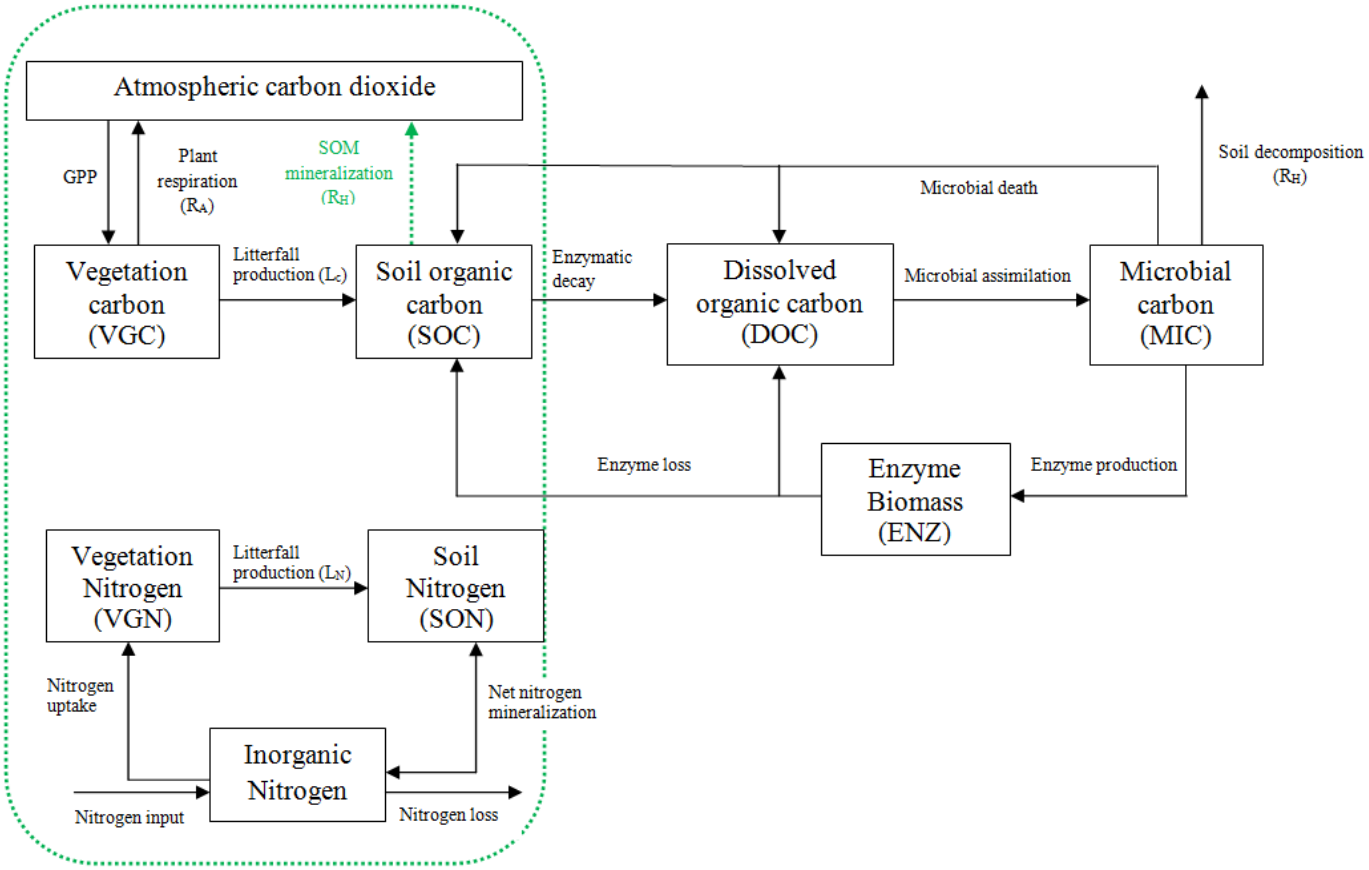


Figure S1. Schematic diagram of MIC-TEM. The green dashed circle is the previous structure used in TEM 5.0 (Zhuang et al 2003), without considering the effects of detailed microbial dynamics. The previous heterotrophic respiration is proportional to SOC (green dashed arrow). In MIC-TEM, new heterotrophic respiration considers the effects of microbial dynamics and enzyme kinetics. In addition, three new carbon pools (DOC, MIC, and ENZ) and five carbon fluxes (decomposition of SOC, microbial assimilation and death, enzyme production and loss) are considered (Allison et al 2010).

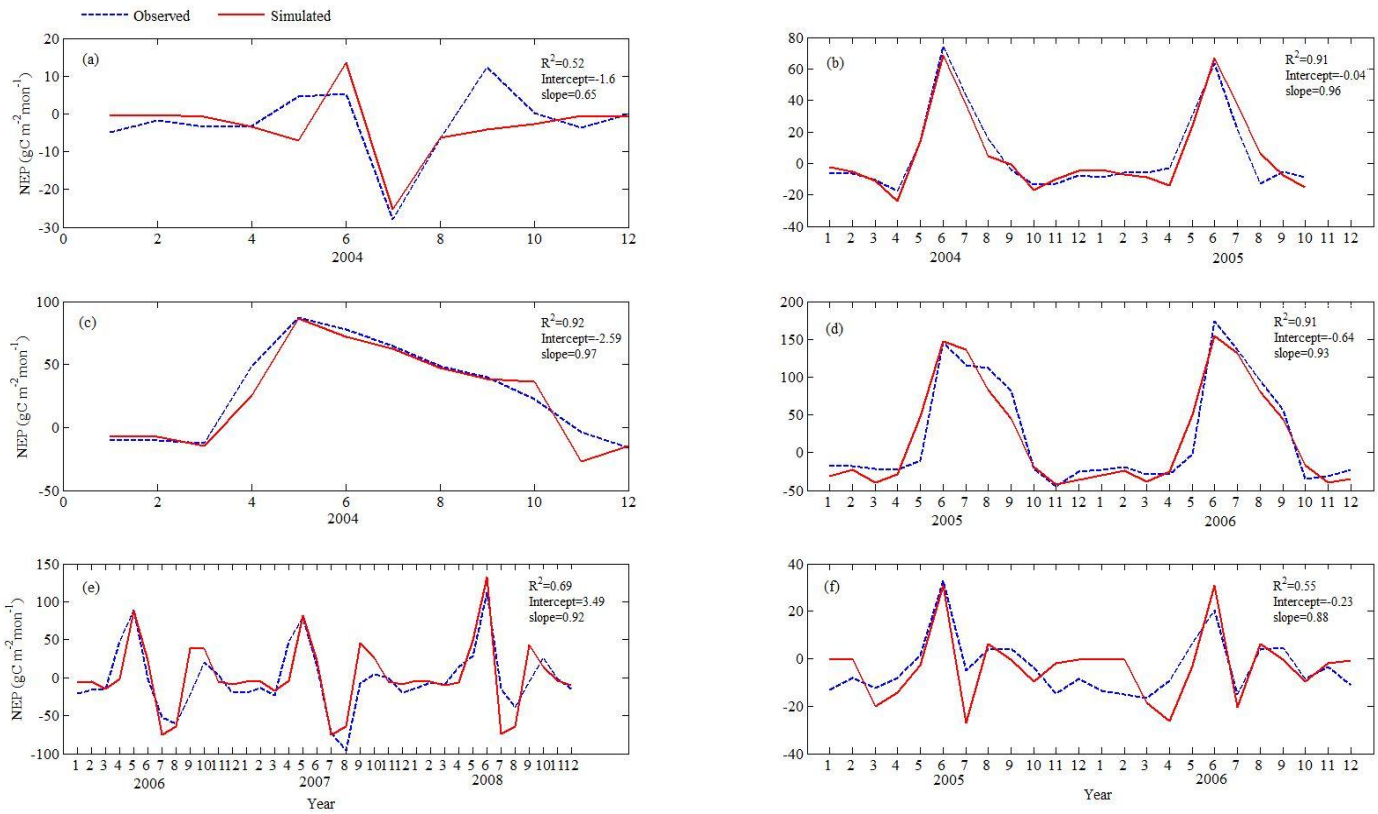


Figure S2. Comparison between observed and simulated NEP (gC $m^{-2}mon^{-1}$) at: (a) Ivotuk (alpine tundra), (b) UCI-1964 burn site (boreal forest), (c) Howland Forest (main tower) (temperate coniferous forest), (d) Univ. of Mich. Biological Station (Temperate deciduous forest), (e) KUOM Turfgrass Field (Grassland), and (f) Atqasuk (Wet tundra). Note: scales are different.

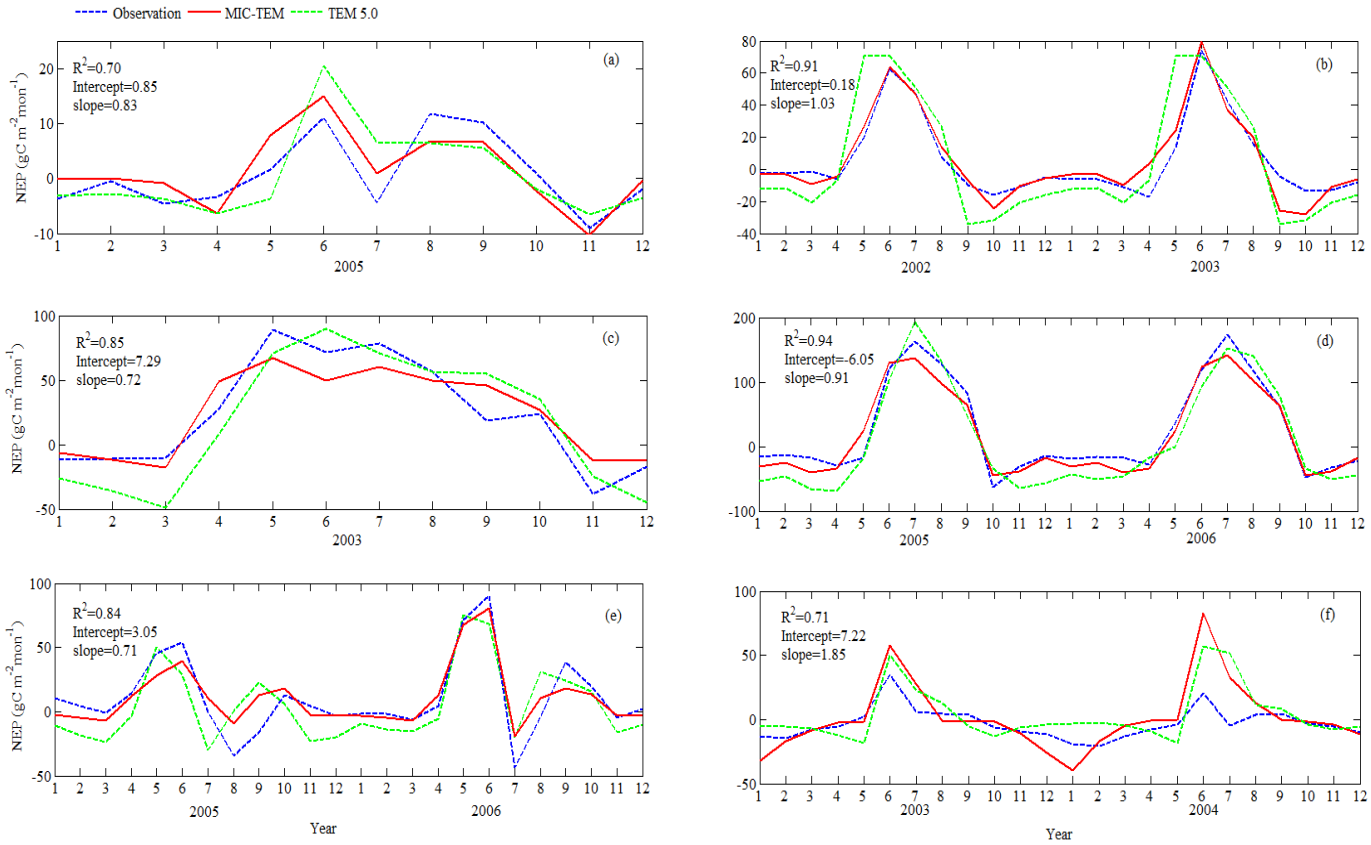


Figure S3. Comparison between observed and simulated NEP (gC m-2mon^{-1}) at: (a) Ivotuk (alpine tundra), (b) UCI-1964 burn site (boreal forest), (c) Howland Forest (main tower) (temperate coniferous forest), (d) Bartlett Experimental Forest (Temperate deciduous forest), (e) Brookings (Grassland), and (f) Atqasuk (Wet tundra). Note: scales are different.

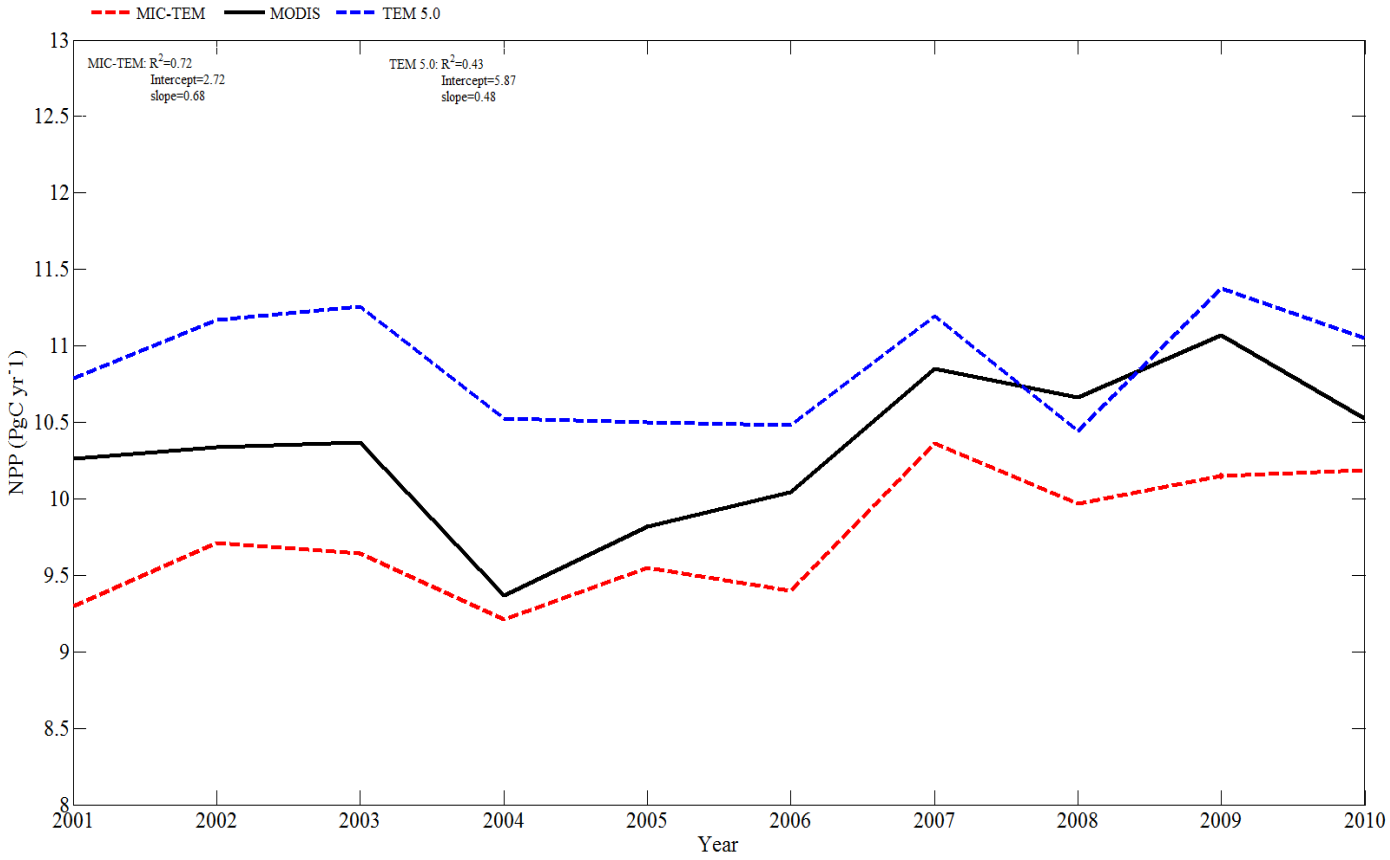
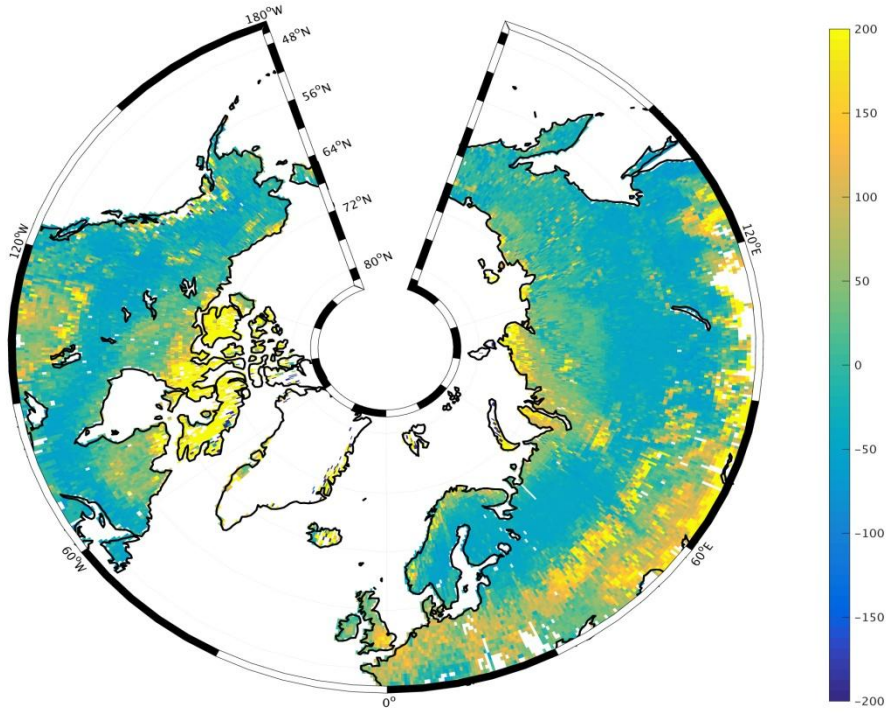


Figure S4. Comparison between regional NPP (PgC yr^{-1} simulated by MIC-TEM (red dashed line), TEM 5.0 (blue dashed line), and MODIS data (black solid line).

(a)



(b)

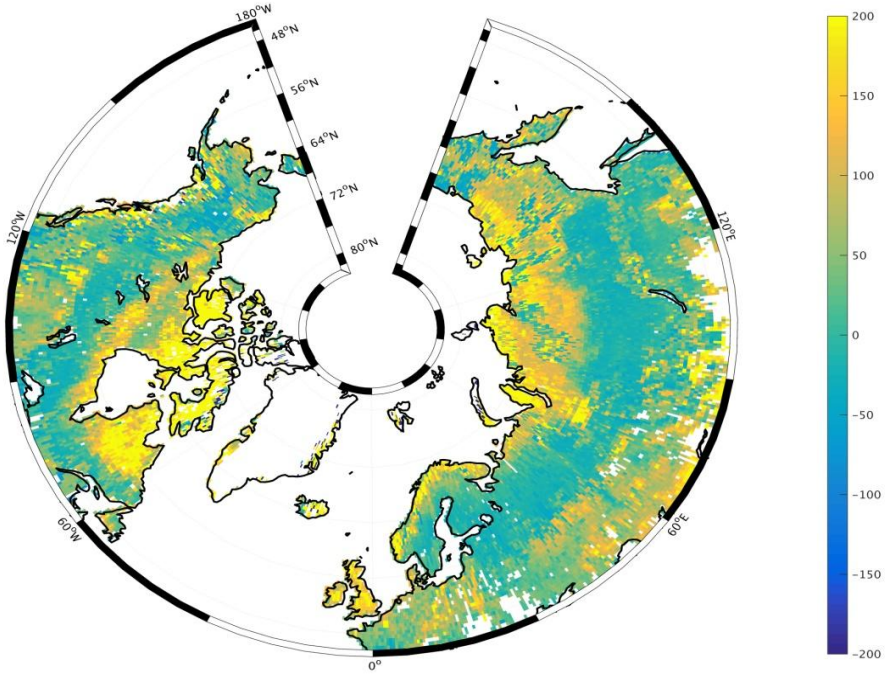


Figure S5. Comparisons between MODIS NPP as baseline and simulated NPP: (a) (MIC-TEM-MODIS)/ MODIS*100% (b) (TEM 5.0-MODIS)/ MODIS*100%. Positive values are overestimates and negative values are underestimates.

Table S1. Site description and measured data used to calibrate MIC-TEM

Site Name	Location (Longitude (degrees) /Latitude (degrees))	Elevation (m)	Vegetation type	Description	Data range	Citations
Univ. of Mich. Biological Station	84.71W 45.56 N	234	Temperate deciduous forest	Located within a protected forest owned by the University of Michigan. Mean annual temperature is 5.83˚C with mean annual precipitation of 803mm	01/2005-12/2006	Gough et al. (2013)
Howland Forest (main tower)	68.74W 45.20N	60	Temperate coniferous forest	Closed coniferous forest, minimal disturbance.	01/2004-12/2004	Davidson et al. (2006)
UCI-1964 burn site	98.38W 55.91N	260	Boreal forest	Located in a continental boreal forest, dominated by black spruce trees, within the BOREAS northern study area in central Manitoba, Canada.	01/2004-10/2005	Goulden et al. (2006)
KUOM Turfgrass Field	93.19W 45.0N	301	Grassland	A low-maintenance lawn consisting of cool-season turfgrasses.	01/2006-12/2008	Hiller et al. (2011)
Atqasuk	157.41W 70.47N	15	Wet tundra	100 km south of Barrow, Alaska. Variety of moist-wet coastal sedge tundra, and moist-tussock tundra surfaces in the more well-drained upland.	01/2005-12/2006	Oechel et al. (2014);
Ivotuk	155.75W 68.49N	568	Alpine tundra	300 km south of Barrow and is located at the foothill of the Brooks Range and is classified as tussock sedge, dwarf-shrub, moss tundra.	01/2004-12/2004	McEwing et al. (2015)

Table S2. Site description and measured data used to validate MIC-TEM

Site Name	Location (Longitude (degrees) /Latitude (degrees))	Elevation (m)	Vegetation type	Description	Data range	Citations
Bartlett Experimental Forest	71.29W/ 44.06N	272	Temperate deciduous forest	Located within the White Mountains National Forest in north-central New Hampshire, USA, with mean annual temperature of 5.61 ℃ and mean annual precipitation of 1246mm.	01/2005-12/2006	Jenkins et al. (2007); Richardson et al. (2007);
Howland Forest (main tower)	68.74W/ 45.20N	60	Temperate coniferous forest	Closed coniferous forest, minimal disturbance.	01/2003-12/2003	Davidson et al. (2006)
UCI-1964 burn site	98.38W/ 55.91N	260	Boreal forest	Located in a continental boreal forest, dominated by black spruce trees, within the BOREAS northern study area in central Manitoba, Canada.	01/2002-12/2003	Goulden et al. (2006)
Brookings	96.84W/ 44.35N	510	Grassland	Located in a private pasture, belonging to the Northern Great Plains Rangelands, the grassland is representative of many in the north central United States, with seasonal winter conditions and a wet growing season.	01/2005-12/2006	Gilmanov et al. (2005)
Atqasuk	157.41W/ 70.47N	15	Wet tundra	100 km south of Barrow, Alaska. Variety of moist-wet coastal sedge tundra, and moist-tussock tundra surfaces in the more well-drained upland.	01/2003-12/2004	Oechel et al. (2014);
Ivotuk	155.75W/ 68.49N	568	Alpine tundra	300 km south of Barrow and is located at the foothill of the Brooks Range and is classified as tussock sedge, dwarf-shrub, moss tundra.	01/2005-12/2005	McEwing et al. (2015)

Table S3. Comparison statistics between MIC-TEM and TEM in model validation

Site Name	Vegetation type	Model	Intercept ($gC\ m^{-2}\ mon^{-1}$)	Slope	R-square	Adjusted R-square	p-value
Ivotuk	Alpine tundra	MIC-TEM	0.85	0.83	0.70	0.67	<0.001
		TEM 5.0	0.04	0.85	0.54	0.5	0.006
UCI-1964 burn site	Boreal forest	MIC-TEM	0.18	1.03	0.912	0.9080	<0.001
		TEM 5.0	-2.8	1.29	0.746	0.735	<0.001
Howland Forest (main tower)	Temperate coniferous forest	MIC-TEM	7.29	0.72	0.85	0.83	<0.001
		TEM 5.0	-8.18	1.1	0.82	0.804	<0.001
Bartlett Experimental Forest	Temperate deciduous forest	MIC-TEM	-6.05	0.91	0.944	0.941	<0.001
		TEM 5.0	-13.6	1.03	0.84	0.83	<0.001
Brookings	Grassland	MIC-TEM	3.05	0.71	0.84	0.83	<0.001
		TEM 5.0	-3.63	0.74	0.6	0.58	<0.001
Atqasuk	Wet tundra	MIC-TEM	7.22	1.85	0.71	0.70	<0.001
		TEM 5.0	6.64	1.15	0.42	0.39	<0.001

Table S4. Correlations between carbon fluxes and environmental variables indicated with Pearson correlation coefficients

		air temperature	precipitation	cloudiness	CO_2	Soil temperature at 20 cm depth	VSM	NMIN
MIC-TEM	NEP	0.10	0.41	0.20	0.31	0.13	0.25	0.37
	NPP	0.70	0.59	0.13	0.62	0.74	-0.16	0.89
	R_H	0.86	0.45	0.12	0.57	0.91	-0.44	0.93
TEM 5.0	NEP	0.15	0.41	0.21	0.39	0.21	0.19	0.35
	NPP	0.55	0.69	0.29	0.69	0.53	0.05	0.87
	R_H	0.75	0.62	0.29	0.86	0.82	-0.21	0.91

Table S5. Parameters associated with more detailed microbial dynamics in MIC-TEM

Process	Parameter	Units	Initial Value	Description	Parameter range	Reference
Assimilation	$Vmax_{uptake_0}$	mg DOC cm^{-3} (mg biomass cm^{-3})$^{-1}$ h^{-1}	9.97e6	Maximum microbial uptake rate	[1.0e4, 1.0e8]	Hao et al. (2015)
	Ea_{uptake}	kJ mol^{-1}	47	Activation energy	-	Allison et al. (2010)
	$Km_{uptake_{slope}}$	mg cm^{-3} $degree^{-1}$	0.01	Temperature regulator of MM for DOC uptake by microbes	-	Allison et al. (2010)
	Km_{uptake_0}	mg cm^{-3}	0.1	Temperature regulator of MM for DOC uptake by microbes	-	Allison et al. (2010)
CO_2 production	CUE_{slope}	$degree^{-1}$	-0.016	Temperature regulator of carbon use efficiency	-	Allison et al. (2010)
	CUE_0	-	0.63	Temperature regulator of carbon use efficiency	-	Allison et al. (2010)
Decay	$Vmax_0$	mg SOC cm^{-3} (mg Enz cm^{-3})$^{-1}$ h^{-1}	9.17e7	Maximum rate of converting SOC to soluble C	[1.0e5, 1.0e8]	Hao et al. (2015)
	Ea	kJ mol^{-1}	47	Activation energy	-	Allison et al. (2010)
	Km_{slope}	mg cm^{-3} $degree^{-1}$	5	Temperature regulator of MM for enzymatic decay	-	Allison et al. (2010)
	Km_0	mg cm^{-3}	500	Temperature regulator of MM for enzymatic decay	-	Allison et al. (2010)
MIC turnover	r_{death}	-	0.02	Microbial death fraction	-	Allison et al. (2010)
	MICtoSOC		50	Partition coefficient for dead microbial biomass between the SOC and DOC pool	-	Allison et al. (2010)
ENZ turnover	$r_{EnzProd}$	-	5.0e-4	Enzyme production fraction	-	Allison et al. (2010)
	$r_{EnzLoss}$	-	0.1	Enzyme loss fraction	-	Allison et al. (2010)

References:

1. Zhuang, Q. et al. Carbon cycling in extratropical terrestrial ecosystems of the Northern Hemisphere during the 20th century: a modeling analysis of the influences of soil thermal dynamics. Tellus B, 55: 751–776. doi:10.1034/j.1600-0889.2003.00060.x (2003).

2. Allison, S. D. et al. Soil-carbon response to warming dependent on microbial physiology. *Nature Geoscience*, *3*(5), 336-340 (2010).

3. Hao, G. et al. Climatic Change 133: 695. doi:10.1007/s10584-015-1490-3 (2015).

4. Gough CM, Hardiman BS, Nave LE, Bohrer G, Maurer KD, Vogel CS, Nadelhoffer KJ, Curtis PS. (2013) Sustained carbon uptake and storage following moderate disturbance in a Great Lakes forest. Ecological Applications 23:1202–1215.

5. Eric A. Davidson; Ivan A. Janssens; Yiqi Luo. 2006. On the variability of respiration in terrestrial ecosystems: moving beyond Q10Global Change Biology. 12:2, 154-164..

6. Hiller, R. V., J. P. McFadden, and N. Kljun. 2011. Interpreting CO2 fluxes over a suburban lawn: The influence of traffic emissions. Boundary-Layer Meteorology 138: 215–230.

7. Jenkins, J.P., A.D. Richardson, B.H. Braswell. S.V. Ollinger, D.Y. Hollinger, and M.-L. Smith. 2007. Refining light-use efficiency calculations for a deciduous forest canopy using simultaneous tower-based carbon flux and radiometric measurements. Agricultural and Forest Meteorology, 143: 64-79.

8. Richardson, A.D., J.P. Jenkins, B.H. Braswell, D.Y. Hollinger, S.V. Ollinger, and M.-L. Smith. 2007. Use of digital webcam images to track spring green-up in a deciduous broadleaf forest. Oecologia, 152: 323-334.

9. Goulden, Michael L, Winston, Gregory C., McMillan, Andrew M. S.; Litvak, Marcy E.; Read, Edward L.; Rocha, Adrian V.; Elliot, J. Rob. 2006. n eddy covariance mesonet to measure the effect of forest age on land-atmosphere exchange, Global Change Biology 12 (11), 2146–2162. doi:10.1111/j.1365-2486.2006.01251.x

10. T. G. Gilmanov; L. L. Tieszen; B. K. Wylie; et al.. 2005. Integration of CO2 flux and remotely-sensed data for primary production and ecosystem respiration analyses in the Northern Great Plains: potential for quantitative spatial extrapolationGlobal Ecology and Biogeography. 14:3 May, 271-292.

11. Oechel, Walter. C., Cheryl. A. Laskowski, George. Burba, Beniamino. Gioli, Aram. A. M. Kalhori (2014) Annual patterns and budget of CO2 flux in an Arctic tussock tundra ecosystem, Journal of Geophysical Research: Biogeosciences, 119(3), 323-339.

12. McEwing, K. R., Fisher, J. P., Zona, D. (2015) Environmental And Vegetation Controls On The Spatial Variability Of CH4 Emission From Wet-Sedge And Tussock Tundra Ecosystems In The Arctic, Plant And Soil, 388(1-2), 37-52.