

Partitioning of net carbon dioxide flux measured by automatic transparent chamber

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Abstract. Mathematical model was developed for describing carbon dioxide fluxes at open sedge-sphagnum fen during growing season. The model was calibrated using the results of observations from automatic transparent chamber and it allows us to estimate autotrophic, heterotrophic and ecosystem respiration fluxes, gross and net primary vegetation production, and the net carbon balance.

1. Introduction

The West Siberia peatlands are important components of the terrestrial carbon cycle and store about 70 Pg of carbon in peat soil [1, 2]. Although the size of the carbon reservoir is considerable, the role of peatlands in the global carbon budget has not been studied deep enough [3].

The gaseous exchange between the atmosphere and the peatlands is dominated by photosynthetic fixation of CO₂ from the atmosphere and by soil and vegetation respiration losses of CO₂. The balance between them is known as the net ecosystem exchange (NEE) of CO₂ [4, 5]. The other major gaseous loss of C into the atmosphere is CH₄ which is produced via anoxic decay of the soil organic matter [6, 7]. The loss of C into the fluvial system occurs via export of dissolved and particulate organic carbon, and dissolved gases (CO₂ and CH₄). Numbers of environmental factors play important roles in governing the rate of net CO₂ exchange in peatlands and the expected climate change may affect these regulating factors [4 -7].

The present climate warming in the Northern hemisphere [8, 9] may increase ecosystem carbon uptake by reducing cold-temperature constraints for plant carbon assimilation and growth. Soil warming also accelerates carbon losses due to exponential effect of temperature on soil respiration [10]. Possible changes in temperature and humidity may alter the peatland carbon budget significantly. Estimation of carbon exchange rates between peatlands and the atmosphere as well as the environmental controls on this exchange under existing climatic changes are important scientific objectives.

Modeling approaches are useful to separate the observed net ecosystem exchange into gross primary production (GPP) and total ecosystem respiration (ER) components, since it provides a better diagnostic of ecosystem processes and their regulating factors [8, 11, 12]. Carbon balance models are used to study the relative importance of different environmental factors, and for filling the gaps in time



series to calculate daily and annual carbon budget [11, 12]. Partitioning of the NEE flux is also needed for better understanding of interannual and spatial variability of the carbon fluxes.

The purpose of this study is to develop a mathematical model for estimating CO₂ exchange fluxes of a meso-oligotrophic fen at West Siberia, and to calibrate the model using field data on CO₂ fluxes obtained using automatic transparent chamber and infra-red gas analyzer.

2. Methods

The measurement site is located in the south of West Siberia (Russia) at the Bakcharskoe bog (area 1400 km²) in the interfluvies of the rivers Iksha and Bakchar in Bakcharsky district of Tomsk region, Russia [13]. The observation site was arranged at mesooligotrophic open sedge-sphagnum fen with continuous moss cover of *Sphagnum magellanicum*. Herbs and sedges cover about 50% of the area and they are represented mostly by *Eriophorum vaginatum*, *Carex rostrata*, *Carex limosa* species [2].

An automated soil CO₂ flux system LI-8100A (Li-Cor Biogeoscience, USA) with transparent long-term chamber LI-8100-104 has been used for carbon dioxide emission measurements during field campaigns in 2014-2015. Measurements were conducted two times in a month during daytime only. Intense field campaigns were held in August 15-17 and August 21-25 for a diurnal observation of CO₂ fluxes.

The chamber was installed at plastic cylindrical basement deepened into the peat to 15 cm. The vegetation cover under the chamber consists of mosses and sedges only. The carbon dioxide fluxes were estimated by increase of CO₂ concentration in the chamber during an exposition. An exposition was 5 min, but only two first minutes were used for total flux calculation when CO₂ concentration changes according to linear manner. The measurements were automatically repeated every 20 minutes. Simultaneous observations of air, surface and peat temperatures, incoming photosynthetically active solar radiation (PAR), atmospheric pressure, air water content, water table level and precipitation were made.

The measured NEE was partitioned into GPP and ER fluxes:

$$NEE = ER - GPP.$$

The total ecosystem respiration was subdivided into heterotrophic respiration (HR) and autotrophic respiration (AR). The plant parts and microbes have different temperature sensitivities and temporal decoupling of autotrophic and microbial processes might therefore enhance the model of the temperature response of respiration. Each respiration component was modeled using an exponential equation (2-3) widely used for ER variations explanation [12, 14 - 16]

$$ER = HR + AR; \quad (1)$$

$$HR = E_H \times \exp(k_H \times T_a); \quad (2)$$

$$AR = LAI \times E_A \times \exp(k_A \times T_a), \quad (3)$$

where T_a is air temperature (°C), E_H and E_A are basal levels of heterotrophic and autotrophic respiration at 0 °C, respectively, k_H and k_A are temperature sensitivity coefficients. Air temperature was used as an explanatory factor. Autotrophic respiration started to increase proportionally to LAI with the growth of green vegetation.

A rectangular hyperbolic function was used for the light response of GPP in daytime [12, 14 - 15]:

$$GPP(PAR) = LAI \times \alpha \times PAR \times G_m / (\alpha \times PAR + G_m), \quad (4)$$

where α is the initial slope of the light response curve at low light (photosynthetic efficiency), G_m is the theoretical maximum rate of photosynthesis at infinite PAR (photosynthetic capacity).

In this study NEE is negative when the value of GPP exceeds the ER value and there is a net removal of carbon dioxide from the atmosphere. NEE is positive when the ER value exceeds the GPP value and the carbon dioxide is released from the ecosystem into the atmosphere.

3. Results and discussion

The mathematical model was calibrated using field observation data. The multiply optimization procedure was performed in MATLAB software using *fminsearch* function. The minimum of the unconstrained multivariable function was found using the derivative-free method. The root-mean-square error was used as minimizing function. The following model parameters were estimated: $G_m = 1603.7 \text{ mgCO}_2 \text{ m}^{-2} \text{ h}^{-1}$, $\alpha = 0.71 \text{ mgCO}_2 \text{ m}^{-2} \text{ h}^{-1} / \mu\text{mol m}^{-2} \text{ s}^{-1}$, $E_H = 59.3 \text{ mgCO}_2 \text{ m}^{-2} \text{ h}^{-1}$, $E_A = 39.5 \text{ mgCO}_2 \text{ m}^{-2} \text{ h}^{-1}$, $k_H = 0.047 \text{ }^\circ\text{C}^{-1}$, $k_A = 0.024 \text{ }^\circ\text{C}^{-1}$. The temperature sensitivity coefficient for heterotrophic respiration is two times greater than the corresponding coefficient for autotrophic respiration. The basal level of heterotrophic respiration exceeds the basal respiration of plants by 67%. There is a good agreement between the model output and the observations in daytime but it is not so satisfactory for night period. The observed night time variations of ecosystem respiration are much greater than the modeled ones.

The proposed mathematical model may be used to calculate daily and annual carbon dioxide fluxes for the studied ecosystem. For the variations of the modeled net daily CO_2 fluxes in 2016 see Figure 1. The NEE values increase from $0.64 \text{ gC m}^{-2} \text{ d}^{-1}$ in the beginning of April to $2.37 \text{ gC m}^{-2} \text{ d}^{-1}$ in the middle of July. The share of plant respiration in ER was accounted as 0.5 in the mid-summer and less than 0.3 at the beginning and the end of the vegetation season. The maximal GPP ($5.02 \text{ gC m}^{-2} \text{ d}^{-1}$) in 2016 was obtained in June 23, the minimal GPP ($0.39 \text{ gC m}^{-2} \text{ d}^{-1}$) – at the beginning of April. The simulated NEE varies significantly from 0.89 to $-2.86 \text{ gC m}^{-2} \text{ d}^{-1}$ during a growing season due to variations of the main controls. The average NEE value is $-0.81 \text{ gC m}^{-2} \text{ d}^{-1}$. Therefore, the carbon assimilation by peatland vegetation is greater than the total ecosystem respiration during a vegetative season. The net carbon accumulation in 2016 for the studied ecosystem was estimated as $149 \text{ gC m}^{-2} \text{ d}^{-1}$. The net primary production ($\text{NPP} = \text{GPP} - \text{AR}$) was $300 \text{ gC m}^{-2} \text{ d}^{-1}$.

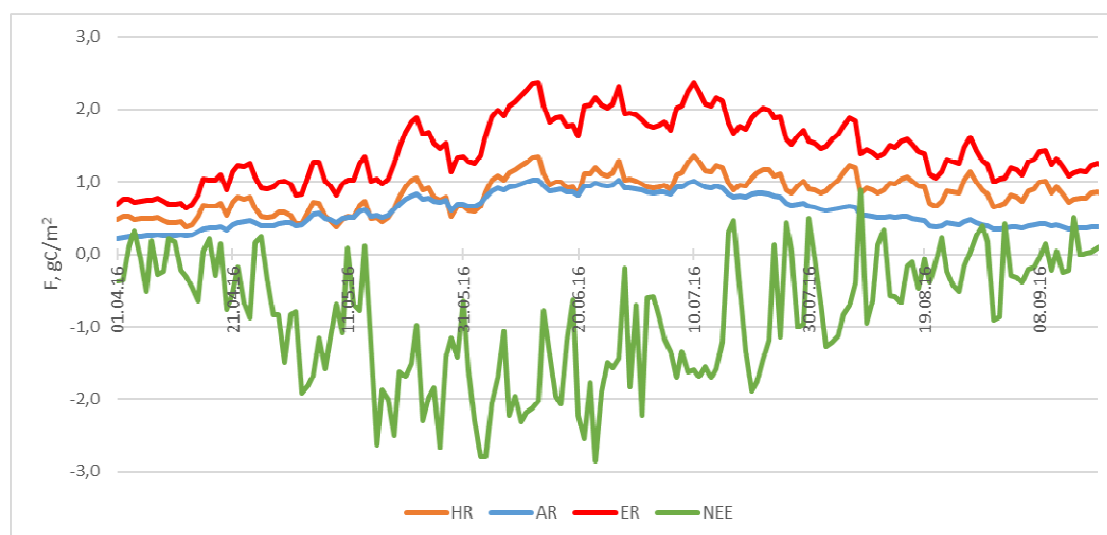


Figure 1. Seasonal variations of modelled daily averaged carbon dioxide fluxes in 2016.

The proposed model was used to calculate variations of net carbon balance and its components during growing seasons of 2011-2016 for mesotrophic sedge-sphagnum fen at Bakcharskoe bog. The data on air temperature and incoming solar radiation were taken from the nearest weather station. It

was found that the studied ecosystem act as a stable sink for the atmospheric carbon (Table 1) accumulating annually from 112 to 148 gC m⁻².

The release of carbon by heterotrophic and plants respiration according to simulation was estimated at 146.2 and 105.6 gC m⁻² respectively. The total ecosystem respiration was evaluated as 251.9 gC m⁻². The gross primary production of fen vegetation (386.6 gC m⁻²) exceeds the ecosystem respiration. The net primary production values (281 gC m⁻²) are in good agreement with the data obtained by the vegetation clipping methods. The net carbon accumulation was estimated as 134.7 gC m⁻² annually (see Table 1).

Table 1. Modelled annual net carbon balance (gC m⁻²) and its components for mesotrophic sedge-sphagnum fen at Bakcharskoe bog in 2011-2016.

Year	GPP	AR	HR	ER	NPP	NEE
2011	379,4	110,2	157,1	267,3	269,1	-112,1
2012	392	108	151,5	259,5	284	-132,6
2013	367,3	99,4	134,1	233,4	268	-133,9
2014	387,3	103,1	139,3	242,4	284,1	-144,8
2015	386,3	105,6	144,6	250,2	280,7	-136
2016	407,4	107,5	151,3	258,8	300	-148,7
Mean	386,6	105,6	146,3	251,9	281,0	-134,7

4. Conclusion

A model of net ecosystem exchange was performed to study the influence of different environmental factors and to calculate daily and growing season carbon budget. The model uses air temperature, incoming photosynthetically active radiation and leaf area index as the explanatory factors for gross primary production, heterotrophic and autotrophic respiration. The model coefficients were calibrated using data collected by automated soil CO₂ flux system with clear long-term chamber at mesotrophic open sedge-sphagnum fen. The results allow us to calculate different temperature sensitivity of heterotrophic and plant respiration. It indicates that the proposed model is a promising tool for a better understanding of ecosystem biogeochemical processes. The model may be applied to the simulation of intra-annual variations in CO₂ flux components in peatland ecosystems.

Acknowledgments

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