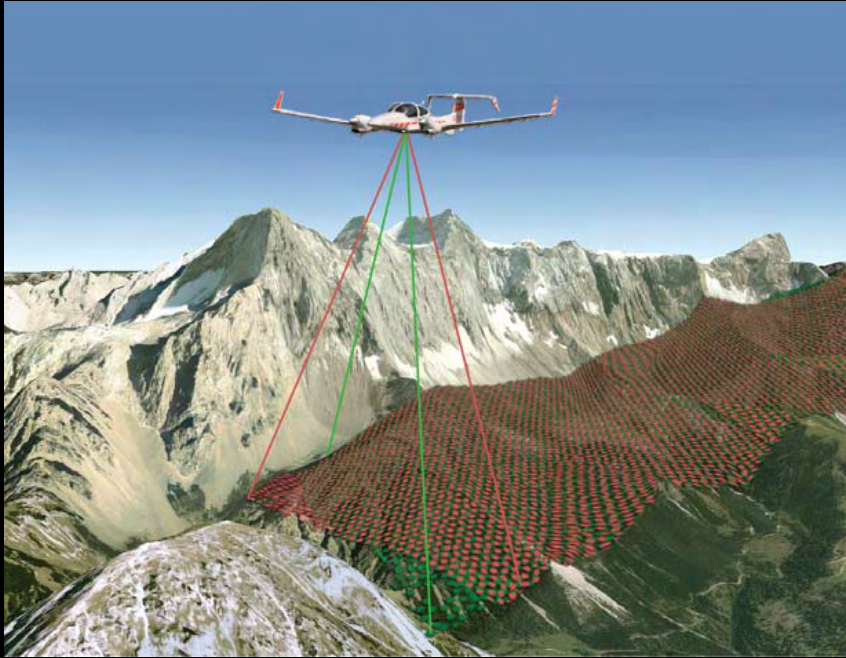


Mapping Brazil National Forest Carbon Stocks



Sassan Saatchi

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA, 91109

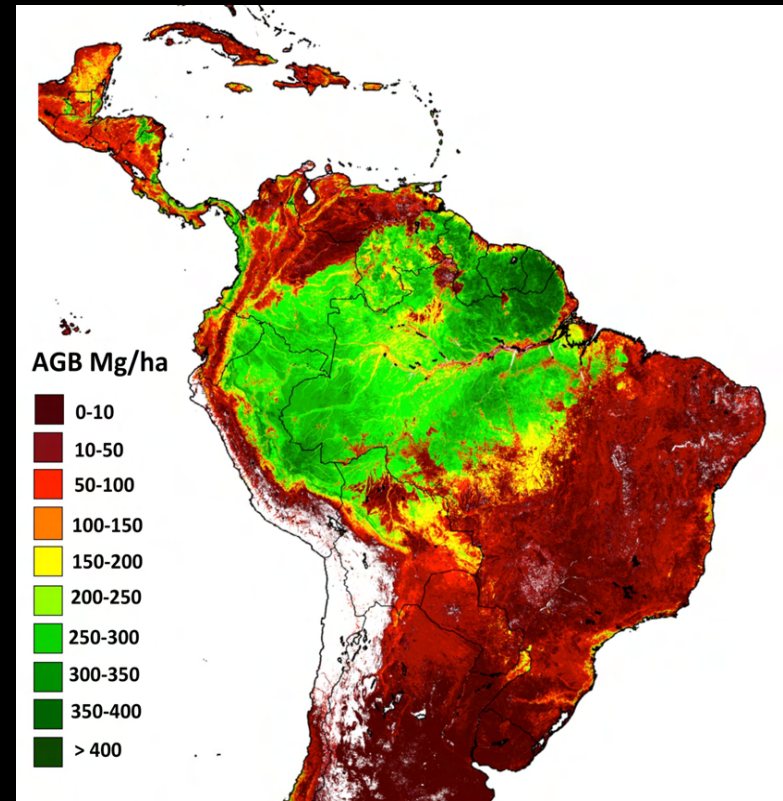


Fig. 3.7a. Distribution of aboveground forest biomass (for trees > 10 cm) of tropical forests of America, aggregated at 1 km spatial resolution, showing variations regionally and across the landscape.

National Carbon Mapping Tool

1. Background
2. Verified Carbon Standard Tool VT0005
3. Examples of Design & Implementation
4. Carbon Estimation
5. Example of Jurisdictional Carbon Map
6. Uncertainty & Improvements
7. Contribution to National Carbon Assessment

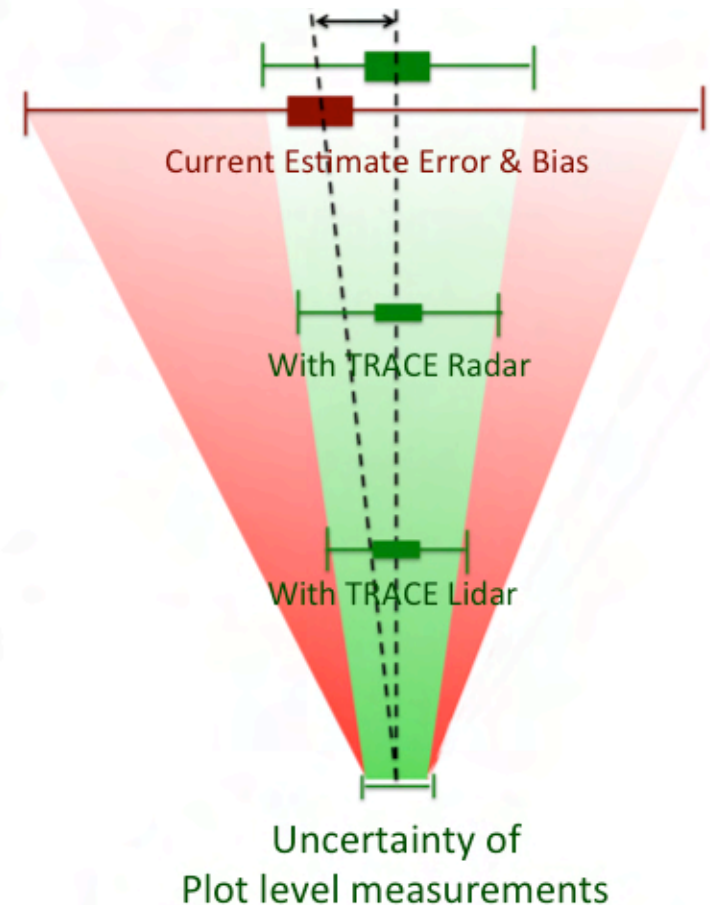


Concept of National Forest Carbon Mapping

National Forest Carbon



Keeping Uncertainty Low



VCS Tool VT0005



VCS Tool

Authors:

Peter Tittmann (UC Berkeley)

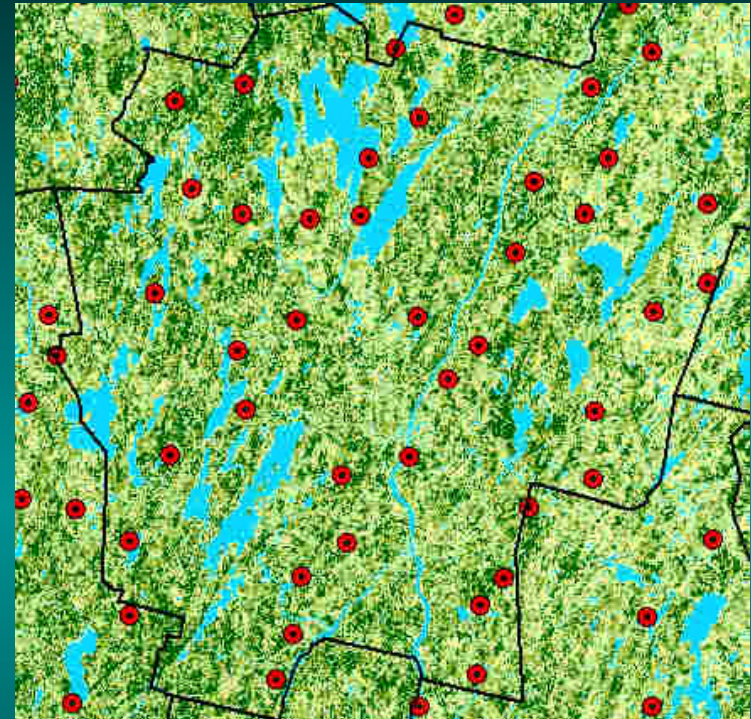
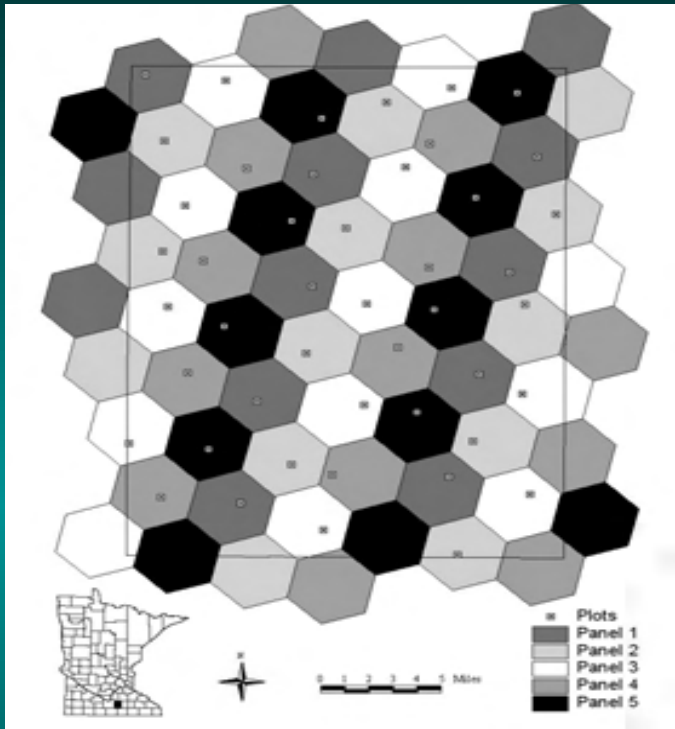
Sassan Saatchi (JPL/CALTECH, UCLA/IOES)

Support: Terra Global Capital

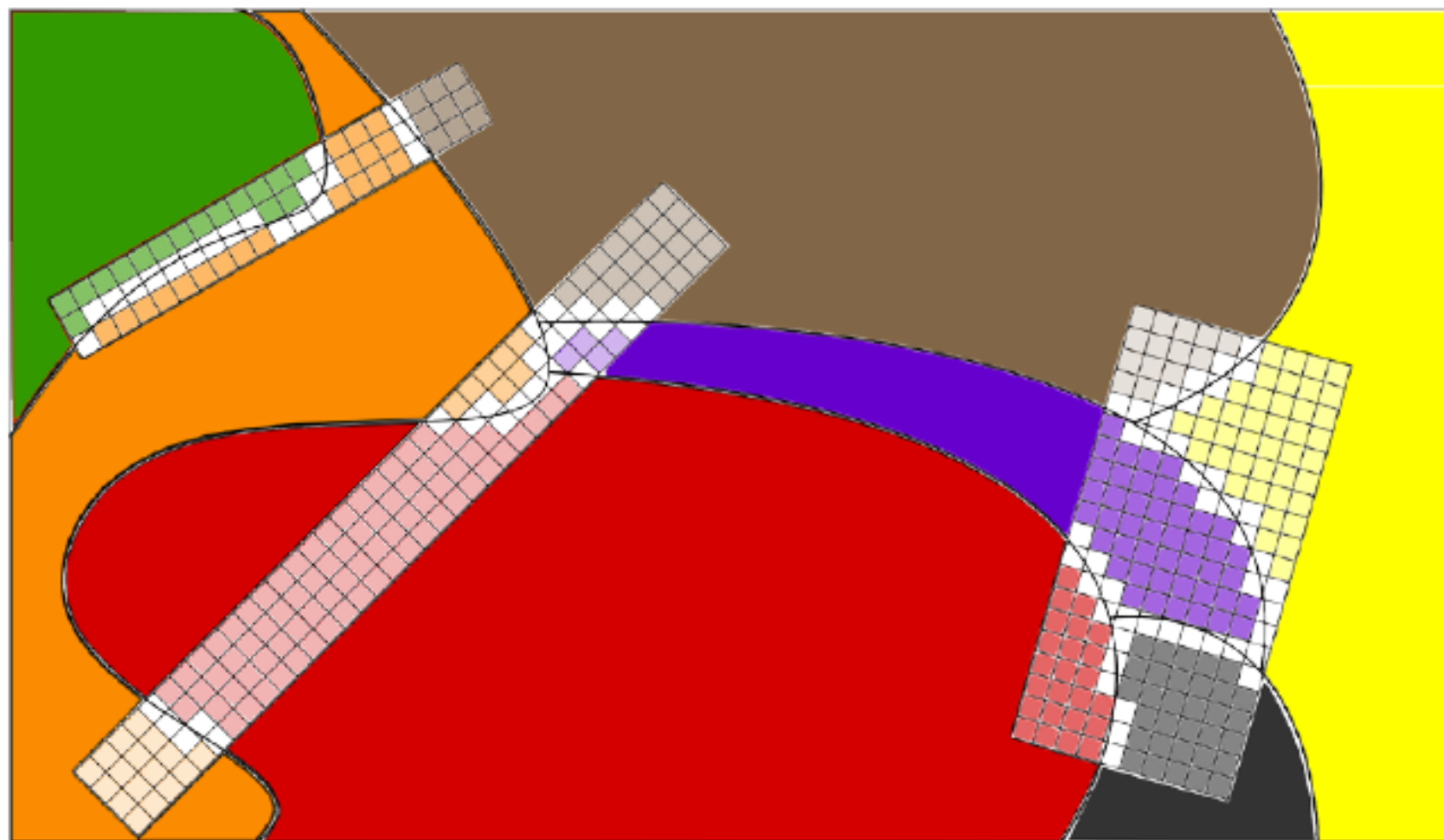
VT0005

**Tool for measuring aboveground live forest
biomass using remote sensing**

Develop National Forest Inventory



Assuming the same variability of the US Forest
One plot per 2500 ha of forest, with systematic random sampling
Require ~ 260000 plots, at least 0.25 ha in size, \$1000-3000/plot
Total Cost: \$260-780m over 10 years



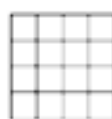
Strata



RSSU_{1...n}



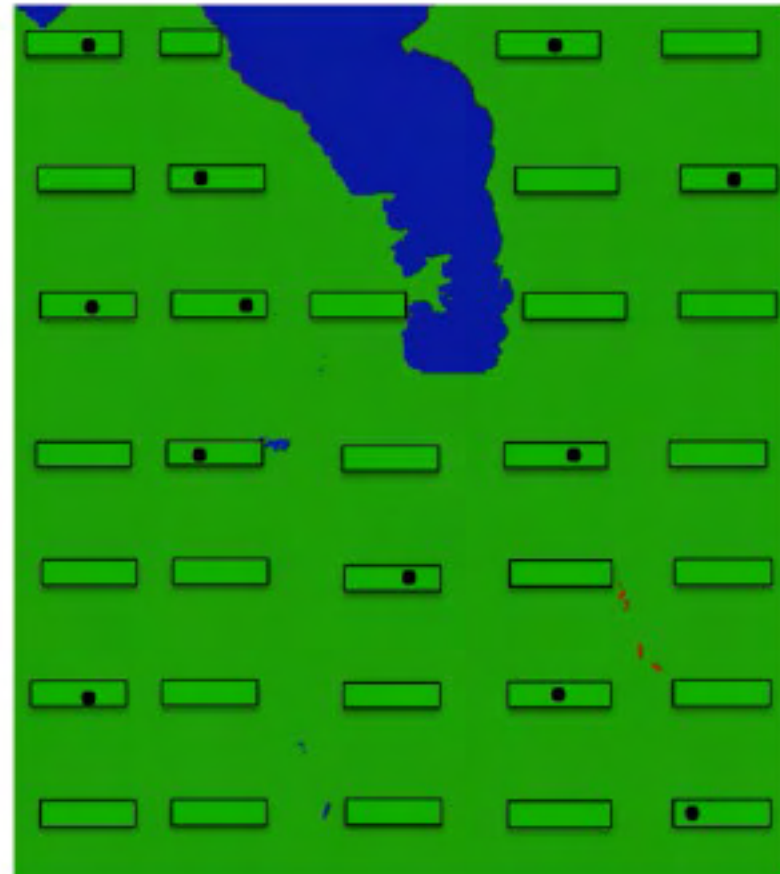
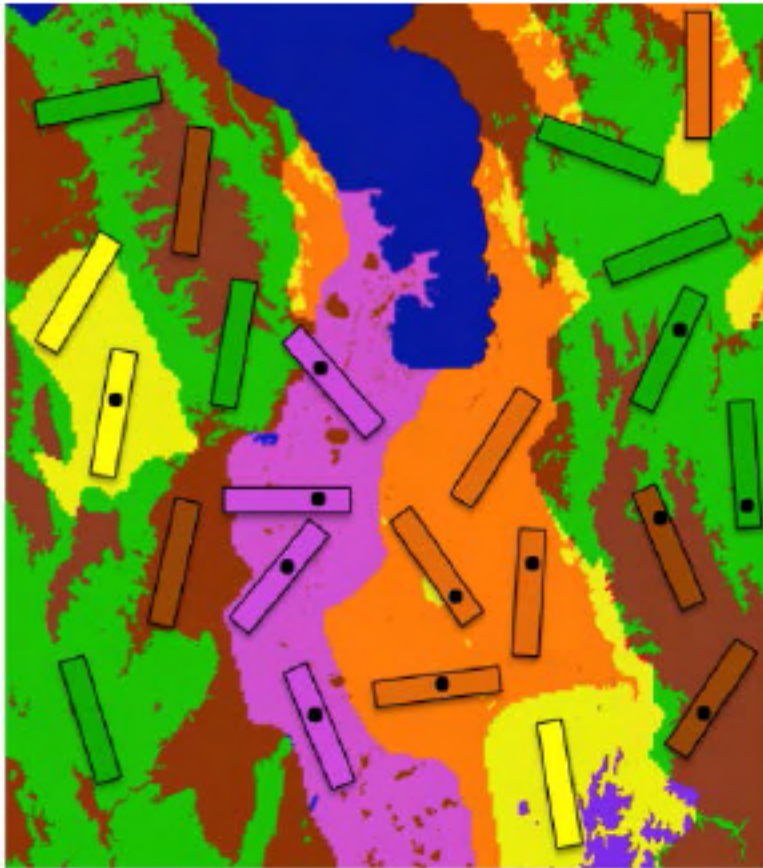
RS Coverage



RSP



Sampling Strategy

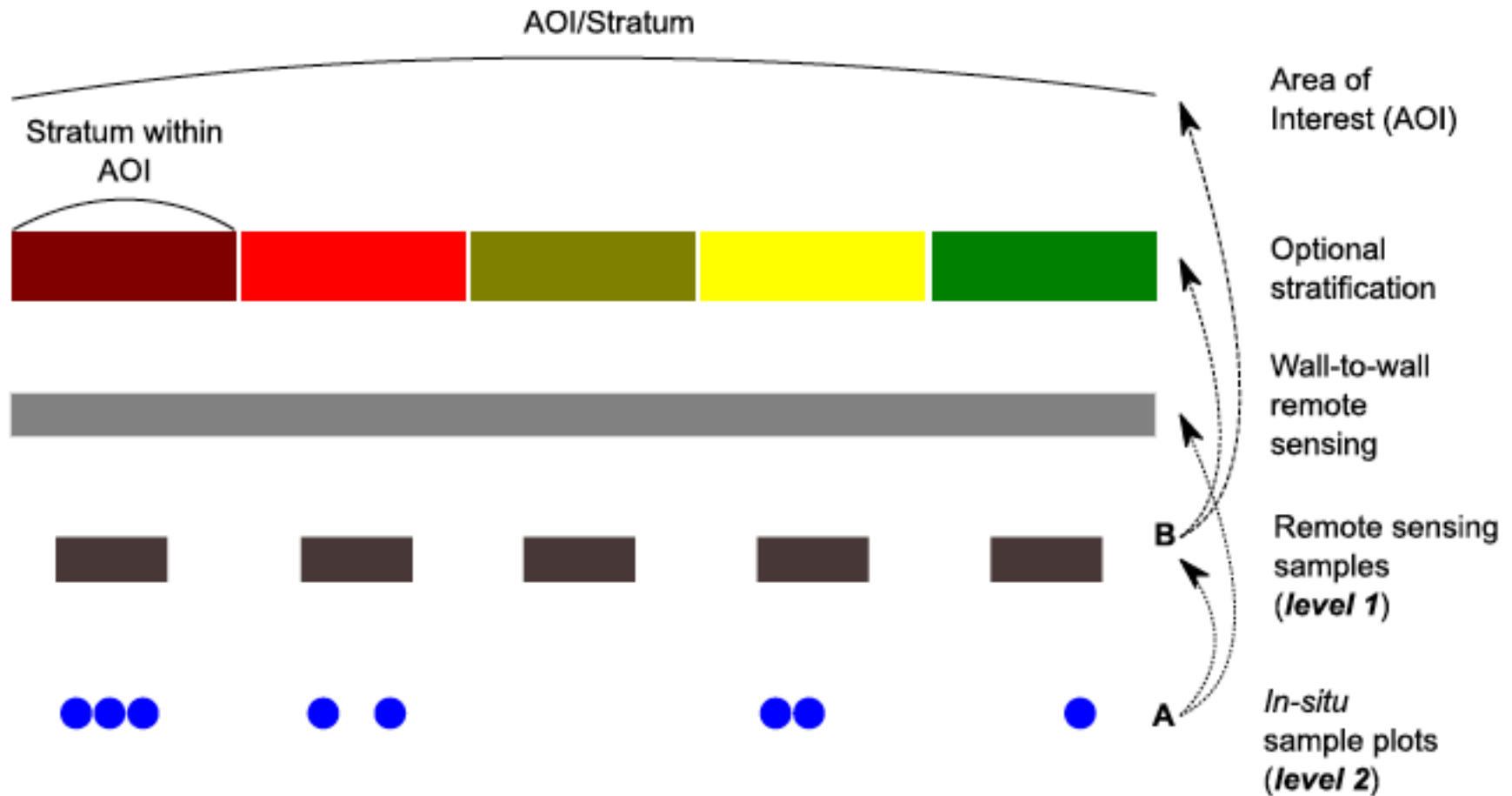


Strata

- StratumA
- StratumB
- StratumC
- StratumD
- StratumE

- Sample Plot
- RS Flightline

Process of Estimating AGB Using Systematic or Random Sampling of RS data calibrate by In Situ Plots

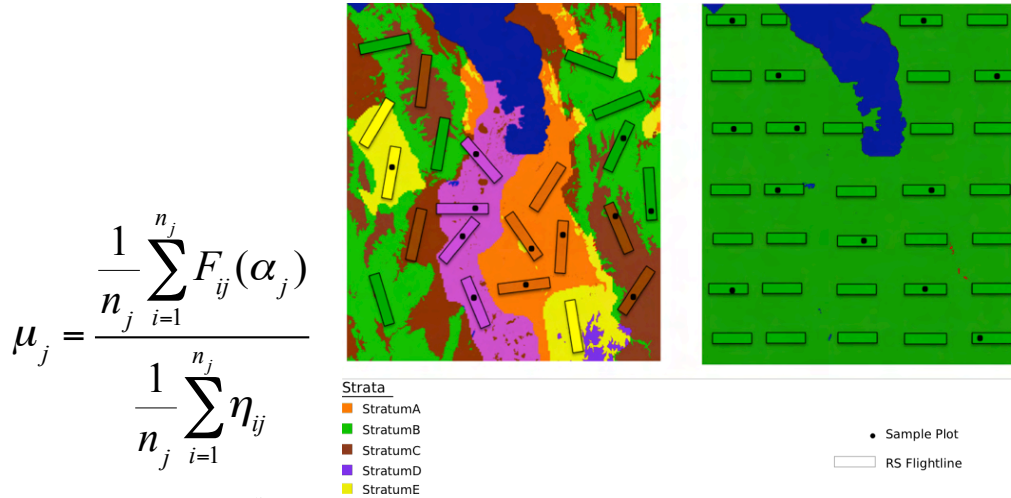


A uses ALFB density in measured in-situ plots to calibrate RS data.

B estimates ALFB density at the stratum or AOI level based on RS sampling

Development of Regional Unbiased Estimators

1. Forest Specific Lidar-AGB allometry
2. Formulate the effect of Lidar Clustering
3. Estimate Mean and Standard Errors for Forest Types of Ecoregions



$$\mu_j = \frac{\frac{1}{n_j} \sum_{i=1}^{n_j} F_{ij}(\alpha_j)}{\frac{1}{n_j} \sum_{i=1}^{n_j} \eta_{ij}}$$

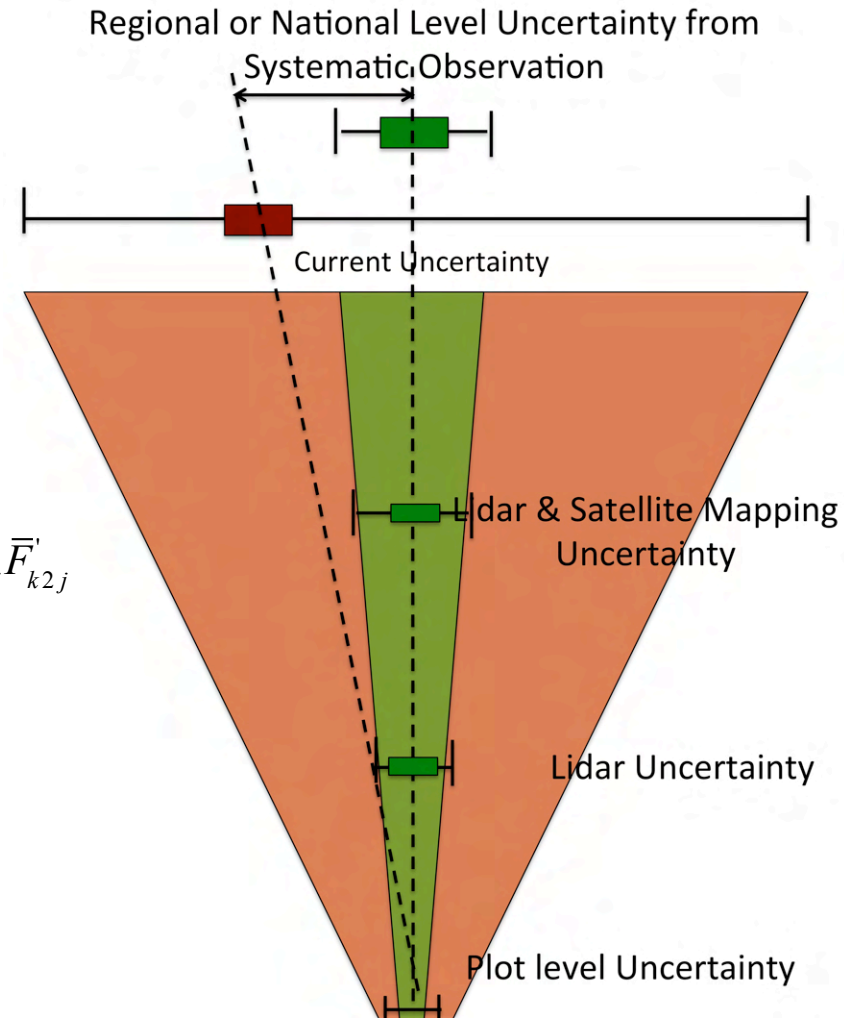
$$\text{var}(\mu_j) = \frac{1}{\bar{\eta}_j^2} \frac{\sum_{i=1}^n (F_{ij}(\alpha_j) - \mu_j \eta_{ij})^2}{n(n-1)} + \frac{1}{\bar{\eta}_j^2} \sum_{k_1}^{p_j} \sum_{k_2}^{p_j} \text{Cov}(\alpha_{k_1j}, \alpha_{k_2j}) \bar{F}'_{k_1j} \bar{F}'_{k_2j}$$

where

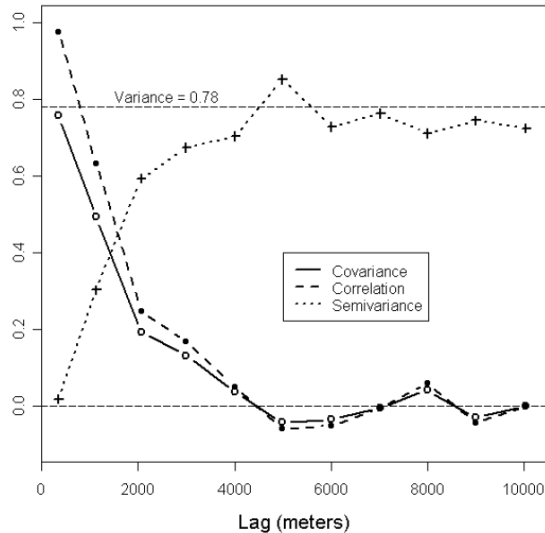
$$\bar{F}'_{k_1j} = \sum_{i=1}^n \sum_{t=1}^T \frac{\partial f(x_{it}, \alpha_{k_1})}{\partial \alpha_{k_1}}$$

where

$$\text{AGB} = f(x, \alpha, \varepsilon) = a(\text{WD}h_{TCH})^b + \varepsilon$$



Minimum Area Covered by Lidar



$$\sigma_L = \frac{1}{N} \sqrt{\sigma_u^2 + \sigma_u^2 \dots \sigma_u^2} = \frac{\sigma_u}{\sqrt{N}}$$

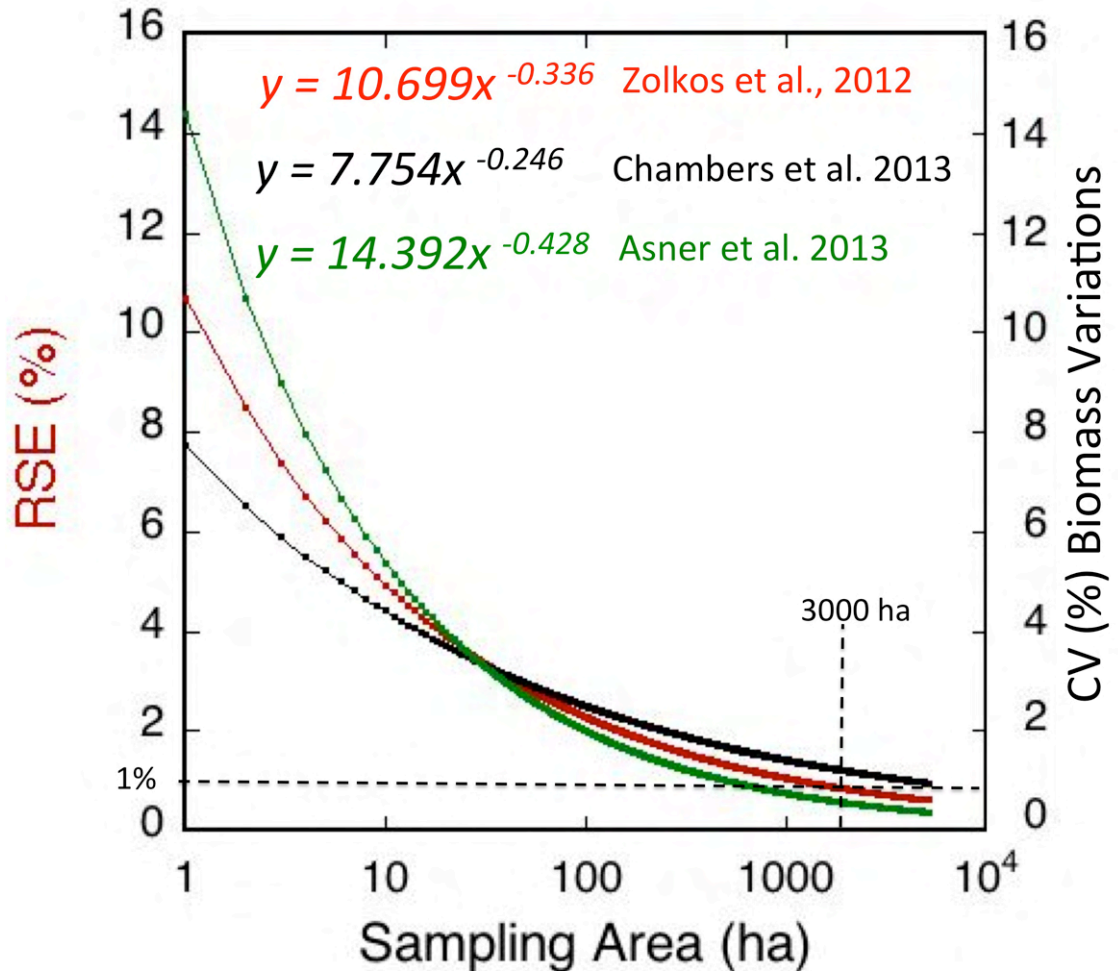
without spatial correlation

$$\sigma_L = \frac{1}{N} \left(\sum_i \sigma_{ui}^2 + 2 \sum_i \sum_j \rho(d) \sigma_{ui} \sigma_{uj} \right)^{1/2}$$

$$\rho(d) = \exp\left(-\frac{d}{cr}\right),$$

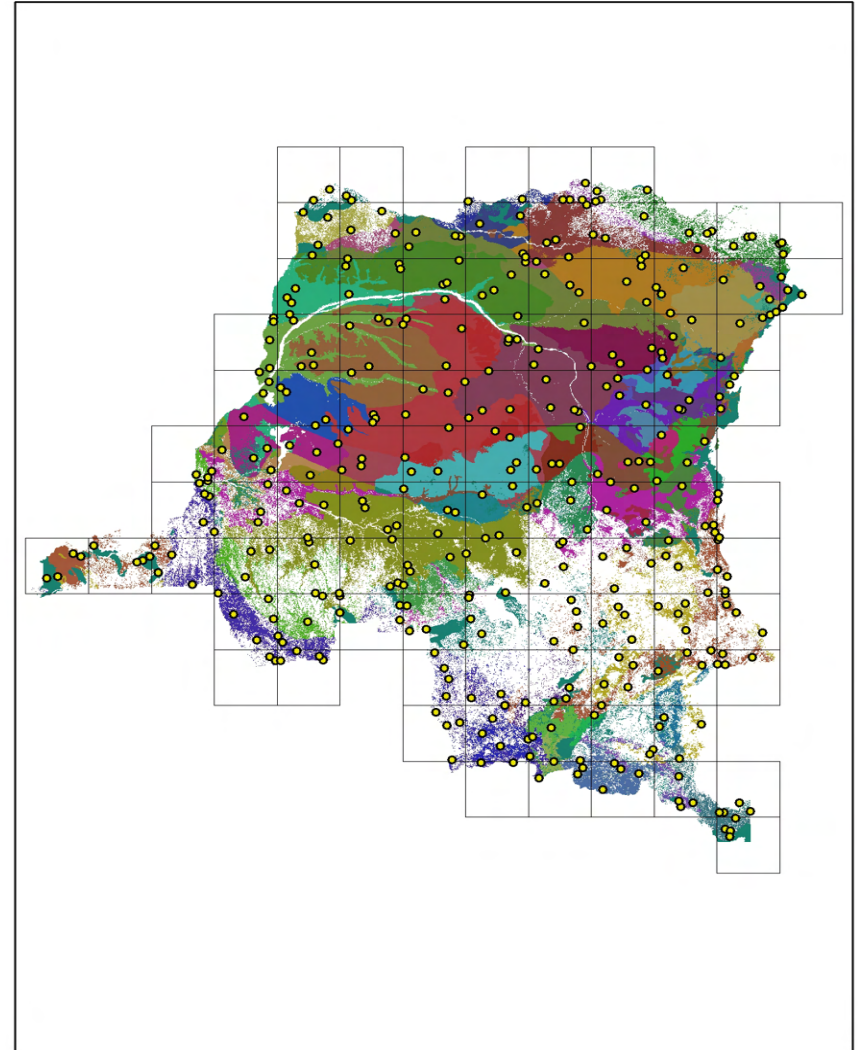
r: range from semivariogram,

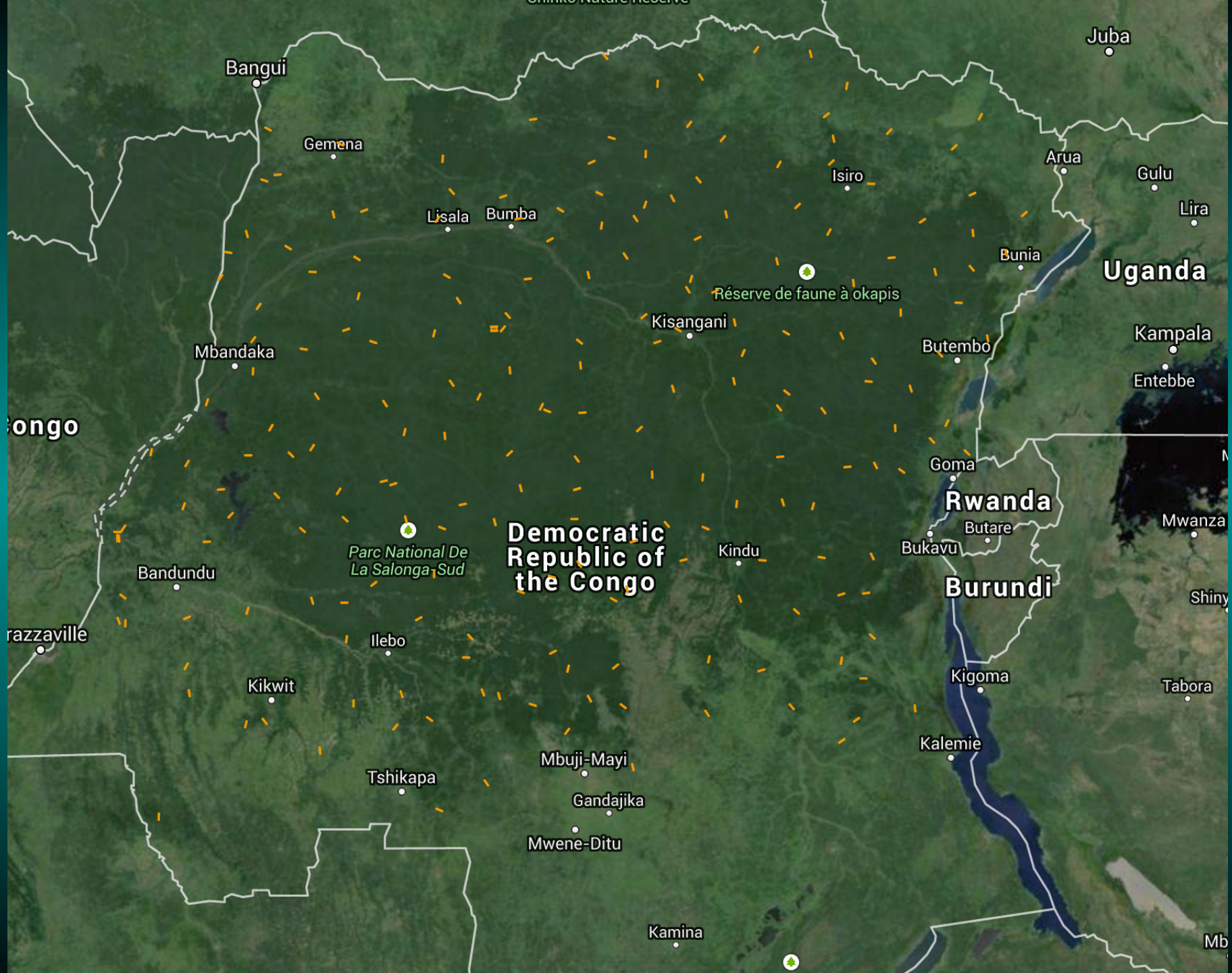
c: coefficient from Moran-I



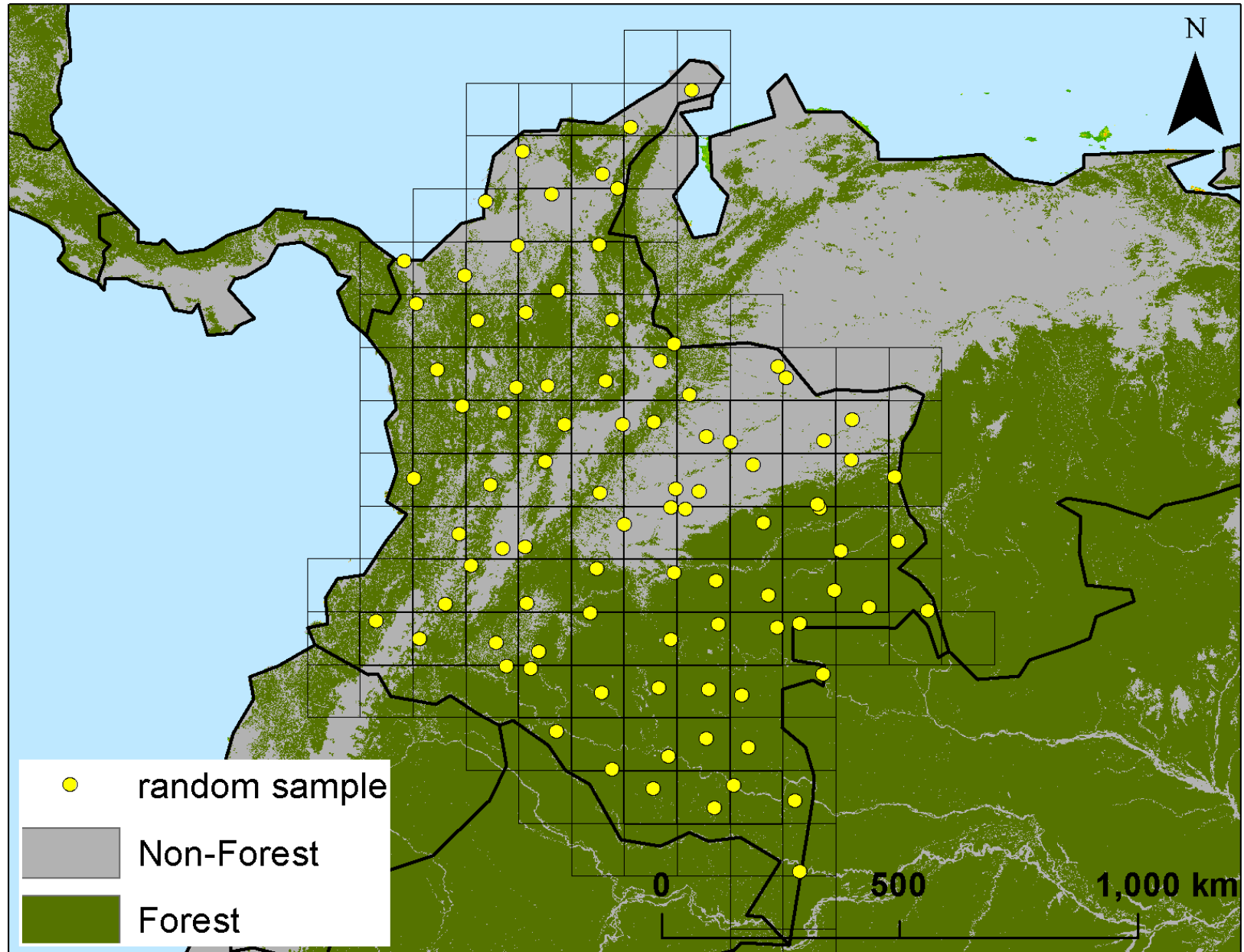
DRC Grid Base Flight Plan

- Using a 1 deg x 1 deg grid
- Random selection of a location within the grid and on forest areas (216 points)
- Choosing the points to develop a transect flight lines
- Flight lines cover areas of about, 2000 ha each
- The flight direction was selected to optimize landscape variations along topography, moisture, ect.
- Total area of systematic sampling: ~430,000 ha
- Additional Ferry 3000 km of ferry line > 150,000 ha





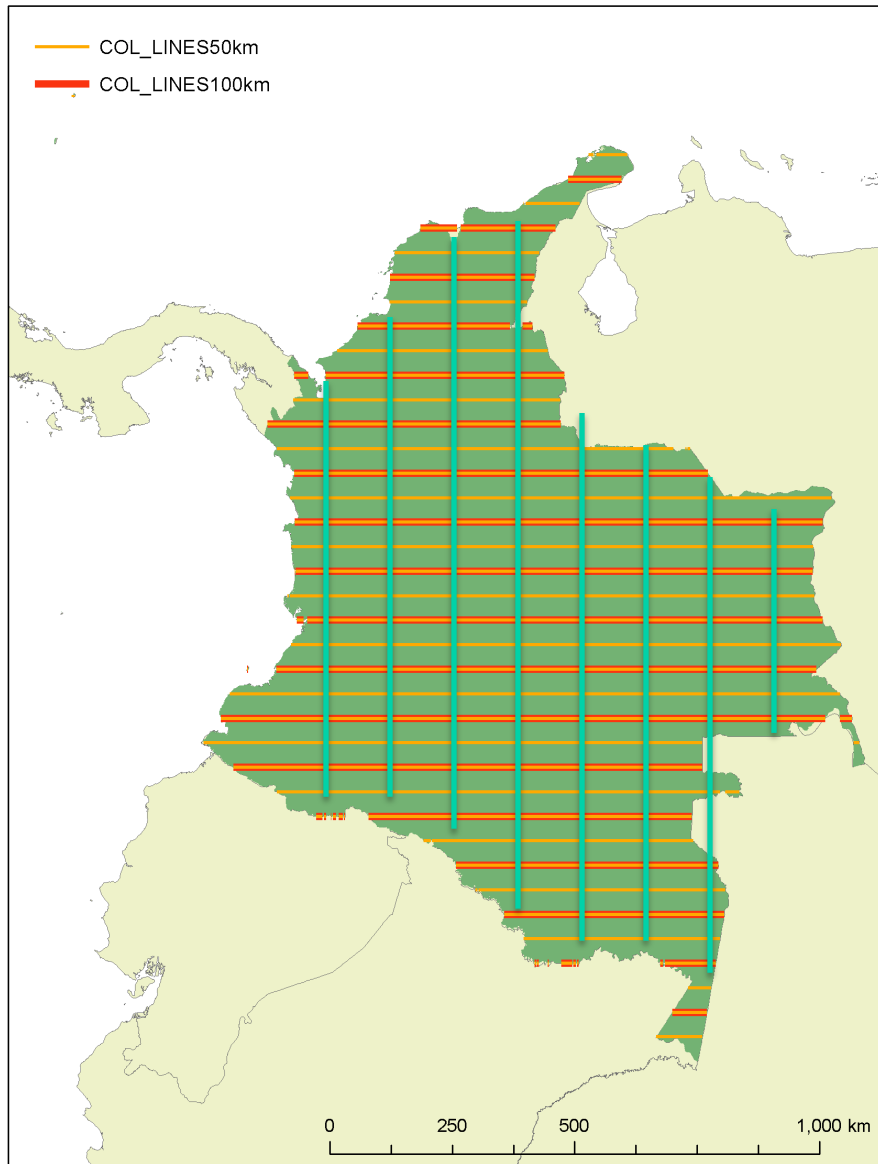
National Inventory Integrating Ground and Space Sampling



Systematic Random Sampling Approach

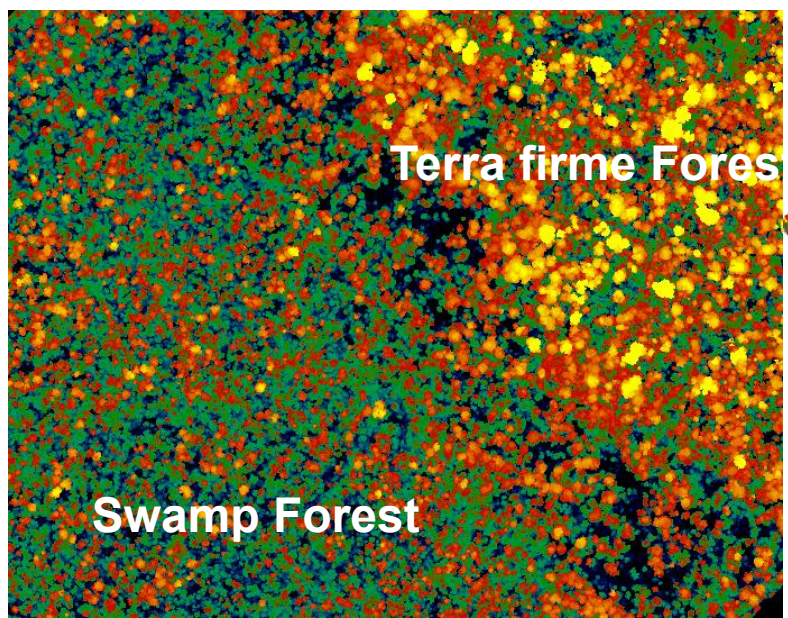
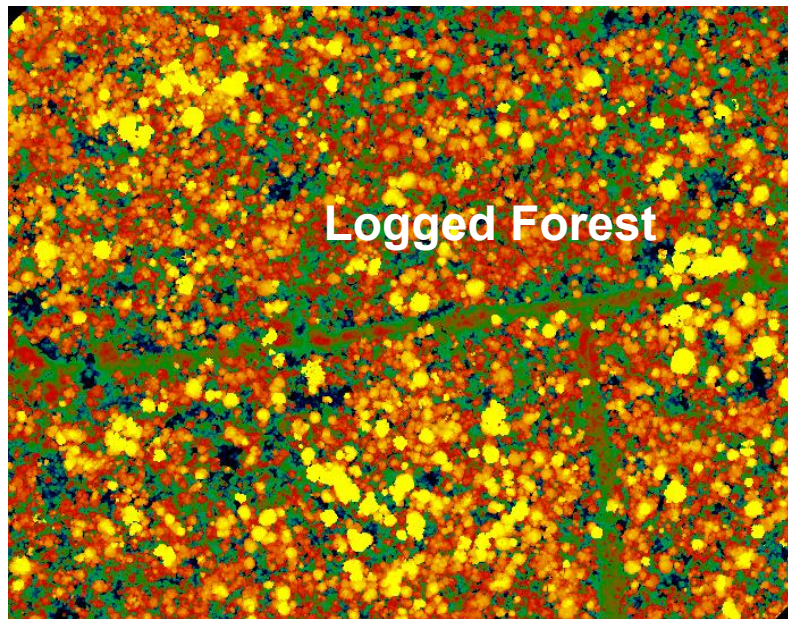


Efficient and Cost Effective Sampling



1. Systematic flights across the country (75 days of flight days)
2. Collect data in seasons with the least cloud cover regionally
3. Each line will be > 1 km wide, > 10 points/m²
4. Collection, Processing, and delivery 18-24 months

Lidar Transect Data



Degraded Forest

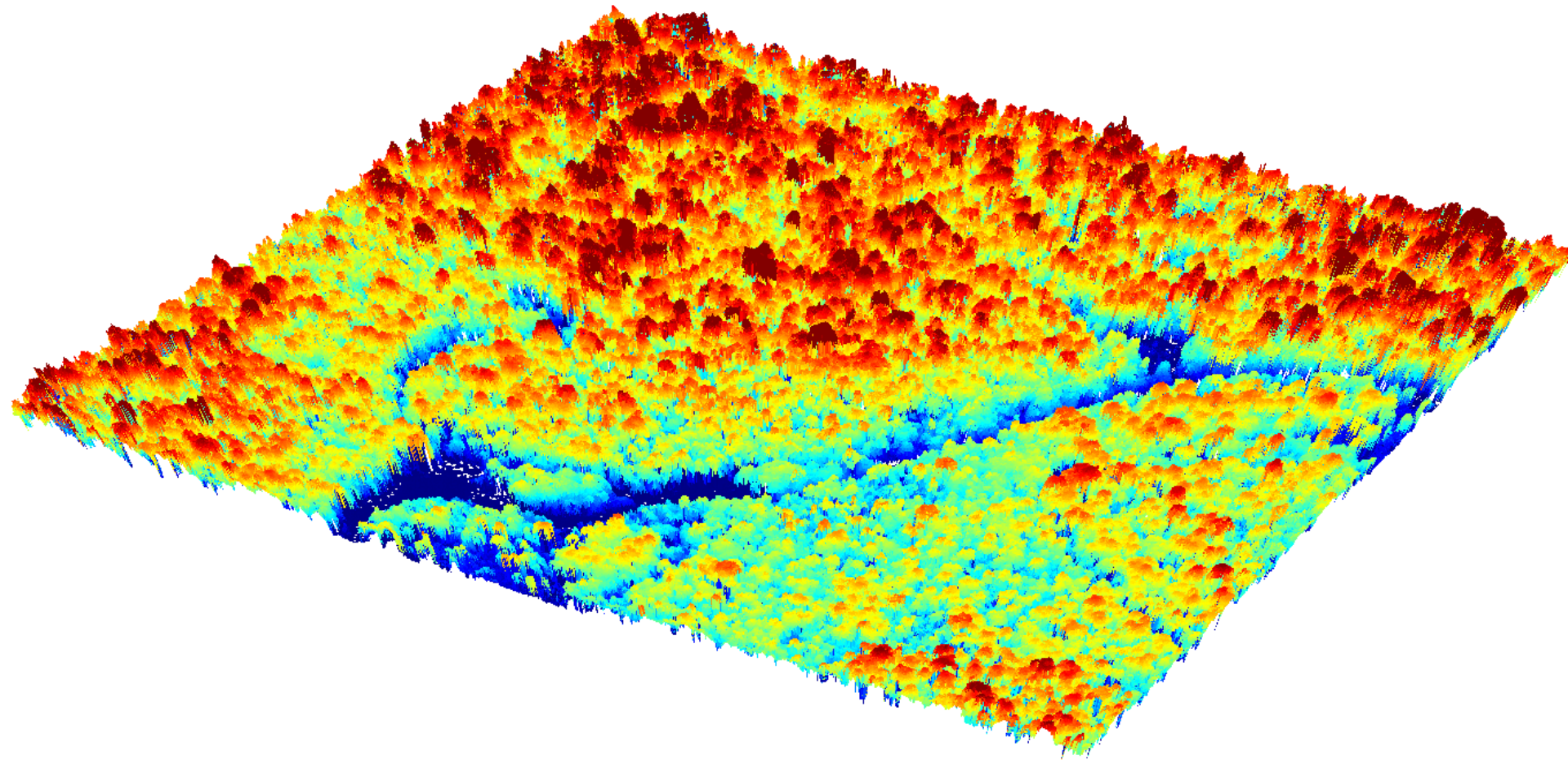
Degraded/Logged Forest

Unlogged Forest

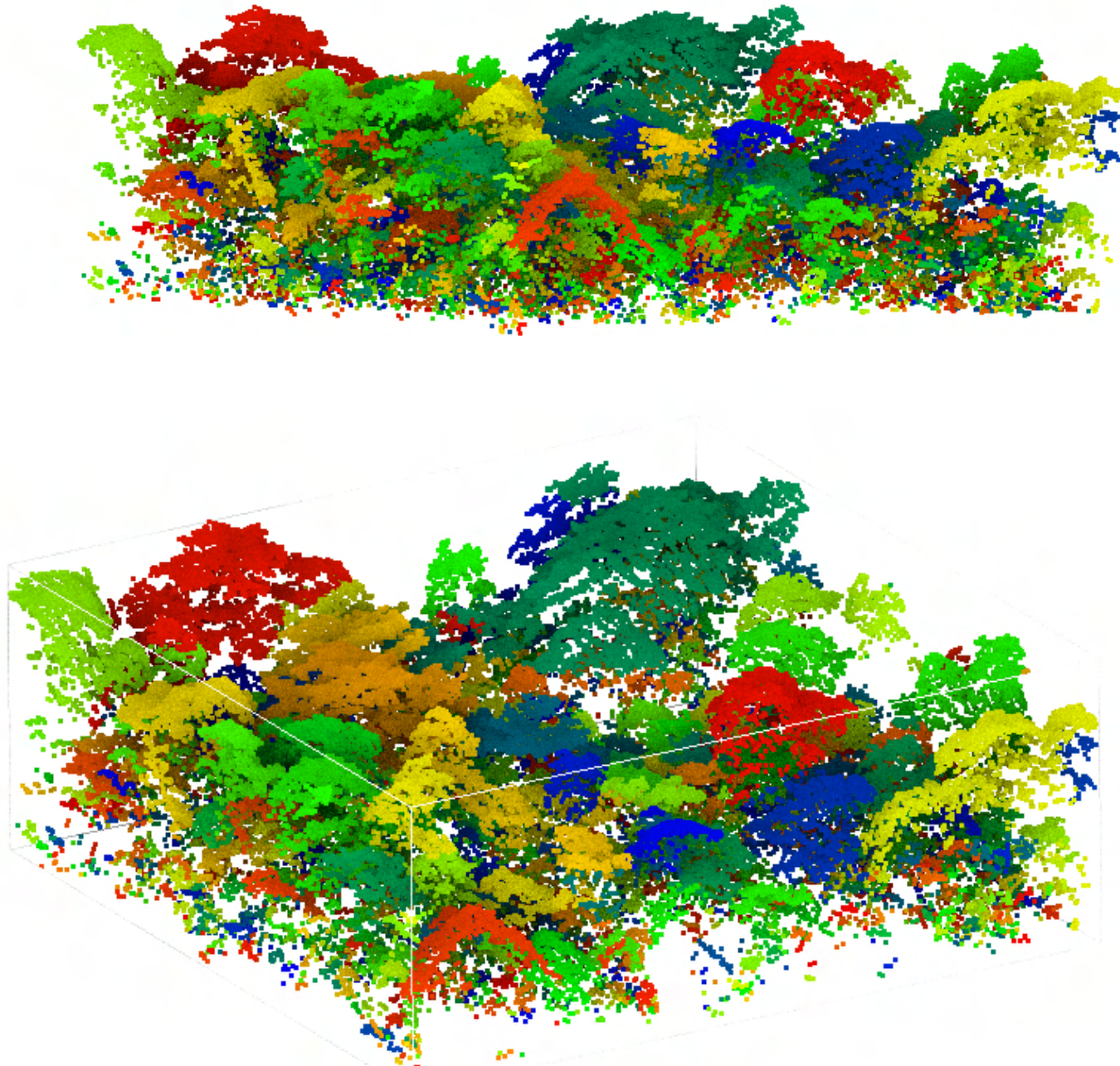
Swamp Forest



Sample of Lidar Transect Showing 3-D structure of Terra Firme and Swamp Forests in around Lake Mai Ndombe



Lidar 3D Structure of Tropical Forests

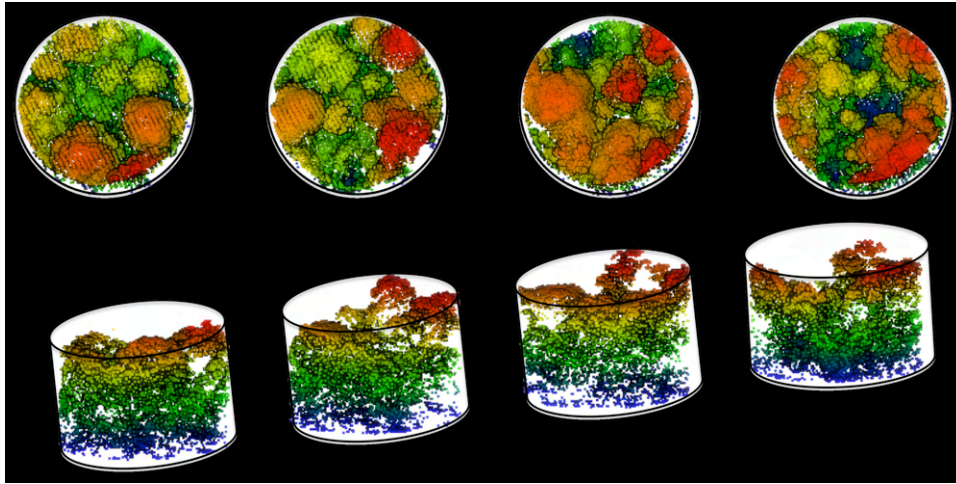


An aerial photograph of a dense forest canopy, showing a mix of green, yellow, and brown tones. Several small, irregular blue polygons are overlaid on the image, highlighting specific areas. Three red arrows originate from these blue polygons and point towards a solid red vertical bar on the right side of the image. The text 'Water Bodies Detected by High Resolution Aerial Imagery' is centered over the left portion of the image.

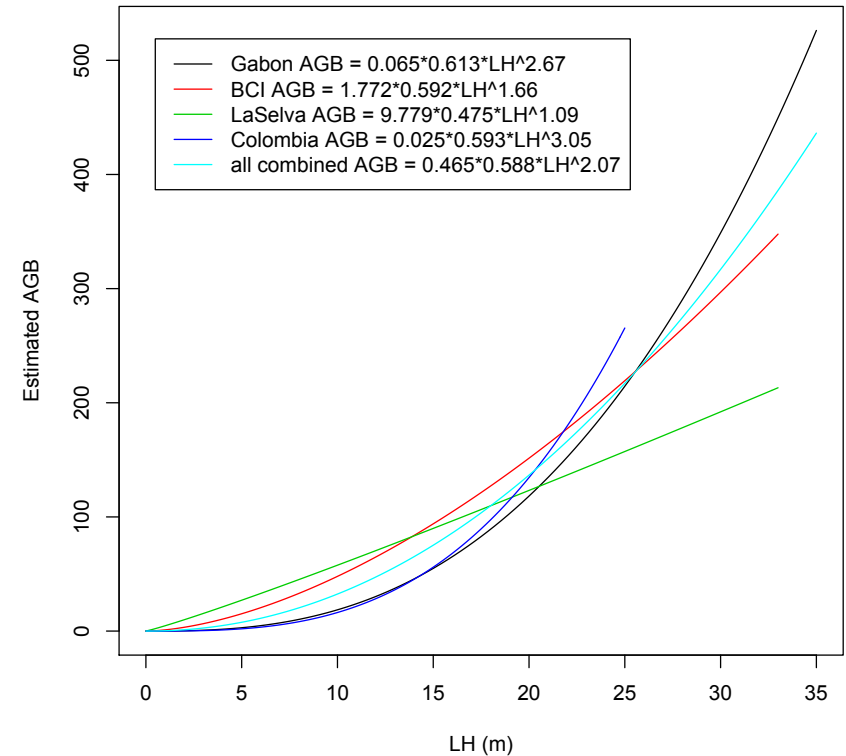
Water Bodies Detected by High Resolution Aerial Imagery

**Standing
Water**

Lidar Biomass Allometry



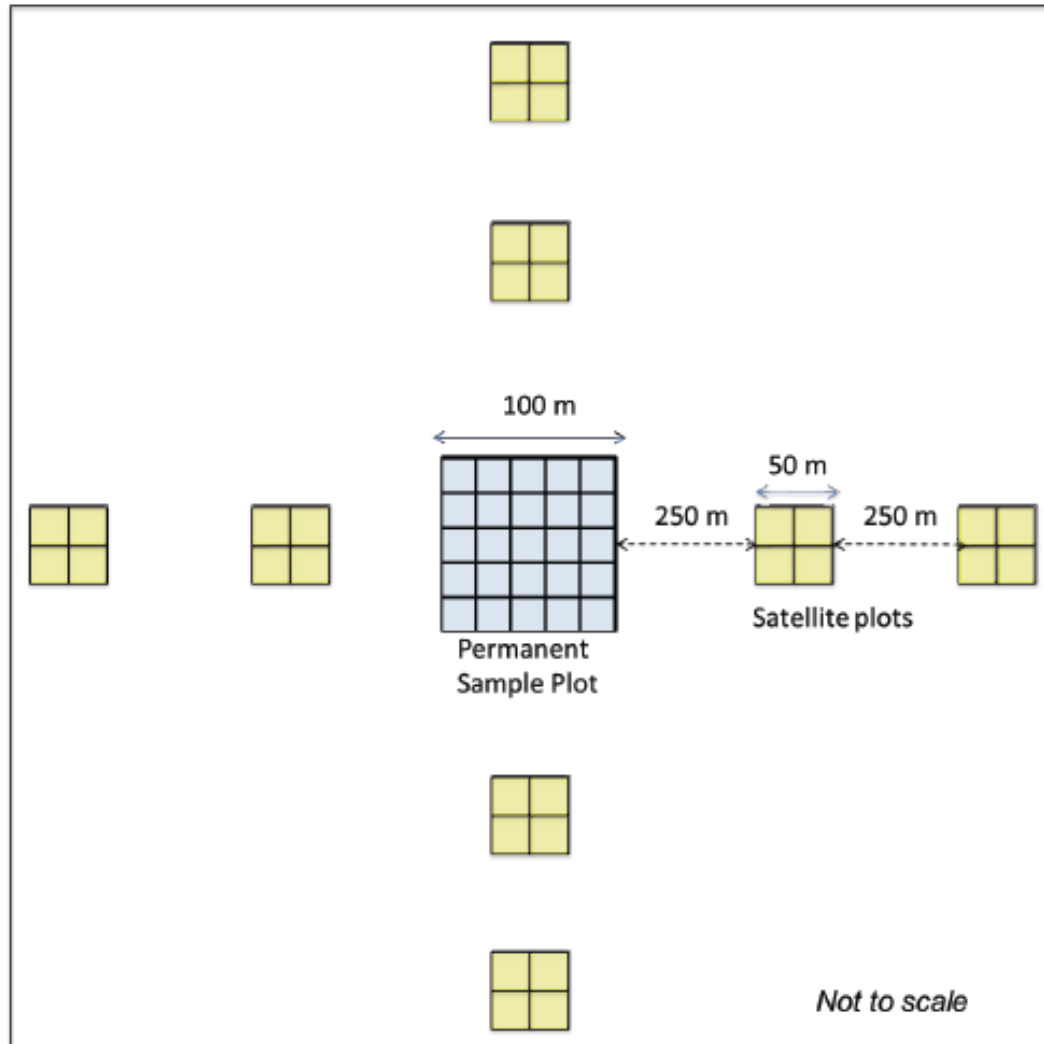
$$AGB = a\bar{\rho}h_{LIDAR}^b$$



Pattern of AGB is defined by:

- 1. Pattern of large trees**
- 2. Pattern of high wood density trees**
- 3. a and b may be dependent on environmental variables**

Design of Lidar Calibration Plots



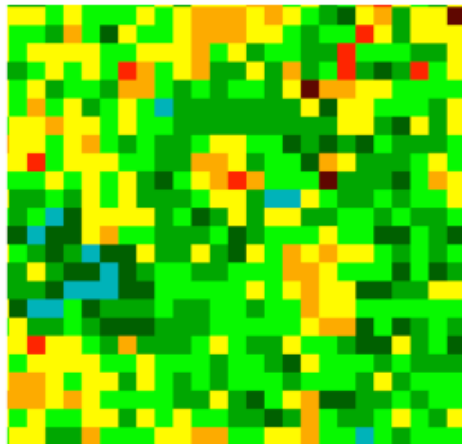
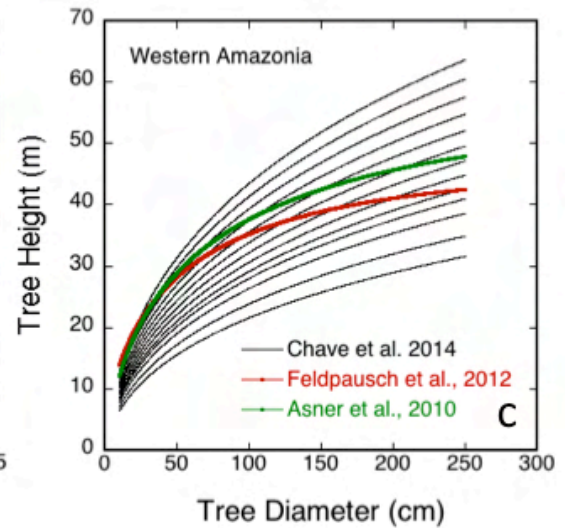
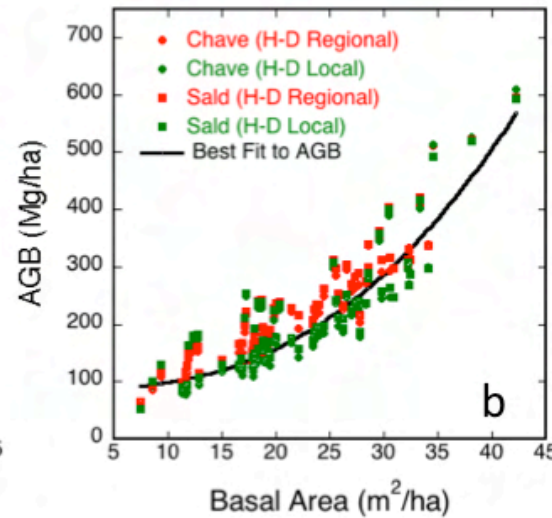
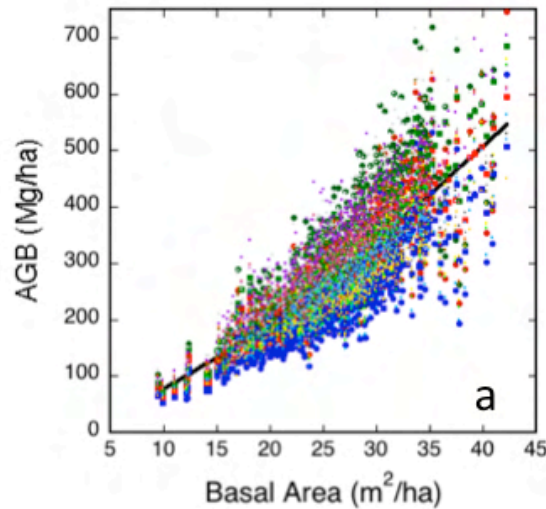
Permanent Plots

- 1-ha plots
- DBH Trees > 10 cm diameter
 - Height
 - Species
- GPS location of corners

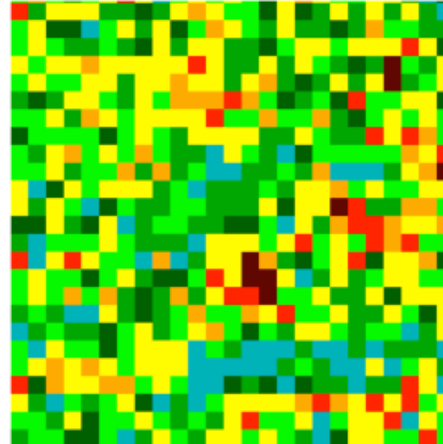
Satellite Plots

- 0.16-0.25 ha plots
- DBH Trees > 10 cm diameter
 - Species
- GPS location of corners

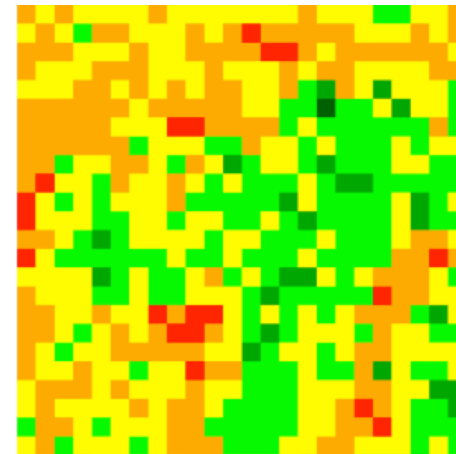
Ground Truth with a Grain of Salt



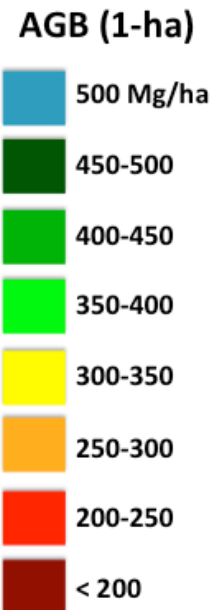
a
Paracou, French Guiana
Mean AGB: 386 Mg/ha
Range: 60-533 Mg/ha



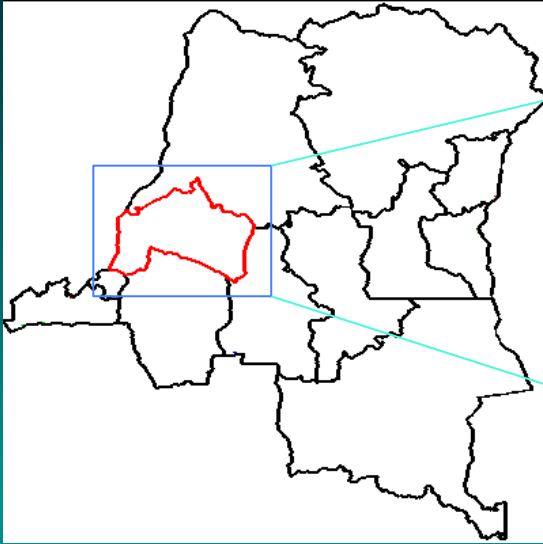
b
Tapajos, Brazil
Mean AGB: 365 Mg/ha
Range: 109-580 Mg/ha



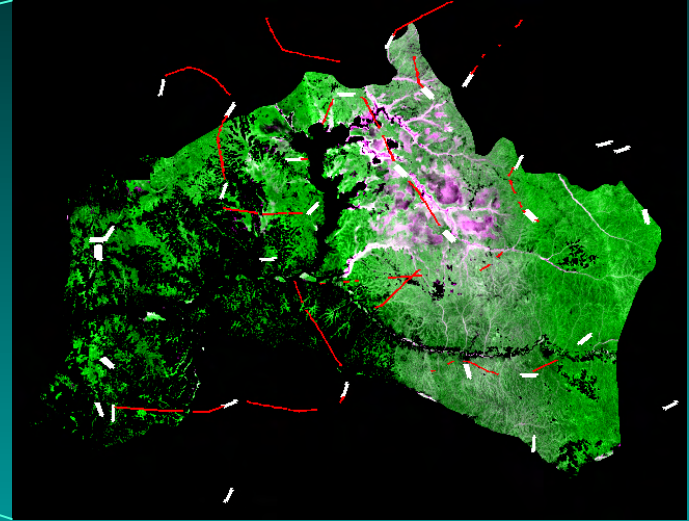
c
Manaus, Brazil
Mean AGB: 331 Mg/ha
Range: 167-497 Mg/ha



Example: Mai Ndombe

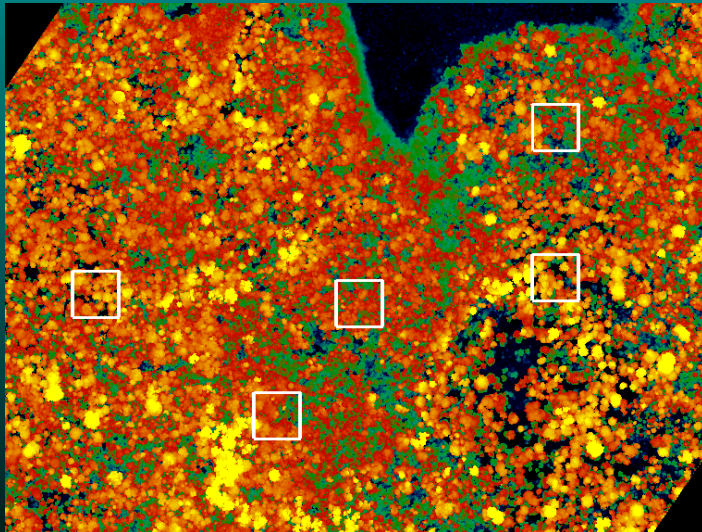


DRC

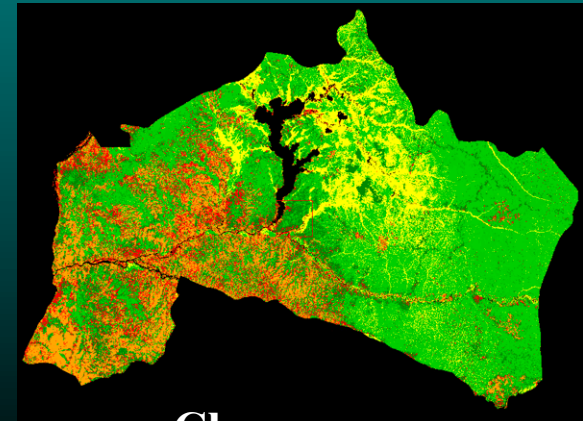


MaiNdombe region

41,945 ha (lidar scenes) + 64,434 ha
(ferry lines) = 106,379 ha



Example of 1ha plots on Lidar image



Class map

Mai Ndombe Lidar Samples

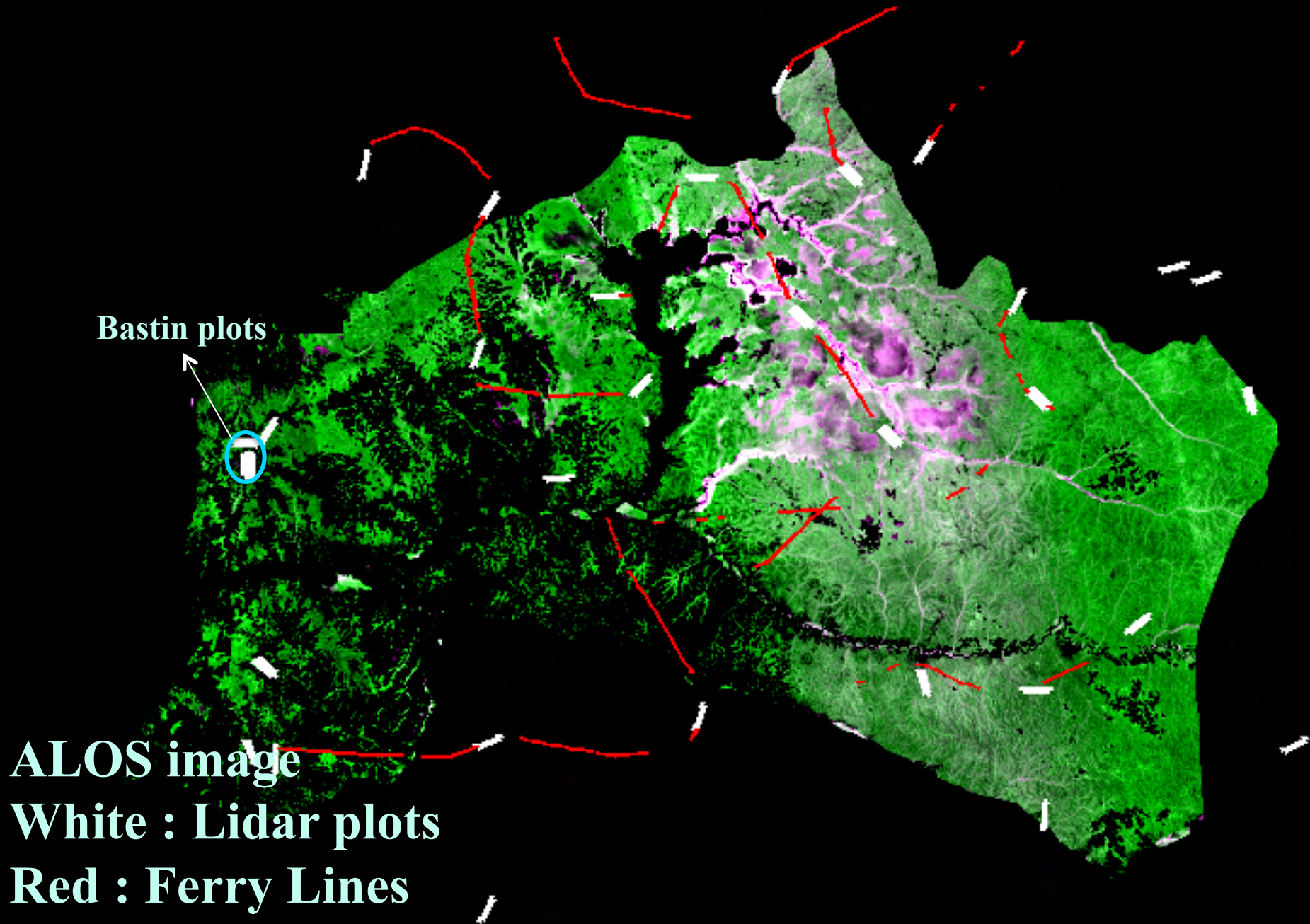
Bastin plots



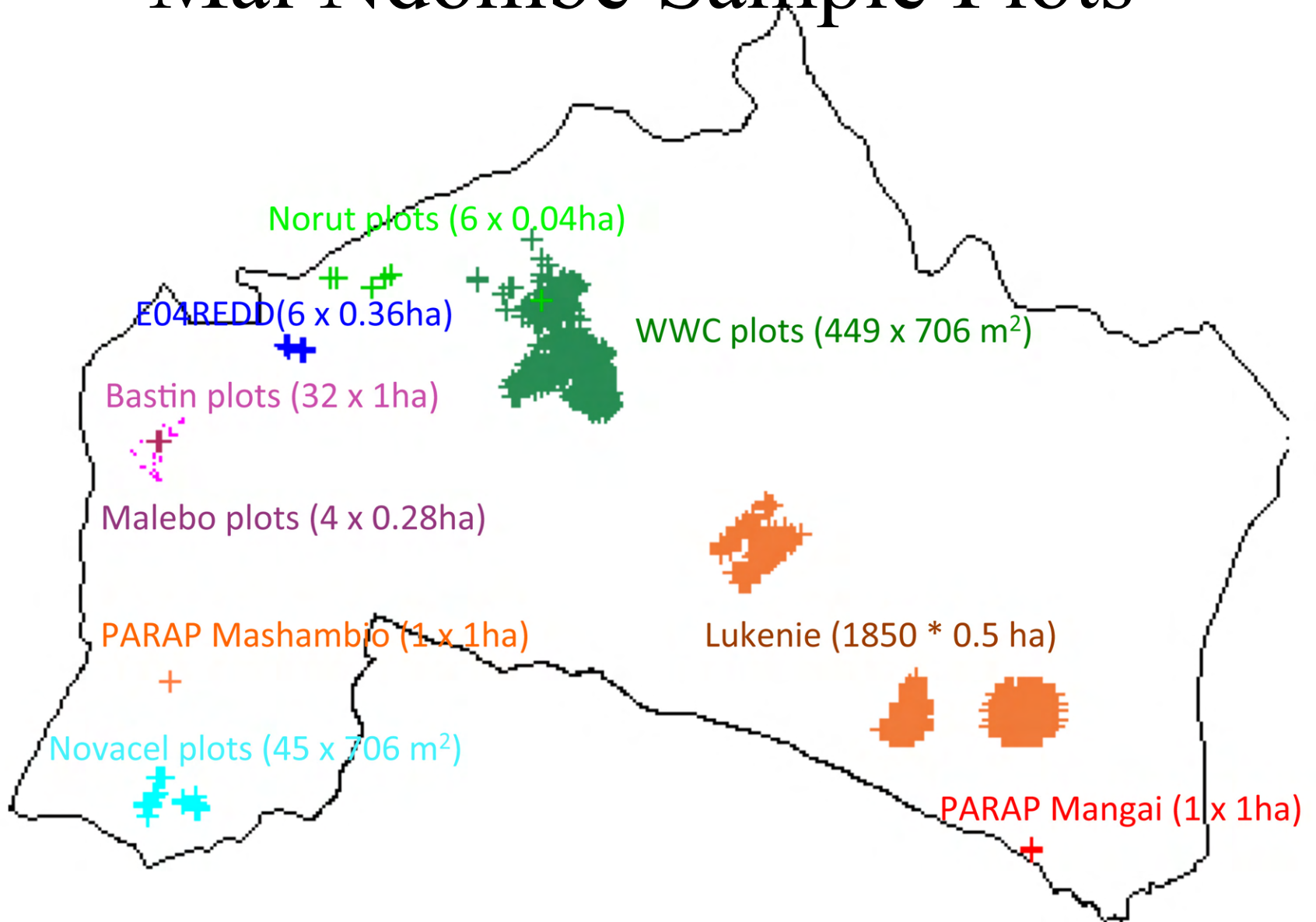
ALOS image

White : Lidar plots

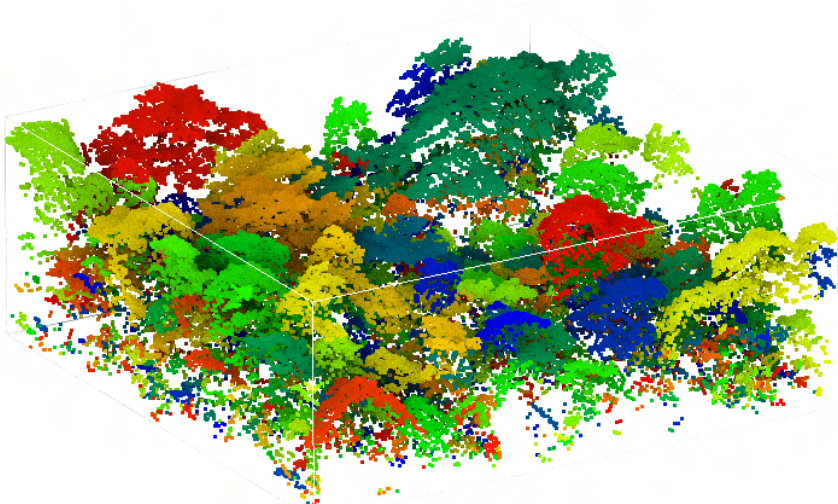
Red : Ferry Lines



Mai Ndombe Sample Plots



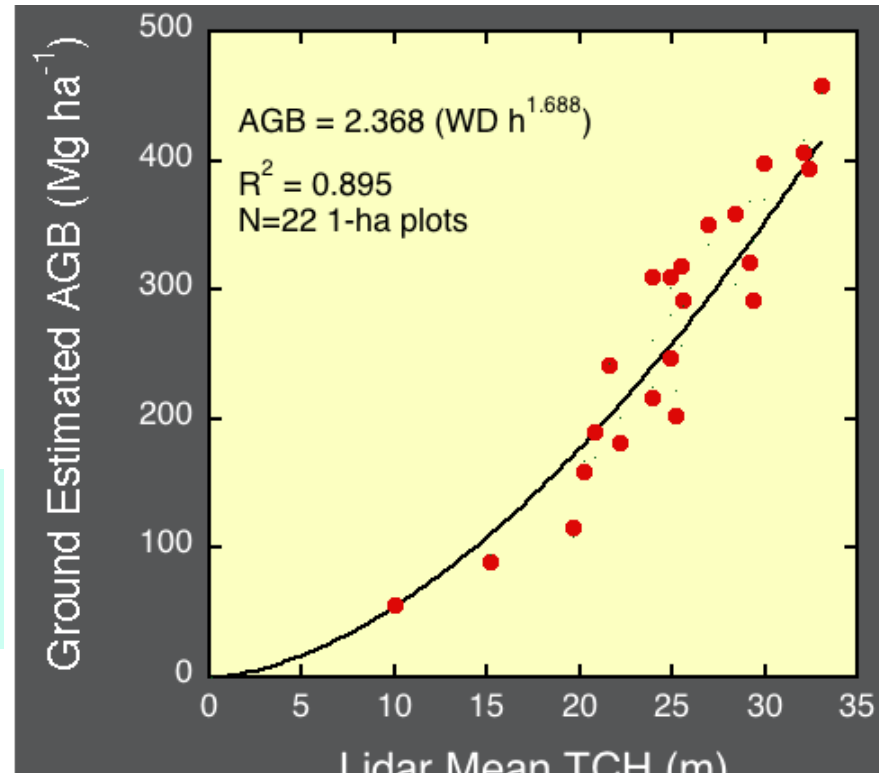
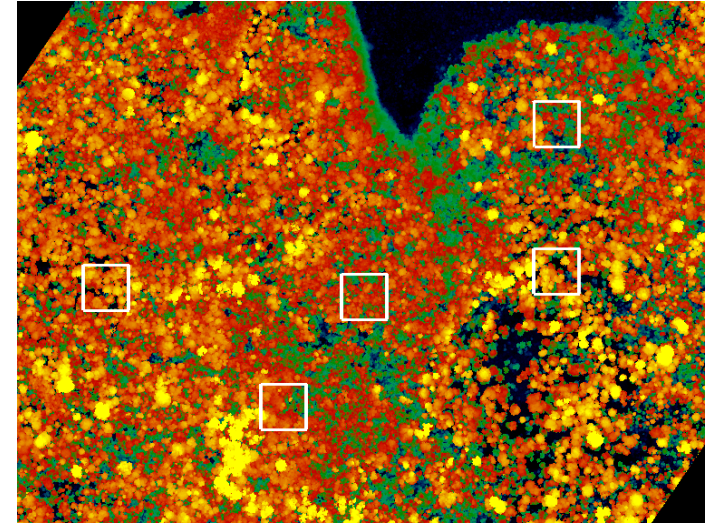
Lidar Biomass Model



**3-D Forest Structure of 1-ha Plots
representing the tree height and
crown size**

**Mean Woody Density from plot data
assigned to stratification map**

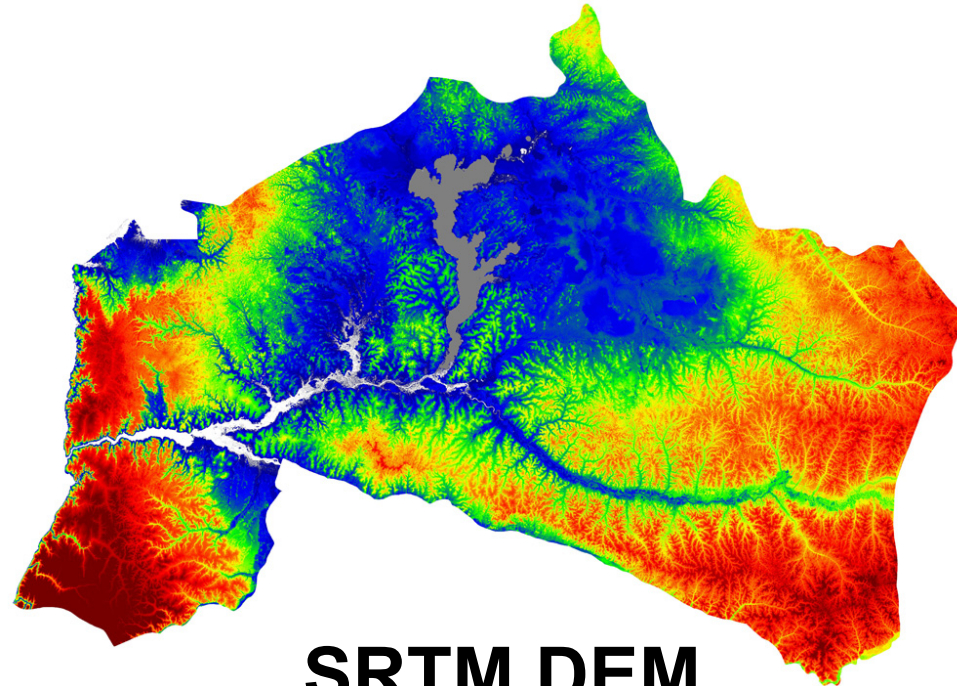
$$AGB = 2.368(WDh)^{1.688}$$



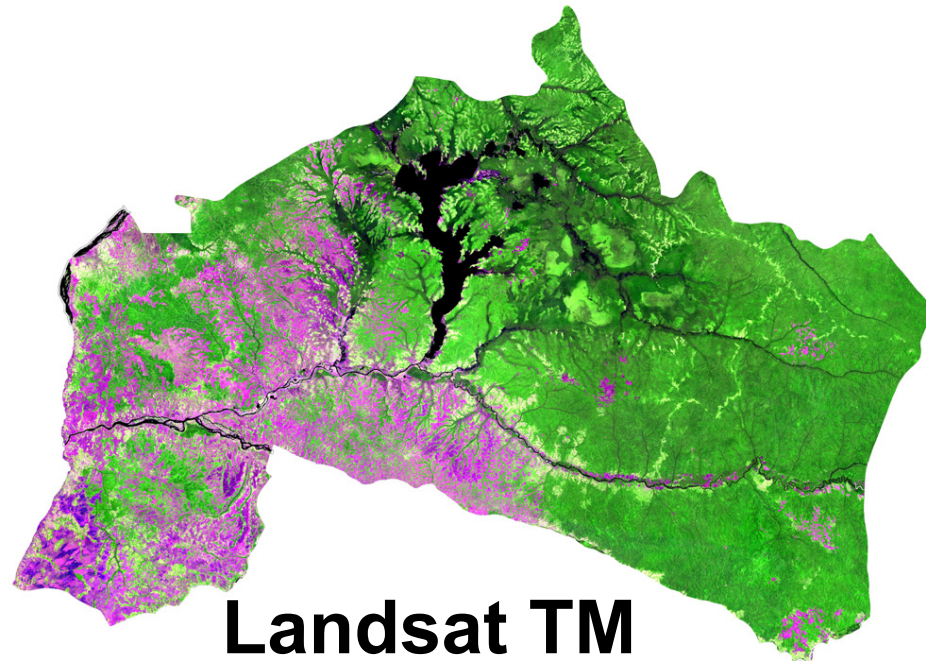
Satellite Imagery



ALOS PALSAR

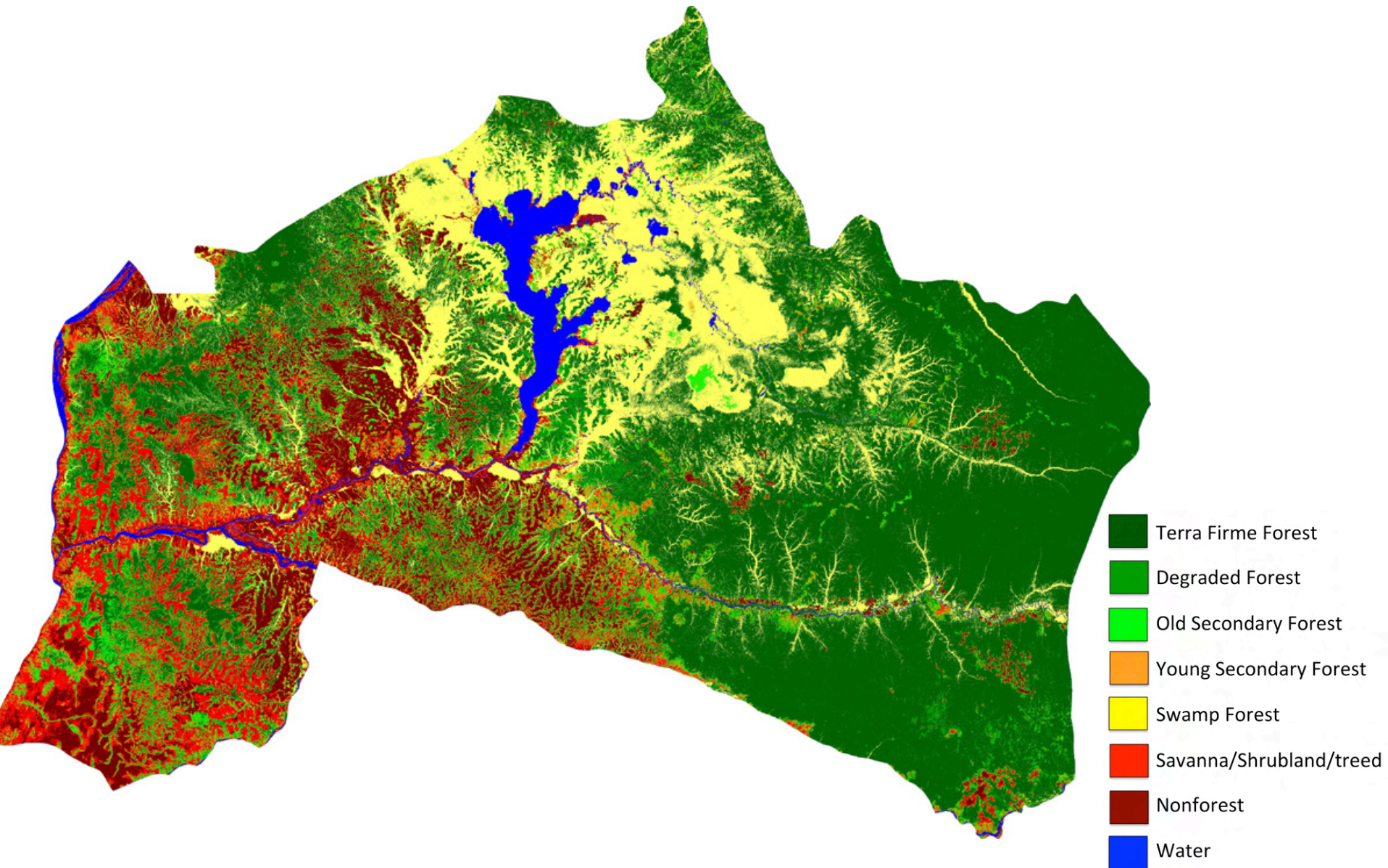


SRTM DEM

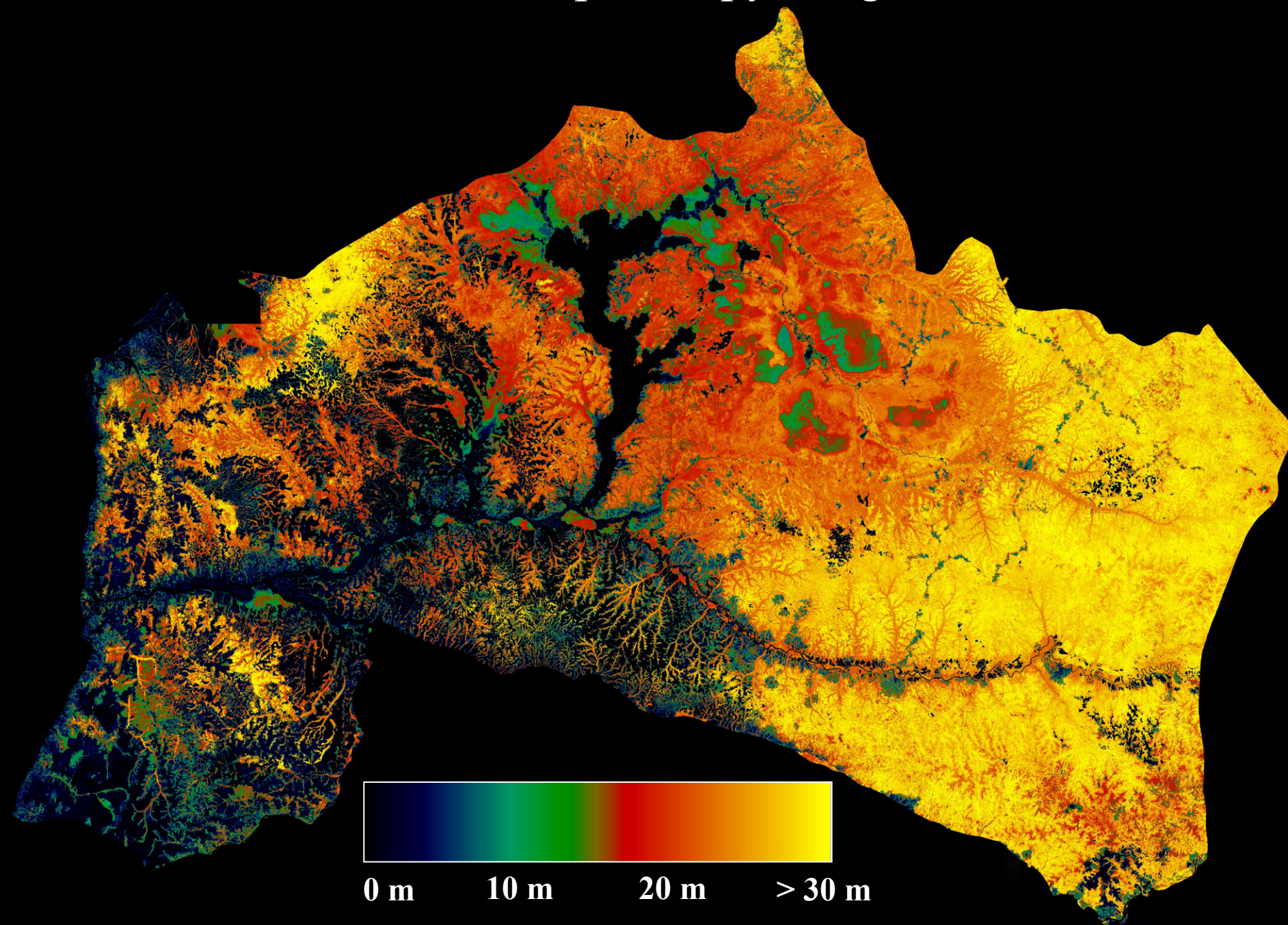


Landsat TM

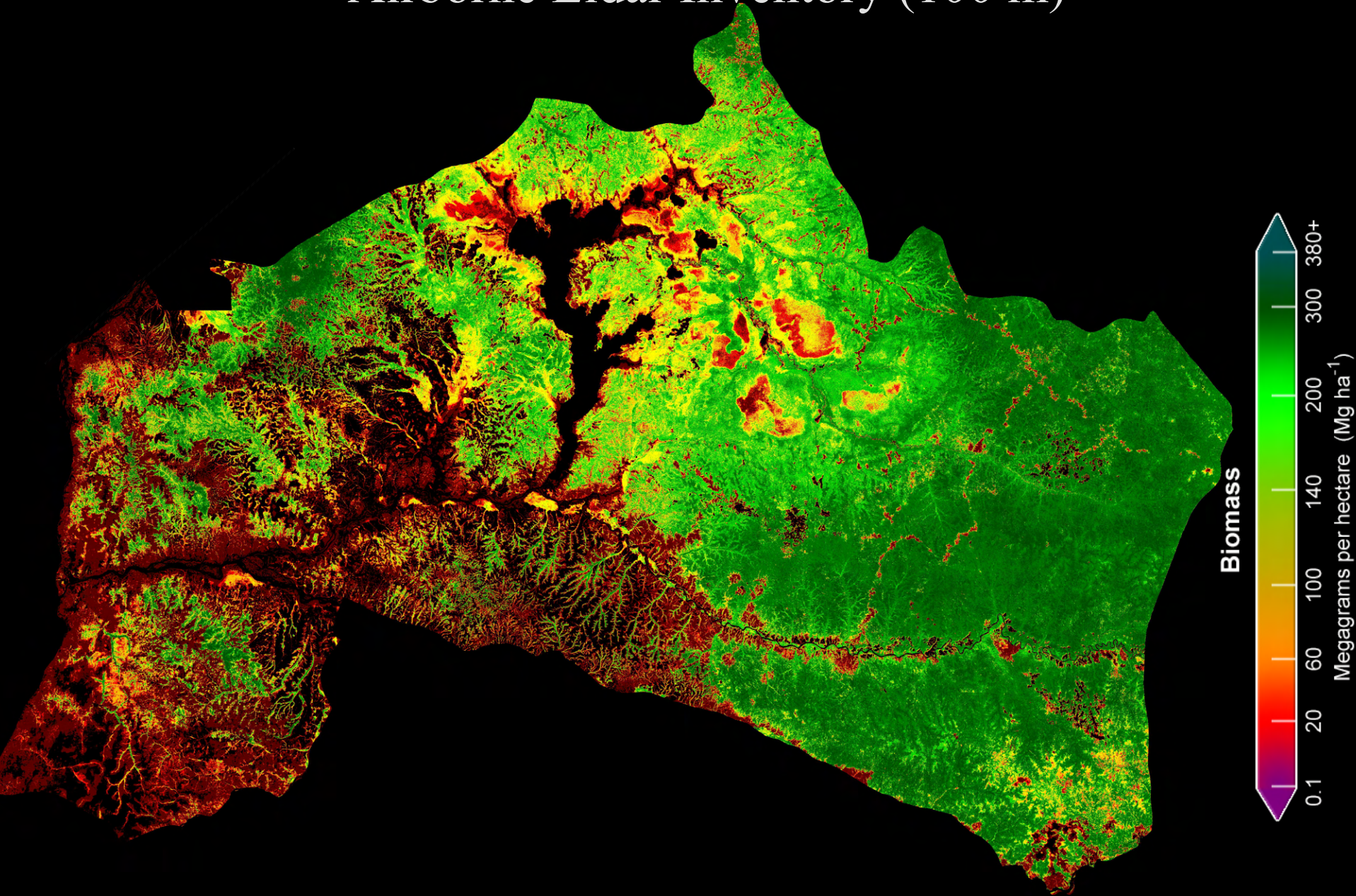
Mai Ndombe Forest Stratification Map

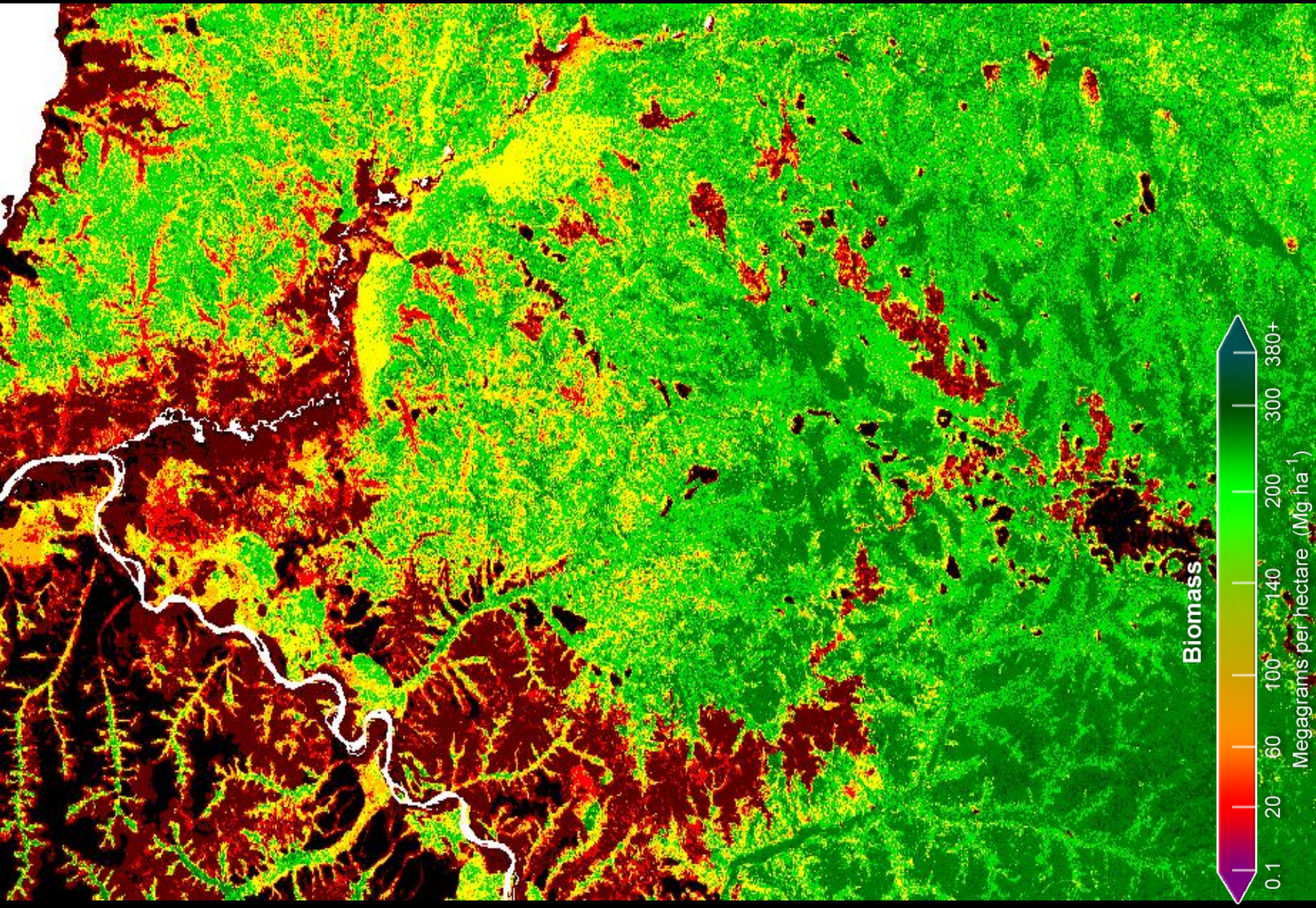


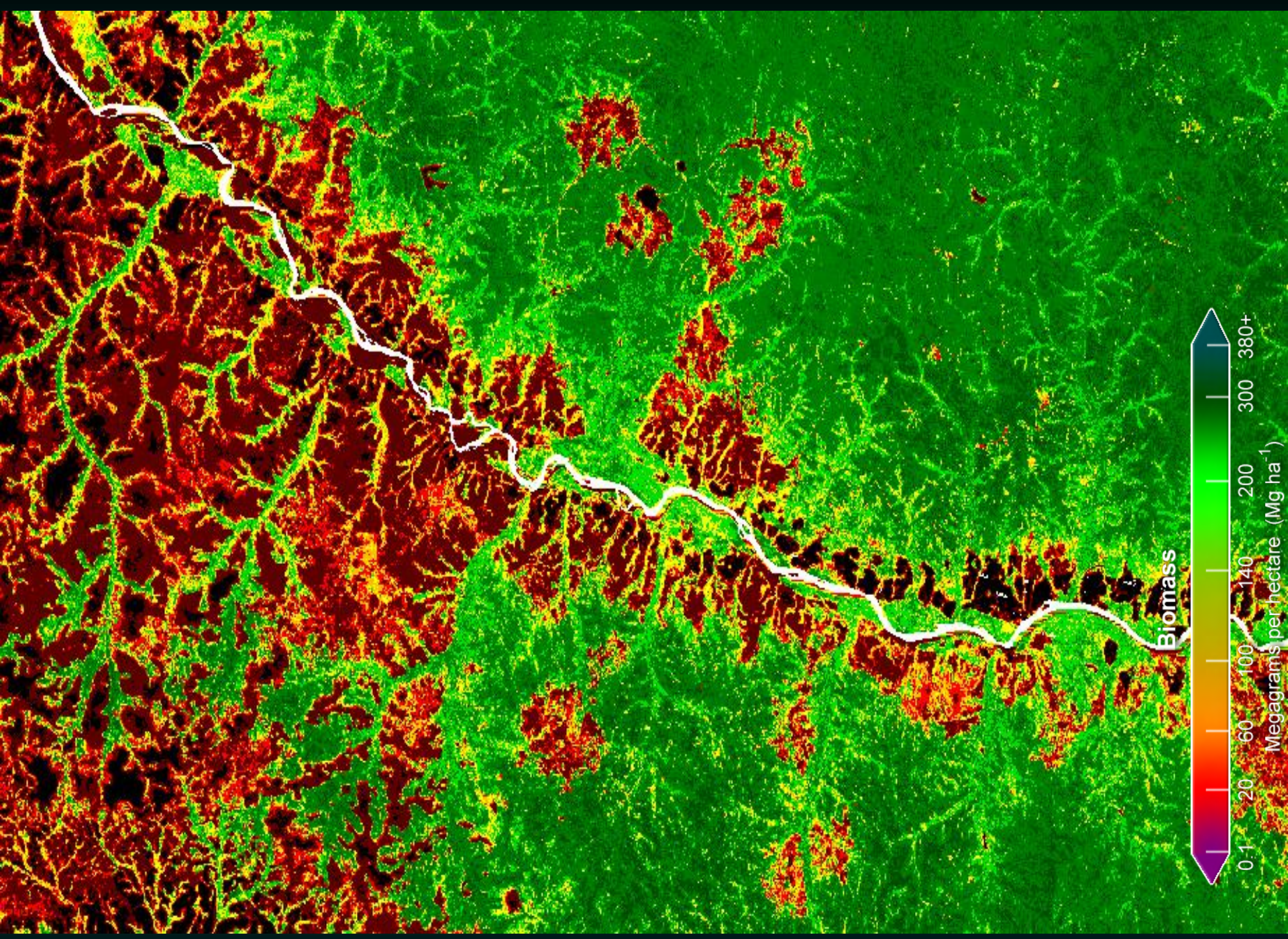
Mean Top Canopy Height



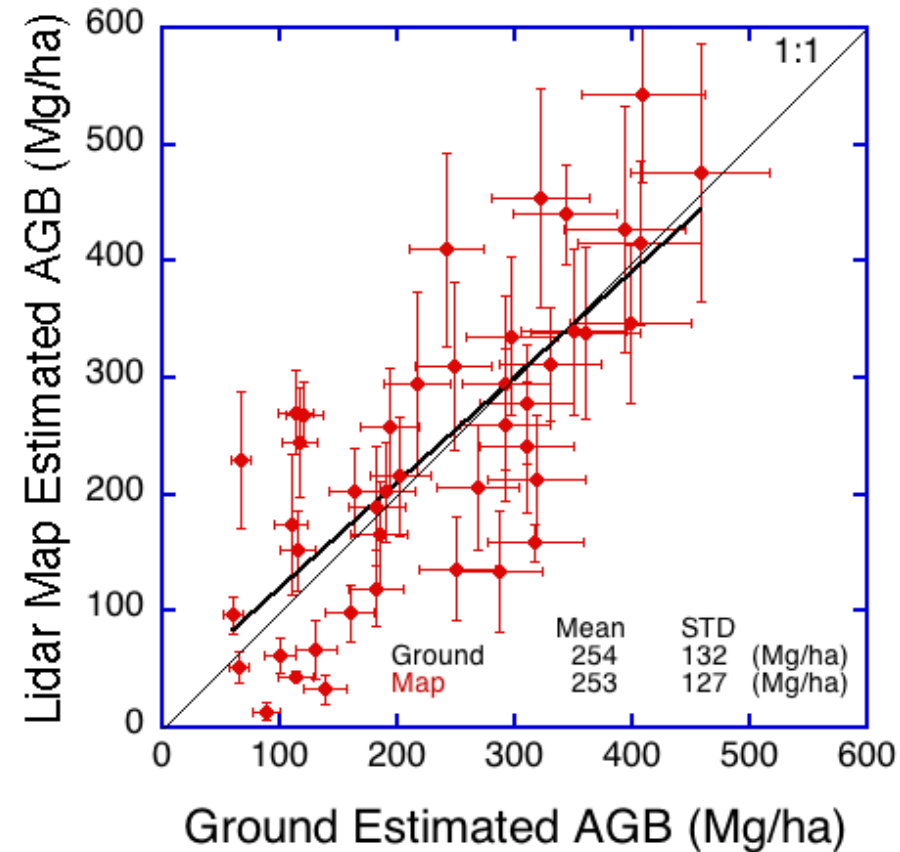
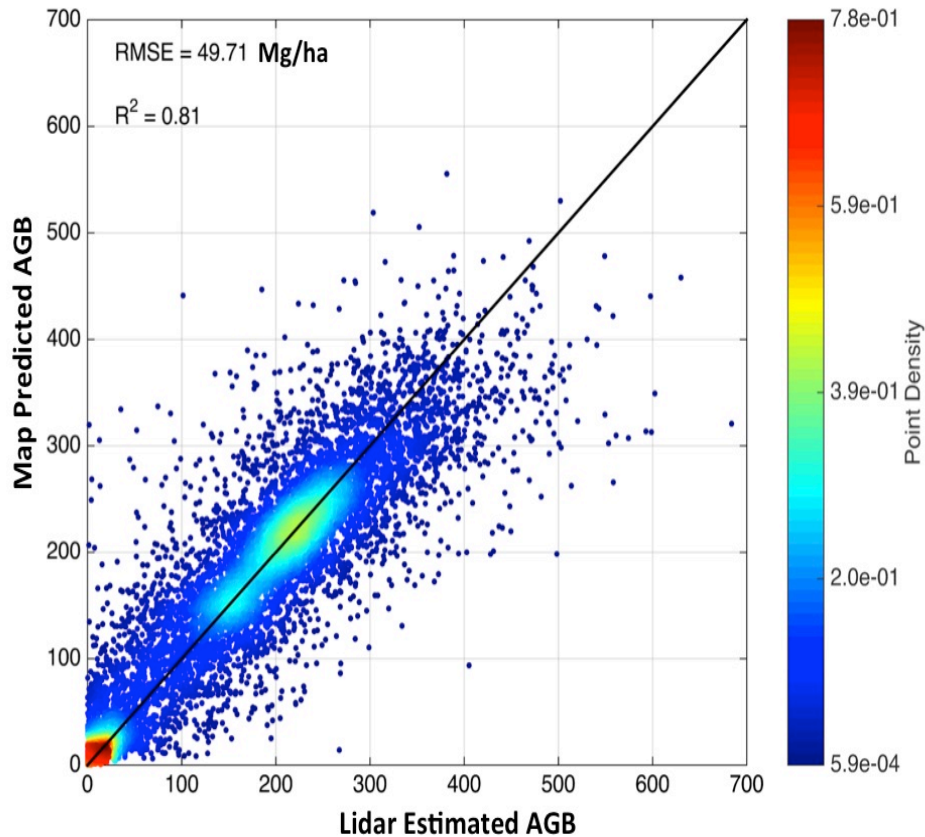
Global Map from Airborne Lidar Inventory (100 m)



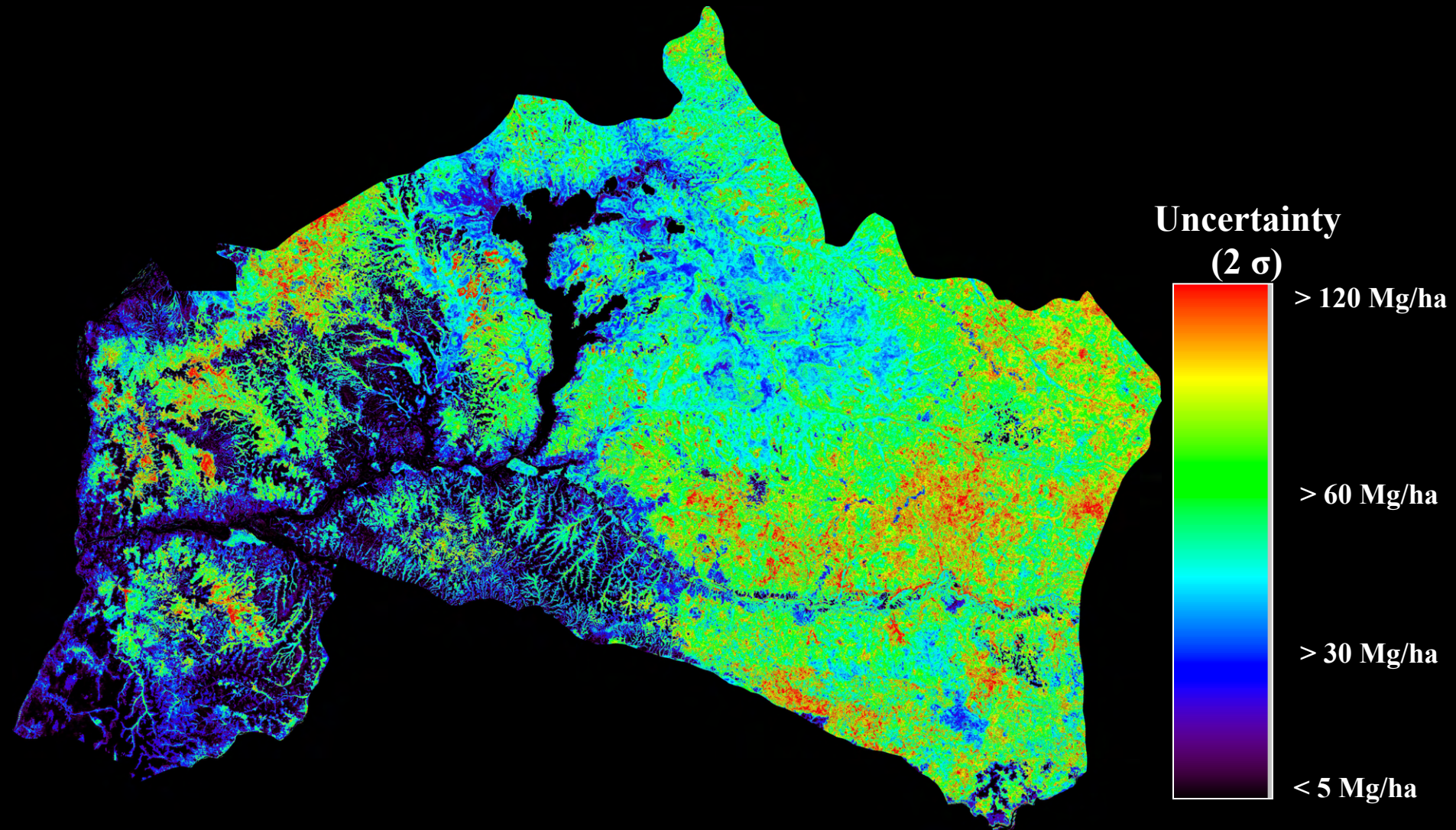




Validation of Carbon Map



Spatial Uncertainty



Application of the Map for REDD and Emission Reduction Projects

Table 2. Mean above and below ground biomass and carbon stock in each stratified vegetation type in the Mai Ndombe Region.

Vegetation Type	Mean AGB (Mg/ha)	STD AGB (Mg/ha)	Mean BGB (Mg/ha)	STD BGB (Mg/ha)	Area (ha)	AGB + BGB (Mg/ha)	AGC + BGC (MgC/ha)
Mature Forest	296.76	58.92	69.75	13.85	5065456	366.51	183.26
Degraded Forest	197.93	82.96	45.99	20.18	561509	243.92	121.96
Young Secondary Forest	30.03	16.04	6.17	3.55	708432	36.20	18.10
Old Secondary Forest	124.78	43.75	27.85	11.30	1327966	152.63	76.32
Swamp Forest	192.15	70.63	44.69	17.25	2171521	236.85	118.42
Non Forest	1.96	5.63	0.83	1.60	2078266	2.79	1.39
Savanna	11.34	15.53	4.17	4.04	411143	15.51	7.75

National Carbon Assessment

- 1. This is the first national map designed based on approved VCS tool**
- 2. National map will provide detailed information on carbon stocks at local to regional scales**
- 3. National map can be used to develop project and jurisdictional ER programs and land use plans**
- 4. The map can be evaluated and improved as ground data becomes available**
- 5. All data used for the map including lidar samples, satellite information and lidar models, ground data, will be available for transparency.**