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APPLICATION OF THE AUTOMATED CHAMBER METHOD FOR LONG-TERM MEASUREMENTS OF CO_2 AND CH_4 FLUXES FROM WETLAND ECOSYSTEMS OF THE WEST SIBERIA

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The use of automated systems when studying greenhouse gas (GHG) fluxes allows accurate measurements at minimal disturbance of the soil surface to be carried out and high resolution datasets for extended periods of time to be obtained. Due to the above advantages, chamber measurements play an important role while establishing long-term observations in the framework of such research infrastructures as Integrated Carbon Observation System (ICOS).

CO_2 and CH_4 fluxes from Bakchar bog, West Siberia, were measured by means of a solar powered automated system (Flux-NIES) consisted of six static chambers installed along the transect and connected to the LI-820 NDIR analyzer and modified commercial methane sensor TGS-842, respectively.

The water vapor can significantly affect the measurement accuracy of most gas-analyzers. It is recommended the ambient air to be completely or moderately dehumidified before supplying it to a measurement cell. We used a three-stage drying unit before supplying the air sample to the analyzers: an auto drain water trap, the Nafion dryer, and the chemical desiccants.

Observations were carried out during the growing season (from May to October) in 2013–2019 at the sedge fen (E-site). Correlation analysis made it possible to derive the dependences of CO_2 and CH_4 fluxes on the local hydrometeorological conditions.

The seasonally integrated net CO_2 uptake shows that Siberian wetland ecosystems are a strong sink of atmospheric carbon. Drier environmental conditions lead to a decreasing carbon sink and higher soil water content enhances the net CO_2 uptake efficiency. Similar effect was revealed for methane emissions, except for the case of June 2018, when unexpectedly low values of CH_4 fluxes were observed under the heavy flood conditions those resulted in a weak methanogenesis due to a nutriment scarcity in the peat beds and significant changes in soil pH.

GHG fluxes have a local spatial variability: higher net CO2 uptake and CH_4 emissions are observed at wet mesotrophic locations with higher photosynthesis and respiration rates; lower net uptake of CO_2 and CH4 emissions were observed in the meso-oligotrophic landscape.

Keywords: automated chamber method; surface-atmosphere GHG exchange, water content in peatlands.

ACCEPTED ABBREVIATIONS

WL — water table level,
FC — foliage cover.

INTRODUCTION

The long-term and high-precision measurements of GHG fluxes and effluents and their evolution be requisite for understanding the causes of Earth's climate change and planning the necessary measures to prevent dire consequences. Standardized measurements and calculations of gas fluxes increase the availability and usability of collected data for existent processes modeling. Automated chamber systems operating in closed dynamic mode are suggested as the main method for GHG fluxes measuring at the soil surface – atmosphere boundary at monitoring stations included in the ICOS (Integrated Carbon Observation System) [Pavelka et al., 2018].

The chamber methods of trace gases fluxes measurements at the soil surface – atmosphere boundary have been carried out for almost 100 years [Vadyunina and Korchagina, 1961, pp. 137–140; Pavelka et al., 2018]. Different research methods including statistic and dynamic ones are used to record the major GHG fluxes. The chamber methods are relatively cheap and easy to operate. These methods can be adapted for a wide range of studies from local to global spatial scales in combination with mathematical modeling methods. The standardization of chamber research methods facilitates their application in various monitoring networks of various Earth's ecosystems.

Carbon dioxide (CO_2) and methane (CH_4) are greenhouse gases that are largely controlled by the chamber method. CO_2 is one of the most common gases and takes on enormous importance in the land–ocean–atmosphere system. It has both natural and anthropogenic sources. Also, CO_2 plays an essential role in a number of biological processes (photosynthesis, respiration, etc.) in the natural carbon cycle. Atmospheric carbon dioxide concentrations increased by 40%, from 278 million^{-1} in 1750 to 406 million^{-1} in 2017 [NOAA/ESRL, 2017].

CH_4 also has a strong greenhouse effect and plays a significant part in determining the troposphere oxidative capacity and stratospheric ozone depletion. Like carbon dioxide, it has both natural and anthropogenic sources. There are still a great number of regions with $\boldsymbol{CH_4}$ sources that are poorly understood. For instance, the vast areas of the Russian Arctic are poorly studied. There, the presence of natural wetlands and the use of fossil fuels lead to significant atmospheric $\boldsymbol{CH_4}$. Over the same period of time as the observed increase in the $\boldsymbol{CO_2}$ content, the atmospheric $\boldsymbol{CH_4}$ concentration increased by 150% – from 722 billion^{-1} in 1750 to 1859 billion^{-1} in 2017 [NOAA/ESRL, 2017].

Thus, the atmospheric concentrations of CO_2, CH_4 and other greenhouse gases have increased since pre-industrial era due to anthropogenic emissions associated with the burning of fossil fuels used as an energy source and with changes in land using. The observed changes in the atmospheric GHG concentrations are the result of a disturbance in the dynamic balance between anthropogenic emissions and natural processes that lead to the partial removal of these gases from the atmosphere [Ciais et al., 2013].

The chamber measurement methods are beneficial determining temporal and spatial discontinuities of GHGs fluxes and dividing the total $\boldsymbol{CO_2}$ fluxes into their components (respiration/absorption), etc. The use of automated systems when studying GHG fluxes at the surface-atmosphere boundary allows to make accurate measurements at minimal disturbance of the soil surface regardless of the weather and time of day and receive high-resolution data for extended periods of time.

The literature data suggests that the Russian scientific groups use automated chambers of different constructions for gas fluxes measurements. For instance, gas analyzers LI-8100A (Licor Inc., USA) with integral small chamber in the form of an inverted bowl are wildly used [Mahnykina et al., 2016; Ivanov et al., 2017].

Other researchers develop and manufacture chambers by themselves for specific targets [Maximov et al., 2012; Molchanov, 2017]. The automation of chambers consists in developing a mechanism which can open and close a particular chamber according to a given time cycle. For this purpose, either a pneumatic drive or an electromechanical one is usually used. It is worth noting that a major number of researchers prefer chambers of pneumatic design since the use of DC motors is associated with a number of problems.

Two solutions have been found for the internal volume aeration of chambers. First involves lifting up the top cover-cap, second- lifting the entire cap above the base [Bealan et al., 2017; Dyukarev et al., 2019].

A group of Russian and Japanese scientists under the general supervision of Prof. G. Inoue (Glagolev, 2010, p.3) should be recognized as the pioneers in the application of the automated chamber method for the study of gas fluxes at the soil – atmosphere boundary in Russia (Western Siberia). The first automatic system prototype was installed on the territory of the Bakchar bog (Tomsk region) in 1997 [Nakano et al., 1998]. Since then, the structure of the measuring complex has undergone numerous changes both in the hardware composition and in ensuring the continuity of autonomous measurements.

On if and when occurred basis, engineered automated complex received its own name "Flux-NIES". This article provides an immediate description of the complex structure and discusses the results obtained from long-term observations of measuring seasonal gas fluxes in wetland ecosystems of the southern taiga zone of Western Siberia.

MATERIALS AND METHODS

The "Flux-NIES" measuring system with 6 automatic chambers was developed jointly by the National Institute for Environmental Studies (NIES, Tsukuba, Japan) and V.E. Zuev Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Science (IAO SB RAS, Tomsk, Russia) in the late 1990s and early 2000s to study methane and carbon dioxide fluxes at the soil – atmosphere boundary [Maksyutov et al., 1999; Krasnov et al., 2013]. Since then, its composition has been repeatedly changed and modernized. Currently, two almost identical measuring systems are operated at the Plotnikovo field station (Fig. 1).

The measuring equipment includes a modified semiconductor sensor TGS-842 (Figaro Inc., USA) with a sensor element based on a tin dioxide slice (SnO_2) as a CH_4 gas-analyzer [Suto and Inoue, 2010]. A non-dispersive infrared NDIR gas-analyzer LI-820 (Licor Inc., USA) is applied for measuring the CO_2 concentration. The air sample from the chambers to the gas analysis devices is supplied by a discharge pump N86KN (KNF Neuberger GmbH, Germany) using a system of polyethylene

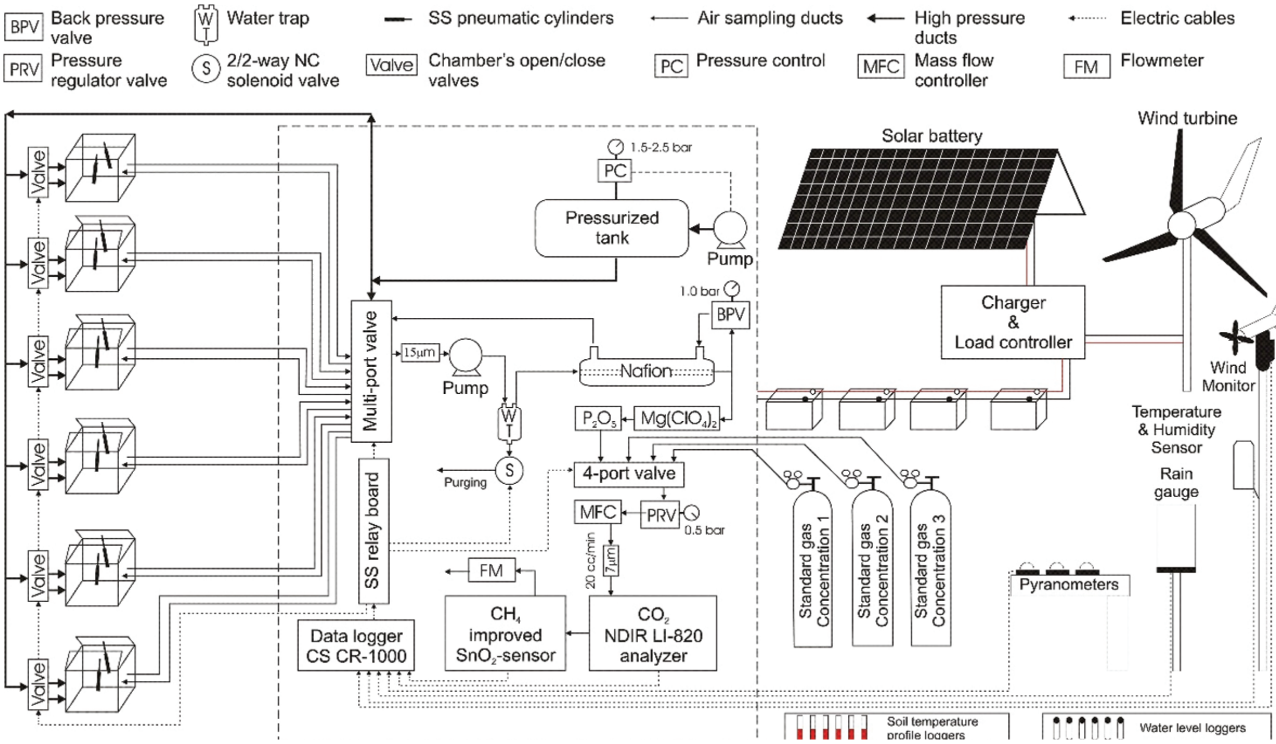

Fig. 1. The scheme of the automatic chamber system «Flux-NIES»

pipes (Ø 4 mm) and pneumatic electric valves. The CR1000 data logger (Campbell Sci., USA) is used to control the measuring system, collect and store information.

Much attention is paid to the preparation of the air sample during gas analysis: cleaning of solid aerosol fractions, dehumidification and stabilization of the flow and temperature in the devices. For this purpose, the "Flux-NIES" measuring complex includes in series (Fig. 1): fine filters (15 and 7 microns), pressure regulator (RPV), air sample flow regulator (MFC), condensate collection and discharge system (WT and S), nafion desiccant (Nafion), and final chemical powder desiccants ($Mg(ClO_4)_2$ и P_2O_5).

A set of rechargeable batteries is used for the autonomous operation of the complex as an uninterrupted source of electricity. The batteries are recharged during the day by solar electric panels or a wind turbine.

The main environmental parameters are monitored by: atmospheric pressure sensor RX2760 (OMEGA, USA); atmospheric temperature and relative humidity sensor HMP45A (VAISALA, Finland); wind speed/direction sensor 05103VM; precipitation sensor 52202H (R.M. Young Com., USA); pyrgeometer/radiometer PIR (Eppley Lab., USA); pyranometers of solar integrated radiation PCM-21 and photosynthetically active radiation PQS-1 (Kipp&zonen, the Netherlands). Additional measurements of soil temperature at depths of 5, 10, 20, 30, 40 cm are recorded separately by iButton DS1921G thermochronometric sensors (Maxim Integrated, USA), and the ground water level is measured by HOBO U20-001-04 sensors (Oneset Comp. USA) on various wetland areas.

The measurement method is based on recording changes in the studied gases concentration inside the chamber that is briefly isolated from the atmosphere (Fig. 1). The analyzed air is fed through the tubes through a controlled multi-way valve of the chamber selection. It is supplied to the input of the gas analysis unit at a speed of 3 l/min. The high-pressure valve (BPV) divides the air flow from the working chamber into two flows. The smaller one (20–30 ml/min) enters the gas-analyzers and is controlled by an air flow sensor (FM), and the remaining part returns to the chamber through the external circuit of the Nafion dehumidifier through the return pipe, thereby achieving a constant air pressure inside its insulated volume [Krasnov et al., 2013]. Taking into account that the maximum length of the tubes in the measuring system does not exceed 100 meters, the time air sample riches the gas analysis system is no more than 0.5 minutes.

In the normal state, all the chambers are open except for one (working), from which an air sample is taken. The order of chambers operation, the duration and time of their opening and closing are determined by the control program in the logger. Most commonly, the mode of five-minute exposure of the working chamber with a five-minute interval in its closed state was used.

The calibration procedure for standard gas mixtures is used twice a day to determine the sensitivity of the gas-analyzers in the FluxNIES measuring system. The CO_2 and CH_4 concentrations in three cylinders (in a neutral environment of pure synthetic air in atmospheric proportions) were selected in the following way: in the first case they obviously exceeded the highest concentrations of these gases achievable in working (closed) automatic chambers (and in different years were from 450 to 612 million^{-1} for CO_2 and from 5 to 10 million^{-1} for CH_4), in the second case, they were comparable to atmospheric background values and in the third case, they were very low (from 0 to 318 million^{-1} for for CO_2 and from 1.7 to 1.8 million^{-1} for CH_4). The current value of the calibration coefficient of the device *S(t)* (million^{-1}/mV) is determined by changing the signals of the gas-analyzers *dC (t)* depending on the known concentrations in the gas mixtures. The current value ideally should be constant. However, the analysis of calibration cycles (during the entire measurement period) showed that the obtained *S(t)* values for the used gas-analyzers are not constant and depend on external weather conditions, so the additional correction is required (for the CO_2 analyzer it is insignificant while the methane sensor needs it constantly).

A significant correlation of the signal with atmospheric pressure P (hPa) was found for NDIR $\mathbf{CO_2}$ gas-analyzer. CH_4 measurements are more affected by changes in the ambient temperature T (°C) and associated with it by the flow fluctuations of the air sample through the analyzed volume.

To reduce the variability of *S(t)*, the results of all measurements were adjusted with the found dependencies applying the following formulas:

$$S_{CO_2}(t_k) = \Delta C_{CO_2}/(dC_{CO_2}(t_k) + K_{CO_2} \cdot (P_0 - P(tk))),$$
$$S_{CH_4}(t_k) = \Delta C_{CH_4}/(dC_{CH_4}(t_k) + K_{CH_4} \cdot (T_0 - T(tk))), \quad (1)$$

where t_k is the calibration time, ΔC_{CO_2} and ΔC_{CH_4} are the maximum concentration differences in standard gas mixtures (million^{-1}), $dC_{CO_2}(tk)$ and $dC_{CH_4}(tk)$ are the corresponding differences in gas-analyzer signals (mV), K_{CO_2} (mV/hPa) and K_{CH_4} (mV/°C) are the empirical coefficients, $P_0 = 1000$ hPa and $T_0 = 0$ °C are the primary pressure and ambient temperature.

The least square adjustment method with determining the linearity of the process by the pair correlation coefficient *R* was applied with the purpose of the most accurate determination of the gas fluxes value when processing changes in the output signals of the gas-analyzer $dC(t)/dt$ (mV/sec^{-1}) in the closed chamber mode. The width of the data filtering window was determined by the maximum value of R^2 which corresponded to the highest values of the detected emissions/runoff of the studied gases at the soil – atmosphere boundary. Since a 20 seconds averaging of the measurement data of the gas analysis instrument signals was used, the size of the filtration windows ranged from 2 to 4 minutes (or 6–12 reference points) due to the difference in the length of the air paths for the individual chambers of the system.

For the convenience of further data analysis in the measurement of gas fluxes, it is customary to switch to the weight characteristics (mg·m^{-2}·h^{-1}) which are calculated using the well-known formula [Ivanov et al., 2017]:

$$F(t) = S_n(t) \cdot dC(t)/dt \cdot 100 \cdot P/(273{,}15 + T) \times \times M/8312{,}6 \cdot V/S \cdot 3600, \quad (2)$$

where *Sn(t)* are the calibration coefficients of the device (see formula (1) above), *P* is the atmospheric pressure (hPa), *T* is the average air temperature during the chamber exposure (°C), *M* is the molar mass of the gas (g·mol^{-1}), 8312.6 is the universal gas constant (J·kmol^{-1}·K^{-1}), *V* and *S* are the volume and base area of the used chambers (m^3 and m^2, respectively), 3600 is the number of seconds per hour.

MEASURING STATION

The measurements were carried out at the “Plotnikovo” field station provided by the Institute of Soil Science and Agrochemistry SB RAS (ISSA, Novosibirsk, Russia) on the Bakchar bog in the Tomsk region during the warm season (from May to October). The measuring site marked with the letter “E” is located about 16 km from the settlement Plotnikovo in the Bakcharsky district [Maksyutov et al., 1999; Krasnov et al., 2013]. The site coordinates are 56°51’ N, 82°51’ E.

The satellite image and the automatic chambers configuration on the measuring platform are represented on figure 2.

Methane fluxes were determined by the means of the automatic method of closing dynamic chambers (non-steady-state through-flow systems) according to the ICOS recommendations [Pavelka et al., 2018]: six identical chambers made of transparent plexiglass (0.9·0.9·0.5 m^3) with pneumatically driven upper lids were installed on a moistened part of an open mesotrophic bog covered mainly with grass and moss. They were placed on different sections of the bog microrelief in such a way that the type of geological substate on each of them corresponded to a characteristic plant association.

The profile of observer points formed by the chambers is laid from the waterlogged wetlands to the pine-shrub-sphagnum phytocoenosis.

The first and second observation points correspond to the cotton grass-sphagnum phytocenosis.

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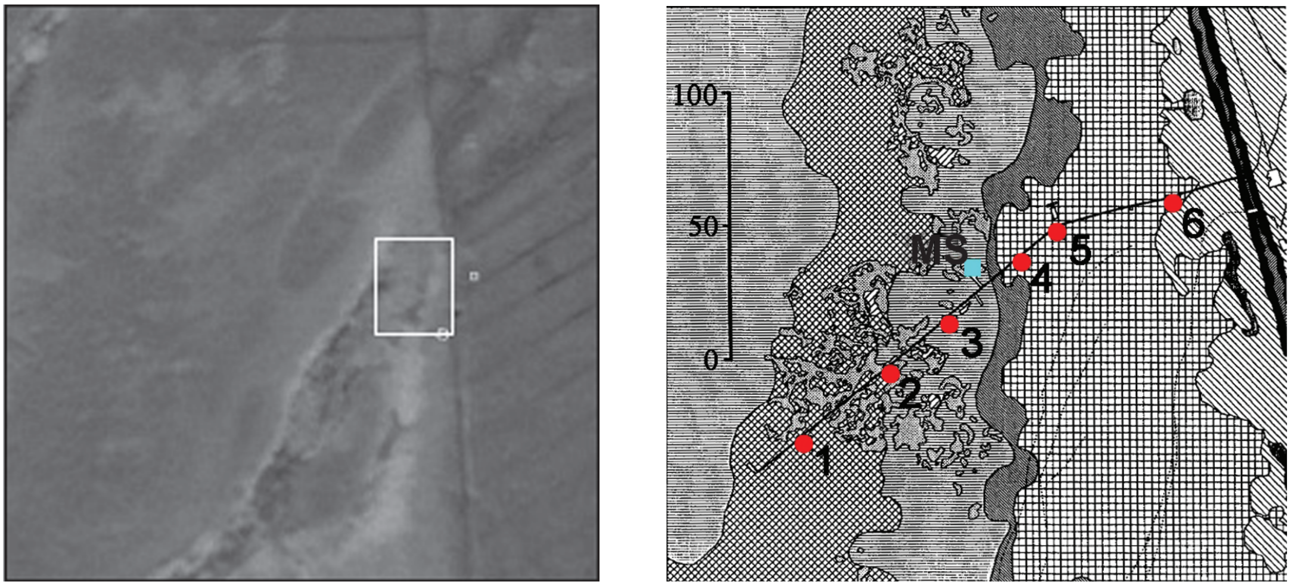


Fig. 2. Satellite image of the area and the layout of the automated system "Flux-NIES" on the bog site "E" according to [Maksyutov et al., 1999]. (•) the installation points of the measuring chambers and their numbers; (■) the location of the measuring station (MS) for gas analysis and registration of meteorological parameters

Chamber 1 is located at a certain elevation, the grass layer is represented by *vaginatum L.* – foliage cover (FC) is 50%, *Equisetum palustre* – foliage cover is 30%, *Carex limosa* – foliage cover is 5%, there are also single *Menyanthes trifoliata*. The moss cover consists mainly of *Sphagnum angustifolium* (FC 80%). Chamber 2 is characterized by a higher degree of water content, the herbaceous vegetation is represented by *Eriophorum vaginatum L.* (FC 50%), single specimens of *Menyanthes trifoliata*, *Carex limosa* and *Equisetum palustre*. The moss cover consists mainly of *S. cuspidatum* which foliage cover is 70%.

The third and fourth observation points are located in the sedge-sphagnum phytocenosis which vegetation cover consists of *Carex rostrate, Carex limosa* (FC 50%), there are single specimens of *Menyanthes trifoliata* and cranberry *Oxycoccus microcarpus Turcz*. In chambers 3, the moss cover is represented by *Sphagnum angustifolium* (FC 100%), in chamber 4 *S. angustifolium* and *S. pappilosum* are common (FC 80%).

Shrubs *Chamaedaphne calyculata* appear in the vegetation cover (FC 10%) closer to the forested part of the bog margin. Also there are single specimens of *Andromeda polifolia*, in the grass layer *Carex limosa* predominates (FC 40%) in combination with *Eriophorum vaginatum L.* (FC 20%). In the moss cover of chamber 5, *Sphagnum angustifolium* and *S. lindbergii* are found (FC 80%).

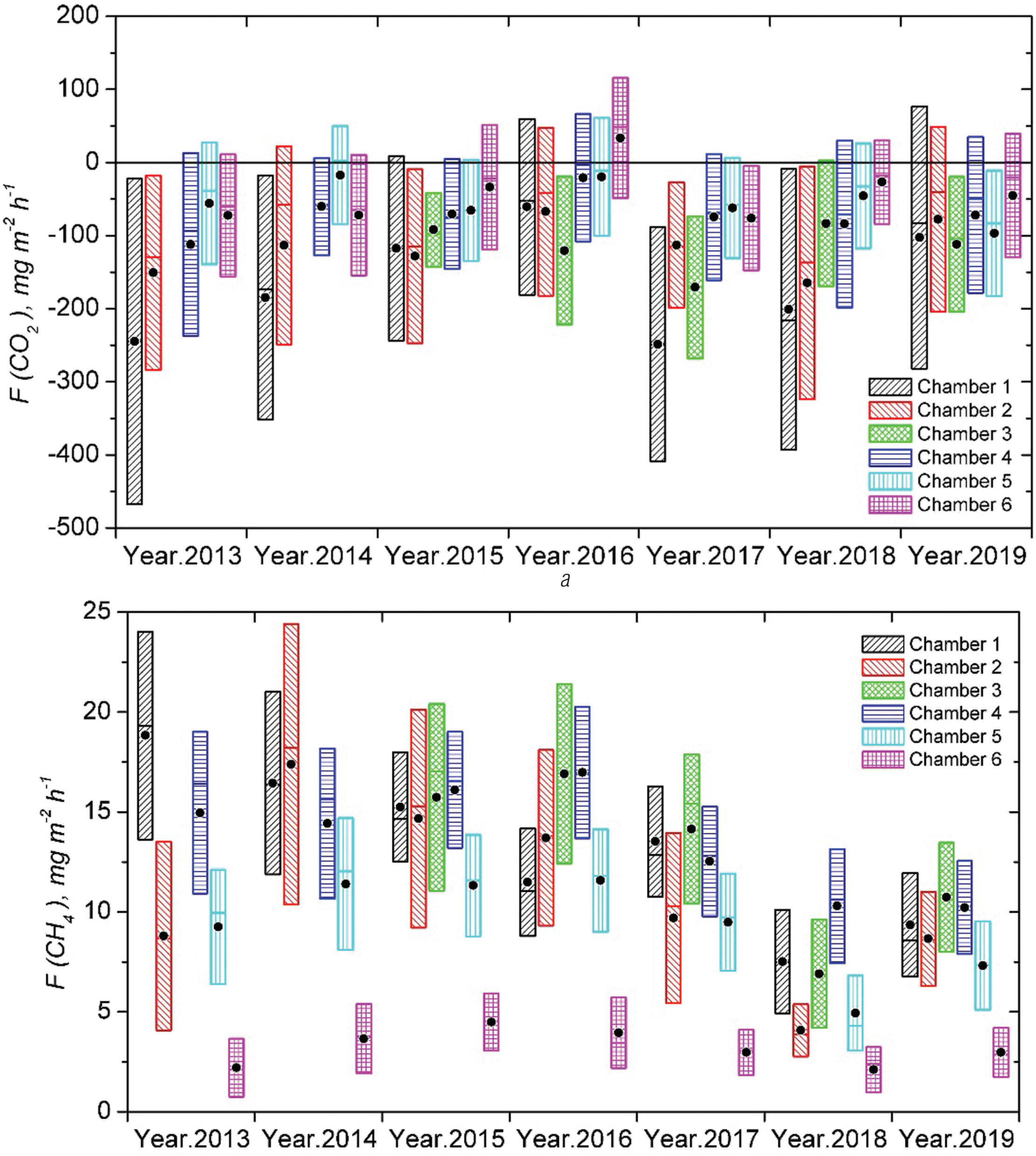
The sixth observation point is located in the pine-shrub-sphagnum phytocenosis. The tree layer is sparse and is represented by *Pinus silvestris f. Litwinowii* with a height of 2–3 m. In the shrub layer, *Chamaedaphne calyculata* dominates (FC 10%), there are single bushes of *Ledum palustre L.*, cranberry grows quite abundantly on tussocks (FC 15%), in the grass layer *Eriophorum vaginatum L.* prevails (FC 40%) and *Rubus chamaemorus* occurs (FC 3%). The moss cover in chamber 6 is mosaic represented by several species of sphagnum mosses (*Sphagnum fuscum, S. angustifolium, S. magellanicum*) with patches of green moss (*Polytrichum strictum*).

RESULTS AND DISCUSSION

Figure 3 represents the resulting gas fluxes at the soil – atmosphere boundary obtained during the measurement campaigns of recent years. The data analysis shows that the most dynamic CO_2 emission and uptake in the wetland plant associations were observed for chambers 1–3 which refer to the central section of the open bog. Smaller values of CO_2 fluxes were recorded at the edge of the bog in chambers 5 and 6.

The average seasonal uptake of CO_2 from the atmosphere varies significantly year by year both for individual plant associations and for the whole ecosystem. For example, the total CO_2 uptake to the bog surface in 2017 significantly exceeded the values observed in the 2016 measurement season (Figure 3, *a*).

The reasons for such variation in the absorption of atmospheric carbon by the bog surface lie in the weather conditions of a particular year of observation. Although bogs are difficult to consider



b

Fig. 3. Average seasonal (June-September) fluxes of CO_2 (*a*) and CH_4 (*b*) at the wetland soil – atmosphere boundary in the Bakchar bog in 2013–2019. (•) average daily values; (–) median daily values; (–) медианные суточные значения; (▌) areas of standart deviations

Table 1

Correlation data analysis and seasonal average values for wetland ecosystem moistening in 2014–2019

Years	2015	2016	2017	2018	2019	WL avg±STD, m	WL min, m	WL max, m	$T_{130\,cm}$ avg,°C
2014	0.570	0.369	***0.872***	0.688	***0.698***	–0.125±0.083	–0.252	0.054	+6.21
2015	1	–0,26	0.286	0.199	–0.06	–0.120±0.059	–0.261	–0.002	+6.88
2016		1	0.519	0.481	***0.752***	–0.166±0.068	–0.298	–0.052	+6.42
2017			1	0.690	***0.771***	–0.141±0.062	–0.263	–0.018	+6.92
2018				1	***0.803***	–0.038±0.042	–0.114	0.075	+5.96
2019					1	–0.132±0.083	–0.264	–0.004	+6.40

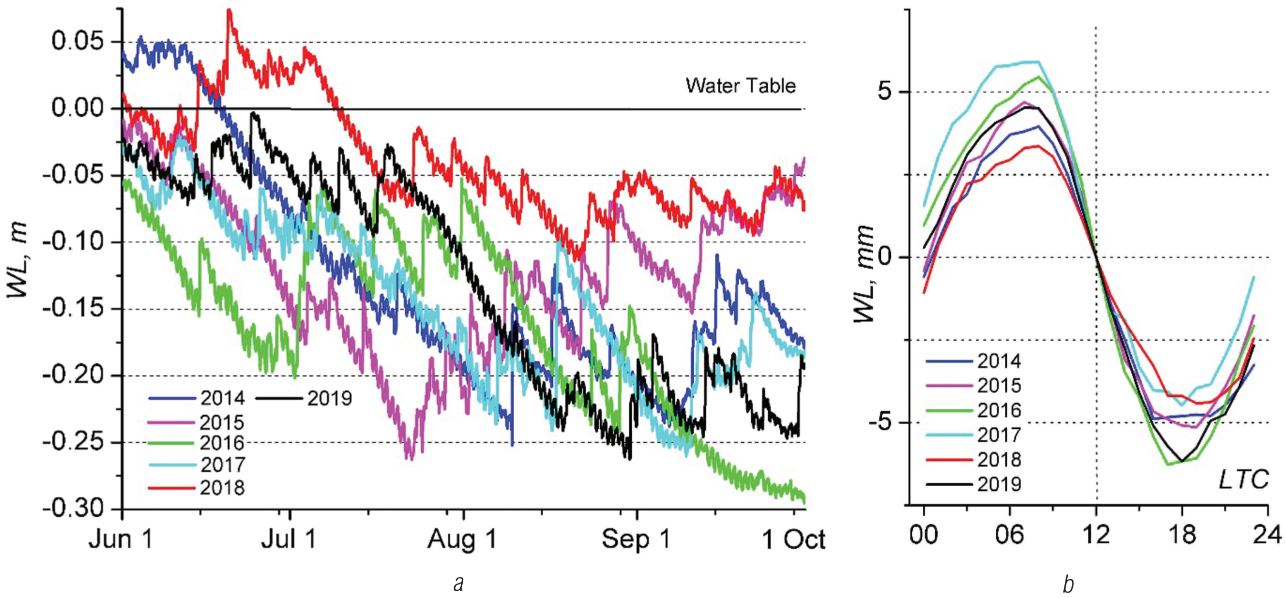


Fig. 4. Long-term seasonal dynamics of the soil water level (a) and its daily course (b) normalized to the average daily value and reduced to 12 hours of local time (LTC). (Bakchar bog, 2014–2019)

as drought-affected areas, seasons of low ground water levels are also observed here which affects the productivity of local plant associations.

Figure 4, *a* shows a record of long-term seasonal indicators of the water table level (WL) according to the HOBO U20-001-04 sensor installed in the center of the measuring platform "E" at a depth of 130 cm. A detailed inter-seasonal analysis of the WL data in Table 1 revealed a high significant correlation of the dynamics of soil waters in 2014 and 2017 when the most active CO_2 uptake was observed in bog ecosystems (Fig. 3, *a*).

However, the seasonal variation criterion of WL is not so reliable applying for average carbon exchange fluxes. For example, a correlation in the dynamics of soil waters over 2015 and 2019 was not found while the values of CO_2 uptake were similar. At the same time, in 2019, WL fluctuations showed an exceptional correlation with other measurement seasons which makes it considered a reference for this characteristic of the studied bog ecosystem (Table 1).

It is worth noting the presence of a stable diurnal course in WL (Fig. 4b) determined by the daytime evaporation from the peat beds and the night advection of water over the entire area of the bog [Eppinga et al., 2008]. For the decline in CO_2 uptake observed in wetland ecosystems in 2016, an increased evaporation of soil moisture was recorded compared to other seasons (Fig. 4, *b*).

The recorded interannual dynamics of methane fluxes in the studied ecosystem showed fairly stable values of CH_4 emissions in 2013–2017, and the total methane emission in the open fen (chambers 1–5) was significantly higher compared to the ryam section (Chamber 6). However, in the 2018 season, the CH_4 emission values showed an almost universal drop of 1.5–2 times (Fig. 3, *b*).

The reasons for such a critical change in gas exchange at the march ecosystem surface were associated with the observed abnormal amounts of precipitation and high WL values during the period when the processes of methanogenesis reached the seasonal maximum in late June and early July 2018 (Fig. 4, *a*). The influx of excess atmospheric moisture could cause the leaching and removal of the nutrient substrate necessary for the vital activity of methanogenic microorganisms outside the bog as well as disrupt the balance of biochemical processes which are significant in CH_4 oxidation in bog ecosystems [Kalyuzhny, 2018]. The daily course of WL in 2018 showed the smallest amplitude of oscillation (Fig. 4, *b*).

The influence of the 2018 weather anomaly on gas exchange in wetland ecosystems is discussed in detail in [Dyachkova et al., 2019].

The amount of gas fluxes in bog ecosystems is determined both by the level of soil water and by the seasonal behavior of such environmental characteristics as the insolation of the geological substate and the warming of the peat beds. The paper [Krasnov et al., 2015] provides detailed data on measuring the temperature of bog soil at different depths for two sections of the measuring site "E"at the Plotnikovo field station: with increased (chamber 2) and reduced (chamber 5) moisture content. Using the Fourier theory of thermal conductivity, the delay time of the heat pulse penetration in the peat layer was determined for the period of active development of methanogenesis processes in June 2014. Unfortunately, in this work, the fluxes of CH_4 were calculated using overestimated calibration coefficients (due to the output of the methane sensor characteristic in the region of nonlinearity), so that only a qualitative dependence of their value on the temperature of the peat beds warming on individual days of the measurement campaign can be traced.

On the other hand, the authors of paper [Veretennikova and Dyukarev, 2017] described in detail the relationship between the dynamics of methane emission and peat temperature for an open fen in another section of the Bakchar bog in 2013–2014 but obtained clearly underestimated median values of the daily CH_4 fluxes (less than 2 $mg \cdot m^{-2}/h^{-1}$). It should be noted that in this study, the method of portable static chambers was used for measurements which does not allow covering a sufficiently long time period.

In papers [Sabrekov et al., 2013; Glagolev et al., 2017], data from large-scale studies of CH_4 fluxes (using the same static chamber method) and the temperatures of the topsoil in the Bakchar bog in 2008, 2011 and 2015. In an open fen area comparable to the conditions for chambers 1–5 of the Flux-NIES measuring complex, the measured methane fluxes in July 2008 were 10.5–36 $mgS \cdot m^{-2} \cdot h^{-1}$ (or 14–48 $mg \cdot m^{-2} \cdot h^{-1}$). A dilute CH_4 emission with a median value of 0.3 $mgS \cdot m^{-2} \cdot h^{-1}$ (or 0.4 $mg \cdot m^{-2} \cdot h^{-1}$) was registered in August 2015 at the ryam site in a pine-shrub-sphagnum community (with Pinus sylvestris dominated in microrelief), comparable to the conditions for chamber 6 of the Flux-NIES measuring complex.

Finally, the authors of paper [Friborg et al., 2003] conducted studies of gas fluxes directly at the Plotnikovo field station by the method of turbulent pulsations (eddy covariance). Based on data from three measurement campaigns in May, July, and September 1999, the following seasonal average fluxes were obtained: –2247 $mg \cdot m^{-2} \cdot day^{-1}$ (or about -100 $mg \cdot m^{-2} \cdot h^{-1}$) for CO_2; 136 $mg \cdot m^{-2} \cdot day^{-1}$ (or ~$mg \cdot m^{-2} \cdot h^{-1}$) for CH_4. Comparing the different studies results of gases fluxes in this wetland ecosystem with two automatic methods, we get a good match if we take the microrelief between chambers 5 and 6 as the point of turbulent measurements (the so-called footprint).

CONCLUSIONS

The long-term applying of the automated chamber method has shown the effectiveness of its application for studying the dynamics of gas fluxes on the bog surface on a temporal and spatial scale.

The integral values of the $\boldsymbol{CO_2}$ fluxes over the entire measurement period show that the surfaces of the West Siberian wetland are a powerful "absorbent" of atmospheric carbon. At the same time, the values of CH_4 emissions from different areas of the bog depend both on the type of vegetation and on the level of moisture and warming of the peat beds. The highest values of CH_4 emissions from wetland are observed in July and reach quite large values in open bogs (15–25 $mg \cdot m^{-2} \cdot h^{-1}$). The lowest values of CH_4 emission were observed in the ryam section (2–3 $mg \cdot m^{-2} \cdot h^{-1}$).

A significant decrease in values of CH_4 emission from the bog surface was observed in almost all measuring areas in 2018. This is linked to the observed weather anomalies during the period when the processes of methanogenesis reached their maximum seasonal values.

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