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BIOSAR 2010 – A SAR CAMPAIGN IN SUPPORT TO THE BIOMASS MISSION

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ABSTRACT

The ESA funded campaign BioSAR 2010 was carried out at the forestry test site Remningstorp in southern Sweden, in support to the BIOMASS satellite mission under study. Fully polarimetric SAR data were successfully acquired at L- and P-band using ONERA's multi-frequency system SETHI. In addition with other data types gathered, e.g. LiDAR and *in-situ* measurements, the compiled data set will be used for analyses and comparisons with biomass estimation results obtained at the same test site in the campaign BioSAR 2007, in which DLR's E-SAR made the SAR imaging. Detection of forest changes, robustness of biomass retrieval algorithms and long-term P-band coherence will be in focus as well as cross-validations between the two SAR sensors.

Index Terms— SAR, backscatter, forest biomass, polarimetry, SETHI

1. INTRODUCTION

BIOMASS is one of three remaining candidates undergoing Feasibility Study (Phase A) for the seventh Earth Explorer Mission within ESA's Living Planet Program [1]. The BIOMASS mission will consist of a single satellite equipped with a P-band polarimetric SAR sensor operating at a centre frequency of 435 MHz with a bandwidth of 6 MHz [2]. The overall goal is to provide polarimetric and interferometric radar mapping of forested areas to improve our understanding of carbon sinks and sources in the context of climate and vegetation modeling. Primary mission objective is to produce global maps of biomass stocks and its change at a spatial resolution of 100 m. Secondary mission objective is exploratory and focuses on sub-surface and inundation mapping using long wavelength radar.

One important part of the current studies is the development and validation of biomass retrieval algorithms based on SAR backscatter and polarimetric interferometry (Pol-InSAR). In order to obtain relevant SAR data, ESA has

funded a number of airborne SAR campaigns designed to mimic the imaging geometries and operational modes defined for BIOMASS as well as include representative forest types and ground conditions. It has also been important to acquire airborne L-band data simultaneously to be able to assess the expected benefits of P-band since the former data source is available today from space. The first two campaigns BioSAR 2007 and BioSAR 2008 were conducted in Sweden during the Assessment Study (Phase 0) and the E-SAR system operated by DLR in Germany was used as the radar instrument [3].

BioSAR 2007 took place at the test site Remningstorp in southern Sweden [4-5]. The main objectives were to assess the potential for biomass estimation in hemiboreal forests and to investigate temporal decorrelation at L- and P-band. The latter was facilitated with three separate SAR acquisitions between March and May.

BioSAR 2008 mapped forests found in a catchment, Krycklan, in northern Sweden. The main objectives of this campaign were similar but now for higher latitude boreal forest conditions. Temporal decorrelation at L- and P-band was, however, not addressed in this case and data were thus acquired during one experiment occasion only. Instead topographic effects were added as an important topic for the evaluation which put requirements on possible test sites as well as the detailed flight program [6]. The data sets from both campaigns in Sweden have also been used in studies on SAR tomography [7-8].

The first campaign in support of BIOMASS during Phase A was TropiSAR 2009. SAR data were gathered at L- and P-band over tropical forests in French Guiana [9-10]. Two main test sites were used and exhibited both fairly flat and more topographic parts. The experiment layout was defined to address the same problems as for the boreal forest registrations, including tomographic flight lines. The acquired data set enables investigations on temporal decorrelation up to three weeks maximum. The airborne SAR system SETHI, developed and operated by ONERA in France, was used for the TropiSAR 2009 data collection.

The second and most recent campaign during Phase A is BioSAR 2010 which is in focus of this paper.

2. BIOSAR 2010

The BioSAR 2010 campaign was carried out at Remningstorp, i.e. the same test site as during BioSAR 2007. The SAR instrument used for the data collection was SETHI, configured with both L- and P-band in a fully polarimetric mode. The program was limited to one flight mission with eight imaging passes. As in the previous campaigns, various ground data were collected (e.g. forest parameters and soil moisture) as well as LiDAR mapping of the test site using a helicopterborne laser scanner.

2.1. Remningstorp test site

Remningstorp is located in southern Sweden (58°28'N, 13°38'E) and covers 1200 ha of forested land divided into over 300 stands. The forested area is classified as hemiboreal with Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birch (*Betula* spp.) as the dominant species, see Fig. 1. It is mainly a production forest with a range of stem volume conditions up to a maximum value of about 620 m³/ha. The area is overall rather flat with a topographic elevation range of about 20 m. However, local ground slopes are in some areas sufficient to give an impact on the forest backscatter despite the small range of elevation variation. In BioSAR 2010 two 5 m trihedrals were deployed and used to verify the radiometric calibration of the generated SAR images. Fig. 2 shows a map of the test site with the locations of the trihedrals marked as well as the four soil moisture sensors in operation during the campaign period.

2.2. SETHI SAR system

SETHI is the next generation multi-frequency and fully polarimetric airborne SAR system developed by ONERA to replace the predecessor RAMSES [11]. Presently, electronics for VHF/UHF-, P-, L- and X-band have been developed. The radar hardware units are installed in the cabin of a Falcon 20 aircraft together with two pods under the wings encompassing the accompanying radar antennas, see Fig.3. Radar raw data are stored on a disk system in real-time and after landing copied to external disks in the SAR processing facility using an optical fiber.

Similar waveforms developed for TropiSAR 2009 were used in BioSAR 2010. For P-band a signal ranging from 220 to 460 MHz was transmitted and for L-band 1250-1400 MHz. After radiometric calibration a common swath width of about 3 km is obtained in ground range, from a flight altitude of 4 km, and the typical data acquisition length in azimuth is 10 km. The two transmitted bandwidths are wide enough to filter out proper portions for comparison with BioSAR 2007 SAR images that were generated and analyzed based on waveforms defined for E-SAR.



Fig. 1. Photos from different forest stands in Remningstorp.

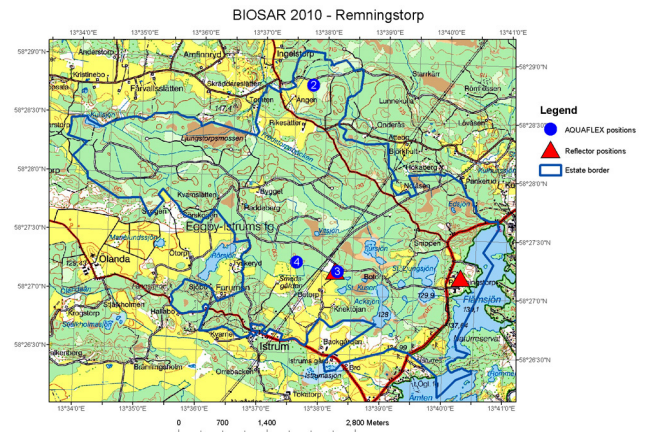


Fig. 2. Map with the estate boundary given in blue and the trihedrals and the soil moisture sensors indicated by filled triangles and circles, respectively. (Map: © Lantmäteriet Gävle 2011. Ref. no. I 2011/0727).



Fig. 3. The Falcon 20 aircraft and the right wing pod with the L-band antenna. (Photo: Pia Ericson, FMV).

2.3. Campaign objectives

In the context of the BIOMASS mission BioSAR 2010 shall provide feedback on:

- The ability of BIOMASS in detecting and mapping changes by updated retrieval of forest parameters (due to forest growth or disturbances such as thinning or clear-cuts).
- Cross-calibration between the ONERA SETHI airborne SAR system and DLR E-SAR to ensure consistent interpretation of radar signatures across campaign data sets and the validity of global retrieval algorithms developed based on such data sets.
- Robustness of biomass retrieval algorithms with respect to changes in forest conditions, e.g. soil moisture and local ground slopes.
- Long-term coherence of P-band over forested and other natural surfaces.

These objectives will be achieved through the collection and analysis of airborne SAR data at P- and L-band from BioSAR 2007 and BioSAR 2010 over selected areas with relevant co-located ancillary data (e.g. LiDAR height measurements and *in-situ* forest data).

3. STATUS OF THE CAMPAIGN ACTIVITIES

All airborne LiDAR and SAR data registrations have been undertaken and most of the *in-situ* forest data collection is completed. Processing efforts of the different data sources are in progress to compile a campaign data set with all necessary ground parameters (measured or retrieved) and raster data available to be able to perform the BioSAR 2010 analysis in accordance with the main campaign objectives.

3.1. LiDAR mapping

Almost the entire estate has been mapped from an altitude of 400 m using the Swedish system TopEye MKIII, with a laser wavelength of 1550 nm, a pulse width of about 3 ns and a beam divergence ≤ 0.5 mrad. The acquisitions made from a helicopter required two days and took place on 29 August and 9 September 2010.

The measured laser point-cloud has been used to estimate and generate a number of raster products, e.g. a digital elevation model (DEM), a digital surface model (DSM), height percentiles (distribution of LiDAR returns in the canopy) and a vegetation ratio defined above a certain height threshold. The variables extracted from LiDAR data at the field plot locations will be used together with biomass estimates based on manual field measurements on the plots to model biomass as a function of LiDAR variables. Tree species proportions needed for this are retrieved from aerial photos acquired in other research projects recently.

3.2. SAR mapping

The measurements with SETHI were undertaken on 23 September 2010 with P- and L-band SAR data successfully acquired from all eight imaging passes planned. Six of them were derived from the zero baseline waypoints used by E-SAR in BioSAR 2007 as input, just slightly adjusted to compensate the geometrical differences of the mounted GPS and P-band antennas on the two platforms. The SETHI data quality was checked by quick-look (QL) images generated the next day and found to be nominal. Fig. 4 shows a comparison between uncalibrated QL-images based on P-band polarimetric data acquired by E-SAR in 2007 and by SETHI in 2010. Most of the area is observed to have similar character but there are also signs of clear-cutting.

The off-line high quality SAR image processing has been completed, including radiometric calibration and geocoding in the geodetic datum WGS84 [12-13]. Work on transforming the SAR images into the UTM (Universal Transverse Mercator) projection are in progress.

3.3. Forest inventory

The field survey to perform *in-situ* measurements of forest parameters started in October 2010, i.e. shortly after the SAR registrations. Most of the planned efforts could be carried out before the unexpectedly early winter with a lot of snow prohibited any further work in an effective manner. The minor part that remains to conduct is scheduled to take place in the time frame May-June 2011.

The field inventory conducted in BioSAR 2010 consists of creating new field plots as well as visiting and updating old ones. In the latter case, 849 circular plots with a radius of 10 m and a spacing of 40 m were available, covering an area in the central part of the estate and established in 2004 and 2005. The performed field survey concluded that 455 of those plots were unaffected and they have been updated with growth corrections. The new field plots were allocated over the whole estate using 200 m grid spacing co-located to the existing dense grid of plots. About 250 plots were found to be on forested land but quality checks reduced the number to 242 since the GPS post-processing failed for some locations. The radius for the new circular plots was also 10 m except for regenerating and young forests where the value was reduced to 5 m. Finally, a number of 80 m x 80 m field plots with individual tree measurements used in the BioSAR 2007 data analysis will also be updated. This work has not been completed yet since some field surveys are still missing.

The processed circular field data in combination with LiDAR derived variables calculated at the plot locations have been used for biomass regression modelling to estimate the biomass for the entire laser scanned area. The plotwise biomass estimates can be aggregated to stand level figures.

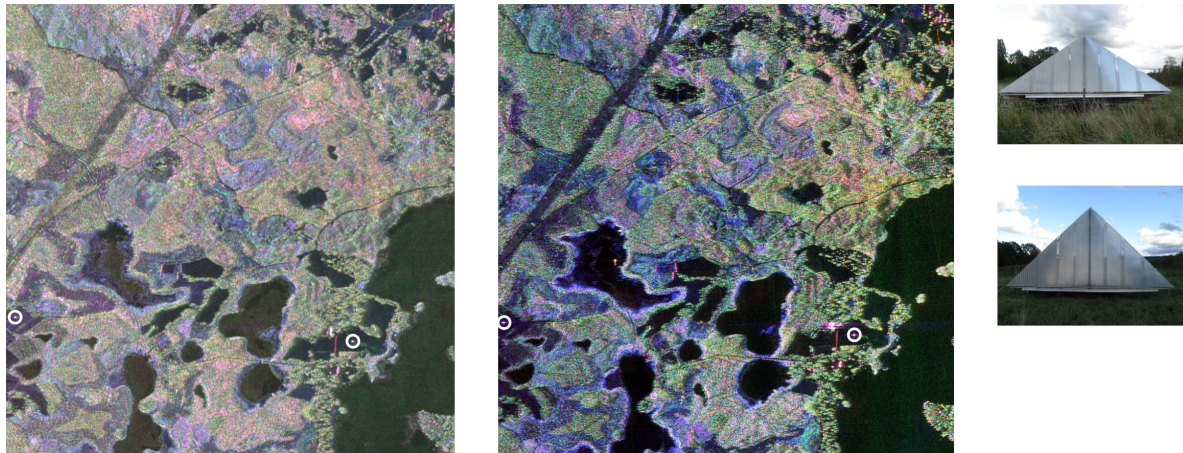


Fig. 4. P-band QL-images from Remningstorp generated based on E-SAR data (left, BioSAR 2007) and SETHI data (right, BioSAR 2010), covering the eastern section of the estate according to the map in Fig. 2. The two white circles indicate the trihedrals deployed in near range (west) and far range (east). The photos were captured during BioSAR 2010 and show the trihedrals adjusted for an incidence angle of 34° (top, western unit) and 50° (middle, eastern unit), and pointing towards a flight heading of 178° with the L- and P-band SAR sensors looking left. (Color coding, HH: red, HV: green, VV: blue).

4. SUMMARY

Most of the different data collected during BioSAR 2010 have been processed and quality checked. Analyses and comparisons with the data set acquired at Remningstorp during BioSAR 2007 will be made. Main topics to address are the potential to detect forest changes, the robustness of biomass retrieval algorithms and the long-term coherence of P-band over forested and other natural surfaces.

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