IDENTIFICATION OF SNOW USING SAR POLARIMETRY TECHNIQUES

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KEY WORDS: Polarimetry, Radar Snow Index, Decomposition, Polarization Fraction, Eigenvalues

ABSTRACT:

The full polarimetric L-band ALOS-PALSAR data of snow cover area in Himalayan region have been analyzed based on various component scattering mechanism models and all model results are compared. Various polarimetric descriptors (Viz. degree of polarization, co-polarization coherence, total power, phase difference, polarization fraction) are also applied for snow discrimination. Based on these techniques, a new method i.e. Radar Snow Index (RSI) has been developed for total snow discrimination from other targets.

1. INDRODUCTION

1.1.1.1 Mapping of snow and ice covered areas is important for many applications such as prediction of floods, snowmelt runoff modeling, water supply for irrigation and hydropower stations, weather forecasts and understanding climate change. Snow cover mapping through ground surveys are nearly impossible to carry out in the high relief Himalayan region, and aerial photographic surveys are insufficient. Visible and near-Infrared (NIR) remote sensing techniques are proved to be promising for snow cover mapping. But, in the presence of cloud cover and different weather conditions visible and NIR fail in acquiring snow cover information. Microwave remote sensing has an advantage over visible and NIR techniques due to its all weather capability, penetration through clouds and independence of sun illumination. Microwave observations of snow are sensitive to surface moisture variations, and thus, provide useful information concerning the variation in its physical state. Conventional SAR data at intermediate and low frequency (e.g. C -, L-band) is useful to detect only wet snow from other targets (Venkataraman et al., 2008). Due to high penetration capability and low attenuation of dry snow cover at intermediate and low frequency, dry snow cover behaves like transparent media. Hence discrimination of total (wet + dry) snow cover using intermediate and low frequency SAR data, still remains a problematic research approach (Venkataraman et al., 2008; Martini, 2005). The full polarimetric SAR data does contain more information than the corresponding single or dual polarization SAR data. Full polarimetric data gives an optimization of the polarimetric contrast and other polarimetric parameters which may be very useful for accurate target discrimination between snow and non-snow covered areas. Therefore, SAR polarimetry may produce great potential to map snow-covered areas and polarimetric SAR data analysis is also extremely useful to develop methodology to discriminate snow from other surface features. The main job proposed under this study, to investigate and develop innovative snow cover identification method by exploring and integrating various polarimetric SAR decomposition model parameters.

Due to the limited availability of fully polarimetric PALSAR data, investigation is confined to Badrinath region in Himalayas. This is used as a test-site for an extensively snow-covered area having many glaciers of varying dimensions that act as a huge fresh water reservoir. The test-site covers Panpatia, Satopanth, Bhagirath Kharak, and Suraji Bank glaciers. Numerous small-sized glaciers also occur within the neighborhood . The area falls between latitude 30° 30' N and 31° 15' N and longitude between 79° 15' E and 79° 30' E.

In this study, the full polarimetric L-band ALOS PALSAR data (acquisition date May 12) are used for snow discrimination over Badrinath area, Uttarakhand in Indian Himalayan region. ALOS-AVNIR data (acquisition date, May 6, 2007) is used to interpret snow-covered area and non snow-covered area and it helps in the selection of the training sample of different features for supervised classification.

2. METHODS AND TECHNIQUES

2.1 Target Decomposition Models

SAR polarimetry can be important to snow study and to discriminate snow and non snow cover. In this study, to find out L-band PALSAR capability for discriminating snow from other targets and to classify PALSAR data, existing target decomposition models have been applied.

In literature, both coherent and incoherent target decomposition theorems are available viz coherent decomposition: Pauli and Krogager decomposition and incoherent decomposition: decomposition of Freeman and Durden (1998), Cloude and Pottier (1997), and Yamguchi (four component scattering model) (2007) etc.. Most of target in our test site is natural, thus incoherent decomposition may provide good results. In this investigation, incoherent target decomposition models have been applied.

The incoherent decomposition theorems can be expressed as

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$$[T] = q_1[T_1] + q_2[T_2] + q_3[T_3] + .. + q_k[T_k] \qquad (1)$$

Cloud and Pottier

The H/A/ α decomposition technique is based on the three eigenvalues (λ_1, λ_2 and λ_3 with decreasing magnitude) of the coherency matrix [T], and defines the Entropy H, the anisotropy A and the α angle. This method does not depend on the assumption of a particular underlying statistical distribution and it is free from the physical constraints imposed by such multivariate models.

The real nonnegative diagonal matrix [Λ] of eigenvalue of coherency matrix is defined as

$$[\Lambda] = \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \qquad (2)$$

if only one eigenvalue is nonzero then the scattering can be related to pure target (i.e. point target or coherent target), if all eigenvalue are nonzero and identical then the average coherency matrix represent a complitly decorelated, unpolarized random scattering target. In between these two extreme case, scattering matix represent the distributed or partially polarized scatters. Based on this eigen decomposition three secondary parameter i.e. entropy, anisptropy and alpha can be defiened as function of the eigenvalues of the coherency matrix.

Yamaguchi

Based on three component scattering decomposition approach, Yamaguchi proposed a four component scattering decomposition technique by introducing an additional term corresponding to nonreflection symmetric case $<S_{hh}S^*_{hv}> \neq 0$ and $<S_{hv}S^*_{vv}> \neq 0$. Further modification of the four-component scattering mechanism model based decomposition theorem, also presented by Yamaguchi (2007). According to this theorem, the coherency matrix can be decomposed into

$$[T] = f_s[T_s] + f_d[T_d] + f_v[T_v] + f_c[T_h] \qquad (3)$$

where *fs, fd, fv* and *fc* are surface, double bounce, volume and helix scattering coefficients respectively.

2.2 Polarization Fraction

Polarization fraction can be calculated based on eigenvalue

$$Polarization\ Fraction\ (PF) = 1 - \frac{3\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3} \qquad (4)$$

where λ_1, λ_2 and λ_3 are the eigenvalues of 3×3 coherency matrix. Polarization fraction for each pixel in the image can be calculated using equation (4).

2.3 Radar Snow Index (RSI)

The proposed algorithm flow chart for discriminating snow from other features is shown in Figure 1. Eigenvalue based polarization fraction image shows that the snow cover has high polarization fraction (PF) value as compared to other targets. Therefore polarization fraction parameter can be used to discriminate snow from other targets. PF value over layover affected area due to low incident angle of ALOS-PALSAR and high topography of Himalaya is also high. But this part of image is snow free. Hence there is need to explore supporting parameters to eliminate this ambiguity. In this investigation, eigenvalue images of coherency matrix have been generated and based on these images other parameters namely entropy (H),

anisotropy (A), scattering mechanism angle (alpha), (1-H) and H (1-A), Luneburg anisotropy, Radar Vegetation Index (RVI), SERD, DERD, PPD, co-poarization coherence have been studied. These parameters have been analyzed to find out which one can help to overcome the uncertainty in the results of snow discrimination obtained through polarization fraction. Entropy, H(1-A), Luneburg anisotropy, and RVI show low values over the snow cover due to pure target and high value over the other distributed targets (e.g. ablation area of debris covered glacier and vegetation).

On the other hand anisotropy and asymmetry exhibit high value over snow area. All of these parameters are also capable of discriminating snow from other targets but do not have adequate range to suppress layover affected snow free area from snow. Shannon entropy (Lee and Pottier, 2009) shows the capability to suppress distorted area in the classified image but it failed to discriminate snow from other targets in some parts of image. Eigenvalues λ_1, λ_2, λ_3 of coherency also show sufficient range for suppressing this unwanted area from the snow cover area and show very high value for layover affected area in the image. For selected portion of image which is affected by topographic distortion, the normalized λ_1 is varying in narrow range (0 to 0.56) as compared to λ_2 range (0 to 0.80) and λ_3 (0 to 1) range. Hence λ_1 is not able to discriminate snow from other targets.
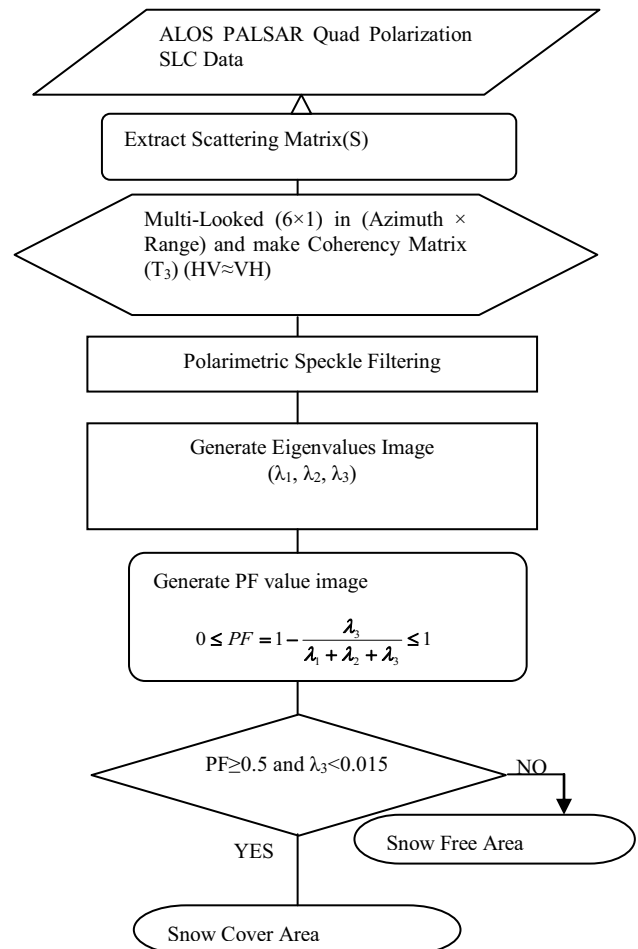

Figure 1. Methodology flow chart of Radar Snow Index development

Normalized λ_2 range is mixing with layover affected area in the upper part of image. Normalized λ_3 have wide range from 0 to 1, and hence it is able to separate the affected area and other features. Hence, Normalized λ_3 has been used to remove the ambiguity in the discrimination of snow using fractional polarization value. Thus, Radar Snow Index (RSI) has been developed using eigenvalues of coherency matrix of fully polarimetric SAR data and these eigenvalues based polarization fraction (PF).

3. RESULTS AND DISCUSSION

The decomposition schemes are applied on L-band PALSAR data of May 12, 2007 over the Badrinath region where the land cover includes snow, vegetation, glacier, and rocks etc. With the help of AVNIR-2 images, field information and Survey of India topography map, training samples are selected. Supervised Wishart classification technique was applied on coherency matrix and training samples are selected based on H-A-Alpha color combination and four scattering component images, which are generated by speckle filtered PALSAR data. When training sets for snow cover class and other classes have been allotted on the basis of visually comparing H/A/Alpha color combination image (it is not illustrated here) with AVNIR-2 snow cover image. By this way, ALOS PALSAR data has been classified into six major classes including snow, non snow and unidentified/layover, etc. (Figure 2(a)). User accuracy in case of H/A/Alpha based snow classification is 95.26%. When supervised Wishart classification technique has been employed on coherency matrix and training samples has been allotted on the basis of visually comparing four scattering component color composite image with AVNIR-2 snow cover image and field information. By this way, user classification user accuracy reaches 98.55%. Classified image is shown in Figure 2(b). It is clear that 4-scattering component model based classification provides slightly higher user accuracy for snow cover as compared to H/A/Alpha based classification method.

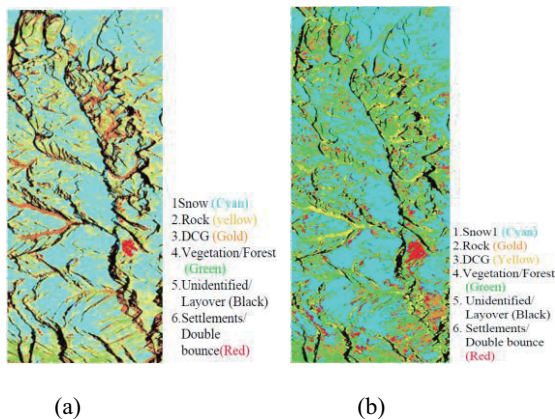(a)   (b)

Fig. 2 (a) H-A-Alpha based Wishart supervised classified image (b) 4- scattering component model based Wishart supervised classified image.

The important aim of this exercise is to compare the snow cover maps obtained through RSI, H-A-Alpha-Wishart supervised classifier and 4-component based Wishart supervised classifier with AVNIR-2 image derived snow cover map. For this purpose a subset of about 34 km^2 area in the vicinity of Chirbitiya glacier has been chosen as this area is totally free from cloud cover in AVNIR-2 image. However, the optical data and PALSAR data have a temporal difference of 6 days. As this study area lies in the higher reaches of Himalayas (Tibet), it can be safely assumed that there may not be any significant difference in the snow cover extent, particularly in early summer period when melting would not have started in these high altitudes. RSI, H-A-Alpha-Wishart supervised classifier and 4-component decomposition and Wishart supervised classifier scheme have been applied on fully polarimetric PALSAR data of the study area of May 12, 2007. ALOS-AVNIR-2 image of May 6, 2007 covering Chirbitiya glacier is shown in Figure 3(a). Snow classified map of AVNIR-2 is presented in Figure 3(b). Figure 3(c) represents RSI classified total snow cover area over Chirbitiya glacier. Total discriminated snow-covered area through 4-component decomposition based Wishart supervised classification in the vicinity of Chirbitiya glacier is presented in Figure 3(d).Snow cover classified by H-A-Alpha-Wishart supervised classification is shown in Figure 3(e).
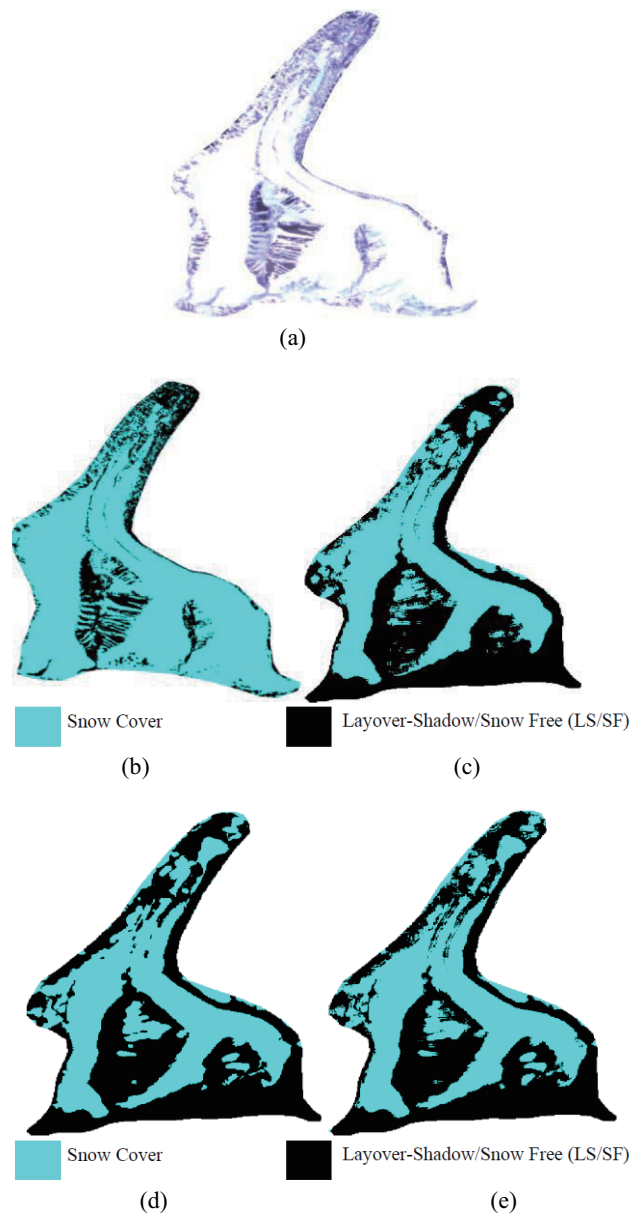

(a)

Snow Cover   Layover-Shadow/Snow Free (LS/SF)

(b)   (c)

Snow Cover   Layover-Shadow/Snow Free (LS/SF)

(d)   (e)

Figure 3 (a) ALOS AVNIR-2 image of Chirbitiya glacier for 06-05-20073(b) Snow cover map from ALOS-AVNIR-2 image (c) RSI based snow cover map (d) 4-component decomposition based Wishart supervised classification basedsnow cover map (e) H-A-Alpha-Wishart supervised classification based snow cover map

Table 1 shows the classification performance of H-A-Alpha-Wishart supervised classifier, 4-component decomposition based Wishart supervised classifier and RSI with reference to the mapping of snow-covered area. RSI provides a slightly higher snow cover area as compared to other two techniques. Based on visual analysis, it is observed that RSI snow cover map seems to be more or less matching with the AVNIR-2 snow cover map. Thus, RSI algorithm based on PF and normalized third eigenvalue of coherency matrix, proves to be more reliable and robust than the supervised classification methods. RSI method does not require training sets and topographic information for snow discrimination from other targets. RSI map exhibits more snow covered area than the other two classifications. There is a difference of about 6.3 km^2 snow cover area between AVNIR-2 and RSI maps. AVNIR-2 data discriminates more snow cover area than RSI map. This may be attributed to the intrinsic character of SAR sensor which causes significant layover and shadow effects due to the incident angle and topographic relief of the terrain.

Table 1. Area statistics of snow-covered over the Chirbitiya glacier

Classification Techniques	Snow Area (km^2)	LS/SF Area (km^2)
AVNIR-2	22.68	11.61
H-A-Alpha based Wishart	16.06	18.20
4-Component based Wishart	15.87	18.39
RSI	16.35	17.91

4. SUMMARY AND CONCLUSIONS

In this investigation, Pauli decomposition, H/A/Alpha, three and four scattering component decomposition models were applied on L-band full polarimetric ALOS-PALSAR data for extracting snow cover information. Using Wishart classifier, ALOS-PALSAR data have been classified into major distinct classes viz., snow cover, vegetation, debris covered glacier, rock and layover/unidentified areas. The ALOS PALSAR images are classified using H/A/Alpha Wishart unsupervised classifier. Furthermore, it has been observed that H/A/Alpha target decomposition theorem classifies more units of snow as compared to four component target decomposition theorem but user accuracy of snow is marginally better in four component target decomposition based classification. The polarization fraction value for snow is high as compared to other features, which indicates that the return signal is polarized or can be said that L- band ALOS PALSAR data is capable of discriminating snow from other targets.

A novel Radar Snow Index (RSI) is introduced by integrating decomposed parameters. It has been observed that RSI maps a slightly more snow covered area over Chirbatiya glacier as compared to other two supervised techniques viz. H-A-Alpha-Wishart supervised classifier and 4-component decomposition-Wishart supervised classifier. Thus, this novel RSI classification algorithm of full polarimetric SAR data based on PF and normalized third eigenvalue of coherency matrix (which represents or highlights the more distributed targets or statistical disorder of targets), is observed to be more robust and simple to implement than supervised methods like H-A-Alpha-Wishart supervised classifier and 4-component decomposition-Wishart

supervised classifier for snow cover mapping. In addition, RSI does not require any training sample and topographic information for snow discrimination from other targets. Through extensive exploration and analysis, it is concluded that SAR polarimetry techniques based on quad polarization mode measurements of PALSAR have produced encouraging results for discrimination of snow from other associated targets and for mapping total snow cover extent.

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