Remote Sensing: Principles and Applications
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Lecture-49
Active Microwave Remote Sensing-Radar-Part-6

Hello everyone, welcome to the next lecture in the topic remote sensing with imaging radar. So, in the last lecture we discussed briefly about the radar equation, what are all the different factors that will control or that will influence the radar backscattering coefficient? And we started discussing about surface roughness. Today we will continue exploring the other factors that will influence radar backscattering coefficient. So, the next important property other than surface roughness that will influence backscattering coefficient is the moisture content of the surface. When we discussed about passive microwave radiometry, I told you that addition of water to the soil will increase its conductance thereby increasing its reflectance and lowering its emissivity.

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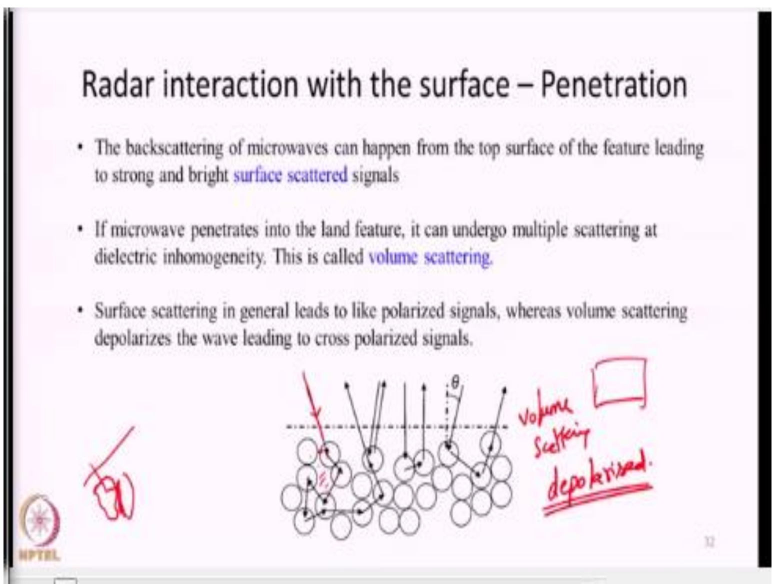

So, wet soil surfaces will have lower brightness temperatures, we have seen this is in passive microwave. There I told you that adding water to the soil will increase its reflectance which means backscattering. So, the backscattering of the soil or whatever features on the earth surface will increase with increasing moisture content. So, higher the moisture content of the surface higher will be it is backscattering coefficient.

The water will also reduce the penetration capacity of the microwave signals. So, the depth of penetration will reduce as the moisture content of the surface increases, the penetration will be lower for wet surface**.** Penetration will change the way how microwave interacts with the objects. Not only microwave any electromagnetic radiation when interacts with the surface feature most likely it will undergo surface scattering or surface reflection. Most likely the polarization of the wave that is incident upon will be preserved, may not change. Whereas if the signals penetrate through the object of interest there are high chances that the signal will interact with different discontinuities within the object, may get reflected multiple times, leading to a more diffuse kind of scattering in which the polarization of the signal may change, that is the signal may get depolarized.

Let us say some electromagnetic radiation is penetrating into the object. So, there maybe molecules or whatever features present within object, it has lot of air gaps and everything. Because of this discontinuity, when there is like a change in medium within the same object itself, microwave wavelength undergoes multiple scattering leading to an overall volume scattering in which the wave can be depolarized**.** That is, let us say horizontal polarization was incident upon the surface. If it is a pure surface reflection and the microwave has not penetrated through the object, most likely a large fraction of energy may still be horizontally polarized that is reflected back from the object. On the other hand if the electromagnetic radiation penetrates through the object and interacts with large fraction of the discontinuity within the object, most likely it may become depolarized.

And the large fraction of energy that is being backscattered by the object may now be in vertical polarization. So, the penetration of microwave has the capacity to change the polarization of the incident signal. With these general backgrounds we will briefly see the general characteristics of interaction of microwave signals with different features on the earth surface. So, the first thing is vegetation, how microwave signals will interact with vegetation or what are the factors of vegetation that will influence this backscattering coefficient.

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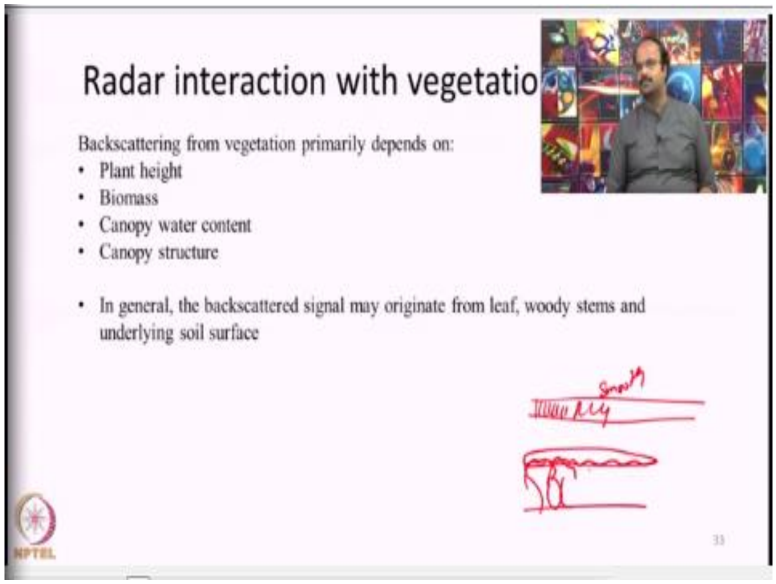

So, some of the important factors of vegetation are the biomass content whether it is a dense vegetation or it is a sparse vegetation, the total biomass content, the plant height whether it is a woody or non woody tree. All these things will influence the backscattering coefficient. The canopy structure whether it is like a needle structure, whether it is like a broad leaf structure, how rough the total canopy structure is, like a well maintained grassland may appear as perfectly smooth if you look at it at some angles**.** But a forest canopy may appear totally rough to our eyes. So, both of them are vegetation, grassland and forest canopy, but they may have different, different surface roughness.

So, this overall geometry of the canopy, water content within the canopy whether the vegetation is dry or not, all these factors will influence the backscattering coefficient from the vegetation. And here we have to remember that, unlike optical remote sensing where either reflection or emission will be happening only from the top millimeters of the surface. In case of microwave, the signal that has been backscattered will not only be from the canopy part or the leafy part, it may also happen from the stems, branches, leaves even the soil underneath the canopy cover.

It can happen depending upon the wavelength involved, canopy water content and so on. So, the signals that we may get in radar images may not only give us information about the leaves but also about the various features present underneath the canopy**.** This thing we always have to keep in mind while we use radar images for applications related to vegetation monitoring.

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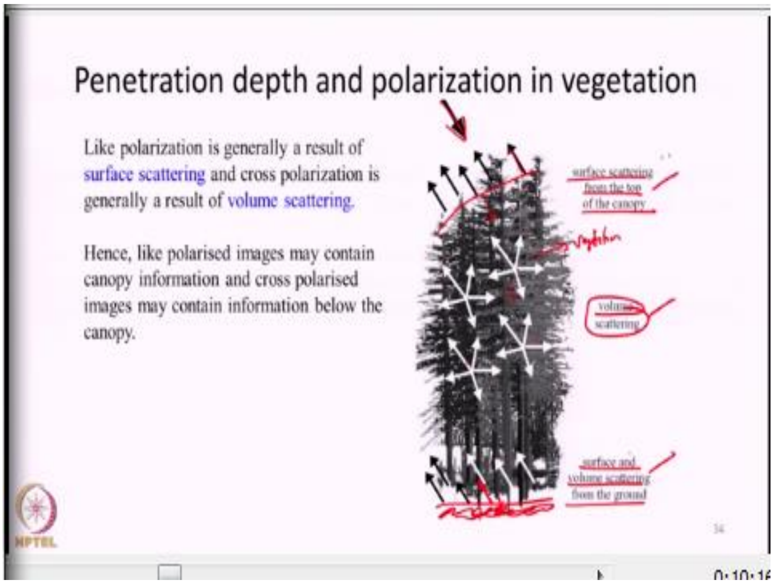

So, this is a schematic or highly simplified explanation of radar interaction with vegetation. So, any incoming signal may just get reflected by the surface, that is undergo surface scattering from the top of the canopy, it may go back. Some fraction of incident radiation may penetrate into the canopy and can interact with the stems, branches, leaves and something else that is present entering the canopy and all these things.

So, this is what we call as volume scattering, like scattering happening underneath the canopy but still everything is confined within this vegetation. So, this is a dense network of trees, so everything is still happening under the domain of vegetation alone. So, here we call it as volume scattering. A further fraction of the incoming signal may still reach the surface and undergo surface reflection or may even penetrate under the surface and undergo volume scattering by the soil elements under the surface and can still come out.

So, essentially the incident signal can take this multiple paths, surface scattering from the top of the canopy, volume scattering within the vegetation, volume or surface scattering from the ground. So, essentially not only the vegetation properties but also the surface properties whether the surface is dry or wet will have a combined effect in the backscattering coefficient that got recorded in the radar image.

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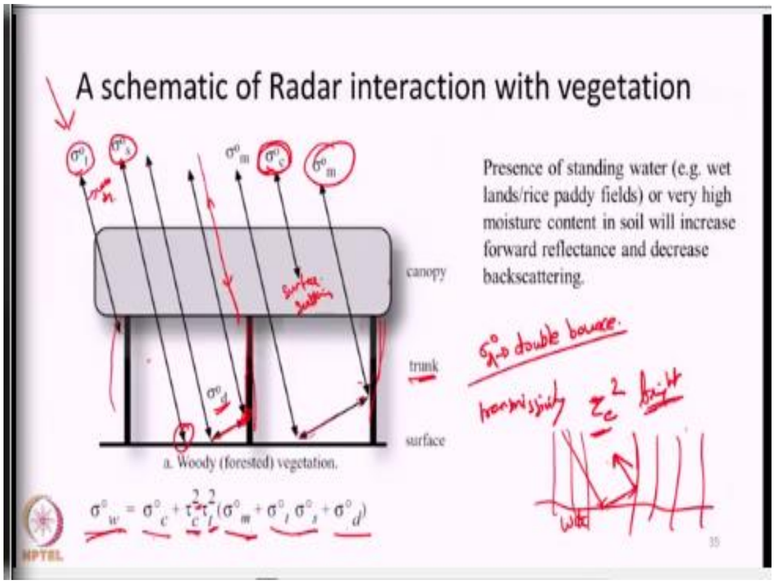

So, just to drive this point further, we will look at a highly simplified model of microwave interaction with the vegetation. We will first take an example of woody vegetation, like a forested trees, large trees with huge branches, stems, barks and everything. So, the incident microwave signal will get backscattered from the canopy. Or some of it may penetrate and interact with the trunk part and may be reflected back. So, this is the backscattering from the woody portion, a certain fraction of the incident radiation may have higher penetration and can reach the surface and can directly escape this canopy part. So, this is the reflection coming back from the surface.

A certain fraction of it might have reached the surface, get forward reflected and interact with the trunk and may come out. So, this is what we call as double bounce, like a good fraction of the incident radiation may be reflected in the forward direction and a vegetation trunk maybe standing in front of it which may reflected towards the sensor. Or there can be multiple reflected signals, but the same wave of the radiation can undergo multiple reflection within this canopy itself and may finally escape. So, the net resultant backscattering coefficient that got recorded depends on the surface scattering from the canopy, the surface scattering from the trunk and the surface, the double bounce effect and the multiple reflected microwave signals.

So, apart from this surface scattering from the canopy, for all other components that is happening below the canopy must pass through the canopy once. So, the transmissivity of the canopy comes into picture**.** So, here we have to put a square because it has to first travel inwards crossing the canopy, then the backscatter signal should also travel outwards again crossing the same canopy. So, that is why we have this square term, similarly the trunk also has some sort of penetration cover capacity. So, in a simplified manner if you want to think of the net resultant energy that is reaching the radar antenna depends on not only the canopy characteristics, but also the surface characteristics, the trunk and the geometry of alignment. Let us say the canopy is not very dense, then a high fraction of energy will reach the soil and interact with whatever present in the soil and can come back.

Also imagine, a good fraction of energy is going towards the surface and the surface soil has good amount of moisture content, then it may produce a bright backscattering coefficient towards the radar, so that surface scattering component can be really stronger. On the other hand let us say there is a standing water present, maybe like a wetland or a rice paddy field where the paddy crop is just emanating from the standing water column. Let us say some microwave radiation is incident upon it. Since this is a standing water column, this will specularly reflect and a large fraction will move towards this vegetation. And since this is a healthy vegetation, it will have high backscattering coefficient and it will reflect a strong signal towards the radar antenna.

So, this kind of double bounce has the capacity to produce a really bright backscattering effect. So, it depends on how much microwave that penetrates through the canopy, if the microwave is not able to penetrate the canopy when it has very high amount of water content and we are sensing in very shorter wavelengths, say X band. Then the penetration capacity will get lower, signal may not even reach the surface. So, based on the sensor characteristics and the object characteristics, the backscattering received by the radar from vegetation will be having a complex signal embedded within it.

Let us say there is a identical vegetation canopy, if we irradiate it with 3 different bands X band radar, C band radar, and L band radar. Most likely the shorter wavelengths will contain information only about the canopy part. Whereas C band may have little bit higher penetration, may provide some information about the entire canopy depth and also something about this woody part. If we look in L band radar then it may even contain signal about the soil that is present underneath it.

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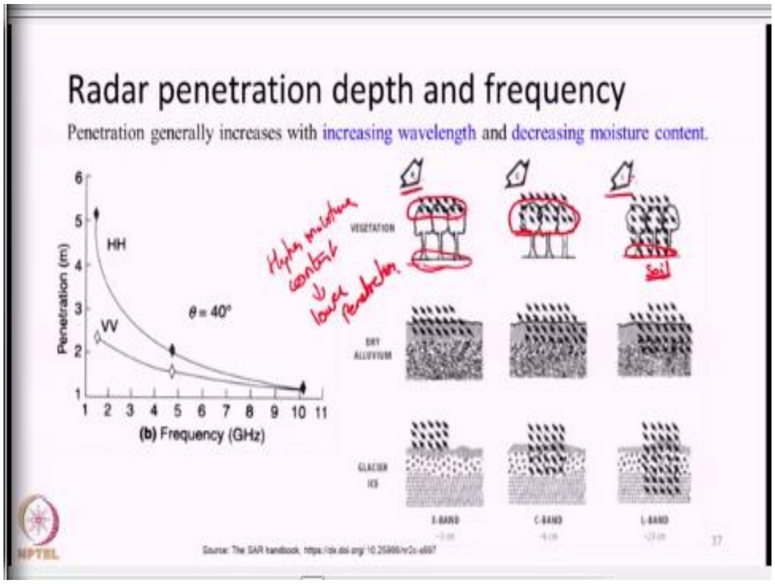

So, by changing the observation frequency or the observation wavelength, we may get information about different components of vegetation whether just the leaves or like the entire leaves plus woody part or even like the underneath soil. So, longer the wavelength more will be the penetration, that is one thing. And also depending on the moisture content, higher the moisture content lower will be the penetration, this also we have to remember in mind**,** higher moisture content lower the penetration. Also, longer wavelengths may penetrate deep into the canopy and the radar may have the capacity to produce images in multiple polarizations HH, HV and so on.

So, most likely the cross polarized images like the HV image or VH image may contain information about underneath the canopy part, the volume scattered part, the trunks, stems, branches and so on. Whereas the like polarized image may contain information about the top surface canopy part. Because of this surface scattering and volume scattering, volume scattering may tend to depolarize the signal, if it is horizontally incoming the outgoing maybe vertical.

Depolarization may occur as a result of volume scattering. So, using multiple polarized radar images within a given frequency and different polarizations may give us different information about the vegetation. So, this slide gives an example for a radar image of a portion of Amazon rainforest in X band VV polarization, C band radar HV and L band radar HV.

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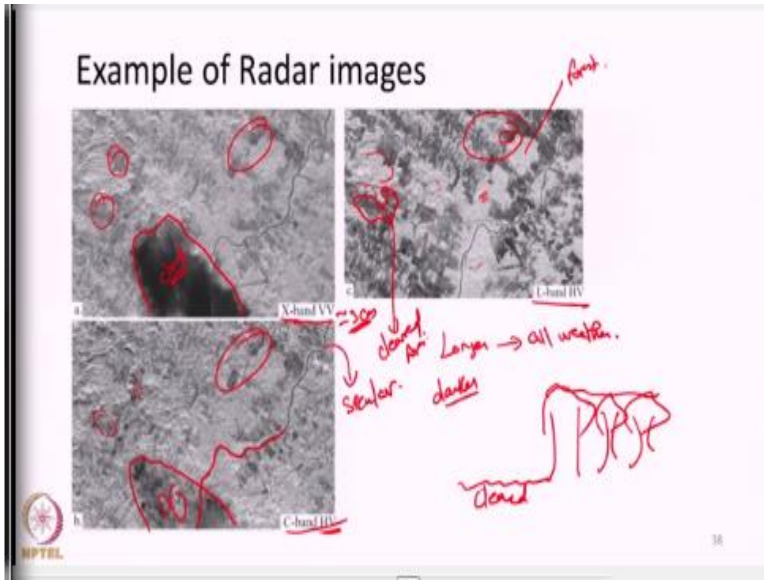

So, these 2 are cross polarized, this is polarized**,** this is a rain bearing cloud containing good amount of water. So, in X band radar around 3 cm wavelength, the cloud is clearly visible; that is the radar is not able to penetrate through the cloud because of its rain bearing, so it may also be raining during the time of image acquisition. So, due to which we are not able to see what is present below the cloud, in C band the cloud is present but still we are able to see some portion of the land surface. Whereas in L band, the cloud is almost absent, we are clearly seeing the ground surface without any interference from the cloud.

So, this tells us longer wavelengths are useful for all weather monitoring, this is one information we get from this analysis. Second thing, this is a river channel since water acts as a specular reflector in microwave wavelengths, in all the images river channels appears much darker. So, any water bodies present in microwave images may appear darker, this is another thing that we may get from these particular images.

Then one more thing that you can observe is, take a look or compare these X band, C band image, especially these patches. Here we are able to see alternative dark patch and a bright patch. In L band image, these bright patches represents forest, whereas this dark patches represent deforested land. So, this is a bare soil surface here, so these are deforested lands. So, in X band radar, say this is soil, this is the tree, so this is cleared deforested area, this is a still forested area, not vegetation is still present. Both of them will have some sort of surface roughness, the top of the canopy and also the soil. So, here in X band, being like a shorter wavelength even the bare soil appeared rough to the radar and it produced good amount of backscattering coefficient in comparison to the forest surface. Whereas in L band radar, the bare soil surface appears smooth and hence it is appearing dark in L band signals.

Whereas forest surface, due to the presence of healthy vegetation with high water content and good surface roughness, it is appearing bright in all the images. So, the same area but imaged in different, different frequencies gives a different view of the land surface and we may get different or complementary information out of these images. And also if you have a look at the images again, we can see the L band images is kind of cross polarized, HV polarized image. So, it may contain not only the information about the canopy but also information about the volume scattering elements present below the canopy.

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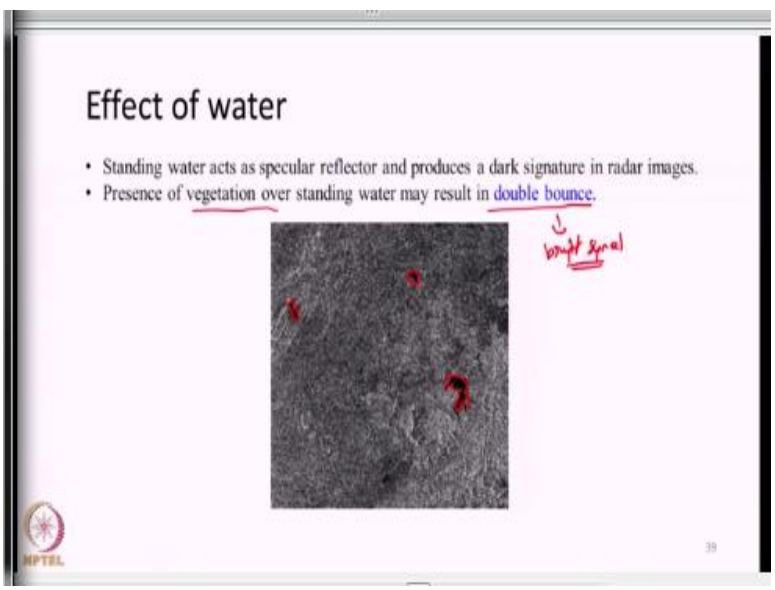

So, this slide tells us again the effect of water on the radar image. So, as I already told you water bodies may appear completely dark in radar images because of the highly specular reflection nature of the water bodies. And presence of vegetation over standing water may result in double bounce leading to a very bright signal in the radar image.

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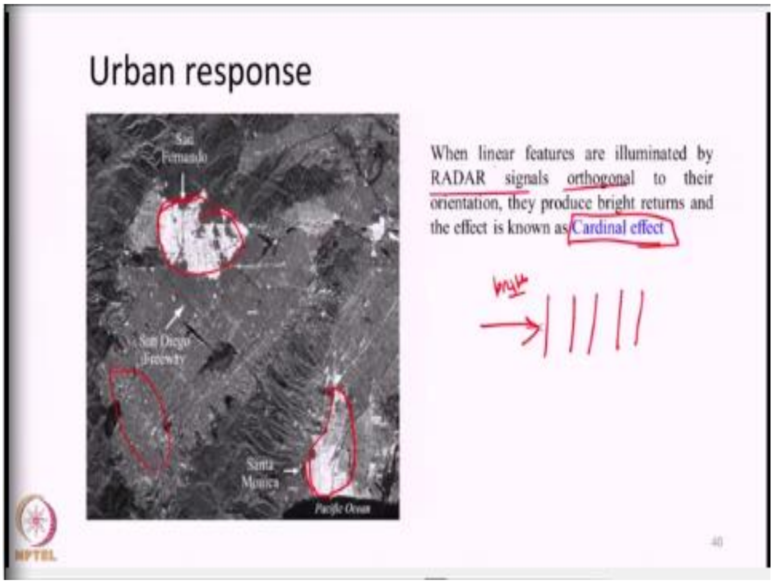

The orientation of urban structures like buildings or whatever features on the urban cities, if they are present in a direction orthogonal to radar signals they may produce a cardinal effect. Say, this is a Los Angeles county in the United States, this is San Fernando and this is Santa Monica. Here this urban area appearing darker but this appears much brighter. This is because if the urban features are oriented in a direction perpendicular to the incoming radar signal they may produce bright backscattering, that is known as the cardinal effect. So, this is again one more example for radar interaction and the geometrical nature of objects, how it will change the radar backscattering coefficient.

Another major advantage of using satellite-based radar imagery is, the recent radar remote sensing satellites has the capacity to image the ground in different, different modes. So, what are the different modes means we know each imaging system has certain characteristics like swath width, spatial resolution and so on. So, a radar can change its characteristics or we can tune the radar image acquisition based on our needs. Say for certain application we may have to increase our swath width for covering a larger area that may be possible or for some applications we may be required to get very fine spatial resolution images. So it is also possible, we can configure the radar antenna even after it is launched. So, nowadays the recent radar remote sensing satellites has this multiple imaging capabilities or multiple imaging modes for getting images based on our needs.

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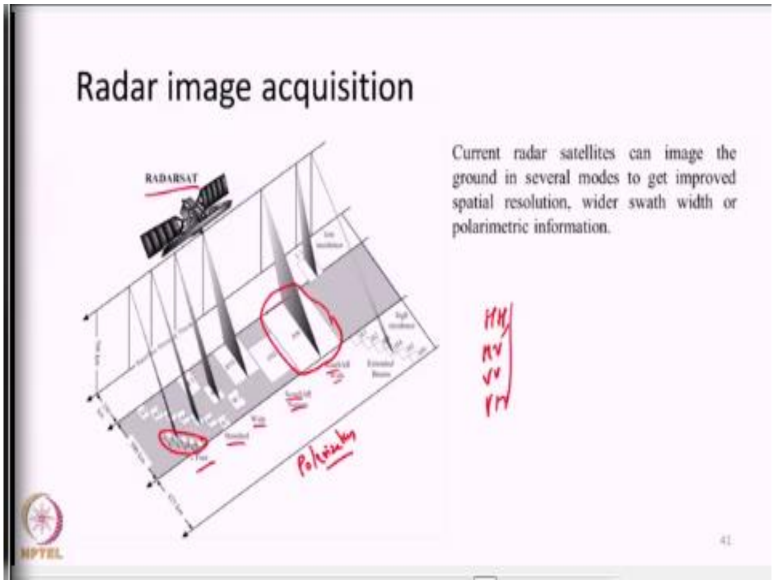

Say an example is given with respect to a RADARSAT satellite which is a commercial satellite where we have to pay and get the images. So, here you can see, it has lot of different, different modes of image acquisition. It can produce very fine spatial resolution image, sacrificing the swath width or it may produce a image over a large area covering a very wide swath sacrificing the spatial resolution. Or we can even increase the spatial resolution decreasing its polarization capacity. Like we can reduce the number of polarization modes rather than collecting images in HH, HV, VV and VH in all the 4 polarization we can reduce some of them for spatial resolution. So, in radar remote sensing the satellites are now has the capacity of multiple imaging modes in which we can obtain images based on our needs.

So, normally this feature is not widely seen in optical remote sensing satellites. So, once a satellite is launched swath width, spatial resolution everything is fixed. The only advantage what we can have is we can tilt the cameras, some of the optical remote sensing satellites has the capacity to tilt its sensor and observe a location away from its nadir. That is possible by changing the swath increasing the spatial resolution on the go or may not be possible, but in radar it is possible. So, this is one advantage of radar image acquisition, satellites has its multiple imaging modes which can produce images based on our own needs. And finally before we conclude this topic, I want to just introduce you the topic of radar interferometry

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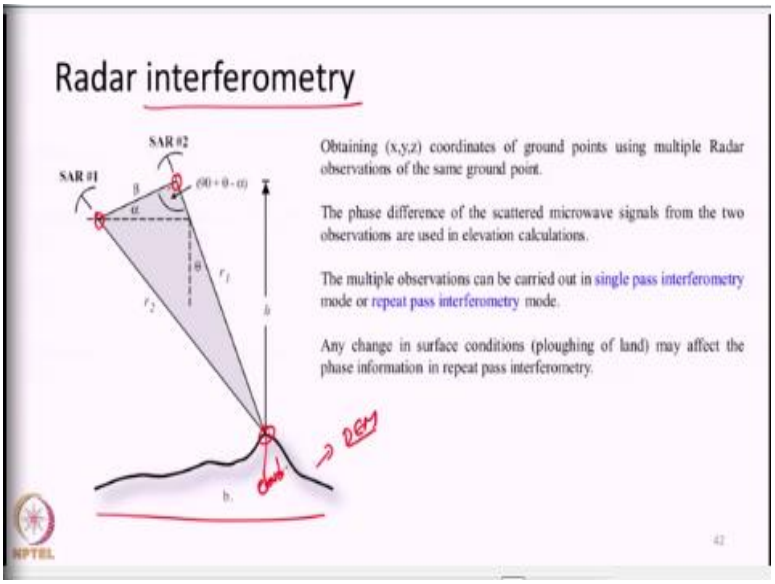

Radar interferometry is not only used for imaging purposes but by looking at the terrain from two different positions in the space. Let us assume a ground point 1 whose image is taken and the sensor is shifted to a new position and the same ground point is imaged again. Looking at this or imaging the same ground point from different position in the space will help us to calculate the elevation of this particular point with respect to a given data. So, radar images can be used for calculating the elevation of different points on the earth surface and produce DEM digital elevation model. So, this particular technology is known as radar interferometry.

Here we use the phase information from the radar, radar not only stores power it also stores the phase information we have seen it. Using this phase information we can collect elevation information about terrain features. SRTM the shuttle radar topographic mission of the United States had sent multiple space shuttle missions to the space. There in one such mission in which they attached radar antenna in the underbelly of the space shuttle. It had 2 antenna one in the cargo bay and one at a certain distance away from the cargo bay, some 60 meters or so. One will transmit microwave another will be receiving the microwave**.** So, one antenna transmits, another antenna is just a passive, it will be just receiving this reflected signal. So, using this phase information between these 2 radar images people mapped the elevation of almost the entire globe giving rise to a radar based DEM. So, this is an example of one of the applications of radar remote sensing, so not only imaging but also we can map that terrain using this radar interferometry.

The radar interferometry can happen either in a single pass interferometry where we acquire 2 images from 2 different positions in space of the same ground point. If it happens in one shot as I said before 2 radar antennas attached at a certain distance from each other then, there is a distance between them which produce different, different view angles to the same ground point giving rise to single pass interferometry, the information needed is collected in only one go. Whereas if the 2 images collected over 2 different passes of satellites, we call it as a repeat pass interferometry. So, in general collecting elevation information using multiple observation of the same ground point is known as interferometry and it is one of the most widely used applications of radar remote sensing.

So, in this particular lecture we discussed about the important characteristics of terrain surface features which may influence radar backscattering coefficient. Especially we discussed about vegetation, the moisture content, how it will affect the penetration capacity of the microwave signals, how it will change the polarization and all those things. So, with this we end this lecture and also we end the topic of active microwave remote sensing.

Thank you very much.