Patterns and Variability in $\Delta^{14}C$ of CO$_2$ in Northern Hemisphere Background Air

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Calculating fossil fuel-derived CO$_2$ using $\Delta^{14}$C
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$$
\delta C_{ff} = C_{\text{meas}} \frac{\Delta_{bg} - \Delta_{\text{meas}}}{\Delta_{bg} + 1000\%} + \beta
$$

$$
\approx \frac{\Delta_{bg} - \Delta_{\text{meas}}}{2.7\% \text{ ppm}^{-1}} + \beta
$$

Components of uncertainty:

- measurement uncertainty in $\Delta^{14}$C
- uncertainty in non-fossil influences on $\Delta^{14}$C ($\beta$)
- uncertainty in background $\Delta^{14}$C
  for application of interest
Target precision:

Achieving ±25% in emissions requires ±2-3‰ in $\delta \Delta_{ff}$ at urban and continental scales

<table>
<thead>
<tr>
<th>City</th>
<th>Emissions (Mton CO$_2$ yr$^{-1}$)</th>
<th>Boundary Layer 1 km $\delta C_{ff}$ (ppm)</th>
<th>$\delta \Delta_{ff}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>73.2</td>
<td>4.3</td>
<td>-12</td>
</tr>
<tr>
<td>Chicago</td>
<td>79.1</td>
<td>5.4</td>
<td>-15</td>
</tr>
<tr>
<td>Houston</td>
<td>101.8</td>
<td>6.4</td>
<td>-17</td>
</tr>
<tr>
<td>Indianapolis</td>
<td>20.1</td>
<td>2.4</td>
<td>-6</td>
</tr>
<tr>
<td>Tokyo</td>
<td>64</td>
<td>5.6</td>
<td>-15</td>
</tr>
<tr>
<td>Seoul</td>
<td>43</td>
<td>6.3</td>
<td>-17</td>
</tr>
<tr>
<td>Beijing</td>
<td>74</td>
<td>9.4</td>
<td>-25</td>
</tr>
<tr>
<td>Shanghai</td>
<td>112</td>
<td>15</td>
<td>-41</td>
</tr>
</tbody>
</table>

Pacala et al. 2010

Hsueh et al. 2007
Measurement uncertainty

- Recent efforts have achieved $\pm 1.7 \, \%$ with AMS, equivalent to $\pm 0.6 \, \text{ppm}$ in $\delta C_{ff}$, using air standards (Graven et al. 2007; Turnbull et al. 2007)

Other uncertainties must also be reduced to roughly $2 \, \%$

- Non-fossil influences
  Turnbull et al., JGR, 2009; Graven and Gruber, ACPD, 2011

- **Background $\Delta^{14}C$**
  What is the range in $\Delta^{14}C$ for air entering North America?
$\Delta^{14}C$ in CO$_2$ at Northern Hemisphere measurement sites from Scripps

Mauna Loa: 3400 m ASL
Other sites at sea level
Average NH $\Delta^{14}C$ gradients, 2002-07

Apparent positive $\Delta^{14}C$ gradient with altitude in tropics and midlatitudes, though inter-laboratory offsets possible

La Jolla shows lowest $\Delta^{14}C$ reflecting large-scale gradient, not local influences

Variation across midlatitudes and altitudes is not known

NWR data (2003-06) from J. Turnbull and JFJ data (2002-06) from I. Levin
Year-to-year variability

Weak NH gradients in 2003
Range in $\Delta^{14}$C: ±1.8 ‰

Strong NH gradients in 2005
Range in $\Delta^{14}$C: ±2.6 ‰

Assuming constant meridional gradients could introduce biases
Seasonal variation

Seasonal maximum in fall
Amplitude increases with latitude
Smallest range in Sept-Oct, at the seasonal maximum
Variability in seasonal cycles

Amplitude high at PTB, low at LJO
Variability in seasonal cycles

Amplitude high at PTB, low at LJO

Amplitude low at PTB, high at LJO
What’s driving the patterns and variability? Can it be simulated with models?

Atmospheric transport, including:
- Vertical transport from the stratosphere
- Vertical transport from the boundary layer
- Meridional transport
- Biospheric and nuclear sources

$^{14}$C-enriched stratosphere
What’s driving the patterns and variability? Can it be simulated with models?

Air-sea fluxes, including:
- Evolving oceanic $^{14}$C exchange

Graven et al. in prep

Variable outgassing in the N. Pacific

Hamme and Keeling, 2008; Graven et al. submitted
Variation in background $\Delta^{14}C$ can also provide a measure of global emissions, if non-fossil influences and inter-hemispheric transport are understood.

Present uncertainty:  

<table>
<thead>
<tr>
<th>Total non-fossil-(\text{CO}_2)</th>
<th>Trend $\partial\Delta^{14}C/\partial t$</th>
<th>North – South Gradient $\delta\Delta^{14}C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 (%)/yr</td>
<td>3.0 (%)</td>
<td></td>
</tr>
</tbody>
</table>

This represents a potential precision of about $\pm25\%$ in global fossil fuel emissions, but it could be improved.

Levin et al. 2010
Development of $\Delta^{14}$C-based $\delta C_{ff}$ observations

$$\delta C_{ff} \approx \frac{\Delta_{bg} - \Delta_{meas}}{2.7\%_0 \text{ ppm}^{-1}} + \beta$$

Accomplishments

- Improvements in measurement precision
- Qualitative understanding of contributions to $\beta$

Challenges

- Identifying appropriate $\Delta_{bg}$
- Observing and understanding variability and trends in $\Delta_{bg}$ and $\beta$
Δ

14C data available at 7 sites

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