Reconciling observed and modeled trends in the North Atlantic carbon sink

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Increasing atmospheric fraction of anthropogenic CO$_2$? Oceans role?

“The hypothesis of a recent or secular trend in the AF cannot be supported on the basis of the available data and its accuracy.” Knorr 2009

Canadell et al. 2007

LeQuéré et al. 2009
VOS datasets, linear pCO$_2$ trend 1990-2006 (Schuster et al. 2009)

Data of
Corbiere et al. 2007
Shuster & Watson 2007
Bates 2007
Olsen et al. 2004
Santana-Casiano et al. 2007

If pCO$_2^{\text{ocean}}$ trend > pCO$_2^{\text{atm}}$ trend, sink is declining
Generally consistent <45N, but inconsistent >45N
### W. Subpolar Gyre

**SURATLANT**

<table>
<thead>
<tr>
<th>Study</th>
<th>Years</th>
<th>Trend (µatm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DATA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corbière et al. 07</td>
<td>93-03</td>
<td>2.8</td>
</tr>
<tr>
<td>Schuster et al. 09</td>
<td>93-05</td>
<td>4.0 ± 0.48</td>
</tr>
<tr>
<td><strong>MODELS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomas et al. 08</td>
<td>95-04</td>
<td>3.0</td>
</tr>
<tr>
<td>Ullman et al. 09</td>
<td>92-06</td>
<td>0.9 ± 0.02</td>
</tr>
</tbody>
</table>
Yet, traditional comparisons OK

SURATLANT, W. Subpolar

BERMUDA

Ullman et al. 2009
Motivating Questions

• Is the carbon sink of the western subpolar North Atlantic in decline?

• Are observed trend estimates robust to analysis methodology?

• Can trends from data and models be shown to be consistent?
pCO₂ Analysis

Schuster et al. (2009)

- Data
  - 1993-1997, DIC, SSS, SST
    - ALK from ALK-SSS of 2001-2002
  - 2001-2005, DIC, ALK, SSS, SST
- Processing
  - Average @ monthly, 1x1 degree
  - Group in 5x5 boxes
  - Calculate trend (b) by fitting to
    \[
    pCO₂ = a + bt + c \cos(2\pi t + d)
    \]
- 1σ confidence interval (~ 68.3% )
Are observed trends robust? Can trend estimates be reconciled?

- Impact of ALK-SSS relationship used for 1993-1997 data
- Model to evaluate data analysis
  - Sampling
  - Spatial averaging

Model = Regional biogeochemical MITgcm at $\frac{1}{2}$ degree

(Ullman et al. 2009, Bennington et al. 2009)
Region labels

A B C D E F
$pCO_2$ Analysis
Schuster et al. (2009)
pCO₂ Analysis
Schuster et al. (2009)
Impact of ALK-SSS for 1993-1997

New ALK-SSS makes ALK \(\sim 7\ \mu\text{mol/kg}\) lower, \(p\text{CO}_2\) \(\sim 12\ \mu\text{atm}\) higher for '93-'97

ALK-SSS from 2001-2002 data
\[
\text{ALK} = 43.808 \times \text{SSS} + 713.5
\]

Updated from 2001-2006 data
\[
\text{ALK} = 43.857 \times \text{SSS} + 773.8
\]

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\]
Impact of ALK-SSS for 1993-1997

The graph shows the impact of ALK-SSS with different data series: Schuster09, Model: All, Data: ALK-SSS.
Model to assess impact of sampling

Comparison of trend with all model points and as sampled indicates sampling error

Ullman et al. 2009
Model to assess impact of sampling
Model to assess impact of sampling

For sampled model, real trend does not fall within the error bars
Independence at 1x1?

- $R = 0.92$ for 1x1 points (mean for all regions)
- 1x1 points are **NOT** independent

Schuster et al. (2009) assume each 1x1 point in the 5x5 box is independent.
Independence at 1x1?
No. Use 5x5 average.
95% confidence
Analyzed and true model trends now consistent
Updated analysis of updated data
Data and model consistent

Model: All 95%

Data: Reanalyzed with Box, 95%
Data and model consistent (5 of 6)

Model: All 95%

Data: Reanalyzed with Box, 95%
Indistinguishable from atmospheric trend

ATM = 1.8
Conclusions: pCO$_2$ trends in western subpolar gyre

- Revised ‘93-’05 trend (2.0±1.8 µatm/yr) indistinguishable from atmosphere (1.8 µatm/yr)
- Model and data consistent at 95% (5 of 6 boxes)
- Data analysis – details critical
  - ALK-SSS relationship for ’93-’97
  - Sampling
  - Lack of independence at 1x1
- Model allows evaluation of analysis procedures
Apply methodology to Takahashi database – Poster IT15L-02 Today

A. Fay and G. A. McKinley
Extra Slides
Yet direct comparisons don’t suggest so much difference

Ullman et al. 2009

Corbière et al., 2007

59.7°N/31.5°W

55°N/40°W
Ocean pCO$_2$ change

Ullman et al. 2009
pCO$_2$ and component changes

_Ullman et al. 2009_
**Atmospheric Inversion Comparison**

**Subpolar N. Atlantic (50-79N)**

<table>
<thead>
<tr>
<th></th>
<th>93–96 mean</th>
<th>02-05 mean</th>
<th>Percent change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ullman et al. ‘09</td>
<td>0.22 PgC/yr</td>
<td>0.26</td>
<td>+18%</td>
</tr>
<tr>
<td>Rodenbeck et al. ‘05</td>
<td>0.15</td>
<td>0.18</td>
<td>+20%</td>
</tr>
</tbody>
</table>

Both forward model and inversion suggest increasing sink in subpolar gyre