The challenge
Deep ocean outflow: about 80% occurs in the Southern Ocean

Morrison et al. (Physics Today, 2015)
Consequences for the role of the Southern Ocean in carbon and climate

The ocean south of 30°S accounts for

- Nutrient supply supporting three-quarters of biological production north of 30°S
- Half of the current anthropogenic carbon dioxide uptake by the oceans (43 ± 3% in CMIP5 models)
- About 75% ± 22% of excess heat uptake by the oceans (in CMIP5 models)
The grand challenge

• Despite its critical importance, the Southern Ocean is the least understood region of the world ocean.
  – The meridional overturning circulation and its response to climate change are highly uncertain
  – Biogeochemical and carbon cycling are poorly constrained
  – Current climate models are unable to resolve the crucial contribution of eddies

• And yet
  – It is the least observed region of the world ocean
  – The public is largely unaware of the importance of this region
  – We are sorely lacking in experts on the Southern Ocean
The opportunity
(1) Transformative observing system
- Argo profiling floats
  - have a 4 to 7 year lifetime,
  - Measure T & S from ~2000 m to the surface each 5 to 10 days.
  - data direct to Internet.
Current Argo float distribution

3874 Floats
2-Jun-2015
Southern Ocean: a paradigm shift  
Transformative biogeochemical sensors

- Field developing rapidly:
  - Körtzinger, et al. (2005) – O$_2$
  - Tengberg et al. (2006) – O$_2$
  - Riser and Johnson (2008) – O$_2$
  - Johnson et al. (2010) – ISUS nitrate
  - Johnson et al. (2013) – ISUS nitrate
  - Martz et al. (2010) – Durafet pH
  - Ongoing work
  - E. Boss et al. (2008) – FLBB optics
  - Whitmire et al. (2009) – FLBB optics
  - Boss and Behrenfeld (2010) – FLBB optics
(2) Transformative observational analysis methods

- Southern Ocean State Estimation (SOSE) using data assimilation to produce full 4D estimates of ocean properties
The plan
• **Objective 1:** To develop a new observing system for carbon, nutrients, and oxygen based on ~200 biogeochem floats

• **Objective 2:** To produce an unprecedented 3-dimensional space and time resolved estimate of Southern Ocean biogeochemistry based on SOSE.
The goal of SOCCOM is to measure ~500 profiles per month every month of the year.
Proposed deployment cruises (6 yrs):

Table 2. Proposed float production and research ship deployment, with source of calibration costs. Full chemistry/CTD provided (no cost to SOCOM): (a) U.S. GO-SHIP cruises (ushydro.ucsd.edu) and (b) other, mostly international, cruise collaborations. Some SOCOM calibration costs required: (c) international cruise collaborations with partial SOCOM support (chemistry only), and (d) requested UNOLS cruises requiring full support (chemistry and CTD).

<table>
<thead>
<tr>
<th>Year</th>
<th>Floats</th>
<th>In situ calibration at no cost to SOCOM</th>
<th>In situ calibration costs paid partially or in full by SOCOM</th>
<th>Deploy</th>
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<tbody>
<tr>
<td></td>
<td>Build</td>
<td>Deploy a. US GO-SHIP</td>
<td>Deploy c. Chemistry only d. SOCOM UNOLS cruises</td>
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<td>Indian Antarctic (SOCOM)</td>
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<td>2018/2019</td>
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<td>31</td>
<td>SE Pac (Chile)</td>
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<td>30</td>
<td>Good Hope (S. Africa)</td>
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# Sources of support

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<th>Agency</th>
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<th>Contribution</th>
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<tr>
<td>NSF/PLR</td>
<td>Peter Milne</td>
<td>Core support ($3.5M/yr x 6 yr; PI: J. Sarmiento)</td>
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<tr>
<td>NOAA/CPO</td>
<td>Stephen Piotrowicz</td>
<td>50% of Argo equivalent floats</td>
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<tr>
<td>NOAA/GFDL</td>
<td>V. Ramaswamy</td>
<td>Mesoscale eddying coupled climate model simulations</td>
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<td>NASA</td>
<td>Paula Bontempi</td>
<td>Optical sensors for Argo floats (PI: E. Boss &amp; O. Schofield)</td>
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Accomplishments

SOCCOM started Sept. 1, 2014
### Year 1 accomplishments

<table>
<thead>
<tr>
<th>Theme</th>
<th>Topic</th>
<th>Significant results</th>
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</table>
| Observational       | Floats  | • 12 in pre-SOCCOM (EAGER)  
                    |         | • 13 in Year 1                                                                      |
|                     | Cruises | • P16S Pre-SOCCOM (EAGER) (Pacific)  
                    |         | • Polarstern (Atlantic)  
                    |         | • SOTS (Pacific)                                                                  |
|                     | Data availability | • Available in real time from SOCCOMViz  
                    |         | • pH sensor analysis in progress                                                   |
|                     | State Estimation | • Biogeochemical models setup and being tested                                      |

Some early results from Alison Gray & Ken Johson analysis of pre-SOCCOM P16S cruise
Float trajectories (pre-SOCCOM P16S)
Different regimes

Subtropical Front Zone

Subantarctic Front Zone

Polar Front Zone

South ACC Front Zone

Seasonal Ice Zone
Temperature

\( \theta \), Conservative temperature
Salinity

$S_A$, Absolute salinity
Apparent O$_2$ Utilization

AOU = O$_2$ sat - O$_2$ meas
Nitrate

STF

SAF

PF

SACCF

ICE
pH

Adjusted using N. Williams & L. Juranek algorithm
Alkalinity

Estimated using 3D-window multiple linear regression algorithm, developed by B. Carter based on Velo et al. 2013 (cf. ongoing work by N. Williams, L. Juranek, & R. Feely)

Algorithm is trained using bottle data (GLODAPv1 + PACIFICA + CARINA)

\[ \text{Alk}_{\text{est}} = f(S, \theta, \text{NO}_3, \text{O}_2) \text{ for 3 floats} \]
\[ \text{Alk}_{\text{est}} = f(S, \theta, \text{O}_2) \text{ for 4 floats} \]
Surface $\Delta pCO_2$

$\Delta pCO_2 = pCO_2^{ocn} - pCO_2^{atm}$

Comparison to Takahashi et al. (2009)
Air-sea CO$_2$ fluxes in the Southern Ocean south of 30°S

Pre-industrial from Mikaloff-Fletcher et al. (2006); Contemporary from Takahashi et al. (2009)

Pre-industrial from Mikaloff-Fletcher et al. (2006); Contemporary from Takahashi et al. (2009)
Surface $pCO_2$

$pCO_2 = f(pH_{in\,situ}, \text{Alk}_{est})$

Blue = physics
Red = biology
What’s next?

- Mixed layer budgets
  - Carbon processes
  - Stoichiometric ratios
  - Chl:C ratio

- SOSE (Southern Ocean State Estimate)

- OSSEs (Observation System Simulation Experiments)

- BGC Argo global coverage