Remote Sensing: Principles and Applications
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Lecture No -33
Spectral Properties of Few Common Earth Features in the Visible, NIR and SWIR Bands – Part 7

Hello everyone. Welcome to the next lecture in the course remote sensing principles and applications. Today we are going to continue discussing about the spectral properties of various commonly occurring Earth's surface materials. In the last lecture we discussed about the spectral reflectance property of water and what factors will influence the spectral property. Today, we are going to start with the concept of understanding the spectral reflectance of snow.

So, before moving on to understanding the spectral reflectance of snow we will just get introduced to small introductory concepts about snow.

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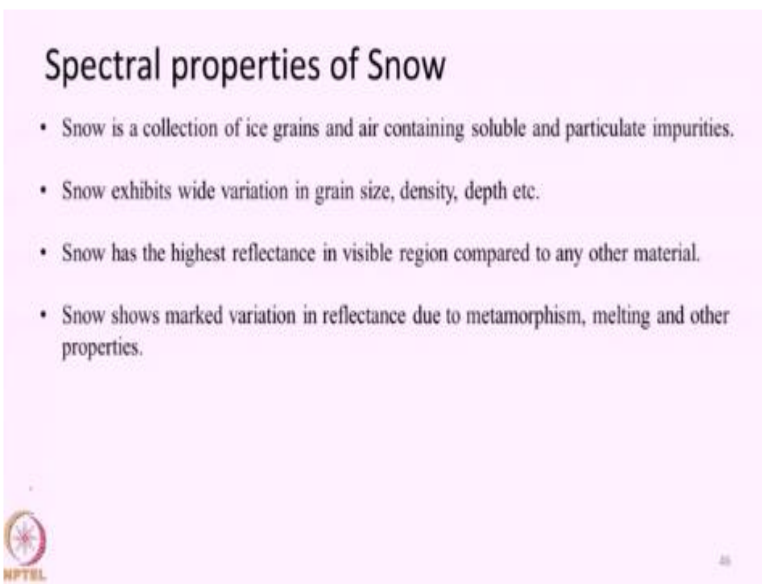

So, snow is nothing but a collection of ice crystals or ice grains, air, water and other contaminants mixed together. The snow occurring at different places in the globe will vary a lot in the size, size means the grain size how big or small the grain sizes, the density or the packing of the snow, the amount of contaminants present etcetera. So, snow exhibits a very high amount of variability from place to place and time to time. And also when compared to any other material in the globe, snow has the highest or brightest reflectance, especially in the visible band. Some of us might have seen snow in real or some of us might have seen it at least in televisions or movies, in which it appears extremely white and bright in the visible domain. So, snow is like the brightest among most other occurring earth surface features.

Snow will be under constant evolution, that is after certain period of time snow will undergo some change. It may become more dense, the grain size may increase or some contaminants may get added to it, etcetera. So, snow shows high degree of change in both spatial and temporal domain. So, when we want to understand the spectral property of snow, we should realize that the final reflectance or the final spectral property, we obtained from snow is an integrated effect of the ice grain, air, water molecules and other contaminants mixed together. So, it is not only the spectral reflectance of ice, but also mixture of several different things that could be present in the snow.

So, some of the factors that influence the spectral properties of snow are first thing is the grain size how big or how small the snow grain size is. Age of the snow, more slightly snow will become larger in size as it ages like more and more accumulation may make it grow larger in size. Hence snow age will influence it. Then presence of any liquid water molecules within the snow will affect the spectral property of snow. Then the solar zenith angle that is the angle in which the sunlight is falling on snow, then presence of any contaminants may affect the spectral reflectance from snow. And also the thickness of the snow packs whether snow is really thick or it is shallow etcetera. All these things will have the ability to change the spectral property of snow.

First we will look at the general spectral reflectance curve of snow and how it changes with grain size as well as the wavelength of observation. Look at this particular slide.

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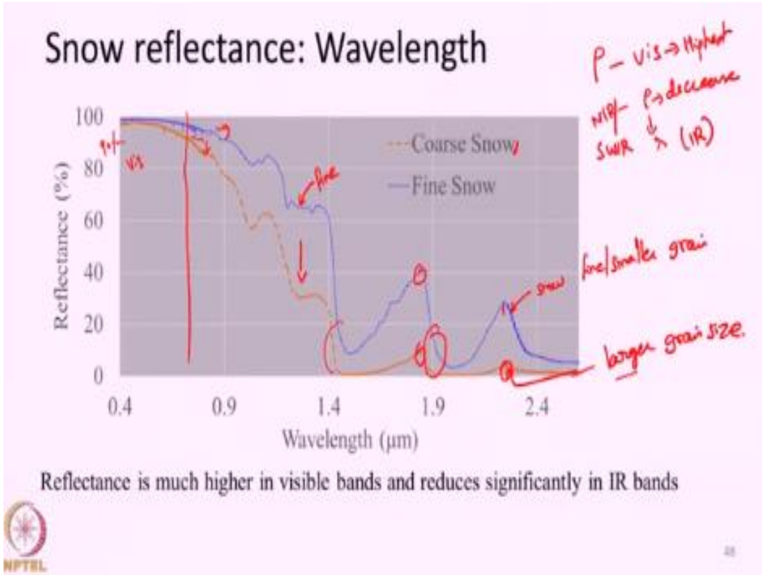

Here, we have plotted two curves, one is the spectral reflectance curve for snow with fine grains and then this orange curve is the spectral reflectance curve for snow with larger grain size. If you look at them, first what we are observing is, whatever be the grain size, the general pattern in visible band say up to 0.7 micrometers, the reflectance of snow is extremely high in the order of about 90%.

So, the reflectance of snow is extremely high in the visible domain. Only when the wavelength enters the NIR band, that is, after it crosses the 0.9 micrometers, the reflectance begin to decrease drastically and after crossing 1.4 micrometers, the reflectance is quite low when compared to the reflectance in visible. So, highest reflectance occurs in visible band and the reflectance begins to decrease in NIR. We can observe the overall decreasing trend as the wavelength increases. So, in general the reflectance will decrease with increase in wave length in the IR domain. Except these two small peaks almost the overall trend of reflectance is coming down or decreasing as the wavelength increases starting from NIR band. So, this is the general property of snow or general spectral reflectance curve for snow.

Snow with coarse grained or larger grain size will have still lower reflectance than snow pitches composed of fine grains. So, finer the grain size higher will be the reflectance, coarser the grain size or larger the grain size lower will be the reflectance. So, this will be in general applicable across all bandwidths.

And this effect will be more pronounced in the NIR and SWIR ranges. So, we will again go back to the curve. Here if you look at or compare both the curves, the difference between both the curves is very minimal in the visible domain. Both the curves are almost close to each other. Once we cross this 0.8 micrometer, when we enter the NIR portion of electromagnetic spectrum the differences begin to increase.

As we progress or as we increase along the wavelength, we can observe larger difference in reflectance between fine grains snow and coarse grains snow. These differences again highly amplified in the SWIR domain. This is one thing and also we can note a characteristic dip closer to the water absorption bands. So, in general to understand the spectral reflectance property of snow, snow has very high reflectance in the visible bandwidth and the reflectance begins to decrease starting from NIR and the reflection decreases as wavelength increases.

Then for fine grained snow or snow pack with smaller grain size, the reflectance will be higher than the snow with larger grain size and this difference in grain size is highly amplified in the infrared domain especially in NIR and SWIR domain of electromagnetic spectrum.

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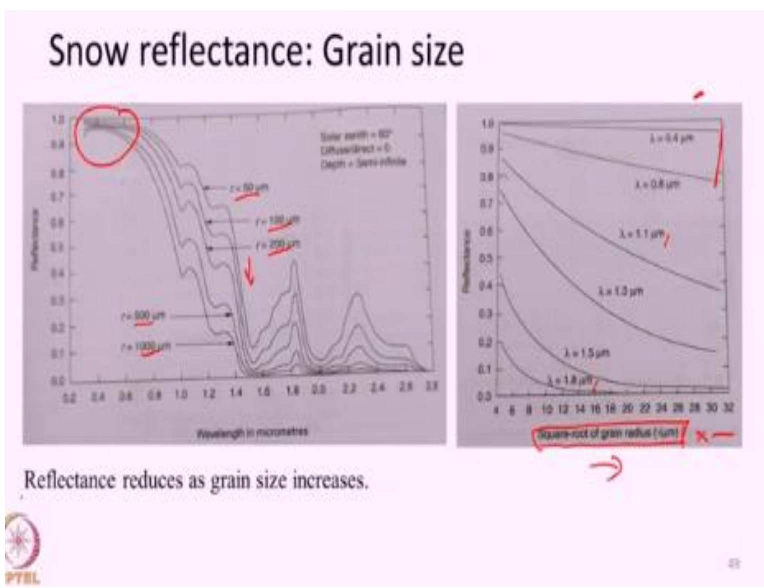

So, this particular slide further emphasizes how grain size influences the spectral reflectance of snow. So, the figure given in the left side, spectral reflectance of snow having grain size with varying radius is being plotted. The radius starts from 50 micrometers and goes all the way up to

1000 micrometers. We can observe, as the grain size increases the reflectance keeps on decreasing continuously.

The difference is not much in the visible domain, but it is much higher in the NIR and in SWIR domain. Here we can see how the reflectance varies as a function of square root of grain radius. So, in x axis, we have square root of grain radius, in the y axis we have the reflectance. We can see in visible domain or even up to say 0.8 micrometers, the change in slope of this curve is fairly shallow, which signifies that the reflectance does not vary much with the increasing grains size up to 0.8 micrometers. Once we cross this 0.8 micrometer domain, then the reflectance begins to increase quite fast as the grain size increases.

This signifies that grain size plays a major role in controlling the reflectance of snow and this difference is highly amplified in the infrared domain of electromagnetic spectrum.

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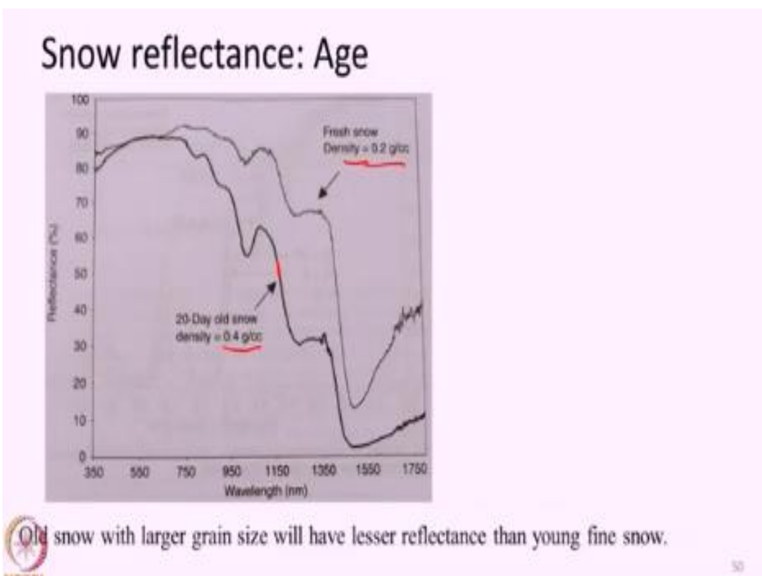

The next feature that we are going to see is the snow age. We have already seen that as a snow ages or becomes older, the grain size tends to increase more and more. It may become densely packed and the grain size may increase and when the grain size increases, we know the reflectance will decrease. So, in general as the snow ages the reflectance decreases primarily because of increase in grain size. An example is given here in this particular slide.

So, this is the spectral difference of fresh snow with the density of about 0.2 grams per cubic centimeters. Here it is a 20 day old snow, this dark black line with a higher density. So, as the snow becomes older, it will get more dense and its grain size will increase leading to a decrease in spectral reflectance observed.

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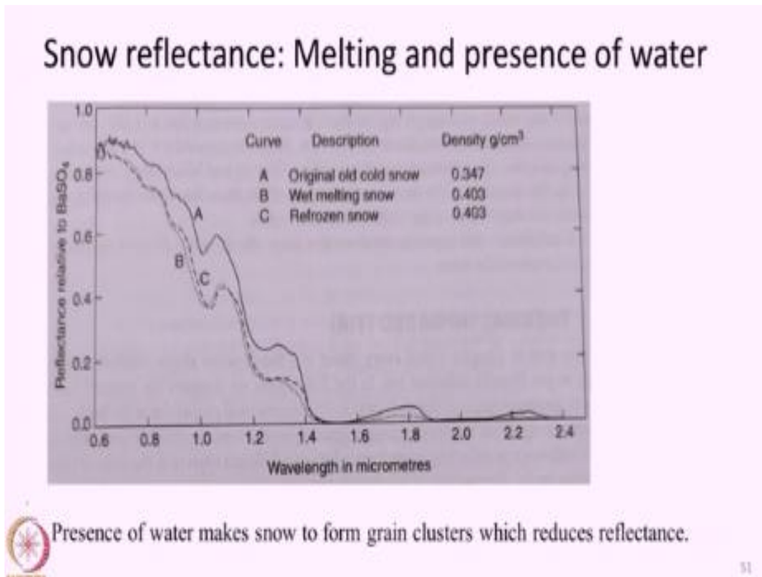

Then snow may undergo process of melting and refreezing or water may get added to the snow pack. So, presence of water in the snow pack will make the snow to form larger clusters. Snow particles may tend to form cluster when water droplet is present in it. And in general it becomes one large mass or one large cluster. Many number of smaller grain crystals may surround it and became one larger cluster which will affect the spectral reflectance.

So, primarily if snow forms cluster because of presence of water molecules within it, then its reflectance will go down because it is more related with the change in grain size rather than the presence of change in water. And also once snow melts and then refreezes the reflectance may not be as high as the first initial phase. That is given here in the slide.

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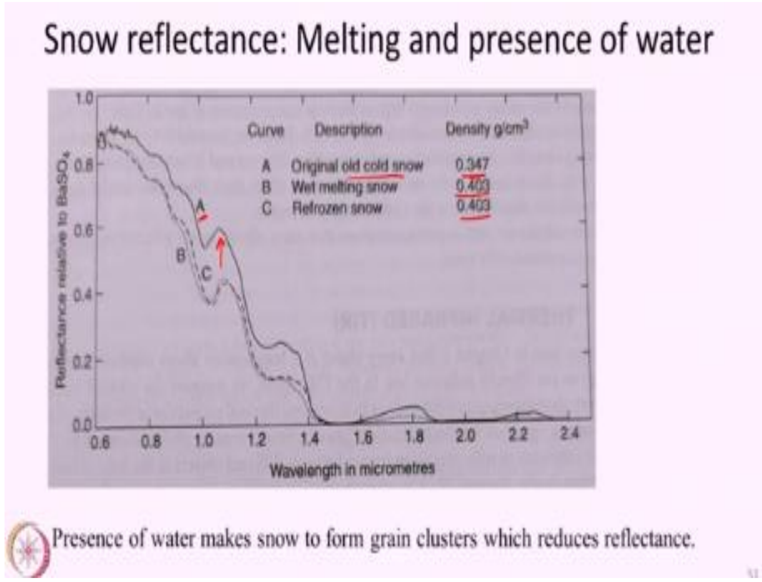

Say here the spectral reflectance curve A indicates original old cold snow with some density value. Then when the snow melts the reflectance curve falls to curve B which is a dotted black line represented here. So, the reflectance decreases as the snow melts. Then the same snow refreezes, but for the refrozen snow, the reflectance will not increase as much as the original condition.

Reflectance will increase from the melted state, but still the density has increased and hence the reflectance will be lower than the original reflectance. So, presence of water will try to bring down the reflectance of snow particles.

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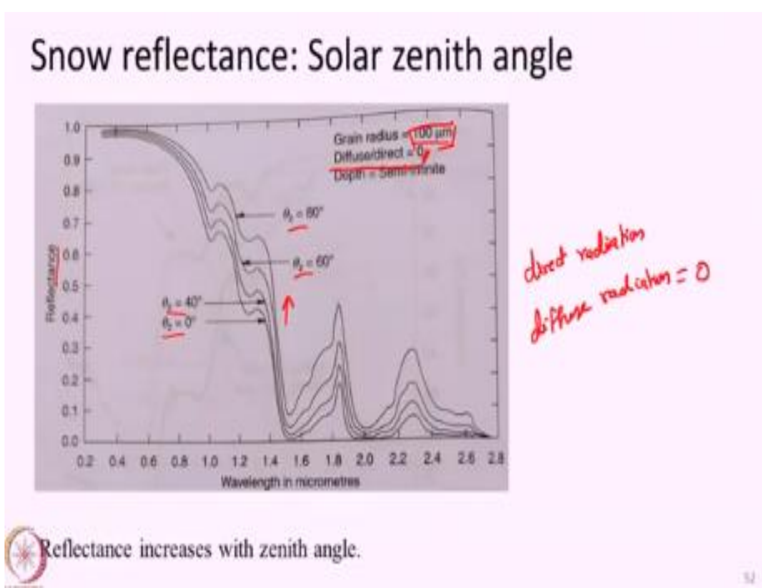

The next property we are going to observe is the solar zenith angle. So, solar zenith angle basically signifies in which angle solar radiation comes and falls on the snow pack. So, in general as the solar zenith angle increases the reflectance will increase. Let us assume that the sun is directly shining from overhead of the snow surface, that is zenith angle is 0. If that is the case, we can measure one sort of reflectance curve. Then as the sun's zenith angle increases, the snow pack reflectance will increase. So, an example is given in this particular slide. Say here you can see the reflectance curve is plotted for one particular snow grain size with varying solar zenith angle. So, we can observe in general the reflectance increases as the solar zenith angle increases.

And everything is measured with direct solar radiation. So, whatever is the energy measured or plotted in this particular curve everything is primarily due to the direct radiation from the sun. And the diffuse radiation is completely controlled for building this curve and diffuse radiation is 0. So, that is why the diffuse to direct ratio is given as 0. This is because objects may behave differently under the influence of diffuse radiation. So, in order to understand the effect of direct solar radiation, controlled lab experiments are carried out, where the diffuse radiation was completely cut out and only direct solar radiation was allowed to fall.

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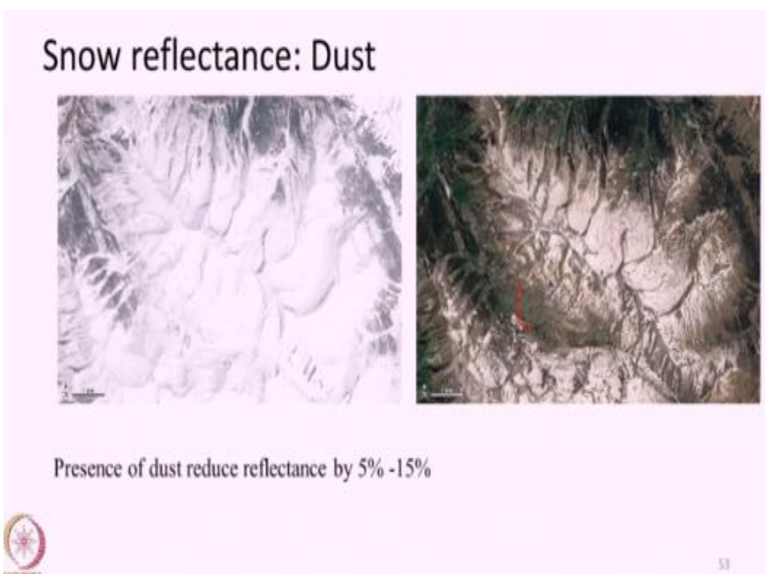

And finally presence of any contaminants, so I told you before that snow has the highest reflectance among most of the commonly occurring earth surface features, especially in the visible domain. So, whatever be other objects, when it falls on snow, it will reduce the reflectance of snow. Say some sort of dust, some sand particles, some vegetation, whatever falls on snow will in general have low reflectance than the original reflectance of snow.

This is highly true in visible domain. So, presence of any contaminant will decrease the overall reflectance of snow. A very good example is given in this particular slide. So, here we can see a fresh snow taken during just after winter on the left side and on the right side it is taken after certain time period in spring and in summer season where a large fraction of snow has melted. And due to this spring and summer season a lot more particles got travelled and got settled in top of the snow cover. And this changes the total reflectance of snow. So, deposition of any dust particles over the snow will lower its reflectance, which will alter the energy balance of the snow pack, it may faster or it may make the melting to occur more fast.

So, the presence of dust will not only change the reflectance, it also has a larger implication in maintaining the surface energy balance of snow. So, this covers the spectral reflectance property of snow basically. But remember one thing, whatever the spectral properties or whatever the different factors that control them, we have discussed with most of the curves have been obtained under strict lab conditions. Also in the previous example about the solar zenith angle, in order to study the property of snow only under the influence of direct sunlight, diffuse skylight was made zero by controlling other factors in the laboratory. It is possible only in controlled lab conditions. But during field experiments or during field visits, we may not see the patterns.

A very good example for this is soil. When I explained about the properties of soil, I told you that fine grained soils like silt or clay has higher reflectance than coarse grained soils like sand. This is under lab conditions, but under field conditions this may be completely reverse. Fine grain soils like clay or silt may have lower reflectance because of various other factors involved. So, on field and in laboratory, the conditions may be extremely different. And we should always apply our due diligence when we try to compare the spectral reflectance curve obtained during field measurements with the spectral reflectance curve obtained under controlled laboratory conditions.

We should always consider what are all the differences or what are all the other factors that may play a role in changing the spectral reflectance curves obtained under field conditions. So, if we look, different remotes sensing images, and if the image has both snow and cloud, then there may be a confusion for us to identify which one is snow and which one is cloud. We may be able to identify using some other features like snow may be occurring over a large part or clouds may have some specific patterns or it may cast shadow on the ground. All those things may act as close to us when we look at an image. But how to differentiate cloud and snow spectrally? We will see if from this particular slide.

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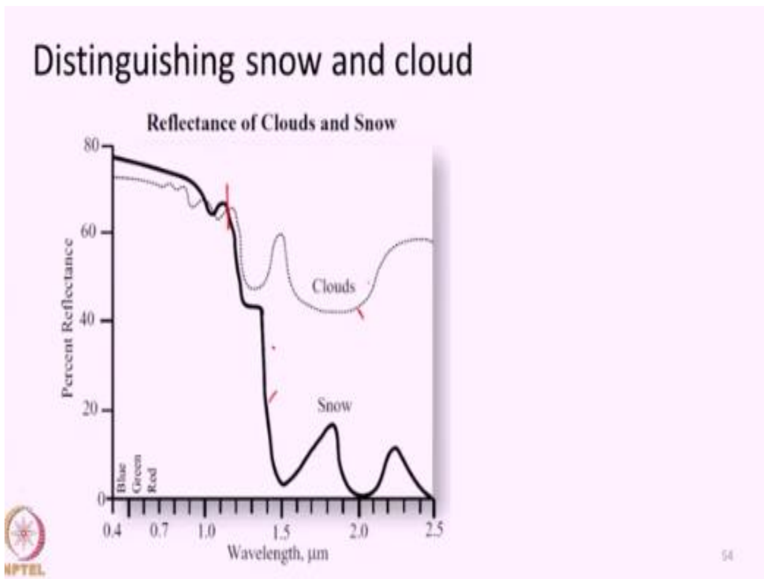

So, in this slide the spectral reflectance curve of snow and cloud is actually being represented. So, here you can see in the visible domain or even up to NIR bandwidth, the reflectance of snow and cloud are more or less similar. So, it will almost be impossible for us to spectrally differentiate cloud or snow up to NIR domain say up to 1.4 micrometers. But once we cross the 1.5 micrometer domain, then the reflectance of snow will decrease drastically, but cloud will still have higher reflectance.

So, the best possible band to observe cloud or to differentiate cloud and snow will be the SWIR band, short wave infrared band greater than 1.5 micrometers. In wavelength less than this value or less than this threshold, reflectance of snow or cloud will be more or less the same and we may not be able to differentiate them spectrally. So, with this we end the spectral properties of snow.

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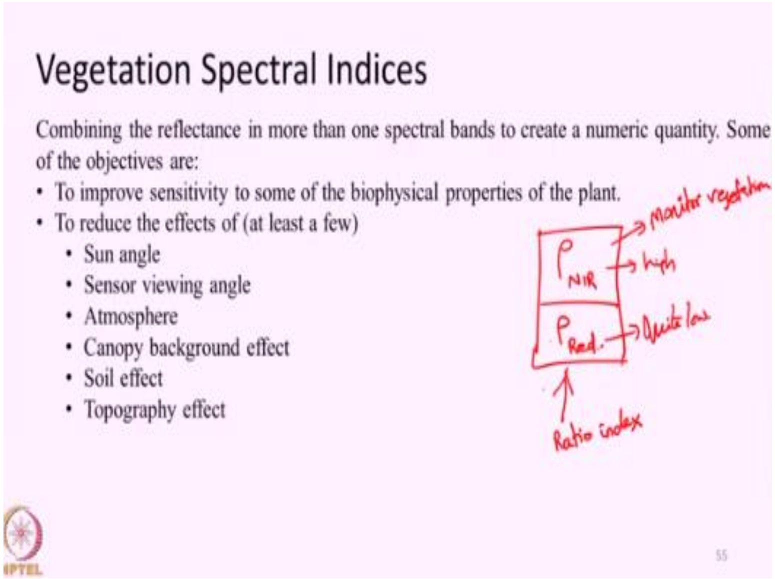

The next topic we are going to enter is what is known as spectral indices or more commonly known as vegetation indices. I prefer to use the term spectral indices, because nowadays such indices are being developed and used, not only for studying about vegetation but also for various other features on the earth surface. So, in common we will use the term spectral indices. But when we talk especially about vegetation, then we may use the term vegetation indices.

So, spectral index is a combination of reflectance in more than one band of electromagnetic spectrum. Here band, especially I am talking in wavelength less than 2.5 or 3 micrometers, that is visible, NIR and SWIR domain. So, if we combine the reflectance of certain feature in more than one band, such that the combination produces one single numerical value out of it.

Like we may divide one over the other, we may add something or we may multiply one with some other factor whatever. Essentially we are combining the spectral reflectance of feature in two or more than two different bands such that they produce one number, one numerical value. And by looking at that particular numerical value, we will be able to tell some information about the physical or other properties of that particular feature of interest.

So, one of the earliest spectral indices that was developed is a ratio index that is for vegetation. Say in olden days when remote sensing was primarily used for understanding or monitoring the vegetation, people were having difficulties in comparing the spectral reflectance images acquired during different dates or during different places etcetera. As I told you the spectral reflectance curve we obtained from remote sensing images may not only be affected by the terrain. But it may also be affected due to surface topography, solar illumination angle, atmosphere and various other factors. So, in order to remove those effects, people were trying different concepts or different methodologies. One such simple methodology that was developed was using a ratio index.

So, ratio index is just dividing the spectral reflectance or reflectance value in the red band or combining the spectral reflectance value in red band and NIR band. That is ρ_{NIR} by ρ_{red}. So, this was one of the earlier developed spectral index we call it as the ratio index. Because it is a simple ratio dividing the spectral reflectance in NIR band by red band. And the primary use of this is to monitor vegetation.

That was the major aim with which this index was developed. So, what it will do, if you look at this, NIR is in the numerator red is in the denominator. So, we already know that for a healthy vegetation NIR reflectance will be quite high and red reflectance will be quite low. And when vegetation undergoes stress, red reflectance will increase. We have seen how red reflectance has increased and how blue shift occurs that is how the redshift move towards the shorter wavelengths. Those things we have already seen.

So, for a healthy vegetation this ratio will be very large and for stressed vegetation or some sort of diseased vegetation, this ratio will be smaller. So, just by looking at the value people were able to get some information about the vigor of vegetation, vigor means the healthiness of vegetation. And also by using this ratio, people were also able to remove some effect of topography, solar illumination etcetera. These two are like contiguously placed bands next to each other. So, the effects may be more or less equal. So, when people took the ratio of these two spectral reflectance values, they were able to observe the features more clearly or they were able to reduce the effect of topography, solar illumination and various factors. So, the primary aims of developing such ratios or such spectral indices were to increase the information content about any one biophysical property of the feature that is under discussion.

Let us see, here is an example showing how healthy a vegetation is. So, just by looking at this number, this ratio value, we will be able to tell higher the number, healthier the vegetation is. That sort of simple analogy we will be able to reach. And also, it will reduce some other unwanted effects due to topography, solar illumination, atmosphere and so on. So, spectral indices help us to remove some unwanted effects and also brings to the front more clearly some important biophysical characters about the feature of our interest. So, this was one of the earliest spectral index that was developed. But the problem here in the ratio index is, the values are unbounded. Unbounded in the sense, let us say due to some reason, the reflectance in red goes very close to zero. Then the ratio becomes extremely high, it will approach towards infinity. And also due to other reasons or even the difference due to calibration may take the index to negative values. Sometimes it will happen.

If you process some satellite data, you will understand. Due to the varying calibration constants used, some reflectance value may go to negative region. Mathematically it will happen but not physically. So, under certain circumstances, the ratio or the number may behave very widely. It is unbounded, as red reflectance decreases the value may increase suddenly. All these problems will occur. So, from this particular simple ratio index, people started developing other indices. So, that simple biophysical factor can be studied more in detail or in a clear way and at the same time some other unwanted effects will be removed.

So, in this particular lecture we have seen about the spectral reflectance property of snow, what factors will influence the spectral reflectance properties and also, we have started discussing about what is known as a spectral index. So, in the next lecture we will see or we will get introduced to some of the few commonly used spectral indices and the major applications for which they are employed. With this we end this lecture.

Thank you very much.