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New Tools for Estimating Emissions from Land Use Activities

Tracking carbon between land and atmosphere

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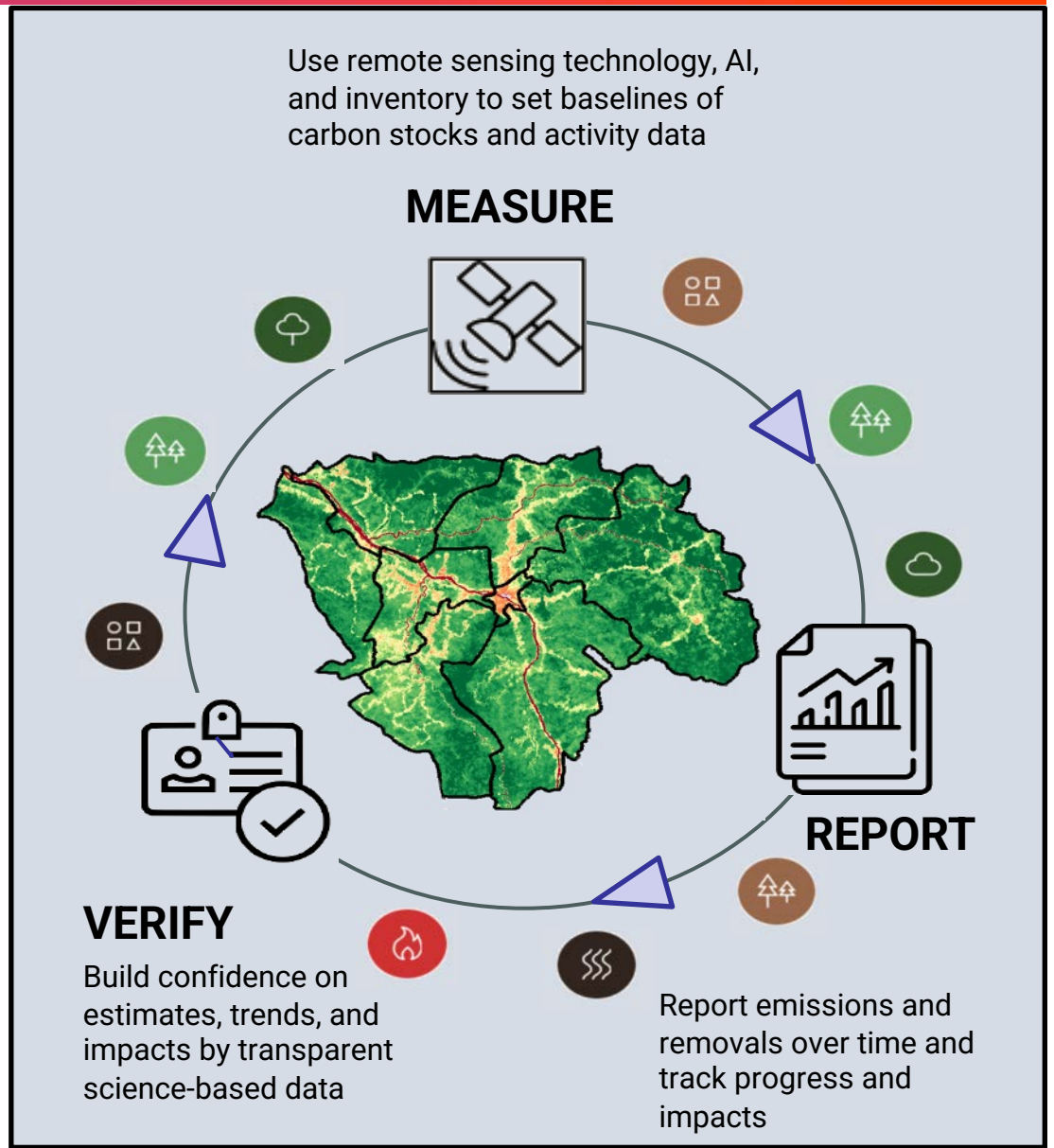
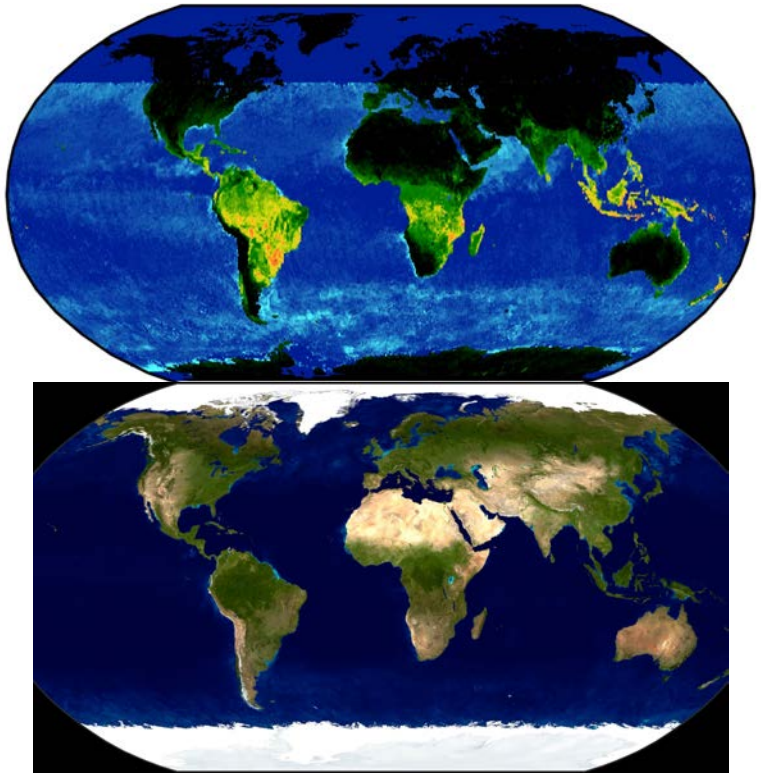
Outline

- Advances in remote sensing-based forest carbon monitoring
- Methodology & products to meet LULUCF reporting requirements
- Uncertainty & challenges
- Steps towards integrating RS techniques in global stocktake



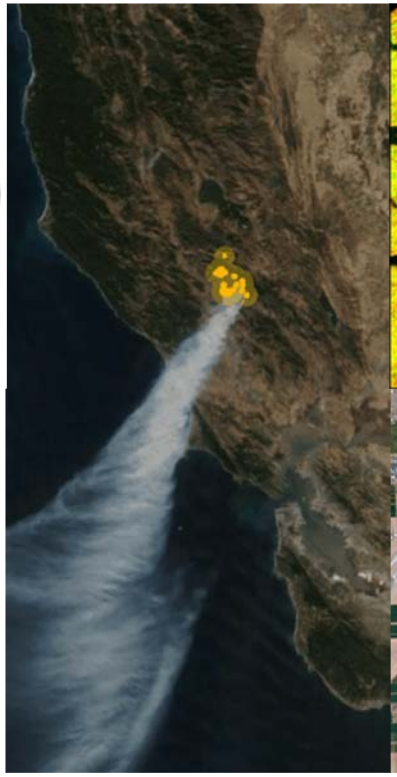
New observations of carbon stocks and dynamics

SIF Measurement (TROPOMI)

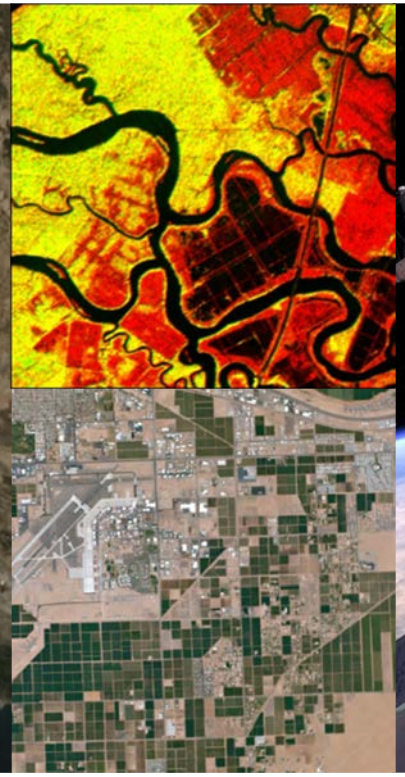


NASA OCO-2 Observations

VIIRS Fire



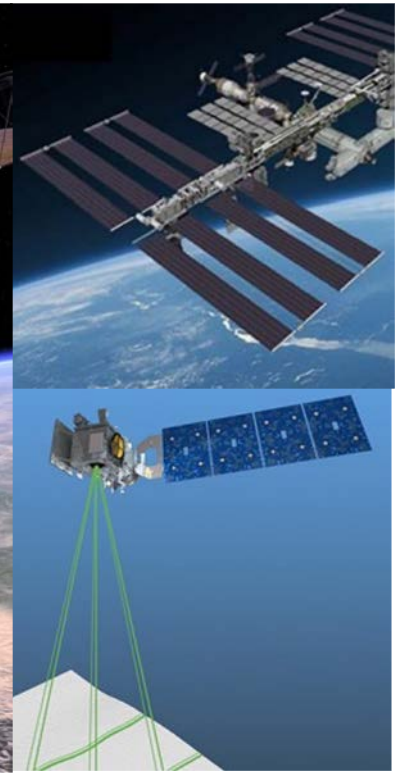
SAR Sentinel-1



PlanetScope

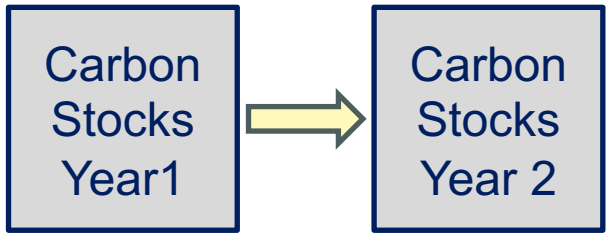
Biomass & NISAR 2024

GEDI 2018



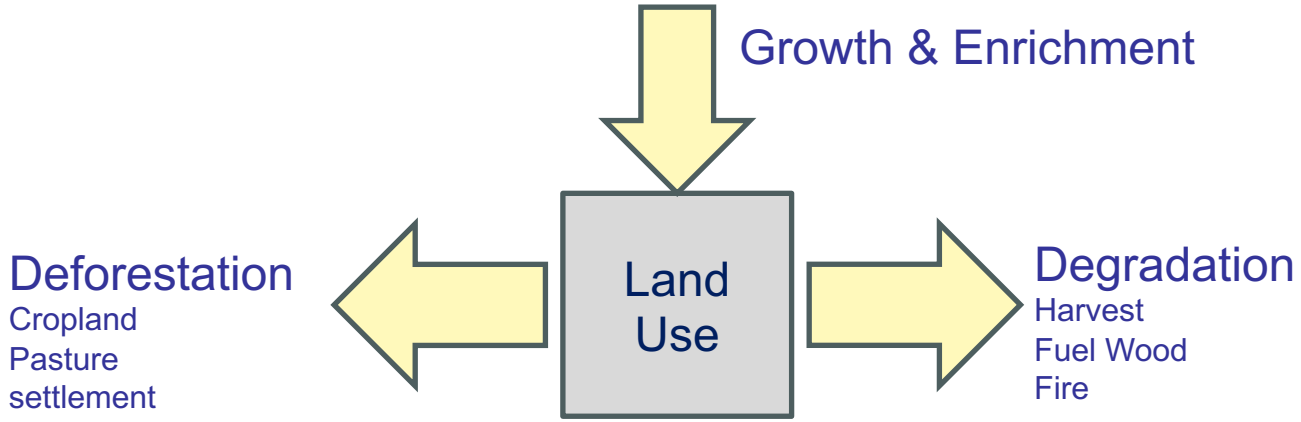
ICESat-2 2018

Methodology for Reporting LULUCF Emissions



$$\Delta C = (C_{t2} - C_{t1})/(\mathrm{t2} - \mathrm{t1})$$

Stock Change Method

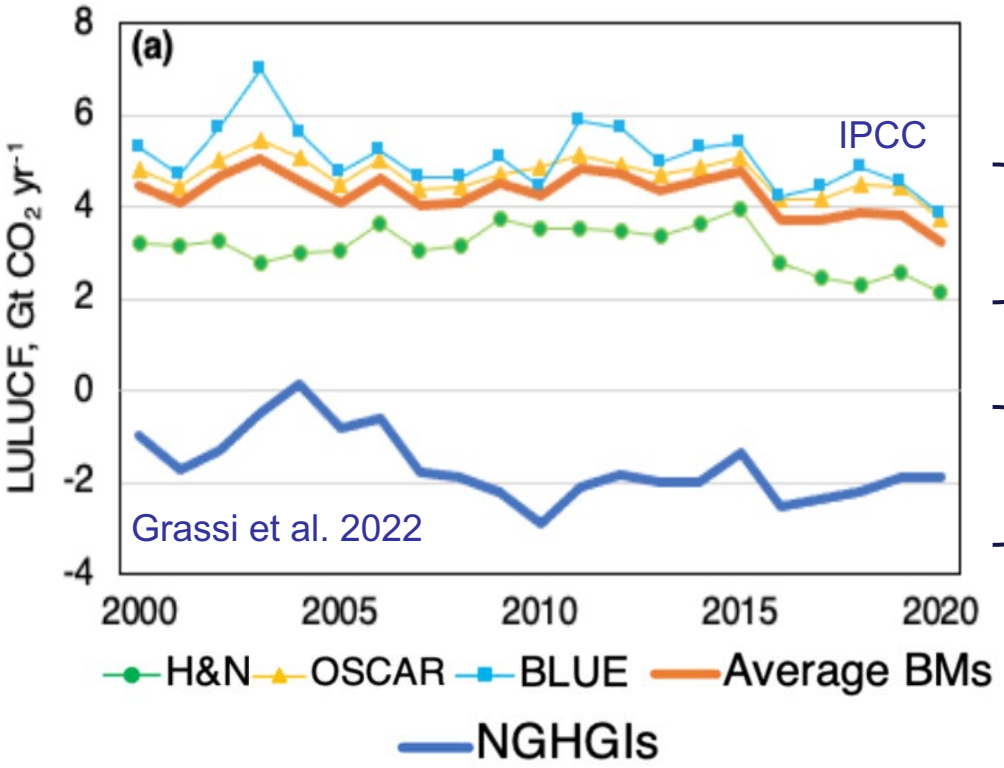


$$\Delta C = A_{LUCF} \times (C_G - C_L)$$

Gain & Loss Method

RS-based Hybrid Approach
(Xu et al. 2021)

State of Reporting & Global Assessment



Average (2000-2020)
Three book-keeping models
4.8 (3.2-5.6) GtCO2 yr^{-1}

Report from 195 countries
-1.9 GtCO2 yr^{-1}

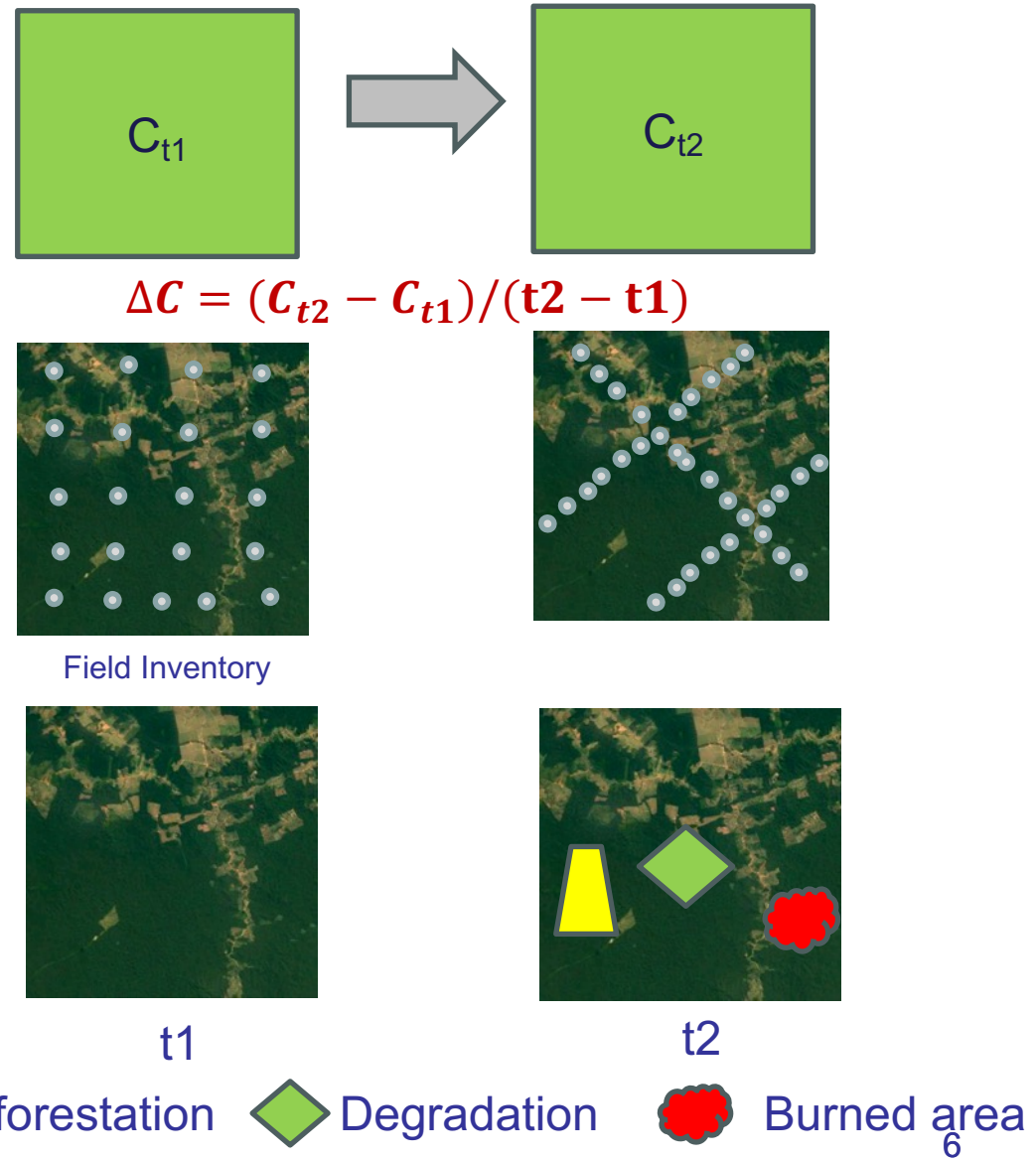
Sources of Uncertainty

BMs
Land use activity data
Emission factors
Model assumptions

NGHGIs
NFI data
Definition of forest
Deforestation & Degradation
Fire
Non-forest lands
managed & unmanaged land

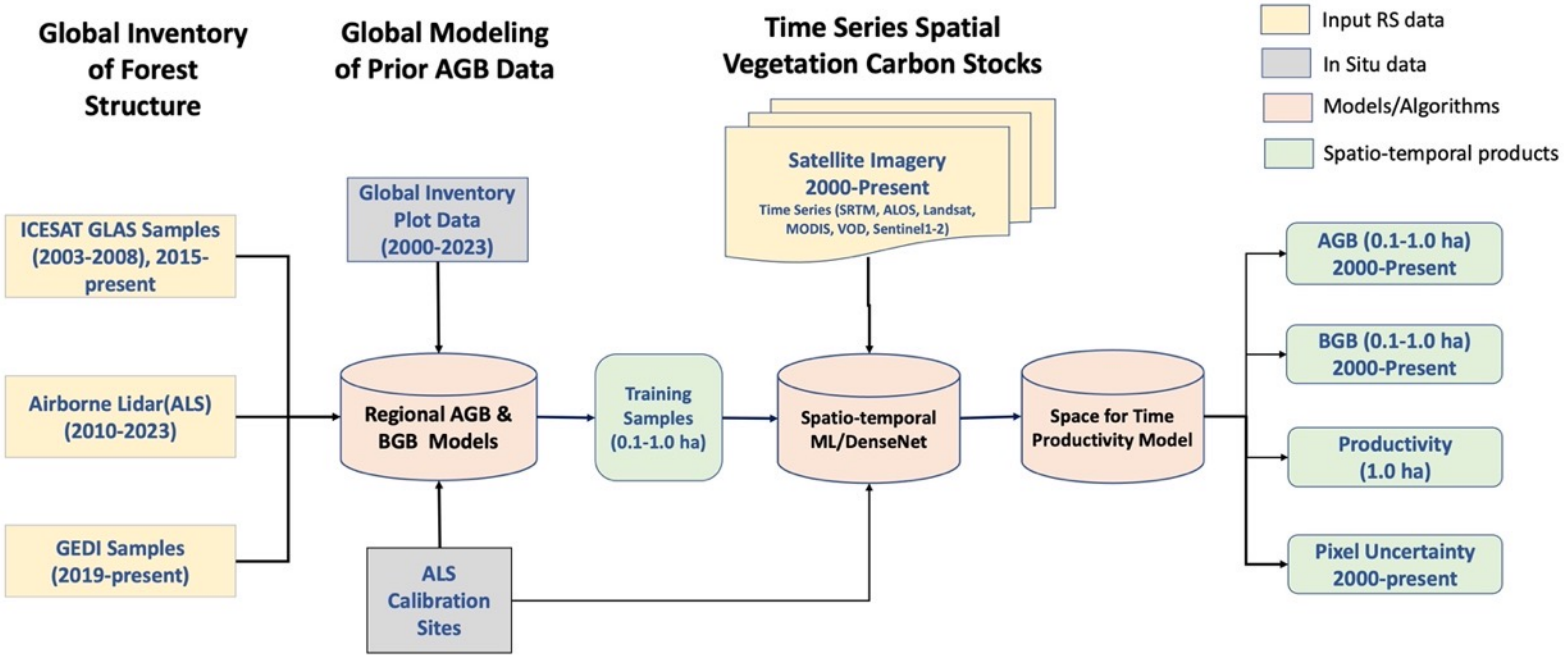
RS-based Land Emissions & Removals

- **Global and geospatial**
  - Carbon stock change
  - Satellite and Inventory observations
- **Land use activities**
  - Deforestation (forest conversion)
  - Degradation (forest remaining forest)
  - Fire
- **Emissions**
  - Pixel level emissions
  - Committed emissions
  - Direct and indirect
- **Removals**
  - Stock change
  - Global Forest Productivity model
- **Uncertainty**
  - Error propagation
  - Spatial uncertainty assessment
  - Comparison with country level data

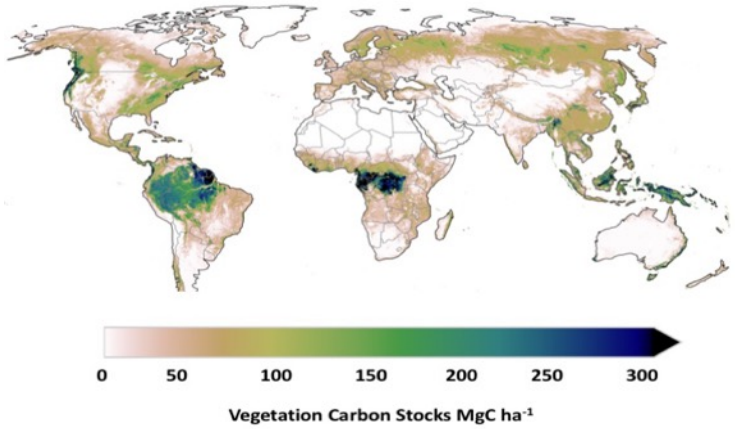


Carbon Stock Changes 2000-2023

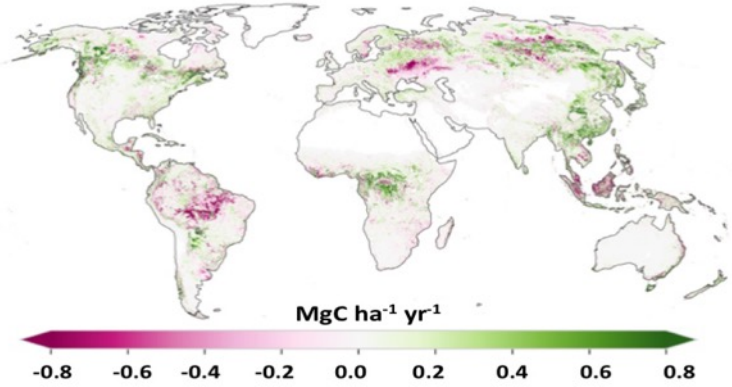
- Develop systematic and spatially explicit bottom-up estimates of global live woody vegetation biomass stock changes annually from 2000 to 2023.
- Develop space for time analysis combined with inventory data to model forest productivity



Carbon Stock



Carbon Stock Changes



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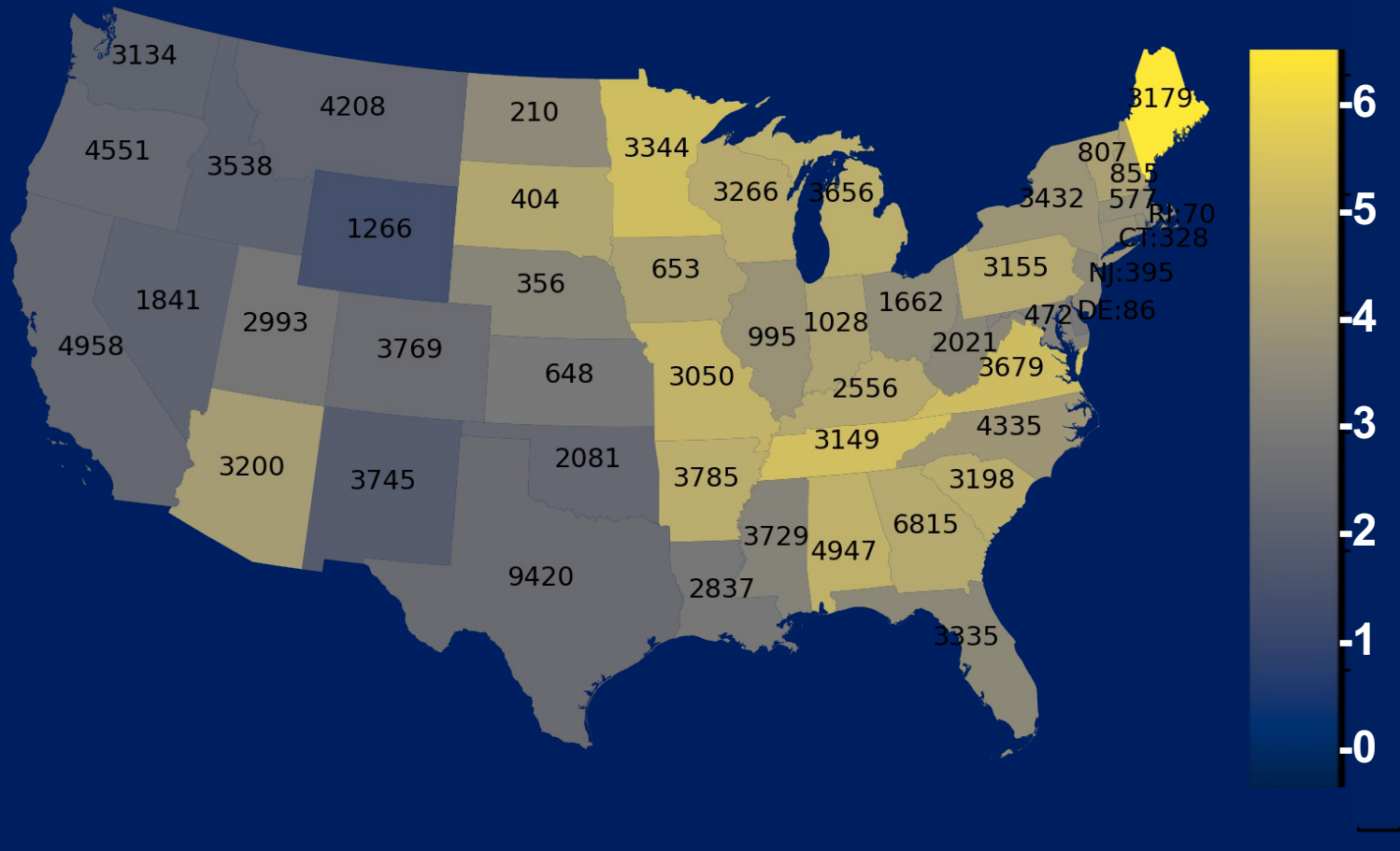
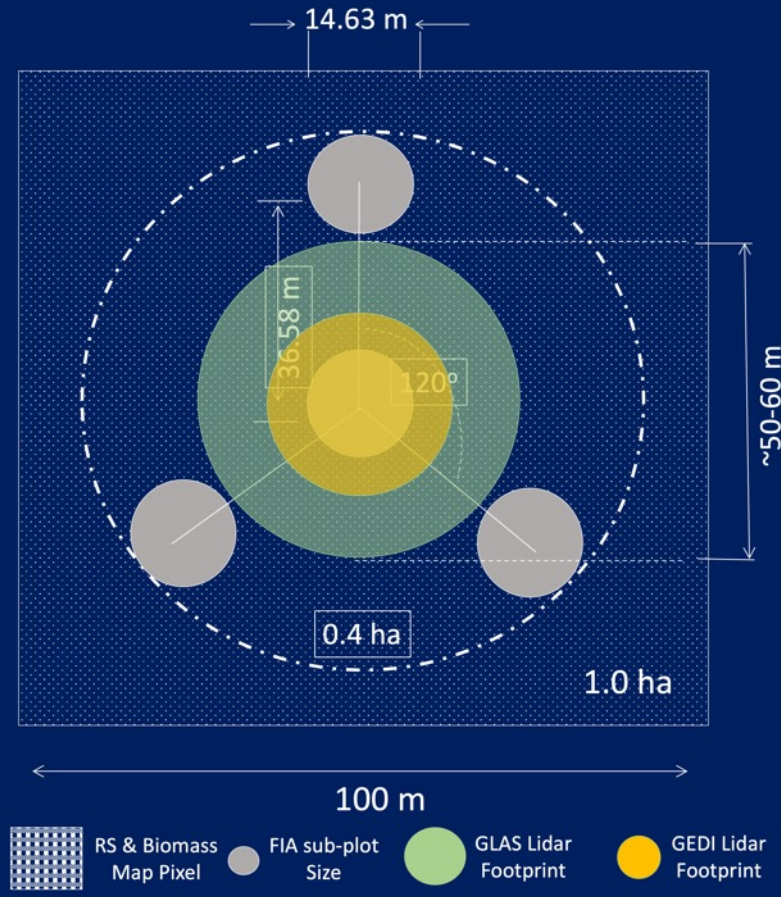
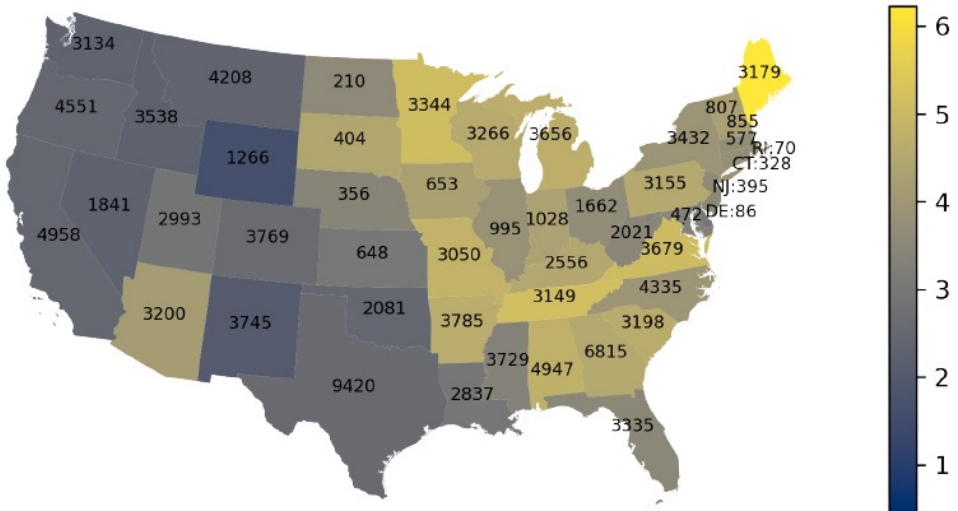
Forest Inventory: Necessary but not Sufficient

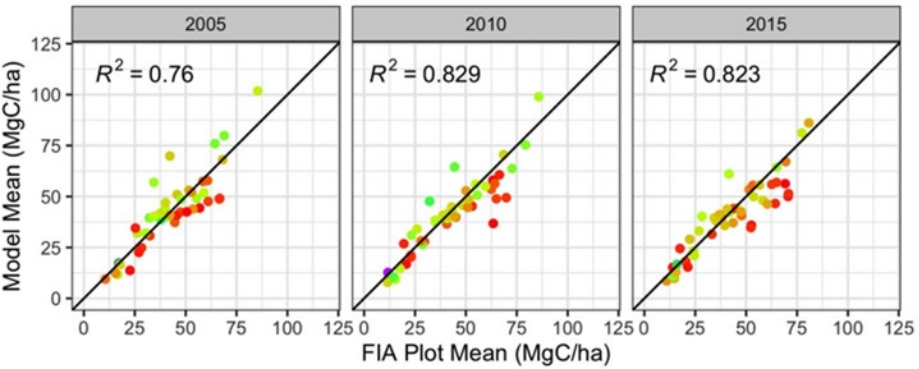
10-20% of inventory plots collected annually

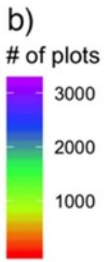


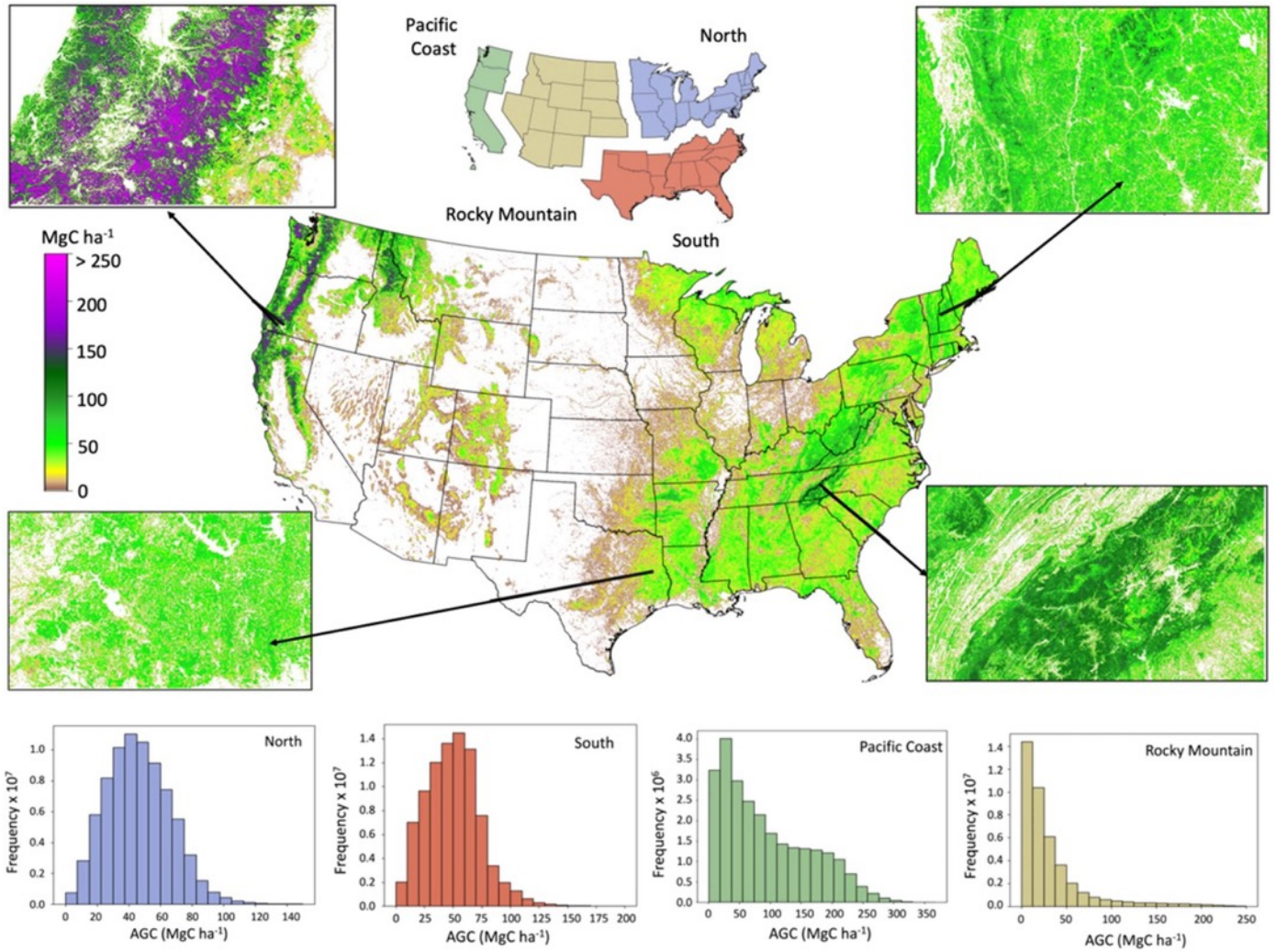


Harmonizing National Inventory in Space & Time





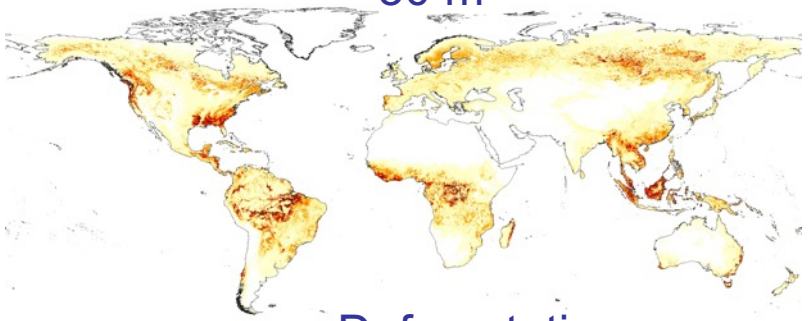




Yu et al. ERL 2022

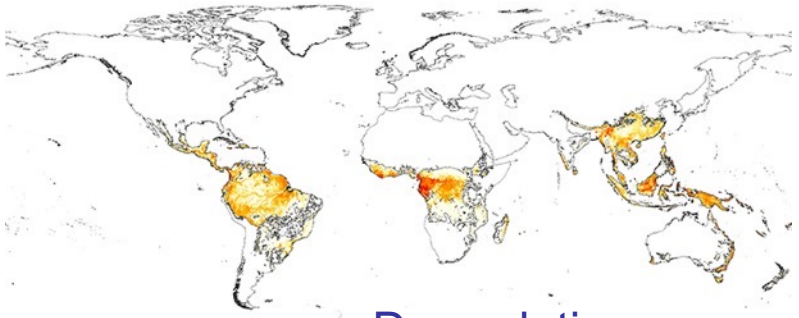
Emissions and Removals

30 m



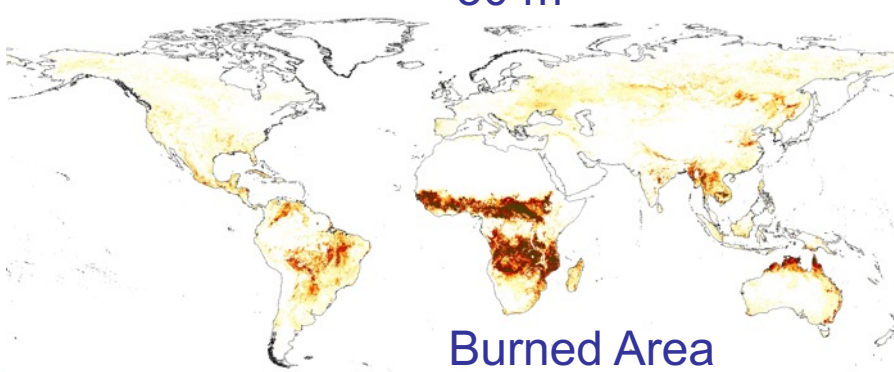
Deforestation

30 m



Degradation

30 m



Burned Area

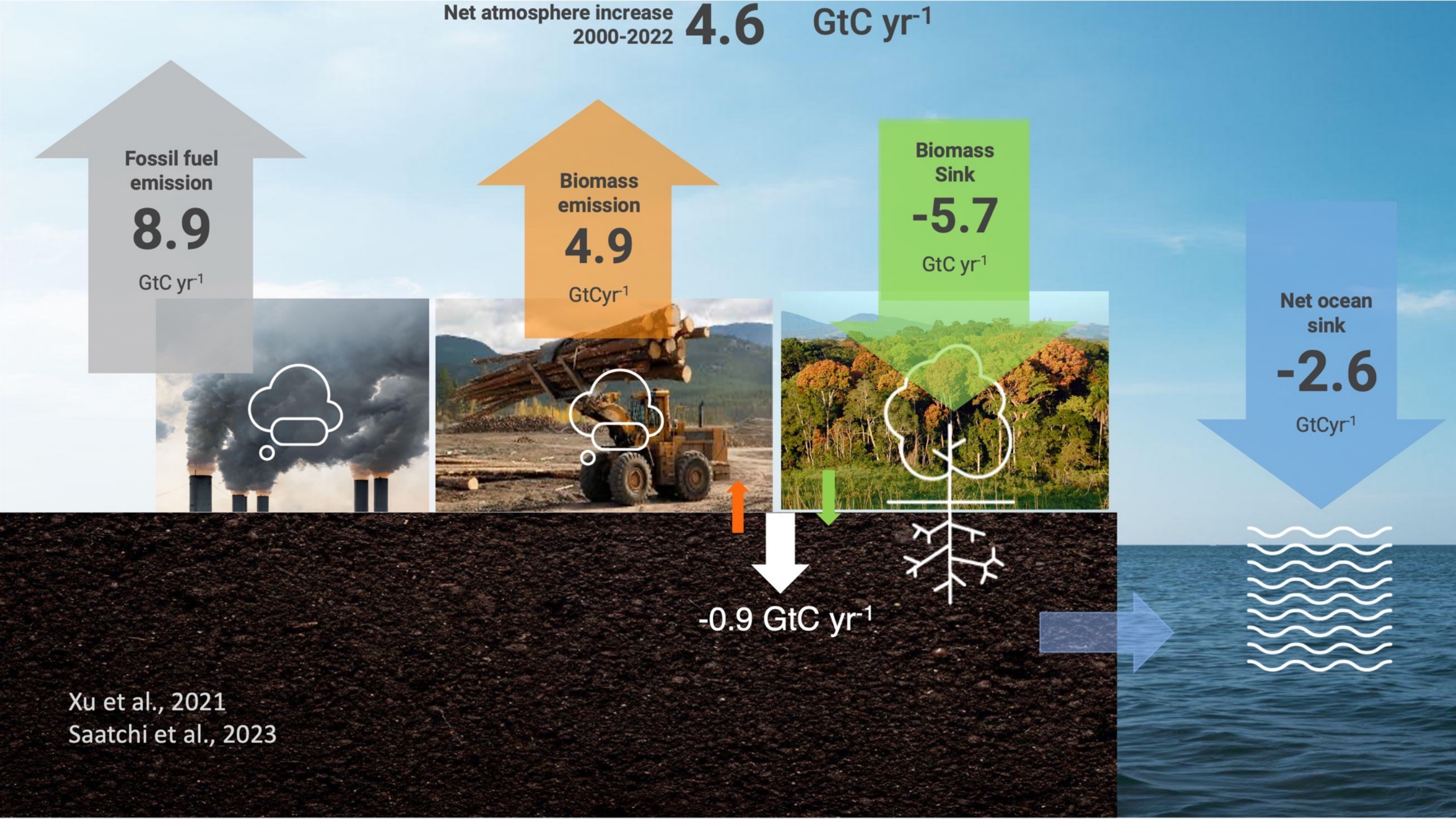
deforestation

degradation

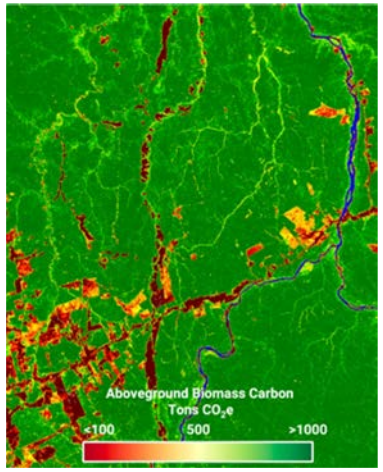
Regeneration

Fire

$$\Delta C = \sum_{i}^{N} \Delta A \cdot B \cdot E_{def} + \sum_{i}^{N} A \cdot \Delta B \cdot E_{deg} + \sum_{i}^{N} A \cdot \Delta B \cdot E_{fire} - \sum_{i}^{N} A \cdot \Delta B \cdot S_{Reg}$$

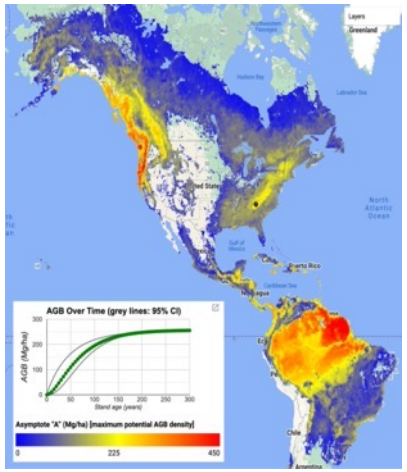

Net atmosphere increase
2000-2022
4.6
GtC yr-1
Fossil fuel emission
8.9
GtC yr-1
Biomass emission
4.9
GtCyr-1
Biomass Sink
-5.7
GtC yr-1
Net ocean sink
-2.6
GtCyr-1
-0.9 GtC yr-1
Xu et al., 2021
Saatchi et al., 2023

CTrees Data Products



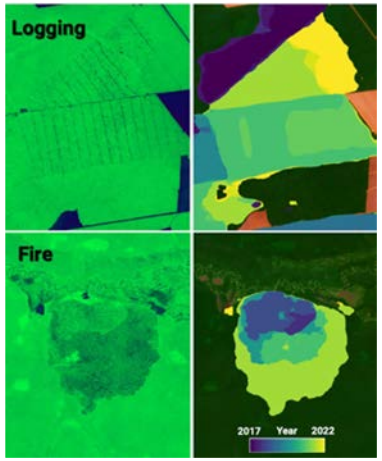
Land Carbon Map

Carbon stocks in all forest & non-forest land globally 2000-2023



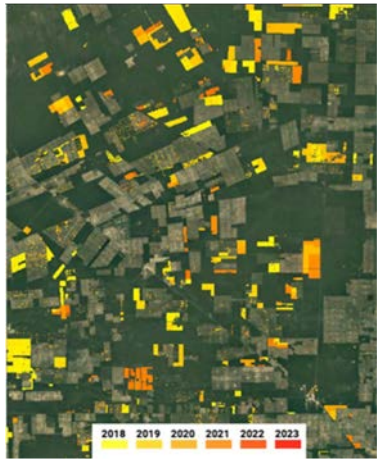
Forest Productivity

Biomass carbon regrowth model at landscape scale & driven by climate



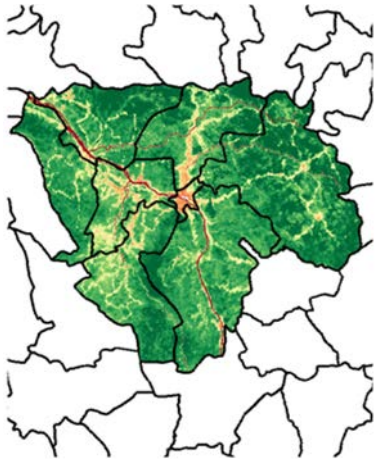
Activity Data

Deforestation, forest degradation, & regeneration



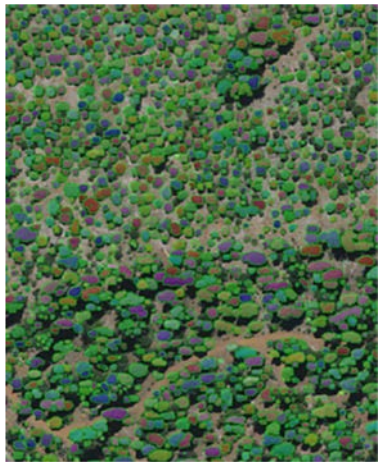
Land Use Change Alerts (LUCA)

Near-real-time I information on disturbances in forests worldwide



Jurisdictional MRV

Carbon stocks, emissions, & removals at national & sub-national



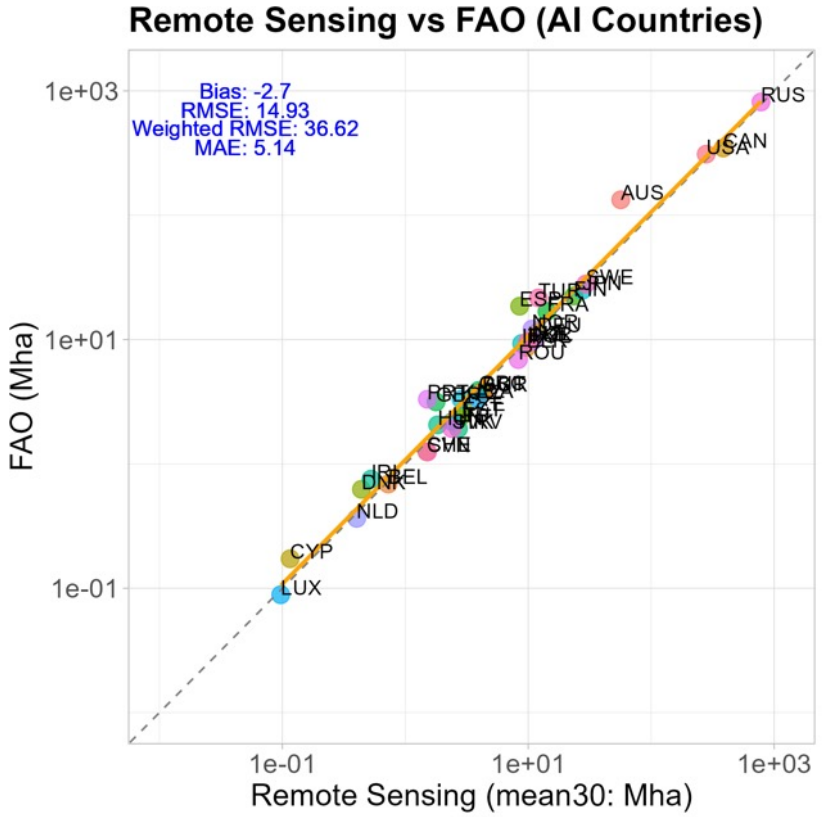
Tree-level Data

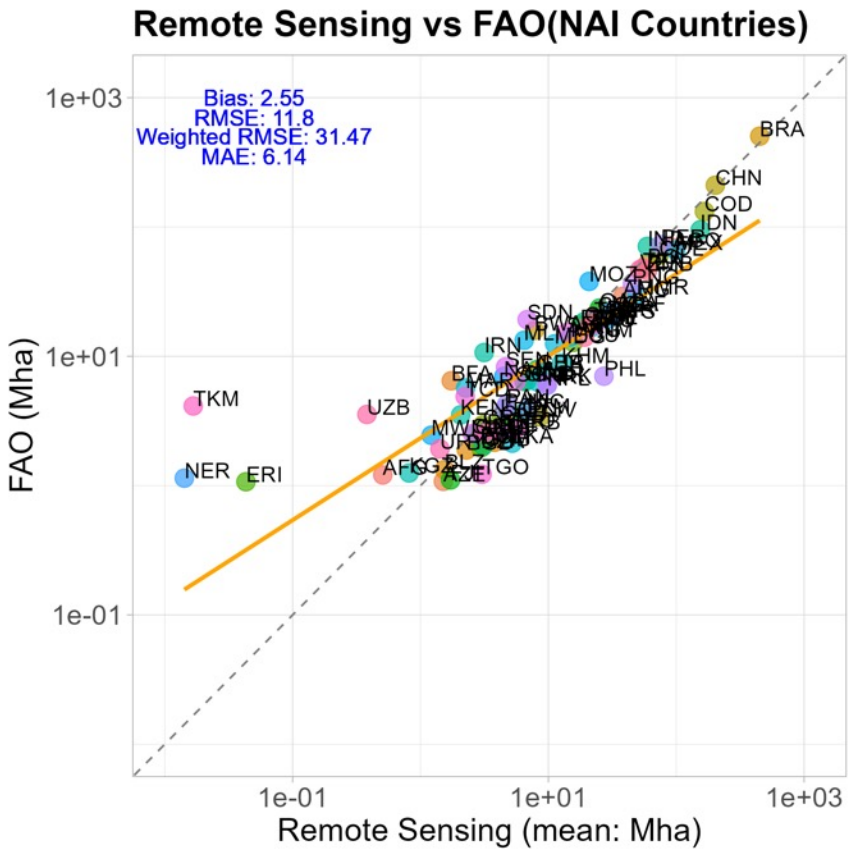
Map of individual trees at local to national

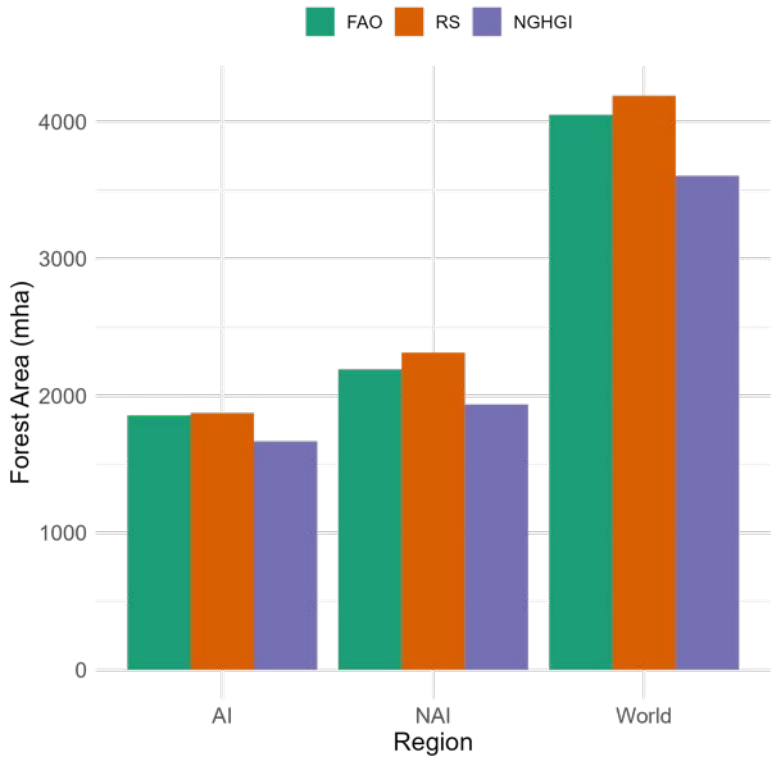
Comparison of RS-based GHG Inventory with Country Reports

- **Challenge 1: Forest Area**
  - Definition of forest
  - Managed & Unmanaged
- **Challenge 2: Carbon Stocks**
  - NFI data
  - Cycle of NFI & Interpolation
  - Accuracy vs Precision
- **Challenge 3: Carbon Stock Change**
  - Definition (NFI or Area-based)
  - Emissions
  - Removals

Challenge 1: Forest Area



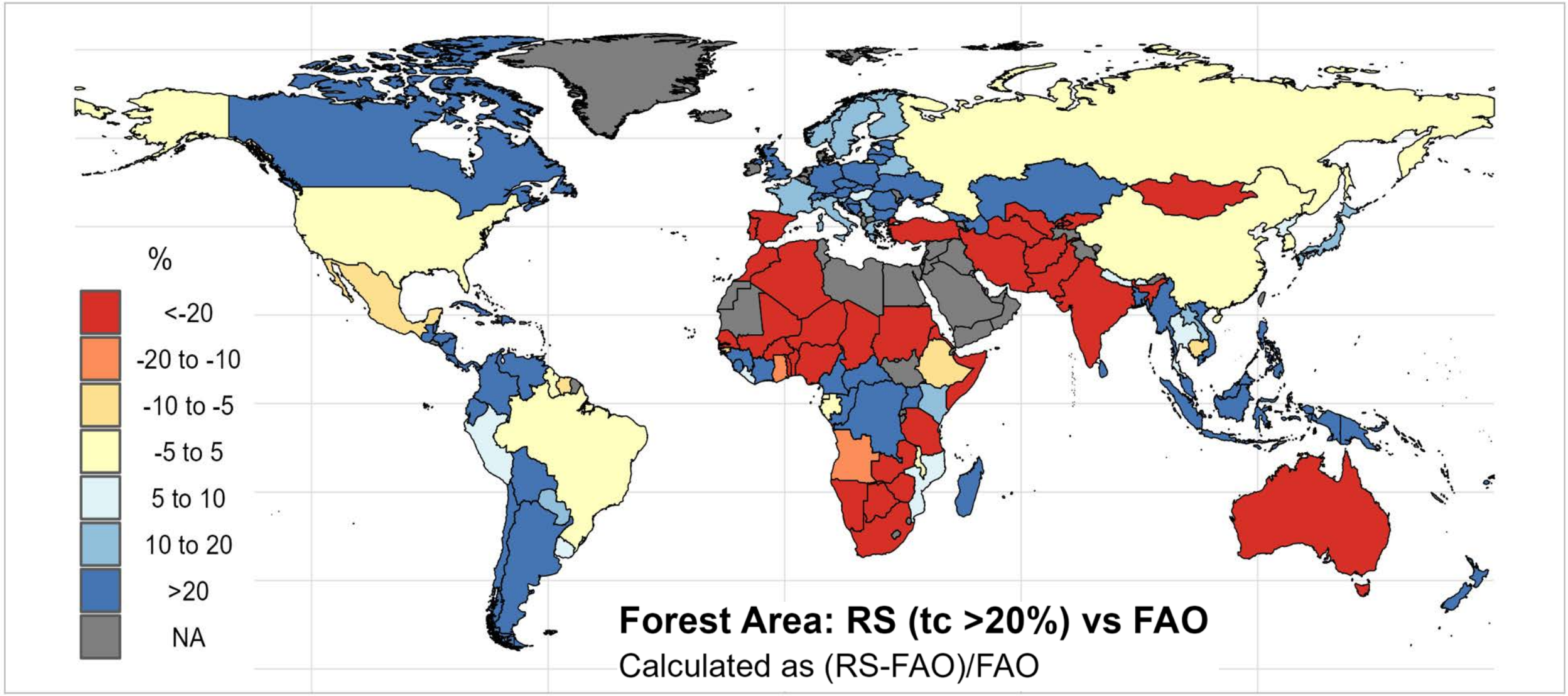




FAO	World total	4051 (Mha)
NGHGI	World total	3605 (Mha) (managed)
RS	World total	4190 (Mha)

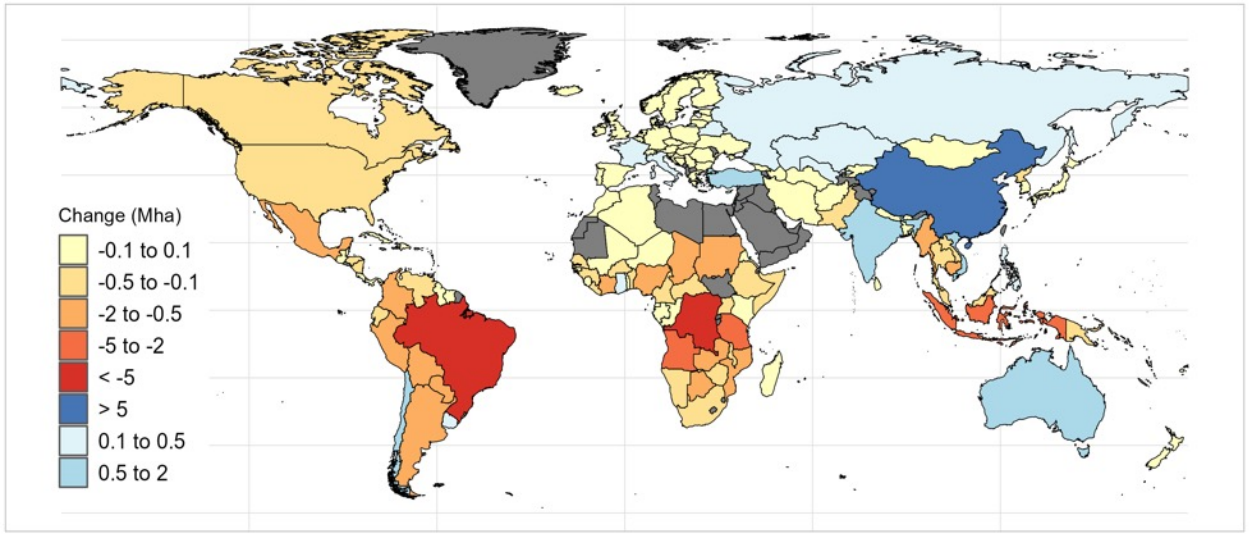
Global: 139mha, RS is 3.4% higher than FAO
AI: 13mha, RS is 0.86% higher than FAO of total forest area in AI
NAI: 123mha, RS is 5.6% higher that FAO of total forest area in NAI

Challenge 1: Forest Area

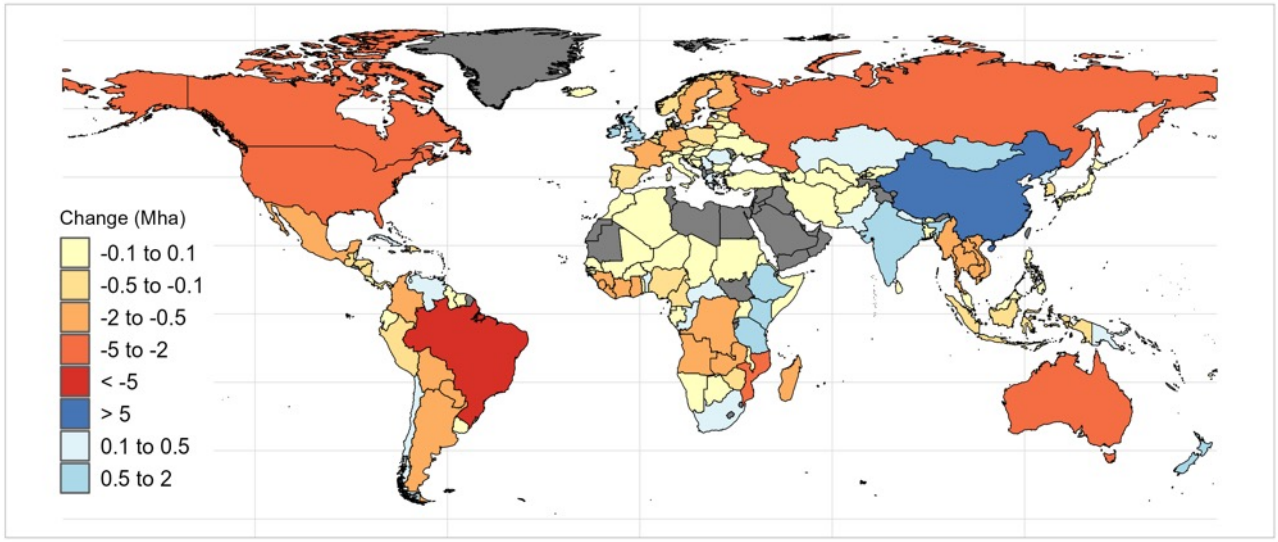


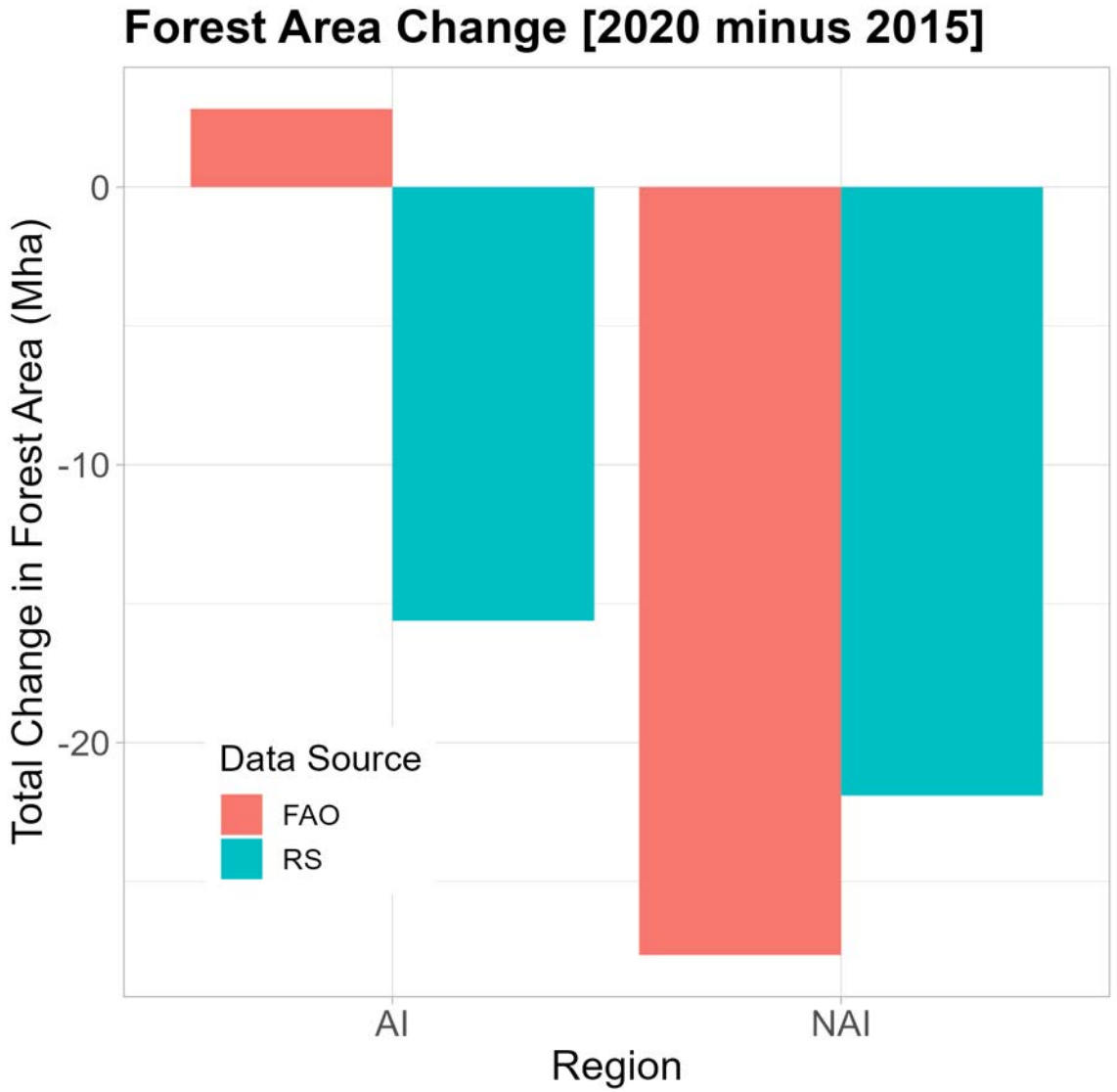
Challenge 1: Forest Area

Forest Area Change by FAO (2020 minus 2015)

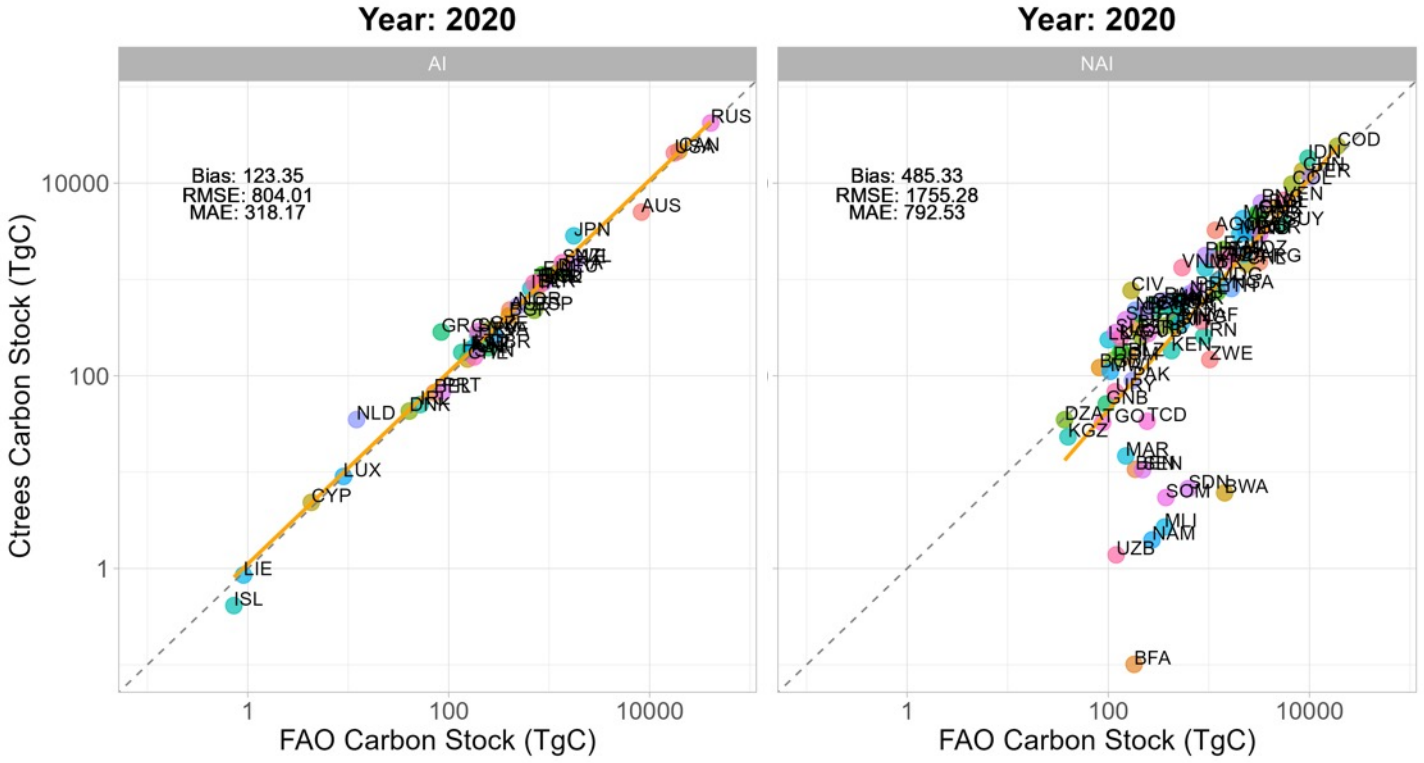


Forest Area Change by RS (2020 minus 2015)



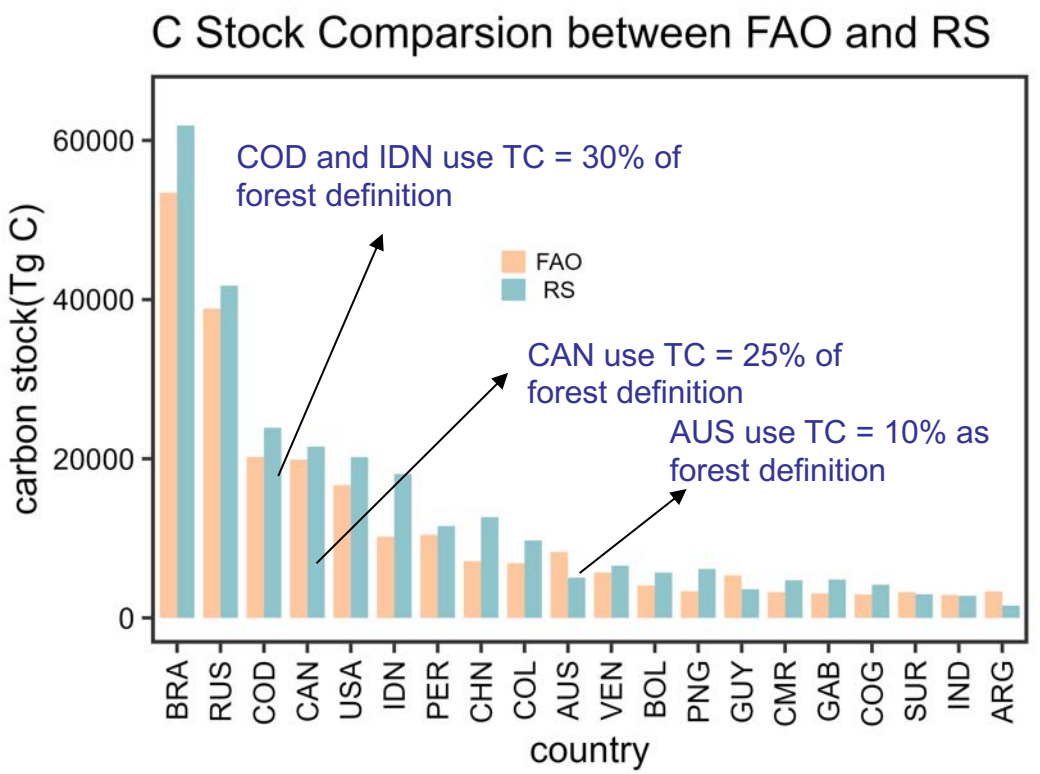


Challenge 2: Carbon Stocks



AI Countries

NAI Countries

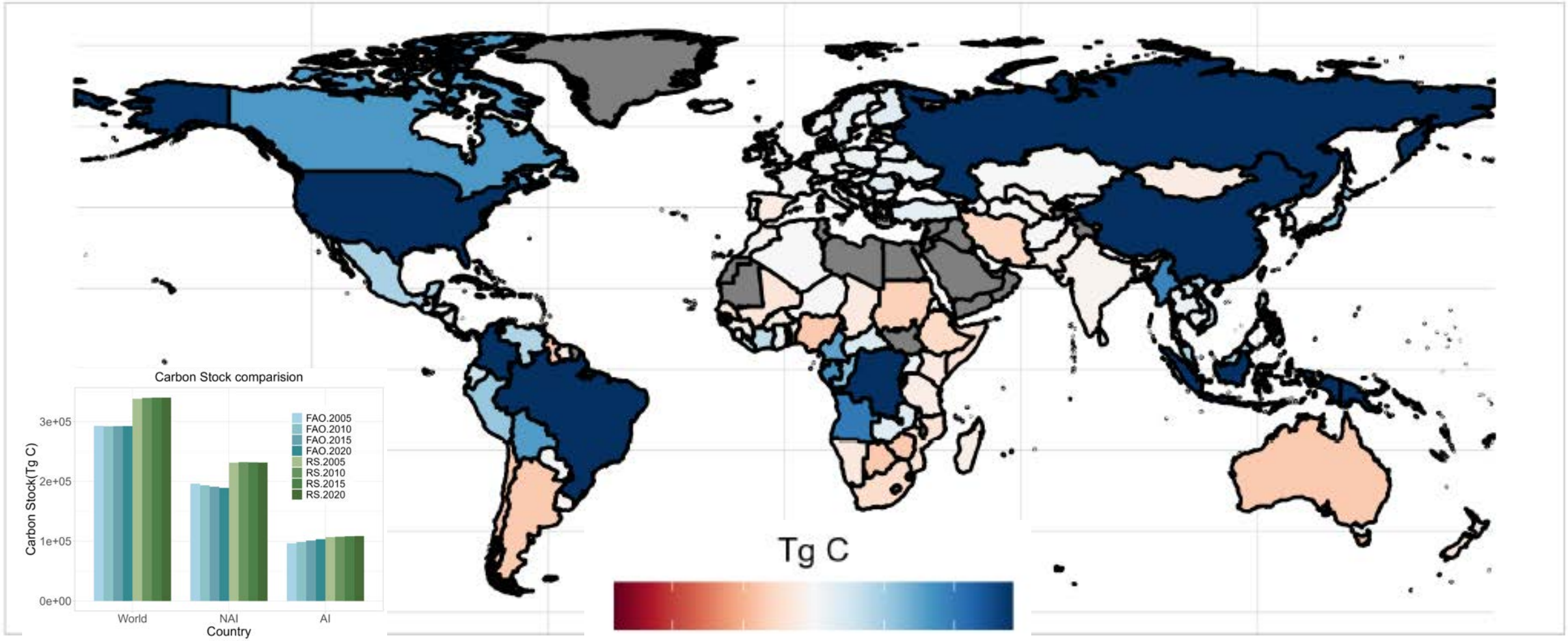


- Emission factors in AI countries are similar but differ in NAI countries
- NAI countries do not have national inventory (i.e. Brazil, DRC, etc.)
- Forest cover/definition in NAI countries influence the comparison.

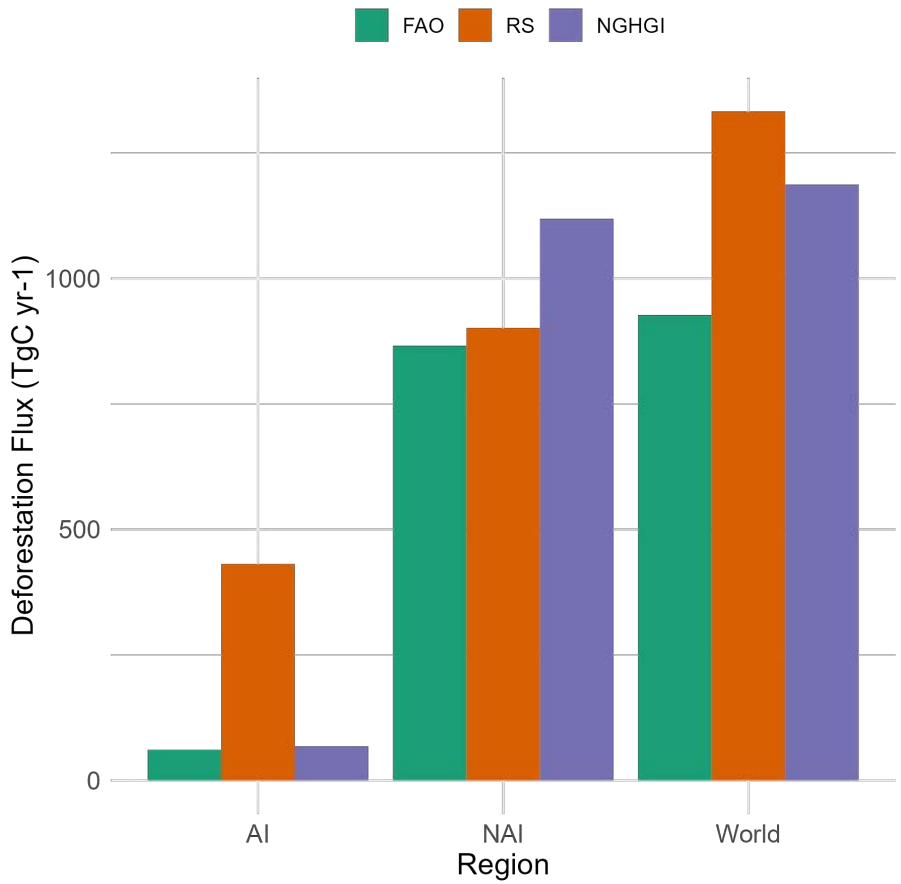
Challenge 2: Carbon Stocks

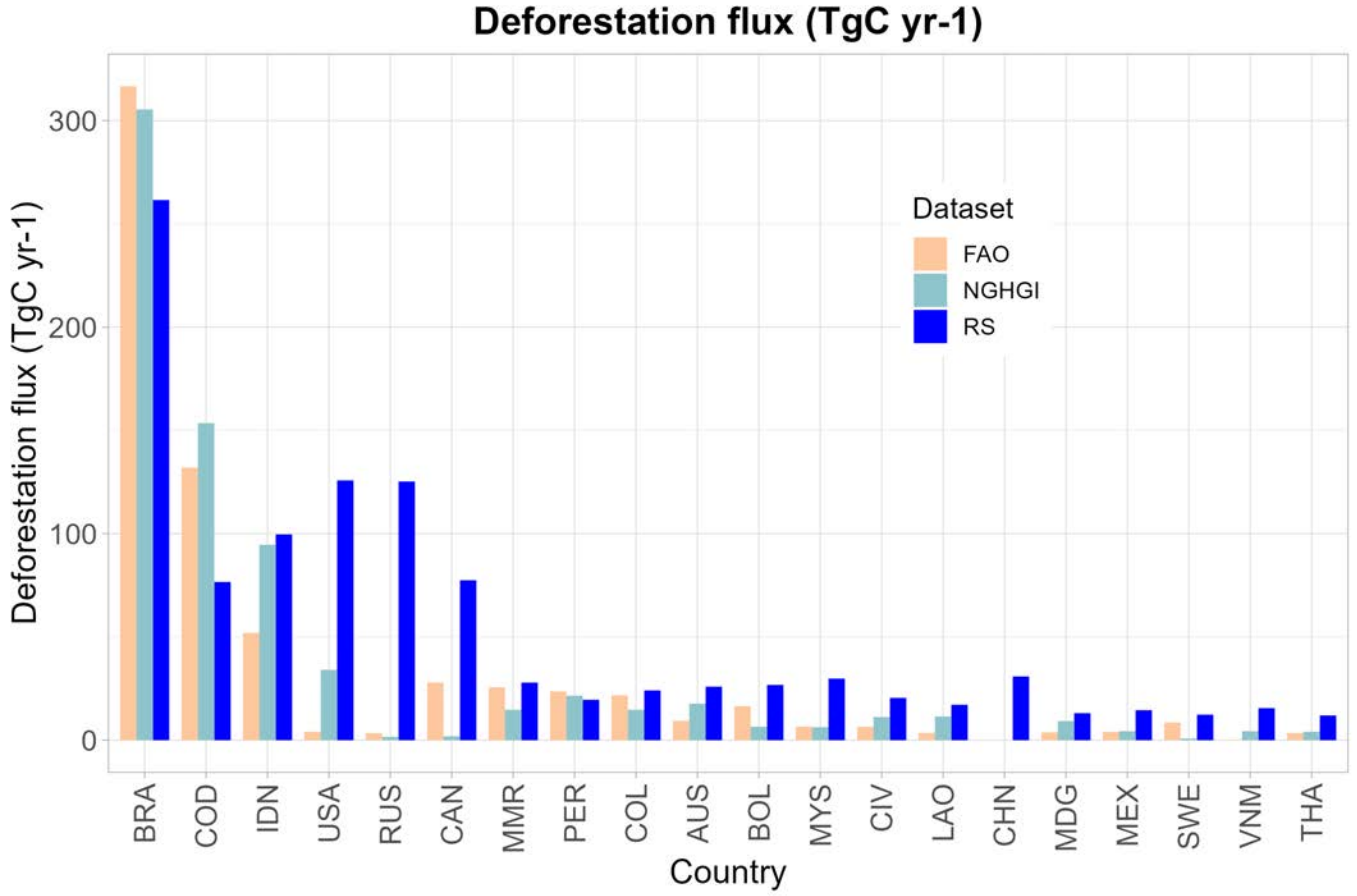
Carbon Stock Difference between RS and FAO (RS-FAO: TgC)

2000-2020 Mean



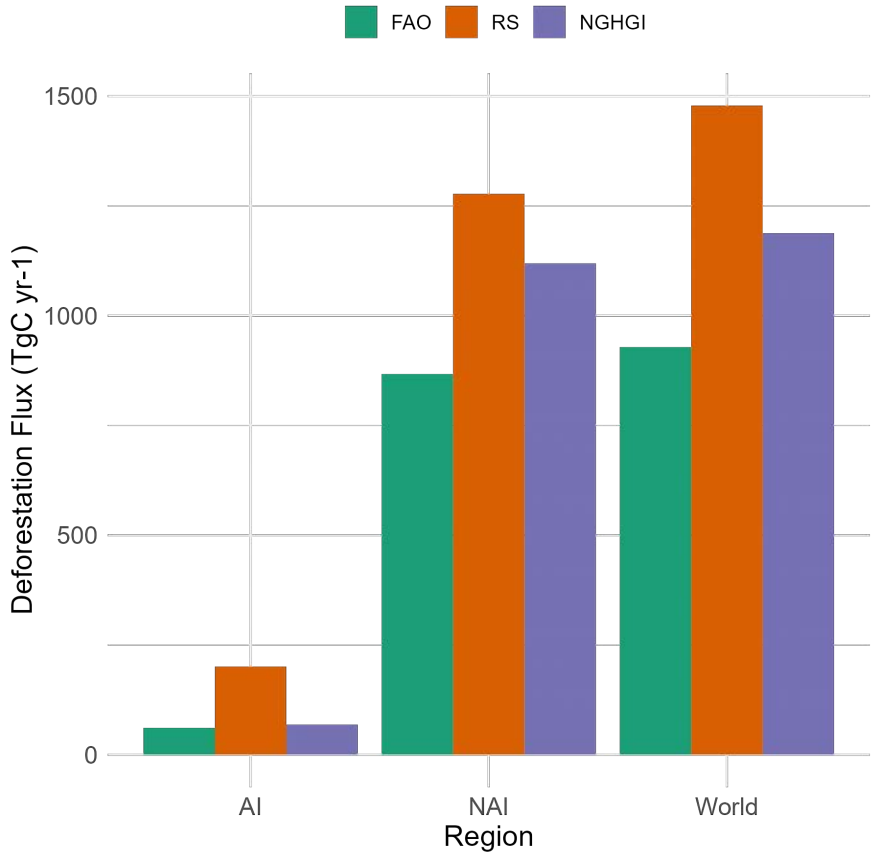
Challenge 3: Carbon Flux (Emissions)

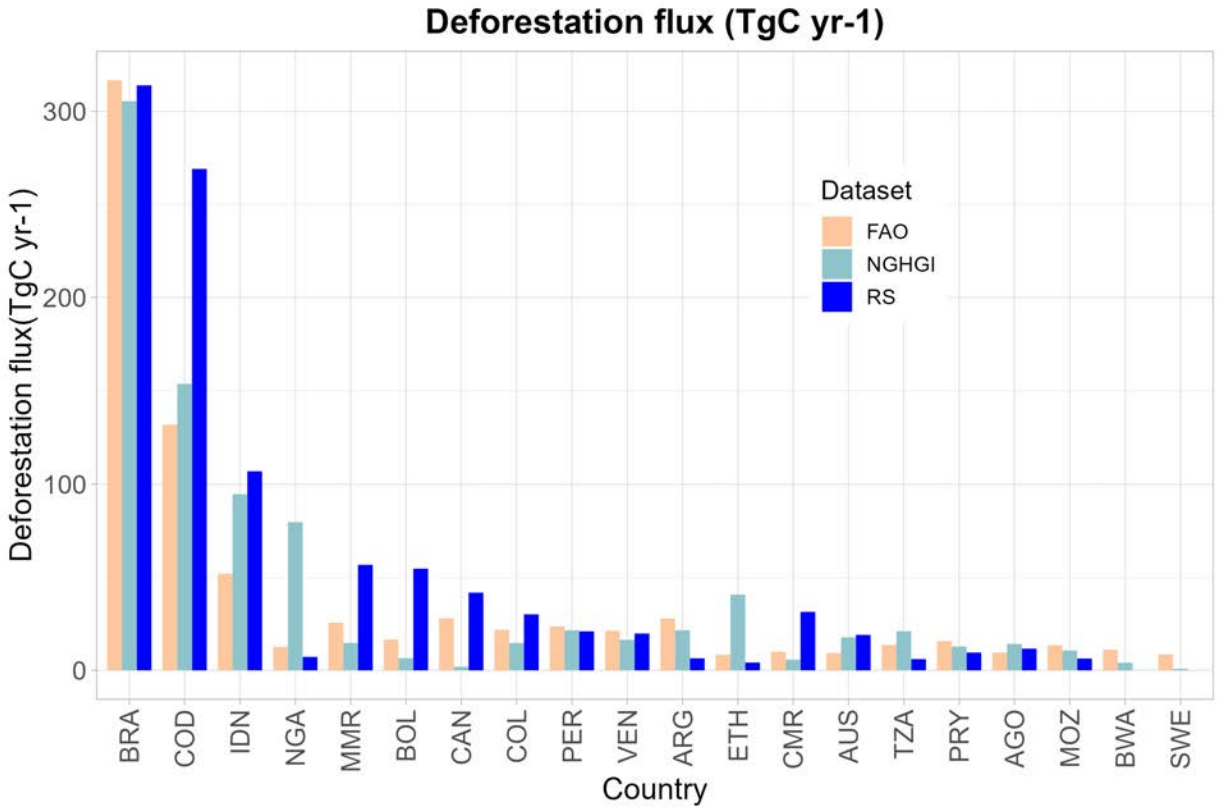




- Due to the fact that forest clearing is calculated as committed emission, that the
  - AI counties: forest clearing emission > deforestation emission (HWP sink is included in the NGHGI report)
  - NAI counties: forest clearing emission < deforestation emission (deforestation fire is included in the NGHGI report, but excluded from the forest clearing

Challenge 3: Carbon Flux (Emissions)



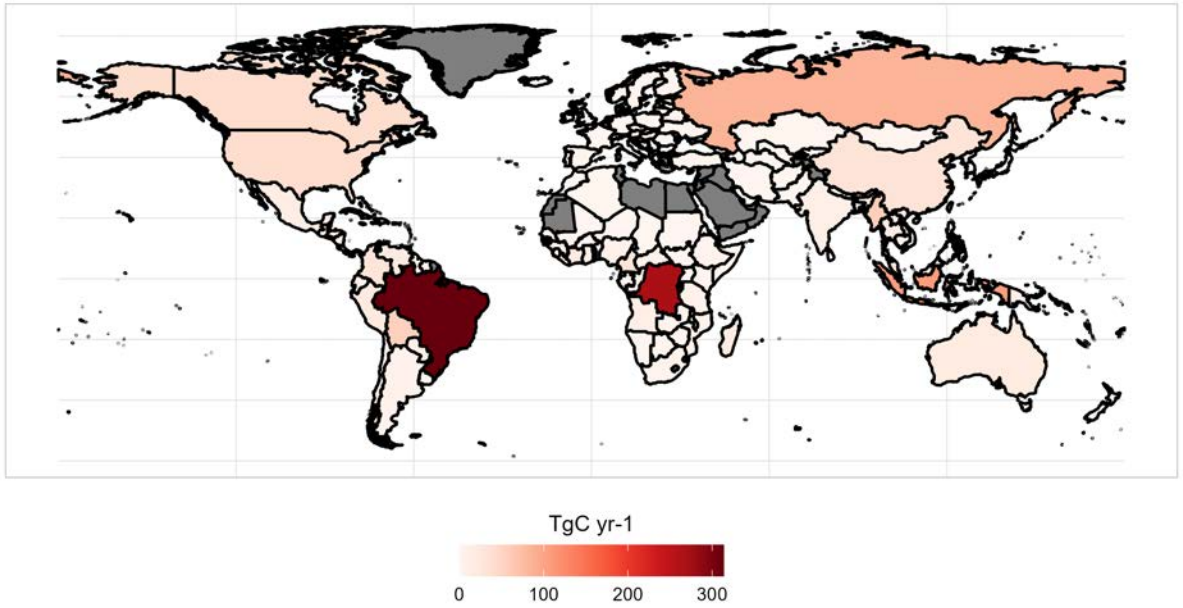


- AI countries: deforestation = forest clearing flux – HWP. [note, HWP here assume committed HWP emission once deforestation occurs, while NGHGI use decay curve to calculate the HWP emission]
- NAI: forest fire emission was added to deforest flux for certain tropical countries.

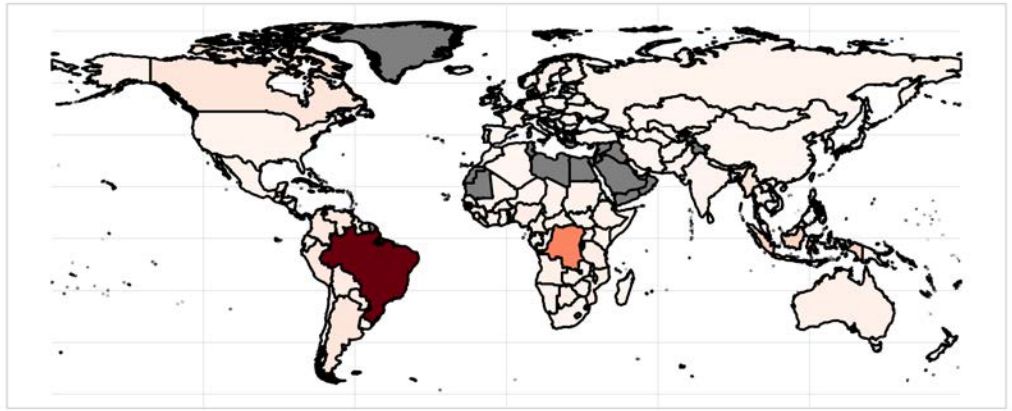
Challenge 3: Carbon Flux (Emissions)

- Larger differences in stock changes among estimates
- Tropics remain the largest difference in estimates
- HWP and fire emissions are the largest source of differences in AI countries

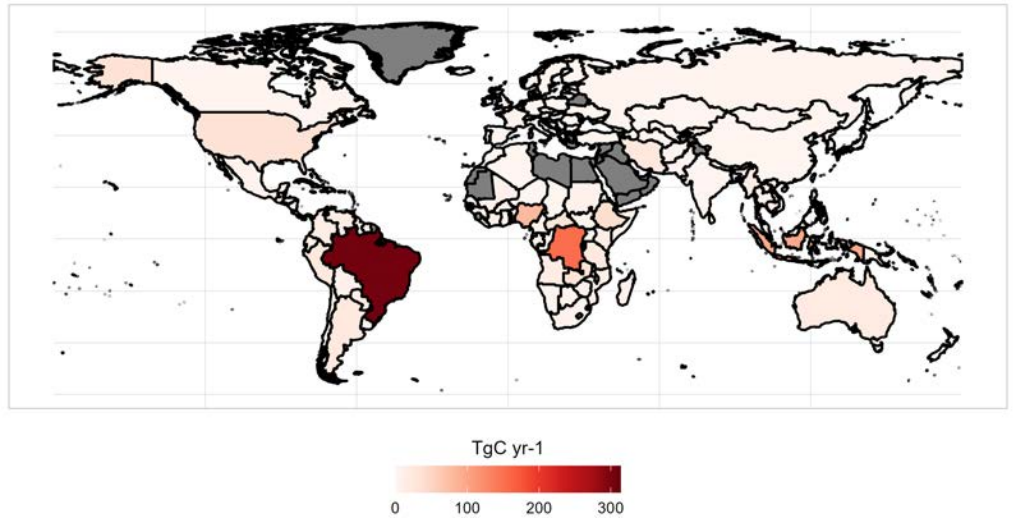
Deforestation Carbon Emission (RS: TgC yr-1)
Mean (2000-2020)



Deforestation Carbon Emission (FAO: TgC yr-1)
Mean (2000-2020)

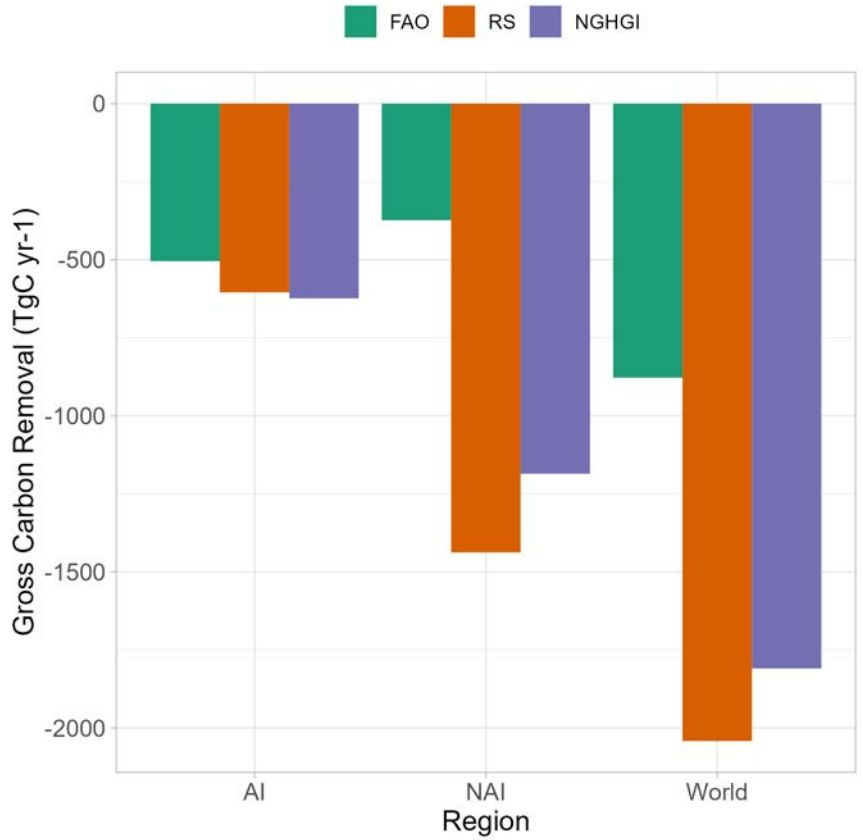


Deforestation Carbon Emission (NGHGI: TgC yr-1)
Mean (2000-2020)



Challenge 3: Carbon Flux (Removal)

Replaced by Zhihua

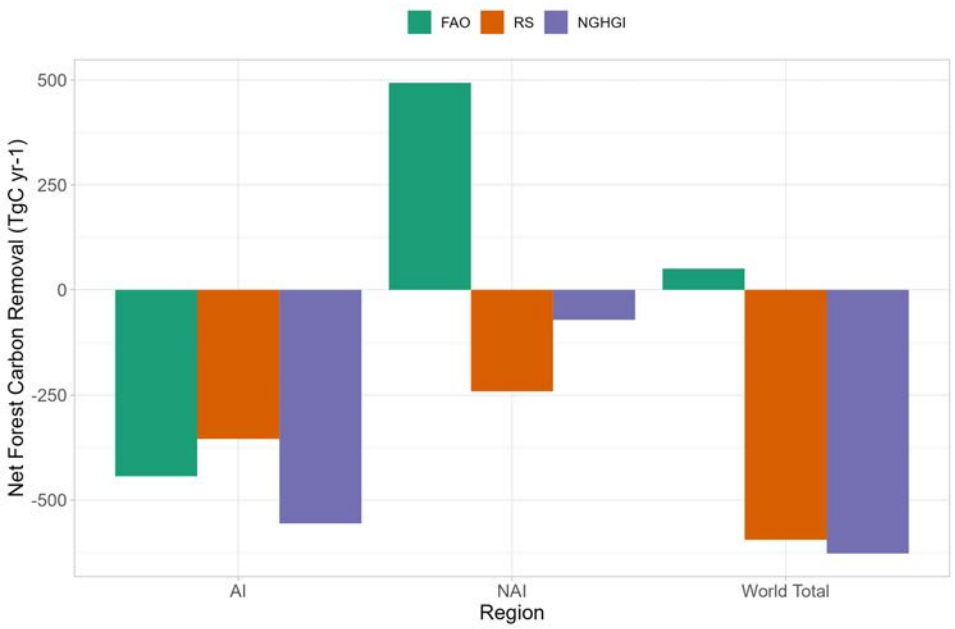


Database	Region	Gross Carbon removal flux (TgC/yr)
FAO	AI	-504
FAO	NAI	-374
NGHGI	AI	-624
NGHGI	NAI	-1186
RS	AI	-604
RS	NAI	-1439
FAO	World total	-878
NGHGI	World total	-1810
RS	World total	-2042

Gross forest C removal is calculated as:

RS: ΔC + emission from degradation and forest fire (i.e., emission from forest land)

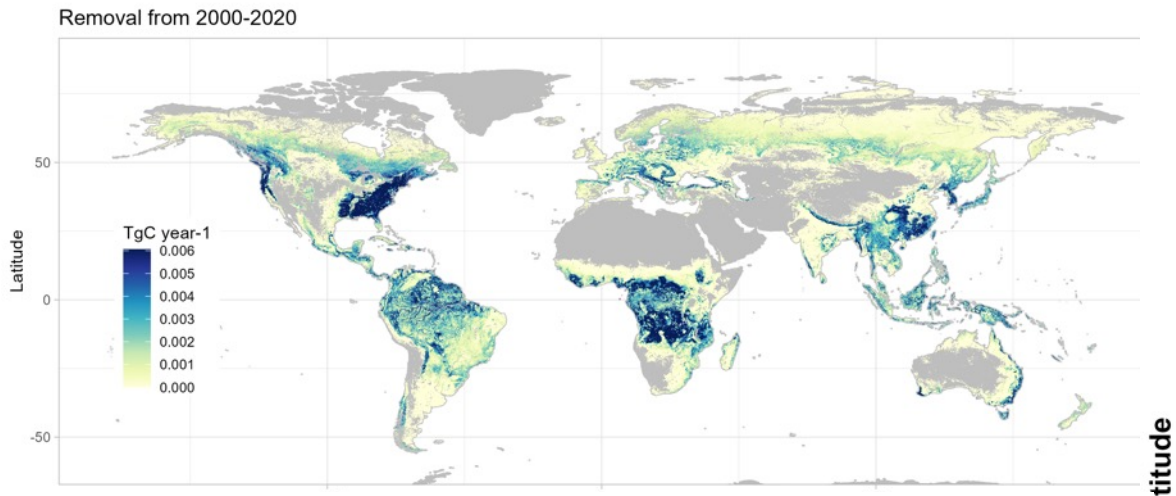
Challenge 3: Carbon Flux (Removal)

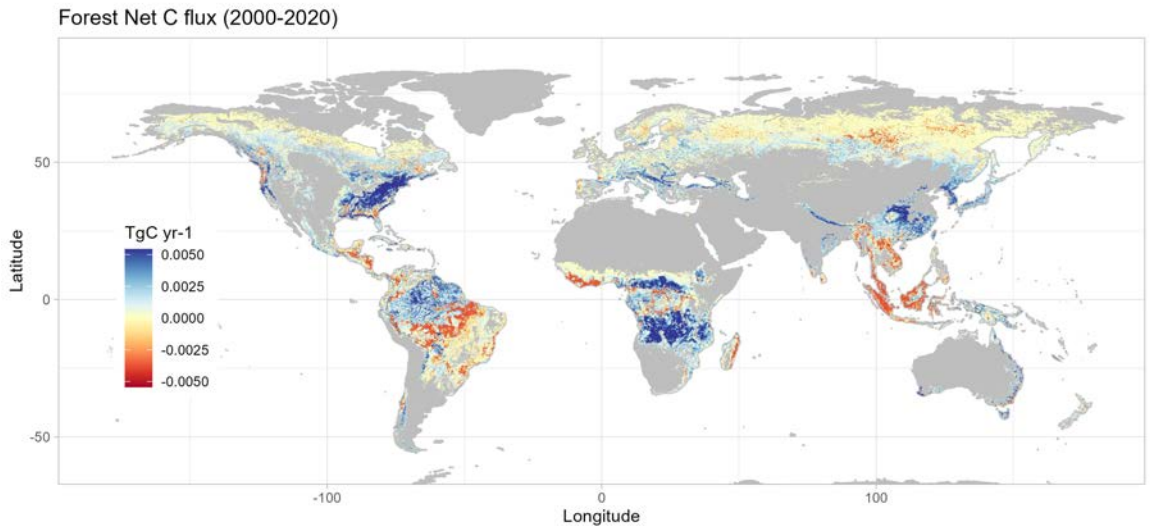


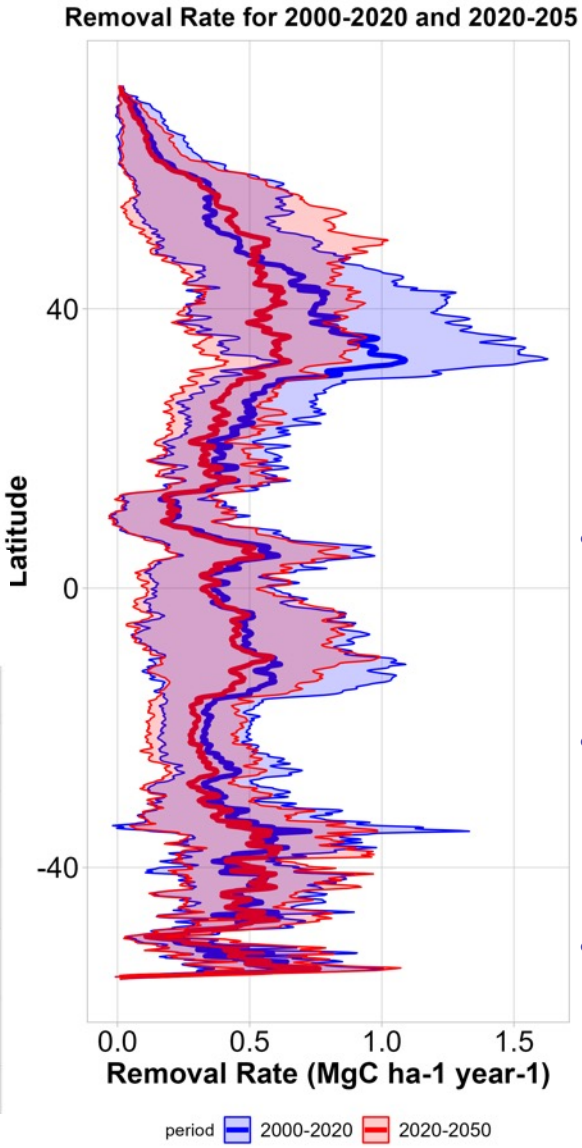
Database	Region	net forest Carbon flux w/HWP (TgC/yr)	Non-forest region (TC < 20%)
FAO	AI	-443	
FAO	NAI	494	
NGHGI	AI	-556 (-511 if HWP [-44]removed)	
NGHGI	NAI	-72 (-34 if HWP[-38] removed)	
RS	AI	-360	-78
RS	NAI	-189	-276
FAO	World total	50	
NGHGI	World total	-627 (-546 if HWP[-82] removed)	
RS	World total	-549	-353

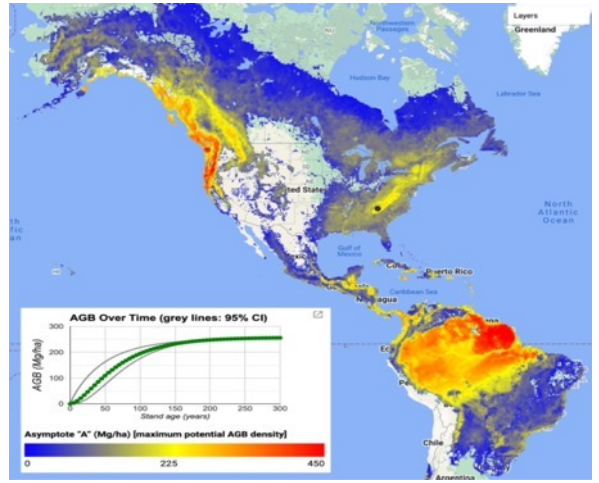
HWP is included in the RS calculation
HWP Carbon sink for AI: 253TgC/yr (931 TgCO2/yr),
HWP Carbon sink for NAI: 171 TgC/yr (628 GtCO2/yr)

Challenge 3: Carbon Flux (Removal)









- Based on forest age inferred from the biomass map at 2020 (forest age at 2020) and our growth curve parameters (A/k/m)
- Forest C removal (TC > 10%, stock-change approach)
  - 2000 - 2020: -1.83 PgC yr^{-1};
  - 2020-2050: -1.76 PgC yr^{-1};
- Other results (forest removal):
  - Grassi et al., -1.75 PgC yr^{-1} (2000- 2020)
  - FAO: -0.87 PgC yr^{-1} (2000- 2020)

Summary

- RS-based estimates of forest area, carbon stocks are ready to improve national reporting
  - Harmonizing forest area definition & consistent monitoring
  - For countries with NFI, RS-based estimates can improve precision after removing the bias
  - For countries with no NFI, RS-based estimates can be used for reporting and monitoring
  - Inclusion of RS measurements to harmonize NFI across AI countries and improve NFI cycle interpolation
- RS measurements and new tools are improving significantly
  - GEDI, NISAR, and BIOMASS missions are solutions to MRV and global stocktake
  - Generative AI and VHR satellite data improve attributions of LULUCF emissions
- Role of UNFCCC to encourage improved GHG inventory
  - Increasing NFI data acquisition across global south
  - Separating natural and agroforestry systems, reporting on managed and unmanaged
  - Recommendation of using RS-based estimates in national reporting