A discussion on the paper "Diel cycle of lake-air CO_2 flux from a shallow lake and the impact of waterside convection on the transfer velocity"

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1 Background

Estimations of the magnitude of global CO_2 emissions from lakes are still questionable due to uncertainties in estimations of the amount of CO_2 in the water, the surface area of global inland waters, and the parameterization of the gas transfer velocity. *(Raymond et al, 2013)*

CO_2 gas flux (FCO_2) over an air-water surface is driven by the difference in partial pressure of CO_2 in the water (pCO_{2w}) and in the air above (pCO_{2a}) and the efficiency of the gas transfer, the gas transfer velocity (k)

$$FCO_2 = K_0 \, k \, (pCO_{2w} - pCO_{2a}) \qquad (1)$$

K_0 is a gas specific solubility constant

Most commonly, the transfer velocity (k) is parameterized solely by horizontal wind speed, and k is parameterized as follow when calculate diffusive gas fluxes from lakes according to Cole and Caraco (1998)

$$k = 2.07 + 0.215\, u_{10}^{1.7} \qquad (2)$$

u_{10} is wind speed at 10 m

However, other processes are also important for *k*, e.g., wave breaking, spray, bubbles, and waterside convection *(Woolf, 1993;MacIntyre et al, 2001; Zappa et al, 2001; Rutgersson et al, 2010).*

Rutgersson and Smedman (2010) proposed that the transfer velocity parameterization should have one part depending on wind speed and one depending on the strength of waterside convection according to the measurement of k at the interface of sea-air.

The strength of waterside convection can be expressed with a waterside convective velocity scale (w_{*w}) defined as

$$w_{*w} = (B\ h)^{1/3} \qquad (3)$$

h is the mixed layer depth

B is the waterside buoyancy flux defined as:

$$B=(g\ a\ Q_{eff})/(c_{pw}\ \rho_w) \qquad (4)$$

g is the acceleration of gravity; a is the thermal expansion coefficient; Q_{eff} is the effective surface heat flux, cpw is the specific heat of water; and ρw is the density of the water

MacIntyre et al(2001) proposed that waterside convection will be important when wind speeds are lower than $5 m\ s^{-1}$.

Rutgersson and Smedman (2010) proposed that waterside convection is important only when w_{*w} is larger than $0.006 m\ s^{-1}$.

Imberger (1985) studied the ratio of waterside friction velocity (u_{*w}) and w_{*w},

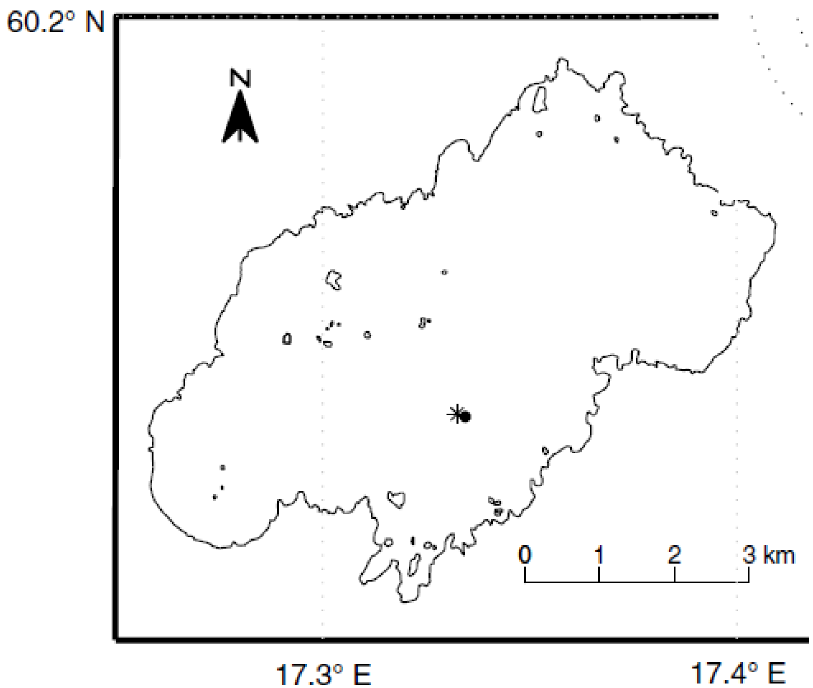
$u_{*w}/w_{*w} > 0.75$, wind dominates the waterside turbulence,

$u_{*w}/w_{*w} < 0.75$,waterside convection dominates.

$u_{*w} = u_{*a}(\rho_a/\rho_w)$, u_{*a} is the friction velocity in the atmosphere

and ρ_a and ρ_w are the densities of the atmosphere and the water, respectively.

2 Study site



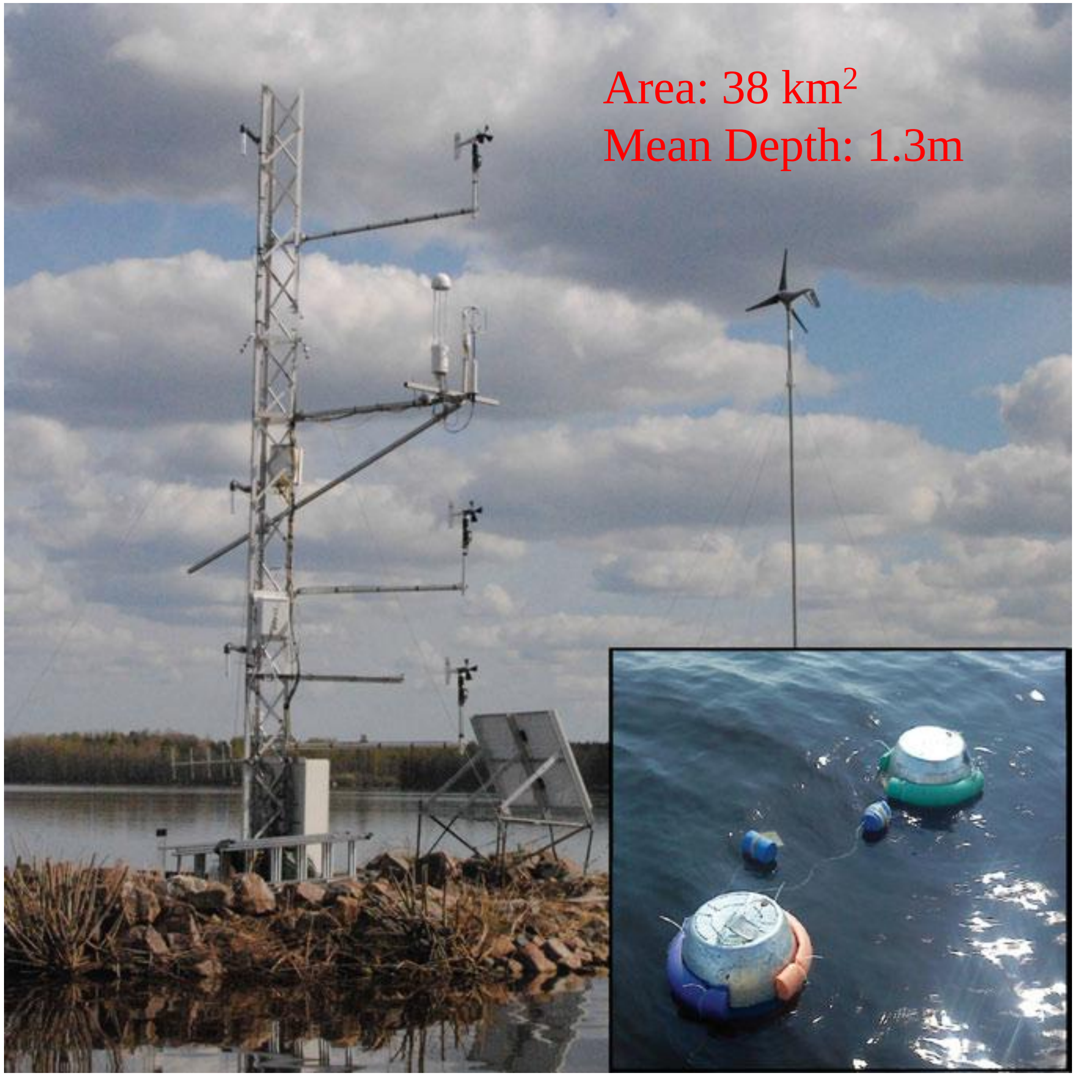


Figure 1. Map of Lake Tamnaren
The dot and star mark the position of EC tower and the float

A float was positioned and equipped with a Submersible Autonomous Moored Instrument Sensor which could continuously measured $p\mathrm{CO}_{2\mathrm{W}}$

3 Results

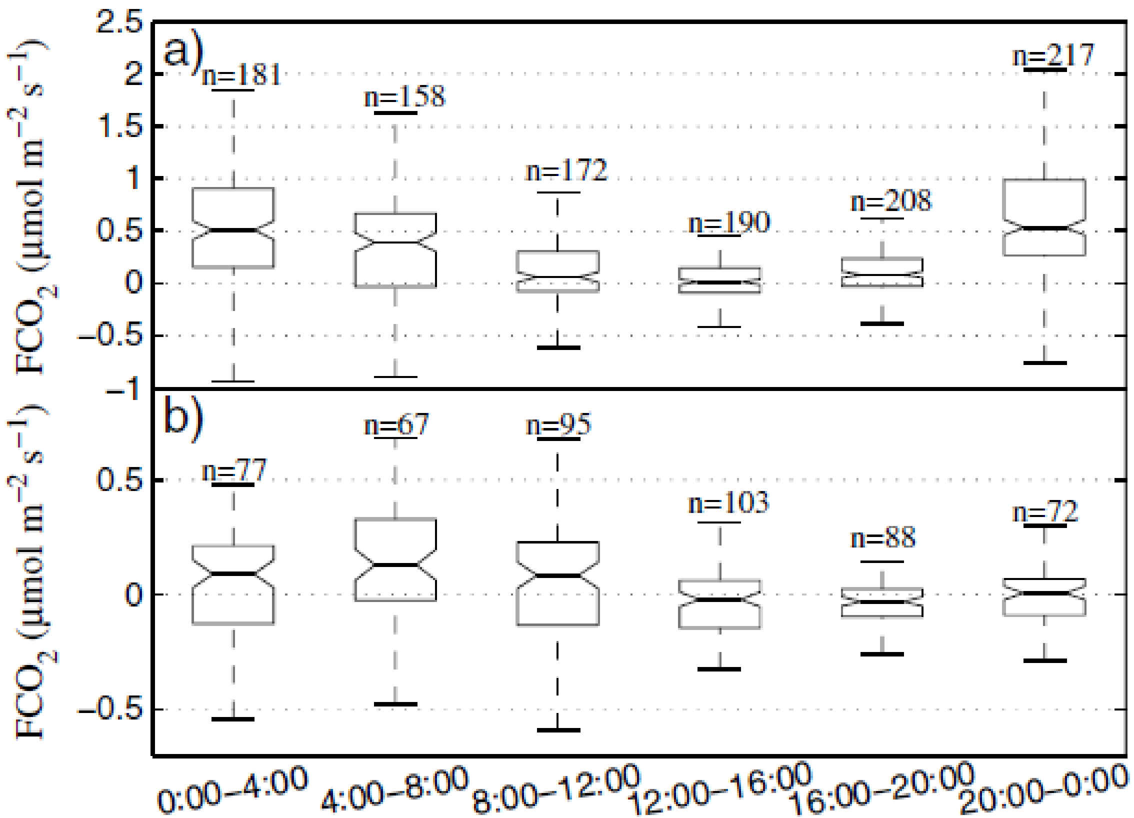


Figure 2 (a) CO_2 fluxes measured during summer (b) CO_2 fluxes measured during autumn

A diel cycle is seen with higher fluxes during nighttime and lower during Day at summer and autumn

The high nighttime fluxes are not explained by changes in wind speed or ΔpCO_2

The mean FCO_2 ($\mu mol\ m^{-2}\ s^{-1}$) and pCO_{2w} (ppm)

	Summer	Autumn
FCO_2	0.36	0.04
pCO_{2w}	652	521

Transfer velocity

The high nighttime fluxes is studied with focus on transfer velocity *(k)*

$$FCO_2 = K_0\ k\ (pCO_{2W} - pCO_{2a}) \qquad (1)$$

$$\Rightarrow \quad k_{600,\ meas} = \frac{FCO_2}{K_0(pCO_{2w} - pCO_{2a})}$$

FCO_2 is measured by EC method(Li-7500), and pCO_{2w} and pCO_{2a} were measured simultaneous

According to *Cole and Caraco (1998*), the transfer *velocity(k*) which is parameterized solely by horizontal wind speed defined as

$$k_{600,cc} = 2.07 + 0.215\ u_{10}^{1.7}$$

$(k_{600,meas} - k_{600,cc})$ can representative the effect of waterside convection on transfer velocity

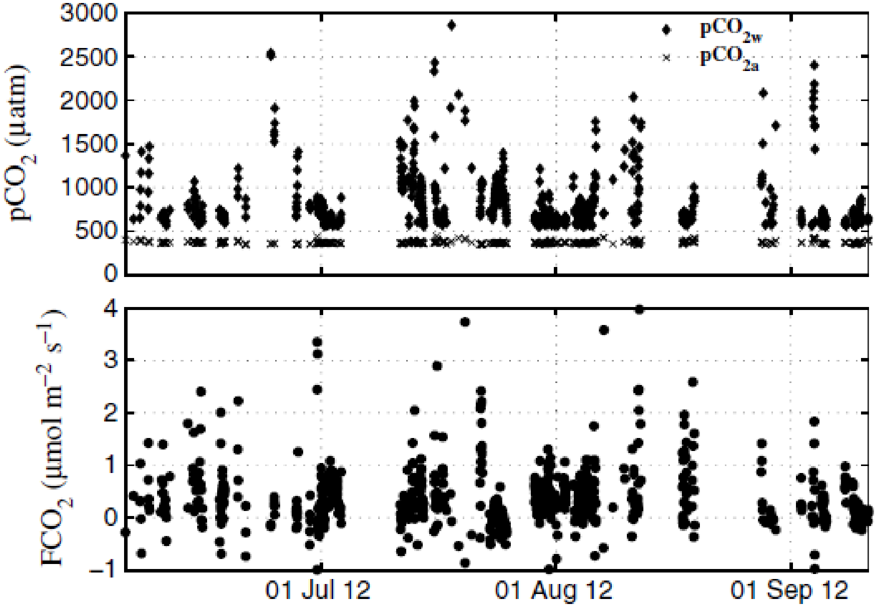


Figure 3. Half –hour mean values of
(a) pCO_{2a}(crosses) and pCO_{2W}(dots)
(b) CO_2 flux measure during wind directions coming from the float

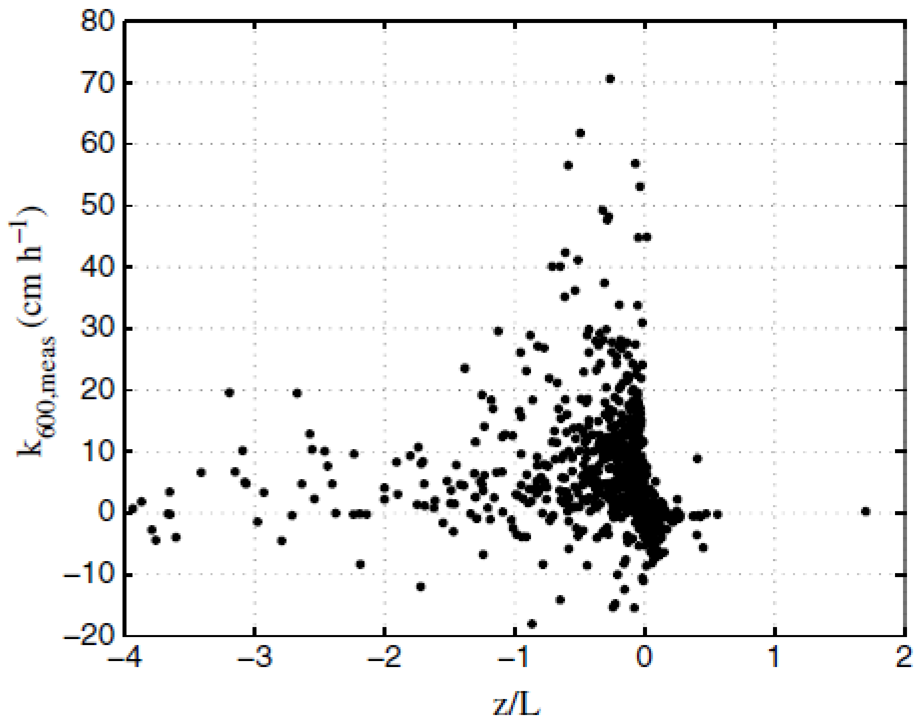


Figure 4. Half –hour mean transfer velocities as a function of atmospheric stability expressed by *z/L*

The lake was always suspersaturated with CO_2, and negative CO_2 flux may be caused by the stably stratified of atmosphere ($z/L > 0$)which could resulted in negative transfer velocities. All data during stable stratification are disregarded.

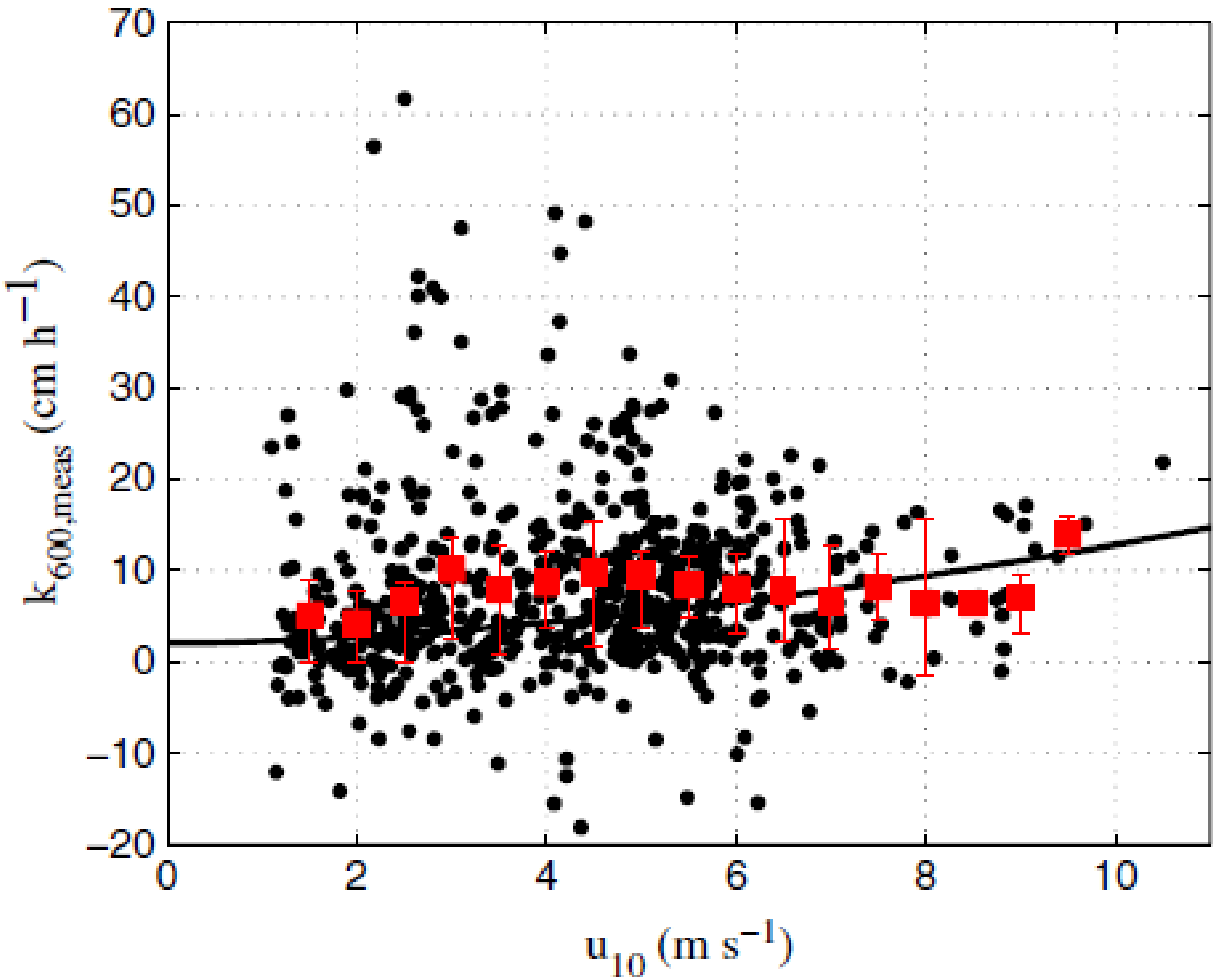


Figure 5. Transfer velocity ($k_{600,meas}$) as function of wind speed. The red squares represent the bin averaged values (bin size 0.5m s $^{-1}$), and the bars represent the 25th and 75th percentiles for each bin. The line represents the parameterization of *Cole and Caraco* ($k_{600,cc}$)

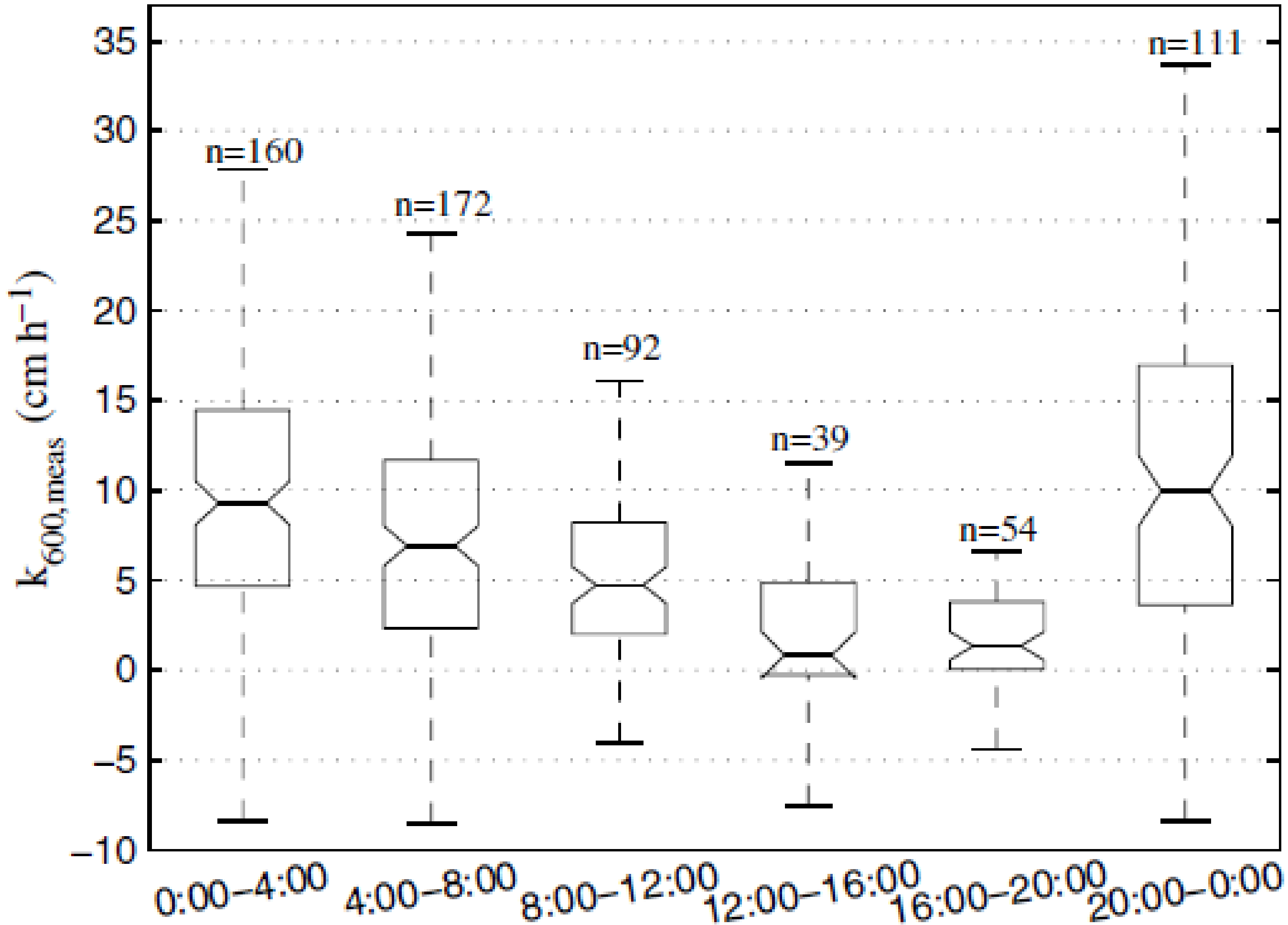


Figure 6. Transfer velocities as function of the time of day

The results in this paper indicate that waterside convection can partly predict the elevated fluxes during nighttime.

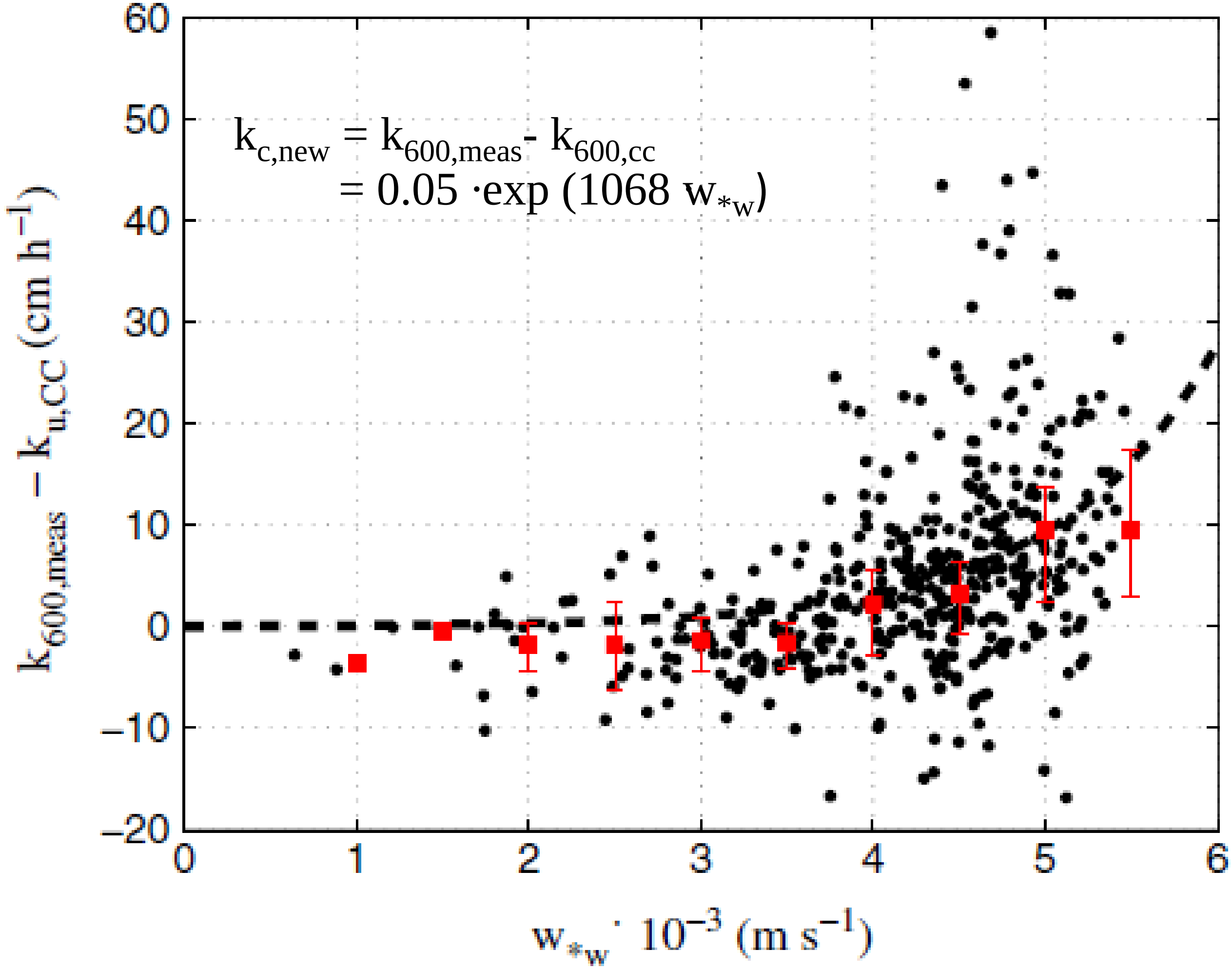
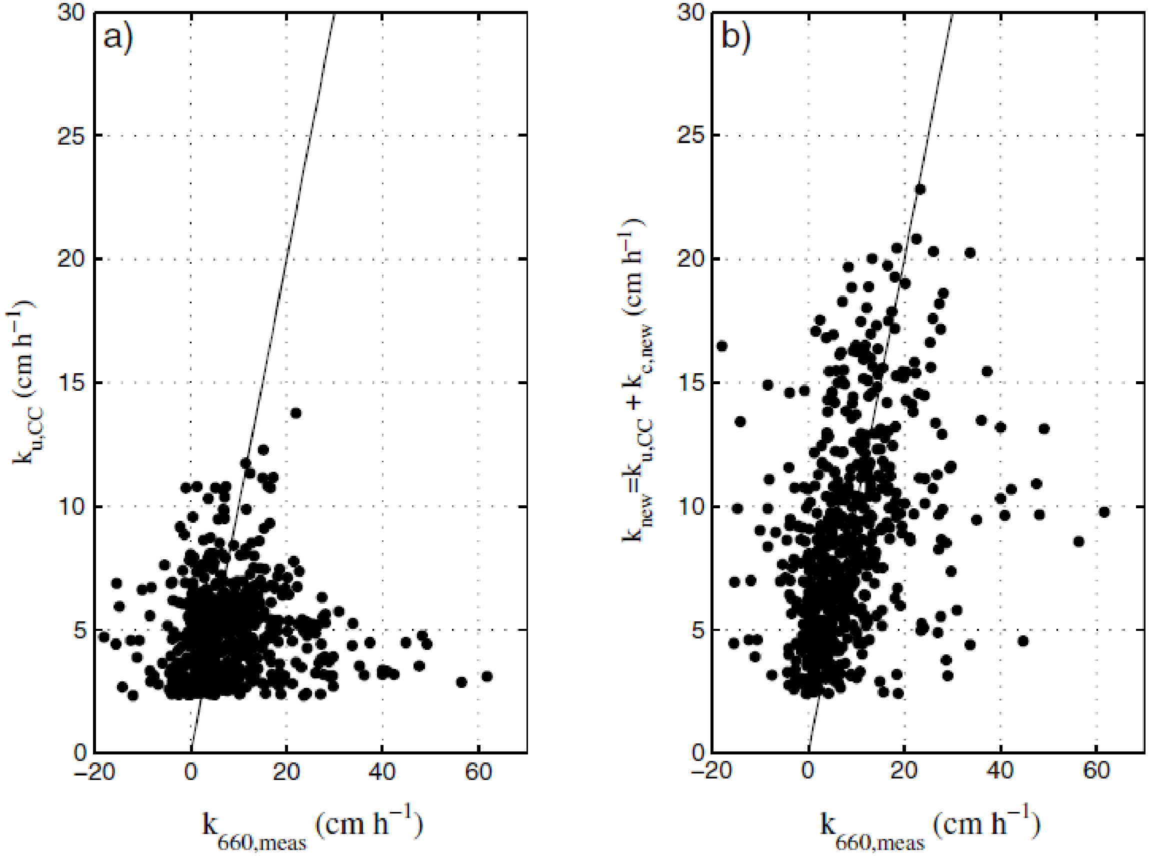


Figure 7. Measured transfer velocities subtracted by the wind speed dependent ($k_{600,meas} - k_{600,cc}$)parameterization as function of w_{*w}. The red squares represent bin averaged values (bin size $w_{*w} = 0.5$m s^{-1})

4 Discussion



$k_{600,meas}$: the measured transfer velocity by EC

$k_{u,cc} = k_{600,cc}$
$= 2.07 + 0.215\, u_{10}^{1.7}$

$k_{c,new} = k_{600,meas} - k_{600,cc}$
$= 0.05 \cdot \exp(1068\, w^*w)$

$k_{new} = k_{u,cc} + k_{c,new}$

Figure 8. (a) The wind speed dependent ($k_{u,cc}$) parameterization as function of the $k_{600,meas}$, and (b) the new transfer velocity parameterization as function of the $k_{600,meas}$

$$k_{600,\ meas} = \frac{FCO_2}{K_0(pCO_{2w} - pCO_{2a})}$$

The gas flux (FCO_2) measured represents the flux from an upwind area, while the waterside measurements, pCO_{2w}, are point measurements at a certain depth.

Conditions with a varying pCO_{2w} in the flux footprint not related to the measured flux and consequently an erroneous transfer velocity

In an attempt to estimate such inhomogeneity, the transfer velocity was calculated for two additional cases with a pCO_{2w} varying with ±200 ppm

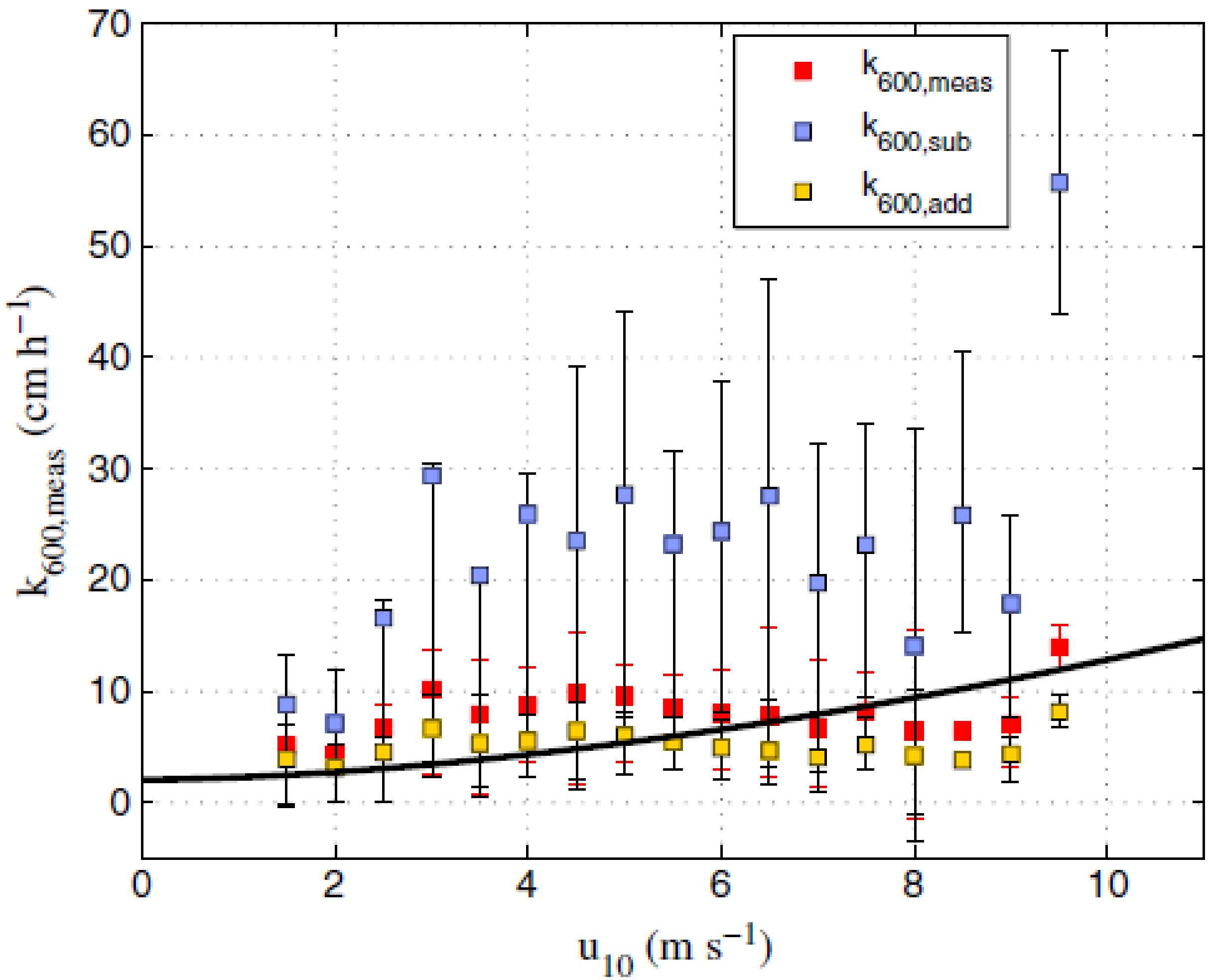


Figure 9. Bin averaged values (bin size 0.5m s $^{-1}$) of the transfer velocity as a function of wind speed. The red squares represent the transfer velocities calculated using the observed pCO_{2w}, the blue squares represent the transfer velocities calculated using pCO_{2w} -200 ppm, and the yellow squares represent the transfer velocities calculated using pCO_{2w} + 200 ppm.

Waterside convection is the dominate process for air-water gas transfer according to three previous studies

1. $u<5\ ms^{-1}$ *(MacIntyre et al, 2001)*

2. $w_{*w} > 0.006\ m\ s^{-1}$ *(Rutgersson and Smedman,2010)*

3. $u_{*w}/w_{*w}<0.75$ *(Imberger, 1985)*

However, elevated transfer velocities were observed for wind speeds > 5 m s^{-1}, $w_{*w}< 0.006$m s^{-1}, and $u_{*w}/w_{*w} > 0.75$ in the paper.

Thus, it may not be possible to set a universal limit of w_{*w} for classification of cases when waterside convection impacts the air-water gas transfer

Most studies estimating global CO_2 emissions from lakes use transfer velocities parameterized by wind speed.

The mean wind speed dependent parameterization is approximately 60% lower than the mean knew, which depends on both wind speed and waterside convection in the paper

By basing global CO_2 emission estimates on transfer velocity parameterizations that include waterside convection, lakes would probably have an even larger impact on the global carbon cycle compared to current estimates.

Thank you