The Drake Passage and detecting changes in the Southern Overturning Circulation

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Robert Key, Corinne Le Quere,
Keith Rogers, Sara Mikaloff-Fletcher, Britt Stephens
Drake Passage
Underway Sampling
Underway sampling
2002-2011

Surface TCO₂ at discrete locations

SSTs at discrete locations

Total CO₂

Surface Temperature
Underway sampling 2002-2011

Alkalinity

Salinity
Continuous Underway pCO$_2$

$\Delta$ pCO$_2$ \(\Rightarrow\) Out

$\Delta$ pCO$_2$ \(\Rightarrow\) In

2002 – 20011 = 204 crossings
ΔT = 2°C
ΔT = 4°C
ΔpCO₂ = 20 uatm
S. Polar Front

N. Polar Front

Temp

$\Delta pCO_2 = 60 \mu \text{atm}$
ΔpCO₂ = 25 µmol/Kg

ΔTCO₂ = ~27 umol/Kg
Wind Stress

~15% increase in wind speeds over the last 50 years

Wind Stress Maximum
- Low pressure anomalies over Antarctic force wind stress maximum towards south pole.
pCO$_2$ Wintertime Trend Analysis

Atmospheric Trend = 1.63 uatm/yr

Ocean Trend = 1.98 ± 0.38 uatm/yr

0.8C < SST < 1.5C

wintertime

Takahashi et al., 2009
**pCO$_2$ Wintertime Trend Analysis**

Atmospheric Trend = 1.63 uatm/yr

Ocean Trend = 2.66 ± 0.38 uatm/yr

Takahashi et al., 2009
Comparing pCO$_2$ trend with Models

Le Quere
$1.38 \pm 0.31$

Lovenduski
$1.34 \pm 0.41$

Data
$2.66 \pm 0.38$

Models are significantly underestimating rise in CO$_2$

Takahashi et al., 2009
### Trend in surface water pCO$_2$

#### Models are significantly underestimating rise in surface water CO$_2$ at SSTs between 1.5C and 5.5C

<table>
<thead>
<tr>
<th>SST</th>
<th>Takahashi 2009</th>
<th>LeQuere 2007</th>
<th>Lovenduski 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Takahashi sampling</td>
<td>All regions</td>
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</tr>
<tr>
<td>0.8 to 1.5</td>
<td>1.98 ± 0.44</td>
<td>1.50 ± 0.36</td>
<td>1.30 ± 0.46</td>
</tr>
<tr>
<td>1.5 – 2.5</td>
<td>2.59 ± 0.44</td>
<td>1.38 ± 0.31</td>
<td>1.34 ± 0.47</td>
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<tr>
<td>2.5 – 3.5</td>
<td>2.95 ± 0.45</td>
<td>1.58 ± 0.37</td>
<td>2.63 ± 0.56</td>
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<td>3.5 – 4.5</td>
<td>2.78 ± 0.68</td>
<td>1.83 ± 0.31</td>
<td>2.16 ± 0.42</td>
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<td>4.5 – 5.5</td>
<td>2.01 ± 0.41</td>
<td>2.45 ± 0.32</td>
<td>1.67 ± 0.45</td>
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<td>5.5 – 6.5</td>
<td>1.39 ± 0.43</td>
<td>2.38 ± 0.54</td>
<td>1.77 ± 0.50</td>
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#### Mean Atmospheric Trend: 1.63 uatm/year
Why is surface pCO2 rising so fast?

- Increase in temperature?
- Decrease in biological uptake?
- Increase in Overturning circulation?
Change in Surface water $\Delta^{14}C$

1973 - 2006

$\Delta^{14}C$ (‰)

Comparison of surface water $\Delta^{14}C$ 1973 - 2006 suggests change of 70‰
Comparison of surface water Δ¹⁴C 1990 - 2006 suggests change of 40 ‰.
Atlantic

$\Delta^{14}C$ change
1973 – 1990
$= -70 \%$
Indian

$\Delta^{14}C$ change
1978 – 1995
= -50 ‰?
Δ$^{14}$C change
1974 – 1996
= -50 ‰
Gas Exchange for $\Delta^{14}C$

MOM4 Ocean GCM run with climatological forcing $\Delta^{14}C$

Courtesy of Rogers and Mikaloff-Fletcher
Gas Exchange for $\Delta^{14}C$

MOM4 runs shows only 50% of the total 70% observed change in $\Delta^{14}C$ due to bomb $^{14}C$ pulse

Courtesy of Joe Majkut
Gas Exchange only accounts for 75% of the change $\Delta^{14}C$ since 1973

There has been a significant change $\Delta^{14}C$ gradient (45‰ to 85‰)

Surface $\Delta^{14}C$ in the Drake Passage

- Gas Exchange only accounts for 75% of the change $\Delta^{14}C$ since 1973
- There has been a significant change $\Delta^{14}C$ gradient (45‰ to 85‰)
Gas Exchange only accounts for 75% of the change $\Delta^{14}C$ since 1973.

There has been a significant change in the $\Delta^{14}C$ gradient (45‰ to 85‰).

### Drake Passage Region

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<th>Gas Exchange</th>
<th>GEOSECS – WOCE ($%$)</th>
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Surface $\Delta^{14}C$ in the Drake Passage
• Gas Exchange only accounts for 75% of the change $\Delta^{14}C$ since 1973
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There has been a significant change in $\Delta^{14}$C gradient (45‰ to 85‰).

**Surface $\Delta^{14}$C in the Drake Passage**

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20% 70% 50%
Conclusion

• Data suggests that the models may actually may be significantly underestimating the decrease in the southern ocean sink.

• $^{14}$C decrease in surface waters suggest that MOC may be the cause of CO$_2$ sink decrease

Caveats

• More $^{14}$C data is needed to confirm results throughout the Southern Ocean

• Better models needed to confirm role of gas exchange with respect to $^{14}$C