ESTIMATION OF FOREST STEM VOLUME USING ALOS-2 PALSAR-2 SATELLITE IMAGES

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ABSTRACT

A first evaluation of ALOS-2 PALSAR-2 data for forest stem volume estimation has been performed at a coniferous dominated test site in southern Sweden. Both the Fine Beam Dual (FBD) polarization and the Quad-polarimetric mode were investigated. Forest plots with stem volume reaching up to a maximum of about 620 m^3 ha^{-1} (corresponding to 370 tons ha^{-1}) were analyzed by relating backscatter intensity to field data using an exponential model derived from the Water Cloud Model. The estimation accuracy of stem volume at plot level (0.5 ha) was calculated in terms of Root Mean Square Error (RMSE). For the best case investigated an RMSE of 43.1% was obtained using one of the FBD HV-polarized images. The corresponding RMSE for the FBD HH-polarized images was 43.9%. In the Quad-polarimetric mode the lowest RMSE at HV- and HH-polarization was found to be 39.8% and 47.4%, respectively.

Index Terms— Synthetic Aperture Radar, forestry, above-ground biomass

1. INTRODUCTION

The current most important environmental challenge facing the world today is the understanding of global change and its effect on the Earth. This is critical knowledge to the world's communities for making predictions and decisions, and for designing strategies for mitigation and adaptation. Release of carbon dioxide into the atmosphere by human activity, mainly through fossil fuel burning, is known to be the major driver of climate change [1]. The terrestrial biosphere plays a significant role in this context and acts as both a carbon source through land-use change, including deforestation and fires, and as a carbon sink through vegetation growth. Through such processes the terrestrial biosphere has acted as a net carbon sink, removing from the atmosphere about one third of the carbon dioxide produced from fossil fuel burning and thereby reducing the impact on global change [2]. However, little is known about the future of this mechanism since the evolution of the terrestrial biosphere is the least understood and the most uncertain among the different elements of the carbon cycle.

Important parameters in the carbon cycle are biomass, i.e., the mass of living organic matter, and biomass change (flux), its spatial distribution and temporal evolution. Land vegetation comprises about 99% of the world's biomass, and forests comprise about 80% of terrestrial above-ground biomass. Despite its significant role in the carbon cycle, the distribution of forest biomass and biomass change is poorly known because of the difficulties in measuring biomass globally. Due to its importance, a global grid with biomass has been identified by the Global Climate Observing System (GCOS), as an Essential Climate Variable needed to reduce uncertainties in our knowledge of the climate system [3].

To meet the requirements of forest biomass and biomass change data to global climate modeling, recent research has shown that long-wavelength L-band ALOS PALSAR data [4] have great potential to provide accurate estimates of forest biomass. This was reported within the ALOS Kyoto & Carbon Initiative in Phases 1, 2, and 3, and is now continuing in Phase 4 [5-12]. Among all spaceborne Synthetic Aperture Radar (SAR) systems of today, ALOS-2 PALSAR-2, successfully launched on May 24, 2014, is the most suitable system for mapping and monitoring biomass at regional to global scales, providing new L-band SAR data in the same fashion as for the previous ALOS mission. The SAR system's strength lies in being able to measure the forest using wavelengths that penetrate the canopy and capture the forest structure, thus, allowing the retrieval of biomass. The SAR images can also be obtained independently of weather conditions, although rain and moisture affects the radiometry in the acquired images. ALOS-2 PALSAR-2, the successor of ALOS PALSAR, has higher performance than any previous L-band SAR sensor with higher spatial resolution and shorter satellite revisit time (depending on the satellite's orbit, location, and swath of the sensor).

The objective of this study is to investigate the usability of ALOS-2 PALSAR-2 satellite images acquired in Fine Beam Dual polarization mode and Quad-polarimetric mode for stem volume estimation at plot level.

2. MATERIAL AND METHODS

2.1. Test site

The Remningstorp test site is located in the south of Sweden (58°30' N, 13°40' E). The test site covers about 1,200 ha of productive forest land managed by Skogssällskapet and is owned by the Hildur and Sven Wingquist's Foundation for Forest Research. The forest is divided into stands with a range of stem volume conditions reaching up to a maximum of about 600 m^3 ha^{-1} at stand level. Prevailing tree species are Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birch (*Betula* spp.). The topography is fairly flat with a ground elevation between 120 m and 145 m above sea level.

2.2. Field data

At the test site, 48 plots with a radius of 40 m (0.5 ha) inventoried in 2014 were used for training and validation purposes. To cover a wide range of species composition and stem volume and to avoid the effects of stand boundaries, the plots were manually positioned well inside existing stands. At each plot, trees were callipered at breast height and tree heights were measured for a sub-sample of trees. The plot locations were measured using DGPS with post-processing producing sub-meter accuracy. For the 48 plots, the estimated stem volume from field data ranged from 10 to 620 m^3 ha^{-1}.

2.3. ALOS PALSAR-2 data

L-band SAR data from the ALOS-2 PALSAR-2 sensor used in this study were acquired during the period 2014-09-18 to 2015-10-06. The operating sensor frequency is 1.270 GHz, which corresponds to a wavelength of 23.6 cm. SAR images from the Fine Beam Dual (FBD) polarization mode and the Quad-polarimetric mode were available. The FBD polarization dataset consisted of 20 pairs of HH- and HV-polarized images (off-nadir angle between 28.2° and 36.2°). The Quad-polarimetric dataset consisted of 2 quadruplets acquired at HH-, HV-, VH- and VV-polarization (off-nadir angle between 25.0° and 34.9°). In particular here we concentrate on the HH and HV images given the strong similarity between cross-polarized data and the poorer sensitivity of VV-polarized backscatter data in forests [13]. Images were available from both ascending and descending orbit passes. The data were provided in SLC format, from which images of the radar backscattered intensity were obtained. As a trade-off between speckle reduction and spatial resolution, all images were multi-looked to obtain a pixel size of approximately 20 m in range and azimuth. Consequently, all images were geo-coded to 20 m in order to match with the size of the forest plots used for this preliminary investigation of stem volume retrieval from ALOS-2 PALSAR-2 data. The data were geo-coded with the approach described in [13]. For this preliminary investigation, the geo-coding procedure relied on a coarse 50×50 m DEM provided by the Swedish National Land Survey (Lantmäteriet). Given the rather flat terrain at the test site, compensation for angular effects and pixel area were not applied.

2.4. Statistical analysis

Modeling SAR backscatter from forest is complex and requires assumptions concerning scattering elements (e.g. type of elements, distribution, and dielectric properties) and that the scattering mechanisms are considered. To assess retrieval of stem volume the average backscattered intensity from each forest plot was measured. An exponential model derived from the Water Cloud Model including scattering components from the ground and the vegetation was used:

$$\sigma^{\circ}_{for} = \sigma^{\circ}_{gr} \times e^{-\beta V} + \sigma^{\circ}_{veg} \times (1 - e^{-\beta V}) + \varepsilon\ , \tag{1}$$

where σ°_{for} is the average backscatter intensity from the forest plot, and σ°_{gr} and σ°_{veg} are the backscatter from the ground and the vegetation, respectively. V is the plot-wise stem volume (m^3 ha^{-1}), β is an empirically defined coefficient (ha m^{-3}), and ε is the random deviation assumed to be independent and $N(0, \sigma^2_{\varepsilon})$. The usefulness of this type of semi-empirical model has been demonstrated, e.g., in [14-16]. Using a training dataset of backscatter and stem volume from field measurement, the unknown coefficients σ°_{gr}, σ°_{veg}, and β in (1) were estimated by means of least squares criterion through non-linear regression analysis. By inverting (1), plot-wise stem volume was estimated for a test dataset using the corresponding backscatter measurement, $\sigma^{\circ}_{for,meas}$,:

$$\hat{V} = -\frac{1}{\beta} \times \ln\left(\frac{\sigma^{o}_{veg} - \sigma^{o}_{for,meas}}{\sigma^{o}_{veg} - \sigma^{o}_{gr}}\right)\ . \tag{2}$$

As described above, one dataset for establishing the relation between backscatter and stem volume and one dataset for evaluation of stem volume estimation was used. Therefore, the number of plots available was divided into two datasets by sorting according to ascending stem volume and assigning each dataset every second plot. The accuracy assessment was presented in terms of Root Mean Square Error (RMSE).

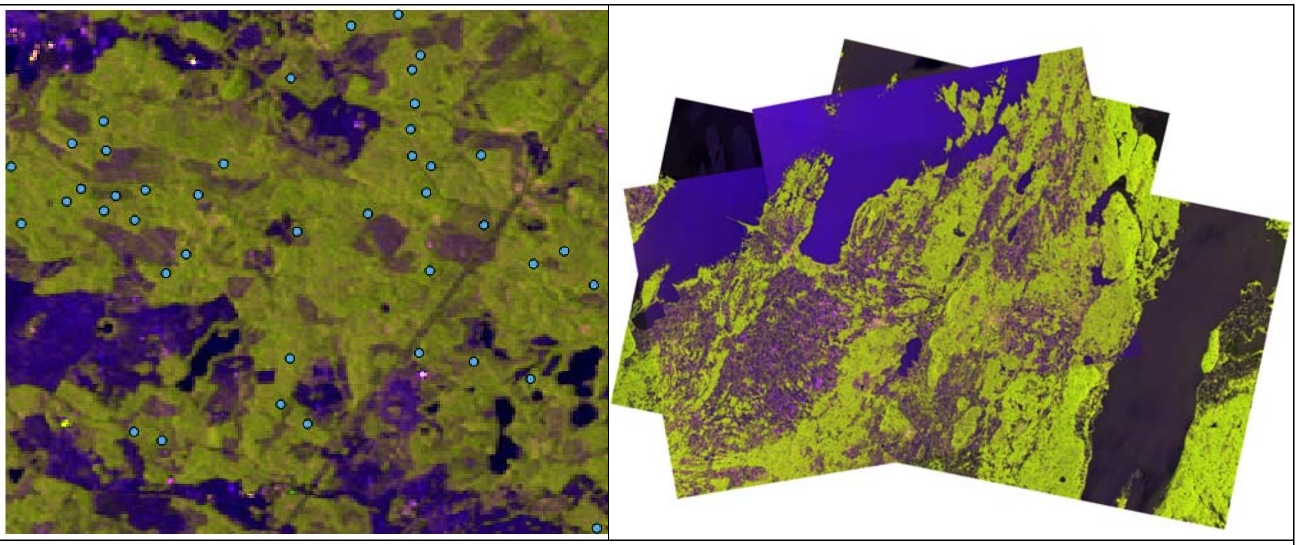

Fig. 1. Left: PALSAR-2 imagery (5.7 km × 4.7 km) with the 48 plot locations covering Remningstorp (red: average HH backscatter, green: average HV backscatter, blue: ratio of average HH / average HV backscatter). Right: PALSAR-2 imagery (147.6 km × 108.1 km) covering a larger area surrounding Remningstorp.

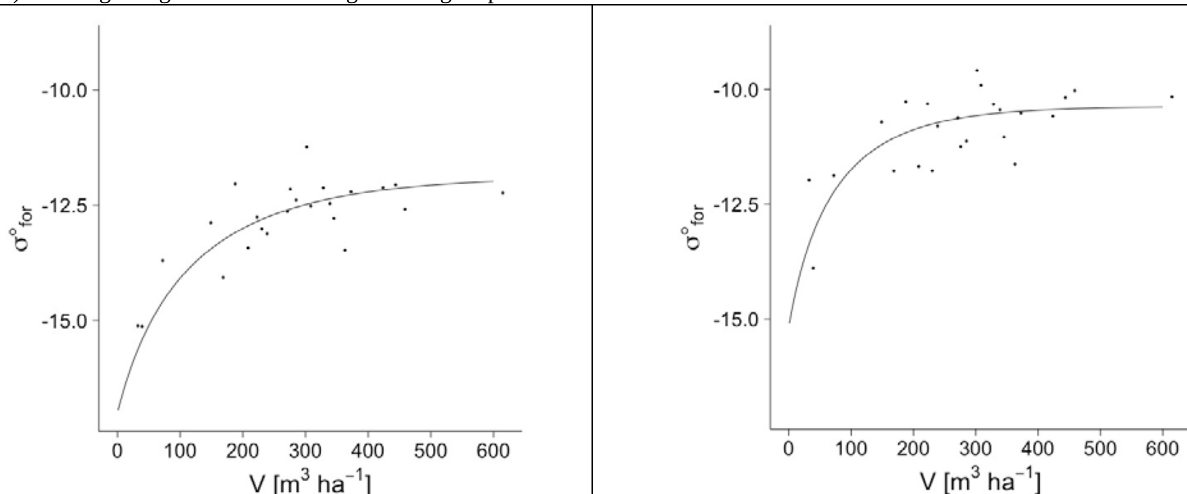

Fig. 2. Left: PALSAR-2 FBD HV backscatter, 2015-06-11. Right: PALSAR-2 Quad-pol. HV backscatter, 2015-10-06.

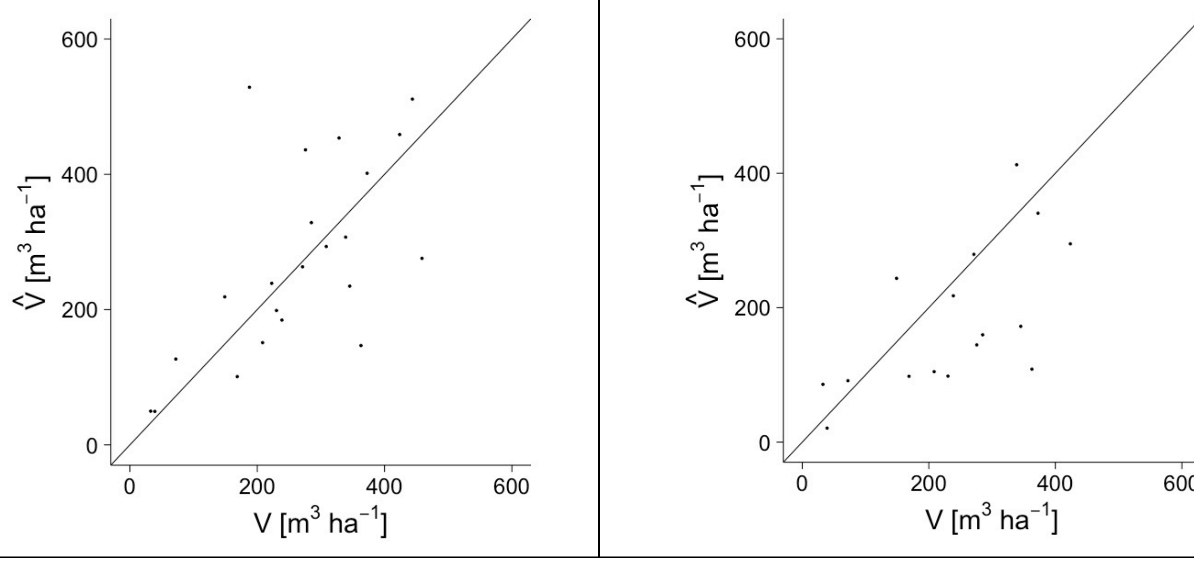

Fig. 3. Left: PALSAR-2 FBD HV backscatter, 2015-06-11. Right: PALSAR-2 Quad-pol. HV backscatter, 2015-10-06.

3. RESULTS AND DISCUSSION

The results show that ALOS-2 PALSAR-2 data are of high quality (Fig. 1) and can be used for stem volume estimation (Figs. 2 and 3) even at plot level (0.5 ha). The best case showed an RMSE of 39.8% (with a bias of -21.1 $m^3 ha^{-1}$) and was obtained using one of the Quad-polarimetric HV-polarized images. However, the variation in estimation accuracy of stem volume was large between SAR images acquired with the same mode and look angle at different dates and ranged from about 40% to 115% RMSE (where the corresponding bias ranged from about -80 to 30 $m^3 ha^{-1}$). This could probably be related to differences in season and weather conditions. To get a deeper understanding of the obtained results, meteorological data registered at the test site need to be analyzed. To improve the estimation accuracy of stem volume further processing of SAR will be undertaken and multi-temporal combination of individual images might also improve the stem volume estimation accuracy.

4. ACKNOWLEDGMENT

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