National forest mapping of stem volume using TanDEM-X

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Abstract

In this study, we have used a nation-wide collection of 518 TanDEM-X images, an ALS based DTM, and 7-10 m sample plots from the Swedish National Forest Inventory (NFI) in order to create a nation-wide pixel product of stem volume. The overall prediction accuracy was about 24%-25% at the stand-level, depending on the region that was used. However, the accuracy varied spatially depending on weather and forest conditions, and improved predictions can possibly be achieved by using scene-wise models with additional care taken to e.g. temperature and Euclidian distance to the reference data.

1 Introduction

In Sweden, remote sensing has long been used for wall-to-wall forest mapping, demanded both by the wood industry and for more general mapping of natural resources. In the past, satellite based products at 25 m resolution have been a valuable resource and more recently, the entire country has been laser scanned and resulted in a forest mapping product with 12.5 m resolution, with the majority of the forest being covered during 2009 to 2015 [1–3]. However, the parts that were scanned in 2009-2012 have already become outdated and there is a widespread demand of new, accurate mapping products that can be repeated with much shorter intervals. The German SAR mission TanDEM-X, has since 2010 been mapping the Earth in order to generate a new global, accurate digital elevation model [4–6]. This X-band system (3.1 cm wavelength) has shown to be an accurate tool for mapping the forest as well [7–10], and in this study, the potential and challenges of doing so nationally were explored.

2 Material

2.1 Coverage

The material used in this study covered Sweden wall-to-wall, which implied a land area of 41 million ha, of which 23 million ha was productive forest. Sweden is situated almost completely in the boreal forest region, though the southernmost parts are within the hemiboreal and nemoral regions. About 5.2 million ha covered mountainous vegetation, 5.1 million ha were wetland, and 2.9 million ha were farming land [11, 12].

2.2 Field reference data

The Swedish National Forest Inventory (NFI) is inventorying about 11,000 permanent (10 m radius) and temporary (7 m radius) field plots annually, randomly located all over Sweden [11, 13]. For this study, only forested plots were selected, and based on the trees with a diameter breast height ≥ 0.04 m, reference stem volume was computed, using established relations [14, 15]. For evaluation, several hundreds of stands that were sampled with 3-14 circular sample plots of typically 8 m radius each, were used.

2.3 Remote sensing data

There were 518 TanDEM-X acquisitions collected over Sweden during October 2, 2015 until January 31, 2016. For Sweden, this corresponded to fall and winter conditions with temperatures ranging from -32°C to +11°C. The images were acquired in strip-map mode, about 3 m resolution, and in the HH polarization. The height-of-ambiguity (HOA) were in the range of 55 to 65 m for all acquisitions except the first three passes, where the HOA was in the range of 24 to 32 m.

3 Methods

The TanDEM-X data were delivered in Coregistered Single look Slant range Complex (CoSSC) format and they were multilooked with a factor of 5×5 in range and azimuth respectively. Following a rather common processing approach with forming a complex interferogram, and extracting and unwrapping the phase, a phase height map could be computed. Additionally, the coherence and the backscatter were extracted. Some regions with particular conditions had to be handled semi-automatically, such as scenes with a HOA being around the height of the surrounding trees, scenes covering the archipelago with isolated islands, and scenes acquired in frozen conditions.

The phase height, coherence and backscatter were used as explanatory variables in robust linear regression models to estimate the stem volume, described by the NFI data. However, it was found, that the overall best results were achieved by a straightforward model without intercept, and only relying on the phase (Φ) as explanatory variable (1).

$$Volume = 13.1\ \Phi \tag{1}$$

The model was used to create a nation-wide map of stem volume that was evaluated at the stand-level on the independent dataset.

4 Results

To evaluate the accuracy, the root mean square error (RMSE) and bias were computed and they are presented in **Table 1**. They were similar across the different study areas which proves a certain robustness. Moreover, the bias was limited, which is an important criterion to enable averaging and possibly further increase accuracy at larger area levels. The agreement between maps predicted from either TanDEM-X or airborne laser scanning appeared high, and are illustrated in **Figures 1** and **2**.

Test site	RMSE m^3/ha	RMSE%	Bias m^3/ha	*N*
Northern Sweden	55.3	25.2	-11.1	11
Central Sweden	52.4	25.0	4.9	222
Southern Sweden	65.1	24.0	23.1	15

Table 1: Prediction accuracy (RMSE and bias)

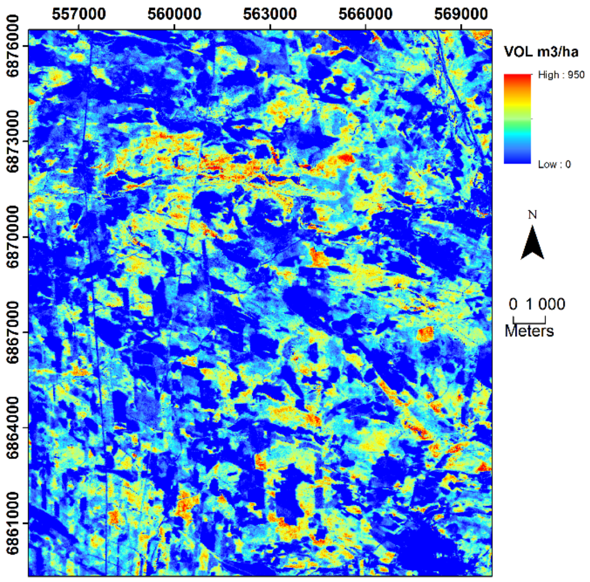

Figure 1: Stem volume predicted from NFI data and TanDEM-X radar data.

5 Discussion

The results are promising and a substantial improvement compared to the earlier satellite based products. However, the accuracy was lower than a similar laser based product (19.2% to 25.1% RMSE) [3]. In the currently presented results, a single model is used to relate the phase height to stem volume for the entire country, which is clearly a very coarse model. We hope to improve the nation-wide accuracy by developing models for the individual scenes and moreover also including the importance of weather conditions. Possible improvements are especially expected in northern Sweden where frozen ground conditions were present, a fact that is known to influence both the phase height and coherence.

6 Conclusions

In this study, a set of 518 TanDEM-X scenes were interferometrically processed and mosaicked to the national level. In addition to traditional SAR processing steps, a number of challenging conditions originating in the SAR data or in the study region required additional semi-automatically adjustments of the processing scheme. Robust regression models were developed to relate the SAR observables to field reference data and finally predict the stem volume for the entire Sweden. When evaluated against independently inventoried stand estimates, the accuracy in form of RMSE (about 25%) and bias (below 9%) was lower than existing satellite based predictions and slightly higher than existing laser scanning based predictions. Overall, the method of using TanDEM-X radar data appears promising for continuous monitoring of the forests at the national level.

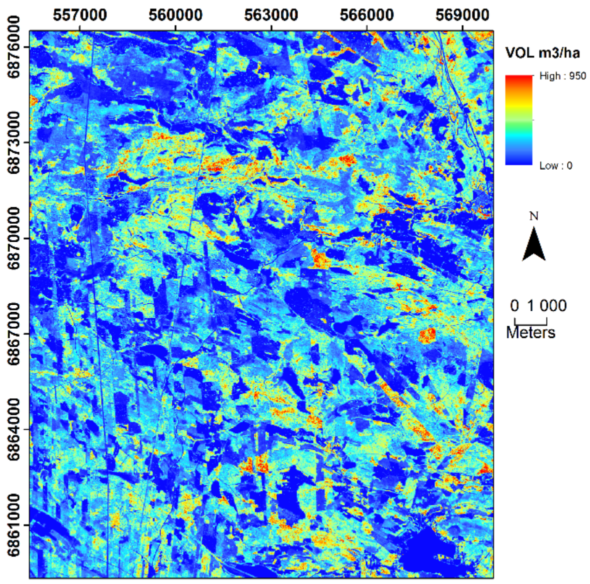

Figure 2: Stem volume predicted from NFI data and airborne laser scanning data.

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