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CO_2 EMISSION FROM OLIGOTROPHIC PEATLAND SOIL OF WESTERN SIBERIA

Golovatskaya E.A., Dyukarev E.A.

Institute of monitoring of climatic and ecological systems SB RAS, Tomsk

golovatskaya@imces.ru

The data on diurnal and seasonal carbon dioxide emission rates determined by static chamber technique from the surface of oligotrophic mire in southern taiga in Western Siberia in 2005-2007 are presented. The general dynamics of CO_2 emission during the summer period is the increase of CO_2 emission intensity to the middle of summer and a subsequent decrease towards autumn. The mean values of CO_2 emission was 118 mg CO_2 m^{-2} h^{-1}. Analysis of diurnal variations in CO_2 emission has showed that the maximum CO_2 flux has been observed at 4 PM, and the minimum flux at 7 AM. The average magnitude of daily fluctuations of CO_2 emission was 74 mg CO_2 m^{-2} h^{-1}. Ambient CO_2 concentration has maximum at 4 AM and minimum at 4 PM. The mean magnitude of CO_2 background concentration was about 160 ppm. Established relationships between air temperatures and CO_2 flux were used to estimate CO_2 fluxes between measurement periods. It was found that the best time interval for measuring CO_2 fluxes in summer time is from 10 AM to 1 PM.

Keywords: *peatlands, carbon dioxide emission, temperature.*

INTRODUCTION

Long-term studies of ecosystem carbon dioxide (CO_2) emission improve our understanding of the links between climate and the carbon cycle. It is important that we continue to develop such understanding for all major terrestrial ecosystems in order to resolve current uncertainties in carbon cycling [Canadell et al., 2000; Baldocchi et al., 2001]. The current climate warming is more significant in high latitudes of continental areas in the Northern hemisphere [IPCC, 2001; Kabanov, 2006]; therefore, possible changes in temperature and humidity may alter the peatland carbon budget significantly. Determination of carbon exchange rates between peatlands and the atmosphere, as well as the ecological and climatic controls on this exchange under existing climatic changes represent important scientific objectives.

Peatland ecosystems play an important role in the biosphere. They are store of soil carbon, sink for carbon dioxide and source of atmospheric methane. Peatlands could provide a significant positive feedback for climate changes if warming stimulates decomposition of bulk soil organic matter enhancing CO_2 release to the atmosphere [Bubier et al., 2003a; Zavarzin, 2007]. Peatlands occupy only about 3-5% of the terrestrial surface, but the global peat resources are estimated at 120 - 455 PgC [Gorham, 1991; Vomperskii, 1994]. The peat carbon pool of Russia is estimated at 215 PgC [Botch et al., 1995]. The area of peatlands in Western Siberia is about 42% of the area of Russian peatlands. Western Siberia peatlands deposit about 36% of Russia’s total soil carbon pool [Vomperskii, 1994; Efremov, 1994; Titlyanova, 1998]. Carbon content in Western Siberia peatlands varies from 55 Pg [Efremov, 2007] to 70 Pg [Sheng, 2004]. Although the size of the carbon reservoir is considerable, the role of peatlands in the global carbon budget is still unclear.

The carbon budget of a peatland ecosystem is estimated using Net Ecosystem Production (NEP), i.e. the net accumulation of organic matter or carbon by an ecosystem.

$$NEP = GPP - Recosys; \quad Recosys = Ra + Rh$$

Gross primary production (GPP) refers to the total amount of carbon fixed in the process of photosynthesis by plants in an ecosystem. «Recosys» is ecosystem respiration equal to sum of respiration of plants (Ra), animals and soil microbes (Rh).

$$NPP = GPP - Ra$$

Net primary production (NPP) refers to the net production of organic carbon by plants in an ecosystem usually measured over a period of a year or more. It is GPP minus the amount of carbon respired by plants themselves in autotrophic respiration.

$$NEP = NPP - Rh$$

NEP is the difference between the rate of production of living organic matter (NPP) and the decomposition rate of dead organic matter (heterotrophic respiration, Rh) including losses by the decomposition of organic remains by soil biota [Zavarzin, 2007].

Soil CO_2 efflux is comprised of autotrophic respiration from plant roots and heterotrophic respiration from soil organisms. Total soil CO_2 efflux is often also referred to as soil respiration, whereas other researchers refer to soil respiration as only the CO_2 efflux originating from heterotrophic respiration in the soil and use it as distinct from the autotrophic respiration originating from plant roots.

A number of environmental factors play an important role in governing the rate of net CO_2 exchange in peatlands, and expected climate change can affect these regulating factors [Bubier et al., 2003]. For example, previous studies have shown the importance of the temperature [McKenzie et al., 1998; Bubier et al., 1998; Silvola et al., 1996; Kim, Verma, 1992] water table [Christensen et al., 1998; Moore et al., 1998; Alm et al., 1997; Chapman et al., 1996; Johnson et al., 1996], plant activity [Whiting, Chanton, 2001; Griffis et al., 2000; Bellisario et al., 1998; Silvola et al., 1996], and mineral nutrient characteristics of soil [Bridgham et al., 1998; Thormann, Bayley, 1997; Updegraff et al., 1995] on NEE and respiration. The most studies have shown the influence of temperature on CO_2 emission [Moore and Dalva, 1993; Updegraff et al., 1998; Lafleur et al., 2005; Strack et al., 2006].

CO_2 fluxes have strongly pronounced diurnal and seasonal dynamics [Naumov, 1994; Pomazkina et al., 1996; Subke et al., 2003; Naumov, 2004; Hirano, 2007; McDermitt et al., 2007; Karelin, Zamolodchikov, 2008] due to variations in soil temperature, moisture or wind-induced pressure pumping. Diurnal dynamics of CO_2 fluxes is usually studied the eddy covariance technique. It offers the advantage of a high temporal resolution and an integrated flux measurement at ecosystem scale. Chamber measurements are more suitable to examine processes operating at small scales and to cover the small scale variability of microsites [Forbitch et al., 2010]. Chamber measurements in a day-round regime are rare especially in peatlands.

Karelin and Zamolodchicov [2008] obtain the largest of chamber measurements dataset (about 1000 observations) at tundra region and illustrate diurnal rhythms in CO_2 emission, but authors put main attention on relations between photosynthetic active radiation and CO_2 fluxes to determine GPP. Studying diurnal dynamics of CO_2 emission Naumov A.V. [2009] have registered maximum of emission in evening (6-10 PM) and minimum in morning (6-10 AM). Diurnal rhythms of CO2 emission at peatlands of North and South Taiga zone are similar at similar temperature variatons. Measurements of CO_2 emission from oligotrophic peatland at North-Western Russia [Kalyuzhny and Lavrov, 2004] have shown strong influence of air temperature. Authors have found that this dependence breaks in evening, when occurs some increase in emission due to heat accumulation by peat deposit. The minimum of CO_2 emission was registered at 4-7 AM. Automatic closed chambers that sample CO_2 every 3 hours over the diurnal cycle [Bubier et al, 2003] allows to reveal short-term response of peatlands to changes in temperature and precipitations. Linear regression analysis have shown that both temperature and water table are important in predicting night time CO_2 flux. Kutzbach et al. [2007] mentioned diurnal cycle presence in CO_2 fluxes at the flark sites ta Finland peatlands, but does not discuss it.

In this study, we investigate variation of diurnal and seasonal CO_2 emission from the surface of peatland. We measured CO_2 emission in a round-a-day regime using static chamber technique for three growing seasons (May through October) in 2005-2007 years at large oligotrophic bog in West Siberia. The total number of CO_2 emission measurements is about 600. Specifically we examine relationship between CO_2 emission and the air temperature. Given the very small number of flux measurement using chamber technique in the studied area, our flux estimates are highly relevant to understanding carbon cycling in West Siberian peatlands.

MATERIALS AND METHODS

The experimental plots were located between Iksa and Bakchar rivers (56°58`N 82°36`E) at the Bakcharskoe bog in Tomsk region, Russia. The total bog area is 1400 km^2. The measurement site is situated on the oligotrophic bog, 200 m from the bog boundary. Vegetation at the observation point is a raised bog (in Russian: “ryam”) with pine – dwarf shrub –sphagnum phytocenosis. The tree layer consists of *Pinus sylvestris f. Litwinowii*. Mean trees height is 3 m, mean tree diameter at breast height is 3 cm, and projective crown coverage about 30%. Main species of the dwarf shrub layer are *Ledum palustre L., Chamaedaphne calyculata (L.) Moench, Andromeda polifolia L., Oxycoccus microcarpus Turcz. ex Rupr.* Shrub projective coverage is about 60%. Herb layer is badly developed and consists of *Eriophorum vaginatum L., Rubus chamaemorus L., Drosera rotundifolia L.* Herb projective coverage is less 5 %. Mosses form a closed cover and consist of *Sphagnum fuscum Klinggr.* (95%), *Sph. angustifolium C. Jens.* and *Sph. magellanicum Brid.*

A detailed description of the vegetation at the study area is presented in the paper by Golovatskaya and Porokhina [2005]. The site is located 7 km from the nearest village, and 200 km from the nearest town and therefore have not been subjected to any anthropogenic impact before experiment. The peat layer is 2 m thick and 3000 – 5000 yrs old [Kabanov, 2002].

Flux measurement

An infrared gas analyzer OPTOGAS 500.4 (OPTEC Corp., St.-Petersburg, Russia) attached to a static opaque plastic chamber (height 26 cm, diameter 29 cm) fitted with a small circulation fan has been used for carbon dioxide emission measurements since 2004. The chamber is covered with light reflecting aluminum foil to prevent chamber heating from sunlight. We used three chambers in each measurement in order to reduce the influence of spatial heterogeneity of fluxes. To decrease the disturbance of vegetation cover and exclude lateral gas exchange at the moment the chambers were placed, we put them on the preinstalled iron cylindrical collars deepened to the peat to 25 cm. Three collars were installed permanently at the observation point during the whole period. Collars were installed close to each other at flat lawn surface. CO_2 flux was determined using the rate of increase of CO_2 concentration in the chamber for a period of 30 minutes.

Air from the chamber was pumped through the gas analyzer at the rate of 1 $L \cdot minute^{-1}$. The linear increase in volume concentration was determined by measuring CO_2 concentration at the frequency of three times per second. The total number of CO_2 values registered for each chamber during each measurement was about 5000. Data sets were stored in computer and transformed to mass concentration units according to equation 1:

$$dc = f*10^{-6}*P*M/(R*T), \quad (1)$$

where, P is air pressure in Pa, M is molar weight (44.0096 g/mole), R is the universal gas constant (8.31 $J \cdot mole^{-1} \cdot K^{-1}$) [Smagin, 2005], dc is CO_2 mass concentration growth in $g \cdot m^{-3} \cdot hr^{-1}$, f is volume concentration increase in $ppm \cdot hr^{-1}$.

The CO_2 emission rate from the sampling area was calculated as:

$$F = dc*V/S, \quad (2)$$

where F is emission rate in $g \cdot m^{-2} \cdot hr^{-1}$, V is the chamber volume, S is the chamber basal area.

The measurements of the carbon dioxide mixing ration (concentration CO_2 in the ambient air) were conducted using the infrared gas analyzer at the height of 50 cm from the surface. CO_2 mixing ratio was calculated as average from 900 values recorded during 5 minutes of measurements with frequency about 3 times per second.

The microrelief at the place of flux measurements is flat. The vegetation cover under the chamber consisted of mosses only. A small amount of herb was tightly cut above the moss layer each month before measurements were taken. No any shrubs were inside collars. The sites were kept plant free by regular cutting. Surface litter was kept inside collars.

The total efflux from surface consisted of heterotrophic respiration, the fraction of autotrophic moss respiration, and fraction of respiration of plant roots. Any damage to moss cover to exclude autotrophic respiration would bring a dramatic disturbance to thermal regime and therefore to soil respiration as such.

The measurements were conducted during growth seasons in 2005-2007. We measured CO_2 fluxes each 3 hours from May till October over 8 days of each month in a round-day regime. In total about 600 measurements of ambient CO_2 concentration and CO_2 flux from the soil surface were conducted.

The local climate parameters were determined from data of weather station “Bakchar” (WMO ID 293280, 57°05'N 81°55'E). Weather station located 30 km west of the observation point. Air temperature and atmospheric pressure were monitored at the observation point at 15 min intervals by automatic equipment (HOBO Onset Corporation, USA) with data logger. Relative air humidity and temperature of peat deposit were recorded at 8 depths up to 1 m by automatic station for temperature monitoring of soils MODUL-T (Joined Institute of Geology, Mineralogy and Geophysics SB RAS, Novosibirsk, Russia).

RESULTS

Weather characteristics

The long-term (1988-2007) average annual temperature was 0.53 ^oC, standard deviation (STD) was 0.56 ^oC. (Hereinafter STD is given after “±” sign.) The annual air temperature varied from -0.35^oC in 2006 to +1.74 ^oC in 2007. The average total annual precipitation was 488 ± 117 mm. The average May - September air temperature was 13.6 ±0.7 ^oC. About 58% of total precipitation (or 285 ±91 mm) fell during these months. Climatic conditions of winters and summers varied during the studied years. The average May-September temperatures in 2005-2007 were higher than the 20-year average one. June and September 2006 were extremely warm (3.81 and 3.35 ^oC above the 20 – year mean value), but the temperature in August was 2.63 ^oC lower than the average temperature. As for precipitation, each year the precipitation regime appeared to be different. The driest May-September period was in 2006 (189 mm). May-September period of 2007 was much wetter (416 mm), than the 20-year mean value (285 mm). In May and June of 2007 precipitation was by two and three times as much as the 20-year mean value As a result, there was an extremely high water table in summer 2007. The studied years can be characterized as normal (2005), dry (2006), and wet (2007).

Seasonal dynamics of air temperature, ambient CO_2 concentration and CO_2 emission

Air temperature and CO_2 flux demonstrated prominent seasonal trends Air temperature rose from May to July and then fell in September. The monthly mean July temperature averaged for 2005-2007 was 20.2 ^oC, May and September monthly mean 2005-2007 temperatures were 9.4 and 9.9 ^oC, correspondingly The maximum temperature during 2005-2007 was 36.7 ^oC on 27 May 2005, and the minimal temperature was – 5.1 ^oC on 28 September 2006. Figure 1 shows variations of air temperature, ambient CO_2 concentration and measured CO_2 flux during growth seasons of 2005-2007 at the experimental site. The basic statistics for measured parameters for different months are given in the Table 1.

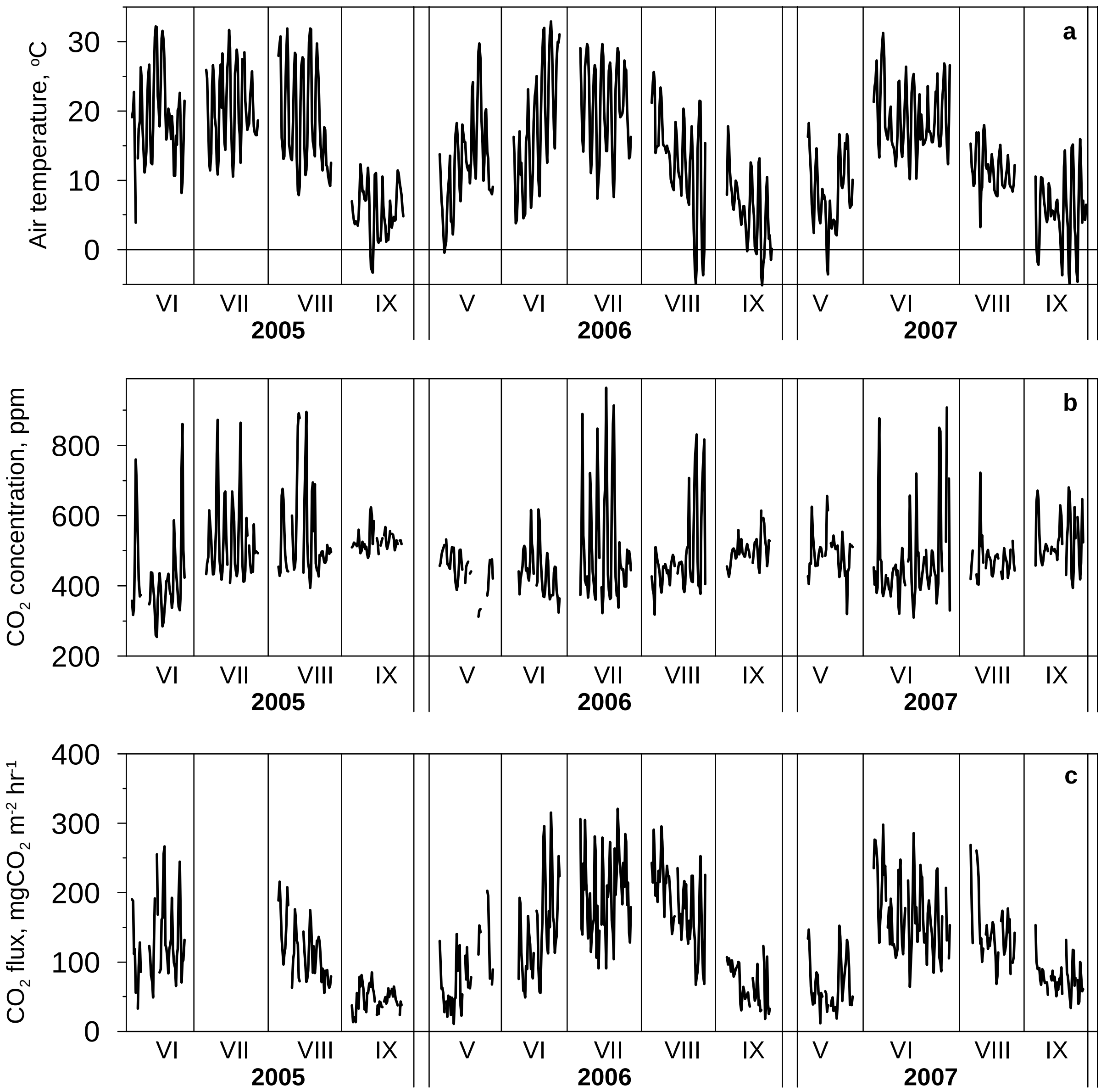

Fig. 1. Time series of air temperature (a), ambient CO_2 concentration (b) and CO_2 flux (c) during growth seasons in 2005 - 2007. Measurement periods are referred at the bottom axis.

The ambient concentrations of CO_2 during the vegetation period varied from 250 to 964 ppm. Some increase in CO_2 concentration occurs at the end of season, but diurnal variations of concentration were much higher. Ambient concentration of CO_2 is mainly defined by plants respiration and emission from the peat. Plant photosyntesis and CO_2 assimilation in dark time is absent. Night calm conditions and low turbulence in the atmosphere brings to increase of CO_2 concentrations in near surface air at night time. The highest concentrations

(~670 ppm) recorded in night time in July may be referred to period of strongest vegetation respiration [Aurela et al., 2001].

Table 1. Mean values and standard deviations (STD) of air temperature (T), ambient CO_2 concentration (C) and CO_2 flux (F) for different periods. N –number of measurements.

Year	period	n	T, °C		C, ppm		F, $mgCO_2\ m^{-2}\ hr^{-1}$	
			Mean	STD	Mean	STD	Mean	STD
2005	20 Jun – 27 Jun	46	19.2	6.4	418	124	130.9	56.4
	22 Jul – 29 Jul	48	20.3	5.7	527	111		
	17 Aug – 24 Aug	51	19.0	7.5	544	131	115.5	40.2
	22 Sep – 29 Sep	50	6.3	3.1	528	30	46.4	17.6
2006	20 May – 27 May	42	12.5	6.8	450	51	81.4	47.8
	14 Jun – 20 Jun	43	17.7	8.8	439	68	146.5	68.3
	17 Jul – 24 Jul	53	20.4	6.5	510	161	198.2	59.8
	13 Aug – 20 Aug	55	12.8	7.3	485	119	184.2	55.2
	23 Sep – 29 Sep	44	5.8	5.0	502	40	66.5	28.9
2007	19 May – 25 May	43	8.0	5.2	492	58	66.9	36.5
	23 Jun – 03 Jul	73	19.0	4.8	466	125	169.9	54.4
	10 Aug – 16 Aug	40	11.4	3.0	476	54	142.7	44.7
	19 Sep – 26 Sep	46	5.5	5.1	527	72	76.6	22.8

CO_2 fluxes represent a prominent seasonal pattern (Figure 1). CO_2 emission intensification occurs at the onset of spring snowmelt. In summer CO_2 emission tends to rise up to June, and then decreases. The high values of ambient CO_2 concentration in July is the result of enhanced plant respiration, as well as WTL decrease and an acrotelm layer of the peat soil warming. July is characterized by high air temperatures and rare rainfalls. Thus, the acrotelm layer of peat gets warmer and CO_2 emission goes up. Carbon dioxide emission in September is low because of low temperatures [Bubier et al., 2003a, Smagin, 2005].

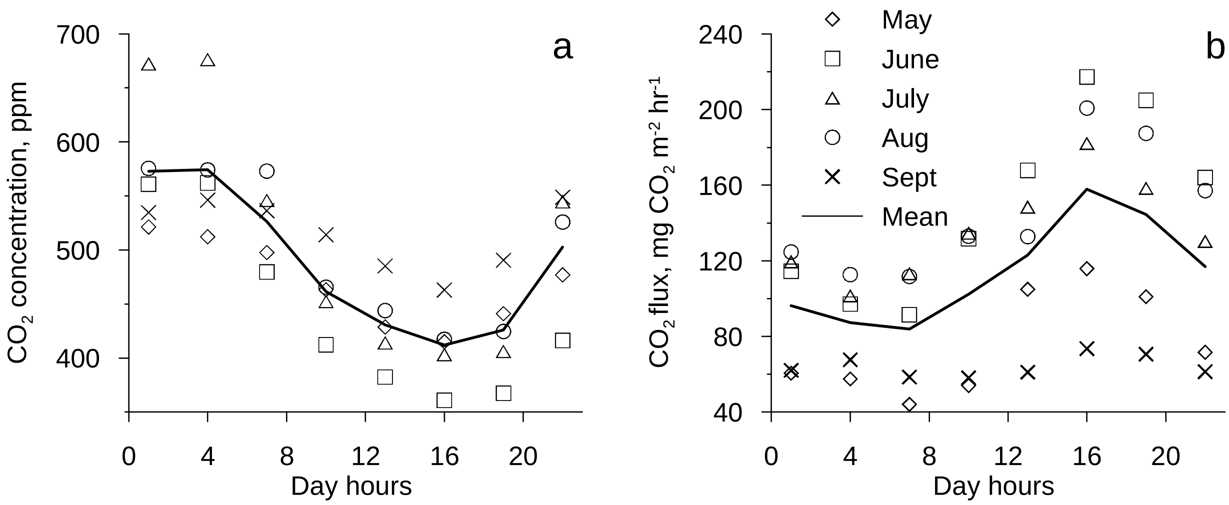

Fig. 2. Diurnal cycles of ambient CO_2 concentration (a) and CO_2 emission (b) for different months. Averaged values for 2005-2007.

Diurnal dynamics of CO_2 ambient concentration and CO_2 emission

Ambient CO_2 concentration and emission rate have high temporal variations. Average values for a certain time of a day (1,4,7,10 AM, 1,4,7,10 PM) was calculated for each month to illustrate diurnal variations. Figure 2 shows monthly-mean diurnal variations in ambient carbon dioxide content and CO_2 emission rate. CO_2 concentration decreased gradually from the early morning and reaches minimum in the late afternoon or in the evening. Ambient CO_2 concentration has maximum at 4 AM and minimum at 4 PM. The average magnitude of diurnal course of CO_2 concentration is about 160 ppm. The diurnal variations of CO_2 concentration were similar for different months. September was an exception: it showed weaker dynamics at high mean values. The average diurnal range in September was 84 ppm with mean value 514 ppm.

Studying of dynamics of CO_2 emission allowed to reveal variation in diurnal CO_2 emission. As shown on Figure 2b, the maximum flux was observed at 4 PM and minimum one at 7 AM. The average magnitude of daily fluctuations of CO_2 emission is 74 mg CO_2 m^{-2} h^{-1}. Daily dynamics was most prominent in June when the maximal CO_2 was measured. The amplitude of diurnal changes in CO_2 flux in June was 126 mgCO_2 m^{-2} h^{-1}; the mean daily flux was 149 mg CO_2 m^{-2} h^{-1}. In May and September CO_2 flux dynamics were different from those in summer months. The mean flux value calculated for May was about as low as 76 mgCO_2 m^{-2} h^{-1}, but difference between day and night emissions was rather high (72 mgCO_2 m^{-2} h^{-1}). Mean flux in September (64 mgCO_2 m^{-2} h^{-1}) was close to that in May, but diurnal course was negligible with magnitude of 15 mg CO_2 m^{-2} h^{-1}.

DISCUSSION

CO_2 emission and ambient CO_2 concentration

Flux measurements in the dark chamber represent the sum of heterotrophic respiration, autotrophic moss respiration, and the fraction of respiration of plant roots. At the moment we cannot separate CO_2 flux from peat decomposition and mosses respiration. We assume that the CO_2 flux we have measured present total emission from the surface of peatland, covered by sphagnum mosses, and it does not include respiration of above-ground parts of herbs, shrubs and trees.

The dynamics of CO_2 emission was controlled mainly by temperature and moisture conditions during a growth season [Aurela et al., 2001; Bubier et al., 2003]. Low values of CO_2 emission in May are explained by high water table level and low air temperatures. A frozen layer of peat hinders the intense CO_2 flux to the atmosphere [Elberling, 2007].

An established reduction of CO_2 fluxes in the wet year, and increased respiration in the dry year were also reported by a number of authors [Moore and Dalva, 1993; Bubier et al., 2003; Strack et al., 2006]. Lafleur et al. [2003] suggested that water table position is the most important determinant in inter-annual differences in the peatland growth season net ecosystem exchange and therefore in the annual CO_2 balance as well.

The mean values of CO_2 emission was 118.2 mg CO_2 m^{-2} h^{-1}. The average estimations of CO_2 emission from West Siberian peatlands obtained by Naumov (2004) vary from 24.5 mgCO_2 m^{-2} h^{-1} at sedge-sphagnum community in middle taiga to 150.6 mgCO_2 m^{-2} h^{-1} at minerotrophic sedge-sphagnum mire in northern taiga. Heikkinen et al. (2004) observed CO_2 emission variations from 14.8 at bare peat on peat plateau to 162 mgCO_2 m^{-2} h^{-1} at a lake margin in the discontinuous permafrost zone in East European Russian tundra. The typical summer respiration observed on a mesotrophic fen in northern Finland was 540 mgCO_2 m^{-2} h^{-1} [Aurela et al., 2001].Waddington and Roulet (1996) found that topographically different areas, such as hollows and hummocks, pools and ridges, plateaus and peatland margins have significant differences in CO_2 emission (from 70 to 674 mgCO_2 m^{-2} h^{-1}).

In the middle of summer green biomass production is maximal and plants are in good climatic conditions (warm and humid). Carbon dioxide uptake by plants and C accumulation in the form of live biomass provides by photosynthesis in daytime. Lowest values of ambient CO_2 concentration in daytime in June indicate high photosynthetic activity of plants. The increase of ambient CO_2 concentration is related to decrease of photosynthesis in autumn.

The character of diurnal dynamics of CO_2 concentration agrees well with variations of CO_2 flux. Elevated ambient air CO_2 concentration suppresses soil CO_2 efflux under cold night-time conditions [McDermitt et al., 2007], as expected from diffusion theory. The near surface concentration of CO_2 decreases at sunrise due to carbon dioxide uptake at photosynthesis and due to increased turbulent mixing in the unstable atmosphere. Lowering ambient CO_2 concentration acts as one of the mechanisms moving CO_2 out of the soil into the atmosphere. Increase of soil temperature during the day stimulates both heterotrophic and autotrophic respiration. CO_2 emission rises from the morning to the afternoon and reaches the maximum at 4 PM, when the top layers of soil are well heated.

Diurnal variations in CO_2 flux are related to variations in intensity of biological processes in the soil and in diffusion rate. Earlier Hirano (2005) reported that top soil respiration under snow pack in a temperate deciduous forest showed clear diurnal variations with a maximum early in the afternoon. Day time increase in CO_2 efflux under snow pack is caused by increase in soil moisture through enhanced heterotrophic respiration by the additional substrate supply [Hirano, 2005].

Analysis of diurnal variations in CO_2 emission from the studied peatland have showed that afternoon emission of CO_2 are higher than daily mean fluxes by 13- 52 % depending on the month. Measurements of fluxes in natural conditions by chamber method usually are performed in a daytime only. Such limitations are connected with difficulties in reaching the experimental site, organization of round day measurements with manually operated chambers or absence of automatic monitoring systems. Our detailed studies of diurnal CO_2 emission proved that using only day time flux measurements in calculation of annual emission can result in overestimation of the real values of CO_2 emission by 20-50%. The reliable data of chamber measurements of CO_2 emission can be obtained in summer in the daytime from 10 AM to 1 PM. In autumn reliable measurements can be made at any time period due to weak variations in soil temperatures.

Sensitivity of CO_2 fluxes to air temperatures

CO_2 emission from peatlands is strongly correlated to air and soil temperatures [Moore and Dalva, 1993; Updegraff et al., 1998; Subke et al., 2003; Lafleur et al., 2005; Strack et al., 2006]. Temperature is more important control on CO_2 flux than water table position because most of the CO_2 is generated close to the peatland surface [Lafleur et al., 2005; Hirano, 2005].

The response of CO_2 fluxes and ambient concentration to air temperature has been analyzed by correlation analysis. A positive dependence between CO_2 emission and air temperature was revealed. The linear Pearson correlation coefficient (r) determined for the whole time series presented at Figure 1 is equal to 0.63. Direct intensification of CO_2 flux is provided by increase of air temperature.

The relationships between carbon dioxide emission and other environmental characteristics at the experimental site are presented in the paper by Golovatskaya et al. [2008]. CO_2 emission correlated well with the water table level (r =–0.67), soil moisture (r=−0.41), and temperature (r=0.65). Also, a good correlation was revealed for CO_2 emission and air humidity and pressure (r=–0.40 and –0.53, respectively).

Negative linear correlation (r = -0.53) was found between ambient CO_2 concentration and air temperature. Partially this relation can be explained by an intensification of plant photosynthesis activity at temperature increase. An enhancement of incoming solar radiation in the period from the morning to the middle of the day results in warming up the earth surface and increase of air temperature. Reversely, the higher radiation in daytime promotes CO_2 fixation by plants and thus reduces ambient CO_2 concentration. The sensitivity of ambient CO_2 to air temperature is statistically significant at the level $p<0.05$, and it will be used for filling up gaps in series of experimental data.

We calculate linear correlation coefficients for each month of growth seasons in 2005-2007 in order to estimate influence of different factors on the CO_2 emission and ambient concentration. Correlation coefficients are presented in Table 2. Correlation coefficients between air temperature and CO_2 flux vary usually from 0.61 to 0.86 for summer months. Relatively low correlations exist in July 2005 and September 2005-2007. The worsening of linear links in September probably can be explained by presence of high values of CO_2 emission at temperatures below 0 ^{o}C. According to [Kurganova, 2007] some acceleration of CO_2 emission occurs at freeze-thaw events. Linear correlation coefficients between air temperature and ambient CO_2 concentrations calculated for each month changes from -0.4 in September 2005 to -0.91 in May 2006.

Table 2. Parameters of linear regression and correlation coefficients (r) between CO_2 flux (F), ambient CO_2 concentration (C) and air temperature (T) for different measurement periods.

		F = aT +b			C = aT + b		
		r	a	b	r	a	b
2005	20 Jun – 27 Jun	0.63	5.6	23.6	-0.79	-14.3	691
	22 Jul – 29 Jul				-0.79	-15.9	848
	17 Aug – 24 Aug	0.79	4.2	37.2	-0.65	-11.2	754
	22 Sep – 29 Sep	0.25	1.4	36.1	-0.40	-2.8	540
2006	20 May – 27 May	0.52	3.8	38.3	-0.91	-7.0	530
	14 Jun – 20 Jun	0.80	6.3	29.4	-0.81	-6.3	556
	17 Jul – 24 Jul	0.61	5.6	84.4	-0.79	-19.6	909
	13 Aug – 20 Aug	0.79	5.9	109.9	-0.89	-14.4	664
	23 Sep – 29 Sep	0.58	3.4	42.4	-0.84	-6.5	537
2007	19 May – 25 May	0.86	5.8	18.8	-0.81	-8.7	564
	23 Jun – 03 Jul	0.65	7.7	26.6	-0.52	-14.0	728
	10 Aug – 16 Aug	0.69	10.7	24.4	-0.72	-13.4	624
	19 Sep – 26 Sep	0.23	1.0	71.2	-0.84	-12.1	590

The relationships between air temperatures, CO_2 flux and ambient concentration were used to estimate fluxes at the peatland between measurement periods. Regression coefficients are given in Table 2. Coefficient “a” reflects the degree of influence of air temperature on the emission process. Usually, it has maximal values in June and July. In combination with raised values of day air temperatures in the mid-summer it results in an increase of fluxes variations. Simulated and experimental data on CO_2 flux and air concentration are given at Fig. 3.

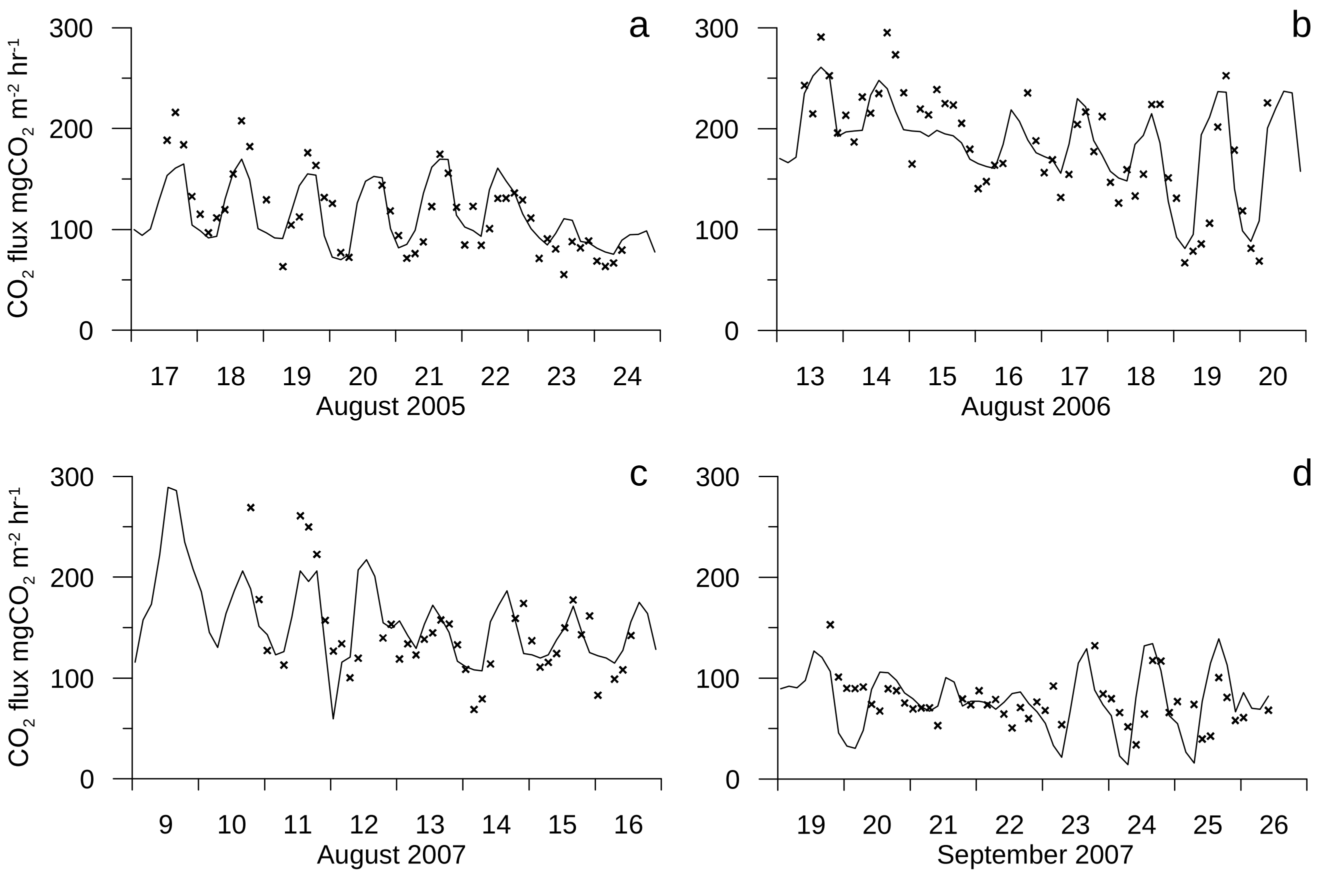

Fig. 3. Comparison of measured (dots) and calculated (lines) values of CO_2 flux for August 2005 (a), August 2006 (b), August 2007 (c) and September 2007 (d).

The mean values of the calculated time series are equal to the mean values of measured CO_2 flux and concentration. Mean measured CO_2 emission is 118.17 mg CO_2 m^{-2} h^{-1} (restored value is 118.98), mean measured concentration is 489 ppm (restored value is 488.9). Standard deviation for calculated time series of CO_2 concentration (STD = 93 ppm) was slightly lower than for measured ones (106 ppm). Restored and measured time series have close correlation links (see Fig.3). Correlation coefficients are equal to 0.72 for CO_2 concentration and 0.86 for CO_2 flux. Using this procedure we can calculate missing data of observations and estimate the dynamics of parameters in time intervals between field expeditions. Time series of observed parameters can be prolonged from the beginning to the end of the vegetation period. We receive data on CO_2 flux for the period with air temperature above 0 ^{o}C. Time series of modeled CO_2 fluxes are given at Fig.4. Estimation of fluxes for Aplil and October were made using correlation links obtained for May and September. The winter-spring fluxes of CO_2 from permanently and seasonally frozen soils represent a sufficient proportion of annual carbon budget varying from 5 to 50 % [Kurganova, 2007], but extrapolation of our measurements to winter season is impossible because characteristics of winter CO_2 emissions are considerably different from those for summer emissions [Grogan, 2006].

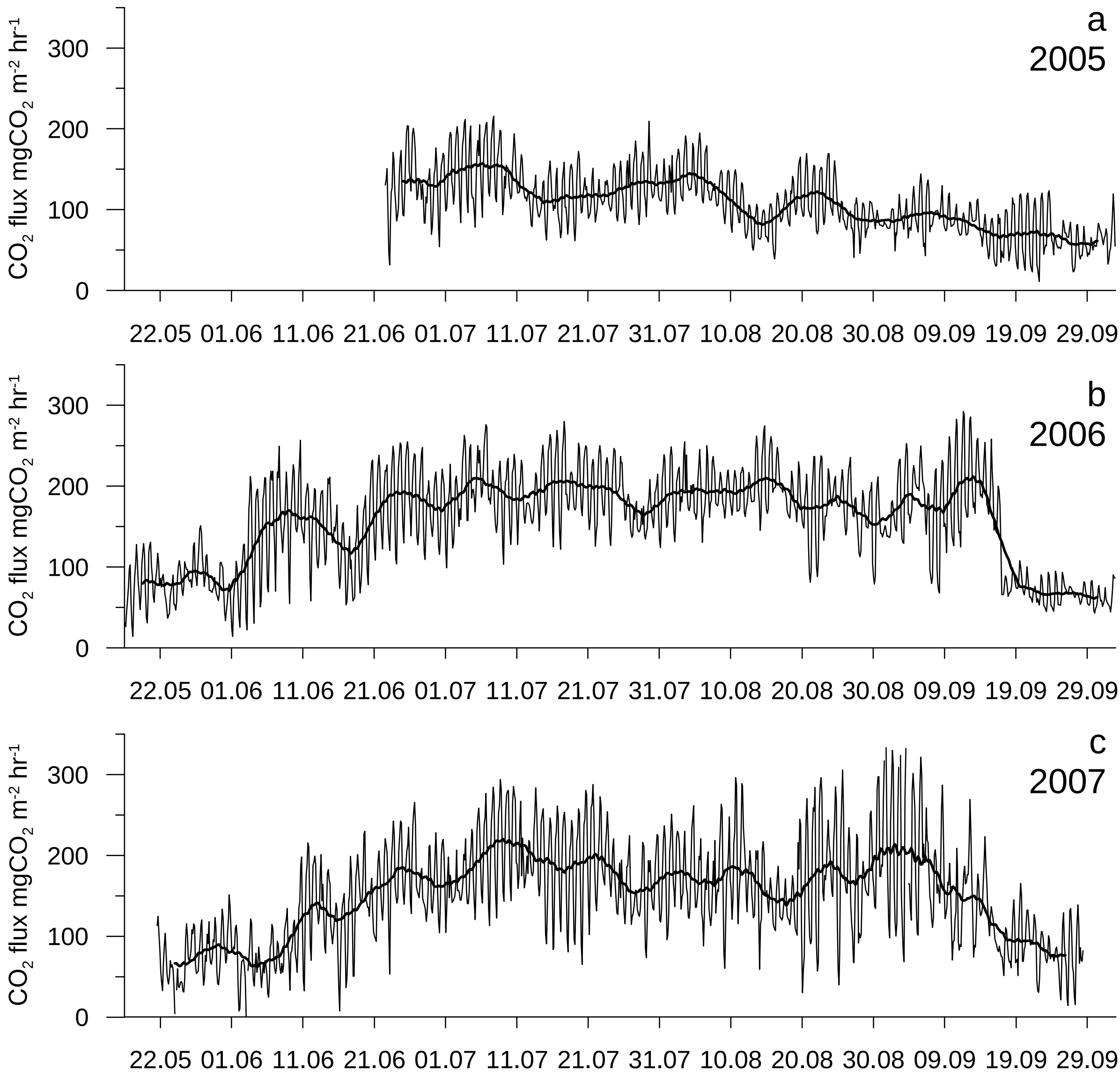

Fig. 4. Modeled CO_2 fluxes in 2005 (a), 2006 (b), and 2007(c). Bold line shows 5-day running average.

Conclusions

Chamber measurements of carbon dioxide emission with high temporal resolution performed in diurnal time scale have provided a powerful tool for analysis of CO_2 fluxes in peatlands. The results provide detailed information that was used for the analysis of environmental factors influencing the emission. The revealed temperature dependence of CO_2 flux was taken into account for precise estimation of the total carbon fluxes during the snow-free period.

The detailed investigation of diurnal dynamics in CO_2 emission suggests that usage of only daytime flux measurements in calculation of annual emission can result in overestimation of the real values of CO_2 fluxes by 20-50%. The reliable data of chamber measurements of CO_2 fluxes can be obtained in summer in the daytime from 10 AM to 1 PM. In autumn representative measurements can be made any time due to weak variations in soil temperatures.

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ЭМИССИЯ CO_2 ОЛИГОТРОФНЫМИ БОЛОТНЫМИ ПОЧВАМИ ЗАПАДНОЙ СИБИРИ

Головацкая Е.А., Дюкарев Е.А.

В работе представлены результаты исследования суточной и сезонной динамики эмиссии CO_2 с поверхности олиготрофного болота в южно-таежной подзоне Западной Сибири в 2005-2007 гг. В течение летнего периода происходит увеличение интенсивности эмиссии CO_2 от весны к середине лета и последующее снижение к осени. Среднее значение эмиссии CO_2 составило 118 мгCO_2 $\cdot$м$^{-2}\cdot$ч$^{-1}$. Анализ суточной динамики эмиссии CO_2 показал, что максимальный поток CO_2 наблюдается в 16 часов, а минимальный - в 7 часов утра. Средняя амплитуда суточных колебаний эмиссии CO_2 составляет 74 мгCO_2 $\cdot$м$^{-2}\cdot$ч$^{-1}$. Выявленные зависимости между температурой воздуха и потоком CO_2 позволили рассчитать эмиссию углекислого газа в периоды между измерениями. Было выявлено, что для оценки эмиссии CO_2 камерным методом в летнее время, оптимальным является период с 10 часов утра до 13 часов.

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