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1. Characteristics of Solar Radiant Energy

The Sun is the only source of radiant energy for remote sensing. The energy emitted by the Sun is divided into 40% visible light (VI), 50% IR, 9% UV and 1% x-ray, radio, etc. It is the VI and IR energy, which is used for the remote sensing for getting the information about the surface features.

2. Interaction of EMR with the Atmosphere

The solar radiation and electromagnetic radiation (EMR) from the sun before reaching the surface of the Earth has to pass through the atmosphere and then strikes the surface of the Earth and then again passes through the atmosphere before a sensor on board a satellite detects it. The interaction of EMR with the atmosphere is important to remote sensing for two main reasons. First, information carried by EMR reflected/emitted by the earth's surface is modified while traversing through the atmosphere. Second, the interaction of EMR with the atmosphere can be used to obtain useful information about the atmosphere itself.

In order to understand the potential and limitations of remotes sensing, it is necessary to consider what happens to solar electromagnetic radiation on its path from the sun to the satellite or airborne sensor. All of the solar EMR passes through space to reach the top of the Earth's atmosphere, but not all reaches the Earth's surface. The atmosphere scatters, absorbs and reflects a portion of the in-coming solar radiation. The Earth scatters, absorbs and reflects the solar radiation that gets transmitted through the atmosphere. Finally, the atmosphere scatters, absorbs and reflects the electromagnetic radiation that is reflected off the Earth's surface back toward the sensor.

The atmospheric constituents scatter and absorb the radiation modulating the radiation reflected from the target by attenuating it, changing its spatial distribution and introducing into field of view radiation from sunlight scattered in the atmosphere and some of the energy reflected from nearby ground area. Both scattering and absorption vary in their effect from one part of the spectrum to the other. The solar energy is subjected to modification by several physical processes as it passes the atmosphere viz.

i. Scattering
ii. Absorption
iii. Refraction

2.1 Atmospheric Scattering

Atmospheric scattering is the redirection of EMR by particles suspended in the atmosphere or by large molecules of atmospheric gases. Scattering not only reduces the image contrast but also changes the spectral signature of ground objects as seen by the sensor. The amount of scattering depends upon various factors like i) size of the particles, ii) their abundance, iii) the wavelength of radiation, depth of the atmosphere through which the energy is travelling and iv) the concentration of the particles. The concentration of particulate matter varies in both time, space and season. Thus, the effects of scattering will be uneven spatially and will vary from time to time.

Theoretically scattering can be divided into three categories depending upon the wavelength of radiation being scattered and the size of the particles causing the scattering. The three different types of scattering from particles of different sizes are summarized in the Table 1.

Table 1: Types of scattering

Scattering process	Wavelength	Approximate dependence particle size	Kinds of particles
Selective			
i) Rayleigh	λ^{-4}	< 1 µm	Air molecules
ii) Mie	λ^{0} to λ^{-4}	0.1 to 10 µm	Smoke, haze
Non-selective	λ^{0}	> 10 µm	Dust, fog, clouds

2.2 Raleigh Scattering

Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation. It occurs when the diameter of the matter (usually air molecules) are many times smaller than the wavelength of the incident electromagnetic radiation. All scattering is accomplished through absorption and re-emission of radiation by atoms or molecules in the manner described in the discussion on radiation from atomic structures. It is impossible to predict the direction in which a specific atom or molecule will emit a photon, hence scattering. These could be particles such as small specks of dust or nitrogen and oxygen molecules. The energy required to excite an atom is associated with short-wavelength, high frequency radiation. The amount of scattering is inversely related to the fourth power of the radiation's wavelength. For example, blue light (0.4 µm) is scattered 16 times more than near infrared light (0.8 µm).

Rayleigh scattering occurs due to the scattering of shorter wavelengths of EMR, and it is the dominant scattering mechanism in the upper atmosphere. The fact that the sky appears "blue" during the day is because of this phenomenon (Fig. 1). 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 the 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. The approximate amount of Rayleigh scattering in the atmosphere in optical wavelengths (0.4-0.7 µm) may be computed using the Rayleigh scattering cross-section algorithm:

$$\tau_m = \frac{8\pi^3\left(n^2-1\right)^2}{\left(3N^2\lambda^4\right)}$$

Where n = refractive index,
N = number of air molecules per unit volume, and
λ = wavelength.

The amount of scattering is inversely related to the fourth power of the radiation's wavelength. Radiation in blue wavelengths, which is shorter, is scattered towards the ground much more strongly than radiation in the red wavelength region. Due to Rayleigh scattering, multi-spectral data from the blue portion of the spectrum is of relatively less usefulness. There is strong scattering in the forward as well as backward directions. The strong backward scattering is responsible for the appearance of hot spots in aerial photographs, which is taken in hazy atmosphere by wide-angle cameras when the direction of solar radiation falls within the field of view of the sensor. The effects of the Raleigh component of scattering can be eliminated by using minus blue filters.

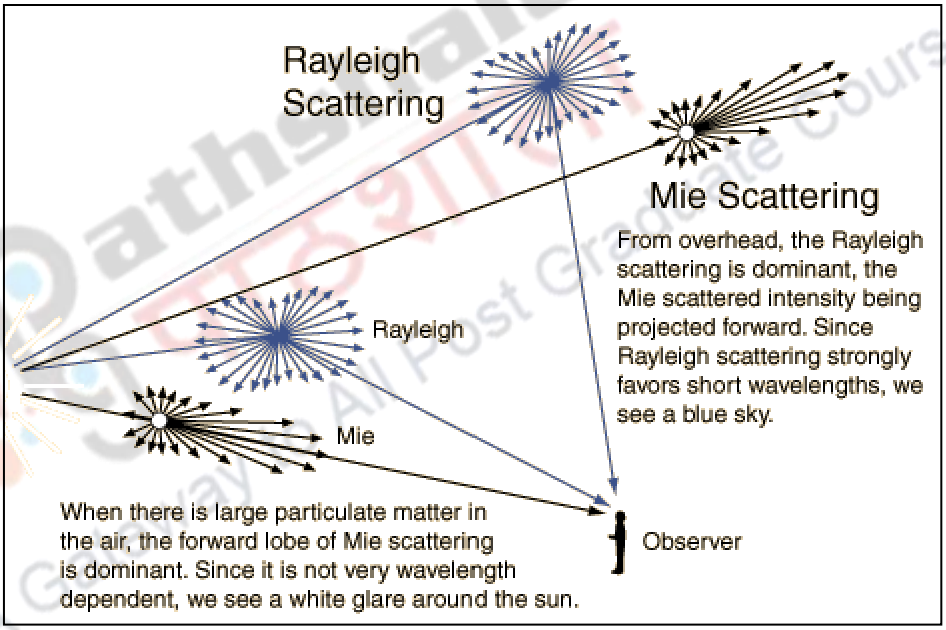


Fig. 1

2.3 Mie Scattering

Mie scattering occurs when the wavelength is *approximately equal to the size of the scattering particles* (Fig. 1). For visible light, water vapor, dust, and other particles ranging from a few tenths of a micrometer to several micrometers in diameter are the main scattering agents. Mie scattering occurs mostly in the lower portions of the atmosphere i.e. lesser than 5 kms where larger particles are more abundant, and dominates when cloud conditions are overcast. The amount of scatter is greater than Rayleigh scatter and the wavelengths scattered are longer. *Pollution* also contributes to beautiful *sunsets* and *sunrises*. The greater the amount of smoke and dust particles in the atmospheric column, the more violet and blue light will be scattered away and only the longer *orange* and *red* wavelength light will reach our eyes.

The final scattering mechanism of importance is called non-selective 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. Non-selective scattering gets its name from the fact that all wavelengths are scattered about equally. This type of scattering is non-selective, i.e. all wavelengths of light are scattered, not just blue, green, or red. Thus, water droplets, which make up clouds and fog banks, scatter all wavelengths of visible light equally well; causing the cloud to appear white (a mixture of all colours of light in approximately equal quantities produces white). Scattering can severely reduce the information content of remotely sensed data to the point that the imagery loses contrast and it is difficult to differentiate one object from another.

2.4 Non Selective Scattering

The third type of scattering is non-selective scattering; it takes place when the particles are much larger than the wavelength of the radiation (Fig. 2). Non-selective scattering gets its name from the fact that all wavelengths are scattered about equally. This type of scattering usually takes place when there is lots of dust atmosphere especially in summer season that results in a severe attenuation of the received data. This type of scattering is non-selective, i.e. all wavelengths of light are scattered, not just blue, green, or red. Water droplets and large dust particles can cause this type of scattering. Thus, water droplets, which make up clouds and fog banks, scatter all wavelengths of visible light equally well; causing the cloud to appear white (a mixture of all colours of light in approximately equal quantities produces white). Scattering can severely reduce the information content of remotely sensed data to the point that the satellite image losses its contrast and become difficult to differentiate one object from another for image classification.

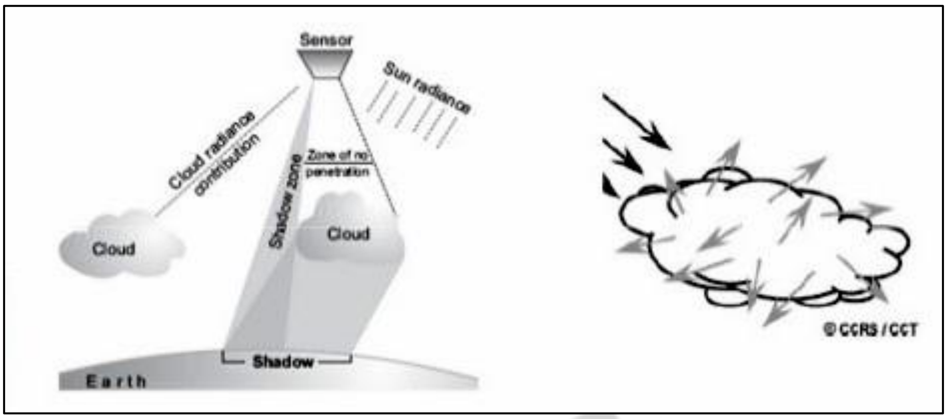


Fig. 2

All three above scattering Rayleigh, Mie Scattering and Non Selective Scattering can be easily and best understood in the following Fig. 3.

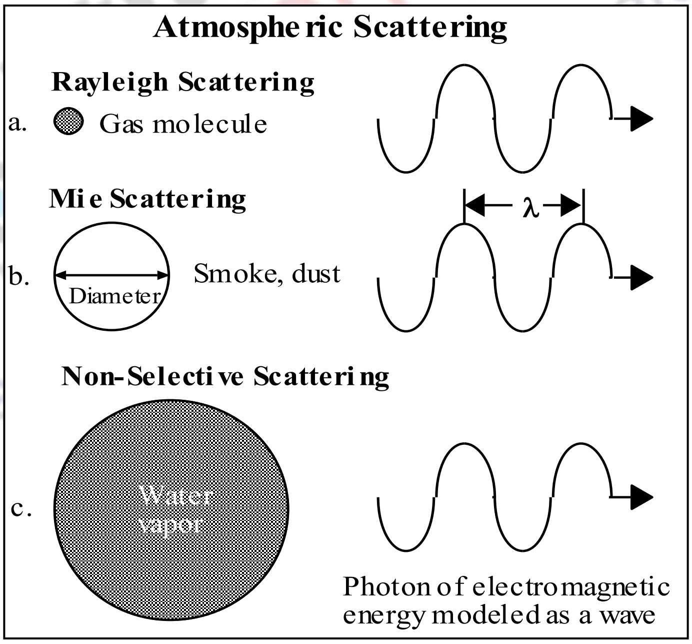


Fig. 3

2.5 Atmospheric absorption

Atmospheric absorption is another mechanism, which works when electromagnetic radiation (EMR) interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Absorption occurs when energy of the same frequency as the resonant frequency of an atom or molecule is absorbed, producing an excited state. If, instead of re-radiating a photon of the same wavelength, the energy is transformed into heat motion and is re-radiated at a longer wavelength, absorption occurs. When dealing with a medium like air, absorption and scattering are frequently combined into an extinction coefficient. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents, which absorb radiation. Ozone absorbs the high energy, short wavelength portions of the ultraviolet spectrum ($\lambda < 0.24\mu m$) thereby preventing the transmission of this radiation to the lower atmosphere. Carbon dioxide is important in remote sensing as it effectively absorbs the radiation in mid and far infrared regions of the spectrum. It strongly absorbs in the region from about 13-17.5 µm, whereas two most important regions of water vapour absorption are in bands 5.5-7.0 µm and above 27 µm. Absorption relatively reduces the amount of light that reaches our eye making the scene look relatively duller. The cumulative effect of the absorption by the various particles/objects can cause the atmosphere to close down in certain regions of the spectrum. This is not good for remote sensing because there will be no energy that can be used for sensing.

3. Interaction of EMR with the Earth's Surface

The radiant energy from the Sun, after passing through the atmosphere when reaches the Earth's surface, three things happens i) some portion energy is reflected by the earth surface, ii) some portion of energy is transmitted into the surface iii) and some portion of it is absorbed and emitted by the earth’s surface later on. The EMR, on interaction with earth’s surface, experiences a number of changes in the magnitude, direction, wavelength, polarization and phase etc. The remote sensor detects these changes and that enable the interpreter to obtain useful information about the object or features of a particular interest. Let us examine each one of the above-mentioned features one by one in detail.

3.1 Reflectance

It is the process whereby radiation reflects back from earth/terrain. This process involves re-radiation of photons in unison by atoms or molecules in a layer one-half wavelength deep. Reflection exhibits fundamental characteristics that are important in remote sensing. The incident radiation, the reflected radiation, and a vertical to the surface from which the angles of incidence and reflection are measured all lie in the same plane. The reflection intensity depends on the surface refractive index, absorption coefficient and the angles of incidence and reflection. Depending upon whether the surface is smooth or rough, the reflection can be either specular or diffuse. Surface roughness is a function of the wavelength of incident radiation. As per the Rayleigh criterion, if surface height variations are less than $\lambda/8$, then the surface can be called as smooth surface, otherwise, rough surface. Therefore, it is the wavelength of the incident EMR which determines the surface roughness. There are four types of reflecting surfaces as shown below in Fig. 4.

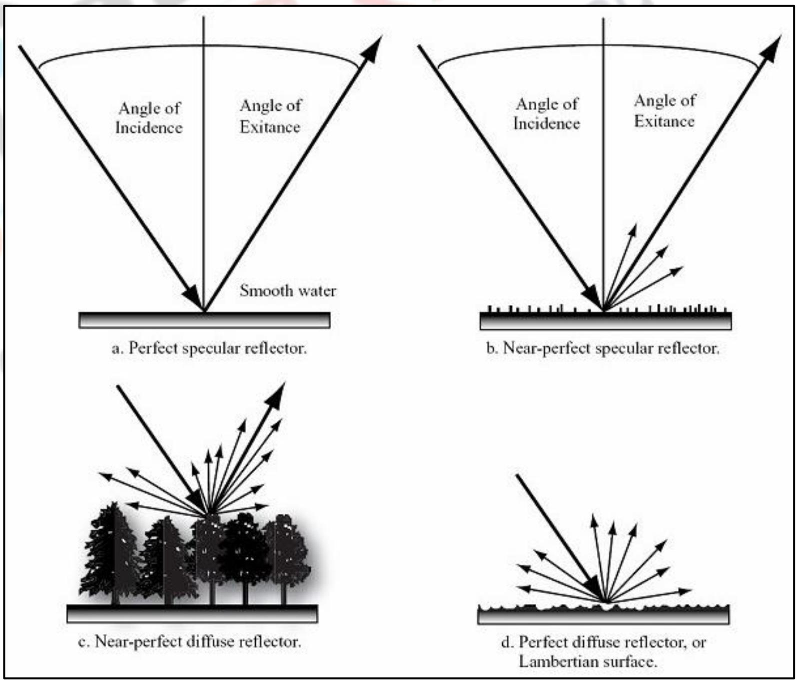


Fig. 4

a) Perfect specular reflection mainly takes place when the surface from which the radiation is reflected is perfectly smooth i.e. surface of a water bodies (fig. 4a) where the average surface profile is several times smaller than the wavelength of radiation striking the surface.

b) Near perfect specular reflection mainly takes place when the surface is rough, and the reflected rays from the surface go in many directions, depending on the orientation of the smaller reflecting surfaces (Fig. 4b). For example, paper white powders and other materials reflect visible light in this diffuse manner.

c) Near perfect diffuse reflection takes place when the surface is so rough that there are no individual reflecting surfaces e.g. group of trees (Fig. 4c) then scattering may occur in all the direction.

d) Perfect diffuse reflection is also known as Lambert surface or perfectly diffuse surface (Fig. 4d). It is one for which the radiant flux leaving the surface is constant for any angle of reflectance to the surface normal. These surfaces could be sand and tilled soils. Mixed reflections occur most frequently in nature and in this case, a reflecting surface returns radiant energy both diffusely and specularly.

3.2 Transmission

Transmission of radiation takes place when radiation passes through an object without significant attenuation. For a given thickness, or depth of an object, the ability of a medium to transmit energy can be measured as transmittance, which is represented by tou (τ).

$$\tau = \frac{Transmitted\ radiation}{Incident\ radiation}$$

3.3 Spectral Signature Curve

Spectral reflectance ρ(λ), cab be defined as the ratio of reflected energy to incident energy as a function of wavelength. Various earth's surface features weather natural or manmade have different spectral reflectance characteristics.

Spectral reflectance is responsible for the color or tone in an image of an object. Trees appear green because they reflect more of the green wavelength. The values of the spectral reflectance of objects averaged over different, well-defined wavelength intervals comprise the spectral signature of the objects or features by which it can be identified or distinguished. A typical reflectance curve of surface features, like vegetation, concrete, sandy loamy soil and clear lake water etc. is shown in Fig. 5.

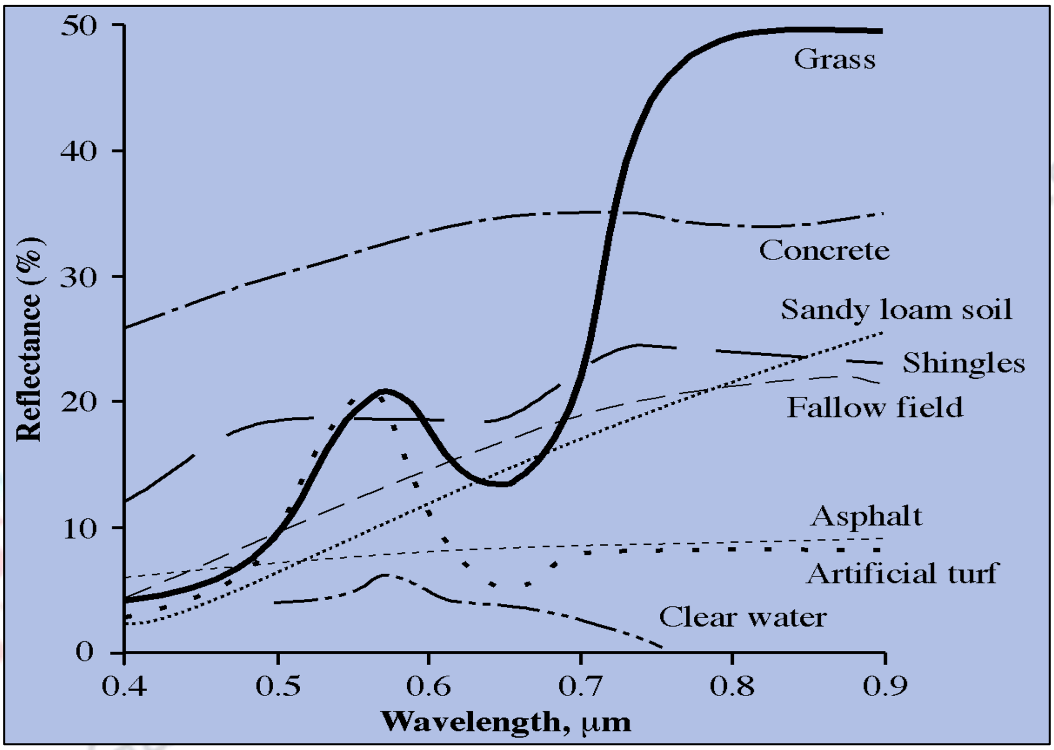
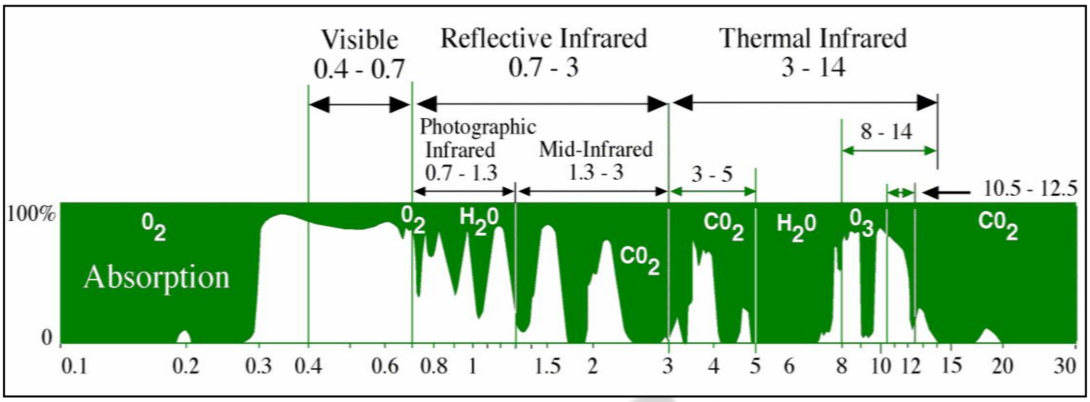


Fig. 5 Typical Spectral reflectance curves for various Earth's surface features.

3.4 Atmospheric Windows

The Regions in the electromagnetic spectrum (EMS) that pass Sun's energy and allow sensing the earth surface features are called *atmospheric windows* is remote sensing. In other words, the spectral bands for which the atmosphere is relatively transparent are known as atmospheric windows (Fig. 6). There are certain regions of EMS, which does not allow to pass the sun's light to pass rather that regions are opaque/blocked by e.g. water vapor (H_2O), carbon dioxide (CO_2), and ozone (O_3) cannot be used for remote sensing.



Wavelengths in micro meters (µm)

Fig. 6

3.5 Refraction

Refraction is the bending of electromagnetic rays as they pass between two media i.e. lighter medium into darker another both medium has a different index of refraction. It takes place in the atmosphere as electromagnetic rays passes through the atmospheric layers, which have different layers where clarity, humidity and temperature etc. are different. The refraction index is wavelength dependent, so that the angle of bending varies systematically from red (longer wavelength; lower frequency) to blue (shorter wavelength; higher frequency). The process of separating the constituent colours in white light is known as dispersion (Fig. 7). These phenomena also apply to radiation of wavelengths outside the visible e.g. a crystal's atomic lattice serves as a diffraction device that bends x-rays in different directions.

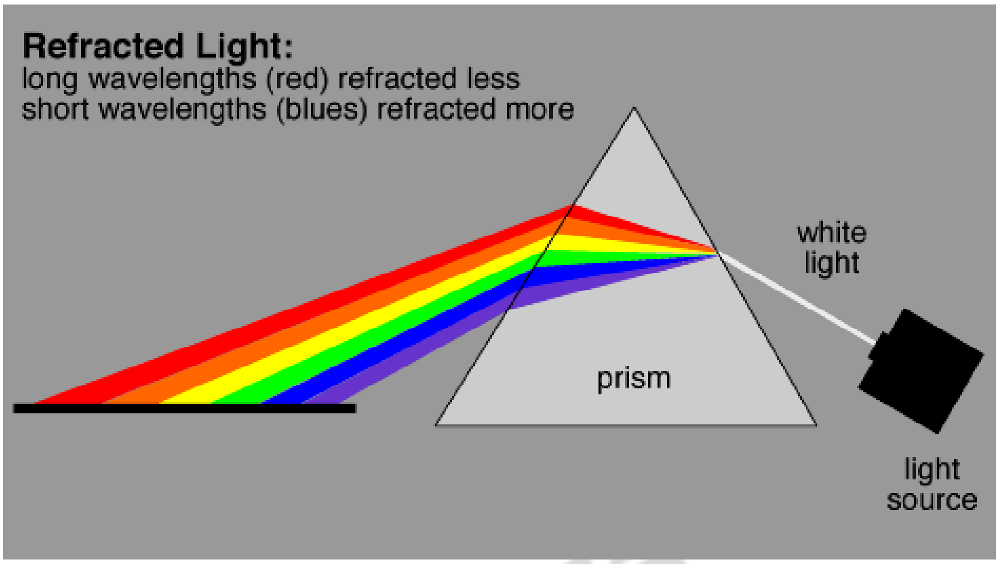


Fig. 7

5. Effects of Atmospheric Haze Scattering in Remote Sensing

Atmospheric scattering is important mainly in the visible and near infrared regions of EMS. Scattering of radiation by the atmospheric gases causes degradation of the remotely sensed images. Most noticeably, the solar radiation scattered by the atmosphere towards the sensor without first reaching the ground produces a hazy appearance in the image. This effect is particularly severe in the blue region of visible spectrum due to the stronger Rayleigh scattering for shorter wavelength radiation (Liew, 2001). Further, the light from a target outside the field of view of the sensor may be scattered into the field of view of the sensor and this effect is known as the adjacency effect. Near to the boundary between two regions of different brightness, the adjacency effect results in an increase in the apparent brightness of the darker region while the apparent brightness of the brighter region is reduced. Scattering also produces blurring of the targets in remotely sensed satellite images due to spreading of the reflected radiation by scattering, resulting in a reduced resolution image (Liew, 2001).

References

Liew S. C. (2001) *Principles of Remote Sensing*, 2nd Edition Centre for Remote Imaging, Sensing and Processing (CRISP), Singapore, http://www.crisp.nus.edu.sg/~research/tutorial/rsmain.htm

5.1 Contrast Reduction

The most serious effect of atmospheric haze leads to reduction in contrast in the satellite image. The downward component of scattered light (skylight) reduces the brightness difference and hence the contrast between sunlit and shaded areas of the ground. The upward component of scattered radiation (sky radiance) increases the irradiance in the camera image plane and reduces the contrast in the image.

$$C = \frac{E.\rho\,\max.\tau A + \pi L}{E.\rho\,\min.\tau A + \pi L}$$

Where **E** is irradiance due to sun and sky,

ρ max. & **ρ min.** is reflectance of scene highlight and low light areas,

τ is atmospheric transmittance and

L is atmospheric radiance.

7. Summary

To get understanding of the science of remotes sensing, it is important to learn what happens to solar electromagnetic radiation (EMR) from the Sun, interactions with atmosphere and earth before it reaches satellite or airborne sensor. All of the solar EMR passes through space to reach the top of the Earth's atmosphere, but not all reaches the Earth's surface. The atmosphere scatters, absorbs and reflects a portion of the in-coming solar radiation. The Earth scatters, absorbs and reflects the solar radiation that gets transmitted through the atmosphere. Finally, the atmosphere scatters, absorbs and reflects the electromagnetic radiation that is reflected off the Earth's surface back toward the sensor. The interaction of EMR with the atmosphere is important to remote sensing for two main reasons. First, information carried by EMR reflected/emitted by the earth's surface is modified while traversing through the atmosphere. Second, the interaction of EMR with the atmosphere can be used to obtain useful information about the atmosphere itself. The atmosphere scatters, absorbs and reflects a portion of the in-coming solar radiation. The solar energy is subjected to modification when it passes through the atmosphere i.e. Scattering, Absorption and Refraction. After passing though these stages, the electromagnetic radiation reaches the Earth's surface. Thereafter three things happens i) some portion energy is reflected by the earth surface, ii) some portion of energy is transmitted into the surface iii) and some portion of it is absorbed and emitted by the earth's surface later on. The EMR, on interaction with earth's surface, experiences a number of changes in the magnitude, direction, wavelength, polarization and phase etc. The remote sensor detects these changes and that enable the interpreter to obtain useful information about the object or features of a particular interest.

Frequently Asked Questions-

Q1. What do you understand by atmospheric scattering?

Atmospheric scattering is the redirection of EMR by particles suspended in the atmosphere or by large molecules of atmospheric gases. Scattering not only reduces the image contrast but also changes the spectral signature of ground objects as seen by the sensor. The amount of scattering depends upon various factors like i) size of the particles, ii) their abundance, iii) the wavelength of radiation, depth of the atmosphere through which the energy is travelling and iv) the concentration of the particles.

Q2. What are the conditions for the Mie Scattering and where it mainly takes place?

Mie scattering takes place under the condition when the wavelength is approximately equal to the size of the scattering particles. For visible light, water vapor, dust, and other particles ranging from a few tenths of a micrometer to several micrometers in diameter are the main scattering agents. Mie scattering mostly occurs in the lower portions of the atmosphere i.e. lesser than 5 kms where larger particles are more abundant, and dominates when cloud conditions are overcast.

Q3. What happens when EMR interacts with the Earth's Surface features?

When the incoming short wave solar radiation reaches the Earth's surface, three things happens i) some portion energy is reflected by the earth surface, ii) some portion of energy is transmitted into the surface iii) and some portion of it is absorbed and emitted by the earth's surface later on. The EMR, on interaction with earth's surface, experiences a number of changes in the magnitude, direction, wavelength, polarization and phase etc.

Q4. How Spectral Signature Curve does is useful in remote sensing?

Spectral reflectance is the ratio of reflected energy to incident energy as a function of wavelength. Various earths' surface features have different spectral reflectance characteristics in different wavelength region. By understanding the reflective behavior, we can distinguish one feature with another distinctively on a remote sensing satellite data. Trees appear green because they reflect more of the green wavelength.

Q5. Discuss the usefulness of the atmospheric windows in remote sensing?

Atmospheric windows in remote sensing are various regions of electromagnetic spectrum (EMS) that allows Sun's energy to pass to reach the earth surface. In other words, the spectral bands for which the atmosphere transparent are known as atmospheric windows. There are certain regions of EMS, which does not allow passing the sun is light to pass rather that regions are opaque/blocked by e.g. water vapor (H_2O), carbon dioxide (CO_2), and ozone (O_3) cannot be used for remote sensing.

Multiple Choice Questions-

1. Approximate how much energy emitted by the Sun in visible light reaches the earth

(a) 60%
(b) 50%
(c) 40%
(d) 30%

2. Mie scattering occurs when the wavelength is

(a) Approximately equal to the size of the scattering particles
(b) Less than the size of the scattering particles
(c) Equals to the size of the scattering particles
(d) None of the above

3. What type of reflection happens when the surface from which the radiation is reflected is perfectly smooth

(a) Near perfect specular
(b) Perfect diffuse reflection
(c) Perfect specular
(d) All of the above

4. Which of the phenomenon is responsible for the appearance of sky "blue" during the daytime

(a) Mie scattering
(b) Non-selective
(c) Rayleigh scattering
(d) Atmospheric Scattering

5. What happens when rays of light pass between two media i.e. from lighter medium into denser medium

(a) Reflection
(b) Refraction
(c) Transmission
(d) Absorption

Suggested Readings:

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