Remote Sensing: Principles and Applications
Prof. R. Eswar
Assistant Professor
Department of Civil Engineering and Interdisciplinary
Program in Climate Studies
Indian Institute of Technology, Bombay

Lecture No -28
Spectral Properties of Few Common Earth Features in the Visible, NIR and SWIR Bands - Part 2

Hello everyone. Welcome to the next lecture in the topic of analyzing the spectral difference curve of commonly occurring earth surface features. In the last lecture we started discussing about the spectral reflectance curve of vegetation. We have covered what factor influences the reflectance curve of vegetation in the visible part of EMR and we have also started discussing about the NIR portion. So, today we will continue with the particular topic.

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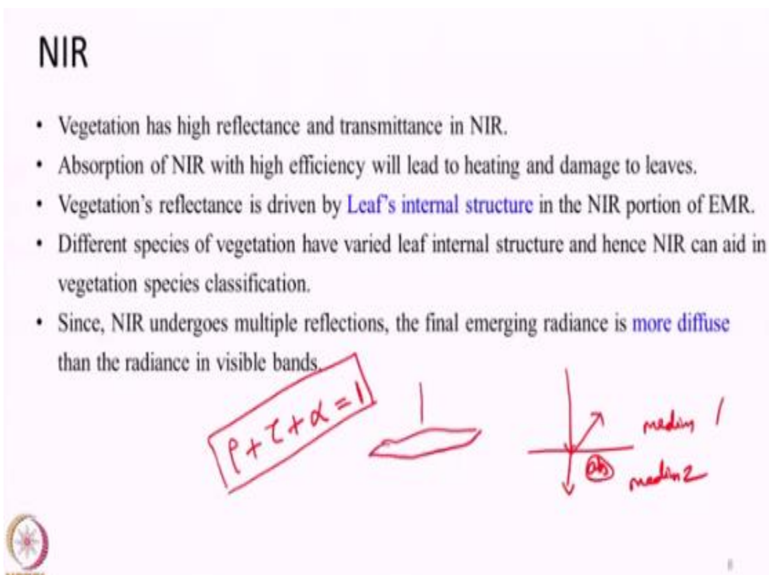

So, as I told you it is the leaf's internal structure, that is the orientation of different types of cells and the air gaps that will control the reflectance of leaf in NIR portion. And I also said that leaves has typically very high transmittance and reflectance in the NIR part. And what we can decipher from this is since each type of vegetation has a different internal structure, different orientation of cells and so on, it influences the NIR portion of the EMR to a great extent causing the reflectance to be useful in vegetation classification or species classification. That is one advantage we can remember. Even some people have attempted to classify the different vegetation species by looking at NIR reflectance.

Second thing what we have to remember is I told you that the energy in NIR portion that is entering the leaf will undergo multiple reflectance’s that is as it encounters different surface between a cell and air gap between a cell and water it will undergo multiple reflectance which will cause the out coming reflectance to be more diffuse. That is I told you that reflectance can be specular or diffuse. And the final net reflected energy that is coming out of the leaf will be more diffused in nature when compared with visible portion which can be specular reflection. That is normally the EMR which is reflected in a diffuse manner will contain more information about the object that reflected. That is it has interacted little bit more with the object from which it got reflected and it will carry additional information about the particular object.

Normally we prefer to have a diffused reflectance than specular. Because in specular high amount of energy will be reflected in one particular direction which may cause a bright spot in the image which may not tell us more information about the object of interest. When we look at still calm water bodies from certain angle, we may get a bright reflectance like a sun glint we call.

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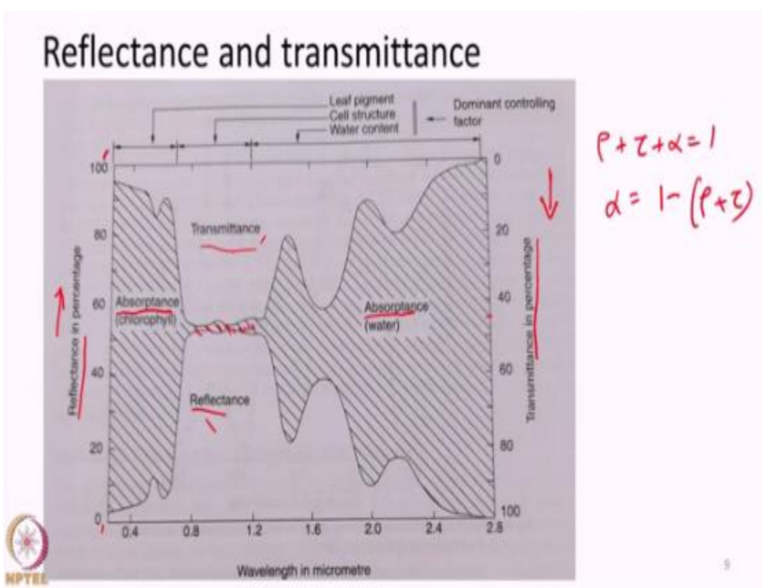

So, such sort of bright reflectance spots may not provide us more information about the object but the radiance which are coming in from the object normally or which is reflected in a diffuse manner will carry some information about the object of interest. So, essentially the energy in the NIR portion will be more diffuse when compared with the energy that is being reflected in the visible portion of EMR.

Coming back to the general reflectance and transmittance characteristics of leaf, we will just look at this particular figure in the slide. So, here if you can see this particular portion on the left side of the axis, we have reflectance. On the right side of the axis we have transmittance. So, reflectance increases from 0 to 100 along this direction and transmittance increases from 0 to 100 in the secondary axis from top to bottom.

So, if you see essentially the reflectance and transmittance curves are almost like superimposable on each other. If the reflectance is low transmittance is low, if the reflectance is high transmittance is high and so on. So, essentially they have a very close relationship with each other. And also we know that

$$\rho + \alpha + \tau = 1$$

$$\alpha = 1 - (\rho + \tau)$$

So, this shaded portion in between is the absorptance or the energy that is absorbed. If you look at these particular things what we can sense is, in the visible domain that is less than 0.7 micrometers absorptance is pretty high with very low reflectance and transmittance. On the other hand when we move the NIR portion that is from 0.7 to 1.4 micrometers, reflectance is pretty high somewhat close to say 50% or something.

Transmittance is also pretty high around say 40, 45% and an absorptance is quite low. And again the absorptance increase when we move to the SWIR portion. Maybe we will study about SWIR portion little later. But what I want you to just observe is compare the absorptance between the visible portion and the NIR portion. In visible absorptance is very dominant with very low reflectance and transmittance whereas in the NIR portion absorptance is very minimal with really high amount of reflectance and transmittance.

And as I already told you this behavior of high transmittance and high reflectance is essential to prevent the leaf from undergoing irreparable damage. And hence leaves will absorb very little amount of NIR. So, may be the visible portion and the NIR portion can give certain information about the amount or the presence of a vegetation and its healthiness. So, for a healthy green vegetation, if you just remember the spectral reflectance curve their reflectance is pretty low in the red portion and the reflectance is very high in the NIR portion. So, maybe we will just try to understand how the reflectance will vary in the red and NIR portion for a vegetation starting from its initial stages to its harvest stages.

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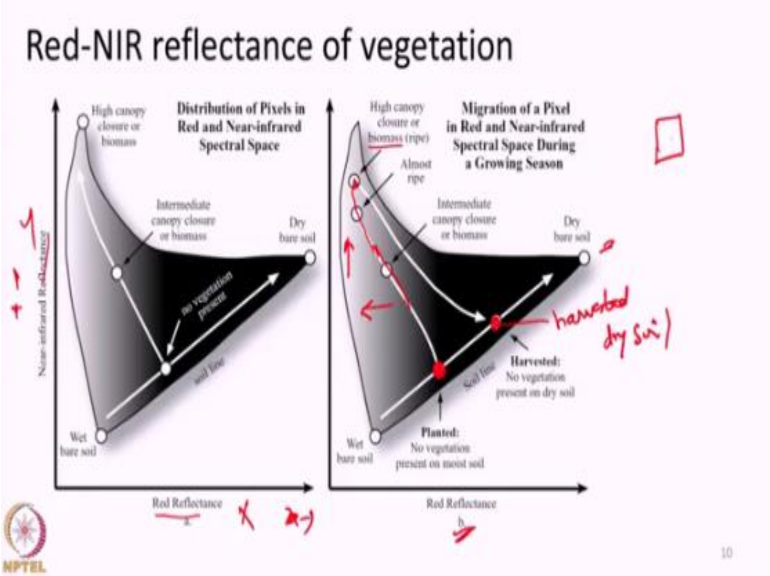

So, that is given here in this particular scatter plot. Here what we are going to see is, if we plot red reflectance versus NIR reflectance, with red reflectance in the x axis and NIR reflectance is there in the y axis. If we can plot the reflectance, we will be able to clearly decide for between bare soil line under vegetation line. That is, we will see in the later part of this lecture or in the upcoming lectures that soil has almost a linearly increasing curve almost.

So, as the wavelength increases the reflectance of soil will increase. So, essentially a red reflectance and any other reflectance terms will slightly increase like this. It will be a linear line high reflectance in red normally will have higher reflectance in NIR and so on. But for vegetation, as vegetation grows to a bigger level then reflectance in NIR will be increasing and there will be a strong absorption in the red portion.

That is low reflectance in red, high reflectance in NIR. That is we will come to this particular slide or this particular figure b here. So, let us imagine one particular pixel or one particular land parcel which is essentially we are starting with bare soil. Let us say it is a small agricultural plot, the farmer is going to prepare the plot for agricultural purposes. So, before agriculture the farmer will prepare the land, he or she will water the land, the land will be prepared.

So, let us say it is the point somewhere here, the reflectance, the red and NIR reflectance somewhere here. This is corresponding to wet soil; wet soil will have relatively lower reflectance in all the bands in compared to a dry soil. So, now the vegetation begins to sprout and begins to grow. When that happens as vegetation grows reflectance in red will go down because of the strong absorption of red because of chlorophyll pigment. On other hand reflectance in NIR will increase.

So, this particular point may move along this particular curved line. That is decreasing red reflectance increasing NIR reflectance. So, there will be a point where the crop would have reached its maximum growth cycle. After that the plant will be ready for harvest. Once when it reaches its maximum growth cycle, it may be ready for harvest the farmer would have harvested it. And then this particular point may land up somewhere here indicating a harvested land containing just a dry soil without any vegetation.

So, this is how particular pixel vegetation grows will typically behave. So, what is the take home message from this particular slide is? vegetation has a characteristic reflectance and if we combine the red portion and NIR portion, we will be able to study about the growth of vegetation. So, as vegetation grows, essentially reflectance in red portion will go down and down, because of high absorption of red wavelength by chlorophyll.

On the other hand when vegetation grows, it leaf’s size will increase and the internal structure of leaf will develop and hence NIR will be strongly reflected and transmitted and hence the reflectance in NIR will increase. So, that is why if we observe the reflectance of one particular land parcel in a full growth cycle of a crop we can observe this particular pattern in which the reflectance data moves or aligns itself.

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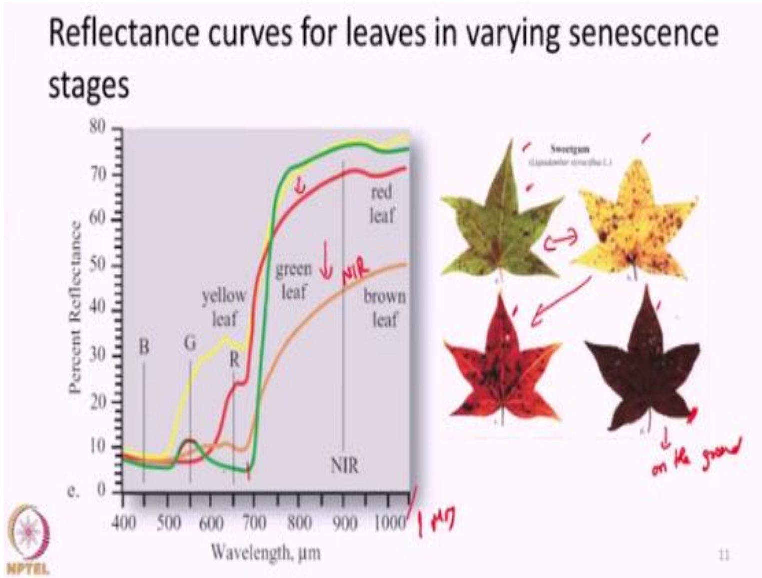

Now we have seen general introduction about behavior of leaf in visible and NIR portion. Now we will take leaves in different stages of its emergence that is different stages of its life cycle and then we will analyze how the spectral reflectance curve look. So, in this particular slide we have four different leaves, a green leaf, yellow leaf, red leaf and a dark brown leaf. The dark brown leaf is kind of dead leaf where the sample was collected below the tree.

And these three, the green, yellow and red were still alive, present in the tree itself and this is collected from the ground at the bottom of the tree. So, we will start with the healthy green leaf. For a green leaf what we are observing is typical low reflectance in blue portion, low reflectance in red portion, which is pretty low even compared with blue and a slightly higher reflectance in the green portion.

After this in the NIR portion, reflectance increases drastically and it remains high almost up to about one micrometer. Now, we will move to the yellow leaf, yellow leaf means that the change in pigment from chlorophyll. Now chlorophyll has become less dominant and some other pigments starts to dominate the leaf’s characteristics. So, for yellow leaf, the reflectance in red also increases reflectance in green also is pretty high and reflectance is low only in blue.

So, green plus red combined together will give a yellowish color to the leaf. And in NIR portion still we are observing quite high reflectance value. Now comes, the red leaf. So, after this is another stage of maturity in leaf. So, there the leaf is strongly absorbing in both blue and green portions. That is chlorophyll is almost absent and only some other pigments are present.

So, this leaf is almost towards the end of its life cycle. So, what happens, only red reflectance dominates a lot and NIR reflectance slightly reduces. For this brown leaf the entire visible portion reflectance is pretty low and then the reflectance in NIR has fallen down. So, the general observation from these four leaves are if the leaf is healthy then typically the reflectance of red will be very low and leaf will be green in color.

Because of increased reflectance in green portion by chlorophyll and as the leaf moves to its different stages, its chlorophyll pigment will begin to reduce, some other pigments may start to dominate which will give a different color to the leaf. If the leaf undergoes stress, some sort of water stress, nutrient stress, infestation by some insects or whatever then some other pigments may try to dominate. And hence the color of leaf may change. Essentially it is indicated by change in reflectance in the red portion first. For a healthy leaf, reflectance in red will be very low. But when leaves undergo certain amount of stress, or when some other pigment dominates, reflectance in red will increase. If you look at the NIR portion till the leaf is almost at its final stages, except for the red leaf, the NIR reflectance was pretty high.

Because until the leaf's internal structure is damaged completely, leaves will maintain its high reflectance in NIR portion. Only when the leaf's internal structure itself is damaged because of the final stages of leaf or the leaf is about die and fall off, then only NIR reflectance will go down. So, what it means is? NIR reflectance will be relatively higher even when the leaf is undergoing significant amount of stress or some other pigment is dominating.

Like normally we would have seen in our daily life that when vegetation undergoes water stress, when we do not water our plants. After few days, its leaf color will start turning yellow and then the leaf made die. We have observed that. So, when the leaf turns yellow what it means, because of absence of water the plant underwent or undergoing a water stressful, its chlorophyll content is beginning to reduce and it is not able to sustain itself. Some other pigments are now becoming dominant which gives leaves its characteristic yellowish colour or reddish colour. That means reflectance in red has already increased. But till then NIR reflectance will be fairly high. Only when the leaf has undergone change in its internal structure itself like the leaf is now dead, it is now crumbling. Then only the reflectance in NIR will be coming down.

So, if you look at the visible and NIR portion of the spectrum only in these two parts, the first signal of a leaf senescence or the first signal of leaf stress, whatever either due to senescence or due to stress it will be shown characteristically as increased reflectance in red portion rather than decreased reflectance in NIR band. So, you should remember this. I am talking only about visible and NIR range. Whenever leaves are undergoing different stages of life cycle or whenever leaves are undergoing some sort of stress, it will be signaled through increased reflectance in the red portion first, then there will be the change in reflectance along the different portion of visible. Reflectance in green may come down, reflectance in red may increase a lot in compared to green and so on.

And finally only when the leaf's internal structure itself is going to change, NIR reflectance will come down. So, if you compare visible and NIR, visible is pretty useful for understanding vegetation stress or vegetation senescence and so on. So, that is why normally we will see that combining NIR and red portion or reflectance coming in NIR and red portion will help us to understand the healthy or healthiness or how bigger of vegetation that is present in the surface.

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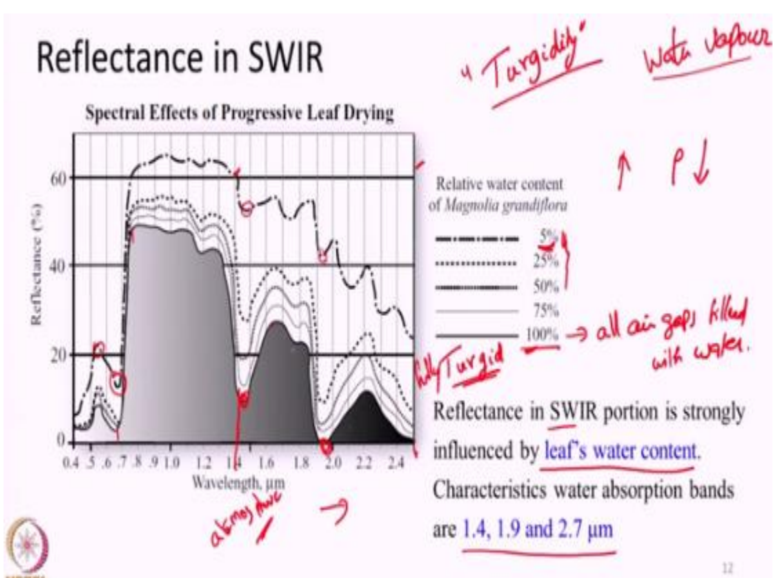

Till now we have seen the spectral reflectance property of vegetation in the NIR and visible portions. Now, we will move on to understanding the spectral reflectance property of leaf in the SWIR portion that has wave length starting from 1.4 to say 2.5 or even 3 micrometers. So, the reflectance in SWIR portion is strongly influenced by leaf's water content. As leaf's water content increases, reflectance decreases in the SWIR portion.

In this particular figure given in the left side of the slide we have plotted leaves with different water content level and how its spectral reflectance will look. Maybe we will start with leaf with 100% water content where all the air gaps are filled with water. We call this the amount of water content and leaf as turgidity. So, turgidity normally refers to the amount of water content within the leaf, it is a general term we use.

And if a leaf is completely filled with 100% water, we call that particular leaf as turgid. It is fully turgid. That is it is filled with water. So, maybe we will start with such a fully turgid vegetation that is the dark black curve given here. This is a typical characteristic healthy vegetation curve that we have already seen, with a very low reflectance in red very high reflectance in NIR.

And if we come to the SWIR portion the reflectance is red in low that is lower than NIR but fairly higher than the visible part. And also if you look only in the SWIR portion, that is after 1.4, we can see as wavelength increases, reflectance goes down linearly. So, this we have to remember. In the SWIR part as wavelength increases reflectance goes down almost linearly, this we have to remember.

And also reflectance in general goes down with increasing water content. So, this is for healthy leaf, this will be the curve. And also there are three strong dips in the 1.4, 1.9 and 2.7 micrometer portions of EMR spectrum. That is as vegetation water content increases this particular absorption bands in this 1.4 and 1.9 will become very dominant and it will become very strong.

And as the leaf's water content decreases say now the leaf water content move to 75%, reflectance has increased slightly and also the absorption band has become slightly less stronger. And as it move higher and higher we can see that this 5% curve, this dotted line the top line reflectance is very high in the SWIR portion. And the characteristic dips seen around this 1.4 and 1.9, micrometers are almost absent.

That is the dips are present only very minimally. And you can also see that even at this stage of very low water content, NIR reflectance is pretty high. Actually it will also increase with the drying out of leaf but you can see that at 5% means vegetation will undergo a significant water stress, and it may not be able to do photosynthesis with full efficiency. And hence, red reflectance is increased also green reflectance increase.

This leaf is not dead nor undergone full effect of water stress. Only water has reduced at that particular time and Hence it shows very high reflectance. So, it means the amount of water content will in general influence all portion, as the water content increases the reflectance will go down. But this is very strongly seen in SWIR portion of vegetation.

So, if you want to study vegetation water stress, the immediate signal will be coming from SWIR portion. It may take some time for vegetation to undergo stress for the change in red reflectance. It may take still longer time for the vegetation or for the leaf's internal structure to completely get disturbed for reduction in NIR reflectance, But in SWIR portion as soon as the vegetation water content changes, the reflectance will change. So, this is one of the most suitable band for studying about how much water content a leaf has. So, as the leaf's water content increases the reflectance will go down, pretty fast in the SWIR portion of electromagnetic spectrum. But if you want to use these characteristic dips 1.4 and 1.9 we will not be in a position to use them. Because we have already seen that, atmospheric absorption also plays a major role in remote sensing.

And the same portions 1.4, 1.9, 2.7 are water vapor absorption band that is present in atmosphere. So, when we take a remote sensing image, we will not be able to clearly see these particular dips. We will not be able to understand whether these dips are due to atmospheric water vapor or due to vegetation water content. So, we will not be using this. But the other surrounding portions here roughly 1.5 to 1.7 or after 2 all these things will carry certain information about leaf water content, which we will use for studying whether the leaf is having water or not.

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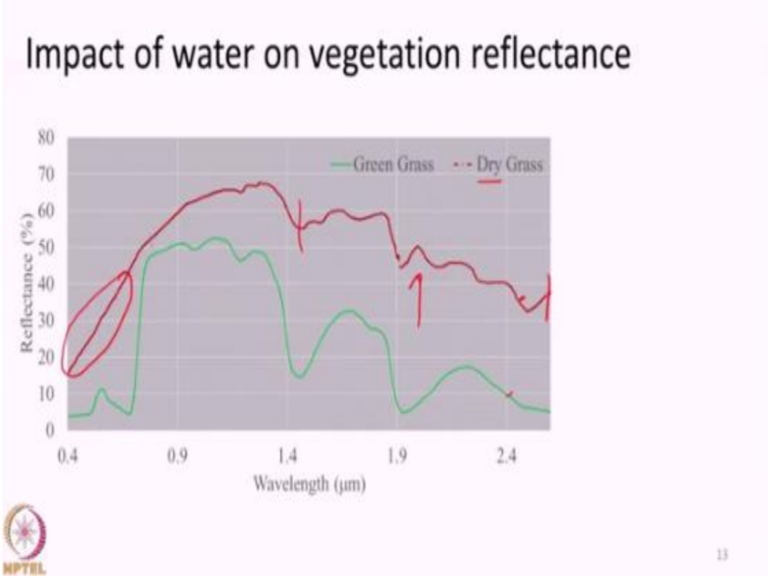


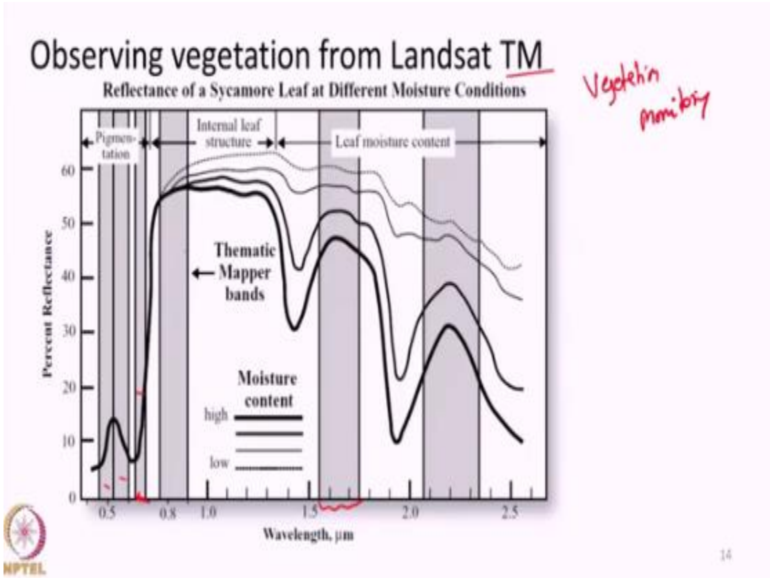
So, this particular slide gives another example of how a green grass and a dry grass look. That is a green grass with good amount of water and a dry grass which is almost dead. You can see as the leaves became dry the reflectance increases in general in almost all bands. And this is undergone lot of stress and hence, the reflectance in visible portion also has changed drastically.

So, very high reflectance in red portion, green portion and everywhere but NIR still remains. So, NIR is, not a very good portion to study the water stress but it helps us to study some other thing, we will see later. But for understanding water stress it is always good to use the SWIR portion which will first show immediate signals.

It will take some lag time or sometime will be used up before water stress influences leaf's pigment and causes a change in leaf color. It will take some time and it will take further time to change the reflectance in NIR. So, as leaf dries out its reflectance will increase. This is what we have to remember.

So, I already told you that the 1.4, 1.9 or the 2.7 micrometer wavelength which are characteristic water absorption bands, we will not be in a position to use it for remote sensing purposes because of atmospheric absorption. So, when Landsat thematic mapper sensor, one of the early sensors

Landsat 5 satellite was launched, its one of the major application was global vegetation monitoring.



So, the bands were chosen such that the different properties of vegetation are observed clearly. That is it has bands in green and red where it absorbs the pigments contained within the leaf and then it also has a NIR portion which will help us to tell whether the leaf is really healthy or not. This signals about leaf's internal structure and it also had a band around 1.5 to 1.7 micrometer range, which will help us to study the leaf's water content.

So, different bands of this particular sensor was chosen such that different properties of leaves or different properties of vegetation can be properly observed and understood. So, essentially in this particular lecture what we have seen is how reflectance of vegetation will vary in the NIR and SWIR portion. So, primarily in the SWIR portion, it is the leaf's water content that controls the spectral reflectance property of leaf.

So, just as the summary of the entire thing, the spectral reflectance curve of vegetation can be divided into three portions, the visible part, NIR part and SWIR part. In the visible part, the leaves pigments or the absorption by those pigments will dominate the spectral reflectance pattern. In the

NIR portion the leaf's internal structure will dominate the spectral reflectance pattern and then in the SWIR portion the leaf's water content will influence the spectral reflectance property.

So, whenever vegetation undergoes water stress, it will be first signaled in the SWIR portion and when the vegetation undergoes some sort of stress because of lack of water for some time or change in growth cycle, then there will be a change in reflectance in the visible portion, because of change in pigments. And later once the vegetation was in significant amount of stress for a prolonged time, then only reflectance in NIR will change. Till then reflectance in NIR will be pretty high. So, with this we will end this particular lecture.

Thank you very much.