Gabon’s Forests...
Mapped and Monitored to reduce climate change
Mapping and Monitoring Carbon Storage: Fusion of Ground and Space Measurements

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Fusing ground and space measurements

• What can ground data tell us about carbon stocks and change over time?

• What can satellite data tell us about carbon stocks and change over time?

• What can a fusion of both tell us?
Tropical Forests and Climate Change

- Changing land-use and forest degradation are the cause of 10-20% of anthropogenic carbon emissions; \( \sim 1.5 \text{ Pg C yr}^{-1} \) (Van der Werf et al. 2009, Nature Geoscience).

- Conversely, tropical forests absorb 10-15% of all human-induced emissions of carbon; \( 1.3 \text{ Pg C yr}^{-1} \) (Lewis et al. 2009, Nature).
What can ground-based direct measurements tell us?

• Calculate carbon storage in a defined area to:
  – Allow ‘painting by numbers’
  – Calibrate remote sensing product outputs
  – Validate remote sensing product outputs

• Monitor changes that satellites can’t

• Provide measurements of IPCC pools that satellites can’t, e.g.
  – Litter
  – Coarse woody debris
Obtaining aboveground live tree carbon (plot) data

- Define area, measure, map, identify all trees >threshold size, often 10 cm diameter
- Note: not technically difficult except botany, but easy to get wrong
- Exact methods have converged over time, see RAINFOR, CTFS, AFRItron, TEAM networks of plots
Check, manage and process the data
<table>
<thead>
<tr>
<th>Plot Code</th>
<th>Terrain commercial</th>
<th>Pays</th>
<th>Continent</th>
</tr>
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<tbody>
<tr>
<td>ASN-02</td>
<td>Asenanyo F.R. 2</td>
<td>GHANA</td>
<td>Africa</td>
</tr>
<tr>
<td>ASN-04</td>
<td>Asenayo</td>
<td>GHANA</td>
<td>Africa</td>
</tr>
<tr>
<td>ASU-01</td>
<td>Asukese F.R. 1</td>
<td>GHANA</td>
<td>Africa</td>
</tr>
<tr>
<td>ASU-02</td>
<td>Asukese Plot 100</td>
<td>GHANA</td>
<td>Africa</td>
</tr>
<tr>
<td>BIS-01</td>
<td>Bissombo Plot 1</td>
<td>CAMEROON</td>
<td>Africa</td>
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<tr>
<td>BIS-02</td>
<td>Bissombo Plot 2</td>
<td>CAMEROON</td>
<td>Africa</td>
</tr>
<tr>
<td>BIS-03</td>
<td>Bissombo Plot 3</td>
<td>CAMEROON</td>
<td>Africa</td>
</tr>
<tr>
<td>BIS-04</td>
<td>Bissombo Plot 4</td>
<td>CAMEROON</td>
<td>Africa</td>
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<td>BIS-05</td>
<td>Bissombo Plot 5</td>
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<td>Africa</td>
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<td>BIS-06</td>
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<td>CAMEROON</td>
<td>Africa</td>
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<td>BOR-05</td>
<td>Bonsa River 05</td>
<td>GHANA</td>
<td>Africa</td>
</tr>
<tr>
<td>BOR-06</td>
<td>Bonsa River 06</td>
<td>GHANA</td>
<td>Africa</td>
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<tr>
<td>BUD-17</td>
<td>Budongo Plot 7 &gt;10 cm dbh, 76-92</td>
<td>UGANDA</td>
<td>Africa</td>
</tr>
<tr>
<td>BUD-27</td>
<td>Budongo Plot 7 &gt;20 cm dbh, 39-92</td>
<td>UGANDA</td>
<td>Africa</td>
</tr>
<tr>
<td>CAM-01</td>
<td>Campo Ma'an 1</td>
<td>CAMEROON</td>
<td>Africa</td>
</tr>
</tbody>
</table>
Individual passwords to view or view and edit data, or make data public to registered users

Automated error checking of data

Automated checking of valid species names from African flowering Plants database, including synonymy

Integrated wood mass density database

Integrated height data when available, or specify height-diameter relationship for a plot or group of plots

Percolates uncertainty in allometric equations

Carbon storage value per plot with one click, download to excel
Ground-based measurements across the Congo Basin

- 240 plots (forest and woody savanna)
- DRC, Cameroon, Central African Republic, Republic of Congo, Equatorial Guinea, Gabon

- Mean area 1.3 ha
- Mean above-ground carbon storage, 198 Mg C ha\(^{-1}\).
- 122 multi-census plots

www.afritron.org
Plots incr: +0.80 Mg C ha yr\(^{-1}\) (95% CI, 0.4-1.1; \(n = 94\))

Congo basin carbon sink: 0.19 Pg C yr\(^{-1}\) (95% CI, 0.11-0.23)
Measuring Forest Biomass from Space
DESDynl & BIOMASS Missions
Forest Carbon of 2020
Current State-of-the-art Forest Carbon of 2010
Integrative Approach to Map Biomass Distribution at 500-1000 m resolution

GLAS Lidar & Inventory Plots

19 Remote Sensing Data Layers

- MODIS_LAI
- MODIS_NDVI, EVI, Bands
- QSCAT, Seasonal metric
- SRTM-DEM, Slope, Roughness
- PALSAR(JERS) Sigma, texture
- MODIS_VCF

Statistical Model Biomass Estimator

Decision Rule Classifier for Forest > 150 Mg/ha biomass

Regression Model Estimator for Forest < 150 Mg/ha biomass

AGB Map

AGB Uncertainty Map

Vegetation Map
Integrative Approach to Map Biomass (Cont.)

1. A probabilistic framework
2. Develop incomplete empirical probability distribution based on the occurrences
3. Approximate with a probability distribution of maximum entropy
4. Use environmental variables as constraints
5. A rule classifier to produce forest biomass map

\[ H(\pi) = \sum_{x \in X} \pi(x) \ln \pi(x) \]
ICESAT GLAS Lidar Measurements
Forest Height

Waveform recording lidar
Input Biomass Data:
139 scientific inventory plots (0.1-1.0 ha)
2250 forestry inventory plots (0.3 ha)
7089 ICESAT GLAS Derived Biomass
Maximum Entropy Probabilistic Predictions of Biomass

Red: 75-100  
Grn: 150-200  
Blue: 300-350
Distribution of Aboveground Forest Biomass in Gabon

AGLB Mg/ha
- Bare
- Savanna
- 0-25
- 25-50
- 50-75
- 75-100
- 100-150
- 150-200
- 200-250
- 250-300
- 300-350
- 350-400
- > 400
Accuracy Assessment

Accuracy: 61%
95% Confidence Interval

<table>
<thead>
<tr>
<th>Country name</th>
<th>AG carbon</th>
<th>BG carbon</th>
<th>Total carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gabon</td>
<td>3,318,669,136</td>
<td>856,388,067</td>
<td>4,175,057,202</td>
</tr>
<tr>
<td>Gabon (20% random error)</td>
<td>3,317,345,723</td>
<td>829,336,430</td>
<td>4,146,682,153</td>
</tr>
<tr>
<td>National Error Estimates</td>
<td>2.86%</td>
<td>3.26%</td>
<td>3.2%</td>
</tr>
</tbody>
</table>
Sources of Errors

- Statistical extrapolation (Maxent, Random Forest, multiple regression, etc.) has large errors when sensitivity to AGB is low.

- Plot level inventory (small plots) & biometry
- Conversion of forest height to biomass (no allometry exists)
- Time differences in ground and satellite observations
- Spatial scale of analysis
- Errors in plot location vs satellite pixel
\[ \Delta C = AGB \times \Delta A \]  
Deforestation

Using \( < AGB >= 294 \text{ Mg/ha}, \Delta A = 1 \text{ ha}, \Delta C = 294 \text{ Mg} \)

\[ \Delta C = \Delta AGB \times A \]  
Small scale disturbance or Recovery

However, \( 150 \text{ Mg} < \Delta C < 495 \text{ Mg} \)
Improvements in Estimates of Land-Based Emissions

Sassan Saatchi (UCLA-NASA/JPL),
Nancy Harris, Silvia Petrova and Sandra Brown (Winrock International)
William Salas and Stephen Hagen, Applied Geosolutions
Fred Stolle and Lauriane Boisrobert (WRI)
Matt Hansen (South Dakota State University)

Pan-tropical Estimates of Aboveground Biomass

1. Ground Inventory plot data (4,087 plots)
2. GLAS lidar data (150,449 points): height converted to biomass using allometric equations
3. Nineteen satellite layers (1 km resolution)
Distribution of Aboveground Forest Biomass In Tropical Africa

AGLB Mg/ha
- Bare
- Savanna
- 0-25
- 25-50
- 50-75
- 75-100
- 100-150
- 150-
- 200-
- 250-
- 300-
- 350-40
- > 400
# Total Carbon in Central African Forests Circa 2000

## Total Carbon stocks in 2000 Forest (t C)

<table>
<thead>
<tr>
<th>Country name</th>
<th>AG carbon</th>
<th>BG carbon</th>
<th>Total carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameroon</td>
<td>3,611,198,768</td>
<td>941,777,346</td>
<td>4,552,976,114</td>
</tr>
<tr>
<td>Central African Republic</td>
<td>1,743,934,051</td>
<td>492,015,859</td>
<td>2,235,949,910</td>
</tr>
<tr>
<td>Democratic Republic of the Congo</td>
<td>19,309,925,377</td>
<td>5,079,793,670</td>
<td>24,389,719,048</td>
</tr>
<tr>
<td>Equatorial Guinea</td>
<td>377,419,446</td>
<td>97,367,759</td>
<td>474,787,206</td>
</tr>
<tr>
<td>Gabon</td>
<td>3,318,669,136</td>
<td>856,388,067</td>
<td>4,175,057,202</td>
</tr>
<tr>
<td>Republic of Congo</td>
<td>2,984,524,266</td>
<td>783,744,793</td>
<td>3,768,269,059</td>
</tr>
<tr>
<td>Sao Tome and Principe</td>
<td>8,518,697</td>
<td>2,214,747</td>
<td>10,733,443</td>
</tr>
</tbody>
</table>

**Total (t C)**

| 31,354,189,741 | 8,253,302,239 | 39,607,491,981 |

**Total (Gt C or Pg C)**

| 31 | 8 | 40 |
Future Work
Test Driving Prototypes
LHH
LHV
LHV Texture

Radar Degradation Index

© JAXA, METI Analyzed by JAXA
Monitoring Deforestation and Forest Degradation

2007

2007
Monitoring Deforestation and Forest Degradation
ALOS PALSAR L-HV Sensitivity to AGB

LHV (dB) = -22.5 + 3.0Log(AGB)
Distribution of Aboveground Forest Biomass in Borneo

AGLB Mg/ha

- Bare
- Savanna
- 0-25
- 25-50
- 50-75
- 75-100
- 100-150
- 150-200
- 200-250
- 250-300
- 300-350
- 350-400
- > 400
Assessment of Biomass Class Accuracy

AGB Class  AGB Mg/ha

- Bare
- Savanna

3  0-25
4  25-50
5  50-75
6  75-100
7  100-150
8  150-200
9  200-250
10 250-300
11 300-350
12 350-400
13 > 400

Accuracy: 72%
95% confidence interval
AGB from Fusion of ALOS & GLAS Lidar

AGLB Mg/ha

- Bare
- Savanna
- 0-25
- 25-50
- 50-75
- 75-100
- 100-150
- 150-200
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SUMMARY

Ground and Satellite Data Fusion has the potential of providing global distribution of aboveground biomass.

L-band PALSAR can measure forest disturbance and recovery at 100 m spatial resolution. Seasonality of moisture and phenology will impact the estimation.

National level estimation can be achieved at reasonable accuracy. However, spatial accuracy is variable.

Standardizing and increasing inventory plots will improve accuracy of biomass distribution.

New allometry is required for tropical forests with consideration of spatial scales of satellite data.