Boreal Forest Biomass Mapping with P-band SAR Backscatter

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I. Introduction

One of the most promising tools for accurate, global scale biomass mapping is P-band Synthetic Aperture Radar (SAR). Due to its all-weather functionality, good biomass sensitivity, and relatively high temporal stability (as compared to higher frequency bands such as L-, C-, and X-band), P-band SAR is very interesting for forestry applications, which has been studied thoroughly during the last two decades. Due to the recent opening of the P-band at frequencies 432–438 MHz for spaceborne use, a new, fully polarimetric P-band SAR satellite system called BIOMASS has been proposed to European Space Agency (ESA) for the 7$^{\text{th}}$ Earth Explorer mission [9]–[11]. It is currently undergoing a feasibility study. The system is planned to employ both intensity-based biomass retrieval (see for example [7], [10] and references therein) and PolInSAR-based height retrieval [1]. The two methods show different performance in different environments and are complementary, thus extending the capability of the proposed satellite.

In this paper, a new model for biomass retrieval from polarimetric SAR backscatter is presented. The model is compared to some previously published models, and evaluated using two sets of test data. The data were acquired within two BioSAR campaigns performed in 2007 and 2008 in the two test sites Remningstorp and Krycklan, respectively, both situated in Sweden. The test sites are located approximately 700 km apart (straight-line measurement with Google Earth), and represent two different cases of boreal forest. In previous papers dealing with biomass retrieval from BioSAR data, the two test sites were treated separately [5], [7]. In this paper, models fitted to data from one test site are evaluated on the other. This way, the extrapolation capabilities and performance of the models are tested.

The paper begins with a brief description of the experimental data (Sec. II). Next, in Sec. III, the previously published models are presented and the new models are introduced. Thereafter, the models are evaluated in terms of mapping performance (Sec. IV). The results are summarised and a conclusion is made in Sec. V.

II. Experimental Data

BioSAR 2007 was conducted at Remningstorp in southern Sweden [3], [7]. It is a production forest with biomass up to 300 tons/haon stand level. Topographic variations are overall small with an elevation range of only 20 m, but local ground slopes can be significant. The objectives of the experiment were to assess the potential for biomass estimation in boreal forests using P-band SAR and to study temporal decorrelation for polarimetric interferometry. The latter was addressed with three separate acquisitions from March to May. Results show that temporal correlation spanning two months from late winter to summer is adequate for repeat-pass interferometry [3].

BioSAR 2008 was conducted at Krycklan in northern Sweden [2], [8]. It is representative of higher latitude boreal forests and biomass varies up to 200 ton/ha on stand level. Topographic variations are higher than in Remningstorp, with ground elevation between 125 and 350 m. The objectives were slightly different compared to BioSAR 2007 and focussed more on evaluating the effects of topography and multiple heading data were collected.

The dominant tree species for both sites are Norway spruce (Picea abies), Scots pine (Pinus sylvestris) and birch. The SAR acquisitions were complemented by field measurements of forest parameters as well as high density helicopter lidar data.

III. Retrieval Models

Let

$$\widehat{\mathcal{W}} = \log_{10} \mathcal{B}, \tag{1}$$

where $\mathcal{B}$ is the above ground dry biomass. Six retrieval models were compared. Two previously published models were used as reference:

$$\widehat{\mathcal{W}}_{\mathrm{R1}} = C_0 + C_1([\gamma^0_{\mathrm{HV}}]_{\mathrm{dB}} - b_0), \tag{R1}$$

$$\widehat{\mathcal{W}}_{\mathrm{R2}} = a_0 + a_1 [\sigma^0_{\mathrm{HV}}]_{\mathrm{dB}} + a_2 [\sigma^0_{\mathrm{HV}}]^2_{\mathrm{dB}} + a_3 [\sigma^0_{\mathrm{HH}}]_{\mathrm{dB}} + a_4 [\sigma^0_{\mathrm{HH}}]^2_{\mathrm{dB}} + a_5 [\sigma^0_{\mathrm{VV}}]_{\mathrm{dB}} + a_6 [\sigma^0_{\mathrm{VV}}]^2_{\mathrm{dB}} . \tag{R2}$$

In (R1), the constants are $C_0 = 3.8914$ and $C_1 = 0.1301$ as presented in [4], and only one parameter b_0 to be fitted to training data. Model (R2) was mentioned, but not thoroughly studied in [6]. The main model presented in [6] could not be used for this study due to insufficient reference data and too high complexity of the model. Note, that in (R2), σ^0 is used instead of γ^0.

Additionally, the following four models were studied:

$$\widehat{\mathcal{W}}_{\mathrm{M1}} = a_0 + a_1 [\gamma^0_{\mathrm{HV}}]_{\mathrm{dB}} + a_2 [\gamma^0_{\mathrm{HH}}]_{\mathrm{dB}} + a_3 [\gamma^0_{\mathrm{VV}}]_{\mathrm{dB}} , \tag{M1}$$

$$\widehat{\mathcal{W}}_{\mathrm{M2}} = a_0 + a_1 [\gamma^0_{\mathrm{HV}}]_{\mathrm{dB}} , \tag{M2}$$

$$\widehat{\mathcal{W}}_{\mathrm{M3}} = a_0 + a_1 [\gamma^0_{\mathrm{HV}}]_{\mathrm{dB}} + a_2 \left([\gamma^0_{\mathrm{HH}}]_{\mathrm{dB}} - [\gamma^0_{\mathrm{VV}}]_{\mathrm{dB}}\right) , \tag{M3}$$

$$\widehat{\mathcal{W}}_{\mathrm{M4}} = a_0 + a_1 [\gamma^0_{\mathrm{HV}}]_{\mathrm{dB}} + a_2 \left([\gamma^0_{\mathrm{HH}}]_{\mathrm{dB}} - [\gamma^0_{\mathrm{VV}}]_{\mathrm{dB}}\right) + a_3 \cdot + u \left([\gamma^0_{\mathrm{HH}}]_{\mathrm{dB}} - [\gamma^0_{\mathrm{VV}}]_{\mathrm{dB}}\right) . \tag{M4}$$

Some of these models have been used in previous publications [7], [12]. The last term including the surface slope angle u introduced in (M4) is a first approximation of a topography correction function.

IV. Model Evaluation

All six models have been evaluated in terms of across-site retrieval. The models were fitted to stand-level data from Krycklan (97 circular stands, 0.5 ha each, four headings) and evaluated on stand-level data from Remningstorp, see

Fig. 1. The best model was (M4) due to its low bias and low variability. This model was then used to create biomass map of Remningstorp, see Fig. 2. In the same figure, a biomass map based on model (M4) fitted to Remningstorp data is also shown together with a lidar-based biomass map. As it can be observed, the difference between the two SAR based biomass maps is small. The lidar-based biomass map should not be treated as a true reference due to some known problems related to the biomass estimation algorithms. Consult [3] for more information on this topic.

With model parameter estimated in Remningstorp, stand-wise biomass in Remningstorp could be estimated with root-mean-square errors of 38–78 tons/ha (21–42 % of the mean biomass in Remningstorp, 185 tons/ha) for model (M4), which was better or comparable to the other models. With model parameters estimated in Krycklan, biomass in Remningstorp could be estimated with root-mean-square errors of 40–59 tons/ha, or 22–32 % of the mean biomass. The other models produced errors that were at least 50 % higher.

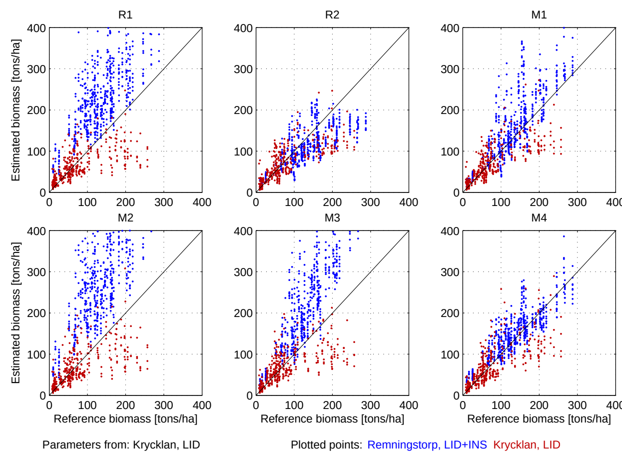

Fig. 1. Comparison of the six evaluated models: training on Krycklan and evaluation on Remningstorp.

V. Summary and Conclusions

The errors observed during the evaluation could in most cases be related to the representation of biomass and/or slope in the training data. Compared to other models, the new model shows very good results in terms of accuracy, giving low prediction bias.

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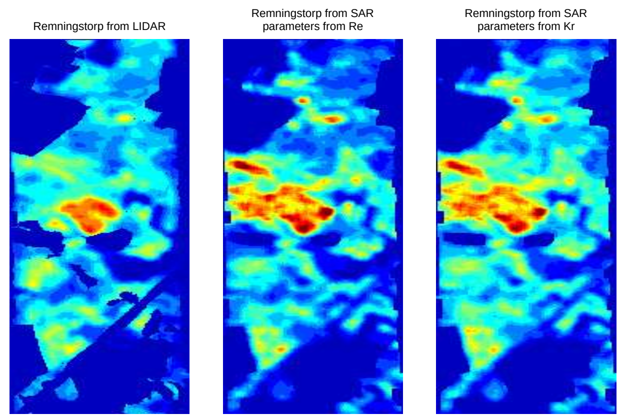

Fig. 2. Extracted biomass maps for Remningstorp and Krycklan. Model (M4) was used to create these maps. For Remningstorp, the north direction is upwards. All Krycklan-maps have been rotated by 45° counter-clockwise for better viewing and the north east direction is upwards. In all images, the resolution is $70\,\mathrm{m} \times 70\,\mathrm{m}$. Images for Remningstorp and Krycklan have different scales.

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