Climate Variability Research in the Southern Ocean

Alex Orsi and Kevin Speer

on behalf of the

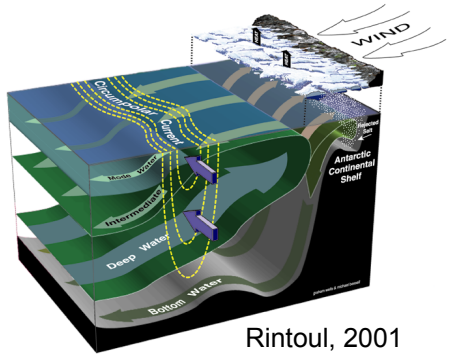
Southern Ocean Region Implementation Panel

http://www.clivar.org/organization/southern/southern.php

U.S. CLIVAR Summit, Denver, 7 July 2010

Southern Ocean-Cryosphere-Atmosphere interactions

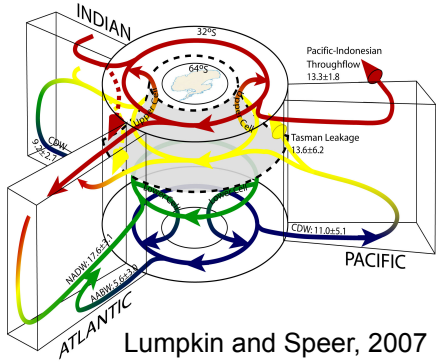
Stability of the Southern Ocean overturning circulation; Southern Ocean role in global heat and freshwater balance



Rintoul, 2001

Stability of the Antarctic ice sheet; contribution to sea-level rise

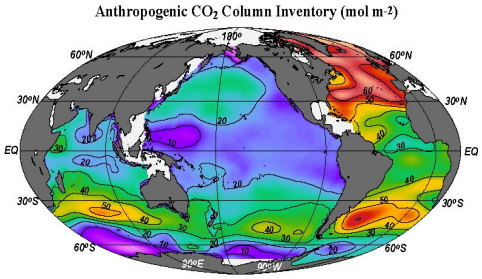
Future of Antarctic sea ice



Lumpkin and Speer, 2007

Future of Southern Ocean carbon uptake; contribution to rising acidity levels

Impacts on Antarctic ecosystems



Sabine et al., 2004

How do we proceed?

Progress with ***observational programs and modeling***

Observations fall into two categories:

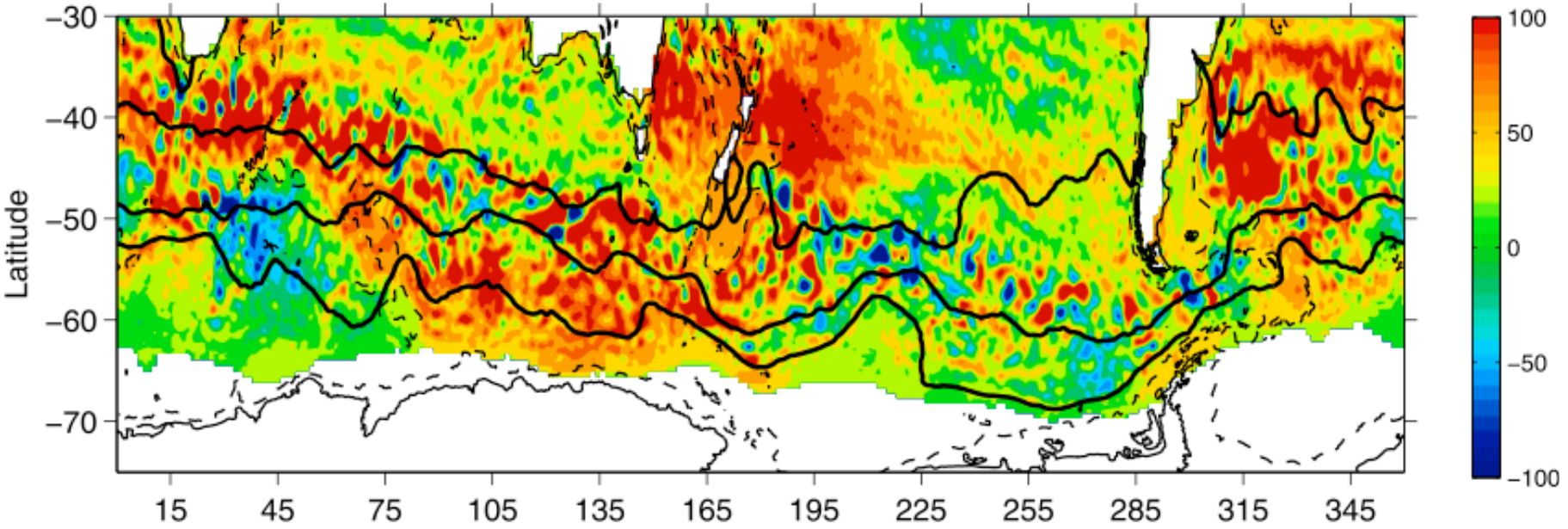
- **Process studies** of limited duration and targeted scope
  (e.g. DIMES)

- **Sustained long-term** measurements
  (e.g. CLIVAR repeat sections, moored time series)

There is always a ***need to identify and revise*** the most important science questions for CLIVAR to address based on the latest research

Science Highlight: trends in sea surface height

Evidence of modal (SAM) control on ACC frontal positions, and of influences on dynamics over interannual and longer time scales



Linear trends in SSH (mm) in the Southern Ocean in 1992–2007.

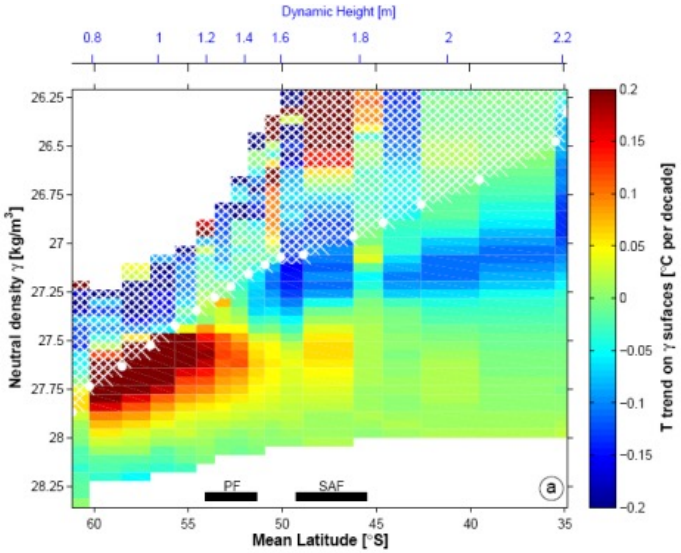
Sokolov and Rintoul (2009)

ACC may be in eddy-saturation regime, i.e. stronger westerlies do not translate into larger transport but in enhanced eddy activity

Meredith and Hogg (2006), Screen et al. (2009)

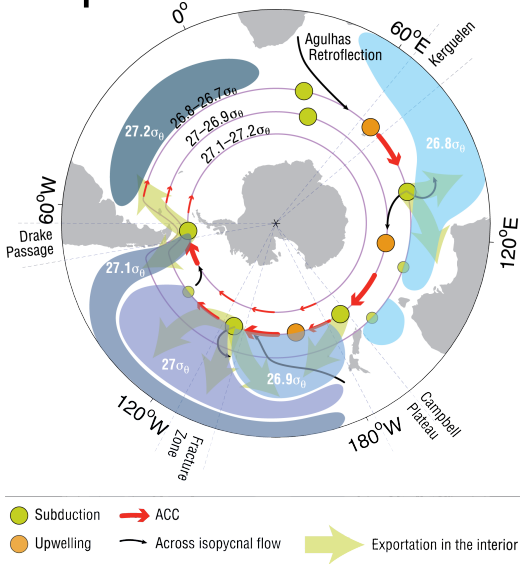
Science Highlight: water mass changes in the upper ocean

Evidence of climatic modes projected into the Southern Ocean interior



Böning et al. (2008)

Changes in eddy activity imprinted on Subantarctic Mode Waters



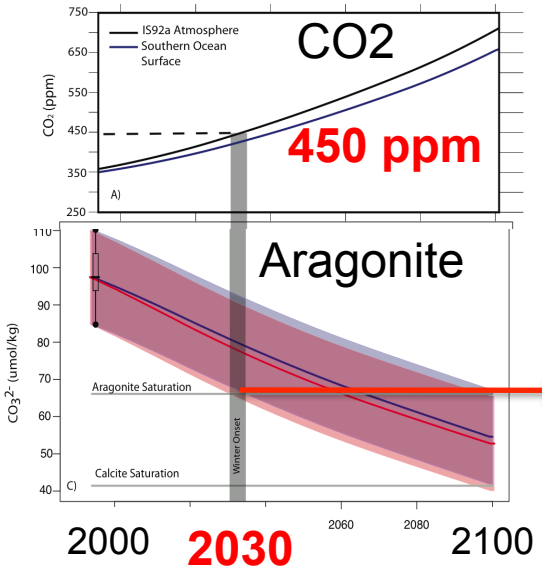
Sallee et al. (2009)

Science Highlight: Southern Ocean still a sink

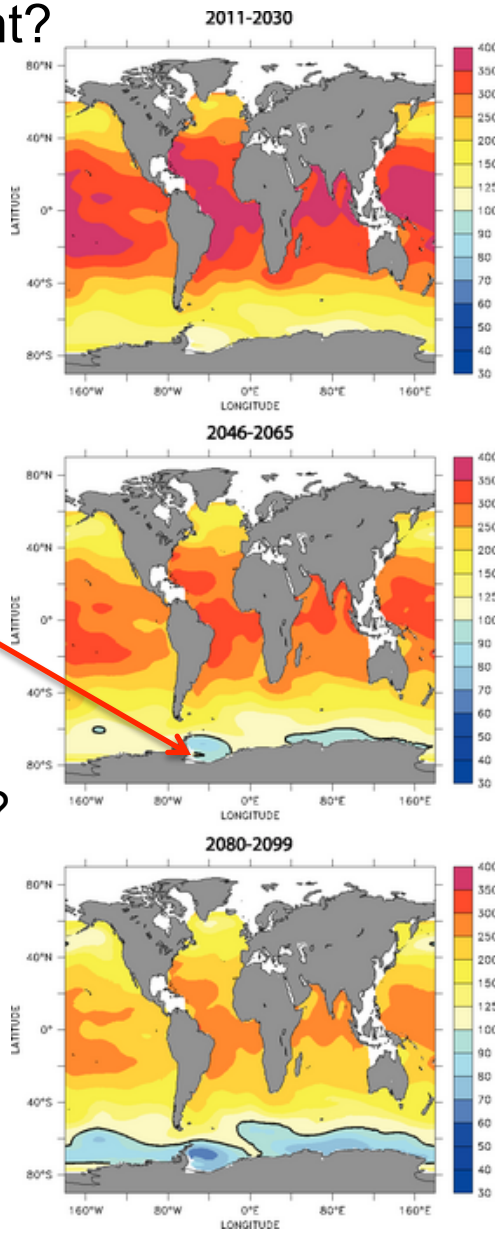
CO2 fluxes weakening as SAM changes?

Acidification near tipping point?

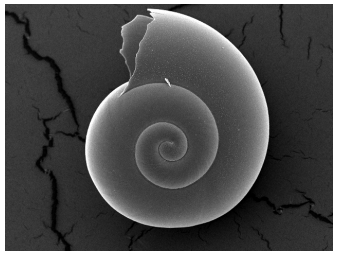
OCMIP-2 models predict



undersaturation (blue) by 2030?



Aragonite % saturation

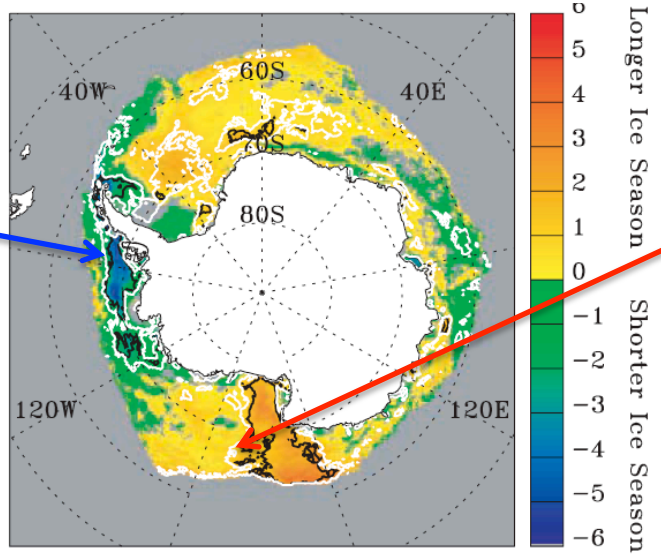


Aragonite Pteropod:
a major food source may start to dissolve

Orr et al. (2005)

Science Highlight: regional changes in Antarctic sea ice

Ice season duration over 1979 – 2004



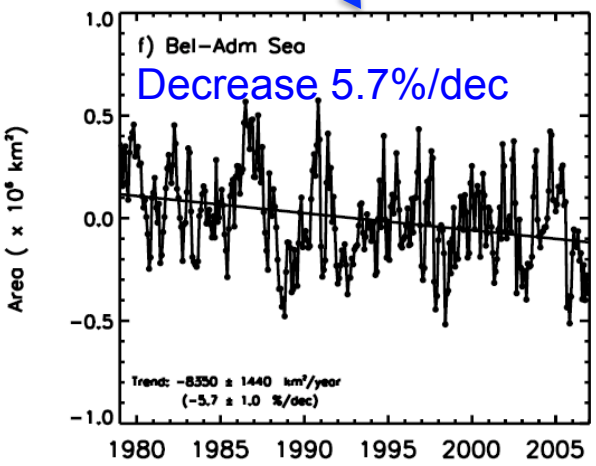
Bellinghausen -Amundsen seas

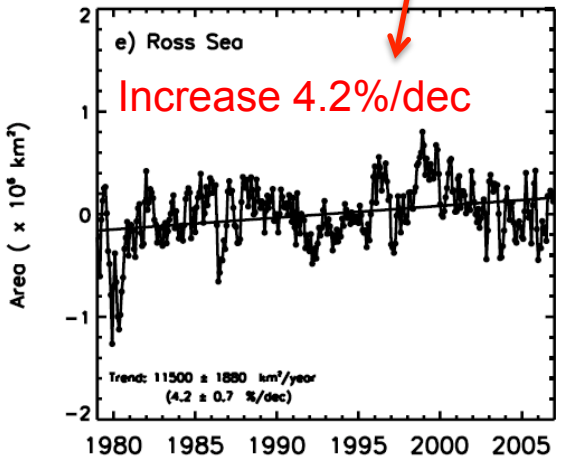
-83 ± 23 days

Ross Sea

57 ± 13 days

Stammerjohn et al. (2008)





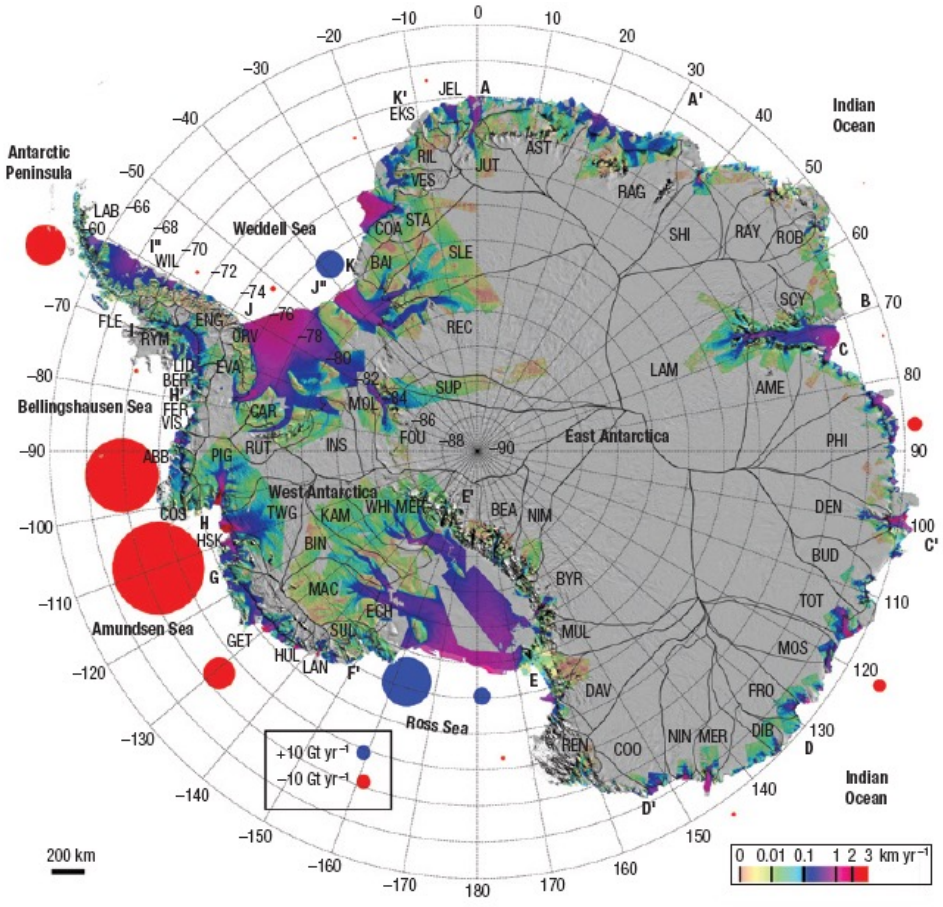
SO increase: 1%/dec

Comiso and Nishio (2008)

Science Highlight: increased loss of Antarctic ice mass

75% in last decade as a result of warmer air and ocean temperatures

Most from Pine Island Bay sector of West Antarctica

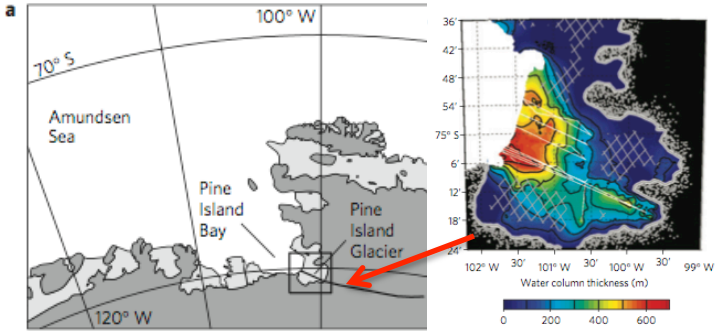


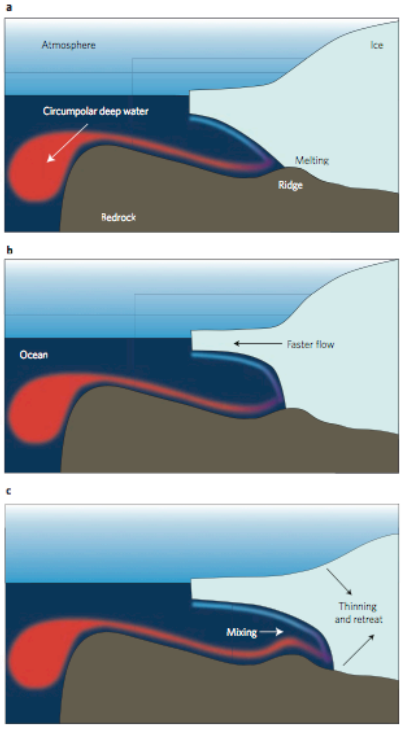
Rignot et al. (2008)

Science Highlight: accelerated basal melt of ice shelves

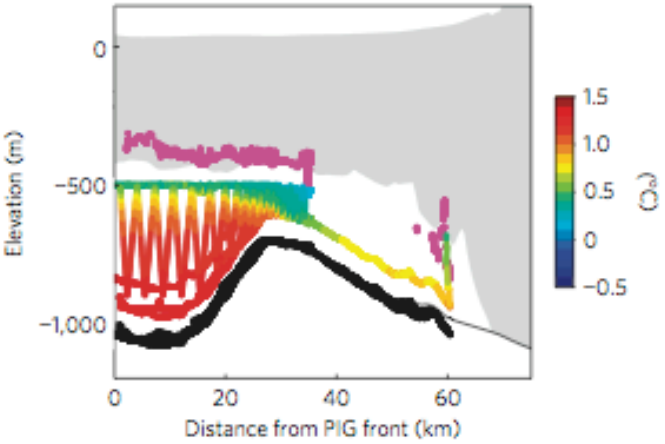
Process Experiment: Ocean – ice shelf interaction

fueled by intrusions of Circumpolar Deep Water (CDW)
freshened surface waters (AASW) of the Amundsen Sea





Autosub under Pine Island Glacier



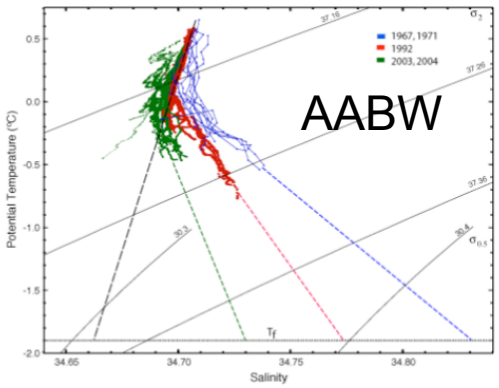
Even stronger as SAM changes?

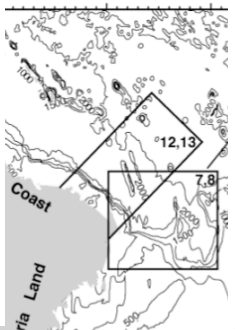
Jenkins, Jacobs et al. (2010), Schoof (2010)

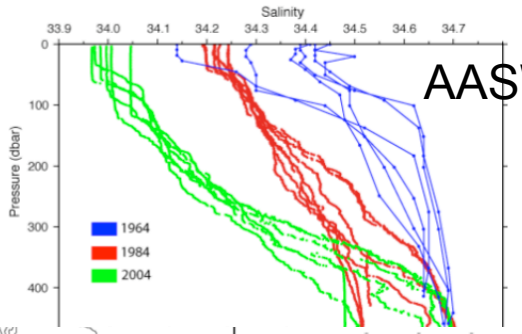
Science Highlight: long-term change at overturning site

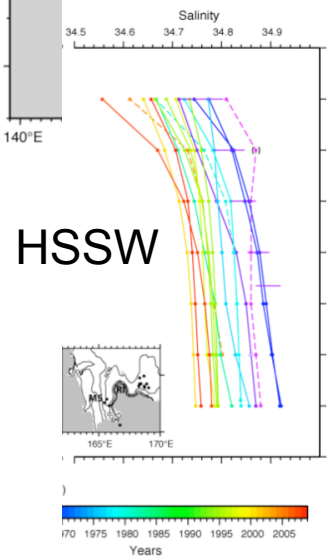
50-year freshening trend of Ross Sea waters

Jacobs and Giulivi (in press)

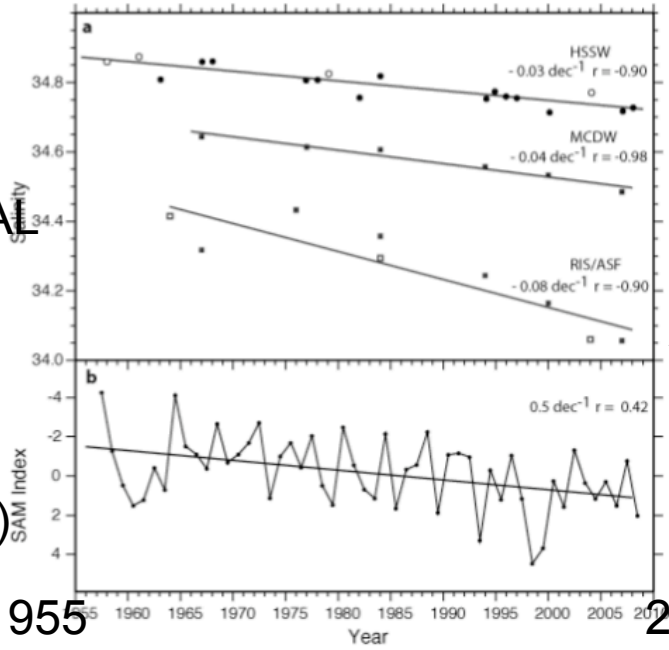








SAL

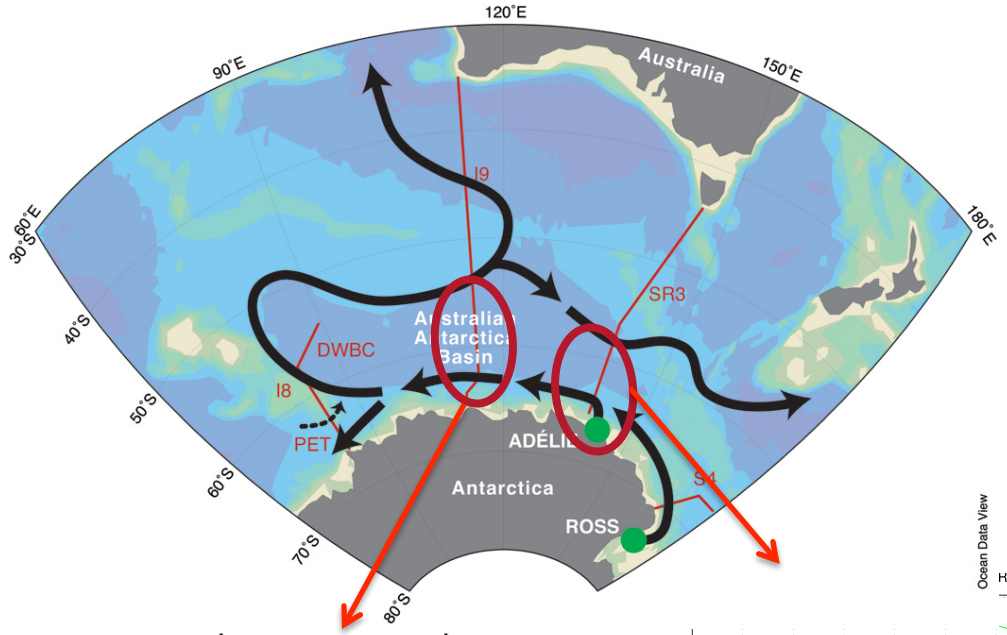


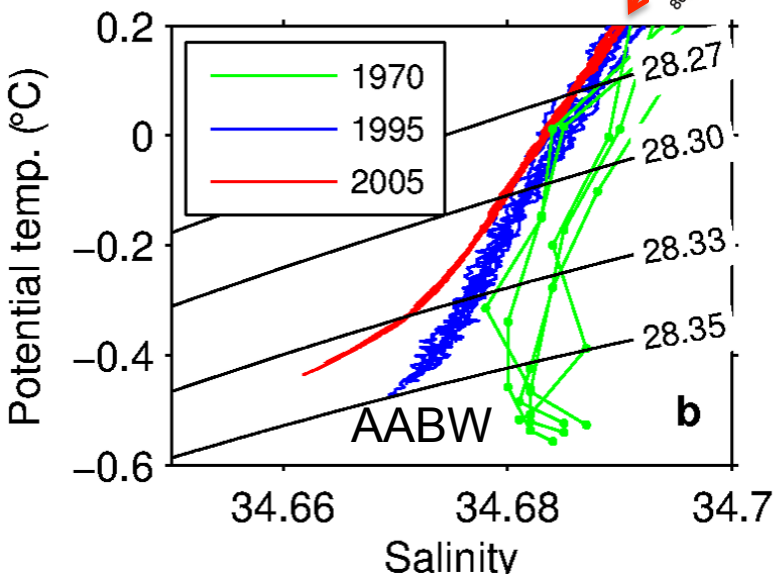
SAM (flipped)

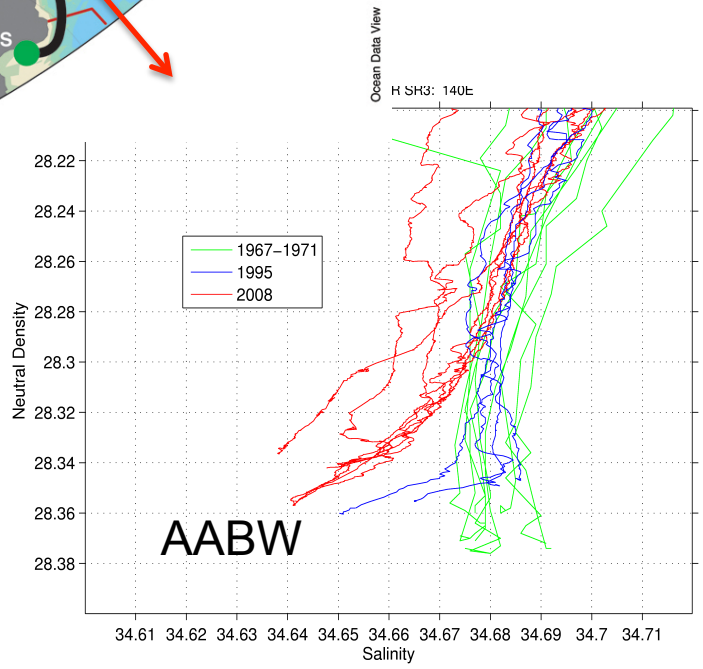
1955

2010

Science Highlight: widespread freshening of AABW







Rintoul (2007)

CLIVAR requested the development of:

IMPERATIVES

and

FRONTIERS

of climate science in the Southern Ocean

And here they are…

http://www.clivar.org/organization/southern/Vision_SO_15May09_update.doc

CLIVAR IMPERATIVES

- **ABSOLUTE** need to maintain ARGO, full water column depth hydrographic (water sampling), and extend sampling or observational techniques to the under-ice-covered ocean, up to the ice shelf grounding line.
- The Southern Ocean appears to be eddy saturated but we don't understand the role of eddies with respect to transport and mixing; importantly the IPCC models are not eddy resolving, which is so **CRUCIAL** to address this effect.
- **VITAL** to address the gap in estimates of air-sea fluxes of heat and moisture, CO2, wind stress, and boundary layer parameterization near the continent.
- Broader evaluation of the **IMPACT** of acidification and the ecosystem response.
- More accurate **DIAGNOSES** of freshwater and moisture transfers among the coupled Southern Ocean-Cryosphere-Atmosphere system, and associated feedbacks.

CLIVAR FRONTIERS

- **What is the future of Antarctic ice?**

  sea ice (albedo and surface heat flux feedbacks)
  ice shelves (enhanced CDW intrusions and warming waters)
  land ice (sea-level)
  Improve models of ocean upwelling, overturning, and interactions with continental shelf.

- **What is the future of carbon uptake and acidification?**

  carry out reanalyses using coupled models with biochemical representations of the carbon cycle: syntheses of ocean/ice/atmosphere data and models

- **What is the future of the Antarctic continental margin?**

  evaluation and improvement of Earth system models in the high latitudes of the Southern Hemisphere, including runoff from ice shelf lakes.

High Latitude Meteorology and CLIVAR

There are still open questions on basic meteorology

- **US CLIVAR working group on high-latitude fluxes** ongoing (Spring 2010 Boulder workshop)

- Effects of correct flux boundary conditions, clouds, waves, presence of ice not well represented in reanalyses

CLIVAR Process Study

DIMES 2007-2012:

Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean

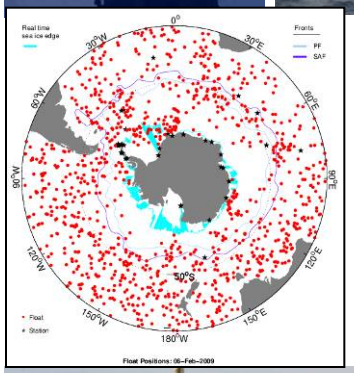
- to refine the present paradigm of mixing and upwelling in the ACC, and improvement of *climate model parameterizations of ocean physics*

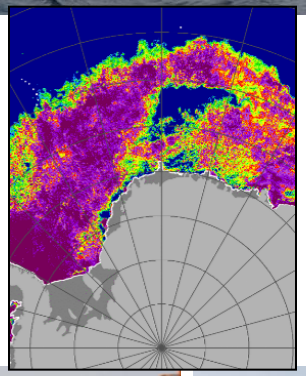
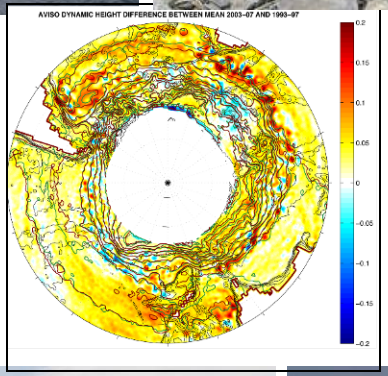
- to constrain models of the Meridional Overturning Circulation

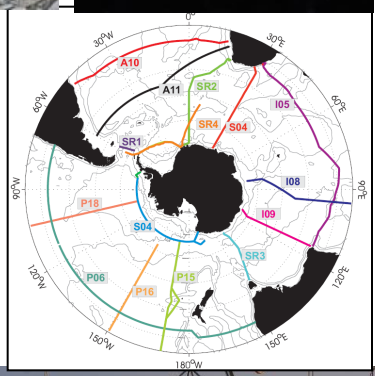
The Southern Ocean Observing System: A Legacy of the International Polar Year

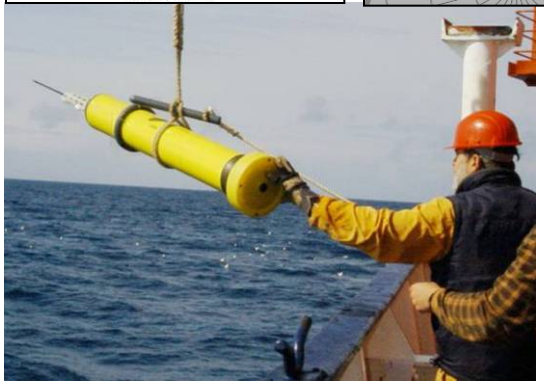










http://www.clivar.org/organization/southern/expertgroup/SOOS.htm

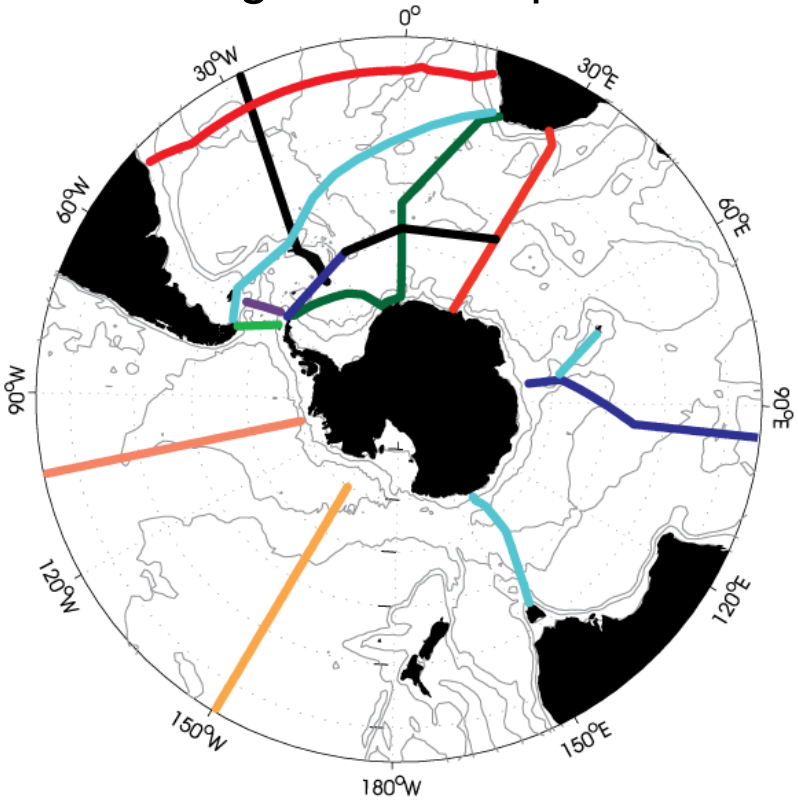
Southern Ocean Observing System Elements

- **Global drifter program**
- **Argo: maintain and enhance (including under ice) + SeaOS: Animal-borne sensors and multiple species**
- **Repeat hydrography + tracers + biology**
- **High density lines: Underway sampling, with enhanced biology observations, XBT but now also ADCP, pCO2, etc.**
- *Remote sensing: altimetry SSH, SST, winds ocean colour, gravity, ice*
- **Tide gauges, moored time series: focus on dense overflows/export, DBCs**
- *Sea ice and Meteorological observations*
- *Continuous plankton recorders*
- *Ecosystem monitoring enhanced with physics/bgc msmts*

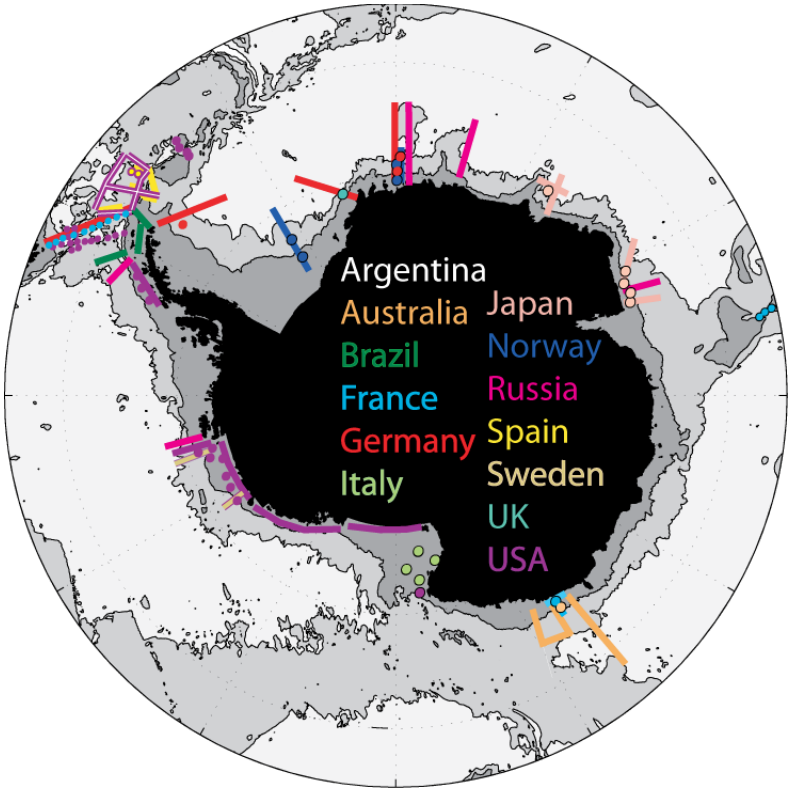
http://www.clivar.org/organization/southern/expertgroup/SOOS.htm

IPY (2007 – 2009)
Hydrography, carbon, tracers, biology ...

- first full-depth “synoptic” snapshot (> 30 cruises in < 18 months)
- multidisciplinary (first iron and other metal sections; biodiversity; air-se interaction)
- tracking the circumpolar evolution of water mass properties

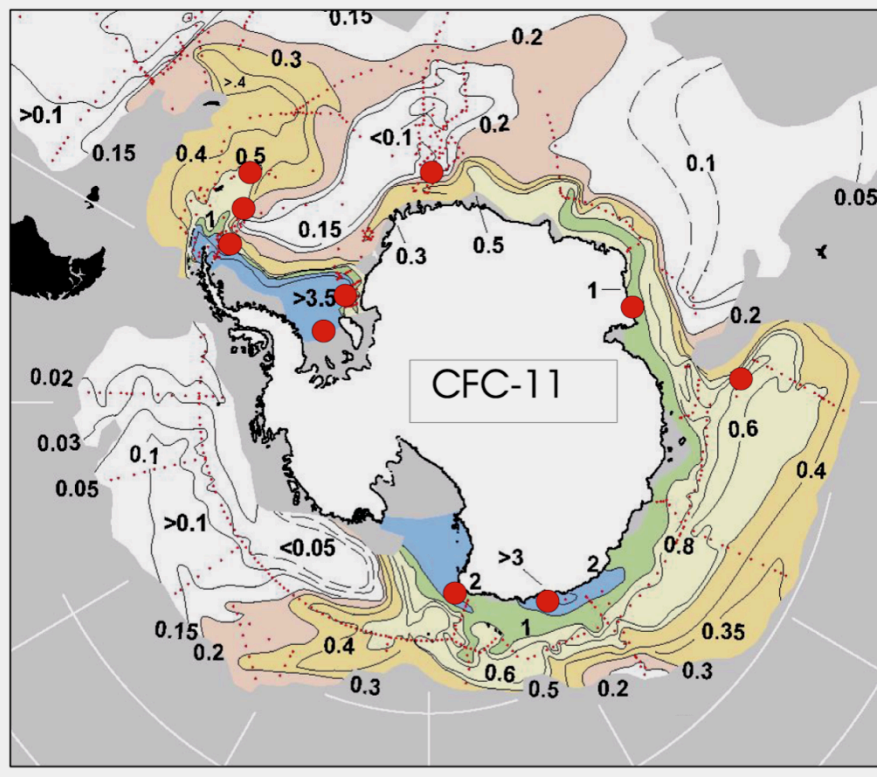


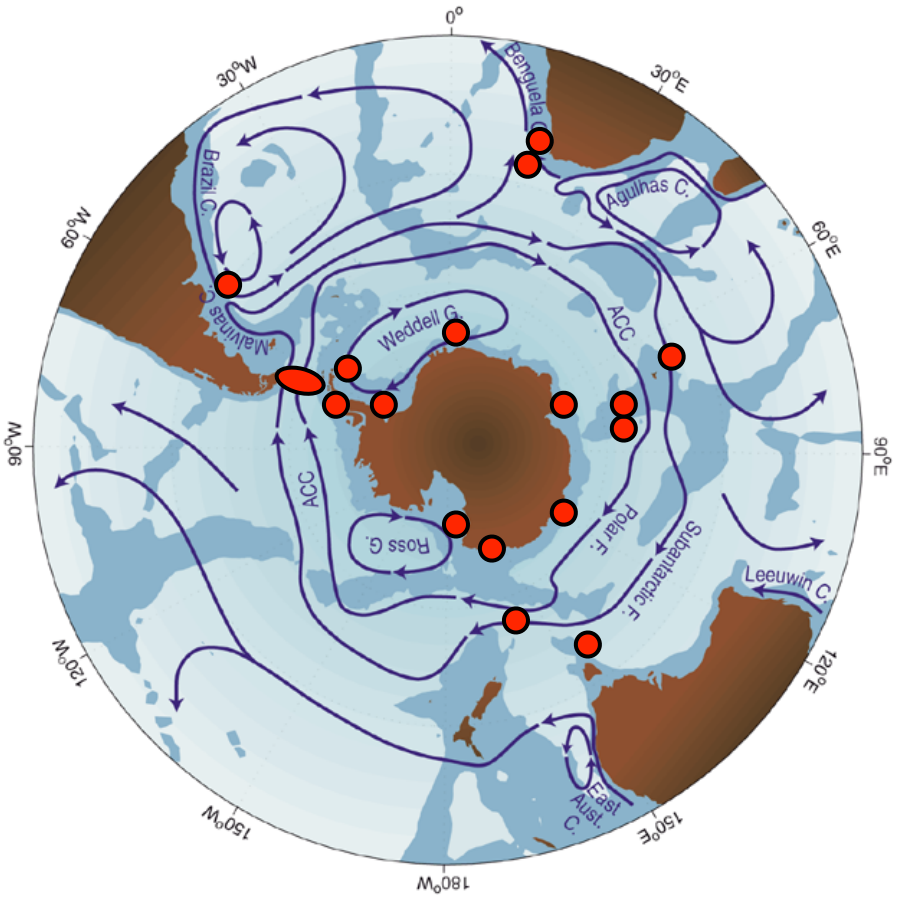
CASO



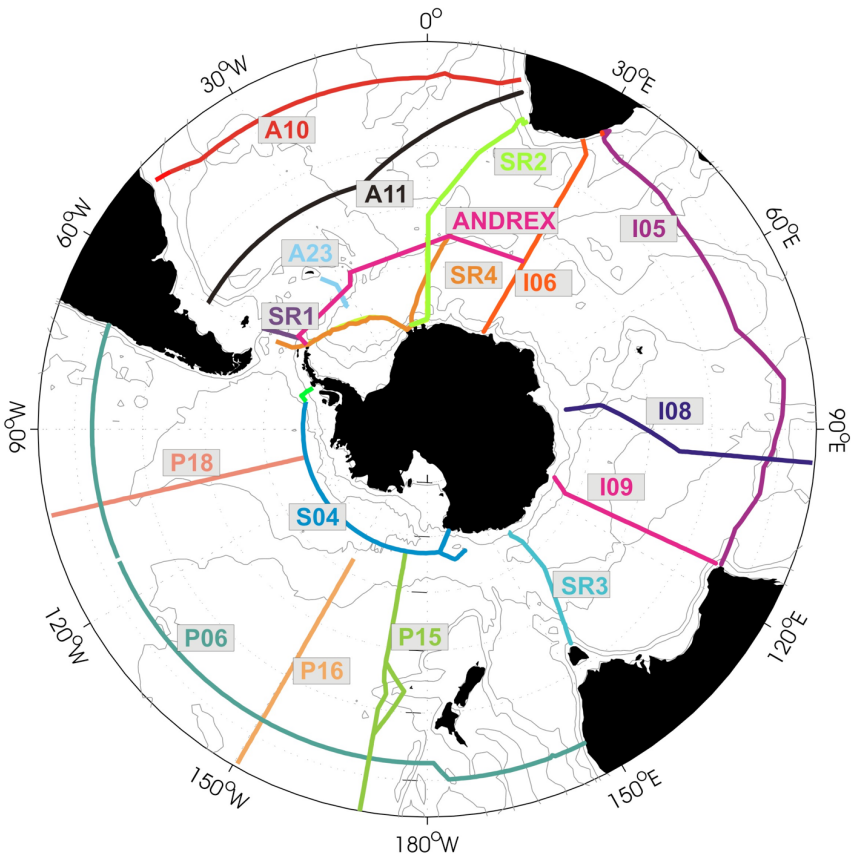
SASSI

Time series measurements

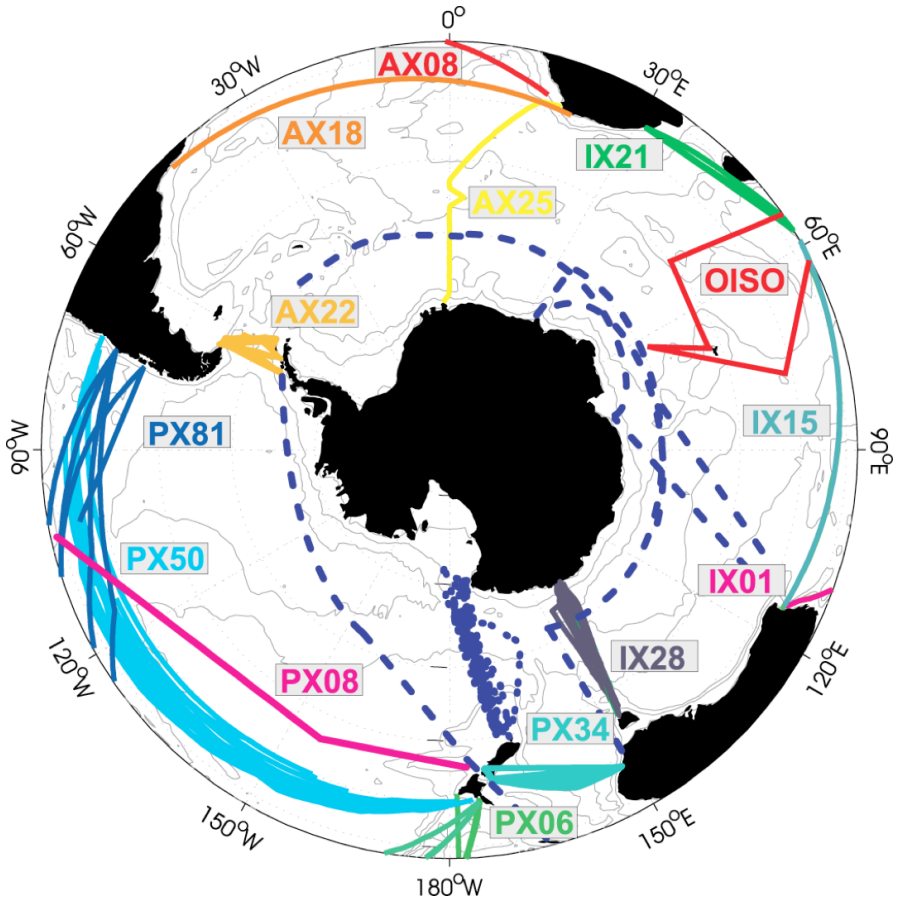




Repeat Hydrography & Tracers



SOOP: underway obs (ADCP, XBT, pCO2)

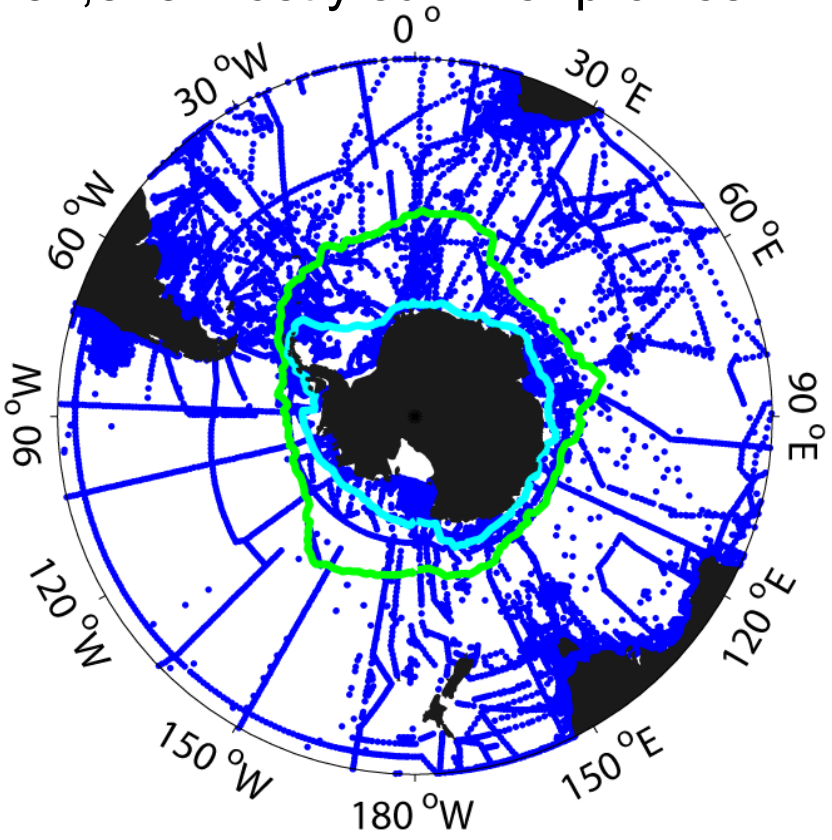


Need to improve observational techniques, specially for **under-ice-covered** regions, up to the grounding lines of ice-shelves

ARGO

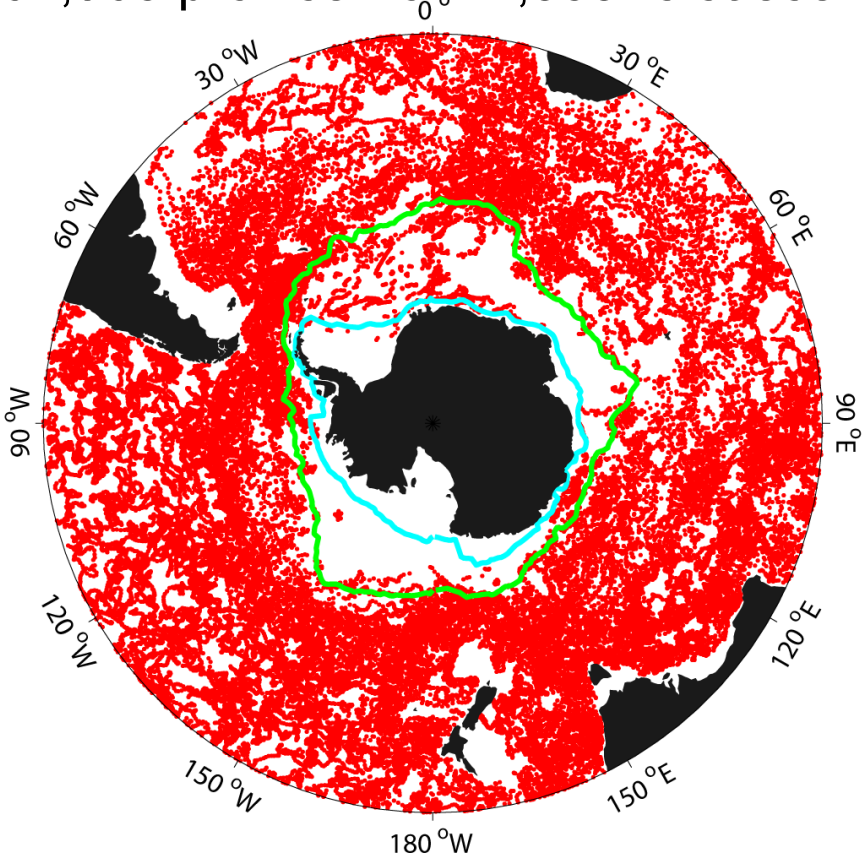
Historical ship [since early 1980s]

32,873 mostly summer profiles



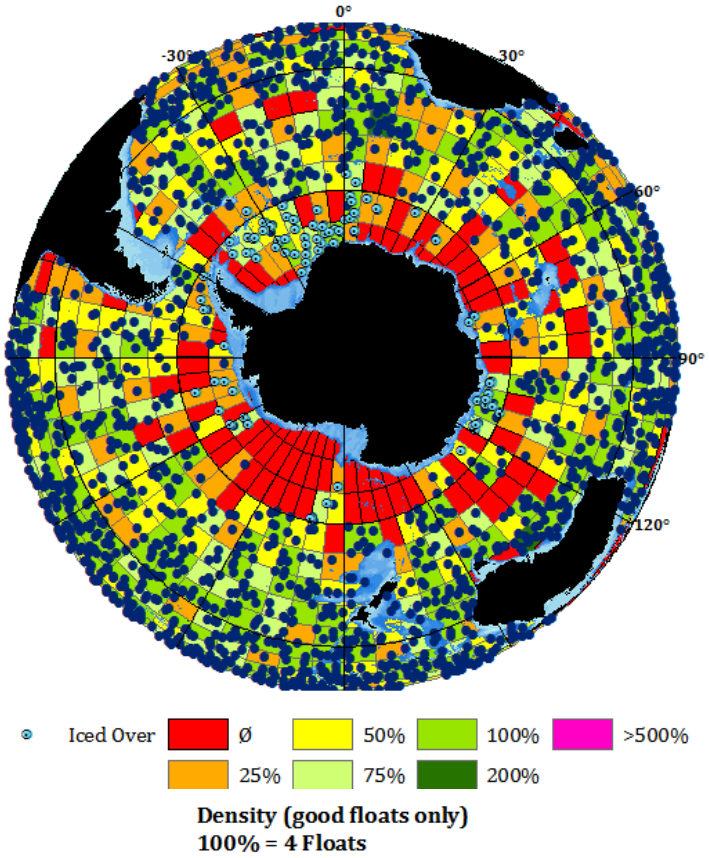
Argo during IPY [03/2007 – 03/2009]

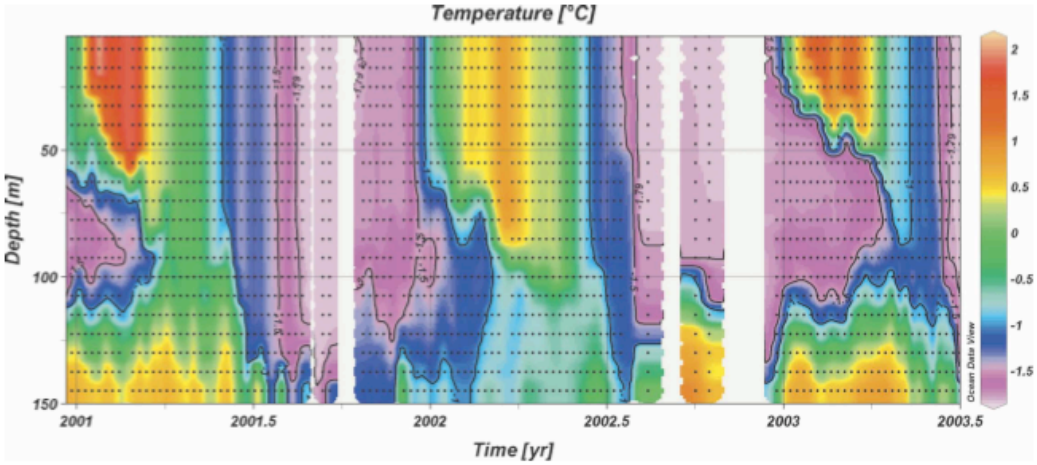
61,965 profiles from 1,353 releases



Under sea ice Argo measurements in the Weddell Sea (Klatt et al., 2007; Fahrbach), and off Wilkes Land (Wong and Riser)

Under cover ARGO



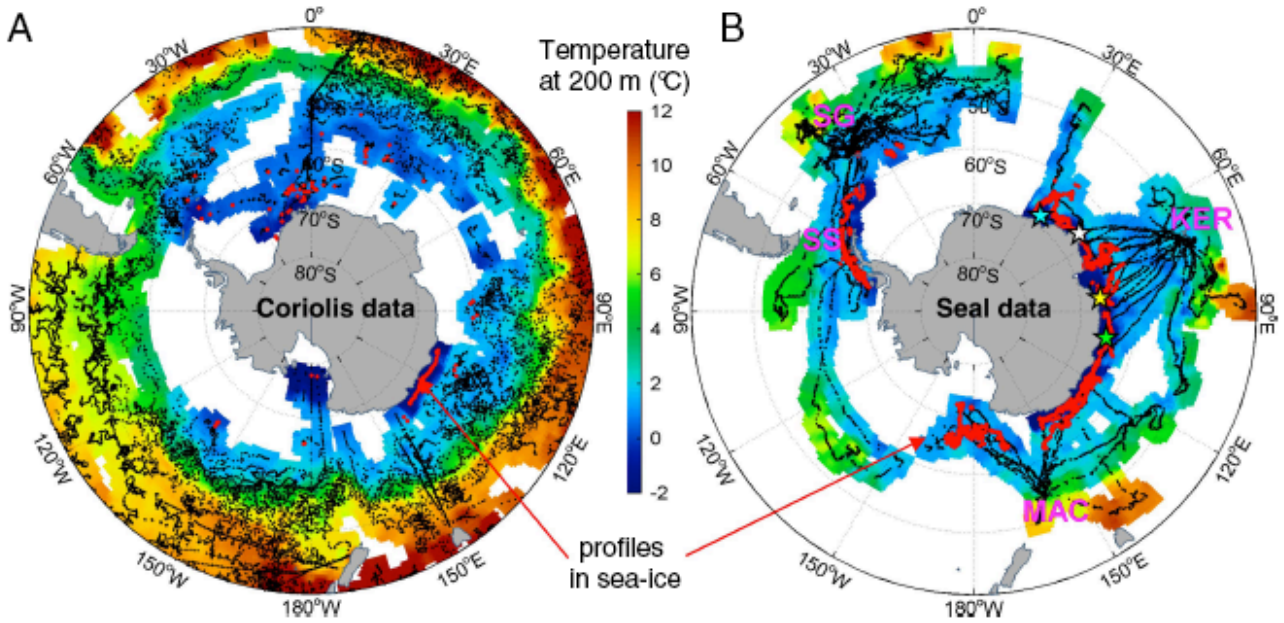


resolved seasonal cycles of sea-ice growth/decay, and the evolution of winter mixed layer

Klatt et al. (2007)

Marine Mammals Exploring the Oceans Pole to Pole (MEOP)

- simultaneous biological and physical measurement
- need to add biochemical sensors



[2004-2005]
14,470 profiles from (XBT+ARGO+ships) vs.
16,500 from seals CTD

9:1 south of 60°S
Under-ice (red dots)

Charrassin et al. (2008)

Southern Ocean Climate Variability
Issues and challenges

Southern Ocean's role in Earth's climate is dominant
Dynamical understanding – coupling, feedbacks, and key modes
Observational progress – process studies and sustained measurements

The SOOS is a first for climate spanning multiple disciplines
Vast, remote, logistically difficult to access – *among least sampled on Earth*
Design/implement for *physical, biogeochemical* and *ecological* processes
Requires involvement of multiple nations and agencies

Observing gaps still exist
Ecosystem monitoring onto Argo profiling
CO2 gas exchange
Must expand ocean coverage within sea-ice zone
Must include atmospheric boundary layer within sea-ice zone
Must include ice interaction regions

Thank You

Modeling Highlights

- SOSE: Southern Ocean State Estimate (reanalysis)

- IPCC models show large variation in sea-ice representation (yet they reproduce some long-term variations realistically)

- Accurate surface fluxes and waves (surface boundary layer meteorology) impacts prediction of winds and storms

- Models - generally improving representations of water-masses and circulation metrics