Modern Surveying Techniques

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Lecture - 7

Electromagnetic Spectrum

In my previous session, I had introduced to you the basic concept of remote sensing and the characteristics of electromagnetic radiation. In this session, I will focus on the interaction mechanism of EMR with atmosphere and the earth's surface and its role in remote sensing.

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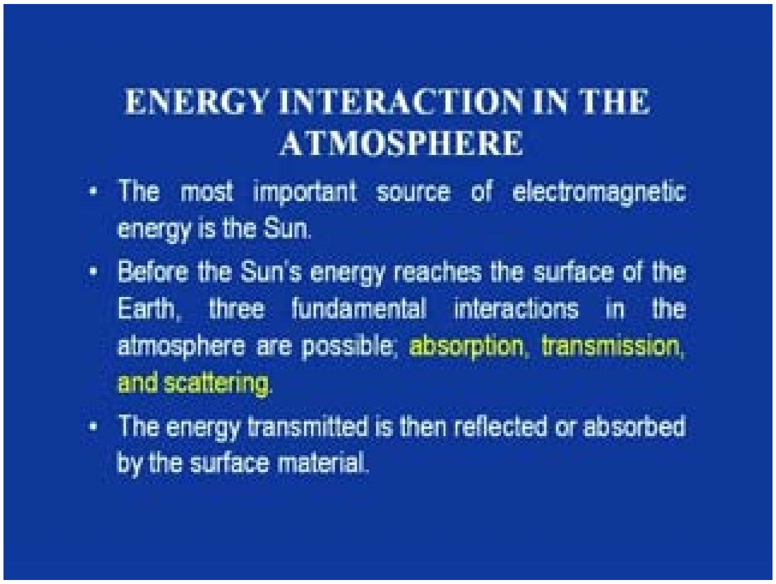

So, let us look at the energy interaction in the atmosphere. The most common source of electromagnetic energy is the sun. Before the sun's energy reaches the surface of the earth, 3 fundamental interactions in the atmosphere are possible. These are absorption, transmission and scattering. The energy transmitted through the atmosphere is then reflected or absorbed by the surface material.

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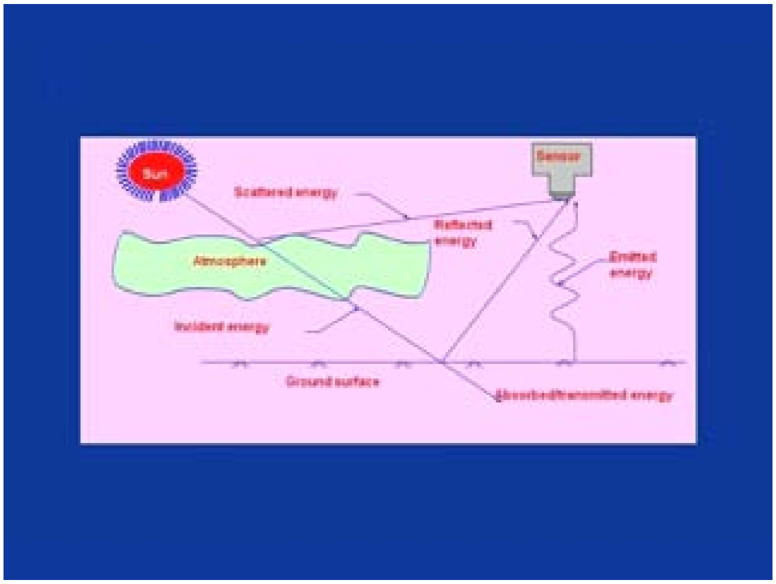

This slide shows a schematic representation of the electromagnetic radiation interacting with the atmosphere and thereafter on reaching to the earth surface, the interaction that takes place. Based on the interactions which take place, the energy reflected both from the atmosphere and from the earth surface is now recorded by the sensor.

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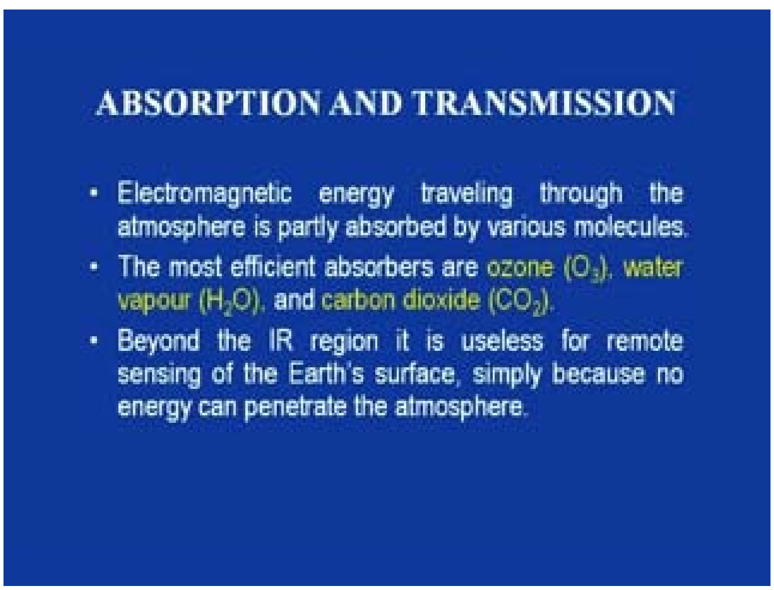

So, looking at the energy interactions at the atmosphere level, first let us look at what is absorption and transmission and its role. Electromagnetic energy traveling through the atmosphere is partly absorbed by various molecules. The most efficient absorbers are ozone, water vapours and carbon dioxide. Beyond the infrared region, it is useless for remote sensing of the earth surface simply because no energy can penetrate the atmosphere.

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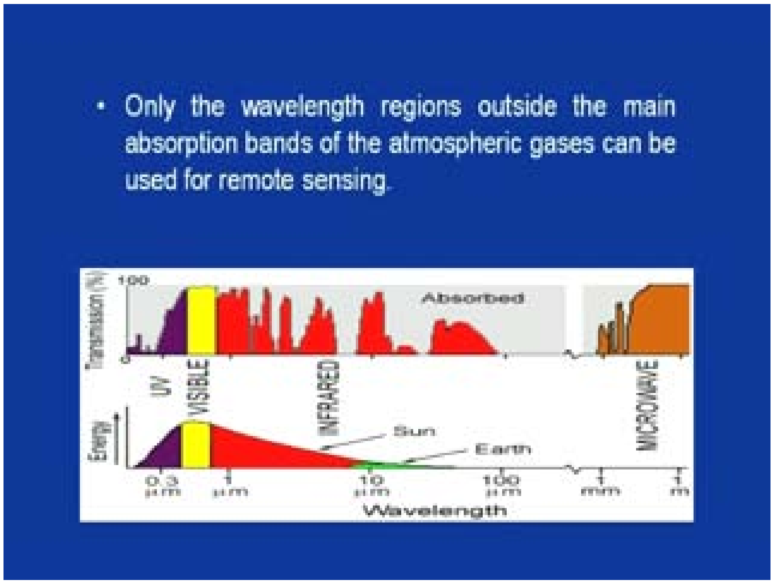

Only the wavelength regions outside the main absorption bands of the atmospheric gases can be used for remote sensing. In the graphic shown below, one can see the amount of energy which can be transmitted through the atmosphere level and one can see that the major part of the transmission of the energy is very close to the ultraviolet or visible region or there are certain sectors within the infrared region where there is the large amount of energy which gets transmitted through the earth's atmosphere while the rest gets absorbed.

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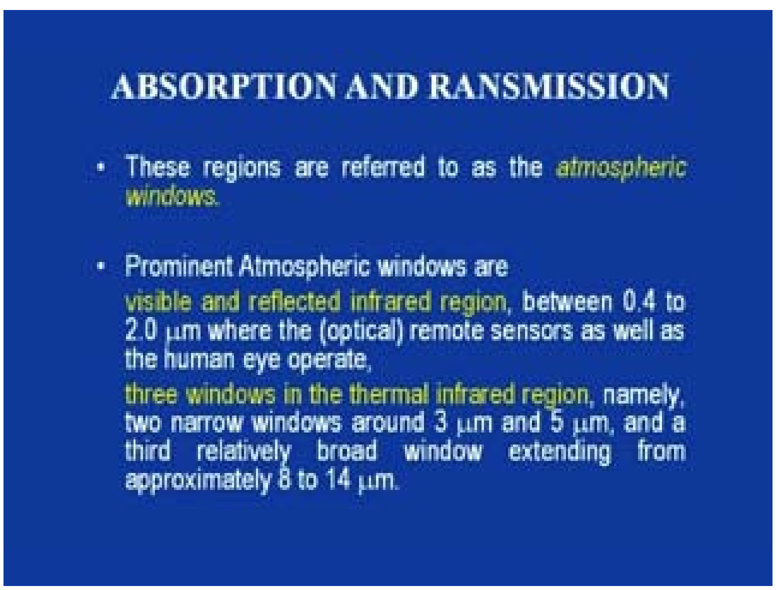

These regions where we have large amount of energy transmission through the earth's atmosphere are referred to as the atmospheric windows. Prominent atmospheric windows are in the visible and reflected infrared region between 0.4 to 2.0 mu meters where are the optical remote sensing as well as the human eye operate.

There are 3 windows in the thermal infrared region, namely 2 narrow windows around the 3 mu meters and 5 mu meters and a third relatively broad window extending from approximately 8 to 14 mu meters.

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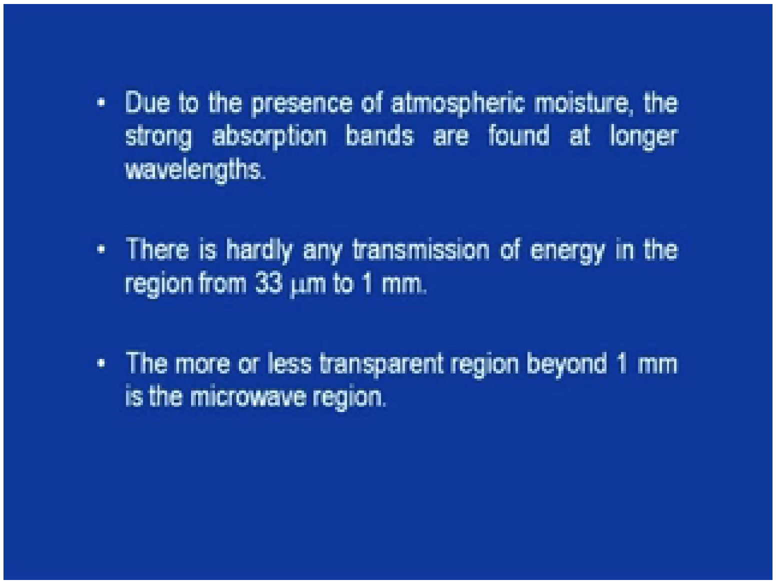

Due to the presence of atmospheric moisture, this strong absorption bands are found at longer wavelengths. There is hardly any transmission of energy in the region from 33 mu meters to about 1 millimeter. It is found that the more or less transparent region beyond 1 mm is the microwave region.

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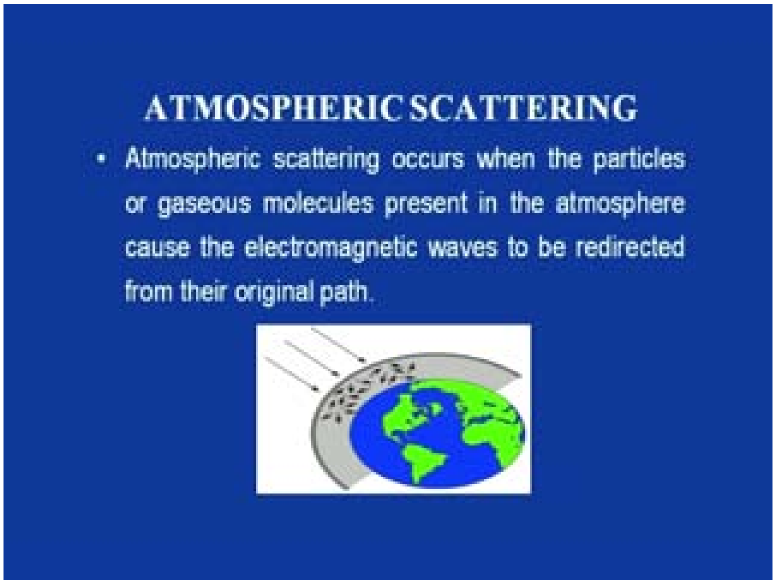

Now, let us to look at the third phenomenon when the electromagnetic energy interacts with the atmosphere and that is atmospheric scattering. Atmospheric scattering occurs when the particles or the gases, gaseous molecules present in the atmosphere cause the electromagnetic waves to be redirected from their original path.

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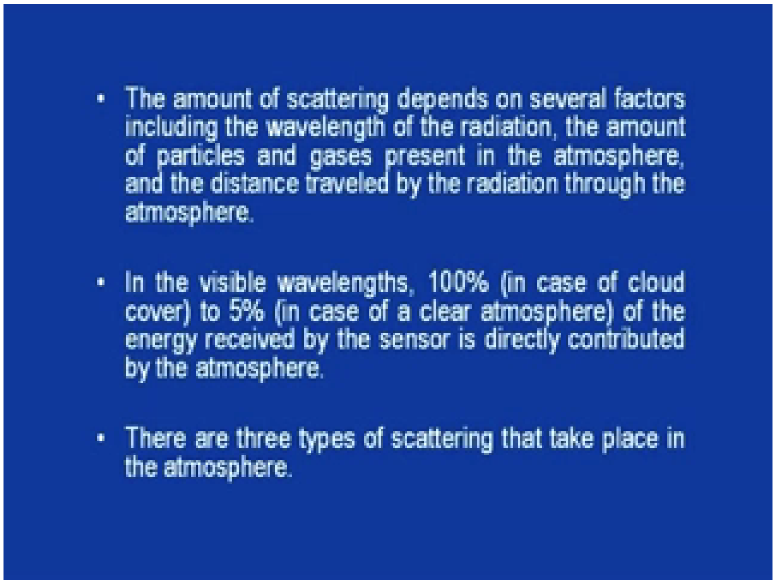

The amount of scattering depends upon several factors including the wavelength of the radiation, the amount of particles and gases present in the atmosphere and the distance traveled by the radiation through the atmosphere.

In the visible wavelengths 100 % in case of cloud cover to 5% in case of clear atmosphere of the energy received by the sensor is directly contributed by the atmosphere. There are 3 types of scattering that take place in the atmosphere.

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These are Rayleigh scattering, Mei scattering and non selective scattering. So, let us look at these 3 types scattering which are there.

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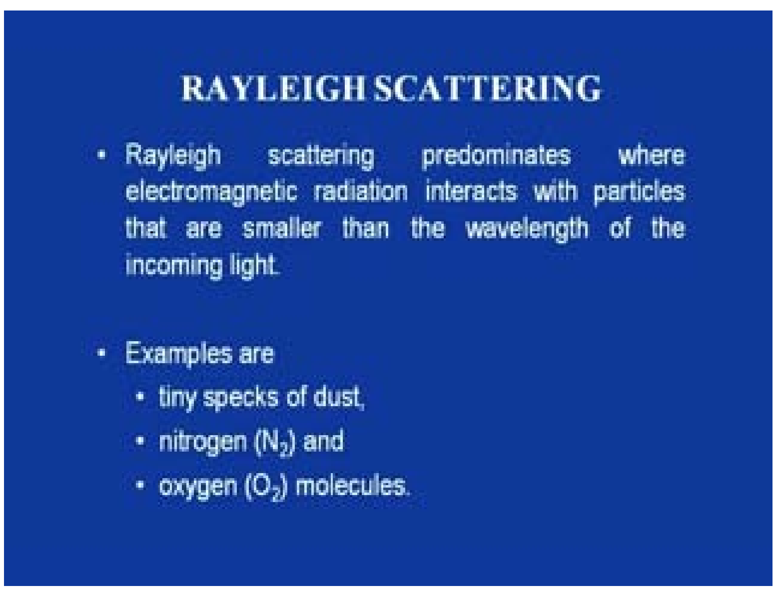

Rayleigh scattering predominates where the electromagnetic energy or radiation interacts with the particles that are smaller than the wavelength or the incoming light. For example; tiny specks of dust nitrogen gas and oxygen molecules.

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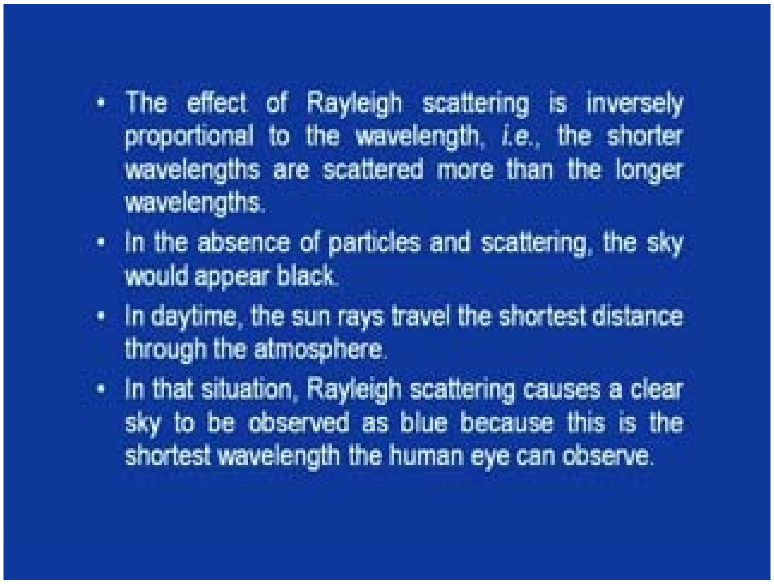

The effect of Rayleigh scattering is inversely proportional to the wavelength that is shorter wavelengths are scattered more than the longer wavelengths. In the absence of particles and scattering, the sky would appear to be black. In the daytime, the sun rays travel the shortest distance through the atmosphere. In that situation, Rayleigh scattering causes a clear sky to be observed as blue because this is the shortest wavelength that the human eye can observe.

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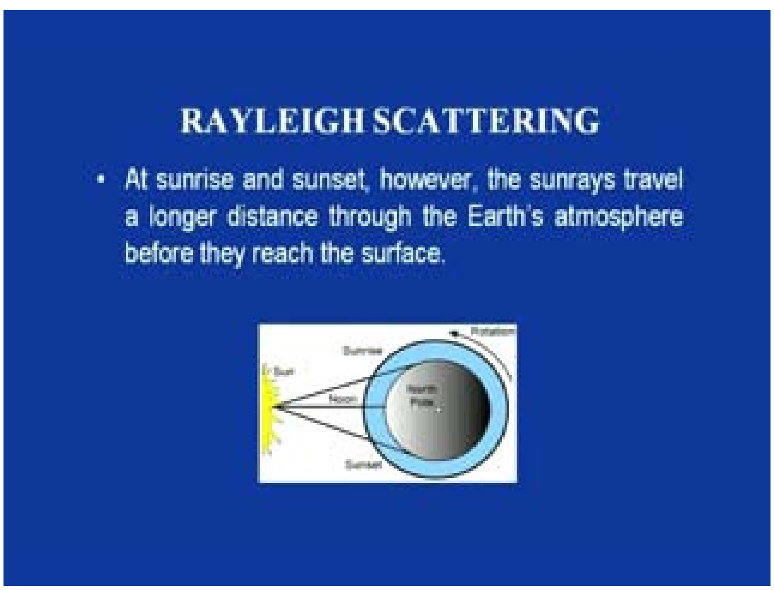

At sunrise and sunset, however the sunrays travel a longer distance through the earth's atmosphere before they reach the earth surface.

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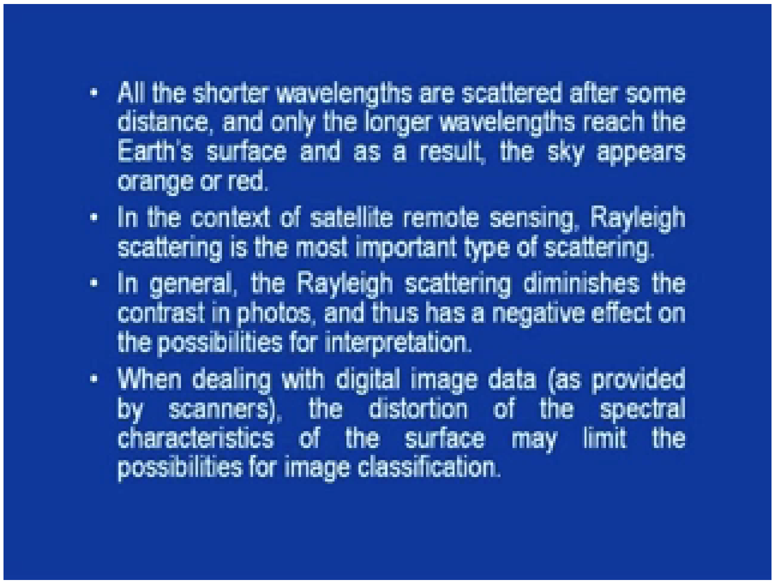

All the shorter wavelengths are scattered after some distance and only the longer wavelengths reach the earth's surface and as a result of this the sky appears orange or red. In the context of satellite remote sensing, Rayleigh scattering is the most important type of scattering. In general, the Rayleigh scattering diminishes the contrast in photos and thus, has a negative effect on the possibilities for interpretation.

When dealing with digital image data as provided by scanners, the distortion of the spectral characteristics of the earth surface may limit the possibilities for image classification.

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Now, we look at the effect of Mie scattering. Mie scattering occurs when the wavelength of the incoming radiation is similar in size to that of the atmospheric particles. Mie scattering is caused by aerosols which are mixture of gases, water vapour and dust.

It is generally restricted to the lower atmosphere where larger particles are more abundant and dominates under overcast cloud conditions. Mie scattering influences the entire spectral region from the near ultraviolet including the near infrared.

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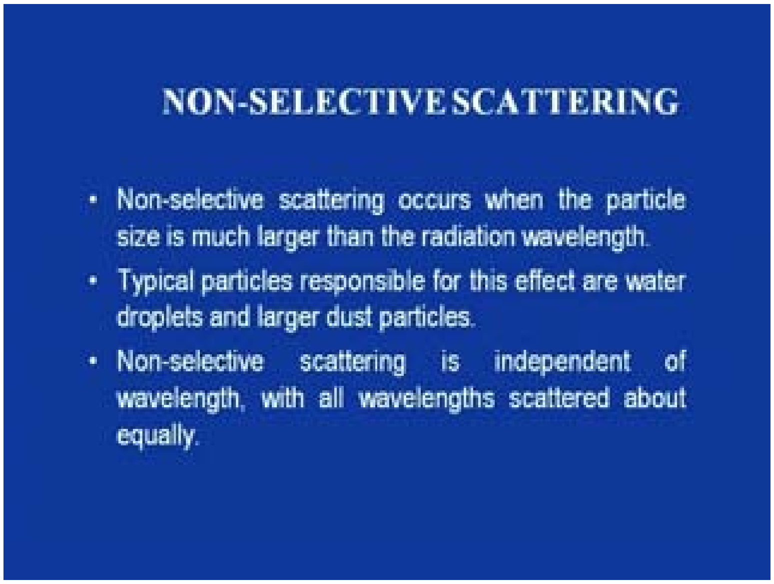

The third type of scattering which may take place is the non selective. Non selective scattering occurs when the particle size is much larger than the radiation wavelength. The typical particles responsible for this effect are water droplets and larger dust particles. Non selective scattering is independent of the wavelength with all wavelengths scattered about equally.

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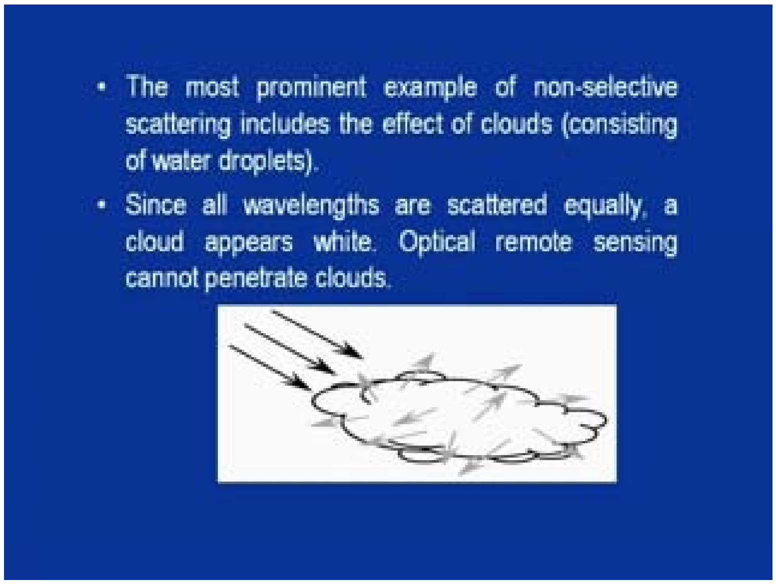

The most prominent example of non selective scattering includes the effect of clouds consisting of water droplets. Since all wavelengths are scattered equally, a cloud appears to be white. Optical remote sensing cannot penetrate clouds.

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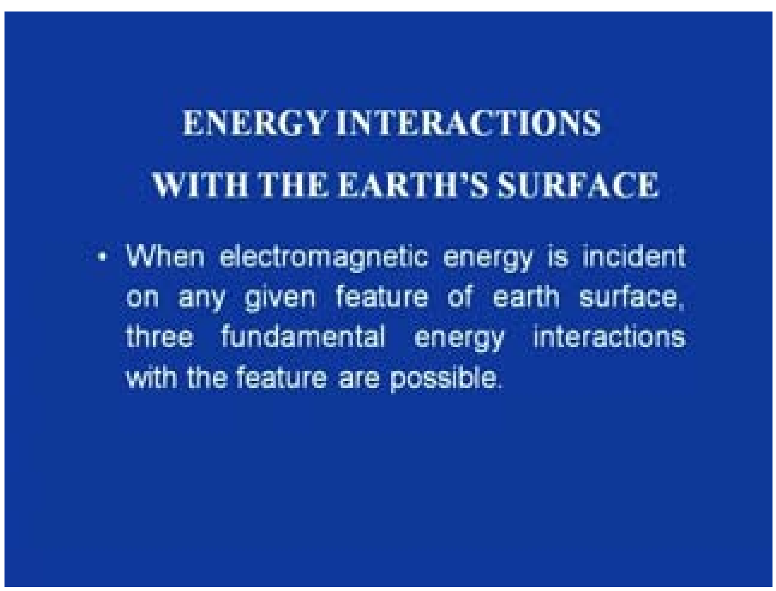

Once the interaction at the atmosphere level takes place; now, based on the transmission characteristic which is dependent on the wavelength, the energy now reaches the earth surfaces.

So, let us look at what happens when the electromagnetic energy reaches the earth. When the electromagnetic energy is incident on any given feature of the earth surface, 3 fundamental energy interactions with the feature are possible.

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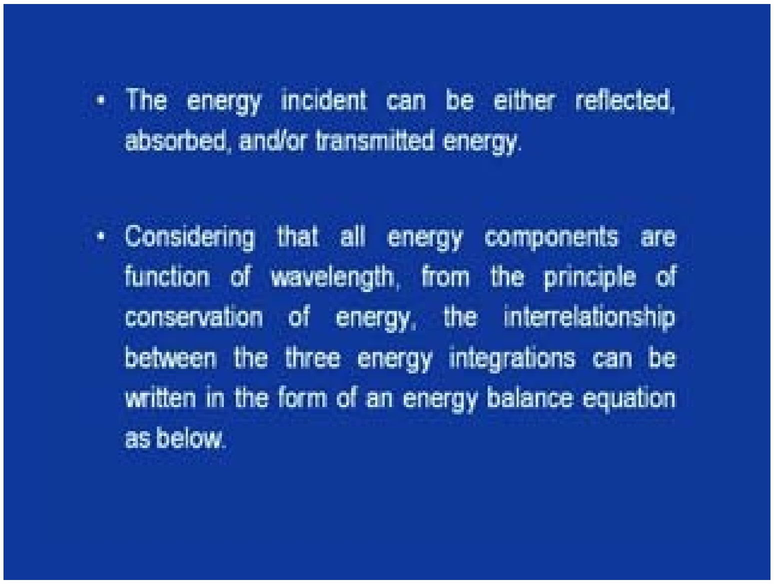

The incident energy can be either reflected, absorbed and or transmitted energy. Considering that all the energy components are function for wavelength; from the principle of conservation of energy, the interrelationship between the three in energy integrations can be written in the form of an energy balanced equation as given below.

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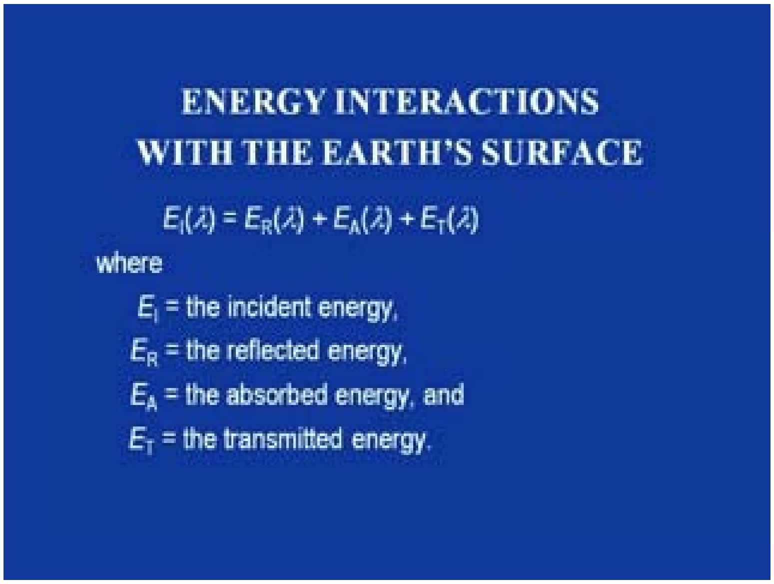

That is E_I lambda is equal to E_R lambda plus E_A lambda plus E_T lambda where E_I lambda is the incident energy, E_R lambda is the reflected energy, E_A lambda is the absorbed energy and E_T lambda is the transmitted energy.

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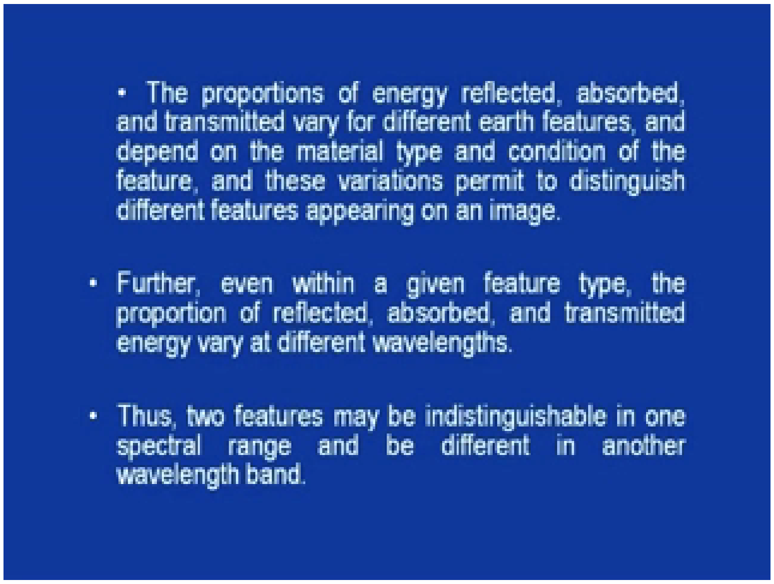

The proportions of the energy reflected, absorbed and transmitted vary for different earth surface features and depend on the material type and the condition of the feature and these variations permit to distinguish different features appearing on an image. Further, even within a given feature type, the proportion of reflected, absorbed and transmitted energy can vary at different wavelengths.

Thus, two features may be indistinguishable in one spectral range and be different in another wavelength band.

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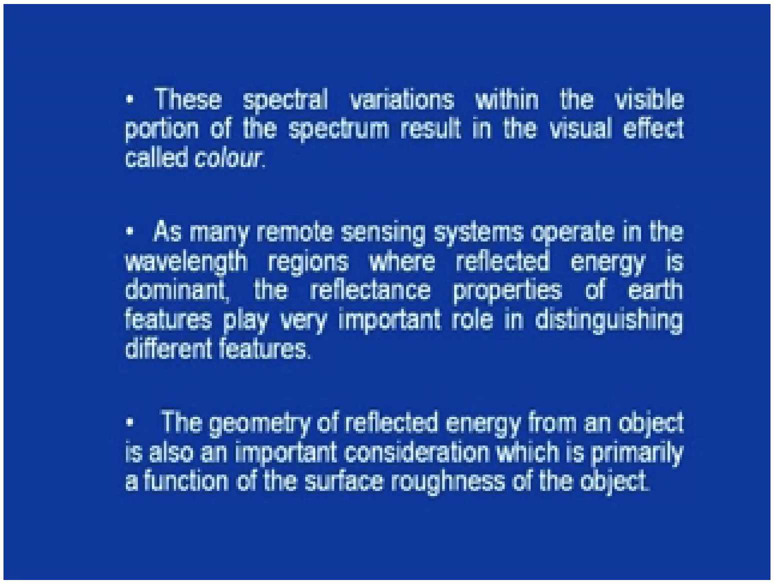

These spectral variations within the visible portions of the spectrum result in the visual effect called colour. As many remote sensing systems operate in the wavelength regions where reflected energy is dominant, the reflectance properties of earth features play very important role in distinguishing different features. The geometry of reflected energy from an object is also an important consideration which is primarily a function of the surface roughness of the object.

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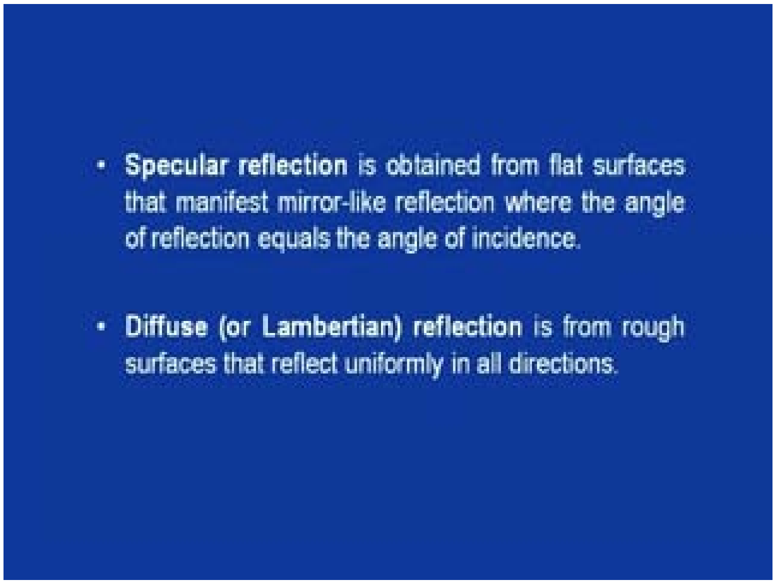

Based on this, we can have two types of reflection; one is specular reflection which is obtained from flat surfaces like mirror - like reflections, where the angle of reflection is equal to the angle of incidence. The second type of reflection could be diffuse or Lambertian reflection and is from rough surfaces that reflect uniformly in all directions.

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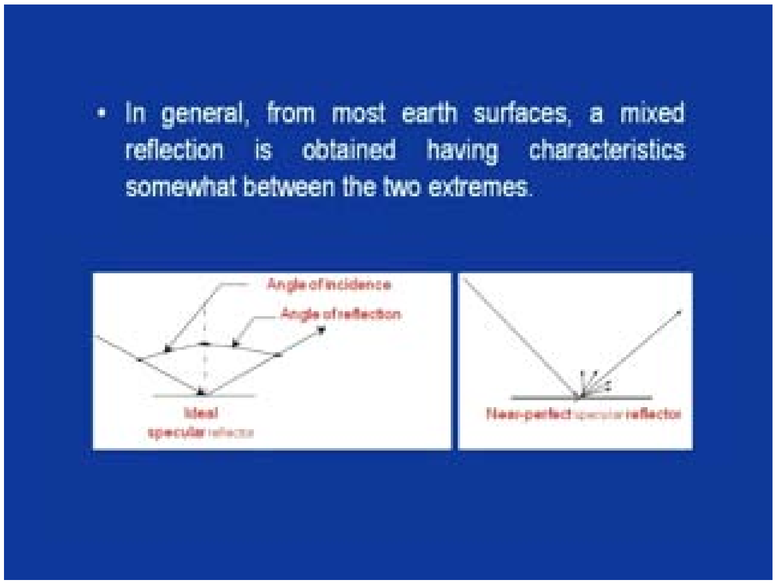

In general, most earth features or surfaces have a mixed reflection is obtained having characteristics somewhat between the two extremes.

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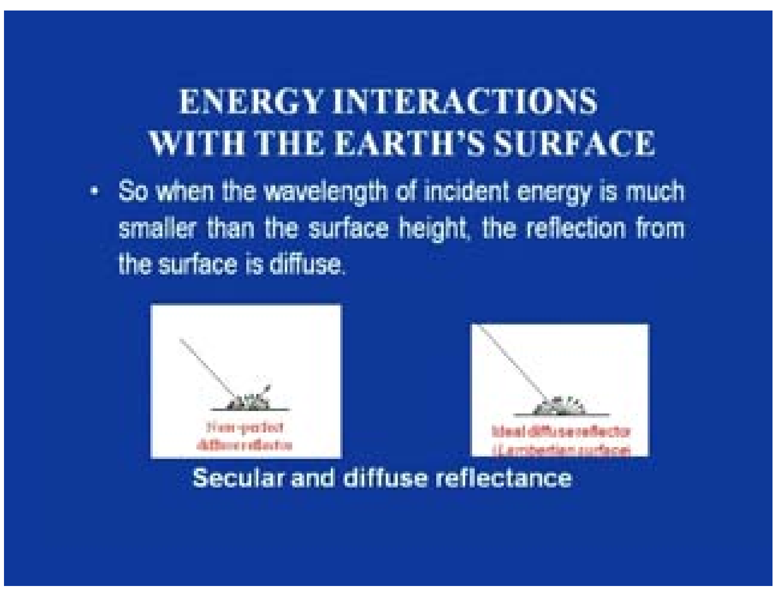

So, when the wavelength of incident energy is much smaller than the surface height, the reflection form the surface is diffused.

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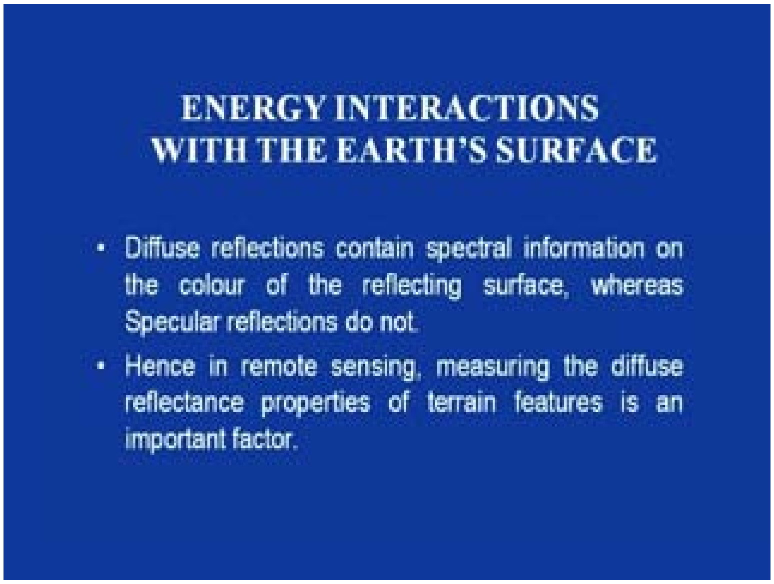

Diffuse reflections contain spectral information on the colour of the reflecting surface, whereas, specular reflections do not. Hence, in remote sensing, measuring the diffuse reflectance properties of terrain features is an important factor.

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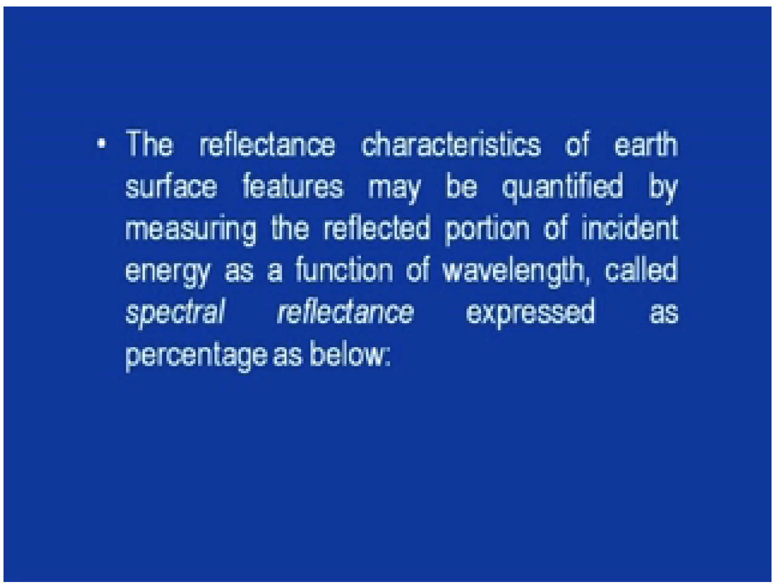

The reflectance characteristic of earth surface features may be quantified by measuring the reflected portion of the incident energy as a function of wavelength called spectral reflectance expressed as a percentage as given below.

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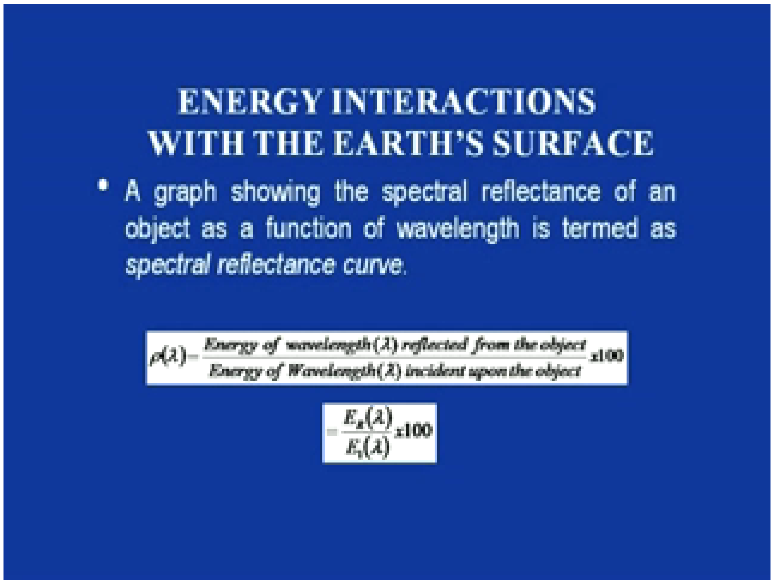

That is rho lambda is a ratio of the energy of the wavelength lambda reflected from the object to the energy of the wavelength lambda incident upon the object and taking the percentage of the sale. So, it can be simplified that ER lambda divided by E_I lambda multiplied by 100 is a function of the spectral reflectance.

A graph showing the spectral reflectance of an object as a function of wavelength is termed as spectral reflectance curve. So, now let us look at the spectral reflectance curve and what role it has to play in remote sensing.

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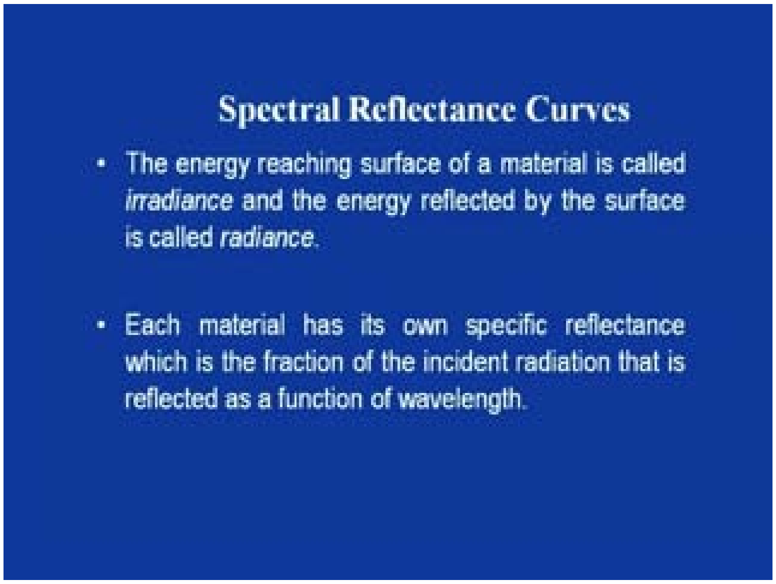

The energy reaching the surface of a material is called radiance and the energy reflected by the surface is called reflectance. Each material has its own specific reflectance which is the fraction of the incident radiation that it reflected as a function of wavelength.

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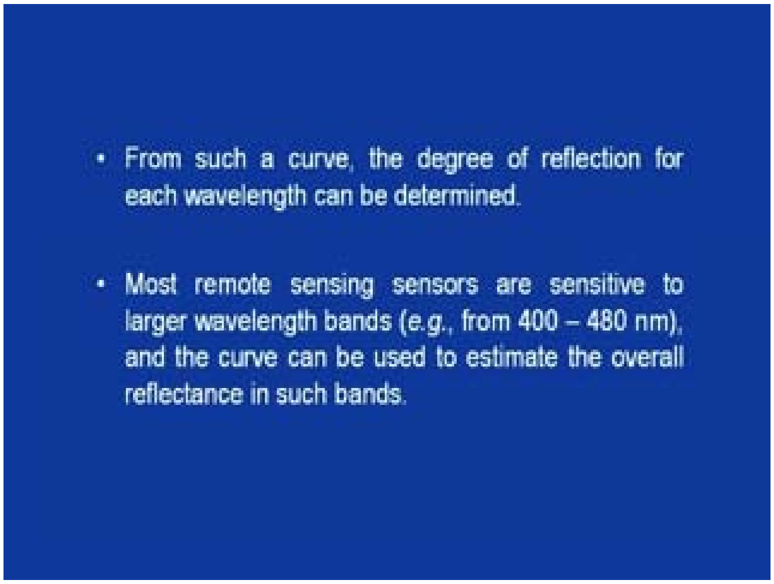

From such a curve, the degree of reflection for each wavelength can be determined. Most remote sensing sensors are sensitive to larger wavelengths bands. That is from 400 to 480 nanometers and the curve can be used to estimate the overall reflectance in such bands.

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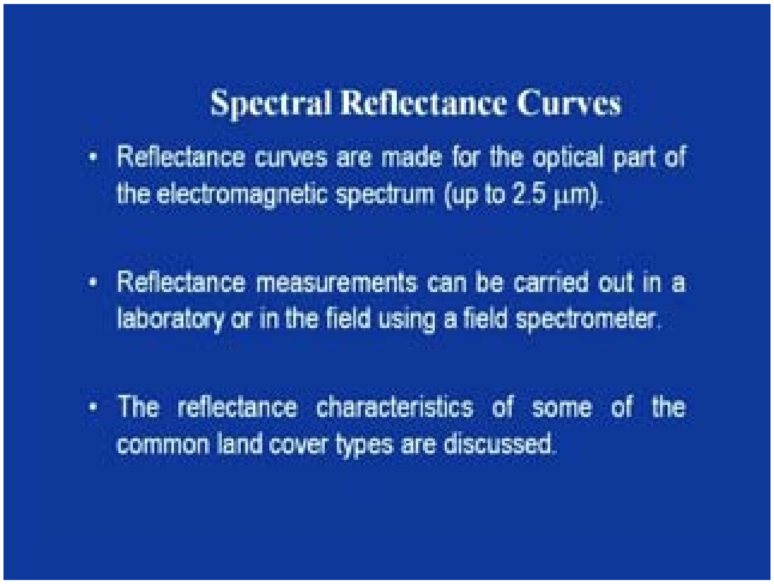

The reflectance curves are made for the optical part of the electromagnetic spectrum up to 2.5 mu meters. The reflectance measurements can be carried out in a laboratory or in the field using a field spectrometer. The reflectance characteristics of some of the common land cover types are discussed. First of all, there are 3 broad categories of land cover that are there. That is vegetation, soil and water.

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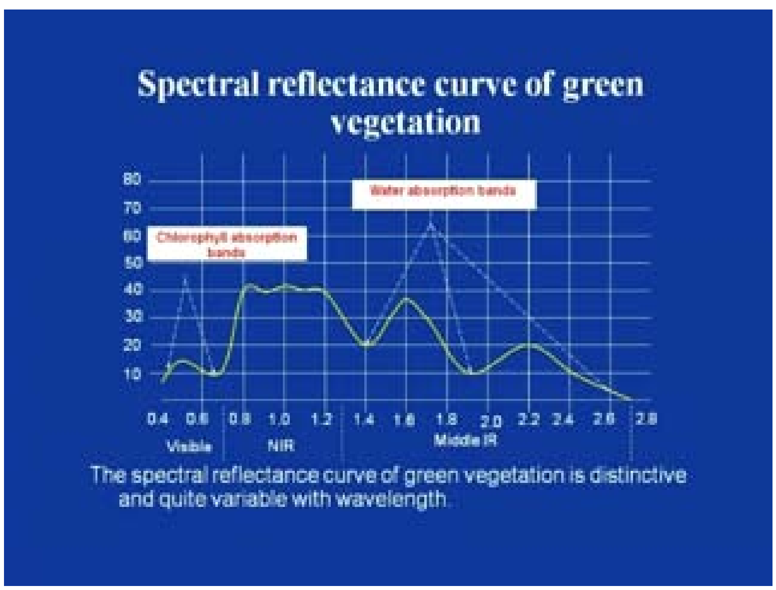

So, we look at first, the spectral reflectance curve of green vegetation. In this particular slide, we can observe that the spectral reflectance curve of green vegetation is not a uniform one. It varies from different regions of the electromagnetic spectrum. Within the visible region, the reflectance is of a very low order ranging between 10 to 15. But as move into the near infrared, the reflectance properties change drastically and this rises to of the order of about 40 to 42%.

Beyond the near infrared region, the reflectance again dips. And, what we find that in the middle infrared, there are three such troughs which come up and these are primarily due to the water absorption bands. So, in the nutshell, one can understand that the spectral response curve of green vegetation is a complex one and thus it would be proved it if we look at each of these regions one by one and understand the behavior of green vegetation as it interacts with electromagnetic radiations.

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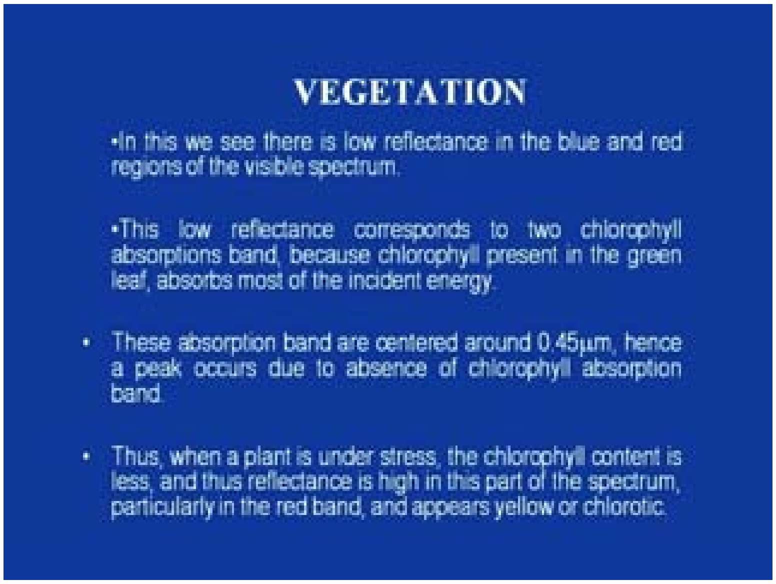

Here, we see that there is low reflectance in the blue and red regions of the visible spectrum.
This low reflectance corresponds to two chlorophyll absorption bands because chlorophyll present in the green leaf absorbs most of the incident energy. These absorption bands are centered around 0.45 mu meters. Hence, a peak occurs due to the absence of chlorophyll absorption band.

Thus, when a plant is under stress, the chlorophyll content is less and thus the reflectance is high in this part of the spectrum, specifically in the red band and appears yellow or chlorotic.

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Apart from this, there are other pigments also. That is carotheses and xanthophylls that is red yellow pigment and anthocyanins which is the red pigment. Carotheses and xanthophylls are frequently present in leaves but have absorption band in the blue region that is 0.45 mu meter where chlorophyll is dominant and hence, the carotheses and xanthophylls that is the yellow pigment is masked out. In the absence of the chlorophyll, these pigments assume prominence.

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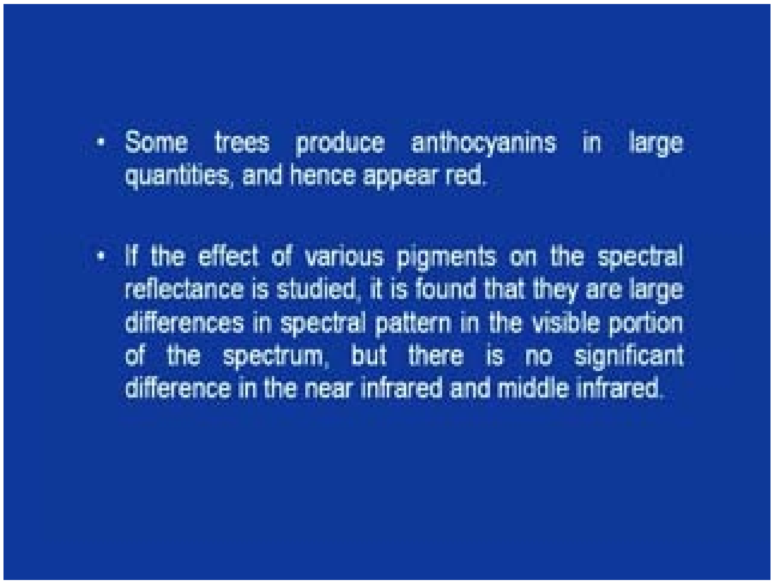

Some trees produce anthocyanins in large quantities and hence appear red. If the effect of various pigments on the spectral reflectance curve is studied, it is found that there are large differences in the spectral pattern in the visible portion of the spectrum. But there is no significant difference in the near infrared and middle infrared region.

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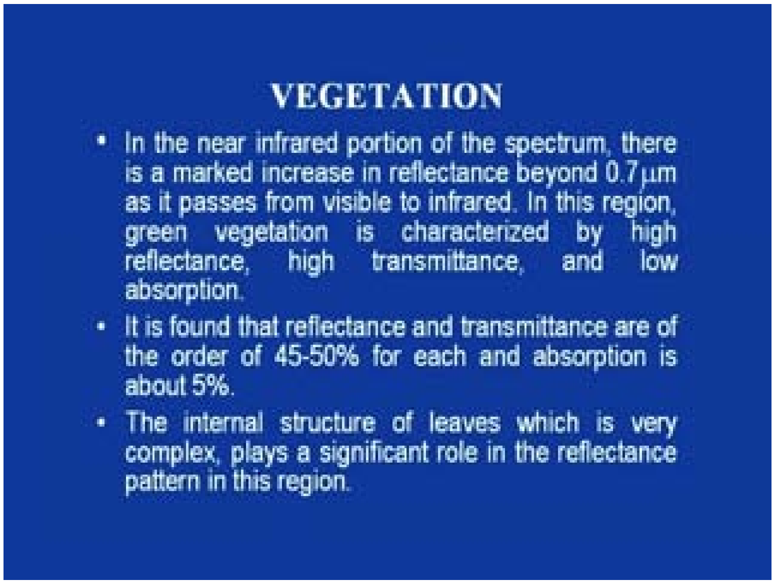

In the near infrared portion of the spectrum, there is a marked increase in reflectance beyond 0.7 mu meters as it passes from visible to infrared region. In this region, the green vegetation is characterized by high reflectance, high transmittance and low absorption.

It has been found that reflectance and transmittance are of the order of 45 to 50% for each absorption and absorption is about 5%. The internal structure of leaves which is very complex plays a significant role in the reflectance patterns in this region.

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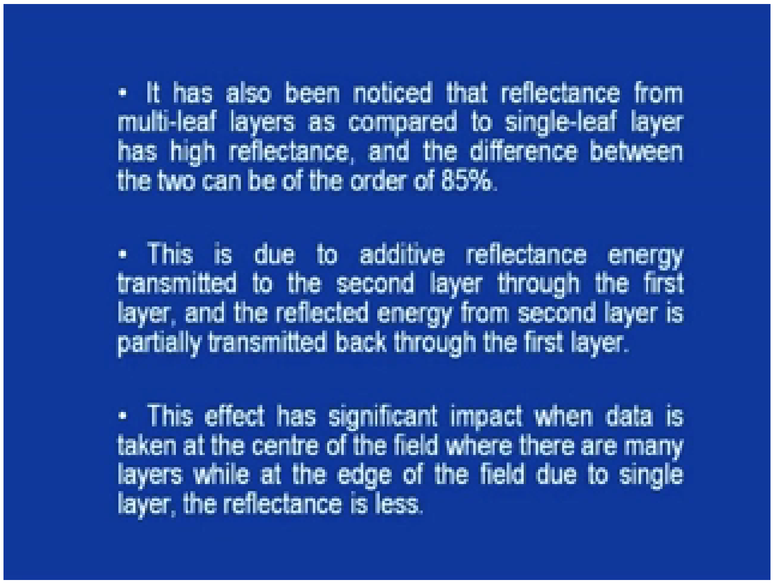

It has been noticed that reflectance from multi-leaf layers as compared to single-leaf layers has high reflectance and the difference the two can be of the order of about 85%. This is due to additive reflective energy transmitted to the second layer through the first layer and the reflected energy from the second layer is partially transmitted back to the first layer. This effect has significant impact when data is taken at the center of the field where there are many layers while at the edge of the field due to single layer the reflectance is less.

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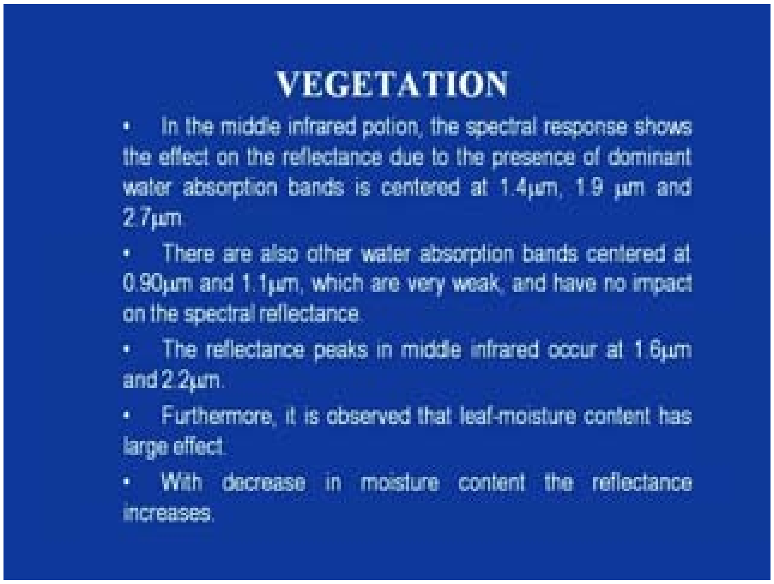

Now, coming to the middle infrared portion; the spectral response shows the effect on the reflectance due to the presence of dominant water absorption bands centered at 1.4 mu meters 1.9 mu meters and 2.7 mu meters.

There are also other water absorption bands centered at 0.9 mu meters and 1.1 mu meters which are very weak and hence have no impact on the spectral reflectance. The reflectance peaks in the middle infrared occurs at about 1.6 mu meters and 2.2 mu meters. Further, it is observed that the leaf moisture content has a large effect. With decrease in moisture content the reflectance increases.

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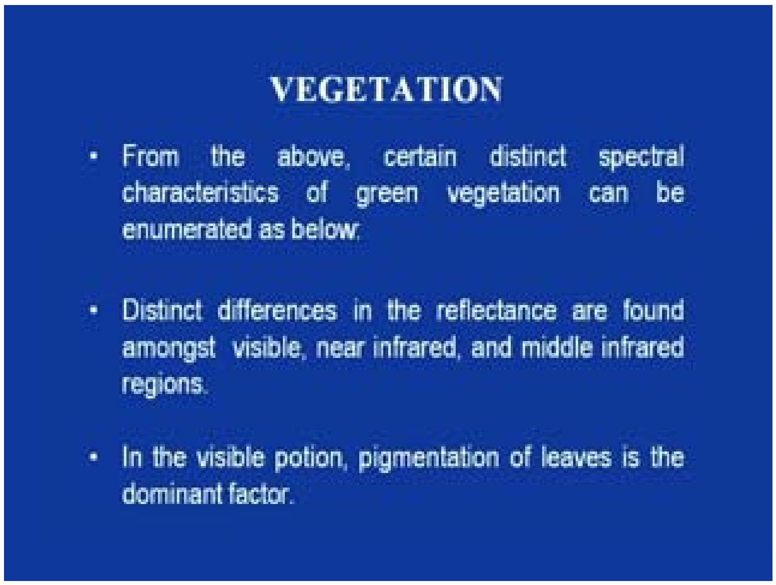

So, from the above certain distinct spectral characteristics of green vegetation can be enumerated as below. Distinct differences in the reflectance are found amongst visible and infrared and middle infrared region. In the visible portion, pigmentation of the leaf is the dominant factor.

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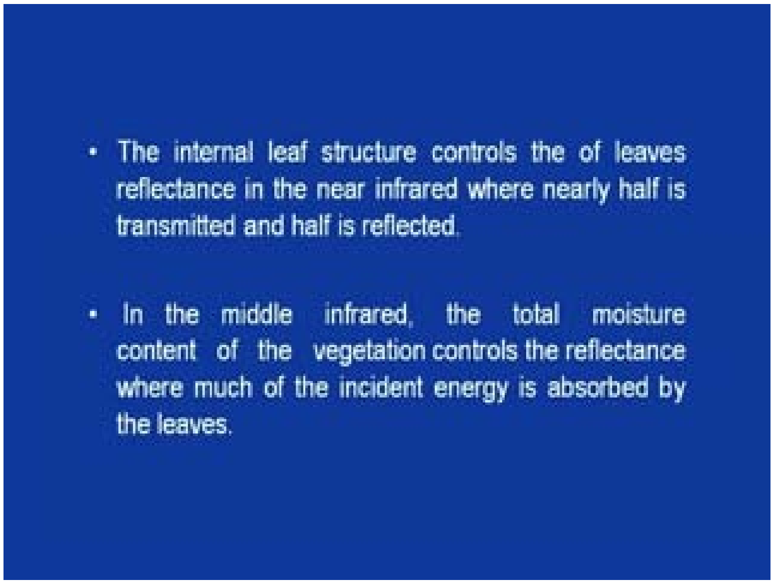

The internal leaf structure controls the leaf reflectance in the near infrared region where nearly half of it is transmitted while the other half is reflected. In the middle infrared region, the total moisture content of the vegetation controls the reflection where much of the incident energy is absorbed by the leaves.

Now, we come to the next broad category of earth feature which is bare soil. Spectral reflectance curves of most structure controls the leaf reflectance in the near infrared region where nearly half of it is transmitted while the other half is reflected. In the middle infrared region, the total moisture content of the vegetation controls the reflection where much of the incident energy is absorbed by the leaves. Now, we come to the next broad category of earth feature which is bare soil.

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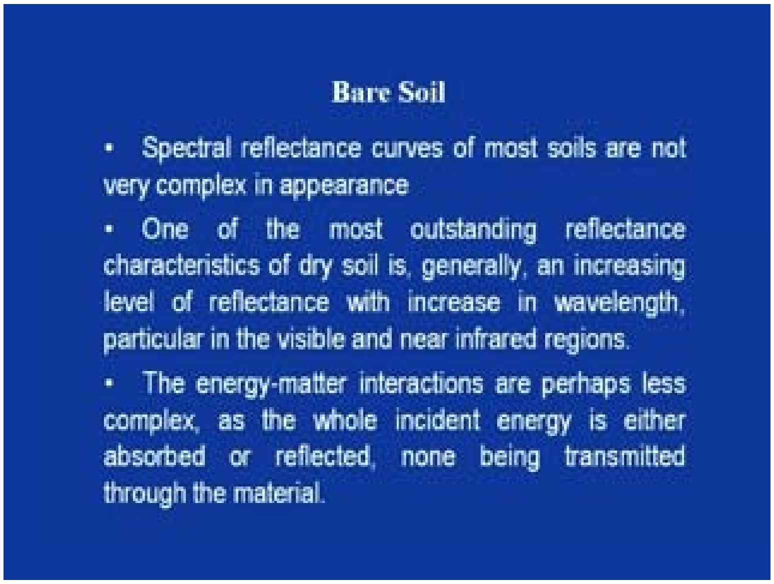

Spectral reflectance curves of most soils are not very complex in appearance. One of the most outstanding reflectance characteristic of dry soil is generally an increasing level of reflectance with increase in wavelength, particularly in the visible and near infrared region. The energy matter interactions are perhaps less complex as the whole incident energy is either absorbed or reflected, none being transmitted through out the material.

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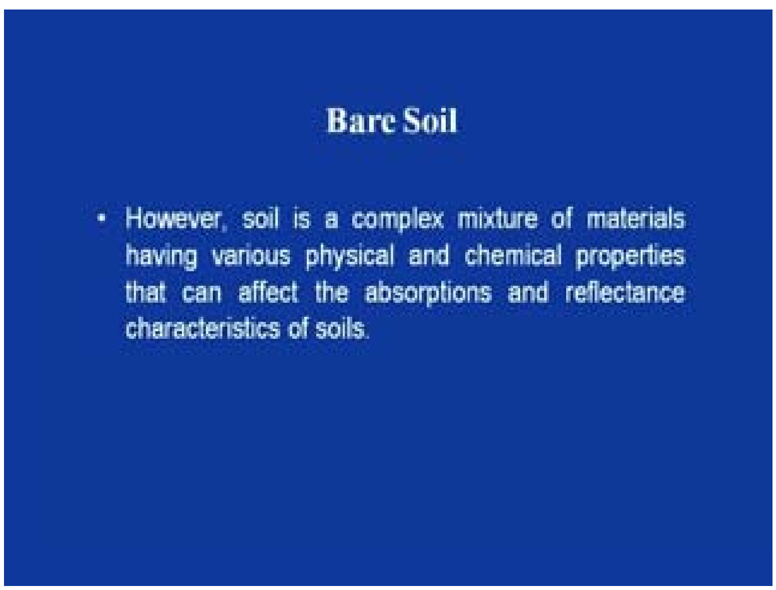

However, soil is a complex mixture of materials having various physical and chemical properties that can affect the absorption and physical characteristics of the soils.

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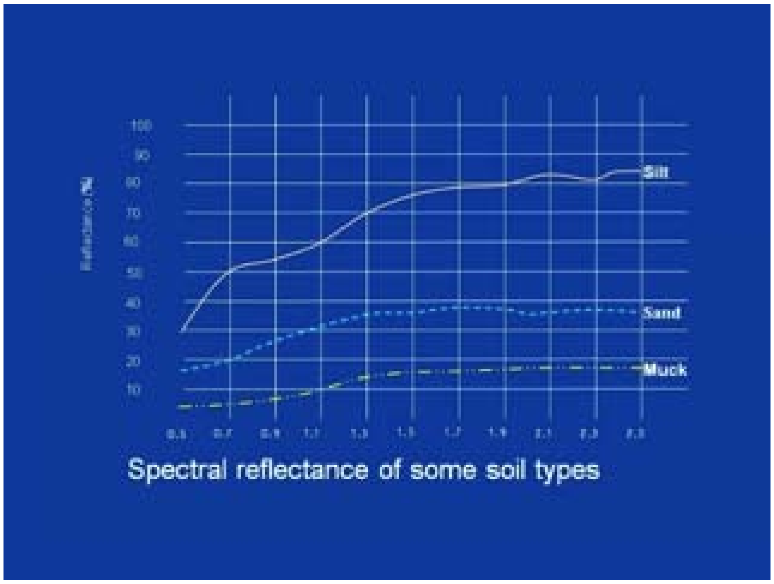

This particular slide shows the spectral reflectance curve of some of the soil types which are there. We can see that the general nature of the soil curves, spectral curves of the soils are rising from the visible region into the near infrared region and thereafter there is a flattening in the spectral response curves. For different types of soil materials the reflectance may vary between different regions of the electromagnetic radiations.

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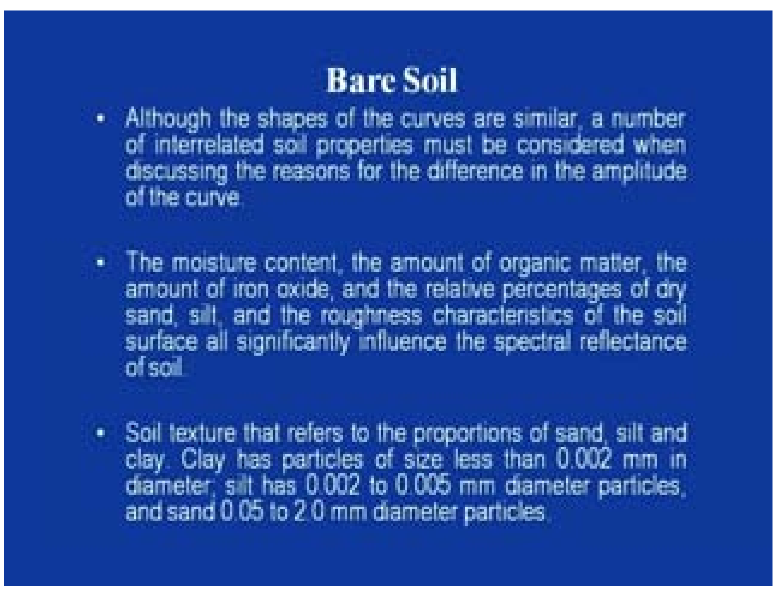

Although the shapes of the curves are similar, a number of interrelated soil parameters must be considered when discussing the reasons for the differences in the amplitude of the curve. The moisture content, the amount of organic matter, the amount of iron oxide and the relative percentages of sand, silt and the reference characteristics of the soil surface, all significantly influence the spectral reflectance of the soil.

Soil texture that refers to the proportion of sand, silt and clay: clay has particles of size less than 0.002 millimeter in diameter, silt has 0.002 to 0.005 millimeter diameter particles and sand has 0.05 to 2.0 millimeter diameter particles.

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Due to the particle size, the number of particles is present in clay compared to sand. When the moisture is present, each particle will be covered by a very thin layer of water which will occupy some space between the soil particles. Even though the film is very thin, millions of such particles will hold a large amount of water. Thus, it is evident that the relationship between soil particles and moisture content has a significant impact on the soils.

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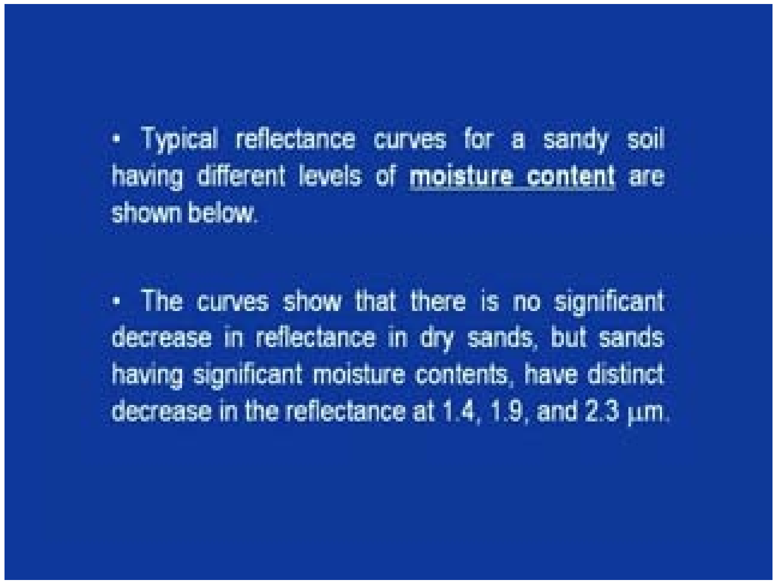

Typical reflectance curves for a sandy soil have different for different levels of moisture content are shown below.

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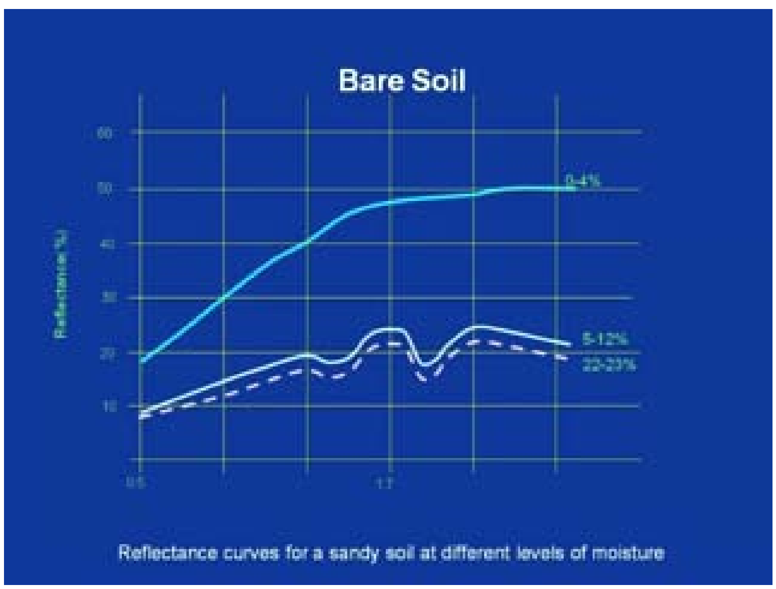

This particular slide, it shows the reflectance curve for a sandy soil at different levels of moisture. For a dry sand having moisture between 0 to 4%, the reflectance is significantly higher in comparison to moisture contents ranging between 5 to 12 or 22 to 23 degree %.

We can see that when we look at the impact of moisture, there are distinct decrease in the reflectance at about 1.4, 1.9, and 2.3 mu meters and this can be seen in this in the slide again that there are certain dips which come into play.

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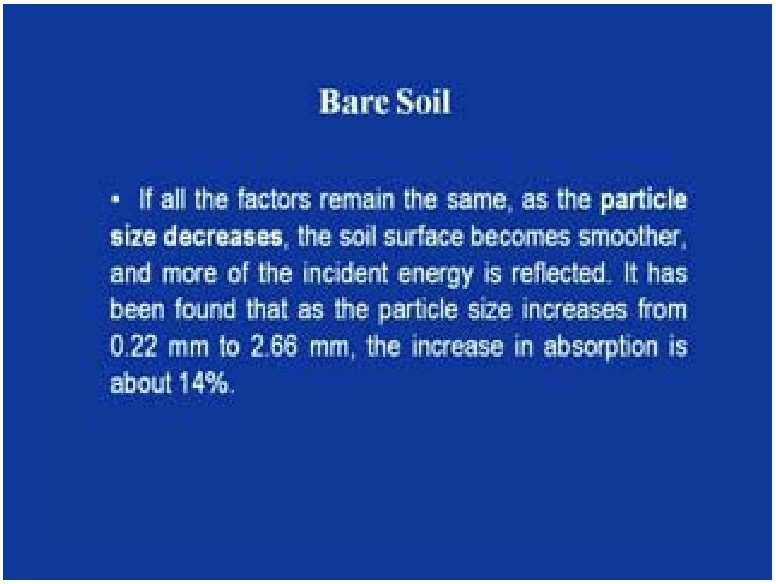

If all the factors remain the same; as the particle size decreases, the soil surfaces become smoother and more of the incident energy is reflected. If it has it has been found that as the particle size increases from 0.22 millimeter to 2.66 millimeter, the increase in absorption is of about one about 14%.

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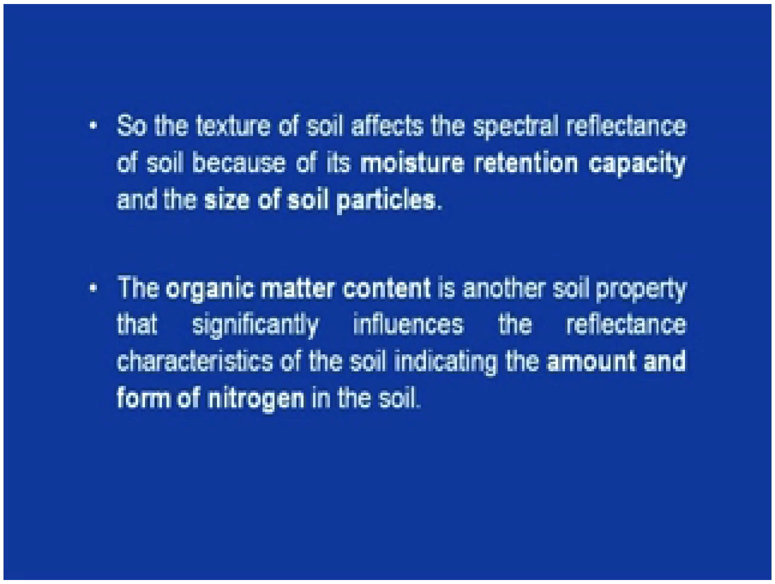

So, the texture of soil affects the spectral reflectance of soil because of its moisture retention capacity and the size of the soil particles. The organic matter of soil is another soil property that significantly influences the reflectance characteristics of the soil indicating the amount and the form of nitrogen in the soil.

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Although it is found that in most temperate zones the organic content varies from 0.5% to 5%, a soil with about 5% organic matter usually appears dark brown or black in colour, whereas, soils with lower organic content are usually light brown in colour or light shades of grey. The relationship between organic matter and the reflectance within the visible range of the spectrum is curvilinear.

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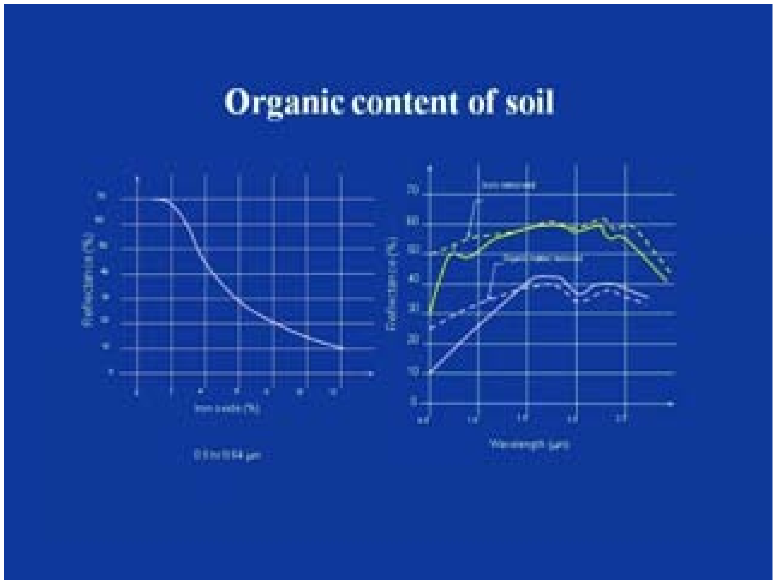

This particular slide; the left hand graph shows the impact of iron oxide on the reflectance and what we find is as the iron oxide increases, the reflectance decreases drastically and it is virtually 10% of the incident energy. On the right hand side, it shows the overall impact of this spectral reflectance when both iron and organic matter is present and when these are individually removed, how does the reflectance properties of soil change?

By and large, it is found that when iron and organic matter are removed within the visible and near infrared region, there is an increase in the reflectance characteristics. However, in case of iron oxide, it is observed that there is a rise in the reflectance beyond near infrared region. But in case of iron organic matter, the reflectance decreases.

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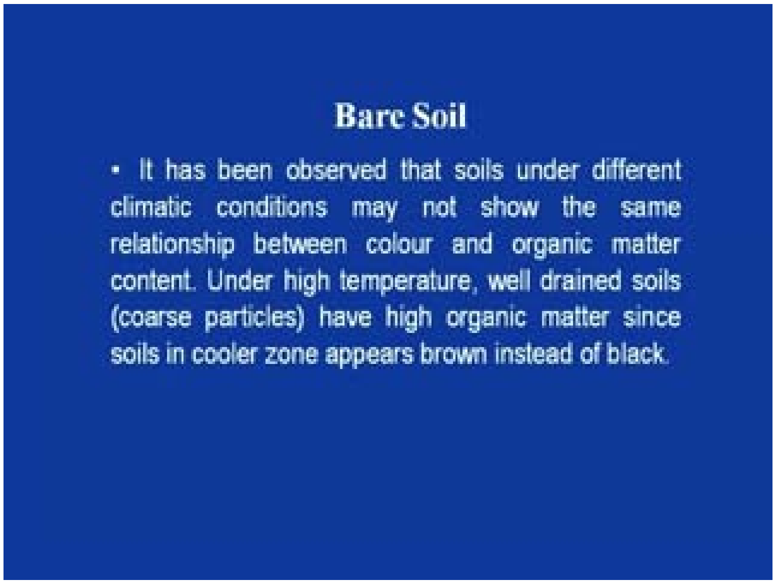

Further, it has been observed that soils under different climatic conditions may not show the same relationship between colour and the organic matter content. Under high temperature, well drained soils, that is having coarse particles have high organic matter; since colour in cooler zones appear brown instead of black.

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Thus, the climatic region and the drainage conditions much be taken into account when considering the relationship between organic matter and the spectral reflectance. Iron oxide present in soils has significant influence on the spectral reflectance characteristic of soil as it can cause a significant decrease in the reflectance at least in the visible bands.

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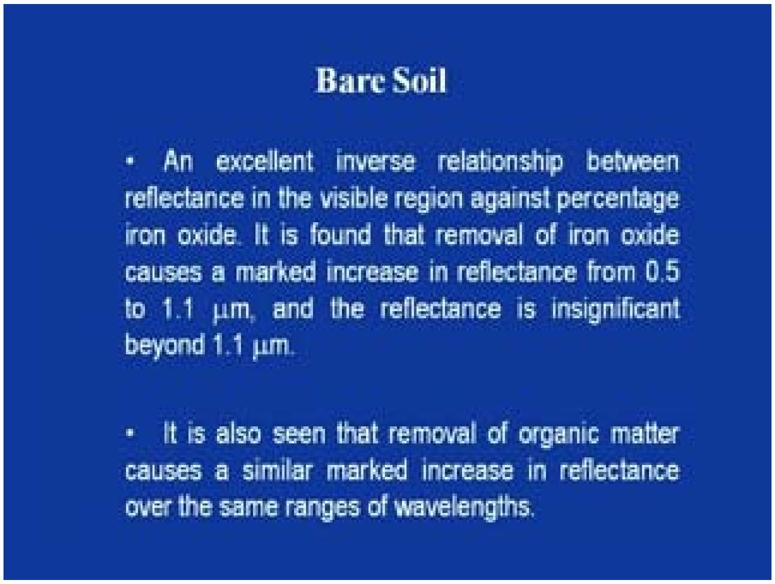

An excellent inverse relationship between the reflectance in the visible region between the percentage iron oxide has been found. It is found that the removal of iron oxide causes a marked increase in the reflectance between 0.5 to 1.11 mu meters and the reflectance is insignificant beyond 1.1 mu meters. It can also be seen that the removal of organic matter causes a similar marked increase in the reflectance over the same ranges of wavelengths.

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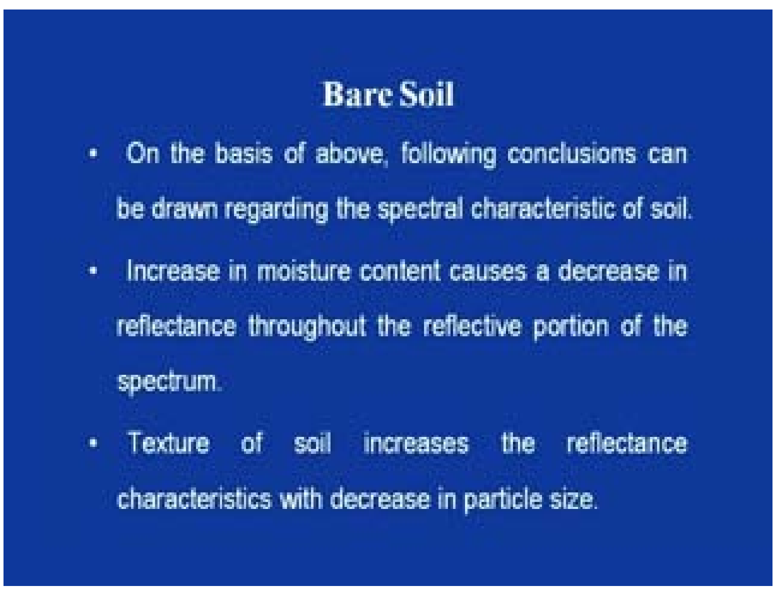

On the basis of the above, following conclusions can be drawn regarding the spectral characteristics of soil. Increase in moisture content causes a decrease in reflectance throughout the reflective portion of the spectrum. Texture of soil increases the reflectance characteristics with decrease in particle size.

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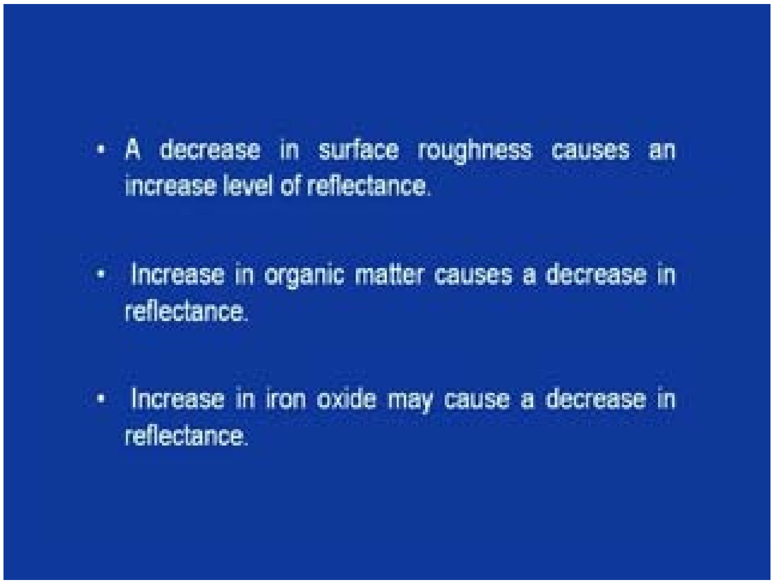

And, decrease in surface roughness causes an increase level of reflectance. Increase in organic matter causes a decrease in reflectance. Similarly, increase in iron oxide may cause a decrease in the reflectance. Now, let us look at the third common feature on the earth surface and that is what.

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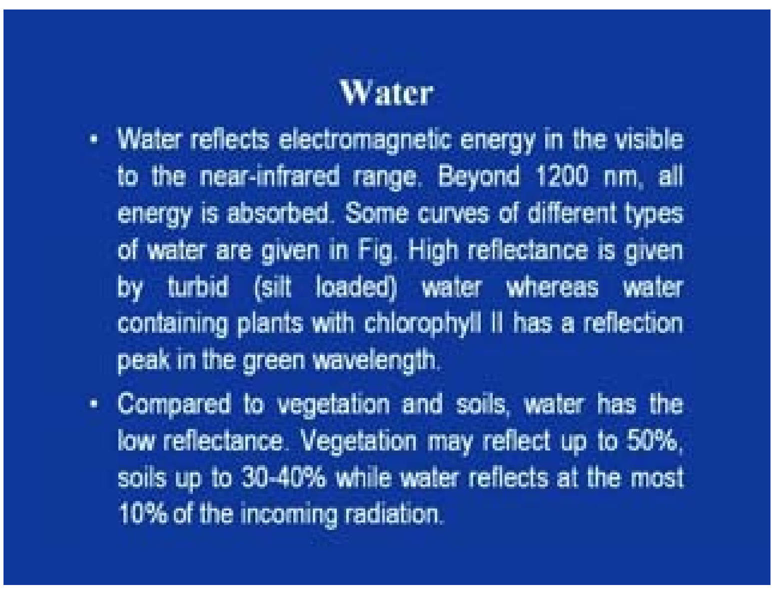

Water reflects electromagnetic energy in the visible to the near infrared region. Beyond 1200 nanometers, all energy is absorbed. Some curves of different types of water are given in figure, shown in the next slide.

It is found that the high reflectance given by turbid that is silt loaded water, whereas, water containing plants within with chlorophyll II has a reflection peak in the green wavelength. Compared to vegetations and soil, water has low reflectance. Vegetation may reflect up to 50 %, soil up to 30 to 40%, while water reflects at the most 10% of the incoming radiation.

Having discussed the spectrum properties of three broad classes of land features, now we go on to the next area and that is the role of resolution in remote sensing.

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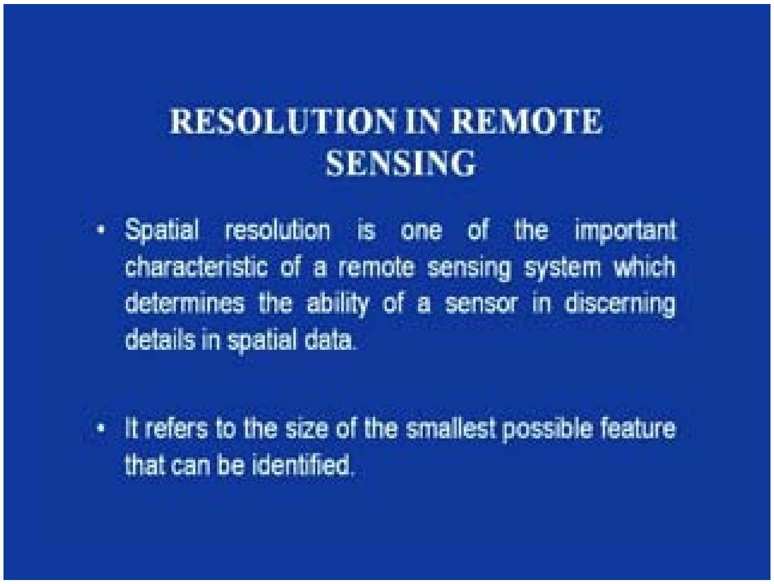

Spatial resolution is one of the important characteristics of remote sensing system which determines the ability of a sensor in discerning details in a spatial data. It refers to the smallest possible feature that can be identified.

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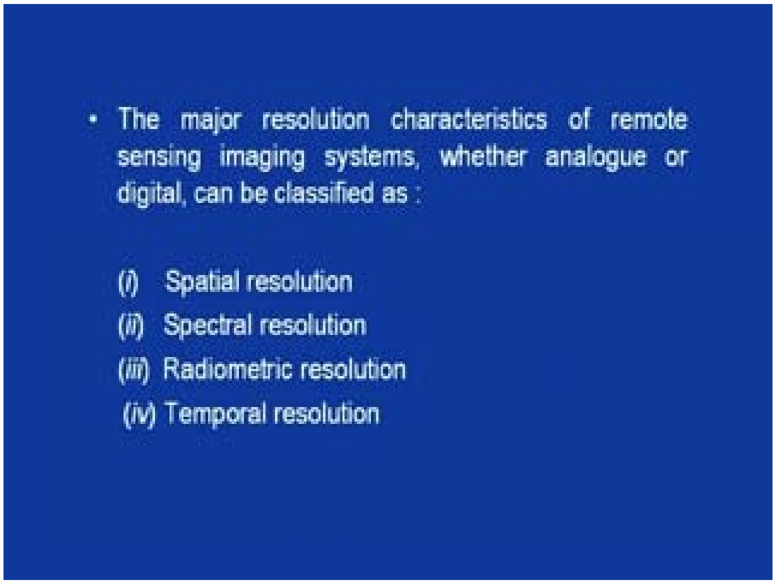

The major resolution characteristics of remote sensing imaging systems whether analogue or digital can be classified as spatial resolution, spectral resolution, radiometric resolution and temporal resolution. So, let us look at each of these resolutions one by one.

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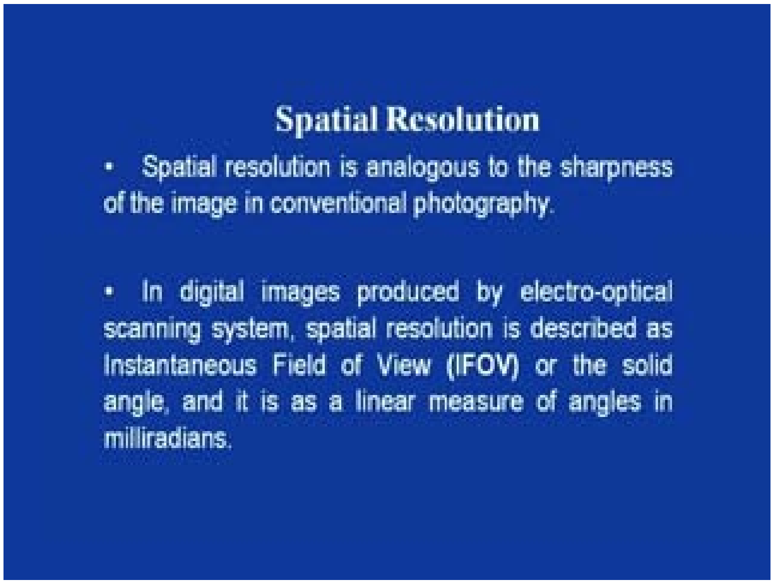

First is spatial resolution. Spatial resolution is analogous to the sharpness of the image in conventional photography. In digital images produced by electro-optical scanning systems, spatial resolution is described as the instantaneous field of view or the solid angle and it is a linear major of angles in milli radians.

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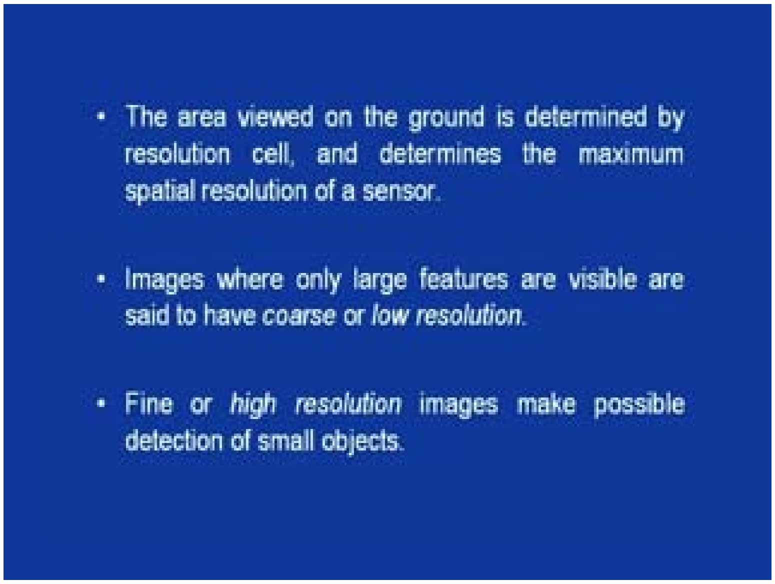

The area viewed on the ground is determined by the resolution cell and determines the maximum spatial resolution of a sensor. Images where only large features are visible are said to have coarse or low resolution. Fine or high resolution images make possible detection of small objects.

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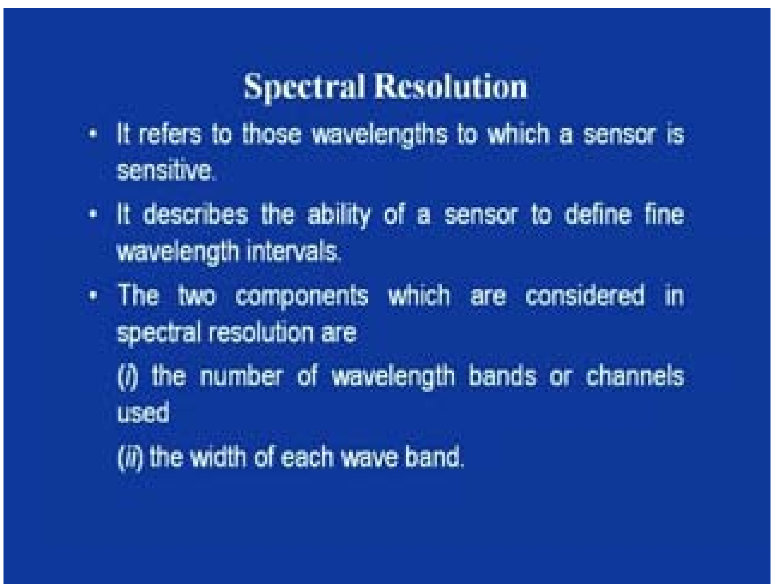

The next type of resolution is spectral resolution. It refers to those wavelengths to which a sensor is sensitive. It describes the ability of a sensor to define 5 wavelength intervals. The two components which are considered in spectral resolution are the number of wavelength bands or a channel used and second is the width of each wavelength band.

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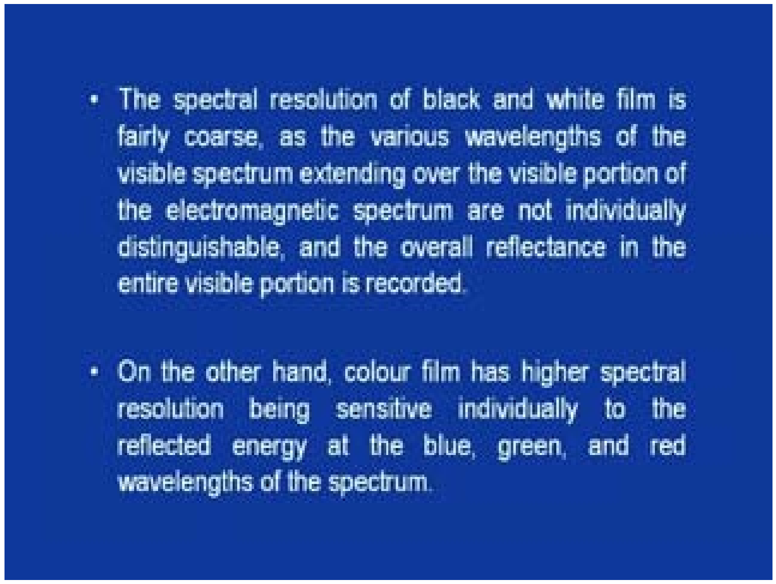

The spectral resolution of black and white film is fairly coarse. As the various wavelengths of the visible spectrum extend over the visible portion of the electromagnetic spectrum are not individually distinguishable and the overall reflectance in the entire visible portion is recorded.

On the other hand, colour film has higher spectral resolution being sensitive individually to the reflected energy at the blue, green and red wavelengths the spectrum.

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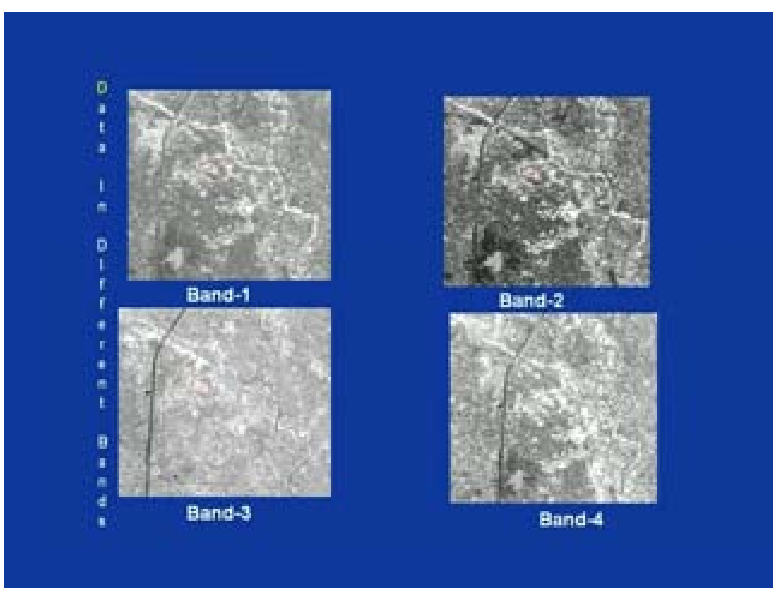

In this particular slide, an attempt has been made to show the impact of looking at the same area at different spectral regions of the electromagnetic spectrum. Here, four data sets of the Indian remote sensing satellite date have been shown and one can see the manner in which the information representation. In all the four bands provide a unique discerning capability to the user to discriminate different objects.

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Further, if one tries to look at the colour information, then probably one can now appreciate the varying differences in information as depicted in this particular image which is coloured. It may be noted that this colour image is a mathematical combination of the first three bands of the data set which has shown you in the previous slide, all right. So, band 1, 2 and 3 have been mathematically combined together to create this colour information and here the information can now be appreciated much better.

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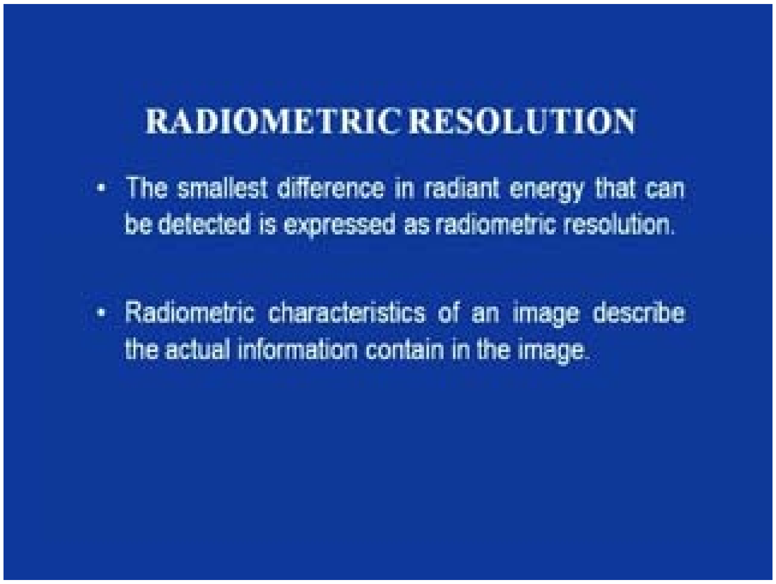

We come to the third resolution which is radiometric. It is the smallest difference in radiant energy that can be detected is expressed as radiometric resolution. Radiometric characteristics of an image describe the actual information contained in the image.

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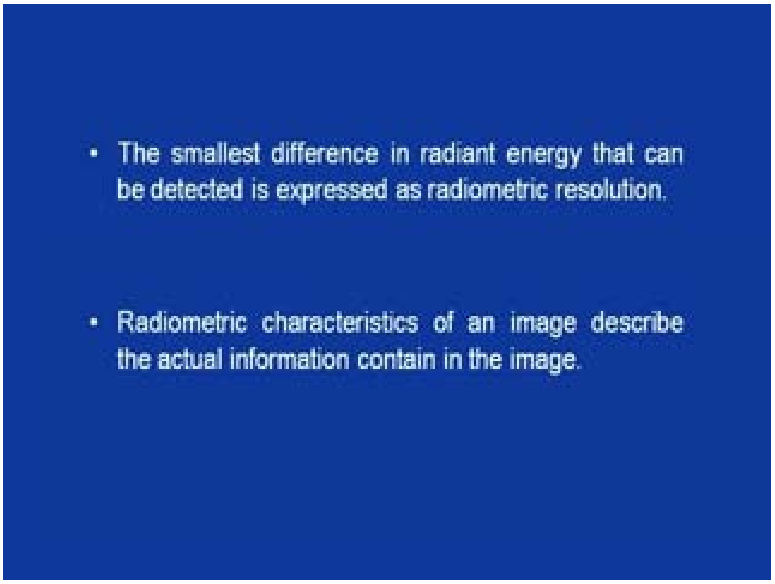

The smallest difference in radiant energy that can be detected is expressed as radiometric resolution. Radiometric characteristics of an image describe the actual information contained in the image.

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This slide as a matter of fact, shows the difference between a 2- bit image and an 8-bit image. The image on the left hand side is a 2-bit image that is we are only able to perceive 4 different levels of grayness. Whereas, the image the same image when it is viewed as an 8-bit image, what we can see is that the information is far better because the information is now being expressed in 256 levels in comparison to 4. Finally, we come to the last type of resolution and that is temporal.

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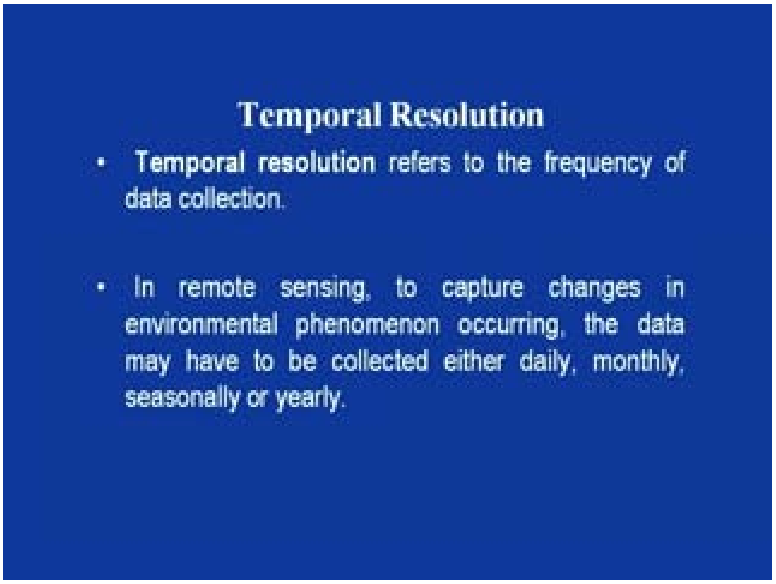

Temporal resolution refers to the frequency of data collection. In remote sensing, to capture changes in environment phenomenon occurring, the data must be collected either daily monthly seasonally or yearly.

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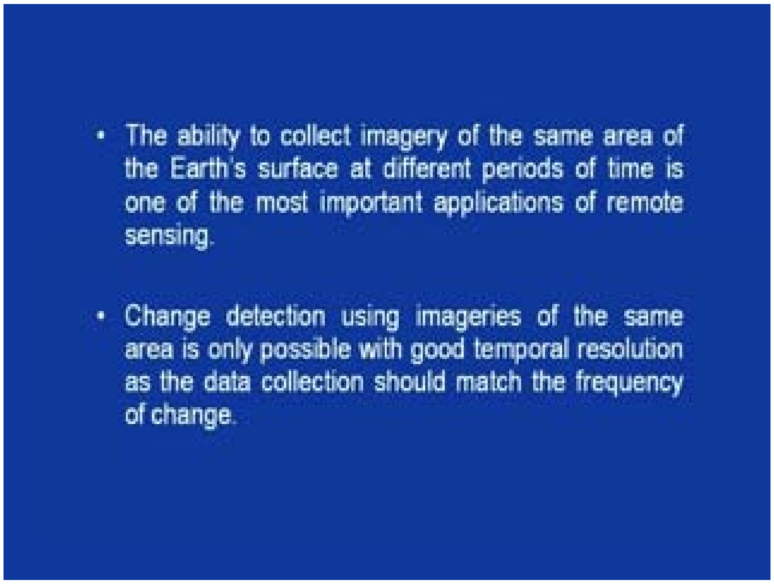

The ability to collect imagery of the same area of the earth surface at different periods of time is one of the most important applications of remote sensing. Change detection using imageries of the same area is only possible with good temporal UH resolution, as the data collection should match the frequency of change.

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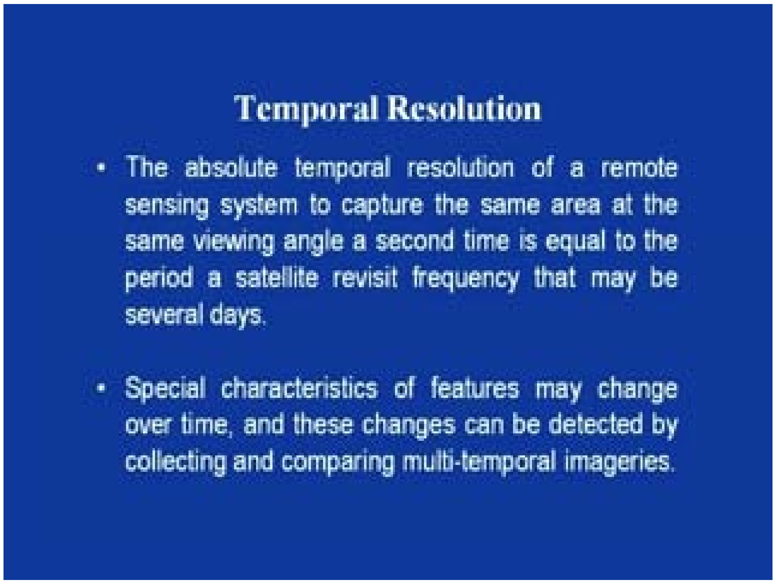

The absolute temporal resolution of remote sensing system to capture the same area at the same view angle a second time is equal to the period a satellite revisit frequency that may be several days. Special characteristics of features may change overtime and these changes can be detected by collecting and comparing multi temporal imageries. Having looked at the resolution, now let us look at one very important aspect and that is the smallest element in the image.

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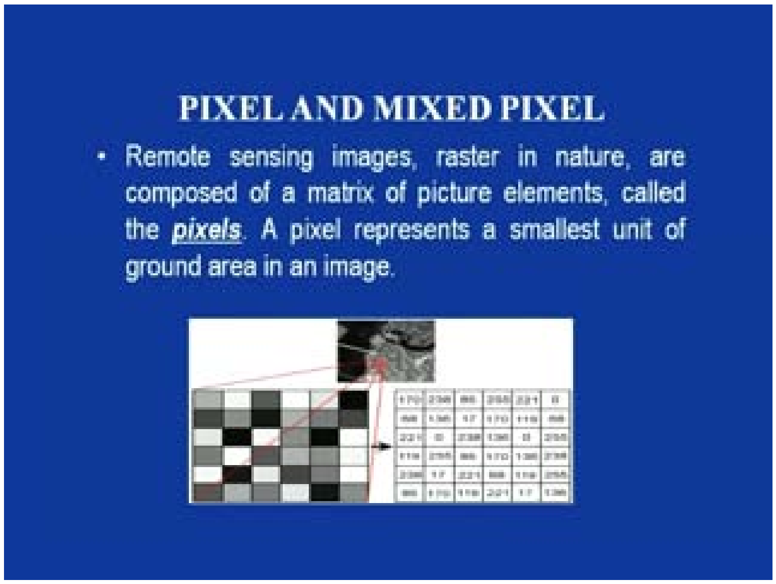

This is what we call it as a pixel. In remote sensing images which are raster in nature is composed of a matrix of picture elements called as the pixel. A pixel represents a smallest unit of the ground area in an image. If one looks at this particular graphics shown below, a digital image has been acquired for a particular area and for a very small portion, a blowout has been provided which shows that the each ground element can be shown in terms of certain cells and each cell is having a variation in terms of the grayness which is ranging from white to black and depending upon the grayness which is there, the corresponding numerical values can be seen on the right hand side again.

For an element which is totally transparent or appears white, the value is equal to 255, whereas for a cell which is totally dark or black, the value recorded is 0.

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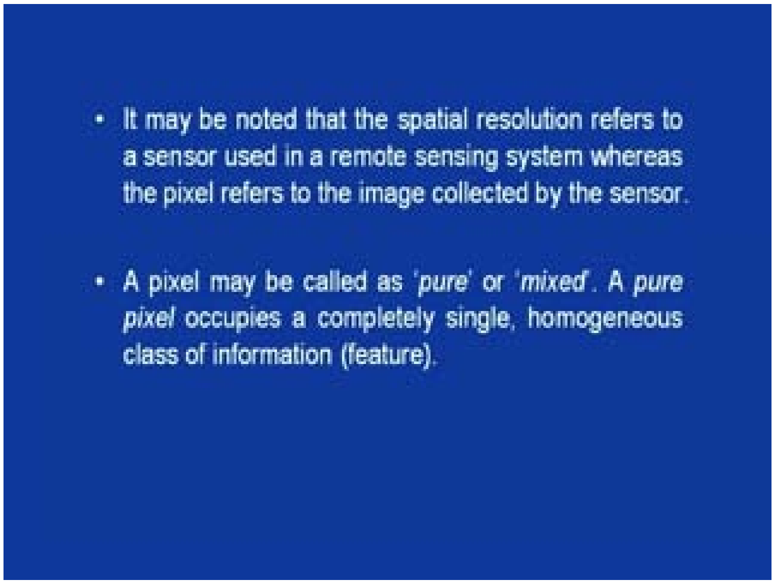

It may be noted that the spatial resolution refers to a sensor used in a remote sensing system, whereas, the pixel refers to the image collected by the sensor. A pixel may be called pure or mixed. A pure pixel occupies a completely single homogeneous class of information or feature.

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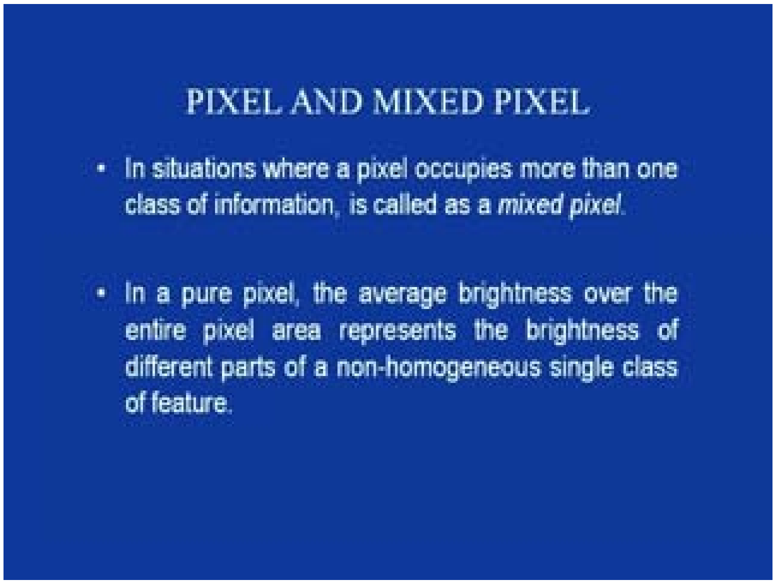

In situations where a pixel occupies more that one class of information, it is called as mixed pixel. In a pure pixel, the average brightness over the entire pixel area represents the brightness of different parts of a non-homogeneous single class of feature.

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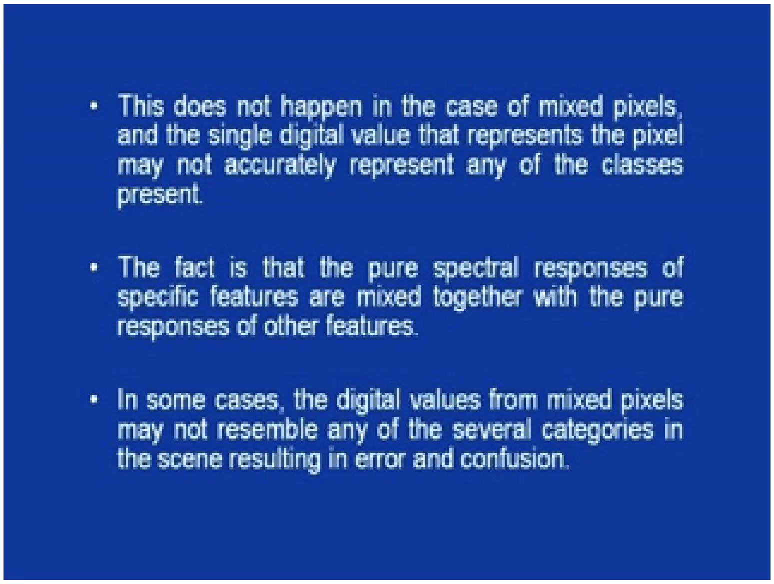

This does not happen in case of a mixed pixel and the single digital value that represents the pixel may not accurately present any of the classes present here. The fact is that the pure spectral responses of the specific features are mixed together with the pure responses of the other features. In some cases, the digital values from the mixed pixels may not resemble any of the several categories in the scene resulting in error and confusion.

In my next session, I would discuss on the basic categorization of the sensors and platforms and discuss briefly regarding some of the important remote sensing missions and their data products.

Thank you.