Biomass: an essential variable for climate

Mathew Williams
University of Edinburgh and
National Centre for Earth Observation
Biomass is linked to climate through the global carbon cycle.
Fate of Anthropogenic CO$_2$ Emissions (2002-2011)

8.3±0.4 GtC/yr

4.3±0.1 GtC/yr

2.6±0.9 GtC/yr

2.5±0.5 GtC/yr

1.0±0.5 GtC/yr net flux

95% tropical net flux

Calculated as the residual of other flux components

Global Carbon Project, 2012
Forest biomass is a key component in the carbon cycle

1. Biomass is ~50% carbon

2. Forests hold 70–90% of Earth’s above-ground biomass, with the majority of forest biomass located within the Tropics

3. Forest biomass is very poorly known and is a major source of uncertainty in carbon flux estimation.

Biomass = dry weight of woody matter + leaves (tons/hectare)
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
Latest tropical above-ground biomass (AGB) maps use non-optimal data and have large biases

Largely based on ICESat—no longer available
Carbon emission estimates from deforestation and degradation are uncertain

Gross carbon emissions

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

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

We need a direct measurement of biomass change exactly where deforestation and degradation occur
Model estimates of biomass are questionable

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

Carbon cycle models need to be evaluated against independent biomass maps
Divergent predictions of climate-carbon coupling

Sensitivity of NPP to climate

<table>
<thead>
<tr>
<th>% NPP change for 1°C increase</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>-6</td>
<td>0.5</td>
</tr>
<tr>
<td>-5</td>
<td>1.0</td>
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<tr>
<td>-4</td>
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<tr>
<td>-3</td>
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<td>2.0</td>
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<tr>
<td>2</td>
<td>3.5</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Sensitivity of NPP to CO₂

<table>
<thead>
<tr>
<th>% NPP change for CO₂ doubling</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>20</td>
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<td>30</td>
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<td>70</td>
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</tr>
<tr>
<td>80</td>
<td>3.5</td>
</tr>
<tr>
<td>90</td>
<td>3.5</td>
</tr>
</tbody>
</table>

NPP=net primary production, i.e. biomass growth

Data from IPCC AR4
C5MIP projections differ significantly

Uncertainty in land carbon uptake due to differences among models is comparable with the spread across scenarios

Jones et al. 2013
biomass

EARTH EXPLORER 7

An Earth Explorer to observe forest biomass

ALOS (JAXA)
GEDI (NASA)
Sentinel

European Space Agency
Biomass ECVs

• Biomass
• Biomass growth
• Biomass residence time
• Biomass removals (harvest/fire)

Calibration and validation activities required with field observations
Terrestrial ecosystem carbon cycle analysis

Parameter probability $p(x|c)$ at each pixel derived using a Metropolis-Hastings MCMC algorithm.

### Drivers:
- Climate Forcing
- Burned area
- Forest change

### C model (DALEC)

### Biometric Data Constraints
- Leaf Area Index (LAI)
- Biomass
- Soil Organic C

**Posterior C Model**
- Parameter Probability
  - $1^\circ \times 1^\circ$ Pixel scale parameter, flux & carbon pool estimates

**C state likelihood function** = observation likelihood & parameter priors
- No spin-up
- No PFTs
- No Steady state

**Bloom et al., in review.**
Mean monthly C exchanges at 1° x 1° constrained by data

2001-2010: global terrestrial carbon cycle analysis.

Bloom et al, in review.
Biomass residence times constrain climate sensitivity

Bloom et al, in review.
Biomass analyses will address key science questions linked to climate:

• land use change and land use
• ecological processes
• climate-carbon coupling
• earth system model evaluation
Biomass ECV actions

• Evaluation of current and future biomass sensors
• Quantify change detection (biomass growth and LUC)
• CAL/VAL interactions
• Tools for generating analysis products
Acknowledgements:

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Funding: NERC, NCEO, ESA, FP7
**Main climate application**
Vegetation above-ground biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation biomass is a global store of carbon comparable in size to atmospheric carbon, while changes in the amount of vegetation biomass due to deforestation significantly affect the global atmosphere by acting as a net source of carbon. Vegetation systems have the potential either to sequester carbon in the future or to become an even larger source. Depending on the quantity of biomass, vegetation cover can have a direct influence on local, regional, and even global climate, particularly on air temperature and water vapour. Therefore, a global assessment of biomass and its dynamics is an essential input to climate change prognostic models and mitigation and adaptation strategies.

Biomass plays two major roles in the climate system: (a) photosynthesis withdraws CO2 from the atmosphere and stores it as biomass, some of which goes into long-term stores in the soil; (b) the quantity of biomass consumed by fire affects CO2, other trace gases, e.g., CH4, CO, and aerosol emissions.

**Contributing Network(s)**
- FAO’s Forest Resource assessment Project (FRA)
- FLUXNET

**Status**
- No designated baseline network exists.
- No global data centre for non-forest biomass exists.
- FRA data currently not applicable for high-resolution spatial analysis.

**Contributing Satellite Data**
- Low-frequency radar, optical and laser altimetry

**Status**
- Laser/radar missions currently planned; need to be implemented.

**Current capability**
- Only above-ground biomass is measurable with some accuracy at the broad scale, while below-ground biomass stores a large part of total carbon stocks and is rarely measured. Most nations have schemes to estimate woody biomass through forest inventories (little is recorded on non-forest biomass, except through agricultural yield statistics). This typically forms the basis for the annual reporting on forest resources required by the UNFCCC. Experimental airborne sensors have demonstrated technologies for estimating biomass (low-frequency radar, lidar) and are suitable for satellite implementation that could provide global above-ground biomass information at sub-kilometre resolutions. There are limitations to these technologies, of which some are known (for example, saturation of radar backscatter at higher levels of biomass) and some still the subject of research.

- National inventories of biomass differ greatly in definitions, standards, and quality, and the detailed information available at national level is normally unavailable internationally. Nonetheless, these form the basis of the country-by-country summary statistics, such as those published by the FAO in their Forest Resource Assessments.

- Progress toward creating global gridded biomass datasets can be achieved by appropriately-designed satellite and aircraft missions, notably active microwave and laser systems. Space agencies should plan for such missions.
GCOS Essential Climate Variables Terrestrial

• River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.
ICOS