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Comparison of flows of greenhouse gases at the atmosphere–soil interface for three areas of the Tomsk Region

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Abstract

Carbon dioxide and methane flows are studied from measurements at the Fonovaya Observatory and two measurement sites in the Iksinsk swamp (Tomsk Region, Russia) in August and September 2019. The measurements were carried out with automatic static chambers. It is shown that in August all the three measurements sites are sinks of carbon dioxide, while in September the flow character becomes intermittent. The both sites in the Iksinsk swamp are sources of methane for the entire period of measurements.

Keywords: atmosphere, air, carbon dioxide, methane, greenhouse gas, flow, soil

Introduction

The greenhouse effect is still considered as a main cause of global climate change owing to the extra, mostly anthropogenic emission of gases and aerosol (Black Carbon) into the atmosphere [1]. The currently observed climate warming has an adverse impact on the environment [2] and causes marked social and economic losses [3]. In addition, global warming has a negative effect on human health [4].

The global warming spans the entire planet [5], which requires for vigorous efforts from all people and in various fields [6, 7]. At the same time, obvious decisions are not always unambiguous. Thus, for example, wind power engineering has a negative effect on wind flows and increased sound level and infrasound adversely impact human health [8].

Modern ideas on the mechanism of global warming are still far from perfect. As a result, all models inadequately reflect the interaction between people and the environment [9]. Available calculations do not cohere with actual data [10, 11]. All of that leads to the necessity of independent monitoring of the state of environment, including the composition of atmospheric air. In particular, it is important to know the natural emission of greenhouse gases, which is usually estimated from measurements of their flows at the soil–atmosphere interface. The corresponding observations are rather complicated and expensive, and therefore they are few in number. To complement the information on the level of emission of greenhouse gases, this paper reports the data of measurements of carbon dioxide and methane flows at the soil–atmosphere interface conducted in 2019 at three measurement sites in the Tomsk Region (Western Siberia, Russia).

Measurement sites

The first measurement site is a part of the Fonovaya Observatory of IAO SB RAS. The detailed characteristic of the instrumentation used at this observatory can be found in [12]. The short information is given below. Taking into account the importance of the climate change problem and the lack of background monitoring stations operating in the continuous mode in the Western Siberia, in 2009 the Institute of Atmospheric Optics decided to organize a background monitoring station in the Fonovaya Observatory located on the east bank of the River Ob 60 km west of Tomsk (56 ° 25 "07" N, 84 ° 04 "27" E). It is characterized by the typical boreal climate (humid continental, southern taiga zone). The territory around the observatory is mostly occupied by conifers with mixed wood (birch, aspen, and pine trees) just near the station. The prevailing winds are mostly from the south and southwest.

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Two other measurement sites are located in the Iksinsk swamp, which is a northeastern arm of the Big Vasyugan Swamp, approximately 16 km of the Plotnikovo Village (Bakchar District, Tomsk Region) at the station of the Institute of Soil Science and Agrochemistry SB RAS (56°51'29" N, 82°50'91" E). Site 1 is located in a ridge pattern complex of untouched swamp. Site 2 is at an edge of distorted (meliorated in the Soviet period) swamp. Identical measuring systems were installed at the both sites [13]. The measuring system at Site 2 was destroyed in 2009 and reconstructed in 2019. The plant cover at the both sites includes low-growing pine trees (Pinus sylvestris f. willkommii) 50 cm high. The grass-shrub level is represented by wild rosemary (Ledumpalustre L.) and moss crop (Eriophorum vaginatum L) with moorberry (Oxycoccus microcarpus Turcz). The moss cover is continuous and consisting mostly of Sphagnum fuscum Klinggr. and Sph. angustifolium C. Jens.

Instruments and methods

The measuring technique at all the sites is based on measurement of changes in the concentration of a gas under study inside a chamber isolated from the atmosphere for a short time. The analyzed air is pumped by pipes through a controllable multi-pass chamber selector valve to the gas analyzers. A high-pressure valve divides the air flow into two flows: the smaller flow (~20 ml/min) comes to the gas analyzers, while the rest part comes back to the chamber, thus maintaining the constant pressure in it [13].

The greenhouse gas flows between the soil and the atmosphere during the growing season were measured by the system consisting of the Picarro G2508 CRDS N2O/CH4/CO2/NH3/H2O gas analyzer and an automatic system of static chambers designed by IAO SB RAS. The G2508 analyzer operates in the recycling mode with the feedback Picarro A0702 vacuum pump. The opaque chamber (OCh) is used for measurement of the ecosystem respiration, while the transparent chamber (TCh) is for the net ecosystem exchange (NEE), which allows us to obtain the gross primary production (GPP). The chambers have volume of $0.324\ m^3$. The chambers are opened and closed automatically by the control pneumo-system by the following schedule: 5 min - TCh closed and OCh open; next 8 min - TCh open and OCh closed; then the both chambers open for 7 min for normalization of the conditions of natural state of the ecosystem, and so on (a total of three cycles per hour).

Results and discussion

Since variations in the flows of greenhouse gases between the soil and the atmosphere depend significantly on the state of the environment, season, and lighting conditions, let us first consider the temporal dynamics of the flows. These data are shown in Figs. 1 and 2. It should be noted that the minus sign means that the flow is directed from the atmosphere into the soil or corresponds to the sink of a gas, while the plus sign shows that we observe emission from the soil into the atmosphere, that is, the surface acts as a source.

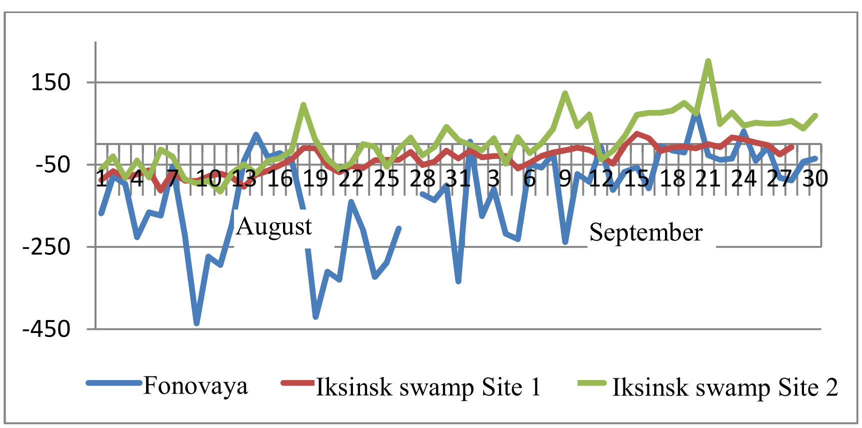

Fig. 1. Daily average values of the carbon dioxide flow (mg m^{-2} $hour^{-1}$) in the Tomsk Region.

One can see from Fig. 1 that the sink of CO_2 from the atmosphere predominated in August at all the three sites, and in the Fonovaya Observatory it was far higher than in the Iksinsk swamp. In September, when the vegetation activity of plants reduced considerably, the character of the diurnal dynamics changed. In the Fonovaya Observatory and at Site 1, both sink and emission of carbon dioxide were observed some days. Site 2 in September mostly emitted this gas into the atmosphere.

Table 1

Monthly average values of the carbon dioxide flows (mg m^{-2} hour^{-1}), standard deviation, maximal and minimal values

	Fonovaya Observatory		Iksinsk swamp, Site 1		Iksinsk swamp, Site 2	
	August	September	August	September	August	September
Average	-185.9	-67.6	-58.5	-15.7	-34.9	37.5
SD	505.0	233.1	184.7	92.7	295.6	137.3
Max	820.6	667.4	298.3	159.8	461.1	263.4
Min	-4377.2	-1488.6	-409.4	-270.1	-602.9	-429.0

The data of Table 1 demonstrate that the sink of carbon dioxide from the atmosphere was observed, on average, in August at all the three sites. It was the highest in the Fonovaya Observatory and the lowest at Site 2. The standard deviations show how variable is this process in time. As to the maximal and minimal values, the following explanations should be given. The CO_2 flow alternates its direction during a day, and it depends on whether plants absorb or emit carbon. Thus, the maximal values correspond to the flow emitted at respiration. The minimal values correspond to the sink of carbon from the atmosphere at photosynthesis. It follows from the data of Table 1 that the maximal absorption of CO_2 by forest is an order of magnitude higher than that by swamp vegetation.

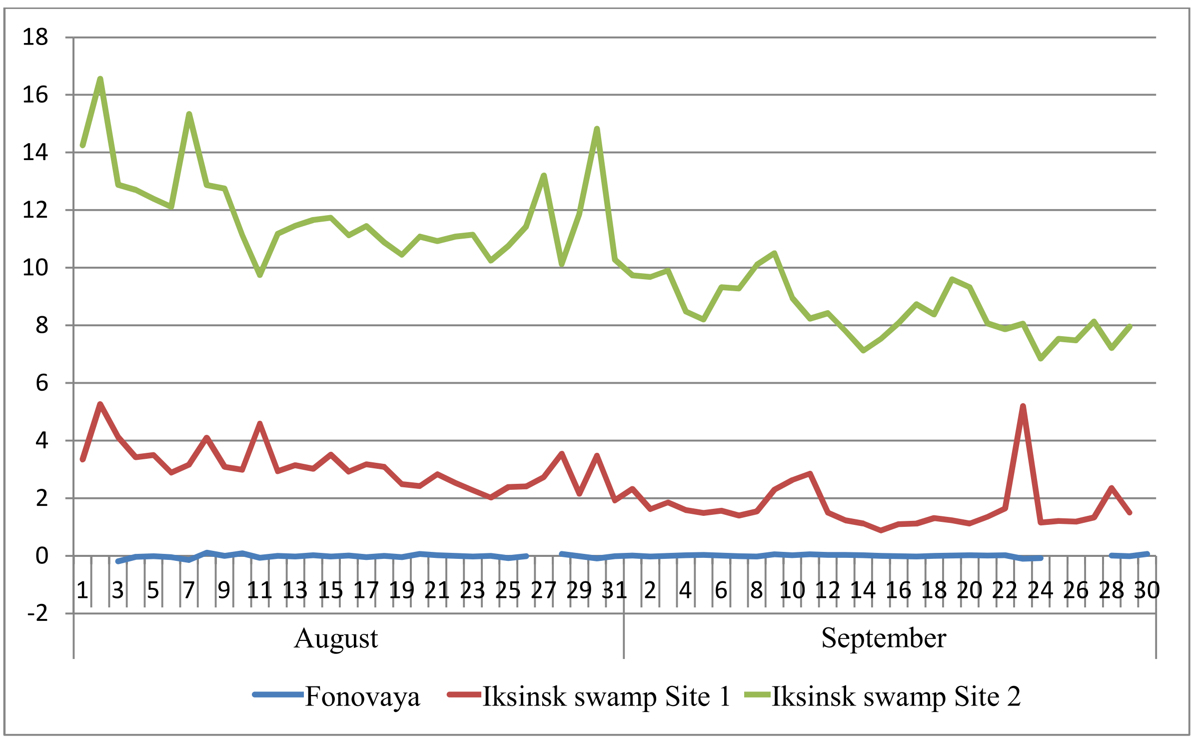

Fig. 2. Diurnal average methane flow (mg m^{-2} hour^{-1}) in the Tomsk Region.

Figure 2 shows that the Iksinsk swamp is a continuous source of methane, and the average flow in some days achieves 17 mg m^{-2} hour^{-1}. One can also see the difference in methane generation in different parts of the Iksinsk swamp. The methane flow in the Fonovaya Observatory is close to zero and has the alternating character. In Fig. 2 we can see one more feature – seasonal decrease in the rate of methane inflow into the atmosphere from the Iksinsk swamp.

The data on average values of the methane flow at the three measuring sites are tabulated in Table 2. It should be noted that the methane flows, in contrast to carbon dioxide flows, do not change their direction during a day.

Table 2

Monthly average values of the methane flows (mg m^{-2} hour^{-1}), standard deviation, maximal and minimal values

	Fonovaya Observatory		Iksinsk swamp, Site 1		Iksinsk swamp, Site 2	
	August	September	August	September	August	September
Average	-0.015	0.005	3.084	1.754	11.972	8.627
SD	0.346	0.176	2.001	2.073	2.890	1.577
Max	2.956	1.498	22.621	20.3978	22.494	14.785
Min	-3.125	-1.1285	1.1475	0.678	5.578	5.307

The data of Table 2 demonstrate that the slight sink of methane was observed, on average, in the Fonovaya Observatory in August. In September, it was alternated by generation. The Iksinsk swamp was a source of methane in both August and September. It is surprising that the meliorated swamp emits fourfold larger amount of methane in August and nearly fivefold larger amount in September than the untouched swamp does. The maximal rate of methane inflow in the Iksinsk swamp achieves 22.621 mg m^{-2} hour^{-1}, whereas at the Fonovaya Observatory it is only 2.956 mg m^{-2} hour^{-1}. The maximal methane sink here is -3.125 mg m^{-2} hour^{-1} .

The obtained data on CO_2 and CH_4 flows fall at the center of the range observed in [14] and above the levels obtained [15]. As was shown in [16], it is an expected result, since the concentrations of greenhouse gases are very variable.

Let us dwell on one more issue. Consider the diurnal dynamics of the flows of greenhouse gases, because it reflects regularities of their generation and sink in the environment.

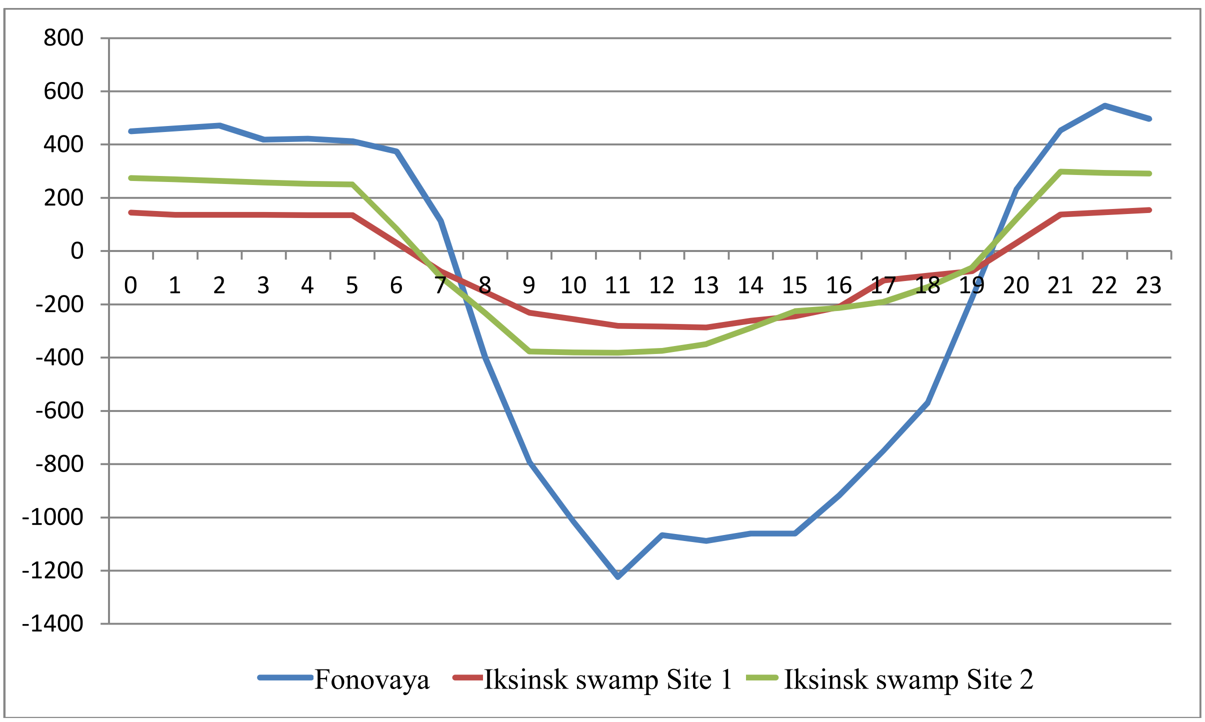

Fig. 3. Diurnal dynamics of carbon dioxide flows in August 2019 at the territory of the Tomsk Region.

Figure 3 shows that in nighttime, when plants respire, all the three sites are sources of carbon dioxide. The transition from generation of CO_2 to its absorption is in a good agreement with the time of sunrise and sunset. As the sun emerges from the horizon, photosynthesis starts in plants, which leads to absorption of carbon dioxide. The maximal absorption is observed before midday. The maximal diurnal amplitude of changes in the flows is observed in the Fonovaya Observatory, while the minimal one characterizes the untouched part of the Iksinsk swamp (Site 1). This amplitude likely reflects the degree of coverage of the territory by plants and its total absorbing area.

The diurnal dynamics of the CO_2 flows in September remained nearly the same as in August. That is why the plot for this month is omitted.

As can be judged from Fig. 4, the diurnal dynamics of the methane flows differs insignificantly from that for carbon dioxide.

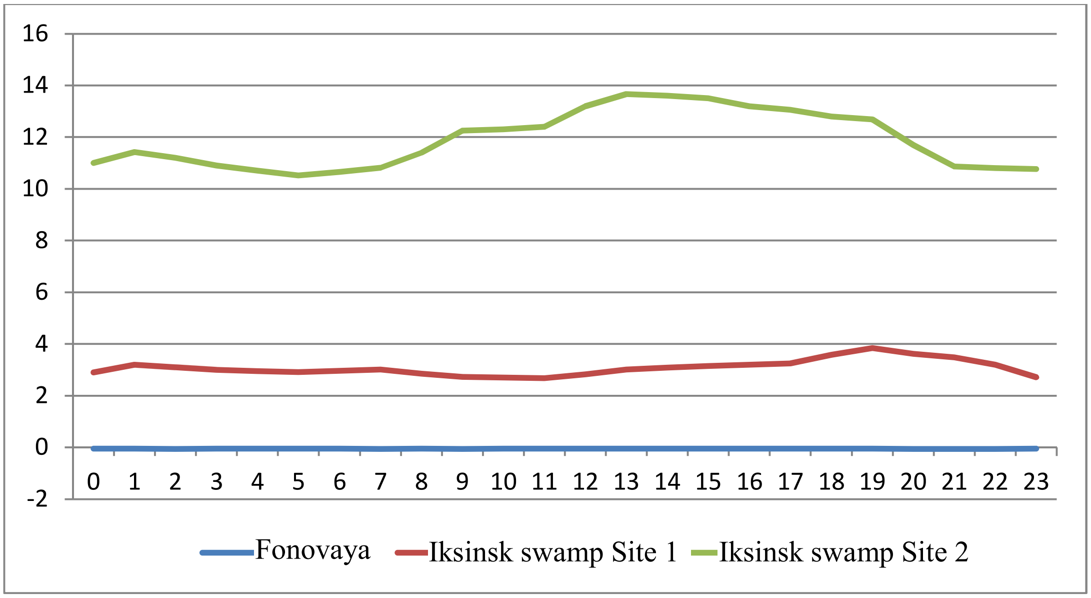

Fig. 4. Diurnal dynamics of methane flows in August 2019 at the territory of the Tomsk Region.

In contrast to carbon dioxide, which is absorbed in daytime, methane is generated in both day- and nighttime at the both sites in the Iksinsk swamp. In the Fonovaya Observatory, flow variations are so small that cannot be resolved at this scale.

In September, the general pattern changes somewhat, as can be seen from Fig. 5.

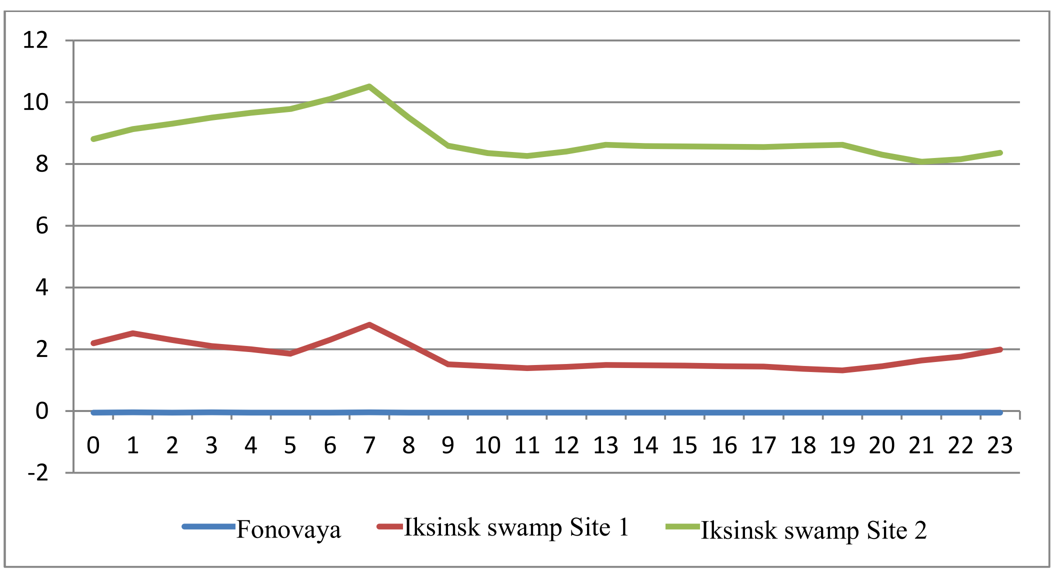

Fig. 5. Diurnal dynamics of methane flows in September 2019 at the territory of the Tomsk Region.

As follows from Fig. 5, in this period the methane generation in the swamp and its emission into the atmosphere shift to the nighttime. The maximal inflow near 7:00 Local Time is clearly seen. The nature of this maximum is hard to explain now. In the Fonovaya Observatory, the flows remain nearly the same for 24 hours.

Conclusions

The comparison of the flows of greenhouse gases at the three measuring site has revealed a difference between them.

All the three sites demonstrate the presence of sink of carbon dioxide in the analyzed period, although its value depends on the geographic position. Moreover, there is a marked difference in CO_2 absorption even between closely located sites in the same region.

The Iksinsk swamp is a source of methane all the time in the period under study. In the earlier meliorated part of the swamp, the flow is four to five time higher than that in the untouched part of the swamp. In the Fonovaya Observatory, low negative CH_4 flows are observed.

There are seasonal features in the diurnal dynamics of the methane flow, but further studies are needed to understand their mechanism.

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