SOCCOM: current status & future planning

Lynne D. Talley

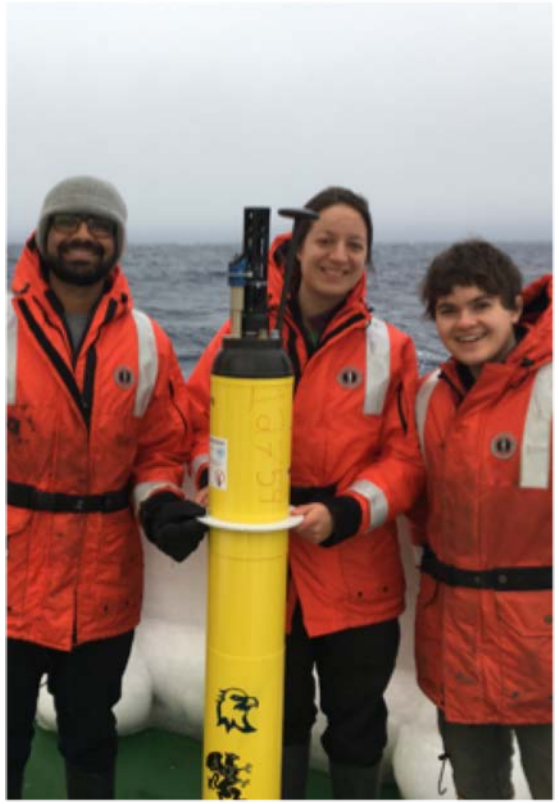
Scripps Institution of Oceanography

J.L. Sarmiento, K.S. Johnson, J. Russell, S.C. Riser, E. Boss, M. Mazloff

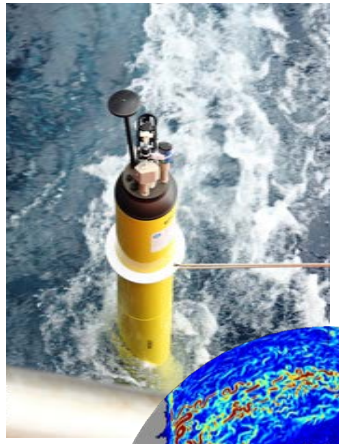
US CLIVAR Summit, POS

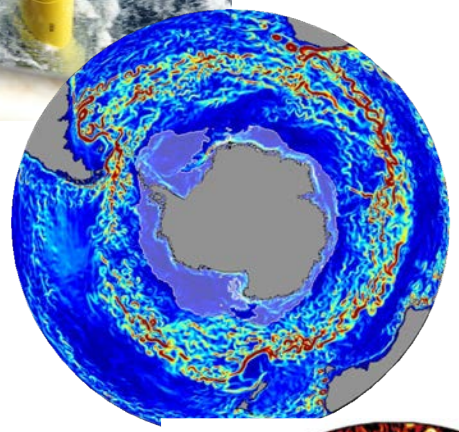
Long Beach, CA

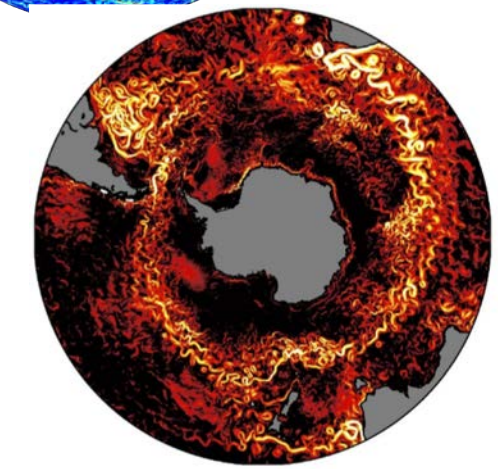
August 7, 2019



SOCCOM Objectives & Components







Observations: To develop a robotic observing system for carbon/pH, nutrients, oxygen, chlorophyll, based on ~200 biogeochemical floats, including under Southern Ocean sea ice

SOCCOM biogeochemical Argo float array (Talley, Johnson, Riser, Boss)

State estimation: To produce an unprecedented space and time estimate of Southern Ocean biogeochemistry, using state estimation

Biogeochemical Southern Ocean State Estimate (B-SOSE) (Mazloff, Verdy)

Modelling: improve high resolution earth system models to increase understanding of the Southern Ocean's current workings and make better projections of the Earth's climate and biogeochemistry.

Southern Ocean Model Intercomparison Project (SOMIP), part of FAFMIP

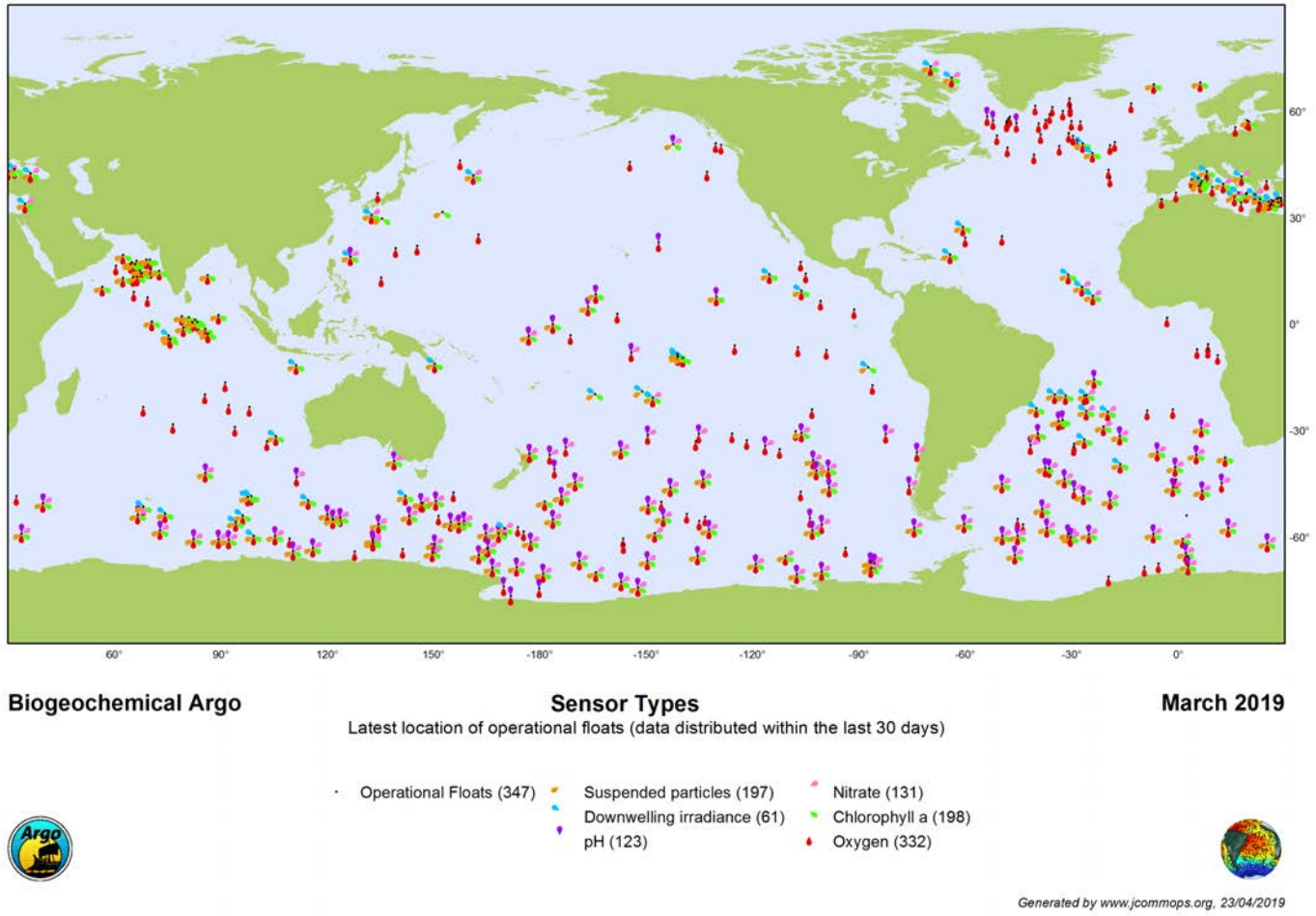
CMIP5 and CMIP6 model analyses, forcing experiments (Russell)

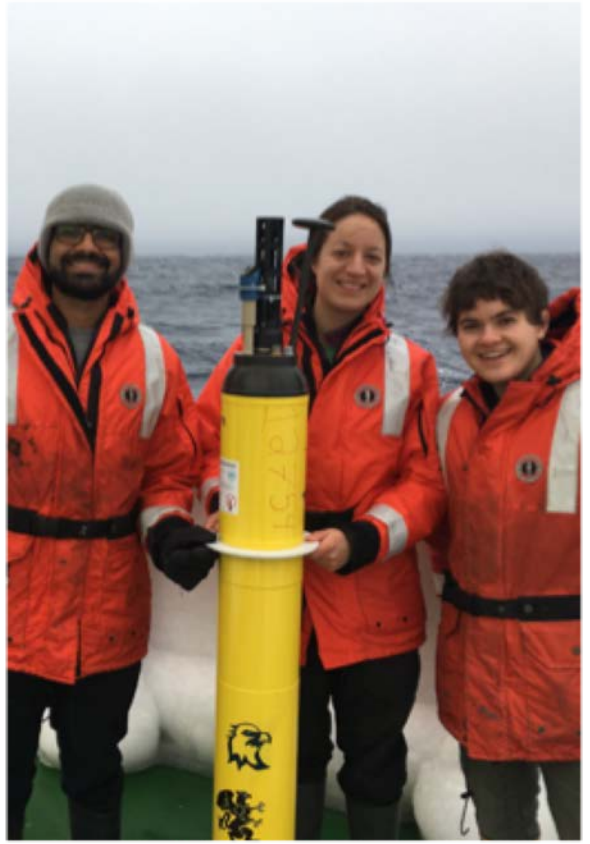
SOCCOM

89 peer-reviewed publications thus far

Biogeochemical Argo profiling floats (including SOCCOM)

Argo profiling floats (10 day profiles, 0-2000 m, 1000 m parking depth) plus:
Oxygen, pH, Nitrate, Fluorescence, Backscatter, (downwelling irradiance)





Southern Ocean: most of these are SOCCOM BGC-Argo floats

SOCCOM floats 2014-2019 and data sets

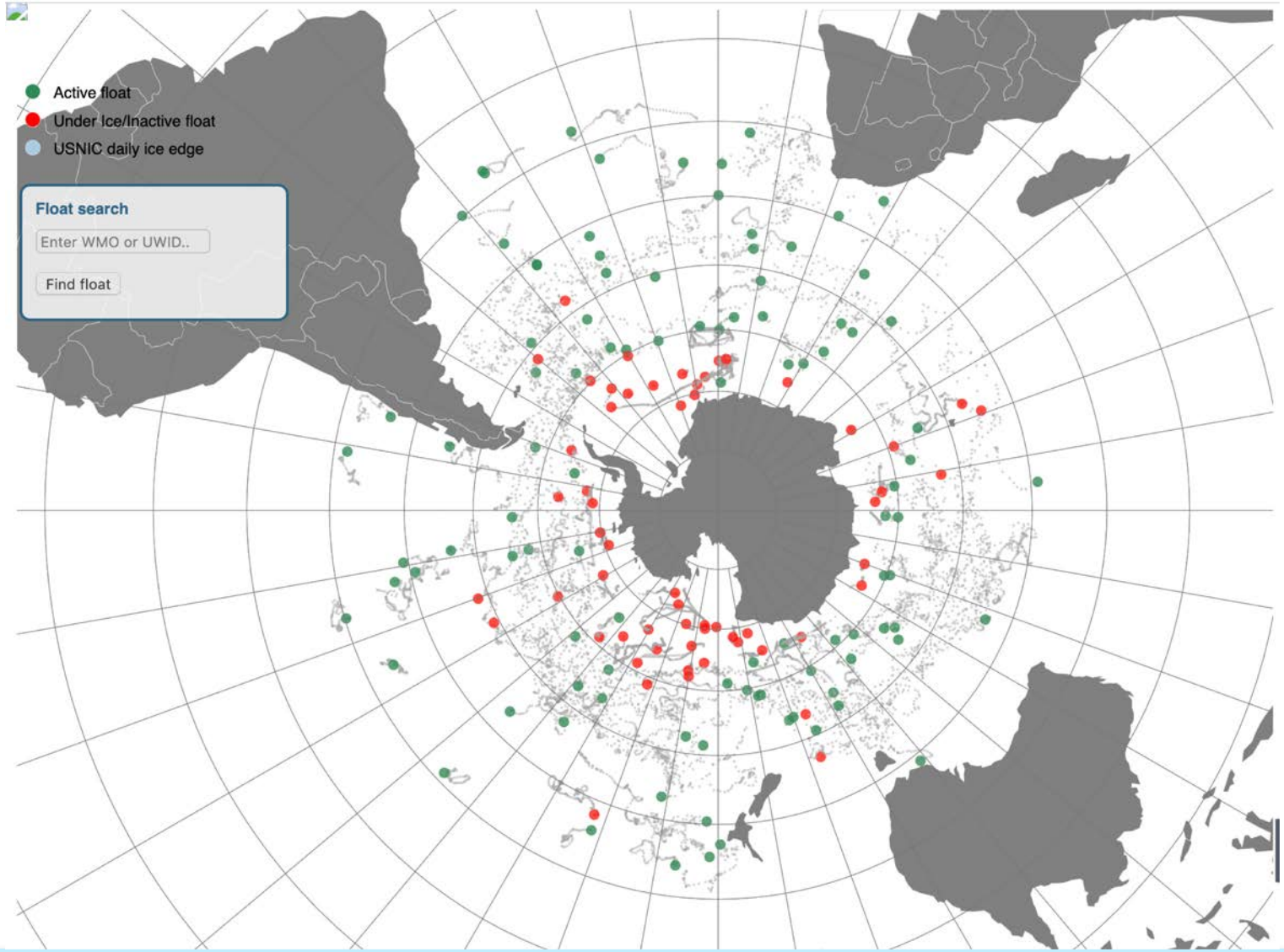
Total number of floats deployed, years 1-5: 158

26 research ship cruises utilized

Total number active: 126

Total number active expected at end of year 7: ~180

Interactive map on SOCCOM website
(Observations->Map Room)

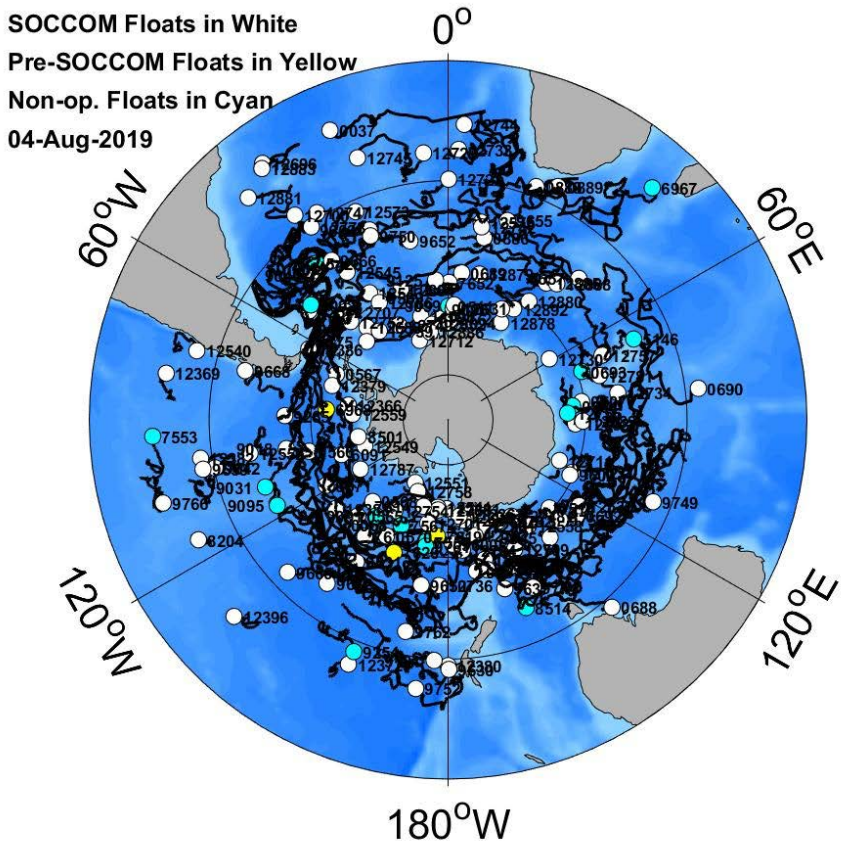


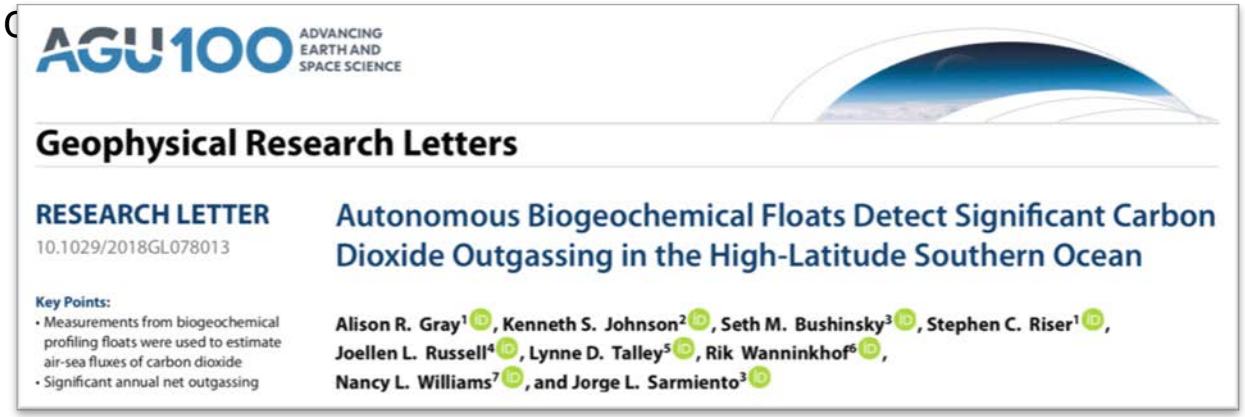
Biogeochemical Argo: carbon

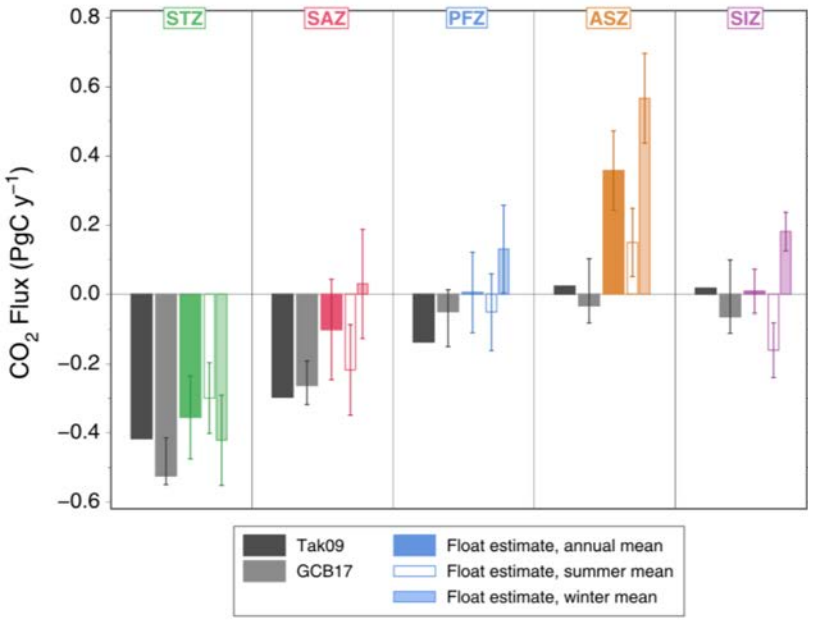
Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM): http://soccom.Princeton.edu

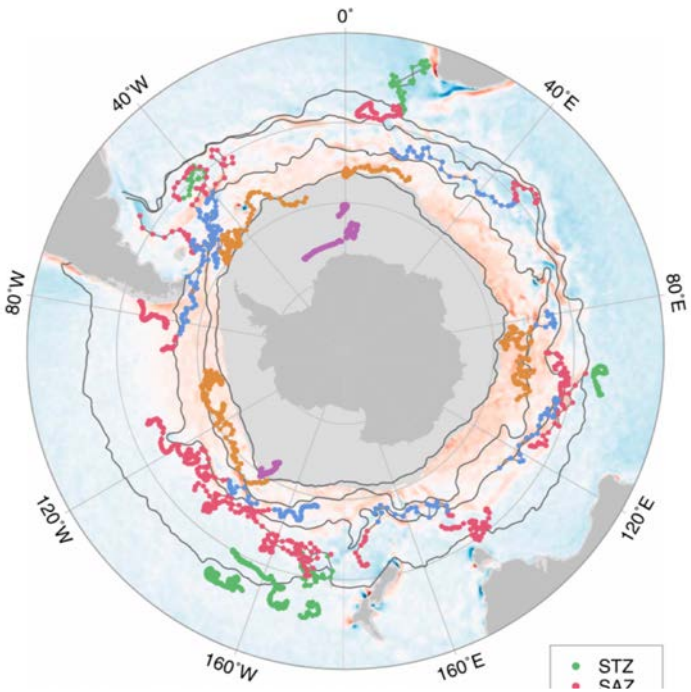
156 active floats, going to 200, started in 2014

Transforming knowledge of carbon cycles in Southern O







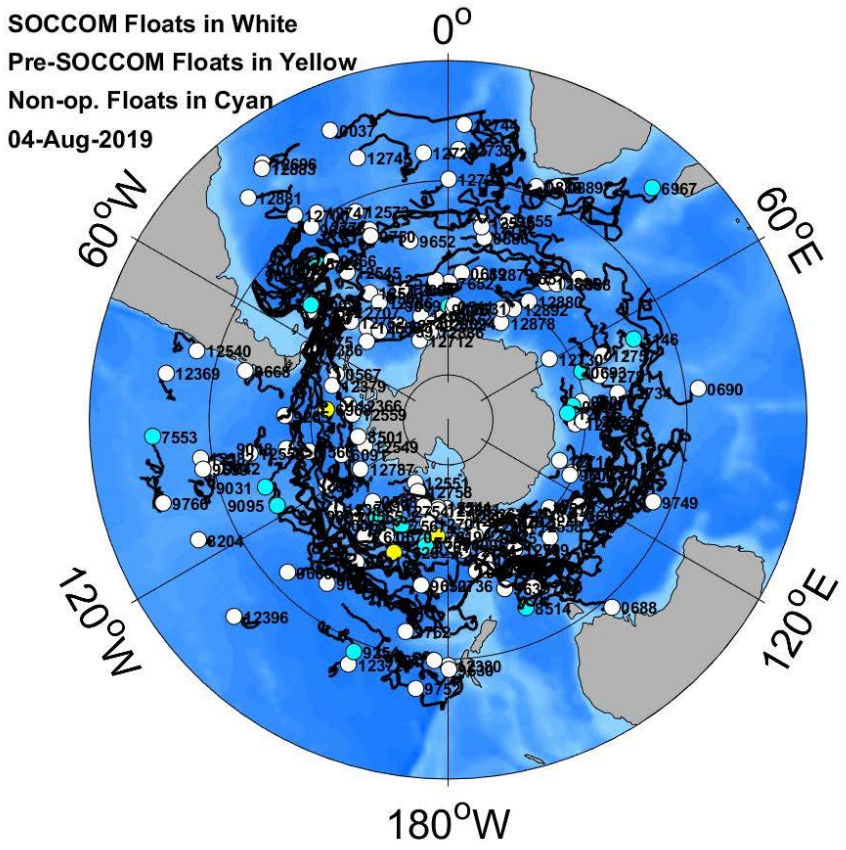


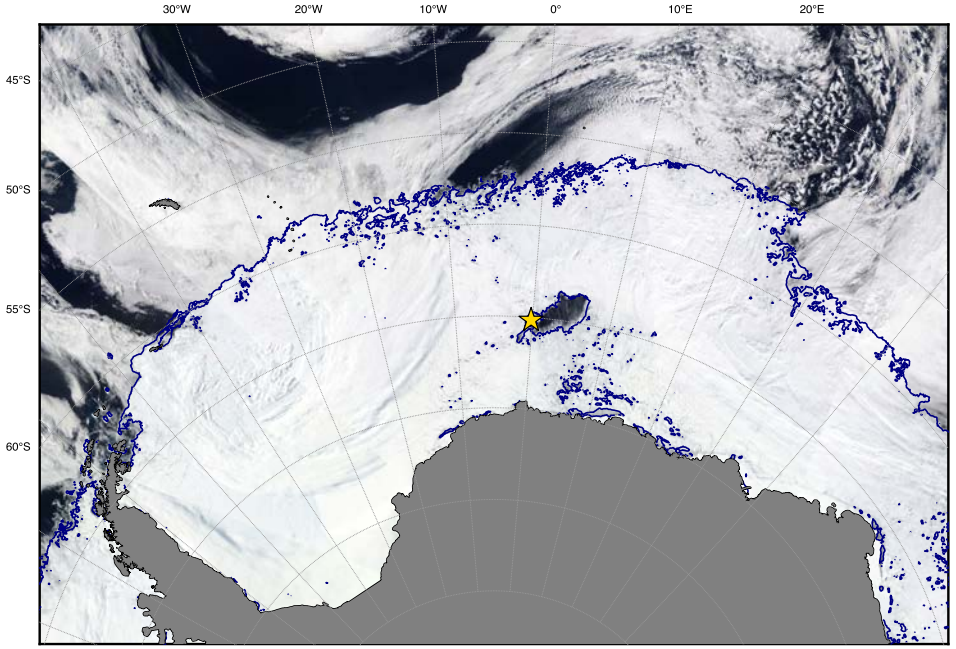
Biogeochemical Argo: sea ice processes and BGC

Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM): http://soccom.Princeton.edu

156 active floats, going to 200, started in 2014

Transforming knowledge of sea ice biogeochemistry and physics





ARTICLE

Nature (2019)

https://doi.org/10.1038/s41586-019-1294-0

Antarctic offshore polynyas linked to Southern Hemisphere climate anomalies

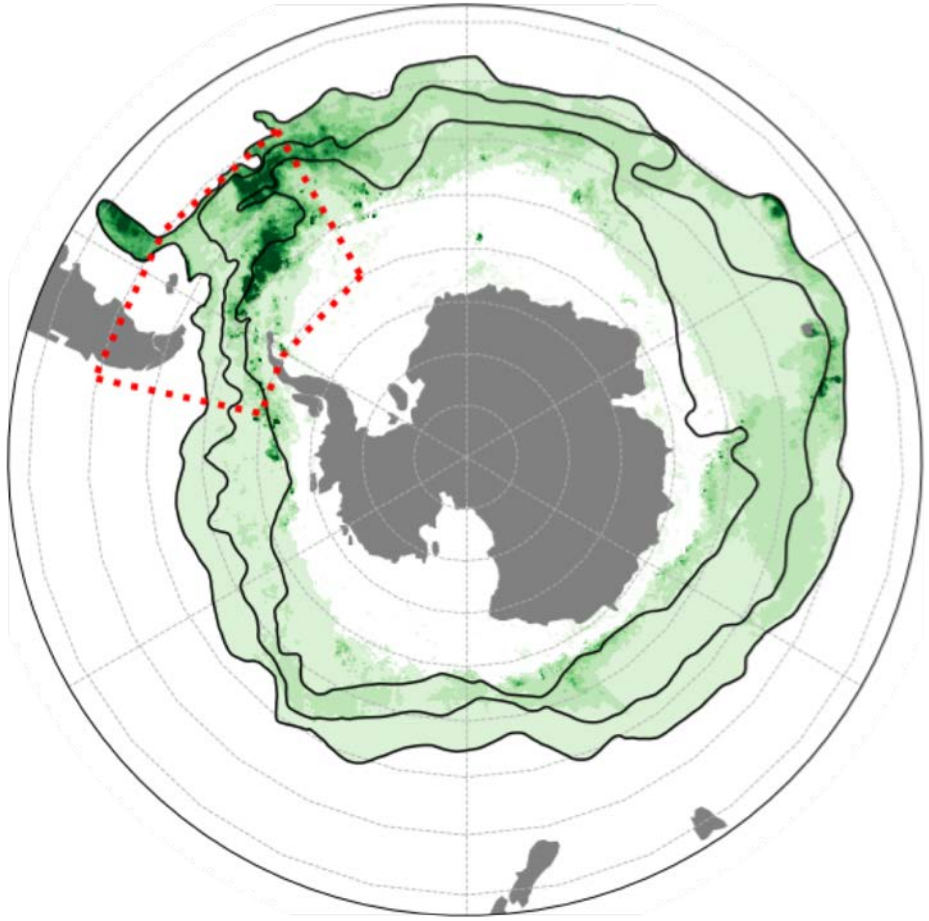
Ethan C. Campbell[1]*, Earle A. Wilson[1], G. W. Kent Moore[2,3], Stephen C. Riser[1], Casey E. Brayton[4], Matthew R. Mazloff[5] & Lynne D. Talley[5]

Biogeochemical Argo: ecosystems

Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM): http://soccom.princeton.edu

156 active floats, going to 200, started in 2014

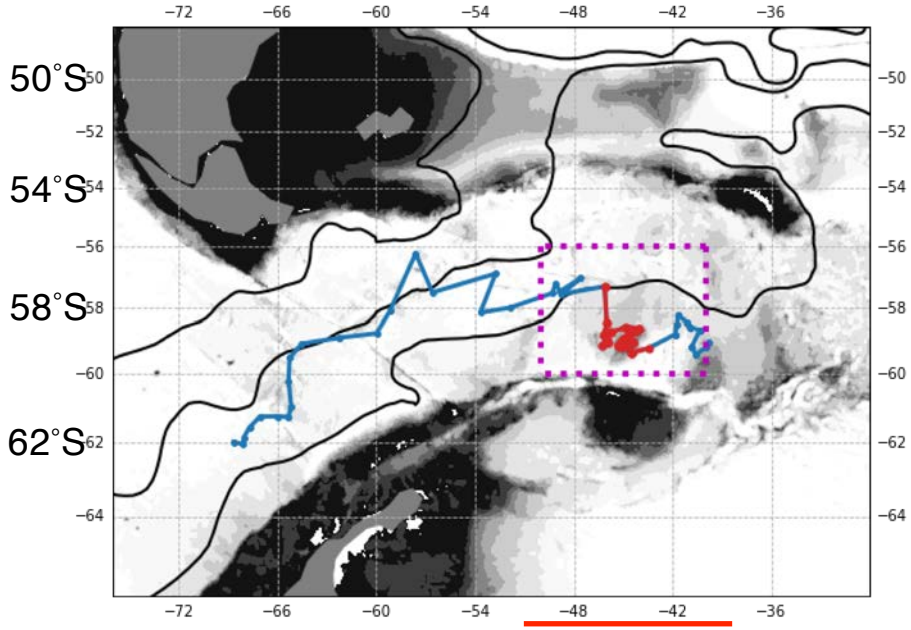
Transforming knowledge of ecosystems in Southern ocean

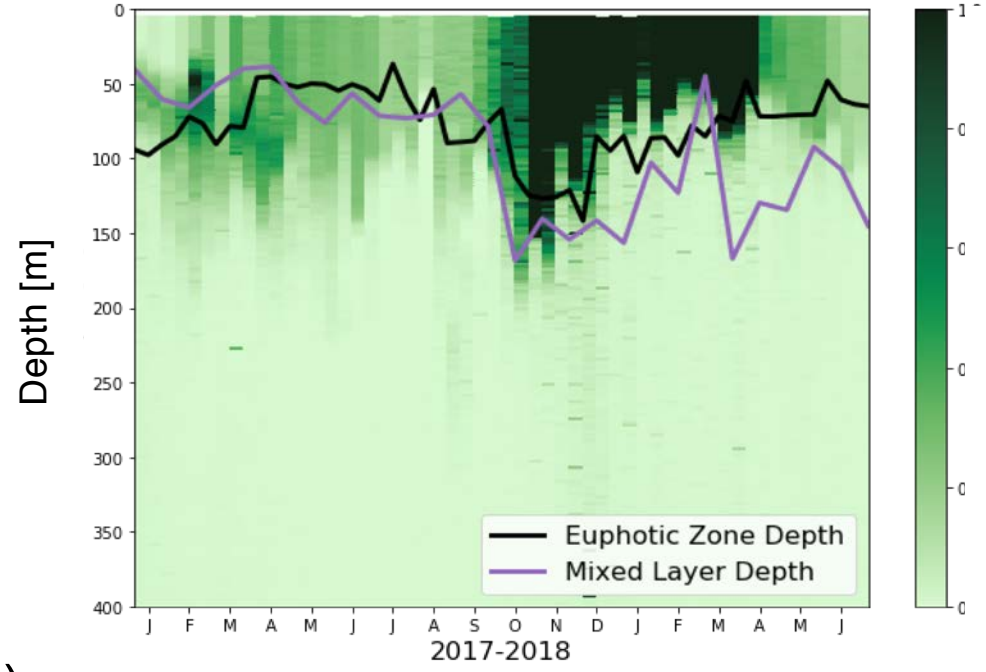


Satellite chlorophyll in October

Large, early bloom every year

SOCCOM floats capture bloom, study causes





Prend et al. (JGRO, accepted)

SOCCOM BGC float development and calibration

- Good calibration requires air oxygen (O2 sensor calibration), linear regression for nitrate (NO3 sensor calibration), linear regression for alkalinity plus Cosys (pH sensor calibration, and derived carbon)
- Shipboard measurements of O2, NO3, pH used for validation

- 2018-2019: continued improvements in pH sensor design (Johnson)
- 2019-2020: move oxygen sensor on Seabird Navis floats out of the pumped CTD to allow air oxygen obs for calibration (Riser, separate funding)

- 2019-2019: calibration methods (GUIs) transferred to other groups for their use (China etc) (Maurer, Johnson at MBARI)

Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1002/2016GB005541

Calculating surface ocean pCO_2 from biogeochemical Argo floats equipped with pH: An uncertainty analysis

N. L. Williams[1], L. W. Juranek[1], R. A. Feely[2], K. S. Johnson[3], J. L. Sarmiento[4], L. D. Talley[5], A. G. Dickson[5], A. R. Gray[4], R. Wanninkhof[6], J. L. Russell[7], S. C. Riser[8], and Y. Takeshita[3]

Key Points:
- Surface ocean partial pressure of carbon dioxide (pCO_{2sw}) is calculated

Float pH

Carbonate system thermodynamics → pCO_2, DIC, CO_3^{2-}, $\Omega_{aragonite}$ with error limits

Empirical Total Alkalinity estimate (Carter et al., 2016, 2017)

LIMNOLOGY and OCEANOGRAPHY: METHODS

ASL

Limnol. Oceanogr.: Methods 00, 2

doi: 10.1002/l

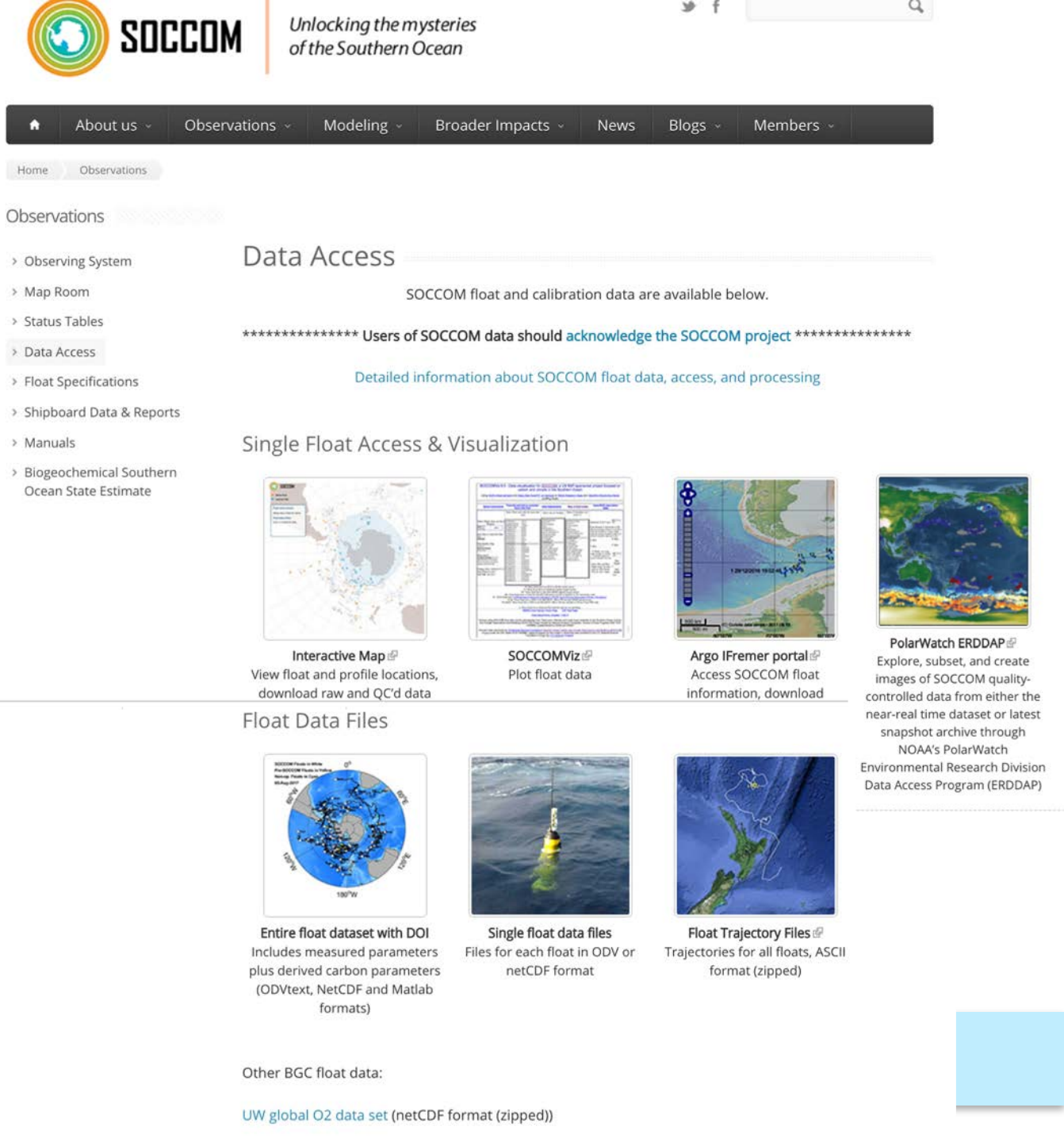
Updated methods for global locally interpolated estimation of alkalinity, pH, and nitrate

B. R. Carter[1,2*], R. A. Feely[2], N. L. Williams[3], A. G. Dickson[4], M. B. Fong[4], Y. Takeshita[5]

SOCCOM data sets

http://soccom.princeton.edu

- Data are public. To assist us with continued funding, please include our data statement in your acknowledgements
- On soccom website: most up-to-date, highest level of QC. Quarterly snapshots with doi. Includes derived parameters (Alk, DIC, pCO2, chlorophyll, POC).
- Argo DAC (with T, S Argo data from the floats)
- New: ERDDAP (NOAA product; Cara Wilson)



SOCCOM

SOCCOM data sets

http://soccom.princeton.edu

Quick-Links and Downloads for MBARI Quality Controlled FloatViz Data

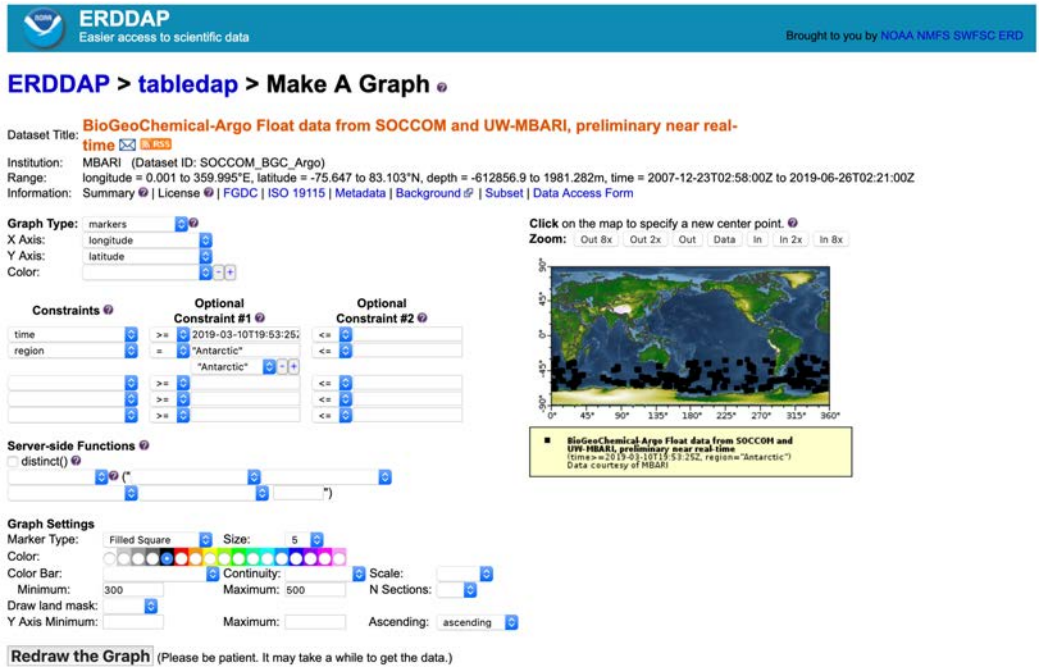
---------- NEAR REAL TIME DATA DOWNLOADS ----------

For the most up-to-date SOCCOM float data, processed every 4 hours by the SOCCOM Data Management team at the Monterey Bay Aquarium Research Institute (MBARI) , visit ftp://ftp.mbari.org/pub/SOCCOM/FloatVizData/. Quick links to various datasets available on this ftp site are listed in the table below. Note that this ftp site also includes data for floats deployed outside of the SOCCOM array.

Link to Low Resolution ODVtext format single profiles	Link to High Resolution ODV text format single profiles
LRQC_LIAR	HRQC_LIAR
LRQC_MLR	HRQC_MLR
LRQC_CANYON	HRQC_CANYON

The ODV-compatible text files outlined above are also available in NetCDF and Matlab formats. These are updated weekly on Monday mornings and provided as .zip files in the table below. Date in filename is YYYYMMDD.
2019-03-12 netcdf file variable attributes "missing_value" changed from character to float.

Download Low Resolution ODVtext format	Download Low Resolution NetCDF format	Download Low Resolution Matlab format
SOCCOM_LRQC_LIAR_odvtxt_20190610.zip	SOCCOM_LRQC_LIAR_netcdf_20190610.zip	SOCCOM_LRQC_LIAR_matlab_20190610.zip
SOCCOM_LRQC_MLR_odvtxt_20190610.zip	SOCCOM_LRQC_MLR_netcdf_20190610.zip	SOCCOM_LRQC_MLR_matlab_20190610.zip
SOCCOM_LRQC_CANYON_odvtxt_20190610.zip	SOCCOM_LRQC_CANYON_netcdf_20190610.zip	SOCCOM_LRQC_CANYON_matlab_20190610.zip

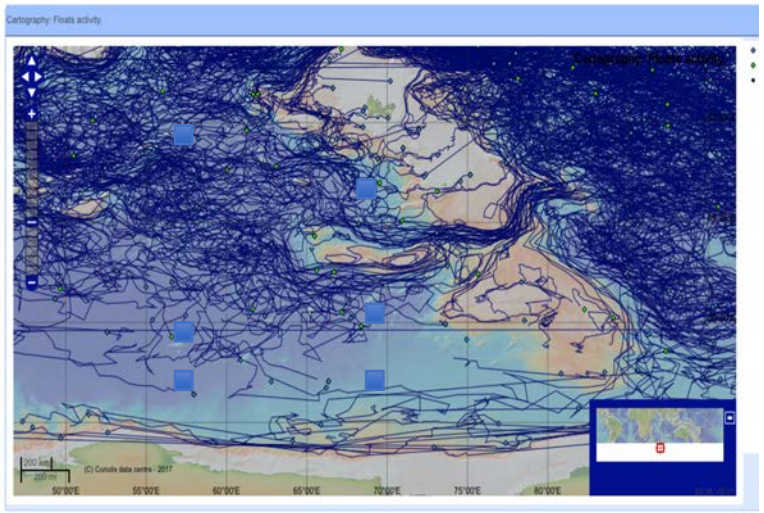


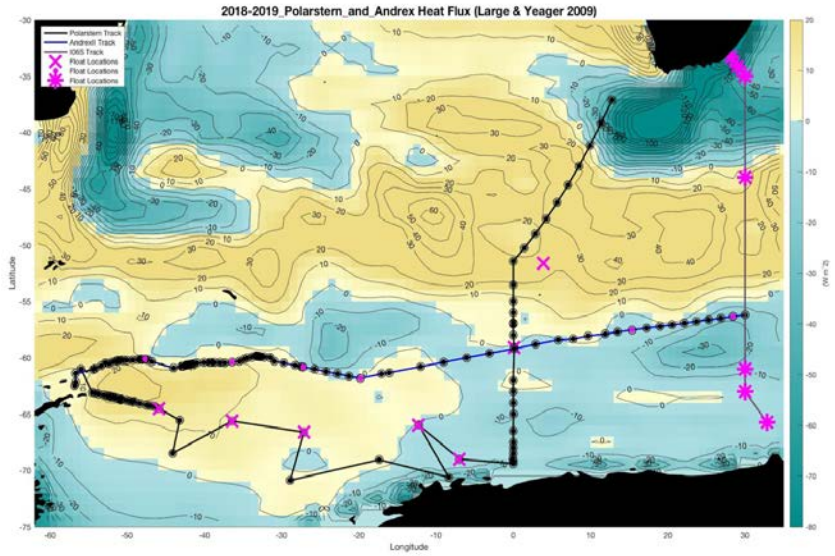
---------- QUARTERLY SNAPSHOT ARCHIVES - Links to DOI ----------

Snapshot Date and Description	Link to DOI, to download Hi and Lo Resolution ODVtext, NetCDF and Matlab formats
31Dec2018 SOCCOM float data set. Include QC Emails, estimated TALK, and derived DIC,pCO2 for methods LIAR, MLR, CANYON.	doi:10.6075/J02J6968
12Mar2019 SOCCOM float data set. Include QC Emails, estimated TALK, and derived DIC,pCO2 for methods LIAR, MLR,	doi:10.6075/J01G0JKT

SOCCOM

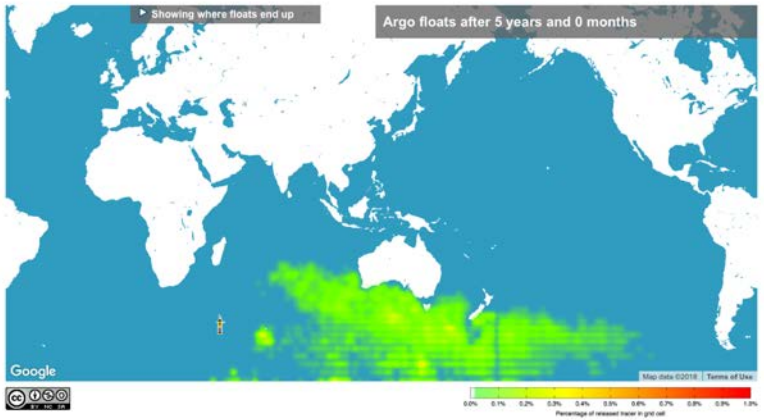
BGC float array design/strategy

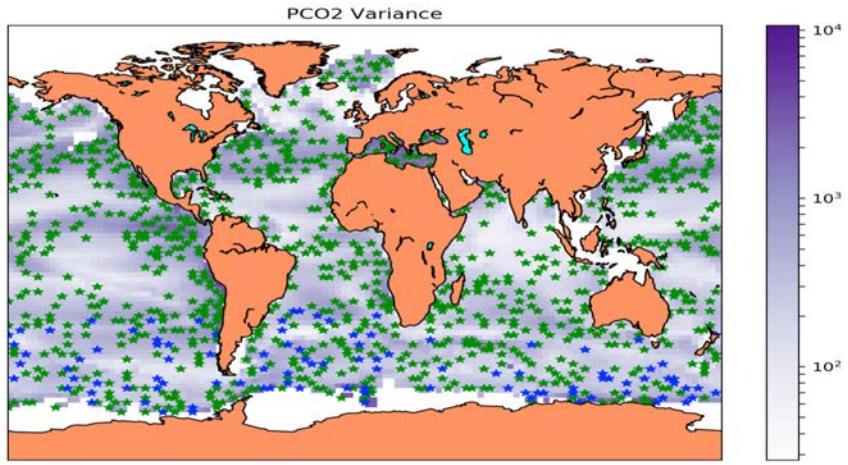




Traditional: Use of prior Argo trajectories and many different background property fields (Talley et al., JGR 2019)

AR-GONE





Future: Argo-trajectory based **transition matrix approach** (Chamberlain et al., in progress)

Based on Van Sebille et al. (2012)

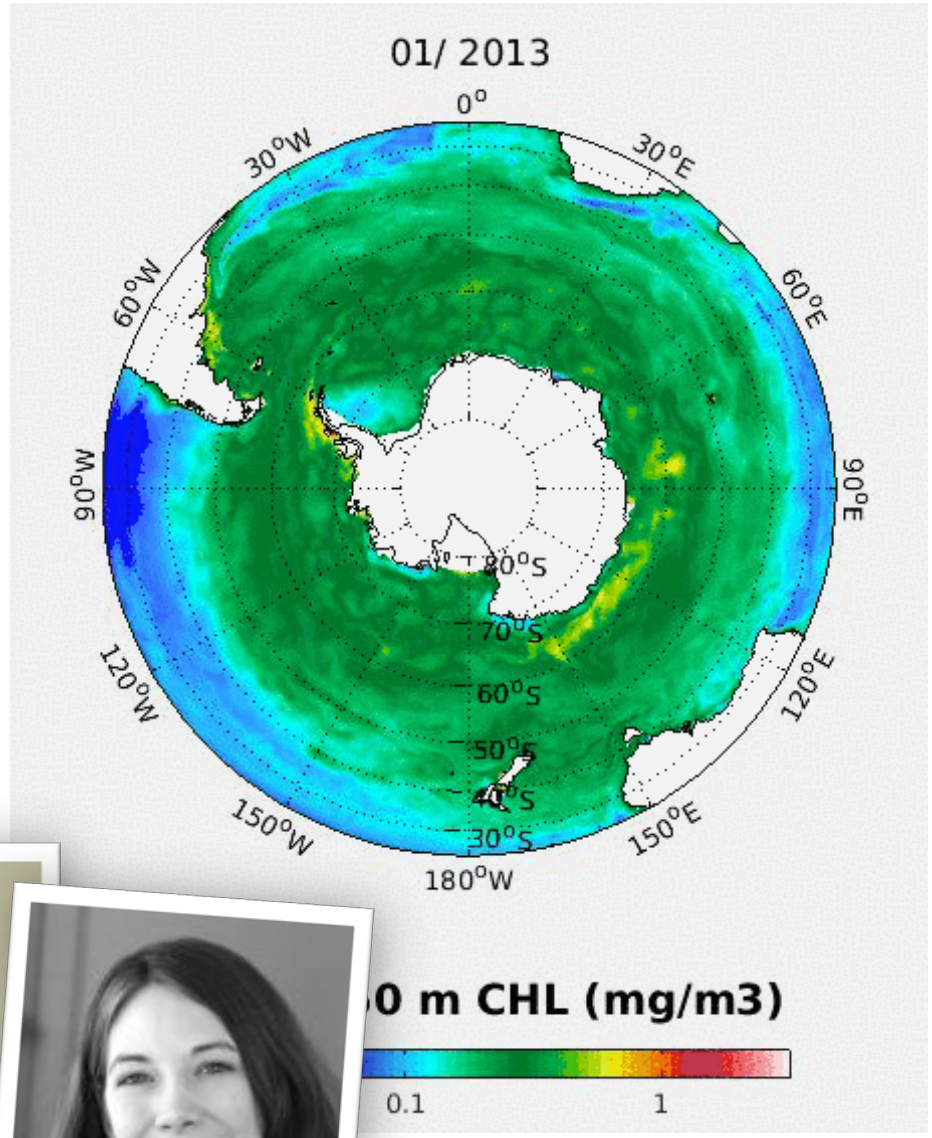
SOCCOM

Collaborating with and using Erik Van Sebille's http://plasticadrift.org

B-SOSE (biogeochemical state estimate)

Mazloff, Verdy

- SOCCOM is the only research group producing large-scale ocean-sea ice-biogeochemical state estimates
  - (Biogeochemical Southern Ocean State Estimate or B-SOSE)
- Establishing best practices for validation of BGC state estimates
- Establishing methods for modelers to engage with the QC process
- Making entire input and output freely available to facilitate technology transfer
- Ensuring code is well-documented, well-organized, and accessible via github, enabling technology exchange with other modeling groups



ts superimposed on B-SOSE

SOCCOM

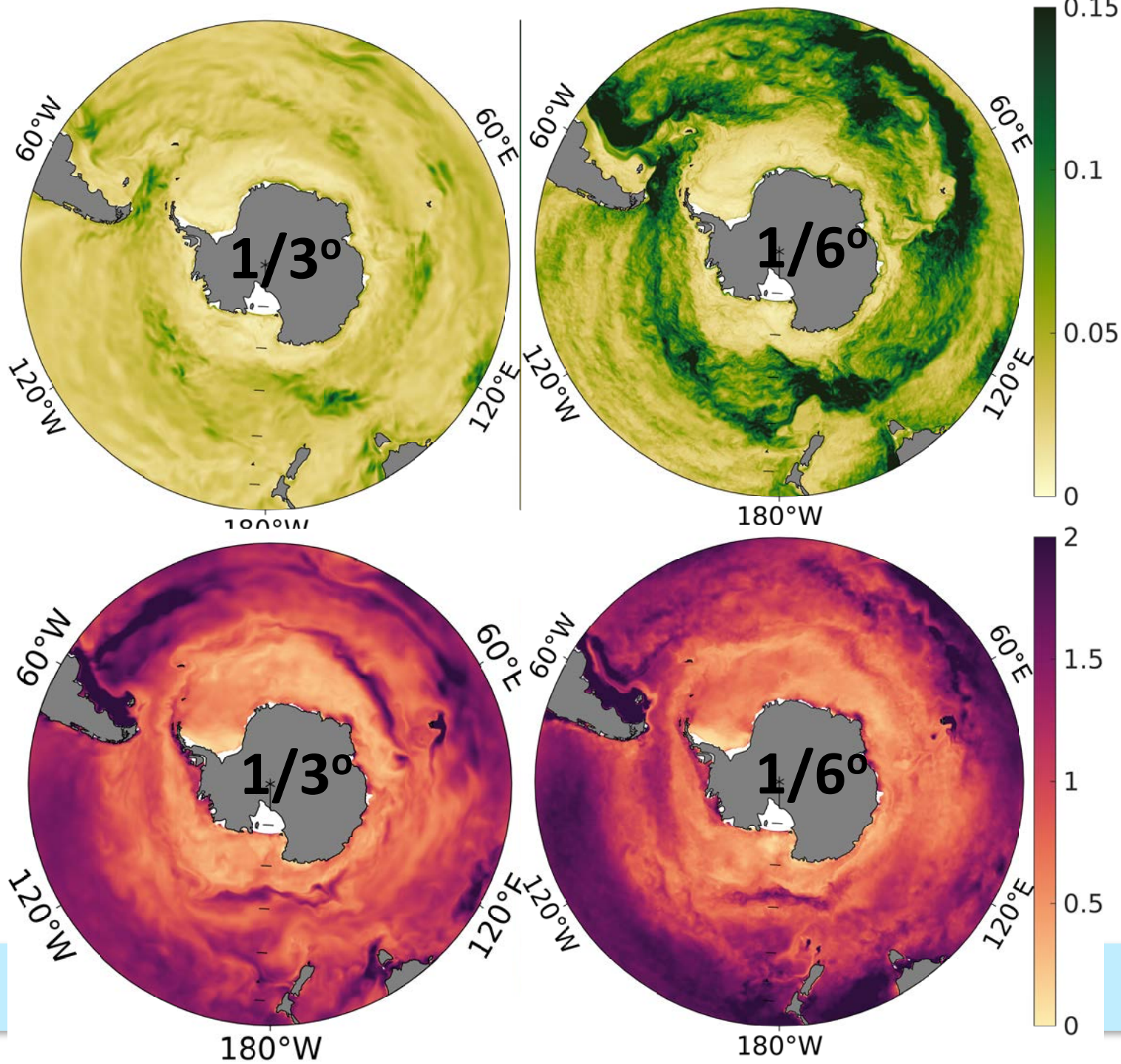
B-SOSE Update

B-SOSE is 1/6° (2008-2017)
(1/12° forward run SOSE)

Comparison of 1/3° & newly released 1/6° BSOSE solution

- Surface speed [m/s] standard deviation

- CO_2 flux [mol/m2/yr]
- standard deviation



SOCCOM

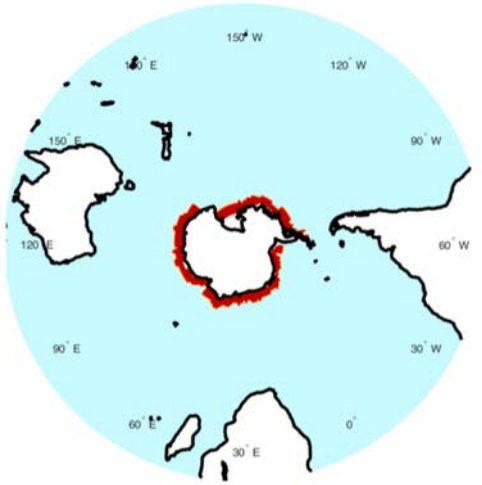
SOCCOM Modeling: Joellen Russell, lead

Experiment on the Southern Ocean in Climate Models

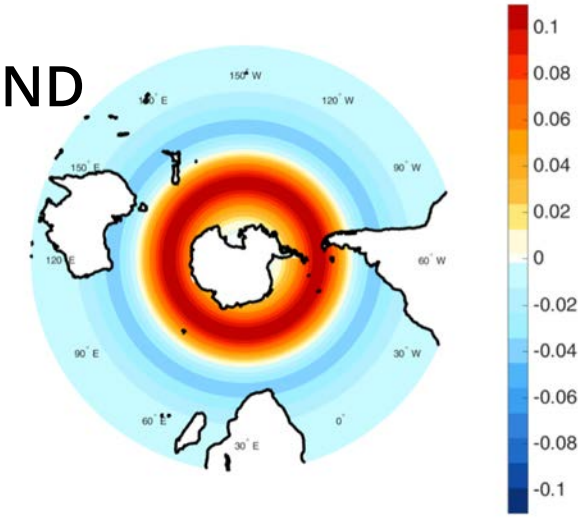
…and invite colleagues to help!

SOMIP: the global warming blindspot

- **MELT:** An experiment where the stability of the Southern Ocean is changed via an external source of fresh water (so-called water hosing).
- **WINDS:** An experiment that increases the winds over the Southern Ocean and shifts them poleward.
- **BOTH:** An experiment that will use both the increased wind forcing and water hosing described above.



Proposal: MELT & WIND perturbations

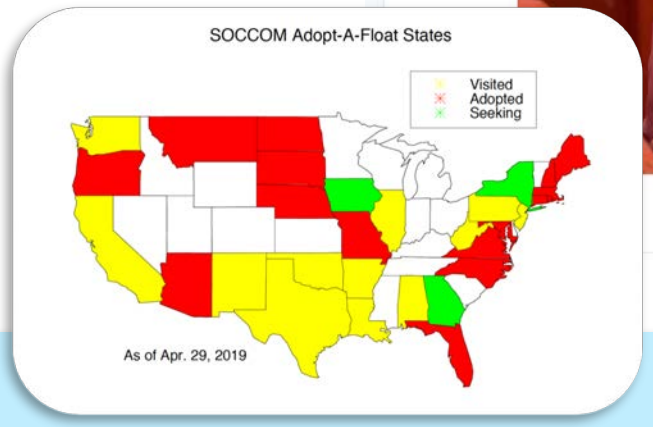


SOCCOM

(southernocean.arizona.edu/SOMIP)

SOCCOM Education: Adopt-a-float and curriculum (90 floats, 58 K-12 schools)

Students with a transparent model BGC-Argo float.



SOCCOM

BGC Argo future in U.S.

SOCCOM Renewal, NOPPs and NOAA COIs

SOCCOM is 6 years, 8/1/14 – 7/31/20

1. SOCCOM renewal proposal for 4 years has been submitted to OPP

- continuing deployments at rate of 30 per year in Southern Ocean. Year 7 with original funding will bring total number of floats to 200. Years 8, 9, 10 will sustain as early floats expire.
    - Reduced shipboard sampling (not all cruises)
- continuing state estimation
- continuing science/modeling funding.

2. NOPP to UW and Sea-bird (lead PIs Riser and Johnson)

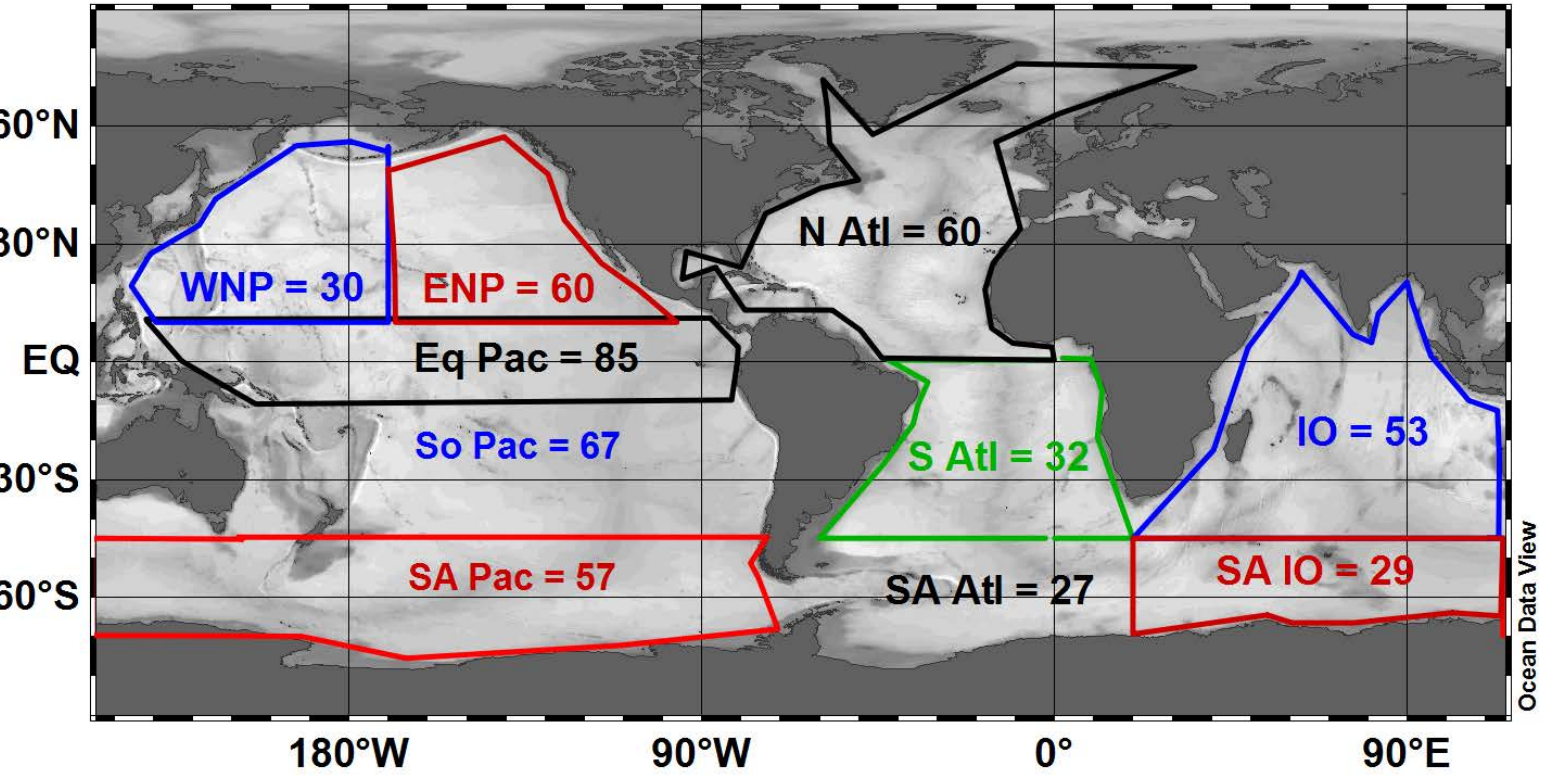
- Development of separated oxygen sensor to allow air sample for O2 calibration
- CTD sensor suite with separated oxygen sensor then also useful on Apex and SOLO II floats – continuous rather than spot sampling

3. NOPP to SIO: development of a BGC SOLO-II float, partner with MRV Systems (lead PI S. Purkey)

4. NOAA COI funding for BGC Argo deployments at HOT and BATS (NOAA/PMEL, and WHOI)

BGC Argo future in U.S.

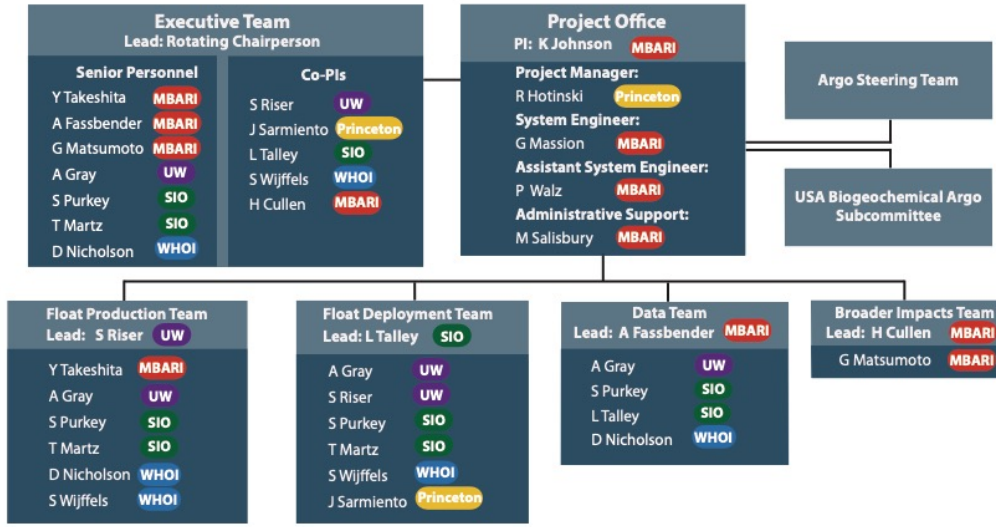
NSF MSRI-2 proposal submitted: 5 years, 500 floats (half of required global array of 1000, which is ¼ of Core Argo)



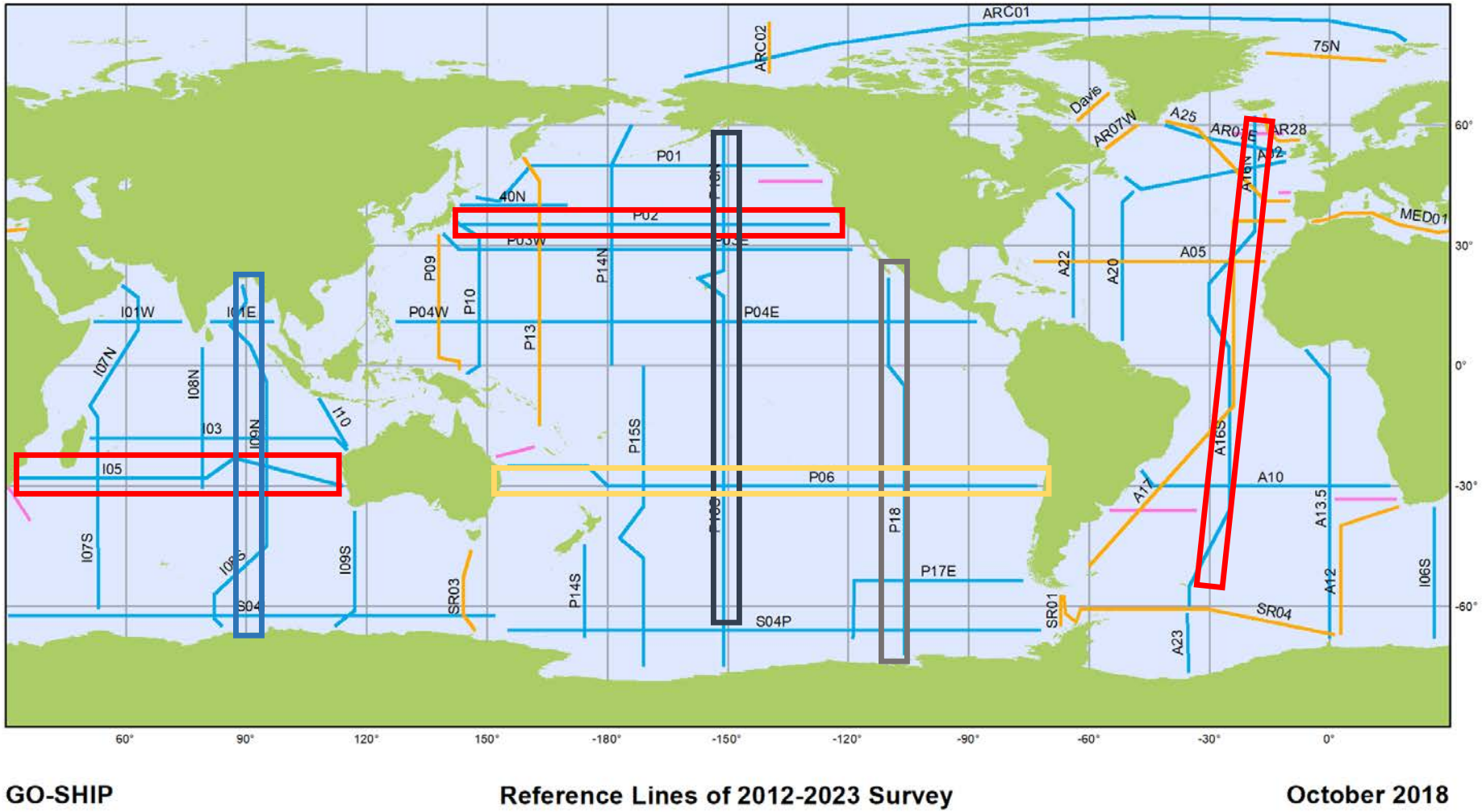
MBARI (Lead, K. Johnson)
Princeton (Sarmiento)

3 Argo institutions:
- UW (Riser)
- SIO (Talley)
- WHOI (Wijffels)

Oversight:
- Argo Steering Team
- OCB BGC Argo subcommittee



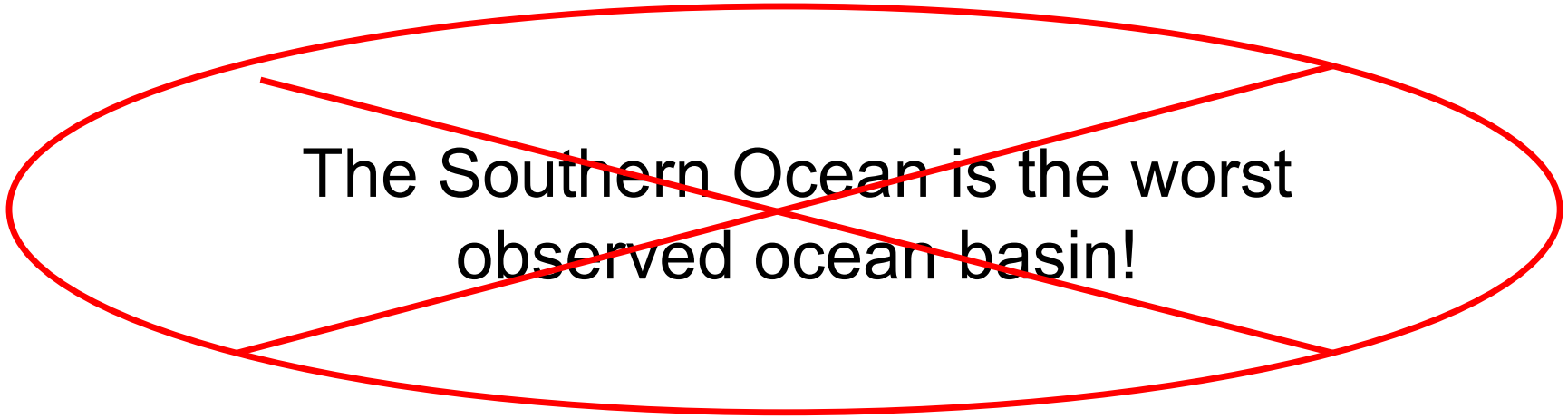
Proposed U.S. BGC-Argo deployments: use US GO-SHIP plus international GO-SHIP extensively for validation shipboard measurements



GO-SHIP **Reference Lines of 2012-2023 Survey** **October 2018**

Year 1 Year 2 Year 3 Year 4 Year 5

SOCCOM



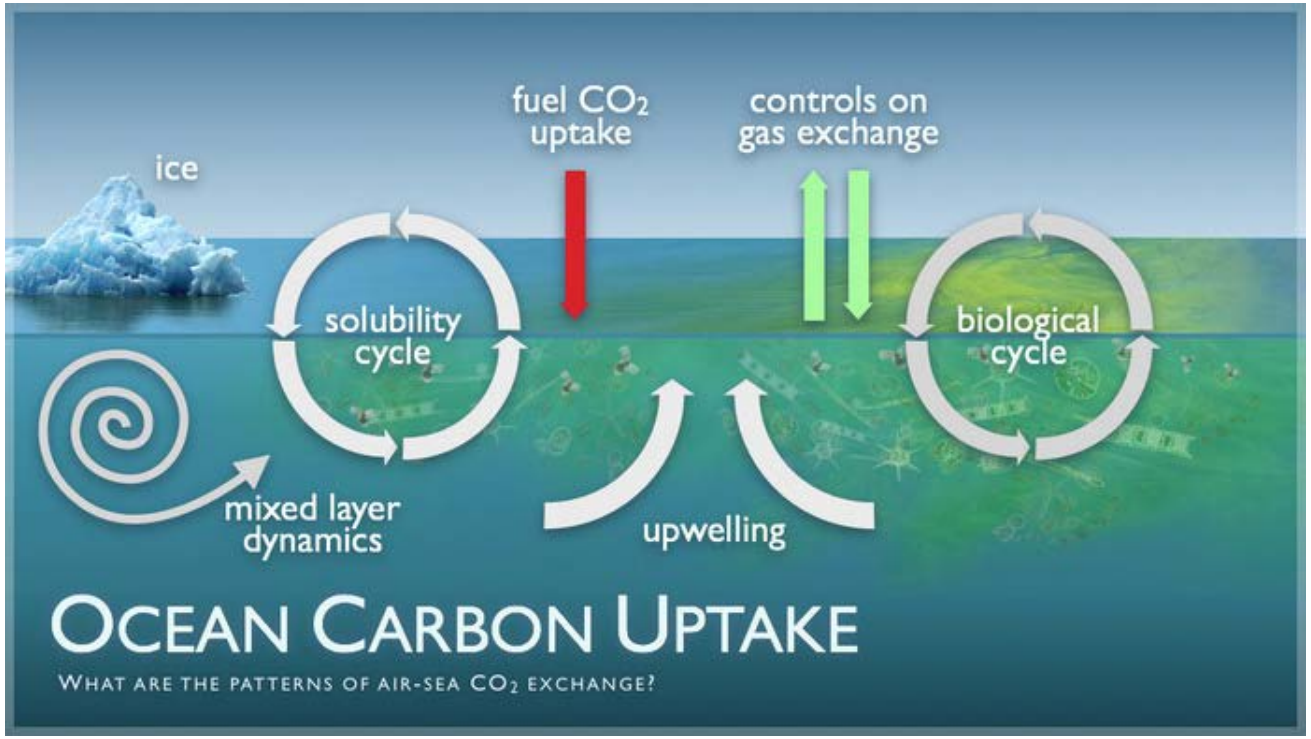
The Southern Ocean is the BEST observed ocean basin!
SOCCOM did it!!

Now that we have all this data (and a state estimate!), what do we do with it??

What non-carbon processes influence the ocean's carbon budget?

- Biological processes
- Physical processes
  - Temperature – solubility
    - Warmer water dissolves less CO2
    - Outgasses more, uptakes less
  - Mixing within ocean
  - Sea ice
  - Circulation: advection and upwelling of high carbon Deep Waters

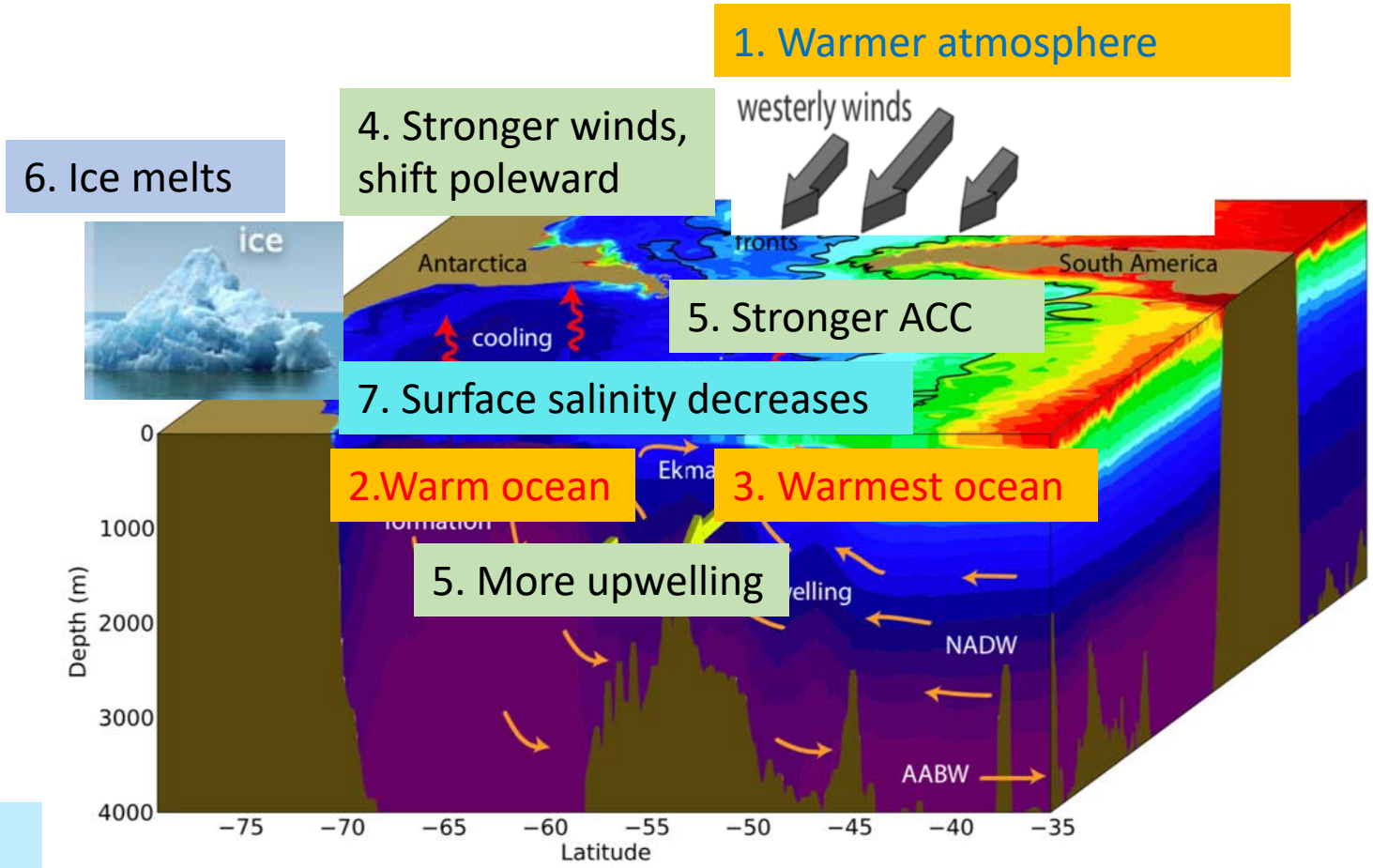
NOAA PMEL carbon website



How do carbon processes affect the physical processes (heat, sea ice, salinity, wind)?

1. GHGs warm the atmosphere

2. Atmosphere warms the ocean
3. Subtropical ocean warms more
4. Westerly winds strengthen, poleward shift
5. ACC stronger, more upwelling
6. Atmosphere and ocean melt and move ice, export freshwater
7. All of the above change salinity, and hence stratification, hence feedback on the processes – more warming
8. All of the above change chlorophyll distributions, which can alter vertical heating distribution



Morrison et al. (Physics Today, 2015)

SOCCOM

Geophysical Research Letters

RESEARCH LETTER
10.1029/2017GL076909

Episodic Southern Ocean Heat Loss and Its Mixed Layer Impacts Revealed by the Farthest South Multiyear Surface Flux Mooring

Key Points:
- The southernmost long-term open ocean mooring yields the first multiyear air-sea flux results south of 50 degrees south
- Episodic turbulent heat loss events

S. E. Ogle[1], V. Tamsitt[1,2,3], S. A. Josey[4], S. T. Gille[1], I. Cerovečki[1], L. D. Talley[1] and R. A. Weller[5]

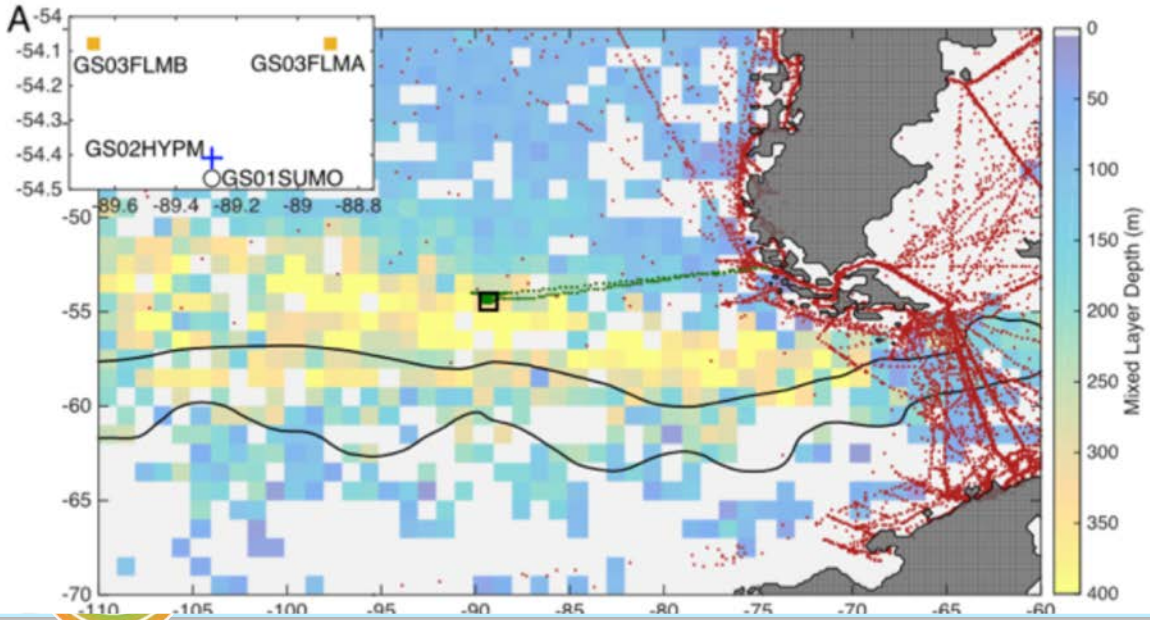
Episodic forcing of deep mixed layers

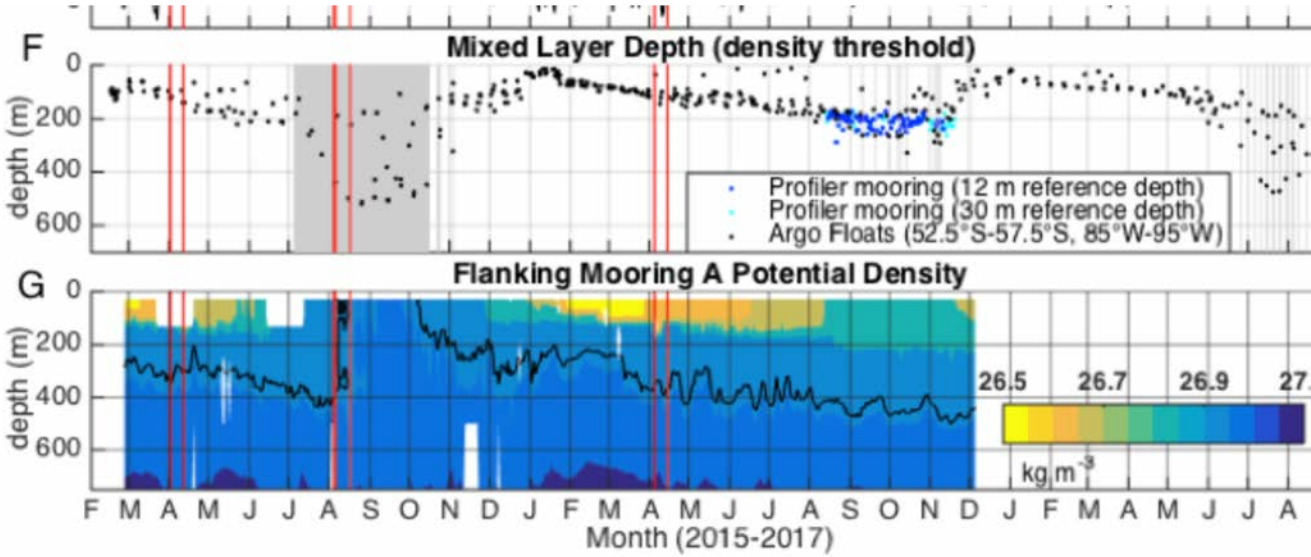
Southeast Pacific

Mixed layer depth
OOI mooring

Mixed layer depth 2015-2017

Much deeper in 2015
Much shallower in 2016





2015 2016 2017

Journal of Geophysical Research: Oceans

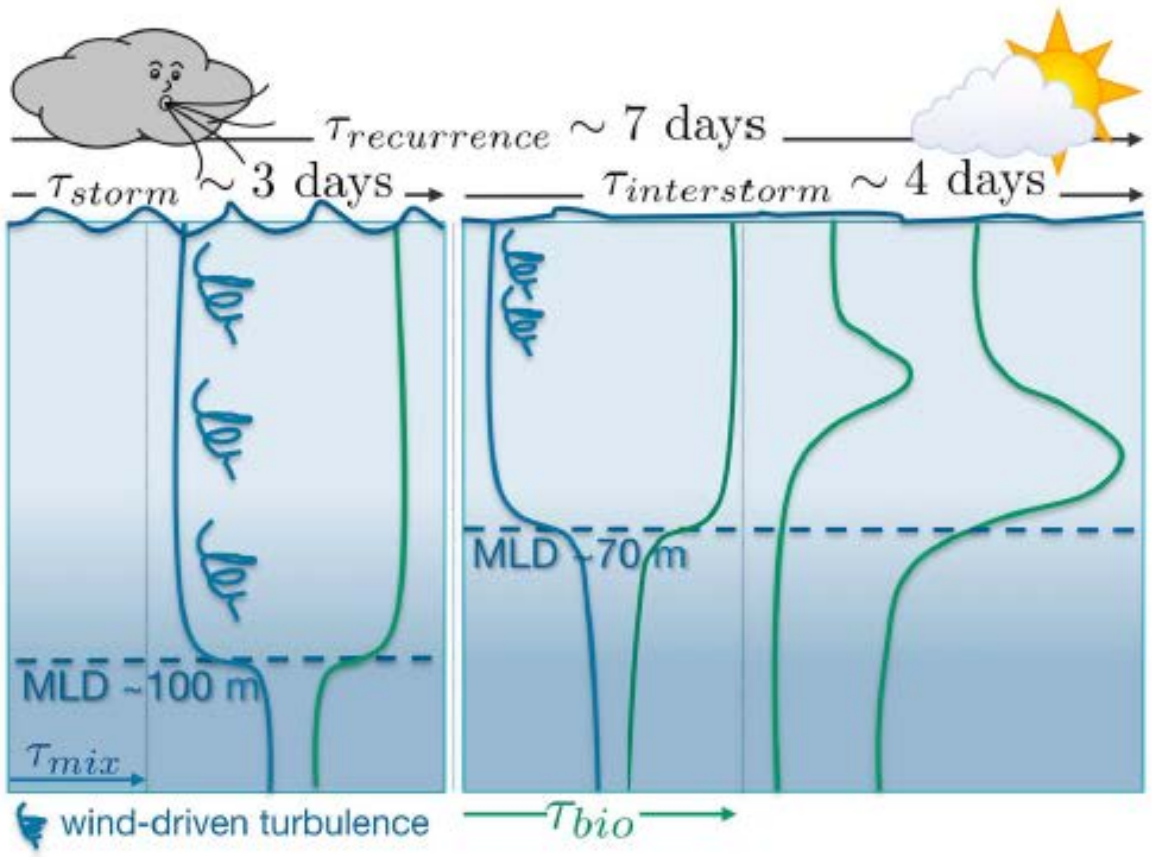
RESEARCH ARTICLE
10.1029/2018JC014416

Special Section:
The Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) Project: Technologies, Methods, and Early Results

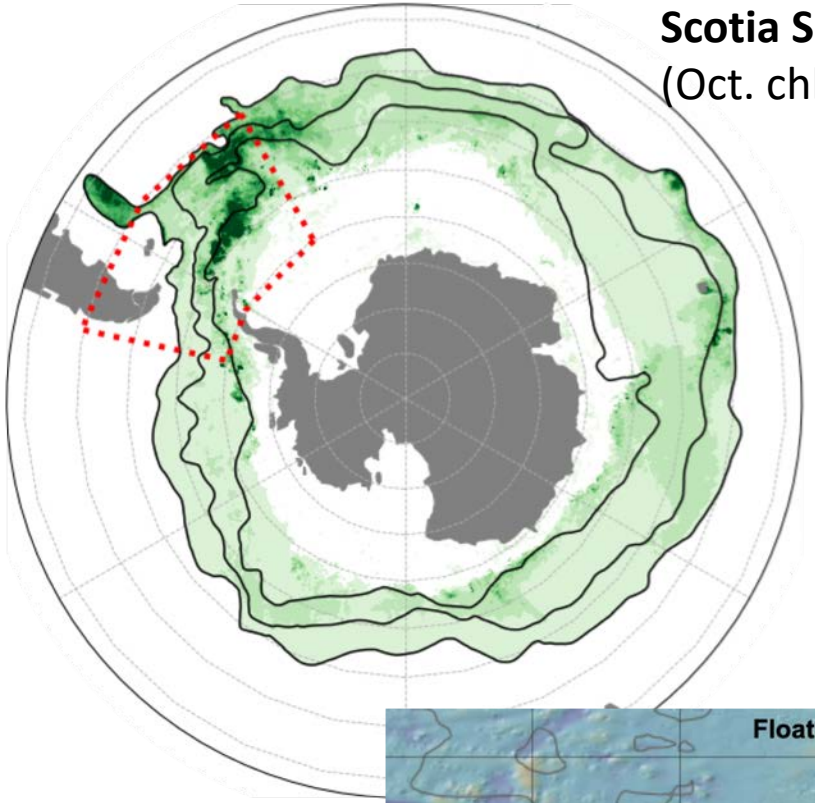
When Mixed Layers Are Not Mixed. Storm-Driven Mixing and Bio-optical Vertical Gradients in Mixed Layers of the Southern Ocean

Magdalena M. Carranza[1,2], Sarah T. Gille[1], Peter J. S. Franks[1], Kenneth S. Johnson[3], Robert Pinkel[1], and James B. Girton[4]

Episodic forcing of chlorophyll in mixed layers

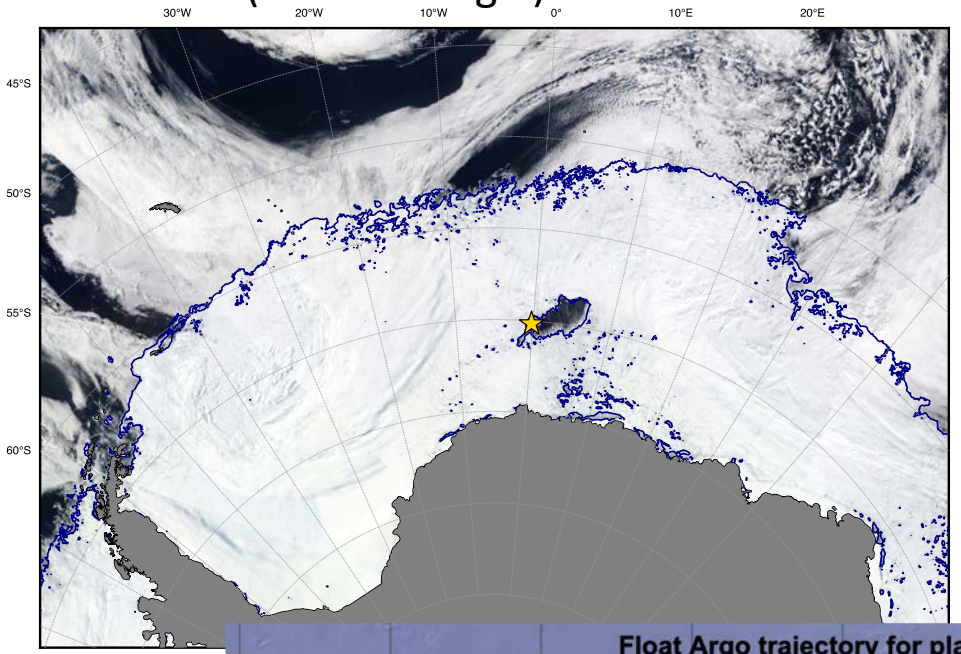


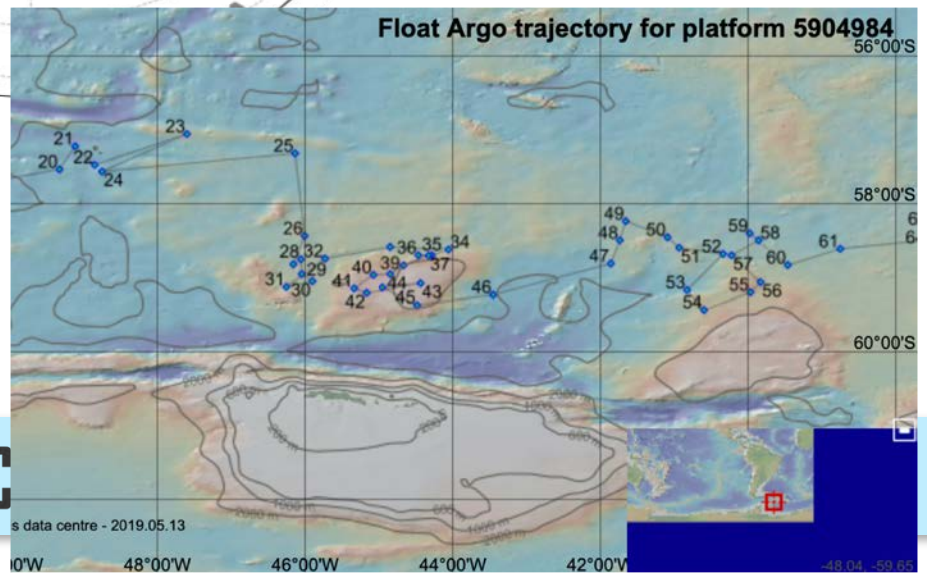
Topographic effects on circulation and vertical mixing: Taylor columns

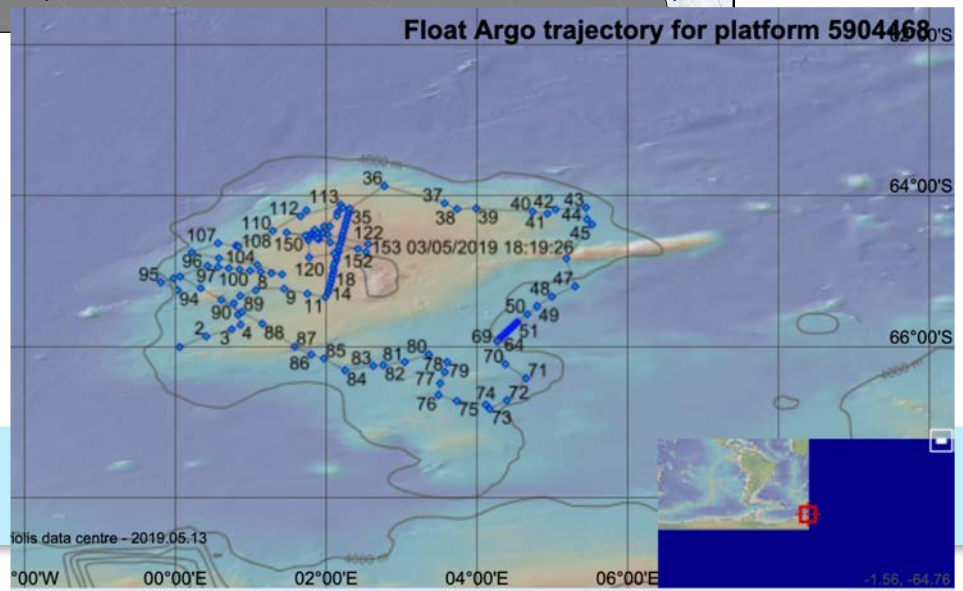


Scotia Sea bloom
(Oct. chlorophyll composite)

Maud Rise polynya 2016-2017
(sea ice image)

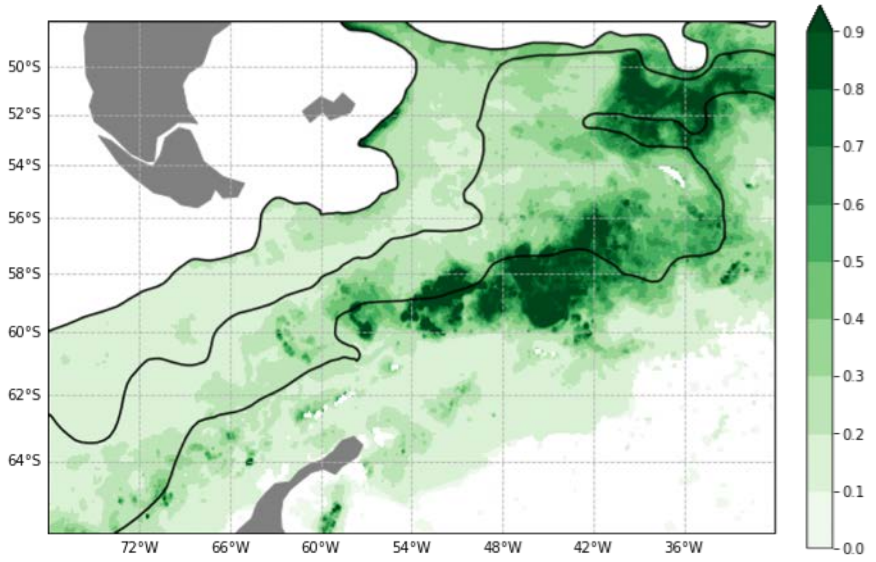




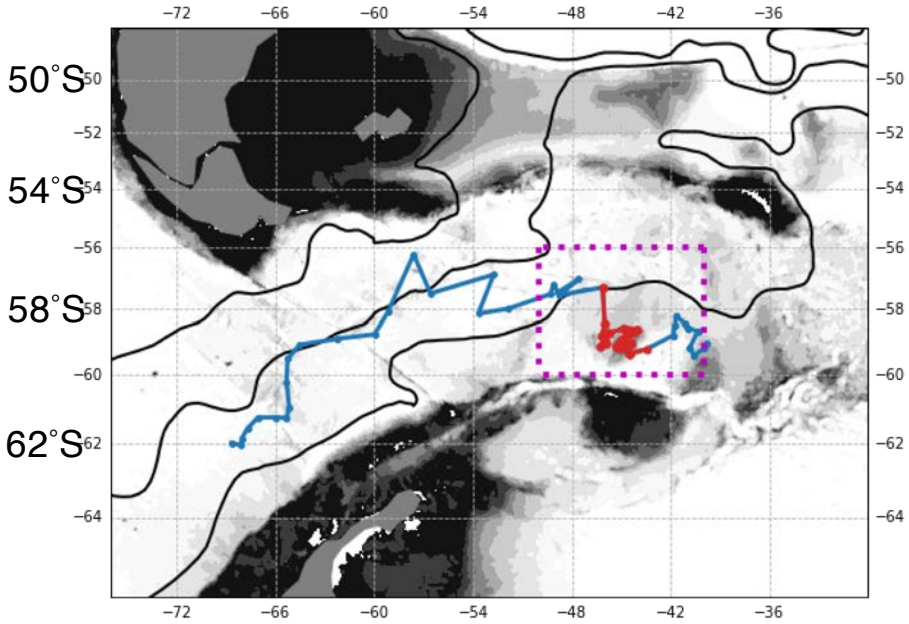


Taylor columns enhance production, early bloom onset

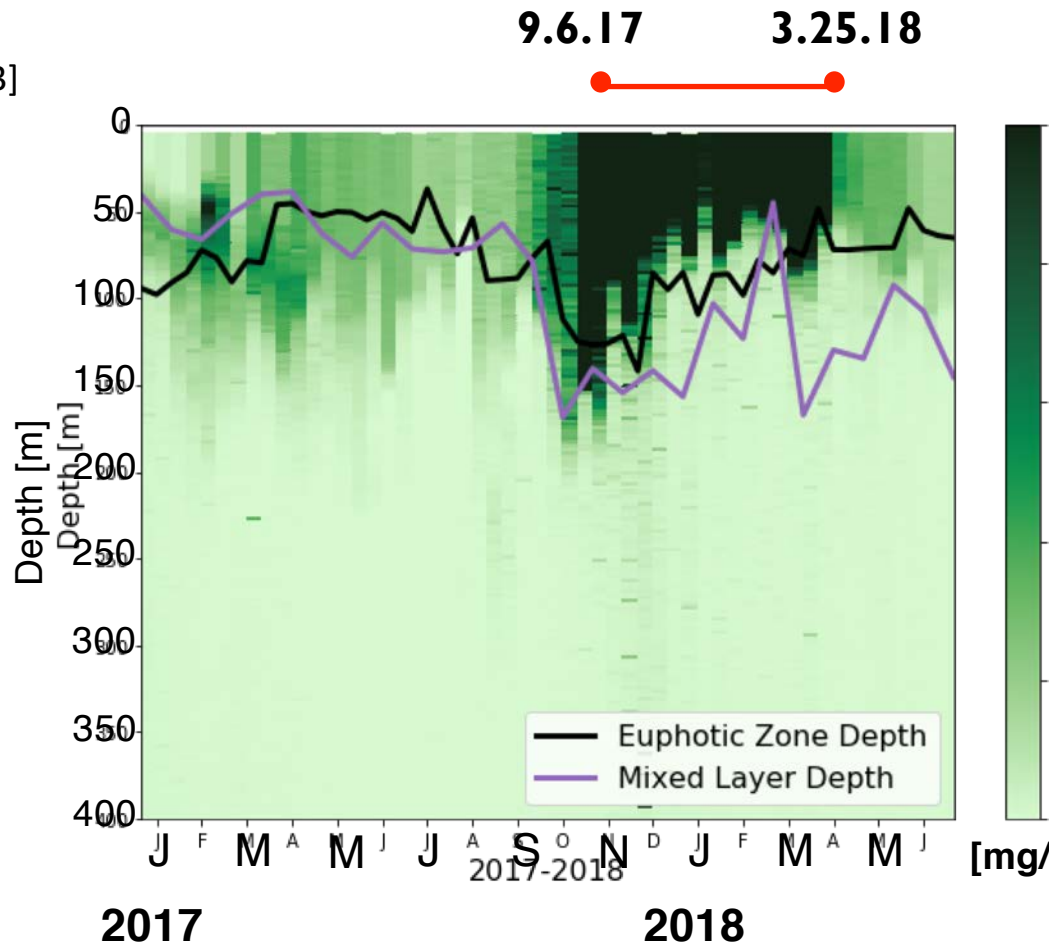
Prend, Gille, Talley, Mitchell, Rosso, Mazloff (JGRO, submitted)



MODIS Aqua satellite 2002-2017 October surface chlorophyll composite [mg m-3]

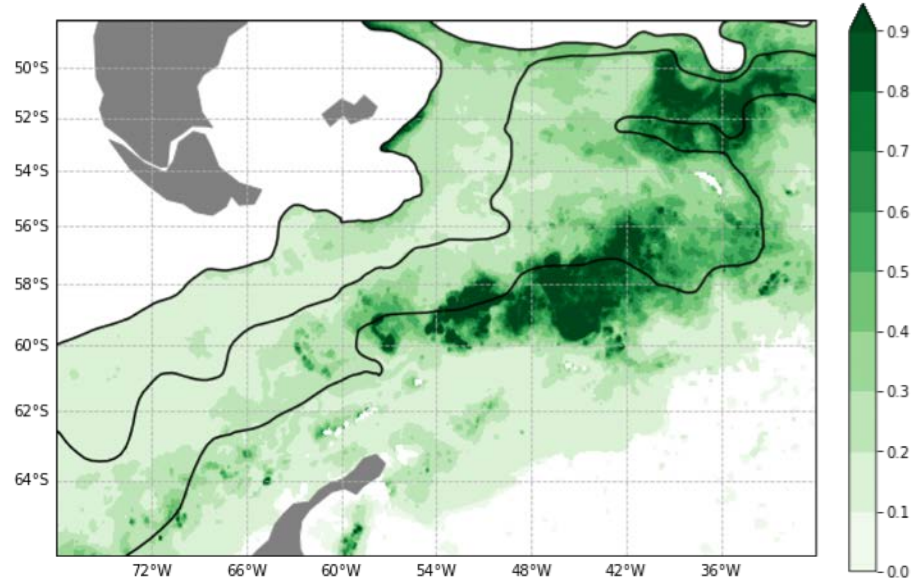


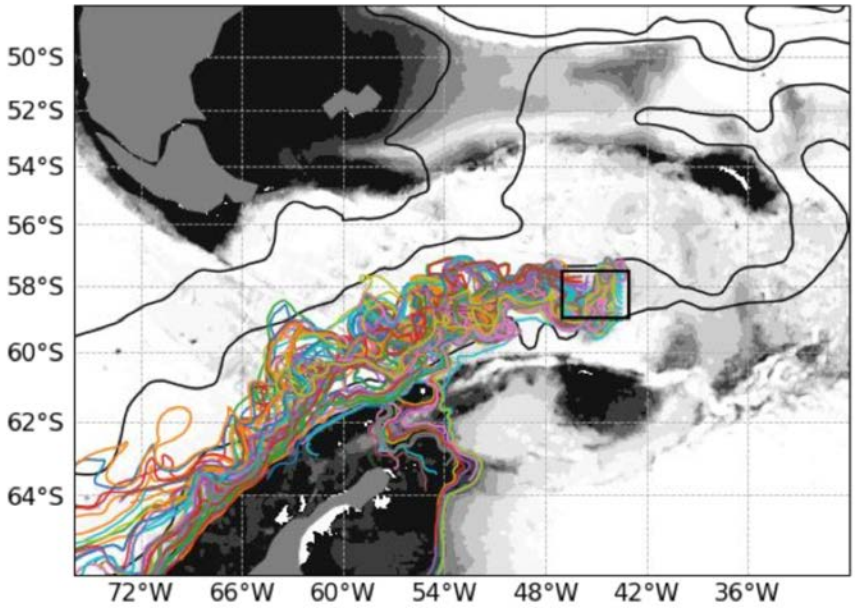
Float 5904984 Chlorophyll

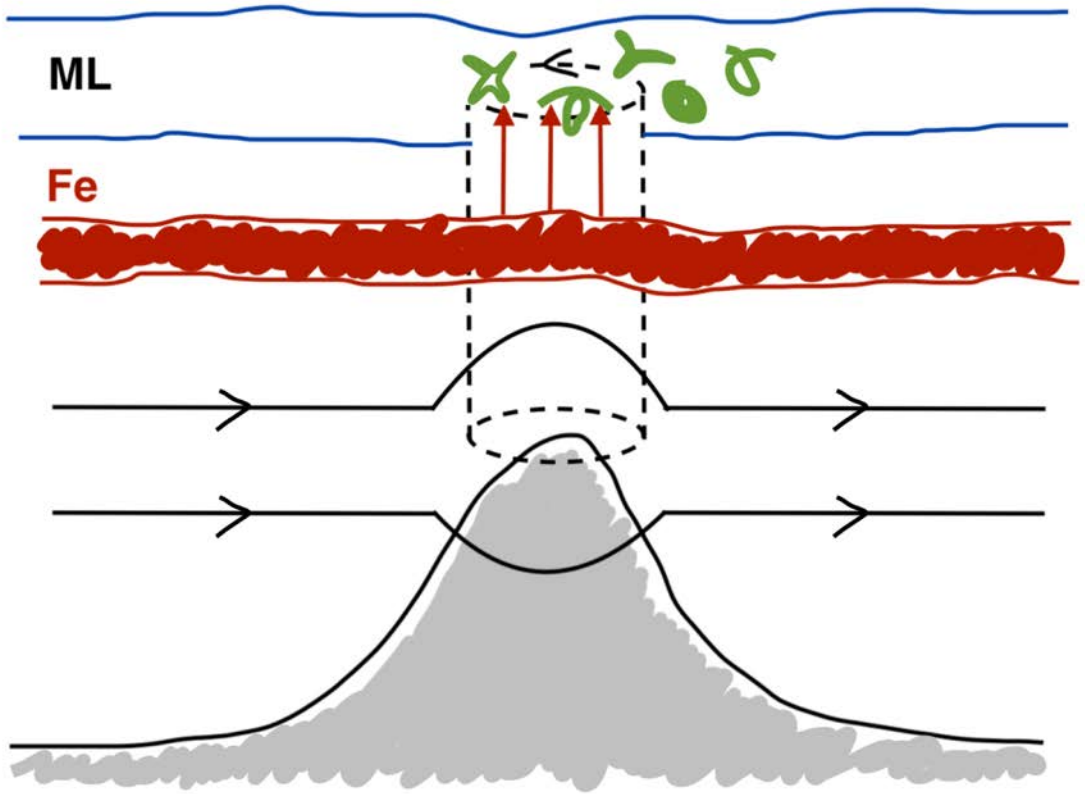


Taylor columns enhance production

Prend, Gille, Talley, Mitchell, Rosso, Mazloff (JGRO, submitted)





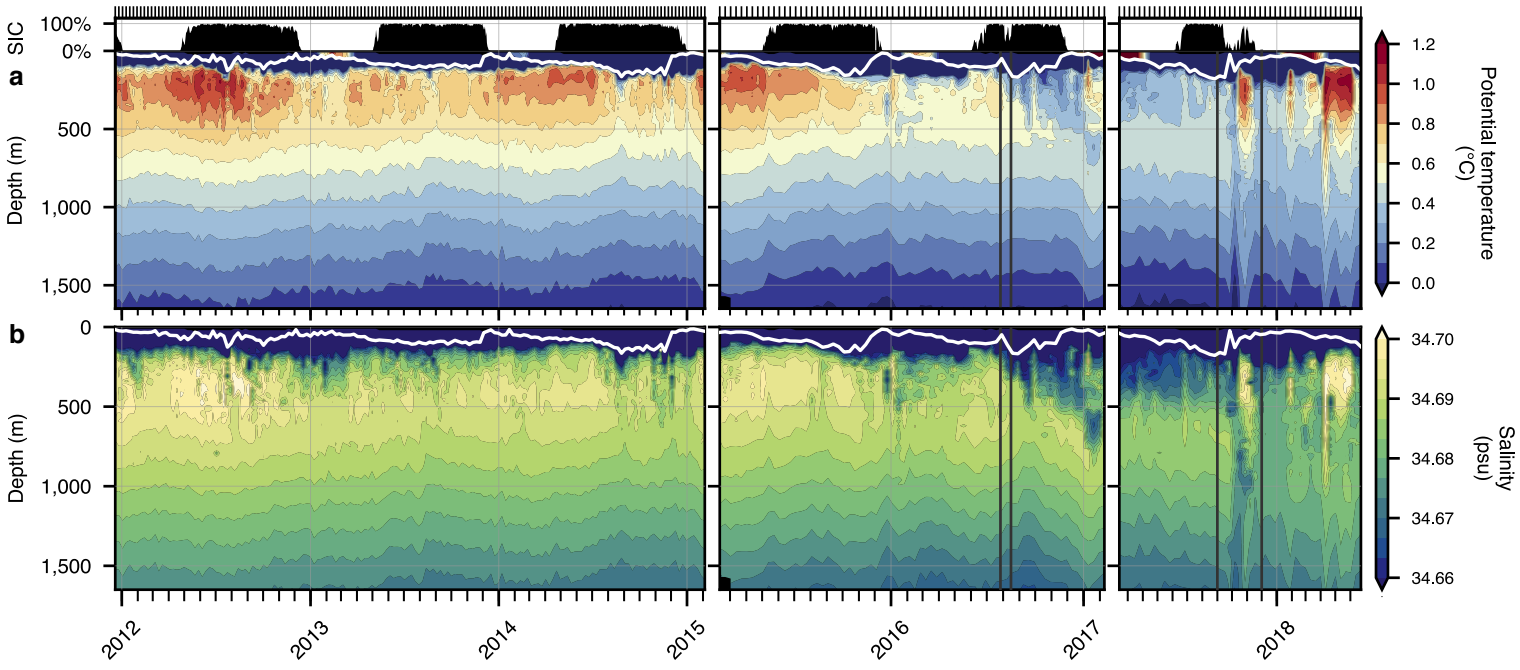


SOSE trajectories show source of water in southern ACC and Weddell gyre. Iron source.

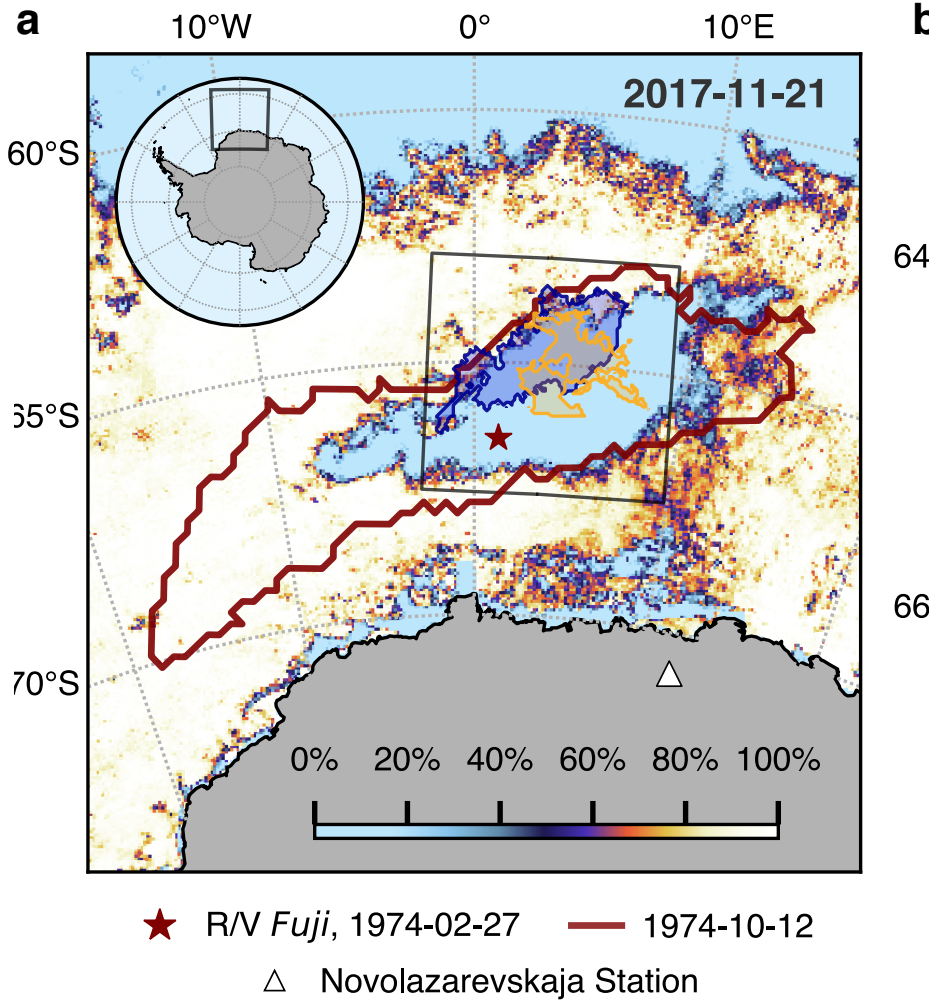
https://doi.org/10.1038/s41586-019-1294-0

Antarctic offshore polynyas linked to Southern Hemisphere climate anomalies

Ethan C. Campbell[1]*, Earle A. Wilson[1], G. W. Kent Moore[2,3], Stephen C. Riser[1], Casey E. Brayton[4], Matthew R. Mazloff[5] & Lynne D. Talley[5]

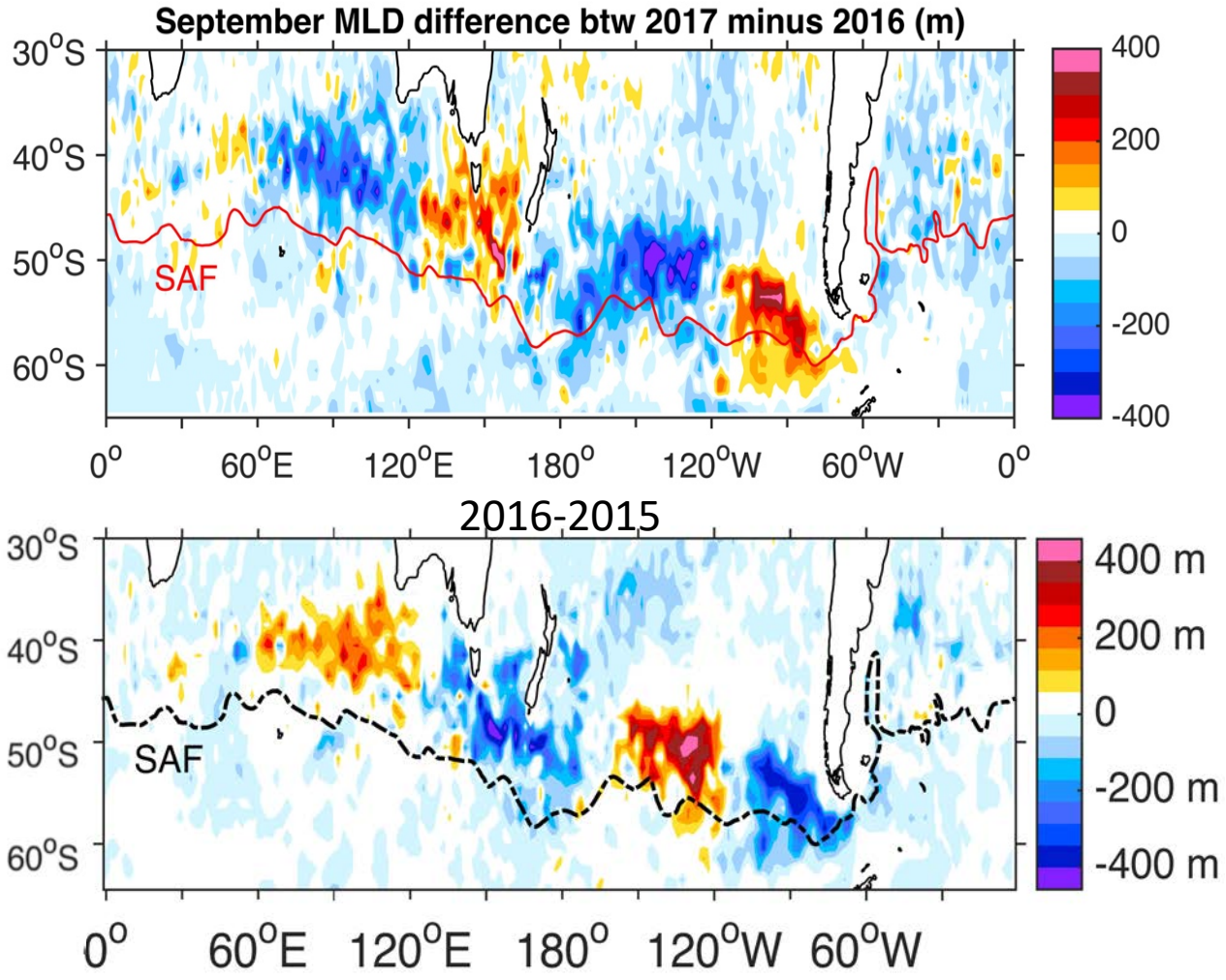


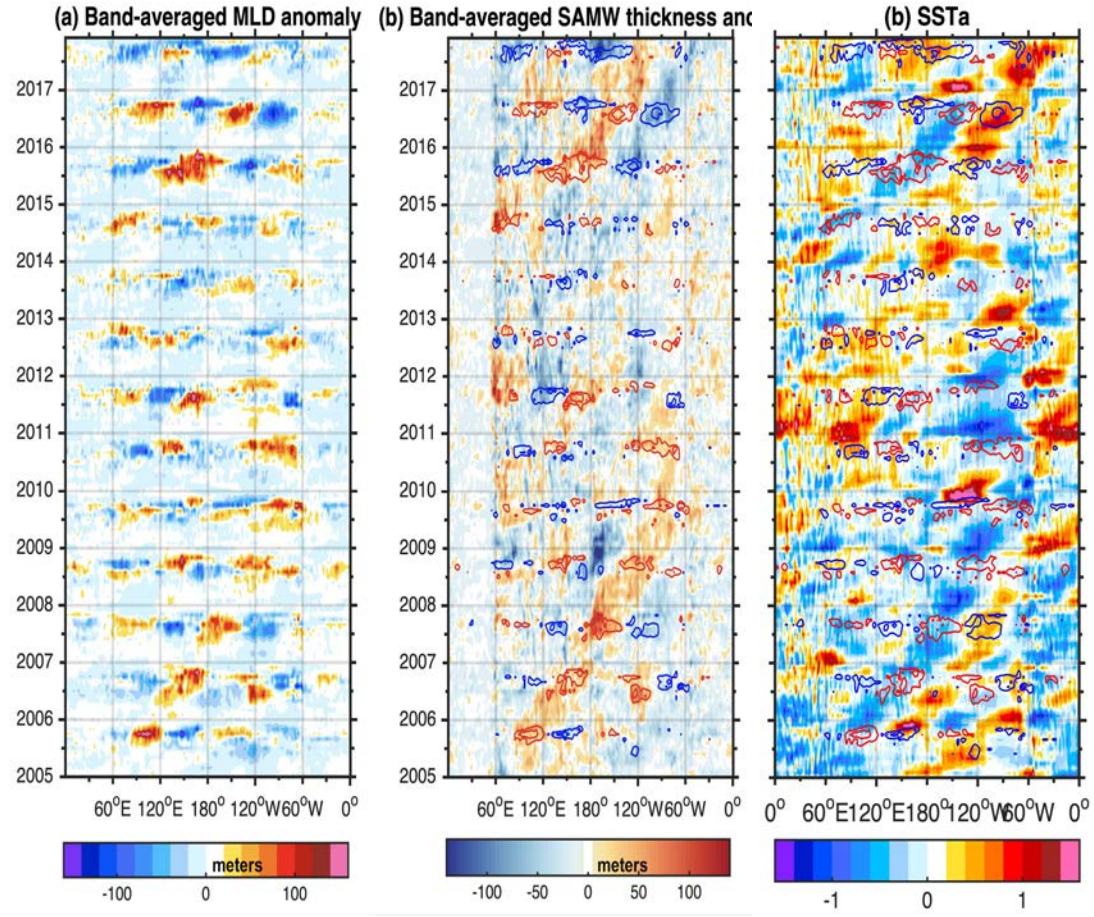
Episodic storm forcing and Maud Rise polynya



Interannual variability in Subantarctic Zone mixed layers and mode waters

Lu, Talley, Cerovecki, Xie, Mazloff, Gille, Liu, Zhang (in preparation)





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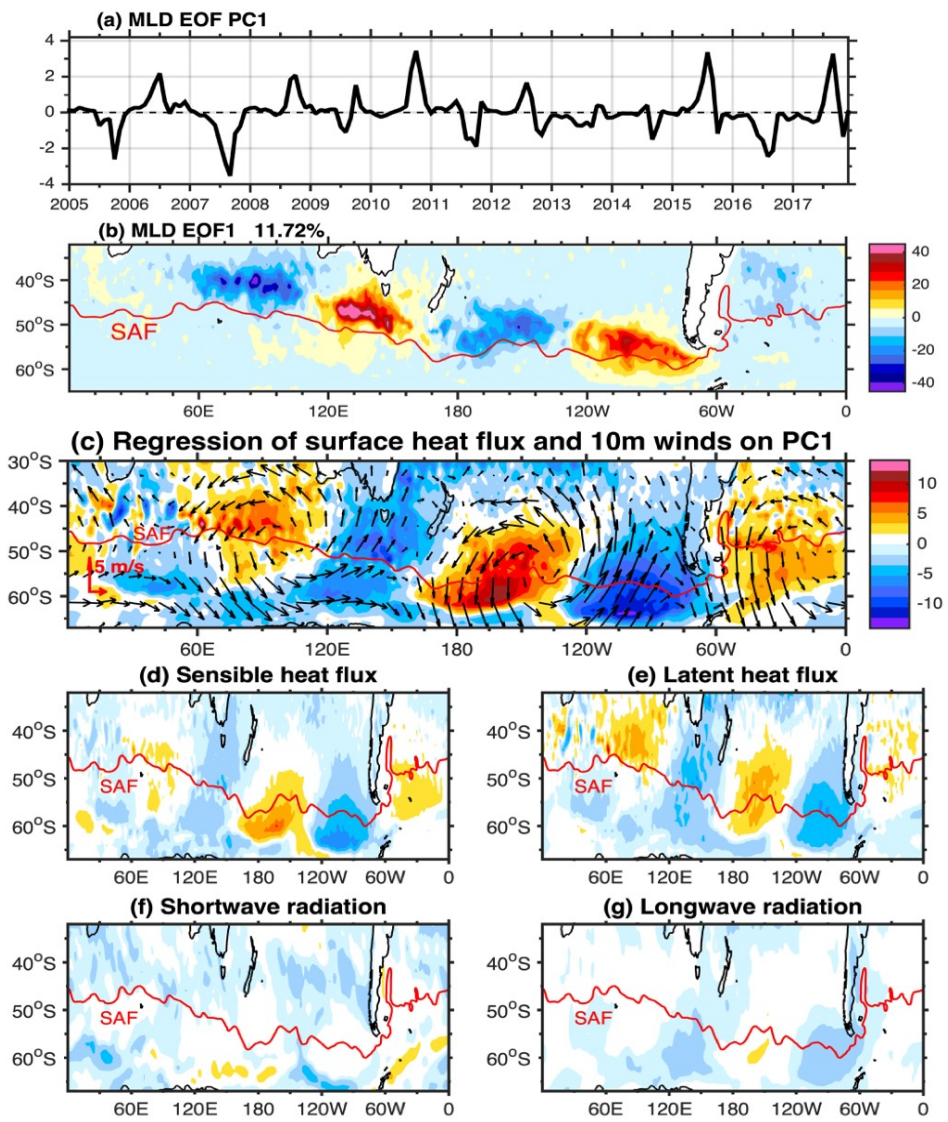
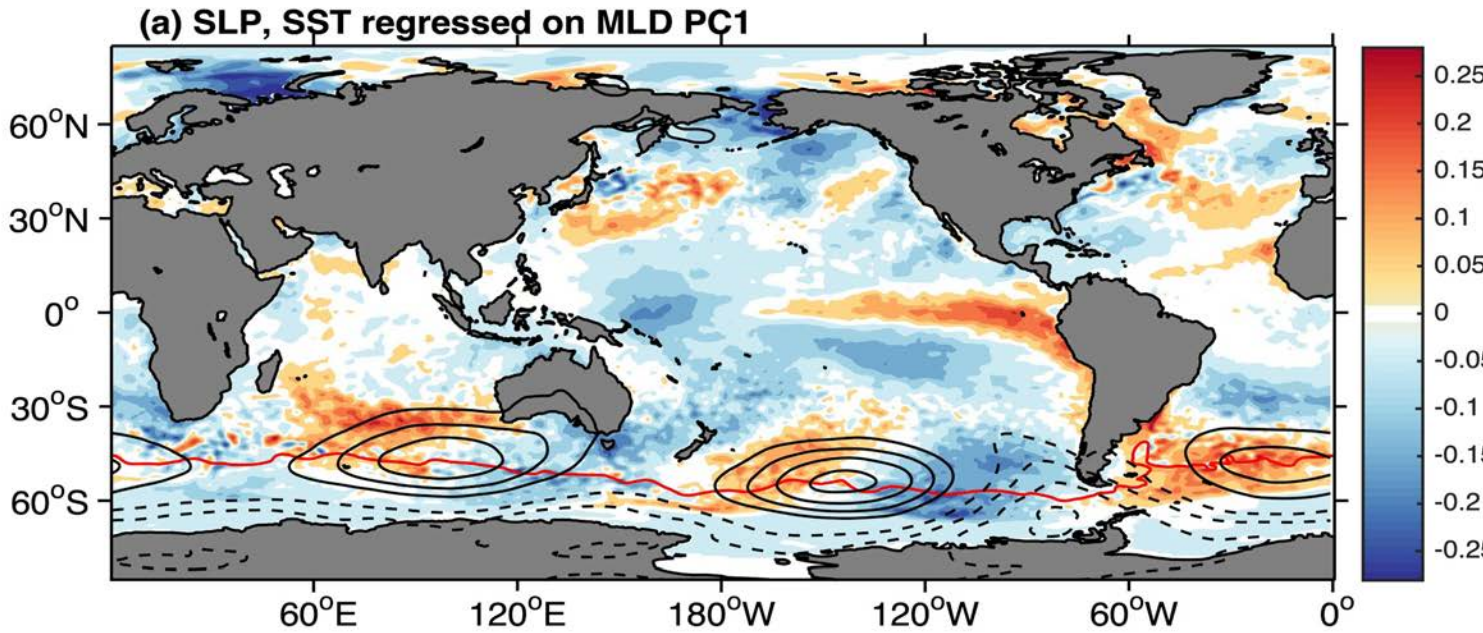
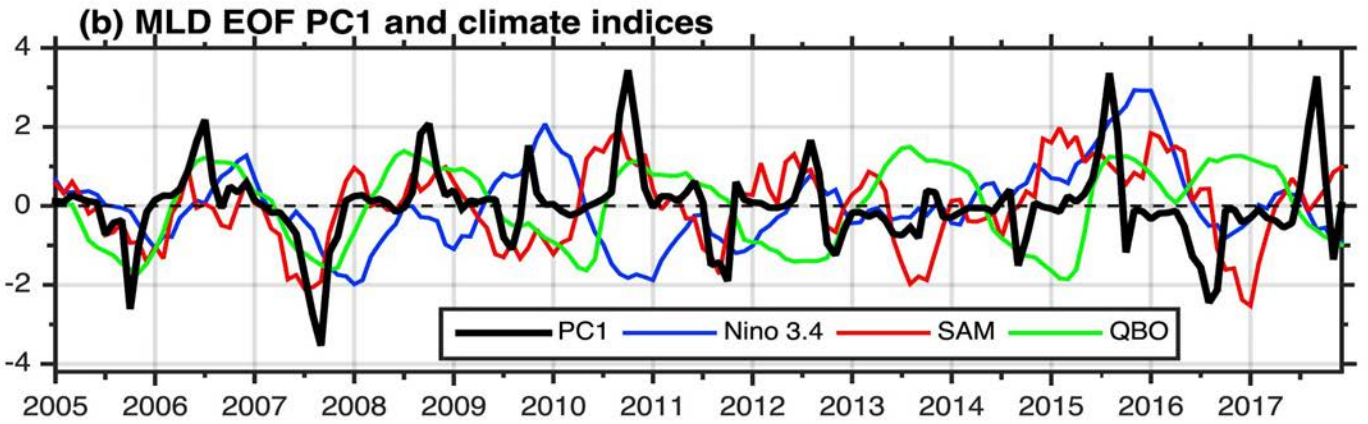
Interannual variability in Subantarctic Zone mixed layers and mode waters

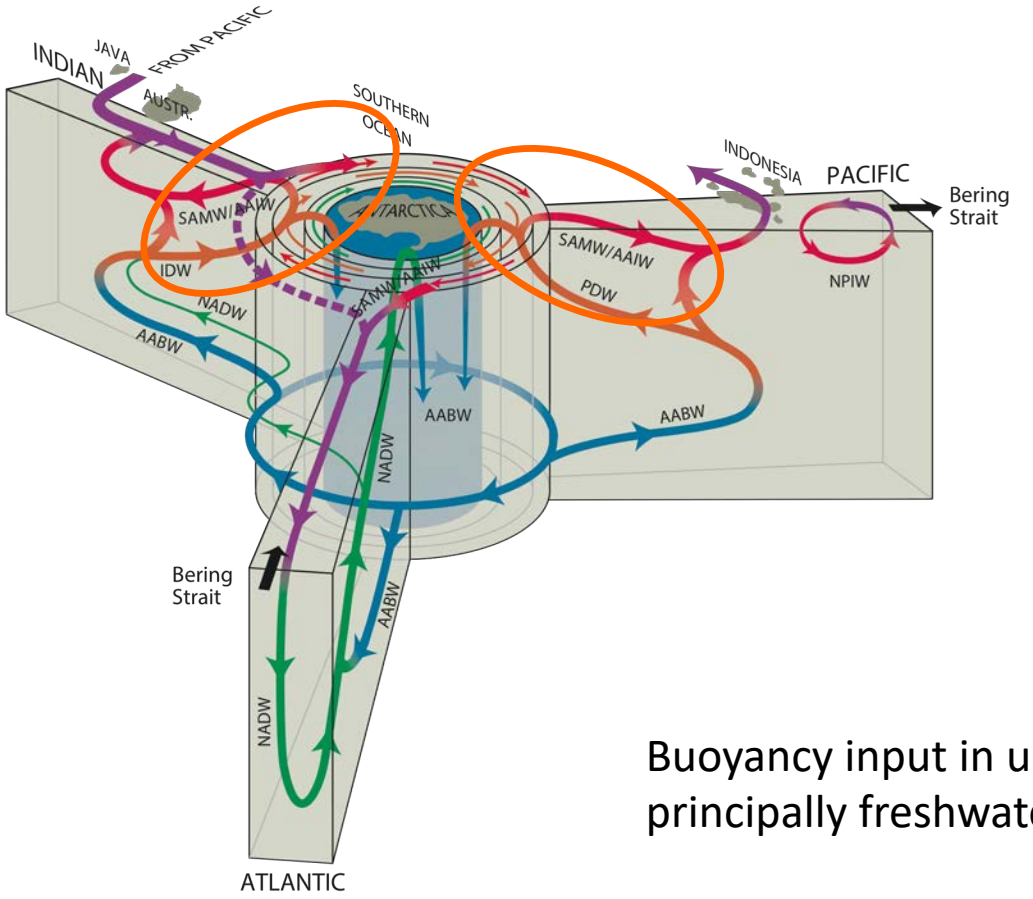
Lu, Talley, Cerovecki, Xie, Mazloff, Gille, Liu, Zhang (in preparation)



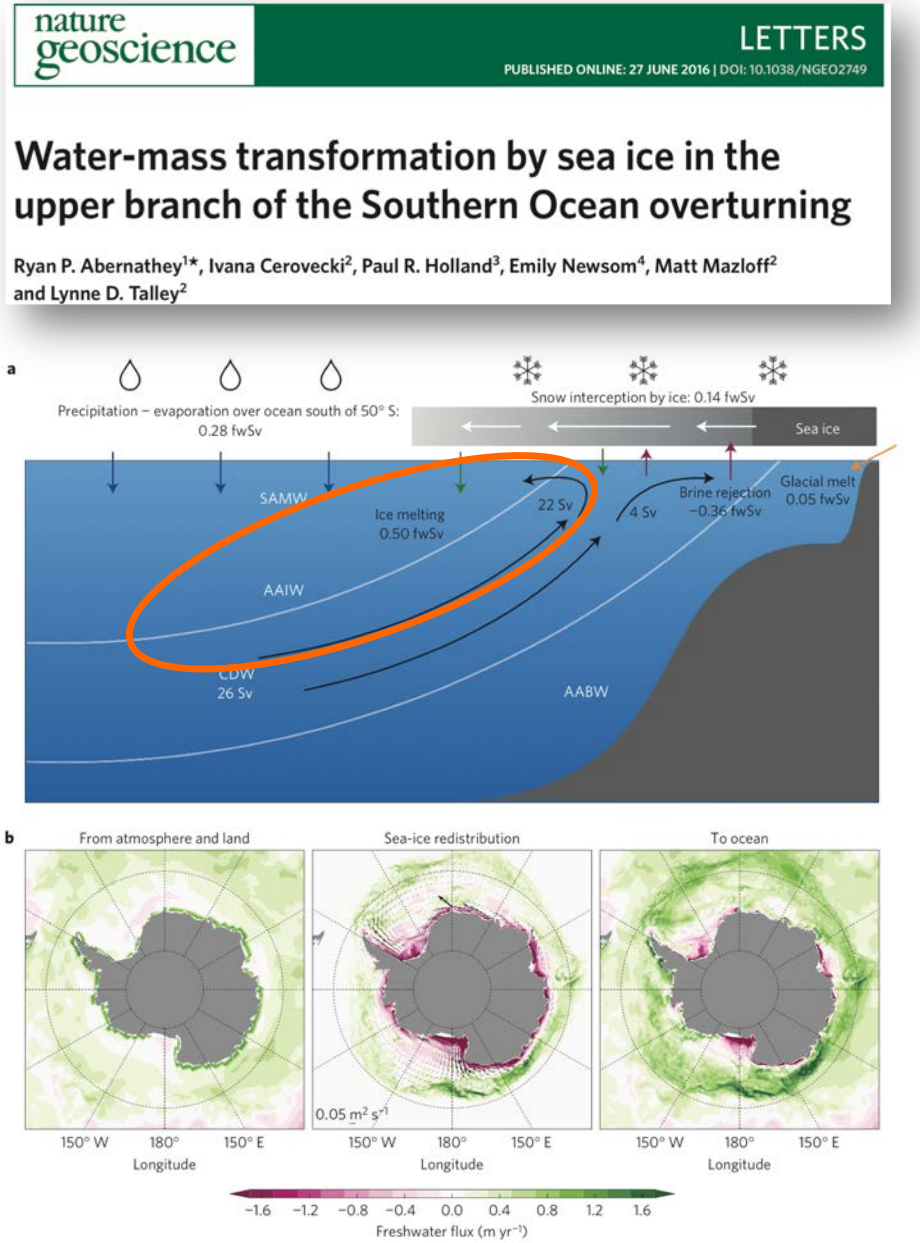




Overturning circulation:
upper limb processes (SOSE)



Buoyancy input in upper limb of SO OTC is principally freshwater from sea ice melt


nature geoscience
LETTERS
PUBLISHED ONLINE: 27 JUNE 2016 | DOI: 10.1038/NGEO2749

Water-mass transformation by sea ice in the upper branch of the Southern Ocean overturning

Ryan P. Abernathey[1]*, Ivana Cerovecki[2], Paul R. Holland[3], Emily Newsom[4], Matt Mazloff[2] and Lynne D. Talley[2]

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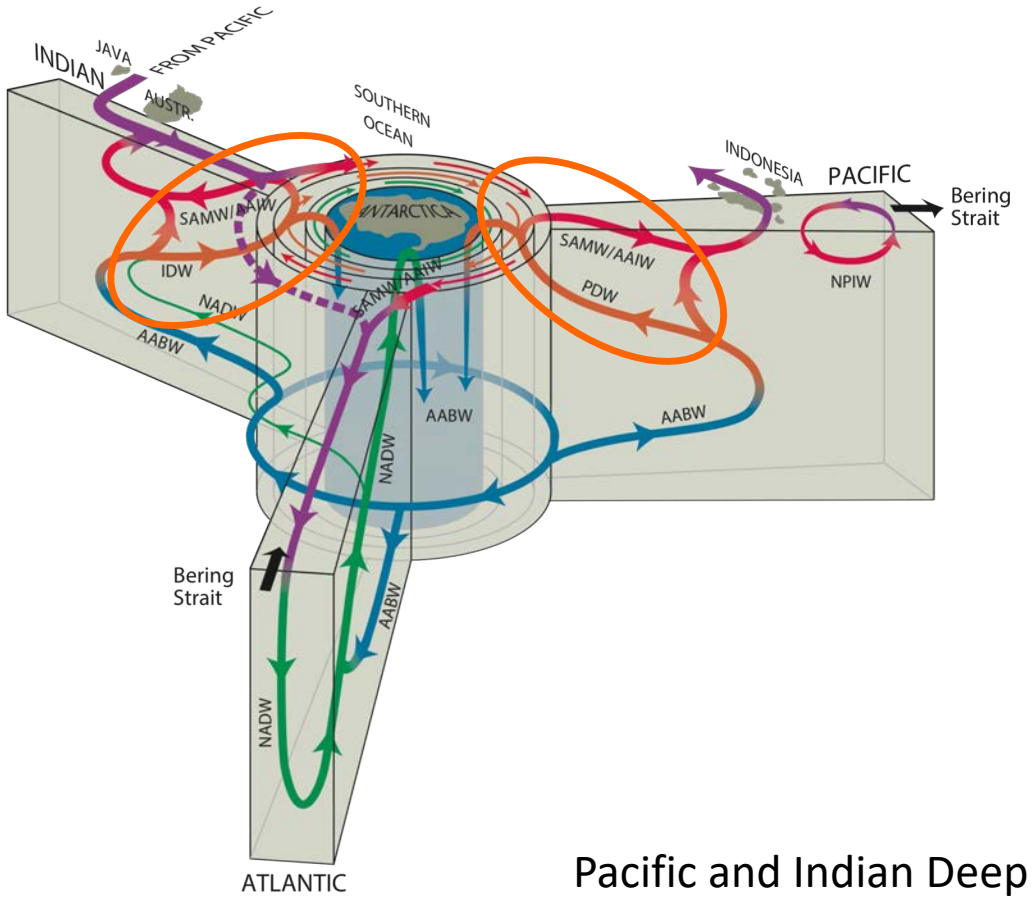
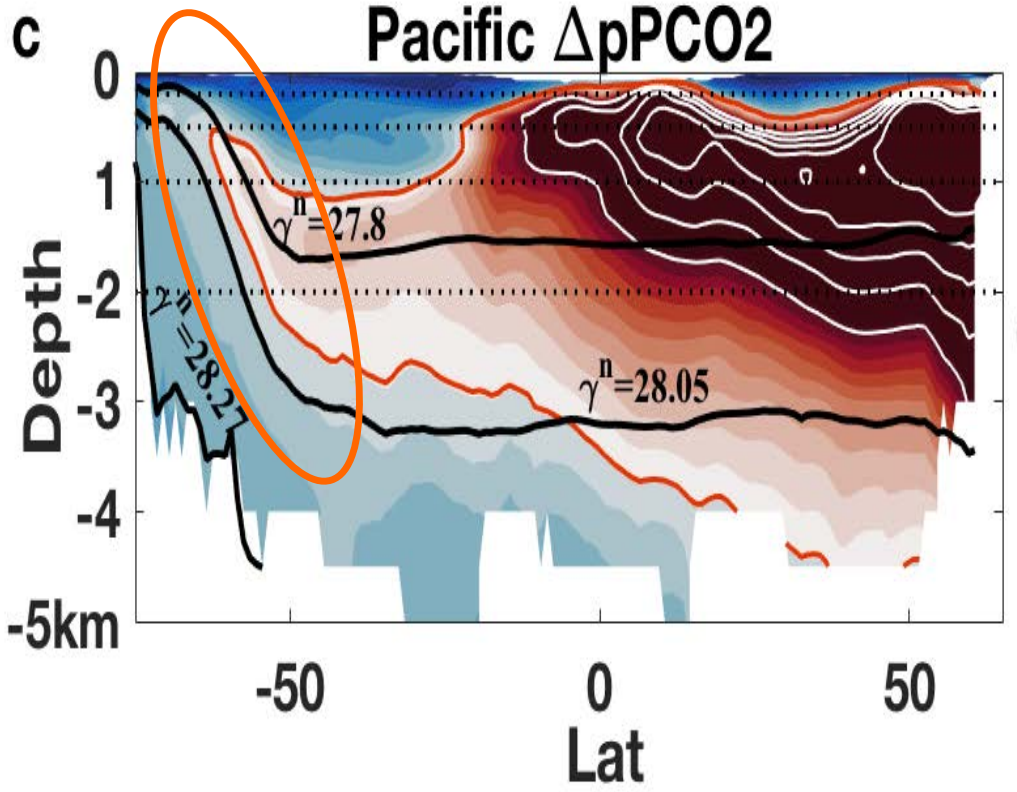
Abernathey et al. (Nat. Geosci. 2016)

Overturning circulation and carbon



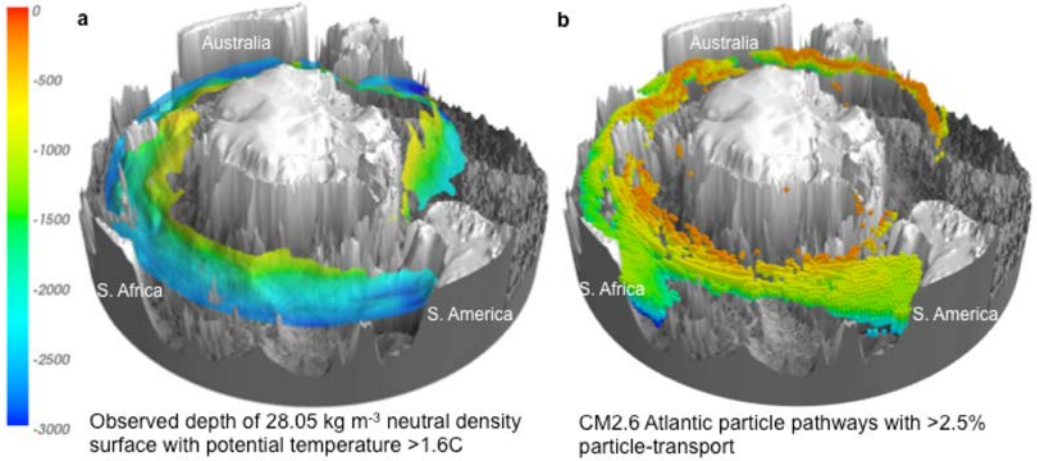


Pacific and Indian Deep Waters are low oxygen, high carbon/nutrients

When they upwell to sea surface they outgas (Gray et al., 2018; Chen et al., in preparation)

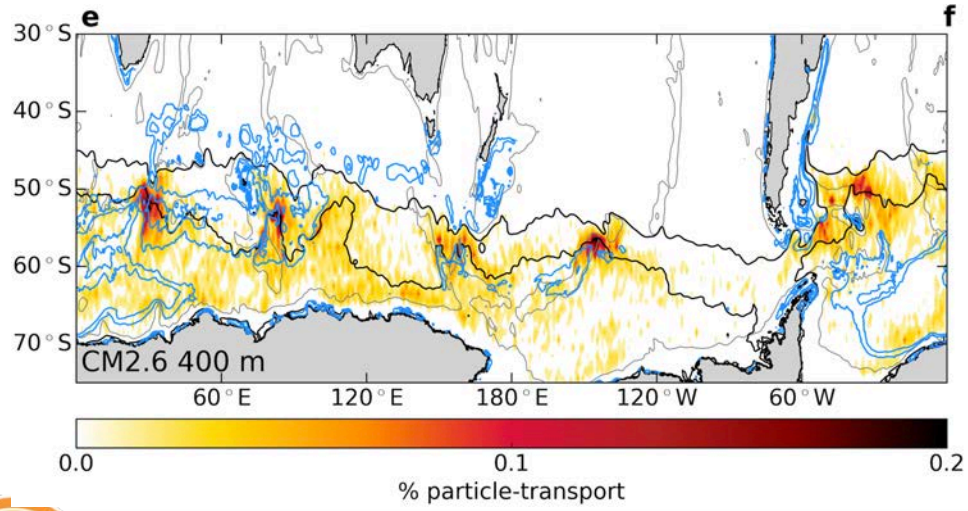
Chen et al. (in preparation)

Overturning circulation:
upper limb processes (SOSE)



Observed depth of 28.05 kg m^{-3} neutral density surface with potential temperature >1.6C

CM2.6 Atlantic particle pathways with >2.5% particle-transport



nature COMMUNICATIONS

ARTICLE

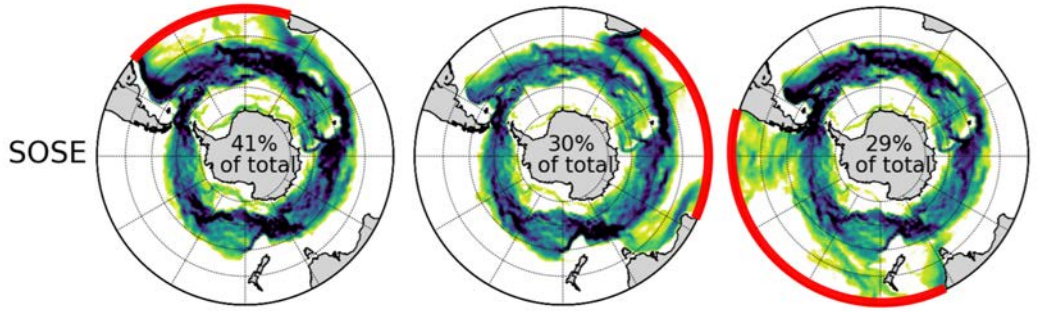
DOI: 10.1038/s41467-017-00197-0 OPEN

Spiraling pathways of global deep waters to the surface of the Southern Ocean

Veronica Tamsitt[1], Henri F. Drake[2,6], Adele K. Morrison[2,7], Lynne D. Talley[1], Carolina O. Dufour[2], Alison R. Gray[2], Stephen M. Griffies[3], Matthew R. Mazloff[1], Jorge L. Sarmiento[2], Jinbo Wang[4] & Wilbert Weijer[5]

Mean circulation pathways for deep waters: Deep Western and Eastern Boundary Currents

Topographic ‘hotspots’ of deep layer upwelling



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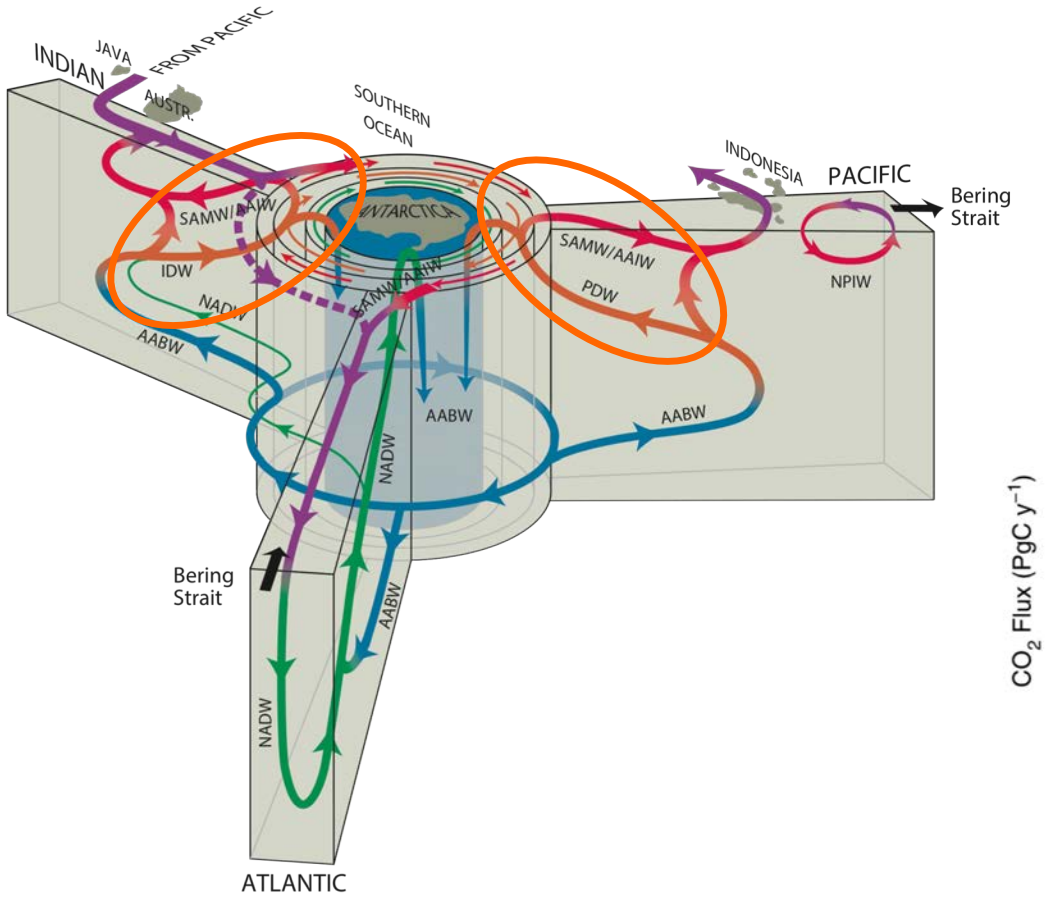
Tamsitt et al. (Nat. Comm. 2017, JGR 2018, JGR 2019)

Overturning circulation and carbon



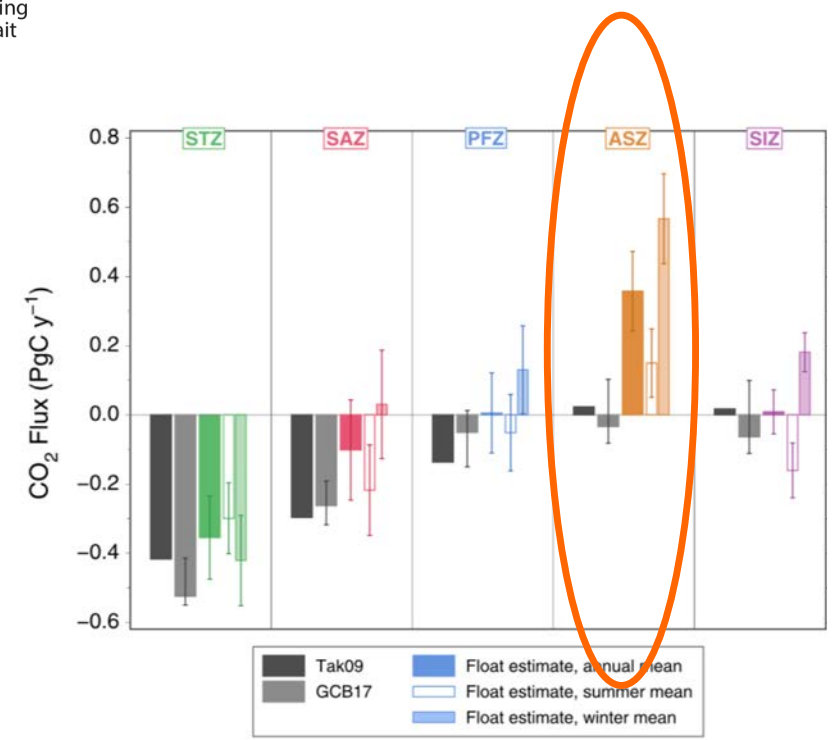
Geophysical Research Letters

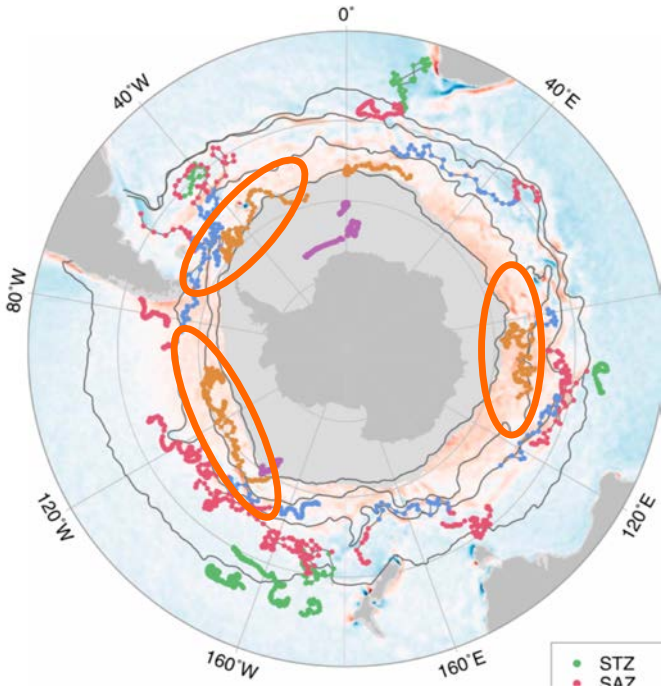
RESEARCH LETTER
10.1029/2018GL078013

Autonomous Biogeochemical Floats Detect Significant Carbon Dioxide Outgassing in the High-Latitude Southern Ocean

Key Points:
- Measurements from biogeochemical profiling floats were used to estimate air-sea fluxes of carbon dioxide
- Significant annual net outgassing

Alison R. Gray[1], Kenneth S. Johnson[2], Seth M. Bushinsky[3], Stephen C. Riser[1], Joellen L. Russell[4], Lynne D. Talley[5], Rik Wanninkhof[6], Nancy L. Williams[7], and Jorge L. Sarmiento[3]



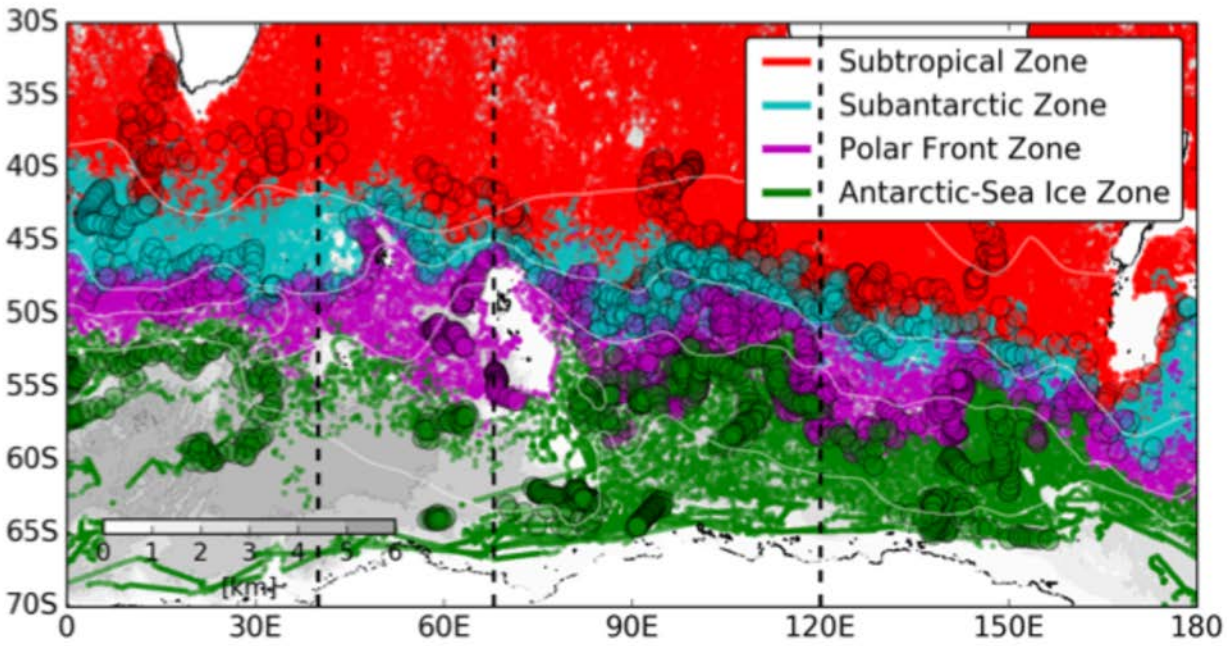


Gray et al. (GRL 2018)

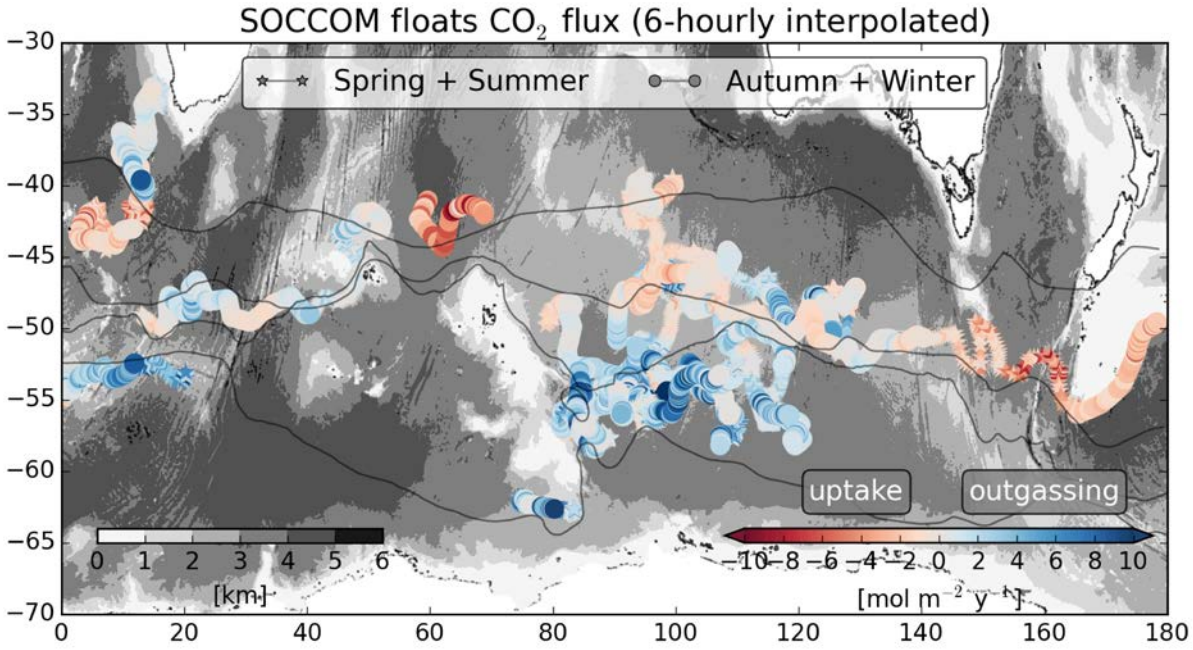
Effect of Kerguelen hotspot on mixing of water masses and fluxes

Intermingling of water masses is vigorous east of Kerguelen (topographic hotspot)

Uses machine learning approach to distinguish zones of each Argo and SOCCOM profile



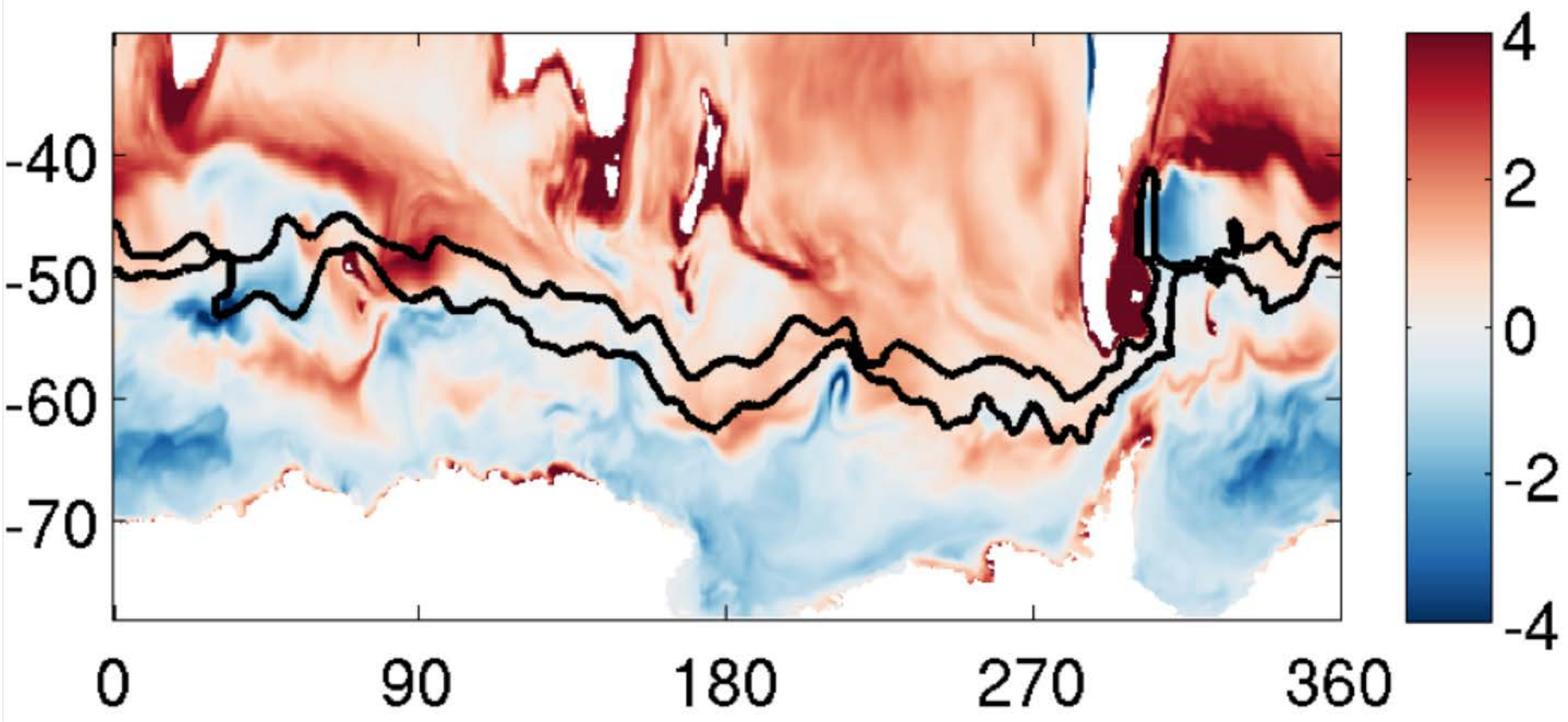
Surface CO2 flux is high east of Kerguelen, where Tamsitt et al. found enhanced upwelling



SOCCOM

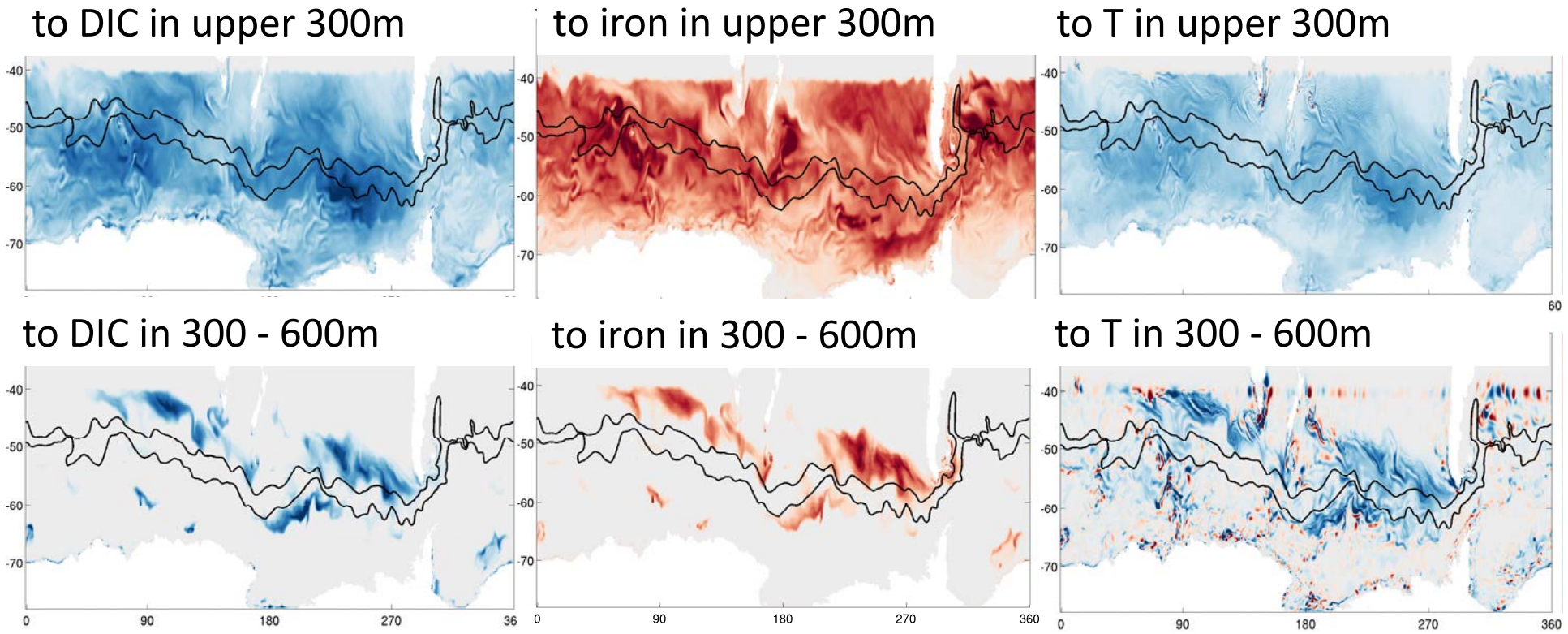
Rosso, Talley, Mazloff, Purkey, Freeman, Maze, Bushinsky, Gray (in preparation)

Sensitivity of air-sea CO_2 flux to multiple parameters (B-SOSE)



- 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.

Sensitivity of air-sea CO_2 flux to September properties (B-SOSE)



Warm colors denote increasing property increases oceanic sink.
Cool colors denote increasing property increases outgassing.