A large Southern Ocean CO$_2$ source detected by biogeochemical profiling floats

A. Gray (postdoc, Princeton), Ken Johnson (MBARI), J. L. Sarmiento (Princeton), et al.

I. Introduction

II. Methods & results
   A. $p$CO$_2$
   B. $\Delta p$CO$_2$
   C. CO$_2$ flux

Conclusion: CO$_2$ flux to atmosphere $>>$ than previous estimates

III. Hypotheses
   A. Methodology is flawed?
   B. Previous studies underestimate winter degassing?
   C. Recent years are anomalous?
Landschützer et al. (2014) climatological air-sea flux estimate for 1998-2011
Undersampling of $p\text{CO}_2$

Months of year with surface $p\text{CO}_2$ measurements based on all measurements between 1970 to 2011 binned in 1° squares. White = no data

Bakker et al. (2014)
SOCCOM Floats (so far...)

As of July 22, 2016

available at: http://soccom.princeton.edu
SOCCOM floats we will discuss (14)

Four zones are defined by the fronts:
• Subtropical Zone (STZ)
• Subantarctic Zone (SAZ)
• Antarctic Circumpolar Current Zone (ACCZ)
• Seasonal Ice Zone (SIZ)

Ekman velocity is from QuikSCAT 1999-2009 winds (Risien and Chelton 2011).
SOCCOM floats we will discuss (14)

Four zones are defined by the fronts:
• Subtropical Zone (STZ)
• Subantarctic Zone (SAZ)
• Antarctic Circumpolar Current Zone (ACCZ)
• Seasonal Ice Zone (SIZ)

MLDs from the de Boyer-Montégut et al. (2004) climatology.
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Conclusion: CO$_2$ flux to atmosphere
>> than previous estimates

III. Hypotheses
   A. Methodology is wrong
   B. Previous estimates are wrong
   C. Recent years are anomalous
pCO₂ from float pH & MLR alkalinity

- All floats are in the Pacific unless labeled otherwise
- Dark gray bar is winter
- Unusual floats:
  - **Float 9313** (yellow) from Atlantic STZ crosses front
  - **Float 9095** (grayed out) from Pacific SAZ: pH sensor had uncharacteristically large drift. Left out of subsequent analyses.
  - **Float 8514** (gold) from Indian Ocean is in an active eddy region
pCO$_2$ in subtropical gyre (Pacific only)
pCO$_2$ in ACC/upwelling zone
\[ \Delta p_{\text{CO}_2} = p_{\text{CO}_2}^{\text{ocn}} - p_{\text{CO}_2}^{\text{atm}} \]

Recall:
- **Float 9313** from Atlantic STZ crosses front
- **Float 9095** (grayed out) from Pacific SAZ: pH sensor had uncharacteristically large drift. Left out of subsequent analyses.
- **Float 8514** from Indian Ocean is in an active eddy region
\[ \Delta pCO_2 \text{ in STZ} \]

\[ \otimes pCO_2 = pCO_2^{ocn} - pCO_2^{atm} \]

Pacific

Atlantic

- Float
- Takahashi et al. 2009
- Landschützer et al. 2014
- SOCAT v3 Bakker et al. 2016
\[ \Delta pCO_2 \text{ in ACC zone} \]

\[ \oslash pCO_2 = pCO_2^{ocn} - pCO_2^{atm} \]

Pacific

Atlantic

- Float
- Takahashi et al. 2009
- Landschützer et al. 2014
- SOCAT v3 Bakker et al. 2016
Sea-air CO₂ flux

- Flux equation: \( F = k_g K_0 \Delta p_{CO_2} \)

  \( k_g = \) wind speed squared dependent gas transfer velocity from Wanninkhof (2014)

  \( K_0 = \) solubility constant

- \( \Delta p_{CO_2} = p_{CO_2}^{ocn} - p_{CO_2}^{atm} \) with \( p_{CO_2}^{atm} \) from Cape Grim monthly data
Annual net CO₂ flux to atmosphere

- Units: mol m⁻² y⁻¹
- Covers region south of 35°S
- Positive indicates net outgassing, negative is uptake.
- Bold numbers are statistically different from zero

For scale, the average anthropogenic CO₂ uptake is 0.46 ± 0.14 mol m⁻² y⁻¹

Note: problematic float 9095 (in parentheses) is not included in mean

<table>
<thead>
<tr>
<th>Zone</th>
<th>Float</th>
<th>Flux May14-May15</th>
<th>Flux May15-May16</th>
<th>Mean mol m⁻² y⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>STZ</td>
<td>P-ST1</td>
<td>-0.09 ± 0.5</td>
<td>-0.2 ± 0.5</td>
<td>-0.6 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>P-ST2</td>
<td>-0.8 ± 0.5</td>
<td>-0.8 ± 0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A-SA1</td>
<td>-</td>
<td>-1.0 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>SAZ</td>
<td>P-SA1</td>
<td>(1.3 ± 0.7)</td>
<td>(2.9 ± 0.8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-SA3</td>
<td>-0.2 ± 0.8</td>
<td>0.1 ± 0.7</td>
<td>0.3 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>I-SA1</td>
<td>-</td>
<td>1.1 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>ACCZ</td>
<td>P-ACC1</td>
<td>2.6 ± 0.8</td>
<td>2.2 ± 0.8</td>
<td>2.4 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>A-ACC1</td>
<td>-</td>
<td>1.9 ± 0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A-ACC2</td>
<td>-</td>
<td>3.1 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>SIZ</td>
<td>P-SI1</td>
<td>-0.2 ± 0.5</td>
<td>0.1 ± 0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A-SI1</td>
<td>-</td>
<td>0.9 ± 0.4</td>
<td>0.2 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>A-SI2</td>
<td>-</td>
<td>-0.006 ± 0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A-SI3</td>
<td>-</td>
<td>0.03 ± 0.16</td>
<td></td>
</tr>
</tbody>
</table>
### Annual net oceanic CO₂ uptake

- Units: Pg C y⁻¹
- Covers region south of 35°S
- Positive indicates net outgassing, negative is uptake.
- Dashes indicate fluxes less than 0.03

<table>
<thead>
<tr>
<th>Zone</th>
<th>SOCCOM floats</th>
<th>Takahashi et. al. (2009)</th>
<th>Landschützer et al. (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STZ</td>
<td>-0.2 ± 0.1</td>
<td>-0.4</td>
<td>-0.5</td>
</tr>
<tr>
<td>SAZ</td>
<td>0.1 ± 0.1</td>
<td>-0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>ACCZ</td>
<td>0.8 ± 0.2</td>
<td>-0.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>SIZ</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TOTA L</td>
<td>0.7 ± 0.2</td>
<td>-0.8</td>
<td>-0.8</td>
</tr>
</tbody>
</table>
Annual net oceanic CO₂ uptake

- Units Pg C y⁻¹
- Covers region south of 35°S
- Positive indicates net outgassing, negative is uptake.
- Dashes indicate fluxes less than 0.03
- Final column is calculated from Landschützer et al. (2015) by subsampling where the float profiles are, then integrating, averaging, and multiplying by the same areas.

<table>
<thead>
<tr>
<th>Zone</th>
<th>SOCCOM floats</th>
<th>Landschützer et al. (2014)</th>
<th>Subsampled as SOCCOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>STZ</td>
<td>-0.2 ± 0.1</td>
<td>-0.5</td>
<td>-0.3</td>
</tr>
<tr>
<td>SAZ</td>
<td>0.1 ± 0.1</td>
<td>-0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>ACCZ</td>
<td>0.8 ± 0.2</td>
<td>-0.1</td>
<td>--</td>
</tr>
<tr>
<td>SIZ</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TOTA</td>
<td>0.7 ± 0.2</td>
<td>-0.8</td>
<td>-0.5</td>
</tr>
</tbody>
</table>
Conclusion: Southern Ocean CO$_2$ flux to atmosphere is greater than previous estimates

- Hypothesis 1: flawed methodology
  - Small number of floats is worrisome, but
  - Good agreement when shipboard data is available is reassuring
  - Method for converting pH to pCO$_2$ looks good.

- Hypothesis 2: Climatological baseline should have a stronger Southern Ocean source
  - Our results support this.
  - However, there must be a larger sink elsewhere to compensate the Southern Ocean source and maintain large ocean carbon sink

- Hypothesis 3: 2014-present is anomalous
  - This appears to be the case, but past history suggest this can only explain ~0.5 Pg C y$^{-1}$ of 1.5 Pg C y$^{-1}$ anomaly we find
Time history of CO₂ fluxes (PgC y⁻¹)

- The 1982 to 2011 time history is from Landschützer et al. (2014)
- Positive is degassing
- The individual points are from SOCCOM floats
- STZ = subtropical zone
- SAZ = subantarctic zone
- ACC = ACC upwelling zone
- SIZ = seasonal ice covered zone

Landschützer et al. (2014)
Conclusion: Southern Ocean CO$_2$ flux to atmosphere is greater than previous estimates

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- **Hypothesis 2:** Climatological baseline should have a stronger Southern Ocean source
  - Our results support this (if there were data in winter, the baseline would shift up)
  - However, there must be a larger sink elsewhere to compensate the Southern Ocean source and maintain large ocean carbon sink

- **Hypothesis 3:** 2014-present is anomalous
  - This appears to be the case, but past history suggest this can only explain ~0.5 Pg C yr$^{-1}$ of 1.5 Pg C yr$^{-1}$ anomaly we find
Landschützer et al. (2014) climatological air-sea flux estimate for 1998-2011
Wind speed anomaly (April 2014 to 2016)

• The ACC region has increased winds which would imply more upwelling & thus outgassing.

• ERA-interim wind fields, calculated as the mean over Apr 2014 - Apr 2016 minus the mean over Apr 1979 - Apr 2016
SST Anomaly
(April 2014 to 2016)

• The subtropics are warmer, consistent with increased outgassing.
• The ACC region has colder temperatures, consistent with higher upwelling.
• ERA-interim SST fields, calculated as the mean over Apr 2014 - Apr 2016 minus the mean over Apr 1979 - Apr 2016
Conclusion: Southern Ocean CO$_2$ flux to atmosphere is greater than previous estimates

- **Hypothesis 1:** flawed methodology
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Future work

• SOCCOM
  – Keep adding floats!
  – SOSE

• Test consistency with other constraints
  – Atmospheric observations & atmospheric inversion models
  – Interior ocean DIC observations & ocean inverse, SOSE, etc.
  – How would addition of float data affect the Landschützer neural network map?
What is driving changes? – ML budget

<table>
<thead>
<tr>
<th>Change in $C_T^{ml}$</th>
<th>Estimated from float obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrainment +</td>
<td>Observed $dMLD/dt$, $C_T(z)$</td>
</tr>
<tr>
<td>Vertical mixing +</td>
<td>Observed $dC_T/dz$, assume $K_z (1 \times 10^{-4} , m , s^{-2})$</td>
</tr>
<tr>
<td>Air-sea flux +</td>
<td>ECMWF wind speed, observed $\Delta pCO_2$, Wanninkhof 2014 coefficient</td>
</tr>
<tr>
<td>Dilution +</td>
<td>ECMWF Evaporation, Precipitation</td>
</tr>
<tr>
<td>Advection +</td>
<td>AVISO $u_{geo}$, ECMWF wind $u_{ek}$, AVHRR SST, linear regression with GLODAPv2</td>
</tr>
<tr>
<td>Biology</td>
<td>Residual optimized with nitrate budget</td>
</tr>
</tbody>
</table>
Mixed layer budget

C:N = 6.0
NCP = 2.3 molC m\(^{-2}\) m\(^{-y}\)

T budget

NO\(_3\) budget

Carbon budget
SOCAT v. 3 data (Bakker et al., 2016)

All SOCAT v3 data- colored by month

SOCAT v3 Winter - colored by year (1992-2013)
Comparison of estimates of $\Delta p\text{CO}_2 = p\text{CO}_2^{\text{ocn}} - p\text{CO}_2^{\text{atm}}$

- **Note 1:** STZ 9313 crosses front
- **Note 2:** Indian Ocean Float (8514; second row, far right) is an active eddy region. Other properties - T, S, O$_2$, NO$_3$ - indicate this float is seeing waters different than the waters sampled by SOCAT
- **Note 3:** Floats in bottom row are in SIZ and the disagreement between floats and shipbased estimates is during the ice covered season.
Cumulative annual air-sea CO\textsubscript{2} flux comparison

- STZ
  - Agreement between estimates is good except float 9313 (yellow) which crosses front
  - Accumulates carbon when water is cold (winter & spring)

- ACCZ
  - Agreement between estimates is bad.
  - Floats show ocean losing carbon, mostly when water is cold

- SAZ and SIZ
Climate is anomalous

Gray et al., in preparation
But where is all the extra carbon going?

Jacobson (pers. comm.)
Monthly mean CO$_2$ at Mauna Loa

- Monthly mean
- Deseasonalized
- Fit to 2011–2014
Anomalous global MBL CO₂

\[ \Delta [\text{CO}_2], \mu \text{mol mol}^{-1} \]

Anomaly (PgC)

Note timing
CO₂ zonal-mean growth rate (μmol yr⁻¹)
**SST anomaly flux anomaly**

2015-09 through 2016-04 SST anomaly (degrees C)

**AOML monthly air-sea CO₂ flux anomaly**

PgC/yr

Jan 2014 - Jul 2016

**Tropics**

**Extratropics**

**Globe**

El Niño

La Niña

**flux anomaly**

2015-09 through 2016-04 AOML CO₂ flux anomaly (mol m⁻² yr⁻¹)
El Niño-driven anomalous CO₂ (PgC)

<table>
<thead>
<tr>
<th></th>
<th>1997-98</th>
<th>2015-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>1.9 to 2.2¹</td>
<td>2.2 to 3.6¹</td>
</tr>
<tr>
<td>Oceans</td>
<td>-0.5² to -0.7³</td>
<td>(-0.3 to) 0.4²</td>
</tr>
</tbody>
</table>

1. This work
2. NOAA AOML monthly pCO₂
3. Chavez et al. (Science, 1999)
Time history of CO₂ fluxes (PgC y⁻¹)

- The 1982 to 2011 time history is from Landschützer et al. (2014)
- The individual points are from SOCCOM floats
- STZ = subtropical zone
- SAZ = subantarctic zone
- ACC = ACC upwelling zone
- SIZ = seasonal ice covered zone
Ocean fluxes calculated by TM5

- From Jacobson (pers. comm.)
- These fluxes are “like” priors using TM5 to compute them.
- TM5-4DVar (Transport Model 5 – Four-Dimensional Variational model), is an atmospheric transport model used for CO$_2$ flux estimation (cf. Basu et al., 2013)
- Gas exchange parameters:
  - solubility and Schmidt No. from WOA09,
  - ERA-interim winds,
  - NOAA marine boundary layer atmospheric pCO$_2$ with extrapolated trend.
- Numbers on the right-hand axis are the time-mean fluxes
**Impact on atmospheric pCO₂ south of 30°S**

- Impact on atmospheric observations of the "experimental" air-sea fluxes in the Southern Ocean.
- The impact is cumulative over time but reaches about 3 ppm after one year.
- No evidence from CarbonTracker that we're missing this large a CO₂ flux difference.
- Jacobson (pers. comm.)
Underway sampling of $pCO_2$ from ships

- The color scale shows the months of the year with surface $pCO_2$ measurements
- Based on all measurements between 1970 to 2011 binned in 1° squares.
- White = no data
Verification of $\text{CO}_2$ estimation

Williams et al. (in preparation)
ΔpCO₂ in seasonal ice zone

Atlantic

\[ \Delta p\text{CO}_2 = p\text{CO}_2^{\text{ocn}} - p\text{CO}_2^{\text{atm}} \]

- Float
- Takahashi et al., 2009
- Landshutzer et al., 2014
- SOCAT v3 Bakker et al., 2016

Pacific
ΔpCO₂ in polar front zone

\[ \Delta pCO_2 = pCO_2^{ocn} - pCO_2^{atm} \]

- **Pacific**
- **Atlantic**

- **Float**
- **Takahashi et al., 2009**
- **Landshutzer et al., 2014**
- **SOCAT v3 Bakker et al., 2016**
$\Delta p$CO$_2$ in subantarctic zone

**Diagram:**

- **Pacific**
  - April 2014 to January 2015
  - W W W W

- **Atlantic**
  - January 2015 to April 2015
  - W W W

Mathematical expression:

$\nabla p$CO$_2 = p$CO$_2^{ocn} - p$CO$_2^{atm}$

Legend:
- Black: Float
- Red: Takahashi et al., 2009
- Cyan: Landshutzer et al., 2014
- Black dot: SOCAT v3 Bakker et al., 2016
\[ \Delta pCO_2 = pCO_2^{ocn} - pCO_2^{atm} \]
CO$_2$ flux estimate

We are interested in the flux of CO$_2$ out of ocean

$$F = k_g * K_0 * \Delta p_{CO_2}$$

- $k_g$ = wind speed squared dependent gas transfer velocity from Wanninkhof (2014)
- $K_0$ = solubility constant
- $\Delta p_{CO_2} = p_{CO_2}^{ocn} - p_{CO_2}^{atm}$

Calculation of $\Delta p_{CO_2}$

- $p_{CO_2}^{atm}$ from Cape Grim monthly data
Annual net oceanic CO$_2$ uptake

- Positive indicates net outgassing, negative is uptake.
- Bold numbers are statistically different from zero.
- Italic numbers in Landschützer column are the total uptake obtained by subsampling where the float profiles are, then integrating, averaging, and multiplying by the same areas.
- The total for the Takahashi estimate is wrong. It should be -0.8, not -1.03.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Total PgC y$^{-1}$</th>
<th>Takahashi PgC y$^{-1}$</th>
<th>Landschützer PgC y$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>STZ</td>
<td>-0.2 ± 0.08</td>
<td>-0.4</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.3</td>
</tr>
<tr>
<td>SAZ</td>
<td>0.08 ± 0.1</td>
<td>-0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.2</td>
</tr>
<tr>
<td>ACCZ</td>
<td>0.8 ± 0.2</td>
<td>-0.2</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>SIZ</td>
<td>0.03 ± 0.05</td>
<td>0.02</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>0.7 ± 0.2</td>
<td>-1.03</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.5</td>
</tr>
</tbody>
</table>
### CO₂ fluxes (mol m⁻² y⁻¹)

<table>
<thead>
<tr>
<th>Pacific</th>
<th>Atlantic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtropics (Significant uptake)</td>
<td></td>
</tr>
<tr>
<td>P-ST1</td>
<td>-0.9 ± 0.7</td>
</tr>
<tr>
<td>P-ST2</td>
<td>-1.6 ± 0.7</td>
</tr>
<tr>
<td>Subantarctic Zone</td>
<td></td>
</tr>
<tr>
<td>P-SA1</td>
<td>-0.1 ± 1.1</td>
</tr>
<tr>
<td>P-SAA3</td>
<td>-1.0 ± 1.1</td>
</tr>
<tr>
<td>Polar Front Zone (Significant degassing)</td>
<td></td>
</tr>
<tr>
<td>P-PF1</td>
<td>1.6 ± 1.1</td>
</tr>
<tr>
<td>A-PF2</td>
<td>2.2 ± 1.3</td>
</tr>
<tr>
<td>Seasonal Ice Zone</td>
<td></td>
</tr>
<tr>
<td>P-SI1</td>
<td>-0.6 ± 0.6</td>
</tr>
<tr>
<td>A-SI2</td>
<td>-0.7 ± 0.3</td>
</tr>
<tr>
<td>A-SI3</td>
<td>-0.3 ± 0.2</td>
</tr>
</tbody>
</table>

For scale, the average anthropogenic CO₂ uptake is 0.46 ± 0.14 mol m⁻² y⁻¹.
CO$_2$ fluxes in Polar Front zone (mol m$^{-2}$ y$^{-1}$)

<table>
<thead>
<tr>
<th></th>
<th>Pacific</th>
<th>Atlantic</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-PF1</td>
<td>1.6 ± 1.1</td>
<td>A-PF1</td>
</tr>
<tr>
<td>A-PF2</td>
<td>2.2 ± 1.3</td>
<td></td>
</tr>
</tbody>
</table>

Anthropogenic CO$_2$ uptake is 0.46 ± 0.14 mol m$^2$ y$^{-1}$
CO$_2$ fluxes in subtropics (mol m$^{-2}$ y$^{-1}$)

<table>
<thead>
<tr>
<th>Pacific subtropics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P-ST1</td>
<td>-0.9 ± 0.7</td>
</tr>
<tr>
<td>P-ST2</td>
<td>-1.6 ± 0.7</td>
</tr>
</tbody>
</table>

Anthropogenic CO$_2$ uptake is 0.46 ± 0.14 mol m$^2$ y$^{-1}$
Causes of CO$_2$ seasonality

Gray et al. (in preparation)
pCO$_2$ in seasonal ice zone
pCO$_2$ in Polar Front zone
pCO₂ in subtropical gyre (Pacific only)
pCO$_2$ in SubAntarctic Front zone
The role of the Southern Ocean in the global climate system.

1. It accounts for 67-98% of the excess heat that is transferred from the atmosphere into the ocean each year.

2. It accounts for up to half of the annual oceanic uptake of anthropogenic carbon dioxide from the atmosphere.

3. Vertical exchange in the Southern Ocean is responsible for supplying nutrients that fertilize three-quarters of the biological production in the global ocean north of 30°S.

Roemmich et al. 2015
Gruber et al. 2009, Landschützer et al. 2015
Sarmiento et al. 2004
Why is the Southern Ocean so important?

- “Window to the deep ocean”
- Southern Ocean is the only place where there is direct upwelling from very deep waters to the sea surface over a very large region.
• Argo profiling floats
  - have a 4 to 7 year lifetime,
  - Measure T & S from ~2000 m to the surface every 5 to 10 days.
  - data direct to Internet.
Undersampling of Nitrate

Animation of actual Southern Ocean nitrate observations

- Background is World Ocean Atlas monthly climatology.
- End of animation shows additional measurements that would have been made if Argo floats had nitrate sensors

Courtesy of R. Slater, Princeton U.
The Opportunity

(1) A paradigm shift – Transformative observing system

- Argo floats (currently required to measure only temperature & salinity)

- Biogeochem sensors now developed for:
  - pH
  - Nitrate,
  - oxygen, and
  - optics (FLBB) – funded by NASA
The Opportunity

(2) Transformative observational analysis methods

- Southern Ocean State Estimation (SOSE) using data fitting to produce full 4D estimates of ocean properties
The Opportunity

(3) Eddy rich-high resolution climate models

1° ocean resolution (GFDL CM2-1deg)

0.1° ocean resolution (GFDL CM2.6)

log10 of surface velocity magnitude in m/s
What is SOCCOM?

SOCCOM’s mission is to drive a transformative shift in our understanding of the role of the Southern Ocean in climate change and biogeochemistry by:

Extending sparse Southern Ocean biogeochemical observations by deploying a robotic observing system composed of ~200 autonomous BGC Argo floats that will provide nearly continuous coverage in time and horizontal space over the entire Southern Ocean, as well as vertical coverage deep into the water column.

Using these observations to analyze and improve a new generation of high resolution (1/10°) earth system models to both increase our understanding of the Southern Ocean’s current workings and make better projections of the future trajectory of the Earth’s climate and biogeochemistry.

Educating a new generation of ocean scientists trained in both ocean observation and simulation, and develop a sophisticated outreach effort to disseminate results to the broadest possible community.
Director
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Executive Board

Theme I Observations
Lynne Talley, UCSD

Steve Riser, U. Washington

Theme II Modeling
Joellen Russell U. Arizona

Broader Impacts
Heidi Cullen, Climate Central
SOCCOM float observations

Extension of decadal-scale GO-SHIP carbon observations into the seasonal and interannual domain

Some details:

(1) Calibration – goal is to produce climate quality data

(2) All data immediately available on the web

(3) Ice avoidance software

(4) Southern Ocean State Estimate (SOSE):
   - Least squares fit to data by the adjoint method (M. Mazloff as part of ECCO consortium funded by the NSF)
   - Earlier development of BGC model was supported by NASA CMS
   - Nominal resolution is 1/6°