Progress Toward a Mechanistic Belowground N Cycle in CLM

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Belowground N Cycle

fungi

gas exchange
wet deposition

heterotrophs

N fixation

Leaf litter
Root litter

sorption

NO, N₂O, N₂

Denitrification
Nitrification

NO₃
NH₄

CO₂

SOM Pool 2
SOM Pool 1

Vertical Mixing & Transport:

\[
\frac{\partial C}{\partial t} = \frac{\partial}{\partial z} \left( D \frac{\partial C}{\partial z} \right) - \frac{\partial}{\partial z} (uC) + R
\]
Soil bacteria exhibit differential growth responses to carbon substrates of varying chemical recalcitrance

- Only growing bacteria were targeted (BrdU captured DNA) analyzed by PhyloChip microarrays
- Growth response of ~2,200 bacterial taxa compared following addition of C substrates of varying chemical recalcitrance.
- Organisms responding to ‘labile’ C were phylogenetically clustered
- Organisms responding to ‘recalcitrant’ C were phylogenetically dispersed.

Atmosphere

Lamarque et al., 2011

Table 4. Continued.
Ocean BGC

Doney et al., 2009
Belowground N Cycle Goals in CLM

• Represent belowground N dynamics in a mechanistic way
• Biological processes
  – Nitrification
  – Denitrification
  – Mineralization, interaction with C dynamics
  – Fixation
  – Biological populations
• Physical and chemical processes
  – Advection (vertical, horizontal)
  – Gas production (CO$_2$, N$_2$O, CH$_4$, NO)
  – Stabilization (aggregation, mineral interactions, etc.)
  – Multi-phase (aqueous, gaseous, sorbed)
  – pH, redox, oxygen
• Current version of CLM4 contains little mechanistic representation of these processes
Two Parallel Paths for Improving CLM’s Belowground N Cycle Representation

- CLM4.5
- CLM4-BeTR
CLM4.5

• C cascade
  – Century structure currently included
  – Easily modified structure and parameters

• Vertical discretization
  – Each layer has the complete C & N cascade
  – Surface and root litter
  – Radiocarbon, $^{13}$C
  – Mixing, cryoturbation

• Century nitrification (Parton et al., 2001), denitrification (DelGrosso et al., 2000), $N_2O$ emissions
  – Nitrification rate: $F_{\text{NO}_3} = \text{Net}_{\text{min}} K_1 + K_{\text{max}} * NH_4 * F(t) * F(WFPS) * F(pH)$
  – $N_2O$ production: $F_{\text{N}_2O} = K_2 * F_{\text{NO}_3}$
  – Denitrification rate: $D_t = \min[F_d(\text{NO}_3), F_d(\text{CO}_2)] F_d(WFPS)$.
  – $N_2O$ production: $R_{N_2/N_2O} = F_r(\text{NO}_3/\text{CO}_2) F_r(WFPS)$. 
Evaluating BG N Cycle Predictions

- Plants complicate interpretation of N observations for soil BGC processes
- Use N observations before emergence or in controls
  - Isolates soil BGC
  - Many such studies exist, often with measurements of NO₃, NH₄ concentrations, rates, and gas fluxes

Baseline model fails to reproduce rates or gas fluxes

Adding microbial activity and updating parameterizations improved dynamics
Rate Dependence on $\Theta$ and $T$ Uncertain

- Multi-model comparison (Rodrigo et al. 1997):

$$h(T, \theta) = f_T \theta$$
Annual Terrestrial $\text{N}_2\text{O}$ Emission = 12.6 TgN $y^{-1}$
CLM4-BeTR

• General reactive/transport solver that includes
  – Arbitrary number of tracers
  – Aqueous, gaseous, sorbed phases
  – Vertical aqueous and gaseous and runoff fluxes
  – Transport into plants
  – Microbial dynamics
  – Isotopes
    • $^{18}$O and D in water (with D Noone and T Wong)
CLM4-BeTR Numerical Scheme

- Processes evolve at different time scales
- Solved with standard numerical solvers at different internal time steps
- Mass conservation maintained at each sub-step
- Diffusion solved with a Crank-Nicolson finite-volume method
- Advection solved with 1\textsuperscript{st} order upstream or 2\textsuperscript{nd} order flux-limited scheme
- Biogeochemical processes solved with a standard ODE solver
CLM4-BeTR N Cycle Simulations
Next Steps

• Model development
  – Integrate microbial processes and evaluate impacts
  – Crop model with fertilization
  – Integration of CH₄ dynamics (CLM4-Me)

• Model testing
  – Existing N experiments and controls
  – Sorption and stabilization mechanisms for C
  – Regional and global N₂O emission predictions against inversions and other estimates

• Model applications
  – Coupled C & N simulations; characterizing atmospheric interactions and feedbacks
  – Priming
  – C stabilization and potential destabilization under climate change
  – ...