The carbon costs of tropical deforestation through changes on regional climate

Yue Li[1], James T. Randerson[1]

and the BGC Team

1 Department of Earth System Science, University of California, Irvine

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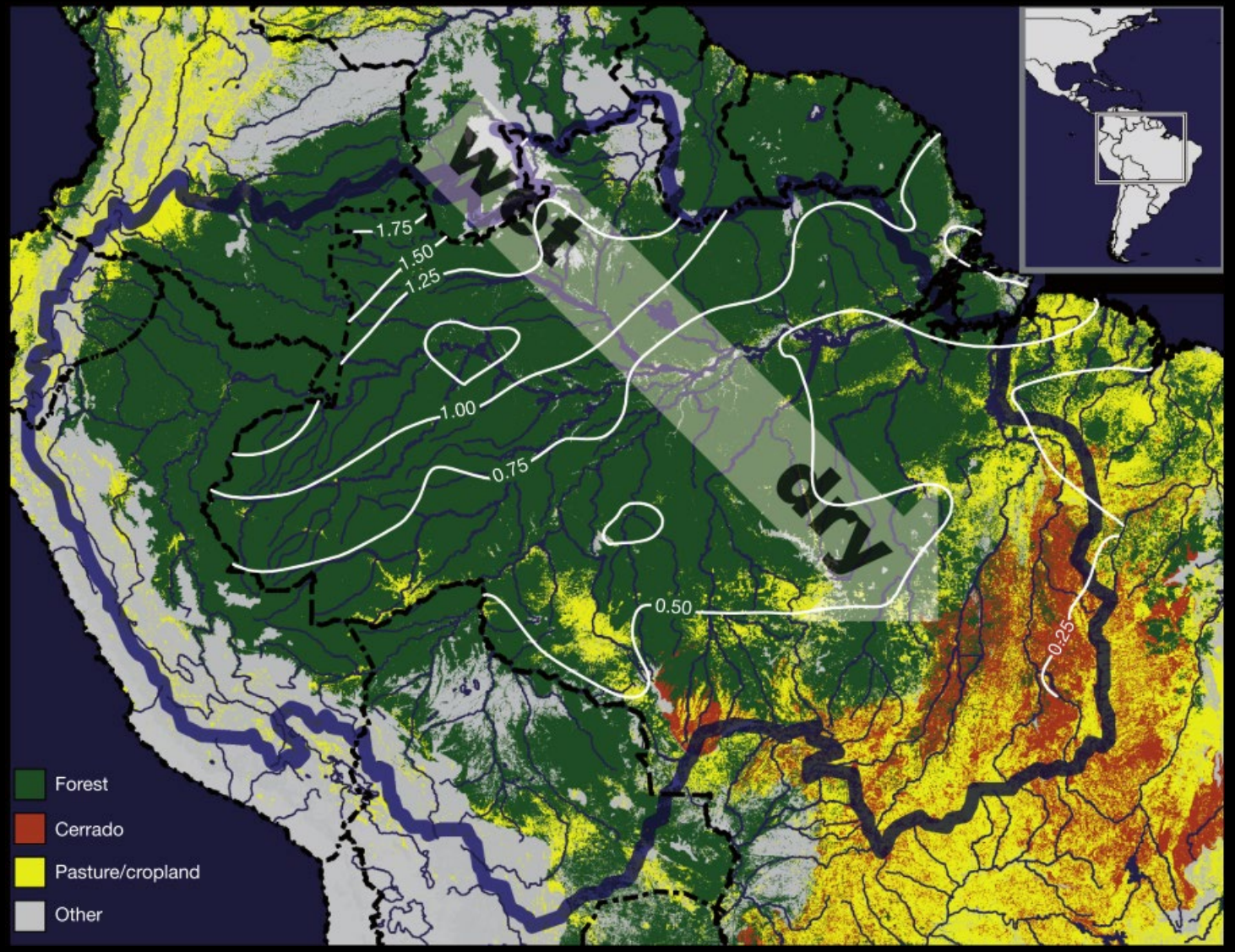
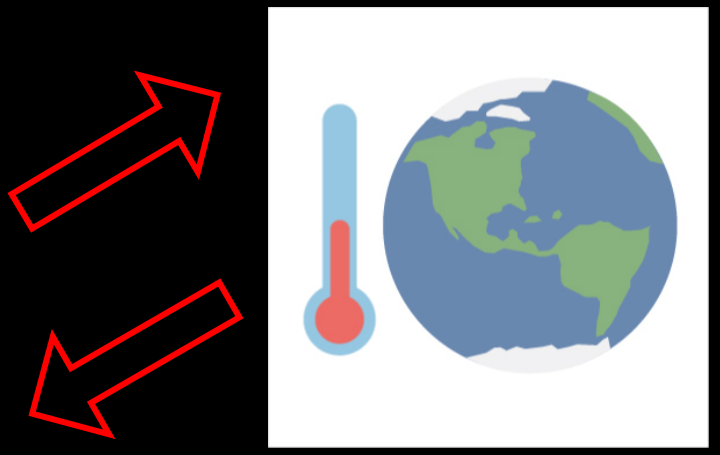
yue.li@uci.edu *@YueLi_LA*

Climate & land-use change are two main risks to tropical ecosystems



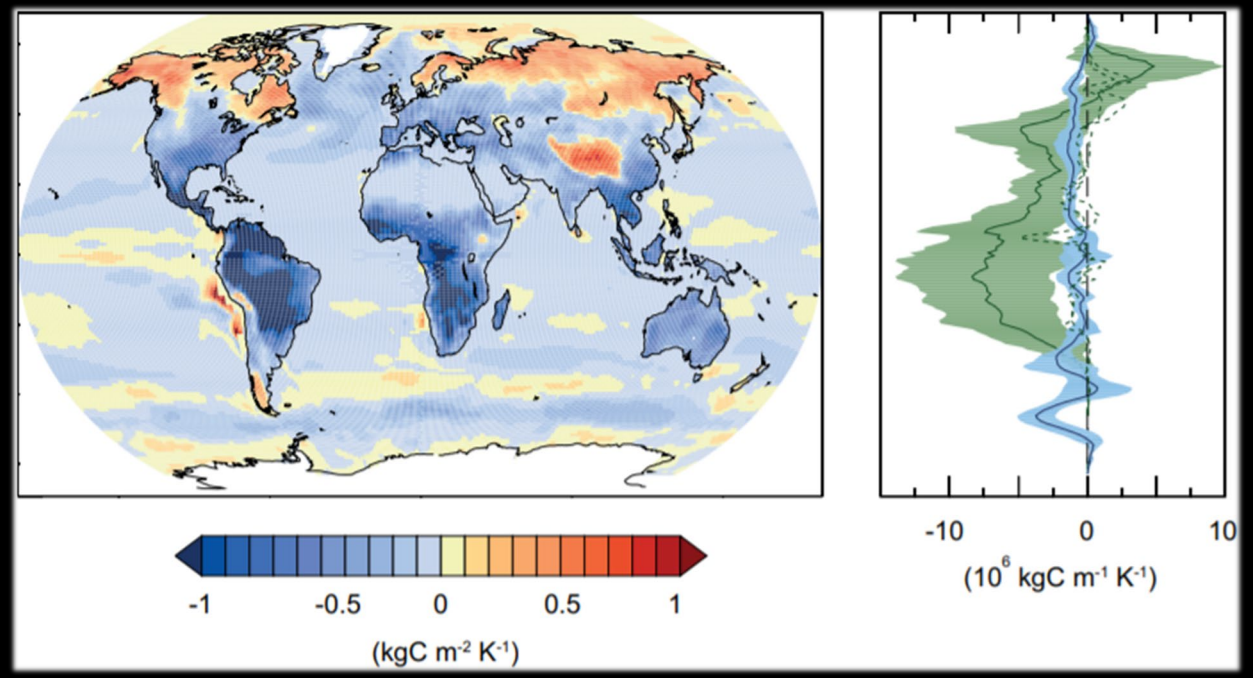
(Davidson et al. 2012, *Nature*)

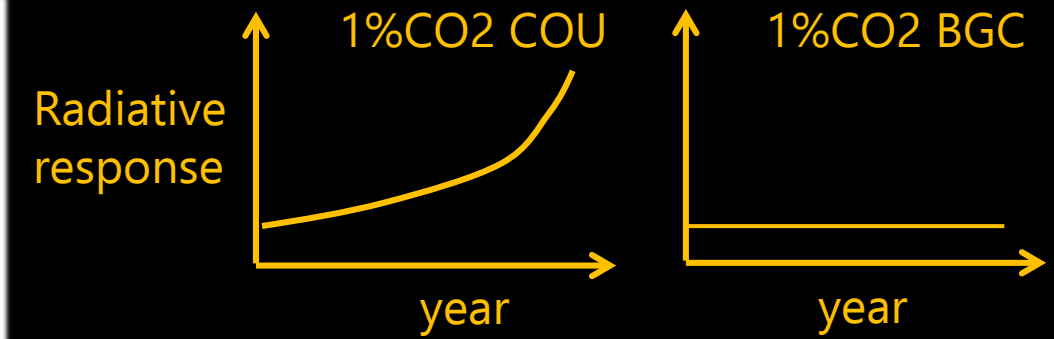


An essential task in biogeochemistry:

Quantify ecosystem response &
ecosystem feedback to carbon cycle

CO_2-driven climate-carbon cycle feedback



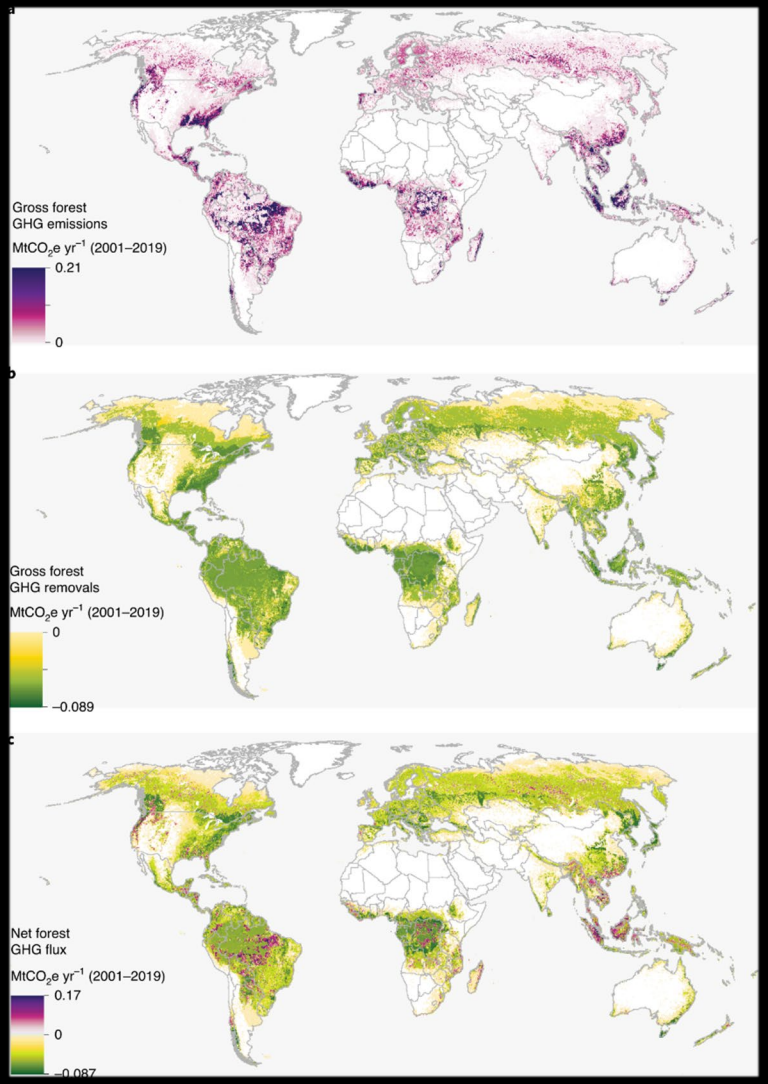


$$\gamma = \frac{\Delta C_{COU} - \Delta C_{BGC}}{\Delta T_{COU}}$$

(Ciais et al. 2013, *IPCC AR5 Chap5*)

This gamma is driven by CO_2-induced climate change, however, other climate change is driven by deforestation.
Question: Does climate change associated with land-use change yield a larger or smaller gamma ?

Complex pathway of land use change in the climate-carbon feedback



(Harris et al. 2021, *Nat Clim Chang*)

Forest GHG emissions → Land-use emissions

- Climate change
- Land cover changes (e.g., deforestation)
- Land management

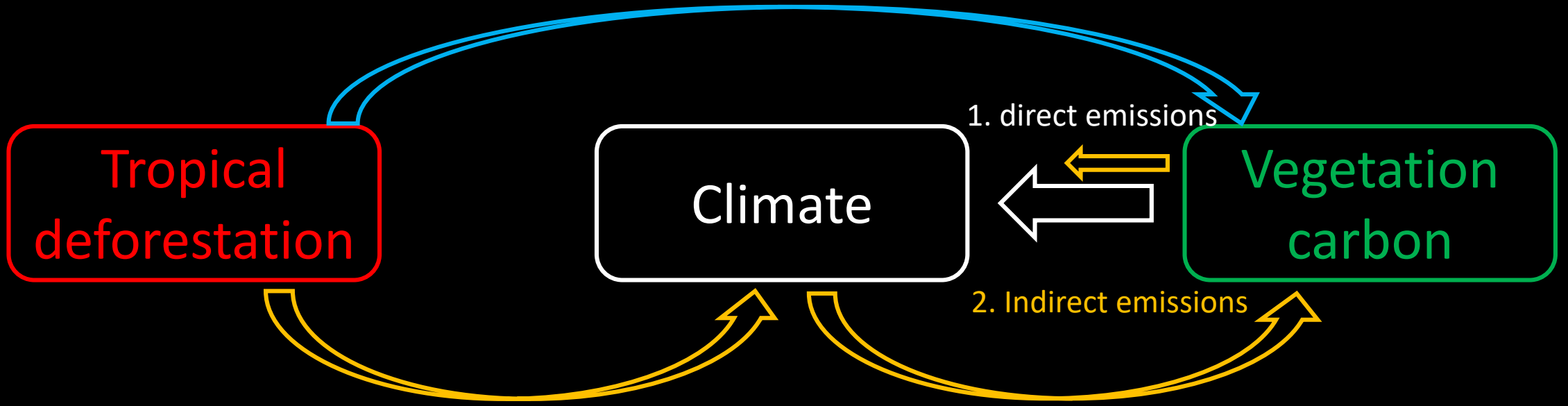
−

Forest GHG removals → Terrestrial carbon removals

- Climate change
- CO_2/Nutrient fertilization /limitation
- Plant dynamics (e.g., growth, mortality)

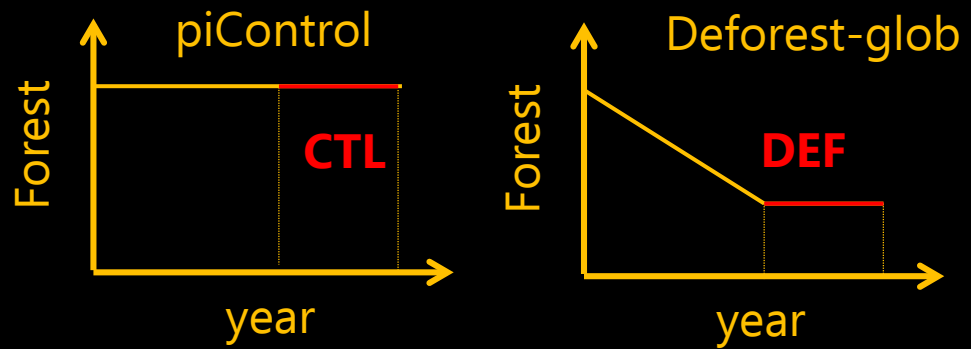
=

Net forest GHG flux → Net carbon uptake



CMIP6-LUMIP, CMIP6-piControl simulations

Deforestation impacts (DEF minus CTL)



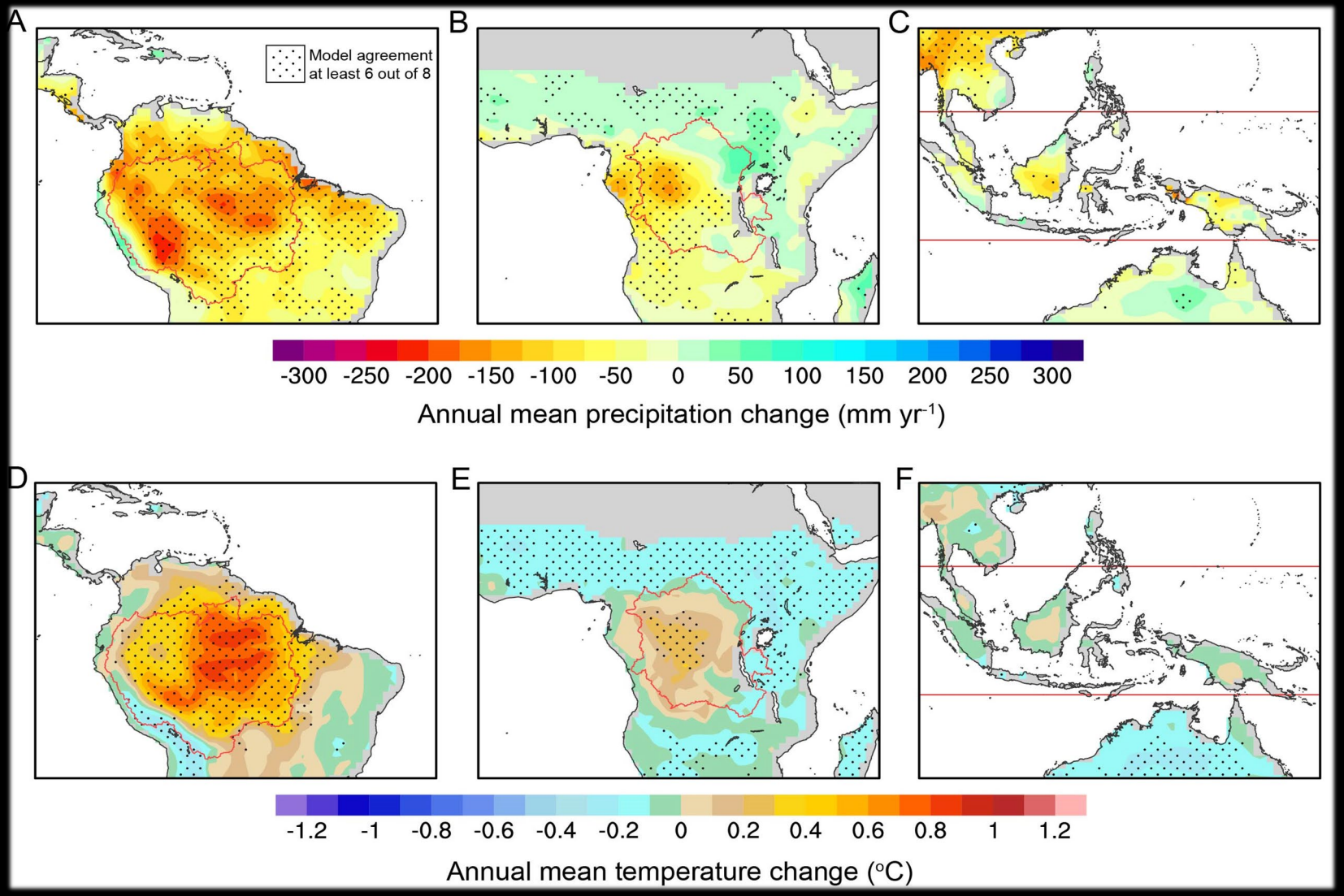
Additional experiments using CESM2 for tropics only

Observational spatial sensitivity

Waveform-based ESA-CCI aboveground biomass

Observational climate products (TRMM rainfall, CRU air temperature)

Idealized deforestation causes local warming & decrease in rainfall



Tree cover fraction

Amazon: -44.7±6.0 %,
Congo: -38.7±8.8 %,
TropAsia:-31.2±8.9 %

Annual rainfall

Amazon:-150±105 mm yr^{-1} (-6.7%)
Congo:-41±56 mm yr^{-1} (-2.7%)
TropAsia:-38±58 mm yr^{-1} (-1.3%)

Annual temperature

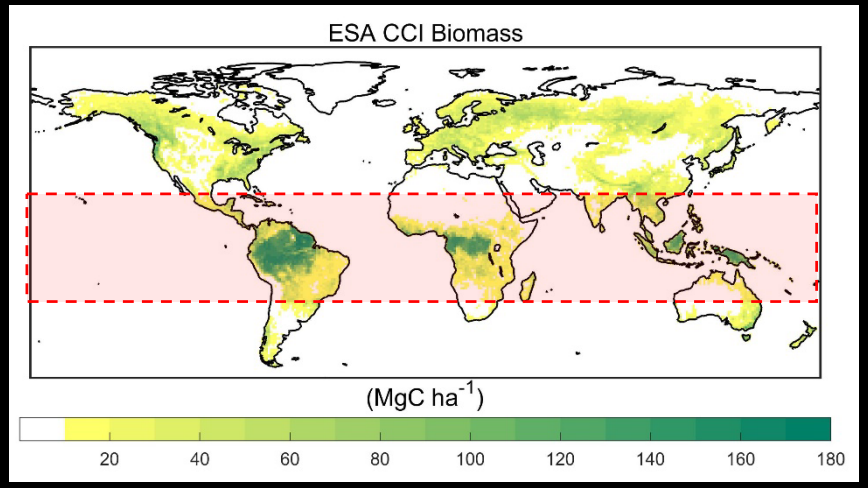
Amazon: 0.5±0.5 °C
Congo: 0.1±0.5 °C
TropAsia: -0.1±0.2 °C

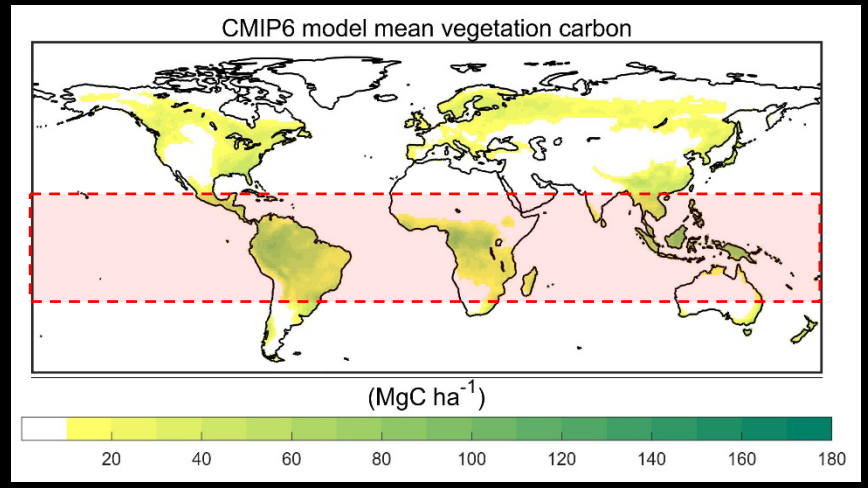
Revisit the observational spatial climate sensitivity of vegetation carbon

AGB: aboveground biomass

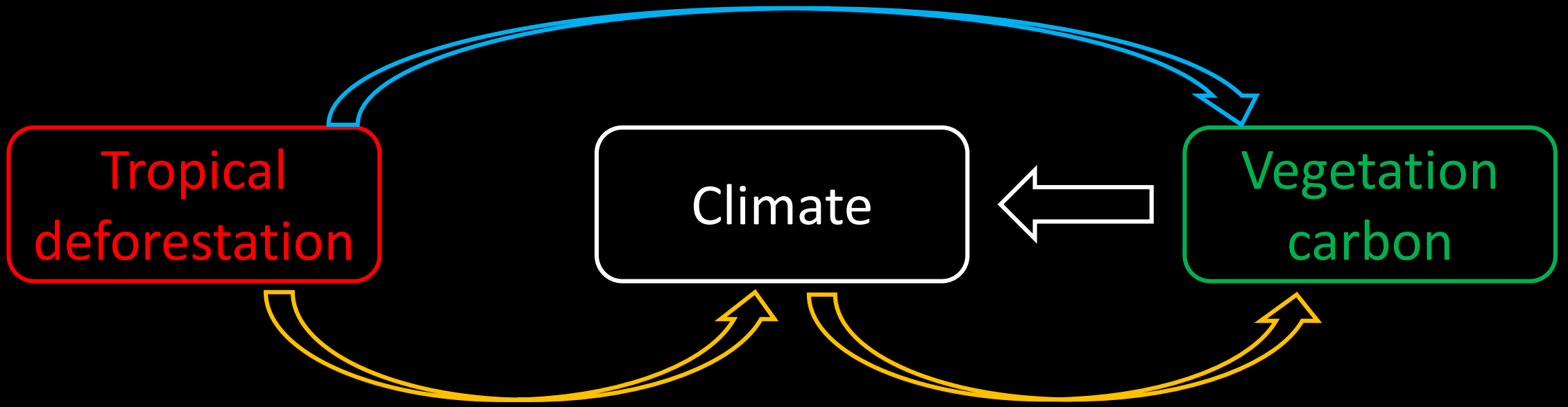
AGB	Rainfall coefficient	Temperature coefficient	R^2	$\partial_{AGB}/\partial_{Rainfall}$	$\partial_{AGB}/\partial_{Temperature}$
Observations*	3.4	-0.32	0.49	8.2% /100mm yr^{-1}	-0.8% /°C
CMIP6 piControl	1.6	-0.02	0.60	6.9% /100mm yr^{-1}	-0.09% /°C

*Equation: Aboveground biomass (AGB) = a*Rainfall + b*Temperature + ε. The units are mm yr^{-1} and °C, and Mg C ha^{-1}. Sensitivity is computed as the relative value of the coefficients a and b to the observed/simulated AGB.



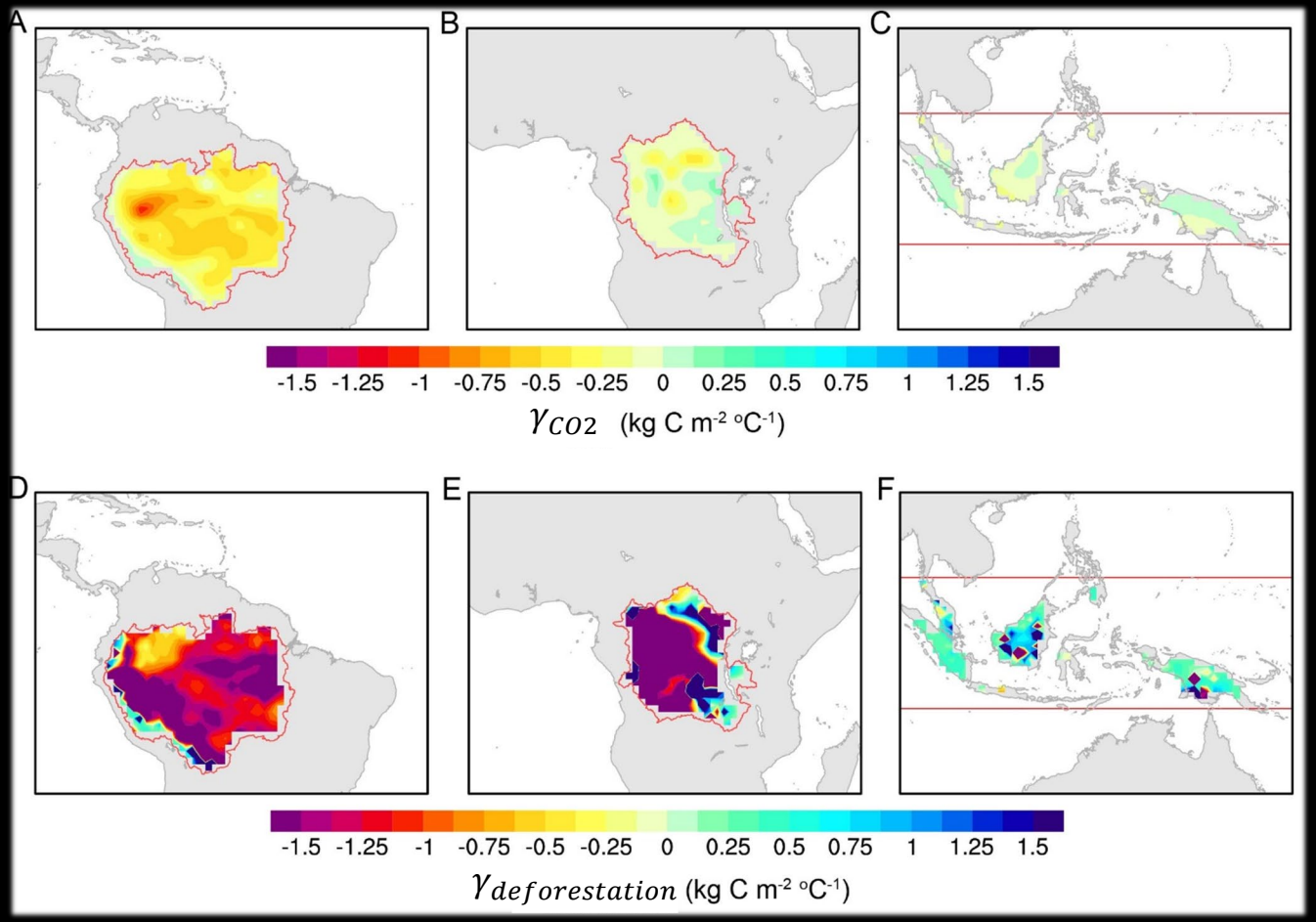


CMIP6 has lower rainfall sensitivity due to a lower magnitude of AGB



Amazon	-150 mm yr^{-1}, +0.5°C	-6.7 Mg C ha^{-1} (6.8%)
Congo	-41 mm yr^{-1}, +0.1°C	-3.1 Mg C ha^{-1} (4.1%)
TropAsia	-38 mm yr^{-1}, -0.1°C	-0.2 Mg C ha^{-1} (0.3%)

Implication: Deforestation-driven climate change yields a larger climate-carbon cycle feedback



- CO_2-driven climate-carbon cycle feedback

$$\gamma_{CO2} = \frac{\Delta Cveg_{COU} - \Delta Cveg_{BGC}}{\Delta T_{COU}}$$

- Deforestation-driven climate-carbon cycle feedback

$$\gamma_{deforestation} = \frac{\Delta Cveg_{def\_biophys}}{\Delta T_{def\_biophys}}$$

Take home message:

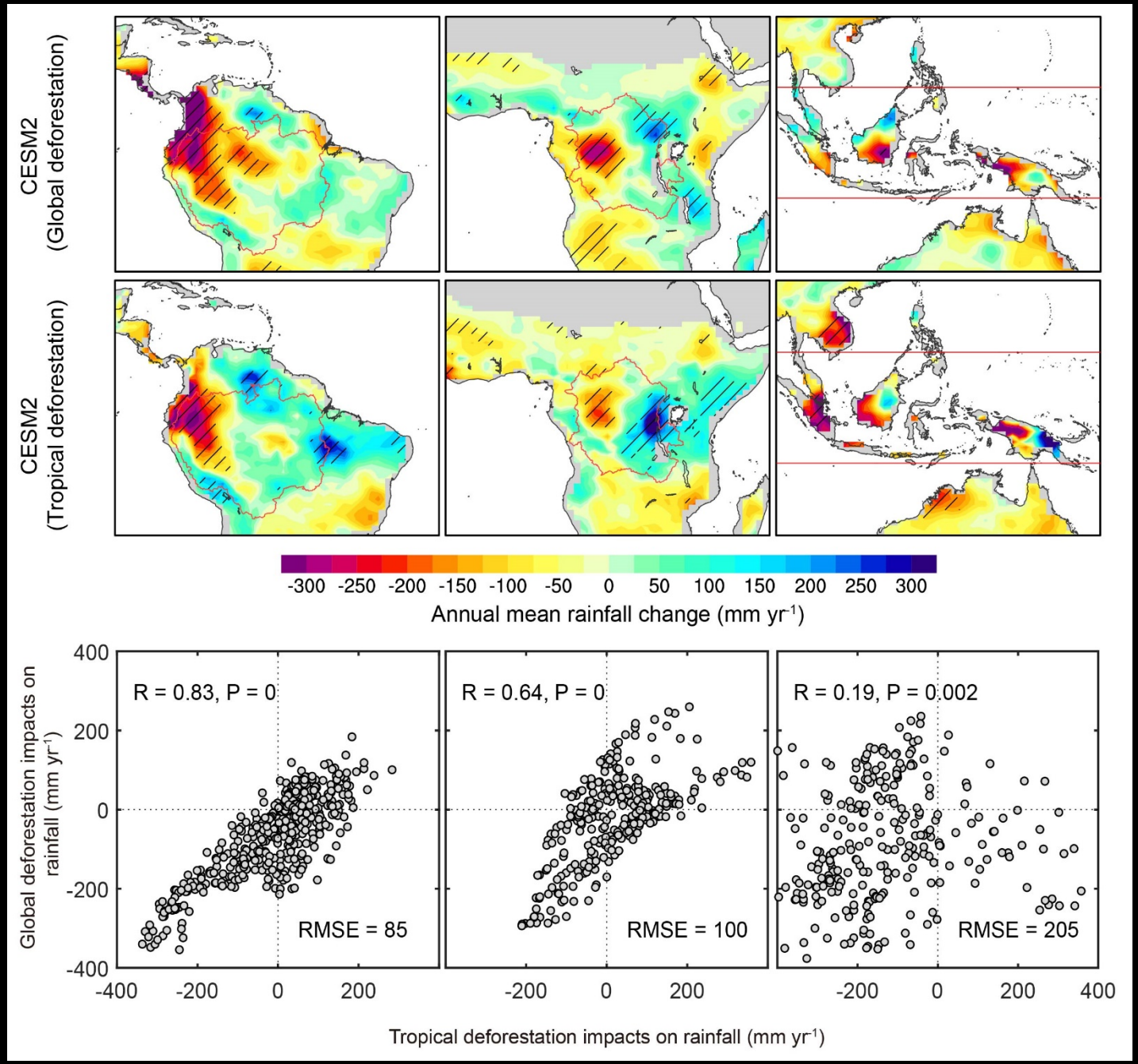
In the Amazon, deforestation-driven climate change causes intact forests to lose an additional 6.8% of their biomass as a consequence of decreasing rainfall.

Carbon credits for avoided deforestation should be larger to account for positive forest effects on regional climate.

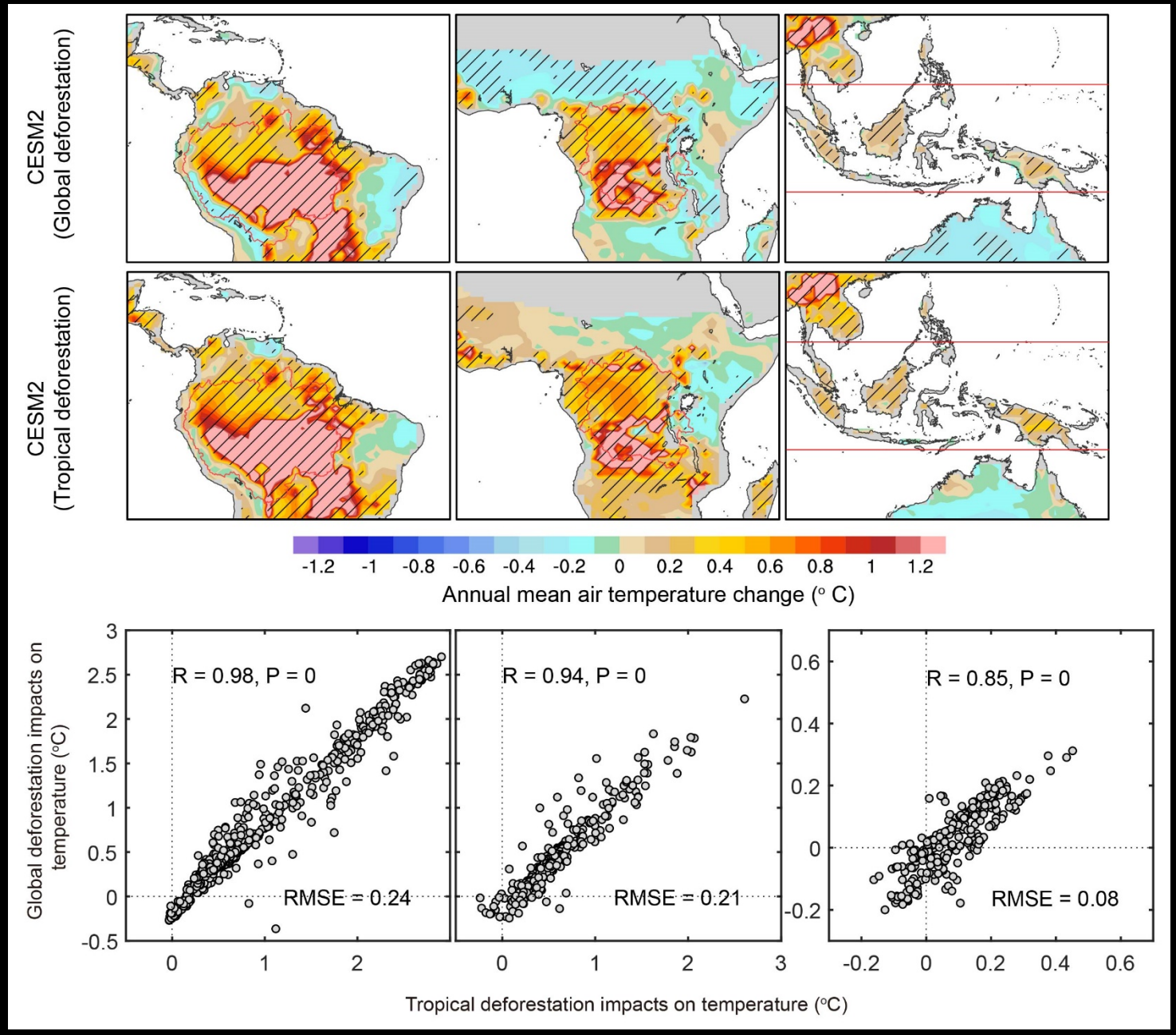
Land use effects on precipitation would amplify the climate-carbon cycle feedback in the tropics.

Thanks for your listening and particular thanks to the NCAR team for early discussions and help on computing on Cheyenne.

Rainfall


CESM2
(Global deforestation)
CESM2
(Tropical deforestation)
-300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300
Annual mean rainfall change (mm yr-1)
Global deforestation impacts on rainfall (mm yr-1)
R = 0.83, P = 0
RMSE = 85
R = 0.64, P = 0
RMSE = 100
R = 0.19, P = 0.002
RMSE = 205
400
200
0
-200
-400
Tropical deforestation impacts on rainfall (mm yr-1)

Temperature



Model (AGB=)	a	b	R^2	RMSE
a*MAP+b*MAT+ε	0.034	-0.316	0.49	32.1
a*MAP+b*Tamp+ε	0.026	-1.148	0.26	40.4
a*MAP+b*MAXT+ε	0.030	-0.280	0.60	29.8
a*MAP+b*VPD+ε	0.026	-0.676	0.25	40.5
a*Pamp+b*MAT+ε	0.136	0.105	0.19	40.3
a*Pamp+b*Tamp+ε	0.210	-3.707	0.12	44.1
a*Pamp+b*MAXT+ε	0.106	0.427	0.01	46.7
a*Pamp+b*VPD+ε	0.193	-1.469	0.00	46.9
a*PRD+b*MAT+ε	0.510	0.888	0.39	34.8
a*PRD+b*Tamp+ε	0.395	1.173	0.06	45.6
a*PRD+b*MAXT+ε	0.393	0.637	0.57	30.9

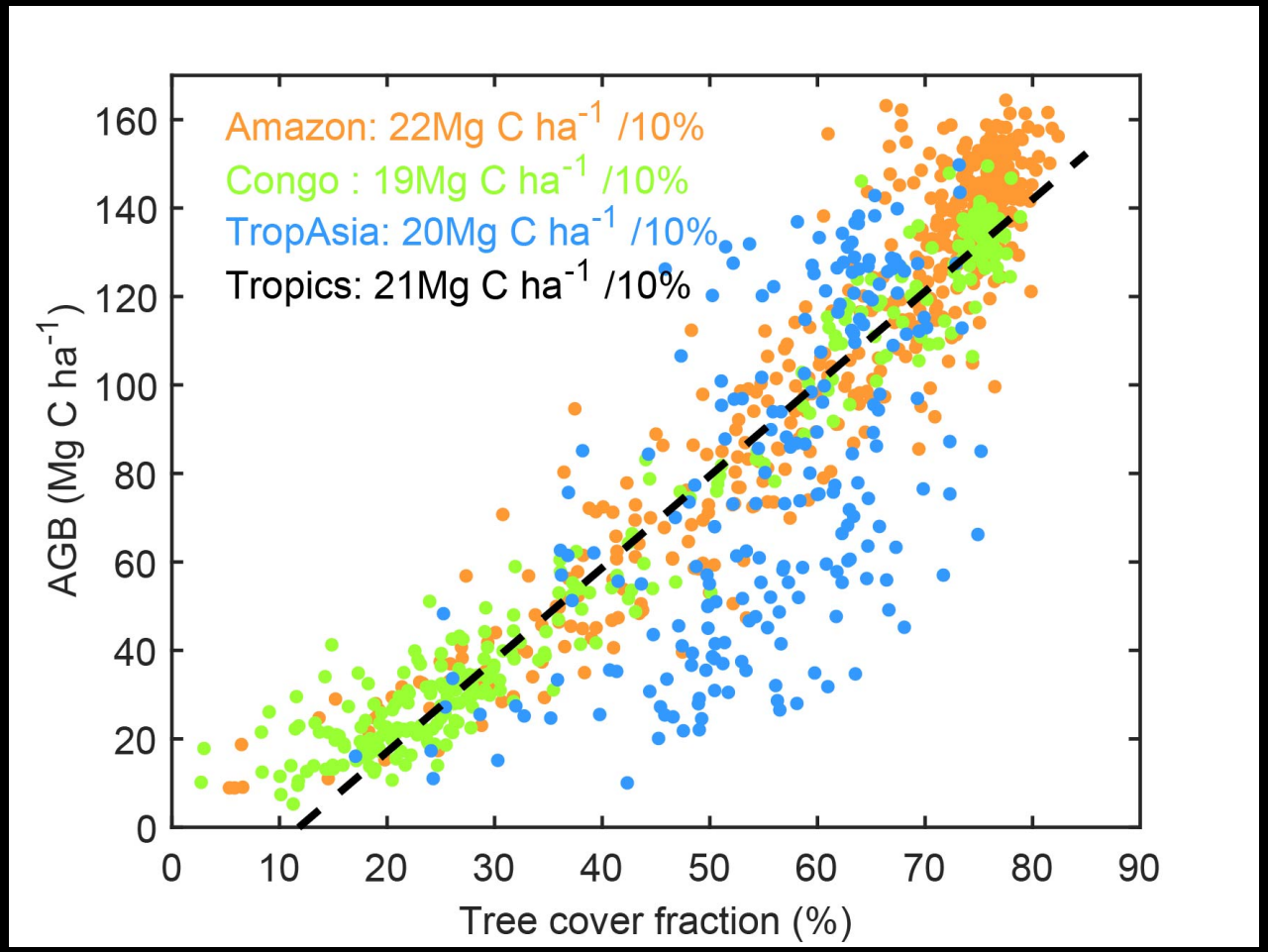
- Key role of rainfall
- High linear correlation among water stress factors or among the energy stress factors

Water stress factors:
MAP: mean annual precipitation (mm yr^{-1})
Pamp: intraannual amplitude of precipitation (mm $month^{-1}$)
PRD: precipitation during the driest season (mm $month^{-1}$)

Heat stress factors:
MAT: mean annual air temperature (°C)
Tamp: intraannual amplitude of air temperature (°C)
MAXT: mean annual maximum air temperature (°C)
VPD: vapor pressure deficit (hPa)

Correction on the AGB using observational AGB-tree cover relationship

ESA-CCI AGB



MODIS VCF