Observations of forest cover and forest growing stock volume in Siberia from PALSAR backscatter and coherence data

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Abstract
The properties of PALSAR L-band backscatter and interferometric coherence of Siberian boreal forest are the topic of this paper. The cross-polarized backscatter (HV) is better suited than co-polarized backscatter (HH) for identification of forest cover changes, e.g. clear cuts and fire scars. Coherence acquired during winter also shows a good contrast between forested and non-forested areas. Our investigation shows that both the HH and the HV backscatter present weak sensitivity to the growing stock volume. The coherence is high also in dense forested areas, which seems to somehow limit the usefulness of this observable in the retrieval of growing stock volume. Results from full resolution Fine Beam data products (geocoded to 25 m) and the Kyoto and Carbon data products (50 m) did not result in significant differences.

Keywords: ALOS PALSAR, SAR interferometry, coherence, backscatter, boreal forest, Kyoto and Carbon Initiative.

1. INTRODUCTION

Spaceborne L-band synthetic aperture radar, SAR, backscatter and interferometric coherence observations of forests have been shown to be suitable for several mapping applications, in particular in boreal forest. The dependency of forest biophysical parameters with SAR backscatter has been shown to be exploitable for retrieval or growing stock volume, i.e. forest above-ground biomass. For boreal forests a number of studies on JERS-1 data have highlighted that summer-time data are more suitable than winter-time data for retrieval [1-3]. In addition, multi-temporal combination of estimates from individual estimates can increase retrieval accuracy [2,3]. The dual polarization capability and the multi-temporal data acquisitions of ALOS PALSAR should guarantee the best possible estimates of forest growing stock volume from L-band data.

Despite of the 44-days repeat-pass interval the JERS-1 coherence showed a strong forest/non-forest contrast during winter for frozen environmental conditions. Such data was therefore found suitable for identification of clear cuts and fire scars [4]. Coherence was also shown to be sensitive to growing stock volume in particular for mapping forest regrowth [2,5]. The major problem with JERS-1 data was the sparse acquisition and the variability of the interferometric baseline. This resulted in very few image pairs that could be combined interferometrically in a successful manner. Compared to JERS-1, ALOS PALSAR has similar repeat-pass period (46 days) but also controlled interferometric baseline thanks to the 500-m orbital tube and a well-defined observation strategy over the boreal zone with two or three data acquisitions each winter.

In the frame of JAXA's Kyoto and Carbon (K&C) Initiative, the Friedrich-Schiller University currently has the task of developing methods for forest disturbance mapping, as well as for forest biomass retrieval, in Central Siberia (80-110 deg E, 50-65 deg N). Gamma Remote Sensing provides technical advice and processing support, in particular for the K&C data products. These consist of data strips of SAR amplitude being several hundred kilometers long and with approximately 50 m pixel size.

In this paper we present first results on investigations concerning properties of PALSAR backscatter and coherence data of Siberian boreal forest.

2. SAR DATASET AND PROCESSING

The PALSAR dataset analyzed consisted of

- Fine Beam Single (FBS) HH-pol K&C data strips acquired during winter 2006/2007
- Fine Beam Double (FBD) HH/HV pol K&C images acquired during summer 2007.
- FBS mode (HH-pol) full resolution image frames in Single Look Complex format.
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The latter were used to form interferometric pairs with 46-days repeat-pass interval from which the coherence has been estimated.

For the K&C data strips processing consisted of conversion of the amplitude data to SAR intensity, radiometric calibration. Interferometric processing consisted of SLC co-registration at sub-pixel level, common-band filtering in range and azimuth and generation of a differential interferogram. This was used in the coherence estimation procedure based on adaptive estimation [6]. All images were geocoded using SRTM-3 height data. The transformation between map and radar image was done by a geocoding lookup table. Because of the non-perfect orbit information, the lookup table was refined using an automated approach based on offset estimation between the actual SAR image and a simulated SAR image from the DEM in several hundred image chips [7]. The geocoding lookup table was used also in the generation of the differential interferogram.

The geocoding procedure resulted in positioning accuracies at sub-pixel level as long as a sufficient number of image chips were retained for the refinement of the lookup table. When flat areas were predominant in the image, the refinement did not improve the geocoding accuracy based on the orbital data. Errors of the order of 1-2 pixels (on average) were obtained. Nonetheless, resampling with the same automated procedure using ortho-rectified Landsat imagery improved the positioning accuracy of the geocoded PALSAR data to sub-pixel level.

Fig. 1 shows a comparison between terrain geocoded K&C SAR intensity data strips acquired under winter/frozen conditions and summer/unfrozen conditions. While the winter-time HH-pol image showed weak contrast between forest and non-forest, the summer-time data, in particular the HV channel, showed a stronger contrast.

Fig. 1 also shows a PALSAR polarimetric RGB for summer data (R=HH backscatter, G=HV backscatter, B=HH/HV ratio). Green areas correspond to forests, which are characterized by strong volume scattering in the HV channel. Pale blue indicates forest free areas because of the weak HV return. Dark blue characterizes agricultural areas and the Angara River because of the very weak HV return.

Fig. 2 shows a mosaic of nine PALSAR coherence images. Forested areas present lower coherence with respect to non-forested areas (clear cuts and fire scars). The possibility to detect different forest covers is shown by the PALSAR coherence product in Fig. 3 (R = coherence, G = backscatter, B = backscatter ratio). Clear cuts and forest scars appear in red because of the high coherence and the low, temporally stable backscatter. Forests show different shades of red and green depending on the forest cover density. The backscatter ratio determines the color of the (frozen) Angara River.

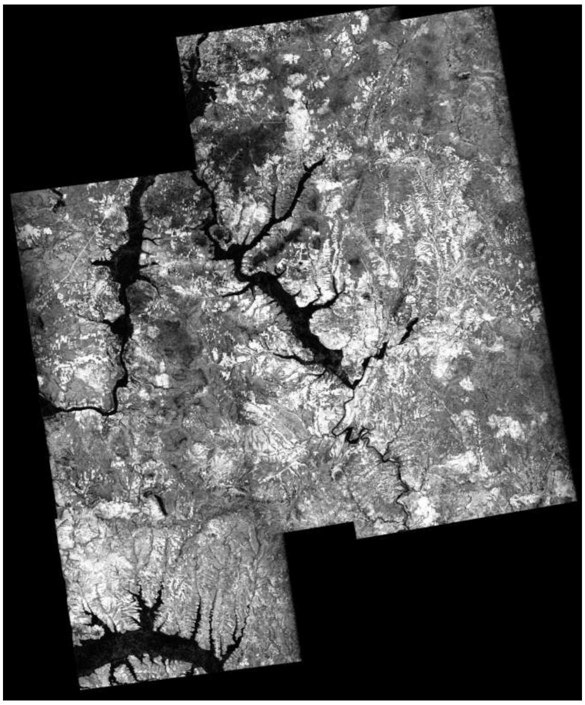

Figure 2. Mosaic of nine PALSAR coherence images with 46-days repeat-pass interval acquired between December 2006 and February 2007.

3. TEST SITE

To study the relationship between backscatter and coherence on one side, and forest cover and growing stock volume on the other side, we made use of the forest inventory data in the extensive SIBERIA-II Project database [8]. The database includes detailed measurements of several forest biophysical parameters for a large number of test sites. Among those parameters the growing stock volume, i.e. the volume of the tree trunks per unit area, has been considered. This is directly sensed by the backscatter and has been shown to be strongly related to repeat-pass coherence.

The ground data consisted of forest masks in digital format delineating forest stands and inventory measurements at the stand level. Stands are forest area with homogeneous forest cover. In this first study we considered the stands of the southwestern forest compartment in the Shestakovsky region (56.2 deg N, 102.9 deg E). This test site was chosen because it was covered by both full resolution and K&C PALSAR datasets. Forest inventory data were last updated in 1998. Despite of the long interval between the last update and the PALSAR acquisitions, the area did not seem to have been affected by relevant changes. In Fig. 3 the digital forest mask is shown overlaid on the PALSAR interferometric RGB. The agreement between the SAR data and the forest mask is remarkable.

4. PROPERTIES OF SAR BACKSCATTER AND COHERENCE

Fig. 4 illustrates the relationship as a function of growing stock volume of HH-pol winter-time SAR backscatter (a), winter-time coherence (b), K&C summer-time HH-pol (c) and HV-pol (d) SAR backscatter. Each cross represents a forest stand. Red crosses have been used for stands larger than 20 ha (25% of forest stands), for which backscatter and coherence measurements should be less affected by noise and inventory errors.

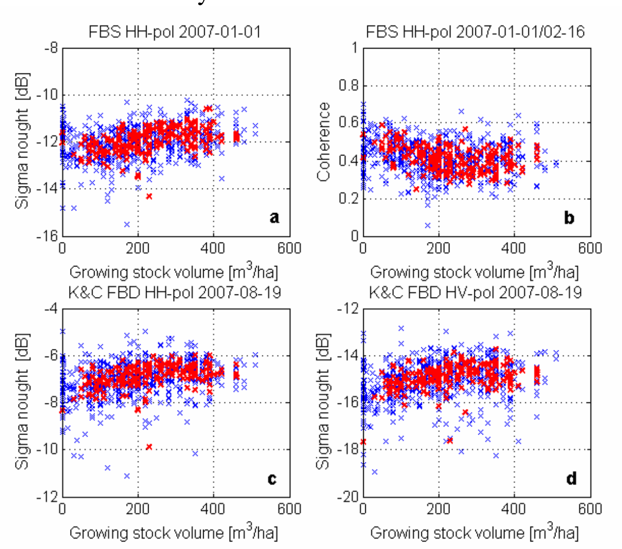

Figure 4. Plots of HH-pol winter-time SAR backscatter (a), winter-time coherence (b), K&C summer-time HH-pol (c) and HV-pol (d) SAR backscatter as a function of growing stock volume.

All plots show a certain sensitivity of the growing stock volume to backscatter and coherence. Winter-time HH-pol backscatter presented a steady increase of about 1.5 dB between non-forest and dense forests, thus confirming winter-time observations with JERS [3]. Summer-time HH-pol backscatter had overall higher backscatter but increased by about the same dB values as the winter-time backscatter and presented saturation at low growing stock volumes. An almost similar behavior was found for the HV-pol data, with a slightly stronger contrast between non-forested and dense forested areas (~ 3-4 dB).

As expected, the coherence decreased for increasing growing stock volume. However, even the densest forests presented some coherence despite of the 46-days repeat-pass interval. This resulted in a weak sensitivity of coherence to the growing stock volume. Weather statistics reported temperatures consistently below 0 °C and low wind speed at acquisition. We can therefore assume that the overall frozen conditions of ground and trees resulted in temporal decorrelation almost independent from the forest density. Another interesting observation concerns the slight increasing trend of coherence for the highest growing stock volumes (> 350 m^3/ha). This was probably caused by volume decorrelation due to the long perpendicular component of the baseline (approximately 1.6 km).

5. CONCLUSIONS

The observation strategy of ALOS PALSAR provides ideal backscatter and coherence for the observation of forests in Siberia. In this first study on the properties of SAR backscatter and coherence of Siberian boreal forest we made the following observations.

- Forest cover can be best monitored with Fine Beam Dual data (HH/HV-pol) acquired during summer and Fine Beam Single-pol coherence. In each acquisition mode one image seems to be sufficient.
- Retrieval of growing stock volume is somehow limited and is probably more feasible using SAR backscatter than coherence.
- Weather conditions seem to play an important role, which pledges for a multi-temporal approach to obtain reasonable retrieval estimates.
- Finally, we did not find the lower resolution of K&C data to play a relevant role when it comes to identifying forest cover changes and defining the relationship between the SAR backscatter and the growing stock volume on a stand-basis.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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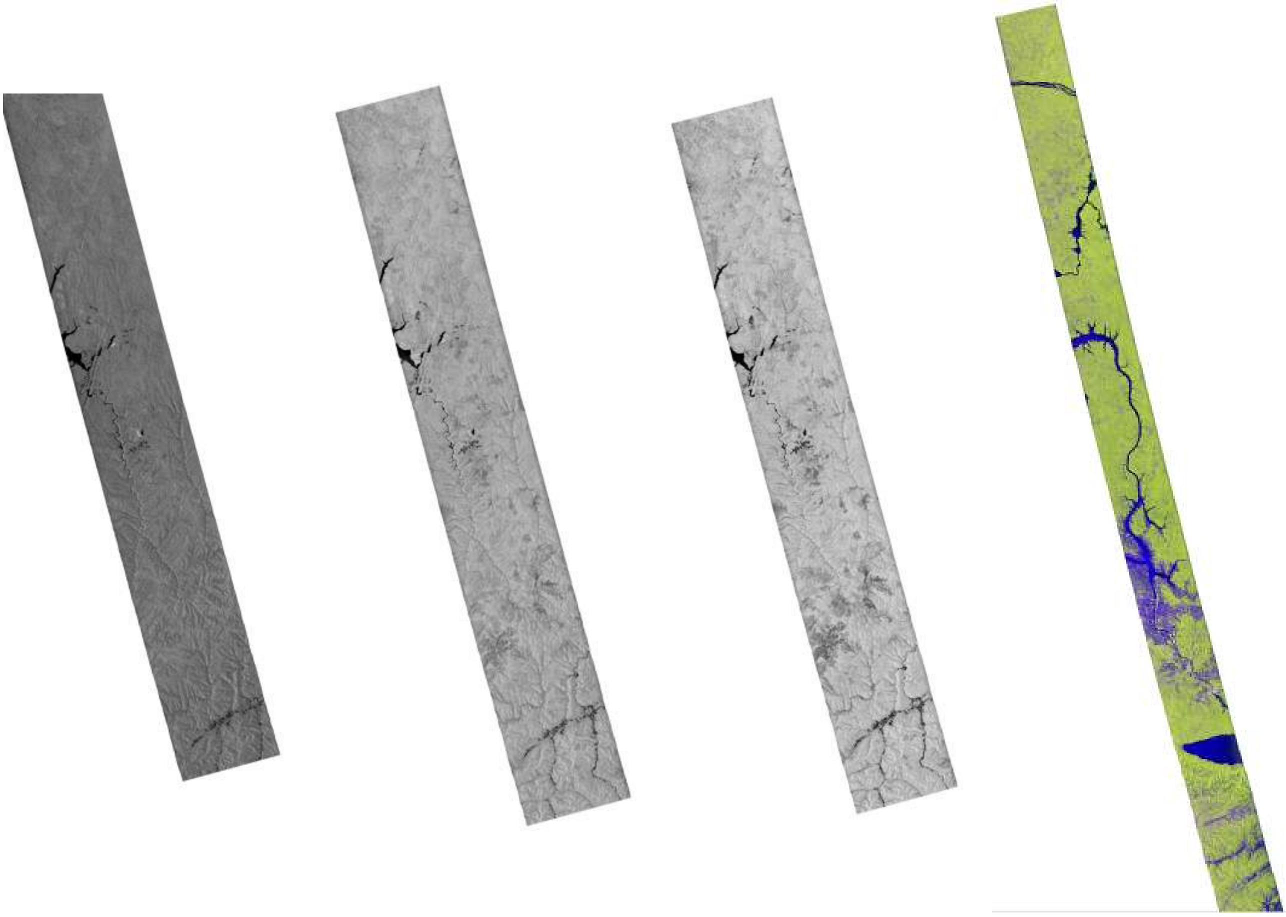

(a) (b) (c) (d)

Figure 1. HH-pol strip acquired on 2006-12-27 (a), HH- and HV-pol strip acquired on 2007-08-14 (b and c). These images have been acquired along RSP 462. PALSAR polarimetric RGB strip (d) (R = HH pol, G = HV pol, B=HH/HV ratio). These images have been acquired on 2007-08-19 along RSP 465.

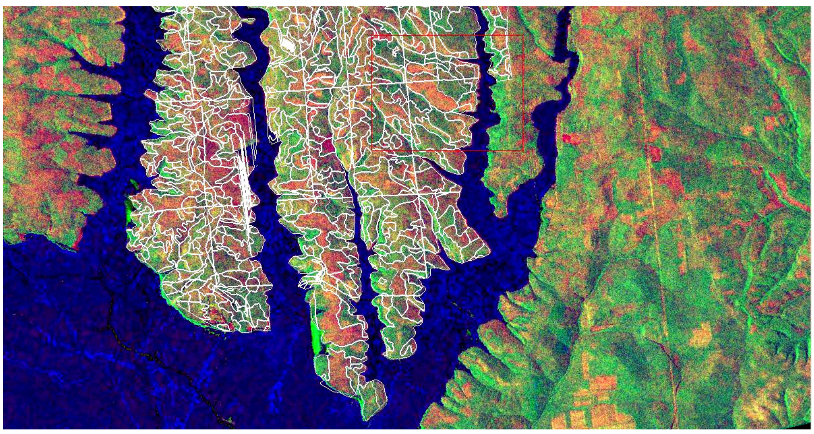

Figure 3. PALSAR coherence product (R = coherence, G = backscatter, B = backscatter ratio). White lines indicated forest stands borders.