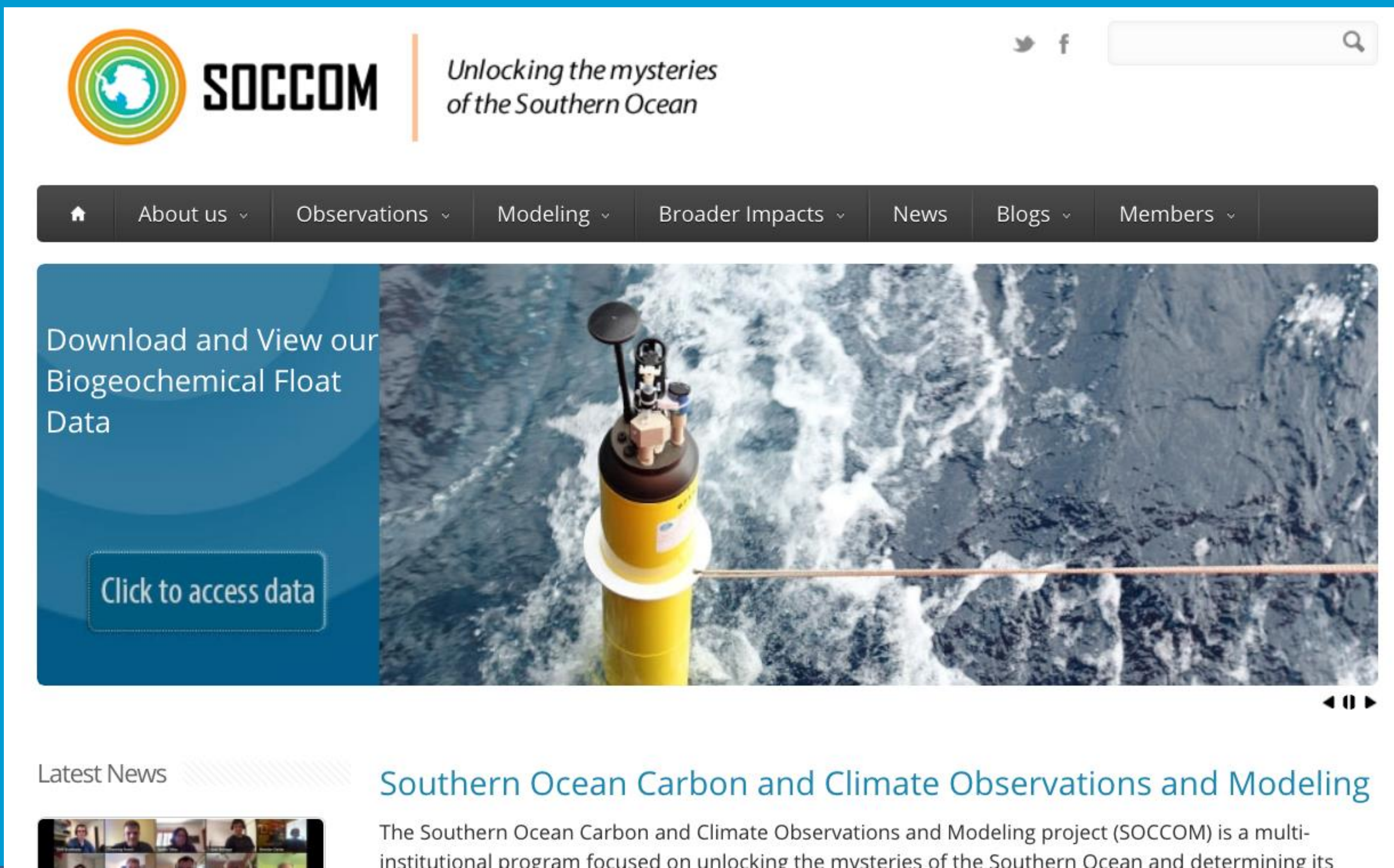
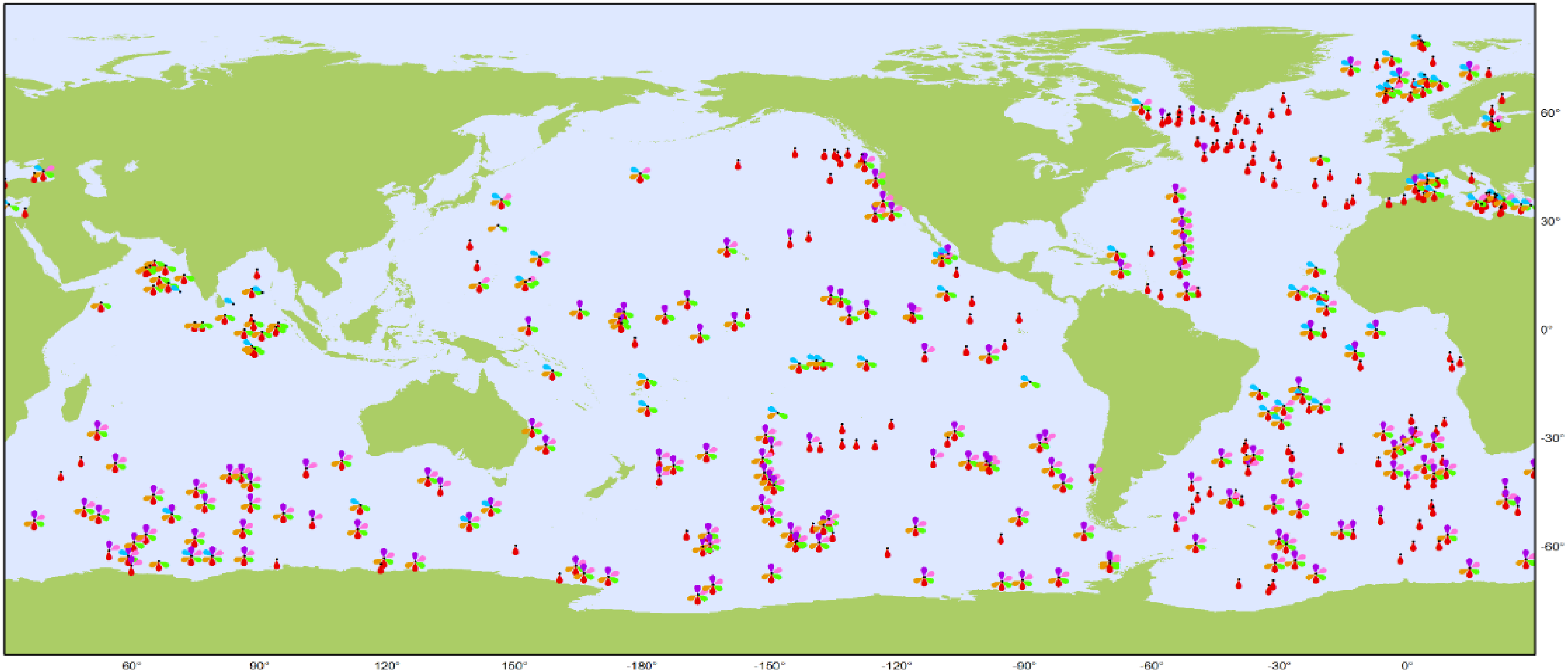
Biogeochemical, ocean, and sea-ice data assimilation in the Southern Ocean

ECMWF/OceanPredict workshop on Advances in Ocean DA

Matt Mazlof & Ariane Verdy, May 2021



BGC-Argo is rapidly expanding, and beginning to provide sufficient coverage of in situ observations to justify a DA effort



Sensor Types **April 2021**

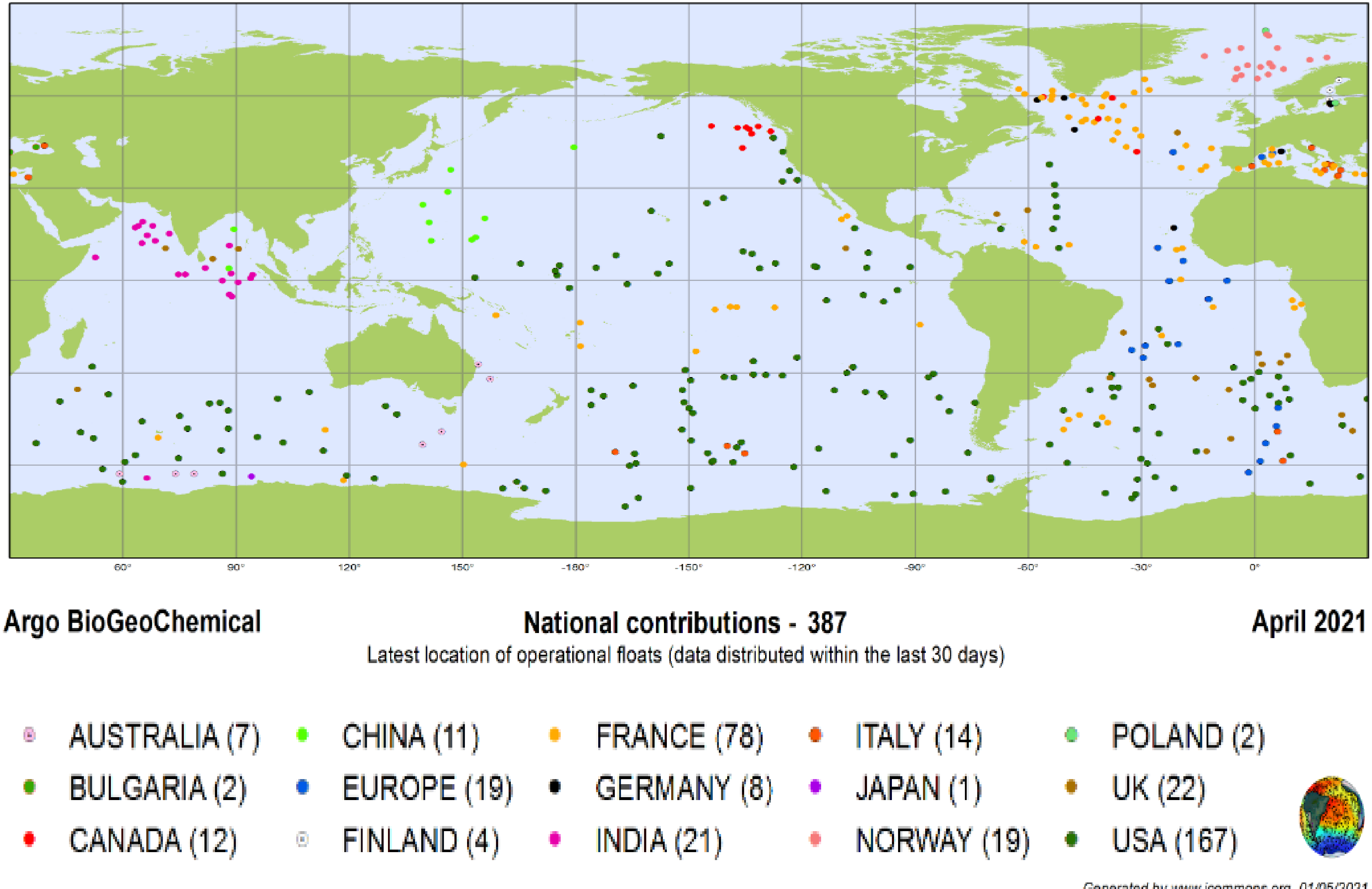
Latest location of operational floats (data distributed within the last 30 days)

Operational Floats (387)

- Suspended particles (211)
- Downwelling irradiance (66)
- pH (165)
- Nitrate (152)
- Chlorophyll a (211)
- Oxygen (376)

Generated by www.jcommops.org, 01/05/2021

BGC-Argo is an international effort in terms of both float investments and deployment efforts



SOCCOM

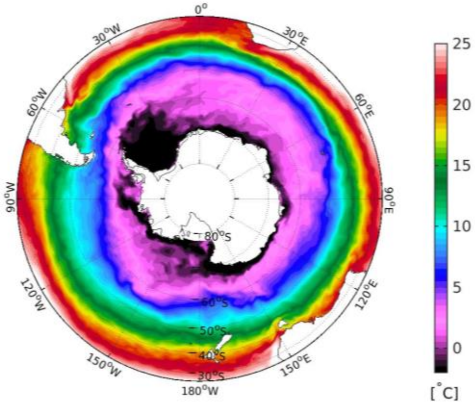
B-SOSE
Biogeochemical Southern Ocean State Estimate

Number of vertical profiles from ship, Argo, BGC-Argo:

	2011	2012	2013	2014	2015	2016	2017	2018	2019
Ship	26876	31112	35942	35454	31022	30178	28843	22156	9477
Argo TS	29187	34197	34806	35174	36957	36699	31928	29045	20957
BGC-Argo O_2	5845	7378	7780	10185	9093	8948	8919	7552	6780
BGC-Argo NO_3	585	1073	2138	2288	2214	2381	3100	3069	3571
BGC-Argo pH	0	32	72	414	609	1055	1616	1434	1513

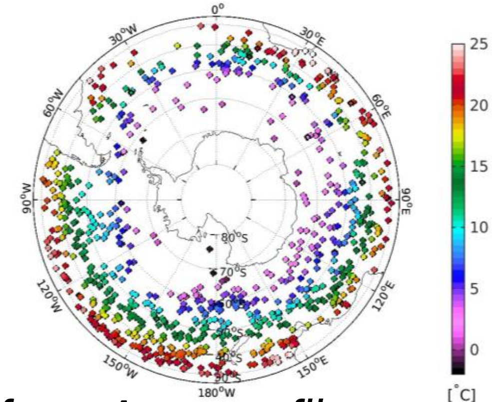
4D-Var, "adjoint" method

adjusting initial conditions & atmospheric forcing



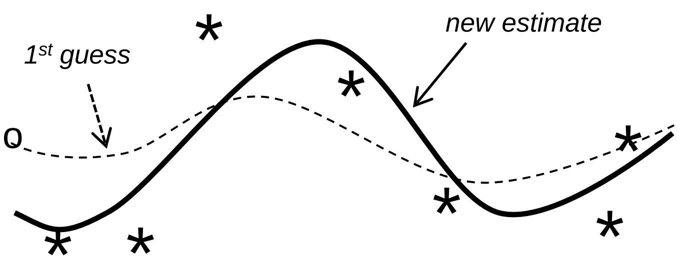
Atmospheric state from ERA5

adjust inputs to bring the model closer to observations of the actual ocean state



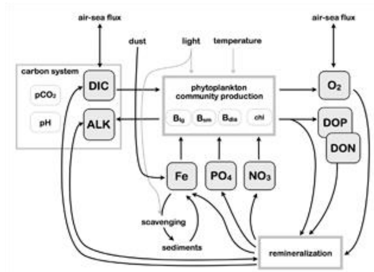
e.g. from Argo profiles, satellites, …

minimize the "cost function" :



Σ (weighted model-observations misfit)^2
+ Σ (weighted adjustment to inputs)^2

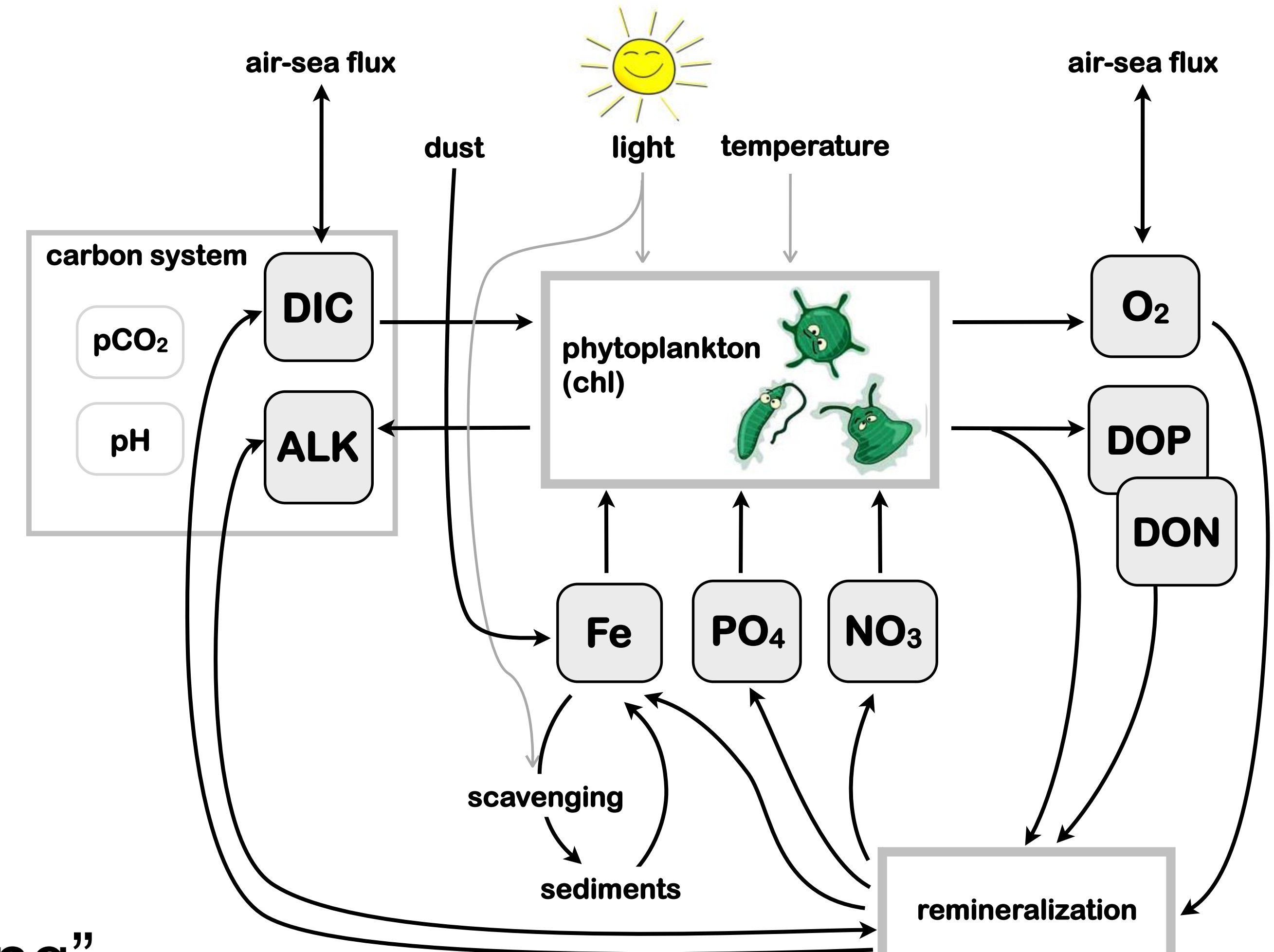
B-SOSE: biogeochemical + physical state optimized together



https://ecco-group.org/

N-BLING: Biogeochemistry with Light, Iron, Nutrients, and Gases

Evolved from Galbraith et al (2010). Currently using 9 prognostic tracers



“N-bling”

all prognostic and diagnostic variables are estimated; can be compared / constrained to observations

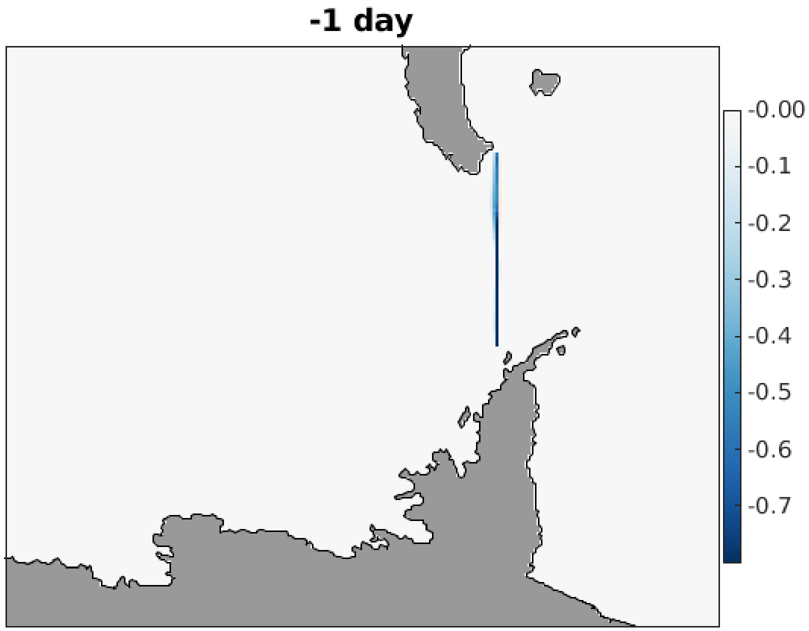
Percent error occurring in back propagation due to linearization assumption

Information propagates forwards in the nonlinear ocean model.

$$\mathbf{x(t+1) = \mathit{M}\ \ x(t)}$$

Information propagates backwards in the linear adjoint model.

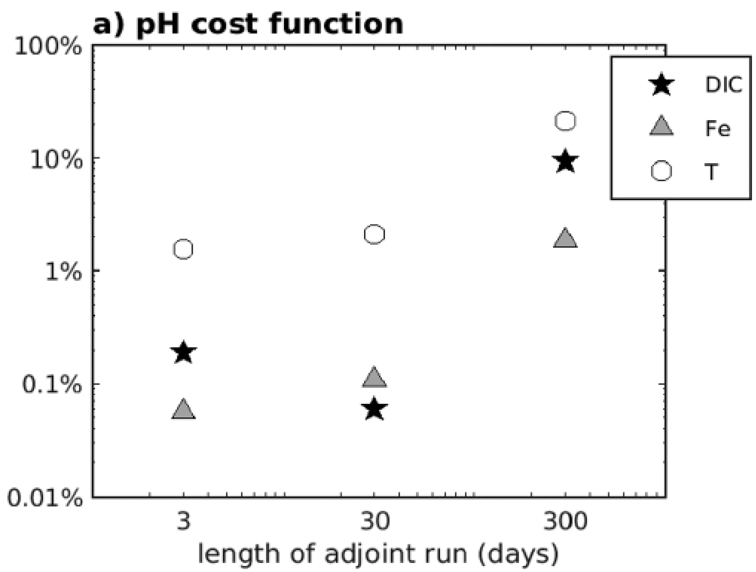
$$\mathbf{x(t-1) = M^T\ \ x(t)}$$

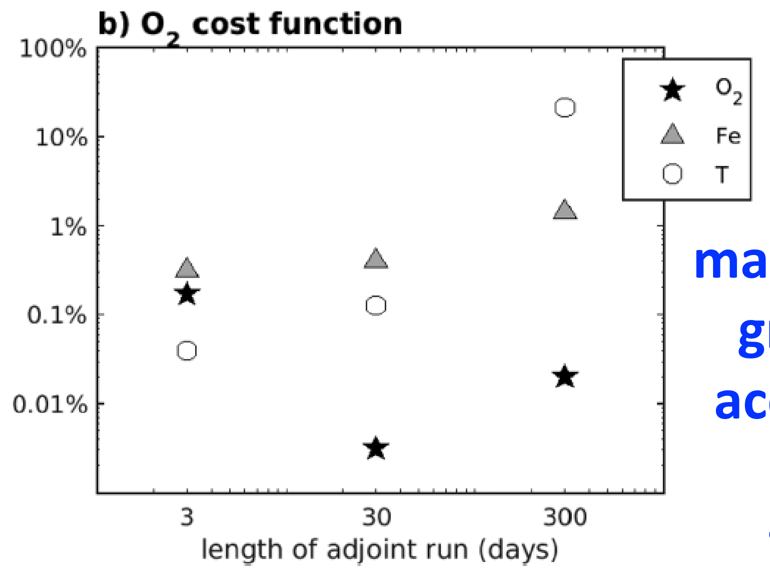


Cost is square of pH (50–100 m depth) and interior oxygen (200–300 m depth)

M gradient = FWD = (cost(+) – cost(-)) / (ΔDIC(+) – ΔDIC(+))

Error = (ADJ – FWD) / FWD



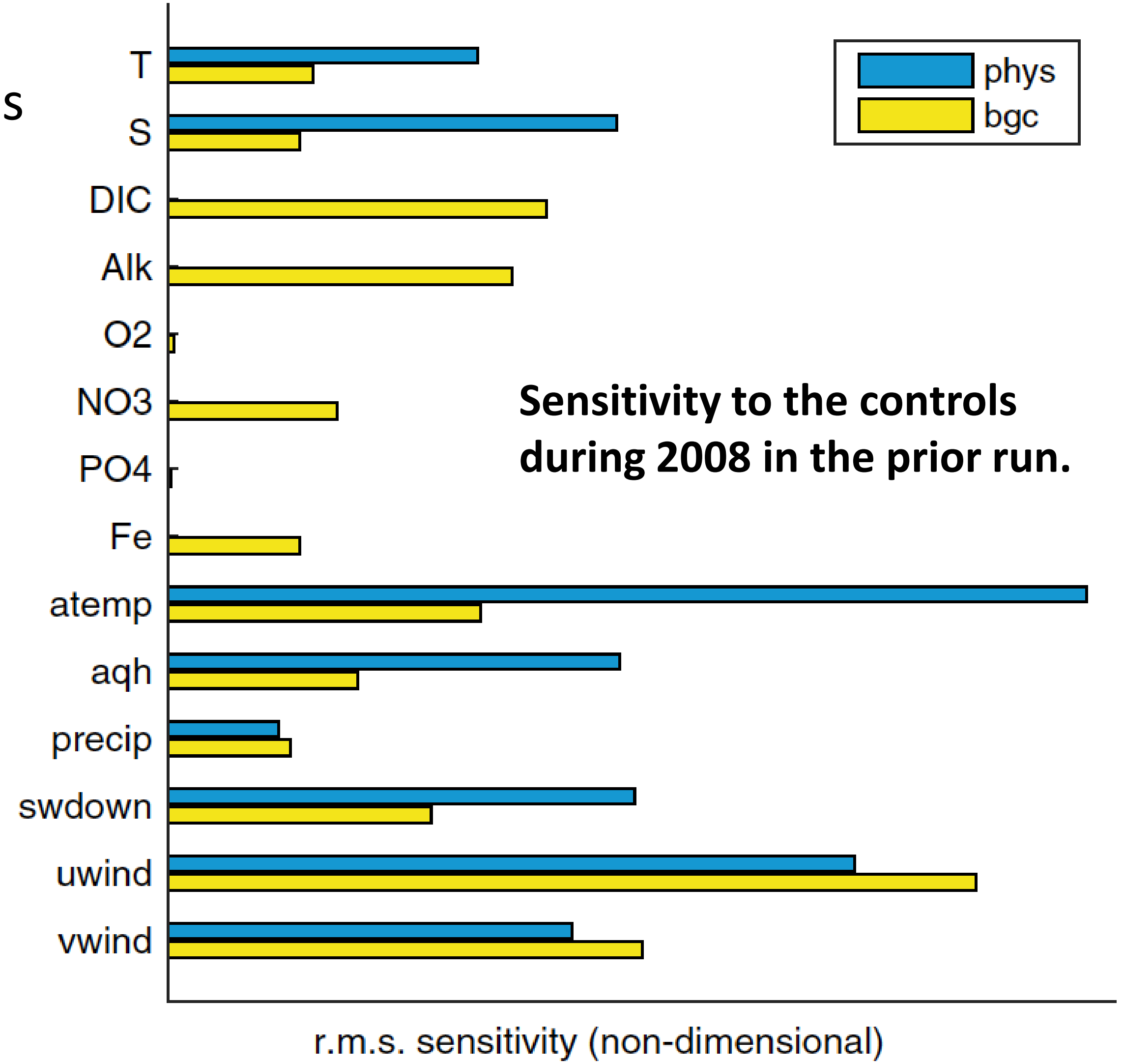


BGC variables act largely like passive tracers, making the adjoint gradients more accurate than for salinity and temperature

Examining sensitivity of prior misfits to the controls quantifies the relative influence of each type of constraint

- Blue: the cost function consists of only physical constraints
- Yellow: the cost function consists of only biogeochemical constraints

The larger the sensitivity, the more influence the constraints have on the optimization.



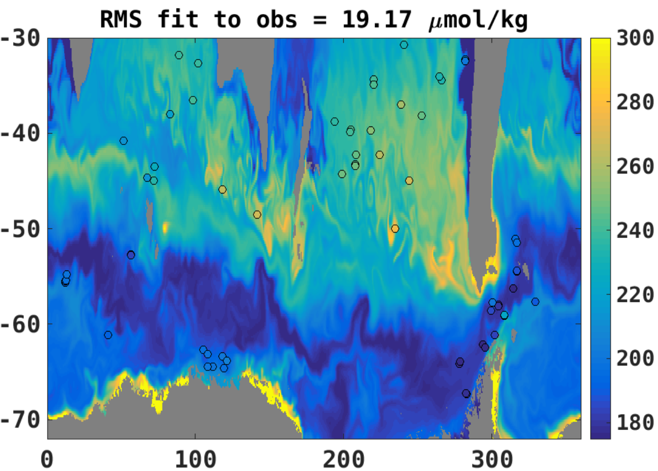
Temperature, salinity, and sea surface height observations constrain the circulation and solubility, giving them a strong impact on bgc properties.

Biogeochemical properties often have strong vertical gradients, allowing them to significantly constrain the circulation and vertical exchanges.

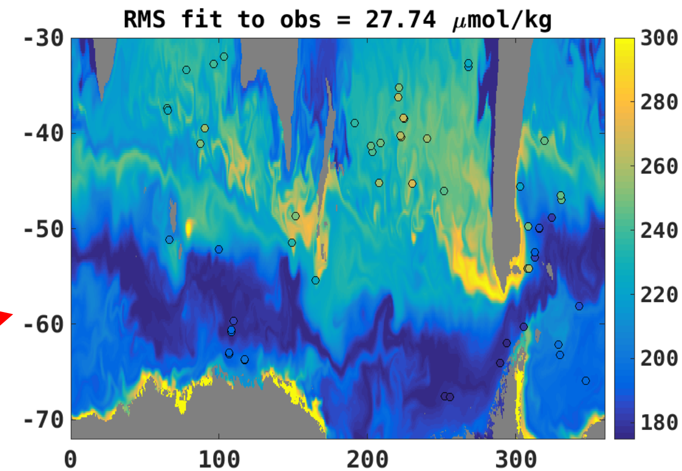
SOCCOM Status in year 2: 2015 - 2016

- Gathering constraints and building automated validation documentation
- Began optimizing 2008-2009 at 1/3° and it worked well!

December 2008



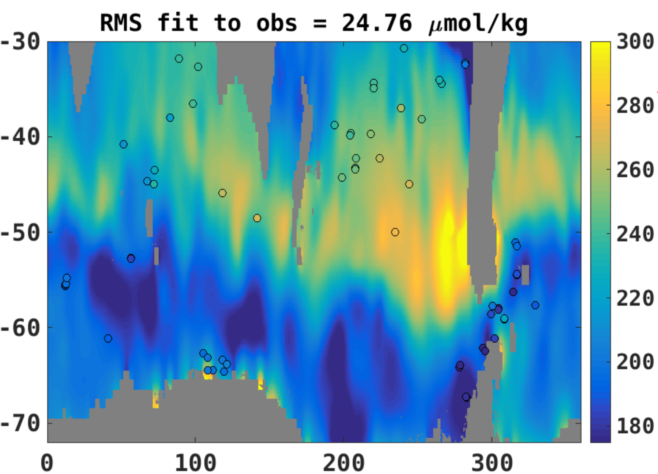
December 2009



Oxygen at 500 m.

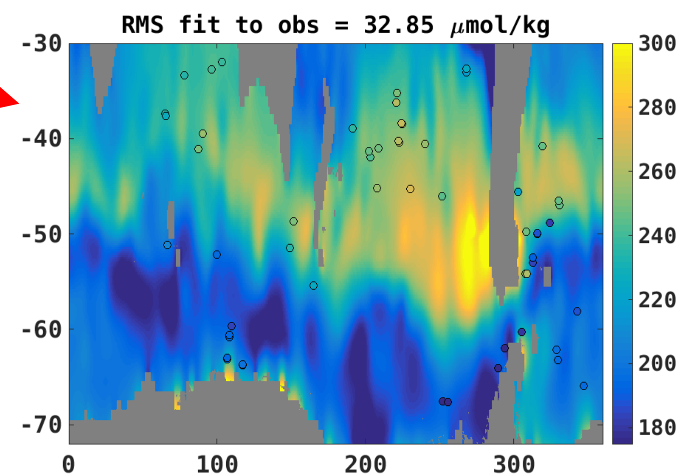
Argo obs shown with filled circles.

B-SOSE Iteration 45



WOA 2009 climatology

B-SOSE is 23% more consistent with obs. In Dec. 2008 and 16% more in Dec. 2009.

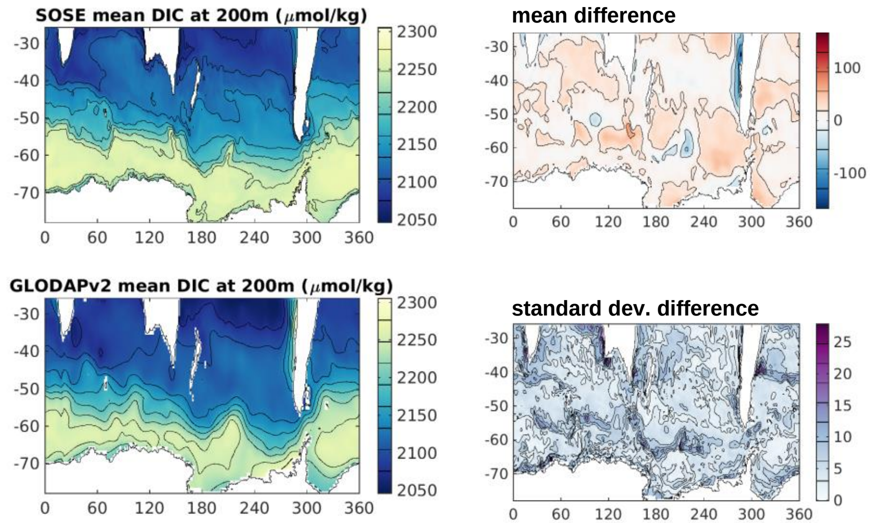


Validation

* = assimilated

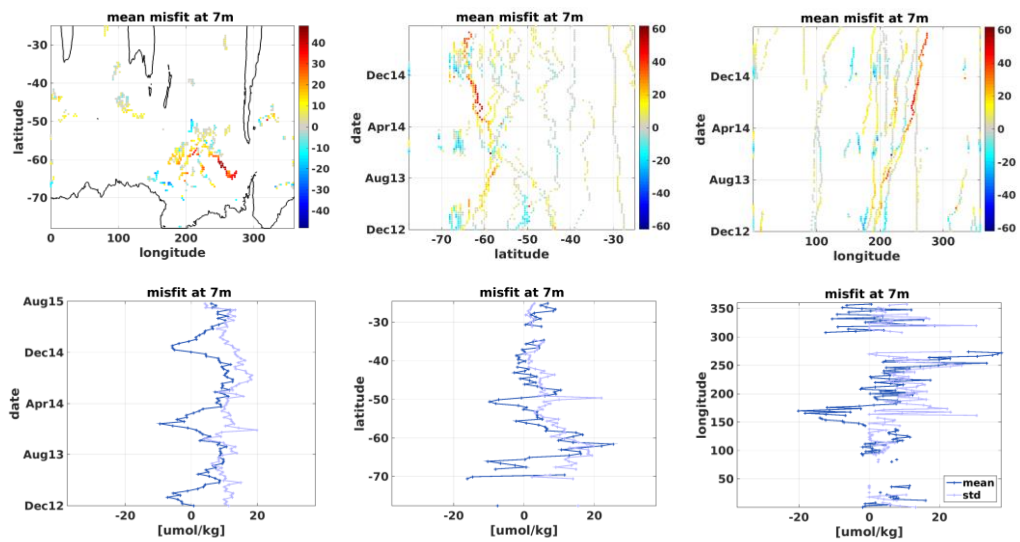
Comparisons with gridded products

* ocean color (chl, POC)
* altimetry
* microwave SST
* sea ice
Argo monthly mapped product
AVISO SSH
GLODAPv2, WOA13, SOCAT climatologies
Landschützer monthly mapped product

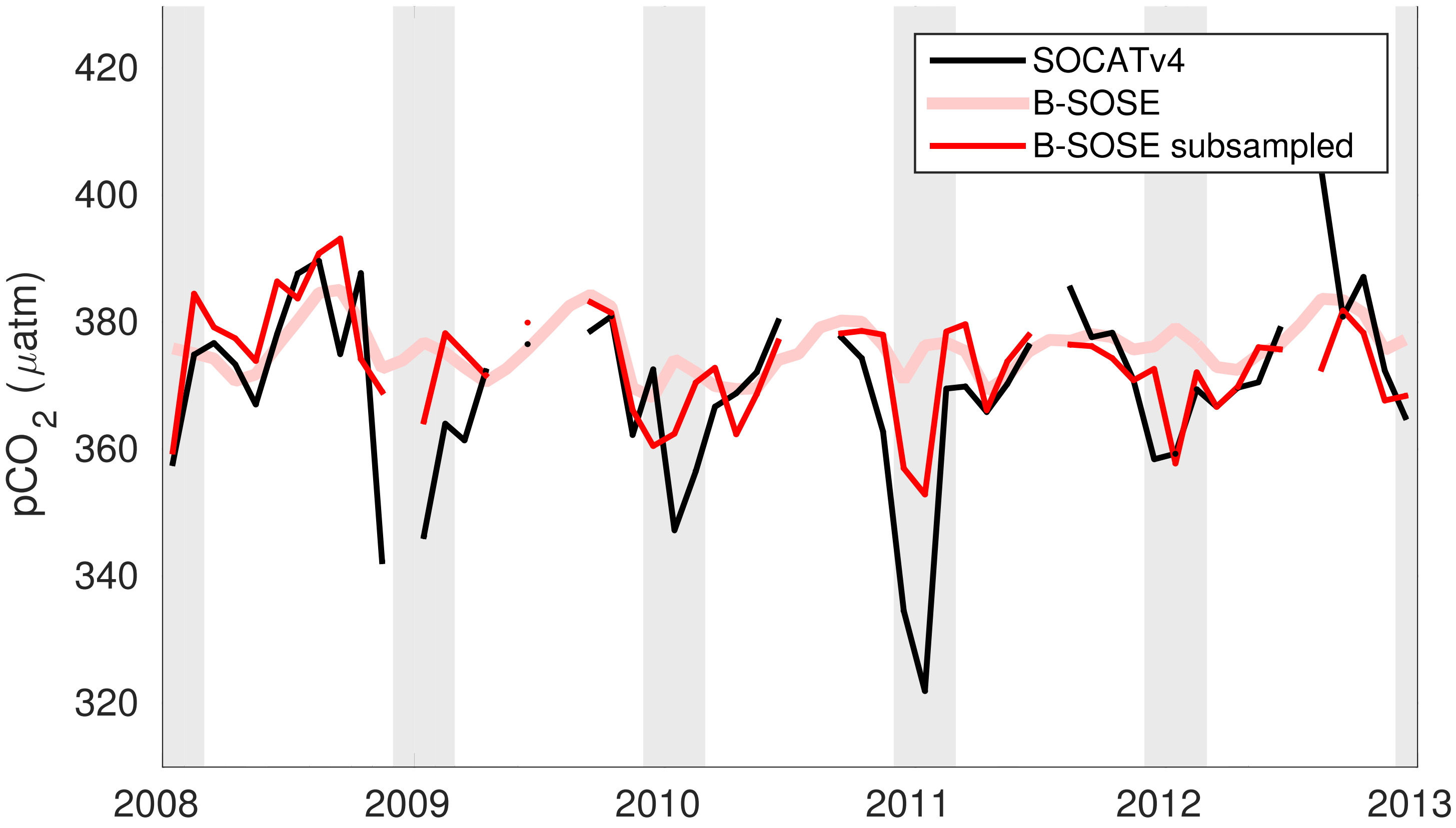


Comparisons with in situ observations

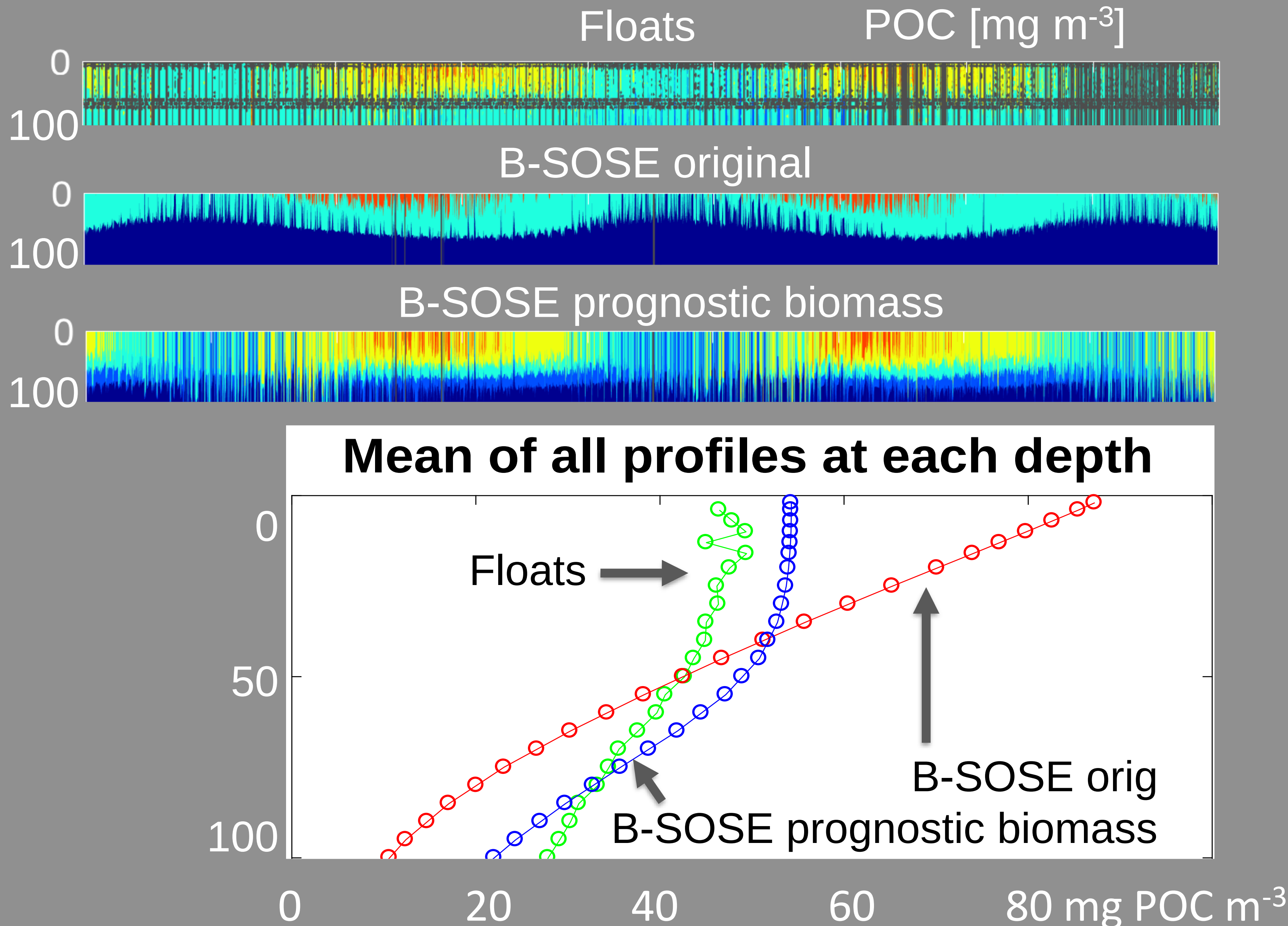
***** Argo profiles (T,S)
* calibrated bgc-Argo (O_2)
* SOCCOM floats
* SOCAT (pCO_2)
* GLODAPv2 (carbon, nutrients)
* CTD (T, S, O_2, chl)
* XBT, MEOP, PIES
GEOTRACES



pCO_2 in Drake Passage



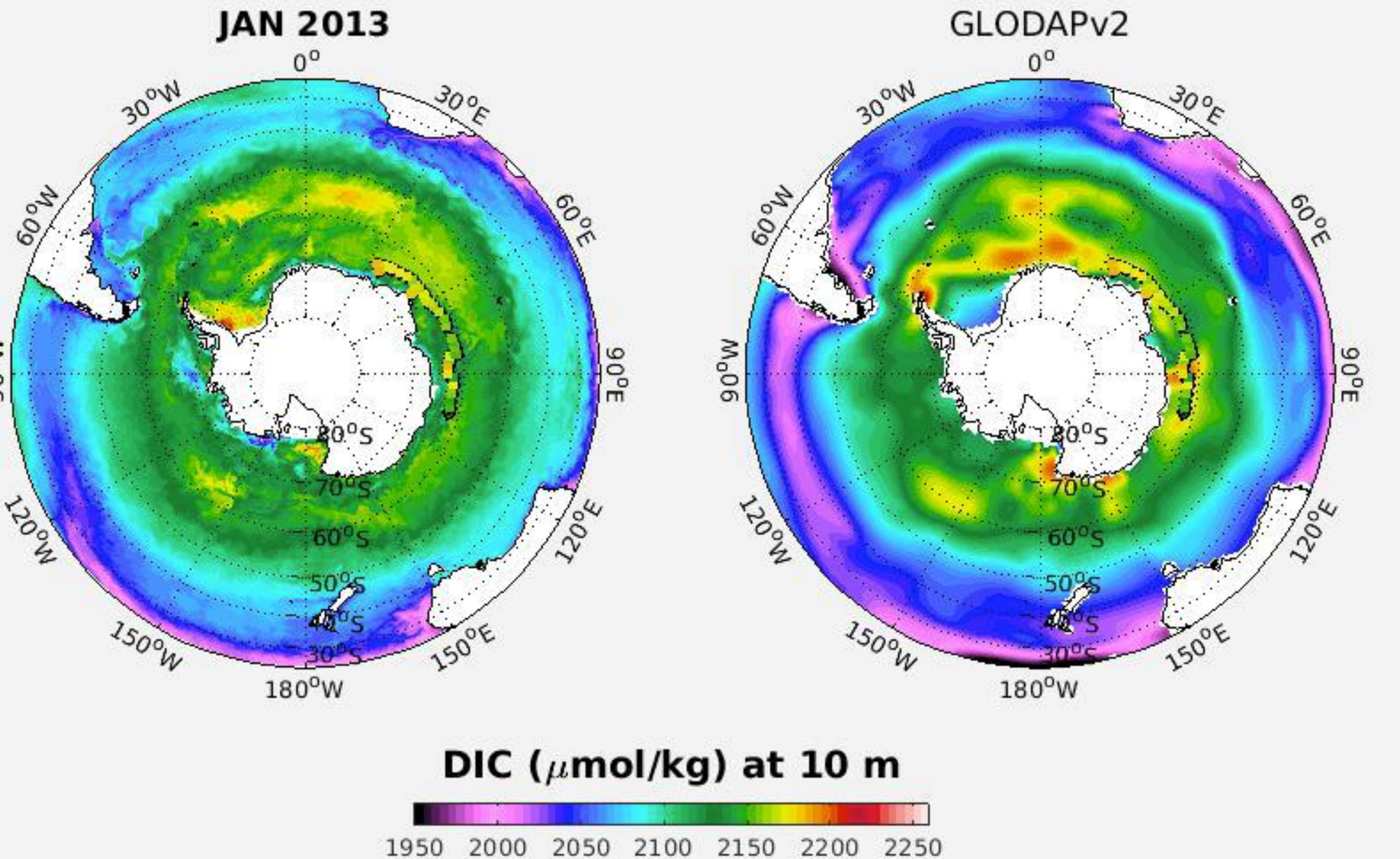
Monthly-averaged pCO_2 in Drake Passage (75°W to 55°W, south of 50°S) from SOCATv4 observations (black) [Bakker et al., 2016; Munro et al., 2015a, 2015b], and from B-SOSE (area average in pink; subsampled at the location of observations in red). Summer months are shaded gray.

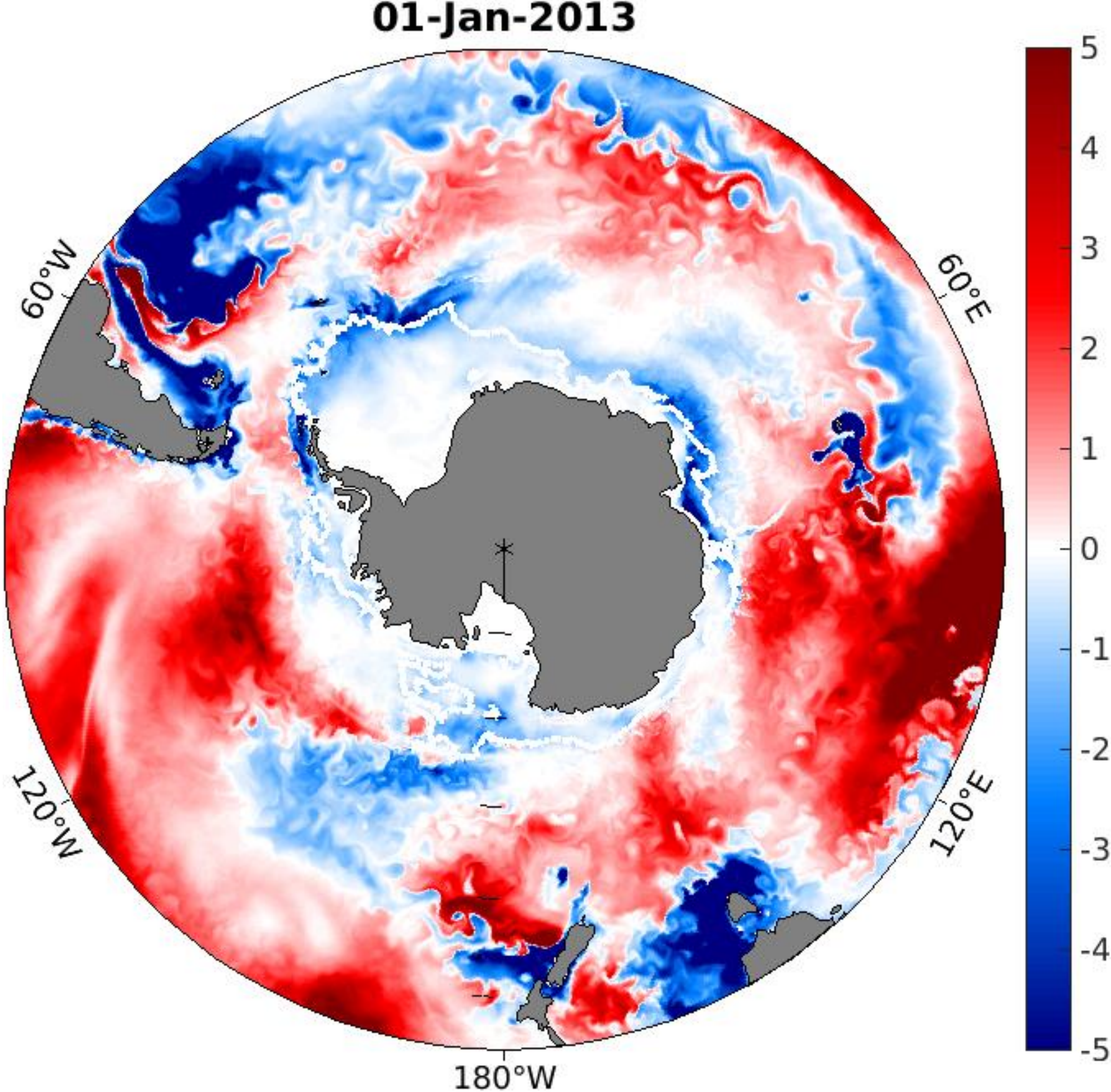


BGC highly sensitive to vertical transport, amplifying problems with the physical model

Ocean carbon content is strongly trending
Cannot assume stationarity

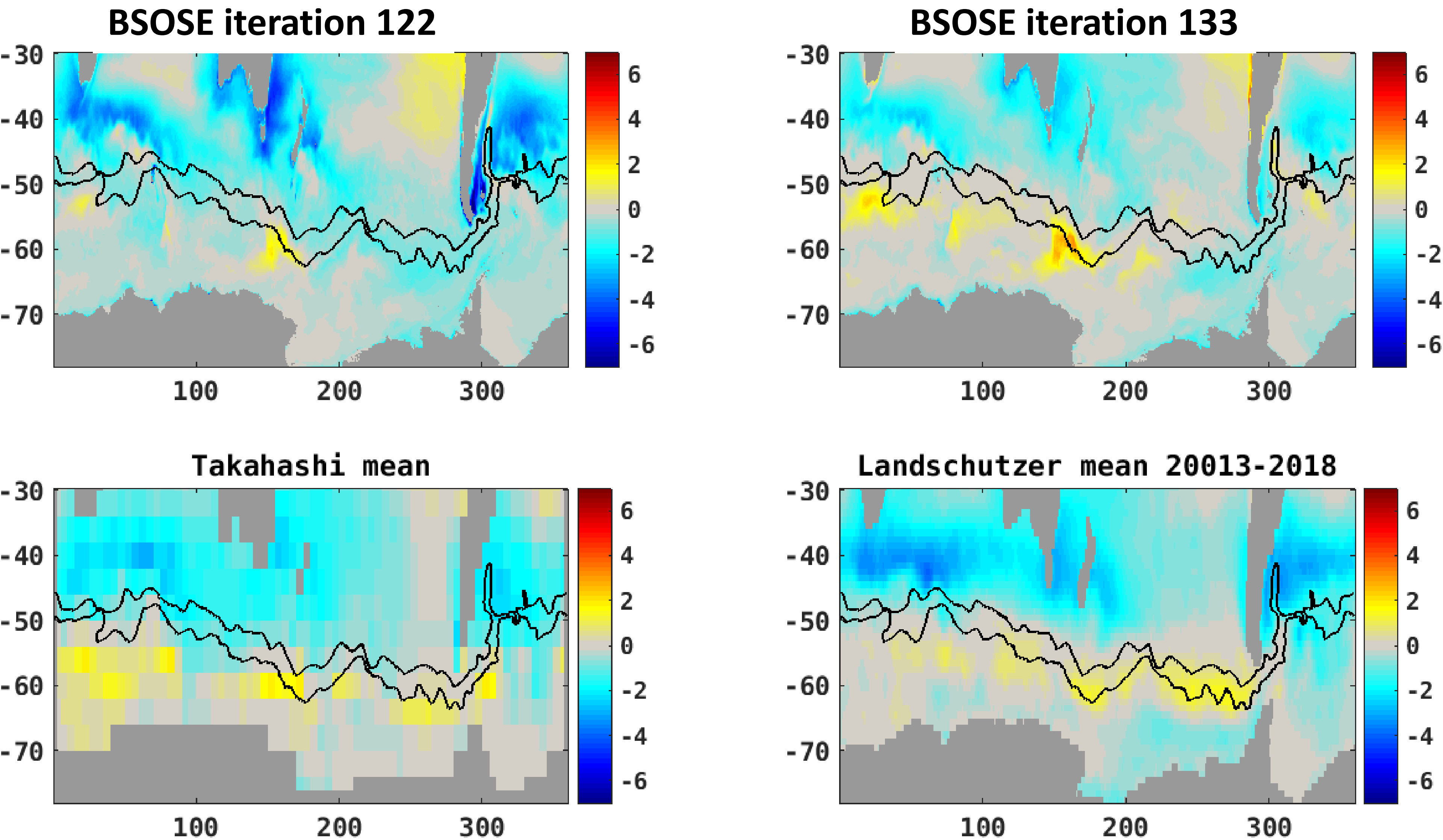
B-SOSE
Biogeochemical Southern Ocean State Estimate





Air-sea CO_2 flux
[mol m^{-2} yr^{-1}]
from B-SOSE
2013 - 2017
solution

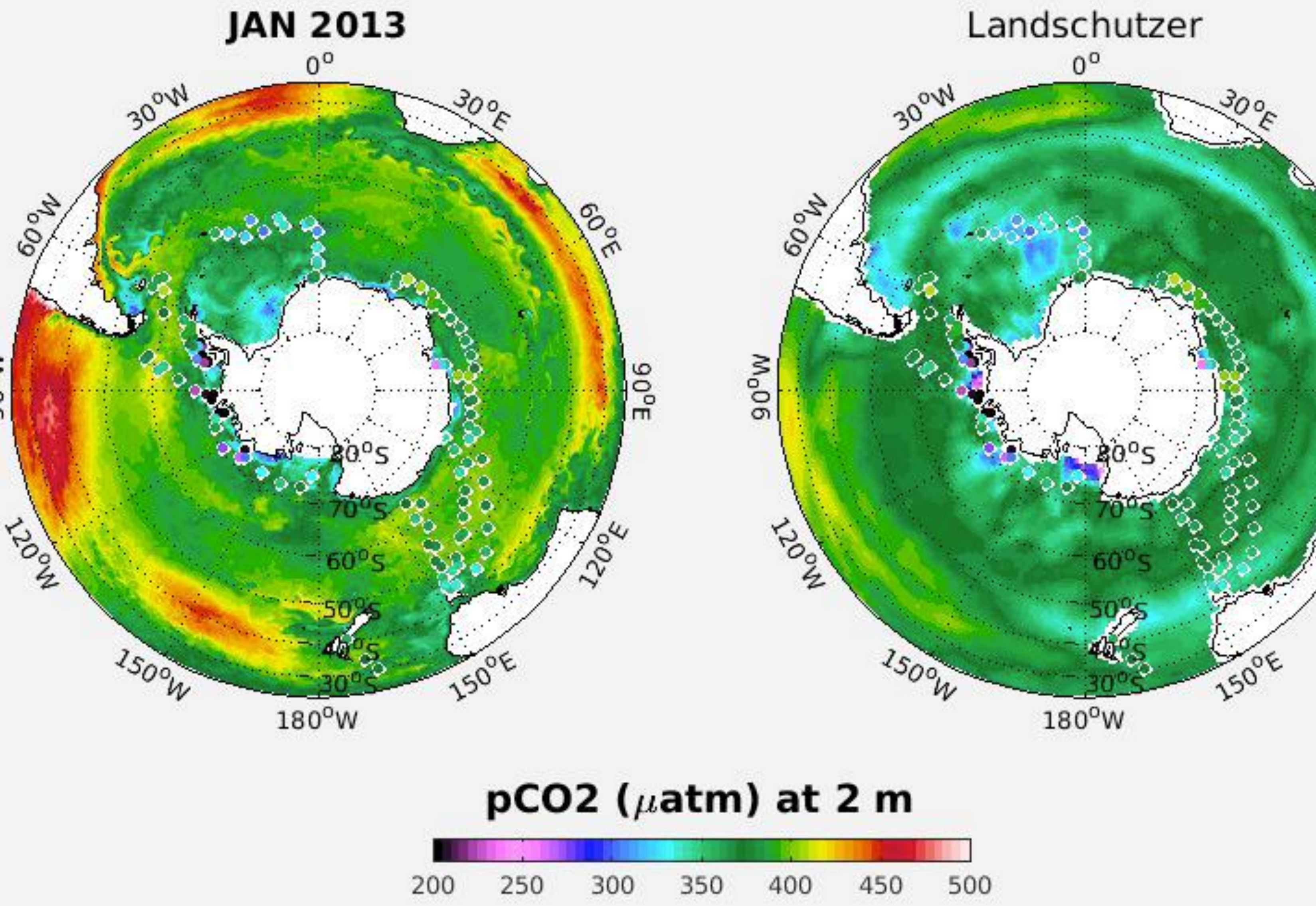
Mean air-sea CO2 flux [mol m^{-2} yr^{-1}]



Mean CO2 flux is highly sensitive to model state and inputs (e.g. mixing parameterizations)

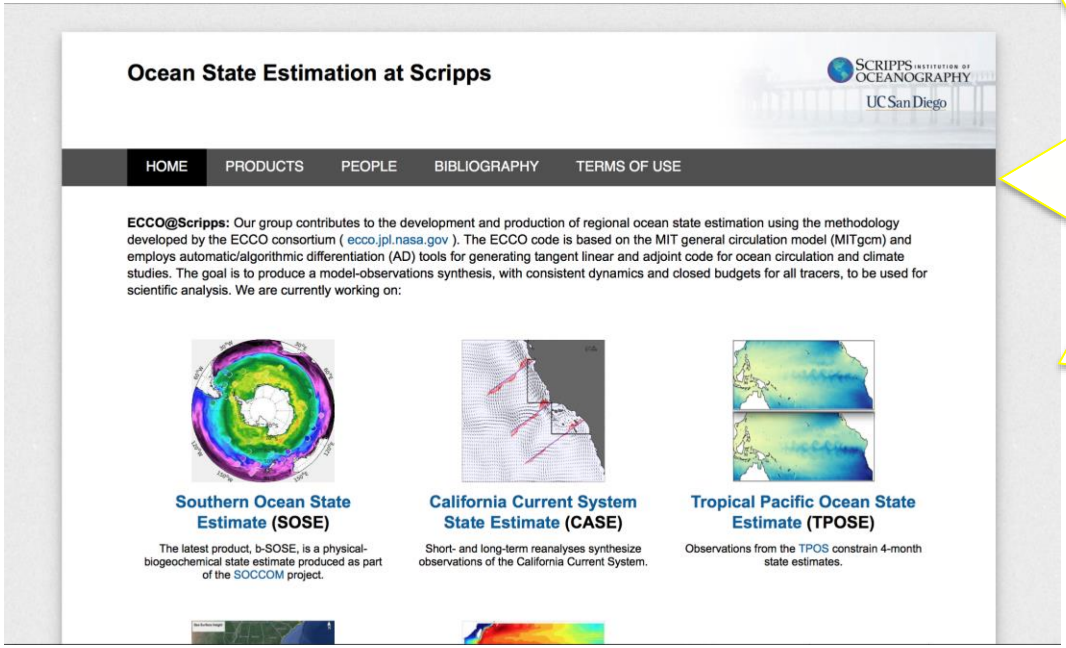
B-SOSE

Biogeochemical Southern Ocean State Estimate



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**

Verdy, A. and M. R. Mazloff (2017), A data assimilating model for estimating Southern Ocean biogeochemistry, J. Geophys. Res. Oceans, 122, 6968– 6988, doi:10.1002/2016JC012650.