Overview of Carbon Dioxide and Methane Cycle Research

Apr 18, 2013 at 南京信息工程大学
Discussion Topics

- Climate change and global warming
- Causes of climate change
- Large-scale research
  - Global observation network
- Ecosystem-scale methods
  - chamber-based flux measurement
  - ecosystem flux
- Methane flux
Glacier retreat!

New Denver Glacier
British Columbia, Canada
Hydrological Cycle Disrupted

Spring of 2010 that affected Yunnan, Guizhou, Guangxi, Sichuan, Shanxi, Henan, Shaanxi, Chongqing, Hebei and Gansu.
Hydrological Cycle Disrupted

Flooding in China 2010 Summer
Damage by 2010 flood

<table>
<thead>
<tr>
<th>Duration</th>
<th>May to Sept 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatalities</td>
<td>3189+ dead, 1056+ missing</td>
</tr>
<tr>
<td>Damages:</td>
<td>$ 51.4 billion</td>
</tr>
<tr>
<td>Areas affected</td>
<td>28 provinces, autonomous regions and municipalities</td>
</tr>
</tbody>
</table>

Flooding in China 2010 Summer
2012 Arizona dust storm
Atmospheric CO$_2$ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
annual mean growth rate of CO$_2$ at Mauna Loa
Atmospheric CH$_4$ Growth Trend
Greenhouse Effect

Radiative forcing is usually quantified as the ‘rate of energy change per unit area of the globe as measured at the top of the atmosphere due to the presence of the gas species.’ When radiative forcing is evaluated as positive, the energy of the Earth-atmosphere system will ultimately increase, leading to a warming of the system.

**IPCC 2007, Changes in Atmospheric Constituents and in Radiative Forcing**

<table>
<thead>
<tr>
<th>Species</th>
<th>Concentrations and their changes</th>
<th>Radiative Forcing</th>
<th>Change since 1998 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>379 ± 0.65 ppm +13 ppm</td>
<td>1.66</td>
<td>+13</td>
</tr>
<tr>
<td>CH₄</td>
<td>1,774 ± 1.8 ppb +11 ppb</td>
<td>0.48</td>
<td>-</td>
</tr>
<tr>
<td>N₂O</td>
<td>319 ± 0.12 ppb +5 ppb</td>
<td>0.16</td>
<td>+11</td>
</tr>
</tbody>
</table>
Causes of Atmospheric $\text{CO}_2$ Increase

Burning fossil fuel
Causes of Atmospheric CO$_2$ Increase

Burning fossil fuel
A Healthy Forest Ecosystem
Causes of Atmospheric CO$_2$ Increase;  Deforestation
Global Energy Flow (W m⁻²)

This component is affected

Trenberth et al., 2009
2.0 to 2.5万年

地球的命运在我们人类的手中

THE EARTH IS IN OUR HANDS
Questions scientists are trying to answer are:

- What are the sources, sinks of CO$_2$, CH$_4$, N$_2$O?
- What are the factors that regulate these source and sink strength?
- Atmospheric CO$_2$, CH$_4$, N$_2$O trend?
- What kind of impact on climate from the changes in atmospheric CO$_2$, CH$_4$, N$_2$O concentrations?
Global Carbon cycle

- Atmospheric monitoring
- Ecosystem exchange
- Industrial monitoring
- Soil flux
- Leaf level exchange
- Sea surface exchange
Atmospheric CH$_4$ Growth Trend

Methanogenesis

- Produced in anaerobic environments
- \( \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 3\text{CO}_2 + 3\text{CH}_4 \)
- Formed at low \( Eh \) (Redox potential) \(< -200 \text{ mV} \)
## Isotopic monitoring (CH$_4$)

<table>
<thead>
<tr>
<th>Source</th>
<th>$\delta^{13}$C (‰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient background air</td>
<td>-47</td>
</tr>
<tr>
<td>Wetland</td>
<td>-70 to -60</td>
</tr>
<tr>
<td>Savanna grassland burning</td>
<td>-20 to -15</td>
</tr>
<tr>
<td>Boreal forest burning</td>
<td>-30 to -25</td>
</tr>
<tr>
<td>Ruminants digesting C$_4$ species</td>
<td>-55 to -50</td>
</tr>
<tr>
<td>Ruminants digesting C$_3$ species</td>
<td>-65 to -60</td>
</tr>
<tr>
<td>Coal and natural gas</td>
<td>-34 to -35</td>
</tr>
<tr>
<td>Rice field</td>
<td>-62</td>
</tr>
</tbody>
</table>

$$\delta^{13}C = \left( \frac{R_{sam}}{R_{std}} - 1 \right) \times 1000$$

$R = ^{13}C/^{12}C$
Keeling plot to identify the source

Research method for ecosystem:

Chamber-based flux measurement

\[ F_{CH_4} = \frac{V}{A} \frac{\partial C}{\partial t} \]

\[ y = 0.0162x + 2.8358 \]

\[ R^2 = 0.9994 \]
Requirements for chamber-based flux measurement

\[ F_{CO_2} = g \times (CO_{2 \, \text{soil}} - CO_{2 \, \text{chamber}}) \]

1. \( CO_{2 \, \text{chamber}} = CO_{2 \, \text{air}} \)
2. \( CO_{2 \, \text{soil}} \) not disturbed
3. \( P_{\text{Chamber}} = P_{\text{ambient}} \)
4. Good mixing inside chamber
5. No disturbance to soil moisture, temperature or radiation balance
Research method for ecosystem:

Eddy covariance flux measurement for $F_{CO_2}$, $F_{CH_4}$, LE, H

Data of Xu and Baldocchi

Example of 10-Hz real data!
Research method for ecosystem:

Eddy covariance flux measurement for $F_{CO_2}$, $F_{CH_4}$, LE, H

$$F = \overline{\rho_a w' s'}$$
Example of instrumentation at a flux station

Instrument Array
Walker Branch Watershed

44 m
Qn, Ra, Rn, T, RH

36 m
Qp, T, RH, Wetness, CO₂

21.1 m
CO₂

9.10 m
CO₂

0.75 m
CO₂

litter
baskets
TDR

soil
moisture

T_Soil

T_Soil
Advantages of the EC Method over other methods

It is a direct measure of the flux density, it is in situ, it introduces no disturbance on the system, it is quasi-continuous, and represents a large upwind area.
Transport of methane to atmosphere

1. Convective flow through plant conduits
2. Diffusion across the air-water boundary layer
3. Water convection
4. Direct injection into the air via bubble transport
Convective flow through plant conduits

*Phragmites Australis*

Photo copyright Henriette Kress
http://www.henriettesherbal.com
Convective flow through plant conduits
Temperature Response ??

Kim et al., Global Change Biology, 1998

(a) DOY347-365, \( Q_{10} = 2.51 \)

(b) DOY129-139, \( Q_{10} = 2.2 \)

DOY180-230, \( Q_{10} = 2.11 \)

Soil temperature (°C) vs. \( R_{eco} (\text{mol} \text{ m}^{-2} \text{s}^{-1}) \).
Diffusive CH\textsubscript{4} flux

\[ F = K_L (C_W - C_O) \]  \hspace{1cm} (1)

where \( F \) is flux in mass/area/time, \( K_L \) is the exchange coefficient across the liquid boundary layer in length/time, and \( C_W \) is the concentration of methane dissolved in the surface water. The calculated concentration of dissolved methane \( (C_O) \) in equilibrium with atmospheric methane can be expressed as

\[ C_O = \alpha p \]  \hspace{1cm} (2)

Via. Water convection

Stable stratification

Land breeze

Unstable stratification

Waterside convection

High CH₄

Increased chance of bubble formation?

Sahlee et al., 2011
Direct injection into the air via bubble transport

CH$_4$ flux vs. barometric pressure studies in the literature

  
  “At Mirror Lake, New Hampshire, we observed that sporadic methane bubble releases (ebullition) from the sediments were correlated with changes in local air pressure.”

  
  “A similar phenomenon has been known to mining engineers in the UK for more than 250 years.”
Changes in barometric pressure and landfill CH$_4$ emission

Coherence between barometric pressure and CH$_4$ emission
A wavelet coherence analysis
$y = 0.0419x + 0.5044$

$R^2 = 0.0015$
Rice paddy CH$_4$ flux

- Very few long-term CH$_4$ flux study from rice paddy in the literature
- 90% of rice production is from Asia?
Photosynthesis and methane emission from rice field

Hatala et al., 2012. *Geophysical Research Letters*, 39:
Methane Sinks

1. Reaction with hydroxyl radical in troposphere and stratosphere (~95%)
   \[ \text{CH}_4 + \text{OH} \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

2. Dry soil oxidation (~5%)
Summary

• Global warming, climate change
• Atmospheric CO$_2$ and CH$_4$ concentration increasing
• Increasing rate unprecedented
• More frequent extreme weather events, including drought, flood, hurricane etc.
• Research on CO$_2$, CH$_4$ sources and sinks
• Mitigation and adaptation
Thank You