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

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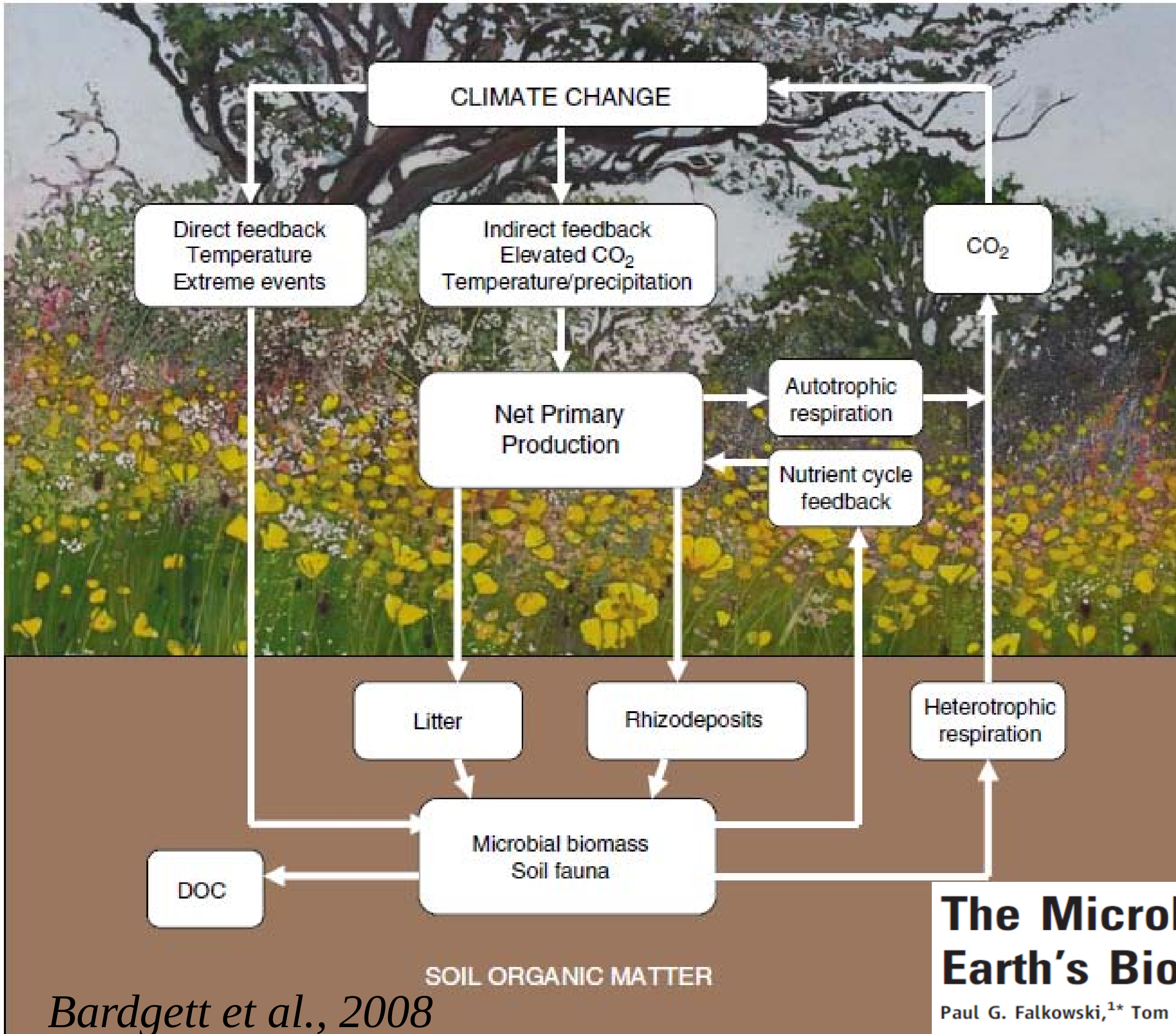
Motivation



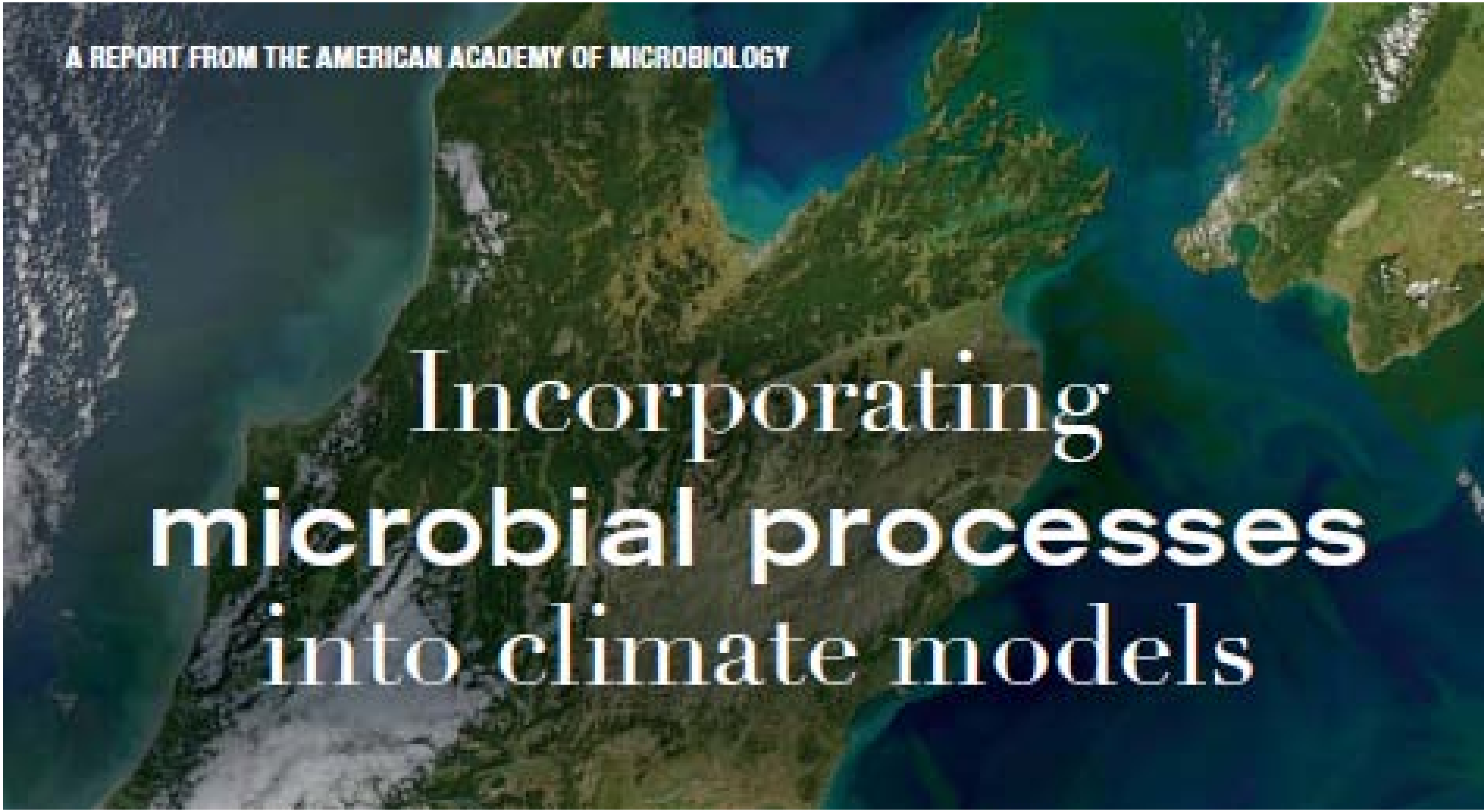
Bardgett et al., 2008

The Microbial Engines That Drive Earth's Biogeochemical Cycles

Science, 2008

Paul G. Falkowski,[1*] Tom Fenchel,[2*] Edward F. Delong[3*]

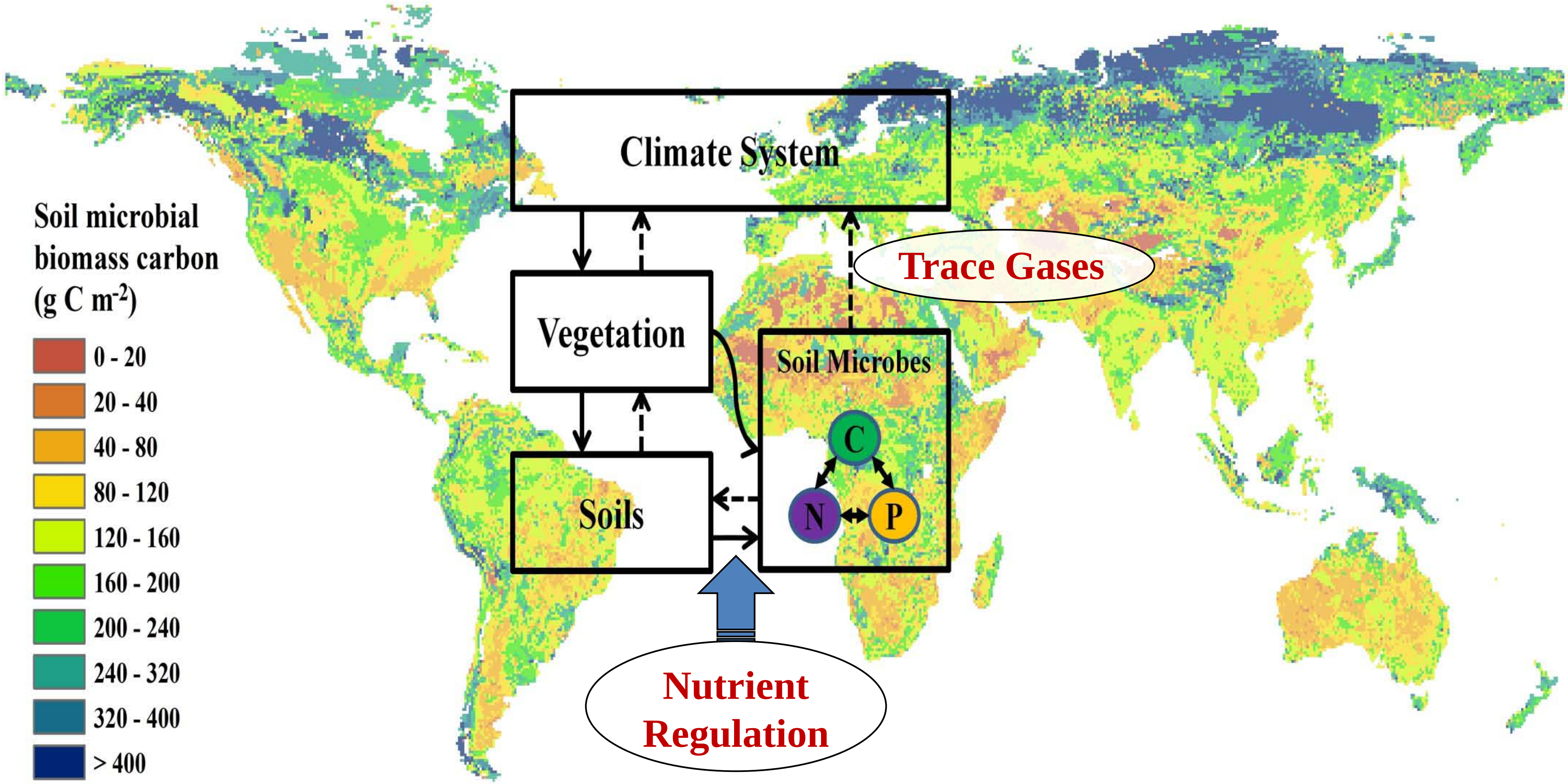
Virtually all nonequilibrium electron transfers on Earth are driven by a set of nanobiological machines composed largely of multimeric protein complexes associated with a small number of prosthetic groups. These machines evolved exclusively in microbes early in our planet's history yet, despite their 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.



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

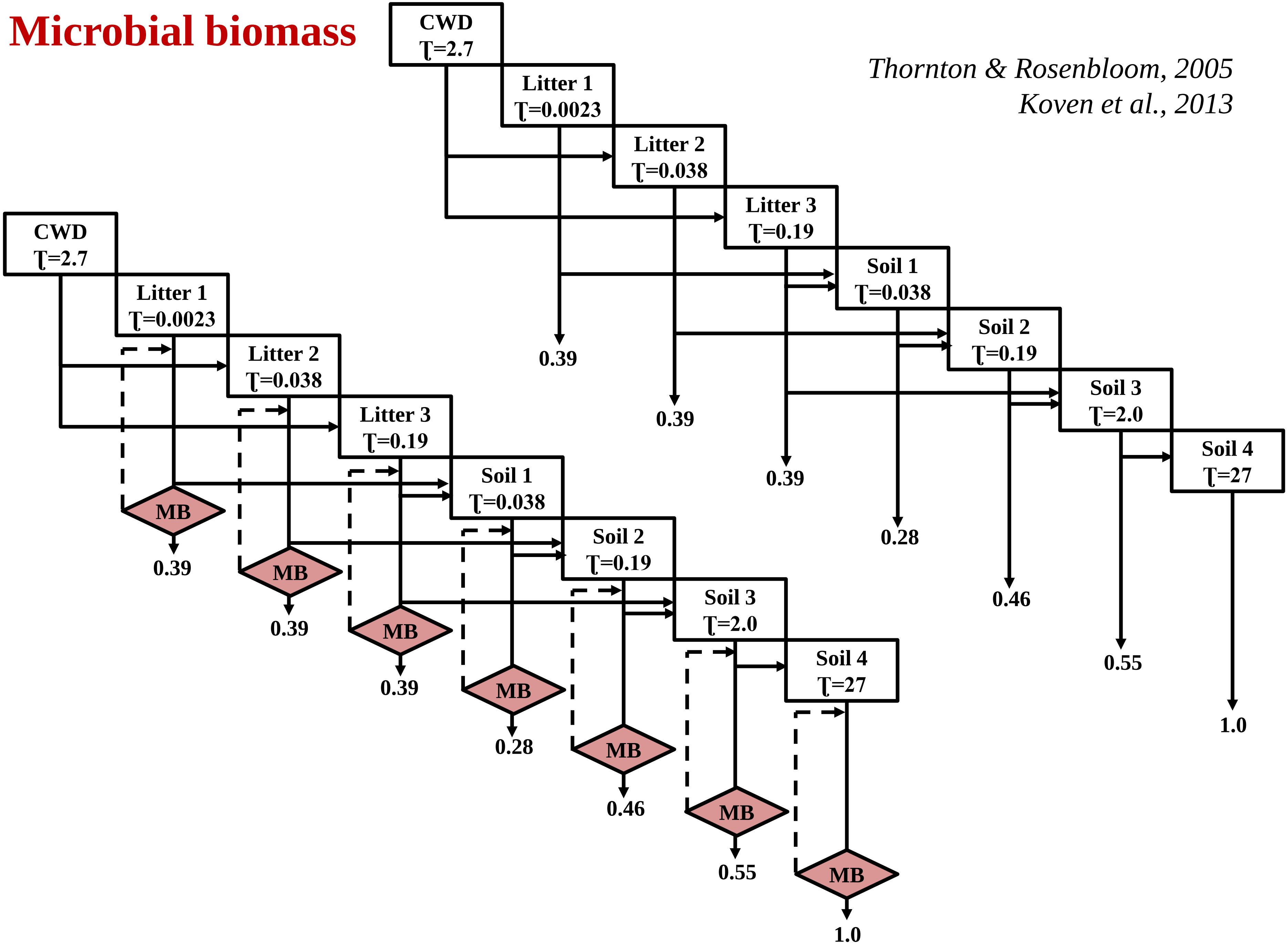
CLM-Microbe: Key components

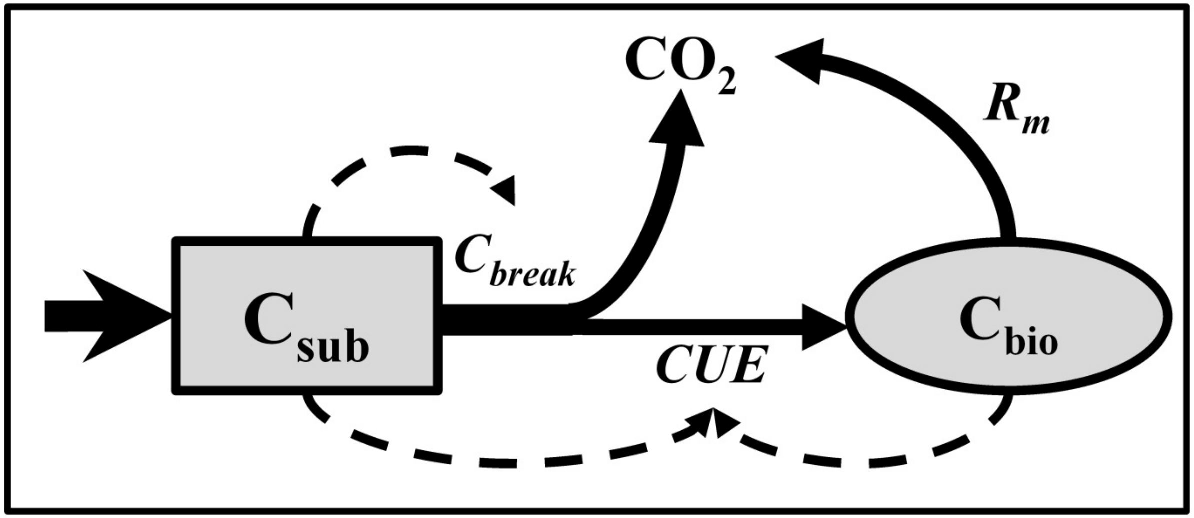
- **Microbial biomass**
- **Trace gas model**
- **Microbial regulation of nutrient (primarily N at current stage)**

Microbial Assimilation of Soil Organic Carbon: *Microbial biomass*

Microbial biomass

Thornton & Rosenbloom, 2005
Koven et al., 2013

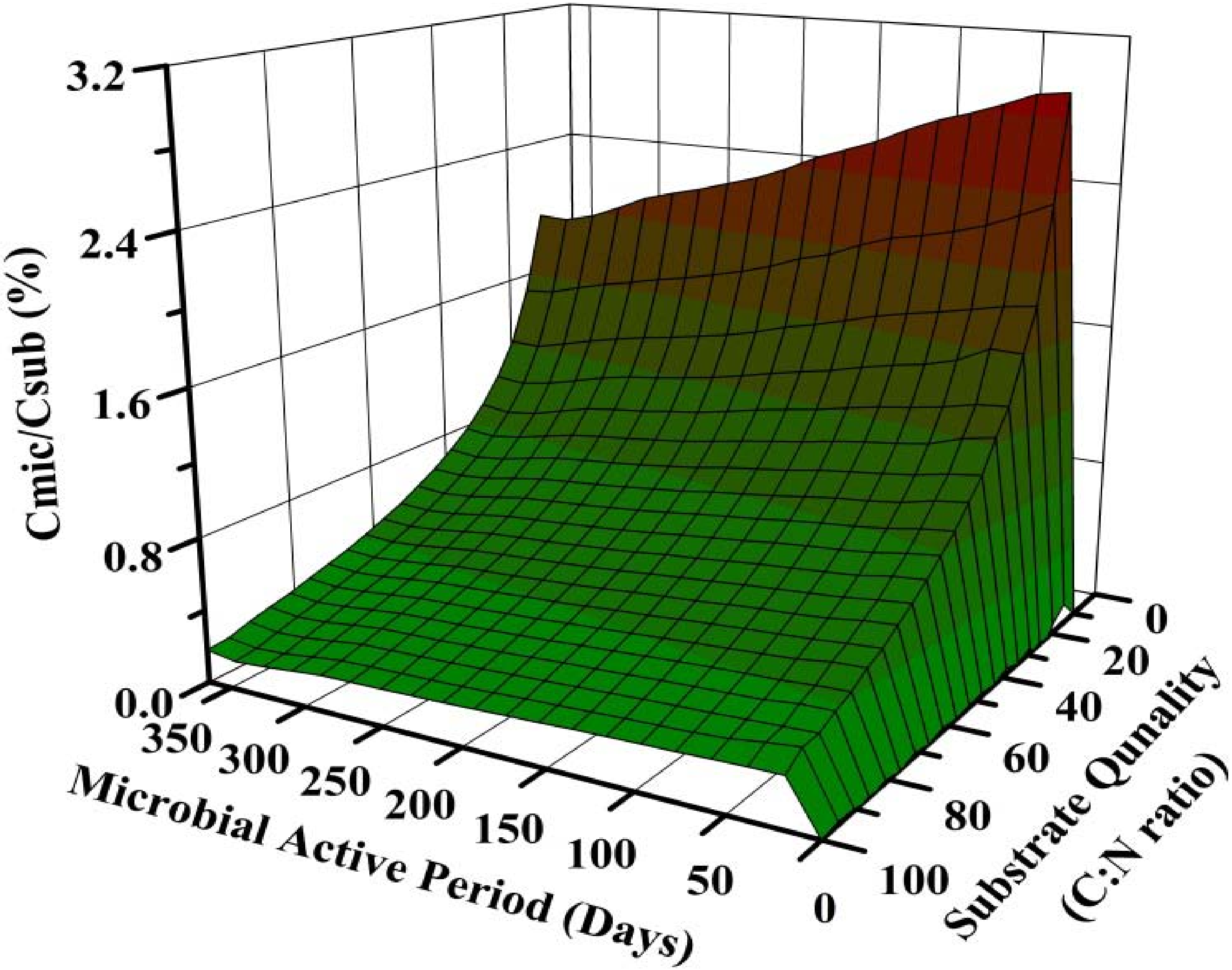




C_{sub} is substrate carbon; C_{bio} is microbial biomass carbon; C_{break} is substrate carbon break down; *CUE* is carbon use efficiency; R_m is maintenance respiration; solid lines indicate fluxes with width for magnitude, and dash lines indicate controls; all processes were controlled by environmental factors including temperature, moisture, and pH, etc.

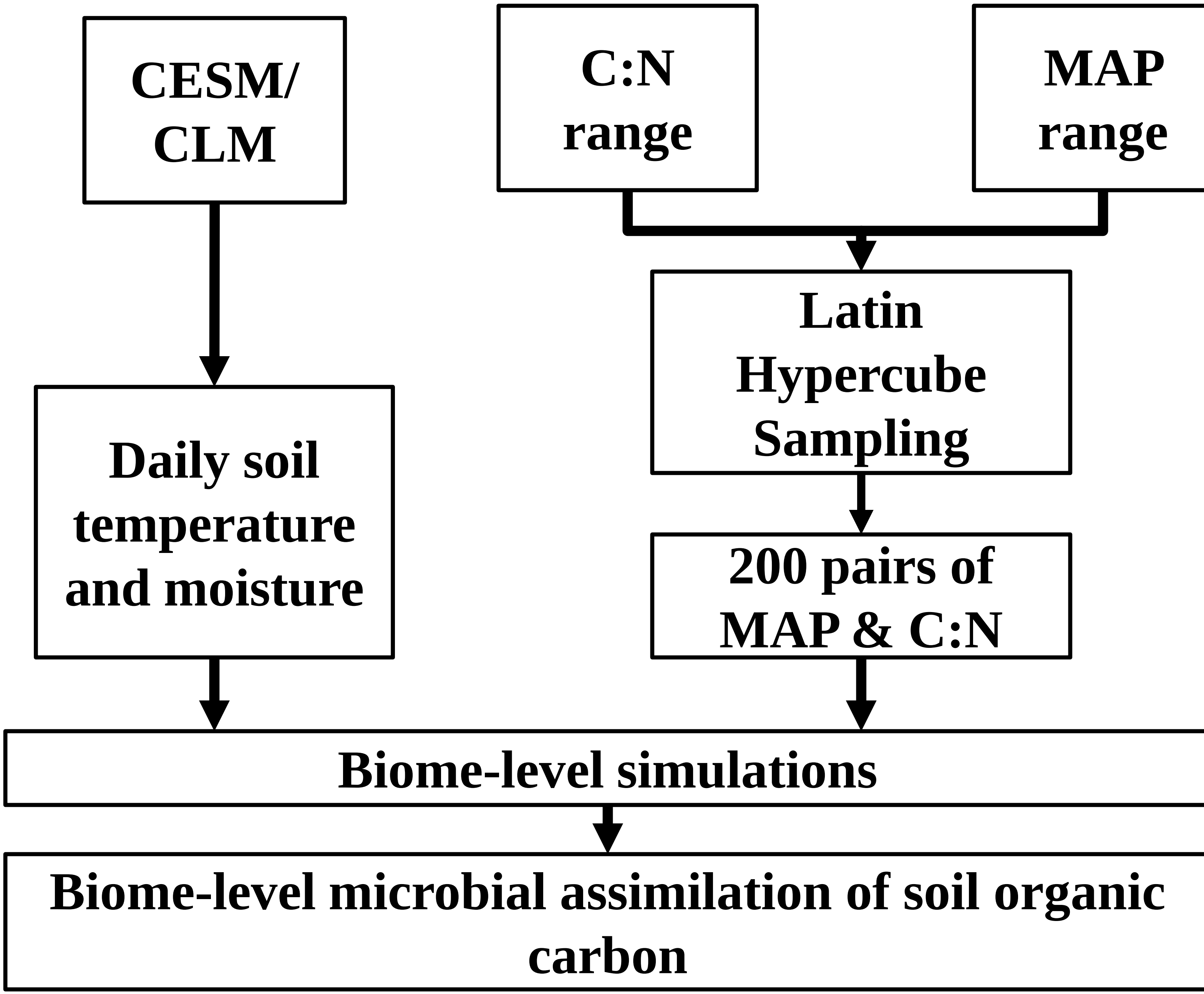
Microbial processes in assimilating carbon from substrate

Xu et al., To be submitted



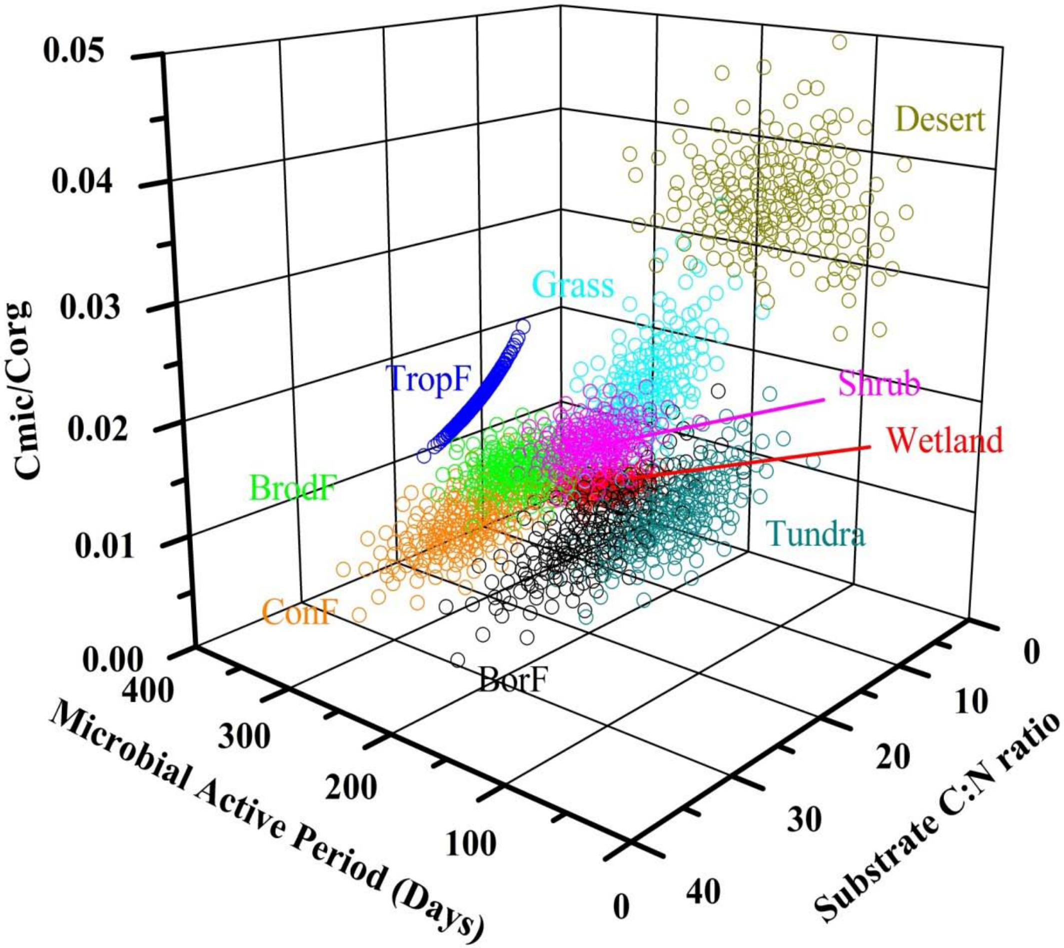
Microbial active period is a new term, which is similar as vegetation growing season; it integrates information of environmental factors and microbial physiology.

Xu et al., To be submitted



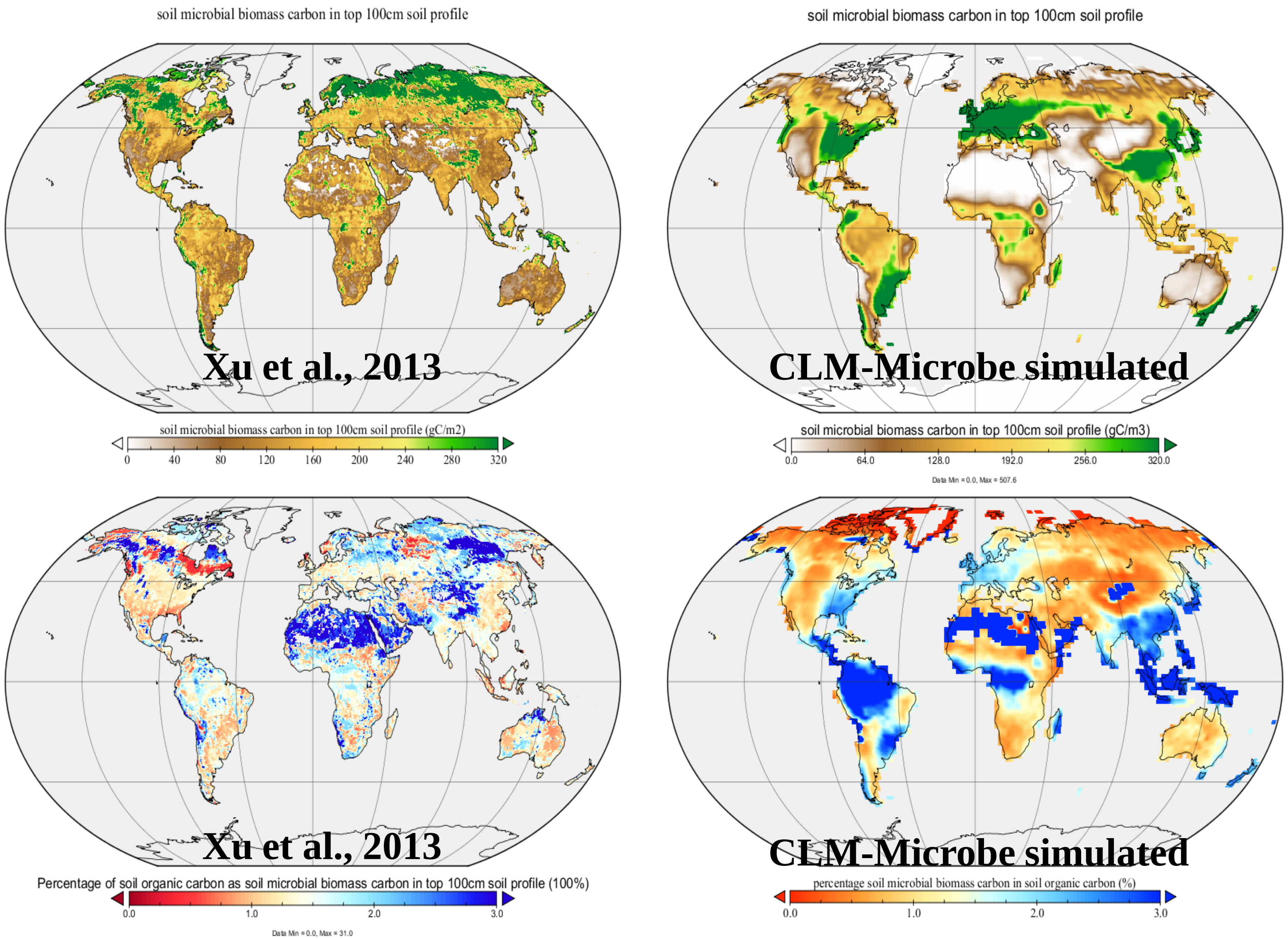
Xu et al., To be submitted

Biome-level Cmic/Csub

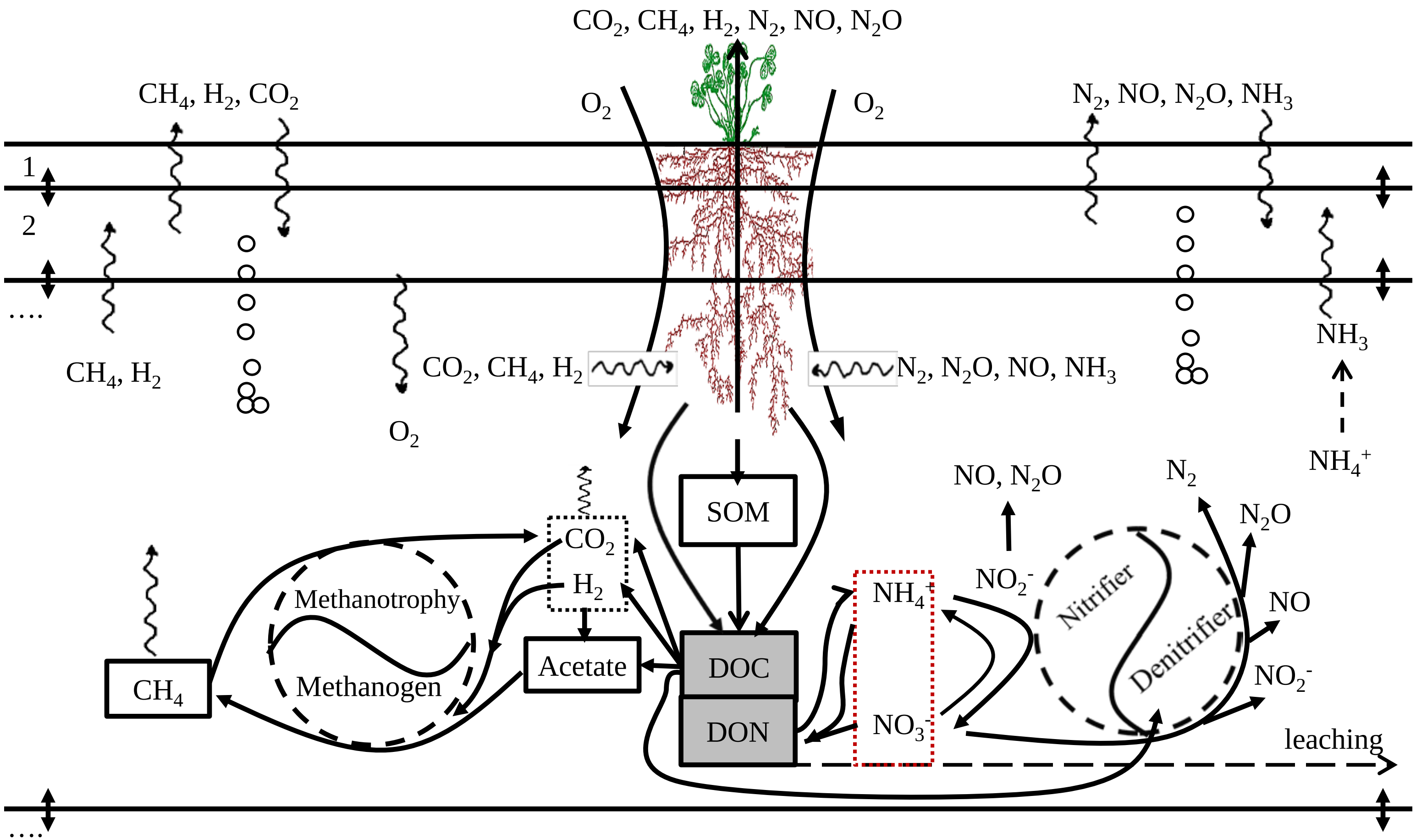


Biome	Modeled C_{mic}/C_{org}	Cmic/Corg (%) (Xu et al., 2013)
Boreal forest	0.97-1.83	1.5-2.1
Temperate coniferous forest	0.90-1.43	0.9-1.1
Temperate broadleaf forest	1.52-2.42	1.1-1.3
Tropical/subtropical forest	0.85-1.27	1.6-2.0
Grassland	1.54-2.92	2.0-2.2
Shrub	1.50-1.98	1.1-1.8
Tundra	1.20-1.98	1.3-2.2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

Xu et al., To be submitted

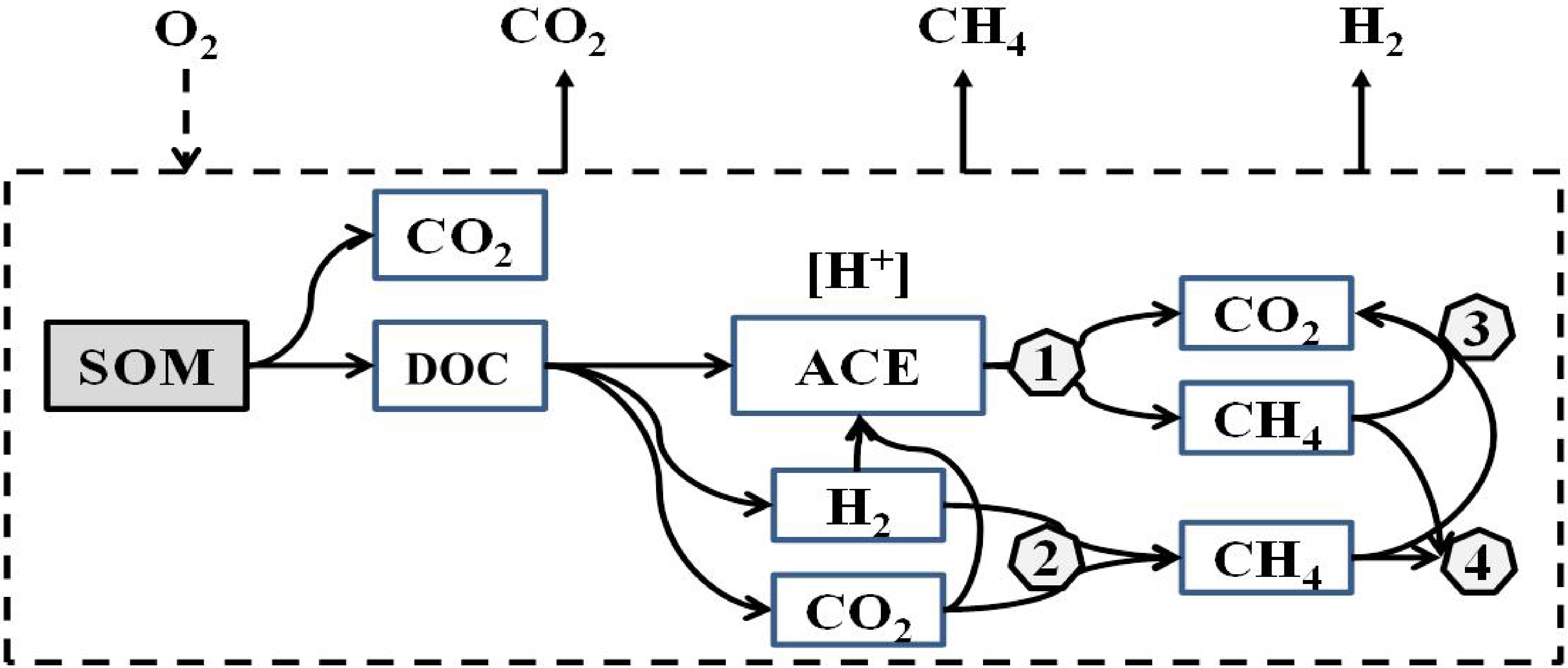

soil microbial biomass carbon in top 100cm soil profile
Xu et al., 2013
soil microbial biomass carbon in top 100cm soil profile (gC/m2)
0 40 80 120 160 200 240 280 320
soil microbial biomass carbon in top 100cm soil profile
CLM-Microbe simulated
soil microbial biomass carbon in top 100cm soil profile (gC/m3)
0.0 64.0 128.0 192.0 256.0 320.0
Data Min = 0.0, Max = 507.6
Xu et al., 2013
Percentage of soil organic carbon as soil microbial biomass carbon in top 100cm soil profile (100%)
0.0 1.0 2.0 3.0
Data Min = 0.0, Max = 31.0
CLM-Microbe simulated
percentage soil microbial biomass carbon in soil organic carbon (%)
0.0 1.0 2.0 3.0

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

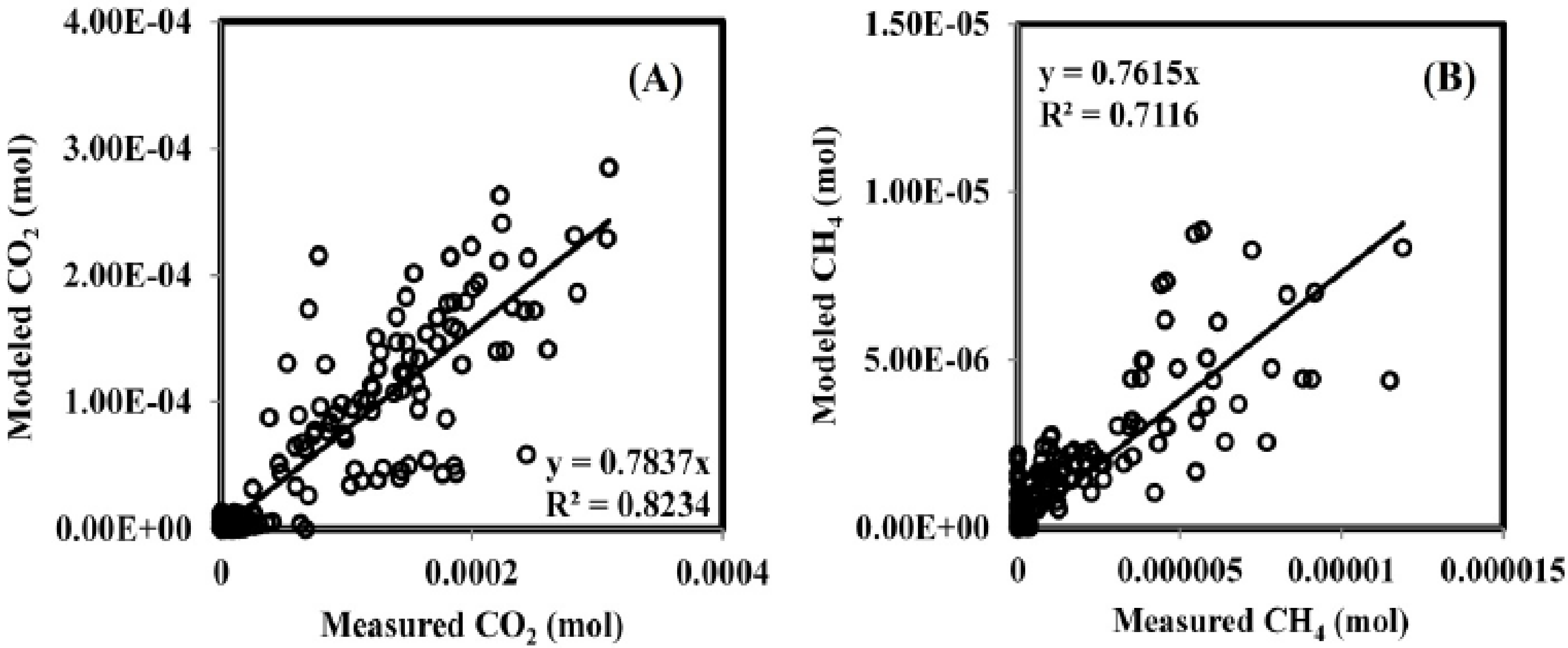
Methane module conceptual structure



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 methanotrophys; 4 indicates anaerobic methanotrophys.

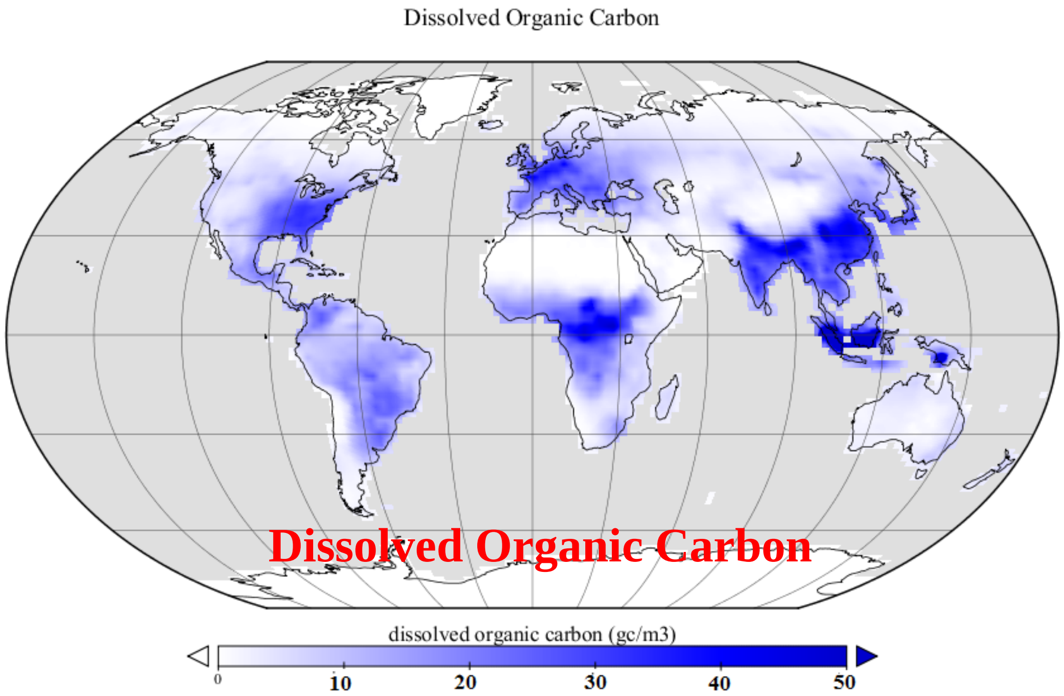
Xu et al., To be submitted

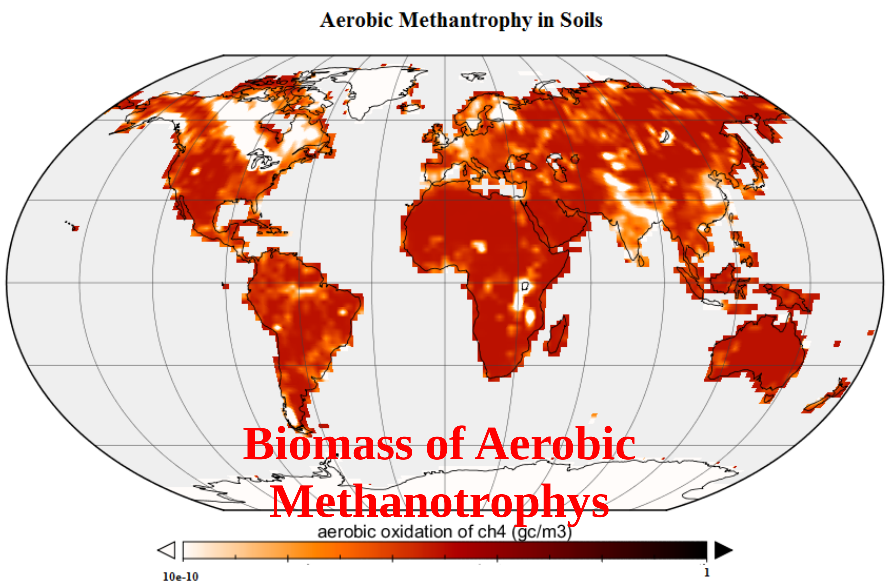
Comparison between measured and modeled (A) CO_2 and (B) CH_4 concentrations

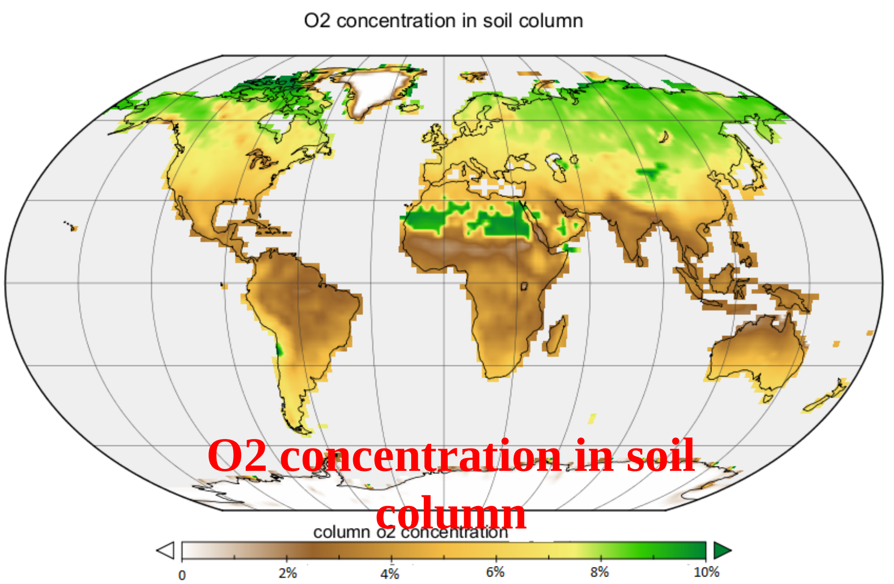


Xu et al., To be submitted

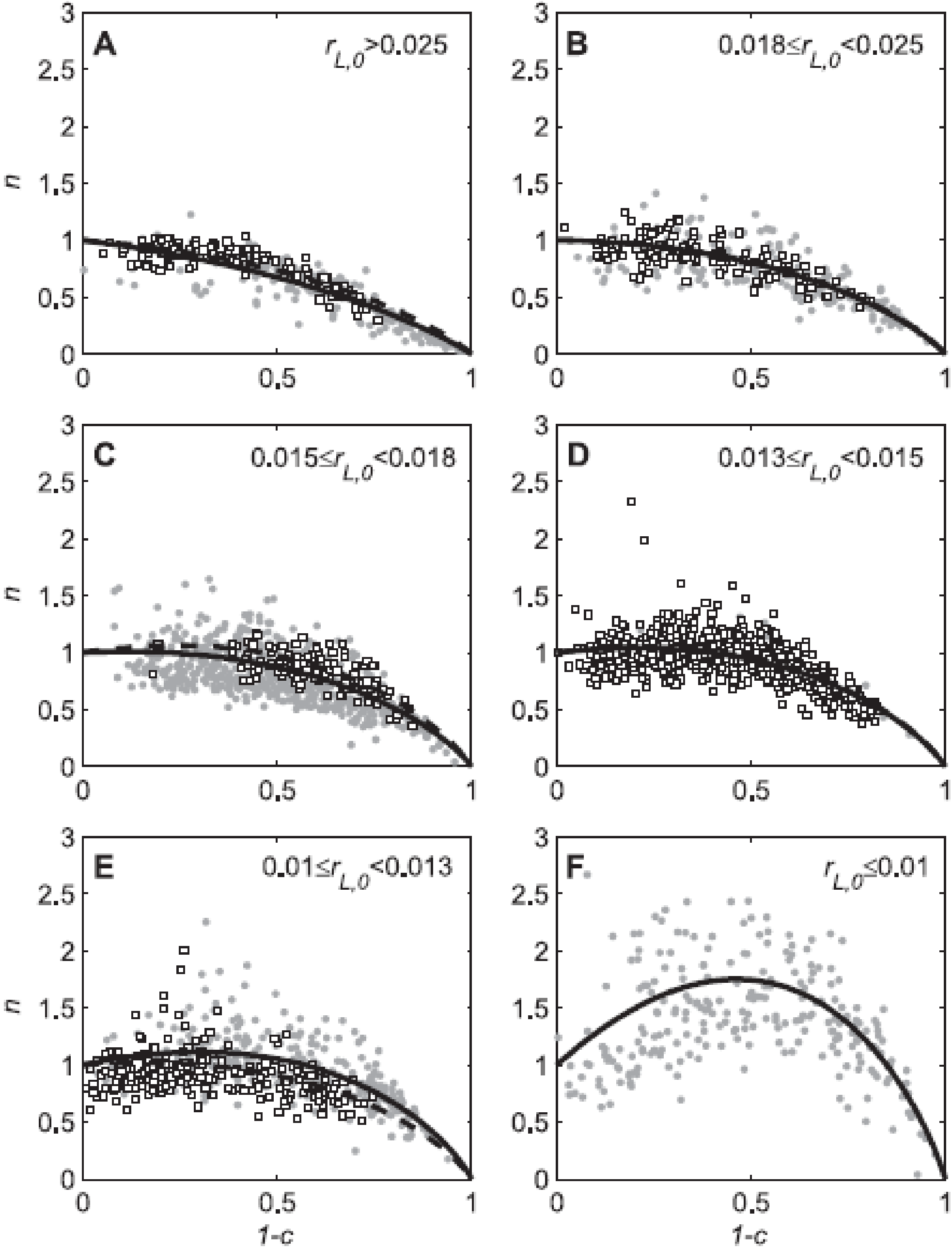
CLM-Microbe Simulation



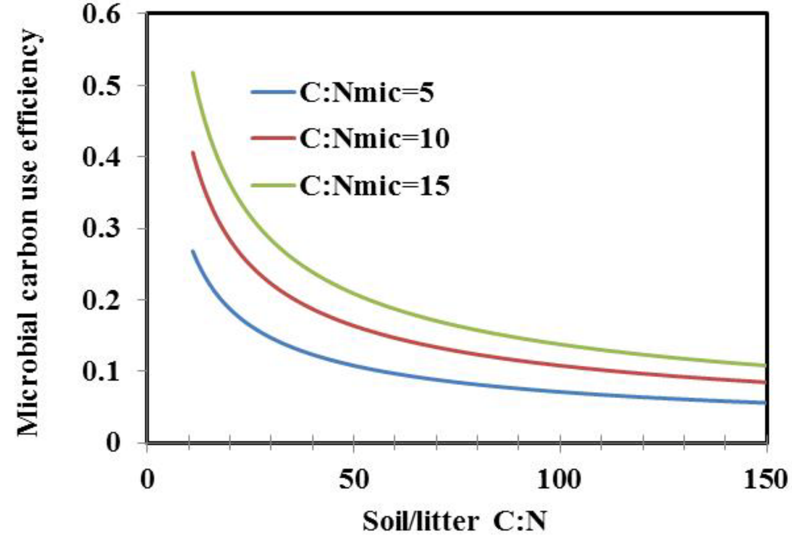




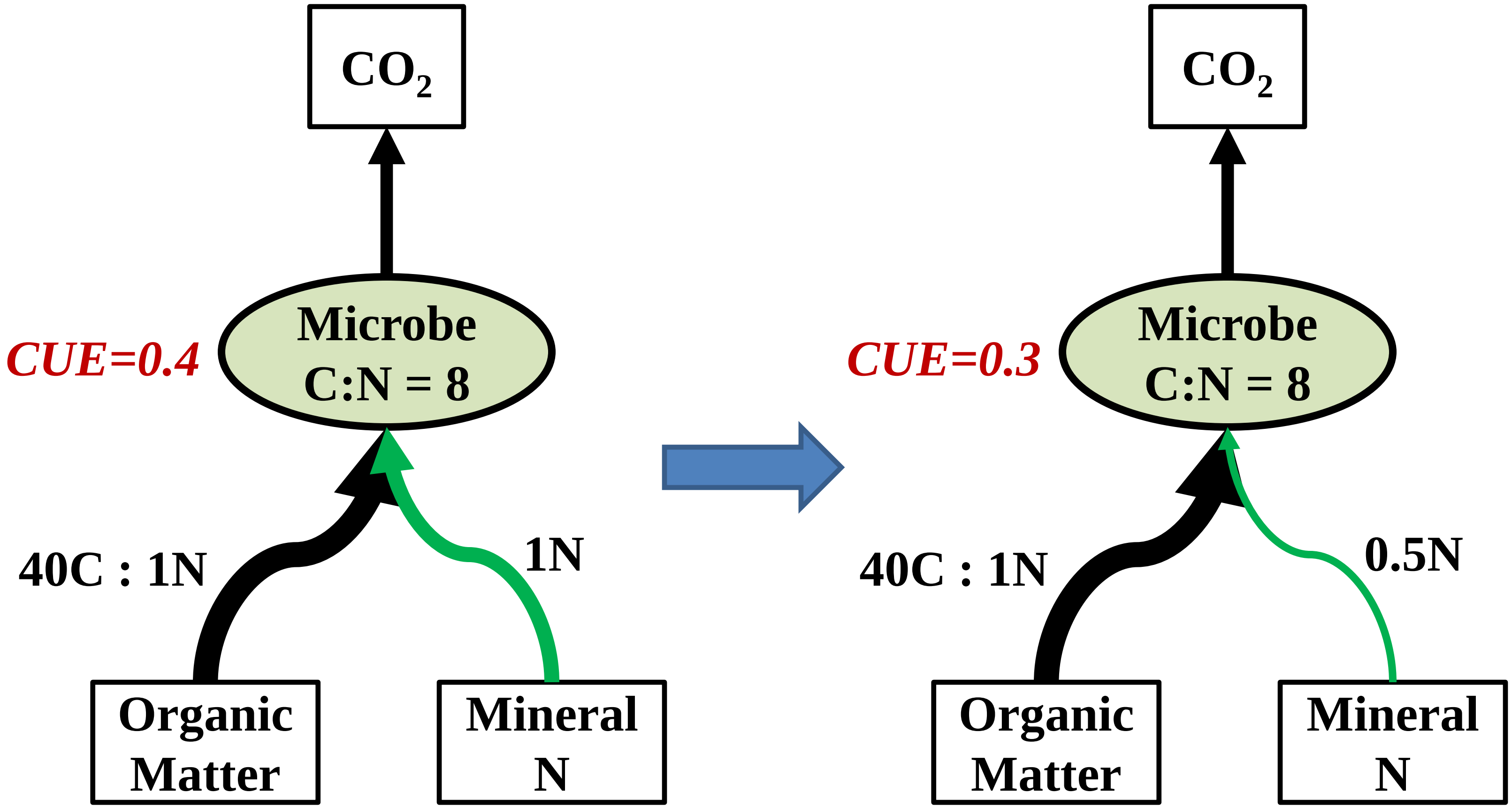
Microbial Regulation of Nitrogen Cycling in Soils



$$e = 0.43 * \left(\frac{r_F}{r_B}\right)^{0.6}$$

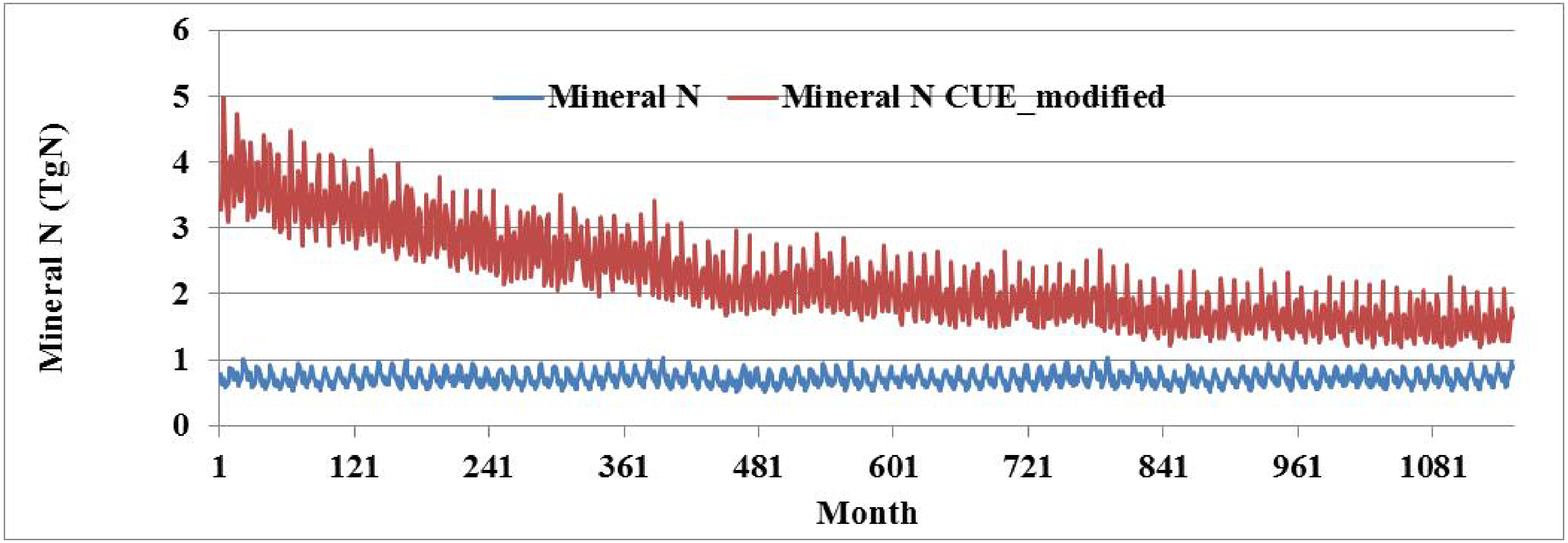


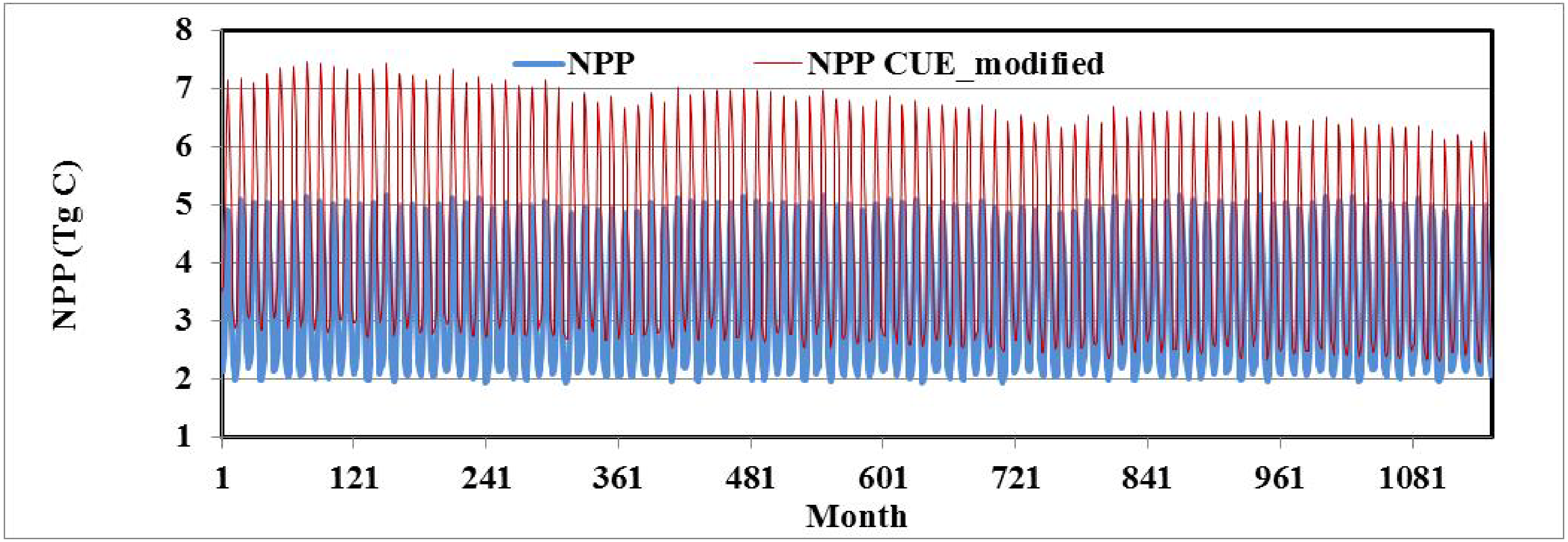
Manzoni et al., 2008



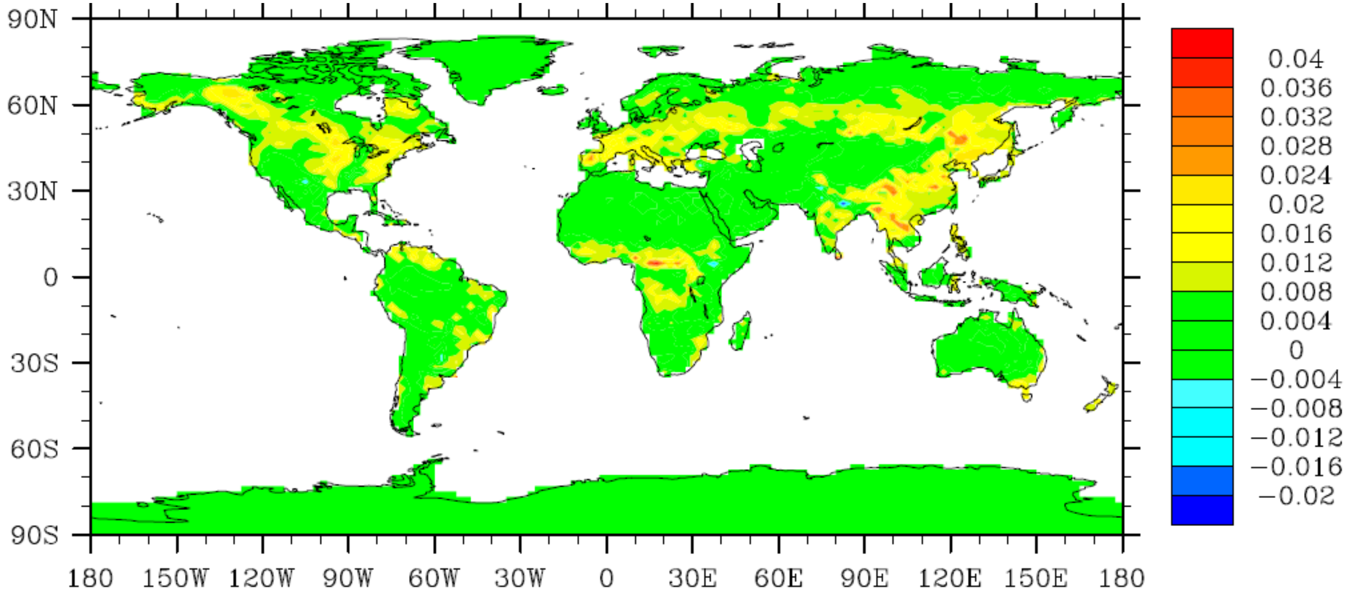
Fixed microbial regulation on N immobilization

Dynamic microbial regulation on N immobilization


Mineral N
Mineral N CUE_modified
Mineral N (TgN)
6
5
4
3
2
1
0
1
121
241
361
481
601
721
841
961
1081
Month

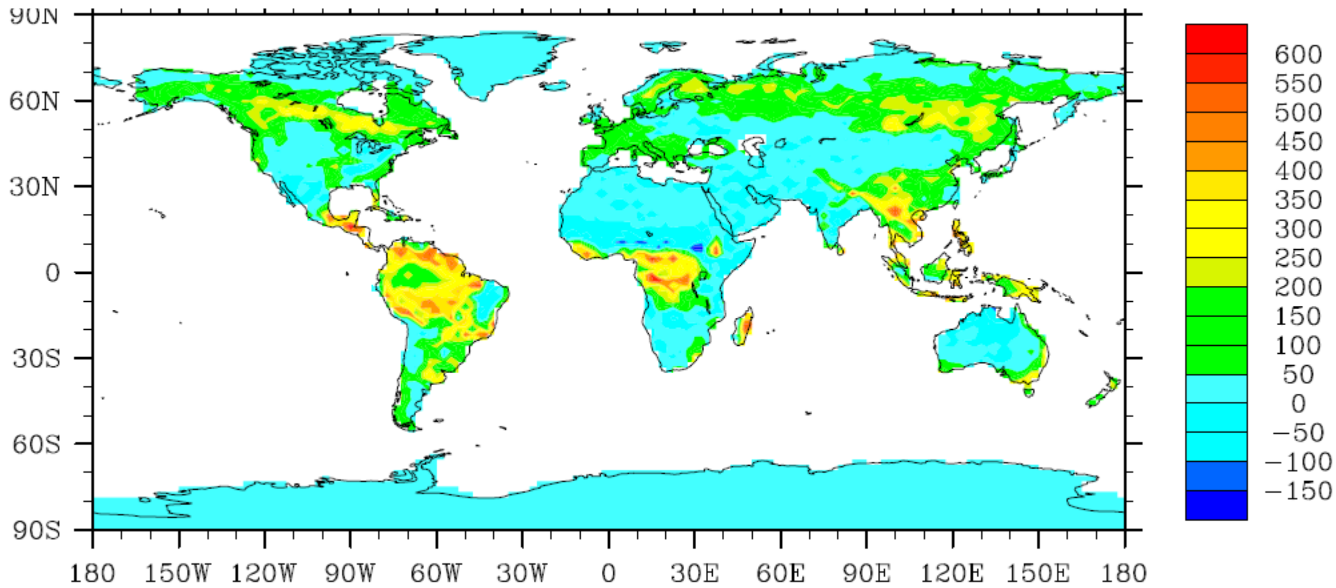

NPP
NPP CUE_modified
NPP (Tg C)
8
7
6
5
4
3
2
1
1
121
241
361
481
601
721
841
961
1081
Month

Mineral N (Dynamics microbial CUE – fix microbial CUE)



More mineral N in soils

NPP (Dynamics microbial CUE – fix microbial CUE)



Better vegetation growth

Summary

- **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