REMOTE SENSING FOR NATURAL HAZARD STUDIES

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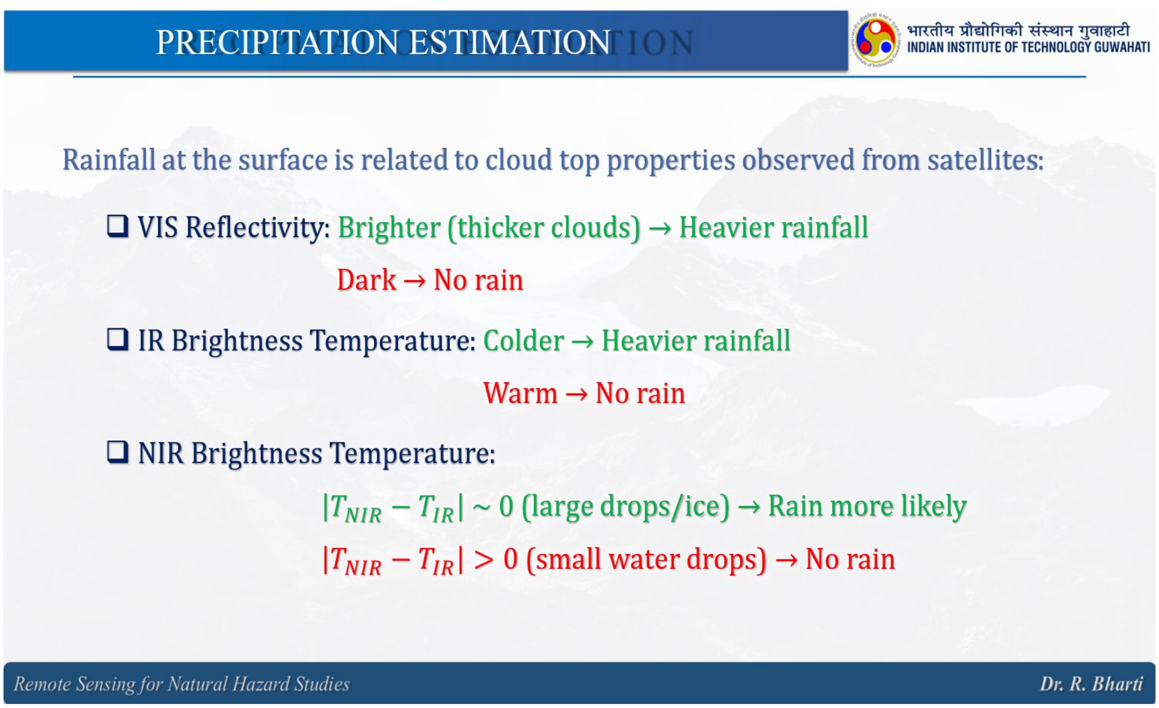
Lec 17a: Remote Sensing for Floods- II Part A

Hello everyone, welcome to Lecture 17. In this lecture, we will continue the discussion on the application of remote sensing for floods. So, in the previous lecture, I started discussing the application of remote sensing in precipitation estimation. So, in this lecture, we will continue that. We will see more details about how we can identify or estimate the precipitation. So, satellite remote sensing techniques to estimate precipitation are infrared remote sensing techniques and microwave remote sensing techniques.

So, we are using both infrared and microwaves. When we talk about the infrared here, we study the relationship between the cloud's temperature, cloud top thickness, and precipitation, and then we try to come up with a model that can provide us with information about the precipitation probability of a particular cloud. Colder cloud top temperatures indicate higher and thicker clouds, which support heavier precipitation.



Now, here you can see that based on the observation, we have come up with this particular statement: colder cloud top temperature indicates higher and thicker clouds. And if we have higher and thicker clouds, they will support the heavier precipitation. Now the next is the relationship between changes in cloud top surface and precipitation that will help us indicate that vertically growing clouds are associated with precipitation. Rainfall at the surface is related to cloud-top properties observed from satellites. So, we will see how these remote sensing datasets are an indicator of precipitation.

When we talk about visible reflectivity, using this data for brighter or thicker clouds will lead to heavier precipitation. Dark means no rain. When we use IR brightness temperature again, we are talking about the infrared remote sensing images. So, here, if it is colder, that means heavier rainfall, and warm means no rain. So, you need to see the relationship between the temperature, which wavelength you are talking about, and then how it is related to the precipitation.

When we use NIR brightness temperature here, we use this relationship, and if it is equal to 0, that means rain is more likely to occur, and here, large drops or ice will be found. When we have this greater than 0, then small water drops will be found, and no rain is expected. In this particular spectrum, you can see that different types of snow grain radii are plotted. So, here, if it is 0.005, this color indicates that blue is 0.5 mm.

So, here you can see that this is 0.5 and 1 mm in yellow, and 0.2 in green. And here, these are optically thick clouds. So, you can see how these absorption features come in different grain sizes. So, here is one thing you can easily observe: if we have a change in the grain size. So, this intensity is increasing, but the pattern remains the same. And when we are talking about the optically thick clouds, they are different from these. So, this is how we can identify or separate these clouds from the snow in high-altitude areas. So, it is very easy when we have high spectral resolution data.

Referring to the band ratio concept, we have several indices, and similarly, we also have some indices for the water. So, now if you refer to this microwave remote sensing, the direct relationship between ice in cold clouds and precipitation indicates that ice scatters radiation back to the surface and appears cold in images. So, cold means that the temperature will be low. The direct relationship between water content in clouds and precipitation using microwave remote sensing. So, here it says that water in clouds emits microwave radiation, and we are referring to this passive microwave, which appears warmer in the image if high water content clouds are present.

PRECIPITATION ESTIMATION

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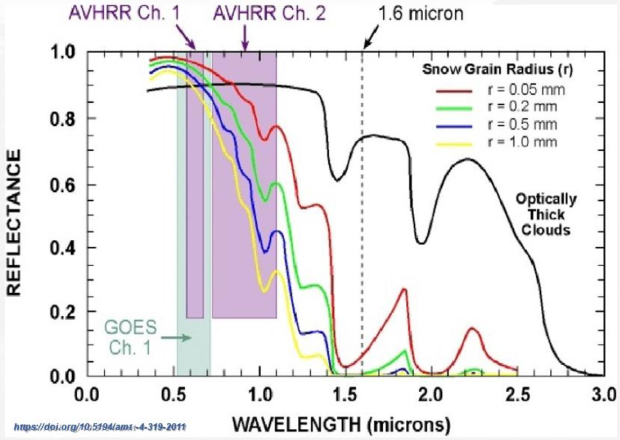

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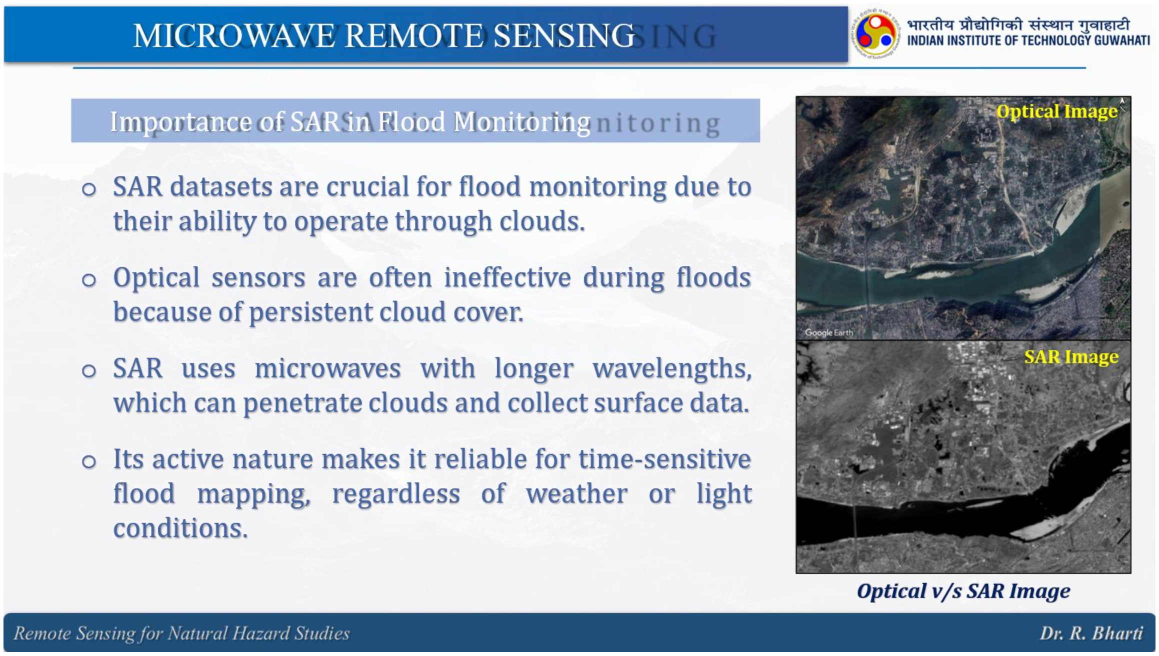
So, this is how we correlate, and we try to estimate the precipitation using the microwave data set. The passive microwave data from a polar-orbiting satellite are very popular in precipitation estimation. Rainfall at the surface is related to microwave emission from raindrops; low-frequency channels are used, and microwave scatters from ice are high-frequency channels. These concepts are utilized, and then the metrological parameters are estimated. Low-frequency channels; here you can see the warm weather, and many raindrops and heavy rain are expected.

Cold means no rain; high-frequency scattering channels indicate that the cold is scattering from large ice particles, and heavy rain is expected. If it is warm, then no rain is expected. So, this is how we utilize microwave remote sensing. Now we will refer to the microwave utility in flood studies. So before that, we have to understand the basics of microwave, though I have covered them in the microwave lectures.

Again, I will be referring to them, and then we will try to understand which and how microwave remote sensing is used in flood studies. Starting with the very basic, SAR datasets are crucial for flood monitoring due to their ability to operate through clouds. Because we are talking about the natural disaster of floods, it is expected that whenever we have a flood, there will be high rainfall in that particular area. If that area is experiencing high rainfall, it means there will be cloud cover; if the cloud cover is present, optical remote sensing will not be of much use. So, in such a situation, microwave remote sensing will become an important source of information because, without visiting the area, we will be able to identify the changes and the inundated areas.

Optical sensors are often ineffective during floods because of persistent cloud cover, as I said, SAR uses microwave with longer wavelengths. Remember, we are talking about the longer wavelength, and we are measuring the backscattered energy, which can penetrate clouds and collect surface data; the wavelengths are long. So, it is expected that clouds will not interfere with our data acquisition. Its active nature makes it reliable for time-sensitive flood mapping regardless of weather or light conditions. So, even at night, we can have this measurement when we are talking about active microwave sensors.

So, here you can see the optical remote sensing and SAR images.



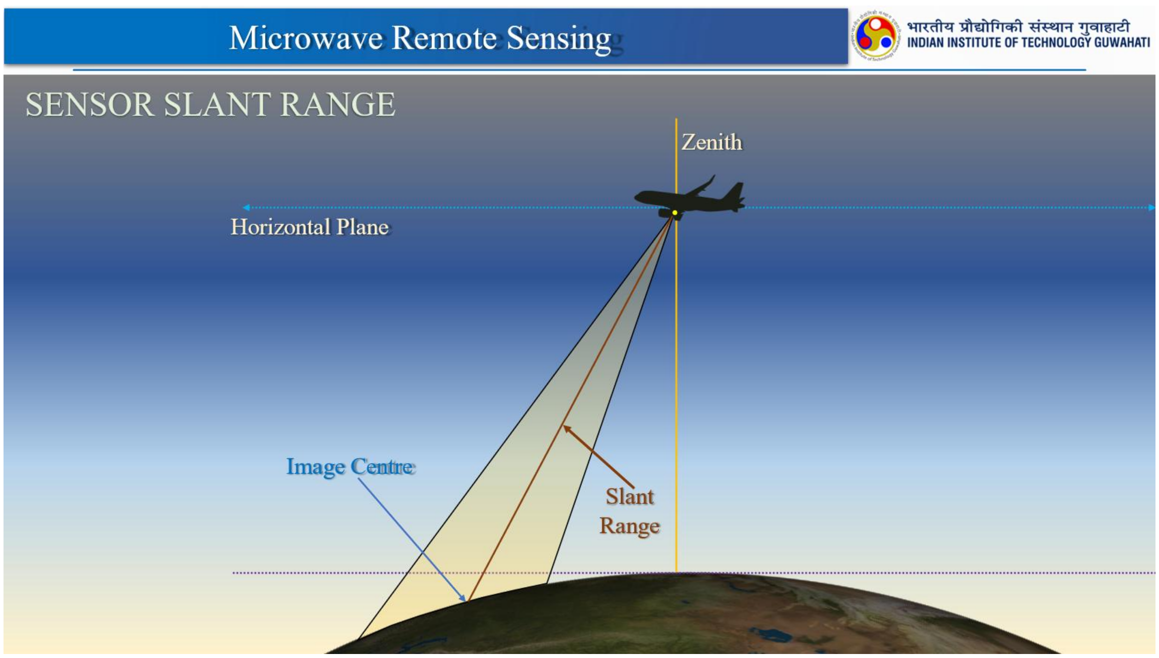
So, this particular river, how does it appear? So, when we talk about optical remote sensing data, we have the option to visualize this particular river in true color composite or false color composite. But when we talk about the SAR data, backscattering energies are measured here.

So, these energies are measured, and then we will be able to identify the features on the ground. So, the modern use of SAR for flood detection is crucial for accurate flood mapping, which is essential for assessing damage and planning relief efforts, especially when the area is inaccessible and we are unable to travel to or visit that particular area.

To estimate the damage or to provide the mitigation measures, we will use this microwave remote sensing to accurately identify the flood-inundated areas. Today's SAR system offers higher resolution and frequent acquisition because temporal resolution is also important here, and the temporal resolution of current microwave datasets is very, very high. So, for example, Sentinel-1 has data acquisition every 12 days. So, that is the revisit period for Sentinel-1. Flood detection via SAR often relies on thresholding of backscattering levels.

So, what happens if you remember in the classification, I said that if you have DN values ranging from 0 to 255, you can go for the density slicing? So, here we will be using the thresholding, which can segregate the water from the non-water areas. Integration with some other sensors enhances flood detection accuracy. You can also utilize some other microwave datasets that measure in different wavelength regions, or you can also utilize the optical remote sensing dataset here. that will enhance or increase the accuracy of your estimation. Challenges include terrain type and surface conditions, which can affect backscattering interpretation.

Here is to explain the different viewing geometries of the microwave sensor. I am using the same slides. So, I hope you will be able to understand easily.



So, here is the aeroplane I am referring to, and here we have a sensor, and this is the nadir, which is perpendicular to the ground, and this is the beam that is illuminating this particular area. So, this is the horizontal plane. So, the flight is moving on this. So, here, the center line of this viewing angle will be your slant range, and this will become the image center.

Microwave Remote Sensing: Viewing Geometry

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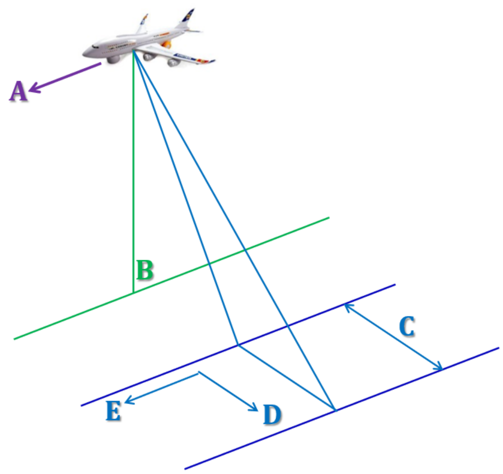

- Similar to optical systems, the platform travels forward in the flight direction (A) with the nadir (B) directly beneath the platform.
- The microwave beam is transmitted obliquely at right angles to the direction of flight illuminating a swath (C) which is offset from nadir.
- Range (D) refers to the across-track dimension perpendicular to the flight direction, while azimuth (E) refers to the along-track dimension parallel to the flight direction.

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So, here we refer to flight direction A and nadir B. So, this is perpendicular to the ground. So, the microwave beam is transmitted obliquely at a right angle to the direction of flight, illuminating a swath C that is offset from nadir. So, you can see this is offset from nadir; it illuminates this area and the range D, which is referred to as the across-track dimension perpendicular to the flight direction.

So, this is D. The azimuth E refers to the along-track dimension parallel to the flight direction. So this is the flight's direction. So, nomenclature, I hope you will remember it. So this is what we have: the incident angle is, and with the nadir, it is creating the look angle. So this is the beam that is falling on this particular surface, and with the flight direction, it will create the depression angle. So, here we will see each other one by one. So, this is your, you see, the animation; it will be very clear. So, the depression angle, then we have the look angle, then you have the incident angle, then you have the near range, this is the far range, and this is the slant range. This is the beam width that illuminates on both sides.

So, here is another representation of viewing the geometry of a microwave remote sensing sensor and how it generates the data using this configuration. Now we will try to understand the different scattering mechanisms. So, let us talk about the surface or diffused scattering; keep looking at this animation. Diffuse scattering occurs when a microwave signal hits a rough, heterogeneous surface. The roughness of the surface is determined by the wavelength of the microwave signal.

For example, bare ground; here I am taking the example of bare ground, then comes the specular reflection. So, again, keep watching this. Specular reflection occurs when the radar pulse hits a smooth or flat surface relative to its wavelength. These pixels appear in a dark tone: a low backscattered value will be measured. So, for example, calm water bodies, roads, and airport runways will be very calm, and these values will be a dark tone.

Then we have double bounce or dihedral scattering. This scattering occurs when the radar pulse hits two relatively smooth, perpendicular surfaces. These pixels appear in a very bright tone, and we will measure the high backscattering value. For example, tall trees are examples of this dihedral scattering.

Now we have volume scattering. Volume scattering occurs when the radar penetrates a 3D body and interacts with particles sensitive to the wavelength. So, here you can see the rough surface of the natural body. So, here you can see that multiple scattering is happening at the same time, and only a part of it is returning to the sensor. For example, tree canopies, dry snow, and vegetated fields are examples of volume scattering. Now we have learned all the different scattering mechanisms. Now we will see how these backscattering values and backscattering mechanisms are used in flood studies.

So, backscatter is the amount of radiation received from a particular illuminated target. It varies significantly between different land covers and land uses. We have learned that different scattering mechanisms will have different values. The darker tone appears due to the specular reflection of the water body. Now it is only related to flood studies, So this darker tone will be related to water bodies, and here the brighter tone will be due to dihedral scattering of urban structures.

Now, here you can see that all these are water bodies. So, here the value you can see will be low. So, when we talk about the flooded area, the smooth water surface reflects radar waves away, making flooded areas appear dark, as we learned in the previous slides as well. Land areas scatter waves back to the radar, creating contrast for flood mapping. So, one object is very dark, one object is very bright; then clearly you will be able to mark the presence of water, which is the first and foremost thing we do in flood studies.

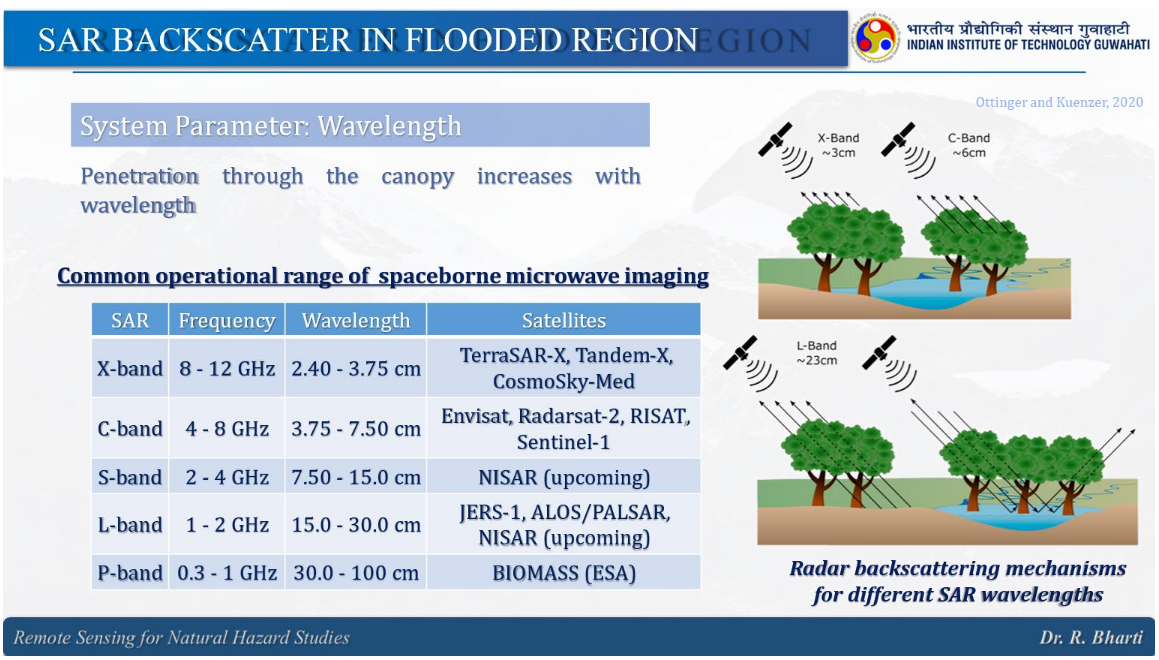
So, in this way, behavior is altered due to wind and urban and vegetated areas, because that will be the problem. So, it roughens the water surface because of the wind, hence increasing backscatter and making it harder to distinguish from land. Because of the wind, you will have different backscattered values for the water, and then it will be camouflaged with the building or any other structure. Urban and vegetated areas, double bounce effects from buildings or flooded vegetation, and volume scattering can elevate backscatter, confusing water classification. So, these two are the major problems when we use the microwave data in flood studies.

Age effects and misclassification of extended vegetation at flood boundaries hinder accurate flood age detection. So, what happens if this is the boundary of the floodwater, and here you have very dense vegetation? So, what will happen at the boundary is that you will be confused whether it is like this or like this. Water-like surfaces, such as roads and roofs, can lead to an overprediction of flood water due to the similar scattering mechanism. So, the area estimation will not always be very accurate.

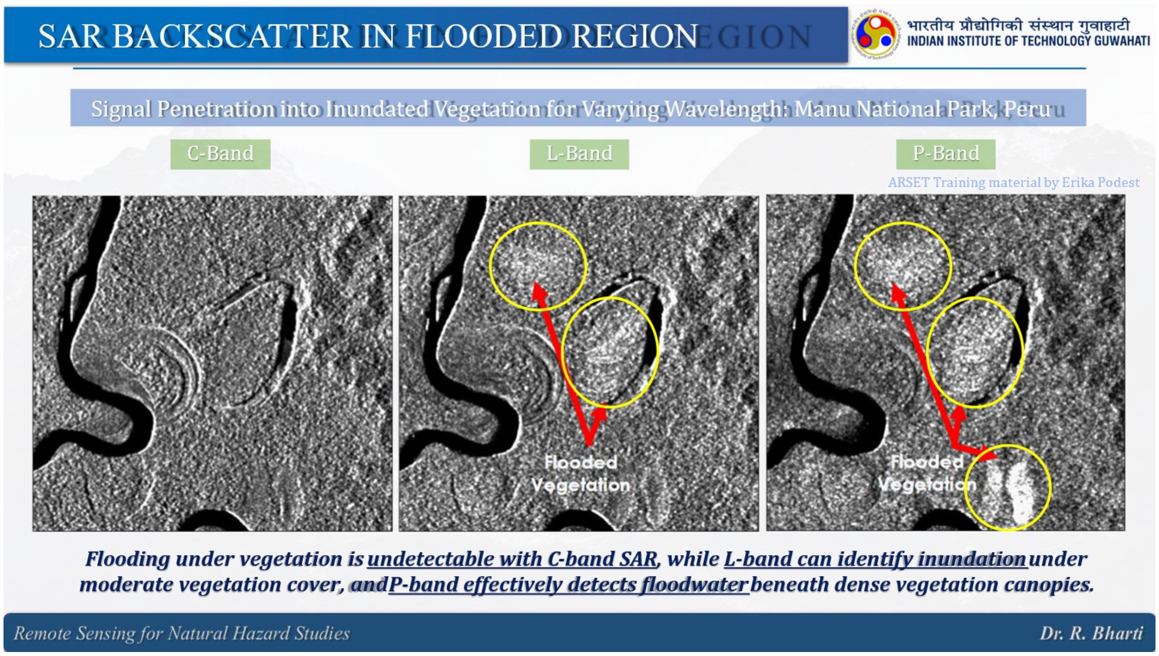
Layover and radar shadow are other problems. In cities, layover hides flooded streets under the prediction of floods. Radar shadows behind buildings or slopes can mimic flood zone overprediction that can happen at this particular moment. Because if you see, this is the building, and your sensor is here, it is looking at this particular area. So, this side will be the shadow zone. So, here you will estimate it, but this estimation can lead to the overestimation of the area.

So, the parameters that affect the backscattering value when we talk about the flood studies. Flooded areas cause specular reflections, leading to low radar backscatters. This creates a high contrast between flooded and non-flooded terrain. However, this radar backscatter behavior is influenced by system parameters and ground parameters. So, what are the things we have in the system parameters? They are wavelength and frequency; then we have polarization; then we have the incident angle.

When we talk about the ground parameter of wind-induced surface roughness, we have seen that because of the wind, we will have either an overprediction or an underprediction of the water. Then, next is the soil moisture. Topography, vegetation, and urban signatures can camouflage the actual flooded region. So, these two parameters greatly influence the study of flood in microwave datasets.



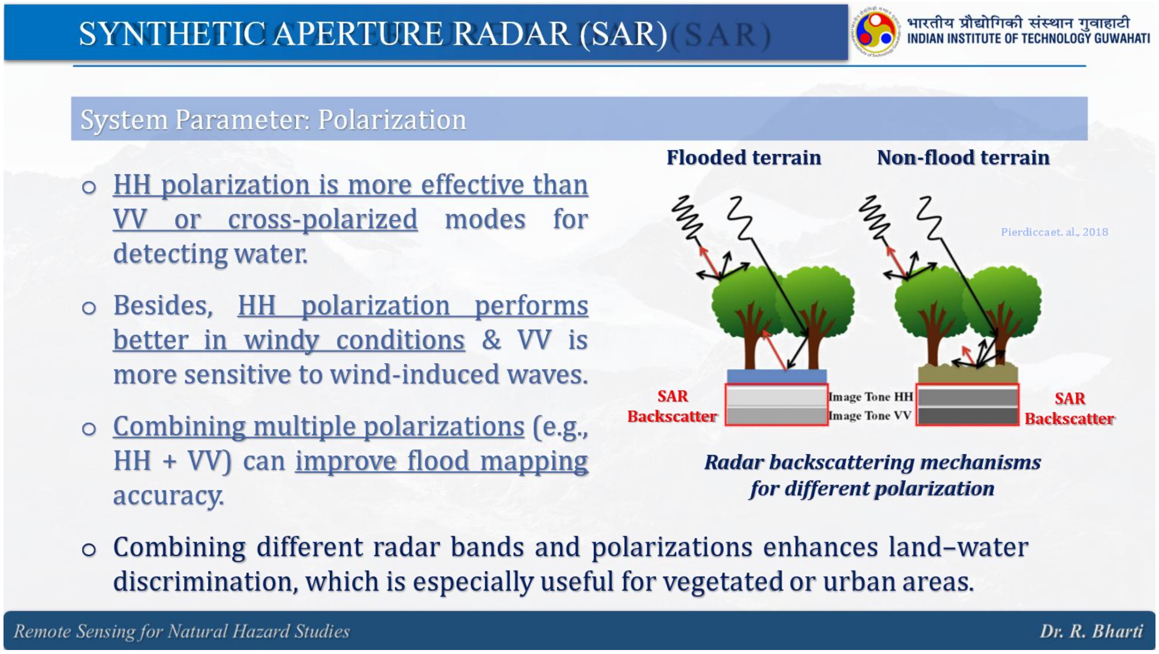
The system parameter is the wavelength. So, the penetration through the canopy increases with wavelength. So, as we move towards longer wavelengths within the microwave domain, we will have better canopy penetration. So, here you can see this is X band, this is C band, and here you have L band. So, how are microwave energies interacting with canopy or vegetation in this particular condition? Common operational range of spaceborne microwave imaging. So, here you have X band, C band, S band, L band, and P band. Here, the frequencies are given, and the satellites that are available nowadays are mentioned; even some of the upcoming missions are also mentioned here regarding signal penetration into inundated vegetation for varying wavelengths.



So, this is Manu National Park, Peru. So, here you can see that the C band, L band, and P band are used. So, the same area has been represented here. So, this is the same river channel. Now, you see the difference; you can identify which particular band is better at estimating the flood-prone areas. Flooding under vegetation is undetectable using C-band SAR; this is C band.

While the L band can identify inundated areas under moderate vegetation cover, the P band effectively detects flood water beneath a dense vegetation canopy. So, if you are talking about the flood studies in the highly vegetated areas. Preferably, we will use the P band dataset. If it is not available, we will go with the next choice, which is L band, but in C band, these inundated areas are not clearly visible. Here you can see that the land surface appears smooth to a long-wavelength radar.

Little radiation is backscattered from the surface. The same land surface appears rough to short-wavelength radar. The surface seems bright in the radar image due to the increased backscattering from the surface. This is the condition. So, a surface is considered rough if this satisfies this particular condition, where we are using the height of surface irregularities, SAR wavelength, and the incidence angle. So, this will help you determine which particular wavelength is better for your study.



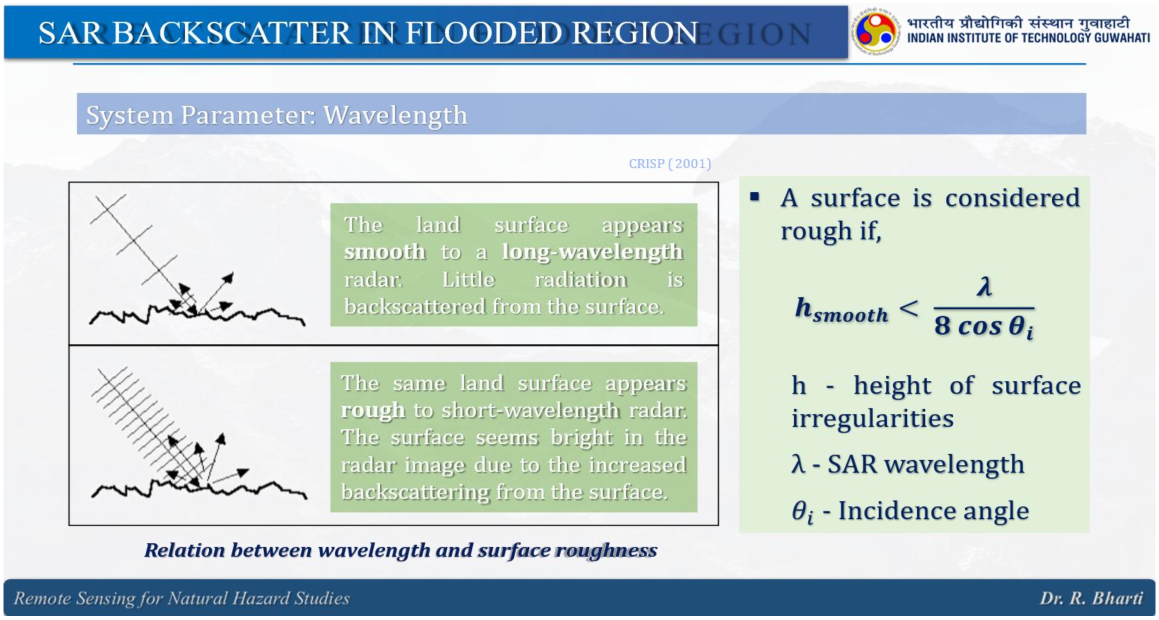
Then comes the polarization; I hope you remember these basics I have covered in microwave remote sensing. Now I am referring to those concepts again here to understand the application or application potential of microwave remote sensing in flood studies. So, the polarization indicates the direction of travel for an electromagnetic wave. Linearly oriented features like buildings tend to reflect and maintain the coherence of the polarimetric signal; hence, they are more effectively detected in co-polarized channels. Randomly oriented elements such as trees and leaves cause multiple scattering, leading to signal depolarization; therefore, they are detected in the cross-polarized channel.

Cross-polarized, if you remember VH and HV, these are cross-polarized, then like polarized HH and VV. So, here these two are like polarization, and these two are cross-polarization. So, cross-polarization will be able to help you in flood studies. HH polarization is more effective than VV or cross-polarized modes for detecting water. Besides, HH polarization performs better in windy conditions; VV is more sensitive to wind-induced waves.

Combining multiple polarizations, for example, HH and VV, can improve flood mapping accuracy. Earlier in the previous slide, I told you that cross-polarization is better. Now, depending on the situation, I am saying that different polarizations are more useful. So, it is not a thumb rule to use cross polarization or like polarization, depending on your condition or the condition of the study area; you use different polarization datasets. Combining different radar bands is also helpful as polarization enhances land-water discrimination, which is especially useful for vegetation and urban areas.

So, not only C band, L band, or P band, you can also refer to different microwave datasets that are available from different sensors, and if fortunately, those are available for your study area, measured at the same time. Then, you combine them, and together they will be more useful. Now comes the incident angle. So, here you can see the contrast is generally higher at larger radar incidence angles due to a sharper decline in water surface reflectivity.

So, here you can see this is not a flood and this is a flood. Terrain tends to remain relatively bright due to broader scattering, irrespective of the value of theta, which is the incident angle. At a lower angle, water appears bright, reducing the contrast. The intermediate angle used in satellites hardly shows this behavior clearly because we are talking about space measurement. So, it will be very difficult.



Now comes the surface roughness. So, strong winds roughen the water surface because of the ripples; it will appear rough. At the same time, we are having the microwave measurement. So, it increases backscatter and reduces contrast with the terrain because earlier, when it is calm, we will get a lower value for the water; the darker pixel will represent the water. But because of this wind, what is happening is that the roughness is increasing, and the backscattering value will be higher. So, it will be very difficult to segregate this information from the topography or other features like urban areas. This makes the flooded area appear less dark and sometimes indistinguishable from the land.

Hence, accurate wind data acquired during the flood event is very, very important. Factors like water depth, obstacles, and terrain add to modeling. Complexity. With this, I will end part 1 of this lecture. We will continue this lecture and discuss the limitations of microwave remote sensing in flood studies, as well as the parameters we should choose carefully to utilize this information in flood studies.

Thank you very much.