Improving canopy processes in the Community Land Model using Fluxnet data: Assessing nitrogen limitation and canopy radiation

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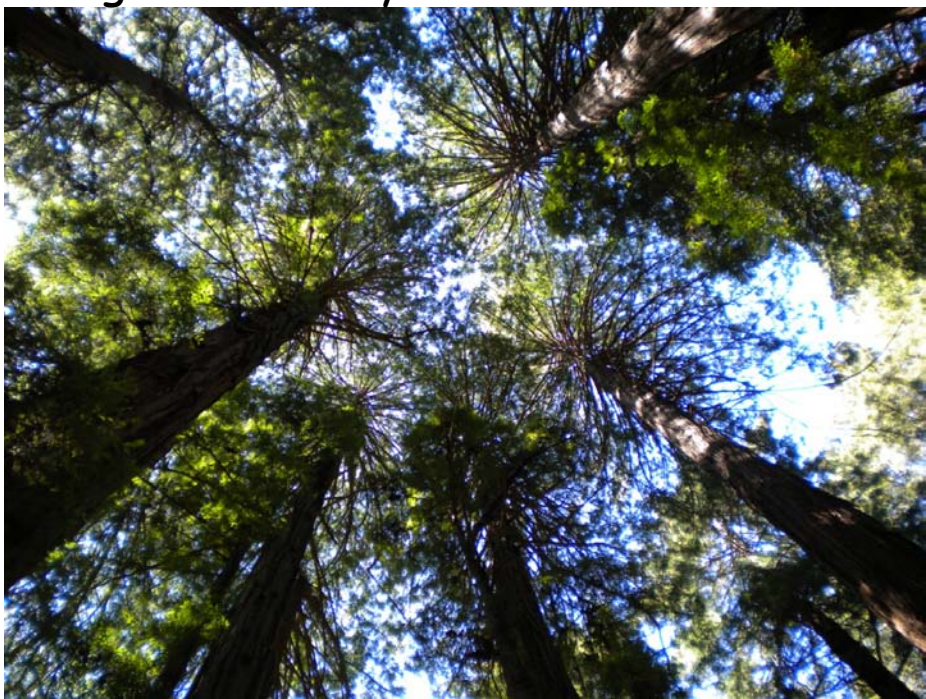
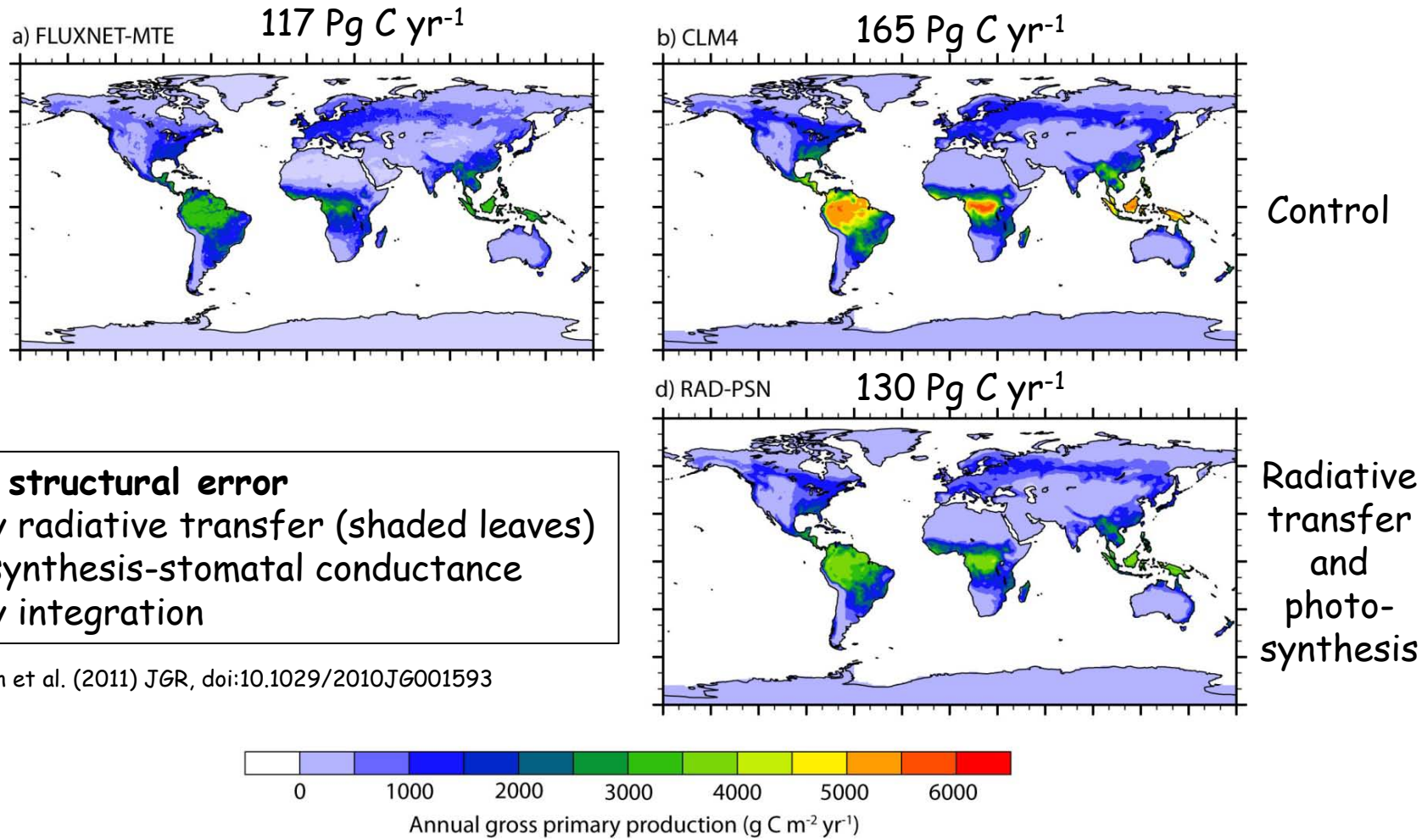


3rd iLEAPS Science Conference
Garmisch-Partenkirchen, Germany
21 September 2011

NCAR is sponsored by the
National Science Foundation

Gross primary production bias



Model structural error
Canopy radiative transfer (shaded leaves)
Photosynthesis-stomatal conductance
Canopy integration

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

CLM4 overestimates GPP. Model revisions improve GPP.
Similar improvements are seen in evapotranspiration.

FLUXNET-MTE data from Martin Jung and Markus Reichstein (MPI-BGC, Jena)

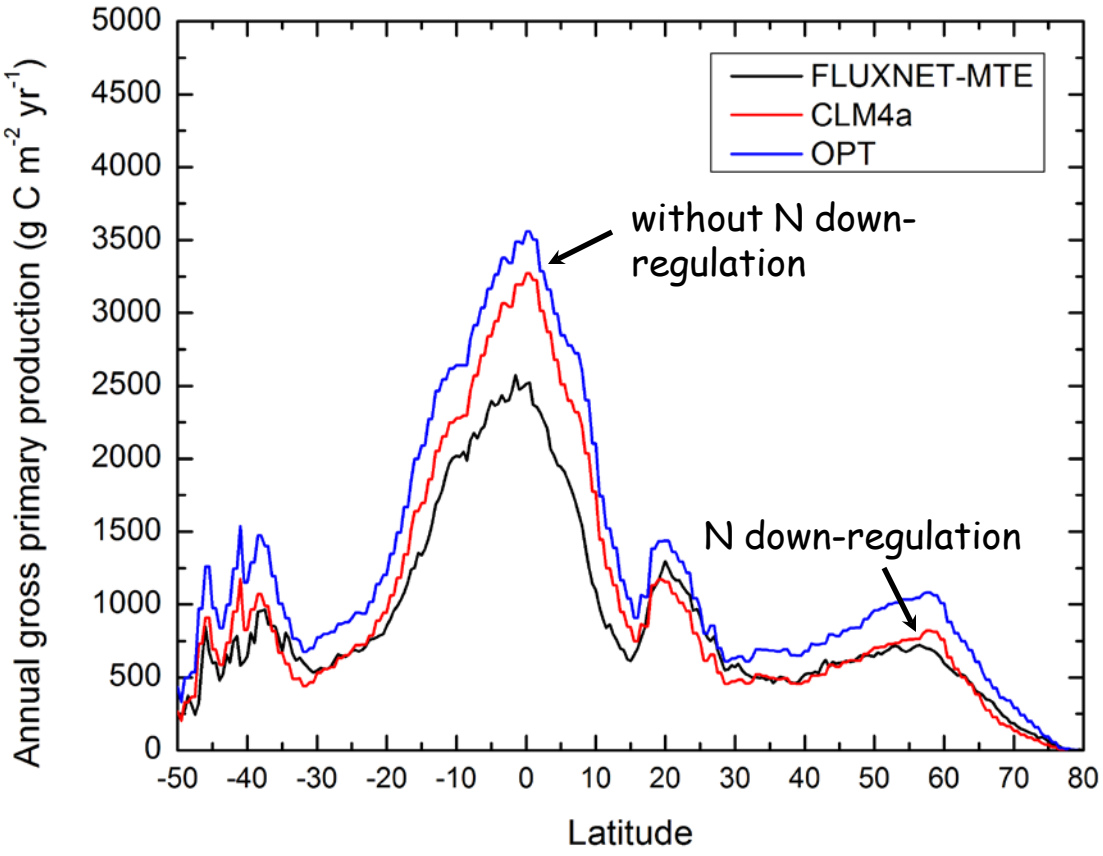
N down-regulation of GPP

CLM4 down-regulates "potential" GPP for nitrogen

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

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

This is seen in both satellite phenology simulations without C-N biogeochemistry (right panel) and also prognostic carbon-nitrogen simulations (CLM4CN)



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 databases of leaf traits provide an answer

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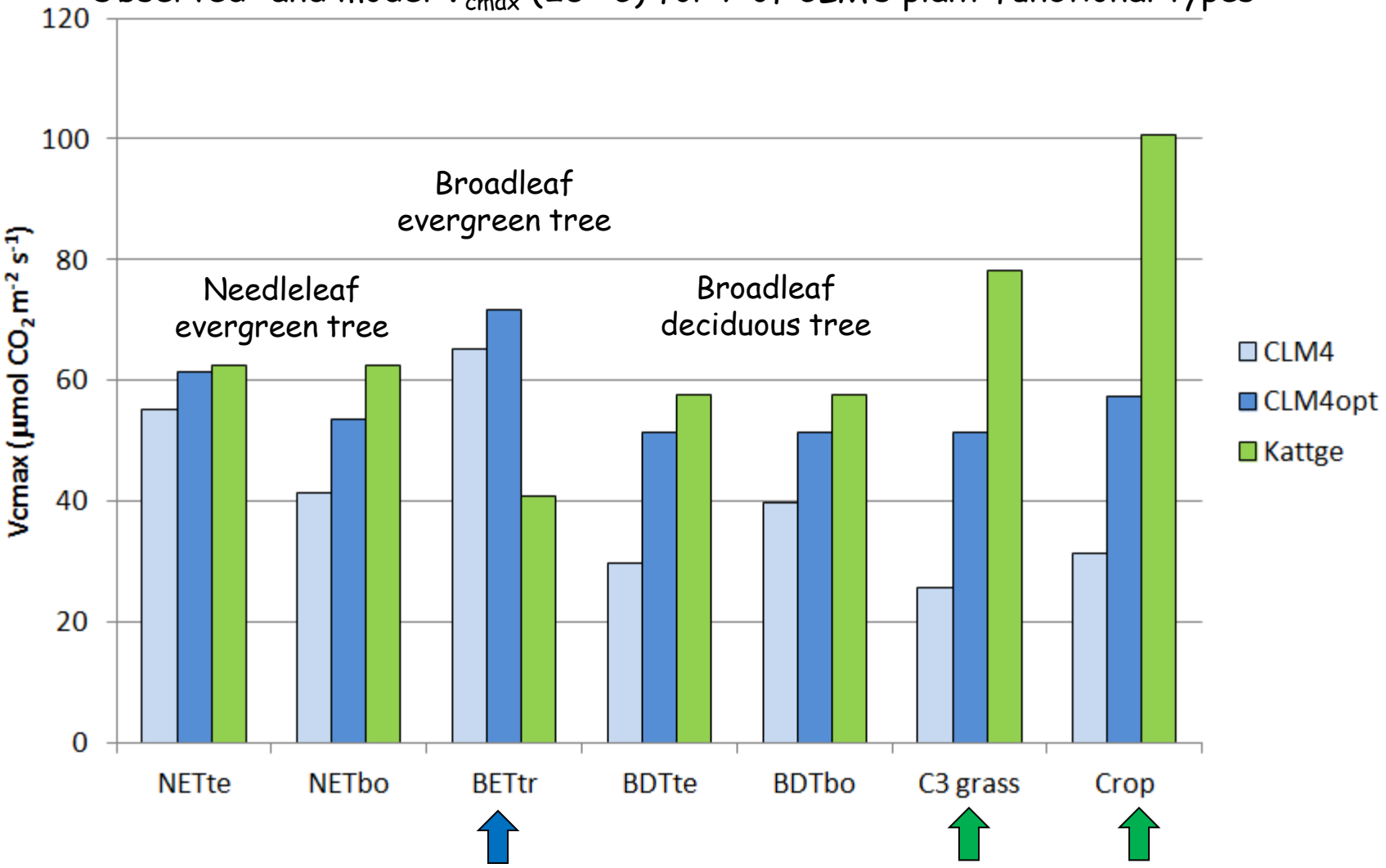
- Derived the relationship between photosynthetic parameter V_{cmax} and leaf N from V_{cmax} (723 data points) and A_{max} (776 data points) studies
- Used measured leaf N in natural vegetation to estimate V_{cmax} for various PFTs
- Most comprehensive estimates of V_{cmax} available
- Includes the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

CLM photosynthetic capacity

"Observed" and model V_{cmax} (25 °C) for 7 of CLM's plant functional types



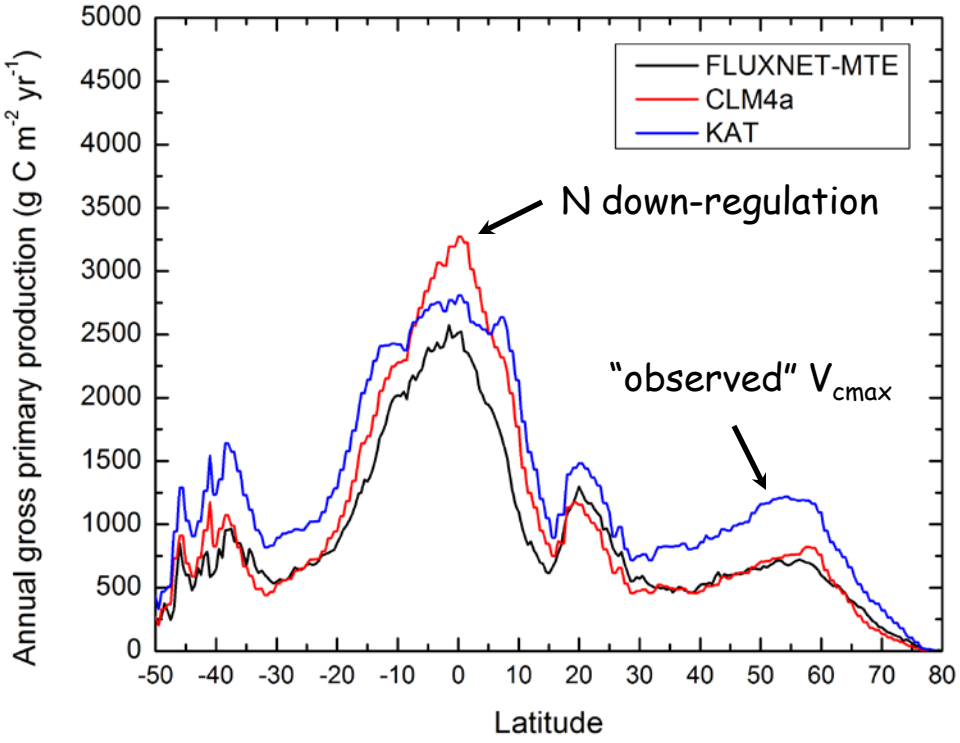
CLM4 down-regulated V_{cmax} is less than Kattge V_{cmax} except for tropical forest
CLM4 maximum V_{cmax} is comparable to Kattge V_{cmax}, with some exceptions

GPP biased high with real-world V_{cmax}

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

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?



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

Bonan et al. (2011):
"We infer that the photosynthetic parameter V_{cmax} remains poorly constrained by observational data and is likely a model-dependent parameter…"

Here, we provide a solution to this discrepancy between the leaf trait database and the FLUXNET database

Canopy light absorption

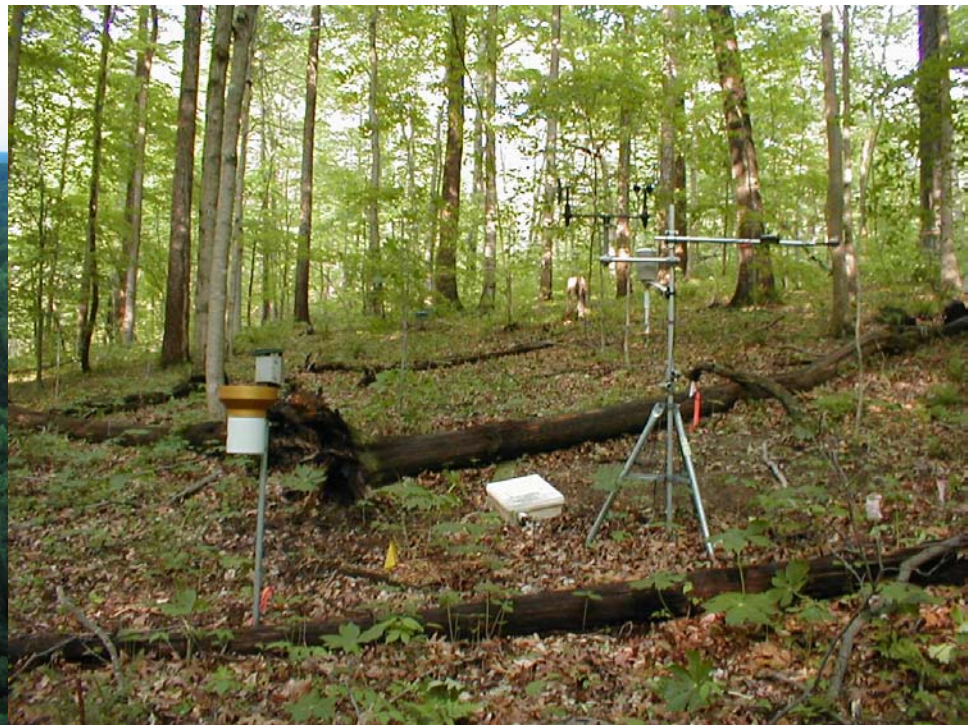
Hypothesis: CLM4 is too productive (high GPP) in the absence of nitrogen down-regulation because of deficiencies in canopy radiation. Nitrogen down-regulation compensates for this deficiency.

Model simulations

- Without C-N biogeochemistry
- With satellite leaf area and prescribed V_{cmax}

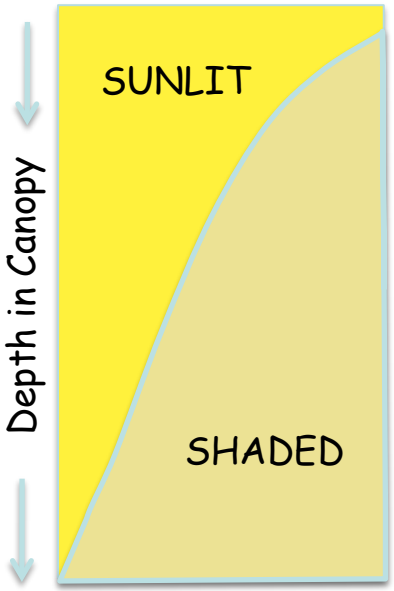
We investigate why CLM requires low V_{cmax} and why it performs poorly with the Kattge et al. (2009) values

Photographs of Morgan Monroe State Forest tower site illustrate two different representations of a plant canopy: as a "big leaf" (below) or with vertical structure (right)



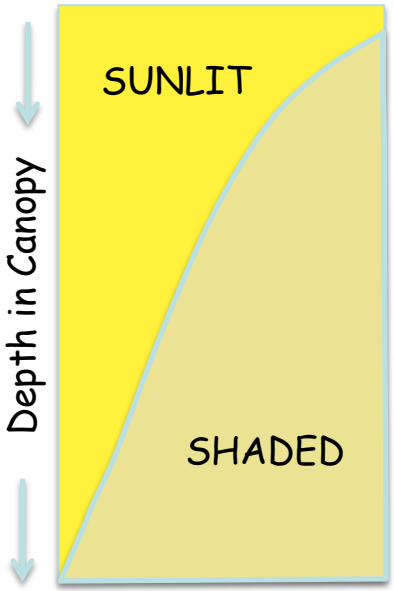
Multi-layer canopy

CLM4



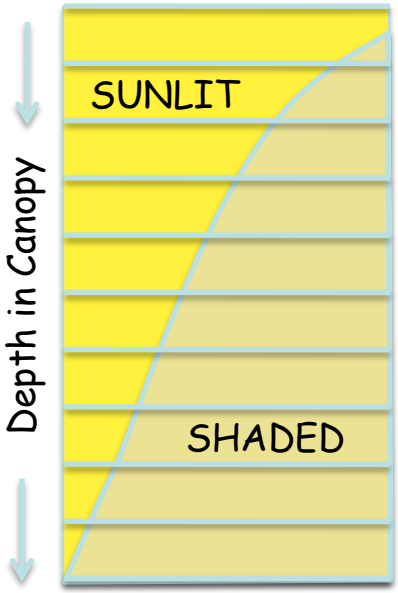
- Two "big-leaves" (sunlit, shaded)
- Radiative transfer integrated over LAI (two-stream approximation)
- Photosynthesis calculated for sunlit and shaded big-leaves

CLM4a



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

CLM4b



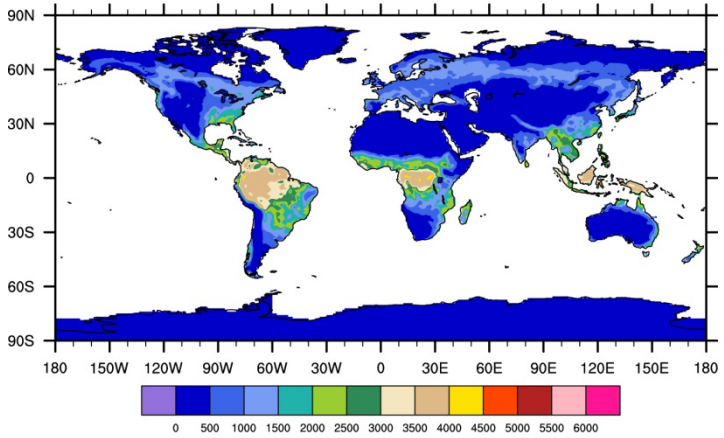
CLM4a and multi-layer canopy

Multi-layer model

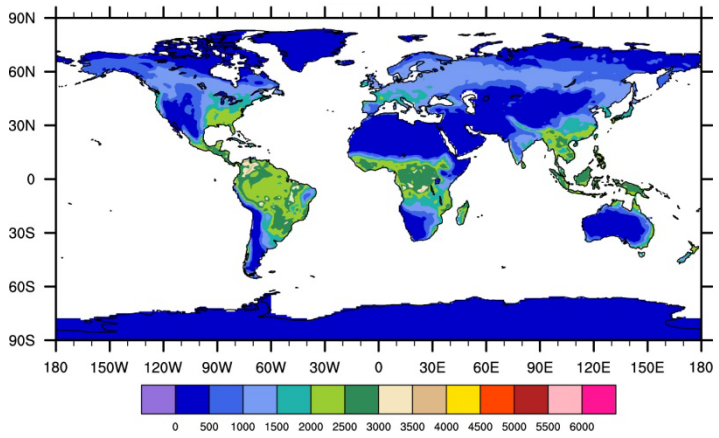
- Two-stream approx-imation for light profile
- Resolves direct and diffuse radiation
- Resolves sunlit and shaded leaves
- Explicit definition of leaf properties with depth
- Nitrogen scaled exponentially with K_n dependant on V_{cmax} (Lloyd et al. 2010)
- V_{cmax} from Kattge et al. (2009)
- J_{max}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

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

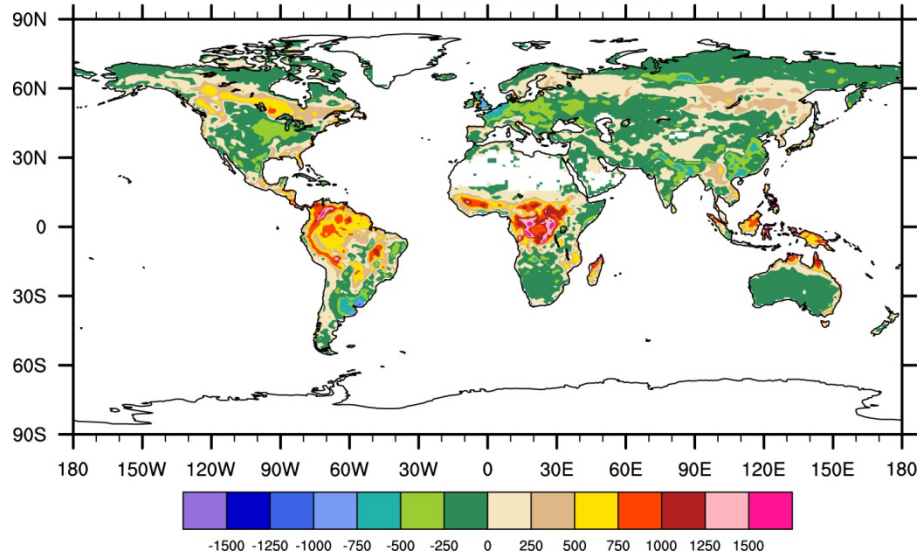
CLM4a



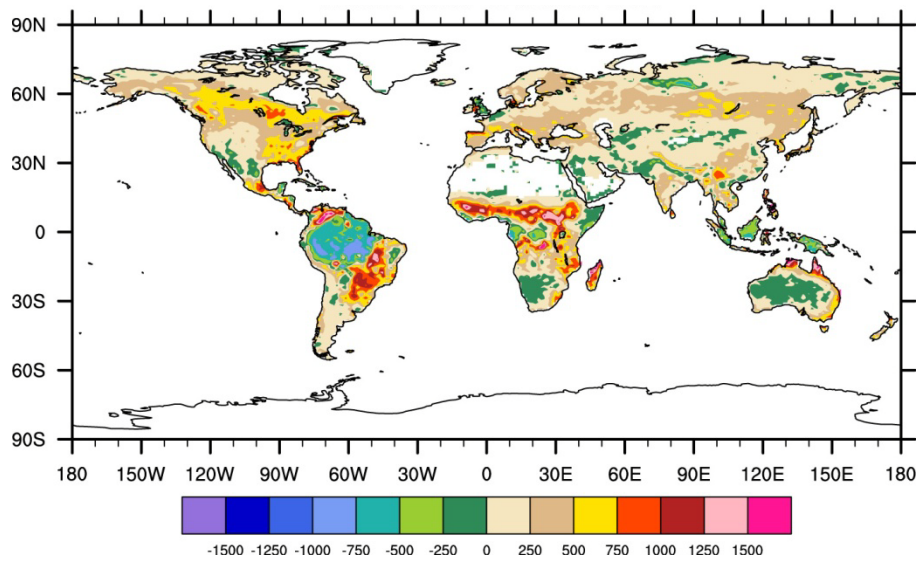
CLM4b



CLM4a - FLUXNET



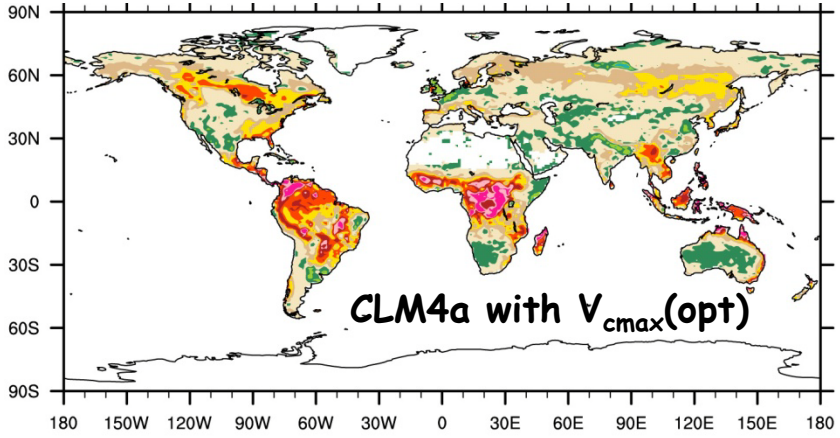
CLM4b - FLUXNET

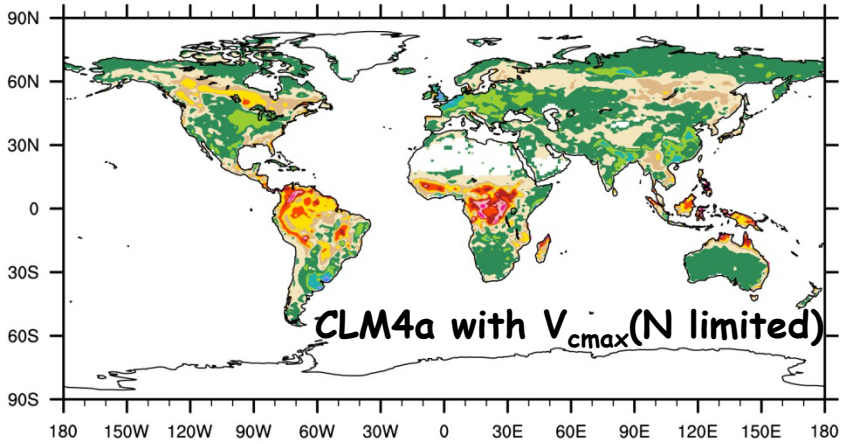


Biases in CLM4b are generally comparable to, though of opposite sign, those of CLM4a

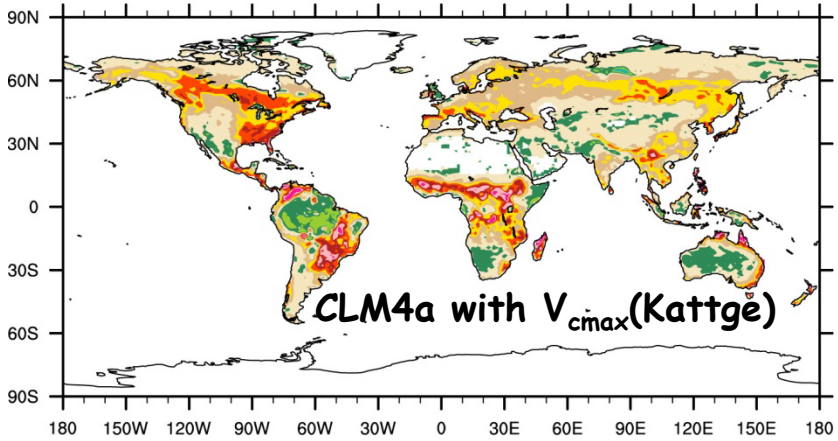
Two ways to get similar GPP

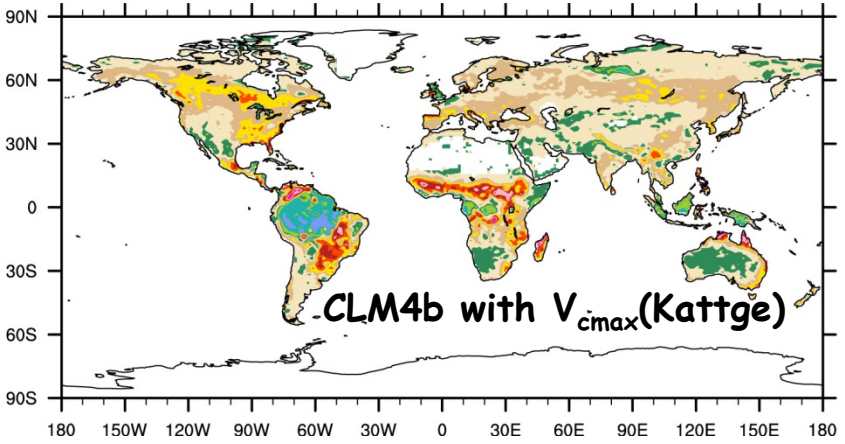
Nitrogen downregulation





Light limitation

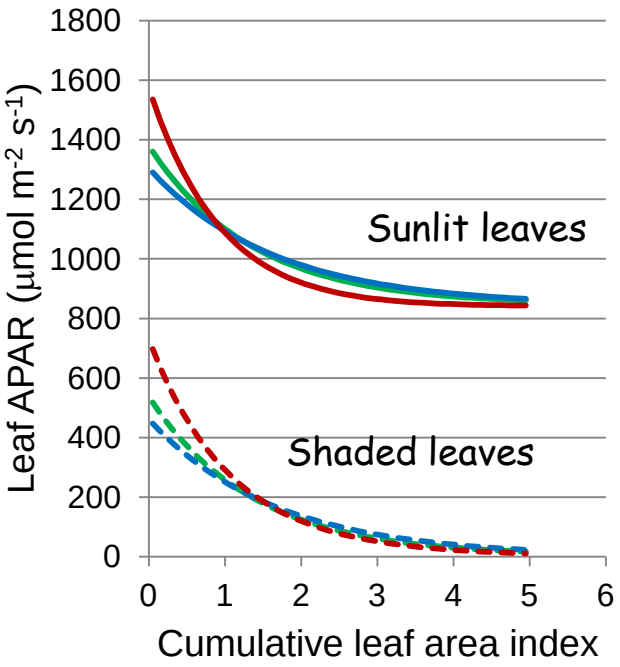


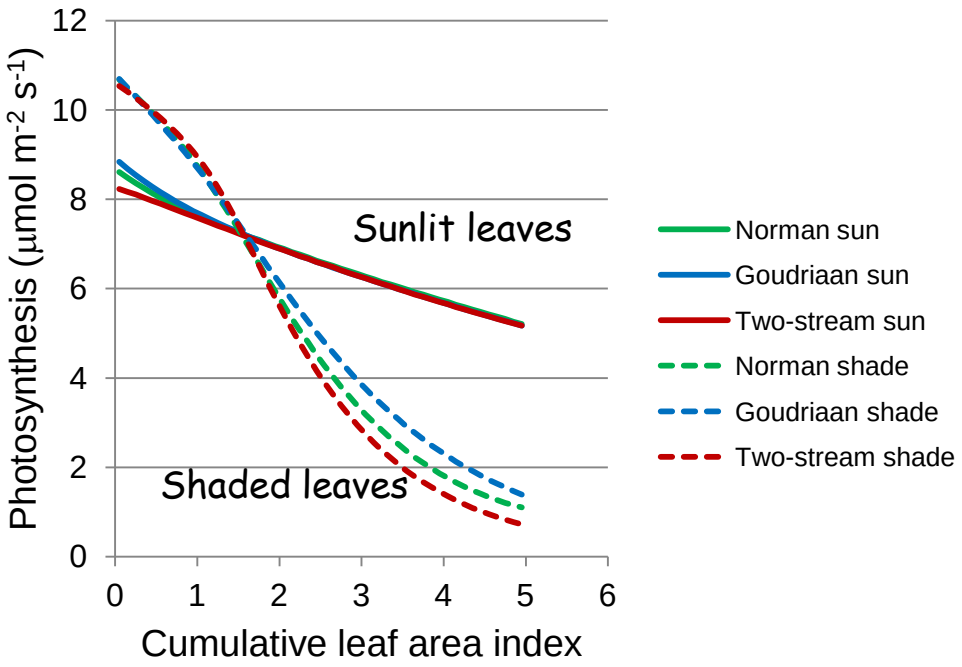


Model - FLUXNET GPP (g C m^{-2} yr^{-1})

CLM4a = two-leaf canopy
CLM4b = multi-layer canopy

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

FLUXNET light-response curves

Global Change Biology (2010) 16, 187–208, doi: 10.1111/j.1365-2486.2009.02041.x

Separation of net ecosystem exchange into assimilation and respiration using a light response curve approach: critical issues and global evaluation

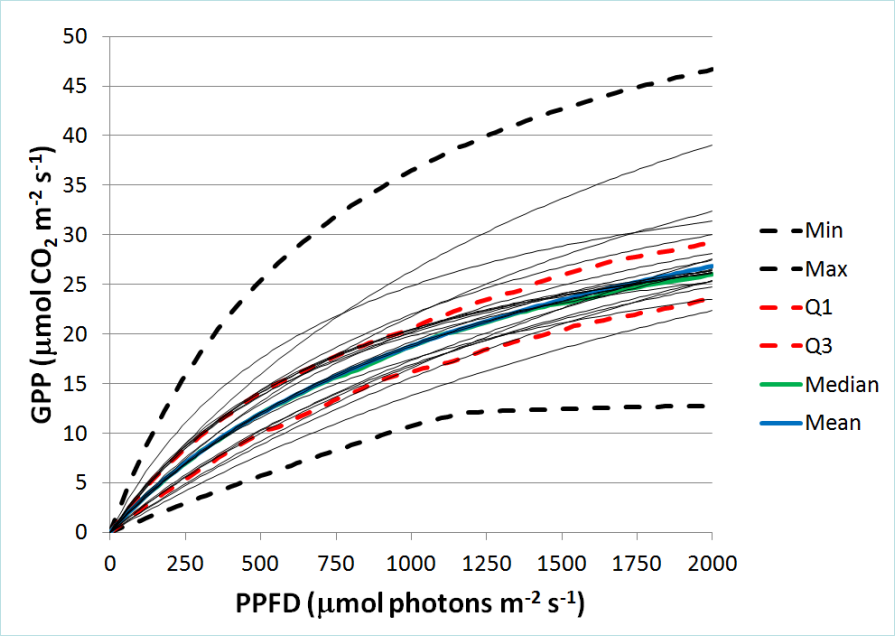
GITTA LASSLOP*, MARKUS REICHSTEIN*, DARIO PAPALE†, ANDREW D. RICHARDSON‡, ALMUT ARNETH§, ALAN BARR¶, PAUL STOY‖ and GEORG WOHLFAHRT**

- Derived light-response curves from half-hourly fluxes
- Fit data to rectangular hyperbolic curve
- Estimated parameters throughout the year to account for temporal variability

Morgan Monroe State Forest
1999-2005
89 light-response curves during July

Shown are 20 individual curves and the statistical composite (minimum, maximum, 1st quartile, 3rd quartile, median, mean)

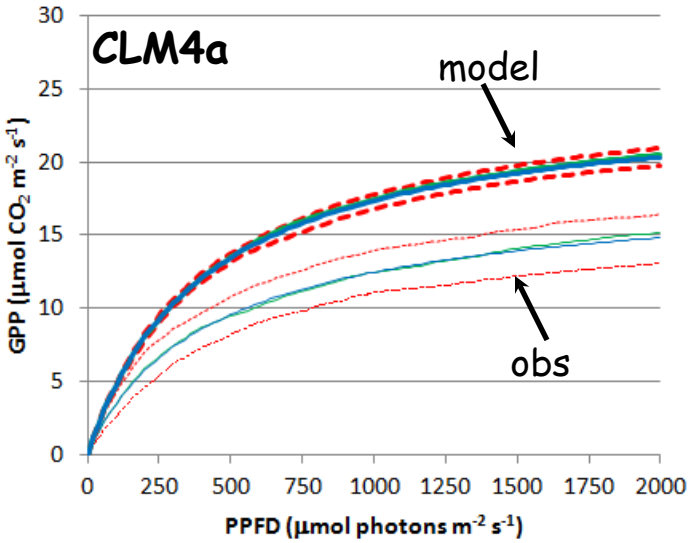
July canopy-scale light response curve

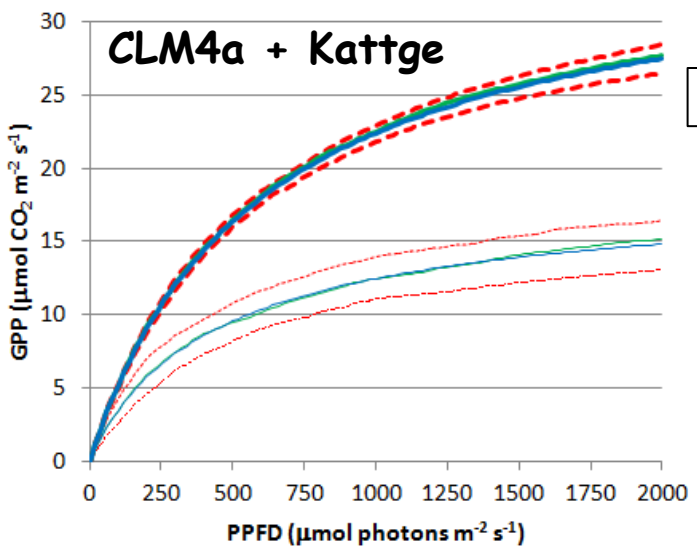


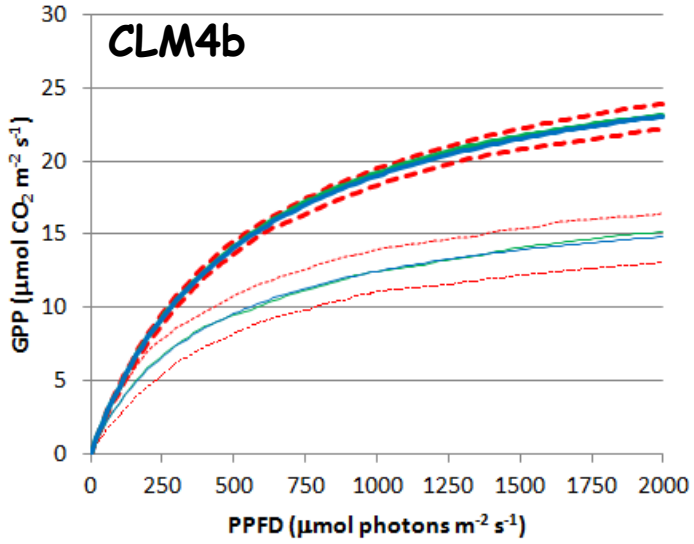
We used monthly light-response curves for 26 FLUXNET sites spanning boreal, temperate, and tropical climates and forest, grassland, and cropland vegetation

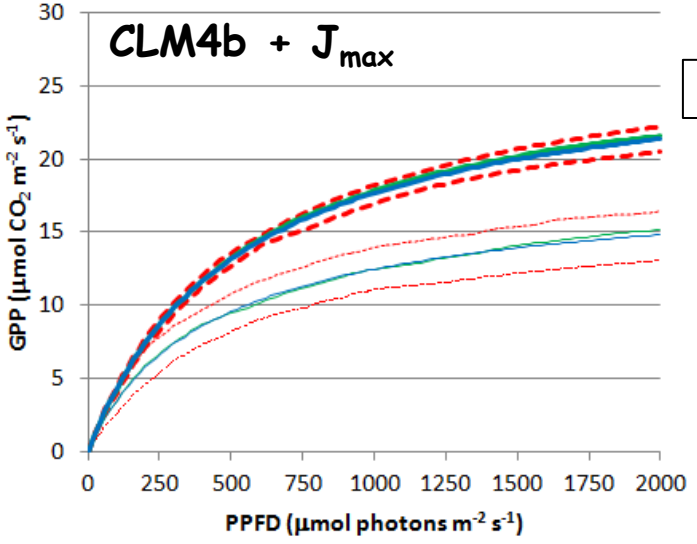
CA-Qfo: Boreal evergreen needleleaf forest

July





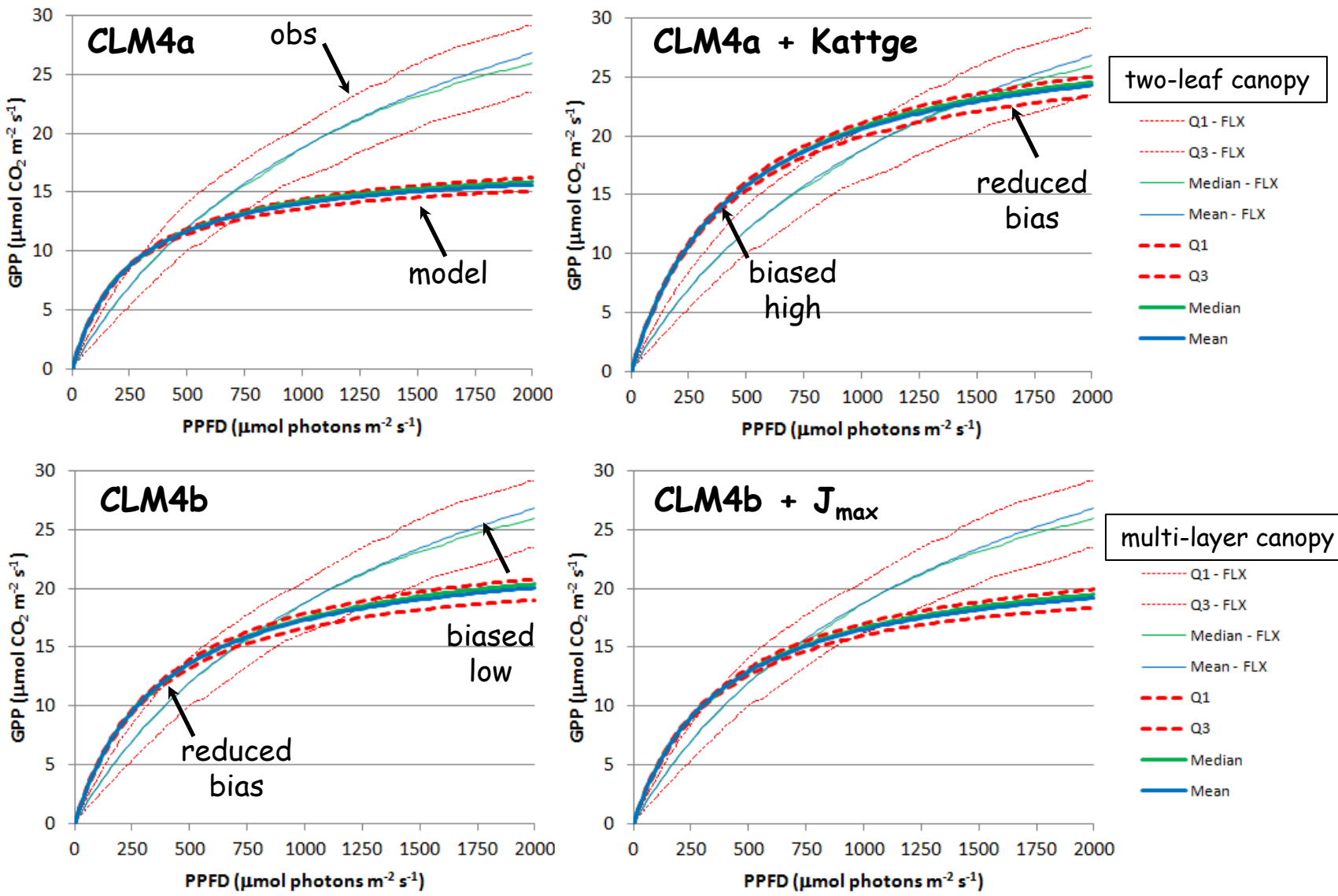




Multi-layer models are improved relative to CLM4a+Kattge

US-MMS: Humid subtropical deciduous broadleaf forest

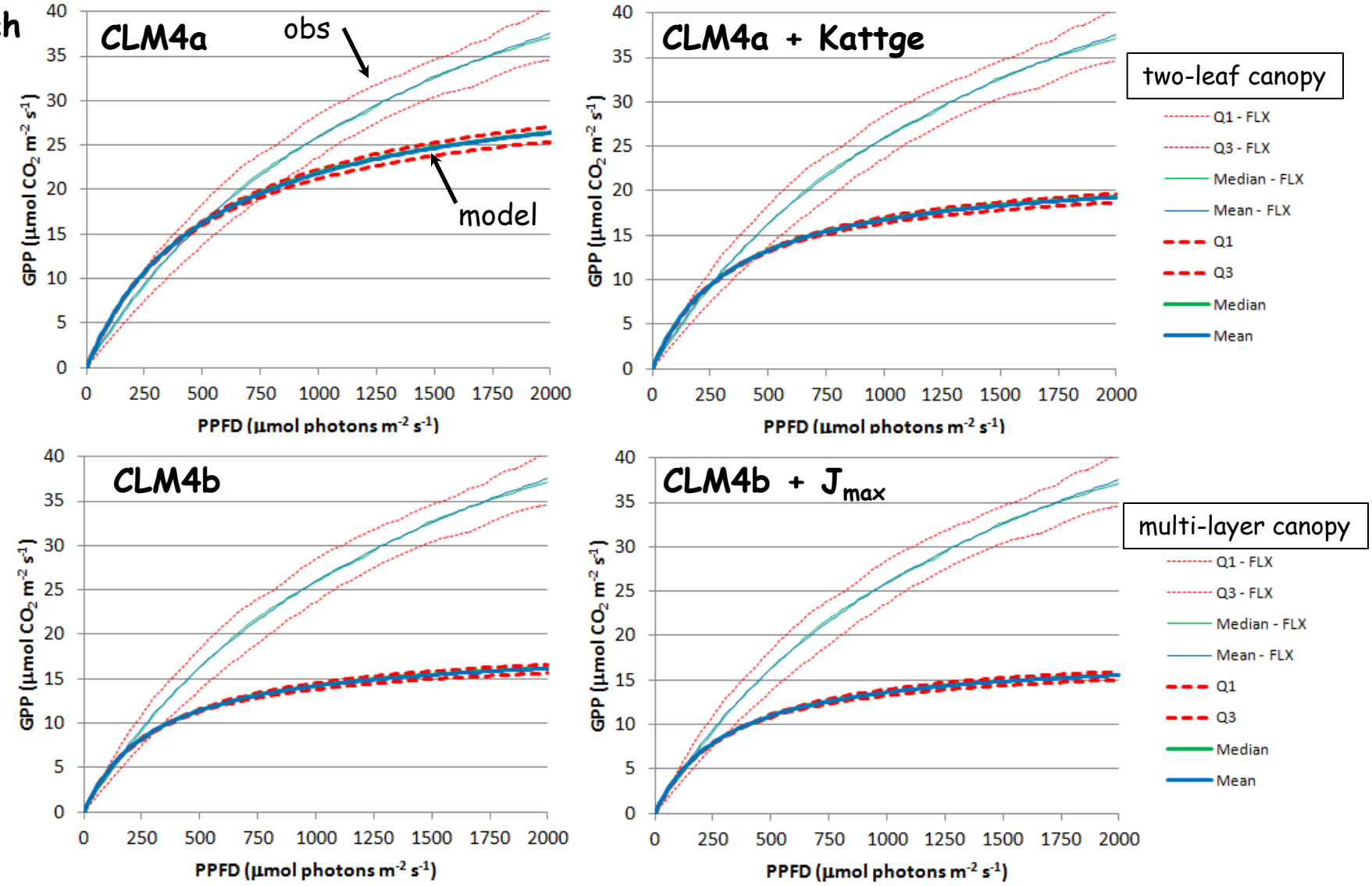
July



Multi-layer models are improved relative to CLM4a

BR-Ma2: Tropical evergreen broadleaf forest

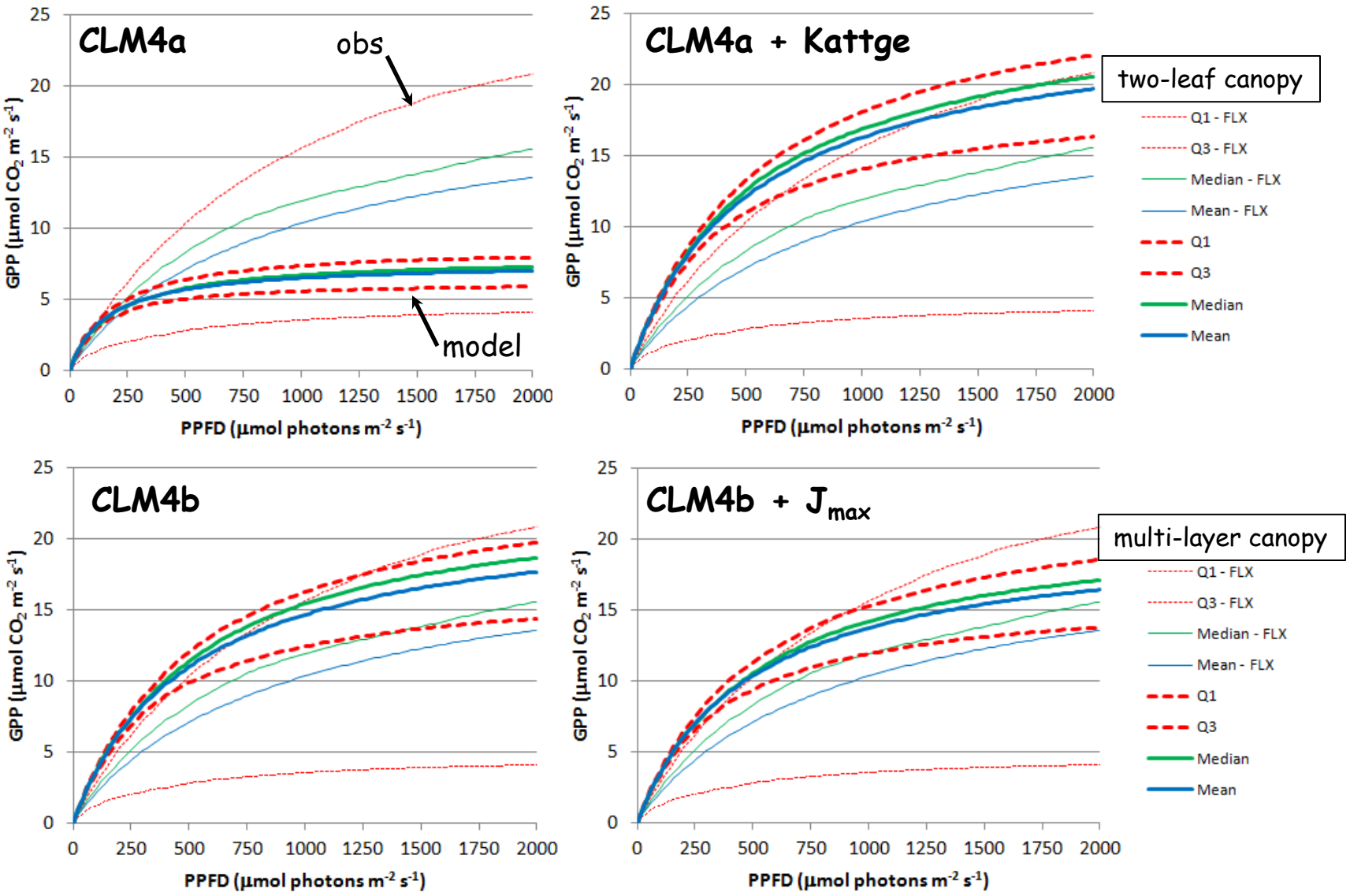
March



Kattge V_{cmax} greatly reduces GPP

CA-Let: Grassland

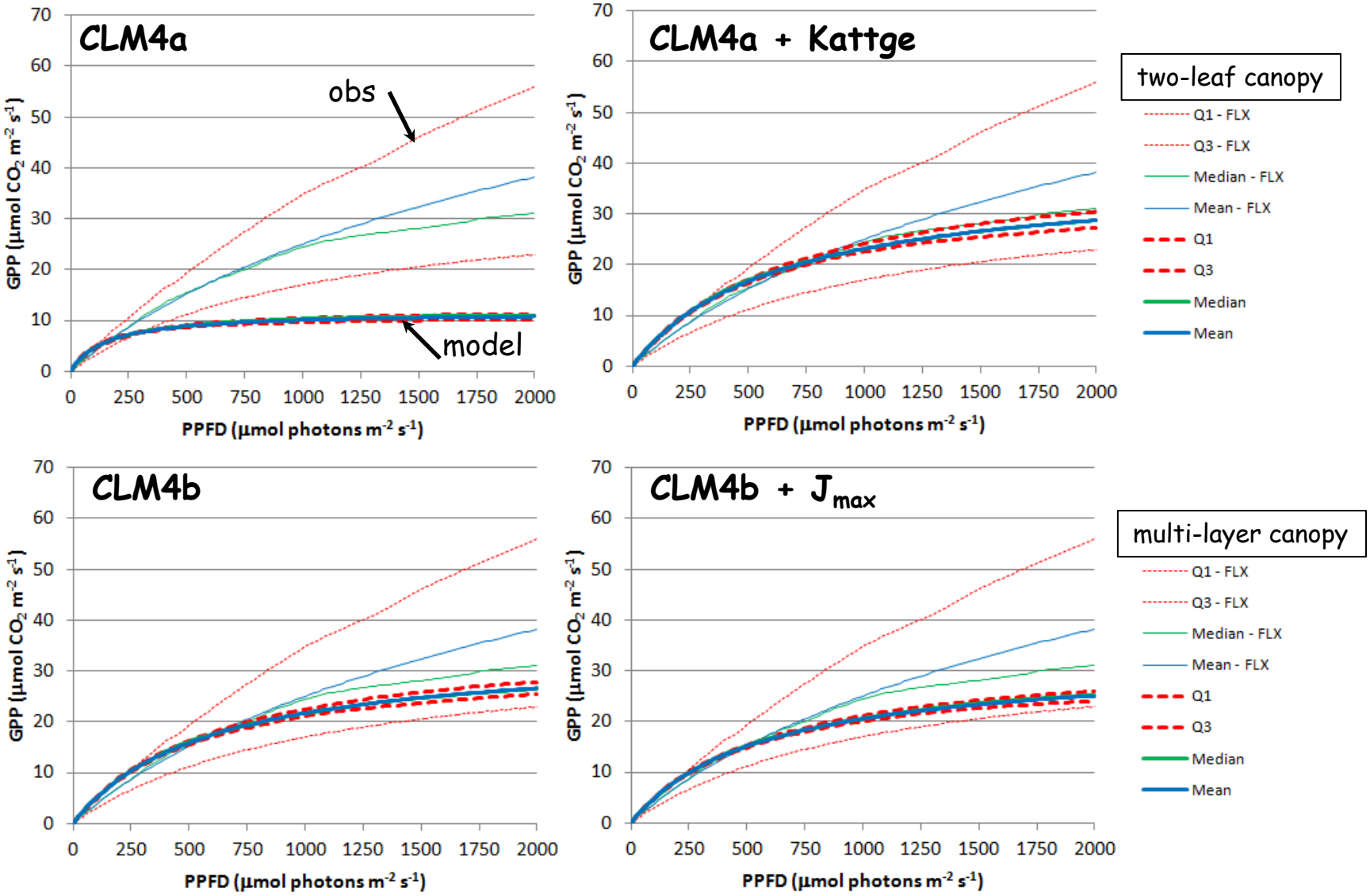
July



Multi-layer models are improved relative to CLM4a+Kattge

US-Ne3: Cropland

July



Kattge V_{cmax} greatly increases GPP

Conclusions

- CLM4 lowers GPP by reducing photosynthetic capacity, assuming limitation on nitrogen supply
- If we put in the observed photosynthetic capacity from a global leaf trait database, GPP is mostly far too high
- Correctly accounting for light and photosynthesis profiles in the canopy brings it down closer to the FLUXNET observations (gridded data, site-level light-response curves)
- 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