In-situ evaluation of the relationship between lake surface turbulence and air-water gas transfer velocity at a small lake in Finland

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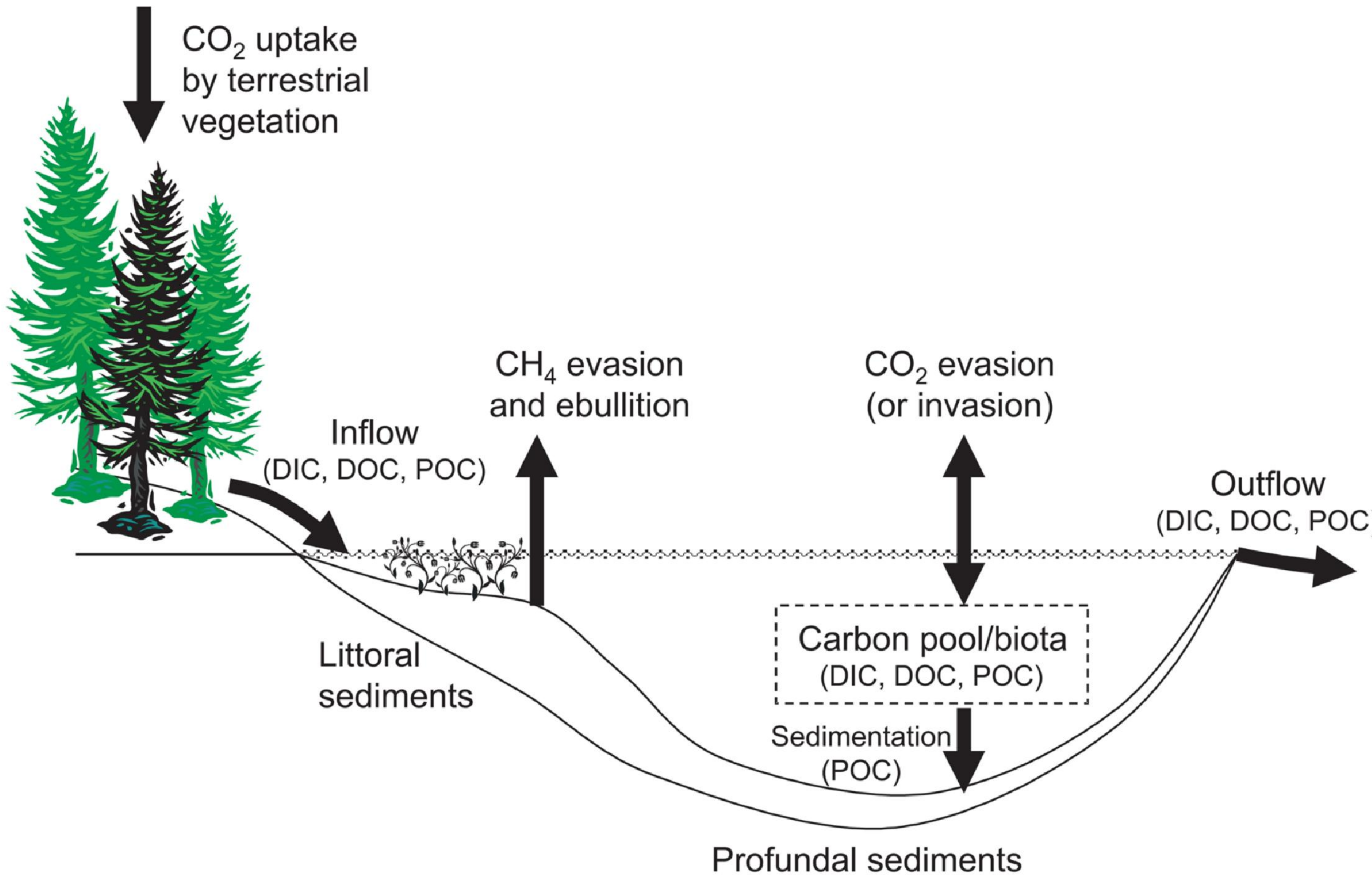
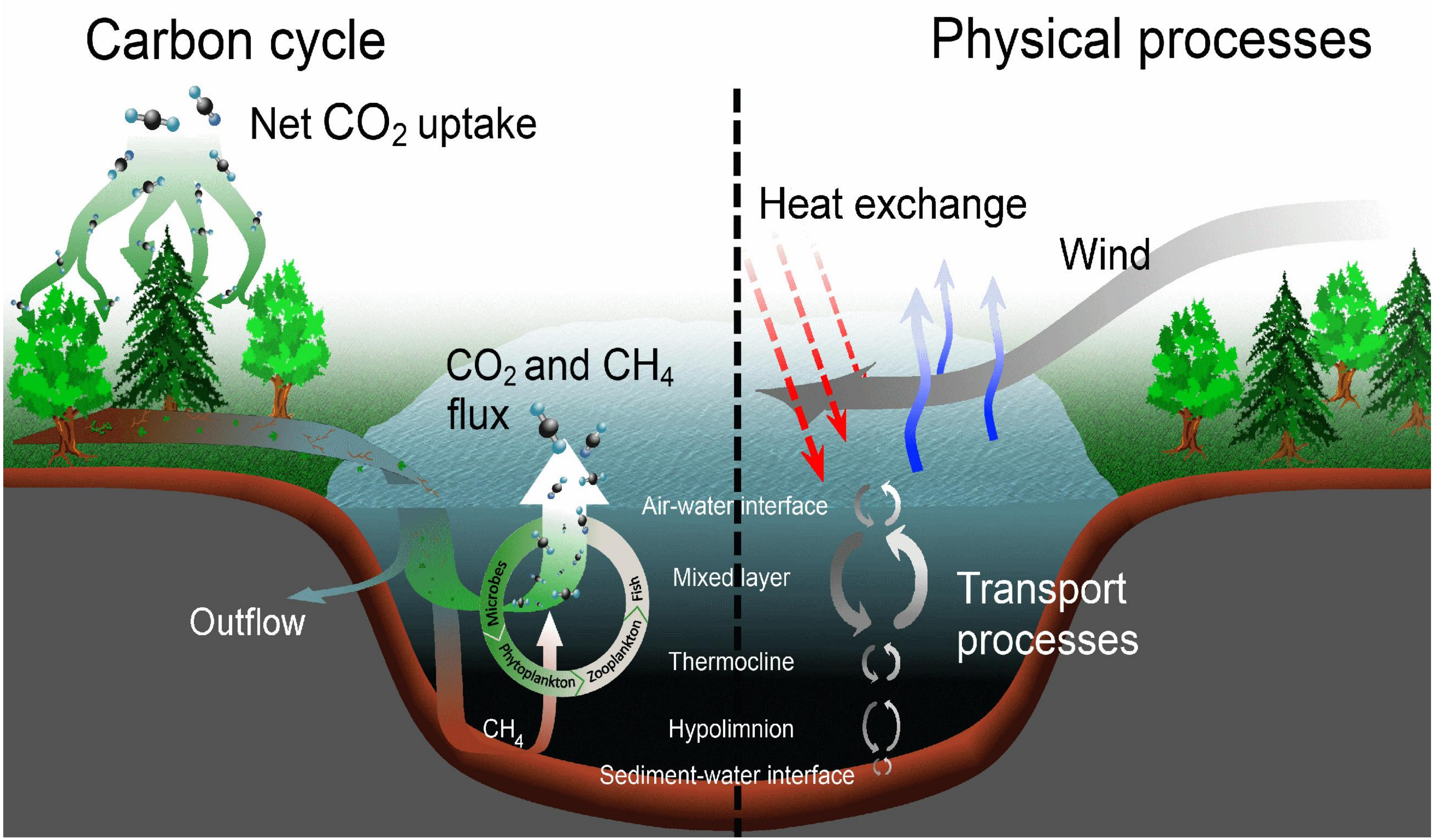
Carbon cycle in inland waters

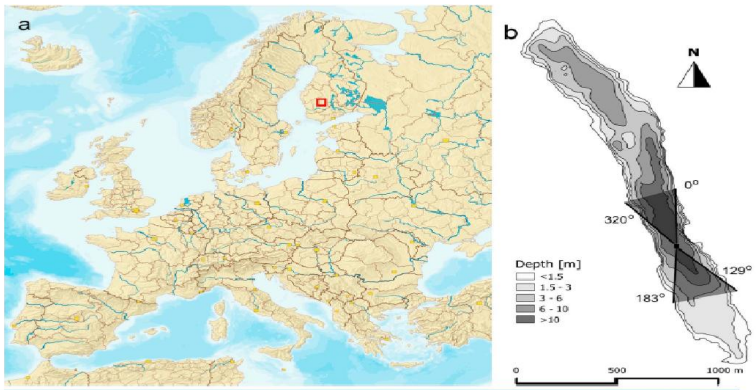


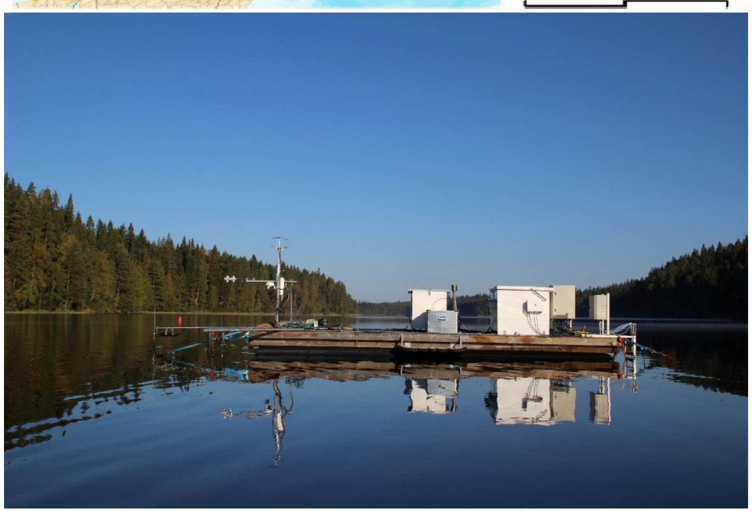
From Benoy et al. 2007

Linking Carbon cycle and Physical processes



Lake-SMEAR (Kuivajärvi, Finland)



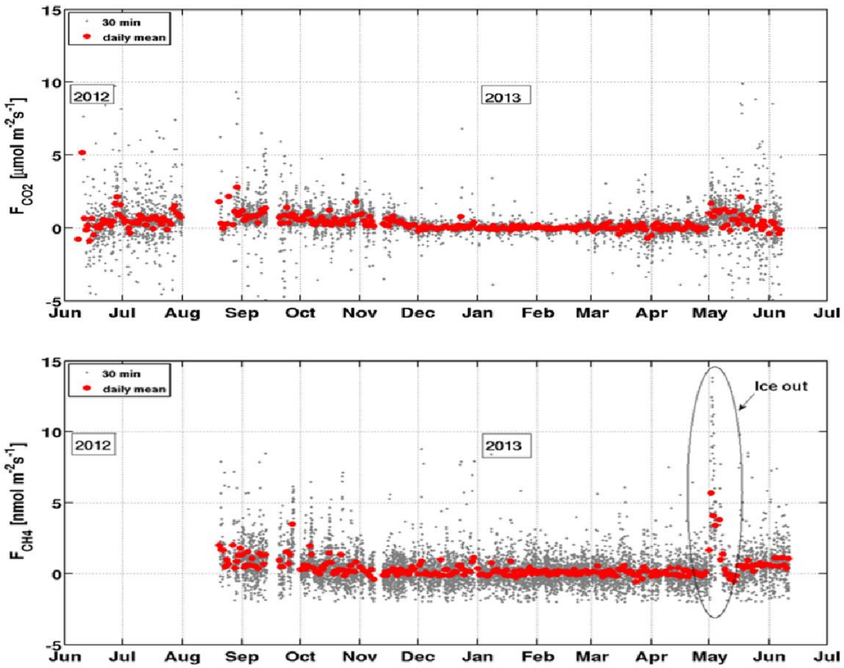


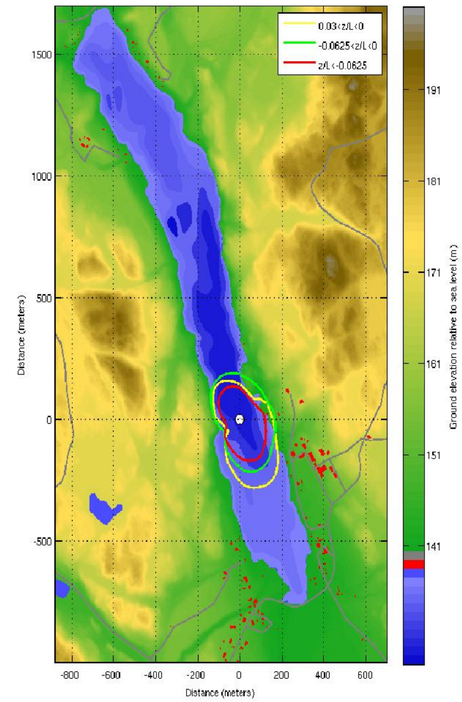
ICOS Ecosystem Associated Station.

Required measurements for a lake super-site:

- Water T at several depths
- Water CO_2 at several depths
- Water PAR at several depths
- Net radiation components
- Air T and RH
- Turbulent fluxes by EC
- Accurate CO_2 concentration in the air

Lake-forest-wetland comparison (CO_2 and CH_4)



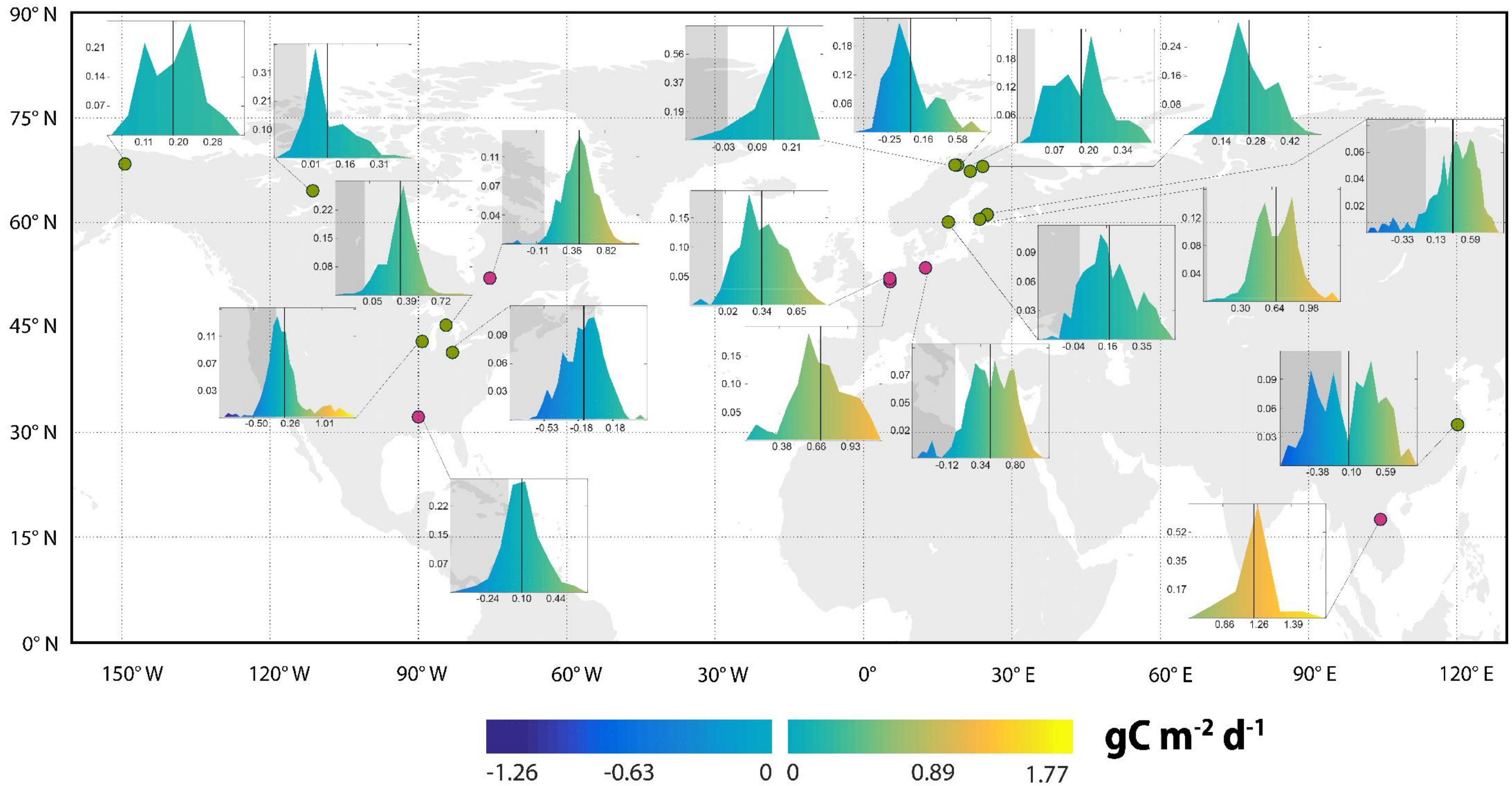


	Kuivajärvi (Lake)	SMEAR II (Scots Pine Forest)	Siikaneva (Wetland)
CO2	+116	-280	-51
CH4	0.2	NA	10

Annual budget (gC m^{-2}) comparison (June 2012–June 2013)

(Mammarella et al., 2015 JGR)

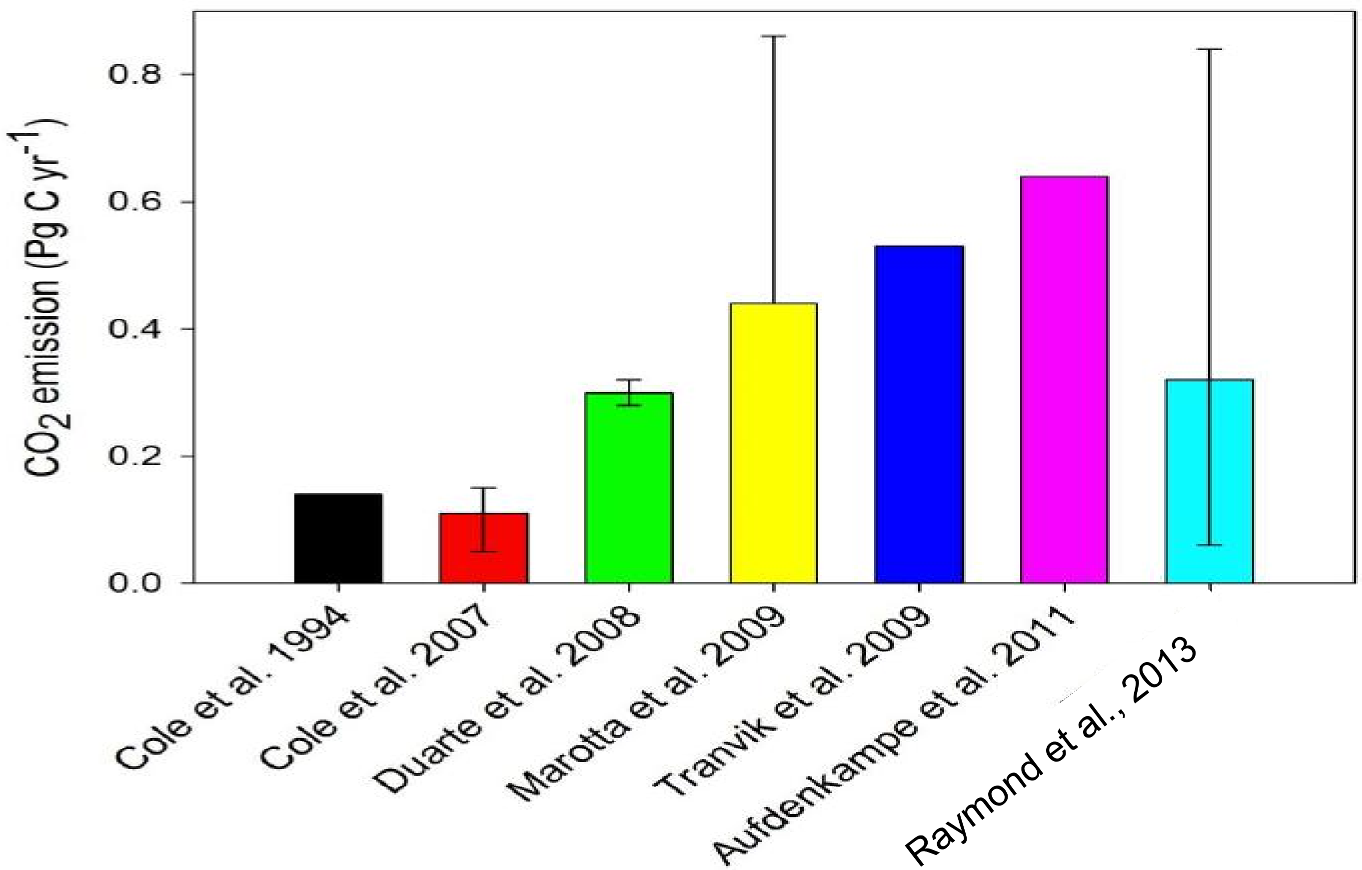
Global synthesis of EC CO_2 fluxes



Temporal patterns of NEE from 20 lakes and reservoirs from six climatic zones.

Golub et al, manuscript

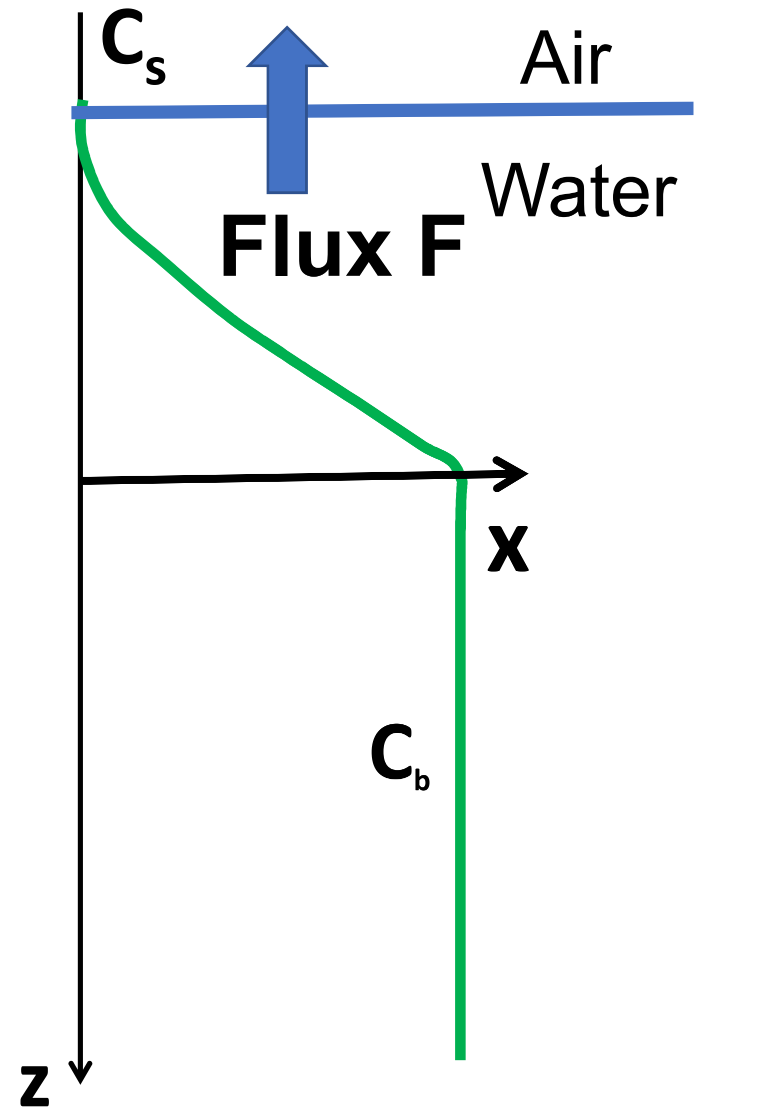
Global CO_2 emission from lakes/reservoirs



Gas transfer velocity at air-water interface

Transfer Velocity

- Flux $F = k \Delta C$;
- Concentration Difference: $\Delta C = C_b - C_s$;
- C_s surface concentration determined from gas phase measurements and Henry's Law (assuming equilibrium)



Models for k

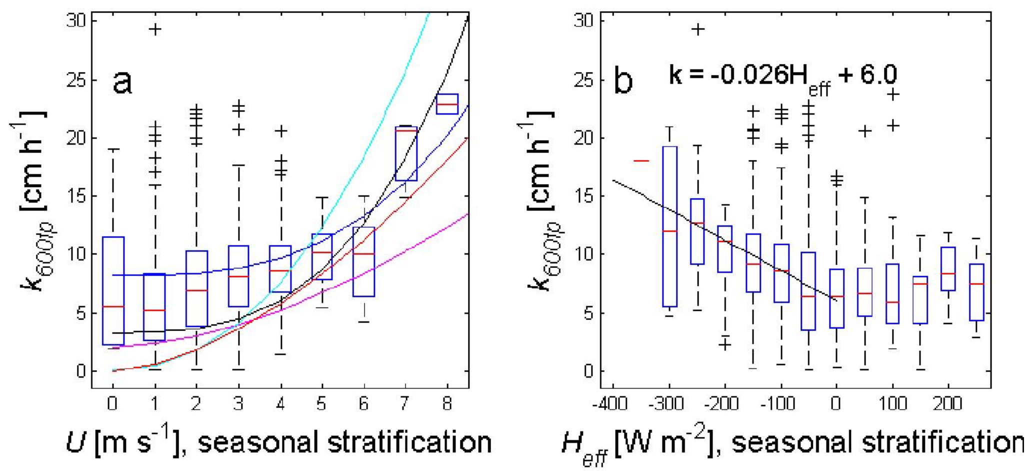
Empirical or semi-empirical models

$$k_{cc} = 2.07 + 0.215 U_{10}^{1.7},$$

Cole and Caraco (1998)

$$k_{HE} = \sqrt{(C_1 U)^2 + (C_2 w_*)^2} Sc^{-\frac{1}{2}},$$

- C_1 and C_2 are empirical constants
- Sc = Schmidt Number
- w_* = convective velocity scale



Heiskanen et al. (2014)

Models for k

Small eddy model
(Lamont and Scott, 1970)

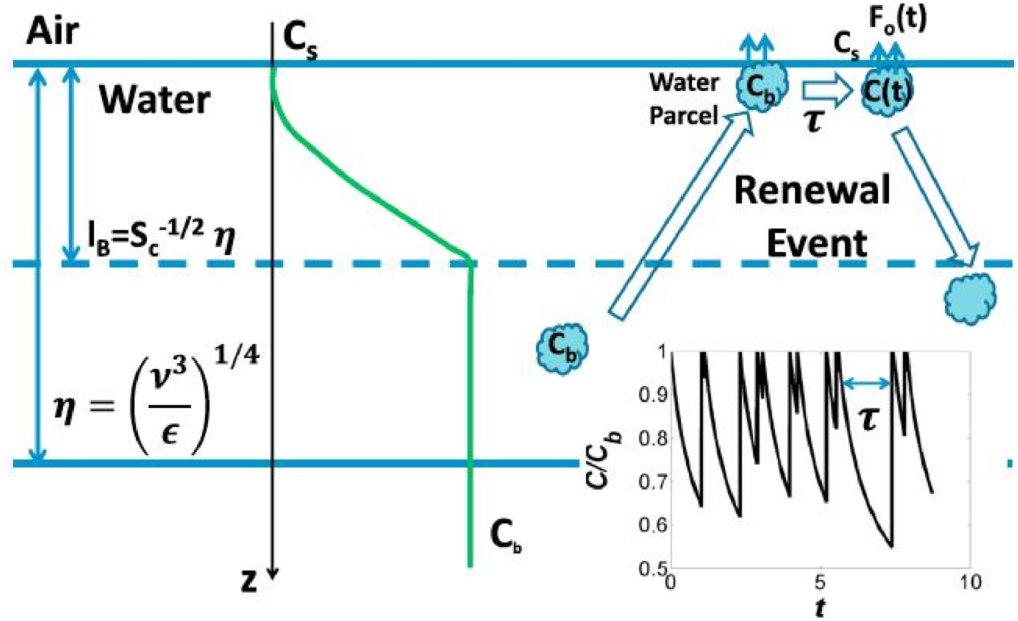
$k = \beta\ (\varepsilon\ \nu)^{0.25}\ Sc^{-n}$

ε = water-side mean turbulent kinetic energy (TKE) dissipation rate

ν = kinematic viscosity of water

β = empirical constant

n = exponent varying between 2/3 and 1/2



Katul and Liu (2017)

Similarity scaling based k model

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2014JC010135

Similarity scaling of turbulence in a temperate lake during fall cooling

Edmund W. Tedford[1,2], Sally MacIntyre[1,3], Scott D. Miller[4], and Matthew J. Czikowsky[4]

Key Points:

Tedford et al. (2014)

$$\varepsilon_{TE} = \begin{cases} \dfrac{c_1 u_{*w}^3}{\kappa z} + c_2|\beta| & \text{if } \beta < 0, \\ \dfrac{c_3 u_{*w}^3}{\kappa z} & \text{if } \beta \geq 0 \end{cases}$$

β = buoyancy flux

u_{*w} = water-side friction velocity

Lake size influences lake-atm interactions

Kuivajärvi

Heat flux influences the gas exchange more in small lakes than in large.

Lakes are typically surrounded by vegetation which reduces the effective fetch.

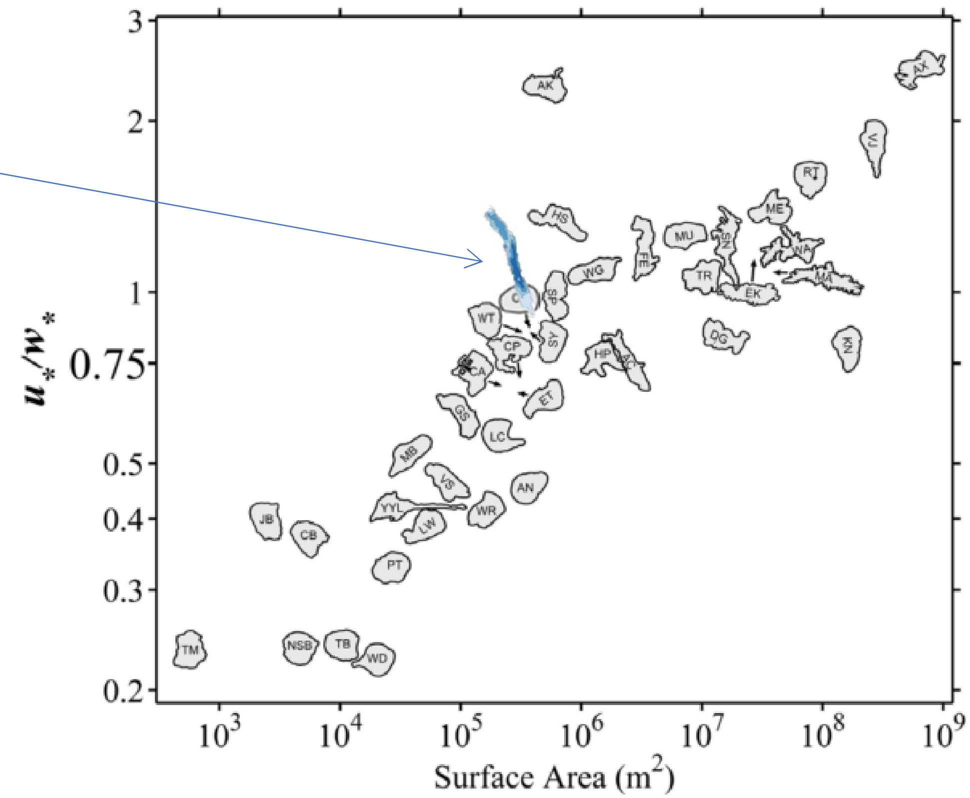
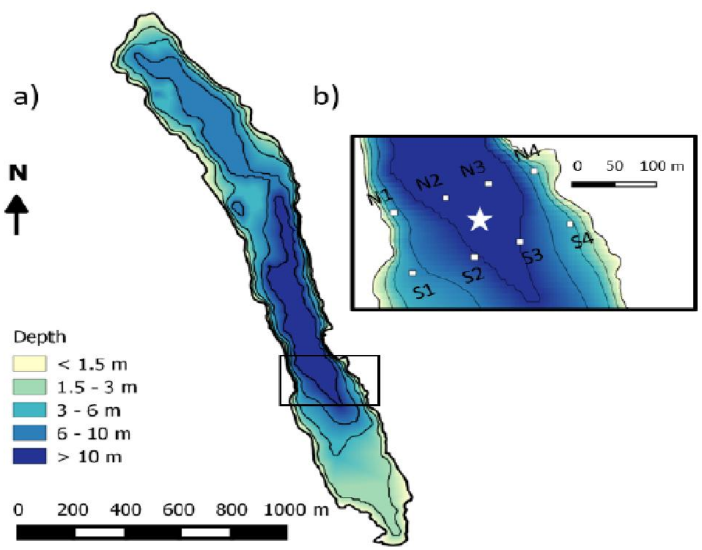


Figure 1. Ratio between the temporally-averaged velocity scales for wind shear (u^*) and convection (w^*), where averages were applied over the entire time series of observations for each lake. Lake shapes were used for plot symbols, and were shifted when overlapping (see tip of arrows).

Read et al. 2012

Lake-SMEAR (Kuivajärvi, Finland)

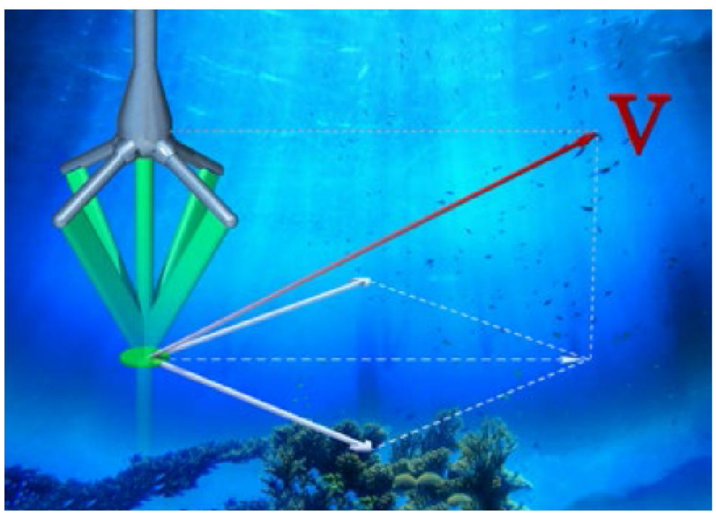


Erkkilä et al., 2017, BGD

Campaign setup (11-27.09.2014)

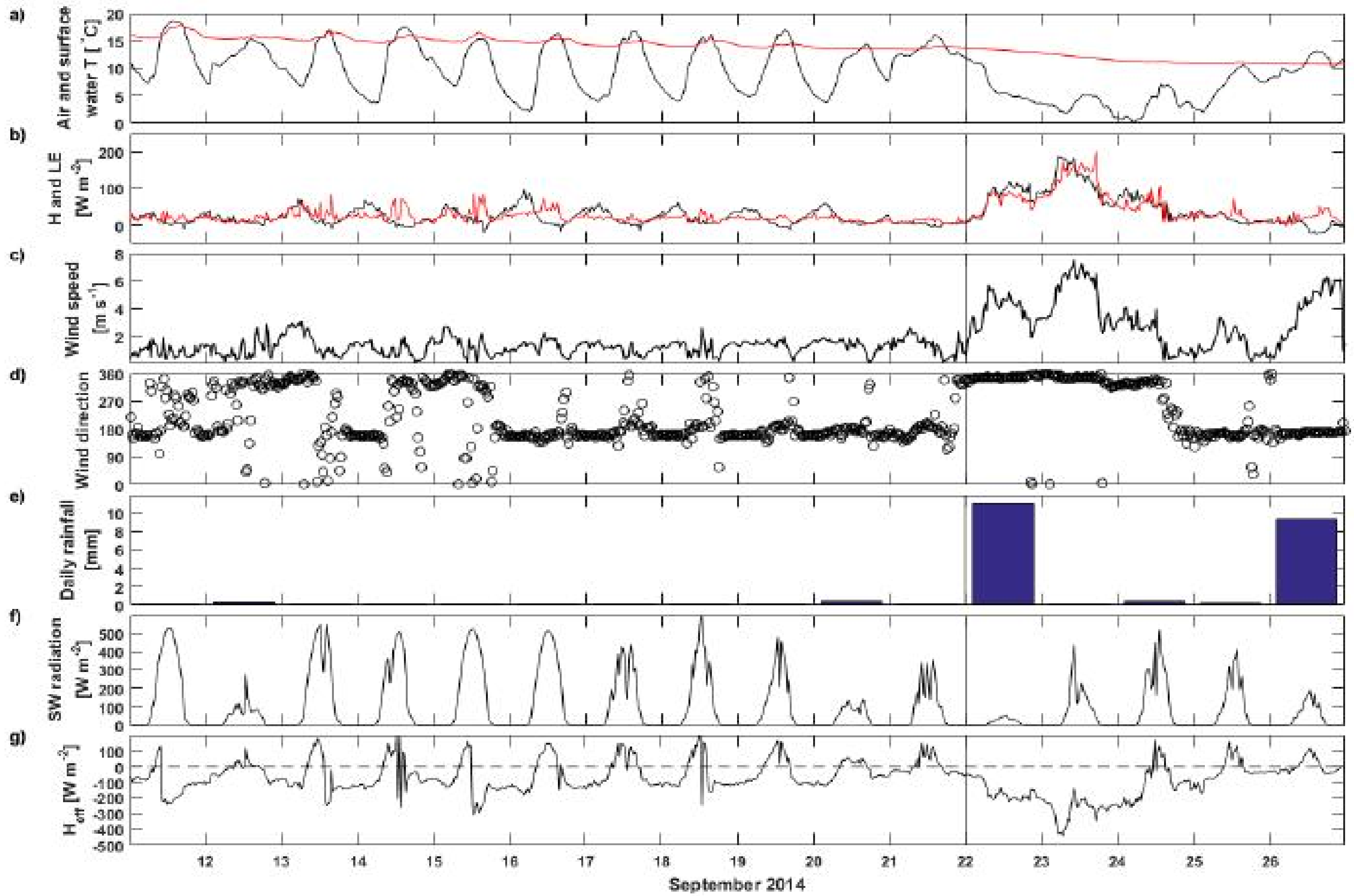
- Water T at several depths
- pCO_2 and pCH_4 at several depths
- Water PAR at several depths
- Net radiation components
- Air T and RH
- EC fluxes (Heat, CO_2, CH_4)
- Floating chamber fluxes
- Water current velocities and turbulence

Water turbulence measurements

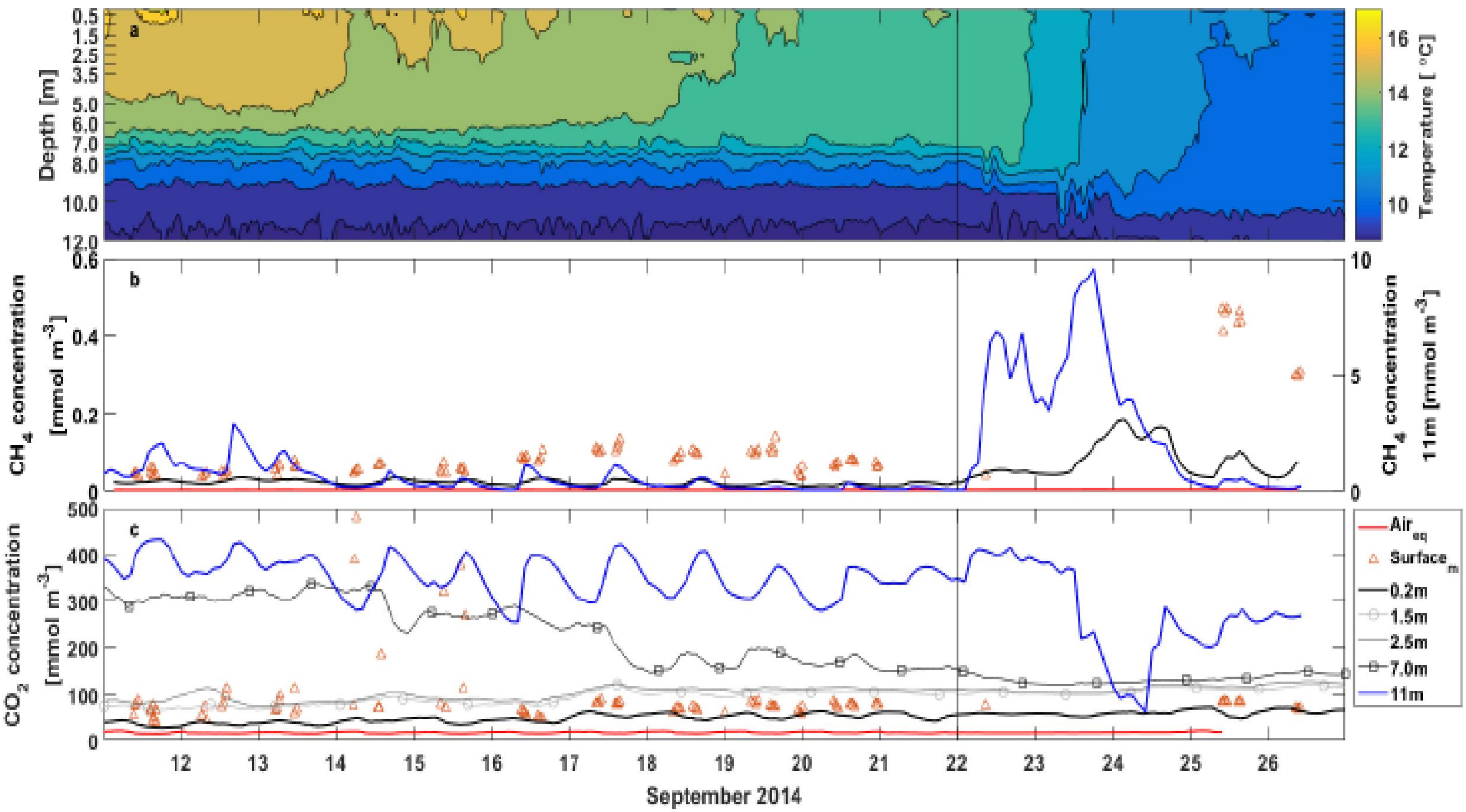


- Acoustic Doppler Velocimeter Field Vectrino from Nortek
- Depth = 20 cm
- Sampling frequency 30 Hz
- Measuring turbulent current velocity fluctuations (u, v, w)

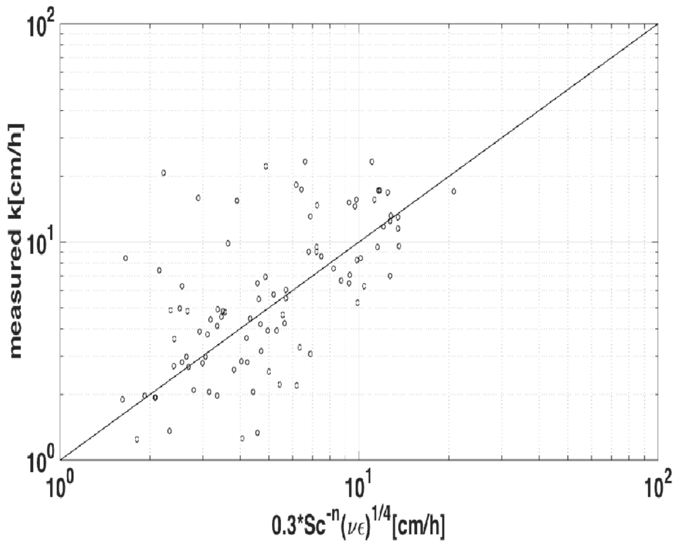
Environmental conditions



Environmental conditions



k comparison campaign in 2014 at Lake-SMEAR

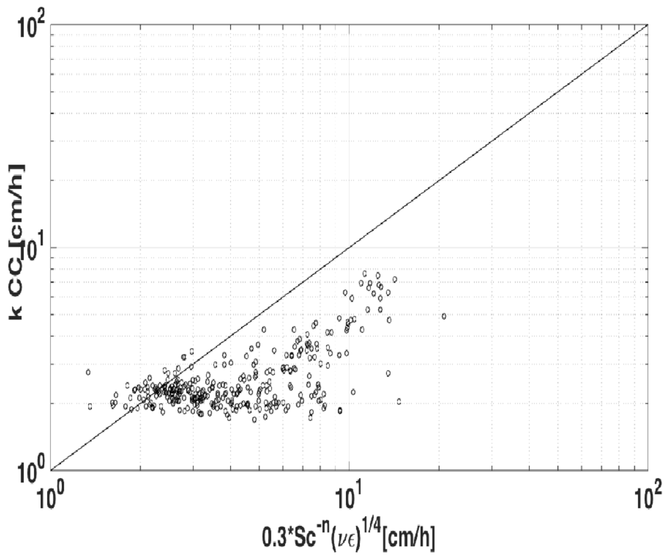


[A]

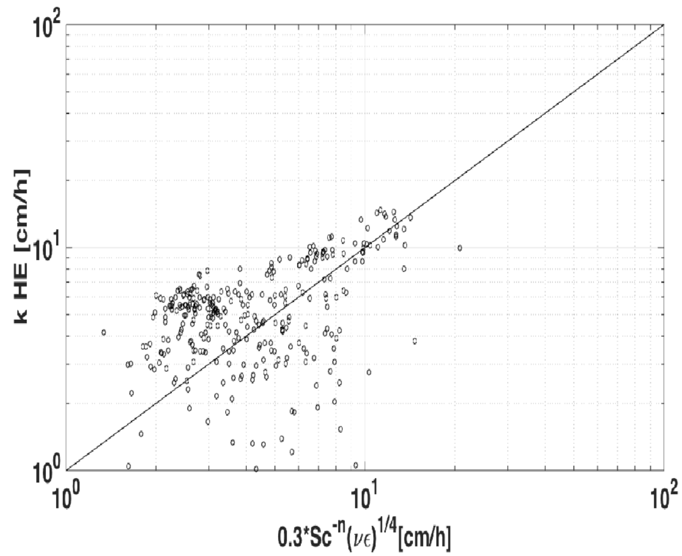
$$k = \beta\ (\varepsilon\ \nu)^{0.25}\ Sc^{-n}$$

versus

- k_m = Flux / (Caq-Ceq) [A]
- $k_{cc} = 2.07 + 0.215 U_{10}^{1.7}$, [B]
- $K_{HE} = \sqrt{(C_1 U)^2 + (C_2 w_*)^2} Sc^{-1/2}$ [C]

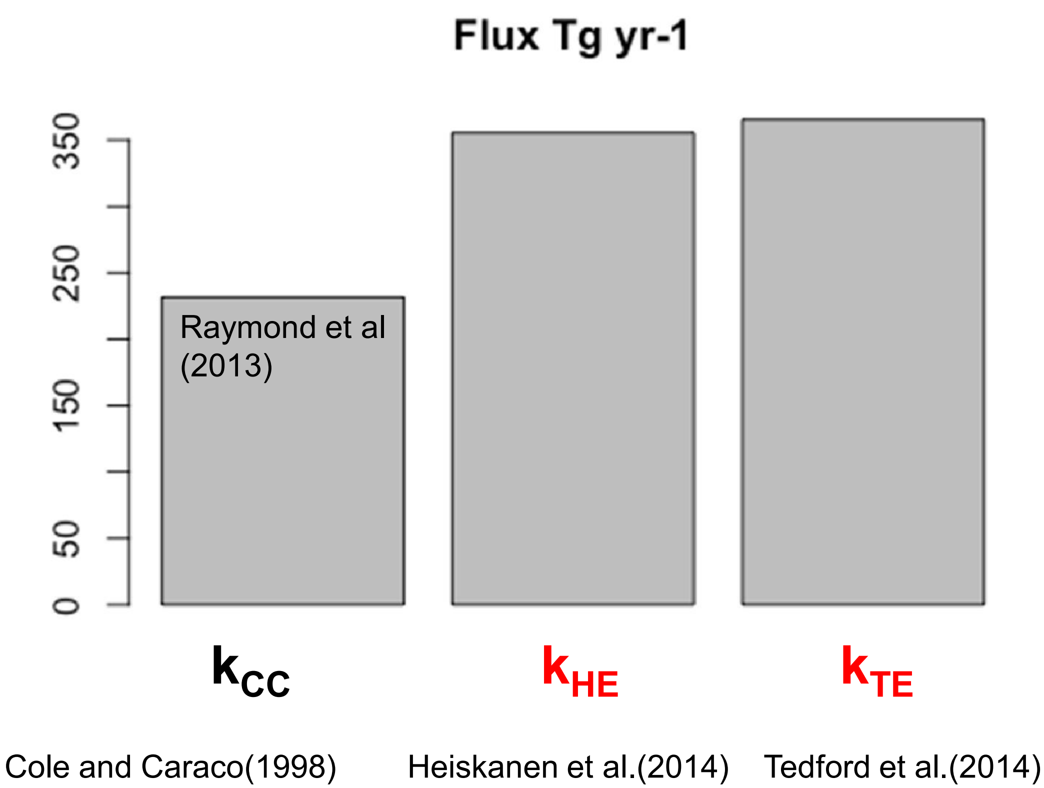


[B]



[C]

New gas transfer velocities and implications for global upscaling of CO_2 fluxes



$$k_{cc} = 2.07 + 0.215 U_{10}^{1.7},$$

$$K_{HE} = \sqrt{(C_1 U)^2 + (C_2 w_*)^2} Sc^{-1/2}$$

$$k_{TE} = C_3 (\varepsilon \nu)^{0.25} Sc^{-1/2}$$

U = wind speed

Sc = Schmidt Number

w_* = convective velocity scale

ε =water-side mean TKE dissipation rate

ν = kinematic viscosity of water

Conclusions and outlook

- Measured k and new k models are in agreement with k obtained from direct water turbulence measurements (via small eddy model).

- New k models have large impact on global upscaled CO2 flux.

- More **flux stations** (Freshwater super-sites, different types of lake across latitudes).

FLUXNET <--> ICOS-RI <-->GLEON<-->DANUBIUS-RI <--> PEEX

- Better methods for integrating aquatic and terrestrial carbon balances (lateral fluxes via coupling catchment model with lake model).

?

- Introduce lacustrine CH_4 and CO_2 dynamics into **land surface scheme** of Earth System Models.

Victor Stepanenko presentation


Thank you
for the
attention!