Simulated biomass retrieval from the spaceborne tomographic Saocom-CS mission at L-band

SIMULATED BIOMASS RETRIEVAL FROM THE SPACEBORNE TOMOGRAPHIC SAOCOM-CS MISSION AT L-BAND

Erik Blomberg[1], **Maciej J. Soja**[1], **Laurent Ferro-Famil**[2], **Lars M. H. Ulander**[1], **and Stefano Tebaldini**[3]

[1]*Dep. of Earth and Space Sciences, Chalmers University of Technology, 412 96 Gothenburg, Sweden, blombere@chalmers.se*
[2]*IETR UMR CNRS 6164, Université de Rennes-1, 35042 Rennes, France, Laurent.Ferro-Famil@univ-rennes1.fr*
[3]*Dipartimento di Electronica, Informazione e Bioingegneria, Politecnico di Milano, 20133 Milano, Italy, stefano.tebaldini@polimi.it*

ABSTRACT

This paper presents an evaluation of above-ground biomass (ABG) retrieval in boreal forests using simulated tomographic synthetic-aperture radar (SAR) data corresponding to the future SAOCOM-CS (L-band 1.275 GHz) mission. Using forest and radar data from the BioSAR 2008 campaign at the Krycklan test site in northern Sweden the expected performance of SAOCOM-CS is evaluated and compared with the E-SAR airborne L-band SAR (1.300 GHz). It is found that SAOCOM-CS data produce retrievals on par with those obtained with E-SAR, with retrievals having a relative RMSE of 30% or less. This holds true even if the acquisitions are limited to a single polarization, with HH results shown as an example.

Key words: Biomass, Carbon Cycle, Forestry, Global Vegetation, Tomography.

1. INTRODUCTION

SAOCOM-CS is a proposed companion satellite to the Argentinian SAOCOM-1B L-band SAR mission under evaluation by the European Space agency (ESA). The addition of a passively receiving companion flying in formation would enable single-pass interferometric and multi-pass tomographic data to be acquired and the feasibility of this configuration was the subject of a recent study. Part of this work was an investigation into whether SAOCOM-CS would be capable of supporting the mapping of boreal forest biomass [1].

Airborne L-band SAR has shown good sensitivity to biomass for the somewhat sparser forests typical of northern latitudes [2, 3, 4]. A spaceborne sensor provides the advantage of global coverage but also imposes design limitations which reduce performance compared to an airborne SAR. Resolving the vertical distribution of the measured backscatter through tomographic processing serves as a tool to lessen the impact of the reduced performance and counteract other effects, such as shadowing and ground clutter contributions, which adversely affect retrievals from SAR images.

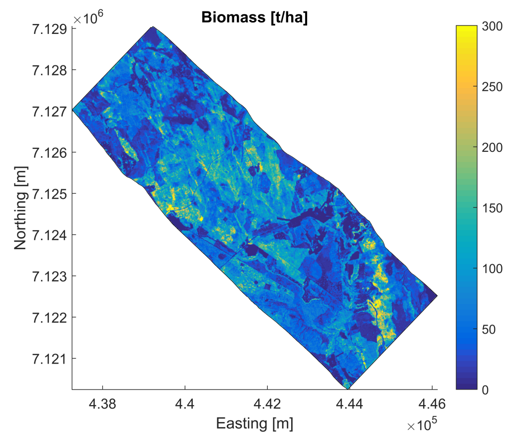


Figure 1: A biomass map of the area covered by the BioSAR 2008 radar acquisitions. This map is based on high resolution airborne lidar data and a stratification based on areal photography, calibrated by in situ measurements.

2. BIOSAR 2 DATA

Both the reference biomass data (Fig. 1) and the SAR data used for this analysis were collected over the Krycklan river catchment during the BioSAR-2 campaign in 2008. This test area, located in the north of Sweden, has a varied topography with ground slopes up to 21° and contains boreal forest comprised mainly of Norway spruce and Scots pine. During part of the airborne data collection with DLRs E-SAR system and with future tomography studies in mind, L-band SAR images were obtained from two different headings (NE-looking and SW-looking) using six baselines each on 15 October 2008 [2].

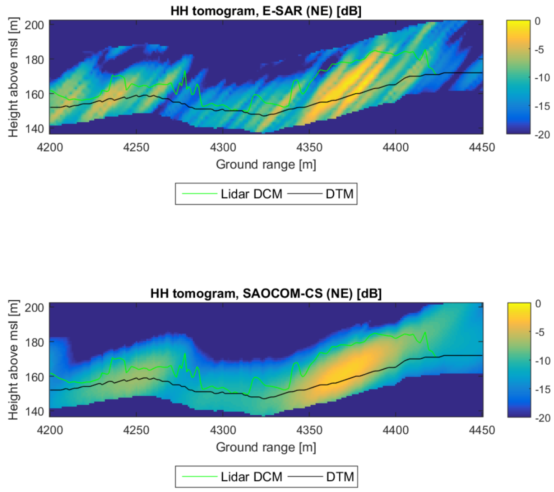


Figure 2: Example NE-looking HH tomograms for E-SAR (top) and SAOCOM-CS (bottom) showing the reduced resolution of the later. A lidar derived forest canopy profile (green line) and the local topography (black line) are included for reference.

Two sets of tomographic data have been generated from the original SAR images, with the first utilizing the full 94 MHz E-SAR bandwidth giving resolution of 2 m in range by 1 m in azimuth. The second set represents the performance expected of SAOCOM-CS, which is dictated by the maximum 50 MHz bandwidth of SAOCOM with considerations taken with regard to relevant factors such as the acquisition geometry. This results in a 10 m by 10 m ground resolution and vertical resolution of about 20 m [2, 1]. See Fig. 2 for a representative example of the tomographic data produced.

3. PARAMETERS AND MODELS

For the original E-SAR L-band intensity data the calibrated and slope-compensated parameter γ^0 is used [2, 5]. γ^0 has previously been shown to produce reasonable biomass retrieval performance at L-band [3, 4]. Two purely tomographic parameters were derived from the tomographic backscatter intensity $\beta^0(z)$: the ratio of volumetric backscatter originating from a height of 10 m and more above ground to the total backscatter, R_{vol}, and the intensity weighted-average scattering height, Z_{avg}, as given by Eq. (1) and Eq. (2).

$$R_{vol} = \frac{\int_{10\mathrm{m}}^{\infty} \beta^0(z)\,\mathrm{d}z}{\int_{-\infty}^{\infty} \beta^0(z)\,\mathrm{d}z} \tag{1}$$

$$Z_{avg} = \frac{\int_{-\infty}^{\infty} z\beta^0(z)\,\mathrm{d}z}{\int_{-\infty}^{\infty} \beta^0(z)\,\mathrm{d}z} \tag{2}$$

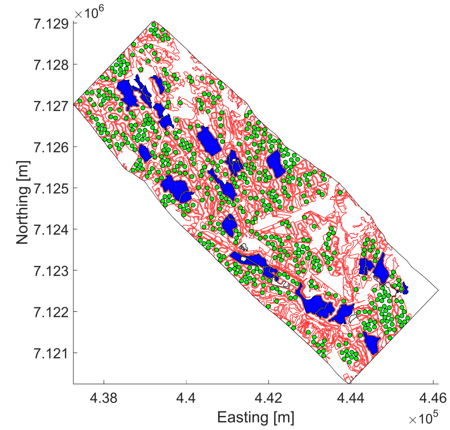


Figure 3: A map of the forest stands in Krycklan (red) with the circular plots used for training data (green) and the in situ stands used as validation data (blue).

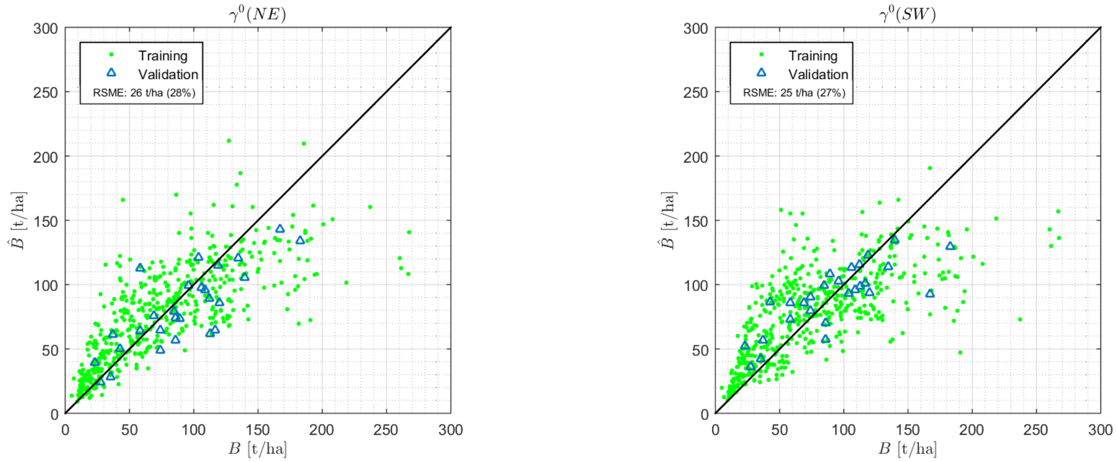
These parameters are only indirectly dependent on the original intensity values and were chosen to minimize dependence on radiometric calibration, incidence angle or local topography. $\gamma^0_{vol} = \gamma^0 \cdot R_{vol}$ is intended to display the potential for improvement with tomography by using portion of the SAR intensity originating from the forest volume. The models used for fitting of the training data incorporates linear combinations of the transformed polarimetric components, see Eq. (3) and Eq. (4). This choice is based on previous results for 2D-SAR data as well as a desire to minimize band-specific model adaptations [3].

$$\begin{aligned} \sqrt{\hat{B}} &= a_0 + a_1 I_{HH} + a_2 I_{VV} + a_3 I_{HV} \\ I &= \gamma^{0,dB}, \sqrt{R_{vol}}, \sqrt{Z_{avg}} \end{aligned} \tag{3}$$

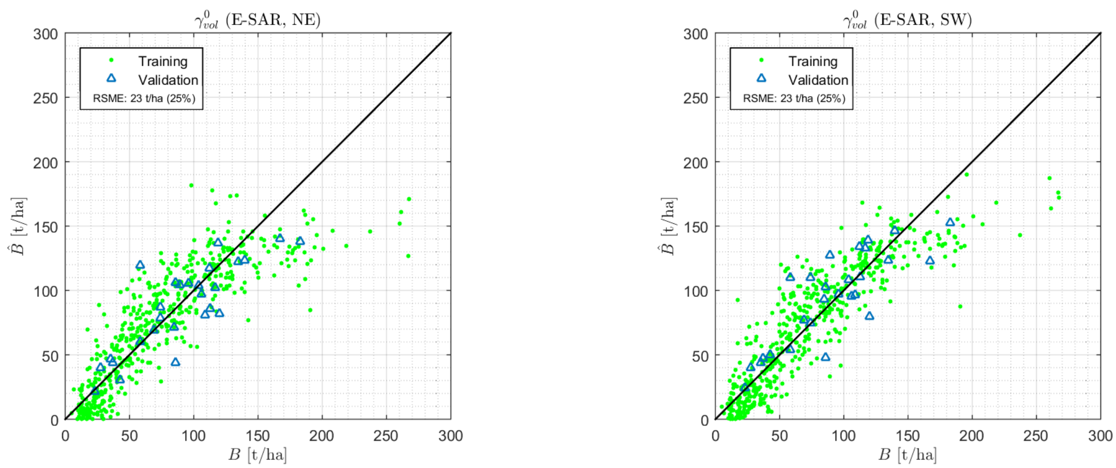
A model combining R_{vol} and Z_{avg} is also evaluated for a single polarization:

$$\sqrt{\hat{B}} = a_0 + a_1\sqrt{R_{vol,HH}} + a_2\sqrt{Z_{avg,HH}} \tag{4}$$

The data used for training are averages over 50-m radius circular plots placed within forest stands to represent homogenous forest and ground slope. Plot-level biomass values, ranging from 5 to 268 t/ha, are extracted from the biomass map shown in Fig. 1 on the preceding page. This map is based on high resolution lidar data calibrated by ground measurements. Stand-wise averages from a separate subset of forest stands for which detailed *in situ* measurements are available is used for model validation, see Fig. 3. All plots and *in situ* stands have minimum separation of 10 m to ensure that there is no spacial overlap of data.



(a) E-SAR: γ^0.



(b) E-SAR: γ^0_{vol}.

Figure 4: Retrievals based on E-SAR intensity data alone (γ^0, top row) and combined with E-SAR tomographic information (γ^0_{vol}, bottom row) for the two headings respectively.

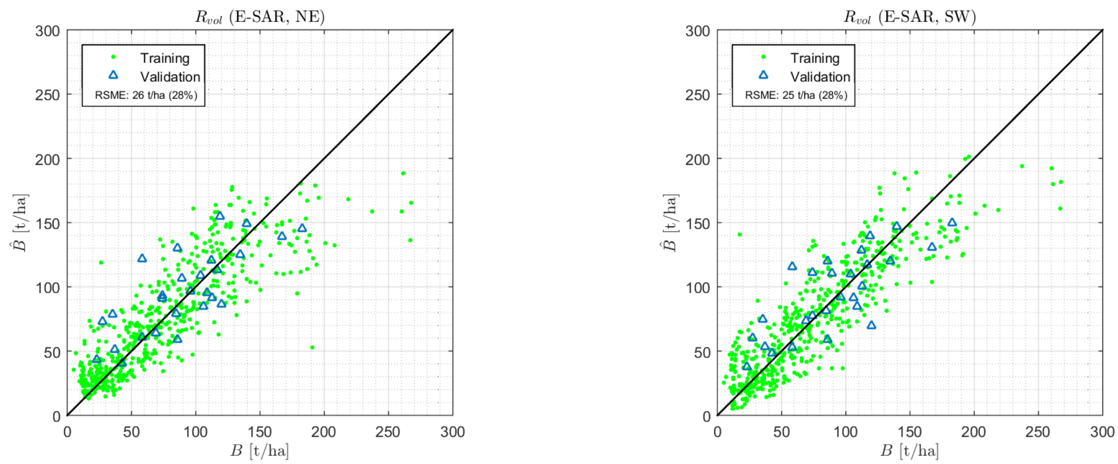
4. RESULTS AND DISCUSSION

Fig. 4 to Fig. 6 on the next page show the forest biomass retrievals obtained with the outlined parameters and models, with a summary of the statistics given in Tab. 1 on page 5. Results of fitting Eq. (3) on the previous page to the E-SAR γ^0 intensity data, seen in Fig. 4a, serve as a benchmark to which both E-SAR and SAOCOM-CS tomographic data are compared. The RMSE is 25 t/ha (26-27%) with no obvious differences between the two look directions. Both show an increasing spread with increasing biomass and possibly some underestimation for the highest biomass values.

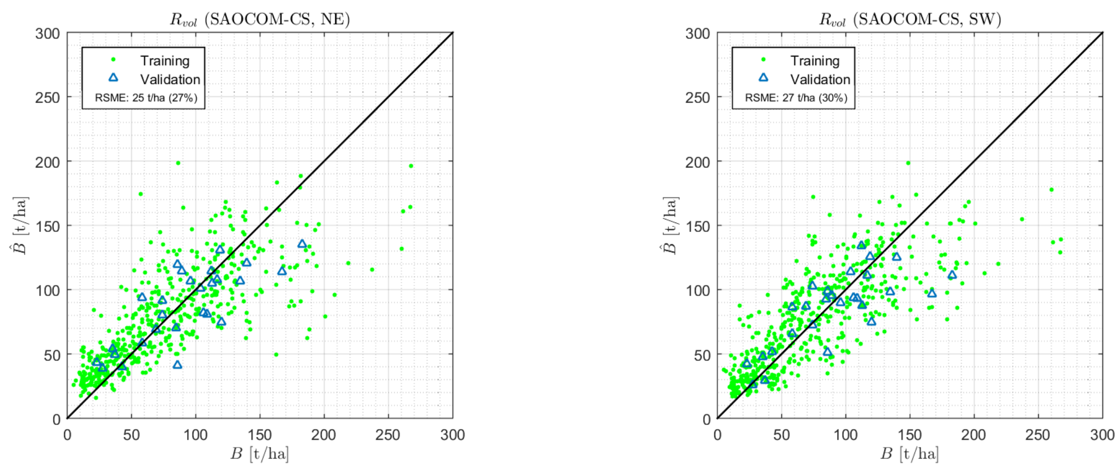
Including tomographic information result in retrievals with a smaller error and a much reduced spread in both training and validation estimates as seen in Fig. 4b. The RMSE is 23 t/ha (25%) and might be a slight underestimation for the smallest biomass values, which is expected due to the 10 m height cut off used to remove the ground backscatter contribution.

Fig. 5 on the following page and Fig. 7 on page 5 demonstrate that using tomographic information alone, while not performing quite as well as when retaining intensity information, is still on par with γ^0 retrievals for E-SAR with an RMSE of 25-27 t/ha (27-30%) and 27-28 t/ha (30%) for SAOCOM-CS R_{vol} and Z_{avg} respectively. The two parameters show more or less equivalent results with Z_{avg} being perhaps slightly more sensitive to the look direction. SAOCOM-CS retrievals thus perform closely to the full resolution data, with an apparent slight increased dispersion of the training estimates not being mirrored by the validation data.

A second model detailed in Eq. (4) on the preceding page is the result of an observation that the different polarization components of the tomographic parameters were highly correlated. This model uses a single polarization, combining R_{vol} and Z_{avg} instead, with HH results shown in Fig. 6 on the next page. VV and HV results are similar and therefore omitted.The loss of polarimeric information is fully compensated for, with the only obvious



(a) E-SAR: R_{vol}.



(b) SAOCOM-CS: R_{vol}.

Figure 5: Retrievals based on the volumetric backscatter ratio, R_{vol}, obtained from tomographic data corresponding to E-SAR (top row) and SAOCOM-CS (bottom row) for the two headings respectively.

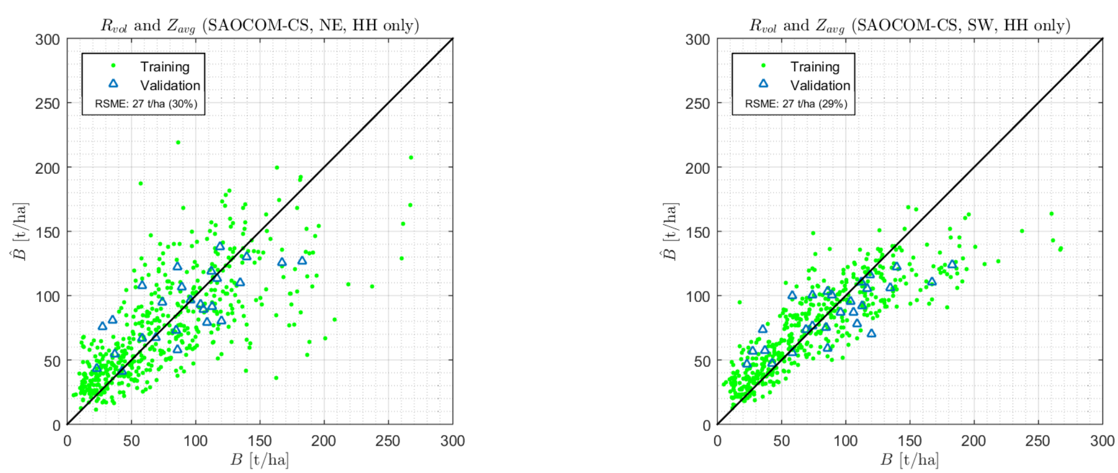
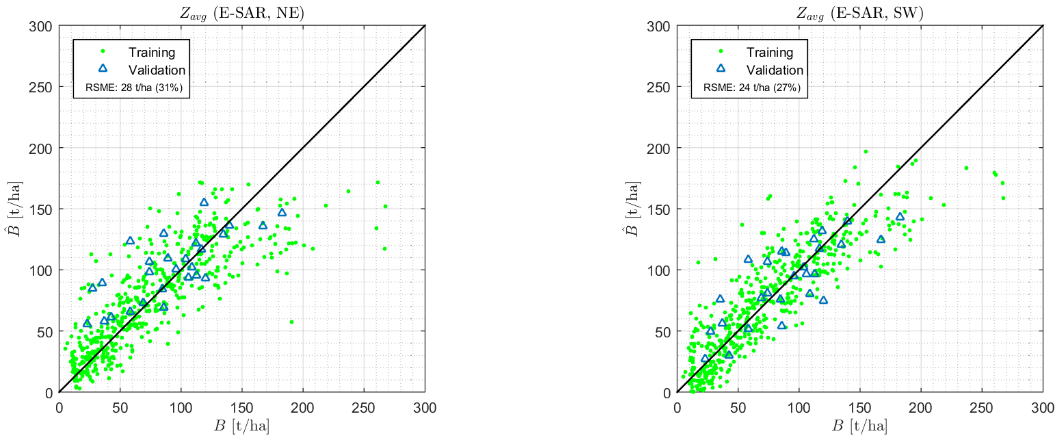
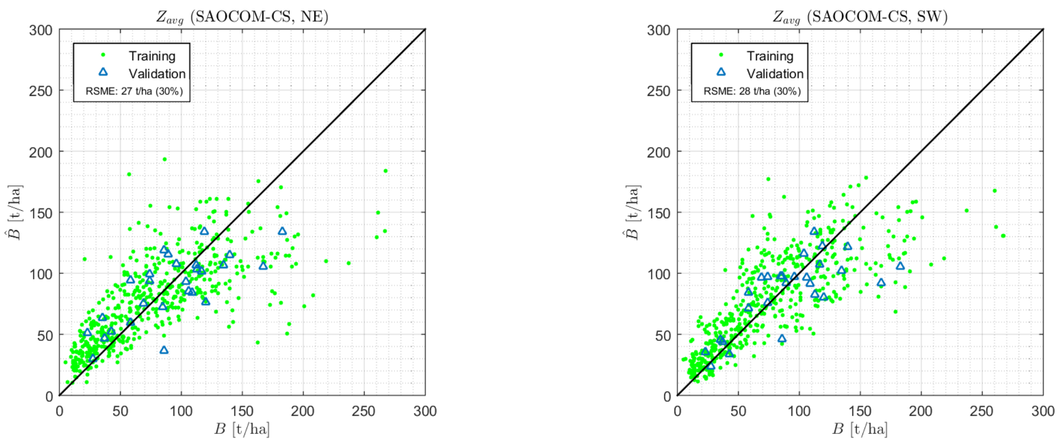


Figure 6: Retrievals obtained for SAOCOM-CS when combining R_{vol} and Z_{avg} for a single polarization (HH).



(a) E-SAR: Z_{avg}.



(b) SAOCOM-CS: Z_{avg}.

Figure 7: Retrievals based on the average backscatter height, Z_{avg}, obtained from tomographic data corresponding to E-SAR (top row) and SAOCOM-CS (bottom row) for the two headings respectively.

difference being an even stronger look direction dependence in the training data. The reason for this result is presently unclear and needs further investigation.

5. CONCLUSIONS

Biomass retrievals from Krycklan boreal forests at L-band are improved by the inclusion of tomographic information. Simulated SAOCOM-CS retrievals consistently perform well compared to results based on SAR intensity, showing that it is possible to compensate for the decreased performance of an orbiting platform. The RMSE varies 27-30% for the SAOCOM-CS simulation with ~50 MHz bandwidth and 27-28% for the original full-bandwidth E-SAR data with 94 MHz bandwidth.

Table 1: Fitting performance statistics for the different parameters and models.

	Input		RMSE [t/ha]	Bias [t/ha]	R^2
E-SAR intensity	γ^0	(NE)	26 (28%)	-10	0.61
	γ^0	(SW)	25 (27%)	-1	0.61
	γ^0_{vol}	(NE)	23 (25%)	-4	0.68
	γ^0_{vol}	(SW)	23 (25%)	3	0.68
E-SAR tomography	R_{vol}	(NE)	26 (28%)	5	0.58
	R_{vol}	(SW)	25 (28%)	3	0.60
	Z_{avg}	(NE)	28 (31%)	10	0.53
	Z_{avg}	(SW)	24 (27%)	1	0.63
SAOCOM-CS tomography	R_{vol}	(NE)	25 (27%)	-4	0.61
	R_{vol}	(SW)	27 (30%)	-6	0.55
	Z_{avg}	(NE)	27 (30%)	-4	0.54
	Z_{avg}	(SW)	28 (30%)	-6	0.52
	R_{vol}, Z_{avg}	(NE)	27 (30%)	1	0.52
	R_{vol}, Z_{avg}	(SW)	27 (29%)	-5	0.55

REFERENCES

1. Tebaldini, S., Guarnieri, A. M., Papathanassiou, K., Pardini, M., Ulander, L. M. H., Soja, M. J., Blomberg, E. M., Woodhouse, I., Nagler, T., Ferro-Famil, L., Minh, D. H. T., Le Toan, T., Laurin, G. V. & Valentini, R. (2015). Study of L- and P-band SAR Tomography Synergies: Final Report. ESTEC Contract 4000112571/14/NL/FF/gp.

2. Hajnsek, I., Scheiber, R., Keller, M., Horn, R., Lee, S., Ulander, L. M. H., Gustavsson, A., Sandberg, G., Le Toan, T., Tebaldini, S., Guarnieri, A. M. & Rocca, F. (2009). BIOSAR 2008 technical assistance for the development of airborne SAR and geophysical measurements during the BioSAR 2008 experiment: Final report. ESA contract no. 22052/08/NL/CT.

3. Sandberg, G., Ulander, L. M. H., Fransson, J. E. S., Holmgren, J. & Le Toan, T. (2011). L- and P-band backscatter intensity for biomass retrieval in hemiboreal forest. *Remote Sensing of Environment* 115(11), 2874-2886. http://dx.doi.org/10.1016/j.rse.2010.03.018

4. Neumann, M., Saatchi, S. S., Ulander, L. M. H., and Fransson, J. E. S., (2012). Assessing Performance of L- and P-Band Polarimetric Interferometric SAR Data in Estimating Boreal Forest Above-Ground Biomass. *IEEE Transactions on Geoscience and Remote Sensing* 50(3), 714-726. doi: 10.1109/TGRS.2011.2176133

5. Ulander, L. M. H. (1996). Radiometric slope correction of synthetic-aperture radar images, *IEEE Transactions on Geoscience and Remote Sensing* 34(5), 1115-1122. doi: 10.1109/36.536527