Methane and carbon dioxide in trees: literature review and local measurement

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YNCenter Video Conference
Nanjing, China, June 7, 2013
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Introduction

Methane in trees

methane has been considered to be a powerful greenhouse gas that is thought to have contributed approximately 50% of the enhanced greenhouse effect of CO₂ since 1850. (Hansen et al., 2000)

although scientists used bottom-up method, top-down inverse method and satellite-based method to estimate the methane flux, ignoring the methane emission contributed by trees yields discrepancies between these measurements of global methane fluxes.
Two cases

1. In tropical forests, trees have the capacity to cope with soil anoxia through development of morphological adaptations. These structures might facilitate egress of soil-produced methane while they transport oxygen into the root zone.

2. In other cases, where the tree is old enough to suffer erosion in its heartwood (bacterial & fungal infection), we may also observe a significant quantity of methane in tree stem.

Either condition will render trees a methane source rather a methane sink.
Carbon dioxide in trees

A tree contain a substantial amount of gas, and carbon dioxide contributes an important part of it.

CO$_2$ concentration has been reported to range from $<1\%$ to over $26\%$, that is $30\sim750$ times higher than ambient atmospheric CO$_2$ concentration.

The seasonal variation in stem CO$_2$, generally, concentration of CO$_2$ are observed to be more during summer, particularly ar early and late summer. And diurnal pattern of CO$_2$ concentration is that CO$_2$ are highest at night and lowest at day.
similarly, there are two source of CO₂ found in stems. one is respiration of stems (live cells in inner bark, vascular cambium, and xylem) and the other is CO₂ from the rhizosphere, while the former is preponderate the latter.

Fig. 1 Schematic of important sources and sinks of CO2 inside a stemsegment of a tree.
To estimate efflux to the atmosphere ($E_A$), we propose a mass balance approach that accounts for all fluxes of carbon dioxide:

$$E_A = R_S - F_T - \Delta S$$

- $R_S$: respiration rate of stem
- $E_A$: CO$_2$ leaving the segment by diffusion through bark (efflux to atmosphere)
- $F_T$: dissolved CO$_2$ entering and leaving the segment in flowing sap (transport efflux $E_T$ - transport influx $I_T$)
- $\Delta S$: the increase or decrease in mean sap [CO$_2$] over time (storage flux, $\Delta S$)
**Fig2.** Conceptual model of CO$_2$ flux from and within a stem segment of a tree.
The contributions of external and internal fluxes (EA, FT and ΔS) to stem respiration (RS) varied diurnally and from tree to tree.

Fig. 3(1-3)

(a) stem respiration (RS) (●) efflux to atmosphere (EA) (□), ransport flux (FT) (○) storage flux (ΔS) (△)

(b) xylem sap [CO₂] above and below the cuvette ([CO₂*])

(c) sap flux and temperature in a sweetgum, beech and sycamore tree.

Measurements were made in situ in October, 2002.
**Table 1.** Six-hour mean (1 h maximum, 1 h minimum) fluxes, relative contribution of fluxes to total respiration, and total CO$_2$ respired over 24 h in three tree stem segments calculated by the mass balance approach. Measurements were made in situ in October and November 2002 at Whitehall Forest, University of Georgia, Athens, GA.
Methods

whether the gas in the stem efflux into the atmosphere ➔ mass diffusivity of wood

Although the outer bark, inner bark and cambium play as an effective barrier, the efflux can not be neglected since 45% ~ 83% CO₂ efflux out of the stem and into the atmosphere (McGuire and Teskey 2004). And we assume that it works for all gases.
Local Measurement

We choose tow plots in Nanjing (Lat. 32°03′N, Long. 118°46′E), and each plot includes 10 trees. The average diameter of trees is 20.8cm.
one is in the top of Longwang Mountain (altitude is 114m)
the other is in **NUIST**(altitude is 9m)
To measure in-situ stem gas methane and carbon dioxide concentrations, we drilled horizontally at breast height (130cm) to center with a 13cm drill bit and paste plasticine to seal the hole immediately. A few days later, the plasticine would be pierced with a 50ml gas-syringe to move 30ml of stem gas from each tree, and within one hour, analyzed by a modified gas chromatograph.
To obtain the **flux** of CH$_4$ and CO$_2$ emitted from trees, we use the diffusion equation:

\[
F = -f \rho \rho_a D \frac{r_1}{r_2} \left( \frac{\partial \omega}{\partial r} \right)_{r_2}
\]

- **F**: radial diffusion flux
- **f**: radial diffusivity scale factor (=0.017)
- **\( \rho \)**: air filled-porosity (=0.07)
- **\( \rho_a \)**: air density (=1.205kg/m$^3$)
- **D**: diffusivity in ambient air
  - (CH$_4$=0.21 cm$^2$s$^{-1}$, CO$_2$=0.57 cm$^2$s$^{-1}$)
- **\( \omega \)**: molar mixing ratio
- **r$_2$**: radius of tree trunk (=10.8cm)
- **r$_1$**: radius of heartwood (=5.4cm)
Covey's method

Since our experiment is mainly based on covey’s first experiment, we skip the one that has already been introduced and move on to their second experiment.
To prove that the stem methane is caused by heart rot not by soil-produced methane transported from the rhizosphere, they collected bark-to-pith increment cores from the same trees, separated them into anaerobic bottles, flushed them with 100%N\textsubscript{2} and sealed for 12h at 20°C. and then gas samples was withdrawn and measured in the same manner as the trunk-gas samples.

Even if the rate comparison is not reliable, it provide evidence for steam wood to produce methane. (Covey, 2012)
Gauci's method

to measure methane flux from tree stems, peatland surfaces and root-aerating pneumatophores, they selected two plots containing trees with a diameter $\geq 7\text{cm}$ at breast height during wet season in a tropical forested peatland located in the upper Sebangau River catchment in Borneo, Indonesia.
Fig. 4 methods for measuring methane fluxes from stems
Results & Discussion

during the last 2 months, we conducted 3 measurements:

Longwang Mountain: 1st 5th Apr. 2nd 10th May\((\text{CO}_2:719.12\text{ppm}; \text{CH}_4:2.04\text{ppm})\)

NUIST: 29th May\((\text{CO}_2:471.99\text{ppm}; \text{CH}_4:2.13\text{ppm})\)
CO2 concentration in Longwang Mountain

CO2 concentration in school
At the second time, a tree has extremely high methane concentration, so we take the averaged methane concentration to replace this value to have a more clear understanding of the whole condition of tree methane concentration in Longwang Mountain.
Rough calculation of global annual flux

Using the averaged data and equation presented before, we get fluxes emitted from trees is $2.45 \times 10^{-7} \text{ g/(m}^2\cdot\text{s)}$ for CH$_4$ and $1.13 \times 10^{-5} \text{ g/(m}^2\cdot\text{s)}$ for CO$_2$.

Next, we assume that only the section below 3m of a tree is taken into consideration and use the averaged tree circumference of 0.761m. Then we get the flux emitted per tree, that is $5.59 \times 10^{-7}/\text{s}$ for CH$_4$ and $2.58 \times 10^{-5}/\text{s}$ for CO$_2$. 
To attain the global annul flux, we assume that the world total forests cover is $403291 \times 10^4$ hectare, and the tree density is 1000 per hectare. And finally, we get $71.09 \text{Tg/a}$ for $\text{CH}_4$ and $3281.24 \text{Tg/a}$ for $\text{CO}_2$. ($\text{Tg/a}=\text{teragrams per year}$)

If we eliminate the extremely high value we obtain in the second time in Longwang Mountain, we still get $0.58 \text{Tg/a}$ as global annul $\text{CH}_4$ flux.
<table>
<thead>
<tr>
<th>Origin</th>
<th>CH$_4$Emission</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass (Tg/a)</td>
<td>Type (%/a)</td>
<td>Total (%/a)</td>
</tr>
<tr>
<td>Natural Emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wetlands</strong> (incl. Rice agriculture)</td>
<td>225</td>
<td>83</td>
<td>37</td>
</tr>
<tr>
<td>Termites</td>
<td>20</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Ocean</td>
<td>15</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Hydrates</td>
<td>10</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Natural Total</td>
<td>270</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>Anthropogenic Emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>110</td>
<td>33</td>
<td>18</td>
</tr>
<tr>
<td><strong>Landfills</strong></td>
<td>40</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td><strong>Ruminants</strong> (Livestock)</td>
<td>115</td>
<td>35</td>
<td>19</td>
</tr>
<tr>
<td>Waste treatment</td>
<td>25</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Biomass burning</td>
<td>40</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Anthropogenic Total</td>
<td>330</td>
<td>100</td>
<td>55</td>
</tr>
<tr>
<td>Sinks</td>
<td></td>
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<tr>
<td><strong>Soils</strong></td>
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<td>-5</td>
<td>-5</td>
</tr>
<tr>
<td><strong>TroposphericOH</strong></td>
<td>-510</td>
<td>-88</td>
<td>-85</td>
</tr>
<tr>
<td><strong>Stratospheric</strong></td>
<td>-40</td>
<td>-7</td>
<td>-7</td>
</tr>
<tr>
<td>Sink Total</td>
<td>-580</td>
<td>-100</td>
<td>-97</td>
</tr>
<tr>
<td>Emissions + Sinks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imbalance (trend)</td>
<td><strong>+20</strong></td>
<td>~2.78 Tg/(nmol/mol)</td>
<td>+7.19 (nmol/mol)/a</td>
</tr>
</tbody>
</table>

Houweling et al. (1999) give the following values for methane emissions.
• We can infer a rough value of the global annul carbon dioxide emissions that is 28386 Tg/a

<table>
<thead>
<tr>
<th>Countries with the highest CO₂ emissions</th>
<th>Carbon dioxide emissions per year (10⁶ Tons) (2006)</th>
<th>Percentage of global total</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>6,103</td>
<td>21.5%</td>
</tr>
<tr>
<td>United States</td>
<td>5,752</td>
<td>20.2%</td>
</tr>
<tr>
<td>Russia</td>
<td>1,564</td>
<td>5.5%</td>
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<tr>
<td>India</td>
<td>1,510</td>
<td>5.3%</td>
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<tr>
<td>Japan</td>
<td>1,293</td>
<td>4.6%</td>
</tr>
<tr>
<td>Germany</td>
<td>805</td>
<td>2.8%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>568</td>
<td>2.0%</td>
</tr>
<tr>
<td>Canada</td>
<td>544</td>
<td>1.9%</td>
</tr>
<tr>
<td>South Korea</td>
<td>475</td>
<td>1.7%</td>
</tr>
<tr>
<td>Italy</td>
<td>474</td>
<td>1.7%</td>
</tr>
</tbody>
</table>
Inspiration & Improvement

1. Because decay is more likely to be found in larger and older trees (Berry and Beaton, 1972; Zillgitt and Gevorkiantz, 1948), but we lack relating knowledge in plant, so it may make our experiment harder.

2. The plasticine may not guarantee a perfect sealing and it sometimes block the syringe, so we prepare to use stopper instead.

3. Gauci’s method for measurement is more likely to obtain an accurate gas emission from trees, but it takes more money and time to construct the equipment and the operation calls for more technique and concern.
4. The way we calculate the global flux is not so precise and may render it unreliable finally. first, there are two cases for trees to obtain methane and carbon dioxide in their stems, and we do little work on soil-produced gas, and can’t distinguish these two mechanisms completely.

second, there are many factors that influence methane emission from trees, but we do not fully figure them out. For example, the relationship between stem gas concentration and stem height, stem gas concentration and tree age and type, and the forest age and forest coverage, et al. In order to achieve a better calculation, we need deeper inspection and meticulous work.
5. Covey has proved that erosion in heartwood will increase methane concentration in trees, and Gauci has showed that trees are major conduits for soil-produced methane. Both of them has claimed that trees might be a significant source of methane. Currently our work is simply repeating others’. Therefore, we must find something new and different, and move further.

6. Our next plan is to estimate Chinese parasols, for we find that Chinese parasols has relatively high value of methane except for the two trees in Longwang Mountain that contain high value of methane, and due to their prevalence in Nanjing, they may have the potential to be important local source of methane here
Acknowledgement

• Professor Xuhui Lee
• Qitao Xiao, M.S. Candidate
• Hanchao Li, M.S. Candidate
• All members in YN Centre.
thank you