Monitoring Changes of Global Forest Biomass Carbon: Linking Science to Policy to Market

Sassan Saatchi, Yan Yang, Anthony Bloom, Kevin Bowman

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

4th Carbon from Space
October 2022

Net Atmosphere Increase (S_{Air})
16.9 [12.1,23.1] $GtCO_2e\ yr^{-1}$
(2000-2019)

Xu_etal_2021

Fossil Fuel Emission
(E_{Fuel})

31.9 [25.3, 36.7]

E^B_{Land}
Live Biomass
Emissions

16.9 [13.6, 21.3]

E_{Fire} 9.2 [7.3,10.6]

E_{FC} 6.2 [3.7,11.4]

E_{FD} 1.5 [1.1,1.9]

-23.1 [-30.8, -14.7]

S_{gross}
Gross Land
Sink

-18.0 (**-20.2**) [-33.4, -9.2]

Live Biomass
Removal
S^B_{Land}

Net Ocean Sink
S_{Ocean}

-8.8 [-9.6,-9.6]

E_δ

S_δ

$\delta_{im} = S_\delta - E_\delta$

-5.1 (**-2.9**) (-13.9, 13.6)
Budget Imbalance

Net Atmosphere Increase (S_{Air})
16.9 [12.1,23.1] $GtCO_2e\ yr^{-1}$
(2000-2019)

Xu_etal_2021

Fossil Fuel Emission
(E_{Fuel})

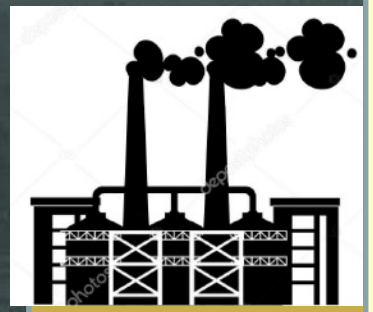
31.9 [25.3, 36.7]

E^B_{Land}
Live Biomass

-23.1 [-30.8, -14.7]

Ocean Sink
S_{Ocean}

-8.8 [-9.6, -9.6]



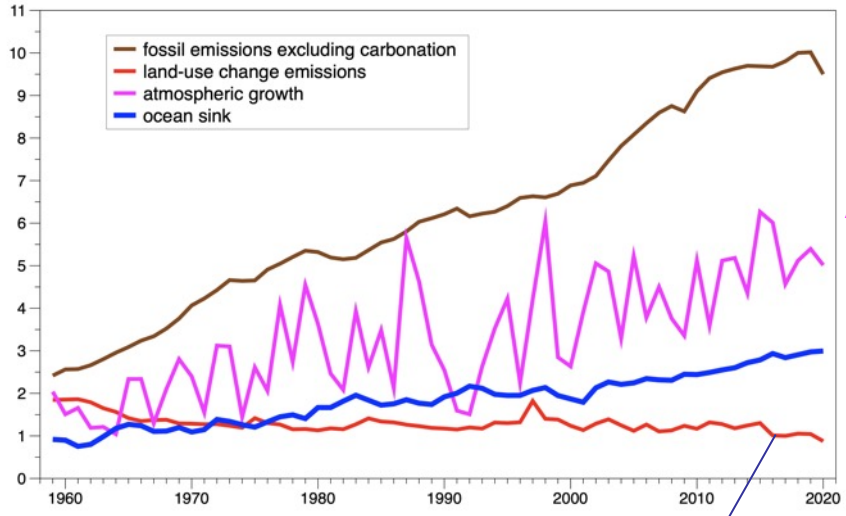
Net Contribution of Forests from Stock Change Approach:

Xu et al 2021: -0.32 $GtCO_2e\ yr^{-1}$ (2010-2019)

Tubiello et al. 2021: -0.2 $GtCO_2e\ yr^{-1}$ (2011-2020)

$\delta_{im} = S_\delta - E_\delta$
-5.1 (**-2.9**) (-13.9, 13.6)
Budget Imbalance

Science & Policy Problems

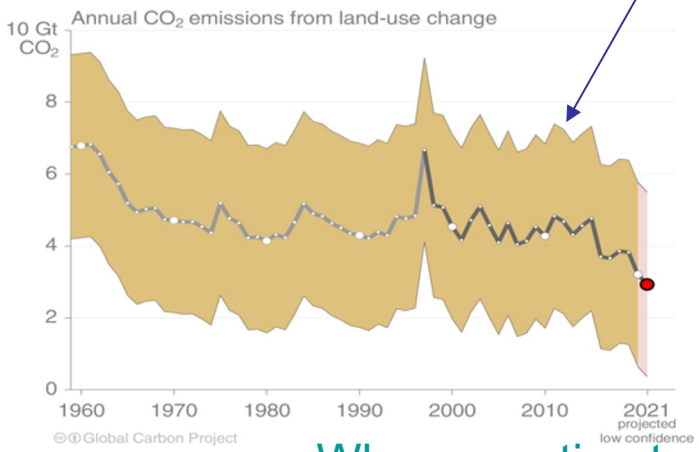


Fossil Fuel Emission (E_{FF})

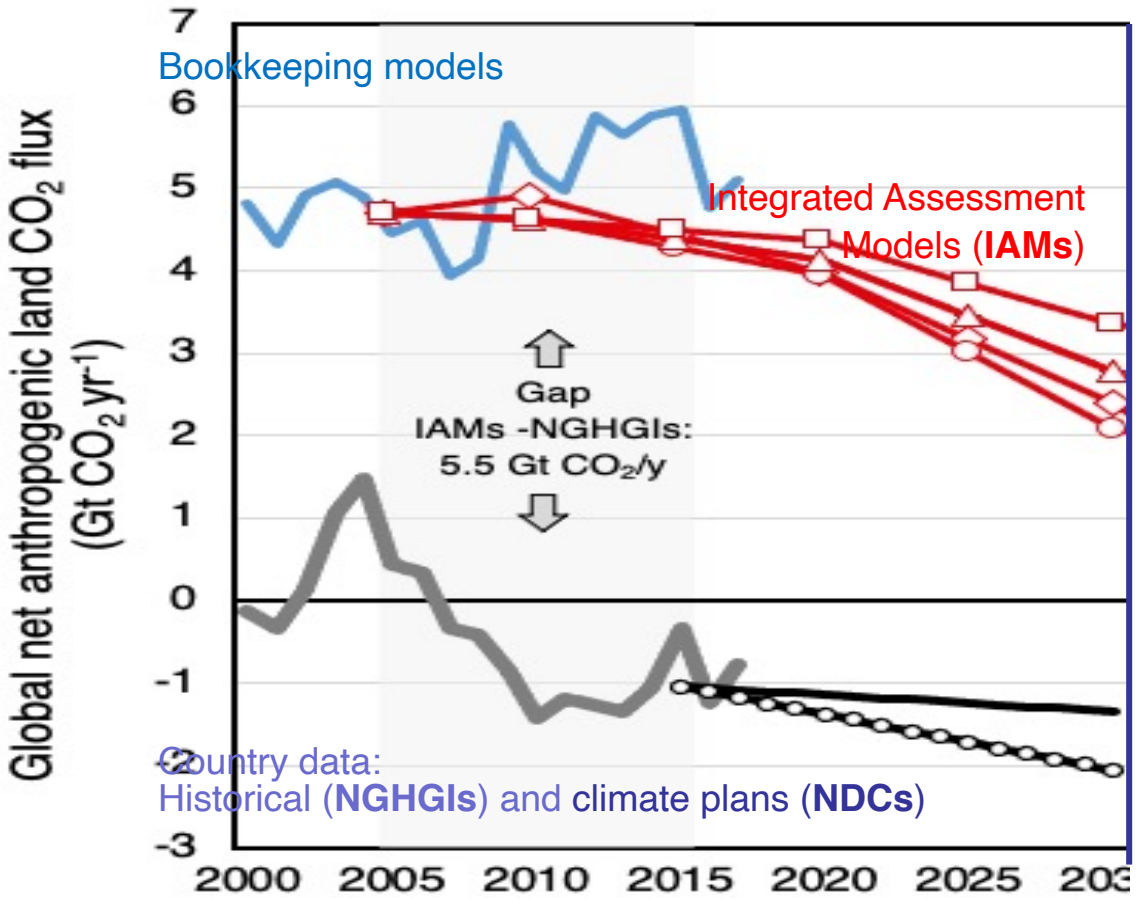
Atmospheric Growth Rate (G_{ATM})

Net Ocean Sink (S_{OCEAN})

Net Land Use Emission (E_{LUC})

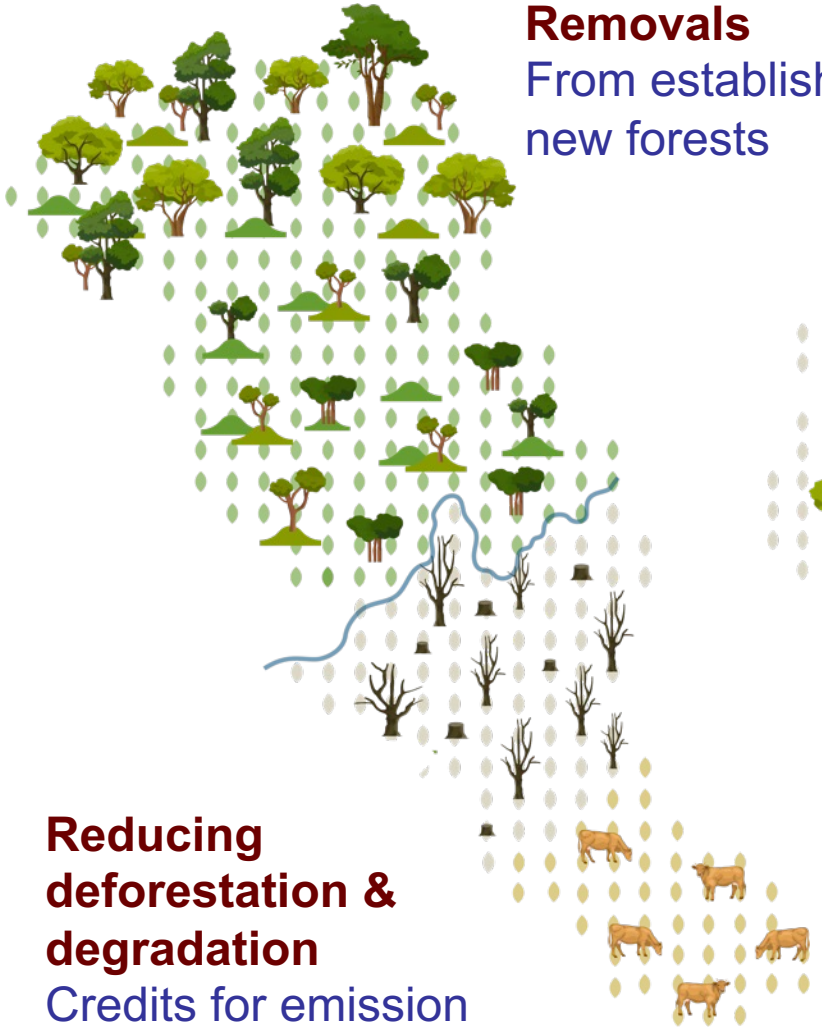


Grassi_etal_2021

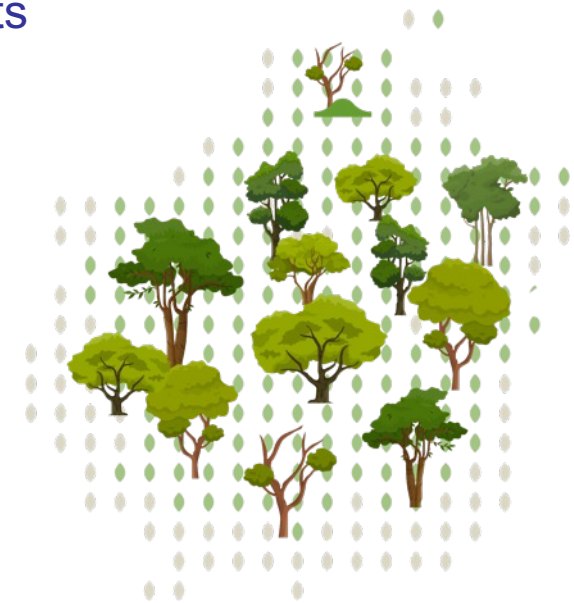


- Why are estimates of CO2 'removals' so important?
- Does the relocation of fluxes change our understanding of the global carbon budget?

Carbon Market & Climate Finance Problems



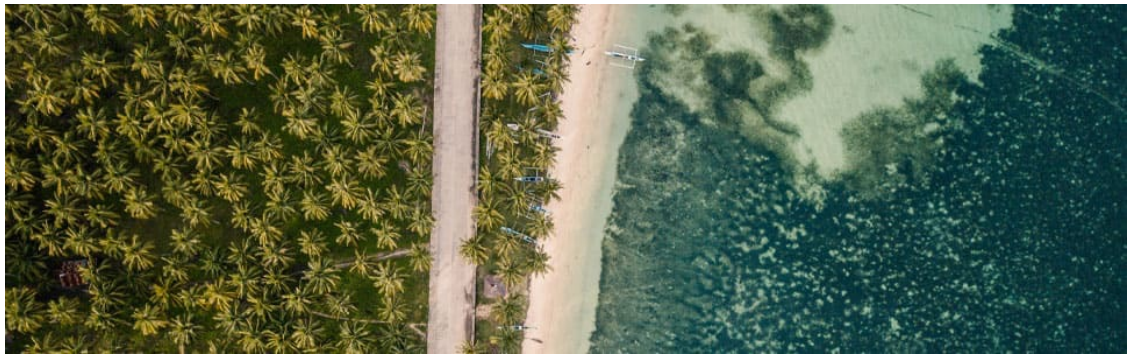
Removals
From establishment of new forests



HFLD
Credits for emission reductions in high forest and low deforestation

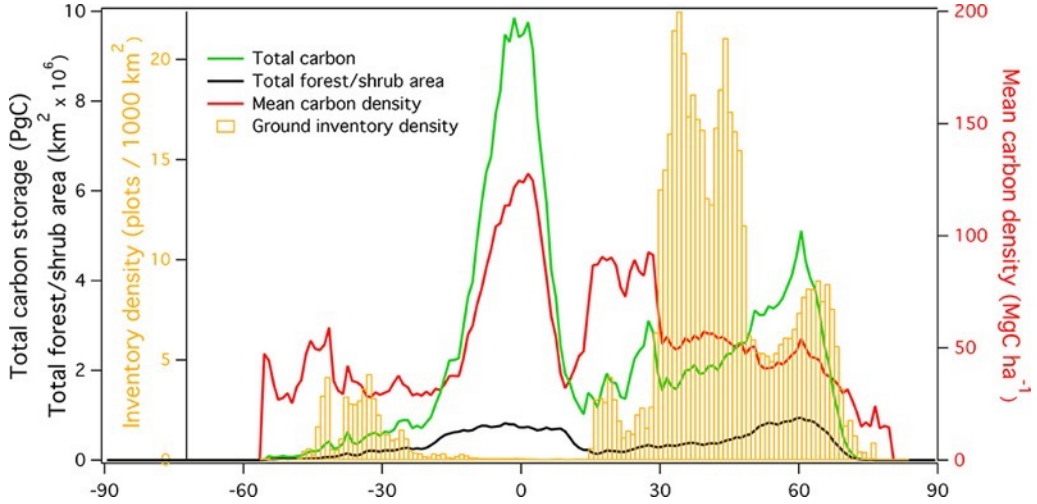
Reducing deforestation & degradation
Credits for emission reductions

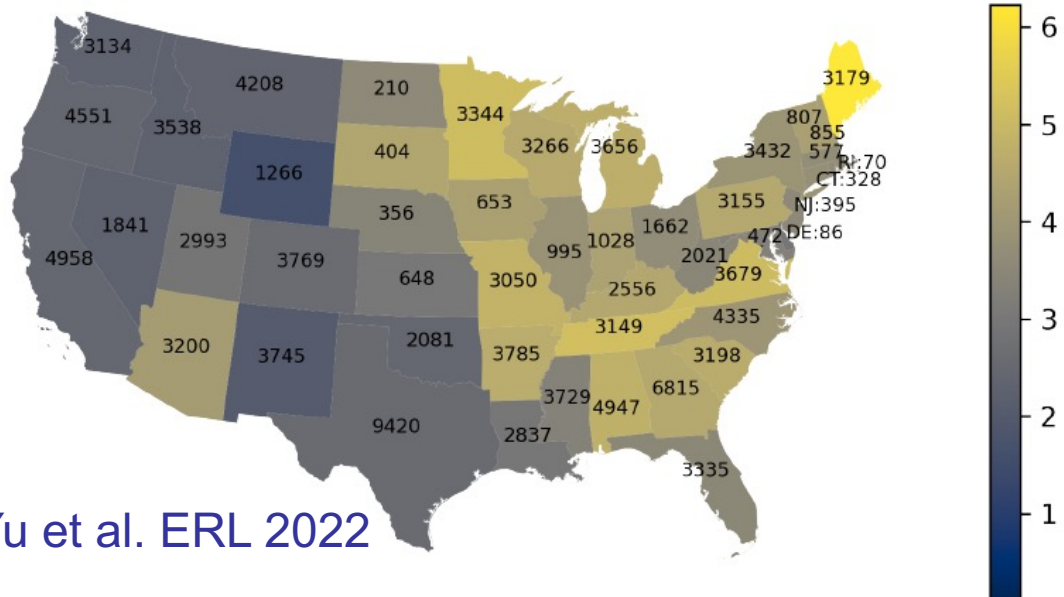
Unholy Trinity +
additionality
permanence
leakage
uncertainty



Data Needs for Estimates of Emissions and Removals

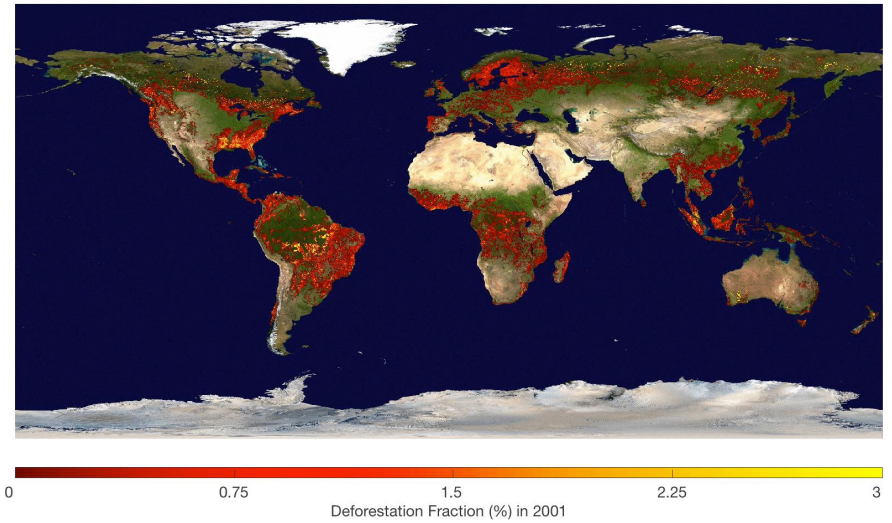
Forest Inventory Data

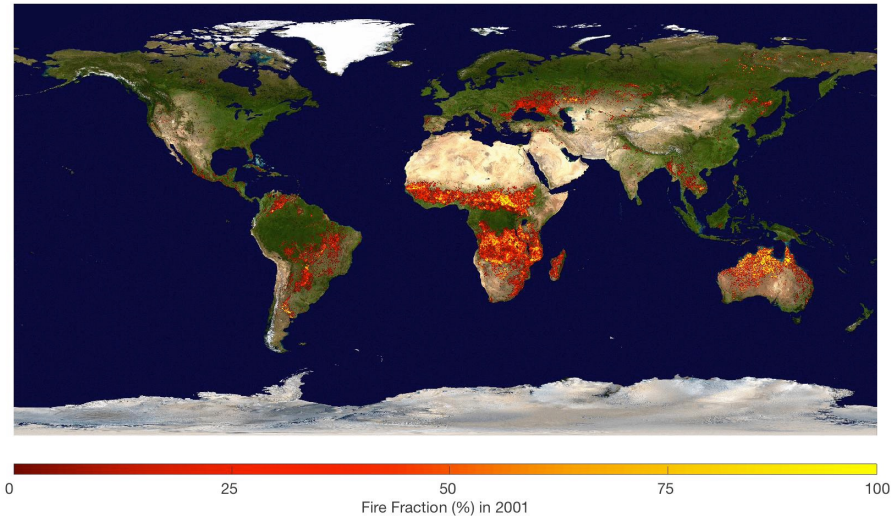




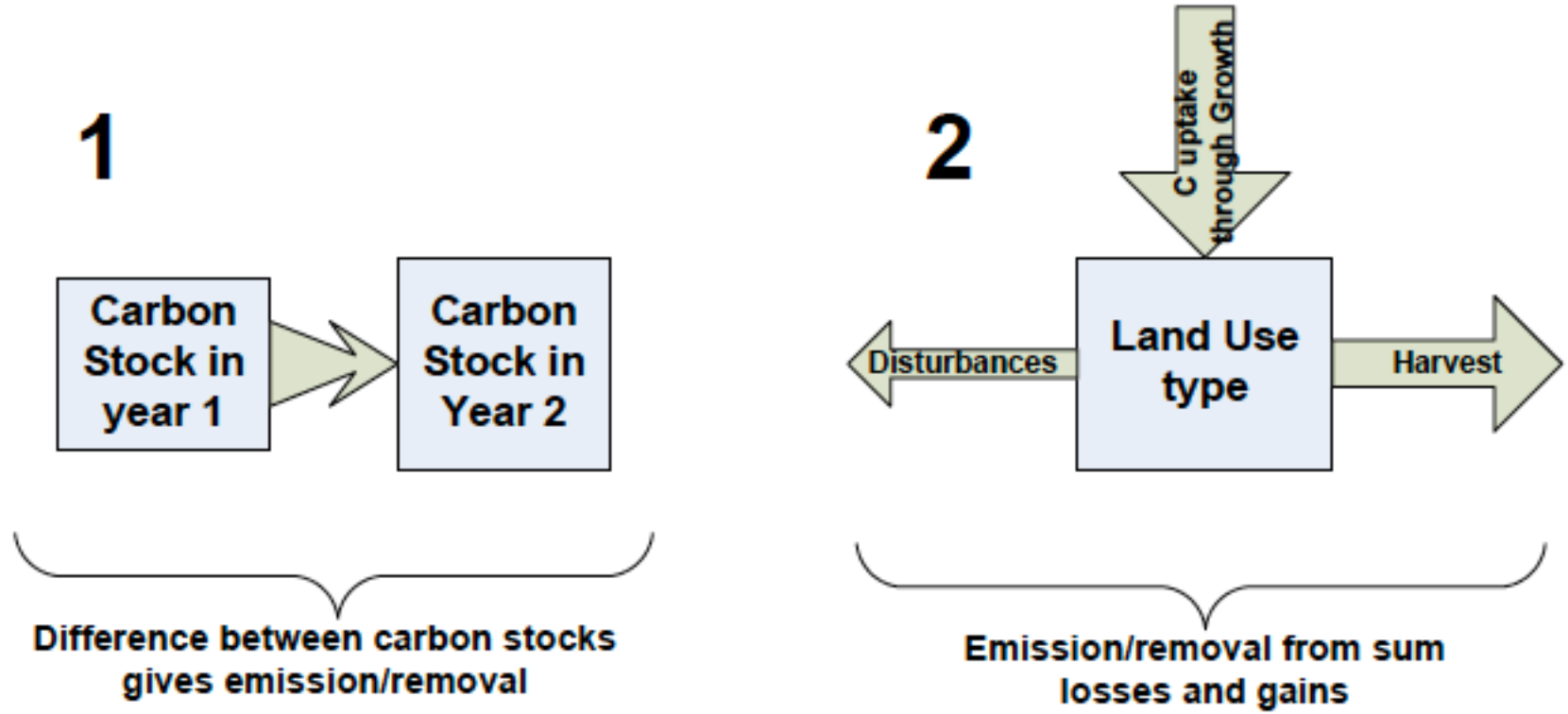
Yu et al. ERL 2022

Activity Data





IPCC Guidelines



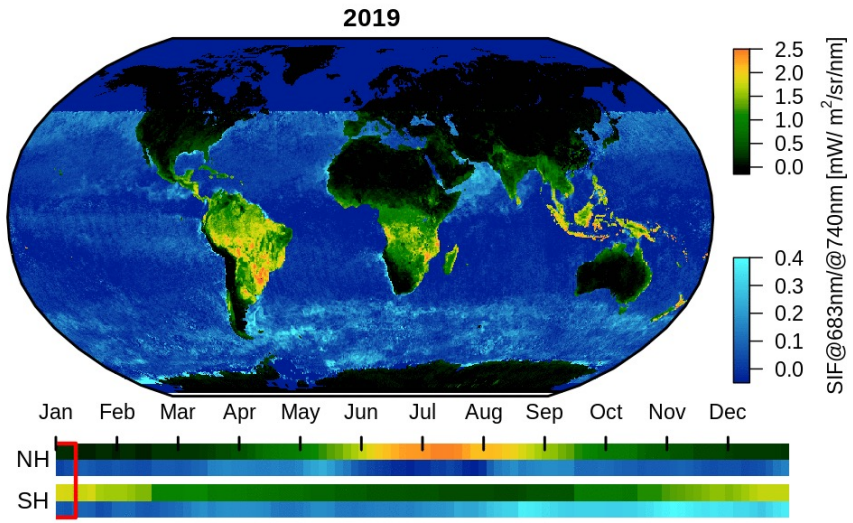
(a) Stock change method

(b) Gain loss method

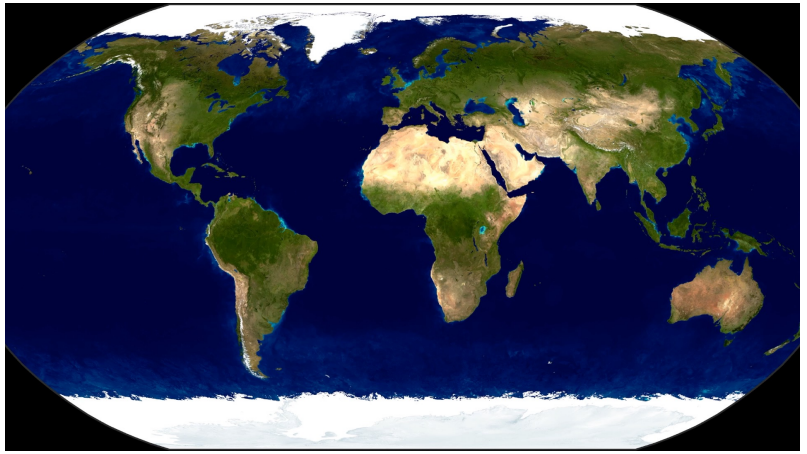
Xu et al. 2021

Harris et al. 2021

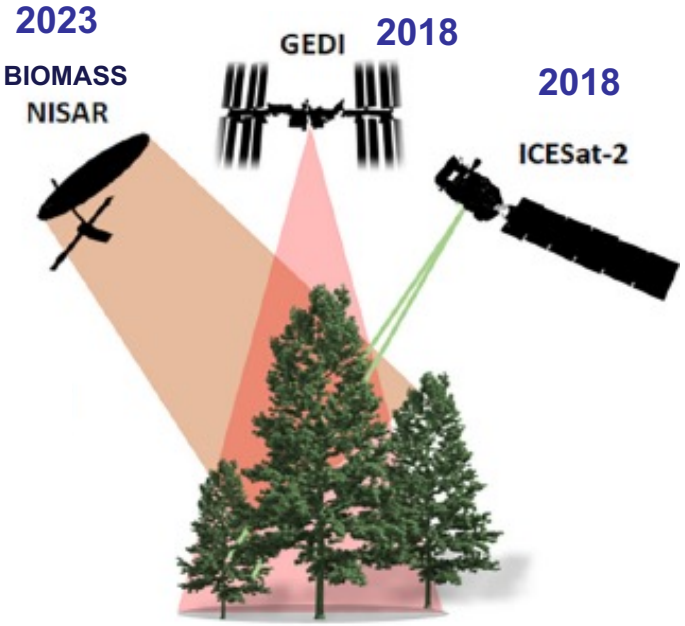
New Observations of Carbon Stocks and Dynamics



History or Evolution of SIF Measurement
Koehler et al (TROPOMI)

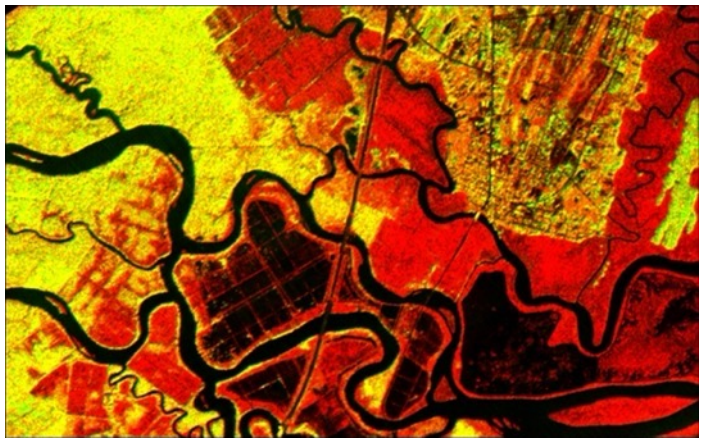


"Bowman et al. 2017: CMS-Flux, courtesy Eastham (MIT)"



10/27/22 VIIRS Fire

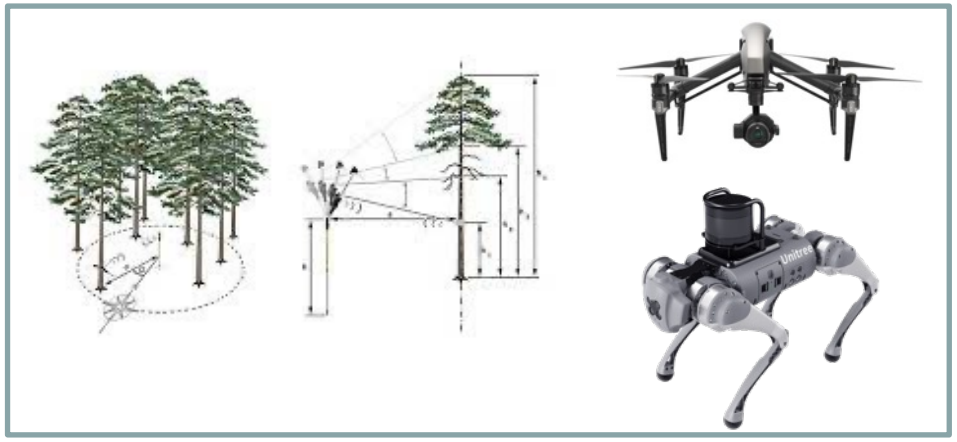
PlanetScope



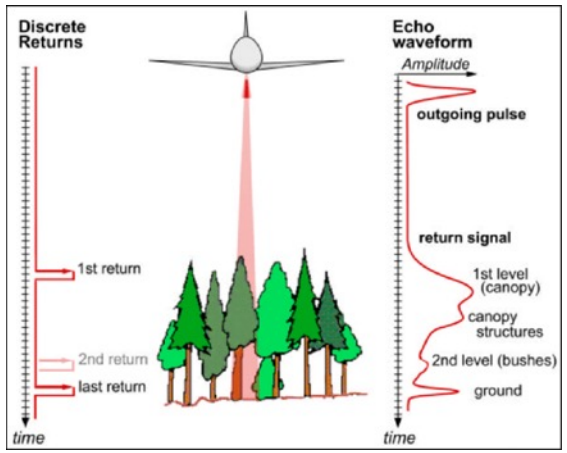
SAR Sentinel-1 Imagery

Bottom-up Methodology
Carbon Stocks Variations & Emission Factors

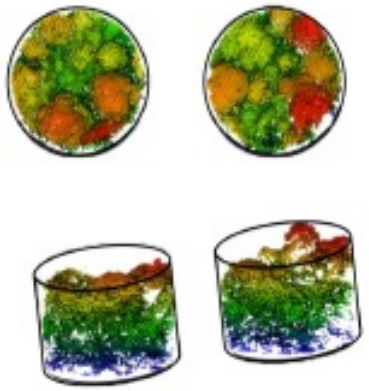
Ground Forest Inventory

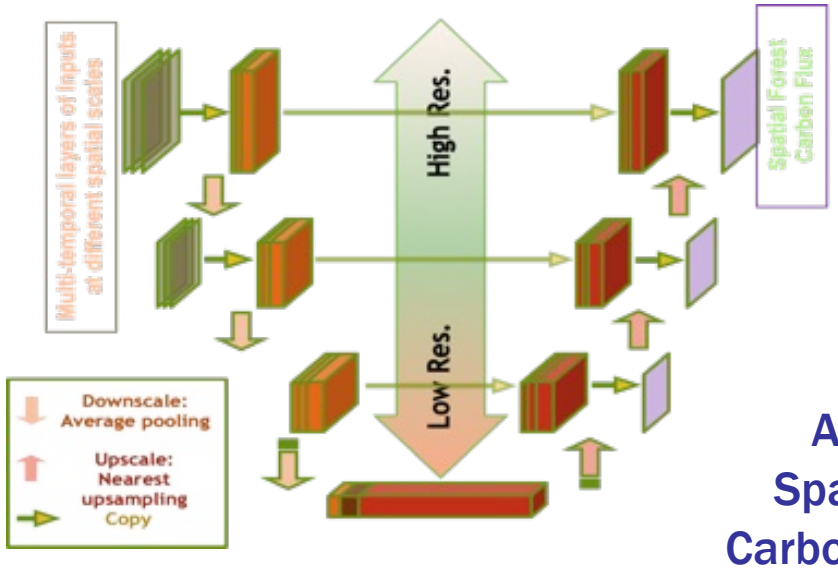


Airborne Forest Inventory

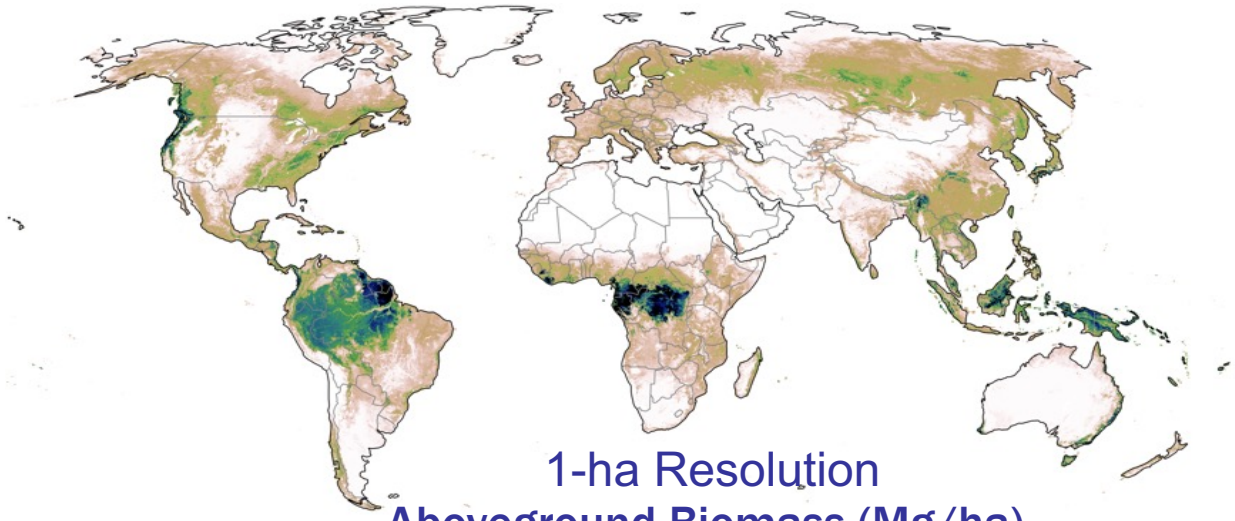


Spaceborne Forest Inventory





AI-enabled Spatial Forest Carbon Estimation



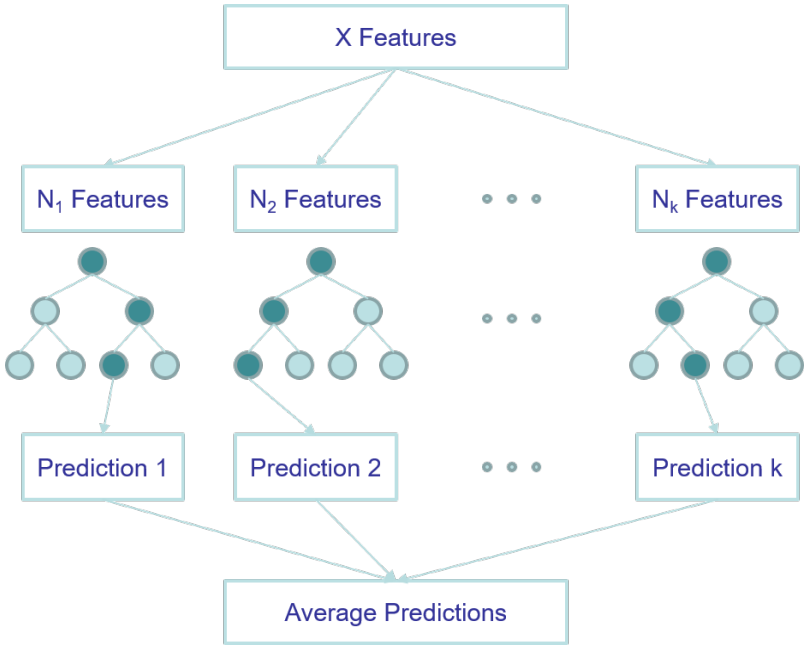
1-ha Resolution
Aboveground Biomass (Mg/ha)

0 50 100 150 200 250 300

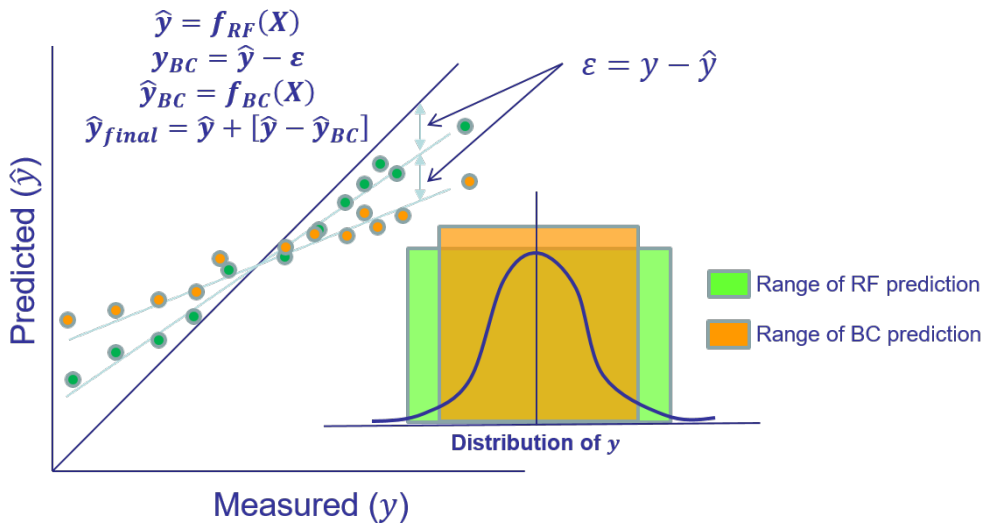
Bottom-up Methodology
Estimates, Validation, Uncertainty

AGU 2019

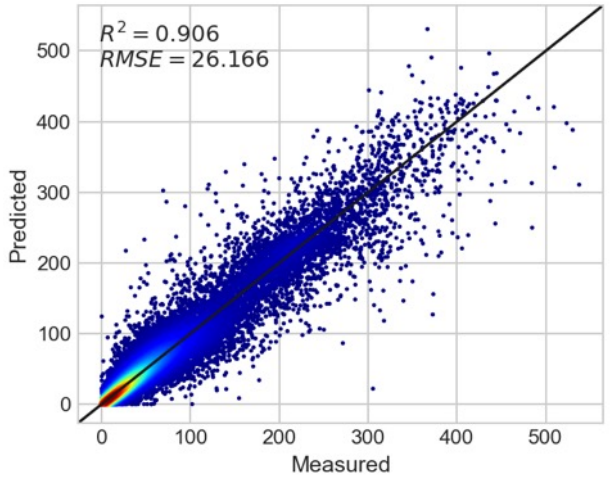
Random Forest Regression



Bias Correction



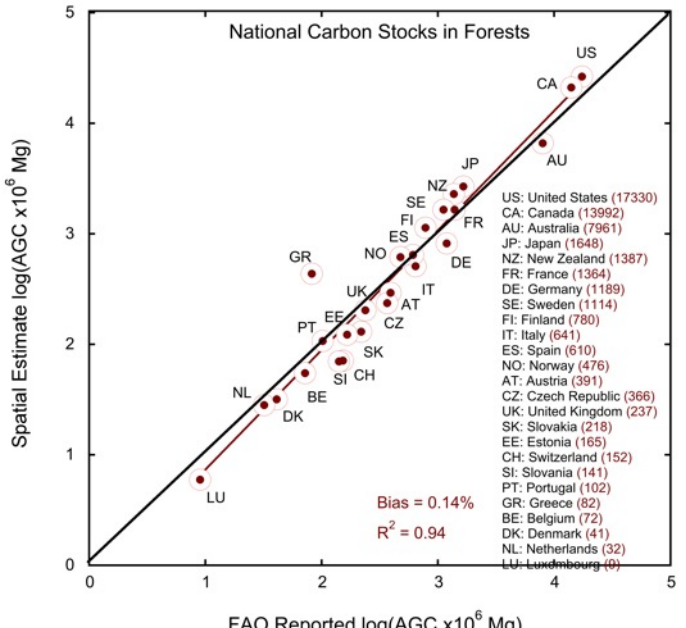
CV results (global)



Regional Uncertainty Estimation

$$\widehat{\mathrm{MSE}}(\hat{\mu}) = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{k=1}^{N}\widehat{\mathrm{Cov}}(\sigma_{\varepsilon,i}, \sigma_{\varepsilon,j}) + \frac{1}{N^2}\sum_{i=1}^{N}\sum_{k=1}^{N}\widehat{\mathrm{Cov}}(\sigma_{\mu,i}, \sigma_{\mu,j})$$

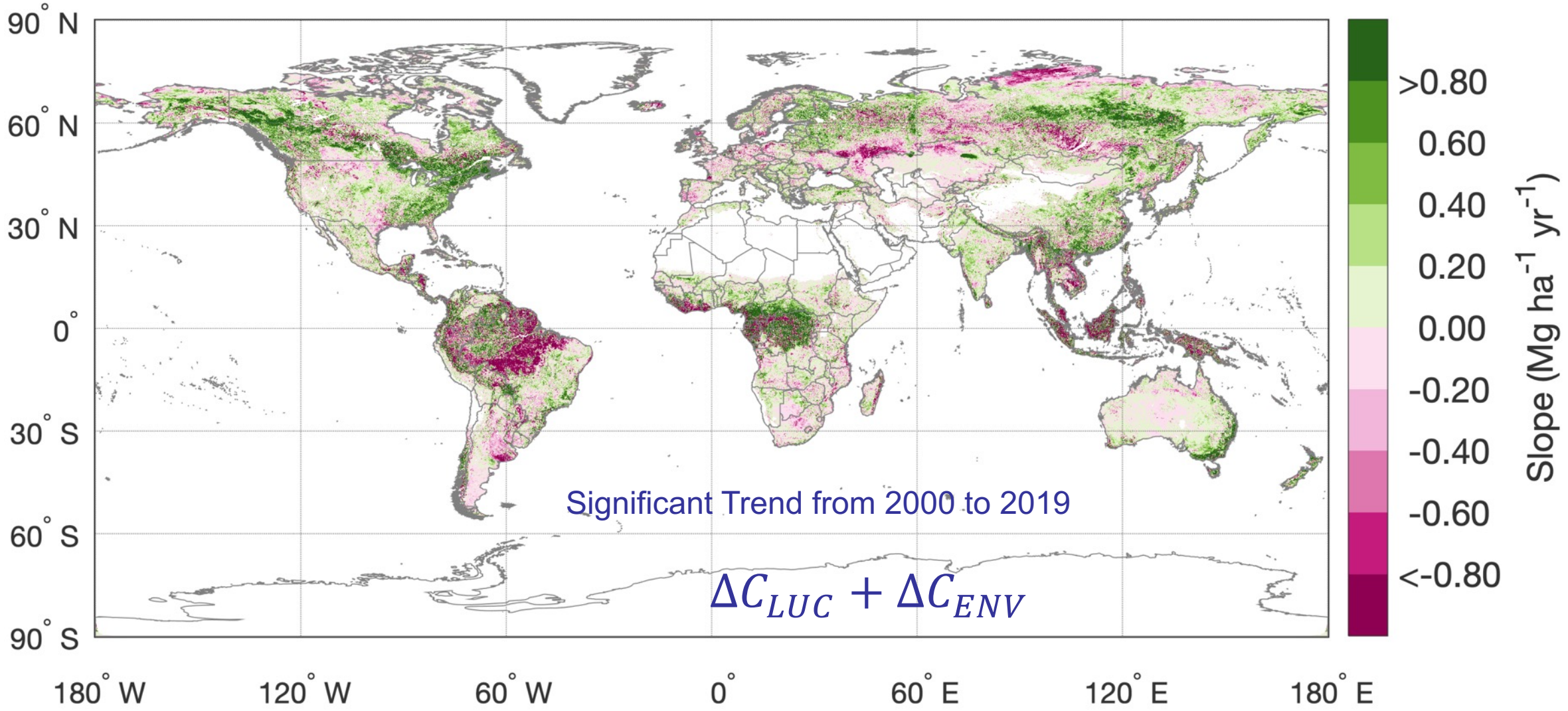
$$= \frac{1}{N}\sum_{i=1}^{N}\widehat{\mathrm{Var}}(\sigma_{\varepsilon}) + \frac{1}{N^2}\sum_{i \neq k}^{N}\sum_{k}^{N}\widehat{\mathrm{Cov}}(\sigma_{\varepsilon,i}, \sigma_{\varepsilon,j}) + \frac{1}{N^2}\sum_{i=1}^{N}\sum_{k=1}^{N}\widehat{\mathrm{Cov}}(\sigma_{\mu,i}, \sigma_{\mu,j})$$



Sources of Uncertainty considered (Chen et al 2016):

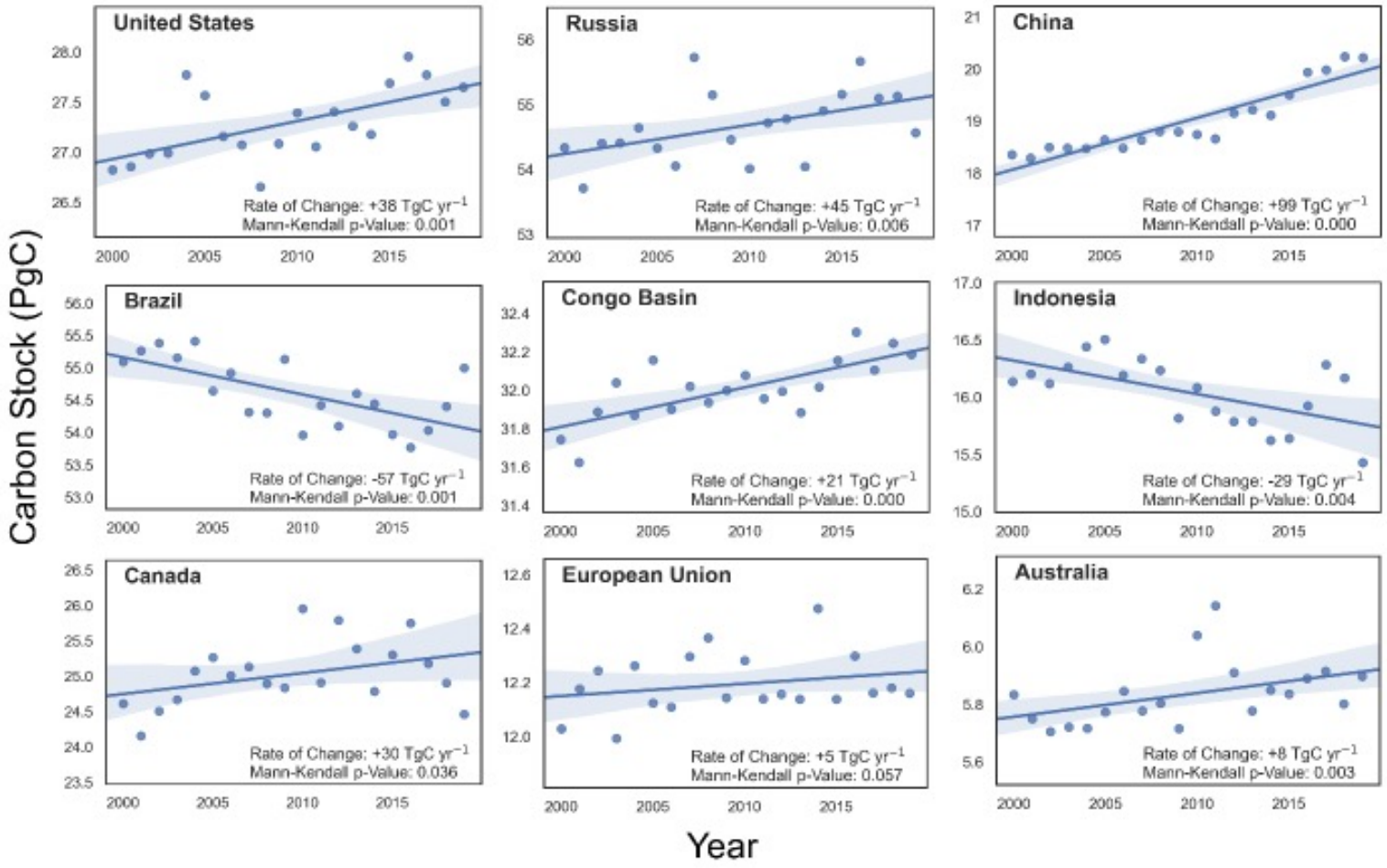
- Pixel modeling error
- Residual covariance due to spatial autocorrelation
- Model parameter error due to sampling variability

Where are gains and losses of biomass located?

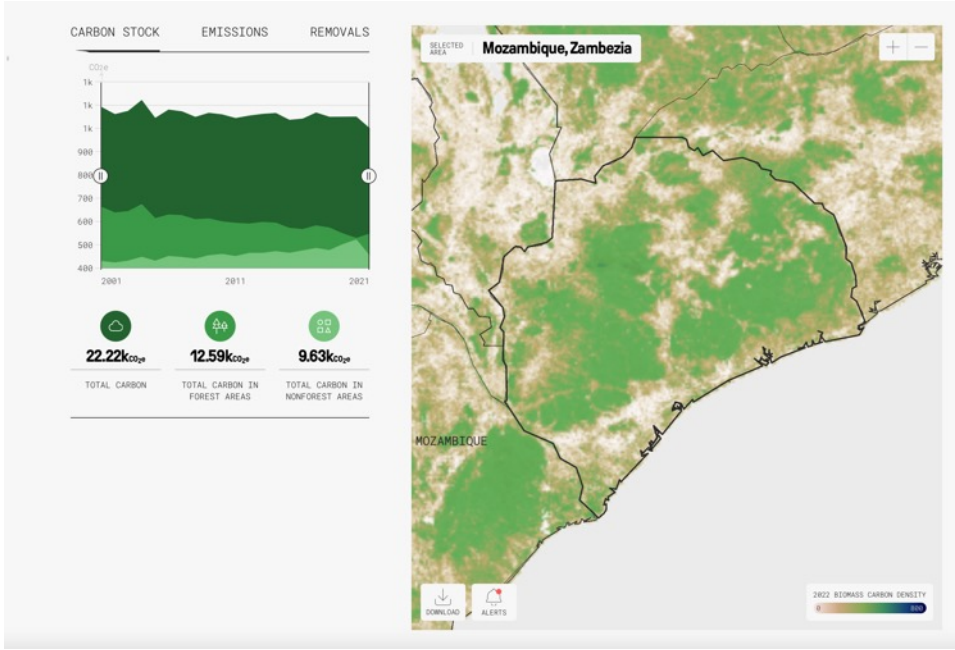


Xu et al., 2021

National Carbon Stock Changes

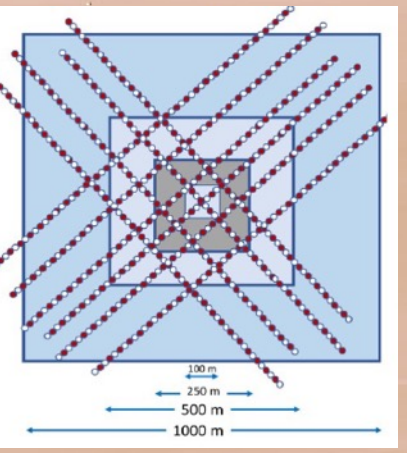


MRV Platform



ICESAT-2 & GEDI

ti-scale Deep-learning

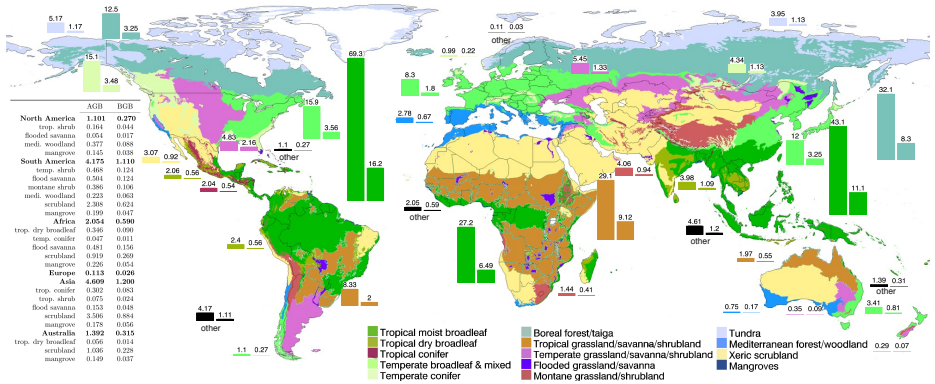


AGB (Mg/ha)

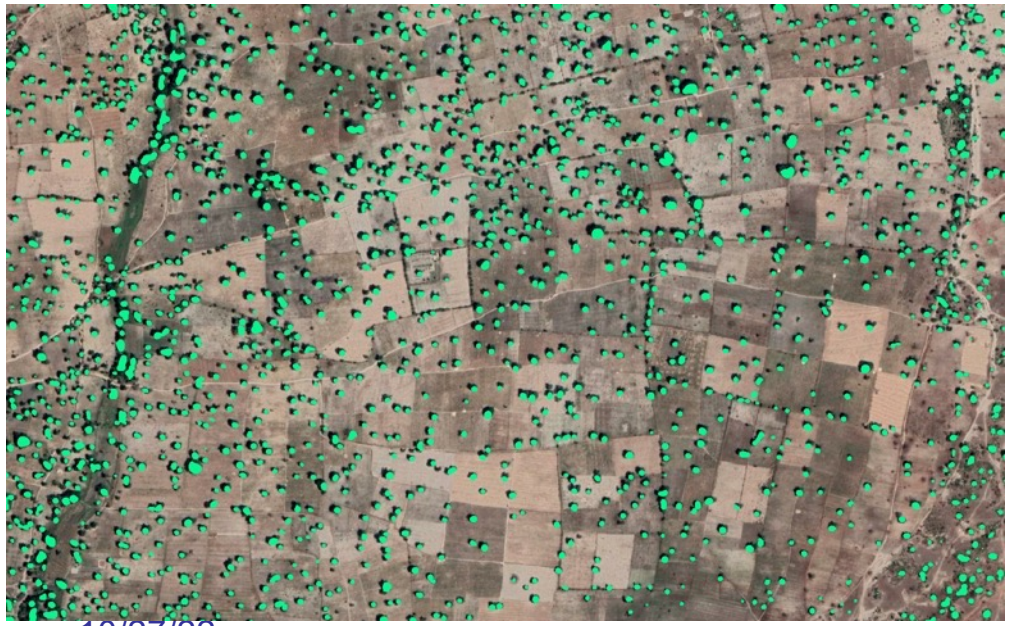
0 100 200 300 400

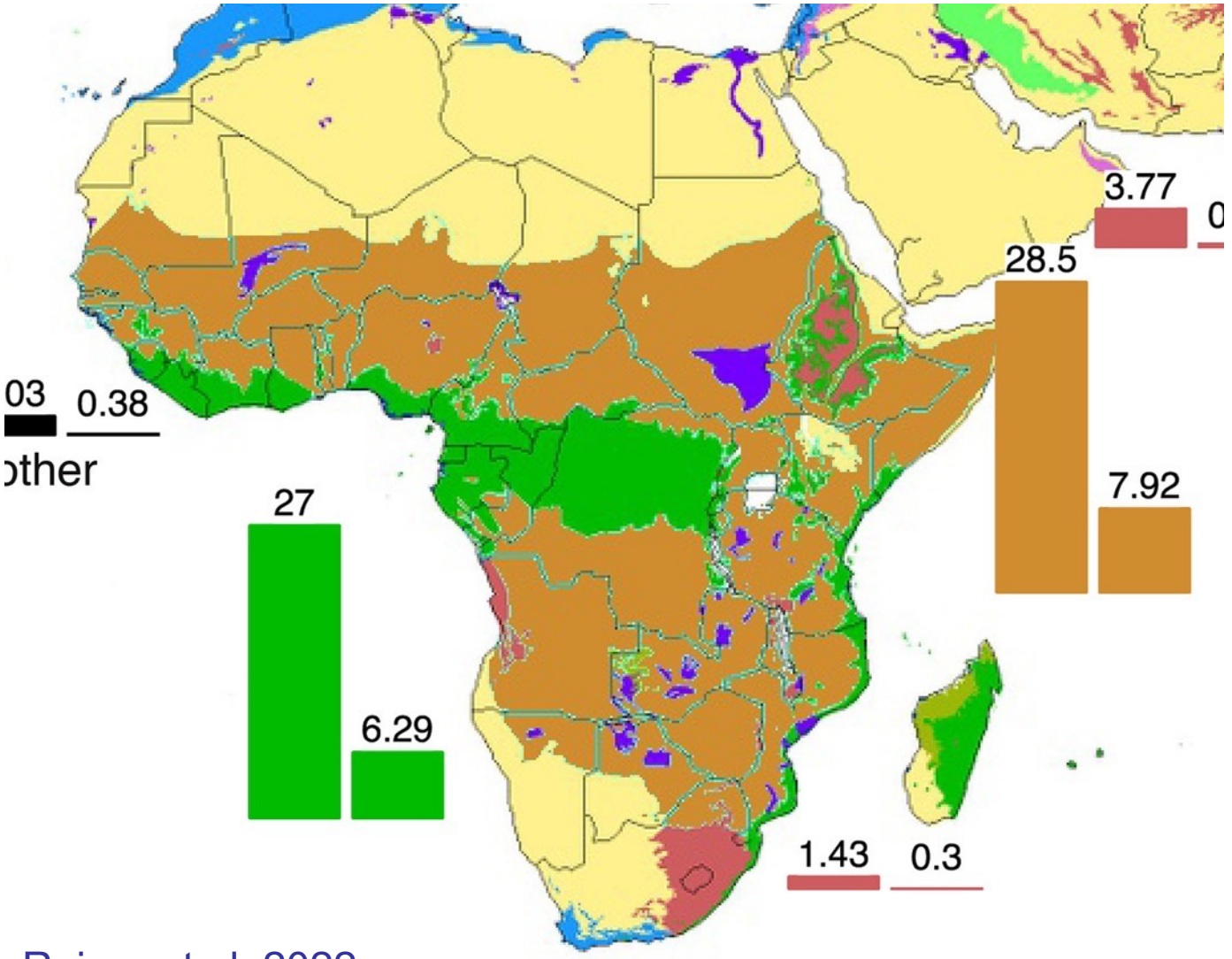
100 m resolution

Trees outside Forest



Trees outside forest





Reiner et al. 2022

Conclusions

Live biomass fluxes: Live Biomass stock changes are small but explains more than 70-80% of global terrestrial sinks and sources

Trees outside forests: Trees outside forests contribute significantly to emissions and removals (~50% of stocks, 80% of fluxes in Africa)

Carbon change from space: Absolute value of carbon stocks requires inventory for model development and bias removals. What about carbon stock change?