GLOBAL SCALE ANALYSIS AND EVALUATION OF AN IMPROVED MECHANISTIC REPRESENTATION OF PLANT NITROGEN AND CARBON DYNAMICS IN THE COMMUNITY LAND MODEL (CLM)

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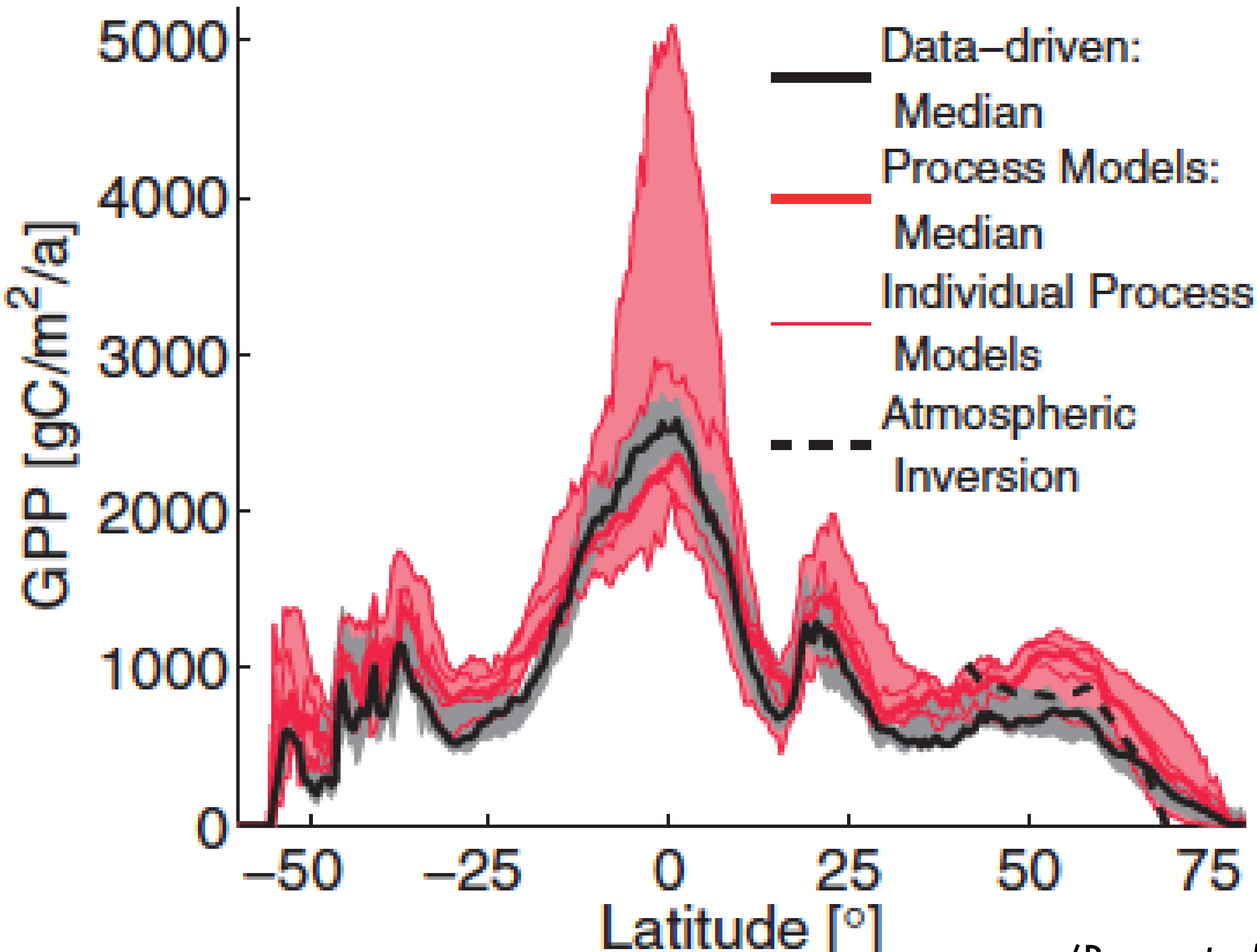
Improvements of Plant Nitrogen Cycle Processes in CLM

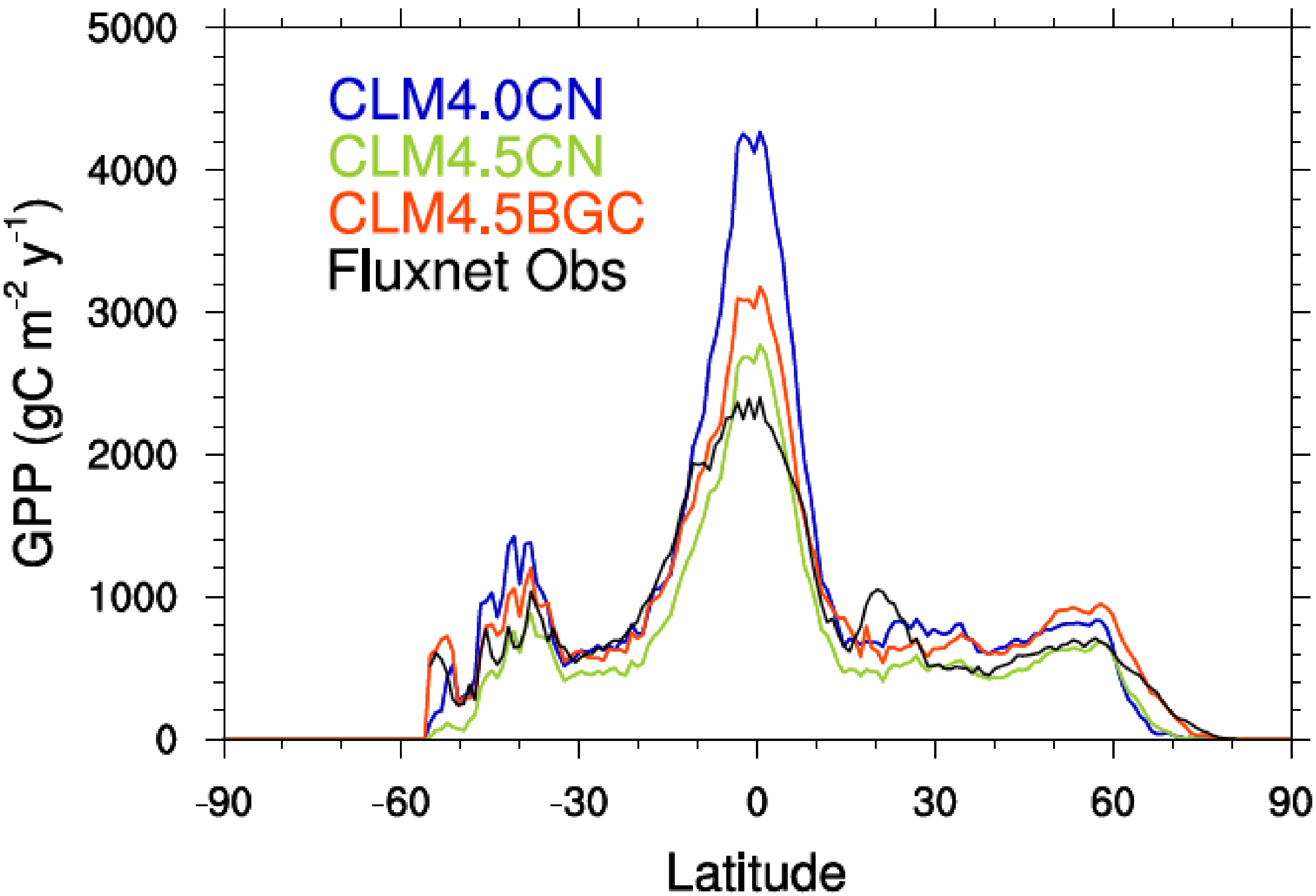
- Plant nitrogen uptake
  - Linked to root physiology
    - Root nutrient uptake efficiency
    - Root biomass
  - Michaelis-Menten kinetics
- Plant nitrogen allocation
  - Plant organs (root, stem, leaf)
  - Functions (photosynthesis, respiration, structure)
- Plant photosynthesis
  - Strongly linked to leaf nitrogen allocated to photosynthetic enzymes

Large uncertainty in model predictions of carbon sinks



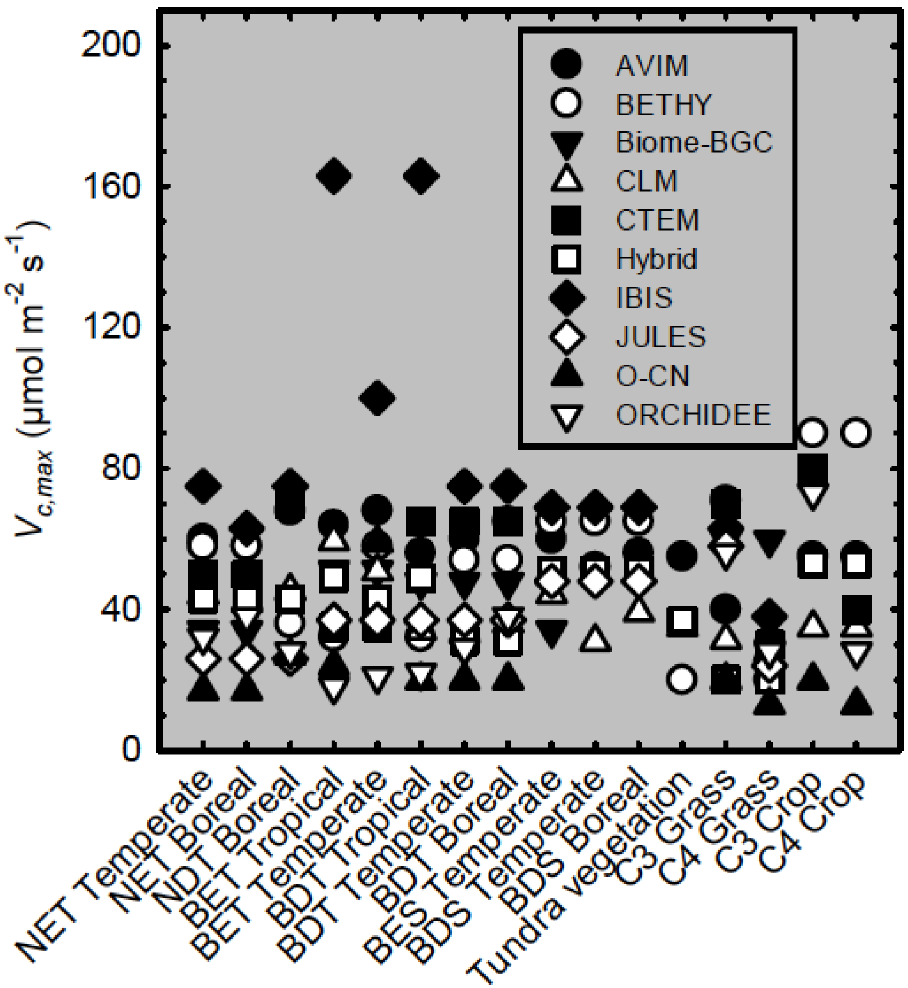
(Beer *et al.* 2010, Science)

CLM predictions of historical carbon sinks



Large variation of Vcmax in models lead to variations in GPP among models

Vcmax is maximum rate of Rubisco-mediated carboxylation



(Rogers 2014, PR)

Modeling Carbon Assimilation

- Farquhar Model

$$A_g = \min\left(W_c, W_j, W_p\right)$$

Rubisco limited carboxylation

$$W_c = \frac{\max\left(C_i - C_p, 0\right)}{\left(C_i + K_{ct}\right)\left(1 + \frac{O_2}{K_{ot}}\right)} V_{cmaxt}$$

Electron transfer limited carboxylation

$$W_j = \frac{\max\left(C_i - C_p, 0\right)}{\left(4C_i + 8C_p\right)} J$$

End product utilization

$$W_p = 0.5 V_{cmaxt}$$

(Farquhar *et al.* 1980, Planta)

Calculation of Vcmax in CLM

$$V_{cmax} = a_{r25}.F_{NR}.F_{LNR}.N_L$$

$$N_L = \frac{1}{CN_L.SLA}$$

a_{r25} = specific activity of Rubisco at 25^{0}C

F_{NR} = nitrogen fraction of Rubisco

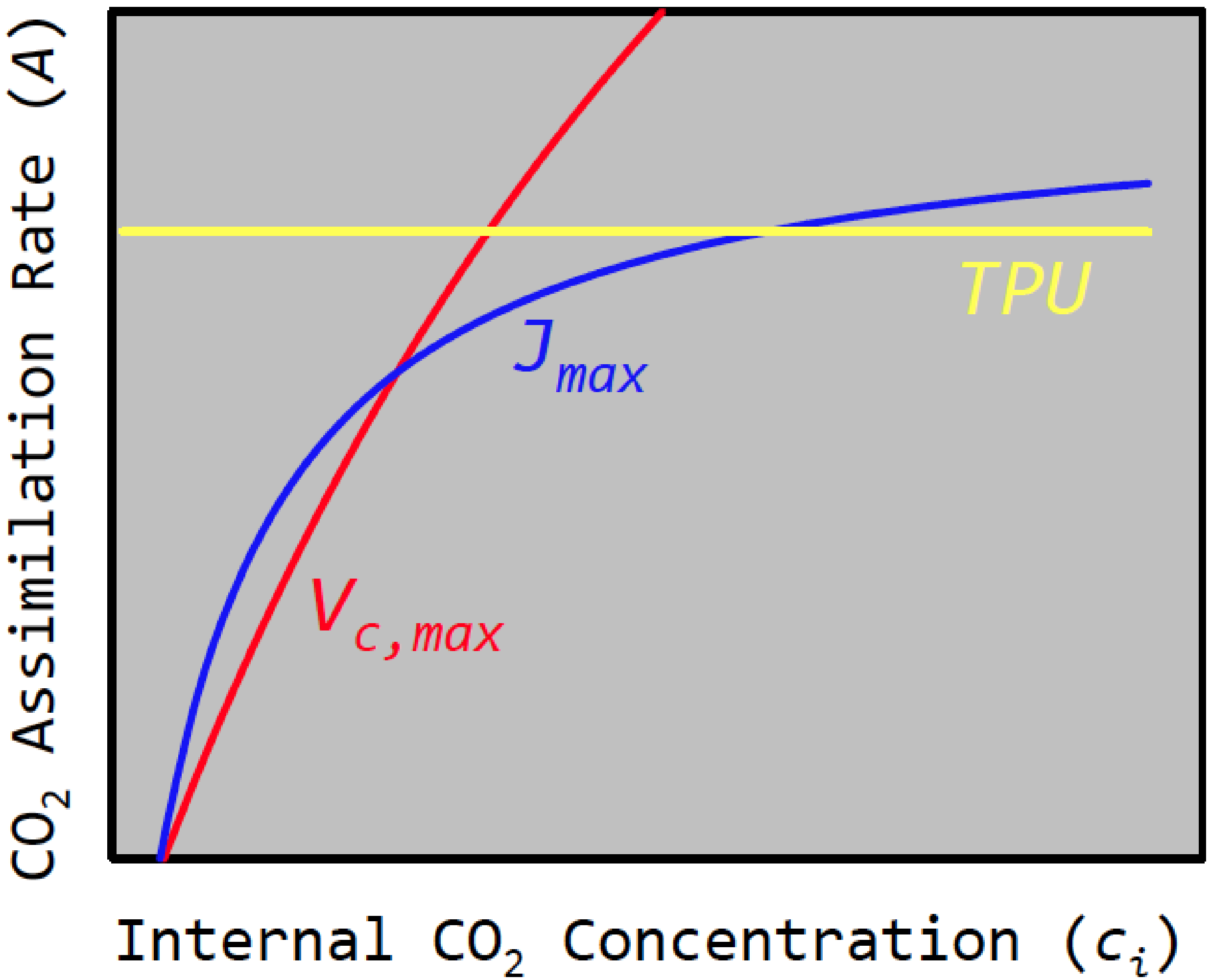
F_{LNR} = fraction of leaf nitrogen in Rubisco

N_L = leaf nitrogen content

CN_L = carbon to nitrogen ratio of leaf

SLA = specific leaf area

Parameters estimated from A-C_i curve

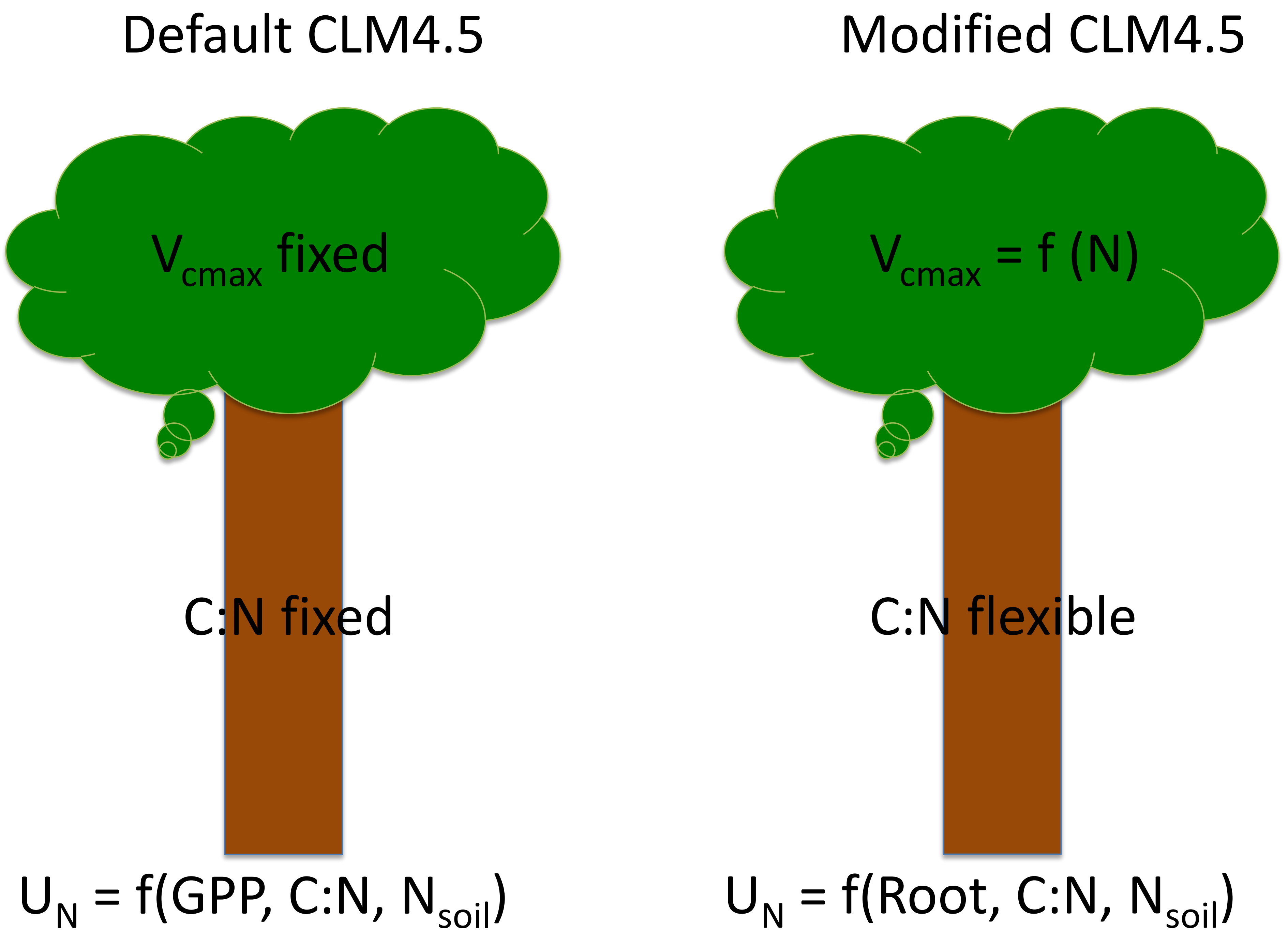


CLM GPP downregulation

- Downregulation of potential GPP based on nitrogen availability
- Potential Vcmax used to calculate potential GPP
- Problems with potential Vcmax
  - Plants do not photosynthesize at potential rates and then downregulate
  - Inconsistent with field observations of actual Vcmax
  - Lack of understanding on modeling these potential photosynthesis rates in a changing climate

Modifications to CLM4.5

- Removal of GPP downregulation
  - Prognostic leaf nitrogen
  - Dynamic Vcmax linked to prognostic leaf nitrogen
- Nitrogen allocation
  - Plant scale N allocation based on carbon allocation and C:N ratio
  - Leaf scale functional N allocation for reaction enzymes
- Flexible C:N ratio
- Plant nitrogen uptake
  - Linked to root traits
    - Root nitrogen uptake efficiency
    - Root biomass
  - Michaelis-Menten equation


Default CLM4.5
Modified CLM4.5
V_{cmax} fixed
$V_{cmax} = f(N)$
C:N fixed
C:N flexible
$U_N = f(GPP, C:N, N_{soil})$
$U_N = f(Root, C:N, N_{soil})$

Quantifying photosynthetic capacity and its relationship to leaf nitrogen content for global-scale terrestrial biosphere models

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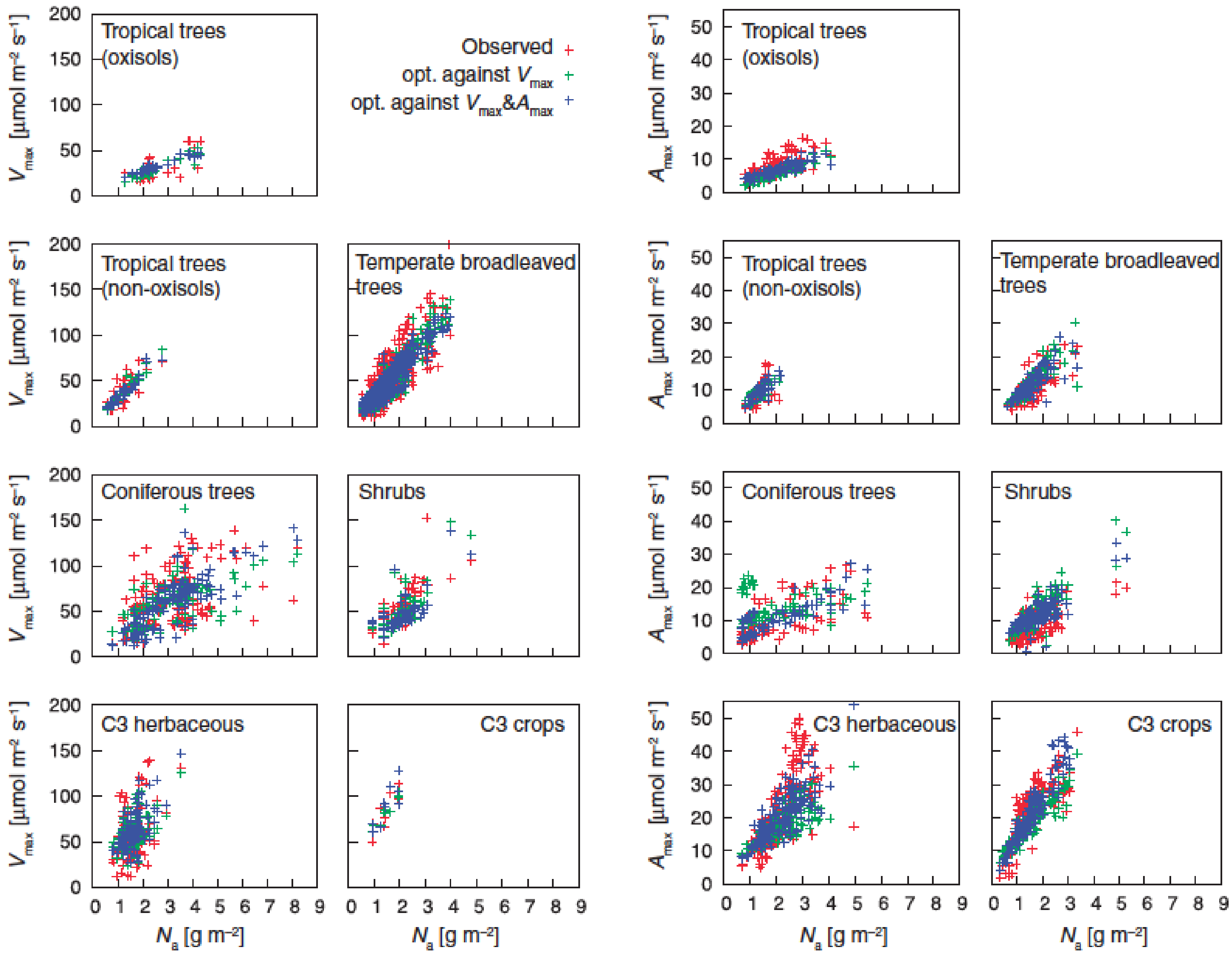
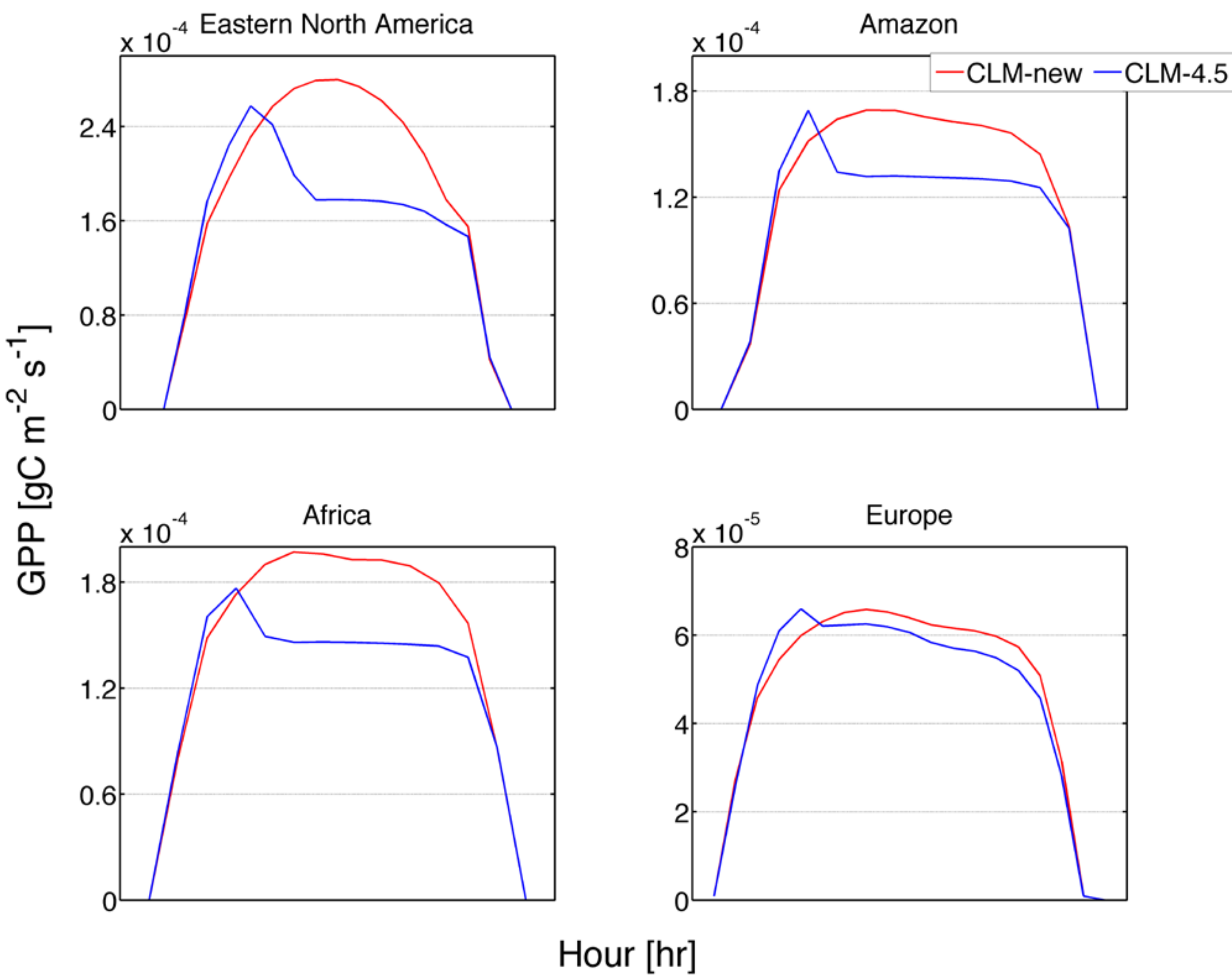


GPP Diurnal Cycle - Point Locations

- Dip in daytime GPP diurnal cycle prior to mid-day in CLM-4.5
- GPP dip is a model structure problem caused by GPP downregulation as plants are limited by nitrogen
- CLM-new does not show the GPP dip because the nitrogen storage in leaves buffer the diurnal nitrogen limitation



Annual GPP Bias Comparison

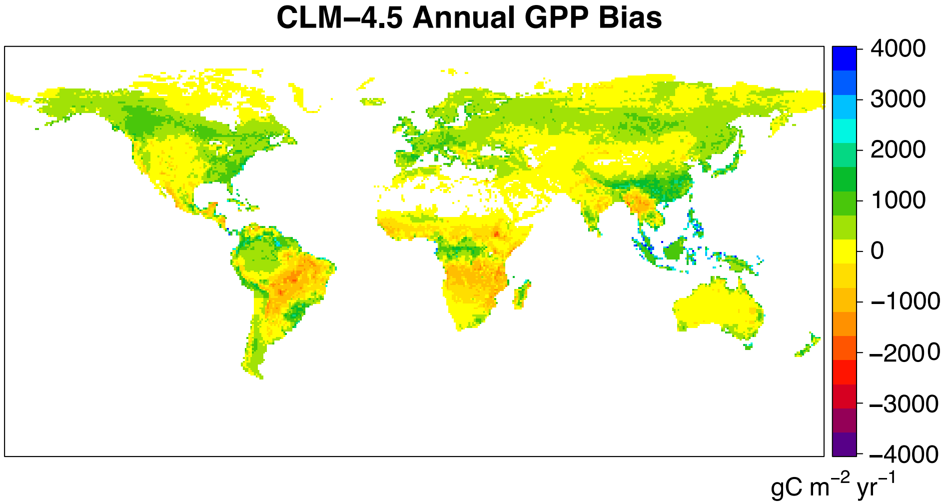
Bias = model – reference

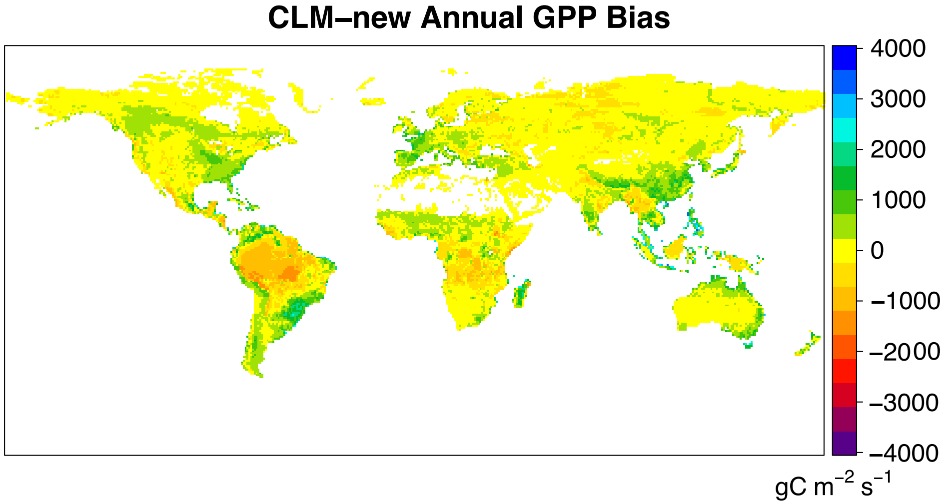
CLM-4.5 over-predicts GPP at high latitudes, especially in North America and Europe.

CLM-new has lower bias in higher latitudes compared to CLM-4.5.

CLM-4.5 over-predicts GPP in Amazon region whereas CLM-new slightly under-predicts GPP.

CLM-4.5 has a global mean bias of 251 gC m^{-2} yr^{-1} and CLM-new has a global mean bias of 87 gC m^{-2} yr^{-1} (i.e. around 65% reduction in bias).



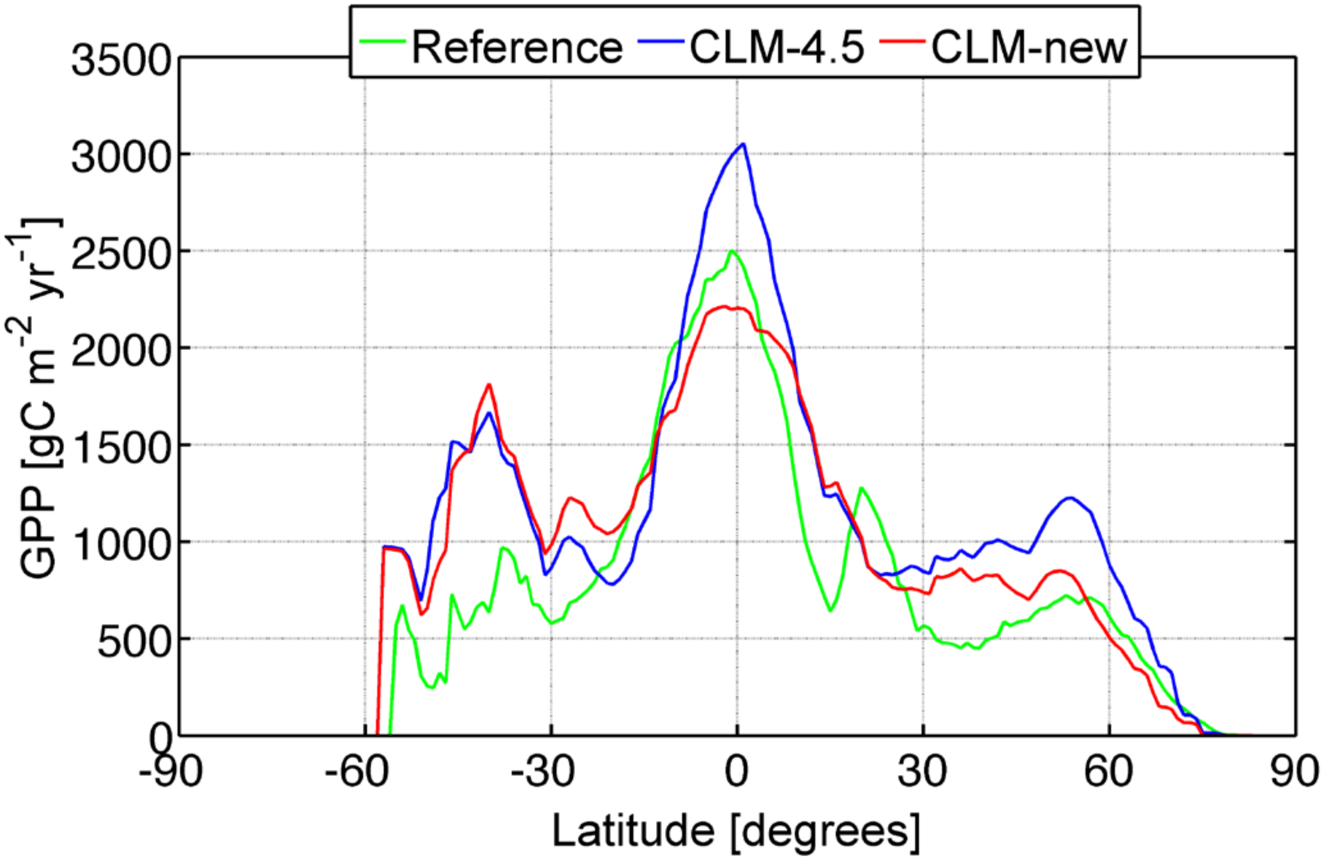


Latitudinal GPP Variation

Tropics:
- CLM-new is closer to reference than CLM-4.5
- Sign of bias flipped for CLM-new and CLM-4.5

Southern Hemisphere (60S to 30S):
- CLM-new and CLM-4.5 are similar

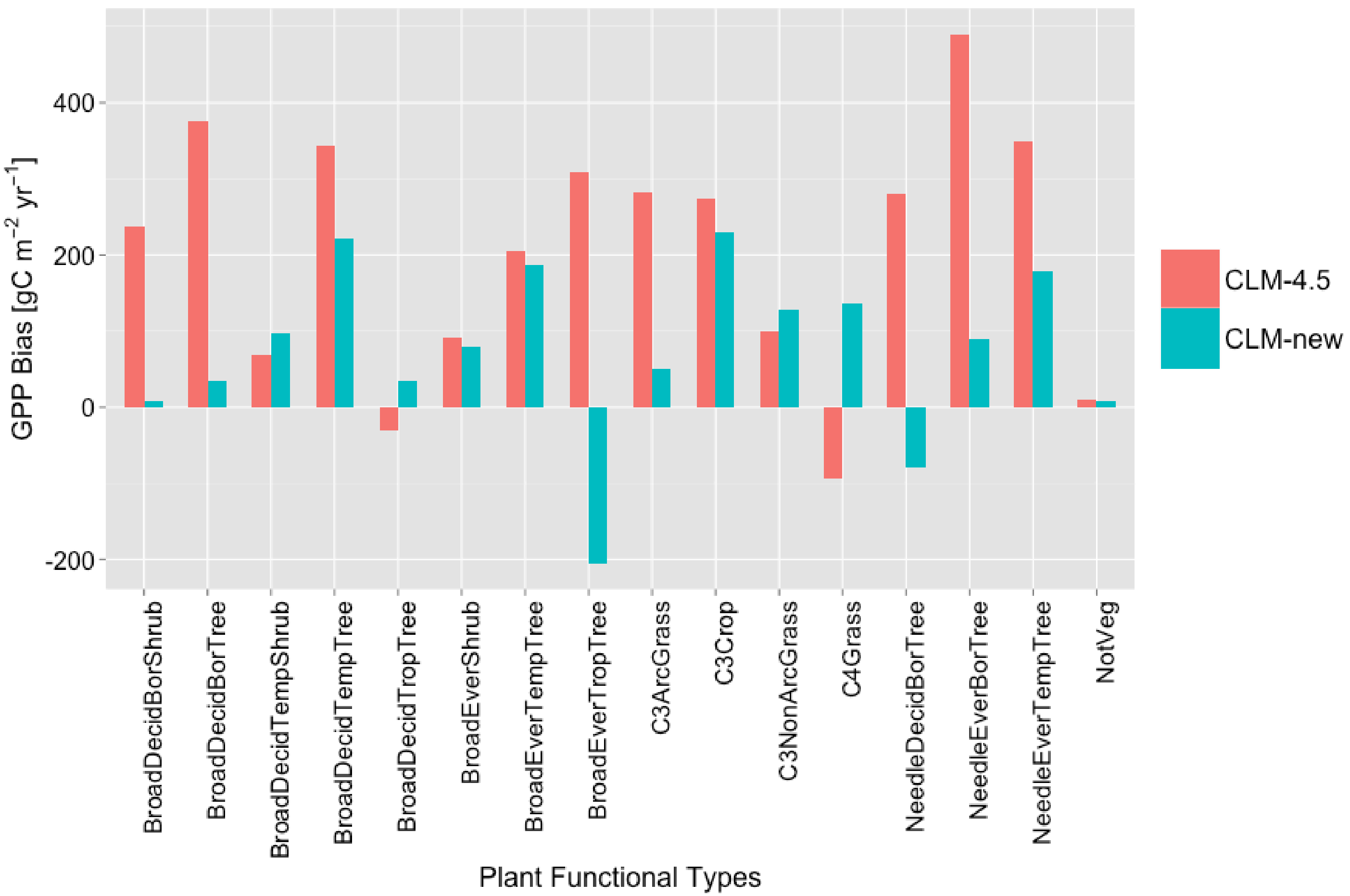
Northern Hemisphere (30N to 60N):
- CLM-new is closer to reference than CLM-4.5



GPP Bias by PFTs

CLM-new has less GPP bias compared to CLM-4.5 for most PFTs

CLM-4.5 GPP bias is more than 200 gC m^{-2} yr^{-1} for most PFTs

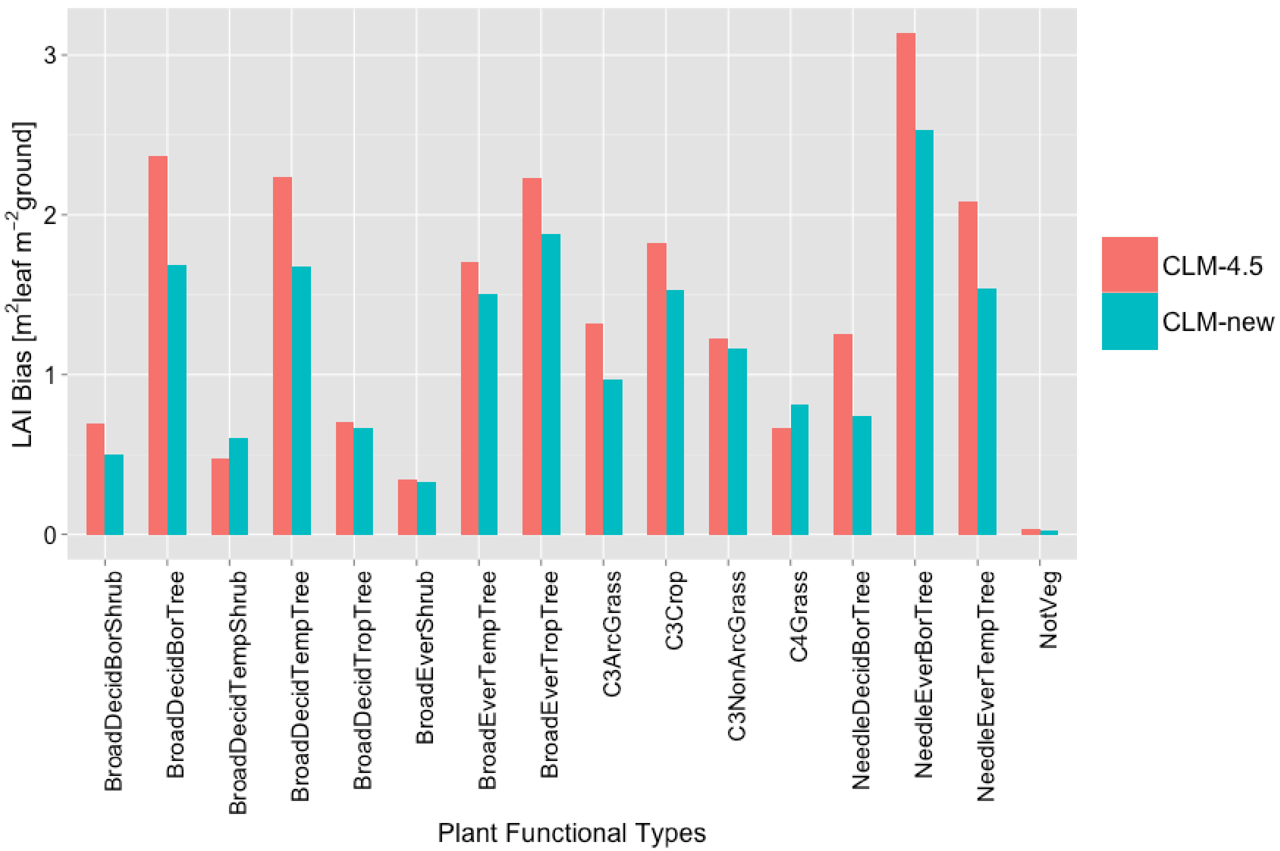


LAI Bias by PFTs

- Prediction of LAI in CLM depends on GPP, specific leaf area and leaf longevity

- Across all PFTs, CLM-4.5 has mean LAI bias of 1.4 and CLM-new has mean LAI bias of 1.1

- Working on incorporating specific leaf area and leaf longevity data from the literature and TRY database



Summary

- Current Model Developments
  - Integration of different plant N cycle mechanisms in the Community Land Model
  - Leaf physiology: Model structure uses actual photosynthetic parameters (as a function of leaf nitrogen) rather than potential rates
  - Root physiology: Plant nitrogen uptake based on root physiology using Michaelis-Menten equation
- Future Model Developments
  - Dynamic C and N allocation based on resource and allometric constraints
  - Bayesian parameter optimization
  - Belowground N competition between plants and microbes

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