Lake Workshop, 18-20 September 2012, Helsinki

Eddy covariance measurements of energy and CO_2 fluxes over a boreal lake in southern Finland

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Background and Motivation

• Worldwide, lakes cover 3% of the Earth's continental surface; in Finland >>> 10 %. About 95% of lakes are less than 1 Km^2 .

• The important role of inland fresh waters (lakes, rivers, ponds) in processing large amounts of organic carbon (Battin et al., 2009, *Nature Geoscience*).

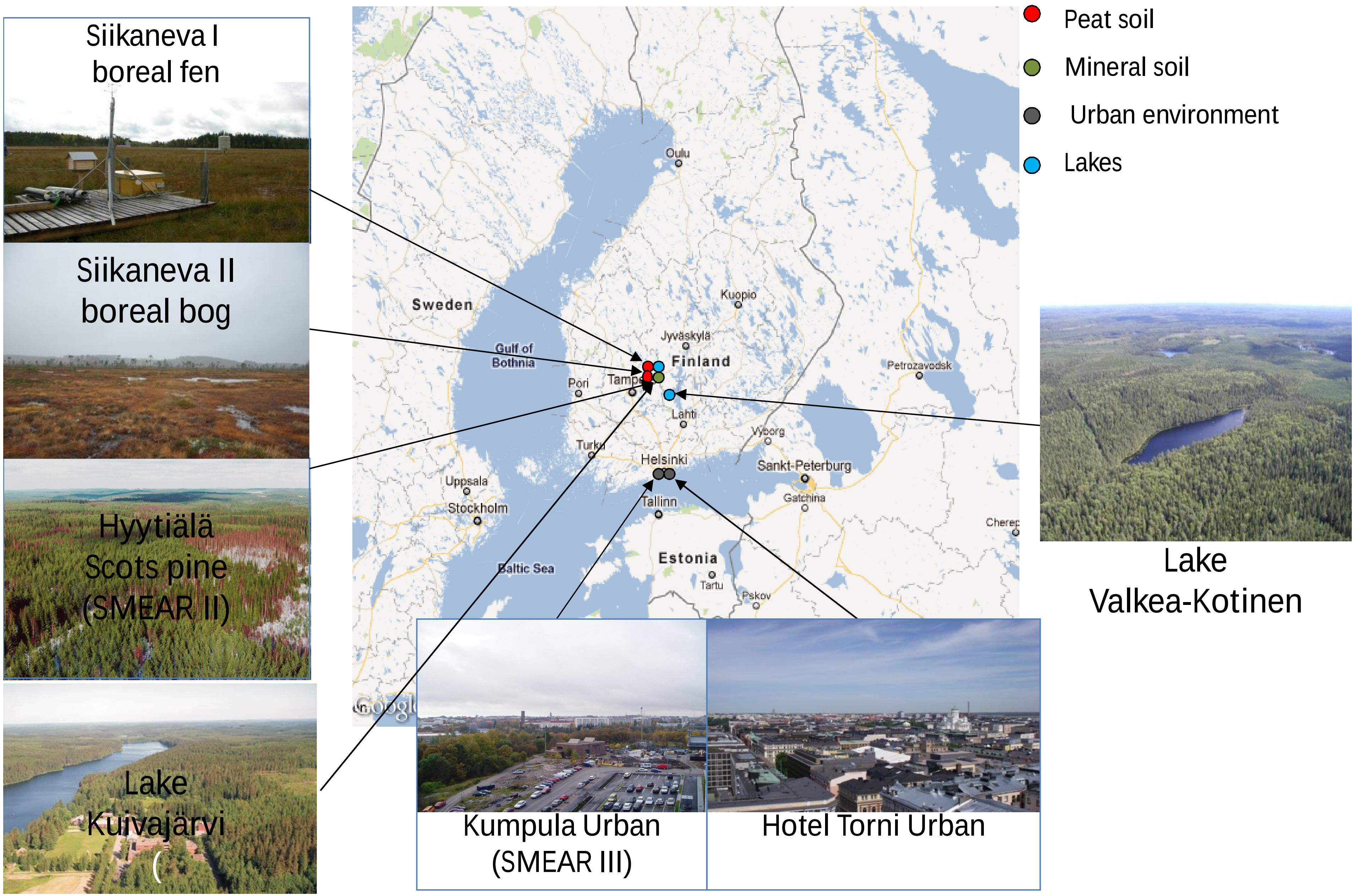
• Lakes have different albedo, lower surface roughness and greater effective heat capacity than surrounding land areas. These properties affect regional climate and energy budgets (Dutra et al., 2010; Jeffries et al., 1999).

• Only few studies have been published on EC flux measurements on fresh water ecosystems.

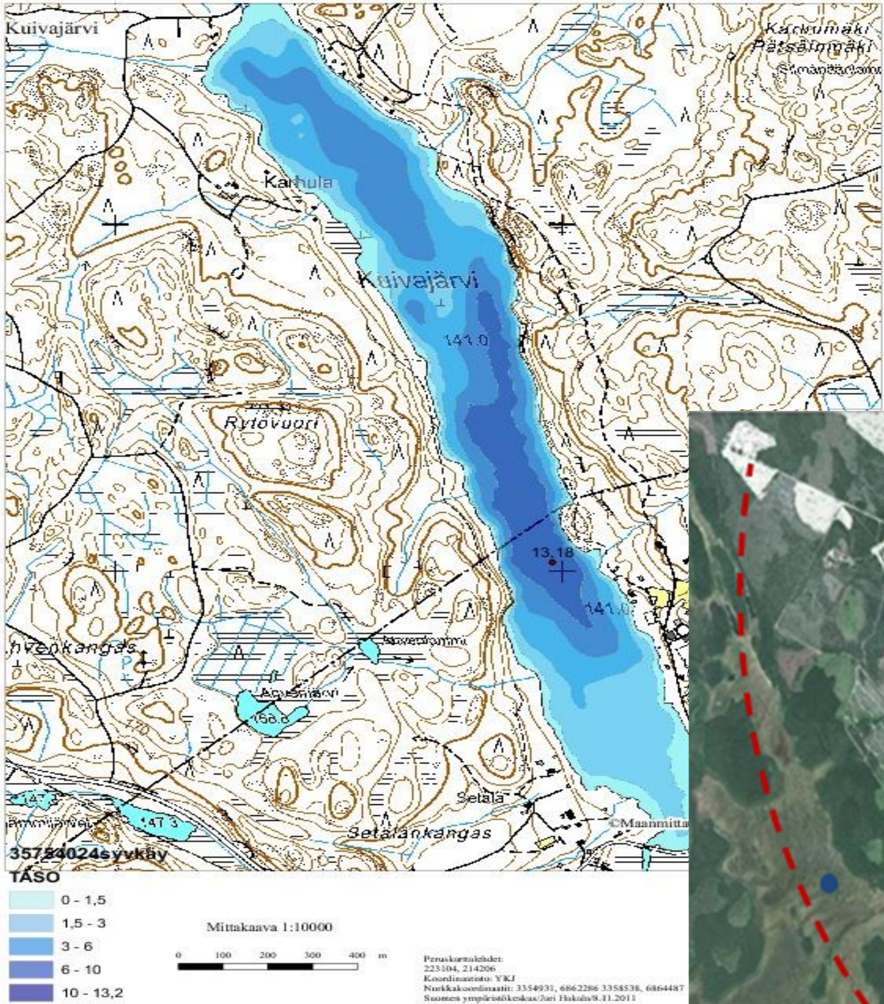
• Long term and continuous flux measurements are needed in order to improve our understanding on:

- short and long term variation of thermal structure and energy balance of such ecosystems.
- gas exchange processes

UHEL EC flux measurement sites



Materials and methods



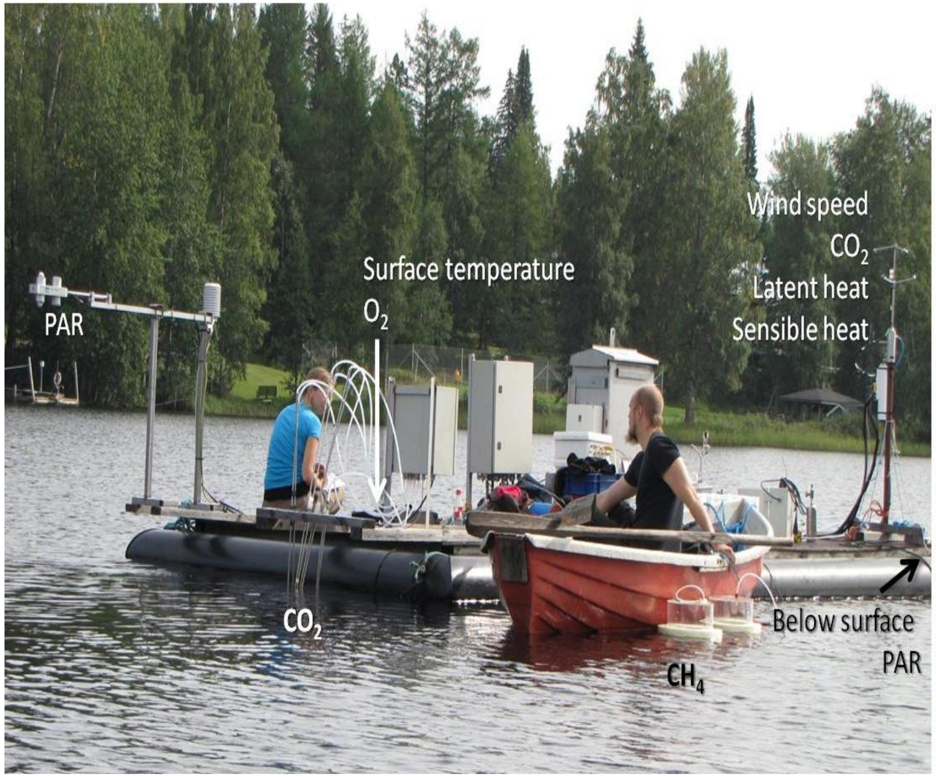
Max depth : 13.2 m.

Length = 2.6 km.

Max width = 400 m.

Source: Maanmittauslaitos

Materials and methods



From J.Heskainen MSc thesis

Ancillary measurements:

Water T Profile: 0.2, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 6, 8, 10, 12.
Water CO2 Profile: 0.2, 0.5, 1, 1.5
Water PAR.
Radiation components.
Tair, RH

Measurement Periods:

June 2009-Feb 2010
June 2010 – Jan 2011
May 2011 – Nov 2011

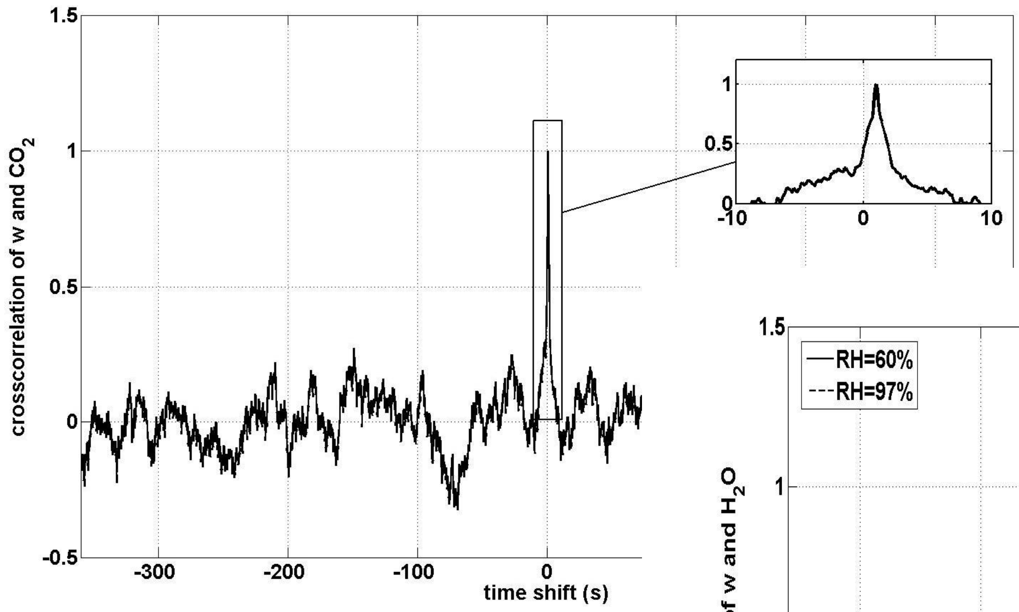
EC measurements:

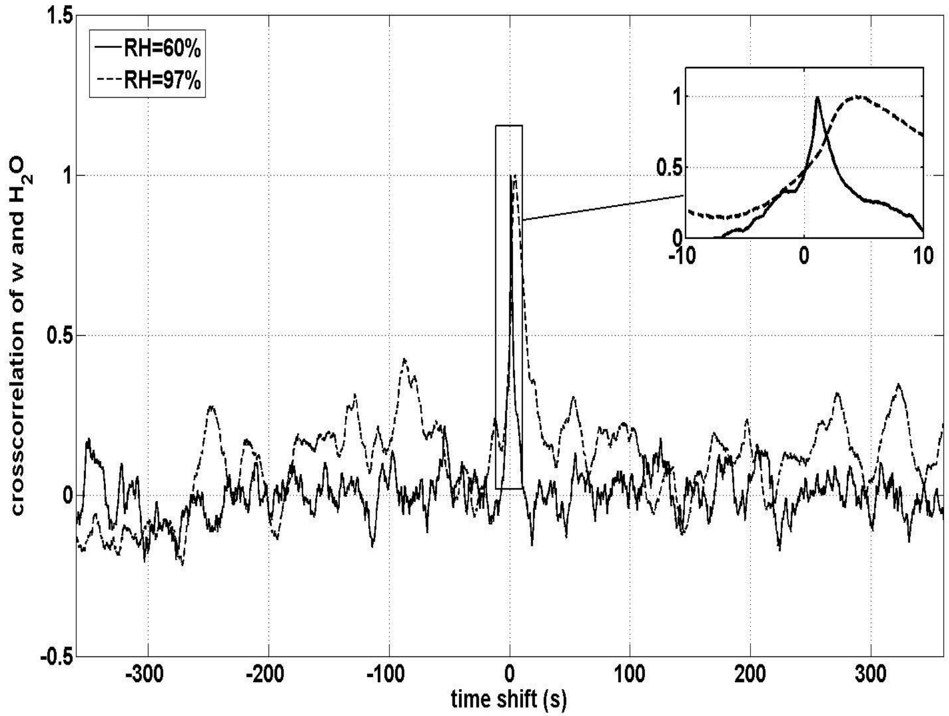
1) June 2009 / Feb 2010 and Jun 2010/Dec 2010.
   Metek USA-1 (momentum and sensible heat fluxes)
   Licor 7000 (CO_2 and H_2O fluxes)

2) Jun 2011 / Nov 2011
   Metek USA-1 (momentum and sensible heat fluxes)
   Licor 7200 (CO_2 and H_2O fluxes)

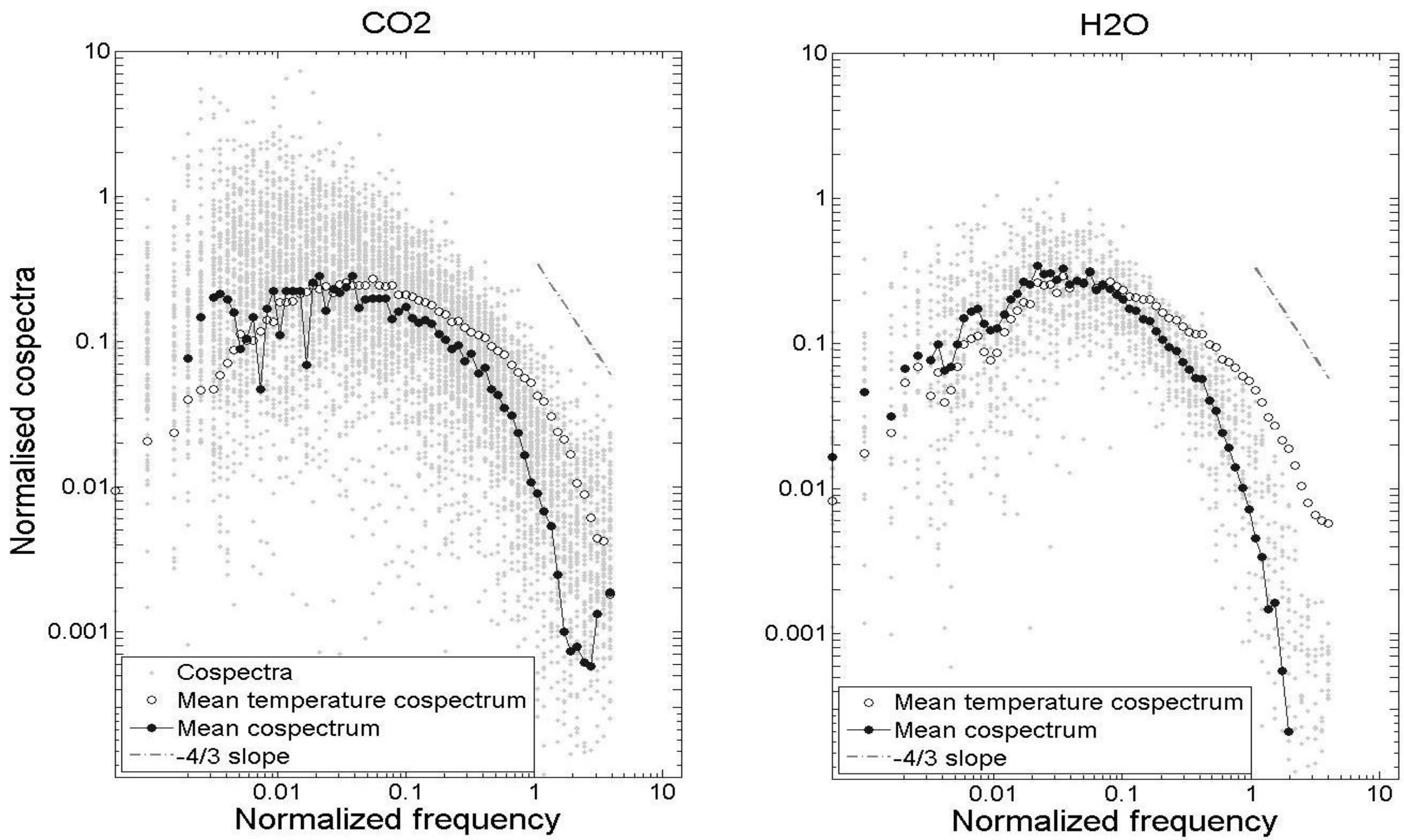
EC data post-processing by EddyUH
http://www.atm.helsinki.fi/~mammarel/Eddy_Covariance/EddyUHsoftware.php.

EC system performance



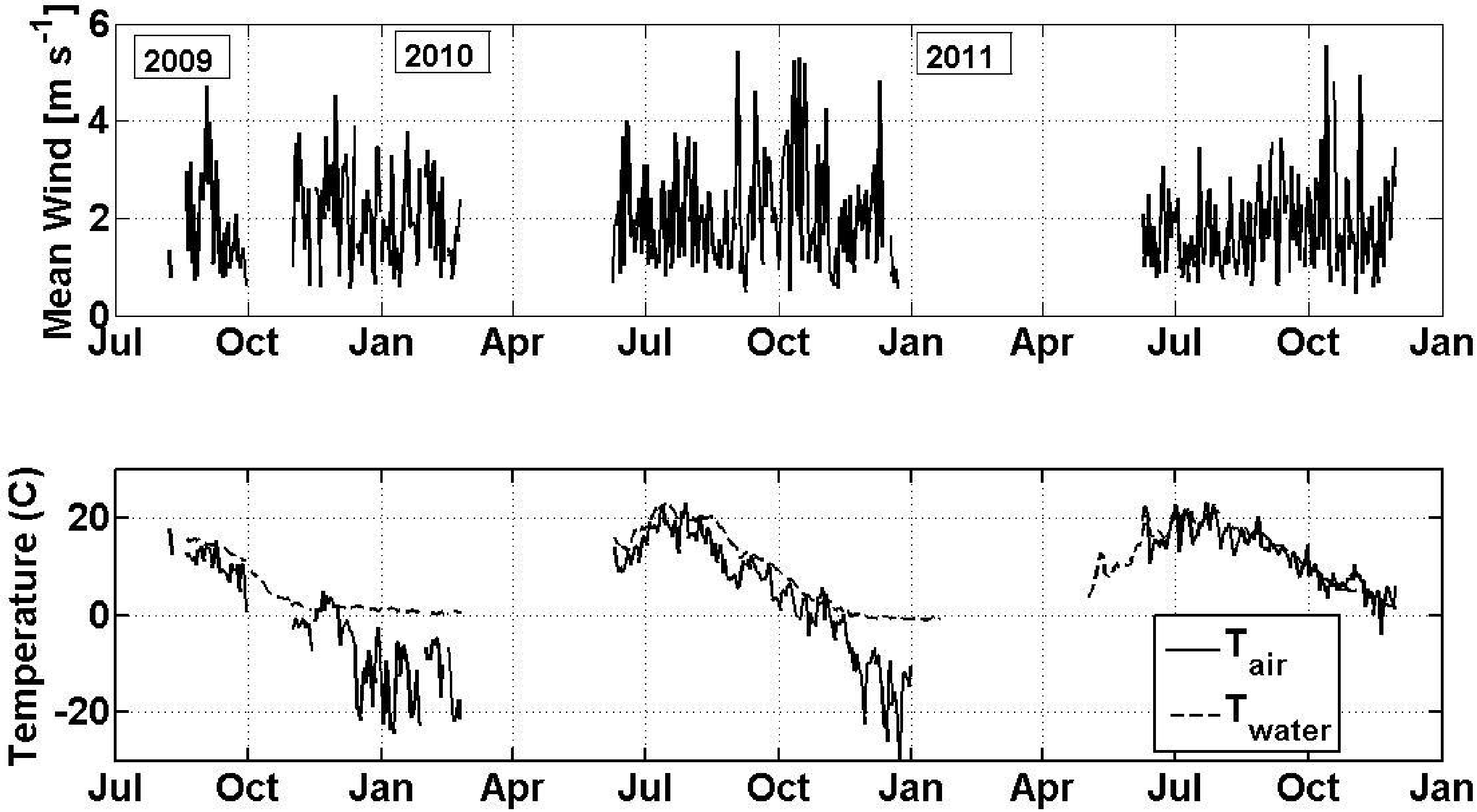


EC fluxes: systematic uncertainty

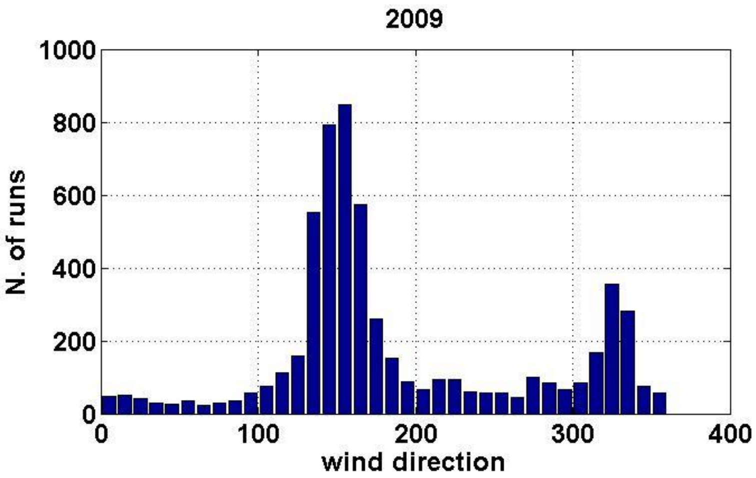


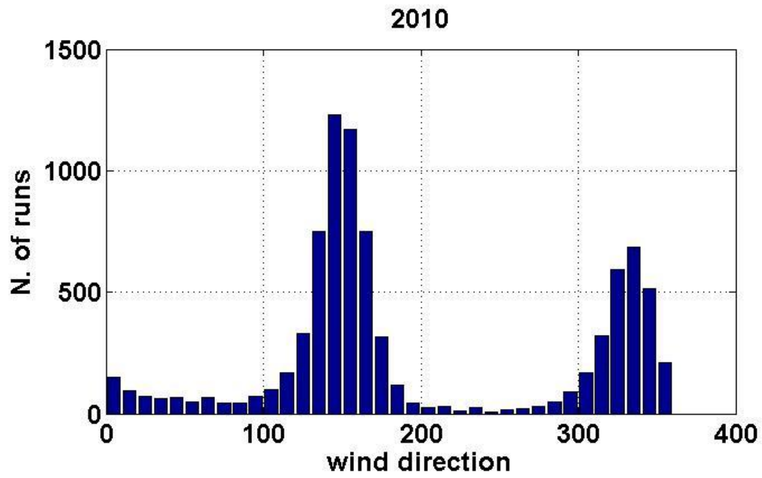
Spectral correction is up to 30% for H2O and 20% for CO2.

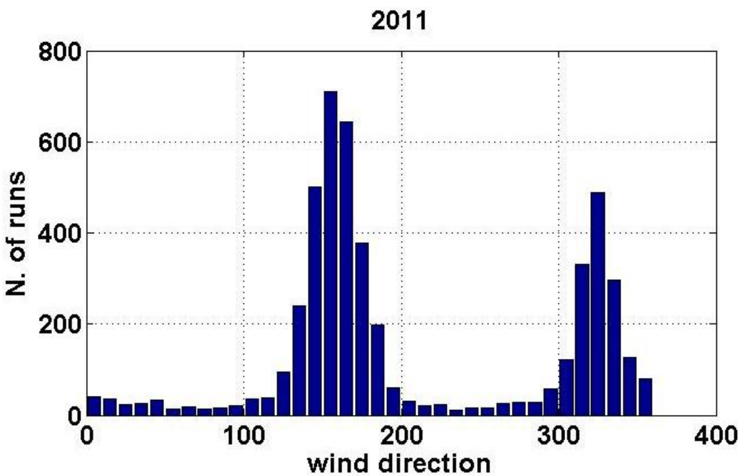
Environmental conditions



Environmental conditions

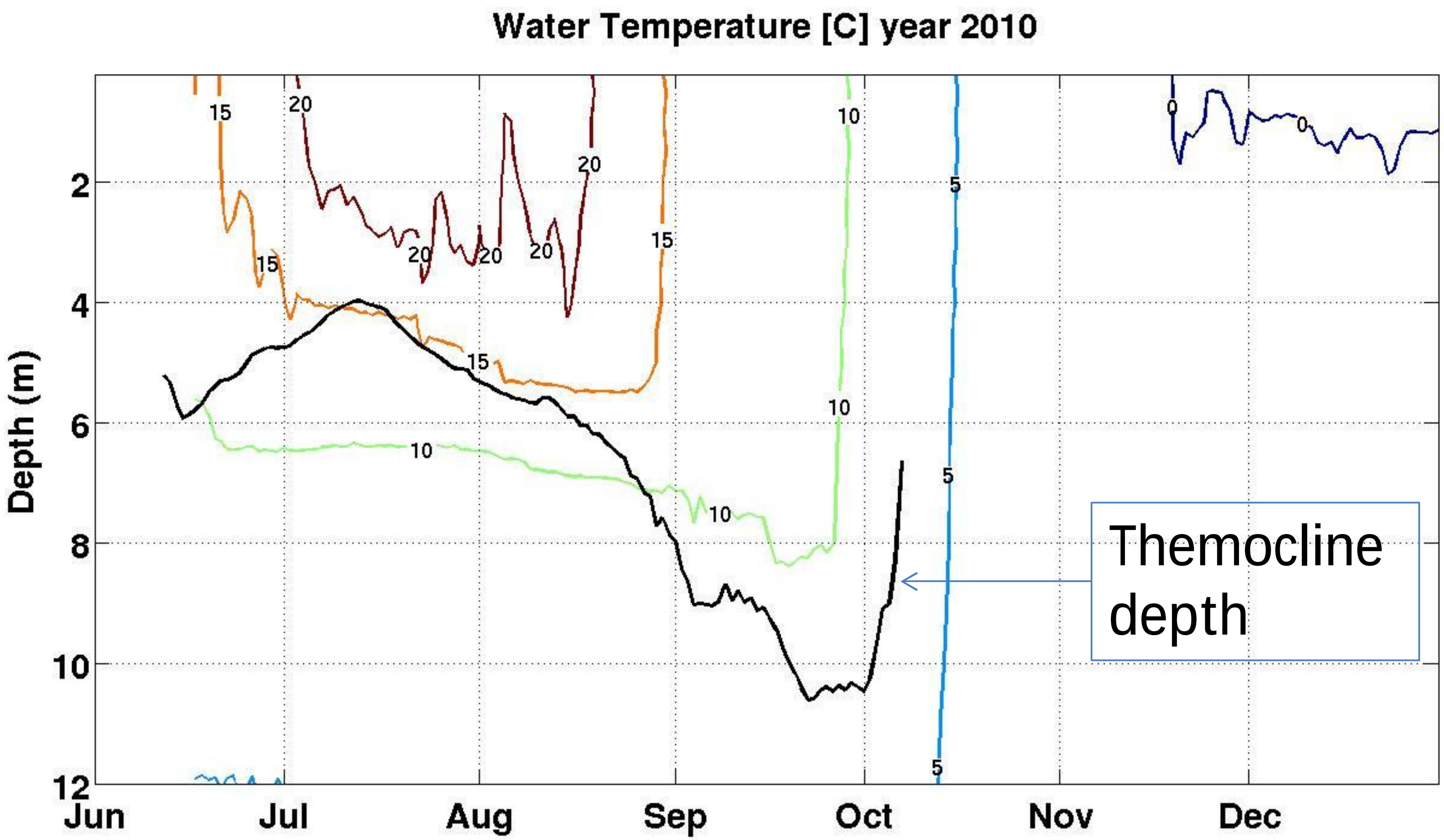


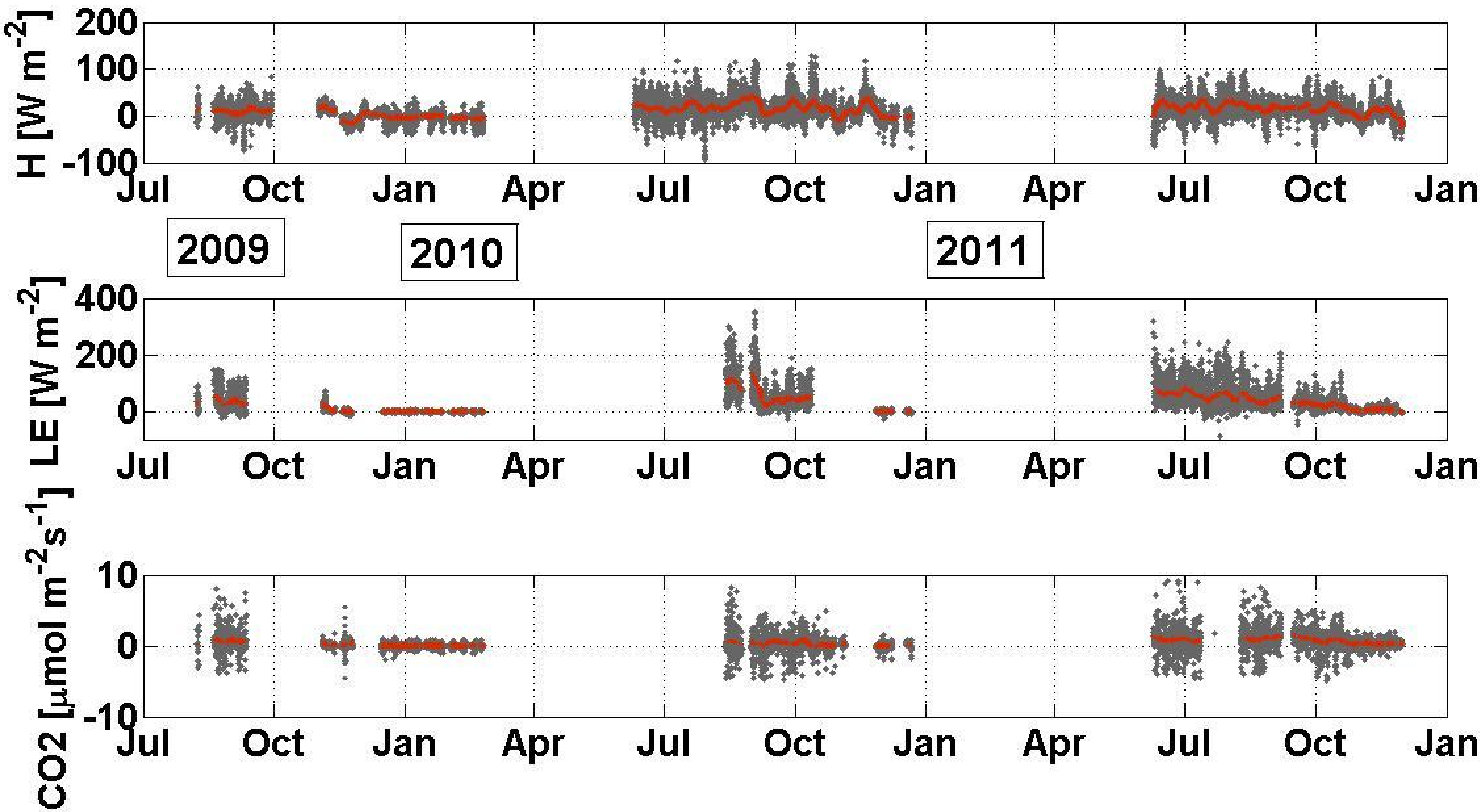




Wind direction at Kuivajärvi is dominantly along lake.

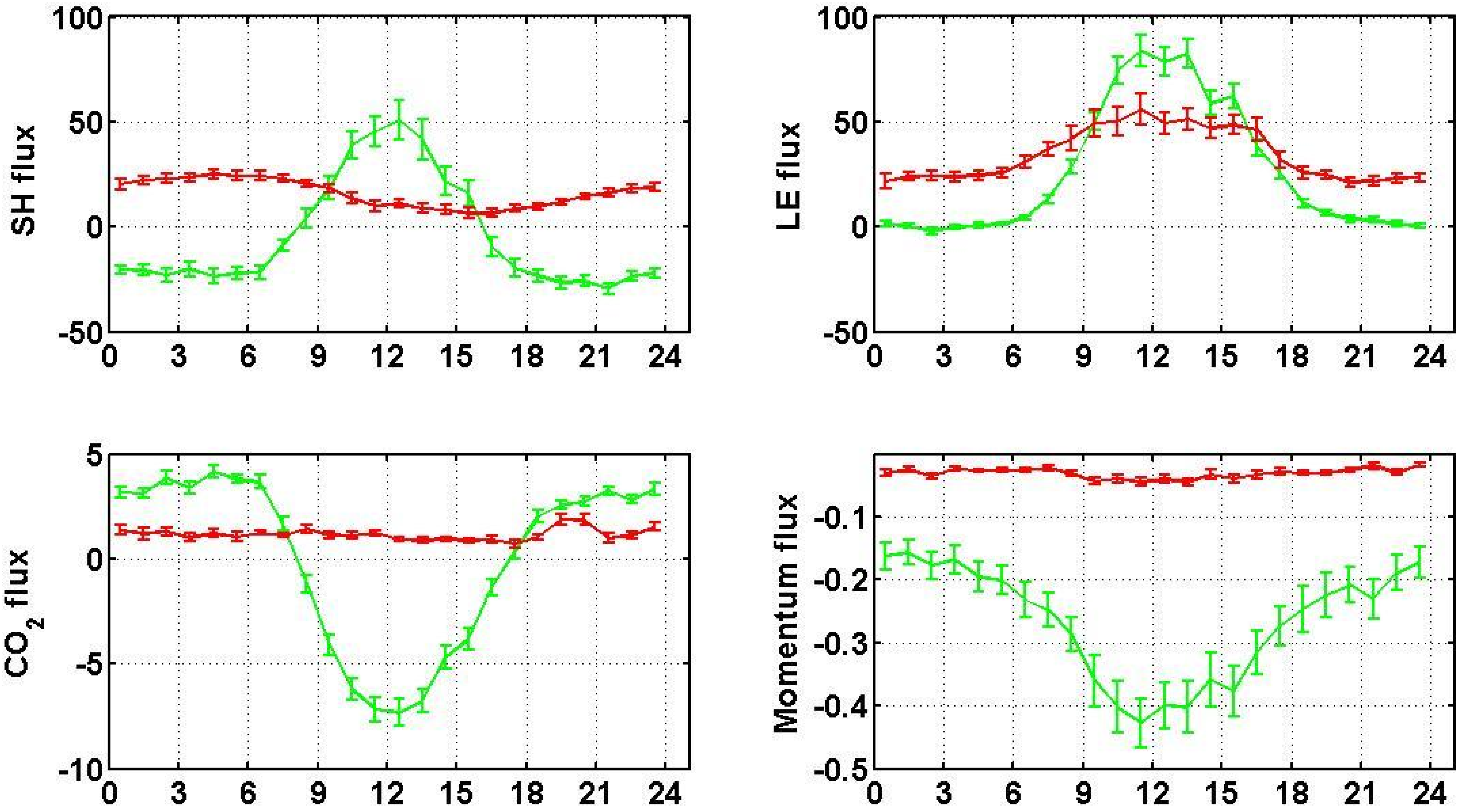
Environmental conditions





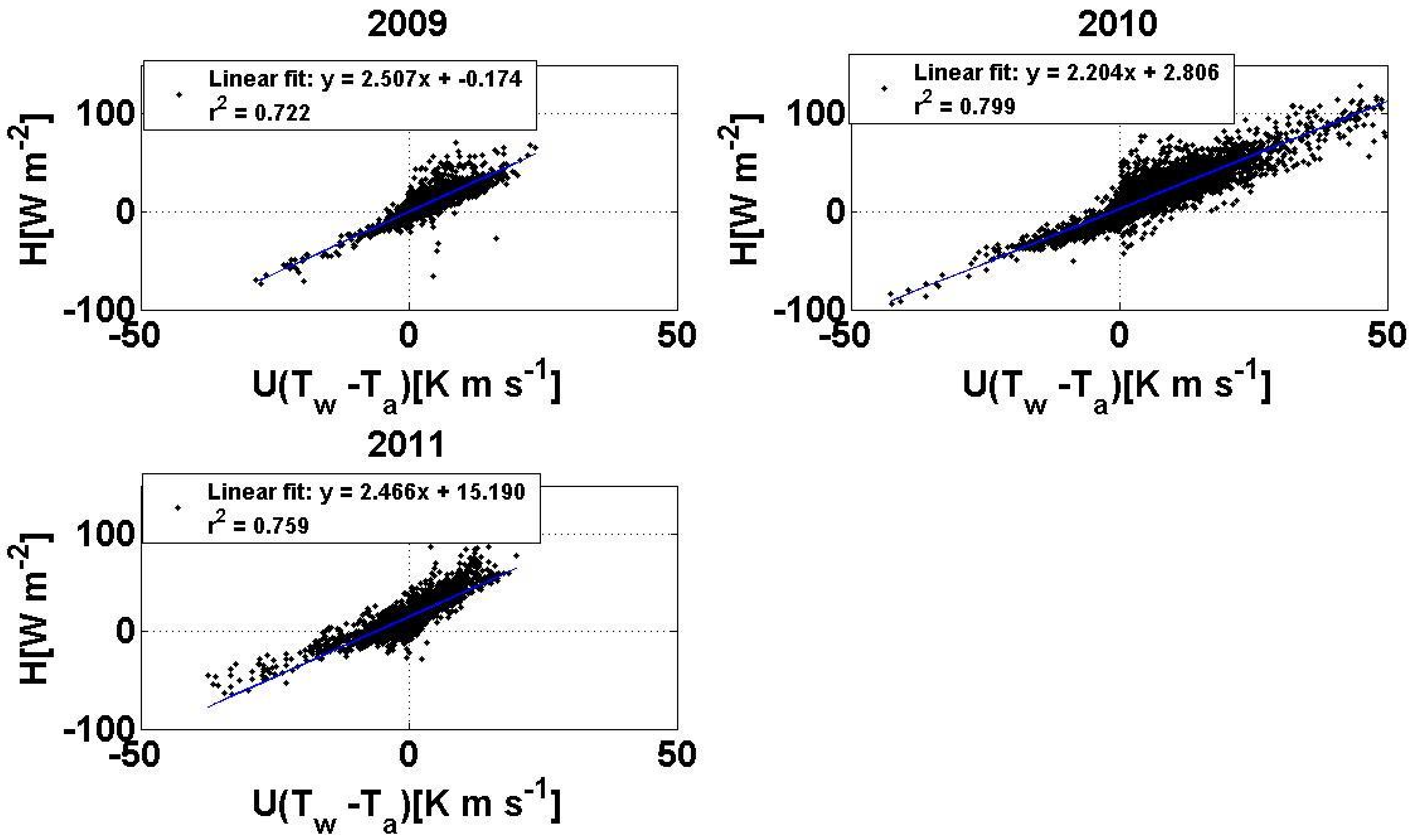
Next we consider only open water periods (e.g. June – October)

Lake vs Scots Pine forest
Sept 2011

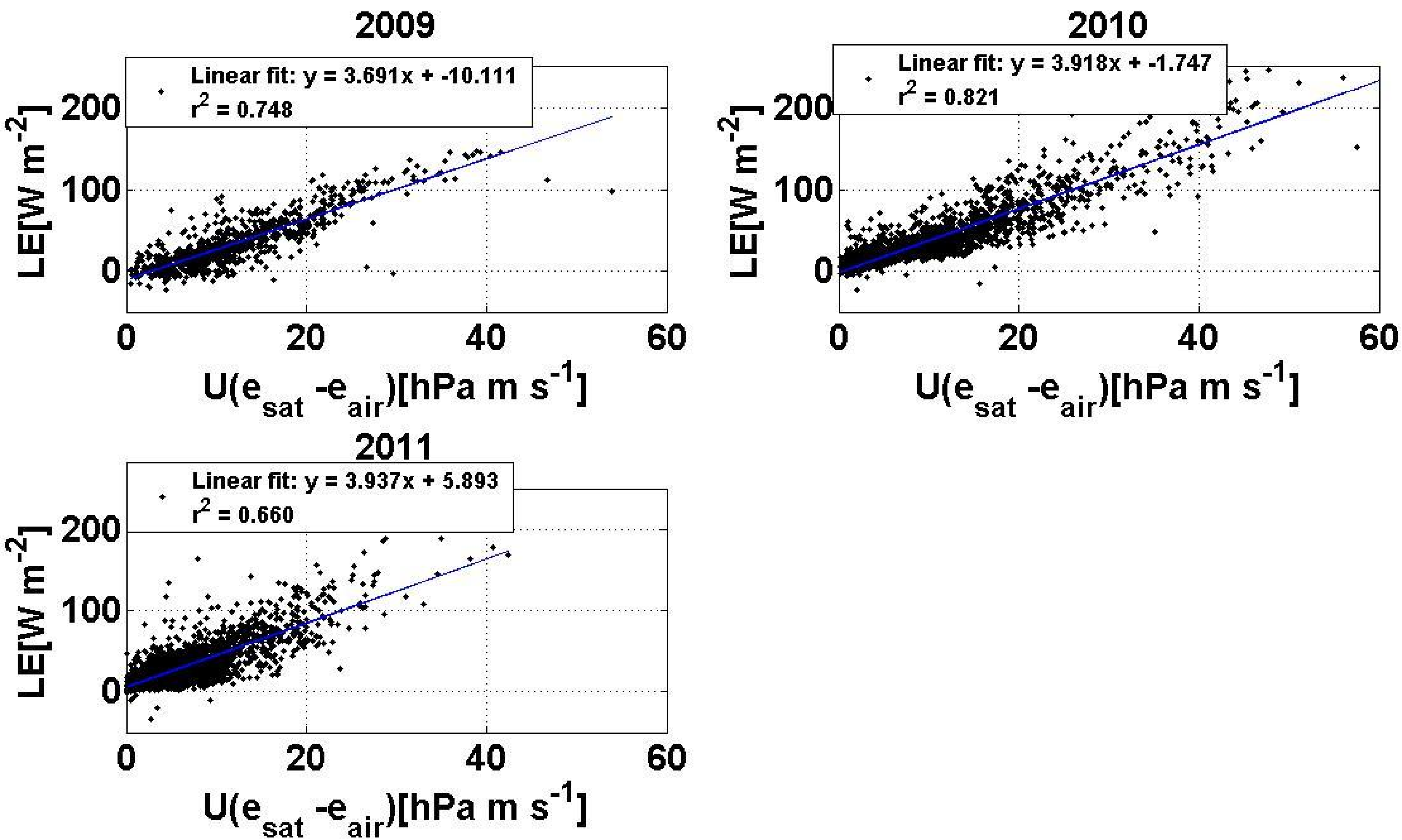


Red = Kuivajärvi, Green = SMEAR II

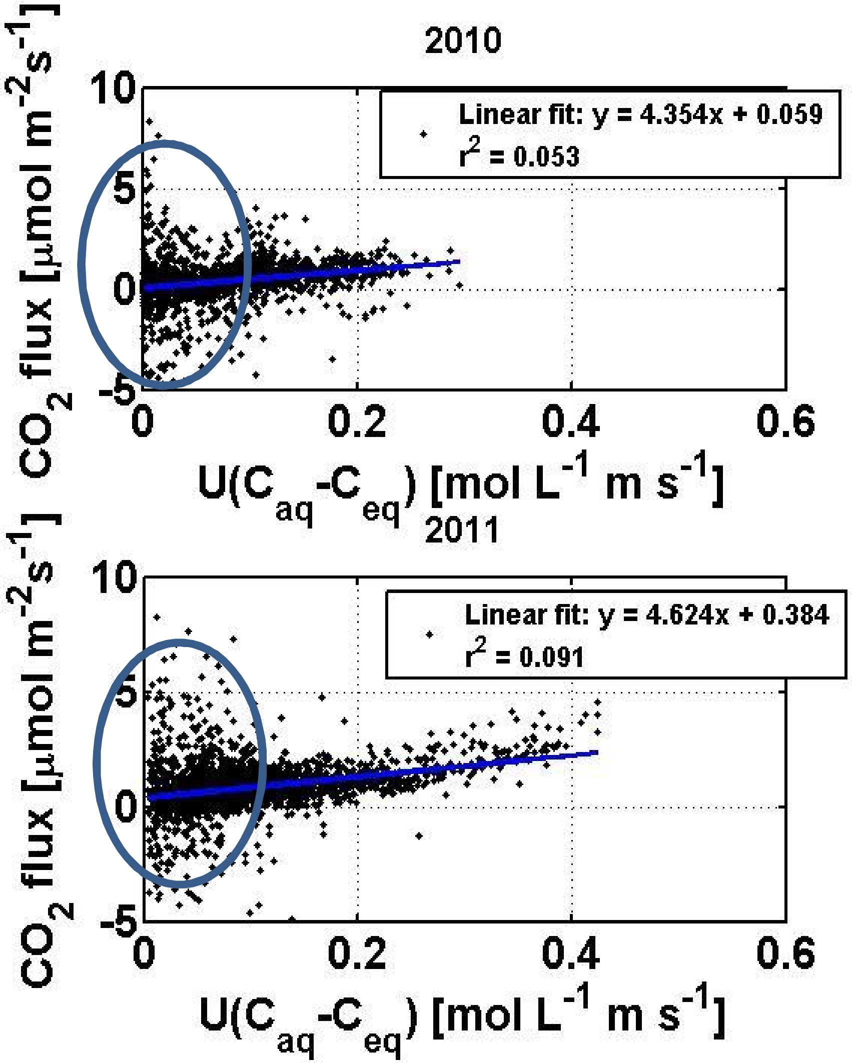
Bulk transfer relationships



Bulk transfer relationships



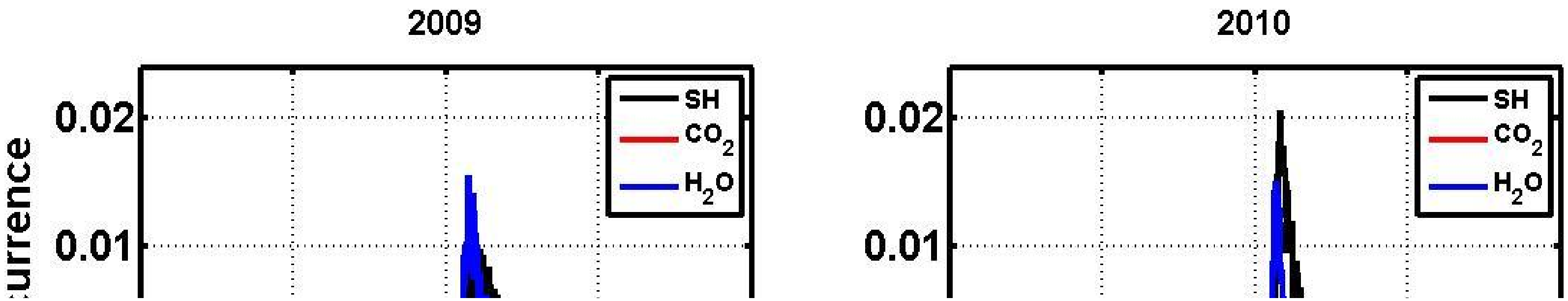
Bulk transfer relationships



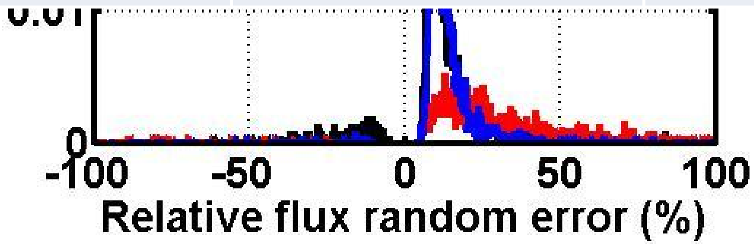
WHY?

-Buoyancy play relevant role.
- Bias in CO2 concentration measurements.
- EC flux random uncertainty

Flux random uncertainty



	SH	CO2	LE
RFRE	17%	35%	20%
RE	2.5 W m^{-2}	0.35 mumol $m^{-2}s^{-1}$	4 W m^{-2}



Flux random uncertainty according to Finkelstein & Sims (2001), JGR

Water turbulent mixing and gas exchange

$$F = k(C_{aq} - \sigma C_{air})$$

k is the gas transfer velocity, which depends on molecular diffusivity of the gas and the MBL variation.

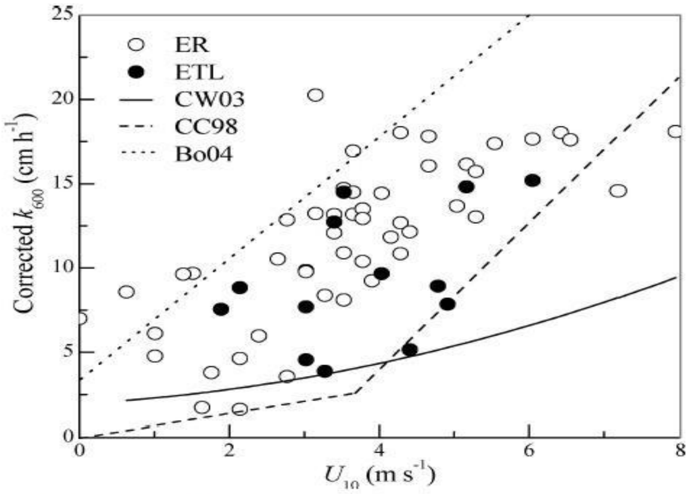


Fig. 7. Corrected k_{600} data plotted against wind speed at 10 m (U_{10}). The dashed line represents the Cole and Caraco (1998) relationship (CC98), the dotted line represents Borges et al. (2004) relationship (Bo04), and the long dashed line represents the Crusius and Wanninkhof (2003) relationship (CW03).

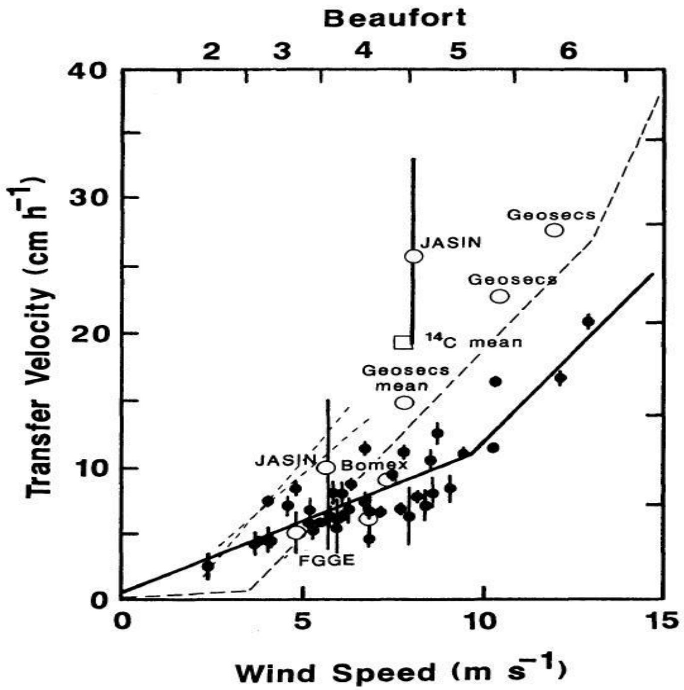


Fig. 8. Gas transfer velocities as a function of windspeed and the corresponding Beaufort Scale number: ●, results from this work; ○, ocean radon averages (Broecker and Peng, 1974; Peng et al., 1979; Kromer and Roether, 1983); □, global ocean bomb-^{14}C mean (Broecker et al., 1985); solid lines, least squares fit to field data (this study); small dashed lines, recent SF_6 results for US lakes (Wanninkhof et al., 1987); large dashed line, extrapolation of the SF_6 results of Wanninkhof et al. (1985) using model equations (Liss and Merlivat, 1986). All data refer to CO_2 at 20°C with windspeeds normalized to 10 m.

Convective mixing : some equations!

We used theoretical framework similar to atmospheric mixed layer, but we apply it to water side (Imberger, 1985).

Convective velocity scale is

$$w_* = \left[Z(-\beta) \right]^{1/3}$$

Z is the mixed layer depth and beta is the buoyancy flux:

$$\beta = \frac{g H_{eff} \alpha}{C_p \rho_w}$$

α = 1.6e-5+9.6e-6*Tw is the thermal expansion of water
Cp = 4192 J/Kg/K is the specific heat capacity
ρw is water density

The effective heat flux Heff is defined as

$$H_{eff} = H_{net} + q(0) + q(Z) - \frac{2}{Z}\int_{z}^{0} q(z)dz$$

where

$$H_{net} = LW_{net} + H + LE$$

is the net surface heat flux and

q is the short wave radiation

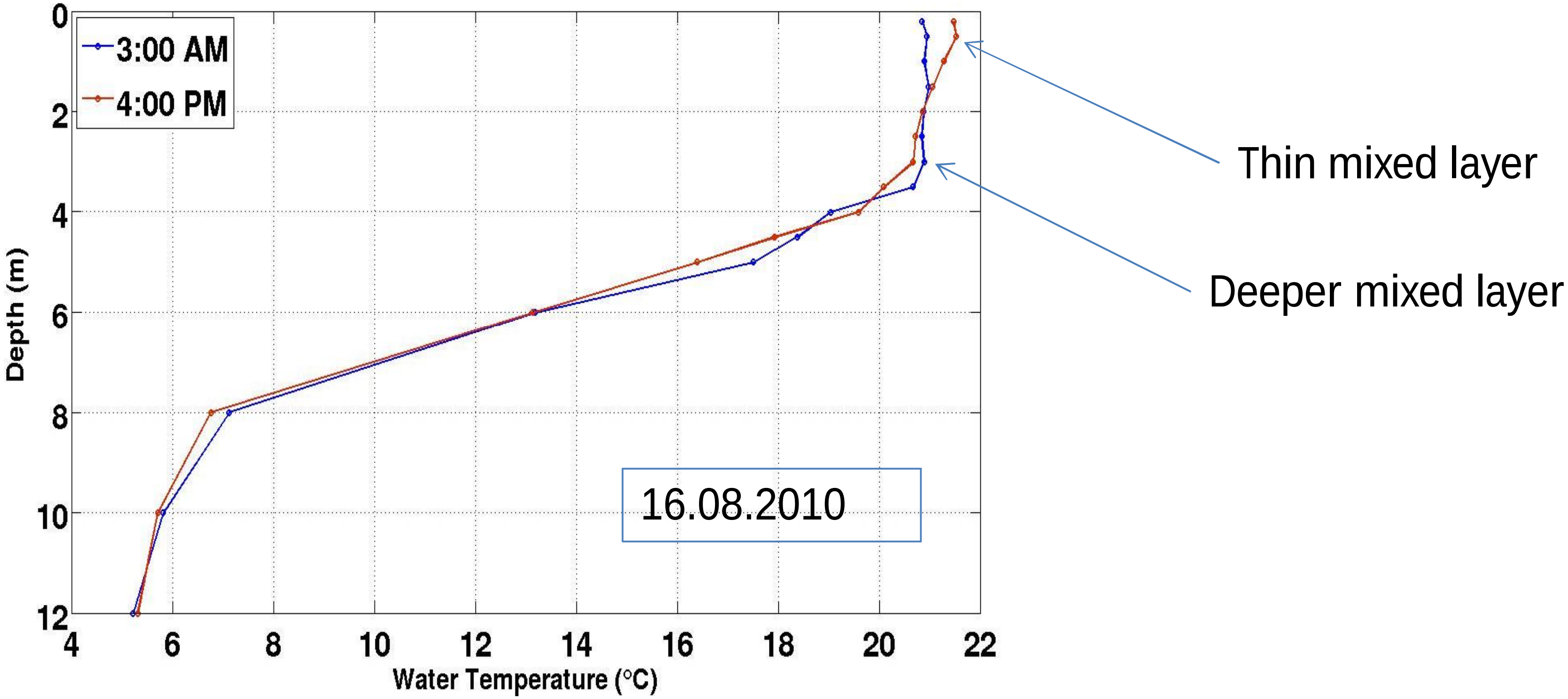
$$q(z) = q(0)\exp(-\gamma z)$$

γ is the light attenuation coeff, taken equal to 3.2 m-1

Beer's law is applied to PAR measurements to quantify the penetration of radiation in the water column.

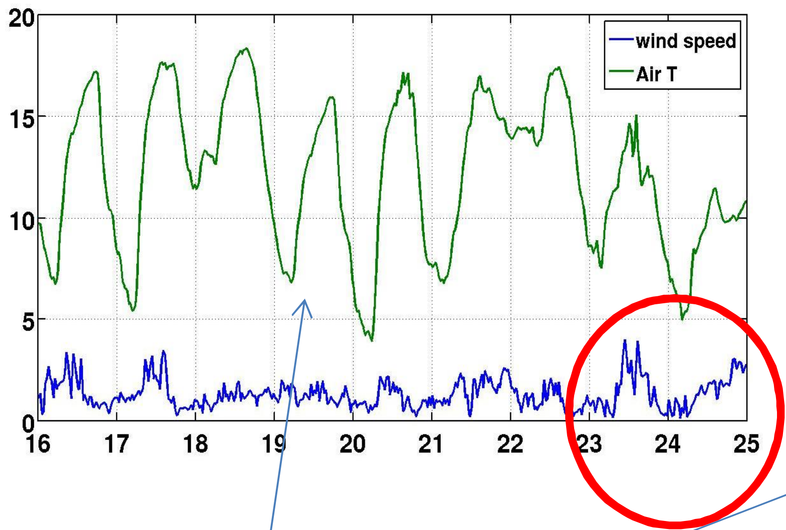
Sign convection for Heff: it is negative when the lake is cooling, and positive when the lake is heating.
Note that during night-time Heff = Hnet.

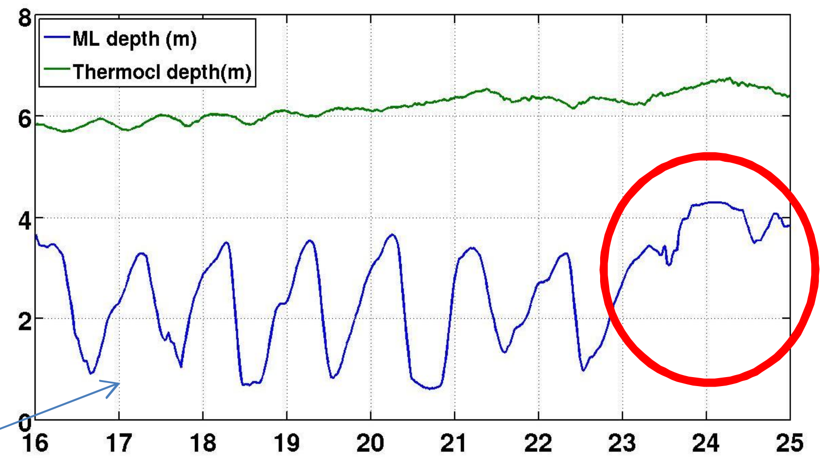
Diurnal variation of water stratification and mixed layer depth during summer

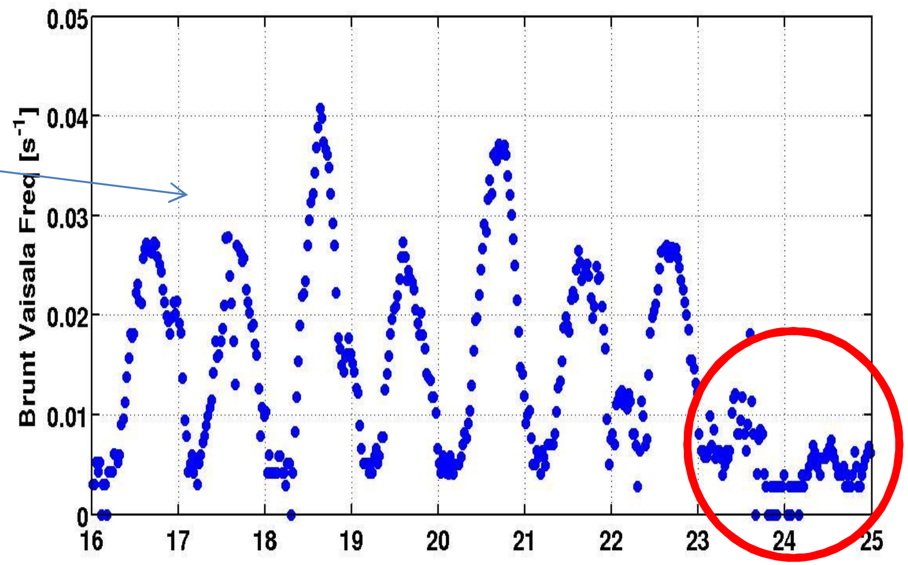


ML depth was estimated from temperature profile as the depth where the temperature deviates more than 0.2 Celsius degree from the surface temperature.

Example (15-25 Aug 2010)



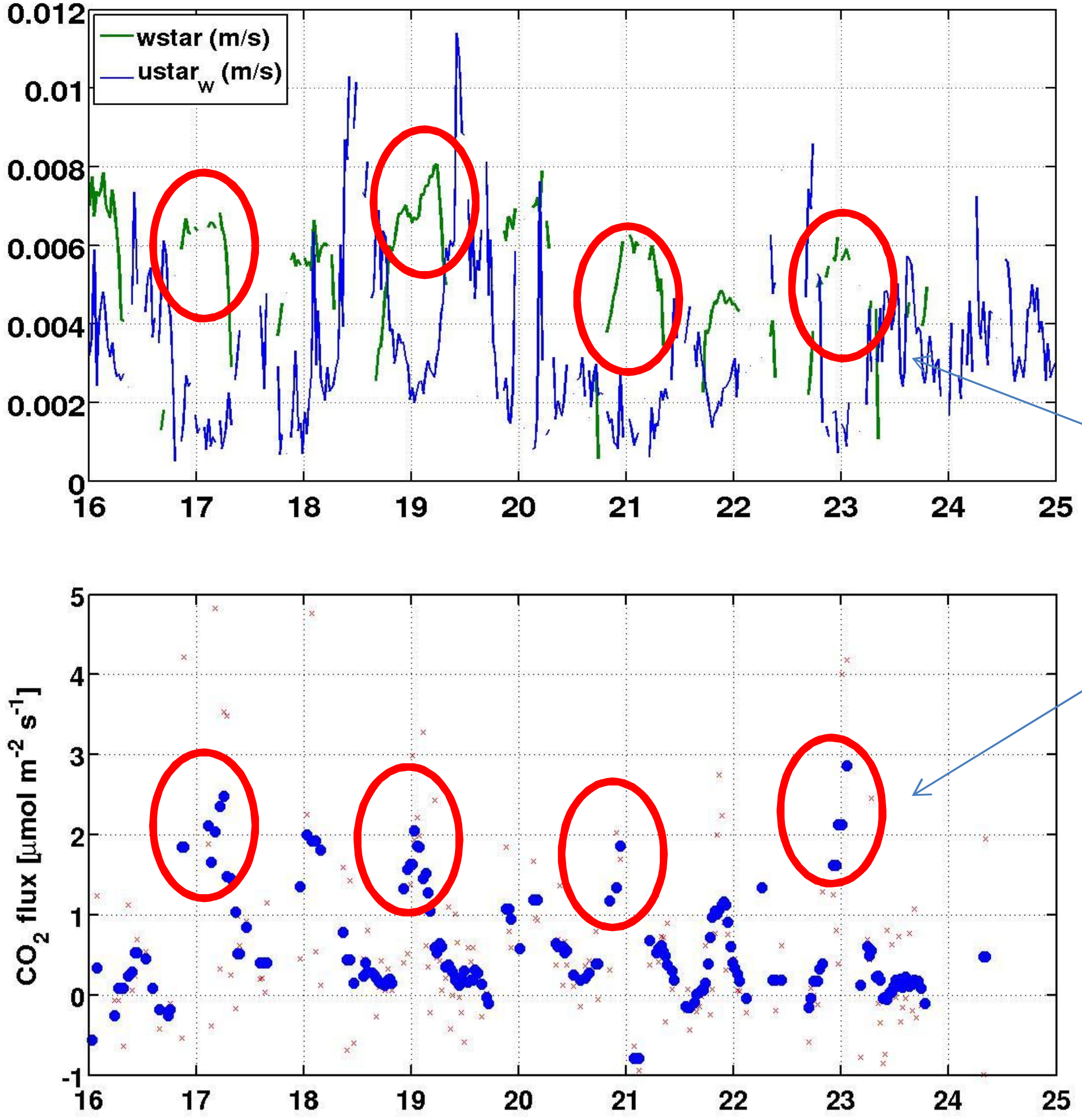




Strong diurnal cycle

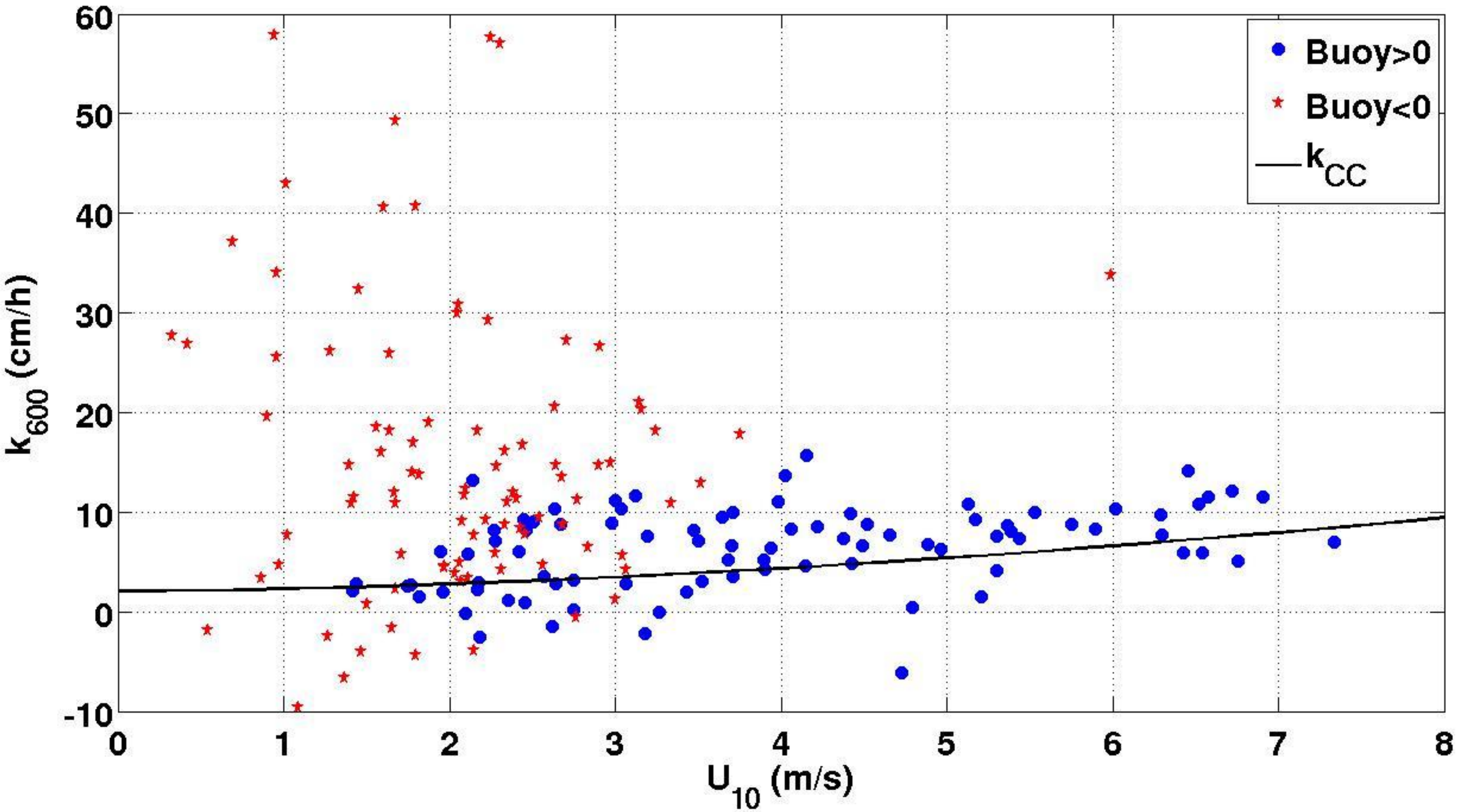
Front breaks the diurnal cycle

Example (15-25 Aug 2010)



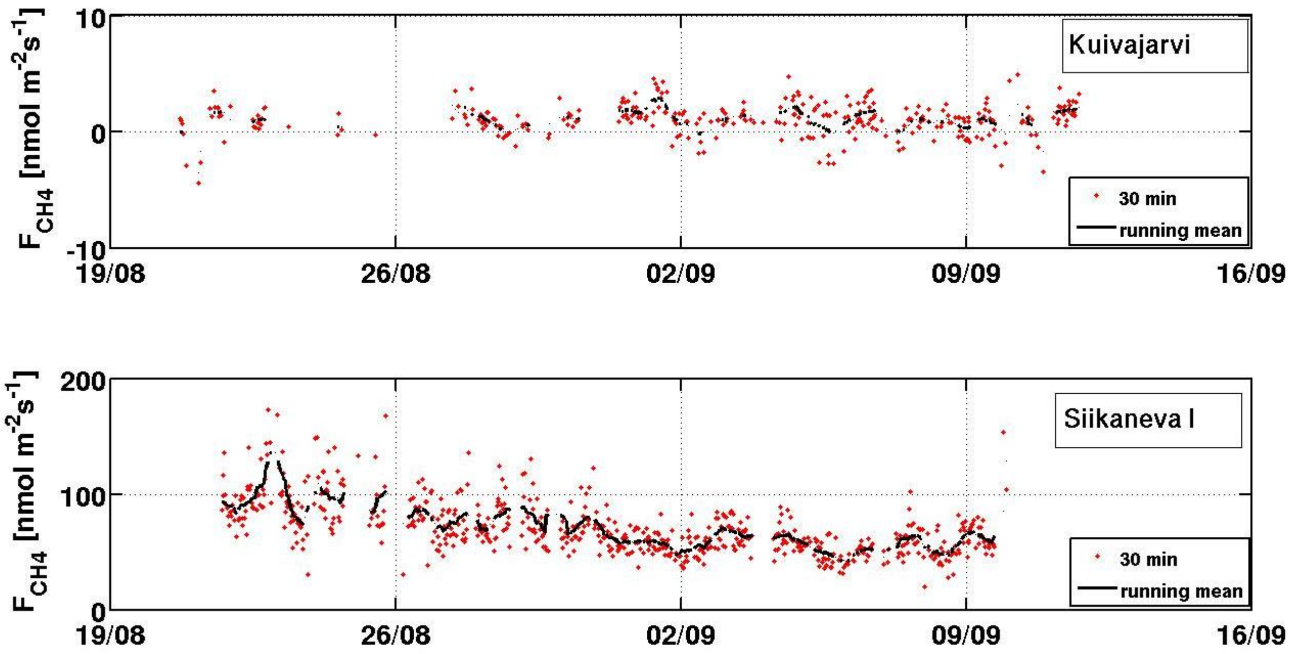
W* > u*

Gas transfer velocity versus wind speed



Near-future plans...

- EC measurements started again in June 2012 (data have been already post-processed).
- On-going EC CH4 flux measurement campaign (Aug 2012 – Nov 2012).



- Turbulence measurement in the water by ADV/microstructure profiler (September 2012 and during next year).

- Compare EC flux with chamber flux.

- Systematic analysis of buoyancy driven mixing events.

- Analysis of energy balance and exchange processes during winter periods.

- Data are available for model validation and comparison studies.


THANKS!!!