Inverse modeling of CO$_2$ sources and sinks using satellite and ground-based observations of CO$_2$

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Cooperative Measurement Programs
NOAA ESRL Carbon Cycle

Additional Measurements: Environment Canada, CSIRO (Australia), Japan, etc. available through the World Meteorological Organization World Data Centre for Greenhouse Gases (WDCGG)
- CO₂ retrieval uses 670-725, 970-990, and 1070-1120 cm⁻¹ spectral regions
- T_{atm}, H₂O, CO₂, cloud parameters and surface temperature are co-retrieved
- TES CO₂ error = 1.7 ppm when averaged monthly on 10° x 10°
- Peak sensitivity found at 511 hPa ~40°S-40°N

*Kulawik et al. (2010), Characterization of Tropospheric Emission Spectrometer (TES) CO₂ for carbon cycle science, ACP*
**GEOS-Chem Model - CO₂ Fluxes**

<table>
<thead>
<tr>
<th>CO₂ Source/Sink</th>
<th>Pg C/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Fuels (Land) &amp; Cement</td>
<td>7.82</td>
</tr>
<tr>
<td>Biomass Burning</td>
<td>2.16</td>
</tr>
<tr>
<td>Biofuel</td>
<td>0.80</td>
</tr>
<tr>
<td>Ocean Flux</td>
<td>-1.40</td>
</tr>
<tr>
<td>Residual Terrestrial Exchange</td>
<td>-5.29</td>
</tr>
<tr>
<td>Ship Emissions</td>
<td>0.19</td>
</tr>
<tr>
<td>Aviation Emissions (3D)</td>
<td>0.16</td>
</tr>
<tr>
<td>CO, CH₄, NMHC oxidation (3D)</td>
<td>1.1</td>
</tr>
</tbody>
</table>

*Shipping*

ICOADS [Corbett & Koehler, 2003; 2004]

*Aviation*

SAGE inventory [Kim *et al.*, 2007]

*Chemical Source*

Column impact of chemical source with surface correction

*Nassar et al.* (2010) Geoscientific Model Development Discussions
Observational constraint on the chemical source

CH$_4$ emissions $\rightarrow$ CO + OH $\xrightarrow{O_2} CO_2 + HO_2$

Assimilate TES CO to correct biases in the CO distribution in GEOS-Chem and improve the CO$_2$ source estimates

TES-based source estimate for 2006 = 1.18 Pg C
Modeled CO₂ and comparison with GLOBALVIEW

2006 Annual Average

~ 5 km

Surface

GEOS-Chem

GLOBALVIEW
Inversion Setup

- GEOS-Chem (GEOS-5) at 2° x 2.5°
- Sampled model at TES observation locations (ocean only, 40°S-40°N) and times to calculate 5°x5° monthly averages at 511 hPa
- Sampled model at 59 surface flask locations to obtain monthly averages
- Conduct time-independent, annual inversion with monthly TES and/or flask data for 2006
- Accept fossil fuel inventories as correct and solve for “natural” fluxes (ocean, terrestrial exchange + biomass + biofuel)
- Assimilated flask data for 2004-2005 for initial conditions on Jan 1, 2006
- A priori flux uncertainties: Baker et al. (2006) for land regions and Gruber et al. (2009) for ocean regions
**Discrepancies in TES CO$_2$**

**Monthly Average CO$_2$ (Jul 2005-Jul 2008)**

- **NH**
  - Mauna Loa (3.5 km)
  - Mauna Loa w/OBS
  - TES (5 km)
  - Carbontracker (5 km)
  - AIRS (9 km)
  - CONTRAIL (10-11 km)

- **SH**
  - Samoa (surf)
  - TES (5 km)
  - Carbontracker (5 km)
  - AIRS (9 km)
  - CONTRAIL (10-11 km)

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Potential origin of discrepancy:
- clouds/aerosols
- spectroscopic errors
- Interferences from gases such as CH$_3$OH or HCOOH

TES is higher in SH in late 2006
~1.0-2.0 ppm?
Inversion Comparisons: 2006

A Priori

-3.7 PgC

Ocean -1.39

Land -2.31

Flask inversion (59 Locations)

-3.6 PgC

Ocean -1.23

Land -2.37

TES inversion

(with CONTRAIL SH bias correction)

-3.9 PgC

Ocean -0.99

Land -2.92

Flask + TES inversion

(with CONTRAIL SH bias correction)

-3.9 PgC

Ocean -1.13

Land -2.77

Nassar et al. (2010), in prep.
Comparison of flask and joint inversion

Degrees of Freedom = 23
(for 40-element state vector)
Conclusions

• TES CO$_2$ data contain information to help constrain CO$_2$ source/sink estimates; TES provides information mainly in the tropics and subtropics

• Combining the TES CO$_2$ and flask CO$_2$ data provides more information than using either dataset separately;
  - with TES: land sink = -2.92 Pg C; ocean sink = -0.99 Pg C
  - with flask: land sink = -2.37 Pg C; ocean sink = -1.23 Pg C
  - combined: land sink = -2.77 Pg C; ocean sink = -1.13 Pg C

• Efforts to better quantify and reduce biases (in particular model transport errors) must continue
Extra Slides
Inversion Comparisons: 2006

A Priori

Land -2.31
Ocean -1.39

-3.7 PgC

Flask + TES inversion (with CONTRAIL SH bias correction)

Land -2.77
Ocean -1.13

-3.9 PgC

CarbonTracker-EU (CarboScope)

Land -1.60
Ocean -2.34

-3.9 PgC

MPI-Jena (CarboScope)

Land -3.45
Ocean -0.51

-4.0 PgC

http://www.carboscope.eu/
Sensitivity to SH Jul-Dec Bias Corrections
Investigating Model Transport Bias

GEOS-4 and GEOS-5
(different vertical resolution and convection schemes)

GEOS-5 – GEOS-4 CO$_2$ near 5 km

Discrepancy in outflow from Asia in spring

Large differences in convection regions

Flux estimates will be sensitive to transport biases in some regions