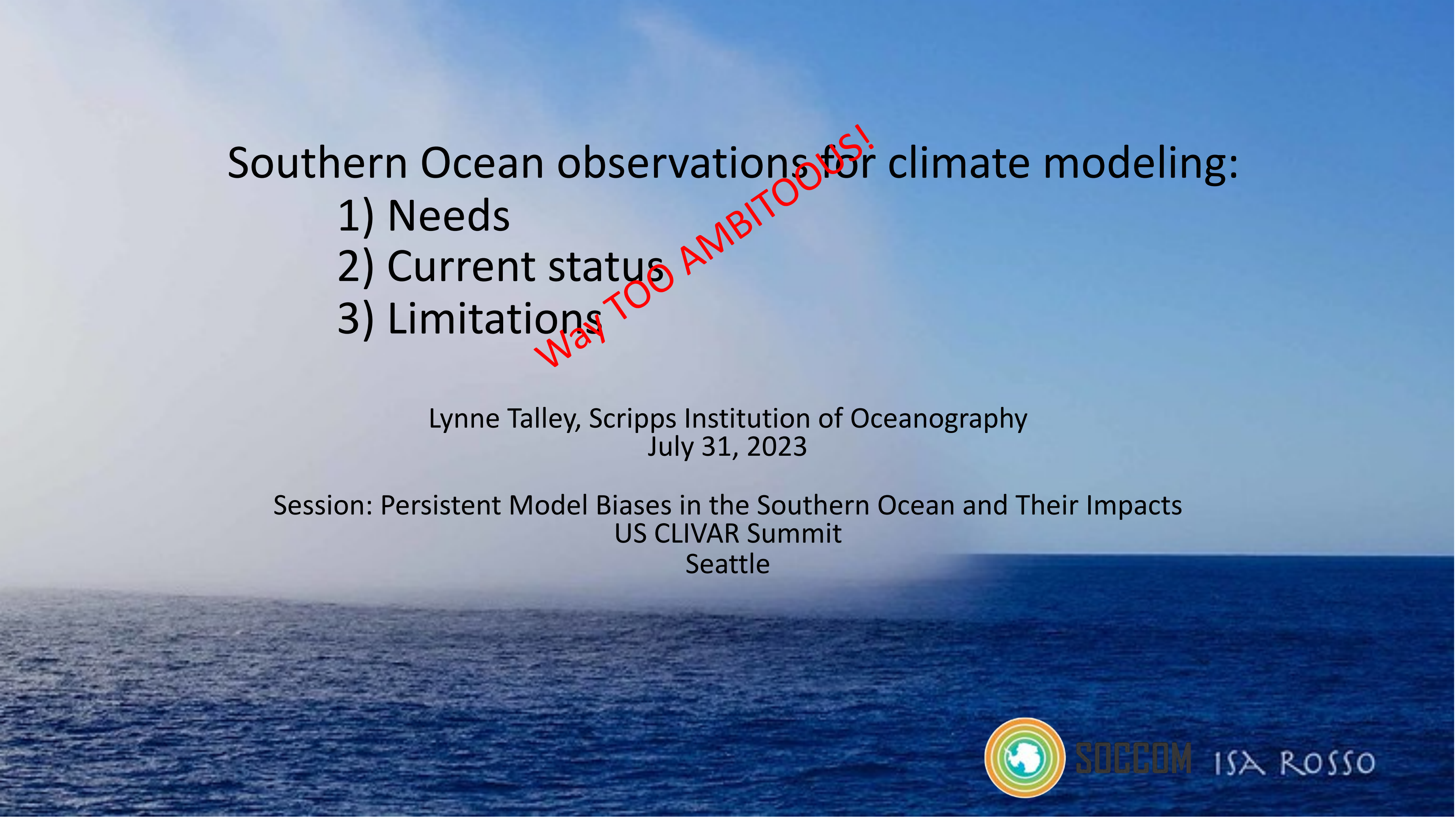


Southern Ocean observations for climate modeling:

1) Needs
2) Current status
3) Limitations

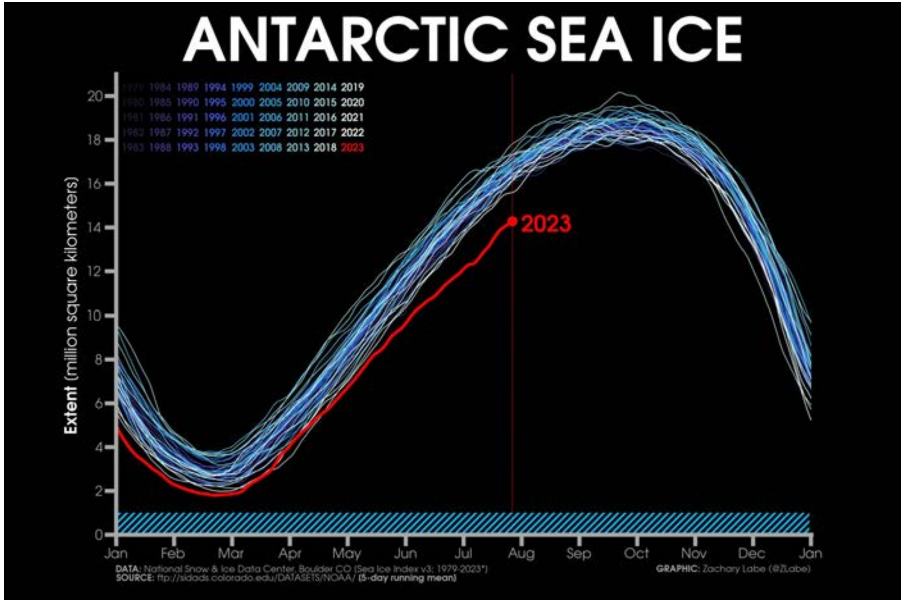
Way TOO AMBITOOUS!

Lynne Talley, Scripps Institution of Oceanography
July 31, 2023

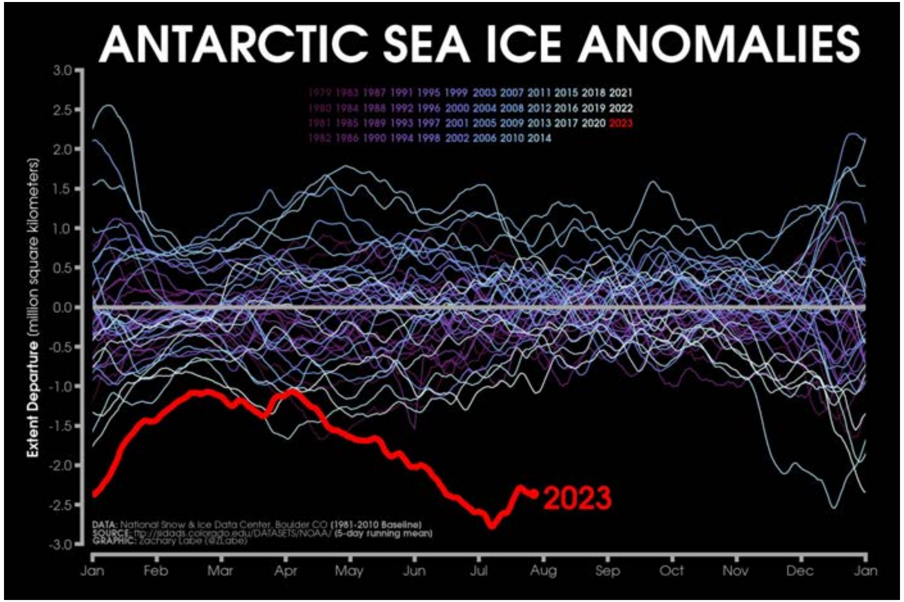
Session: Persistent Model Biases in the Southern Ocean and Their Impacts
US CLIVAR Summit
Seattle

SOCCOM ISA ROSSO

Alarming sea ice


ANTARCTIC SEA ICE

DATA: National Snow & Ice Data Center, Boulder CO (Sea Ice Index v3; 1979-2023*)
SOURCE: ftp://sidads.colorado.edu/DATASETS/NOAA/ **(5-day running mean)**
GRAPHIC: Zachary Labe (@ZLabe)


ANTARCTIC SEA ICE ANOMALIES

DATA: National Snow & Ice Data Center, Boulder CO **(1981-2010 Baseline)**
SOURCE: ftp://sidads.colorado.edu/DATASETS/NOAA/ **(5-day running mean)**
GRAPHIC: Zachary Labe (@ZLabe)

(satellite-era; NSIDC, DMSP SSM/I-SSM)

https://zacklabe.com/antarctic-sea-ice-extentconcentration/

CLIVAR, CLiC and SCAR co-sponsorship of SORP

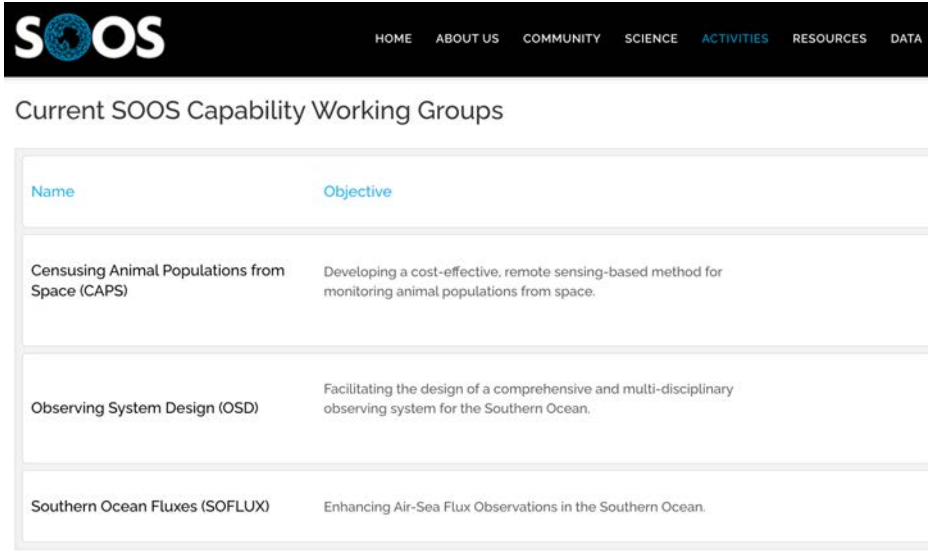
Southern Ocean Regional Panel (SORP): https://www.clivar.org/clivar-panels/southern
Co-chairs T.Martin and A. Purich. Current US member is Ted Scambos.
Met July 26, 2023 Potsdam/Berlin.
Current focus is on freshwater impacts.
'NORP/SORP joint freshwater (polar processes) summer school and a 3-day workshop are being planned for 2024 at ICTP, Trieste, Italy'

SCAR physical science group addresses climate issues. https://www.scar.org/science/psg/home/
INSTANT, AntClimNOW, AsPECT, SORP, TATE and others.

comment….basically not possible in a short talk to thoroughly address aspects of observations that are important for Southern Ocean role in climate. This has to be a full white paper with multiple authors…. i.e. OceanObs19 (next slides)

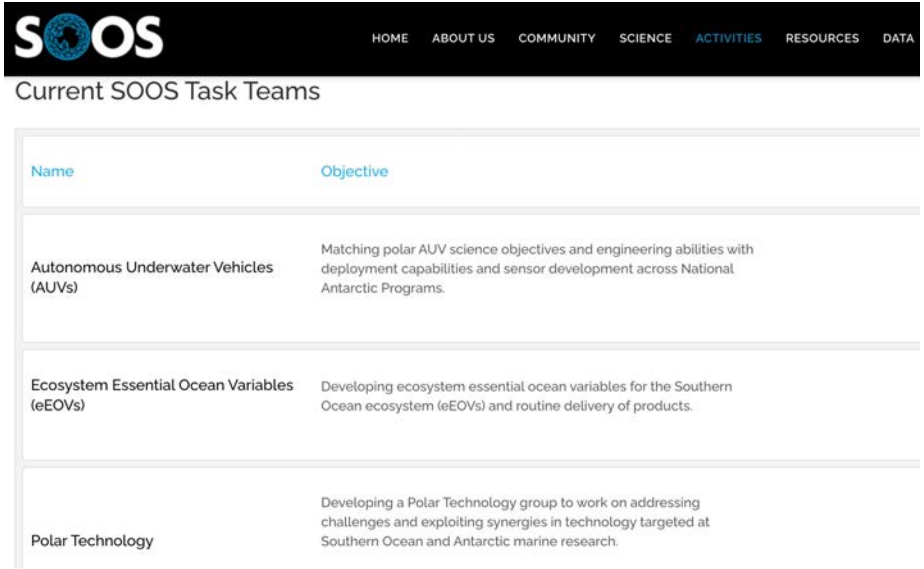
SOOS: Southern Ocean Observing System

https://soos.aq/



Current SOOS Capability Working Groups

Name	Objective
Censusing Animal Populations from Space (CAPS)	Developing a cost-effective, remote sensing-based method for monitoring animal populations from space.
Observing System Design (OSD)	Facilitating the design of a comprehensive and multi-disciplinary observing system for the Southern Ocean.
Southern Ocean Fluxes (SOFLUX)	Enhancing Air-Sea Flux Observations in the Southern Ocean.



Current SOOS Task Teams

Name	Objective
Autonomous Underwater Vehicles (AUVs)	Matching polar AUV science objectives and engineering abilities with deployment capabilities and sensor development across National Antarctic Programs.
Ecosystem Essential Ocean Variables (eEOVs)	Developing ecosystem essential ocean variables for the Southern Ocean ecosystem (eEOVs) and routine delivery of products.
Polar Technology	Developing a Polar Technology group to work on addressing challenges and exploiting synergies in technology targeted at Southern Ocean and Antarctic marine research.

14-18th August 2023

Hobart, Australia

OceanObs'19

OceanObs19 (Frontiers in Marine Science)

Delivering Sustained, Coordinated, and Integrated Observations of the Southern Ocean for Global Impact

Louise Newman, Petra Heil, Rowan Trebilco, Katsuro Katsumata, Andrew Constable, Esmee van Wijk, Karen Assmann, Joana Beja, Phillippa Bricher, Richard Coleman, Daniel Costa, Steve Diggs, Riccardo Farneti, Sarah Fawcett, Sarah T. Gille, Katharine R. Hendry, Sian Henley, Eileen Hofmann, Ted Maksym, Matthew Mazloff, Andrew Meijers, Michael M. Meredith, Sebastien Moreau, Burcu Ozsoy, Robin Robertson, Irene Schloss, Oscar Schofield, Jiuxin Shi, Elisabeth Sikes, Inga J. Smith, Sebastiaan Swart, Anna Wahlin, Guy Williams, Michael J. M. Williams, Laura Herraiz-Borreguero, Stefan Kern, Jan Lieser, Robert A. Massom, Jessica Melbourne-Thomas, Patricia Miloslavich and Gunnar Spreen

doi: 10.3389/fmars.2019.00433

Constraining Southern Ocean Air-Sea-Ice Fluxes Through Enhanced Observations

Sebastiaan Swart, Sarah T. Gille, Bruno Delille, Simon Josey, Matthew Mazloff, Louise Newman, Andrew F. Thompson, Jim Thomson, Brian Ward, Marcel D. du Plessis, Elizabeth C. Kent, James Girton, Luke Gregor, Petra Heil, Patrick Hyder, Luciano Ponzi Pezzi, Ronald Buss de Souza, Veronica Tamsitt, Robert A. Weller and Christopher J. Zappa

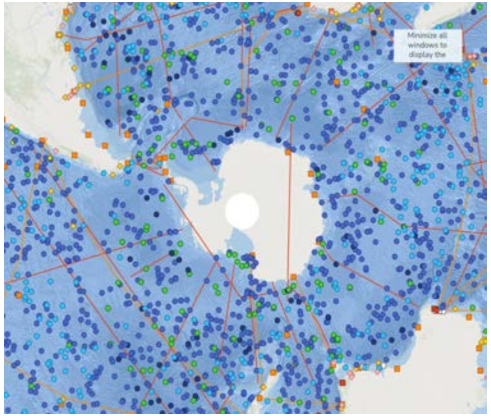
doi: 10.3389/fmars.2019.00421

1) Needs: OceanObs19 Southern Ocean observations (Newman et al., 2019)

Themes: the future of

1. Heat and freshwater
2. Stability of the overturning circulation
3. Role of ocean in Antarctic ice sheet stability; sea level rise
4. Southern Ocean carbon uptake
5. Antarctic sea ice
6. Southern Ocean ecosystems

Drivers/Approaches: Coordination of existing regional observations and address gaps, with centralized data management for availability to all



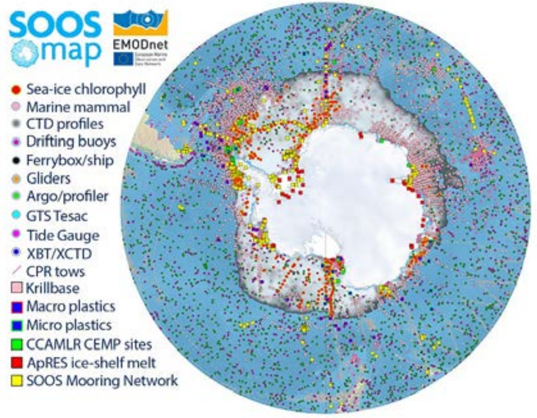


FIGURE 3 | SOOSmap is an interactive webmap that allows users to explore circumpolar datasets. It was developed for SOOS by EMODnet Physics and

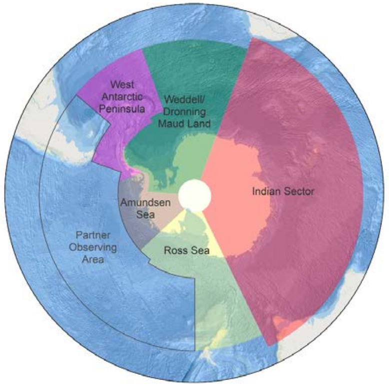


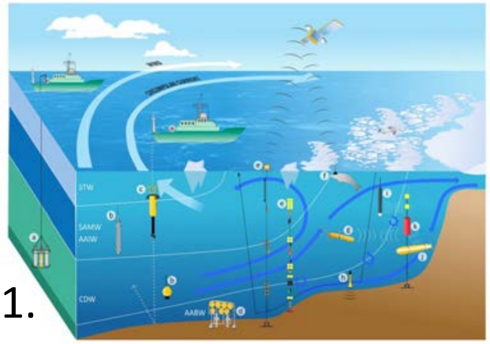
FIGURE 2 | Map of the five Regional Working Groups developed by SOOS to integrate the existing observational efforts in a region and facilitate efforts to address key gaps in observational coverage. The regions are based on the natural areas of focus for nations working in the Southern Ocean and facilitate

1) Needs: **OceanObs19** Southern Ocean observations (Newman et al., 2019)

Priorities:

1. Observing AABW production processes
2. Reducing uncertainties in air-sea and air-ocean-ice fluxes of heat, momentum, FW, carbon
3. Contribution of oceanic heat to ice-shelf basal melt
4. Processes controlling Antarctic sea ice variability and change
5. Observing sea ice thickness and volume
6. Constraining the seasonal carbon cycle
7. Constraining biological energy pathways
8. Assessing status and trends of key Southern Ocean taxa

Diagram and proposed observing system for each problem – 4 examples here



1.

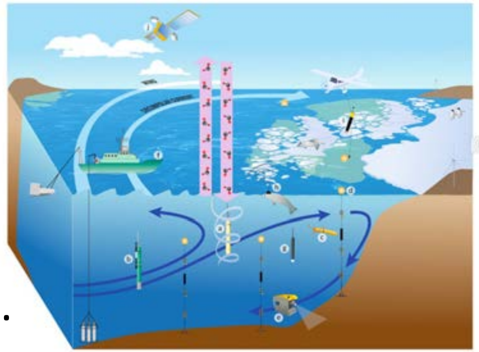
FIGURE 5 | A schematic of the observational platforms required to observe the AABW formation. **(a)** Conductivity-temperature-depth profiler often equipped with additional sensors such as dissolved oxygen, horizontal velocity (lowered ADCP – yellow cylinders), and temperature turbulence; **(b)** Argo profiler, both on core mission (depth < 2000 m) and deep mission (deeper); **(c)** microstructure profiler measuring energy and material dissipation rate; **(d)** bottom lander with a suite of instruments including water sample; **(e)** mooring system with physical (temperature, salinity, velocity) and biogeochemical (sediment trap, etc.) measurements, some with an underwater winch-driven surface buoy for ice avoidance; **(f)** animal tagged profiler; **(g)** glider; **(h)** bottom drifter, a float specially targeting AABW; **(i)** under-ice Argo profiler with acoustic locating capability; **(j)** autonomous underwater vehicle; and **(k)** a sound source for acoustic float locating. Modified from Meredith et al. (2013).

3.

7 | A schematic of the integrated system of observational platforms required to determine the contribution of oceanic heat to ice-shelf melt for a generic configuration. An integrated system to observe the processes important for grounding line retreat and basal melt consists of three main components. First how ocean currents approach and exit the ice shelf cavity, achieved by a combination of ship-based observations, such as hydrographic sections **(a)**; nstrumentation **(b)** deployed in key locations across the front of the ice shelf (e.g., polynyas, dense overflows); ice-capable profiling floats **(c)**; ice-tethered d) and ice-mass buoys **(e)** particularly in fast- or multi-year ice; seal tags **(f)**; and gliders **(g)** for high-resolution transects on the shelf and slope. Secondly, ng changes in ice-shelf thickness, basal melt-rate, and grounding-line retreat, achieved by deployment of satellite **(h)** and airborne **(i)** remote sensing for ic erties; ApRES radars **(j)** for direct basal-melt rates; automatic weather stations **(k)**, GPS, boreholes, and other sensors **(l)** for other properties, such as snow accumulation. Finally, observation of processes within the ice-shelf cavity itself requires AUVs **(m)** for observations of water properties, as well as swath mapping of sea floor and sub-ice shelf topography; sensors/moorings deployed through boreholes **(n)** for sub-ice shelf properties, circulation, and direct basal melt data, including mooring with ITPs and telemetry; moorings deployed by ROVs in ice shelf cavity **(o)**, which is not currently implemented but is a promising technological advance in the coming decade; and bottom landers **(p)** out the front of the ice shelf for a multitude of roles, such as communication gateways, imaging, water sampling, etc. This figure was modified from Meredith et al. (2013) and Rintoul et al. (2014) "seeing below the ice" 2014 strategy available at s.aq/resources/science-strategies?view=product&pid=26.

4.

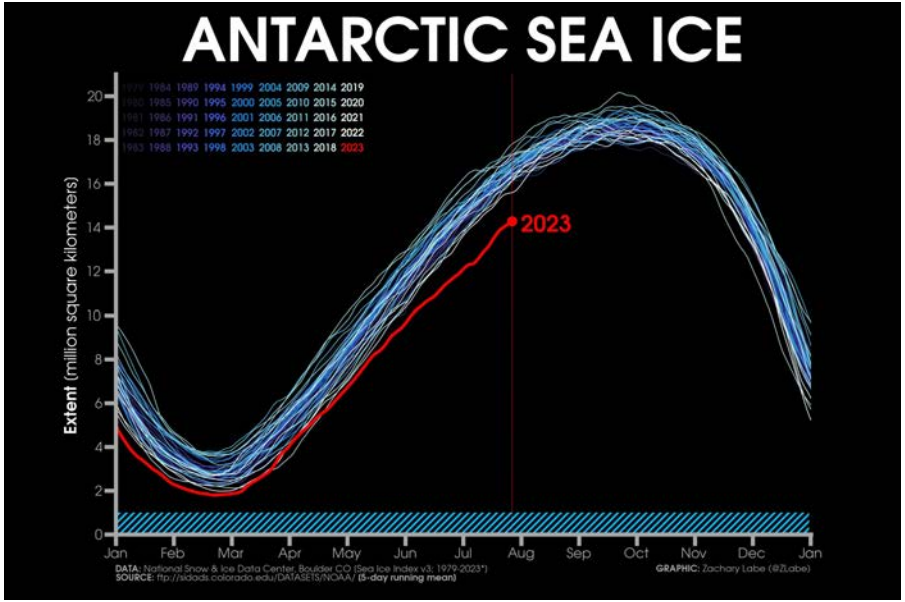
FIGURE 8 | Schematic of the platforms required to observe key sea-ice processes toward capturing circumpolar sea-ice variability (section "Toward a Bett Understanding of Processes Controlling Antarctic Sea-Ice Variability and Change") and deriving sea-ice thickness and volume (section "Observing Sea-Ice and Volume"). Due to the remoteness, vastness, and hostile conditions of the sea-ice zone, autonomous platforms will be crucial. They include high-resolut sensors such as drifting buoys **(a)**; ice-deformation arrays **(b)**, mass-balance- and snow-buoys **(c)**, wave buoys **(d)**, and autonomous underwater **(e)** and a vehicles **(f)**. Observations of snow depth, ice thickness, ice concentration, drift and properties from satellite altimeters, and radars and radiometers **(g)** are sustain for long-term time series. Manned observation platforms include vessels **(h)** (for underway and *in situ* sea-ice sampling **(i)** including ROV deploymen aircraft (e.g., EMBird and NASA's Operation IceBridge), and near-coastal research stations (for fast-ice and sea-ice/ice-shelf studies). Modified from Meredi



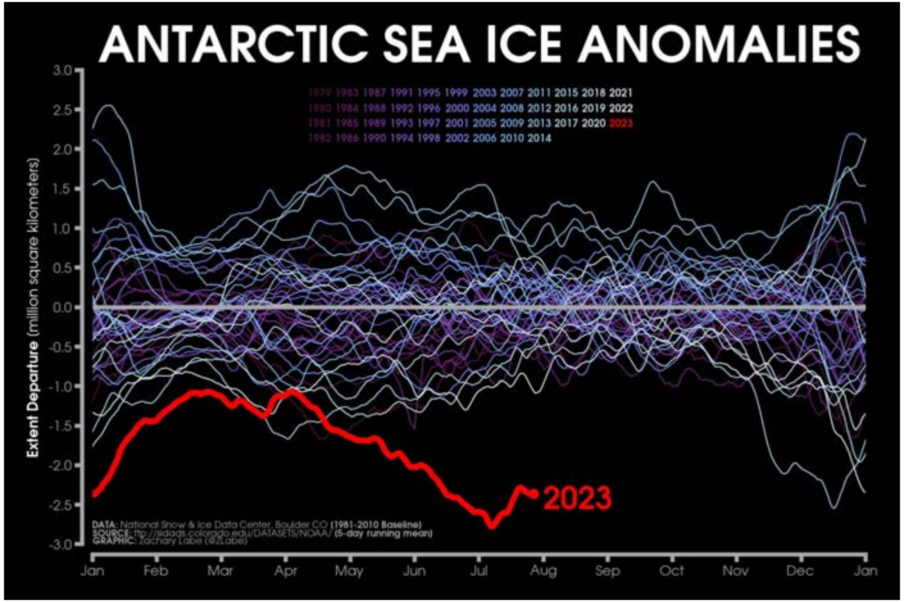
6.

FIGURE 9 | Components of an optimal observing system to constrain and quantify biogeochemical cycling processes in the Southern Ocean. New methodologies such as biogeochemical sensors deployed on SOCCOM **(a)** and SOCLIM **(b)** floats, gliders **(c)**, and moorings **(d)**, and sampling from ROVs **(e)** must be integrated with traditional ship- **(f)** and station-based approaches. Ice-capable bio-Argo floats **(g)** and biogeochemical sensors deployed on marine mammals **(h)** are needed to extend the observational range in time and space. Airborne deployment of ALAMO floats **(i)** could increase spatial coverage substantially. All of these *in situ* approaches should be combined with existing and improved satellite-based measurements **(j)** of sea surface height, sea ice, sea surface temperature, and ocean color to develop an integrated biogeochemical observing system for the Southern Ocean. Modified from Meredith et al. (2013).

Alarming sea ice



DATA: National Snow & Ice Data Center, Boulder CO (Sea Ice Index v3; 1979-2023*)
SOURCE: ftp://sidads.colorado.edu/DATASETS/NOAA/ (5-day running mean)
GRAPHIC: Zachary Labe (@ZLabe)

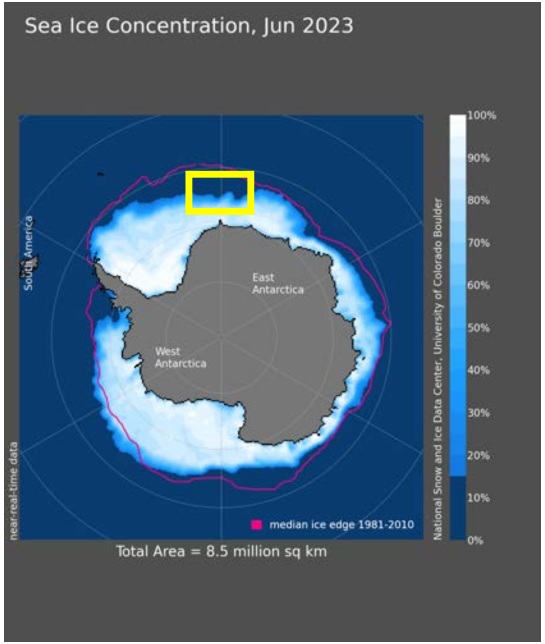


DATA: National Snow & Ice Data Center, Boulder CO (1981-2010 Baseline)
SOURCE: ftp://sidads.colorado.edu/DATASETS/NOAA/ (5-day running mean)
GRAPHIC: Zachary Labe (@ZLabe)

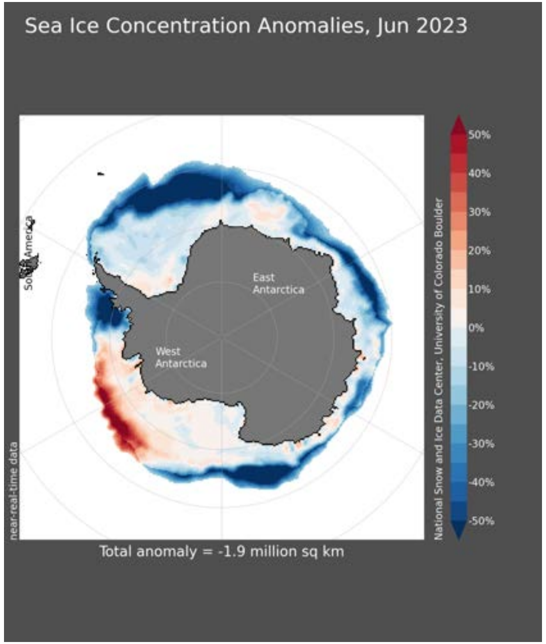
(satellite-era; NSIDC, DMSP SSM/I-SSM)

https://zacklabe.com/antarctic-sea-ice-extentconcentration/

Alarming sea ice


Sea Ice Concentration, Jun 2023

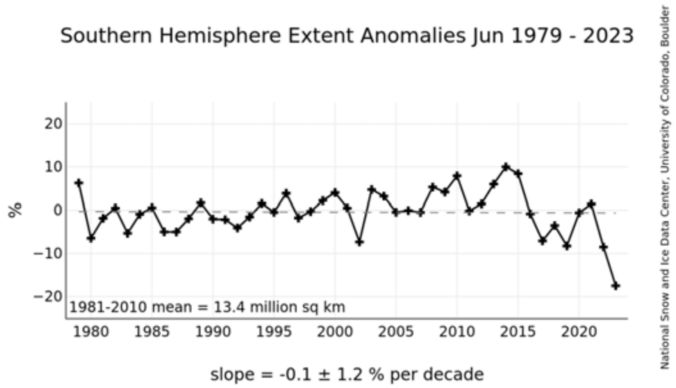
Total Area = 8.5 million sq km


Sea Ice Concentration Anomalies, Jun 2023

Total anomaly = -1.9 million sq km

National Snow and Ice Data Center

Observations: Sea ice products from satellites

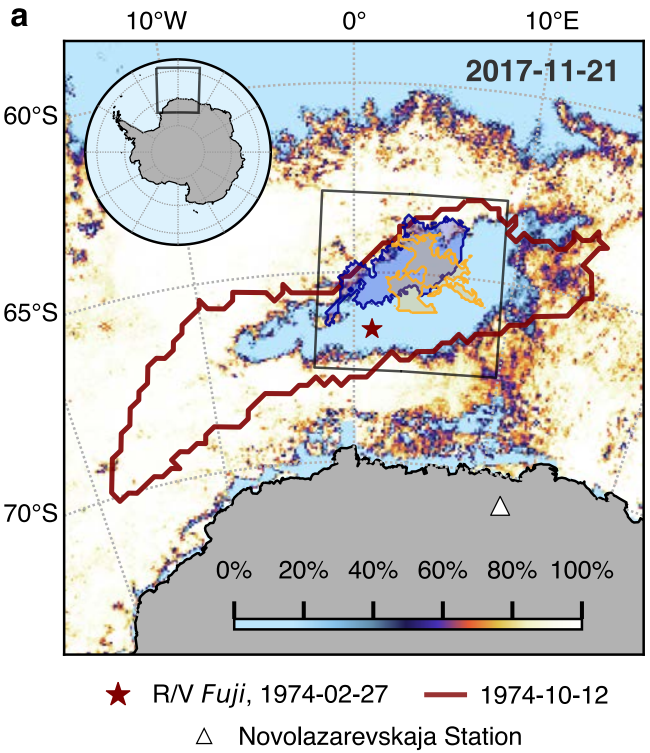

Southern Hemisphere Extent Anomalies Jun 1979 - 2023

slope = -0.1 ± 1.2 % per decade

FIGURE 8 | Schematic of the platforms required to observe key sea-ice processes toward capturing circumpolar sea-ice variability (section "Toward a Better Understanding of Processes Controlling Antarctic Sea-Ice Variability and Change") and deriving sea-ice thickness and volume (section "Observing Sea-Ice Thickness and Volume"). Due to the remoteness, vastness, and hostile conditions of the sea-ice zone, autonomous platforms will be crucial. They include high-resolution *in situ* sensors such as drifting buoys **(a)**; ice-deformation arrays **(b)**, mass-balance- and snow-buoys **(c)**, wave buoys **(d)**, and autonomous underwater **(e)** and airborne vehicles **(f)**. Observations of snow depth, ice thickness, ice concentration, drift and properties from satellite altimeters, and radars and radiometers **(g)** are vital to sustain for long-term time series. Manned observation platforms include vessels **(h)** [for underway and *in situ* sea-ice sampling **(i)** including ROV deployments **(j)**,

(...at this rate there might not be enough sea ice cover to define a polynya...)

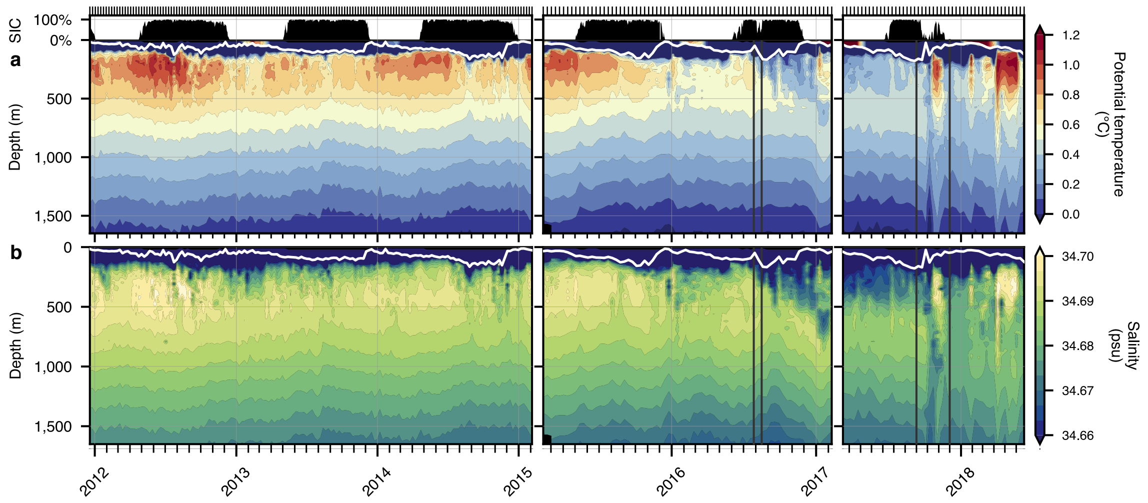
Maud Rise polynya (sensible heat)



Observations:

Satellite ice concentration

Profiling BGC Argo floats on Maud Rise



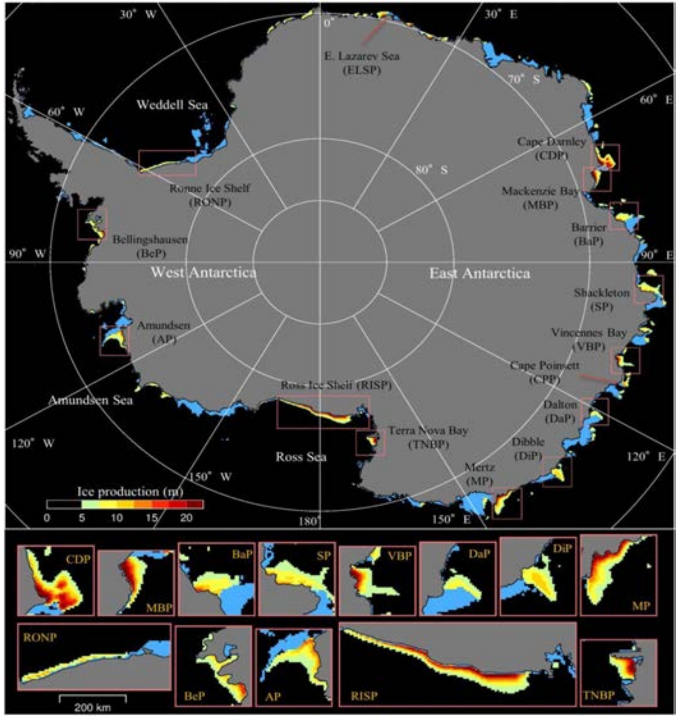
Deep convection during the polynya opening: implications for modeled open ocean polynyas?

Campbell et al. (Nature, 2019)

Episodic atmospheric forcing or part of a longer-term trend?

Coastal polynyas (latent heat): dense water formation through brine rejection

Observations: AMSR-E satellite



Nakata et al. (GRL, 2021)

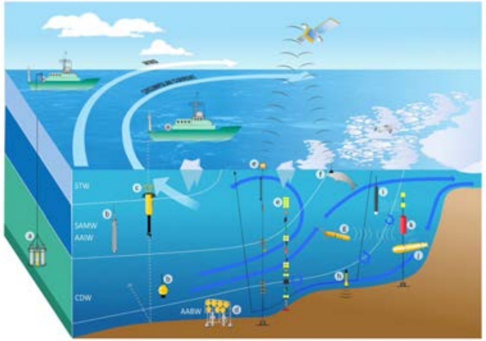


FIGURE 5 | A schematic of the observational platforms required to observe the AABW formation. **(a)** Conductivity-temperature-depth profiler often equipped with additional sensors such as dissolved oxygen, horizontal velocity (lowered ADCP - yellow cylinders), and temperature turbulence; **(b)** Argo profiler, both on core mission (depth < 2000 m) and deep mission (deeper); **(c)** microstructure profiler measuring energy and material dissipation rate; **(d)** bottom lander with a suite of instruments including water sample; **(e)** mooring system with physical (temperature, salinity, velocity) and biogeochemical (sediment trap, etc.) measurements, some with an underwater winch-driven surface buoy for ice avoidance; **(f)** animal tagged profiler; **(g)** glider; **(h)** bottom drifter, a float specially targeting AABW; **(i)** under-ice Argo profiler with acoustic locating capability; **(j)** autonomous underwater vehicle; and **(k)** a sound source for acoustic float locating. Modified from Meredith et al. (2013).

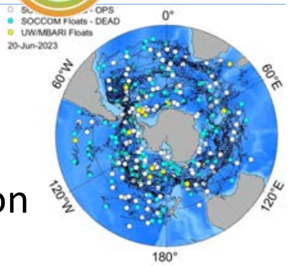
Acidification of Southern Ocean

Observations:

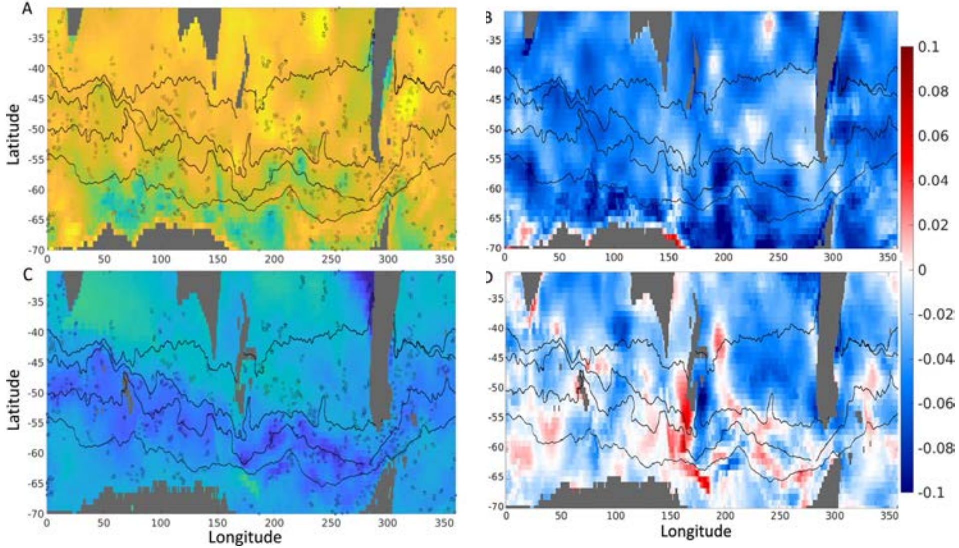
Ship-based from previous decades

SOCCOM BGC Argo floats since 2014

Mapping using scales from state estimation



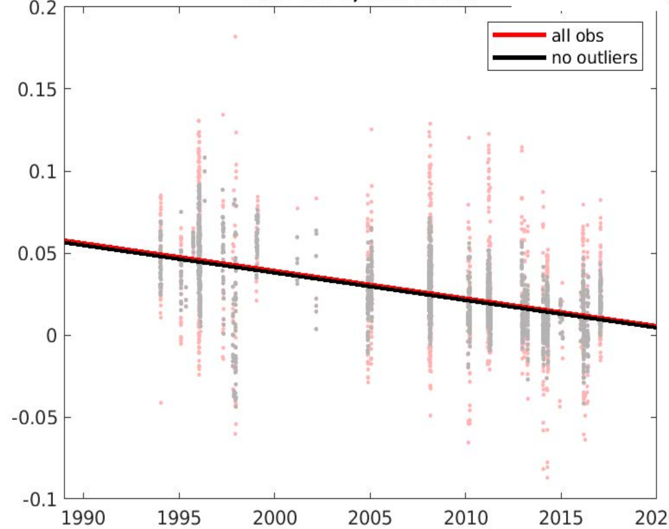
pH changes from ‘2000’ to ‘2018’



Mapped pH at 55 and 700m in Feb.

Difference SOCCOM minus GLODAPv2

Obs<35°S, 100-210m

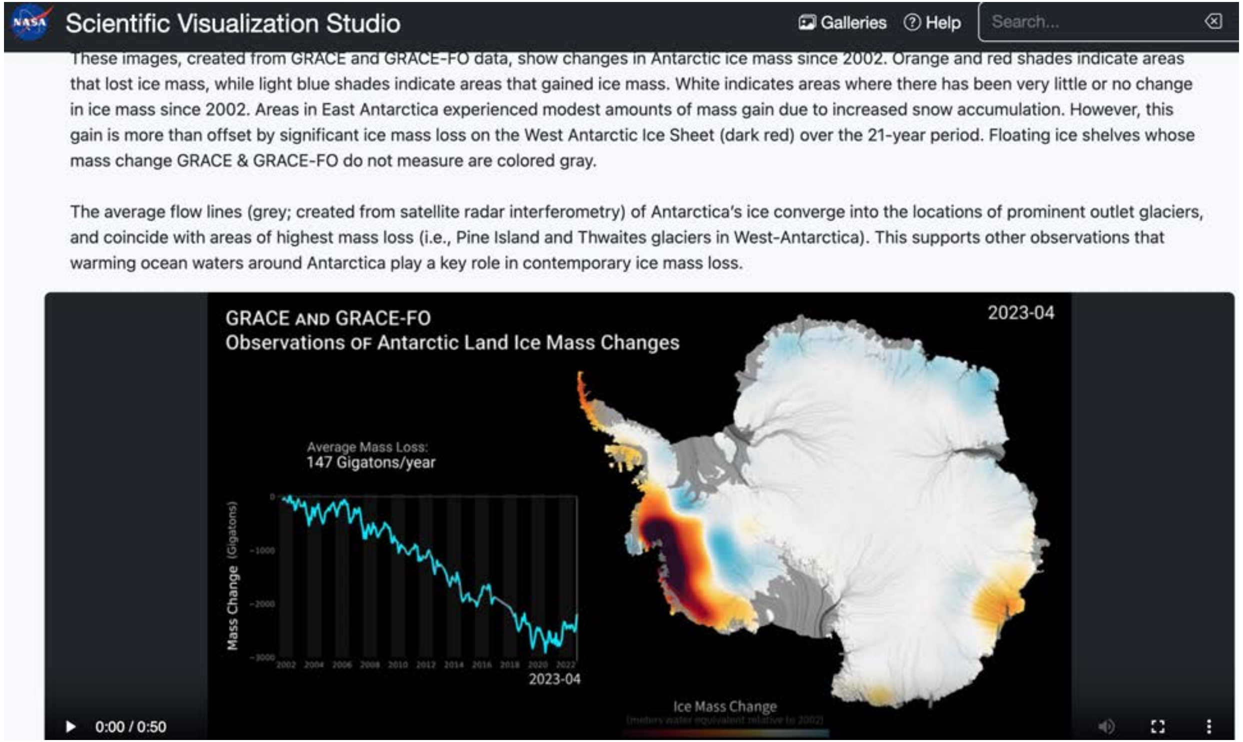


1990

2020

Mazloff et al. (JGR, 2023)

Antarctic ice sheet mass loss and sea level rise



These images, created from GRACE and GRACE-FO data, show changes in Antarctic ice mass since 2002. Orange and red shades indicate areas that lost ice mass, while light blue shades indicate areas that gained ice mass. White indicates areas where there has been very little or no change in ice mass since 2002. Areas in East Antarctica experienced modest amounts of mass gain due to increased snow accumulation. However, this gain is more than offset by significant ice mass loss on the West Antarctic Ice Sheet (dark red) over the 21-year period. Floating ice shelves whose mass change GRACE & GRACE-FO do not measure are colored gray.

The average flow lines (grey; created from satellite radar interferometry) of Antarctica's ice converge into the locations of prominent outlet glaciers, and coincide with areas of highest mass loss (i.e., Pine Island and Thwaites glaciers in West-Antarctica). This supports other observations that warming ocean waters around Antarctica play a key role in contemporary ice mass loss.

FIGURE 7 | A schematic of the integrated system of observational platforms required to determine the contribution of oceanic heat to ice-shelf melt for a generic ice-shelf configuration. An integrated system to observe the processes important for grounding line retreat and basal melt consists of three main components. Firstly, observing how ocean currents approach and exit the ice shelf cavity, achieved by a combination of ship-based observations, such as hydrographic sections **(a)**; moored instrumentation **(b)** deployed in key locations across the front of the ice shelf (e.g., polynyas, dense overflows); ice-capable profiling floats **(c)**, ice-tethered profilers **(d)** and ice-mass buoys **(e)** particularly in fast- or multi-year ice; seal tags **(f)**; and gliders **(g)** for high-resolution transects on the shelf and slope. Secondly, determining changes in ice-shelf thickness, basal melt-rate, and grounding-line retreat, achieved by deployment of satellite **(h)** and airborne **(i)** remote sensing for ice shelf properties; ApRES radars **(j)** for direct basal-melt rates; automatic weather stations **(k)**, GPS, boreholes, and other sensors **(l)** for other properties, such as snow accumulation. Finally, observation of processes within the ice-shelf cavity itself requires AUVs **(m)** for observations of water properties, as well as swath mapping of sea floor and sub-ice shelf topography; sensors/moorings deployed through boreholes **(n)** for sub-ice shelf properties, circulation, and direct basal melt data, including mooring with ITPs and telemetry; moorings deployed by ROVs in ice shelf cavity **(o)**, which is not currently implemented but is a promising technological advance in the coming decade; and bottom landers **(p)** out the front of the ice shelf for a multitude of roles, such as communication gateways, imaging, water sampling, etc. This figure was modified from Meredith et al. (2013) and Rintoul et al. (2014) "seeing below the ice" 2014 strategy available at http://soos.aq/resources/science-strategies?view=product&pid=26.

International Thwaites Glacier Collaboration

1) Needs: Phenomena

Ocean climate characterization
  - Physical climate (heat, freshwater, circulation, dissipation/diffusivity, sea ice, adjoining ice sheet)
  - Biogeochemical climate (carbon system, nutrients, oxygen)
  - *Biological climate*

Ocean climate external forcing/influence characterization
  - Physical climate (wind, buoyancy fluxes, sea ice and ice shelves, bathymetry, ocean biology, BGC ocean and atmosphere)
  - Biogeochemical climate (atmospheric CO2, oxygen, ocean physics, ocean biology)
  - *Biological climate*

1) Needs: Regimes, Spatial scales, and Timescales

Regimes

Circumpolar phenomena and dynamics
- Sea ice zone
- Currents and current zones
- Antarctic Circumpolar Current zones (Southern, Polar)
- Subantarctic Zone north of ACC
- Continental shelf and subice-shelf cavities

Regional
- Ross
- Weddell
- East Antarctic gyre
- Drake Passage
- Antarctic Peninsula
- Topographic hotspots (5 major ones)

Polynyas: coastal and open ocean (Maud Rise, others?)
Overturning circulation

Spatial scales

Turbulence, dissipation
Submesoscale
Mesoscale and frontal
Gyre to large scale

Timescales

Episodic (storms)
Intrinsic dynamics
Seasonal

QBO
ENSO

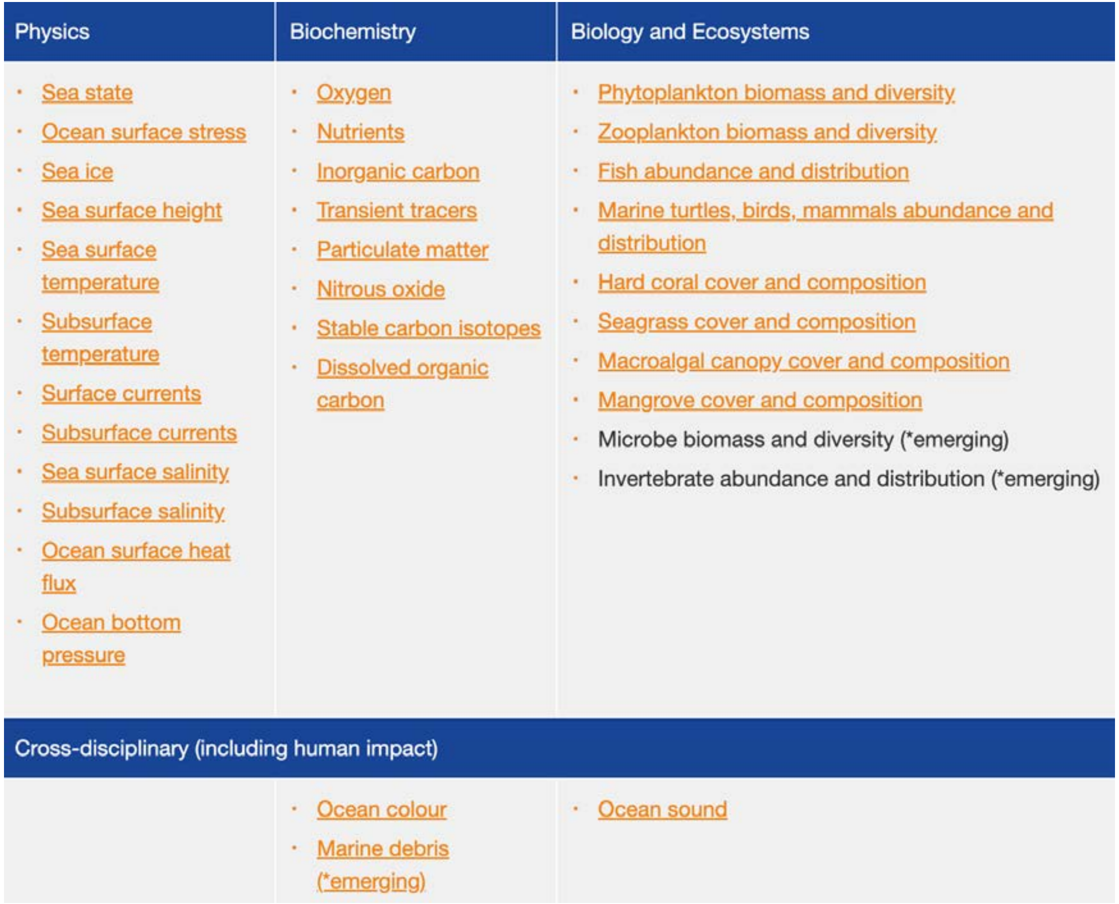
Southern Annular Mode
(Antarctic Oscillation)

Background: Essential Ocean Variables

The Global Ocean Observing System

Home

Essential Ocean Variables



Physics

- Sea state
- Ocean surface stress
- Sea ice
- Sea surface height
- Sea surface temperature
- Subsurface temperature
- Surface currents
- Subsurface currents
- Sea surface salinity
- Subsurface salinity
- Ocean surface heat flux
- Ocean bottom pressure

Biochemistry

- Oxygen
- Nutrients
- Inorganic carbon
- Transient tracers
- Particulate matter
- Nitrous oxide
- Stable carbon isotopes
- Dissolved organic carbon

Biology and Ecosystems

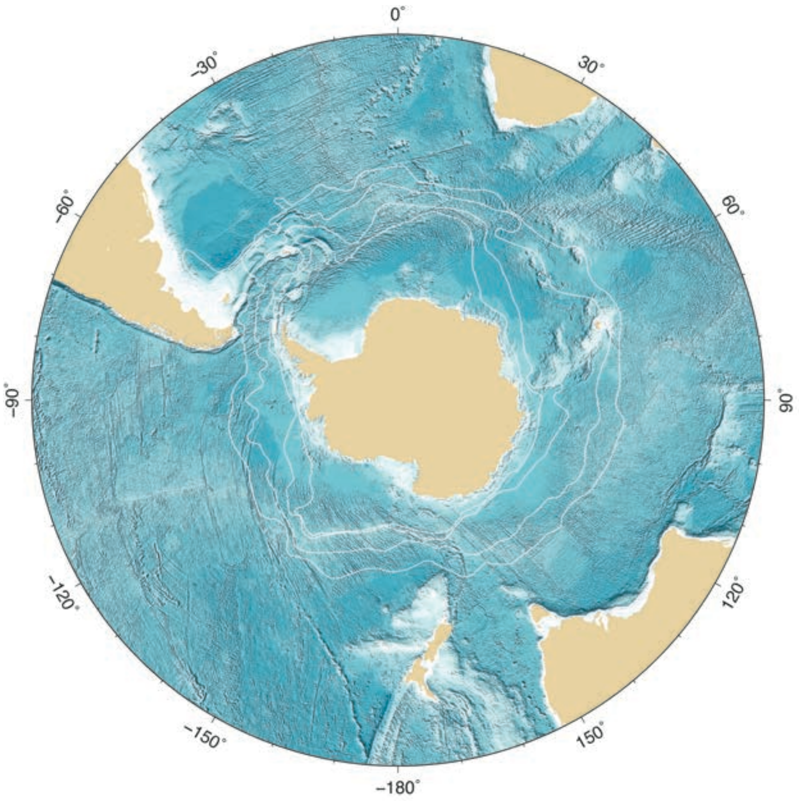
- Phytoplankton biomass and diversity
- Zooplankton biomass and diversity
- Fish abundance and distribution
- Marine turtles, birds, mammals abundance and distribution
- Hard coral cover and composition
- Seagrass cover and composition
- Macroalgal canopy cover and composition
- Mangrove cover and composition
- Microbe biomass and diversity (*emerging)
- Invertebrate abundance and distribution (*emerging)

Cross-disciplinary (including human impact)

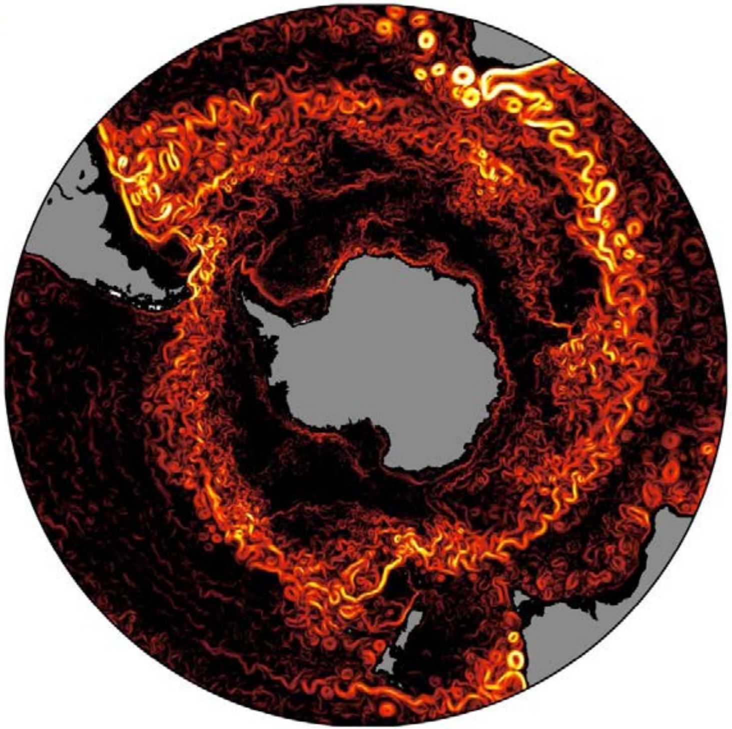
- Ocean colour
- Marine debris (*emerging)
- Ocean sound

https://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

Background: Geography, circulation, overturning cells



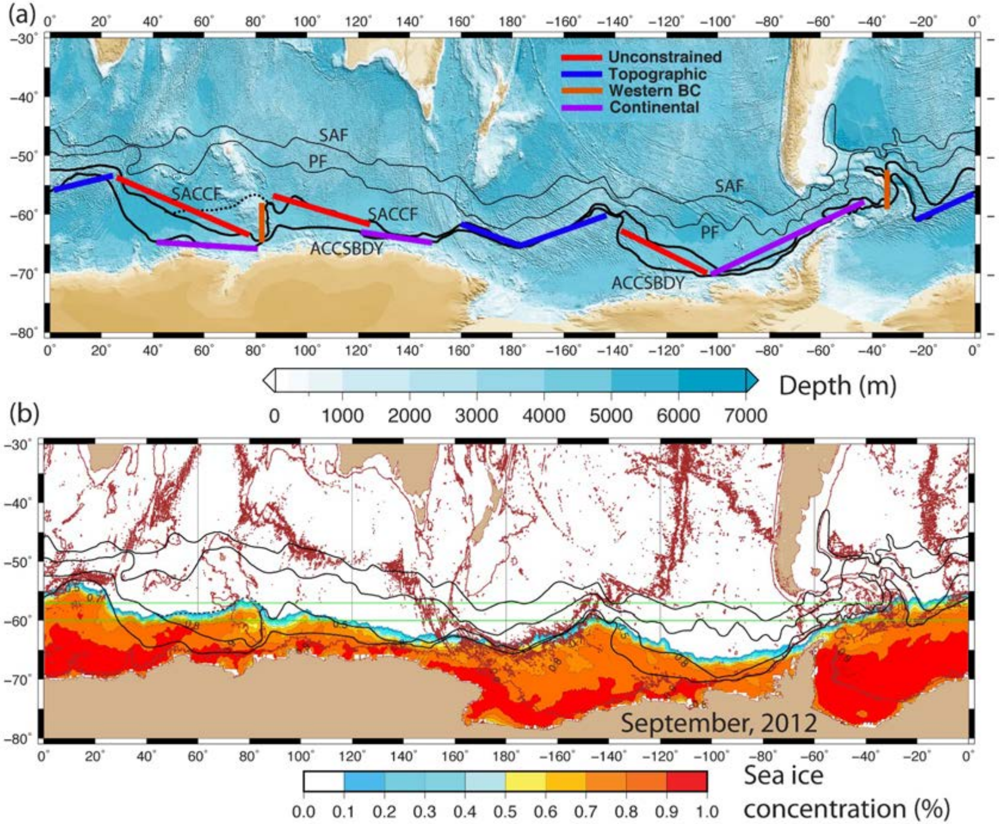
Bathymetry and Orsi et al. (1995) fronts



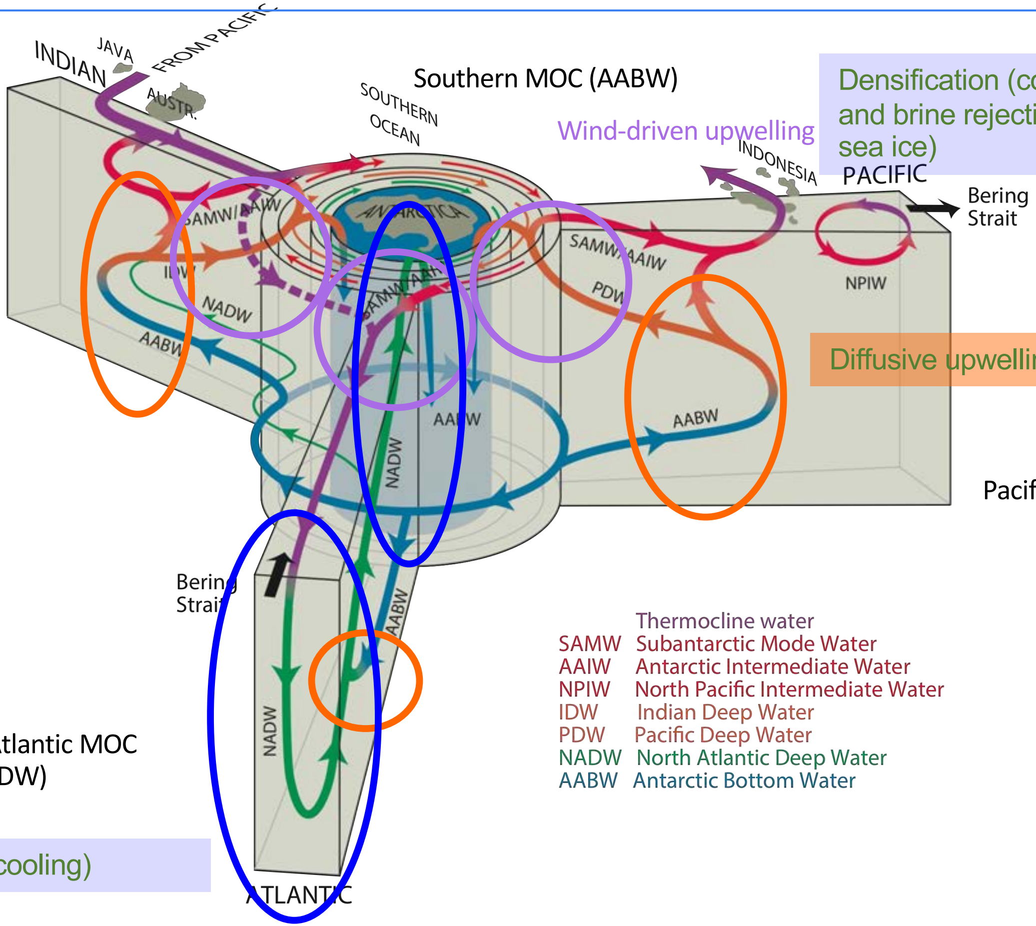
Surface velocity (model) Morrison CM2.6 (circa 2013)

Background: Geography, circulation, overturning cells

Observations: sea ice cover and hydrography



Overturning Circulation schematic and processes



Southern MOC (AABW)

Wind-driven upwelling

Densification (cooling and brine rejection: sea ice)

Indian MOC (IDW)

Diffusive upwelling

Pacific MOC (PDW)

N. Atlantic MOC (NADW)

Densification (cooling)

	Thermocline water
SAMW	Subantarctic Mode Water
AAIW	Antarctic Intermediate Water
NPIW	North Pacific Intermediate Water
IDW	Indian Deep Water
PDW	Pacific Deep Water
NADW	North Atlantic Deep Water
AABW	Antarctic Bottom Water

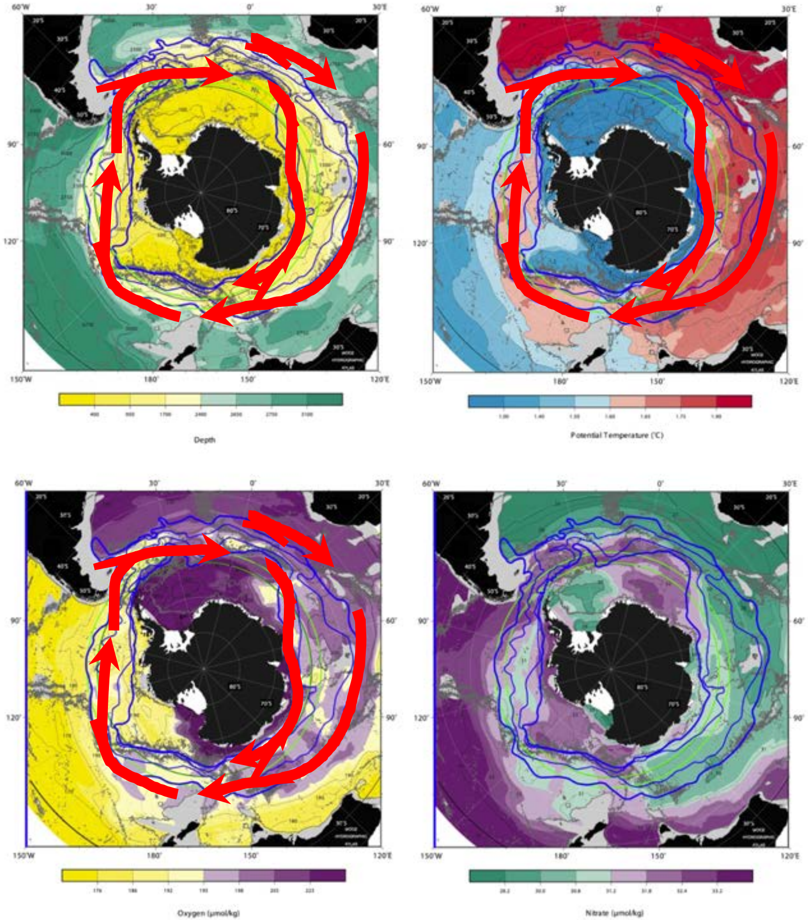
Talley (Oceanography, 2013)
Talley et al. (DPO 6th, 2011)

Background: Geography, circulation, overturning cells

Upward spiral of NADW, PDW and IDW

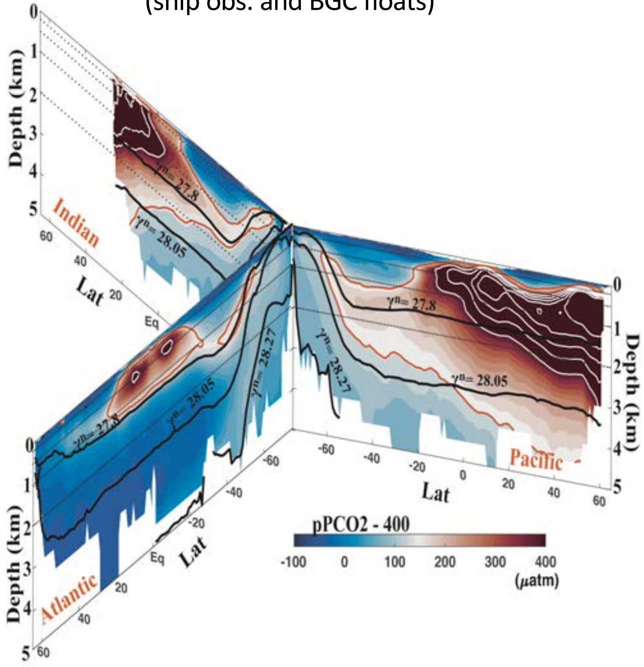
(Tamsitt et al. Nat. Comm. 2016 supp.)

Observations: hydrographic stations
(WOCE and prior historical)



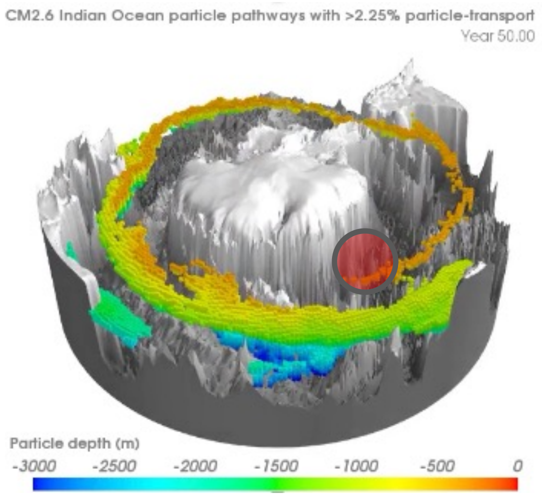
Southern Ocean upwelling of high carbon to surface, outgassing

High carbon Deep Waters reach surface in Southern Ocean
(ship obs. and BGC floats)



Chen et al. (GBC 2022)

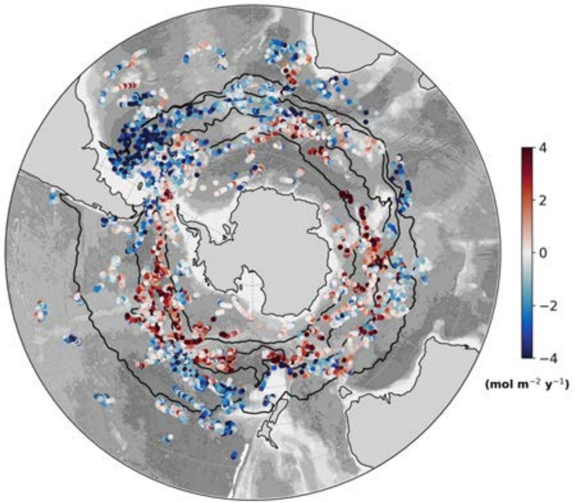
Pathways of high carbon spiral inward and upward (SOSE, CESM, ESM6, matching hydrographic data)



Tamsitt et al. (Nat. Comm. 2017)

Carbon outgasses in southern ACC
(BGC floats)

Outgas Uptake

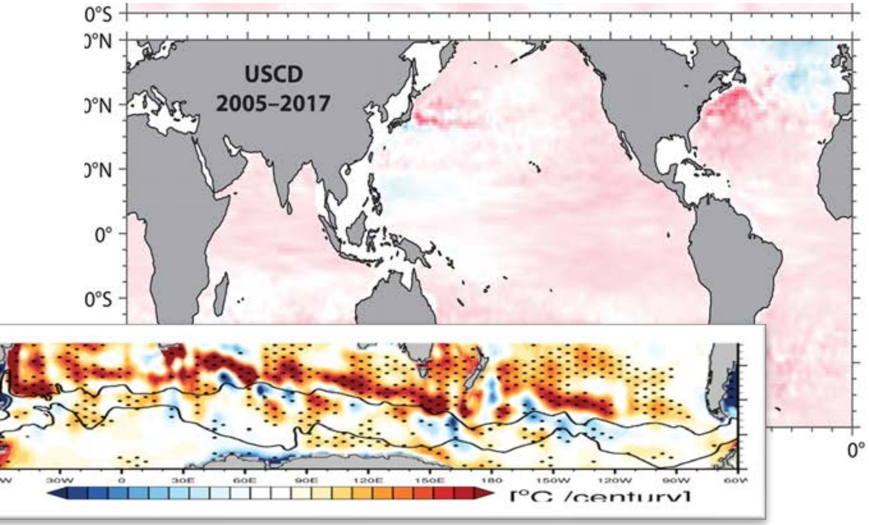


Gray et al. (GRL 2018)
Prend et al. (GBC, 2022)

Anthropogenic heat and carbon

Observations:

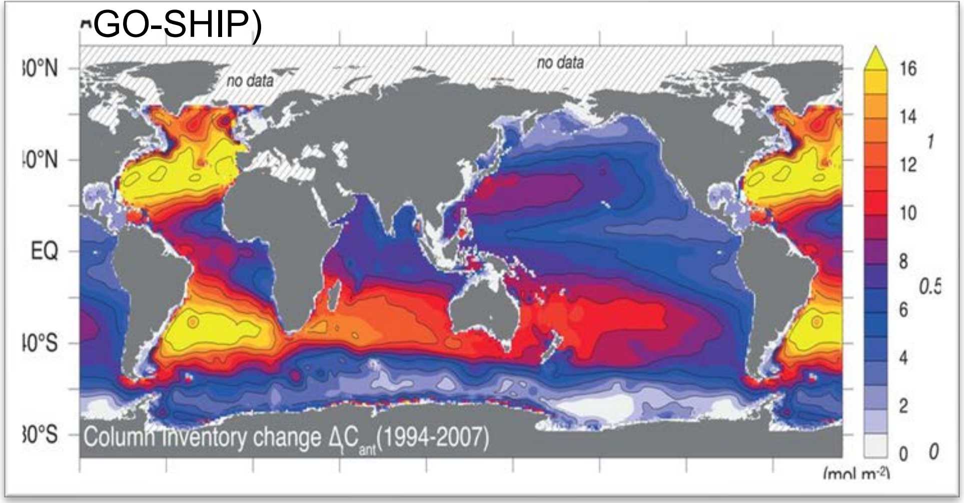
Temperature: Argo and ship-based hydrography
Carbon: ship-based hydrography (WOCE and GO-SHIP)



Argo climatology-based 0-2000 m temperature trend
Durack et al. (Oceanography 2018)

EN4 change in 0-2000 m **potential temperature** from 1993-2018

Shi et al. (Nat. Clim. Ch., 2021)

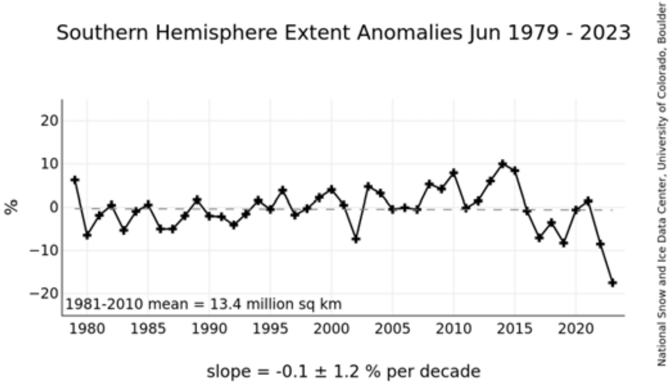


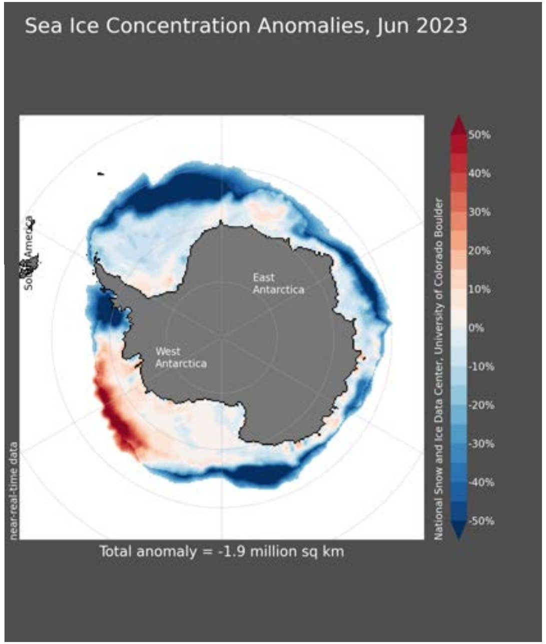
Change in **anthropogenic CO2** from 1994 to 2007

Gruber et al. (Science, 2019)

Sea ice trends

Observations: satellite sea ice concentration and extent



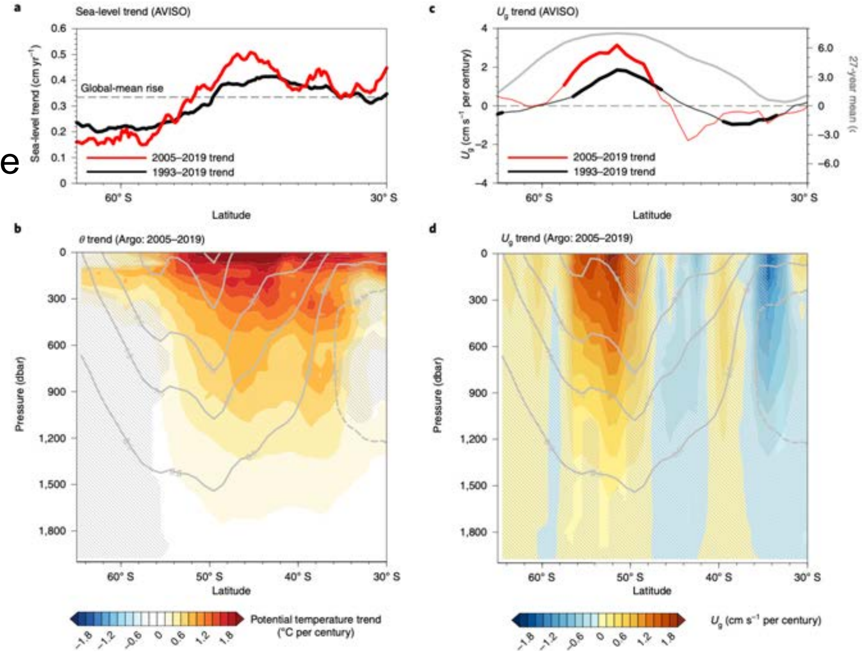


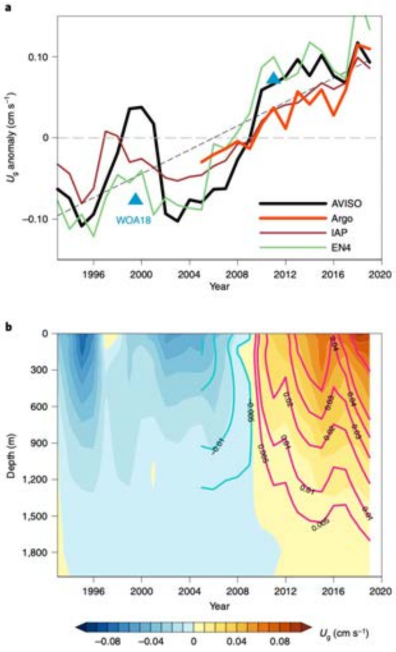
NSIDC website

Circulation changes, wind stress, buoyancy forcing

Observations:

Satellite altimetry
Ship-based and Argo temperature



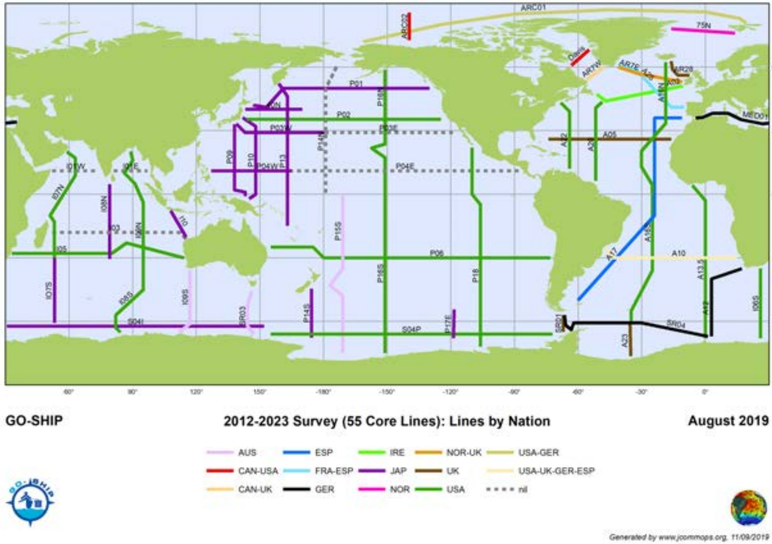


ACC eastward flow acceleration (observations)
Attribution to buoyancy change, not wind (using models)

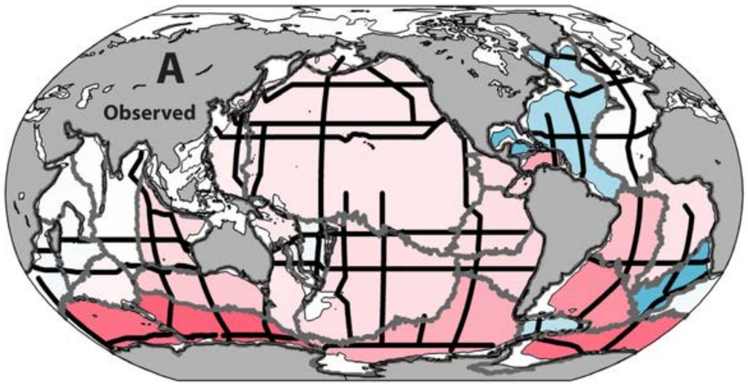
Shi et al. (Nat. Clim. Ch. 2021)

Deep circulation cell changes: abyssal warming

Observations:
Ship-based hydrography along repeating sections (GO-SHIP, WOCE)
New observatory: Deep Argo



Warming below 4000 m: due to reduced dense water (AABW) production



4000 m-bottom trend

Durack et al (Oceanography, 2018)
Extending Purkey and Johnson (2010)

Dense water modification or formation:

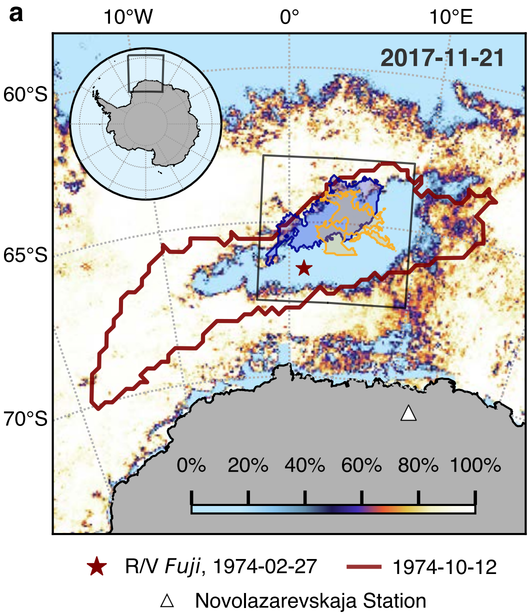
Deep convection (open ocean) vs. brine rejection (coastal polynyas on the Antarctic shelves)

What observations are needed to observe open ocean deep convection and to obser dense shelf water formation?

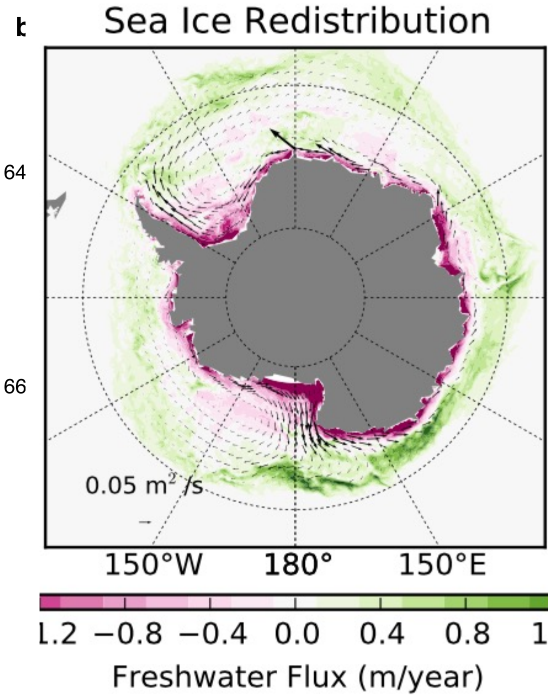
Deep ocean convection more likely in dee glacial periods or in much warmer periods – what is our near future?

Subsurface heat accumulation leads to potential deep convection. Surface freshening due to ice melt shuts it down. Which wins?

Pedro et al. (GRL, 2016)



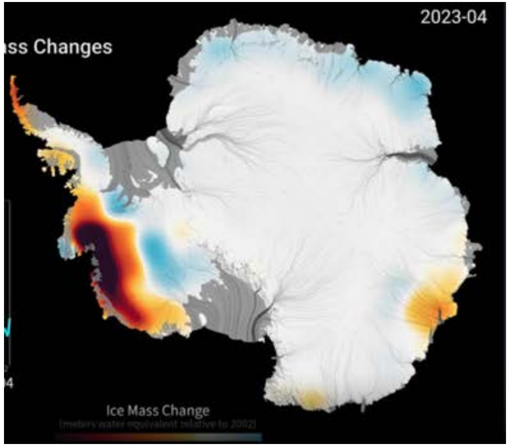
Campbell et al. (Nature, 2019)

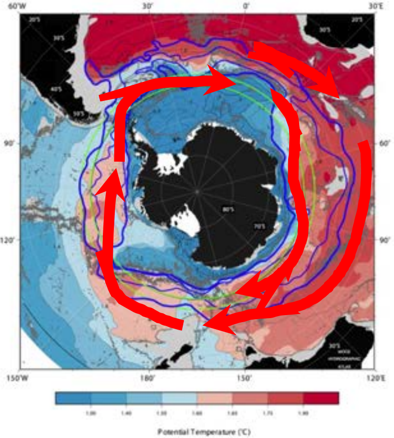


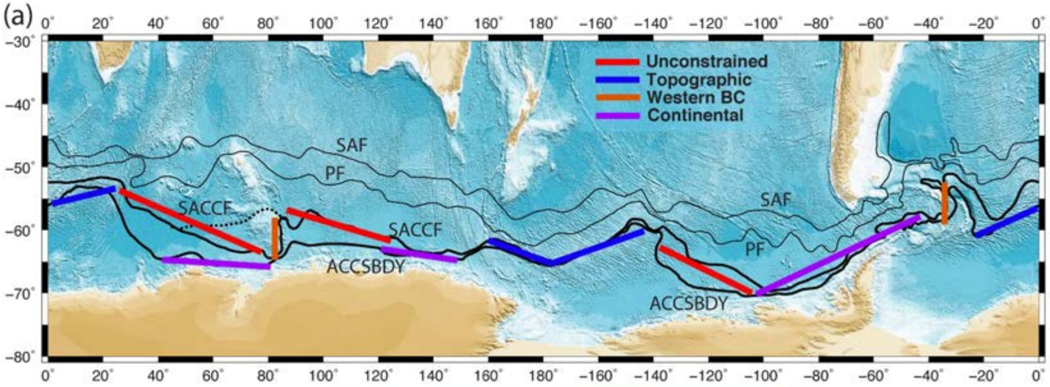
Abernathey et al. (Nature Geo. 2019)

Ocean impact on Antarctic ice sheet

Warm CDW spirals to sea surface
Moves close to continent with the ACC

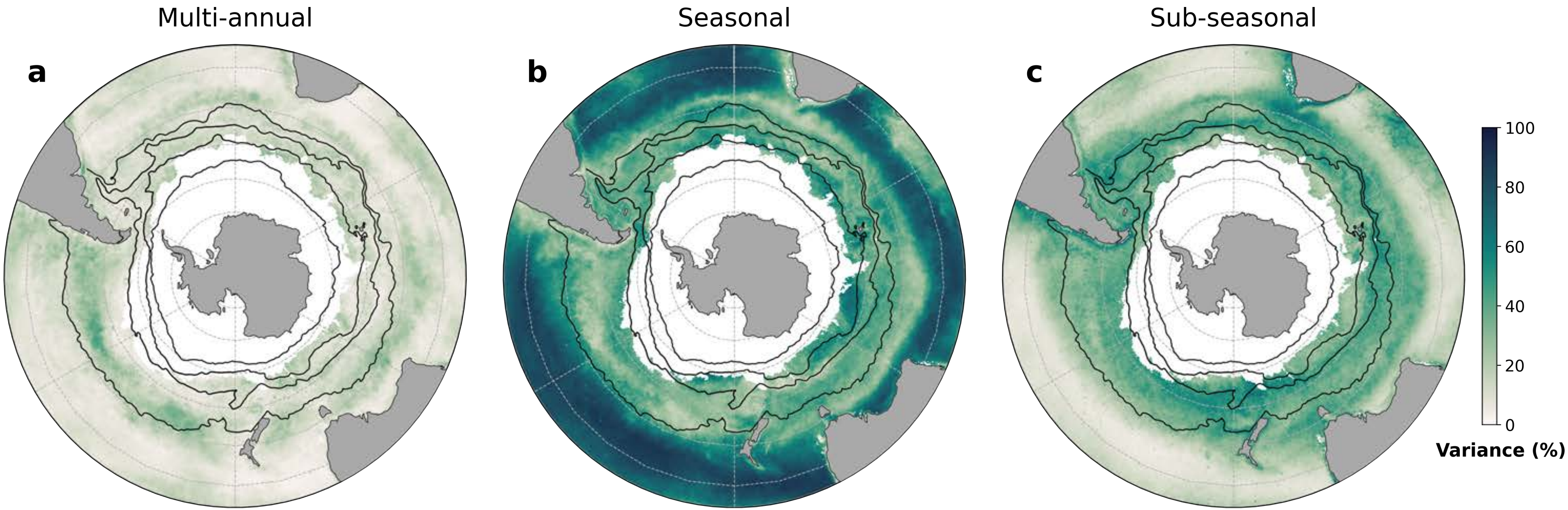






Time and space scales: example from surface chlorophyll

Observations: satellite ocean color



Multi-annual in Subantarctic Zone (SAM) (large spatial scale)

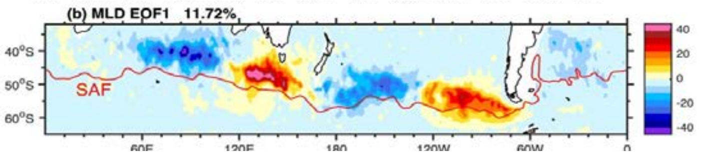
Seasonal subtropics (large spatial scale)

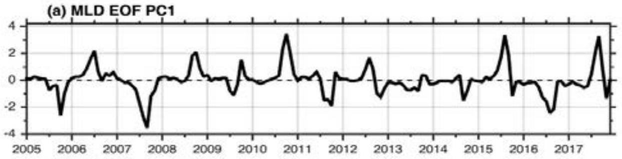
Subseasonal in ACC and to south (episodic, small spatial scales)

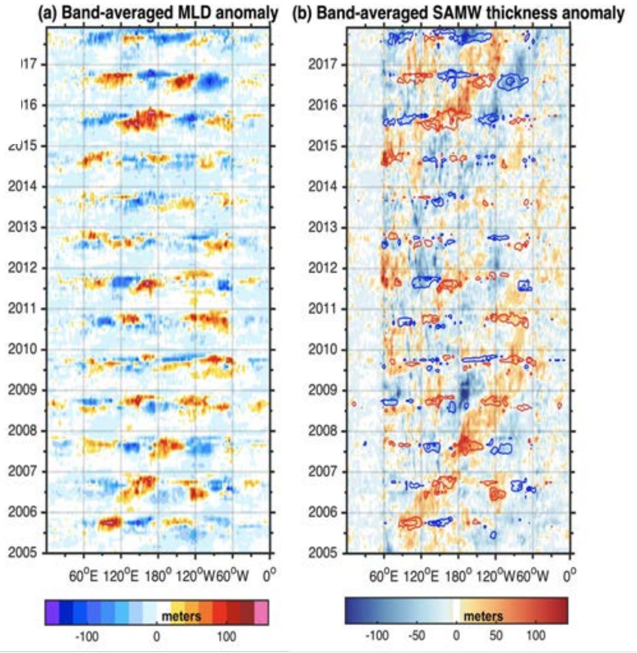
Prend, Keerthi, Levy, Aumont, Gille, Talley (GBC, 2022)

Upper cell circulation and property changes: time and space scales

Observations:
Argo profiles (T, S)







Mixed layer depth:
Dipole in each ocean (wavenumber 3)
Eastward propagation
Dominant biannual signal

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

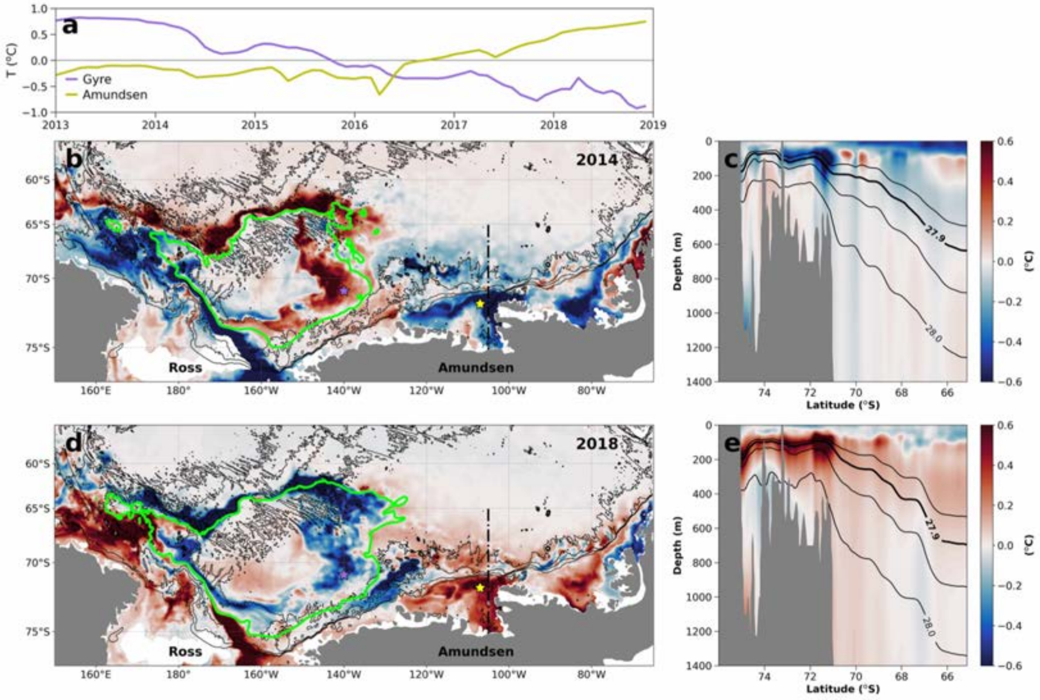
Ocean impact on Antarctic ice sheet

Limitations of current observing system?

->Under ice profiles and circulation observations are limited

State-Estimate (SOSE) based analysis of temperature variability on CDW isopycnal
SOSE assimilates data

Can this signal be detected directly in under-ice measurements?
Potentially: use of both under-ice Argo and AniBOS might show it, but cannot provide the associated circulation

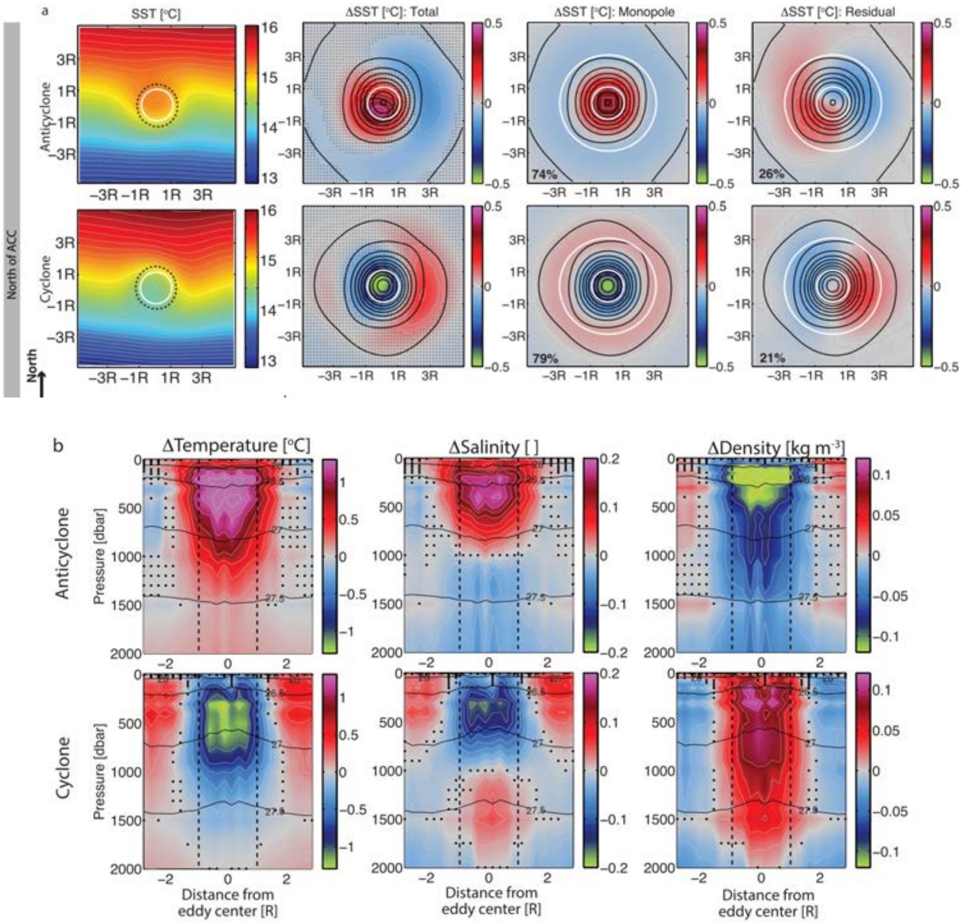


Prend et al. (submitted)

Mesocale observations

Observations:
Satellite altimetry, surface temperature
Profiling floats co-located with surface eddy

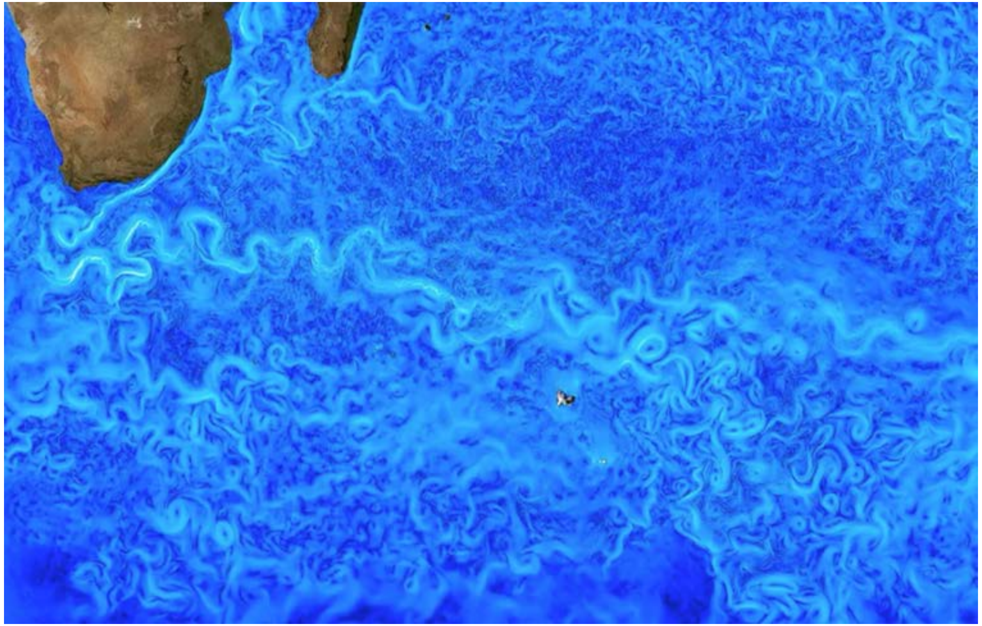
Extended now by several groups, including work on subsurface impacts (Argo T/S) (Chen, Speich), subsurface carbon (BGC Argo) (Keppler)



Frenger et al. (JGR 2015)

Submesocale studies: limitations of current system?

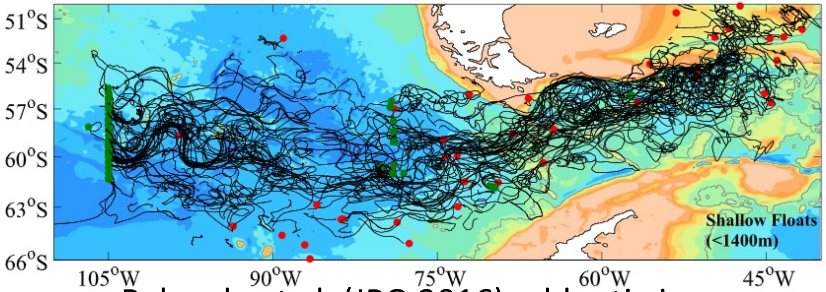
SWOT satellite
Ice detection satellites



Lia Siegelman modeling

Mixing: diapycnal and along isopycnal

DIMES experiment around Drake Passage
http://dimes.ucsd.edu/en/publications/index.html



Balwada et al. (JPO 2016) eddy stirring

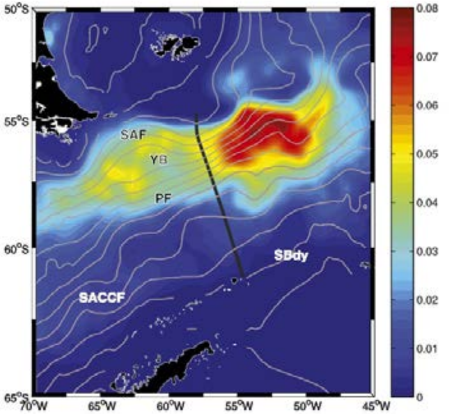
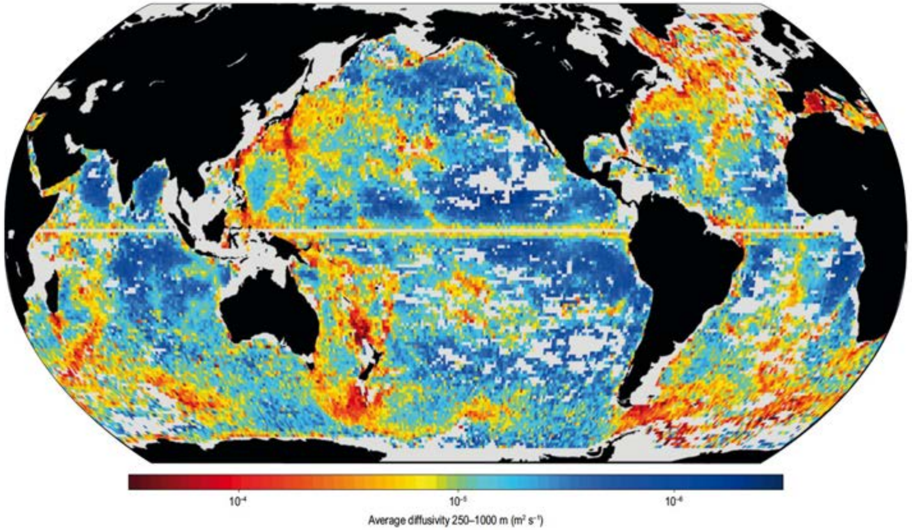


FIG. 2. Position of the SR1b repeat section (in black). Surface

Naveira Garabato et al. (JPO 2016) diapycnal

Observations:
DIMES was a limited-time, intensive CLIVAR experiment with multiple platforms

Global diffusivity: Argo T/S



Argo-based fine structure diffusivity (Whalen et al 2012, recent version)

Southern Ocean Observations: Current status

Hemispheric (international)
Satellites

Circumpolar (in situ) (international)
Argo and Biogeochemical Argo
AniBOS
Ship-based hydrography

Regional (in situ): US foci
West Antarctic Peninsula
Drake Passage
International Thwaites Glacier Collaboration
Add Ross Sea Marine Protected Area focus?

National focused observatories - SOOS working on coordinating, could use support

Satellites

Sea surface height
    AVISO
    SWOT: submesoscale

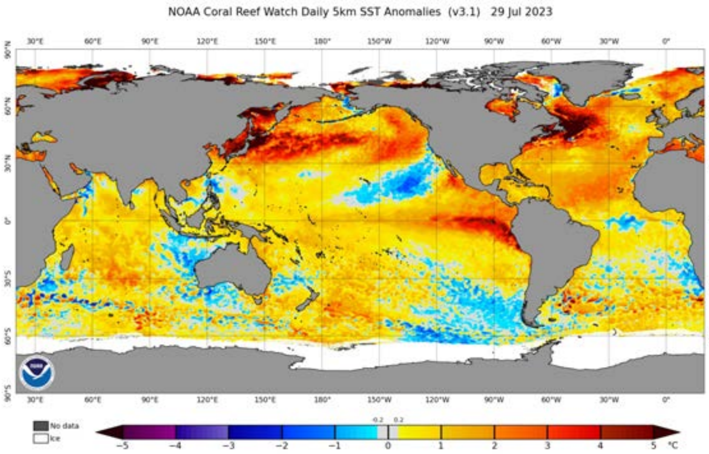
Sea surface temperature

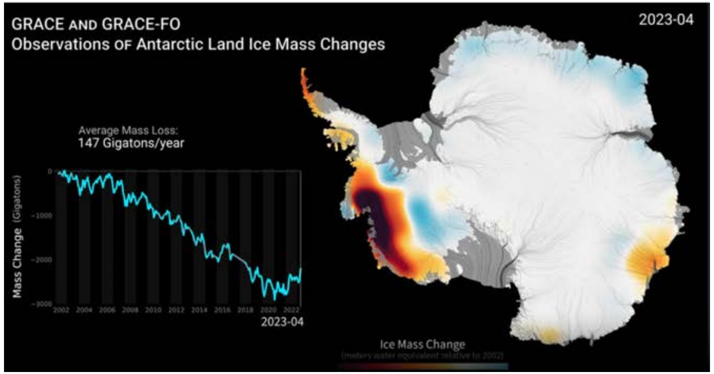
Sea surface salinity

Ocean color

GRACE
    Ice sheet mass
    Ocean bottom pressure

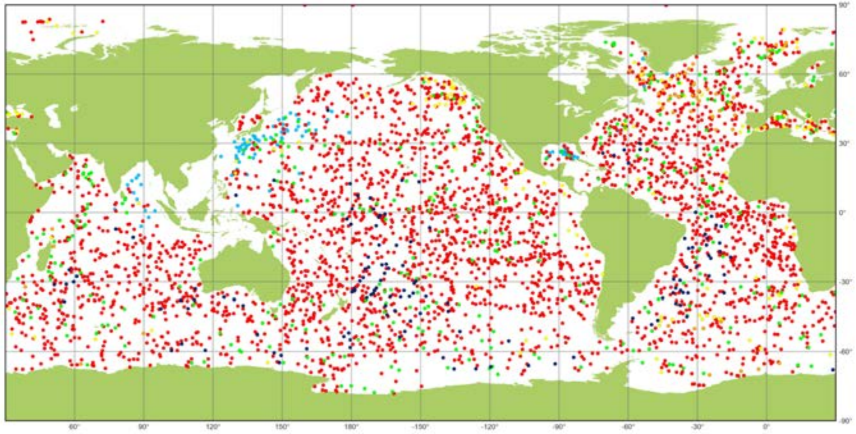
Sea ice properties


NOAA Coral Reef Watch Daily 5km SST Anomalies (v3.1) 29 Jul 2023


GRACE AND GRACE-FO
Observations OF Antarctic Land Ice Mass Changes
2023-04

OneArgo: core (T/S), BGC, Deep

Relatively low density in the Southern Ocean sea ice regions



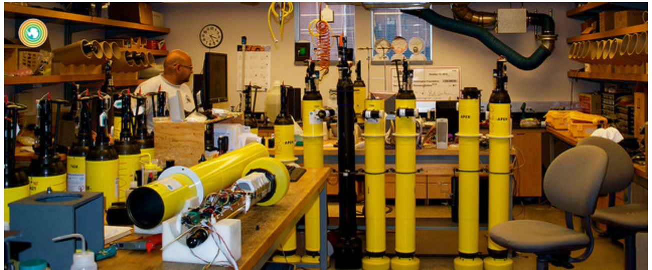
Argo

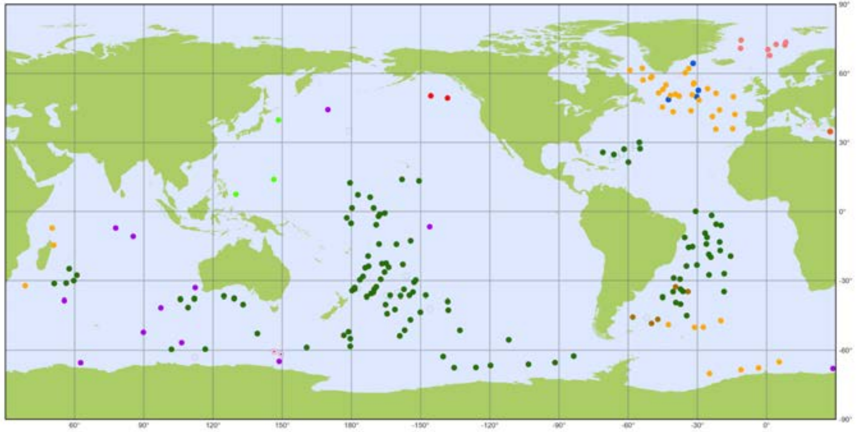
Networks
3849 operational units

June 2023

- ● Deep (TSO only) (55)
- ● Deep (190)
- ● BioGeoChemical (without TSO only) (355)
- ● Core + O2 (TSO) (137)
- ● Core (3059)
- ● Equivalent (156)

Generated by ocean-ops.org, 2023-07-01
Projection: Plate Carree (-150,0000)

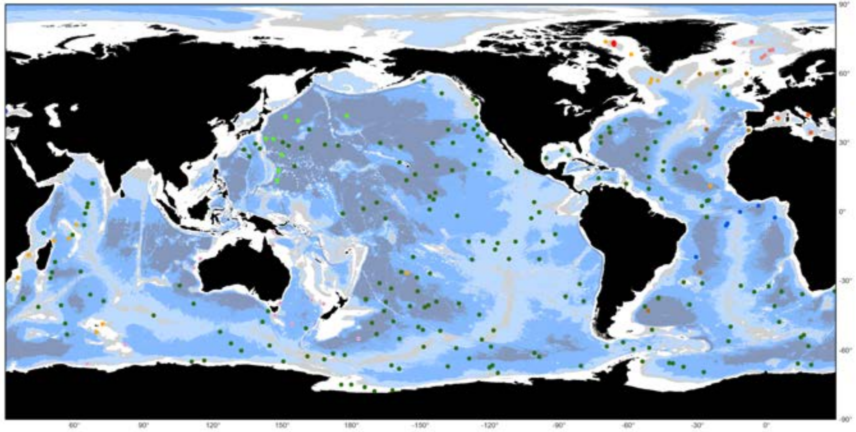




Deep Argo

National contributions - Operational Floats: 191
Latest location of operational floats (data distributed within the last 30 days), pending floats (awaiting data distrbution), or planned floats.

June 2023

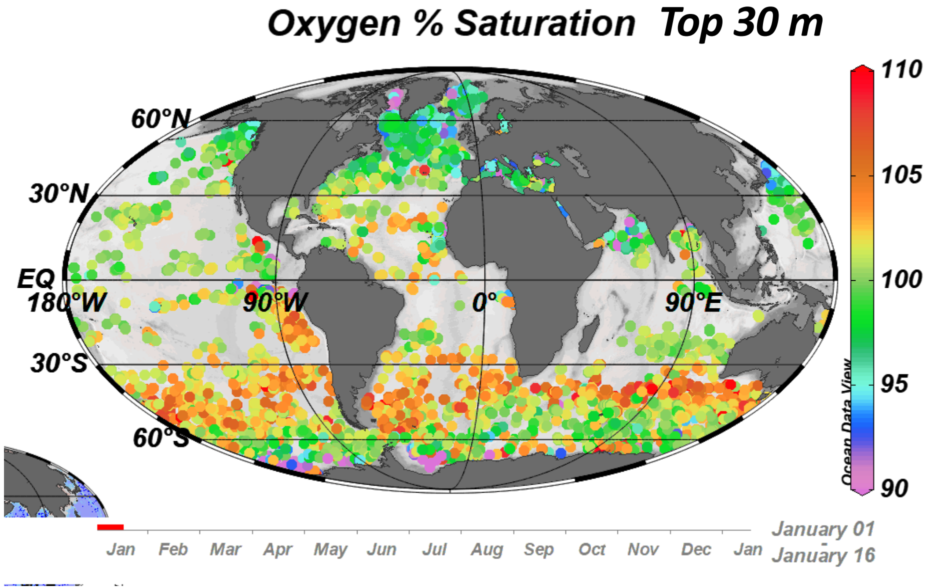


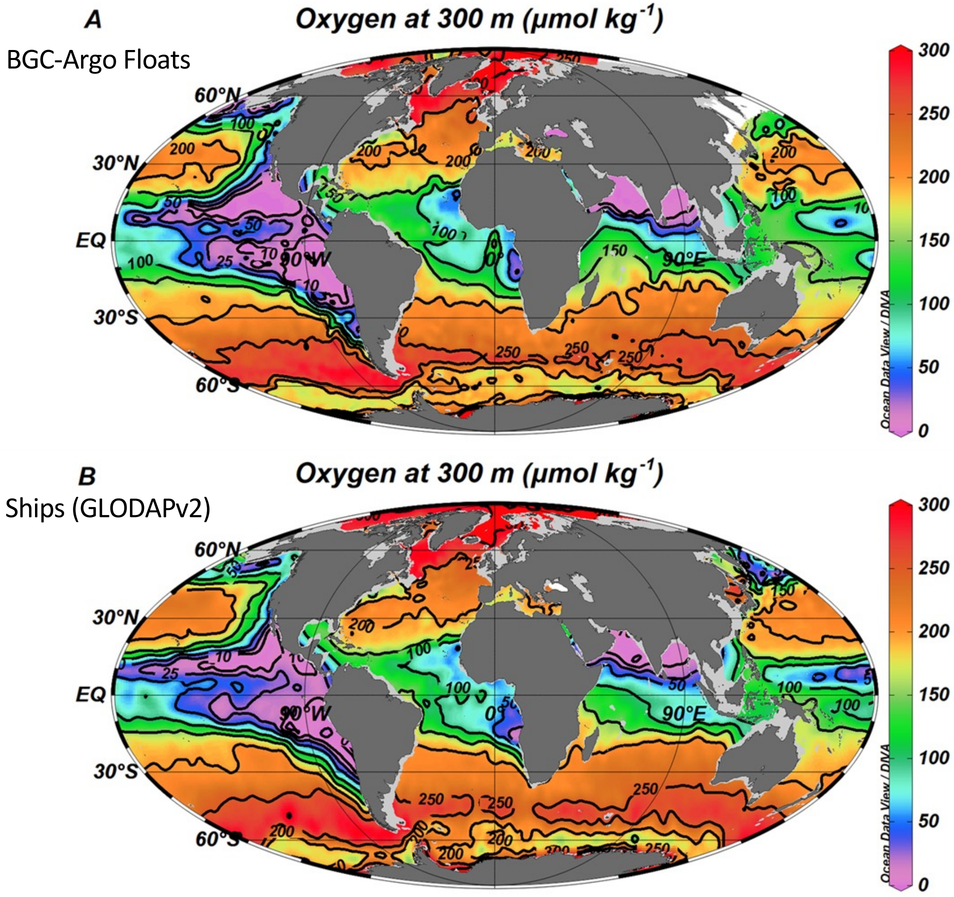
Biogeochemical Argo

Floats sampling 5 or 6 Argo BGC variables - 268
Latest location of operational floats (data distributed within the last 30 days)

June 2023

BGC-Argo floats observe open ocean O_2 with 10 day resolution to ~2000 m





biogeochemical Argo

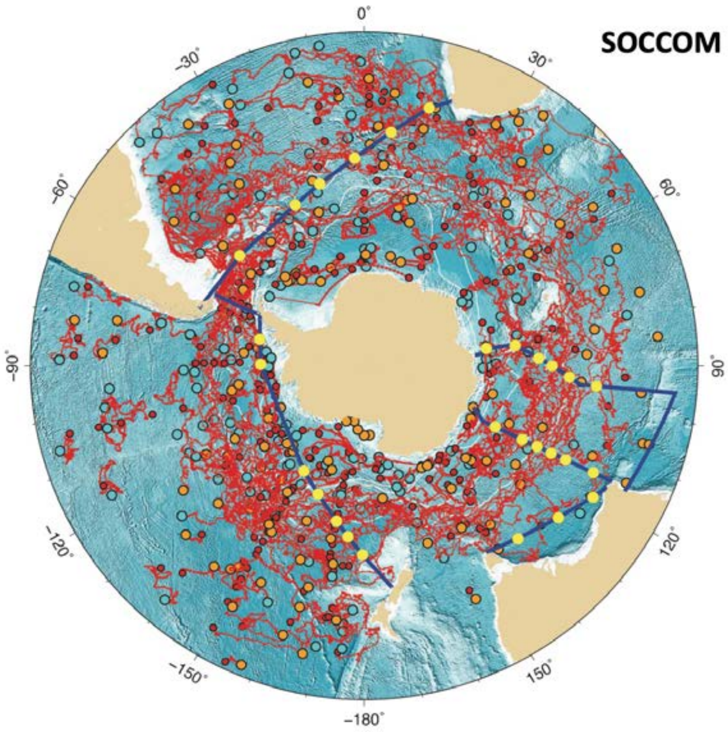
Southern Ocean Carbon and Climate Observations and Modeling

SOCCOM NSF OPP funding 2014-2024

Providing enhanced under sea-ice deployments and BGC sensors

SOCCOM3 proposal has been submitted

GO-BGC NSF infrastructure funding 2020-2025 (global deployments)



SOCCOM Floats Year 10 2023-2024

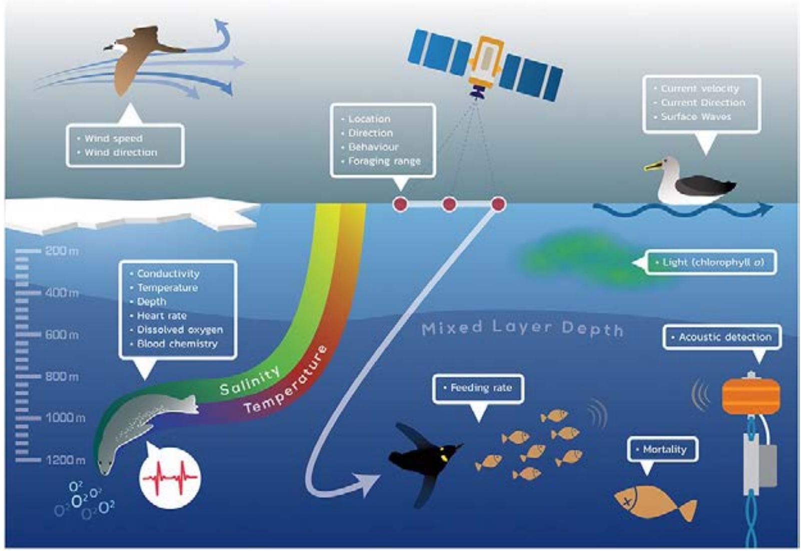
Planned deployments
27 planned
Yellow: Floats
Blue: Sections/stations

Previous deployments
268 deployed; 129 active
Red: trajectories
Orange: current active
Cyan: last dead

July 28, 2023

AniBOS (Animal Borne Ocean Sensors): GOOS

https://anibos.com/about/



Formerly MEOP

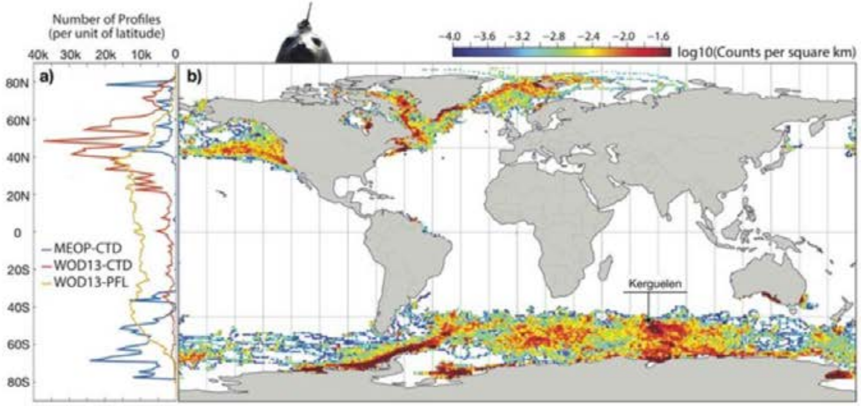
AniBOS (Animal Borne Ocean Sensors): GOOS

https://anibos.com/about/

Data used for supercooling study
Haumann et al. (GRL 2020)

Very helpful for under ice studies

Distribution of CTD, Argo, and AniBOS



Pauthenet (2018)

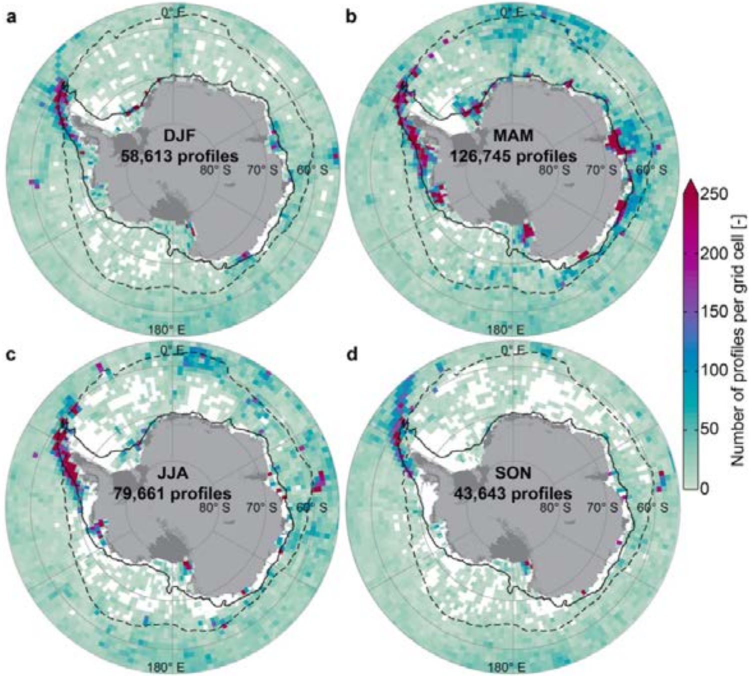
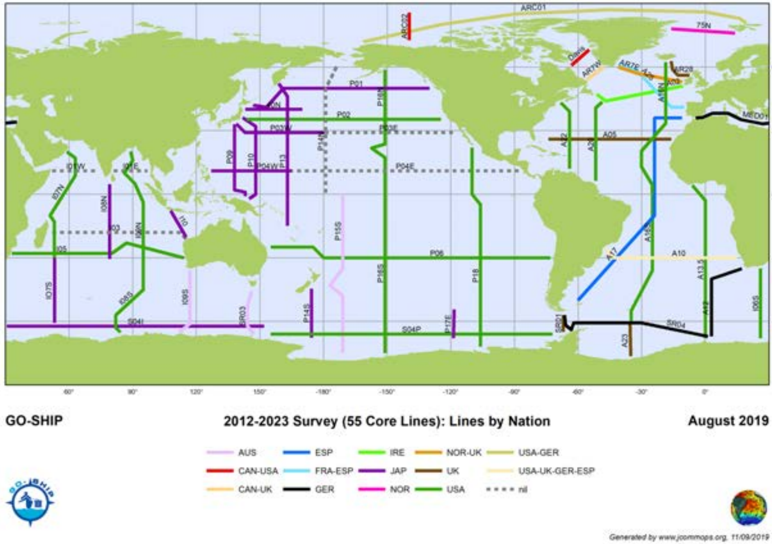
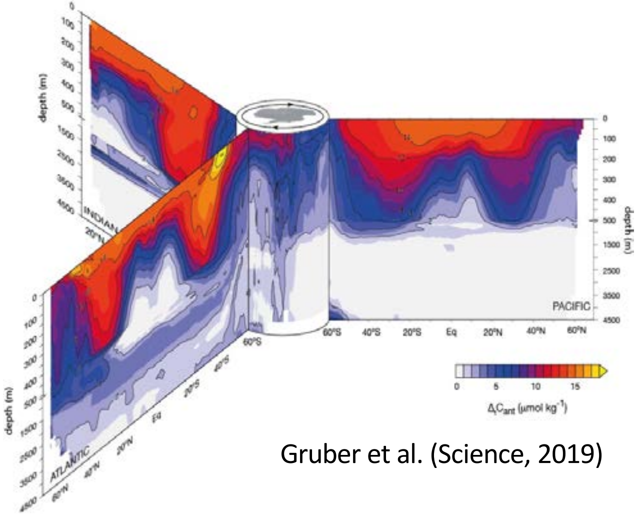


Figure S1. Spatial distribution of observations for each season. a) Austral summer

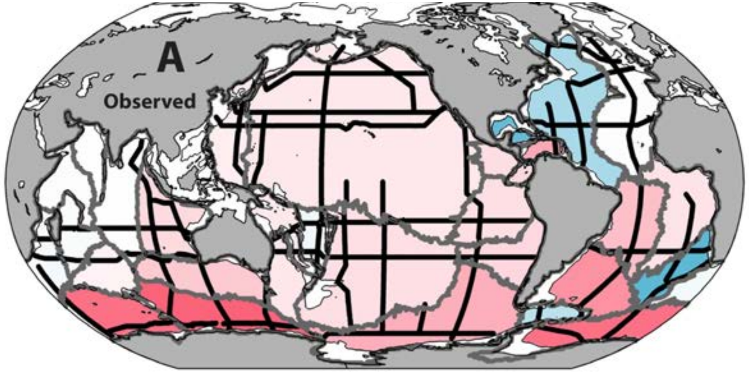
Ship-based hydrography including GO-SHIP and repeated regional surveys

US funding: NSF GEO and NOAA GOMO
Documenting decadal change
Providing platform and reference standard data for autonomous systems
Access to deep ocean
Biogeochemistry
New: Bio GO-SHIP





Gruber et al. (Science, 2019)



Durack et al (Oceanography, 2018)

Circumpolar coverage by national regional survey regions? Consortium experiments?

SOOS regional working groups

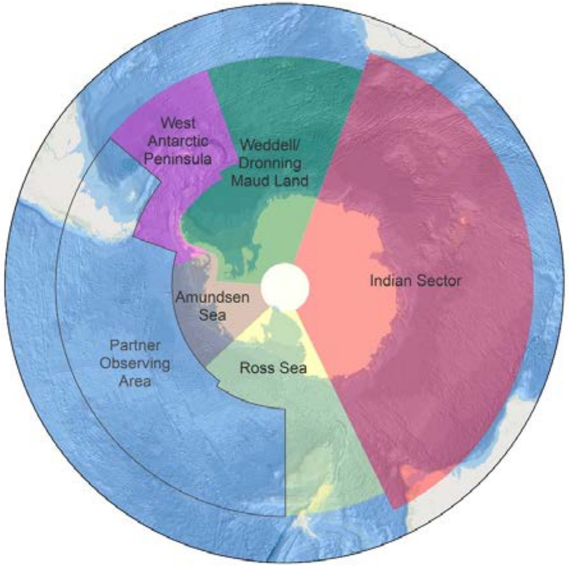
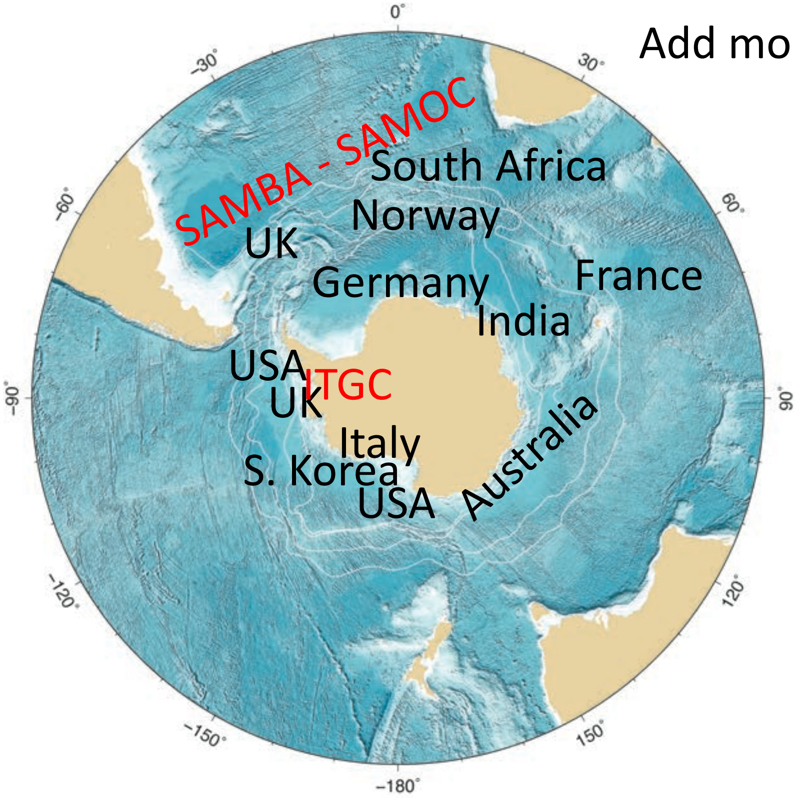


FIGURE 2 | Map of the five Regional Working Groups developed by SOOS to integrate the existing observational efforts in a region and facilitate efforts to address key gaps in observational coverage. The regions are based on the natural areas of focus for nations working in the Southern Ocean and facilitate regional coordination in (1) scientific information exchange, (2) technology transfer/collaboration, (3) standardization of measurements, and (4) sharing of data. The Partner Observing Area is a region not presently covered by a working group. In the interim, the SOOS Scientific Steering Committee will maintain oversight of the observational coverage of this region to ensure requirements are met. Base map data from ESRI, GARMIN, GEBCO, NOAA NGDC, and others.

Add more!



SAMBA - SAMOC
South Africa
Norway
UK
Germany
France
India
USA
ITGC
UK
Italy
S. Korea
USA
Australia

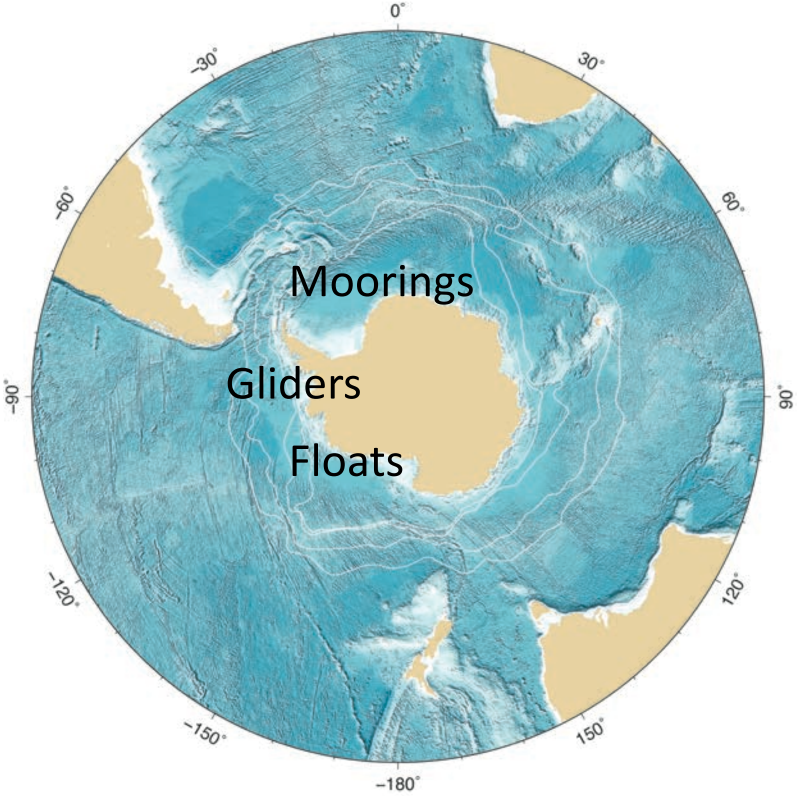
AUV and other profiling float activities

Profiling floats that are not part of Argo
West Antarctic Peninsula

Moorings in Weddell (Germany)

Glider experiments

Subice AUVs



Southern Ocean Observations: What’s working

Somewhat random, rambling, and incomplete list: add your own!

Under SOOS and SCAR international structures, which include the CLIVAR SORP, there is much forward momentum and international coordination of observations

Circumpolar profiling float infrastructure for climate-relevant observations (heat, freshwater, carbon, nutrients, biology)

Regular hydrographic surveys by Antarctic Treaty nations, GO-SHIP

Deep reliance on state estimation and assimilation is excellent, for both providing model-based/observation-informed output, and for providing statistics to map observed fields.

Circumpolar air-sea flux in situ observation improvements are stymied, but are enabled by ocean state estimation.

Opportunity to take full advantage of SWOT to study submesoscale dynamics, in conjunction with SST, ocean color, impacts on larger footprint satellite and in situ (float) observations.

Southern Ocean Observations: Gaps and Limitations

Add your own!

Circumpolar profiling float infrastructure for climate-relevant observations (heat, freshwater, carbon, nutrients, biology) is not quite sufficient, and is endangered.

Circumpolar air-sea flux improvements are stymied, and withdrawal of the US OOI in the SE Pacific was not helpful, although was necessary from cost perspective.

Diapycnal mixing: mostly driven by local experiments. Is there a more hemispheric approach in addition to 0-2000 m Argo? Or is this necessarily limited? Engage all countries with regular observations to carry out mixing-relevant measurements – LADCP, chipods? Develop deep EM-Apex floats and deploy circumpolar array?

Final Thoughts - What might US CLIVAR do organizationally?

Relationship to SOOS
Strong and **activist** support for sustained observing system funding, with specific priorities in the Southern Ocean (see previous slide, but also with input from a broader group than just me)

Participate in coordination of multiple country regional observatories – data management

Consider forming a new US CLIVAR-led international effort to address one of the OceanObs19 priorities/observing systems:

- US is already part of the ITGC (ice sheet melt)
- Focus on sea ice? Ross Gyre and Amundsen Sea? Ross Sea Marine Protected Area? Circumpolar?

Relationship to SCAR

Relationship to the UN Decade of the Ocean (international) for international CLIVAR?
Relationship to the US Ocean Decade for US CLIVAR?