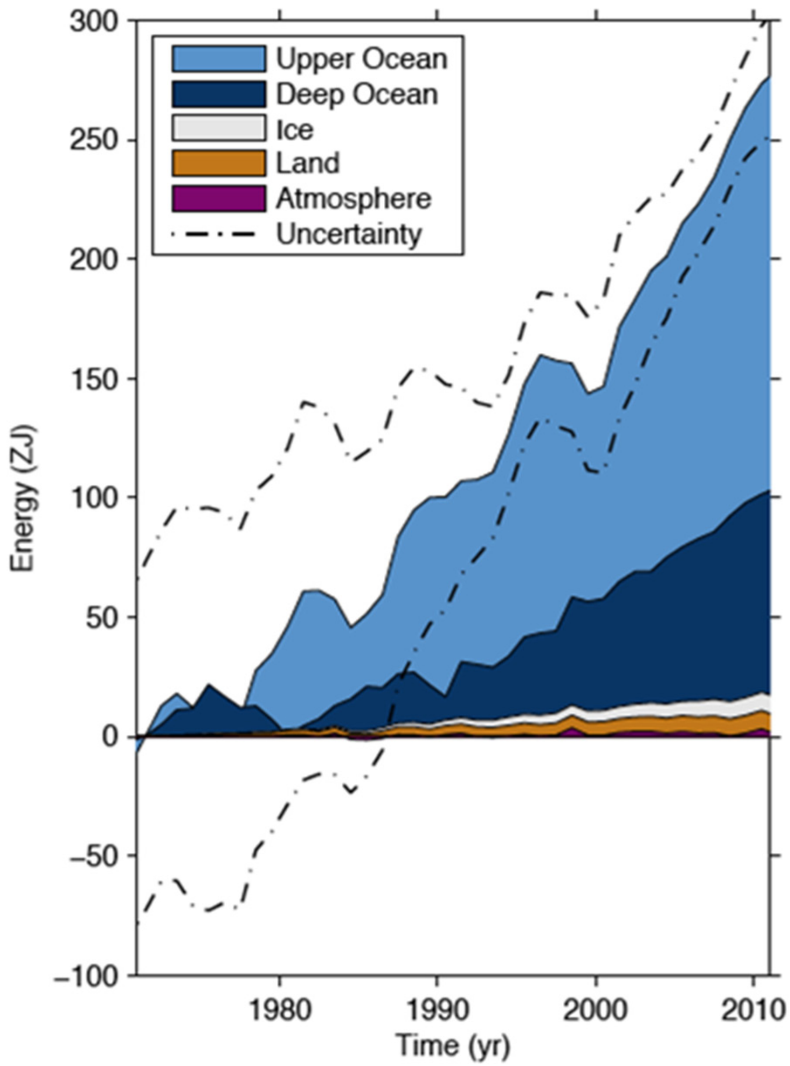
Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) Introduction & Physical Setting

SOCCOM

Lynne Talley, Scripps Institution of Oceanography
OCB Workshop, Woods Hole July 26, 2016

http://soccom.princeton.edu

Global Warming is Ocean Warming



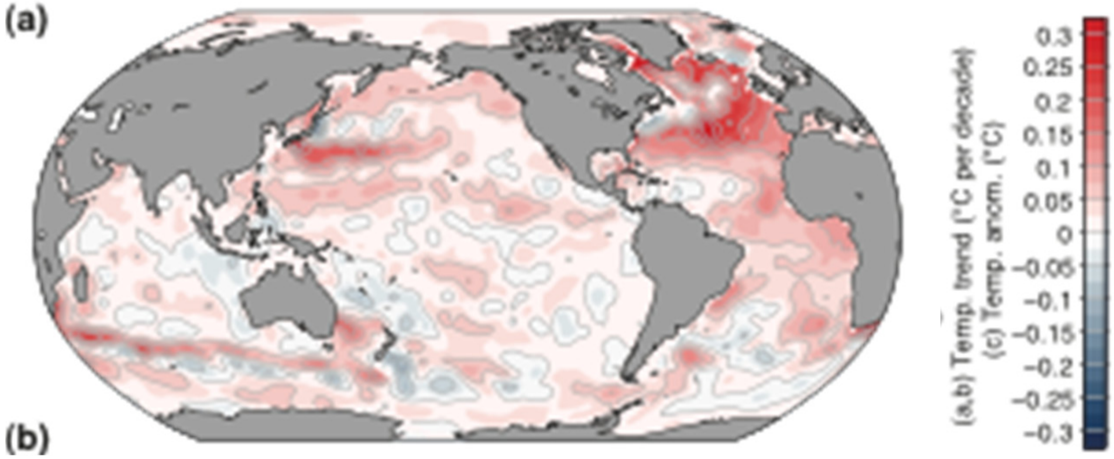
Upper Ocean

Deep Ocean

Atmosphere

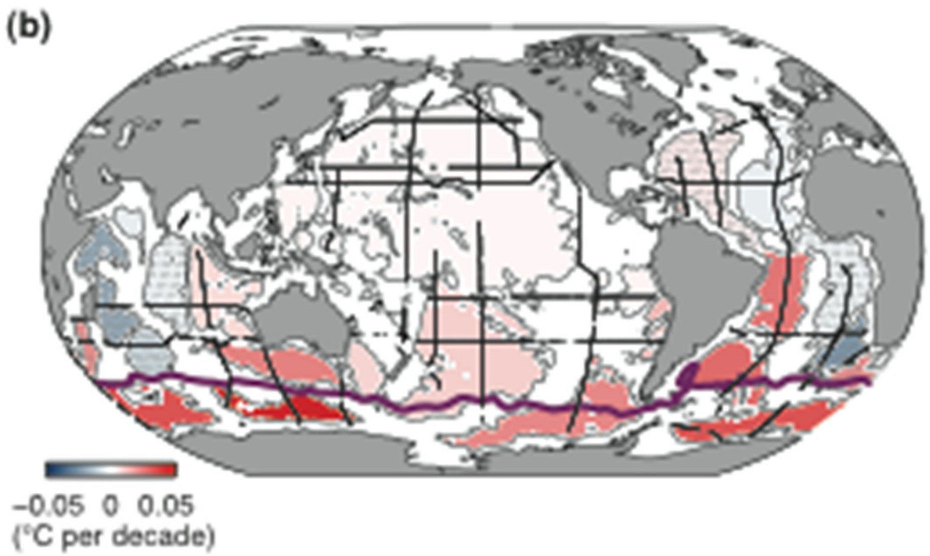
IPCC AR5 (2013) WGI Chapter 3 (ocean observations)

The ocean is warming



Upper Ocean
(0-700 m)
77% of global heat

(Argo, hydrography, XBTs)

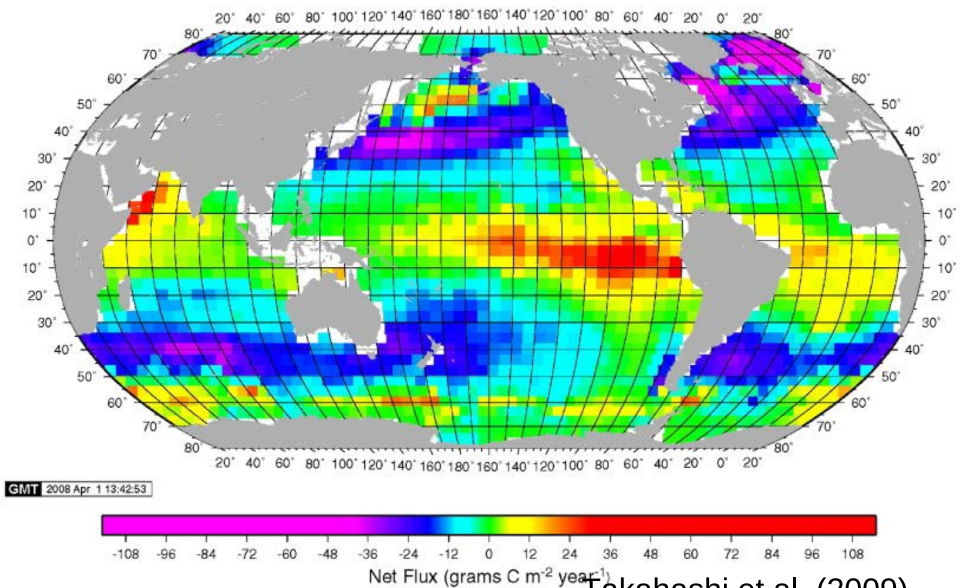


Deep Ocean
(> 4000 m)
16% of global heat

(Hydrography)

IPCC AR5 (2013) WGI Chapter 3 (ocean observations) Purkey and Johnson (2010)

SOCCOM Air-sea carbon fluxes and anthropogenic CO_2



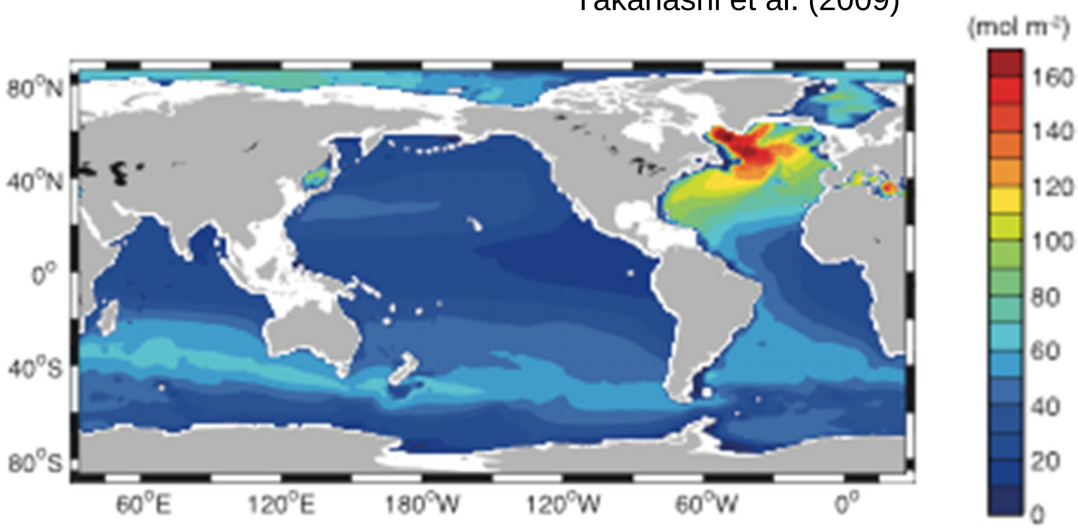
Takahashi et al. (2009)

What are the physical controls on flux signs and magnitudes?

seasonal cycle?

interannual to decadal variability?

(Sparse ship-based observations)



Khatiwala et al. (2013)

Anthropogenic CO_2

What governs this uptake?

(Hydrography & models)

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Why the Southern Ocean?

Studies suggest the Southern Ocean plays an important role in carbon and climate:

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

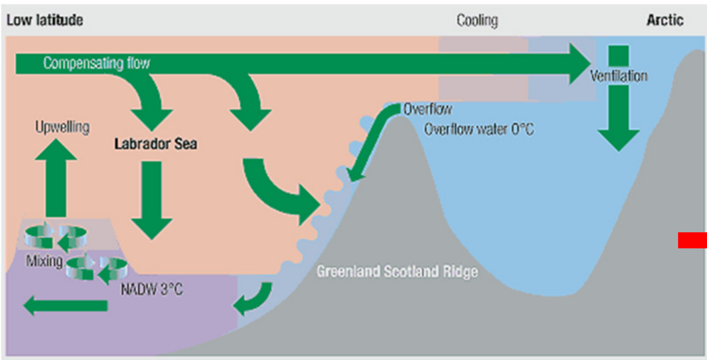
Vertical exchange in the Southern Ocean supplies nutrients that fertilize **three-quarters** of the biological production in the global ocean north of 30°S.

Roemmich et al. 2015

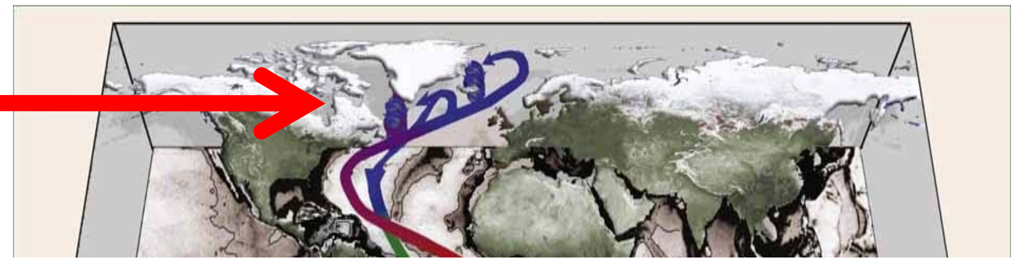
Gruber et al. 2009, Landschützer et al. 2015

Sarmiento et al. 2004

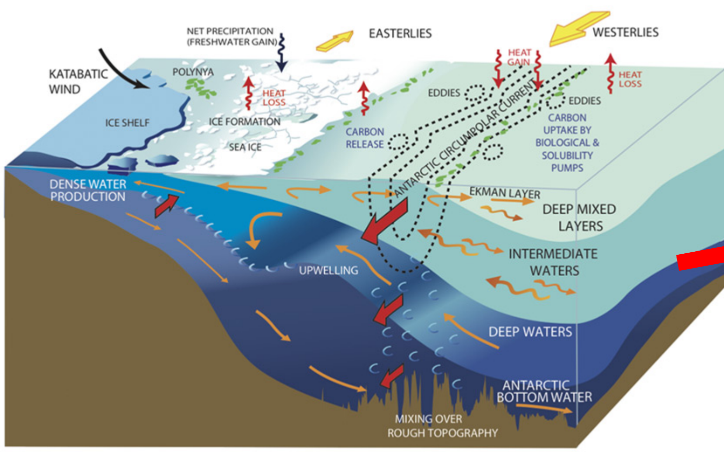
Physical controls : meridional overturning



- NADW production from warm surface water



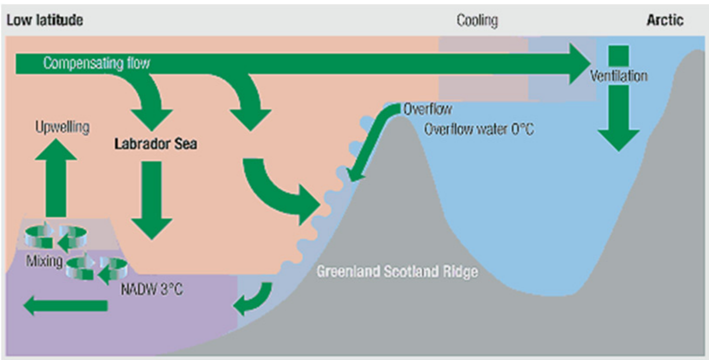
Drake Passage Effect



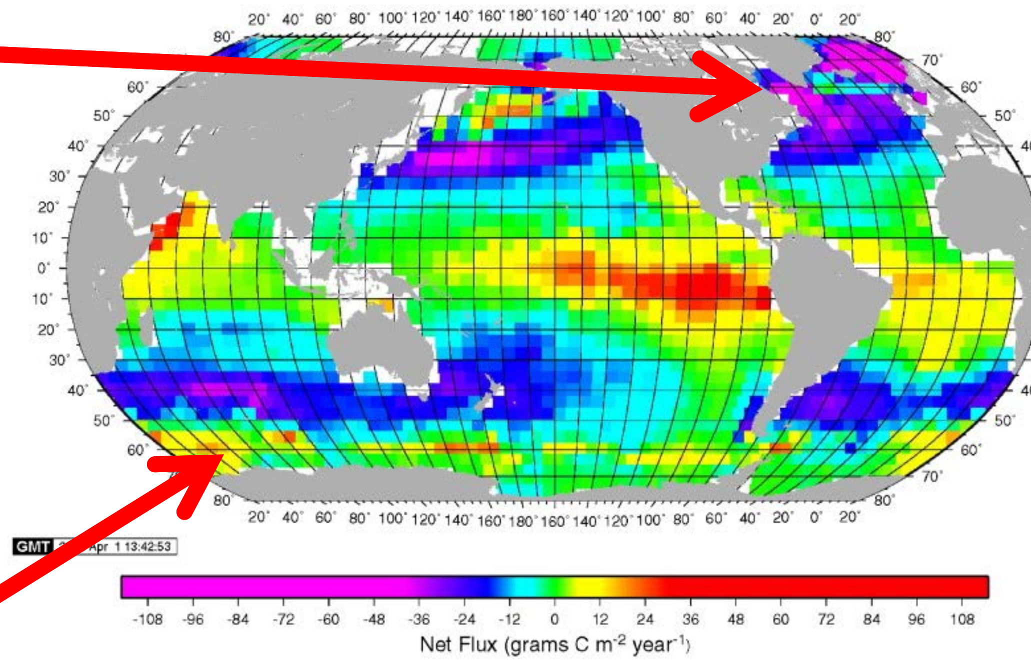
- AABW production under sea ice from upwelled deep water

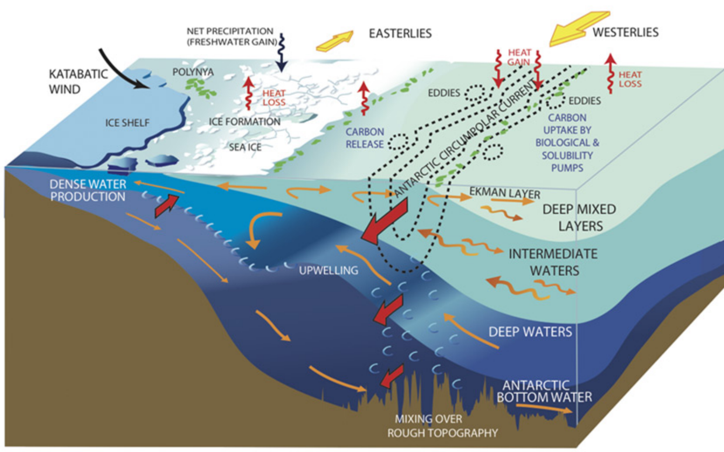
Marshall and Speer, Nat. Geosc. 2012

Physical controls : meridional overturning



- NADW production from warm surface water
- Large CO_2 uptake

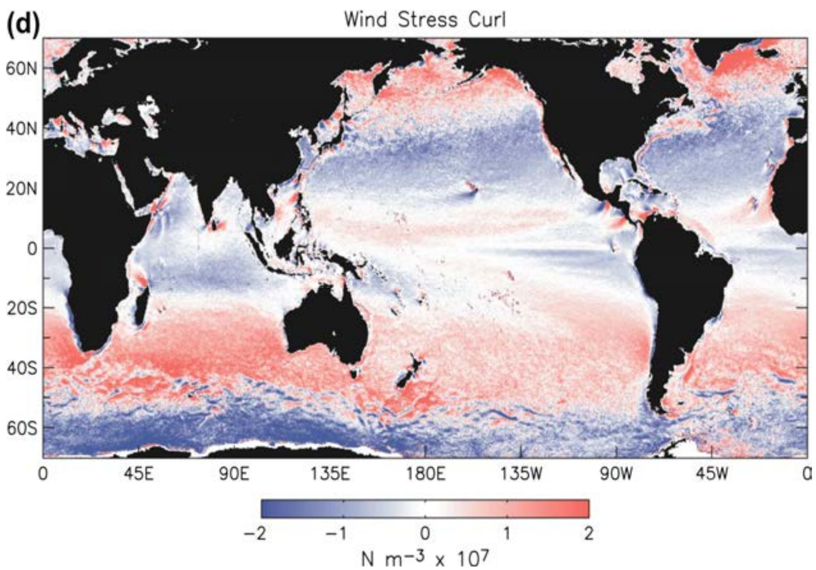




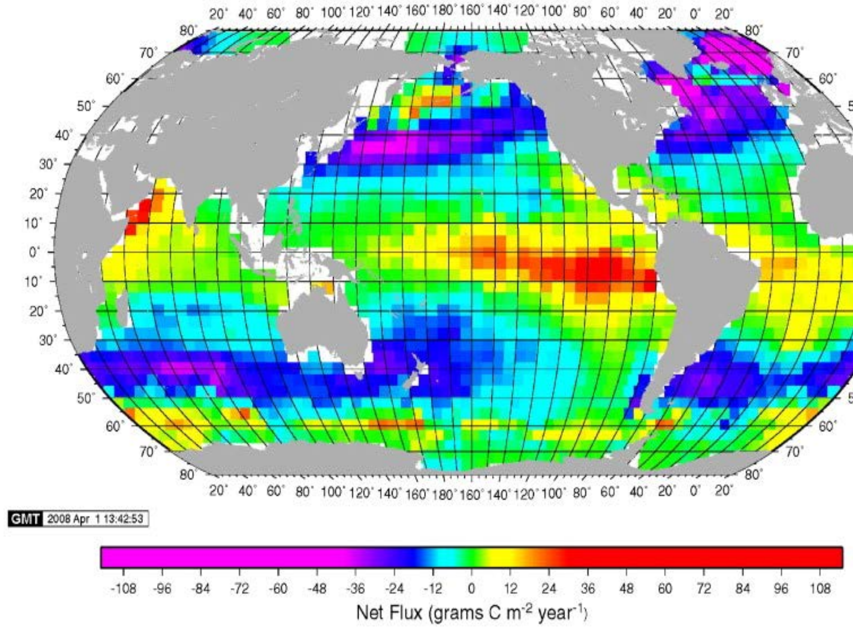
- AABW production under sea ice from upwelled deep waters
- CO_2 release

Physical controls: upper ocean ventilation

- Wind stress curl from Chelton et al. (2004)



Air-sea CO_2 flux from Takahashi et al. (2009)



- Subtropical subduction of surface water, esp. mode waters (CO_2 uptake)
-
- Upwelling of carbon-enriched water to sea surface (CO_2 outgassing), with
- Topographic enhancement (more upwelling)
- Stratification enhancement (bigger vertical carbon gradient)

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SOCCOM motivation

Climate models (CESMs) are imperfect and especially poor in the Sout hern Ocean.

How to improve? Observe, compare, improve

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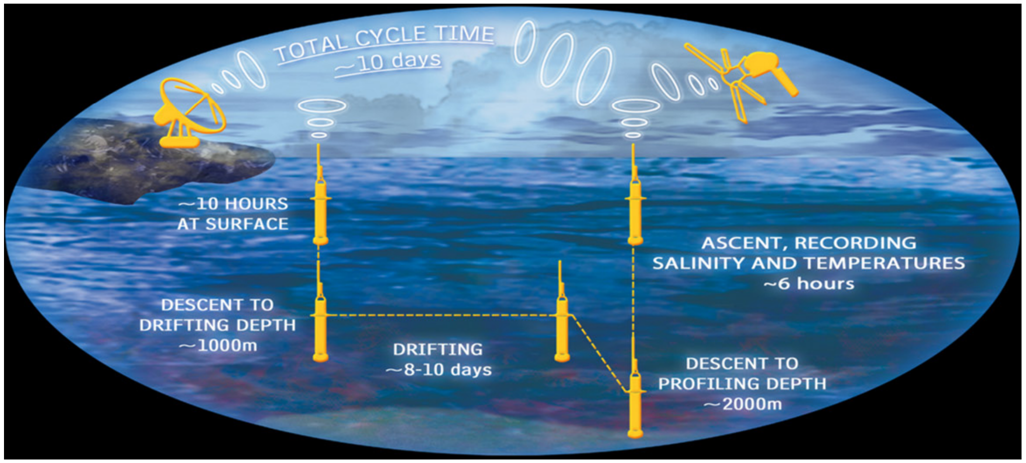
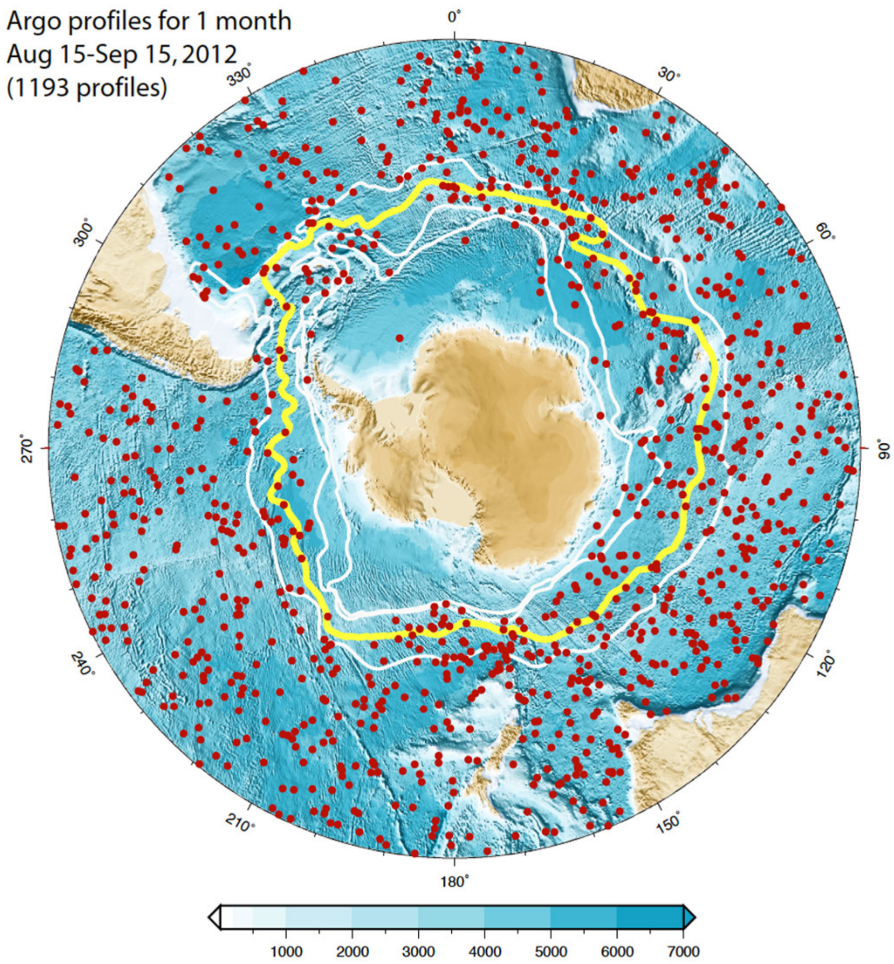
The Grand Challenge

Despite its critical importance, the remote and often hostile Southern Ocean is the least understood and least observed region of the world ocean ...

A transformative observing system

- Argo floats have transformed how we observe temperature/salinity
- (in the ice-free ocean)





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The Opportunity

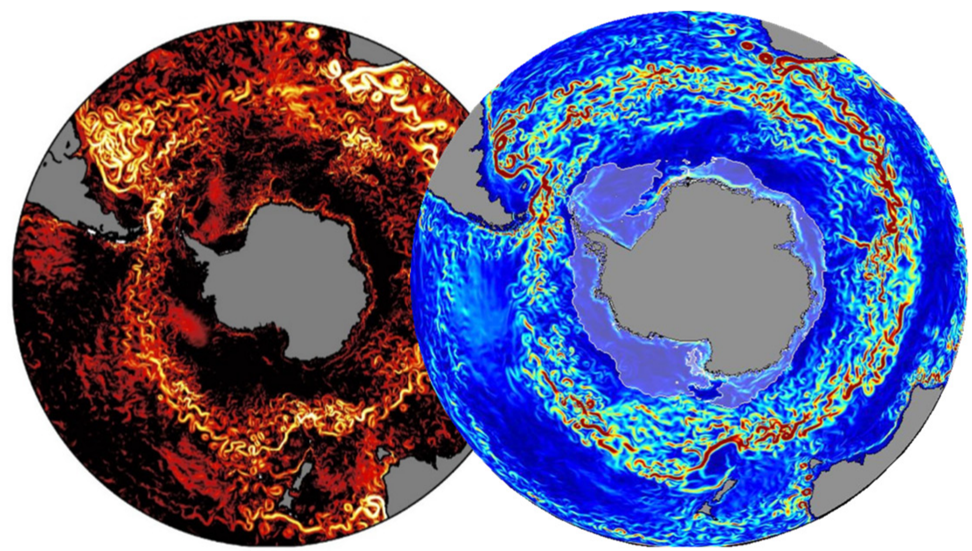
Major developments in oceanographic observation and modeling have the potential to transform our understanding of the Southern Ocean:

Biogeochemical sensors mounted on autonomous profiling floats allow sampling of ocean biogeochemistry and acidification in 3-D

Ice-enabled software permits sampling under seasonal sea ice

- pH
- Nitrate,
- oxygen, and
- optics (FLBB) funded by NASA

Fully coupled climate models that represent crucial mesoscale processes in the Southern Ocean, and corresponding models that assimilate observations to produce a state estimate.



Eddy-resolving ESM's

Southern Ocean State Estimate

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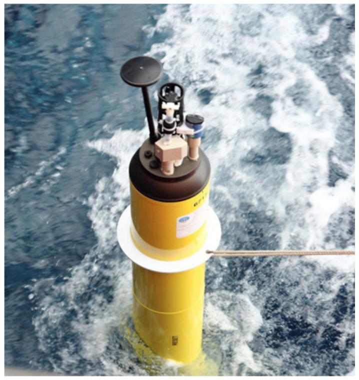
SOCCOM Status & Resources

http://soccom.princeton.edu

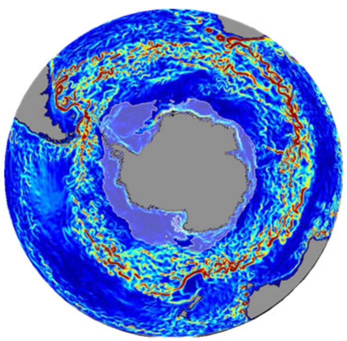
SOCCOM mission and approach

Mission: To enable a transformative shift in scientific and public understanding of the role of the Southern Ocean in climate change & biogeochemistry

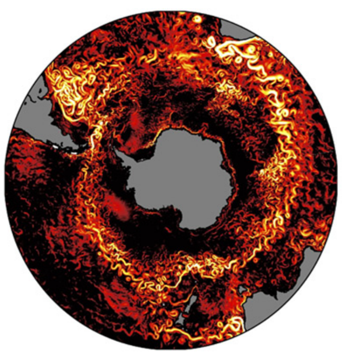


Observations: 180-200 autonomous biogeochemical Argo floats south of 30°S:

2000 m profiles
10 day sampling
under ice coverage
(partnering with Argo; integration with GO-SHIP and other int'l. research ship programs)



State estimation: incorporate observations in high resolution biogeochemical ocean model "Southern Ocean State Estimate"



High resolution (1/10° and higher) earth system models: understanding of the Southern Ocean and better projections of climate and biogeochemistry changes (CM2.6 and CMIP comparisons)

SOCCOM by the Numbers

- 23 senior researchers
- 10 associated investigators
- 8 postdocs
- 11 graduate students
- 25 foreign collaborators

SOCCOM

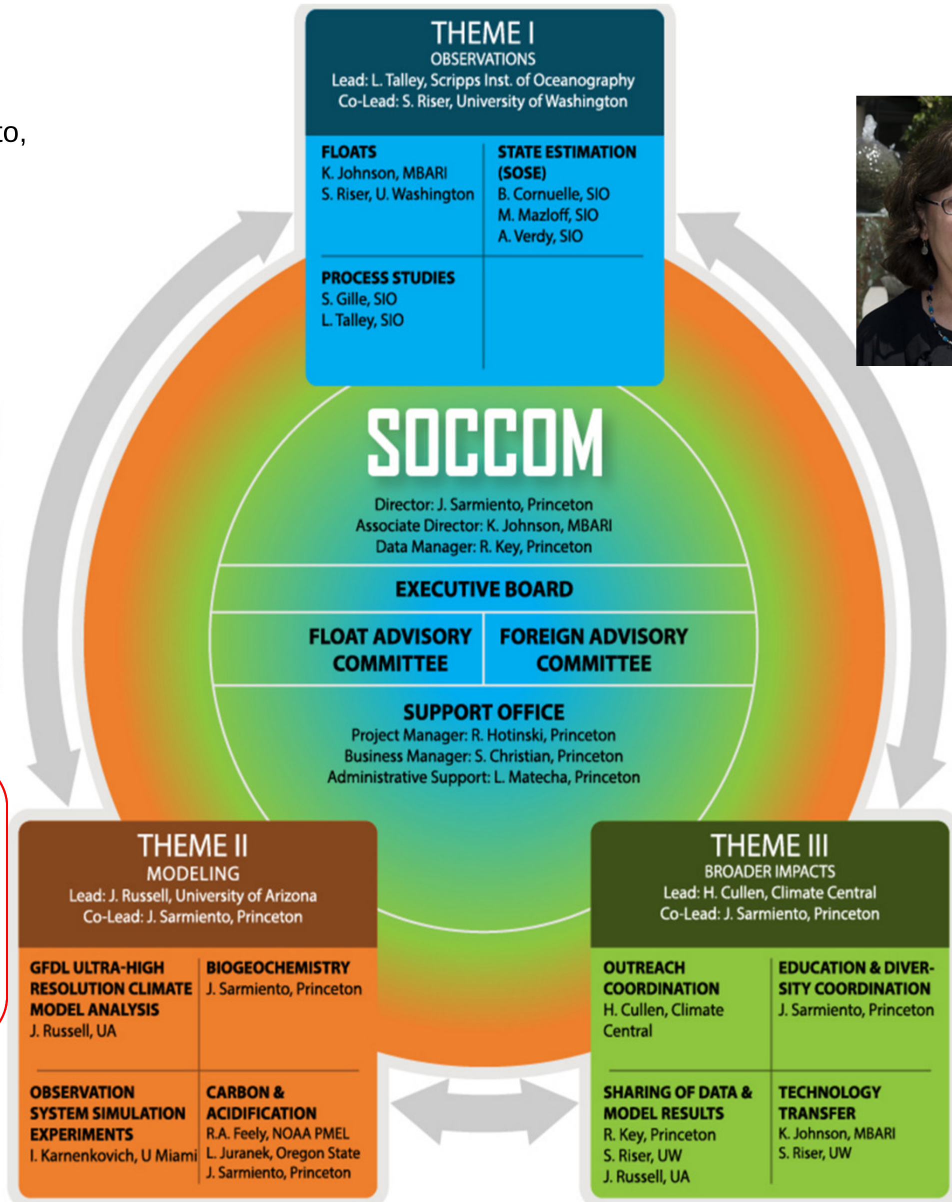
Directorate & Executive Board

Director
Jorge Sarmiento, Princeton

Associate Director
Ken Johnson, MBARI

Project Manager
Roberta Hotinski, Princeton

C&GC connections!



Theme I Observations

Lynne Talley
UCSD

Steve Riser
UW

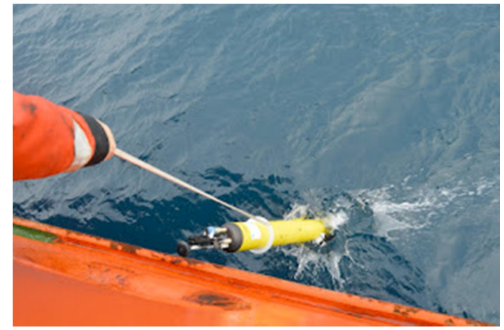
Theme II Modeling

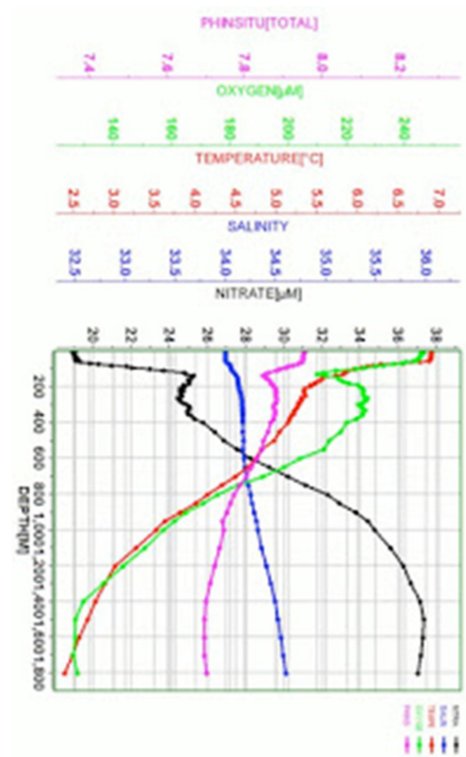
Joellen Russell
U. Arizona

Broader Impacts

Heidi Cullen,
Climate Central

Biogeochemical profiling floats





Floats: Argo mission, Argo data management and principles (non-proprietary and available)

Float types: as of now, UW Apex (most) and Seabird Navis (tech transfer from SOCCOM)

Ice enabled

Sensors: Argo CTD plus
oxygen, nitrate, pH, fluorescence, backscatter

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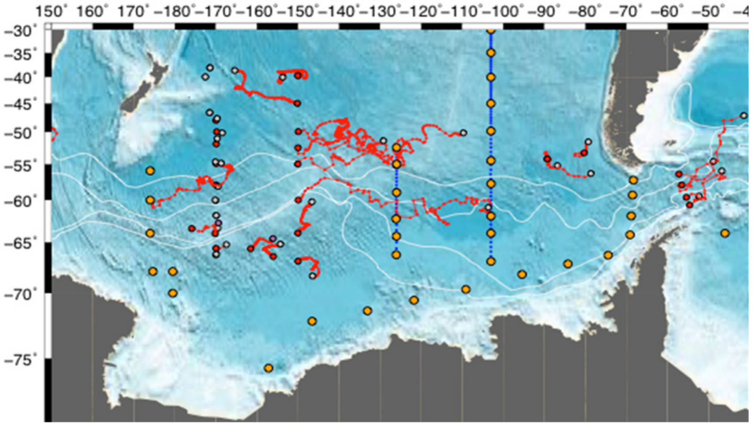
Deploy from research cruises for calibration



Pacific portion of SOCCOM (June, 2016) (red trajectories)
with draft 2016-17 deployment locations (orange)

International GO-SHIP cruises are vital to calibrations – about half of deployments

Calibration measurements for BGC sensors at deployment station:

- CTD
- FLBB
- Oxygen (rosette)
- Salt (rosette)
- Nitrate
- pH
- TA
- DIC

Underway pCO_2 is desirable

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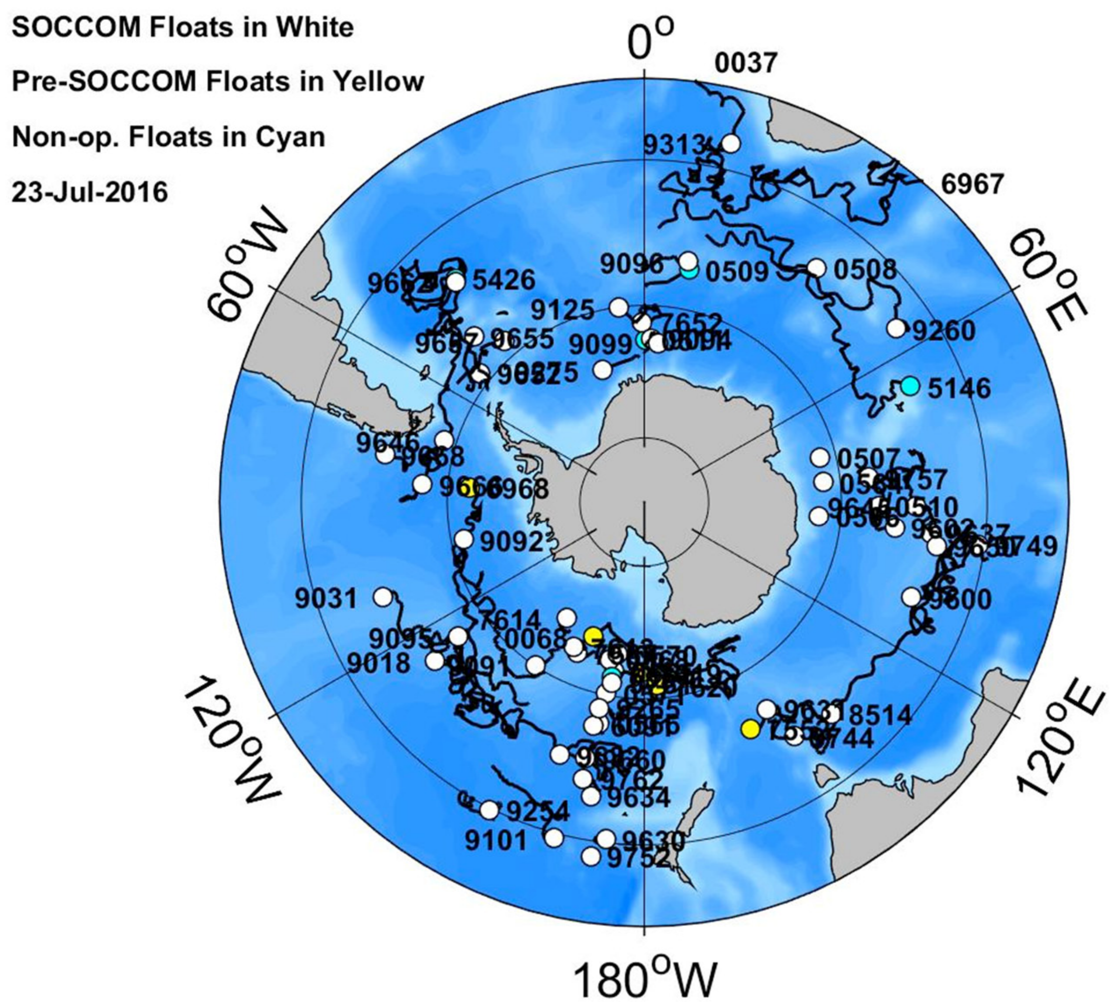
Observing System Status

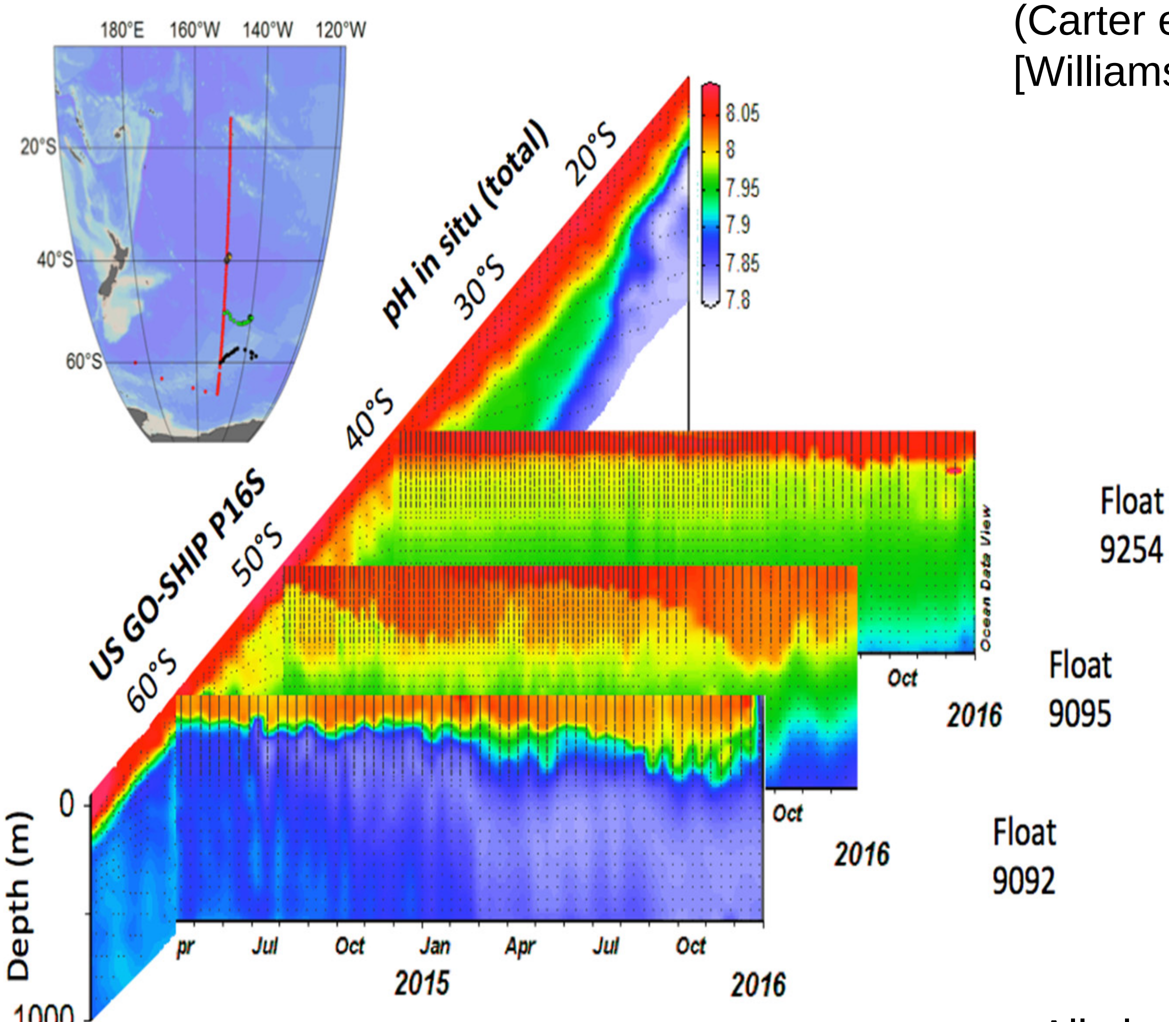


July 26, 2016:

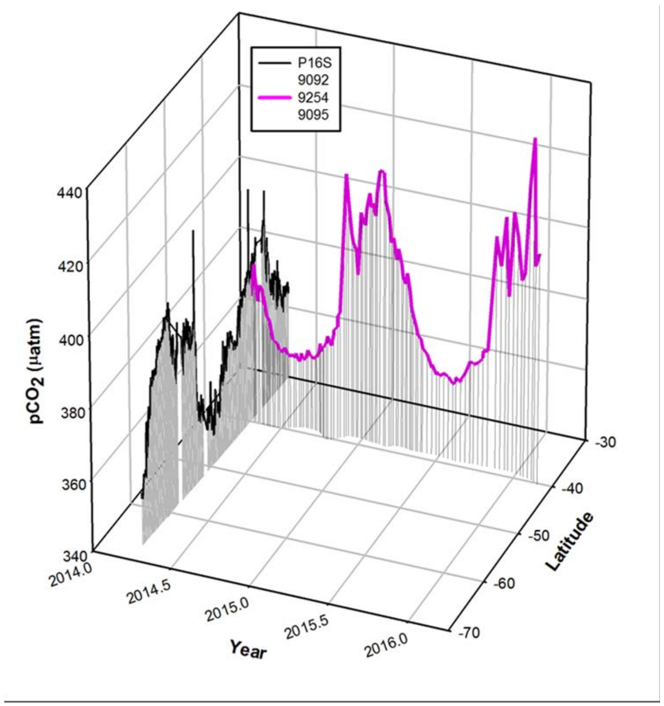
- 50 operational floats (80% with NASA supported optical sensors)
- 44 more for 2016-2017
- Float and shipboard data on website
- BGC data in Argo system

pH and pCO_2 from GO-SHIP and floats

pH measured from ship and on float.

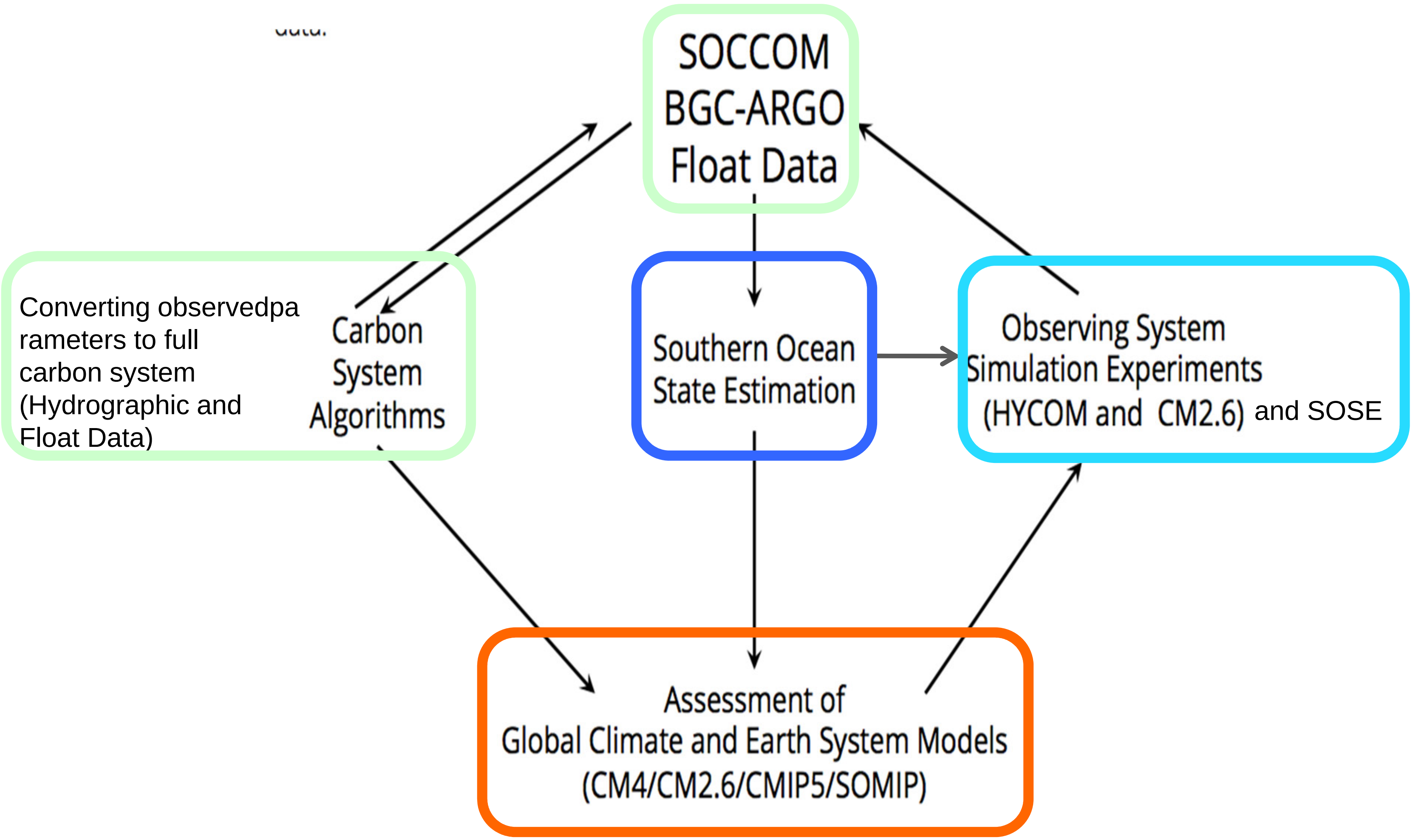


pCO_2 measured from ship and estimated from float (eMLR)
(Carter et al. GBC submitted)
[Williams presentation next]



All plots from Ken Johnson (SOCCOM).

The SOCCOM Modeling Plan



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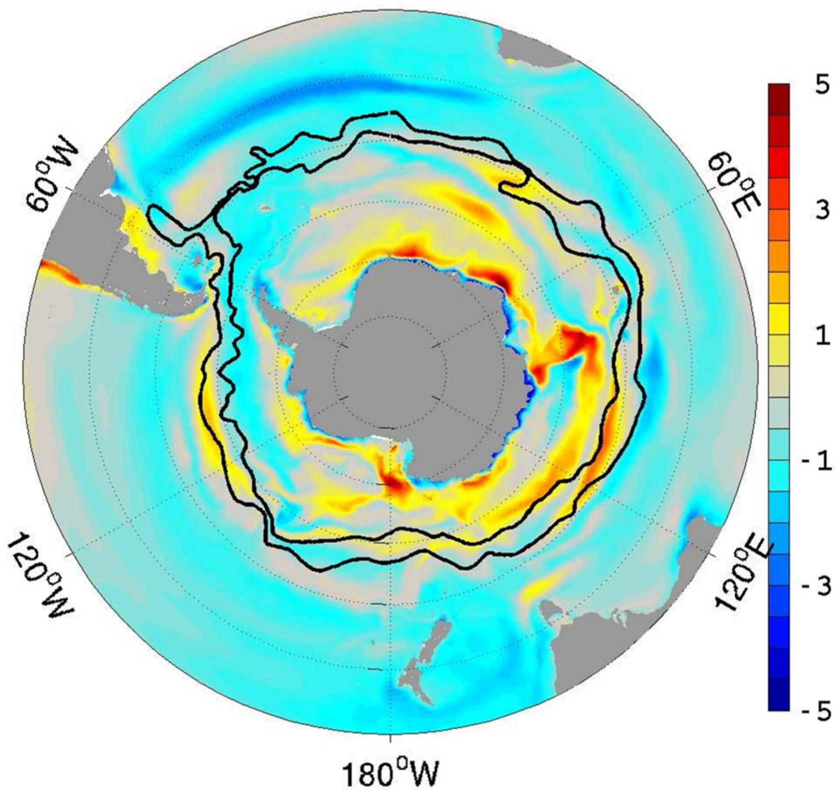
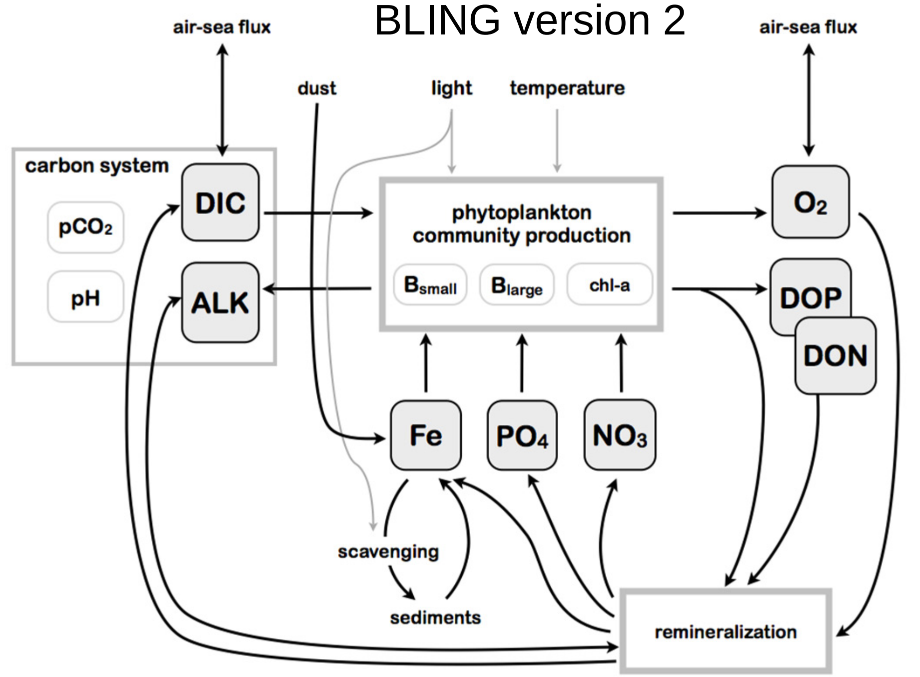
State Estimation: B-SOSE

- Implemented BLING version 2 biogeochemical model into the MITgcm

Mean air-sea CO_2 flux from the ⅓ model simulation [mol m^{-2} yr^{-1}]



BLING version 2



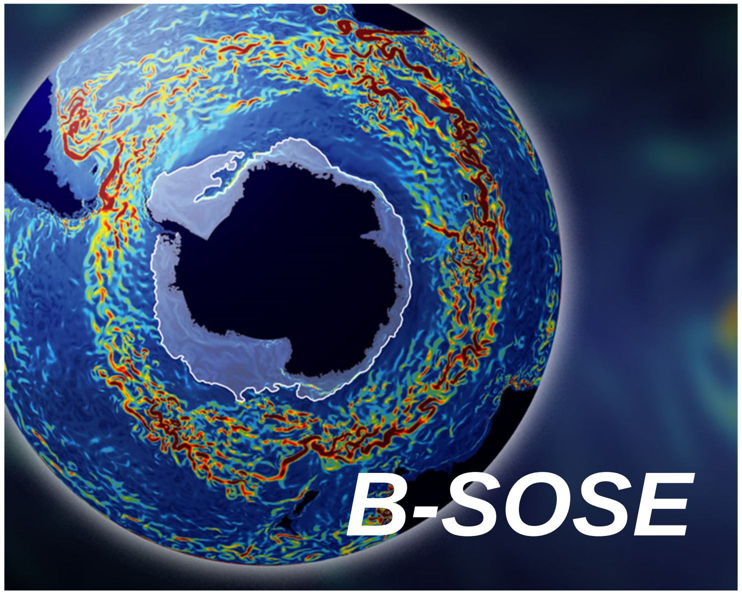
- Models being used for:
  - analyzing upper-ocean budget for Dissolved Inorganic Carbon
  - constructing climatology
  - performing OSSEs
- ⅓ degree model now being optimized via the adjoint method

SOCCOM

State Estimation: B-SOSE

Products available:

1. BLING code available: mitgcm.org/viewvc/MITgcm/MITgcm/pkg/bling
2. 2008-2012 B-SOSE will soon be available at http://sose.ucsd.edu.
3. Validation of current solution available (under "*results*" tab).
4. 2005-2014 forward BGC model solution at 1/3° is available on request.
5. 130 year forward BGC model solution at 1/3° is available on request.
6. 2005-2009 forward BGC model solution at 1/12° is available on request.



B-SOSE publication with sensitivity experiment presented:

1. State estimation for determining the properties and sensitivities of the Southern Ocean carbon cycle. Mazloff and Verdy. *Clivar Variations* 2015.

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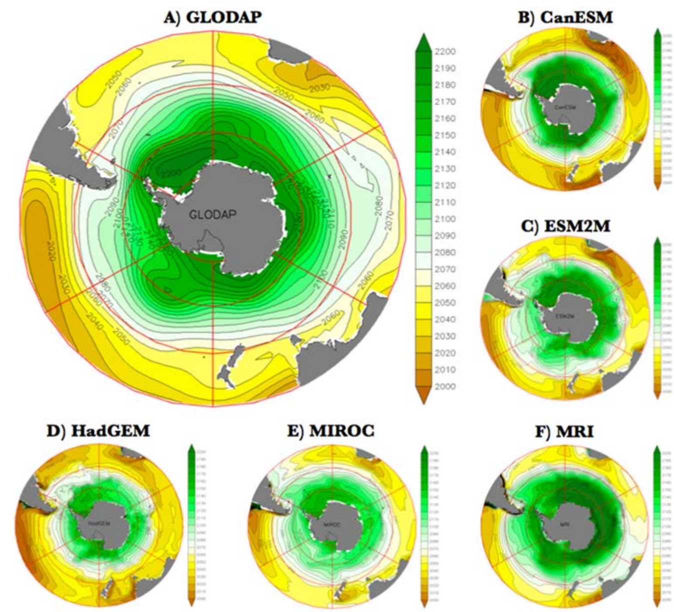
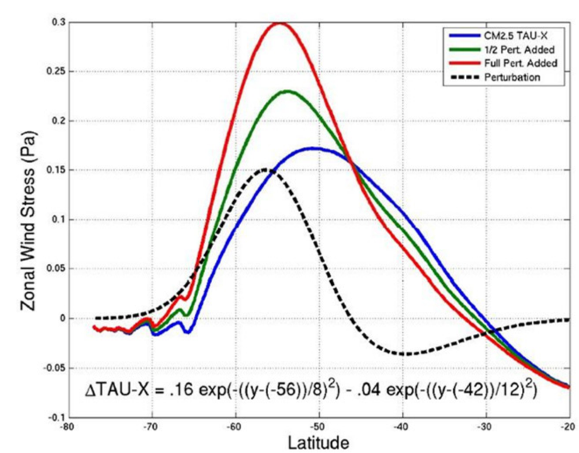
Modeling/Metrics

- Biogeochemical metrics developed and maps available online in Southern Ocean Model Atlas
- http://southernocean.arizona.edu/
- Analysis of CMIP5 and CMIP6 models underway
- Southern Ocean Model Intercomparison Project (SOMIP): initial plans complete and preliminary “proof of concept” simulations and analysis packages to be finished shortly

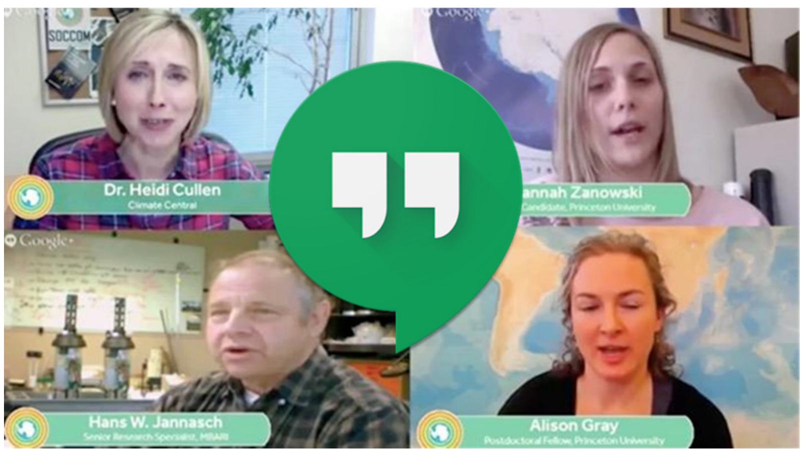
DIC
µmol/kg

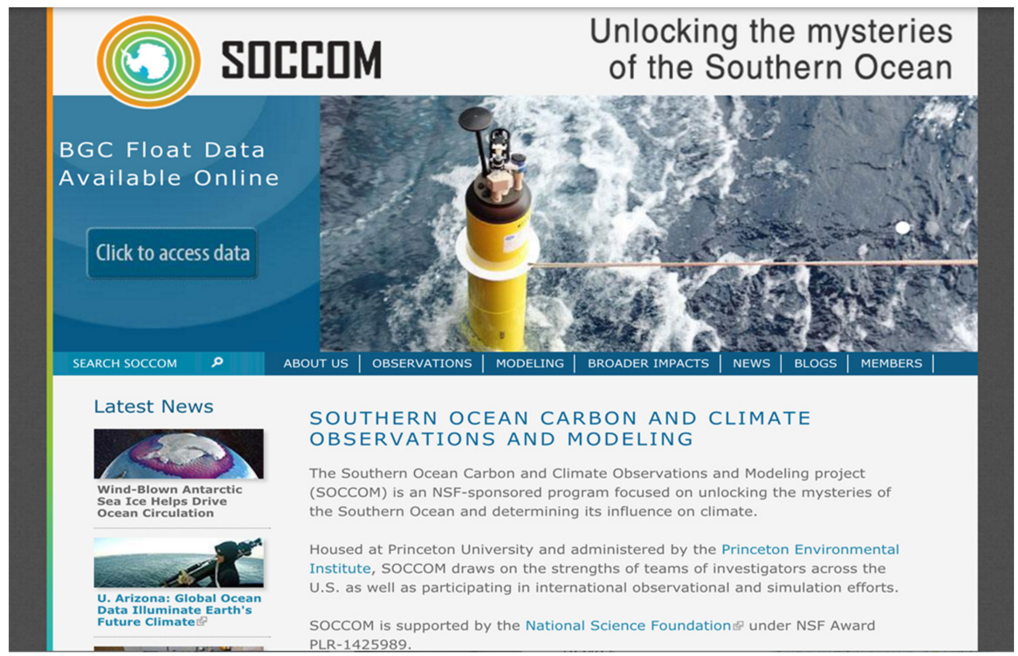


SOMIP: Proposal: Zonally uniform wind perturbation, focused on Drake Passage



Outreach, classroom interaction





http://soccom.princeton.edu

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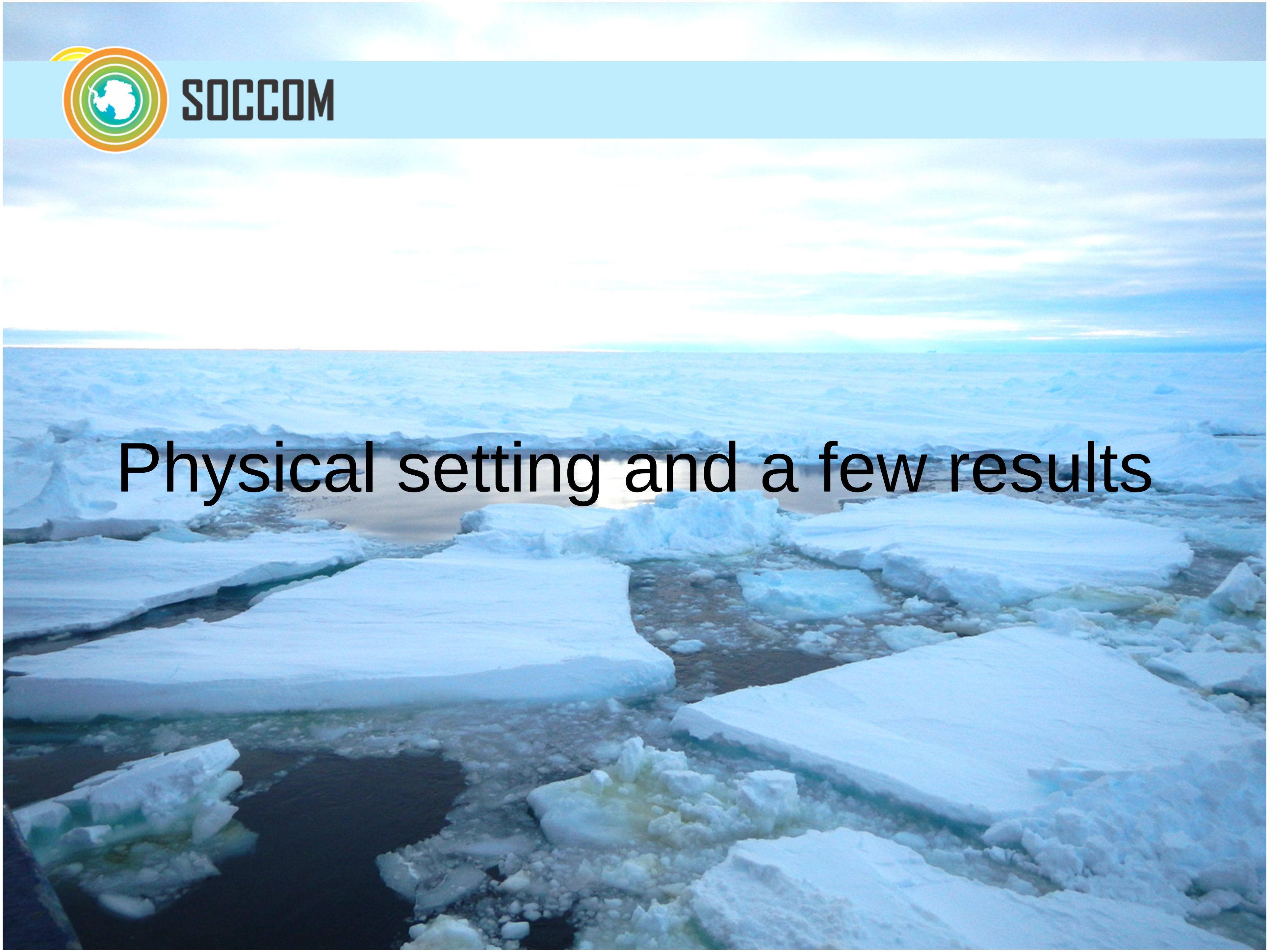
Physical setting and a few results



Physical setting results

What are the physical oceanographers in SOCCOM up to?

See SOCCOM website Publication list

Air-sea fluxes of heat and freshwater

Water mass formation: buoyancy fluxes and rates

Dynamical balances diagnosed from SOSE,
CM2.6 and observations: eddy fluxes, topographic interactions, topographic steering, form stress

Floats: under ice circulation and float tracking

Zonal asymmetries (regionality)

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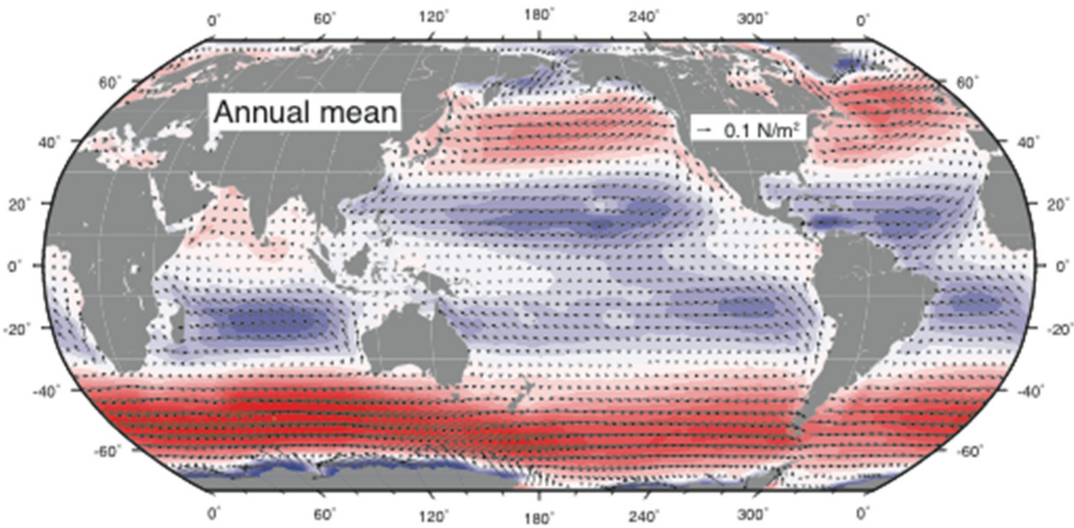
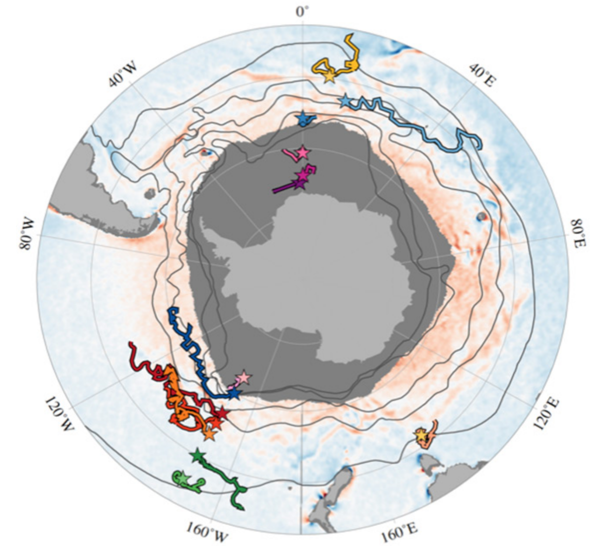
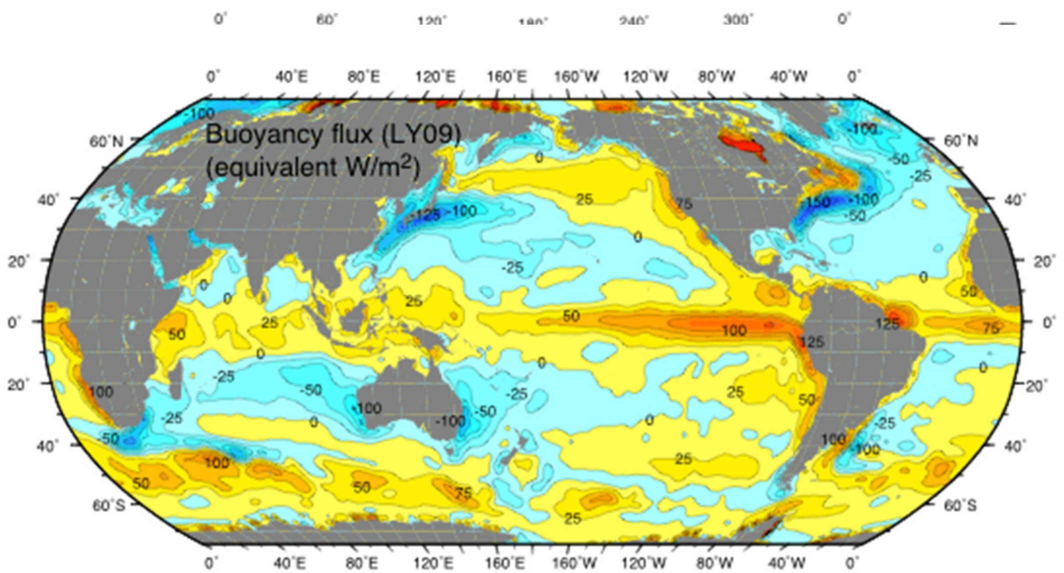
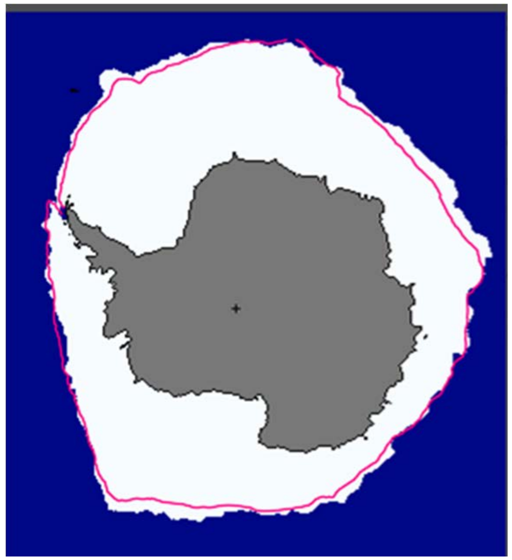
Forcings

Wind and buoyancy (heat, freshwater/sea ice)



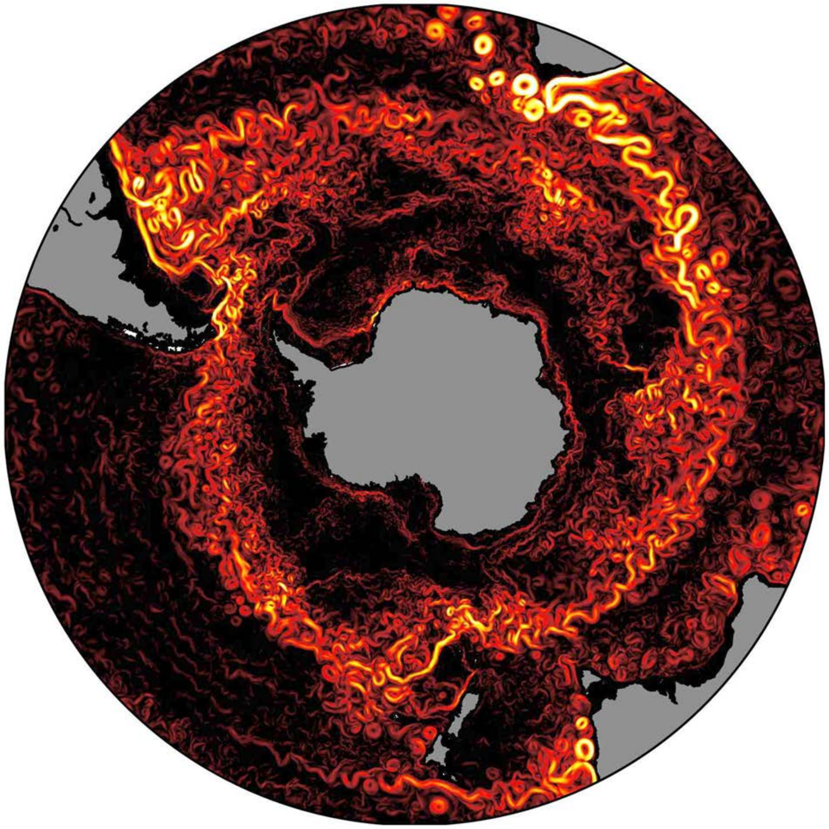






Zonal asymmetry in circulation

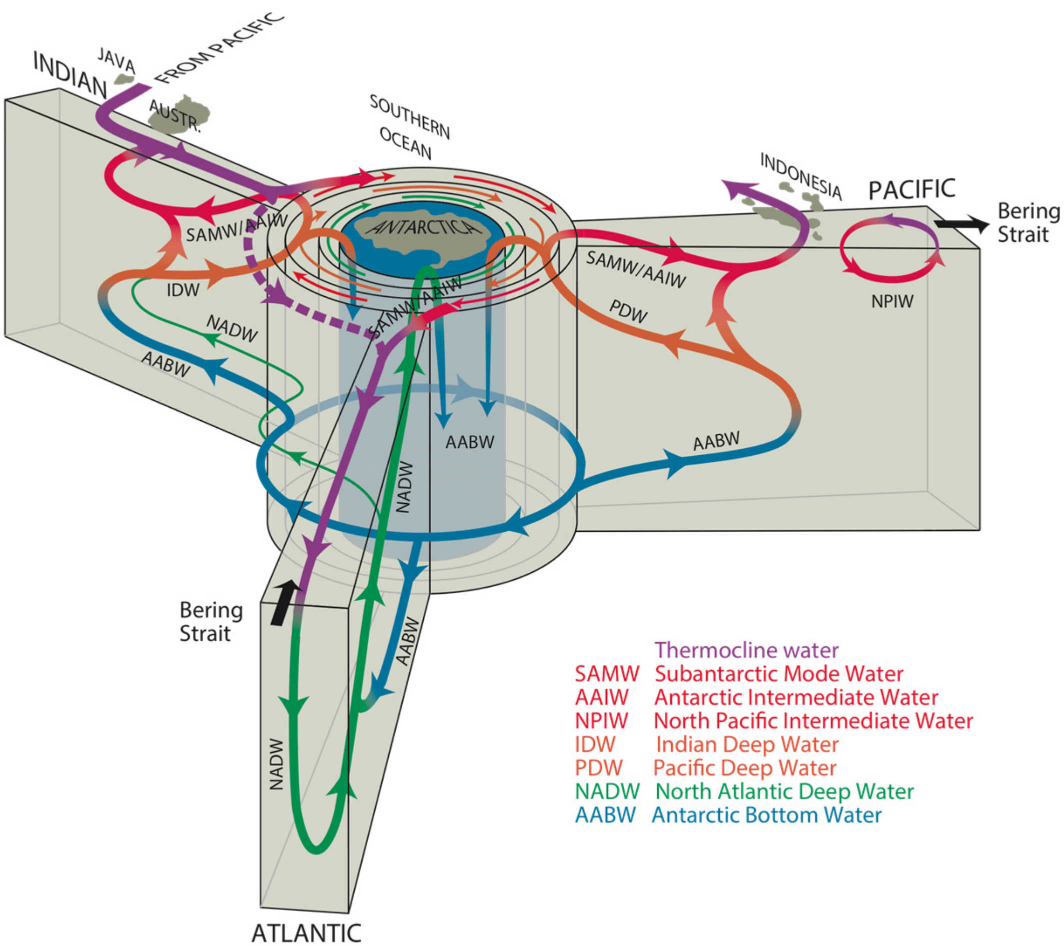
Winds and wind curl create circulation



- Vigorous eddy field
- CM2.6 GFDL circulation 2-d modelled surface circulation (A. Morrison)
- Model used in Morrison et al. (J. Clim. 2016)

Zonal asymmetry in overturning circulation

Wind and buoyancy forcing create overturning circulation



Deep water inflow

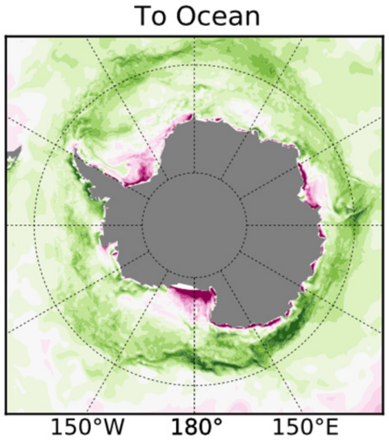
Deep waters rise to sea surface in and south of ACC

Formation of AABW and thermocline waters

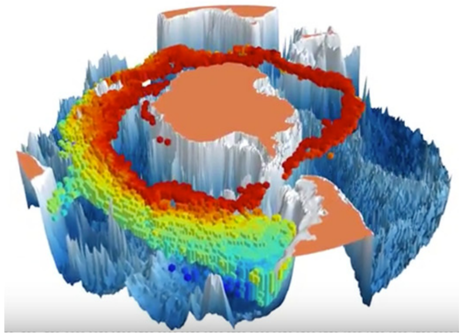
Talley (Oceanography, 2013)

After Lumpkin and Speer (2007), following Schmitz and Gordon

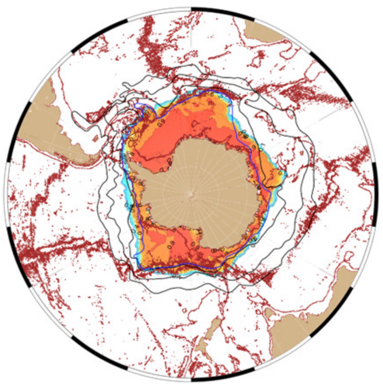
Highlighted physical setting results (2016)



#1. Role of sea ice in water mass transformation in both the upper and lower cells of the overturning circulation
(Abernathey et al., Nat. Geosc. 2016)
(SOSE analysis)



#2. Southeastward and upward spiral of deep waters to sea surface
(Tamsitt et al. joint paper in progress; separate longer papers for JGR issue)
(Observations, SOSE, CM2.6, CESM)



#3. ACC fronts, bathymetry, sea ice edge and its changes
(Talley in progress)
(Observations)

Sea ice and overturning circulation

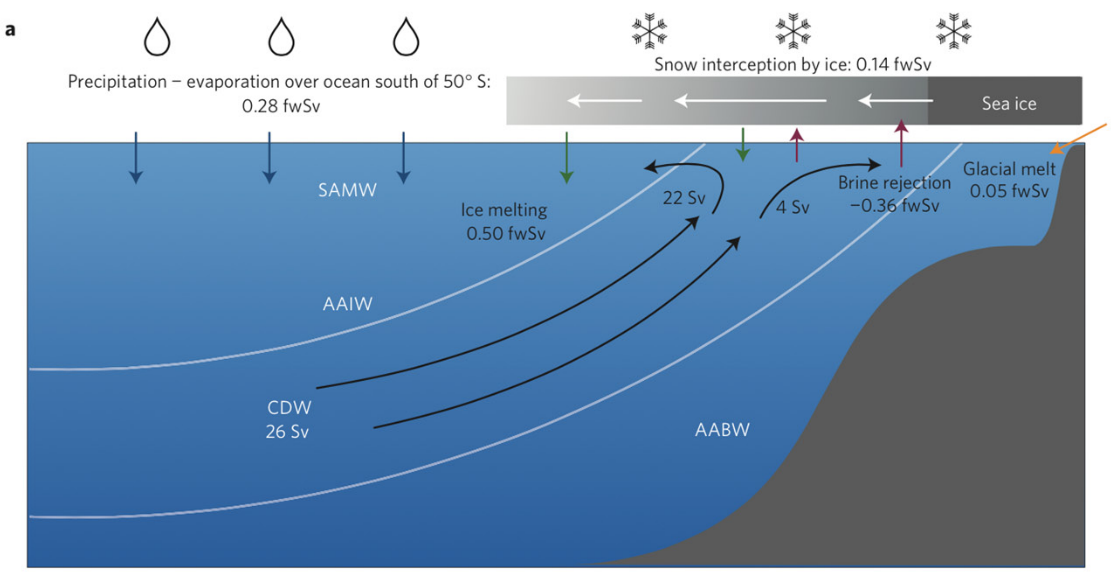
nature geoscience

LETTERS

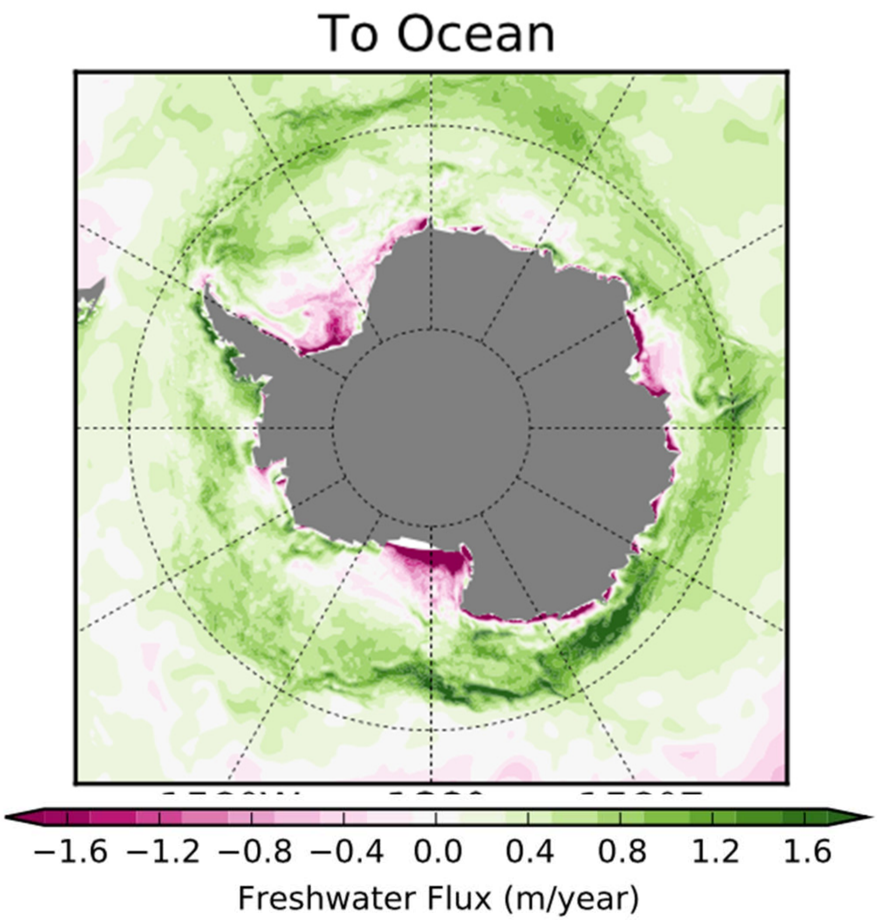
PUBLISHED ONLINE: 27 JUNE 2016 | DOI: 10.1038/NGEO2749

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]



Sea ice and overturning circulation



- Brine rejection produces Antarctic Bottom Water from CDW
- Sea ice melt and P+R-E produces thermocline water from CDW
- Processes exhibit regionality (“zonal asymmetry”)

(SOSE result)

Abernathey et al. (2016)

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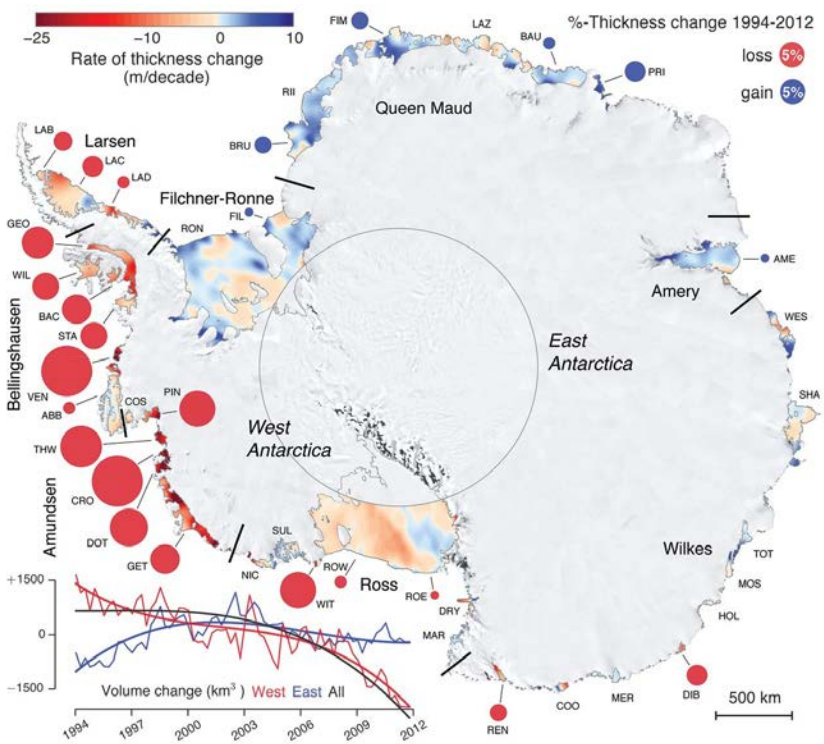
Highlights #2

The upward spiral of global deep waters to the surface in the Southern Ocean

Tamsitt, Drake, Morrison, Talley, Weijer, Griffies, Mazloff, Sarmiento, Wang, Gray, Dufour
In progress, 2016

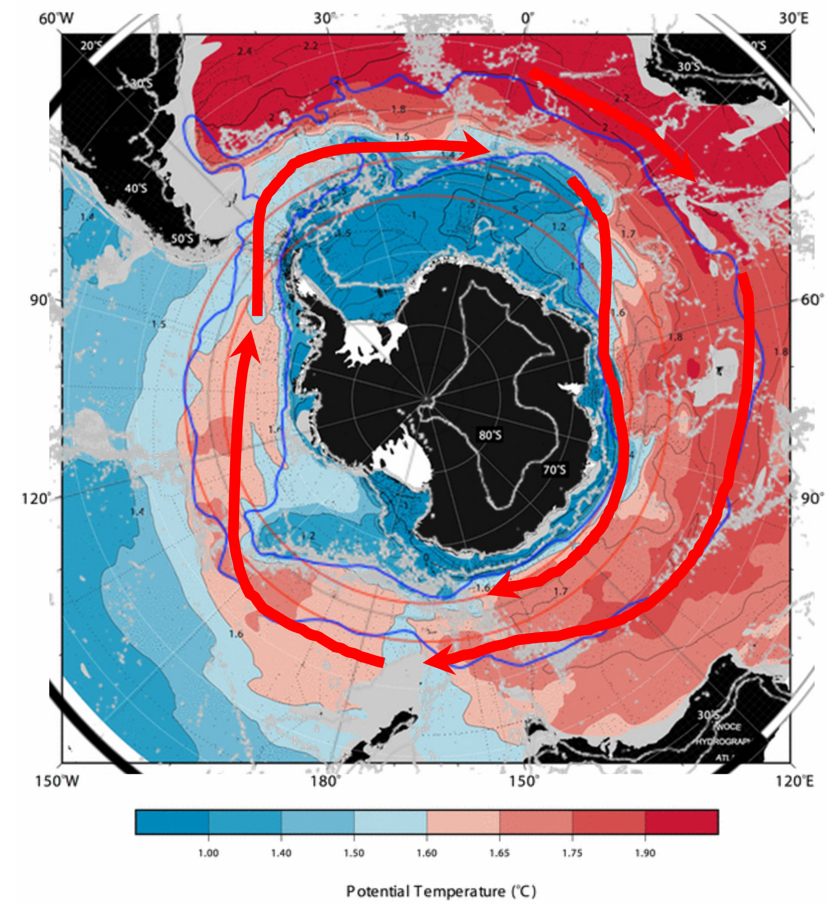
Acceleration of ice shelf melting

100m



Paolo et al. (2015)

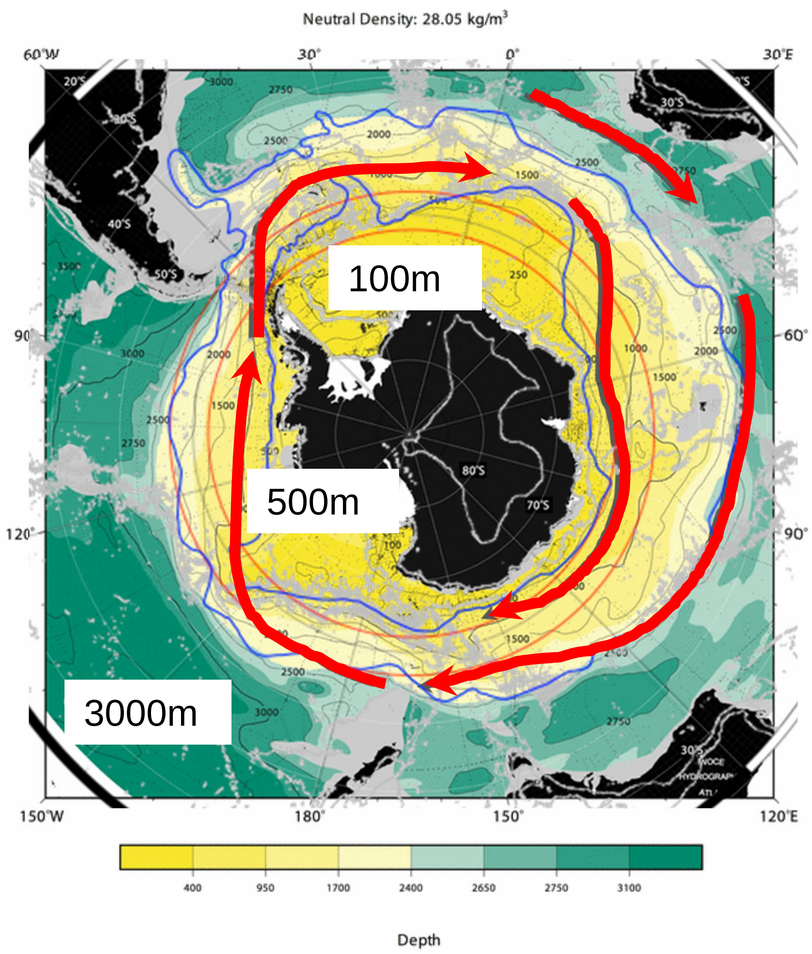
NADW (LCDW) pathway (28.05 γ^N)



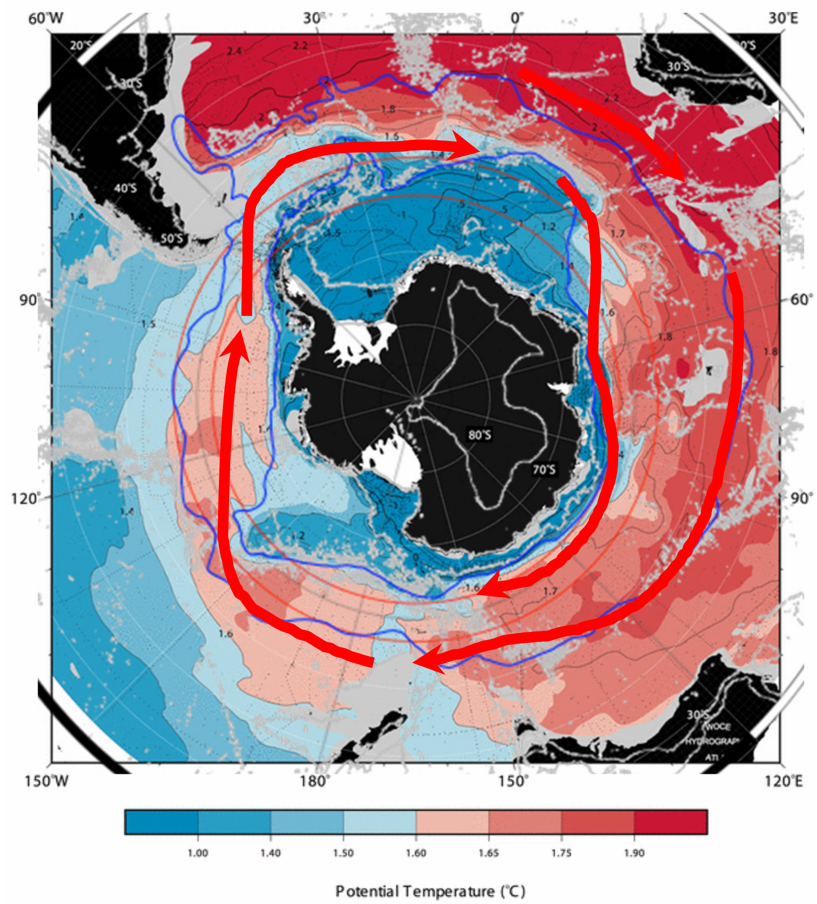
Orsi and Whitworth (2005)

NADW (LCDW) pathway (28.05 γ^N)

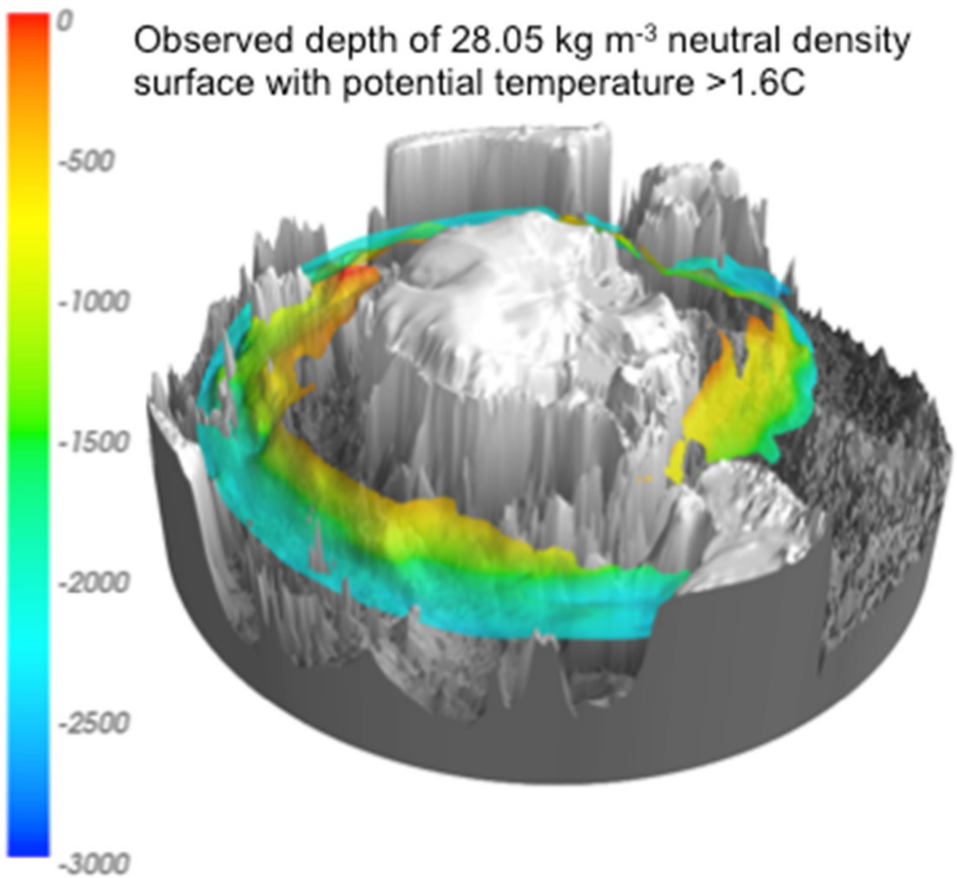
Depth



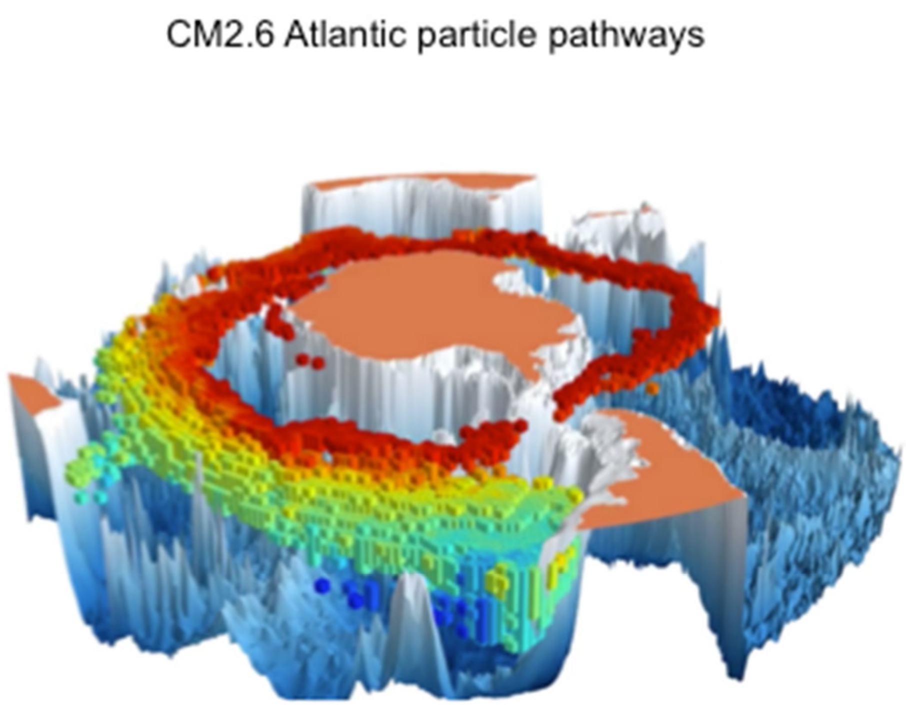
Potential temperature



Highlights #2: upward spiral



Orsi and Whitworth (2005) WHP Southern Ocean atlas , gridded temperature and depth, replotted to show spir al



Particle pathways out of the deep Atlantic to the surface

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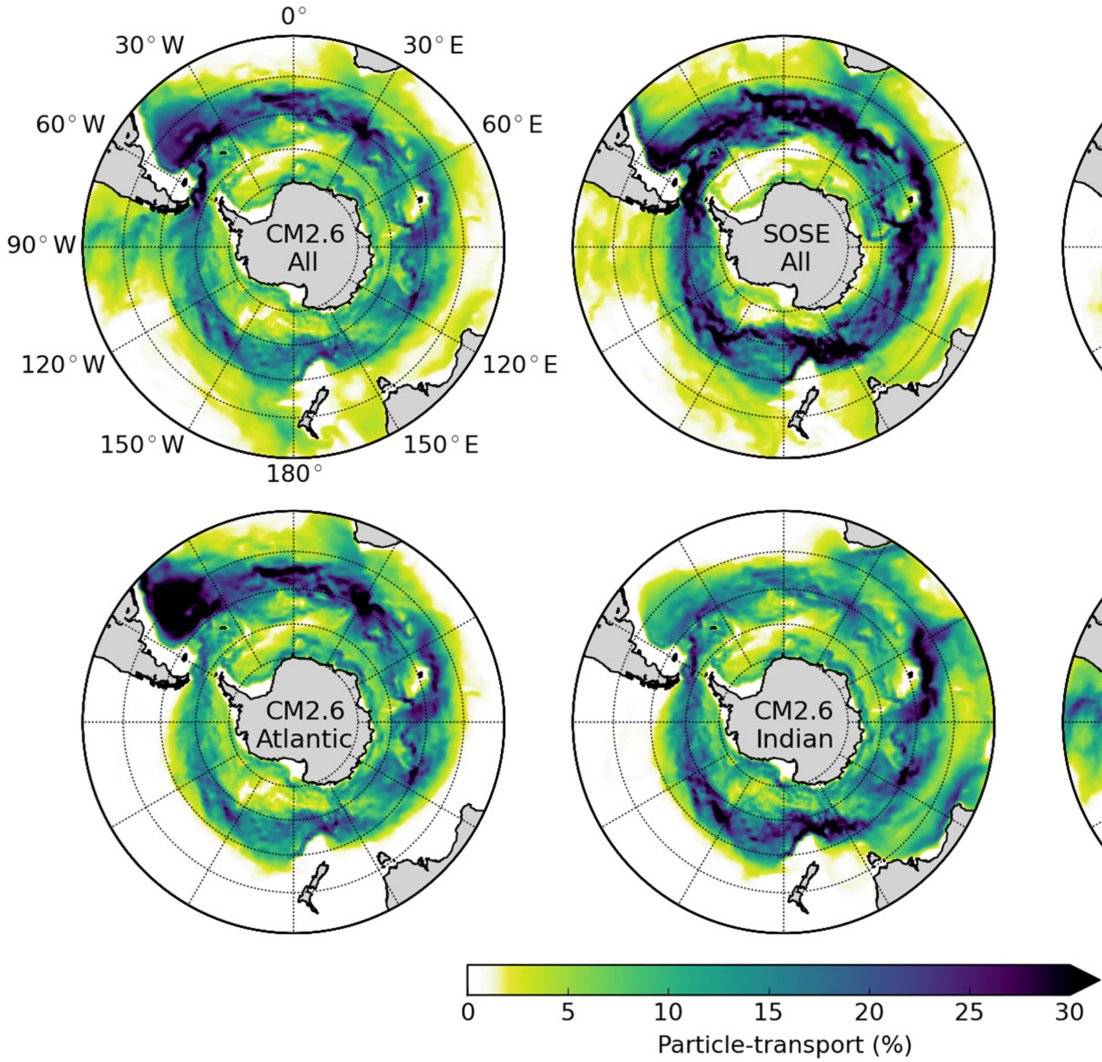
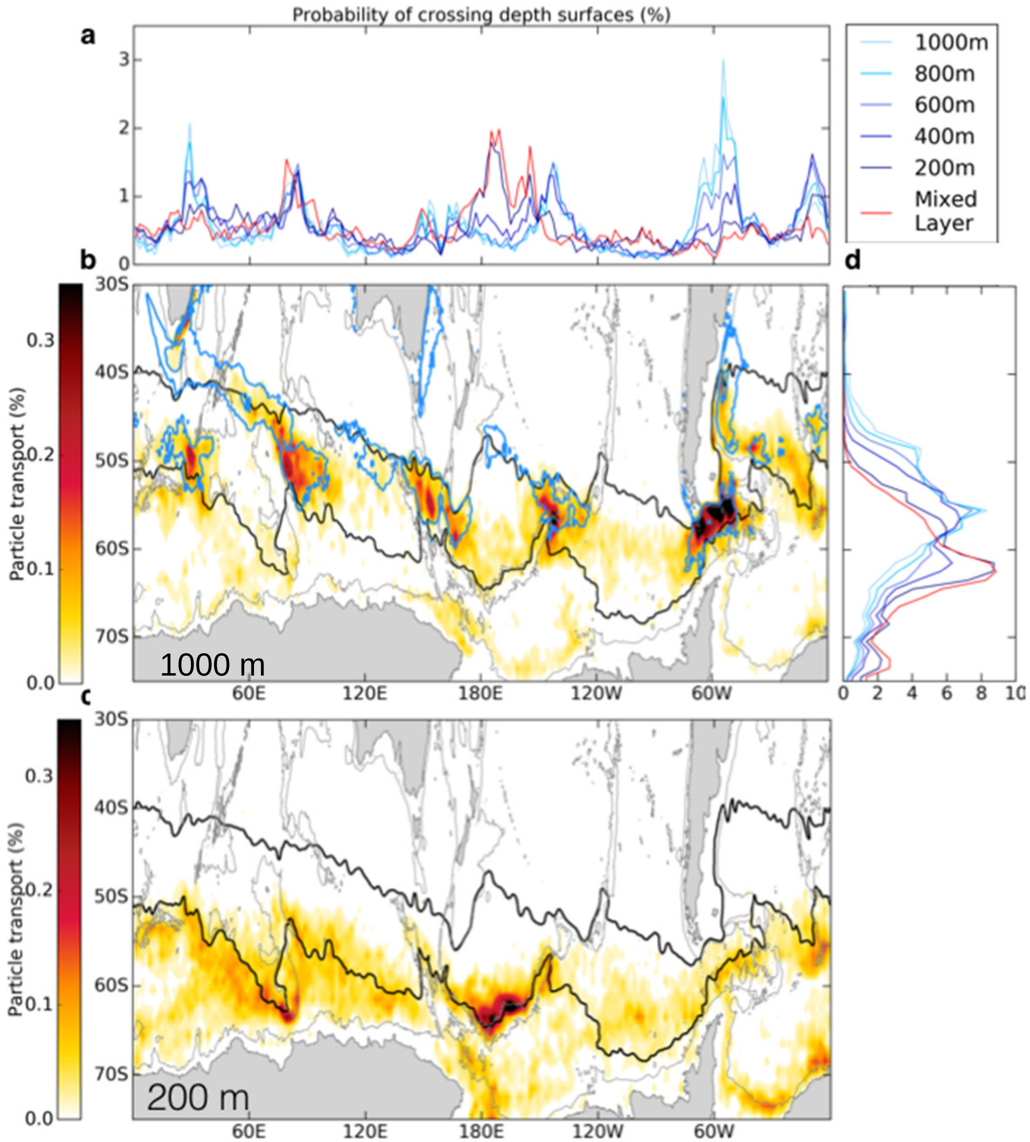
Highlights #2: upward spiral



2.5 million particles released at 30S, 1000-3500 m, all grid boxes. Same experiment in each model.

Highlights #2: upward spiral



Particles crossing 1000 m

“Hotspots” where eddy activity is high. Interaction of AntarcticCircu mpolar Current with topographic features

Particles crossing 200 m

Along and south of ACC Southern Boundary

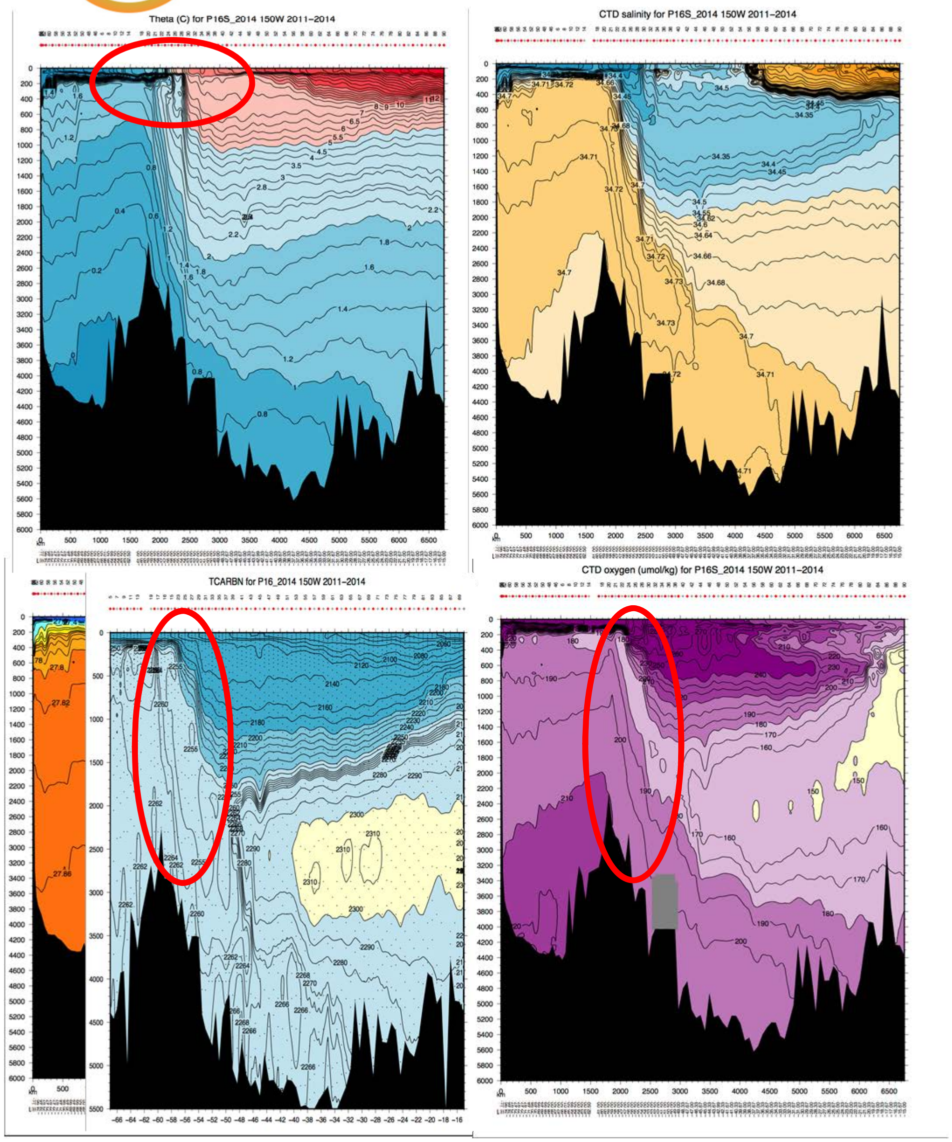
“Hotspot” over ridge where circulation is strongly steered and isopycnals outcrop.

Highlights #2: upward spiral

Upwelling hotspot (200 m)

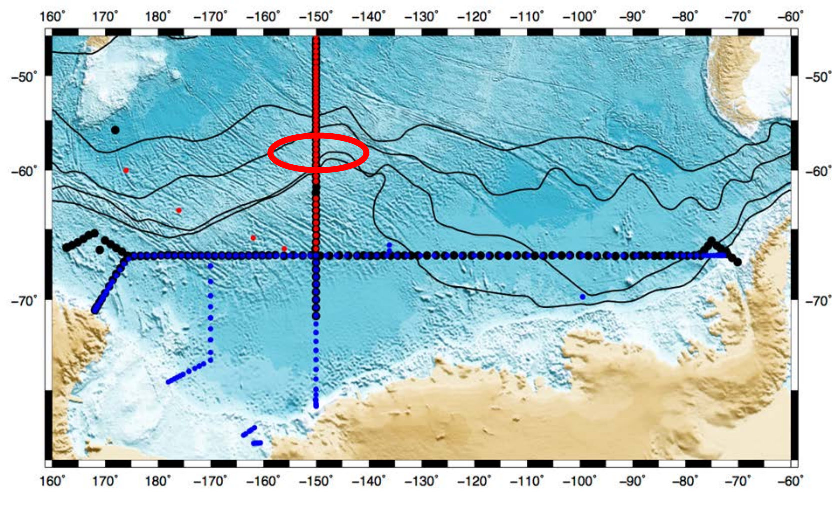
Over Pacific – Antarctic Ridge in SOSE

Also clearly location of upwelling in hydrographic data.



DIC

Oxygen



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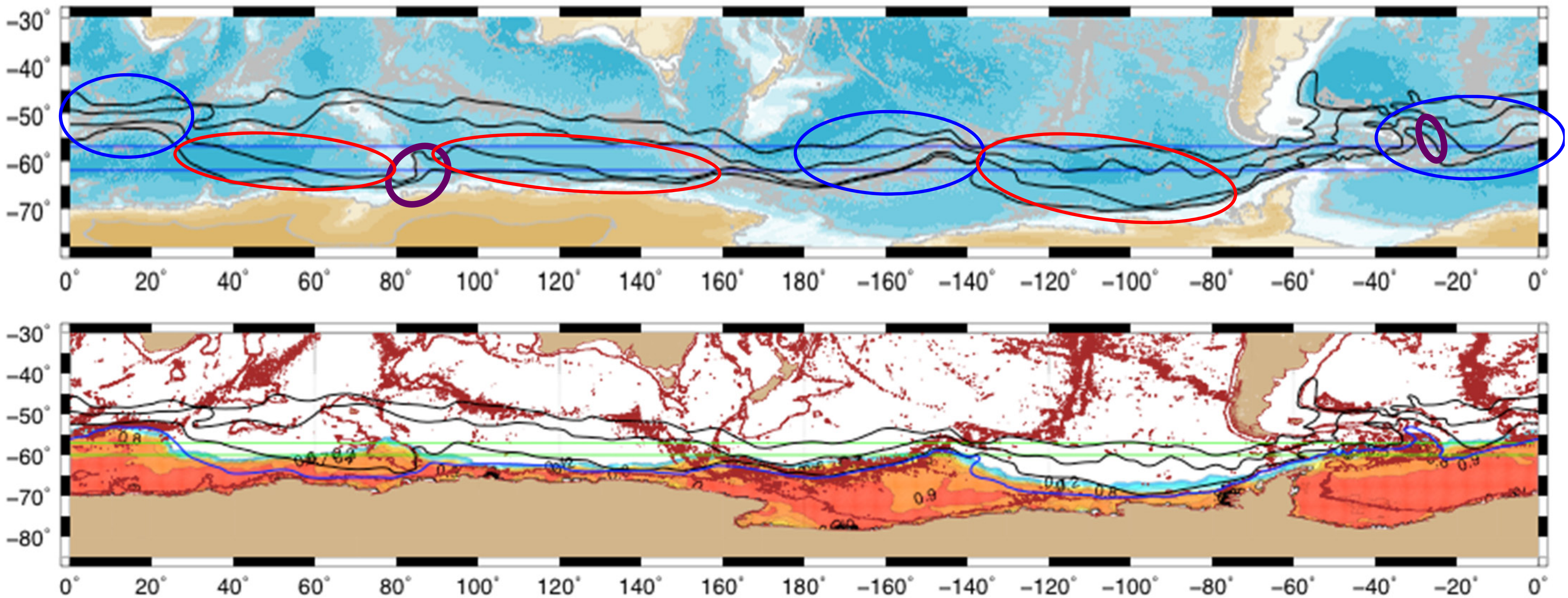
Highlights #3: ACC, sea ice, and topography

Ocean circulation and topographic effects on Antarctic sea ice edge
In progress, 2016



Sea ice edge (winter) strongly associated with southern ACC fronts.

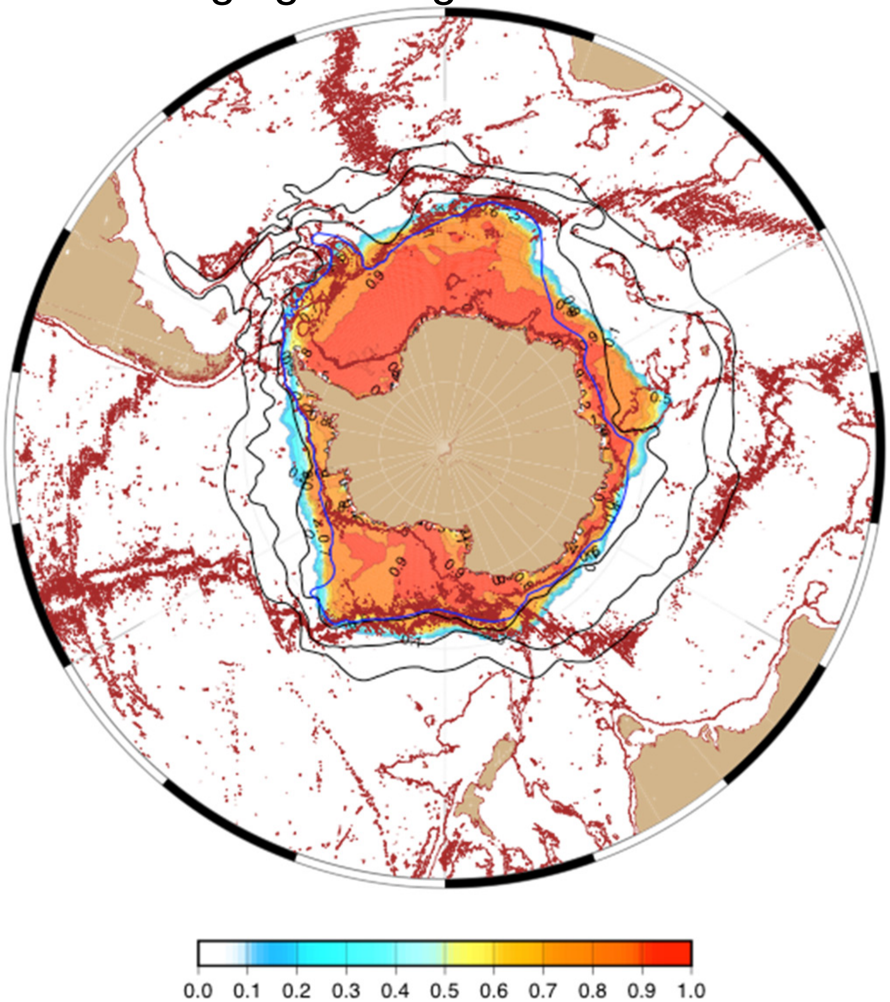
ACC northward over topography or in western boundary currents
ACC southern boundary free flow swings southward back to Antarctica.
(modified Sverdrup balance under upwelling winds)

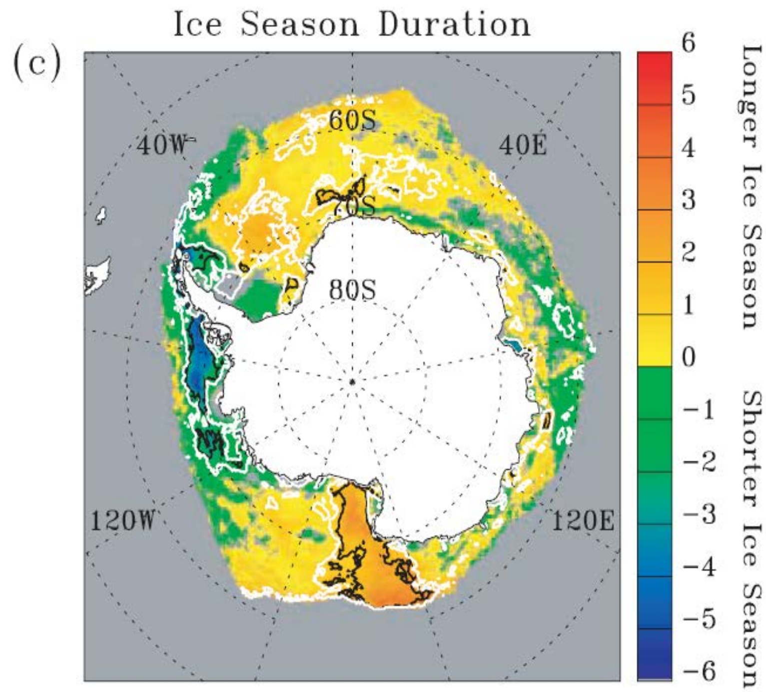
Delivers warm upwelled ACC waters to coastal Antarctica

Highlights #3: Topographic steering

Ocean circulation and topographic effects on Antarctic sea ice edge
In progress, 2016

» ACC fronts steered by topography, set winter ice edge, affect response to changing forcing





Change in sea ice duration: 1979 – 2006

Stammerjohn et al. (2008)

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As we work on mechanisms, we challenge the models: where do they differ from each other and from observations?

This is central to SOCCOM,
although the desire to have robust results has caused some distress over the last couple months as we find important differences between observations and different models.

We also find where all agree, validating those results.

Collaboration with differing expertise is key.