Southern Ocean Carbon Fluxes and Air-sea Gas-exchange from Past and Future Atmospheric $O_2$ Measurements

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Atmospheric $O_2$ Applications

- Global terrestrial/oceanic carbon budget partitioning
- Seasonal hemispheric ocean productivity
- Seasonal hemispheric gas-exchange rates
- North-south ocean and atmosphere transport
- Terrestrial ecosystem dynamics
- Fossil-fuel CO$_2$ source characterization
- Continental air origins and boundary-layer venting
- Thermal vs. biological ocean carbon flux partitioning
- Direct eddy-covariance $O_2$ fluxes
Annual mean TransCom3 results


TransCom3 Southern Ocean *a priori* values and data

Gurney et al., 2002 (-0.58)
Takahashi et al., 2002 (-0.58)
Rödenbeck et al., 2003 (+0.25)
Roy et al., 2003 (-0.3)
Jacobson et al., 2005 (-0.15)

Takahashi 2002 x Wanninkhof 1992

Mean Annual Air-Sea Flux for 1995 (NCEP 41-Yr Wind, 940K, W-92)
LDEO/Takahashi CO2 Group Database, February

[Figure courtesy of S. Sutherland]

LDEO/Takahashi CO2 Group Database, August
The Southern Ocean will play a key role in future anthropogenic CO$_2$ uptake, mediated by strong opposing solubility and biological influences.

2056-65 Global Warming Simulation [Sarmiento et al., Nature 1998]
(Thermal – Biological) component of seasonal pCO₂ cycle
Solubility (thermal) and biological processes have discernable effects on atmospheric O$_2$ and CO$_2$
“CMDL Gradient” =
(TDF+PSA+HBA+SYO+CRZ)/5 - (EIC+SPO+CGO)/3
Red = CMDL: \[(TDF + PSA + HBA + SYO + CRZ)/5 - (EIC + SPO + CGO)/3\]
Green = SIO: \[PSA - (CGO + SPO)/2\]
Blue = Climatology S of 40 S (Takahashi 2002 or Keeling and Garcia 2001 + Gruber 2001)
Black = OCMIP2 Models S of 40 S
Purple = PU: \[SYO - (CGO + AMS)/2\]
**O₂:CO₂ Ratios**

**approximate annual-mean differences**

<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>O₂</th>
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<tbody>
<tr>
<td>SIO</td>
<td>+0.07</td>
<td>-5.0</td>
</tr>
<tr>
<td>PU</td>
<td>+0.16</td>
<td>+4.7</td>
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</tbody>
</table>
“PU Gradient” = SYO – (CGO+AMS)/2
O$_2$:CO$_2$ ratios from 4-sample (~ 2 month) fits

(screening for $R^2 > 0.3$)
$O_2:CO_2$ ratios from 4-sample (~ 2 month) fits

(screening for $R^2 > 0.3$)
Conclusions (part 1)

- There is a clear atmospheric signature of wintertime Southern Ocean CO$_2$ outgassing and approximate annual-mean CO$_2$ flux balance.
- Atmospheric O$_2$:CO$_2$ ratios suggest a dominant biological influence on CO$_2$ fluxes year-round.
- Small Southern Ocean atmospheric gradients are useful in evaluating pCO$_2$ climatologies and the OCMIP2 models.
  - Incorporate existing and future winter pCO$_2$ measurements
  - Continue to evaluate OCMIP2 model physics, and evaluate more sophisticated models
New constraints on air-sea gas-exchange

\[ F_{CO2} = k S (pCO_{2w} - pCO_{2a}) \]

[Figure courtesy W. McGillis]
VUV Absorption O$_2$ Instrument

Deployed at Jefferson County Airport, Colorado

Differential precision: 2 per meg (0.4 ppm) rms in 4 seconds
Short term precision: 2 per meg (0.4 ppm) rms in 1 second
Fundamental response time: $\sim$ 100 Hz
Power spectrum of VUV Signal

Total variance = 25415.7
Variance (w/o DC component) = 6626.26
K = 55, N = 512, nPoints = 27410
Early evening respiration signal

Cross correlation with vertical wind

Cospectra with vertical wind

Red: CO₂
Blue: H₂O
Green: O₂
**O₂ fluxes are generally larger than CO₂ fluxes**

Upper range of HAMOCC3.1 fluxes (mol/m²/year)

<table>
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<tr>
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<th>CO₂ Flux</th>
<th>O₂ Flux</th>
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<tr>
<td>June in the North Atlantic</td>
<td>-5</td>
<td>+30</td>
</tr>
<tr>
<td>February in the Equatorial Pacific</td>
<td>+3</td>
<td>-25</td>
</tr>
<tr>
<td>December in the Southern Ocean</td>
<td>-5</td>
<td>+15</td>
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Conclusions (part 2)

- Preliminary tests suggest that the VUV instrument may be capable of measuring $O_2$ fluxes by eddy-correlation.
- This would enable a new constraint on air-sea gas-exchange rates and their solubility dependence.
- Drying air to a few ppm H$_2$O while maintaining turbulent flow through inlet tubes is the primary challenge.
Large model differences in the Southern Ocean

Simulated 1995 cumulative CO₂ fluxes and inventory