

## **Forest vertical structure characterization for Biomass estimation with Remote Sensing systems (Synthetic aperture radar): Spatial scale implications**

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### **Bulleted list of abstract highlights:**

- Derive Above-Ground Biomass (AGB) from forest vertical structure obtained from Remote Sensing systems (RS), especially Synthetic Aperture Radar (SAR), at different resolution scales.
- Vertical forest structure profiles from ground measurements are used to derive allometric relations that can be applied to vertical profiles derived from SAR systems. The study is carried out over the test site Traunstein located in the SE of Germany.
- AGB inversion results from modeled profiles are shown. Effects of spatial scale, height and structures deviations in the AGB inversion are shown. SAR-derived profiles will be evaluated and used in the AGB allometric inversion.
- Forest vertical structure is connected to AGB due to biophysical relations that exist between trees and their environment. These relations are evaluated using allometric relations and thus AGB estimations are improved. Averaging scale plays a fundamental role in the definition of vertical structure and AGB inversion, especially from RS.

### **Extended Abstract:**

Forest biomass stores an essential part of the terrestrial carbon and is therefore, a key element in the global carbon cycle. Mapping of forest total biomass and change are needed for understanding the development of the carbon fluxes [1]; however, biomass stock and spatial distribution are for many forest regions of the world rather poorly quantified [2]. Therefore, methodologies capable to retrieve biomass and forest dynamics at a global scale are highly demanded.

Remote sensing (RS) systems are capable to measure some forest parameters, like forest height and vertical forest structure over large areas with high spatial and temporal resolution. Forestry

science aims to reduce the effort of measuring biomass with the help of allometric functions which deduce biomass from easier measurable variables. However, the allometric functions derived for single trees are only partly valid for forest variables derived from RS, because these systems cannot retrieve single tree variables with sufficient accuracy. Thus, other allometric relations need to be developed. As a first step, an innovative approach shown in [3] proposes a height to biomass allometric relation ( $B = 1.3B^{1.58}$ ) which allows biomass estimation from RS systems capable of resolving forest height (LIDAR and polarimetric SAR interferometry (Pol-InSAR)) [4]. Yet, for complex forest stands the height to biomass relationship has a large variance due to different structural developments for the same forest heights. Thus, forest structure and especially biomass vertical distribution need to be characterized and their relation to AGB needs to be further investigated.

This work is organized as following: first vertical biomasses are modeled, then a vertical to biomass allometry is derived, spatial scale effects will be studied and finally, these relations will be implemented with SAR profiles.

These investigations rely on data from for the forest test site Traunstein, located in the South-east of Germany. This dataset consists of 221 inventory plots with tree height measurements, diameter at breast height (dbh) measurements and tree species information together with a full-waveform LiDAR and multi-frequency/multi-baseline SAR datasets.

Forest biomass structure is a three dimensional function whose characterization requires a method able to express its complexity for different forest structural stages. Its estimation is done modeling the vertical distribution of biomass along height [5]. First, we have modeled every tree according to a set of allometric functions divided in two sets of tree compartments, crown and stem.

Tree crowns are modeled based on species-specific functions (differentiating between sunlit and shade crown parts) shown in [6], while tree stems are modeled according to the improved brink function from Klaus von Gadow [7] (Eq. 1) (this function shows a good agreement with a theoretical stem shape: the lower section as a neiolid frustum, the middle section as a paraboloid frustum and the upper section as a cone):

$$r(h) = u + ve^{-ph} - we^{qh} \quad (1)$$

$$u = \frac{i}{1 - e^{q(1.3-h)}} + (dbh - i) \left( 1 - \frac{1}{1 - e^{p(1.3-h)}} \right), v = \frac{(dbh - i)e^{1.3p}}{1 - e^{p(1.3-h)}}, w = \frac{i.e^{-qh}}{1 - e^{q(1.3-h)}}$$

$r(h)$  is the tree radius as function of height ( $h$ ),  $h$  the total tree height,  $dbh$  the diameter at breast height,  $i$  a species specific asymptote parameter,  $p$  a species specific parameter describing the lower part of the stem and  $q$  a species specific parameter describing the upper

part of the stem. Then we calculate the biomass enclosed in this volume, with species specific allometric functions for the crown and the wood density of the stem, and finally the biomass of every tree in an inventory plot is summed up to obtain a vertical biomass profile.

Vertical biomass profiles characterize the distribution of biomass along forest height; however, as the resulting function is too complex to be directly used in an allometric relation, we parameterize them in terms of Fourier-Legendre decomposition [5]. Each profile is decomposed into a set of coefficients that represent the degree of adjustment of each polynomial to the profile structure. In order to isolate the vertical information, each profile has been then normalized to the first Legendre coefficient ( $1+a_0$ ;  $a_0=H/B$ ). In this way, the relation between height and biomass is removed from each profile. For this situation, a new allometric relation has been derived accounting for a structure to biomass relation at each height interval. This relation is made with the combination of the normalized coefficients  $a_{01}$  and  $a_{03}$  as following:

$$\begin{aligned} B1 &= 0.64a_{01}(462 - 31H)^{1.15} \\ B3 &= 0.45|a_{03}|(-400 + 24H)^{1.15} \\ B &= 0.5B1 + 0.5B3 \end{aligned} \quad (2)$$

$a_{01}$  and  $a_{03}$  are the normalized Legendre coefficients,  $H$  the profile maximum height and  $B$  the total biomass (AGB).

Forest vertical structure is scale (spatial) dependent. This point is important, not only from the ground inventory point of view, but also from the estimation of structure from RS. Spatial averaging can be performed using the height structures in the horizontal scale or accounting for the variation between vertical structures. Every inventory plot is averaged with its adjacent plots depending on distance and variation in height and structure thresholds. Different thresholds have been selected for distance, height and structure.

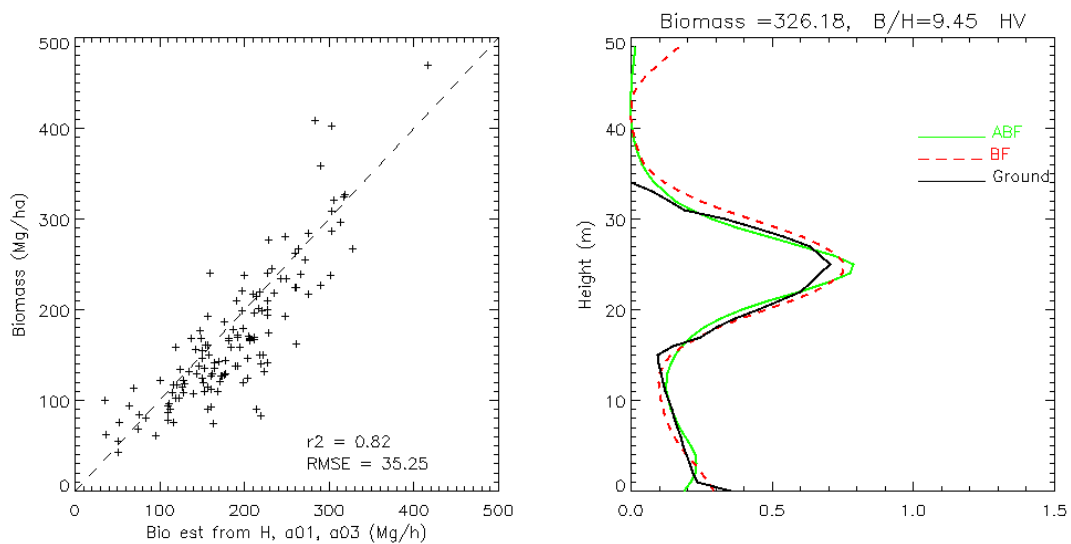
The analysis of the results has shown a trade-off between resolution and precision (Table 1). The biomass inversion is more stable with structure information than with only height estimation; however, if the estimation scale is enlarged over 4 ha (160x160 m window) for height homogenous areas, the height to biomass estimation improves over the structure to biomass; yet with a great loss in spatial resolution. A 100x100 m spatial averaging with a deviation threshold of 0.35 in the Legendre coefficients shows an optimum correlation  $R^2$  of 0.82 (Figure 1 - left).

With the results obtained for the ground estimated profiles, an inversion based on SAR tomographic profiles will be performed and compared for different scales and polarizations. As shown in Figure 1-right, the tomographic profiles show a good agreement with vertical biomass profiles, as well as a great potential for structure to biomass estimations.

A methodology capable to invert biomass at different scales is of especial importance to estimate AGB globally and will facilitate the estimation from different remote sensors and in different forest ecosystems.

**Table 1- Correlation results for the averaging methods tested. Four averaging methods are shown: averaging window of 100x100 and 160x160 m with a height deviation threshold of 2 m and with structure coefficient deviation threshold of 0.35. Biomass is inverted using a height to biomass relation ( $B= 1.3B^{1.58}$ ) and the structure to biomass equation.**

Averaging Method	Correlation - R <sup>2</sup>	
	H to bio	Struc to bio
No averaging	0.33	0.76
160m – 2m Hdev	0.87	0.83
100m – 2m Hdev	0.80	0.80
160m - 0.35 a01 and a03 dev	0.81	0.81
100m - 0.35 a01 and a03 dev	0.80	0.82



**Figure 1 – Left: biomass inversion using an averaging window of 100x100m with a structure threshold ( $a_{01}$  and  $a_{03} < 0.35$ ). Right: normalized vertical profiles example; in black: a vertical biomass profile, from inventory data, and two SAR profiles calculated with an HV polarization using two methods - dashed red Beamforming and green Adaptive Beamforming - .**

**References:**

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