IMPROVING REPRESENTATION OF NITROGEN UPTAKE, ALLOCATION AND CARBON ASSIMILATION IN THE COMMUNITY LAND MODEL

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Improvements of Plant Nitrogen Cycle Processes

- Nitrogen allocation
  - Plant organs (root, stem, leaf)
  - Functions (photosynthesis, respiration, structure)

- Carbon assimilation
  - 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

![Graph showing predictions of historical carbon sinks with different CLM models compared to Fluxnet observations. The x-axis represents latitude, and the y-axis represents GPP (gC m^-2 y^-1). Different CLM models are indicated by different colors, with CLM4.0CN in black, CLM4.5CN in green, and CLM4.5BGC in red. Fluxnet observations are shown in blue. The graph highlights the variation in GPP across different latitudes and compares the predictions of the models to the observational data.]
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**

\[ A_g = \min (W_c, W_j, W_p) \]

- **Rubisco limited carboxylation**

\[ W_c = \frac{\max (C_i - C_p, 0)}{(C_i + K_{ct})(1 + \frac{O_2}{K_{ot}})} V_{cmax} \]

- **Electron transfer limited carboxylation**

\[ W_j = \frac{\max (C_i - C_p, 0)}{(4C_i + 8C_p)} J \]

- **End product utilization**

\[ W_p = 0.5V_{cmax} \]  
(Farquhar et al. 1980, Planta)
Calculation of $V_{cmax}$ in CLM

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

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

$a_{r25}$ = specific activity of Rubisco at 25°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\textsubscript{i} curve

\begin{align*}
\text{CO}_2 \text{ Assimilation Rate (A)} & \quad \text{\quad Internal CO}_2 \text{ Concentration (c}_i\text{)} \\
\end{align*}

- \( J_{\text{max}} \)
- \( V_{c,\text{max}} \)
- TPU
CLM GPP downregulation

- Downregulation of potential GPP based on nitrogen availability
- Potential Vcmax used to calculate potential GPP
- Problems with potential Vcmax
  - Hard to define what we mean by potential Vcmax
  - Inconsistent with field observations of actual Vcmax
  - Difficult to select a function type for performing downregulation
Modifications to CLM4.5

- Removal of GPP downregulation
  - Prognostic leaf nitrogen
  - Dynamic $V_{c\text{max}}$ 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
Two methods to remove GPP downregulation

- **Method 1:**
  - Flexible C:N ratio for storage pools for all plant parts
  - Fixed C:N ratio for growth pools for all plant parts

- **Method 2:**
  - Flexible leaf C:N ratio for both storage and growth/display pools
  - Fixed C:N ratio for both storage and growth/display pools for all other plant parts
Photosynthetic parameters increase with increase in leaf nitrogen at global scale based on TRY data.

\[ y = 14.9x + 32.1 \]

\[ y = 40.0x + 56.3 \]
Fraction N allocated to Rubisco decreases with leaf N at global scale.

- **a. tropical trees**: $y = 0.18 \exp(-0.38x)$
- **b. non-tropical trees**: $y = 0.24 \exp(-0.22x)$
- **c. shrubs**: $y = -0.01x + 0.20$
- **d. herbaceous**: $y = -0.03x + 0.28$
Nitrogen Use Efficiency varies by PFT

(Kattge et al. 2009, GCB)
CLM new has better fit to the Beer et al. data than CLM 4.5.
CLM new has better fit to the Beer et al. data compared to CLM4.5, especially in mid- and late-growing seasons.
Calculation of Leaf Nitrogen Allocation

- Global Plant Traits Database (TRY)
- Allocation to different processes
  - Photosynthesis
    - Carboxylation
    - Electron transfer
    - Light capture
  - Respiration
    - Maintenance
    - Growth
  - Structure
  - Residual

\[
\text{Nitrogen Allocation} = \frac{\text{Process Rate}}{\text{Nitrogen use efficiency}}
\]

Nitrogen use efficiency = (enzyme activity) (nitrogen fraction of enzyme)
Global patterns of leaf nitrogen allocation by PFT
Optimal Leaf Nitrogen Allocation

- CLM has fixed nitrogen allocation for Rubisco
- Optimal leaf photosynthetic nitrogen allocation relies on dynamic allocation for enzymes which varies with environmental conditions
- Optimality framework
  - Maximizes nitrogen-use efficiency given environmental conditions [Niinemets and Tenhunen 1997; Xu et al. 2012]
Optimal Leaf Nitrogen Allocation
Model Evaluation: Barrow Alaska

Optimization based on mean environmental conditions at the site

Vcmax predicted by the optimal allocation model has reasonable fit with observed Vcmax (see figure b).
Summary

- **Current Model Developments**
  - Integration of different plant N cycle mechanisms in the Community Land Model
  - Model structure uses actual photosynthetic parameters rather than potential rates

- **Additional Model Developments**
  - Dynamic C and N allocation based on resource availability
  - Carbon costs of nutrient acquisition
  - Belowground N competition between plants and microbes

- **Scientific Contribution**
  - Prognostic leaf nitrogen dynamically linked to carbon assimilation
  - Leaf nitrogen allocation to processes using optimality theory
  - New understanding of N effects on plant productivity and growth
    - Nitrogen deposition
    - Permafrost thawing
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