

# Combined Land-Cover Classification and Stem Volume Estimation Using Multitemporal ERS Tandem INSAR Data

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**Abstract**— A radar-based method for producing both land-cover classification and stem volume estimates for the forested areas is demonstrated. The method utilizes multi-temporal INSAR data that is segmented into quasi-homogenous segments, and a semi-empirical backscattering-coherence model that is inverted to produce stem volume estimates for the forest segments. Forest stands with known stem volumes are required as training areas for determining the values of the model parameters. The performance of the method was studied by estimating the stem-volumes of 4000+ forest segments and comparing the results with stem volume estimates produced by ground-based estimates and the National Forest Inventory (NFI) of Finland. The method is suitable for operational use and the performance in stem volume estimation is comparable with optical methods.

**Keywords;** SAR Interferometry, coherence, stem volume estimation, land-cover classification

## I. INTRODUCTION

Previous studies have established that forest biomass (stem volume) has a large influence on the interferometric coherence [1,2,3]. However, the strong influence of weather conditions causes problems for stem-volume retrieval. In this study we demonstrate an operationally feasible method for land-cover classification and stem-volume retrieval using multi-temporal INSAR data. The method is based on segmenting the INSAR dataset into quasi-homogenous segments, classifying the segments according to the segment characteristics, and producing stem volume estimates for the forested segments by inverting a semi-empirical backscattering-coherence model. The method requires that forest stands with known stem volumes are available as training regions for determining the model parameters.

## II. TEST SITE AND DATA

Combined land-cover classification and stem volume estimation was studied on the Tuusula test site (60°N 25°E) in Southern Finland. The land-cover in the area is a mixture of agricultural, forested and urban land and the topography of the area is quite flat with some gentle hills. Scots pine and Norwegian spruce are the main species in the southern-type boreal forests of the area.

### A. SAR Data

The SAR data used the study consists of 14 ERS-1/2 Tandem image pairs acquired during 1995-1996. Data processing into 5-look intensity images and interferometric coherence images using various estimator window sizes was performed, and the image data was orthorectified into map coordinates using an INSAR DEM. Image noise was diminished by filtering both the intensity- and coherence image-series with a multitemporal filter described in [4].

### B. Reference Data

The reference data includes ground-based forest inventory data measured at the stand level, as well as the multisource Finnish National Forest Inventory (NFI) that employs Landsat TM data in addition to ground-based sampling in estimating forest stem volume with the k-Nearest Neighbor (k-NN) method [5].

## III. METHODOLOGY

The combined land-cover classification and stem volume estimation method is based on segmenting and classifying the land area, and inverting an empirical backscattering-coherence model for the forest polygons. The model and its inversion is described in detail in [3]. Stem volume estimates for training areas (forest stands) are needed in the model inversion.

### A. Modelling approach

According to the semi-empirical HUT backscattering model the C-band ERS-1/2 observed  $\sigma^o$  of conifer-dominated boreal forests as a function of stem volume [2]:

$$\sigma^o(V, \theta) = 0.131 \cdot a \cos \theta \left( 1 - \exp \left( -5.12 \cdot 10^{-3} \frac{aV}{\cos \theta} \right) \right) + b \exp \left( -5.12 \cdot 10^{-3} \frac{aV}{\cos \theta} \right) \equiv \sigma_{can}^o + \sigma_{floor}^o \quad (1)$$

where  $V$  is the forest stem volume [ $m^3/ha$ ] and  $\theta$  the incidence angle ( $\sim 23^\circ$  with ERS data). Parameter  $a$  is related to the volumetric vegetation water content and parameter  $b$  is the level of backscatter from the ground surface. The level of interferometric coherence as a function of stem volume is

linearly dependent on the ratio  $\sigma_{can}^o(V)/\sigma^o(V)$  [2]. Hence, the interferometric coherence can be modeled as:

$$|\gamma(V)| = c_0 + c_1 \cdot \left( \frac{\sigma_{can}^o(a, V)}{\sigma^o(a, b, V)} \right) \quad (2)$$

where  $c_0$  and  $c_1$  are empirical parameters that are determined using training data.  $c_0$  corresponds to the level of coherence for open areas, and  $c_1$  corresponds to the difference between coherence levels of very dense forests and open areas.

### B. Model inversion

The inversion of the backscattering-coherence model is a three-step procedure. In step I the backscattering model (1) is fitted to observations from training regions separately for each image pair. This step is performed in order to find out the values for the model parameters  $a$  and  $b$ . In step II the empirical coherence model (2) is fitted to coherence data from training regions separately for each image pair using the parameter values  $a$  and  $b$  determined in step I. The fitting is carried out with respect to parameters  $c_0$  and  $c_1$ . In step III the stem volume for any forest area  $j$  is determined by minimizing the squared difference between model predictions and multi-temporal INSAR observations:

$$\min_{V_j} \left\{ \sum_{k=1}^m W_k \left( |\gamma|_{\text{observed},k,j} - |\gamma(V_j)|_{\text{modeled},k} \right)^2 + \frac{1}{2 \cdot \text{Var}([V_1, \dots, V_N])} \left( V_j - \frac{1}{N} \sum_{i=1}^N V_i \right)^2 \right\} \quad (3)$$

such that  $V_j \geq 0$  m<sup>3</sup>/ha. Here  $W_k$  is a weight factor determined from the residuals of the fit in step II,  $k$  denotes image pair and  $V_1 \dots V_N$  are the mean stem volumes of the  $N$  training regions. The second term of (3) is an optional factor that regulates the optimization procedure; in practice it reduces the retrieval bias.

### C. Combined land-cover classification and stem volume estimation method.

The proposed method has five steps:

#### 1) Segmentation of the study area into quasi-homogenous segments.

The quasi-homogenous segments may be created from multi-temporal INSAR data using some standard segmentation algorithm. It is also possible to utilize segments from auxiliary data sources, for example from existing land-cover data and conventional stand-based forest inventory data. In this study a multiresolution segmentation of the mean ERS Tandem coherence image (mean of 14 images) was performed with the commercial software package eCognition.

#### 2) Classification of segments into forest segments and other land-cover classes.

The created segments are classified into forest and other land-cover classes based on their multi-temporal INSAR characteristics. If segments from auxiliary data sources are utilized, this step is not necessary. In this study the segments were classified into forest/water/open/urban – classes in eCognition. The six channels used in classification were mean intensity and mean Tandem coherence (mean for all 14 pairs), mean longtime coherence (35 and 245 days), 1<sup>st</sup> and 2<sup>nd</sup> principal components of the Tandem coherence time-series and 1<sup>st</sup> principal component of the intensity time-series. Overall land-cover classification accuracy of 90% into six classes has been achieved with this dataset using the same channels [6].

#### 3) Fitting the semi-empirical backscattering model (1) into the average $\sigma^o$ values of the training regions.

This is the step I in model inversion and it produces estimates for the parameters  $a$  and  $b$  for each used image pair. In this study two best image pairs from the set of 14 Tandem pairs were selected using forward selection criteria.

#### 4) Fitting the empirical coherence model (2) into the average coherence values of the training regions.

This is the step II in model inversion and it uses the values for parameters  $a$  and  $b$  determined in the previous step and produces estimates for the parameters  $c_0$  and  $c_1$  for each used image pair.

#### 5) Estimation of forest stem volume for any forest polygon by inverting the backscattering-coherence model for multi-temporal INSAR data.

This is the step III in model inversion. Once the parameters  $a$ ,  $b$ ,  $c_0$  and  $c_1$  have been estimated for each used image pair, minimizing (3) produces stem volume estimates for any forest segment.

## IV. RESULTS

The INSAR-based stem volume estimates were compared with ground based measurements and estimates produced by the NFI. The NFI-estimates were also compared with ground-based estimates. The results are presented in Fig. 1, Fig. 2, Fig. 3 and Table I. The results show that INSAR-based estimates have accuracies comparable with the NFI that utilizes optical satellite data. Figures 2 and 3 indicate that both NFI and the presented INSAR-based method seem to underestimate high stem volumes on this test site, and that NFI underestimates high stem volumes more than INSAR.

TABLE I. COMPARISON OF INSAR AND NFI STEM-VOLUME ESTIMATES WITH GROUND BASED REFERENCE DATA.

	BIAS (m <sup>3</sup> /ha)	RMSE (m <sup>3</sup> /ha)	Unbiased RMSE (m <sup>3</sup> /ha)	r
INSAR	-36	107	101	0.79
INSAR without regularization	-25	103	100	0.78
NFI	-27	118	115	0.69

## V. CONCLUSIONS

With the demonstrated radar-based method it is possible to produce a segmented land-cover classification with stem volume estimates for the forest segments. The method is suitable for operational use and it requires that stem volume estimates for training areas are available. The stem volume estimation performance of the method is comparable with estimates produced by optical methods.

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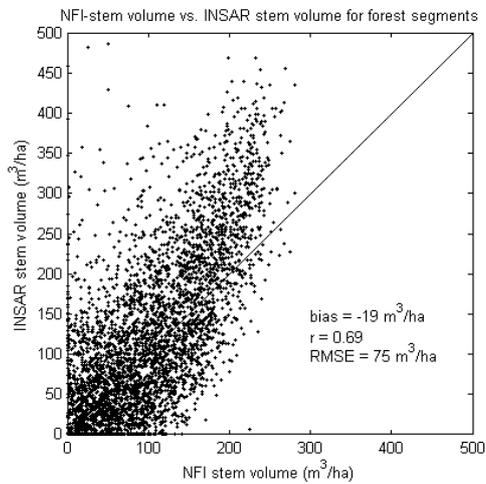


Figure 1. NFI stem volume estimates vs. INSAR estimated stem volume for 4000+ forest segments.

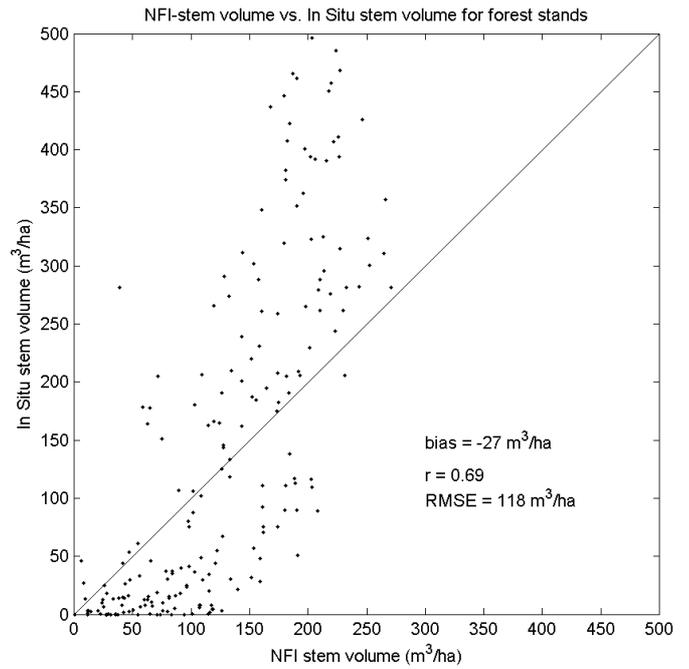


Figure 2. NFI stem volume estimates vs. stem volume measured on the ground for 210 forest stands.

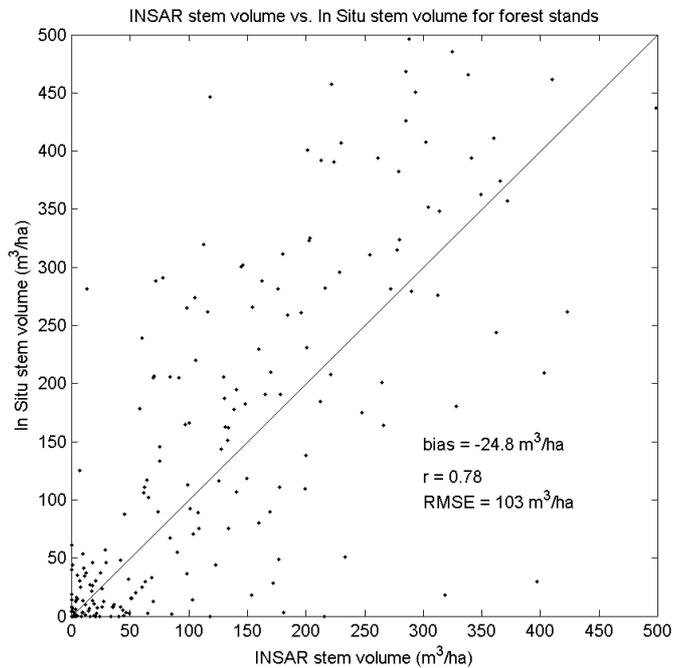


Figure 3. INSAR estimated stem volume (without regularization) vs. stem volume measured on the ground for 210 forest stands.