Supporting Information for

Quantifying Soil Carbon Accumulation in Alaskan Terrestrial Ecosystems during the Last 15,000 Years

Sirui Wang[1], Qianlai Zhuang[1,2*], Zicheng Yu[3]

[1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, Indiana, 47907

[2]Department of Agronomy, Purdue University, West Lafayette, IN 47907

[3]Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA 18015

Correspondence to: qzhuang@purdue.edu

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Introduction

This supporting information provides the description of model parameters of soil carbon accumulation.

Model Description

The core carbon and nitrogen dynamics module of TEM was developed for upland ecosytsems (Zhuang et al., 2003), where NEP is calculated at a monthly time step:

$$NEP = NPP - R_H \quad (1)$$

Soil organic carbon (SOC) heterotrophic respiration (R_H) is calculated as (Table S1):

$$R_H = K_d C_S f(M_V) e^{0.069 H_T} \quad (2)$$

where $f(M_V)$ is a nonlinear relationship that describes the effect of soil moisture in the unsatureted zone on microbial activity for decomposition. Soil moisture affects oxygen level in soils. K_d is the logarithm of heterotrophic respiration rate at 0°C. C_S is the total amount of upland mineral SOC above the plant rooting depth. H_T is mean monthly temperature of the organic layer.

We revised the decomposition to include both aerobic heterotrophic respiration above the water table which produces CO_2 and anaerobic respiration below water table, which produces both CO_2 and methane (CH_4). The soil organic carbon accumulation rate (ΔSOC) is equal to NEP, where NEP is calculated:

$$NEP = NPP - R_H' - R_{CH_4} - R_{CWM} - R_{CM} - R_{COM} \quad (3)$$

R_{CH_4} represents the monthly methane emission after methane oxidation and R_{CWM} represents the CO_2 emission due to methane oxidation (Zhuang et al., 2015). A ratio of 1:1 is assumed to calculate the CO_2 release (R_{CM}) accompanied with the methanogenesis (Tang et al., 2010; Conrad, 1999). R_{COM} represents the CO_2 release from other anaerobic processes (e.g., fermentation, terminal electron acceptor (TEA) reduction) (Keller and Bridgham, 2007; Keller and Takagi, 2013). The ratio of R_{COM}: R_{CH_4} varies largely according to previous studies. The molar ratios (CO_2: CH_4) of the emission rates under inundated conditions were 4-173 for the fen and bog, respectively (Moore and Knowles, 1989), while Freeman et al. (1992) and Yavitt et al. (1987) estimated this ratio as 1. Here we assumed R_{COM}: R_{CH_4} to be 5 so that the simulated CO_2: CH_4 of the emission rates from the anearobic processes is ~10 for a fen. $R_H^{'}$ now represents the monthly aerobic respiration related to the variability of water-table depth (*WTD*) (Table S1):

$$R_H^{'} = K_d C_{S1} f(M_V^{'})e^{0.069H_T} \times \frac{WTD}{LWB} \quad (4)$$

where $M_V^{'}$ represents the soil water content in the unsaturated zone above the *WTD*. The peat SOC throughout the rooting zone (fixed as 1 m) is subject to both aerobic and anaerobic decomposition and the factor (F_{sub}) determines the substrate availability was set to 1.0 within the rooting zone. The effect of F_{sub} was assumed to decrease exponentially with depth below the rooting zone (Walter and Heimann, 2000) as follows:

$$F_{sub} = e^{\frac{-(z-\frac{1}{100})}{10.0}} \quad (5)$$

where z is the peat depth (centimeters).

The initial waterlogging event was assumued to occur 2000 years before peat started to form, providing the necessary hydrological conditions for peatland initiation. The SOC between the lowest water-table boundary (*LWB*, a fixed model parameter, the soil below which is set saturated) and soil surface in the transient condition (C_{S1}) was obtainted after a 2000-year equilibrium run, providing a stable SOC at 15 ka.

Table S1. Variables and model parameters used for calculating heterotrophic respiration in this study.

Variables	Description	Unit
R_H	Monthly heterotrophic respiration of soil organic carbon (upland soils)	$\mathrm{g\ C\ m^{-2}\ mon^{-1}}$
R'_H	Monthly aerobic heterotrophic respiration of soil organic carbon (peatland soils)	$\mathrm{g\ C\ m^{-2}\ mon^{-1}}$
R_{CH_4}	Monthly methane emission	$\mathrm{g\ C\ m^{-2}\ mon^{-1}}$
R_{CWM}	Monthly CO_2 emission due to methane oxidation	$\mathrm{g\ C\ m^{-2}\ mon^{-1}}$
R_{CM}	Monthly CO_2 emission due to methane production	$\mathrm{g\ C\ m^{-2}\ mon^{-1}}$
R_{COM}	Monthly CO_2 emission due to other anaerobic processes	$\mathrm{g\ C\ m^{-2}\ mon^{-1}}$
K_d	Logarithm of heterotrophic respiration rate at 0℃	$\mathrm{g\ C\ g^{-1}\ mol^{-1}}$
C_S	Quantity of the state variable describing total amount of soil organic carbon (SOC)	$\mathrm{g\ C\ m^{-2}}$
C_{S0}	SOC between the lowest water-table boundary and soil surface (Equilibrium)	$\mathrm{g\ C\ m^{-2}}$
C_{S1}	SOC between the lowest water-table boundary and soil surface (Transient)	$\mathrm{g\ C\ m^{-2}}$
M_V	Soil water content (upland soils)	%
M'_V	Soil water content in the unsaturated zone (peatland soils)	%
H_T	Mean monthly temperature of the organic soil layer	℃
LWB	Lowest water-table boundary (fixed model parameter)	mm
WTD	Water-table depth	mm
F_{sub}	Factor (from 0 to 1) determining the substrate availability	unitless

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