Shallow meromictic lakes as a source of methane emissions to the atmosphere

I. Repina, V. Stepanenko, A. Artamonov, S. Guseva

A.M. Obukhov Institute
of Atmospheric Physics RAS

Lomonosov Moscow State University

Motivation

Fresh waters make a disproportionately large contribution to greenhouse gas emissions. Greenhouse gas fluxes from shallow lakes are altered by climate change may have profound implications for the global carbon cycle.

Most lakes in the World are holomictic, that is for at least one period in each year wind driven currents circulate throughout, to their largest depths. As a consequence of this the entire body of water is oxygenated.

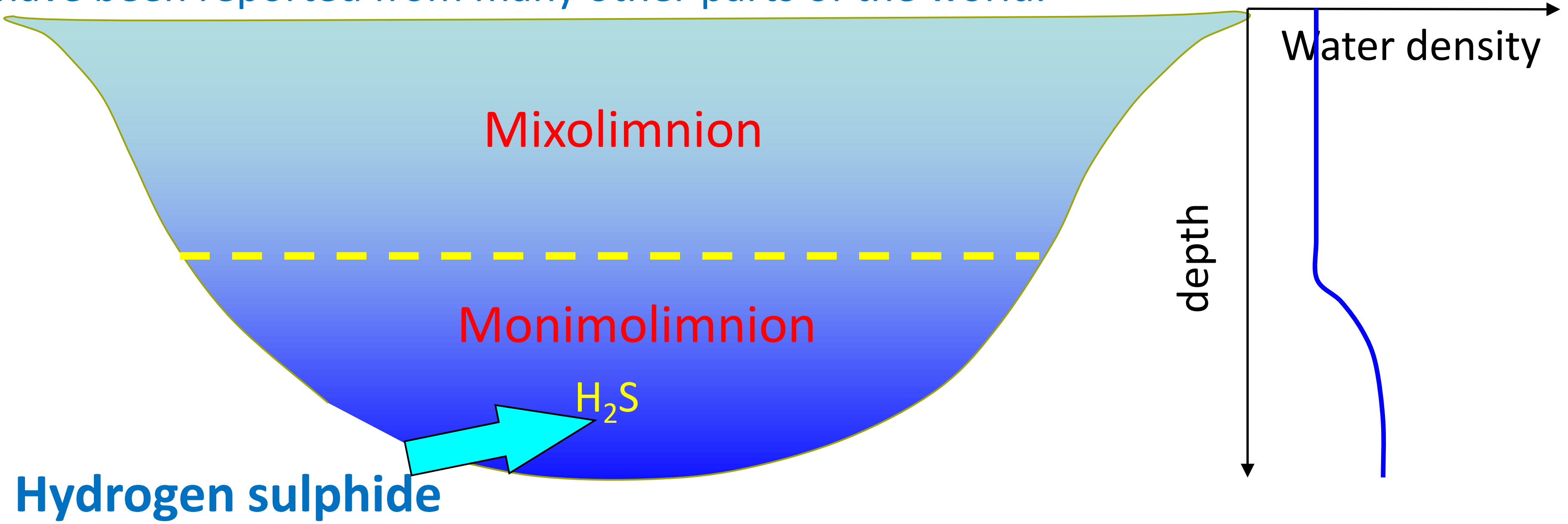
Many saline lakes have a specific mixing regime which is classified as meromictic.

Deep lakes of this type are investigated quite well. But shallow lakes that are fairly common as lakes separating from the ocean or lagoons have not been extensively studied as a source of greenhouse gases.

It is believed that methane produced in bottom sediments is efficiently trapped in a strongly stratified lower layer of these lakes. The task of our work is to determine the key factors of methane emission from shallow meromictic lakes.

Meromictic lakes

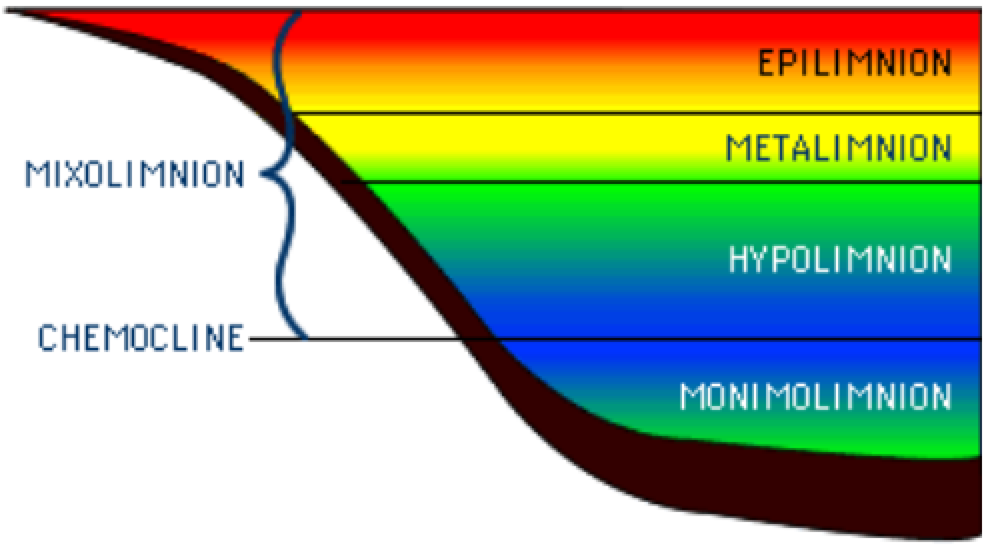
The term was introduced in 1935 by an Austrian limnologist, Ingo Findenegg, to describe the circulation behavior of subalpine lakes in Corinthia. Since then, examples have been reported from many other parts of the world.

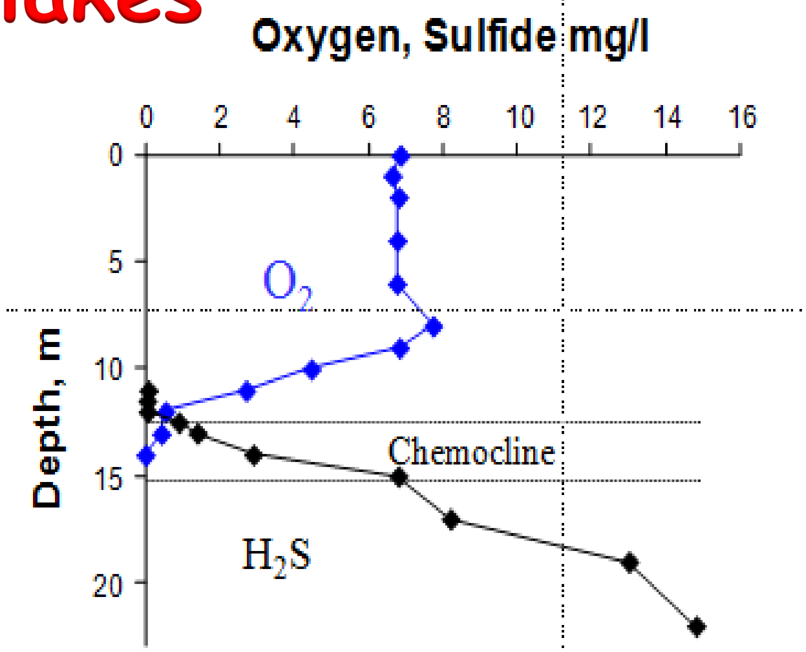


Mixolimnion is subjected to seasonal circulation

Monimolimnion not affected by seasonal circulation for at least more than one year.

Meromictic lakes

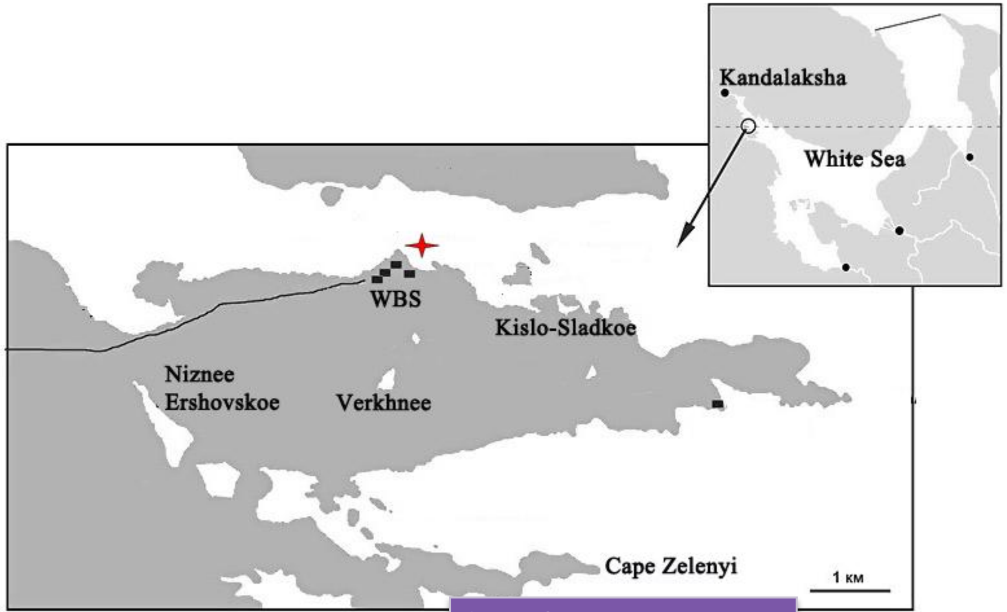


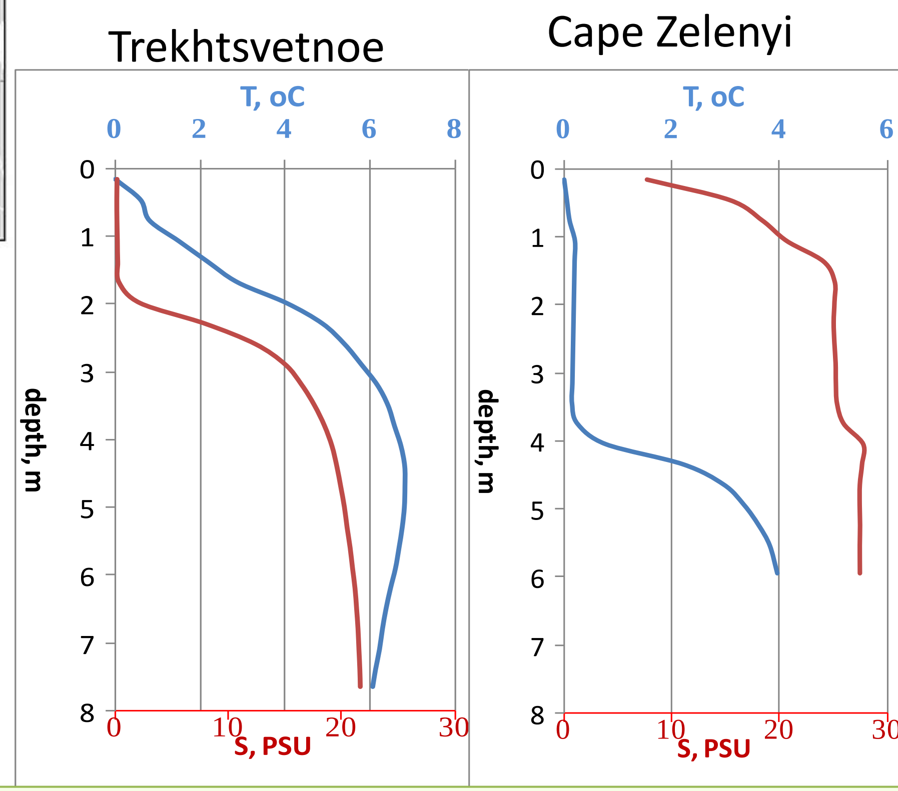


In the **monimolimnion** there is no oxygen and hydrogen sulfide accumulates. Many of these lakes are saline and sulfate-containing water is present in the bottom layers.

- **Monimolimnion: deep stratum, high salinity**
- **Chemolimnion: strong salinity gradient**
- **Mixolimnion: upper stratum (i.e., epi-, meta-, and hypolimnion)**

Meromictic lakes of White Sea coast (winter)



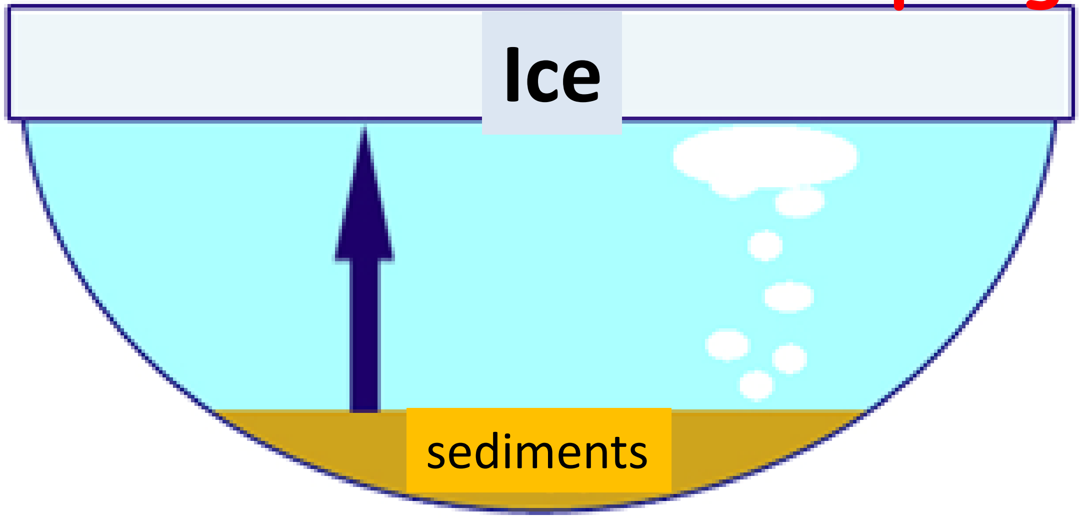


depth, m	CH4 mcmol/l
0.5	40.02
1	0.83
3	187.44
5	499.58
7	1534.08
7	1649.40
8	1700.31

Trekhtsvetnoe	0.5 m	10-50
	7 m	1000-1800

Organic carbon is also concentrated in the bottom layer, and strong stratification prevents its from transport to the surface. The deep anoxic waters contain high concentrations of methane but, contrary to other aquatic systems, almost no methane escapes from the lake by diffusion. Methane is mostly consumed within the oxic-anoxic transition zone.

The first possible mechanism for methane emission from shallow meromictic lakes is seasonal and is associated with spring emissions



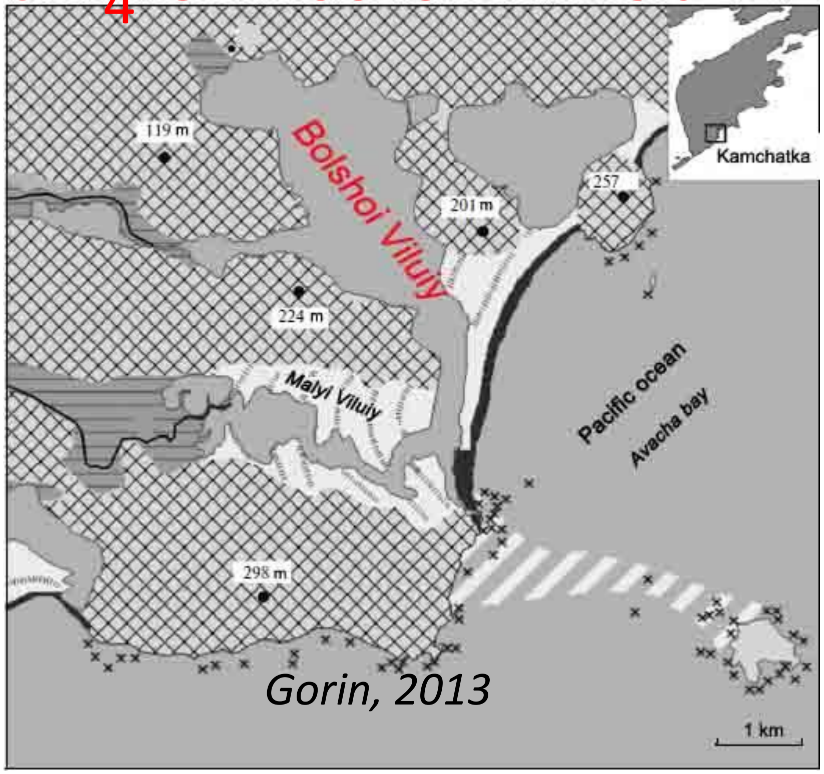
Relatively high concentrations of methane in the upper layer are formed due to bubble transfer. During the winter period, methane accumulation occurs in the ice and water due to the impossibility of its emission into the atmosphere. In the spring, when the ice melts, all this methane goes into the atmosphere.

CH_4 emission in Summer

Bolshoy Vilyui Lake:

area 4.8 km^2 , length =3,8 km, width=1.1 km

Depth average h_{avg}=3 m, h_{max}=6 m

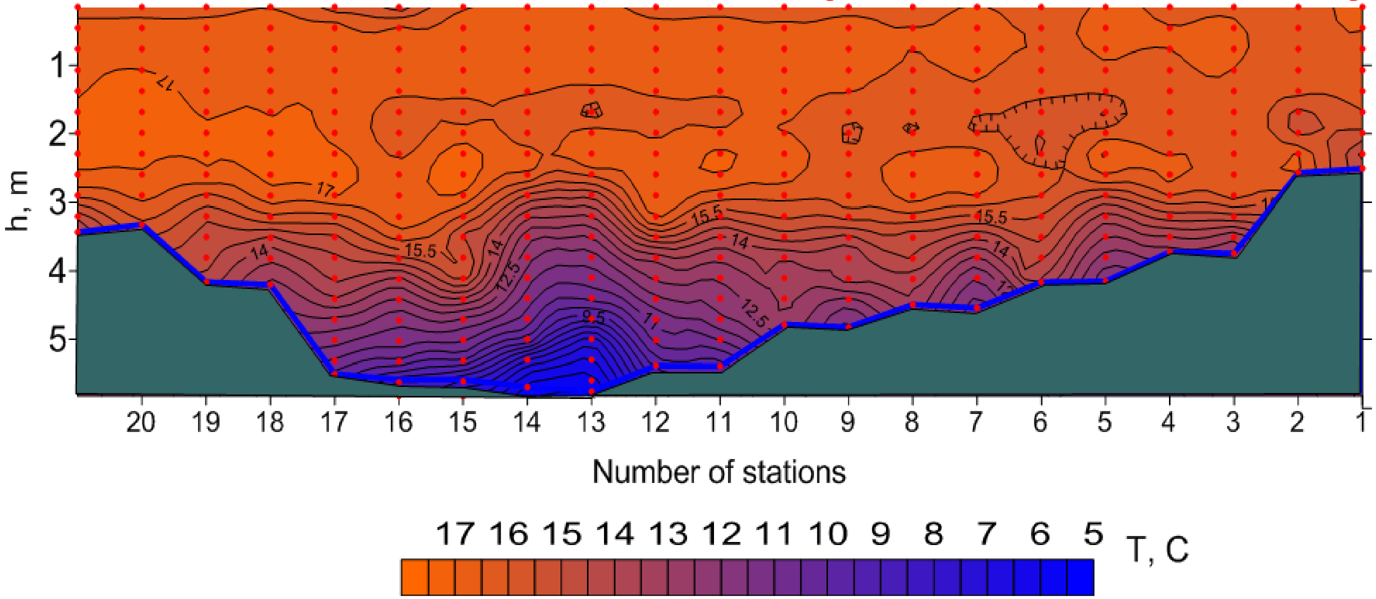


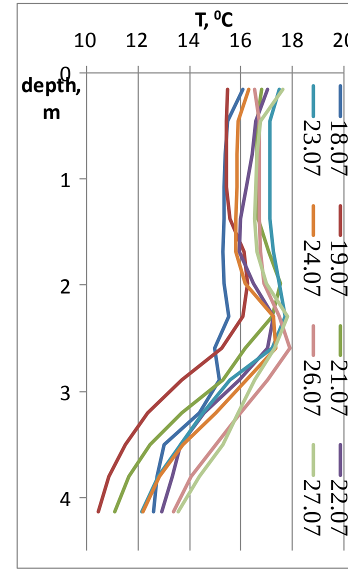
The measurements: (15 -28 July 2015)

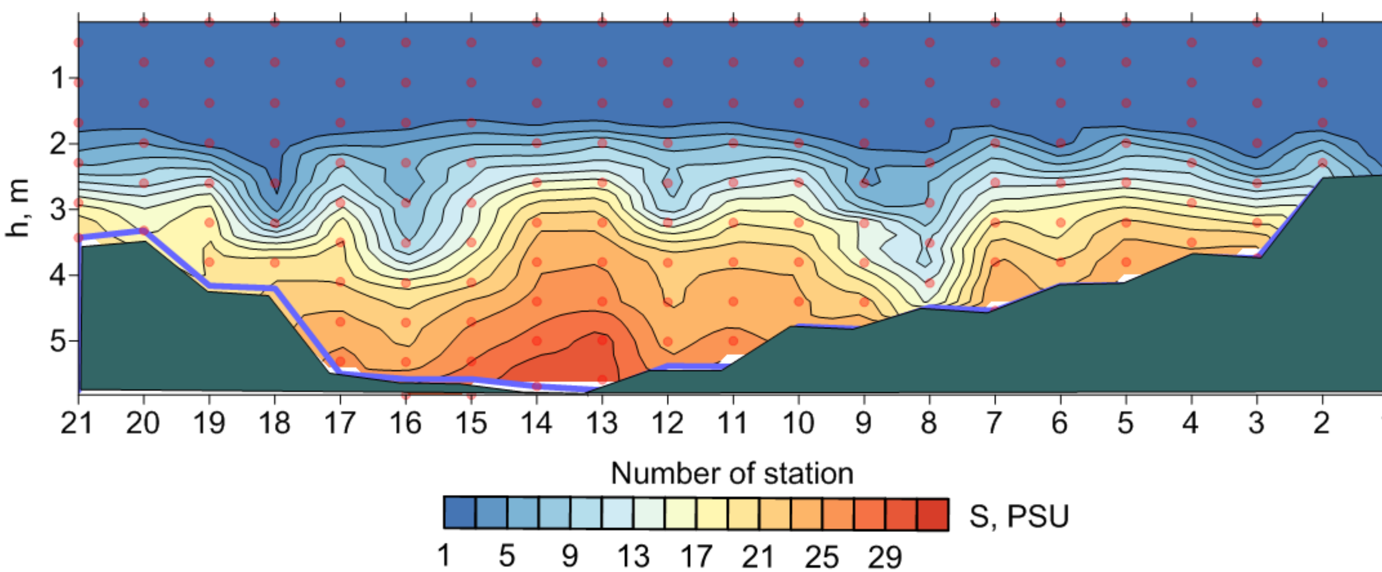
- Shortwave and longwave incoming radiation
- Meteorology: temperature, pressure, humidity, wind, precipitation.
- Eddy covariance measurements of sensible heat, momentum and methane fluxes
- Water sampling for dissolved gases
- Methane concentrations in air
- Water temperature at four levels
- Temperature and salinity profile by STD sounding

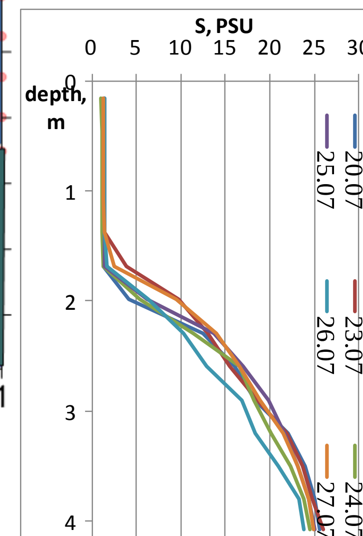
The Bolshoy Vilyui is the estuarine type lake with strong stratification in density and temperature. The depth of top mixed layer is 2,5 m.

Cross-section of Temperature and salinity



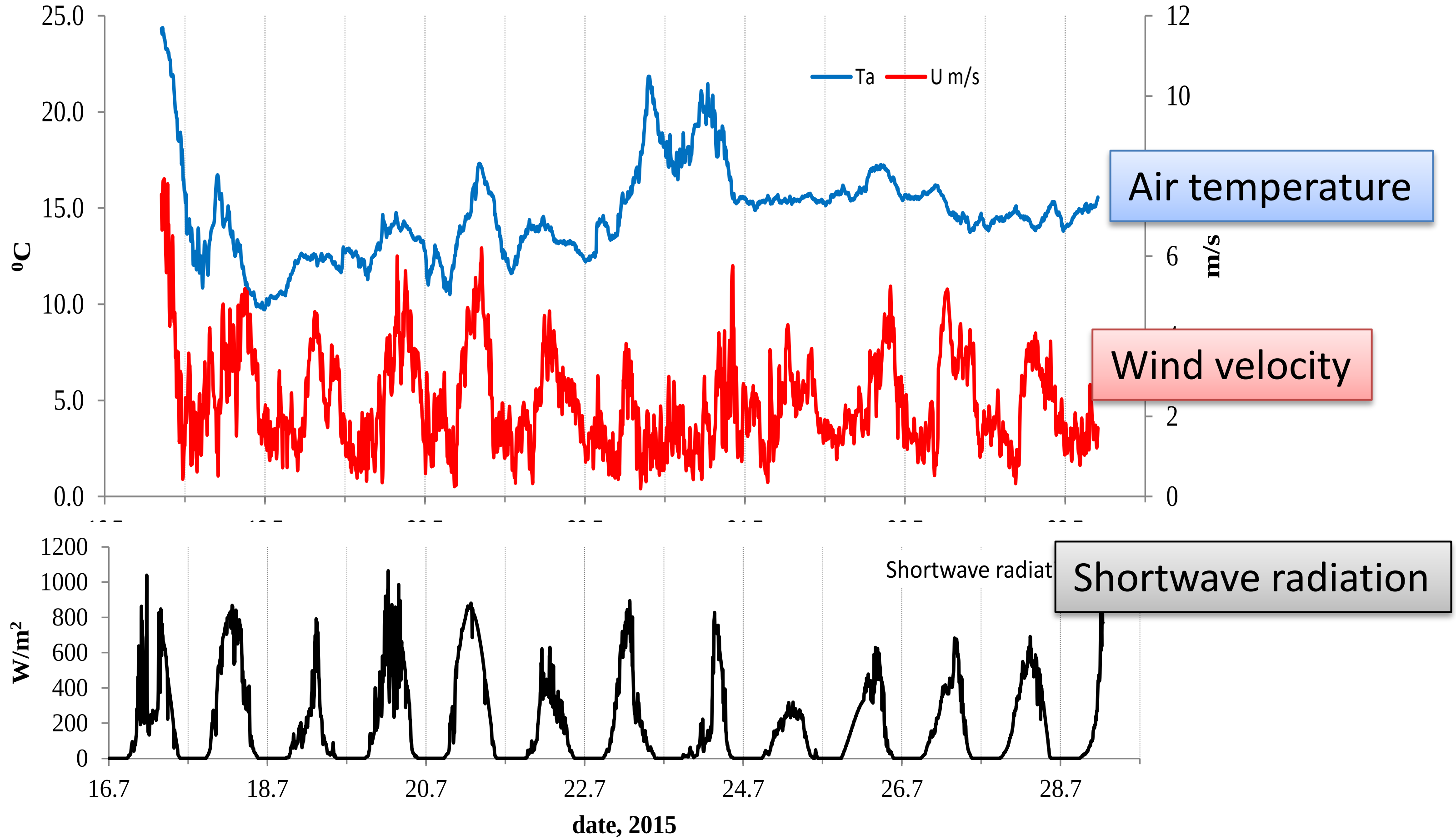




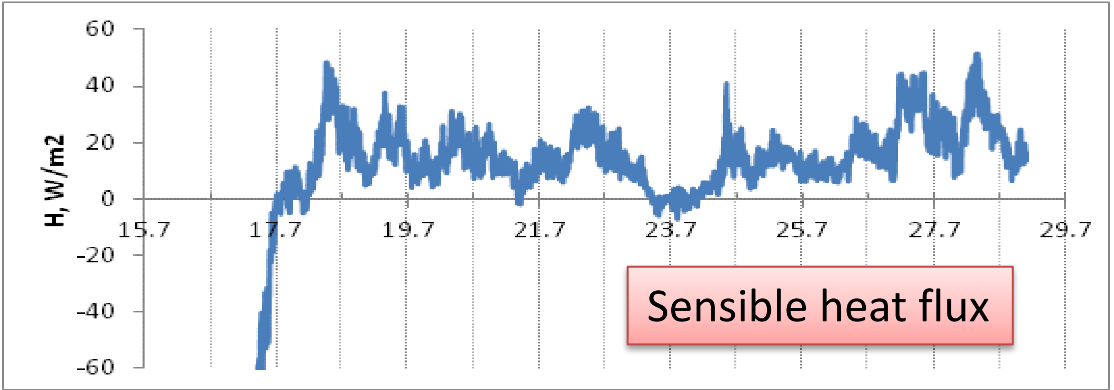


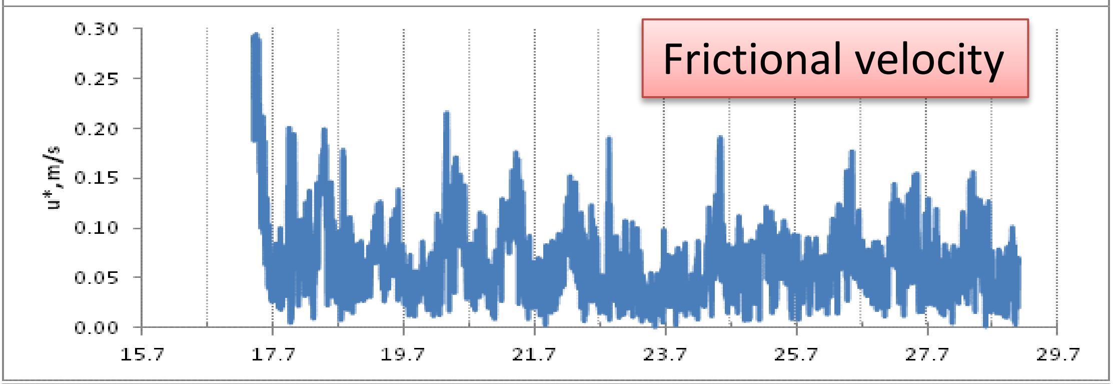
Stepanenko V., Repina I.A., Artamonov A., Gorin S., Lykosov V.N., and Kulyamin D. Mid-depth temperature maximum in an estuarine lake // *Environmental Research Letters. 2018. V. 13*. No 3. 35006. DOI: 10.1088/1748-9326/aaad75.

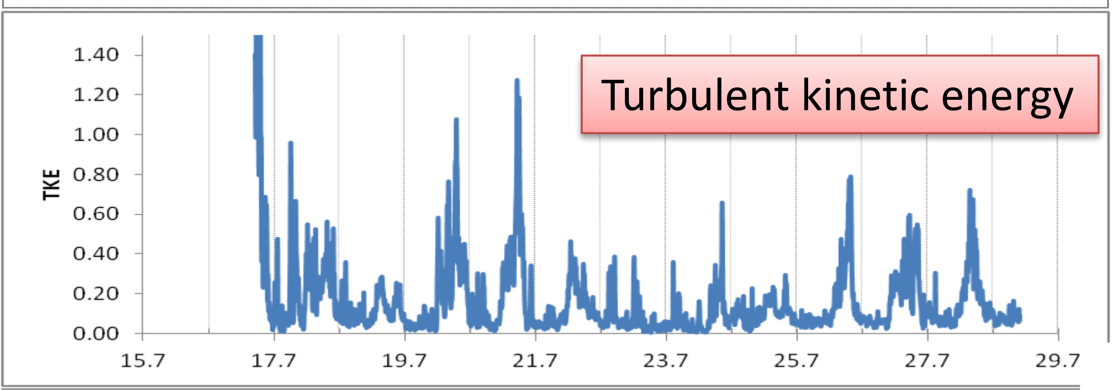
Atmospheric conditions

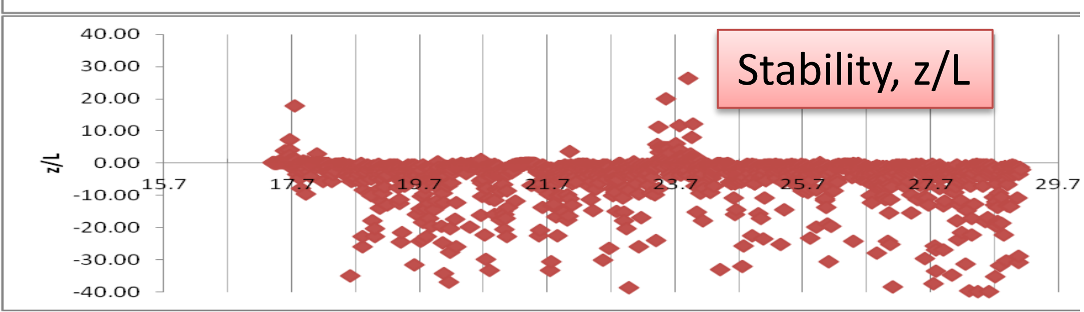


Meteorological conditions were characterized by daily variations in wind speed; stratification -- near to neutral during daytime, and unstable at night.

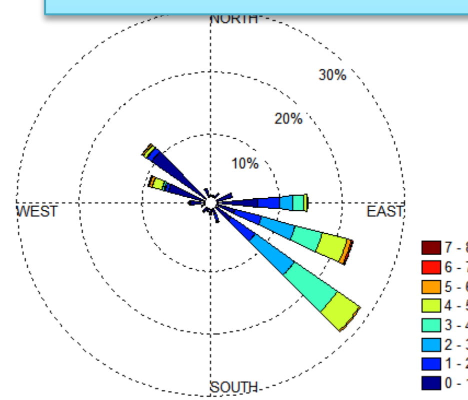






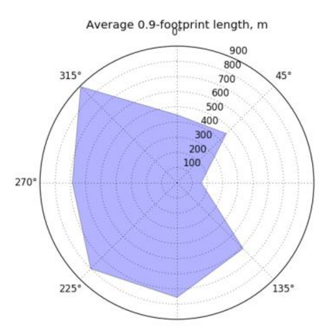


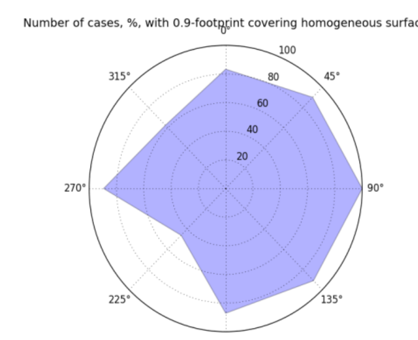
Turbulent exchange was determined by convective processes, especially by free convection at night time and high wind speed at daytime.



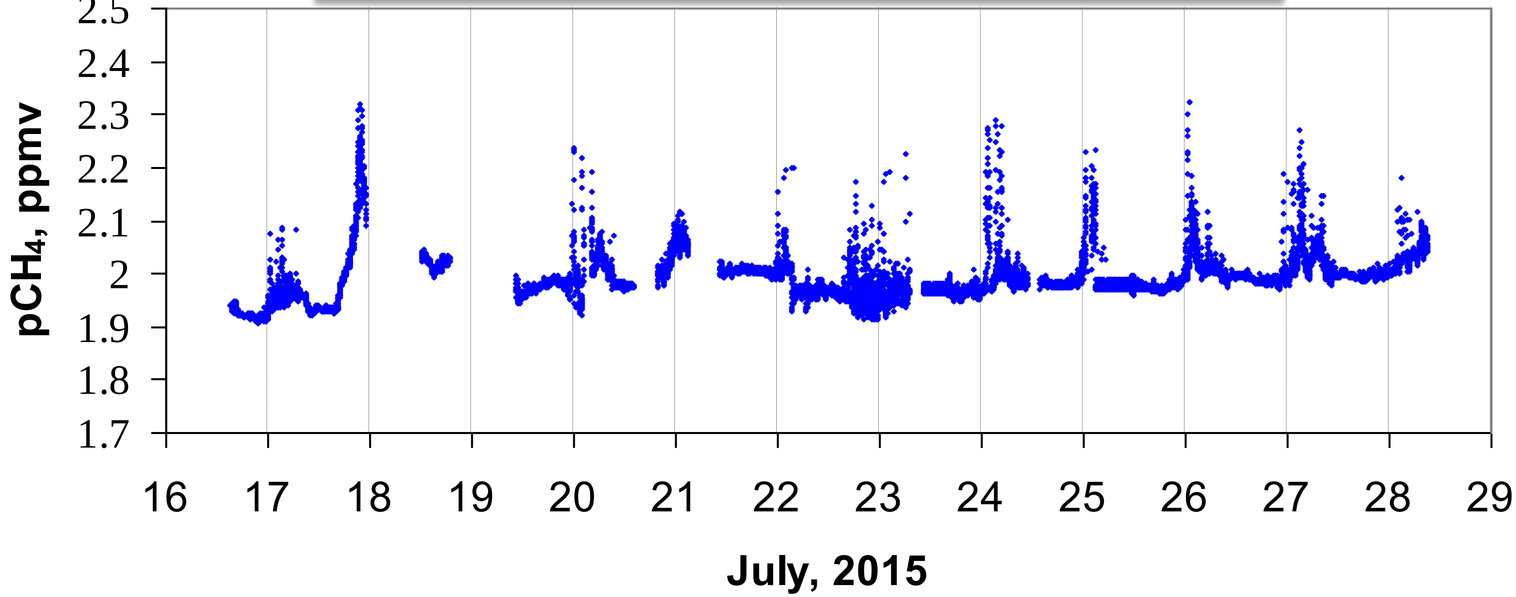
Predominant wind direction was SE (from Avacha bay).

In most cases, 90% of eddy covariance footprint covered the lake surface.

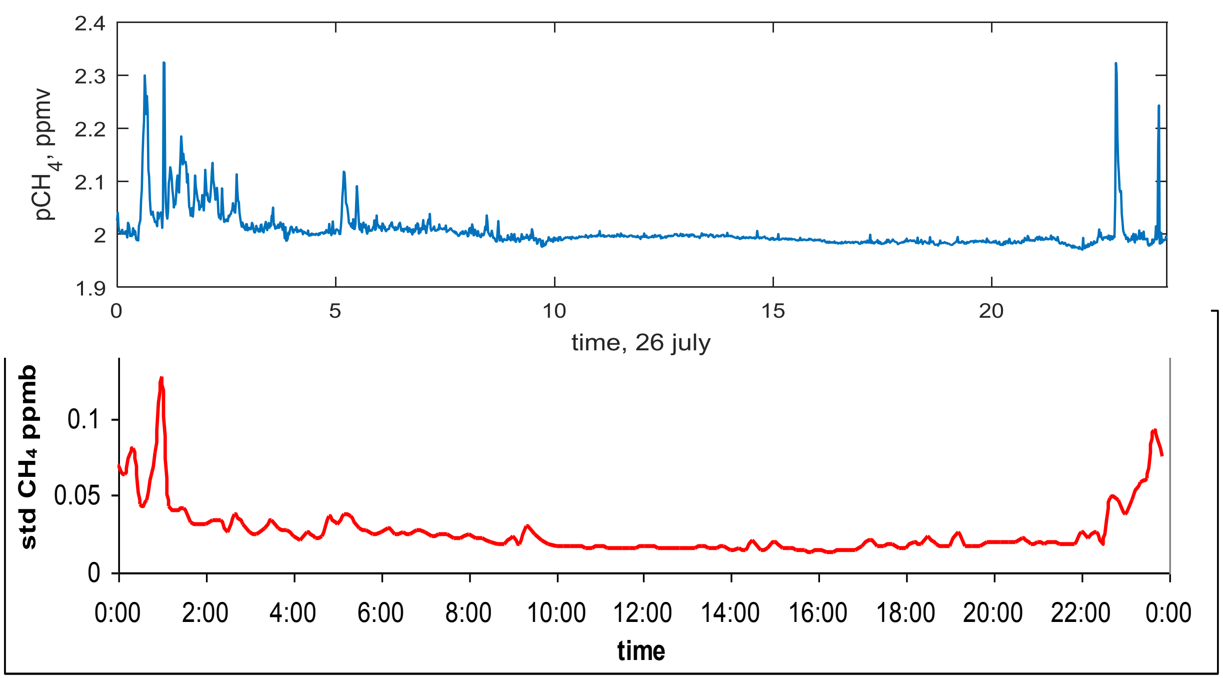




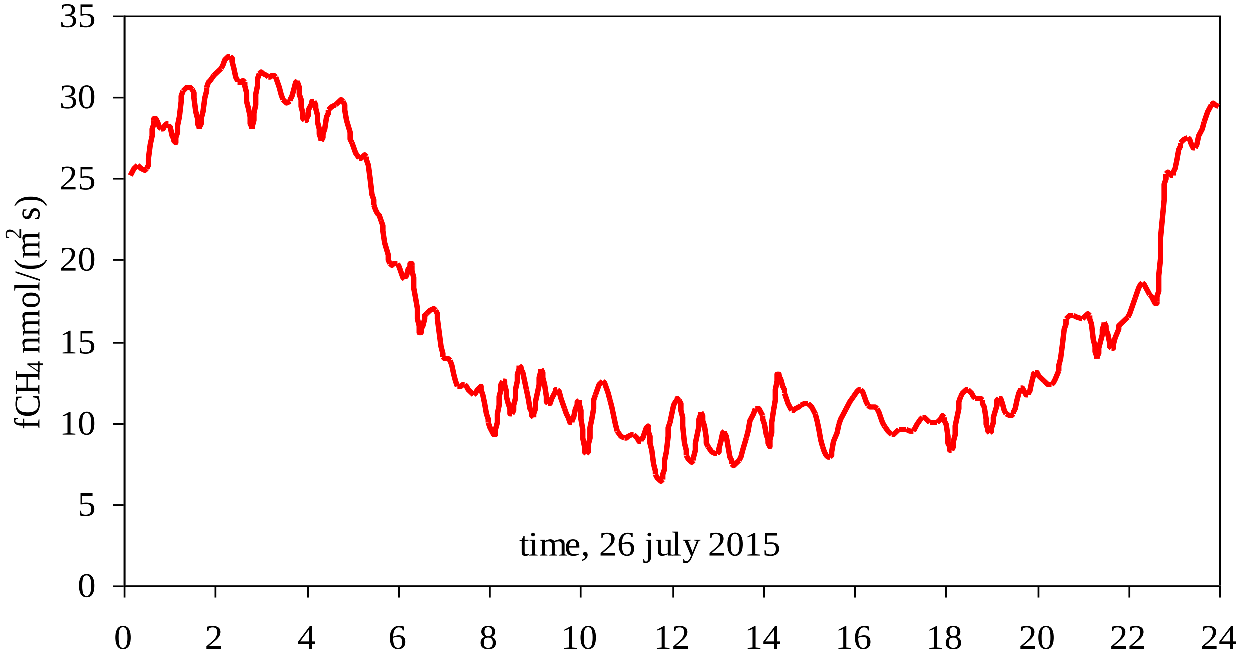
Air methane concentration during experiment



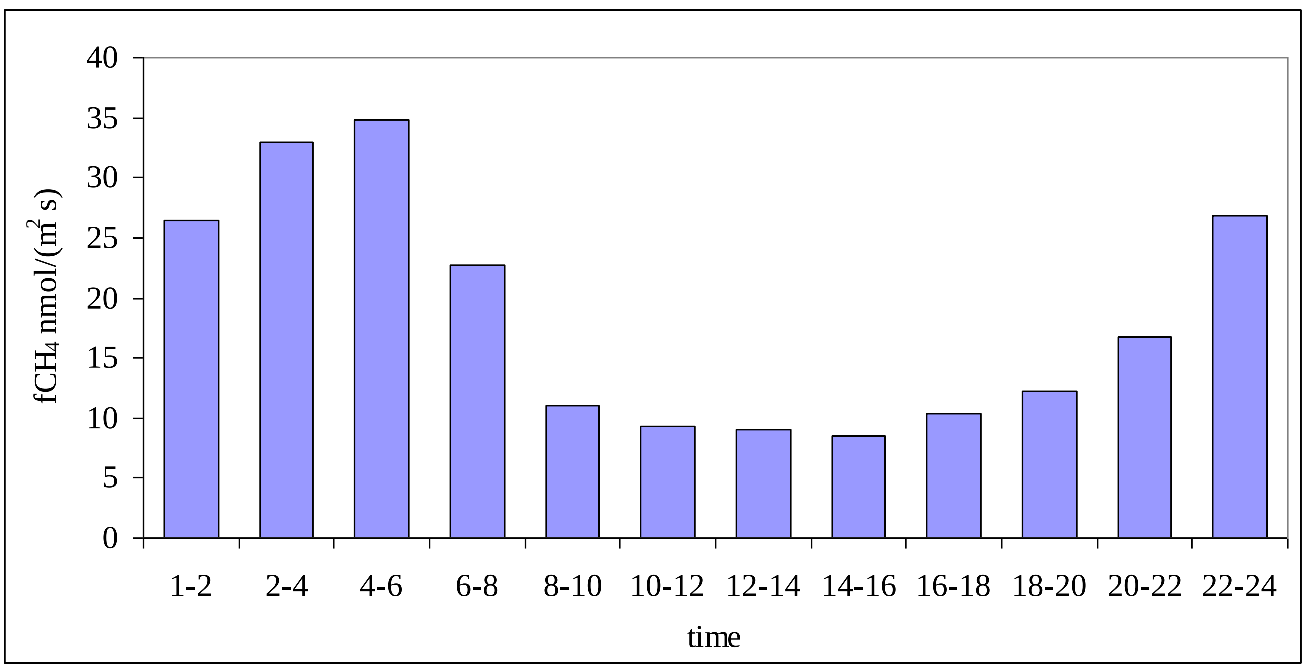
Daily variation of air methane concentration



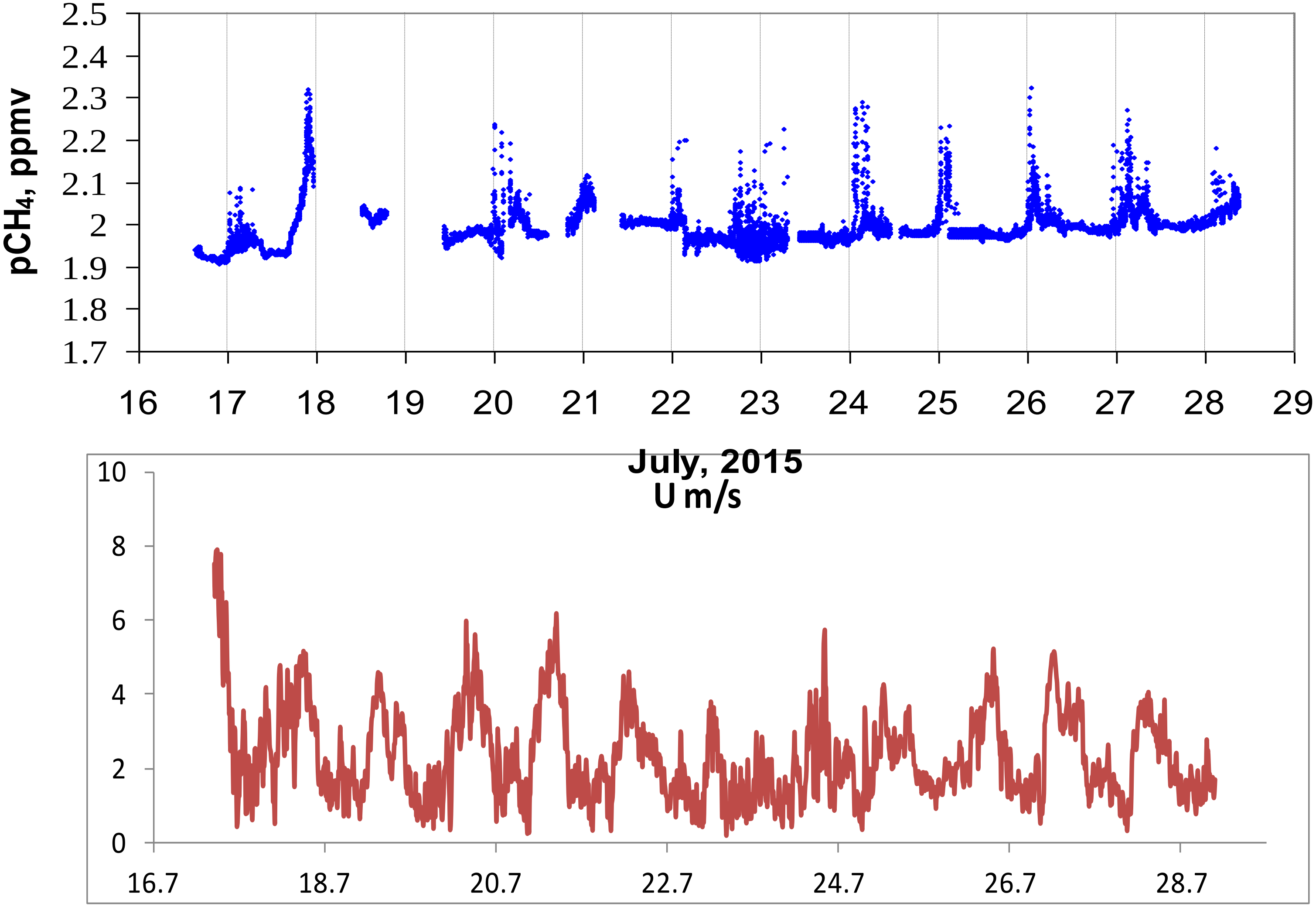
The increased air methane concentrations (2-2.2 ppm) were observed most of the experiment period. At night time regular increasing of methane concentration was recorded. The nocturnal high-frequency variability of concentration values was also elevated.



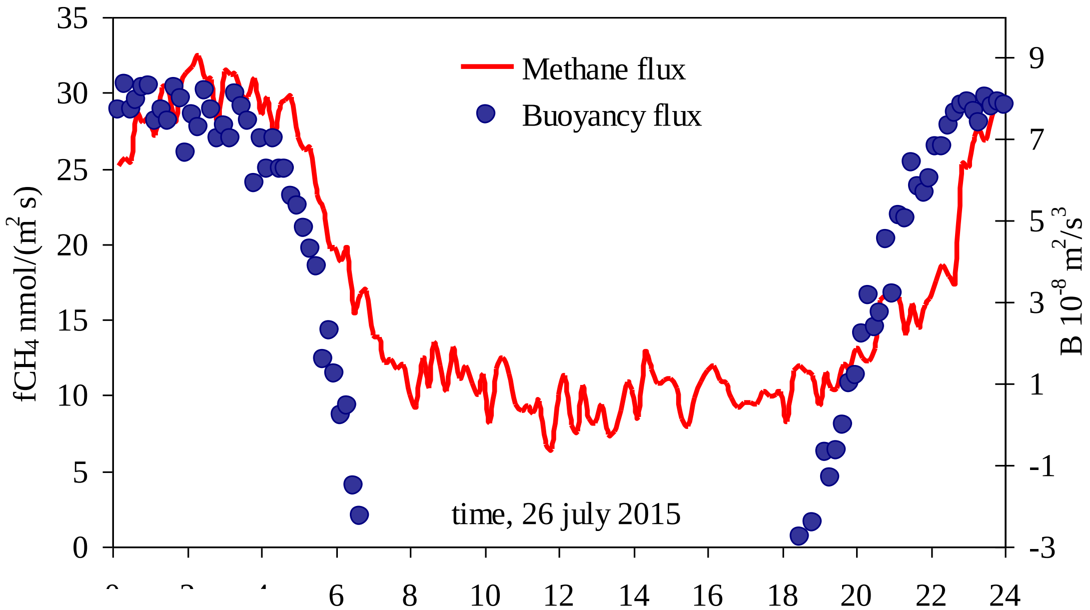
Diurnal course of methane flux (July 26)

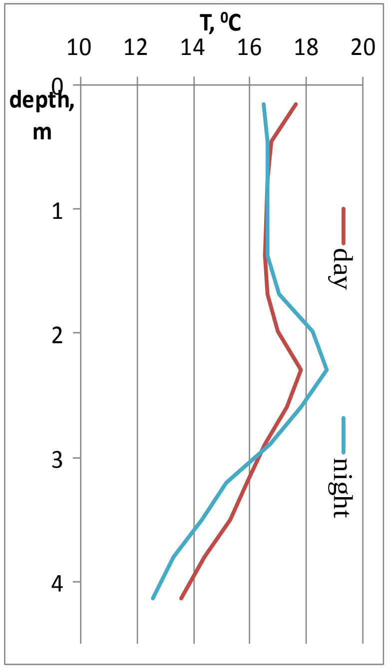


CH_4 fluxes for the whole measurement period (15 -28 July 2015) averaged over subintervals of diurnal period.



The periods of increasing concentrations and emissions coincide with low-wind conditions.





$$B = -\frac{g \cdot a \cdot Q_{eff}}{c_{pw} \cdot \rho_w}$$ waterside buoyancy flux *(Jeffery et al., 2007)*

Mean concentration of methane (ppm)

	surface	bottom	air
Daytime	5-6	150-200	2
Nighttime	8-10	150-200	2.4

Estimations of *B* showed that the high methane fluxes coincided with convective periods. Waterside convection might enhance the transfer velocity and consequently enhance the diffusive flux.

Conclusion:

The small lakes of estuarial and lagoon type may be a source of methane to atmosphere . Evidence of this is the increased air methane concentration over lagoon lakes region at White sea and above the estuary of the Bolshoy Vilyui river.

The increased air methane concentrations (2-2.2 ppm) were observed for the time of experiments. At night time regular increasing of methane concentration was recorded. It is connected with the night methane emission from lake.

Due to the reduced mixing during night, CH4 will accumulate close to the surface and will then be ventilated during the day as a result of higher wind speed. The reason for the increase in concentration in the upper layer of the lake may be a night decrease in oxygen content and hence methane oxidation.

High methane fluxes at night coincided with convective periods. Waterside convection might enhance the transfer velocity and consequently enhance the diffusive flux. But convection is a necessary, but not sufficient, parameter causing high nighttime FCH_4. One more possible reason for elevated nighttime CH_4 fluxes is displacement of eddy covariance footprint (following diurnal wind course) to a lake part with higher bubble flux (possibly caused by hotspots?).