Remote Sensing: Principles and Applications
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Lecture No -24
RS Image Acquisition and RS Systems – Part 7
(Spectral Resolution)

Hello everyone, welcome to the next lecture in the course Remote Sensing principles and applications. Till last lecture we discussed in detail about data collection procedure, characteristic or spatial resolution concepts and h ow objects of small scales can be detected in pixels with a much larger size and so on. This lecture we will move on to the next concept of spectral resolution or the spectral characteristics of a remote sensing system. What is meant by spectral characteristics of a remote sensing system?

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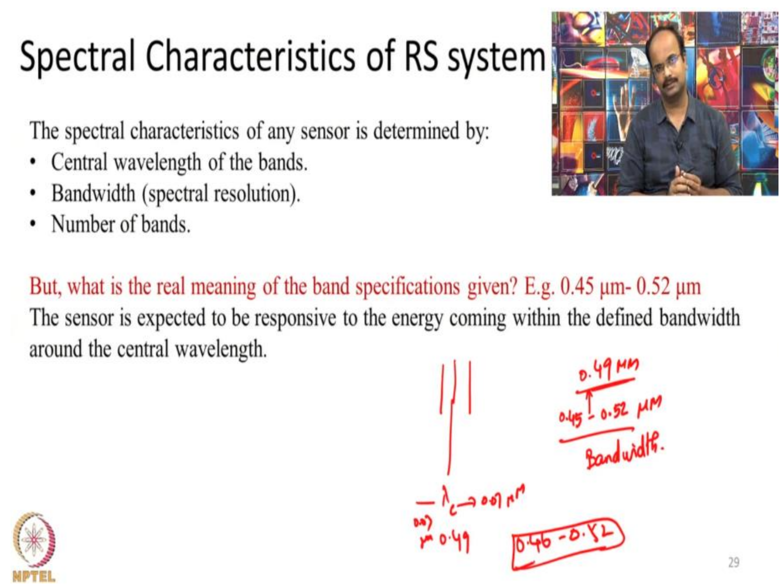

The spectral characteristic of a system is given by first thing the number of bands, how many number of bands does a system has. Then the central bandwidth for each band and then the bandwidth. Say for example, if we say Landsat 7 has 8 bands, including panchromatic, each band has its own central wavelength and a bandwidth surrounding it. Say for example let us say 0.45 to 0.52 micrometers is the bandwidth then the central wavelength of data collection may be around 0.49 micrometer. So, this is λ_c central bandwidth and on both the sides we have 0.03 micrometers.

So, a central wavelength, bandwidth surrounding the central wavelength and the number of bands all these together will define the spectral characteristics of a system. Among these things the spectral bandwidth 0.45 to 0.52 that is 0.07 micrometers, this bandwidth defines the spectral resolution.

So, it is easy for new learners to get confused between the number of bands and spectral resolutions because we have heard young students telling that number of bands is equal to spectral resolution. There is not the case spectral resolution is actually for each band, what is the bandwidth for each band? The bandwidth designated for each band will give us the spectral resolution. So, 0.45 to 0.52, bandwidth of 0.07 micrometers, if you compare this with 0.45 to 0.47, 0.02 micrometers then 0.45 to 0.47 has a finer spectral resolution than 0.45 to 0.52 always keep this in mind that the bandwidth defines the spectral resolution.

We are talking about a central wavelength, bandwidth surrounding and all. What exactly are these, how these things are important? A sensor with a given bandwidth will be or a spectral band with a given bandwidth will be more sensitive to a incoming radiance within that particular bandwidth.

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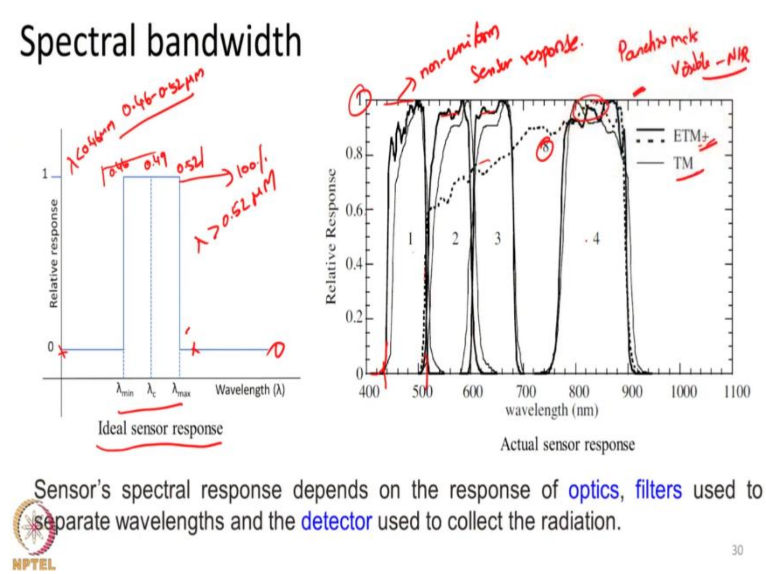

That is, please see this particular figure, on the left side I have what is a ideal sensor response? How ideal sensor or in theory how a sensor should responds to incoming signal? Let us assume some bandwidth for this, let this λ be central wavelength 0.49. let this be 0.46 let this be 0.52. So, this sensor or this band collects data between 0.46 to 0.52 micrometers. If this is the case, in theory or in an ideal sensor it should not produce any output for any radiance coming in wavelength less than 0.46 micrometers and similarly for wavelength greater than 0.52 micrometers. It should not produce any output, output should be 0. On the other hand any radiance coming within this particular spectral bandwidth should be producing signal with 100% efficiency.

The sensor should collect all energy coming within that particular band and should filter out all energy coming outside the band. This is how an ideal sensor should work. Outside this bandwidth everything should be 0 and within the bandwidth the sensor should work with 100% efficiency. In reality this ideal response will not happen rather we will have something what is given on the right side figure. Here this shows the spectral response of different sensors Landsat thematic mapper sensor, Landsat ETM+ sensor and so on. The numbers here denotes different bands within the sensor and you can see it is not perfect like a box given here, it is slightly curved and it is not having 100% efficiency. That is the relative response is not 1. It is slightly less. Even within that particular bandwidth the sensor responses are actually not uniform and within the designated bandwidth sensor will not work with 100% efficiency in all the wavelength within the bandwidth say 0.45 to 0.52 means maybe in 0.46, it may have 100% efficiency, in 0.47 it may not have and so on. So, the incoming energy will not be measured as 100% of incoming level but with some amount of weightage.

So, a sensor with 0.8 relative responses will just collect only 80% of incoming energy and so on. So in reality a sensor response is not similar to what we saw in the ideal case, there will be difference even within the given bandwidth. So certain bands has or certain sensors has different kind of response in different band. This is band 8 for ETM+ sensor which collects data in the entire visible and NIR portion of the spectrum with a very improved spatial resolution. So, look at this particular band, band 8 around this 0.5 micrometers and all. the response is pretty low, something around like just 0.6 whereas the response increases only around this 0.8 micrometers and so on. So, within the selected bandwidth itself sensors will have differing response to the incoming radiance.

We see even within the band there are still some amount of complexity like sensor is not responding uniformly across all wavelength even within the selected bandwidth. So, how people define this bandwidth? People assume the sensor response curve is actually a Gaussian curve and then we get to a concept of what is known as full width at half maximum, we will see it in detail in the next slide.

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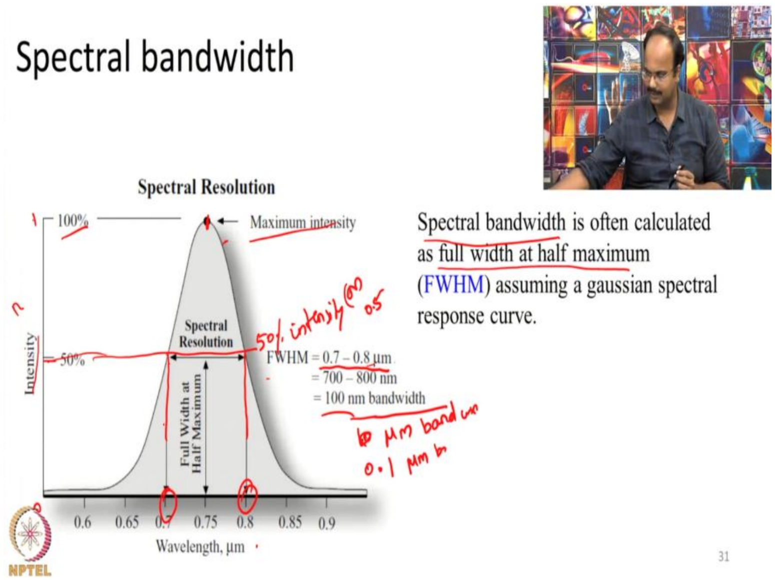

So, this is how the spectral bandwidth of a sensor is often defined. The concept of full width at half maximum, that is, say this is the intensity of the relative spectral responses 0 to 1 factor we will assume. We assume the spectral sensor response is Gaussian in nature or it looks very similar to normal distribution. This is response of factor one or 100% intensity. Everything is exactly stored. So, that is the case and if this is a Gaussian function, there will be some point at which the curve will be at 50% intensity or 0.5 of relative response. So, along the x axis you project this and we will say that the full width at half maximum that is the width along the x axis along the wavelength axis at which the sensor produces 50% efficiency is actually between 0.7 and 0.8 micrometers. That is 0.1 micrometer bandwidth or this is 100 nanometer bandwidth.

So, this is the bandwidth we are interested upon for this particular sensor. Here we assume the spectral response is Gaussian in nature that is for a given incoming signal a sensor will have a Gaussian curve of response. So, we will be able to define a peak point with 100% efficiency and then we will be able to define a range with in which the sensor is working with 50% efficiency. So, for that 50% efficiency at which wavelength it is producing it. We will find the wavelength and that will define the spectral bandwidth. In this example it is 0.7 to 0.8. This is assuming sensors have a Gaussian bandwidth. How this bands are actually defined, we need sensors with multiple bands and hence for each sensor for each band, we will use particular optics, filters and proper detector elements in order to make each sensor sensitive to one particular bandwidth.

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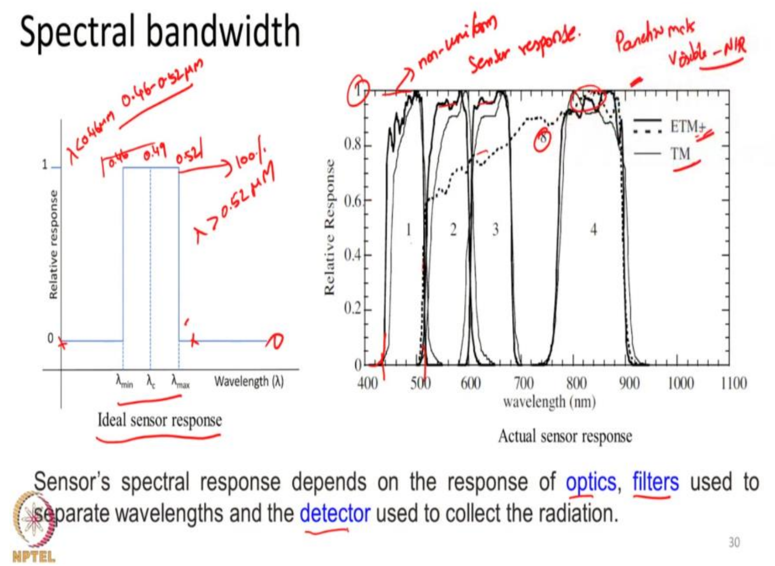

That is there will be a detector. It will have a series of optical elements and filters before it. Those filters will remove unwanted wavelength. Say if a detector has to sense only green wavelength or energy coming in green wavelengths, 0.5 to 0.6 micrometers, they will have filters before it which will remove all other wavelengths and only green will be allowed and also the detector element itself will be sensitive to this particular wavelength. So, in order for us to get multi spectral observations, we use the optical filters and specifically made detector elements which helps us to collect data over different bands.

So, all these elements together will define to which wavelength the sensor is actually responding and that is why many elements are involved and the complexity of the system increases. And hence the response is not matching the ideal case and we saw the concept of full width at half maximum. We assume sensor response is Gaussian in nature, we will be able to identify central peak with 100% efficiency and then we will also be able to identify two points with 50% efficiency. In reality it is not possible for all the sensors. So this slide shows the relative sensor response of different bands like green band, red band, NIR band and short wave infrared bands for different sensors.

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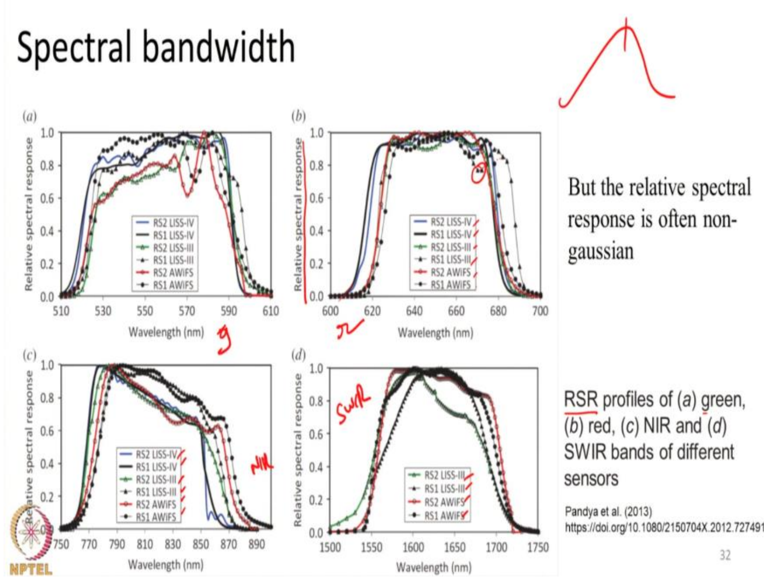

The sensor names are listed here, primarily they are launched by ISRO. So, we can see from this. the spectral response of sensor is not even close to Gaussian. Instead of having one single peak, we have a flat curve here, a high amount of variation here, a long tail here and so on.

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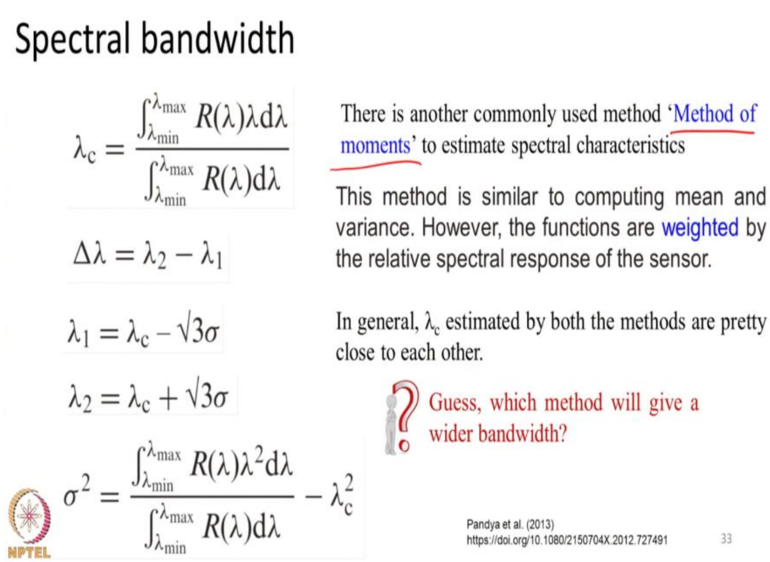

So, ISRO scientist used a concept of what is known as the method of moments in order to define the spectral bandwidth. So, we are not going to go into the details about the method of moment's. Interested people can look at the textbook, fundamentals of remote sensing by Doctor George Joseph or you can also look at the paper referred in this particular slide Pandya et al, 2013. But the basic concept is people use statistical measures very similar to mean and variance to define this spectral bandwidth. So, why I am telling this here is, full width at half maximum is not the only way with which we define the spectral bandwidth. If you look at some specifications, they may put the bandwidth as full width at half maximum. So, we have to assume that this bandwidth is defined assuming the concept of full width at half maximum. So, it means within that particular bandwidth we are very sure, sensor will have at least 50% of response and that is what is known as full width at half maximum concept. So, here if you look; if the bandwidth is defined as 0.7 to 0.8 micrometers then the response from the sensor will be at least 50% of its peak value.

So, within the particular band it will always be at least 50 or more than 50. So, this bandwidth only we define as full width at half maximum. But method of moments is slightly different; it works in the very similar concepts of calculating mean and variance for a continuous distribution function. We are not going to go in detail about it, but just remember full width at half maximum is not the only way of expressing spectral bandwidth. So, now we have some idea about what the spectral bandwidth means. Within that particular bandwidth the sensor will have its maximum response. If we take into the concept of full with the half maximum the sensor collects data with at least 50% efficiency within this bandwidth. So, the location of central wavelength and the bandwidth around it, will help us to identify or will help us to classify different features or different objects on the Earth's surface.

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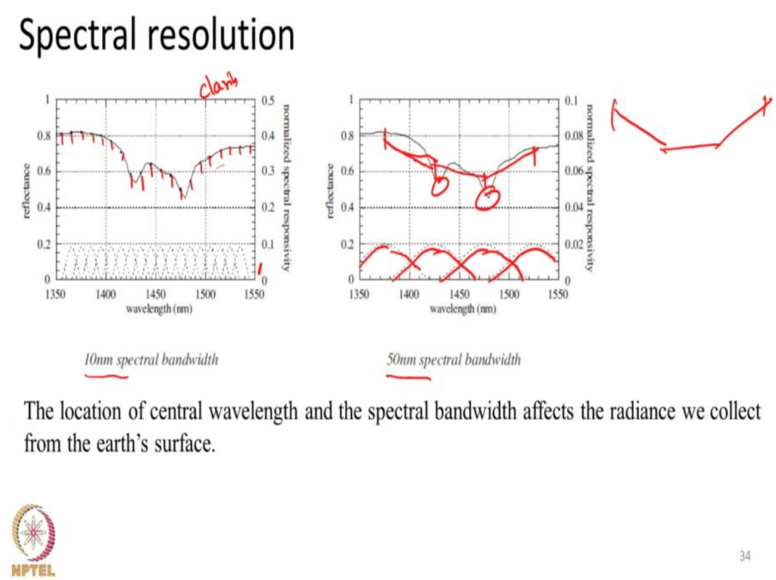

So, let us see an example here. In this particular figure the black dark line is actually a spectral reflectance of any one object. Let us assume for some object, we have measured the spectral reflectance in different wavelength and we have plotted it as a thick dark black line. On below it we have what is the spectral response function of different bands. Here we have many bands each having 10, nanometer spectral bandwidth.

Here, we have smaller number of bands with 50 nanometers spectral bandwidth. So, here we are following the concept of full width at half maximum, we are assuming all bands are behaving in Gaussian way. So, here we have more number of bands with much shorter spectral resolution or much finer spectral resolution 10 nanometer; here it is 15, nanometer. So, we will have more number of samples collected.

Each black dot is one spectral sample each band collects data along the spectral reflectance curve because we have many number of bands with much finer spectral resolution. However here we have only four bands, so there are only 4 samples. So, using these 4 samples, if we join them just imagine how clear we will be able to get this spectral reflectance curve. So, this will be something like this. So, 0.1 here, 0.2 here, 0.3 here, 0.4 is somewhere here.

It is the shape that we are getting here is much different from what we are getting here. We are actually missing this absorption features, but if we use fine spectral resolution with many number of bands, we will be able to sample the spectral reflectance curve with much more clarity or in a more clearer way. So, having many number of bands with finest spectral bandwidths will help us to properly collect spectral information about the object.

Say you have 100 bands for a same pixel and those 100 bands are very close to each other contiguous bands. If you plot all of it wavelength and reflectance we will be able to exactly replicate the spectral reflectance curve for that particular pixel. So, that is why a hyper spectral remote sensing develops.

So, hyper spectral remote sensing means hyperspectral sensors will have a large number of contiguous bands with finer spectral resolution. Large number means the number of bands will be

100, 200 and so on, not like 10, 20 it will be hundreds of bands. Contiguous bands means it will be continuous 0.45 to 0.46, 0.46 to 0.47, 0.47 to 0.48. Much finer spectral bandwidth, it will not be like 100 nanometers, it will be 10 nanometers or even shorter. So, the advantage of having such more number of bands with finer bandwidth is, if for a particular pixel, if you collect reflectance for all the bands and plot them as x axis wavelength y axis reflectance for each pixel, we will be able to properly replicate the spectral reflectance curve for that particular pixel.

Let us imagine the entire pixel is covered with vegetation. So, we will be able to replicate the spectral reference curve of vegetation for the pixel. Almost all the absorption features and everything will be clearly obtained. So, this is really important where to put your bands how many bands everything will define what we get as our spectral output.

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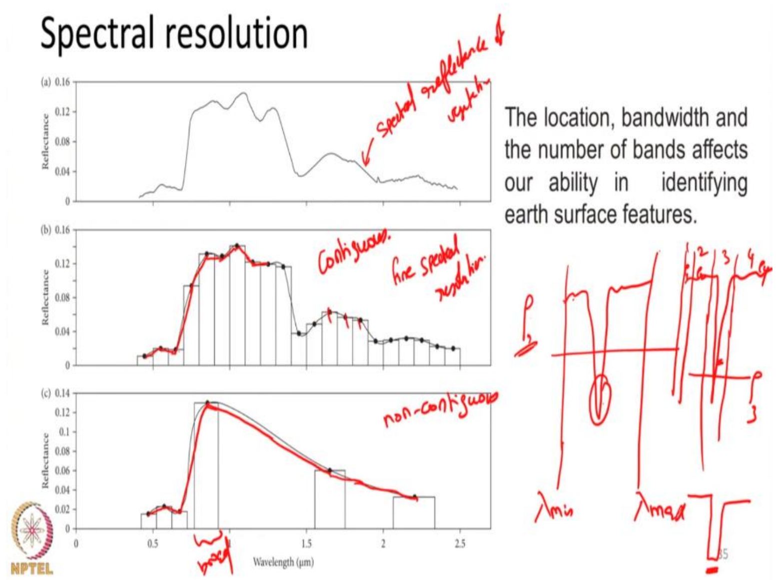

So, this slide is actually another example of the importance of spectral resolution. So, here, this is the spectral response or the spectral reflectance curve of vegetation. This is how it will look for different wavelengths, this is the reflectance. So, let us say we are collecting data using a fine spectral resolution sensor with multiple bands. So, there are many number of bands and each dot represents one spectral sample.

So, let us assume the spectral resolution is much smaller in the order of 10 nanometers. So, for each sample if you join each dot, we will be able to replicate the spectral reflectance of vegetation properly. It more or less represent the spectral effects of vegetation, even if we join them linearly some features we may miss but we are still getting the major absorption features. Here we are not having continuous bands. So, we will not be able to get the proper spectral reflectance curve of vegetation. For vegetation, it is having a smaller number of bands will provide lot of information.

But for other features especially like earth science people who work towards attraction of minerals identifying different types of rocks. For them each and every minute absorption feature in the spectral reflectance curve is very important. Maybe we will see little bit more detail about the absorption features and all in later lectures. But what I want to say is the number of bands, the central wavelength of each band and the spectral bandwidth are essentially the spectral characteristics of the system that will define the amount of information or the proper spectral information that we collect.

Because only within that particular spectral bandwidth we are collecting data, you can just think it analogy with spatial resolution. In spatial resolution what happens whatever the features present within the GIFOV everything will be averaged out and we will get one single value. Similar concept here, whatever be the spectral reflectance within a given bandwidth, we will be finally getting an average reflectance for the band because this is our bandwidth λ_{min} and λ_{max}. We will be getting a average reflectance recorded in our sensor, we will miss this fine absorption feature.

Let us imagine now we have a sensor or we are using a very fine spectral bandwidth like this. In this case, the reflectance may be somewhere here because of our fine bandwidth. If we average everything this will be somewhere here and hence now I have four bands 1, 2, 3, 4. So, this will be rho 1, rho 2, rho 3, and rho 4 if you plot rho 1, rho 2, rho 3, rho 4, it will be like this rho 1, rho 2, rho 3 and rho 4. So, if you use many number of fine spectral bands, we are able to get this absorption feature properly with some accuracy. If we use a single broad band everything is averaged out you are getting only one rho as output.

So, the spectral characteristics of a system will define the information we collect in the spectral space and whatever the energy coming in within that particular spectral bandwidth will be averaged out. So, finer the spectral resolution we will be better able to capture the finer absorption patterns within the spectral reflectance curve.

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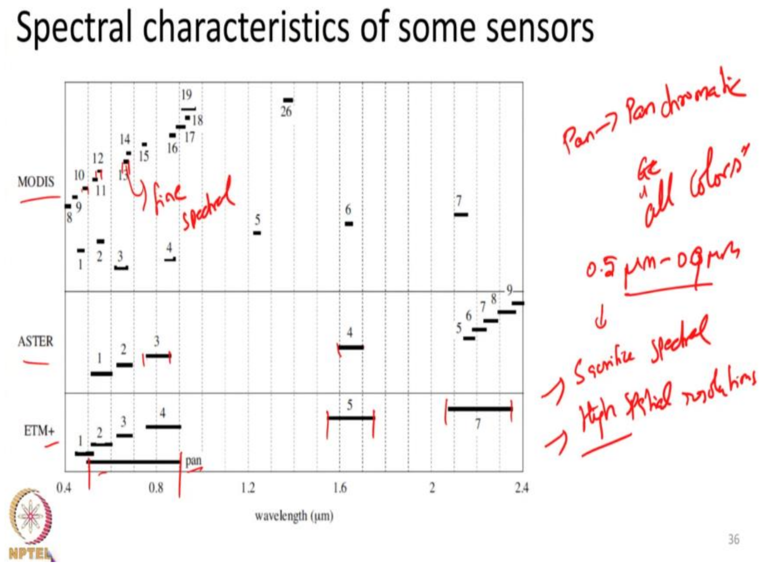

So, this line gives you spectral characteristics of some sensors. This is ETM+ sensor, ASTER sensor, MODIS sensor and so on. So, here you can see what is known as a pan band written as pan, which is panchromatic. So, panchromatic generally means all colors chroma means colour. So, essentially panchromatic band spans a very large bandwidth. Spectral resolution maybe here 0.5 to 0.9 micrometers.

The reason for having a panchromatic band is to sacrifice spectral resolution. But get high spatial resolution. So, we will talk about this in detail. The tradeoff between different resolutions, but still imagine panchromatic generally means a band which is in visible and in NIR range. It will have a very wide bandwidth spanning across entire visible and some in NIR.

We are concentrating on increased spatial resolution instead of the cost of spectral resolution. We are increasing the spectral bandwidth there by losing spectral resolution. But which will help us to achieve high spatial resolution maybe we will see it in detail in the later classes but just imagine panchromatic band means a band with a large spectral bandwidth in the visible NIR portion. M ostly blue will be removed out because we know blue undergoes lot of scattering produces haze in imagery. So, in pan band people will remove blue. So, green, red and NIR these three will be combined to produce one single band. The advantage of pan band is it will have high spatial resolution in comparison to other bands. So, Landsat has a panchromatic band and each line here defines the number of bands a system has and the width of the line is its spectral bandwidth. You can see how wide this particular band 7 and how wide this band 5 in Landsat ETM plus whereas in MODIS, most of the bands are pretty narrow. So, MODIS has these bands as fine spectral resolution than Landsat or ASTER sensors.

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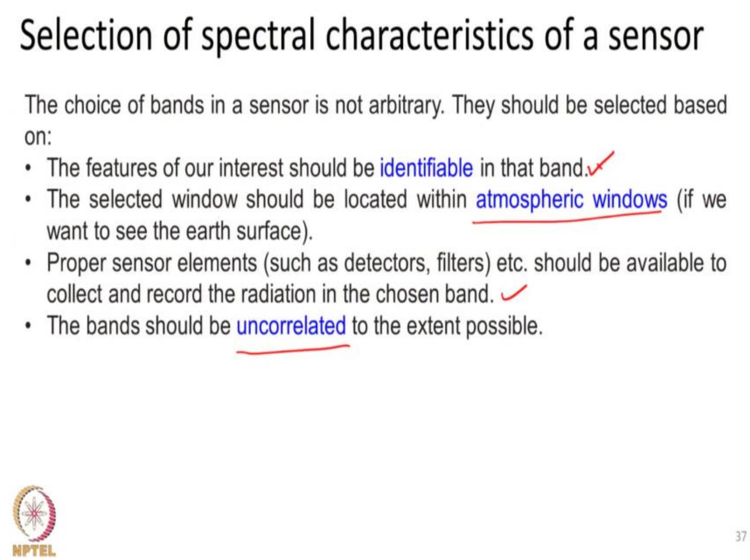

So, the choice of spectral bands or the spectral characteristic of a sensor is not arbitrary. You cannot just speak, this sensor should have 10 bands with these bandwidths. That is not the case, they are not arbitrary. Each thing has to be selected with proper reasoning. Some of the factors that one should consider for selecting the spectral characteristics of a system are:

First thing the feature of our interest should be identifiable in that band. Let us take vegetation as an example, vegetation can be better studied using a combination of NIR and red bands. So, the sensor should essentially work in NIR as one band and red in one band. So, the feature of our interest should be identifiable in that particular band. So, in which band the feature produces a distinctive signature should be selected.

Second thing the selected window or the selected bandwidth should be located within atmospheric windows. Vegetation shows a characteristic water absorption band. Presence of liquid water inside a leaf will produce characteristic absorption bands around 1.4, 1.9 micrometers. But atmosphere also has water vapor, so if you put any sensor around 1.4 micrometers and if you send it to space whatever the energy coming in from the vegetation will be absorbed by atmosphere itself and we will not get any signal in the sensor. So, if you want to study certain characteristics about the object, the band should be selected such that the band should not be an atmospheric absorption band. It should be in atmospheric window where the atmosphere is clear and where it transmits radiation.

Third thing, proper sensor elements should be available that is once we decided this is the bandwidth I am going to use for studying this feature that is present in atmospheric window, no problem, but still we should have some detector to collect that energy. What if there is no detector available in earth to collect energy in that particular band? It is a waste. So, we should have proper materials using which we can produce sensors to collect energy in that particular wave length. In olden days when the sensor technology was evolving, only certain wavelengths can be imaged or can be observed and certain wavelengths cannot be observed. Later with the latest technological development now, we are able to observe in many different wavelengths but in olden days it was a major problem. So, people may use one particular band of their interest but sensor will not be available in that particular band. So, if I give you a normal camera and ask you to take a photograph in NIR band will it be possible? No. The camera should be attached within NIR filter or NIR sensitive sensor, basically a sensor which produces output to NIR signals. Then only we can collect that energy. So, there should be availability of sensors in that particular band.

And finally the band should be uncorrelated to the extent possible. Uncorrelated in the sense, let us say we have two bands, two neighboring bands. If in band 1 DN increases then in band 2 DN increases. If in band 1 DN decreases then band 2 DN decreases. So, essentially, you have a similar response between band 1 and band 2. So, the output finally we get from these 2 bands will be more of the same or we will get equal amount of information from both the bands. If one increases the other increases if one decreases other decreases. So, essentially the bands which we choose should give us new information. That is why we say hyperspectral sensor has a problem of data redundancy and data dimensionality. They have lot of data, hundreds of bands but the information in all the 100 bands will not be unique.

The information 100 bands will be repeated in nature and similar information will be present in many different bands. Each band will occupy a large amount of memory storage in our storage system. So, we should choose correct number of bands.

I do not need 100 bands I can identify the feature only with 10 bands. Choose that particular 10 band. So, that is where in hyperspectral data processing even though there are like hundreds of bands people will select few bands which is of useful for the selected application. Then only this data processing will go smooth else there will be so much of memory consumed and so much of storage will be wasted.

So, the bands should be uncorrelated, each band occupies or produces large volume of data. If you download one Landsat imagery each scene will be in 1, 1.2 gigabytes. So, imagine, for to cover the entire earth how many GBs of data will be produced every day or how many TBs of data will be produced every day. Just imagine each and every added band adds to our increase memory storage.

So, the number of bands we put in a system should provide us as unique information as possible. They should not be related to each other. So, maybe if you come across digital image processing courses there they will explain the concept of identifying similarity between data, removing a redundant data and so on. So, the bands we are going to select should be uncorrelated to the maximum extent possible.

So, the features that we are listed in this particular slide will help us to select spectral bands for any given application. So, as a summary in today's lecture, we have seen concepts related to the spectral characteristic of a system. With this we end this lecture.

Thank you very much.