Development of a Microbial Module, CLM-Microbe in CESM: framework and preliminary results

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Motivation

Bardgett et al., 2008

The Microbial Engines That Drive Earth’s Biogeochemical Cycles
Paul G. Falkowski,1* Tom Fenchel,2* Edward F. Delong2*

Virtually all nonequilibrium electron transfers on Earth are driven by a set of nanobiological machines composed largely of multimeric protein complexes associated with a small number of prosthetic groups. These machines evolved exclusively in microbes early in our planet’s history yet, despite their antiquity, are highly conserved. Hence, although there is enormous genetic diversity in nature, there remains a relatively stable set of core genes coding for the major redox reactions essential for life and biogeochemical cycles. These genes created and coevolved with biogeochemical cycles and were passed from microbe to microbe primarily by horizontal gene transfer. A major challenge in the coming decades is to understand how these machines evolved, how they work, and the processes that control their activity on both molecular and planetary scales.
Incorporating microbial processes into climate models

This report is based on a colloquium convened by the American Academy of Microbiology, February 21-23, 2011, in Dallas, TX
How to incorporate microbial processes and which mechanisms?
Microbial Mechanisms Contributing to the Climate System

Background map is the carbon density in global soil microbial biomass

Xu et al., 2013 Global Ecology and Biogeography
CLM-Microbe: Key components

- Microbial biomass
- Trace gas model
- Microbial regulation of nutrient (primarily N at current stage)
Microbial Assimilation of Soil Organic Carbon: Microbial biomass
$C_{sub}$ is substrate carbon; $C_{bio}$ is microbial biomass carbon; $C_{break}$ is substrate carbon break down; $CUE$ is carbon use efficiency; $R_m$ is maintenance respiration; solid lines indicate fluxes with width for magnitude, and dash lines indicate controls; all processes were controlled by environmental factors including temperature, moisture, and pH, etc.

Microbial processes in assimilating carbon from substrate

Xu et al., To be submitted
Microbial active period is a new term, which is similar as vegetation growing season; it integrates information of environmental factors and microbial physiology.

*Xu et al., To be submitted*
CESM/CLM

Daily soil temperature and moisture

C:N range

MAP range

Latin Hypercube Sampling

200 pairs of MAP & C:N

Biome-level simulations

Biome-level microbial assimilation of soil organic carbon

Xu et al., To be submitted
### Biome-level Cmic/Csub

<table>
<thead>
<tr>
<th>Biome</th>
<th>Modeled $C_{mic}/C_{org}$ (%)</th>
<th>Cmic/Corg (%) (Xu et al., 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal forest</td>
<td>0.97-1.83</td>
<td>1.5-2.1</td>
</tr>
<tr>
<td>Temperate coniferous forest</td>
<td>0.90-1.43</td>
<td>0.9-1.1</td>
</tr>
<tr>
<td>Temperate broadleaf forest</td>
<td>1.52-2.42</td>
<td>1.1-1.3</td>
</tr>
<tr>
<td>Tropical/subtropical forest</td>
<td>0.85-1.27</td>
<td>1.6-2.0</td>
</tr>
<tr>
<td>Grassland</td>
<td>1.54-2.92</td>
<td>2.0-2.2</td>
</tr>
<tr>
<td>Shrub</td>
<td>1.50-1.98</td>
<td>1.1-1.8</td>
</tr>
<tr>
<td>Tundra</td>
<td>1.20-1.98</td>
<td>1.3-2.2</td>
</tr>
<tr>
<td>Desert</td>
<td>2.87-4.56</td>
<td>3.9-6.5</td>
</tr>
<tr>
<td>Natural wetlands</td>
<td>1.18-1.48</td>
<td>1.0-1.5</td>
</tr>
</tbody>
</table>

*Xu et al., To be submitted*
Trace Gas Module in CESM/CLM
SOM: soil organic matter; DOC: dissolved organic carbon; DON: dissolved organic nitrogen; Methanogen: a group of bacteria producing methane; Methanotrophs: a group of bacteria oxidizing methane; Nitrifier: a group of bacteria carrying out nitrification; Denitrifier: a group of bacteria carrying out denitrification
Methane module conceptual structure

DOC: Dissolved Organic Carbon; ACE: acetate acid; the numbers indicate microbial functional groups; 1 indicates methanogens on acetate acid; 2 indicates methanogens on H2+CO2; 3 indicates aerobic methanotrophs; 4 indicates anaerobic methanotrophs.
Comparison between measured and modeled (A) CO₂ and (B) CH₄ concentrations

**A)**
- Modeled CO₂ vs. Measured CO₂ (mol)
- Linear regression line: $y = 0.7837x$ with $R^2 = 0.8234$

**B)**
- Modeled CH₄ vs. Measured CH₄ (mol)
- Linear regression line: $y = 0.7615x$ with $R^2 = 0.7116$

Xu et al., To be submitted
CLM-Microbe Simulation

Dissolved Organic Carbon

Biomass of Aerobic Methanotrophs

O2 concentration in soil column

Dissolved Organic Carbon

Aerobic Methanotrophy in Soils

O2 concentration in soil column
Microbial Regulation of Nitrogen Cycling in Soils
\[ e = 0.43 \times \left( \frac{r_F}{r_B} \right)^{0.6} \]

Manzoni et al., 2008
Mineral N
Organic Matter
Microbe
C:N = 8
CO₂

CUE=0.4
40C : 1N
1N

Organic Matter
Mineral N

Fixed microbial regulation on N immobilization

Dynamic microbial regulation on N immobilization

CUE=0.3
40C : 1N
0.5N
More mineral N in soils

Better vegetation growth
Microbial mechanisms for trace gas fluxes and nutrient cycling in soils are critically important.

CLM-Microbe is able to simulate soil microbial biomass dynamics, trace gas fluxes, and microbial regulation of nitrogen cycling in soils.
AGU session in December 2013

B019. Data-Model Integration for Improving Biogeochemistry-Climate Feedbacks in Earth System Models with Explicit Microbial Mechanisms

Organized by
Xiaofeng Xu, Peter E. Thornton, Santonu Goswami, Yiqi Luo

One of Global Soils SWIRL in AGU Biogeoscience section

Calls for Abstracts