

## Application of radar polarimetry techniques for retrieval snow and rain characteristics in remote sensing

M. Darvishi <sup>a,\*</sup>, Gh. R. Ahmadi <sup>b</sup>

<sup>a</sup> MSc, Group of GIS/RS, Environment and Energy Department, Science and Research Branch, Islamic Azad University, Tehran

mehdidarvishi@yahoo.com

<sup>b</sup> PhD, Geography Department, Science and Research Branch, Islamic Azad University, Tehran  
ahmadigholamreza56@yahoo.com

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### ABSTRACT:

The presence of snow cover has significant impacts on the both global and regional climate and water balance on earth. The accurate estimation of snow cover area can be used for forecasting runoff due to snow melt and output of hydroelectric power. With development of remote sensing techniques at different scopes in earth science, enormous algorithms for retrieval hydrometeor parameters have been developed. Some of these algorithms are used to provide snow cover map such as NLR with AVHRR/MODIS sensor for Norway, Finnish with AVHRR sensor for Finland and NASA with MODIS sensor for global maps. Monitoring snow cover at different parts of spectral electromagnetic is detectable (visible, near and thermal infrared, passive and active microwave). Recently, specific capabilities of active microwave remote sensing such as snow extent map, snow depth, snow water equivalent (SWE), snow state (wet/dry) and discrimination between rain and snow region were given a strong impetus for using this technology in snow monitoring, hydrology, climatology, avalanche research and etc. This paper evaluates the potentials and feasibility of polarimetric ground microwave measurements of snow in active remote sensing field. We will consider the behavior co- and cross-polarized backscattering coefficients of snowpack response with polarimetric scatterometer in Ku and L band at the different incident angles. Then we will show how to retrieve snow cover depth, snow permittivity and density parameters at the local scale with ground-based SAR (GB-SAR). Finally, for the sake of remarkable significant the transition region between rain and snow; the variables role of horizontal reflectivity ( $Z_{HH}$ ) and differential reflectivity ( $Z_{DR}$ ) in delineation boundary between snow and rain and some others important variables at polarimetric weather radar are presented.

### 1. Introduction

The radar hydrology provides data that can be used for input to runoff, flood, storm and avalanche prediction models and related natural disasters. In two past decades, noticeable attention has been focused on radar meteorology, hydrology and distributed hydrological modeling. One most important aspects of radar meteorology is the use of polarimetric radar techniques at various frequencies for measuring SWE. Demonstration of satellite SAR data for SWE measurements was first reported by (Shi and Dozier, 2000a, b). Some researches' modeling (Shi, 2004 and 2006) are shown that dual frequencies at combination of X- and Ku-bands are more suitable for monitoring of SWE. On the other hand, one of the most sophisticated methods for retrieving hydrological parameters of snow is SAR differential interferometry (DInSAR) and use of the differential phase. Retrieving SWE by interferometric phase shift in snow due to differences in travelled paths was first

proposed by Guneriussen et al in 2001. The high performance of GB-SAR in snow cover monitoring has led to the enormous scientific researches (Galahad., 2005-2008 and Morrison et al, 2007). In meteorological science, forecasting is a curtail factor. For an accurate prediction we need real time data from all type of hydrometeors. The power and capability of weather radar is the best for doing that task. In 1993 two researchers defined six variables to get information about hydrometeor. Reflectivity factor ( $Z_h$ ), Doppler velocity ( $v$ ), spectral width ( $\sigma_v$ ), differential reflectivity ( $Z_{DR}$ ), magnitude of the complex correlation coefficient ( $\rho_{hv}$ ) and differential phase shift ( $\varphi_{dp}$ ) to operate the RVP7 processor in dual polarization mode (Doviak and Zrnić, 1993). Polarimetric radars can discriminate many types of hydrometeor and estimate amount of fallen hydrometeors. We will discuss the most significant and practical variables that acquired from polarimetric radars such as  $Z_{DR}$ ,  $LDR$ ,  $\rho_{hv}$ ,  $\Phi_{DP}$  and  $KDP$ .

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\* Corresponding author

## 2. Snow polarimetry with ground scatterometer

Over the past two decades, radar polarimetry is a state-of-the-art topic in radar meteorology. The significant characteristics of active microwave sensors at different polarizations and angles and its strong capabilities to extraction of variety data such as stratigraphy, density profile, grain size profile, temperature profile, moisture and SWE of snow are remarkable and promising. The most common wavelengths that used for snow monitoring are L, C, X, Ku bands. L band is long enough to penetrate into the snowpack and depends on snowpack depth maybe reach to the ground. Ku wavelength in order of mm is related to the roughness and dielectric constant of snow. The addition of different wavelengths, using dual co and cross polarization can be involved more physical information about the snowpack. Most measured microwave data pertain to radar remote sensing of snow has been acquired from truck or sensors which placed at some elevations in snow regions. In figure 1 we can see the typical radar truck system.



Figure 1 . L and Ku band radar at Fraser (Saint-Martin et al, 2003)

The procedures of ground base snow polarimetry involve some important steps. One of critical steps is the calibration of instruments for making sure the high accuracy of acquired data. Often a metallic sphere can be used for calibration purposes, since it presents a wide RCS pattern (orientation independent), a relatively small physical size (easy deployment), and a known exact theoretical RCS (Saint-Martin et al, 2003). This step of calibration must be repeated before and after each measurement cycle to have an independent measure of end-to-end for reliability of system performance. Figure 2 show the typical example of metallic sphere and calibration process.



Figure 2 . A typical metallic sphere for calibration purpose (Saint-Martin et al, 2003)

For obtaining the backscattering coefficients of snowpack, first we need to extract the scattering matrix from acquired data. The elements of scattering matrix involve both magnitudes and phases of the reflected signals relative to that of the incident signal for all polarization combinations

$$\begin{bmatrix} E_H^b \\ E_V^b \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_H^i \\ E_V^i \end{bmatrix} \quad (1)$$

$$s = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \quad (2)$$

With take into account of far and near field considerations, therefore (1) is usually written as though the scattering properties are observed back at the radar

$$\begin{bmatrix} E_H^r \\ E_V^r \end{bmatrix} = \frac{e^{j\beta R}}{R} \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_H^i \\ E_V^i \end{bmatrix} \quad (3)$$

The exponential term accounts for the phase difference induced in transmission which can be ignored since it will affect all components equally (J. A. Richards, 2009). After calculating  $\sigma^\circ$ , we will obtain the backscattering coefficients in dB. Figures 3 and 4 show the results of radar polarimetry in Ku and L band.

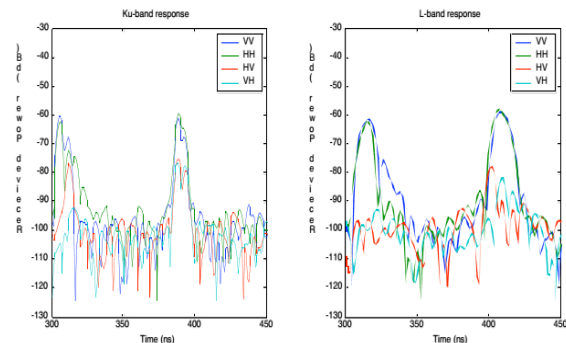


Figure 3. Ku and L band time domain responses of snow (Saint-Martin et al, 2003)

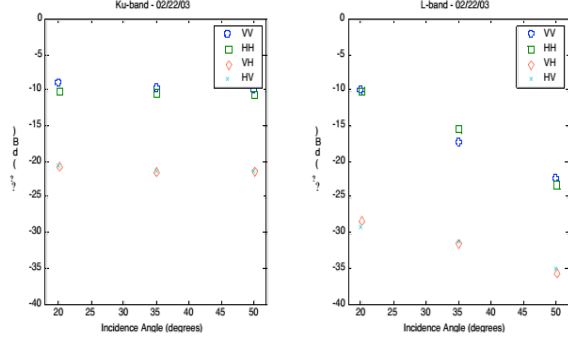


Figure 4 . Backscattering coefficients at Ku and L band (Saint-Martin et al, 2003)

### 3. Snow parameters retrieval with interferometric SAR (DInSAR)

There are many methods for cover and depth snow parameters retrieval both in passive and active remote sensing. Retrieval of those parameters in active remote sensing can be done by space born and air born radar imaging. The use of these methods has some limitations such as lack of appropriate resolutions and low acquisition rate, as well as high cost. In interferometric technique especially SAR differential interferometry (DInSAR), we need consecutive images much higher acquisition rate than the space or air born sensors provided for us. GB-SAR has a high capability for generating the higher acquisition rate in very large time-series of repeat-pass radar images. Having this sort of data can improve the performance of snow parameters retrieval especially in local scale. The acquired snow parameters retrieval often uses in models for estimation snow water equivalent (SWE) as inputs. SWE is a most significant variable for water sources planning and Hydraulic power management. The first step for depth retrieval is phase conversion into height. Backscattering of radar is strongly affected by complex permittivity of snow which is intensely dependent on its liquid water content. The penetration depth  $d_p$  of microwaves at the wavelength in free space  $\lambda_0$  can be estimated from the real  $\epsilon'$  and imaginary  $\epsilon''$  parts of the complex permittivity of snow according to (Mätzler, 1995):

$$d_p = \frac{\lambda_0 \sqrt{\epsilon''}}{2\pi \epsilon'} \quad (4)$$

The imaginary part of the permittivity,  $\epsilon''$ , of dry snow at C- and L-band is of the order of 0.001 to 0.0001, whereas the real part,  $\epsilon'$ , depends only on the snow density  $\rho_s$  (Mätzler, 1995), where  $\rho_s$  is specified in  $\text{g/cm}^3$ .

$$\epsilon' = 1 + 1.6\rho_s + 1.86\rho_s^3 \quad (5)$$

The phase comparison of a pair of complex coherent radar images of the same scene that acquired in different time and Repeat-pass can generate a differential interferometry. If we define  $d_s$  as the depth of whole snow in a particular time and  $d'_s$  as the depth of whole snow in a later time than the previous one and considering the two different paths of pulses emitted (figure 5),  $\Delta r$  will equal to

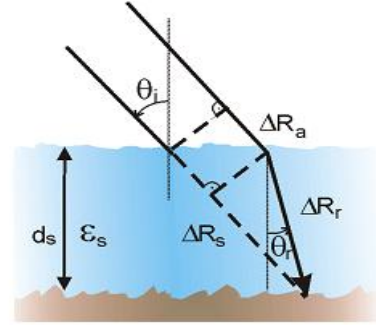


Figure 5 . Propagation path of microwaves (Nagler, 2003)

$$\Delta r = \Delta r_s - (\Delta r'_s + \Delta r_a) = \Delta d_s \frac{\cos(\theta_i - \theta_s) - 1}{\cos\theta_s} \quad (6)$$

Base on the Snell's law, the interferometric phase shift in dry snow related to  $\Delta d_s$  can be written as (Gunteriusen et al, 2001):

$$\Delta\varphi_s = -\frac{4\pi}{\lambda_0} \Delta d_s \frac{\cos(\theta_i - \theta_s) - \sqrt{\epsilon'}}{\cos\theta_s} = -\frac{4\pi}{\lambda_0} \Delta d_s \left( \cos\theta_i - \sqrt{\epsilon' - (\sin\theta_i)^2} \right) \quad (7)$$

Finally, the differential snow depth after substituting some variables ( $\lambda_0$ ,  $\theta_i$  and  $\epsilon'$ ) with a constant  $\alpha$  [m/rad] is obtained

$$\Delta d_s = \alpha \cdot \Delta\varphi_s \quad (8)$$

Sometime constant  $\beta$  is added to the last equation as an offset for calibration purposes.

### 3. Dual Polarization Radars

It has been demonstrated that dual polarization radars can discriminate between the return signals from Types of hydrometeor such as hail, snow and rain drops based on the difference between their polarimetric reflections. Polarimetric radar measures some hydrometeor properties such as size, shape, spatial orientation, and differential



