REMOTE SENSING FOR NATURAL HAZARD STUDIES

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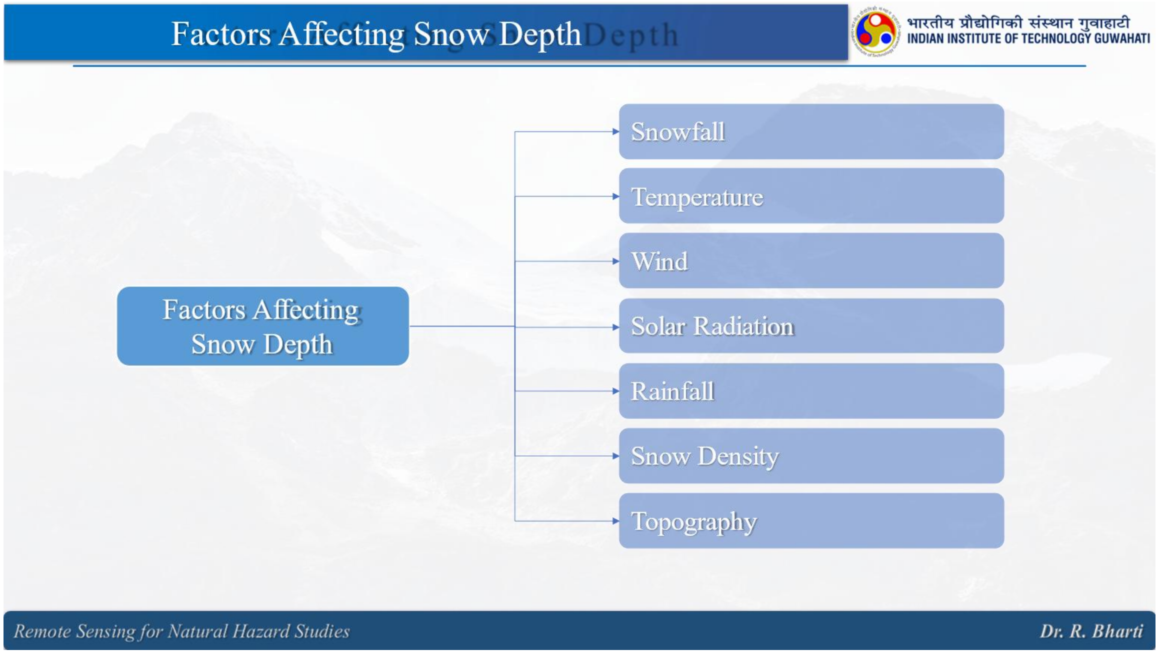
Lec 23 a: Geophysical Parameters of Snow-II Part A

Hello everyone, welcome to Lecture 23. Today, we will continue the discussion on the geophysical parameters of snow. In the previous lecture, I gave you all the details on why the geophysical parameter is necessary to study, what its role is, and why it is important. So, today we will continue that, and we will start with the snow depth. So, snow depth refers to the vertical distance from the surface of the snowpack to the ground. So, let us consider this is ground, not the icy one. So, in that case, this will become the snow, Snow depth. So, here you can see different examples. So, at different places, different depths will be there. So, at higher altitudes, when we have steep topography, the depth varies. from one location to another location. Snow depth is a critical parameter for understanding the extent and volume of snowpack, which plays a key role in hydrological studies. It is an essential indicator for assessing snow water equivalents. So, this is very, very important.

I hope you have understood the role of snow water equivalents. I have covered this in the previous lecture, and today we will see more details about the SWE. It provides valuable insight into water resource management. Snowmelt forecasting and various hydrological applications. So, once you know what the depth of the snow is, you will be able to model how much water will be released with changing temperatures.

So, those kinds of studies have been carried out under these circumstances, monitoring snow conditions has proven to be especially useful using satellite remote sensing techniques, because we all know that in situ measurements are very, very difficult in this terrain because it is rough. The snow parameters have previously been retrieved by researchers employing a variety of optical and radar remote sensing datasets. Optical remote sensing has a constraint because it cannot provide data in foggy conditions, and the snow-covered regions are mostly cloudy throughout the year. So, in contrast, microwave remote sensing offers an advantage by acquiring images even in cloudy conditions.

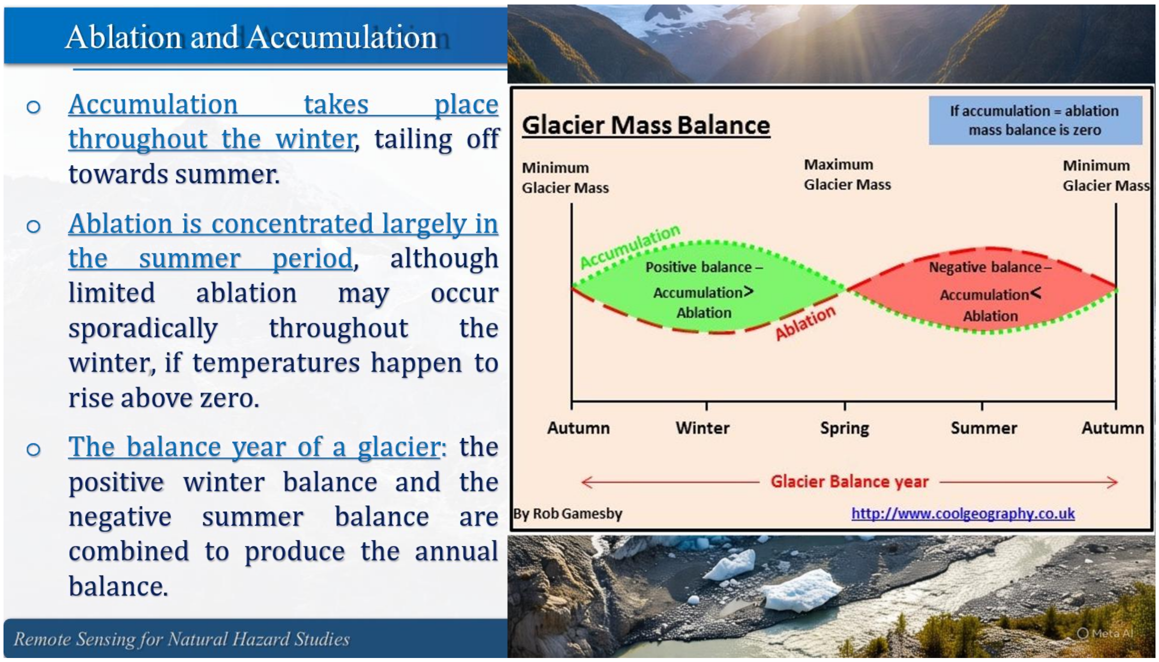
So, these are the advantages of remote sensing; why, at all, do we have to look for an alternative source of information to estimate the geophysical parameters, particularly snow depth?



So, if you see the factors that are affecting snow depth, are snowfall, temperatures, wind, solar radiation, rainfall, which is liquid precipitation, snow density, and topography. These all together define what the depth of the snow from the surface will be. So, just to give you a background, the development of glaciers depends on the complex interaction of climatological, topographical, and geographical factors, of which precipitation and temperature are the most important controlling climatic factors. For glacial development, high annual precipitation is required in solid form. So, that is why, if you remember the positive mass balance.

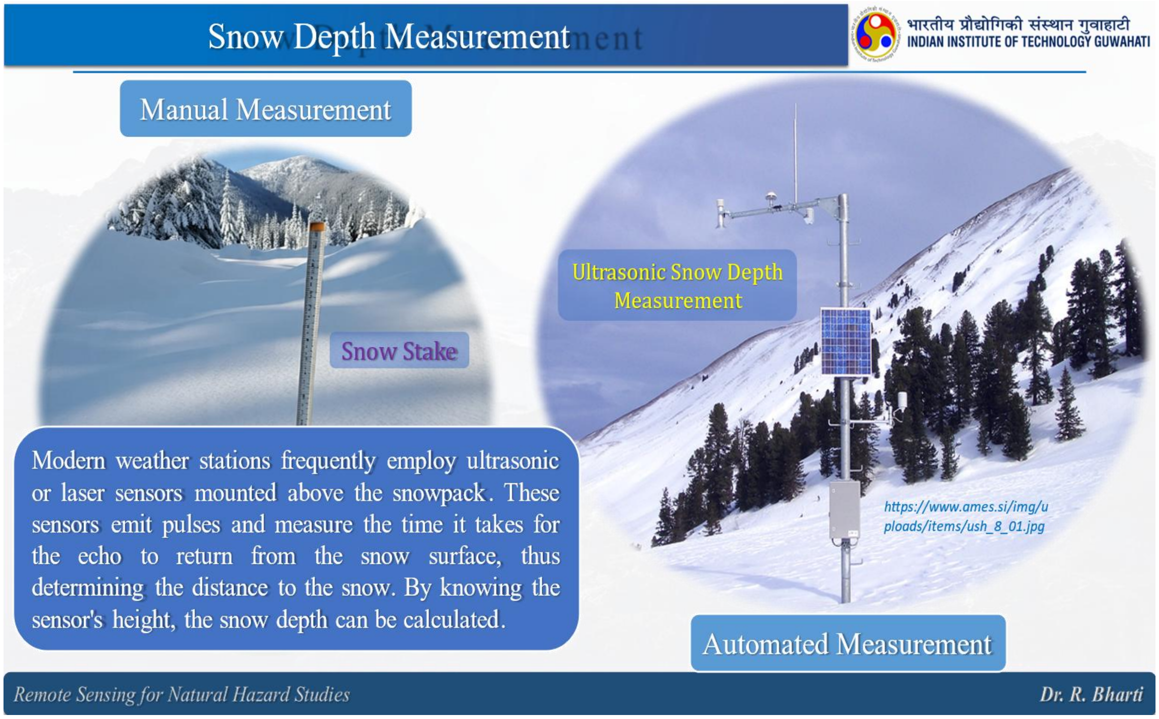
This will only happen when you have a high annual income. Precipitation is the proportion of precipitation received as snow, which is the ratio of snowfall received to total precipitation. So, here the annual snow budget is greatly influenced by solar radiation because the amount of energy falling on it defines whether it will remain on this particular surface or melt. Geographical location also plays an important role because of the topography as well as the height from the MSL. So, those things will define what the amount of solar radiation received by this location will be.

So, here it defines the temperature of the region's distance to the ocean and influences the total or high amounts of precipitation. Then comes the topography. You see, the main mass is somewhere here. It is flowing through this valley. But because of the topography, it remains. So, the topography plays a very important role here in snow accumulation. So, accumulation takes place throughout the winter, as we know that solid precipitation happens only in the winter season, tailing off towards summer. Ablation is concentrated largely in the summer period, although limited ablation may occur sporadically throughout the winter if temperatures happen to rise above. So, here you can see the positive mass balance when accumulation is greater than ablation.



When we talk about this side where the negative mass balance is such that accumulation is less than ablation. So, in the balance year of a glacier, the positive winter balance and the negative summer balance are combined to produce the annual balance. So, if you see this graph here. So, both remain the same on these points because the amount of accumulation and ablation is cancelling each other. So, because of that, there will be no change or net change in the snow accumulation in this area.

So, if the area under both the accumulation and ablation curves is equal, then the budget is balanced, and the glacier is in equilibrium. So, there are no major changes happening in this stock. If accumulation is in excess, then the glacier has a positive budget, and it is growing. So, it will slowly start growing. If the budget is negative, then the glacier is shrinking. So, it will start shrinking, and this mouth will be something like this. Accumulation is greater at higher altitudes, where ablation processes are more limited due to lower temperatures. Ablation dominates accumulation in the lower part of the glacier. So, here the ablation will be more effective in this region. The point at which ablation and accumulation are balanced is the equilibrium line. So, for this, maybe you can say this is an equilibrium line, do not consider this. So, the factors affecting snow depth is how the snowfall, temperature, wind, solar radiation, rainfall, snow density, and topography will play a critical role here.

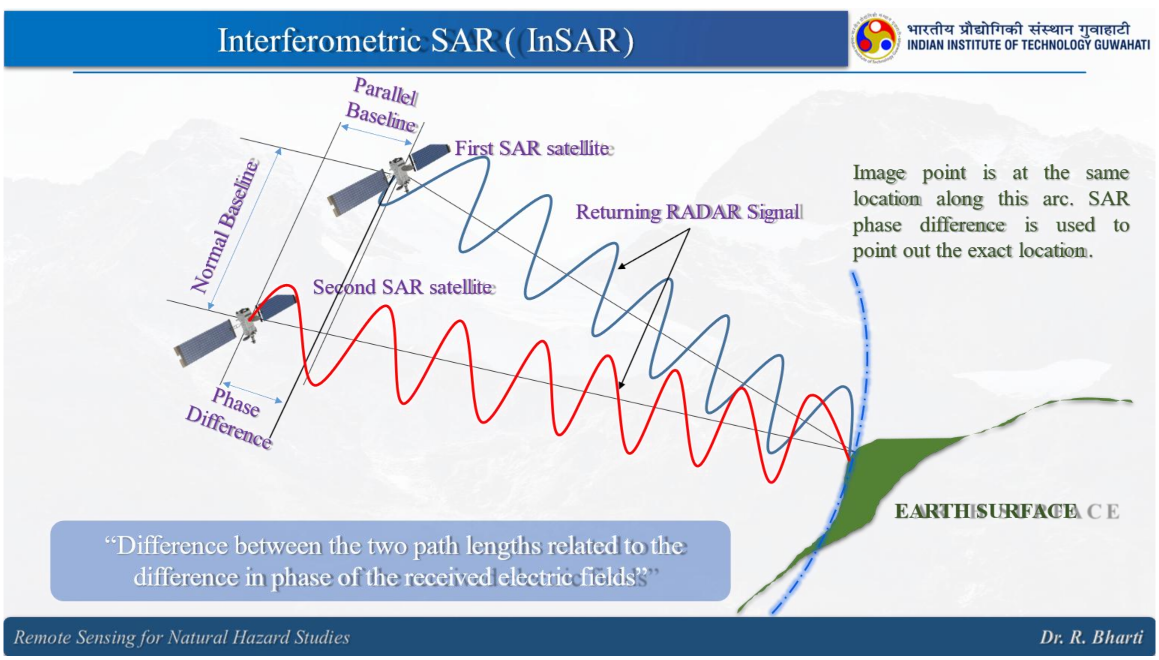


When we were talking about the snow depth. So, there are two types of measurement: one is manual, and the other one is automatic. So, when we say manual, we have a stake. This is a snow stake that has some numbers here. So, you can see that every year we come and mark whether it has gone up or whether it is going down. So, then it will be negative budget when we talk about this automatic measurement. So, here the modern weather station frequently employs an ultrasonic or laser sensor mounted above the snowpack. These sensors emit pulses and measure the time it takes for the echo to return from the snow surface, thus determining the distance to the snow. By knowing the sensor height, the snow depth can be calculated; it releases the pulses and then measures how much time it has taken to return to this sensor. It will have information about this height and then it will calculate how much change there is in the snow in this surface. So, for this, we have done various field investigations. So, this is one example where we have reached the Rathong glacier. So, it was a very difficult trek of 96 kilometers to and fro, and here we have seen different topography available for this glacier, and we have also installed the snow stakes. So, this is my team; we went together, and then we had the installation of these snow stakes.

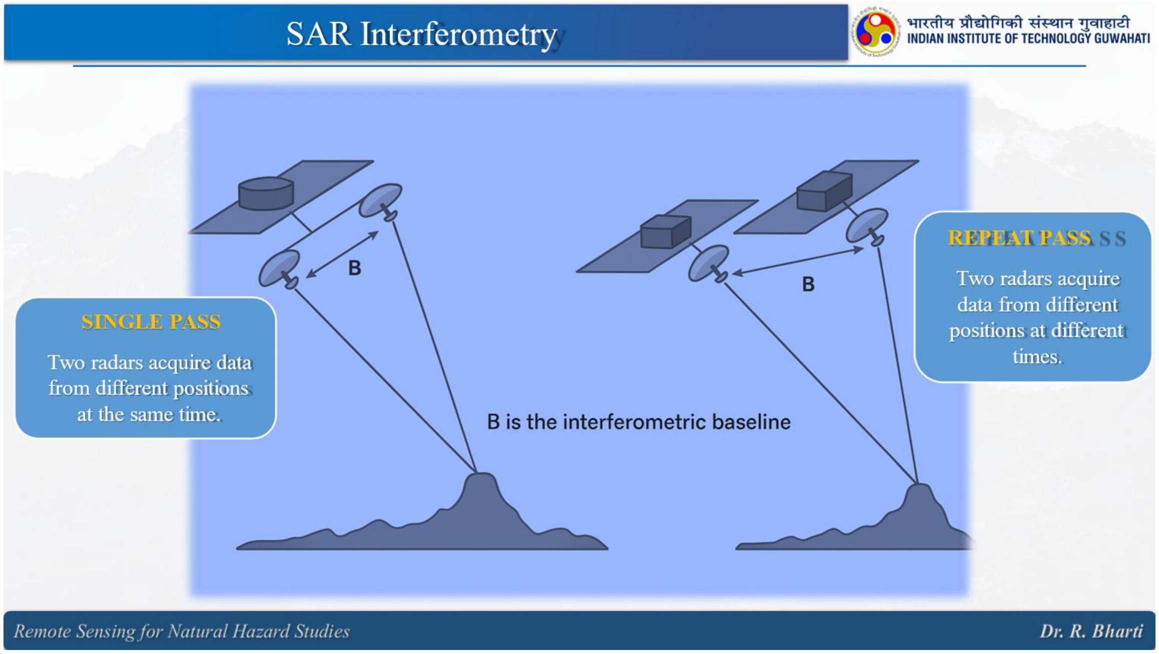
The SAR polarimetry, also called polarimetric SAR, and the SAR interferometry, also known as interferometric SAR, have been proved to be helpful in estimating snow physical parameters such as snow depth, particularly snow density and snow water content. Time series Sentinel-1 datasets are used by various researchers to study the inconsistency of snow depth in the mountains of the northern hemisphere.

The link between particle anisotropy, snow depth, and copolar phase difference is also used to retrieve the snow depth and snow water equivalent. The copolar channels are typically provided by commercial polarimetric SAR data, which are expensive. So, in contrast to sensors like Sentinel-1, there is one copolar and one cross-polar channel, which are VV and VH. are freely available. So, that is why we concentrated on this Sentinel-1, whether we can develop a method that can estimate the snow depth and other geophysical parameters, and this is freely available in the public domain. So, that is an advantage. So, when we talk about microwave remote sensing, you can see the example here. So how are the different birds and the fish using the echolocation method to target their food? Similarly, we have satellites that are looking at the ground from different locations, and we are using this information to derive details about the target. So, I hope you remember the interferometric SAR configuration. So, here you have the first SAR satellite. So, here you have two satellites that are available at two different locations, and these locations are separated by the baseline.

And here you have to see that this particular location or this particular area is being captured by both satellites at the same time or at different times. So, this information can be used further to investigate and derive meaningful information.



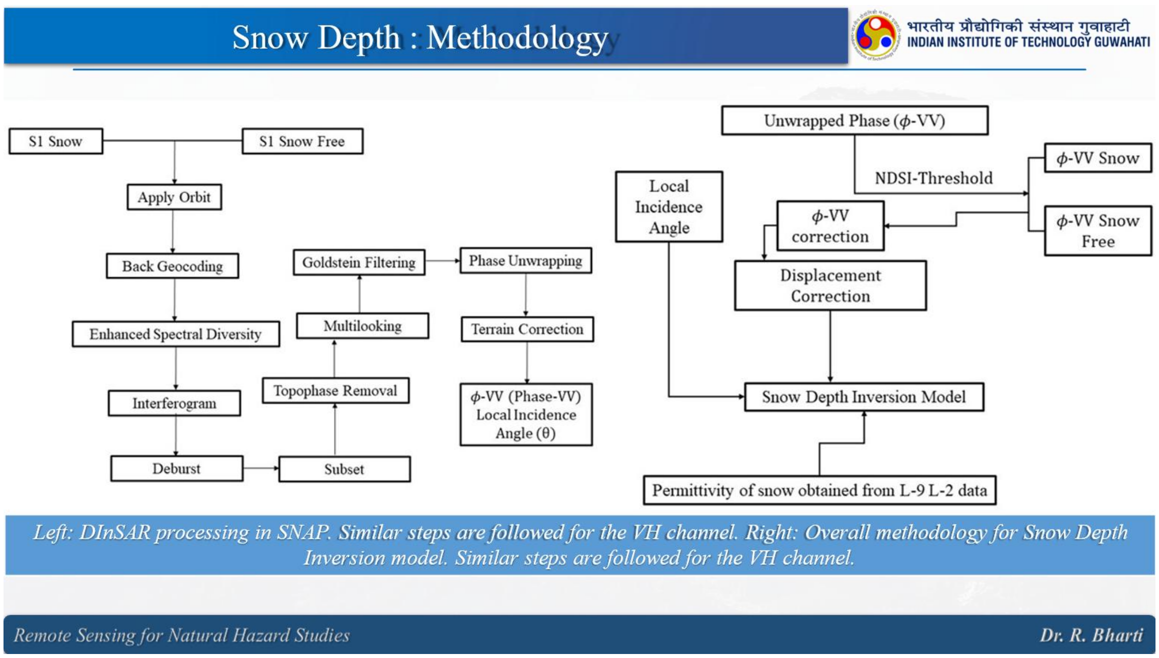
So, the difference between the two path lengths is related to the difference in phase of the received electric field. So, if you see here, because of this, we have the phase difference, and these phase differences are further analyzed to extract the information. So, this is another example of how we measure the images.



From using the single pass and the repeat pass concept. So, here when we talk about the single pass, two radars acquire data from different positions at the same time. So, this is called a single pass. When we talk about the repeat pass here again, we have two radars, but they acquired the data from different positions at different times.

So, that is the difference. So, to understand surface dynamics, especially surface subsidence, the interferometric method that makes use of space-borne SAR has been thoroughly studied. Repeat pass interferometric dataset and approaches, Entrenches in InSAR have been extensively employed for the estimation of snow water equivalent and the analysis of snowpack dynamics. However, InSAR signals are mixed with the topographic phase. To solve this problem, the differential InSAR, the DInSAR technique, is used. So, today I will tell you what it is and how we are doing this. So, the DInSAR method is considered more accurate than InSAR as it can provide relative measures up to a few centimeters or less.

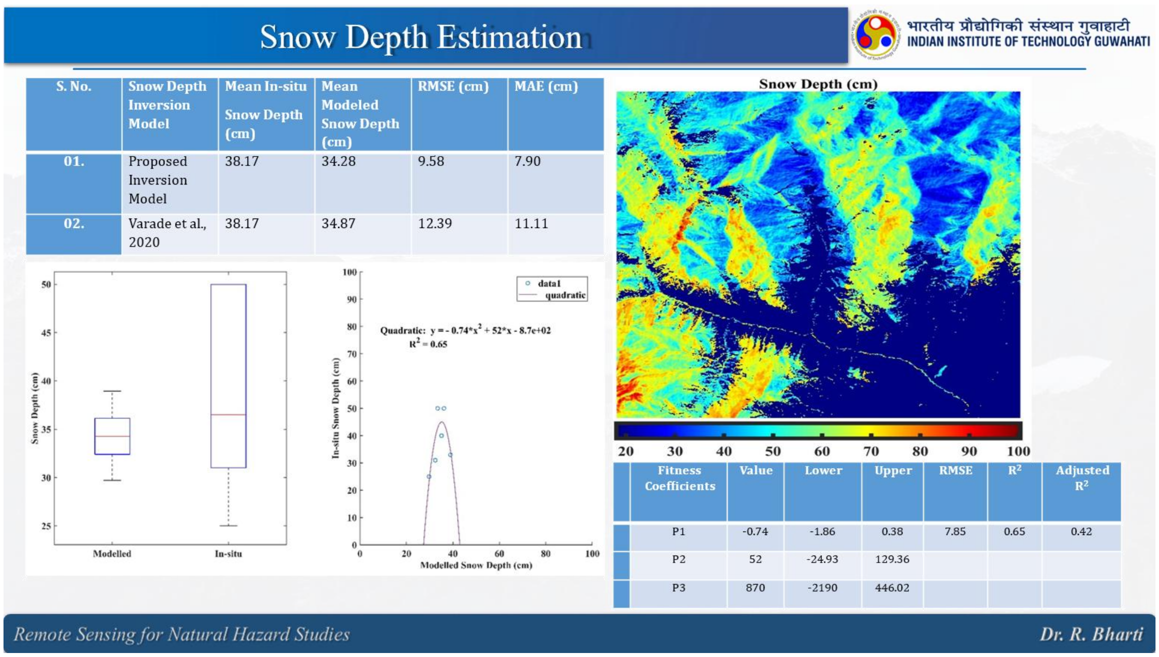
So, the accuracy is very, very high for the differential interferometric SAR. The de-InSAR path has been exploited to project the snow water equivalent for dry snow using interferometric phase information. C-band InSAR, we have Sentinel-1. Records from European remote sensing satellites are utilized subsequently research utilizing Sentinel-1 dataset has focused on estimating snow depth through DInSAR method. So, the obtained snow depth indicates an enhancement in overall accuracy compared to the conventional InSAR technique. So, today I will show you how our results are better than the earlier proposed model and how using this DInSAR helps us to identify the information. The snow depth inversion model is a function of the snow dielectric constant, radar wavelength, and the incident angle or the local incident angle. So, studies also indicated that the estimation of snow depth largely relies on the accuracy of two components: that is, snow phase contribution and the snow dielectric constant. So, this two information are used. So, these two components can be determined through in situ data or from other remote sensing data sources, such as multispectral data or the full polarimetric SAR data. So, full polarimetric means you have VV, HH, VH, HV, all the combinations are available. Researchers have used multispectral database snow cover map threshold for snow face correction. So however, a snow mask derived from Landsat images frequently used to extract the Sentinel-1 backscattering. So, study by Singh et al 2025 employed Landsat 9 based snow cover product and snow geophysical parameter which is wetness density and dielectric for snow depth estimation.



In our research Sentinel-1 data, along with supplementary data derived from in-situ measurement and enhanced version of optical dataset, such as Landsat-9, have been utilized to construct a model for snow depth inversion. So, a state-of-the-art snow depth inversion model has been proposed by my group, integrating information from Landsat and Sentinel-1 data. So, here our study area was Arunachal Pradesh in India, which is, from the eastern Himalayan region. So, here you can see the SAR data, which is used to generate the digital elevation model. So, let us say this is time 1 T1, and this is T2 time if there is a change in the how height that we will consider this snow accumulation.

So, that is being used here for identifying the snow depth, this is further utilizes the other method. So, here you can see the study area and the locations are highlighted here where we have done the field investigation and these some of the field photographs. So, this is the methodology which we have used. So, here the left-hand side is the DInSAR are processing, which we have done in the snap similar step are followed for the VH channel.

right side, we have overall methodology for snow depth inversion model; similar steps are followed for the VH channel. So, this is for the VV, but we have also done the same processing for the VH channel, and then we have estimated the wetness permittivity, and then subsequently we derive the snow depth.



So, here you can see the snow depth inversion model which is developed by my group. So, it has the mean in situ snow depth which is 38.17 and the mean model snow depth that is 34.28, and the RMSE and MAE is given here. Whereas the earlier methods you can see the values are in the similar range, but we have better accuracy. So, here you can see the values lower bound, upper bound, RMSE R-squared, adjusted R-squared, which is given here. So, this modified model incorporates snow permittivity for each pixel value obtained from Landsat 9 level 2 dataset. We set the NDSI threshold for this snow cover map to be greater than 0, guided by our in-situ measurement, because we have visited the field and then we have identified this should be the threshold. The degradation of NDSI value at the measured location is attributed to the presence of vegetation as evidenced by the field photograph from the study area.

The average model snow depth at the measured location was determined to be 36.70 centimeters whereas the expected snow depth observed in the field was 38.17. So, the improvement in RMSE and MAE for our proposed snow depth inversion model can be attributed to alteration in the scaling factor for each VV and VH because we are talking about the Sentinel-1 data and the weight function. Now, still there is room for further enhancement of the efficiency for our model, which could be achieved through in situ analysis of snow physical variables like snow dielectric density and wetness utilization of high-resolution DM instead of SRTM 30 arc second refinement of weight and scaling factor, and additional pre-processing improvement in the DInSAR technique. So, these are the future scopes of this work. So, if anybody is interested, they can go for this future research.

Thank you. I will end part 1 here, and then we will continue this discussion in part 2.

Thank you very much.