**Estimation of forest variables using TanDEM-X data in combination with a high resolution DEM**

# Estimation of forest variables using TanDEM-X data in combination with a high resolution DEM

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**Bulleted list of abstract highlights:**

- Estimation of forest variables in hemi-boreal forest in southern Sweden using spaceborne synthetic aperture radar 3D data acquired by TanDEM-X in combination with a high resolution DEM.
- Standwise tree height and stem volume estimates will be performed using canopy height and density metrics derived from TanDEM-X data and an Airborne Laser Scanning (ALS) DEM. Forest variables are retrieved using regression analysis describing the relationship between forest variables and derived metrics.
- Standwise estimation accuracy is expected to be higher compared to traditional forest inventories based on aerial photo-interpretation or subjective field surveys. It is anticipated that the accuracy will be similar to ALS-based methods and methods based on photogrammetric matching of digital aerial images.
- Results are foreseen to be relevant for updating outdated inventory stand registers in support of forest management planning, implying that 3D data from TanDEM-X have potential for operational use in forestry.

## Extended Abstract:

### Introduction

In forest management it is of great interest to have accurate information about forest variables in order to make reliable decisions for short and long term planning of silverculture treatments. In Sweden, about 23 million ha of the area is covered by managed forest, representing a major natural resource. To cover large areas, satellite remote sensing can play a vital role in mapping the state of the forest in an efficient way. Although a lot of research studies have been performed in forest remote sensing using satellite data, there is still a need for new techniques and methods to be developed. Estimates of forest stem volume (or biomass) using conventional 2D optical data or radar backscatter intensity data from single satellite images have shown a tendency to get saturated at high stem volumes. This is a reason to investigate the possibilities to estimate forest variables using 3D remote sensing.

### Objective

The objective of this study was to investigate the possibilities of estimating tree height and stem volume, at stand level, using single-pass X-band Interferometric SAR (InSAR) 3D data from the TanDEM-X mission together with an Airborne Laser Scanning (ALS) Digital Elevation Model (DEM) and *in situ* data.

### Materials

The study was carried out at the Remningstorp estate, located in southern Sweden (58°30' N, 13°40' E), where extensive remotely sensed and *in situ* data sets have been collected through the years. The estate is managed for timber production and has relatively flat terrain. The forest is mainly dominated by Norway Spruce (*Picea abies*), Scots Pine (*Pinus sylvestris*) and Birch species (*Betula* spp.).

At the test site, high-resolution InSAR TanDEM-X and ALS 3D data, and *in situ* data at both plot level (10 m radius) and stand level (average stand size of 2.8 ha) are available. The *in situ* data sets (updated to year 2010) include i) 334 plots with a tree height range of 2.9-30.3 m (on average 18.4 m) and stem volume 0-804 $m^3$ $ha^{-1}$ (262 $m^3$ $ha^{-1}$) and ii) 24 stands with a tree height range of 4.8-26.9 m (on average 17.8 m) and stem volume 13-455 $m^3$ $ha^{-1}$ (250 $m^3$ $ha^{-1}$). Through processing of the InSAR TanDEM-X data a Digital Surface Model (DSM) of the forest canopy was derived. By combining the DSM and an ALS DEM, the forest canopy height above ground was calculated to produce a Canopy Height Model (CHM). From the point cloud, canopy height (e.g., height percentiles) and density metrics (e.g., proportion of points in the vegetation) were derived at plot level and used in the model development.

## Methods

Models relating the addressed forest variables to the calculated remote sensing metrics were fitted using linear regression analysis on the data from the 344 field plots, where the independent variables (metrics) were selected based on regression model fit statistics and studies of residual plots.

For the evaluation at stand level, a raster modelling approach was used. Here, the regression models (one for tree height and one for stem volume) used 20 m by 20 m raster cells (size corresponding to a field plot) as the observation unit for forest variables and the derived metrics. Given the models, the forest variable estimations were performed for each raster cell using the derived metrics in all non-field measured raster cells. For each of the 24 stands, the average of raster cell estimates were then calculated as well as the average of tree height and stem volume, separately, using the plot estimates based on the field measurements. Finally, stand-level estimation accuracy was assessed using leave-one-stand-out cross-validation (i.e., the forest variables were estimated for one stand at a time using the raster metrics and regression models re-fitted by data from all plots, excluding the plots inside the stand to be estimated). The results were evaluated at stand level in terms of root mean square error and bias (in percent of the surveyed mean).

## Expected results

The estimation accuracy is expected to be higher compared to traditional forest inventories based on aerial photo-interpretation or subjective field surveys. It is also anticipated that the accuracy will be similar to those obtained with ALS-based methods or methods based on photogrammetric matching of digital aerial images for tree height and stem volume estimation.

## Discussion

The outcome of this study is important, since it will contribute to provide results to evaluate the TanDEM-X mission concept. If successful, the proposed method has the potential to retrieve forest tree height and stem volume with high-resolution and accuracy from space in areas where a high-resolution DEM of the ground topography is available. It is, therefore, expected to be a cost-effective way of mapping and updating forest variables.

## Conclusion

The obtained results are foreseen to be relevant for updating outdated inventory stand registers in support of forest management planning, implying that 3D data from TanDEM-X have potential for operational use in forestry.