MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Ecosystem and physiological control of carbon balance in Amazonia

Celso von Randow

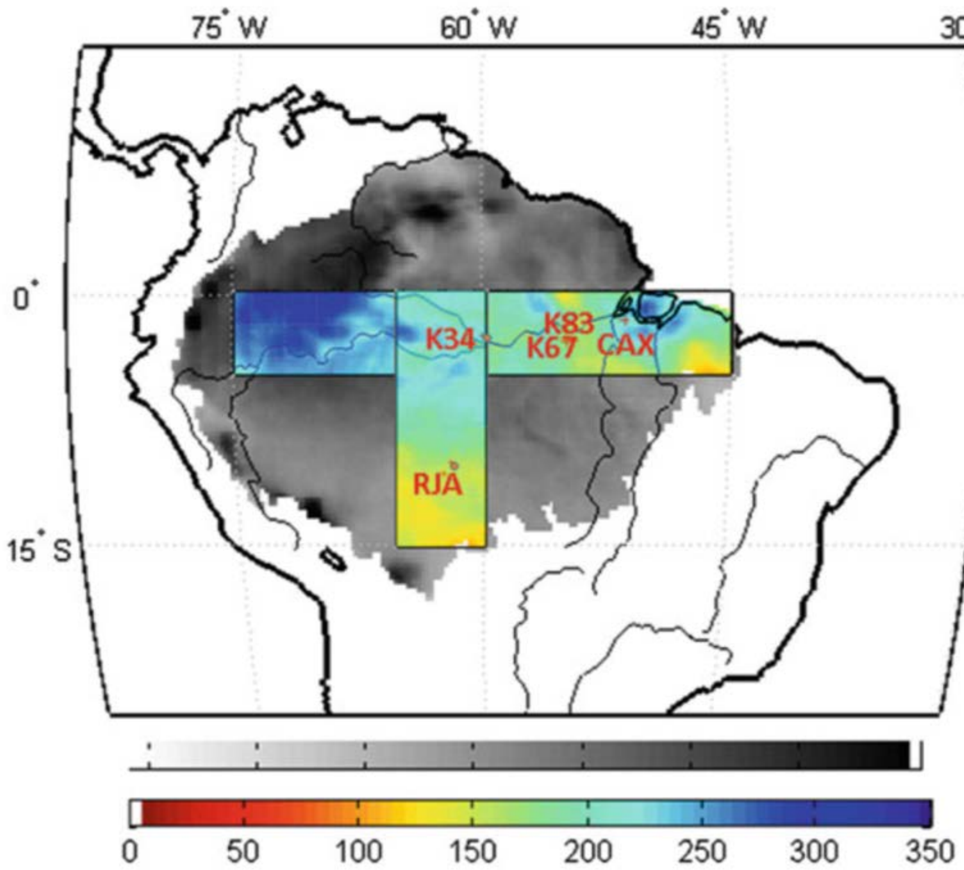
September 2018

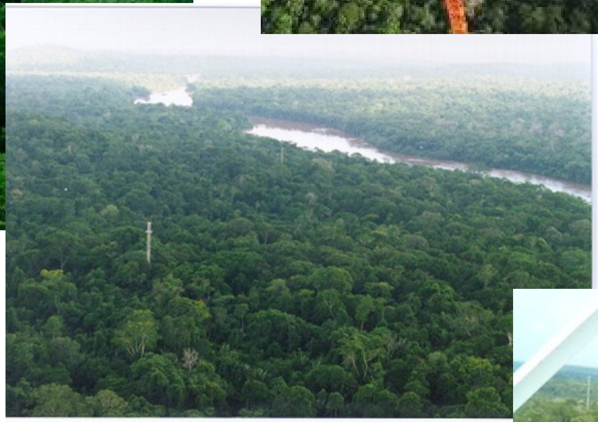
ciência para sustentabilidade

Big science adventures

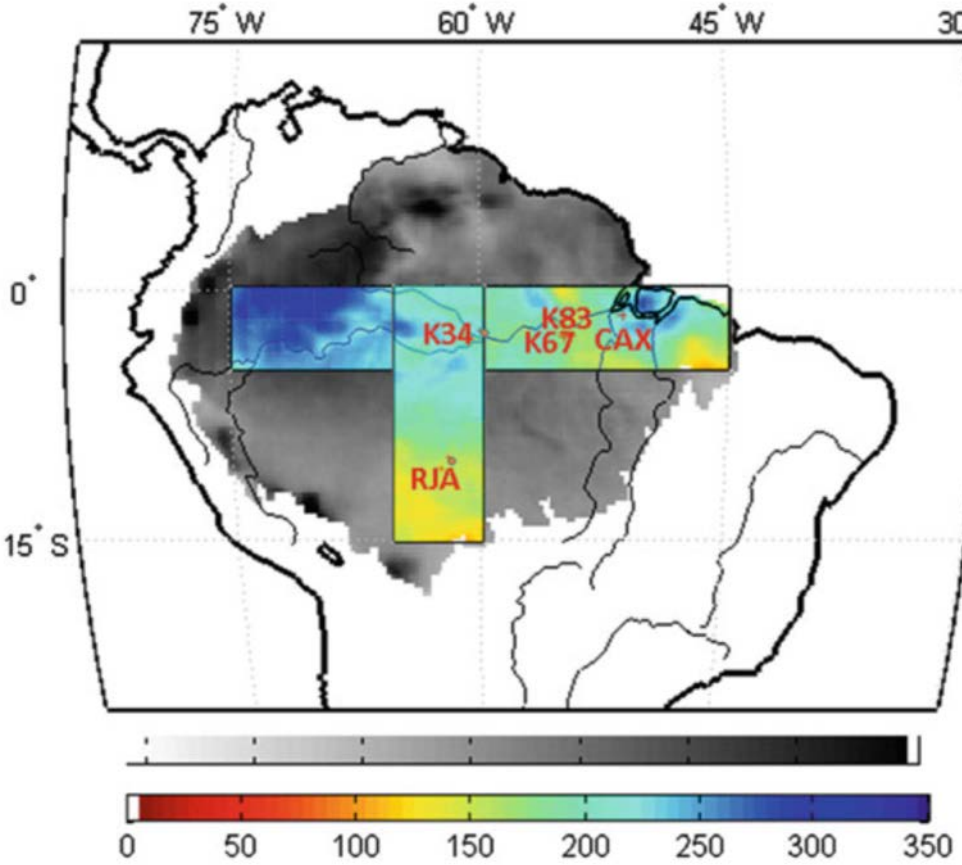
- LBA
- RAINFOR
- GO AMAZON
- ATTO
  - regional GHG balance
  - physical climate, energy, water and winds
  - aerosols, clouds, atmospheric chemistry
  - processes regulating land-air exchange

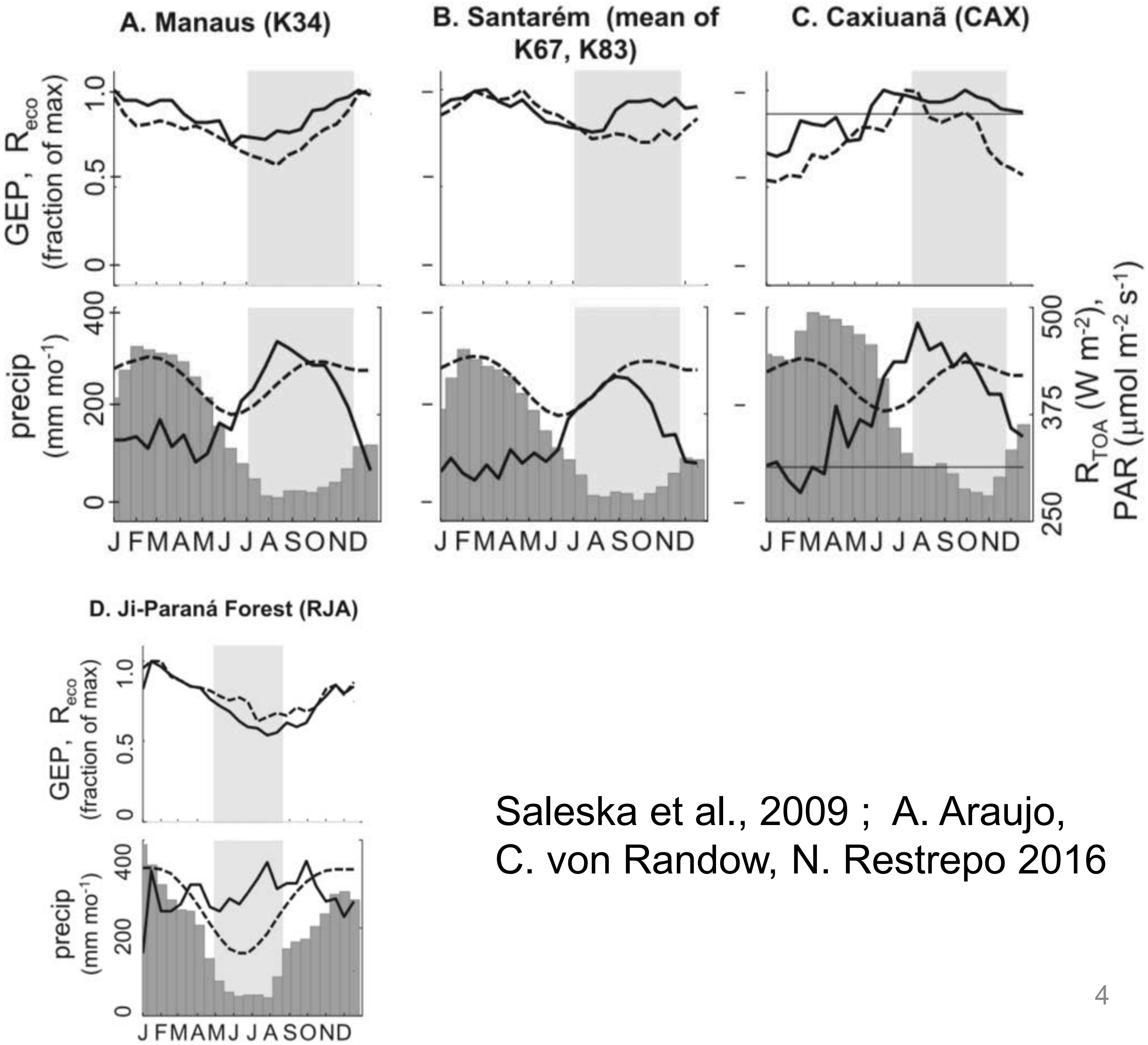
Exchange in undisturbed forest



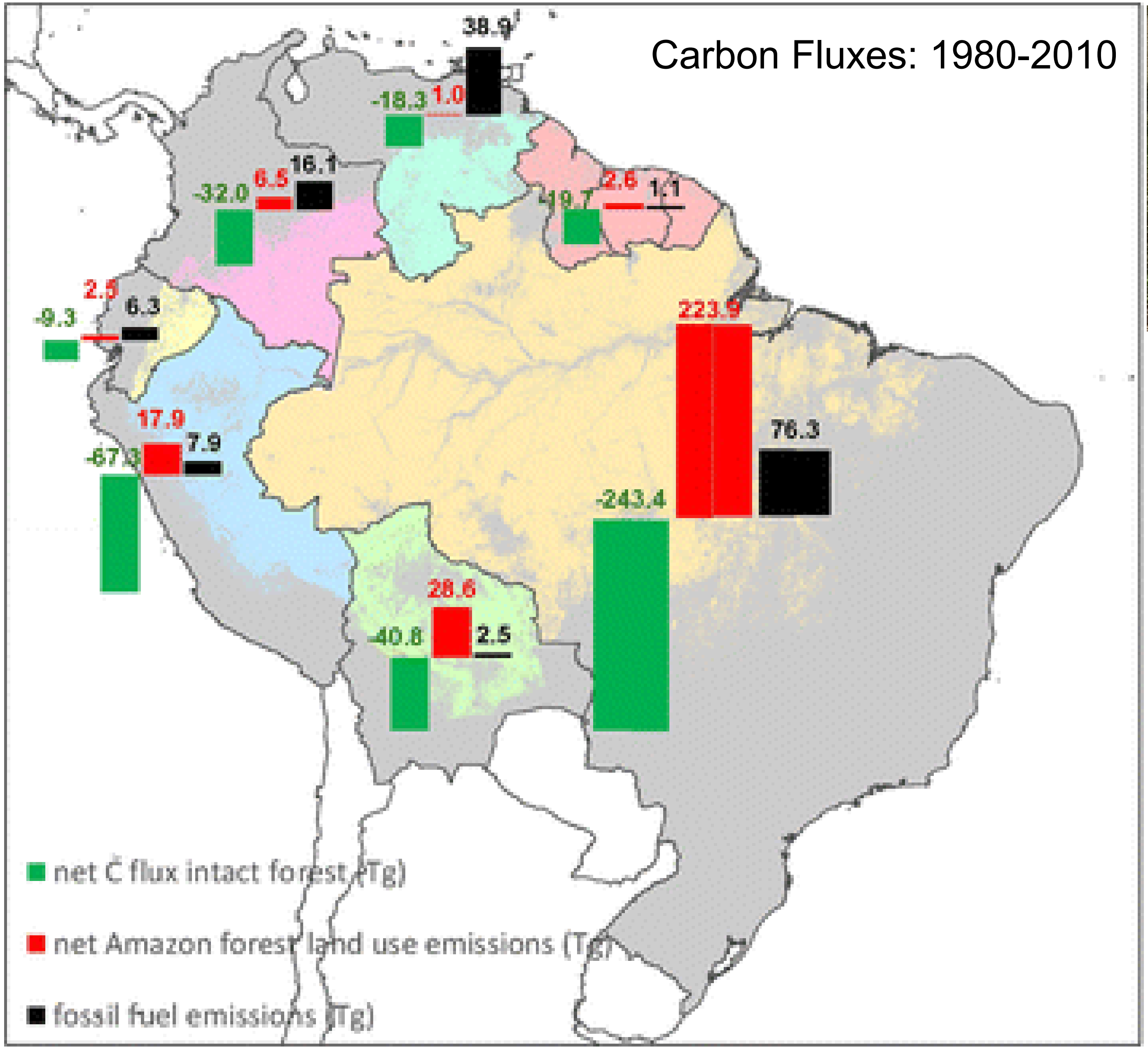


Exchange in undisturbed forest





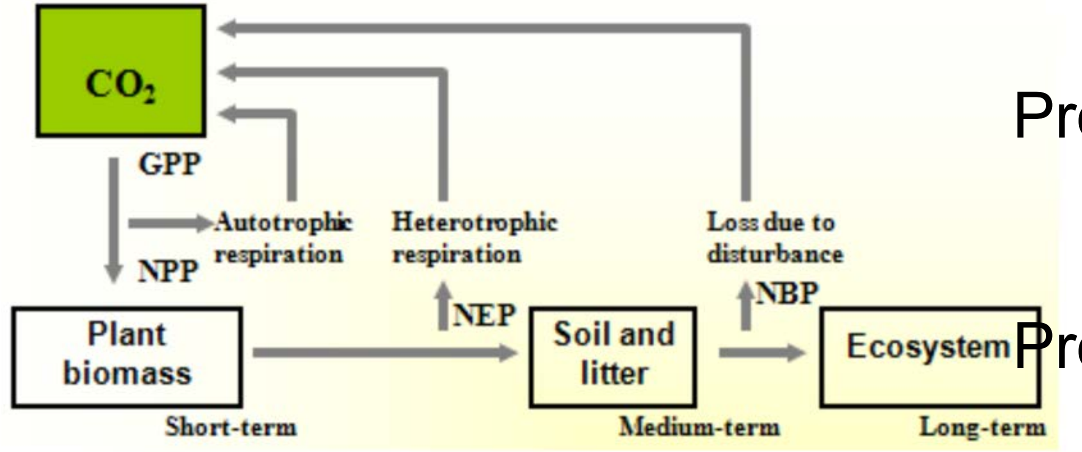
Saleska et al., 2009 ; A. Araujo, C. von Randow, N. Restrepo 2016



Phillips and Brienen, 2017, *Carbon Balance Management*

Carbon budget

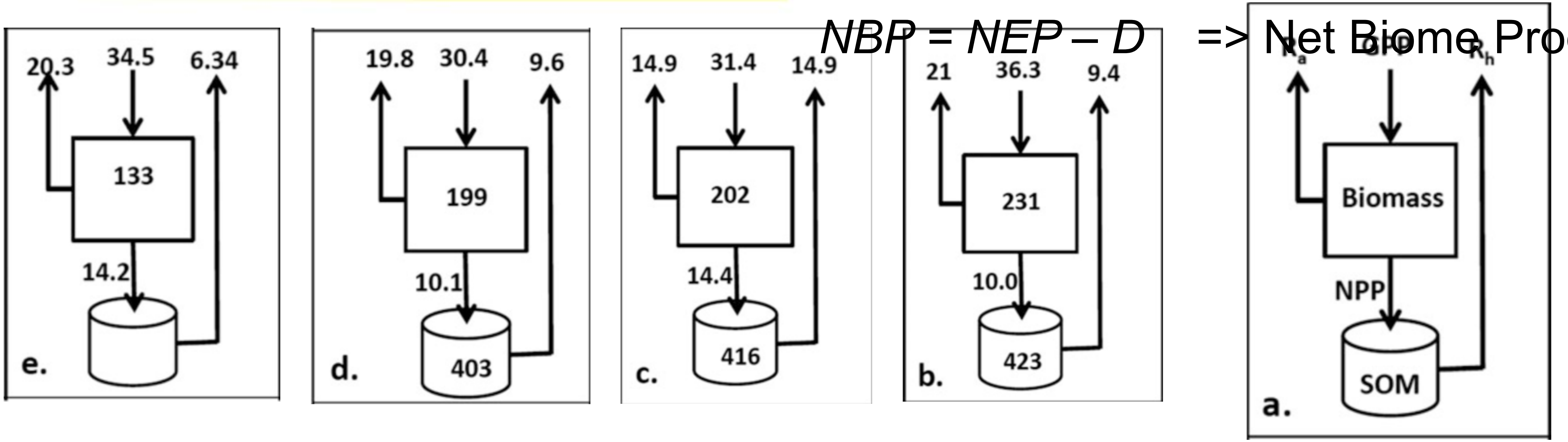
Carbon budget is primarily the balance between photosynthesis and respiration



$NPP = GPP - R_a$ => Net Primary Productivity

$NEP = NPP - R_h$ => Net Ecosystem Productivity

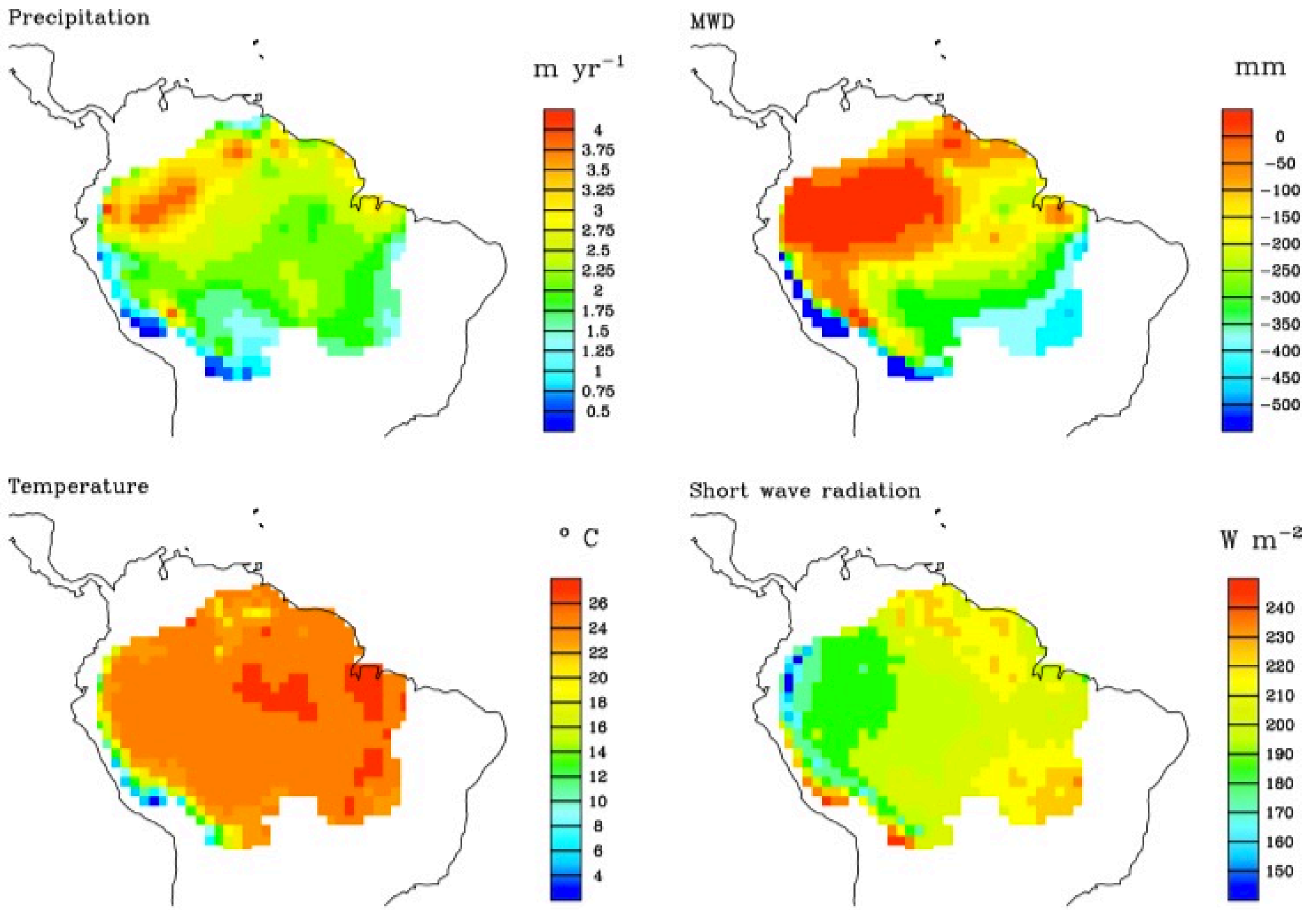
$NBP = NEP - D$ => Net Biome Productivity

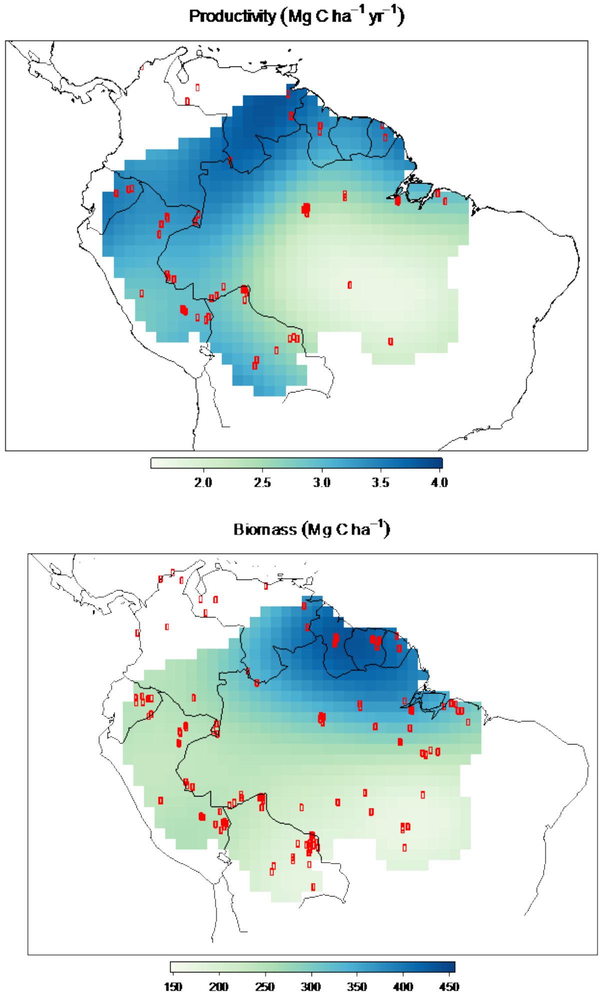


Tambopata | Manaus | Tapajos | Caxiuanã

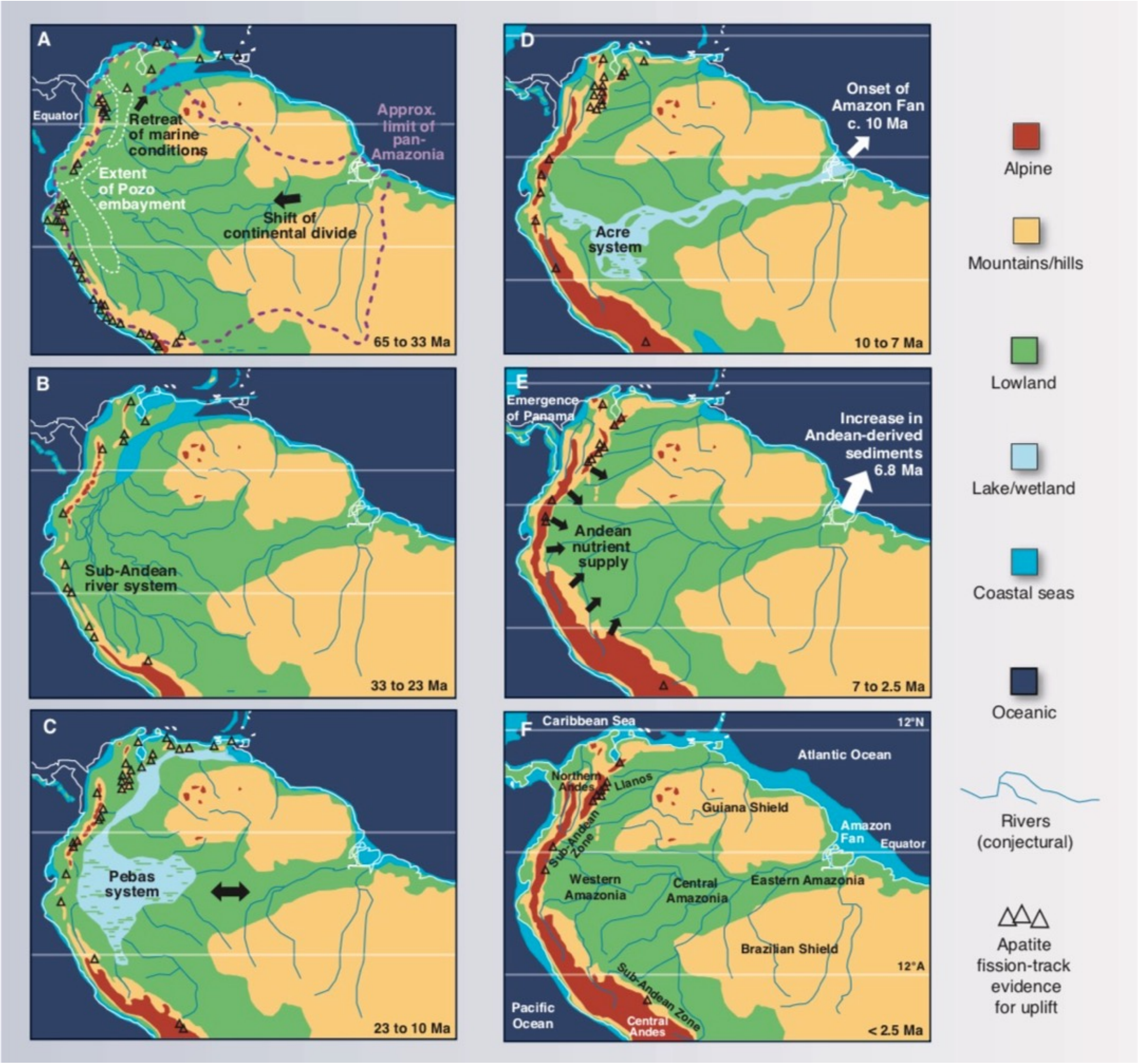
Malhi et al. 2009, Grace, 2016

Climate variability and carbon budget





Johnson et al. 2016, *Glob Change Biol*



(A) Amazonia once extended over most of northern South America

(B) The Andes rise

(C) Mountain building in the Central and Northern Andes (~12 Ma) and wetland progradation into Western Amazonia

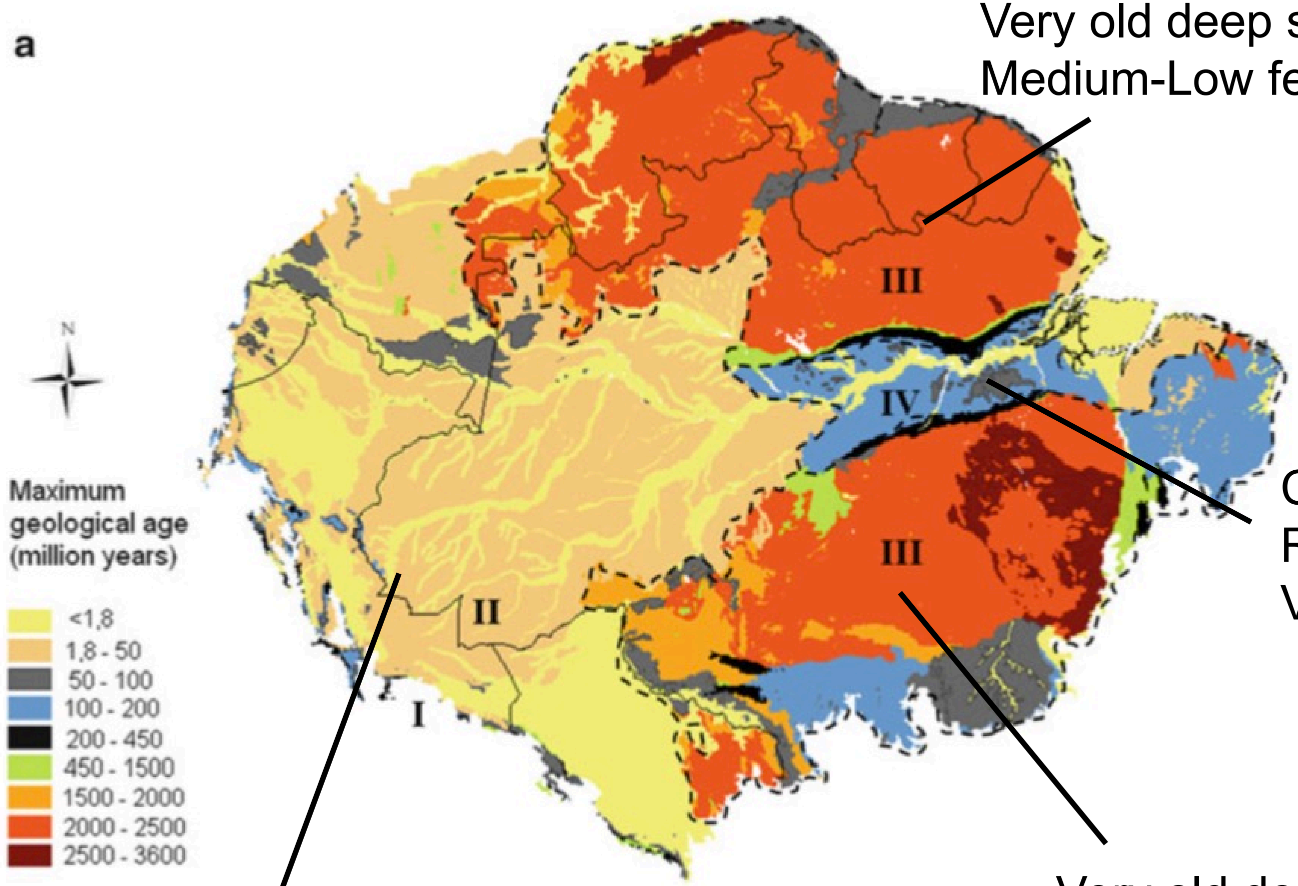
(D) Uplift of the Northern Andes restricted "pan-Amazonia", Andean sediments reach Atlantic and Amazon River fully established (~ 7 Ma)

(E) The megawetland disappeared and terra firme rainforests expanded

(F) Quaternary ice ages, restriction of wetlands, readjustment in river patterns to mosaic patterns of present

Hoorn et al. 2010, Science

Soil formation and fertility

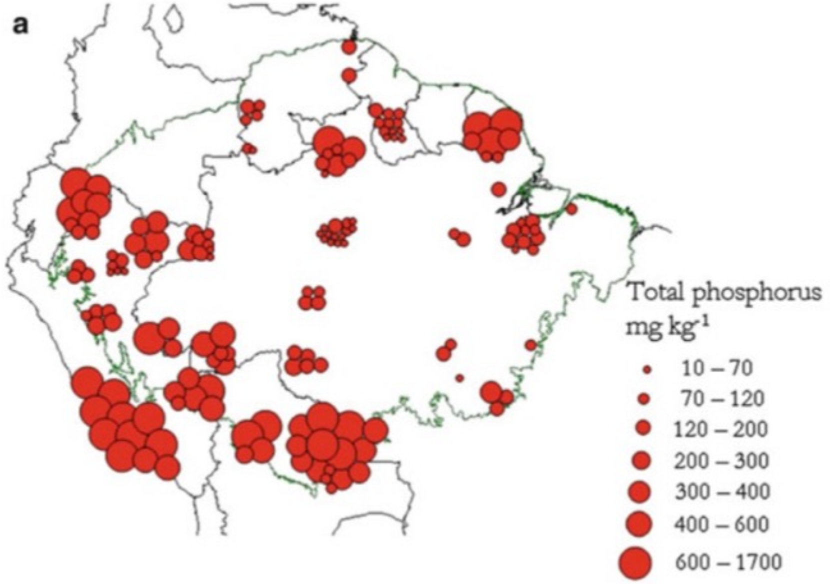


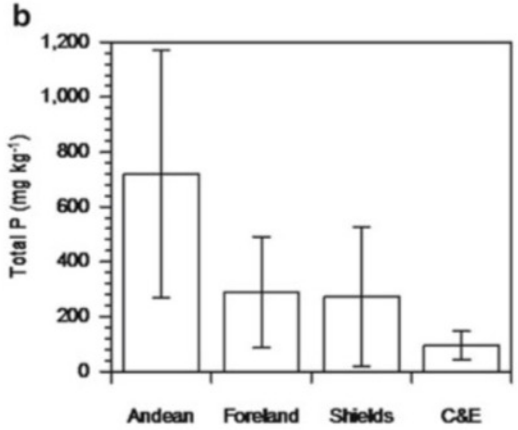
Very old deep soils
Medium-Low fertility

Central-Eastern intra-cratonic basin
Relatively young, but highly weathered
Very low soil fertility

Very old deep soils
Medium-Low fertility

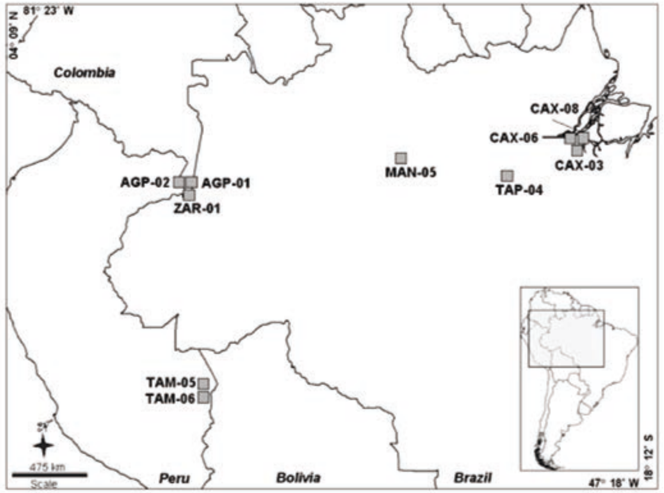
Young shallow soils that were formed on recent sediments that had eroded from the Andes
(low weathering)

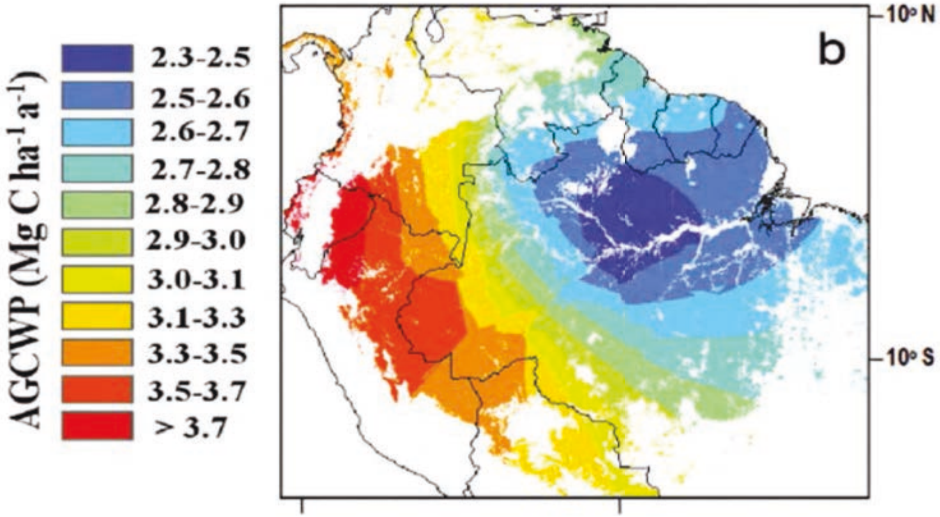




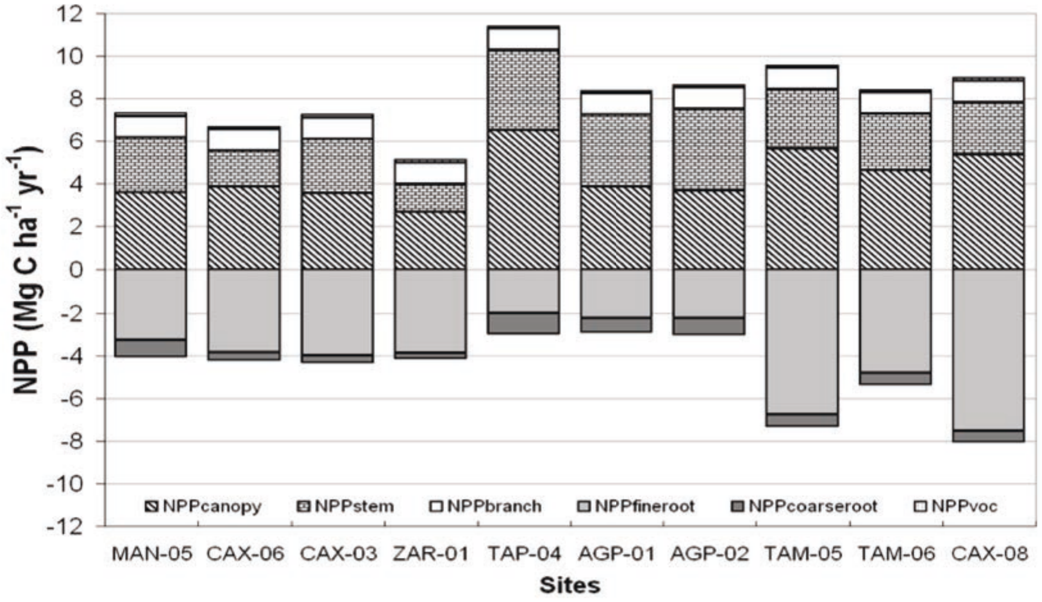
Quesada et al. 2011, *Biogeosciences;*
Quesada and Lloyd, 2016

Gradients in carbon dynamics





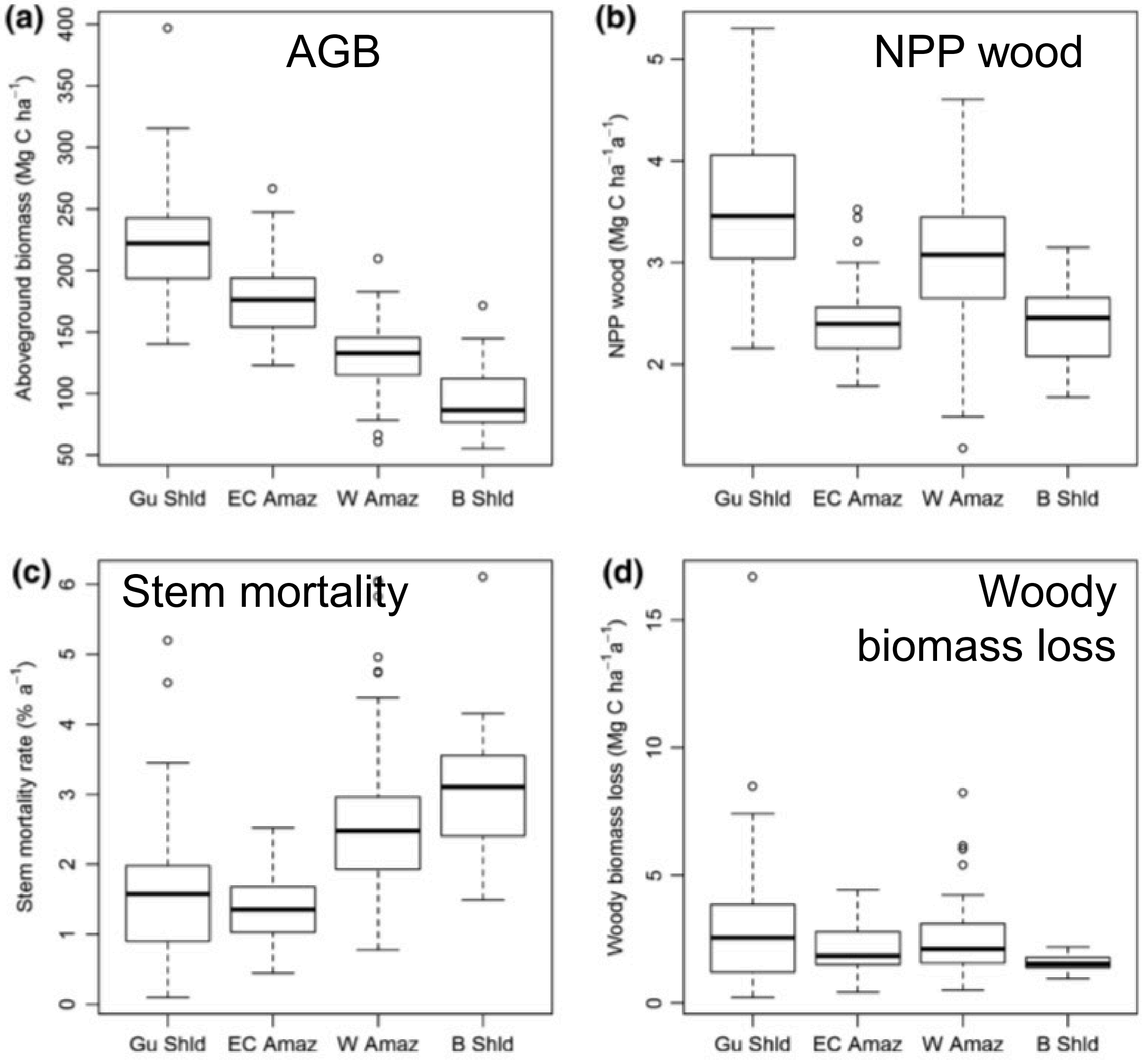
Malhi et al. 2006, *Global Change Biol.*



Soil P availability

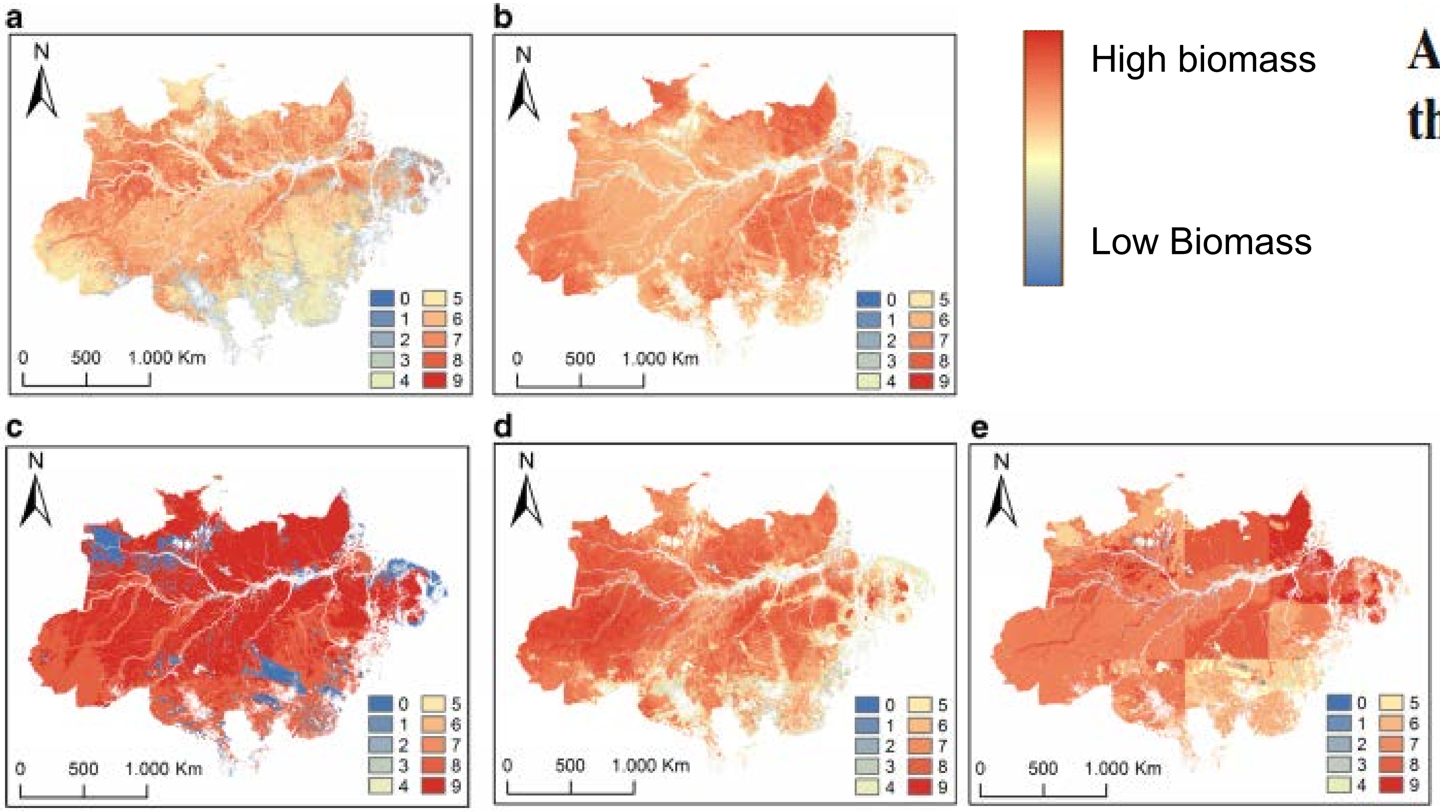
Aragão et al. 2009, *Biogeosciences*

Gradients in carbon dynamics



Johnson et al. 2016, *Glob Change Biol.*

Amazon forest biomass

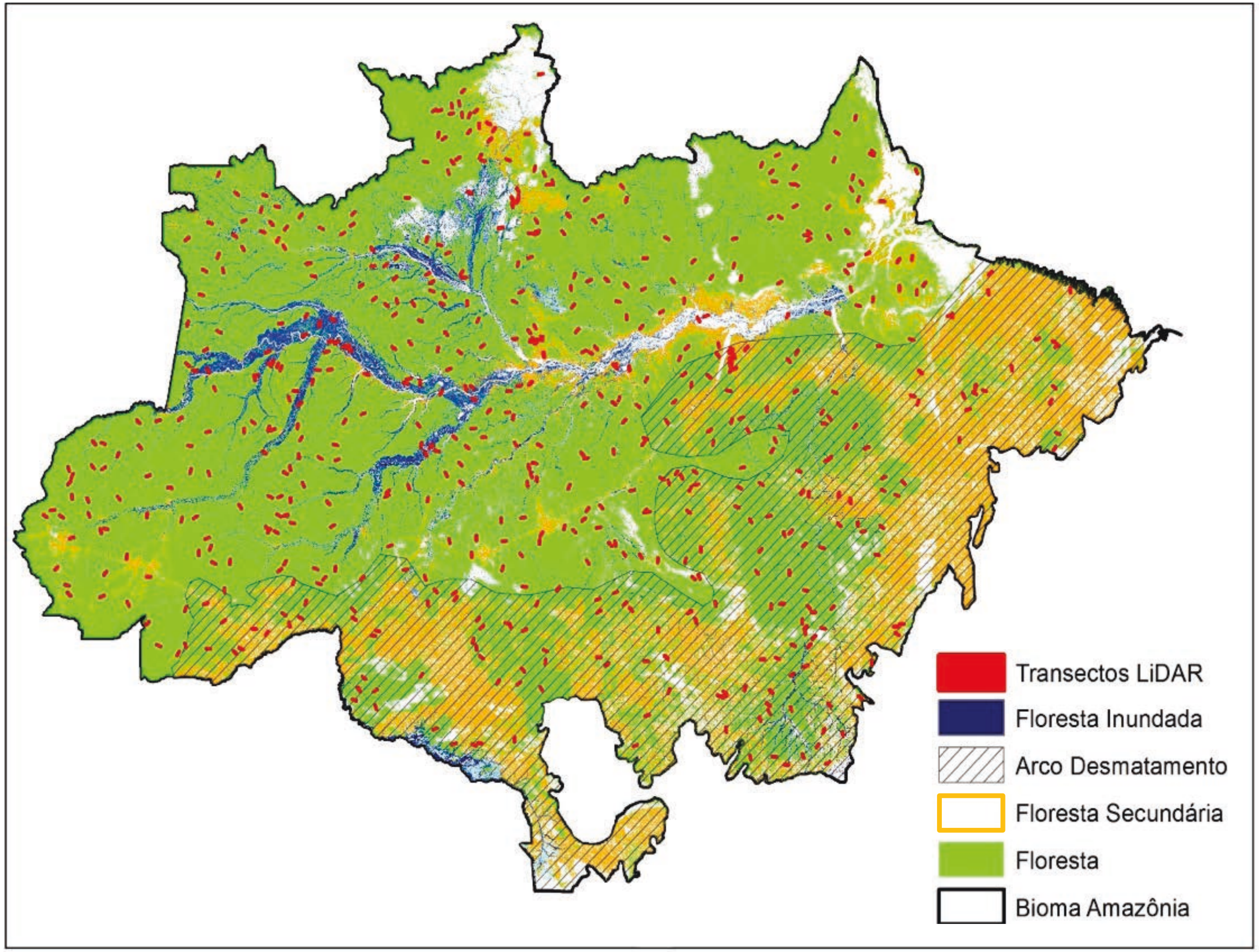


Amazon forest biomass density maps: tackling the uncertainty in carbon emission estimates

a) Saatchi et al. (2007)
b) Saatchi et al. (2011)
c) Nogueira et al. (2008)
d) Baccini et al. (2012)
e) MCTI (2010)

Ometto et al, 2004, Climatic Change

New LiDAR + Hiperespectral measurements



1000 LiDAR transects
Width: **300m**
Length: **12,5Km**
Area covered: 3,750km2 (~0,11%)

192 flown twice (Arc/Degradation)
91 directed to field plots

Randomly distributed:
- PRODES forest
- TERRACLASS Secondary vegetation and
- wetlands

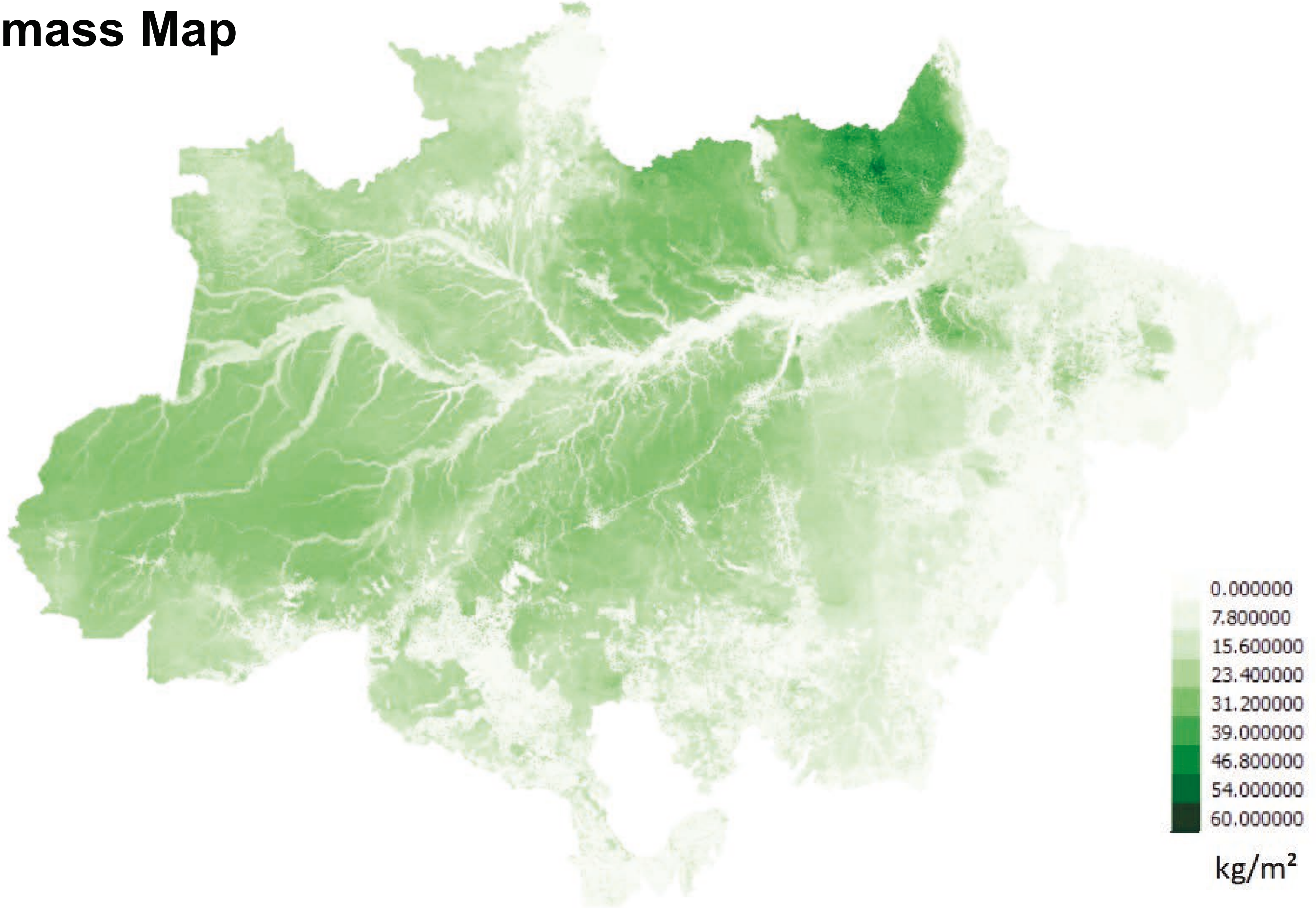
50 Hyperspectral transects

Data Paper Submitted to
PANGEA
Data Publisher for Earth & Environmental Science

INPE CCST Ciência para sustentabilidade EBA Estimativa de biomassa na Amazônia

slide courtesy: Jean Ometto

Forest Biomass Map



EBA

Role of undisturbed forests

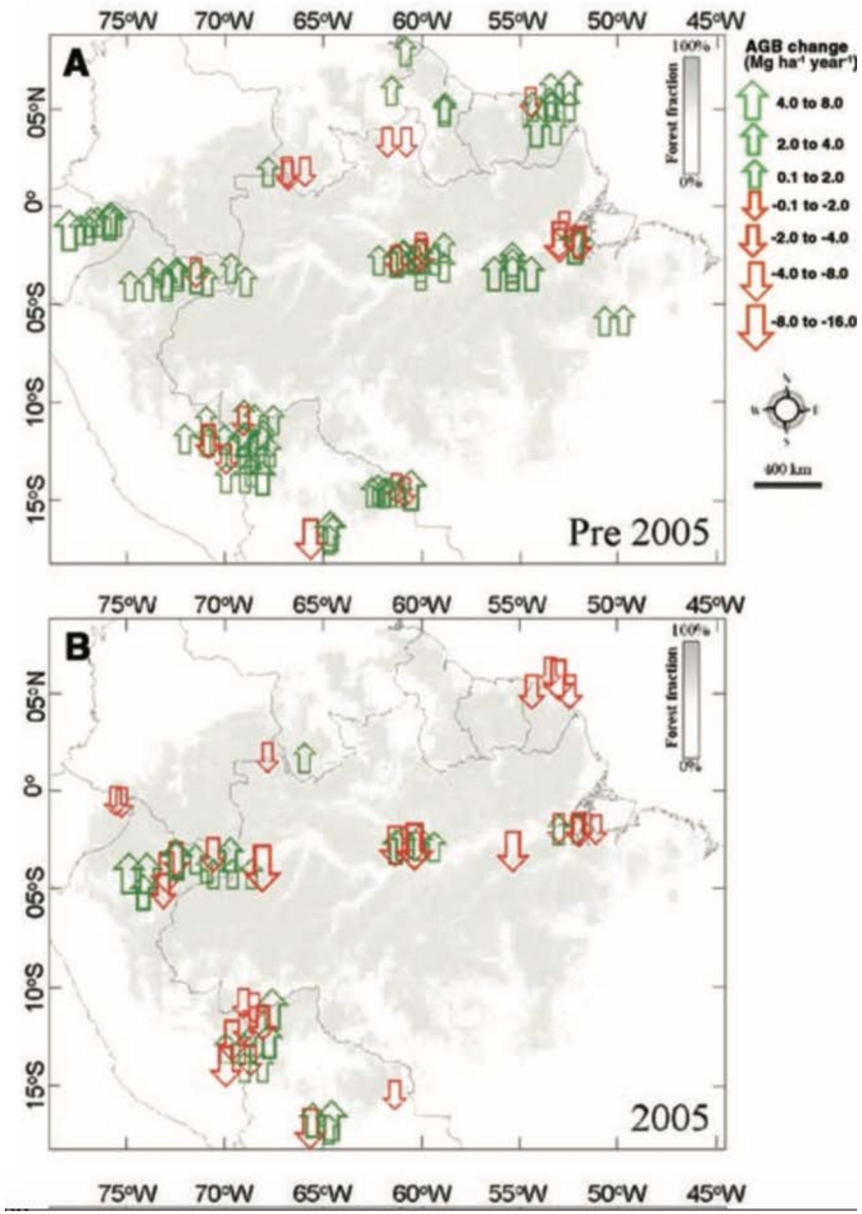
- Interplay between climate, plants and soils drive basin-wide gradient of forest productivity, tree mortality and AGB
- Western Amazon (younger), soils rich (in P) => fast forest growth, high tree mortality, fast turnover
- Eastern Amazon, very deep, less fertile soils => slow growth, low mortality rate, higher AGB

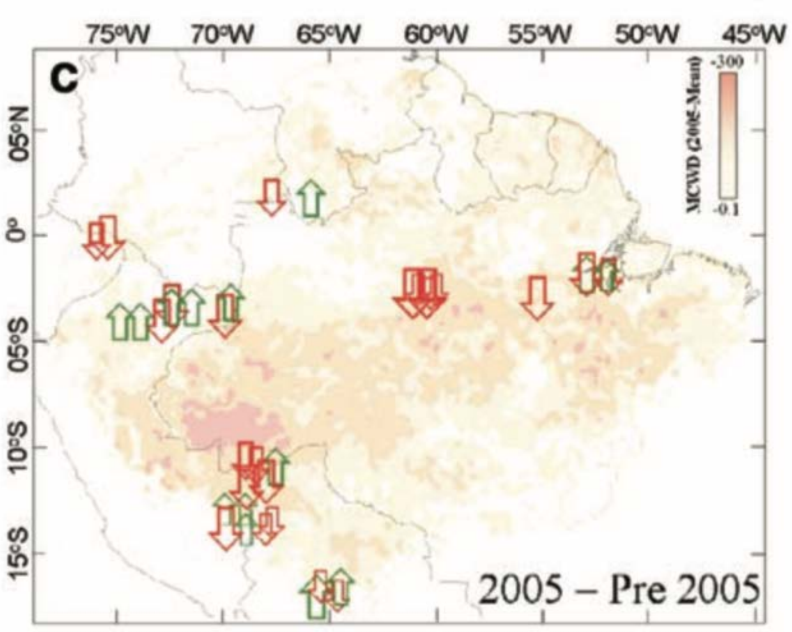
What if we change the climate?

Drought Sensitivity

ABG Change
Pre 2005

ABG Change
in 2005

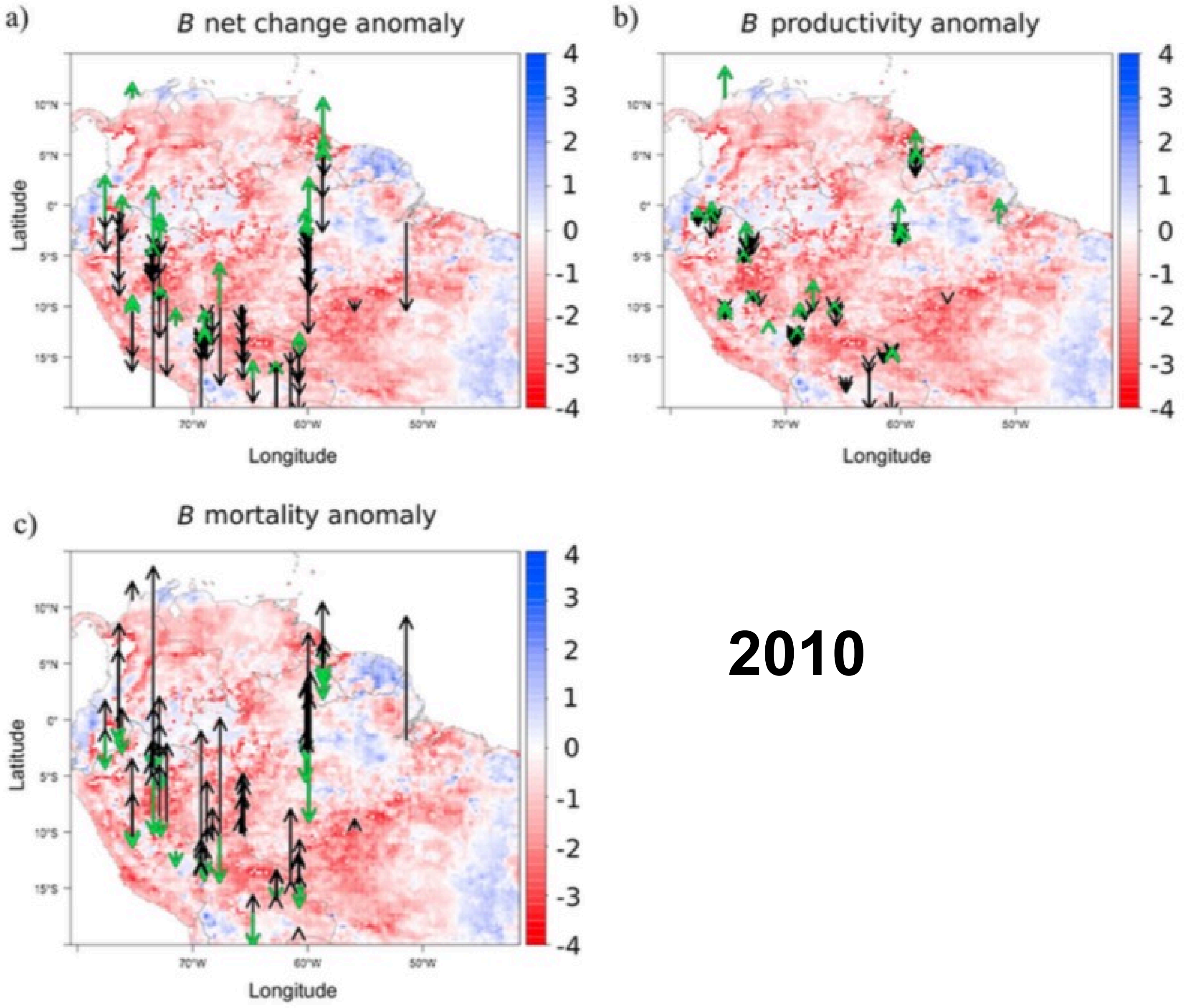




2005 – Pre 2005

Phillips et al., 2009, Science

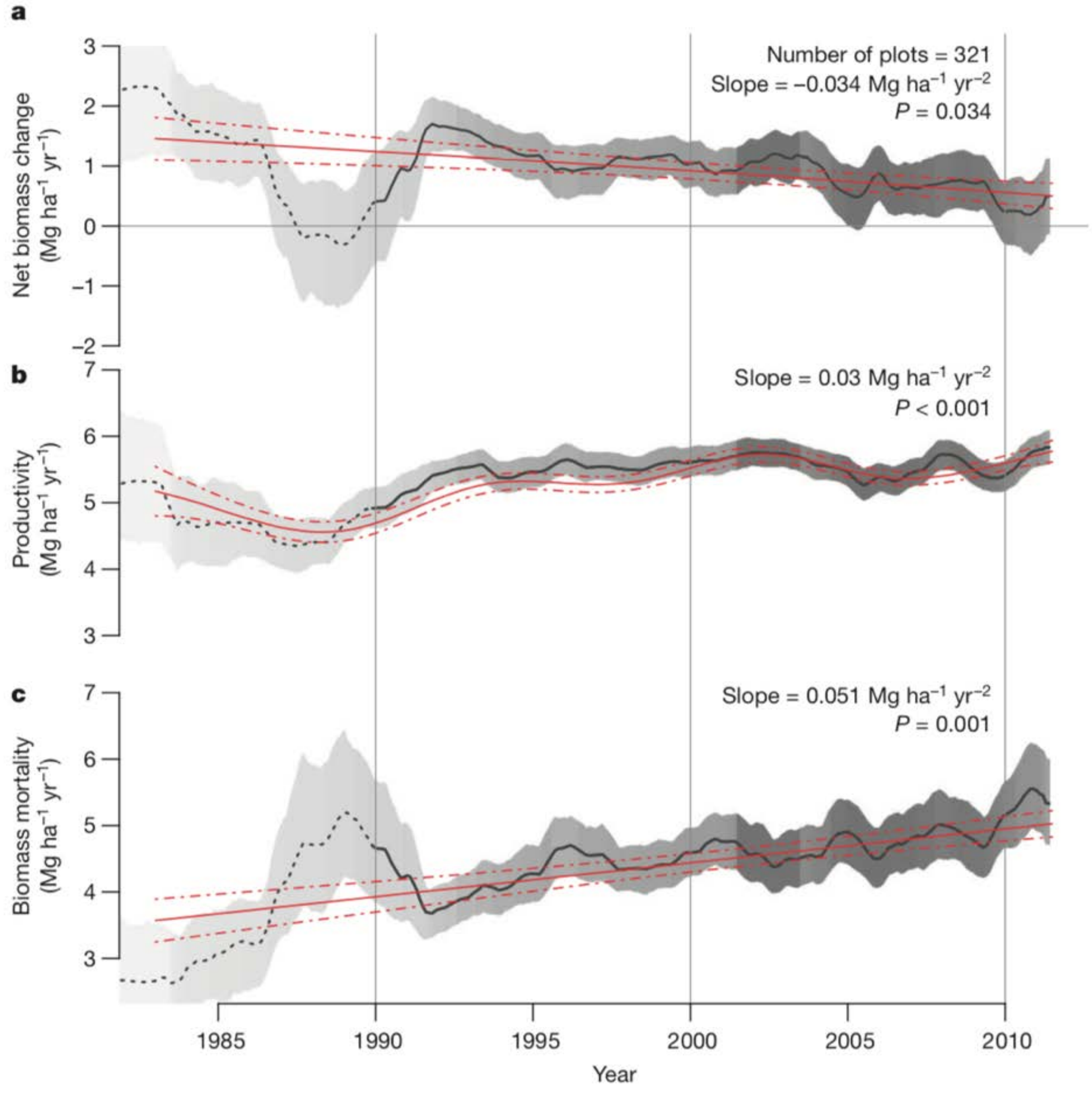
Drought Sensitivity



2010

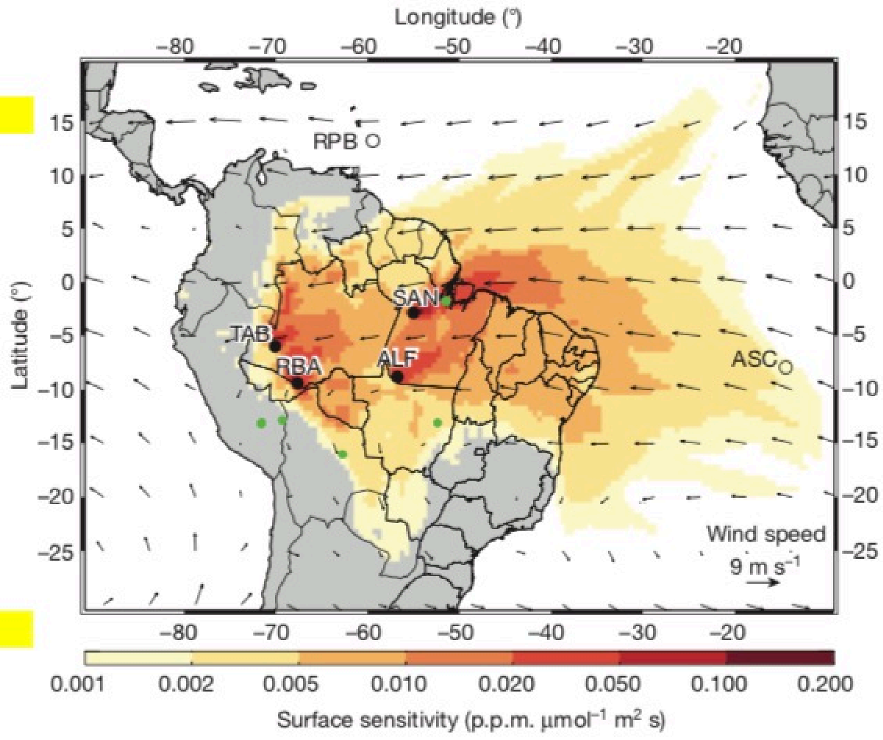
Feldpausch et al. 2016, *Global Biogeochemical Cycles*

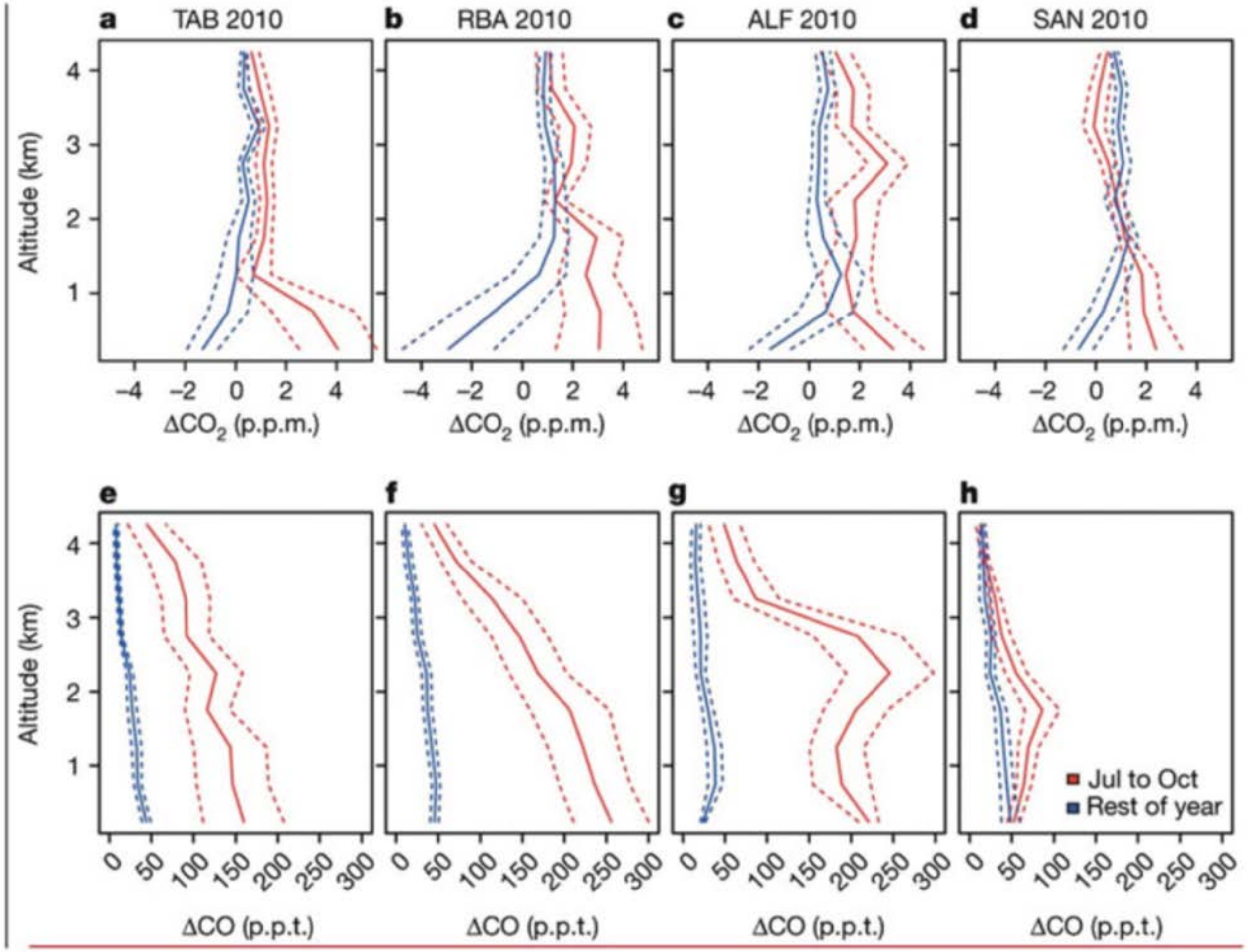
Long term trends



Brienen et al. 2015, *Nature*

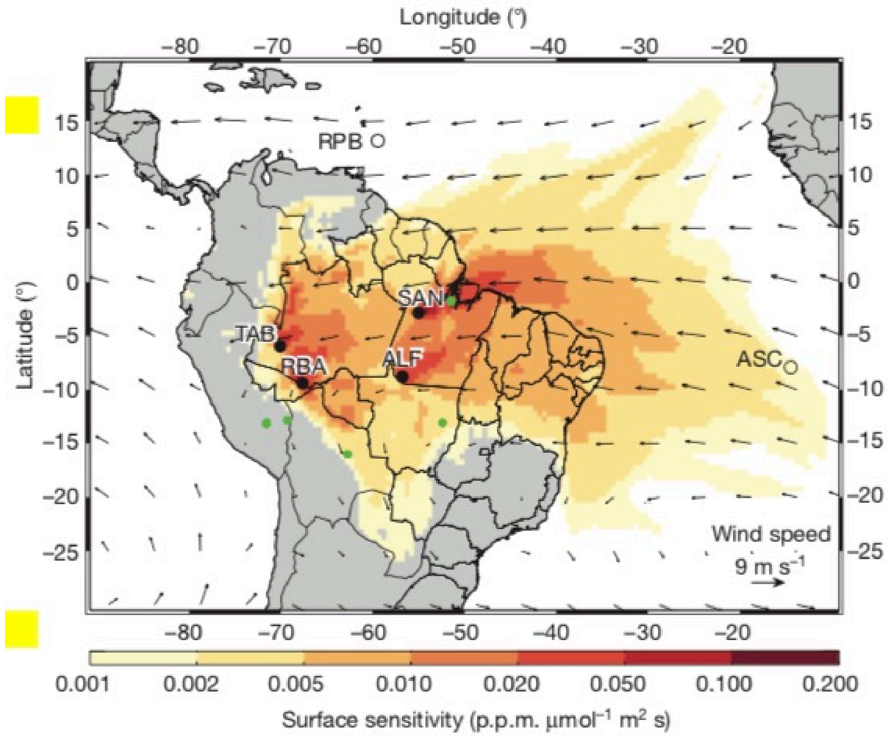
Carbon balance revealed by atmospheric measurements

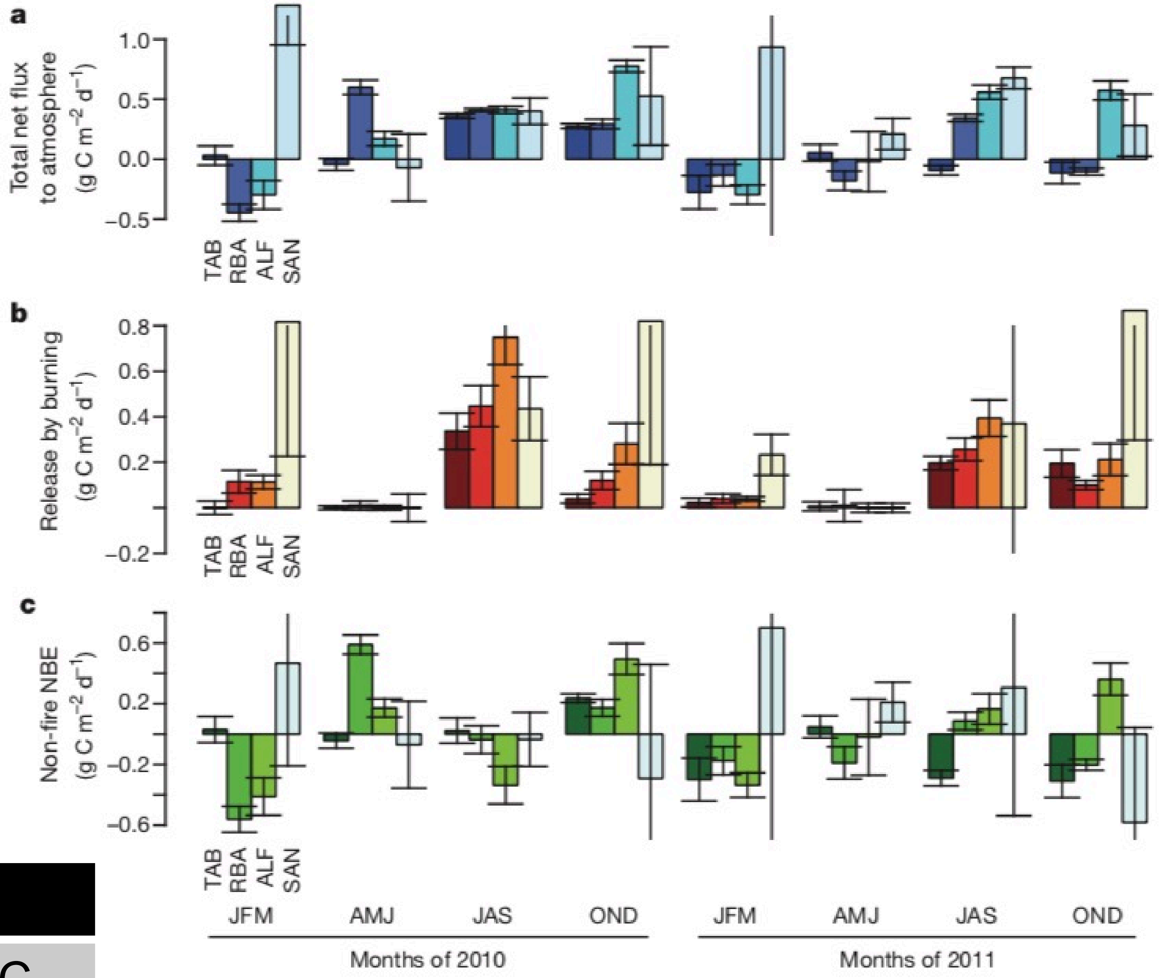




Gatti et al. 2014, *Nature*

Carbon balance revealed by atmospheric measurements





Note:

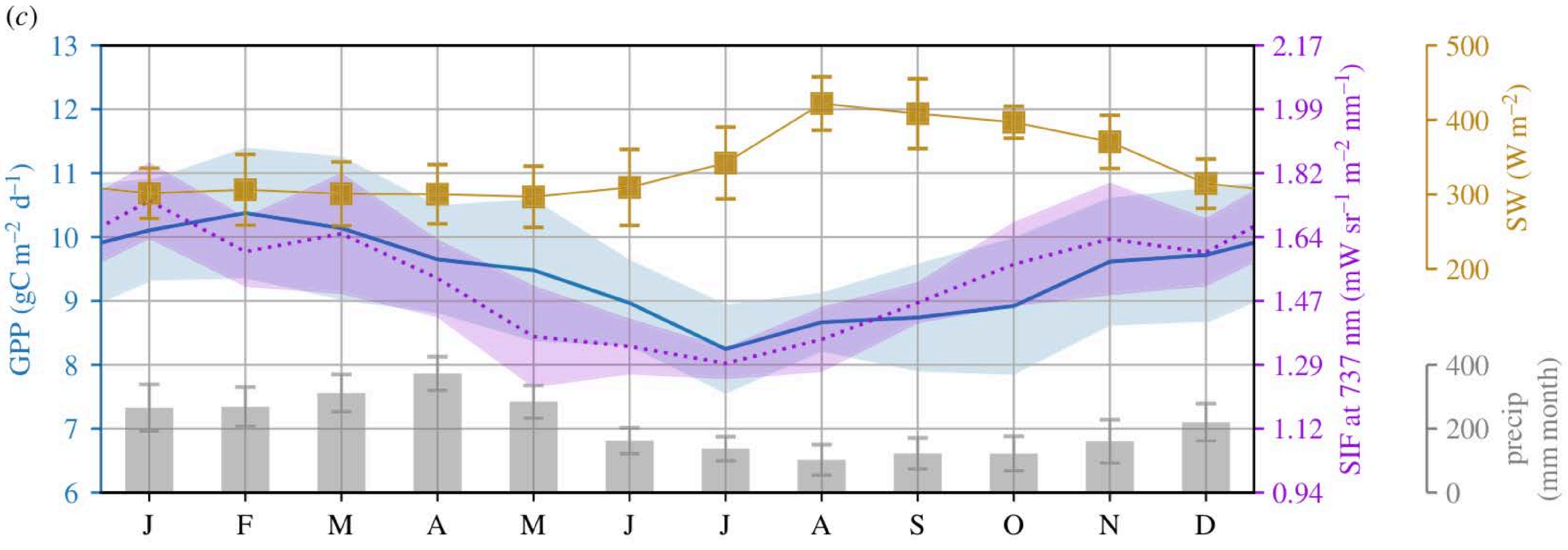
(-) NBP

(-) NEP

	NEP	NBP
2010	-0.03 ± 0.22 PgC yr^{-1}	0.48 ± 0.18 PgC yr^{-1}
2011	+0.25 ± 0.14 PgC yr^{-1}	0.06 ± 0.10 PgC yr^{-1}

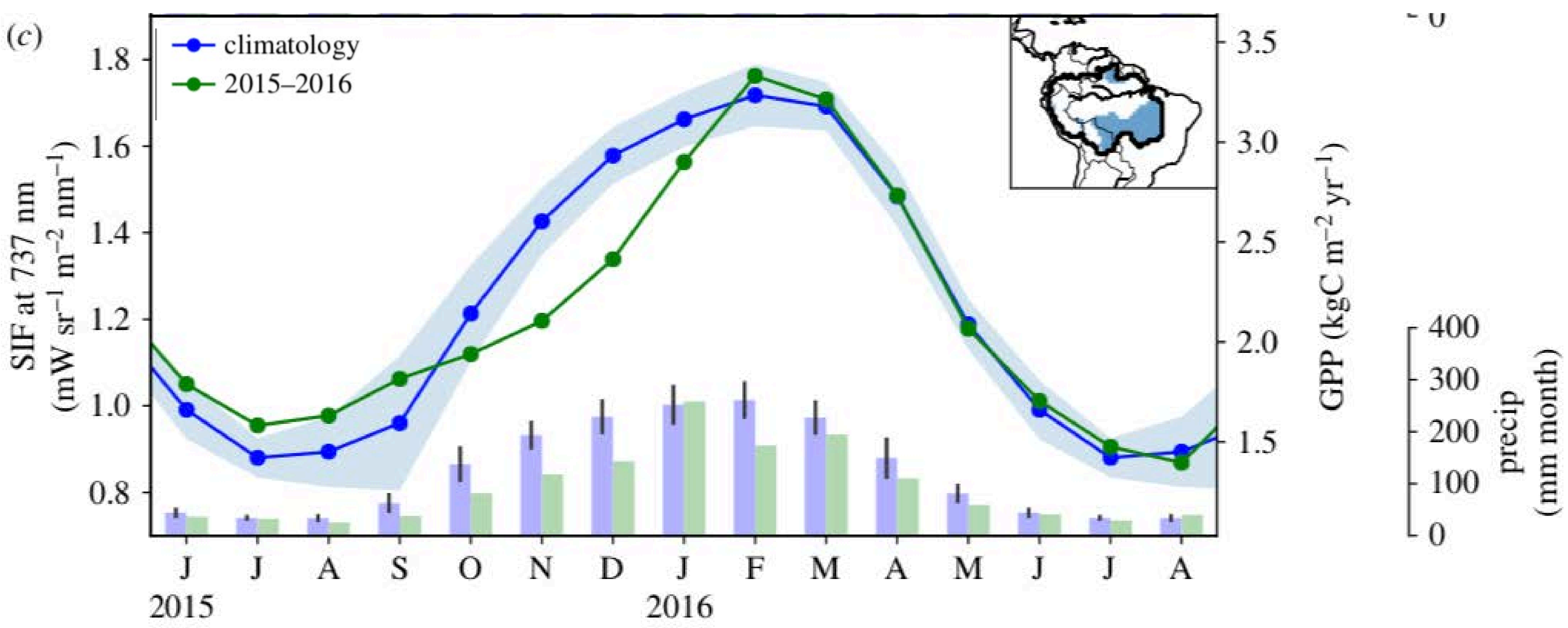
Gatti et al. 2014, *Nature*

Sun induced fluorescence (SIF) x GPP



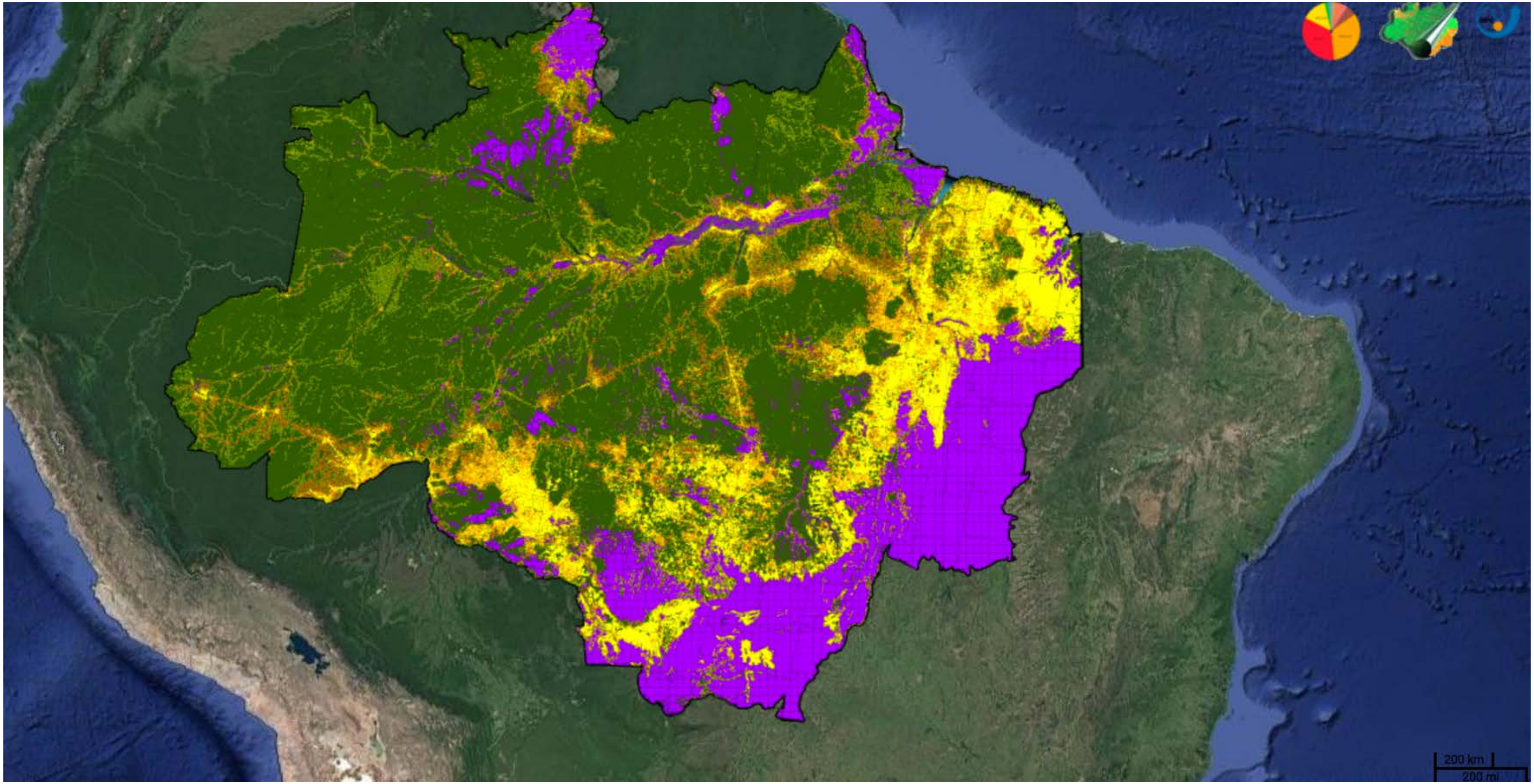
Koren et al., 2018, Phil Trans. B (*in press*)

Effect of 2015-2016 El-Niño

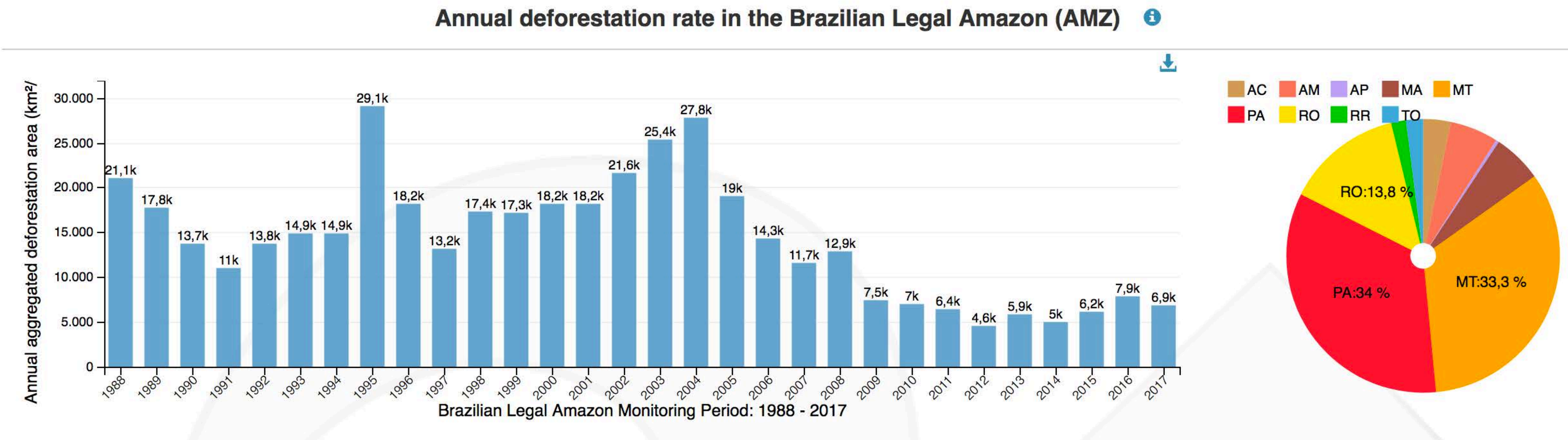


Koren et al., 2018, Phil Trans. B (*in press*)

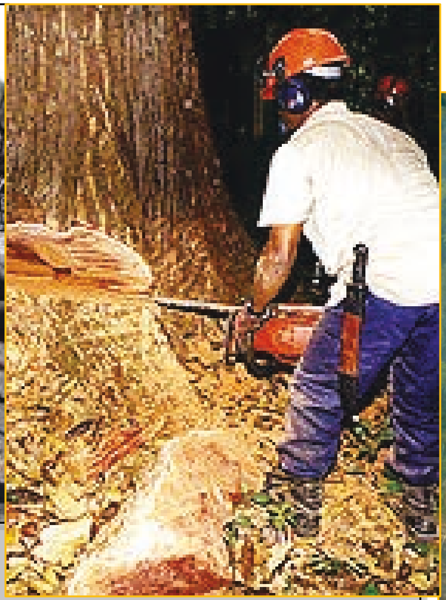
Deforestation monitored by PRODES



Deforestation monitored by the INPE/PRODES



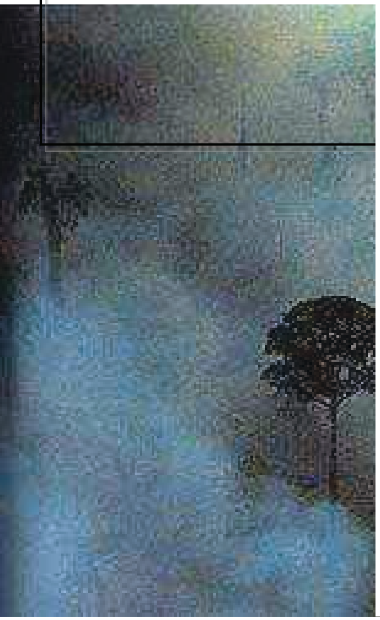
Human driven disturbances



Human driven disturbances

$$NBP = NEP - D$$ => Net Biome Productivity

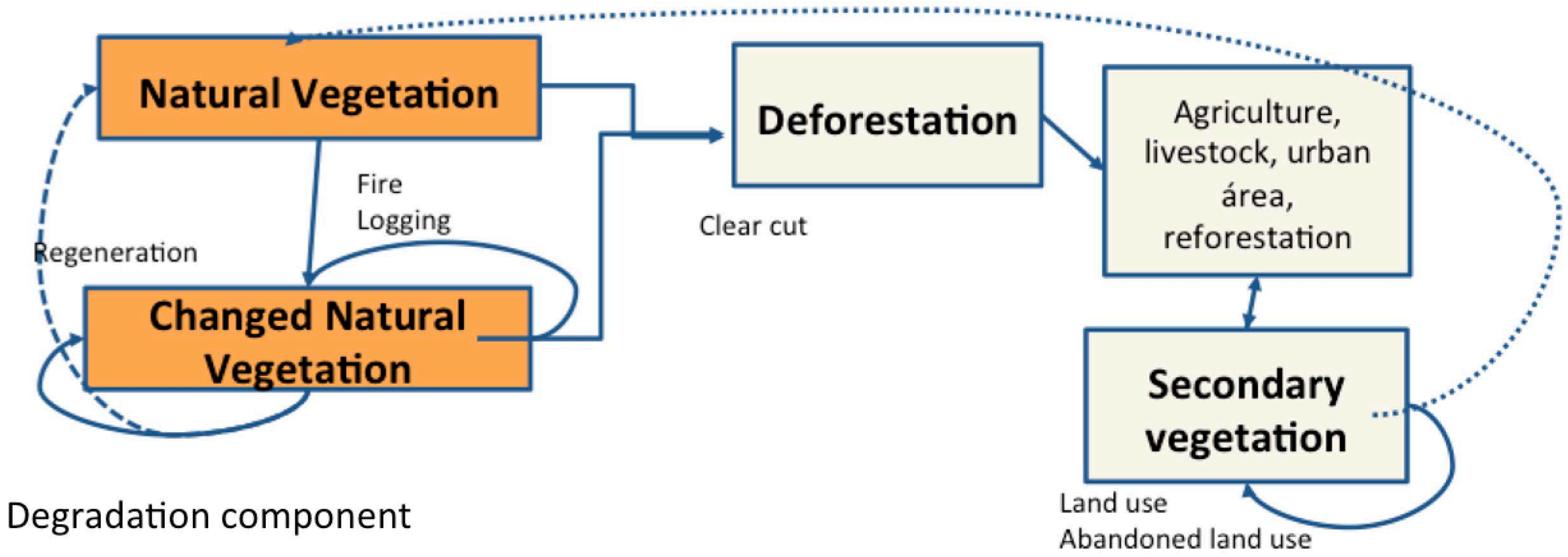
$$D = -D_F - L - F + R_{DF} + R_L + R_F$$



D_F , L *and* F *:* gross emission from deforestation, logging and fires in closed canopies (not deforestation fires)
R_{DF}, R_L *and* R_F *:* uptake by recovering vegetation after deforestation, logging and fires, respectively

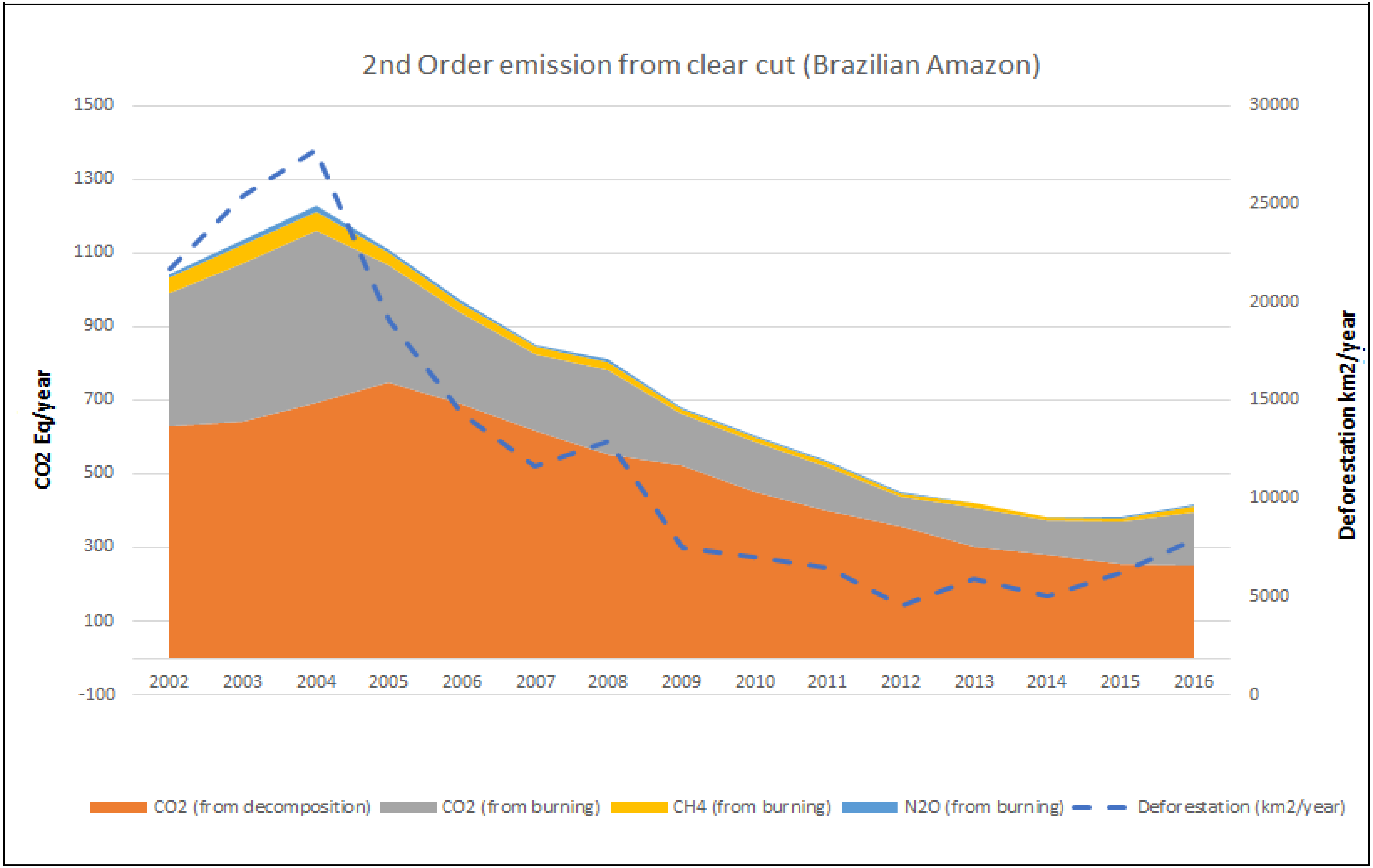
Aragão et al., 2014, *Biol.*

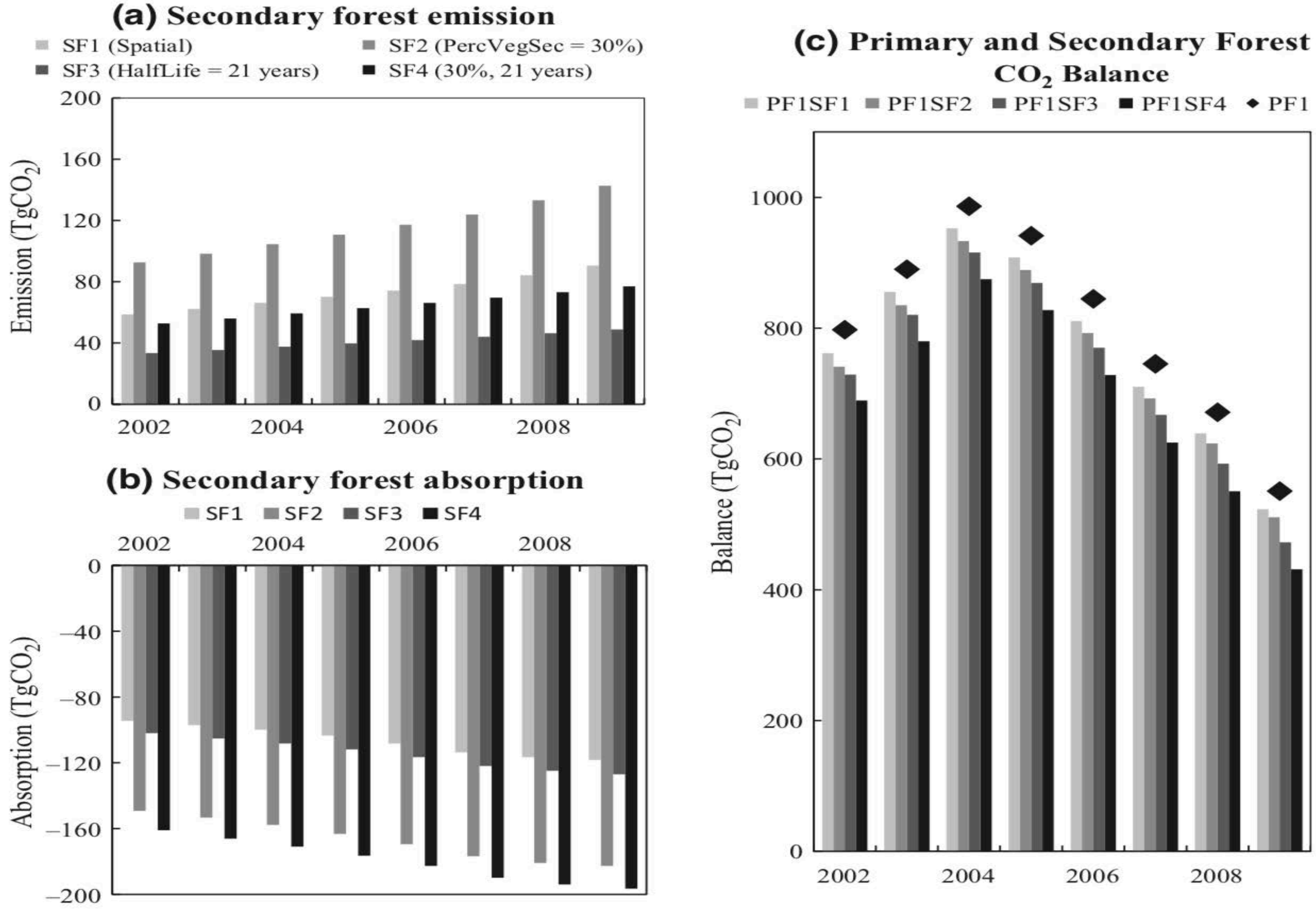
Accounting for LUCC Emissions – INPE Emissions Model



- Includes:
  - 1st and 2nd order emissions
  - Gross / net emissions
  - different GHG (CO_2, CH_4, N_2O, NOx, CO);
  - Spatial distributions for each gas

INPE-EM


2nd Order emission from clear cut (Brazilian Amazon)
CO2 Eq/year
Deforestation km2/year
1500
1300
1100
900
700
500
300
100
-100
30000
25000
20000
15000
10000
5000
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
CO2 (from decomposition)
CO2 (from burning)
CH4 (from burning)
N2O (from burning)
Deforestation (km2/year)

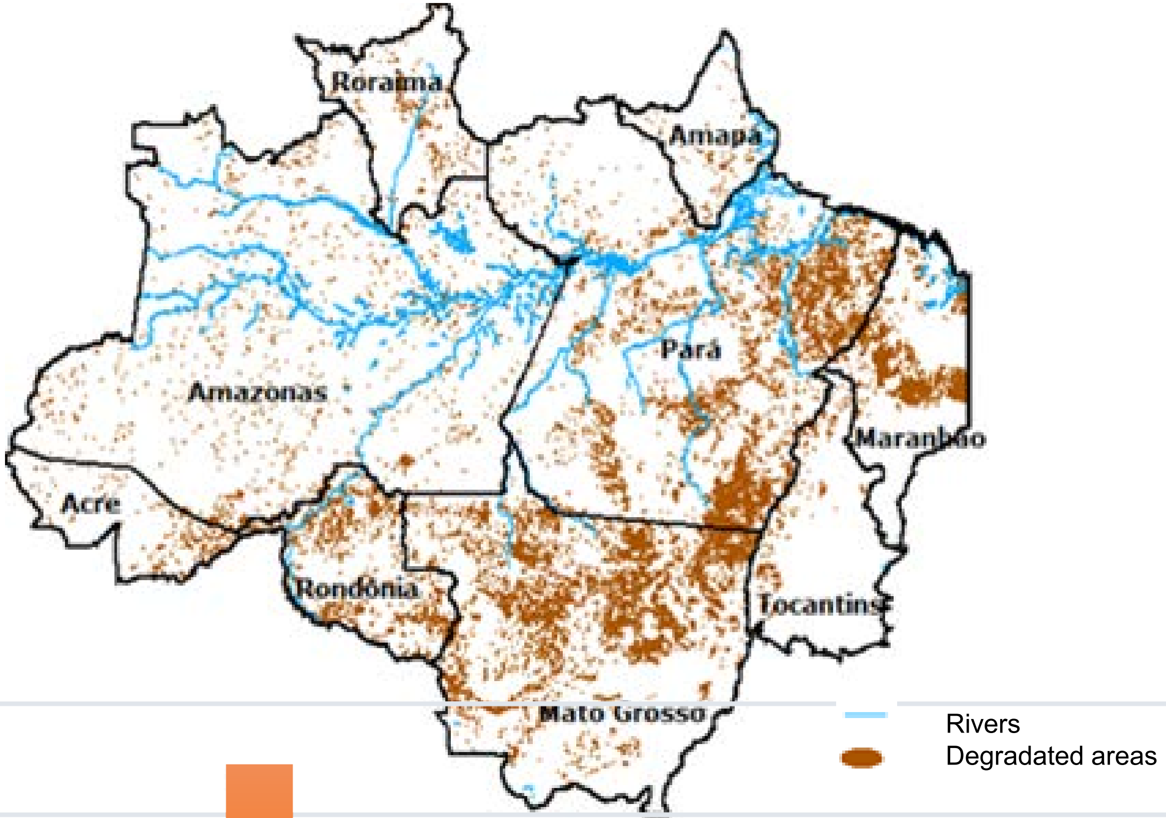


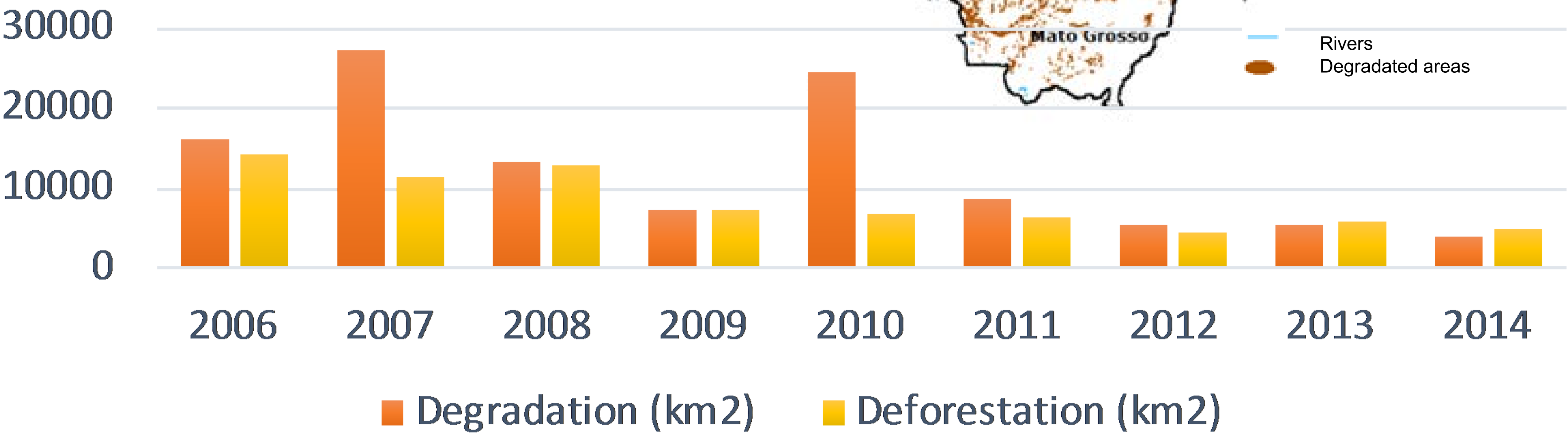
SF1 – SF4, different simulations of secondary forest growth

Aguiar et al., 2012, *Global Change Biol.*

Forest Degradation

INPE DEGRAD system



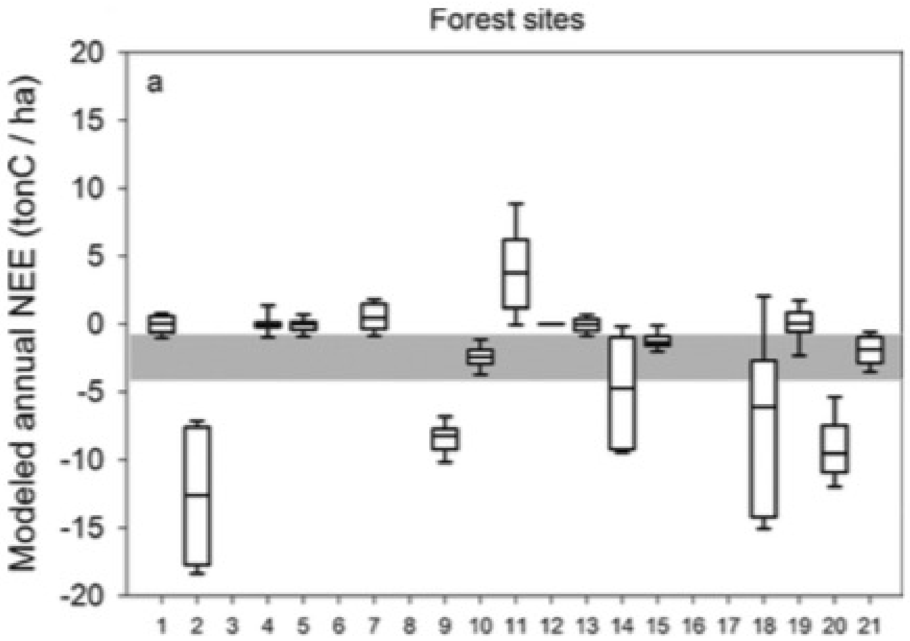


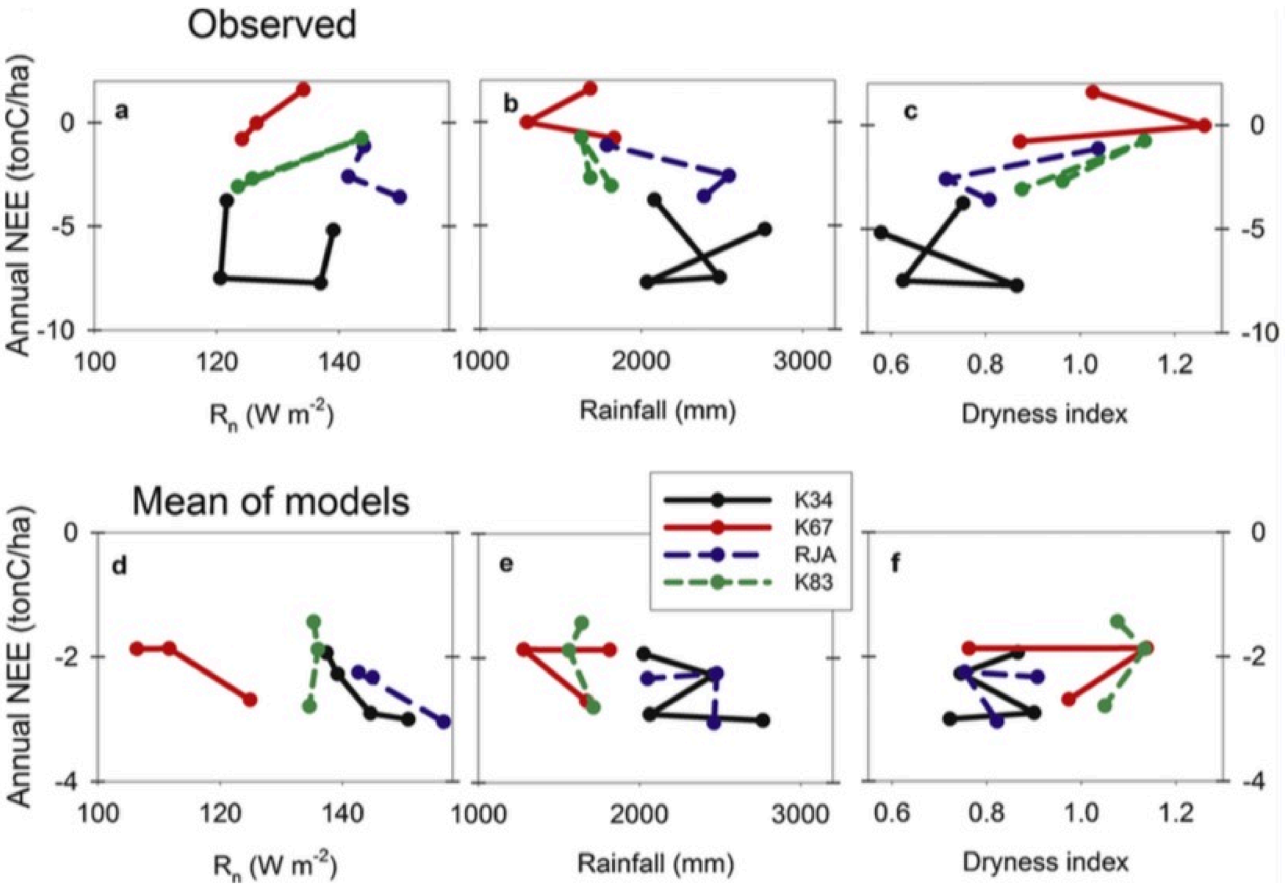
Disturbances in the Amazon carbon balance

- Ground and atmospheric observations show that undisturbed forests act as a carbon sink, but the sink strength appears to have been declining
- Drought events can temporarily revert the sink into a source
- Carbon emissions are dominated by human disturbances - deforestation, degradation, fires – but it is important to account for the carbon recovered after disturbances

What about modeling all this?

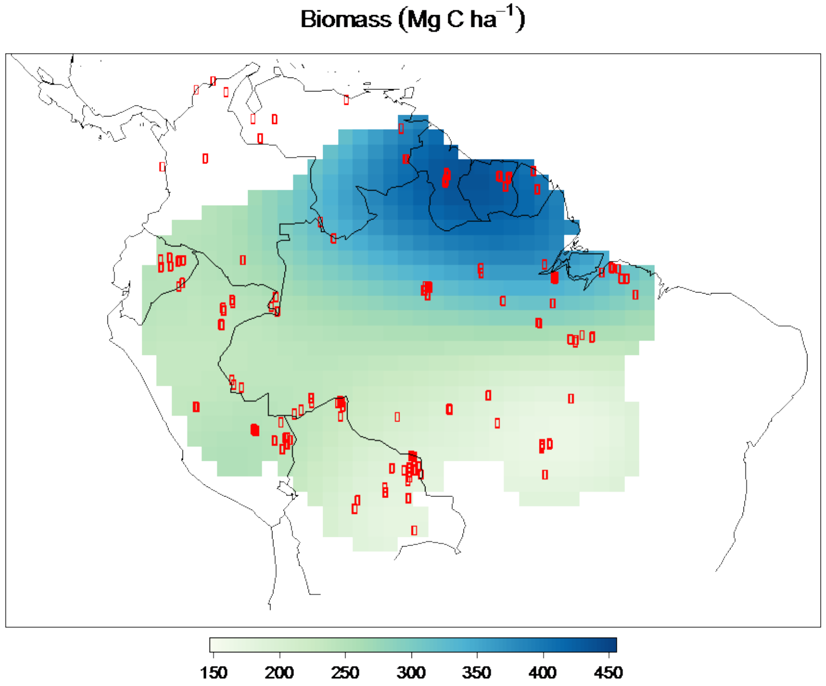
Models performance

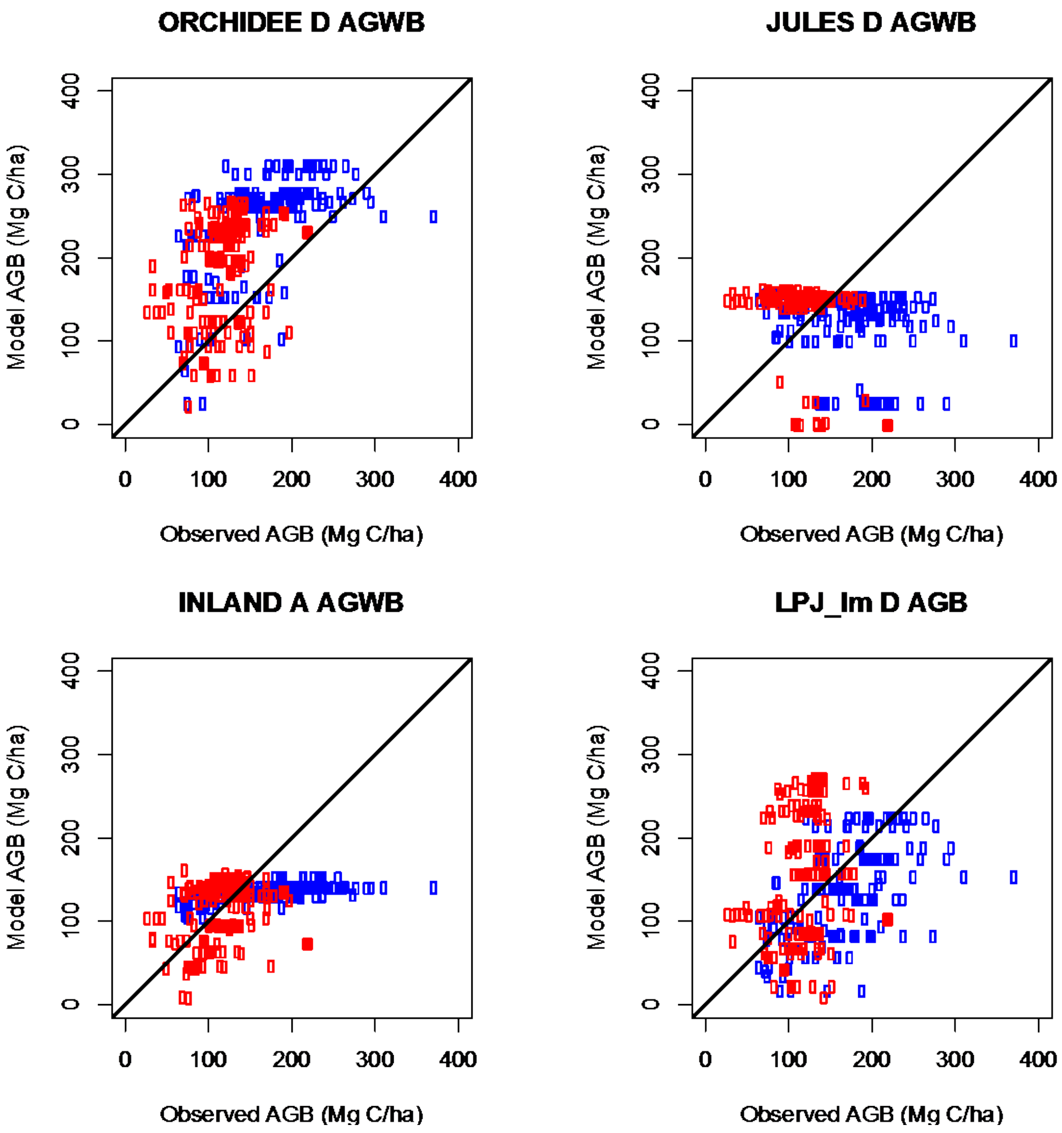




Von Randow et al. 2013, *Agric. Forest Meteorol.*

Biomass simulations





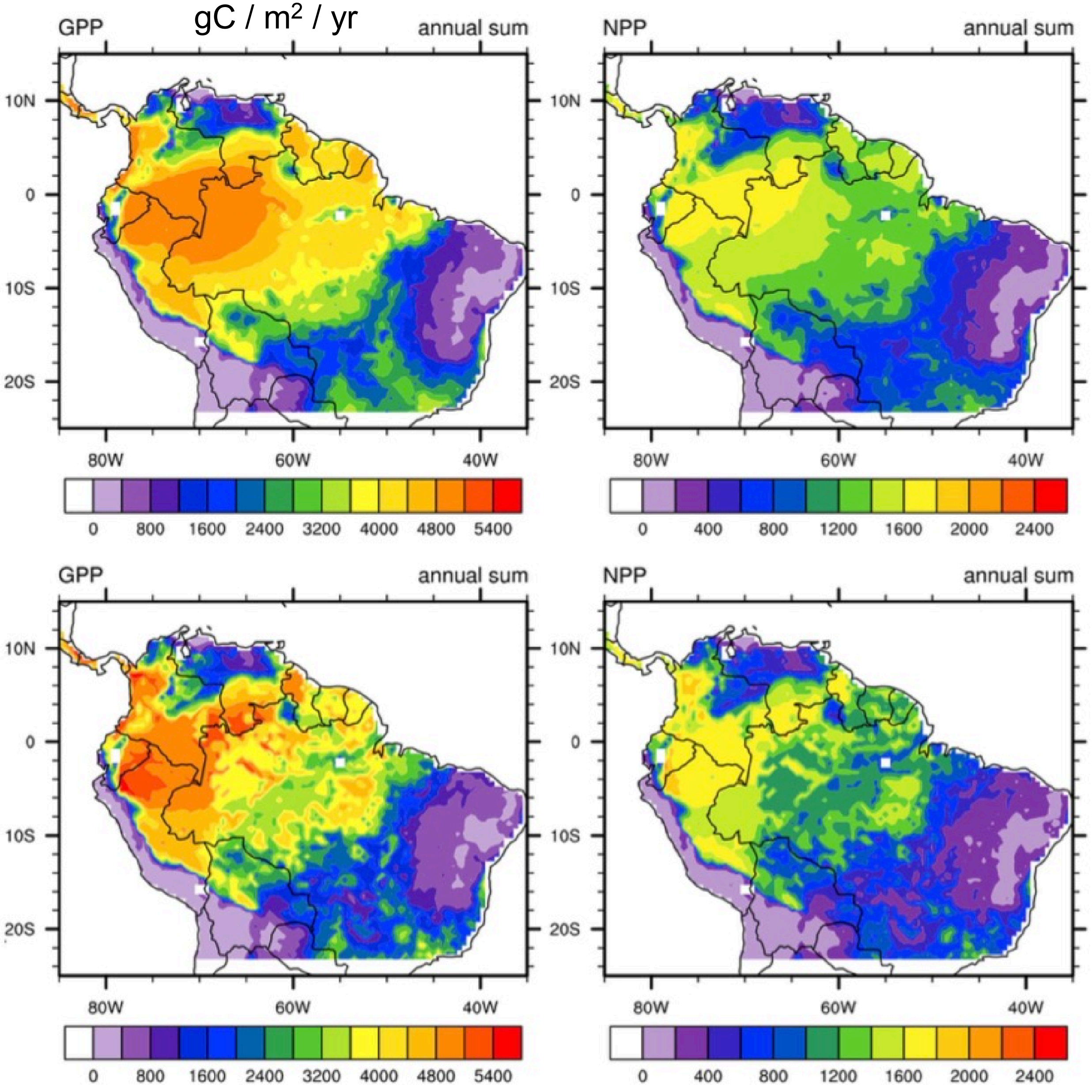
Johnson et al. 2016, *Glob Change Biol*

But… Nutrients may limit CO_2 fertilization!

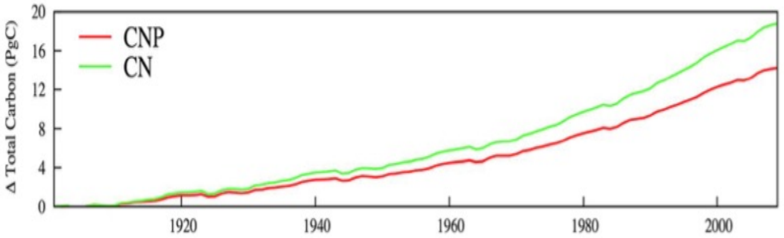
gC / m^2 / yr

CLM-CN

CLM-CNP

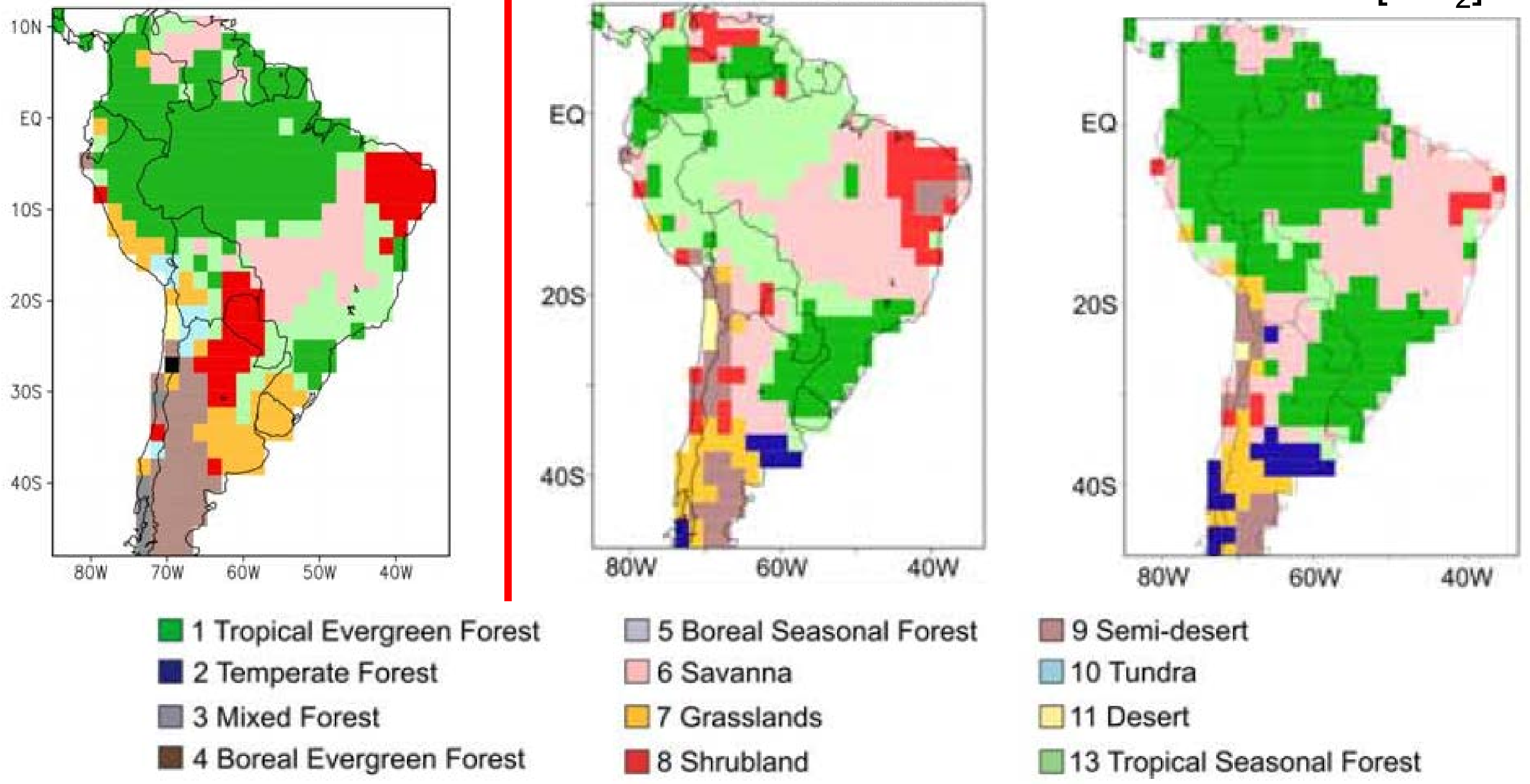


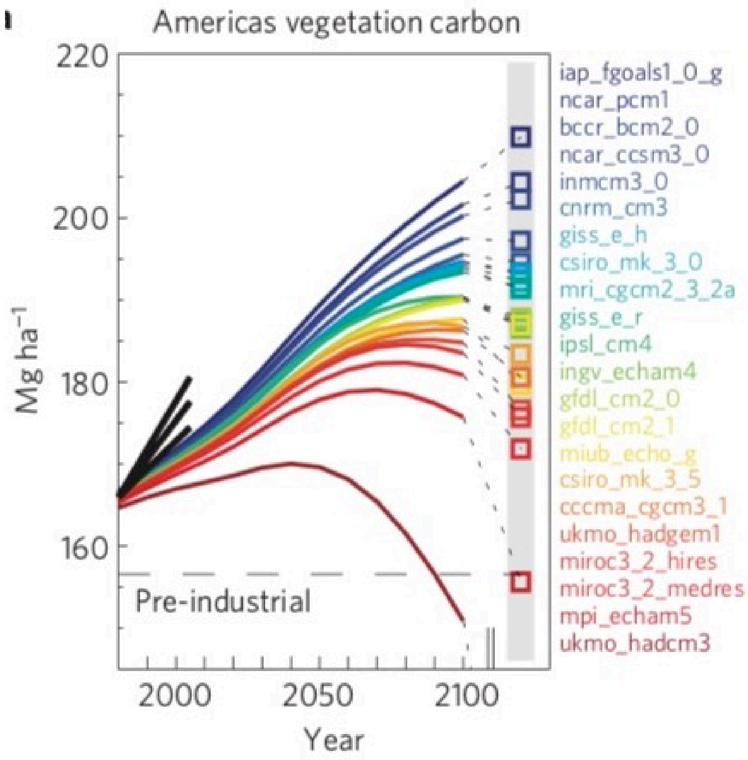
Pg C



Yang et al. , 2013, *Geophys. Res. Letters*

Importance of CO_2 fertilization effect





Lapola et al. , 2009, *Global Biogeochem. Cycles*

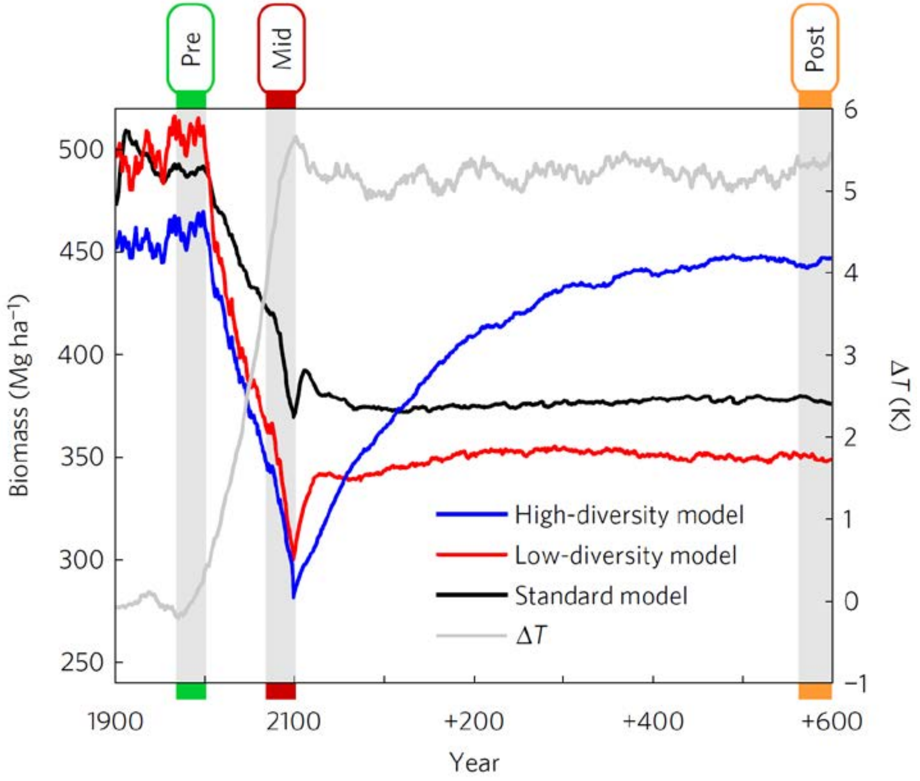
Huntingford et al. , 2013, *Nature*

Simulated rainforest biomass under climate change and different plant trait diversity

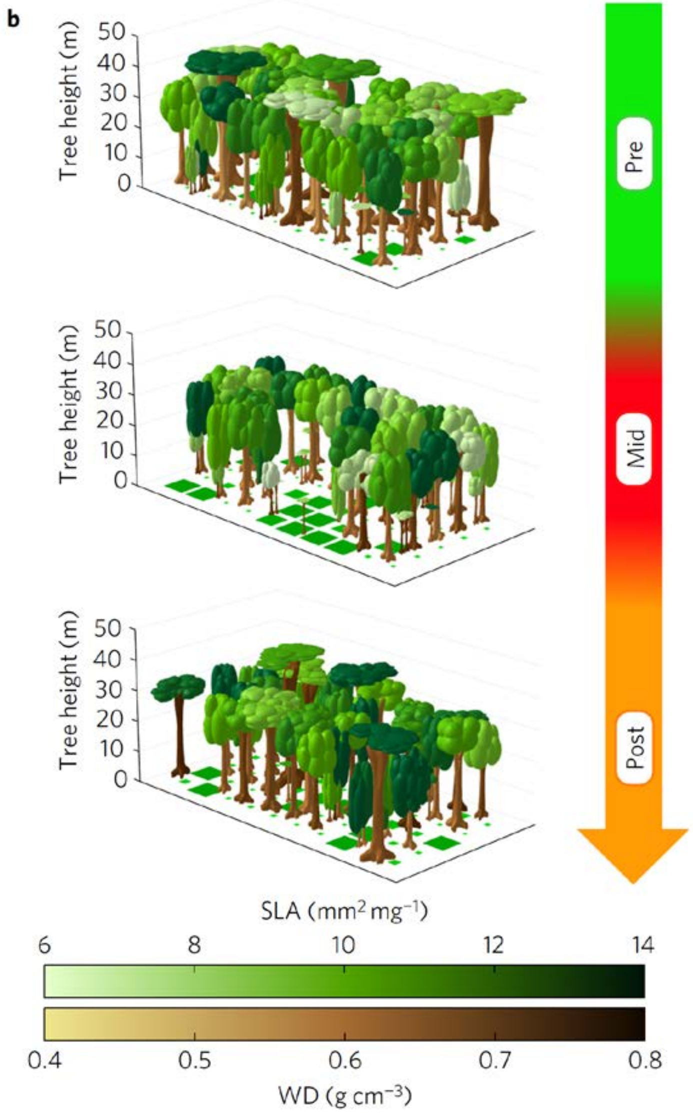
nature climate change
LETTERS
PUBLISHED ONLINE: 29 AUGUST 2016 | DOI: 10.1038/NCLIMATE3109

Resilience of Amazon forests emerges from plant trait diversity

Boris Sakschewski[1,2]*, Werner von Bloh[1,2], Alice Boit[1,2], Lourens Poorter[3], Marielos Peña-Claros[3], Jens Heinke[1,2], Jasmin Joshi[4] and Kirsten Thonicke[1,2]



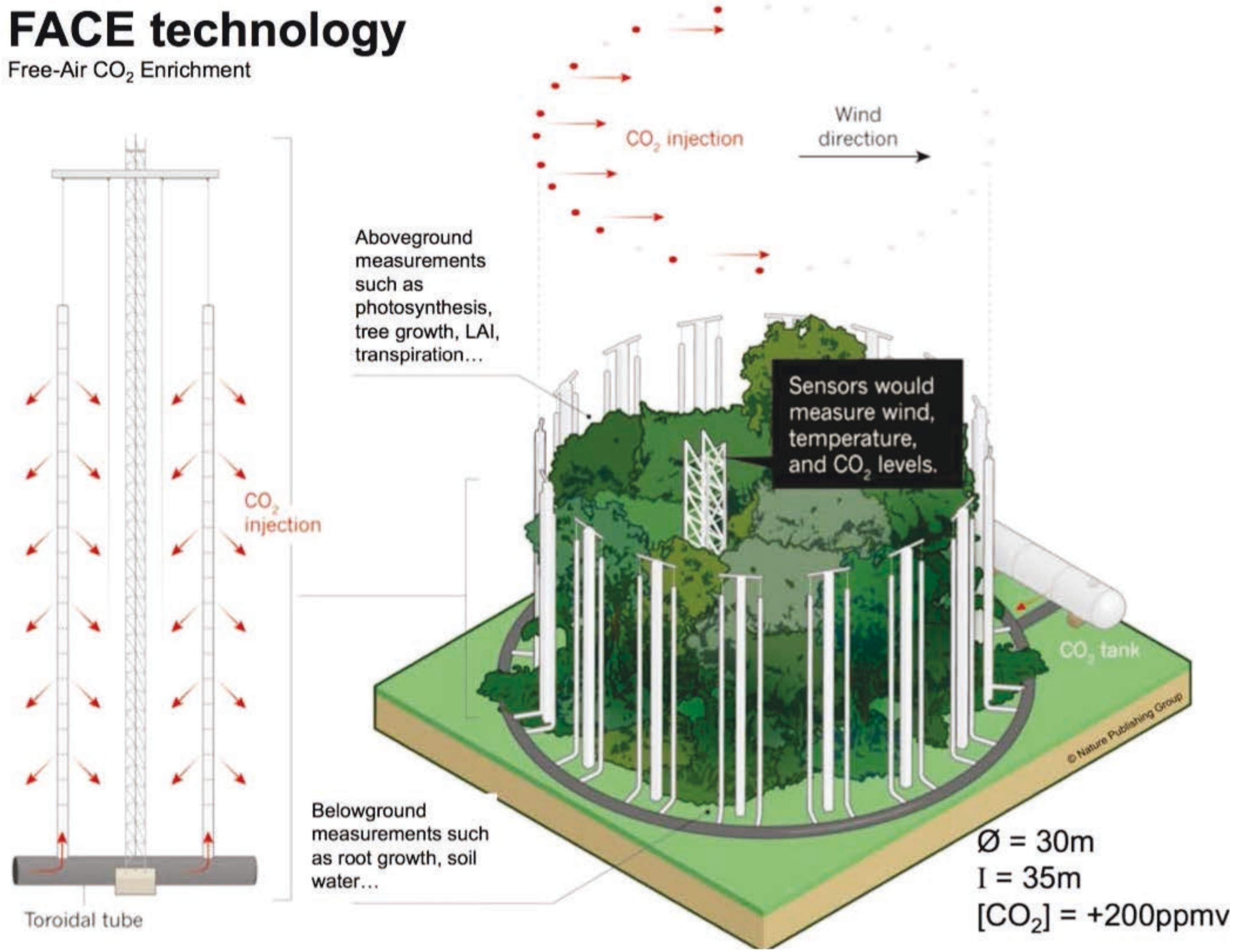
Annual biomass over 800 simulation years for 400 ha of Ecuadorian rainforest from three different versions of the vegetation model LPJmL under a severe climate change scenario (RCP 8.5 HadGEM2). 1*T*: annual temperature difference to the mean temperature of pre-impact time (1971–2000) in K.



Forest height structure recovers with biomass

AmazonFACE

- AmazonFACE is potentially game-changing in our understanding of the key uncertainties in carbon-cycle feedbacks

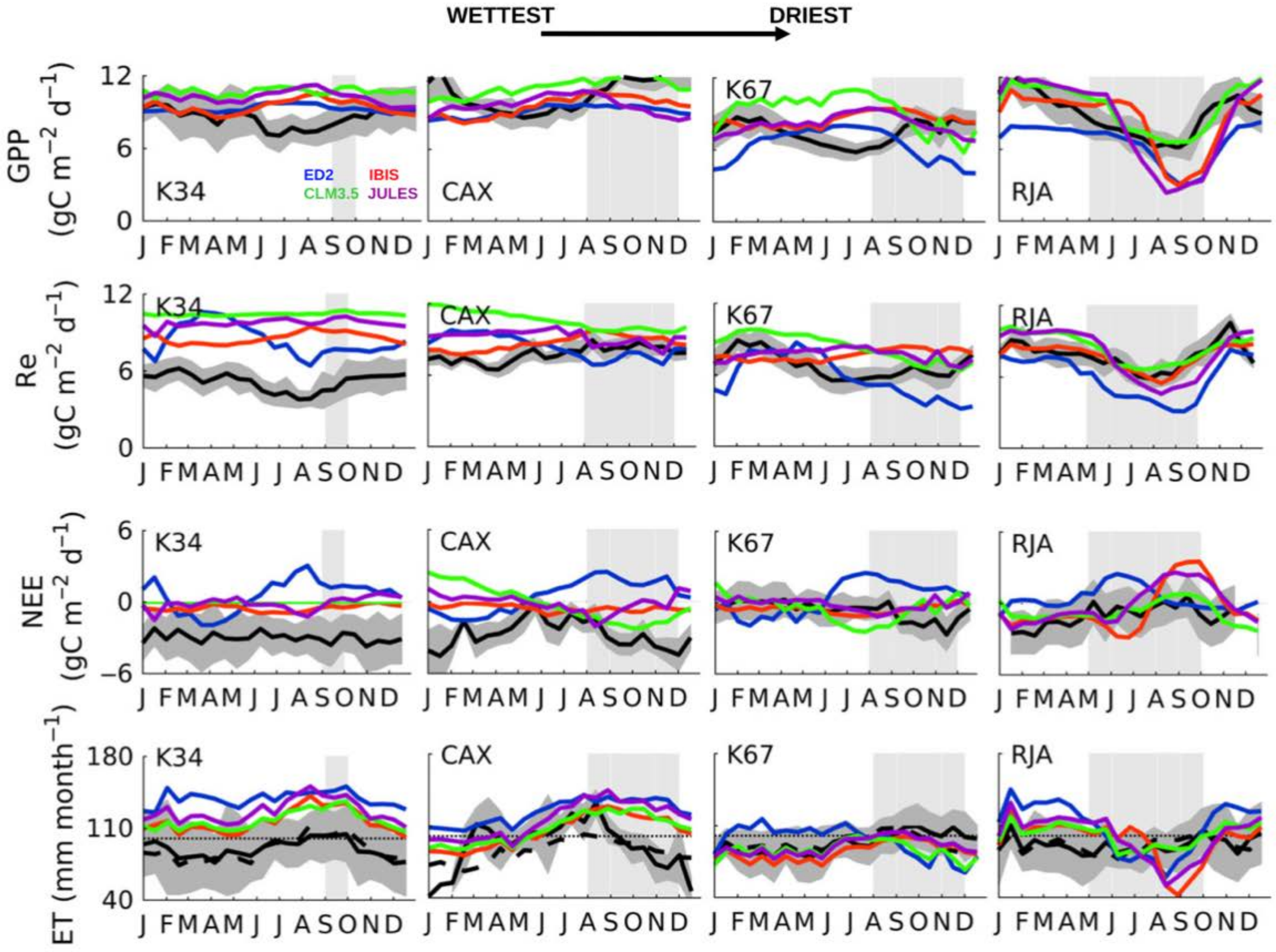


Way forward

- Current and future research on the climate sensitivity of Amazonian vegetation still need systematic inventories of ecosystem state variables and model-driving data, and adapting vegetation models for these processes
- Focus: effects of climate change, nutrient availability, and on ecosystem structure, especially the mortality process


Thanks for the attention!!!

Models performance



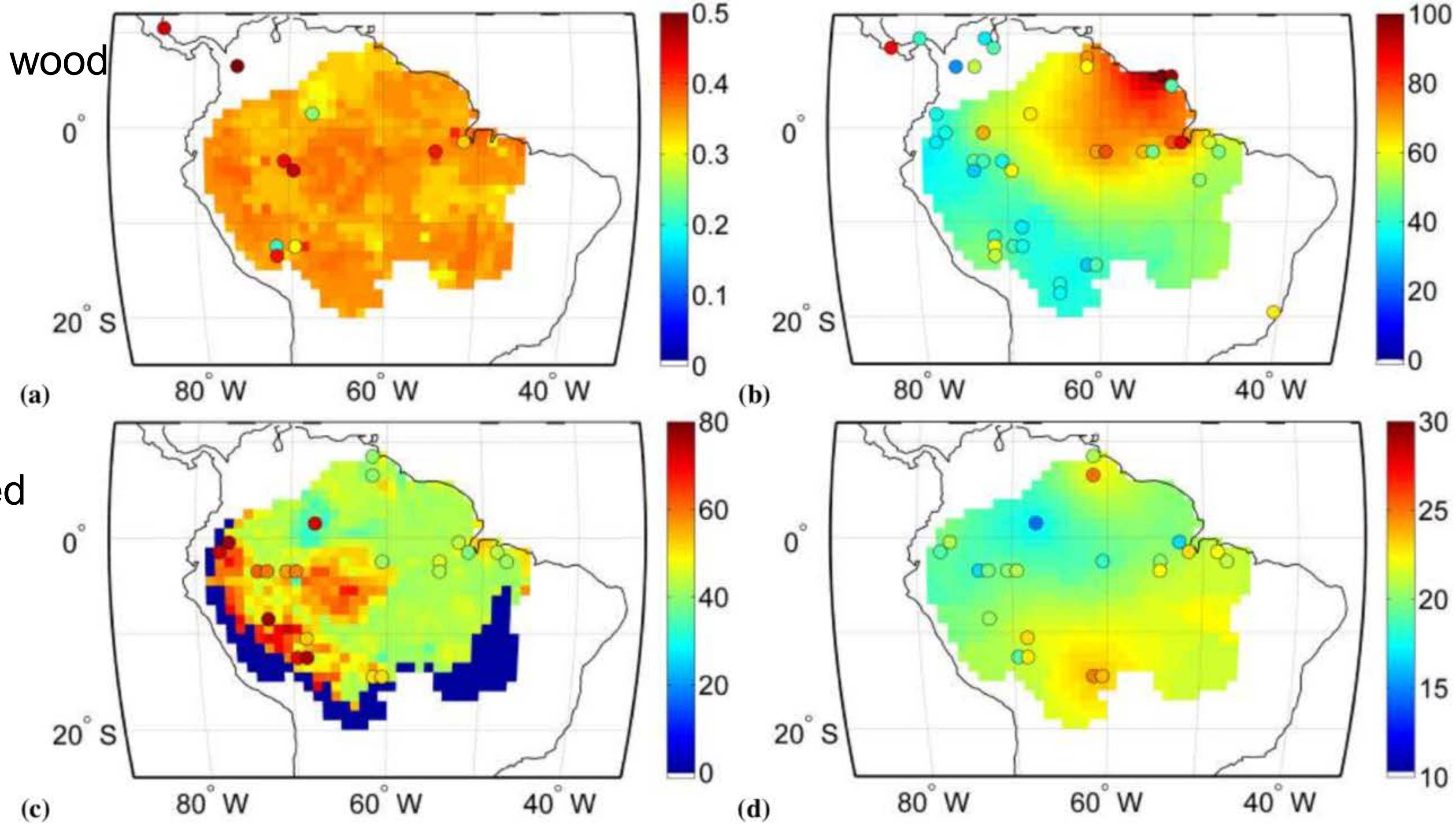
Restrepo-Coupe et al. 2016, *Global Change Biol*

Alocation to wood

Woody biomass residence time

Vcmax (based on soil P)

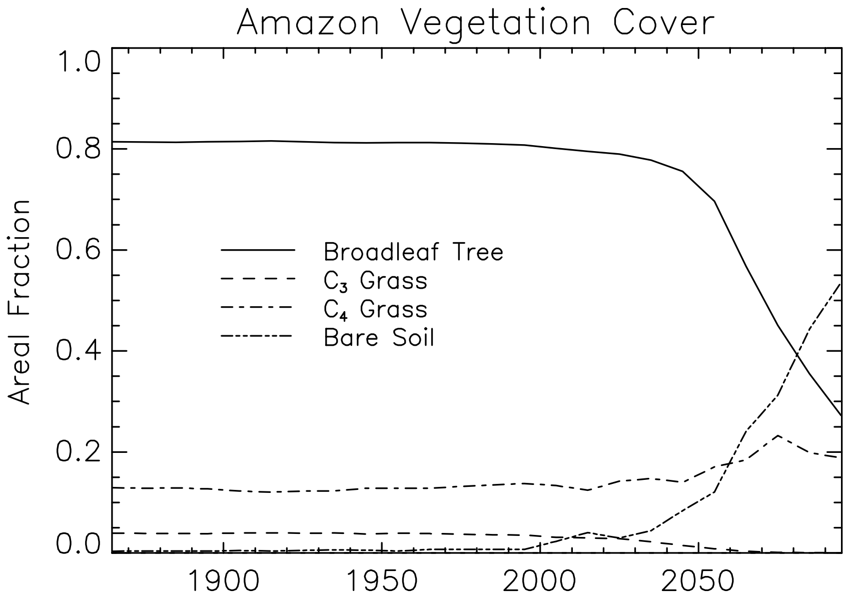
Specific leaf area index

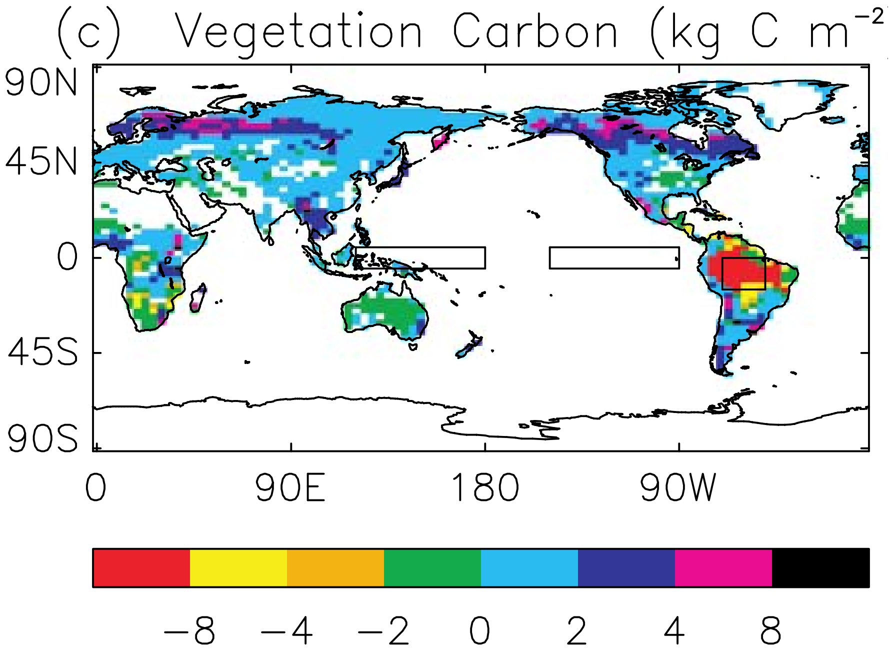


Improving spatial variability based on field observations

Castanho et al. 2013, *Biogeosciences*

Forest 'dieback' hypothesis

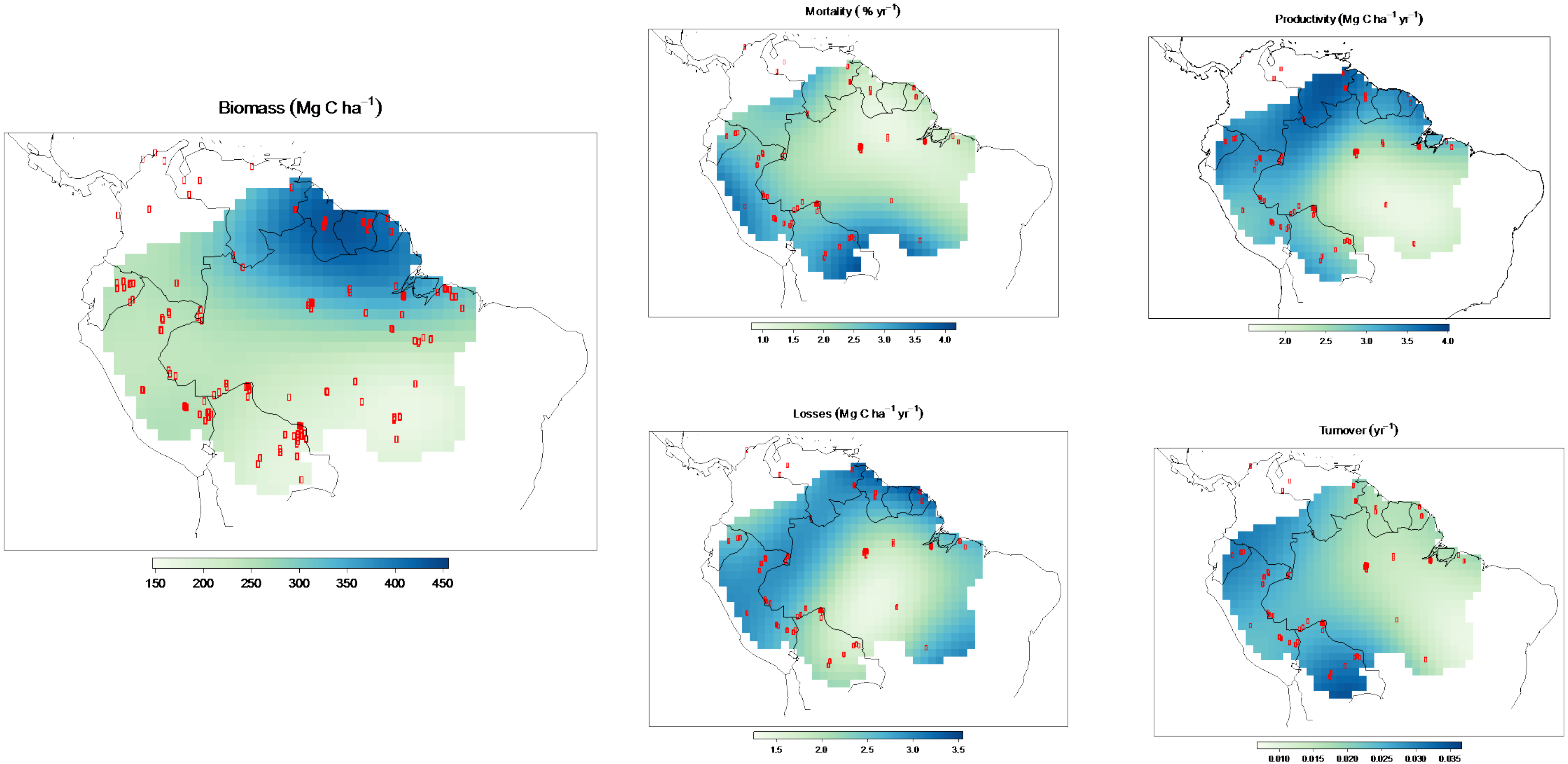




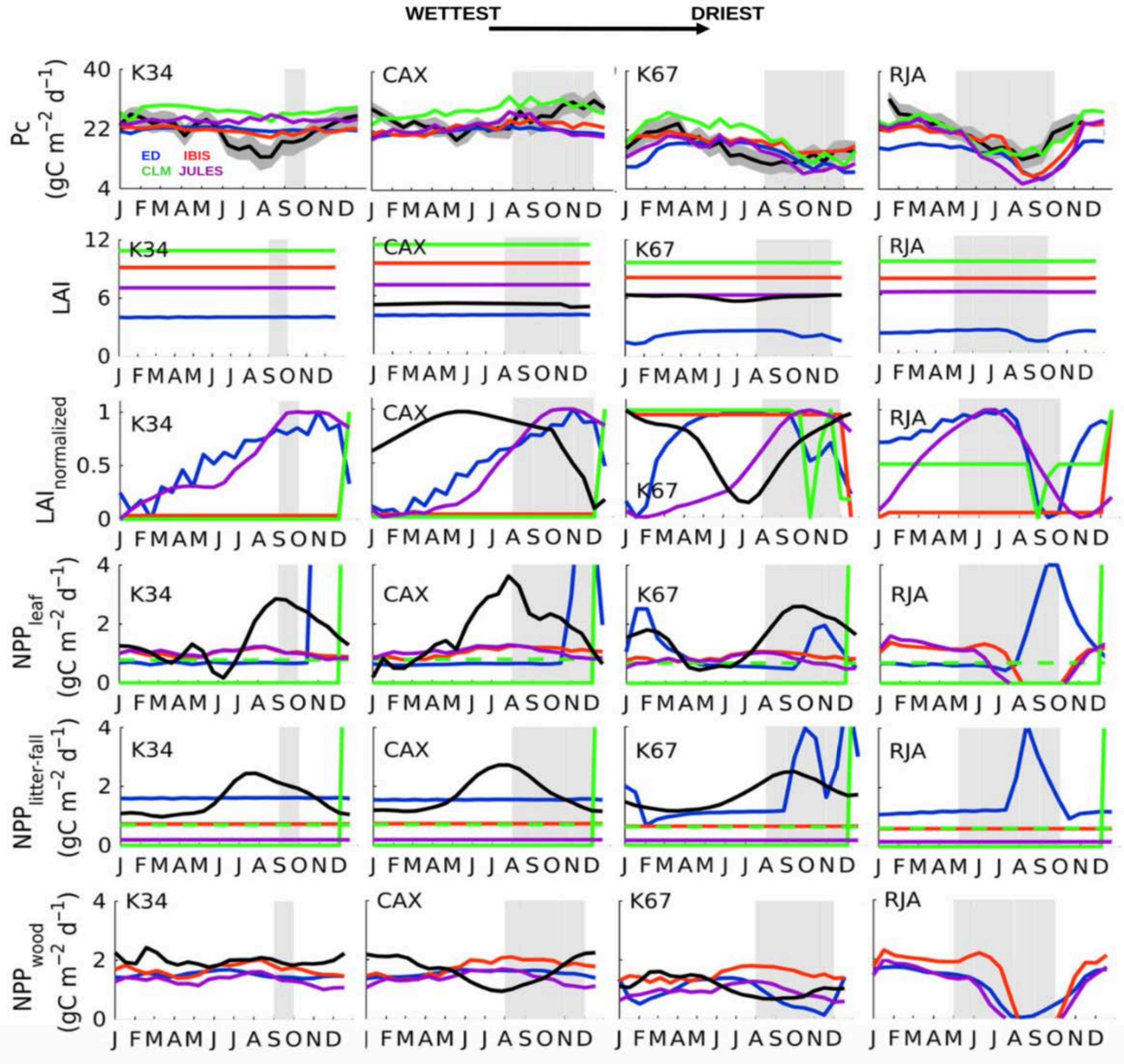
Catastrophic loss of Amazon biomass due to extreme climate change and 'low' resilience of the forest

Cox et al. 2000 *Nature*; Cox et al. 2004 *Theor. Appl. Clim.*; see also Cramer et al. 2001; Scholze et al. 2006; Salazar et al.

Biomass simulations

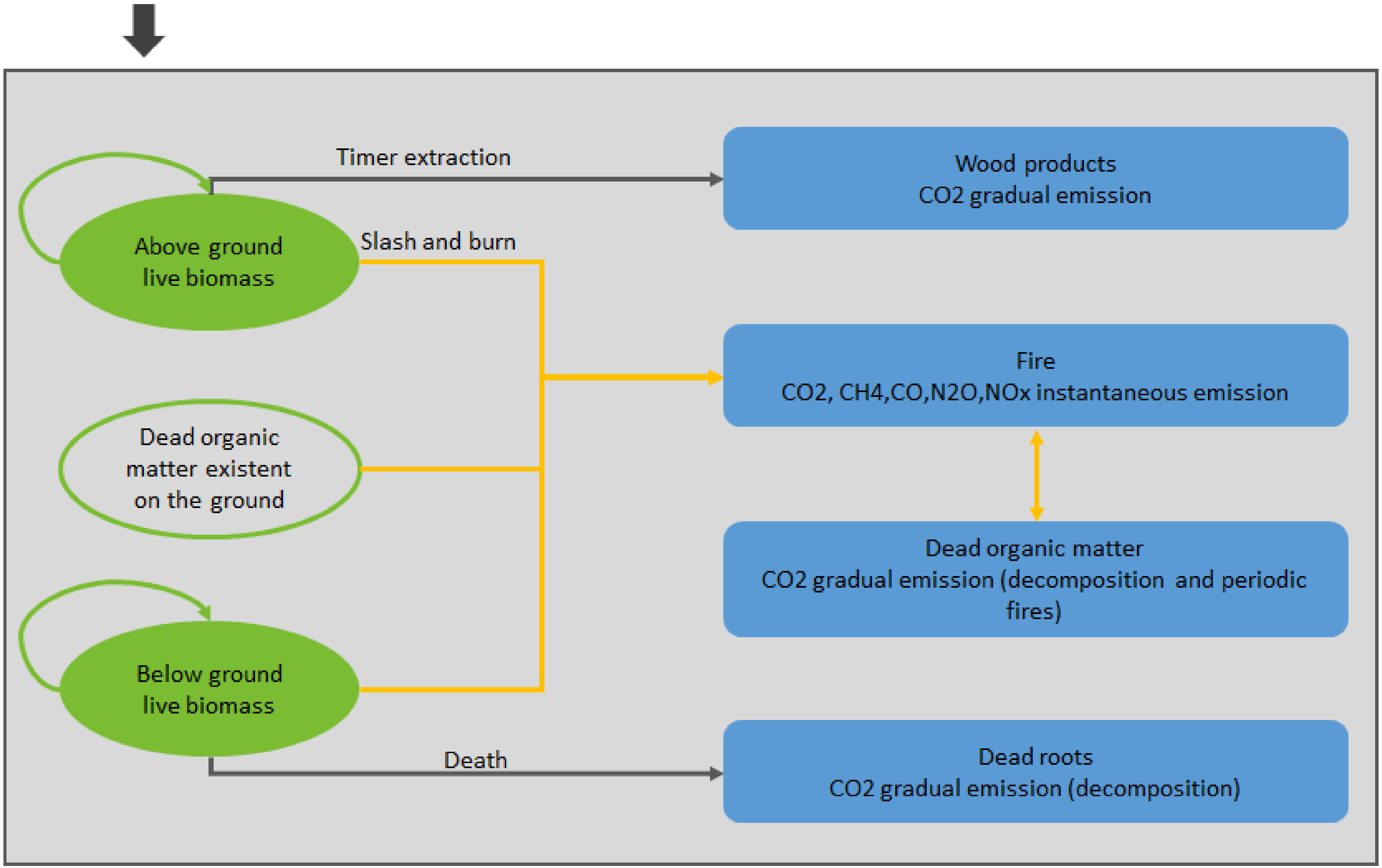


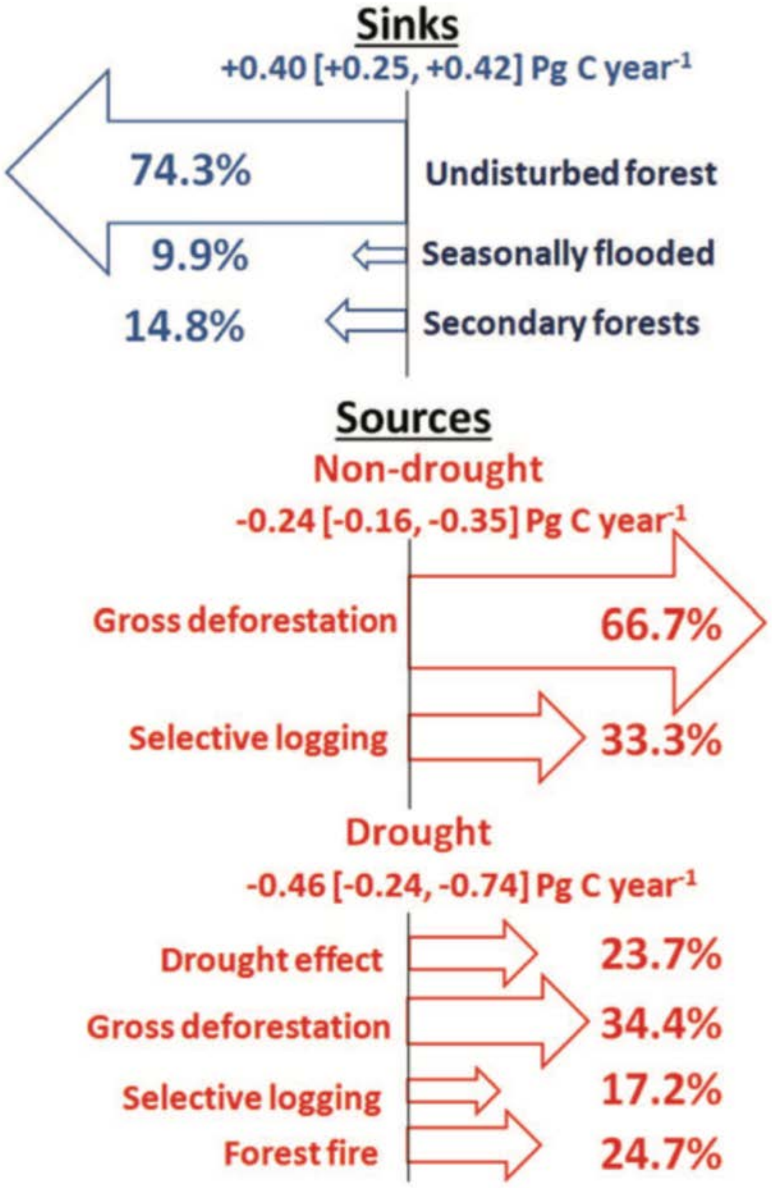
Johnson et al. 2016, *Glob Change Biol*



Restrepo-Coupe et al. 2016, *Global Change Biol.*

Disturbance: clear cut and burnt of forest área to form pasture or crop area





NEP Terra firme (undisturbed) 0.30 Pg C y^{-1}

NEP seasonally flooded 0.04 Pg C y^{-1}

R_{DF} Secondary forests 0.06 Pg C y^{-1}

D_F Deforestation emissions (–) 0.16 Pg C y^{-1}

L logging (–) 0.08 Pg C y^{-1}

Drought mortality (–) 0.11 Pg C y^{-1}

F Fires (–) 0.11 Pg C y^{-1}

Aragão et al. , 2014, *Biol. Rev.*