N$_2$O concentration and flux in Lake Taihu

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Outline

1. Background
2. Objective
3. Material and Method
4. Results and Discussion
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1. Background

- Inland waters are potentially important source of $\text{N}_2\text{O}$ (Beaulieu et al., 2011).

- The $\text{N}_2\text{O}$ emission in lentic ecosystem (lake, reservoir, and pond) are often neglected due to the lower ratio of water area to water volume (Mulholland et al., 2008).

   The N cycle in inland waters
The role of lake in $\text{N}_2\text{O}$ emission of aquatic system

(a) A global assessment of $\text{N}_2\text{O}$ emission fluxes for lakes, rivers, wetlands, and soil (Hu et al., 2016, Global Change Biology)

(b) Regional $\text{N}_2\text{O}$ flux fluxes for lakes, rivers and ponds (Soued et al., 2015, Nature Geoscience)

The $\text{N}_2\text{O}$ emission from lakes show high spatial heterogeneity.
• The denitrification rate of lake was significant higher (Seitzinger et al., 2006. Ecol. Appl).

• The surface area of global lakes ($5 \times 10^6$ km$^2$, Verpoorter et al., 2014) are significant higher that rivers ($6 \times 10^5$ km$^2$, Raymond et al., 2013).

• The longer water residence time in lakes are more effective for N removal (Mulholland et al., 2008).
A New High-Resolution N₂O Emission Inventory for China in 2008 (Zhou et al., 2014, EST)

It was estimated that the global highest N load and N₂O emission from aquatic ecosystem appeared in eastern of China (Seitzenge et al., 1998)
The N budget in Lake Taihu

- Inflow TN: $4.11 \times 10^4$ t yr$^{-1}$
- Outflow TN: $2.38 \times 10^4$ t yr$^{-1}$
- Atmospheric deposition: $1.1 \times 10^4$ t yr$^{-1}$
- Sediment release TN: $\sim 1 \times 10^4$ t yr$^{-1}$
- Inflow N$_2$O: 33 t yr$^{-1}$ (in the study)
- Outflow N$_2$O: 30 t yr$^{-1}$ (in the study)

The effects of anthropogenic N input on water quality and algal bloom in Lake Taihu had been well documented, but its impact on the N$_2$O emission was not clear.
The seasonal variation of (A) TN, (B) PN, (C) TDN, (D) NO$_3^-$, (E) NH$_4^+$, and (F) NO$_2^-$ at the two sampling stations in Lake Taihu (Xu et al., 2010. Limnol. Oceanogr)

The higher denitrification rate at summer may contribute the lower N load in Lake Taihu.
2. Objective

- Characterizing temporal and spatial variability of the N₂O flux in the lake;
- Investigating the biological, chemical and physical controls of the observed variabilities;
- Determining the relative contributions of anthropogenic N load to the lake N₂O emission;
- Quantifying the roles of the lake in the N₂O emission in regional water networks;
3. Material and Method

3.1 Study site

- 29 spatial sampling sites (red dots) at the seven biological zones;
- 51 rivers (green lines, outflow rivers; blue lines, inflow rivers; red lines, rivers with reversible flow);
- Eddy flux sites (red crosses): temporal sampling site;
- The Northwest Zone is hyper-eutrophic due to pollution discharged by urban and agricultural runoffs;
3.2 Flux calculation

The N$_2$O flux ($F_n$) at the water-air interface was calculated using the transfer coefficient method based on the bulk diffusion model, as:

$$F_n = k \times (C_w - C_e)$$

$C_w$ : N$_2$O concentration dissolved in the surface water (at the depth of 20-cm);

$C_{eq}$ : N$_2$O concentration in water that is in equilibrium with the atmosphere at the in-situ temperature;

$k$ : the gas transfer coefficient;
3.3 Emission factor \((EF)\) calculation

<table>
<thead>
<tr>
<th>EF</th>
<th>Equation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>(EF) (a)</td>
<td>(EF(a) = \frac{ER}{L_{\text{DIN}}})</td>
<td>ER is the annual (N_2O)-N emission rate ; (L_{\text{DIN}}) is annual DIN load</td>
</tr>
<tr>
<td>(EF) (b)</td>
<td>(EF(b) = \frac{c(N_2O)}{c(\text{DIN})})</td>
<td>(c(N_2O)) and (c(\text{DIN})) denote dissolved (N_2O)-N and DIN concentrations</td>
</tr>
<tr>
<td>(EF) (c)</td>
<td>(EF(c) = \frac{c(pN_2O)}{c(\text{DIN})})</td>
<td>(c(pN_2O)) is dissolved (N_2O) concentration in excess of equilibrium with atmospheric (N_2O) concentrations</td>
</tr>
</tbody>
</table>

\[
\text{DIN} = \text{NH}_4^+ + \text{NO}_3^- + \text{NO}_2^-
\]
Outline

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The temporal variation of $\text{N}_2\text{O}$ flux from 2011 to 2016
The spatial pattern of $\text{N}_2\text{O}$ flux ($F_n$) at (a) spring, (b) summer, (c) autumn, and (d) winter from 2012 to 2015.
The spatial pattern of DIN (a) and $EF_b$ (b) in Lake Taihu and river during autumn

In Lake Taihu: $EF_a = 0.69\%$; $EF_b = 0.27\%$

In river: $EF_{b\_\text{Inflow}} = 0.15\%$; $EF_{b\_\text{Outflow}} = 0.12\%$
Control factor of N$_2$O flux ($F_n$) temporal variation

- **Eutrophic Zone**
  - $y = 0.49x - 5.08$
  - $R^2 = 0.46$, $p < 0.001$

- **Central Zone**
  - $y = 0.20x - 3.12$
  - $R^2 = 0.38$, $p = 0.01$

- **Macrophyte Zone**
  - $y = 0.31x - 3.33$
  - $R^2 = 0.40$, $p < 0.01$
Spatial variation of environmental factors

(a) DO: dissolved oxygen concentration (mg L\(^{-1}\));
(b) pH;
(c) ORP: oxidation reduction potential (mv);
(d) Spc: specific conductance (ms cm\(^{-1}\));
(e) NH\(_4^+\) concentration (mg L\(^{-1}\));
(f) NO\(_3^-\) concentration (mg L\(^{-1}\))
Control factors of N$_2$O flux ($F_n$) spatial variation

Spatial correlation of the mean N$_2$O flux against mean water quality indices

<table>
<thead>
<tr>
<th></th>
<th>DO</th>
<th>Chl</th>
<th>Spc</th>
<th>ORP</th>
<th>pH</th>
<th>NTU</th>
<th>NH$_4^+$ (c)</th>
<th>NO$_3^-$ (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_n$ (a)</td>
<td>-0.93**</td>
<td>0.20</td>
<td>0.57**</td>
<td>0.18</td>
<td>-0.68**</td>
<td>-0.19</td>
<td>0.95**</td>
<td>0.64**</td>
</tr>
<tr>
<td>$F_n$ (b)</td>
<td>-0.55**</td>
<td>0.26</td>
<td>0.01</td>
<td>0.17</td>
<td>-0.54**</td>
<td>-0.11</td>
<td>0.63**</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*, ** Correlation is significant at the 0.05, and 0.01 level, respectively.
(a) data acquired at all the spatial sampling sites; (b) excluding sites in the Northwest Zone
(c) data acquired at November 2015;

DO: dissolved oxygen concentration (mg L$^{-1}$); Chl: chlorophyll a concentration ($\mu$g L$^{-1}$); Spc: specific conductance ($\mu$s cm$^{-1}$); ORP: oxidation reduction potential (mv); NTU: turbidity

$$F_n = 38.48 \ (\text{NH}_4^+) - 0.05 \ (\text{ORP}) - 16.26 (\text{pH}) + 156$$

$$R^2 = 0.92 \quad p < 0.001$$
The effect of N input on the N$_2$O flux in Lake Taihu (TDN: total dissolved nitrogen)
Anthropogenic N inputs controlled 70% of N$_2$O emission in Lake Taihu

<table>
<thead>
<tr>
<th>Zones</th>
<th>Surface area (km$^2$)</th>
<th>DIN (mg L$^{-1}$)</th>
<th>Mean N$_2$O flux (μmol m$^{-2}$ d$^{-1}$)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meiliang Bay</td>
<td>100</td>
<td>0.31</td>
<td>3.63</td>
<td>3.18%</td>
</tr>
<tr>
<td>Northwest Zone</td>
<td>215.6</td>
<td><strong>2.88</strong></td>
<td>37.12</td>
<td>70.15%</td>
</tr>
<tr>
<td>Central Zone</td>
<td>316.4</td>
<td>0.48</td>
<td>0.39</td>
<td>1.08%</td>
</tr>
<tr>
<td>Gonghu Bay</td>
<td>131</td>
<td>1.13</td>
<td>2.53</td>
<td>2.90%</td>
</tr>
<tr>
<td>East Zone</td>
<td>443.2</td>
<td>0.28</td>
<td>1.03</td>
<td>4.01%</td>
</tr>
<tr>
<td>Dongtaihu Bay</td>
<td>394.1</td>
<td>0.43</td>
<td>2.21</td>
<td>7.63%</td>
</tr>
<tr>
<td>Southwest Zone</td>
<td>737.5</td>
<td>0.26</td>
<td>1.71</td>
<td>11.05%</td>
</tr>
<tr>
<td>Whole lake</td>
<td>2338</td>
<td>0.72</td>
<td><strong>7.36</strong></td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{DIN} = \text{NH}_4^+ + \text{NO}_3^- + \text{NO}_2^-
\]
Lakes contributed 17% of N$_2$O emission from aquatic networks in Taihu basin

<table>
<thead>
<tr>
<th></th>
<th>Lake</th>
<th>River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>2012.2 ~ 2015.11</td>
<td>2013.5 ~ 2016.2</td>
</tr>
<tr>
<td>N$_2$O flux</td>
<td>Range: -7.13 ~ 152.76 (a)</td>
<td>-13.14~572.80 (a)</td>
</tr>
<tr>
<td></td>
<td>Mean: 7.36</td>
<td>51.92</td>
</tr>
<tr>
<td>Area (km$^2$)</td>
<td>3231</td>
<td>2320</td>
</tr>
<tr>
<td>N$_2$O yield (t yr$^{-1}$)</td>
<td>380</td>
<td>1912</td>
</tr>
</tbody>
</table>

(a) Given the large variability in observed fluxes, we proposed the reported values in the study represented all lake and river N$_2$O emission in Taihu basin.
5. Conclusions

- The N$_2$O emission flux in Lake Taihu ranged from -7.13 to 152.76 $\mu$mol m$^{-2}$ d$^{-1}$ showing large temporal and spatial variation;

- Anthropogenic N inputs controlled 70% of N$_2$O emission in the lake;

- Lakes contributed 17% of N$_2$O emission from aquatic networks in Taihu basin;
Water sampling

CO₂, CH₄, N₂O measured by GC

River in Taiu Basin

Paddy field

Algae blooming