Optimizing chambers for stream carbon dioxide evasion estimates; results of a controlled flume experiment

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EGU General Assembly 2020
Introduction

• Inland waters were recently discovered as a relevant player in the global carbon cycle, especially the more turbulent one are responsible of a globally large biogeochemical flux occurring across the air-water boundary.

• Quantification of CO2 degassing in headwater streams requires the estimation of the flux across air-water interface, among the many variables, of the gas exchange velocity (k).

• The k is currently estimated via different methods all of which is associated to high uncertainty.

• Here we report an analysis, supported via experimental data, of i) two differently designed chamber and of ii) two methods available to interpret the chamber data.
Floating chambers and CO2 sensors

• Chamber methodology (CO2 sensor: K33 ELG by SenseAir)

• Chamber types

  - Flexible Foil
  - Standard

... sealing design
Study setup

Configurations analysed

Table 2: Summary of the configurations setup used at the EcoCatch Flumes of the Lunz Mesocosm Infrastructure.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Discharge $[l \text{s}^{-1}]$</th>
<th>Flow velocity $[m \text{s}^{-1}]$</th>
<th>Travel Time $[s]$</th>
<th>Slope $[%]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a R6Q1</td>
<td>2.74</td>
<td>0.083</td>
<td>421</td>
<td>0.5</td>
</tr>
<tr>
<td>b R6Q2</td>
<td>5.50</td>
<td>0.126</td>
<td>278</td>
<td>0.5</td>
</tr>
<tr>
<td>c R4Q2</td>
<td>5.63</td>
<td>0.202</td>
<td>173</td>
<td>2.5</td>
</tr>
<tr>
<td>d R4Q3</td>
<td>7.04</td>
<td>0.261</td>
<td>134</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Total of 4 slope/discharge combinations.

→ Influence of the slope (b-c);
→ Influence of the discharge (a-b), (c-d).
Sampling description

• "Anchored" (i.e. "Steady")
  Fixed in a point (long-term deployments)

• "Drifting"
  Free to follow the current (measurements last up to the travel time of the chamber in the flume)

• Post-process calibration (set to 400ppm initial value)
  (This procedure does not affect k estimated via the anchored chamber)
Methods (1)

Method # 1
I. Linear model
II. CO2 water is needed (derived from steady chambers)
III. Applicable to both steady and drifting observations (in theory)

Method # 2
I. Exponential model (both k and CO2 water are estimated)
II. Applicable only to steady deployments
III. Very robust (simultaneous measure of k and CO2 water, estimate on a lot of data)
Methods (2)

Standardization to k600

→ results independent on temperature and gas type

(temperature data not available, estimated based on daily temperature expression)

\[ k_{600} = k \left( \frac{600}{SC_{CO_2}} \right)^{-n} \]

\[ SC_{CO_2} = 1742 - 91.24 T_w + 2.208 T_w^2 - 0.0219 T_w^3 \]

Generalized Likelihood Uncertainty Estimate, “GLUE”

→ assessing uncertainties

• Random generation of (k, Ce) couples and test on R-squared;
• Posterior bi-variate Probability Density Functions of k and Ce
1. Increasing monotonous trend

2. Ce = 400 ÷ 2000 ppm

3. R-squared > 0.98

4. 2 minutes of constant CO2 (equilibration with air guaranteed)
### Results and Discussion (1)

**STEADY**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$\mu_{k_{600, Std}}$ [m d$^{-1}$]</th>
<th>$CV_{k_{600, Std}}$</th>
<th>$\mu_{k_{600, FF}}$ [m d$^{-1}$]</th>
<th>$CV_{k_{600, FF}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>5.5 (3)</td>
<td>0.33</td>
<td>4.7 (1)</td>
<td>-</td>
</tr>
<tr>
<td>b</td>
<td>9.8 (2)</td>
<td>0.59</td>
<td>10.8 (3)</td>
<td>0.30</td>
</tr>
<tr>
<td>c</td>
<td>9.8 (5)</td>
<td>0.64</td>
<td>21.5 (1)</td>
<td>-</td>
</tr>
<tr>
<td>d</td>
<td>13.2 (3)</td>
<td>0.71</td>
<td>31.3 (2)</td>
<td>0.35</td>
</tr>
</tbody>
</table>

1) **higher values** of $k_{600}$ from FF chamber with respect to Std chamber, despite the lower Turbulence Kinetic Energy (ADV method) induced by the FF chamber.

Mean $k_{600}$ [m d$^{-1}$]:
- FF = 17.2
- Std = 9.46

Mean Coefficient of Variation:
- FF = 0.24
- Std = 0.55

2) **higher variability** for Std chamber with respect to FF chamber.

**DRIFTING**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$\mu_{k_{600, Std}}$ [m d$^{-1}$]</th>
<th>$CV_{k_{600, Std}}$</th>
<th>$\mu_{k_{600, FF}}$ [m d$^{-1}$]</th>
<th>$CV_{k_{600, FF}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>4.0 (3)</td>
<td>0.74</td>
<td>6.8 (2)</td>
<td>-</td>
</tr>
<tr>
<td>b</td>
<td>5.1 (2)</td>
<td>0.17</td>
<td>21.9 (2)</td>
<td>0.15</td>
</tr>
<tr>
<td>c</td>
<td>20.1 (6)</td>
<td>0.76</td>
<td>27.8 (1)</td>
<td>-</td>
</tr>
<tr>
<td>d</td>
<td>8.21 (4)</td>
<td>0.47</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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Results and Discussion (2):

SLOPE

STEADY

- FF:
  Increasing slope, $k_{600}$ increases

- Std:
  $k_{600}$ not influenced by slope

DRIFTING

- FF:
  Increasing slope, $k_{600}$ increases

- Std:
  Increasing slope, $k_{600}$ increases

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Results and Discussion (3): DISCHARGE

**STEADY**

- **FF and Std:**
  Increasing discharge, k600 increases (similar trend for lowest slope, different trend for highest slope).

**DRIFTING**

- **FF:**
  Increasing discharge, k600 increases (available only for the highest slope).

- **Std:**
  Increasing Q, k600 slightly increases (low slope);
  Increasing Q, k600 decreases (high slope).

02/05/20

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Results and Discussion (4): TURBULENCE

Energy dissipation rate vs. k600

(Velocity*gravity*slope)

- FF and Std:
  increasing εD, k600 increases ... 
  ... with different slopes, 
  ... slopes differ from Ulseth et al, 2019 but the data fall in the 95% CI supporting the truthfulness of the chamber data
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• Generalized Likelihood Uncertainty Estimation, “GLUE”

Posterior bi-variate distribution peaked on the best fit couple...
not always
• Overall assessment via the GLUE

best fit = Posterior mean

Bi-modal trend for c and d for the Std chamber;

→ FF gives a reasonable fitting also for Std chamber
Summary

• The Model (1) applied to the entire saturation curve is more robust than the most common linear method (2);

• $k_{600}$ from FF $>> k_{600}$ from Std for high $k_{600}$ (despite lower TKE!);

• FF: consistent patterns (steady vs drift, influence of $Q$ and slope);

• Std: not consistent;

• Relatively small uncertainty in the fitting (peaked post pdfs of $k$);

• When $k_{600}(Std) \neq k_{600}(FF)$, $k_{600}(FF)$ best fit is representative also for the Std;

• The chamber might influence the estimate of $k_{600}$: which is the most reliable? Need comparisons....