Benefits and challenges of long-term eddy covariance measurements over lakes

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Countless discussions with

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Anne **Ojala**, University of Helsinki
Maria **Provenzale**, University of Helsinki
Kukka-Maaria **Erkkilä**, University of Helsinki
Miitta **Rantakari,** University of Helsinki
Jouni **Heiskanen**, University of Helsinki

David **Bastviken**, Linnköping University, Sweden
Ankur **Desai,** University of Wisconsin-Madison
Werner **Eugster**, ETHZ, Switzerland
Sally **MacIntyre**, University of California
Anna **Rutgersson,** Uppsala University, Sweden
Victor **Stepanenko,** Moscow State University
Arkady **Terzhevik**, NWPI

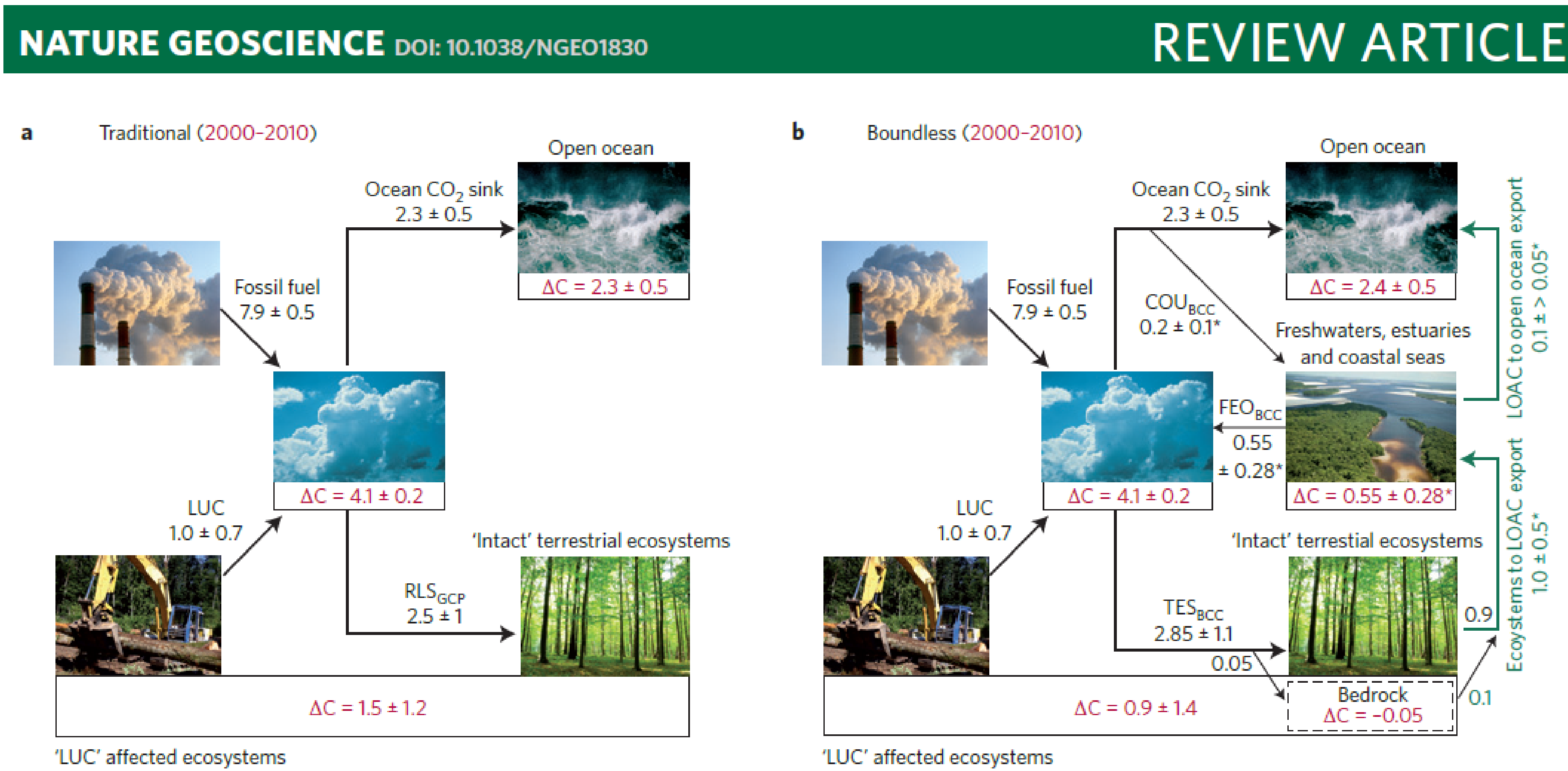
and

Other 80+ workshop participants in Sept. 2014, Hyytiälä, Finland

and

Activities in GHG-LAKE and CarLAC projects.

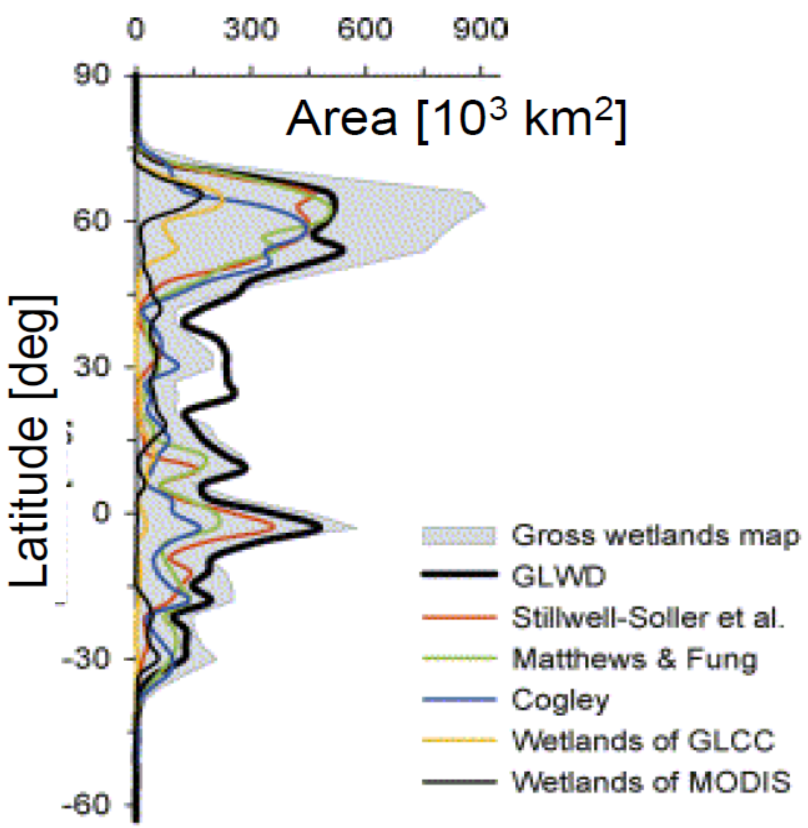
Freshwaters in global carbon cycle



Regnier et al. 2013

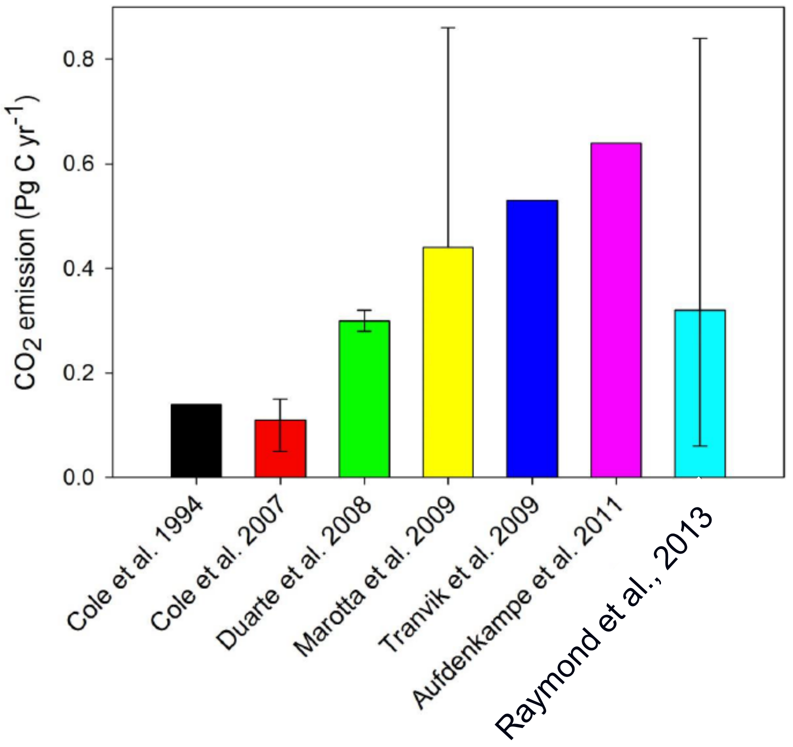
GHG efflux from lakes

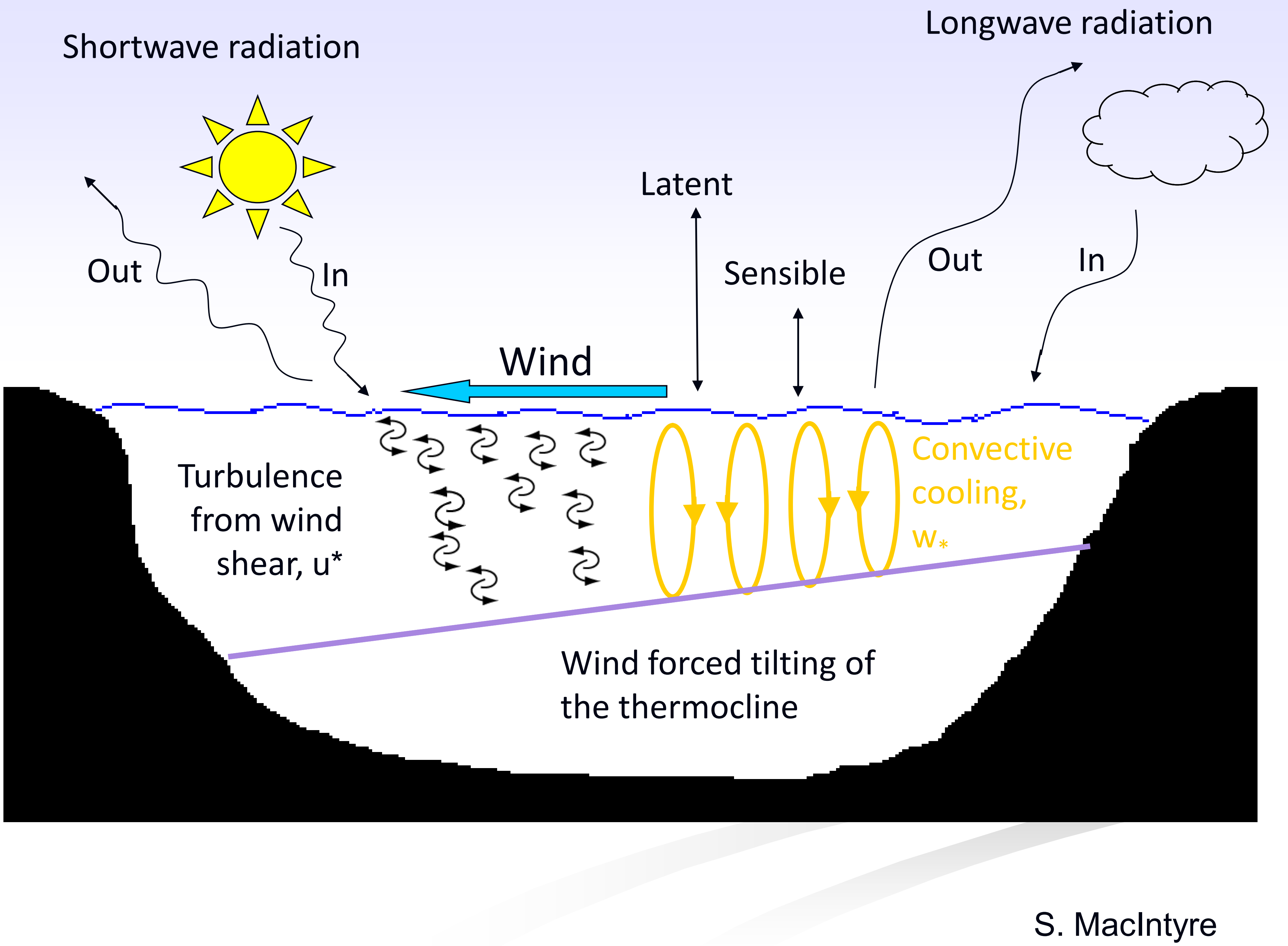
Global distribution of lakes and wetlands



Lehner & Döll (2004) J. Hydrology 296 1-22

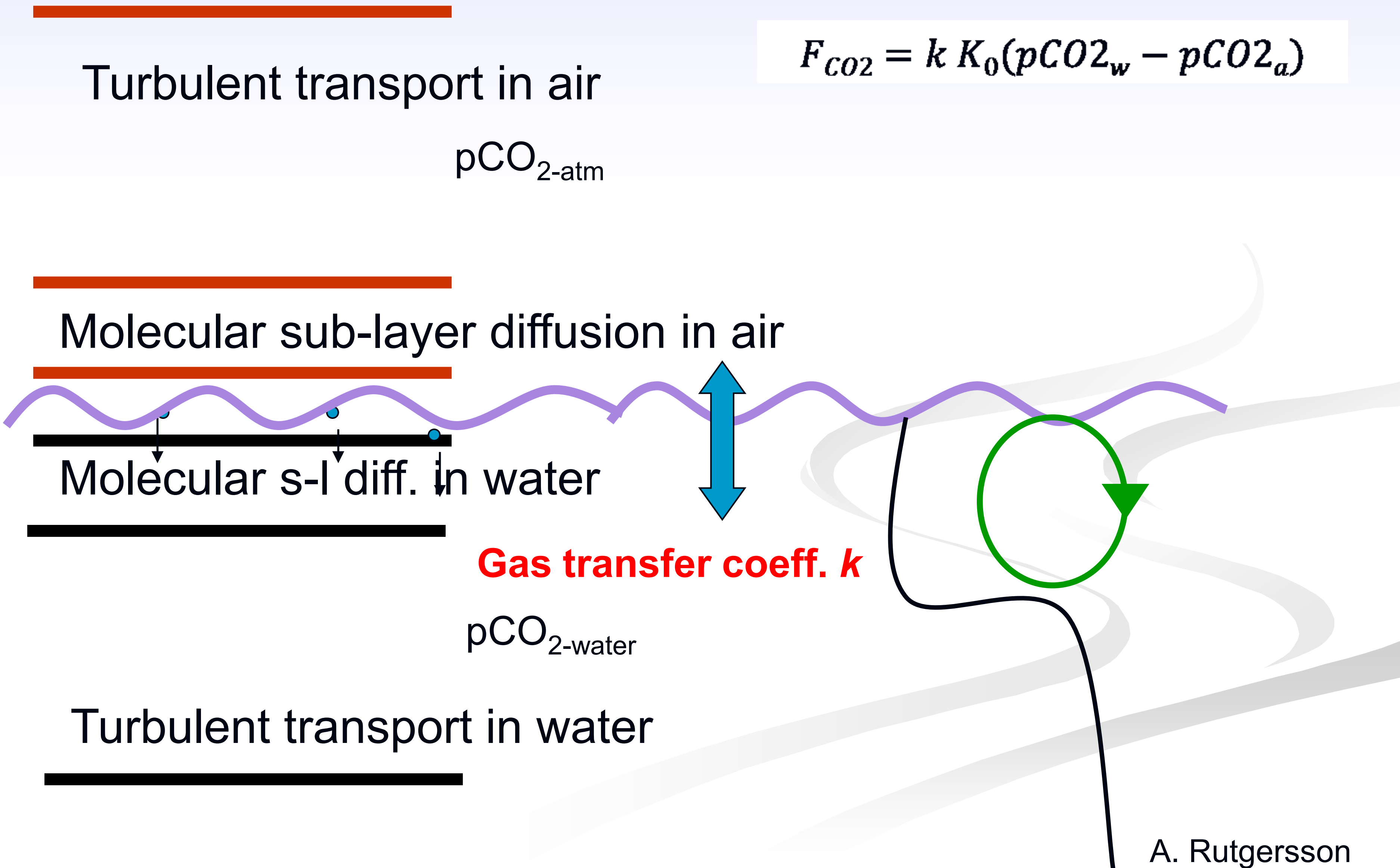
Global CO_2 emission from lakes/reservoirs



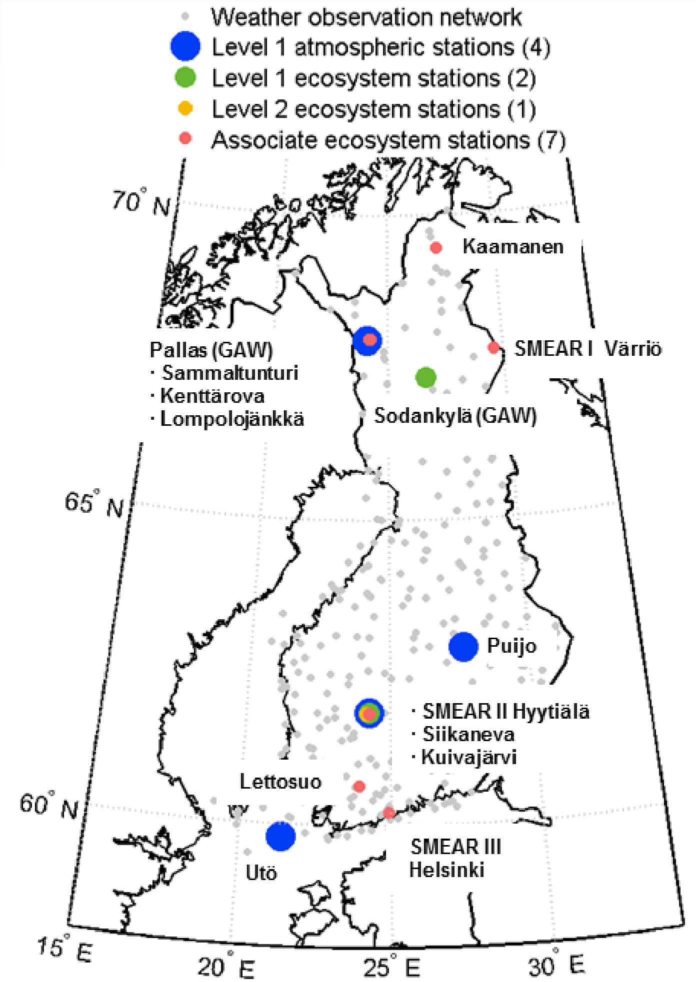

Shortwave radiation
Longwave radiation
Out
In
Latent
Sensible
Out
In
Wind
Turbulence
from wind
shear, u*
Convective
cooling,
w*
Wind forced tilting of
the thermocline
S. MacIntyre

Gas exchange (diffusive flux)

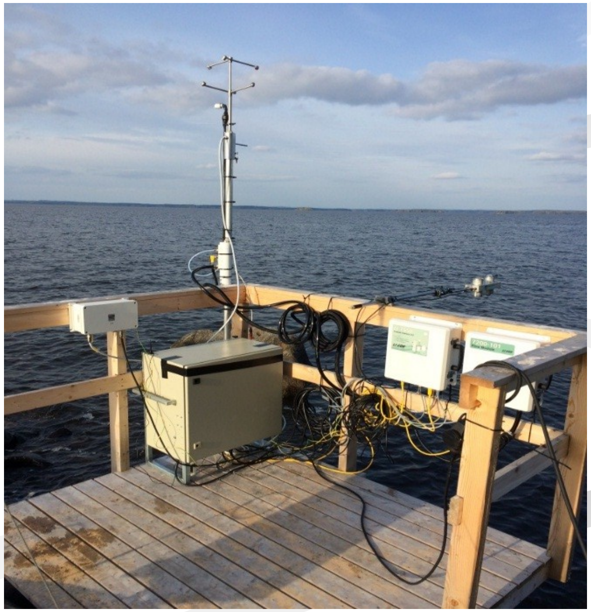
$$F_{CO2} = k\,K_0(pCO2_w - pCO2_a)$$



A. Rutgersson



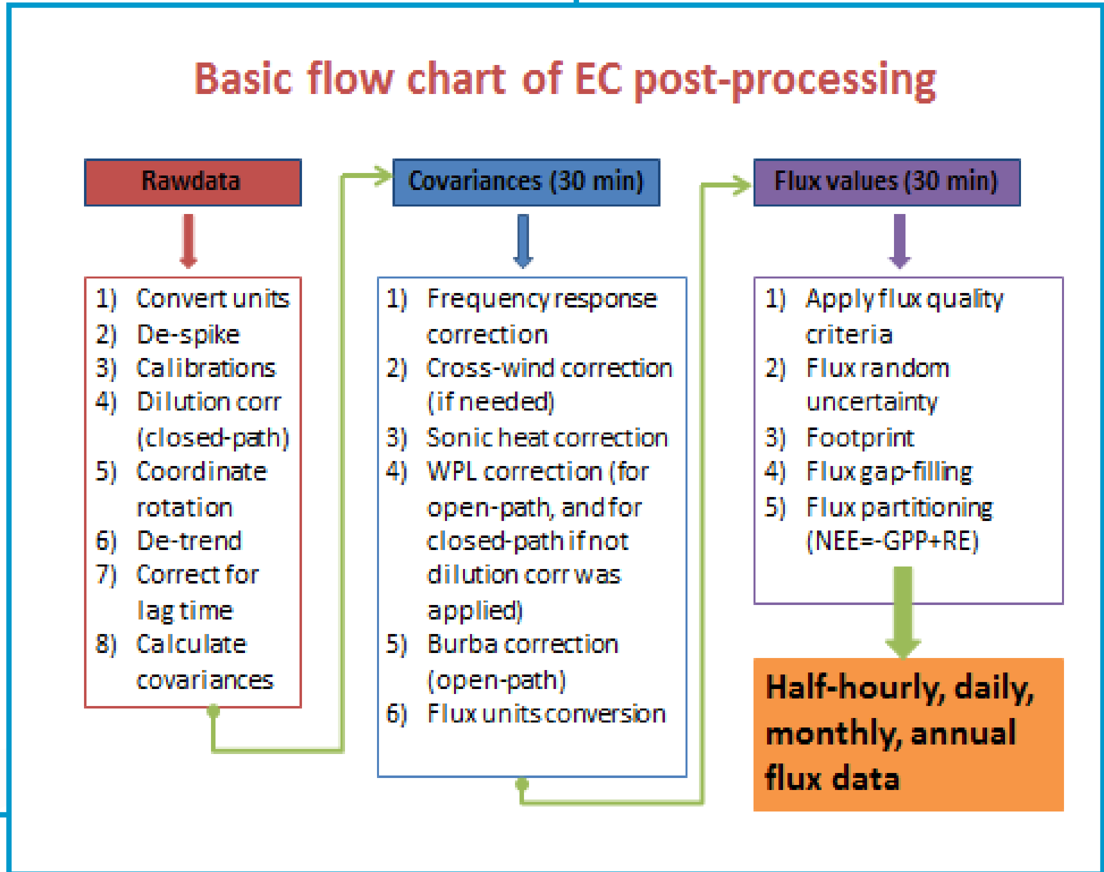
Lake Kuivajärvi



Lake Vanajanselkä

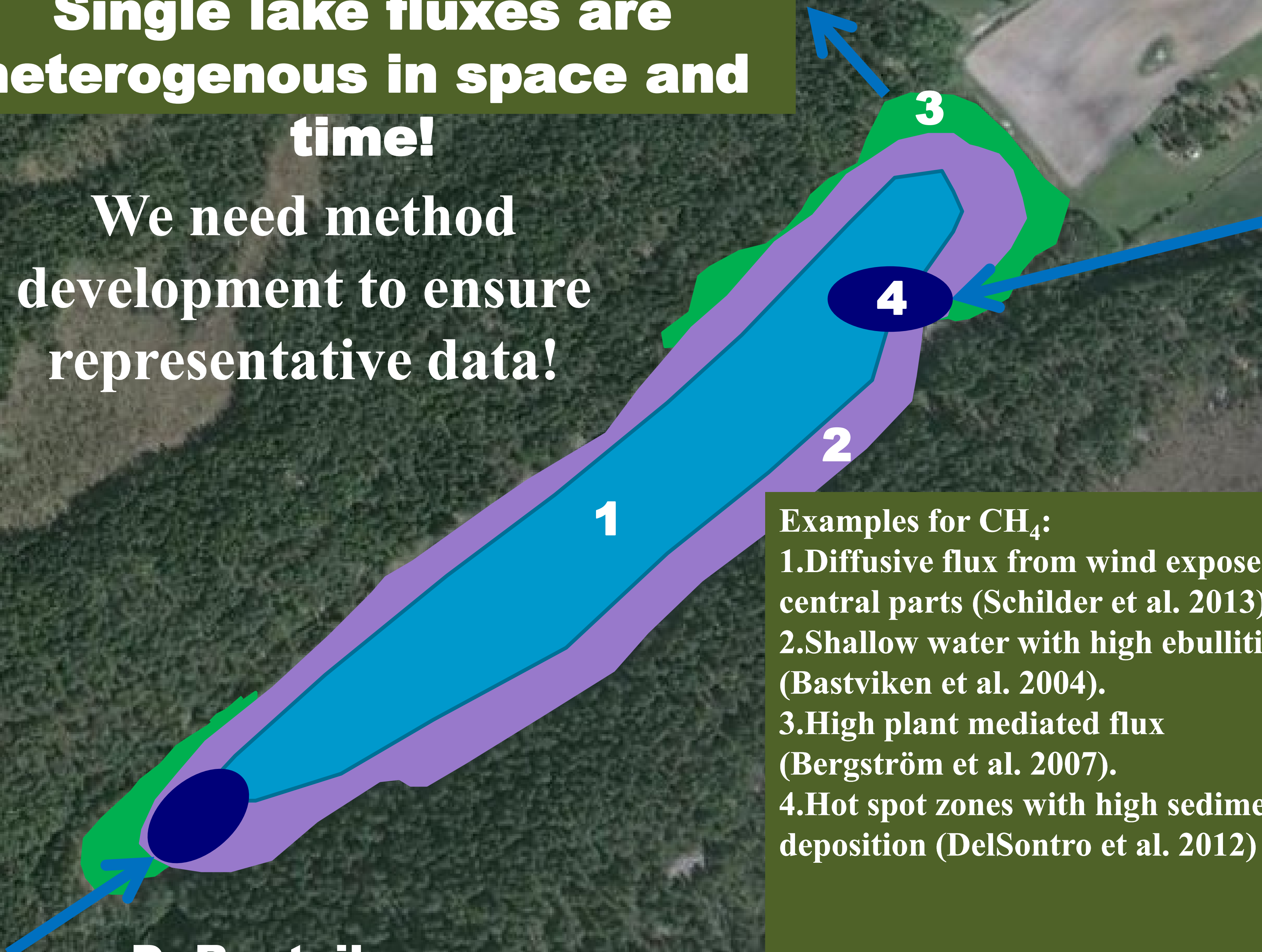
Eddy covariance

- Direct and continuous measurements of net surface exchanges of energy and gases at ecosystem scale
- Time scale half-hour to inter-annual
- Non destructive, non invasive
- Only net fluxes
- Random errors
- Systematic errors
- Data gaps
- Data processing



Single lake fluxes are heterogenous in space and time!

We need method development to ensure representative data!



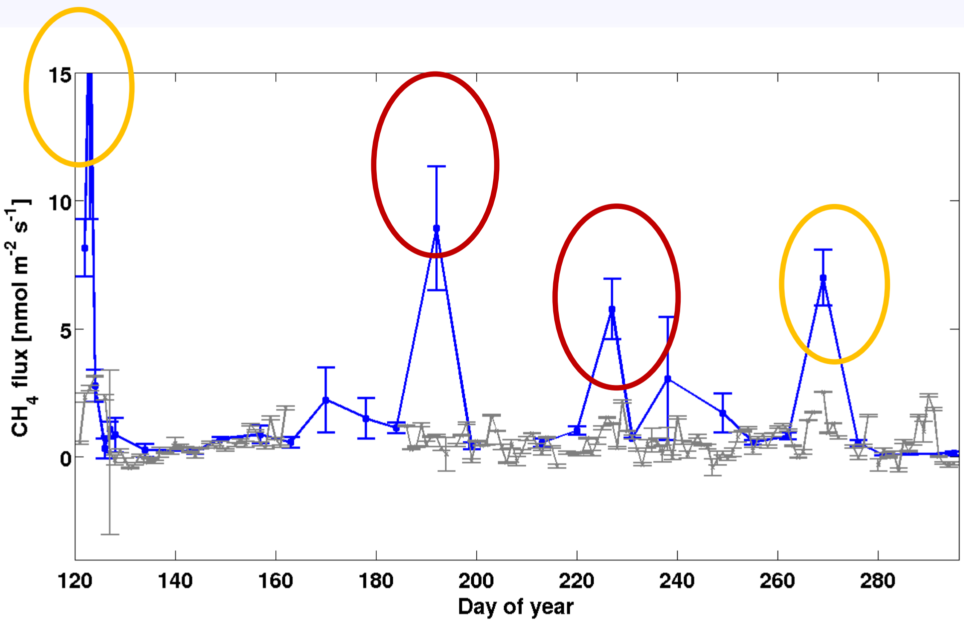
Examples for CH_4:

1. Diffusive flux from wind exposed central parts (Schilder et al. 2013).
2. Shallow water with high ebullition (Bastviken et al. 2004).
3. High plant mediated flux (Bergström et al. 2007).
4. Hot spot zones with high sediment deposition (DelSontro et al. 2012)

D. Bastviken

Lake Kuivajärvi comparison with floating chambers

(preliminary results from year 2013, Kukka-Maaria Erkkilä)



CH4 fluxes

Blue = chamber

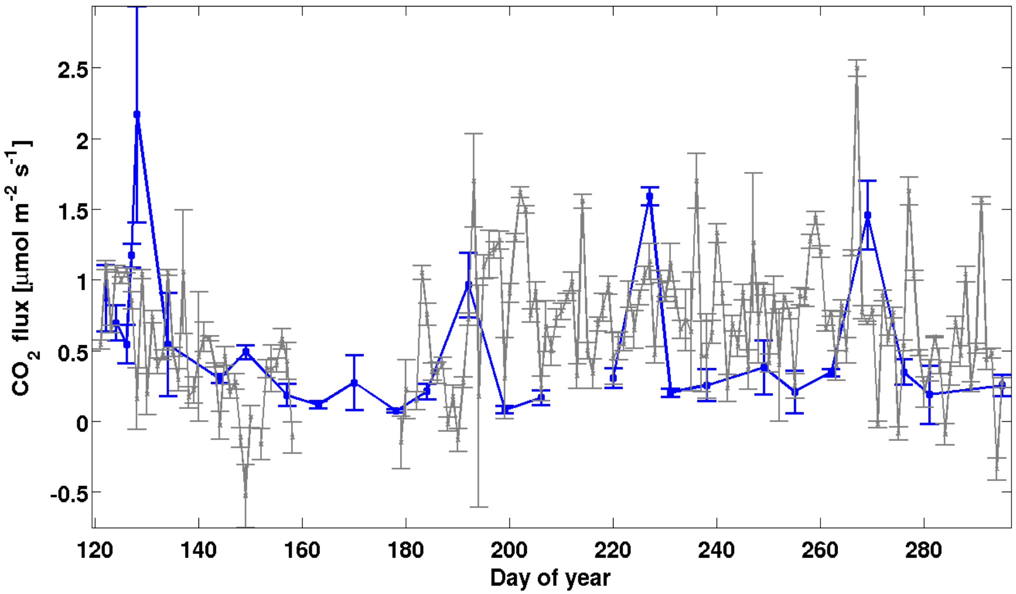
Grey = EC daily mean

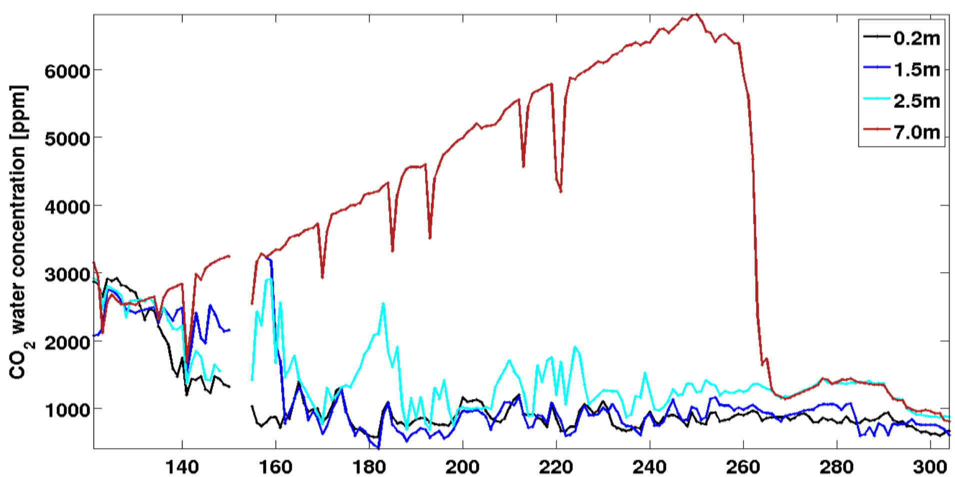
DOY 192 and 227 wind induced mixing events, upwelling

DOY 125 and 269 spring and fall mixing

Comparison with floating chambers

(preliminary results from year 2013, Kukka-Maaria Erkkilä)





CO_2 fluxes

Blue = chamber

Grey = EC daily mean

CO_2 water concentration shows the mixing events

Continuous, distributed flux measurements

How can we select sites, measure well, and spatiotemporally scale lake-atmosphere flux measurements and connect to lake process measurements and models?

- At single sites, regionally, globally
- With protocols for harmonization of measurements and data processing (QA/QC)
- Few monitoring “supersites” and large sample of sites for process understanding/experiments
- Emerging use of EC over lakes for GHGs fluxes (presently about 35 sites at least 1 year data)

A. Desai

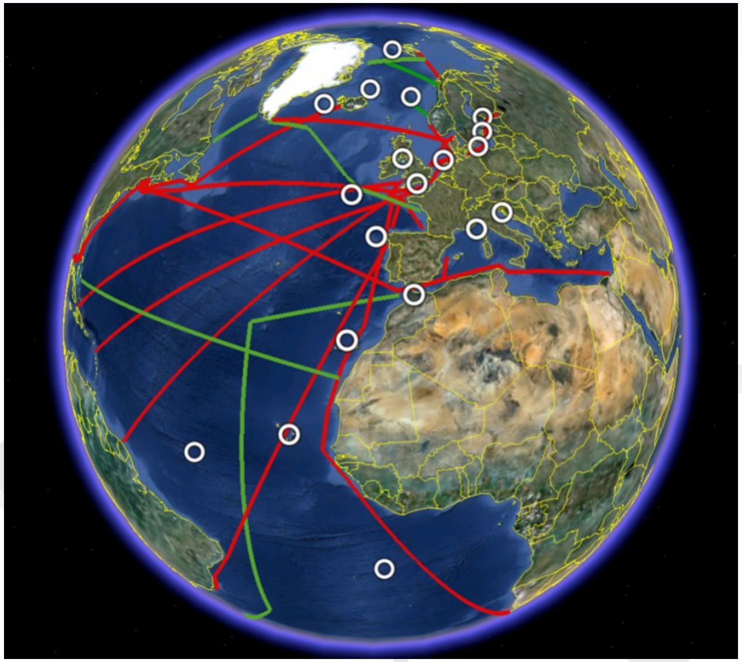
The ICOS station network

integrated carbon observation system

Atmosphere

Ecosystems

Oceans

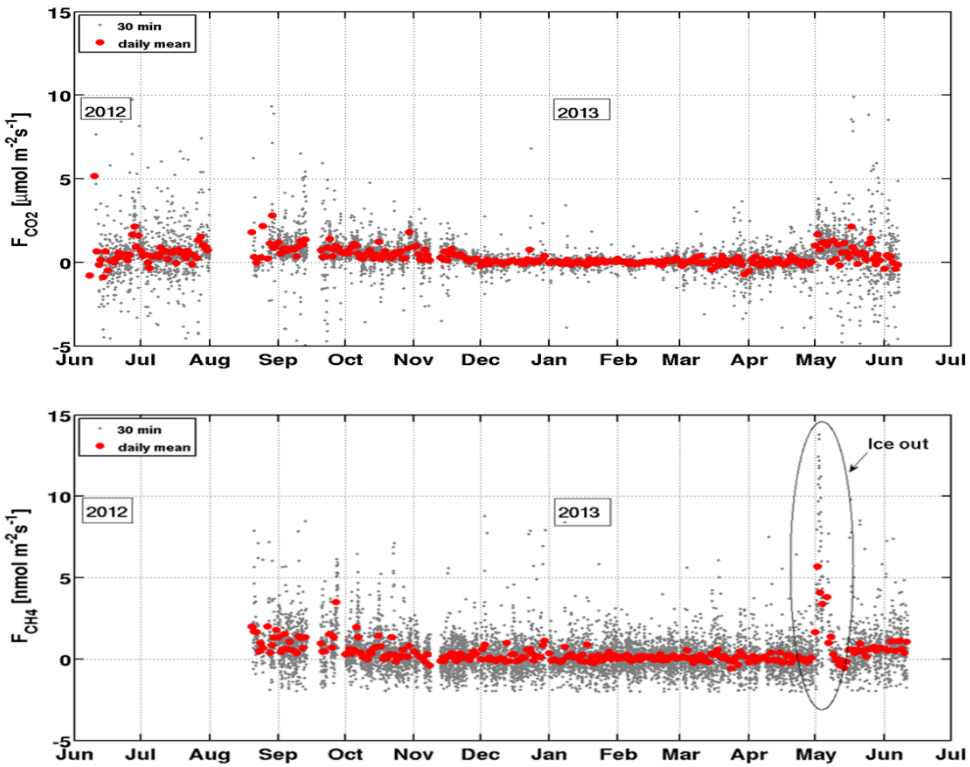


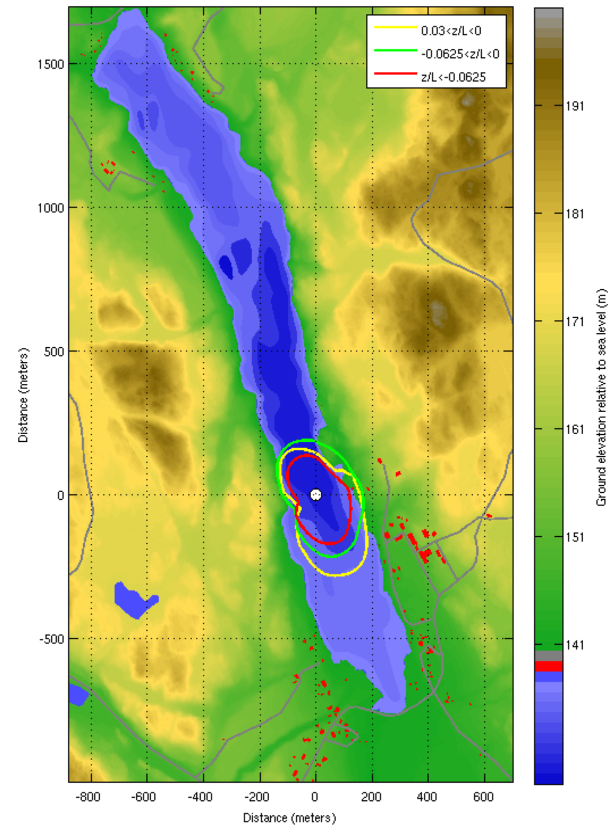
Werner Kutsch

Required measurements for a lake supersite

- 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
- Chamber fluxes
- Water velocities/turbulence

LONG TERM EC MEASUREMENTS OF CARBON DIOXIDE AND METHANE FLUXES OVER LAKE KUIVAJÄRVI





	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)

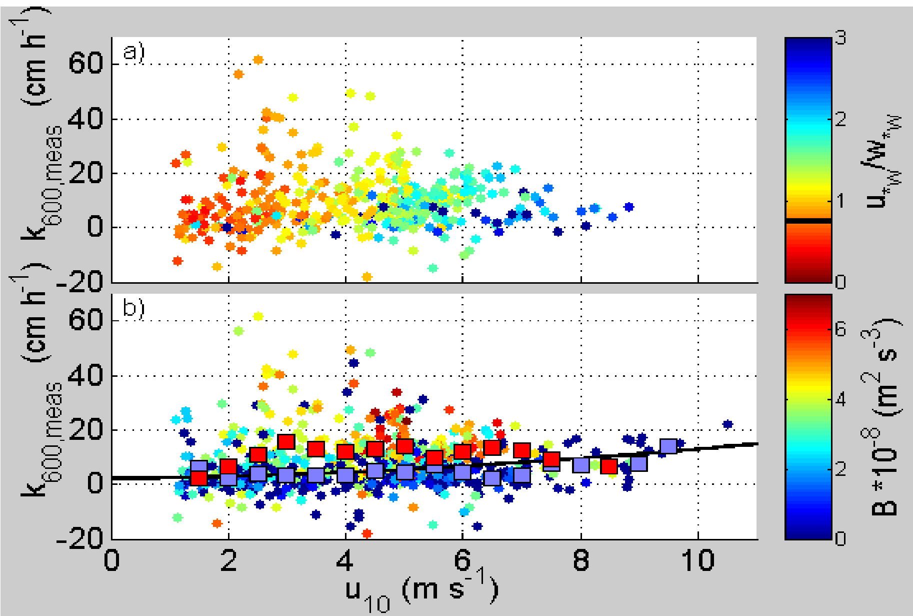
(Mammarella et al., JGR, subm)

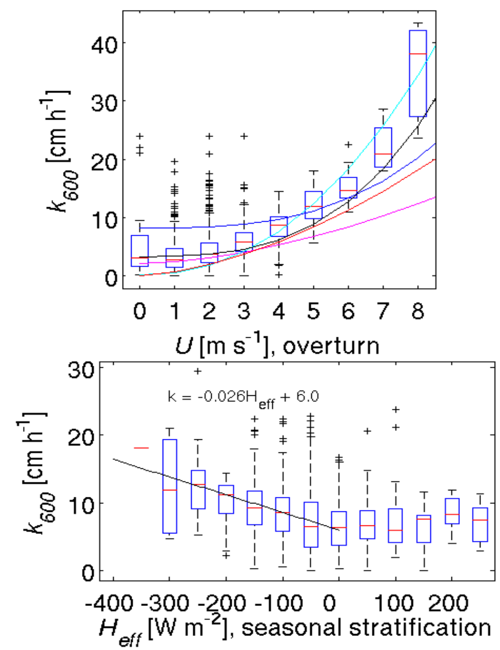
Diffusive flux and gas transfer velocity

$$F_{CO2} = k\,K_0(pCO2_w - pCO2_a)$$

Lake Tammaren (Sweden)

Lake Kuivajärvi (Finland)

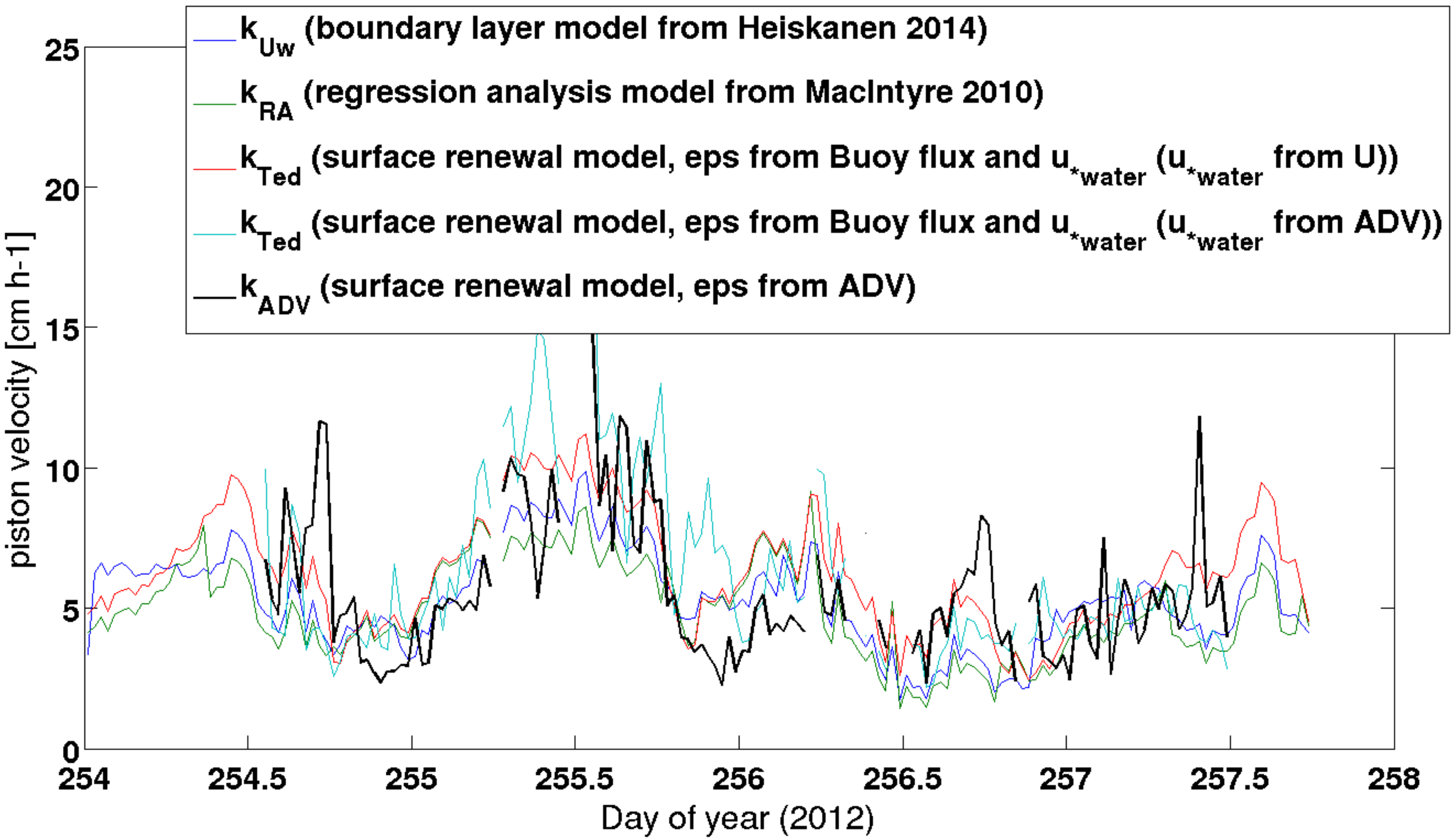




Rutgersson et al (2011) GRL
Podgrajsek et al (2015) JGR

Heiskanen et al, 2014, Tellus B

Other methods are available for estimating the gas transfer velocity k



Jouni H.

EC (eddy covariance) over vegetation aims to Net Ecosystem Exchange to be divided to Gross Primary Productivity and Total Ecosystem Respiration

$$\int_0^h \frac{\partial \overline{c}}{\partial t} dz + \overline{w'c'}(h) = NEE = -GPP + TER$$

Storage	Advective Flux Divergence		Eddy Flux Divergence		Surface exchange

$$\frac{\overline{\partial c}}{\partial t} + \overline{u}\frac{\partial \overline{c}(x,z)}{\partial x} + \overline{w}\frac{\partial \overline{c}(x,z)}{\partial z} + \frac{\partial \overline{u'c'}(x,z)}{\partial x} + \frac{\partial \overline{w'c'}(x,z)}{\partial z} = S(x,z)$$

(The term $\frac{\partial \overline{u'c'}(x,z)}{\partial x}$ is crossed out.)

J. Finnigan

Estimation of algal photosynthesis/respiration using water CO_2 probes

CO_2 exchange:

$$g(t) = -\int_{h_b}^{0} \frac{\partial C(h,t)}{\partial t} dh - F_a + F_u + F_l$$

where:

- C = CO_2 concentration in the euphotic (sun-light) layer of the lake
- h_b = euphotic depth
- F_a = Flux between lake and the air
- F_u = In-lake flux from the deeper layers to the euphotic layer
- F_l = Lateral flux

M. Provenzale

Kuivajärvi lake, Finland – 2013;

C measured by the in-lake probes;

↓

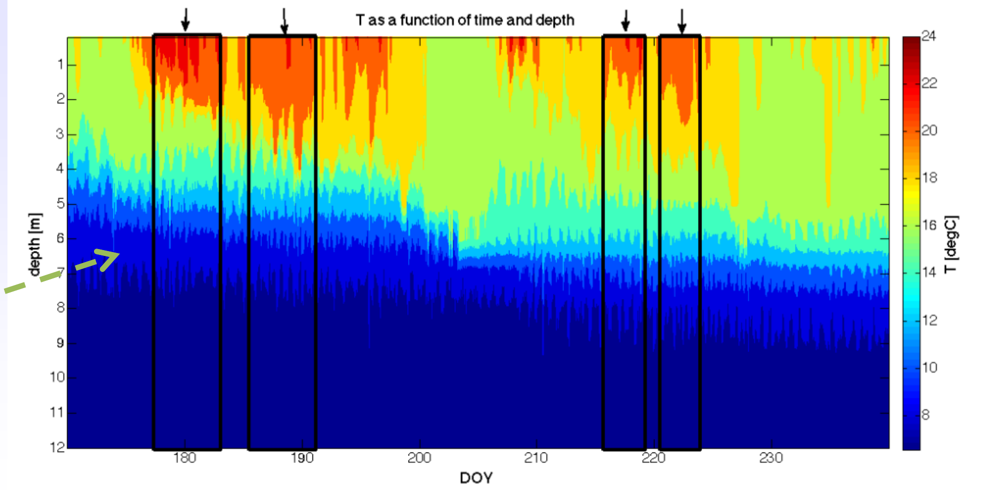
$F_u = 0$ in summer periods with strongly stable stratification;

↓

F_a known from eddy covariance measurements (mean day and night values used);

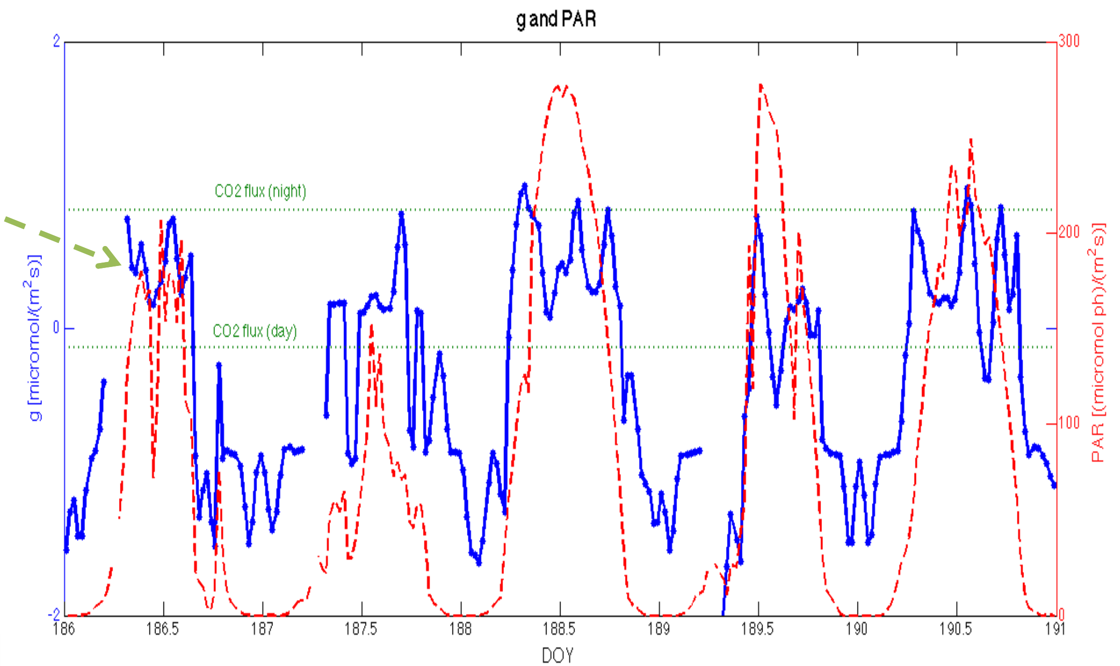
↓

g



from g, photosynthesis and respiration parameters can be obtained:

$$g = p - r = \frac{p_{max} PAR}{PAR + b} - r_0 Q_{10}^{T/10}$$



M. Provenzale

“Data without model is chaos, model without data is fantasy” (Patrick Crill)

Thanks for your attention