MEASUREMENTS OF FOREST BIOMASS CHANGE USING L-BAND SAR BACKSCATTER

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ABSTRACT
Three-year forest above-ground biomass change is to be measured using L-band synthetic aperture radar (SAR) backscatter. Measurements are also made using P-band backscatter for comparison. The radar data were collected in the airborne BioSAR 2007 and BioSAR 2010 campaigns over the hemi-boreal Remningstorp test site in southern Sweden. Regression models for biomass will be developed using reference biomass maps created using airborne laser scanning data and field measurements also collected in the campaigns. A previous study estimated biomass change using P-band data from the same campaigns, and reported root-mean-square errors of about 15% (corresponding to 20 t/ha). Errors for L-band based estimations are expected to be somewhat larger than P-band, due to weaker penetration of the signal into the forest canopy, and the dataset available presents a unique opportunity for thorough comparison of the capability to estimate forest biomass change between the two bands.

Index Terms— Biomass, forestry, L-band, P-band, radar, modelling

1. INTRODUCTION
Global warming is caused by the elevated concentrations of greenhouse gases into the atmosphere. The most prominent of these gases is carbon dioxide [1]. The biosphere acts as net carbon sink, and changes in its efficiency in storing carbon need to be better understood [2]. Forests are a large part of terrestrial biosphere and their carbon storage capacity of forests is proportional to the biomass they contain. This necessitates large-scale mapping of forest biomass. Images from synthetic aperture radar (SAR) systems have the benefit of being insensitive to weather or lighting conditions, making it easy to reliably get useful full coverage data even over large areas. Furthermore, relatively long wavelength of SAR systems is an advantage, as it can penetrate the canopy, and thus allows for retrieval of biomass. Previous studies have used both L- and P-band SAR data to retrieve biomass in boreal and hemi-boreal forests [3, 4], and L-band data has been used to detect clear-cuts and storm damage [5, 6], but estimation of biomass change from growth using L-band data in hemi-boreal forests has not, to the knowledge of the authors, been studied. This study will use airborne SAR data in L- and P-band from the BioSAR 2007 and BioSAR 2010 campaigns over the hemi-boreal test site in Remningstorp in southern Sweden to estimate changes in above-ground biomass in the three years between the two campaigns. Linear regression models will be developed, and a correction method, previously successful for mitigating moisture and calibration uncertainty in P-band SAR data, will be tested on L-band data. P-band data are included in the study to accommodate more direct comparisons with the L-band results.

2. TEST SITE AND DATA
The study uses SAR data, in situ data, and airborne laser scanning data collected in the airborne campaigns BioSAR 2007 and BioSAR 2010. Full descriptions of the campaigns and the data can be found in the final reports [7, 8]. The data were collected in the Remningstorp test site in southern Sweden (58°30′ N 13°40′ E). The site consists of managed forest dominated by Norway spruce and Scots pine with some birch. The ground slopes are on the site are generally small, with elevations between 120 m and 145 m above sea level.

2.1. SAR data
The SAR scenes used are fully polarimetric in L and P-band. For 2007, the SAR data was collected using the German E-SAR system by the German Aerospace Center (DLR), while the 2010 SAR data was collected using the French SETHI system by ONERA. The two systems, and hence the SAR data for the two years are not identical.

The 2007 SAR data, from E-SAR, was delivered with a center frequency of 1300 MHz and a bandwidth of 94 MHz for L-band, and a center frequency of 350 MHz and a bandwidth of 70 MHz for P-band.

The 2010 SAR data, from SETHI, was collected with a center frequency of 1325 MHz and a bandwidth of 150 MHz for L-band, and a center frequency of 360 MHz and a band-
width of 166 MHz for P-band, with some notches and gaps to avoid radio frequency interference.

Each pixel in the full resolution images is calibrated to the average radar cross section per unit ground area, after which a first order correction for variations in incidence angle is applied, to obtain what in the henceforth will be referred to simply as the backscatter. The resulting full resolution backscatter images are then downsampled to create backscatter maps that match the created biomass maps.

2.2. In situ data

The in situ data consists of two 10 m radius field plot grids, which are used for training regression models, and six 80 m by 80 m rectangular plots, which are used for evaluation of the results in this paper. One of the two the plot grids has a plot spacing of 40 m, and was surveyed in 2004-2005. This grid will be used for estimating the true biomass in 2007. The other plot grid has a spacing of 200 m, was surveyed in 2010, and is used in this study to estimate the true biomass in 2010.

Since the field plot grids for the two years were not the same, and the plot overlap is small, changes in biomass could not be directly measured in situ with reasonable amount of data points. Instead, biomass maps were created for each year using the grid of plots and the airborne laser scanning from that year. The biomass maps are further described in 2.3. The difference between these biomass maps at each ground cell are then used as training and test data in regression models using the difference in backscatter between pairs of SAR images at the same position as the predictors.

2.3. Biomass maps

As previously mentioned, the field data used for the two years were not from the same plots, necessitating an indirect approach to retrieve the biomass change from 2007 and 2010 in any location outside of the 80 m by 80 m rectangular evaluation plots. To this end, biomass maps were created. As mentioned, laser scannings were also conducted at the test site for each year. Metrics from the resulting point clouds were used together with the in situ data to produce an above-ground biomass map for both years. The difference between these biomass maps was then used to train and validate the regression models.

3. METHOD

3.1. Backscatter offset correction

Since the intensity of backscatter is not only dependent on the amount of biomass at a certain position, but varies significantly with other variables such as soil, stem, and canopy moisture, and forest structure variables other than biomass such as tree species, number of stems, and spatial distribution of trees. The moisture can vary significantly over both seasons and even days, making it especially challenging. Even if the forest structure is unchanged, and the same imaging geometry is used, the backscatter intensity may vary substantially even from day to day, which presents a challenge when estimating biomass change. To mitigate the effect of soil moisture and calibration errors, Sandberg et al. proposed a backscatter change offset correction method (there used for P-band data), that will be applied on both L- and P-band data in this study [9]. The correction is based on the HH-VV backscatter ratio, found to be relatively insensitive to moisture, and aims to correct the backscatter maps so that areas with very small changes in biomass correspond to areas with very small changes in backscatter.

The procedure is as follows. For each pair of scenes, find the areas with changes in HH-VV ratio lower than some threshold. Then, for each polarization in the pair, calculate the mean backscatter level in these low change areas for each year. Finally, multiply each image by the mean of the two means, and divide by the low change mean of that image. The resulting images have the same mean backscatter in the low change areas for each year. The correction, and its sensitivity to the threshold level are evaluated by varying the threshold, and comparing biomass estimation errors with and without the correction. Additionally, the biomass maps may need to be downsampled before training the models to reduce the variation due to speckle.

3.2. Regression models

Regression models to be applied are generally given by

\[
y = a_0 + a_1 x_{HV} + a_2 x_{HH}^2 + a_3 x_{HV} + a_4 x_{HH}^2 + a_5 x_{VV}^2 + a_6 x_{VV} + \epsilon,
\]

where \( y \) is biomass change on logarithmic (natural logarithm), square root, or linear scale, and \( x_{ij} \) are backscatter change in amplitude, power, or decibel (dB) for a given polarization. The backscatter change measures will not be mixed in the same model. Cross-validation will be applied to determine the best predictor variables on submodels of \( 1 \) with up to five non-zero regression coefficients \( a_k \).

4. DISCUSSION

As discussed in the introduction, the relatively long wavelength of radar as compared to other sensors is a strength when measuring forest biomass via SAR backscatter, due to long wavelengths penetrating deeper into the forest canopy. Since the wavelength is on the order of decimeters for L-band, compared to meters for P-band, we may expect the L-band data to be less sensitive to biomass than P-band data, since the wavelength of L-band radar is considerably shorter than that of P-band radar. Sandberg et al. reported root-mean-square
errors of about 15% (or 20 t/ha), in estimating biomass change using the P-band data from the dataset used in this study [9], and it remains to be seen how the L-band results relate to these figures.

5. REFERENCES


