Integration of forest inventories with remotely sensed data for biomass mapping: First results for tropical Africa

Alessandro Baccini
Nadine Laporte
Scott J. Goetz
Mindy Sun
Wayne Walker
Jared Stabach

The Woods Hole Research Center, 149 Woods Hole Road, Falmouth, MA 02540, USA

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Outline

- Above ground forest biomass
- Remote sensing
- Data and methods
- Results and validation
- How to extend field measurements with remotely sensed data
  - Field protocol optimized for remote sensing applications
- Future work
Above Ground Forest Biomass

- **What is Biomass?**
  
  *Biomass is the total amount of above ground living organic matter in the vegetation expressed as oven-dry mass per unit area*

- **Biomass is relevant for:**
  
  - carbon cycle research
  - climate change studies
  - forest management
  - firewood supply to support human populations (in developing countries wood fuels still provide 70%–90% of energy)
  - in support of mechanisms to Reduce CO2 Emissions from Deforestation and Degradation (REDD)

Biomass estimates show large uncertainty, biomass stored in Brazil’s Amazonian forest vary by a factor of 2 (from 39 PgC to 93 PgC)²
Forest Biomass Information

Forest biomass data can be collected or derived from:

Forest inventory
- Accurate at national scale
- Non continuous in space
- Detailed but representative of small areas
- Time and costs

Biomass
- Conversion of timber inventory data by allometric relations (expansion factors to account for leaves and branches)\(^1\)

\(^1\)Schroeder (1996), Brown (2001), Chave (2005)
Remote Sensing

Advantages
- Continuous in space
- Repeat in time
- Covers large areas at relative low costs

Applications
- Land cover classification
- LAI and FPAR
- Forest structure (tree height, D.B.H, basal area, canopy cover, timber volume, biomass)
  - very few estimates at pixel level

Courtesy: R. Myneni
Data sets

Biomass data:
- Forest inventory measurements and high spatial resolution biomass maps

Remote Sensing:
- Moderate Resolution Imaging Spectroradiometer (MODIS) Nadir Bidirectional Reflectance Distribution Function (BRDF) adjusted reflectance (MOD43B4.V4)
- ICESAT – GLAS lidar measurements
Distribution of Field Biomass Samples
Cameroon, Rep of Congo, Uganda

Field biomass measurements

MODIS 1km NBAR (RGB 2,6,1)
Biomass data
MODIS: System Characteristics

• MODIS Instrument Characteristics
  – 36 spectral bands, VNIR, SWIR, TIR (0.4–14 μm)
    • Seven specifically designed for land observation
  – Spatial resolutions at 250-, 500-, and 1000-m (nadir) depending on waveband
  – Repeat: 2-day global repeat, 1-day or less poleward of 30°

• Improvement over heritage (AVHRR)
# MODIS Land Bands

<table>
<thead>
<tr>
<th>Band number</th>
<th>Spatial resolution</th>
<th>Wavelength, nm</th>
<th>Waveband region</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>250 m</td>
<td>620-670</td>
<td>Red</td>
</tr>
<tr>
<td>2</td>
<td>250 m</td>
<td>841-876</td>
<td>Near-infrared</td>
</tr>
<tr>
<td>3</td>
<td>500 m</td>
<td>459-479</td>
<td>Blue</td>
</tr>
<tr>
<td>4</td>
<td>500 m</td>
<td>545-565</td>
<td>Green</td>
</tr>
<tr>
<td>5</td>
<td>500 m</td>
<td>1230-1250</td>
<td>Near-infrared</td>
</tr>
<tr>
<td>6</td>
<td>500 m</td>
<td>1628-1652</td>
<td>Shortwave infrared</td>
</tr>
<tr>
<td>7</td>
<td>500 m</td>
<td>2105-2135</td>
<td>Shortwave infrared</td>
</tr>
</tbody>
</table>
Key Input Used:
NADIR, BRDF-Adjusted Reflectance
(Schaaf et al., 2002; RSE)
Removes artifacts associated with variable view geometry
Atmospherically corrected and cloud cleared
However…. Artifacts due to clouds residuals and shadow are present
Compositing over time successfully remove artifacts
Reflectance quality

2000 NBAR best quality flagged pixels (full inversion)
Composite of Remote Sensing Images

Pixels mosaic of best quality reflectance over the period 2000-2003
Regression Tree Model

Regression Tree

- *Univariate Decision Tree*
- *Nonparametric*

- Provides robust, repeatable results
- Non linear relationships
- Relies heavily on input training database
Inputs and Model Flow

- **Surface Reflectance (NBAR)**
  - View-angle corrected surface reflectance
  - Pixel mosaic of best quality NBAR
  - 7 land bands

- **Biomass training**

```
Explain Training for Biomass Sites
Estimate Tree Model
Apply Model to Regional Data
Biomass Map
```
MAPPING APPROACH
Regression Tree based on MODIS bands 1-7
Relationship between “observed” biomass and model predictions
A first map of Tropical Africa's biomass from satellite imagery

The tree model explained 82% of the variance in above-ground biomass density, with a root mean square error (RMSE) of 50.5 Mg/ha.
Vegetation structure from Lidar

Lidar metrics have been extensively used to characterize vegetation structure (Sun et al. 2008, Lefsky et al. 2005, Lefsky et al. 1999)

Drake et al. (2003), Lefsky et al. 2005, Drake et al. 2002 found a strong relationship between AGB and Lidar metrics (HOME)
The figure shows 30% of the GLAS L2A (year 2003) shots after screening procedure. We used 1.3 million observation
Relationship between GLAS metrics and model predicted biomass

Predicted biomass (Mg/ha) aggregated in classes of 10 Mg/ha.
The horizontal bars show the standard error for the GLAS metrics.
How to extend field measurements with remotely sensed data
Available Forest Inventory Data

- Only few countries/regions have updated forest inventory data
- Measurements are not consistent (D.B.H, species sampled, design)
- Spatial distribution non optimal for remote sensing integration and scaling up

MODIS 500 m grid over Landsat data and field transects (white lines)
Distribution of Field Biomass Samples
Cameroon, Rep of Congo, Uganda

MODIS 1km NBAR (RGB 2,6,1)
The Geoscience Laser Altimeter System (GLAS)

The figure shows 30% of the GLAS L2A (year 2003) shots after screening procedure. We used 1.3 million observation
Forest inventory design for remote sensing calibration

Objective:

– A **network** of field measurements using a standardized methodology at the sub-national, national and international level

– Optimized for remote sensing integration
  - Predefined locations
  - Plot size similar to remote sensing foot print
Objective:

– A network of new field measurements using a standardized methodology at the sub-national, national and international level

– Optimized for remote sensing integration
  • Predefined locations
  • Plot size similar to remote sensing foot print
  • Representative of biomass range
Sample plot shape

- Predefined location
- Square shape 40 m by 40 m
- Only basic variables recorded
Field Measurements and Data Collection

- Tree DBH measurements
  - All trees with D.B.H > 10 cm

- Tree Height
  - Six trees
    - Tallest 3 trees
    - Average 3 trees

- Land cover/Land use Description
Summary

- Integration of field measurements with RS provides spatially explicit estimates of biomass
- Limited availability of field measurements
- GLAS has the potential to extend field measurements
- A network of forest inventories for calibration and validation