Different mechanisms of soil microbial response to global change result in different outcomes in the MIMICS-CN model

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Abstract

Microbial-explicit models of soil carbon (C) and nitrogen (N) cycling have improved upon simulations of C and N stocks and flows at site-to-global scales relative to traditional first-order linear models. However, before we can draw conclusions from microbial-explicit models about the future behavior of soils in a changing world, we need to thoroughly investigate model behavior with existing data and understand the impact of model development decisions on predictive outcomes. We used the MIcrobial-MIneral Carbon Stabilization Model with coupled N cycling (MIMICS-CN) to explore several ways of interrogating a model with data. We simulated C and N losses from litterbags in the Long-term Inter-site Decomposition Experiment (LIDET) while simultaneously comparing simulated values of soil pools and fluxes against ranges from a continent-wide data synthesis. We also discuss the impact of the way soil experiments are interpreted in the context of models, the importance of evaluating both equilibrium and transient model behavior, and the impact of assigning temperature sensitivity to 3 different aspects of microbial physiology.

Model formulation

MIMICS-CN represents C and N flow through metabolic and structural litter, oligotrophic and copiotrophic microbes, and physically protected, chemically protected, and available SOM pools. C dynamics are driven by reverse Michaelis-Menten kinetics, while N dynamics are driven by input and microbial C:N. N leaves the model as leaked inorganic N and C leaves the model as respired CO_2.

Parameter	Value (g/g)
CNs	85
CNm	12
CNr	6
CNk	10
NUE	0.85

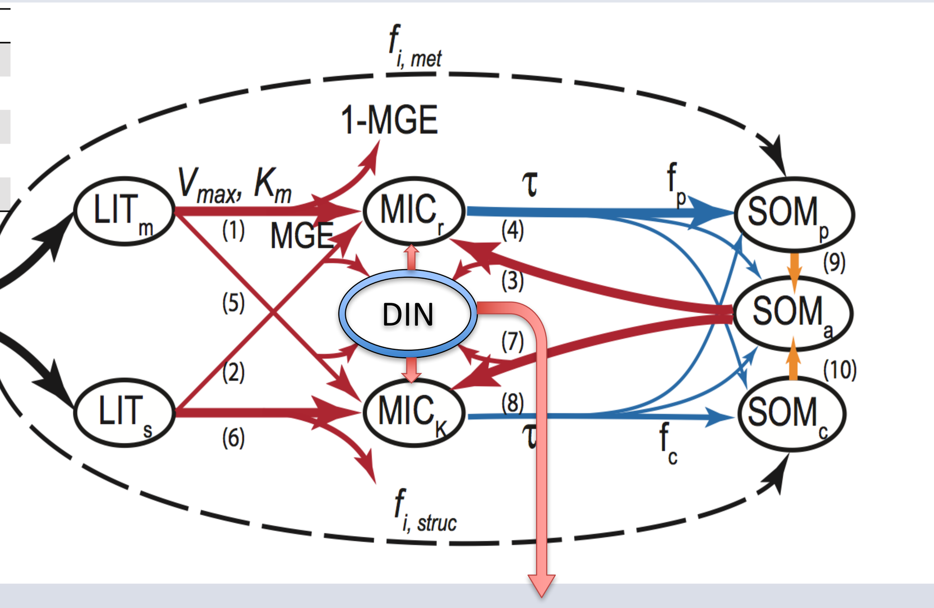
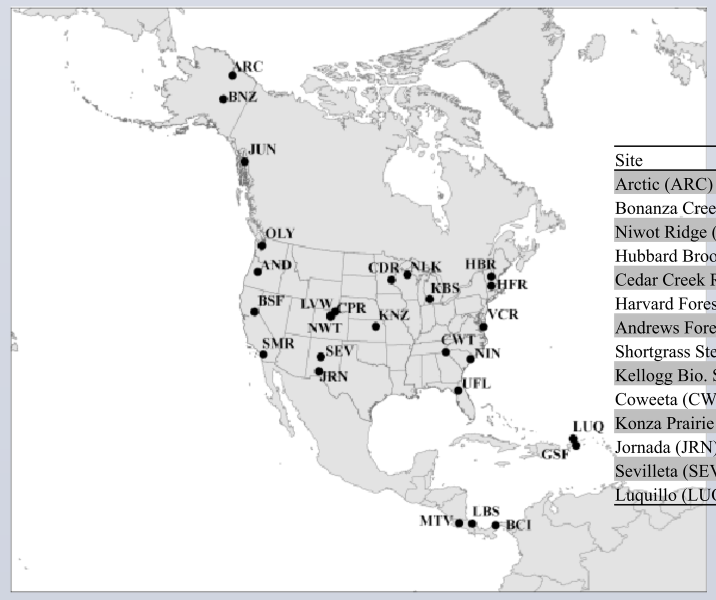


Figure 1. MIMICS-CN model structure and stoichiometric parameters unique to the coupled C-N model. CNs = C:N of structural litter, CNm = C:N of metabolic litter, CNr = C:N of copiotrophs, CNk = C:N of oligotrophs, and NUE = nitrogen use efficiency of both microbial groups.

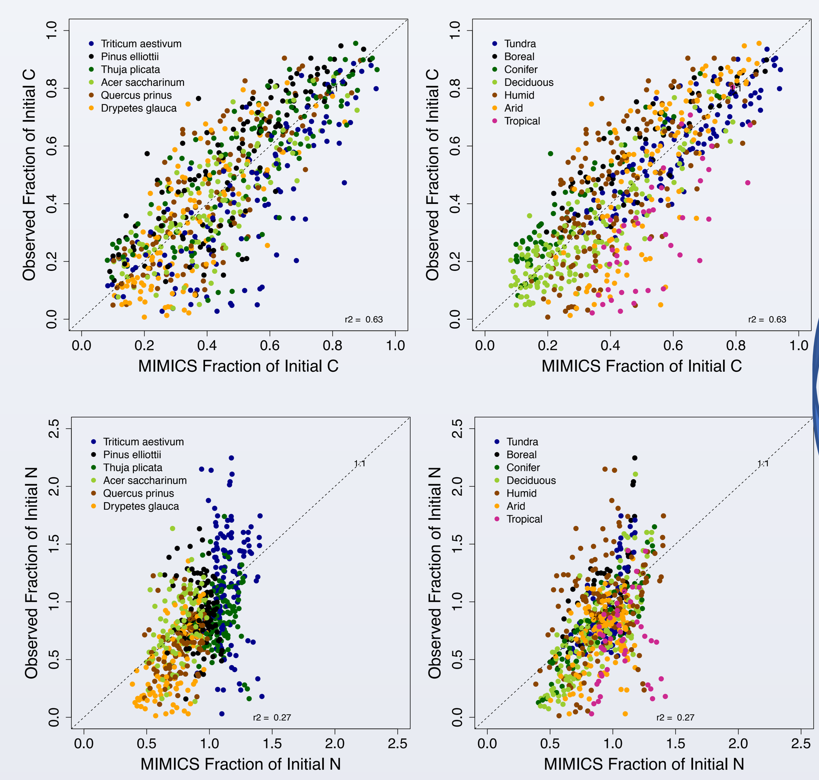


Site	MAT (◦C)	MAP (mm)	ANPP (g C m^{-2} y^{-1})
Arctic (ARC)	-7	327	141
Bonanza Creek (BNZ)	-5	403	300
Niwot Ridge (NWT)	-3.7	1249	199
Hubbard Brook (HBR)	5	1396	704
Cedar Creek Reserve (CDR)	5.5	823	277
Harvard Forest (HFR)	7.1	1152	744
Andrews Forest (AND)	8.6	2309	800
Shortgrass Steppe (SGS)	8.9	440	116
Kellogg Bio. Station (KBS)	9.7	890	431
Coweeta (CWT)	12.5	1906	1460
Konza Prairie (KNZ)	12.8	791	443
Jornada (JRN)	14.6	298	229
Sevilleta (SEV)	16	254	184
Luquillo (LUQ)	23	3363	1050

Figure 2. LIDET sites included in model simulations. Map borrowed from: Harmon, M. E. et al. (2009). Long-term patterns of mass loss during the decomposition of leaf and fine root litter: an intersite comparison. Global Change Biology, 15: 1320–1338.

Reasonable choices with big impacts on soil model evaluation/interpretation

Scope of dataset used for evaluation matters



Working with different datasets simultaneously can reveal behaviors in different parts of the model and constrain parameters

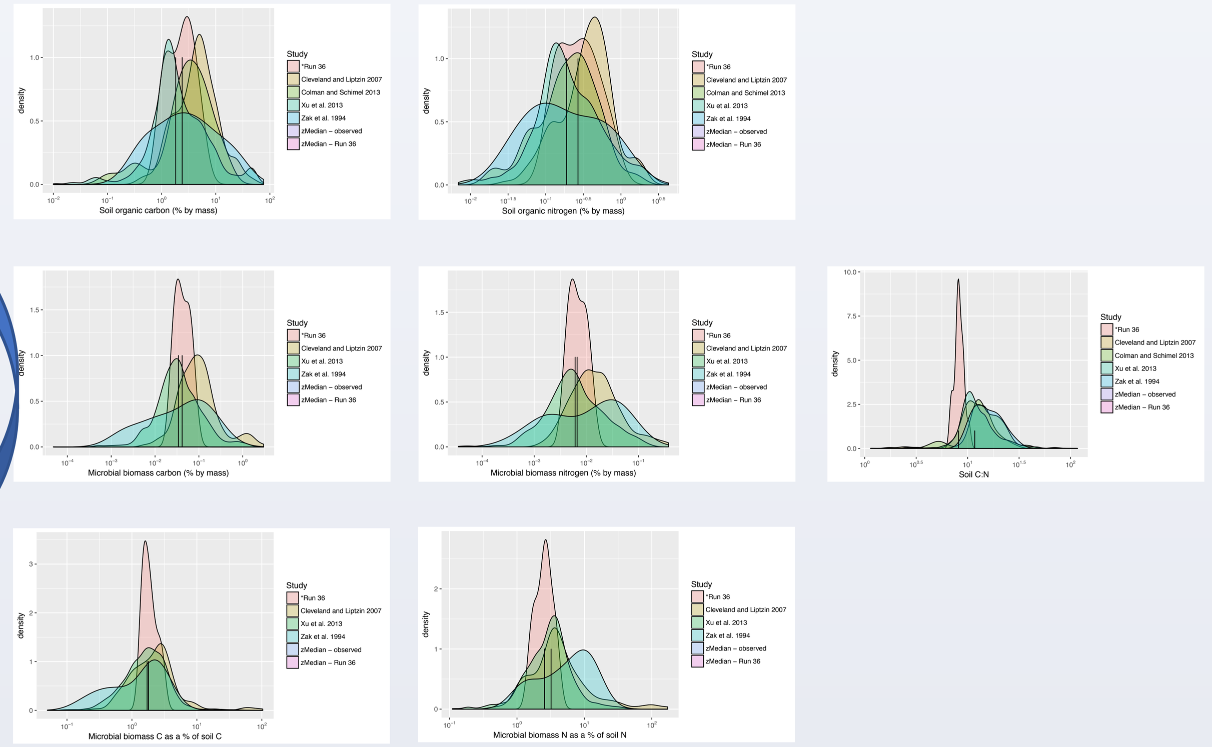
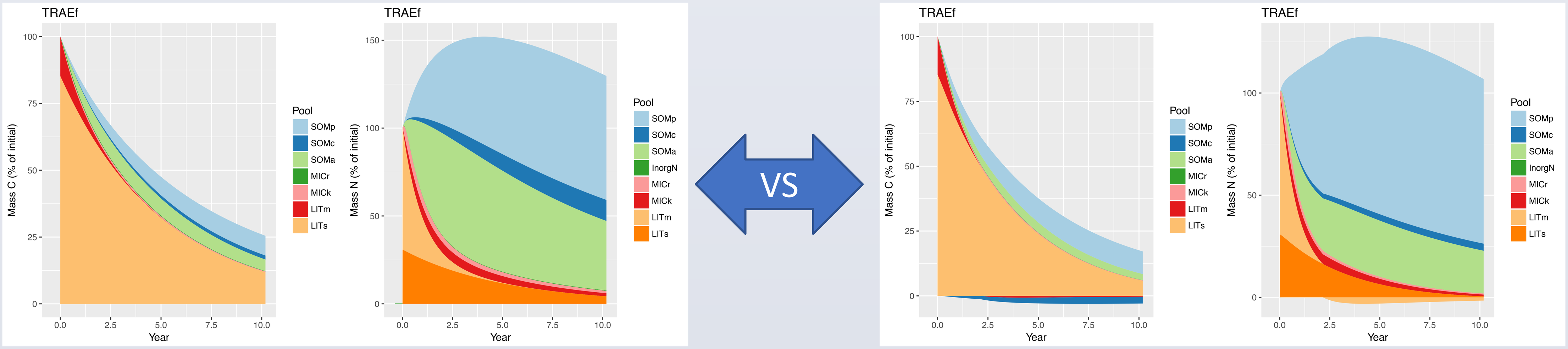


Figure 3. MIMICS-CN simulations of C losses (top) and N remaining (bottom) from litterbags in the LIDET dataset versus observed values, colored by litter type (left) and biome (right).

Figure 4. Distributions of MIMICS-CN estimates of steady-state values for a variety of soil pools and fluxes, compared against observed ranges from several continent-wide data synthesis studies.

Interpretation of experiments within the model matters



Option A: Interpret litterbag as a "tracer"

Option B: Interpret litterbag as an addition that induces feedbacks

Figure 5. MIMICS-CN simulations of C loss (left) and fraction of N remaining (right) for *Triticum aestivum* (wheat) litter at Harvard Forest.

Evaluating transient behavior can reveal new issues

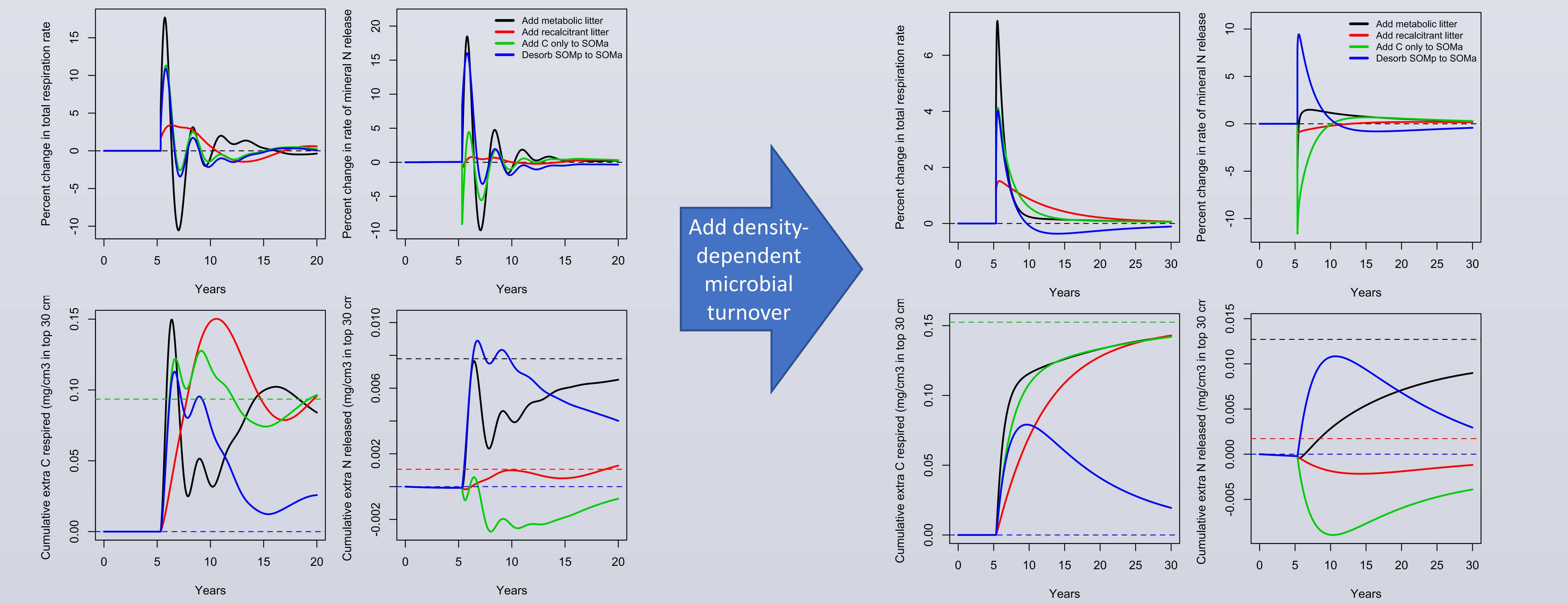


Figure 6. MIMICS-CN modeled responses to 4 types of pulse input: **metabolic litter (black), structural litter (red), simple C added to the "available" SOM pool (green)**, and **desorption of SOM from the "physically protected" pool to the "available" pool (blue).** In the first 3 simulations, enough C was added to equal 1% of the total soil C; in the last simulation, no C was added but a similar about of C was transferred between pools to simulate disruption of organo-mineral associations by plant exudates. The model was spun up to equilibrium at Harvard Forest and run for 15 years following each perturbation. Figure panels show model responses for C (left) and N (right) and show either percent change in C or N loss rates (top) or cumulative C or N lost relative to equilibrium values (bottom). Dashed lines in lower plots show the amount of C or N added in each type of pulse input.

Mechanism of temperature sensitivity matters

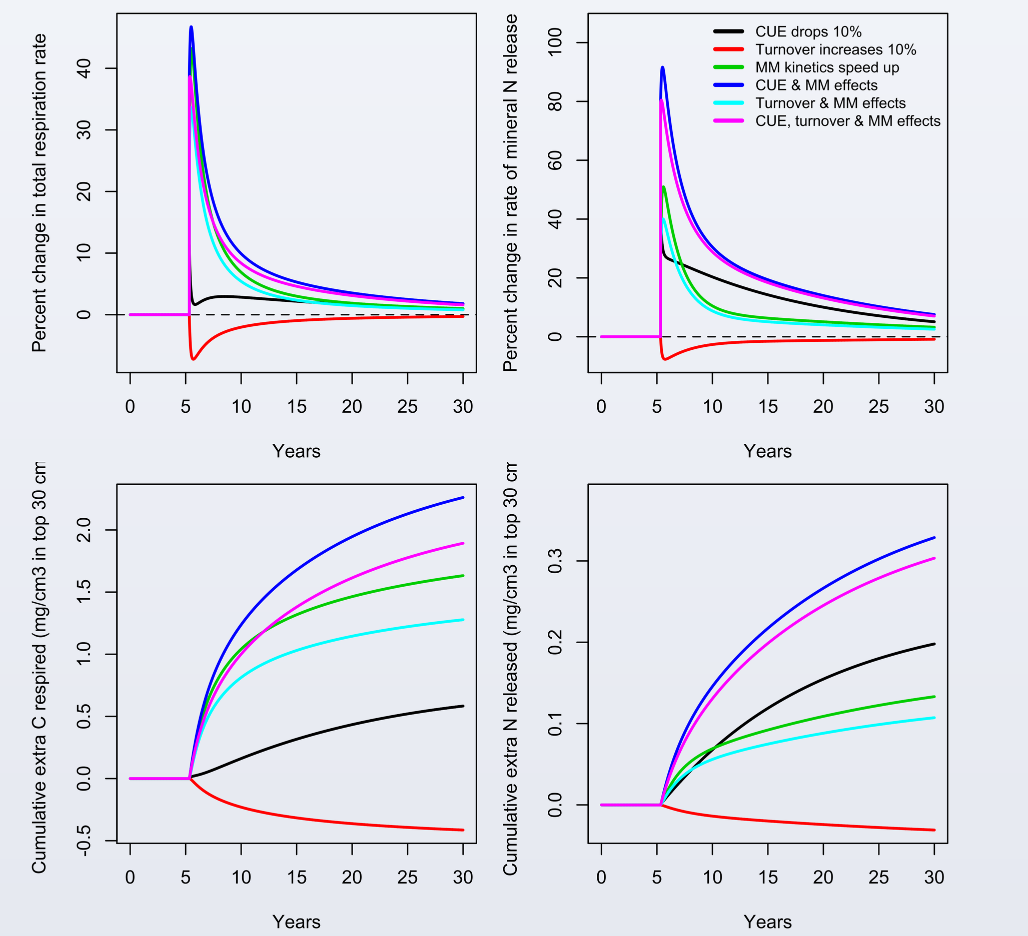


Figure 7. MIMICS-CN model responses to a 5°C increase in temperature, given that either microbial carbon use efficiency (CUE), microbial turnover, or Michaelis-Menten kinetics of microbial growth are temperature sensitive in the model. The model was spun up to equilibrium at Harvard Forest and run for 15 years following each perturbation. Figures show C (left) or N (right) and either percent change in C or N loss rates (top) or cumulative C or N lost relative to equilibrium values (bottom).

So what?

Choices abound during model development, and sometimes arbitrary decisions can generate highly different projections into the future.

Deep interrogation of models at this stage can help identify and resolve issues prior to incorporation into an Earth System Model (where the time and resource costs of fixing problems expands rapidly). For models of soil, this type of interrogation should include:

- Uncertainty due to structure, parameters, and interpretation of experimental validation data
- Equilibrium and transient behavior
- Validation across all measurable pools and fluxes in the model, not just a handful
- Validation of both micro-scale processes and landscape-scale outcomes
- Simulations of both natural and managed systems

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