Spatio-temporal change of methane emission from reservoir

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November 22, 2022

Abstract

Authors present their investigation of spatial and temporal changes of methane emission from the surface of the Mozhaisk reservoir, situated 120 km to the west from Moscow, Russia. Seasonal changes in the content and specific flow of methane were revealed for different morphological areas of the reservoir based on the data of field observations in 2015-2018. In the low-flow Mozhaisk reservoir, the methane content in the surface and bottom layers of the deep-water areas at the end of the summer stratification period may differ by three orders of magnitude. According to the results of flux measuring by ≪floating chambers¿¿ in the entral area of the reservoir from the beginning of June to the end of the period of direct stratification (August-September) methane flux increased from less than 1 to 16 mg 4-C/(m**2 hour). The simultaneous measurements with "floating chambers" of 2 types (simple – for taking samples of the integral flux, and with a shield, rejecting bubbles – for samples of diffusion flux) revealed typical values of these flux components and their change during the sampling period. In the beginning of stratification diffusive flux predominates with mean values 0,2 mg4-/(m2 hour) and forms 100% of the total flux while methane concentration near bottom is low.The increase of the total methane flux is associated with an increase of the bubble component: its ratio grows from 75% to 98.7%. Integral methane flux rapid increase is observed when the upper edge of bottom anoxic zone reaches the lower edge of epilimnion. Supported by RGS 17-05-41095.

SPATIO-TEMPORAL CHANGE OF METHANE EMISSION FROM RESERVOIR*

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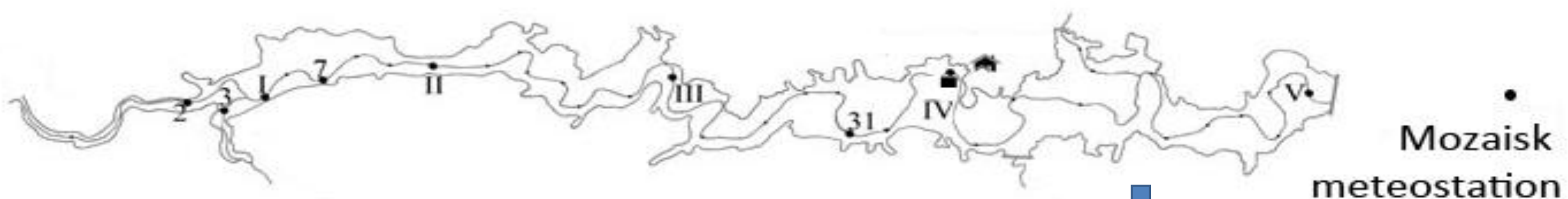
*supported by RFBR-RGS 17-05-41095

The relevance of the study

The artificial reservoirs, with the global area of 305,723 km^2 (excluding regulated lakes), are a widely reported as source of methane to the atmosphere. In reservoirs, methane is the product of anaerobic decomposition of organic matter both transported from catchment and produced in the reservoir. An increase in water temperature intensifies the activity of microorganisms, so that methane emission from reservoirs also depends on this variable. In the temperate zone, methane flux from reservoirs varies from 0.1 to 108.5 mg CH_4 / (m^2 * day), in subtropical zone - from 9.9 to 75 mg CH_4 / (m^2 * day), in subequator zone - from 10 to 1140 mg CH_4 / (m^2 * day). A large scatter of values indicates that climate is not the dominant factor determining methane flux, however at low latitudes emissions of this gas are significantly greater than at high latitudes. A large uncertainty in the estimates of methane flux from reservoirs of the boreal and tropical zones is partially caused by insufficient temporal and spatial coverage of available field data. A significant seasonal and inter-annual variability of oxygen regime in low-flow reservoirs will determine the extent of spatial and temporal variability of methane emissions from their surface. The empirical data on greenhouse gas emissions for reservoirs of Russia are very scarce. More than 70% of Russian reservoirs morphologically belong to the valley type. The purpose of this work is to empirically estimate the seasonal variability of methane flux from the surface of midlatitude Russian valley reservoir with large water residence time

The methods and object of study:

The object of this study is a small simple valley type reservoir Mozhayskoe with low water exchange period located in the upper part of the Moskva river (Fig. 1). It lacks intensive vertical mixing. The volume of the bottom anaerobic water mass, its lifetime and its distance from the dam are effectively controlled by synoptic conditions at seasonal scale of each year and the water level regime of the reservoir. The reservoir has an asymmetrical longitudinal cross-section with an increase in the depth of the submerged river bed of Moskva river from 5-7 m upstream (st.I) to 20-23 m at the dam (st.V). The depth of the flooded floodplain increases from 2-3 m to 10-12 m, respectively.



Characteristic	
Normal retaining level, m abs	183
Surface area, km²	30,7
Maximum depth, m	23
Mean depth, m	7
Full volume, km³	0,235
Useful volume, km³	0,221
Water exchange koeff., 1/year	1,15

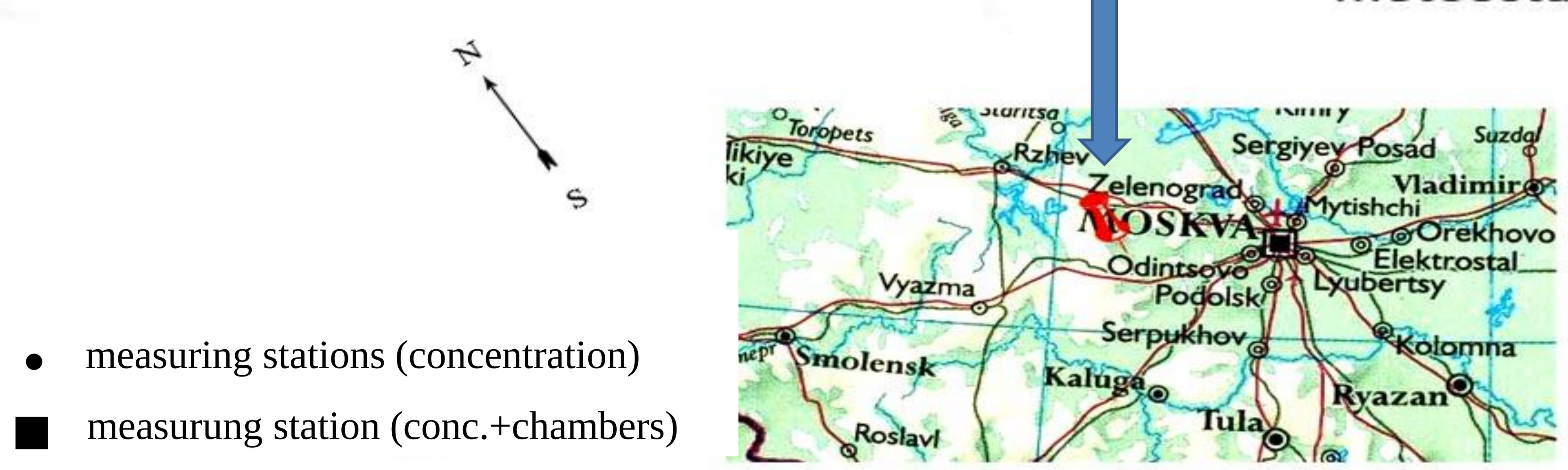


Fig. 1. The scheme of the Mozhaisk reservoir

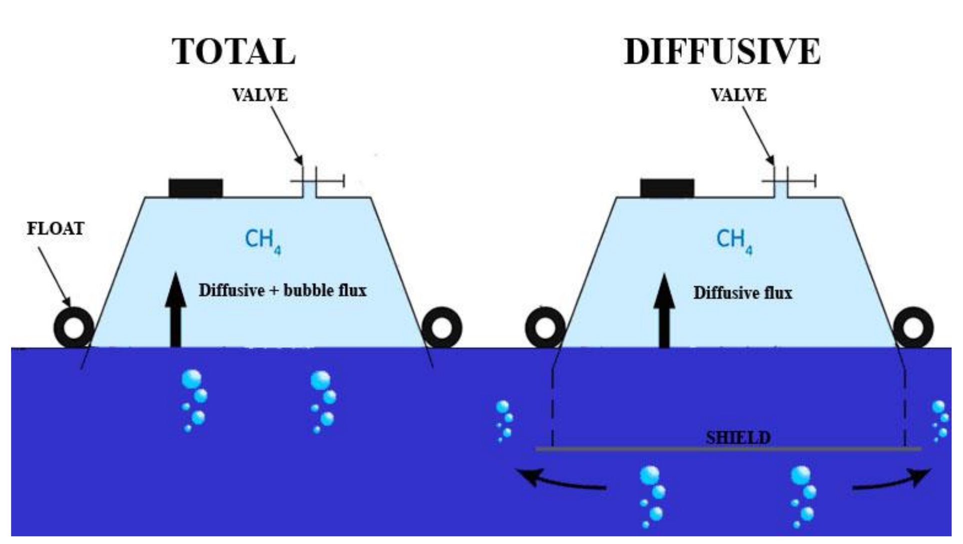


Fig. 2. The scheme of the «floating chambers».

Methane flux measurements were performed during the open water period in the central part of the reservoir (st.IV, Fig. 1) with application of the floating chamber method. In addition, water was sampled from the surface and bottom horizons on stations along reservoir. Phase equilibrium degassing technique was applied to determine the methane concentration in water and air samples. Steam-phase extraction method was applied to transfer the separated gas phase to glass vials for further laboratory studies (volume of water sample 40 ml, air 20 ml). In 2018 total and diffuse fluxes were measured by two chambers simultaneously. A special shield was hung in 70 cm below the diffuse chamber for deflection of the bubbling bubbles. Area of the shield was 2 times biggest than area of the basement area of the chamber. (Fig. 2).

Diffuse methane flux was also calculated by thin boundary layer method (TBL) with exchange coefficients parameterized according to Cole and Caraco. Water temperature and dissolved oxygen concentration in both years were measured by YSI ProODO zond. Regular weather observations at Mozhaysk weather station (WMO ID 27509) were used for analysis of the weather conditions.

Observation results

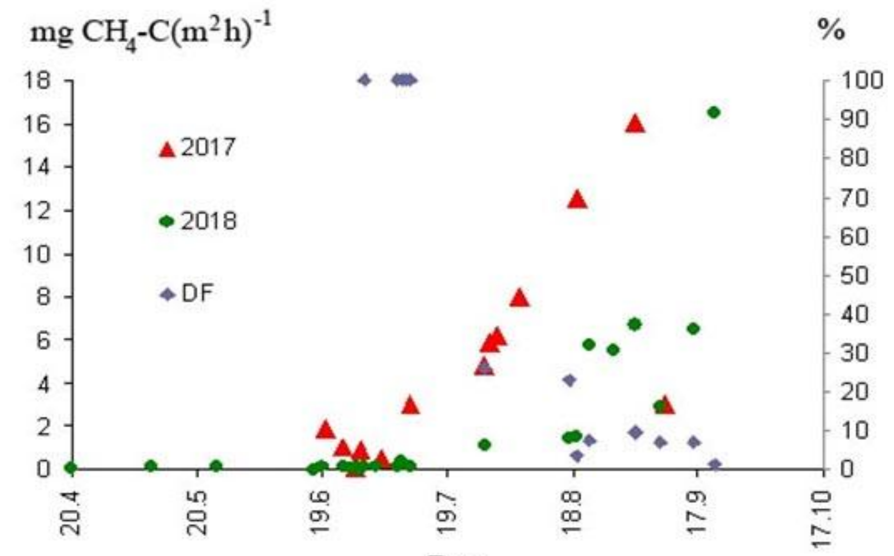


Fig. 3. Methane flux measured by floating chambers (mgCH4-C / (m^2 h)) and the fraction of diffusion flux (DF,%) measured in 2018.

Weather conditions during the sampling periods 2015-2018 were different, which result in differences in hydrological regime of reservoir and methane concentration and emission values. Thus in 2015, 2017 water body was less stratified than in 2016, 2018 due to smaller temperature and density gradients.

Listed feature of hydrological regime result in principal differences between seasonal variations of methane concentration and emission values. The highest content of methane in the surface and bottom layers is noted in August before the destruction of the stratification

The typical pattern during the summer is the increase of the difference between diffuse and total methane flux, which characterizes the intensity of the methane bubble flux, increasing by the time of stratification destruction, up to 90% of the total flow (Fig, 3).

According to the data of complex measurements, a significant seasonal increase in the methane flux occurs when the temperature gradient in the water column decreases: in 2017, by the 1st decade of September, the temperature difference between the surface and bottom layers decreased from 7.9 to 2.6 ° C, and in 2018 by the third decade of September - from 10.8 to 5 ° C (Fig. 4). An increase in the specific methane flux occurs when the upper boundary of the oxygen-free zone reaches the lower boundary of the epilimnion. This pattern became especially vivid in 2018.

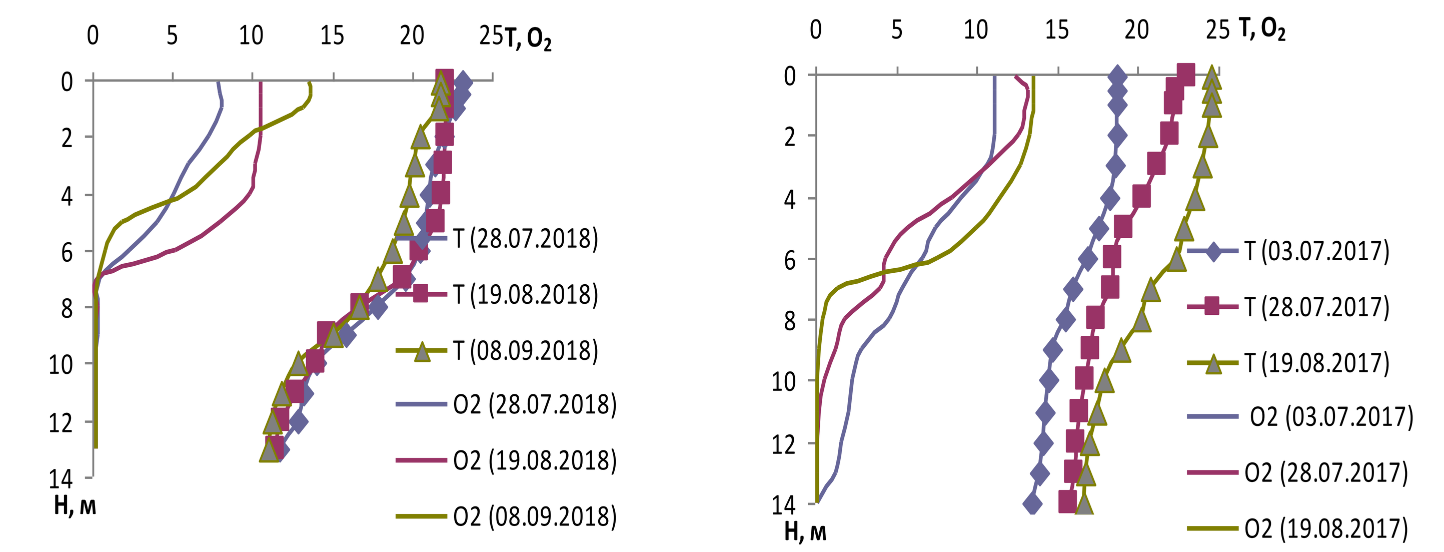


Fig. 4. Vertical distribution of water temperature and dissolved oxygen in 2017-2018 during the period of methane flux growth on the measuring station.

Until the end of July, the flux values measured by both chambers (diffusive and total flux) are virtually the same and upon the average is 0.2 mg C-CH_4 / (m^2 h). After the anoxic zone reached the lower boundary of the epilimnion, the measured values of methane flux for the "diffusive" chamber with a screen turned out to be less than for the "total" chamber. Moreover, part of diffusive flux decreased from 26% to 1.3% with the growth of the total flux, that indicates a significant role of the bubble flux in the total methane flux in the low flow stagnant reservoir.

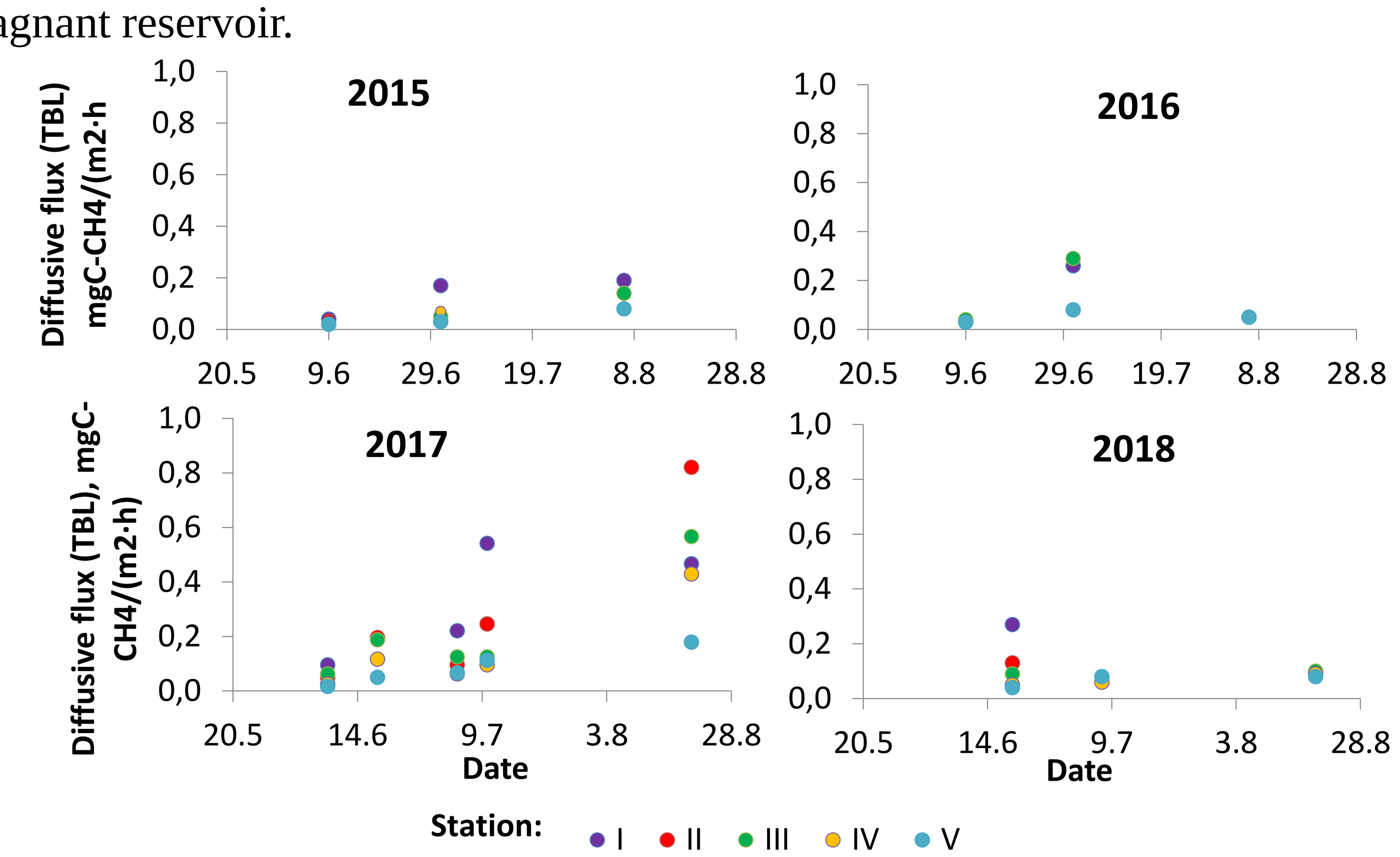


Fig. 5. Spatial distribution of diffusive flux on the measuring stations (from Fig. 1).

The spatial-temporal variability of the diffusion methane flux has the following regularities. In the formation of direct temperature stratification values of the flux upstream are 0,03-0,07 mgC-CH_4/(m^2 h), near the dam – 0,02–0,04 mgC-CH_4/(m^2 h). In 2015, and especially in 2017, an increase in the diffusion flux during the summer period was expressed with the highest methane content in the surface layer due to regular wind mixing and weak stratification (Fig. 5). In 2016 and 2018 the highest values of specific flux (up to 0.3 mgC-CH_4/(m^2 h) upstream) were characteristic, on the contrary, in the first half of summer. In 2018, due to the most stable and long termical stratification, the upper boundary of the oxygen-free zone was also located at 7-8 m, as in 2017, but the low water temperature near bottom in the deep-water compartments caused a lower methane content in the bottom horizon compared to 2017.

Conclusion

The methane content in the reservoir is determined by the meteorological situation, the features of the density stratification, depth, thermal and oxygen regime.

At the beginning of the stratification period prevails a diffuse flux of methane upon the average 0.2 mg CH_4-C / (m^2 h).

An increase of methane flux values is observed when the upper boundary of the anoxic zone reaches the lower boundary of the epilimnion. The greatest values methane flux reaches before the destruction of the straight stratification (around 16 mg CH_4-C / (m^2 h)).