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Numerical study of water-atmosphere gas exchange for a boreal lake

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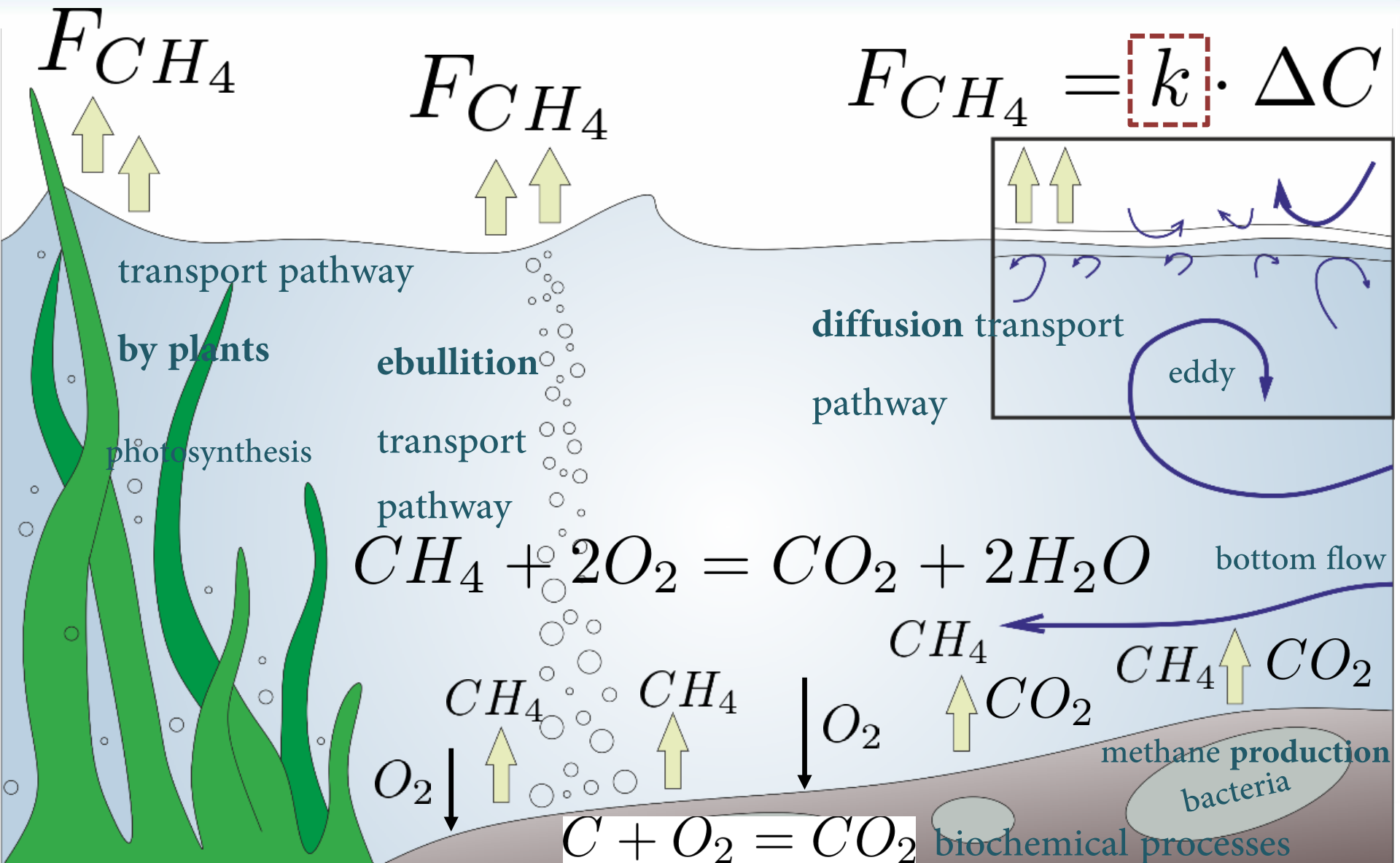
CITES - 2015

Objectives and the study site

- ✓ identification of the key factors influencing the rate of the flux and the concentration of greenhouse gases in a water and surface of lake
- ✓ object - small (S = 9000 m^2), shallow (to 2.6 m) probably thermokarst lake in place, called Seida (Komi Republic ≈ 70 km from Vorkuta)
- ✓ observation data was provided by University of Eastern Finland (*Lind, 2009*)
- ✓ the main research tool – one-dimensional lake model LAKE (*Stepanenko et al., 2011*) with biochemical part for methane emission calculation

Physical and biochemical processes in the lake body and at the surface



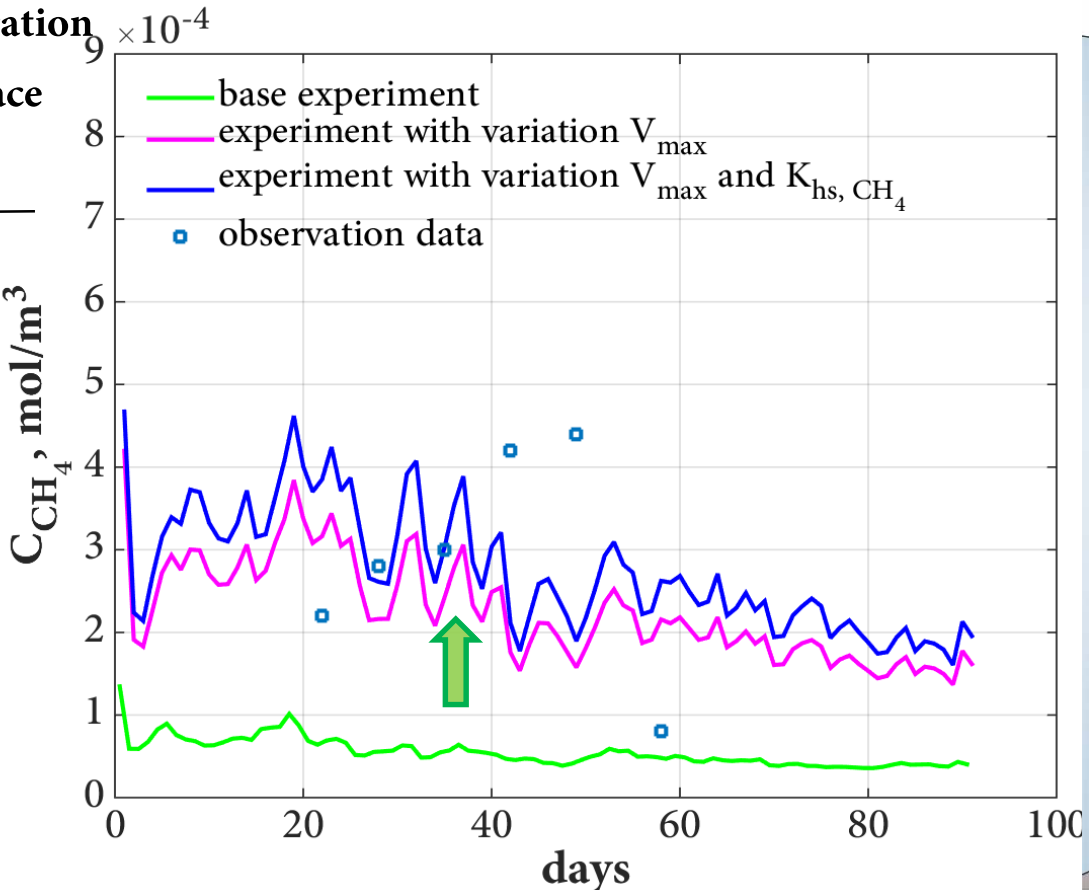
Aerobic methane oxidation (MO)

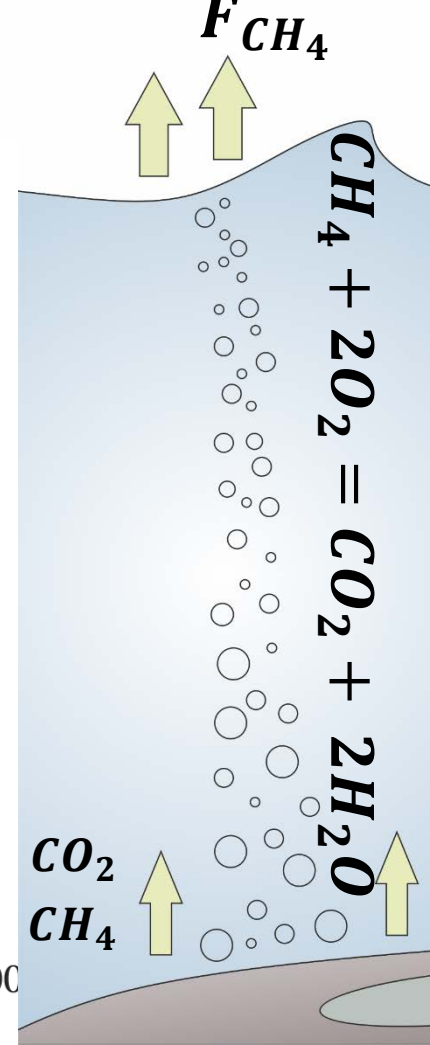
- ✓ variation of potential MO V_{max}
- ✓ variation of half-saturation constant k_{hs,CH_4}

$$O_{CH_4} = V_{max} \cdot \frac{C_{CH_4}}{k_{hs,CH_4} + C_{CH_4}} \cdot \frac{C_{O_2}}{k_{hs,O_2} + C_{O_2}}$$

(*Michaelis-Menten*)

Daily-average concentration of CH_4 at the lake surface (July-September)





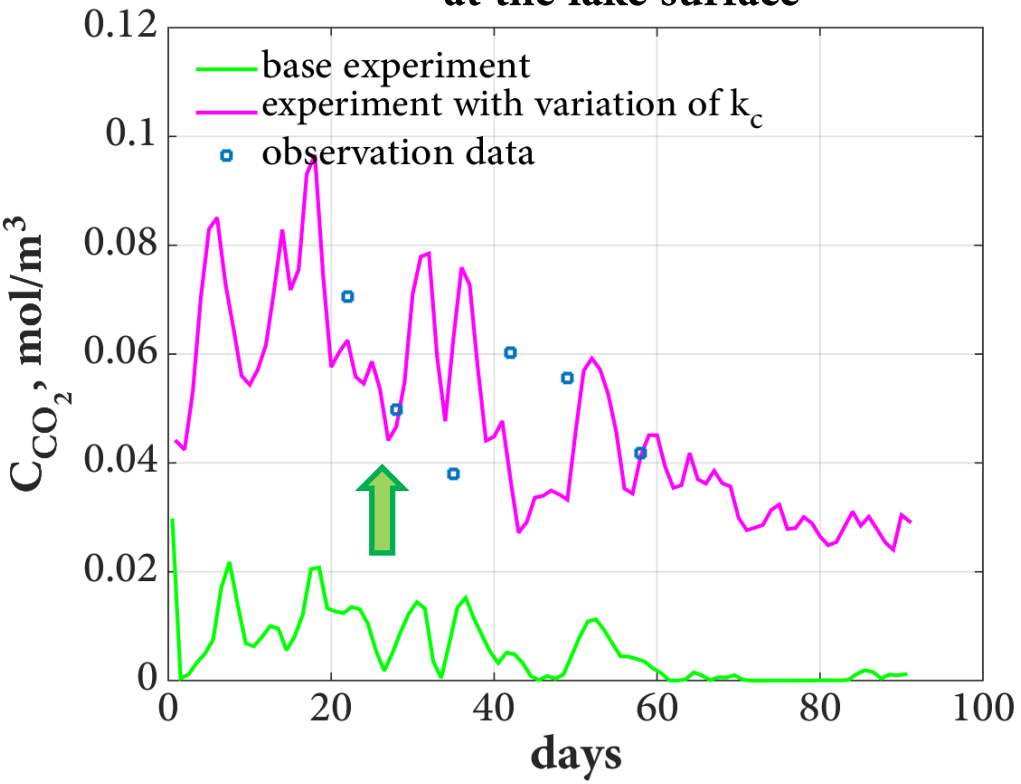
Sedimentary Oxygen Demand

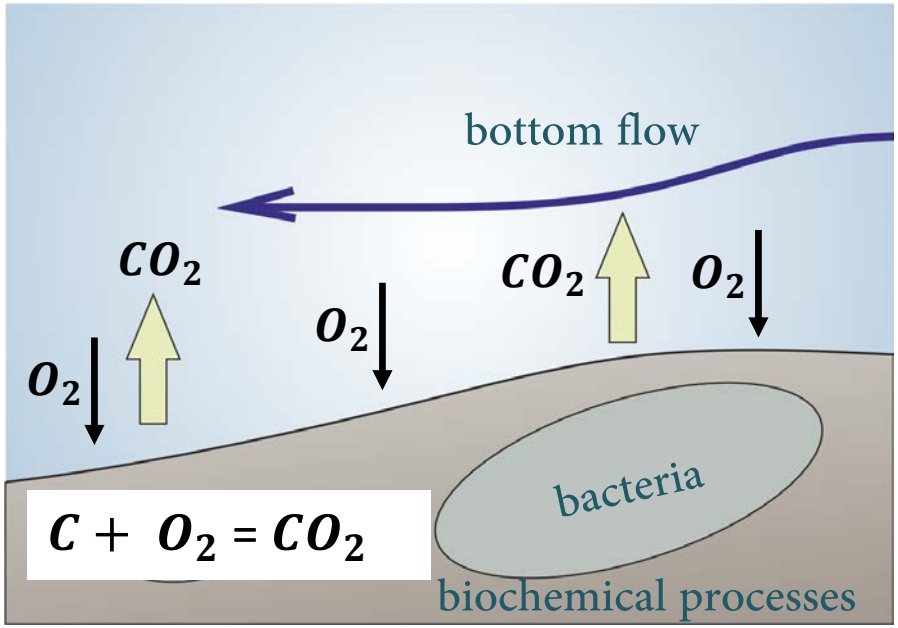
✓ variation of oxygen diffusion constant k_c

$$SOD = \mu_\beta \frac{C_{O_2}}{k_{O_2} + C_{O_2}} + k_c \cdot C_{O_2}$$ (*Walker and Snodgrass, 1986*)

«biological» part ; «chemical» part

Daily-average concentration of CO_2 at the lake surface





Air-water gas exchange parameterizations

✓ **air-water gas transfer velocity, *k*, parameterizations :**

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1) **wind-speed-based empirical parameterization (*Cole and Caraco, 1998* ; *Heiskanen, 2014*) (frequently used for lakes) :** $k = 2.07 + 0.21 \cdot u^{1.7}$

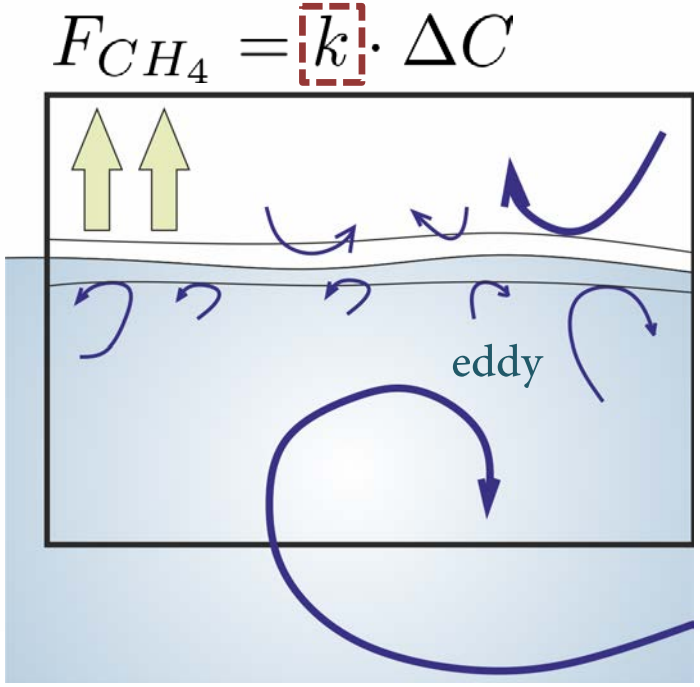
2) **small eddy model (*Lamont and Scott, 1970* ; MacIntyre, 2010) :**

$$k = b \cdot Sc^{-\frac{1}{2}} \cdot (\nu\varepsilon)^{\frac{1}{4}}$$

3) **film model (*Lewis and Whitman, 1970*) :** $k = \frac{D}{\delta}$

4) **solid wall model (*Deacon, 1977*) :**

$$k = 0.082 \cdot Sc^{-\frac{2}{3}} \cdot u_* \cdot \left(\rho_a/\rho_w\right)^{\frac{1}{2}}$$



Model sensitivity to parameters and parameterizations

	(%)
Air exchange parameterizations	84.6
V_{max}	75.9
k_{hs,CH_4}	57.2

$$\Delta\bar{C}^* = \frac{max\bar{C}_i - min\bar{C}_i}{\bar{C}_i} \cdot 100\%$$

$$\frac{|P_{mod} - P_{base}|}{|\bar{C}_i - \bar{C}_1|} = \frac{\Delta\bar{P}}{\Delta\bar{C}}$$ - chosen parameter

$$\Delta\bar{C}_i^* = \frac{\Delta\bar{C}}{\bar{C}_1} \cdot 100\%$$

- significant sensitivity of model to variation of biochemical constants in methane aerobic oxidation
- model demonstrates great sensitivity to application air-gas exchange parameterizations

See you at the poster ..

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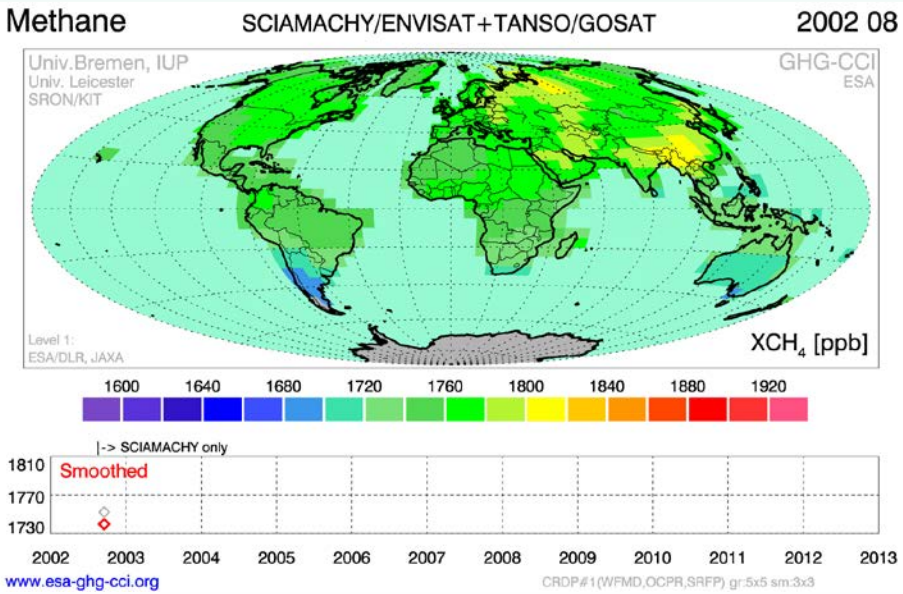
Lakes as source of methane

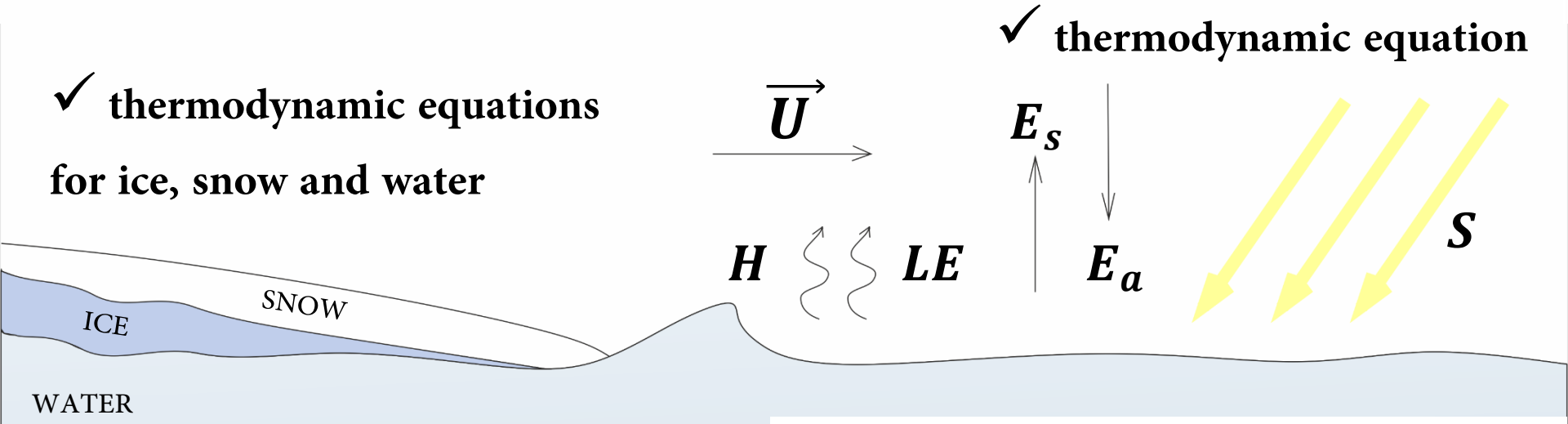
- ✓ CH_4 – one of the most important greenhouse gases, effected on climate system
- ✓ global atmospheric methane concentration from 1978 to 2011 has increased ≈ to 1.5 times



- ✓ emission of CH_4 from lakes by different estimates is 6-16 % from natural biogenic sources (*Travnik et al., 2009*)
- ✓ numerical modeling – one of the main tools to estimate CH_4 fluxes

Lake model LAKE (*Stepanenko, 2011*)

✓ thermodynamic equations for ice, snow and water



✓ thermodynamic equation

✓ hydrodynamic equation

✓ turbulent closure equations $k - \varepsilon$

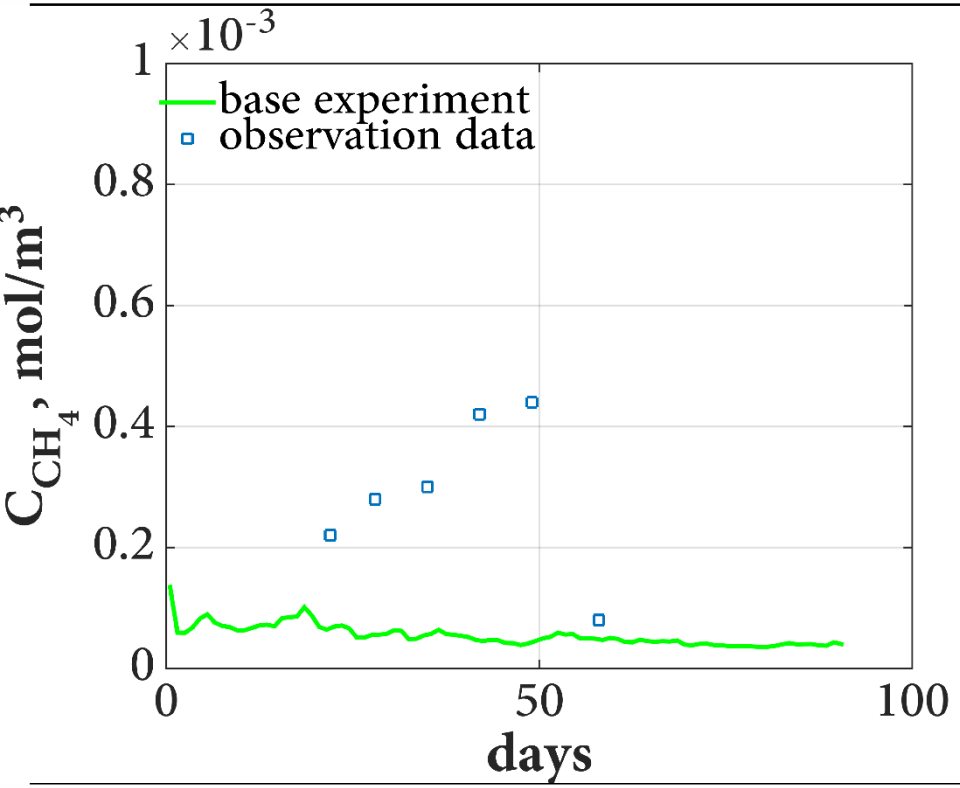
✓ one-dimensional model with boundary conditions at the water surface and at the bottom of the lake

✓ the first model, described all main greenhouse gases dynamics

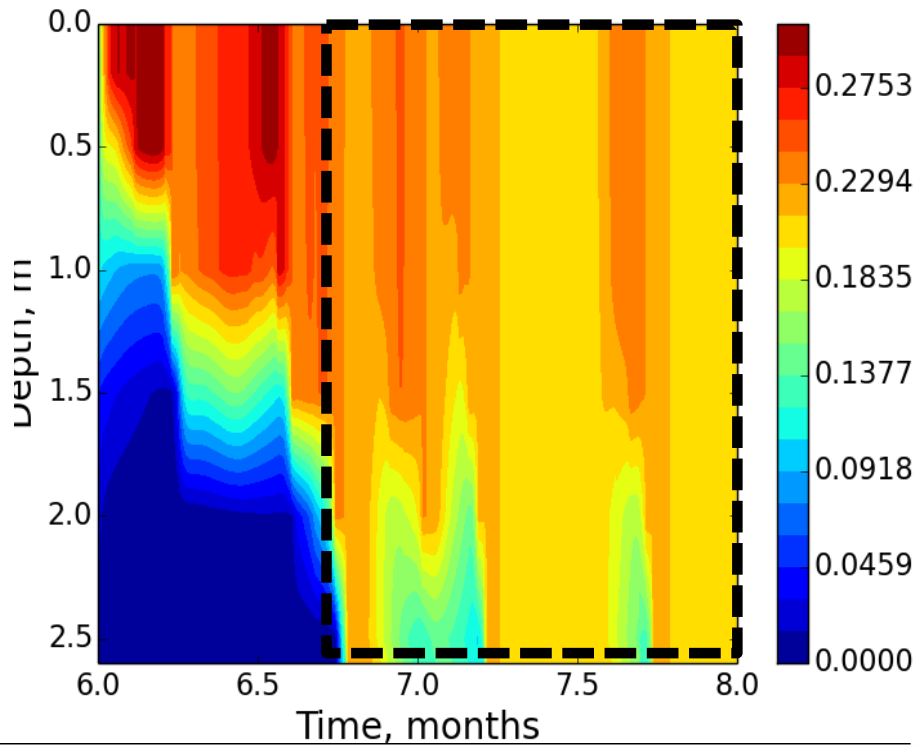
✓ thermodynamics equations for soil

Base model experiment

Daily-average concentration of CH_4 at the lake surface (July-September)



The profile of O_2 concentration (mol/m^3) (July - August)

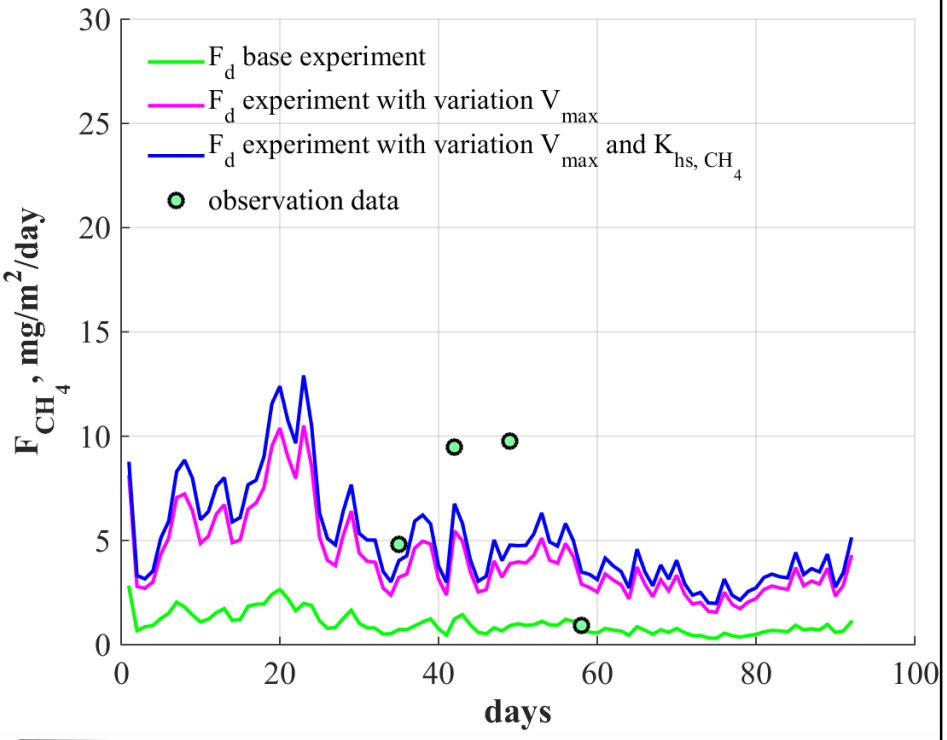


- **CH_4 concentration and diffusion flux are low in one-order in comparison with observation data**

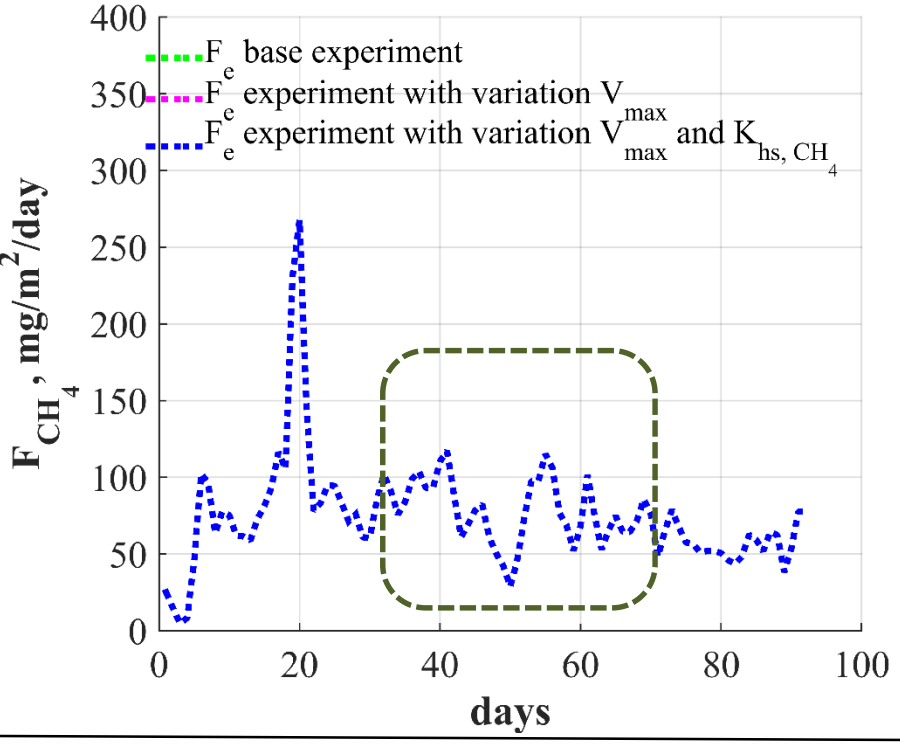
- **hypothesis: influence O_2 on CH_4**

Variation of biochemical CH_4 oxidation constants

Day-average diffusion flux of CH_4 at the lake



Day-average ebullition flux of CH_4 at the lake surface

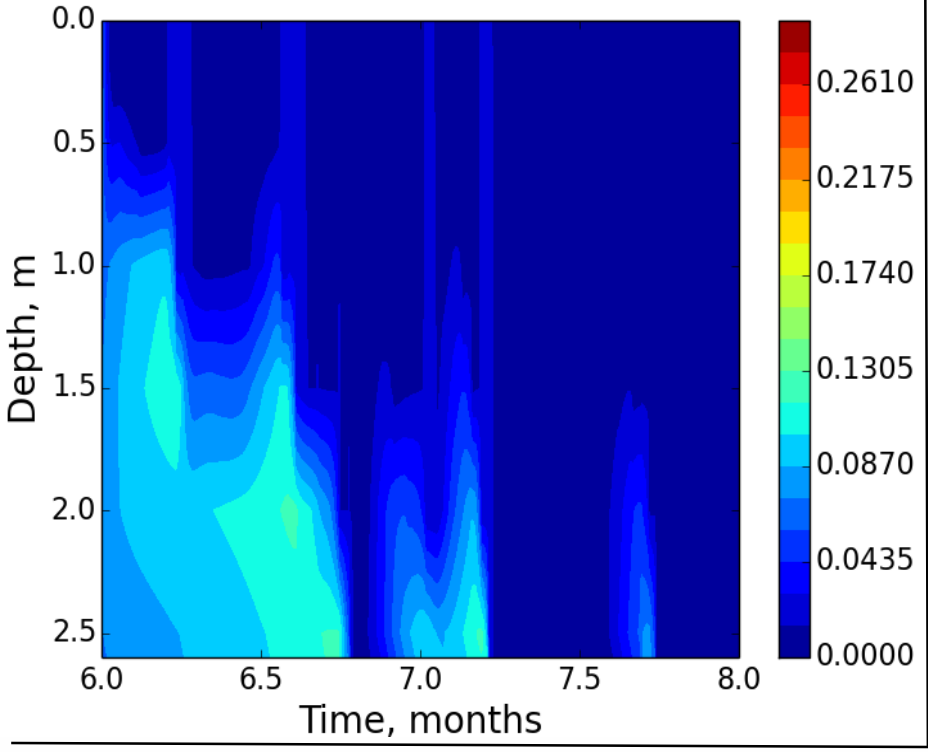


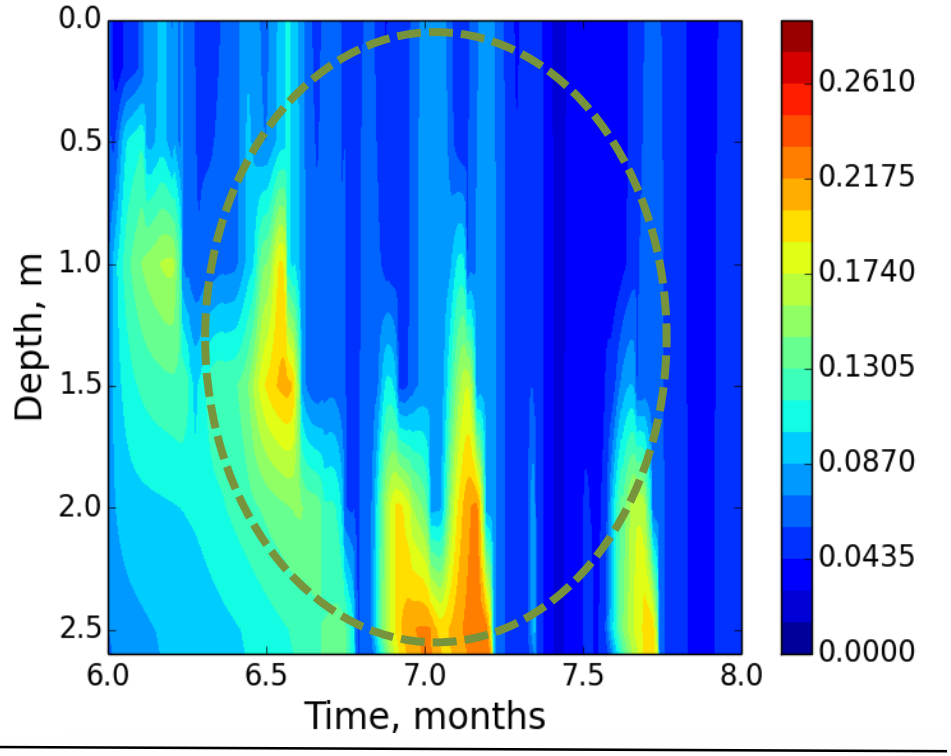
- V_{max} (*Martinez-Cruz et al., 2015*) for non-yedoma lakes in order low base value

- average measured value: 40 mg/m^2/day

Variation O_2 diffusion constant at the lake bottom

Lake's concentration of CO_2 (mol/m^3) profile (July - August)

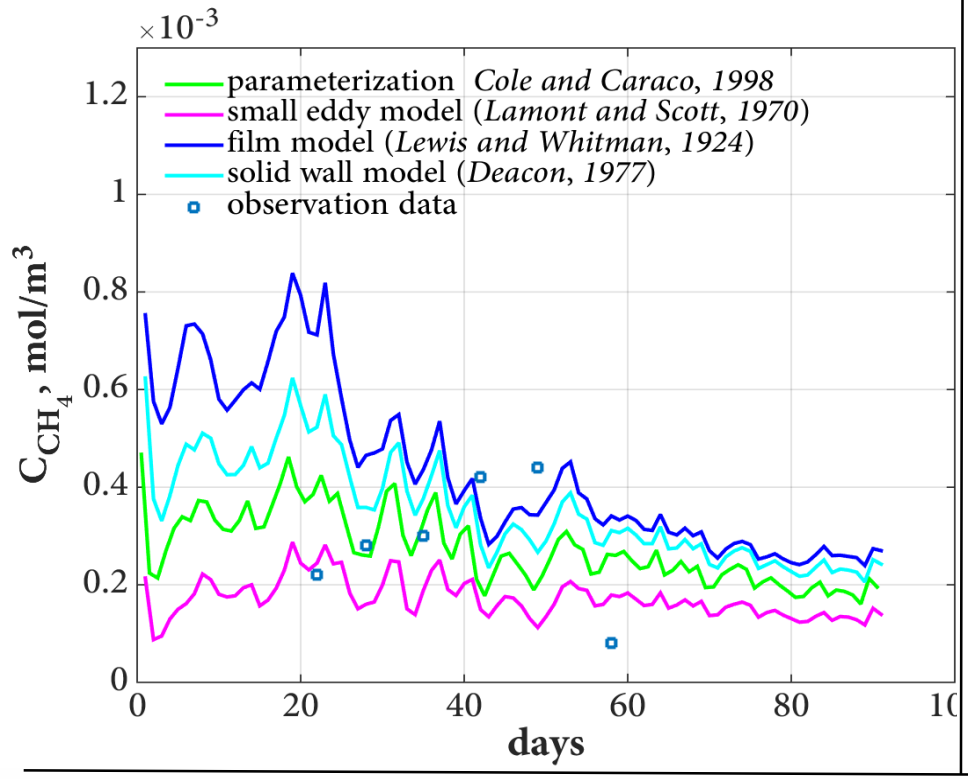




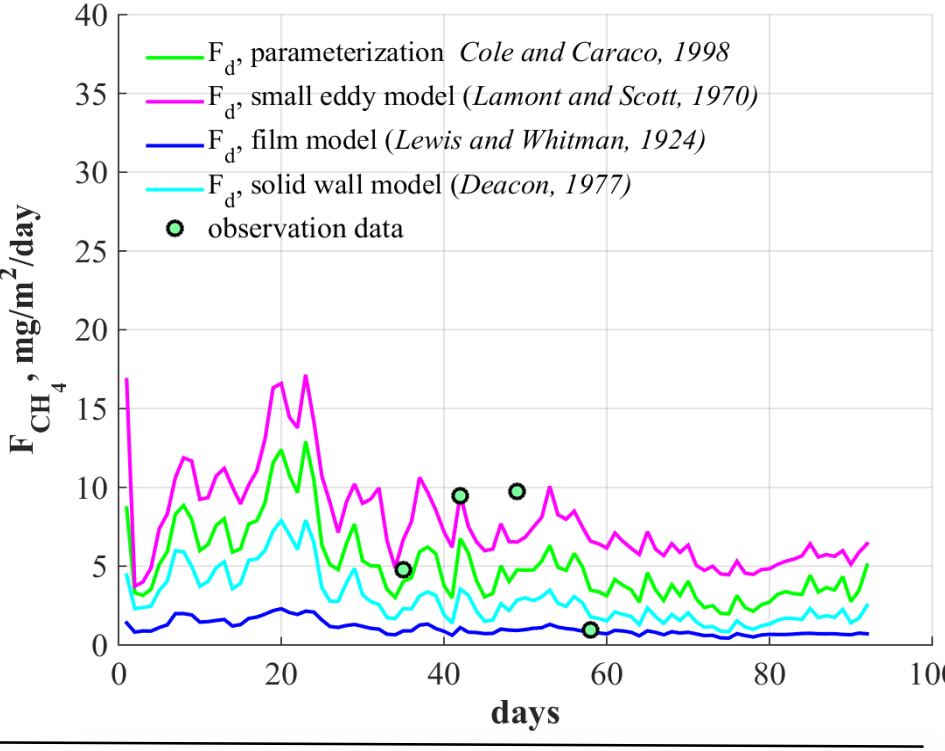
- increasing concentration of CO_2
- distribution CO_2 to upper layers of water

Application of air-water gas exchange parameterizations in LAKE

Daily-average concentration of CH_4 at the lake surface



Daily-average diffusion flux of CH_4 at the lake surface



- great sensitivity of model to appliance of different gas exchange parameterizations
- physically simple models of *k*: film model, solid wall model