UNIT II

EMR INTERACTION WITH ATMOSPHERE AND EARTH MATERIALS

1. ENERGY INTERACTIONS WITH THE ATMOSPHERE

- Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere.
- Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of scattering and absorption.

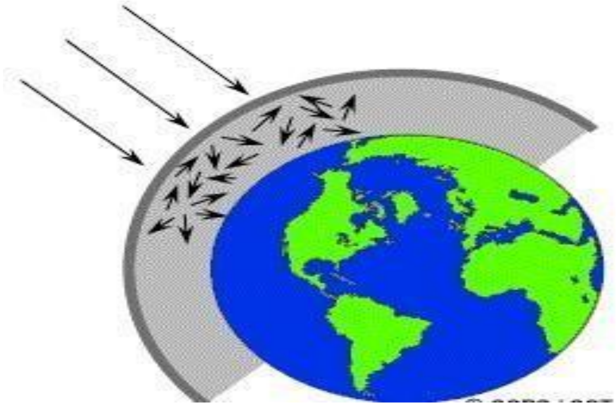


Fig 2.1 Energy Interaction with Atmosphere

1.1 SCATTERING

- Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path.
- The amount of scattering that takes place depends on several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance of the radiation travels through the atmosphere.
- There are three (3) types ofscattering which take place.

1.1.1 RAYLEIGH SCATTERING

- Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation.
- These could be particles such as small specks of dust or nitrogen and oxygen molecules.
- Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths.
- Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere.

- The fact that the sky appears "blue" during the day is because of this phenomenon.
- As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths.
- At **sunrise and sunset** light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere.

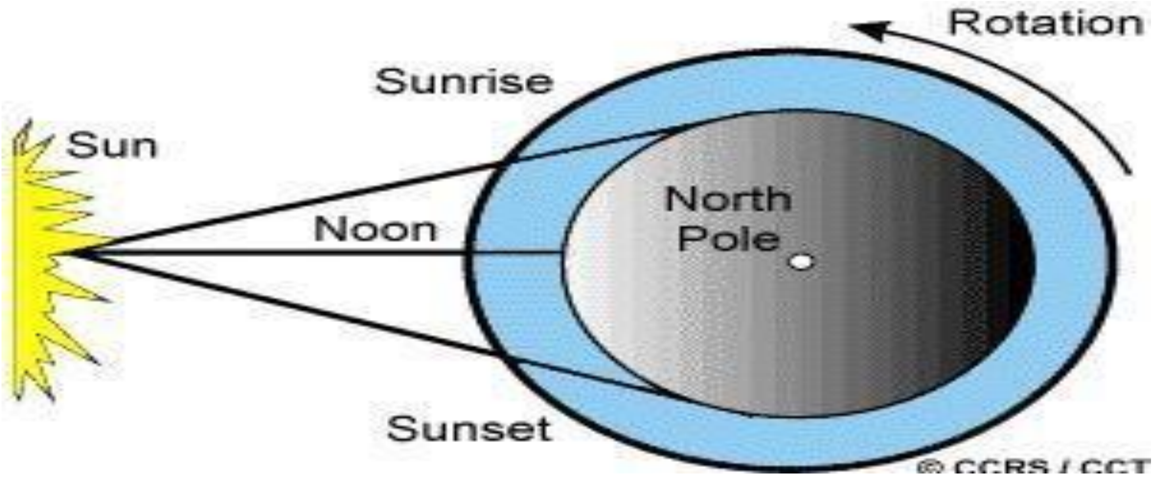


Fig 2.2 Raleigh Scattering

1.1.2 MIE SCATTERING

- Mie scattering occurs when the particles are just about the same size as the wavelength of the radiation.
- Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering.
- Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant and dominates when cloud conditions are overcast.

1.1.3 NON-SELECTIVE SCATTERING

- The final scattering mechanism of importance is called **nonselective scattering**.
- This occurs when the particles are much larger than the wavelength of the radiation.
- Water droplets and large dust particles can cause this type of scattering.
- Nonselective scattering gets its name from the fact that all wavelengths are scattered about equally.
- This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red lightare all scattered in approximately equal quantities (blue+green+red light = white light).

1.2 ABSORPTION

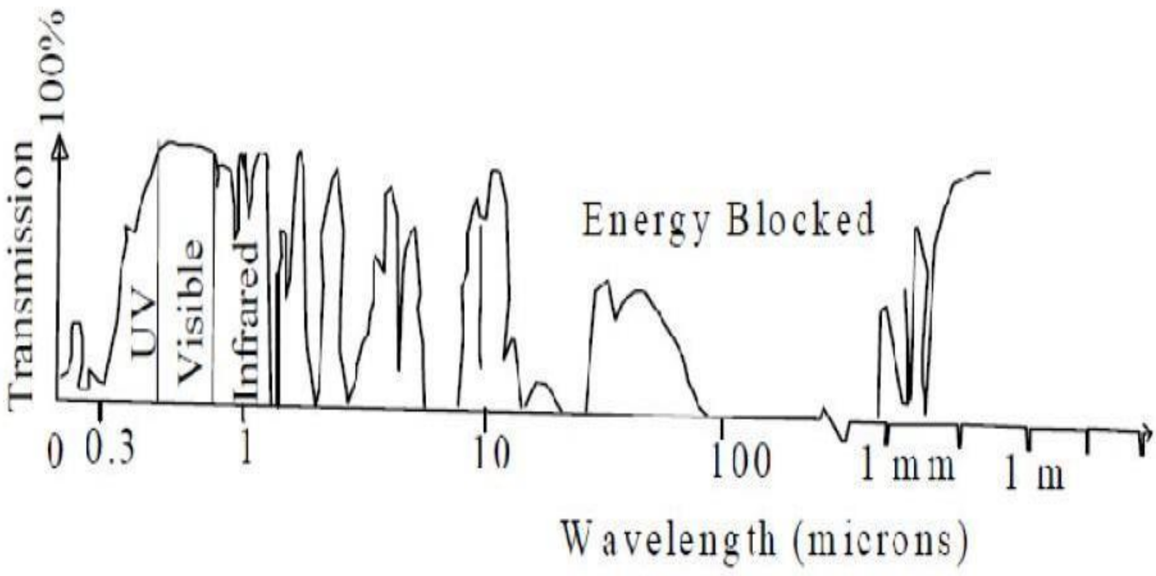
- Absorption is the other main mechanism at work when electromagnetic radiation interacts withthe atmosphere.
- In contrast to scattering, this phenomenon causes molecules in the atmospherето absorb energy at various wavelengths.
- Ozone, carbon dioxide, and water vapor are the threemain atmospheric constituents which absorb radiation.
  - ✓ **Ozone** serves to absorb the harmful (to most living things) ultraviolet radiation for the sun. Without this protective layer in the atmosphere our skin would burn when exposed to sunlight.
  - ✓ **Carbon dioxide** is referred to as a greenhouse gas. This is because it tends to absorb radiation strongly in the far infrared portionof the spectrum - that area associated with thermal heating - which serves to trap this heat insidethe atmosphere.
  - ✓ **Water vapour** in the atmosphere absorbs much of the incoming longwave infrared and shortwave microwave radiation (between 22μm and 1m). The presence of water vapour in the lower atmosphere varies greatly from location to location and at different times of the year.

1.3 REFRACTION

- Refraction is a phenomenon that occurs when radiation, such as light or other electromagnetic waves, interacts with the Earth's atmosphere.
- It involves the bending of the path of the radiation as it passes from one medium (e.g., air) into another medium (e.g., glass or water) with a different refractive index.
- In the case of the atmosphere, refraction primarily affects the path of visible light and radio waves. The factors of refraction are,
  - ✓ **Refractive Index:** Every material has a property known as the refractive index (or optical density), which measures how much the speed of light is reduced when it passes through that material compared to a vacuum. The refractive index of air is slightly greater than 1, meaning that light travels slightly slower in air than in a vacuum.
  - ✓ **Change in Speed:** When light or electromagnetic waves enter the Earth's atmosphere from space (which is close to a vacuum), they slow down due to the refractive index of air.
  - ✓ **Bending of Light:** According to Snell's Law, which describes the behavior of light at the boundary between two different media, the change in speed causes the radiation to change direction. The degree of bending depends on the angle of incidence and the refractive indices of the two media.
  - ✓ **Atmospheric Layers:** The degree of refraction in the atmosphere can vary with altitude and atmospheric conditions. Different layers of the atmosphere have different refractive properties, which can lead to complex bending effects, especially during sunrise and sunset.

2. ATMOSPHERIC WINDOWS

- While EMR is transmitted from the sun to the surface of the earth, it passes through the atmosphere.
- Here, electromagnetic radiation is scattered and absorbed by gases and dust particles.
- Besides the major atmospheric gaseous components like molecular nitrogen and oxygen, other constituents like water vapour, methane, hydrogen, helium and nitrogen compounds play important role in modifying electromagnetic radiation.
- This affects image quality.
- Regions of the electromagnetic spectrum in which the atmosphere is transparent are called atmospheric windows.
- The atmosphere is practically transparent in the visible region of the electromagnetic spectrum and therefore, many of the satellite based remote sensing sensors are designed to collect data in this region.
- Some of the commonly used atmospheric windows are shown in thefigure.



3. SPECTRAL SIGNATURE CONCEPTS-TYPICAL SPECTRAL REFLECTANCE - CHARACTRISTICS OF WATER, VEGETATION AND SOIL:

- A basic assumption made in remote sensing is that a specific target has an individual and characteristic manner of interacting with incident radiation.
- The manner of interaction is described by the spectral response of the target.
- The spectral reflectance curves describe the spectral response of a target in a particular wavelength region of electromagnetic spectrum.
- The spectral reflectance curve depends upon certain factors, namely, orientation of the sun (solar azimuth), the height of the Sun in the sky (solar elevation angle), the direction in which the sensor is pointing relative to nadir (the look angle) and nature of the target.

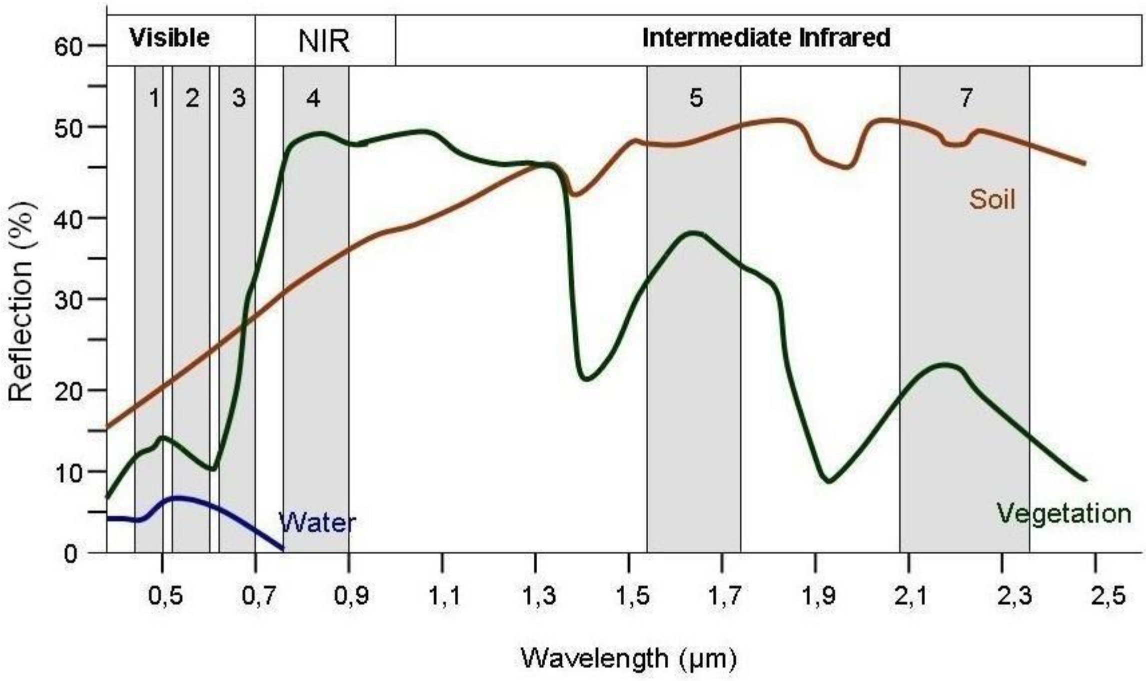


Fig 2.3 Spectral reflectance Curve

Every object on the surface of the earth has its unique spectral reflectance.

The spectral reflectance curves for vigorous vegetation manifsoil, the "Peak- and-valley" configuration.

The valleys in the visible portion of the spectrum are indicative of pigments in plant leaves.

The soil curve shows a more regular variation of reflectance.

Factors that evidently affect soil reflectanceare moisture content, soil texture, surface roughness, and presence of organic matter.

The term spectral signature can also be used for spectral reflectance curves.

Spectral signature is aset of characteristics by which a material or an object may be identified on any satellite imageor photograph within the given range of wavelengths. Sometime &, spectral signatures are used to denote the spectral response of a target.

The characteristic spectral reflectance curve Fig2.3 for water shows that from about 0.5µm, a reduction in reflectance with increasing wavelength, so that in the near infrared range, the reflectance of deep, clear water is virtually a zero (Mather, 1987). However, the spectral reflectance of water is significantly affected by the presence of dissolved and suspended.

organic and inorganic material and by the depth of the water body. Fig. 1.8 shows the spectral reflectance curves for visible and near-infrared wavelengths at the surface and at 20 m depth.

Suspended solids in water scatter the down welling radiation, the degree of scatter being proportional to the concentration and the color of the sediment. Experimental studies in the field and in the laboratory as well as experience with multispectral remote sensing have shown that the specific targets are characterized by an individual spectral response. Indeed, the successful developmentof remote sensing of environment over the past decade bears witness to its validity. In the remaining part of this section, typical and representative spectral reflectance curves for characteristic types of the surface materials are considered.

Imagine a beach on a beautiful tropical island. of electromagnetic radiation with the top layer of sand grains on the beach. When an incident ray of electromagnetic radiation strikes an air/grain interface, part ofthe ray is reflected and part of it is transmitted into the sand grain. The solid lines in the figurerepresent the incident rays, and dashed lines 1, 2, and 3 represent rays reflected from the surfacebut have never penetrated a sand grain. The latter are called specular rays by Vincent and Hunt(1968), and surface-scattered rays by Salisbury and Wald (1992); these rays result from first-surface reflection from all grains encountered.

For a given reflecting surface, all specular rays reflected in the same direction, such that the angle of reflection (the angle between the reflected rays and the normal, or perpendicular to the reflecting surface) equals the angle of incidence (the angle between the incident rays and the surface normal). The measure of how much electromagnetic radiation is reflected off a surfaceis called its reflectance, which is a number between 0 and 1.0. A measure of 1.0 means the 100% of the incident radiation is reflected off the surface, and a measure of 0 means that 0% is reflected.

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 atthe sensors and are analyzed 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.

Energy Interactions

The incident electromagnetic energy may interact with the earth surface features in threepossible ways: Reflection, Absorption and Transmission.

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 the EM energy which is absorbed by the Earth‘s surface is available for emission and as thermal radiation at longer wavelengths.

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 *EI* denotes the incident energy, *ER* denotes the reflected energy, *EA* denotes the absorbed energy and *ET* denotes the transmitted energy. Thenthe principle of conservation of energy (as a function of wavelength λ) can be expressed as

$$EI(\lambda) = ER(\lambda) + EA(\lambda) + ET(\lambda) \qquad (1)$$

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

$$ER(\lambda) = EI(\lambda) - EA(\lambda) - ET(\lambda) \qquad (2)$$

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

Reflection

Reflection is the process in which the incident energy is redirected in such a way that the angleof 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.

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 1or 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 havebeen 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 propertiesmay 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 inthe 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, shows a part of the Krishna River Basin as seen in different bands of the Landsat ETM+ imagery. As the concepts of false colour composite (FCC) have been covered in module4, readers are advised to refer to the material in module 4 for better understanding of the colour 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.

Diffuse and Specular Reflection

Energy reflection from a surface depends on the wavelength of the radiation, angle of incidenceand the composition and physical properties of the surface. Roughness of the target surface controls how the energy is reflected by the surface. Based onthe roughness of the surface, reflection occurs in mainly two ways.

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 surfaceis the maximum along the angle of reflection, whereas in any other direction it is negligible.

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 "color" 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 reflectanceand hence it is easy to differentiate the features.

Based on the nature of reflection, surface features can be classified as specular reflectors, Lambertian reflectors. 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 Near diffusive Near specular Ideal diffusive Ideal specular Angle of reflection Angle of incidence.

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 atone location and for the other locations dark tones will be obtained from the same target. Thisvariation 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 whenthe sensor is located in the direction of the reflected energy.

Spectral Reflectance of Earth SurfaceVegetation

In general, healthy vegetation is a very good absorber of electromagnetic energy in the visible region. Chlorophyll strongly absorbs light at wavelengths around 0.45 (blue) and 0.67 µm (red) and reflects strongly in green light, therefore our eyes perceive healthy vegetation as green. Healthy plants have a high reflectance in the near-infrared between 0.7 and 1.3 µm. This is primarily due to healthy internal structure of plant leaves. As this internal structure varies amongst different plant species, the near infrared wavelengths can be used to discriminate between different plant species.

Water

In its liquid state, water has relatively low reflectance, with clear water having the greatest reflectance in the blue portion of the visible part of the spectrum. Water has high absorption and virtually no reflectance in near infrared wavelengths range and beyond. Turbid water has a higher reflectance in the visible region than clear water. This is also true for waters containing high chlorophyll concentrations.

Ice and Snow

Ice and snow generally have high reflectance across all visible wavelengths, hence their brightwhite appearance. Reflectance decreases in the near infrared portion and there is very low reflectance in the SWIR (shortwave infrared). The low reflection of ice and snow in the SWIRis related to their microscopic liquid water content. Reflectance differs for snow and ice depending on the actual composition of the material including impurities and grain size.

Soil

Bare soil generally has an increasing reflectance, with greater reflectance in near-infrared and shortwave infrared. Some of the factors affecting soil reflectance are:

- Moisture content
- Soil texture (proportion of sand, silt, and clay)
- Surface roughness
- Presence of iron oxide
- Organic matter content