MODULE – 1 LECTURE NOTES – 4

ENERGY INTERACTIONS WITH EARTH SURFACE FEATURES

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

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

2. Energy Interactions

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

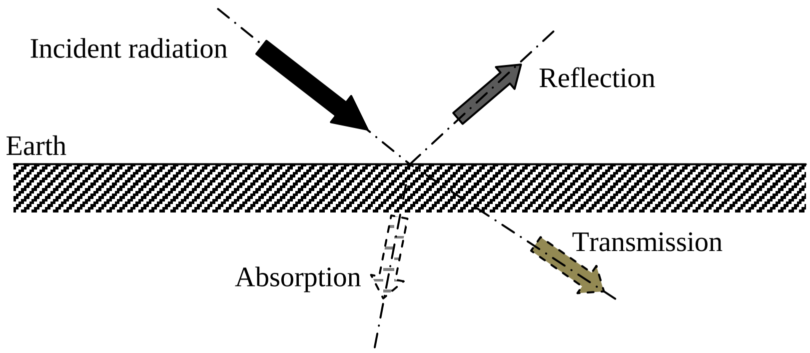


Fig. 1. Energy interactions with earth surface features

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

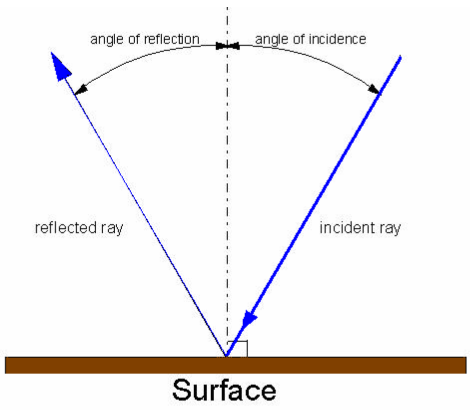


Fig. 2 Energy reflection

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

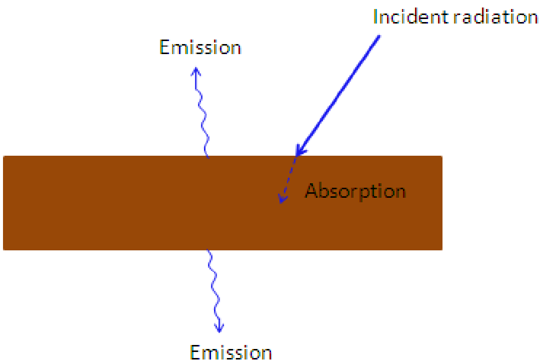


Fig. 3 Energy absorption and emission

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

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

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

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

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda) \quad (1)$$

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

$$E_R(\lambda) = E_I(\lambda) - E_A(\lambda) - E_T(\lambda) \quad (2)$$

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

3. Reflection

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

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

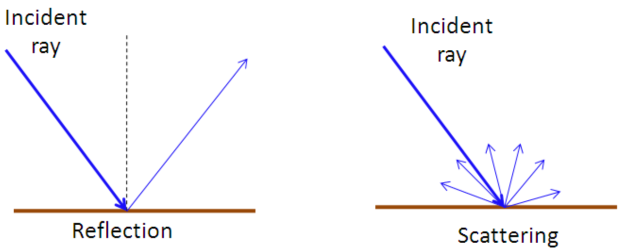


Fig.4 Reflection and scattering

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

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

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

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

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

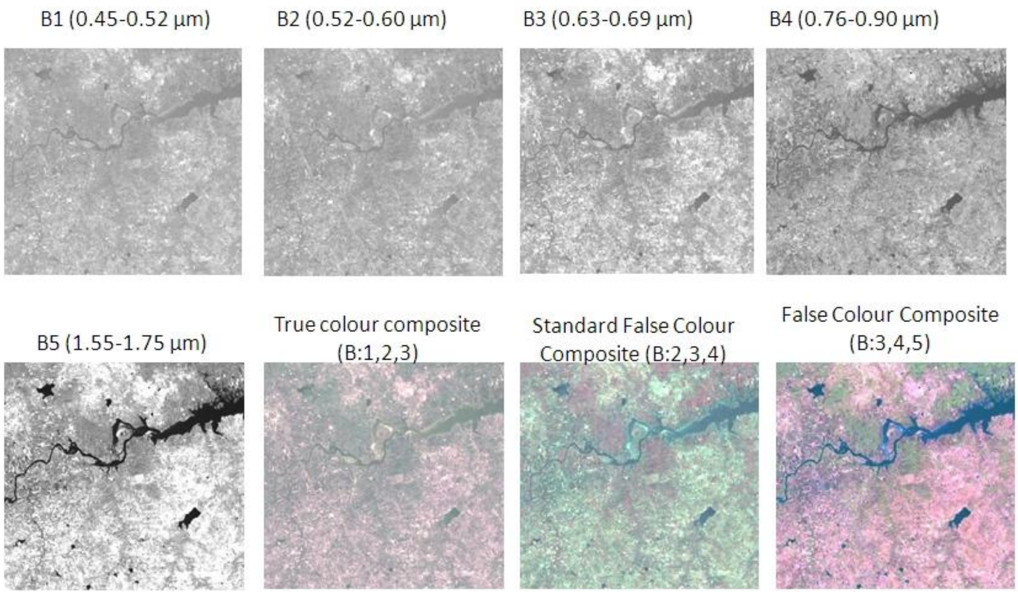


Fig. 5 A part of the Krishna River Basin as seen in different bands of the Landsat ETM$^+$ images

3. Diffuse and Specular Reflection

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

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

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

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

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

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

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

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

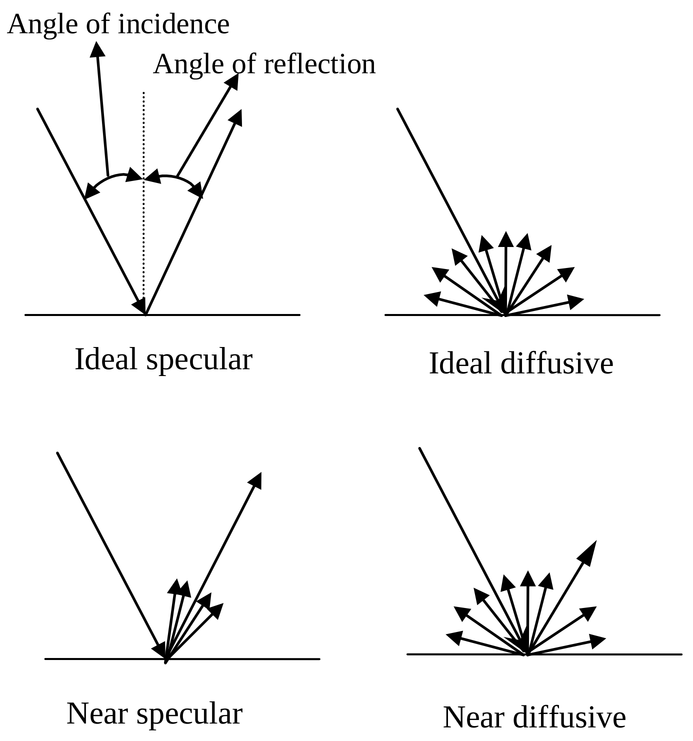


Fig. 6. Different types of reflectors

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

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

4. Spectral Reflectance Curves

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

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

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

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

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

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

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

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

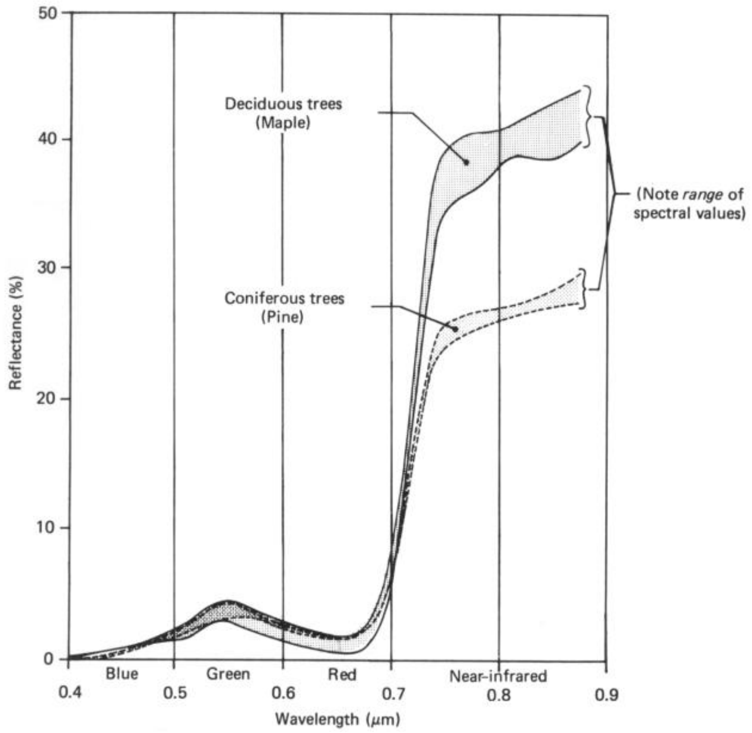
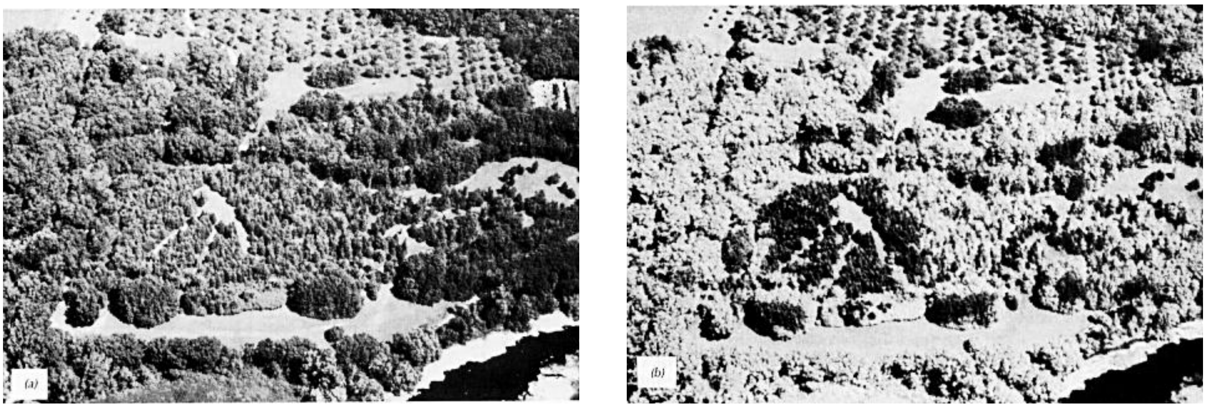


Fig. 7. Spectral reflectance curves for deciduous and coniferous trees (Lillesand et al., 2004)

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

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



(a) (b)

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

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

Bibliography

1. Lillesand, T. M, Kiefer, R. W., Chipman, J. W., [2004]. Remote Sensing and Image Interpretation, John Wiley & Sons, New York, pp. 321-332.