ALOS PALSAR calibration and validation activities in Sweden

Leif E.B. Eriksson(1)**, Gustaf Sandberg**(1)**, Johan E.S. Fransson**(2)**, Mattias Magnusson**(2)**, Lars M.H. Ulander**(1)

(1) Chalmers University of Technology, Department of Radio and Space Science, SE-41296 Göteborg, Sweden
E-mail: leif.eriksson@chalmers.se
(2) Swedish University of Agricultural Sciences, Department of Forest Resource Management, SE-901 83 Umeå, Sweden

Abstract
This paper gives an overview of activities and results from the Swedish part of the international calibration and validation efforts for ALOS PALSAR. Four large trihedral corner reflectors were deployed and the measured co-polar responses showed that the PALSAR system performed well and was stable over time. The cross-talk level was found to be lower than – 34.5 dB. Two different methods for estimation of Faraday rotation were tested and rotations of up to 3º were recorded. An evaluation of the possibilities to retrieve forest variables from PALSAR data has also been performed. The results indicate that clear-cuts can be detected and under favorable conditions the stem volume estimation accuracy for a single image was 30%.

Keywords: PALSAR, corner reflectors, Faraday rotation, stem volume, forest change detection.

1. INTRODUCTION

The Japanese satellite ALOS (Advanced Land Observing Satellite) was launched on 2006-01-24. After the commissioning phase the Japan Aerospace Exploration Agency (JAXA) initiated a worldwide calibration campaign together with several international partners to assess the data quality from the three onboard sensors. This paper focuses on the calibration and validation activities in Sweden and the results for one of the sensors, the Phased Array type L-band Synthetic Aperture Radar (PALSAR). The primary objective has been to investigate the radiometric calibration of the PALSAR instrument in high-resolution and polarimetric modes. The secondary objective was to develop and evaluate algorithms for retrieval of forest variables from PALSAR images. In addition to the calibration site, three more test sites were available for these activities. These were selected to collect SAR data over a broad range of forest conditions. Initial results for change detection and stem volume estimation will be presented.

2. DATA AND METHODS

2.1. Calibration site

The Remningstorp calibration site is located in the south of Sweden (Lat. 58°30' N, Long. 13°40' E). The forest holding covers about 1,200 ha of productive forest land. The prevailing tree species are Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and birch (*Betula* spp.). The dominant soil type is till (i.e. a mixture of glacial debris) with a field layer consisting of different herbs, blueberry (*Vaccinium myrtillus*), and narrow-leaved grass (e.g. *Deschampsia flexuosa*). In denser old spruce stands the field layer is absent. The ground elevation is moderately varying between 120 and 145 m above sea level.

2.2. Corner reflectors

Four large trihedral corner reflectors were built and deployed on open fields in Remningstorp. The trihedrals have a side length of 5 m, which corresponds to a theoretical radar cross section of 47 dBm^2. Each trihedral can be rotated to be correctly directed both for ascending and descending orbit passes and the elevation angle can be adjusted to fit a wide range of incidence angles. A more detailed description of the construction and deployment of the trihedrals can be found in [1]. To evaluate the calibration of the cross-polarizations, three dihedral reflectors were also deployed in the same area. These dihedrals have a theoretical radar cross section of 36 dBm^2 and were rotated with a 45° angle around the line of sight to maximize the return in cross-polarization.

The official calibration and validation phase started in April 2006 and ended 2006-10-24 when ALOS was declared operational. After this the calibration activities in Sweden were gradually reduced. In December 2006 the dihedrals were removed and the trihedrals were left with an azimuth angle for ascending orbits, but without being elevated. In January 2007 one trihedral was damaged by a storm and was taken out of operation. This and one of the other trihedrals were removed from Remningstorp at the end of June 2007, but two trihedrals remain at the calibration site.

2.3. Forest data

Forest data for Remningstorp consisted of 56 stands representation of the entire stem volume range. The field inventory was done according to prescriptions in the forest management planning package (FMPP) [2] developed by the Swedish University of Agricultural Sciences. The FMPP includes an objective and unbiased method for estimation of forest variables like stem volume, tree height and tree species composition at stand level from measurements of individual trees. The inventoried stands hold stem volumes in the range of 45-

650 m^3 ha^{-1} (average 325 m^3 ha^{-1}). The stand size varied between 0.7-11.2 ha with an average of 3.0 ha.

2.4. PALSAR data

During the period May 2006 to November 2007, 37 PALSAR scenes were acquired over Remningstorp. At 17 of these occasions the corner reflectors were directed towards the passing satellite [3]. The analysis has been focused on three different PALSAR modes, FBS34.3, FBD34.3, and PLR21.5, where FBS stands for Fine Beam Single polarization (HH), FBD for Fine Beam Dual polarization (HH and HV), and PLR for polarimetric. The numbers indicate the PALSAR look angles. A majority of the scenes with directed reflectors were PLR21.5 and FBS34.3. These time series allowed a study of the temporal stability.

Images that were used to validate forestry applications were geo-coded using the GAMMA software developed by GAMMA Remote Sensing Research and Consulting AG. In the geo-coding procedure a coarse 50×50 m DEM provided by the Swedish National Land Survey was used. After multi-looking, the pixel spacing for the FBS34.3 images was set to 15 m and for FBD34.3 and PLR21.5 to 25 m. Seven FBS34.3 images acquired between June 2006 and February 2007 were selected to investigate the possibility to detect clear-cuts and wind-thrown forest. The same images were also used to assess retrieval of stem volume, but this assessment also included four FBD34.3 images from summer 2007 and seven PLR21.5 images from 2006.

2.5. Methods

Slant range images in single look complex format subject to polarimetric but not radiometric calibration (processing level 1.1) were used in the calibration analysis. After radiometric calibration the integrated energy from each reflector was calculated using a method described in [4], including estimation of the measurement accuracy (standard deviation of RCS) determined mainly by the signal to clutter ratio. The methods that were used for estimation of crosstalk and Faraday rotation are described in [3, 5]. All calibration, calculations and extraction of parameters were performed in Matlab.

To investigate the possibility to detect forest changes, a controlled field experiment was conducted at the Remningstorp test site. The experiment consisted of 8 old spruce dominated stands with a size of about 1.5 ha. The treatments were carried out on 4 stands and the remaining stands were left untreated for reference. For two of the treated stands the trees were felled in 35° (southwest-northeast direction) and two in 80° (west-east direction). The felling activities took place in mid August 2006 and the trees were left until late December, just prior to an acquisition on 2006-12-31. The forest activities were performed to ensure that PALSAR images were acquired prior to (2 images), during (2 images), and after treatment (3 images). The backscattered intensities for each group of FBS34.3 images were averaged. Hence, the analyzed intensities representing old forest and wind-thrown forest were based on two images respectively, but three images were averaged for the clear-cuts.

To assess retrieval of stem volume the average backscattered intensity from each forest stand was measured. An exponential model including scattering components from the ground and vegetation was used:

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

where $\sigma°_{for}$ is the average backscatter intensity from the forest stand in dB, and $\sigma°_{gr}$ and $\sigma°_{veg}$ are the backscatter from the ground and the vegetation, respectively. V is the standwise 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, σ^2_ε). Using a training dataset of backscatter and stem volume from field measurement, the unknown coefficients $\sigma°_{gr}$, $\sigma°_{veg}$, and β in (1) were estimated by means of least squares criterion through non-linear regression analysis. By inverting (1), standwise stem volume was estimated for a test dataset using the corresponding backscatter measurement, $\sigma°_{for,meas}$. The number of stands available was divided into two datasets, one for establishing the relation between backscatter and stem volume and one for evaluation of stem volume estimation. The stands were sorted according to ascending stem volume and each dataset was assigned every second stand.

3. RESULTS

3.1. Calibration

At HH polarization the integrated energy from the trihedral reflectors varies less than 0.6 dB for the FBS34.3 scenes and at PLR21.5 the variations are within 0.7 dB both for HH and VV polarization. For FBS34.3 the signal to clutter ratios vary between 39.7 dB and 44.7 dB and the peak to side lobe ratio is better than -17.0 dB in azimuth and -11.6 dB in range. The resolution is 4.7 m in slant range and 4.4 m in azimuth. For PLR21.5 the signal to clutter ratios vary between 33 dB and 39 dB for HH polarization and between 32 dB and 38 dB for VV polarization. The values for peak to side lobe ratios and resolutions are approximately the same for PLR21.5 and FBS34.3, except for the range resolution of about 9.5 m.

The crosstalk levels remaining after JAXA's polarimetric calibration were estimated using PLR21.5 images from 2006-10-19 and 2006-12-04. These images were acquired in ascending orbit, corresponding to a local time of 10:57 pm, when the total electron content (TEC) levels in the ionosphere were expected to be low. This assumption was confirmed by TEC maps from the International GNSS Service (IGS) that show 2.5 TEC units (TECU) for the first date and 1.4 TECU for the second date. The crosstalk level was found to be below -34.5 dB, which led to the conclusion that no crosstalk correction had to be made on the images.

The Faraday rotation angle was estimated for each of the eight dates for which polarimetric data were available. Five different estimates were made, one using distributed targets, as proposed by Bickle and Bates [6], and the others using the four trihedral responses. The results are presented in Fig. 1. For more details, see [3, 5].

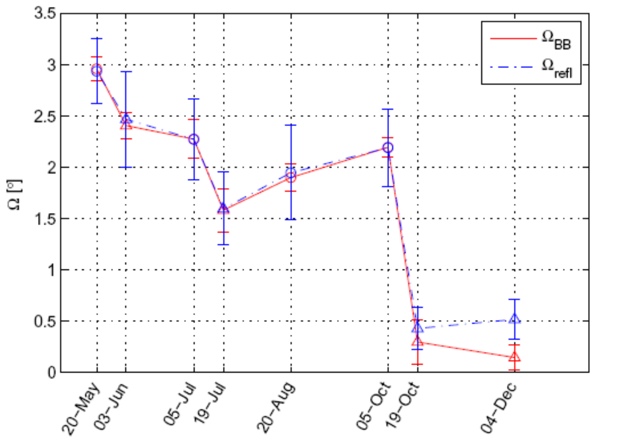

Figure 1. Time series of Faraday rotation estimates for PLR21.5. Ω_{BB} is estimated using distributed targets and Ω_{refl} with the trihedrals. The vertical lines show a 95% confidence interval for each estimate assuming a normal distribution for the errors. Every descending pass (morning pass) is marked with a circle, while the ascending passes (night passes) are marked with triangles.

3.2. Forest change detection

Analysis of variance (ANOVA) was used for the statistical analysis. The null hypothesis tested was that the expected backscattering coefficient values are the same for the treatment and reference stands. This hypothesis could be strongly rejected for the winter ($p < 0.001$) and fall ($p = 0.003$) seasons, but not for the summer season ($p = 0.147$). This implies that differences seen in Fig. 2 are real and not coincidental. The drop in backscattering coefficient between the reference and the clear-felled stands (winter images) was on average 2.1 dB, and the corresponding decrease between the reference and the artificially wind-thrown stands (fall images) was 1.6 dB. Moreover, the difference in backscattering coefficient between the averaged summer and winter images was found to be 2.7 dB for the treated stands, whereas the corresponding difference for the reference stands was 1.0 dB. For more details, see [7].

3.3. Stem volume estimation

The backscatter has been plotted against stem volume from field measurement for all of the seven FBS34.3, four FBD34.3 and seven PLR21.5 images. The dynamic range, i.e. the difference between the backscatter from sparse and dense forest stands, is about 2-3 dB. Two of the FSB34.3 images were acquired during frozen conditions on 2007-01-29 and 2007-02-15. These two images do not seem to give the expected saturation of the backscatter for higher stem volumes. The dynamic range is larger and the spread around the model curve is smaller (see Fig. 3).

The estimated stem volumes were then plotted against stem volumes from field measurements. The stem volume estimation accuracy for the best FBS34.3 image was found to be 30%, corresponding to 97 m^3 ha^{-1} (see Fig. 4). For the investigated FBD34.3 and PLR21.5 images, the stem volume could not be estimated for all stands in the test dataset. This is because the backscatter measurements are outside the modelled values from (1), i.e. if $\sigma°_{for,meas} > \sigma°_{veg}$ or $\sigma°_{for,meas} < \sigma°_{gr}$. The root mean square errors (RMSE) for the best FBD34.3 images were found to be in the range of 76-78%. For the best PLR21.5 images the corresponding RMSEs were in the range 62-81%. For more details, see [8]

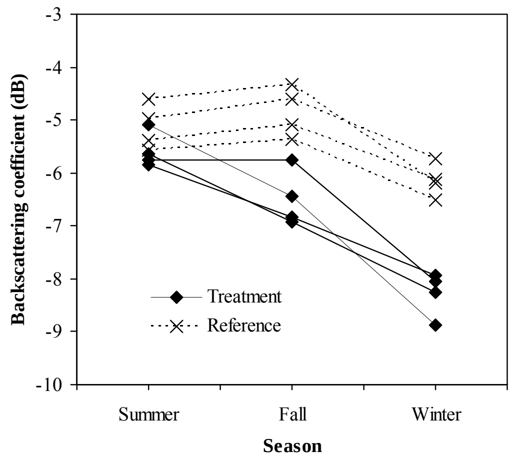

Figure 2. Backscattering coefficient from PALSAR FSB34.3 images (look angle 34.3°, HH-polarization) for 4 reference and 4 treated stands with old forest, artificially wind-thrown forest, and clear-felled forest.

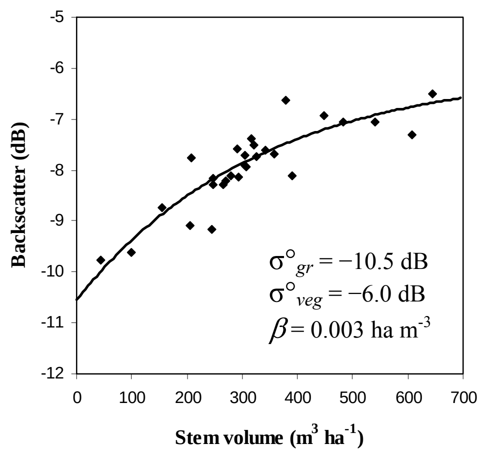

Figure 3. ALOS PALSAR FBS 34.3° HH, 2007-01-29.

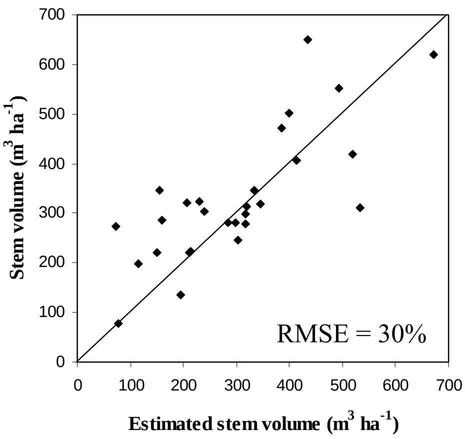

Figure 4. ALOS PALSAR FBS 34.3° HH, 2007-01-29.

4. DISCUSSION AND CONCLUSIONS

The measurements of the co-polarized reflector responses from the FBS34.3 and PLR21.5 PALSAR images show that the system is stable over time. The remaining crosstalk in the level 1.1 data delivered by JAXA was below -34.5 dB, which is low enough that no crosstalk correction was necessary. This simplified the estimation of Faraday rotation and rotations of up to 3° were measured. Correlation between estimated Faraday rotation and measured TEC values was also shown [5].

The results indicate that ALOS PALSAR FBS34.3 images can be used for detection of clear-felled stands equal to or larger than 1.5 ha. The difference in backscattering coefficient between the reference and the clear-felled stands during the winter season was calculated as the average value of three images. Among those, two images were acquired at weather conditions with temperatures below zero and one at unfrozen conditions, dated 2006-12-31. By excluding the latter image in the calculations, the difference changed from 2.1 dB to 2.7 dB. This emphasizes the importance of averaging or comparing SAR images acquired from the same season at the same weather conditions.

For stem volume estimation, most images with HH-polarization, including FBS34.3, FBD34.3 and PLR21.5, give results in line with previous studies for L-band data from the JERS-1 satellite. However, the two FBS images acquired on 2007-01-29 and 2007-02-15 require a closer analysis. In both cases the backscatter does not show any saturation with increasing stem volume. This is a behaviour that deviates from the general opinion that at L-band there is no, or very low, sensitivity to differences in stem volume for dense mature forest. The main difference between the images from 2007-01-29 and 2007-02-15 and the other images is that they were acquired during the winter season. To get a deeper understanding of the obtained results, meteorological data registered at the test site need to be analyzed. It is also desirable to include more acquisitions from similar conditions to evaluate if the results can be repeated. In addition to Remningstorp, a test site in northern Sweden will also be included in the analysis.

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References

[1] L. M. H. Ulander, L. Eriksson, G. Smith-Jonforsen, J. E. S. Fransson, and H. Olsson, "ALOS calibration and validation activities in Sweden," presented at IGARSS 2006, Denver, CO, USA, 2006.

[2] B. Jonsson, J. Jacobsson, and H. Kallur, "The forest management planning package. Theory and application," *Studia Forestalia Suecica*, vol. 189, pp. 1-56, 1993.

[3] L. E. B. Eriksson, G. Sandberg, L. M. H. Ulander, G. Smith-Jonforsen, B. Hallberg, K. Folkesson, J. E. S. Fransson, M. Magnusson, H. Olsson, A. Gustavsson, and B. Flood, "ALOS PALSAR calibration and validation results from Sweden," presented at IGARSS 2007, Barcelona, Spain, 2007.

[4] L. M. H. Ulander, "Accuracy of using point targets for SAR calibration," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 27, pp. 139-148, 1991.

[5] G. Sandberg, L. E. B. Eriksson, and L. M. H. Ulander, "Faraday rotation measured in polarimetric PALSAR images compared with theoretical expectations," presented at Advanced SAR Workshop 2007, Vancouver, Canada, 2007.

[6] S. H. Bickle and R. T. Bates, "Effects of magneto-ionic propagation on the scattering matrix," *Proc. IRE*, vol. 53, pp. 1089-1091, 1965.

[7] J. E. S. Fransson, M. Magnusson, H. Olsson, L. E. B. Eriksson, G. Sandberg, G. Smith-Jonforsen, and L. M. H. Ulander, "Detection of Forest Changes Using ALOS PALSAR Satellite Images," presented at IGARSS 2007, Barcelona, Spain, 2007.

[8] L. E. B. Eriksson, M. Magnusson, J. E. S. Fransson, G. Sandberg, and L. M. H. Ulander, "Stem volume estimation for boreal forest using ALOS PALSAR," presented at 5th International Symposium on Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications, Bari, Italy, 2007.