

Calibrating Empirical Relations Between Airborne Laser Scanning (ALS) and Above-Ground Biomass (AGB) in the Brazilian Amazon

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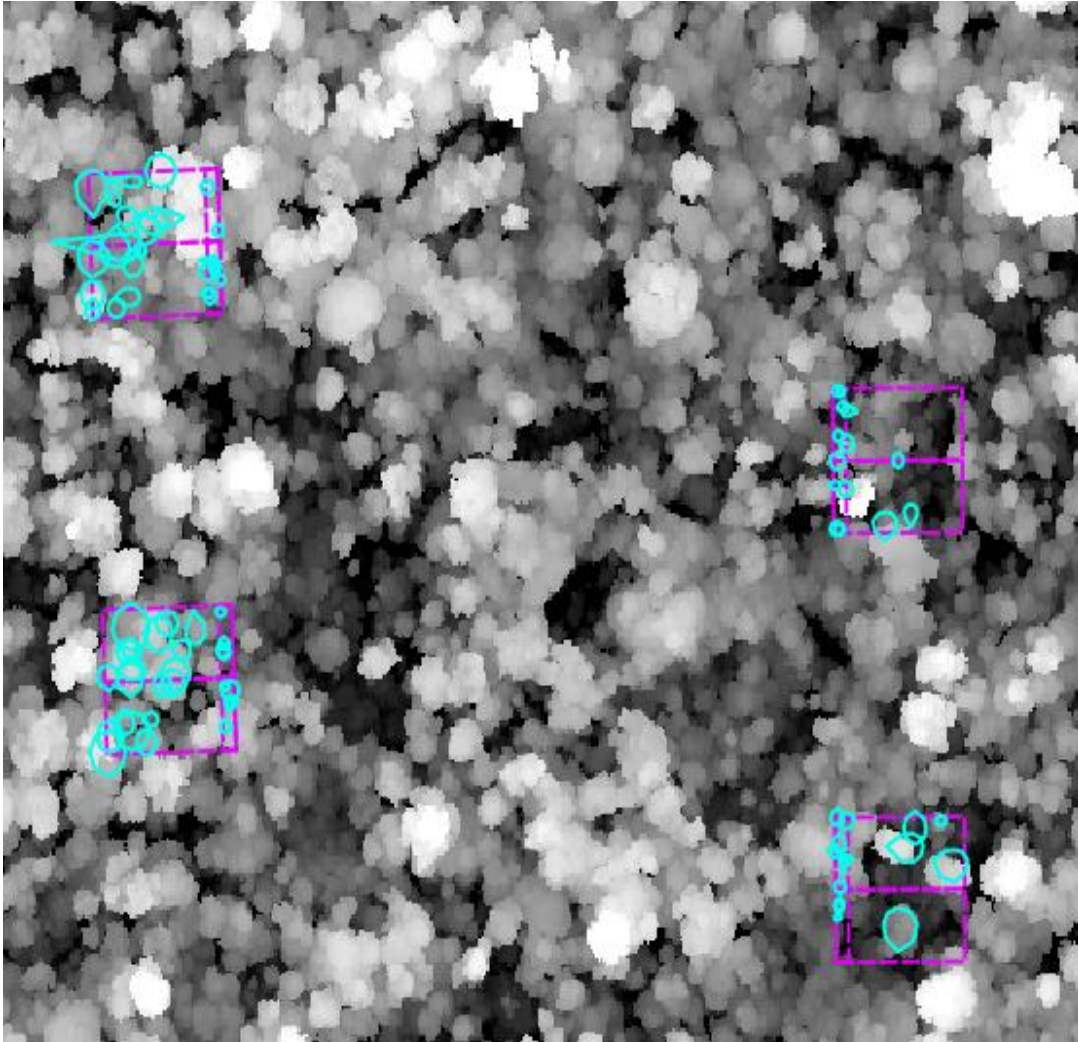
Calibration Talk Outline (1/2)

- The challenge – relating point clouds and trees
- Measuring trees
 - Allometric relations
 - The special challenge of measuring tree height
 - Inventory plots and lidar
- Retrieving data from point clouds
 - Seeing the ground
- Area-based approach to biomass estimation
- Alternative metrics (e.g. large canopy area)

Calibration Talk Outline (2/2)

- The Sustainable Landscapes (SL) Brazil database
- Calibration with alternative fitting approaches
- Cross-validation
- Comparison of SL to existing Amazon biomass maps (Saatchi, Baccini, Nogueira)
- Concluding remarks

Challenge: relate lidar point cloud to trees

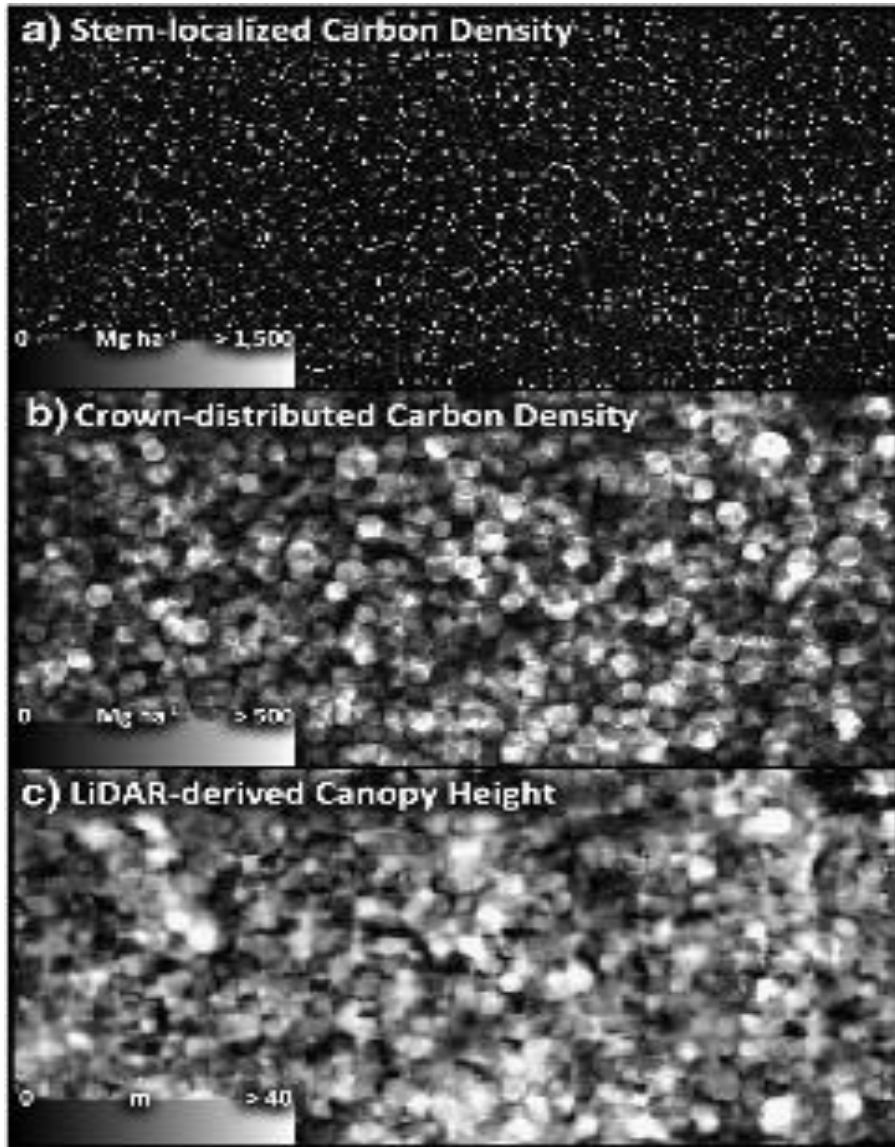


Forest inventories
measure tree
diameters at 1.3 m
(sometimes heights)

Airborne lidar
measures tree
heights from the top

Image: M. Longo

How is biomass distributed on the landscape?

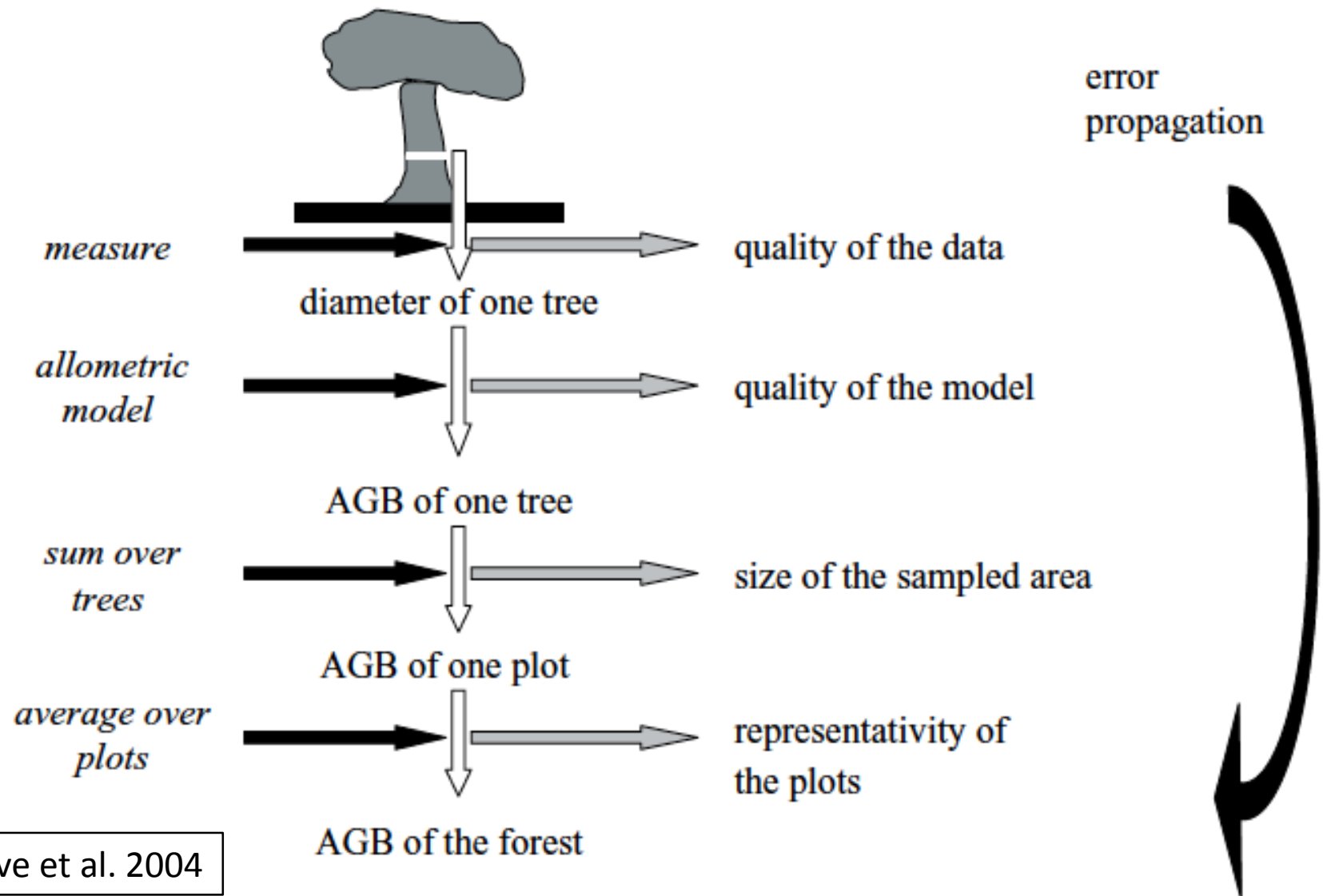


Carbon density of stems

Carbon density
distributed to crowns

Lidar canopy height
model

Estimating AGB from Forest Inventory Data



Allometric relations

$$AGB = f(D, H, \rho) = f_1(D)f_2(H)f_3(\rho)$$

$$\begin{aligned} \frac{\sigma_M^2}{AGB^2} = & \frac{\sigma_D^2}{D^2} \left(\frac{\partial \ln(f)}{\partial \ln(D)} \right)^2 + \frac{\sigma_H^2}{H^2} \left(\frac{\partial \ln(f)}{\partial \ln(H)} \right)^2 + \frac{\sigma_\rho^2}{\rho^2} \left(\frac{\partial \ln(f)}{\partial \ln(\rho)} \right)^2 \\ & + 2 \frac{\sigma_{DH}}{HD} \frac{\partial \ln(f) \partial \ln(f)}{\partial \ln(D) \partial \ln(H)} \end{aligned}$$

$$\sigma_D = aD + b \cong 1 - 2\%, \quad \sigma_H \approx 10\%, \quad \sigma_\rho \approx 10\%$$

Allometric relations selected

- Live trees (Chave et al. 2014)

$$AGC = 0.0673 f_C (\rho_w DBH^2 H_t)^{0.976}$$

- Live palms (Goodman et al. 2013)

-

$$AGC = 0.03781 f_C DBH^{2.7483}$$

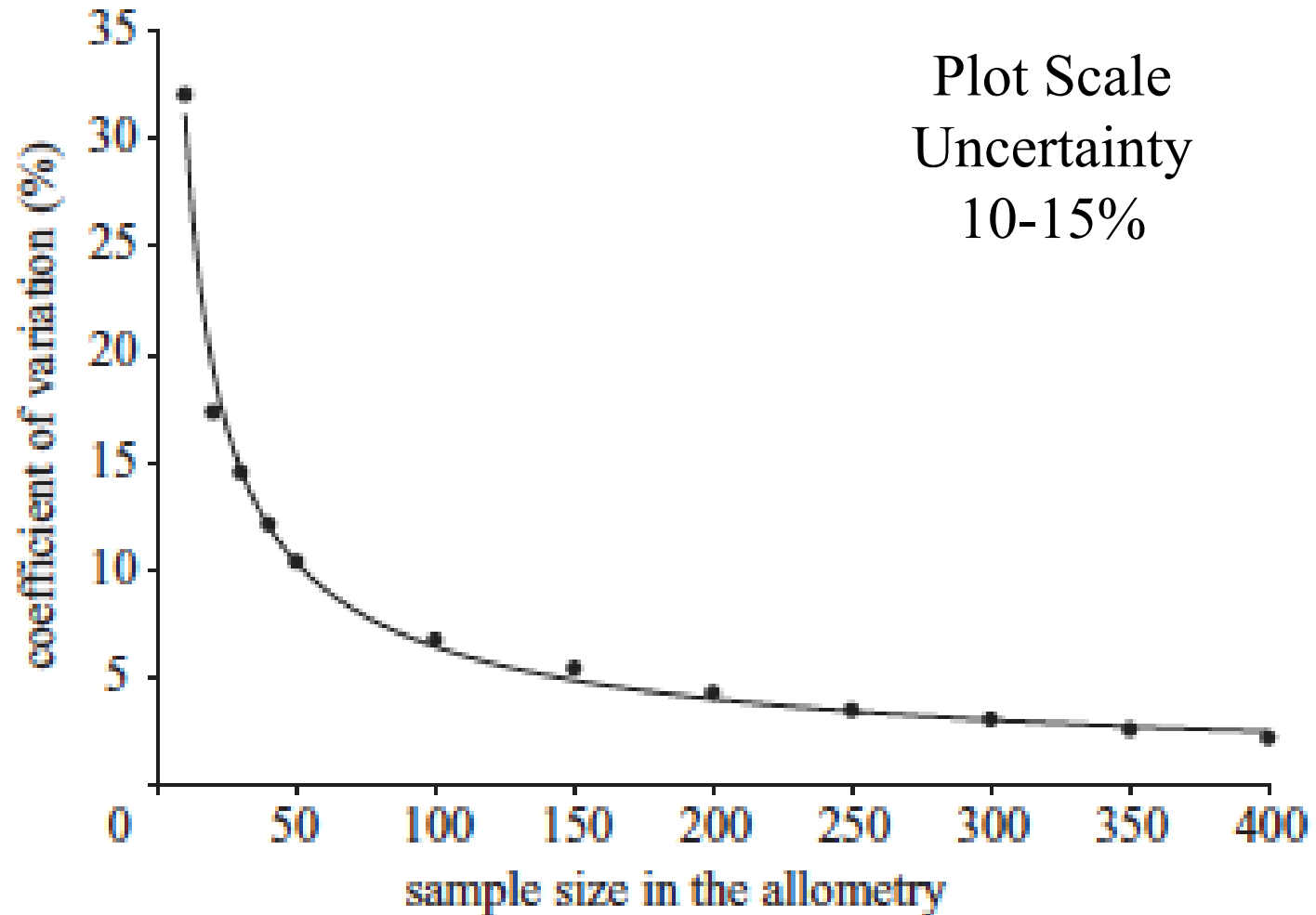
- Live lianas (Schnitzer et al. 2006)

$$AGC = 0.3798 f_C DBH^{2.657};$$

- Standing dead trees (Palace et al. 2007)

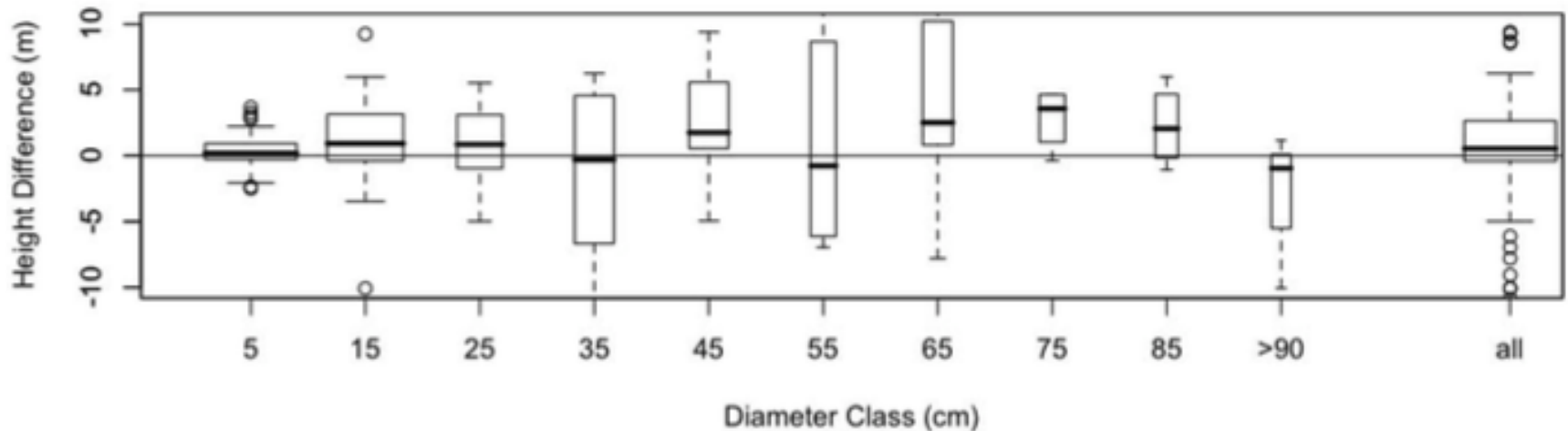
$$AGC = 0.1007 f_C \rho_s DBH^2 H_t^{0.818};$$

Tree allometric uncertainty contribution to plot biomass uncertainty



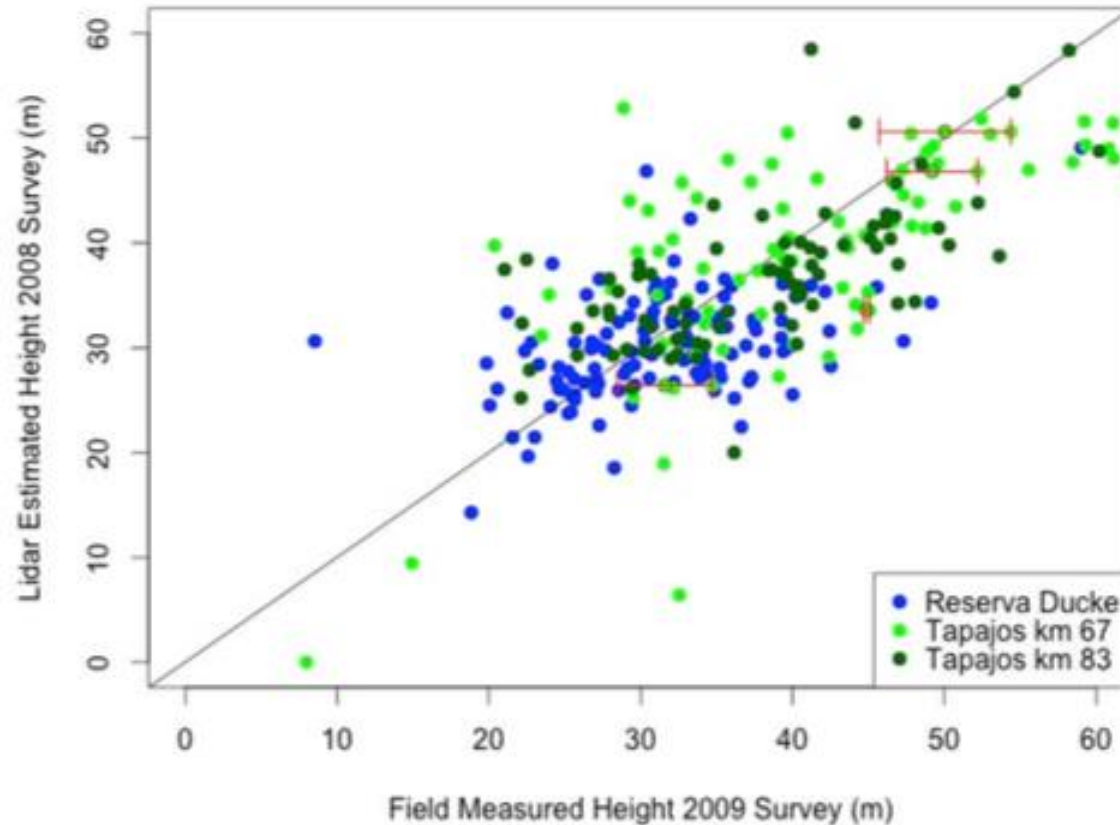
Chave et al., 2005

Tree height measurements in the field



- Repeated measurements of height for 174 trees using a tape measure and clinometer showed that estimates were imprecise ($SD = 4.7$ m for paired estimates) but not biased.
- The greatest difficulty is seeing the *top* of the tree.

Lidar height measurements vs. field heights for emergent trees (RMSE = 7.3 m)



The height difference between emergent crowns measured in the field versus the height estimated using lidar was -1.4 m (lidar – field height). (Hunter et al. *Biogeosciences* 2013)

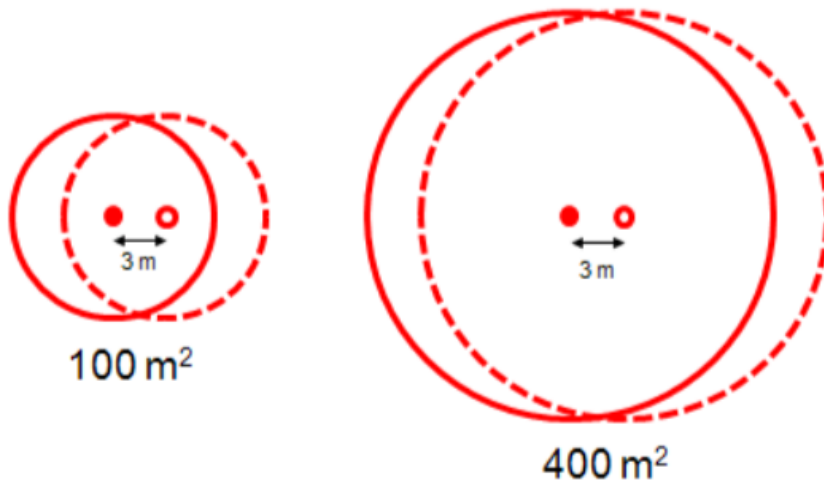
Biomass uncertainty related to height estimate

Site	Transect	Biomass (Mg ha ⁻¹)	95 % confidence interval
Tapajos km 83	1	344	20
	2	310	18
	3	350	21
	4	314	17
	5	263	17
	6	146	13

Plot geolocation and edge effects

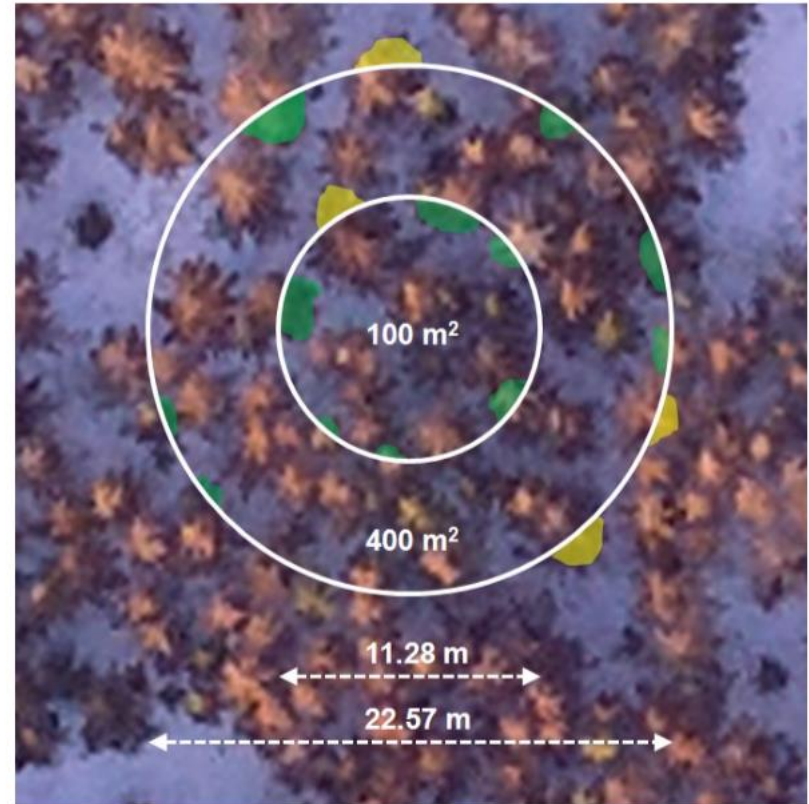
BIGGER is BETTER

3 m geolocation error



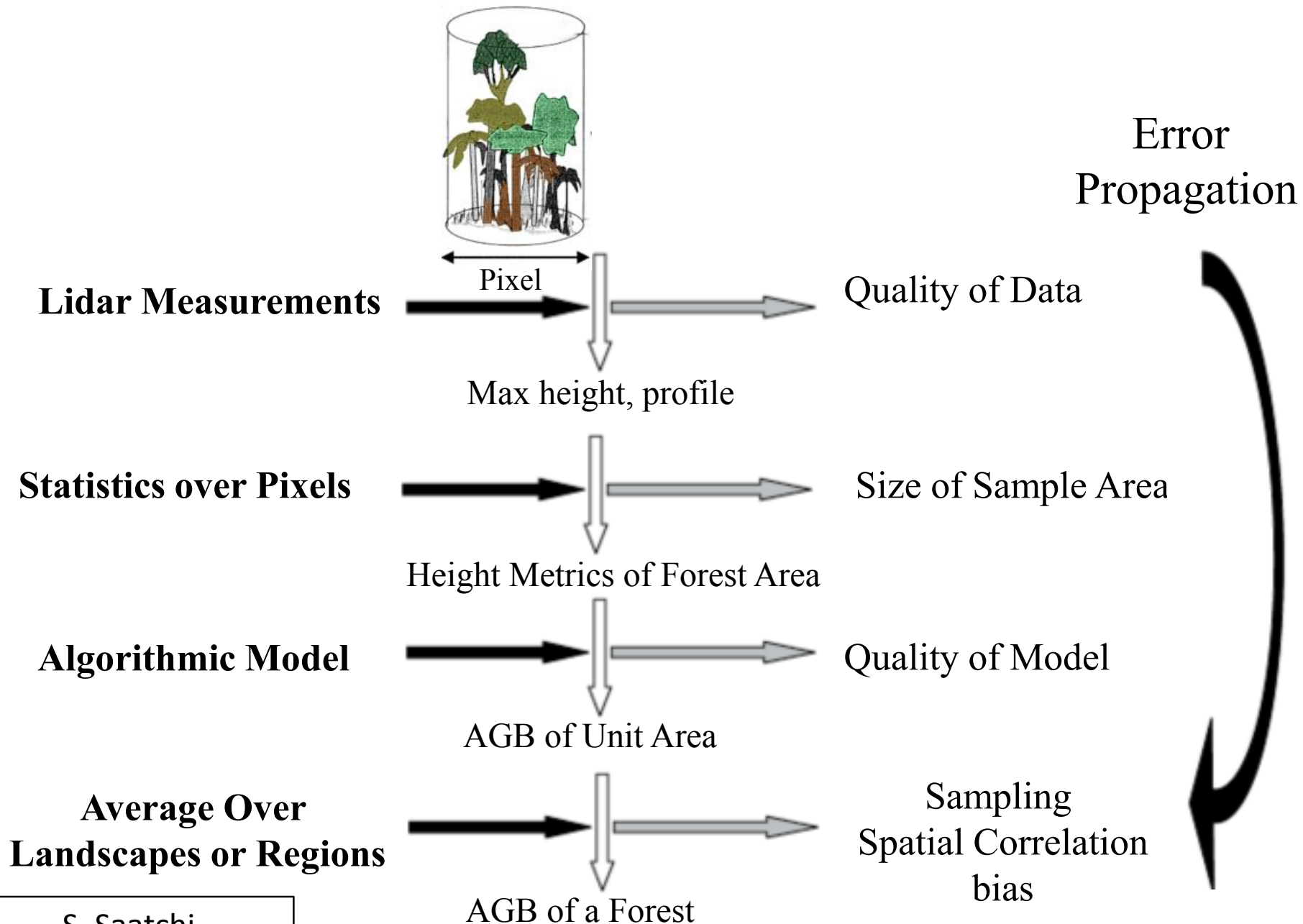
63% overlap

82% overlap

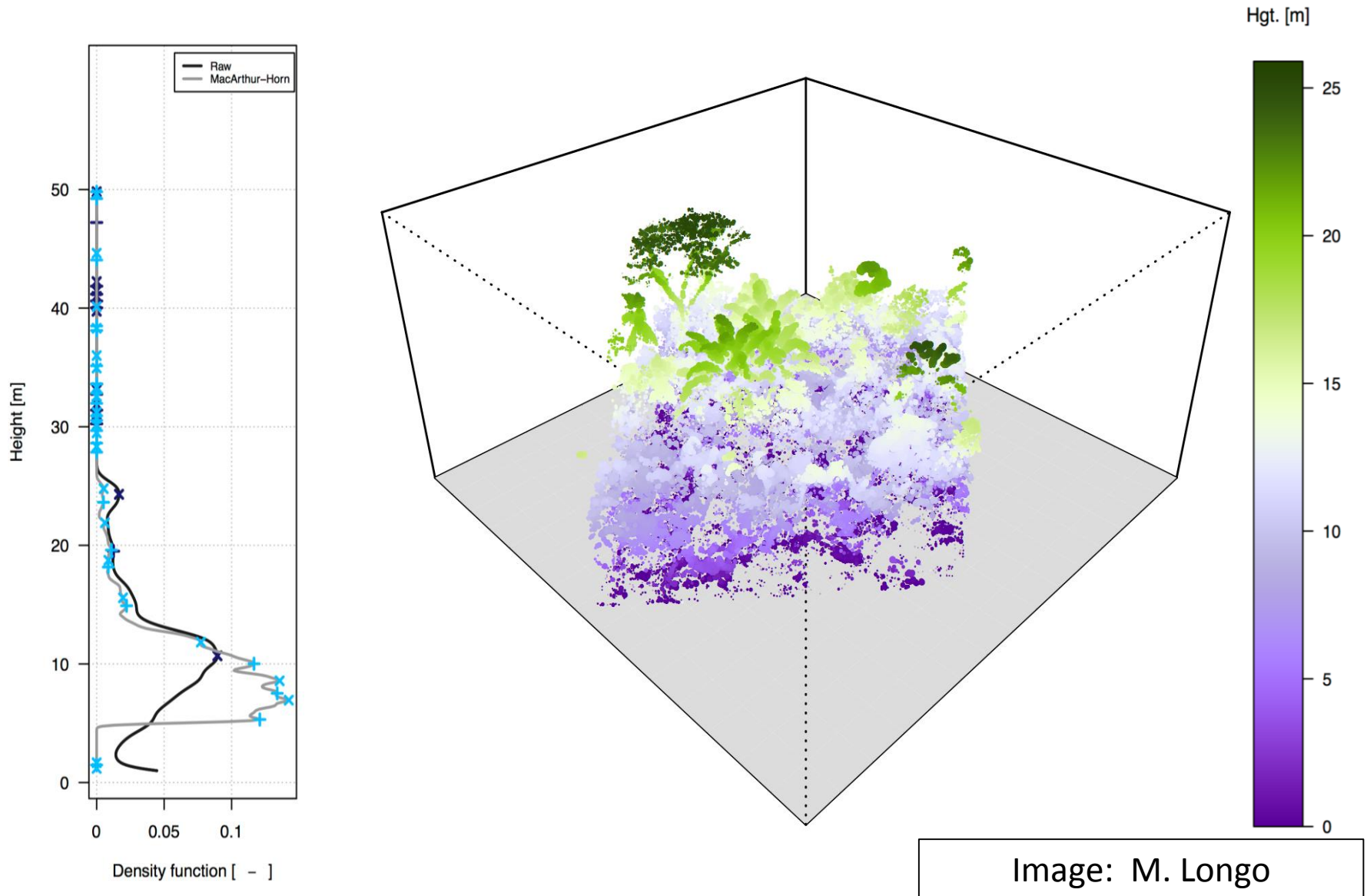


Green = crown in plot but stem outside
Yellow = stem inside but crown outside

Error propagation for estimating AGB from lidar data



Area based approach: height metrics



Area based approach:
regression height metrics

$$\tilde{B} = a_0 + \sum_{i=1}^{I_{\max}} (a_i x_i + b_i \ln x_i)$$

$$\widetilde{\ln B} = a_0 + \sum_{i=1}^{I_{\max}} (a_i x_i + b_i \ln x_i)$$

B = Biomass, x_i = lidar metric i ,

a_0, a_i, b_i = model parameters

Relating lidar metrics to biomass

Multiple
linear
regression

$$\tilde{B} = a_0 + \sum_{i=1}^{I_{\max}} (a_i x_i + b_i \ln x_i)$$

$$\widetilde{\ln B} = a_0 + \sum_{i=1}^{I_{\max}} (a_i x_i + b_i \ln x_i)$$

Random
forests

$$\tilde{B} = f_{NP}(x_1, \ln x_1, x_2, \ln x_2, \dots, x_{I_{\max}}, \ln x_{I_{\max}})$$
$$\widetilde{\ln B} = f_{NP}(x_1, \ln x_1, x_2, \ln x_2, \dots, x_{I_{\max}}, \ln x_{I_{\max}})$$

“Universal
Equation”
(Asner and
Mascaro,
2014)

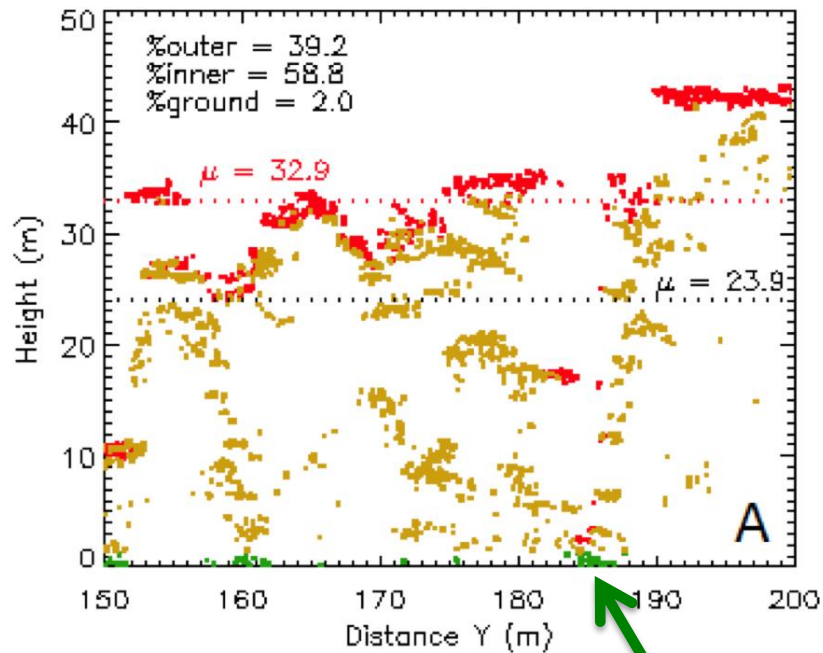
$$\tilde{B} = a_0 z_{\text{TCH}}^{a_1} \tilde{A}_{B_r}^{a_2} \tilde{\rho}_{w_r}^{a_3}$$

$$\tilde{A}_{B_r} = b_{1_r} z_{\text{TCH}}$$

$$\tilde{\rho}_{w_r} = c_{0_r} + c_{1_r} z_{\text{TCH}}$$

Image: M. Longo

Importance of seeing the ground through dense canopies



2% ground returns

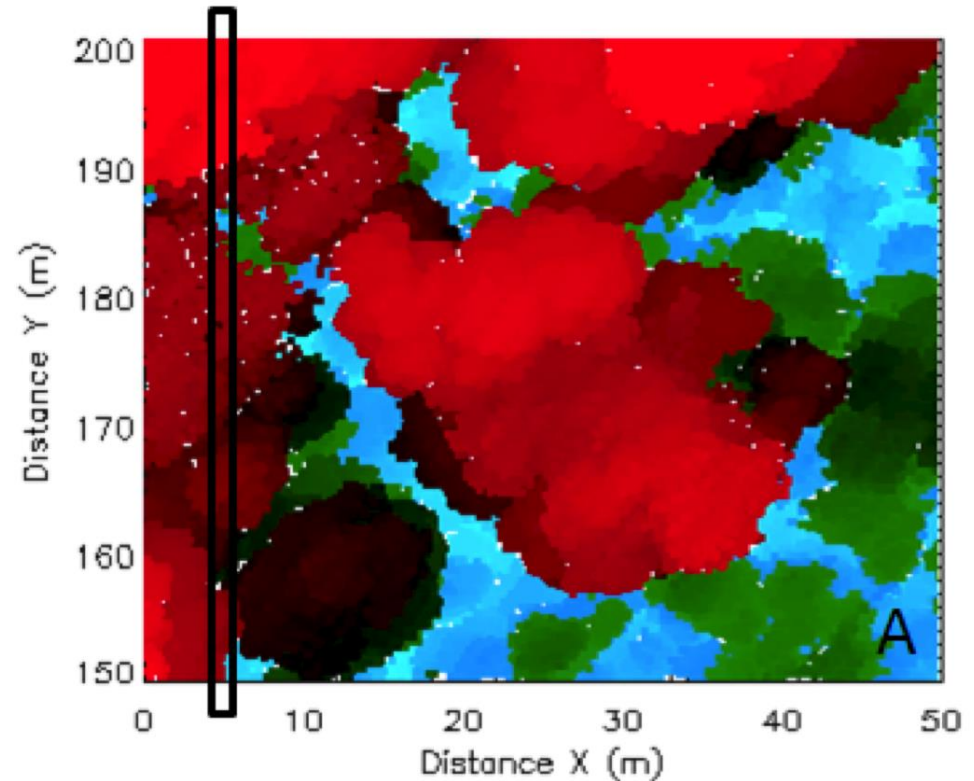
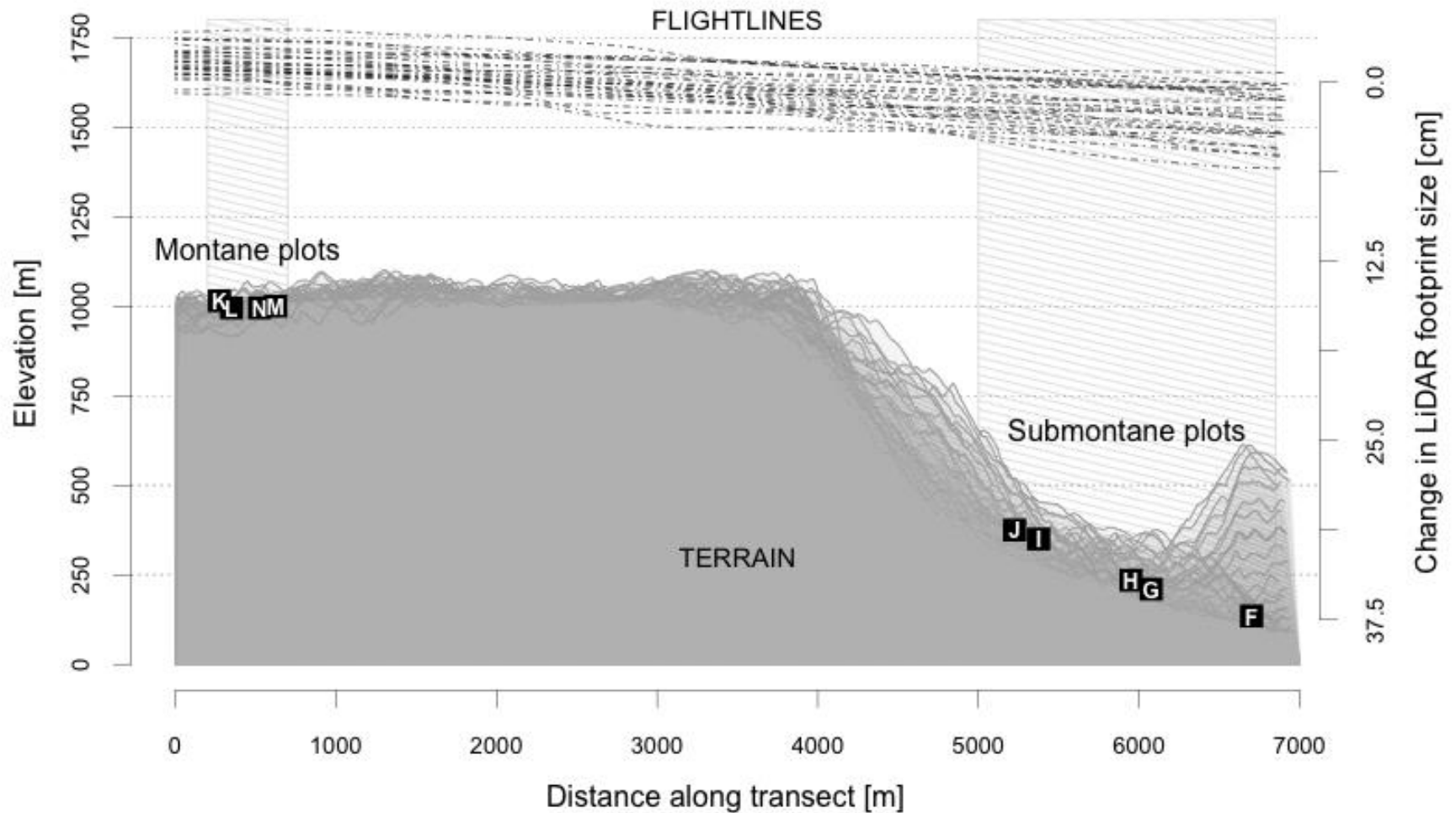


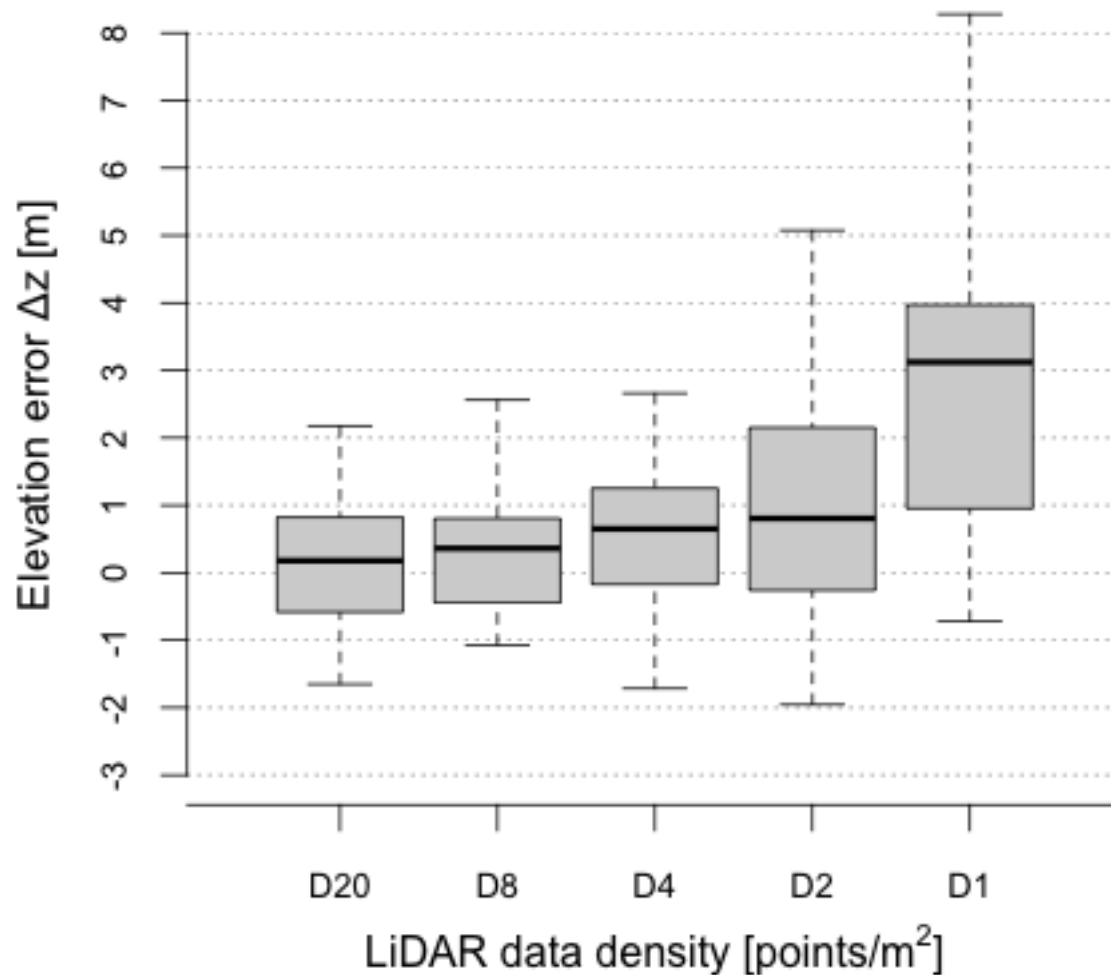
Image: M. Hunter

Importance of seeing the ground

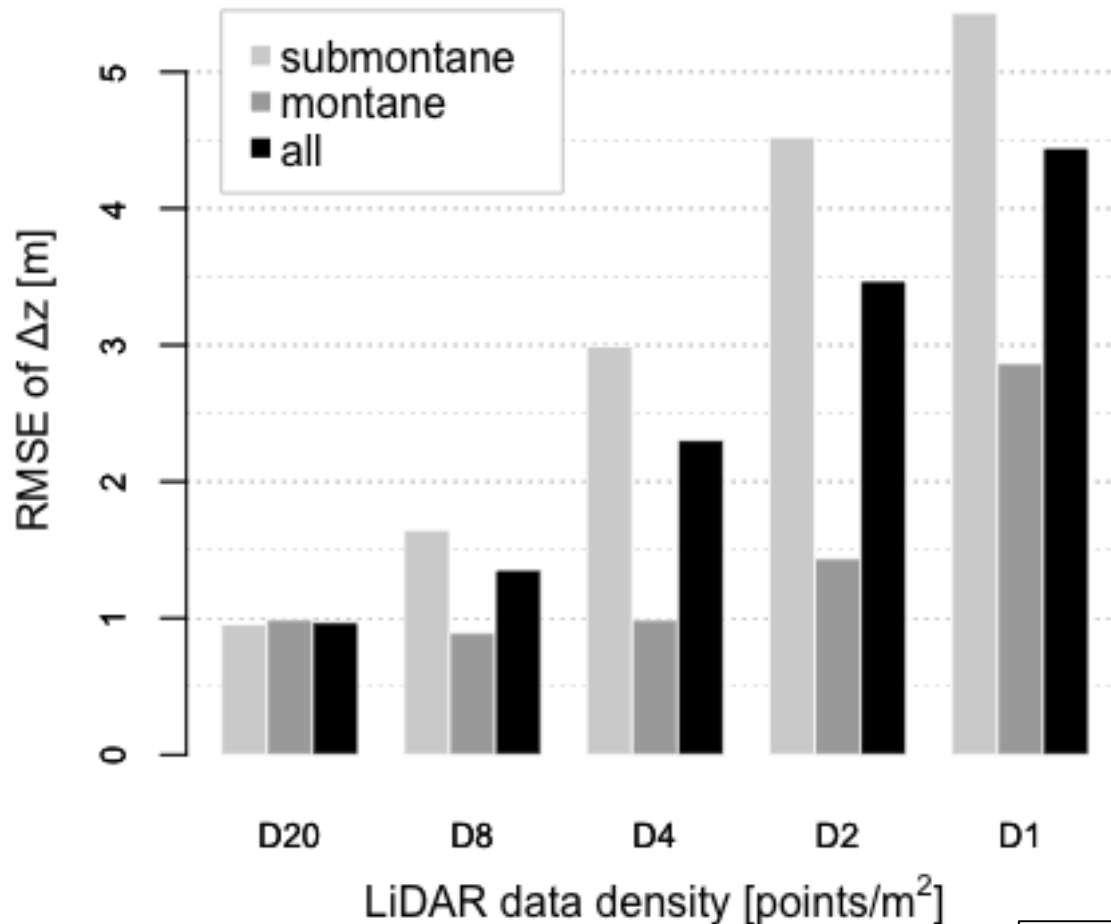
A test in the Serra do Mar



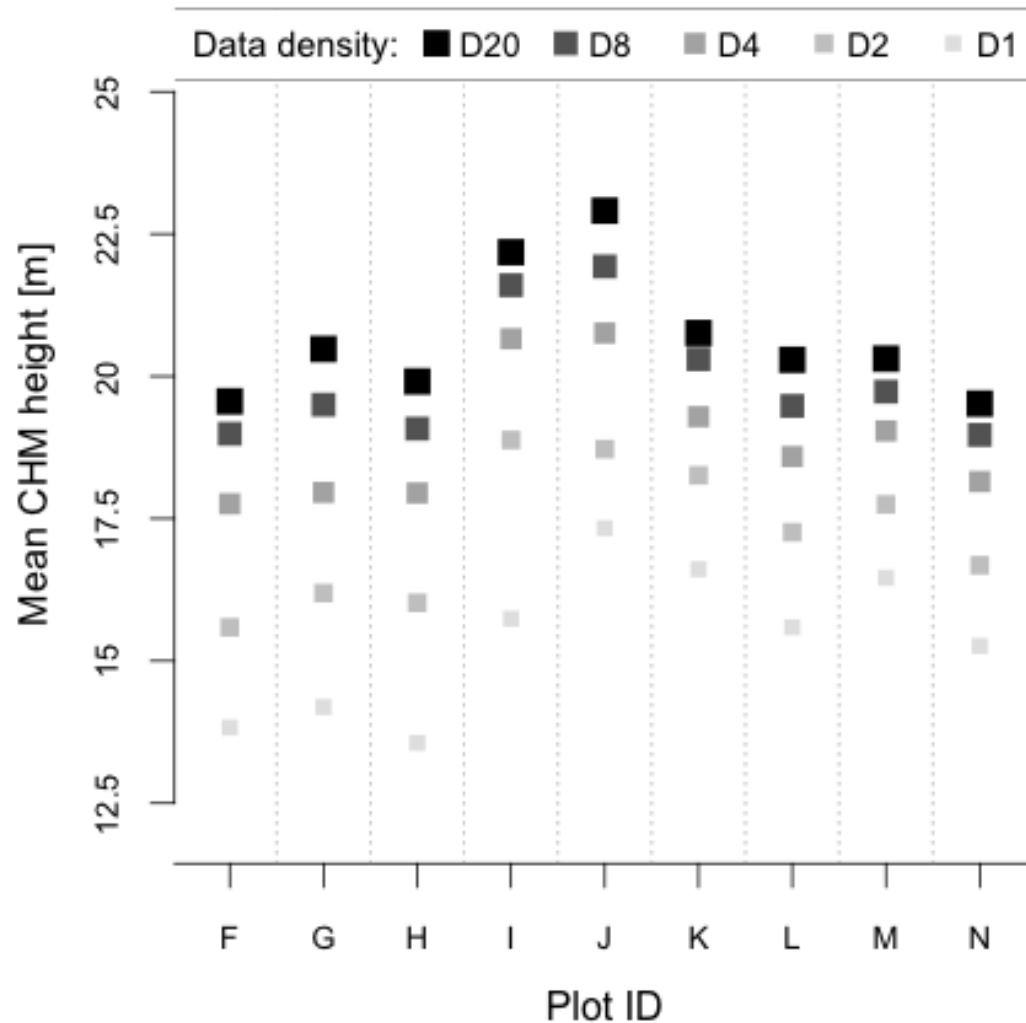
Lidar point density vs. signed elevation error (Lidar based DTM vs. independent GNSS)



Lidar point density vs. RMS elevation error (Lidar based DTM vs. independent GNSS)

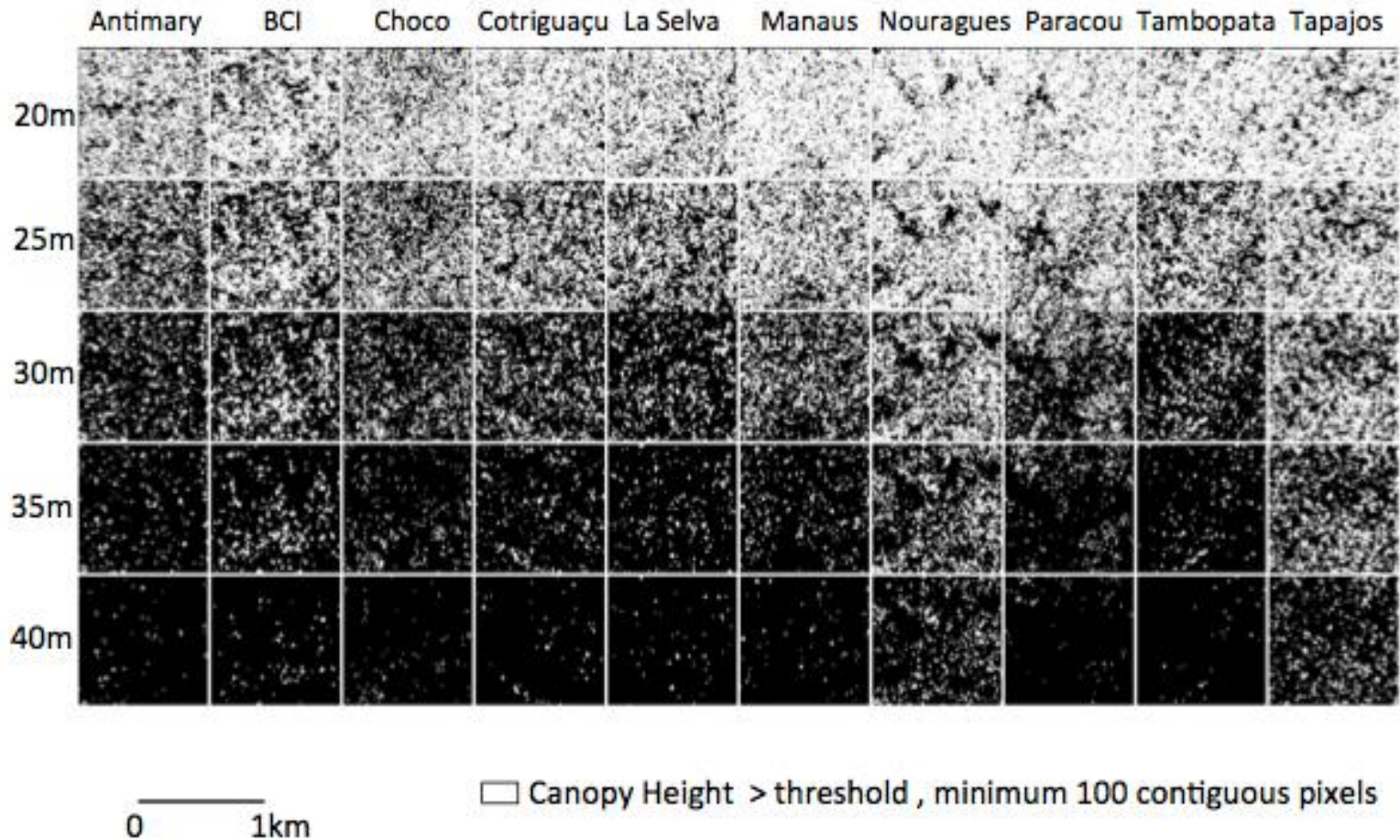


Lidar point density effect on canopy height estimation



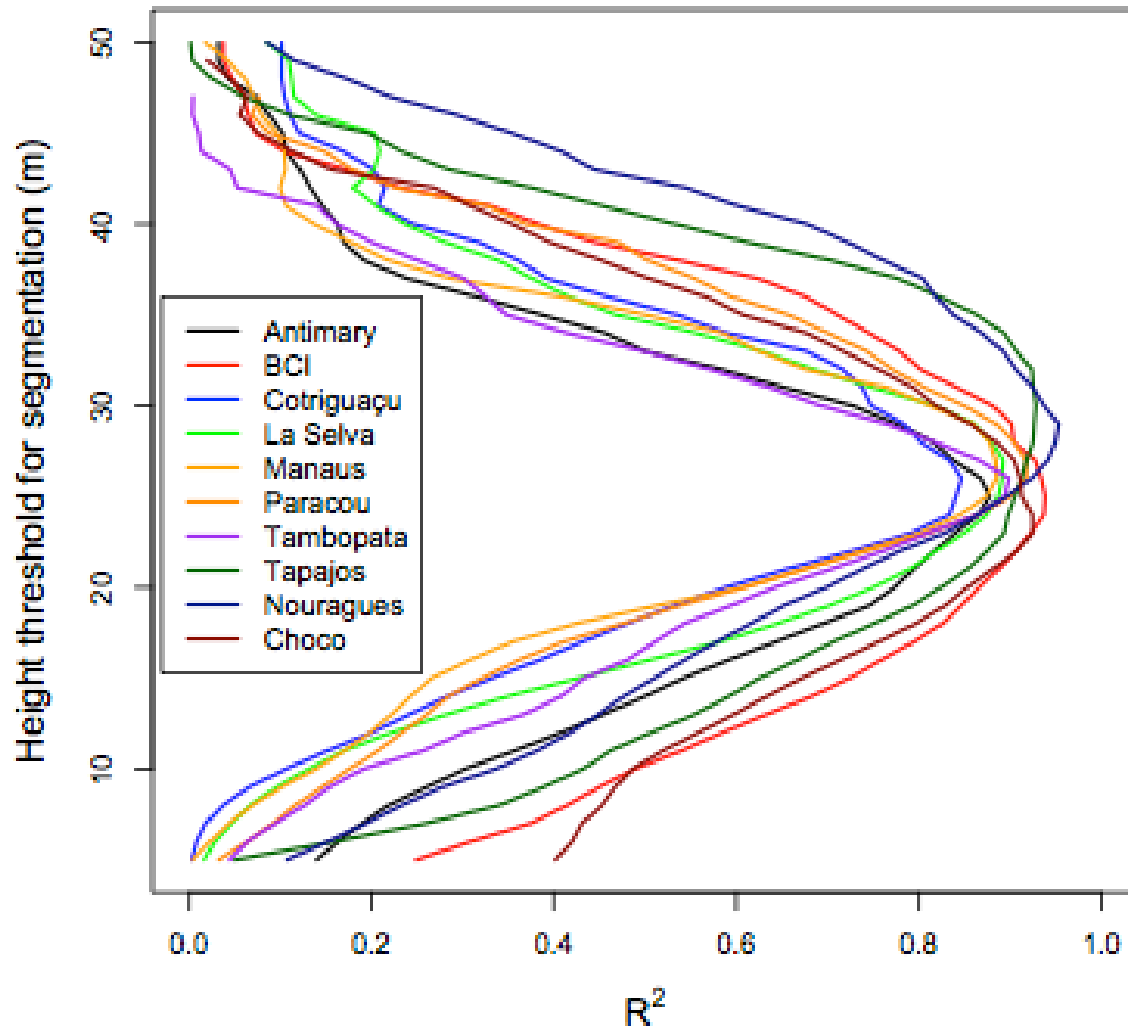
Alternative metrics

Large canopy area



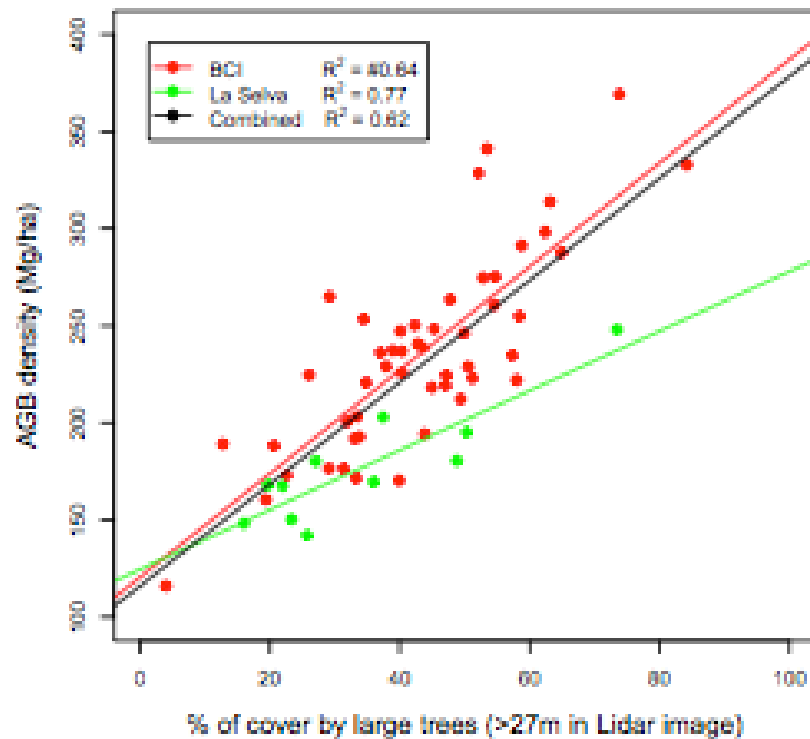
Optimized canopy height

Canopy area vs. biomass

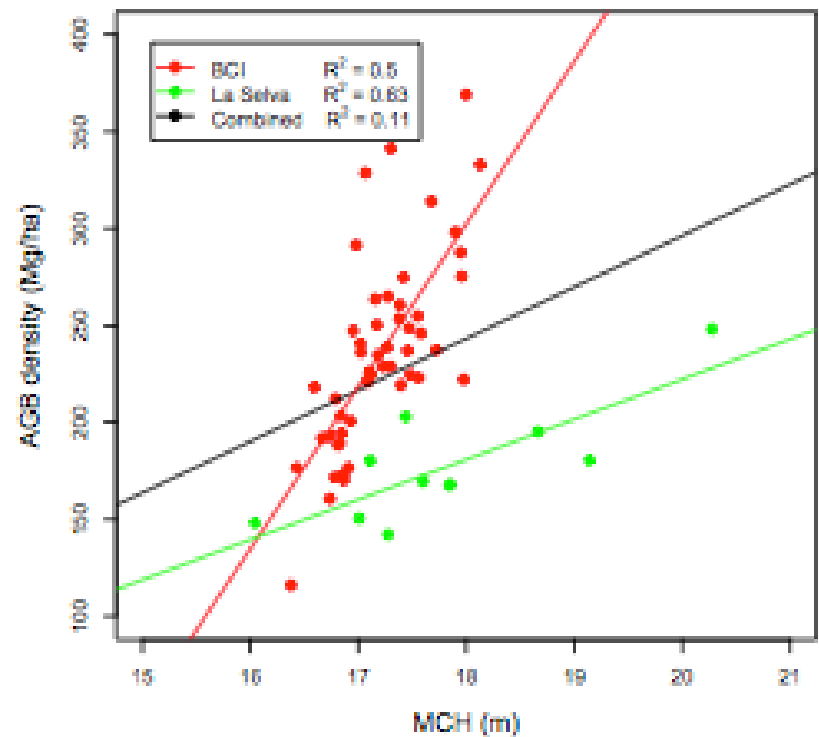


Large canopy area & mean canopy height

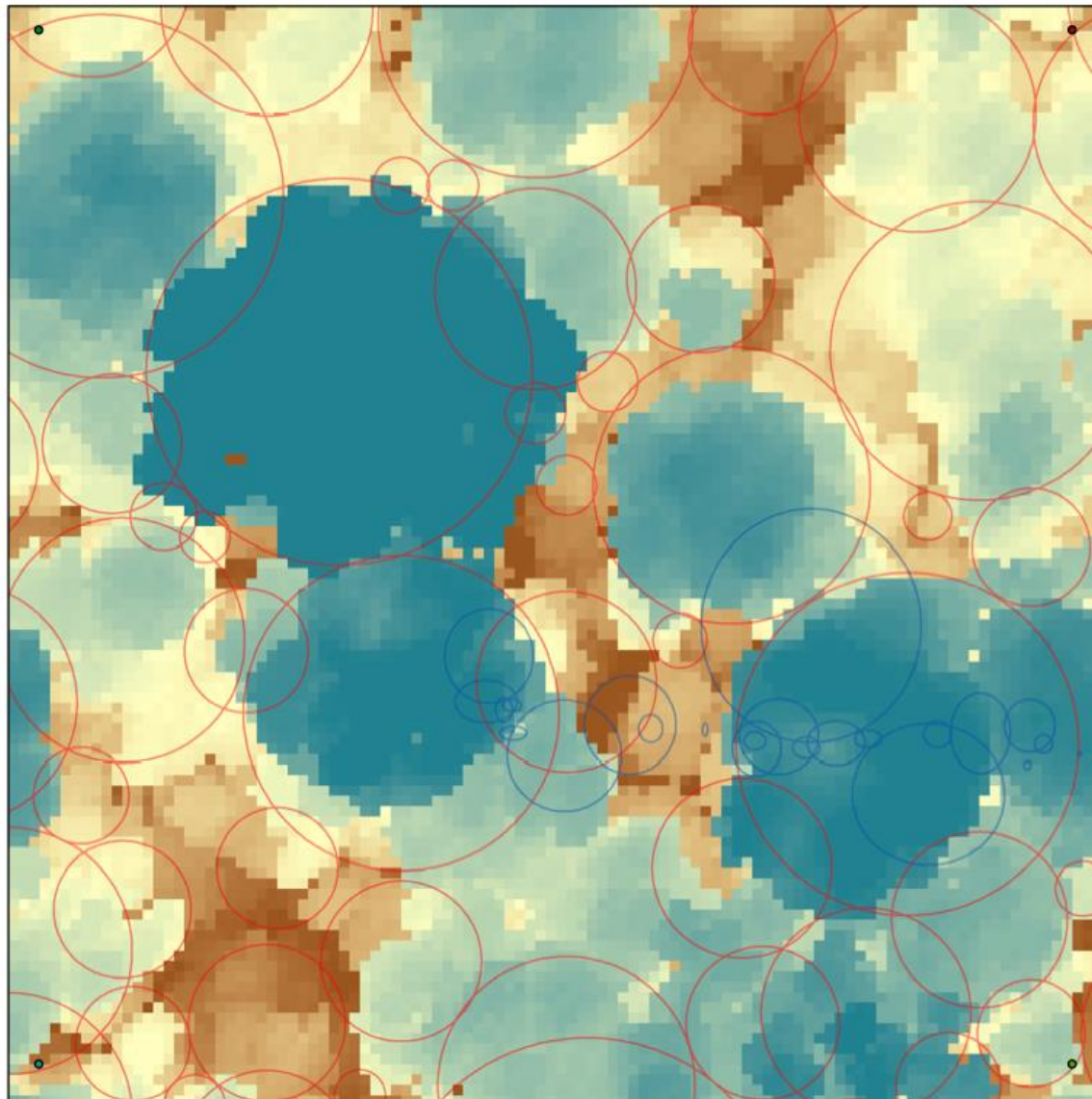
Large canopy area



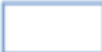
Mean canopy height



Individual based metrics



Legend

-  Field Delineated Crowns
-  Algorithm Delineated Crowns

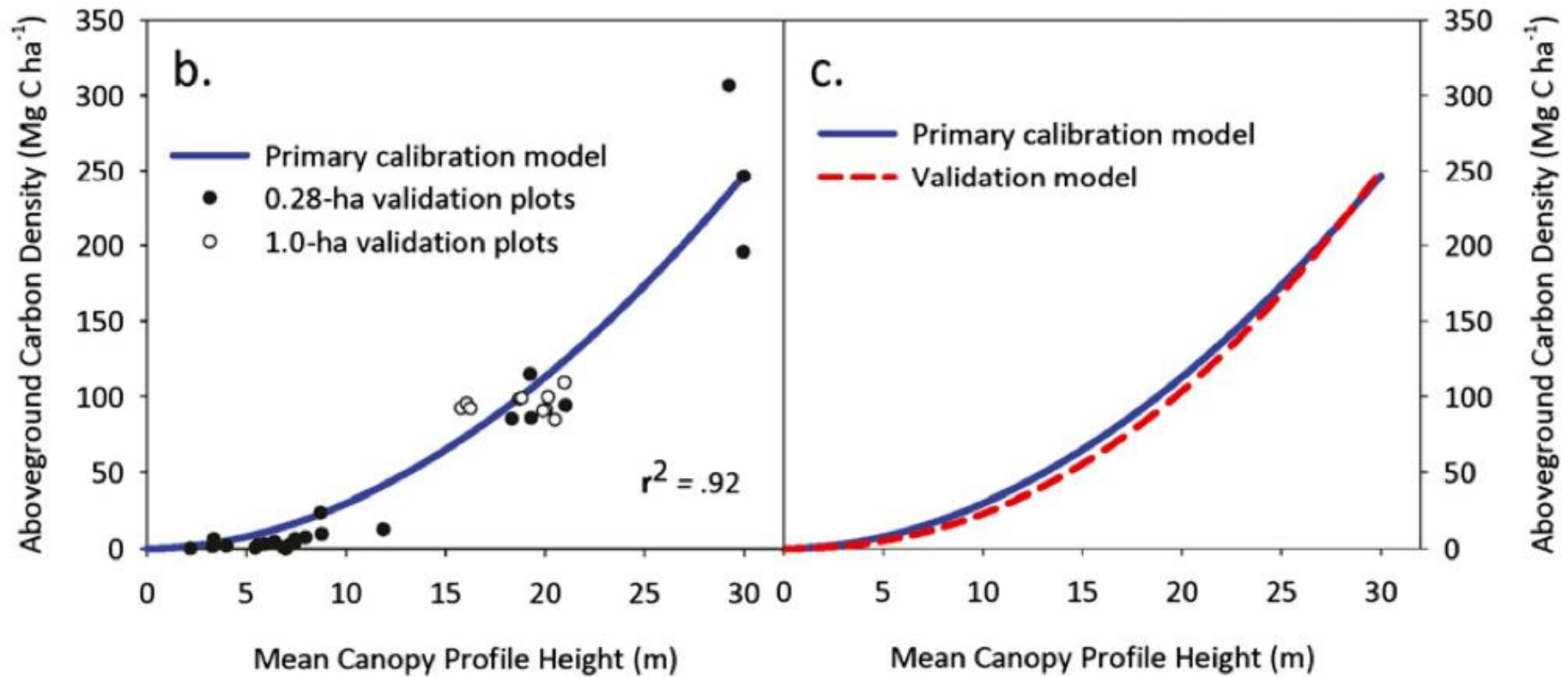
2008 CHM

Meters

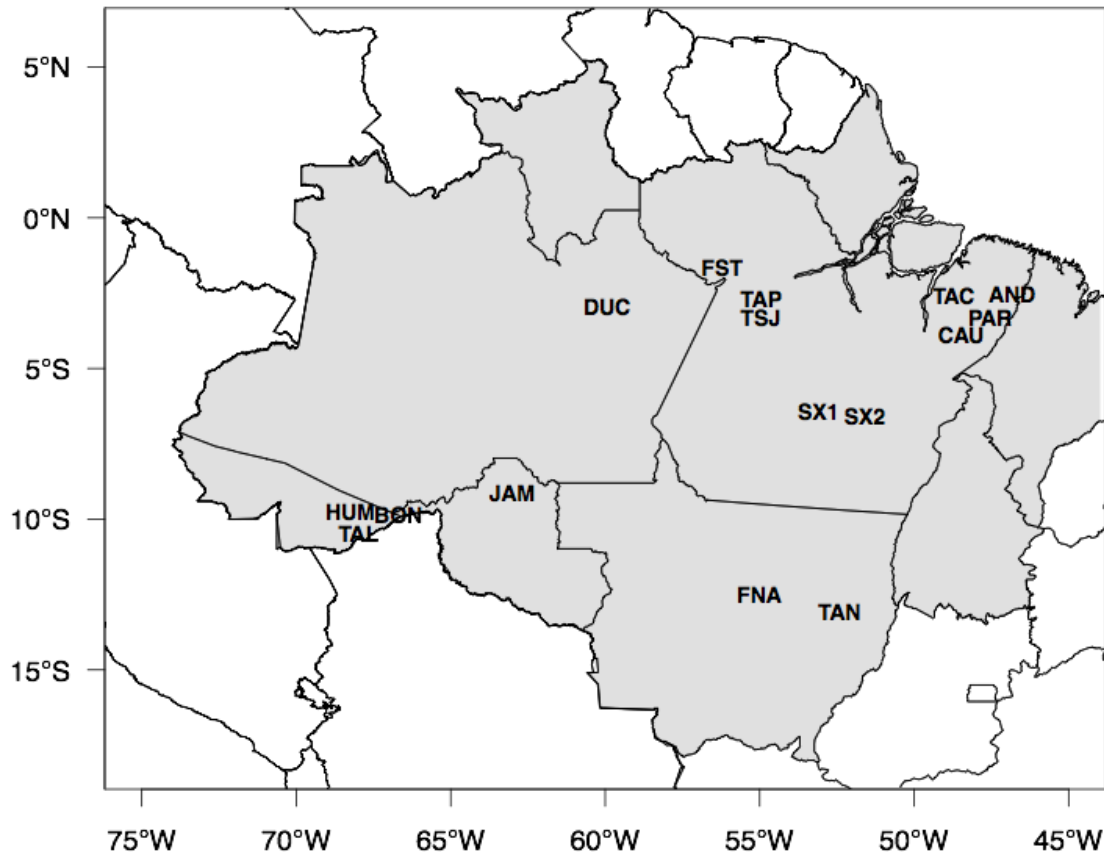


Image: M. Palace;
(Palace et al. *Biotropica*, 2008)

How many plots are sufficient for a given region/vegetation formation? (25 plots?)



Sustainable Landscapes Brazil database



- 338 Inventory plots (~0.25 ha equivalent)
- 84.5 ha inventory area
- ~16000 ha total lidar survey area

Site	Intact	Degraded	Secondary
AND		X	
PAR		X	X
CAU	X	X	
TAC			X
FST	X	X	
TAP	X		
TSJ		X	X
SX1		X	
SX2		X	
DUC	X		
HUM		X	
BON		X	
TAL		X	
JAM	X	X	
TAN	X	X	
FNA		X	

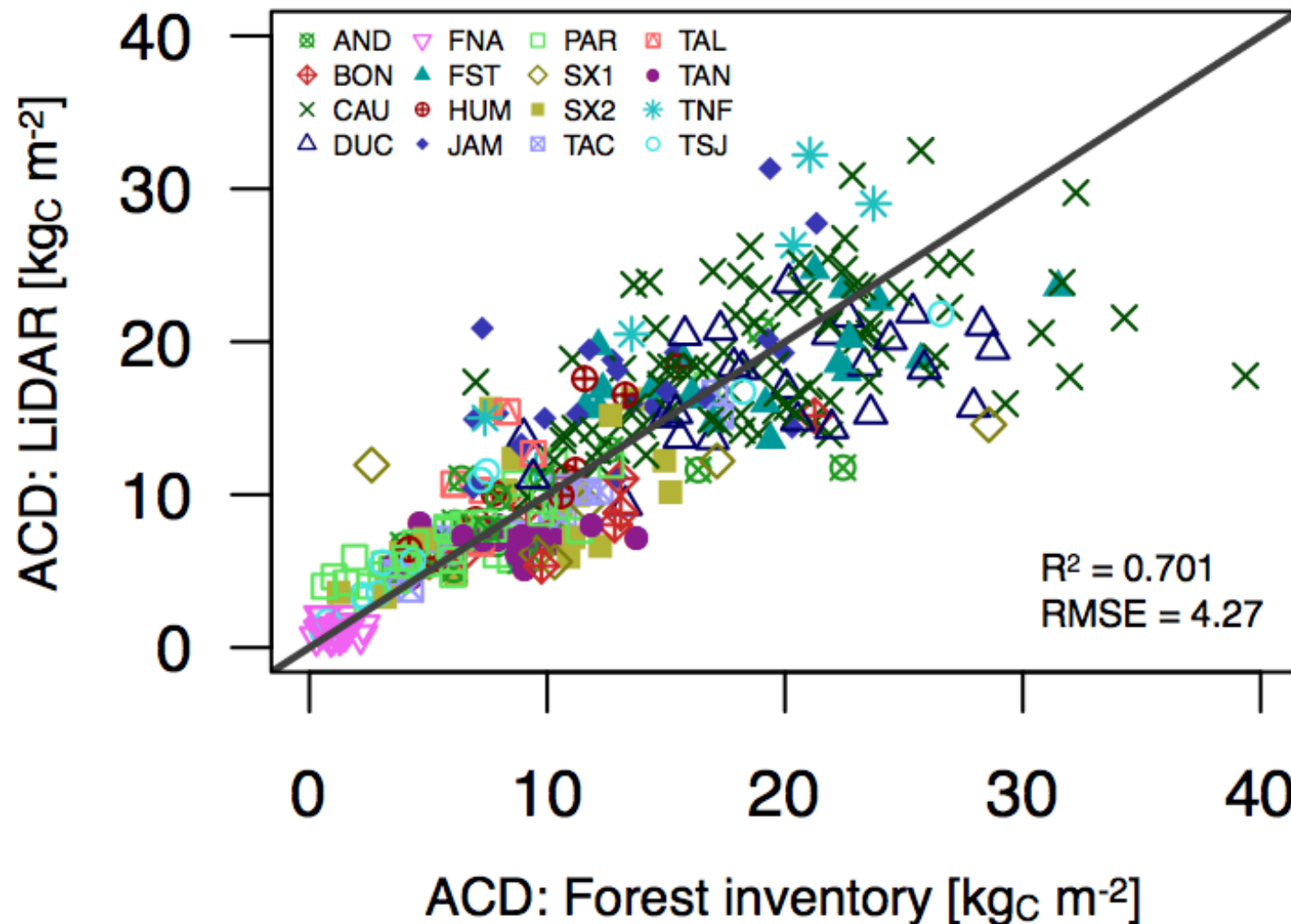
Sustainable Landscapes Brazil database

lidar acquisition characteristics

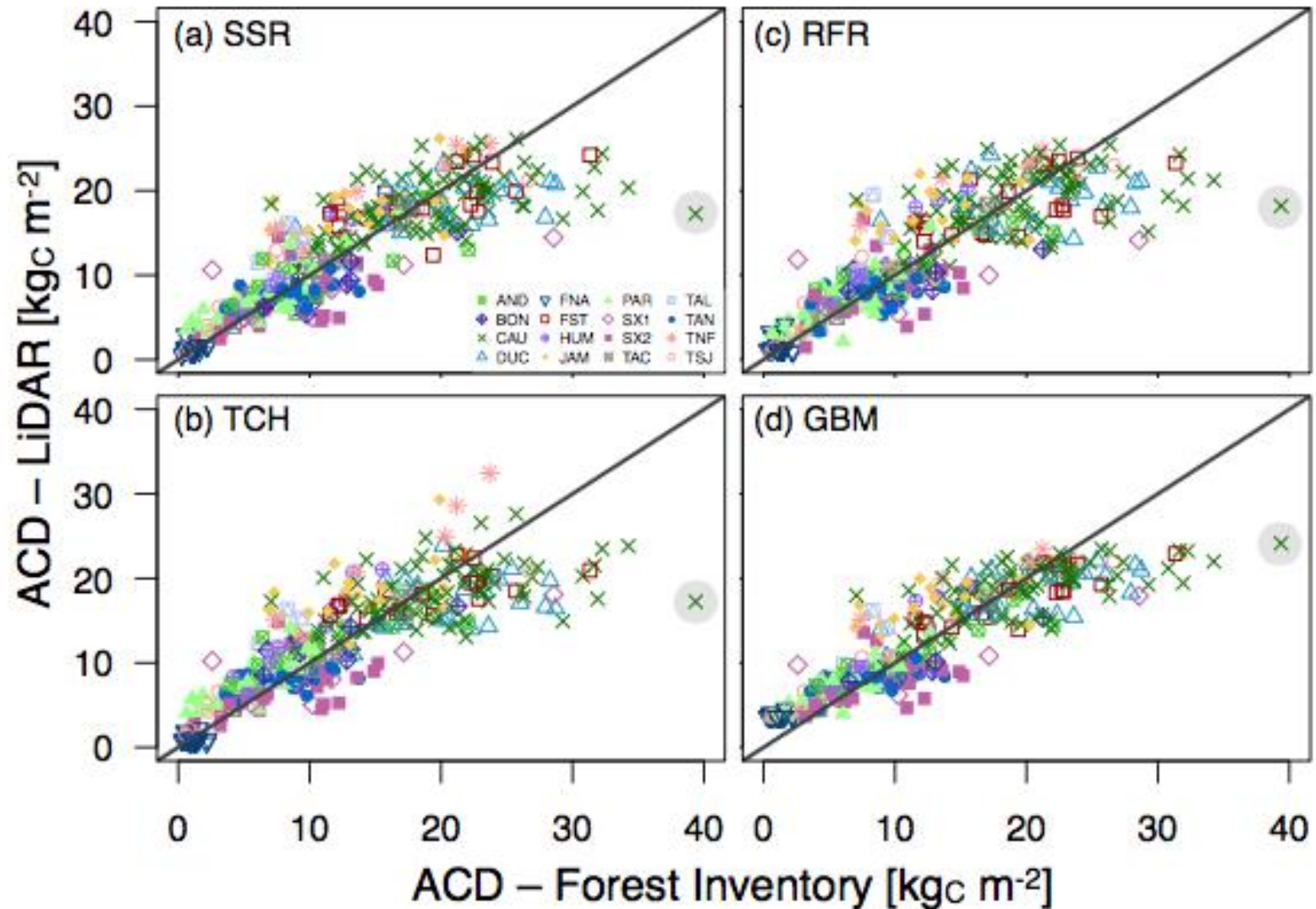
- Instrumentation: Optech Orion M200 or 3100
- Flight altitude (above ground): 850 – 900 m
- Returns per pulse: up to 4
- Ground footprint of pulse: 15 to 30 cm
- Scan Angle: $\pm 5.5^\circ$
- Required return density: 4 m⁻² on 99.5% area
- Average return density: 13 to 67 m⁻²

AGB calibration

$$\text{ACD}_{\text{SSR}} = 0.036(0.011) \mu_z^{2.02(0.11)} z_{75}^{0.04(0.08)} z_{10}^{-0.23(0.03)} \kappa_z^{0.40(0.07)}$$



AGB Calibration (Alternative fits)



AGB Calibration

Full Model

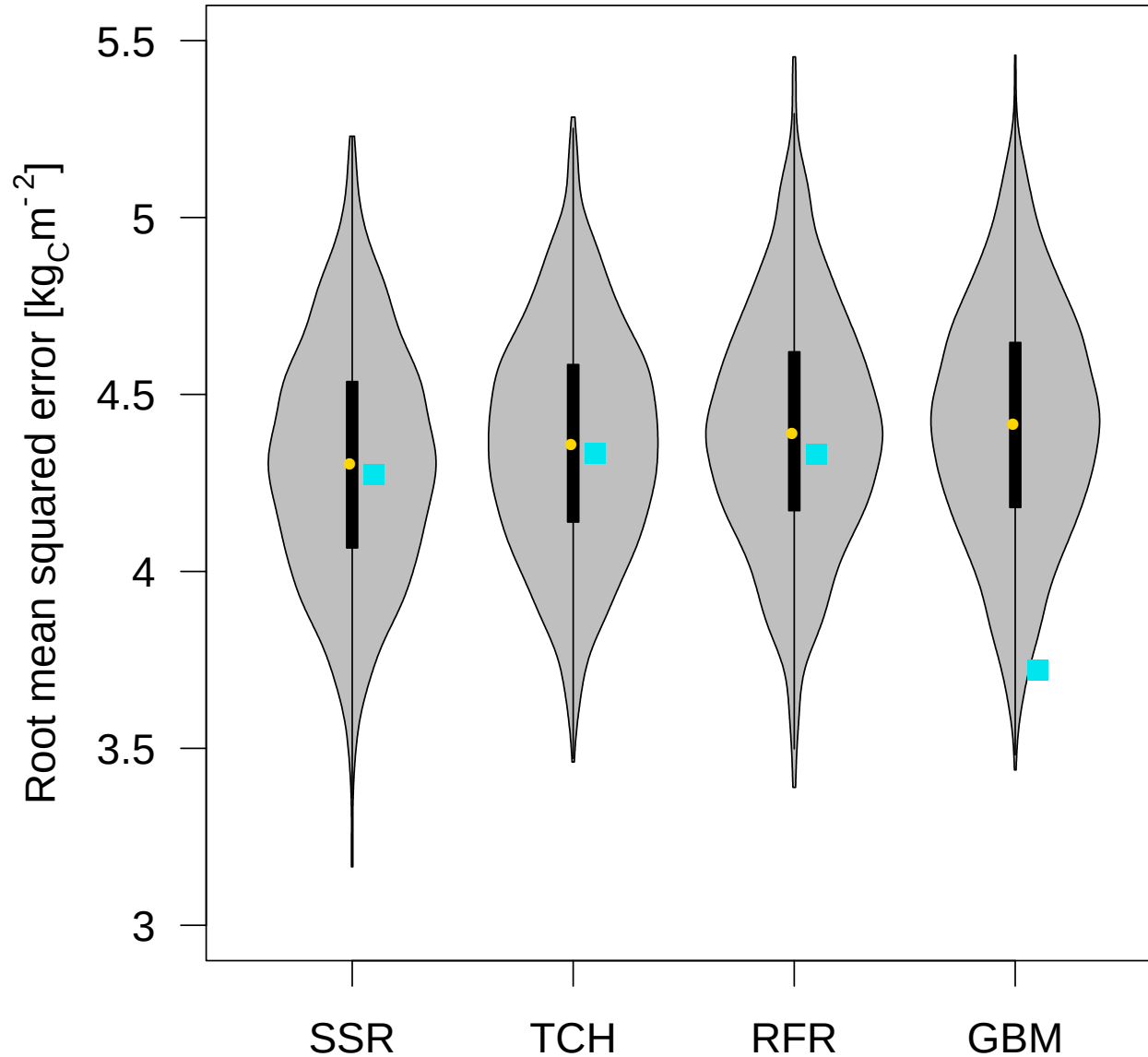
Method	Bias	RMSE	R ²
<i>SSR</i>	<i>0.03</i>	<i>4.27</i>	<i>0.701</i>
<i>TCH</i>	<i>-0.01</i>	<i>4.33</i>	<i>0.692</i>
<i>RFR</i>	<i>-0.01</i>	<i>4.33</i>	<i>0.693</i>
<i>GBM</i>	<i>0.01</i>	<i>3.72</i>	<i>0.773</i>

Cross-Validation

Method	Bias	RMSE	R ²
<i>SSR</i>	<i>0.02</i>	<i>4.30</i>	<i>0.695</i>
<i>TCH</i>	<i>-0.02</i>	<i>4.36</i>	<i>0.688</i>
<i>RFR</i>	<i>0.01</i>	<i>4.39</i>	<i>0.683</i>
<i>GBM</i>	<i>-0.04</i>	<i>4.41</i>	<i>0.682</i>

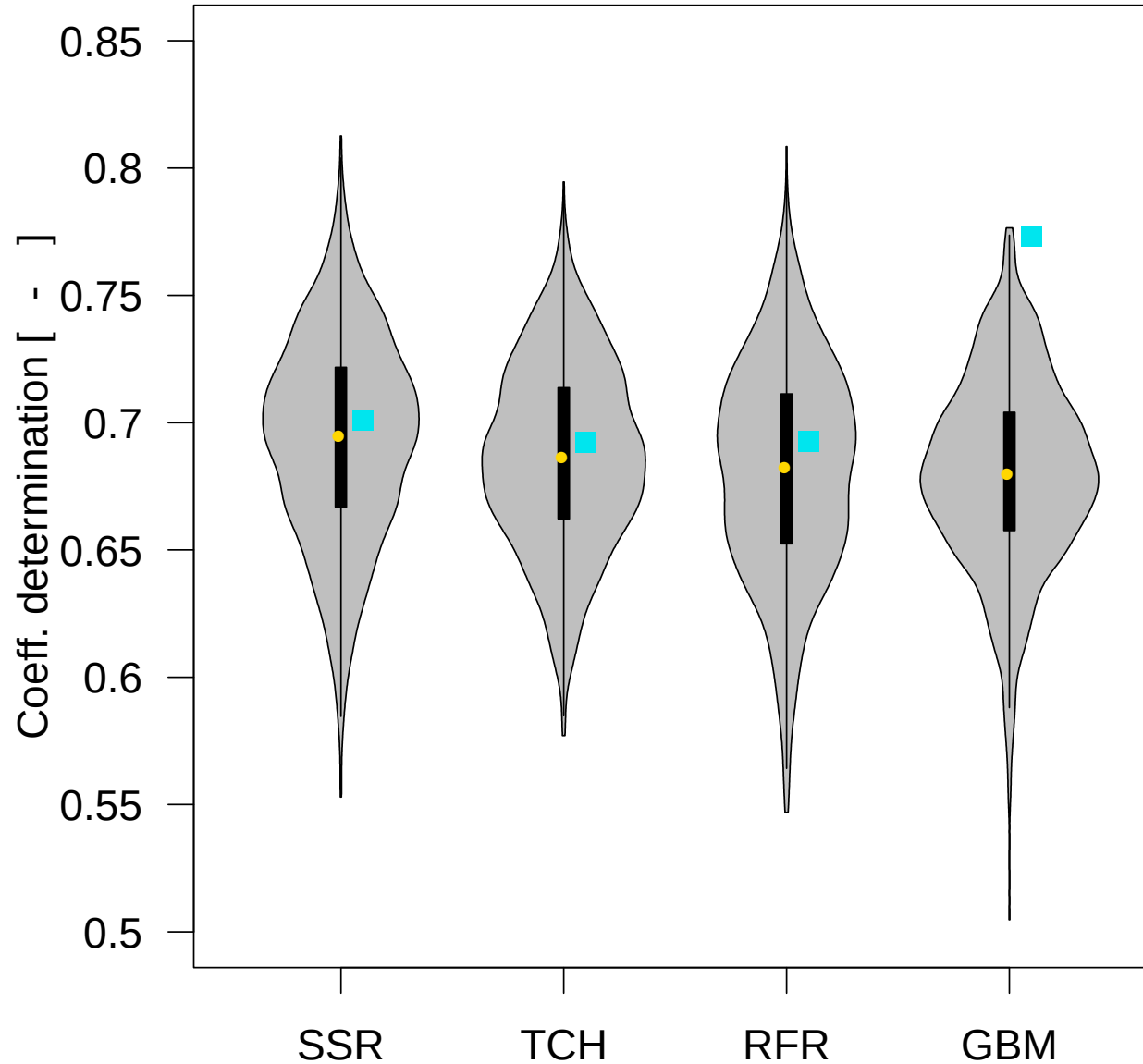
Cross Validation

Above-ground Carbon Density. Plot area: 2500m²

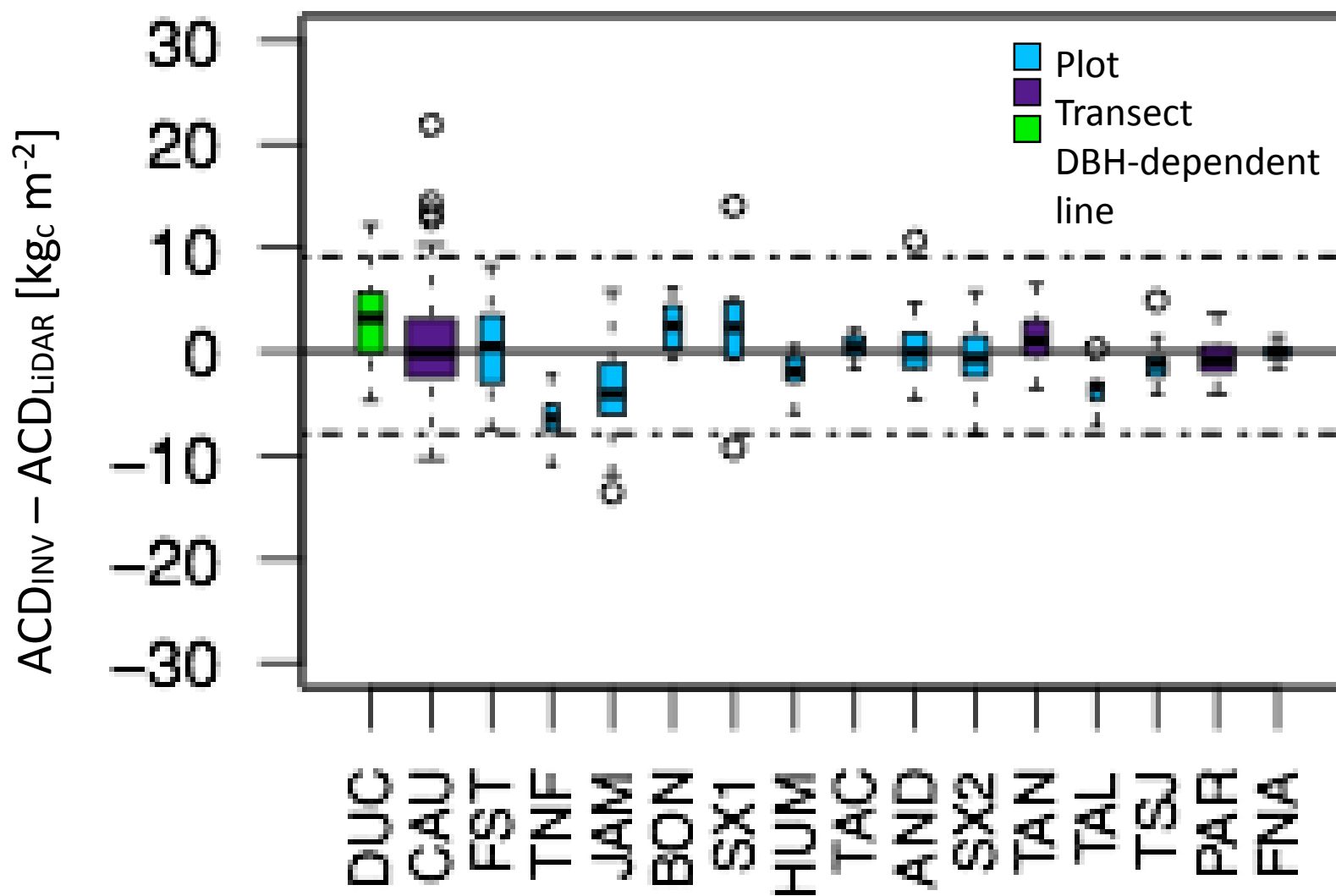


Cross Validation

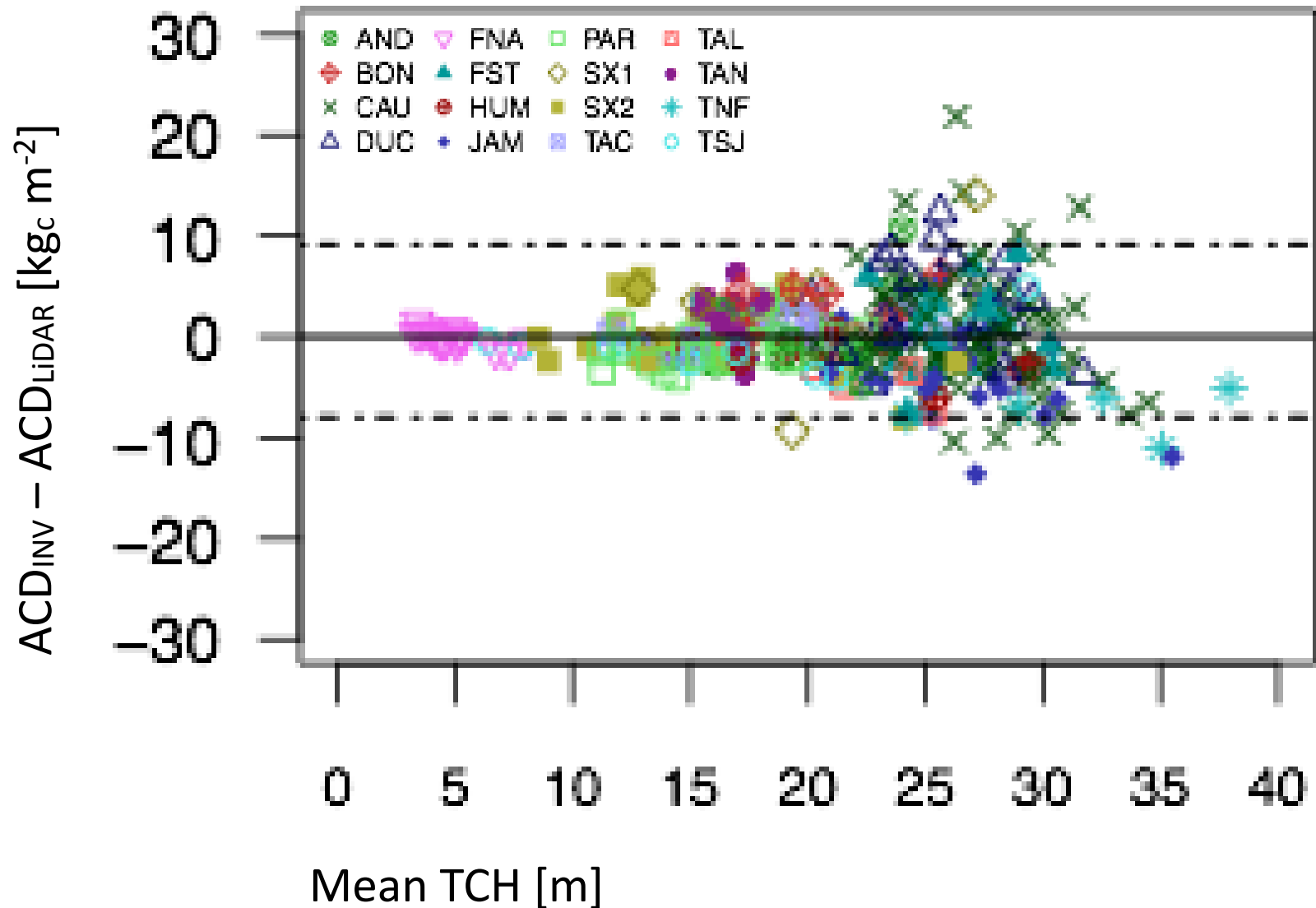
Above-ground Carbon Density. Plot area: 2500m²



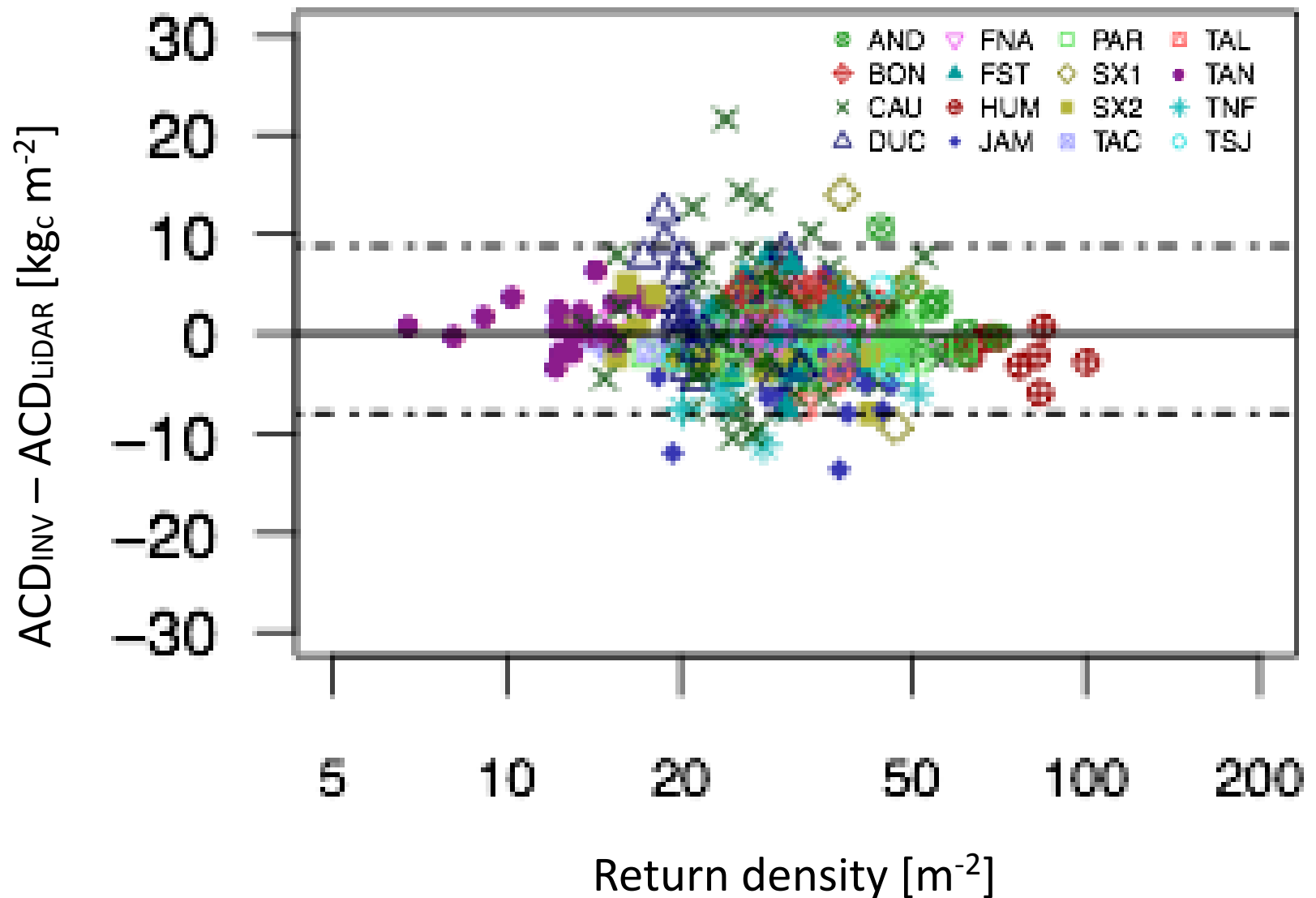
Residuals by site



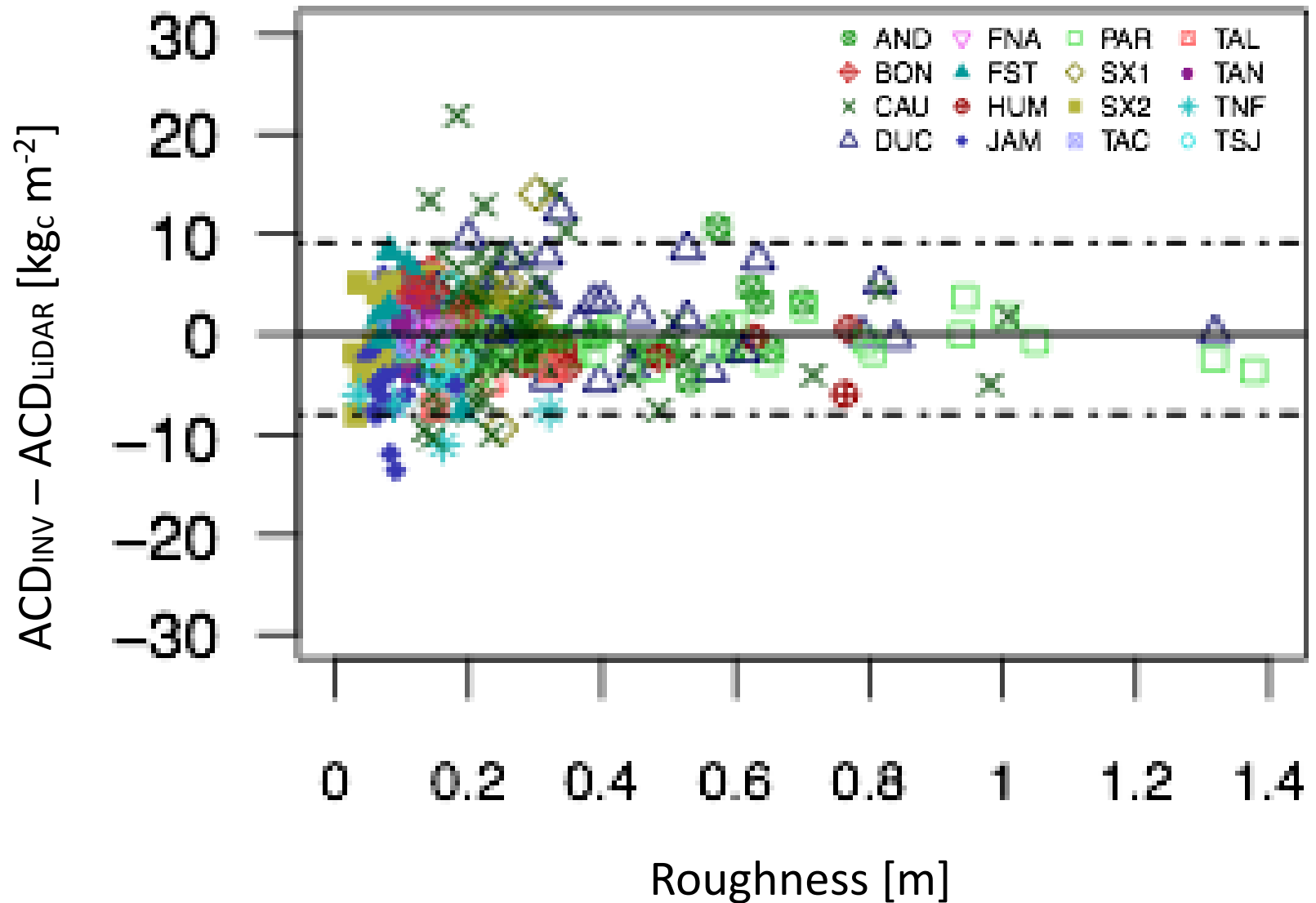
Residuals by top of canopy height



Residuals by lidar return density

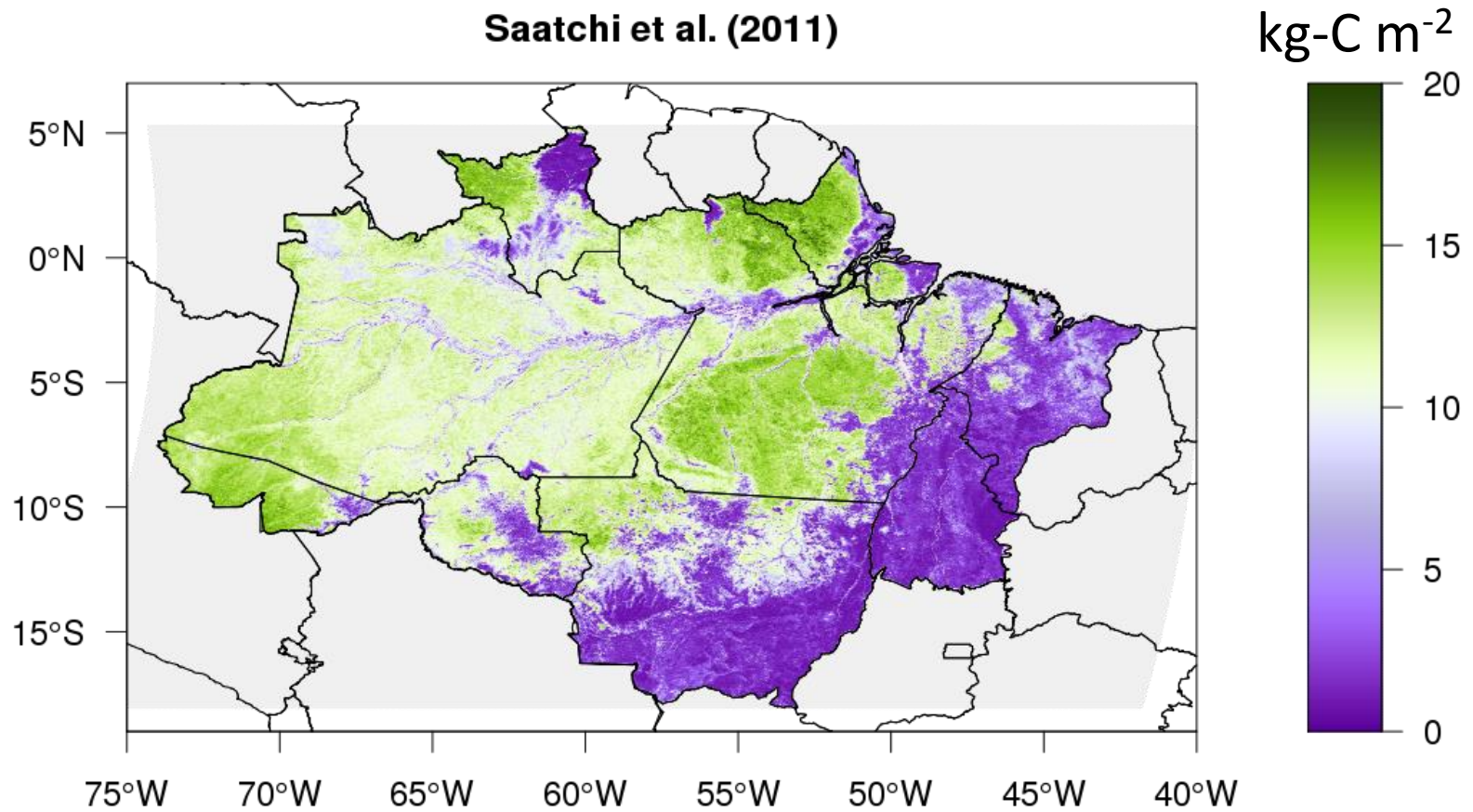


Residuals – Terrain complexity

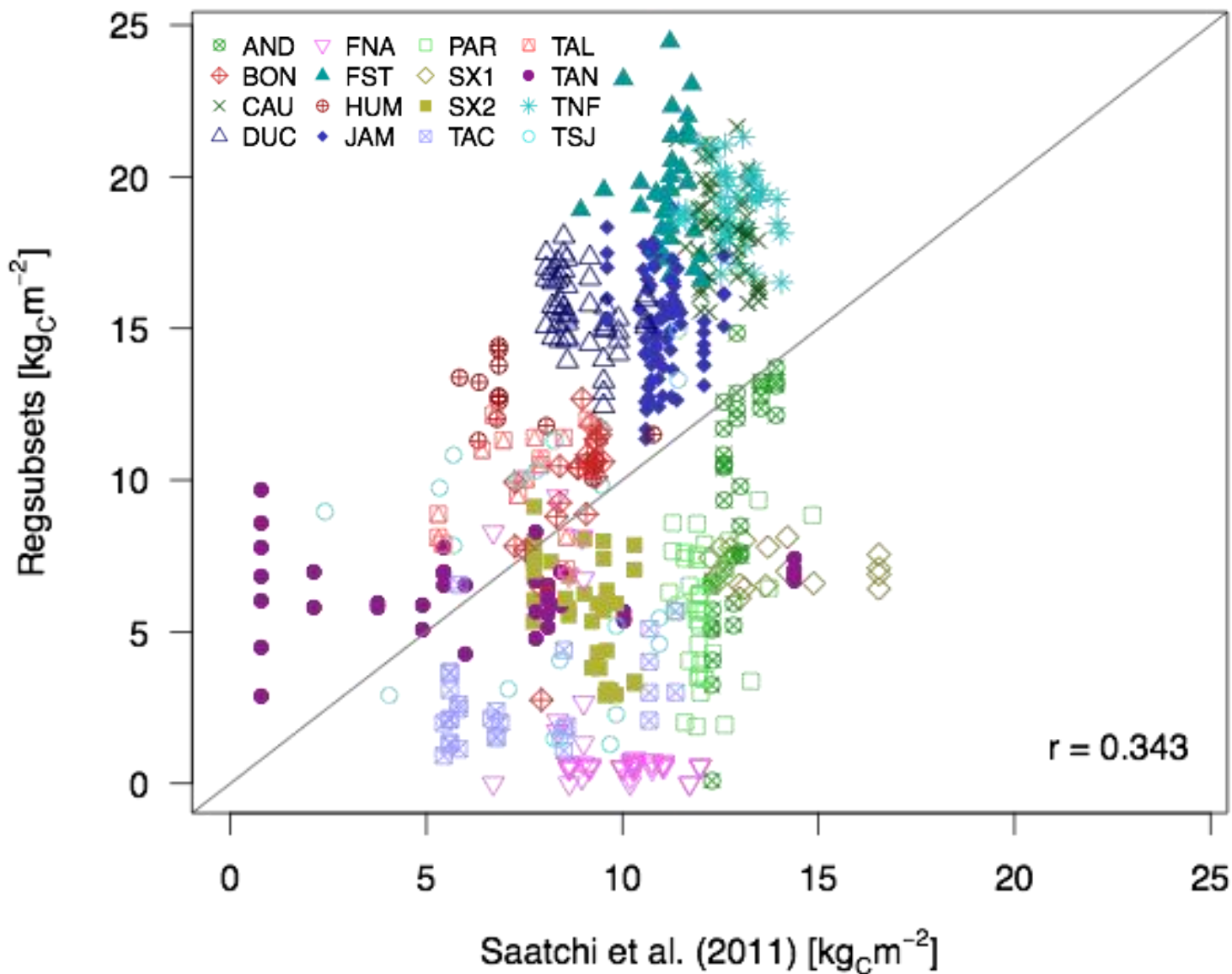


Amazon biomass

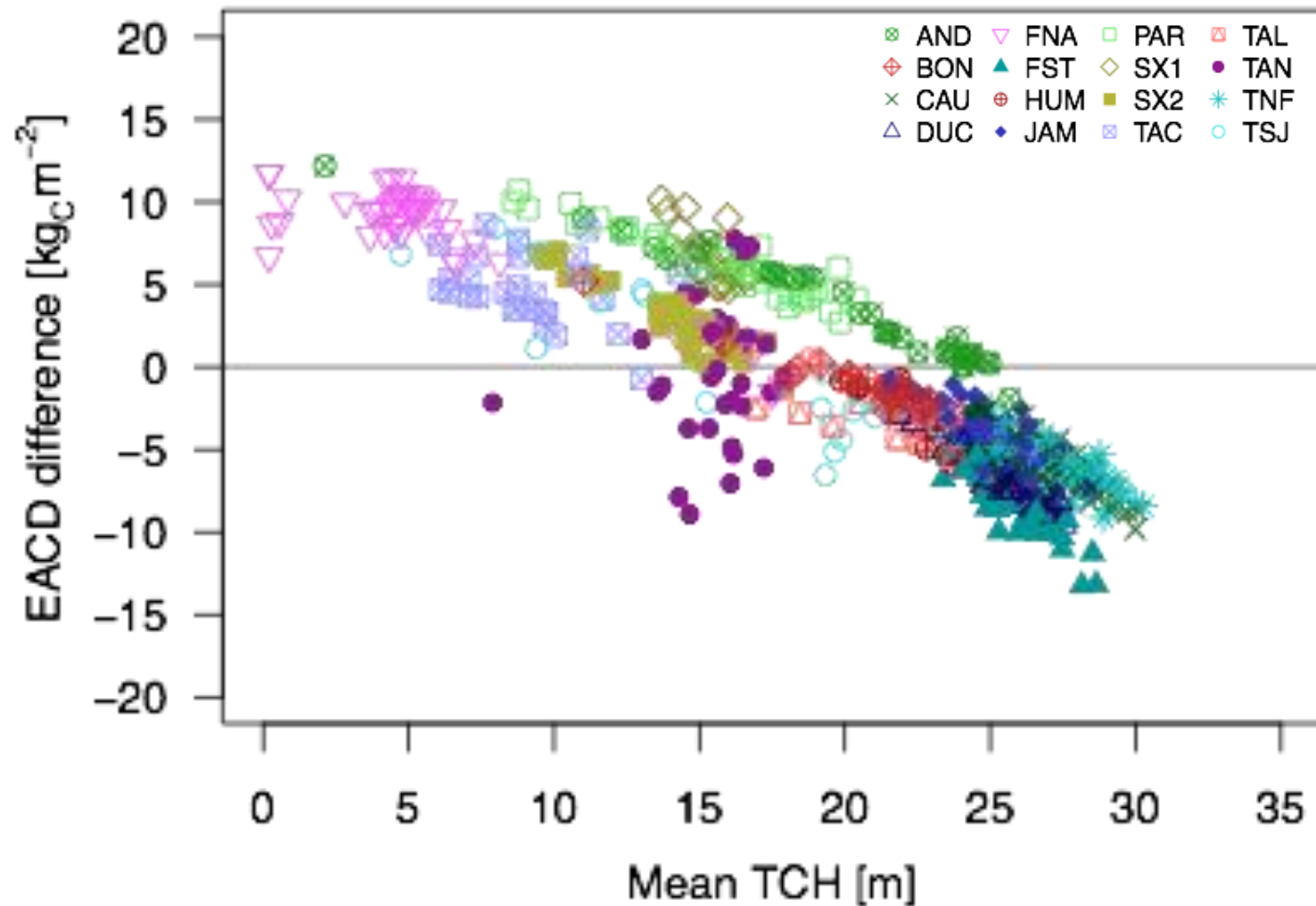
Saatchi et al. (2011)



AGB Comparison –lidar x Saatchi

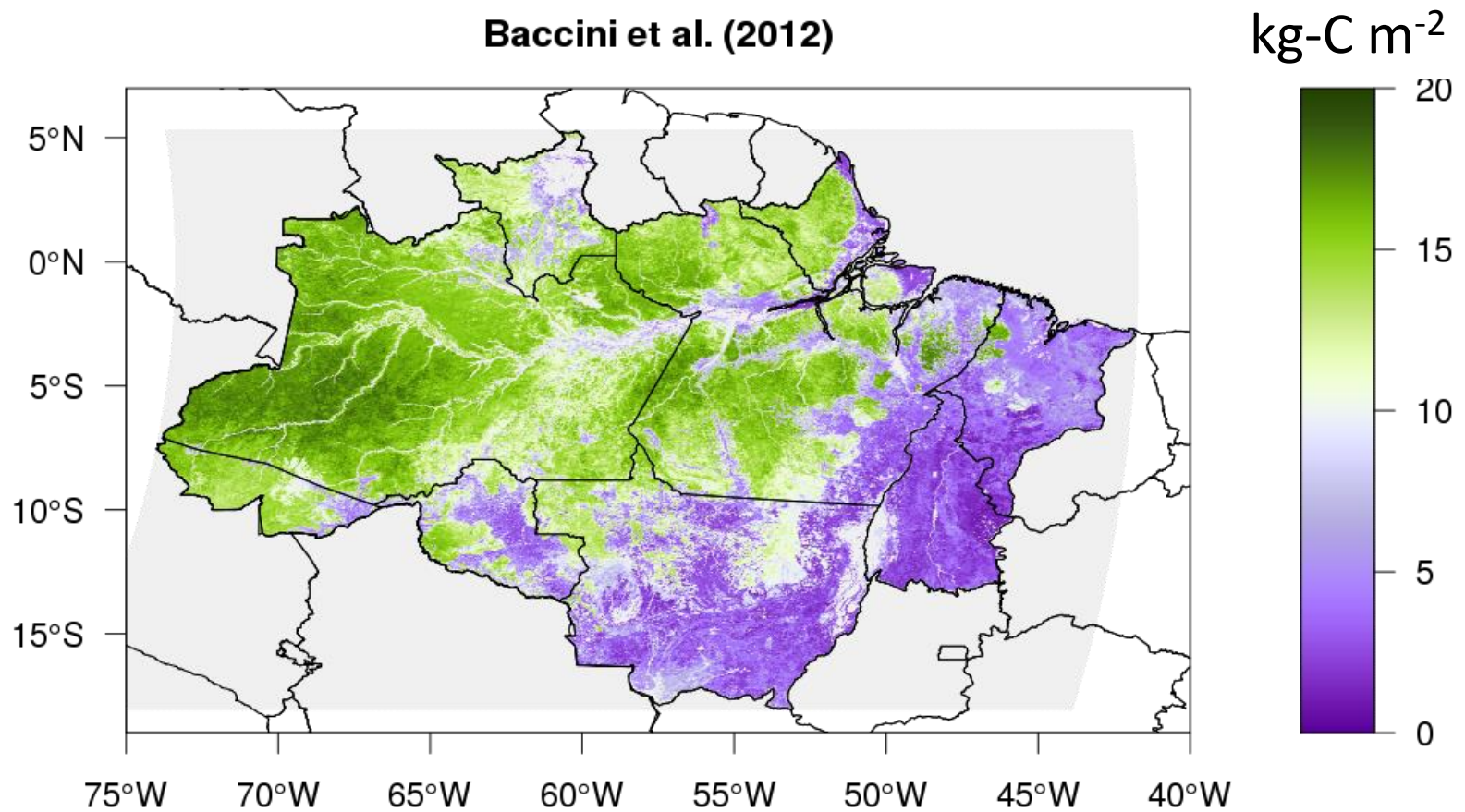


Differences as a function of TCH: Saatchi-lidar

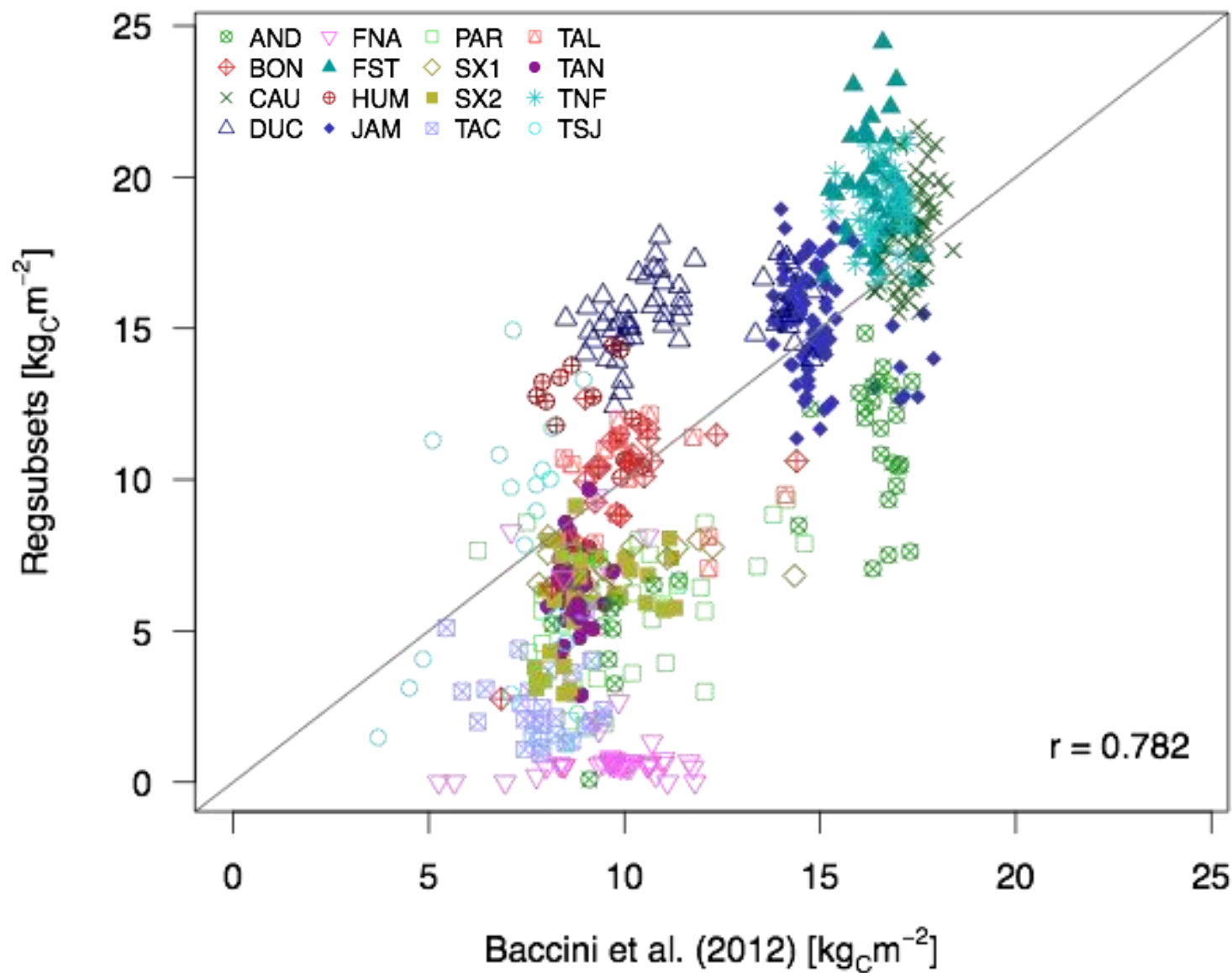


Amazon biomass

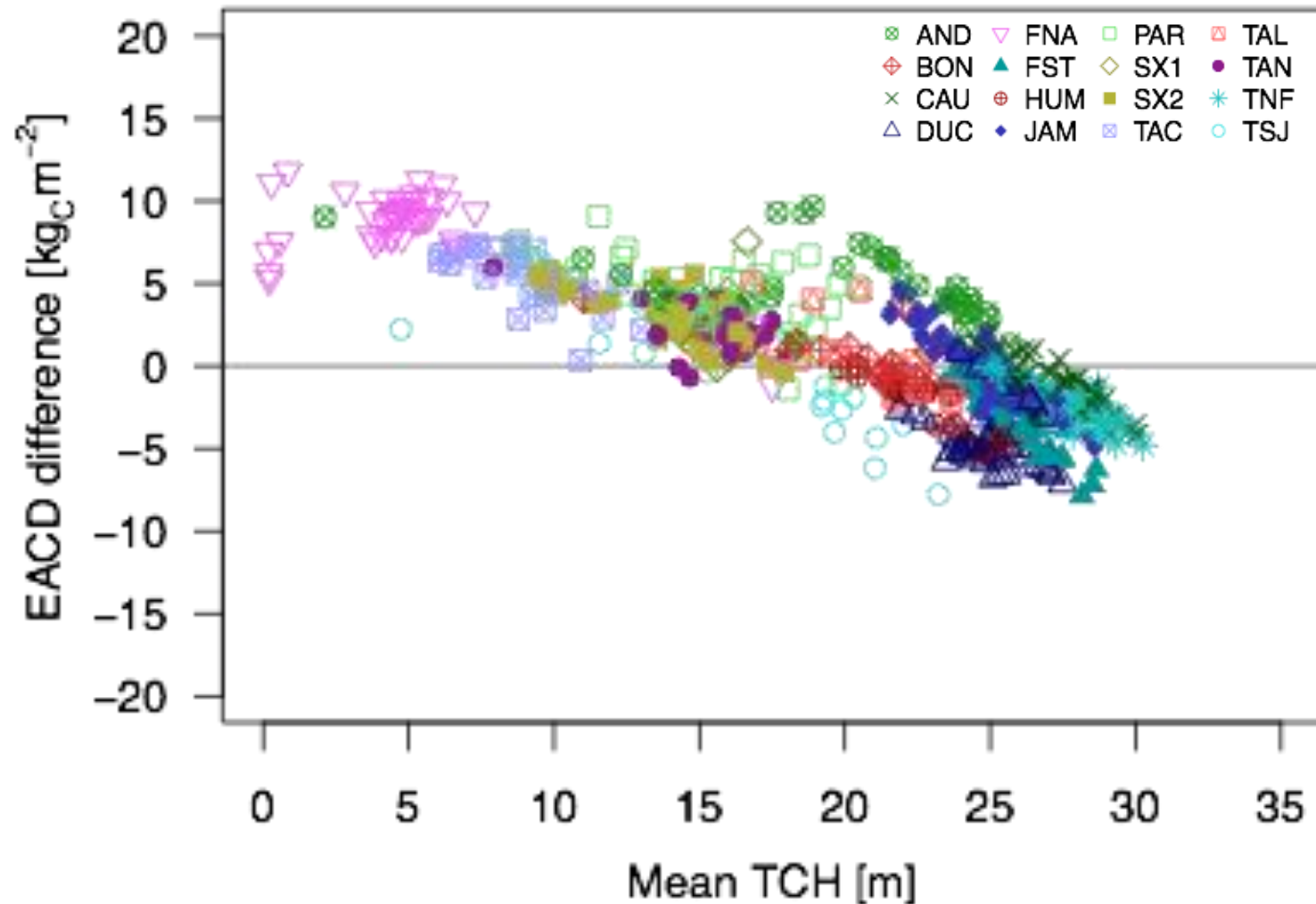
Baccini et al. (2012)



AGB Comparison – lidar × Baccini

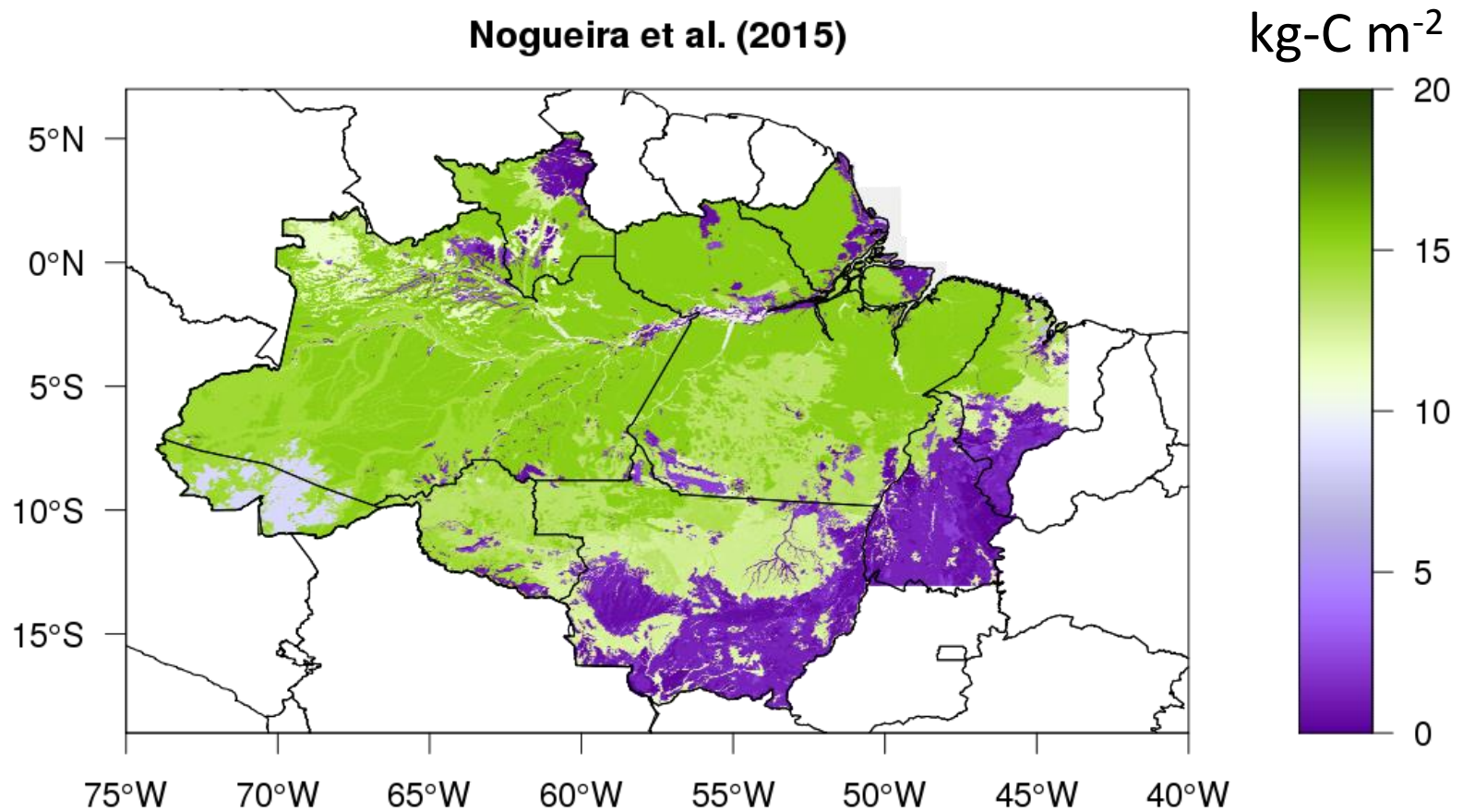


Differences as a function of TCH: Baccini-lidar

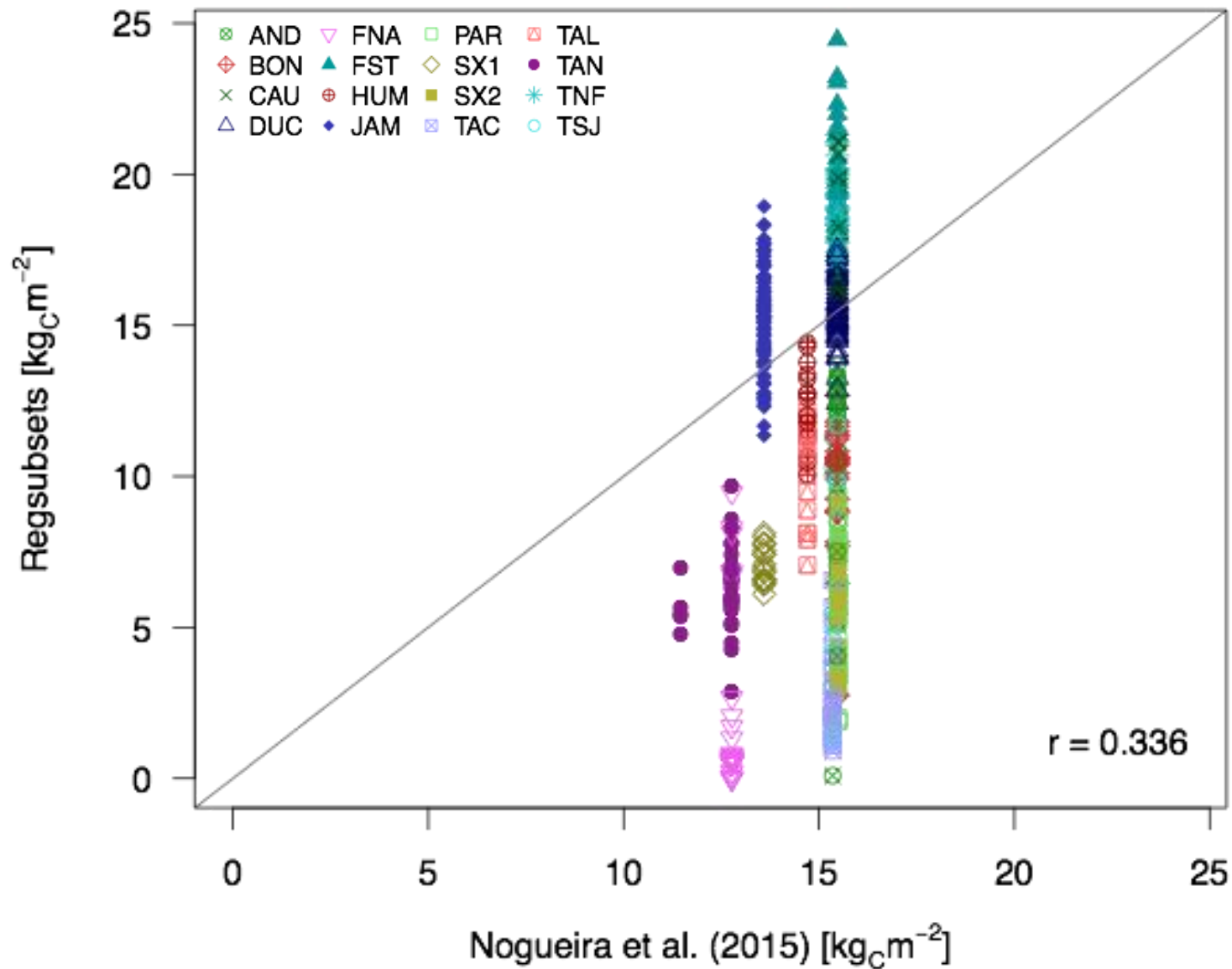


Amazon biomass

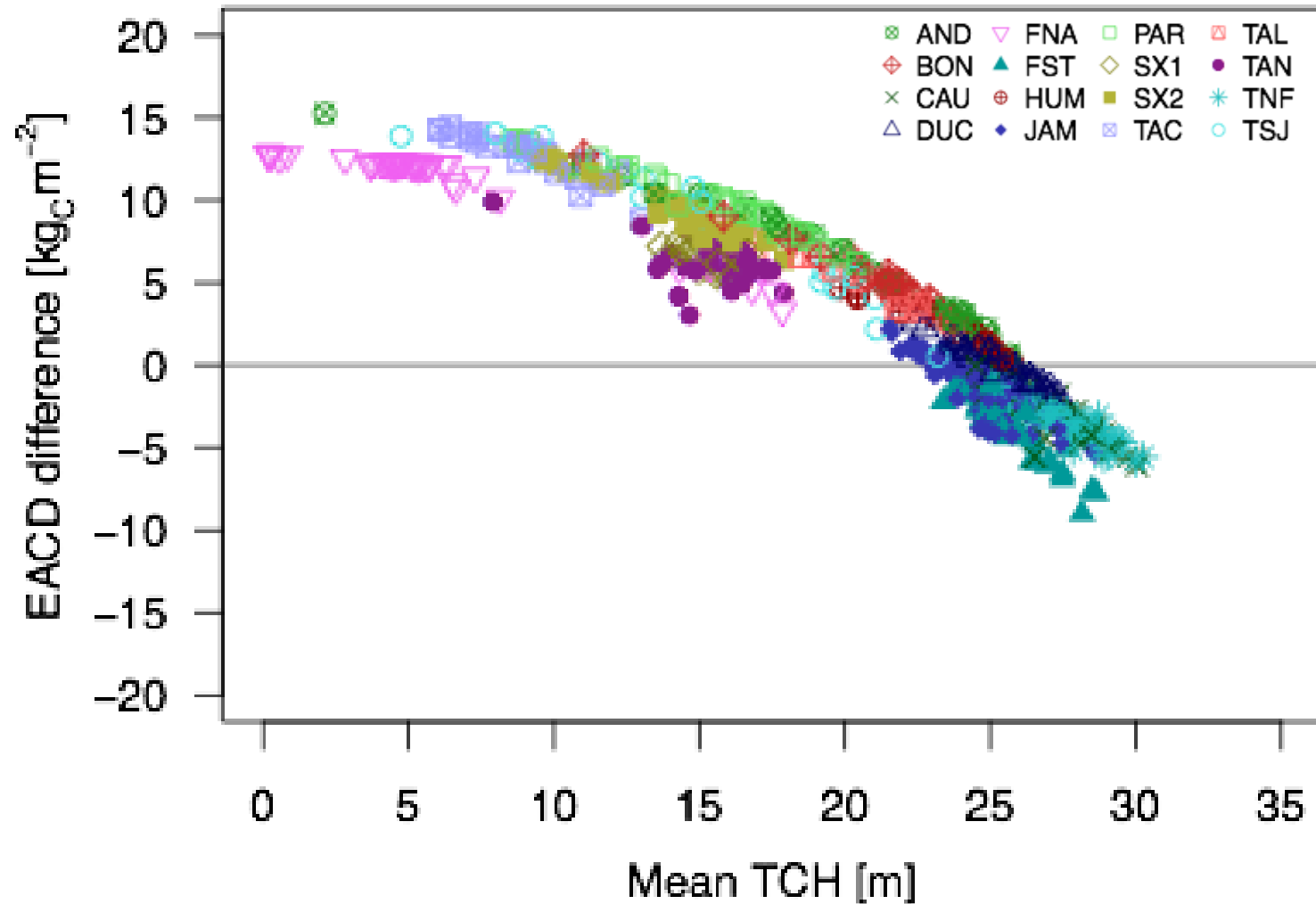
Nogueira et al. (2015)



AGB Comparison – lidar x Nogueira



Differences as a function of TCH: Nogueira-LiDAR



Concluding remarks

- Robust calibration for upland forests
 - But 20% of the Amazon Basin is seasonally inundated
 - NW Amazon and complex terrain under-represented
 - High return densities for lidar data
- Calibration uncertainty is still relatively high
- Current remote sensing based biomass maps suffer from dilution error (they are mean-seeking) and (not surprisingly given their source data) they fail to represent local variability

Design considerations for improved calibrations

- Greater spatial extent
 - NW Amazon
 - Wetlands
- Larger plots especially for high biomass regions?
- Larger sample (only MUCH larger will make a difference!) and stratified design
- Improved tree allometry (terrestrial laser scanning?)

Sustainable Landscapes Brazil: Data Availability

<http://mapas.cnpm.embrapa.br/paisagens sustentaveis/>



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