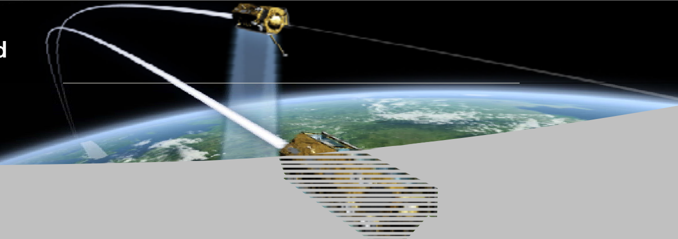

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# Forest Vertical Structure Characterization for the Estimation of Above-Ground Forest Biomass towards its Application in Radar Remote Sensing

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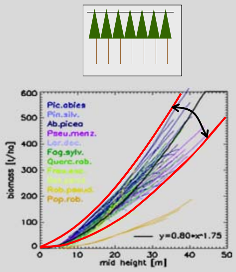
Above Ground forest Biomass (AGB) stock, spatial distribution and dynamics are critical ecosystem parameters unknown today for large regions of the world. High spatial resolution mapping and monitoring of these parameters on a global scale require advanced Remote Sensing (RS) techniques. Polarimetric SAR Interferometry (Pol-InSAR) allows the estimation of vertical structure profiles which are related to forest biomass. The analysis of vertical biomass distribution can be used in the development of a generalized RS based AGB estimation by means of Synthetic Aperture Radar (SAR).

## Height (H100) to Biomass allometry [1,2]

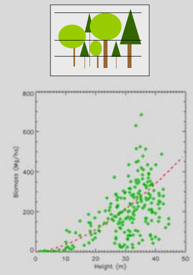
- Best performance for homogeneous closed canopy forests: Single species, homogenous in structure and density;
- Height allometry shows a reduced bias for most temperate forest species;
- Performance decreases in structured forests: Internal structure affects the biomass stock;
- Height to Biomass relation looses accuracy;
- An additional input parameter is needed (density, structure).
- Forest inventory data from Traunstein tests site is analyzed:
    - Traunstein is a highly structured forest stand.

[1] Mette, T., Papathanassiou K. and Hajnsek, I. Applying a common allometric equation to convert forest height from Pol-InSAR data to forest biomass.IGARSS proceedings 2004 .

[2] Köhler, P., Huth, A. Towards ground-truthing of spaceborne estimates of above-ground life biomass and leaf area index in tropical rain forests. Biogeosciences, 7, 2531–2543,2010.




Allometric curves for homogeneous stands and tree species.




Biomass vs. Height in a diverse structure stand (Traunstein).

### Traunstein data set

228 inventory plots in 100x100m grid.

## Forest Vertical Structure Characterization: Vertical Profiles and Structure Descriptors

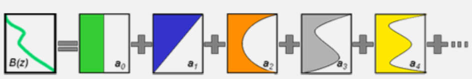
Available SAR systems can measure forest vertical structure. Vertical biomass profiles are modeled from ground inventory data and normalized to obtain the vertical distribution of biomass.

The Legendre decomposition is used as a structure descriptor. A low number of Legendre polynomials (4) is enough to distinguish between different levels of biomass .

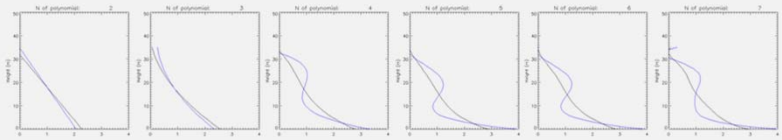
$$B(z)=\sum_n a_n P_n(z); \quad \text{where:}$$

$$a_n=\frac{2n+1}{2}\int_{-1}^{1} B(z)P_n(z)dz$$

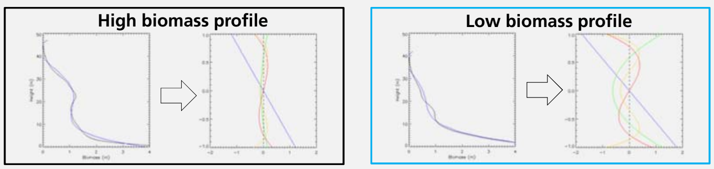
B = Total biomass (Mg/ha)
H = Total height (m)
$a_n$ = Legendre coefficient
$P_n$ = Legendre characteristic polynomial




$$P_0(z)=1\ ;\ P_1(z)=z\ ;\ P_2(z)=\frac{1}{2}(3z^2-1)\ ;\ P_3(z)=\frac{1}{2}(5z^2-3z)\ ;\ P_4(z)=\frac{1}{8}(35z^2-30z+3)$$




**Maximum (black) and minimum (blue) biomass profile reconstruction at 35 m. 4 Legendre polynomials are sufficient to detect differences in the profile.**

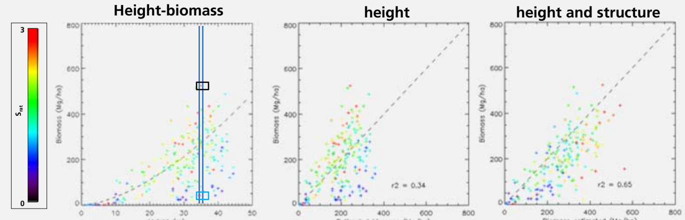



**Biomass profile and Legendre decomposition for 4 polynomials. Original biomass profile (black), reconstructed profile with 4 Legendre polynomials (blue).**

- High biomass profiles are characterized by a low frequency profiles, as a mature stand approaches presents a homogeneous biomass distribution. For the same dominant height a stand with less biomass is characterized by a higher frequency profile
- A structure ratio calculated between low and high frequency Legendre polynomials can characterize the changes in biomass for a constant height:

$$S_{rat}=\frac{|a_{01}|}{|a_{02}|+|a_{03}|+|a_{04}|}$$

- The height to biomass allometry can be then modified by correcting the forest height with the structure ratio. The structure ratio converts the measured forest height into a virtual height at the allometric curve, reducing the bias and improving the biomass estimation

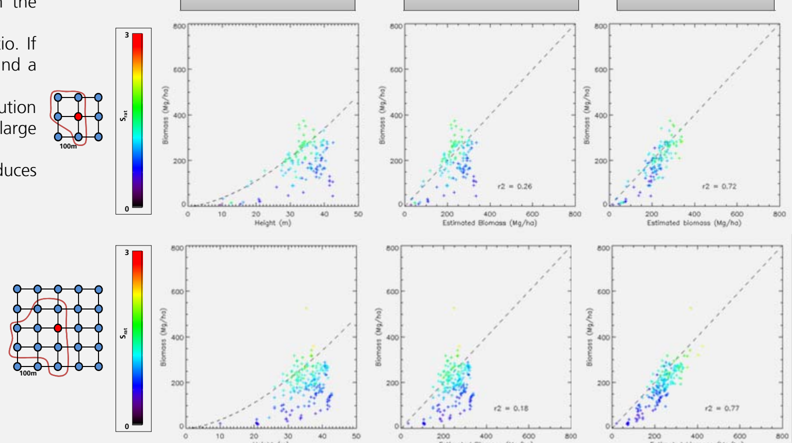



$B = l_a \cdot 1.66 H^b$ | $B = l_a \cdot 1.66 H^b$ | $B = 1.1 * 0.7^{0.4} S_{rat} H^{1.7}$

## Structure to Biomass: a Scale Dependent Problem

Vertical structure is also sensitive to the horizontal scale used in the estimation of the biomass profile.

- Inventory plots can be aggregated according to the structure ratio. If the ratio difference is lower than 0.5 the plots are aggregated and a new ratio is calculated;
- If the cluster size is too small, small changes in the forest distribution severely impact the structure profile but if the averaging is too large structure is too smoothed and becomes insensitive to biomass;
- A higher averaging window decreases the allometric level and reduces the structure ratio range.




## Conclusions

1. Structure to Biomass allometry is able to improve the estimation of (AG) biomass;
2. A vertical structure descriptor base on Legendre polynomials is sensitive to (AG) biomass.
3. Low frequency vertical structure components are sufficient for (AG) biomass reconstruction;
4. An adequate averaging scale must be selected to improve the biomass estimation without sacrificing the resolution.