A discussion on the paper
“Diel cycle of lake-air CO₂ flux from a shallow lake and the impact of waterside convection on the transfer velocity”
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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 ($p_{CO_2w}$) and in the air above ($p_{CO_2a}$) and the efficiency of the gas transfer, the gas transfer velocity ($k$)

$$F_{CO_2} = K_0 \ k \ (p_{CO_2w} - p_{CO_2a})$$ (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)

$$k = 2.07 + 0.215 \, u_{10}^{1.7}$$

($2$)

$u_{10}$ 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

\[
w_{*w} = (B \cdot h)^{1/3}
\]  

(3)

\(h\) is the mixed layer depth

\(B\) is the waterside buoyancy flux defined as:

\[
B = \frac{g \cdot a \cdot Q_{\text{eff}}}{c_{pw} \cdot \rho_w}
\]  

(4)

g is the acceleration of gravity; \(a\) is the thermal expansion coefficient; \(Q_{\text{eff}}\) is the effective surface heat flux, \(c_{pw}\) is the specific heat of water; and \(\rho_w\) is the density of the water
MacIntyre et al (2001) proposed that waterside convection will be important when wind speeds are lower than 5m s\(^{-1}\).

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

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

\[
\frac{u_{*w}}{w_{*w}} > 0.75, \text{ wind dominates the waterside turbulence,}
\]

\[
\frac{u_{*w}}{w_{*w}} < 0.75, \text{ waterside convection dominates.}
\]

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

and \( \rho_a \) and \( \rho_w \) 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 measure $pCO_{2w}$
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 mean FCO$_2$ (μmol m$^{-2}$ s$^{-1}$) and $p$CO$_2w$ (ppm)

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCO$_2$</td>
<td>0.36</td>
<td>0.04</td>
</tr>
<tr>
<td>$p$CO$_2w$</td>
<td>652</td>
<td>521</td>
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</tbody>
</table>

The high nighttime fluxes are not explained by changes in wind speed or Δ$p$CO$_2$
Transfer velocity

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

\[
FCO_2 = K_0 \cdot k \cdot (pCO_{2w} - pCO_{2a}) \quad (1)
\]

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

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

\[
k_{600,cc} = 2.07 + 0.215 \cdot u_{10}^{1.7}
\]

\((k_{600,\text{meas}} - k_{600,cc})\) can representative the effect of waterside convection on transfer velocity.
The lake was always supersaturated with CO₂, and negative CO₂ 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 0.5 m 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 \((k_{600,\text{meas}} - k_{600,\text{cc}})\) parameterization as function of \(w_{*w}\). The red squares represent bin averaged values (bin size \(w_{*w} = 0.5\text{ m s}^{-1}\)
4 Discussion

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

\[ k_{600,\text{meas}} : \text{the measured transfer velocity by EC} \]

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

\[ k_{c,\text{new}} = k_{600,\text{meas}} - k_{600,cc} = 0.05 \cdot \exp(1068 \cdot w \cdot w) \]

\[ k_{\text{new}} = k_{u,cc} + k_{c,\text{new}} \]
The gas flux \( \text{FCO}_2 \) measured represents the flux from an upwind area, while the waterside measurements, \( p\text{CO}_2w \), are point measurements at a certain depth.

Conditions with a varying \( p\text{CO}_2w \) 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 \( p\text{CO}_2w \) varying with \( \pm 200 \text{ ppm} \)
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. \( u < 5 \text{ ms}^{-1} \) (MacIntyre et al, 2001)

2. \( w_w > 0.006 \text{ m s}^{-1} \) (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\(^{-1}\), \( w_{*w} < 0.006 \text{m s}^{-1} \), 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