Multi-layer canopy processes: Assessing nitrogen limitation and light limitation for photosynthesis

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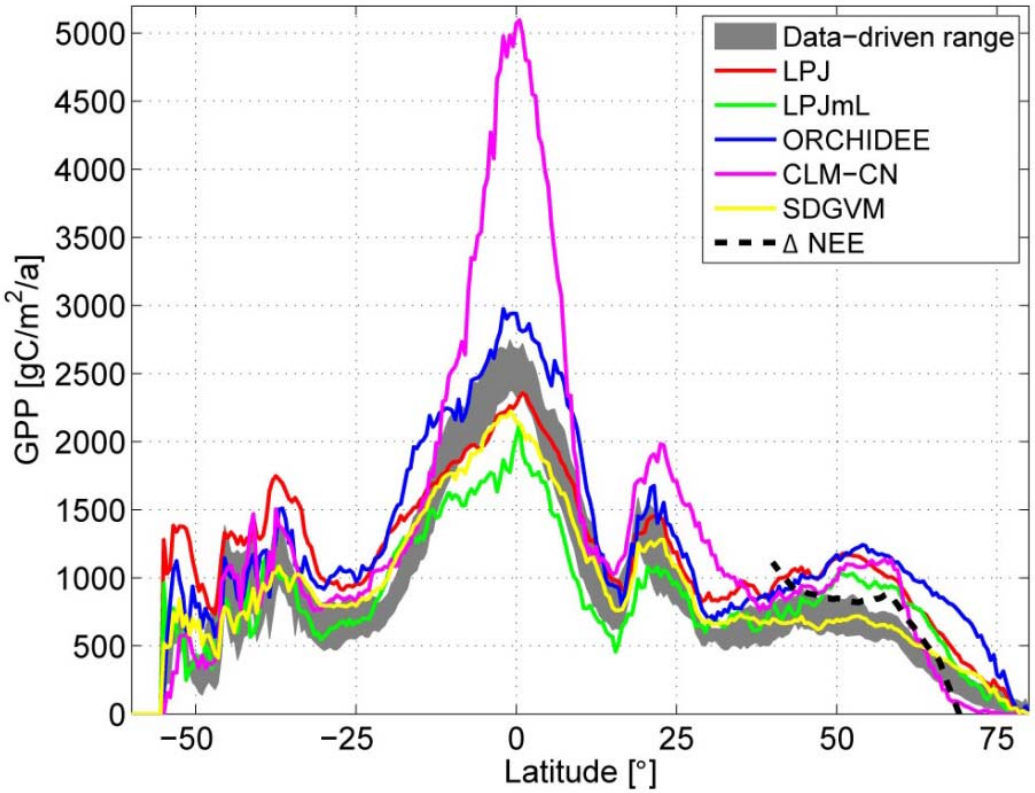
Gross primary production biases

CLM4 (purple line) overestimates annual gross primary production (GPP) compared with data-driven estimates and other models



Beer et al. (2010) Science 329:834-838

Causes of GPP bias

Model structural error
Canopy radiative transfer
Photosynthesis-stomatal conductance
Canopy integration

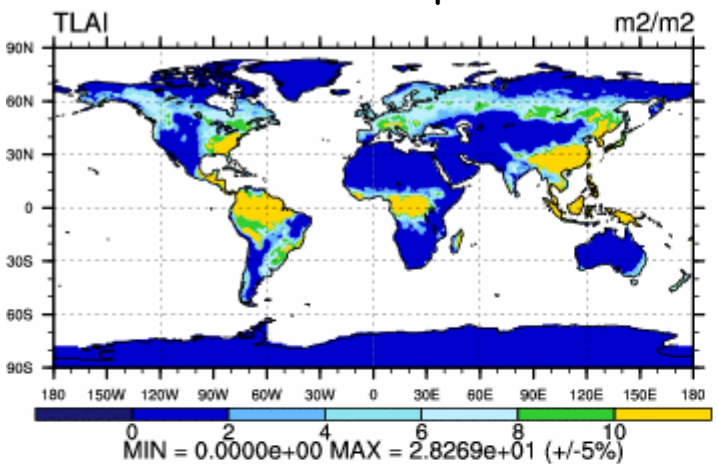
Model parameter uncertainty
V_{cmax}

Bonan et al. (2011) JGR, doi:10.1029/2010JG001593

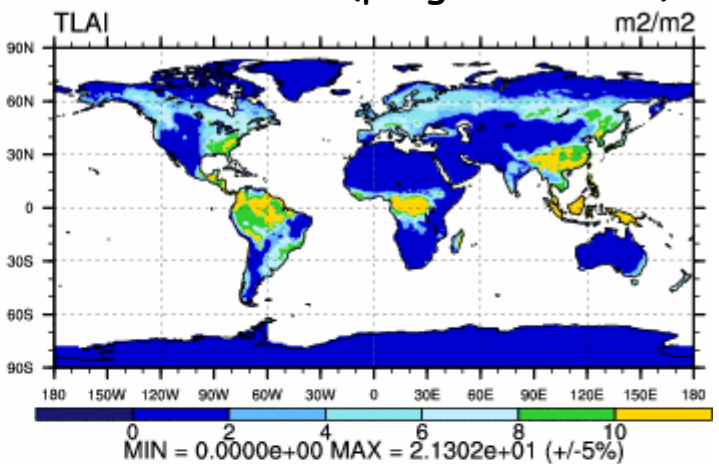
Leaf area index biases?

Simulated leaf area index (Jun, Jul, Aug)

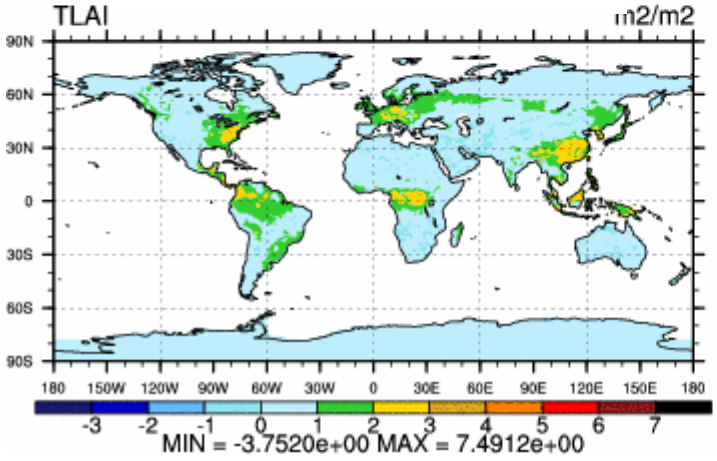
N fertilization experiment



CLM4 control (prognostic LAI)

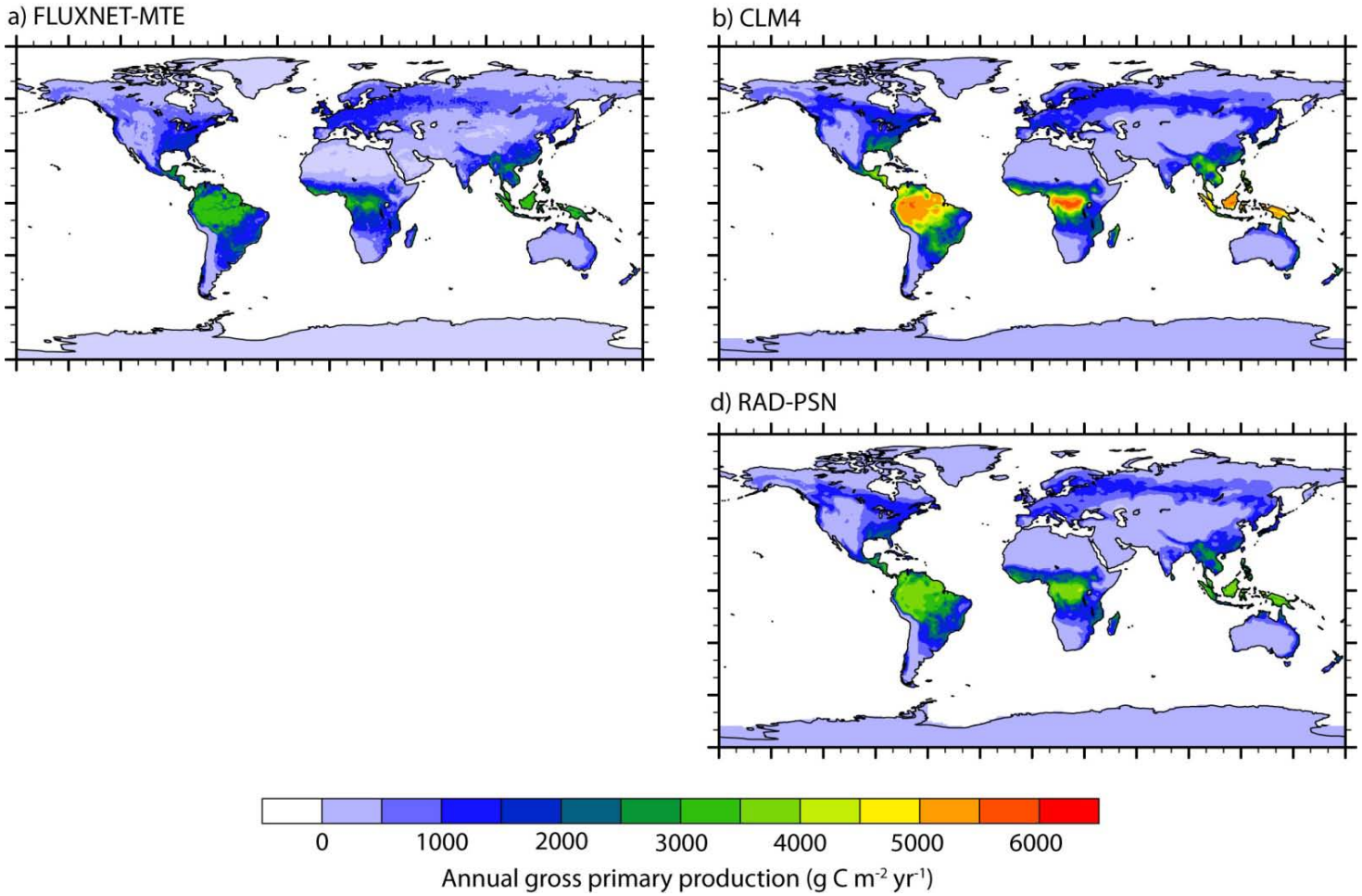


N fertilization - control



CLM4CN has high LAI (>10) and allows additional LAI with N fertilization

Gross primary production bias reduction



Similar improvements are seen in evapotranspiration

FLUXNET-MTE data from Martin Jung and Markus Reichstein (M-P-I Biogeochemistry)

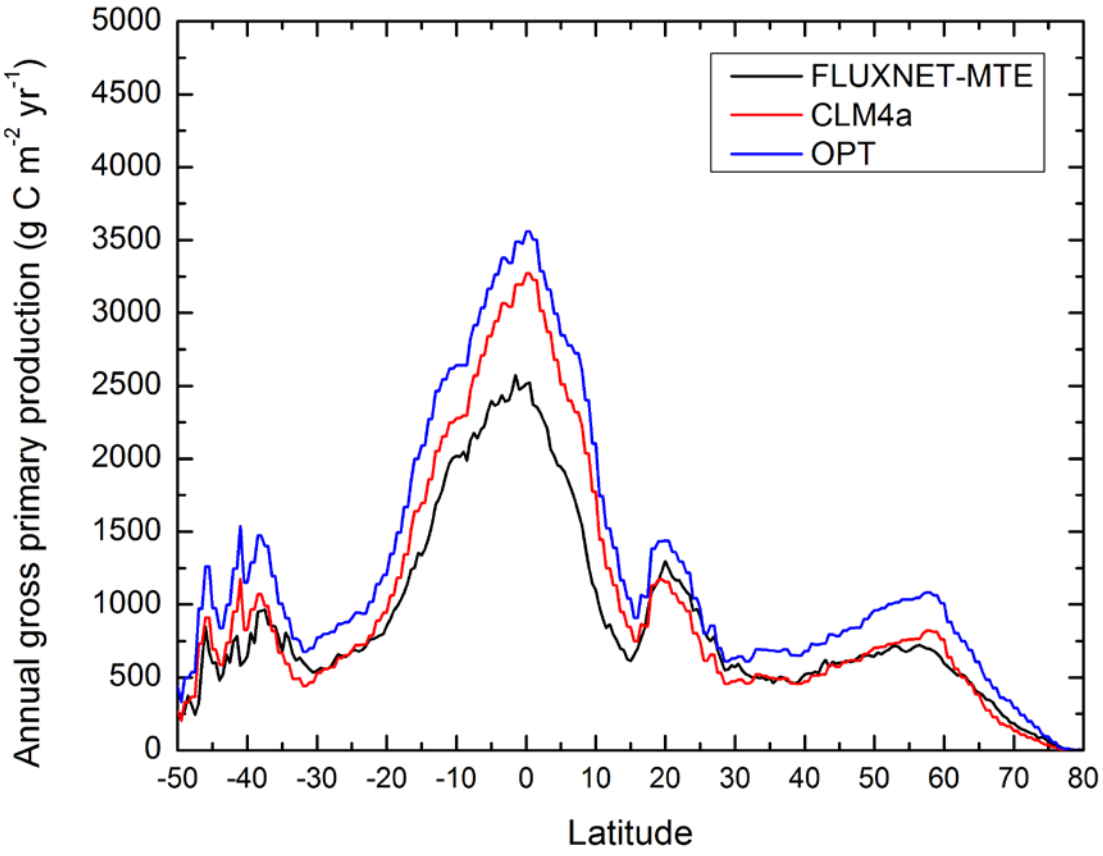
Bonan et al. (2011) JGR, doi:10.1029/2010JG001593

N down-regulation of GPP

Model down-regulates "potential" GPP for N

The result is that N limits GPP throughout much of the world

When we remove this down-regulation, the model is too productive



Bonan et al. (2011) JGR, doi:10.1029/2010JG001593

Is the CLM photosynthetic capacity consistent with observations?

To match observed GPP, CLM4 needs to infer strong N down-regulation (with therefore reduced photosynthetic capacity)

How does this compare with observations of photosynthetic capacity, *including* N limitation?

Global Change Biology (2009) **15**, 976–991, doi: 10.1111/j.1365-2486.2008.01744.x

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

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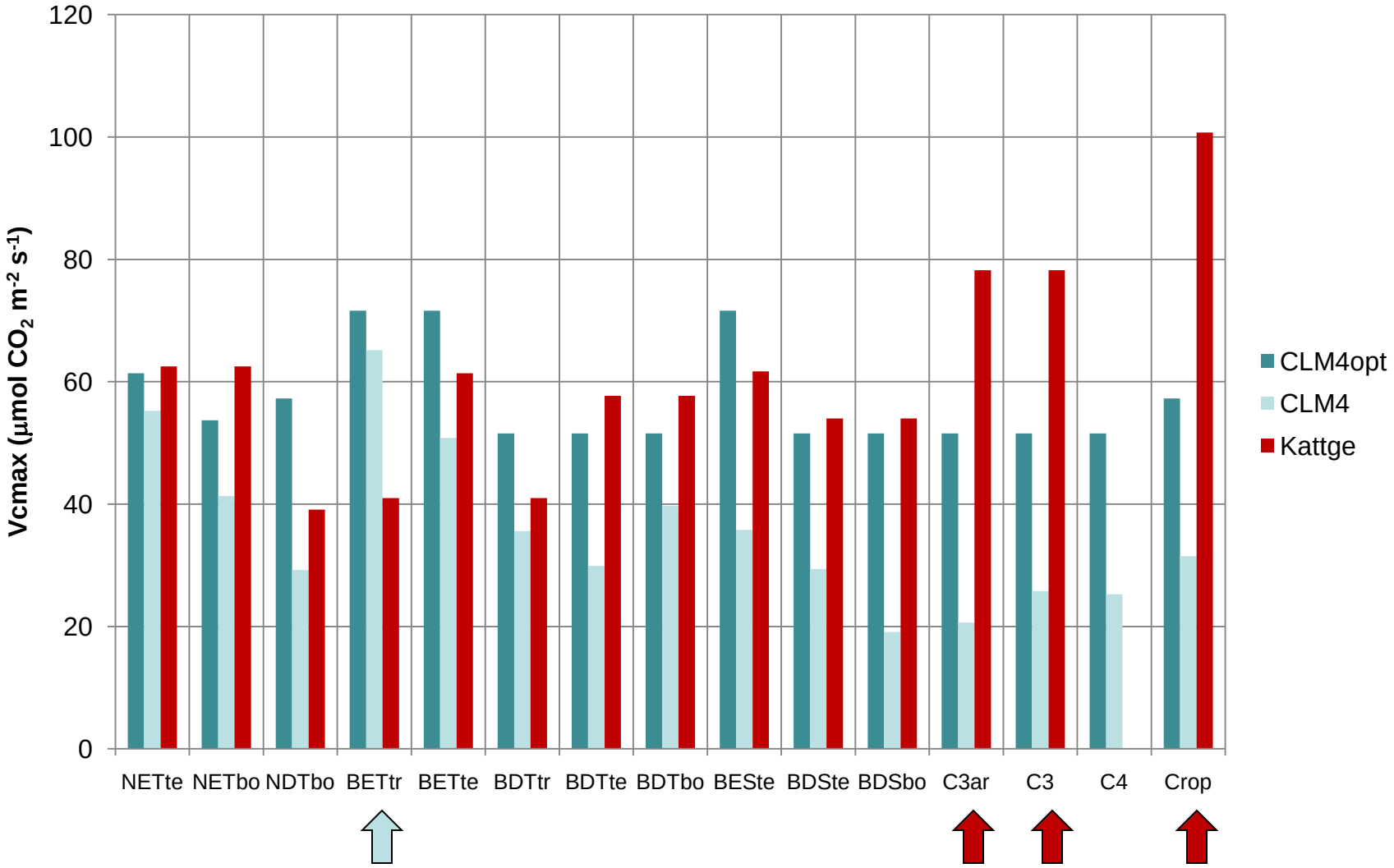
- Derived the relationship between photosynthetic parameter V_{cmax} and leaf N from V_{cmax} (723 data points) and A_{max} (776 data points) studies
- Used measured leaf N in natural vegetation to estimate V_{cmax} for various PFTs
- Most comprehensive estimates of V_{cmax} available
- Includes the effects of N limitation

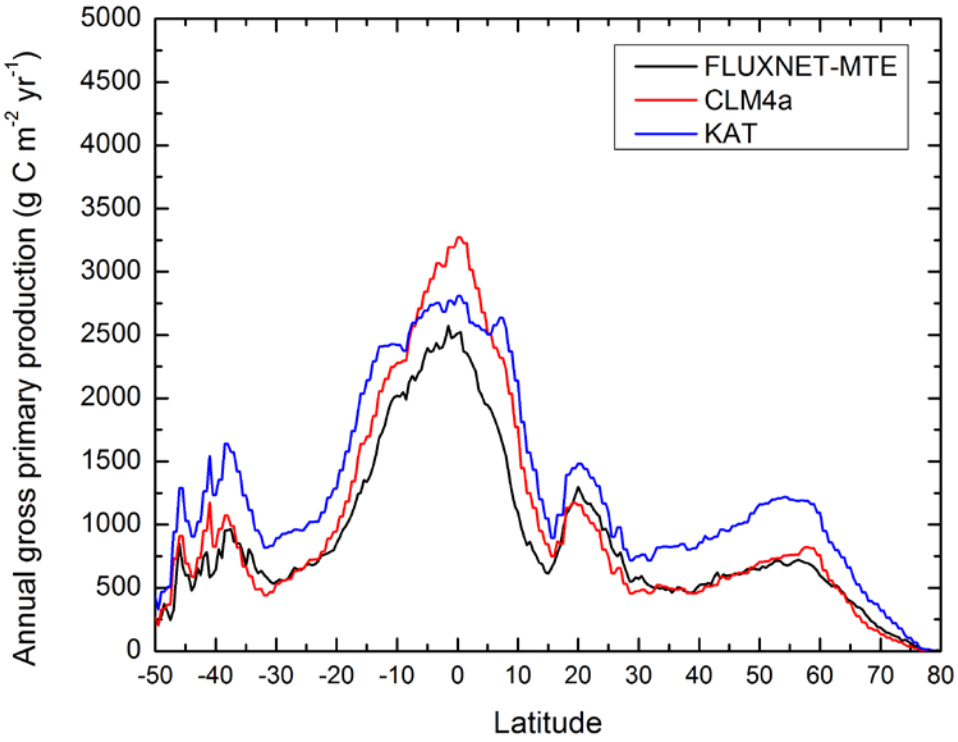
CLM photosynthetic capacity



- CLM4 N down-regulated V_{cmax} is less than Kattge V_{cmax} except for tropical forest
- CLM4 optimal V_{cmax} is comparable to Kattge V_{cmax}, with some exceptions

GPP biased high with real-world V_{cmax}

What happens when we use the Kattge V_{cmax} values?



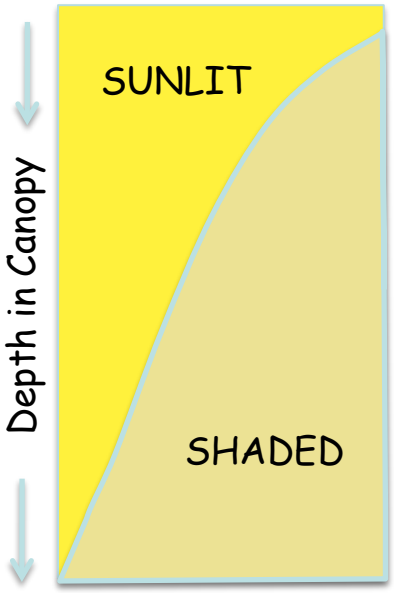
Bonan et al. (2011) JGR, doi:10.1029/2010JG001593

Kattge V_{cmax} values increase GPP except in the tropics, which declines because of lower V_{cmax}

Why is GPP so high if we are using the correct enzyme-limited photosynthetic capacity? What is missing in the model?

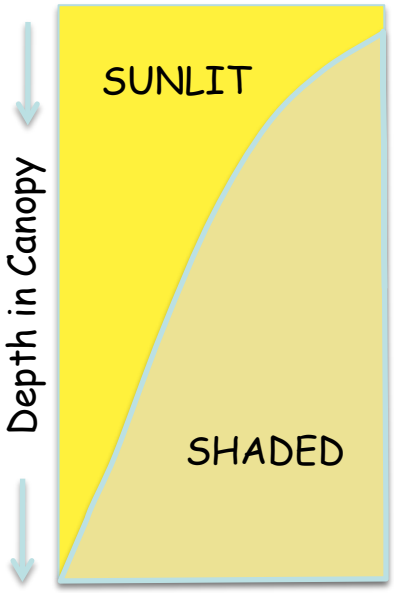
Canopy light absorption

CLM4



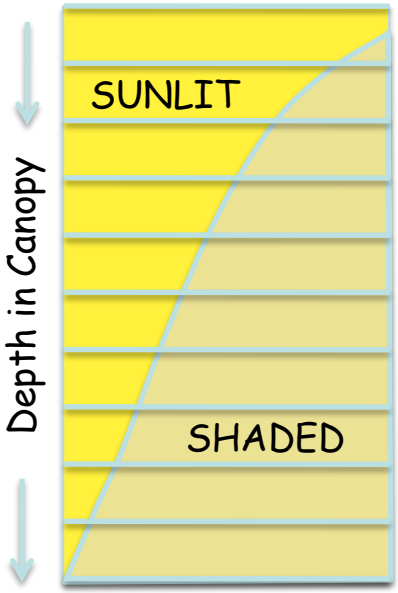
- Two "big-leaves" (sunlit, shaded)
- Radiative transfer integrated with depth (two-stream approximation)
- Photosynthesis calculated for sunlit and shaded big-leaves

CLM4a



Same model structure as CLM4, but with revisions described by Bonan et al. (2011) JGR, doi:10.1029/2010JG001593

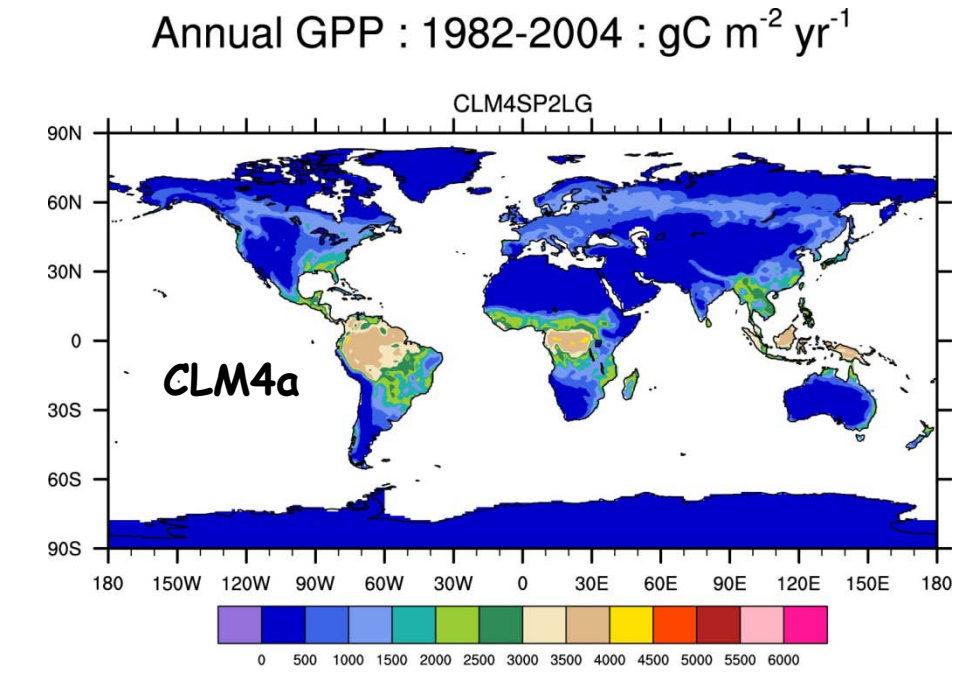
CLM4b

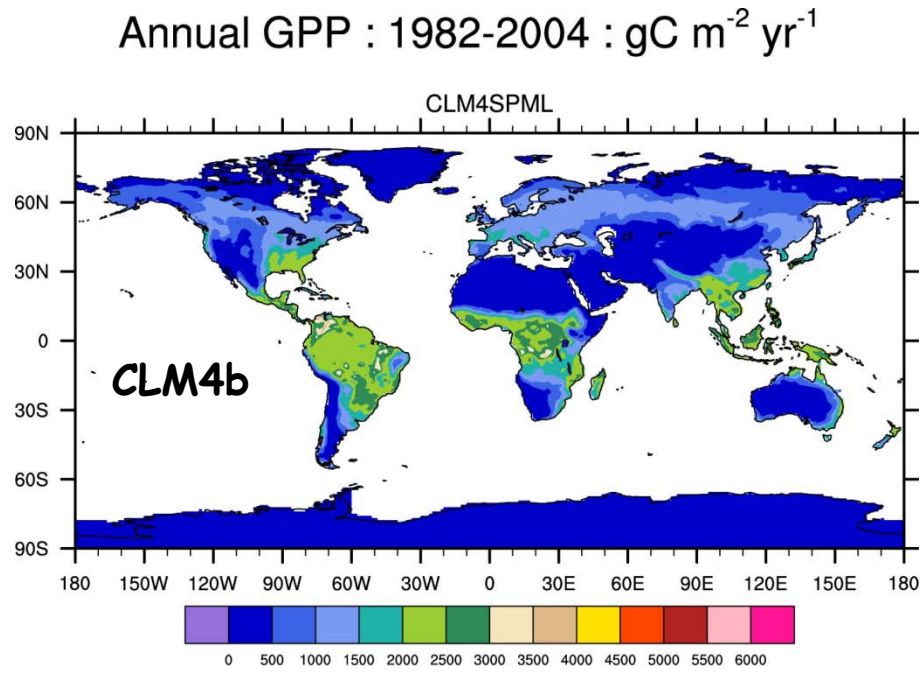


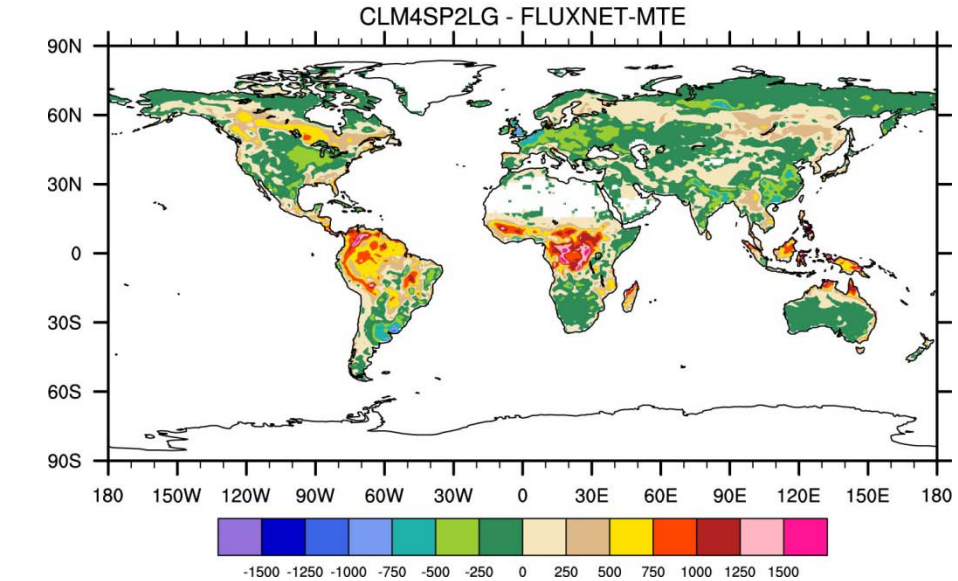
Multi-layer model

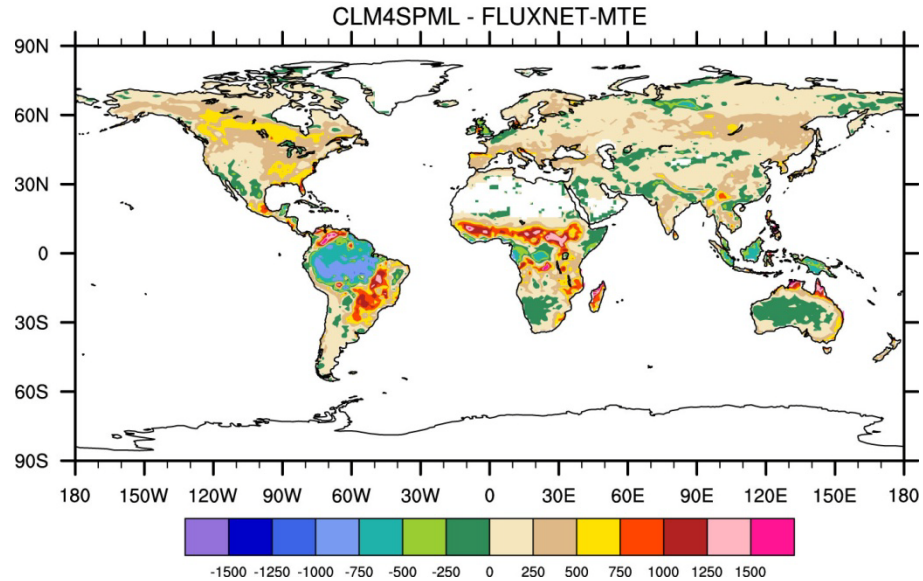
- Two-stream approx-imation for light profile
- Resolves direct and diffuse radiation
- Resolves sunlit and shaded leaves
- Explicit definition of leaf properties with depth
- Nitrogen scaled exponentially with K_n dependant on V_{cmax} (Lloyd et al. 2010)
- V_{cmax} from Kattge et al. (2009)
- J_{max} from Medlyn et al. (2002)

GPP biases in the two models



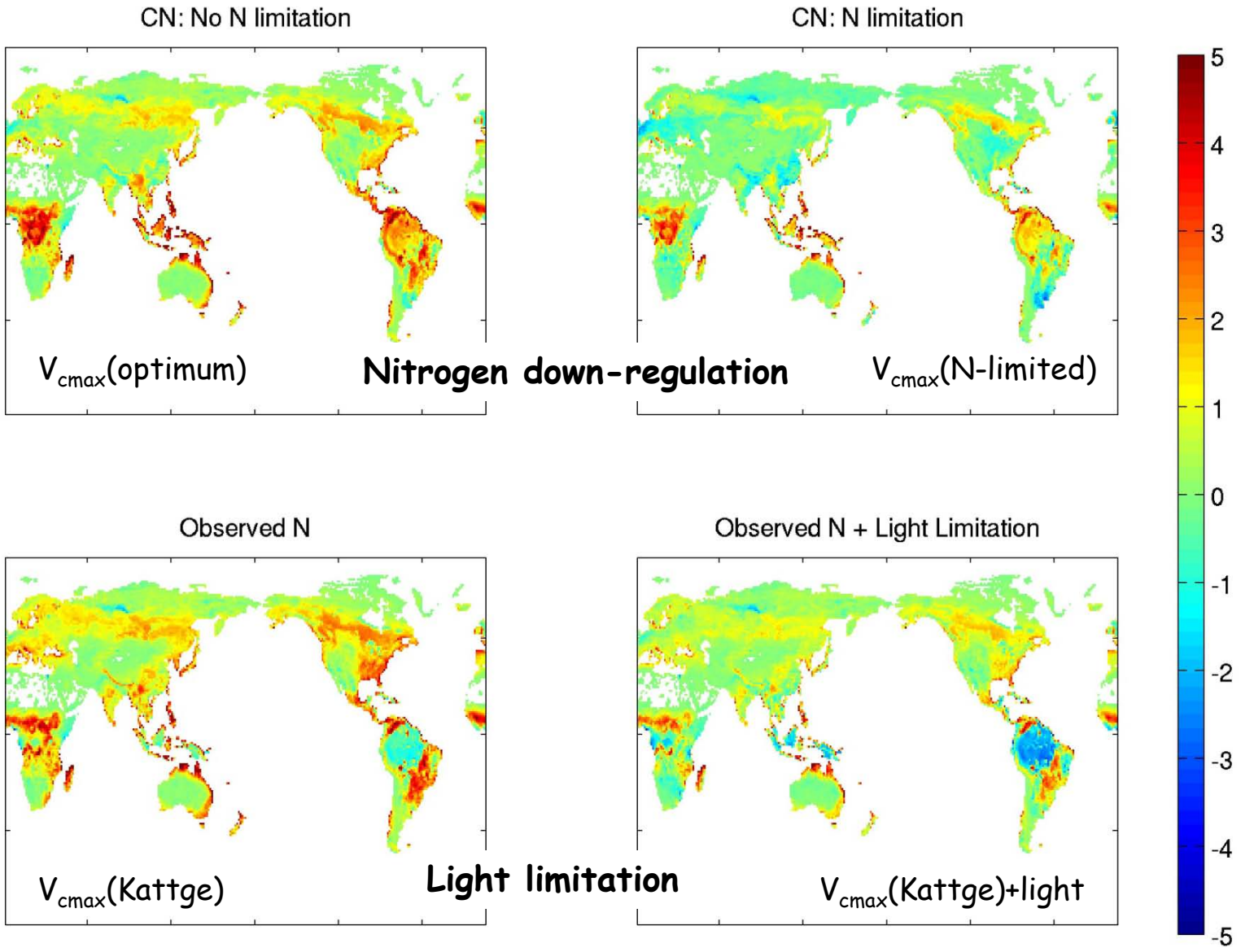






Two ways to get similar GPP

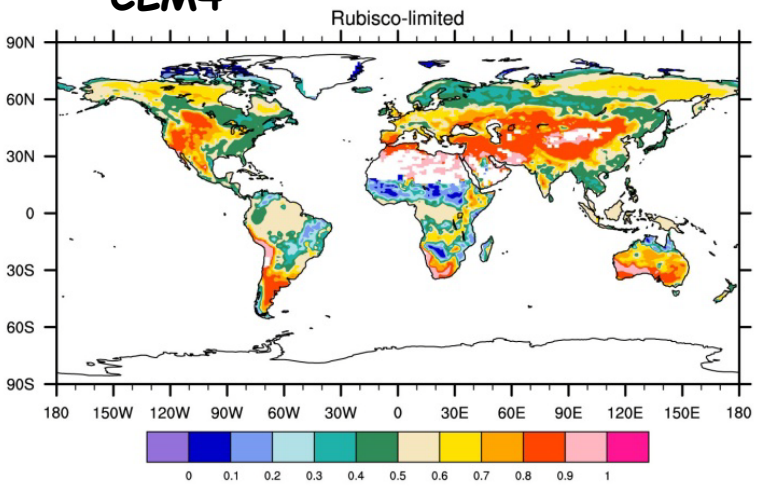
Simulated -Observed GPP (g C m^{-2} day^{-1})



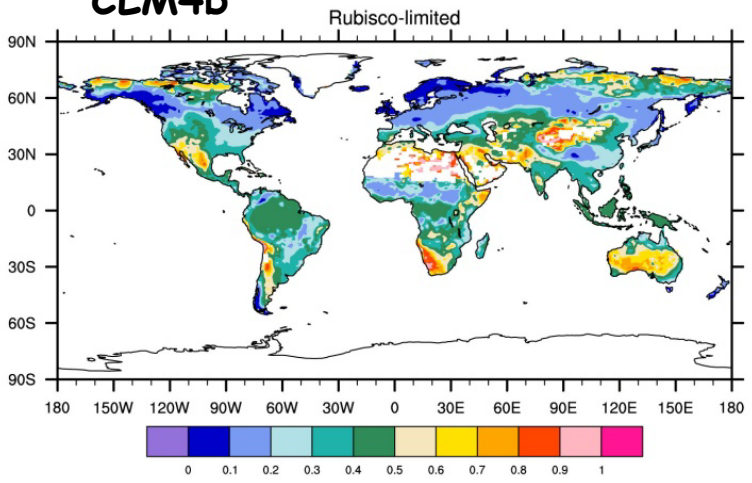
How does CLM4b affect GPP?

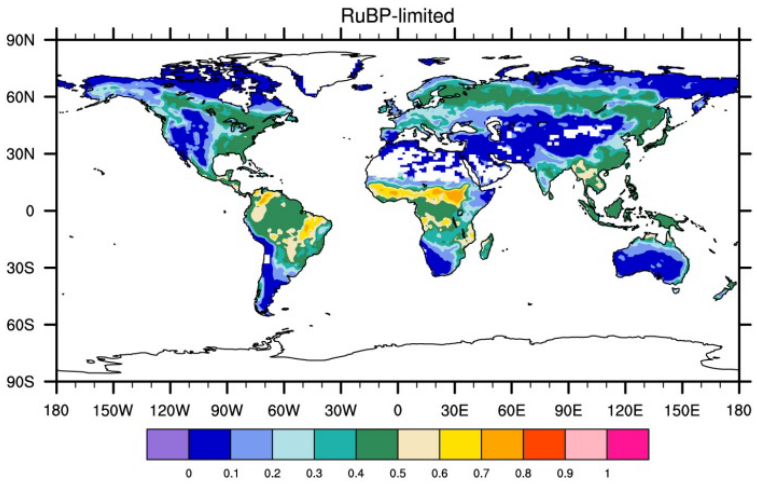
Fraction of annual GPP that is rubisco-limited or light-limited

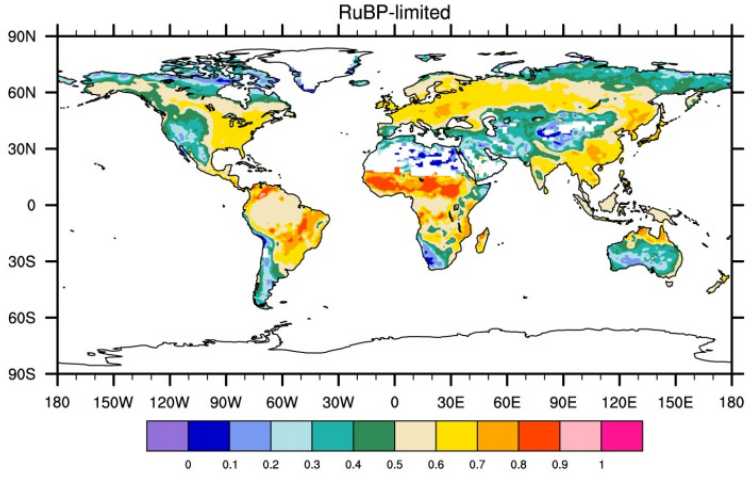
CLM4



CLM4b

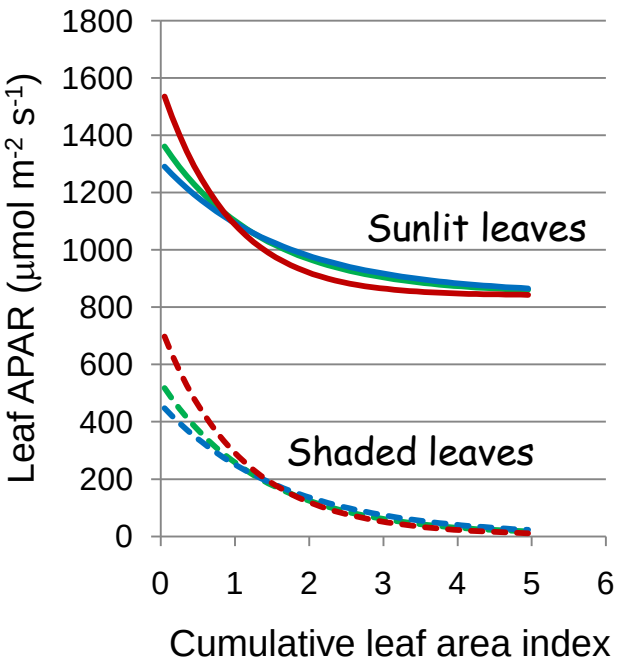


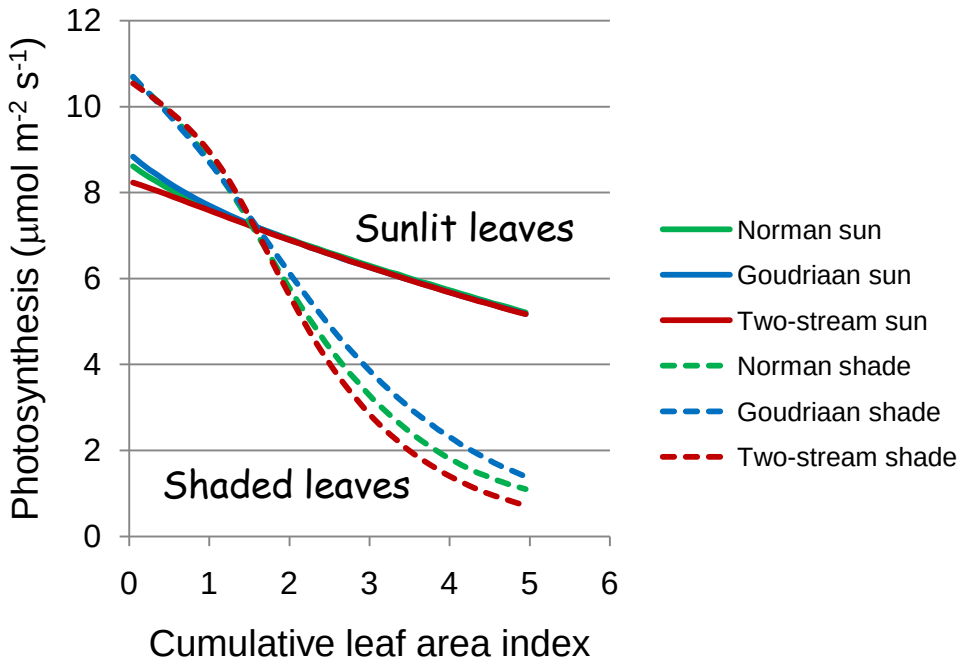




Greater fraction of annual GPP comes from the light-limited rate

Comparison with radiative transfer theory



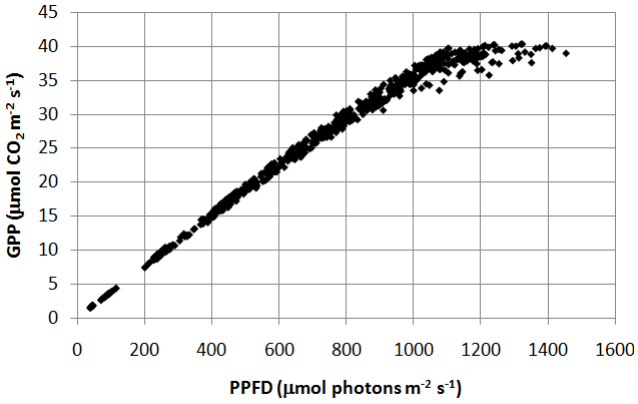


- Two-stream light profile agrees with theoretical models of Norman and Goudriaan
- Resulting leaf photosynthetic rates are comparable among models

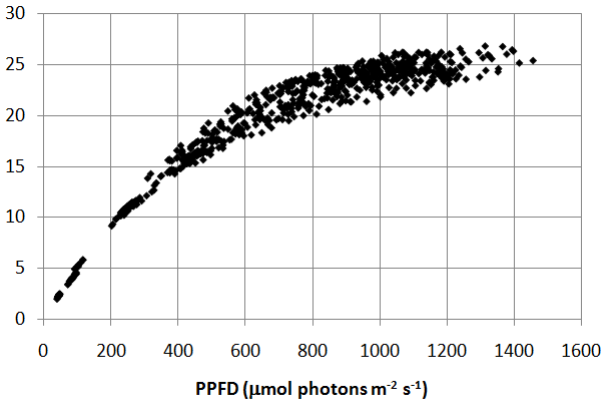
Comparison with observations

Canopy-scale light response curve

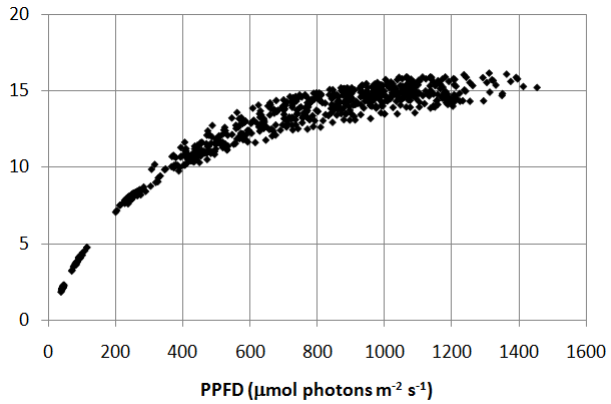
CLM4



CLM4a

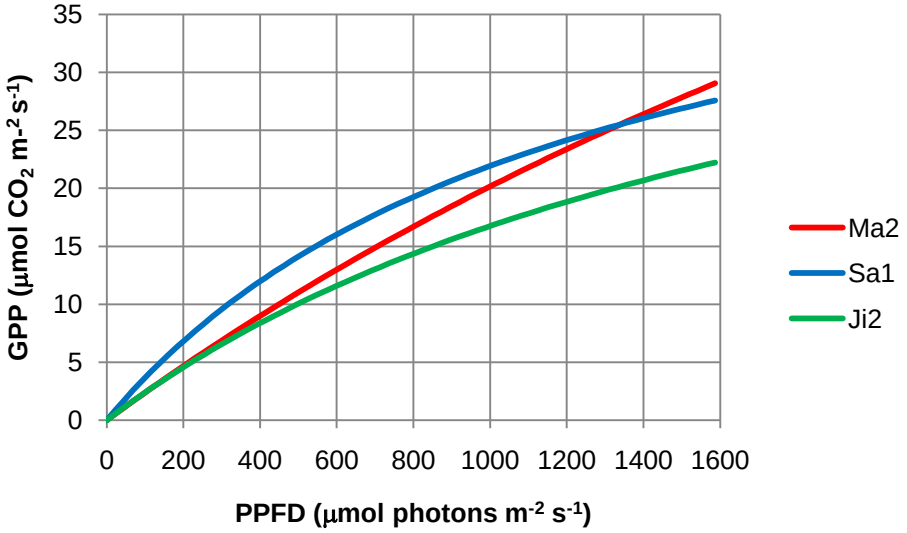


CLM4b



- Model data for a single grid cell in Amazonia
- FLUXNET data for three tower sites

FLUXNET



Conclusions

- CLM lowers GPP by reducing photosynthetic capacity, assuming limitations on nitrogen supply
- If we put in the observed photosynthetic capacity, GPP is mostly far too high
- Correctly accounting for light and photosynthesis profiles in the canopy brings it down closer to the FLUXNET observations
- It is *not necessary to invoke N down-regulation* to get this right
- Much of the transient behavior of CLM is caused by N down-regulation. This new model will have qualitatively different behavior