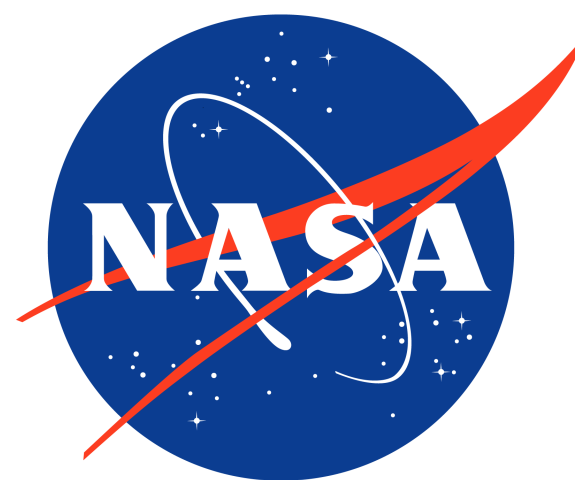


Using satellite observations  
of CO<sub>2</sub> to evaluate our  
process-based  
understanding of the global  
terrestrial carbon cycle



William Daniels, Kristan Morgan, Scot Miller

Dept. of Environmental Health and Engineering  
Johns Hopkins University



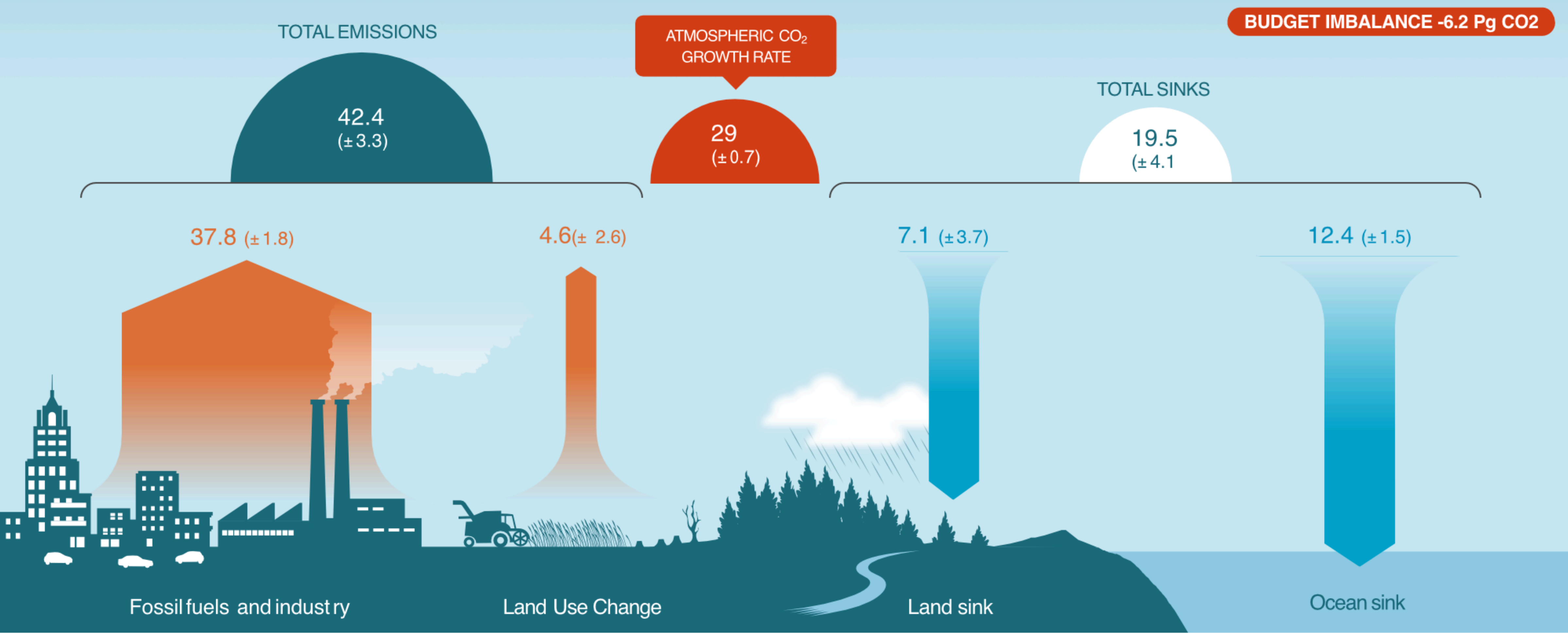
Jeralyn Poe, Deborah Huntzinger  
School of Earth and Sustainability  
Northern Arizona University



# The Global Carbon Budget

**EMISSIONS AND SINKS**  
In billion-tons CO<sub>2</sub> per year (Pg CO<sub>2</sub>/ yr), in 2024

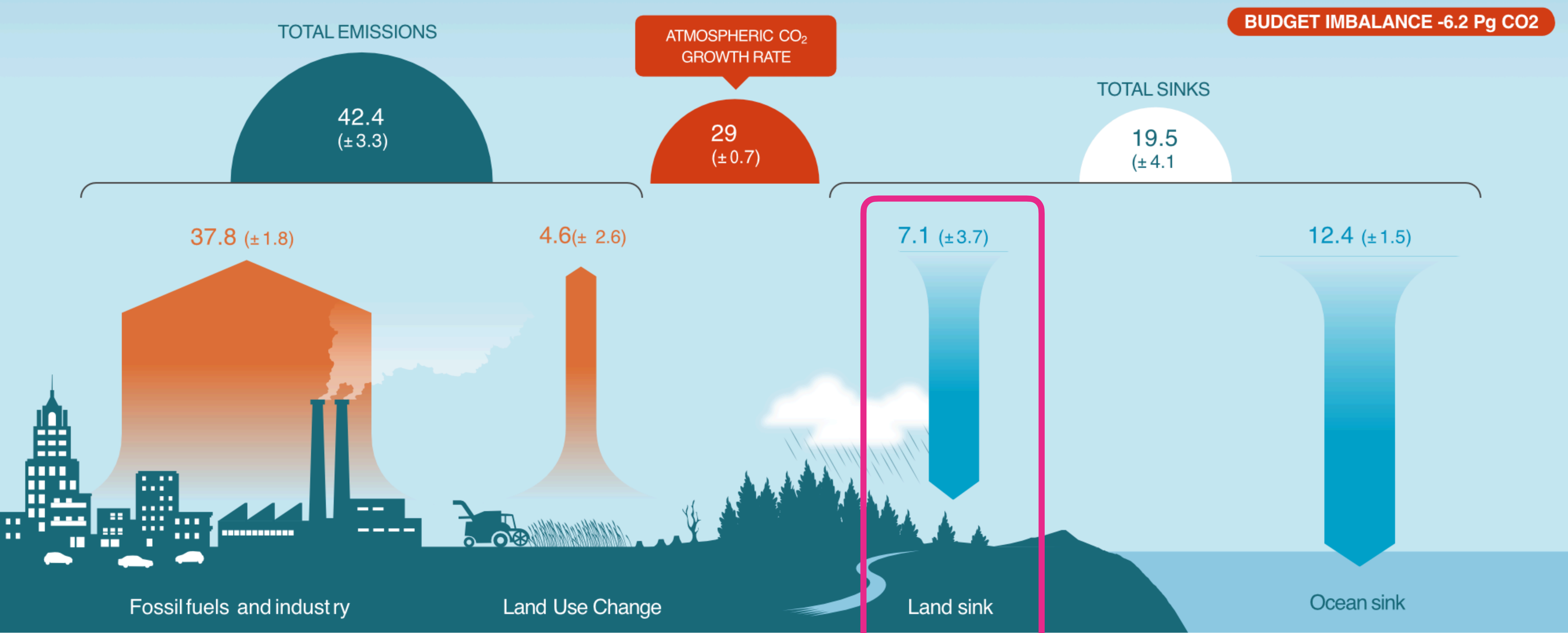
Anthropogenic emissions      Sinks of anthropogenic emissions



# The Global Carbon Budget

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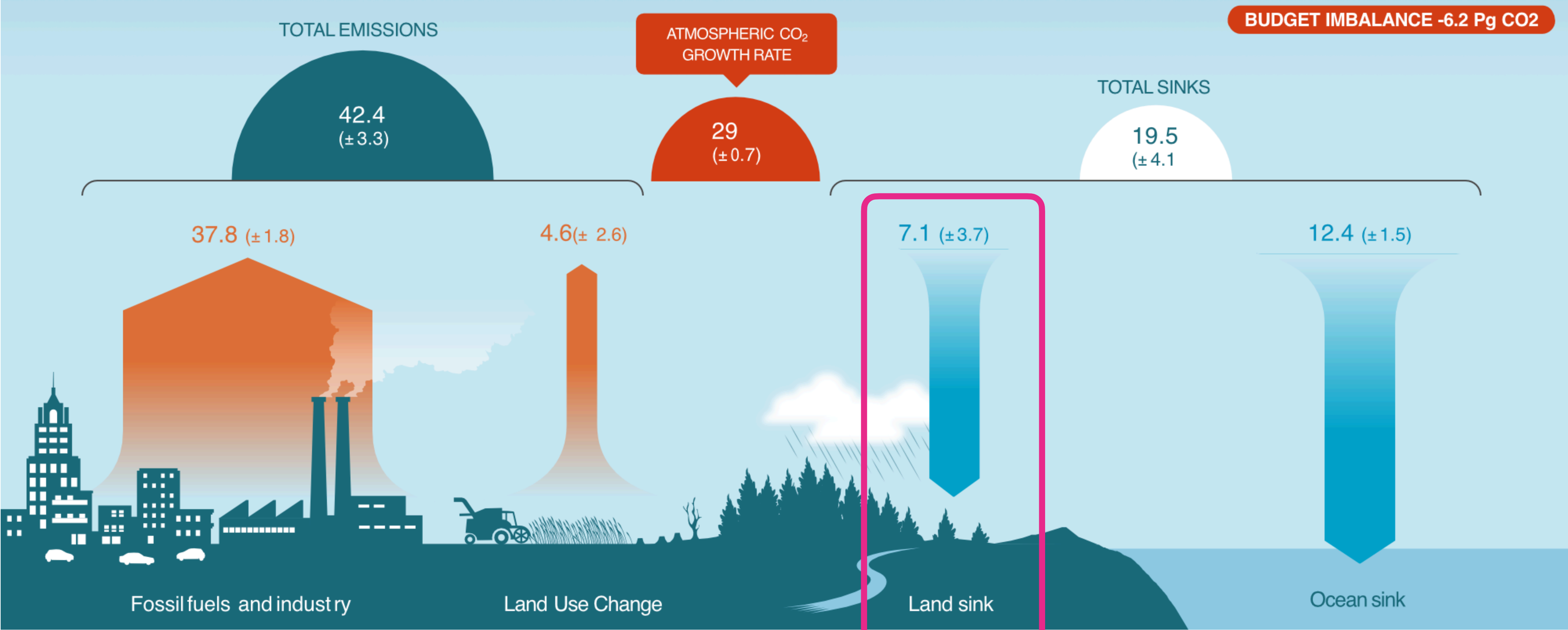
# The Global Carbon Budget

## EMISSIONS AND SINKS

In billion-tons CO<sub>2</sub> per year (Pg CO<sub>2</sub>/ yr), in 2024

Anthropogenic emissions      Sinks of anthropogenic emissions

- The **land sink** has the most uncertainty and is the most variable term in the budget.
- The drivers of the **land sink's** variability are poorly resolved. Unclear if the sink will continue under future climate scenarios.

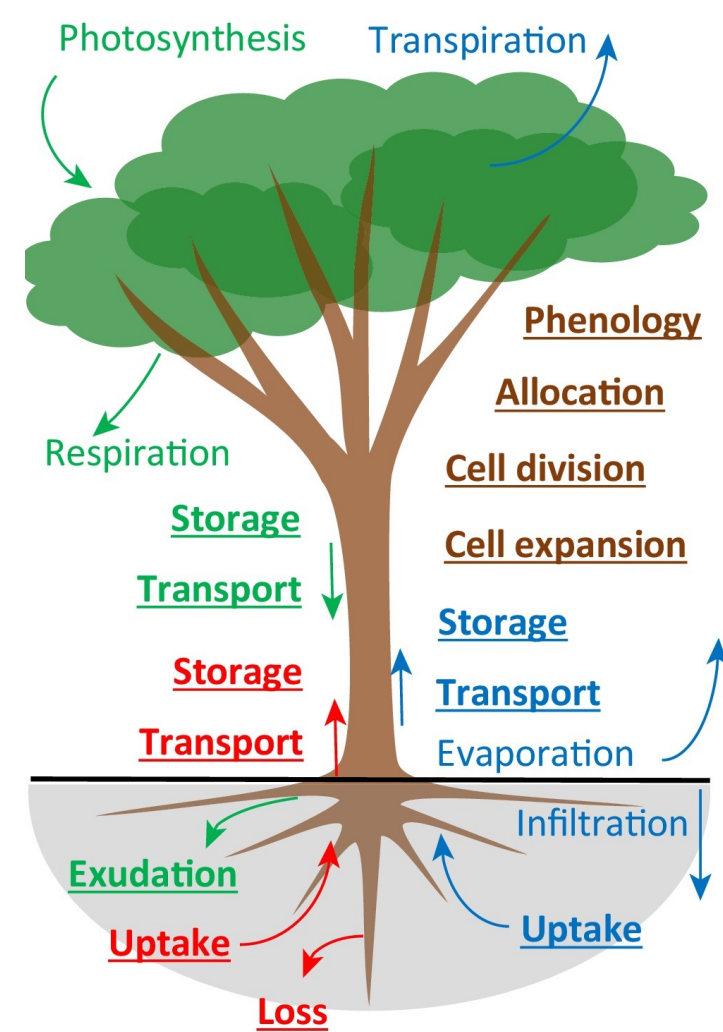


Two approaches for  
estimating the land sink



**Land-atmosphere CO<sub>2</sub> flux**

Two approaches for estimating the land sink



Bottom-up estimate

Land-atmosphere CO<sub>2</sub> flux

Process-based models:  
Simulations of terrestrial carbon cycling and ecosystem processes

Climate forcing:  
meteorology, CO<sub>2</sub> concentrations, land cover, etc

TRENDY global vegetation model ensemble



**Top-down estimate**

**Satellite XCO<sub>2</sub> retrievals:**  
observations of column-averaged atmospheric CO<sub>2</sub> (XCO<sub>2</sub>)



**Atmospheric inversions:**  
prior, transport model, and optimization framework

**OCO-2 model intercomparison project (MIP) ensemble**

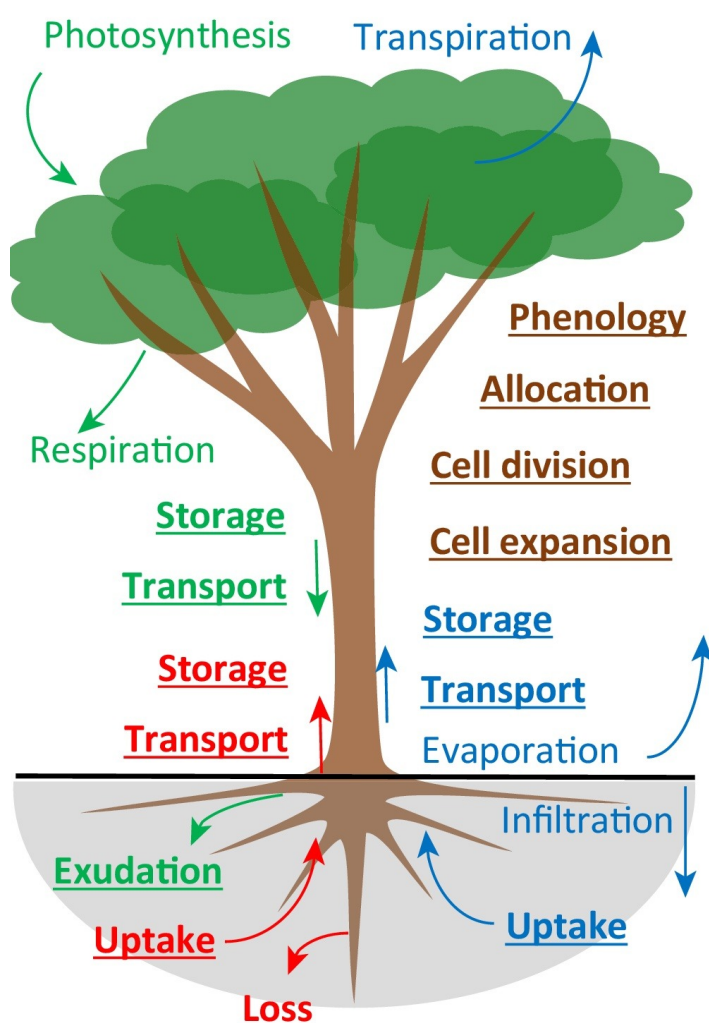


**Land-atmosphere CO<sub>2</sub> flux**

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**Bottom-up estimate**



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**Bottom-up  
estimate**

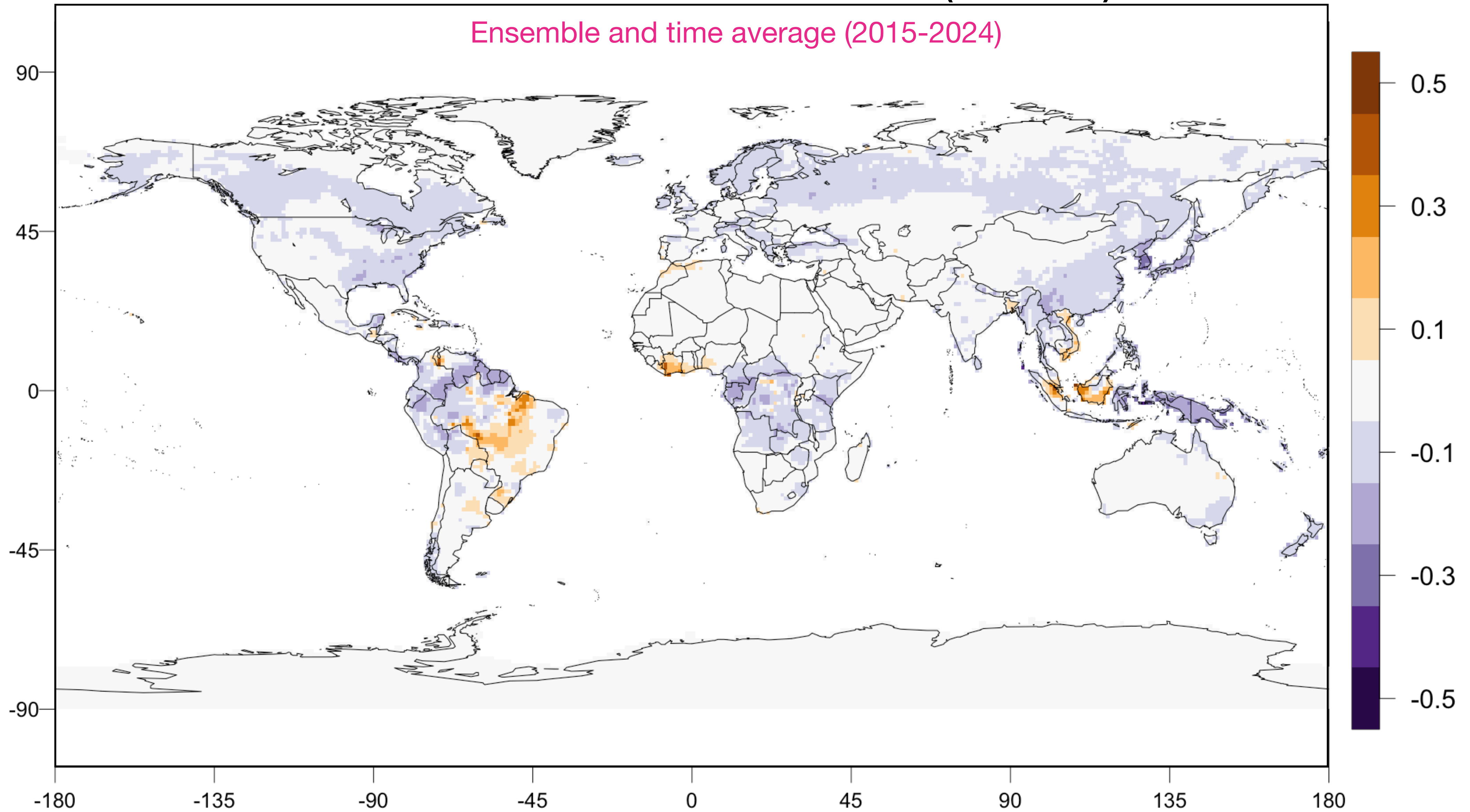
The **bottom-up estimate** is used in  
the Global Carbon Budget.

Can we use the top-down estimate  
to evaluate the bottom-up estimate?

# Process- and satellite-based estimates disagree on magnitude and spatial pattern of the land flux

## Process-based estimate of the land flux ( $\mu\text{mol}/\text{m}^2/\text{s}$ )

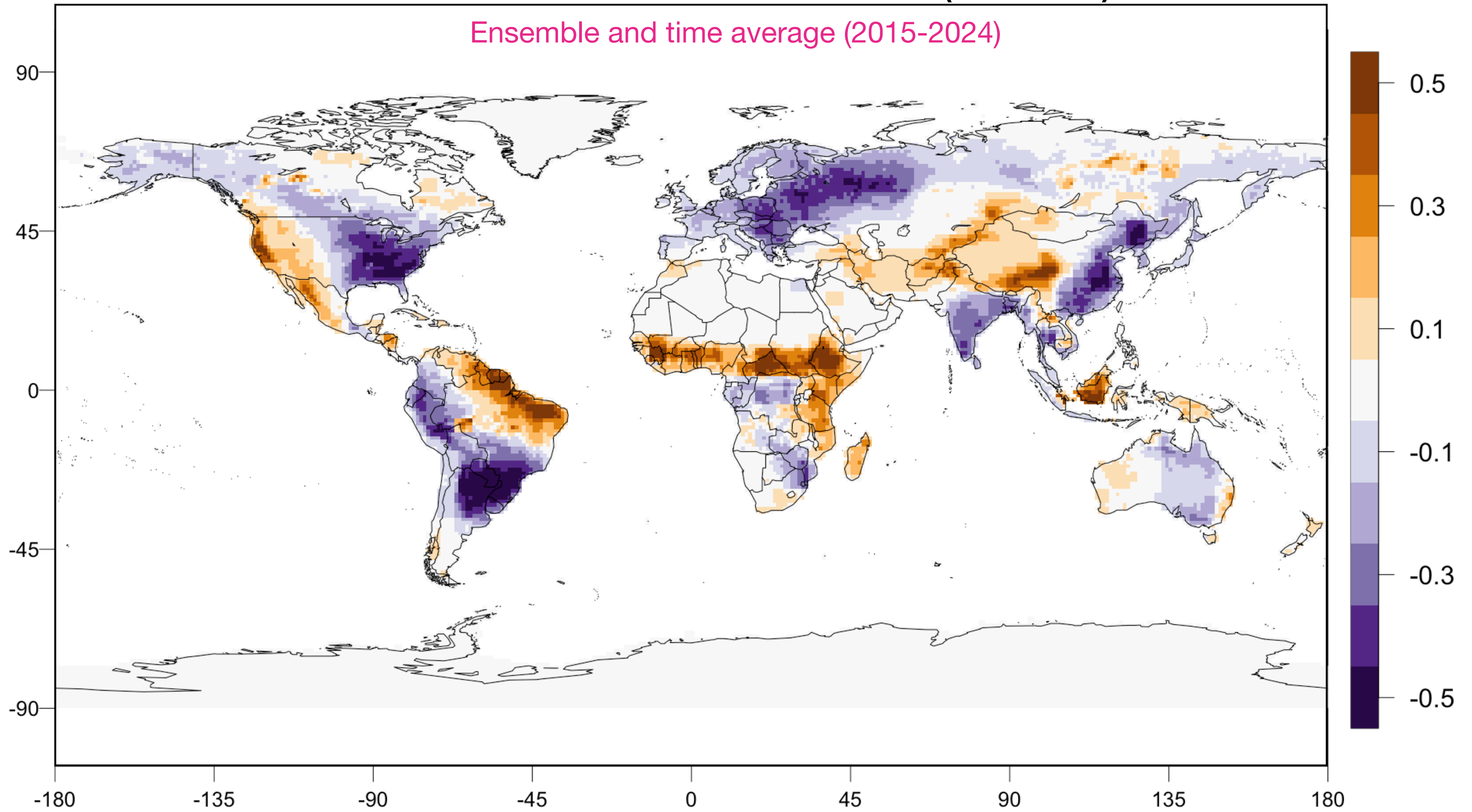
Ensemble and time average (2015-2024)



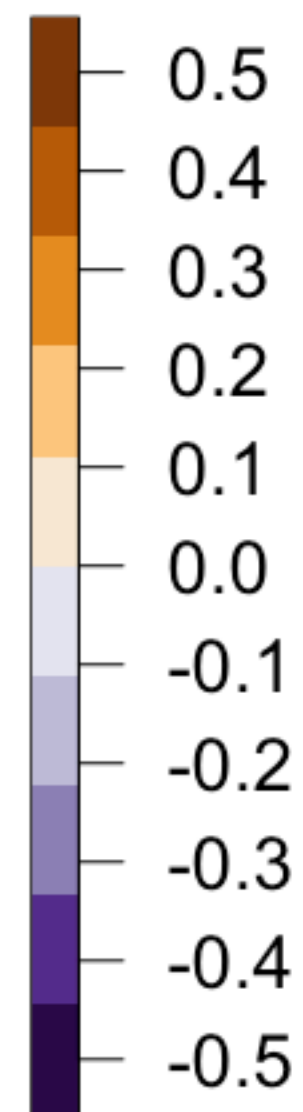
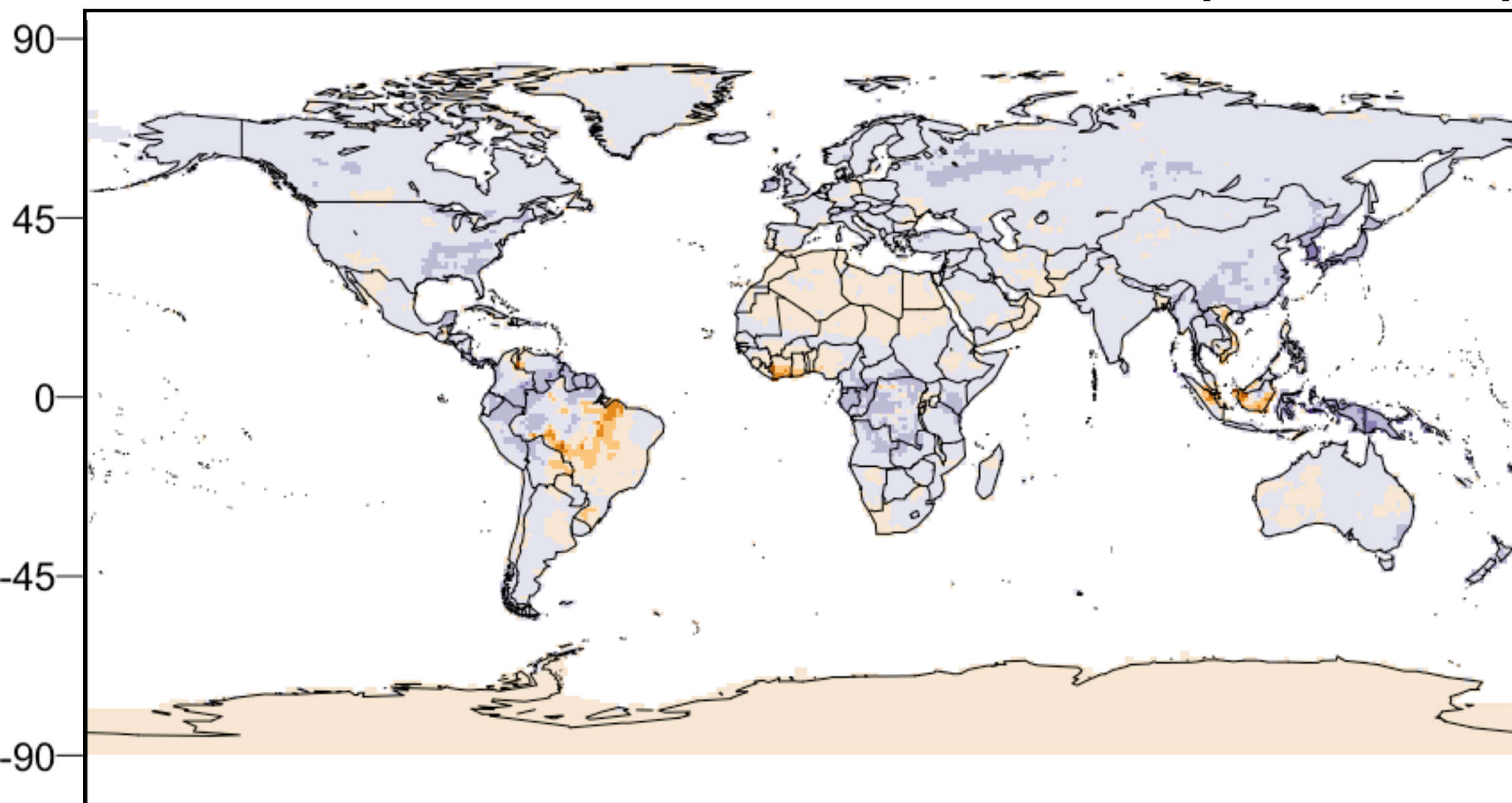
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## Satellite-based estimate of the land flux ( $\mu\text{mol}/\text{m}^2/\text{s}$ )

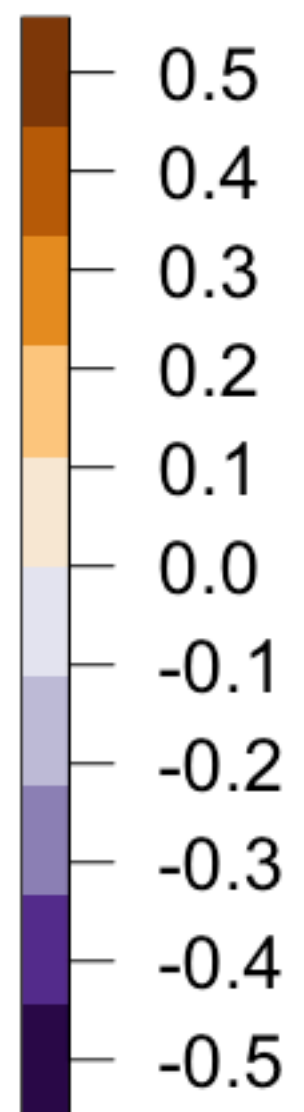
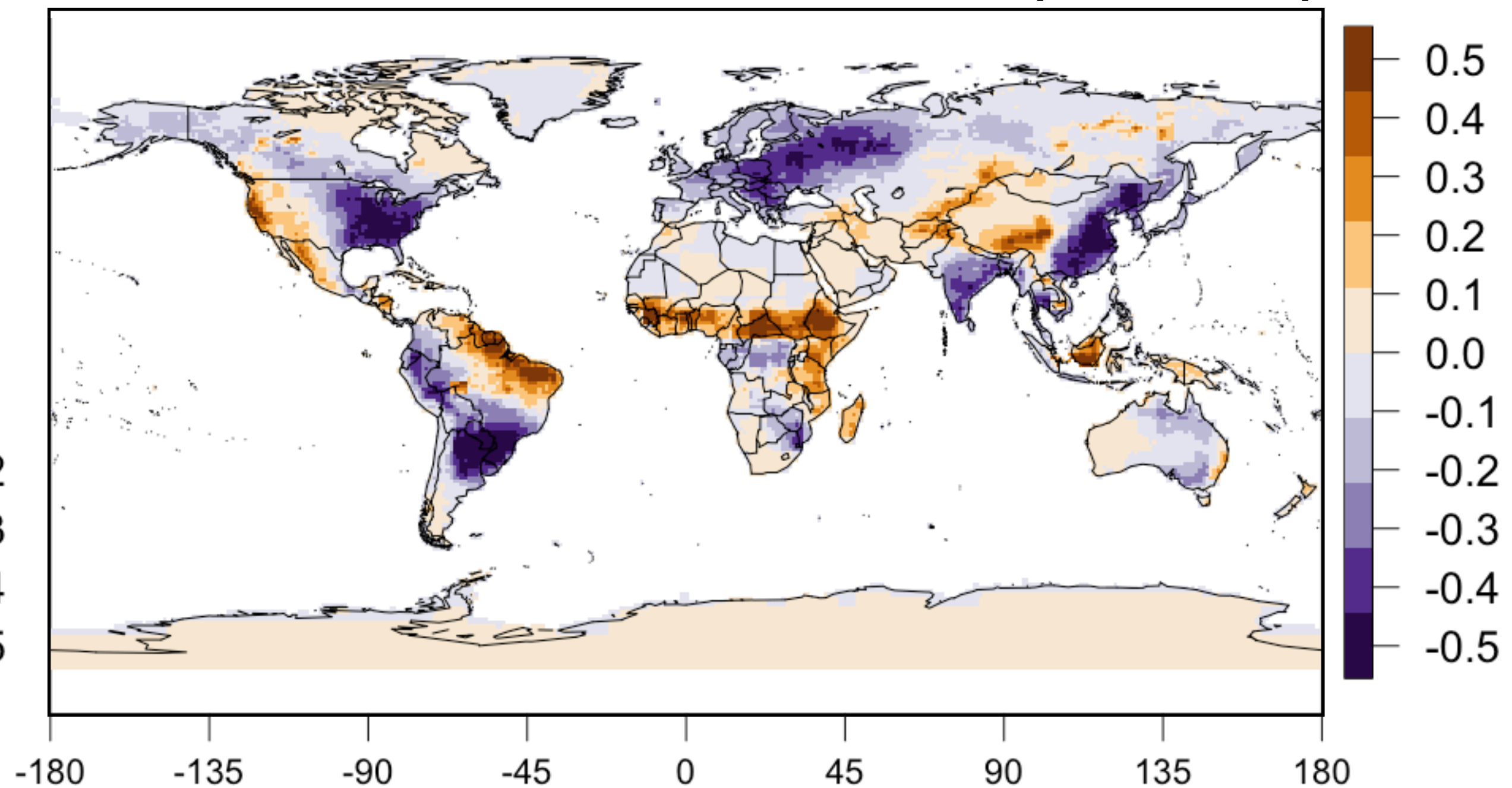
Ensemble and time average (2015-2024)



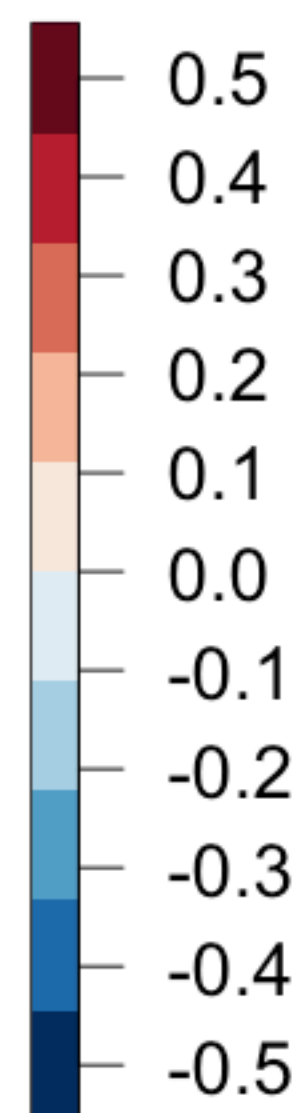
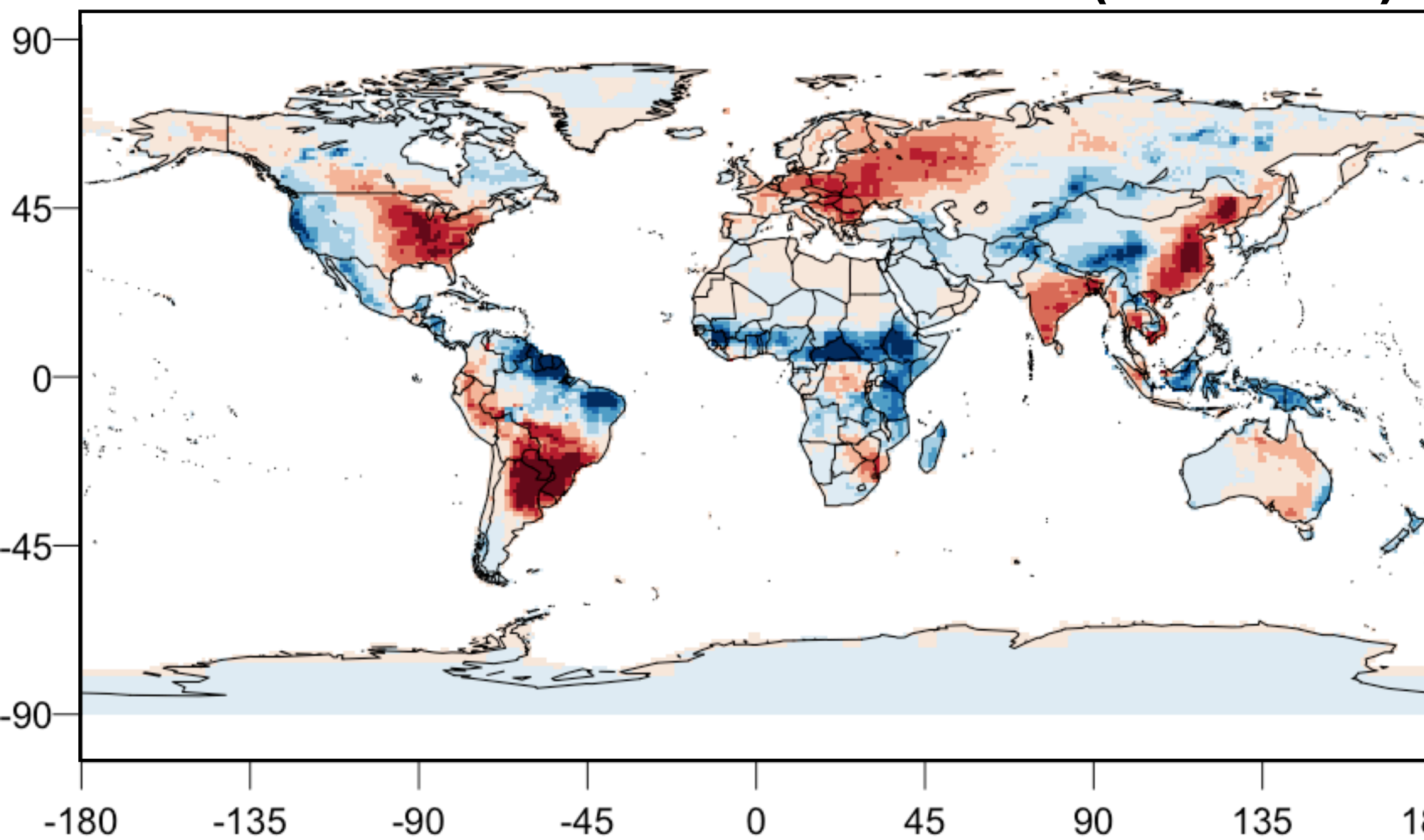
**Process-based estimate of the land flux (umol/m2/s)**



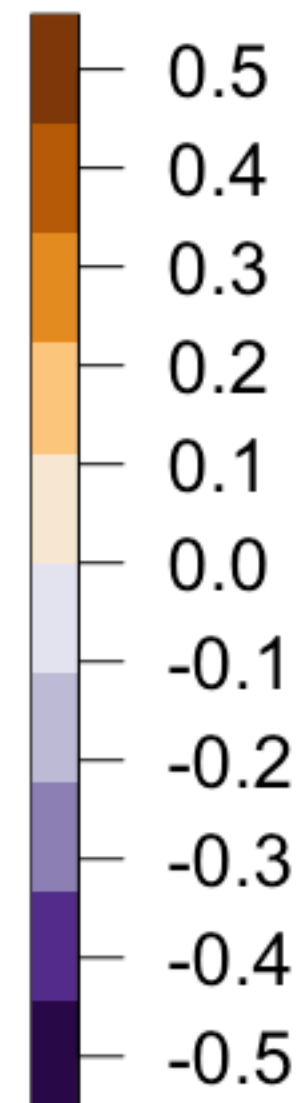
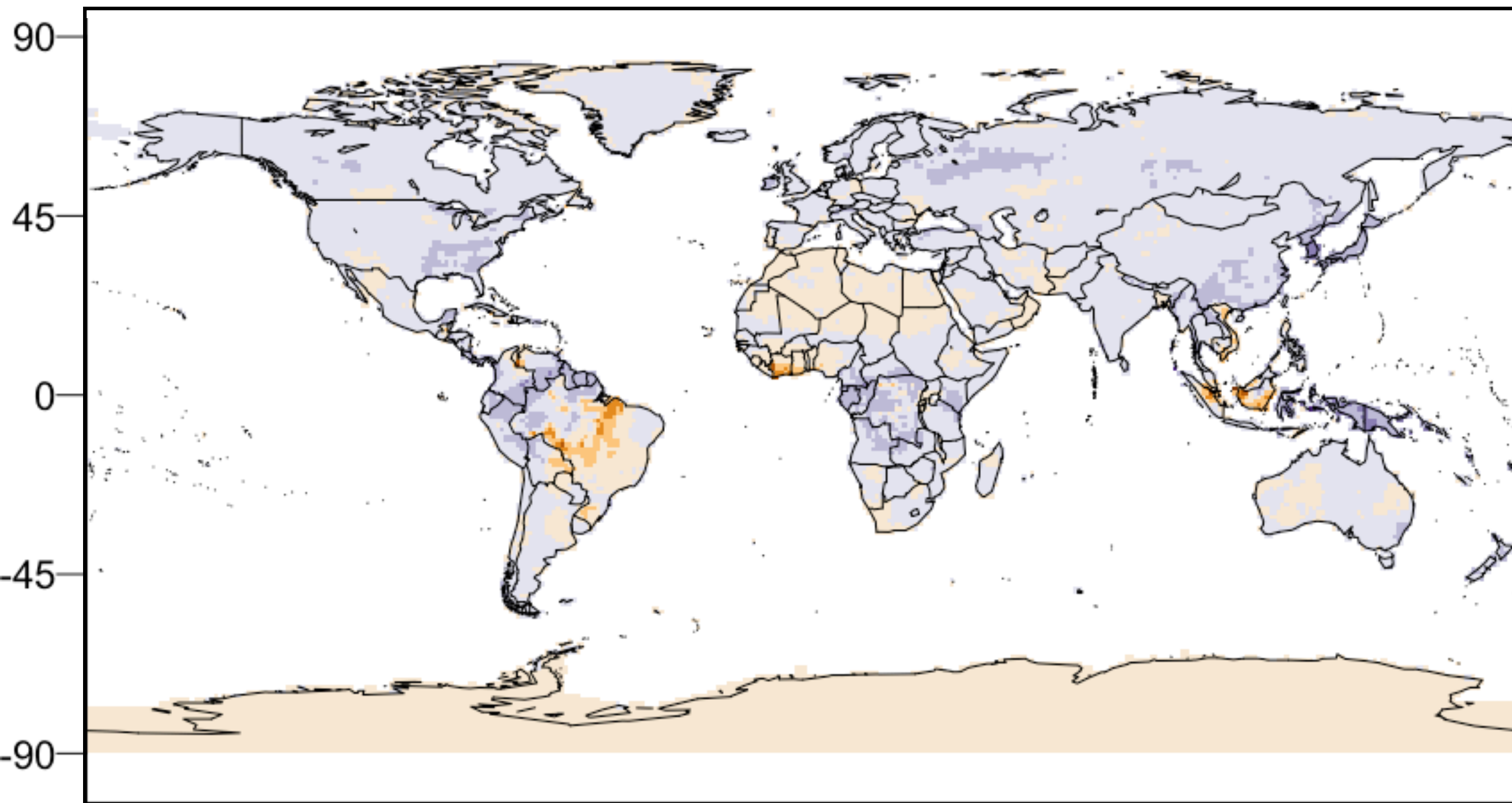
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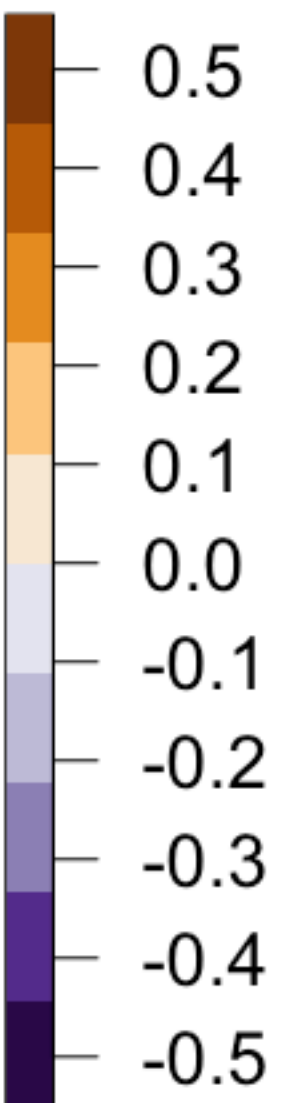
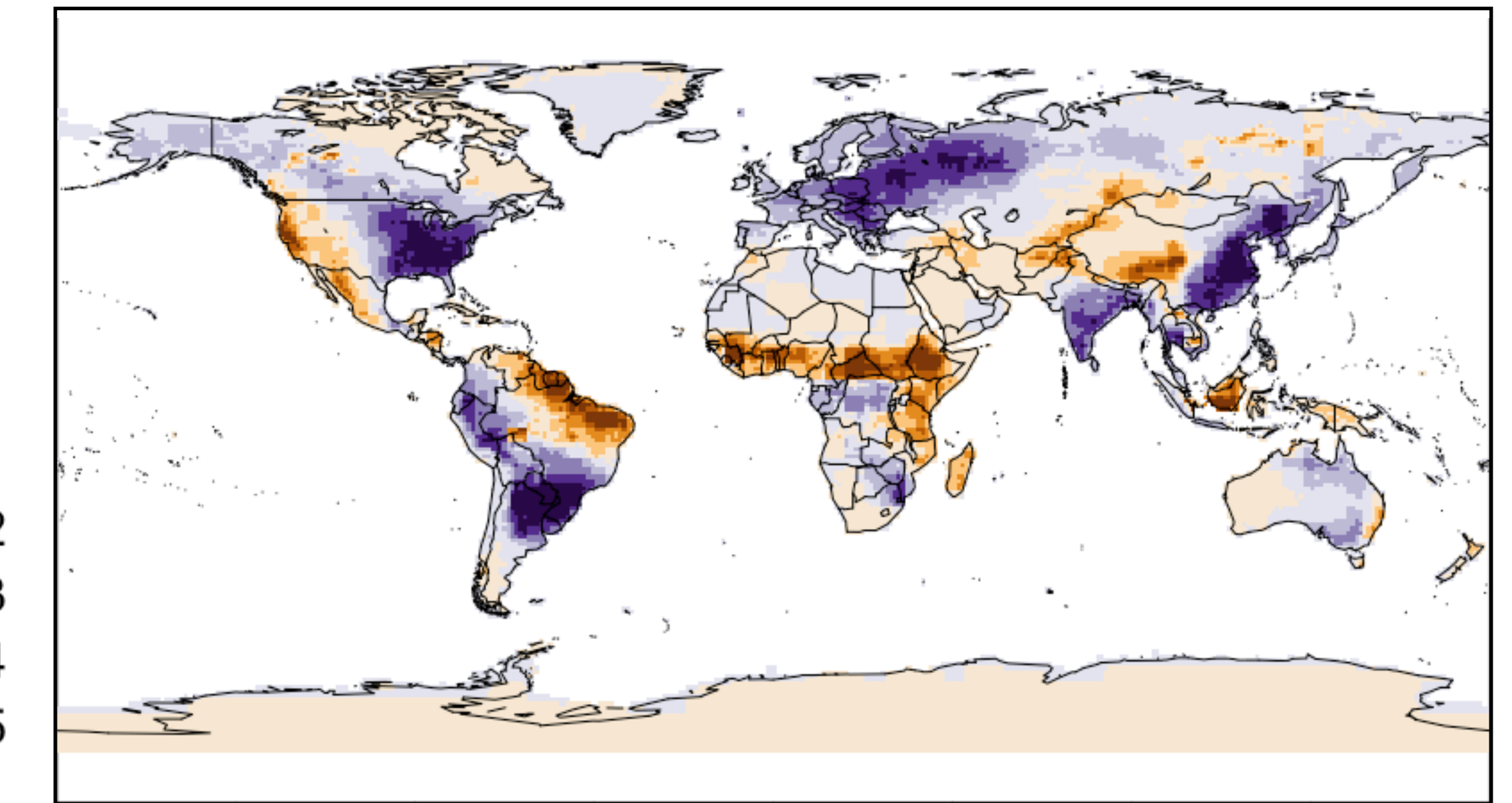
**Process-based minus satellite-based (umol/m2/s)**



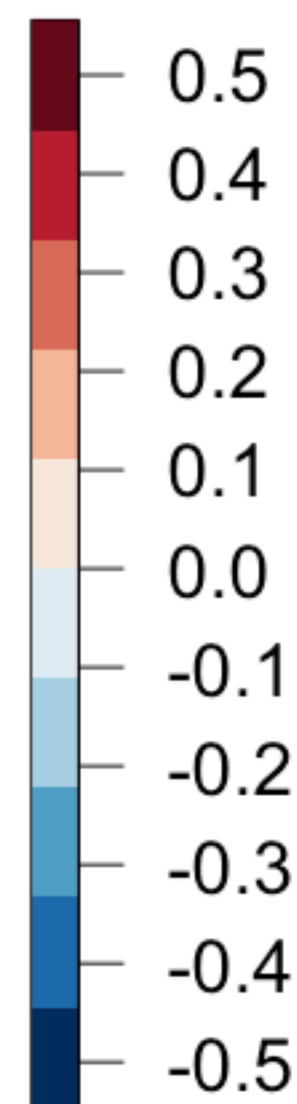
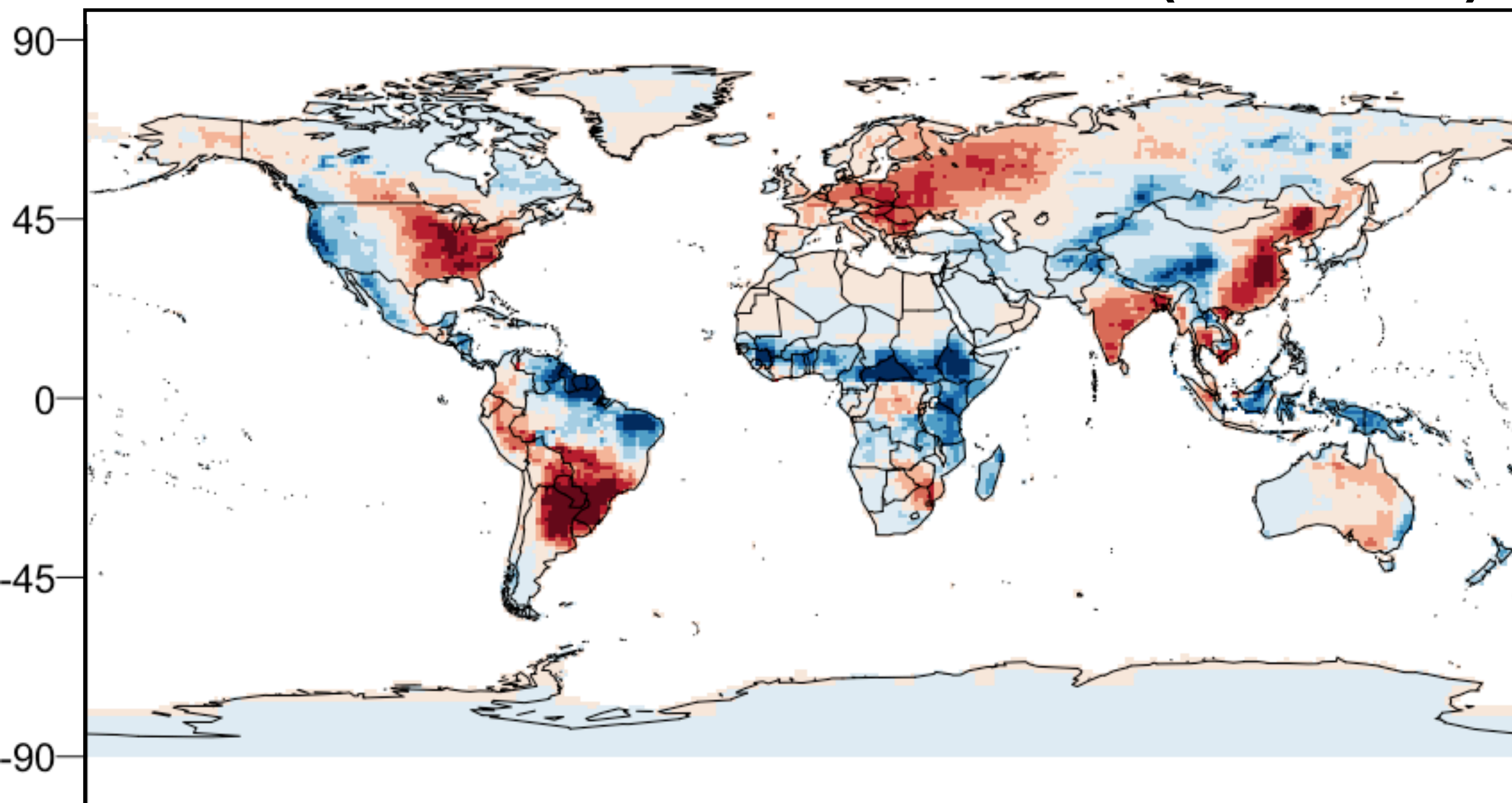
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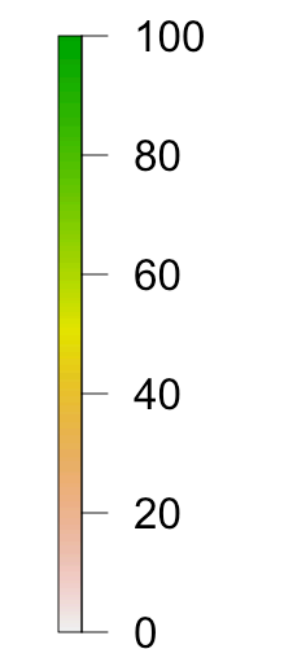
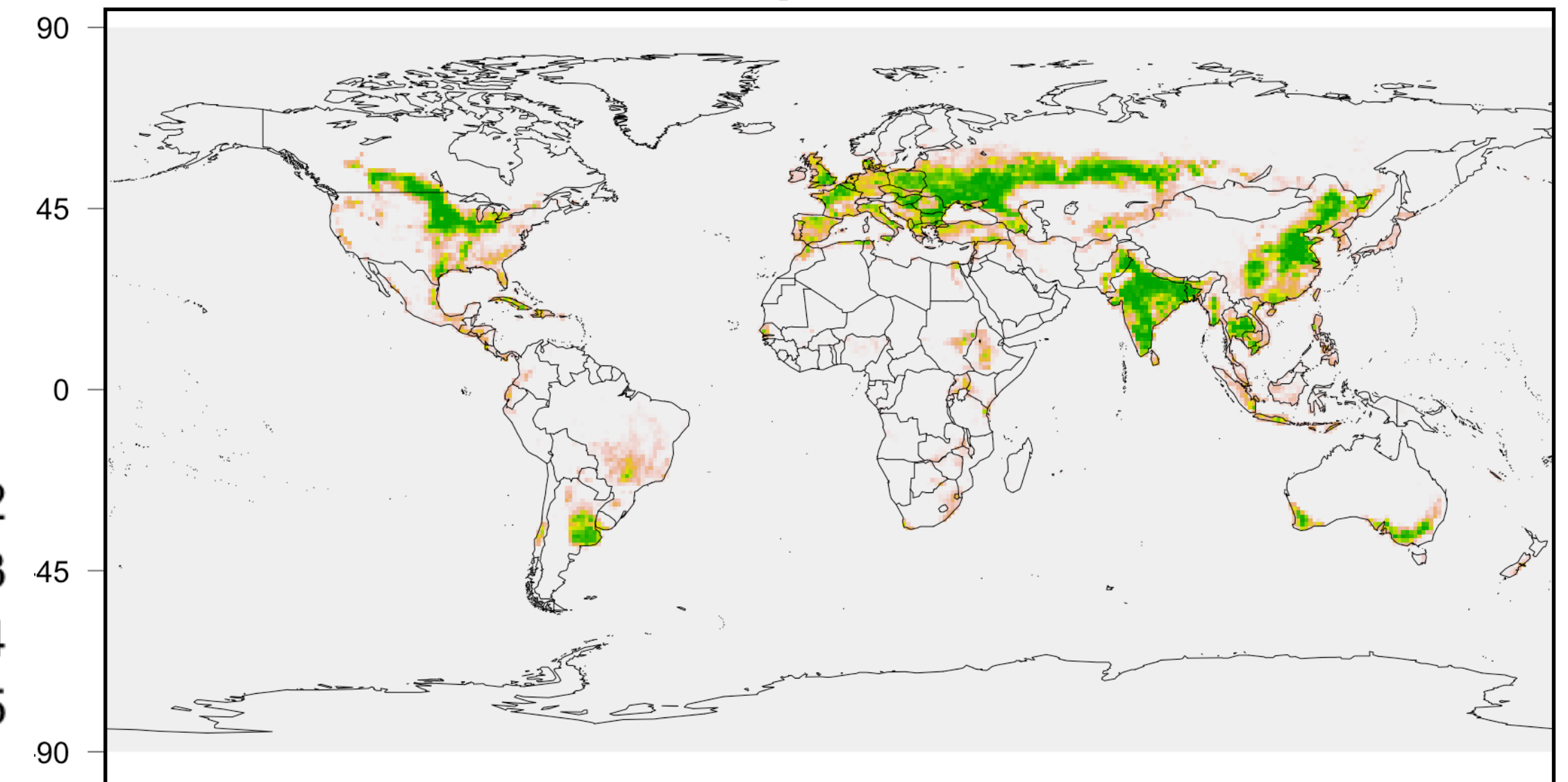
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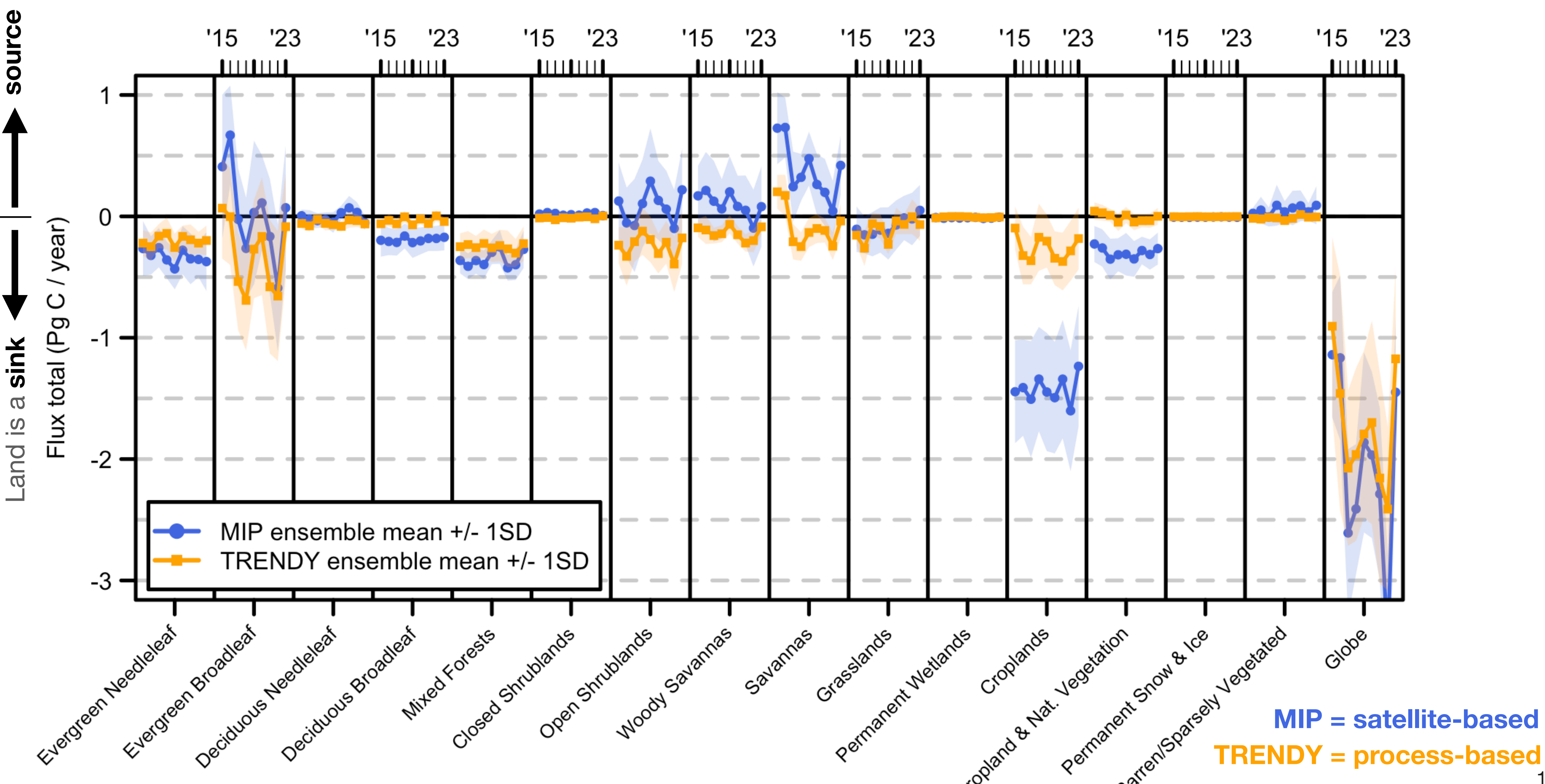
**MODIS Cropland Fraction**



-180 -135 -90 -45 0 45 90 135 180

-180 -135 -90 -45 0 45 90 135 180 12

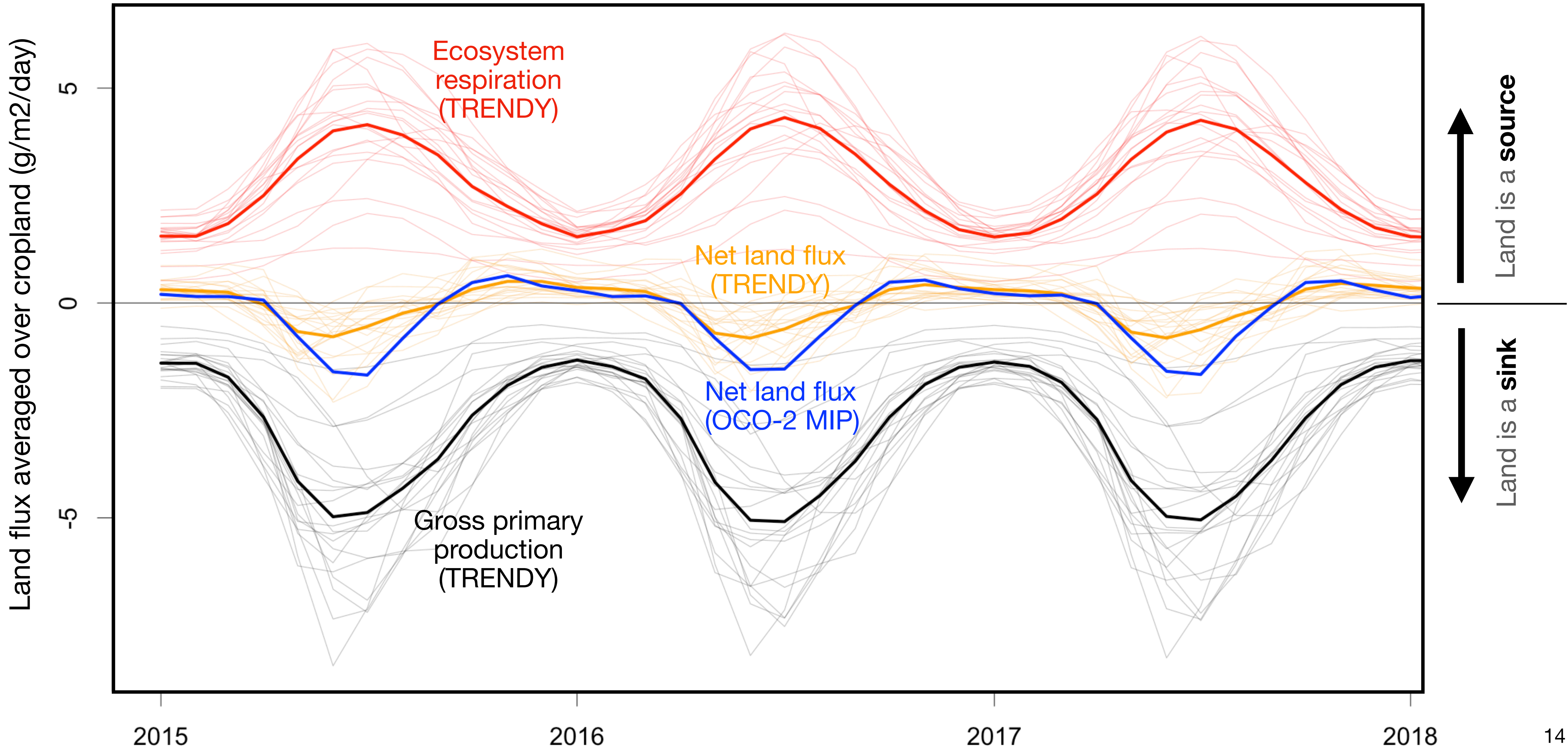
# Landcover class partially explains the difference between process- and satellite-based estimates



# Zoom in on cropland: process-based models miss uptake during peak growing season

**TRENDY = process-based**  
**MIP = satellite-based**

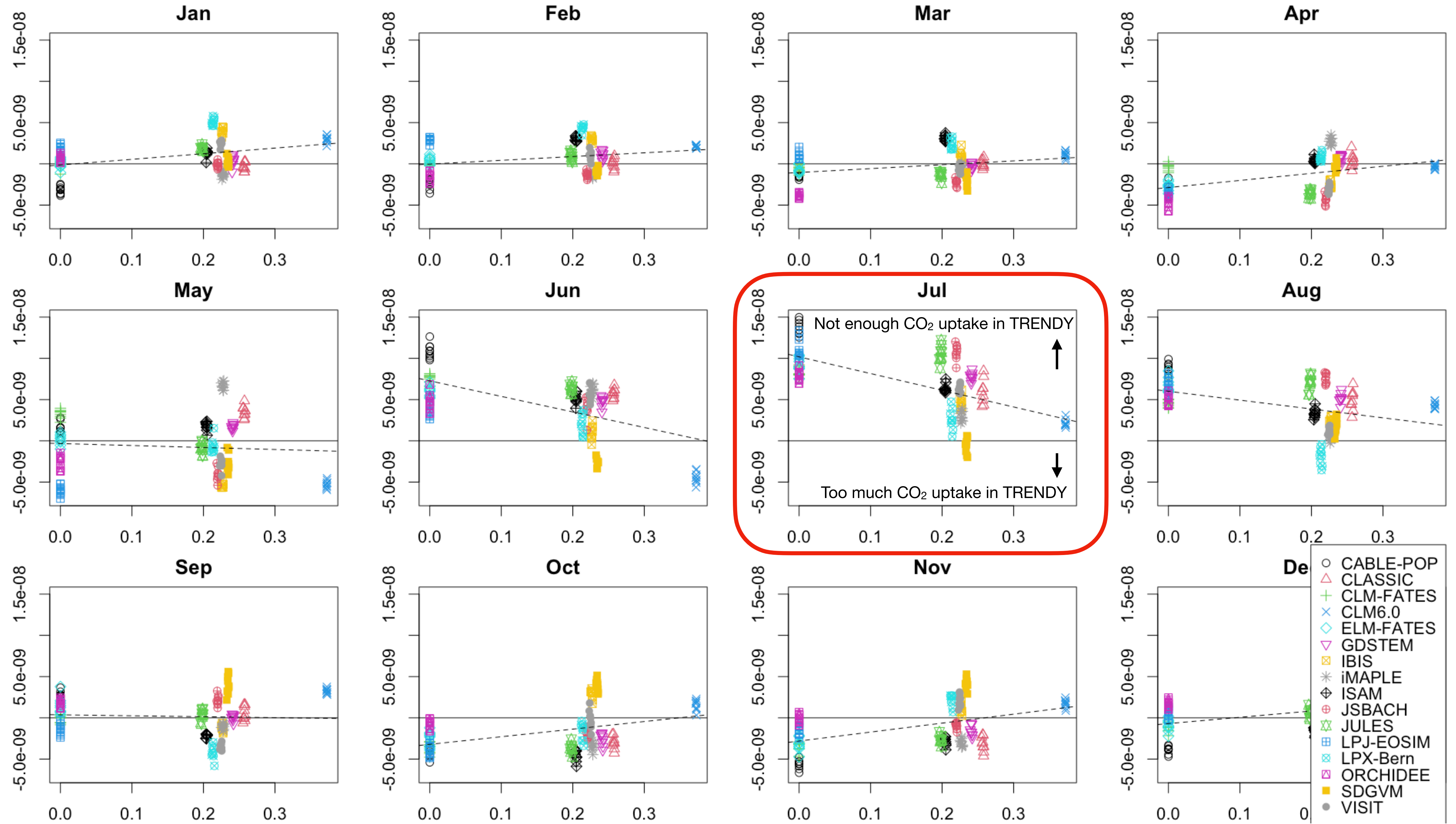
Spatial average over just cropland



**Horizontal axis:** percent cropland according to the TRENDY models

**Vertical axis:** TRENDY flux - MIP flux

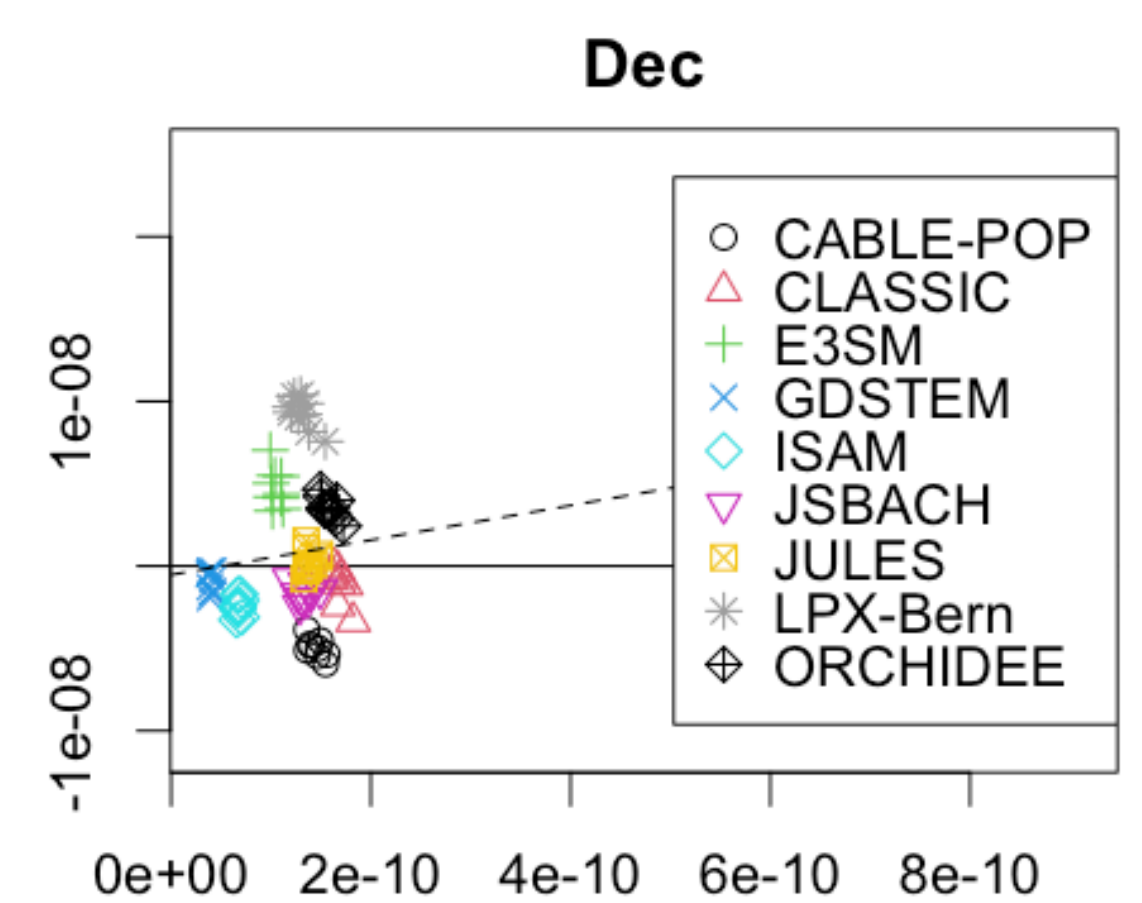
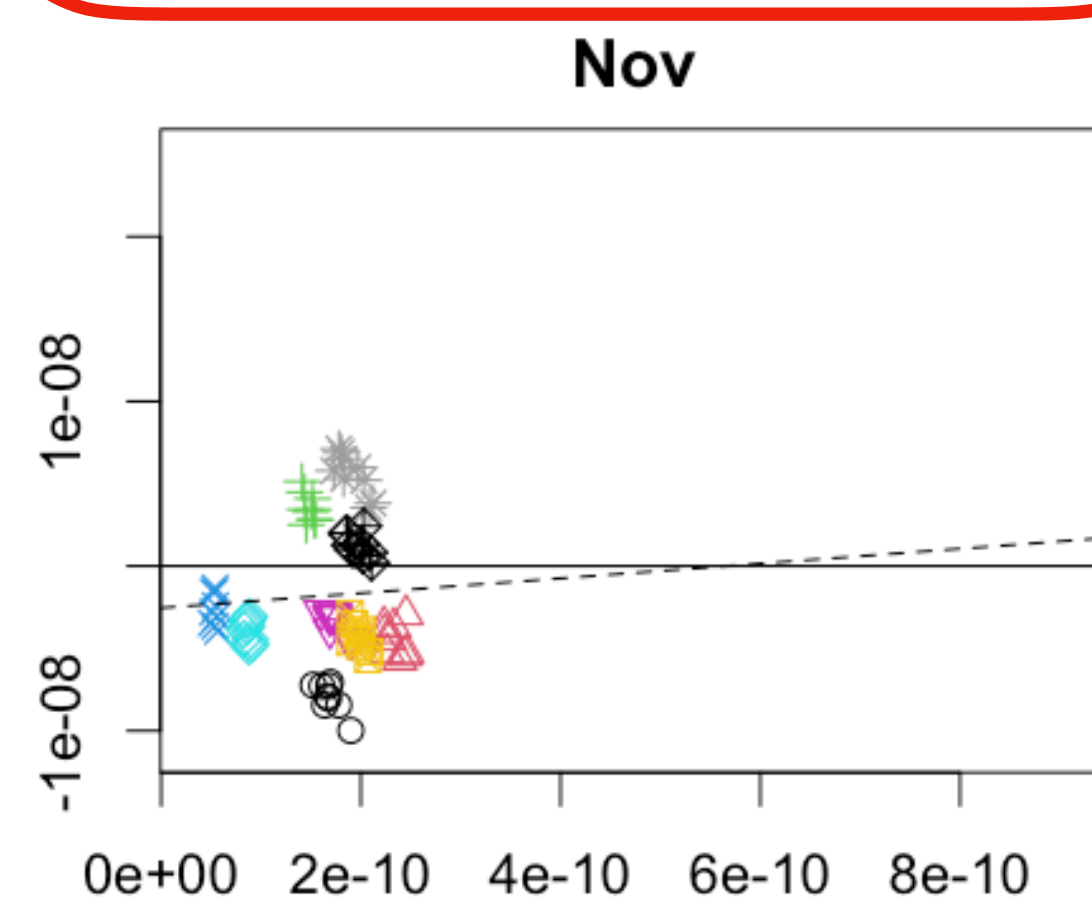
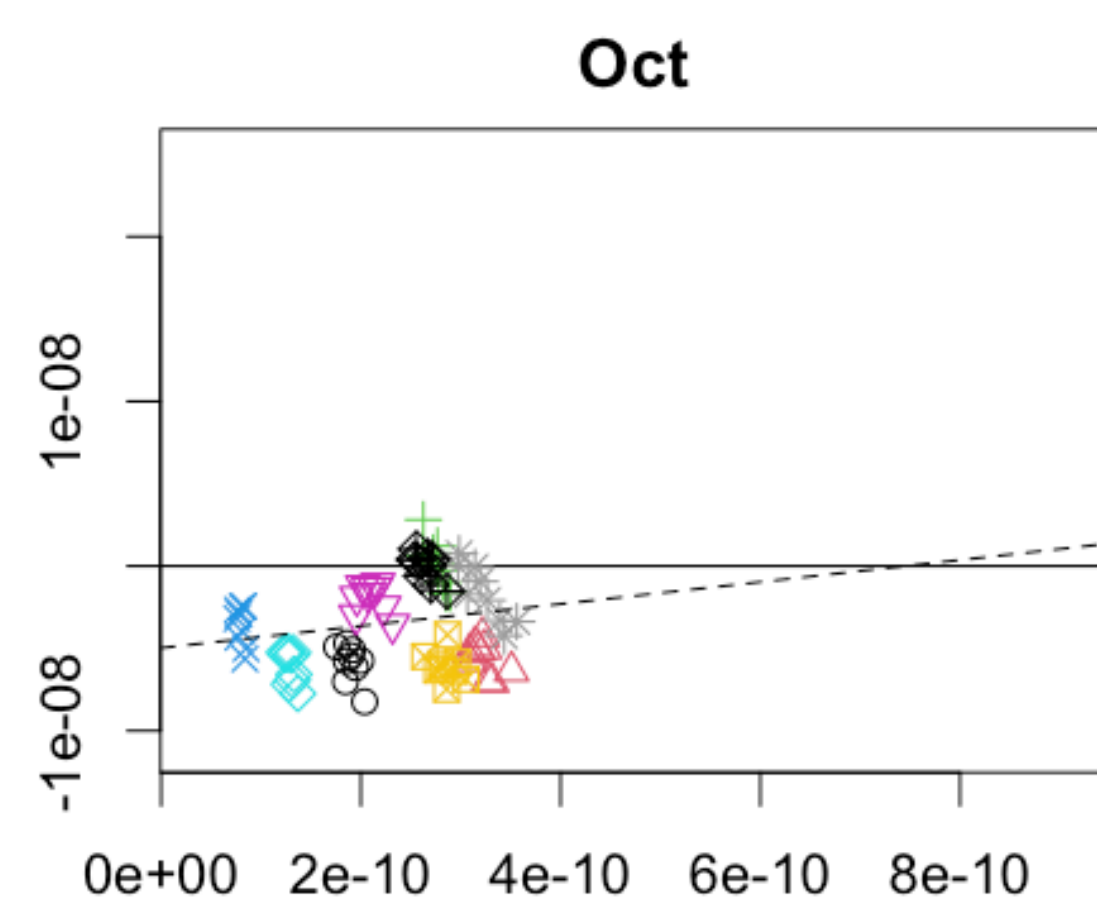
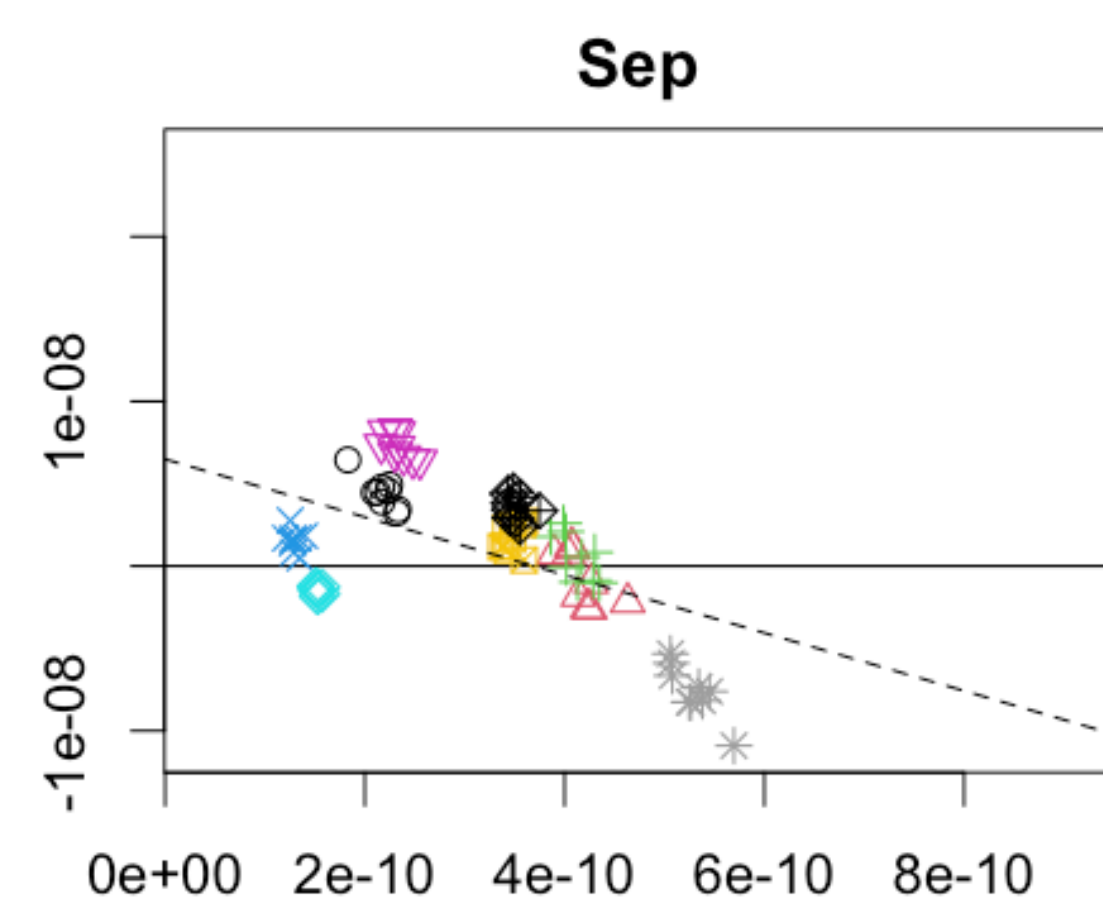
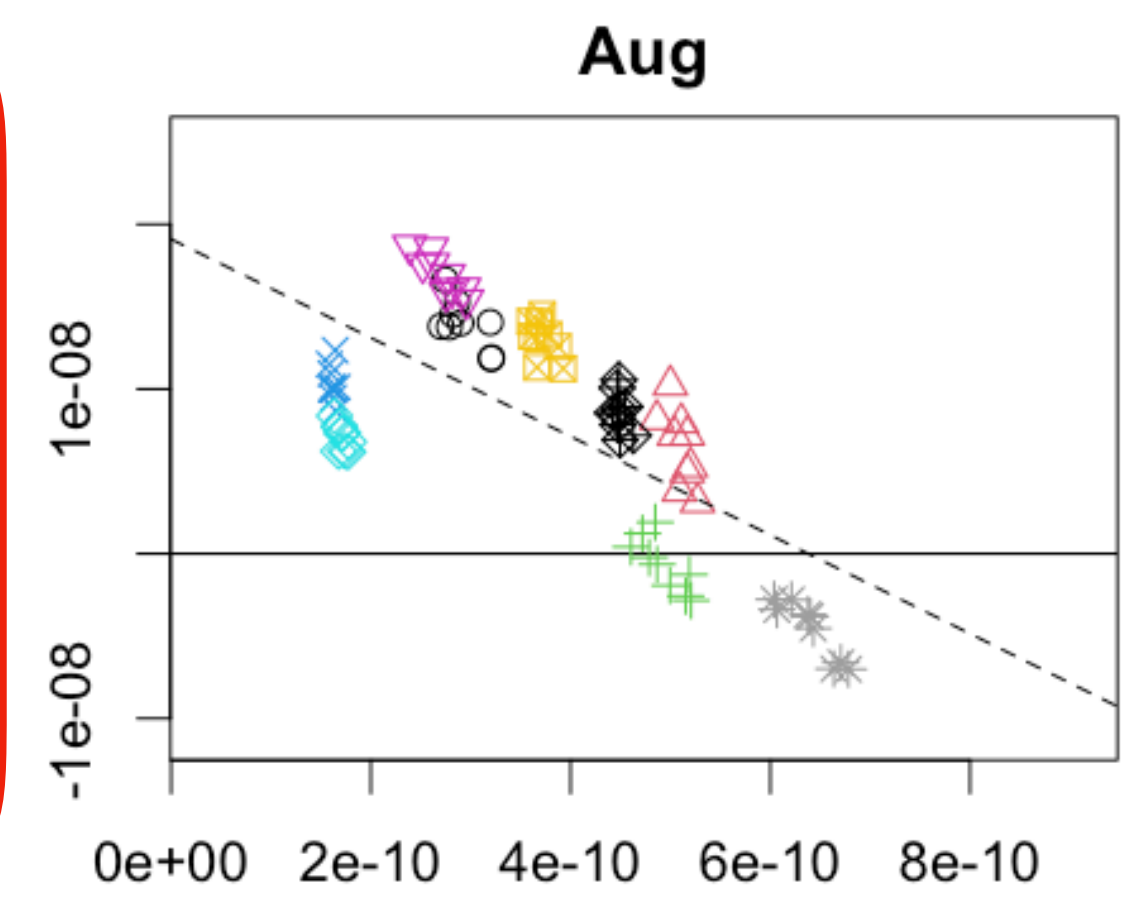
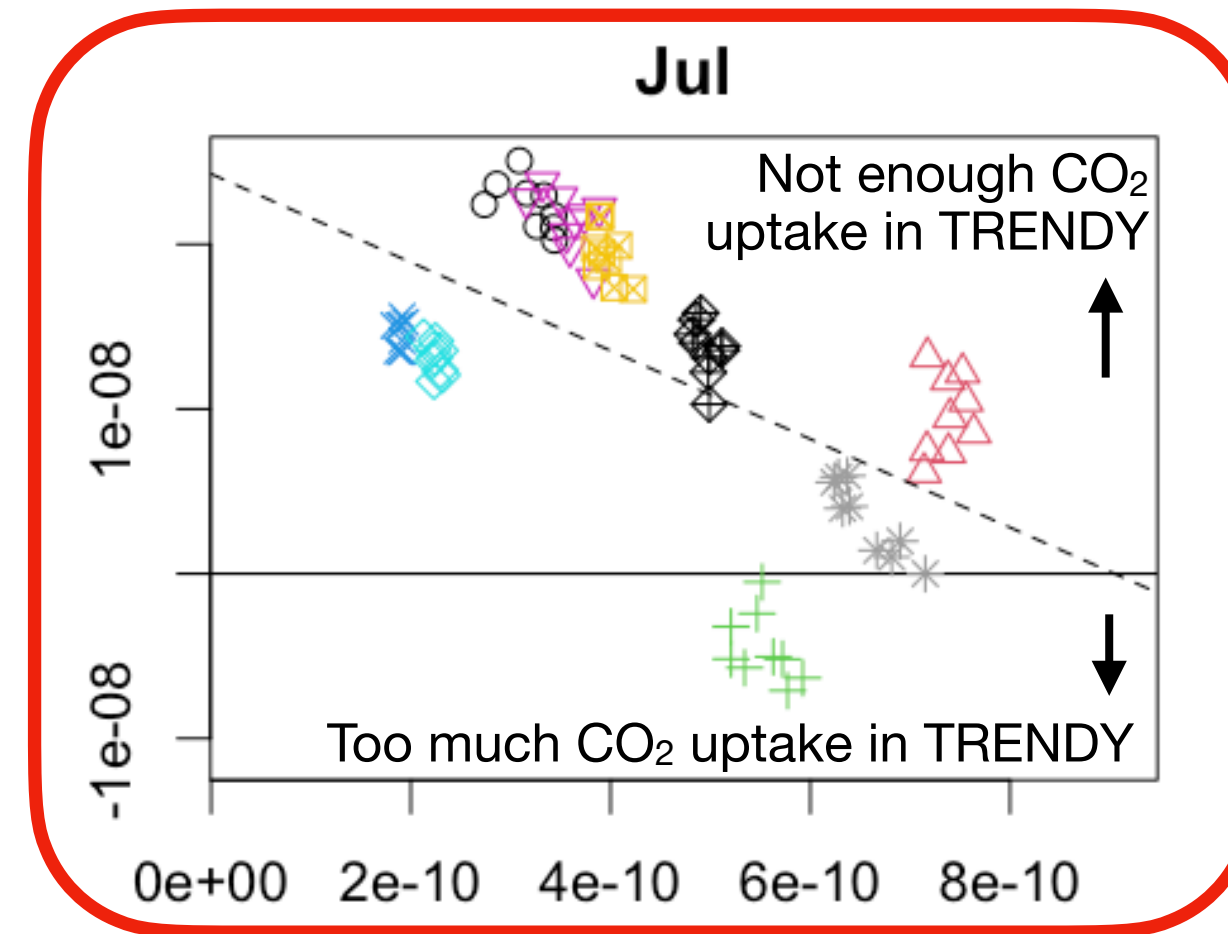
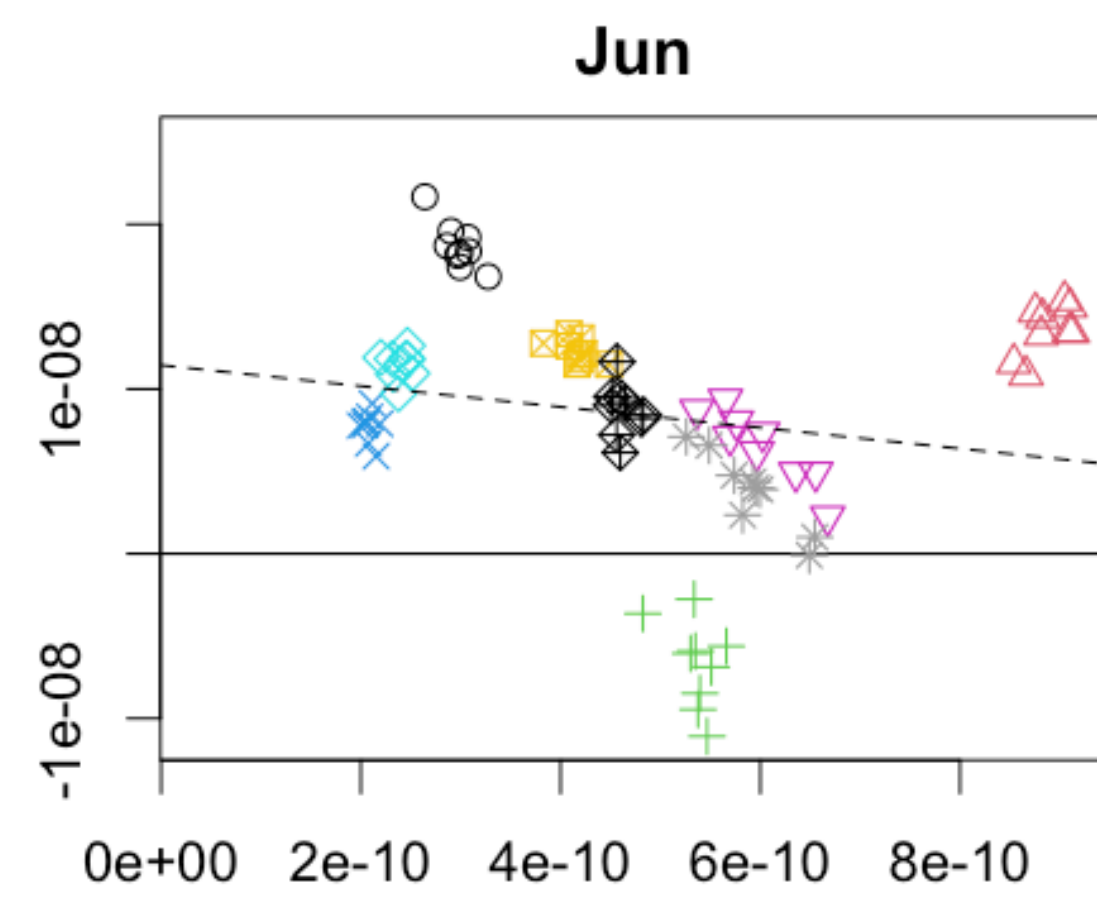
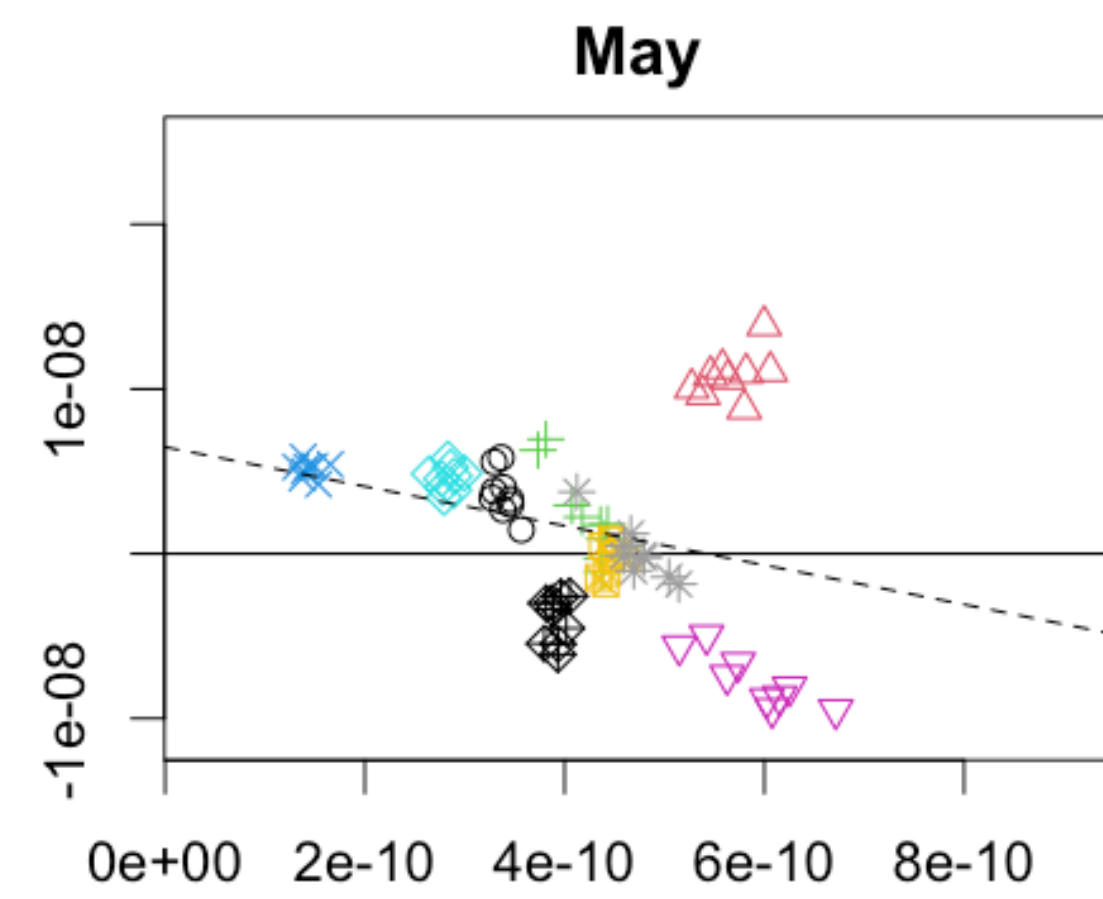
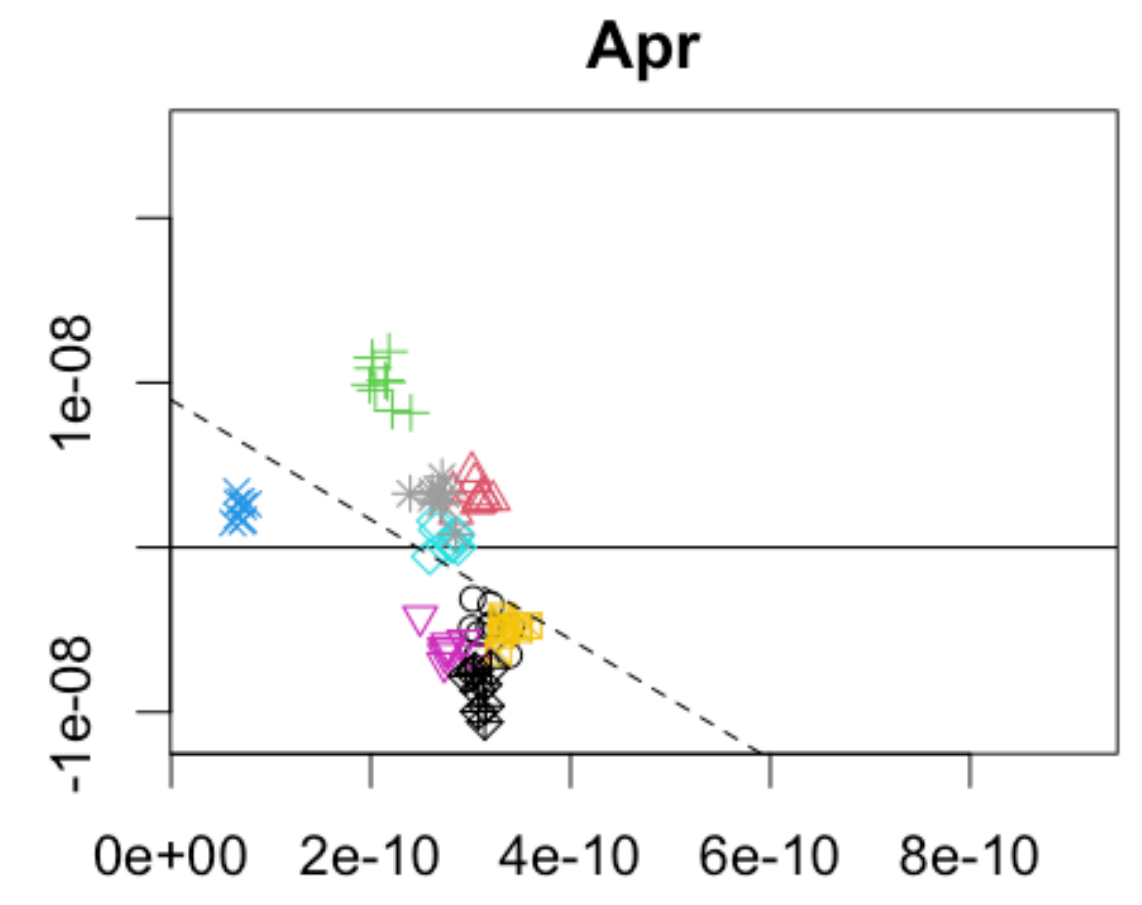
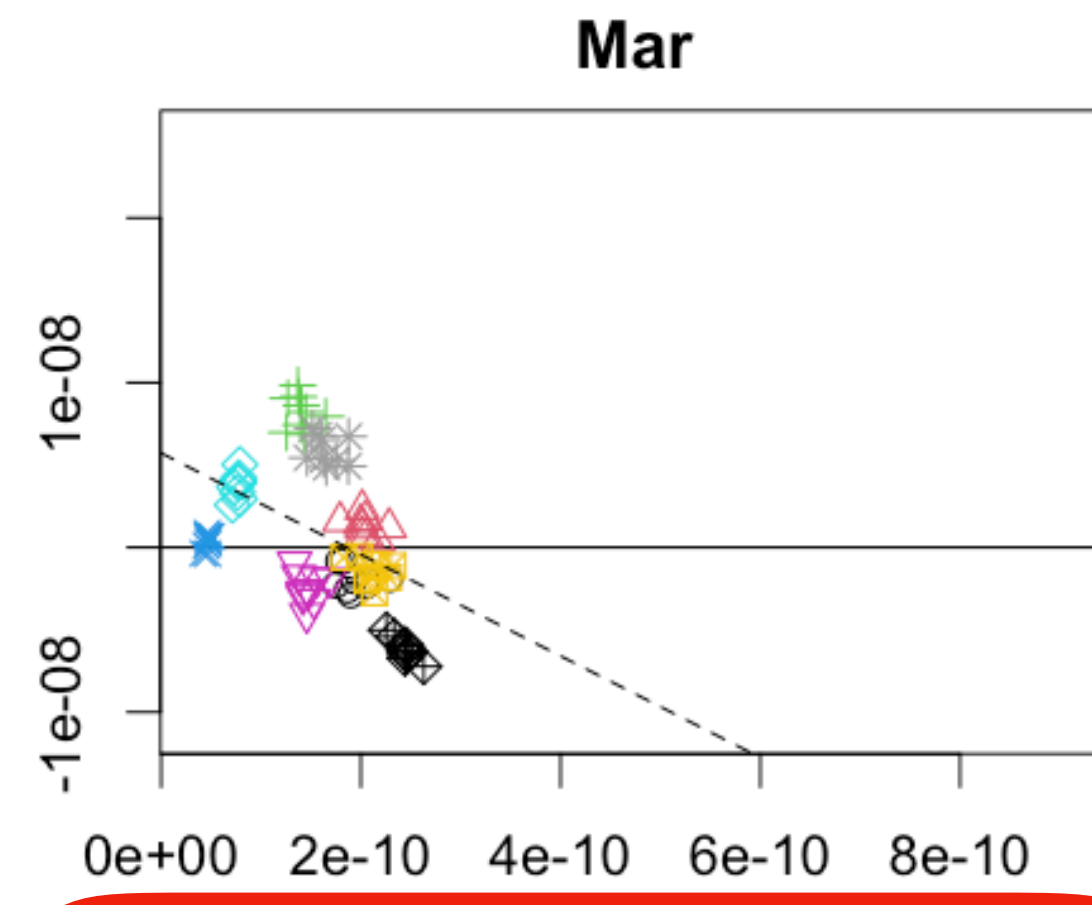
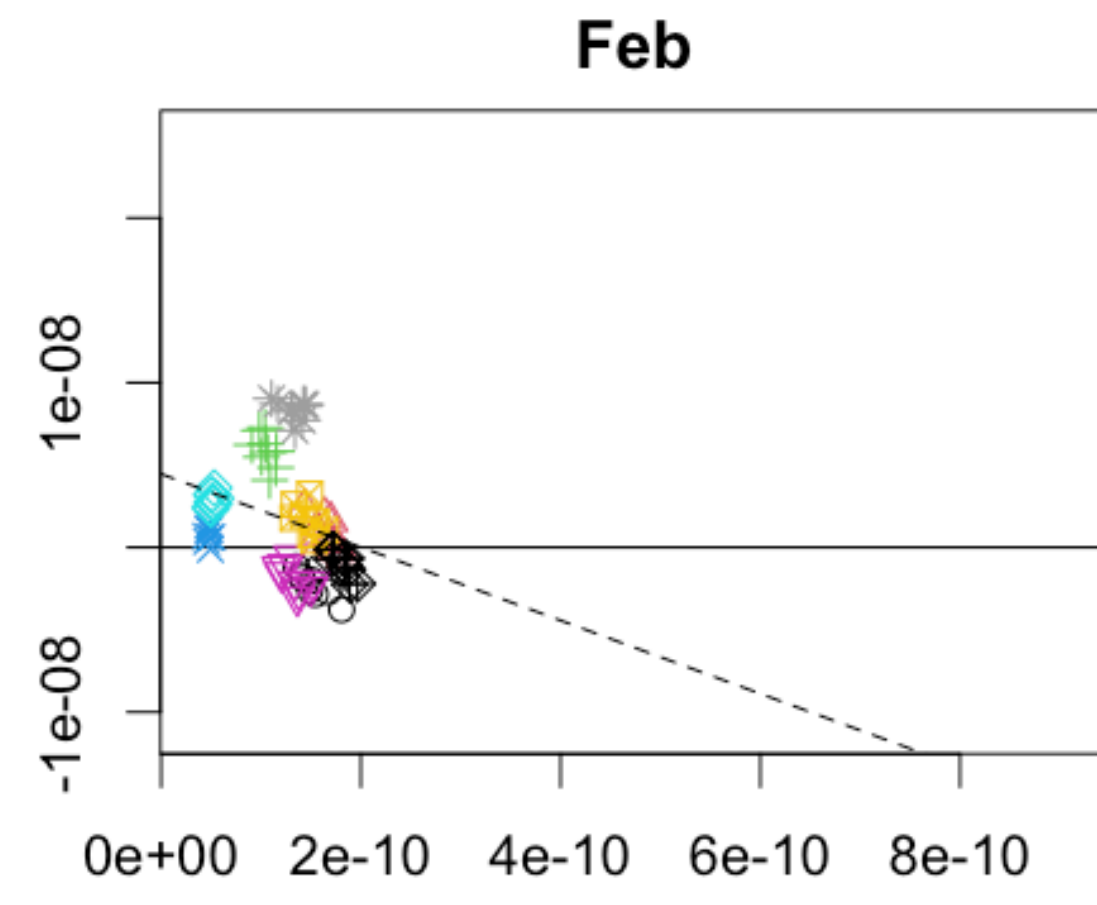
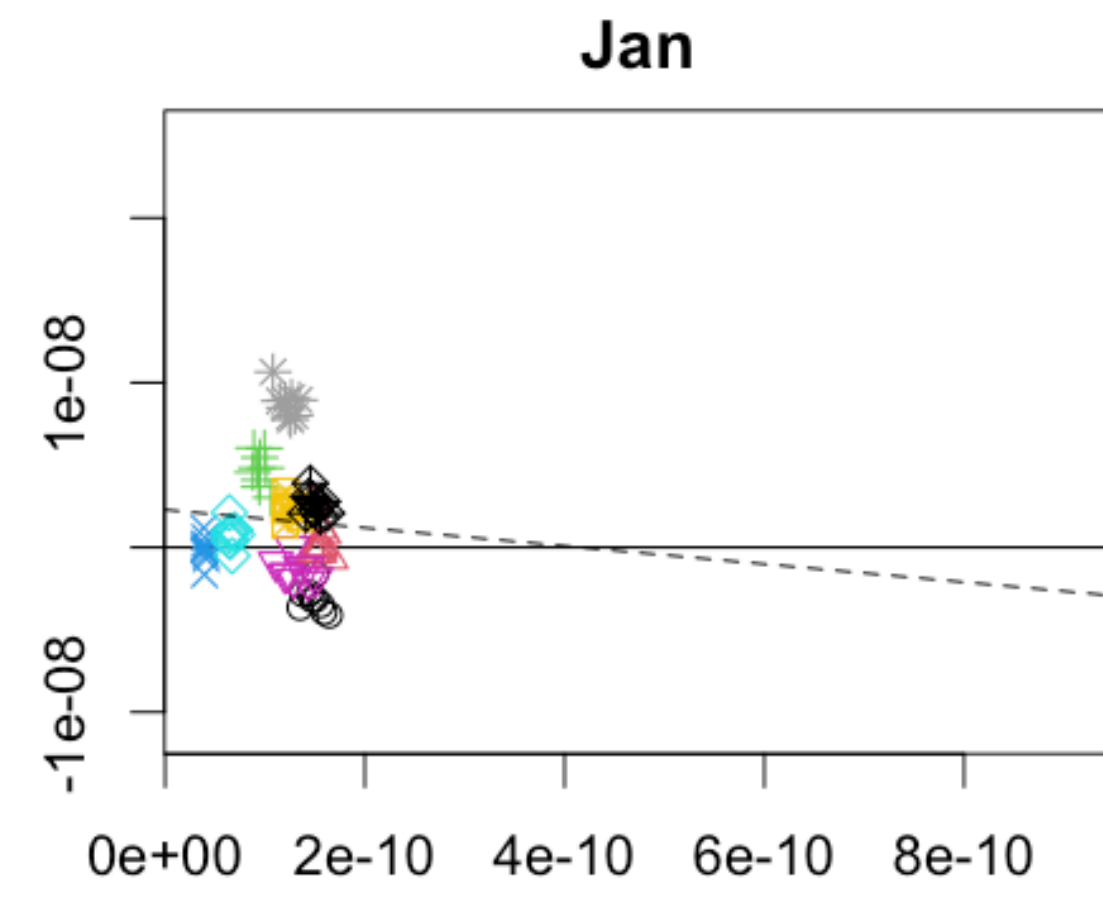
Process-based (TRENDY) flux minus satellite-based (MIP) flux [ $\mu\text{mol}/\text{m}^2/\text{s}$ ]



**Horizontal axis:** total plant N uptake (according to TRENDY)

**Vertical axis:** TRENDY flux - MIP flux

Process-based (TRENDY) flux minus satellite-based (MIP) flux [ $\mu\text{mol}/\text{m}^2/\text{s}$ ]



# Summary and take-aways

- We are comparing top-down, satellite-based estimates of the terrestrial carbon cycle to bottom-up, process based models

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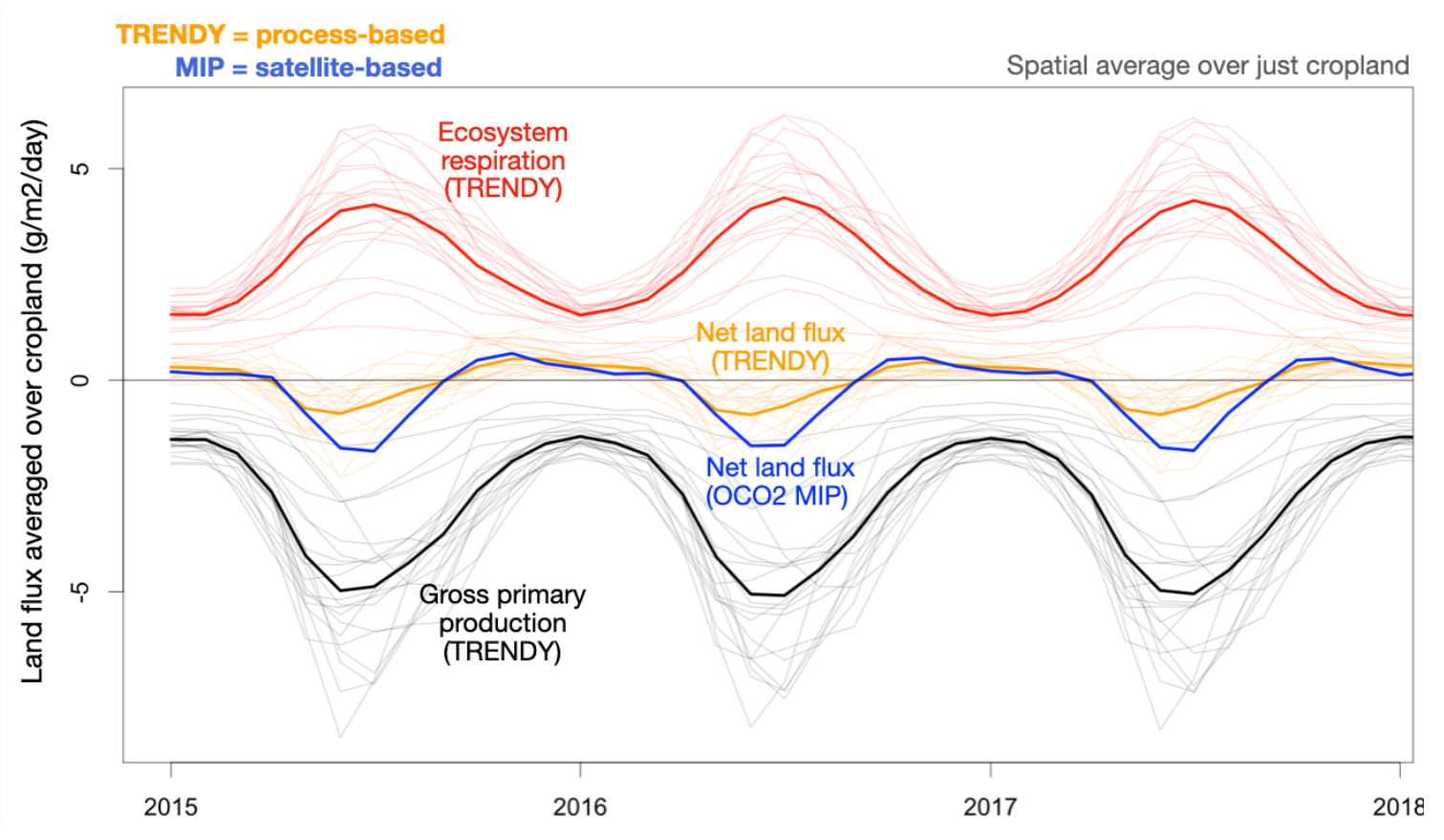
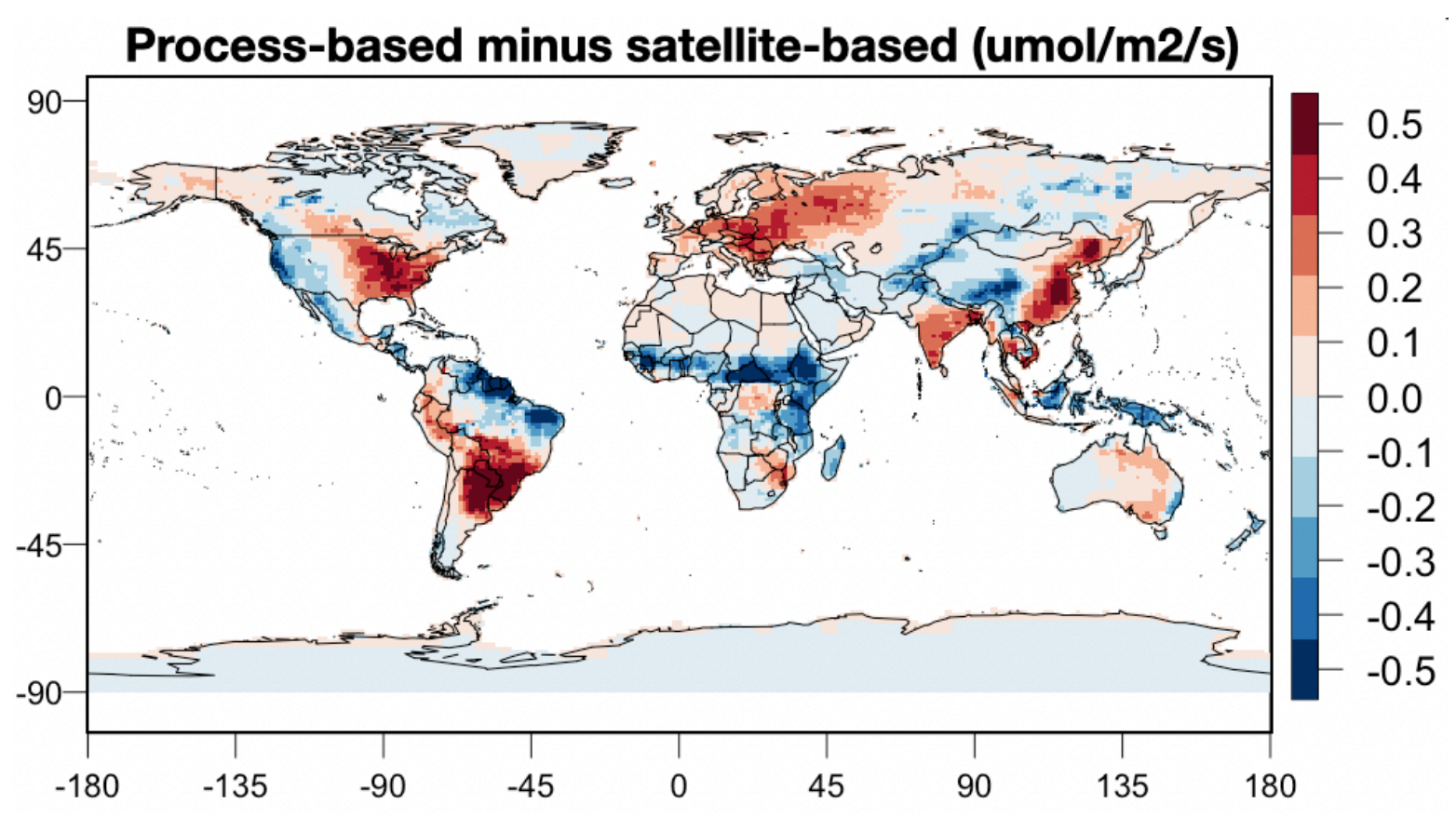
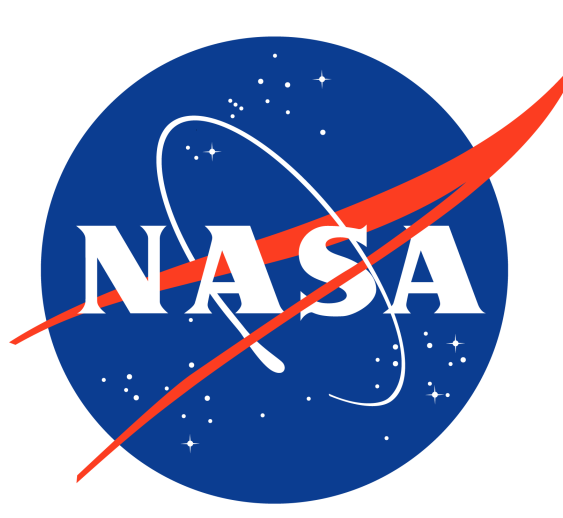
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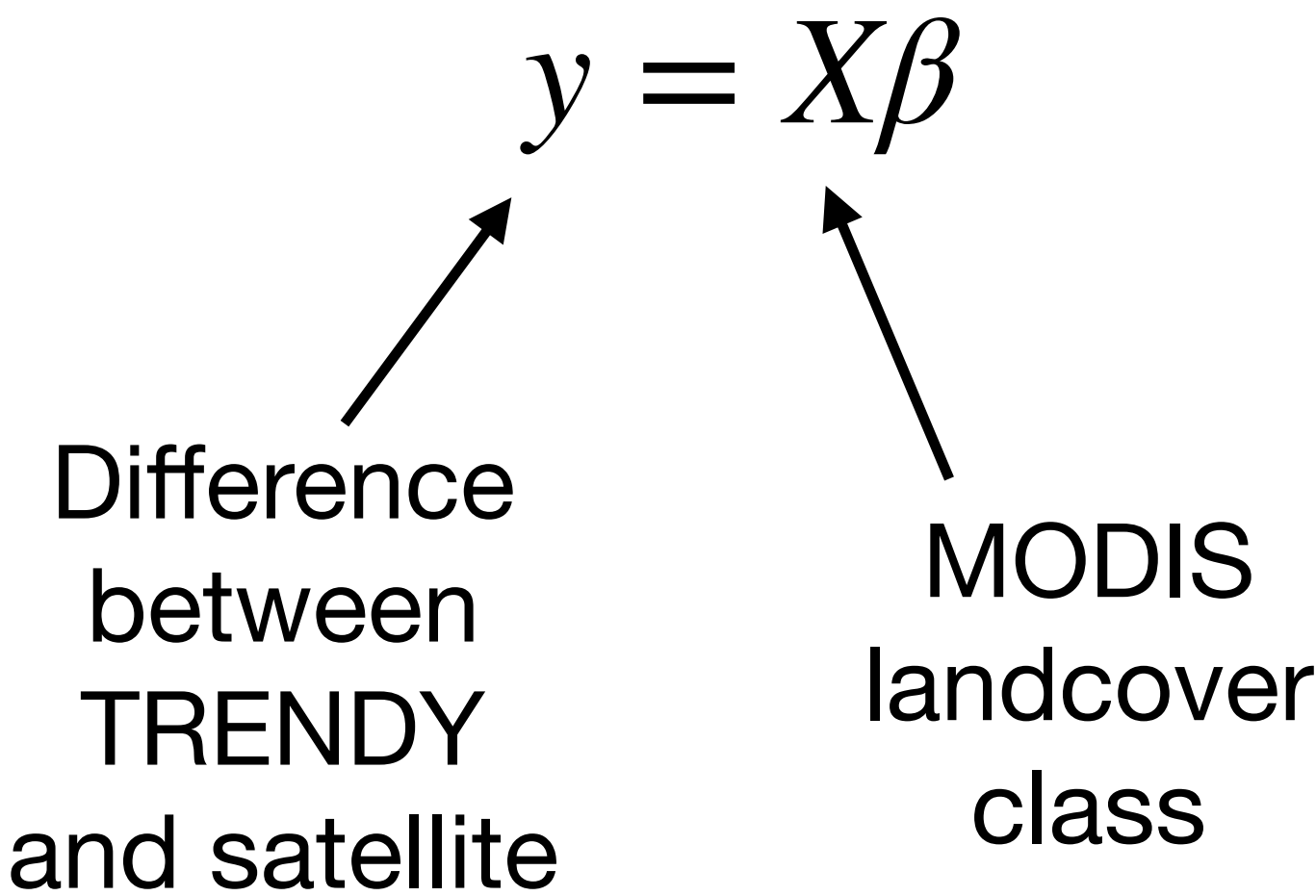
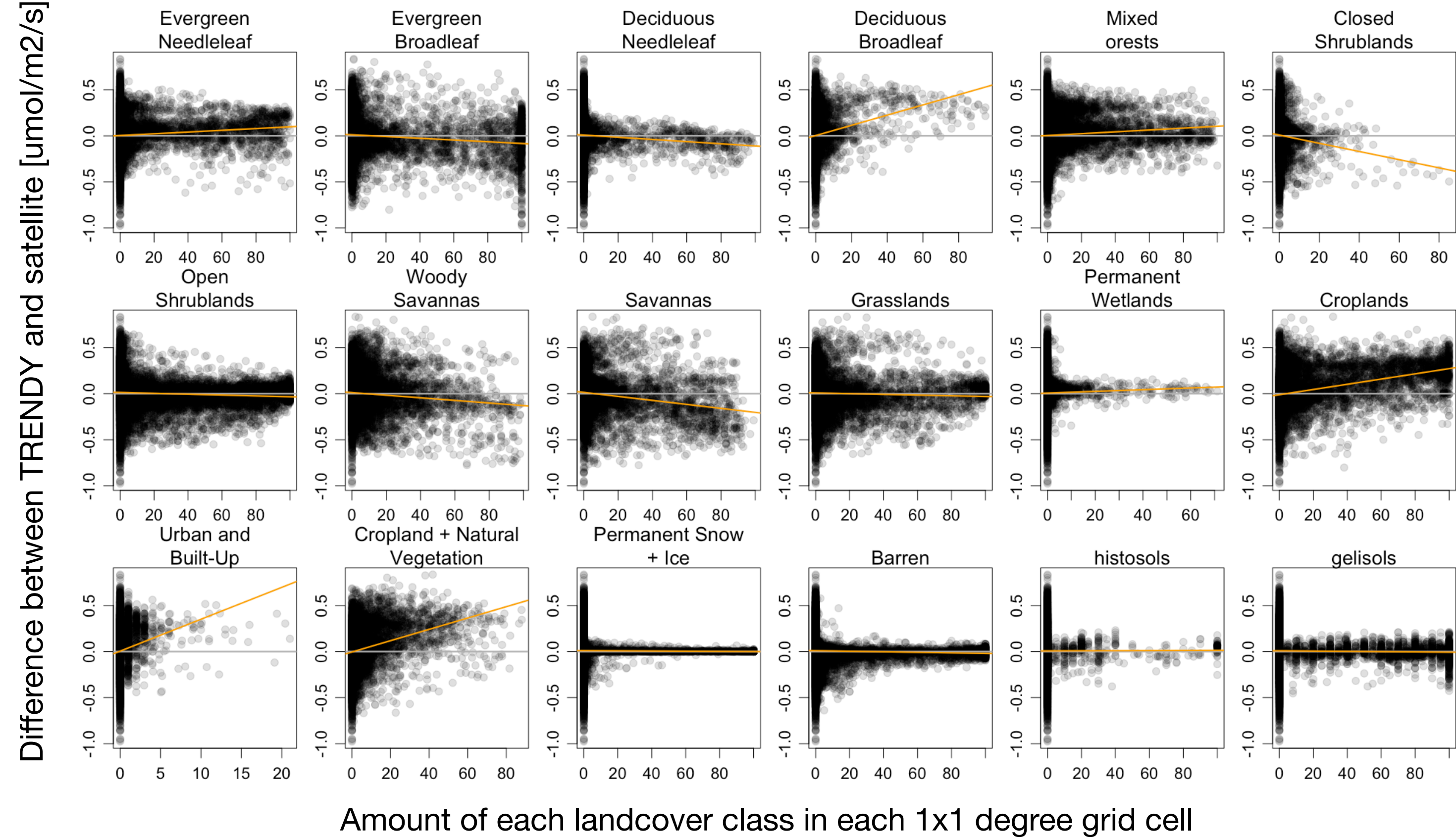
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- **Next steps: incorporate lateral fluxes and uncertainty in satellite-based inversion**

Thank you! Questions?

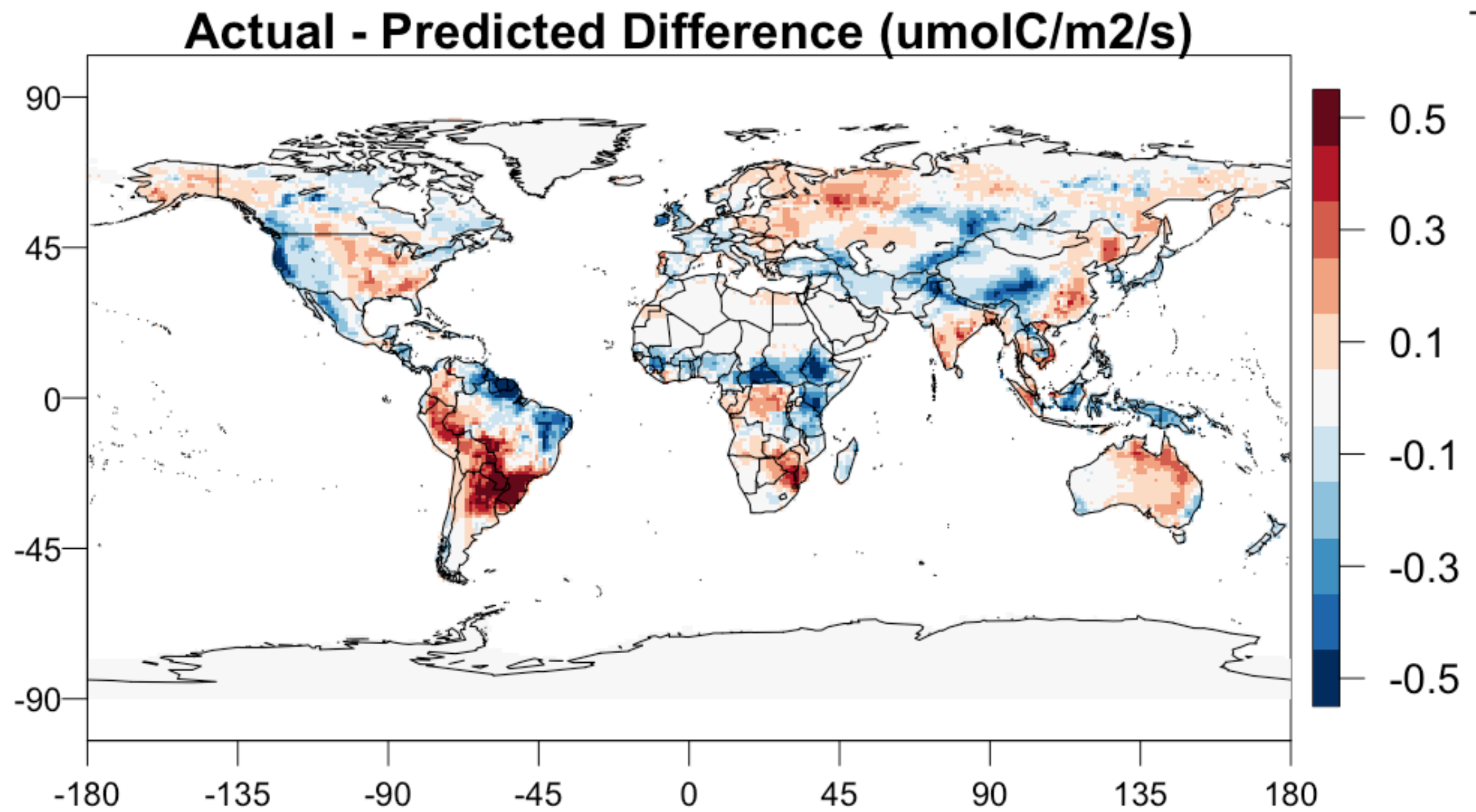
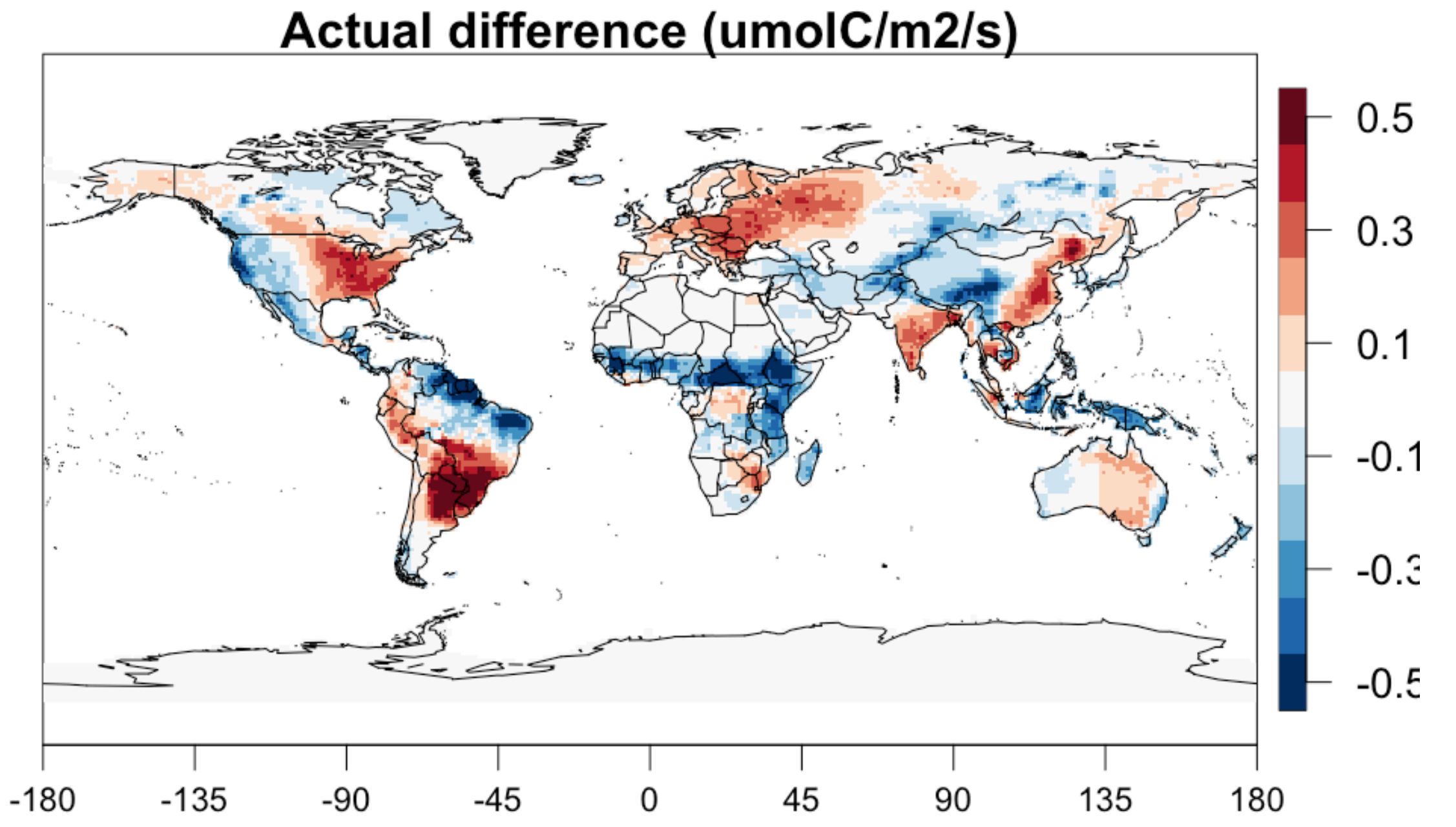
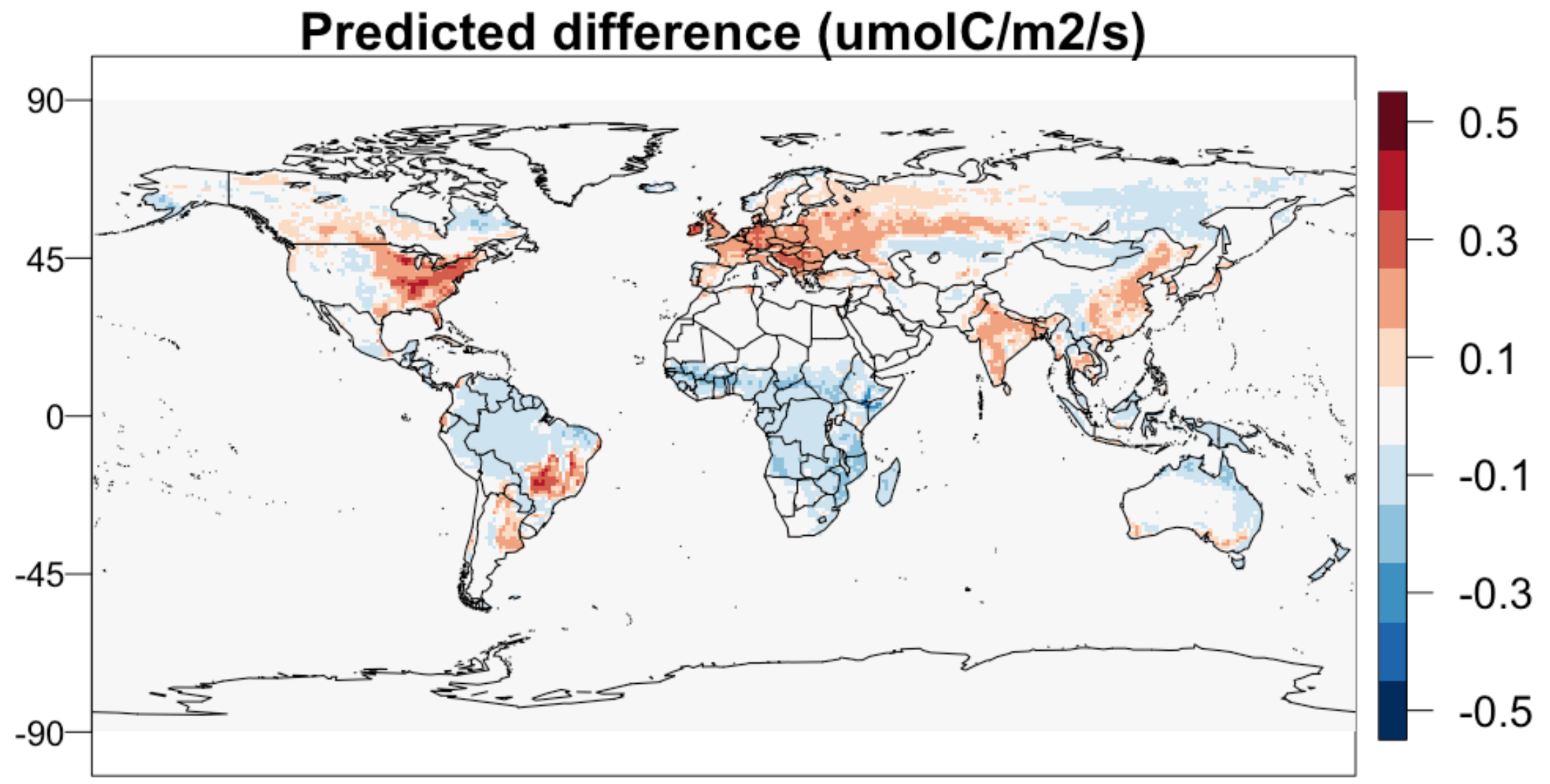
wdanie16@jh.edu



# Landcover class partially explains the difference between process- and satellite-based estimates



# Landcover class partially explains the difference between process- and satellite-based estimates



Landcover explains some of the difference, but definitely not all of it!

# Next step:

Don't just model the differences using landcover classes.  
Instead use information about how each TRENDY model "views" the world within a given landcover class.

We have many variables that can help with this:

- Near-Surface Air Temperature
- Precipitation
- Total Soil Moisture Content
- Total Runoff
- Total Evapo-Transpiration
- Carbon in Vegetation
- Carbon in Above-ground Litter Pool
- Carbon in Soil (including below-ground litter)
- Carbon in Products of Land Use Change
- Fractional Land Cover of PFT
- Fractional Ocean Cover
- Burnt Area Fraction
- Leaf Area Index
- Carbon in Leaves
- Carbon in Wood
- Carbon in Roots
- Carbon in Coarse Woody Debris
- Carbon in individual soil pools
- Total Carbon Flux from Vegetation to Litter

- Carbon Flux from Leaves to Litter
- Carbon Flux from Wood to Litter
- Carbon Flux from Roots to Litter
- Total Carbon Flux from Litter to Soil
- Total Carbon Flux from Vegetation Directly to Soil
- Carbon Flux from individual soil pools
- Temperature of Soil
- Evaporation from Canopy
- Water Evaporation from Soil
- Transpiration
- soil moisture
- Tree heights
- CO2 Flux to Atmosphere from Grazing
- CO2 Flux to Atmosphere from Crop Harvesting
- Irrigation
- Nitrogen in Vegetation
- Nitrogen in Above-ground Litter Pool
- Nitrogen in Soil (including below-ground litter)

Difference between TRENDY and satellite

$$y = X\beta$$

