ECAS 2022

Proceeding Paper

Seasonal Variability of Carbon Dioxide and Methane Fluxes in a Subarctic Palsa Mire in North-Central Siberia †

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† Presented at 5th International Electronic Conference on Atmospheric Sciences, 16–31 July 2022; Available online: https://ecas2022.sciforum.net/.

Abstract: The main goal of the study was to obtain new experimental data on seasonal variability of carbon dioxide (CO_2) and methane (CH_4) fluxes in a subarctic palsa mire in North-Central Siberia, as well as to assess the sensitivity of the CO_2 and CH_4 fluxes to environmental changes. The results of field measurements in 2017 and 2018 years showed that the palsa mire served as a sink of CO_2 from the atmosphere for the period between mid-June to the end of August for both years. Maximum daily CO_2 uptake rates in 2017 were observed at the beginning of July (up to 4.5 gC m^{-2} d^{-1}) mainly due to high incoming solar radiation, optimal air temperature and sufficient soil moisture conditions. Seasonal variability of CH_4 fluxes was relatively high and governed mainly by weather conditions. During both growing seasons the palsa mire served mostly as a CH_4 source for the atmosphere. The periods with prevailed CH_4 emission alternated with periods of CH_4 uptake and the fluxes varied between −8.3 to 13.6 mgC m^{-2} per day in 2017 and between −4.5 to 21.8 mgC m^{-2} per day in 2018.

Keywords: carbon dioxide and methane fluxes; eddy covariance; palsa mire; North-Central Siberia; northern taiga; forest-tundra ecotone; permafrost

Academic Editor: Andreas Matzarakis

Published: 14 July 2022

1. Introduction

The modern climate changes manifested in increase of global temperature, change of precipitation pattern and increase of the frequency and severity of extreme weather events are associated with growth of greenhouse gas (GHG) concentrations in the atmosphere mainly due to anthropogenic activity [1]. Achieving the overall goal of carbon neutrality and balance between GhG emission and uptake in the middle of 21th century requires comprehensive information about anthropogenic and natural GHG emission and uptake in different biomes of the world [2]. The area of Northern Eurasia is represented by extremely diverse plant communities and soil types situated within various natural zones including tundra, forest-tundra, forest, wetland and grasslands, and their contributions into the global and regional atmospheric GHG budgets are still very poorly investigated [3,4]. Information about GHG fluxes in this area can be also very important because the largest part of Northern Eurasia is underlined by continuous permafrost [5]. The thawing of permafrost due to global warming may result in sharp increase of GHG emission into the atmosphere that can have a significant impact on the climate [6]. The relevant information on GhG fluxes in those ecosystems could obviously serve as a basis for a reliable prediction of future climate change and mitigation measures.

The main goal of the study was to obtain new experimental data on seasonal variability of carbon dioxide (CO_2) and methane (CH_4) fluxes in a subarctic palsa mire, as well as to assess the sensitivity of these CO_2 and CH_4 fluxes to changing environmental conditions. Palsa mires are complex wetland ecosystems with permanently frozen peat components [7]. They are often situated in high latitude environments of Fennoscandia, Russia, Canada and Alaska and may have a significant influence on local and regional atmospheric processes.

2. Materials and Methods

2.1. Study Site

The palsa mire is situated in the northern taiga and forest-tundra ecotone in Turukhansky district of Krasnoyarsk Krai in Russia. The peatland occupies 21.7 ha in the catchment of the small Little Grawijka Creek, approximately 10 km north of town of Igarka [8,9]. It is located at elevation of 20–38 m a.s.l. on the 1st floodplain terrace in the right bank of the Yenisei River Valley. The area is underlined by continuous permafrost. The climate of the area is subarctic (*Dfc*) according to the Koeppen classification scheme with long, very cold winters, and short, cool summers. The mean annual temperature is −7.0 °C, and annual precipitation amount is about 560 mm.

Vegetation of the peatland is a mosaic of perennial frost mounds and peat plateau with a height of 1–1.5 m and flat, mostly unfrozen hollows, 150–200 m wide and extensive mineral ridge (100–300 m wide, up to 1.5 m in a height) covered by *Larix-Picea-Betula* woodlands. Lichens and feather mosses in combination with *Betula nana* L., *Ledum palustre* L., *Rubus chamaemorus* L. and bare peat as well, occupy the mounds, while various species of Carex, feather mosses and herbs are common within the hollows.

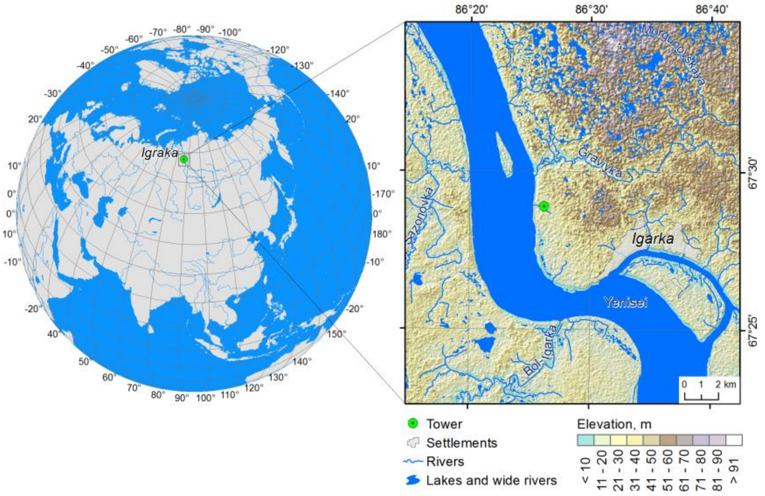

Figure 1. Geographical location of the study area.

2.2. Eddy Covariance and Meteorological Measurements

The CO_2 and CH_4 turbulent fluxes at the experimental site were continuously measured using the eddy covariance method [10]. The flux tower has a height of 6 m and it is situated at the central part of selected palsa mire.

The eddy covariance system was mounted on the top of the tower and included enclosed CO_2/H_2O gas analyzer LI-7200A (LI-COR, Lincoln, NE, USA), open-path CH_4 analyzer LI-7700 (LI-COR, Lincoln, NE, USA), and 3-D ultrasonic anemometer USA-1 (Metek, Germany). Meteorological equipment includes devices for continuous measurements of net radiation (CNR4, Kipp & Zonen, The Nederlands), photosynthetically active radiation (LI-190SA, LI-COR, Lincoln, NE, USA), air temperature and humidity (HMP155, Vaisala, Finland), precipitation (TR-525M, Texas Electronics, Dallas, TX, USA), and soil temperature and humidity (Stevens Hydra Probe II, LI-COR, Lincoln, NE, USA). The eddy covariance data were collected using analyzer interface unit LI-7550 (LI-COR, Lincoln, NE, USA) with frequency of 10 Hz.

Data post-processing was conducted according to existed recommendations for data analysis [10]. The CO_2 and CH_4 fluxes were calculated from the raw data at 30-min time intervals using the EddyPro data processing software (LI-COR Lincoln, NE, USA), which implemented all required statistical tests and corrections (de-spiking, rotating coordinates, correcting for time delays, de-trending, correcting for frequency response and density, etc.). After data post-processing all fluxes containing the spikes, associated with e.g. rain and dew events, as well as the fluxes measured under weak turbulence and low wind, were removed from the data sets.

Intensive field measurement campaigns were conducted from the late winter (early May) to fall (early October) since 2016 (from snow to snow). For data analysis the periods from April to September 2017 and from July to October 2018 were selected. These periods were selected because of the minimal number of gaps in the measured data series.

3. Results and Discussion

The results of CO_2 flux measurements in 2017 and 2018 showed that the mean daily Gross Primary Production (GPP) significantly exceeded Ecosystem Respiration (ER) for the period between mid-June to the end of August for both years, i.e., the palsa mire during the growing season served as a sink of CO_2 from the atmosphere. Maximum daily CO_2 uptake rates in 2017 were observed at the beginning of July (about 4.5 gC m^{-2} d^{-1}) mainly due to high incoming solar radiation, optimal air temperature and sufficient soil moisture conditions after a 2-week rainy period. A high temperature and low precipitation have not any significant effect on net CO_2 fluxes despite of the highest rates of ER in the period. From the end of July to the end of August the difference between CO_2 uptake and CO_2 release is steadily reduced and it was close to zero at end of summer period. The net CO_2 fluxes were positive in September showing the net efflux of CO_2 into the atmosphere. The temporal variability of CO_2 fluxes since mid-July of 2018 showed a trend quite similar to 2017 mainly due to similar meteorological conditions.

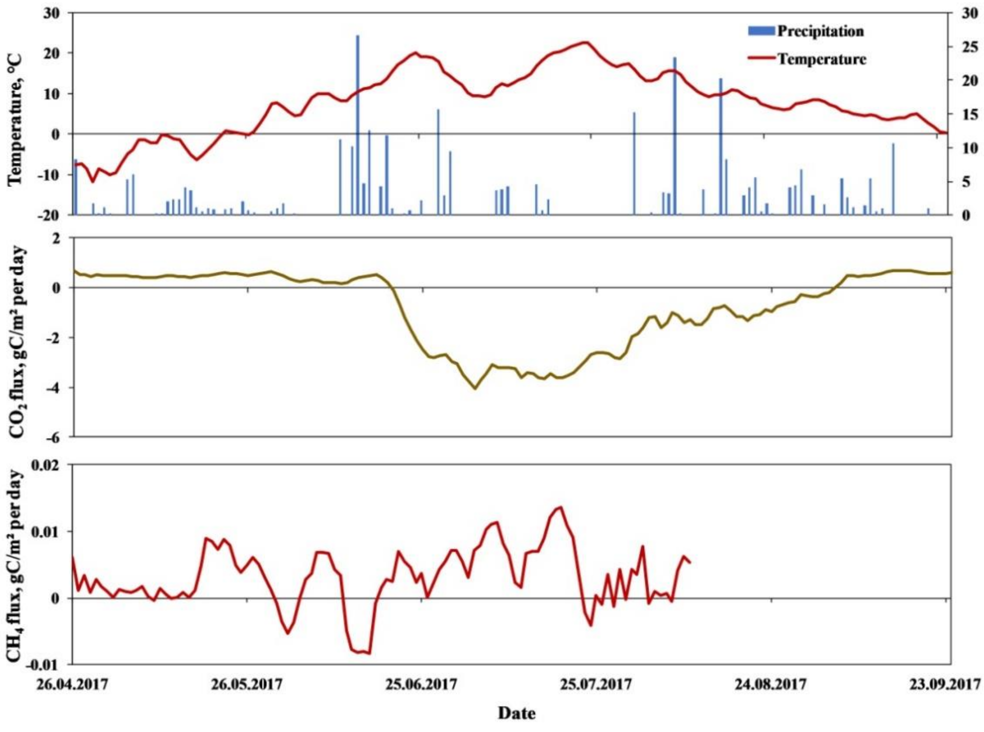

Figure 2. Seasonal variability of the mean daily air temperature, precipitation, CO_2 and CH_4 fluxes in the palsa mire in 2017.

A close dependence of net CO_2 fluxes on incoming solar radiation and the air temperature is a key feature of CO_2 exchanges in subarctic palsa mire under sufficient moisture conditions. In particular the similar seasonal variability and maximum CO_2 flux rates in July were detected in subarctic palsa mire in Sweden [7]. The possible effect of permafrost degradation is also very important topic of GHG flux studies in permafrost areas. It can be expected that the small increase of CO_2 fluxes in the second part of July under high air temperatures can be associated with permafrost thawing. However as it was shown by Olefeldt et al. [11] from measurements in northern Sweden the net carbon accumulation of a high-latitude permafrost palsa mire can be similar to permafrost-free peatlands.

Temporal variability of CH_4 fluxes was relatively high varying between −8.3 to 13.6 mgC m^{-2} per day in 2017 and between −4.5 to 21.8 mgC m^{-2} per day in 2018. Such variability was mainly associated with weather conditions, peat aeration, vegetation growth and functioning, nutrient level, peat temperature, permafrost melting and microbial processes responsible for net release of CH_4. The maximum of CH_4 release in 2017 is obtained at the middle of May, at the beginning of June and at the beginning and in the second half of July. Whereas the maximum CH_4 release in May and June is well correlated with time of snow cover melting and soil thawing, other maximums are mainly associated with soil temperature oscillations. Similar close relationships between CH_4 release rate and soil temperature can be found and in July and August of 2018. The periods of methane uptake were detected in early and mid-June 2017, as well as in September 2018. They may be associated with long periods of warm and mostly rainless weather, under decreased the soil moisture and ground water level and as a result of increased oxidation rate of methane by soil bacteria. Comparison of obtained results with previously published data indicates their good correlation with CH_4 flux measurements in other sub-arctic regions. Particularly the similar results were obtained by Nykänen et al. [12] from soil chamber measurements in a subarctic palsa mire in Finland and by Flessa et al. [8] from measurements in the forest tundra ecotone in northern Siberia.

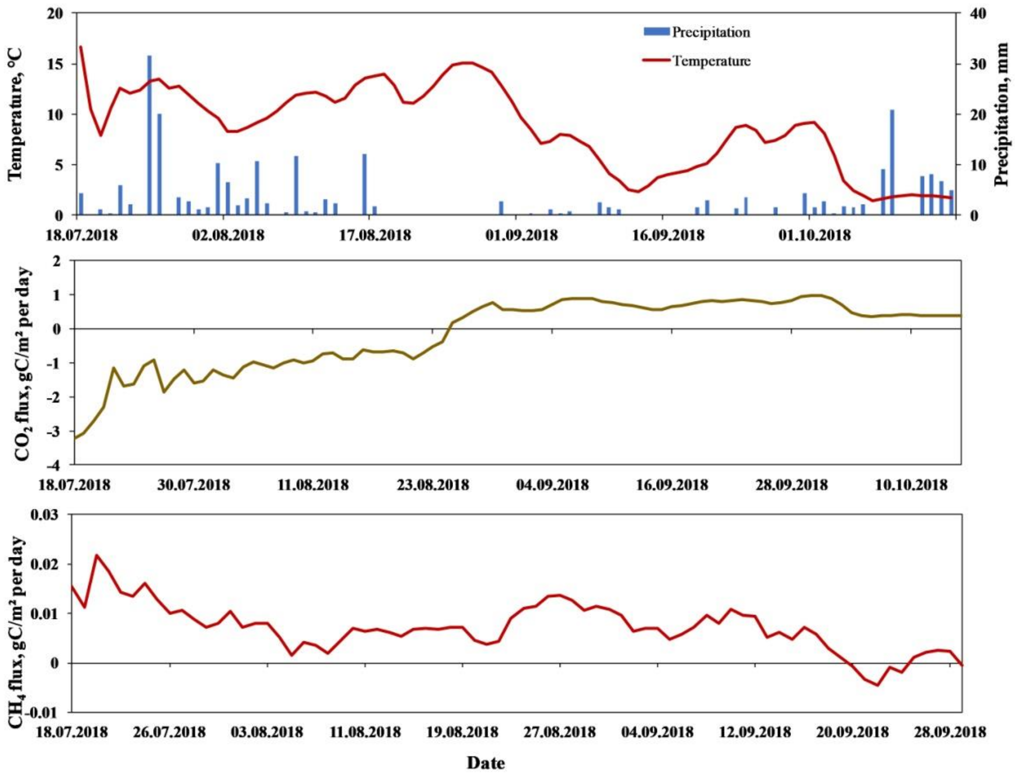

Figure 3. Seasonal variability of the mean daily air temperature, precipitation, CO_2 and CH_4 fluxes in the palsa mire in 2018.

Obtained results illustrate a wide range of the CO_2 and CH_4 flux variability that is highly dependent on various environmental conditions. Integrated studies of GHG fluxes in different sub-Arctic ecosystems using different experimental approaches are very necessary to quantify the regional GHG flux pattern in Siberia and throughout entire Northern Eurasia.

4. Conclusions

The results of the CO_2 and CH_4 flux measurements in the subarctic palsa mire in North-Central Siberia showed a significant flux variability determined by both meteorological (temperature, solar radiation, precipitation) and biophysical factors. It was shown that the mean daily CO_2 uptake rates significantly exceeded CO_2 emissions for the period between mid-June to the end of August for 2017 and 2018 years, i.e., the palsa mire ecosystem in the growing season served as a sink of CO_2 from the atmosphere. The CH_4 fluxes were almost positive and mainly governed by weather conditions, soil temperature, snow cover and ground water level variations. The CH_4 uptake was detected in summer periods under low groundwater levels due to prolonged warm and dry weather conditions. Obtained results are well agreed with the published data on temporal variability of CO_2 and CH_4 fluxes measured in palsa mire ecosystems in different sub-arctic regions of the world. Taking into account very limited information about the CO_2 and CH_4 fluxes in the northern taiga and forest-tundra ecotone of Russia our results are very important for more accurate estimations of regional carbon balance and better understanding of the temporal and spatial variability of CO_2 and CH_4 fluxes under changing environmental conditions.

Author Contributions: Conceptualization, A.O. and A.P. (Anatoly Prokushkin); methodology, V.Z., A.P. (Anatoly Prokushkin); field measurements, V.Z., A.P. (Alexey Panov), A.P. (Anatoly Prokushkin); data curation, E.S.; writing—original draft preparation, A.O., E.N., I.M., A.P. (Anatoly Prokushkin); writing—review and editing, A.O., A.P. (Anatoly Prokushkin); visualization, A.O., E.S., A.P. (Anatoly Prokushkin); project administration, A.P. (Anatoly Prokushkin). All authors have read and agreed to the published version of the manuscript.

Funding: The field measurements provided by V. Zyrianov and A. Panov were founded by the joint grant of the Russian Foundation for Basic Research and Krasnoyarsk Regional Science Foundation (20-45-242908). Landscape description conducted by A. Prokushkin and E. Novenko was supported by the grant of the Russian Science Foundation (20-17-00043). The data analysis conducted by A. Olchev was supported by the grant of the Russian Science Foundation (22-17-00073).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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