Snow Depth estimation with Co-polar phase difference using multi-temporal spaceborne TerraSAR-X data

Shubham Awasthi[1], Shashi Kumar[2] Praveen Kumar Thakur[3], Snehmani[4]
[1,2]Photogrammetry and Remote Sensing Department
[3]Water Resource Department
[1,2,3]Indian Institute of Remote Sensing, ISRO
Dehradun, Uttarakhand, India
[1]shubham.iirs@gmail.com, [2]shashi@iirs.gov.in, [3]praveen@iirs.gov.in,
[4]Snow & Avalanche Study Establishment, DRDO, Chandigarh, India
[4]snehmani@sase.drdo.in

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ABSTRACT: Snow Depth is an important parameter which gives an idea about the thickness of the freshly fallen snow in a particular region. Hence proper estimation of the snow depth estimation is required. This study tries to estimate the snow depth using Co-polar phase difference. When the microwave travels inside the dielectric medium phase difference is generated between the polarization channels HH and VV leading to the Co-polar phase difference (CPD). This property of the microwave has been utilized in this study. This co-polar phase difference (CPD) is highly dependent on the structural and dielectric properties of the snow pack (Parrella, Hajnsek, & Papathanassiou, 2016) . For this study six multi-temporal datasets of TerraSAR-X acquired during December 2014 and March 2015 in the stripmap mode were used to observe the change of the Co-polar phase difference with snow depth variation. The rise in snow depth lead to the corresponding increase in CPD. The increase in the CPD was due to the increase in co-polar phase difference experienced by the microwave travelling inside the fresh snow pack. Also decline in the CPD was also observed due to the increase in compactness of the snow pack. The main reason behind this snow pack compactness was snow melt-off which was increasing the water content inside the snow pack. The rise in the water content led to the increase in dielectric constant of the snowpack, which ultimately prevents the microwave penetration inside the snow pack. This study was able to assess and the variation in the CPD with snow depth using the theoretical model.

1. INTRODUCTION

Microwave remote sensing provides the opportunity for the retrieval of various parameters related to the snow. It has the property of penetration inside the snow pack and is effected by the dielectric properties of the snow pack. When the microwave penetrates inside the snow pack volume the co-polarization channels (HH and VV) acts dielectrically dissimilar inside the snow hence creating a phase delay ($\phi_c = \phi_{HH} - \phi_{VV}$) between the co-polarization channels. Co-polar phase difference (CPD) variation is experienced with the change in the depth of the snow volume(Leinss, Parrella, & Hajnsek, 2014). Hence providing with the opportunity to utilize this for estimating the snow depth in various snow covered regions like the Himalayan region. Past studies has been done using the using the passive microwave remote sensing techniques (Das & Sarwade, 2008; Singh et al., 2015) having the drawback of very low resolution up to 100m to 1km range (Park, Choi, Katkovnik, & Kim, 2004). The other researchers have used the differential interferometric techniques for the snow depth retrieval (Dozier, Shi, & Dozier, 2000; Guneriussen, Hogda, Johnsen, & Lauknes, 2001; Leinss et al., 2015; Li, Wang, He, & Man, 2017a; Weber Hoen & Zebker, 2000). But fast snow meltoff and snow pack deformation leads to high coherence loss in the snow cover (Li, Wang, He, & Man, 2017b; Tedesco & Knight, 2014).Presently available active microwave sensors operating in L, C and X bands like Radarsat-2, TerraSAR-X, ALOS PALSAR-2 and Sentinel-1 provide has the temporal receptivity between 11- 46 days which is sufficient for the significant loss in the coherence in the snow. Hence, it limits the utilization of the differential interferometric techniques for snow parameters estimation using the space borne data. In this study the snow depth estimation is done utilizing the co-polar phase difference properties of the microwave datasets. The cross-polar channels were showing ambiguous results of the phase difference in the snow pack due to significant backscattering from the snow volume. Utilizing the multi-temporal datasets of TerraSAR-X the variation in the co-polar channels was seen and was correlated with the ground datasets of the same date from the AWS stations installed in the study area of SASE (Snow & Avalanche Study Establishment), DRDO, Chandigarh.

2. STUDY AREA AND DATASETS USED

2.1 Study Area

The Beas River Basin up to Manali town with area of 350.21 km^2 has been selected for this study, in the state of Himachal Pradesh situated in Northern India. Area is at an altitude of 4350m above mean sea level, 51km north of Manali. The terrain is relatively undulating and is a part of North-Western Himalayas.

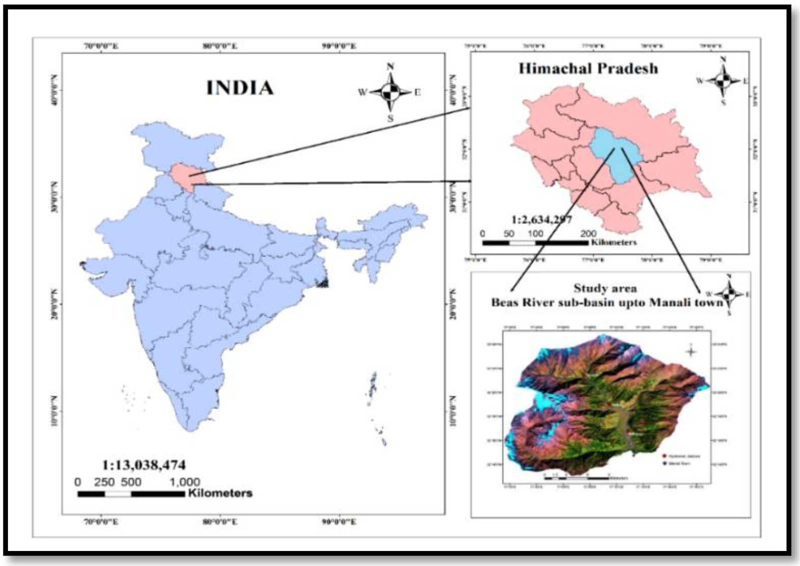

Figure 1-Study Area

2.2 Datasets Used

The TerraSAR-X sensor datasets operating in the X-band were utilized in the study. Datasets were acquired on the different dates from December 2014 till March 2015. This period is winter season in North Indian region and majority of the snow fall occurs in this season. The 19-Dec-2014, 11-Jan-2014, 21-Jan-2015, 22-Jan-2015, 12-Feb-2015, 7-March-2015. The detailed specifications of the datasets are mentioned in the table1 below.

Data Specification	**TerraSAR-X Datasets (freq-9.64Gz)**			
	Date of Acquisition	**Orbit Direction**	**Resolution (Rg x Az)**	**Acquisition Mode/Polarization**
Img-1	19-Dec-2014	Descending	3x3m	Strip-map/Quad pol
Img-2	11-Jan-2014	Ascending	3x3m	Strip-map/Quad pol
Img-3	21-Jan-2015	Descending	3x3m	Strip-map/Quad pol
Img-4	22-Jan-2015	Ascending	3x3m	Strip-map/Quad pol
Img-5	12-Feb-2015	Ascending	3x3m	Strip-map/Quad pol
Img-6	7-March-2015	Descending	3x3m	Strip-map/Quad pol

Table 1-SAR data Specification

3. METHEDOLOGY

Snow Depth is an important parameter which gives us the idea the thickness of the freshly fallen snow in a particular area. Co-polar phase difference (CPD) is effected by the depth of the snow volume (Leinss, Parrella, & Hajnsek, 2014). The phase delay ($\phi_c = \phi_{HH} - \phi_{VV}$) is observed between different polarization channels act dielectrically dissimilar inside the snow. Hence utilizing this phase delay the snow depth is measured.

3.1 Methodology flow diagram: -

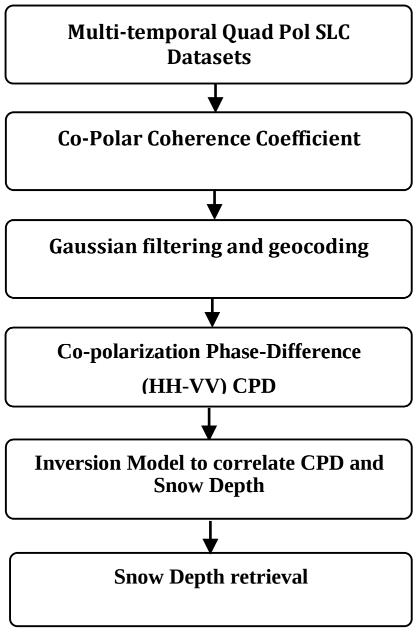

Figure 2-Methodological chart

This phase delay between the two co-polarization channels HH and VV is caused when transmitted SAR wave is travelling inside the snow volume they experience The wave experiences the phase difference across the co-polar channels HH and VV because snow volume reacts differently with various co-polar channels horizontal and vertical polarizations (Parrella et al., 2016).

The Polarimetric Co-polar coherence (HH and VV) correlation between the co-polarized phase channels HH and VV in the multi-Polarimetric radar. The normalized complex correlation coefficient is calculated as the average of the product between the complex amplitude of the HH channel and the conjugate of the complex amplitude of the VV channel. The normalization of the product is done by dividing the product by the the square root of the product of the powers in the HH and VV channels. If the value of correlation coefficient is one, then both polarization channels are linearly related. If the value of the complex correlation coefficient is less than one, it indicates the phase delay between the polarization channels HH and VV which ultimately means they are not directly related. It also indicates that noise is present on one of the two channels.

$$\check{\gamma}_c = \gamma_c . e^{i\phi_c} = \frac{\langle S_{VV} S_{HH} \rangle^*}{\sqrt{\langle |S_{VV}|^2 \rangle . \langle |S_{HH}|^2 \rangle}} \qquad (1)$$

CPD can be defined as the ensemble average of the co-polarized phase difference between HH and VV polarization channels in a multi-polarized or polarimetric radar(Leinss et al., 2014). It is the phase angle of the co-pol correlation coefficient (Rodionova, 2009). The co-polar phase difference can be used to classify the image. The single bounce has the co-pol phase difference of 180^o while an ideal double bounce (or even-bounce) scatterer will have a co-polar difference as 0 ^{o}. For the volume scatterers the value of CPD lies between -180^o to 180^o.The cross phases does not show any such correlations between the channels hence cross polar phase difference is insignificant. It is uniform for the most of the features but co-polar phase difference shows Gaussian Power distribution function.

$$\Phi_C = \Phi_{HH} - \Phi_{VV} = \frac{\langle Im(S_{VV}S_{HH}^*)\rangle}{\langle Re(S_{VV}S_{HH}^*)\rangle} \tag{2}$$

Φ_c is the co-polarimetric phase difference (CPD)and the S_{HH} and S_{VV} are the Horizontal and vertical co-polar channels in SLC(Single look complex) form. This Φ_c can be used for the polarimetric data classification.

4. RESULTS

The time series variation of the Co-polar phase difference and correlating it with the observed snow depth is done. The variation in the CPD depends on fresh snow volume and snow water content. The fresh snow acts as a transparent dielectric CPD is increasing between 9-Dec-2014 and 11-Jan-2015, 11-Dec-2014 and 21-Jan-2015 corresponds to the increase snow depth . Sudden fresh snowfall on 21-Jan-2015 lead to sudden increase in the CPD between 21-Jan-2015 and 22-Jan-2015.Although there is some increase in snow depth value the co-polar phase difference is decreasing between 22-Jan-2015 and 12-Feb-2015.The CPD and snow depth giving the good correlation between 12-Feb-2015 and 7-March-2015.

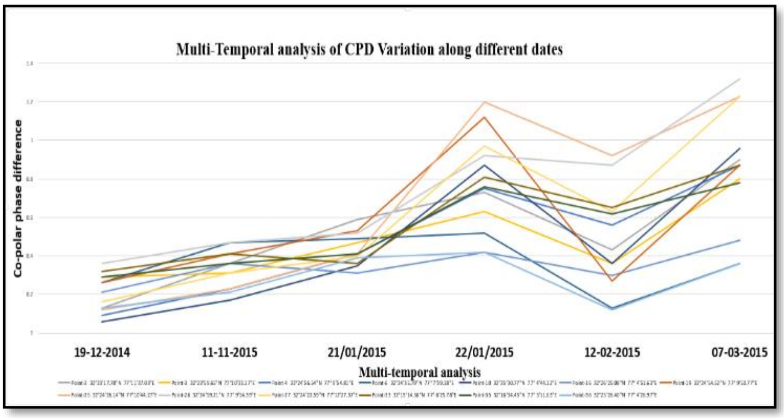

Figure 3-Multitemporal CPD variation

The variation in the CPD was validated with the corresponding snow depth variation ground data from the automatic weather station. The snow depth is nearly constant in the initial period but it increases further in time due to the snow fall. The Co-polar phase difference also shows the simultaneous increase in the due to upsurge in the phase difference between the co-polar channels HH and VV as microwave in the different polarization channels experience dissimilar phase delays while travelling inside the dielectric medium like snow pack. Hence Co-polar phase difference can give the correct information about temporal variation in the snow depth.

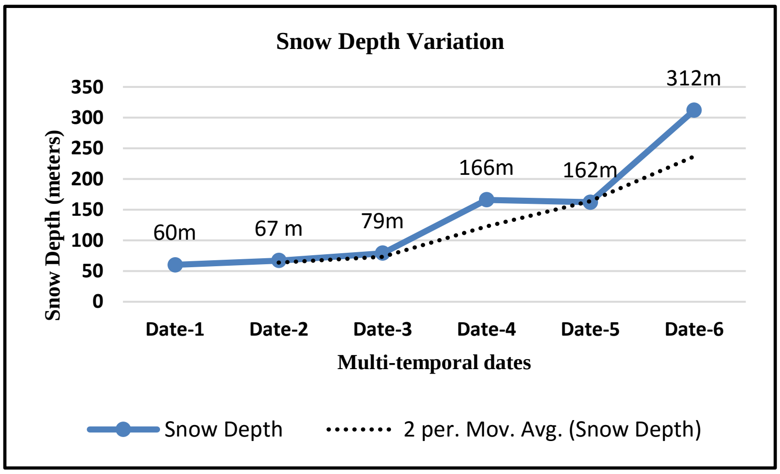

Figure 4-Snow Depth Variation

5. CONCLUSION

The time series variation of the Co-polar phase difference and correlating it with the observed snow depth is done. The variation in the CPD depends on fresh snow volume and snow water content. The fresh snow acts as a transparent dielectric medium whereas there is no interaction of microwave radiation with the wet snow.

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