CLM-CN Update: Progress toward CLM4.0

Peter Thornton, Sam Levis and the C-LAMP team
Distinguishing characteristics of CLM-CN

- **Flexible, nested sub-grid hierarchy**

  - **Landunits:** Geomorphologically distinct. Intended for special cover types (glacier, lake, etc.), heterogeneity in soil texture and depth, and for downscaling.

  - **Columns:** Snow and soil state variables. Necessary for representing disturbance history and age class distribution.

  - **Plant functional types:** Vegetation state variables. Either independent or competing for column-level resources.

- Allows competition among PFTs, facilitated urban and crop models
Distinguishing characteristics of CLM-CN

- Two-leaf canopy with vertical gradient in leaf thickness

- Explicitly links canopy structure and function, corrects biases from CLM3, and allows prognostic leaf growth from nascent LAI
Distinguishing characteristics of CLM-CN

- Litter and soil model captures trophic structure of decomposer community

- Converging-cascade design supported by $^{14}$C decomposition experiments
- Plant-microbe competition for N supported by $^{15}$N labeling experiments
Distinguishing characteristics of CLM-CN

- Robust spin-up algorithm: accelerated decomposition

- ~5x acceleration to steady-state, good performance across climates and vegetation types
Distinguishing characteristics of CLM-CN

• C-N feedback couples autotrophic and heterotrophic dynamics

• Nexus for influence of $[\text{CO}_2]_{\text{atm}}$, N deposition, disturbance and climate change
Distinguishing characteristics of CLM-CN

- C-N feedbacks affect coupled climate

Nitrogen cycle influence on atm CO₂

- N influencing:
  - CO₂ fertilization of land biosphere
  - Land climate-carbon feedback
  - Both fertilization and climate
  - No influence of N

Range of uncertainty: We don’t know how these C-N interactions will be expressed over time

- Dynamics not adequately constrained by existing experimental evidence
Distinguishing characteristics of CLM-CN

- Represents natural and anthropogenic disturbances

- Additional development efforts still underway: age-class distributions, age-related mortality, anthropogenic fire, rotation wood harvest
Progress on C-LAMP recommendations

• All 5 major recommendations have been addressed to some extent
  – Modifications to CN algorithms
  – Modifications to CLM hydrology
• Many improvements, but…
• Still more to do:
  – Standardize the transport analysis to evaluate seasonal cycle
  – Improve site-level model-data comparisons
Science recommendations (1)

- Model estimates of the growing season net flux are too small by factor of 2-3, based on both Ameriflux NEE and Globalview CO$_2$ observations

- Proposed changes:
  - 1. Revise the prognostic leaf area routine in the models. Peak LAI should shift from August in boreal ecosystems to July.
  - 2. Revisit low temperature controls on GPP. Ameriflux observations show the models have too much GPP during the dormant season in temperate ecosystems.
  - 3. Reduce the temperature sensitivity of respiration (e.g. the Q10 factor). There is no reason to expect a priori a specific value for the time step and spatial scale of the models.
  - Probably all three are needed.

- Consequences:
  - These changes will have important consequences for climate-carbon feedbacks. Reducing the temperature sensitivity of respiration will decrease the magnitude of carbon release with climate warming. Its less clear how changing LAI and GPP will influence feedbacks.
  - Other C4MIP models probably have the same deficiency
LAI Phase: CLM-CN compared to MODIS

3.1 Modification of CLM-CN phenology parameter (fcur)

3.5/3.6
LAI: CLM-CN compared to obs

3.1  →  3.5  →  3.6

Obs
NPP: CLM-CN compared to obs

3.1  3.5  3.6

Model NPP (gC/m²/y)  Obs NPP (gC/m²/y)  NPP bias (model – MODIS)

NPP: CLM-CN compared to obs
Science recommendations (2)

- Model estimates of Amazon aboveground live biomass are high by a factor of 2-3 as compared with measurements from Saatchi et al. [2007]

- **Proposed changes:**
  - 1. Reduce model GPP in the tropics by ~20%
  - 2. Develop a mechanistic autotrophic respiration and allocation subroutine for CASA. Observations suggest autotrophic respiration is close to 2/3 of GPP in tropical ecosystems
  - 3. Revisit allocation scheme of NPP for CN. Increase allocation to leaves. Current tropical leaf NPP is 125 gC/m²/yr. Observed leaf NPP is ~460 gC/m²/yr.
  - Wood turnover times look reasonable compared with observations (~40 years).

- **Consequences:**
  - Getting this pool right is crucial for getting the models to capture land use change effects on climate via the biogeochemistry
Amazon biomass: CLM-CN compared to obs

3.1

Obs: 69 PgC

153 PgC

101 PgC

(bias)
Science recommendations (3)

• Model estimates of sensible heat are too low during winter and spring in many boreal and temperate forest ecosystems

• Proposed changes:
  - 1. Additional changes in CLM hydrology are probably needed
  - 2. Future changes in CLM hydrology must be evaluated against all aspects of the surface energy budget from Ameriflux and Fluxnet. This includes $R_n$ and the seasonal cycle of sensible heat.
  - May be partly resolved with site-level evaluations.

• Consequences:
  - Surface energy exchange is important for simulating land cover change effects on regional climate
Harvard Forest – main tower (MA)

LH, SH, GPP, NEE
Science recommendations (4)*

• Litter turnover times are too fast in CN

• Proposed changes:
  - 1. Perform an optimization against leaf litter decomposition observations for both CN and CASA
    • These are available from Yiqi Luo
  - 2. Separate leaf and root litter pools in CN to enable more direct comparisons with observations
  - 3. Allow for direct CO$_2$ loss from coarse woody debris pool - tropical observations support this flux

• Consequences
  - More rapid cycling of carbon in CN is the primary reason for smaller present-day sink estimates than CASA. Not the sensitivity of NPP to global change.

* Conclusion depends on observational constraints of litter-bag studies: CN litter decomposition is consistent with $^{14}$C labeling studies.
Litter turnover time:
CLM-CN modification results in slower litter turnover

<table>
<thead>
<tr>
<th>Biome Class</th>
<th>Litter Flux (gC/m²/year)</th>
<th>Litter Pool (gC/m²)</th>
<th>Litter Turnover Time (year)</th>
<th>Litter Turnover Time (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Vegetated</td>
<td>8.8</td>
<td>4.9</td>
<td>0.55</td>
<td>0.84</td>
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<tr>
<td>Needleleaf Evergreen Temperate Tree</td>
<td>360.1</td>
<td>92.5</td>
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<td>0.35</td>
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<td>Needleleaf Evergreen Boreal Tree</td>
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<td>164.1</td>
<td>0.75</td>
<td>1.18</td>
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<tr>
<td>Broadleaf Evergreen Tropical Tree</td>
<td>813.2</td>
<td>99.5</td>
<td>0.12</td>
<td>0.11</td>
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<tr>
<td>Broadleaf Evergreen Temperate Tree</td>
<td>414.3</td>
<td>109.6</td>
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<td>0.31</td>
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<tr>
<td>Broadleaf Deciduous Tropical Tree</td>
<td>622.1</td>
<td>135.7</td>
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<td>31.7</td>
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<tr>
<td>C3 Arctic Grass</td>
<td>94.1</td>
<td>95.7</td>
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<td>C3 Non-Arctic Grass</td>
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<tr>
<td>C4 Grass</td>
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<tr>
<td>Corn</td>
<td>383.6</td>
<td>148.8</td>
<td>0.39</td>
<td>0.54</td>
</tr>
<tr>
<td>All Biome</td>
<td>-</td>
<td>-</td>
<td>0.35</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Science recommendations (5)

• Transient dynamics of models need better testing. Models do not capture variability in contemporary fire emissions

• Proposed changes:
  - 1. Adjustment of the fire emissions model in CN so it integrates land use and climate drivers (underway)
  - 2. Develop a fire emissions model for CASA
  - 3. Future comparison with Carbontracker and Transcom for interannual variability (underway)

• Consequences
  - Aerosol forcing of climate likely to be underestimated in future model simulations
Fire distribution: CLM-CN compared to obs

- Shifted soil moisture (proxy for fuel moisture) (top 50 cm to top 5 cm)
- Fixed unit error in critical fuel load threshold value (200 to 100 gC/m²)
Amazon biomass: CLM-CN compared to obs

3.1 (3.5) 3.6

Obs: 2.31 PgC/yr

0.68 PgC/yr

0.98 PgC/yr

Fire : All Biome

Fire : Needleleaf Evergreen Boreal Tree
Recent developments: coupling CN to DGVM and crop model

DGVM runs in natural (primary) vegetation landunit

C-N biogeochemistry for all modules

Prognostic land use

Managed grassland (pasture) module?

Managed forest module?

Crop model runs in managed landunit

(wood harvesting)

The goal...
CNDV: Dynamic Vegetation & CLM-CN

**Year 1:**
Bioclimatology accumulators

End of year 1:
Establishment

\[ f_1^{\text{bare}} = 1.0 \]

**Year 2+:**
Bioclimatology accumulators
Biogeochemistry
Photosynth., respir., growth, mortality

End of year 2+:
Establishment
Competition for Light (space)

Levis et al.
(Shrub model from Zeng et al., in press)
250-year CNDV simulation: CLM3.5 driven with Qian et al. (2006) weather
Prognostic Crop Life-Cycles in the CLM

AgroIBIS (Kucharik & Brye, 2003)
Corn, wheat, & soybean life cycles:

GDD accumulators ➞  
Planting, leaf emergence, grain fill, maturity, harvest

C allocation & N limitation ➞  
Leaf area and height

Realistic irrigation (Sacks et al.)
25-year CN-crop simulation
CLM3.5 driven with Qian et al. (2006) weather

CORN LAI in Arlington, WI (43°N 89°W)

CN-crop

Notes for the comparison:

N not limiting to plant growth given land mgmt in Mead

Leaf emgnce ~end of May w/ presc. planting May 13th
Peak ~5.5 ~Jul 15th; ~flat ~1 month; harv. ~Sep 1st
Obs peak ~4.25

2002 presc. planting May 20th
Peak ~3 ~Aug 1st; ~flat ~4 weeks ; harv. by mid-Sep
Obs peak ~same

2004 presc. planting Jun 3rd
Peak ~4.5 ~Aug 15th; ~flat ~2 weeks; harv. by mid-Sep
Obs peak ~same

AgroIBIS

Kucharik & Twine (2007)
CLM-CN stress deciduous phenology

CN-crop phenology