Constraints on global carbon and heat exchanges from measurements of atmospheric O$_2$ and related tracers.

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Credits to Laure Resplandy, Yassir Eddebar
 Controls on atmospheric CO\textsubscript{2} increase

CO\textsubscript{2} + CO\textsubscript{3}\textsuperscript{2-} + H\textsubscript{2}O ⇌ 2 HCO\textsubscript{3}⁻
Controls on atmospheric $\text{CO}_2$ and $\text{O}_2$

$$\text{CO}_2 + \text{CO}_3^{2-} + \text{H}_2\text{O} \leftrightarrow 2 \text{HCO}_3^{-}$$
Scripps CO$_2$ and O$_2$ Sampling Networks

Measurements of CO$_2$ Concentration and isotopes: $^{13}$C/$^{12}$C, $^{18}$O/$^{16}$O, $^{14}$C
Measurements of O$_2$/N$_2$ ratio and Ar/N$_2$ ratio
Archive of pure CO$_2$ extracted from samples
$\delta(O_2/N_2) = \frac{(O_2 / N_2)_{sample} - (O_2 / N_2)_{reference}}{(O_2 / N_2)_{reference}}$

4.8 per meg $\sim$ 1 ppm
Controls on atmospheric CO$_2$ and O$_2$
## CO₂ budget 2000-2010 (Pg C/yr)

<table>
<thead>
<tr>
<th>Source</th>
<th>CO₂ Emissions (Pg C/yr) ± Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuel emissions</td>
<td>7.8 ± 0.6</td>
</tr>
<tr>
<td>Land use emissions</td>
<td>1.1 ± 0.8</td>
</tr>
<tr>
<td><strong>Total Sources</strong></td>
<td><strong>8.9 ± 1.0</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sink</th>
<th>CO₂ Emissions (Pg C/yr) ± Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>4.0 ± 0.2</td>
</tr>
<tr>
<td>Ocean sink</td>
<td>2.3 ± 0.7</td>
</tr>
<tr>
<td>Residual land sink</td>
<td>2.6 ± 1.2</td>
</tr>
<tr>
<td><strong>Total Sinks</strong></td>
<td><strong>8.9 ± 1.0</strong></td>
</tr>
</tbody>
</table>

- **IPCC AR5**

![Diagram showing sources and sinks]
Controls on atmospheric CO₂ and O₂
Controls on atmospheric CO₂ and O₂
Controls on atmospheric CO$_2$ and O$_2$

Atmospheric Potential Oxygen

\[ \text{APO} \sim \text{O}_2 + \text{CO}_2 \]
\[ = \text{APO}_{ff} + \text{APO}_{anth} + \text{APO}_{climate} \]

Land Biosphere  Industry

\[ \text{CO}_2 + \text{CO}_3^{2-} + \text{H}_2\text{O} \leftrightarrow 2 \text{HCO}_3^- \]
O₂, CO₂, and APO trends
APO constraint on warming

Ocean warming calculation:

\[
\frac{(1.2 \text{ per meg/yr})}{(0.87 \text{ per meg/}10^{22}\text{J})} = 14 \text{ ZJ yr}^{-1}
\]

\((1 \text{ ZJ} = 10^{21} \text{ J})\)
Increase in global ocean heat content

14 ± 4 ZJ yr⁻¹
Establishing the connection between $APO_{\text{climate}}$ and ocean warming
Manuscript in Review:

Measurements of Ar/N$_2$

Quantifying global ocean heat content changes
Measurements of trends in $\text{Ar}/\text{N}_2$ ratio

$$\delta(\text{Ar}/\text{N}_2) \text{ (per meg)} = \left( \frac{(\text{Ar}/\text{N}_2)_{\text{sample}}}{(\text{Ar}/\text{N}_2)_{\text{reference}}} - 1 \right) \times 10^6$$
Measurements of trends in Ar/N₂ ratio

(4.0 ± 1.6 per meg/decade)

\[ \frac{2.57 \text{ per meg/100 ZJ}}{10 \text{ year/decade}} \]

= 15 ± 6 ZJ/yr
Global energy balance equation

\[ \text{Heat Storage} + \alpha \Delta T_s = G \]

IR to space due to $T_s$ increase

\[ 1/\alpha = \text{climate sensitivity} \]

$\degree\text{C per W/m}^2$ of forcing, or $\degree\text{C per CO}_2$ doubling
Larger *Heat Storage* implies higher climate sensitivity

- IPCC AR5 sensitivity range +1.5K to +4.5K per doubling
  
  Used ~8 ZJ/yr for heat storage

- Upwards revision of heat storage by 5 ZJ/yr increases lower bound from 1.5 to 2.0 K per doubling.
Thank you
Temperature (°C) | 0 | 10 | 20
\hline
\(\delta(\text{Ar}/\text{N}_2)\) sensitivity (per mg/100 ZJ) | 3.9 | 2.6 | 1.8