Remote Sensing: Principles and Applications
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Lecture No -29
Spectral Properties of Few Common Earth Features in the Visible,
NIR and SWIR Bands – Part 3

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. We have been discussing about the spectral reflectance properties of few common earth surface features in which we started discussing about the spectral reflectance curve of vegetation and what factors that influences it. In today lecture we are going to continue with the topic of spectral reflectance properties of vegetation and also, we will move ahead with other commonly occurring earth surface features.

So, till the last class I told you that the spectral reflectance curve of vegetation can be broadly divided into three the visible, NIR and SWIR ranges. And we have also seen in detail the factor that influences the spectral reflectance property in each of these portions of electromagnetic spectrum. Today we are going to get introduced to a concept of what is known as a red edge. Red edge is defined as the transition portion where the reflectance, suddenly increases.

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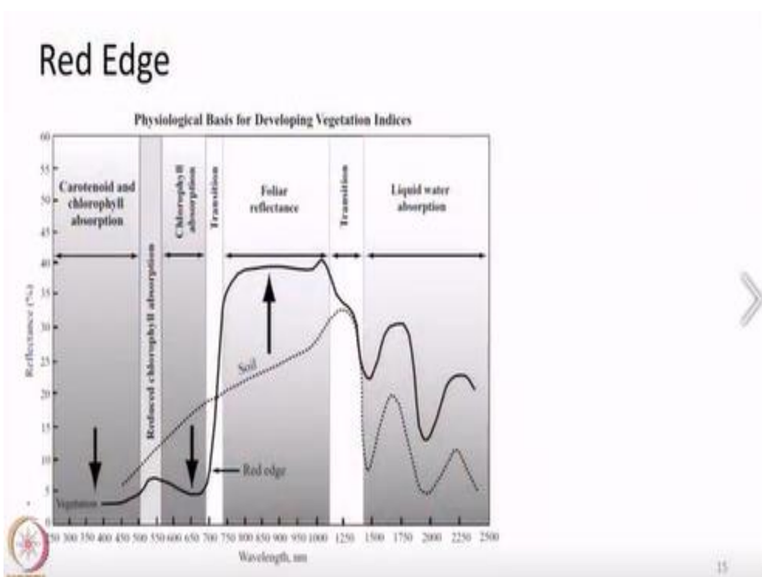

Let us look at the spectral reflectance curve of vegetation here. If we can observe in this curve, after the red portion somewhere around 0.68 micrometer range, the reflectance suddenly increases and it reaches a very high value. So, there is a small portion of bandwidth where this transition occurs, that is, from a very low reflectance in the red portion to a very high reflectance in the NIR portion.

This transition zone or this portion of the spectral reflectance curve where there is a sudden transition of reflectance happens, we call that as the red edge. So, the red edge actually has certain applications in vegetation monitoring.

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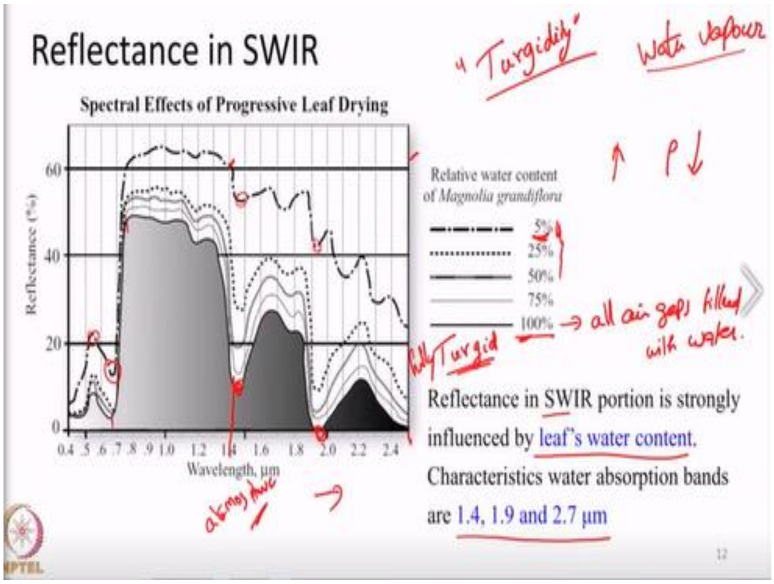

If you look at this particular slide, we can see that the spectral reflectance will vary when there is change in water content in the leaf. Here you observe what happens to the red edge as the leaf dries out. Basically, it will undergo water stress and once it undergoes water stress then the reflectance in red will begin to increase.

Because we have seen that as vegetation undergoes any sort of stress it will begin to reflect in the red portion of the spectrum. So, the reflectance in the red portion now has suddenly increased here. Similarly, there is also a change in the NIR reflectance. So, as the vegetation property changes, be it some sort of stress or be senescence or be it like abundant growth of vegetation, whatever happens it affects the red edge.

And also, it affects the wavelength range at which this red edge occurs. So, essentially speaking the red edge is the transition zone or the increase in reflection from red portion to NIR portion in the electromagnetic spectrum of vegetation. Also, one more important thing to notice is the portion at which or the portion of EMR at which this transition occurs.

That is around 0.67 micrometers to 0.72 micrometers, within that very short range, the wavelength transitions from red band to NIR band occurs. So, this red edge and also the wavelength position at which the red edge occurs will help us to know certain properties about vegetation. The wavelength at which the red edge occurs will change based on the condition of vegetation.

As the vegetation undergoes some sort of stress or when the vegetation undergoes some senescence cycle or when the vegetation matures then the red edge the wavelength at which this transition occurs will start to move towards shorter wavelengths. We call it as the blue shift.

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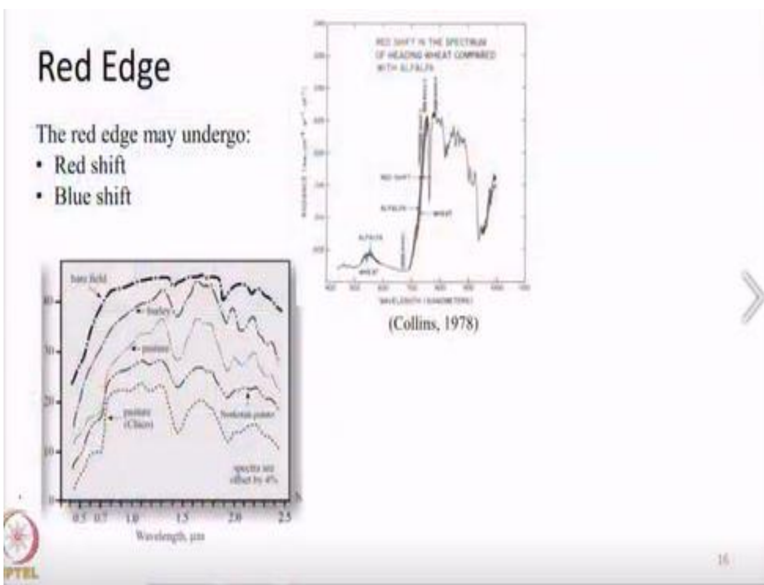

That is, let us assume the vegetation curve is something like this. So, let us say this transition occurs somewhere around 0.68 micrometers, the position at which this reflectance changes. If the vegetation undergoes some sort of stress then this curve will become something like this. The reflectance in red will increase. Similarly, the portion at which the transition occurs at which the change occurs will move towards shorter wavelength.

Now this wavelength may not be 0.68 it may be let us say 0.65 micrometers. So, this sort of shift will happen towards the shorter wavelength, we call this as blue shift of the red edge. So, when blue shift will occur? Blue shift will occur whenever the vegetation is undergoing senescence or when it is undergoing some sort of stress. That is when the red reflectance increases then the wavelength at which the red edge occurs will move to a shorter wavelength.

Similarly, when the vegetation is under active growing phase like it starts from very small plant and suddenly increases to a large canopy, then the red edge portion will move towards longer wavelength. That is, the dark red curve has now moved to the position of this dotted curve. So, this signifies the red edge is now moving towards longer wavelengths, we call this as red shift of the red edge. So, observing this red edge and the position at which it occurs will help us to understand certain properties about vegetation and also for agricultural crop monitoring or in general vegetation monitoring etcetera. But one thing what we have to remember is the wavelength range at which the red edge occurs is actually of very short bandwidth.

I told you it may fall around like 0.67 to 0.72 micrometers. And even when blue shift occurs or when red shift occurs the change in wavelength also will be in the order of say 1 micrometer or even less than 1 micrometer. The change will be occurring over very narrow bandwidths of wavelength. And hence in order for us to properly observe this red edge and the position of the red edge we may not be able to do it with our normal multi-spectral systems with wider bandwidths.

Let us say one system has bandwidth of 0.65 to 0.75 micrometers crisscrossing red, NIR or one may be having 0.62 to 0.68 another one may be having the next band may be 0.70 to 0.79 micrometers etcetera. This sort of wider bandwidth sensors which are typically present in our multispectral systems may not be able to capture this red edge or the position of the red edge. For observing the red edge, we need what is known as imaging spectrometers or hyperspectral sensors.

So, what exactly are hyperspectral sensors? Hyper spectral sensors are such sensors which observe in many short continuous bandwidths.

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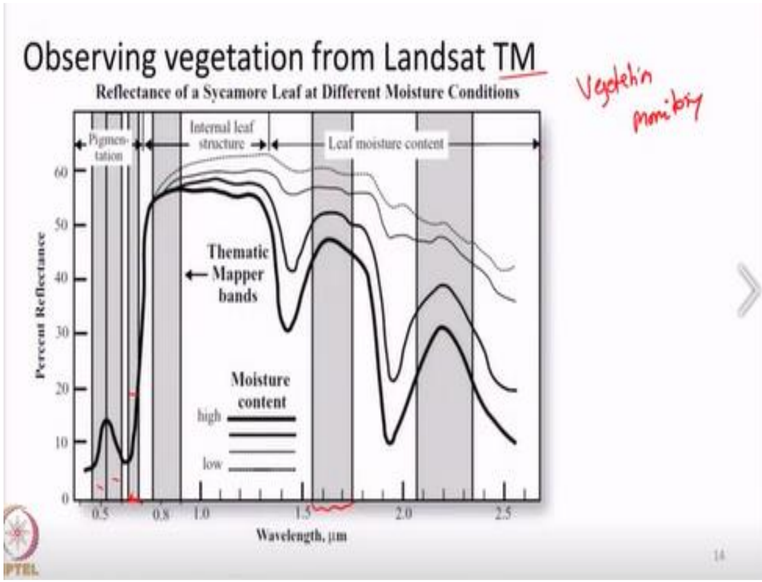

This particular figure in the slide actually tells us the different bands present within the Landsat thematic mapper sensor. So, it has band 1, band 2, band 3, band 4, band 5, band 7 and so on. So, this is for thematic mapper sensor. This is an example for what is known as a multispectral system. So, multispectral system is a system or sensor which has a limited or a small number of wider bands that may be or may not be contiguous.

Contiguous in the sense, they are not continuous. Their band 4 is here in the NIR range and suddenly band 5 has moved to SWIR range in the wavelength of say 1.5 micrometers. This sort of non-contiguous wider bandwidths sensors are called as multispectral sensors. On the other hand, hyperspectral systems or hyperspectral sensors will observe lot of small small bandwidths that are continuous.

Say it may be 0.41 to 0.42 micrometers 0.42 to 0.43 micrometers like this. Even for hyperspectral sensors they will classify everything in nanometers 410 to 420 nanometers 420 to 430 nanometers. It is convention to use nanometers to represent hyperspectral sensors. So, they will have large number of continuous bands with very narrow bandwidths. So, the presence of this continuous bands without any gap 0.41 to 42, 42 to 43, 43 to 44. Like this they will have large number of continuous bandwidths without any gap along the electromagnetic spectrum. But here it will be in order of tens of nanometers or even shorter. So, presence of large number of such continuous narrow bandwidths and the sensor containing such bands are known as hyperspectral sensors. And for observing this red edge we will be, needing such hyper spectral sensors. It is not possible to observe red edge from normal multispectral sensors. But nowadays certain satellites are having a specific band known as the red edge band, which is occurring in the transition zone of red and NIR. Very few satellites has this in order to observe this red edge. But most of the commonly used satellites for which data is freely available to us, do not have the specific red edge band. They have the traditional green, red, NIR bands or such that.

Very few satellites have this red edge band built within them. But using hyperspectral sensors it will be possible for us to observe this red edge and also the position at which the red edge occurs. So, I told you that the position at which red edge occurs will help us to understand about certain properties of vegetation. So, how to calculate the position of red edge? There are like many different ways, many different indices are available to calculate this red edge, red edge position etcetera.

A very simple example we are going to see in this lecture. We are going to calculate red edge position using what is known as a derivative spectroscopy.

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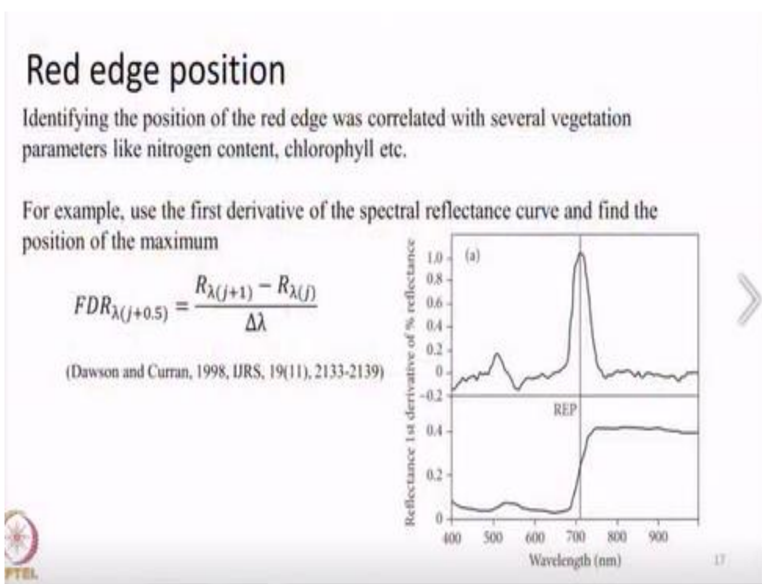

We have seen that for a normal spectral reflectance curve the red edge is the portion at which the reflectance suddenly increases. So, if you talk in terms of mathematical functions, the position at which red edge occurs is nothing but the point at which the slope of this reflectance curve is maximum.

So, how to calculate slope of the curve? In mathematics we have seen it using the derivative. The first derivative of a function say if y is equal to f(x) then the first derivative of the function dy/dx will tell us the information about the slope of the curve. Similar concept we apply here. We take the slope of the reflectance curve with respect to wavelength. How the reflectance changes with respect to wavelength is studied to identify a point where the change in slope is the maximum.

So, we identify that particular point or the wavelength at which the maximum change occurs. That particular point we classify it as the position of the red edge. So, this is possible from hyperspectral sensors this is reflectance in band (j+1) this is reflectance in band j divided by bandwidth.

So, you will be keep on calculating this and (j+0.5) the band at which maximum change occurs we will classify it as the position of red edge. This is one of the very simplest ways in which red edge position can be calculated. But as I said there are plenty of ways or there are separate chapters on how to use red edge for vegetation monitoring and so on. But we will not go in detail in this particular course.

The main aim of this particular topic is to introduce you to the concept of red edge and its importance. Till now we have spoken about the reflectance property of a single leaf or grass etc. In reality when a remote sensing sensor observes vegetation from space. It will not be observing a single leaf but it will be observing a collection of leaves or a bunch of leaves plus the stem, some soil, flowers, fruits etcetera, etcetera.

Normally a remote sensing system or a sensor will observe a vegetation plus its background like non-leafy things stems, branch, fruits, flowers etc. So, how these will change the reflectance of vegetation? That is what we are going to discuss in the subsequent slides. First, we will talk about what is known as a leaf additive reflectance.

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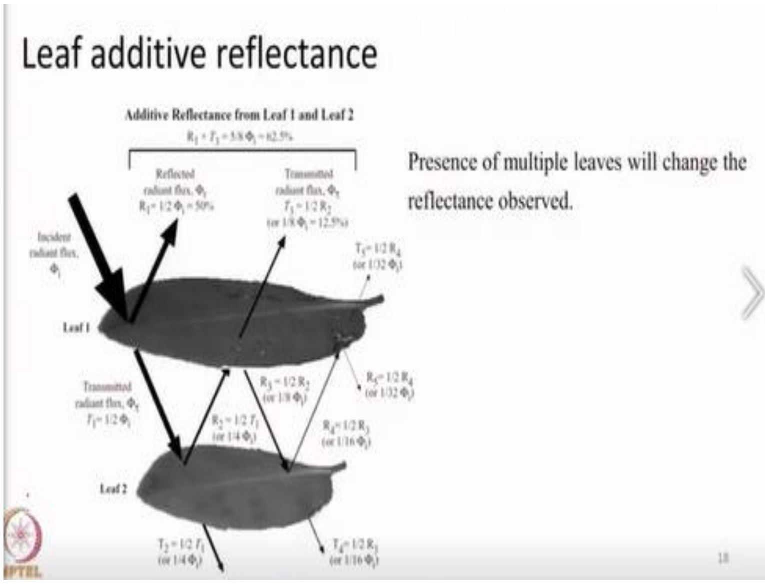

While discussing about the NIR portion, I told you that leaf transmits a large fraction of incoming energy in the NIR portion. And it also reflects other large fraction of energy say the transmission will be about 40% reflectance also will be about 40%. Both are equally high in compared with the total absorptance. So, what happens to this transmitted energy? If a single leaf is present and some radiation is incoming towards it, a part of the radiation or a large chunk of the radiation is transmitted towards it.

So, it just passes through without undergoing any change. If it is just a single leaf it would have just passed through and it was interacted with whatever was there underneath it. But normally as I told a vegetation will contain more than a single leaf, there will be tens or even sometimes 100's of leaves arranged in kind of a stack depends on how thick the canopy is or how big the canopy is. So, what happens to this transmitted energy? The transmitted energy in general will interact with the leaf underneath it, and that will again transmit certain portion of it and reflect certain portion of it.

So, the transmitted energy from one leaf will act as input energy to the leaf underneath it, which will again add up to the reflectance that is finally coming out. So, if you see this particular slide, this is leaf in the top let us say leaf number 1. This is leaf number 2. So, what happens? Certain amount of energy is coming and falling over it. Let us assume 50% of it is reflected back. Again, let us assume another 50% is transmitted. So, let us assume the absorptance is almost 0. So, 50% is reflectance, 50% is transmittance with almost 0, absorptance. If that is the case the 50% energy is now transmitted to leaf 2. Now what will happen? This leaf will reflect 50% of this incoming energy. So, that is from the total 50% came in and from this ϕ_i 0.5 of ϕ_i came in out of which another 50% will be reflected. That is $1/4^{th}$ of original incoming energy, will be reflected and another is now transmitted through. So, this is also will pass through.

Again, the bottom portion of the leaf will reflect some portion again here. And again a 50% of it will be transmitted. So, this $1/4^{th}$ will further become half. $1/8^{th}$ will be again reflected by the bottom portion of leaf. Remaining $1/8^{th}$ will be transmitted towards the upper portion. In the upper portion we have the first half of reflected portion plus this $1/8^{th}$ of reflected portion or 12.5 %. So, these two will add up and it will finally make up for 62.5% of reflectance. That is whatever the original energy came in, a part of it got transmitted, this transmitted energy gets reflected by the leaves underneath and while this is passing through, this will undergo multiple reflection even by the bottom of the leaves also.

And finally, the total reflectance observed by a sensor at the top of this first leaf will be more than what is being reflected by this single leaf. So, the final reflectance or rather than putting final I will say the total reflectance observed by a sensor due to multiple leaves will be greater than the reflectance produced by single leaf. This is because of the presence of multiple leaves underneath it. So, in this example for the sake of simplicity we took this leaf reflects 50% transmits 50% without any absorption. This is just for explanation sake.

Though the numbers may change but the concept is this, whatever is being transmitted by the leaf on the top will act as an input source of energy to the leaf at the bottom and it will undergo certain reflection and it will add up to the total reflection recorded by the sensor at the top of the canopy. So, this figure in the below slide actually tells us more about the leaf additive reflectance. This leaf additive reflectance is very clearly observed in the NIR band because, the leaf has the greatest transmittance in the NIR band that we have seen. And also, now we would have understood that for leaf additive reflectance, this transmitted energy is one of the major input sources. So, in NIR band as the number of leaves increases, the reflectance increases quite sharply.

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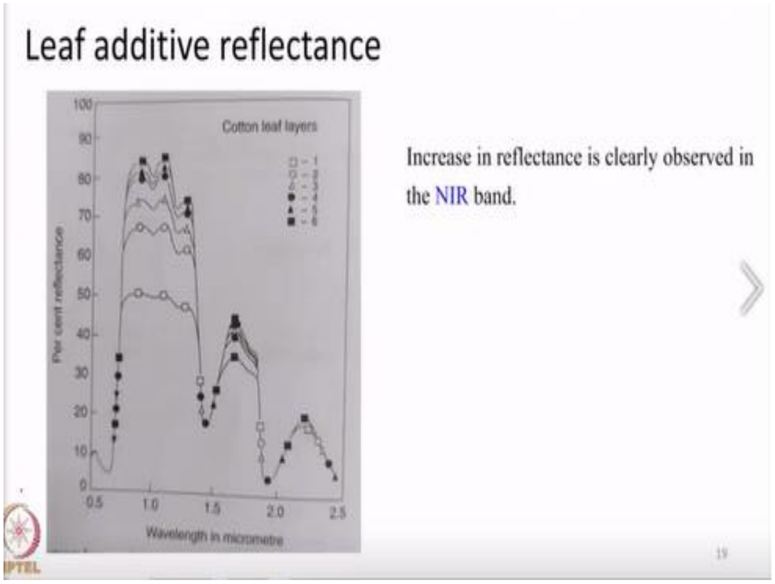

This is also observed in SWIR portion to some extent. So, area of one side of the leaf to the total area of the ground, this is what we call as leaf area index LAI. LAI may increase because of when large number of leaves gets added up underneath. As the number of leaves grows in a canopy the LAI will increase. As this happens, the reflectance in NIR portion and also to some extent in the SWIR portion will increase because of this added number of leaves. Primarily because of the transmitted energy from the leaf at the top acts as input energy to the leaf at the bottom and the reflection from the leaves at the bottom will add up to the total reflectance observed by the sensor on top of the canopy.

In addition to this leaf additive reflectance I also told you whenever a sensor observes vegetation it will not only observe leaves, it will also observe other non-leafy components such as stems, branches, flowers, fruits even the background soil. So, all of these combined together will create integrated signal in the remote sensing sensor, so this kind of effect whether a sensor is observing leaf or it is observing non leafy portions etcetera depends on both the illumination geometry and also the viewing geometry. Maybe we will quickly see an example.

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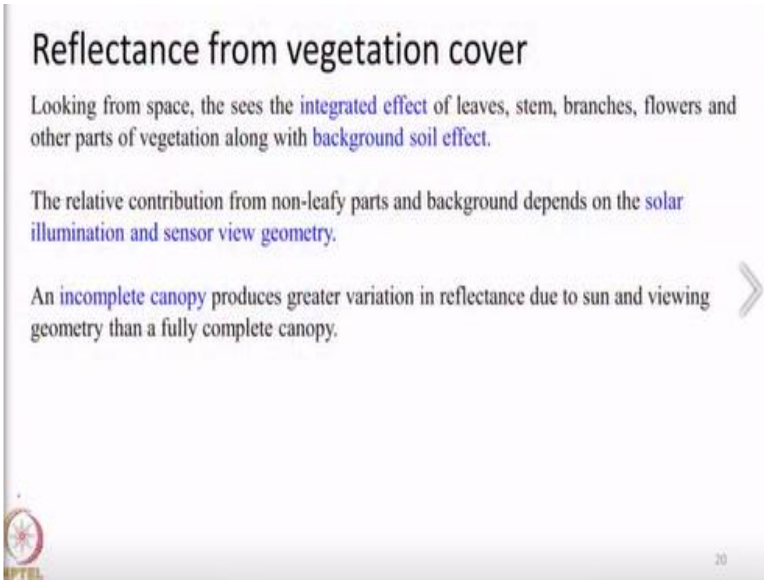

Let us take an example of a row crop. So, this is a land parcel where crops are planted in kind of rows like this. So, each red line here represents one row of crop. Whenever such row cropping is being practiced the in-between portion will normally be left barren or left fallow without any vegetation. So, the in-between portion will be a soil portion. Let us say a sensor is looking directly from overhead. So this particular sensor looks both the crops plus the soil in between. In other case let us say the sensor is located here and row crop is standing something like this.

Most of the sensors view is going to be limited for just by observing the vegetation portion or the leafy part rather than looking at the soil. And also let us take sun is present somewhere here now. The sun is going to illuminate this other side of the vegetation whereas the sensor is seeing another side. So, essentially the reflectance is going to vary. If the sun is present here, so the same angle as the top the sensor. So now the sensor is going to observe a bright portion of vegetation.

So, all these things combine together, the sensors or how the vegetation is aligned? Whether it is a row crop or whether it is like a randomly distributed forest canopy or how the solar illumination geometry is? All these things are going to create an integrated effect of radiance in the sensor. So, essentially when we do remote sensing most likely we may not get only the leafy part. It is possible only been a very thick canopy is present. That is when the sensor is observing over a large thick forest such as amazon. When observing over such thick forest, the sensor might be seeing only the canopy parts, only the leafy portions.

But when there is sparse vegetation such as some agricultural lands with row cropping pattern or some shrub lands where vegetation is quite sparse, then the final reflectance or the radiance observed by the sensor is going to have an integrated effect of soil, leaf and other non-leafy part. So, we should always keep this in mind, when we compare the reflectance from vegetation with the spectral reflectance curve of leaf taken from a laboratory.

The spectral reference curve we get from remote sensing sensor may not exactly be obtained from a leaf. It may be obtained from several different features. We should always keep this in mind when we do this curve matching what is being obtained from laboratory and what is obtained from remote sensing image. When we compare them, we should always keep in mind. Most likely we should compare only the pixels which had only pure vegetation in order for us to do our classification in a better way. In addition to all these we have also come across that vegetation is a non-Lambertian reflector. That is vegetation will look differently as the sensor viewing angle changes. That is, in one of the classes I told you that vegetation is primarily a backward scatter. That is, it reflects a good chunk of energy in the direction from which it is coming itself. Similarly, the vegetation's reflectance property will change as the sensor viewing geometry changes.

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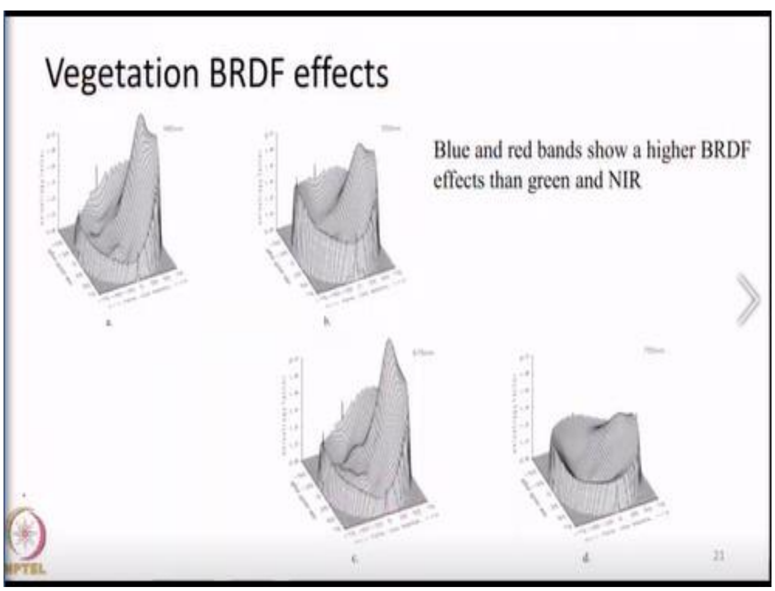

Here an example is given in this particular slide. So, here we have plotted what is known as the anisotropy factor. So, anisotropy factor is the reflectance for a given viewing geometry that is θ_v,

ϕ_v divided by the reflectance when taken from a nadir looking sensor. So, this will give us the anisotropy factor. So, how the reflectance will be, when taken from any one particular angle that is divided by the reflectance of the same vegetation observed at nadir.

$$Anisotropy\ Factor = \frac{\rho(\theta_v, \Phi_v)}{\rho_{nadir}}$$

If we plot this ratio along with the viewing zenith angle and azimuth angle, then we will get a three-dimensional plot which tells us, at which angles the anisotropy is the maximum. So, what essentially it means is the viewing angle of the sensor has a larger BRDF effects with respect to vegetation. Vegetation when observed at different angles may look completely different and blue and red bands show higher BRDF effects than green and NIR band as per some experiments.

So, all these things suggest that observing vegetation may not be a straightforward task. When we observe vegetation and when we take certain decisions about vegetation and its properties, we should keep in mind several things. That is, what we observe as vegetation may not be pure leaves. It may be soil or it may be non-leafy parts and the difference in viewing angle and the sensor illumination geometry might have played a role which would have affected the reflectance that we have obtained.

So, all these things we should keep in mind when we make certain important decisions. I will tell a very good case study when we discuss about what is known as spectral indices. How to combine this reflectance to create spectral indices? I will explain you when we discuss that in the later part of lectures in the same topic.

So, with this we end the spectral effects properties of vegetation. In the next lecture we will start with studying about the spectral reflectance property of soil, water and snow.

Thank you very much.