ALOS Palsar Data in Boreal Forest Monitoring and Biomass Mapping

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Abstract

Polarimetric Palsar data were ortho-rectified for analysis of polarimetric signatures of forested stands. A strong positive correlation of 0.93 was found between Palsar HV amplitude and forest stem volume in stands with a stem volume of 150 m^3/ha or below. For HH data, the correlation coefficient was 0.82.

Key words: Forest, biomass, SAR, Boreal forest, Palsar, ALOS.

1. INTRODUCTION

Information on forest biomass and its temporal variation are needed for reinforcement of sustainable forestry and monitoring of international treaties like the Kyoto protocol of the UN Framework Convention on Climate Change. Geo-information on forest resources are also needed by forest industries. ALOS/Palsar, and possibly other new polarimetric SAR sensors, can be considered as promising instruments for obtaining this information.

Project NewSAR was launched by VTT, Helsinki University of Technology, and Finnish Geodetic Institute to study the utilization techniques for data from the novel SAR sensors. This paper focuses on the activities of VTT in studies aiming at forestry applications and change detection. Two ALOS AO projects (ESA-3557: Forest biomass mapping and monitoring and ESA-3713: Nuclear repository monitoring) were included in the ALOS Aden campaign, which is coordinated by the European Space Agency ESA.

2. MATERIALS AND METHODS

2.1. Study Sites and Ground Data

The main forest study site was in Heinavesi (center: 62°17' N, 28°26' E) in eastern Finland. This site is gently hilly. Forests are mainly pine forests or spruce-dominated mixed forests (main species Scots pine *Pinus sylvestris*, Norway spruce *Picea abies*, and birch *Betula pendula*, *Betula pubescens*). Stem volume ranges from 0 to 437 m^3/ha. The forest owner UPM Kymmene provided stand-wise forest inventory ground data for an area of 1100 ha.

Another forest study site was in Kuortane (center: 62°49' N, 23°32' E) in western Finland. The Kuortane site is almost flat. Forests are mainly spruce-dominated mixed forest. Stem volume ranges from 0 to 314 m^3/ha. The main ground reference data in the Kuortane site was the land cover map made by the Finnish Environment Institute (SYKE) in preparation of the Corine 2000 land cover map. Stand-wise forest inventory ground data (2600 ha) were obtained from "Etelä-Pohjanmaan Metsäkeskus" for the Kuortane site due to the missing polarimetric Palsar acquisitions in spring 2007 in the Heinavesi site.

Table 1. Palsar scenes used.

Site	Scene ID	Date	Mode	Off-N
Heinavesi	ALPSRP043141260	2006-11-15	Pol	9.7
Heinavesi	ALPSRP073631240	2007-06-12	Dual	34.3
Heinavesi	ALPSRP080341240	2007-07-28	Dual	34.3
Kuortane	ALPSRP042561260	2006-11-11	Pol	21.5
Kuortane	ALPSRP062691260	2007-03-29	Pol	21.5
Kuortane	ALPSRP069401260	2007-05-14	Pol	21.5
Kuortane	ALPSRP075821250	2007-06-27	Dual	34.3

A third study site was planned in Olkiluoto nuclear power plant site for change detection studies (the construction of a new reactor guarantees lots of man-made changes in the site), but this site was in a gap between adjacent polarimetric scenes. Change detection studies were then focused on the Kuortane forest site.

Digital elevation models (DEM) with a pixel spacing of 25 m (elevation RMSE, Residual Mean Square Error, about 2 m) were purchased from the Finnish Land Survey for both Heinavesi and Kuortane sites.

2.2. Palsar Data

Tab. 1 shows the Palsar scenes used. The primary site in Heinavesi was covered partly in the first polarimetric scene acquired on 15 November 2006. As the nominal off-nadir angle was only 9.7 degrees (the steepest polarimetric mode) and the site was at the near-range end of the scene, the site was dominated by surface scattering. The resolution was also poor (about 45 m in range). The Kuortane site had better Palsar coverage with three polarimetric acquisitions.

2.3. Pre-Processing Techniques

All ground data were in a well defined geodetic reference system (the Finnish "Kartastokoordinaattijärjestelmä"). The SAR scenes were in a variety of imaging geometries depending on the image acquisition mode and the orbit track. To simplify the use of ground data, ALOS/Palsar data were ortho-rectified to the geodetic reference system of the ground data.

Polarimetric scenes were ortho-rectified using a method described in [1]. Radiometric effects due to topography were corrected (normalized by projected pixel area) in connection with ortho-rectification. The scattering matrix data of level-1.1 polarimetric ALOS/Palsar products were converted to Stokes matrix form [2] and averaged over 3 lines in azimuth (along an orbit).

Geo-location in ortho-rectification was based on the equations presented in [3] and [4]:

$$I \quad : \quad \frac{x^2+y^2}{a^2}+\frac{z^2}{b^2}=1 \tag{1}$$

$$II \quad : \quad \frac{-2}{\lambda R}\left[v_x(x_s-x)+v_y(y_s-y)+v_z(z_s-z)\right]=f_D$$

$$III \quad : \quad \sqrt{(x_s-x)^2+(y_s-y)^2+(z_s-z)^2}=R \tag{2}$$

Here:

a	=	semi-major axis of the reference ellipsoid,
b	=	semi-minor axis of the reference ellipsoid,
x, y, z	=	coordinates of the point to solve,
x_s, y_s, z_s	=	coordinates of the satellite in the instance when the point was imaged,
v_x, v_y, v_z	=	satellite velocity components,
λ	=	radar wavelength,
R	=	the measured (slant) range,
f_D	=	Doppler frequency used in SAR processing.

Equation 1 was multiplied by a to improve numeric stability of the solution process:

$$I : \frac{x^2+y^2}{a}+\frac{az^2}{b^2}=a \tag{3}$$

Iterative solution of the geo-location equations was based on least-squares adjustment [5]:

$$\mathbf{l}=\left[\begin{array}{c} \frac{x^2+y^2}{a}+\frac{az^2}{b^2}-a \\ \frac{-2}{\lambda R}\left[v_x(x_s-x)+v_y(y_s-y)+v_z(z_s-z)\right]-f_D \\ \sqrt{(x_s-x)^2+(y_s-y)^2+(z_s-z)^2}-R \end{array}\right] \tag{4}$$

and

$$\mathbf{A}=\left[\begin{array}{ccc} \frac{\partial I}{\partial x} & \frac{\partial I}{\partial y} & \frac{\partial I}{\partial z} \\ \frac{\partial II}{\partial x} & \frac{\partial II}{\partial y} & \frac{\partial II}{\partial z} \\ \frac{\partial III}{\partial x} & \frac{\partial III}{\partial y} & \frac{\partial III}{\partial z} \end{array}\right] \tag{5}$$

Normal equations:

$$\mathbf{N} = \mathbf{A}^{\mathbf{T}}\mathbf{A} \tag{6}$$

$$\mathbf{U} = \mathbf{A}^{\mathbf{T}}\mathbf{l} \tag{7}$$

$$\mathbf{NX}+\mathbf{U} = \mathbf{0} \tag{8}$$

were solved for the improvements $\mathbf{X}$.

2.4. Analysis Techniques

Scatter plots were used to study the dependence of radar amplitude on forest biomass. Eigenvalue decomposition, the so called Cloude decomposition [6] was used to visually study the scattering mechanisms present in various types of forest. Polarimetric signatures [7] were plotted both for the total backscatter and for each of the three eigenvalue components to facilitate visual analysis of the polarimetric data.

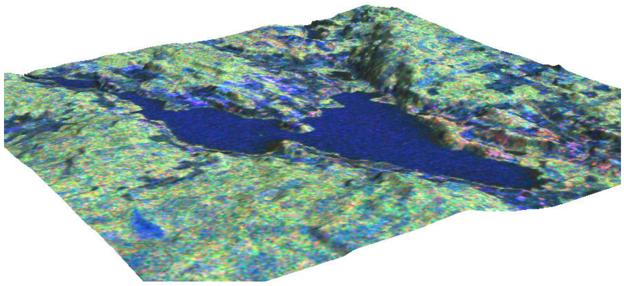

Figure 1. Polarimetric view of Kuortane 2007-05-14. Red = HH-VV, green = HV, blue = HH+VV. ©JAXA and METI 2007.

In change detection, various polarimetric and non-polarimetric change detection techniques [8] were applied to polarimetric Palsar scenes.

3. RESULTS

Ground control points were used to revise the geo-location data that had been computed from orbit data and Doppler frequency data of the Palsar scenes. This guaranteed the fit between Palsar data and DEM and ground data in the used datum. Scene to scene registration was obtained using correlation-based tie points between scenes of the same acquisition mode. Fig. 1 shows an example of ortho-rectified polarimetric Palsar scene (12.5-m pixel spacing, bi-linear resampling of 3-look Stokes data).

Starting with stand-wise averaged Stokes matrices, polarimetric signatures and their eigenvalue decompositions were computed for all forest stands over 2 ha in area (and more than 0 m^3/ha of stem volume) in the Kuortane site (scene 2007-05-14). Fig. 2 shows three selected stands of low, moderate, and high stem volume. In each stand, the left column is co-polarized signature and the right column the cross-polarized signature. The top row is the total signal, rows 2 to 4 the eigenvalue components 1 to 3 (in decreasing order of eigenvalue).

In the lowest-stem-volume stand (1 m^3/ha), the total signature resembles the signature of pure surface scattering. Very little is left after the first eigenvalue component. In the moderate-biomass stand (105 m^3/ha), the first component also resembles surface scattering, but slightly deformed (HH in the middle of the co-pol signature is higher than VV at the margins). The remaining two co-polar components have a tilted plane (like in the signature of right and left helix) superimposed with some undulation. In the third component, this undulation resembles the signature of dihedral scatterer both in co-pol and cross-pol signatures.

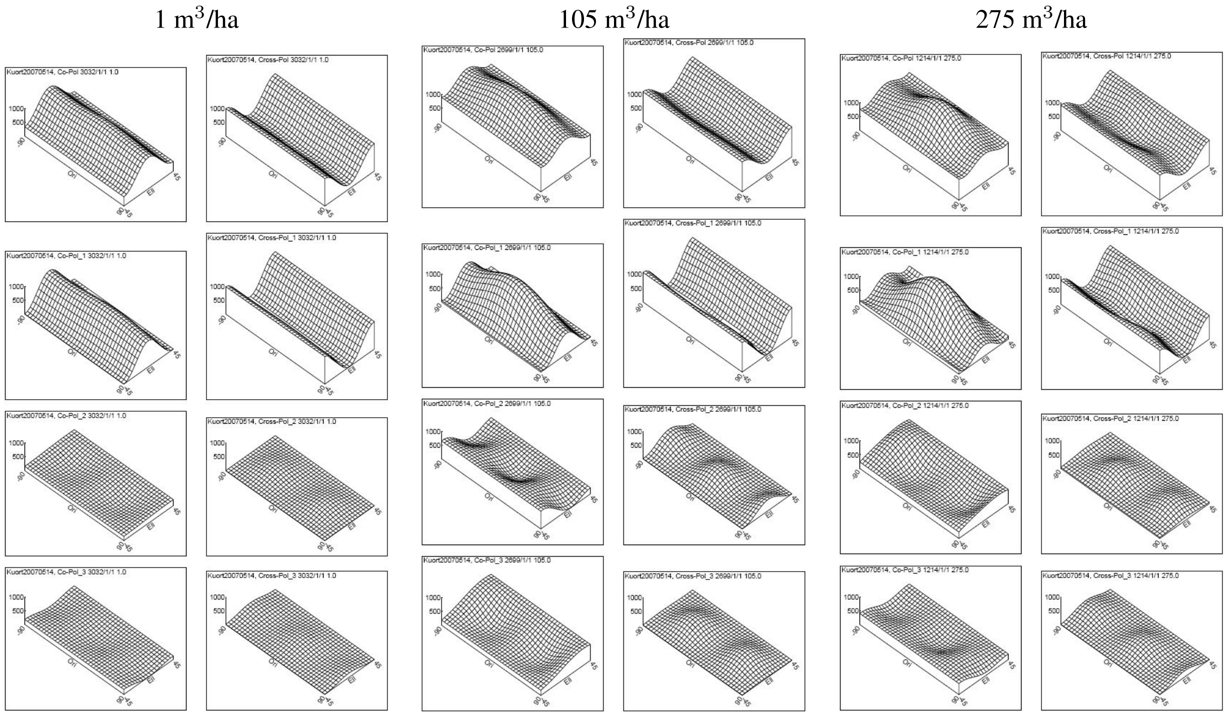

Figure 2. Polarimetric signatures and their eigenvalue decomposition (Cloude decomposition) for three stands in the Kuortane site (from left to right): 1, 105, and 275 m^3/ha, respectively.

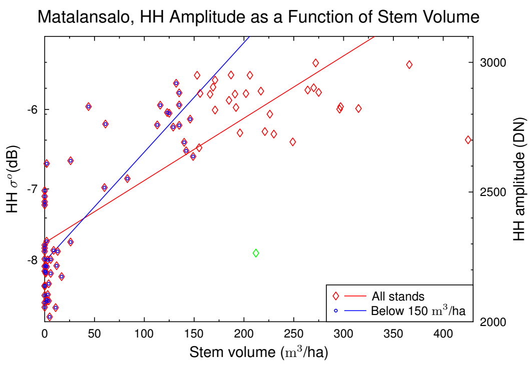

Figure 3. HH amplitude of Palsar/Dual-polarized data as a function of forest stem volume. The red and blue lines are regression lines. Heinavesi site, 2007-06-12.

The signature of the highest-biomass stand (275 m^3/ha) is similar to the moderate-biomass one. The co-pol difference (HH-VV) is larger, the handedness of the helix components is reversed between the 2nd and 3rd components, and the dihedral undulation is now in the 2nd component instead of the 3rd one.

Fig. 3 shows HH backscattering coefficient as a function of forest stem volume for stands over 2 ha (after erosion by one pixel of 12.5 m). The observation shown in green (212 m^3/ha) was a stand that had been clear-cut after the inventory in March 2007. This observation was ground-verified and left out from further analysis. Correlation coefficient was 0.82, both for the whole dataset and for the set of stands below 150 m^3/ha. This is very similar to the correlations obtained earlier [9] with JERS-1 data. The backscatter level of forest is also very similar to that of JERS-1. Fig. 4 shows the cross-polarized backscattering coefficient as a function of forest stem volume. Over the whole dataset, the correlation was 0.82. Limited to stands below 150 m^3/ha, the correlation rose to 0.93. The out-lier at 2 m^3/ha was a stand with a strong topography, mainly facing towards the radar. Here the radiometric correction of topographic effects has not made a sufficient correction. The reason for under-correction requires further studies.

As seen in figures 3 and 4 the amplitude-stem-volume relation saturates at approximately 150 m^3/ha. Fig. 5 shows a field photograph from a stand, which has about the L-band saturation limit of forest biomass. Stands with higher stem volume than this do not show significantly higher response in L-band SAR.

Polarimetric change detection methods [8] were studied in the Kuortane site. A technique called Wishart Diagonal change detection was among the most promising techniques.

In a comparison study of classification techniques [10], supervised Wishart classification using fully polarimetric data improved the overall classification performance by 5 percents compared to techniques that utilized amplitude data only.

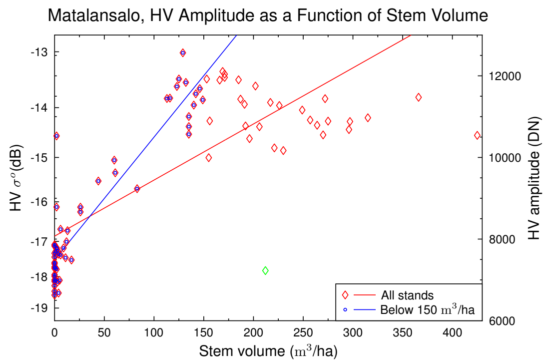

Figure 4. HV amplitude of Palsar/Dual-polarized data as a function of forest stem volume. Heinavesi site, 2007-06-12.

Figure 5. A pine stand with 155 m^3/ha.

4. DISCUSSION

Ortho-rectification of polarimetric Palsar data enabled the direct comparison of SAR and ground data. Radiometric effects of topography were strongly reduced by the radiometric correction, which did not introduce artefacts to polarimetric signatures.

Cross-polarized Palsar data showed higher correlation coefficients between SAR amplitude and forest stem volume than Palsar HH data and earlier JERS-1 SAR data. The saturation limit was very similar (about 150 m^3/ha) in both of these datasets.

ACKNOWLEDGMENTS

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