Influence of phosphorus cycle coupling on land model response to changes in atmospheric CO_2 and climate

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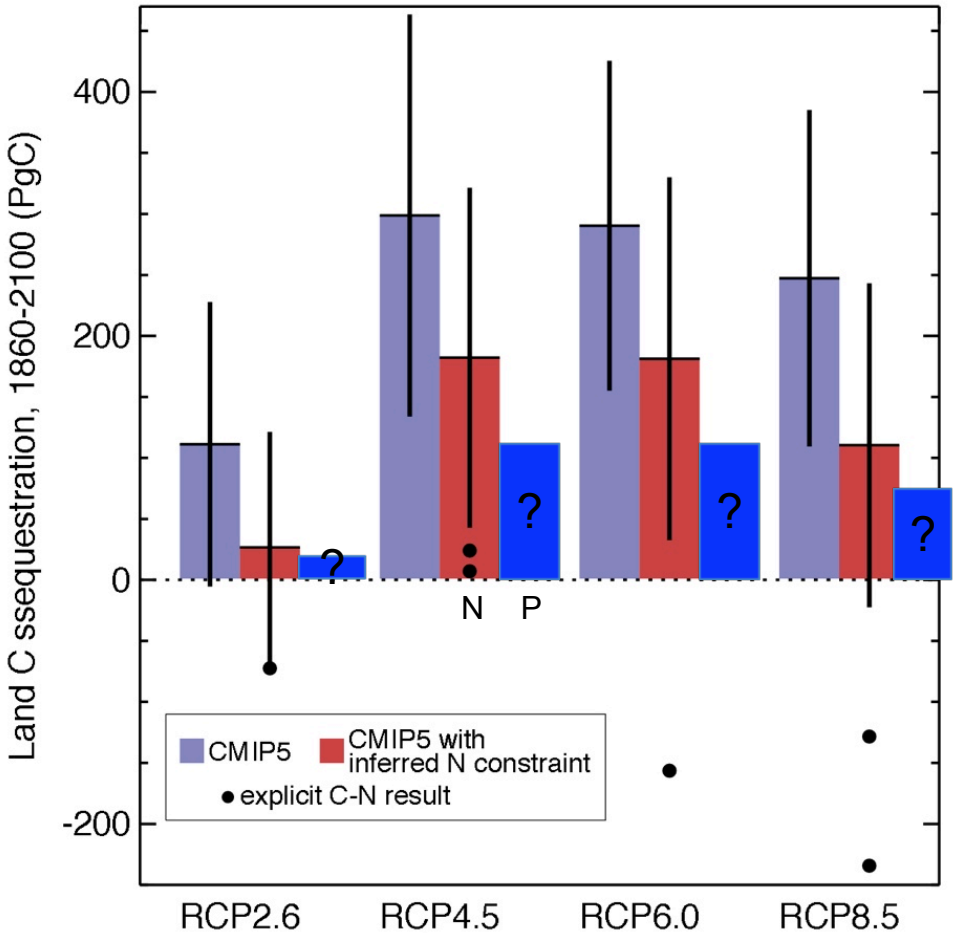
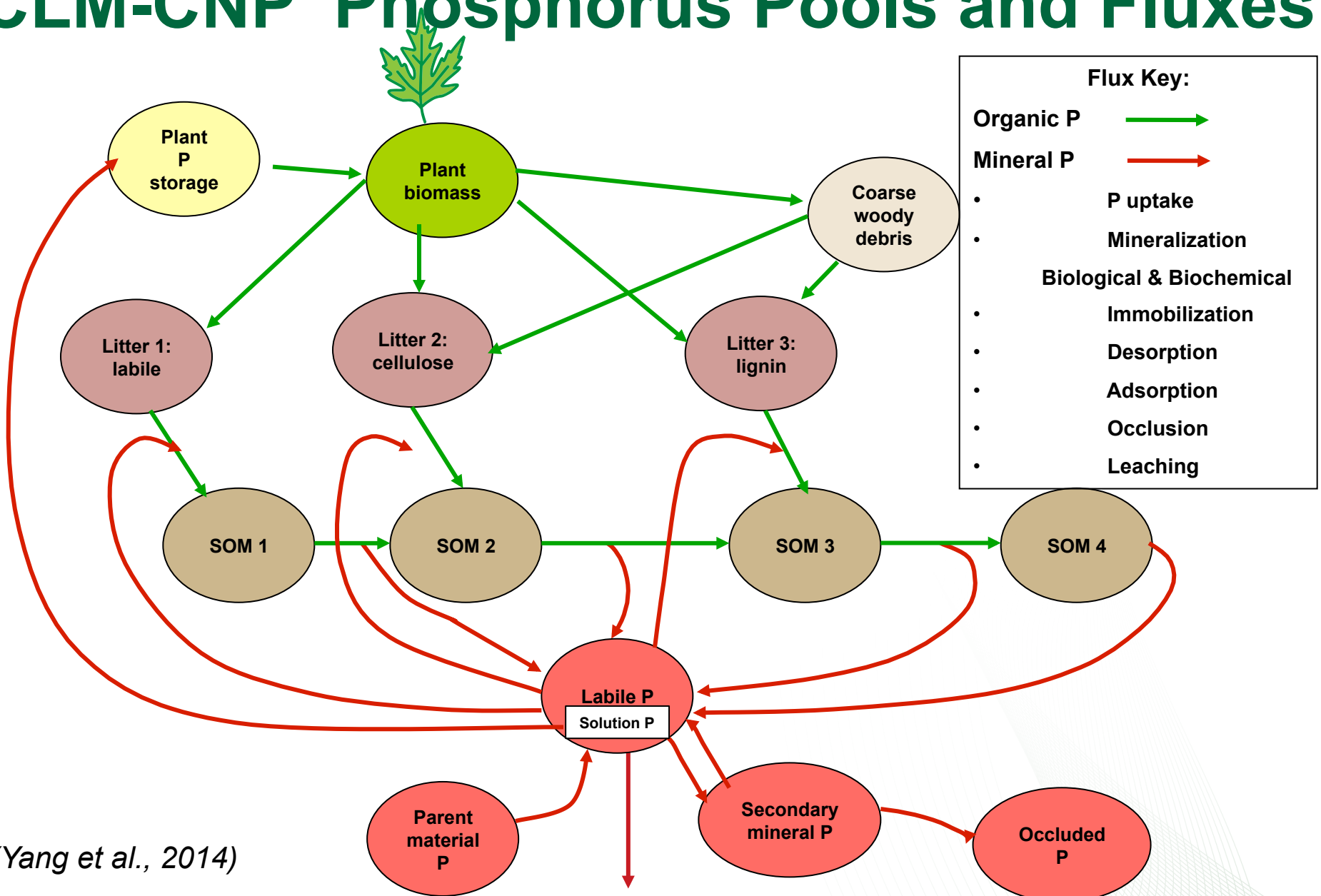
Nutrient limitation will reduce the global land carbon storage projected by CMIP5 C-only models



(IPCC,2013)

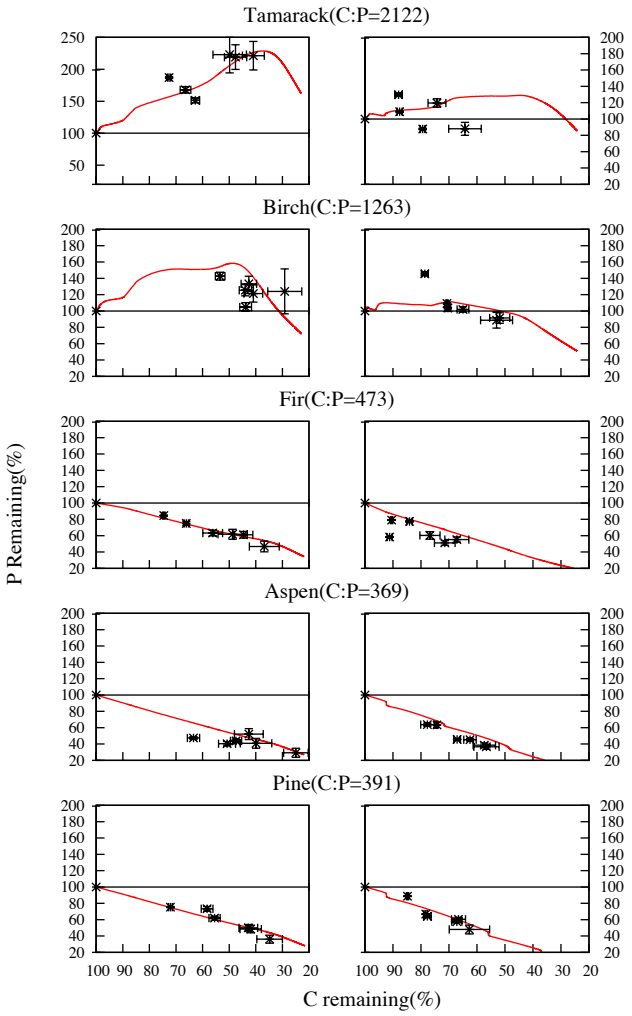
CLM-CNP Phosphorus Pools and Fluxes



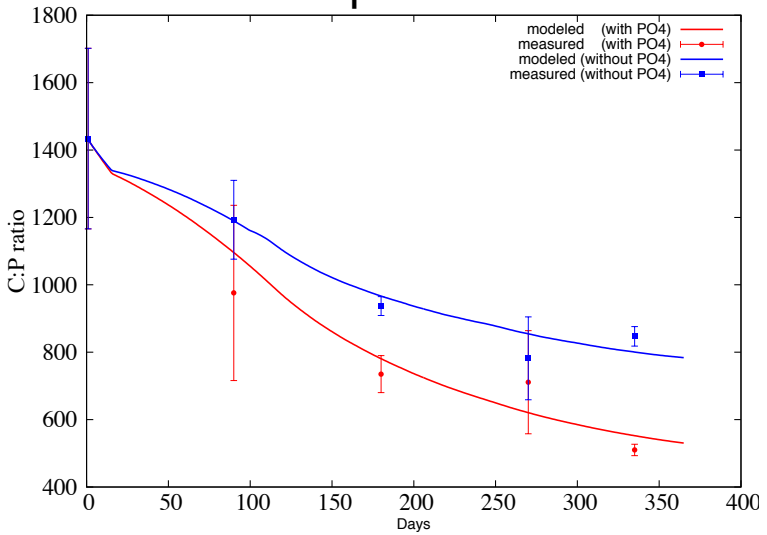
(Yang et al., 2014)

Litter bag studies – evaluation of P dynamics during decomposition

Two CIDET sites



P fertilized plot in Brazil

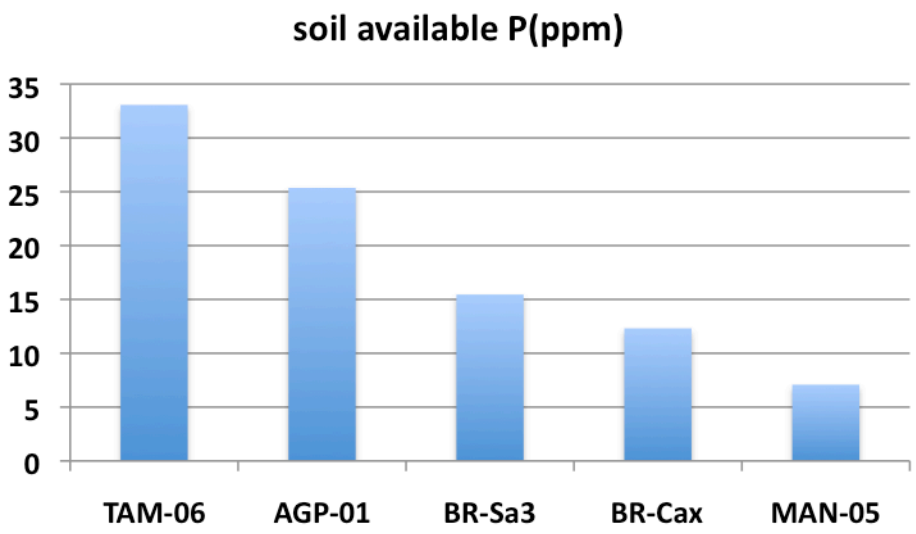


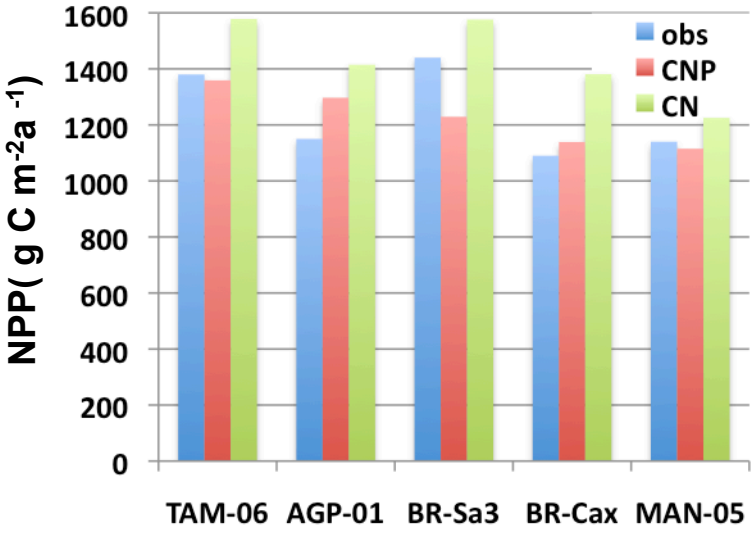
Biochemical mineralization

- **With PO4: off**
- **Without PO4: on**

- Stoichiometric relationship can explain P dynamics during decomposition when there is adequate available P in soils.
- P cycle can be decoupled from C and N during decomposition when soil available P is in short supply, due to biochemical mineralization of organic P
- Measurement data from McGroddy et al. (2004)

Introduction of P limitation improved model simulated NPP in tropical forests

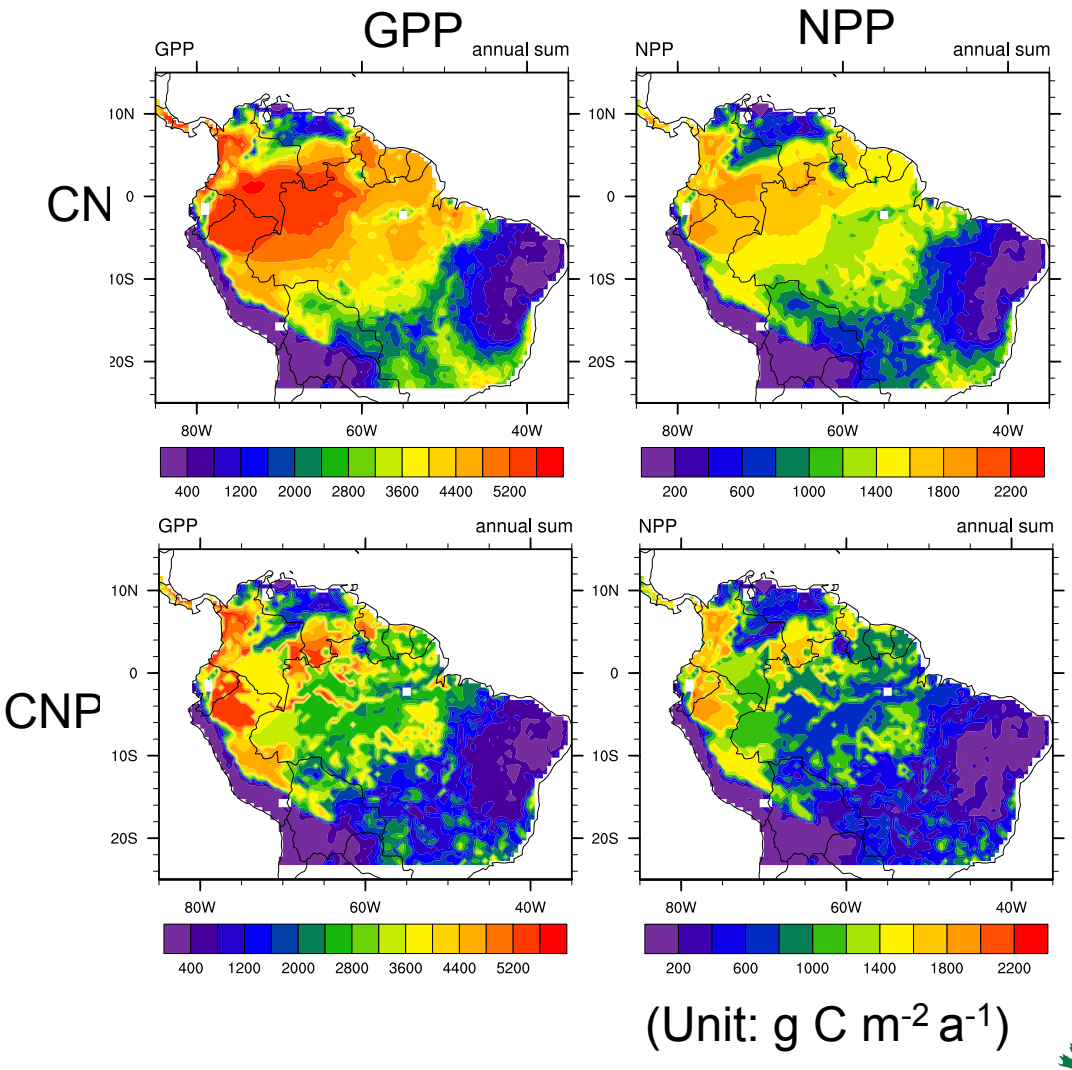




- Observations show that NPP tends to decrease with decreasing soil P availability
- Model simulations using CNP model capture the overall trend in NPP along the P availability gradient
- Site characteristics and land use history need to be considered to explain the discrepancy between models results and observations

(Yang et al., 2014)

Mean annual simulated fluxes for the period 2000-2009



(Unit: g C m^{-2} a^{-1})

- Improved heterogeneity of simulated GPP & NPP in CNP model.
- NPP decreases from west to east across the Amazon basin following the gradient of total soil P.
- Spatial pattern of NPP consistent with field observations(Quesada et al., 2012; Aragão et al., 2011; Malhi et al., 2004).
- Comparison with satellite products in progress.

(Yang et al., 2015, in revision)

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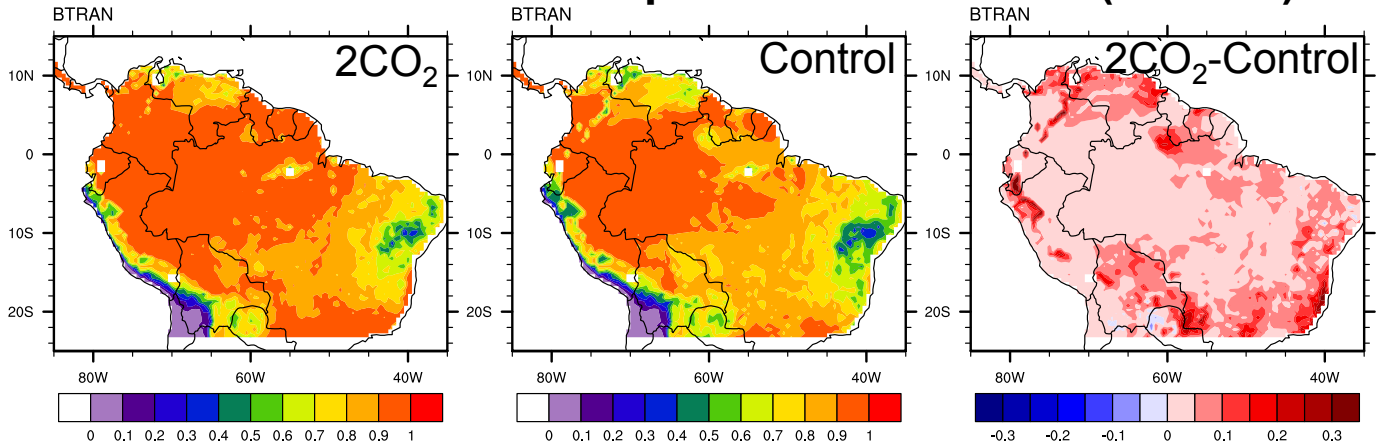
Exploratory model experiments

- Question: how does nutrient cycling interact with increasing [CO_2] and warming to affect future C uptake in the Amazon region?
- Three exploratory simulations (2010-2050)
  - #1 : 2CO2
  - #2 : +4 °C
  - #3 : +4 °C and constant RH

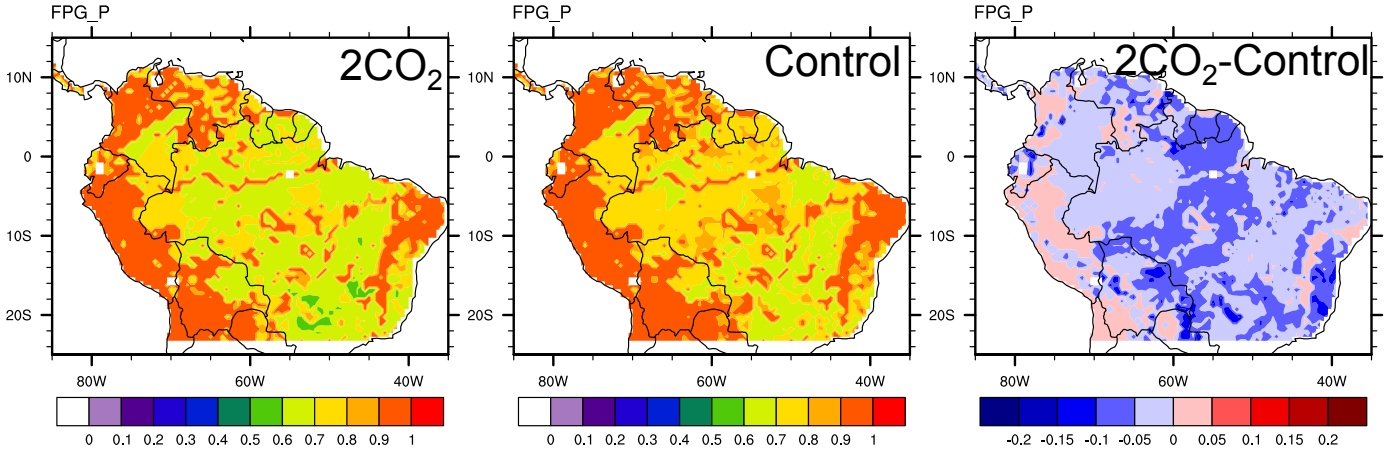
2CO2

Annual Means of Transpiration Beta Factor(BTRAN)



- Elevated CO_2 increases WUE and reduces water stress, especially in drier areas.

P limitation factor

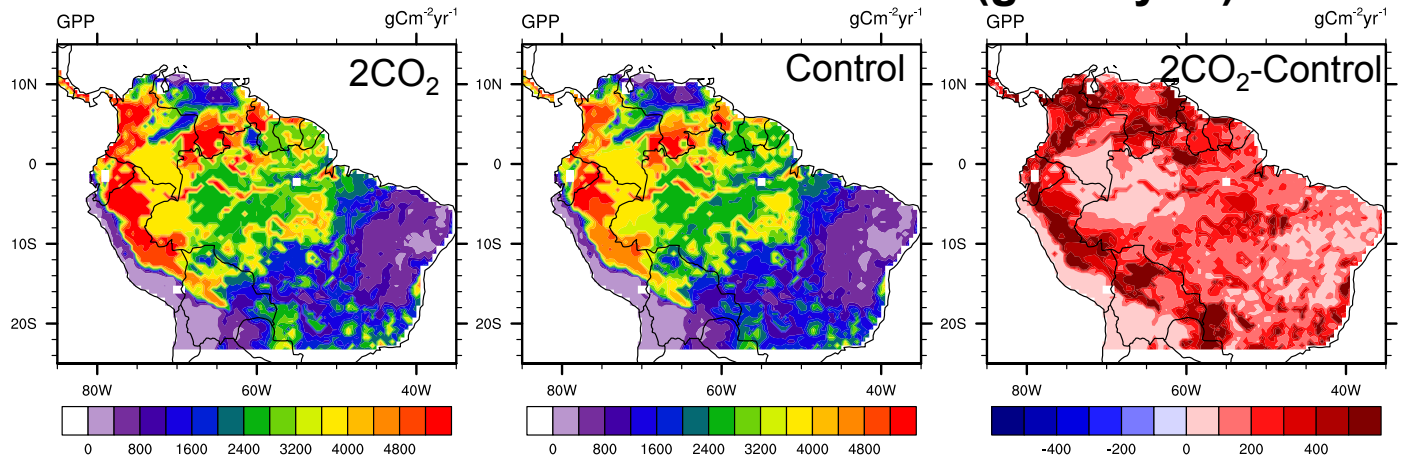


- Phosphorus becomes more limiting under elevated CO_2 condition.

(Yang et al., 2015, in revision)

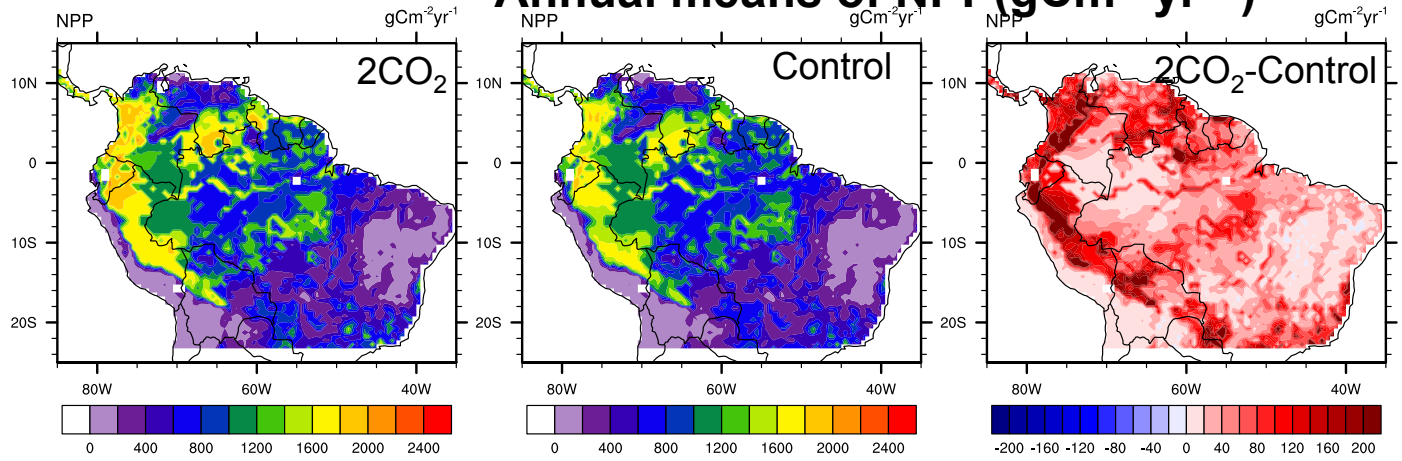
2CO2

Annual means of GPP(gCm $^{-2}$yr $^{-1}$)



- Productivity is enhanced with elevated CO2, especially in drier regions because of improved WUE.

Annual means of NPP(gCm $^{-2}$yr $^{-1}$)

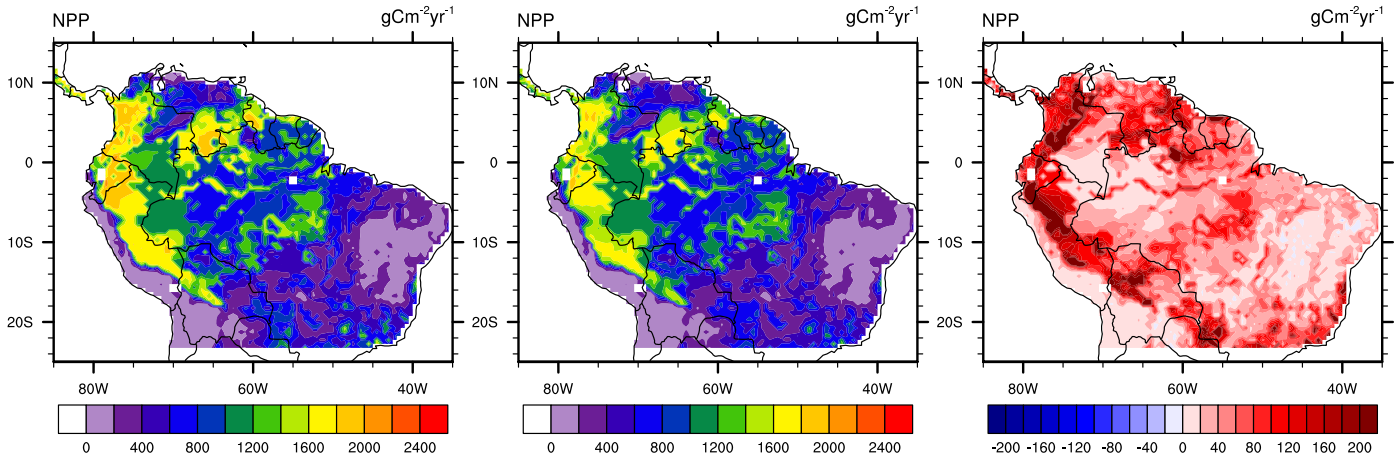


- CO2 fertilization effect is constrained by P availability in lowland tropical forests on highly weathered soils.

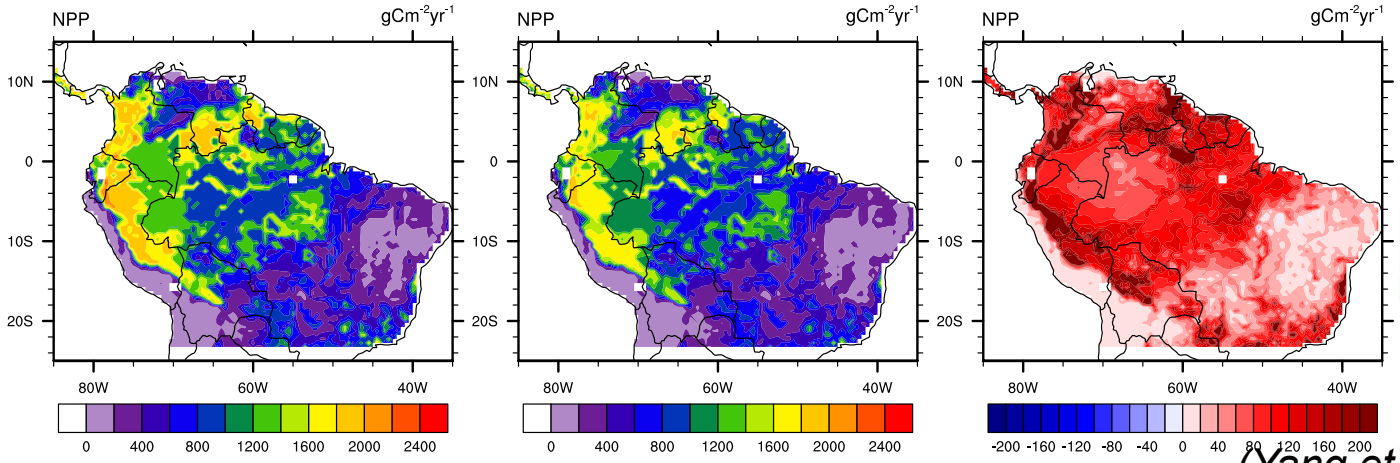
(Yang et al., 2015, in revision)

Enhanced phosphatase activity under elevated CO_2 could alleviate P limitation

NPP(Default model parameters for phosphotase activity)



NPP(Enhanced phosphatase activity)



(Yang et al., 2015, in revision)

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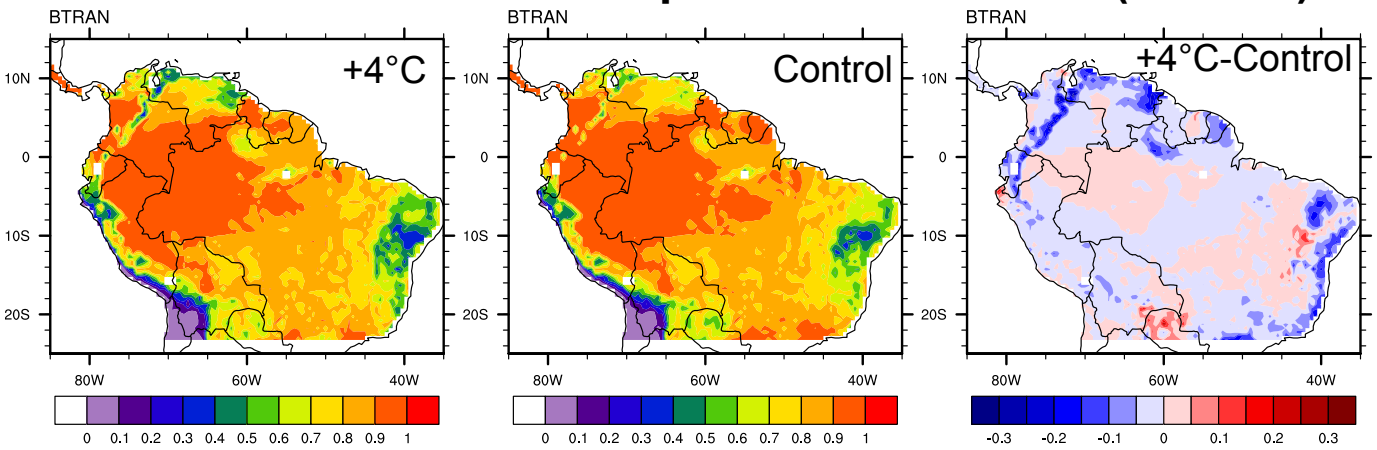
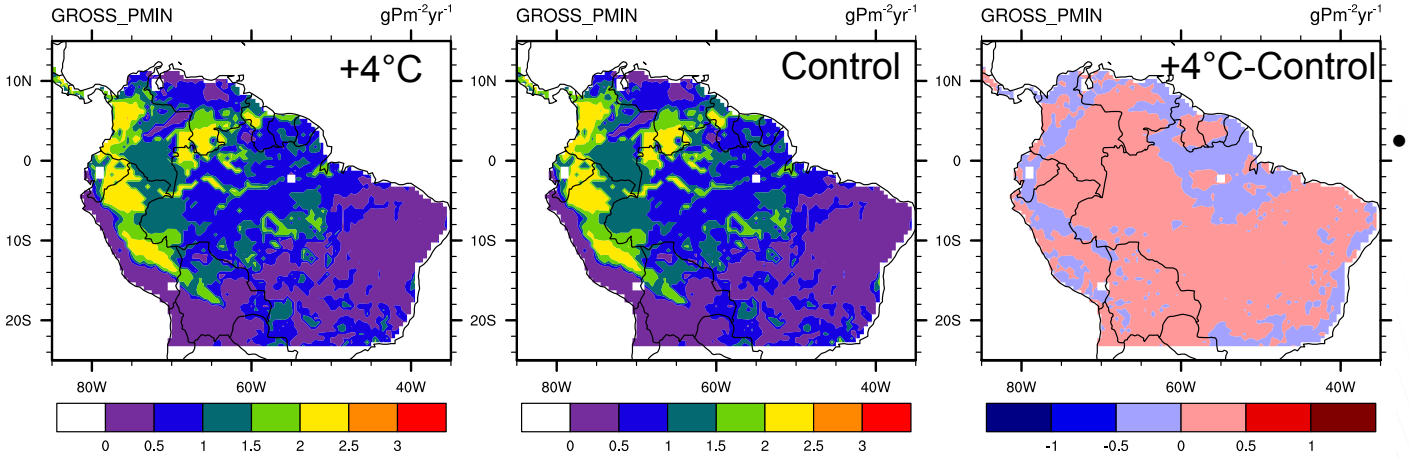
Warming(+4°C)

Annual Means of Transpiration Beta Factor(BTRAN)



- Higher temperature leads to deepening of dry season water stress.

Annual Means of P mineralization(gPm $^{-2}$yr $^{-1}$)

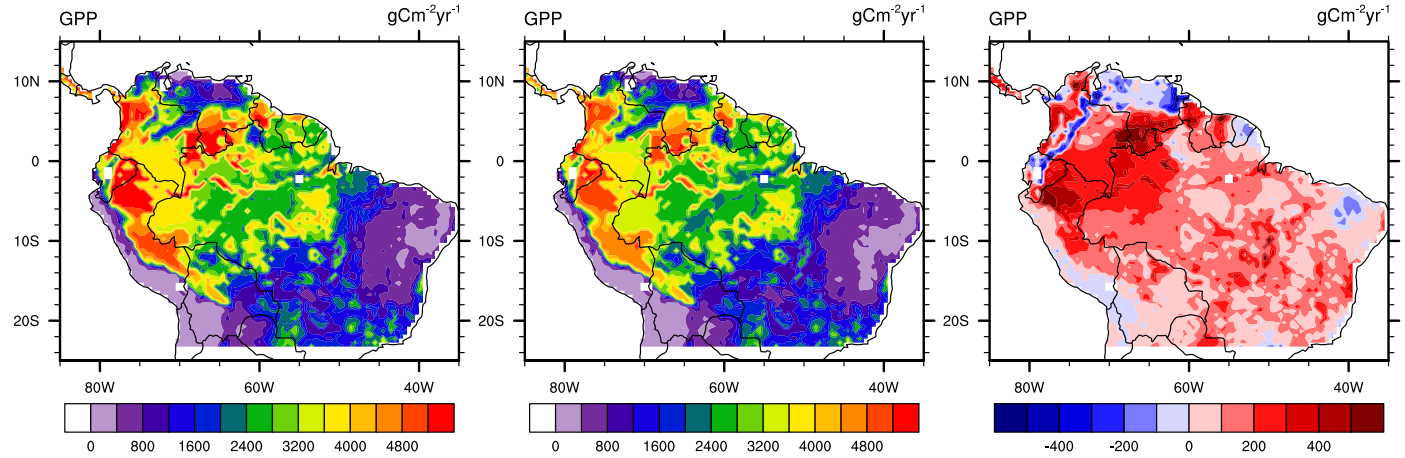


- Warming leads to increased nutrient mineralization.

(Yang et al., 2015, in revision)

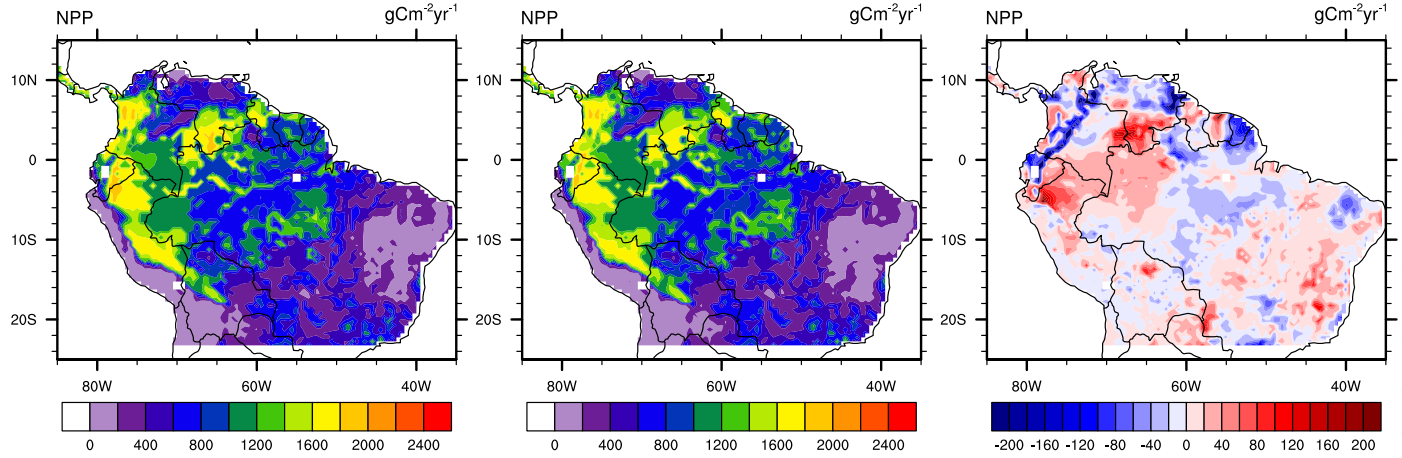
Warming(+4°C)

Annual means of GPP(gCm $^{-2}$yr $^{-1}$)



- Wet season GPP is increased due to enhanced nutrient mineralization.

Annual means of NPP(gCm $^{-2}$yr $^{-1}$)



- Autotrophic respiration response to warming greatly limits NPP response.

(Yang et al., 2015, in revision)

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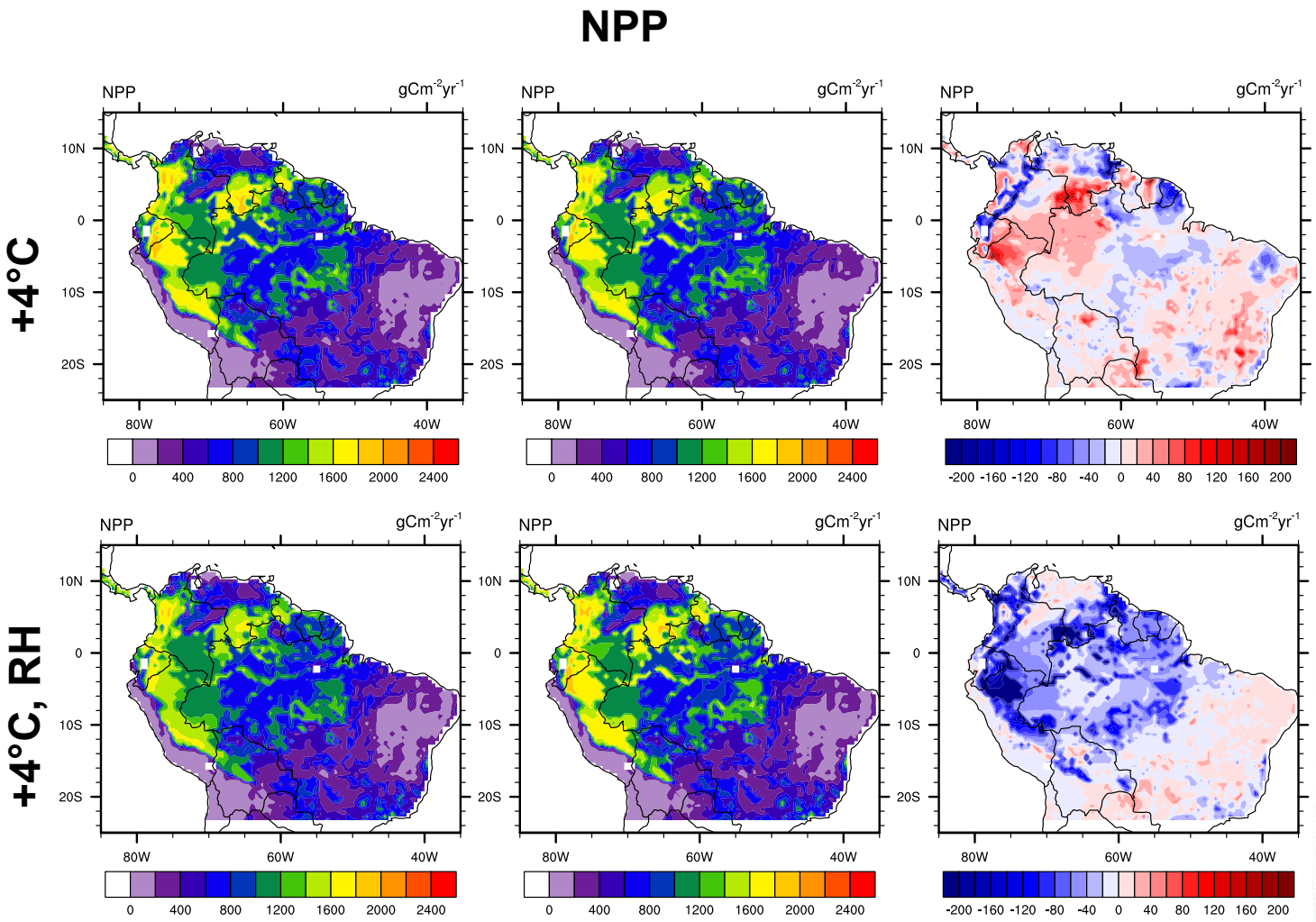
The effect of maintaining constant RH

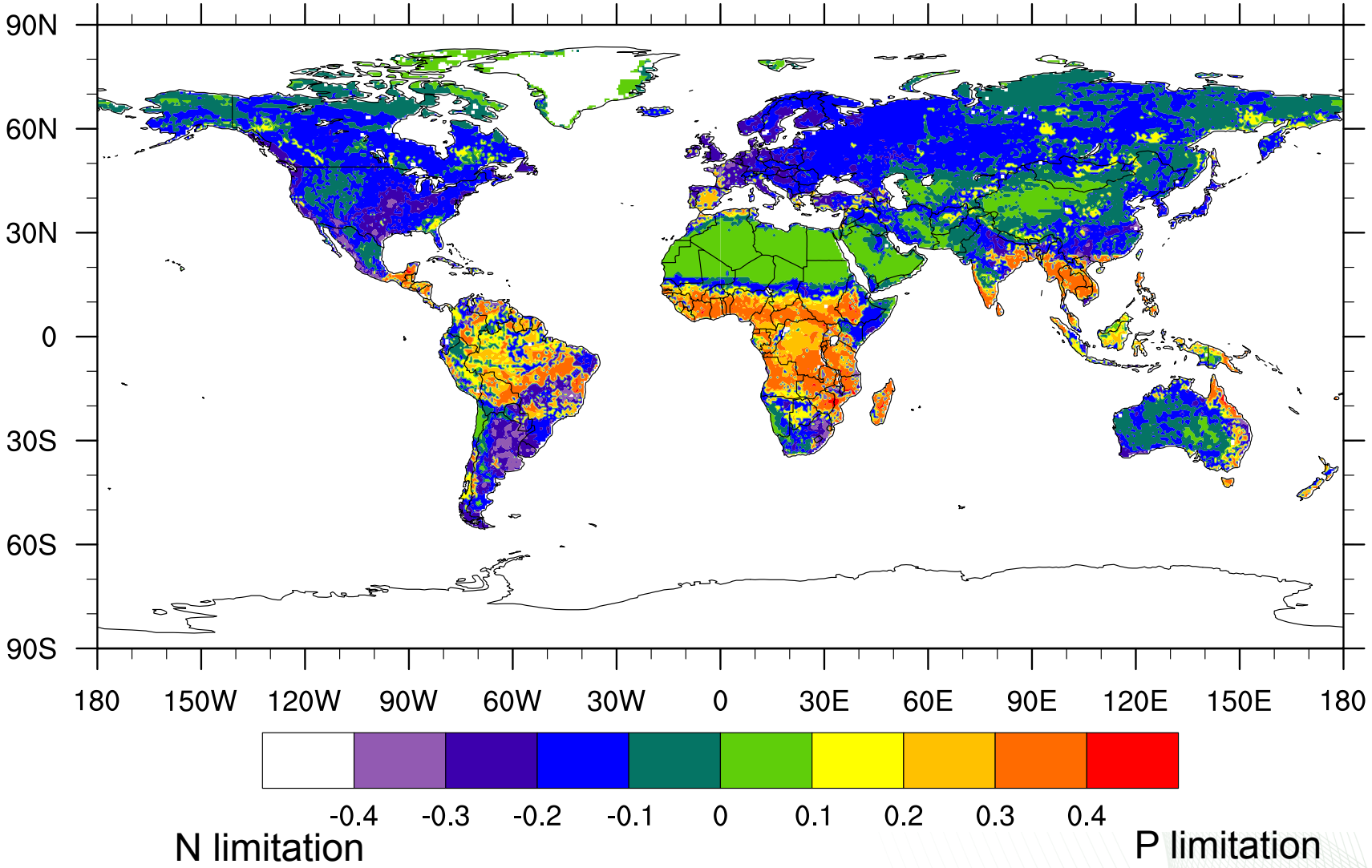


(Yang et al., 2015, in revision)

Global Simulations

- CLM4-CNP and CLM4-CN
- 0.5-by-0.5 degree
- Offline mode
- Steady-state simulations (Pre-industrial spinup)
- Transient simulations
  - CRU-NCEP reanalysis fields 1901-2009
  - historical [CO_2]

Distribution of N vs. P limitation



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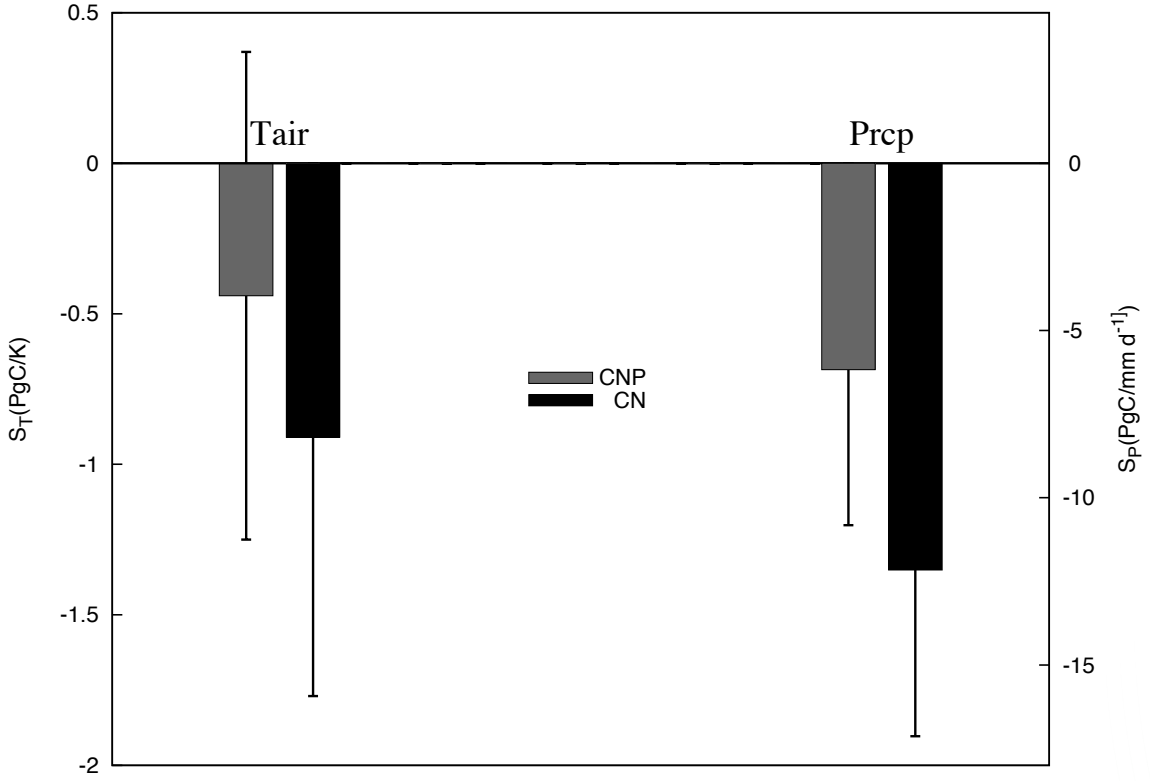
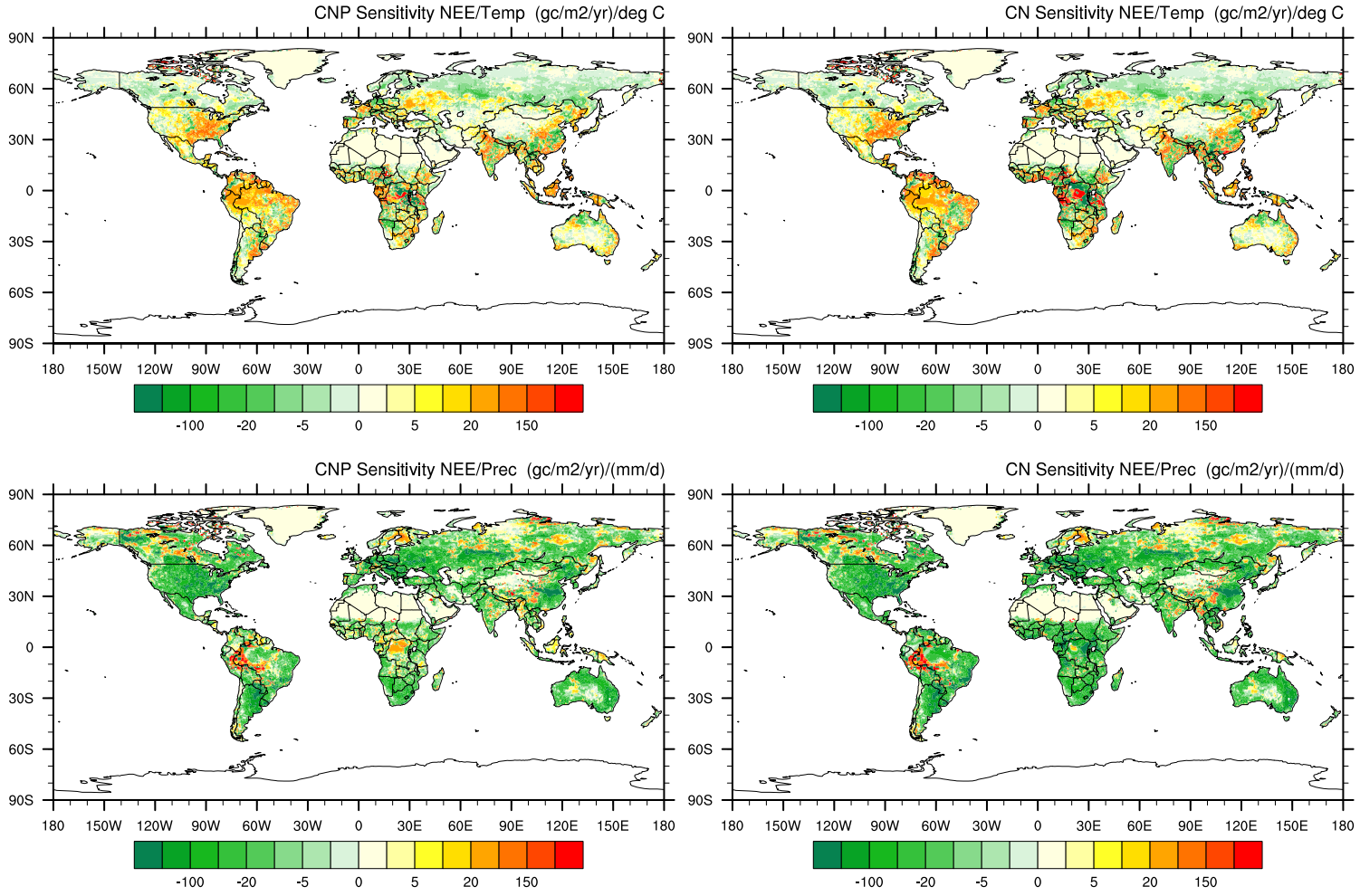
Phosphorus cycle dynamics reduce the sensitivity of global NEE to variations in temperature and precipitation

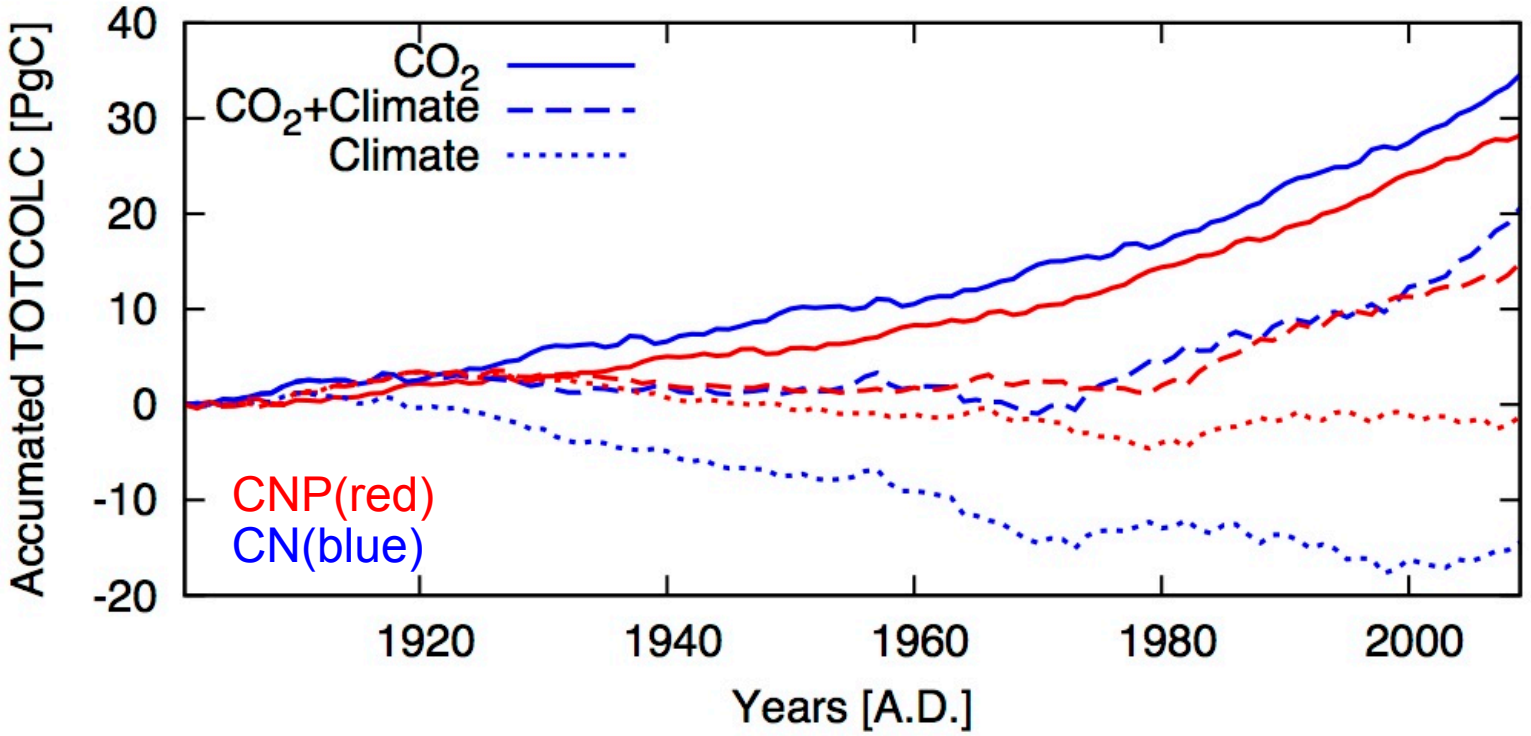


- Global integrated NEE against variations in global mean temperature and precipitation, assessed using multiple least-squares regression, following the methodology of Thornton et al. (2007)
- In particular, CN model shows significant negative relationship between NEE and precipitation, but slope is reduced for CNP model

NEE sensitivity to variations in temperature and precipitation (CLM-CNP vs. CLM-CN)

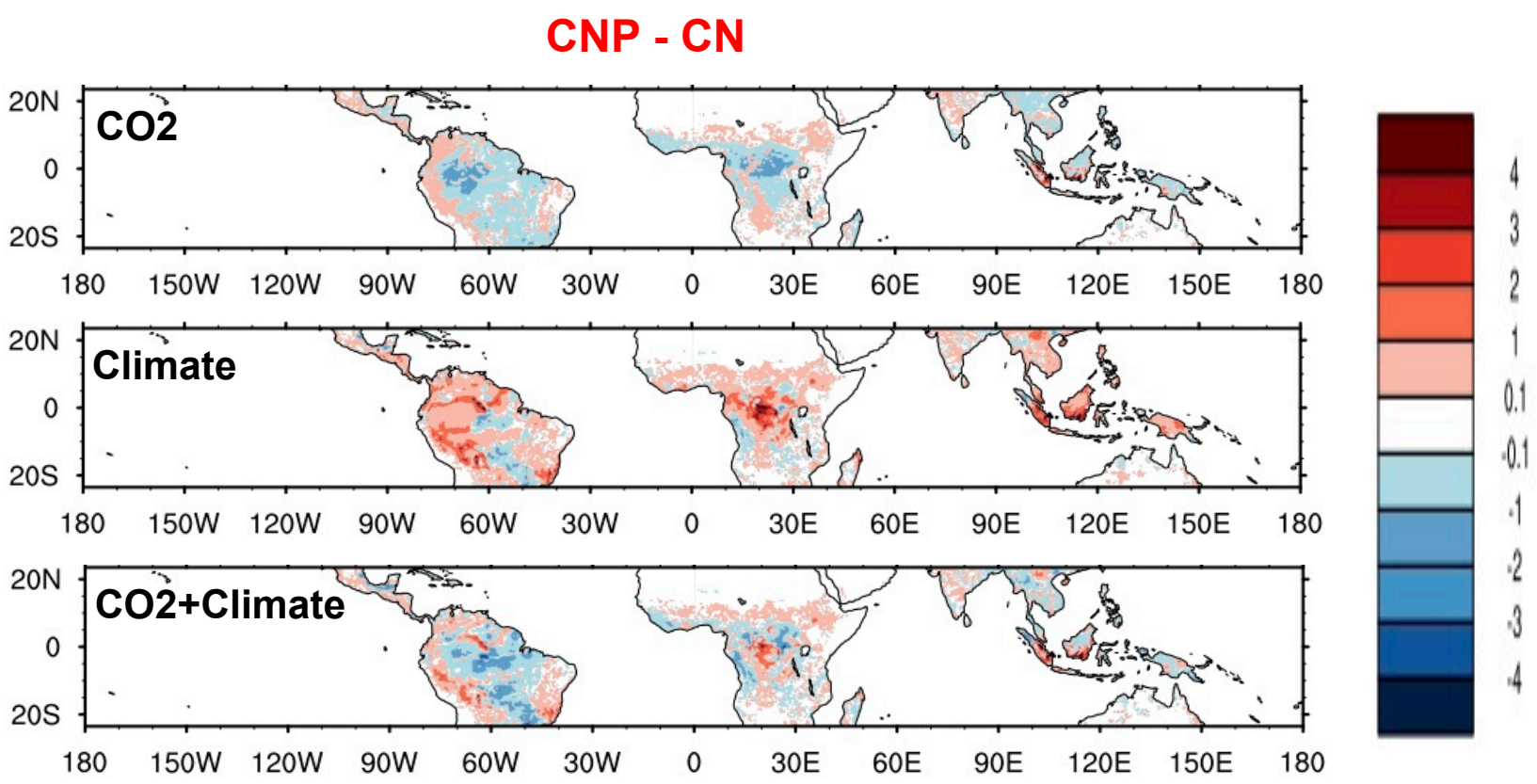


The role of phosphorus in tropical ecosystem responses to changes in [CO_2] and climate



- P limitation leads to a reduced CO2 fertilization effect
- Carbon release associated with historical climate change is reduced with P coupling, as warming induced mineralization may lead to indirect fertilization effect in P-limited ecosystems

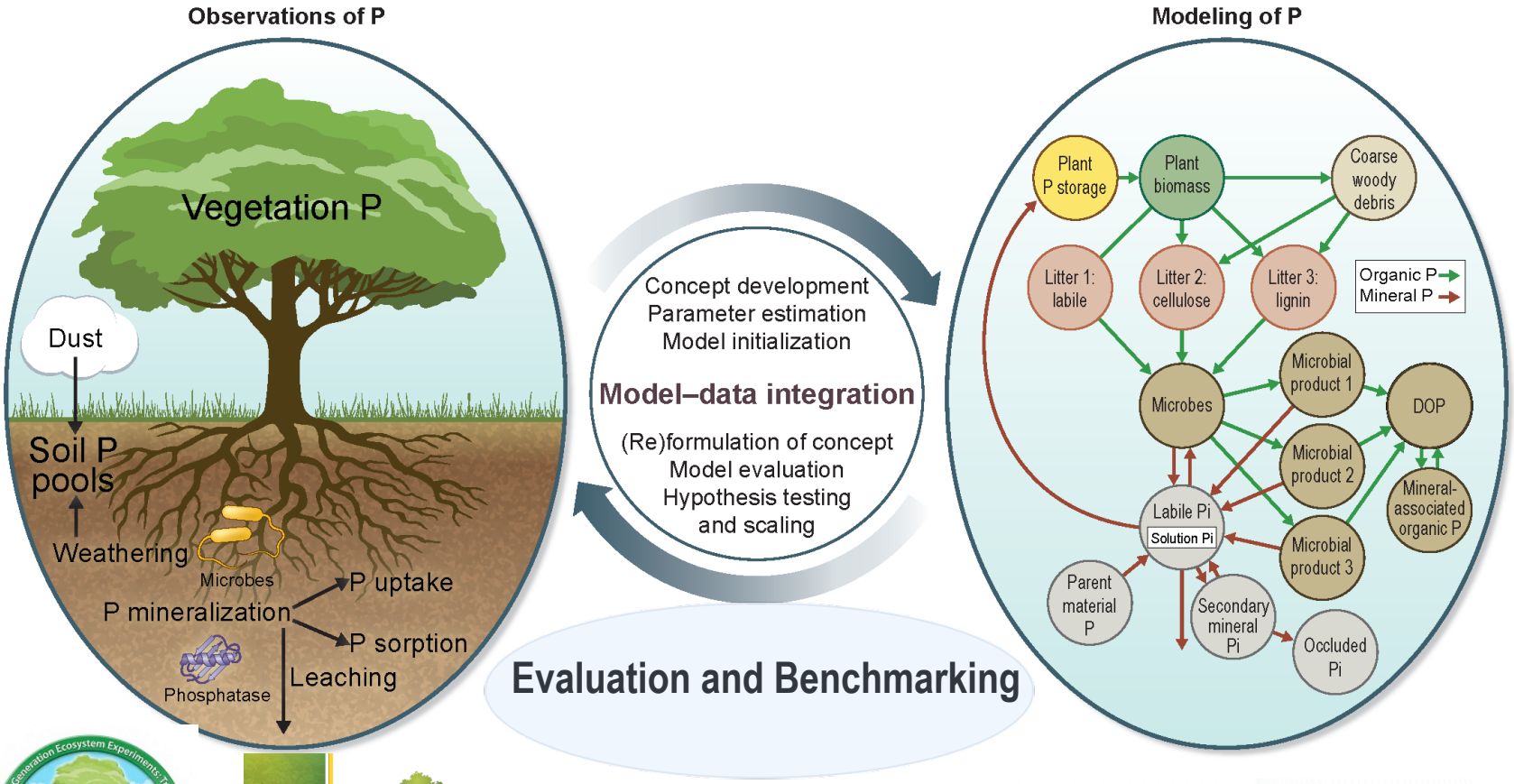
The role of phosphorus in tropical ecosystem responses to changes in [CO_2] and climate



Summary

- The introduction of P cycling and limitation improved model simulated NPP at site-level and heterogeneity of simulated GPP & NPP across the Amazon region, relative to the original CLM-CN model.
- Introduction of P coupling leads to a smaller CO_2 fertilization effect and warming-induced CO_2 release from tropical ecosystems
- P cycle dynamics tend to reduce the sensitivity of NEE to inter-annual variation in temperature and precipitation

Path forward



NGEE-Tropics

AMAZONFACE

TRACE

EucFACE

(Reed, Yang and Thornton, 2015)

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