Snow cover monitoring and snow density estimation using ALOS-PALSAR data

G. Venkataraman, Gulab Singh, Y.S. Rao
Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay
Mumbai (India)
Email-ID: gv@iitb.ac.in ; Phone.No.91-22-25767686

Abstract
Snow cover mapping is a very important parameter for snowmelt runoff modeling and forecasting. Snow cover information is also useful for managing transportation and avalanche forecasting. This study will discuss the capability of full polarimetric L-band ALOS PALSAR data for snow classification. Therefore, Polarimetric decomposition and the complex Wishart classifier will be applied on ALOS-PALSAR data. Results will be compared with the optical data simultaneously. For snow density estimation, IEM model based inversion model will be adopted. Inversion model requires HH and VV polarization combination data. The radar backscattering from a vegetated surface will have the integrated effect of the vegetation and underlying snow. To improve the results obtained from the inversion model in vegetated area, vegetation correction will be applied to inversion model. For this purpose, HV polarization data is essential. Hence, ALOS PALSAR full polarimetric data will be used for this study. Survey of India (SOI) topographical sheet in 1: 50000 scale will be used for preparation of elevation, road and settlement maps and for the registration of satellite data. A number of maps viz: DEM, slope, aspect etc. will be derived based on respective thematic maps using GIS techniques. Field data will be collected synchronous with satellite passes. The PALSAR backscattering coefficient and incidence angle will be used in the inversion model. The inversion model gives the snow dielectric constant which can further be related to snow density using Looyenga's semi-empirical formula.

Keywords: PALSAR, IEM, snow cover, snow density Classification techniques

1. INTRODUCTION

Microwave remote sensing has great potential to determine the extent and properties of snow cover. Interesting results have been obtained by Shi and Dozier using polarimetric multifrequency data from SIR-C/XSAR, obtaining snow density estimates with an average error of 13 % [1]. In our previous study, we have developed an empirical model based on field measured snow density and ASAR derived backscattering coefficient in Himalayan region. The correlation coefficient between snow density and ASAR backscattering coefficient was found to be high [2].

We had never experienced full polarimetric data analysis for snow study in Himalayan region. The full polarimetric data does contain more information than the corresponding single or dual polarization data. Full polarimetric data is essential for accurate snow classification because an optimization of the polarimetric contrast and other polarimetric parameters are needed for discrimination between snow and non-snow covered areas. Hence, this study will discuss the capability of full polarimetric L-band ALOS PALSAR data for snow classification. In addition we will determine the snow density using inversion model. The inversion model gives the snow dielectric constant which can further be related to snow density. The radar backscattering from a vegetated surface will have the integrated effect of the vegetation and underlying snow. To improve the results obtained from the inversion model in vegetated area, vegetation correction will be applied to inversion model. For this purpose, HV polarization data is essential. Hence, ALOS PALSAR full polarimetric data will be required for this study.

1.1. Study Area

Two suitable study areas in the Indian Himalayan snow covered region are chosen to classify the snow cover and to determine the snowpack properties with the help of ALOS-PALSAR data

i. Manali-Dhundi(see Figure1)- Beaskund Glacier Area (latitude 32° 15' N to 32° 30' N and longitude between 77° E and 77° 15' E).

Figure1. Photograph of Dhundi observatory

ii. Gangotri Glacier area (Figure 2) and its surrounding (latitude 30° 30' N to 31° 00' N and longitude between 79° E and 79° 30' E)

Figure2. Photograph of Gangotri glacier

2. METHODS AND TECHNIQUES TO BE USED

2.1. PALSAR Data Processing

For any meaningful and quantitative analysis of ASAR images, it is necessary to convert the DN values of these intensity images into their corresponding radar backscattering coefficient (σ^o) values. ALOS PALSAR data will be processed and converted into backscattering coefficient. PALSAR images will be despeckled using polarimetric filter, namely Lee [3] and Mean (also known as Boxcar) filters with fixed window size (e.g.3 x 3). The performance of each polarimetric filter will be assessed based on the criteria of Sheng and Xia [4]. The best filter should be capable of retaining the land cover features. Which filter is superior will be found later.

In our work, we will relate SAR data to geophysical parameters on ground and hence it will be required to calibrate and georeference to a map projection. This will involve correction of SAR data for terrain distortion and radiometric calibration. The terrain distortion correction will be performed by relating each pixel in the SAR image into cartographic reference system using high precision DEM and knowledge of the imaging and processing geometry.

2.2. Polarimetric Signature of Features

Co-polarized ratios (HH/VV) and cross polarized ratios (HV/HH and VH/VV) polarimetric signatures will be representing the synthesized backscatter response from snow, rock, vegetation and other features.

2.3. Methods for snow cover classification

2.3.1. Unsupervised Classification Techniques

We will carry out two different techniques of unsupervised classification in this study. First, entropy-anisotropy-Alfa –Wishart classifier [5] will be used to classify filtered image pixel. Cloude and Pottier [5] proposed an algorithm to identify in an unsupervised way polarimetric scattering mechanisms in the H-α plane. The key idea is that entropy arises as a natural measure of the inherent reversibility of the scattering data and that α can be used to identify the underlying average scattering mechanism. The H-α classification plane is sub-divided into 8 basic zones characteristic of different scattering behaviors. The basic scattering mechanism of each pixel of a polarimetric SAR image can then be identified by comparing its entropy and α parameters to fixed thresholds. The different class boundaries, in the H-α plane, have been determined so as to discriminate surface reflection (SR), volume diffusion (VD) and double bounce reflection (DB) along the α axis and low, medium and high degree of randomness along the entropy axis.

Even if the computation of H and α requires fully polarimetric data, these two parameters do not represent the whole polarimetric information. The use of other indicators such as the span or specific correlation coefficients may improve the classification results in a significant way. In this study we will use wishart segmentation procedure.

Phase difference between HH and VV polarization (φ_{hhvv}) will be also studied and classified into (1) surface class where | φ_{hhvv} |<60^0 ,(2) double bounce class where | φ_{hhvv} |>120^0, and (3) unknown class [6].

2.3.2. Supervised Classification Based on the Complex Wishart Distribution

The Complex -Wishart distribution is

$$P\left(\langle[T]\rangle/[T_m]\right)=\frac{L^{Lp}\left|\langle[T]\rangle\right|^{L-p}e^{-LTr\left([T_m]^{-1}\langle[T]\rangle\right)}}{\pi^{\frac{p(p-1)}{2}}\Gamma(L)\ldots\Gamma(L-p+1)\left|[T_m]\right|^{L}} \qquad (1)$$

Where L is number of look and p is polarimetric dimension. Using the complex Wishart distribution of the coherency matrix **T**, an appropriate distance measure, d, can then be written according to Bayes maximum likelihood classification as [7,8]

$$d_m\left(\langle[T]\rangle\right)=LTr\left([T_m]^{-1}\langle[T]\rangle\right)+L\ln\left(\left|[T_m]\right|\right)-\ln\left(P\left([T_m]\right)\right)+K \qquad (2)$$

Thus leading to a minimum distance classification independent of the number of looks used to form the multi-looked coherency matrix <T>:

$$\langle[T]\rangle \in [T_m] \quad if \quad d_m(\langle[T]\rangle) < d_j(\langle[T]\rangle) \quad \forall\, j \neq m \qquad (3)$$

2.4. Inversion Model

Generally dry snow layer behaves as an inhomogeneous medium due to different size of ice particles and microstructure. Hence total scattering from a snow cover includes surface, volume scattering and snow ground interface scattering. For this investigation, the main assumption is that dry snow behaves as transparent medium at L-band because snow surface, volume scattering and extinction are expected to be not significant because the imaginary dielectric constant of ice is very small and ice particle size is also relatively small in comparison with L-band incidence wavelength. Therefore, total backscattering coefficient comes from snow ground interface and ground surface backscattering is given by IEM model. Using Snell's law, we can relate the incidence angle at snow surface and snow ground interface. The effect of change of the incidence angle can be easily explained through Snell's law. It describes the change in the incidence angle at the snow-ground interface as a function of the dielectric constant of snow, which is proportional to snow density, and the change in incidence angle. Based on the scattering mechanism which is described above, shi and Dozier developed an inversion model for estimating snow density [1]. The inversion model can be written as:

$$\begin{aligned}
&10\log 10(\sqrt{\sigma_t^{vv}}/T_{vv} + \sqrt{\sigma_t^{hh}}/T_{hh}) = a_d(\theta_r) + b_d(\theta_r) \\
&\times 10\log 10\left(\sqrt{\sigma_t^{vv}\sigma_t^{hh}}\Big/T_{vv}T_{hh}\right) + c_d(\theta_i) \qquad (4) \\
&\times 10\log 10(\sigma_t^{vv}/T_{vv}^2 + \sigma_t^{hh}/T_{hh}^2)
\end{aligned}$$

where a_d ,b_d, c_d are the regression coefficients given by Shi and Dozier [1], σ_t^{hh} and σ_t^{vv} are total backscattering coefficients for HH-polarization and VV-polarization respectively, θ_i is local incidence angle. The effect of vegetation can be taken into account using the ratio between HV and VV polarized data.

3. CONCLUSIONS

We have recently procured ALOS PALSAR full polarimetric data over Badrinath (adjacent area of Gangotri glacier) in Indian Himalayan regions. PALSAR data has been processed and classified using supervised and unsupervised techniques. These conventional training techniques did not give good classification. When we use Entropy-Anistropy-Alph-Wishart classifier for training the samples, we get better classification than any other available classification techniques.

Availability of quad pol L-band data can enhance the accuracy in measurement of snow physical parameters (e.g. snow density) due to its higher penetration capability.

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