Interferometric observation of the phase centers displacements in forest covers in winter

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Abstract

Studies of seasonal variations of the scattered signal's phase centers in forest covers are of importance for the better understanding of radiophysical properties of forest vegetation. Interferometric techniques provide possibility of centimeter-scale observations of the displacements. The data used in the study are on PALSAR-2 interferometric pairs acquired over Selenga river delta. According to double differential approach, interferometric phase of forests under study was corrected from the phase of nearby fields. Phase differences were corrected further in order to reduce phase delay in snowpack on the fields as well as in snow layers intercepted by trees. The phase centers displacements were discovered to be less than 2 cm for all observation intervals, and the displacement velocity decreases in the middle of winter.

1 Introduction

Scattering properties of forested area in moderate latitudes vary significantly with seasons of year. Winter conditions in forest are known to reduce the backscattering level in C- and L-band [1,2], and here we discuss phase difference effects. SAR interferometry is sensitive to effective phase centers drift. Interferometric application results (e.g., surface displacements estimation) can be improved by taking into account variations of effective phase centers in forest. In spring and summer a phase center in forest canopy can raise due to vegetation processes. In autumn and winter the phase centers are expected to be near constant. Phase centers position estimation was recently implemented for PALSAR [3] and TerraSAR-X [4] data acquired in different seasons of year. In this study we use new PALSAR-2 data over the same forest test sites in fall and winter.

2 Backscattering Properties of Test Sites Covers

Nine data takes in 2014-2015 winter season were selected for interferometric processing, and 6 pairs with 14, 28, and 42-days interval were processed. In **Figure 1** one can see normalized backscattering coefficient σ^0, in dB, for two forest areas (forest Ist: area in Istomino forest, forest Dub: area in Dubinino forest) and adjacent field areas. The decrease backscattering level at HH polarization in the beginning of observation period, which coincided with a start of freezing period for both types of surfaces, is about 5-6 dB in accordance with [1]. Since November 24 (20141124 in the format yyyymmdd) the backscattering level increases at 2 dB and since that varies slowly (1-2 dB) in both forests. Fields demonstrate greater raise of backscatter and larger variations. The increase of backscatter can be explained by heavy snowfall and permanent snow accumulation in both fields and forests, though there is more complicated snow dynamics in the latter case taking in mind snow interception by tree branches and snow dropping in a windy days. 2 dB decrease of backscatter in fields is well-explained by 10° larger SAR observation angle on 20141208, 20141222 and 201501119, in accordance with cos^4 (4th degree of cosine) angular dependence of backscatter in a model of plain rough surface.

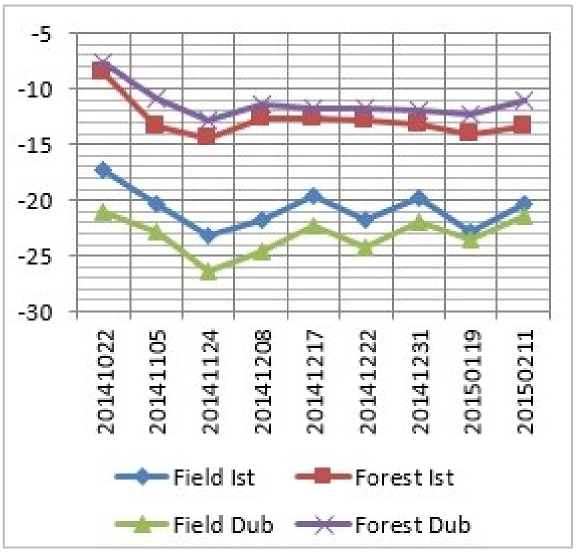

Figure 1: σ^0, dB, for area of interest: two forest sites and two field sites. HH polarization.

Sites backscattering properties at signal cross polarization HV are presented in **Figure 2**. Cross polarization backscatter is lower than co-pol backscatter HH by 5-8 dB for forests and by 9-13 dB for fields. Snow accumulation effect in fields and forests may be observed here also – since start of snow fall on 20141124. Growth of diffuse backscatter in snow during December may be seen at HV in **Figure 2** for both fields. We can state that presence of snow covers both in fields and forests can be seen in signal amplitude data. Low sigma-naught values lead low interferometric coherence and make phase measurements unreliable, therefore in next sections we do not discuss phase information for our test sites at HV, but at HH polarization only.

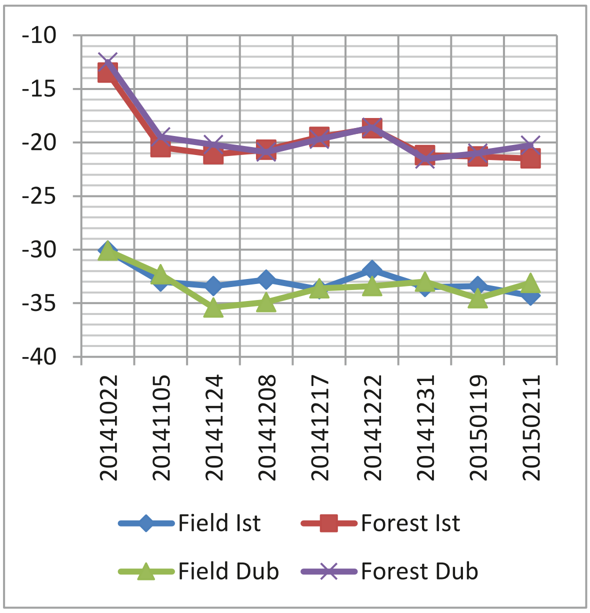

Figure 2: σ^0, dB, for area of interest: two forest and two fields. HV polarization.

3 Forest Phase Centers Measuring

Six interferograms with 14, 28, and 42 days interval were generated over Selenga delta area near Baikal Lake, Siberia. Istomino test site includes a fragment of a mixed forest and a field to the south from it. Dubinino test site consists of a pine forest patch and a field to the west from it. Small baseline approach was applied in order to reduce topography influence on phase difference. Heights of ambiguity for all pairs one can find in **Table 1**.

Estimated forest height near forest border is about 14 m [3], thus phase jump between field and forest due to elevation change does not exceed 0.2 radians for the pair 20141217-20141231 with the shortest height of ambiguity value, and is smaller for the rest of pairs.

Dates (yyyymmdd)	Ambiguity height, m	Time interval, days
20141022-20141105	447	14
20141124-20141208	466	14
20141208-20141222	553	14
20141217-20141231	437	14
20141222-20150119	1029	28
20141231-20150211	552	42

Table 1: Ambiguity heights and time intervals for 6 pairs.

Phase difference between forest and neighboring field for time intervals from several days to months shows variations of phase centres positions. In **Figure 3** one can find phase difference values for two test sites.

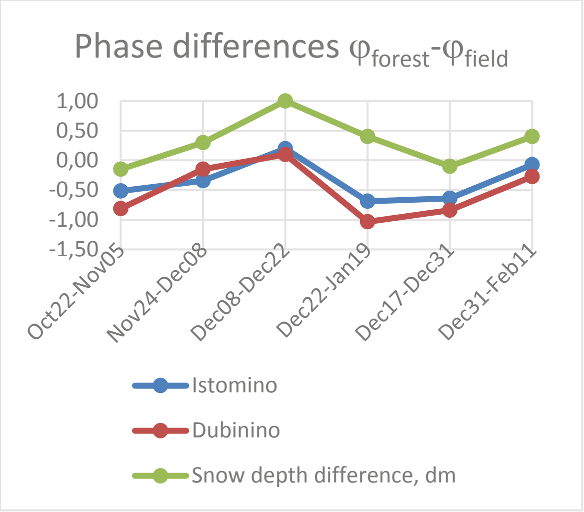

Figure 3: Forest/field phase difference, in radians, for two test sites (Istomino and Dubinino) and snow depth change, dm, between the observation dates.

Instead of near-constant line around 0.2 rad (topographic phase component) there are two polylines with the maximum in the point that corresponds to December 8-22, 2014, pair. The same pair show the maximal snow depth change between observations (10 cm, see **Table 2**). Pearson correlation coefficient between phase difference and snow depth change is 0.78 for Istomino forest and 0.7 Dubinino forest. Consequently, we need snow delay correction.

Dates (yyyymmdd)	T, 1st date, °C	T, 2nd date, °C	Snow depth change, cm
20141022-20141105	-1	-5	-1.5
20141124-20141208	-6	-17	3
20141208-20141222	-17	-6	10
20141217-20141231	-4	-20	-1
20141222-20150119	-6	-10	4
20141231-20150211	-20	-13	4

Table 2: Weather conditions for 4 pairs of observation dates.

Dry snow cover can cause two-way phase delay [5]

$$\Delta\varphi = {}^{4\pi}/_{\lambda}\, h_s \left(\cos\theta - \sqrt{\varepsilon_s - \sin^2\theta}\right), \qquad (1)$$

where

λ wavelength,
h_s snow depth,
θ incidence angle,
ε_s dielectric constant of snow.

As all dates of observations were frosty (**Table 2**), snow was conceivably dry, thus we can correct phase differences using (1). Snow depth in the forest we should not take into account because the phase center position has an average height of 14 m above the ground [3]. Phase profile after correction one can see in **Figure 4**. Phase differences still do not have near-constant values: total variation for Istomino is 0.81 rad, for Dubinino 1.0 rad). It decreases slightly in comparison with initial values on Figure 3 (0.89 rad and 1.13 rad, respectively). Consequently, there is an alter source of phase changes between observations. On the same plot (Figure 4) we put the third polyline. It demonstrates difference in precipitation volume during three days before the first and the second observation dates with wind speed coefficients:

$$\Delta prec = \frac{v_2}{10} prec_2 - \frac{v_1}{10} prec_1 \qquad (2)$$

where

$v_{1,2}$ wind speed in the 1st and the 2nd date,
$prec_{1,2}$ cumulative precipitation volume for 3 days before the 1st and the 2nd date.

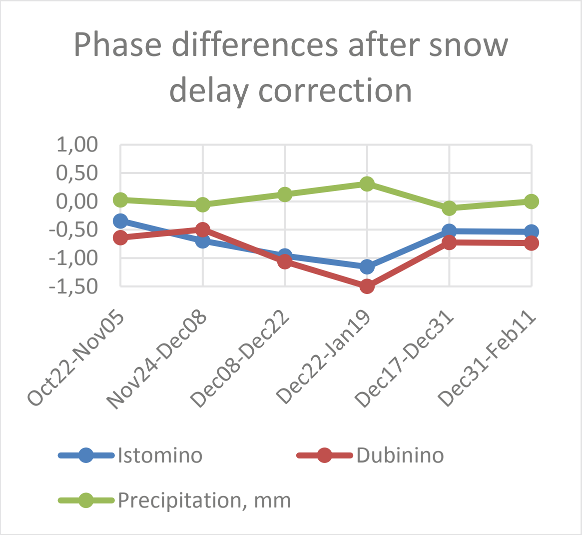

Figure 4: Forest-field phase difference, radians, for two test sites after snow delay correction and precipitation difference rate.

We use a simplified assumption on a relationship between wind and amount of snow on trees: wind speed 10 m/sec and above blows out all snow from trees' branches, windless conditions keep snow on trees, and every 1 m/sec of wind speed increase drops down 10% of snow from trees.

Phase differences are sensitive for changes in snow layer, as we can see in Figure 3. In addition, Figure 4 shows that phase differences and precipitation rate calculated following (2) look similarly. Pearson correlation coefficient is -0.79 for Istomino test site and -0.92 for Dubinino test site. Negative sign here (Figure 4) and positive one in the previous correlation (Figure 3) show that we deal with the first and the second terms of phase difference $\varphi_{forest} - \varphi_{field}$. Thus, the influence of precipitation should be taken in account. But we cannot use the formula (1) directly this time. Firstly, we should convert precipitation rate (that indicates amount of water after snow melting) into snow height. For fresh snow coefficient is 20-25 (1 mm of precipitation corresponds to 2-2.5 cm of snow depth); we use 20. Secondly, dielectric constant ε_s for fresh snow is less than ε_s for settled snow. Finally, a slant signalpath can traverse several snow-covered branches, that increases total delay. We use an empirical coefficient 14 that minimizes total variation of corrected phase differences. Total variation after correction is equal to 0.53 for Istomino forest and 0.41 for Dubinino forest (**Figure 5**). Comparing Figure 3 and Figure 5, one can state that after two correction procedures the total variation for both forests was reduced by half.

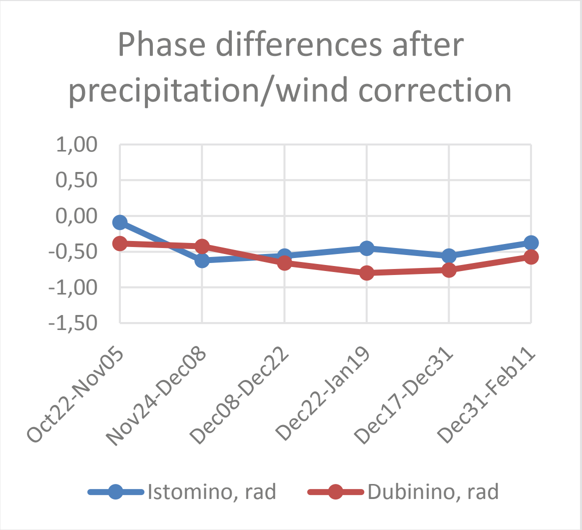

Figure 5: Phase differences for 6 pairs after precipitation/wind correction.

As it was mentioned above, effective phase centers height in our forests was estimated as 14 m for L-band.

Using ambiguity height values from the Table 1, we removed the phase component induced by this height difference. Thus, after three corrections (snow depth difference in field, snow precipitation difference in forest, and height difference correction) we can convert resulting phase differences into displacements (**Figure 6**).

Forest phase centers' displacements are positive and constitute 1-2 cm for both forests. Soil freezing processes can explain this effect: different looseness of soil in field and forest results in different freezing progress speed. In the beginning of the cold season the displacement rate increases, and two last pairs show decrease of displacement values. It is worth noting that the last pair has the longest time interval between observation (42 days), consequently, after normalization by time factor 3, the mean displacement is under 0.5 cm per 2 weeks for both test sites.

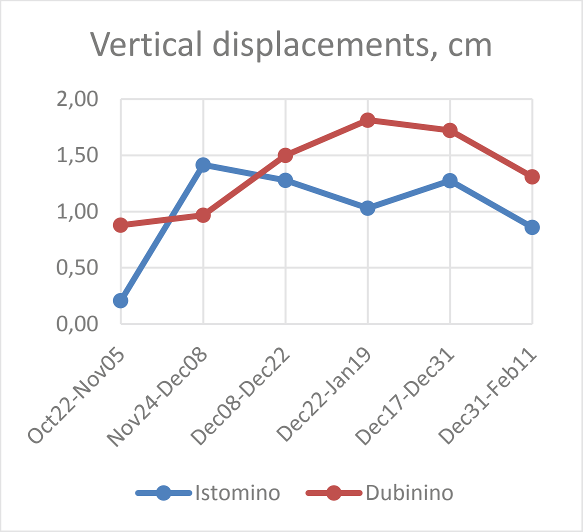

Figure 6: Vertical displacements corresponded to corrected phase differences.

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4 Conclusions

SAR backscatter analysis allows state that presence of snow covers both in fields and forests can be observable in signal amplitude data. SAR interferometric measuring of forest phase centers drift shows, firstly, that in the double-differential procedure at least two different snow effects should be taken into account (phase delay in snowpack and in snow on trees), and, secondly, that measured displacements are positive. Thus the most appropriate season for forest phase centers position measuring is the middle of winter, when trees and soil are frozen enough.

References

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