3.5 Patterned ground lakes and their function as sources of atmospheric methane

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3.5.1 Introduction

Lakes are important sources of atmospheric methane (CHANTON et al. 1989; THEBRATH 1991; MICHMERHUIZEN & STRIEGL 1996; SEMILETOV et. al. 1996; PHELPS et al. 1998; DUCHEMIN et al. 1999; MAKHOV et. al. 1999; HUTTUNEN et al. 2001). Permafrost landscapes of the Lena-Delta are often covered by polygonal tundra and patterned ground lakes, respectively. Up to now little is known about the contribution of those small but widespread lakes regarding their function as sources of atmospheric methane. Thus, surveying patterned ground lakes is a necessary part of investigations for estimating both global and local methane fluxes.

3.5.2 Objectives and Methods

In this study, patterned ground lakes were investigated in order to measure their methane fluxes toward the atmosphere. Following questions were set up.

1. How much methane is emitted from the investigated lakes?
2. Which meaning has the path of emission (plant mediation, diffusion, ebullition)?
3. Which habitat parameters (sedimentary, hydrological and atmospheric parameters) are crucial for the emission behavior?

Measurements of methane emissions were carried out by two different types of floating chambers (three of each type) from beginning of July 2002 to beginning of September 2002. Chamber type I was used for measuring methane emissions by plant mediation. The measuring field was stationary and placed within the edge of the lakes where vegetation penetrates the water surface. Plants enclosed by the chamber were *Carex aquatilis* in case of lake IS, *Carex a.*, *Carex chordorhiza* and *Potentilla palustris* concerning PS1 and *Arctophila fulva* within PS2 (Figure 3-33) The enclosure time for plant mediated emission measurements was 30 minutes. Chamber Type II was stationary installed within a non-vegetated lake area (except water mosses at the lake bottom) for measuring both diffusion and ebullition. This type consists of a chamber (diffusion measurements) likewise type I and an additional assembled pyramid below (ebullition measurements) (Figure 3-33). The enclosure time for emission measurements was approx. 48 h. Gas samples from Type I and Type II (concerning only diffusion) were taken by gastight glass receptacles (Gasmaus) (cf. PFEIFFER et al. 1999). Ebullition samples were taken by syringes through a rubber stopper and were immediately conserved in gastight glass tubes filled with saturated NaCl-solution. Emission measurements by the different chamber types were carried out in a time frame of 12.00 to 16.00 o´clock in an alternating

2-day-rhythm. All methane gas analysis were conducted by a gas chromatograph (CP 9003).

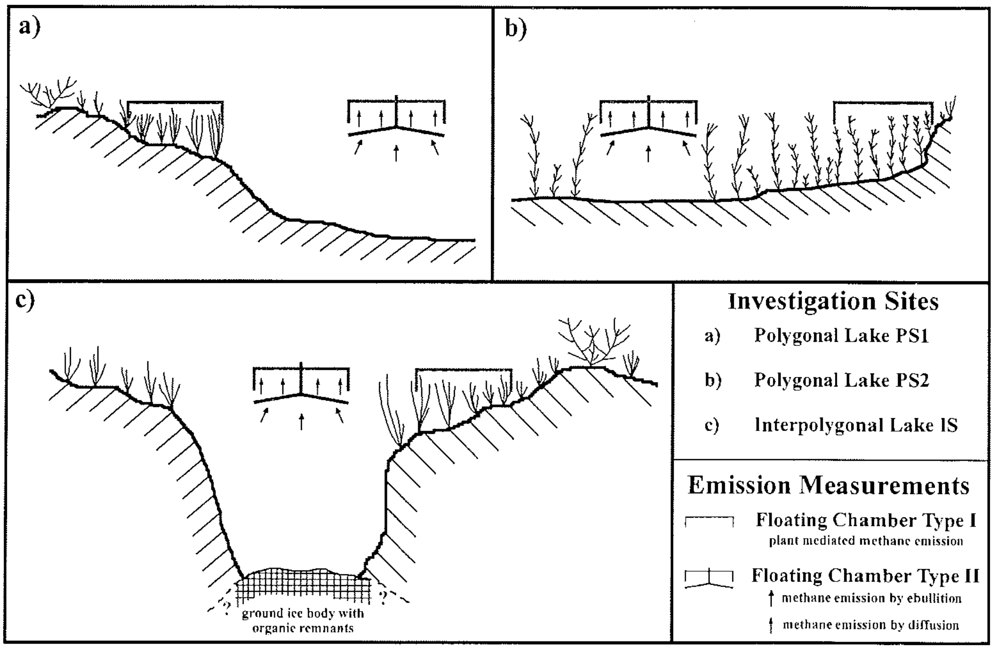

Figure 3-33. Application of floating chambers for methane emission measurements.

Accompanying the methane gas sampling, measurements of permafrost depth, water level, sediment temperature, water temperature, dissolved oxygen (OXI 325 / WTW company) and climatic parameters (temperature, moisture, pressure, wind direction and velocity) where conducted on a daily basis.

Dissolved methane in lake water was analyzed in intervals of 10 to 14 days (Table 3-16). Water samples were collected in gastight glass receptacles (3 parallel samples). Previously an adequate amount of NaCl-salt was weighted into the receptacles to force dissolved methane into headspace. Gas concentrations were analyzed after 1 to 2 days of storage at a room temperature of approx. 18 °C.

For the investigation of lake sediments, 4 drilling cores were captured from PS1 and PS2, respectively (Appendix 3-2). One core in each case were cut up for measuring methane content. Fresh sediment samples (15 to 25 g) were weighted into a 50 ml glass jar (3 parallel samples). 20 ml saturated NaCl-solution was added subsequently to force methane gas into headspace. The glass jar was closed with a septum and a screw cap and gas concentrations were analyzed after one day of storage under cold conditions (0 to 2 °C). The 6 remaining drilling cores were used for analyzing water content, raw density, grain size, pH-value, TOC and DOC as well as for experiments concerning methane production and methane oxidation (Appendix 3-2). For surveying methane gas enclosed in the ground ice body of lake IS (Figure 3-33), one drilling core of ice was obtained and gas concentrations were analyzed (likewise dissolved methane analysis).

For a general description of investigated sites pH-values of the lakes were analyzed. Vegetation was mapped within an area of 2 to 3 m² spreading from the surrounding lake area to the shallow edge of the lakes. Samples of mosses and lichens were taken for later characterization (Appendix 3-1). Morphology and position of the lakes were surveyed by a tachymeter device.

3.5.3 Investigation Sites

Samoylov Island, as a representative example for Polygonal Tundra, is covered by a large number of small patterned ground lakes. Based on the polygonal network of ice-wedges, superficial depressions enable the formation of patterned ground lakes, that can be distinguished in polygonal and interpolygonal lakes. The first type is formed within a lowered center of an ice-wedge-polygon. Interpolygonal lakes are formed between the polygons within lowered frost-cracks.

During the Expedition "Lena-Delta – New Siberian Islands 2002" two polygonal (PS1 and PS2) and one interpolygonal lake (IS) were investigated. All three lakes are situated close to each other in the middle of Samoylov Island in an area of degenerated ice-wedge-polygons. PS1 is nearly round shaped, approximately 15 m in diameter and 0.9 to 1.0 m in depth. PS2 is of an elliptical shape with an a-axis of approx. 18 m and a b-axis of approx. 9 m. The depth reaches 0.6 to 0.7 m. The lake IS is of an elongated network structure with a maximum extension of approx. 40 m. The depth exceeds 1.2 m in some parts .

The investigated lakes are characterized by some remarkable differences. The lake area of PS2 is densely covered by *Arctophila fulva* grass, whereas this is completely absent within PS1 and IS. Lake IS showed large ground ice bodies (ice wedge?). The upper lake sediments of PS1 and PS2, however, were unfrozen during the field work.

3.5.4 Preliminary results and discussion

Methane emission rates within the vegetated edge of investigated lakes show mean values of 58.6 ± 12.5 mg m^{-2} d^{-1} for PS1, 41.7 ± 13.6 mg m^{-2} d^{-1} for PS2 and 34.2 ± 8.0 mg m^{-2} d^{-1} for IS. The maximum rate of 88.7 ± 0.8 % mg CH_4 m^{-2} d^{-1} was measured on 14th of August for PS1. The minimum rate of 13.7 ± 5.0 % mg CH_4 m^{-2} d^{-1} was measured on 31st of July for PS2 (Figure 3-34).

Relatively high rates are caused by mainly plant mediated methane emissions. The amount of emitted methane depends on composition and density of vegetation cover. Plant mediated methane emissions could be proven for *Arctophila fulva* (Figure 3-34). and *Carex aquatilis* (not depicted) as dominant species within the vegetated edges of the lakes. Additionally, sediment temperature shows a distinct influence of emission strength. In case of PS1 the temperature (5 cm depth) correlates significantly (r = 0.80) with the methane emission rate. PS2 and IS show less dependency on sediment temperature, but a weak seasonal trend of the emission strength.

The distinct variability of emission rates from vegetated edges of the lakes is assumed to be mainly caused by the continuous change in air temperature and its feedback in microbial activity as well as plant mediation. The higher emission rates of PS1 may be caused by the density and composition of vegetation (see investigation sites) at the measuring field which acts positive on nutrient cycles and methane formation.

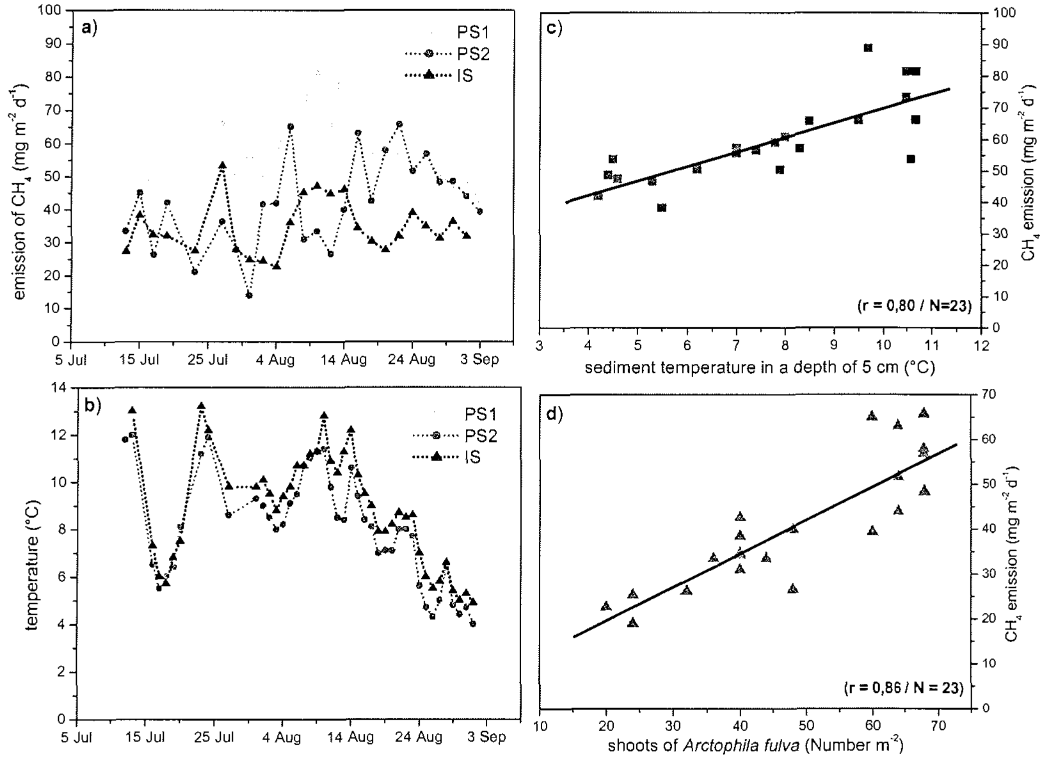

Figure 3-34. Preliminary results of methane flux measurements from vegetated edges of the lakes. (a – methane emission rates; b – sediment temperature in depth of 5 cm; c – temperature dependence of methane emission (PS1); d – plant mediated methane emission by *Arctophila fulva* (PS2))

Methane emission rates from water surface by diffusion show mean values of 1.9 ± 1.1 mg m-2 d-1 for PS1, 3.0 ± 1.6 mg m-2 d-1 for PS2 and 2.2 ± 2.0 mg m-2 d-1 for IS. The maximum and minimum rate were measured for lake IS on 16th of July with 9.9 ± 5.0 % mg m-2 d-1 and on 21st of August with 0.51 ± 1.3 % mg m-2 d-1, respectively. Lake IS shows highest diffusion rates during July whereas PS1 and PS2 increase their diffusion rates at the end of August (Figure 3-35). In case of lake IS the ground ice body is the methane source. Thus, highest emission rates occur in spring time when methane enriched ice from the freezing period of the previous year is melting. Similar effects were already discussed by Phelps (1998) and Michmerhuizen & Striegl (1996). Diffused methane concerning PS1 and PS2 was currently produced by methanogens within the lake sediment. Thus, highest emission rates occur at the summer and early autumn when microbial activity reaches its maximum.

The diffusion behavior towards the atmosphere shows repeating impulses with emission rates up to 7 times of the mean value (Figure 3-35). Following processes are considered to be causal. Regarding air temperature, higher rates occur after rapid temperature decreases (not depicted). Subsequently the vertical water temperature becomes more homogenous and bottom water enriched with dissolved methane (Table 3-16) can be moved easier to the air-water interface by mass transport. Additionally, diffusion at the air-water interface is intensified during a low gradient between water and air temperature.

Methane emission rates from water surface by ebullition show most distinct differences between the lakes. With mean values of 11.7 ± 8.1 mg m^{-2} d^{-1} only lake PS2 can be considered as important for methane emissions by ebullition. The maximum and minimum rate were measured on 23rd of August with 30.24 ± 0.3 % mg m^{-2} d^{-1} and on 18th of July with 1.27 ± 5.0 % mg m^{-2} d^{-1}, respectively. Emission rates of lake PS1 and IS were continuously lower than 1 mg m^{-2} d^{-1}. In contrast to PS2 diffusion from water surface is the dominant path of emission (Figure 3-35).

Differences of ebullition are caused by the volume and methane content of released bubbles. Mean volume of captured bubbles show 3.8 ± 2.4 ml m^{-2} d^{-1} for PS1, 40.0 ± 20.4 ml m^{-2} d^{-1} for PS2 and 3.1 ± 2.7 ml m^{-2} d^{-1} for lake IS. The methane content, however, seems to be of greater influence. Bubbles released from PS2 show a distinct increase up to 50 % methane towards the end of the season, which remains rather constant. Captured bubbles from PS1 show lower methane contents. Only in mid of July and mid of August some higher values up to 19 % were reached. Different conditions for methane formation and/or oxidation within the sediment are considered to be responsible for measured differences. Bubbles from lake IS show lowest methane contents. The bubble release is considered to work similar to the diffusion where melting ice regulates the emission (Figure 3-35).

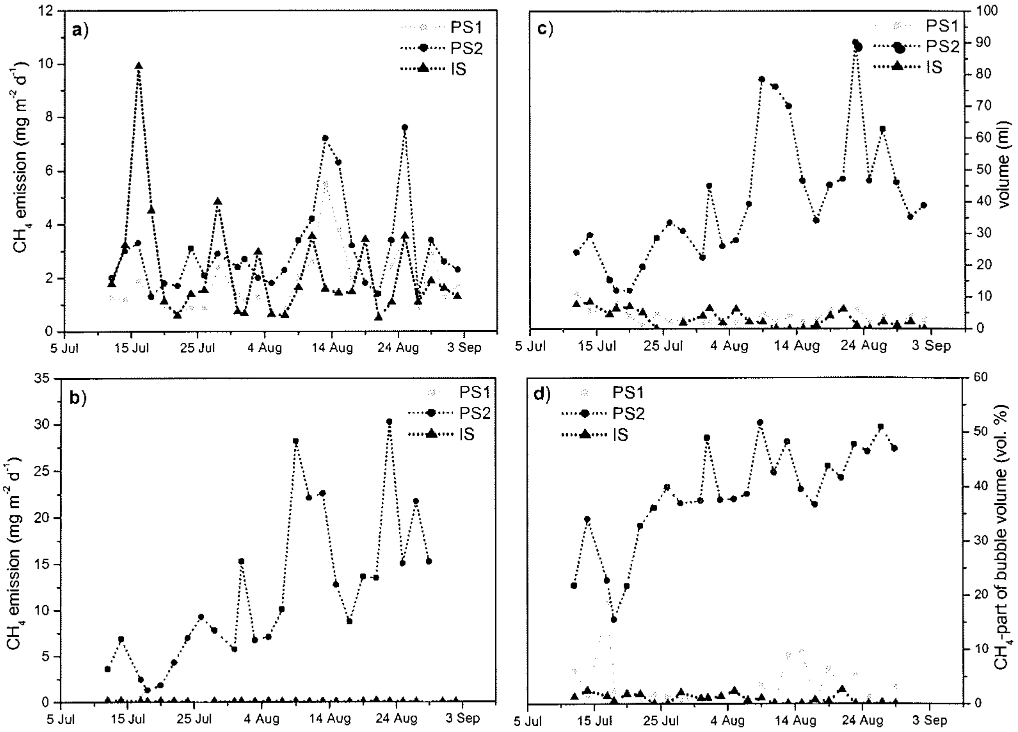

Figure 3-35. Preliminary results of diffusion and ebullition flux measurements from water surface. (a – methane emissions by diffusion; b – methane emissions by ebullition; c – volume of released gas bubbles; d – methane concentration of released gas bubbles).

Table 3-16. Dissolved methane in lake water.

Date of sampling	*surface water (µmol/L)*			*bottom water (µmol/L)*		
	PS1	**PS2**	**IS**	**PS1**	**PS2**	**IS**
14. Jul. 2002	0,40	0,98	1,17	0,48	41,09	33,05
24. Jul. 2002	0,34	1,56	1.08	0.38	3,09	32,68
3. Aug. 2002	0,97	1.26	3.97	1.10	0.87	1,48
19. Aug. 2002	1,49	1,50	1.12	1,34	1.99	3,01
31. Aug. 2002	1,45	2,51	2,02	1.83	2.38	2,81

In general, methane emissions from vegetated edges of patterned ground lakes occur similar to methane emissions from wet polygons as described by Pfeiffer et al. (1999; 2000) and Wagner et al. (2001). Emission by plant mediation acts as the most efficient path for methane gas release into the atmosphere. Thus, vegetated edges of lakes are most important methane sources within investigated lakes. Regarding the efficiency, diffusion as well as ebullition only serve as ancillary paths of methane release towards the atmosphere. Only in few cases methane emission rates reach values of plant mediated emissions. However, considering the spatial distribution of lake areas unbiased by plant mediation the importance of diffusion and ebullition should be assumed to be higher.