ESTIMATION OF SNOW COVER PARAMETERS BY ALOS-2 PALSAR INTERFEROMETRY

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ABSTRACT

An applicability of spaceborne radar interferometry for the measurements of snow layer thickness and snow water equivalent was studied. Experimental dataset in the measurements of thickness and snow water equivalent consisted of two datasets from ALOS-2 PALSAR observations made in snow free conditions and in the presence of snow cover. Theoretical relations between interferometric phase difference, snow layer thickness and snow water equivalent for a given observation geometry and radar signal wavelength are presented. An essential feature of the experiment was the deployment at the test field of the reference corner reflector having stable level of radar cross section and scattered signal phase center location. Its interferometric phase difference was used as reference in calculations of the phase differences induced by snow cover on the test field. The calculations of snow depth made using theoretical relations, interferometric phase difference measurements, as well as direct measurements of snow layer thickness at the test field are in good agreement.

***Index Terms*—**synthetic aperture radar, differential interferometry, ALOS-2 PALSAR, snow cover, snow water equivalent.

1. INTRODUCTION

Seasonal snow cover in the regions of temperate and northern latitudes is an essential natural factor. Snow has a big impact on the climate, hydrological and soil processes, plant and animal life, human activity. The major characteristics of the snow cover are its height and snow water equivalent (SWE), which are important for practical applications [1, 2].

A convenient tool for the characterization of the snow cover are the synthetic aperture radars (SAR) with a high spatial resolution [3]. There are several methods for studying the characteristics of snow using SAR. Among of them is differential interferometry (DInSAR). Differential interferometry allows to detect the earth's surface deformation and movement with great precision [4].

Direct measurements of SWE using differential interferometry was first proposed in [5]. In this paper, a relation is derived that connects the interferometric phase with the SWE value. It is based on the phase change due to refraction and wave propagation in the snow cover with a non-unit dielectric constant. This paper also shows the results of the experiments in C-band with the use of remote sensing satellites ERS-1 and ERS-2, which show agreement with the calculated dependencies. The theoretical dependence of the interferometric phase from SWE was also used in [6] for comparison with experimental data obtained by L-band airborne SAR. The data obtained approximately correspond to measurements of snow depth at weather stations located near the study area. Similar results were obtained in [7, 8] when comparing the calculated values of the interferometric phase with experimental data of airborne and spaceborne SARs in C-band. Comparison was carried out in [9] of the numerical formulas for dry snow SWE evaluating and experimental results.

This paper presents the results of the snow height and SWE estimation obtained with help of ALOS-2 PALSAR. The corner reflectors as reference scatterers were used in experiments for more accurate results.

2. THEORY

The estimation of the radar signal phase change due to the formation of snow cover is the basis of the interferometric method for the determination of SWE [5]. Fig. 1 shows the geometry of the problem. A radar wave fall from the medium with permittivity $\varepsilon = 1$ on snow cover with a height d_s and permittivity ε_s, lying on the earth's surface. After refraction and backscattering from the ground rough surface it returns along the same path to the radar. Here, θ_i and θ_r are the incidence and refraction angle respectively. The difference between the optical paths of incidence and backscattered

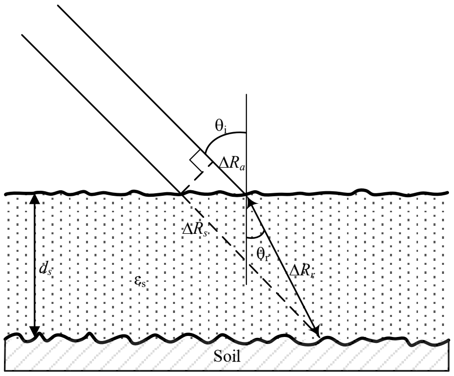


Fig. 1 Geometry of the problem.

waves in absence of snow cover is determined by the relationship

$$\Delta R = 2(\Delta R_a + \sqrt{\varepsilon}\Delta R_r) - 2\Delta R_s \quad (1)$$

It follows from the geometry of the problem and the Snell's law that phase difference corresponding to the scattered wave which went twice through the snow and the wave scattered from the ground without snow cover may be expressed in the following form [5]

$$\Delta\Phi = 2kd(\sqrt{\varepsilon_s - \sin^2\theta_i} - \cos\theta_i). \quad (2)$$

Here k is a wave number.

It should be noted that backscattering originates from the rough surfaces of the soil under the snow. Scattering from the "air – snow" interface is not considered due to the lesser roughness of snow and the relatively small value of the permittivity.

Dry snow is a mixture of ice and air and its permittivity depends on density ρ As shown in [10] the real part of permittivity of the snow can be expressed by semi-empirical equation (value of ρ is measured in g/cm^3)

$$\varepsilon_s = 1 + 1{,}6\rho + 1{,}86\rho^3, \quad (3)$$

which is valid in frequency range 10 MHz – 10 GHz.

The imaginary part of permittivity of the snow does not exceed 10^{-3} in L-band, i.e. dry snow is almost a dielectric. It allows radio waves to penetrate freely into the deep snow. The density of fresh snow can vary from 0.02 g/cm^3 to 0.15 g/cm^3. As a result of subsidence, processes of metamorphism, wind pressure the density of dry snow can reach values of 0.2 - 0.5 g/cm^3.

When ρ is small ($\rho < 0.5$) we may substitute the expression (3) into (2), expand it into series and take into consideration only the first order term [7]

$$\Delta\Phi = \frac{1{,}6kd\rho}{\cos\theta_i} = \frac{1{,}6k}{\cos\theta_i}W \quad (4)$$

Expression (4) shows a simple linear relationship between the interferometric phase difference and the snow water equivalent. ALOS-2 PALSAR operates at wavelength λ = 24.2 cm with incidence angle $\theta_i = 28.6°$, so we can write

$$\Delta\Phi = 0{,}485 d\rho = 0{,}485W \quad (5)$$

$$W = 2{,}06\Delta\Phi \quad (6)$$

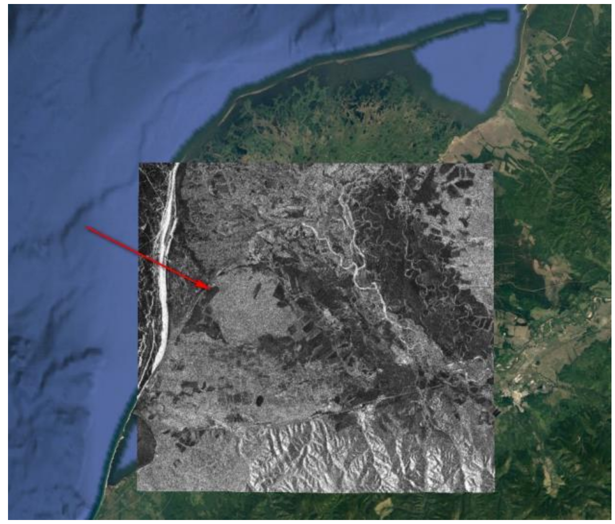


Fig. 2 Test area location (red arrow) at Google Earth map and geocoded amplitude image of ALOS-2 PALSAR.

In formulas (5) and (6) the value of snow height and SWE expressed in centimeters. For example, if the snow height is 10 cm and ρ = 0.2 g/cm^3 then interferometric phase is equal 0.97 radian.

3. EXPERIMENT AND RESULTS

The study area is located approximately in 100 km northwest from Ulan-Ude, Russia near the eastern coast of the Lake Baikal in the delta of Selenga river (Fig. 2). The study area was a flat region with size approximately equaled 2 km^2.

Radar imaging was carried out by ALOS-2 PALSAR operating in L-band at the center frequency 1236.5 MHz. Interferometric pair of images acquired September 21, 2016 at the lack of snow and February 8, 2017 with the presence of snow cover was used for processing and analysis. The incidence angle in both cases was equal to 28.6° and perpendicular baseline was 68 m. Image processing was carried out using the ENVI+SARScape software. As a reference digital elevation model (DEM) we use the model constructed with help of TerraSAR-X/TanDEM-X interferometric pair obtained on September 8, 2015 (perpendicular baseline was equal to 1356 m). Resulting DEM has spatial resolution 10 m for the areas with coherence greater than 0.3. Such coherence threshold allows neglect the influence of neighboring forest and water.

The trihedral corner reflectors (CR) were used as the reference targets during surveys (fig. 3). They have facets with 2 m length and made from duralumin.

Fig. 4 shows the geocoded amplitude images, obtained at different times. Numbers 1, 2, 3, 4 denote places where reflectors were situated. Only at point number 2 CR was located in both imaging dates as seen from fig. 4. Hence, phase measurements make sense only for that CR.

Plots at fig. 5 are the spatial distribution of backscattering coefficients along the meridional line passing through the point 2. These dependencies show that the amplitudes of the

Fig. 3 Trihedral corner reflector on the test field.

signals scattered by the corner reflector exceed signals from neighboring pixels by 20 dB or more.

Fig. 6 shows the distribution of interferometric phase along the lines from North to South and from West to East, which cross at point 2. CR at point 2 was in an unchanged position during both surveys (in the absence and in the presence of snow cover). Therefore, the phase difference between the signals from CR is not affected by the snow layer, formed on the ground between imaging. The difference between phase from CR and surrounding pixels reaches 2.1 – 3.3 radian. This difference is caused solely by the passage of radar wave through the snow layer during the second survey.

Calibrated data analysis showed that the radar cross section (RCS) of corner reflector is equal to 12 dB during the first survey. RCS of the test field surface during the surveys were -22 dB for the first date and -23 dB for the second. Signal to noise ratio (SNR) was equal to 34 dB. To estimate the accuracy of phase difference measurements σ_φ (in radians) we can use following equation

$$\sigma_\varphi = \sqrt{2/SNR}\ .$$

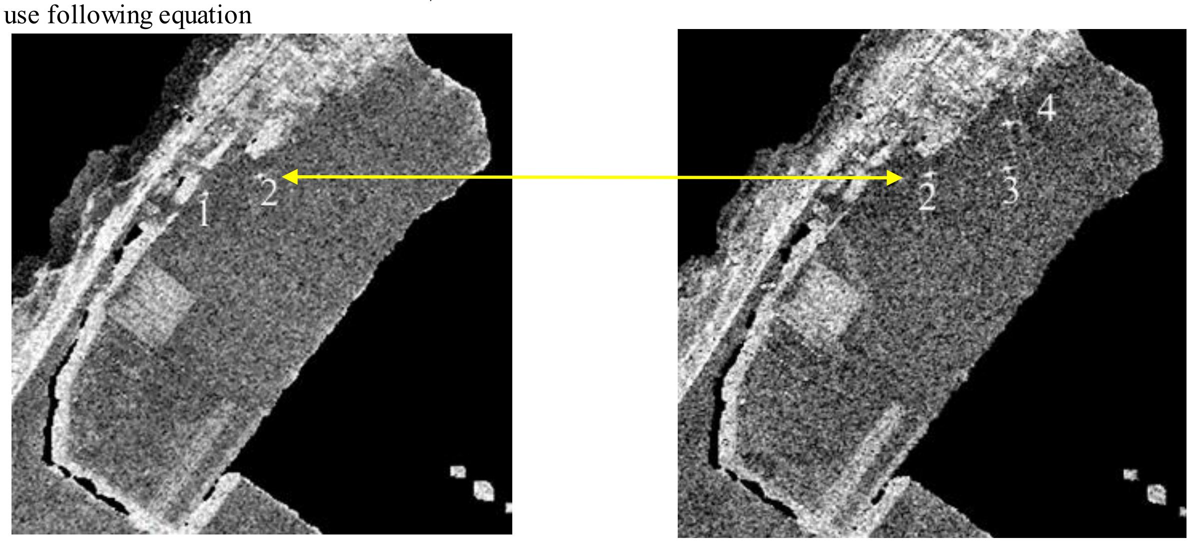
For corner reflector it is 2°, which leads to the measurement error equal to 0.7 mm in terms of length.

Direct measurements of snow height carried out on the test field during the ALOS-2 PALSAR imaging in February 8, 2017 showed that the snow depth was 20 – 30 cm and the determined snow density was 0.2 – 0.21 g/cm^3. According to theoretical results, these parameters correspond to phase difference from 2 to 3.2 radians, which agrees well with the measured values.

4. CONCLUSIONS

The work discusses the possibility of determining the snow height and its water equivalent by the radar interferometry method in L-band with help of ALOS-2 PALSAR data obtained in a snow-free period and with presence of snow cover. A corner reflector was used as a reference target, backscattering from which does not depend on the absence and presence of snow. The calculations of snow height made using theoretical relations, interferometric phase difference measurements, as well as direct measurements of snow layer thickness on the test field are in good agreement.

This work was supported in part by the Federal agency of scientific organizations and Russian Foundation for Basic Research (Grant No. 18-05-01051). Original ALOS-2 PALSAR data granted by Japan Aerospace Exploration Agency (JAXA) under ALOS-2 RA-6 (PI number: 3402). TanDEM-X data granted by the German Aerospace Center (DLR) under project XTI_HYDR0485.



a) b)

Fig. 4 Amplitude radar images of the interferometric pair: a) September 21, 2016, b) February 8, 2017.

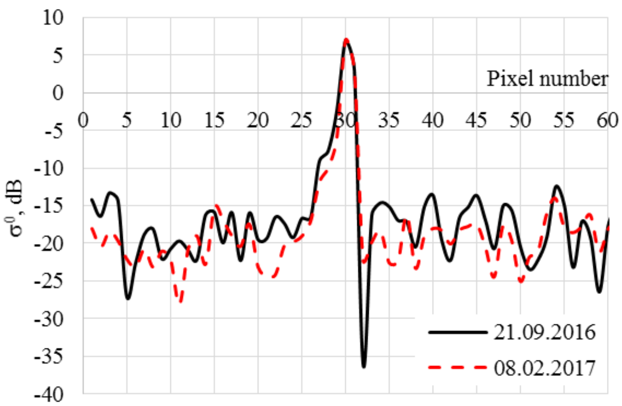


Fig. 5 Backscattering coefficients along the meridional line passing through the point 2.

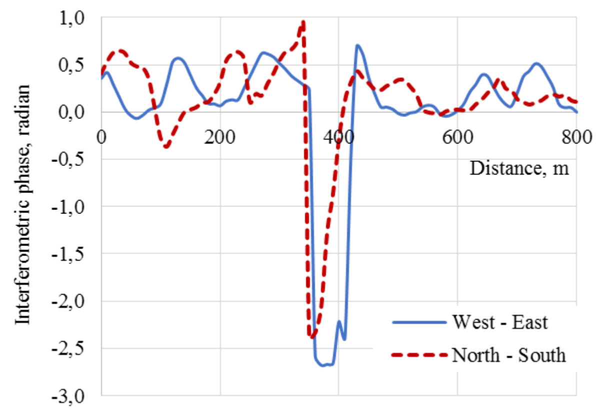


Fig. 6 Interferometric phase along the lines from North to South and from West to East, which cross at point 2

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