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

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1. Introduction

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)
1. Introduction

**Gross primary production bias**

**Radiative transfer for sunlit and shaded canopy**

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)

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.

- 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.


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

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CLM photosynthetic capacity

2. The problem

- 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.
What happens when we use these $V_{c_{\text{max}}}$ values?

Best simulation uses low $V_{c_{\text{max}}}$. When we remove the N down-regulation, the model is too productive.

Kattge observed $V_{c_{\text{max}}}$ increases GPP except in the tropics, which declines because of lower $V_{c_{\text{max}}}$.

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

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

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 $V_{\text{cmax}}$

We investigate why CLM requires low $V_{\text{cmax}}$ 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)
3. A solution

Multi-layer model

- Two-stream approximation 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)

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

- Corrected radiative transfer for sunlit and shaded canopy
- Corrected \( A \) and \( g_s \)
- Nitrogen scales exponentially with \( K_n = 0.11 \)
3. A solution

Two ways to get similar GPP

- **Nitrogen down-regulation**
  - 2Lpot
  - CLM4a with $V_{cmax}(pot)$
  - 2Lnit
  - CLM4a with $V_{cmax}(N \text{ reduced})$

- **Light limitation**
  - 2Lobs
  - CLM4a with $V_{cmax}(obs)$
  - MLkn
  - CLM4b with $V_{cmax}(obs)$

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

Model - FLUXNET GPP (g C m$^{-2}$ yr$^{-1}$)
4. Is the new model right?

FLUXNET light-response curves

- 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)

We used monthly light-response curves for 26 FLUXNET sites spanning boreal, temperate, and tropical climates and forest, grassland, and cropland vegetation.
4. Is the new model right?

Multi-layer models are improved relative to CLM4a & observed $V_{cmax}$
4. Is the new model right?

**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 $V_{c_{max}}$ (2Lobs) improves simulation. Multi-layer canopy (MLkn, MLjmx) has less effect

**DBF**
Kattge $V_{c_{max}}$ (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 $V_{c_{max}}$ (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.