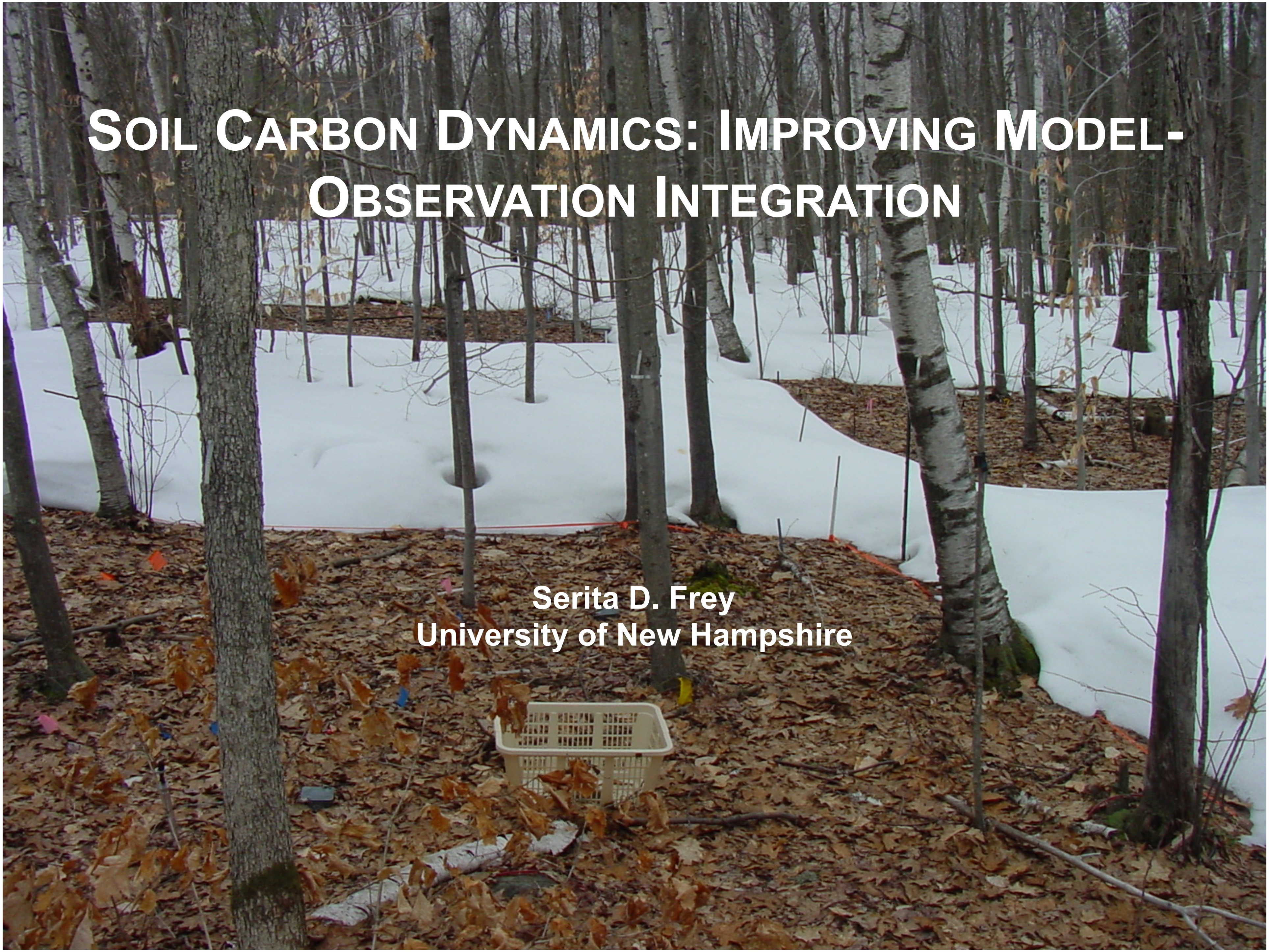
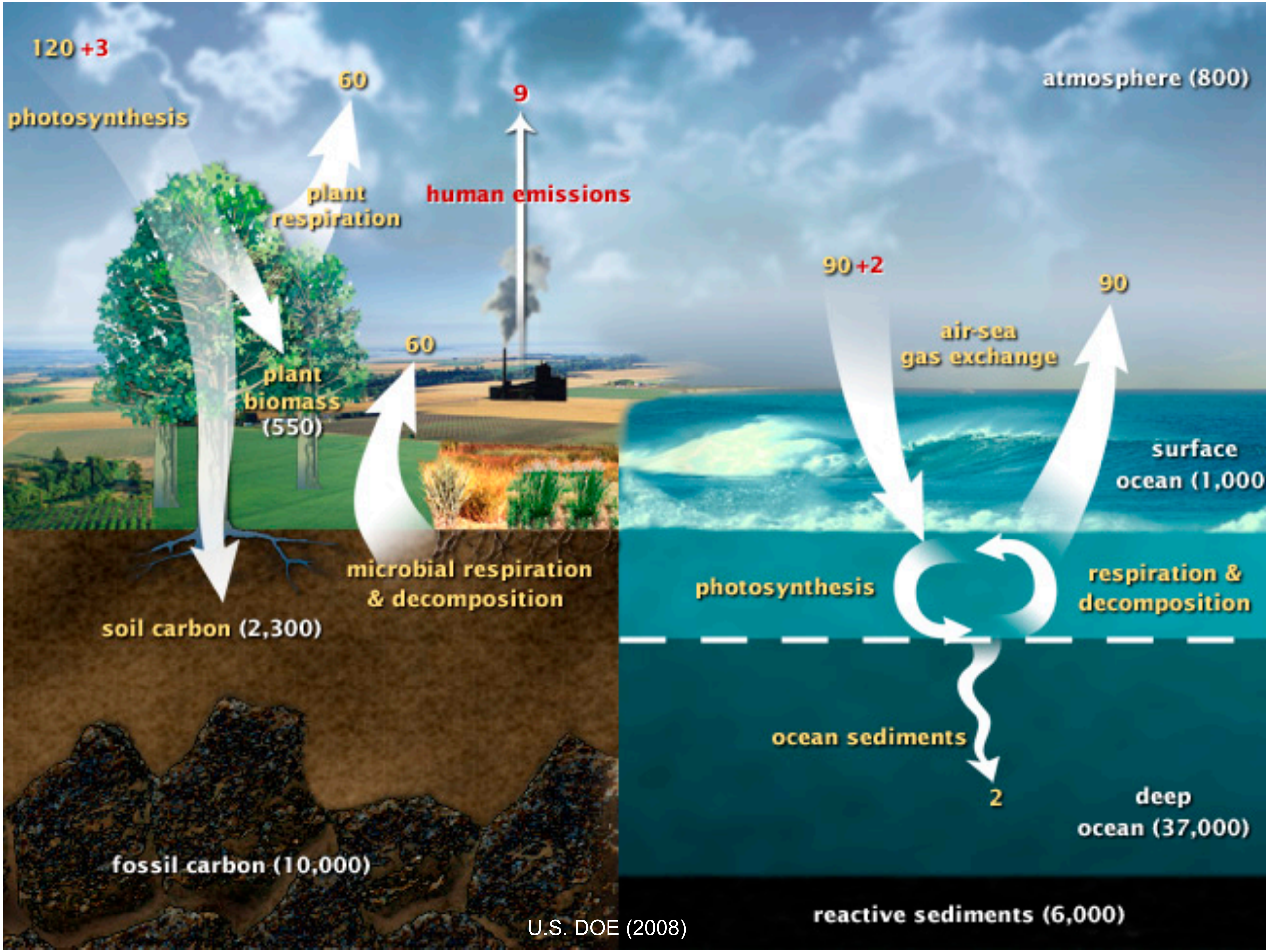
Soil Carbon Dynamics: Improving Model-Observation Integration

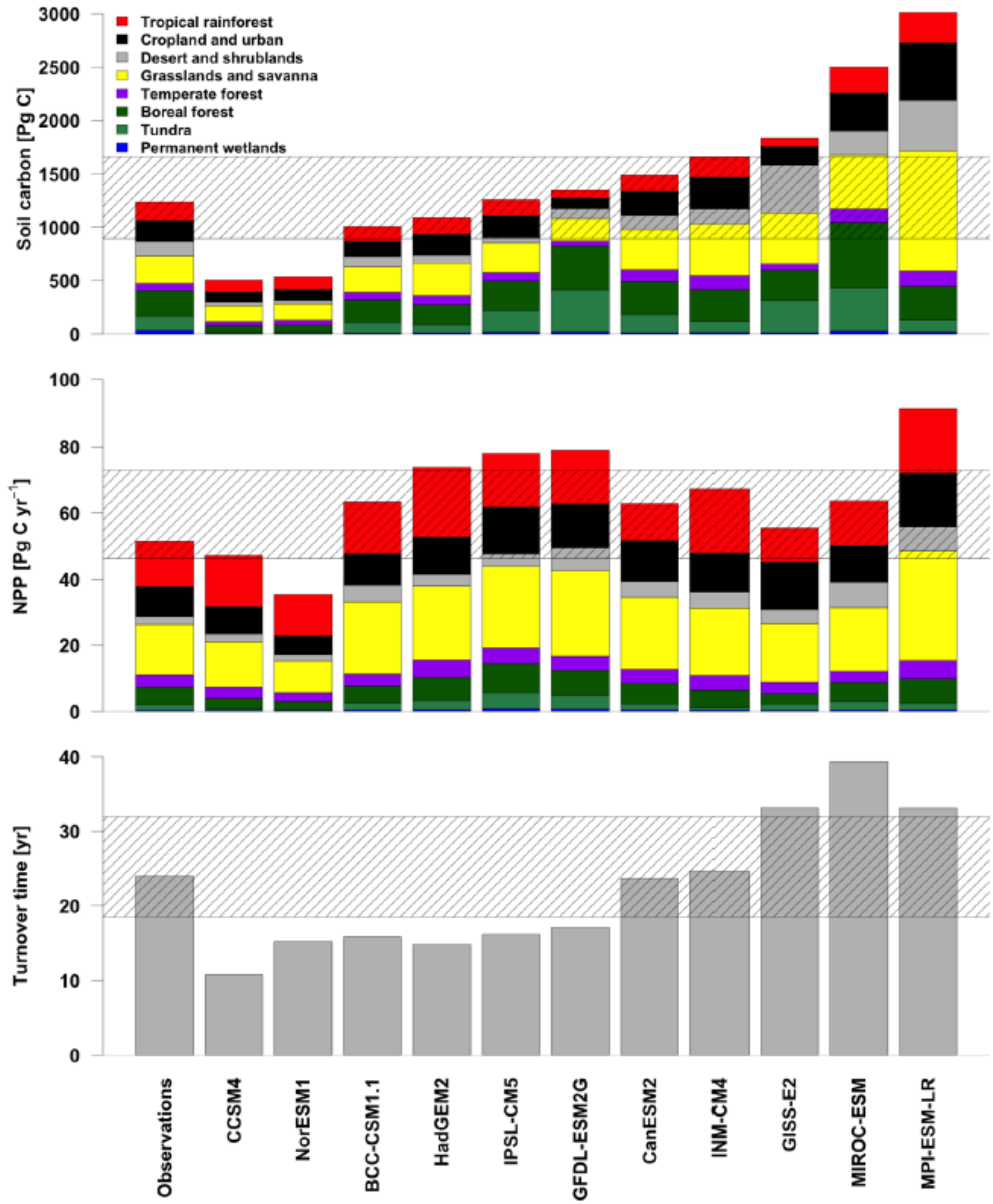


Serita D. Frey
University of New Hampshire

- Background
- Observations from climate change experiments
- Highlight some of the challenges to understanding and modeling soil carbon cycle-climate interactions (temperature, microbial physiology, and N feedbacks)
- Research Needs (observations and modeling)


120 +3
photosynthesis
60
plant respiration
9
human emissions
atmosphere (800)
60
plant biomass (550)
90 +2
90
air-sea gas exchange
surface ocean (1,000
microbial respiration & decomposition
soil carbon (2,300)
photosynthesis
respiration & decomposition
ocean sediments
2
deep ocean (37,000)
fossil carbon (10,000)
reactive sediments (6,000)

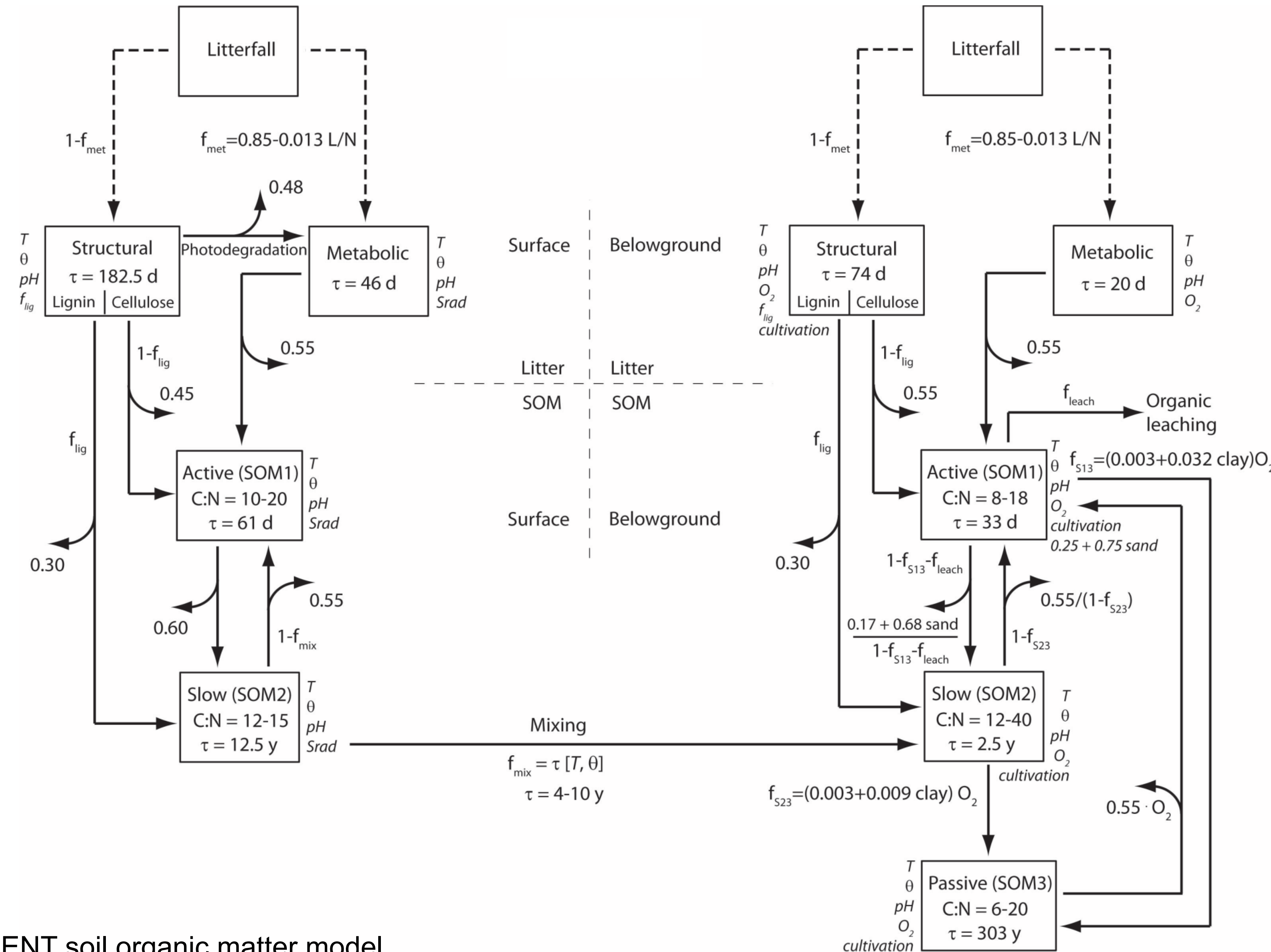
U.S. DOE (2008)



- Uncertainty in observational data
- Variation in modeled NPP
- Differences in how T_s represented
- Models don't incorporate processes important for soil C stabilization/destabilization

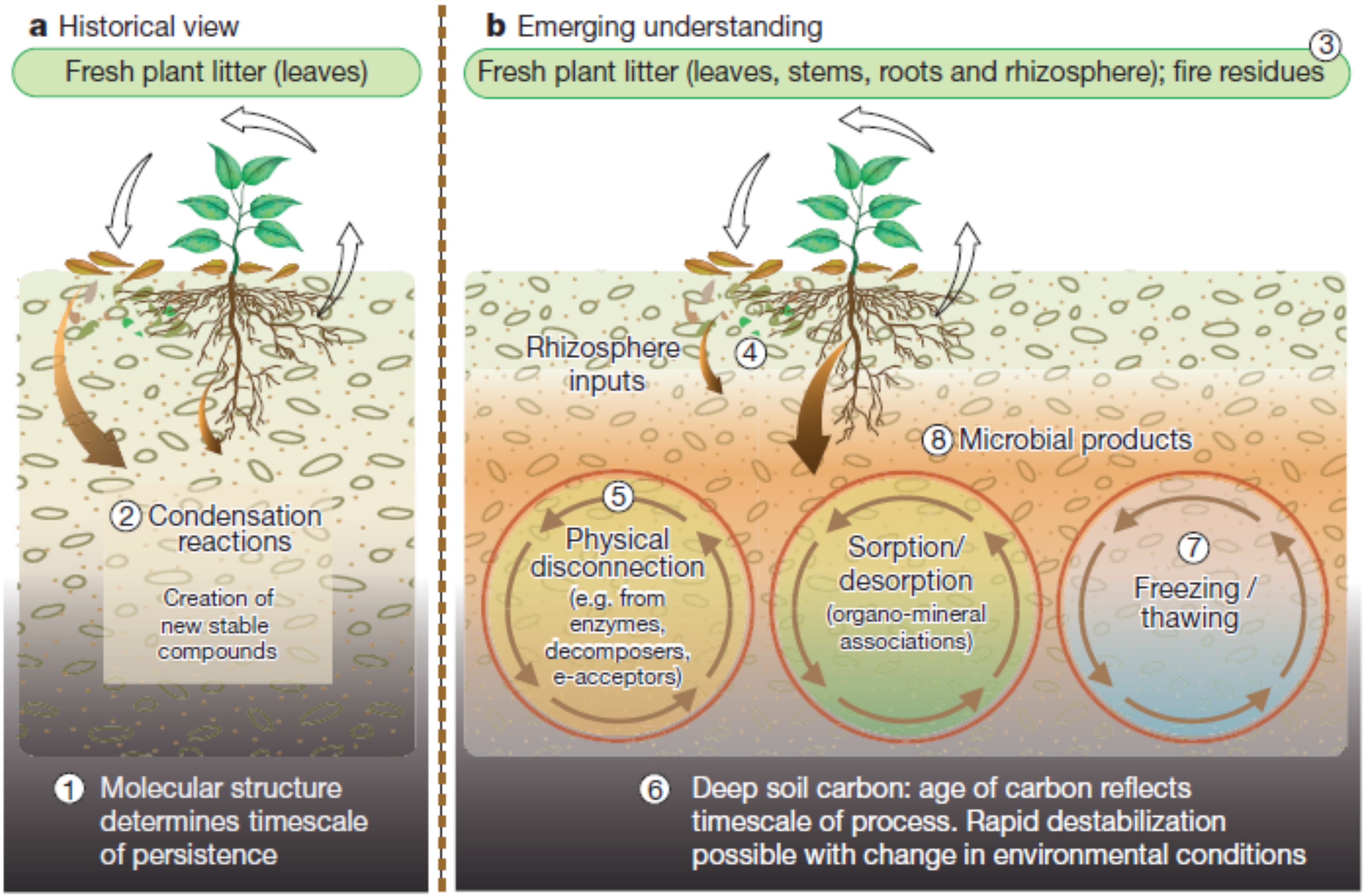
Todd-Brown *et al*. (2013)

Modeling Soil Carbon Pools and Fluxes



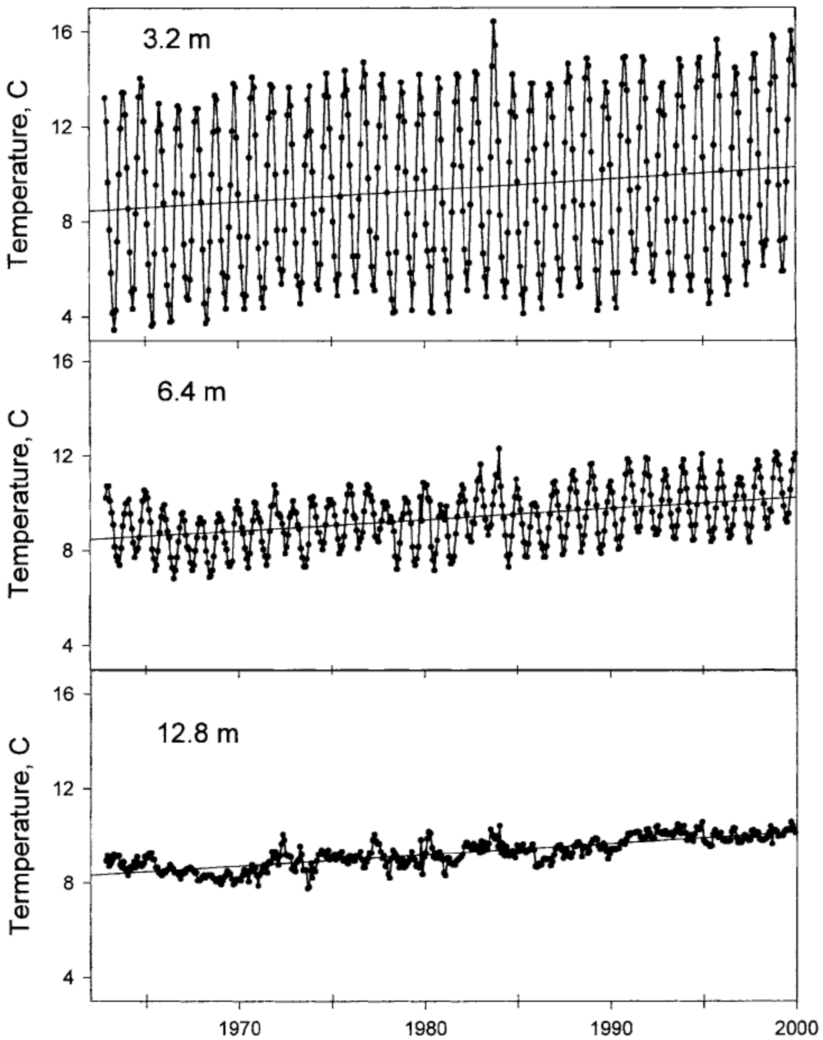
DAYCENT soil organic matter model

Historical and Emerging Views of Soil C Cycling

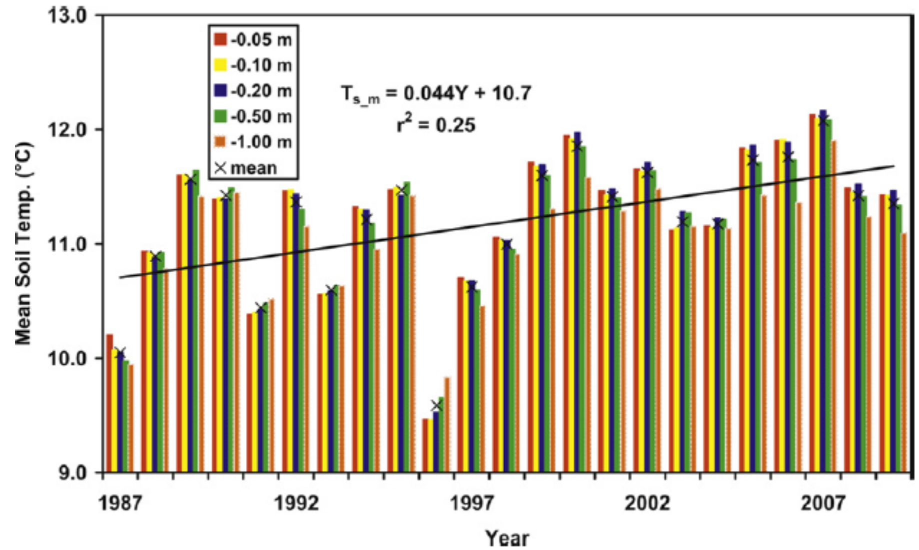


Schmidt et al., 2011

Soil Temperature



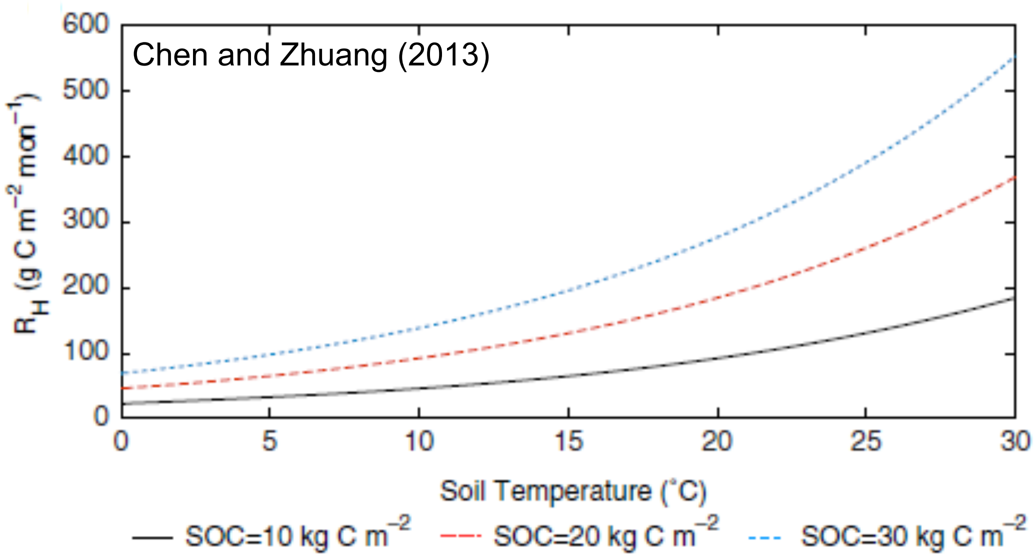
Baker and Baker (2002)



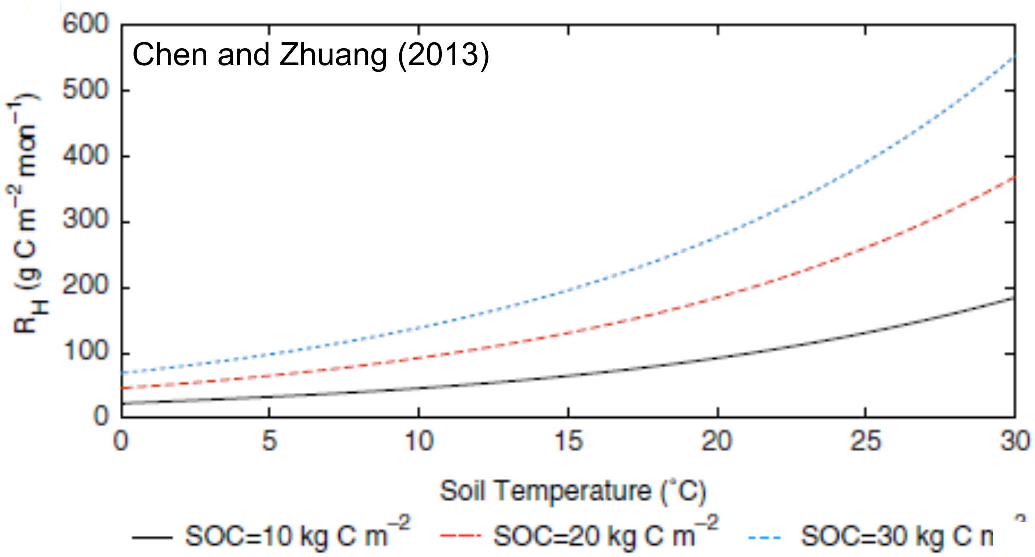
Jacobs *et al*. (2011)

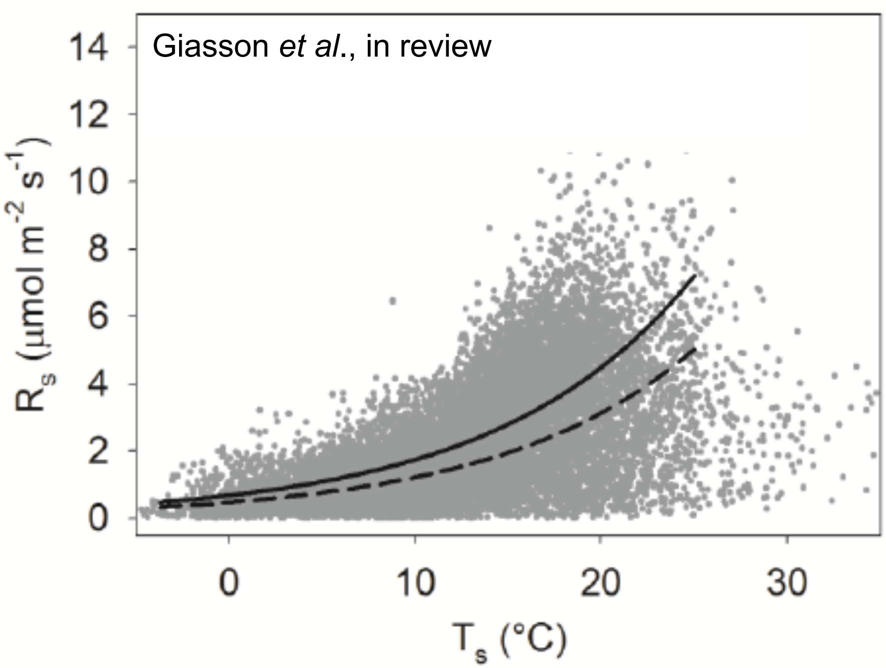
Soil T increase of 0.037-0.049°C yr^{-1}

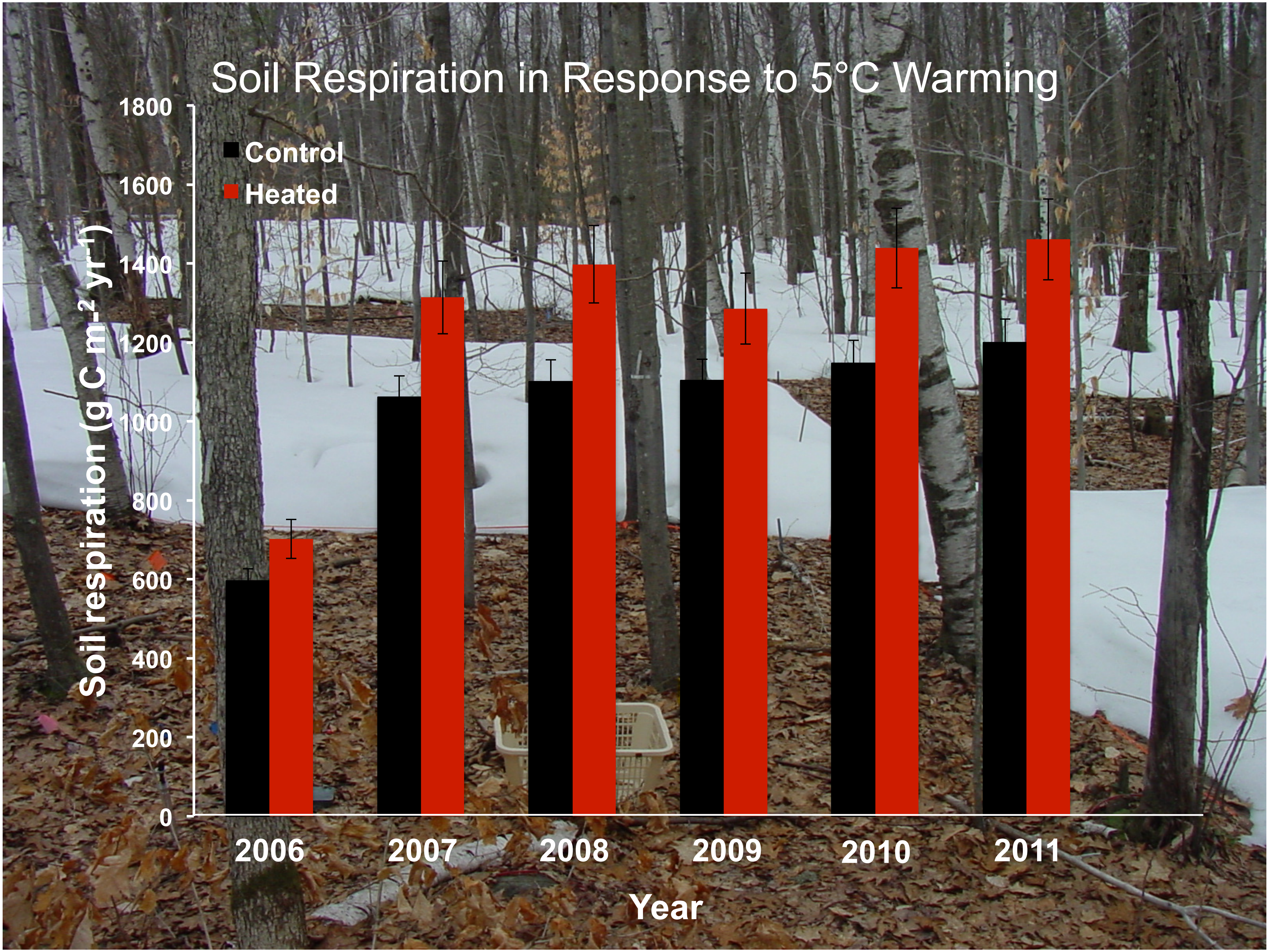
Temperature Response of Soil C Flux



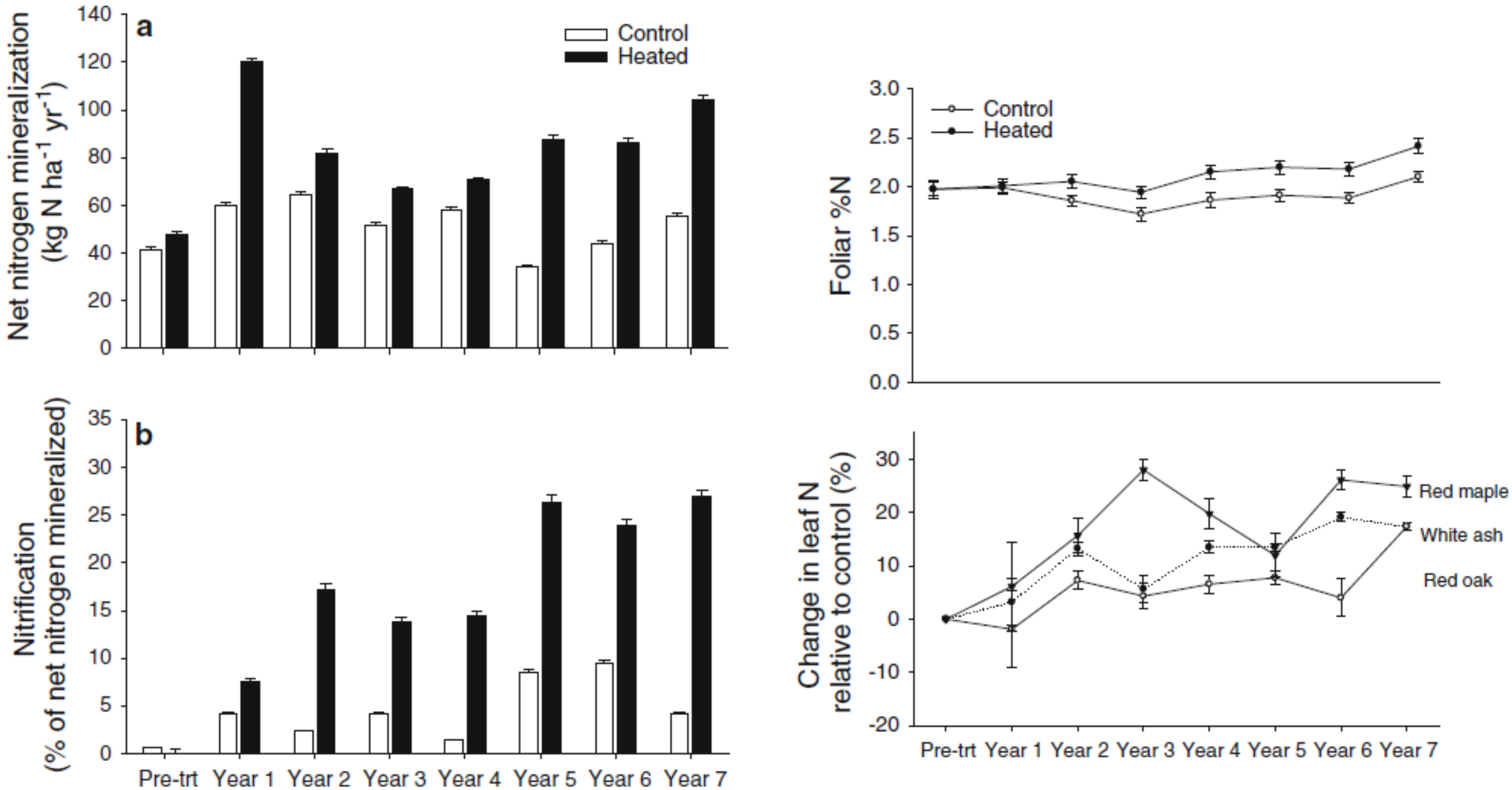
Temperature Response of Soil C Flux






Soil Respiration in Response to 5°C Warming
Control
Heated
Soil respiration (g C m-2 yr-1)
1800
1600
1400
1200
1000
800
600
400
200
0
2006
2007
2008
2009
2010
2011
Year

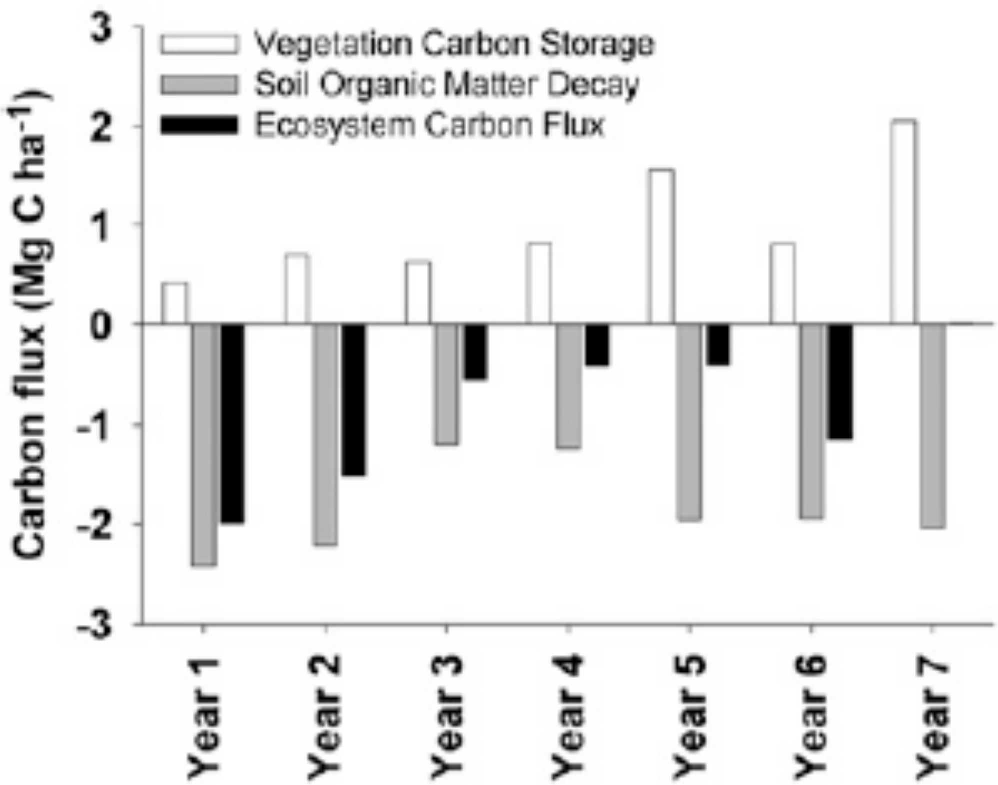
Soil Warming Stimulates the Nitrogen Cycle
Harvard Forest (Barre Woods)



Estimated increase in N availability: 27 kg N ha^{-1} yr^{-1}

Butler *et al*. (2012)

Net Carbon Balance in Response to Soil Warming
Harvard Forest (Barre Woods)



Melillo *et al.* (2011)

Ecosystem Responses to Experimental Warming

Global meta-analysis of 85 studies

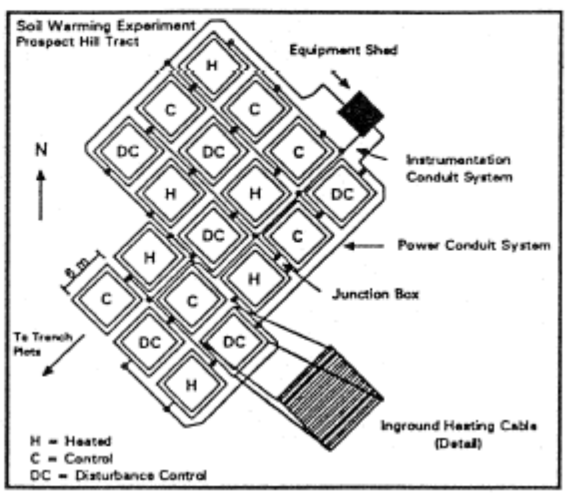
	Warming
Total biomass	0 0 0 + (7)
Aboveground biomass	+ + + + (32)
Belowground biomass	–0 0 0 (6)
TNPP	+ + + + (6)
ANPP	0 0 0 0 (18)
BNPP	+ + + + (5)
Ecosystem respiration	+ + + + (28)
Aboveground respiration	+ + + + (2)
Soil respiration	+ 0 + + (27)
Net ecosystem exchange*	0 0 0 0 (26)
Ecosystem photosynthesis	+ + + + (24)

Soil respiration increased 12% on average

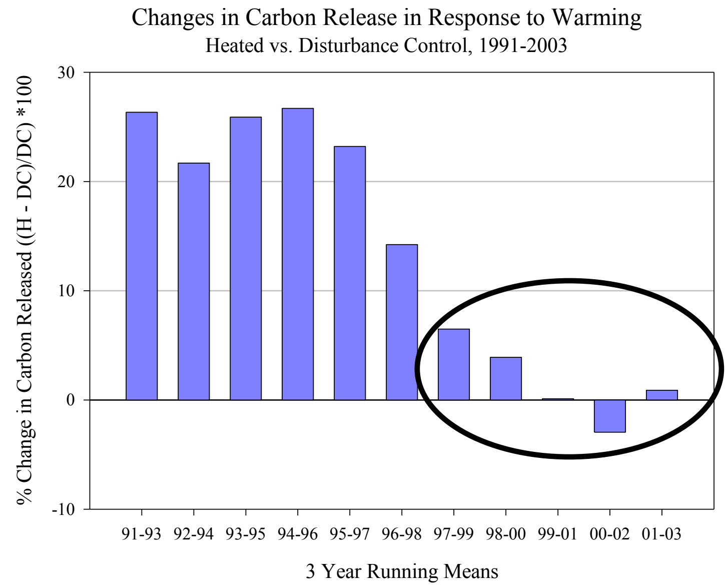
Wu et al., 2011

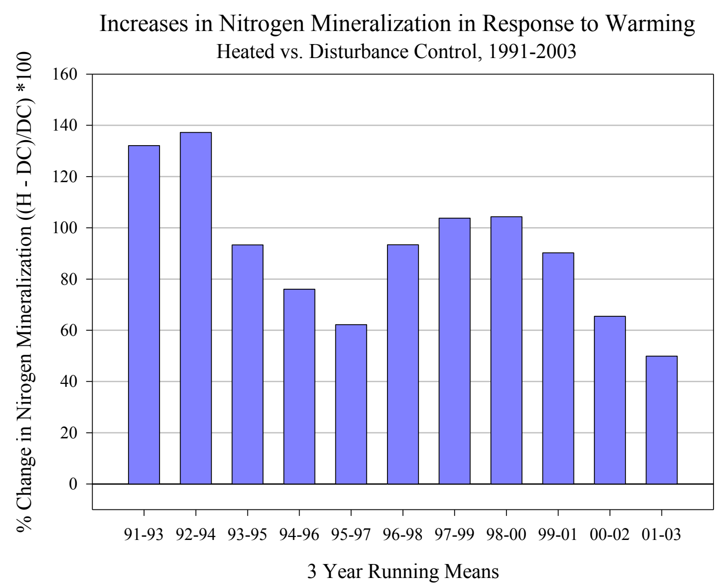
Short-term studies do not anticipate longer term responses

Harvard Forest Soil Warming Study

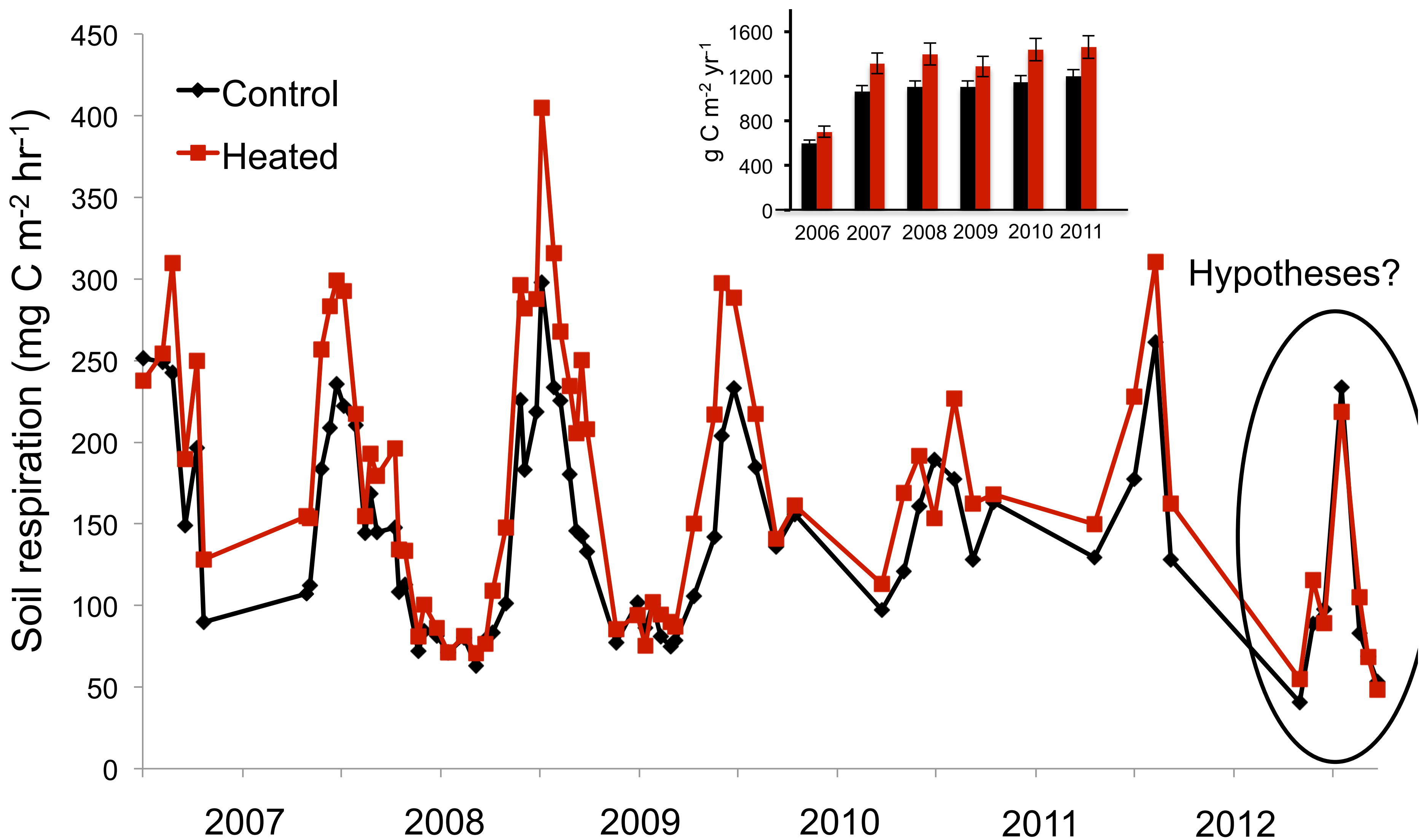


Heated plots:
5ºC above ambient





Melillo et al. (2002)


Soil respiration (mg C m-2 hr-1)
450
400
350
300
250
200
150
100
50
0
Control
Heated
2007
2008
2009
2010
2011
2012
g C m-2 yr-1
1600
1200
800
400
0
2006 2007 2008 2009 2010 2011
Hypotheses?

Research Needs

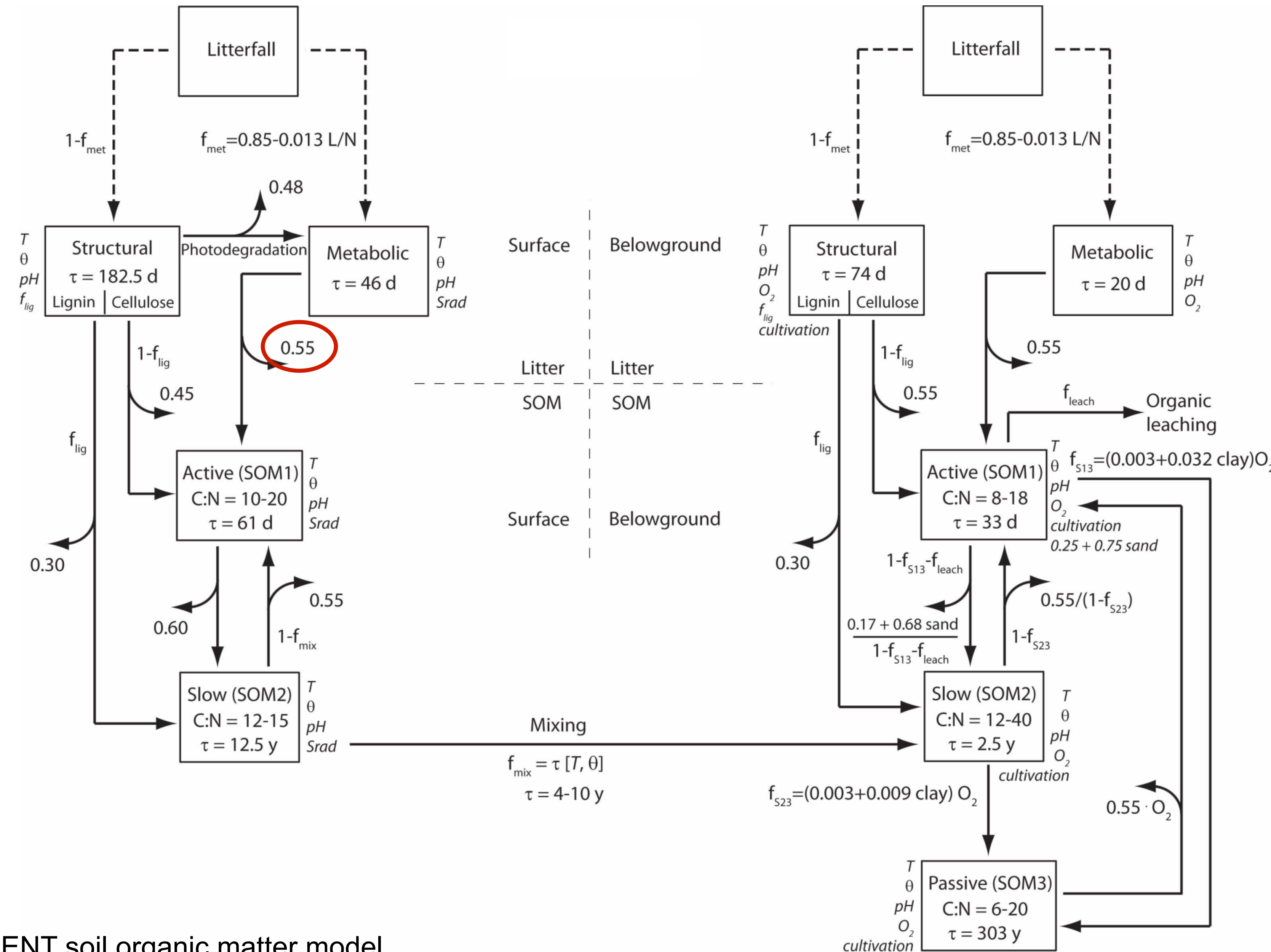
Observations

- Is there differential temperature sensitivity of various SOM compounds?
- What are the mechanisms underlying the reduced respiratory response following long-term warming?

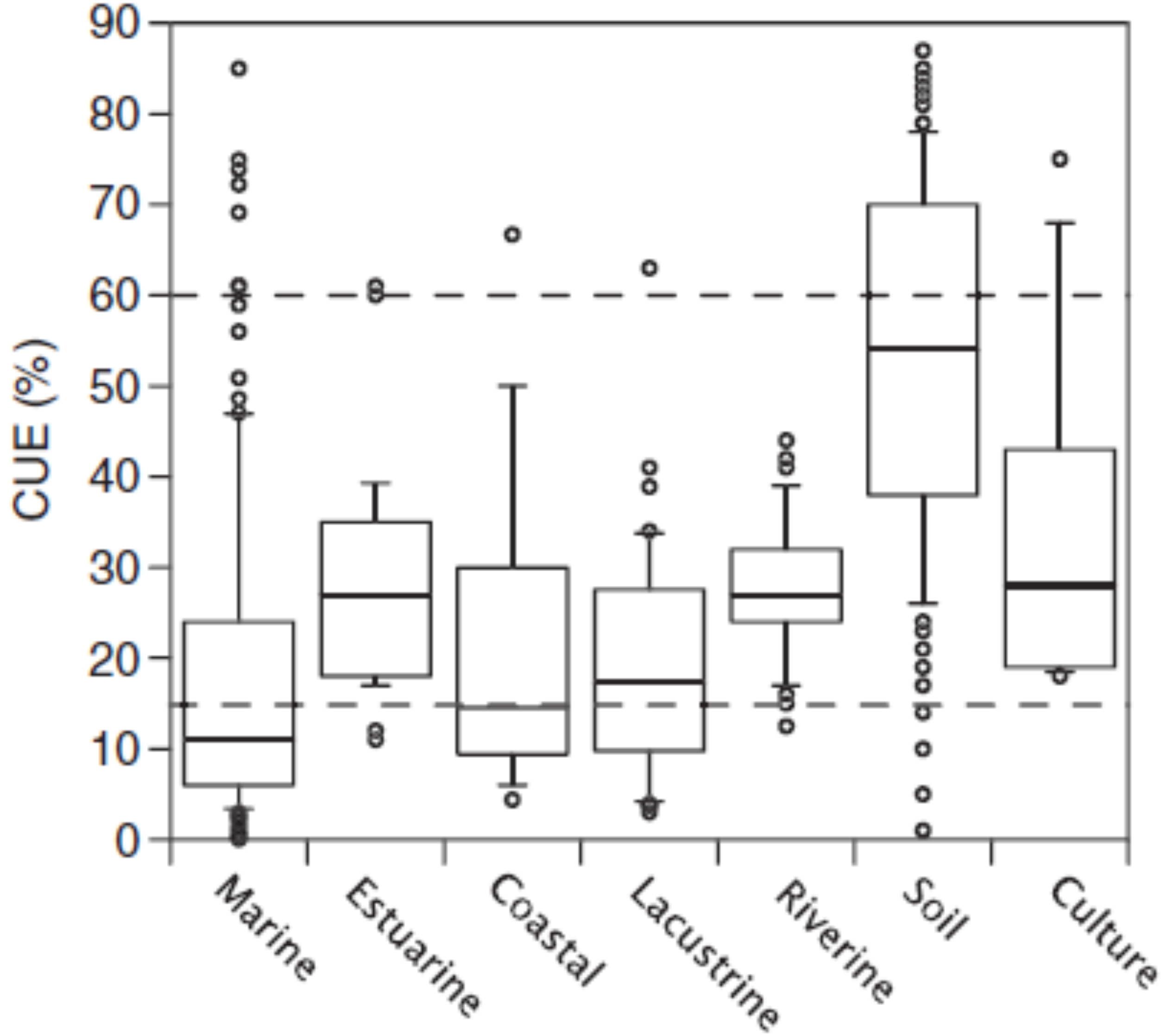
Modeling

- Better capture temperature responses, including “acclimation” of the soil C flux in response to long-term warming

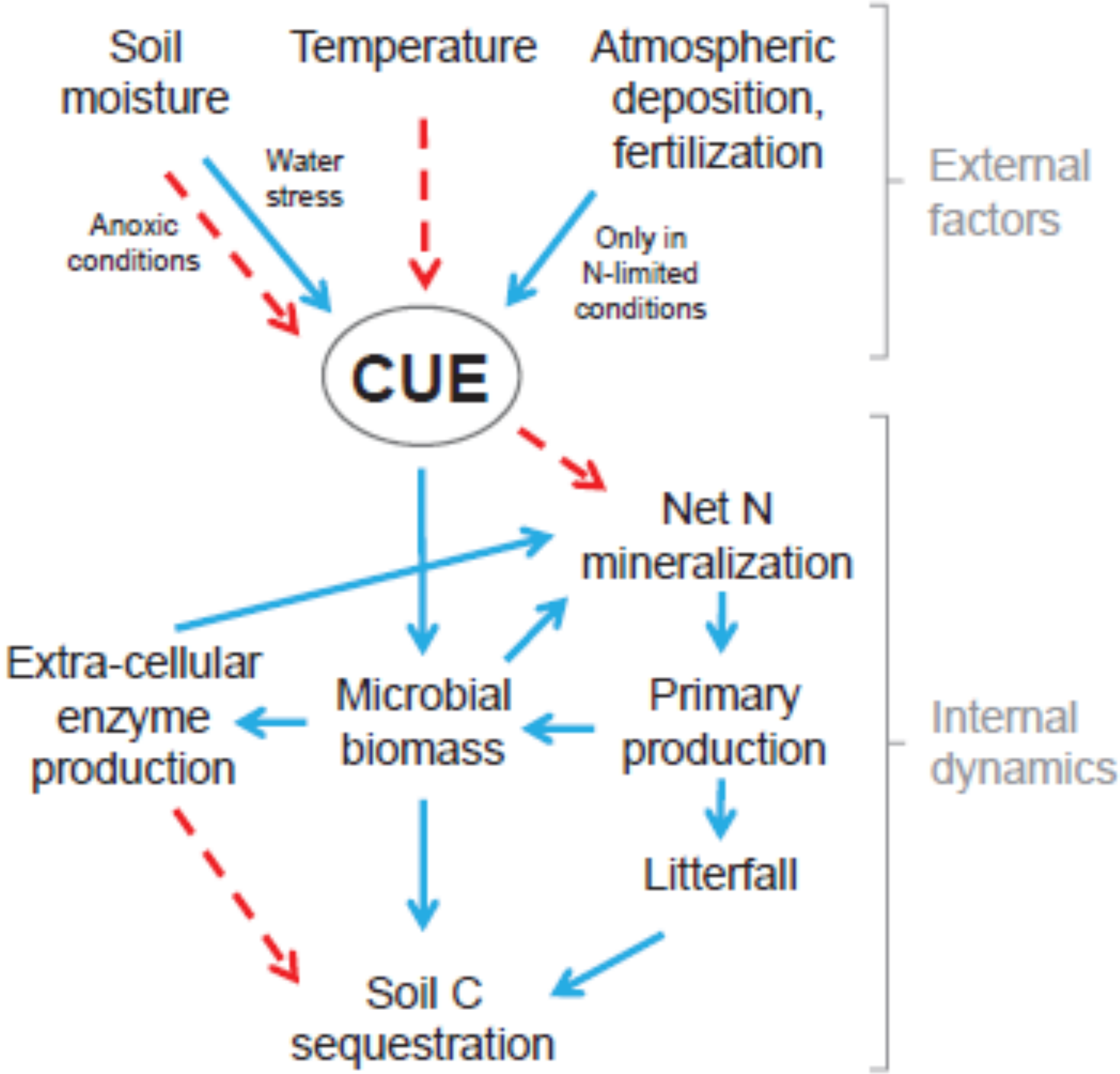
Modeling Microbes



DAYCENT soil organic matter model

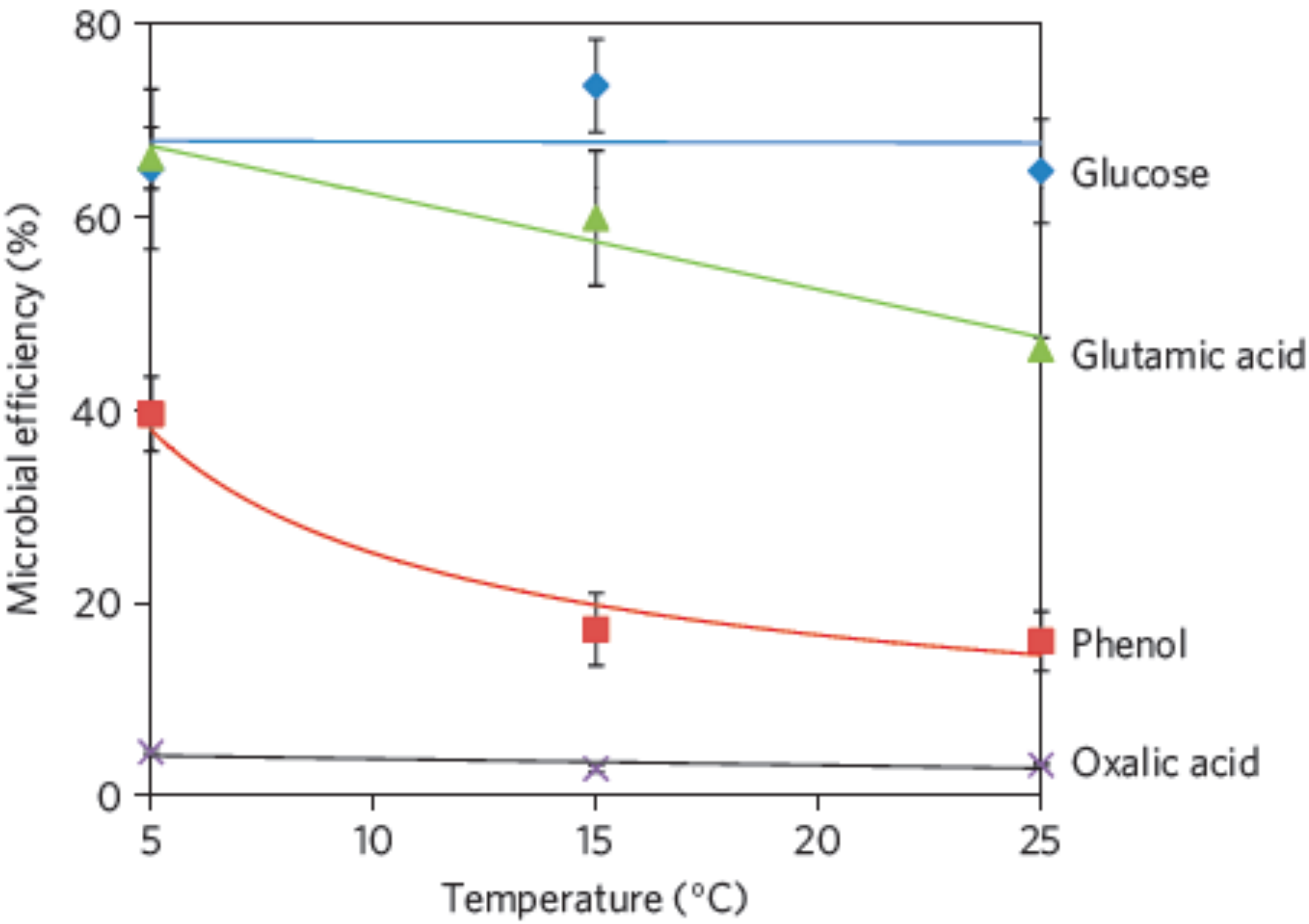


Manzoni *et al.* (2012)

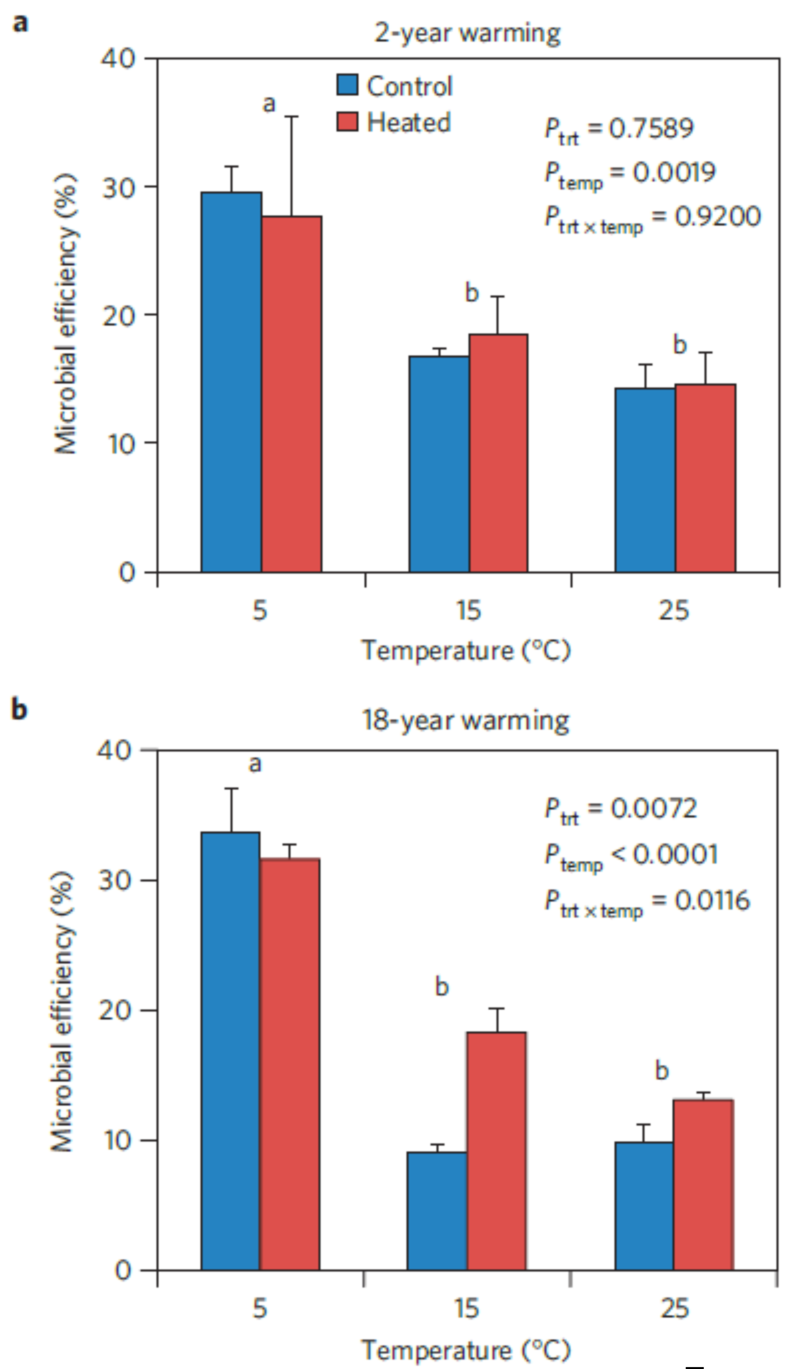


Manzoni *et al*. (2012)

Temperature Response of Microbial Efficiency

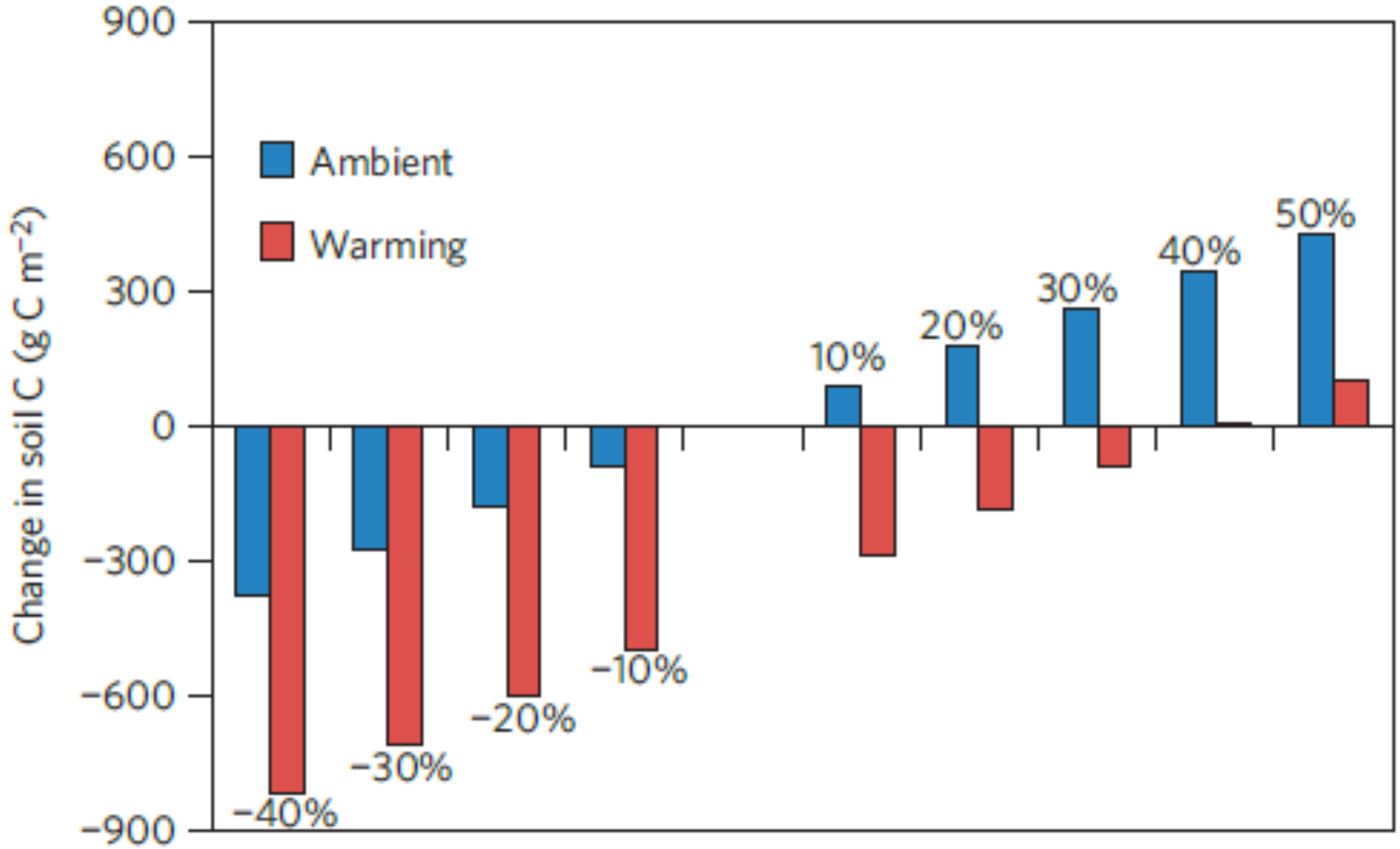


Frey *et al*. (2013) Nature Climate Change

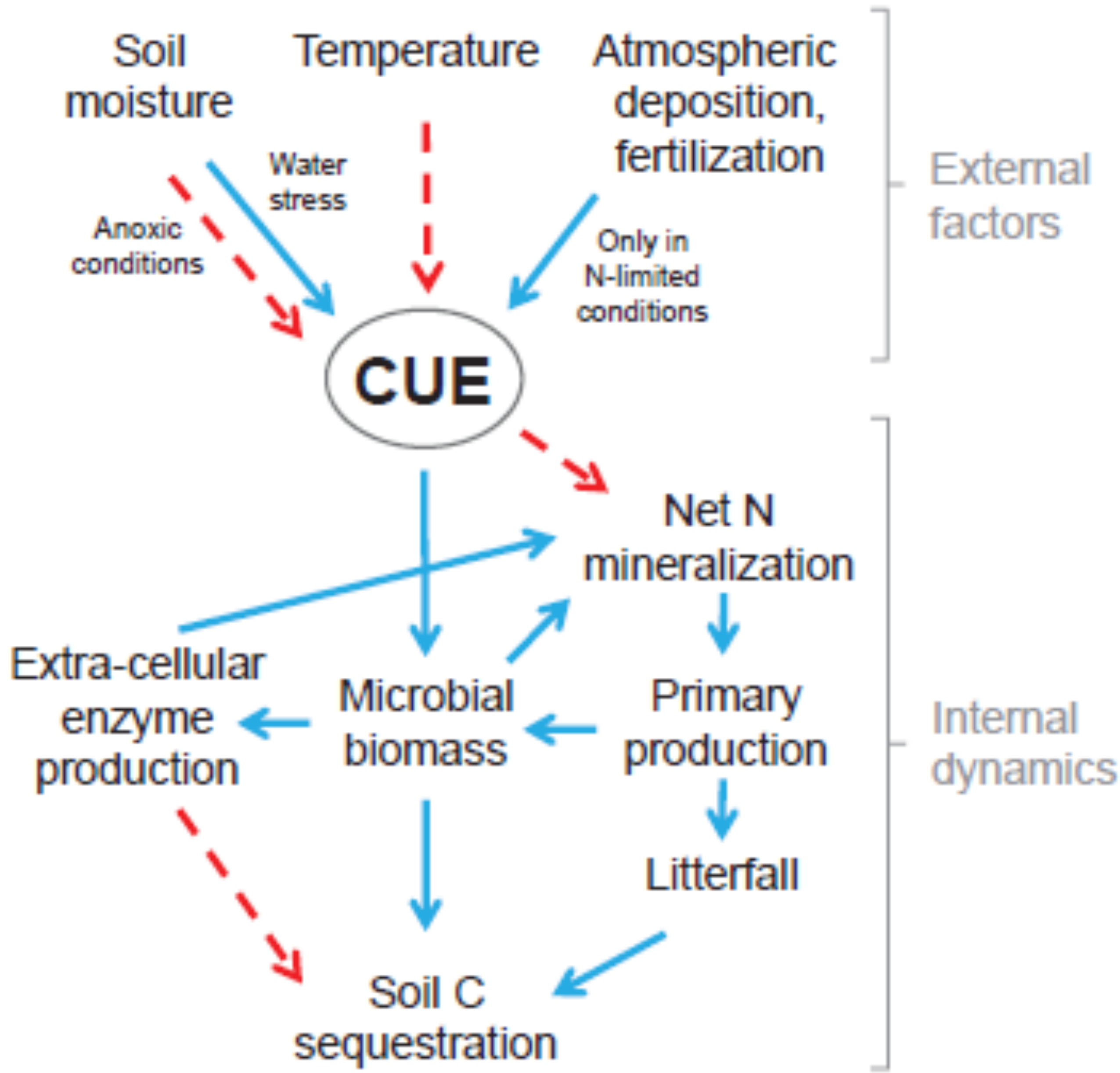


Frey *et al*. (2013) Nature Climate Change

Soil C Response to varying Microbial Efficiency
(DAYCENT)



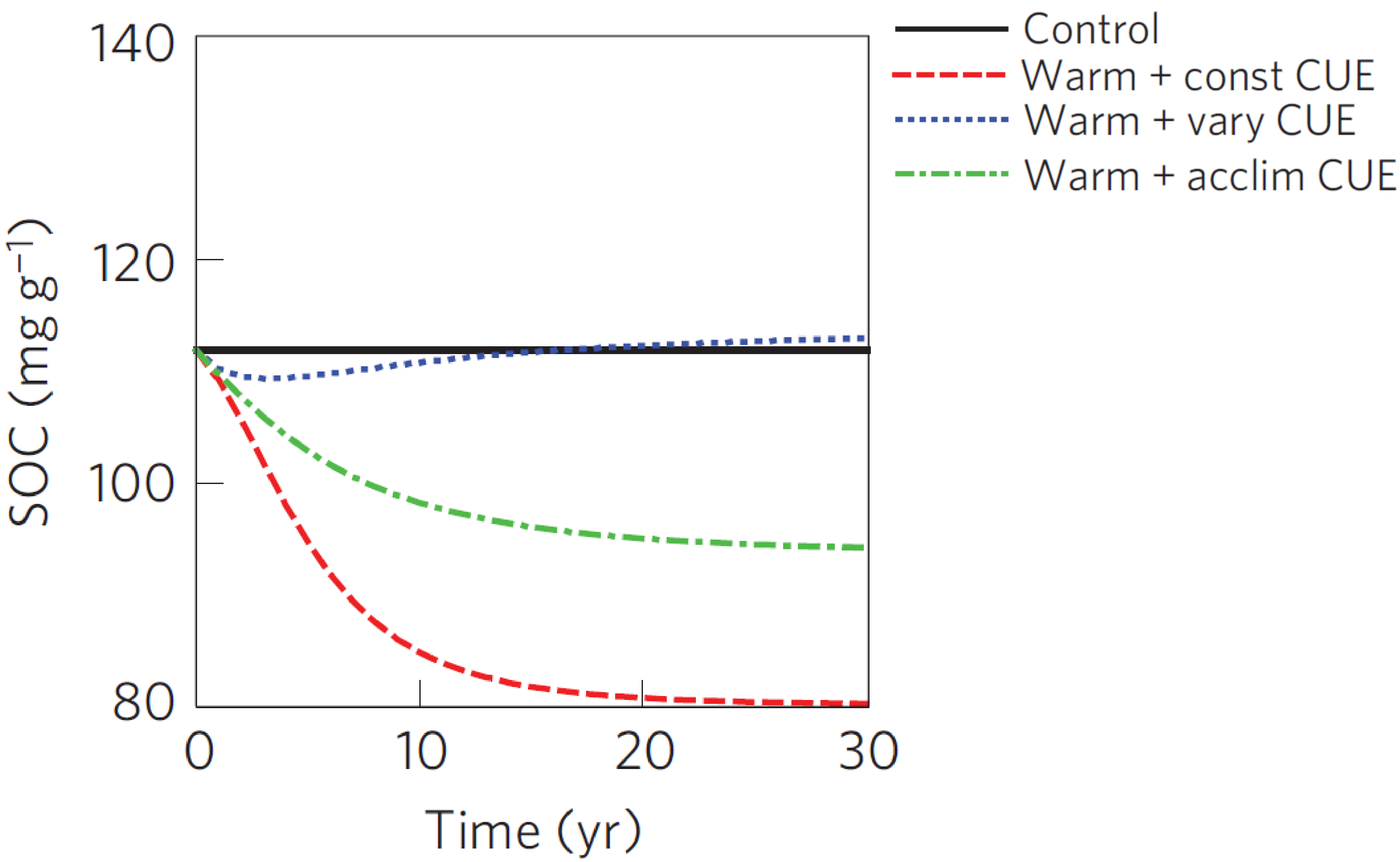
Frey *et al*. (2013) Nature Climate Change



Manzoni *et al*. (2012)

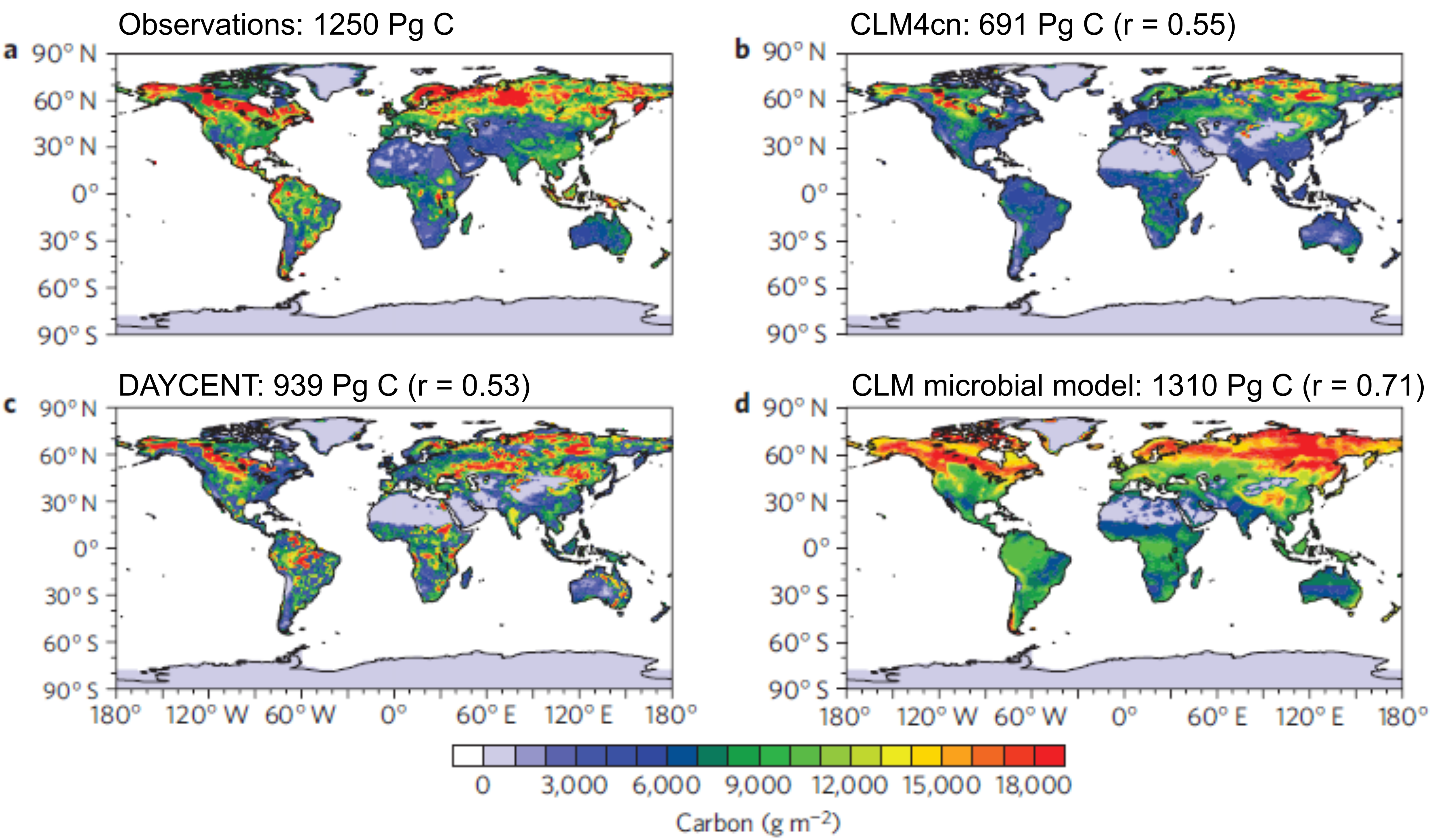
Soil C Response to varying Microbial Efficiency

(Allison et al., 2010)

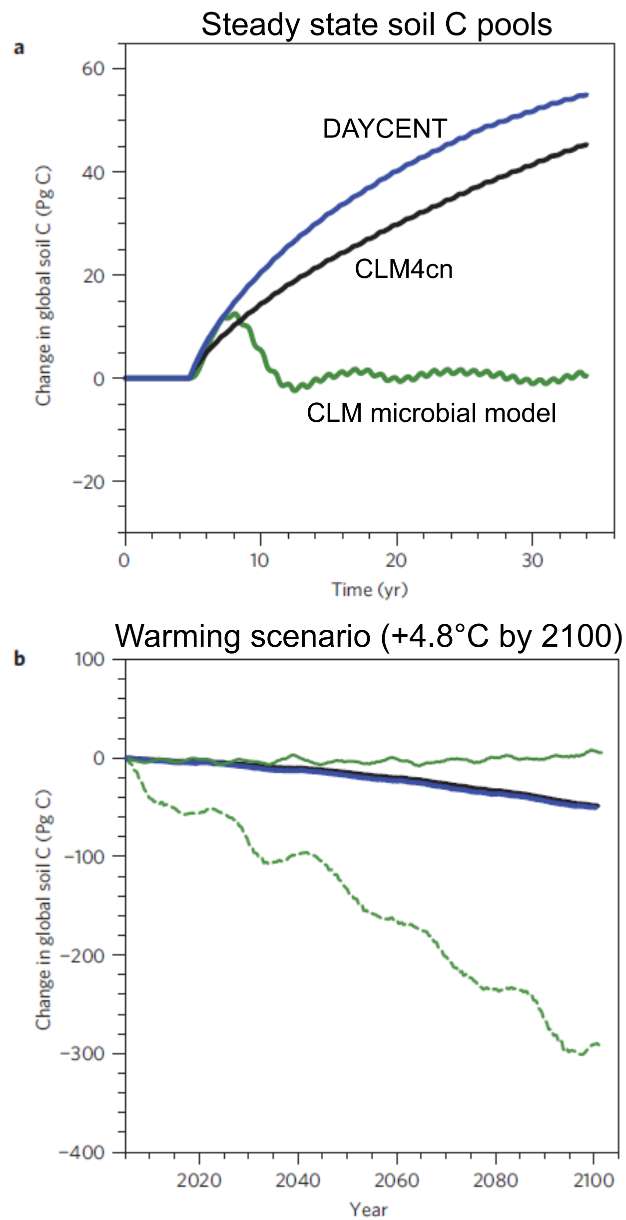


Soil C Response to varying Microbial Efficiency

(Weider et al., 2013)



Divergent model responses of global soil C pools



Wieder *et al*. (2013)

Research Needs

Observations

•Is there differential temperature sensitivity of various SOM compounds?

•What are the mechanisms underlying the reduced respiratory response following long-term warming?

•What are the key regulators of microbial C use efficiency?

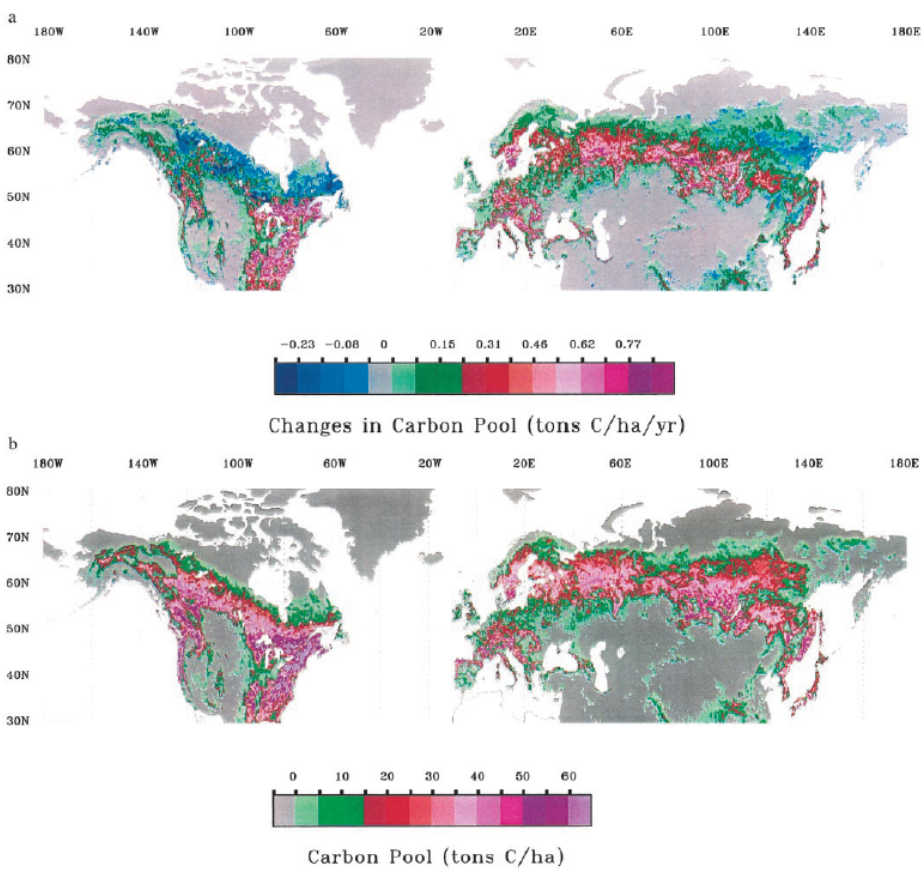
Modeling

•Better capture temperature responses, including “acclimation” of the soil C flux in response to long-term warming

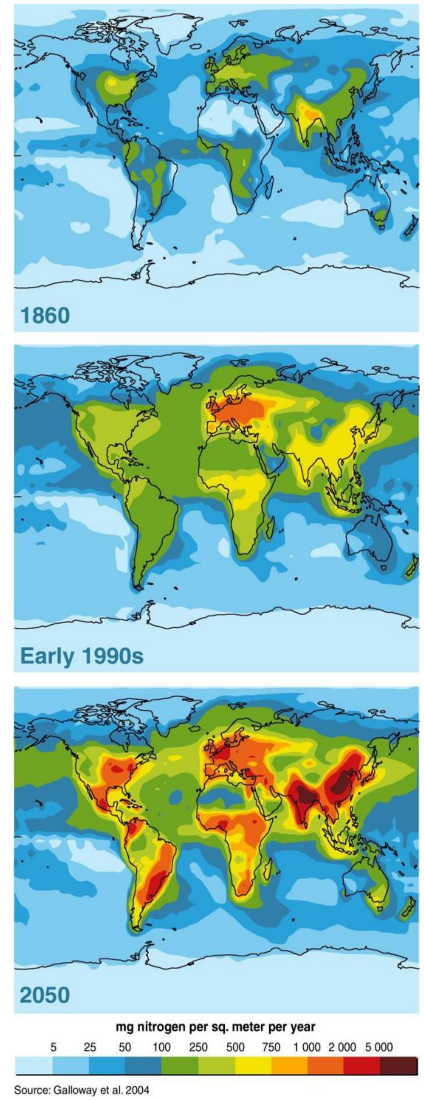
•Incorporate microbial physiology and other soil biogeochemical mechanisms into ESMs

Coupled Biogeochemical Cycles: Nitrogen Deposition and Soil Carbon Storage

Changes in the woody biomass carbon pool of northern temperate and boreal forests

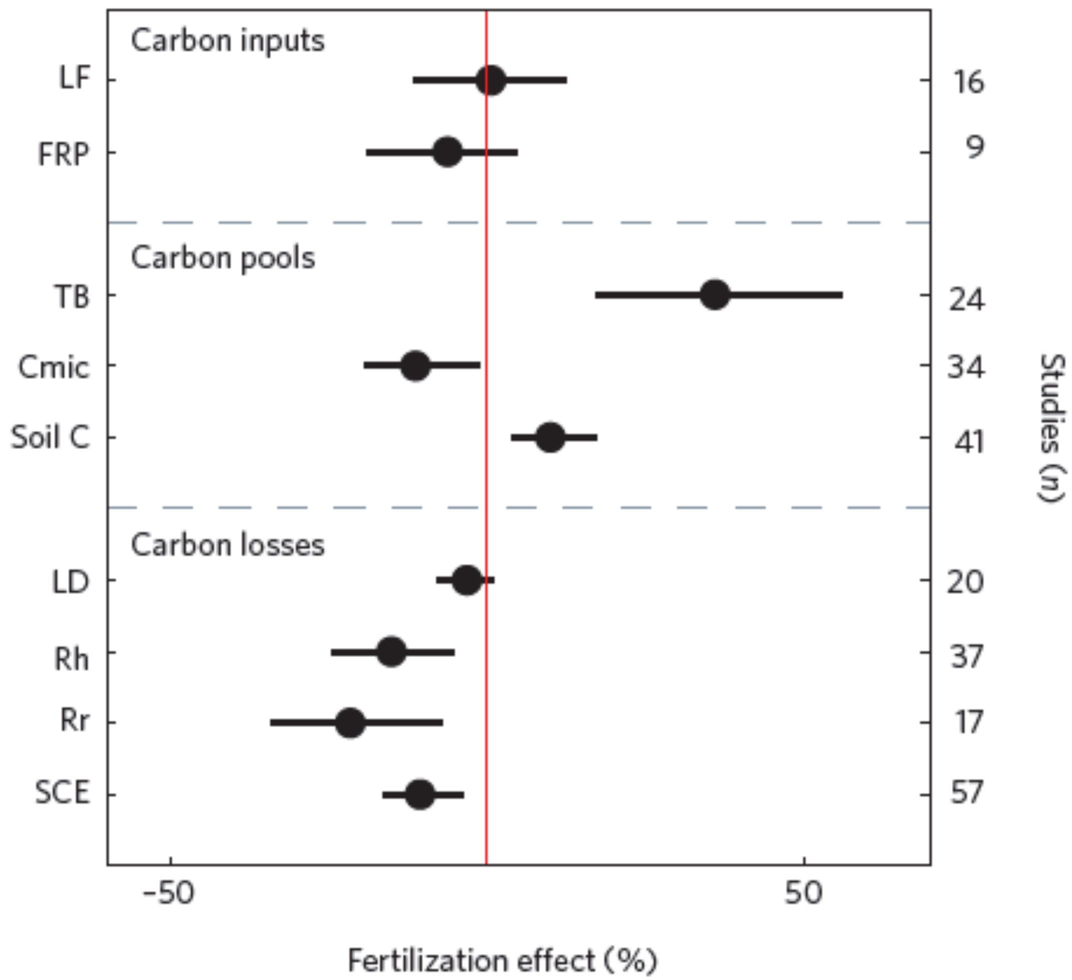


Terrestrial biomass C sink: 0.68 ± 0.34 Pg



Myneni et al. (2001)

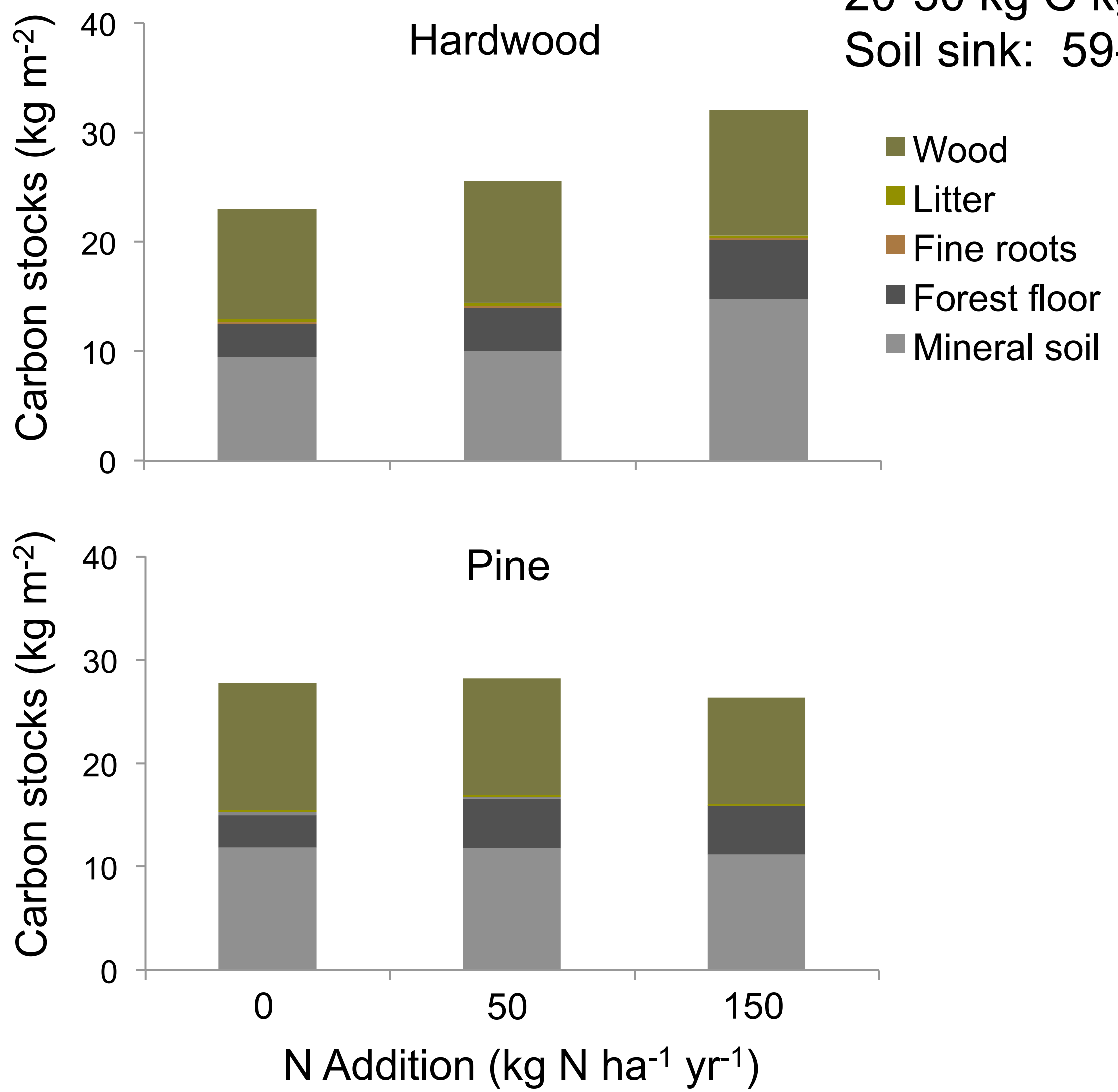
Galloway et al. (2004)



Janssens et al. (2010)

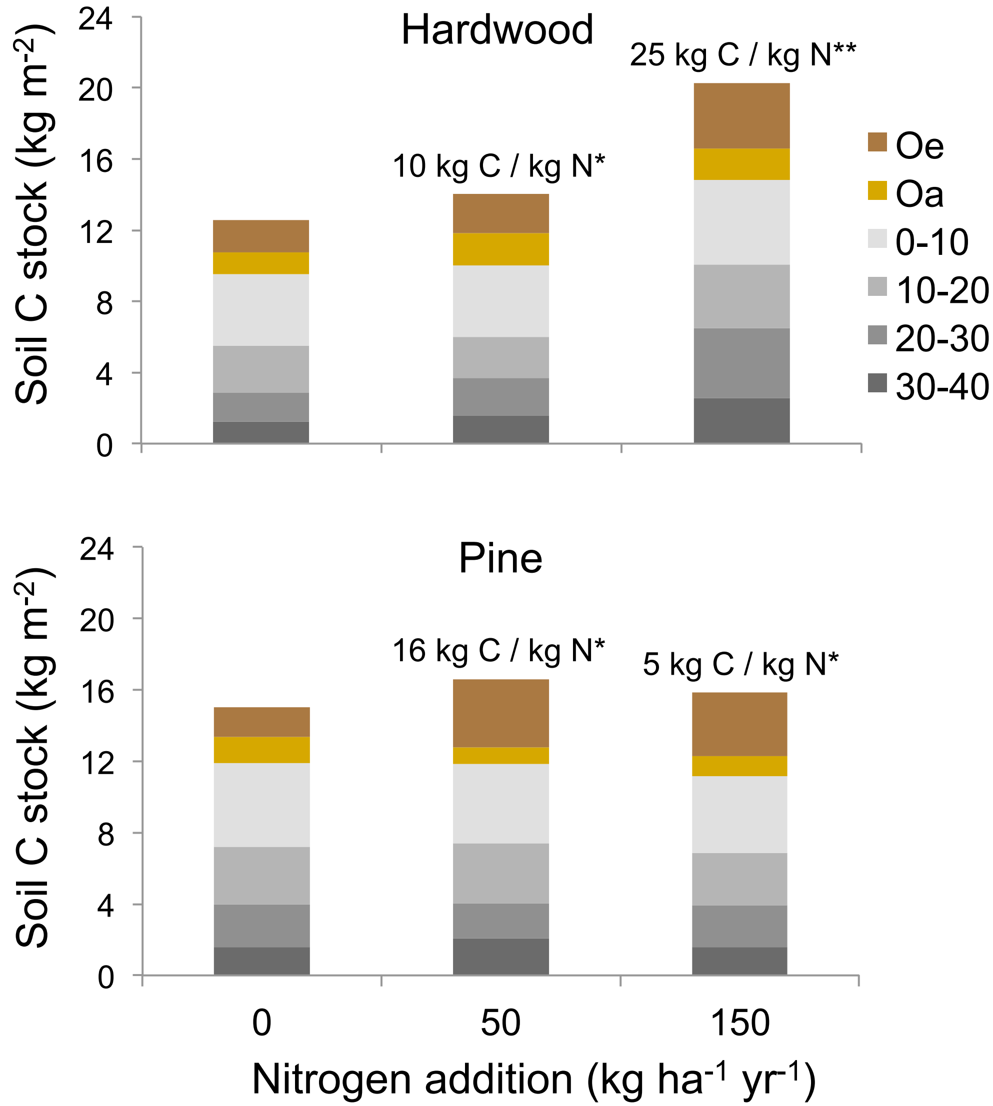
Carbon Stocks in Control and Nitrogen Fertilized Plots

20-30 kg C kg^{-1} N added
Soil sink: 59-87% of total



Frey *et al*. (Nature Geoscience, in prep)

Soil Carbon Stocks



*Forest floor only
**Forest floor plus mineral soil

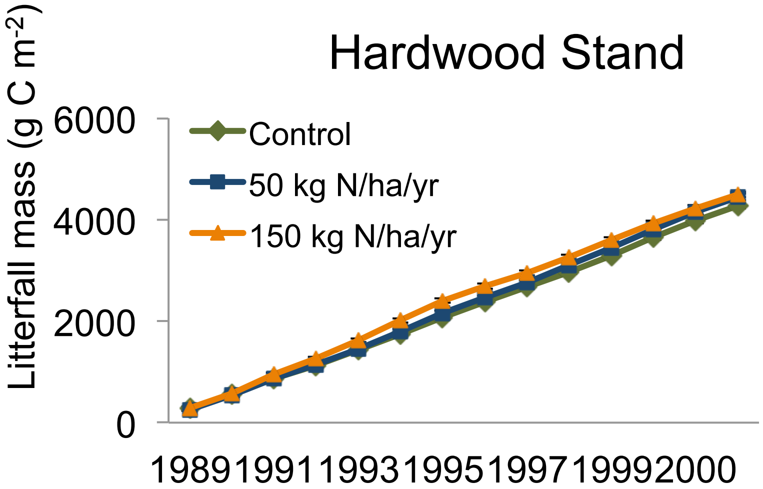
Carbon Sequestration in Temperate Forests per unit Nitrogen Added

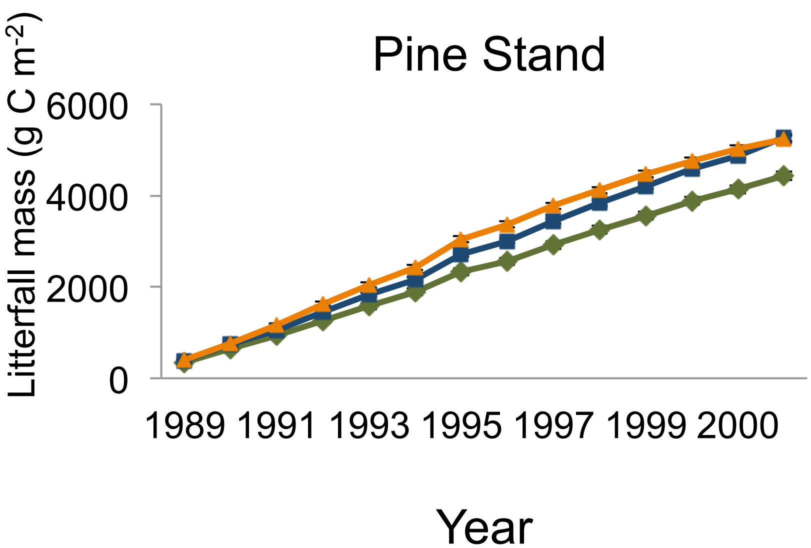
	Study	Nitrogen inputs	Carbon response (kg C kg^{-1} N)			
Study location	duration (yr)	(kg ha^{-1} yr^{-1})	Trees	Soil	Total	Reference
N. America & Europe (9 sites)	1-3	4-58	25[‡]	21	46	Nadelhoffer *et al*. (1999)
Europe (121 plots)	40	2.8	11[δ]	15	26	de Vries *et al*. (2006)
Finland, Sweden (15 sites)	14-30	30-200	25	11	26	Hyvönen *et al*. (2008)
Michigan, USA (4 sites)	10	30	0	14	14	Zak *et al*. (2008)
Meta-analysis (20 experiments)	--	28-300	--	19[£]	--	Janssens *et al*. (2010)
Deciduous stand (MA, USA)	20	50	10	10	20	This study
Deciduous stand (MA, USA)	20	150	5	25	30	This study
Pine stand (MA, USA)	20	50	-10	16	6	This study
Pine stand (MA, USA)	20	150	-7	5	-2	This study

Growing consensus that the soil C pool is as or more responsive to N additions than is NPP

Frey *et al*. (Nature Geoscience, in prep)

Carbon Inputs to Soil

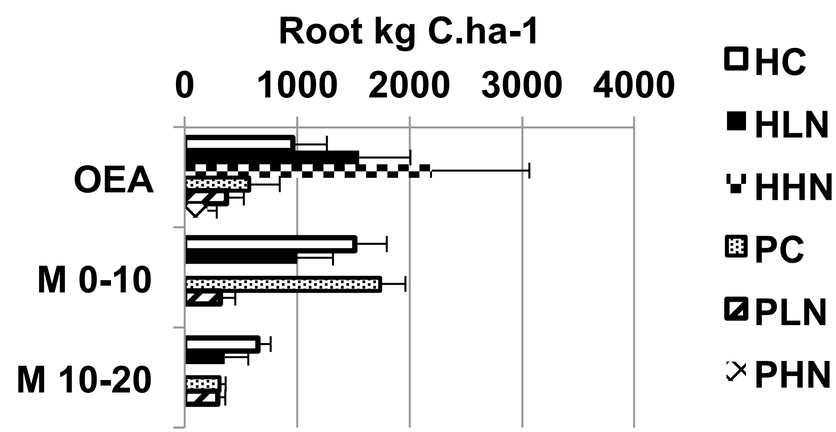




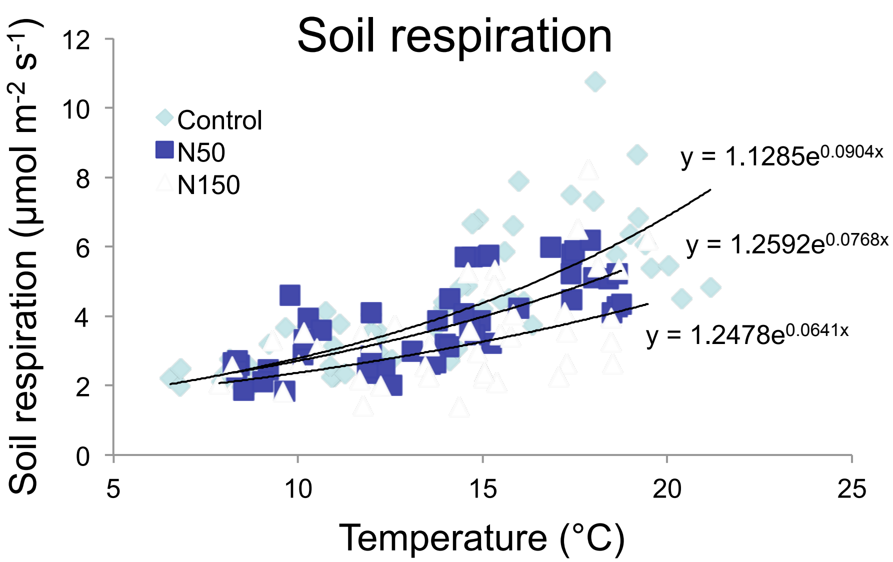
With N fertilization:

	Hardwood	Pine
Litterfall	↔	↑
Root biomass	↔	↓
Root productivity	↔	?
Root respiration	↔	↔ ↓

C inputs not dominant mechanism (~10-30%)

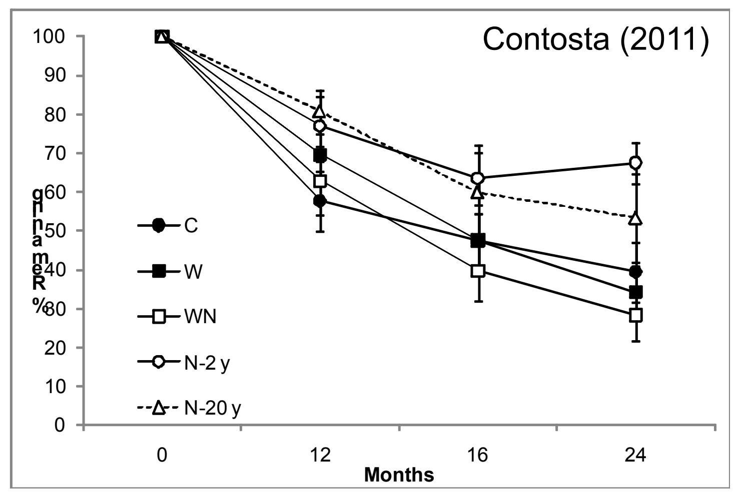


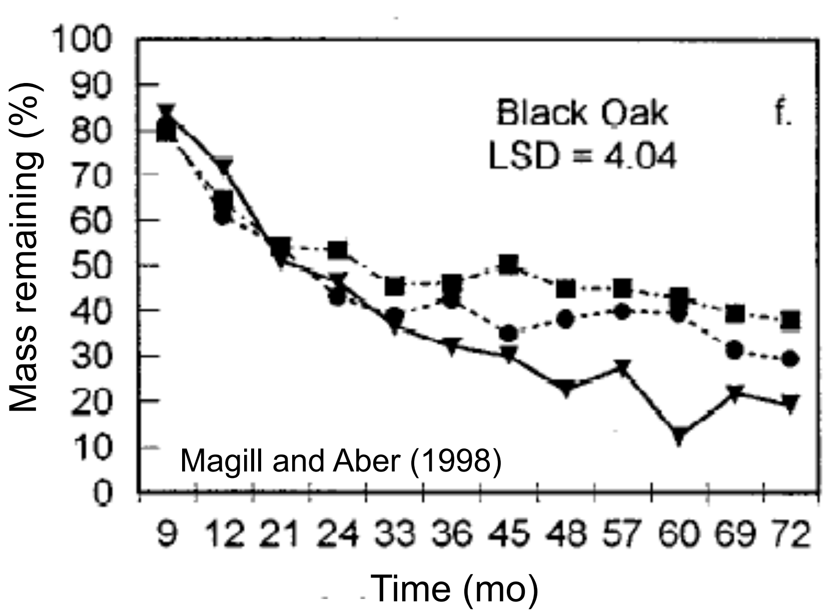
Carbon Outputs



With N fertilization:

- Soil respiration consistently lower
- Litter and wood decay suppressed



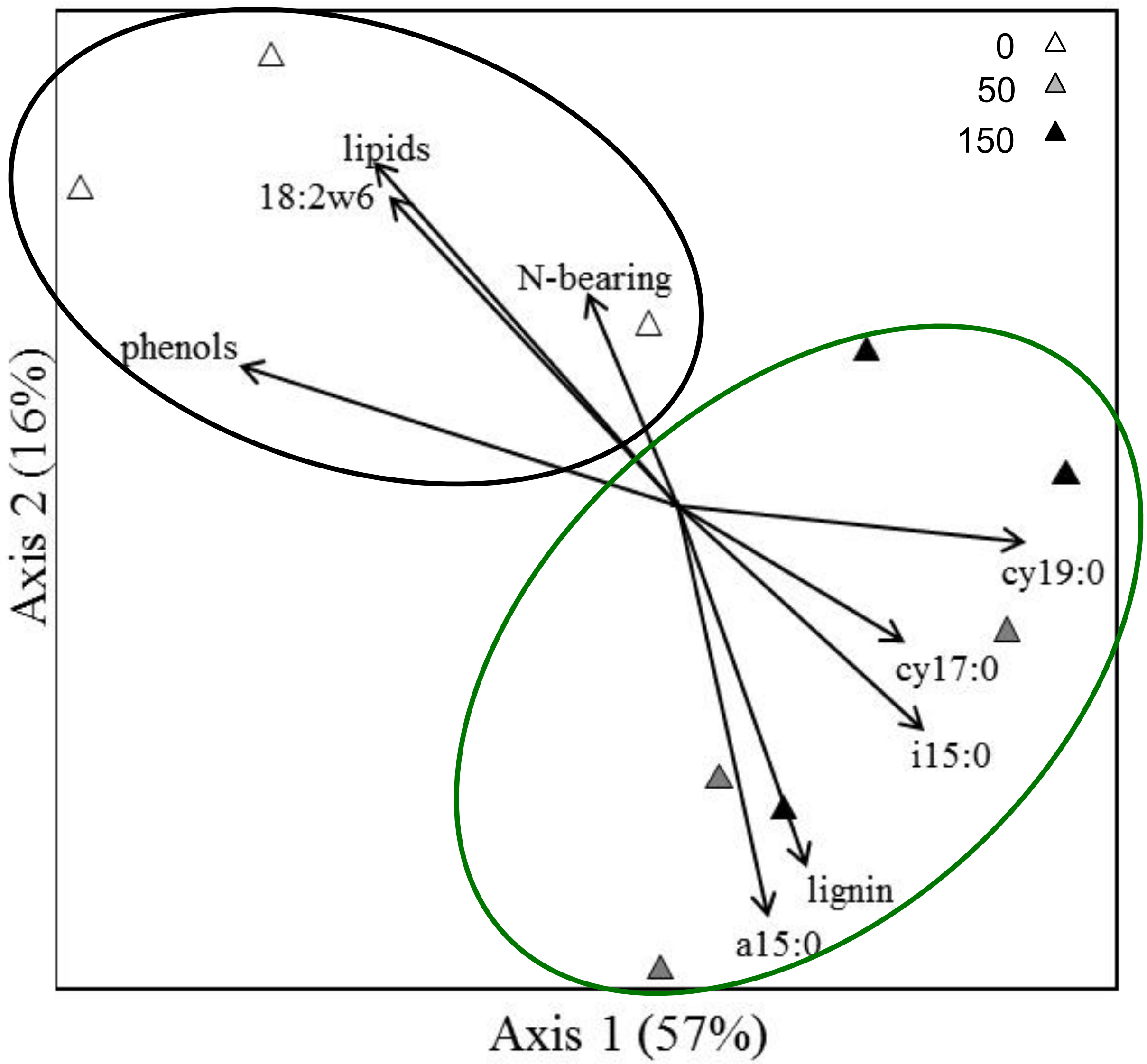


Magill and Aber (1998)

Photo by
K. Dudzik

Organic Matter Chemistry

Pyrolysis-GCMS of forest floor material (hardwood stand)



Frey *et al*. (Nature Geoscience, in prep)

Research Needs

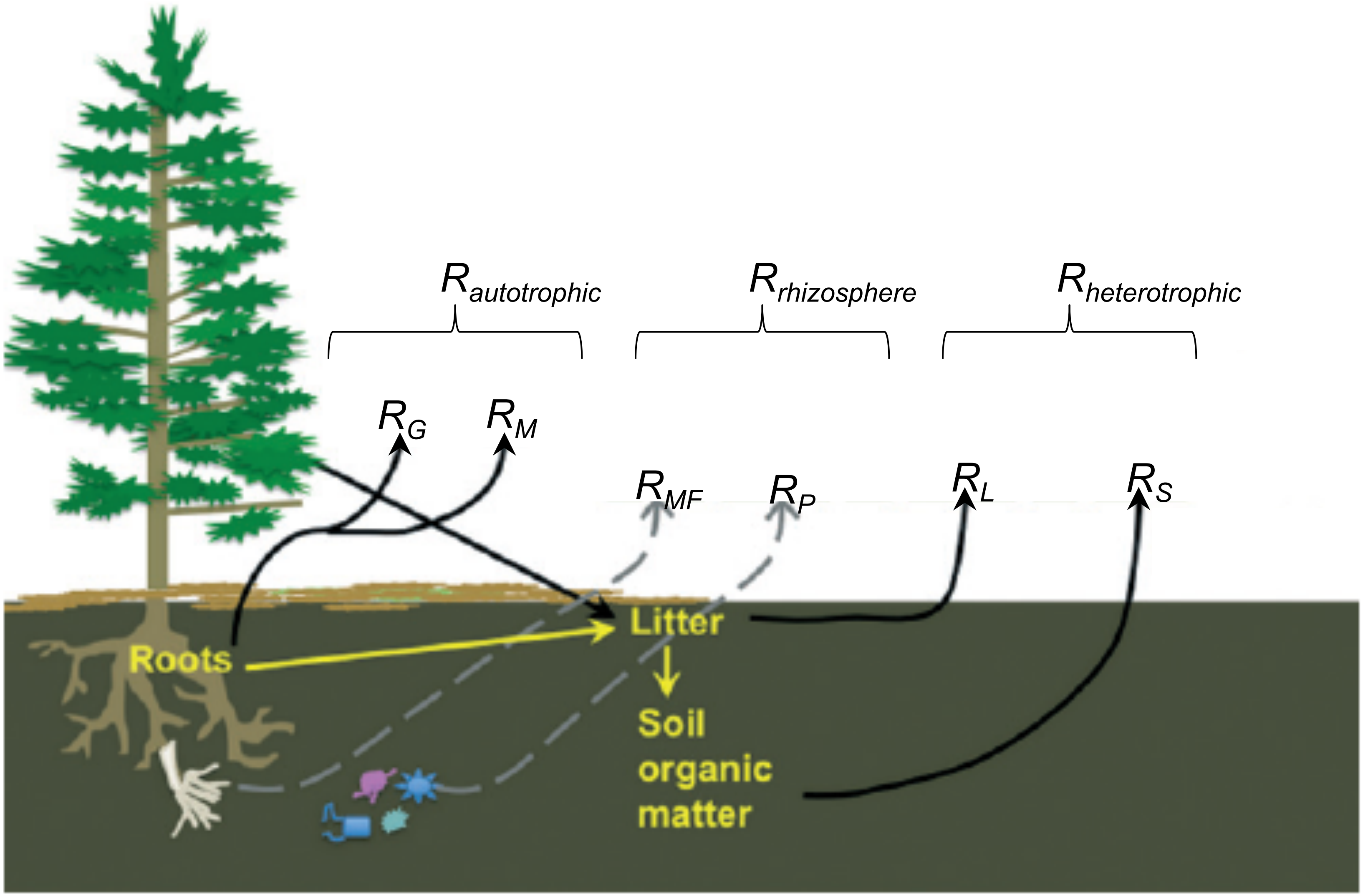
Observations

•Is there differential temperature sensitivity of various SOM compounds?
•What are the mechanisms underlying the reduced respiratory response following long-term warming?
•What are the key regulators of microbial C use efficiency?
•Need better estimates of global soil C stocks
•Priming

Modeling

•Better capture temperature responses, including “acclimation” of the soil C flux in response to long-term warming
•Incorporate microbial physiology and other biogeochemical mechanisms into ESMs
•Incorporation of N feedbacks on soil C storage (N deposition rates predicted to double by 2050)
•Priming

Soil Respiration Components



Modified from Hopkins *et al*. (2013)