Community update: Biogeochemical-Argo
ECCO summer school, May 2019
Matt Mazloff (SIO), Ken Johnson (MBARI)
Biogeochemical Argo

Sensor Types

Latest location of operational floats (data distributed within the last 30 days)

- Operational Floats (343)
  - Suspended particles (195)
  - Downwelling irradiance (61)
  - pH (121)
  - Nitrate (128)
  - Chlorophyll a (195)
  - Oxygen (328)

April 2019

Generated by www.jcommops.org, 09/05/2019
What is a BGC-Argo float?

Mature sensor suite

- biooptical sensors: chlorophyll fluorescence, backscatter, light intensity.
- chemical species: dissolved oxygen, nitrate, and pH.

Protocols have been established based on peer-reviewed publications and international working groups.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Oxygen</th>
<th>Nitrate</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial accuracy</td>
<td>2 µmol/kg</td>
<td>1 µmol/kg</td>
<td>0.01</td>
</tr>
</tbody>
</table>

New sensors must be accompanied by quality calibration and validation procedures until demonstrated that specifications are achieved with the "factory calibration". Must also be means available to assess the changing performance of sensor over time.

https://soccom.princeton.edu/content/float-specifications

For what is a SOCCOM float and sensor references
What is a BGC-Argo float?

Mature sensor suite
- biooptical sensors: chlorophyll fluorescence, backscatter, light intensity.
- chemical species: dissolved oxygen, nitrate, and pH.

Data management
- real-time data delivery for operational purpose
- delayed-mode quality-controlled data delivery for science
- new products complying with end-user requirements

Critical Ocean Processes for climate variability, ecosystem health, management marine resources, carbon budgets
- ocean carbon uptake
- ocean deoxygenation, oxygen minimum zones and related cycles of denitrification
- ocean acidification
- the biological carbon pump
- phytoplankton communities.
Navis
APEX
Provor

SOLO-II
SIO
In development
The Biogeochemical-Argo Implementation Plan

- An international plan
- 1000 profiling floats with $O_2$, pH, $NO_3^-$, bio-optics
- Observe seasonal and interannual change in carbon cycling, OMZ’s, nutrient flux, acidification, biological carbon pump, phytoplankton phenology
- Ocean management of living marine resources & carbon budget verification
- Sustaining 1000 floats requires ~250 floats/year
- ~$25,000,000/year (~$12,500,000/year for US share?).

http://biogeochemical-argo.org
Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM): A basin scale program.
136 active floats (May 2019)

The goal is ~200 floats with $O_2$, $NO_3^-$, pH, bio-optics in So. Ocn.

Funded by NSF Polar Programs with NASA, NOAA add-ons.

All data publically available, in real-time at http://soccom.princeton.edu and through the Argo Global Data Assembly Centers.
<table>
<thead>
<tr>
<th>Country</th>
<th>Count</th>
<th>Country</th>
<th>Count</th>
</tr>
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<tbody>
<tr>
<td>Canada</td>
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<tr>
<td>India</td>
<td>20</td>
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</tbody>
</table>

**Total** 124

But note that the sensor load is quite variable. Some have $O_2$ only. Some have $O_2$, $NO_3$, pH, Chloro, Backscatter, Irradiance. And everything in between!
Johnson et al., JGR, 2017
Figure from Seth Bushinsky
BGC-Argo Network
1000 profiling floats with T & S, oxygen, nitrate, CDOM & chl fluorescence, backscatter, irradiance and pH

Operational Centres
Global and regional models assimilate RT data for forecasting and DL-mode data for reanalyses

Improved model products for applications ranging from climate predictions, carbon accounting, assessment of ocean acidification and deoxygenation, and primary production estimates to management of living marine resources.
Biogeochemical Southern Ocean State Estimate
Data assimilation of carbon and other biogeochemical constraints

Ariane Verdy, Matt Mazloff

Lynne Talley, Sharon Escher, Bruce Cornuelle, Isa Rosso, Natalie Freeman, Joellen Russell, Jorge Sarmiento, Ken Johnson, Emmanuel Boss, Matt Long, John Dunne, Eric Galbraith
State estimation

4D-Var, “adjoint” method

Models are used to hindcast the ocean state (T, S, V, SSH) using inputs: initial conditions & atmospheric forcing. Adjust those inputs to bring the model closer to observations of the actual ocean state.

Minimize the “cost function”:

\[
\sum (\text{weighted model-observations misfit})^2 + \sum (\text{weighted adjustment to inputs})^2
\]

E.g. Southern Ocean 2013-2017

E.g. T & S from Argo maps, winds & air temp, etc. from ECMWF

E.g. from Argo profiles, satellites, …

B-SOSE: biogeochemical + physical state optimized together

ECCO.JPL.NASA.GOV
Biogeochemical model

“N-bling”

All **prognostic** and **diagnostic** variables are estimated; can be compared / constrained to observations.
B-SOSE product

2008-2012, 1/3 degree

Verdy and Mazlof (2017), A data assimilating model for estimating Southern Ocean biogeochemistry, JGR-Oceans

2013-2018 in production  (with SOCCOM floats constraints)
B-SOSE vs climatology with SOCCOM float observations
B-SOSE vs climatology
with SOCCOM float observations
B-SOSE surface speed

Movie from Stan Swierczek
Air-sea CO$_2$ flux [mol m$^{-2}$ yr$^{-1}$] from B-SOSE 2013 - 2017 solution
NO3 at 20m run at 1/3°
initialize from BSOSE

NO3 at 20m in 1/6° BSOSE

Movie from Stan Swierczek
Validation [http://sose.ucsd.edu/bsose_valid.html](http://sose.ucsd.edu/bsose_valid.html)

* = assimilated

Comparisons with gridded products
* ocean color (chl, POC)
* altimetry
* microwave SST
* sea ice
Argo monthly mapped product
GLODAPv2, WOA13, SOCAT climatologies
Landschützer monthly mapped product

Comparisons with in situ observations
* Argo profiles (T,S)
* calibrated bgc-Argo (O₂)
* SOCCOM floats
* SOCAT (pCO₂)
* GLODAPv2 (carbon, nutrients)
* CTD (T, S, O₂, chl)
* XBT, MEOP, PIES
GEOTRACES
Comparisons with in situ observations

7 m $O_2$ in B-SOSE 2013-2017 is compared to bgc-Argo
Monthly-averaged pCO₂ in Drake Passage (75°W to 55°W, south of 50°S) from SOCATv4 observations (black) [Bakker et al., 2016; Munro et al., 2015a, 2015b], and from B-SOSE (area average in pink; subsampled at the location of observations in red). Summer months are shaded gray.
We have the adjoint tool. Use it to address question:
What is the sensitivity of October air-sea carbon

October mean CO$_2$ flux in model [mol m$^{-2}$ yr$^{-1}$]. Warm colors are CO$_2$ uptake by ocean. Cool colors are CO$_2$ outgassing.
What is the sensitivity of October air-sea carbon exchange poleward of $40^\circ$S?

Sensitivity calculated as RMS of adjoint gradient normalized by standard deviation of respective property.
Sensitivity of October air-sea CO₂ flux to properties in September:

Warm colors denote increasing property increases oceanic sink. Cool colors denote increasing property increases outgassing.
Assimilating ocean color observations

cost function = surface chlorophyll from VIIRS satellite, 2013

red = where adding iron would reduce the misfit with observations
Higher resolution, multi-grid assimilation
Rosso et al. (2017), Space and time variability of the Southern Ocean carbon budget. JGR-Oceans.
Getting the products

B-SOSE output: sose.ucsd.edu
+ validation
+ documentation

- netCDF
- CF compliant
- available for model comparisons

MITgcm BLING model and adjoint: github.com/MITgcm/MITgcm
<table>
<thead>
<tr>
<th>TOTAL PROFILES</th>
<th>2019 PROFILES</th>
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<td>2019 O₂ PROFILES ACQUIRED BY</td>
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<td>TOTAL CHL A PROFILES</td>
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</table>

<table>
<thead>
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<th>TOTAL SUSPENDED PARTICLES PROFILES</th>
<th>2019 SUSPENDED PARTICLES PROFILES ACQUIRED BY</th>
</tr>
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<tbody>
<tr>
<td>65237</td>
<td>697</td>
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</table>
Biogeochemical Southern Ocean State Estimates (B-SOSE)

http://sose.ucsd.edu/

- Have produced a 1/6° resolution 2008-2012 pre-SOCCOM B-SOSE
- Produced a 1/6° resolution 2013 - 2017 SOCCOM era B-SOSE and now extending it.

Providing biogeochemical and physical budgets, extensive validation, and analysis software, enabling researchers and stakeholders to understand the variability in our marine resources

Verdy and Mazlof, 2017. A data assimilating model for estimating Southern Ocean biogeochemistry. JGR.