Forest biomass estimations derived from 3D forest structure for application in remote sensing (LiDAR, Radar)

Astor Toraño Caicoya

German Aerospace Center (DLR)

Microwaves and Radar Institute
The terrestrial (Vegetation) component is the largest unknown parameter in the Global Carbon Balance.

Carbon balance and (Forest) Biomass

IPCC 2010. Quantities in millions of tones/year

$\Sigma$ Carbon balance and (Forest) Biomass

- Fossil emissions: $1.0 \pm 1.1$
- Land use changes: $2.2 \pm 0.4$
- Ocean sink: $2.6 \pm 1.7$

“Missing” Terrestrial Sink

Carbon emissions into the Atmosphere (Total): $3.2 \pm 0.1$
Biomass characterizes the spatial distribution of Carbon (50% of Biomass is C);

Biomass Inventory & Dynamics are globally unknown!

... estimation varies from 39 to 93 GtC

Amazonas basin
Introduction. Motivation and Context

- Forest biomass is a second order parameter:

\[ B = \frac{\pi \cdot DBH^2}{4} \cdot H \cdot f_{\text{species}} \cdot \rho_{\text{wood}} \]

- Reduce of number of parameters (allometry) - empirical relations.

Allometry: Science that studies the relations between the size dimensions of living forms (trees).

- Reduce effort of measurements using Remote Sensing

- Mette with Pol-InSAR (Radar).
  Height - Biomass allometry.

\[ B = l_a \cdot 1.66H^{1.50} \]

Lidar/Radar resolve structural forest parameters

HEIGHT
Vertical backscattering STRUCTURE.
Traunstein Test Site

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Temperate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography</td>
<td>Moderate slopes</td>
</tr>
<tr>
<td>Height</td>
<td>25 ~ 35m</td>
</tr>
<tr>
<td>Species</td>
<td>N. Spruce, E. Beech, White Fir</td>
</tr>
<tr>
<td>Biomass</td>
<td>40 ~ 450 t/ha</td>
</tr>
</tbody>
</table>

Total Biomass [Mg/ha] vs (Top) Height (H100) [m]

r² = 0.52

LiDAR

Radar
**Influence of structure in the biomass**

- **Height Biomass relation:** works best for traditional forest structure. High density, single species, even aged.

- **Complex forest structure:** Internal structure affects the biomass stock.
  - Height – Biomass relation loses accuracy.
  - Second parameter is needed: e.g. Density or STRUCTURE.

**Forest vertical structure changes with time and forest height, i.e. with forest evolution**
Vertical structure characterization: Vertical Biomass profiles

kd = crown diameter
kra = crown height
rl = light crown radius
rs = shadow crown radius
a, b, c, d = species specific parameters
h = tree height
bdh = breast height diameter
lo = length of light crown
lu = length of shadow crown
E = Distance to the top

Field Plot

Trees with dbh < 10cm
10 cm < tree dbh < 30cm
trees with dbh > 30cm
Vertical structure characterization: Legendre Decomposition.

Legendre Coefficients:
- Each Coefficient represents the degree of adjustment of the polynomial with the original curve (biomass profile).

\[
B(z) = a_0 + a_1 P_1(z) + a_2 P_2(z) + a_3 P_3(z) + a_4 P_4(z) + \ldots
\]

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

\[
B = \sum_{i=0}^{H} \sum_{j=0}^{n} a_j \cdot P(z)
\]

- \( B = \) Total Biomass (Mg/ha)
- \( H = \) Total Height (m)
- \( a = \) Legendre coefficient
- \( P = \) Legendre characteristic Polynomial
Legendre Decomposition: individual coefficients

- **$a_0$**: Total Biomass (Mg/ha) vs. Biomass contribution of Component 0 (Mg/ha), $R^2 = 1.00$
- **$a_1$**: Total Biomass (Mg/ha) vs. Biomass contribution of Component 1 (Mg/ha), $R^2 = 0.88$
- **$a_2$**: Total Biomass (Mg/ha) vs. Biomass contribution of Component 2 (Mg/ha), $R^2 = 0.08$
- **$a_3$**: Total Biomass (Mg/ha) vs. Biomass contribution of Component 3 (Mg/ha), $R^2 = 0.81$
- **$a_4$**: Total Biomass (Mg/ha) vs. Biomass contribution of Component 4 (Mg/ha), $R^2 = 0.40$
\[ B = l_a \cdot 1.66H^{1.58} \]

Minimum height with cylindrical poles

\[ R^2 = 0.54 \]

\[ B = l_a \sum_{i=0}^{3} \sum_{j=1}^{H} a_j \cdot P(z) \]

\[ R^2 = 0.81 \]

Coefficients 1+2+3

Components 1+2+3

\[ B = 2.88x \]

\[ R^2 = 0.92 \]
Sum the total intensity of the elements that fall within 1 m height bins.

Tree Heights
Traunstein

Intensity (amplitude)
horizontal projection
LiDAR validation and decomposition. Biomass inversion.

\[ x = \left[ -1, 1 \right] \]
\[ y = -\frac{9}{40} + \frac{1}{12} x - \frac{1}{360} x^2 \]

\[ y = \log(x^{5.8} + 1) \]

\[ R^2 = 0.76 \]
Traunstein Test Site: PolInSAR height
Vertical Forest Profile Reconstruction

Test site: Traunstein, Germany, L-band @ HV Polarization
Traunstein Test Site

\[ B = l_a \cdot \sum_{i=0}^{H} \sum_{j=1}^{3} a_j \cdot P(z) \]
Joint future mission between Germany-DLR and The USA-Nasa(JPL)

State of the art implementation is able to provide at a spatial resolution on the order of 7x2m

- Every week: forest / non-forest mapping at 10x10m
- Every 2 weeks: forest height change detection at 30x30m
- Every 2 months: global structure map
  - forest height map at 30x30m
  - forest structure map 50x50m

Future missions: Tandem-L

swath width: 350 km
duty cycle: 30 min / Orbit

IPCC 2010. Angaben in Milliarden Tonnen Kohlenstoff / Jahr
Thank you for your attention, Questions?

POlarimetric SAR image