the objects again interacts with the atmosphere (D) to finally reach the sensor system (E). These analogue signals received by the sensors are converted into digital signals, and transmitted back to ground receiving station (F). From ground receiving station, signals are pre-processed and sent to data archive centre where these are stored and given to the users on demand (G). The users then carry out the interpretation and analysis of images, and apply the results to the application (H) in hand.

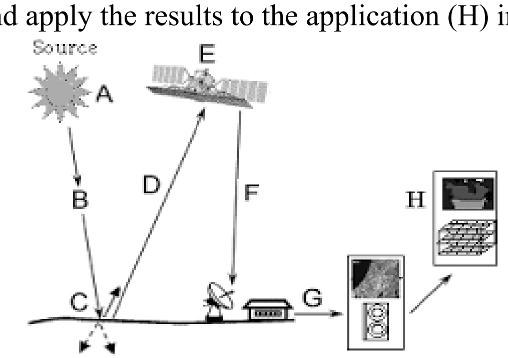

Figure 5.1 A complete passive remote sensing system (Jenson, 1986)

5.5 Technical Terms

There are various technical terms to understand the use of remote sensing, as given below:

Electro-magnetic spectrum (EMS)

The EMS consist of a range of energy which contains several parts, such as the gamma ray, x-ray, ultraviolet, visible, infrared, microwave (radar), radio waves. Different parts of the EMS have different wavelengths and frequencies which travel with the same speed as the velocity of light (2.98×10^8 m/s).

Reflected energy
Electromagnetic energy when strikes the objects on the Earth surface can be reflected/emitted, absorbed, scattered or transmitted. The part of the incident energy that is returned back from the objects and measured by the sensor is called reflected energy.
Absorption
It is the process by which electromagnetic energy is absorbed and converted into some other forms of energy.

Transmission
It is the amount of radiations of different wavelengths that a medium (e.g., atmosphere) will transmit or allow to pass through.

Platform
A remote sensing platform is usually a satellite or an airplane, carrying different sensors.

Sensor
A sensor is an electronic device that detects EMR, and converts them into signals that can be recorded as digital numbers, in the form of bits and bytes, and displayed as an image.

Spectral band
The sensors are designed to operate in several wavelength ranges to gather the EMR reflected from or emitted by the ground features/objects. The wavelength range is called a *channel* or a spectral band or simply a *band*. The sensors can collect the data in a number of spectral bands, and may be grouped as; panchromatic (single band), multispectral (more than one band), or hyperspectral (usually over 100 bands) sensors.

Image
The picture resulting from the sensing process is called an image. A remote sensing image can be in paper format or digital format. A digital satellite image is also called a *raster image* which can be displayed on a computer monitor.

Gray scale
It is a medium to calibrate the variations in the brightness of an image that ranges from black to white with intermediate gray values.

Pixel
The word pixel is made from "*picture element*". It is smallest element in an image. As the image is composed of row and columns, one small grid is called a pixel.

Digital Number (DN)
Digital Number in remote sensing system is a variable assigned to a pixel, usually in the form of a byte. In an 8 bit image (2^8), it ranges from 0–255 into 256 grey levels. The DN value is very important as digital analysis of remote sensing images is based on the variation in these values.

Swath
The satellite moves north to east in the orbit and collects EMR reflected/emitted from the ground objects. The width of the area covered on the ground when satellite sensor scans the Earth surface while moving in an orbit is called a swath. This swath width is different for different satellites and sensors, for example, it is 185 km wide by earlier LANDSATs.

Path-Row number
Since the reflected radiations from the ground are continuously recorded by the sensor, each orbit is given a unique number for identification of the ground scene/area, called Path number. The length of the scene defines the Row number. Thus, each scene can be located with its unique Path-Row number. It varies from sensor to sensor and satellite to satellite.

Histogram
A graphical representation of DN values in a set of data is called a histogram. In a histogram, individual DN values are displayed along x-axis, and the frequency of their occurrence is displayed along y-axis.

Brightness of an image
It can be defined as the amount of energy output by a source of light relative to the source to be compared. Brightness is a relative term, and it depends on our visual perception. For example, in some cases we can easily say that the image is bright, or image is dull.

Contrast of an image
Contrast can be simply explained as the difference between the maximum and minimum DN values in an image. It is an important factor in any subjective evaluation of image quality. Contrast is the difference in visual properties that makes an object distinguishable from other objects and with the background.

Classification
It is the computational process of assigning the pixels or objects into a set of categories, or classes, having common spectral characteristics or DN values.

Thematic map
A map that displays the spatial distribution of an attribute related to a single topic, theme, or subject, is called a thematic map. Usually, a thematic map displays a single attribute, such as soil type, vegetation, rivers, geology, land use or habitation.

5.6 Electromagnetic Spectrum (EMS)

The EMS consist of a broad spectrum ranging from very low frequency to very high frequency or from very long wavelength to very short wavelength. The electromagnetic radiation (EMR) travels with the velocity of light, and does not require a material medium to propagate. All EMRs travel in sinusoidal form with different wavelengths and frequencies. It can be broken down in two components; *Electric field* and *Magnetic field*, which are mutually perpendicular to each other (Figure 5.2). The distance between the two successive peaks in the same phase is called the *wavelength*, and is measured in cm, mm or µm. Whereas, the *Frequency of wavelength* is defined as the number of peaks passing through a given point at any given instant of time, and is measured in Hz, GHz.

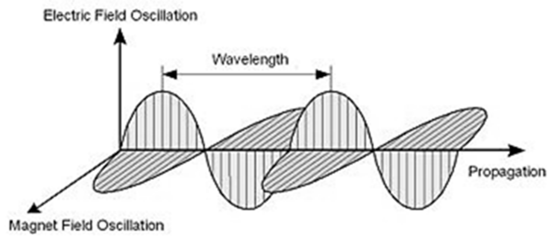

Figure 5.2 Propagation of EMR

The frequency (v), wavelength (f) and velocity ($c = 2.9979 \times 10^8$ m/s) of the EMR can be related as-

$$\lambda = c / \nu \qquad (5.1)$$

According to this relationship, the wavelength of the emitted radiation is inversely proportional to its frequency. Lower the wavelength, higher the frequency and vice versa.

All electromagnetic waves travel with a wide range of frequencies, wavelengths, and photon energies. The EMS ranges from the shorter wavelengths to the longer wavelengths, as shown in Figure 5.3. It has γ-ray and x-ray regions, ultraviolet (UV) region, visible region, infrared (IR) region, microwaves and radio waves. Each part of this spectrum has some specific utility. Table 5.1 presents various wavelength regions and their specific applications. The γ-ray and x-ray regions are not used in remote sensing but these regions are useful in medical science for investigation. The Ultraviolet (UV) radiations (0.3 to 0.4 µm) is mostly absorbed by Ozone at an altitude of between 20 and 40 km in the atmosphere, so, a very little part of UV reaches the Earth surface.

Visible spectrum (0.4 to 0.7 µm) is an important part of the EMS, as human eyes are sensitive to detect this region. The visible region occupies a very tiny portion of the entire EMS; the longest wavelength is red and the shortest is violet. This portion of the spectrum is associated with the concept of colours; Blue, green, and red being the *primary colours*. All other colours in the spectrum can be formed by combining the three blue, green, and red primary colours in various proportions. Sun energy reflected from the Earth during daytime is recorded in this part of wavelength region by many satellite sensors.

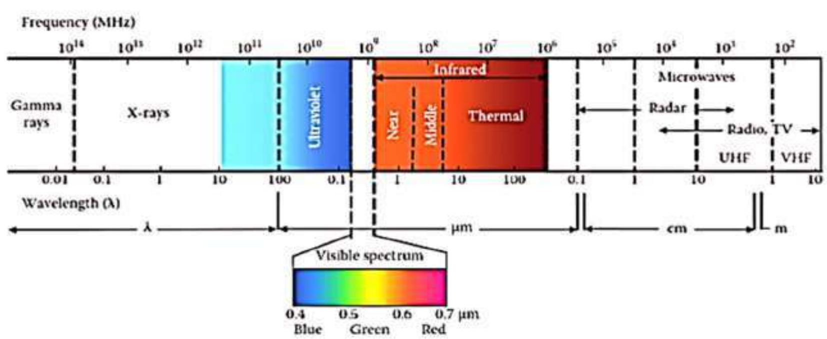

Figure 5.3 Various part of the EMS (https://rs9956125.wordpress.com/2018/11/02/2-remote-sensing-out-of-this-world/)

Table 5.1 Principal divisions of the EMS (Gupta, 1991)

Wavelength	Description/Application

γ- rays	Gamma rays are used in medical sciences.
x-rays	x-rays are used in medical sciences.
Ultraviolet region (0.3- 0.4μm)	This region is beyond the violet portion of the visible wavelength. UV radiation is largely scattered by earth's atmosphere, and hence not used in field of remote sensing.
Visible region (0.4-0.7μm) **Violet (**0.4-0.446μm) **Blue (**0.446-0.50μm) **Green (**0.50-0.578μm) **Yellow (**0.578-0.592μm) **Orange (**0.592-0.620μm) **Red (**0.620-0.7μm)	It is most important portion of spectrum used in optical remote sensing. Human eyes can detect this light. This part of the spectrum can be associated with the colours.
Infrared region **NIR** (0.75-1.4μm) **SWIR** (1.4-3μm) **MIR** (3-8μm) **LWIR** (8-15μm) **FIR** (15-100μm)	Infrared region is a longer portion of the spectrum. Reflected IR (0.7μm-3.0μm) is used for remote sensing. Thermal IR (3μm-14μm) is the radiation emitted from Earth's surface in the form of heat.
Microwave region (1mm - 30cm) **L band** (15cm-30cm) **S band** (7.5cm-15cm) **C band** (3.75cm-7.5cm) **X band** (2.5cm-3.75cm) **Ku band** (1.7cm-2.5cm) **K band** (1.13cm-1.7cm) **Ka band** (0.75cm-1.13cm)	This is a large part of wavelength used in remote sensing. The main advantage of this spectrum is its ability to penetrate through rain, fog and clouds.
Radio waves >30cm	This is the longest portion of the spectrum, mostly used for commercial broadcast and meteorology.

The infrared (IR) region covers the wavelength range from approximately 0.7 μm to 100 μm; more than 100 times as wide as the visible part. The IR can be divided into two categories based on their radiation properties. The near infrared (NIR) and shortwave infrared (SWIR), also known as the *Reflected IR*, refers to the main infrared component of the solar radiation reflected from the Earth's surface. The middle-wave infrared (MWIR) and long wave infrared (LWIR), also known as the *Thermal Infrared*. Reflected IR region (0.7 to 3.0 μm) is used in remote sensing in similar way as the visible region. The region from 0.7 to 0.9 μm is detectable with film, and is called the *photographic IR band*. The thermal IR region (3.0 to 100 μm) is quite different than the visible and reflected IR portions, as this energy is emitted from the Earth's surface in the form of heat. Principal "atmospheric windows regions" occur in the thermal region.

The microwave region (1 mm to 1 m) covers a large part of wavelength used in remote sensing. The shorter wavelengths have properties similar to the TIR region, while the longer wavelengths are used for radio broadcasts. Longer wavelengths can penetrate through clouds, fog and rain. This portion of the EMS is used in active remote sensing. Radar images are acquired at various wavelength bands.

5.7 Black Body Radiations

All objects with a temperature above absolute zero (^{0}K, or -273°C) would emit energy in the form of electromagnetic radiation. A blackbody is a body which absorbs all the radiations falling on it, and also a perfect emitter over all wavelengths. While, a white body is a non-absorber and non-emitter, it is a perfect reflector. Ideally, we do not have a perfect black body or a white body. Natural objects behave in-between a perfect black body and a perfect white body; called the *grey body*. The emissivity of a perfect black body is 1, while for a perfect white body it is zero.

The characteristics of blackbody radiation can be described in terms of several laws:

1. Planck's Law:

The energy of an EMR can be quantized. The basic unit of energy for an electromagnetic wave is called a *photon*. The energy *E* of a photon is proportional to the frequency *f* of wavelength–

$$E = h\,f \tag{5.2}$$

It can also be written in terms of wavelength as-

$$E = h\,(c/\lambda) \tag{5.3}$$

Where *h* is the Planck's constant = 6.62606957×10^{-34} joule·second.

The energy *E* radiated is inversely proportional to the wavelength of EMS, as product (*h*c*) is a constant quantity. It means that lower the frequency, higher will be the energy carried by the photons and electrons. Since, γ-rays, *x*-rays, etc., have higher frequency due to their lower wavelength, these are able to penetrate through the skeleton/human body, and extremely useful in medical sciences.

Planck's law determines the spectral energy density of the emission at each wavelength (E_λ) at a particular absolute temperature (T). The spectral radiance can also be measured per unit wavelength (λ) instead of per unit frequency. In this case, spectral energy is given by:

$$E_\lambda = \frac{8\pi hc^2}{\lambda^5\left(e^{(hc/\lambda kT)}-1\right)} \tag{5.4}$$

where h is the Planck's constant

c is the velocity of light = 2.9979×10^8 m/s

λ is the wavelength of radiation

k is the Boltzmann's constant = 1.38×10^{-23} J /K

T is the Absolute temperature of the radiating body in degree Kelvin (K)

2. Wien's Displacement Law:

This law states that the frequency of the peak of emission increases linearly with absolute temperature (T). As the temperature of the body *increases*, the overall radiated energy increases, and the peak of the radiation curve moves to shorter wavelengths, as shown in Figure 5.4. The maximum radiation is derived from the Planck's formula, and the product of the peak wavelength and the temperature (T) is found to be a constant.

$$\lambda_{\max} = \frac{b}{T} \tag{5.5}$$

Where, b is a constant of proportionality known as Wien's displacement constant = 2.898×10^{-3}mK.

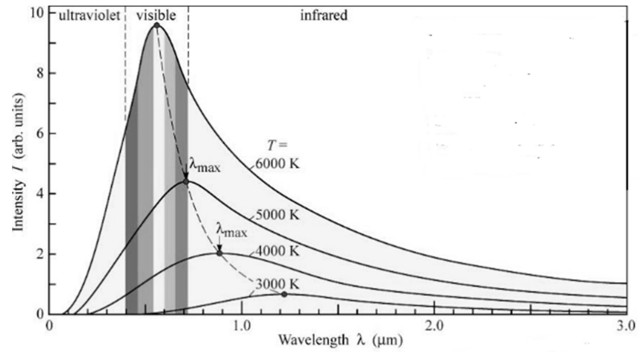

Figure 5.4 Intensities of EMR at different wavelengths and temperatures (Castleman, 1996)

3. Stefan–Boltzmann Law:

It relates to the *total* energy emitted *(E)* by a body with its absolute temperature (T). The wavelength of the peak of blackbody radiation curve decreases in a linear fashion as the temperature is increased (Figure 5.4). *The Stefan-Boltzmann Law states that the total amount of energy per unit area emitted by an object is proportional to the fourth power of the absolute temperature*, and can be represented as:

$$E = \sigma T^4 \quad (5.6)$$

Where σ is Stefan–Boltzmann constant = 5.67×10^{-8} W/($m^2 K^4$)

The Sun produces more spectral energy at 6,000 ^{0}K than the Earth at 300 ^{0}K. As the temperature increases, the total amount of radiant energy increases and the radiant energy peak shifts from higher wavelength to shorter wavelengths.

5.8 Interaction of EMR with Atmosphere

When EMR strikes a material/object on the ground, it is called *incident radiation*. This incident radiation will first interact with atmosphere and then on the surface of Earth, and then again with atmosphere before it reaches the sensor. Four types of interactions will take place with the atmosphere and surface/objects; scattering, absorption, transmission and reflection, as shown in Figure 5.5. These interactions in the atmosphere would depend on the angle of incident radiation, wavelength of radiation and atmospheric conditions. Whereas, on the surface of objects, these would depend upon the angle at which radiations strike the surface, the compositional and physical properties of the surface, and the wavelength of incident radiation.

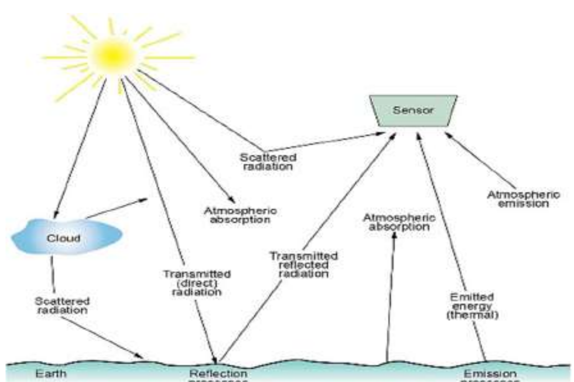

Figure 5.5 Four types of interactions: transmission, reflection, scattering and absorption (Colwell, 1983)

5.8.1 Types of interactions

The four types of interactions are explained below.

1. Reflection

It is the process whereby incident radiation bounces-off the surface in a single predictable direction. Reflection is caused by the surfaces that are smooth relative to the wavelengths of incident radiation. As per Snell's law, the angle of reflection is always equal and opposite to the angle of incidence. The amount of reflected energy will depend upon the material of the object, wavelength region, and the atmospheric condition.

2. Scattering

It is the process by which small particles diffuse a portion of the incident radiation in all directions. Scattering occurs when incident radiation is dispersed or spread out unpredictably in different directions. Scattering occurs with the surfaces that are rough relative to the wavelengths of incident radiation. Scattering of radiation by the constituent gases and aerosols in the atmosphere causes degradation of remotely sensed images. In the real-world, scattering is much more common than the reflection. Scattering produces *blurring* of the objects in remotely sensed images, resulting in poor resolution.

Three types of scattering commonly take place in the atmosphere: Rayleigh scattering, Mie scattering and Non-selective scattering. These will depend on the wavelength of incident radiant energy, and the size of gas molecule, dust particle, and/or water vapor droplet interacting with the EMR. These are explained below;

(i) Rayleigh Scattering

Rayleigh scattering mainly consists of scattering from the gases present in the atmosphere. It is primarily caused by air particles i.e., O_2 and N_2 molecules. Rayleigh scattering takes place when the dimension of the particles present in the atmosphere is much smaller than the size of wavelength λ, and can be represented as:

Rayleigh scattering $\propto 1 / \lambda^4$ (5.7)

Since, scattering is inversely proportional to the fourth power of the wavelength, radiations in the shorter wavelength (blue of visual part) will scatter much more strongly than the radiations in red wavelengths, as shown in Figure 5.6. Due to Rayleigh scattering, the colour of the sky therefore appears blue, and during the sunset it appears as red. During the sunset, the rays actually follow a longer path through the denser atmosphere, and the shorter wavelength radiation is strongly scattered out of the line of sight, leaving only the radiation in longer wavelengths (i.e., red and orange) to reach our eyes. Multispectral remote sensing data taken in the blue portion of spectrum is therefore has limited use due to this scattering.

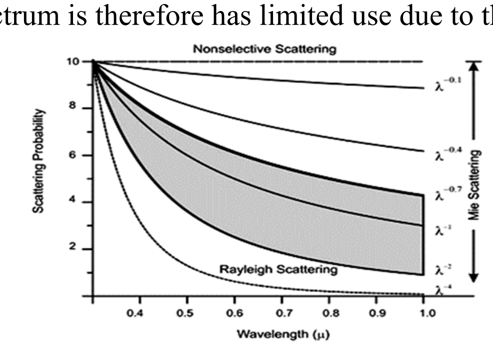

Figure 5.6 Types of scattering (Gibson, 2000)