Carbon fluxes and transport in North America: A new perspective from three-dimensional CO$_2$ sampling

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In the framework of NACP, NOAA/ESRL/GMD is measuring vertical profiles of CO₂ and other trace-gases at 20 stations in North America, at least twice a month, up to 8 km.

- Study of CO₂ transport pathways over North America.
- Design of new methods to estimate CO₂ sources and sinks in North America.

Since 2008, some sites have been discontinued because of funding cuts…

We focus here on the 2004-06 period.

http://www.esrl.noaa.gov/gmd/ccgg/aircraft/index.html
Deriving a climatology of CO$_2$ vertical profiles (eg. CAR)

Observations

Detrended using MLO trend

Mean over the 7 years
The NOAA/ESRL network

- Strong CO$_2$ gradient between the boundary layer and the free troposphere.
- West coast show well mixed CO$_2$ throughout column relative to east coast (influence of oceanic air).
- South to North and West to East CO$_2$ gradients due to transport and flux distribution (vegetation uptake, respiration, and fossil fuel emission).

- West $\rightarrow$ East Transect

- West coast sites lagged by one month
First step: Kriging interpolation of the CO$_2$ vertical profiles

Monthly distribution of the interpolated CO$_2$ field in the Boundary Layer
First step: Kriging interpolation of the $\text{CO}_2$ vertical profiles

Monthly distribution of the interpolated $\text{CO}_2$ field in the **Free Troposphere**
Second step: Estimation of horizontal transport fluxes

\[ F_{\text{horizontal}} = \iint_S \rho \chi u \, n \, dS \]

Interpolated \( CO_2 \) and NCEP wind

Horizontal transport fluxes (GtC yr\(^{-1}\))
Third step: The Direct Carbon Budgeting Approach

Carbon mass budget equation

\[ F_{\text{surf}} = \int \int_S \rho \chi u \cdot n dS - \left. \frac{\partial C}{\partial t} \right|_{\text{vertical}} + \frac{\partial}{\partial t} \iiint_V \rho \chi dV \]

Edges

\[ FF + F_{\text{nat}} \]

Top

CO\(_2\) profile

Wind

Volume

CO\(_2\) profile

Exchanges with the upper atmosphere (convection, advection)

In

Out

8 km

h

surface CO\(_2\) fluxes
Estimates of regional $CO_2$ surface fluxes in North America

- Fossil Fuel Emission
- Air-Land Flux

Fluxes are in GtC yr$^{-1}$

Coterminous US

Legend:
- Evergreen
- Deciduous Needleleaf
- Deciduous Broadleaf
- Mixed Forest
- Woodland
- Wooded Grassland
- Closed Shrubland
- Open Shrubland
- Croplands
Estimates of regional CO\(_2\) surface fluxes in North America

- **Crop uptake**: 61%
- **Boreal forest**: 18%
- **Secondary forest regrowth**: 21%

**Coterminous US sink**: -0.51 ± 0.41 GtC.yr\(^{-1}\)

 Fluxes are in GtC.yr\(^{-1}\)
### Estimates of regional CO₂ surface fluxes in North America

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<tbody>
<tr>
<td>Temperate NA sink</td>
<td>-0.71 to</td>
<td>-1.2</td>
<td>-0.81</td>
<td>-1.26</td>
<td>-0.93</td>
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<tr>
<td></td>
<td>-0.37</td>
<td>± 0.4</td>
<td>± 0.72</td>
<td>± 0.23</td>
<td>± 0.71</td>
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<tr>
<td>Reference</td>
<td>Pacala et al., 2001</td>
<td>Fan et al., 1999</td>
<td>Gurney et al., 2002</td>
<td>Gurney et al., 2004</td>
<td>Baker et al., 2006</td>
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<tr>
<td>Method</td>
<td>Land</td>
<td>Atmospheric Inversion</td>
<td>IAV atm.</td>
<td>Joint O/A</td>
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<td>ENSO Ind.</td>
<td>High</td>
<td>Neutral</td>
<td>Moderate</td>
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<tr>
<td>Volcanic eruptions</td>
<td>El Chichón</td>
<td>Pinatubo</td>
<td>Aftermath of Pinatubo</td>
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- Estimate of fossil fuel emission for 2006-06: 1.73 GtC.yr⁻¹
- The **uncertainty** is derived from the kriging estimate of interpolation error.
- A potential **bias** comes from the convective flux, even if small at 8 km (included in uncertainty).
The NOAA/ESRL network

- The 7 years of aircraft profiles available from the NOAA/ESRL GMD network reveal strong distinct signals originating from surface fluxes and also from short and long-range transport and suggest distribution of many sources/sinks for CO$_2$ (and also of CO, SF$_6$, N$_2$O and CH$_4$).

- The aircraft profiles offer an independent estimate of regional scale fluxes.

- Based directly on the observations, the Direct Carbon Budgeting Approach confirms a weak sink in North America for 2004-2006, about a third of fossil fuel emissions, in good agreement with land-based estimates.

- Crop uptake proves to be a significant part of the US atmospheric sink, followed by secondary forest regrowth in the East.

- A potential bias of this result comes from convection.
  - Satellite obs. could help.
- The same method could be applied in other regions (South America, etc).

- This new aircraft dataset needs to be exercised by good science!

http://www.esrl.noaa.gov/gmd/ccgg/aircraft/index.html
Thank you for your attention!
Estimates of regional CO₂ surface fluxes in North America

Biome map

North American Biomes or Floristic Regions

Boreal
Prairie
Earnest Deciduous
Plain Evergreen

Cropland
The NOAA/ESRL network

West → East Transect

- West coast sites lagged by one month