A new era for measuring global forest properties: the ESA Biomass mission

Shaun Quegan
University of Sheffield
Centre for Terrestrial Carbon Dynamics

The Biomass Mission Advisory Group: Shaun Quegan, Jerome Chave, Jorgen Dall, Thuy Le Toan, Kostas Papathanassiou, Andrea Perrera, Fabio Rocca, Sassan Saatchi, Klaus Scipal, Hank Shugart, Lars Ulander & Mathew Williams
Biomass will map forest biomass, height and change from space with unprecedented accuracy

Forest biomass and forest height:
global, 200 m scale, every 6 months for 4 years, 20% accuracy in biomass, 20-30% accuracy in height

Disturbances: global, at 50 m scale
The effects of forest changes on climate

8.3±0.4 GtC/yr

1.0±0.5 GtC/yr net flux

4.3±0.1 GtC/yr

2.6±0.9 GtC/yr

2.5±0.5 GtC/yr

95% of net flux is in the tropics

Calculated as the residual of other flux components

Global Carbon Project, 2012
Changes in biomass affect the benefits we gain from forests

Changes in forest biomass have major effects on the socio-economic, material, energy, protective, biodiversity & cultural benefits offered by forests.
Biomass is needed as a reference for international treaties and carbon trading
Carbon emission estimates from deforestation and degradation are very uncertain.

\[ \Delta C = \sum \Delta A \cdot B \cdot E + \sum A \Delta B \cdot E \]

where \( A \) is the area of forest type, with biomass \( B \) and an emission efficiency factor \( E \).

BIOMASS will provide direct measurements of biomass change exactly where deforestation and degradation occur.
Model estimates of biomass are unreliable

Biomass estimates from 3 state-of-the-art Dynamic Vegetation Models

Carbon cycle models need to be evaluated against independent biomass maps
The observed relationship between biomass and Net Primary Productivity
Biomass information tells us about forest mortality

If the rate of loss of biomass is proportional to biomass, with rate coefficient $\alpha$, then

$$B = \frac{\overline{P}_B}{\alpha}$$

where $\overline{P}_B$ is mean production of biomass (which is proportional to Net Primary Productivity)
Landscape carbon dynamics are written in biomass

Polarimetric P-band SAR image of Yellowstone Park (2003)

A week after burn
P-HV = - 27 dB

60-80 years after burn
P-HV = - 12 dB

15 years after burn
P-HV = - 19 dB
Carbon flux depends on the disturbance regime

\begin{align*}
\text{M} &= \text{mean loss of biomass} \\
\text{F} &= \text{severity of disturbance} \\
\text{P} &= \text{probability of disturbance}
\end{align*}
How can biomass be measured from space?

A radar sensor with long enough wavelength:

1. can penetrate the canopy in all forest biomes
2. interacts with large, stable woody vegetation elements
3. allows forest height to be estimated with a single satellite

Implication: use a radar with the longest possible wavelength from space, i.e. ~70 cm (P-band).
The Biomass mission will make 3 types of measurement relevant to biomass:

- **PolSAR** (SAR Polarimetry)
- **PollInSAR** (Polarimetric SAR Interferometry)
- **TomoSAR** (SAR Tomography)
The mission will be supported by key worldwide *in situ* networks

In situ network led by Smithsonian, including Centre for Tropical Forest Science
Tropical biomass: La Selva, Costa Rica

Land use: La Selva Biological Station

Biomass from NASA AirSAR P-band polarimetry & forest height

Accuracy assessment: radar estimates vs ground estimates

Landsat image with sample plots marked
Summary

• Biomass products address urgent scientific, political and societal issues, and will be of immediate value to the global community of carbon cycle and climate scientists, climate treaty negotiations, carbon traders and resource managers.

• Biomass measurements give key information on the Land Use Change flux (both emissions and uptake), forest mortality, and carbon dynamics.

• Effective collaboration with the *in situ*, lidar and modelling communities is essential, both to train and validate Biomass measurements, and to weave them into our overall carbon monitoring systems.
Space Object Tracking Radar constraints have little effect on primary mission objectives.
Sensitivity of radar to biomass increases with wavelength

Landes forest, France
L-band SAR: RAMSES
P-band SAR: AirSAR
VHF SAR: Carabas
Global forest cover & biomass distribution is concentrated within the tropics

Total Forest Area: 31% of the land surface

<table>
<thead>
<tr>
<th>Forest Biome</th>
<th>Area (Millions of hectares)</th>
<th>Biomass (tons/hectare)</th>
<th>Total Biomass (gigatons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal</td>
<td>1372</td>
<td>83-128</td>
<td>110-176</td>
</tr>
<tr>
<td>Temperate</td>
<td>1038</td>
<td>114-270</td>
<td>118-280</td>
</tr>
<tr>
<td>Tropical</td>
<td>1755</td>
<td>190-390</td>
<td>350-680</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4165</td>
<td>mean 129-262</td>
<td>718-1300</td>
</tr>
</tbody>
</table>

Pan et al., 2011; Houghton et al., 2009
Forest biomass is a key element of Earth’s carbon cycle

1. Biomass is ~50% carbon

2. Forests hold 70–90% of Earth’s above-ground biomass, with the major part located in the tropics

3. Changes in forest biomass represent carbon sources (deforestation and forest degradation) and carbon sinks (forest growth)

Biomass = dry weight of woody matter + leaves (tons/hectare)