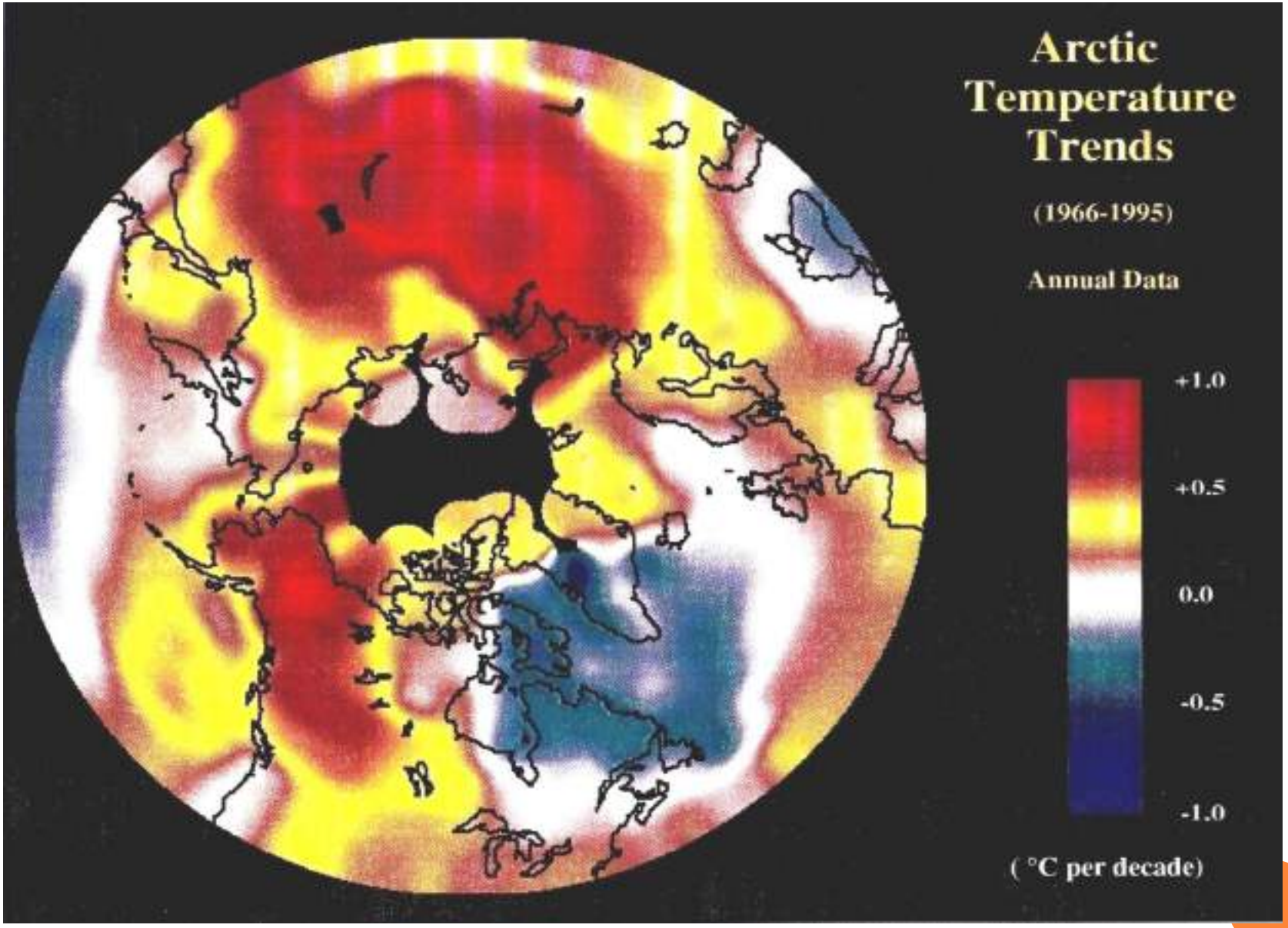


PURDUE
UNIVERSITY

Towards a new generation of C and N biogeochemistry models by incorporating more detailed Plant and microbial traits and physiological processes

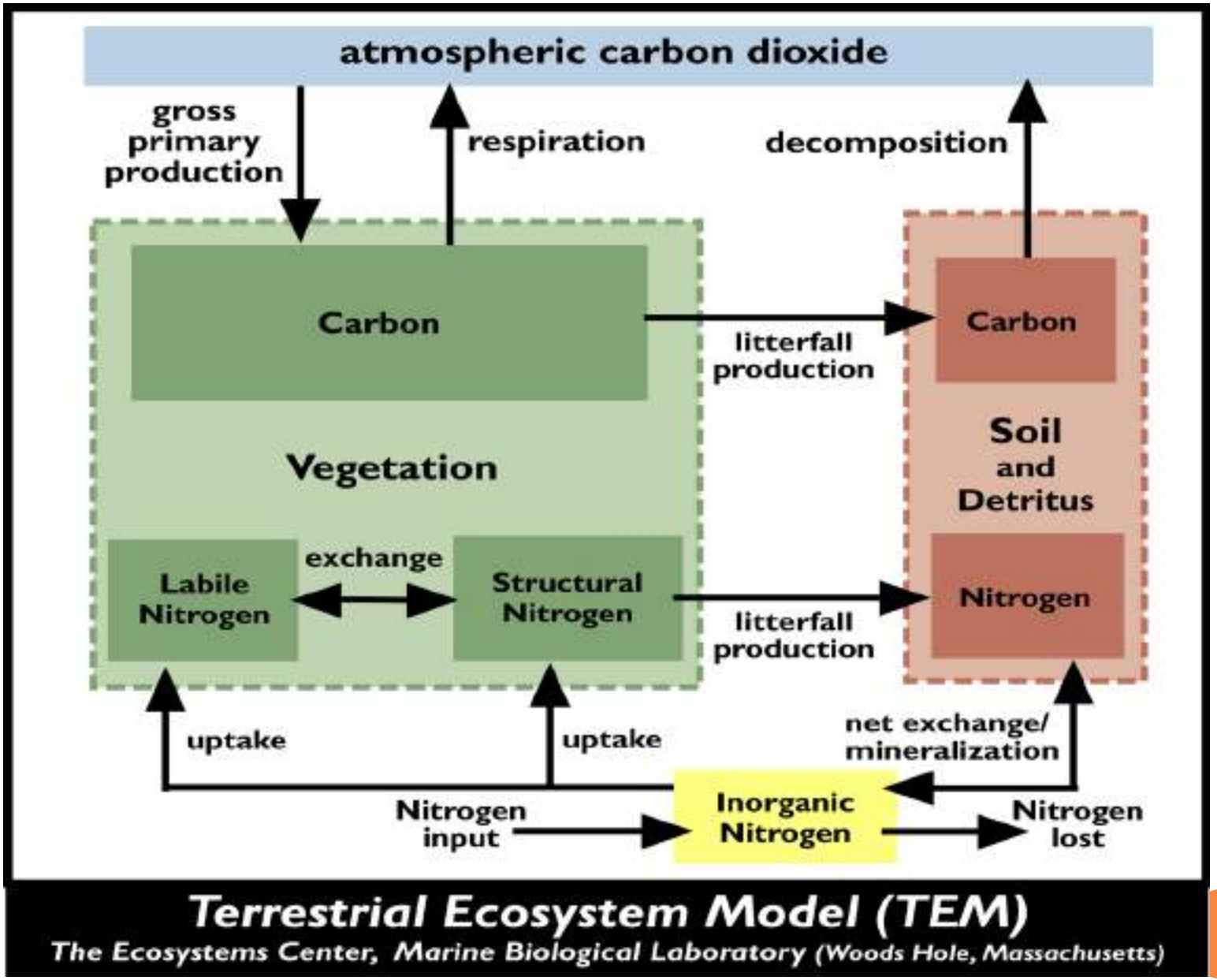
Qianlai Zhuang



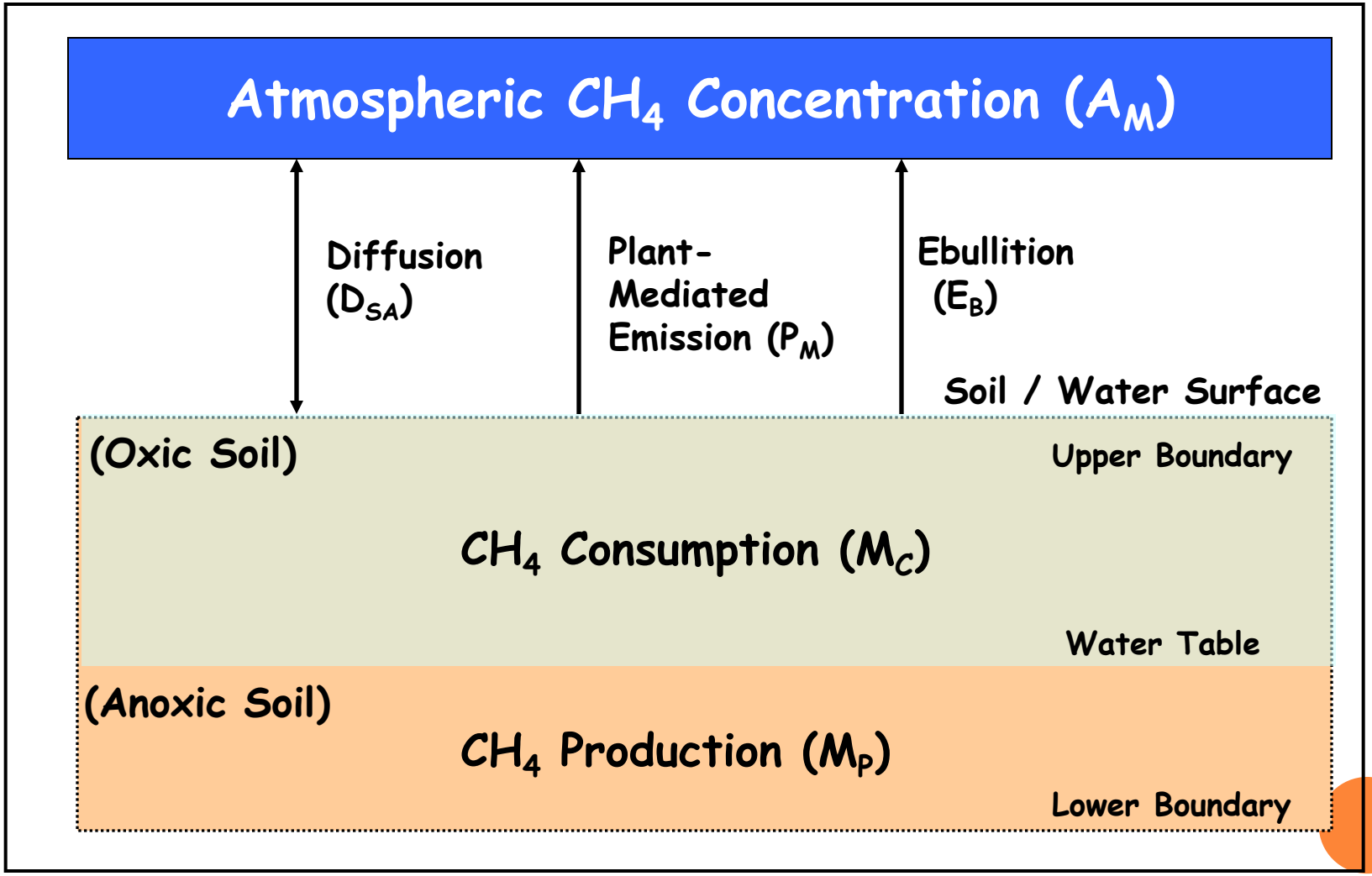
(Serreze et al. 2000, Climatic Change)

Overarching Questions

- What is the current budget of CO_2 and CH_4 of the global land ecosystems?
- How will the budget change over the 21st century?
- What is the impact of the budget change on climate in the 21st century?

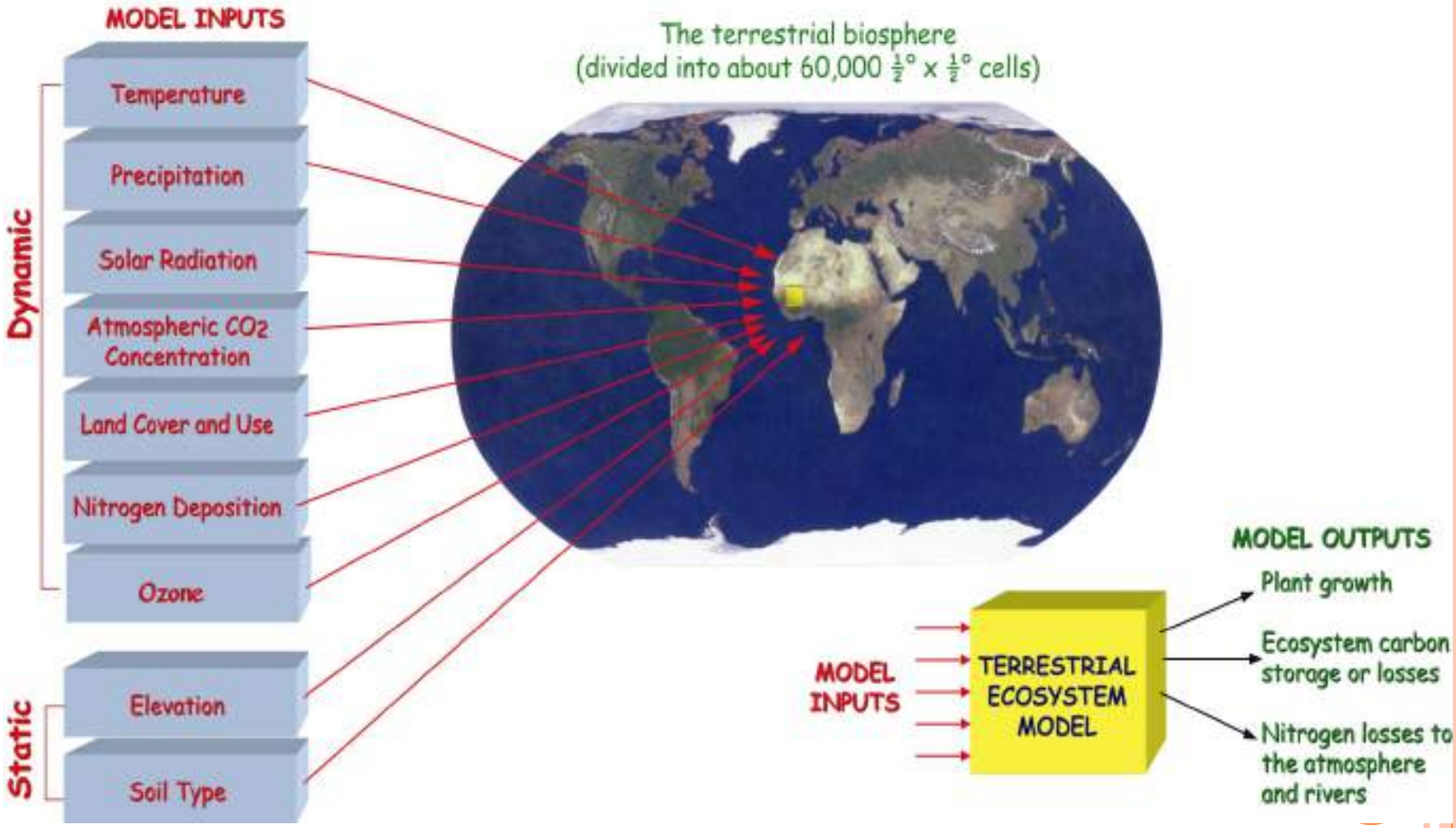

atmospheric carbon dioxide
gross primary production
respiration
decomposition
Carbon
Vegetation
litterfall production
Carbon
Soil and Detritus
Labile Nitrogen
exchange
Structural Nitrogen
litterfall production
Nitrogen
uptake
uptake
net exchange/ mineralization
Nitrogen input
Inorganic Nitrogen
Nitrogen lost
Terrestrial Ecosystem Model (TEM)
The Ecosystems Center, Marine Biological Laboratory (Woods Hole, Massachusetts)

Methane Consumption and Emission Model

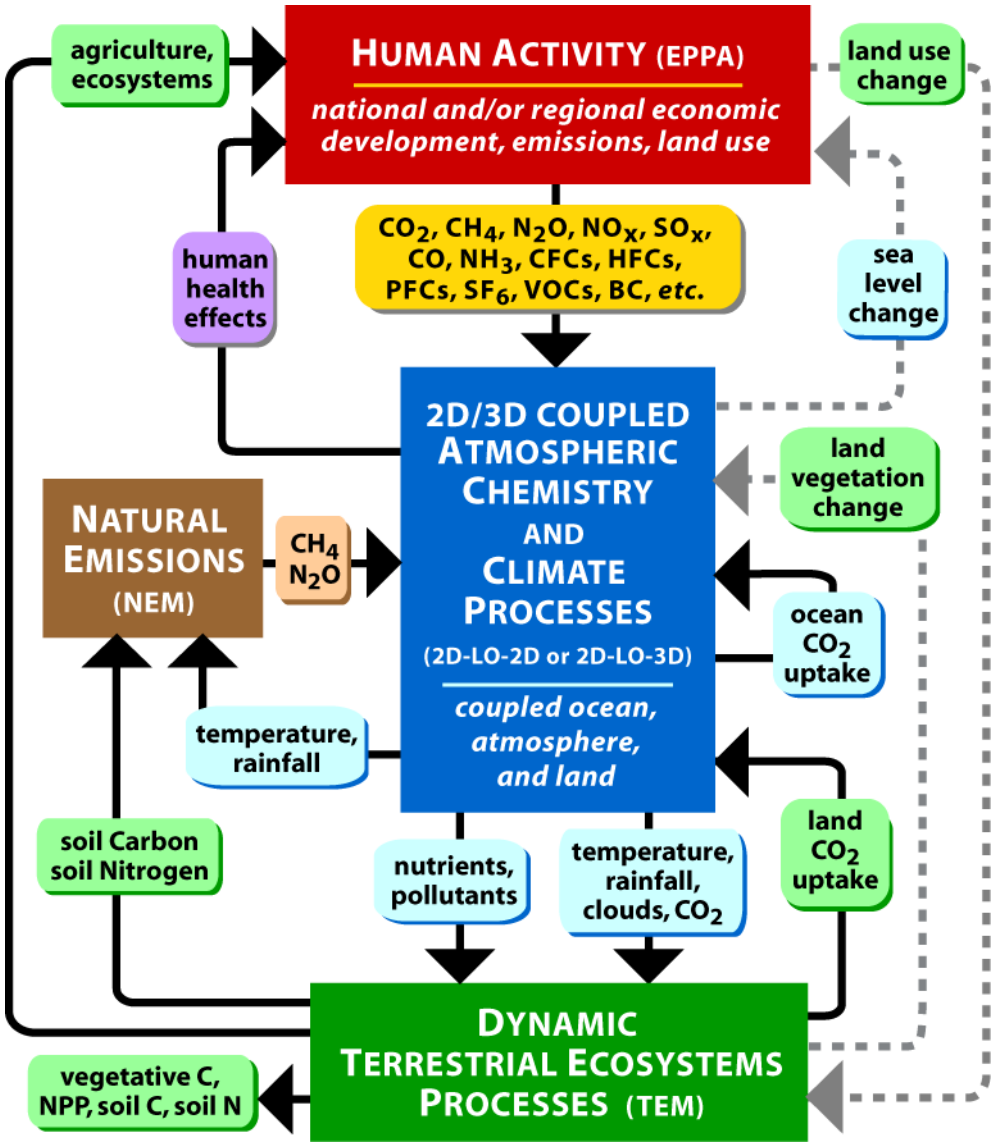


(Zhuang et al., 2004 GBC)

MODELING GLOBAL BIOGEOCHEMISTRY



MIT Integrated Global System Model (IGSM)



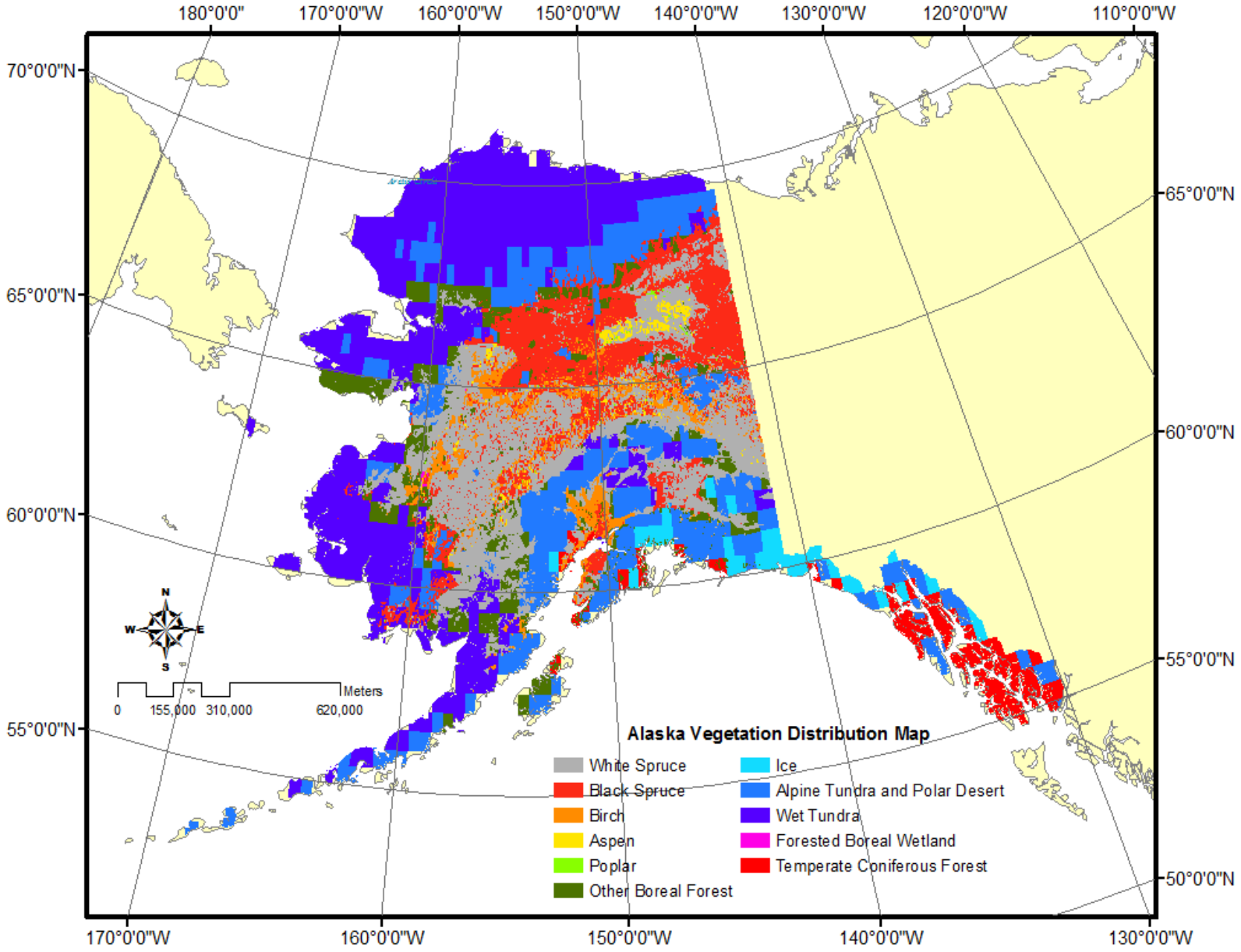

180°0'0"
170°0'0"W
160°0'0"W
150°0'0"W
140°0'0"W
130°0'0"W
120°0'0"W
110°0'0"W
70°0'0"N
65°0'0"N
60°0'0"N
55°0'0"N
50°0'0"N
N
W
E
S
0
155,000
310,000
620,000
Meters
Alaska Vegetation Distribution Map
White Spruce
Black Spruce
Birch
Aspen
Poplar
Other Boreal Forest
Ice
Alpine Tundra and Polar Desert
Wet Tundra
Forested Boreal Wetland
Temperate Coniferous Forest

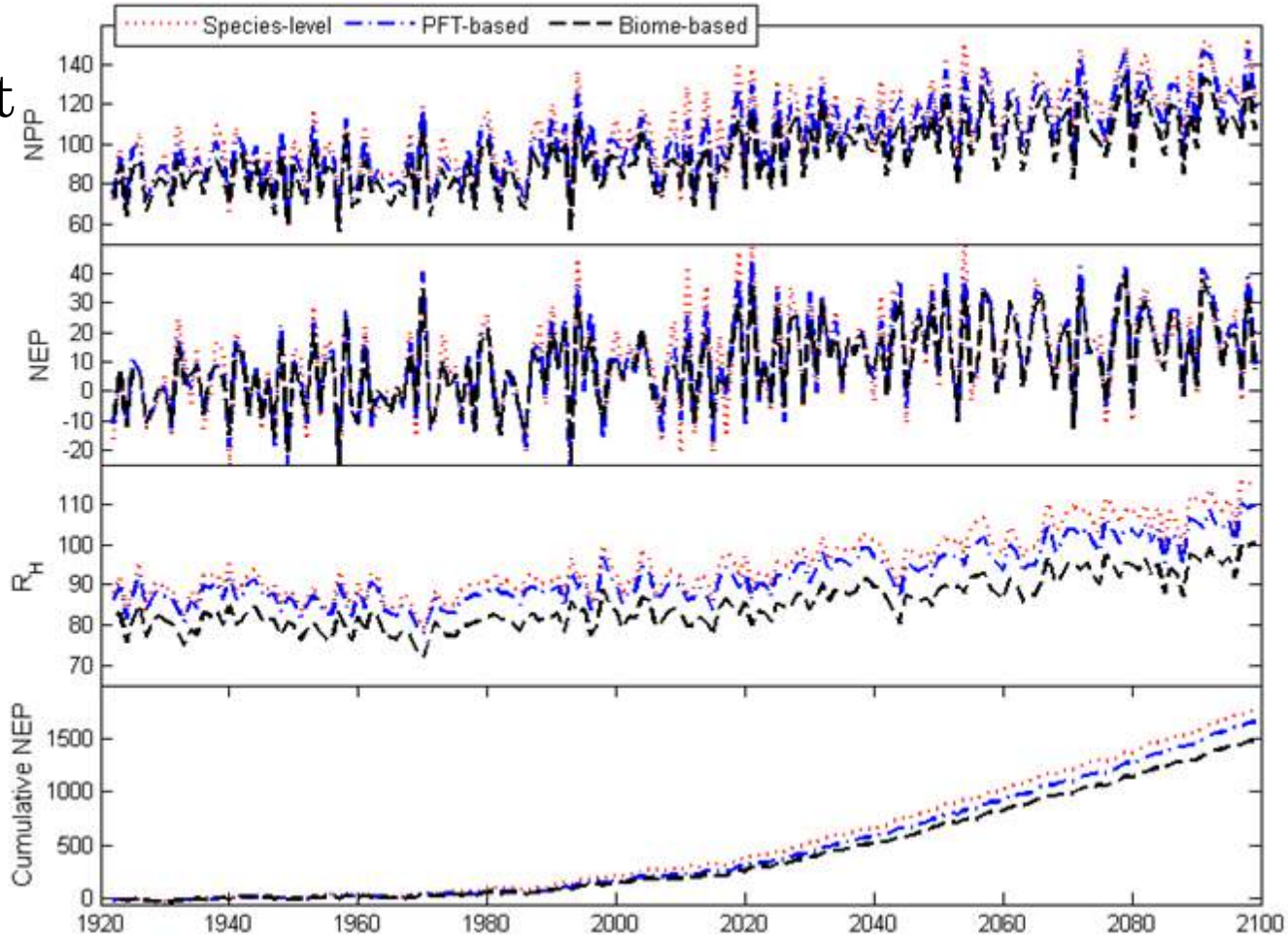
Table 2-1. Pools and fluxes used to calibrate the rate-limiting parameters of the Terrestrial Ecosystem Model. The pools and fluxes of PFT-level and biome-level simulations were calculated by weighted average across corresponding areas of each species.

	Species-level					PFT-level		Biome-level
	White Spruce	Black Spruce	Birch	Aspen	Poplar	Needle-leaf	Broad-leaf	Boreal Forest
GPP	1087	834	809	977	951	984	842	963
NPP	217	152	279	337	328	190	290	204
C_V	10356	3250	6624	7180	7183	7460	6736	7358
N_V	34.25	15	35	35	33	26	35	27
C_S	10527	15000	7755	6256	13045	12350	7671	11693
N_S	400	505	546	310	617	443	506	452
N_{AV}	1.23	0.5	1.53	1.84	1.97	0.93	1.60	1.03
NPPSAT	326	228	419	505	492	286	436	307
N_{uptake}	1.96	1.8	7.31	7.67	6.94	1.89	7.36	2.66

* Units for annual gross primary production (GPP), net primary production (NPP), saturation response of NPP to nitrogen fertilization (NPPSAT), and annual N uptake by vegetation (N_{uptake}), are g C m^{-2} yr^{-1} and g N $m^{-2}yr^{-1}$, respectively. Units for vegetation carbon (C_V) and soil carbon (C_S) are g C m^{-2}. Units for vegetation nitrogen (N_V), soil N (N_S), and available inorganic N (N_{AV}) are g N m^{-2}.

Results (1)

- Biome-level had the lowest estimates
- Total C sequestration
  - Species: 1.75 Pg
  - PFT: 1.65 Pg
  - Biome: 1.5 Pg



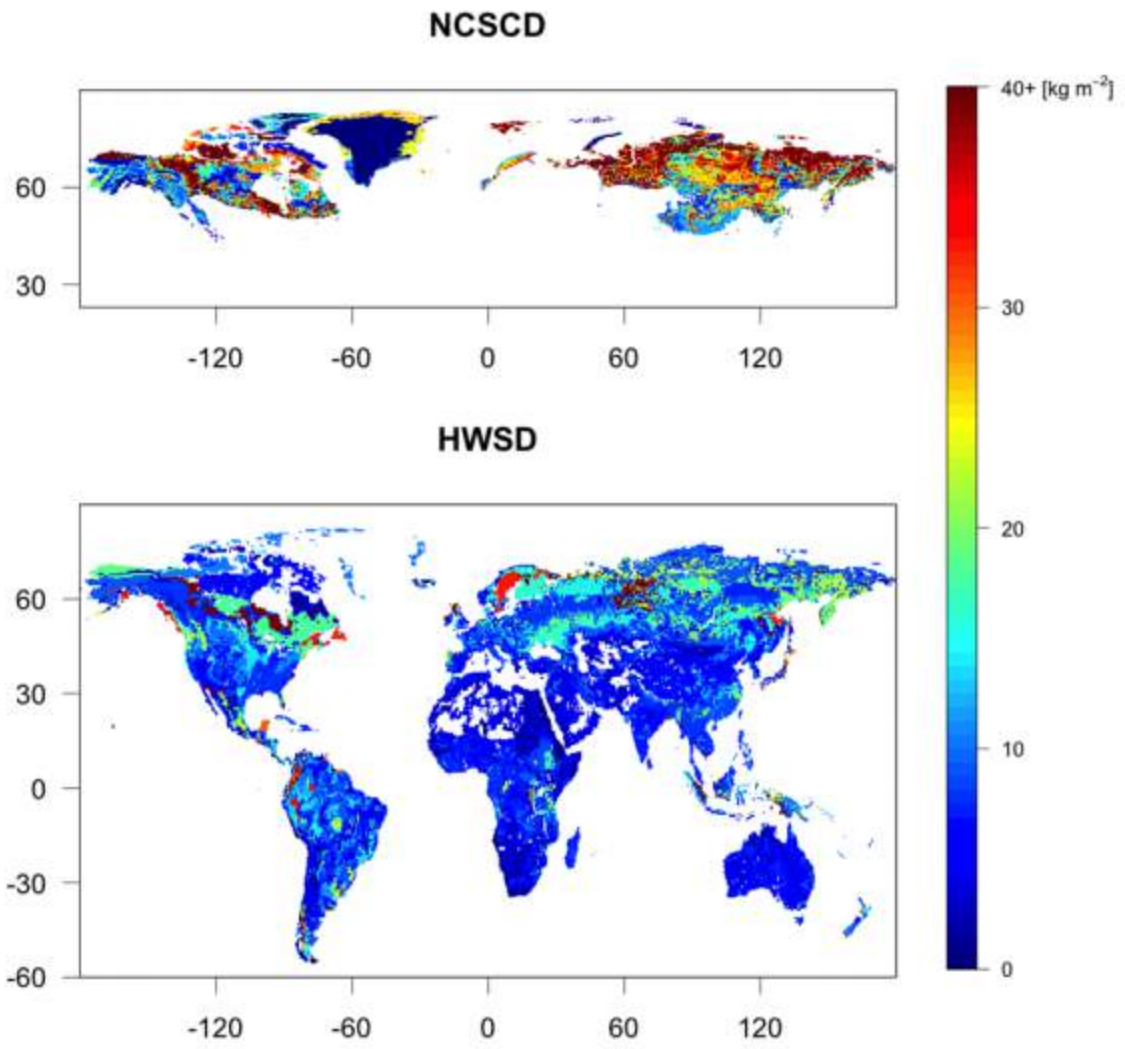
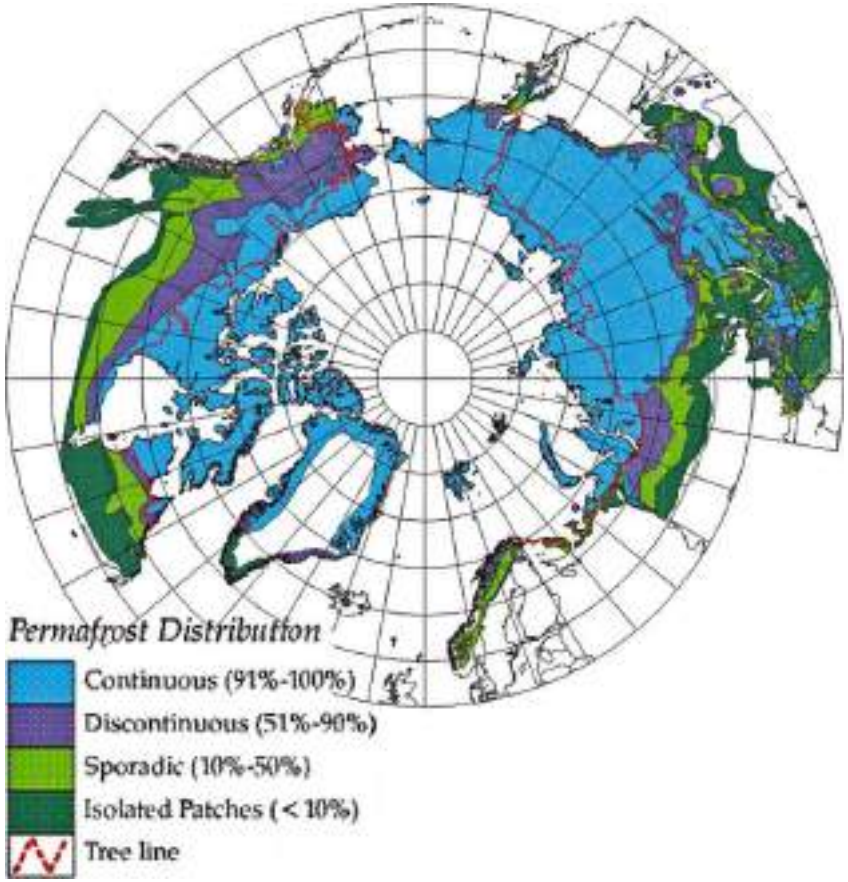


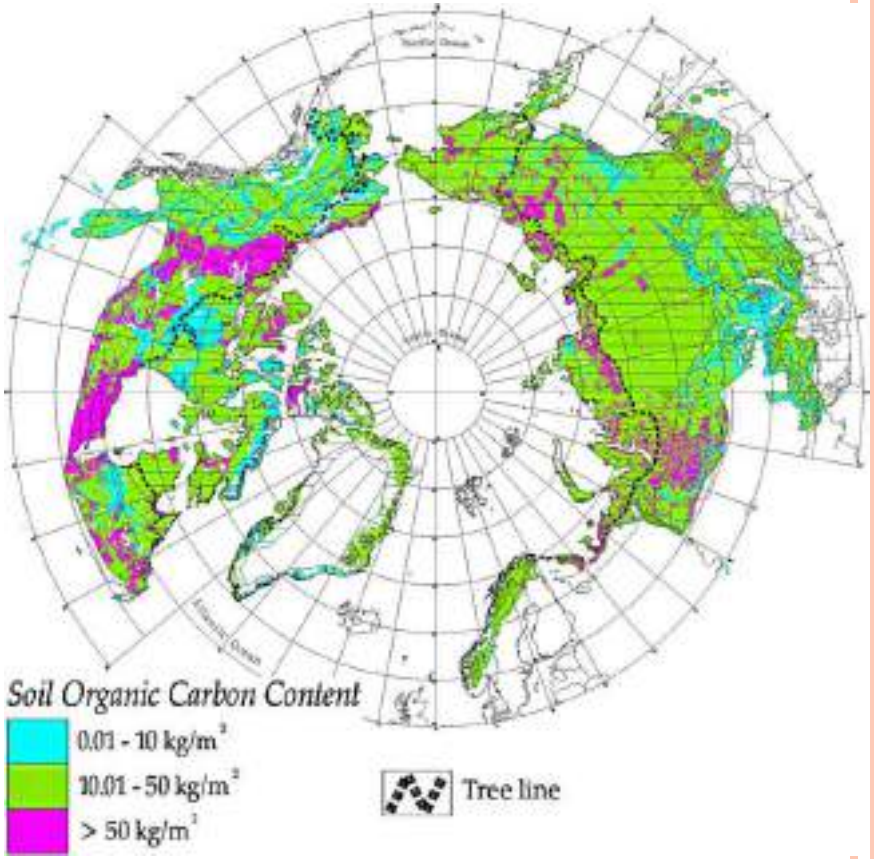
Fig. 1. Carbon density [kg m^{-2}] in the top 1 m of soil from the Northern Circumpolar Soil Carbon Database (NCSCD) (Tarnocai et al., 2009) and Harmonized World Soil Database (HWSD) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012).

Todd-brown et al. (2013)



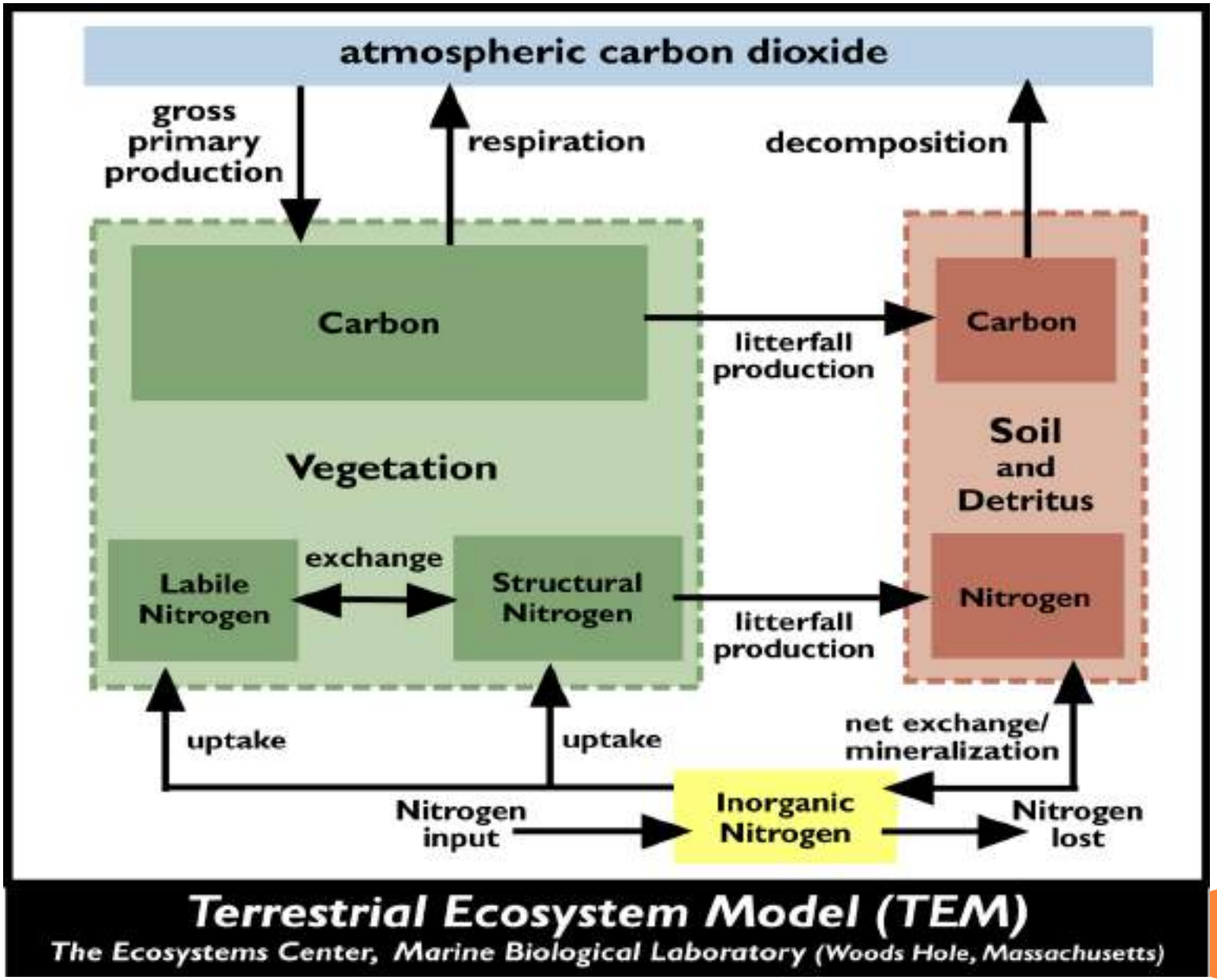
11.2 to 13.5 million km^2

(Zhang et al., 2000, Polar. Geogr.)



1672 Pg C in soils and permafrost or ½ the belowground organic C

(Tarnocai et al. 2009)


atmospheric carbon dioxide
gross primary production
respiration
decomposition
Carbon
Vegetation
litterfall production
Carbon
Soil and Detritus
Labile Nitrogen
exchange
Structural Nitrogen
litterfall production
Nitrogen
uptake
uptake
net exchange/ mineralization
Nitrogen input
Inorganic Nitrogen
Nitrogen lost
Terrestrial Ecosystem Model (TEM)
The Ecosystems Center, Marine Biological Laboratory (Woods Hole, Massachusetts)

Key Research Questions

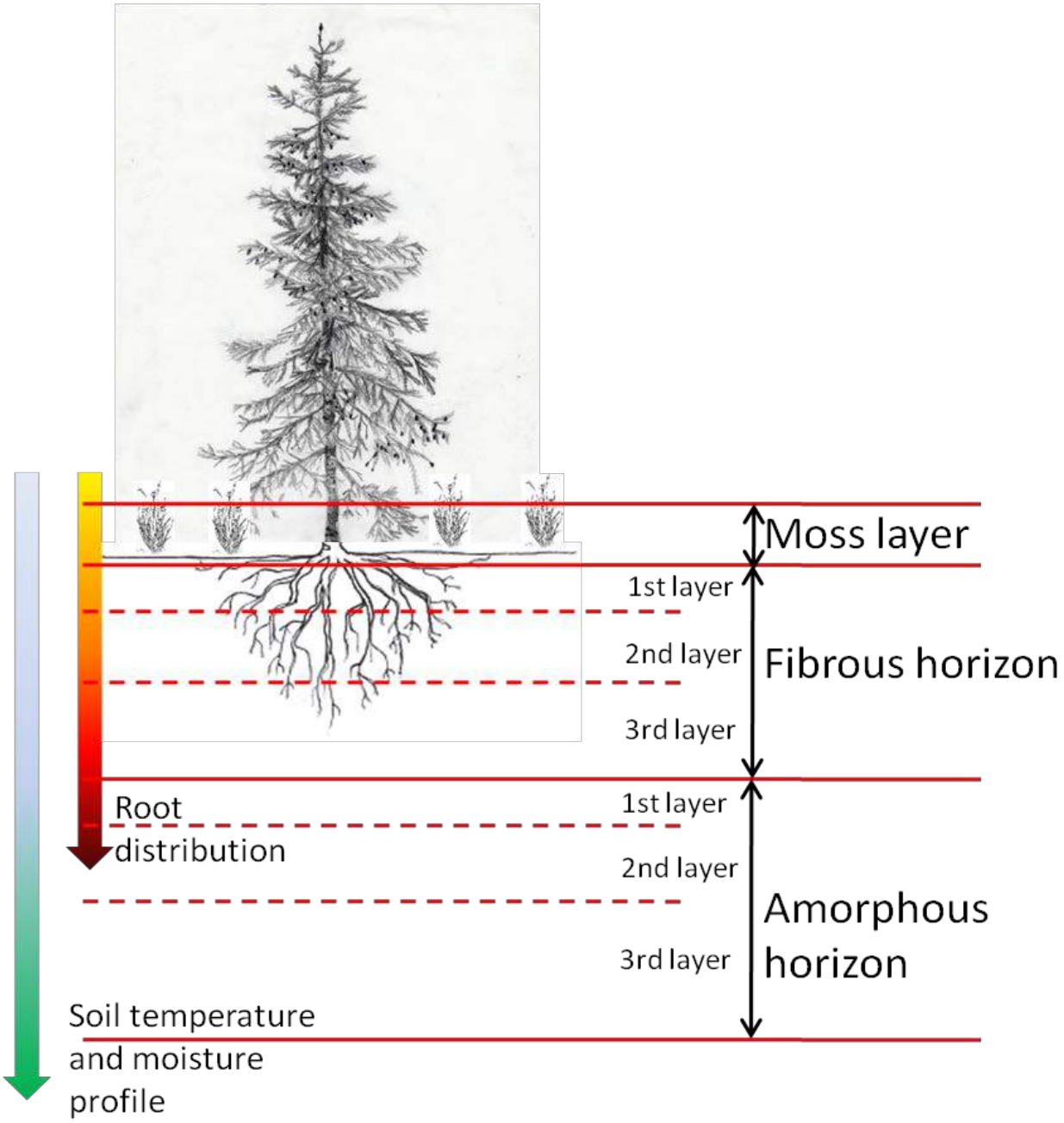
- Large stocks of SOM in northern high latitude ecosystems

  → one of the largest potential feedbacks to climate change

- Regional and global scale decomposition models omit key biogeochemical mechanisms

- Microbial models have the potential to outperform traditional Q10 models (Allison et al., 2010; Wieder et al., 2013)

He et al. (2014) Biogeosciences


Moss layer
1st layer
2nd layer
Fibrous horizon
3rd layer
Root
distribution
1st layer
2nd layer
Amorphous
horizon
3rd layer
Soil temperature
and moisture
profile

$$V_{\max_{S_x}} = \alpha_{S_x} * e^{-E_{a_{S_x}}/RT} \qquad V_{\max_{uptake}} = \alpha_{uptake} * e^{-E_{uptake}/RT} \qquad V_{\max_{SOC}} = \alpha_{SOC} * e^{-E_{SOC}/RT}$$

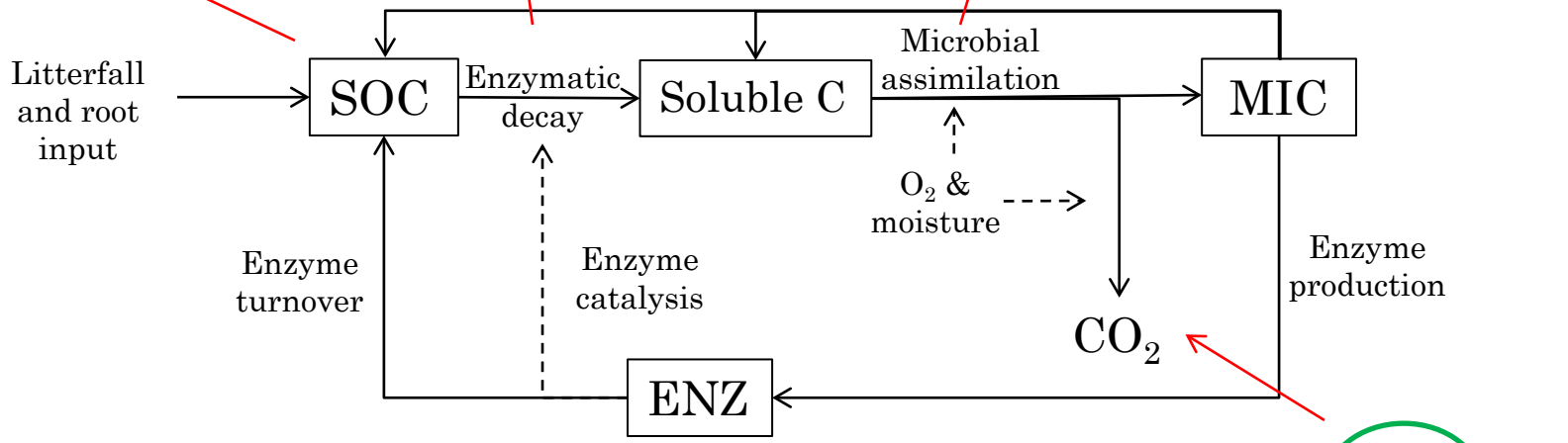
$$DECOMP = V\max_{soc} * Enz * \frac{SOC}{kM_{SOC} + SOC}$$

$$ASSIM = \mathrm{Vmax}_{uptake} * MIC * \frac{[S_x]}{\mathrm{kM}_{[S_x]} + [S_x]}$$

$$[S_x] = [S_{xsoluble}] \times D_{liq} \times \theta^3$$

$$\frac{dSOC}{dt} = inputSOC + DEATH * MICtoSOC + ELOSS - DECOMP$$

Microbial death



$$CO_2 = V_{\max_{[S_x]}} * \frac{[S_x]}{kM_{S_x} + [S_x]} * \frac{[O_2]}{kM_{O_2} + [O_2]} * MIC$$

$$\frac{dSoluble C}{dt} = DEATH * (1 - MICtoSOC) + DECOMP - ASSIM$$

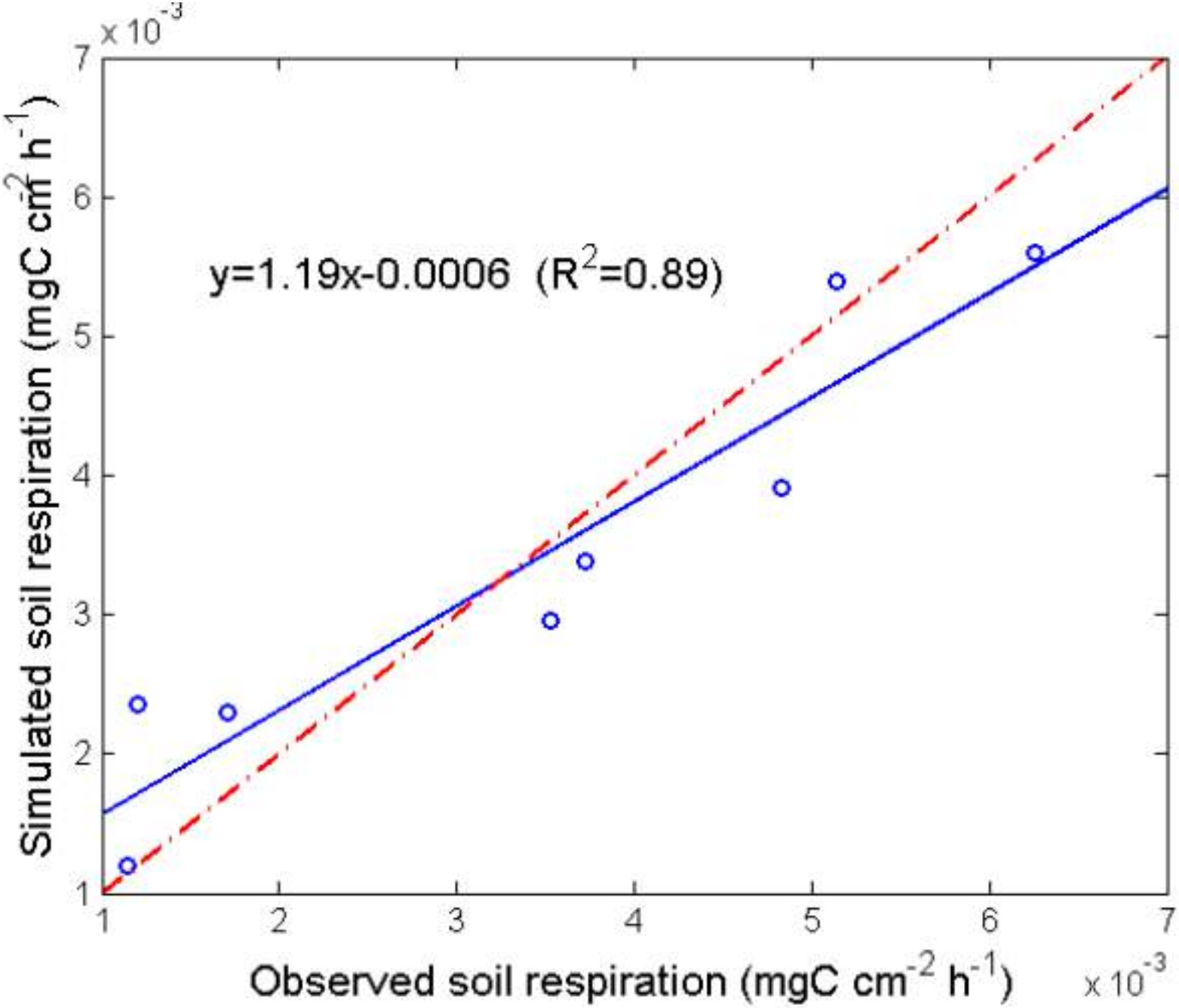
$$\frac{dEnz}{dt} = EPROD - ELOSS$$

$$\frac{dMIC}{dt} = \mathrm{ASSIM} - \mathrm{CO_2} - \mathrm{DEATH} - \mathrm{EPROD}$$

$$CUE = 1 - CO_2 / ASSIM$$

$$[O_2] = D_{gas} \times 0.209 \times a^{4/3}$$

$$a = 1 - \frac{BD}{PD} - \theta$$


x 10^-3
Simulated soil respiration (mgC cm^-2 h^-1)
y=1.19x-0.0006 (R^2=0.89)
Observed soil respiration (mgC cm^-2 h^-1)
x 10^-3
1
2
3
4
5
6
7

Summary

- Soil decomposition models should explicitly represent different soil horizons and soil-microbial interactions

Incorporating microbial dormancy into Soil models

$$\frac{dSOC}{dt} = Input - \overbrace{V_{\max} Q_{10\,enz}^{\frac{temp-15}{10}} ENZ \frac{SOC}{K_m + SOC}(120 - CN_{soil})}^{\text{Decomposition}}$$

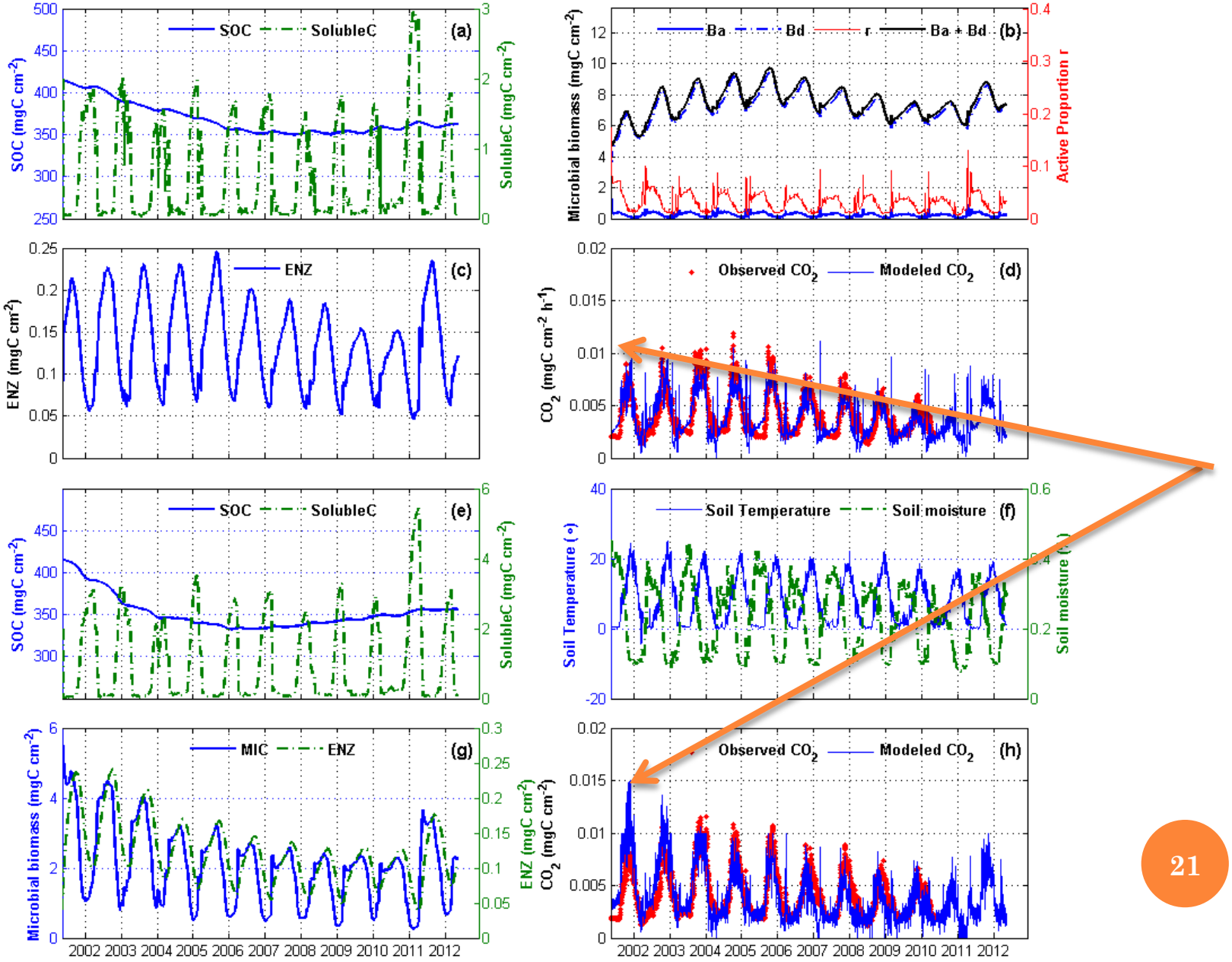
$$\frac{dSolubleC}{dt} = Decomposition - \overbrace{\frac{1}{Y_g}\frac{\phi}{\alpha} m_R Q_{10\,enz}^{\frac{temp-15}{10}} B_a \left(\frac{CN_{soil}}{CN_{mic}}\right)^{0.6}}^{\text{Microbial uptake}} + B_a r_{death} + ENZ r_{loss}$$

$$\frac{dB_a}{dt} = \left(\frac{\phi}{\alpha} - 1\right) m_R Q_{10\,mic}^{\frac{temp-15}{10}} B_a \left(\frac{CN_{soil}}{CN_{mic}}\right)^{0.6} \overbrace{- (1-\phi) m_R Q_{10\,mic}^{\frac{temp-15}{10}} B_a}^{\text{Transition from active to dormant}} \overbrace{+ \phi m_R Q_{10\,mic}^{\frac{temp-15}{10}} B_d}^{\text{Transition from dormant to active}} - B_a r_{prod} - B_a r_{death}$$

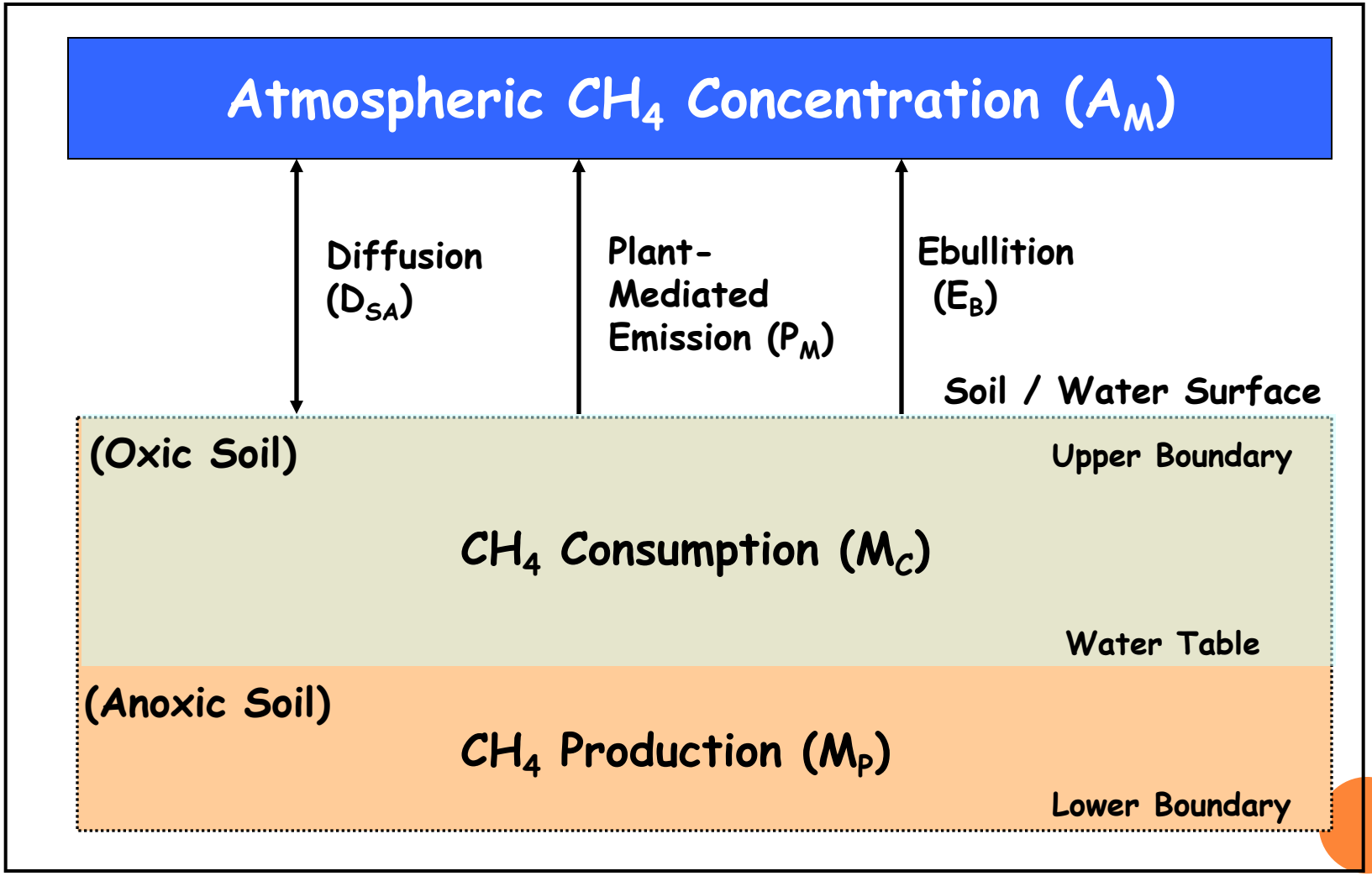
$$\frac{dB_d}{dt} = -\beta m_R Q_{10\,mic}^{\frac{temp-15}{10}} B_d + (1-\phi) m_R Q_{10\,mic}^{\frac{temp-15}{10}} B_a - \phi m_R Q_{10\,mic}^{\frac{temp-15}{10}} B_d$$

$$\frac{dENZ}{dt} = B_a r_{prod} - ENZ r_{loss}$$

US-Me2 site

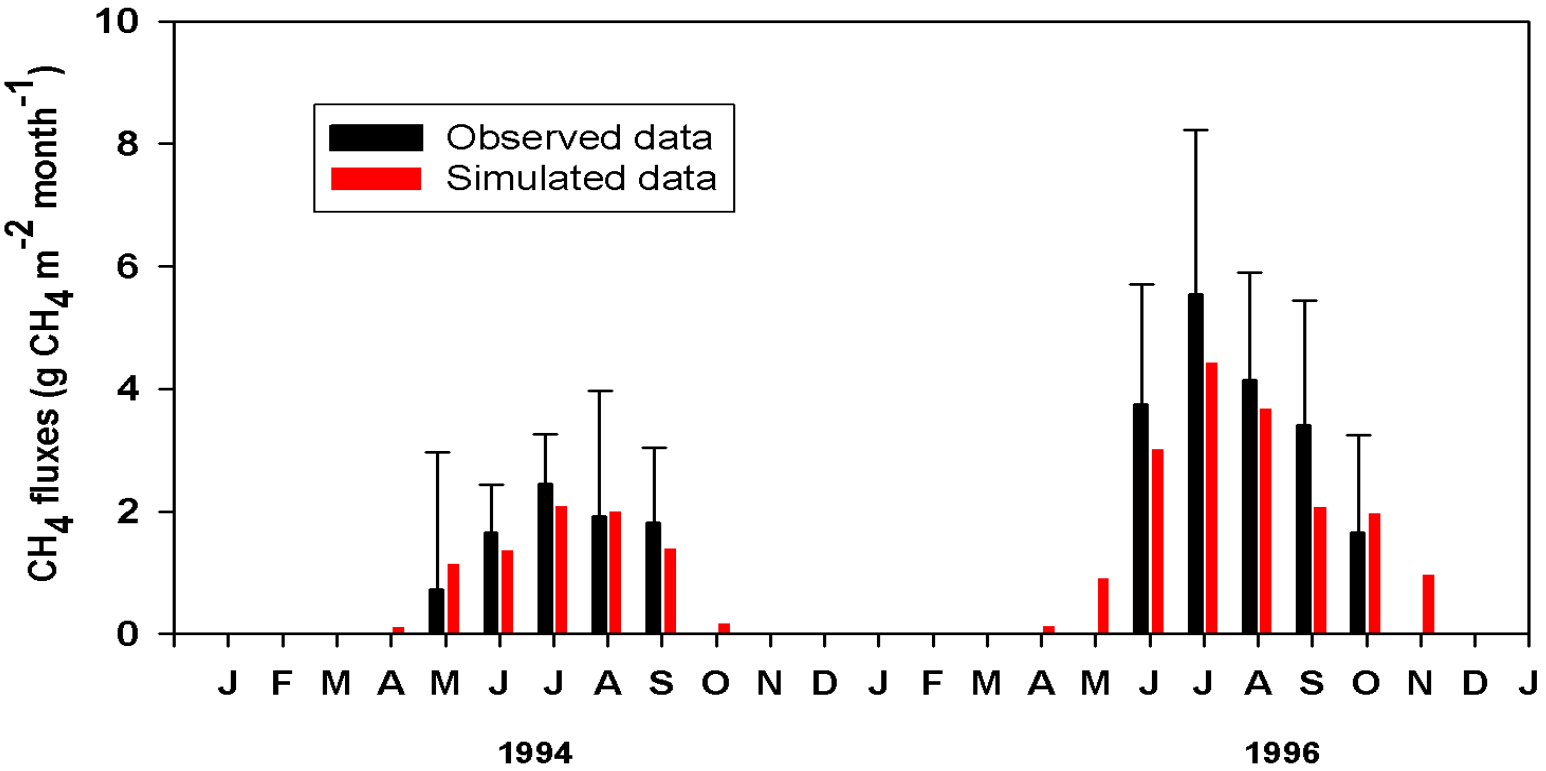

SOC
SolubleC
(a)
SOC (mgC cm-2)
SolubleC (mgC cm-2)
Ba
Bd
r
Ba + Bd
(b)
Microbial biomass (mgC cm-2)
Active Proportion r
ENZ
(c)
ENZ (mgC cm-2)
Observed CO2
Modeled CO2
(d)
CO2 (mgC cm-2 h-1)
(e)
Soil Temperature
Soil moisture
(f)
Soil Temperature (°)
MIC
(g)
(h)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

Methane Consumption and Emission Model



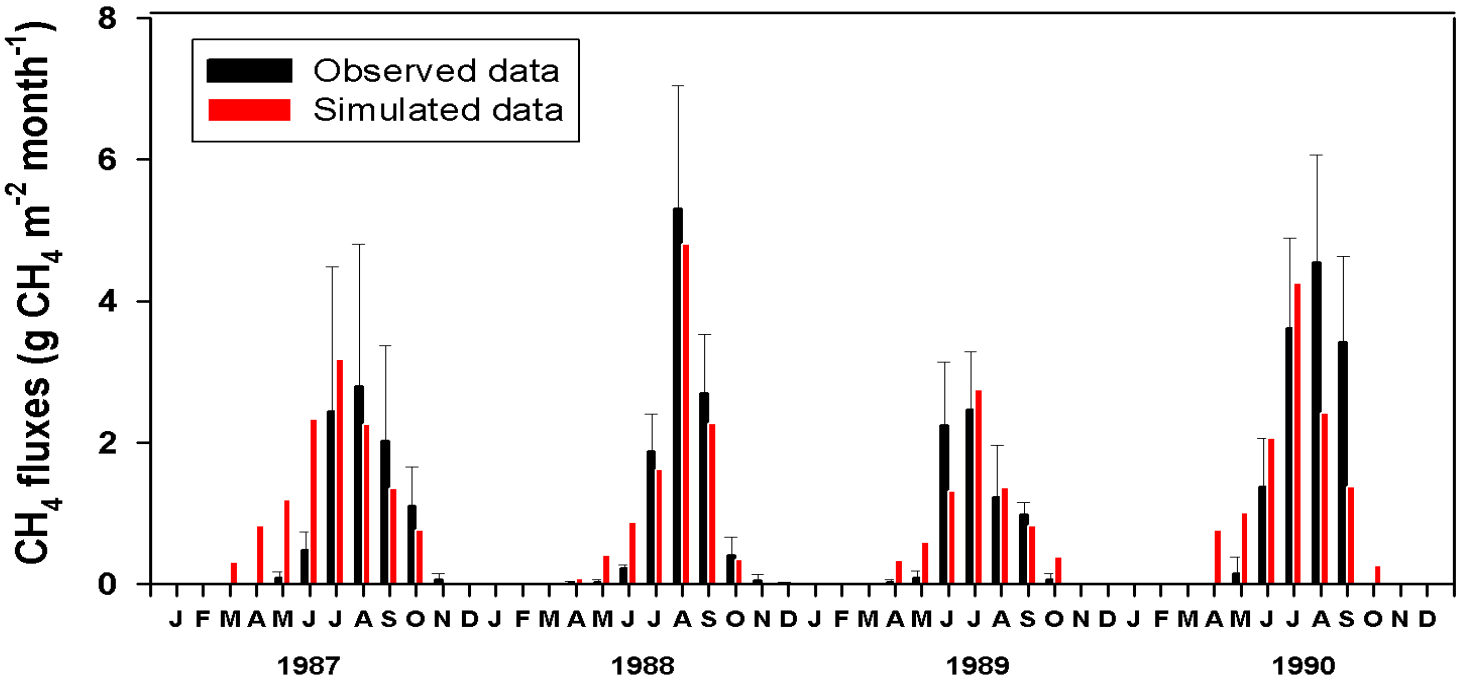
(Zhuang et al., 2004 GBC)

Methane Fluxes at a Fen Site in Canada



(Zhuang et al., 2004 GBC)

Methane Fluxes of a Wet Tundra Ecosystem in Alaska



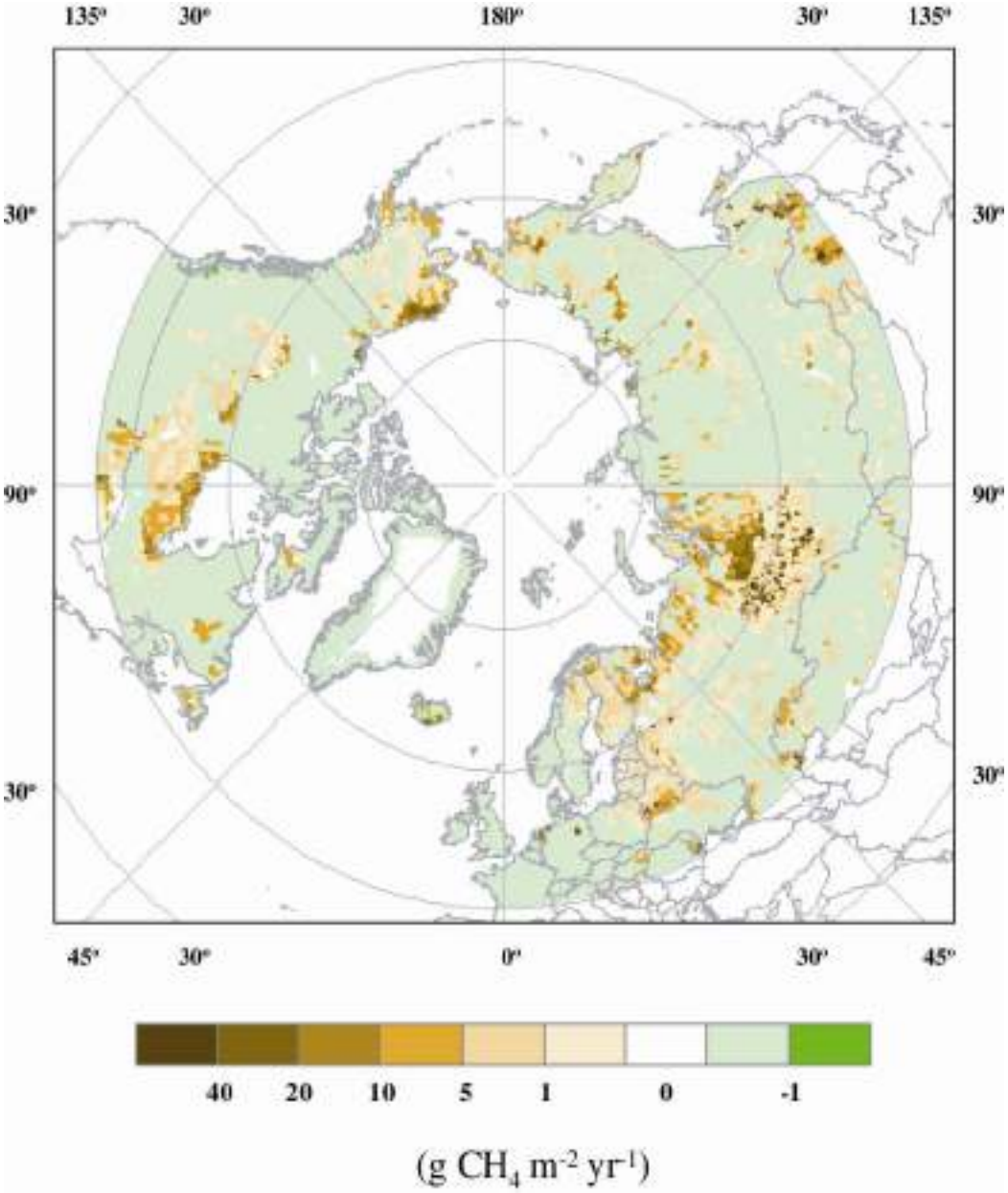
(Zhuang et al., 2004GBC)

Net Methane Fluxes in the 1990s

Emissions
= 56 Tg CH_4 yr^{-1}

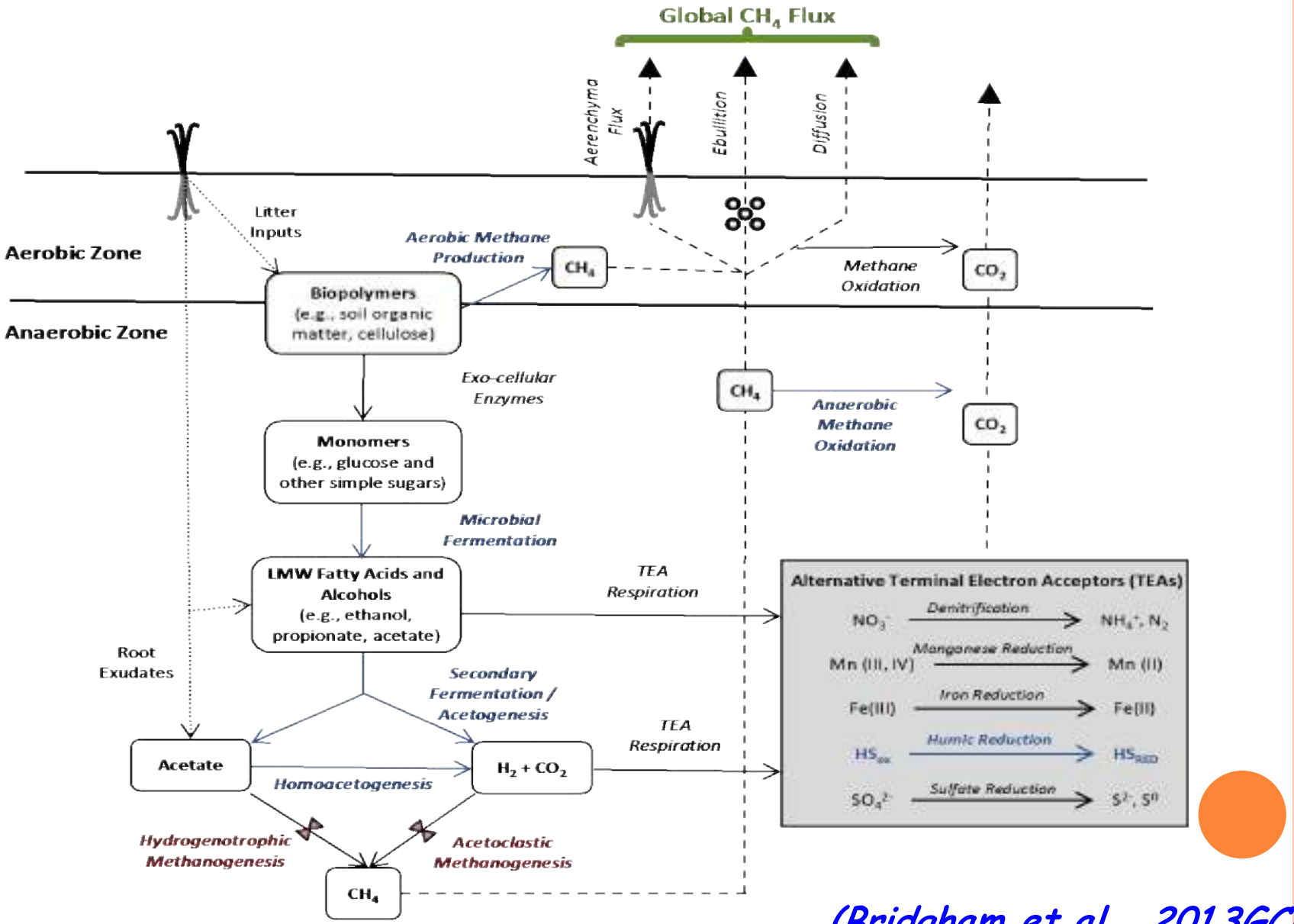
Consumption
= -7 Tg CH_4 yr^{-1}

Net Methane Fluxes
= 49 Tg CH_4 yr^{-1}



(Zhuang et al., 2004GBC)

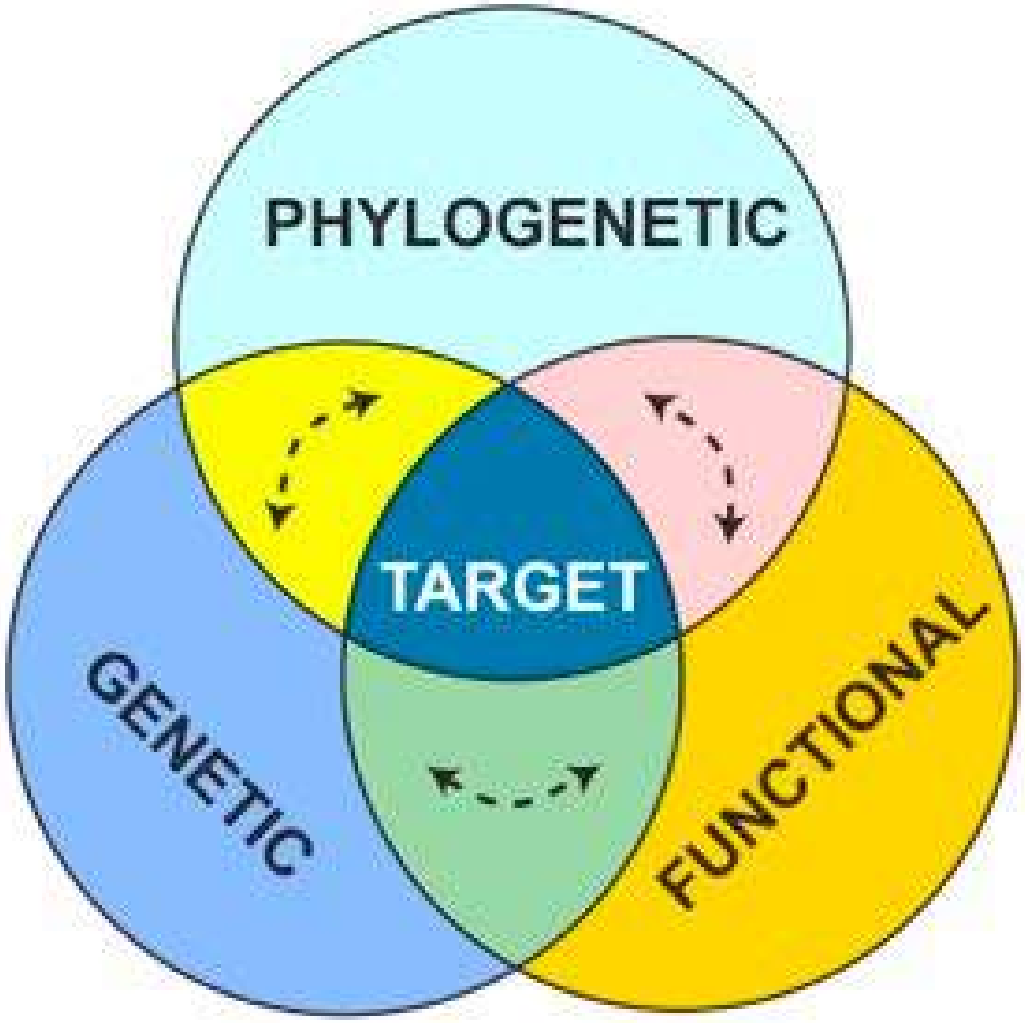
Biogenic Methane Emissions from Wetlands



(Bridgham et al., 2013GCB)

Summary

- Dormancy produced more realistic microbial biomass and soil R_H
- Species level of high plants might be eventually needed
- More detailed microbial traits shall be included in global biogeochemistry modeling of carbon


PHYLOGENETIC
TARGET
GENETIC
FUNCTIONAL

ACKNOWLEDGEMENT

1. Ecosystems and Biogeochemical Dynamics Lab at Purdue:



2. Funding Agencies:

U.S. DEPARTMENT OF ENERGY

NSF

NASA