REMOTE SENSING FOR NATURAL HAZARD STUDIES

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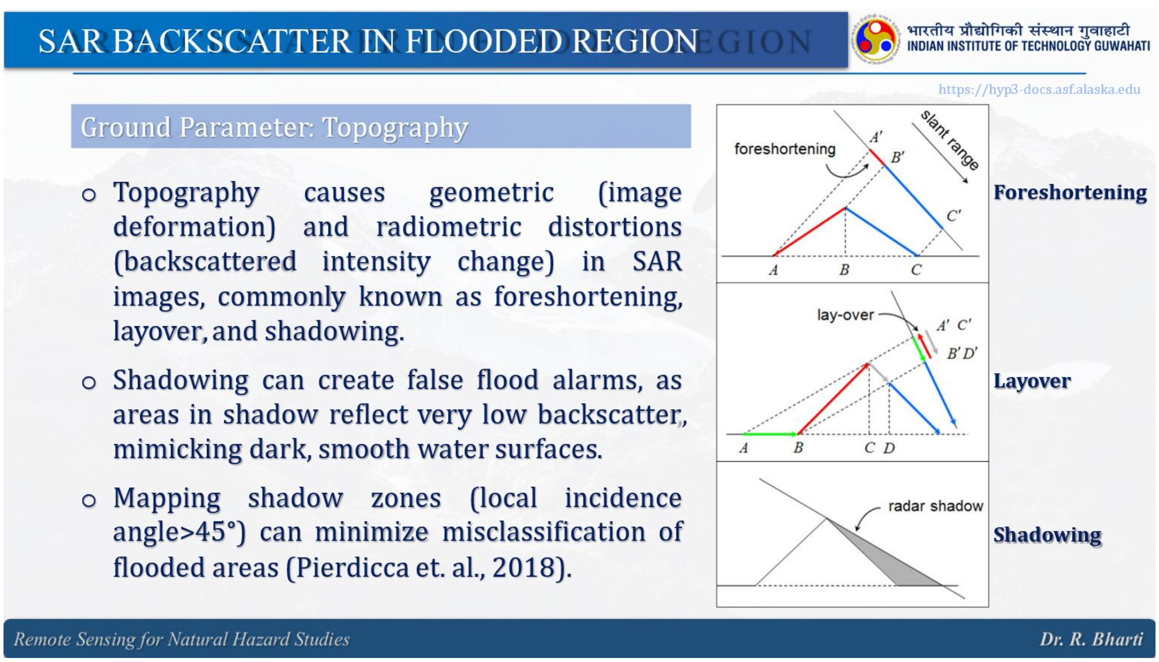
Lec 17b: Remote Sensing for Floods- II Part B

Hello everyone, welcome back to Part 2 of Lecture 17. So, we were discussing the different parameters that influence or hinder the utilization of microwave remote sensing data in flood studies. So, let us continue with that. So, let us talk about soil moisture. So, here you can see that higher soil moisture content increases soil permittivity and radar backscattering. This enhances the contrast between flooded and non-flooded areas, especially in moist soil.

Wet soil can create a complex backscattered signature within a single radar resolution cell, which may complicate the detection of small or mixed water bodies. So, this is one of the limitations when you have high soil moisture in the surrounding area. Accurate modeling requires a detailed knowledge of soil moisture content distribution. So, post-event we can have all these measurements, and if we have continuous measurements pre- and post-event, then this utilization of microwave remote sensing will be very, very effective.

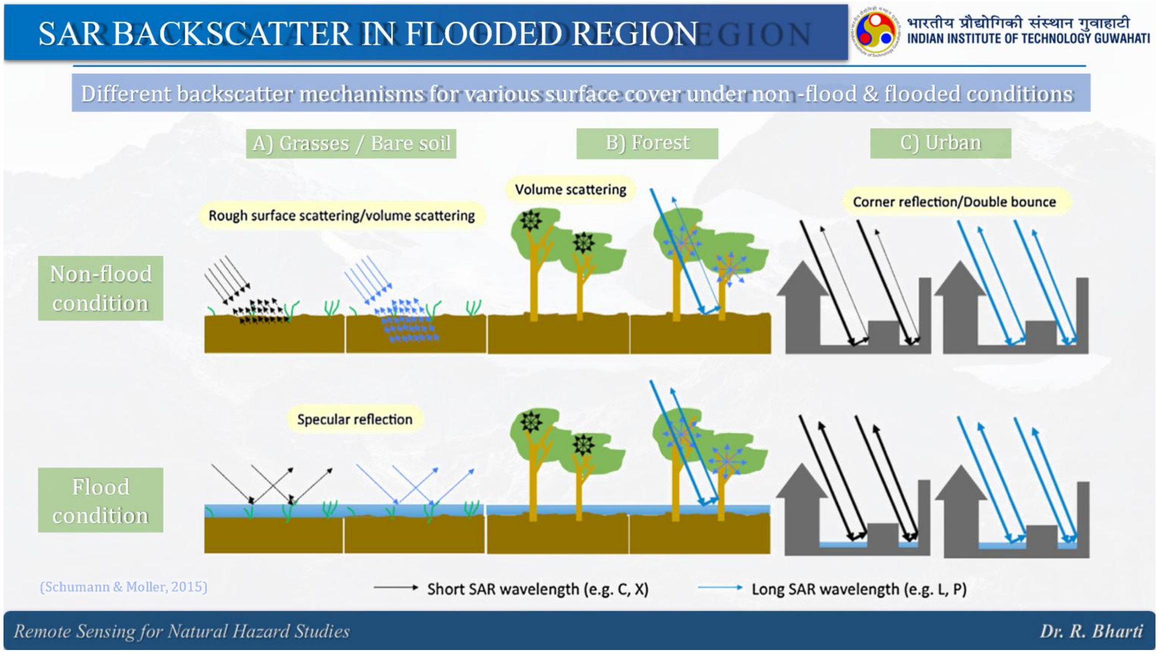


Then comes the topography, which causes geometric or image deformation and radiometric distortion in SAR images commonly known as foreshortening, layover, or shadowing. Shadowing can create false flood alarms as areas in shadow reflect very low backscattered values, which will mimic the dark. and smooth water surface. So, because of the shadow zone, we will be confused about whether it is water or whether it is a shadow. Mapping shadow zones with a local incidence angle greater than 45 degrees can minimize the misclassification of flooded areas.

So, there are different papers that have reported this one. So, here you can see the examples of foreshortening, layover, and shadowing. So, these are one of the limitations of utilizing microwave remote sensing in flood studies. Then comes the vegetation, and we have understood the different scattering mechanisms. So, you need to refer to those concepts here, and then you will be able to understand how these scatterings are happening and how to utilize them to correct your information.

Flooded vegetation enhances radar backscatter through dihedral scattering, which comes from the water surface and vertical elements like tree trunks, unlike bare soil, where water typically reduces backscatter. So, here, because of these tree trunks and the vertical structures, you will have more information due to the dihedral scattering. So, this signal will get modified, and you will have brighter pixels in the radar returns. It is highly dependent on vegetation type or structure and radar system parameters like frequency, polarization, and incident angle. The vegetation structure, such as height, density, and biomass, critically influences wave interaction and backscattering; this is what is explained here.

So, in agriculture, increasing water depth initially enhances double bounce in crops. However, beyond a certain depth, emergent vegetation is too sparse to maintain this effect, causing reduced backscattering. Now, there will be confusion again. For mature crops or dense canopy vegetation, scattering dominates, and flood presence becomes hard to detect because here we are talking about saturation. Thus, radar sensitivity to water under vegetation depends heavily on ground stays.



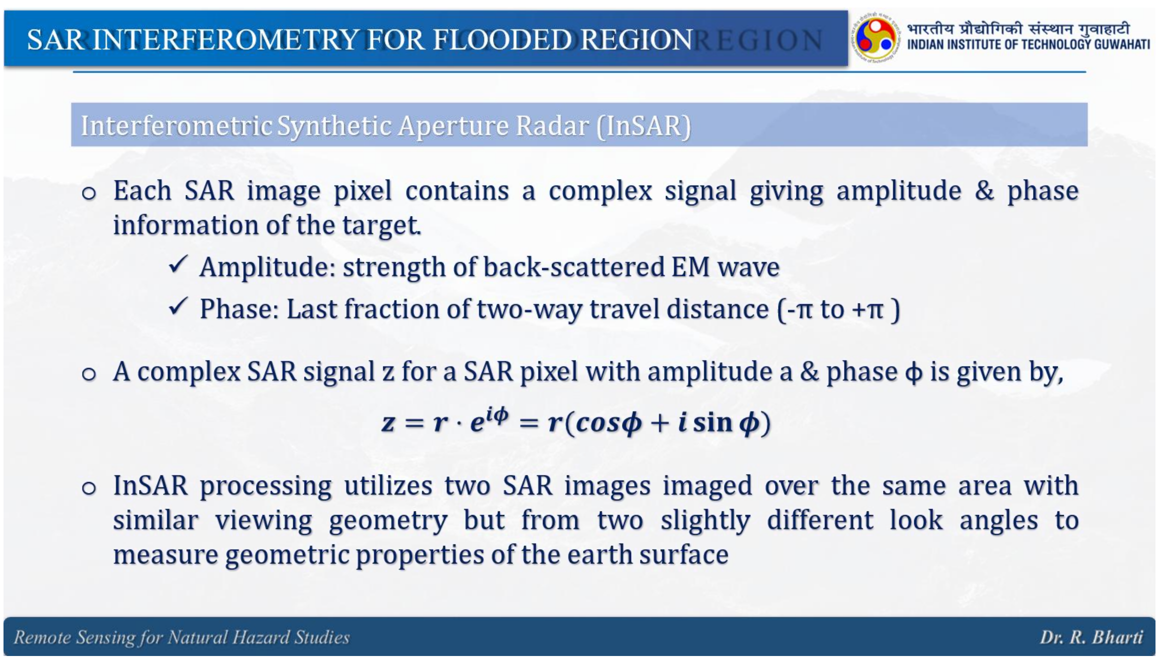
Plant structure and water level. Here, optical detection occurs during intermediate water levels with partial submergence; you can see the partial submergence. Then we will see how the urban structures confuse the whole estimation. So, the radar imaging in an urban setting is complex, especially with low spatial resolution, because if the spatial resolution is low, the whole building or these two buildings will be in one pixel. In such a situation, it will be very hard to detect.

High backscattering from dihedral reflections, which are ground and building walls, results in very bright radar signals. Additionally, effects such as layover from rooftops and shadows behind buildings further complicate signal interpretation. Mutual shadowing, multiple scattering effects, triple bounds, and reflection from windows and gable roofs will together cause the multiple scattering between buildings in dense urban settlements, reducing flood detection reliability. So, even if you are using the microwave data, you will not be able to prove the efficacy or the accuracy of your results. Different backscatter mechanisms for various surface covers under non-flood and flooded conditions.

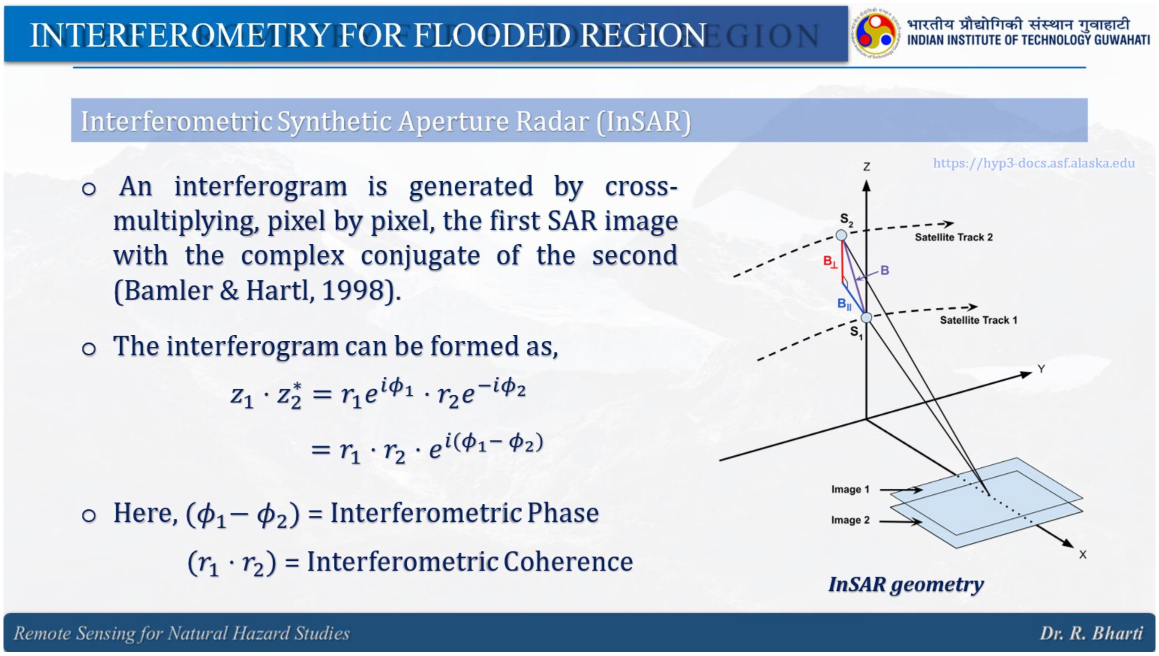
So, here you can see there is the first condition when you have bare soil and grasses, then you have the next one when you have a forest, and the sea here is urban. So, this is the non flooded condition. Here you can see that the water is not saturated; normal soil moisture will be present, and the surface is visible in urban areas; it is also visible right in the forest. When we have flood conditions, the specular reflection will start working, and this area will be partially submerged in water, and this is also happening in the urban area. So, because of the double reflection or the double bounce reflection, it will be hard to detect, or the signal will get modified, and it was supposed to come with a dark pixel, but it will be a brighter pixel, so, different scattering mechanisms are responsible here for different types of structure.

I hope you understand this particular concept. Backscattering intensity over grass and bare soil land cover under non-flood and flooded conditions is represented here. So, this is non-flood SAR intensity and flood SAR intensity. So, these images are post-flood, and these are without flood. So, under non-flooded conditions, these surfaces generally exhibit moderate backscatter due to surface roughness.

When flooded, the smooth water surface causes a specular reflection, reducing the radar signal return. As a result, SAR backscatter intensity significantly decreases over flooded grass and bare soil areas. Now with the sparsely built-up areas. How does the remote sensing data set appear? So, this is again the non-flood SAR intensity; this is post-event. So, here you can see the sparse urban areas have a mix of open spaces and built structures leading to moderate backscatter under normal conditions. So, this is normal condition. When flooded, a partially submerged building shows an increase in backscattering from double-bounce scattering. So, here you can see that this is the double bounce. Here, the intensity variation is more noticeable than the improvement of flood detectability. Now, when we have a dense urban area. How does it appear? So, here you can see this is a normal condition; this is the flood condition. So, in non-flooded conditions, buildings or manmade structures cause strong radar reflections, especially via the double-bounce mechanism. During flooded conditions, backscattering may remain unchanged if water does not affect radar geometry. Hence, dense urban environments obscure the presence of floodwater, making intensity-based detection less reliable. So, it will be very hard to utilize the microwave remote sensing data in flood studies in the dense urban area.



Now let us see the interferometric synthetic aperture radar in SAR. Each SAR image pixel contains a complex signal giving amplitude and phase information of the target. So, the amplitude indicates the strength of backscattered electromagnetic waves, and the phase is basically the last fraction of the two-way travel distance, from minus pi to plus pi. A complex SAR signal Z for a SAR pixel with amplitude A and phase φ is given by this equation. In SAR processing, we utilize 2 SAR images over the same area with similar viewing geometry, but from 2 slightly different look angles to measure geometric properties of the Earth's surface; that is what we have when we talk about the InSAR configuration.



So, an interferogram is generated by cross-multiplying pixel by pixel the first SAR image with the complex conjugate of the second. So, the interferogram can be formed with this; here, the interferometric phase and the interferometric coherence will be calculated. I hope you remember the microwave remote sensing lecture. So, then you will be able to utilize those concepts here. Coherence or correlation is a measure of the similarity between two radar signals captured over the same area at different times.

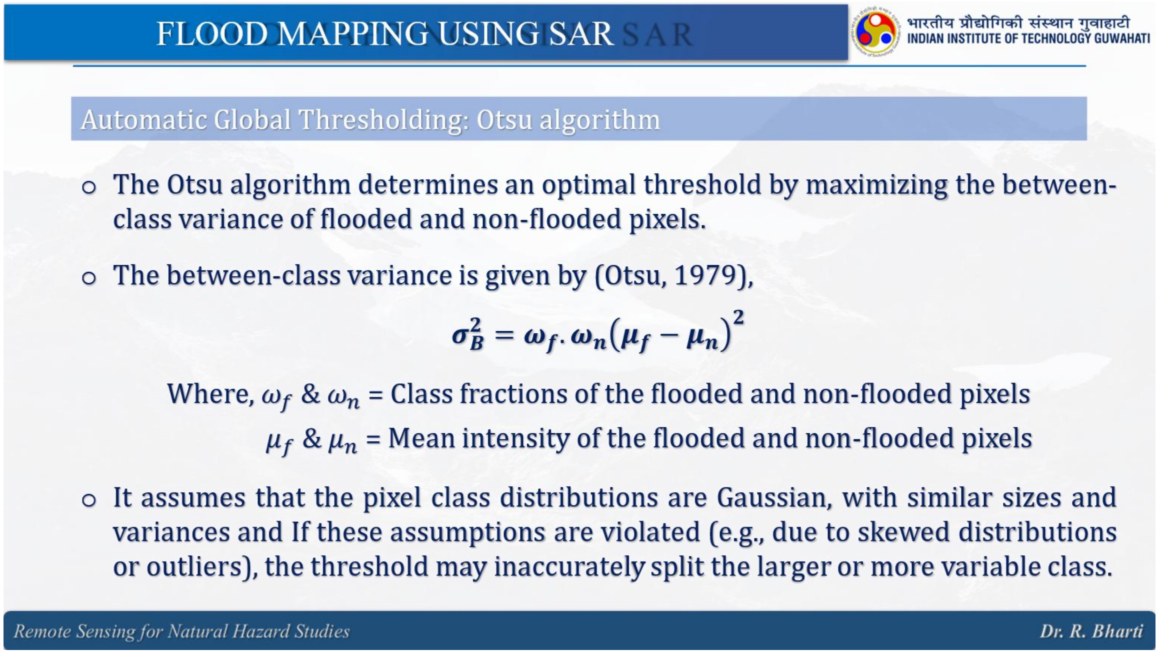
So, it quantifies how similar SAR signals are in both amplitude and phase, and here we will have the value range between 0 and 1. 0 means no similarity, a completely de-correlated signal, and 1 means perfect similarity, a fully coherent signal. So, here you have the example of water, vegetation, and exposed lava. So, this de-correlation. Due to various factors that affect the similarity between two SAR images acquired at different times.

The first one is the temporal de-correlation, then the spatial de-correlation, and then the volume de-correlation. So, when we talk about this temporal de-correlation, it happens due to changes on the ground between two SAR acquisitions, such as vegetation growth, human activities, or water level. So, it could be a flood. It is caused by the difference in the viewing geometry and the baseline because we are talking about the two measurements of the same area from two different positions, but the baseline will be the same. So, the volume de-correlation occurs due to inconsistent phase information as the radar signal penetrates the canopy, scattering from different depths.

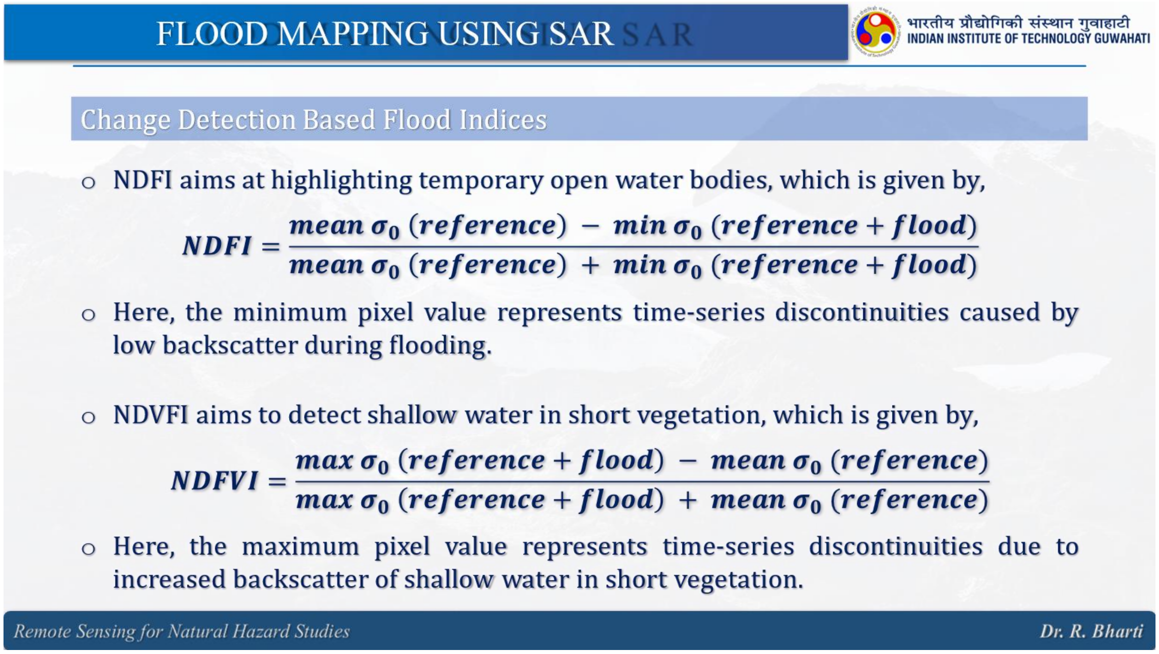
So, that will come from the volume of correlation. Coherence can also drop due to other reasons, such as widespread rainfall, making it essential to analyze overall and normalized coherence trends. Water bodies can be recognized as areas with low coherence between two SAR images, distinguishing them from land areas that typically exhibit higher coherence. Flooded areas show reduced coherence due to surface changes, allowing maximum flood extent detection even if water is not present in both images. So, we are talking about the InSAR.

Event coherence maps are generally used to detect flood-related changes, where a drop in coherence greater than 0.3 is often used as a threshold to classify a pixel as flooded or non-flooded areas. So, here we are using this coherence image, and the threshold will be greater than 0.3. Vegetation and the fast-changing terrain can also cause low coherence, which may complicate this analysis.

Coherence helps to separate vegetation from bare soil, reducing reliance on optical or land cover data to detect vegetation. It also helps in differentiating increased backscatter from water beneath vegetation linked to double bounce scattering from that caused by bare soil moisture, which shows significantly lower coherence. Further, combining backscatter intensity and interferometric coherence enables clearer separation of flooded vegetation from non-flooded areas, improving map reliability. However, in the case of dense vegetation, coherence is generally low due to temporal de-correlation caused by factors like wind or plant growth, making it ineffective for detecting changes associated with flood water. So, when we use the INSAR, we have to be very, very careful about why this coherence image is coming. Why are these values coming? That is what we need to understand and answer. Flood mapping using intensity assumes reduced backscatter in the flooded areas and increased double-bounce intensity for partially flooded buildings. However, SAR intensity data alone may misrepresent flooding in complex urban settings because of the scattering mechanisms due to orientation and multiple scattering in urban areas. Built-up areas usually exhibit stable coherence due to their structural stability over time, as they do not change very frequently. Hence, a decrease in coherence around structures indicates potential flooding in the area.

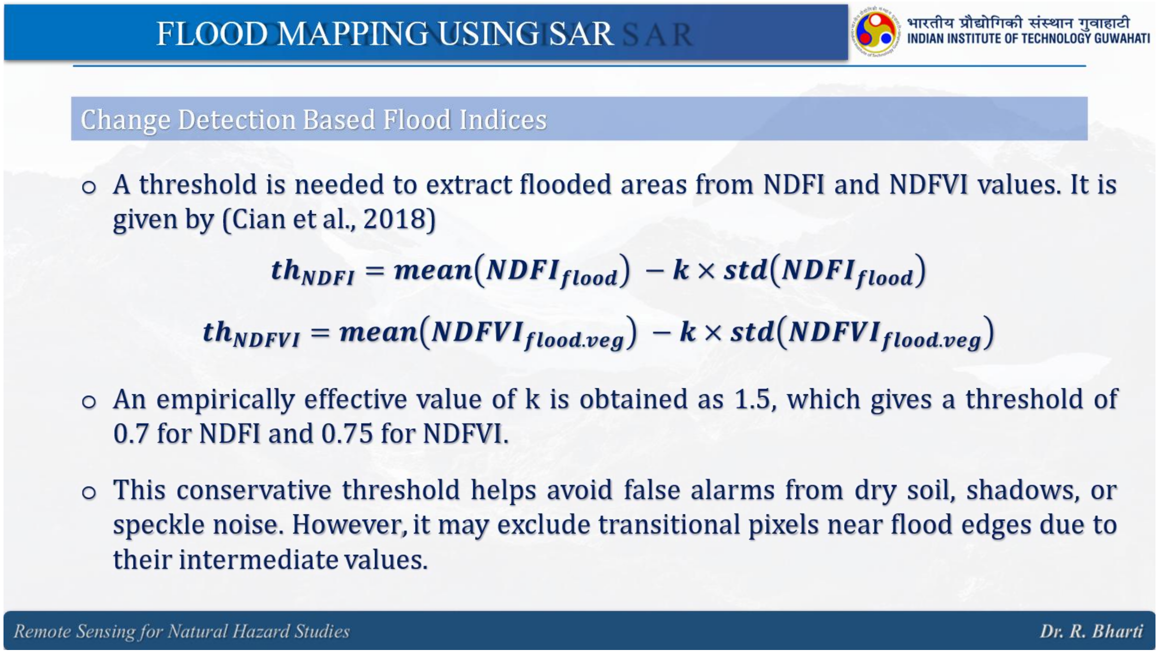


Because the structures are not changing every day, there will be slight modifications in the structure. But, because of that, if you are having the coherence values that are coming in these particular areas, then it could be because of the flooding. The urban area remains temporarily stable unless vegetation is present; therefore, INSAR coherence is used to complement intensity, capturing both amplitude and phase correlation between image pairs. So, when we have grass and bare soil land, how does the microwave remote sensing data set appear? So, this is the normal condition, this is the flood condition. So, grass-covered areas may exhibit moderate to low coherence even in non-flooded conditions because of vegetation movement. Flooding in grassy areas reduces coherence as water causes temporal de-correlation and changes the scattering mechanism. This difference helps distinguish between vegetation type and flood presence when combined with SAR intensity. When we have these sparsely built-up areas. So, here this is the normal condition, this is the flood condition.



Sparse built-up areas usually display moderate to high coherence in non-flooded conditions due to relatively stable manmade structures. During flooded conditions, coherence significantly decreases as per flood water depth. Building orientation and surface changes. Flood detection becomes more effective when coherence loss aligns with known built-up zones that are utilized together. For the dense urban area, this is the normal condition, this is the flood condition, and here you have the coherence value.

Dense urban areas typically soak up consistently high coherence in non-flooded scenarios. In flooded conditions, coherence often remains high or with minimal loss, making flood detection using coherence alone less effective in such areas. Combining coherence with SAR intensity or phase information is essential for reliable flood detection in densely urbanized areas. Limitation of coherence-based flood mapping, InSAR faces challenges over open water due to specular reflection and surface roughening, which cause a complete loss of temporal coherence, making interferometric analysis difficult or impossible. Further temporal and spatial baselines affect coherence, with the temporal baseline influencing the detection of flooded vegetation and the spatial baseline being more critical in urban flood mapping.



High coherence persists in built-up areas even during floods due to dominant points like scatter masking water presence, making analysis difficult. Further, radar imaging in urban settings is complex, especially with low spatial resolution, where multiple scatterers are within the same pixel. Now, combining SAR intensity and coherence for flood mapping. So, we continue with that one intensity-based method, assuming fresh water in hand is backscattered by double bounce; however, complex urban areas or dense vegetation disrupt this effect, making such approaches unreliable. The coherence-only flood detection method suffers from the low spatial resolution of the coherence map, limiting its precision in identifying small or detailed features combining SAR intensity with SAR coherence which helps to overcome this limitation. So, here we will have both techniques, and here we will be able to identify the regions affected by flooding using two criteria. So, the first one is a drop in coherence between the pre- and co-event images; then we have a change in backscatter intensity. So, now we will try to understand the flood mapping technique through microwave remote sensing. So, SAR enables the spatial mapping of flood-affected water bodies.

Flood extent derived from SAR can be overlaid on existing datasets for damage assessment, which helps in disaster response planning and resource allocation. Then, flood mapping is performed using the following techniques. The first one is visual interpretation and digitization. Then, we have manual thresholding, automatic global thresholding, and change detection based on flood indices. So, the visual interpretation and digitization will not be recorded.

So, here you can see the spatiotemporal flood map of Kerala obtained from Sentinel-1 imagery and an automated OTSU thresholding algorithm. So, here you can see the permanent water body and the flooded areas in green and red colors. This particular slide has all the references that I have been using in this particular lecture. So, you can refer to it if you need more information about these topics. So, you will have more information about this particular aspect.

Thank you very much.