What carbonyl sulfide teaches us about Earth's biosphere

Elliott Campbell
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1) A new tracer for the terrestrial biosphere
(Campbell et al., *Science*, 2008)
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Carbonyl Sulfide (COS or OCS)
(Campbell et al., *Science*, 2008)
(Campbell et al., *Science*, 2008)
(Campbell et al., EOS, 2017; Montzka et al., JGR, 2007; Campbell et al., Science, 2008)
Global Sources and Sinks

(Campbell et al., *Nature*, 2017)
Remote Sensing

(Glatthor et al., *GRL*, 2015)
Assessing a New Clue to How Much Carbon Plants Take Up

Current climate models disagree on how much carbon dioxide land ecosystems take up for photosynthesis. Tracking the stronger carbonyl sulfide signal could help.
Assessing a New Clue to How Much Carbon Plants Take Up

Current climate models disagree on how much carbon dioxide land ecosystems take up for photosynthesis. Tracking the stronger carbonyl sulfide signal could help.

1. **Continental**: Spatial separation of dominant sink and source

2. **Hemispheric**: Seasonality driven by plant uptake

3. **Northern Extratropics**: Long-lifetime and relatively little buffering
2) COS application: Continental Scale
(Hilton et al., *Nature Climate Change*, 2017)
(Hilton et al., *Nature Climate Change*, 2017)
Northern Site
Central Site
Southern Site

(Hilton et al., Nature Climate Change, 2017)
3) COS Applications: Northern Extratropics
Ny-lesund

Time series seasonal component

Range of the seasonal cycle
3) COS Applications: Global Scale
a) Year

COS (ppt)

1750 1800 1850 1900 1950 2000

(b) Year

COS (normalized)


(Montzka et al., JGR, 2004)

FTIR Southern Hemisphere:
- South Pole Mean (Firn, Ice, Flasks)
- Arrival Heights, Antarctica
- Wollongong, Australia
- Lauder, New Zealand

FTIR Northern Hemisphere:
- NOAA Global Surface Sites (Flasks)
- Kitt Peak, U.S.
- Jungfraujoch, Switzerland

(Private communication from F. Montzka at NOAA, 2017)
a) Current Budget

b) Industrial Source

c) Ocean Source

d) Plant Uptake

(Campbell et al., Nature, 2017)
a) Optimize $F_{OC}$
- Observation
- Model (11.5±0.9)

b) Min GPP Growth ($\Phi_{GPP} = 5\%$)
- Observation
- Model: $F_{AN}$ High (16.6±0.8)
- Model: $F_{AN}$ Med (10.4±0.4)
- Model: $F_{AN}$ Low (10.0±0.2)

c) Max GPP Growth ($\Phi_{GPP} = 34\%$)
- Observation
- Model: $F_{AN}$ High (6.8±0.4)
- Model: $F_{AN}$ Med (10.6±0.6)
- Model: $F_{AN}$ Low (17.5±0.5)

d) Optimize $F_{OC}$, $F_{AN}$, $\Phi_{GPP}$
- Observation
- Model (5.1±0.2)

(Campbell et al., Nature, 2017)
MSE samples from MCMC simulation

- Red: All parameters except $\Phi_{GPP}$
- Blue: All parameters

(Campbell et al., *Nature*, 2017)
(Campbell et al., *Nature*, 2017)
Annual mean and latitudinal distribution of TRENDSY model ensemble members.
EXTRA SLIDES
3) Next Steps: Amazon
DOE - Terrestrial Ecosystem Sciences Grant (DE-SC0011999)

- Modeling and data assimilation (UC Santa Cruz / UC Merced)
- ATTO ambient concentration measurements, eddy flux, leaf chamber, and soil chamber (UCLA/INPA)
- Airborne flask sampling (INPE / Carnegie / UC Merced)
Continental Drawdown

(Campbell et al., Science, 2008)
Leaf Chamber Observations

(Sandoval-Soto et al., JGR Biogeosciences, 2005)
Regional Analysis

(Hilton et al., *Nature Climate Change*, In Press)
More Leaf Chamber Observations

\[ \text{LRU} = \frac{F_{\text{COS}_{\text{leaf}}}}{[\text{COS}]} / \frac{F_{\text{CO}_2_{\text{leaf}}}}{[\text{CO}_2]} \]

(Stimler et al., *New Phytologist*, 2010)
Eddy Flux Observations

**ARM/SGP**

**Harvard**

(Maseyk et al., *PNAS*, 2014; Commane et al., *PNAS*, 2015)
### Terrestrial Climate Feedbacks

#### Feedbacks associated with human-mediated changes in the biosphere (W m$^{-2}$ K$^{-1}$)

<table>
<thead>
<tr>
<th>Process</th>
<th>Level of scientific understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>C cycle: CO$_2$ fertilization</td>
<td>VL</td>
</tr>
<tr>
<td>C cycle: climate</td>
<td>L</td>
</tr>
<tr>
<td>C cycle: N limit to CO$_2$ fertilization</td>
<td>VL</td>
</tr>
<tr>
<td>C cycle: N mineralization reducing climate feedback</td>
<td>VL</td>
</tr>
<tr>
<td>Permafrost and C in peatlands</td>
<td>VL</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>VL</td>
</tr>
<tr>
<td>O$_3$ phytotoxicity</td>
<td>VL</td>
</tr>
<tr>
<td>O$_3$: variable BVOC-to-NO$_x$ ratio</td>
<td>VL</td>
</tr>
<tr>
<td>Fire</td>
<td>VL</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
</tbody>
</table>

Mixed Results

(Duke FACE; MODIS NDVI; Graven et al., Nature, 2014)
Photosynthesis in Carbon-Climate Models

![Graphs showing CO2 levels and GPP normalized against different models over time.](image)
Large-Scale Variability

(Campbell et al., EOS, In Press)
New era for COS

• **First** eddy flux (Maseyk et al., PNAS, 2014)
• **First** global satellite maps (Kuai et al., JGR, 2015; Glatthor et al., GRL, 2015)
• **First** obs of glacial transition (Aydin et al., JGR, 2016)
• Anthropogenic inventory (Campbell et al., GRL, 2015)
• Soil incubations (Whelan et al., ACP, 2016)
• Column spectrometer (Wang et al., ACP, 2016)
• NOAA network (Montzka et al., JGR, 2007)
## Global Budget

**Table 1.** A Compilation of the Global Sources and Sinks Used for PCTM Simulations of Atmospheric COS$^a$

<table>
<thead>
<tr>
<th>Sources</th>
<th>Kettle <em>et al.</em>, 2002</th>
<th>This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct COS Flux From Oceans</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>Indirect COS Flux as DMS From Oceans</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>Indirect COS Flux as CS$_2$ From Oceans</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>Direct Anthropogenic Flux</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Indirect Anthropogenic Flux From CS$_2$</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>Indirect Anthropogenic Flux From DMS</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Biomass Burning</td>
<td>11</td>
<td>136</td>
</tr>
<tr>
<td>Additional (Photochemical) Ocean Flux</td>
<td></td>
<td>600</td>
</tr>
</tbody>
</table>

### Sinks

<table>
<thead>
<tr>
<th>Sinks</th>
<th>$-94$</th>
<th>$-101$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destruction by OH Radical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uptake by Canopy</td>
<td>$-238$</td>
<td>$-738$</td>
</tr>
<tr>
<td>Uptake by Soil</td>
<td>$-130$</td>
<td>$-355$</td>
</tr>
<tr>
<td>Net Total</td>
<td>$-5$</td>
<td>$-2.5$</td>
</tr>
</tbody>
</table>

$^a$Units are $1.0 \times 10^9$ g of sulfur. Fluxes changed in this study are highlighted with bold type.
Leaf Uptake of COS and CO$_2$

(Berry et al., JGR Biogeosciences, 2013)