REMOTE SENSING FOR NATURAL HAZARD STUDIES

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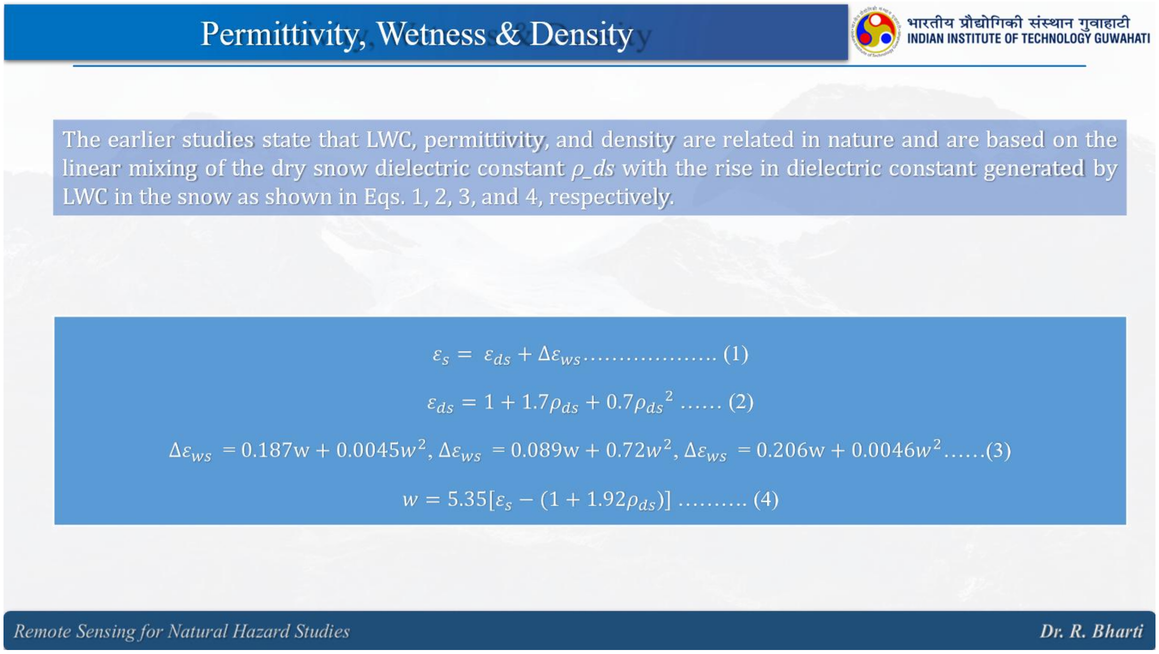
Lec 23 b: Geophysical Parameters of Snow-II Part B

Hello everyone, welcome to Part 2 of Lecture 23. So, we discussed the snow depth estimation in the previous part. Now, in this part, we will try to discuss the density, permittivity, and other parameters, and how we can estimate them using satellite remote sensing. So, when we talk about the density, which is a fundamental property of snow, it is defined as the mass of the snow per unit volume. It varies significantly depending on the snow's age, condition, and other factors. Fresh, dry snow has relatively low density, while older or wet snow can be significantly denser, because you can just try to visualize this when you are experiencing the snowfall.

So, these are the fresh snow and the ferns that have accumulated here slowly; what happens on top of it is that there will be another accumulation of snowfall, and these will be the overburden to this first layer. And, because of the increased temperature and pressure, there will be solidification; they will be more compact. So, when we talk about fresh snow, it has very low density compared to denser snow or older snow. So, the factors that affect this snow density are this type of snow.

Temperature, wind, metamorphism, compaction, and the liquid water content. So, what is the liquid water in this particular snowpack that also defines the density, and what will be the density in this particular snow?



Similarly, we have permittivity. So, the measure of its ability to store energy in an electric field is highly dependent on its state, whether it is dry snow or wet snow, and the presence of liquid water. So, because all are related, whether it is dry or wet snow, we have wet snow; then we have more liquid water content. So, to understand its state and the presence of liquid water is very, very important.

Dry snow, primarily composed of ice and air, has a lower permittivity than wet snow, which includes liquid water; similarly, we have the factors that affect snow permittivity: snow density, liquid water content, temperature, snow type, and snow microstructure. So, when we talk about the microstructure, we mean the crystal size and the orientation, which also define the permittivity. Then comes the wetness. So, it is also known as the liquid water content, which refers to the amount of liquid water present within a snowpack. So, this particular image is just to explain that this ice has more water content.

So, visually you can identify it, but when we talk about the liquid water content present in snow, whether our snow is dry or wet, we need an instrument to measure it. So, this particular image is just meant to explain how these two are different. So, here you can easily see that this is wet snow. But when we talk about the snow in ideal conditions, you need an instrument to measure the wetness. It is a crucial factor in understanding snow hydrology, seasonal snow changes, and regional climate variability.

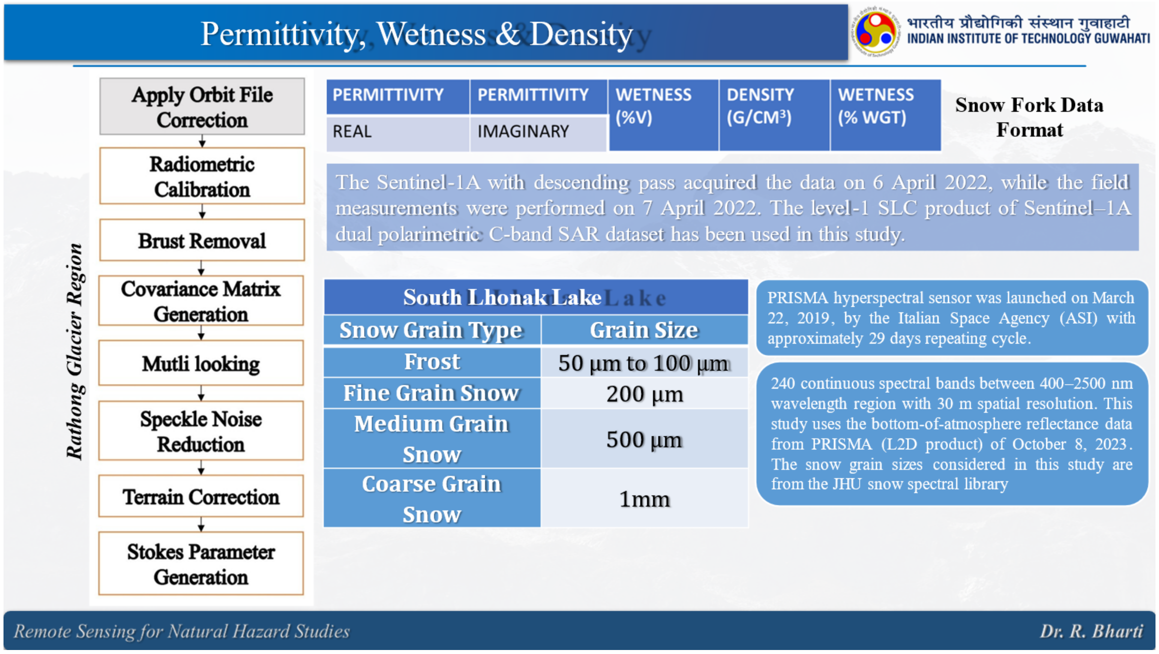
The presence of even a small percentage of liquid water significantly alters the physical, thermal, and electromagnetic properties of snow. Here are the factors that affect snow wetness: temperature, solar radiation, air temperature, snowpack density, precipitation, slope, and aspect, because we are talking about snow wetness. So, the wetness will increase when we have more energy in the system. So, the temperature is very simple to understand; the solar radiation will play a role here. This particular area or this snowpack will receive more energy or less energy.

Air temperature: What is the ambient temperature? The density of the snow, the precipitation, and the liquid precipitation are all factors we know; the water droplets also bring energy with them, which will change the liquid water content of this particular snowpack, as well as the slope and aspect, because the flow will occur depending on the topography. So, if there is precipitation, whether it will be here or there, it will be defined by the slope or the gradient. So, the geophysical properties of snow are essential to studying this snow or glacier system and can be used as indicators of any related hazards because the stability and status of that glacier will be defined by these geophysical properties. The important geophysical parameters of snow, like dielectric constant, density, and liquid water content, play a vital role in avalanche studies, hydrological modeling, and flood monitoring. Our study attempts to model the geophysical properties of snow, such as dielectric density and wetness, using Sentinel-1 and PRISMA data, which is a hyperspectral data set.

The inversion model was developed utilizing a dataset for two distinct glacier regions in the Sikkim Himalayas. So, we have South Sikkim and North Sikkim. So, both the areas we have considered in our study and the inversion model we have developed. Snow is a heterogeneous mixture of air, ice, and liquid water. To characterize snow, it is important to understand the dielectric properties of the mixture.

So, the snowpack, the earlier studies state that liquid water content, permittivity, and density are related in nature and are based on the linear mixture of the dry snow dielectric constant. With the rise in dielectric constant generated by the liquid water content in the snow, as explained in equations 1, 2, 3, and 4. So, you can see that this particular relationship is very, very important. So, I will strongly suggest that you please go through the papers that I have listed at the end of this lecture to understand the different methods used in snow geophysical parameter estimation using hyperspectral, multispectral, and microwave remote sensing data sets.

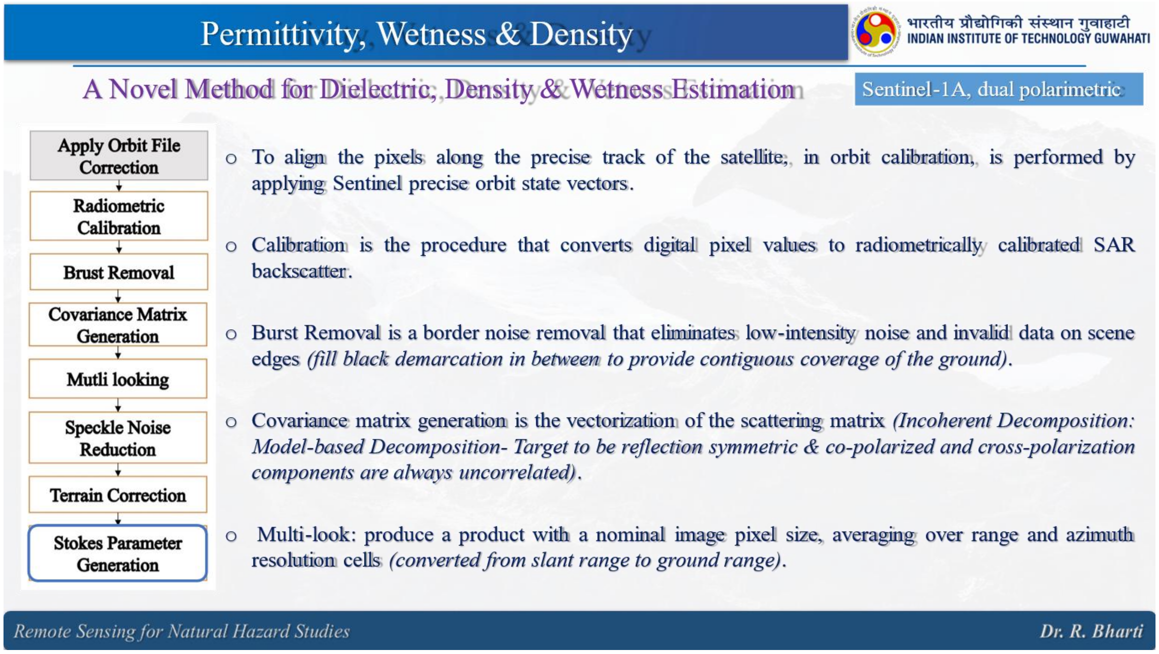
So, here you can see the study area; all these star marks are our field locations where we have investigated. So, these are some field photographs. And, this is again the South Lhonak Lake, and you have already seen this in 2015, 2016, 2017, 2018, 2019, 2020, and now in 2023, showing how it has changed after the South Lhonak glacial lake outburst. So, for this estimation, we have used this particular flow; this is the broad methodology.



So, here we have applied the orbit file correction, then radiometric calibration, burst removal, covariance matrix, multi-look, speckle noise reduction, terrain correction, and then we have used the Stokes parameter, which is further used to estimate the geophysical parameters of the snowpack.

So, here we have also used a snow fork, which is an in-situ measurement that can measure the permittivity, wetness, and density. So, here you can see the Snow fork data format. So, we have a snow fork instrument that can measure the wetness density and the permittivity in the field. The Sentinel-1A, with a descending pass, acquired the data on 6th April 2022. While in the field for measurements, we visited that area on 7th April 2022.

So, there is a one-day gap because it is very difficult to match the time on these rough terrains. So, the level 1 SLC product of the Sentinel-1A dual polarimetric C-band SAR dataset has been used in this particular study. And, as I mentioned earlier, the Prisma hyperspectral sensor was also used here, which is from the Italian Space Agency and has 240 contiguous spectral bands between 400 and 2500 nanometers. A 30-meter spatial resolution is available for this dataset. This table explains the different snow grain sizes that we have considered. So, a novel method for estimating dielectric density and wetness has been developed using the Sentinel-1A dual polarimetric data.

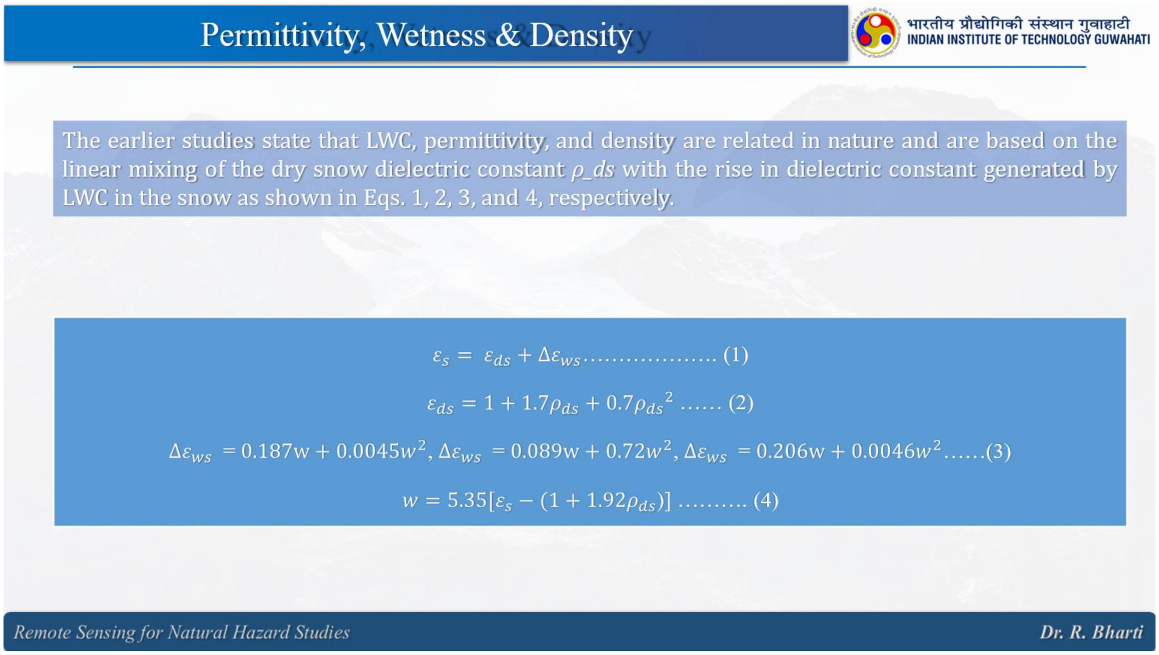


So, here, as I mentioned in the previous slide, these are the processing steps that we have used to generate the Stokes parameters. To align the pixels along the precise track of the satellite in orbit, calibration is performed by applying Sentinel precise orbit state vectors. Calibration is the procedure that converts digital pixel values to radiometrically calibrated SAR backscattered values. So, here you can see it. Then burst removal, which is here, is a broader noise removal technique that eliminates low-intensity noise, invalid data, and scene edges. Then comes the generation of the covariance matrix. So, it is the vectorization of the scattering matrix. Then comes the multi-look, so it produces a product with a nominal image pixel size averaging over range and azimuth resolution cells. Then we have done the speckle noise reduction and terrain correction; these are the standard procedures.

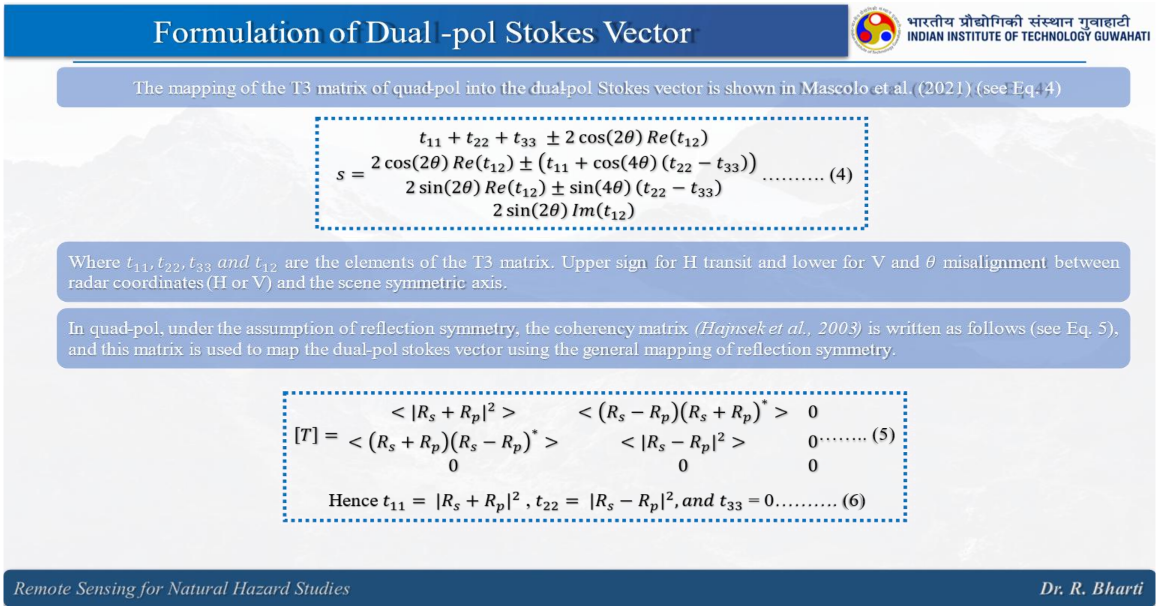
Then the novelty comes in this Stokes parameter generation. So, in the field, you can see this is the snow fork instrument that is being used to generate in situ measurements at different depths. So, this is one of the representative photographs, but we have many vertical sections that we have considered in the field. So, this is another photograph; you can see this is the location, this is the field photograph. And here in 2022, we have visited this in South Sikkim again.

So, this is the paper I was talking about, that inversion model for snow geophysical parameter estimation using Sentinel-1 Stokes parameter. This is a state-of-the-art inversion model that is developed using Sentinel-1 Stokes parameters to estimate the snow dielectric. So, here you can see how we have formulated the dual-pole Stoke's parameter.

So, as I mentioned, the Sentinel-1 dual-pole SLC data was used, and after doing all the processing, it was saved as complex output in order to obtain a two-element complex vector called the coherency matrix C2 matrix. So, here you can see that the C2 matrix has been calculated using this equation.

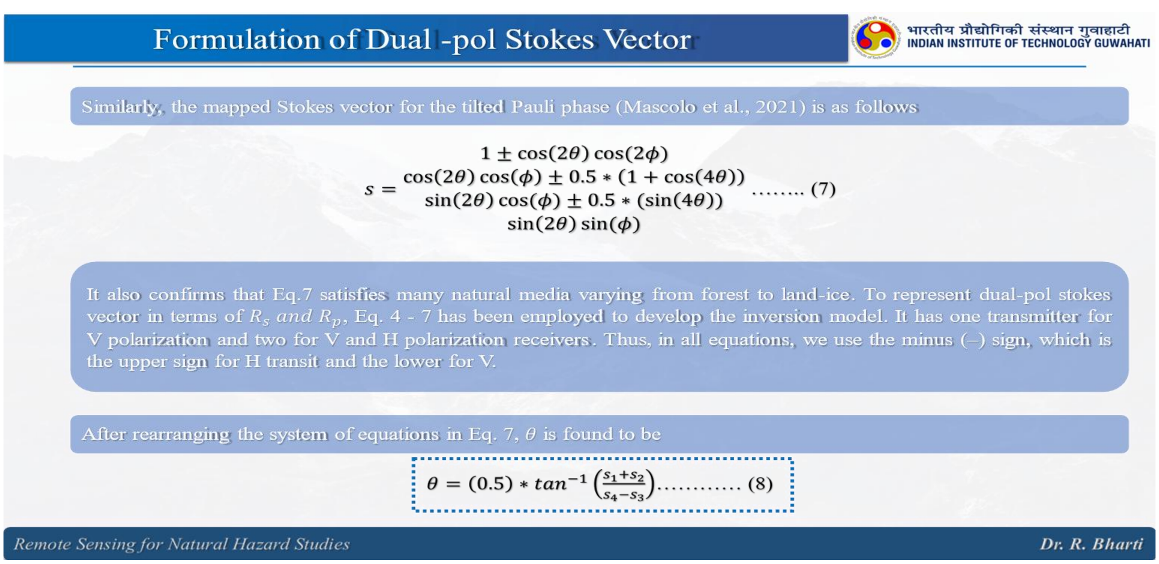


And, the Stokes vector for the scattered wave is entirely determined from the C2 matrix as following: equations 2 and 3. So, here you can see this T3 matrix of quad pole into dual pole Stokes vector shown in this particular equation, where T11, T22, T33. So, these are the elements of the T3 matrix. Upper sign of H transit and lower for V and theta misalignment between radar coordinates and the seen symmetric axis. In quad pole, under the assumption of reflection symmetry, the coherency matrix is written as this, and this matrix is used to map the dual pole Stokes vector using the general mapping of reflection symmetry.

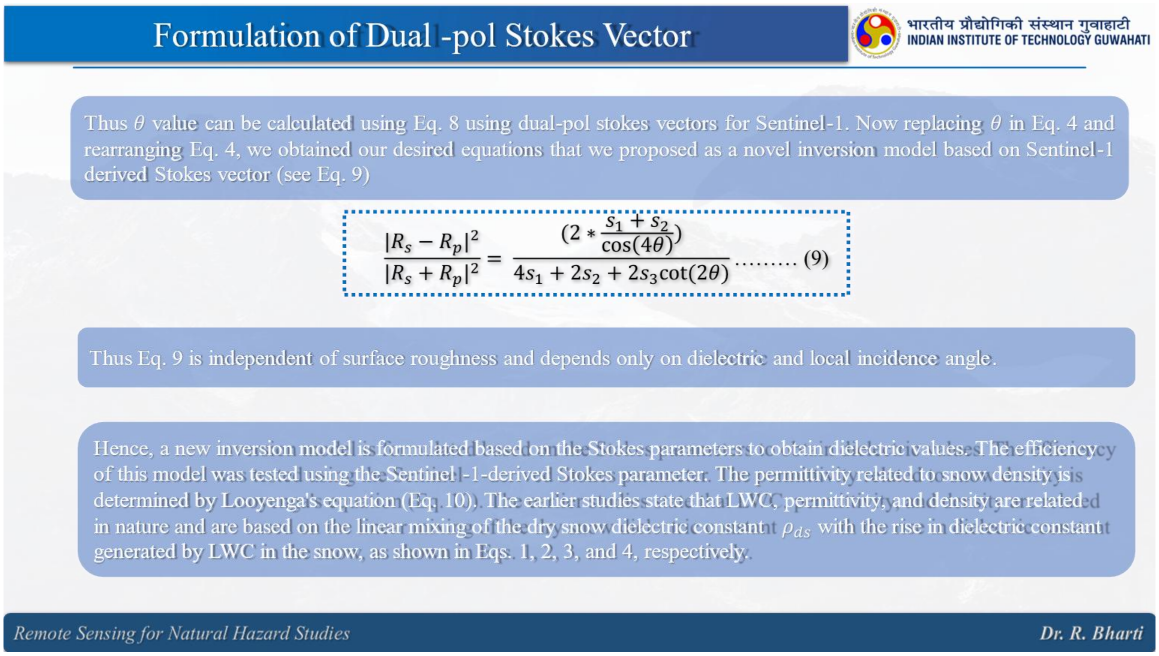


So, this is the further derived equation from 5. So, similarly, the mapped Stokes vector for the tilted polyphase is given as equation 7. After rearranging this, we have equation 8, which can be used to calculate the theta value. So, S1, S2, S3, and S4 are all used here. The theta value can be calculated using equation 8 with the dual-pole Stokes vector for Sentinel-1.

Now, by replacing theta in equation 4 and rearranging equation 4, we obtain our desired equation that we propose as a novel inversion model based on the Sentinel-1 derived Stokes vector. So, this is the one. So, it is independent of surface roughness and depends only on the dielectric and the local incidence angle. Hence, a new inversion model is formulated based on the Stokes parameter to obtain dielectric values. So, this is the novelty of this particular work.



The efficiency of this model was tested using Sentinel-1 derived Stokes parameter. The permittivity related to snow density is determined by Looyenga's equation. The earlier study states that liquid water content, permittivity, and density are related in nature and are based on the linear mixture of the dry snow dielectric constant. With the rise in dielectric constant generated by the liquid water content in the snow, which is shown in equations 1, 2, 3, and 4. Further, for the snow wetness, the end member from the JHU spectral library was extracted and then resampled to the spectral resolution of Prisma data, which is a hyperspectral sensor, and using spline, we have resampled it.



The atmospherically corrected prisma hyperspectral cube is subjected to dimensionality reduction to extract the most informative bands corresponding to the GHU spectral library, because this is the library that we have used. So then, we can calculate the NDSI. The soil moisture assessment of the trapezoidal or triangular feature space based on the land surface temperature, the LST or NIR reflectance, and the NDVI has been utilized extensively in the literature. The response of the near-surface snowpack can be studied using spectral data in the visible and infrared bands in an integrated framework for monitoring the liquid water content in the snowpack. The approach relies on the physical interaction between light and snow, where snow properties such as grain size and liquid water content affect the spectral reflectance observed in the electromagnetic spectrum, which is in the visible and near-infrared regions.

So, how is the surface reacting to the change in the grain size or the wetness that has been studied here? So, the NIR band sensitivity to snow grain size is identified to be 1.03 micrometers. So, this is very critical, which is opted for snow surface wetness estimation, and then we can calculate. So, the liquid water content, permittivity, and density are among the snow geophysical parameters coupled in nature. Snow dielectric and density are estimated using state-of-the-art empirical models.

The least squares solution for snow dielectric was found using the corresponding value of liquid water content. Furthermore, the derived snow dielectric calculates snow density using the model defined by Looyenga. So, this is Looyenga 1965, and he has given this particular relationship, and this is very, very useful. So, based on that, you have to identify different geophysical parameters. So, each component of S1, S2, S3, and S4 that we have mentioned in equation 10 is considered non-zero when the stroke vector for Sentinel 1 is calculated.

The theta is the angle formed by the scattered symmetric axis and the radar-transmit polarized signal axis. Since the study area is hilly terrain, it will hardly have such values. The histogram plot for theta is shown in the figure and is observed to be non-zero. So, here you can see it. So, the proposed inversion model based on Sentinel-1 derived Stokes parameter or the Stokes coefficient is applied to the proportion of the Sentinel-1 scenes acquired on 6th April 2022.

The model equation shown in equation 9 is solved to retrieve the dielectric values, and subsequently, density can be estimated. So, here you can see the dielectric density and the wetness that have been estimated for the Rathong Glacier region. So, here you can see the box plot. So, the map of this scene shown here also covers the Rathong Glacier, and the density of the glacier ranges from this to that range. Based on the density range, the snow can be classified into four categories: fresh, settled, old, and moist.

The measured snowpack in the field has been determined to be settled, old snow, and moist. It is observed from the field data because we have the field information that reflects the continuous nature of snow transformation, which is very common in glacial environments. A few statistical analyses have been performed to check the efficiency of the proposed inversion model. And the box plot for the model here shows the efficiency of this model. Snow dielectric density and wetness are compatible with the measured values, according to the median shown in the box plot you can see here.

It is also evident from the box in the plot that the model parameters have been overestimated. The linear fit between the model and measured values is shown in the table along with its scale and bias parameters. You can see that the graph of the correlation between the model and the measured parameters is shown in the figure. The estimated values of the dielectric density and liquid water content are found according to the measured values, where we have obtained the R-squared, which is greater than 07.

Due to the absence of intermediate values, it can be observed in the box plot that all the parameters deviate from the standard normal distribution. So, here is our model; these are the earlier models that have been developed by various researchers, and here it significantly tells us that our model has improved the efficiency of estimating the geophysical parameters. So, here you can see it. Different spectra that have been considered, you have also seen in the different lectures. So, to mask the glacial lake from the NDSI-derived snow cover map, spectral unmixing is performed using the GHU snow spectral library.

The resulting abundance fraction map shows the abundance of snow in each pixel in the range from 0 to 1. This study considered a threshold greater than or equal to 0.5 to identify a pixel as snow-covered. The end members derived from the snow pixels are identified as coarse, medium, fine, and frost concerning the GHU snow grain spectral library using a widely accepted and reliable SAM method. So, here you can see that using this, we have also estimated the wetness, dielectric, and density.

So, the wetness of each snow grain size agrees with the theory that the snow grain size increases with increasing water content through a process known as wet snow metamorphism; water functions as a lubricant, helping the snow grains bond and round. Grain clumps come together and form larger grains due to the capillary action produced by liquid water. Additionally, this procedure promotes a quicker melting and refreezing cycle, further enhancing grain growth. The fern density, which is the fresh snow converted to glacier ice density, is equal to 830 to 927 kg per cubic meter. The proposed model can forecast the density of the Indian Himalayan region within the permissible range.

So, I will strongly recommend reading these papers. To understand various methods that have been used in estimating the snow geophysical parameters. So, these are the references. This is from my research group, and you can see all the details that are relevant for the snow geophysical parameter estimation using the satellite remote sensing dataset. So, this is some additional information; here, you can see some of the other aspects of how you can investigate the Indian Himalayas with different objectives.

This is my research group. So, you can see different members here; some of the existing ones some of them are graduated. So, all of them have contributed. Their studies are considered in all these lectures, and some of the field photographs, particularly while doing field investigation, can be seen here. So, this is the glacial snout.

Thank you very much.