ESTIMATION OF FOREST VARIABLES USING RADARGRAMMETRY ON TERRASAR-X DATA IN COMBINATION WITH A HIGH RESOLUTION DEM

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ABSTRACT

This study uses the backscattered intensity information from SAR images acquired with TerraSAR-X to derive Digital Surface Models with radargrammetry. Then the known ground elevation (from airborne lidar) is subtracted to get Canopy Height Models that are analysed and linked through regression analysis to the forest variables above-ground biomass and tree height. It was found, that the used constellation of image pairs and prediction models produced biomass estimations at stand level with 25.9% and 33.8% relative RMSE, while the height estimations were 11.5% and 12.3%. The analyses were tested at the Swedish test sites Krycklan and Remningstorp.

1. INTRODUCTION

The international interest for accurate estimations of bounded carbon [1] has in combination with new remote sensing techniques inspired to this study for estimating forest above-ground biomass (AGB) and its strongest dependent variable tree height (H). Many methods are well known and already long tested but new sensors and developed analyzing methods have put some of them once more into the light of evaluation. This study focus on radargrammetry, that is stereogrammetry applied to radar images. It makes use of the same idea and methods as photogrammetry but radargrammetry requires backscattered Synthetic Aperture Radar (SAR) intensity images acquired from different incident angles (intersection angles). The intersection angle should approximately lie between 10-20° for accurate reconstruction of the terrain elevation [2, 3], i.e. a Digital Surface Model (DSM). The ground elevation is well known in Sweden and many other countries after having been flown with airborne lidar. The difference between the DSM and the ground elevation is called Canopy Height Model (CHM) and contains information about the forest above-ground biomass and tree height.

The aim of this study is to evaluate the potential of using radargrammetry with TerraSAR-X images for estimating stand-wise AGB and H.

2. MATERIAL AND METHODS

For this study two Swedish test sites have been evaluated, with slightly different site conditions. The first one is a river catchment area located in northern Sweden called Krycklan (64°N). There are 7,470 ha divided into 1,751 stands. Out of these, 6,780 ha (1,380 stands) are forested. Prevailing tree species are Scots pine (*Pinus sylvestris*; 49%), Norway spruce (*Picea abies*; 35%) and birch (*Betula pendula* and *Betula pubescens*; 15%). The region is quite hilly with elevations between 125 m and 350 m above sea level and slopes up to 61°. For this study 102 field plots with 12 m radius were randomly distributed within strips covered by airborne lidar used in [4]. They were surveyed during the field season 2008. The distribution of field plots is supposed to be representative for the entire test site.

The second test site, Remningstorp, is located in southern Sweden (58°N) and holds about 1,200 ha forest divided into 531 stands. Prevailing tree species are Norway spruce, Scots pine and birch. It is a rather flat region with moderately varying ground elevations between 120 m and 145 m above sea level. In total, 212 field plots with 10 m radius were allocated over the test using 200 m grid spacing and surveyed during 2010.

For both test sites airborne lidar scanning data were available from the same years as the field plots were inventoried and the radar images were acquired. These lidar data were related to the respective test sites' field plots to create forest above-ground biomass and tree height rasters used as reference data for the radargrammetry modeling. The lidar derived rasters for Krycklan contained estimation errors in terms of RMSE for AGB and H as 15.6% and 8.1%, respectively. The corresponding figures for Remningstorp were 12.7% and 11.2%.

TerraSAR-X data were acquired in spotlight mode for Krycklan on October 16-17, 2008 and Remningstorp August 22 and 25, 2010, causing negligible temporal differences both within the satellite image pairs and between satellite data and the field surveyed data. The spotlight scene for Krycklan did unfortunately not cover the entire test site and therefore only 59% of the available stands could be used for the modeling and evaluation.

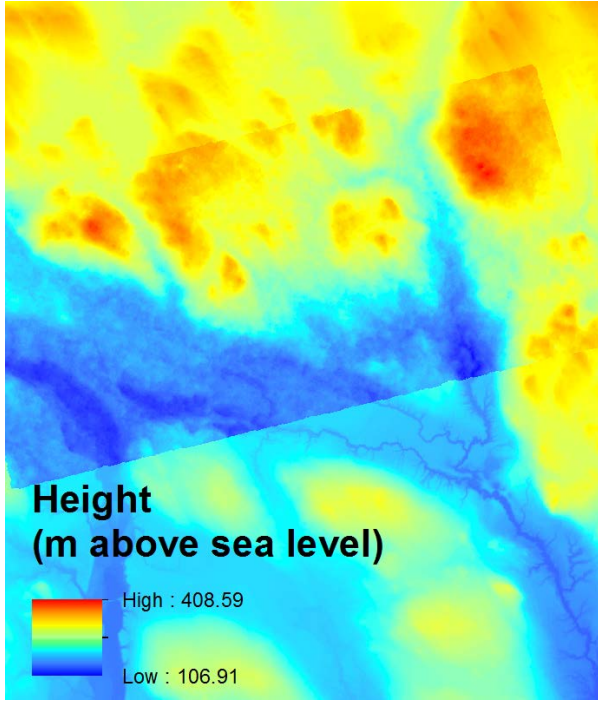The DSMs were reconstructed for respective image pair with the same procedure but different parameter

Figure 1. Lidar ground elevation overlaid by the calculated DSM from TerraSAR-X data from the Krycklan test site.

Figure 2. Slope map from Krycklan overlaid by the delineation of 1751 stands.

$$AGB = CHM_{mean}{}^{2} + CHM_{mean} + std(DEM) \qquad (1)$$

$$H = CHM_{mean}{}^{3/2} + CHM_{mean} + std(CHM) \qquad (2)$$

$$AGB = CHM_{mean} + std(CHM) + std(DEM) \qquad (3)$$

$$H = CHM_{mean}{}^{2} + CHM_{mean} + std(CHM) \qquad (4)$$

settings. The images were pre-filtered with a GammaMAP 5×5 filter and then about 50 tie-points related the two images within each satellite scene to each other. An affine polynomial transformation was then calculated for the next step that coarsely quasi-epipolar matched the images by using a 6 point-cubic resampling of one image to the other. The image matching is then based on hierarchical feature vector matching with an adaptive cost function. The used cost function uses normalized cross-correlation with the first pyramid level having a kernel with 15×15 pixels, the second level 7×7 and the third 3×3 pixels. The size of the search window is a dynamic step that was chosen empirically and differed for each test site and image pair tested. The geocoding used the attached TerraSAR-X geo-data that is known to be accurate [5] and the output raster (DSM) was generated with 10 m pixel size. Fig. 1 illustrates the DSM from Krycklan, overlaying the lidar ground elevation in the background.

For each test site, statistical metrics were then extracted stand-wise. The main metrics used were mean, median, max and min CHM heights and the standard deviations of the CHM and the DEM, respectively. Using multiple linear regressions, the AGB and H were calculated at stand level and evaluated using leave-one-out cross-validation.

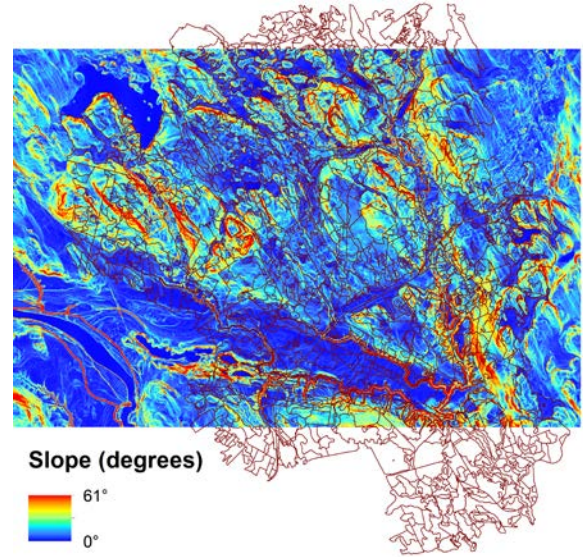The regression models for Krycklan (Eqs. 1-2) and Remningstorp (Eqs. 3-4) were found to be:

3. RESULTS

The AGB was estimated with an RMSE of 26.9 tons ha^{-1} at Krycklan, which corresponds to 33.8% relative RMSE (Tab. 1). For H the RMSE was on average 1.7 m, which corresponds to 12.3% relative RMSE. At the second test site, Remningstorp, the AGB was estimated to 28.2 tons ha^{-1}, which is 25.9% relative RMSE and for H the accuracy was 2.1 m, corresponding to 11.5% relative RMSE. The q-values were calculated to show how over fitted the models were but all models had q-values equal to 1.00 or 1.01, which shows that the models were not over fitted. For Krycklan 815 stands were used for AGB and 816 for H while Remningstorp offered 456 stands for the AGB estimation and 452 for the estimations of H. A 3 sigma outlier reduction was applied to reduce some big outliers, giving a slightly different stand number between AGB and H. The figures for amount of forested stands also differs compared to the figures in the material section because of the none-wall-to-wall covering satellite scene for Krycklan, and in the case of Remningstorp some stands laid outside the lidar scanned region.
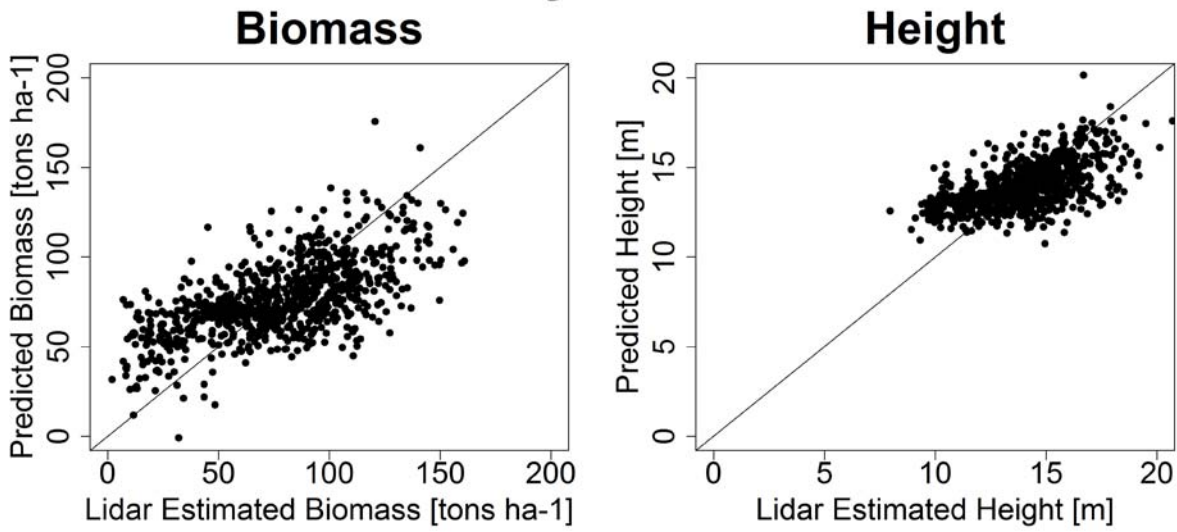
Krycklan

Biomass

Height

Figure 3. Biomass and height estimations for the Krycklan test site
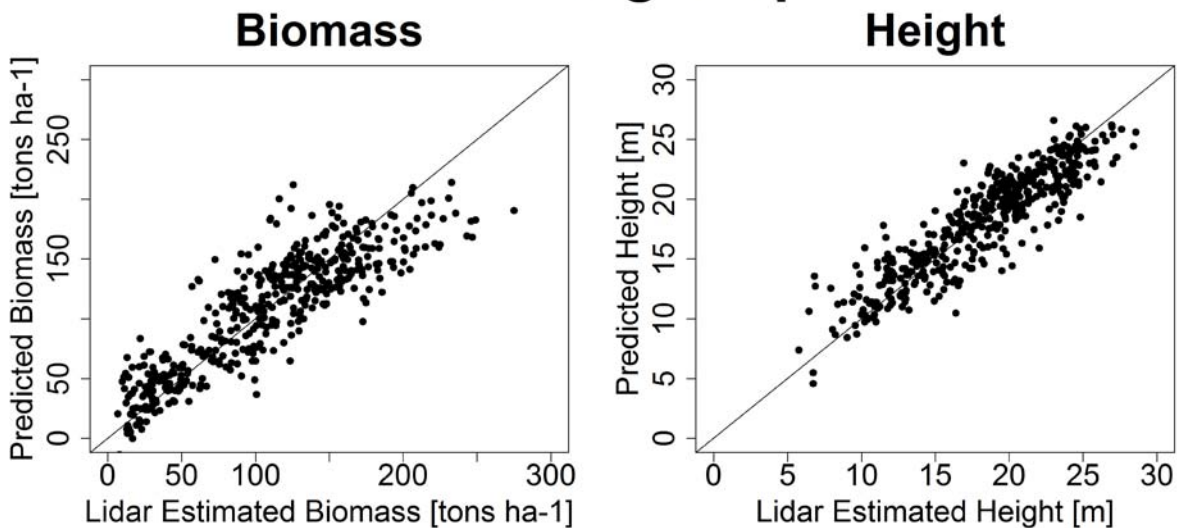
Remningstorp

Biomass

Height

Figure 4. Biomass and height estimations for the Remningstorp test site

Table 1. Results for biomass and height estimations for respective test site.

BIOMASS

Test site	R^2adj	RMSE (tons ha^{-1})	RMSE (%)	q	No. of stands
Remningstorp	0.76	28.2	25.9%	1.01	456
Krycklan	0.40	25.9	33.8%	1.01	815

HEIGHT

Test site	R^2adj	RMSE (m)	RMSE (%)	q	No. of stands
Remningstorp	0.81	2.1	11.5%	1.01	452
Krycklan	0.36	1.7	12.3%	1.00	816
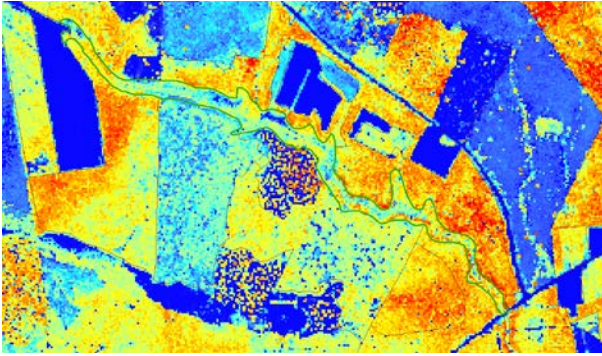
Figure 5. Lidar measured percentile 100 with dehydrated river bed marked in green from Krycklan.

Figure 6. CHM calculated from TerraSAR-X data with dehydrated river bed marked in green from Krycklan.

4. DISCUSSION AND CONCLUSIONS

The spread about the regression functions are quite large for Krycklan (Fig. 3) that also has a smaller range of available biomasses and tree heights. This gives a more compact model with a lower adjusted coefficient of determination (R^2_{adj}). The Remningstorp models show a higher degree of linearity with a smaller spread (Fig. 4) and this is clearly reflected in the R^2_{adj} that are very much higher than for Krycklan, without giving considerably lower RMSEs (Tab. 1). Possible reasons for this are the more varying terrain in Krycklan (Figs. 1-2) which makes the image matching much more difficult. Also fewer field plots covering a smaller ratio of the entire test site might give less representative reference data than for Remningstorp. This is partly reflected in the higher RMSE for the derived above-ground biomass raster over Krycklan. It was also noted that the regions generating the biggest problems are almost always young stands with low forest heights or sparse forest. This is rather often the case in Krycklan and less frequent in Remningstorp. A crucial part of the image matching involves choosing appropriate search window sizes and this clearly depends on the topography.

It was noticed that the Krycklan test site required search windows on the order of 10 times higher in the range direction than for Remningstorp, which seemed to be entirely a consequence of topography. This unfortunately also leads to more false matches, especially in fast varying terrain. This became visually clear when a few stands lying in dehydrated river beds were investigated (Figs. 5-6). The ground elevation goes down while the DSM remains, resulting in unusually high heights in difference. Out of the slope map (Fig. 2) it can also be seen, how regions with strong slopes are influenced by layover effects.

Further work includes specie specific modelling as well as a deeper analysis of how hilly terrain affects the DSMs in radargrammetry. In summary, it can be concluded that radargrammetry has potential to estimate forest above-ground biomass and tree height with high accuracy at stand level.
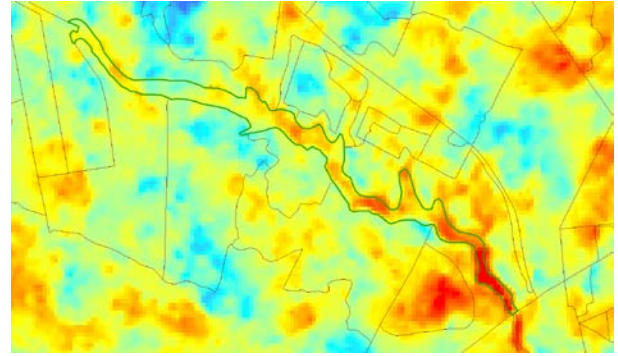
5. ACKNOWLEDGMENT

6. REFERENCES

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