Field test of a portable flux-gradient system for measuring methane emission from fish ponds

Zhao Jiayu
2015.08.14
Outline

- Background
- Objectives
- Methods
- Results and Discussion
  1. Zero-gradient test result
  2. Flux-gradient observation result: CH$_4$
  3. Flux-gradient observation result: $F_c$, LE
- Conclusions
Background

- CH$_4$ is an important greenhouse gas, and the global warming potential of CH$_4$ is 25 times that of CO$_2$ (Forster et al., 2007).

- Inland waters are thought to be important natural sources of methane (Bastviken et al., 2004); in recent years, the research of greenhouse gas in the inland waters mainly focused on lake, reservoir, river, etc. Pond is a part of inland waters, but documentation of emissions from this source has been limited.

- Ponds are centers of sediment accumulation characterized by organic-rich clays. The movements of animals can trigger CH$_4$ bubbling/ebullition in the Lagoons (Gondwe et al. 2014).

- According to national fishery economic statistical bulletin, the area of pond is 26619 km$^2$, which contributes about 43.77% of freshwater aquaculture (2014).
## Background: method

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
</table>
| **Box chambers/ Anchored funnels** | 1. Easy-to-operate  
2. Low cost  
3. Ebullition (AF) | 1. Short measurement  
2. Strong labor |
| **Eddy covariance**         | 1. Directly and fast response  
2. Less interference for study site | 1. Density corrections  
2. Self-heating effects |
| **Water equilibrium method**| Multiple sites                                 | Uncertainty for the $k$                  |
| **Flux-gradient method**    | 1. Simultaneously measure the flux of $\text{H}_2\text{O}$, $\text{CO}_2$, and $\text{CH}_4$;  
2. Negligibly small density corrections;  
3. Resolve small $\text{CH}_4$ gradient and flux;  
4. Continuous and noninvasive operation. | (Xiao et al., 2014) |
Objective

- Test the portable flux-gradient system performance.
- Examine hypothesis: Pond is a strong source of CH$_4$, estimating CH$_4$ emission flux from fish pond.
Outline

- Background
- Objectives
- Methods
- Results and Discussion
  1. Zero-gradient test result
  2. Flux-gradient observation result: CH$_4$
  3. Flux-gradient observation result: $F_c$, LE
- Conclusions
Site information

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude and Longitude</th>
<th>Area</th>
<th>Water depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puhao Ecological Garden</td>
<td>32.2417° N, 118.6877° E</td>
<td>3720 m²</td>
<td>1.5m</td>
</tr>
</tbody>
</table>

A: Dining kitchen (5° — 21°)
B: Fruiter (21° — 92°)
C: Underground parking
D: Fish pond (92° — 106°) (161° — 182°)
E: Vinyl house (106° — 161°)
F: Chicken pen
G: Lobster pond (182° — 280°)
H: Fish pond (280° — 360°) (0° — 5°)
Wind Rose and Footprint

Footprint ---- FSAM model
(Condition: wind direction: 92° — 106°, ε < 0)
Instrument information

Met Station
Eddy correlation
Flux-gradient
air inlet
Eddy correlation
Met Station
Instrument information

Zero-gradient
(07.14 16:00 – 07.15 17:00)

Normal observation
(07.15 19:00 – 07.24 24:00)

Upper: 1.05m
Lower: 0.35m
Flux-gradient system

Gas intake

Gas intake

1.05m

filter

filter

0.35m

Solenoid

Buffer

4L

Buffer

4L

LGR:UGGA

1L/min

Flow meter

1.5L/min

Flow meter

1.5L/min

Bypass

pump

60s

10cm
Constant temperature heating device

UGGR

Flux-gradient system
 Principle: Off-Axis integrated cavity output spectroscopy.
- The instrument signal was recorded at 1 Hz.
- The 100 sec precision supplied by the manufacturer for the analyzer is 0.6 ppb for CH$_4$, 100 ppb for CO$_2$, and 60 ppm for H$_2$O.

Step changes in the H$_2$O, CO$_2$, and CH$_4$ mixing ratio from around 20:42:00 to 20:47:00 on DOY 201, 2015.
Flux-gradient calculation method

\[ F = -c\rho_a K \frac{r_2 - r_1}{z_2 - z_1} \]

- **F**: flux of CO\(_2\) (mg m\(^{-2}\) s\(^{-1}\)), CH\(_4\) (\(\mu\)g m\(^{-2}\) s\(^{-1}\)), or H\(_2\)O (g m\(^{-2}\) s\(^{-1}\))
- **c**: unit conversion constant (44/29 for CO\(_2\), 16/29 for CH\(_4\), and 18/29 for H\(_2\)O)
- **K**: eddy diffusivity (m\(^2\) s\(^{-1}\))
- **\(\rho_a\)**: air density (kg m\(^{-3}\))
- **r**: the half-hourly mean dry air mixing ratios
Water equilibrium method

Sample Frequency : 3h
GC: Agilent 7890B

The sample site of fish pond
(Circle: Edge of pond; Rhombus: in the pond; 2015.07.21 11:30)
GC: Agilent 6890N
Water equilibrium calculation method

\[ F = k(C_w - C_{eq}) \]

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

\[ k_{600} = 2.07 + 0.215 U_{10}^{1.7} \]

\[ \frac{U_{10}}{U} = \frac{\ln(10/z_0)}{\ln(1.5/z_0)} \]

- **\( F \)**: flux of GHGx (mol m\(^{-2}\) d\(^{-1}\), or mmol m\(^{-2}\) d\(^{-1}\))

- **\( k \)**: gas transfer coefficient (m d\(^{-1}\))

- **\( C_w \)**: measured GHGx concentration, mol m\(^{-3}\) → GC

- **\( C_{eq} \)**: GHGx concentration in equilibration with the atmosphere.
Ancillary Measurements

- Eddy covariance
  - Orientation: 180°
  - Measurements: $u_*, \theta_v, H_c, LE, F_c$

- Meteorological observation
  - Orientation: 0°
  - Wind direction
  - Wind speed
Ancillary Measurements

Water thermometer: water temperature (20cm)
YSI: water temperature (20cm), dissolved oxygen (DO), oxidation-reduction potential (ORP), specific conductance (SC).
Outline

- Background
- Objectives
- Methods
- Results and Discussion
  1. Zero-gradient test result
  2. Flux-gradient observation result: CH$_4$
  3. Flux-gradient observation result: $F_c, LE$
- Conclusions
1.1 Frequency distribution of $\text{H}_2\text{O}$, $\text{CO}_2$, and $\text{CH}_4$

<table>
<thead>
<tr>
<th></th>
<th>$\text{H}_2\text{O}$ (%v)</th>
<th>$\text{CO}_2$ (ppm)</th>
<th>$\text{CH}_4$ (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean value</strong></td>
<td>$4.3 \times 10^{-3}$</td>
<td>-0.009</td>
<td>1.30</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>0.0034</td>
<td>0.138</td>
<td>1.10</td>
</tr>
<tr>
<td><strong>Mean mixing ratio</strong></td>
<td>2.72</td>
<td>423.17</td>
<td>2317</td>
</tr>
<tr>
<td><strong>Relative percentage</strong></td>
<td>0.15%</td>
<td>0.002%</td>
<td>0.05%</td>
</tr>
</tbody>
</table>
1.2 Frequency distribution of $LE$, $F_c$, and $F_m$

<table>
<thead>
<tr>
<th>Flux</th>
<th>$LE$ (W m$^{-2}$)</th>
<th>$F_c$ (mg m$^{-2}$ s$^{-1}$)</th>
<th>$F_m$ ($\mu$g m$^{-2}$ s$^{-1}$)</th>
<th>$K$ (m$^2$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>-7.2</td>
<td>0.002</td>
<td>-0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>SD</td>
<td>6.5</td>
<td>0.019</td>
<td>0.07</td>
<td>0.01</td>
</tr>
</tbody>
</table>
## 1.3 Comparison with results of other papers

<table>
<thead>
<tr>
<th>Location</th>
<th>Method</th>
<th>CH$_4$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLW</td>
<td>Flux-gradient (picarro G1301)</td>
<td>0.2 ppb</td>
<td>(Xiao et al. 2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.016 µg m$^{-2}$ s$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Peatland surfaces</td>
<td>Closed-chamber</td>
<td>0.026 µg m$^{-2}$ s$^{-1}$</td>
<td>(Chan et al. 1998)</td>
</tr>
<tr>
<td></td>
<td>Bowen-ratio methods</td>
<td>0.6 – 7.08 µg m$^{-2}$ s$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Rice paddy field</td>
<td>TDLAS (TGA 100)</td>
<td>0.2 ppb</td>
<td>(Simpson et al. 1995)</td>
</tr>
<tr>
<td>Boreal beaver pond</td>
<td>Gas chromatography (Shimadzu Mini II)</td>
<td>4 ppb</td>
<td>(Roulet et al. 1997)</td>
</tr>
<tr>
<td>Dairy farm</td>
<td>EC system (QCL spectrometer)</td>
<td>0.67µg m$^{-2}$ s$^{-1}$</td>
<td>(Kroon et al. 2010)</td>
</tr>
<tr>
<td>Water surfaces</td>
<td>Automatic CH$_4$ chamber</td>
<td>0.053µg m$^{-2}$ s$^{-1}$</td>
<td>(Duc et al. 2012)</td>
</tr>
<tr>
<td>Fish pond</td>
<td>Flux-gradient (UGGR 915)</td>
<td>1.3ppb</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.07µg m$^{-2}$ s$^{-1}$</td>
<td></td>
</tr>
</tbody>
</table>
2.1 Temporal variation of CH$_4$ emission

Red point: open fetch; Blue point: limited fetch

$F_m$ (µg m$^{-2}$ s$^{-1}$)

2015/07/18 03:30 /199.1458
CH$_4$ flux: 5.23 µg m$^{-2}$ s$^{-1}$
2.2 Frequency distribution of $F_m$

93% of CH$_4$ half-hourly fluxes were higher in the magnitude than the measurement precision (0.07$\mu$g m$^{-2}$ s$^{-1}$).

<table>
<thead>
<tr>
<th></th>
<th>$F_m$ (µg m$^{-2}$ s$^{-1}$)</th>
<th>$K$ (m$^2$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>0.91</td>
<td>0.05</td>
</tr>
<tr>
<td>SD</td>
<td>1.05</td>
<td>0.02</td>
</tr>
</tbody>
</table>
2.3 Comparison with water equilibrium results

1. Comparison with flux-gradient calculation result, the water equilibrium calculation result (0.002 μg m\(^{-2}\) s\(^{-1}\)) was 445 times lower (This study).

2. Boundary model estimates were 5–30 times lower leading to a strong underestimation of methane fluxes from aquatic systems (J. Schubert et al. 2012).
Wind rose diagrams of CH$_4$ flux from different zones near the ponds

### Table: CH$_4$ Flux from Different Zones Near the Ponds

<table>
<thead>
<tr>
<th>Surface</th>
<th>Range (µg m$^{-2}$ s$^{-1}$)</th>
<th>Mean value (µg m$^{-2}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dining kitchen</td>
<td>(0.01, 1.44)</td>
<td>0.27</td>
</tr>
<tr>
<td>Fruiter (park, WC)</td>
<td>(0.01, 2.33)</td>
<td>0.38</td>
</tr>
<tr>
<td>Fish pond</td>
<td>(0.04, 5.23)</td>
<td>0.91</td>
</tr>
<tr>
<td>Vinyl house</td>
<td>(0.17, 0.46)</td>
<td>0.32</td>
</tr>
<tr>
<td>Lobster pond</td>
<td>(0.20, 1.38)</td>
<td>0.60</td>
</tr>
<tr>
<td>Fish pond</td>
<td>(-0.20, 2.32)</td>
<td>0.47</td>
</tr>
</tbody>
</table>
## 2.5 Comparison with results of other papers

<table>
<thead>
<tr>
<th>Location</th>
<th>Method</th>
<th>Flux (µg m(^{-2}) s(^{-1}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLW (2012.05 ~ 2014.01)</td>
<td>Flux-gradient</td>
<td>0.056</td>
<td>(Xiao et al. 2014)</td>
</tr>
<tr>
<td>BFG (2014.5~ 2014.8)</td>
<td>EC (Model Li-7700)</td>
<td>0.367</td>
<td>Xiao report</td>
</tr>
<tr>
<td>Taihu</td>
<td>Water equilibrium</td>
<td>0.017</td>
<td>Zhang report</td>
</tr>
<tr>
<td>Min jiang</td>
<td>Shrimp pond</td>
<td>0.28</td>
<td>(Yang et al. 2012)</td>
</tr>
<tr>
<td></td>
<td>Culturing pond</td>
<td>1.59</td>
<td></td>
</tr>
<tr>
<td>Min jiang (Pond)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AFC</td>
<td>0.14</td>
<td>(Duc et al. 2012)</td>
</tr>
<tr>
<td>Fish pond (Puhao)</td>
<td>Flux-gradient</td>
<td>0.91</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>Water equilibrium</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Lagoons (Delta)</td>
<td>Static chamber</td>
<td>4.69</td>
<td>(Gondwe et al. 2014)</td>
</tr>
<tr>
<td>Nihe reservoir (summer)</td>
<td>Floating chamber</td>
<td>3.74</td>
<td>(Yu et al. 2012)</td>
</tr>
<tr>
<td>Ditches</td>
<td>Floating chamber</td>
<td>9.36</td>
<td>(Schrier et al. 2011)</td>
</tr>
</tbody>
</table>
3.1 Flux-gradient test result : $F_c$

1. 90% of CO$_2$ half-hourly fluxes were higher in the magnitude than the measurement precision (0.019 mg m$^{-2}$ s$^{-1}$).

2. Comparison with flux-gradient result (0.042), the water equilibrium result (0.009 mg m$^{-2}$ s$^{-1}$) was 5 times lower (This study).

\[ y = 0.40(\pm 0.05)x + 0.03(\pm 0.001) \]
\[ (R^2=0.02, p < 0.05) \]

where $y$ is the FG flux; $x$ is EC flux.
3.2 Flux-gradient test result: $LE$

$80\%$ of $H_2O$ half-hourly fluxes were higher in the magnitude than the measurement precision ($6.5W \text{ m}^{-2}$).

$y = 0.63(\pm0.05)x + 0.81(\pm2.12)$

($R^2=0.42$, $p < 0.001$)

where $y$ is the FG flux; $x$ is EC flux
Outline

- Background
- Objectives
- Methods
- Results and Discussion
  1. Zero-gradient test result
  2. Flux-gradient observation result: CH$_4$
  3. Flux-gradient observation result: $F_c, LE$
- Conclusions
Conclusions

- Results of zero-gradient test show that the flux measurement precision of 6.5 W m\(^{-2}\) for water vapor, 0.019 for CO\(_2\) mg m\(^{-2}\) s\(^{-1}\), and 0.07 for CH\(_4\) µg m\(^{-2}\) s\(^{-1}\).

- During the flux-gradient measurement period, 80%, 90%, and 93% of H\(_2\)O, CO\(_2\), and CH\(_4\) half-hourly fluxes were higher in the magnitude than the measurement precision. According to the zero-gradient test results, the flux-gradient system had adequate precision for the fish pond measurement.

- The mean CH\(_4\) flux from fish pond is 0.91 µg m\(^{-2}\) s\(^{-1}\).
Future work

1. Comparison $LE$ and $F_c$ between EC and FG by using MBR method.

2. Find the reason about the times between flux-gradient results and water equilibrium results.

3. Analyzing the relationship between CH$_4$ flux and water quality parameter.

4. Summary of experiments.
Thank you