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FOREST BIOMASS ESTIMATION USING ALOS PALSAR IMAGES IN CHALLENGING NATURAL FOREST AREA IN FINLAND

Karjalainen Mika[(1)], Pyysalo Ulla[(2)], Karila Kirsi[(3)], Hyyppä Juha[(4)]

[(1)]Finnish Geodetic Institute, Geodeetinrinne 2, 02430 Masala, FINLAND, Email:mika.karjalainen@fgi.fi
[(2)]Finnish Geodetic Institute, Geodeetinrinne 2, 02430 Masala, FINLAND, Email:ulla.pyysalo@fgi.fi
[(3)]Finnish Geodetic Institute, Geodeetinrinne 2, 02430 Masala, FINLAND, Email:kirsi.karila@fgi.fi
[(4)]Finnish Geodetic Institute, Geodeetinrinne 2, 02430 Masala, FINLAND, Email:juha.hyyppa@fgi.fi

ABSTRACT

SAR images are feasible to estimate the forest biomass to some extent. Particularly, L and P bands have provided relatively good correlations with the SAR backscattering coefficient and stem volume. Moreover, polarimetric and interferometric capabilities of the SAR systems have increased the estimation accuracy. However, the biomass estimation is more challenging in the case of natural mixed forests developing free from the influence of humans. Additionally, in Finland, the natural forests are located in areas of intermediate relief, which complicates the biomass estimation. This paper shows some results of the forest biomass extraction using ALOS PALSAR Fine beam polarimetric and dual polarization images. High-density airborne laser scanning was used as reference data. The test area is located in southern Finland in Nuuksio National Park, which mainly consists of natural forest. Airborne laser scanning is the only available method to produce relatively accurate biomass estimates when the extent of the test area is considered.

1. INTRODUCTION

In Finland, about 76% of the land area is forested, which is the highest percentage amongst the European countries [6]. Therefore, forests have high impact on the Finnish economy and environment. The Finnish national forest inventories have been based systematic sampling in field surveys, in which aerial and satellite images and various maps have been used as an additional data. In general, the inventory results are accurate, but they lack of detailed information, which might be helpful for paper companies in planning of wood supply.

In the past 10 years, a considerable amount of research has been carried out in laser scanning based forest information extraction. The results have been very promising, and the forest stem volume estimation accuracy has been equally good or even better than in other methods [4]. Therefore, airborne laser scanning (ALS) is already nearly operationally used in wood supply planning. However, ALS is somewhat expensive when very large areas are considered and the repeatability is not very good either (mapping of whole Finland might be possible only at the interval of 10 years or so).

Space-borne SAR images have shown potential in forest mapping. Naturally, the advantage of SAR images is high temporal resolution, but also the possibility to cover simultaneously larger areas than in the case of ALS. For example, single-pass SAR interferometry, such as SRTM, can provide relatively good forest biomass maps [10]. On the other hand, backscattering amplitude information can also be used in biomass estimation. For example, multitemporal JERS SAR (L band) images were used in Finland to estimate wide area stem volume estimates with the accuracy of about 60 m^3/ha [8]. The quad polarization capability of ALOS PALSAR can be expected to somewhat increase the estimation accuracy. It has already been shown that PALSAR images can be used to detect changes in forested areas [2]. Moreover, studies on forest stem volume estimation using PALSAR data have been carried out. In [5], dual polarization images were found better in stem volume estimation that quad polarization images. R^2 of 0.77 was achieved for estimation, and it was noticed that the SAR signal saturated after the level of 200 m^2/ha [5].

In this paper, we present the results of the forest biomass estimation studies based on ALOS PALSAR dual and quad polarization images. Small-footprint ALS data was used as reference data in order to generate a biomass estimation model. Furthermore, the estimation model was used to create a forest biomass map for the whole area of the Nuuksio National Park.

2. TEST AREA AND DATA

The test area is shown in Fig. 1. The test area also includes the Nuuksio Natural Park, and it is located in southern Finland near the Helsinki Metropolitan Area. The forests in the Nuuksio National Part are dense and they remain in their natural condition. Therefore, with respect to the exploitation of SAR images in biomass

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estimation, the test area can be described as challenging. Additionally, there are a lot of small lakes and steep rocky slopes in the area. The acreage of the test area is over 250km^2.

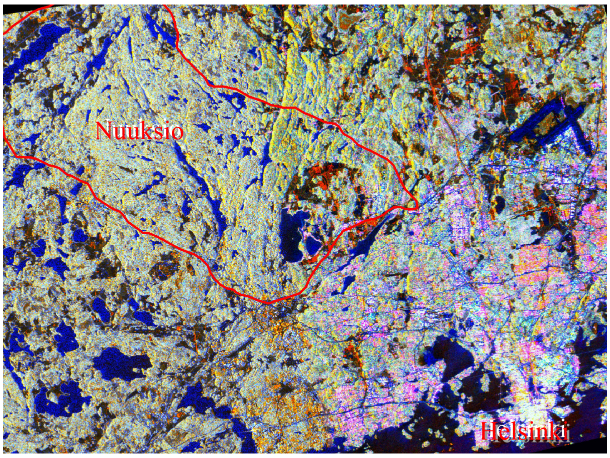

Figure 1. Fusion image of all input PALSAR scenes. Red polygon delineates the test area. Helsinki metropolitan area is in the lower right corner.

Our objective was to use Fine Beam Polarimetric ALOS PALSAR images, but it was noticed that the polarimetric mode images did not cover the whole test area because of the caps between possible scenes. Therefore, two dual polarization images were ordered also. The set of test images is shown in Table 1. Due to the systematic observation strategy of JAXA, the temporal coverage of PALSAR scenes is very good i.e. images from all seasons of a year are included [5].

Table 1.List of PALSAR images

Acquisition date	Sensor Mode	Orbit/ Incidence Angle (center)
29 Mar 2007	Fine beam polarimetric (HH+HV+VH+VV)	Ascending/ 24.1°
14 May 2007	Fine beam polarimetric (HH+HV+VH+VV)	Ascending/ 23.8°
27 Jun 2007	Fine beam dual polarization (HH+HV)	Ascending/ 38.7°
27 Sep 2007	Fine beam dual polarization (HH+HV)	Ascending/ 38.7°
14 Nov 2007	Fine beam polarimetric (HH+HV+VH+VV)	Ascending/ 23.9°

All PALSAR images were ordered in the processing level of 1.1, which corresponds to a Single Look Complex product, which can be used in polarimetric SAR processing. The PALSAR images were processed using the PolSARpro software. The PolSARpro software can be freely downloaded from the ESA internet site under the terms of the GNU General Public License. The PolSARpro software can be used to calculate various polarimetric descriptors from SAR data. In this study, only a few polarimetric descriptors were used; namely, the famous Alpha-Entropy-Anisotropy decomposition [1]. Additionally, the backscattering coefficients (intensities) were calculated for each image as well as phase differences between polarization channels. Moreover, interferometric coherence between two dual polarization images were calculated using the Earthview InSAR software by MDA. The descriptors derived from the SAR images are listed in Table 2.

Table 2. Descriptors derived from PALSAR images.

Descriptor	Remark
HH backscattering	
HH/HV phase difference	
HH/VV phase difference	Quad pol only
HV backscattering	
HV/VV phase difference	Quad pol only
VV backscattering	Quad pol only
Alpha	
Entropy	Quad pol only
Anisotropy	Quad pol only
Interferometric coherence (HH and HV)	Dual pol only

Then, all input PALSAR images were georeferenced using the Erdas Imagine software into the Finnish Map Coordinate System (UTM, Zone 35 North), in which ancillary data already existed. In the case of dual polarization images, 16 well-defined Ground Control Points (GCPs) were used and the resulting RMS errors were 0.3 and 0.4 pixels in the range and azimuth directions respectively. Similarly, quad polarization images were georeferenced using 16 GCPs, and in this case the RMS errors were 0.3 and 0.8 pixels (range and azimuth). The output images were visually compared with digital maps and a very good agreement was observed.

ALS data was used as reference information. ALS data was collected in 2006 using Optech ALTM 3100 airborne laser scanner. The point density was at minimum 3/m^2, and all points contained height values of both first and last pulse. From the laser scanning data a Canopy Height Model (CHM) was created. CHM values were calculated by subtracting the Digital Surface Model (DSM) values from the Digital Elevation Model (DEM) values. The DEM was fetched using ground points only. The DSM was created by fetching all the measurement points that have reflected from each land cell and by giving the highest z co-ordinate of these points as the value of the corresponding matrix cell. CHM calculation was carried out in a 1x1 meter grid.

Next, 111 test stands consisting of visually uniform forest were manually digitized using LIDAR CHM as a background image. Examples of test stands are represented in Fig. 2.

Figure 2. Example of LIDAR CHM and test stands (White corresponds to ground level and dark green is approximately 35m above ground).

Because the PALSAR images and LIDAR CHM were georeferenced very accurately, it was possible to calculate stand-wise attributes from the CHM data and PALSAR images. The CHM values corresponds to the Above Ground Volume (AGV) of the stands. Even though, AGV is not directly related to the stem volume, it can be used to estimate stem volume relatively accurately [3][7].

3. RESULTS

The stand-wise values of PALSAR backscattering amplitude, dual polarization coherence, polarimetric descriptors, and CHM AGVs were analysed using regression analysis. To be more precise, a forward stepwise regression analysis was used in order to find the most important PALSAR image descriptors, which can be used to estimate the above ground biomass of forests.

In the case of dual polarization images the following regression model was obtained:

$$AGV_{ref} = a_0+a_1D_1+a_2D_2+a_3D_3+a_4D_4 \quad (1)$$

where AGV_{ref} is the above ground volume estimate from LIDAR CHM, D_1 is HV amplitude in 27 June 2007, D_2 is alpha from the polarimetric decomposition in 27 June 2007, D_3 is HH amplitude in 27 September 2007, D_3 is alpha from the polarimetric decomposition in 27 September 2007, and a_0-a_4 are the coefficients of the regression model. The coefficient of determination (R^2) of the model was 0.36, which implies relatively low correlation between the predictors and reference values.

Then, interferometric coherence between dual polarization images was introduced into the regression analysis. Then, the following model was obtained:

$$AGV_{ref}=a_0+a_1D_1+a_2D_2+a_3D_3+a_4D_4+a_5D_5 \quad (2)$$

where the predictors D_1-D_4 are the same as in the equation (1), but D_5 is interferometric coherence in HV polarization images between 27 Jun 2007 and 27 Sep 2007. The addition of HH coherence did not increase the estimation accuracy; therefore, it was not used in the regression modelling. By adding the interferometric coherence into the regression analysis the coefficient of determination increased to 0.53 (see Fig. 3).

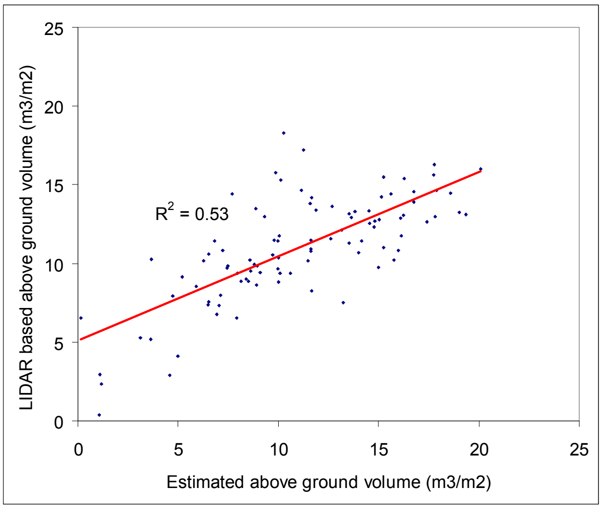

Figure 3. Line fit plot of regression analysis in case of dual polarization PALSAR images.

Similar forward step-wise regression analysis was carried out in the case of quad polarization images as well. The following regression model was achieved:

$$AGV_{ref} = a_0+a_1D_1+a_2D_2+a_3D_3+a_4D_4+a_5D_5 \quad (3)$$

where D_1 is alpha from polarimetric decomposition in 14 November 2007, D_2 is VV amplitude in 14 May 2007, D_3 is entropy from polarimetric decomposition in 29 March 2007, D_4 is HV/VV phase difference in 14 November 2007, D_5 is HH/VV phase difference in 29 March 2007. In the case of quad polarization images the R^2 value of 0.72 was obtained, which is clearly better that in the case of dual polarization images. The line fit plot of the regression analysis is represented in Fig. 4.

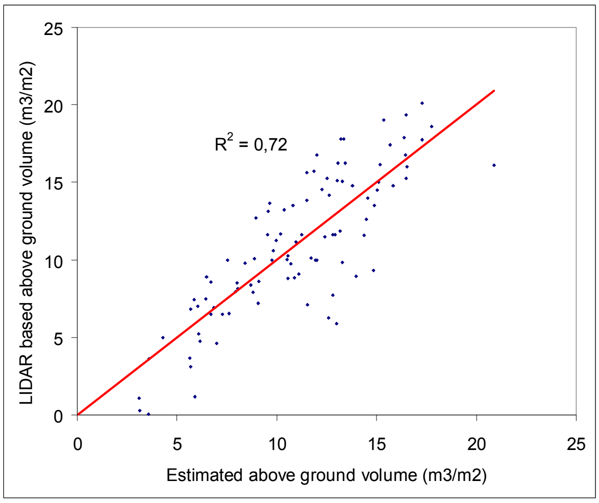

Figure 4. Line fit plot of regression analysis in case of quad polarization PALSAR images.

Finally, the regression models (Eqs. 2 and 3) were used to estimate the above ground volume for the rest of the test area. The quad polarization images covered the test area only partially. Therefore, it was not possible to produce quad polarization estimation for the whole test area. However, a smaller area is presented in Fig. 5. The area shown in Fig. 5 is the same as in LIDAR CHM example in Fig. 2. One can see clear similarities between the maps implying moderate estimation capability. The spatial resolution of PALSAR based map is naturally worse than in the case of LIDAR CHM.

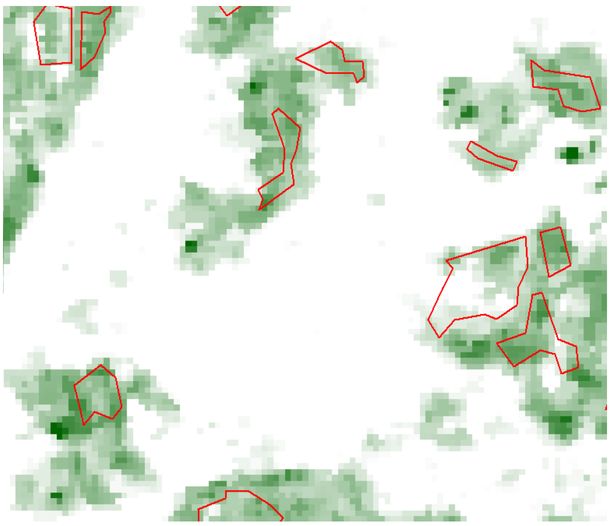

Figure 5. Estimated AGV using Quad Pol PALSAR images (White corresponds to ground level and dark green is approximately 35m above ground level).

On the other hand, the dual polarization images covered nearly the entire test area. The dual polarization based AGV map is represented in Fig. 6. Even though, the R^2 value was quite low in the case of dual polarization images, one can see at least the locations of the open areas (agricultural fields mainly) and the forested areas. However, the variation in the forested areas is quite low indicating poorer biomass estimation capability than in the case of quad polarization images.

Figure 6. Estimated biomass using the best regression model Quad Pol PALSAR. (White corresponds to ground level and dark green is approximately 35m above ground level).

4. CONCLUSIONS

It has been shown previously in many studies, that SAR images can be used to extract forest biomass related information. ALOS PALSAR uses L band microwaves, which are in general more suitable in case of forests than C or X bands if only the amplitude of backscattering is considered. Moreover, PALSAR is able to capture quad polarization images, which most likely enhance the estimation capability when compared to single polarization systems. In this study, the forest biomass estimation capability of PALSAR images was analyzed using small-footprint ALS points as reference data, which provides very good estimations of stem volume. The results of this study showed that the PALSAR based estimation seems possible, even though the test area was known to be a challenging one (consisting of natural mized forest with moderate terrain relief). R^2 values of 0.53 and 0.72 were obtained for the AGV estimation, in the cases of dual and quad polarization images respectively. Additionally, it was possible to use the regression models to estimate AGV maps for a larger area; however, validation of these maps was not possible to carry out.

5. ACKNOWLEDGMENT

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