BIOMASS ESTIMATION AS FUNCTION OF VERTICAL FOREST STRUCTURE AND FOREST HEIGHT. POTENTIAL AND LIMITATIONS FOR REMOTE SENSING (RADAR AND LIDAR)

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ABSTRACT

Forest biomass stock and spatial distribution are still unknown parameters for many regions of the world. Today's information is largely based on ground measurements on a plot basis without remote regions coverage. Thus, a method capable of quantifying biomass by means of Remote Sensing could help to reduce these uncertainties and contribute to a better understanding of the carbon cycle (Houghton *et al.*, 2009).

In Mette *et al.* (2004) a biomass estimation using the power law allometric relationship between biomass and forest height from ground inventories has been proposed: $B= 1.66\ H^{1.58}$ where B is the biomass and H forest top height. Thus, this height to biomass allometry allows biomass estimations from remote sensing systems capable to resolve forest height (LIDAR and polarimetric SAR interferometry (Pol-InSAR)). However, this approach meets its limitations for forest ecosystems under changing conditions in density and structure. Thus, to improve biomass estimation accuracy additional parameters need to be measured. Pol-InSAR and LIDAR allow getting, besides forest height, vertical backscattering profiles which are connected to forest vertical structure (Cloude, 2007; Lefsky, 1999).

The main objective of the present study is to investigate whether vertical forest structure, is linked to total above-ground biomass (AGB) and to develop a methodology for the estimation of AGB from forest structure parameters. Later these structure parameters will be related to vertical backscattering profiles obtained from LIDAR and radar systems.

Therefore inventory data from three different test sites situated in the South of Germany which represent different management systems are investigated: Traunstein, National Park "Bayerischer Wald" and Ebersberger Forst. The Traunstein test site is a temperate mountainous forest, the National Park "Bayerischer Wald" a close natural forest without management and Ebersberger Forst an intensively managed forest site.

Forest vertical structure can be characterized by forest vertical biomass distribution. The AGB of a single tree can be divided into two main components: crown and stem. Defining the form of stems and crowns as well as amount of biomass per compartment for every tree (Pretzsch, 2001; Zianis *et al.*, 2005), a vertical biomass distribution can be reconstructed.

The sum of the biomass distribution for all trees within a certain area (measurement plot) results in characteristic biomass profiles, as shown in Figure 1-left.

The best characterization of forest vertical structure is obtained using the Legendre polynomials. Biomass profiles can be then characterized by the decomposition into a set of basis functions. The Legendre decomposition is based on the Legendre series B(z) described as:

$$B(z) = \sum_n a_n P_n(z); \quad where: \qquad a_n = \frac{2n+1}{2}\int_{-1}^{1} B(z)P_n(z)dz \tag{1}$$

where a_n is the Legendre coefficient P_n represents the polynomials up to the fourth order as a function of height: $P_1(z)$ where n stands for the order (0 to 4).

$$\begin{aligned} P_0(z) &= 1 \\ P_1(z) &= z \\ P_2(z) &= \frac{1}{2}\left(3z^2 - 1\right) \\ P_3(z) &= \frac{1}{2}\left(5z^2 - 3z\right) \\ P_4(z) &= \frac{1}{8}\left(35z^2 - 30z + 3\right) \end{aligned} \tag{2}$$

Legendre polynomials tend to reconstruct the original profile with few components and can adopt the main low frequency features of a profile as shown in Figure 1-right.

Polynomials P_1 *(z)* to P_3 *(z)* seem to be sufficient to cover the sensitivity of structural parameter to total AGB. In Figure 2 biomass covered by Legendre polynomial P_1 *(z)* to P_3 *(z)* is plotted against total biomass for the three test sites, following a linear relationship, which can be described by:

$$B = Al \sum_{i=0}^{H} \sum_{j=1}^{3} a_j \cdot P_j \tag{3}$$

where B is the biomass in Mg/ha, Al the allometric level, H the height of the profile in m, a the Legendre coefficient, i the samples along height (intervals of 1m), P the Legendre polynomial and j the order of the Legendre polynomial. Values are in the range from 0.88 (Ebersberg) to 0.95 (Bavarian forest).

Changes in the allometric level Al (slope of the linear fit) among the test sites modify the allometric equation; however the variation for the three used Legendre components is minimal: the mean slope is for all the fitted lines 3.10 with a STDV of 0.10 (see Figure 3-left). Different behaviors according to the management system can be observed. With more intense management a higher contribution from the low frequency components is observed while in more natural environments the contribution of the higher frequencies increases. However, in all cases the biomass contributed by the Legendre components P_1 *(z)* + P_2 *(z)* + P_3 *(z)* explains more than the 90% of the total biomass (see Figure 3- right).

With the structure to biomass allometry, AGB can be potentially inverted if forest vertical structure is known. Vertical backscattering profiles can be provided by LIDAR or radar (Pol-InSAR techniques). However backscattering profiles are strongly depend on the sensor used. E.g. LIDAR profiles are more sensitive to leaves and crowns while Pol-InSAR tends to reconstruct more the woody compartments (stems and branches).

In this study vertical backscattering profiles from short footprint airborne LIDAR, ICEsat (large footprint spaceborne LIDAR system), and Pol-InSAR data are evaluated for their potential to reconstruct vertical forest structure. With the Legendre decomposition it is possible to parameterize the vertical backscattering profiles and relate them to forest biomass; even though for each remote sensing system different transfer methodologies must be derived. Research in this area is ongoing and will be presented. Figure 4 shows two examples of vertical backscattering profiles obtained from an Airborne LIDAR system (left) and a SAR tomographic profile (right) from the test site Traunstein. The similarity of these profiles with the vertical biomass distribution profiles, shown in Figure 2, is promising to be used for the potential derivation of biomass from remote sensing data.

Keywords: LIDAR, SAR, forest structure, above-ground biomass, Pol-InSAR.

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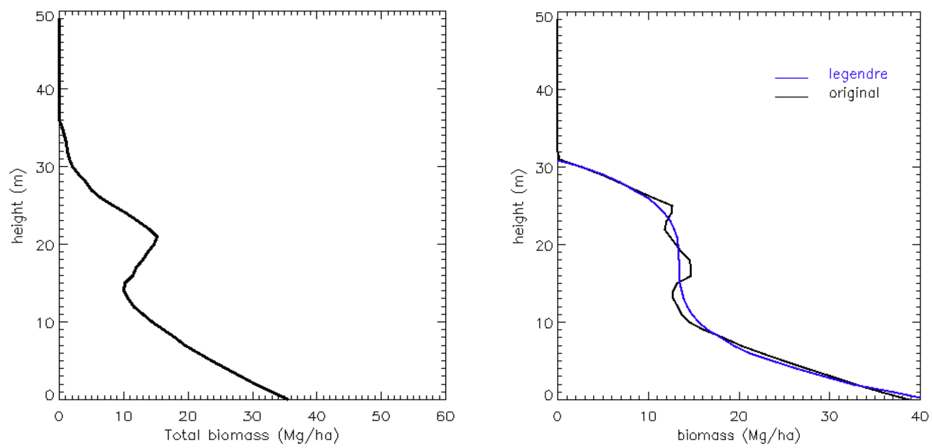

Figure 1. Left: Forest vertical biomass profiles from ground measurements. Right: Legendre reconstruction with 4 components of a forest vertical biomass profile.

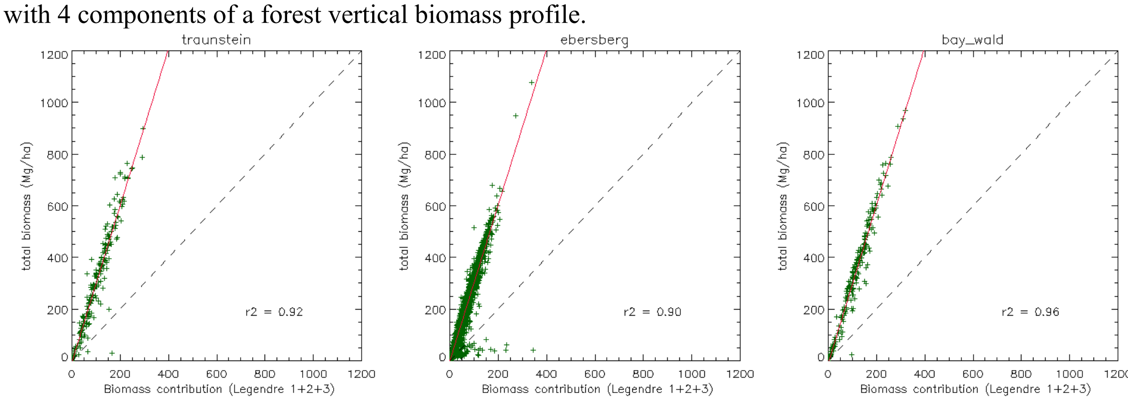

Figure 2. Biomass represented by Legendre Coefficient 1 to 3 for three test sites.

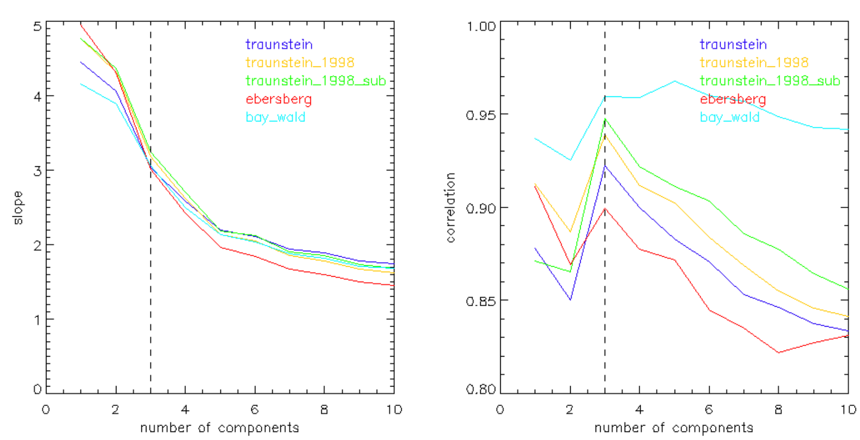

Figure 3. Influence of the number of Legendre components on the structure to biomass allometry. Left: slope of the linear fit vs. number of polynomials. Right: influence on the correlation factor r^2 vs. number of polynomials.

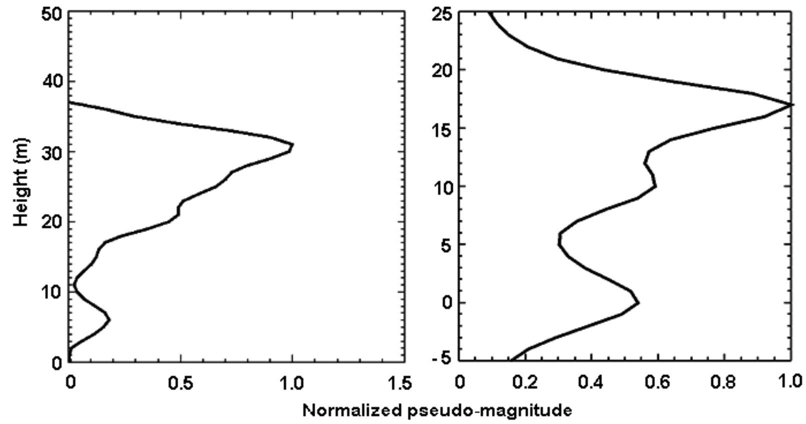

Figure 4. Vertical backscattering profiles. Left: Airborne Lidar profile. Right: SAR Tomographic profile.