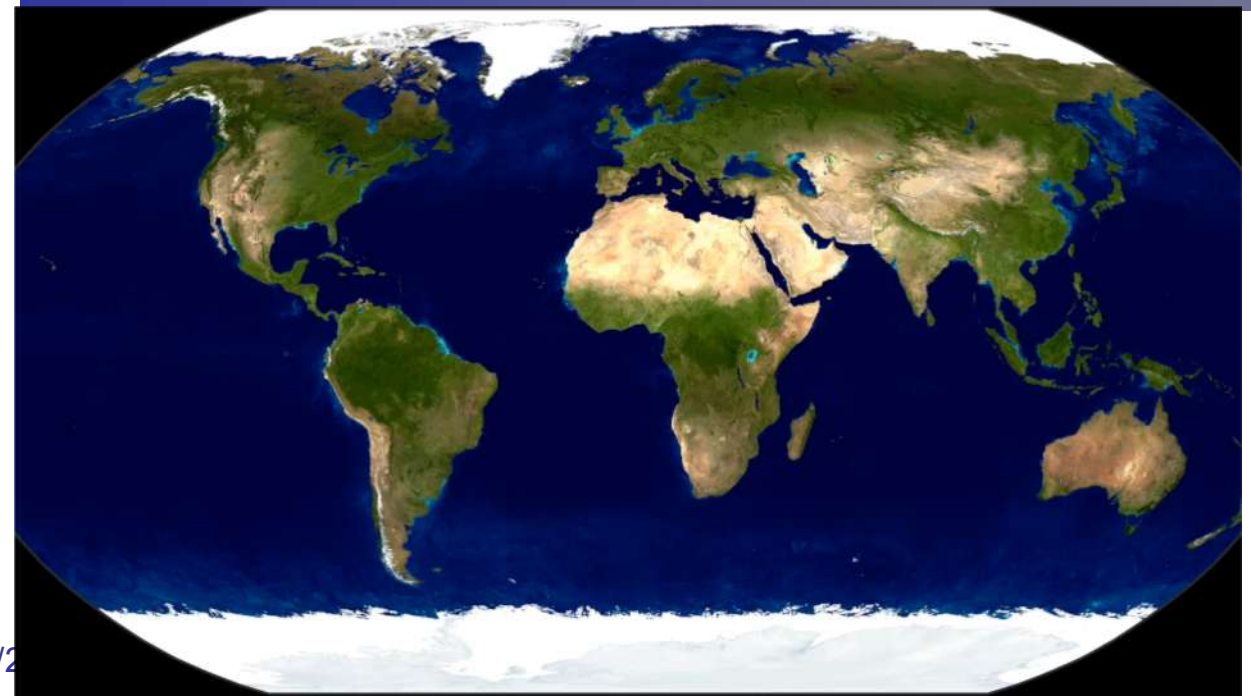
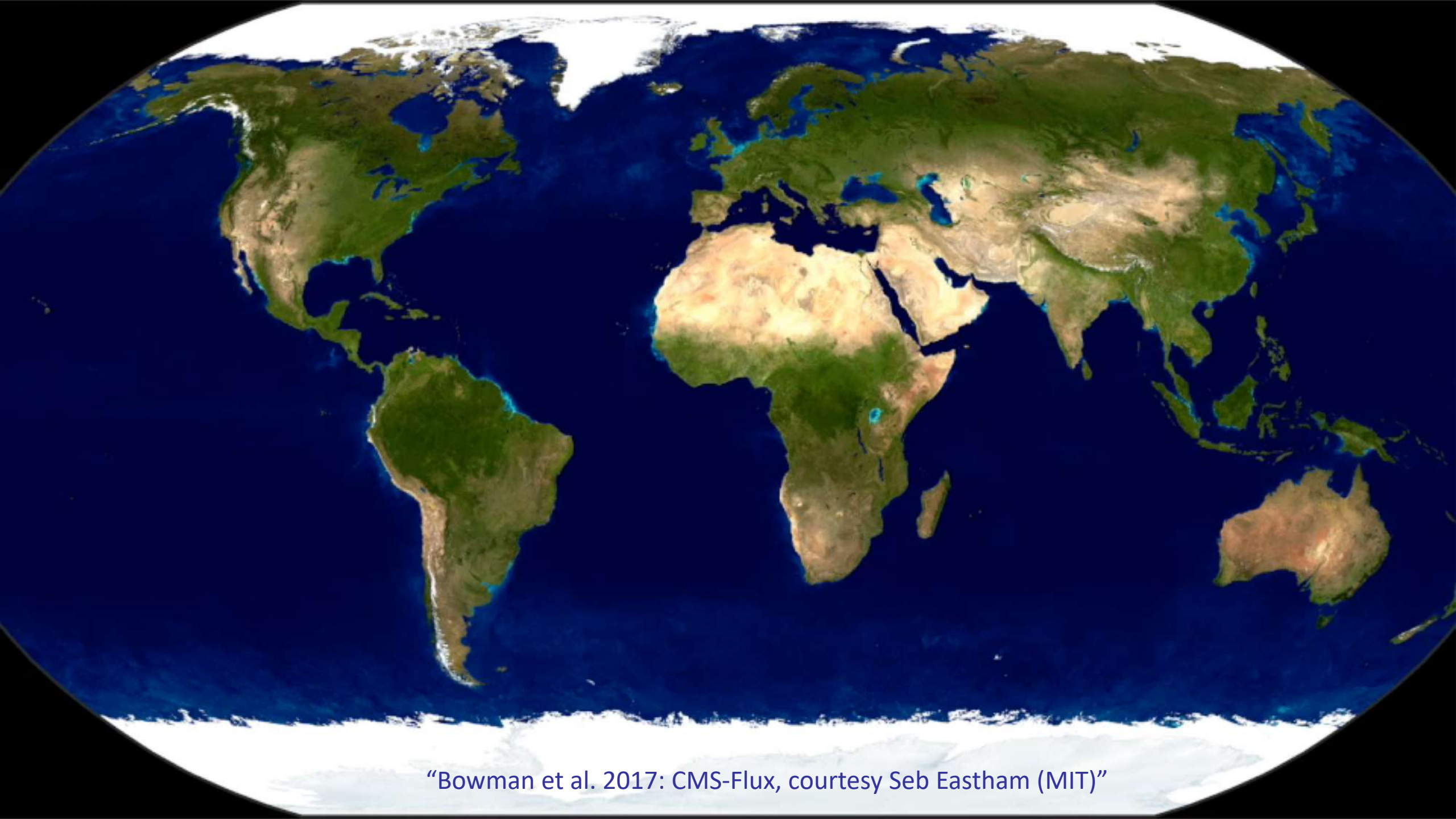
Global Vegetation Carbon Dynamics and Regional Patterns of Sources and Sinks from Satellite Observations

Sassan S. Saatchi, Liang Xu, Yan Yang, Yifan Yu



Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109, USA
saatchi@jpl.nasa.gov

Living Planet
May 12-17, 2019



“Bowman et al. 2017: CMS-Flux, courtesy Seb Eastham (MIT)”

Global Sources and Sinks of Carbon

GCP, 2018

87%
34.4 $GtCO_2$/yr

13%
5.3 $GtCO_2$/yr

Sources

≈

5%
1.9 $GtCO_2$/yr

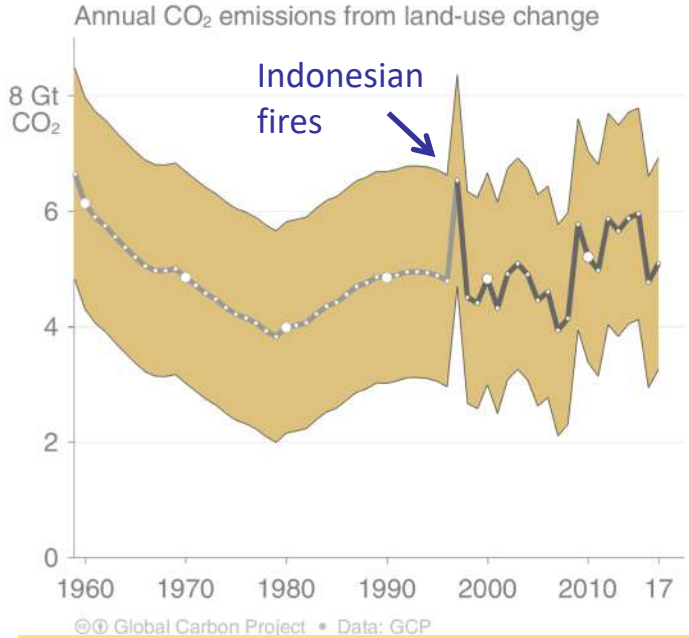
Budget Imbalance

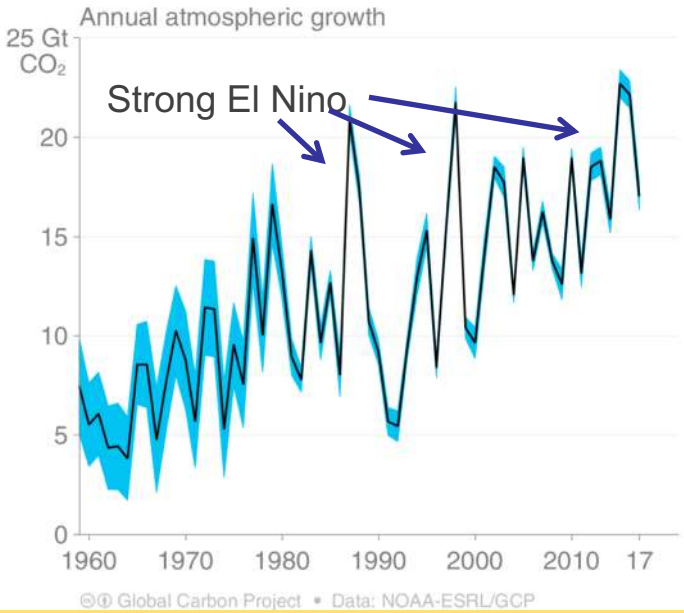
44%
17.3 $GtCO_2$/yr

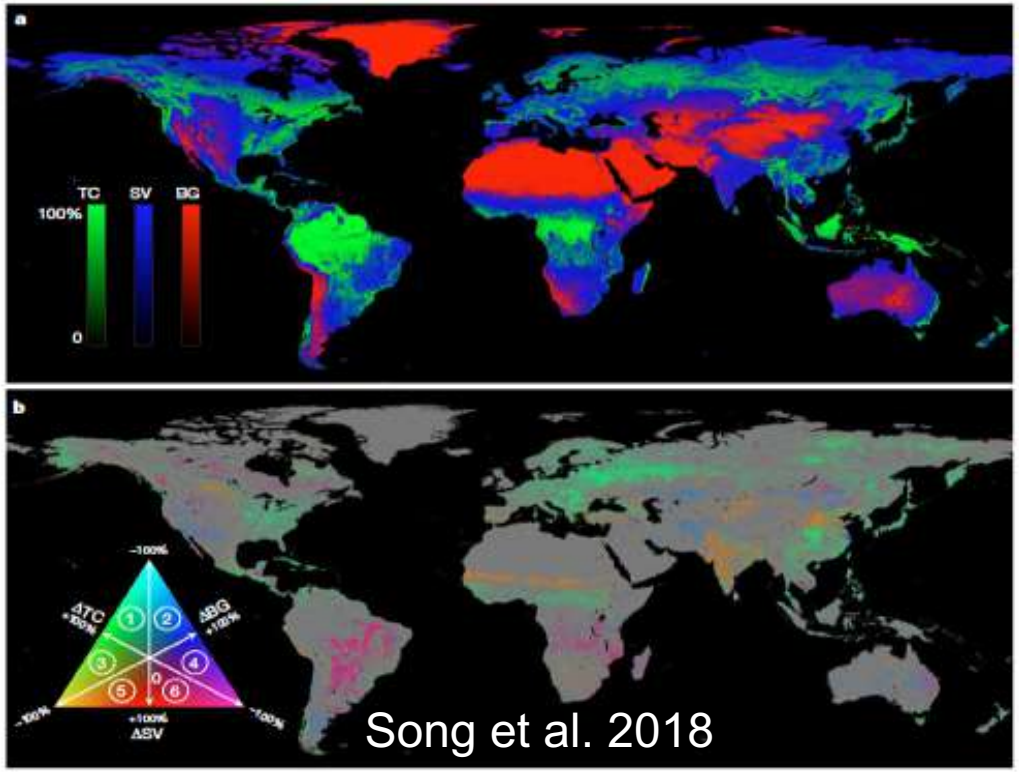
29%
11.6 $GtCO_2$/yr

22%
8.9 $GtCO_2$/yr

Sinks





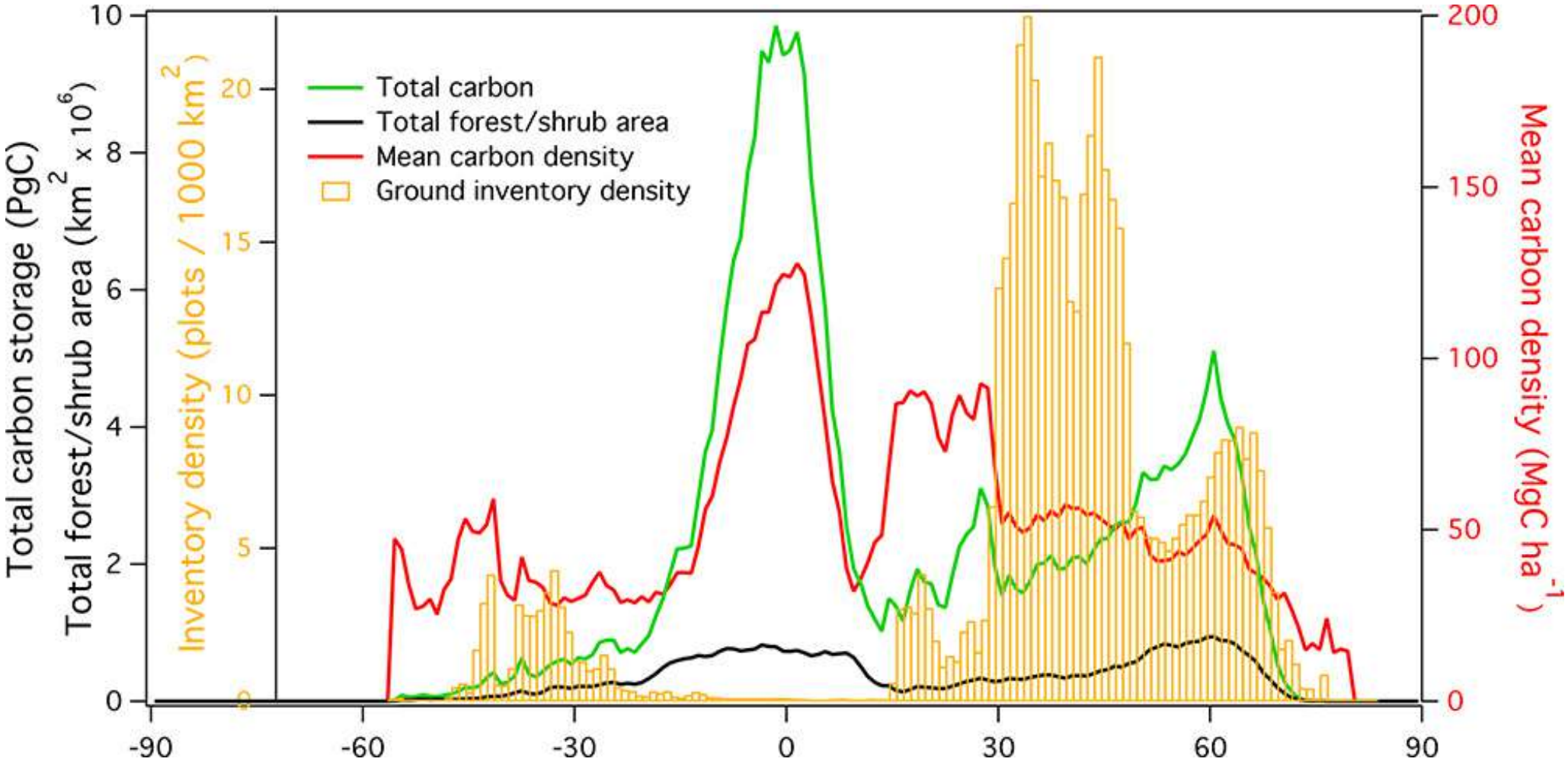


Land sink was 11.6±3 GtCO2/yr during 2008–2017 and 13.9±3 $GtCO_2$/yr in 2017

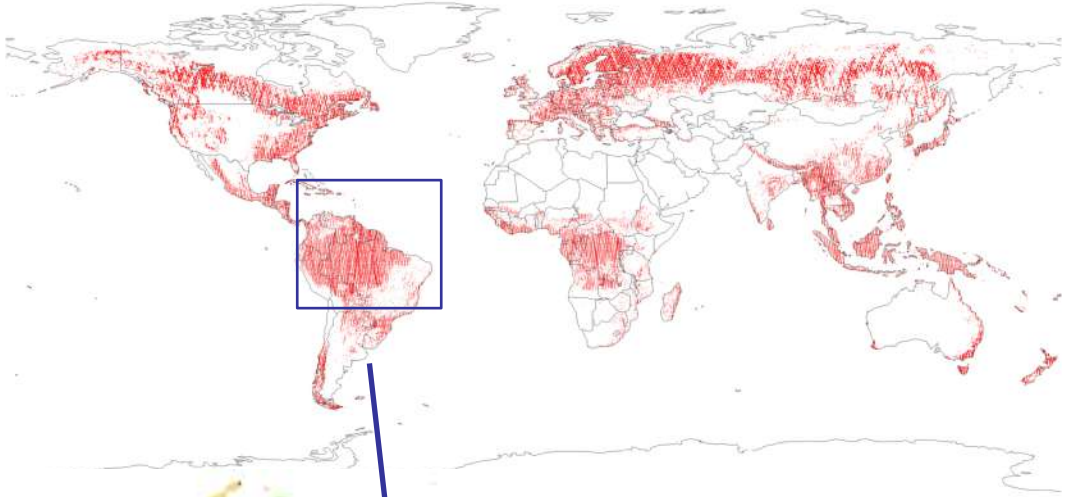
bottom-up approach to quantify global vegetation carbon dynamics

1. Global Vegetation Carbon Stocks
   - Inventory plots, Airborne and Spaceborne Lidar
   - Time series satellite imagery (2000-2017)
   - Machine learning estimation & uncertainty
2. Spatial and temporal variations of forest carbon
   - Geographic variations of carbon stocks
   - Ecoregions and carbon dynamics
3. Bottom-up and top-down comparisons
   - Emissions from land use and fire
   - Contributions to atmospheric carbon growth rate

State of Carbon and Inventory of Global Forests

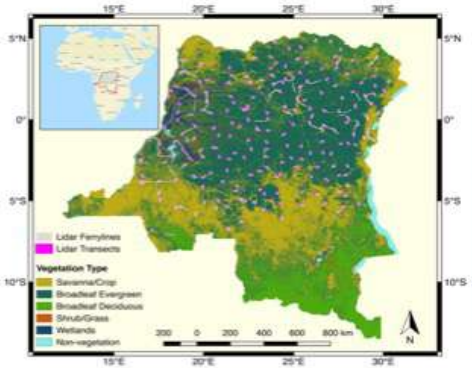


Forest Inventory from Space



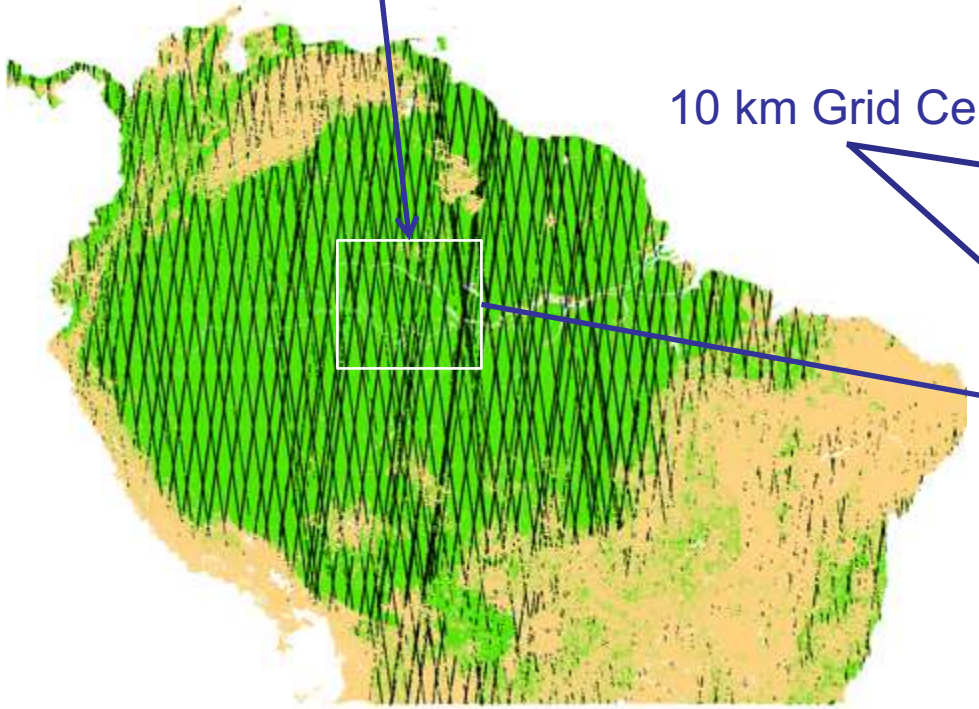
Pan-tropical Airborne Lidar Samples

Brazilian Amazon

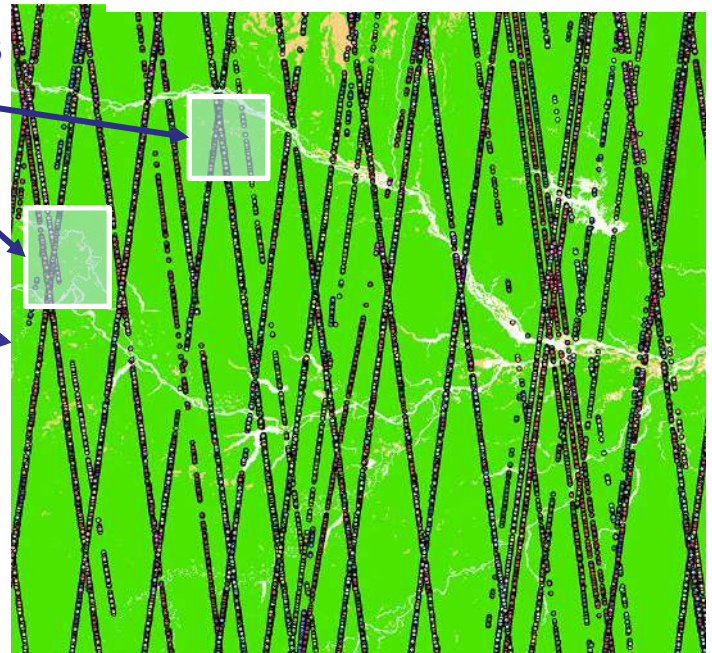


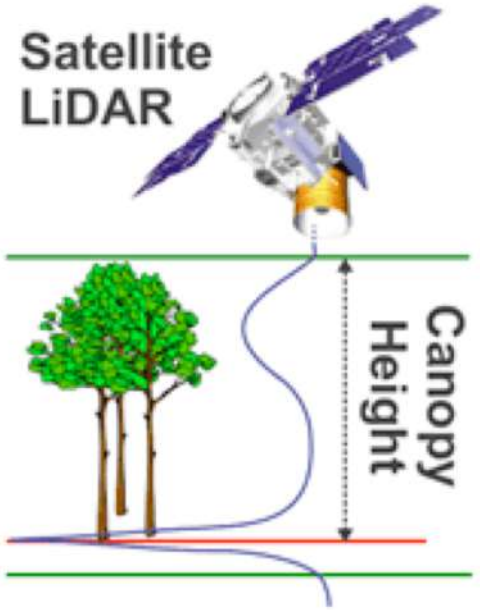
Democratic Republic of Congo

Kalimantan Indonesia

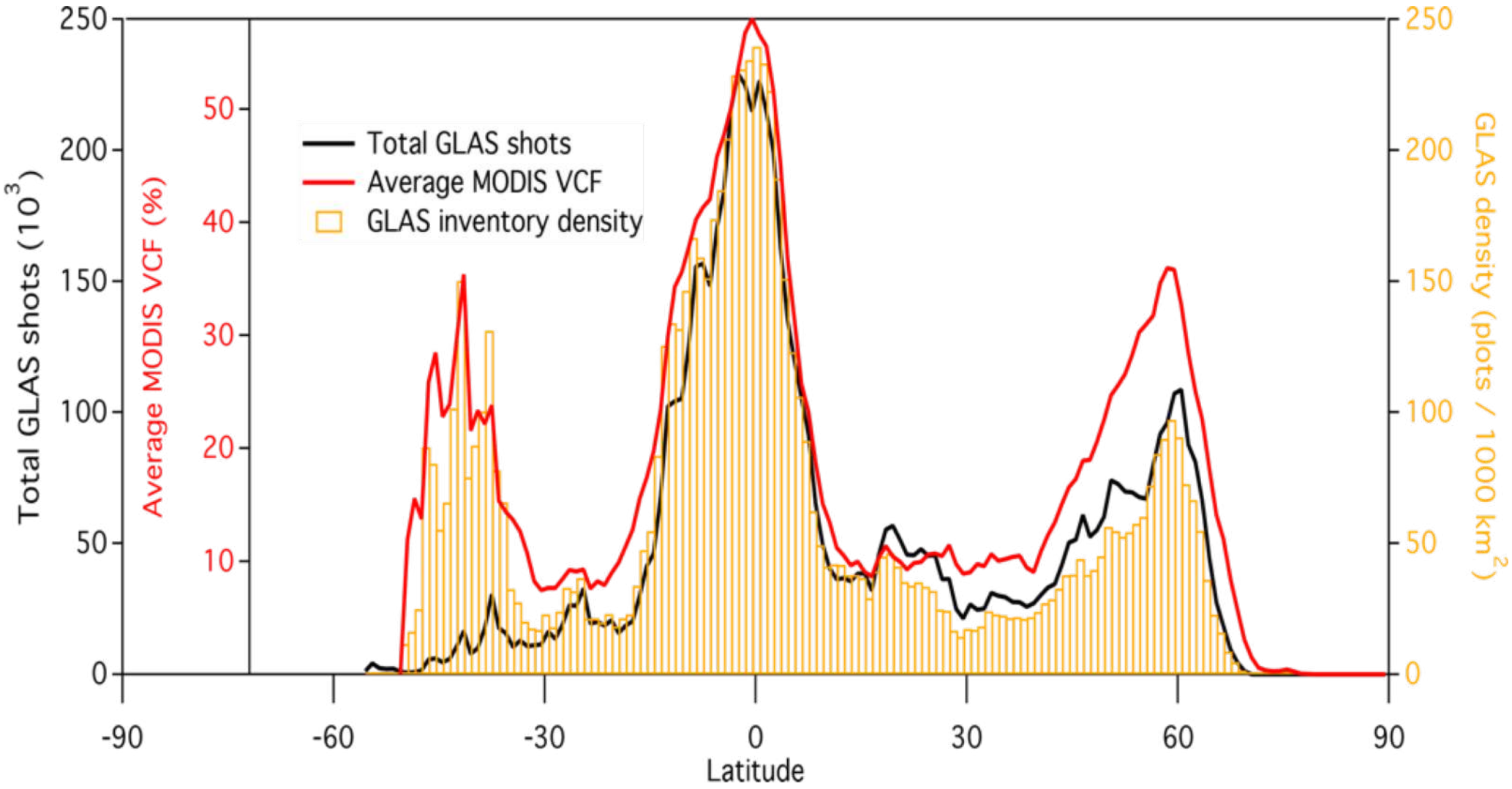


10 km Grid Cells

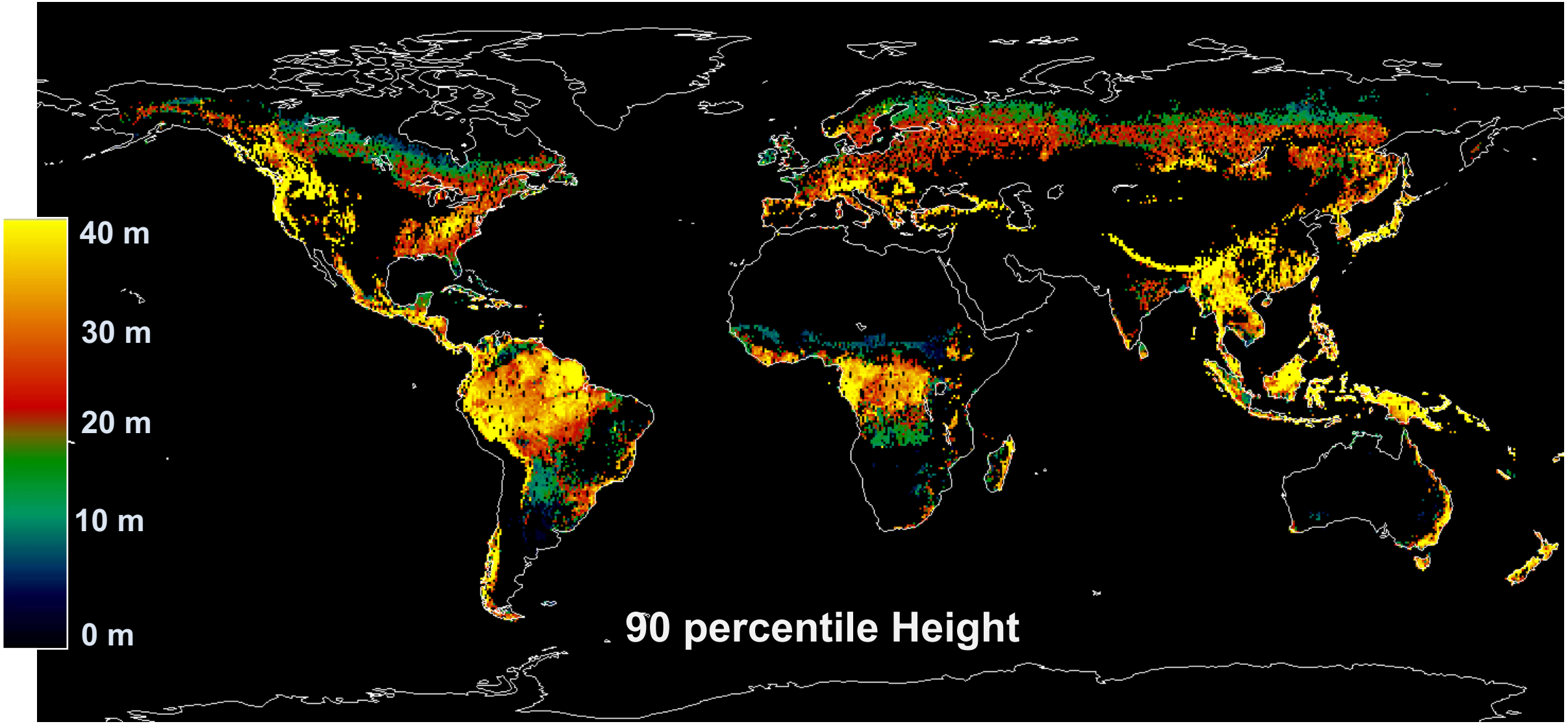




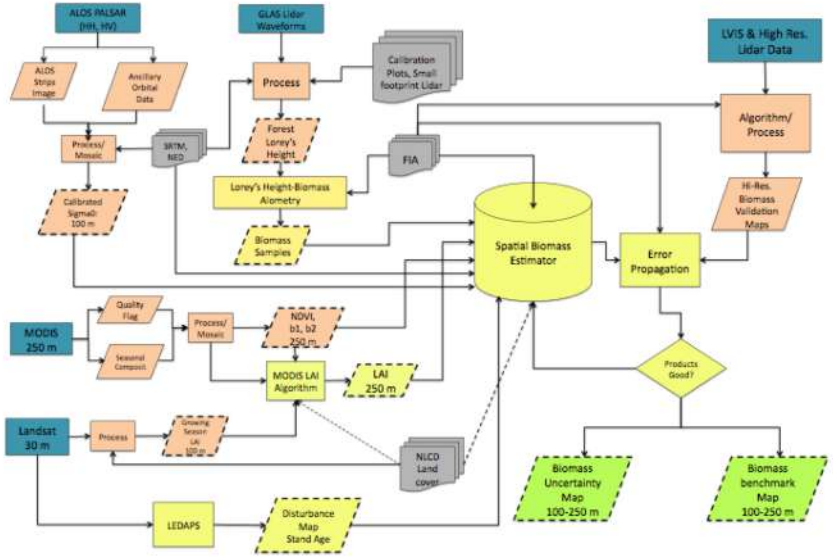
State of Carbon and Inventory of Global Forests



Lidar Vegetation Height Distribution

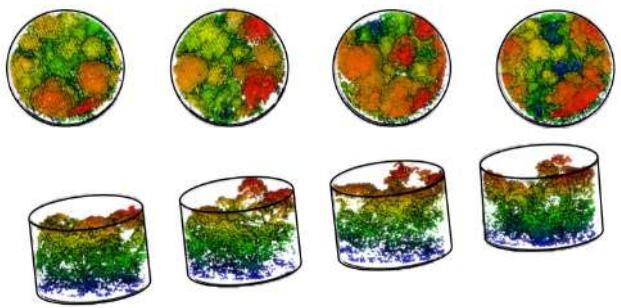


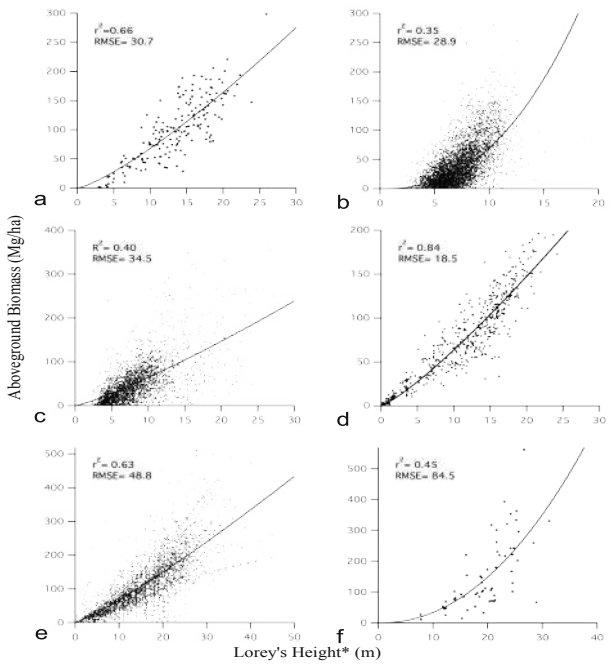
Spatial Modeling Approach



$$\langle H_{i,j} \rangle = \frac{\sum_{k=1}^{n} Pr\left(H_{min,k} < H_{i,j} < H_{max,k} \middle| A_k\right)^m Pr(A_k)\overline{H}_k}{\sum_{k=1}^{n} Pr\left(H_{min,k} < H_{i,j} < H_{max,k} \middle| A_k\right)^m Pr(A_k)}$$

$$\sigma_{\hat{B}} = \sqrt{\frac{\sum_{k=1}^{N}\left(B_k - \hat{B}\right)^2 P_k P(A_k)}{\sum_{k=1}^{N} P_k P(A_k)}}$$



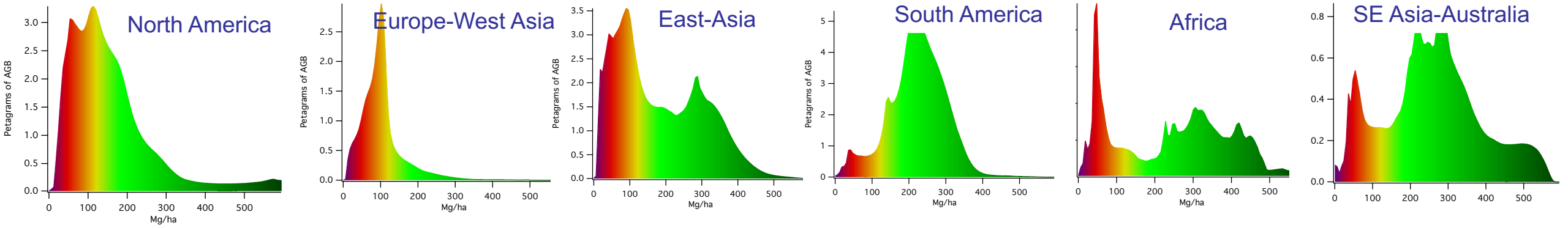


$$AGB = a\bar{\rho}h^b_{LIDAR}$$

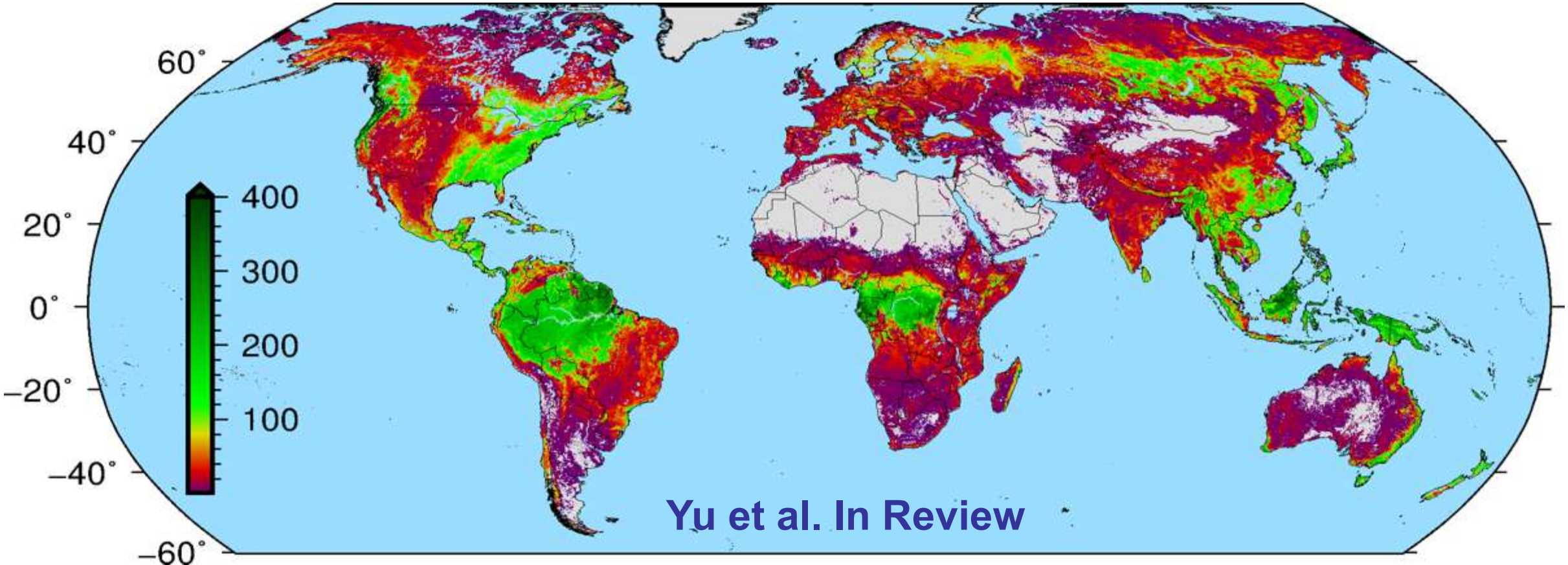
Pattern of AGB is defined by:

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

Vegetation Type	LiDAR to AGB Conversion	R^2	RMSE (Mg/ha)	n	Root:Shoot BGB to AGB
Africa					
Broadleaf Evergreen	$AGB = 0.2788H^{2.12}$	0.80		75	$0.489AGB^{0.89}$
Woodlands	$\dagger AGB = 0.12363H^{2.3533}$	0.86	95.5	49	$0.4933AGB$
Eurasia					
Broadleaf Deciduous (east)	$AGB = 0.26089H^{2.1192}$	0.45	84.5	60	
Boreal (east)	$*AGB = 4.5925H^{1.1627}$	0.63	48.8	2796	
Boreal (west)	$AGB = 3.9314H^{1.2103}$	0.84	18.5	468	
Mediterranean	$\dagger AGB = 1.4243H^{1.5953}$	0.71		257	
North America					
Broadleaf Evergreen	$AGB = 0.6011H^{1.894}$	0.86		298	
Broadleaf Deciduous	$AGB = 1.1799H^{1.536}$	0.48	44.9	48587	$0.196631AGB$
Temperate Conifer (east)	$AGB = 0.68255H^{1.6939}$	0.62	36.6	6083	$0.221198AGB$
Temperate Conifer (west)	$AGB = 0.71774H^{1.6892}$	0.67	79.1	8217	$0.221198AGB$
Boreal (mixed)	$AGB = 3.6407H^{1.2722}$	0.66	30.7	184	
Mixed	$AGB = 0.6898H^{1.6932}$	0.59	36.3	3401	$0.20634AGB$
Temperate Savanna, Shrubland	$AGB = 1.3403H^{1.4694}$	0.60	32.6	3089	
Mediterranean Forests, Woodlands	$\dagger AGB = 2.3053H^{1.3171}$	0.44	49.2	322	
Forest Wetland	$AGB = 1.799H^{1.536}$	0.48	44.9	48587	$0.203549AGB$
Tropical Dry Broadleaf	$*AGB = 0.24888H^{2.4469}$	0.35	28.9	4833	
Tropical Conifer	$*AGB = 6.4389H^{1.0556}$	0.32	31.4	15408	
South America					
Broadleaf Evergreen	$AGB = 0.6011H^{1.894}$	0.86		298	$0.489AGB^{0.89}$
Southeast Asia					
Broadleaf Evergreen	$AGB = 0.2788H^{2.12}$	0.80		75	$0.489AGB^{0.89}$

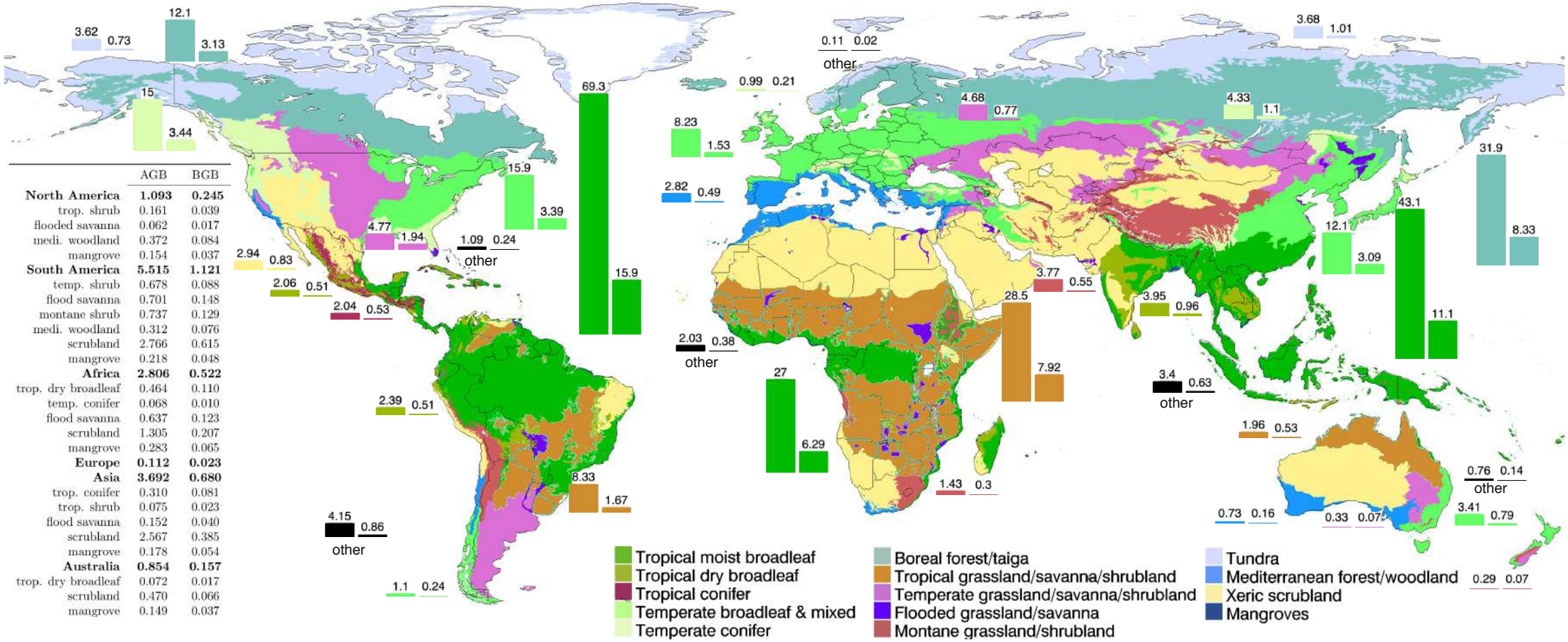


Global Aboveground Biomass Map (100 m)

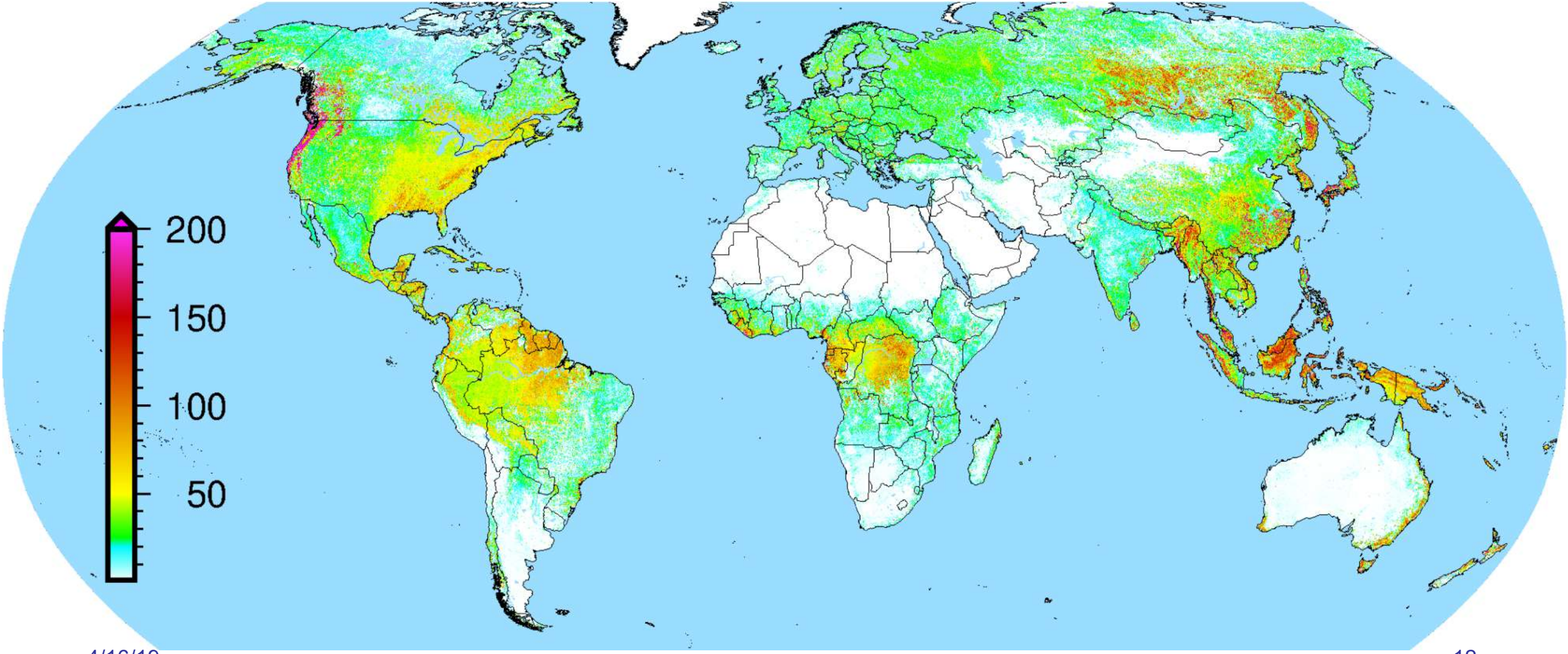


Distribution of Carbon Stocks

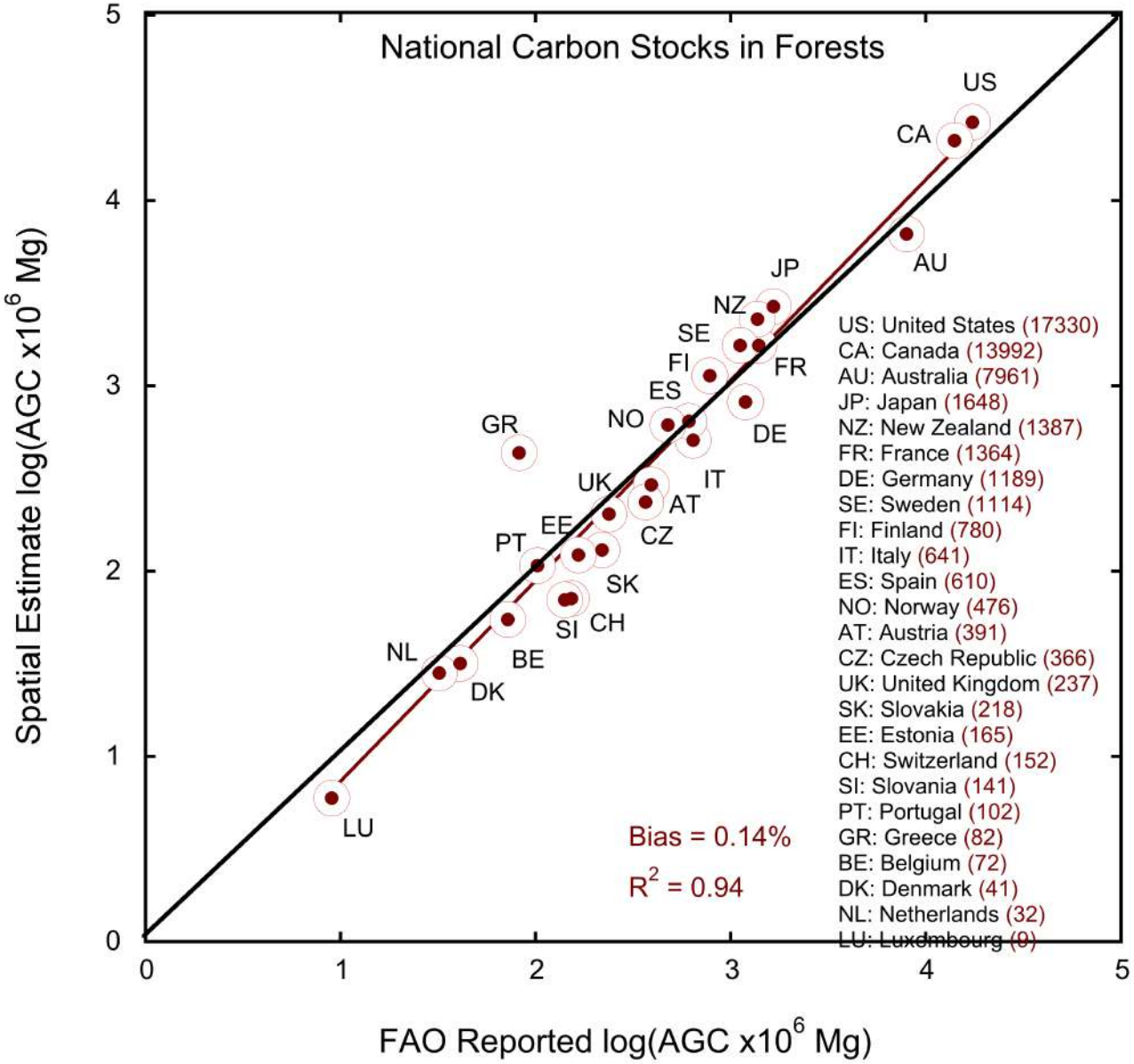
	AGB	BGB
North America	**1.093**	**0.245**
trop. shrub	0.161	0.039
flooded savanna	0.062	0.017
medi. woodland	0.372	0.084
mangrove	0.154	0.037
South America	**5.515**	**1.121**
temp. shrub	0.678	0.088
flood savanna	0.701	0.148
montane shrub	0.737	0.129
medi. woodland	0.312	0.076
scrubland	2.766	0.615
mangrove	0.218	0.048
Africa	**2.806**	**0.522**
trop. dry broadleaf	0.464	0.110
temp. conifer	0.068	0.010
flood savanna	0.637	0.123
scrubland	1.305	0.207
mangrove	0.283	0.065
Europe	**0.112**	**0.023**
Asia	**3.692**	**0.680**
trop. conifer	0.310	0.081
trop. shrub	0.075	0.023
flood savanna	0.152	0.040
scrubland	2.567	0.385
mangrove	0.178	0.054
Australia	**0.854**	**0.157**
trop. dry broadleaf	0.072	0.017
scrubland	0.470	0.066
mangrove	0.149	0.037

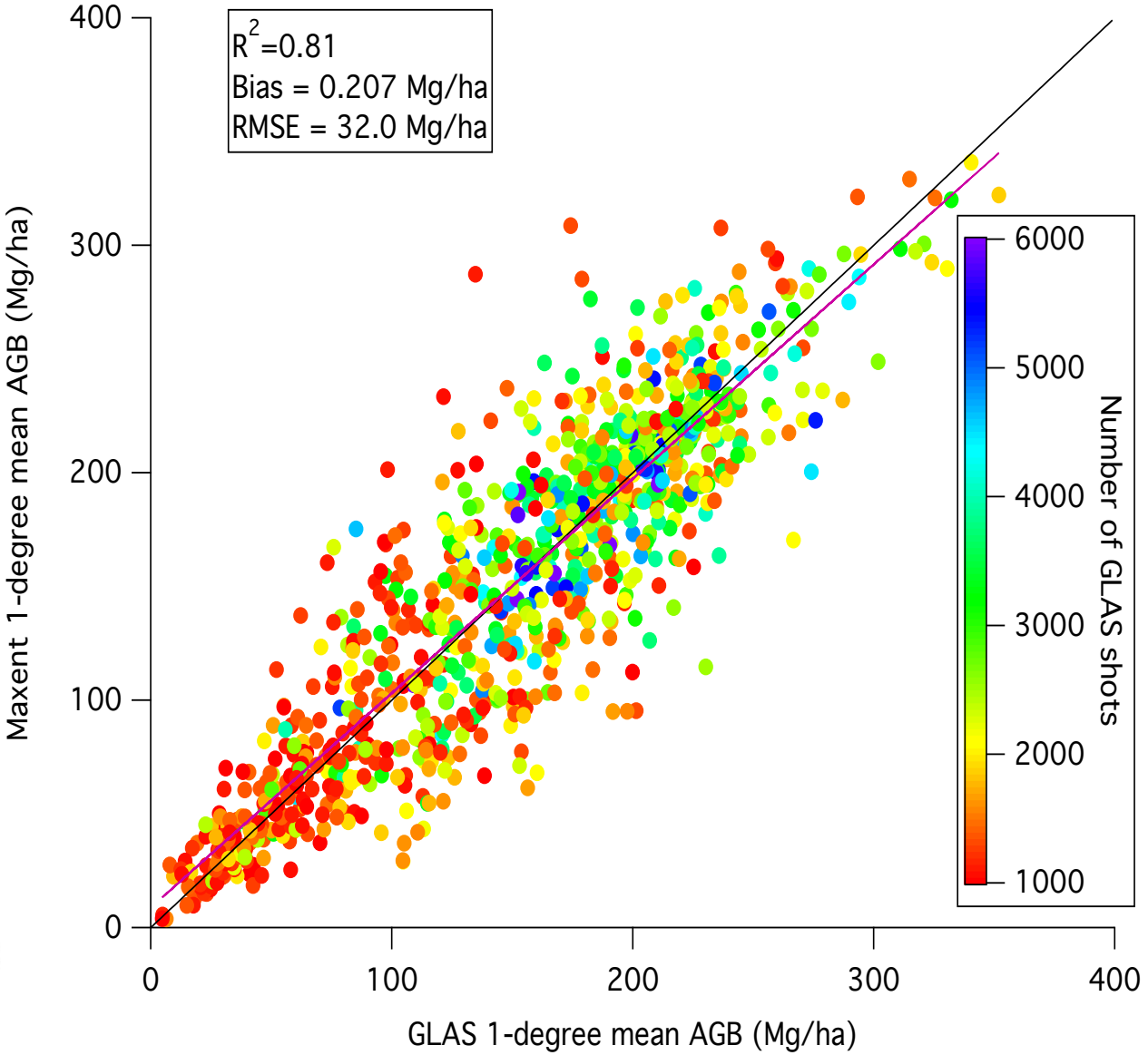


Uncertainty Distribution

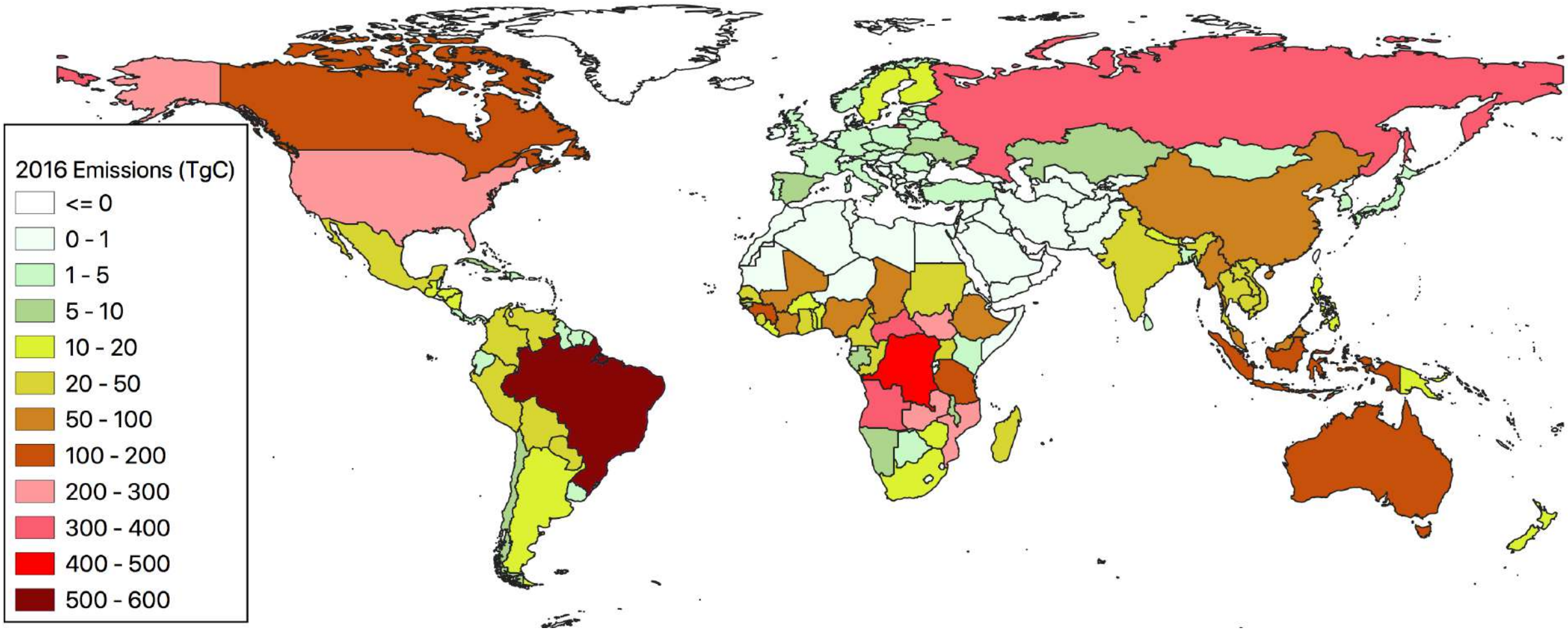


Validation and Uncertainty Assessment





Emissions from Land Use and Fire



Methodology for Mapping Forest Carbon Change

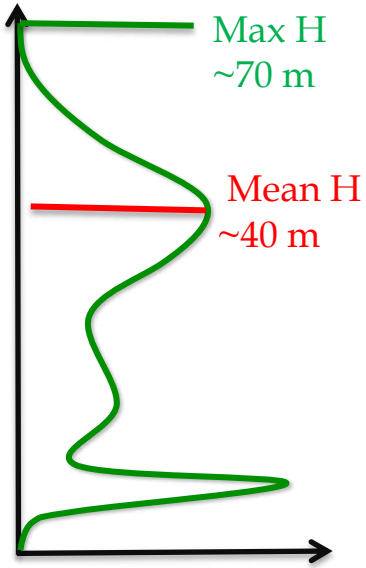
- **AGB Training Data**
  GLAS sampling (2004-2007): Min of 25 GLAS Shots
  - VCF corrections: $AGB_{pixel} = \overline{AGB}_{shot} \times \frac{VCF_{pixel}}{\overline{VCF}_{shot}}$
  - Airborne Lidar corrections:

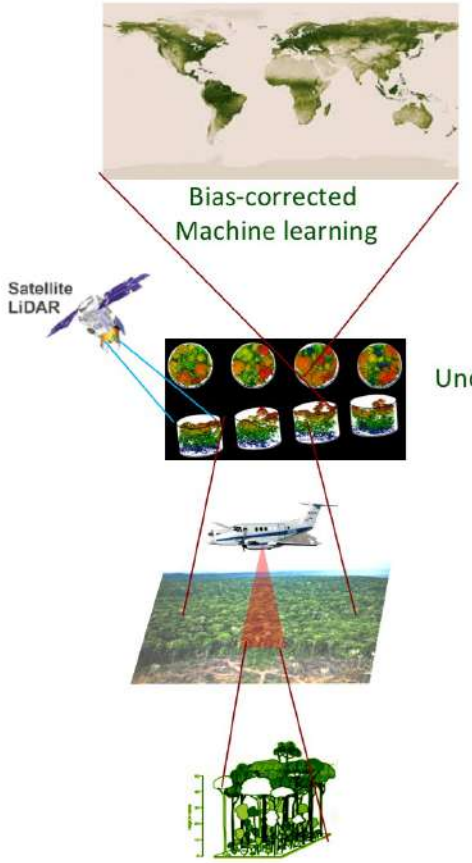
$AGB_{Africa} = 1.65 * AGB_{glas} - 12.10$

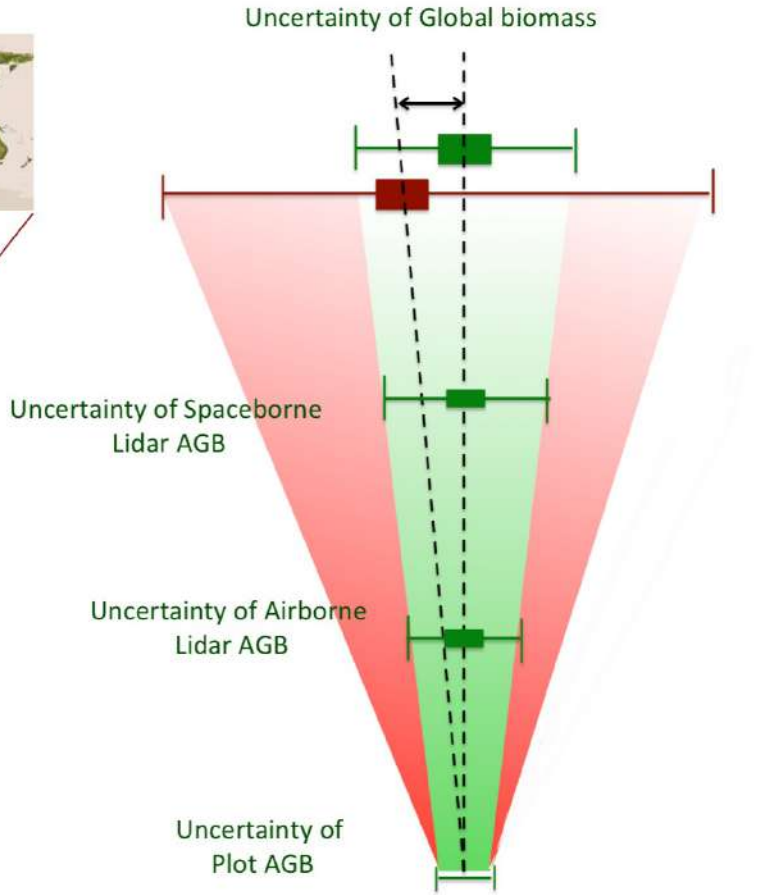
$AGB_{Asia} = 1.39 * AGB_{glas} - 18.56$

  - ALOS AGB estimation for low vegetation < 100 Mg/ha
  - Correction of understory biomass for boreal and temperate forest
  - Correction for small trees < 10 cm in tropics

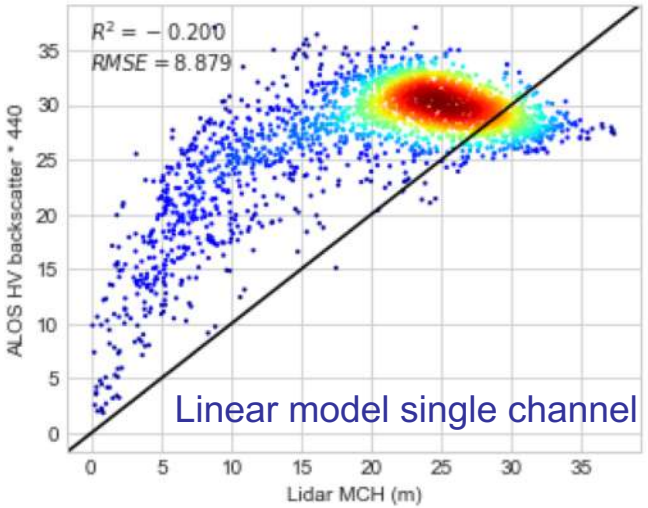
Layer Name	NBAR	LST	QUICKSCAT	BIOCLIM	SRTM
Number of Bands	10	4	3	7	2
Number of Years	18	18	18	1	1
Total Bands	180	72	54	7	2



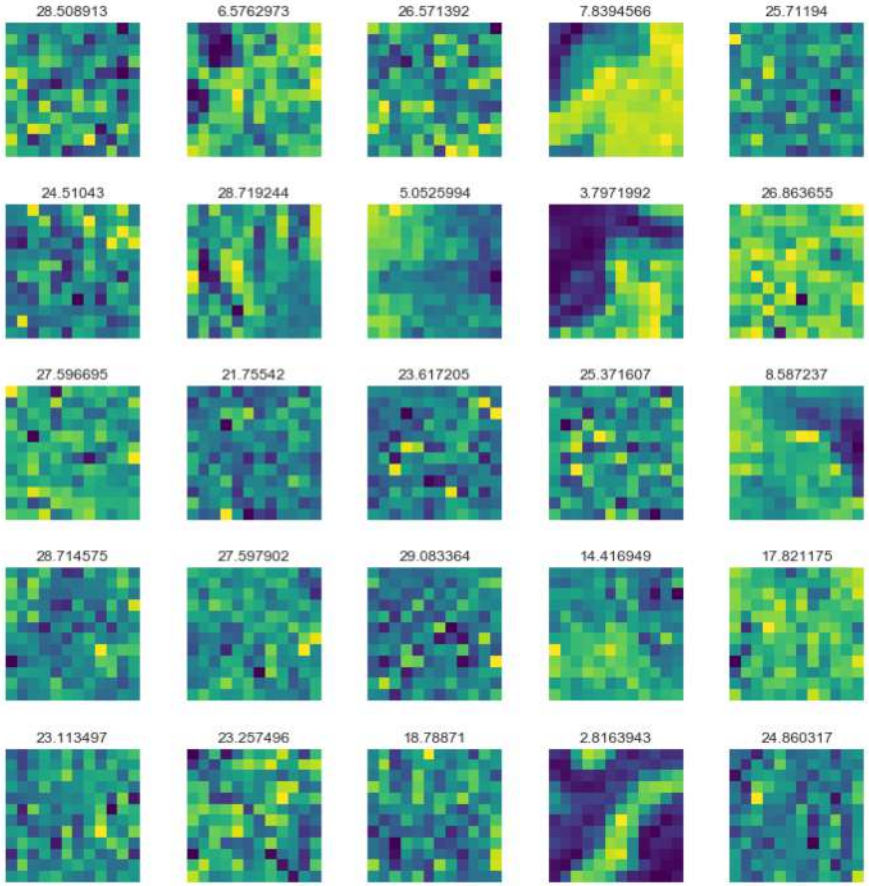


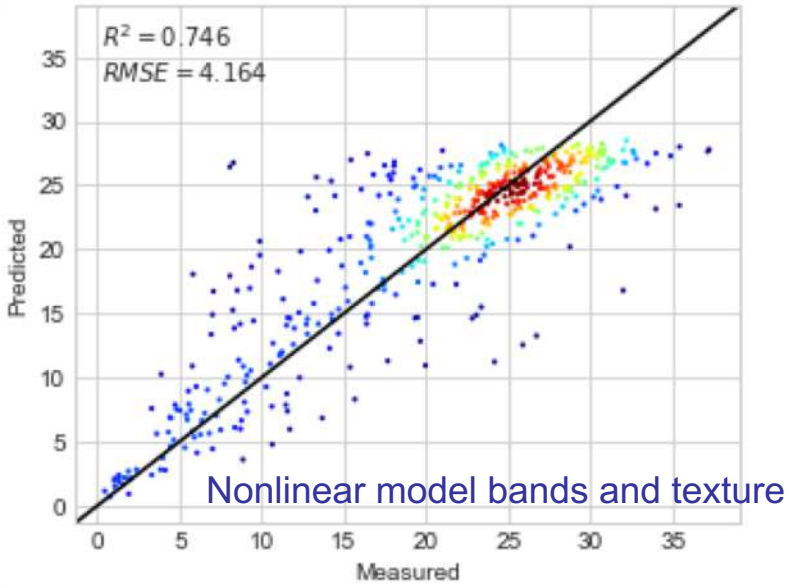


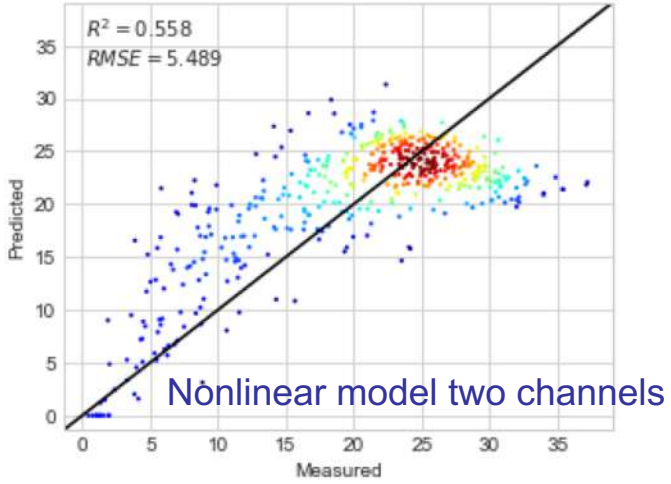
Lidar & Radar Fusion

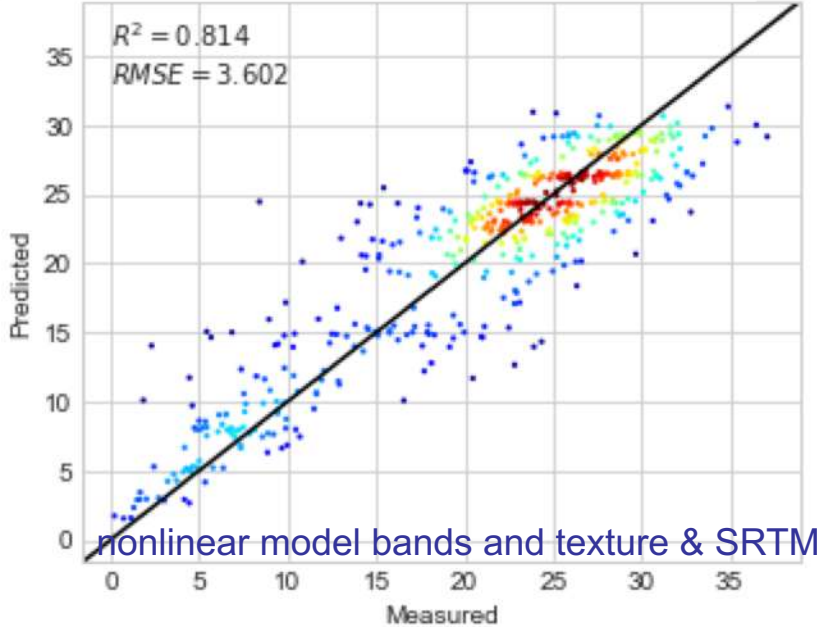


1-km texture from ALOS HH, HV, SRTM
Total of 72 layers at 1 km grid cells
Deep-learning Algorithm
Validation with ALS data over Congo





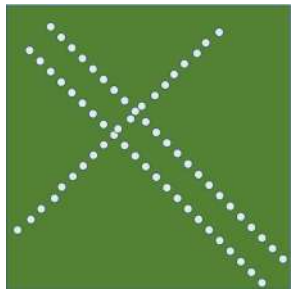


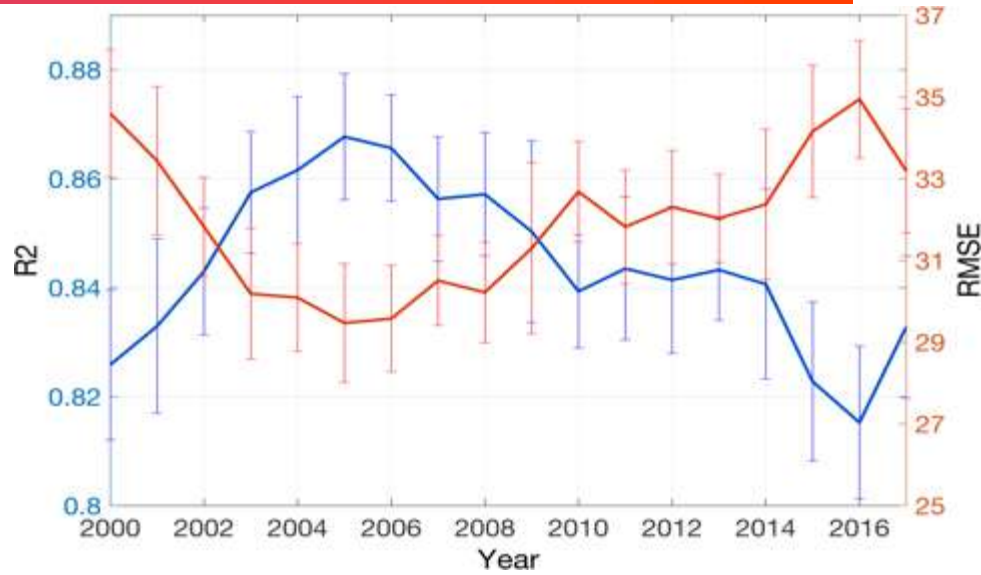


Global Time Series of Carbon Stocks

Training Data:
High Biomass: min of 25 GLAS derived mean AGB points in each 10 km pixel corrected with MODIS VCF
Low Biomass: ALOS Derived AGB over open woodlands and shrublands and grasslands using regional models

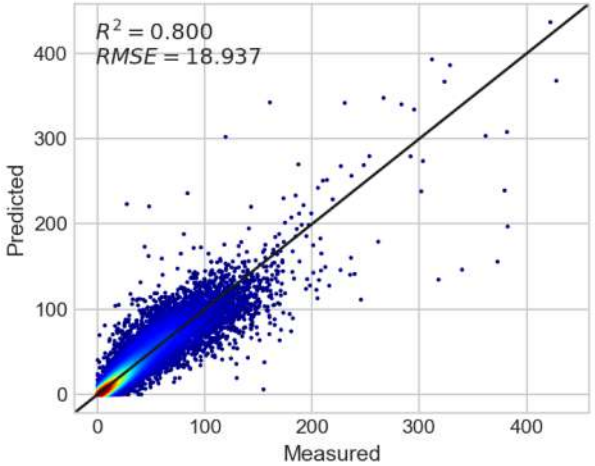
10 km

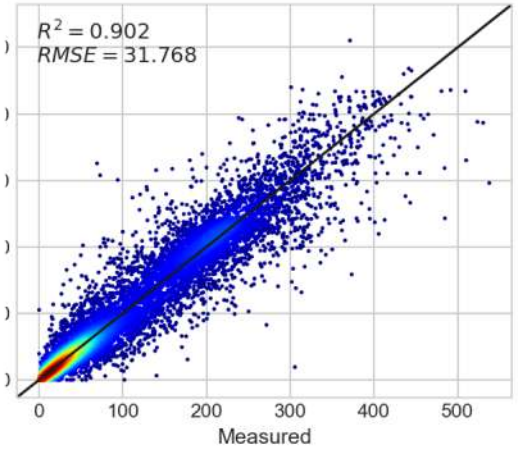




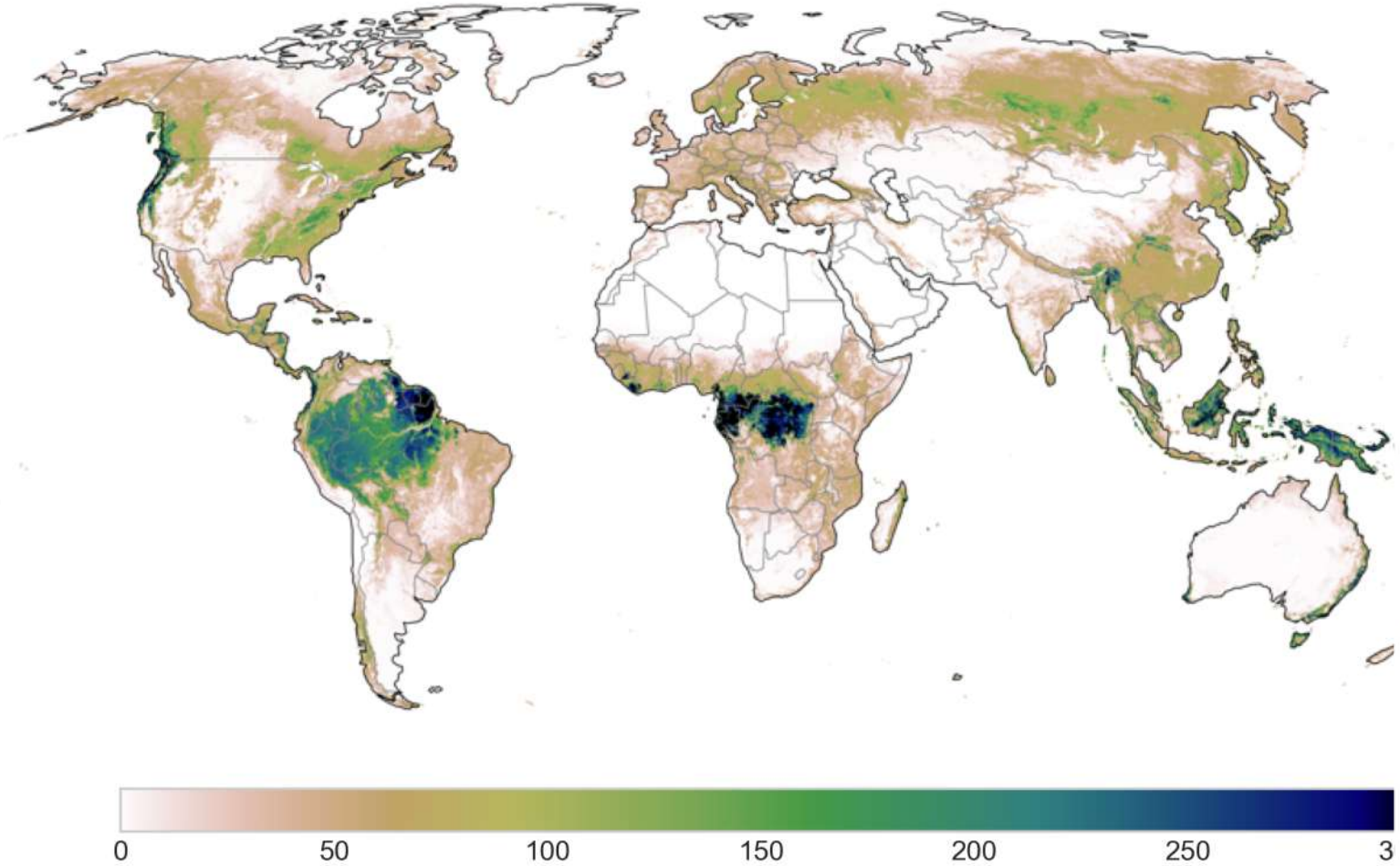
Imaging Layers:
(2000-2017) MODIS NBAR seasonal (bands 1,2,4,5)
(2000-2017) LST Seasonal (bands “night” & “day”)
(2000-2017) QuikSCAT HH & VV Seasonal
Fixed layers : WorldClim, STRM mean and std
QuikSCAT 2010 onwards: OceanSAT & Products using predictions from using GRACE/LST/TRMM/

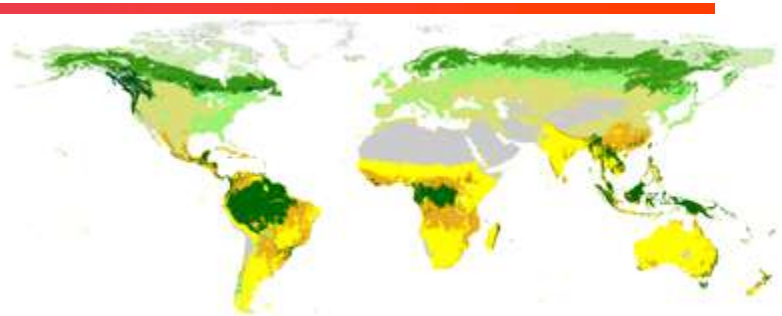
Machine learning:
Model: Random-Forest, Super-vector Machine, CNN (all with Bias Correction)
Train: 2004-2007 data for X and Y; Prediction: each year from 2000 to 2017
Validation: 30% independent test
Temporal Validation: Test R2 and RMSE of training data vs. annual predictions for each year.

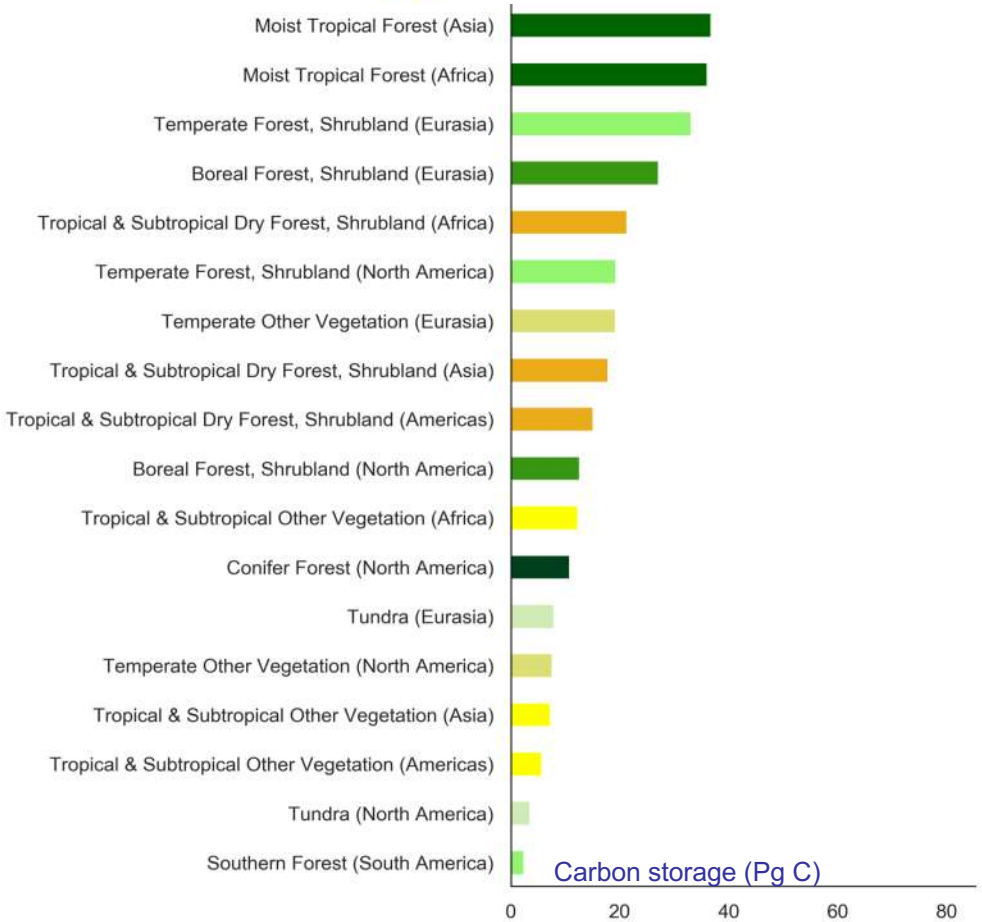




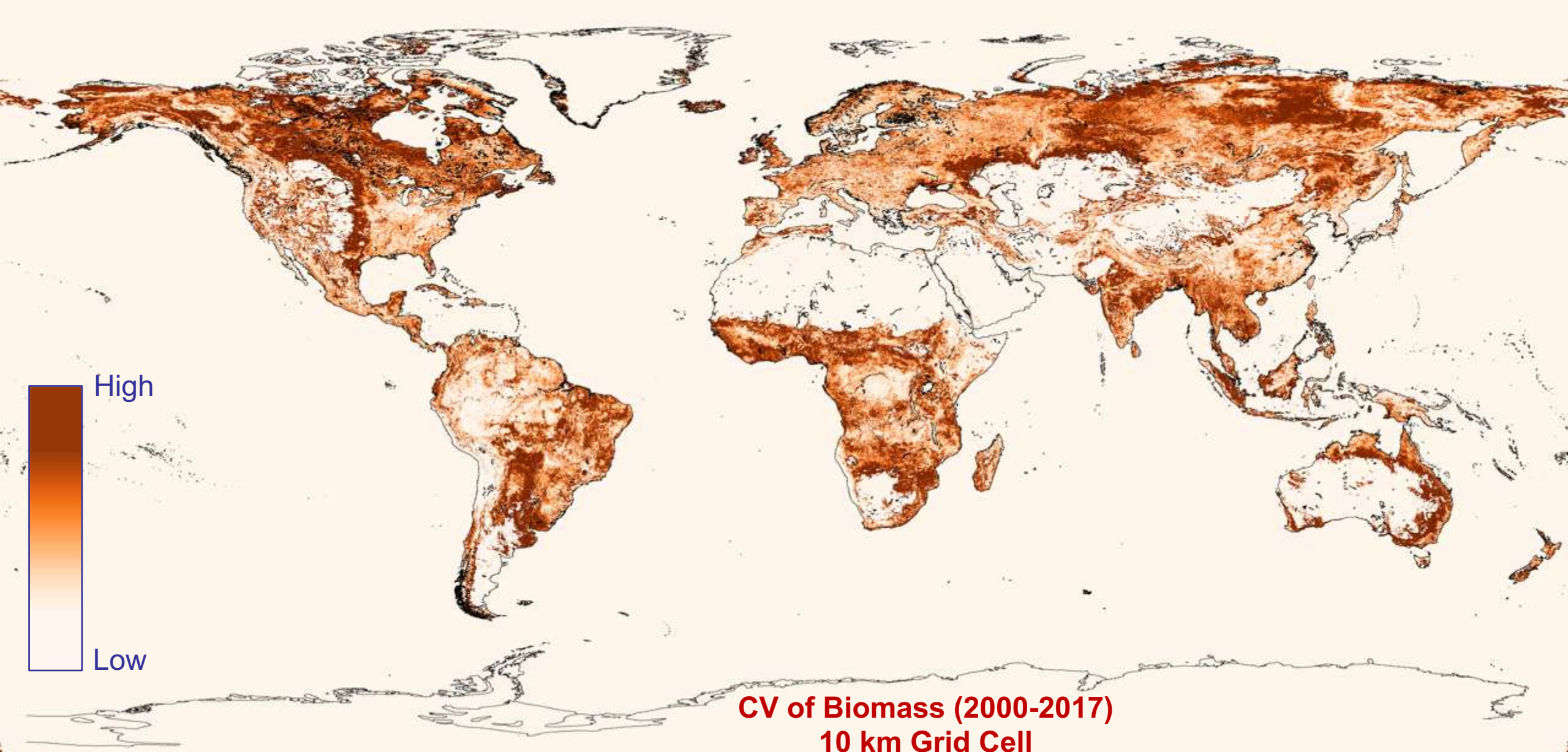
Distribution of Carbon in Global Vegetation



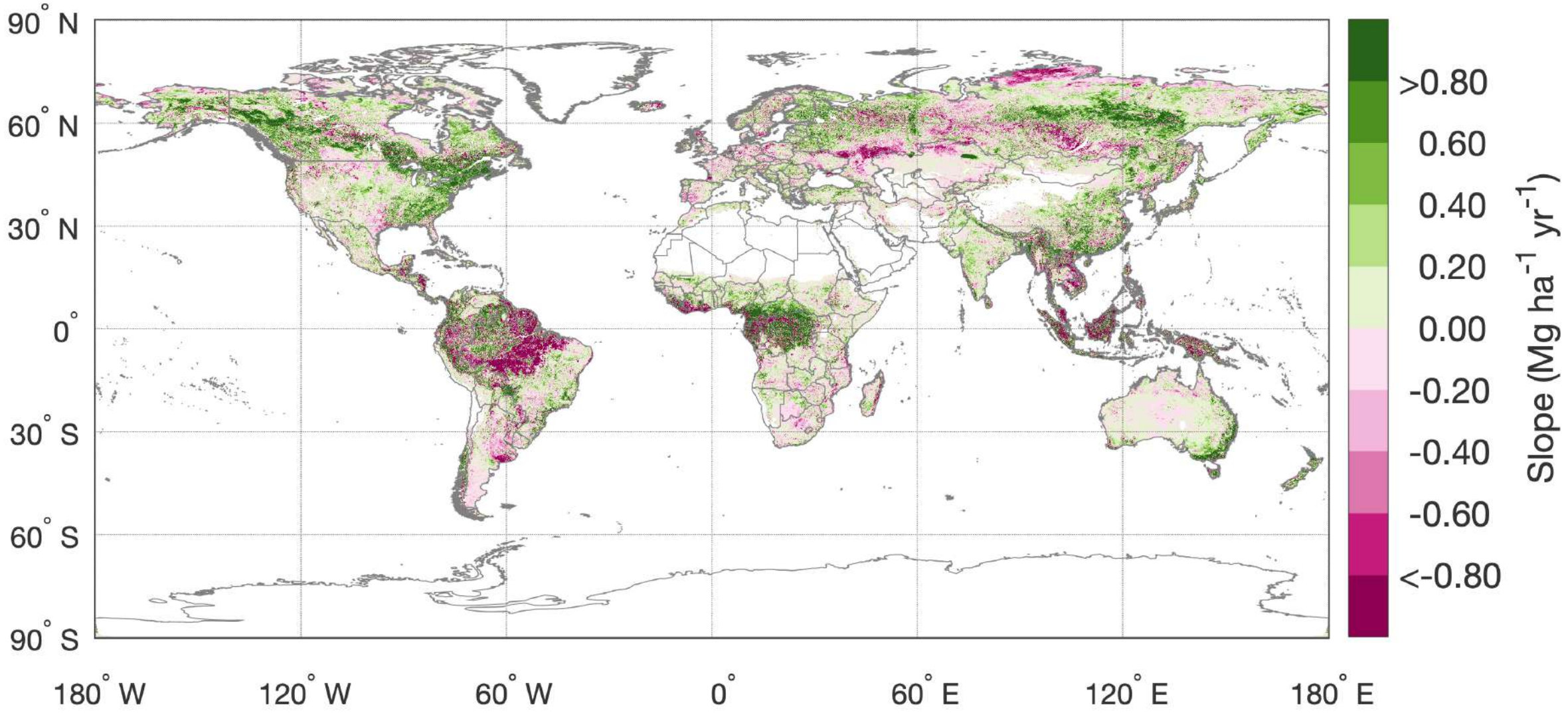




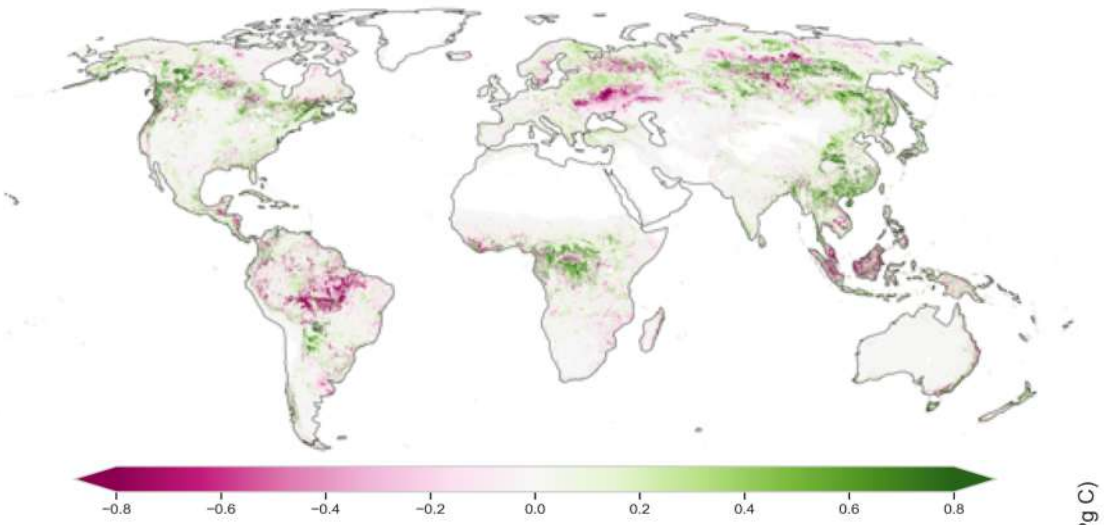
Global Vegetation Biomass Dynamics

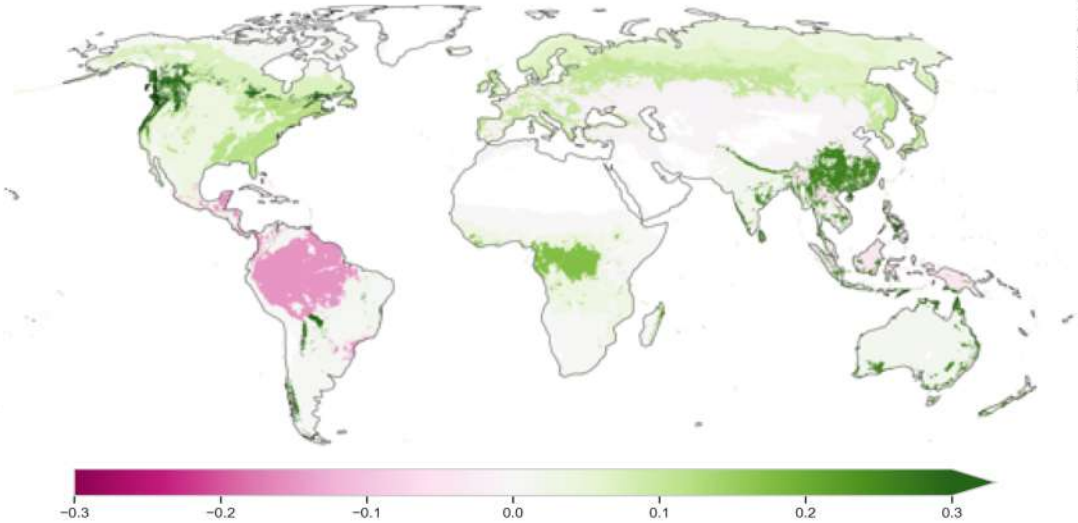


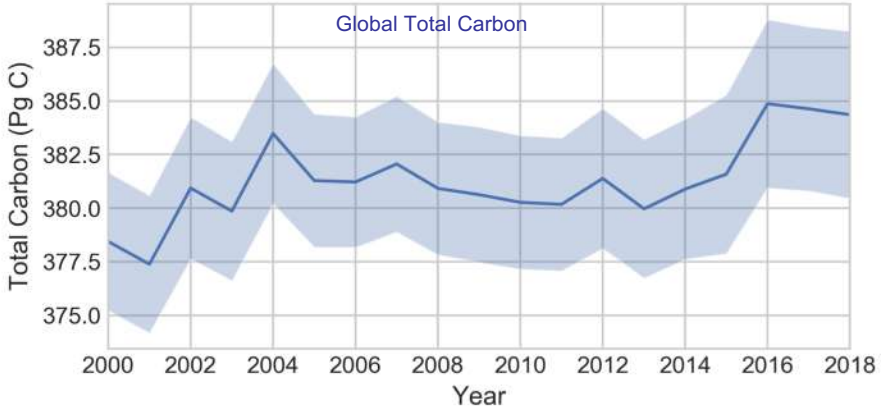
Trend in Global Biomass Change

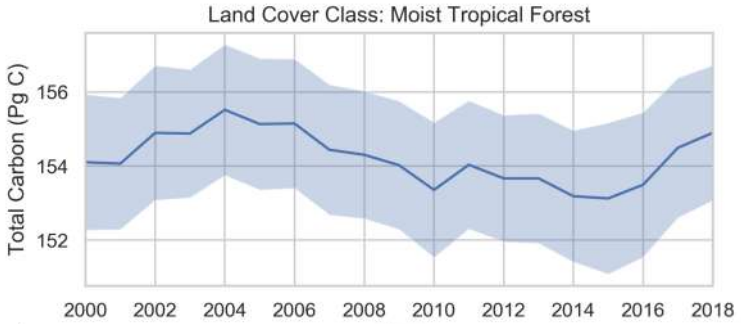


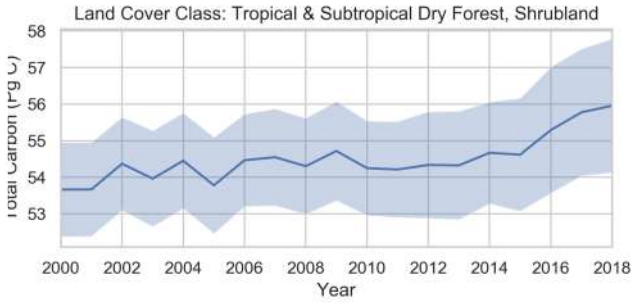
Figures (global, tropical, boreal, temperate, woodlands ts MODIS)

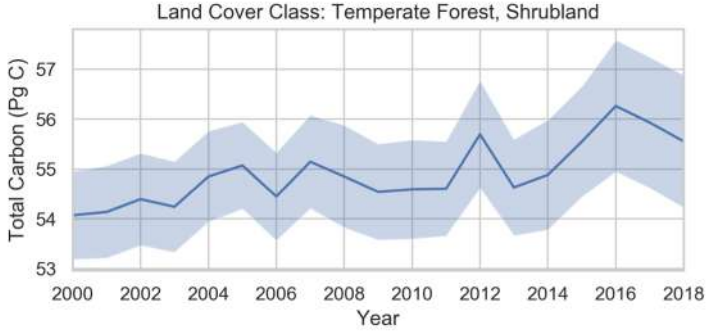


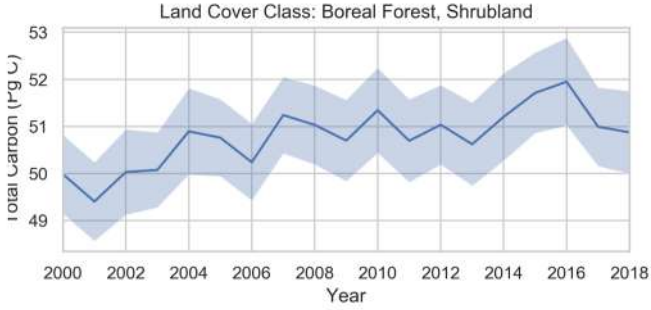


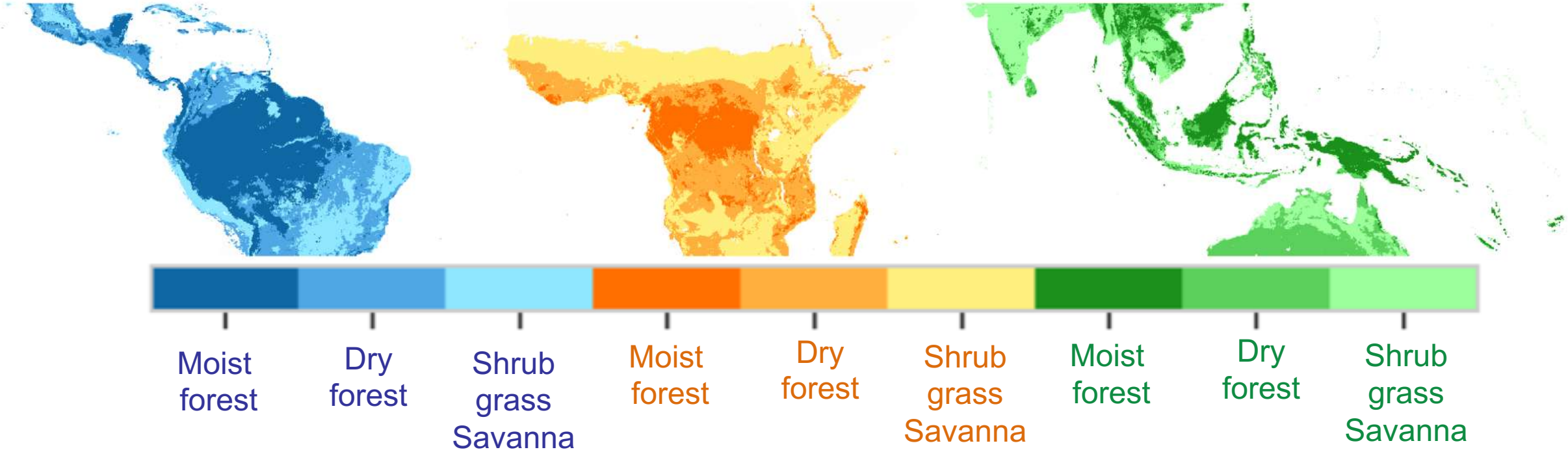




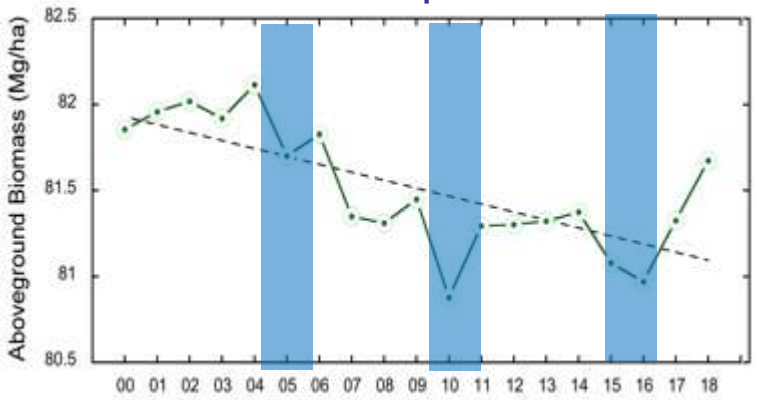






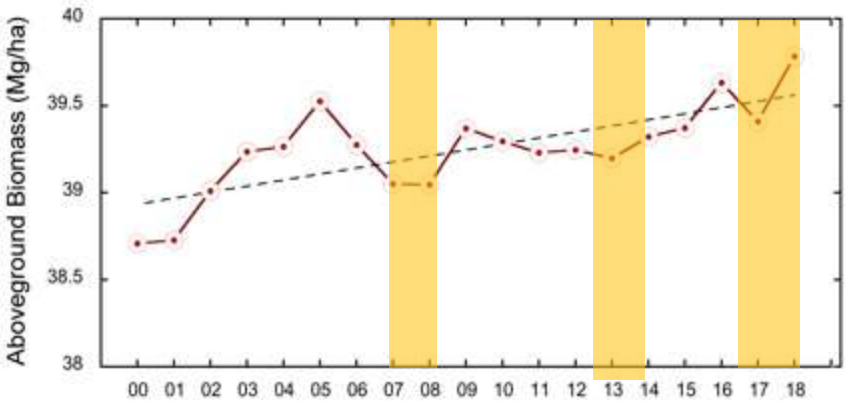


Moist Tropical America



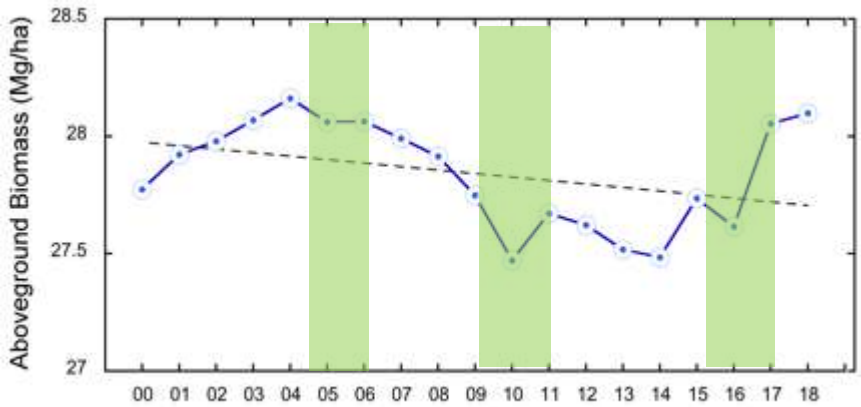
Trend line: $R^2 = 0.51$

Moist Tropical Africa



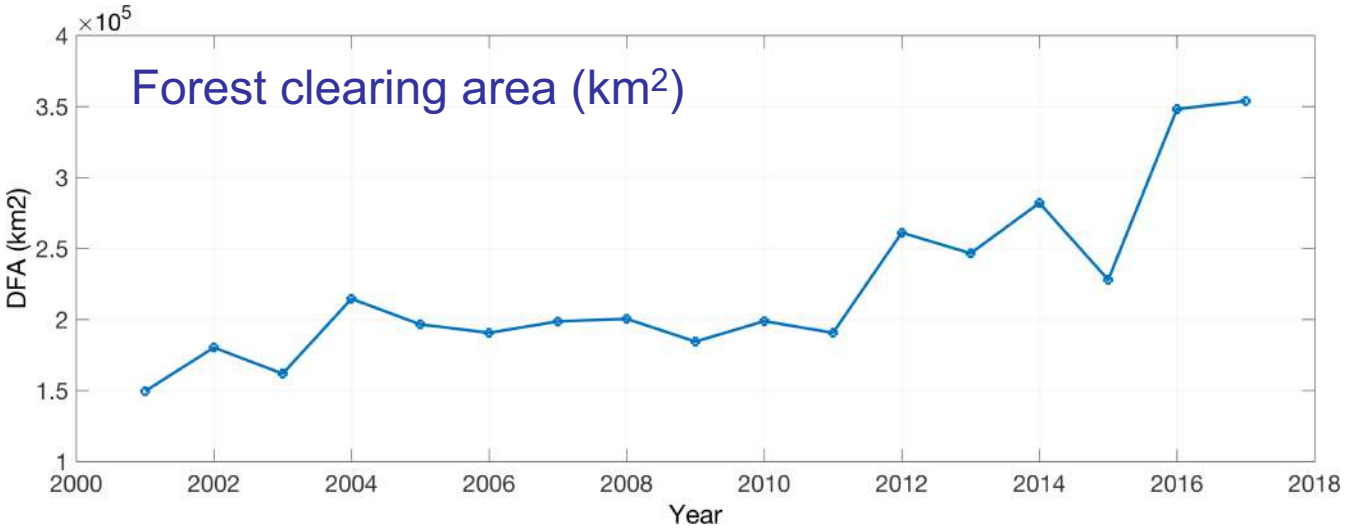
Trend line: $R^2 = 0.53$

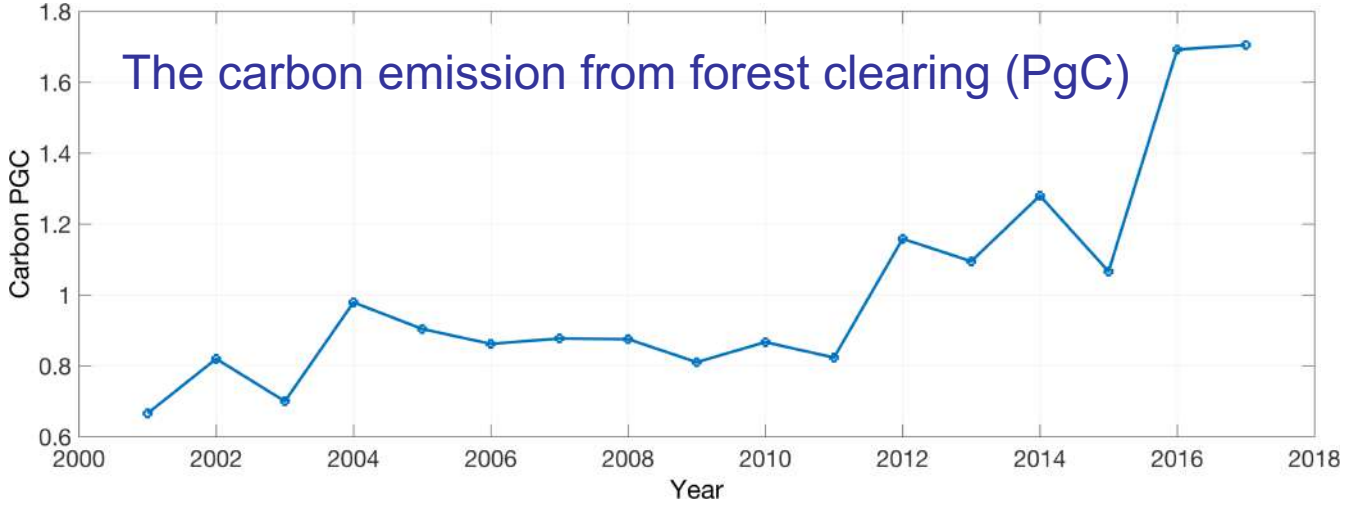
Moist Tropical Asia



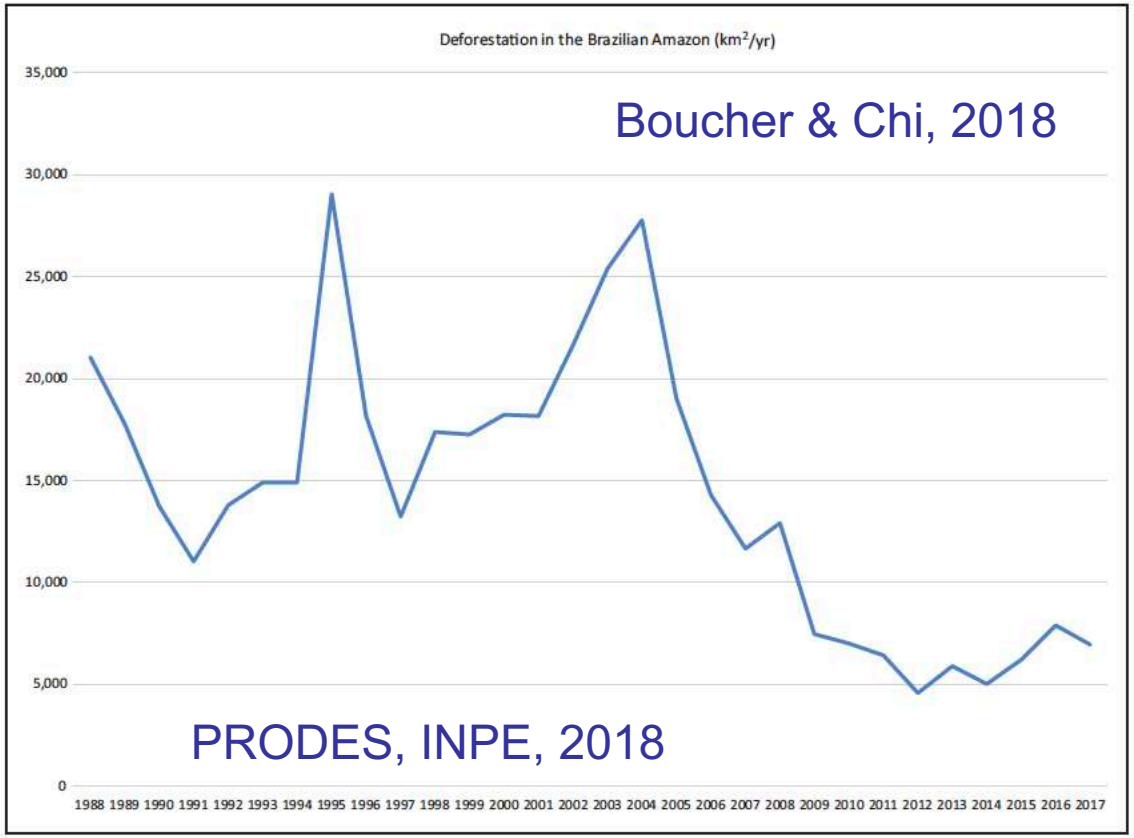
Trend line: $R^2 = 0.13$

Trends in Global Forest Change

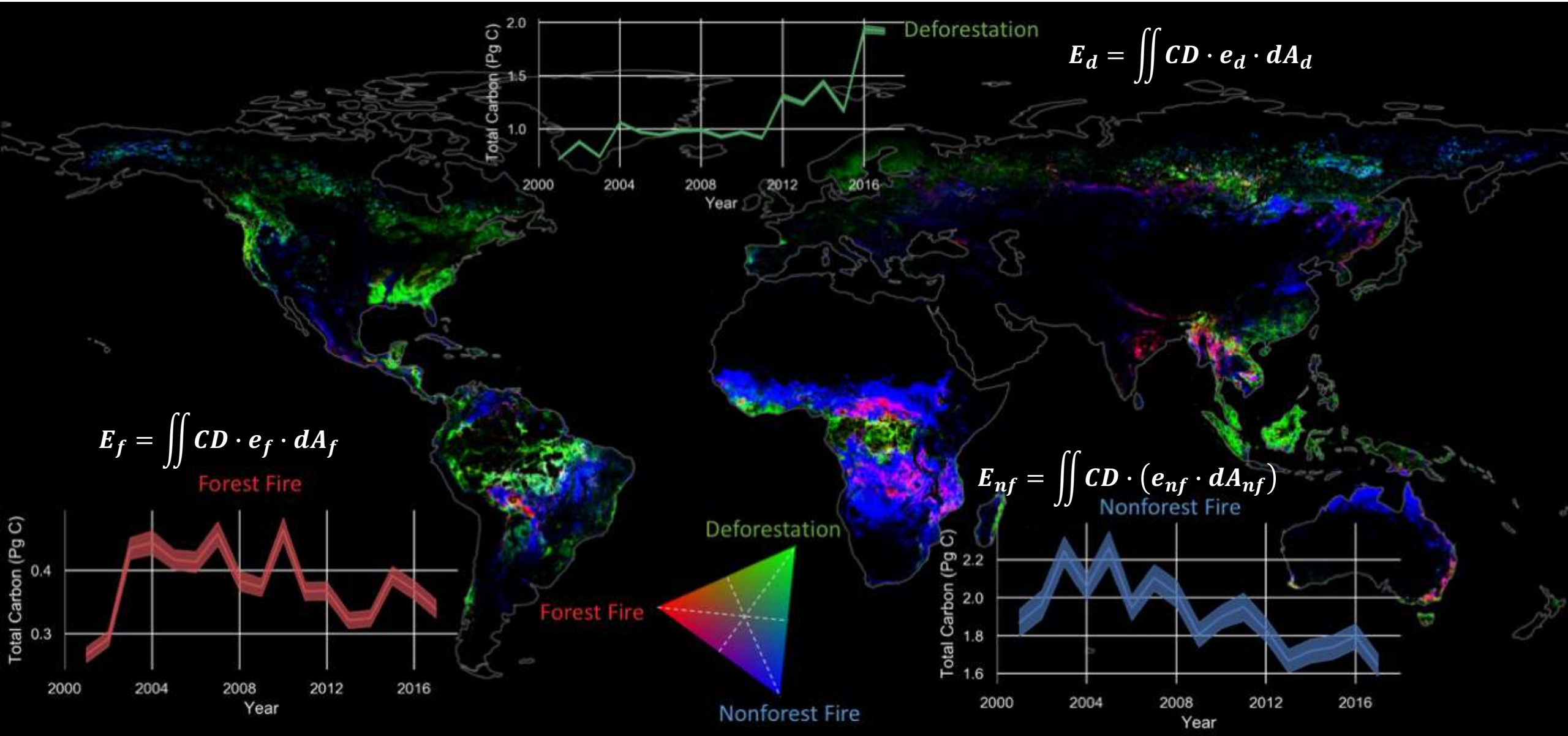




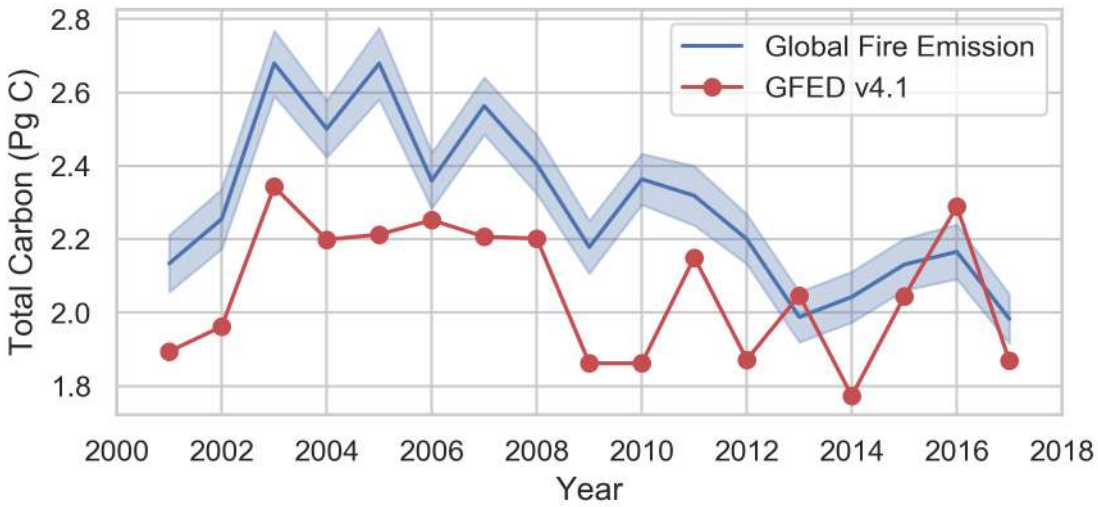
Deforestation in Brazilian Amazon (km²/yr)



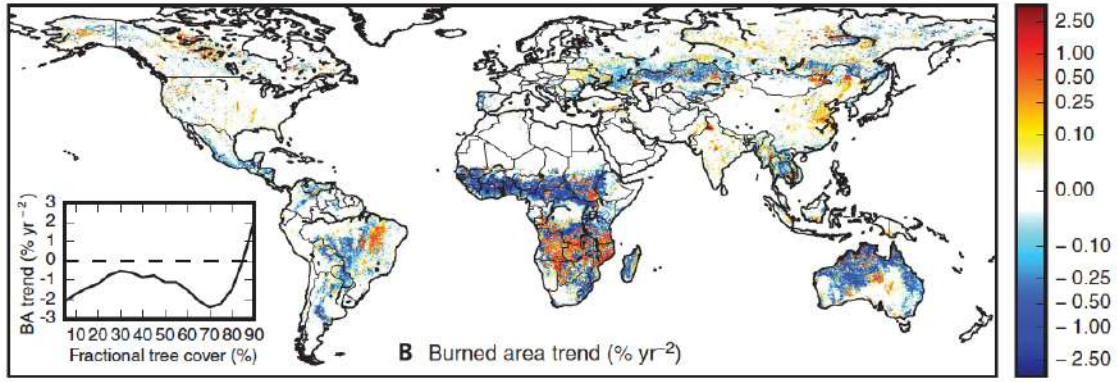
Global Emissions from Fire & Land Use

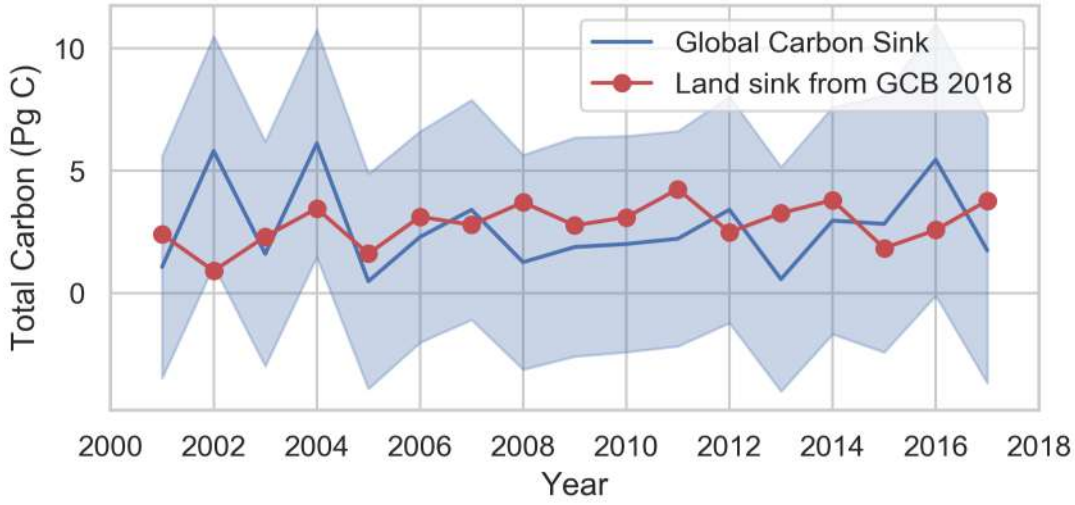


Global Emissions from Fire & Land Use



Mean (2001-2017): 2.29±0.22
GFED Mean (2001-2017): 2.06±0.18

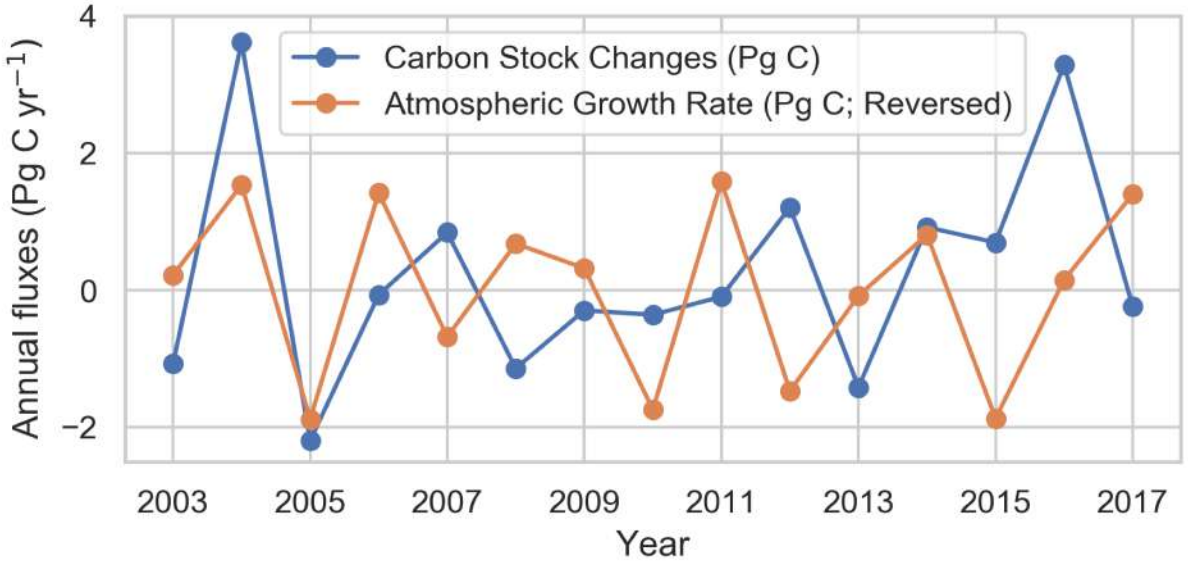




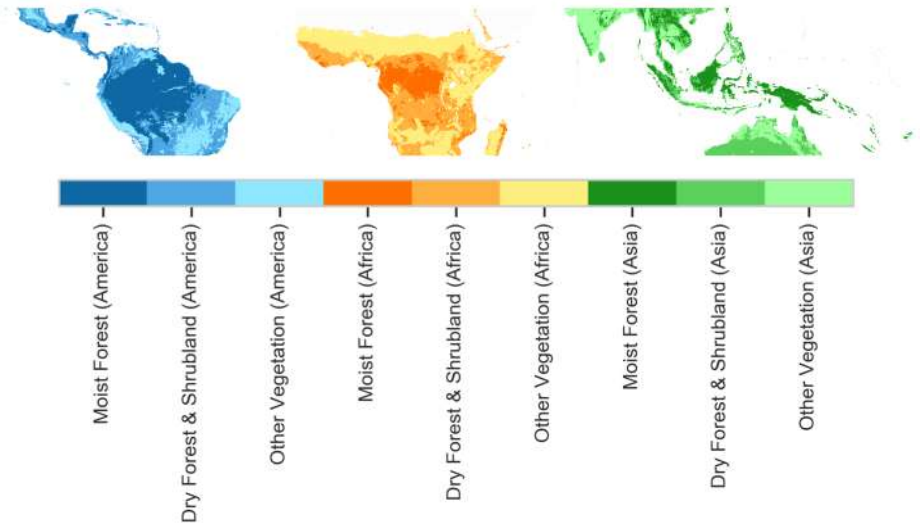
Mean (2001-2017): 2.66±1.73 std
GCB Mean (2001-2017): 2.84±0.87

Tropics Control IAV of Atmospheric Growth Rate

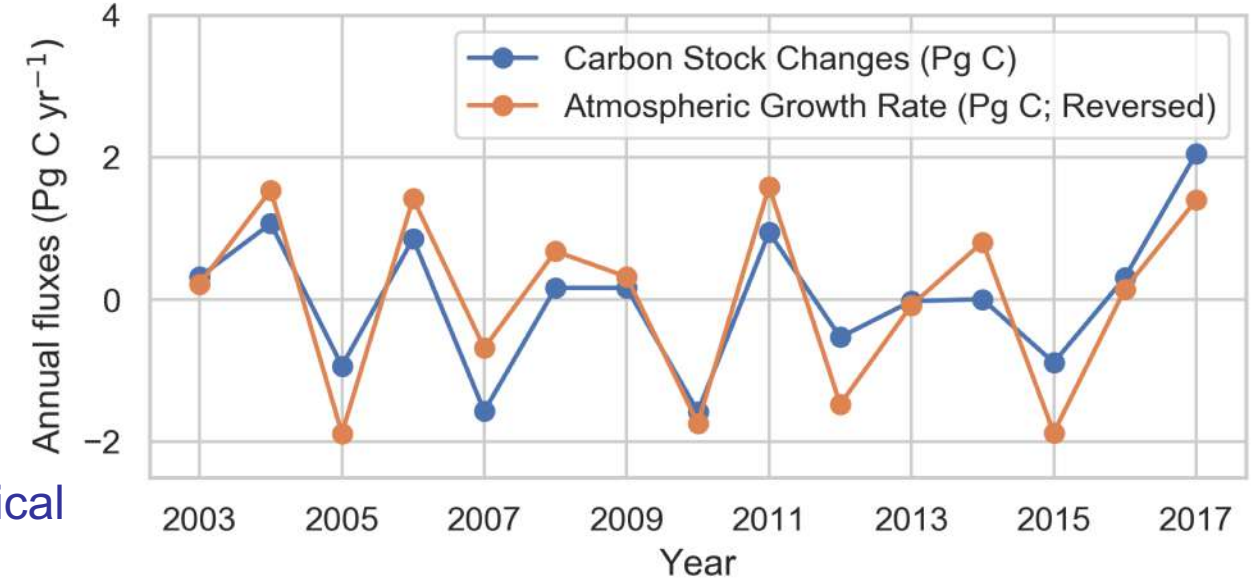
Global

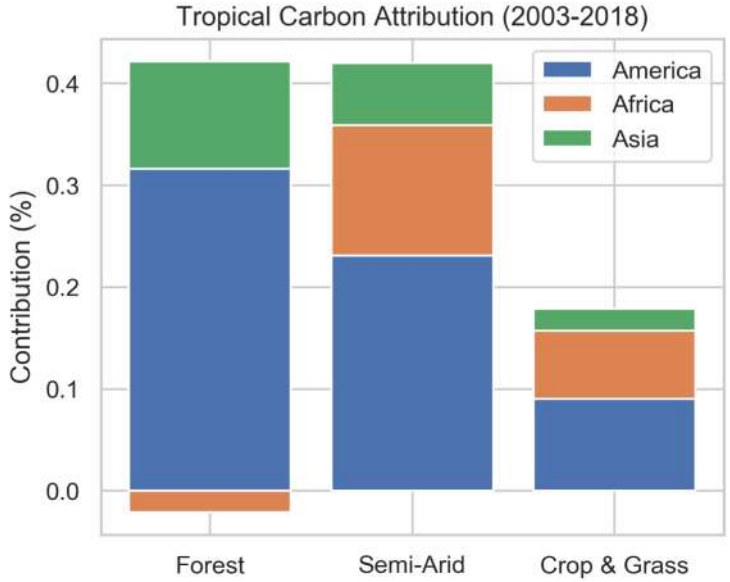


Tropical region (23.5° S – 23.5° N)

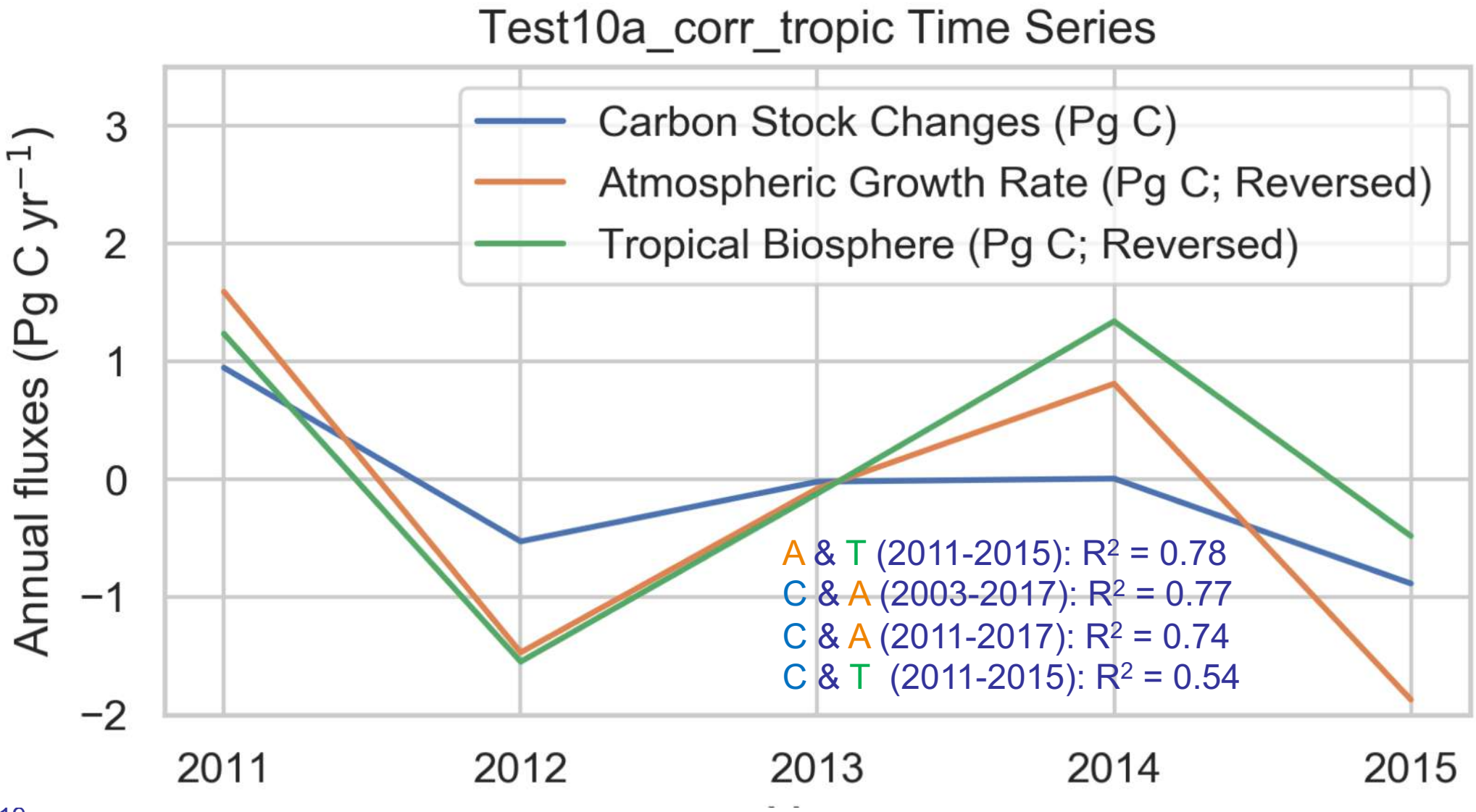


Tropical





Comparison with Top-down Estimates



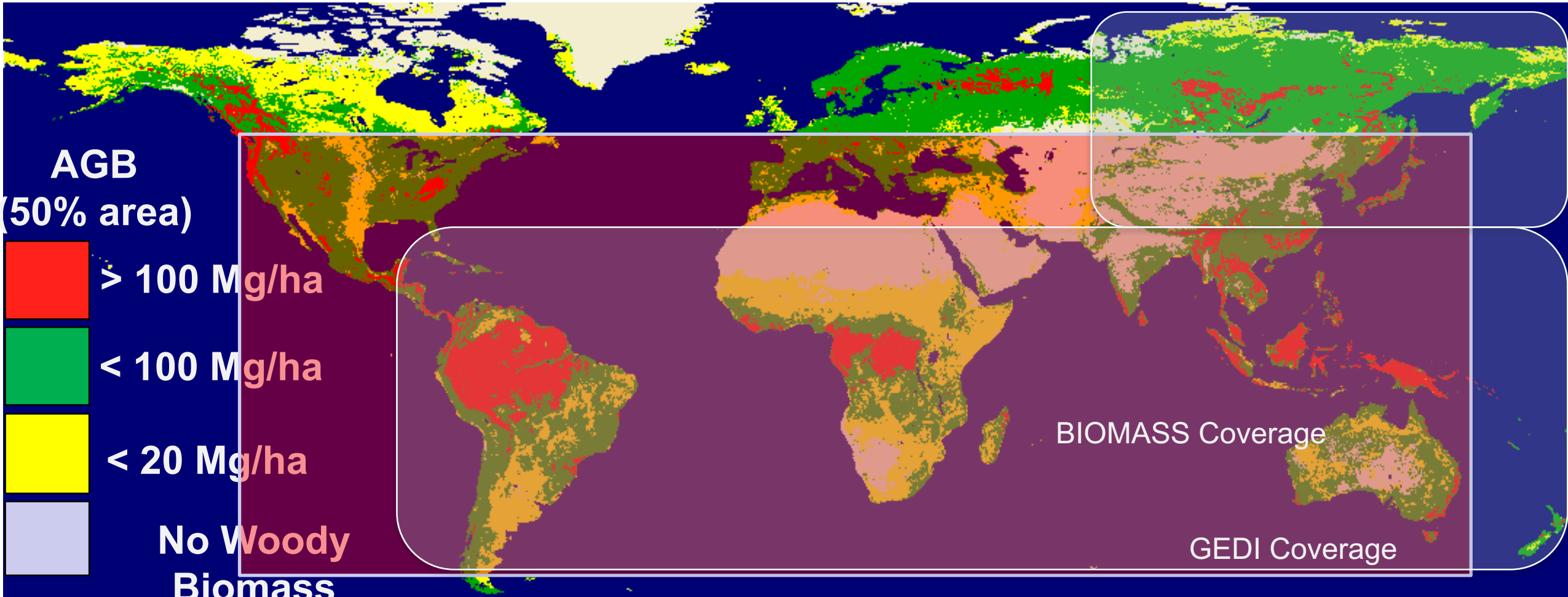
Summary

- 1. **Global Biomass Map** at the scale of disturbance regimes is important for accounting and policy implementations. Products improves over time when regional and national data become rich.

- 2. **Vegetation Carbon sink** is largely concentrated in extra-tropics (management & climate) dominated in areas of low biomass in African woodlands, and temperate and boreal regions. Future missions (e.g. NISAR) will play a significant monitoring role.

- 3. **Global humid tropical forest** biomass has a declining trend from deforestation/degradation, and climate induced effects. BIOMASS mission will allow monitoring the sources and sinks of carbon in tropics

- 4. **Interannual variability** of atmospheric growth rate is largely explained by the carbon fluxes in tropical regions (23.5 N and 23.5 S) dominated by fluxes in moist and dry forests.

Synergistic Forest Observations from Space

- **GEDI**:Sampling between 50 deg North and South, Sensitivity to AGB > 20 Mg/ha
- **NISAR**: Global Coverage, sensitivity to AGB < 100 Mg/ha
- **BIOMASS**: Tropical and East Eurasia Coverage, Sensitivity to AGB > 50 Mg/ha