Reconciling leaf physiological traits and canopy-scale flux data: Use of the TRY and FLUXNET databases in the Community Land Model

Gordon Bonan, Keith Oleson, and Rosie Fisher
National Center for Atmospheric Research
Boulder, Colorado, USA

Gitta Lasslop and Markus Reichstein
Max-Planck Institute for Biogeochemistry
Jena, Germany

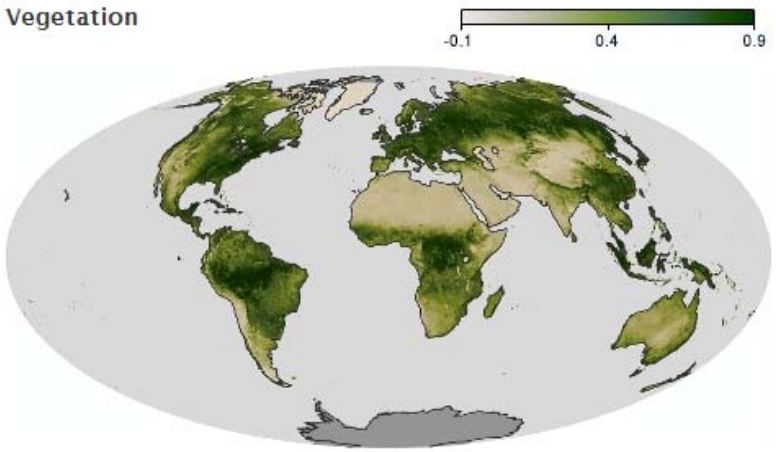
2011 AGU Fall Meeting
San Francisco, California
6 December 2011

NCAR is sponsored by the National Science Foundation

Multi-scale model evaluation

Canopy fluxes
GPP, latent heat flux

Lasslop et al. (2010) GCB 16:187-208



Global vegetation
GPP, latent heat flux

Jung et al. (2011) JGR, 116, doi:10.1029/2010JG001566

Canopy processes
Theory
Numerical parameterization

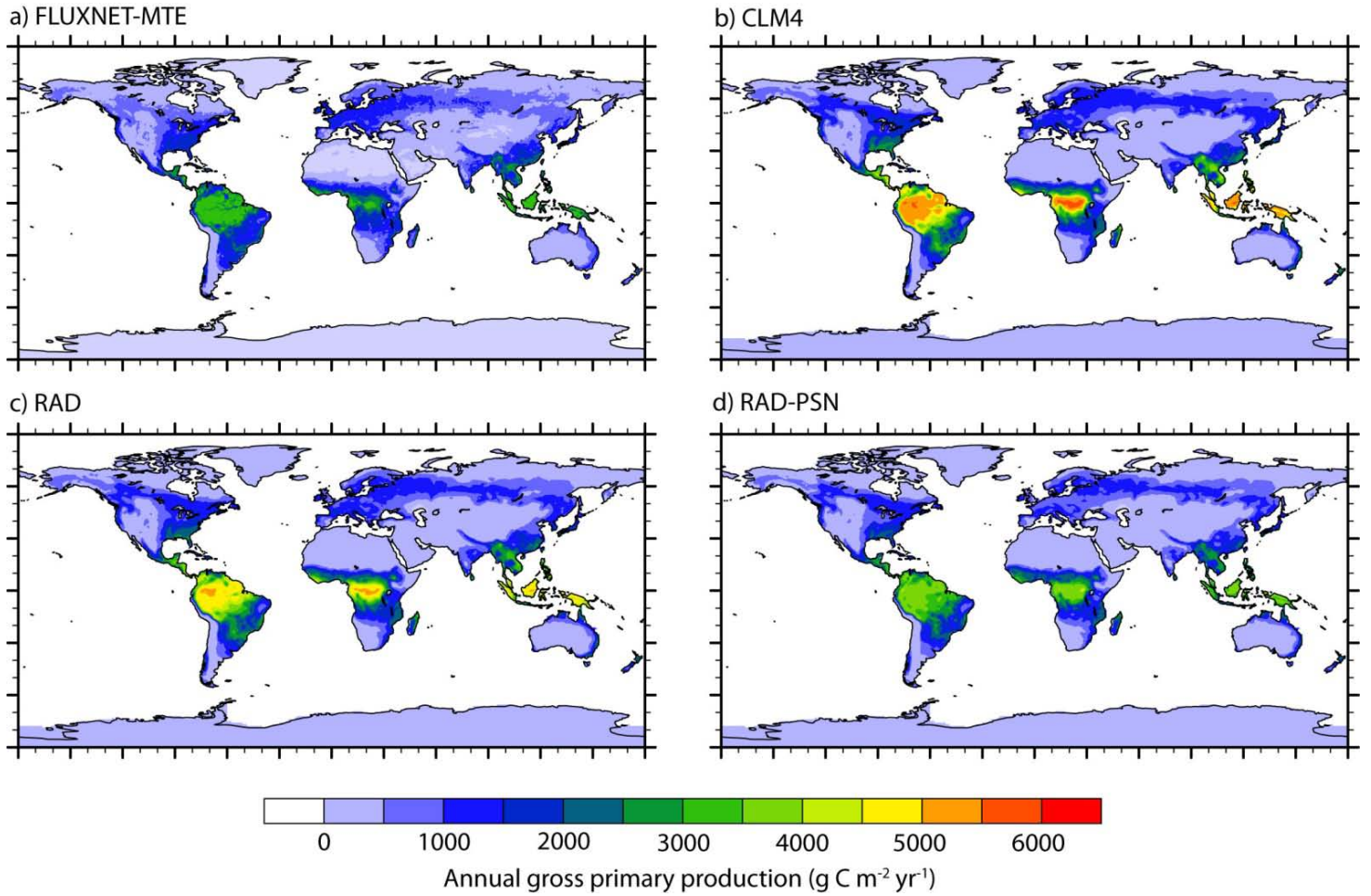
Profiles of light, leaf traits, and photosynthesis

Leaf traits
Nitrogen concentration, V_{cmax}

Kattge et al. (2009) GCB 15:976-991

Consistency among parameters, theory, and observations across scales (leaf, canopy, global)

Gross primary production bias



Control

Radiative transfer for sunlit and shaded canopy

Radiative transfer and photo-synthesis

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)

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 reduction of GPP (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

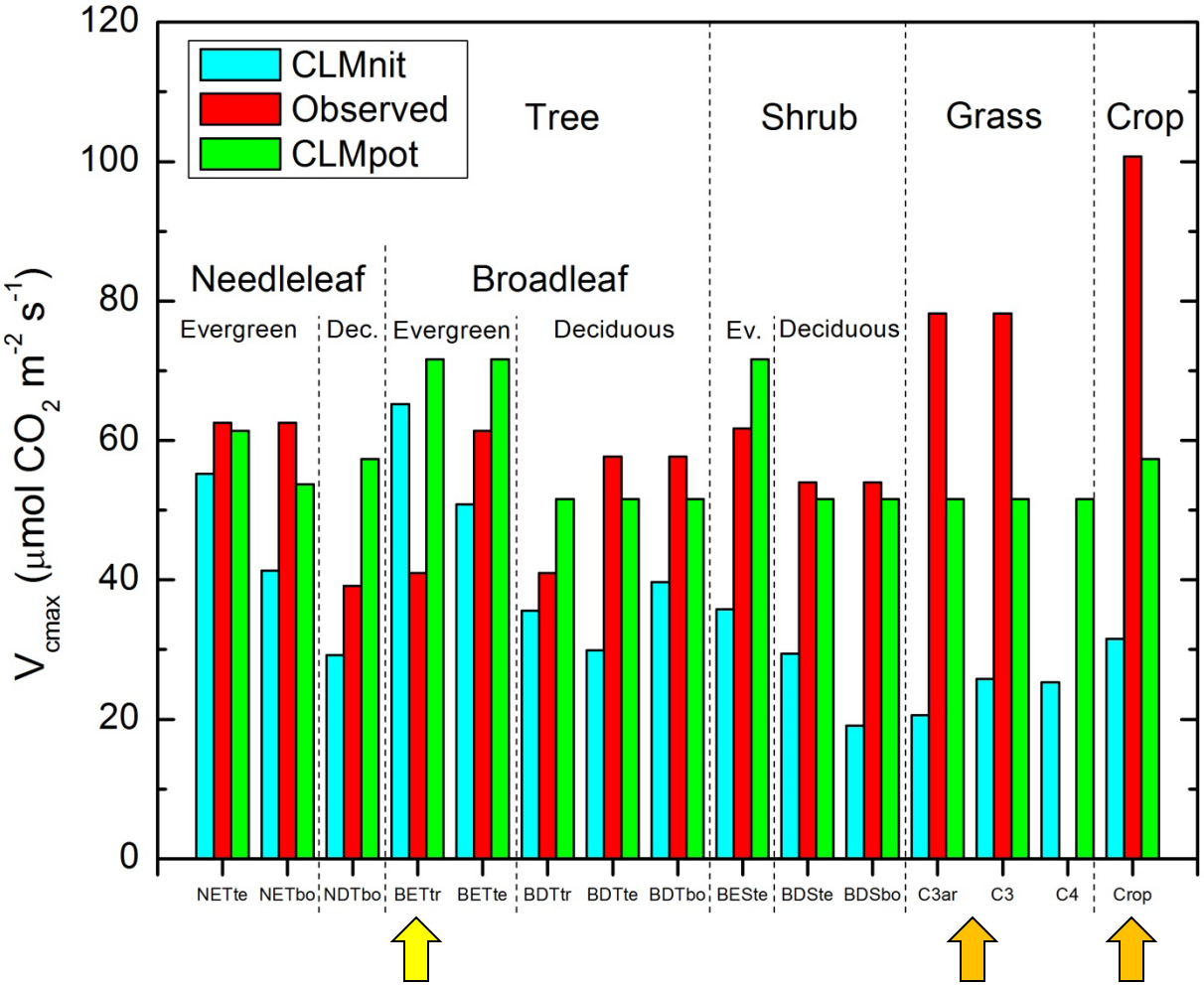
Quantifying photosynthetic capacity and its relationship to leaf nitrogen content for global-scale terrestrial biosphere models

JENS KATTGE*, WOLFGANG KNORR†, THOMAS RADDATZ‡ and CHRISTIAN WIRTH*
*Max-Planck-Institute for Biogeochemistry, Hans-Knöll Street 10, 07745 Jena, Germany, †QUEST, Department of Earth Sciences, University of Bristol, Wills Memorial Building, Queen's Road, BS8 1RJ, UK, ‡Max Planck Institute for Meteorology, Bundesstraße 53, 20146 Hamburg, Germany

- 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 CLM plant functional types



- CLM realized V_{cmax} after N down-regulation is less than Kattge observed V_{cmax}, except for tropical forest
- CLM potential V_{cmax} before N down-regulation is comparable to Kattge observed V_{cmax}, with some exceptions

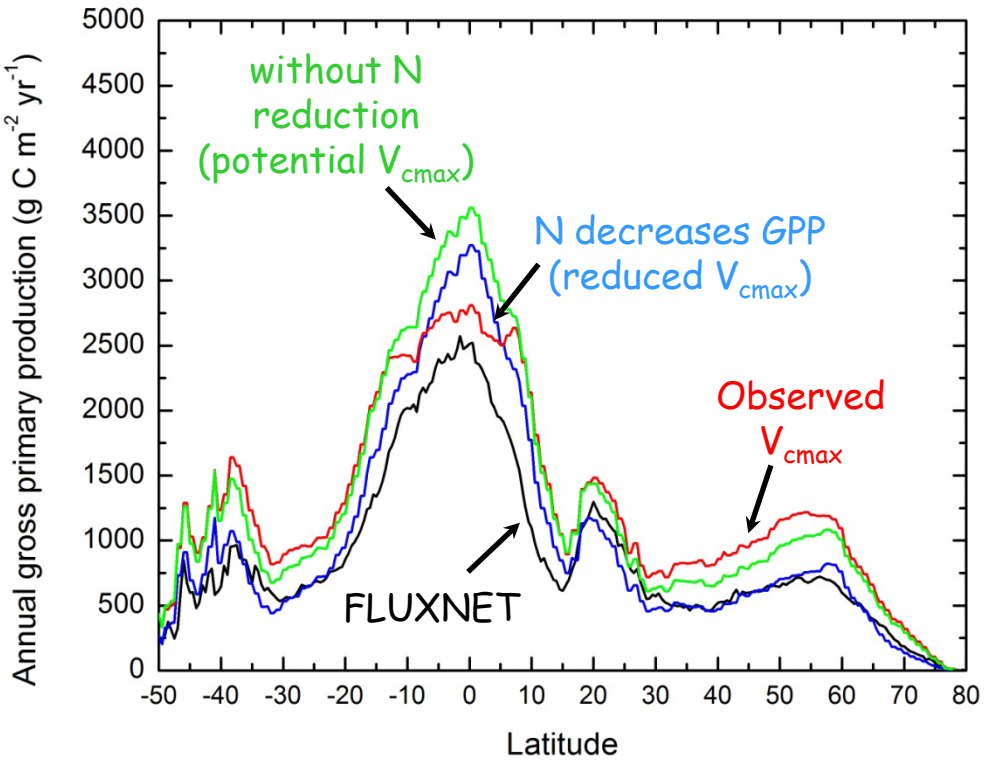
CLM requires low V_{cmax}

What happens when we use these V_{cmax} values?

Best simulation uses low V_{cmax}. When we remove the N down-regulation, the model is too productive

Kattge observed V_{cmax} increases 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

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

Canopy light absorption

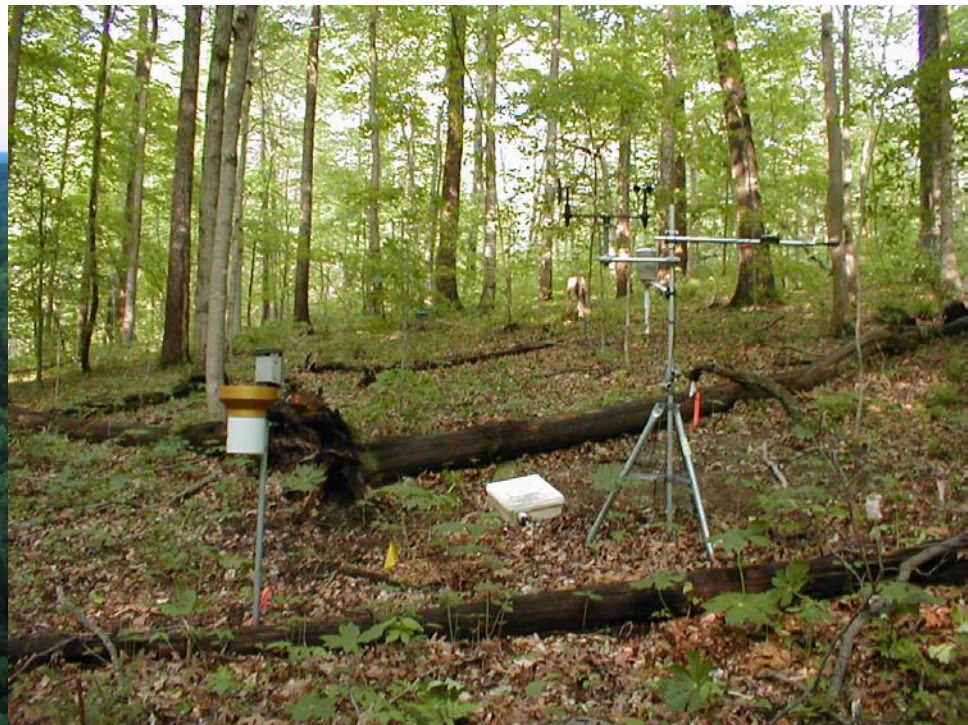
Hypothesis: CLM4 is too productive (high GPP) in the absence of N down-regulation because of deficiencies in the canopy parameterization. The CLM nitrogen down-regulation compensates for this deficiency

Model simulations

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

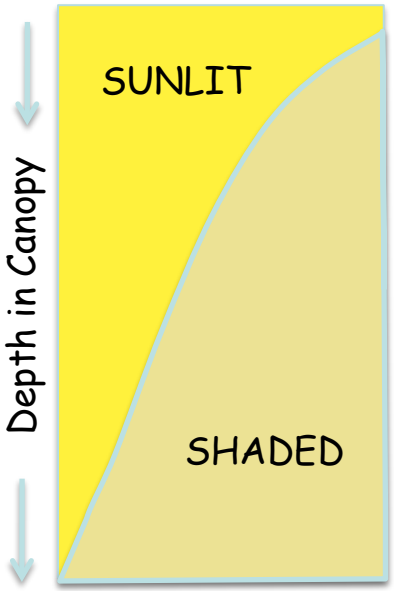
We investigate why CLM requires low V_{cmax} and why it performs poorly with the Kattge et al. (2009) values

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)



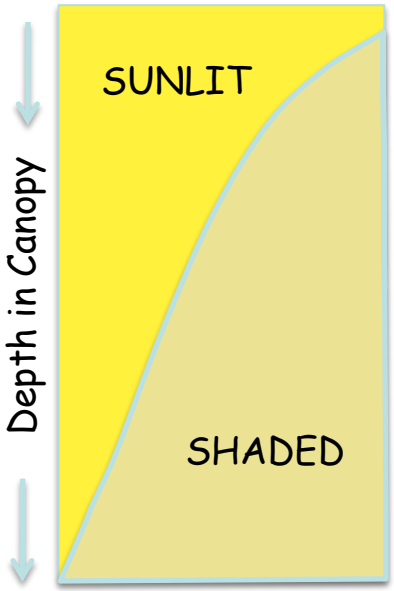
Multi-layer canopy

CLM4



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

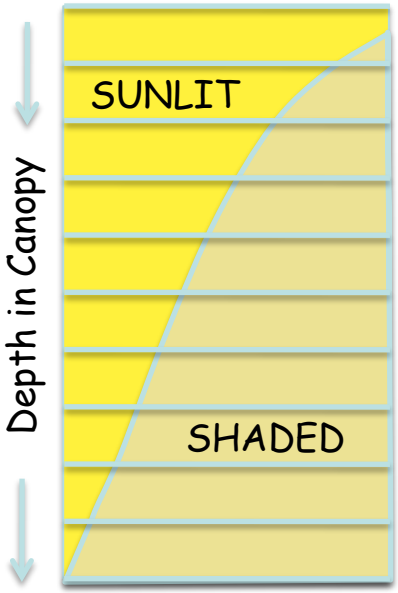
CLM4a



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

- Corrected radiative transfer for sunlit and shaded canopy
- Corrected A and g_s
- Nitrogen scales exponentially with K_n=0.11

CLM4b



CLM4a and multi-layer canopy

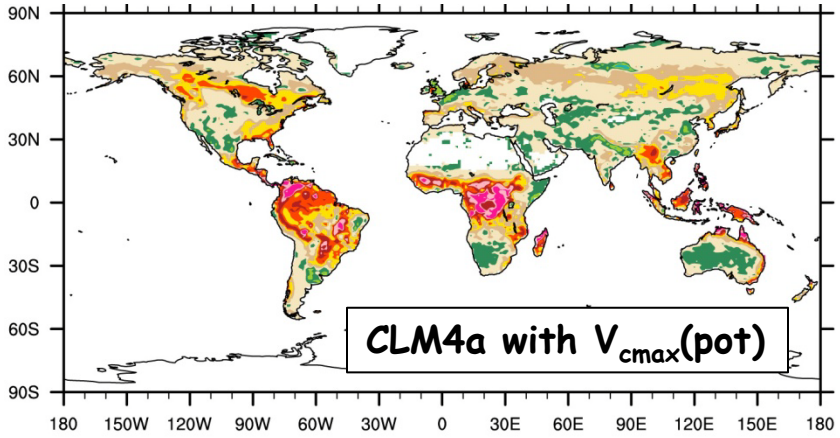
Multi-layer model

- 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)*

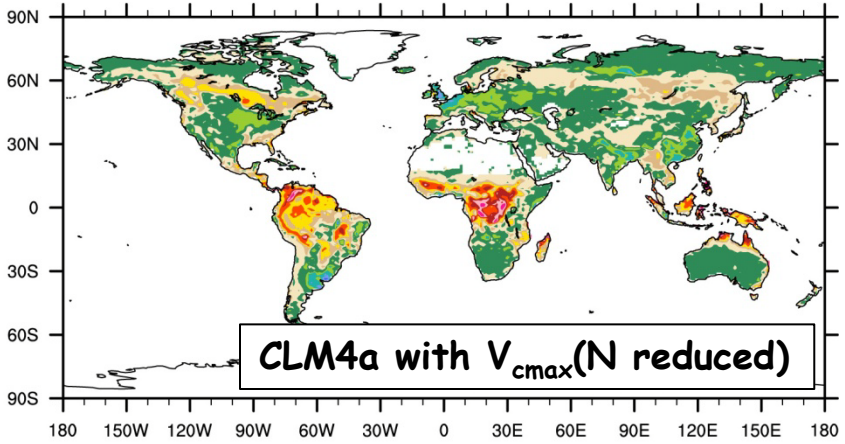
Two ways to get similar GPP

Nitrogen down-regulation

2Lpot

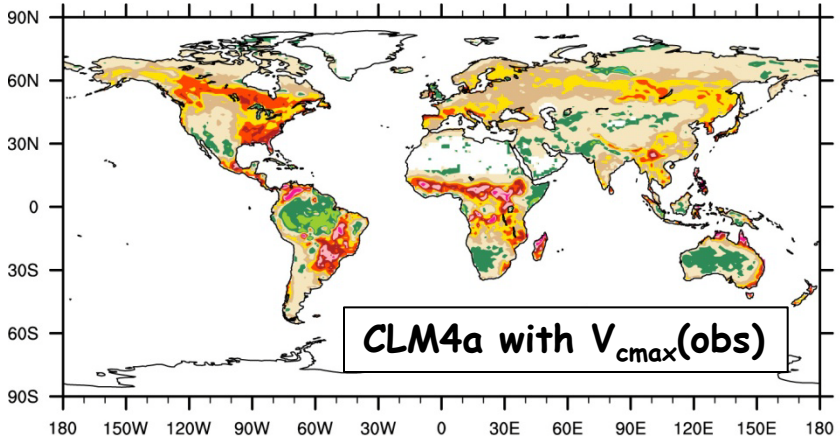


2Lnit

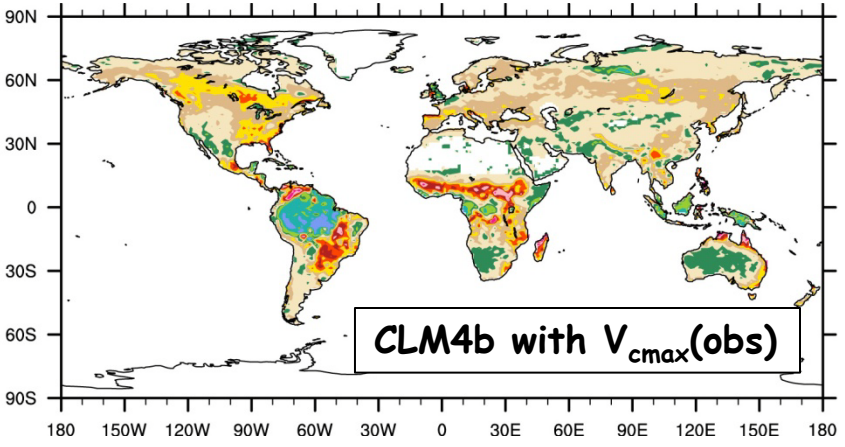


Light limitation

2Lobs

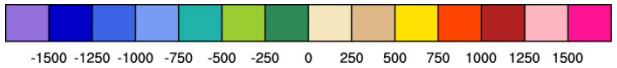


MLkn



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

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



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

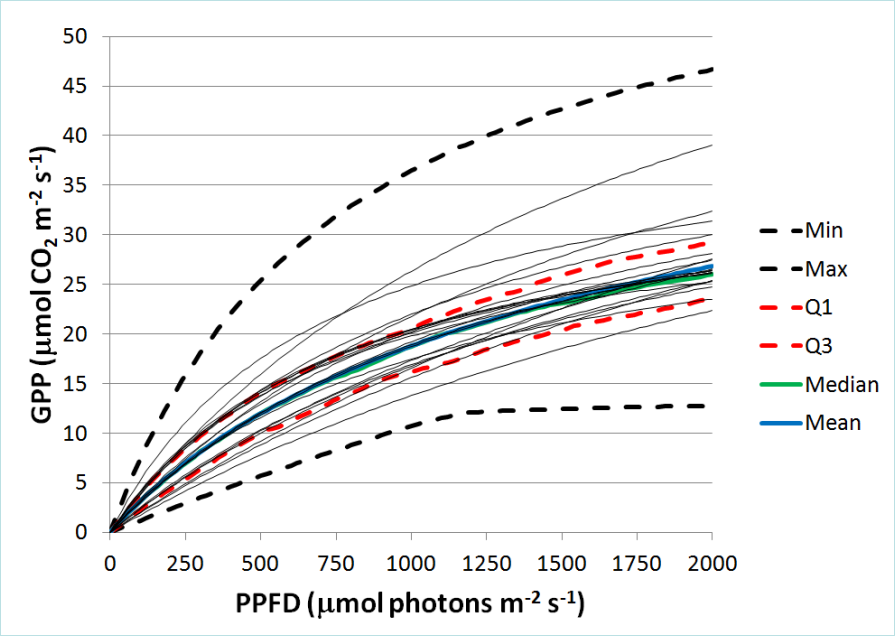
GITTA LASSLOP*, MARKUS REICHSTEIN*, DARIO PAPALE†, ANDREW D. RICHARDSON‡, ALMUT ARNETH§, ALAN BARR¶, PAUL STOY‖ and GEORG WOHLFAHRT**

- Derived light-response curves from half-hourly fluxes
- Fit data to rectangular hyperbolic curve
- Estimated parameters every two days 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

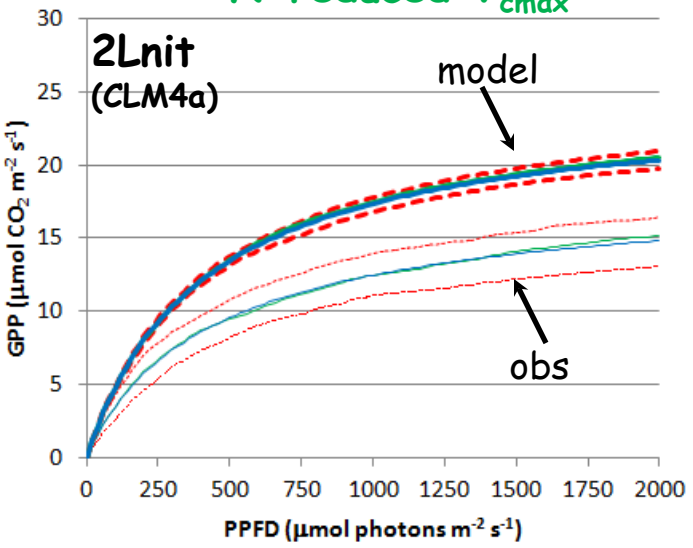


We used monthly light-response curves for 26 FLUXNET sites spanning boreal, temperate, and tropical climates and forest, grassland, and cropland vegetation

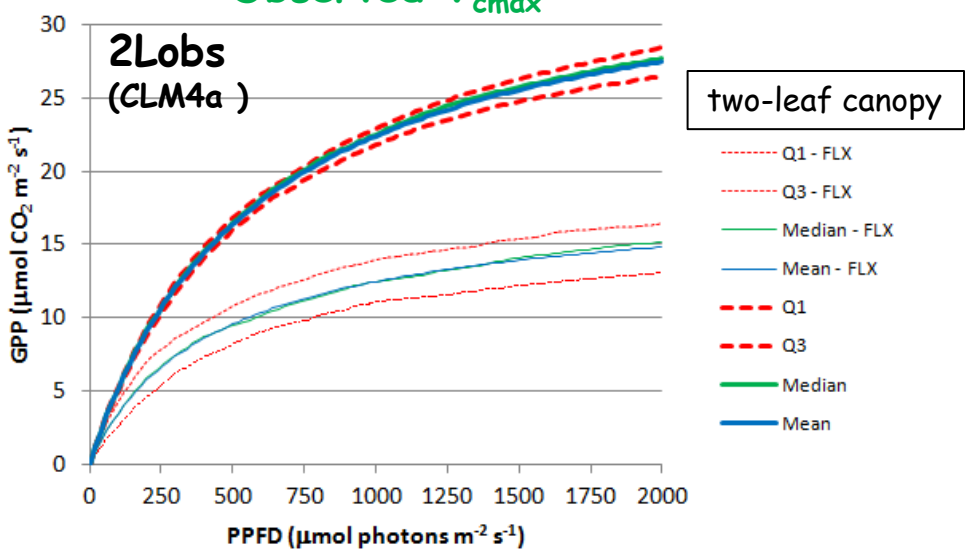
CA-Qfo: Boreal evergreen needleleaf forest

July

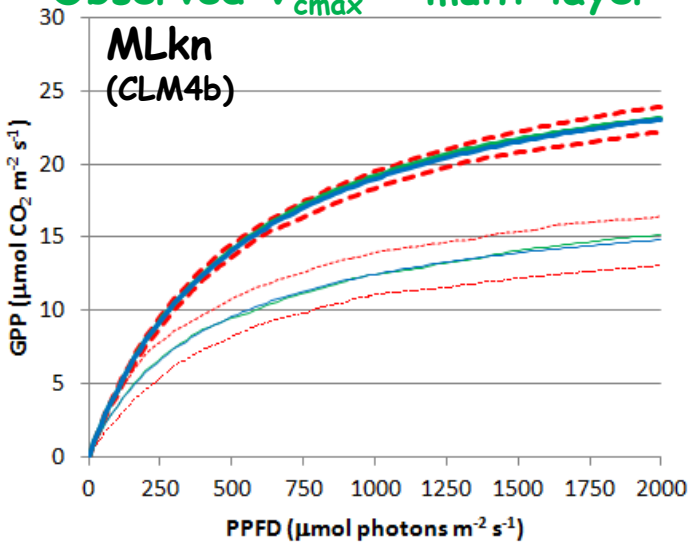
N-reduced V_{cmax}



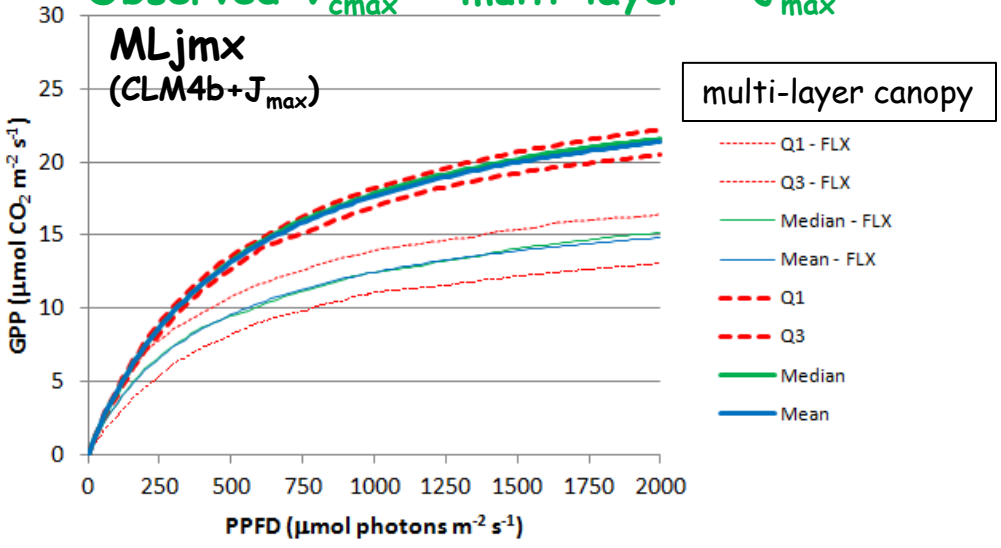
Observed V_{cmax}



Observed V_{cmax} + multi-layer

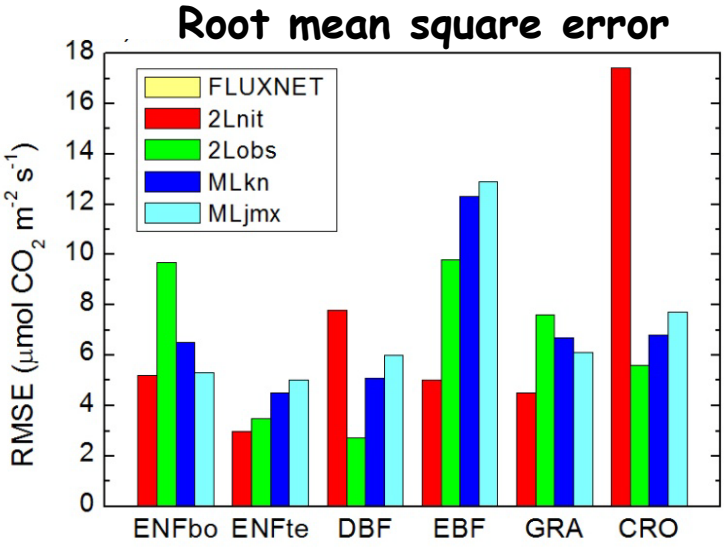


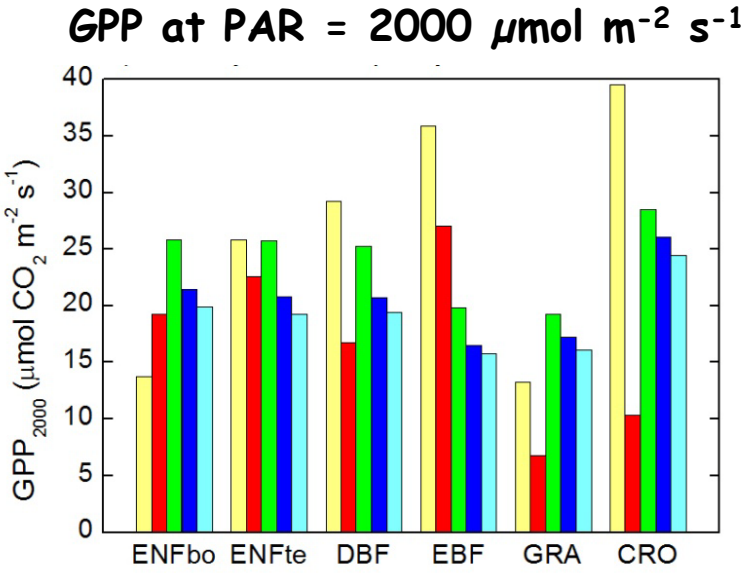
Observed V_{cmax} + multi-layer + J_{max}



Multi-layer models are improved relative to CLM4a & observed V_{cmax}

Light-response curves





ENF (boreal)
Multi-layer models (MLkn, MLjmx) are improved relative to CLM4a+Kattge (2Lobs)

Grassland (GRA)
Multi-layer models (MLkn, MLjmx) are improved relative to CLM4a+Kattge (2Lobs)

Cropland (CRO)
Kattge V_{cmax} (2Lobs) improves simulation. Multi-layer canopy (MLkn, MLjmx) has less effect

DBF
Kattge V_{cmax} (2Lobs) improves simulation. Multi-layer models (MLkn, MLjmx) are improved relative to CLM4a (2Lnit), but degraded relative to 2Lobs

ENF (temperate)
Small degradation with multi-layer canopy

EBF
Kattge V_{cmax} (2Lobs) greatly reduces 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 is more robust, but also seen in site-level light-response curves). Amazonia is an important exception.
- The multi-layer model is consistent across scales (leaf, canopy, global)
- It is not necessary to invoke additional N down-regulation beyond that represented in extant foliage N to get this right
- Much of the transient behavior of CLM is caused by N down-regulation. This new model will have different behavior