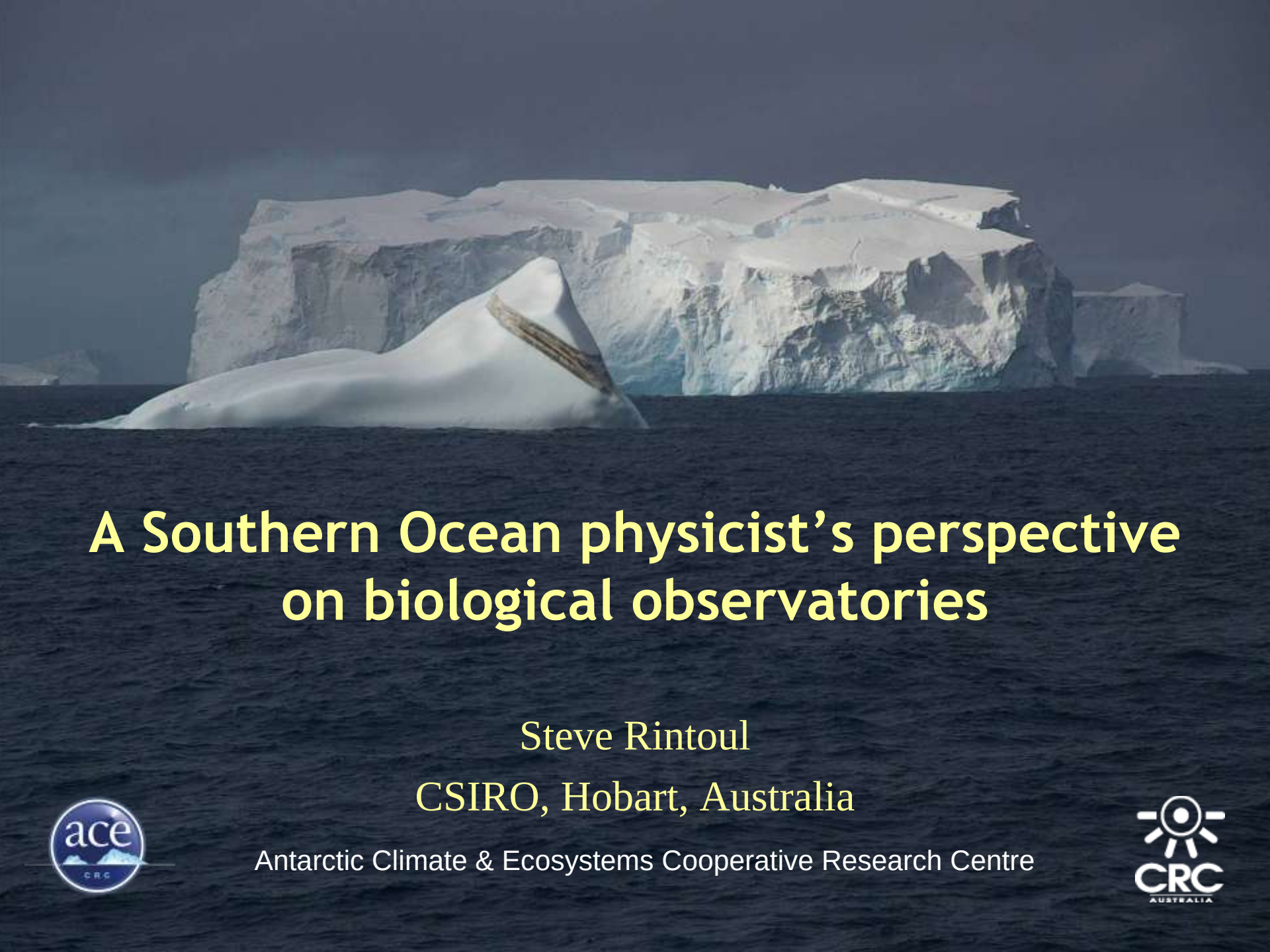


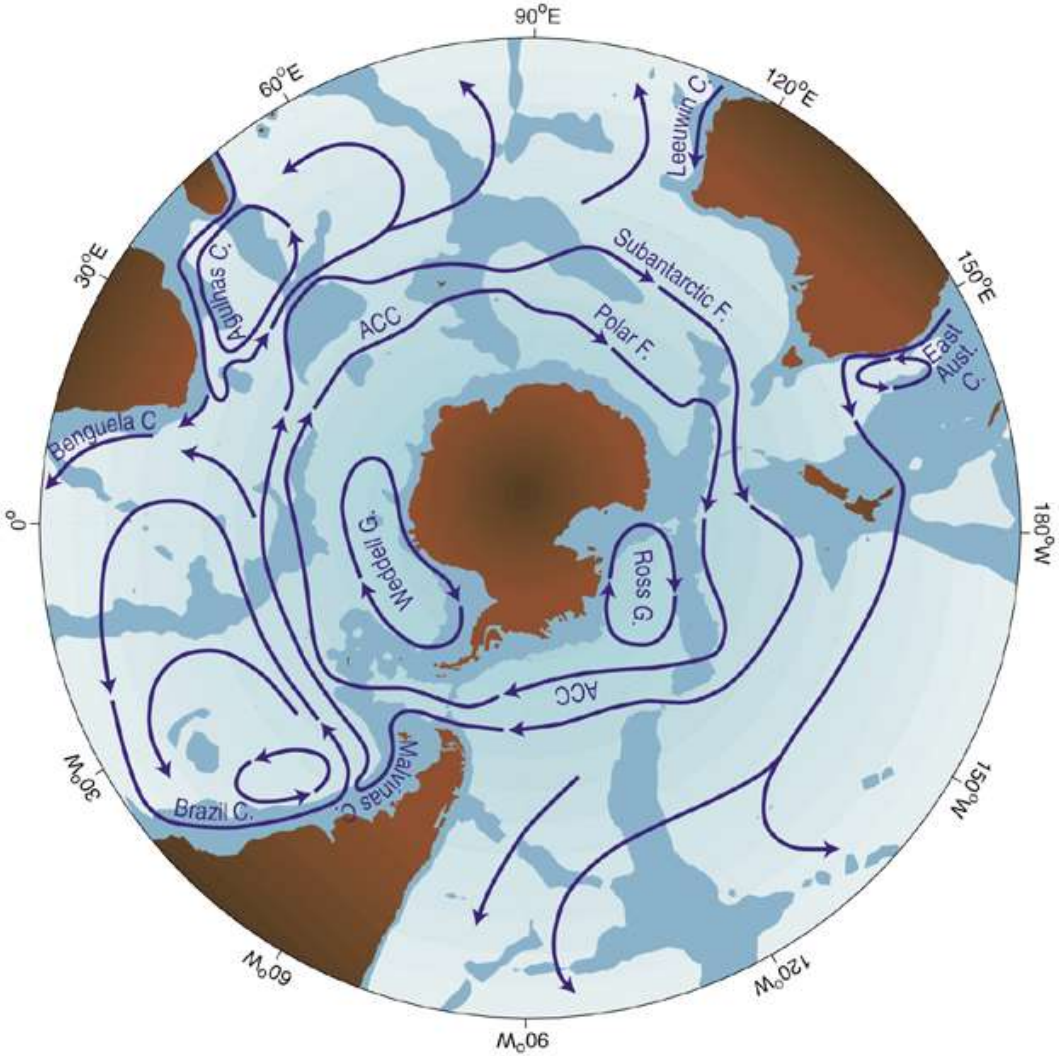
A Southern Ocean physicist's perspective on biological observatories

Steve Rintoul

CSIRO, Hobart, Australia

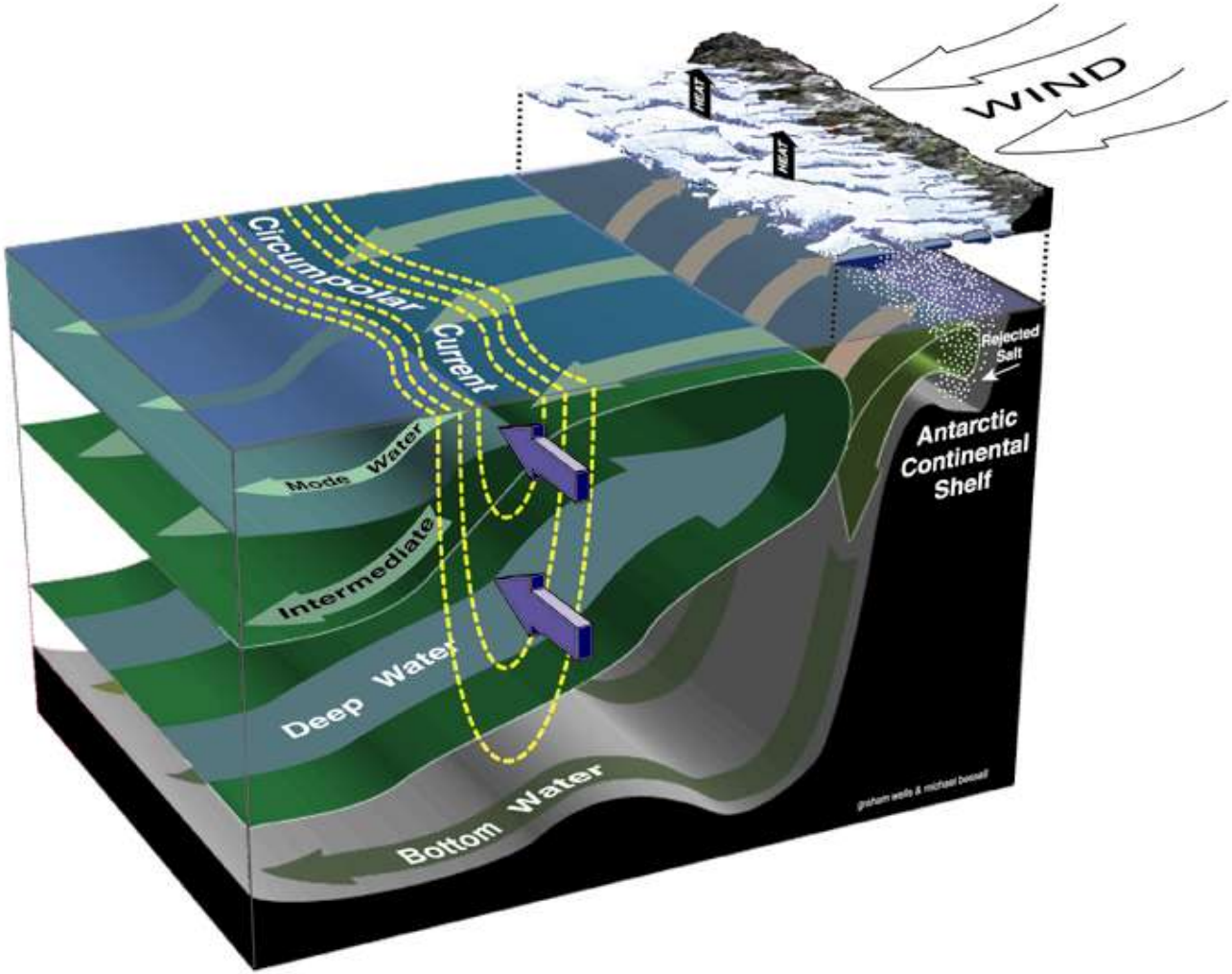
Antarctic Climate & Ecosystems Cooperative Research Centre

Connecting the ocean basins



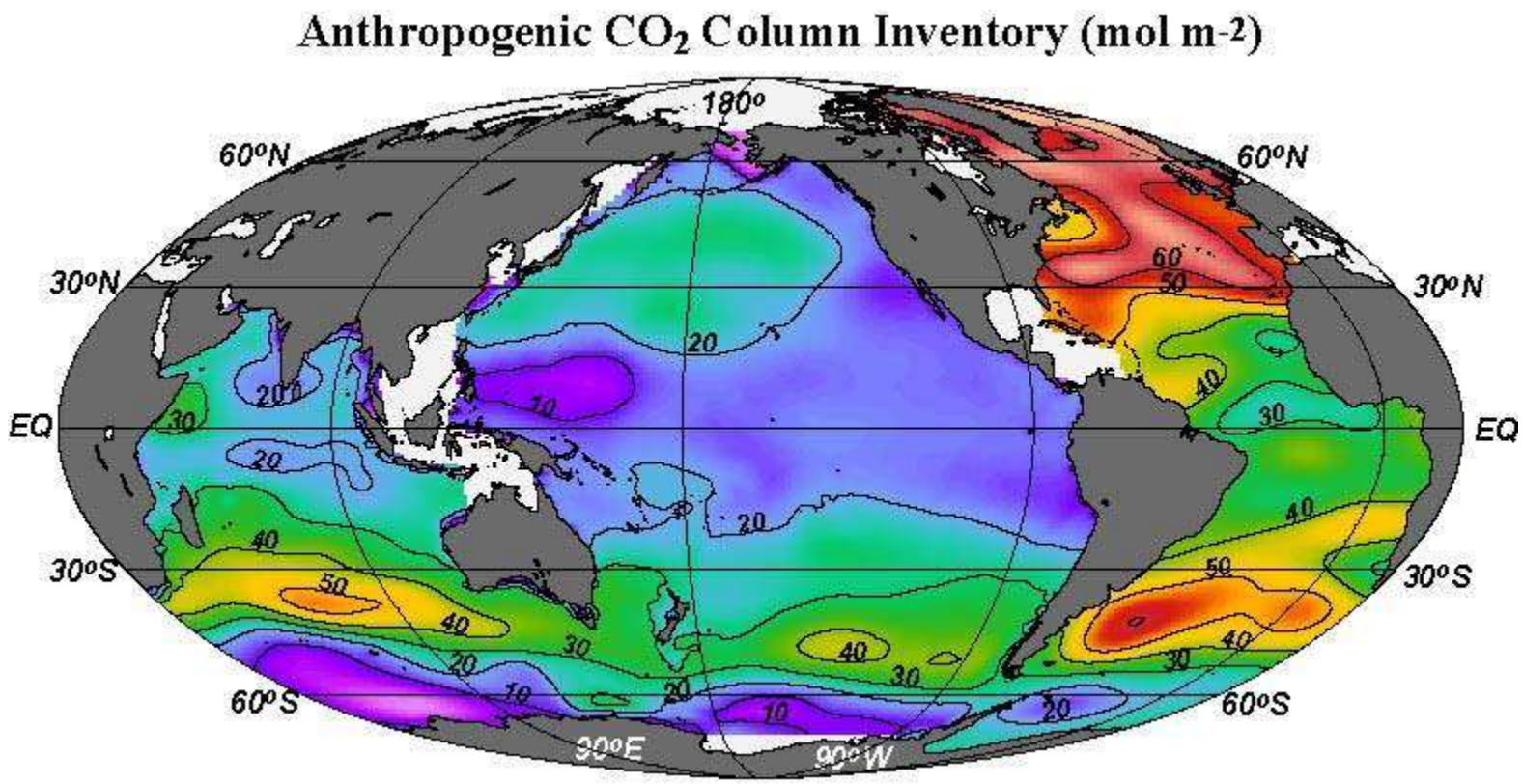
Rintoul et al., 2001

Southern Ocean overturning circulation



Rintoul (2001)

Southern ocean uptake of anthropogenic CO2



Sabine et al., 2004

Key challenges requiring sustained obs.

- Role of Southern Ocean in global heat and freshwater balance
- Stability of Southern Ocean overturning
- Stability of Antarctic ice sheet and future contribution to sea-level rise
- Future of Southern Ocean carbon uptake
- Future of Antarctic sea ice
- Impacts of climate change on Antarctic ecosystems

Sustained observations required

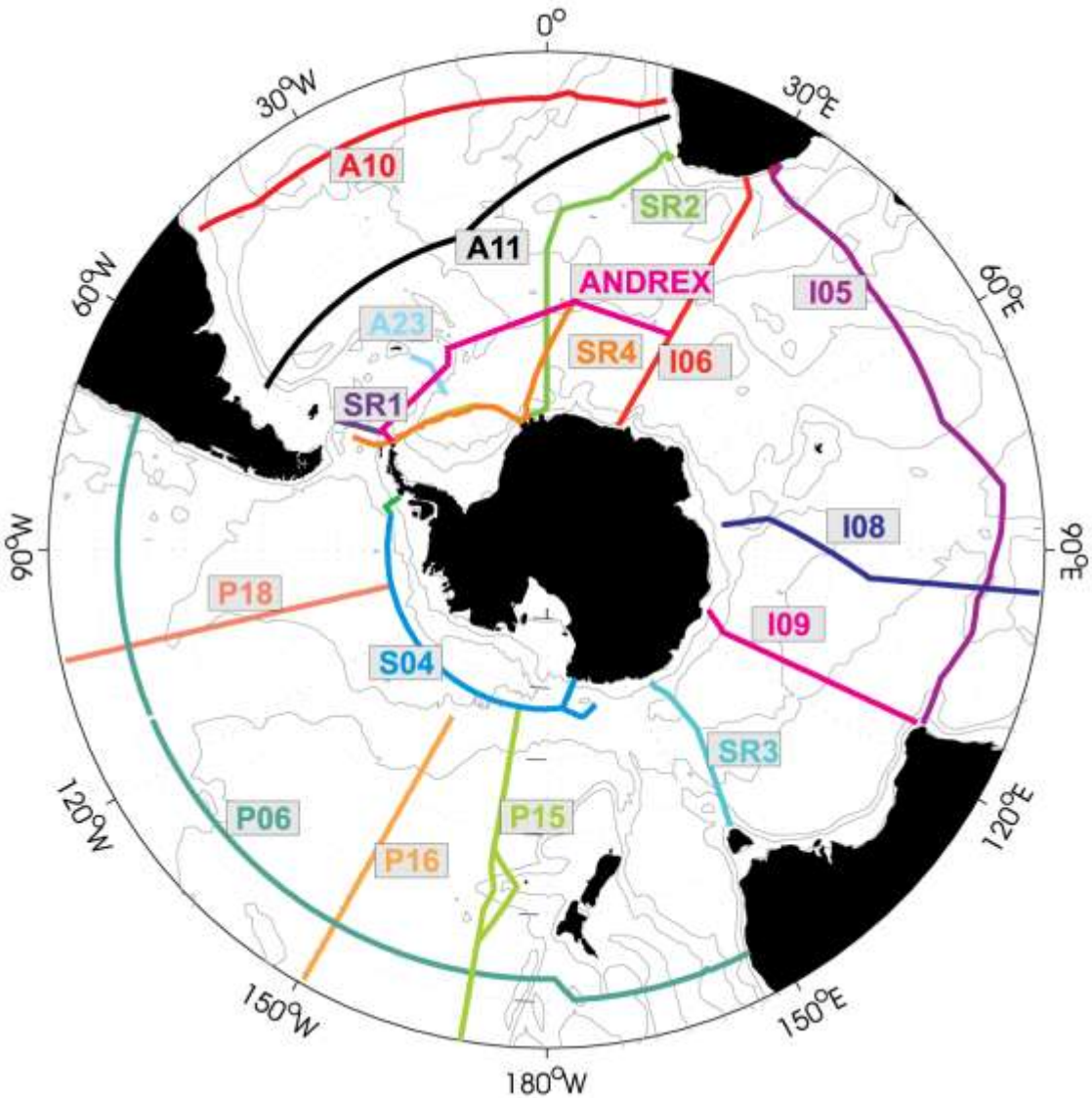
Platforms

	repeat hydgrography	Argo	underway sampling	moorings	animal sensors	CPR	glider/AUV	satellite	ice stations	acoustics	trawls/nets	bottom landers	drifters
stratification (T(z),S(z))	X	X			X		X		X				
SST, SSS	X		X					X					X
velocity	X	X		X			X			X		X	X
tracers	X												
CO2	X		X	X									
nutrients	X		X										
oxygen	X	X											
sea ice			X	X			X	X	X				
wind	X		X					X					
air-sea flux (heat, FW)	X		X	X									X
sea surface height	X	X						X					
Seabed pressure												X	
phytoplankton	X		X	X		X		X					
zooplankton						X				X	X		
fish										X	X		
mammals					X								

Southern Ocean Observing System

GCOS Global Climate Observing System
GOOS Global Ocean Observing System
WCRP World Climate Research Programme
OOPC Ocean Observations Panel for Climate
CLIVAR
CLIC
SCAR
International Co
Scientific Committee on Ocean

Repeat hydrography



Full depth

Multi-disciplinary:

-T,S,O,N,P,Si,C,CFC,Fe

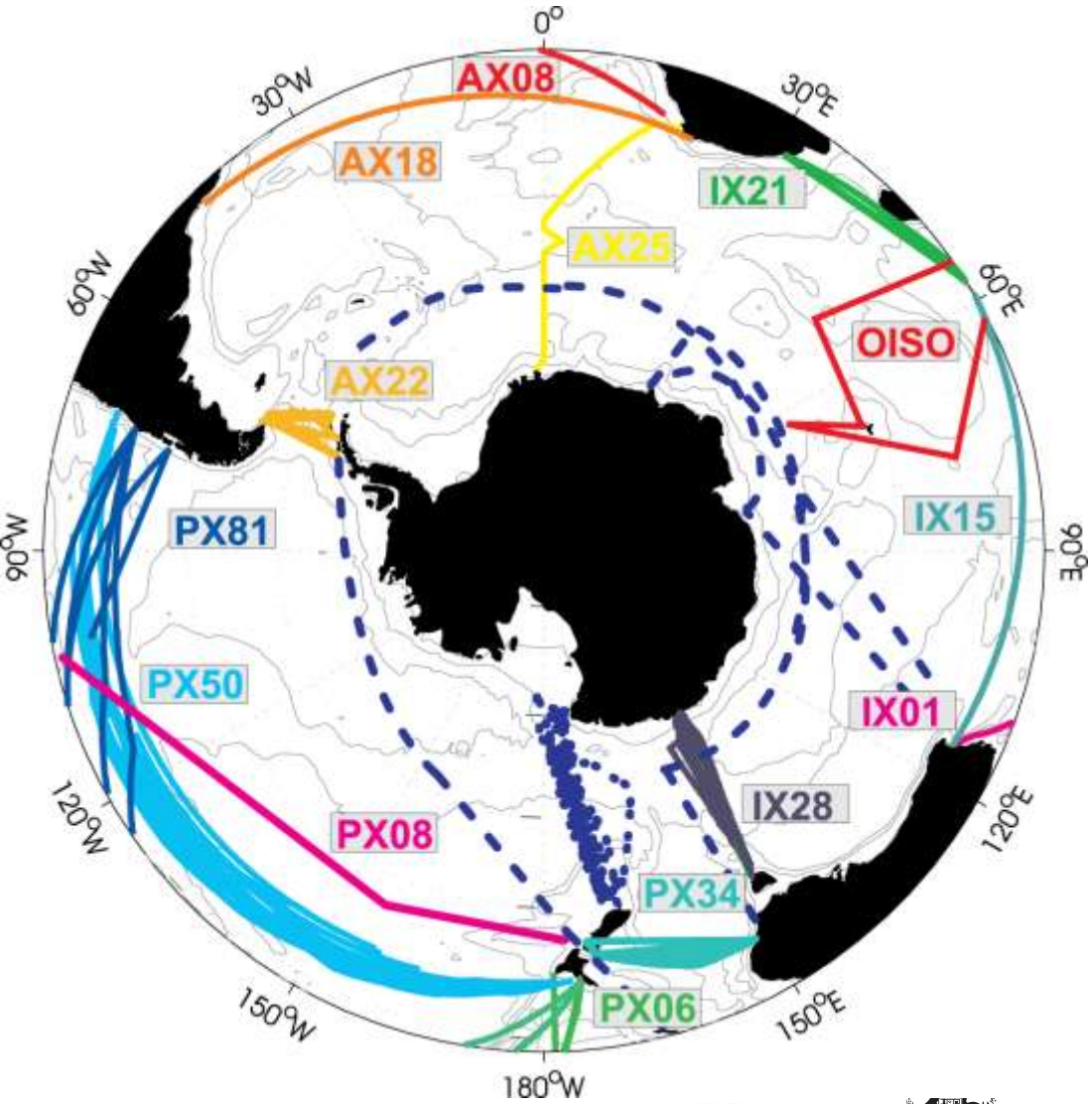
- ADCP

- HPLC, bio-optics

- acoustics? Net tows?

Repeat 5-7 yr (annual in Drake): aliasing a significant issue.

Underway sampling



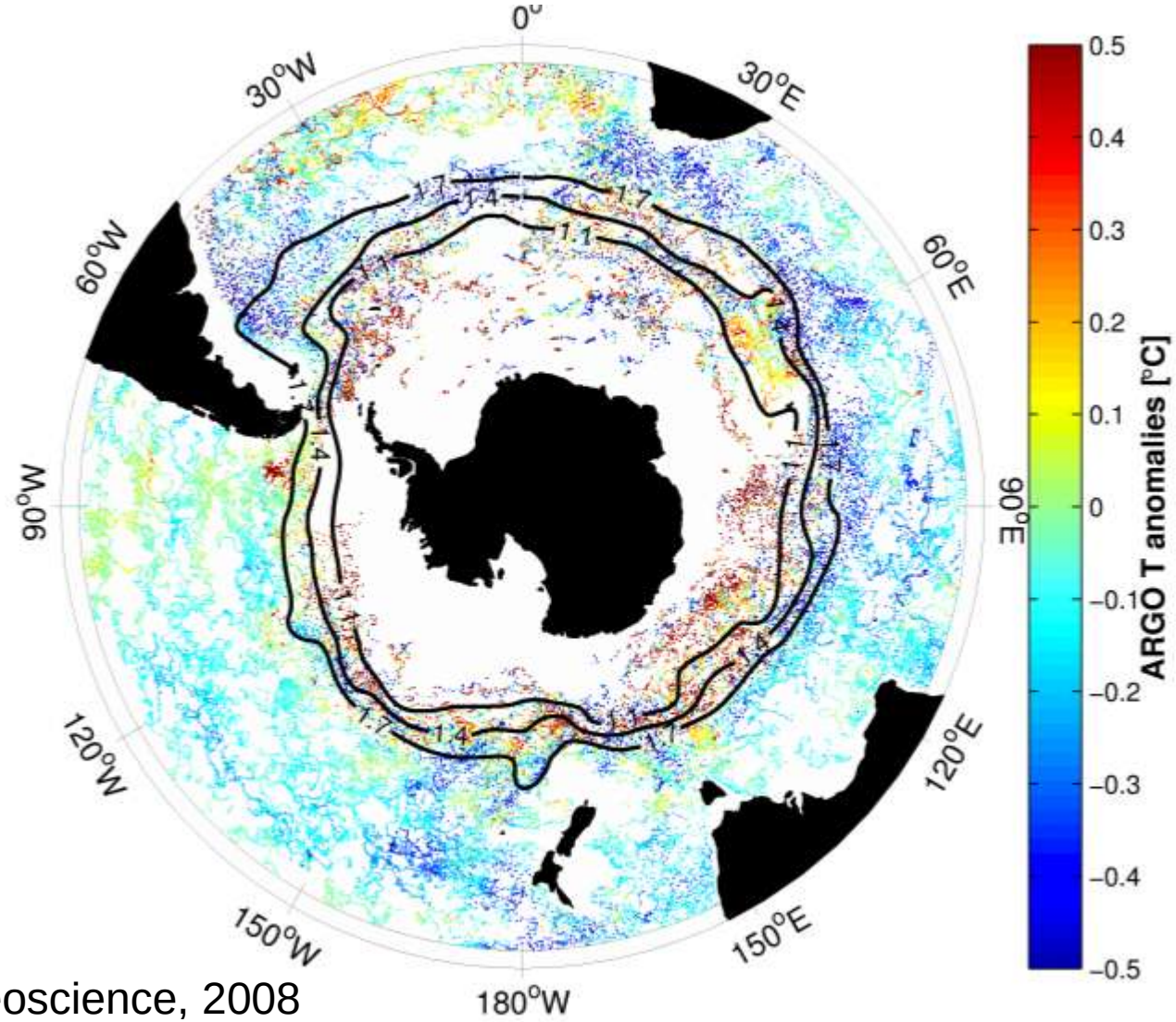
Multi-disciplinary:

- XBT/XCTD
- surface T,S,O,N,P,Si,C
- surface HPLC, bio-optics
- CPR
- acoustics? Net tows?

Typically multiple sections each year, but limited to summer (Oct – Mar).

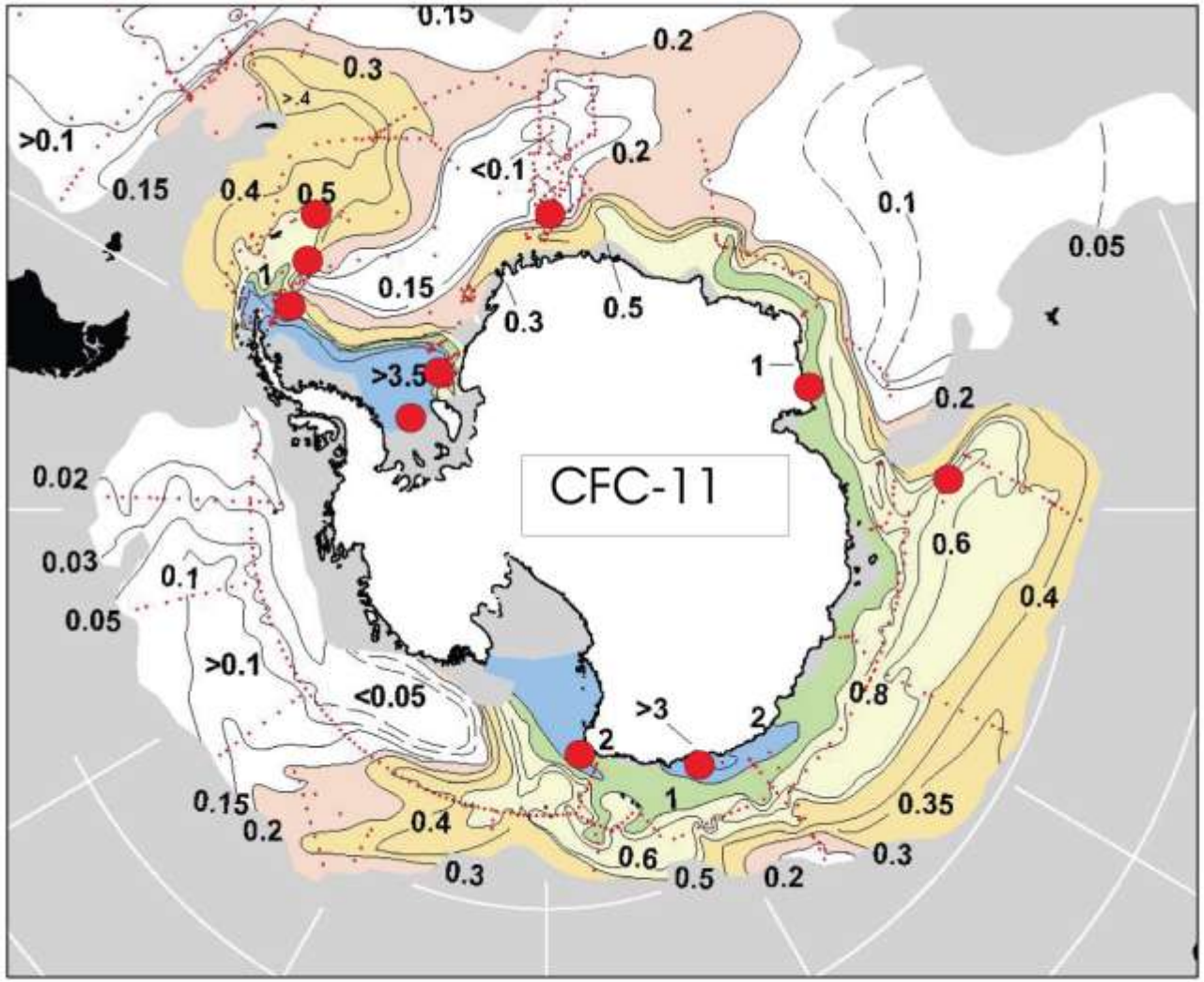
Argo

Change in temperature (Argo – CARS climatology, γ_n = 26.9 – 27.7)

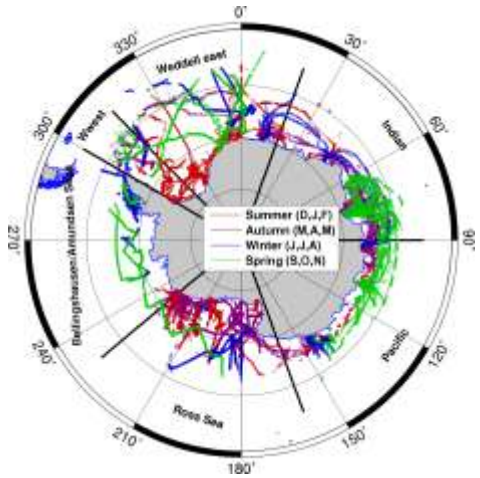


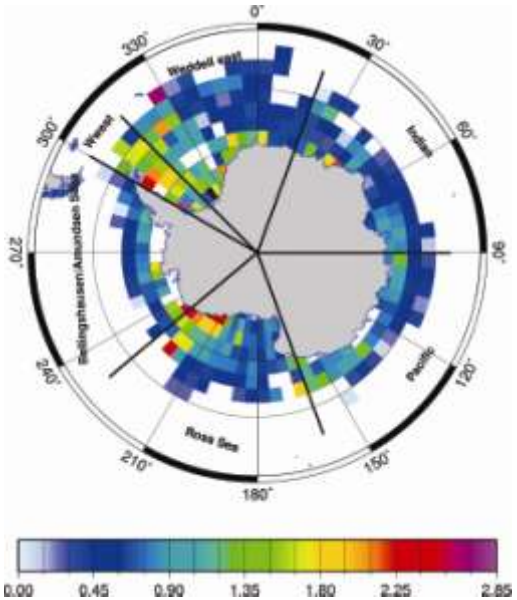
Böning et al., Nature Geoscience, 2008

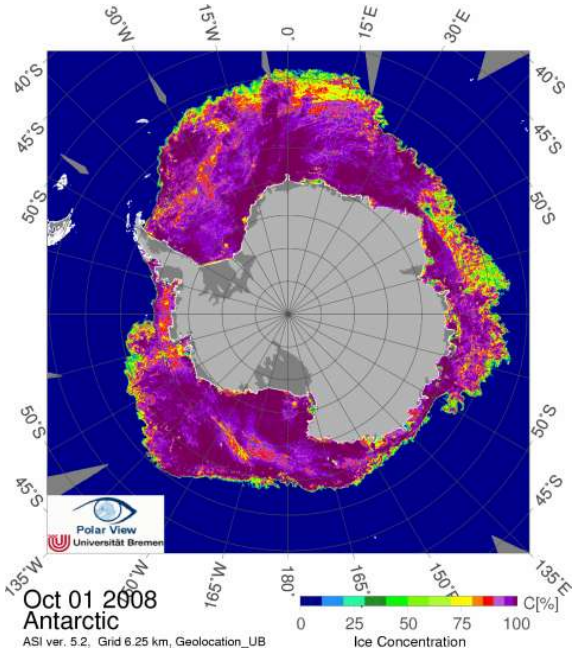
Bottom water time series moorings



Sea ice sampling





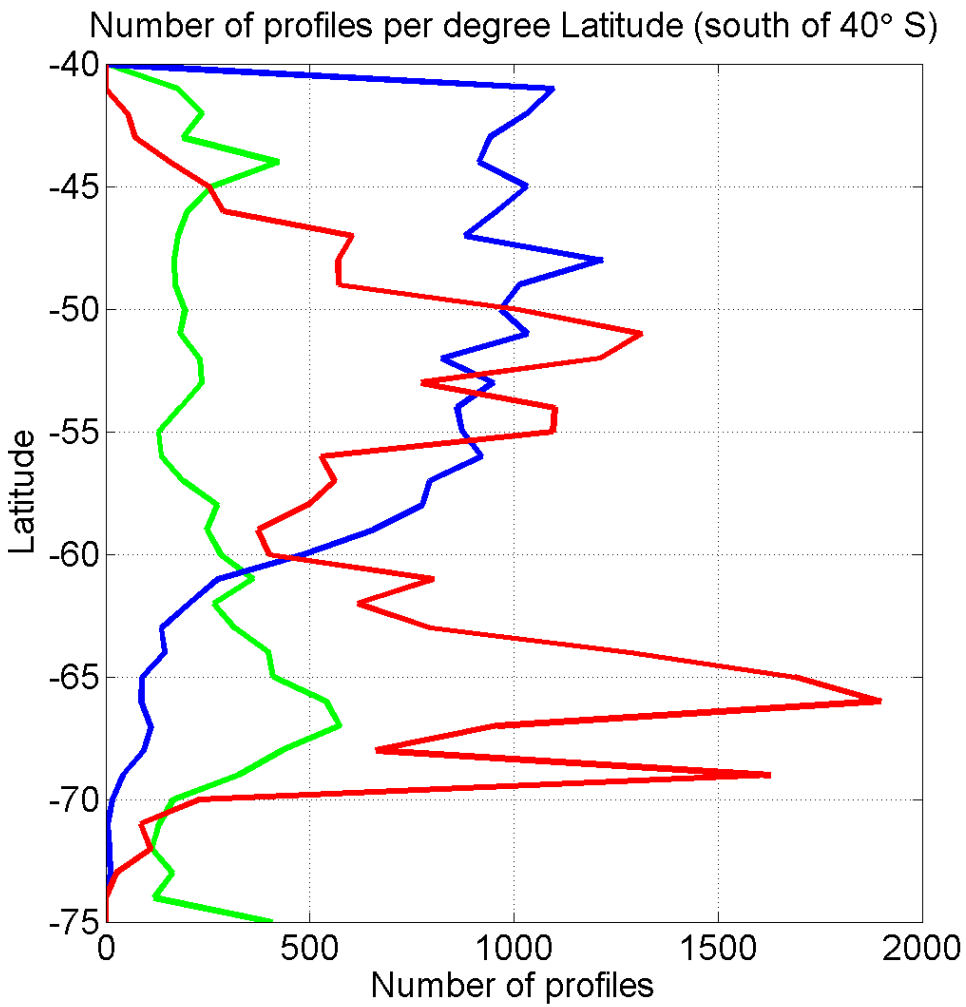


Australian Government
Bureau of Meteorology

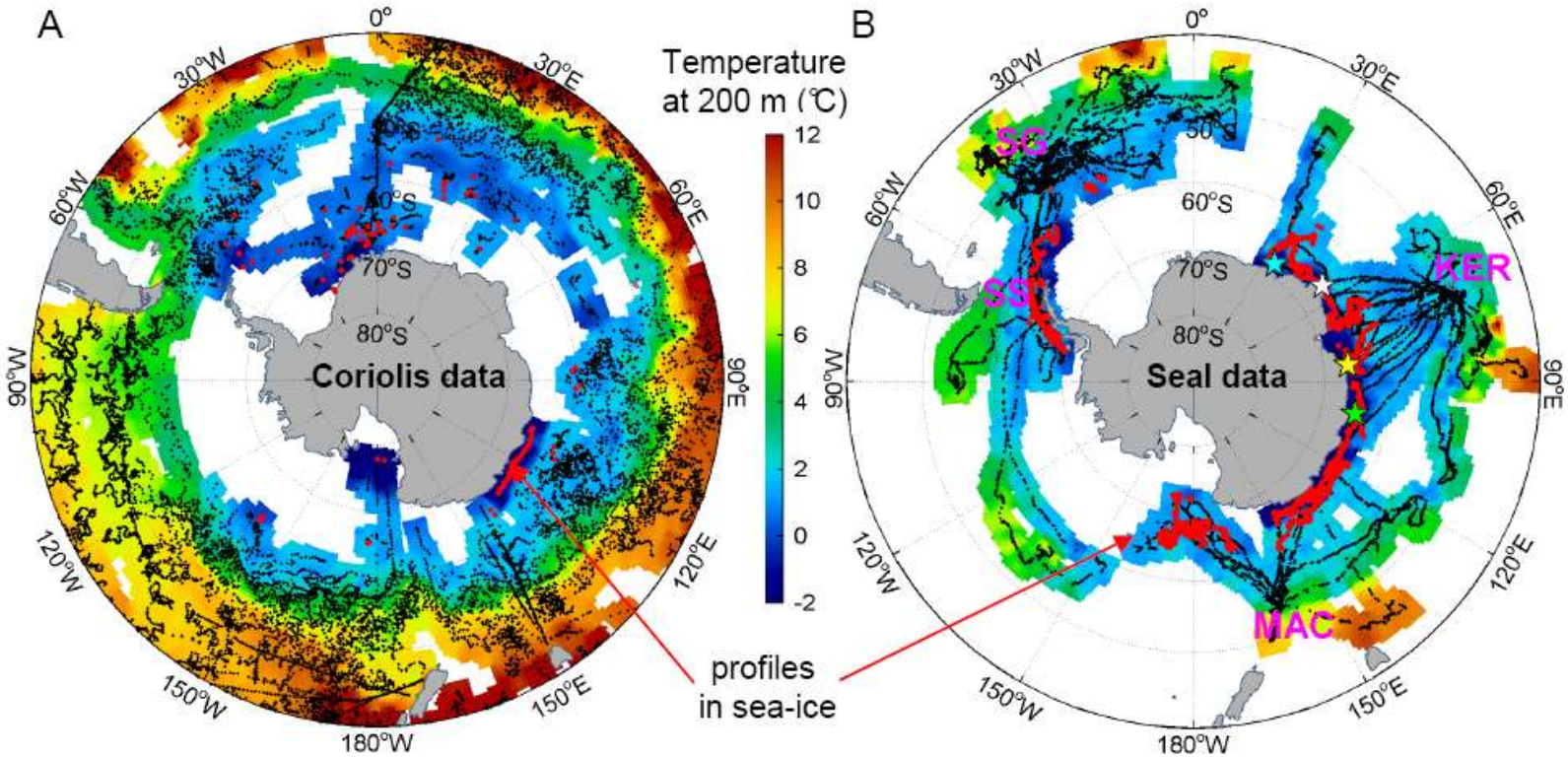
The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

Ocean sensors on animals

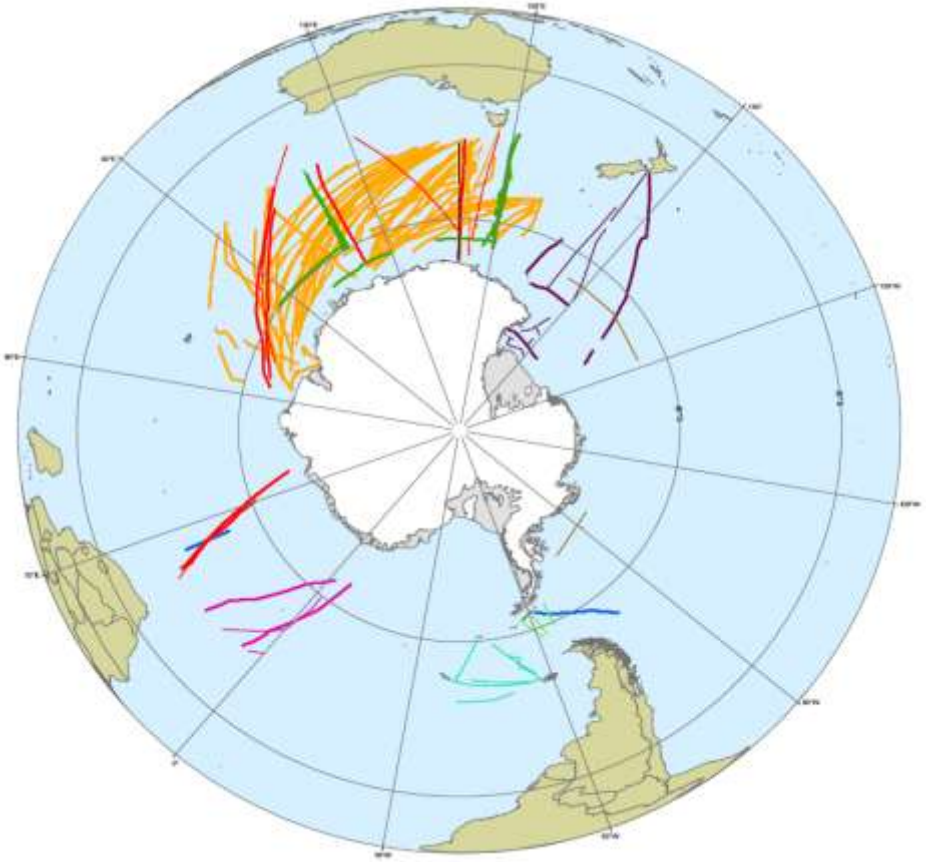


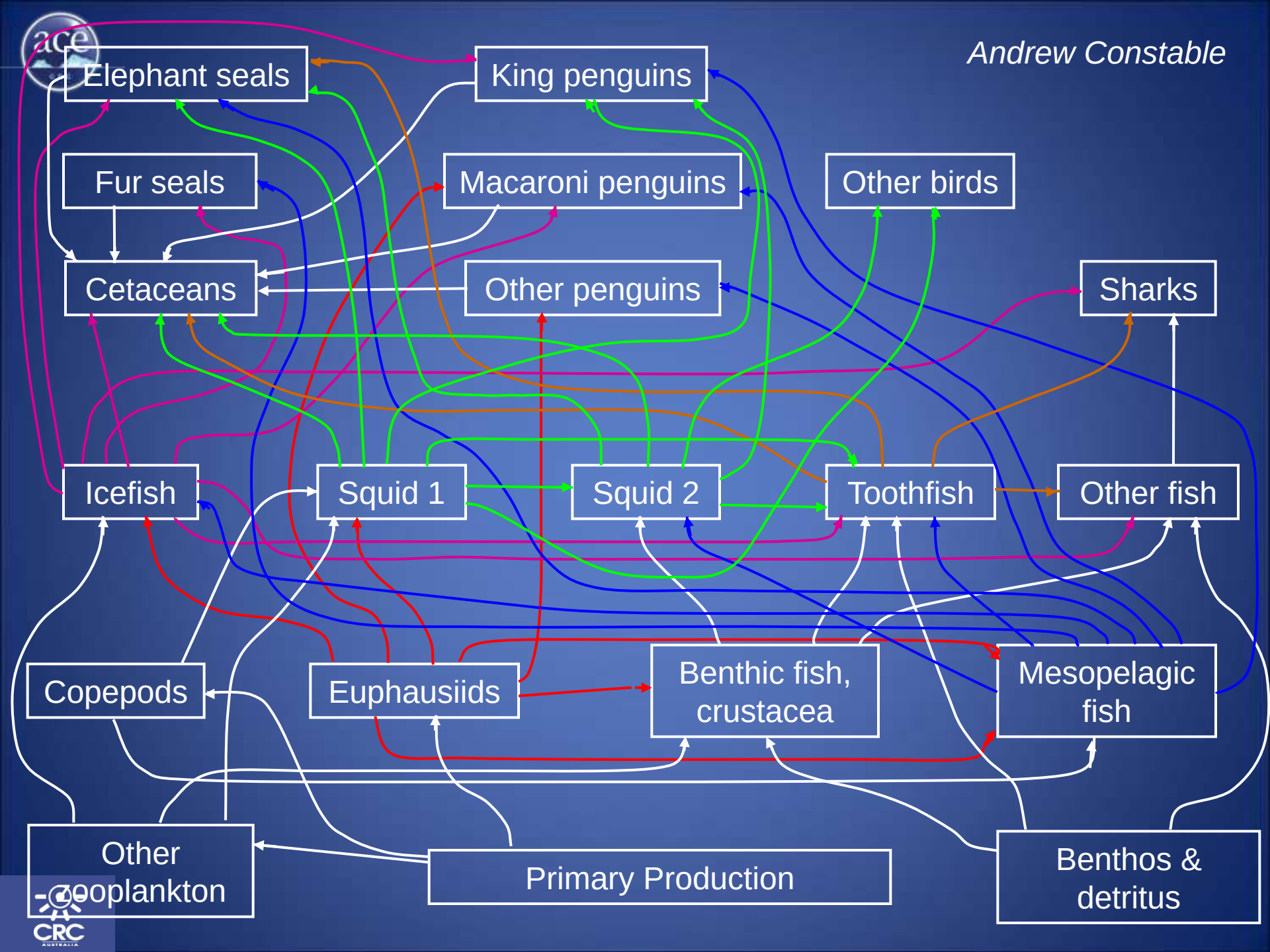
Illuminating the “blind spot” under ice



Charassin et al., PNAS, 2008

Continuous Plankton Recorder: 2001-2008

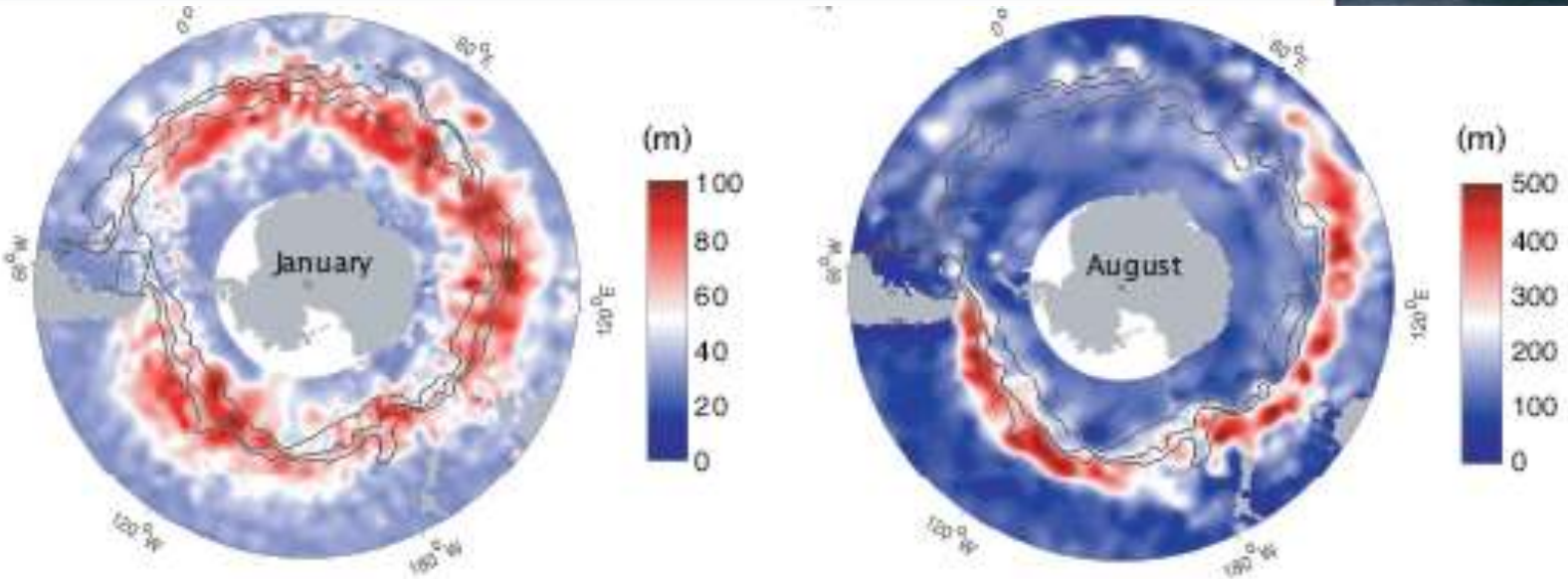


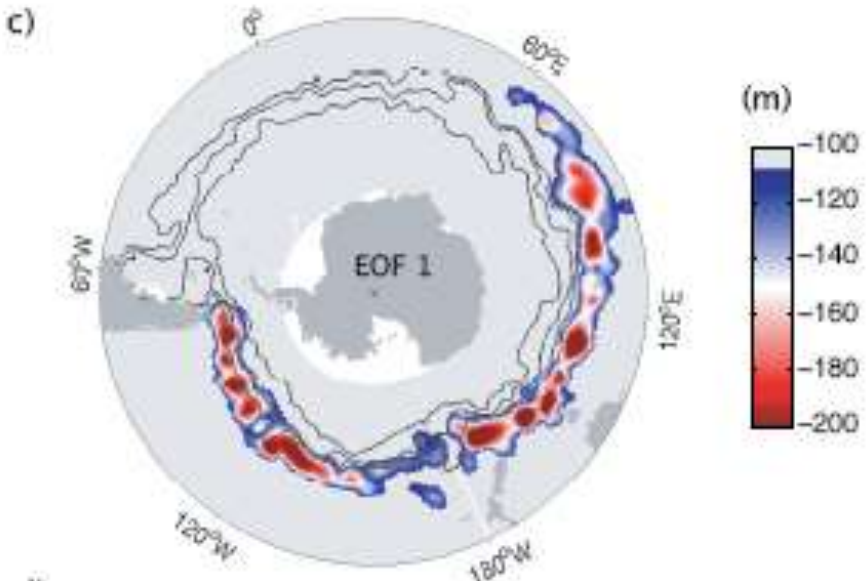

Andrew Constable
Elephant seals
King penguins
Fur seals
Macaroni penguins
Other birds
Cetaceans
Other penguins
Sharks
Icefish
Squid 1
Squid 2
Toothfish
Other fish
Copepods
Euphausiids
Benthic fish, crustacea
Mesopelagic fish
Other zooplankton
Primary Production
Benthos & detritus

Controls on phytoplankton biomass

- light
  - mixed layer depth
  - cloudiness
  - sea ice
- nutrients
  - nitrate/phosphate, silicate, iron
  - supply depends on upwelling + stratification
- grazing by zooplankton
- ocean chemistry (acidification)?

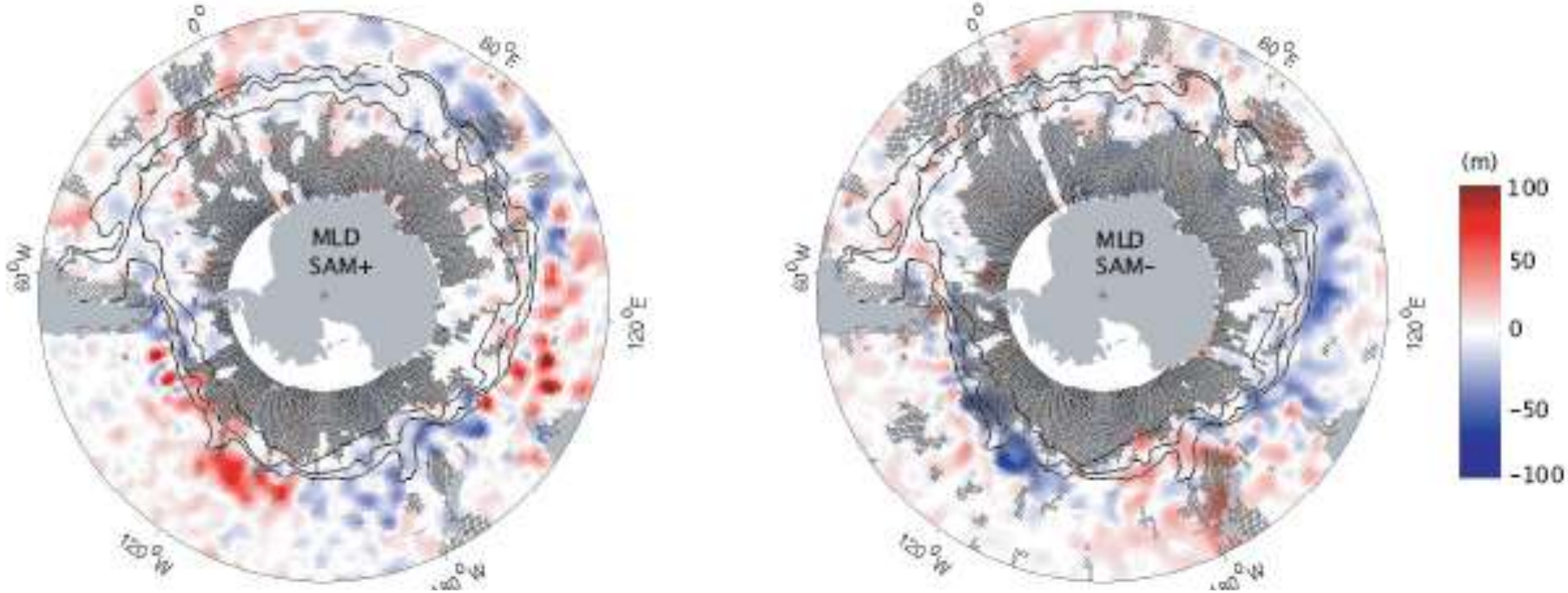
Seasonality of the mixed layer

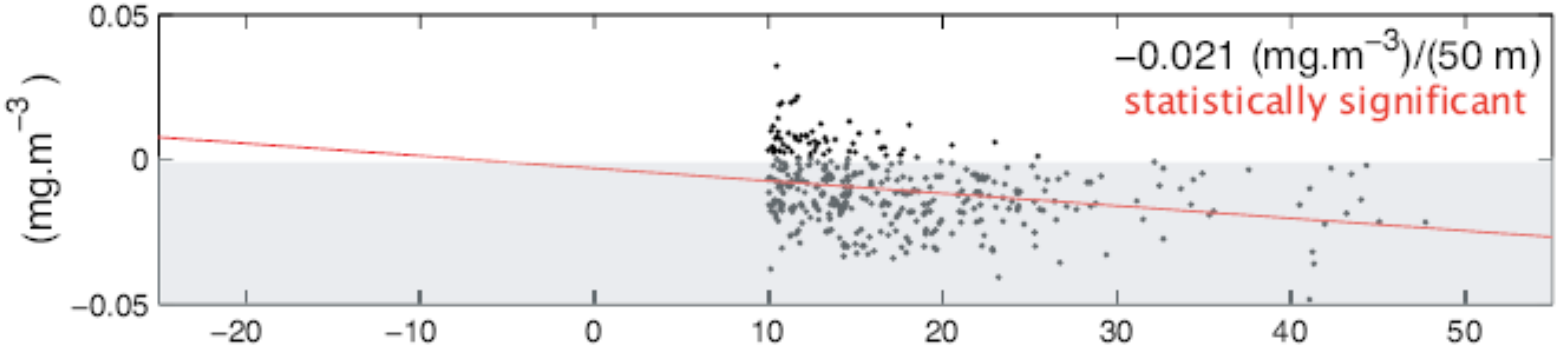




Sallée et al., 2009b

Variability of MLD associated with SAM





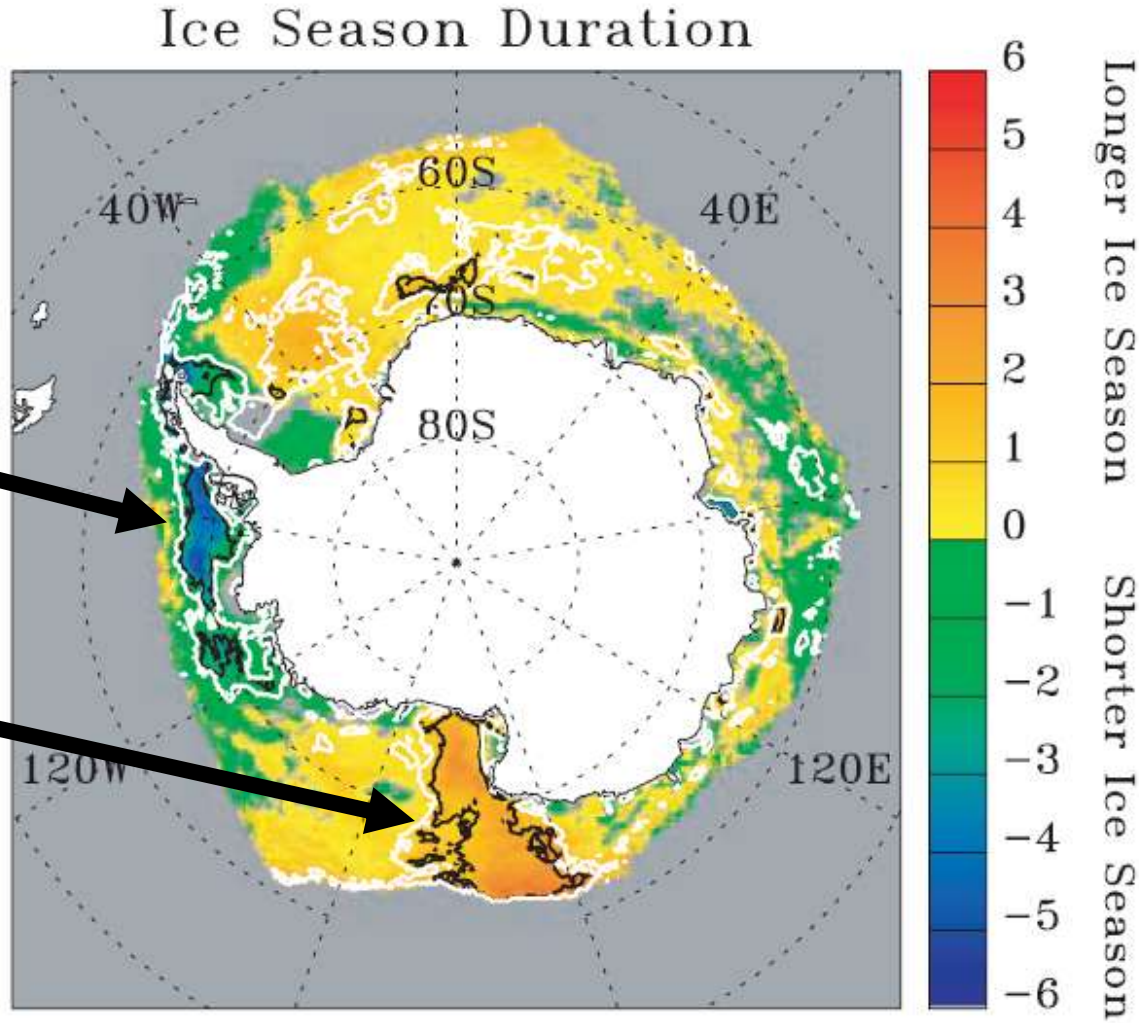
Sallée et al., 2009b

Large regional changes in Antarctic sea ice

Changes in sea ice duration: 1979 – 2006

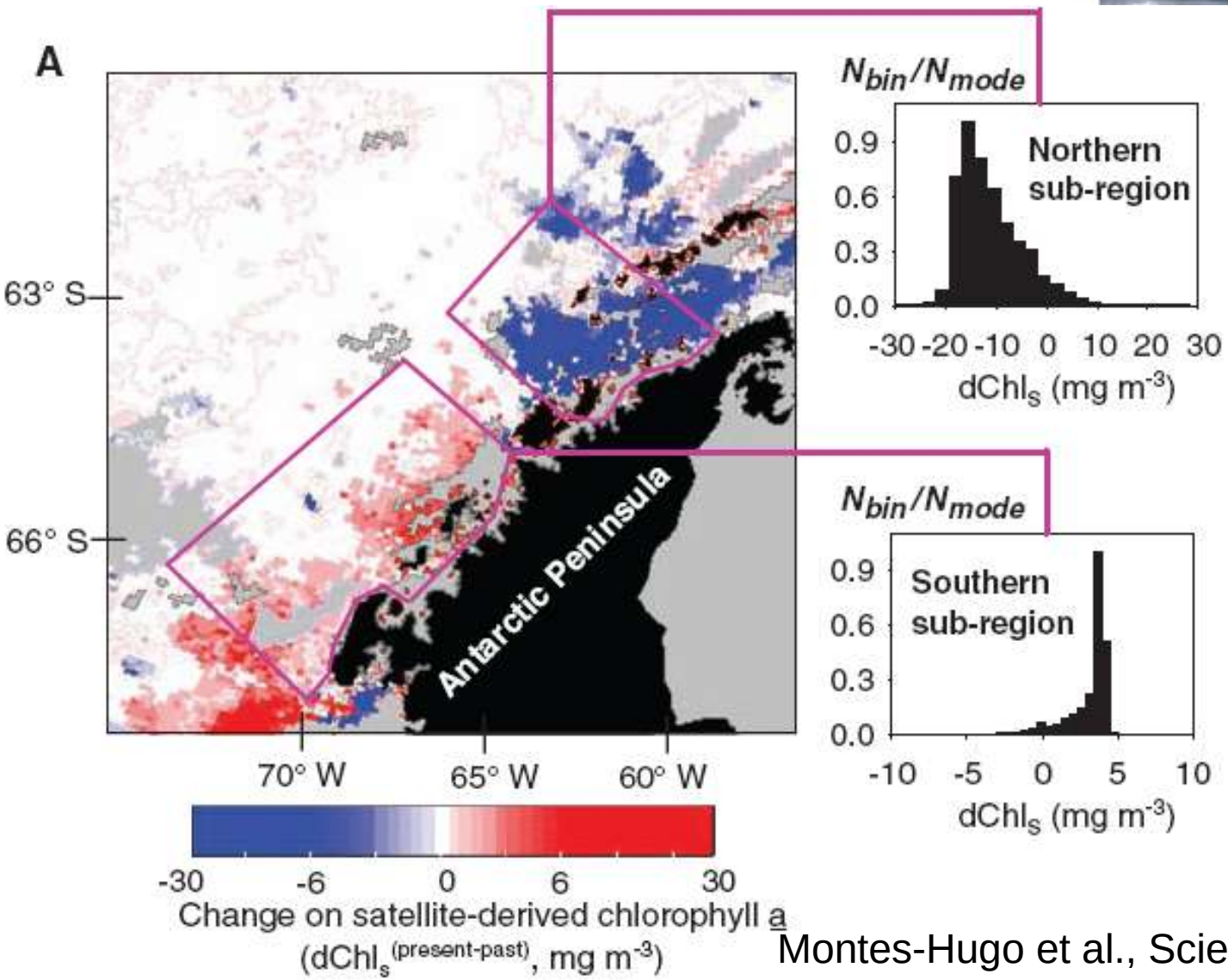
-83 ± 23 days

57 ± 13 days



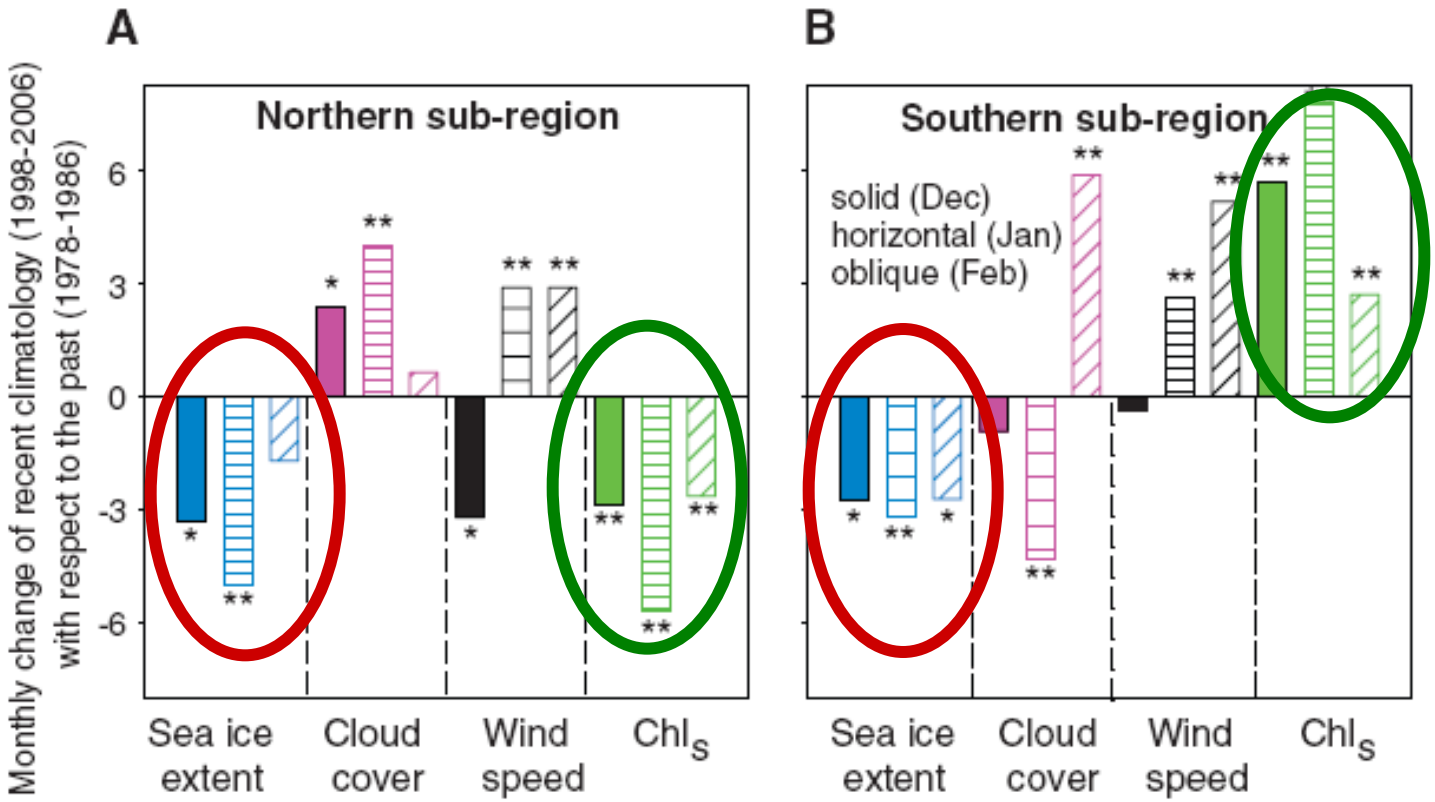
Stammerjohn et al. (2008)

Effect of changes in sea ice on phytoplankton



Montes-Hugo et al., Science, 2009

Sea ice decline results in different response



Montes-Hugo et al., Science, 2009

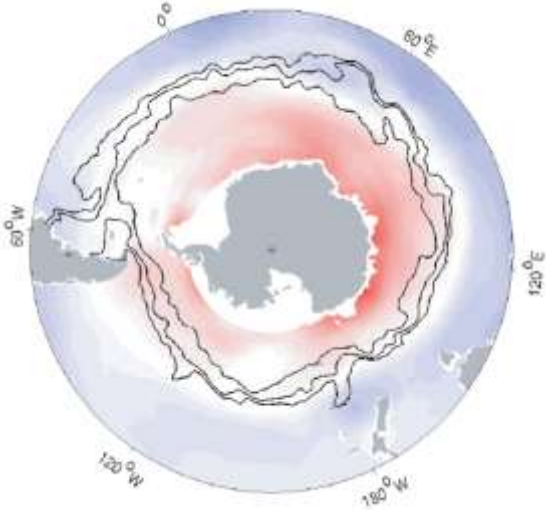
Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

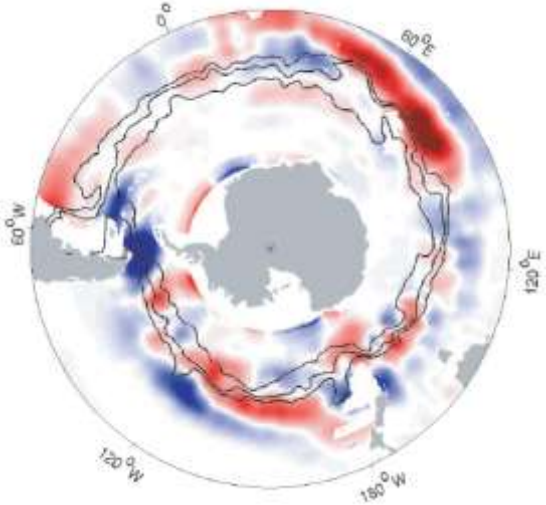
CSIRO

Subduction and upwelling in the SO

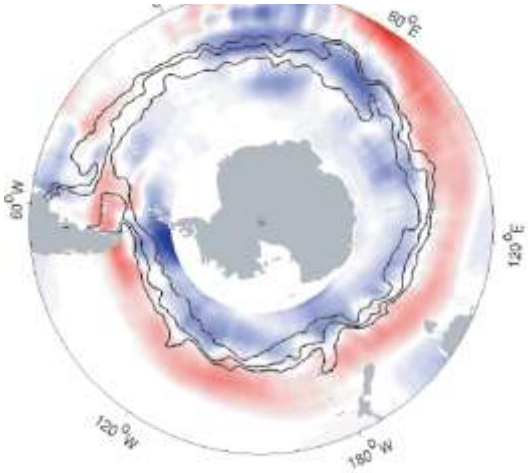
EKMAN



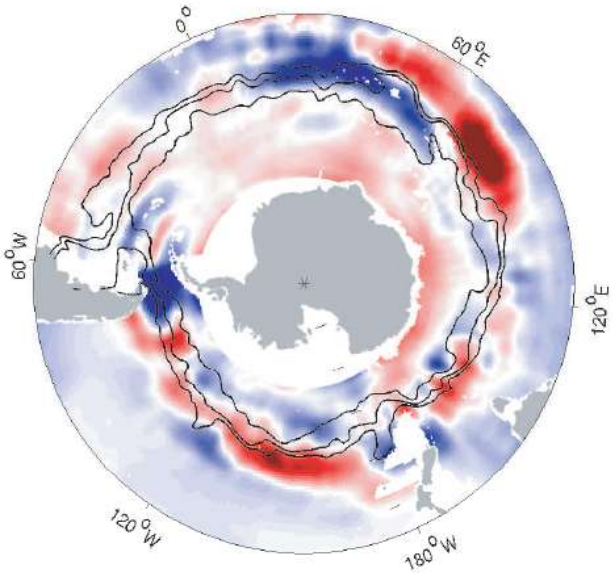
MEAN FLOW



EDDY



The subduction/ upwelling pattern (hence nutrient supply) depends on mean flow and eddies, not just wind.

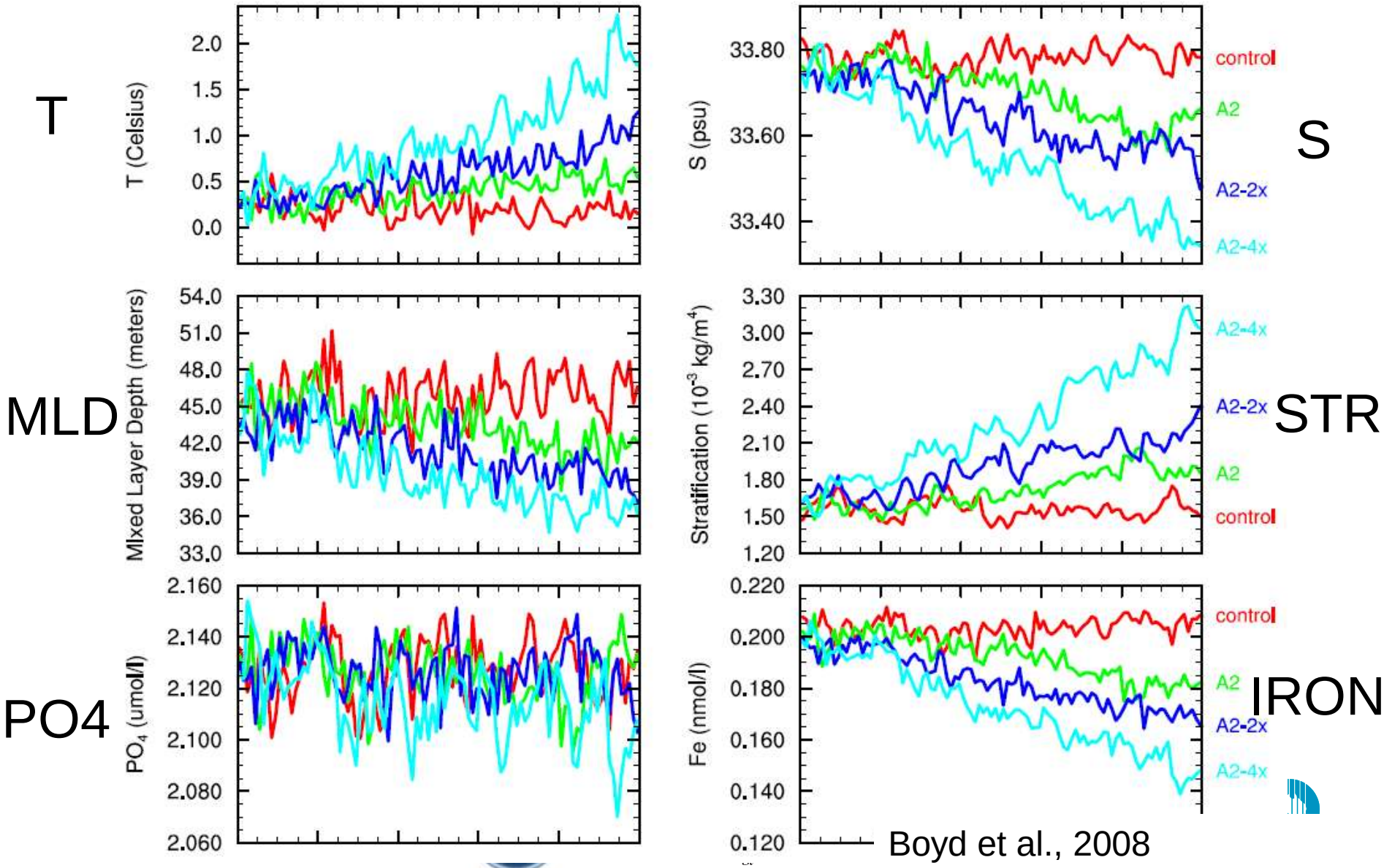


TOTAL

Sallée et al., 2009

ather and Climate Research
nd the Bureau of Meteorology

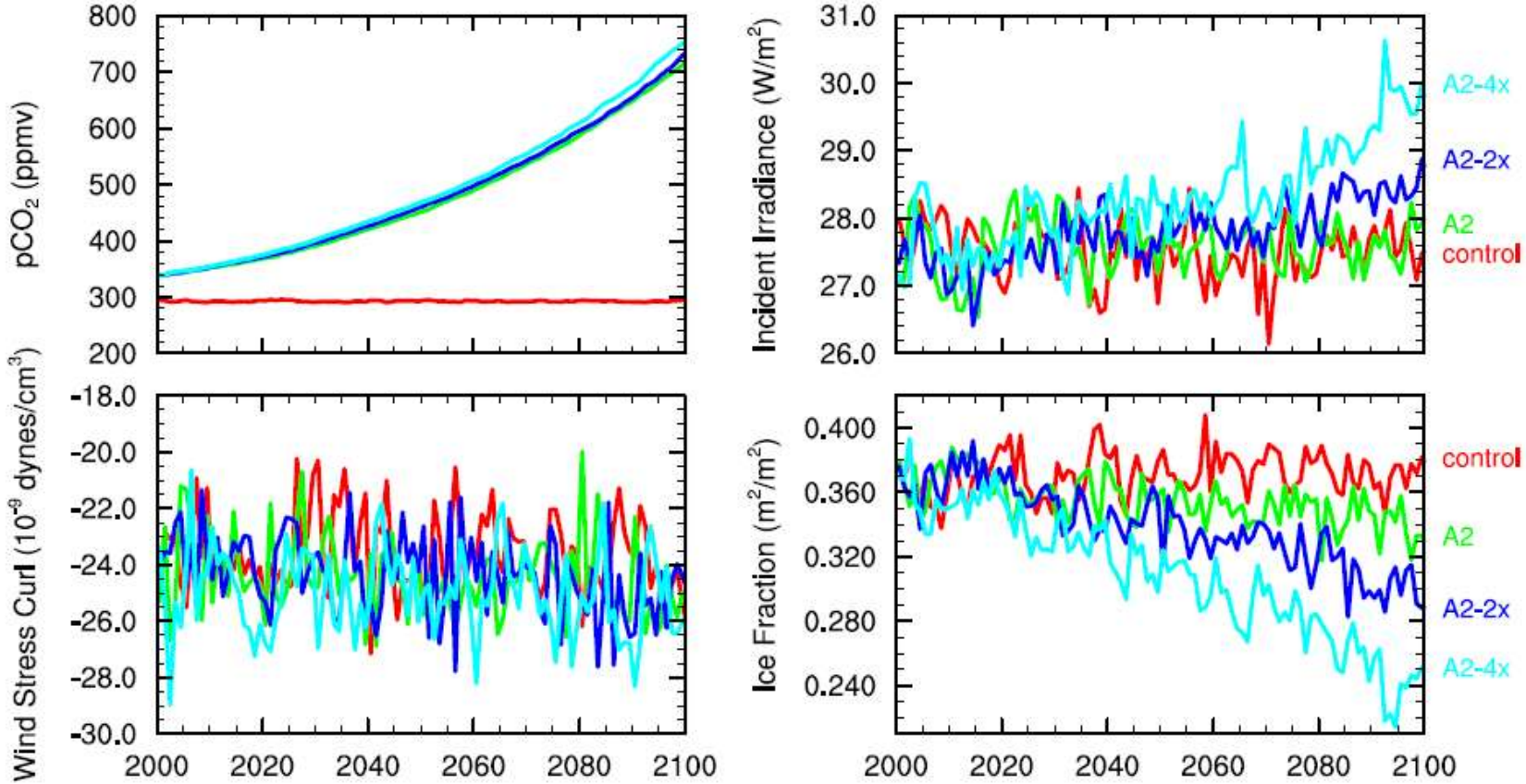
How will the Southern Ocean change?



Boyd et al., 2008

pCO2

LIGHT



WIND STRESS CURL

SEA ICE

Boyd et al., 2008

Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

Summary of expected SO changes

- warmer, fresher surface layer
- stronger stratification
- stronger and more poleward winds
- overturning stronger? Weaker? Stays the same?
- poleward shift of ACC fronts
- reduction in iron supply
- reduction in sea ice
- acidification / change in solubility

How might ecosystems respond to change?

3 scenarios for phytoplankton response:

- Ecosystems are plastic: cells adapt to change over time-scales of years to decades
- A “new” community or ecosystem arises
- Poleward migration of fixed biomes

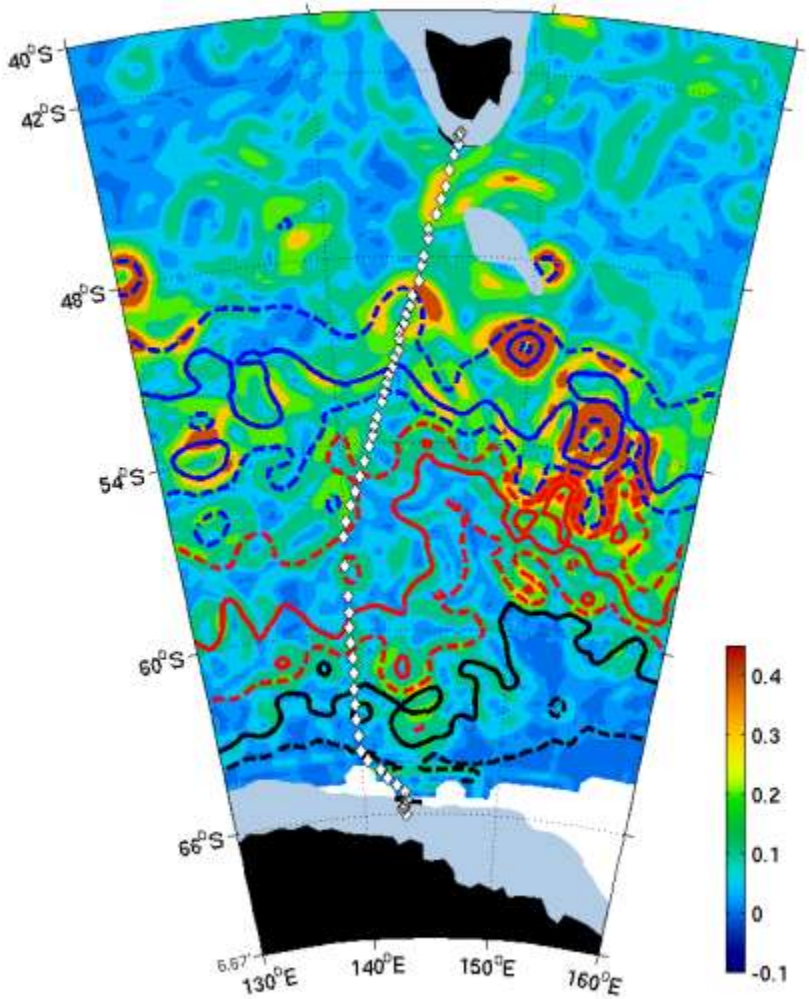
Are we likely to be able to use observations to determine which scenario holds?

- Probably not: natural variability obscures climate change signal for at least a few decades.

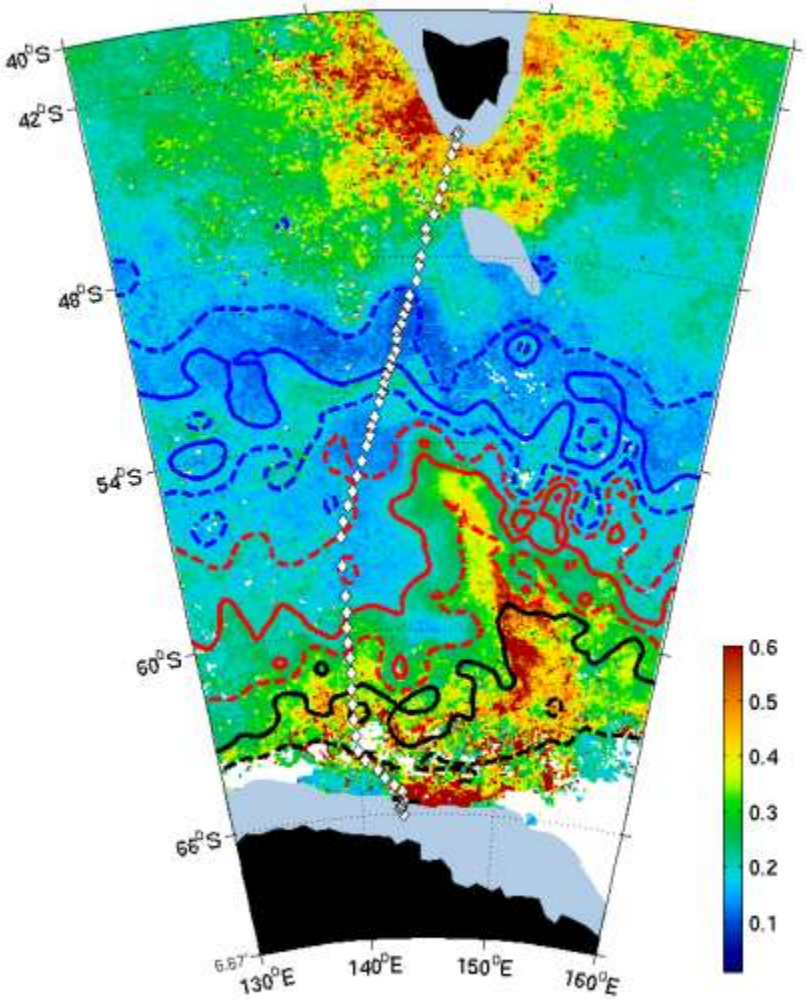
Boyd et al., 2008

Fronts define boundaries between zones with similar chl; chl is not enhanced along fronts

SSH gradient (color), fronts (contours)

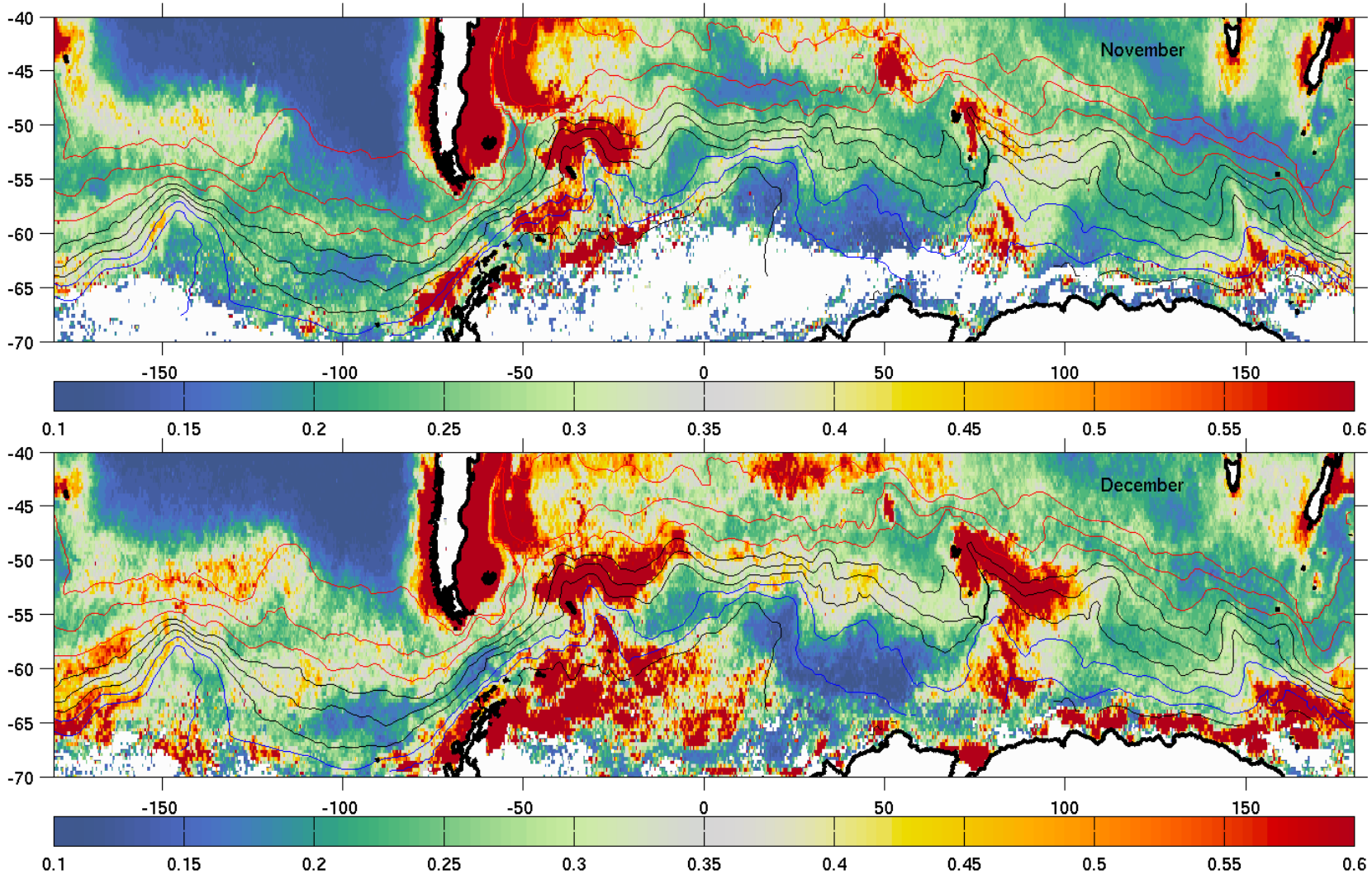


Surface chlorophyll (color), fronts (contours)



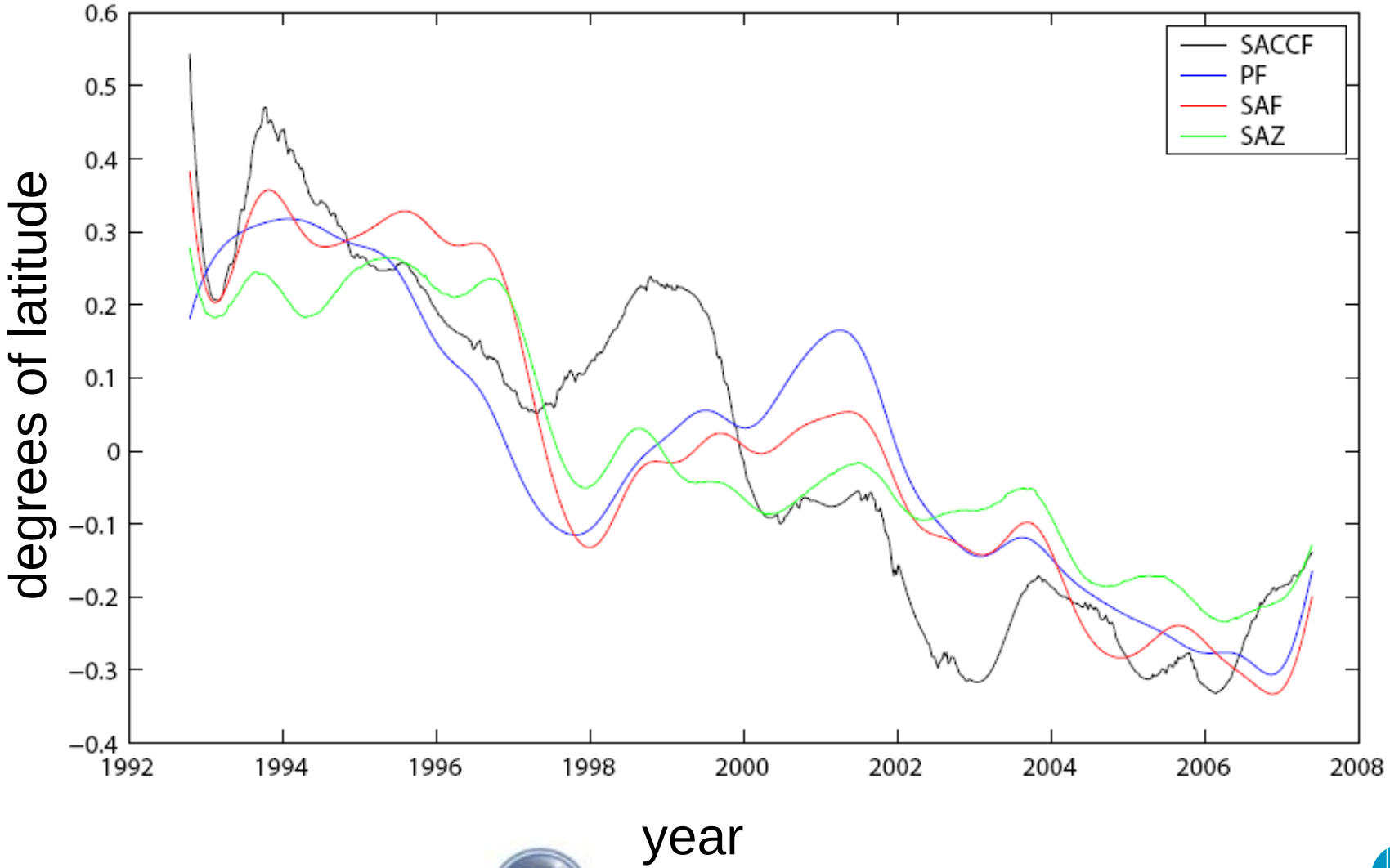
Sokolov and Rintoul, 2007

Relationship between fronts and ocean colour



Sokolov and Rintoul, 2007

Circumpolar average southward shift of fronts



Sokolov and Rintoul, 2009

Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

SOOS biology strategy: phytoplankton

- Start now: measure what we can, where we can
  - HPLC on repeat hydrography and underway lines
  - Bio-optics
  - Mixed layer depth+properties (Argo, XBT, hydro): primary control on primary production
  - sea ice
- Ocean colour will remain the only tool to provide biological observations with adequate spatial and temporal resolution
  - Need to refine algorithms used to translate surface colour to integrated primary production in the Southern Ocean?

Biology/Ecology strategy: higher trophic levels

- Zooplankton:
  - maintain/expand CPR (eg Pacific; winter).
  - Make acoustic data accessible.
  - Develop a strategy for sustained network of acoustics and net tows
  - “acidification detection system” (eg pteropods, forams)
  - Krill surveys
- Fish:
  - No sustained observing strategy articulated to date
- Mammals and birds:
  - Maintain existing long-term sites (eg LTER, CEMP, French): add value by enhancing environmental measurements where needed
  - Tags, multiple species
  - Explore potential for monitoring of “hot spots” or “cold spots”
- Benthic organisms:
  - No strategy so far

The future

- genomic sensors, observing community and function
- autonomous floats measuring everything
- no one will think of doing a repeat hydrographic cruise without biological measurements any more than they would a cruise that didn't measure salinity
- cost-effective, multi-purpose moorings with data capsules
- the growing fleet of tourist ships measures everything a research vessel can while underway
- satellite data is more useful because ship data enhances interpretation of surface measurement
- fast towed pumps allow filtering of large volumes

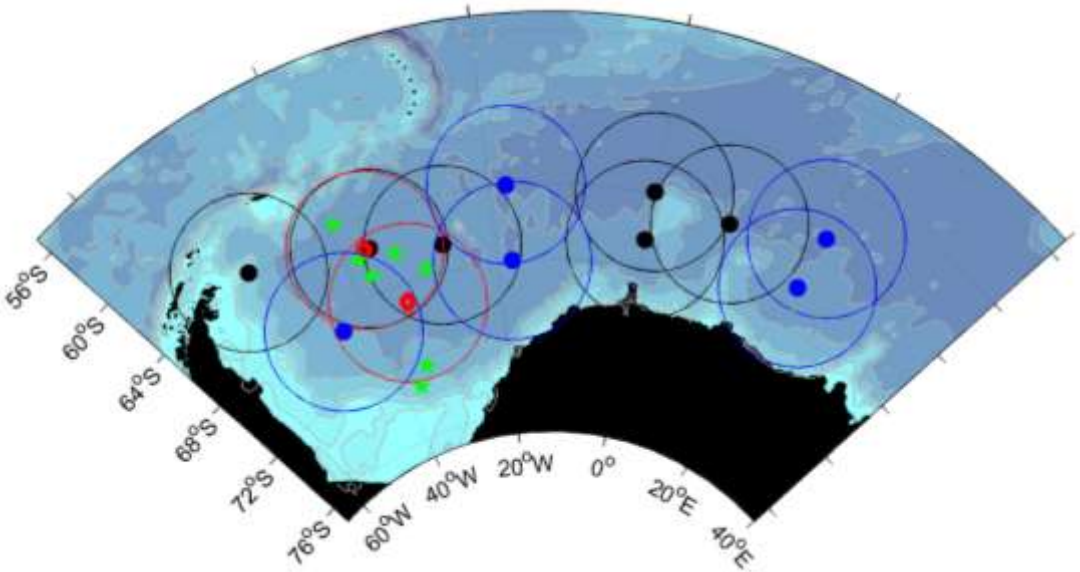
Summary 1: science

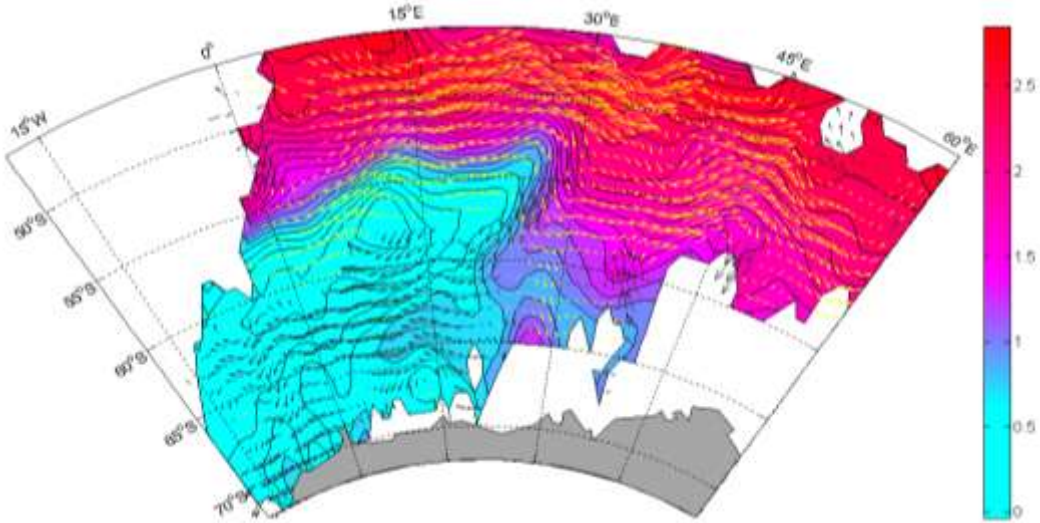
- Phytoplankton biomass controlled by light, nutrients (including iron) and grazing
- Climate models suggest the Southern Ocean will change in ways that will affect these factors
  - warming, freshening and increased stratification
  - decrease in iron supply (?)
  - changes in circulation (eg front shifts) and changes in sea ice
- Models suggest changes may be subtle and dominated by natural variability for decades
- Biomass distribution structured by ocean physics (eg fronts). Most likely change is shift in biomes?
- Interpretation of change is difficult because observations are sparse. Need a SOOS.

Summary 2: philosophy

- Advances in physical observations are good news for biologists (year-round msmts of mixed-layer depth, altimetry), at least in a bottom-up world
- Case has not yet been made for the biological component of SOOS
- Need to articulate what needs to be measured, why, and how in a more rigorous and more detailed way
- In the mean time, we can start with what is feasible
- New technology is crucial
- But new ideas are even more important
- Need champions

Acoustic tracking of floats under ice





Fahrbach(pers. comm.)

Australian Government

Bureau of Meteorology

The Centre for Australian Weather and Climate Research

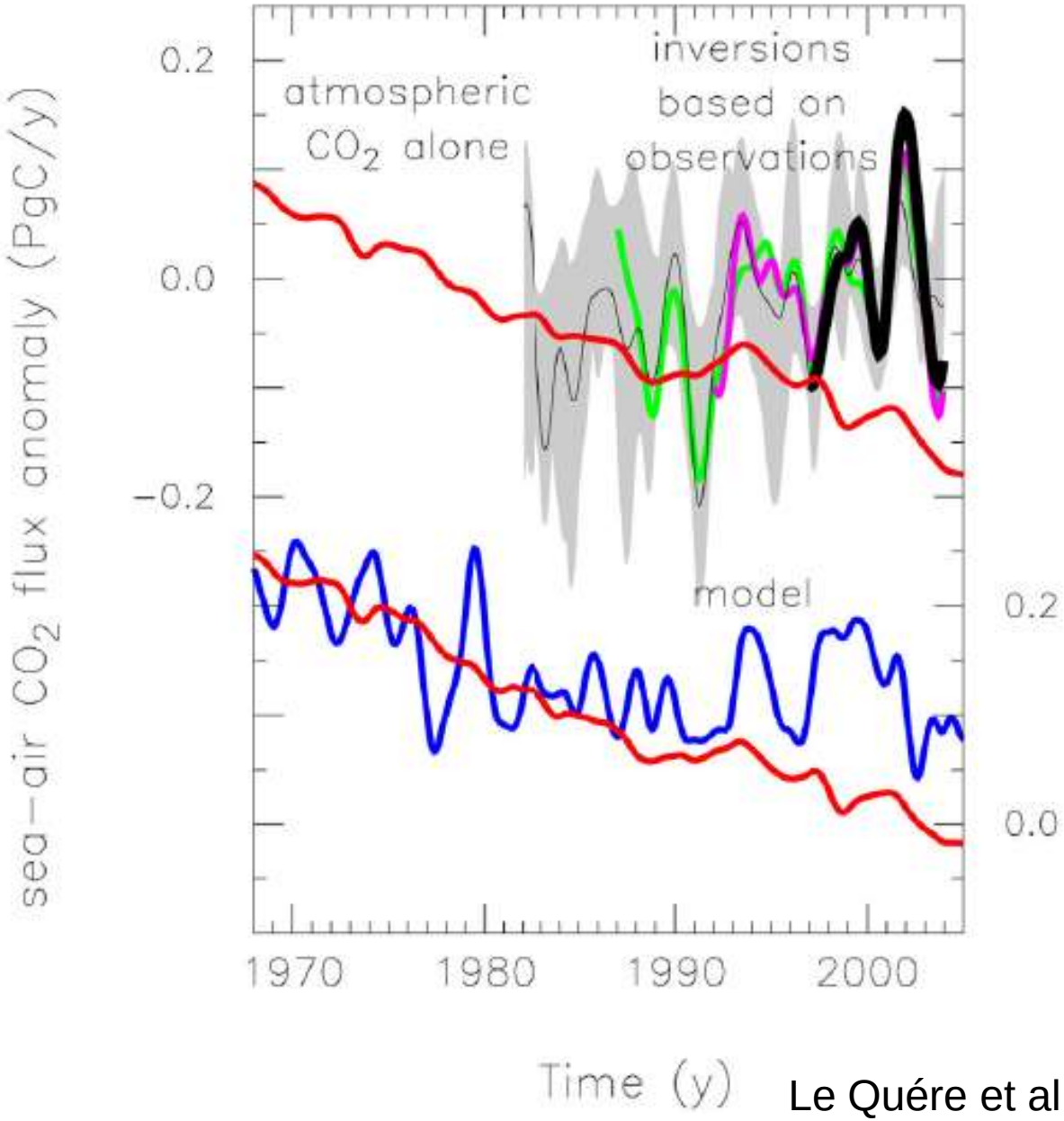
A partnership between CSIRO and the Bureau of Meteorology

Steve Rintoul

Phone: (03) 6232-5393
Email: steve.rintoul@csiro.au
Web: www.cawcr.gov.au

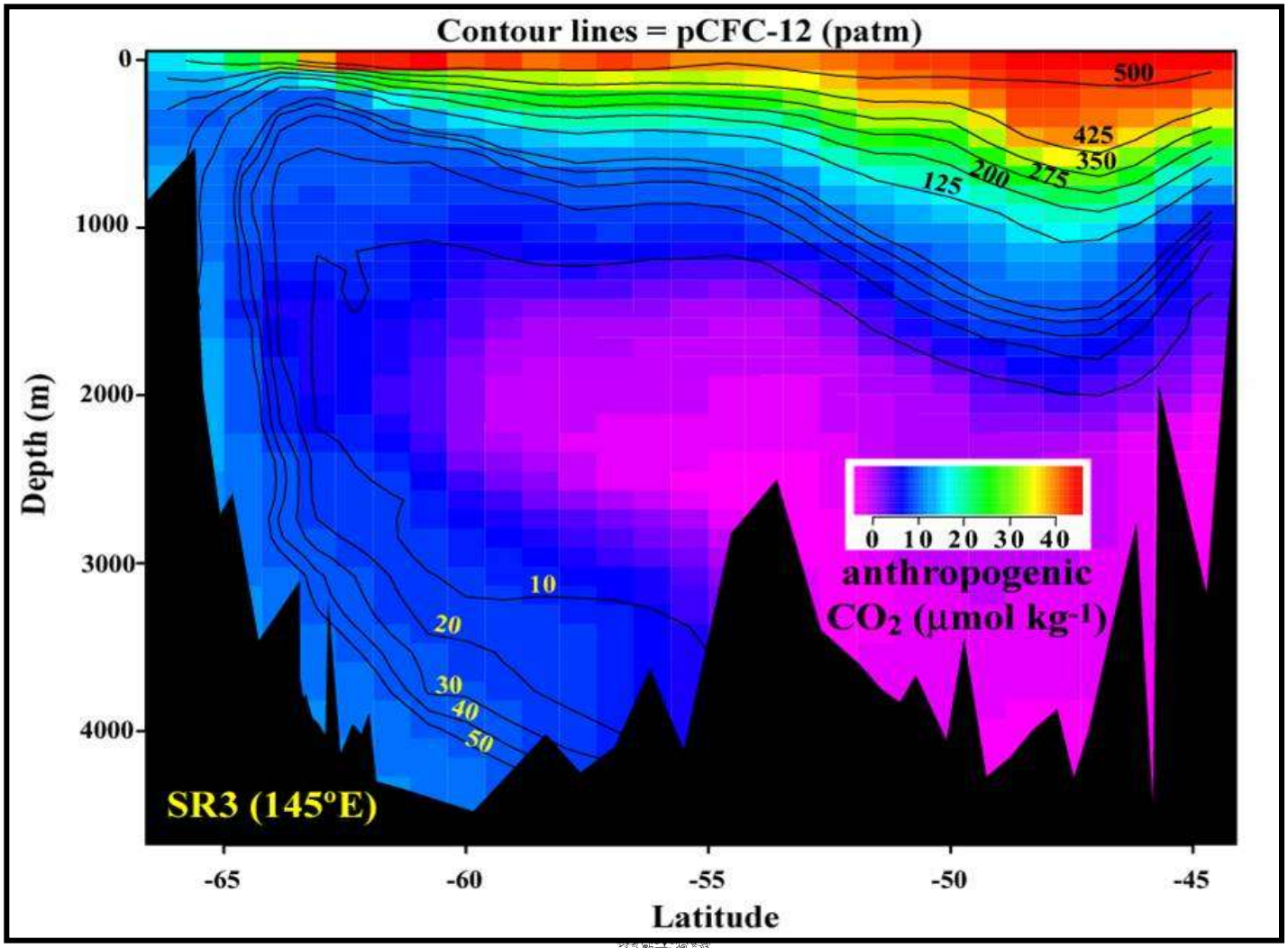
Thank you

www.cawcr.gov.au



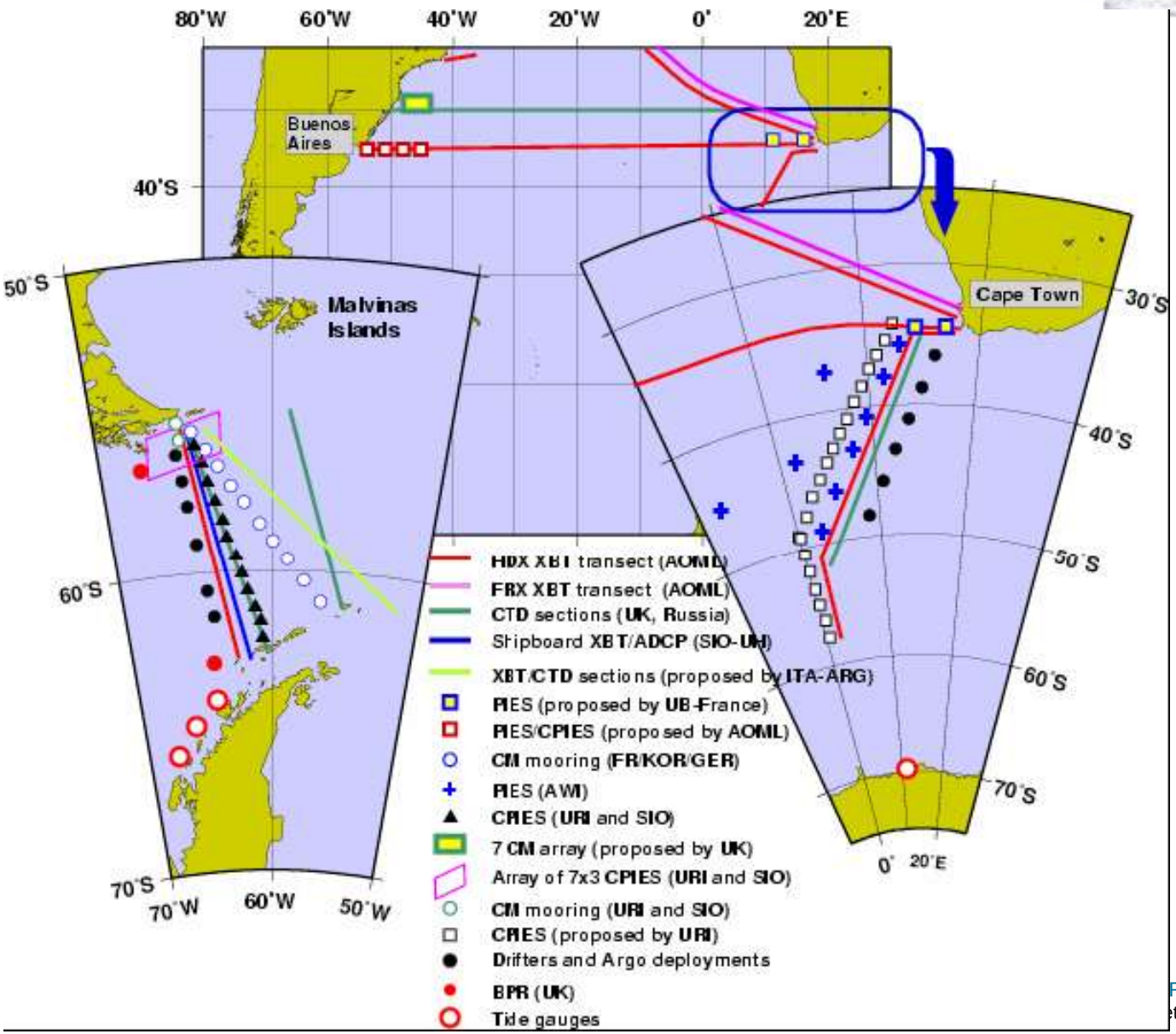
Le Quére et al., Science, 2007

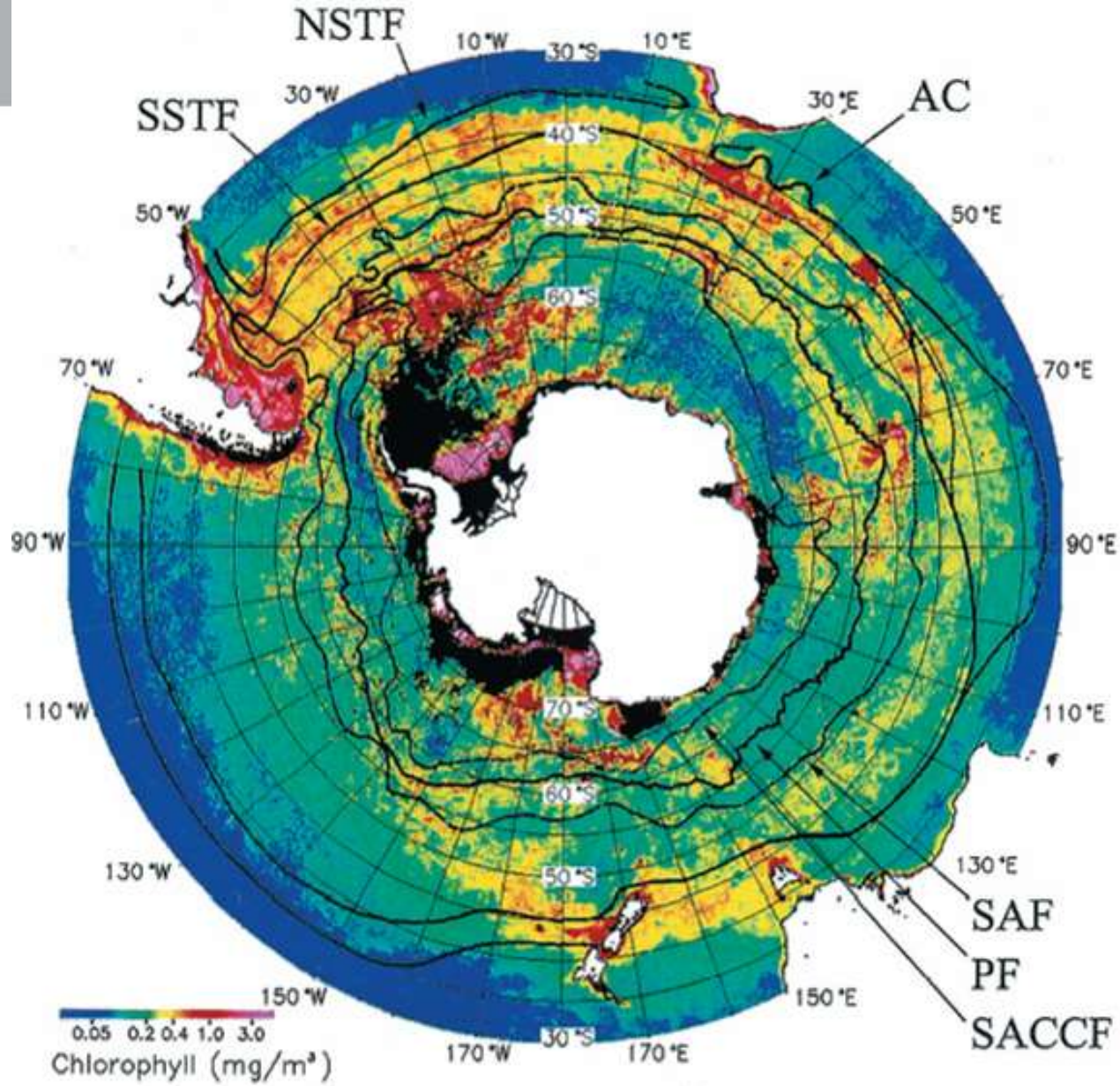
Overturning exchanges carbon with interior



Tilbook, Warner and Bullister

South Atlantic plans (SAMOC)

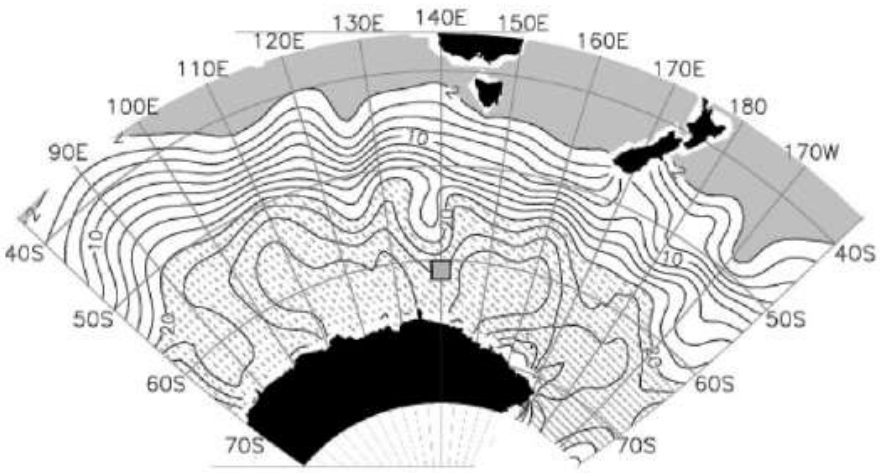




Moore and Abbott, 2000

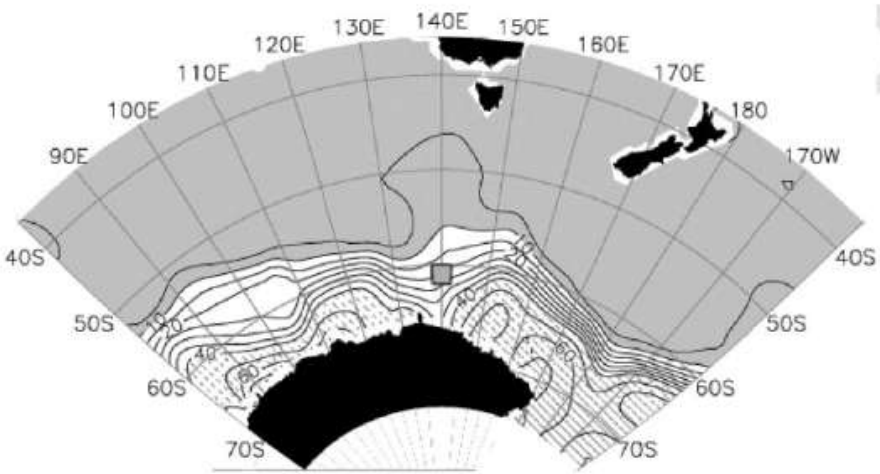
Nutrient levels in the mixed layer

Nitrate



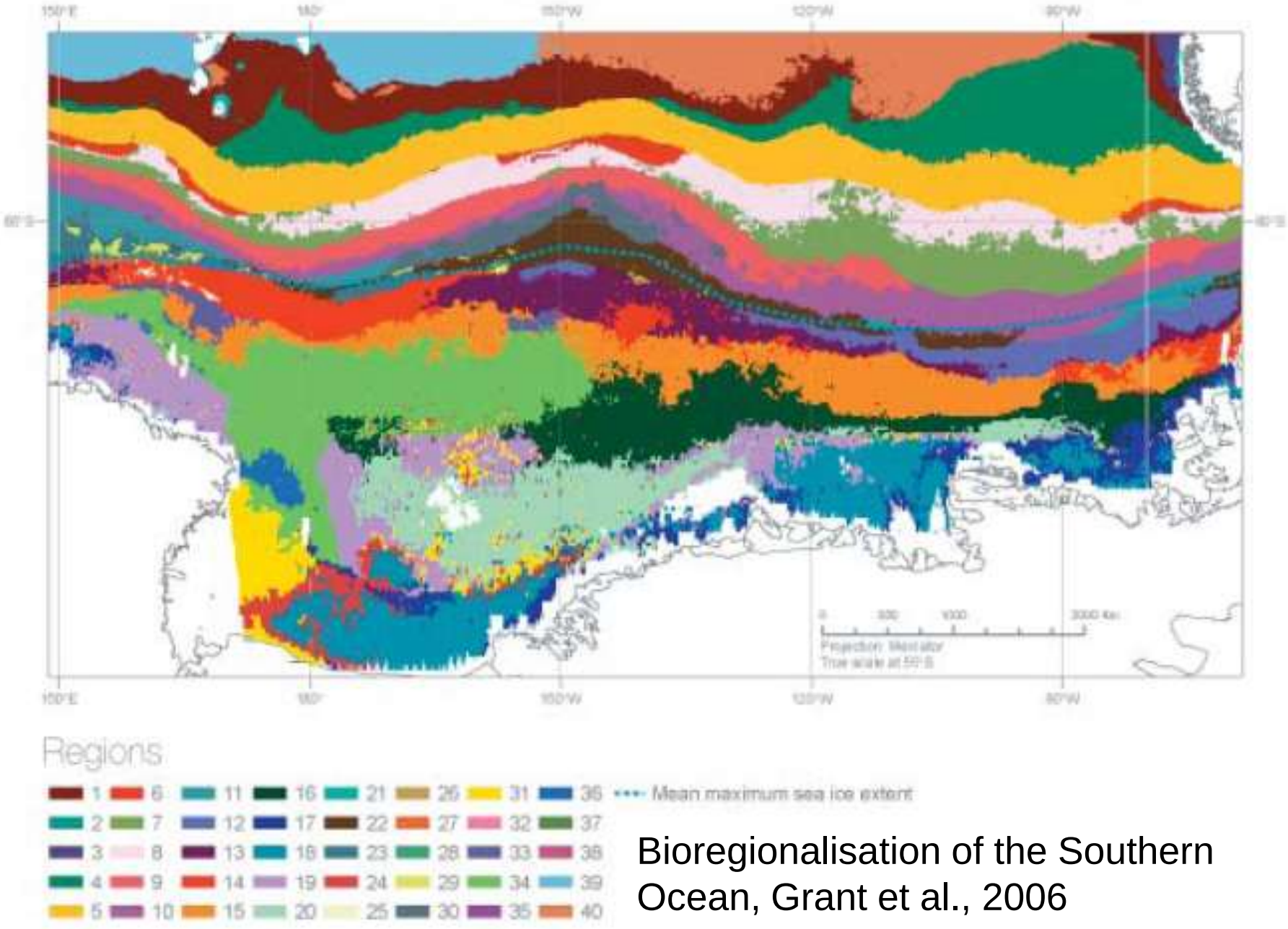
(a) nitrate

Silicate



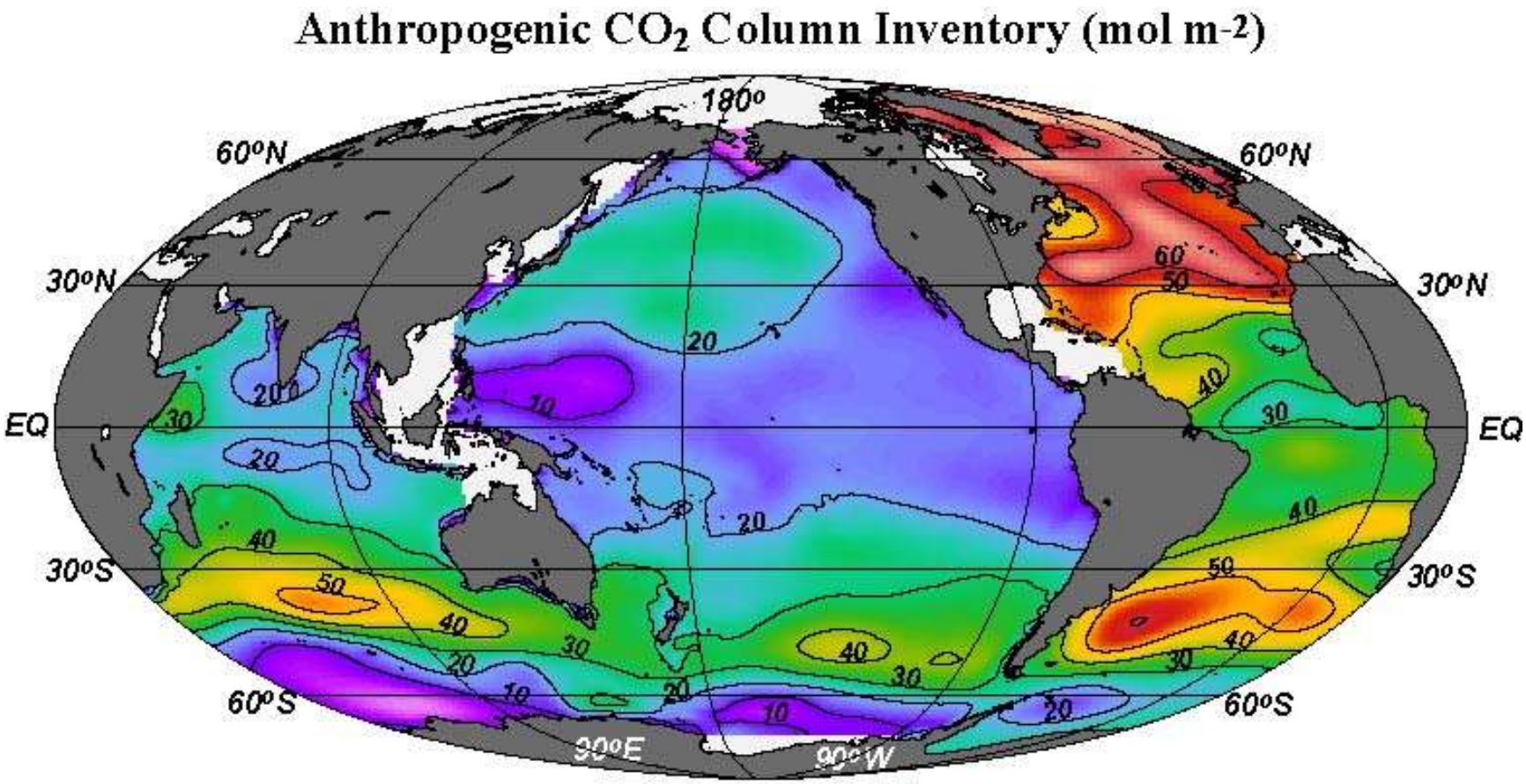
(b) silicate

Trull et al., 2001



Bioregionalisation of the Southern Ocean, Grant et al., 2006

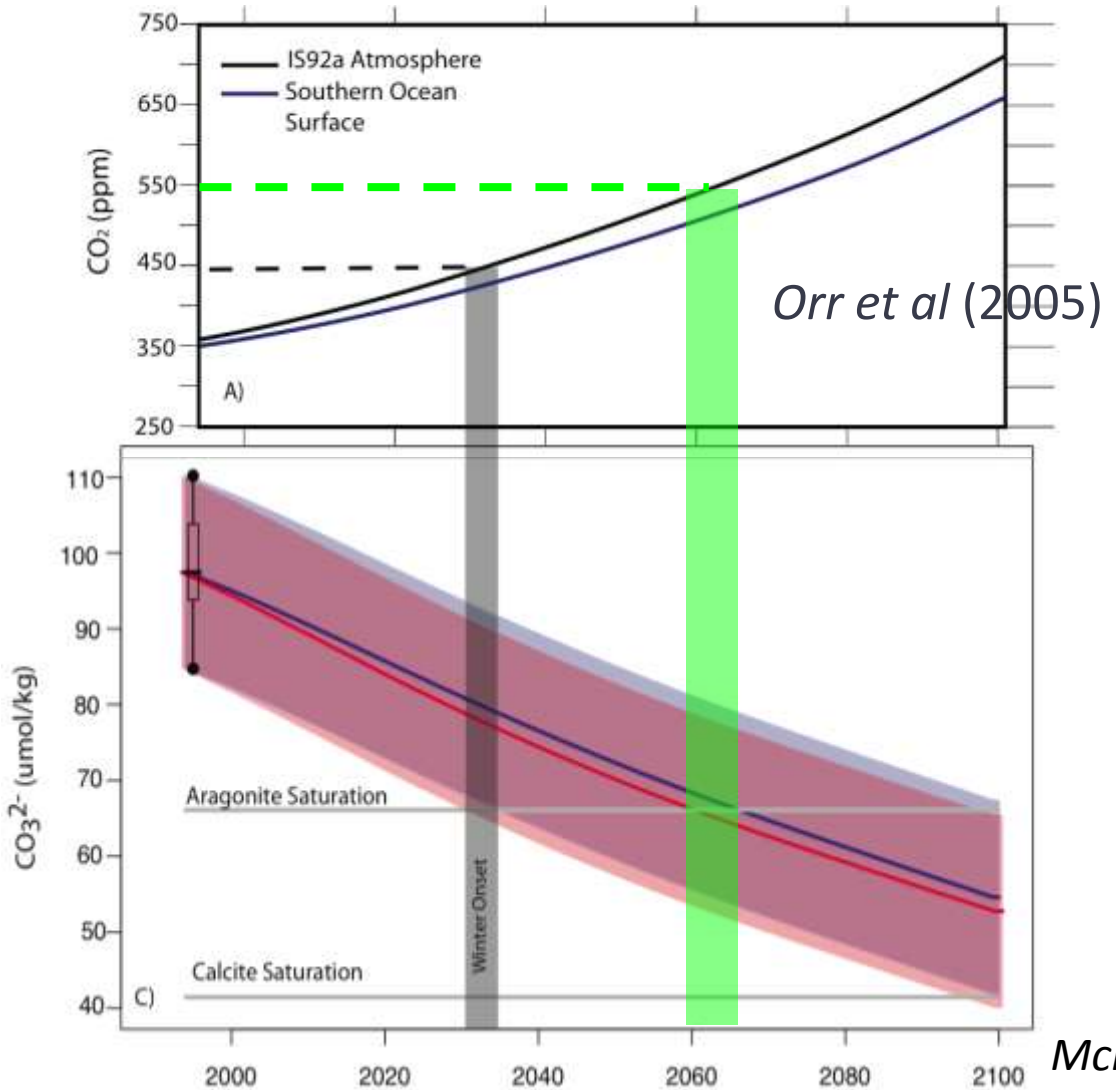
Southern Ocean has absorbed 40% of anthropogenic CO_2



Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

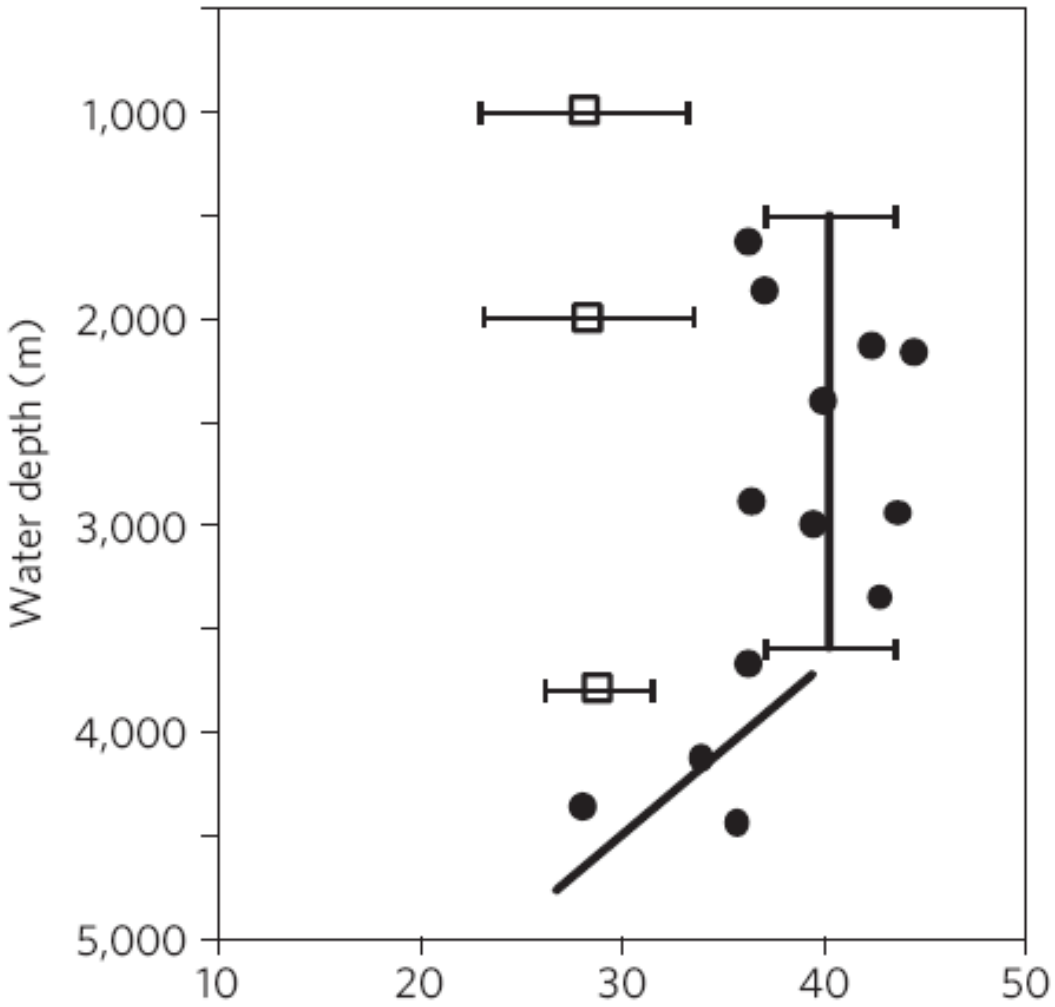
CSIRO

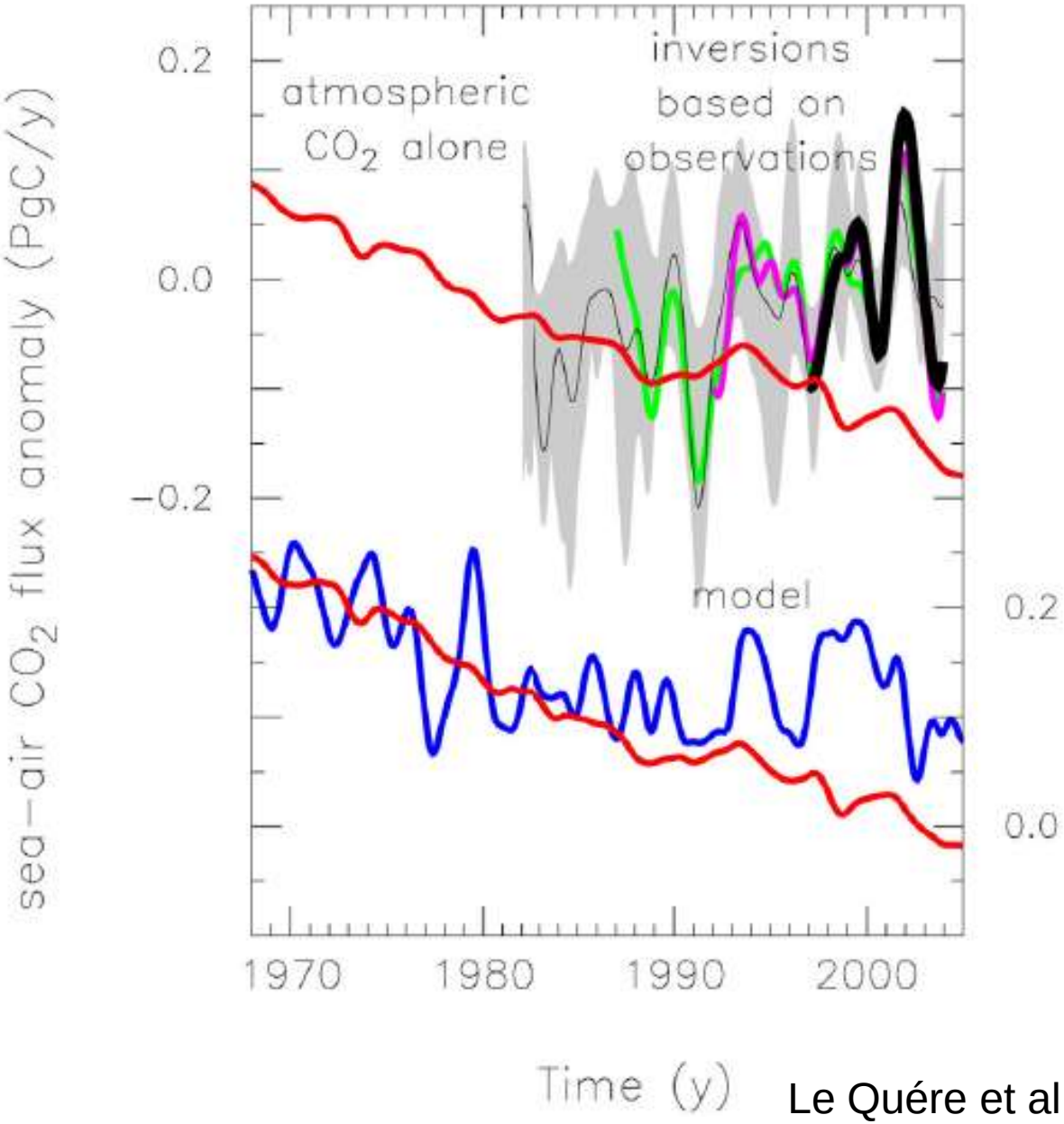


If take seasonality into account, SO will be undersaturated with respect to aragonite by 2030. Corresponds to atmosphere concentration of 450 ppm.

Moy and Howard (2009) suggest effects can already be observed.

McNeil & Matear PNAS 2008


Water depth (m)
1,000
2,000
3,000
4,000
5,000
10
20
30
40
50



Le Quére et al, Science, 2007

Australian Gover

Bureau of Meteo

CSIRO

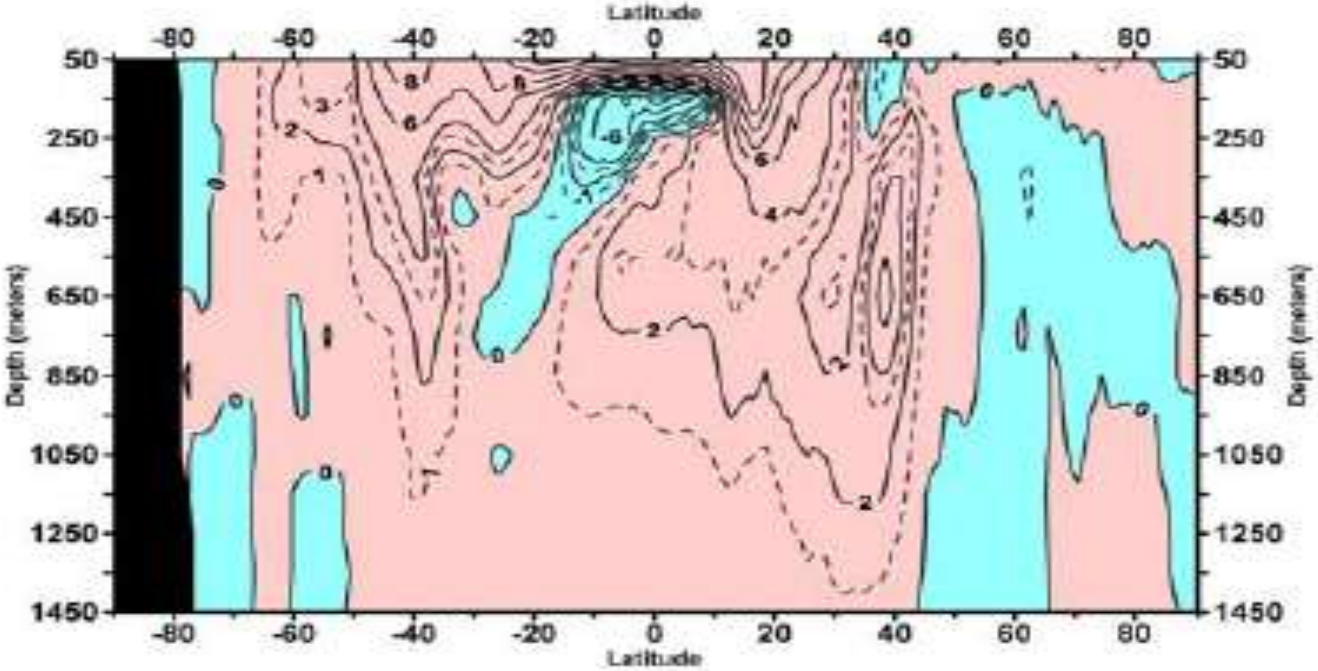
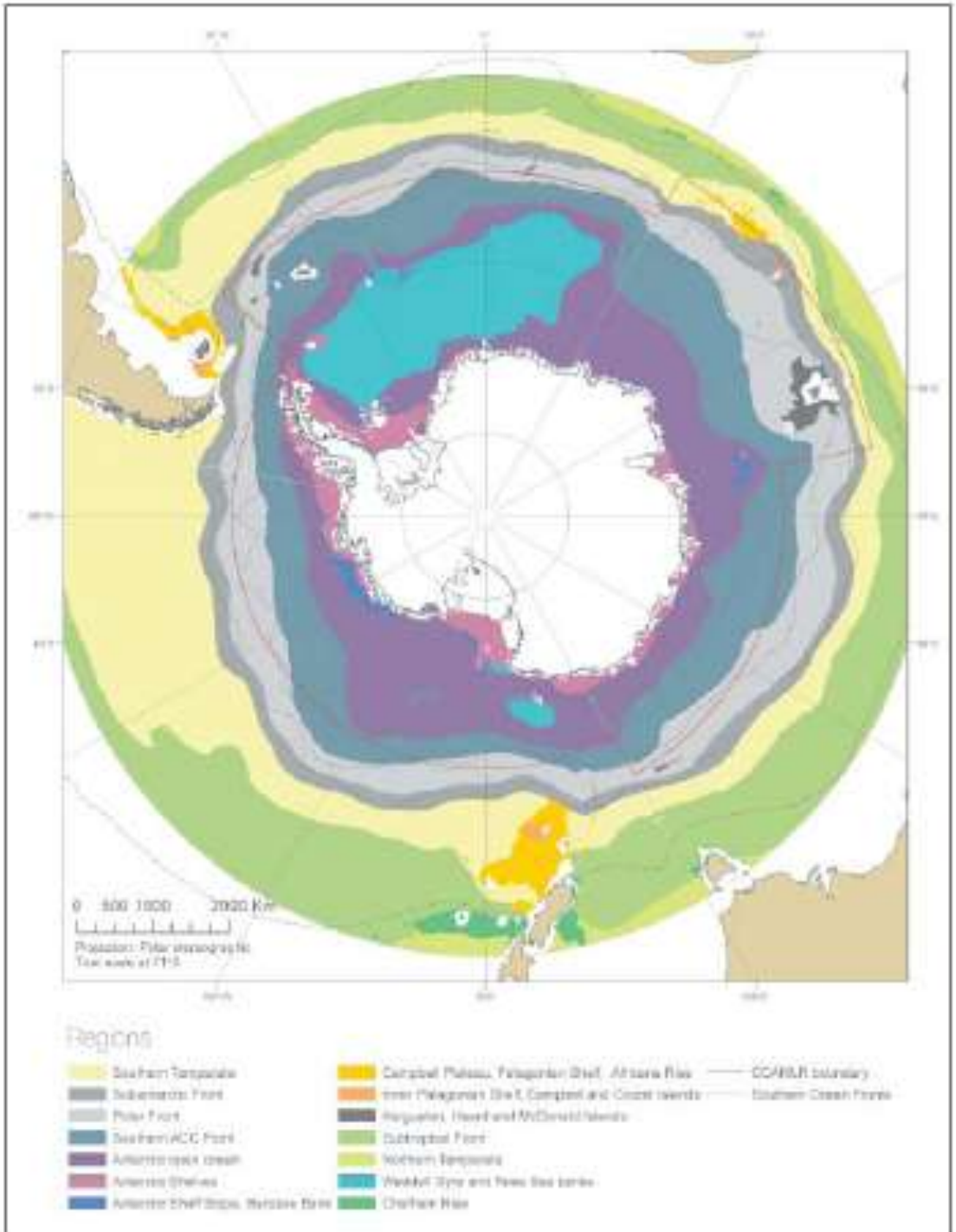


Figure 2. Linear trend (1955–2003) of the zonally integrated heat content of the world ocean by one-degree latitude belts for 100-m thick layers. Heat content values are plotted at the midpoint of each 100-m layer. Contour interval is 2×10^{18} J year^{-1}.

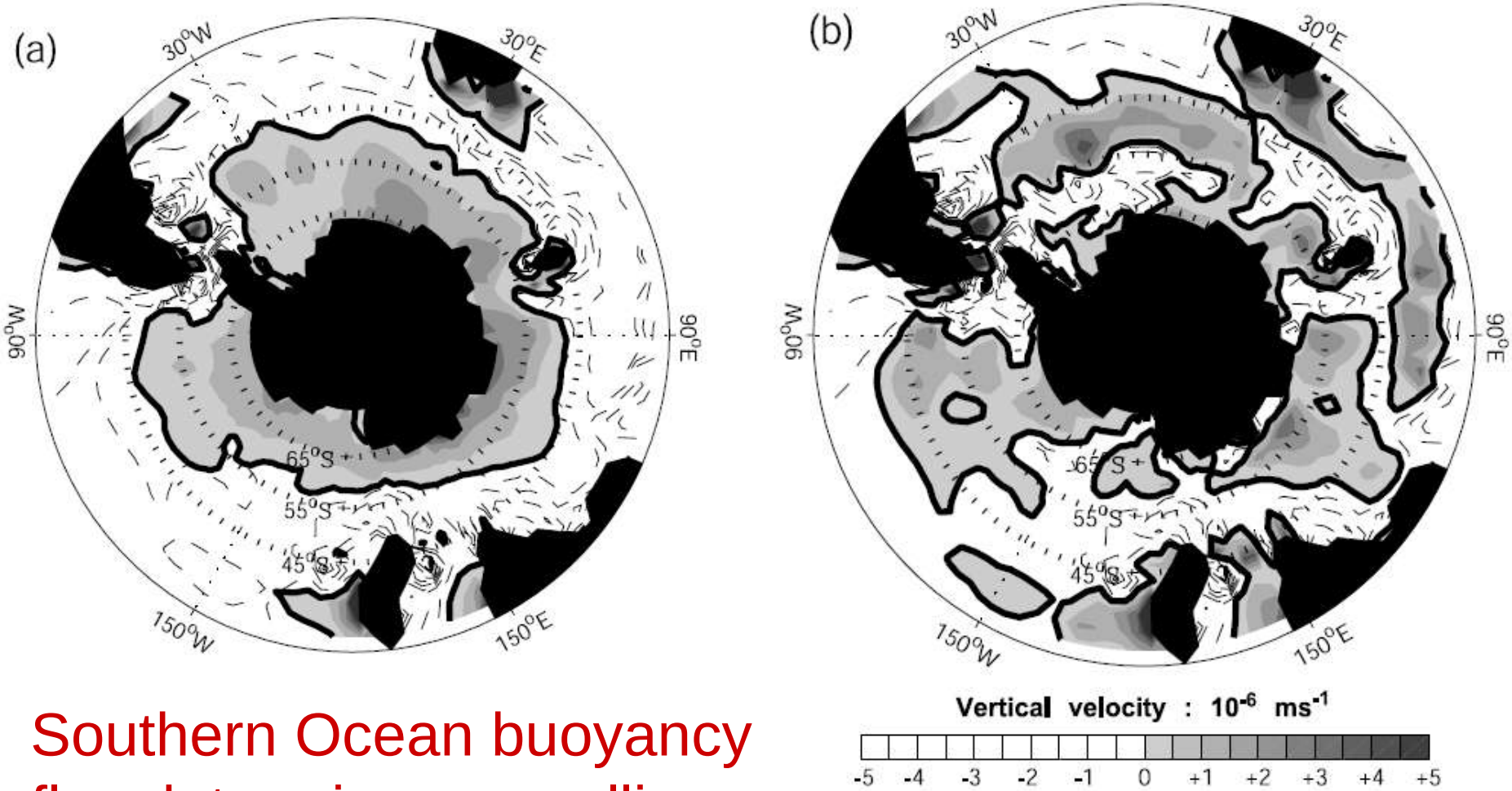


nate Research
of Meteorology

CSIRO

Ekman pumping

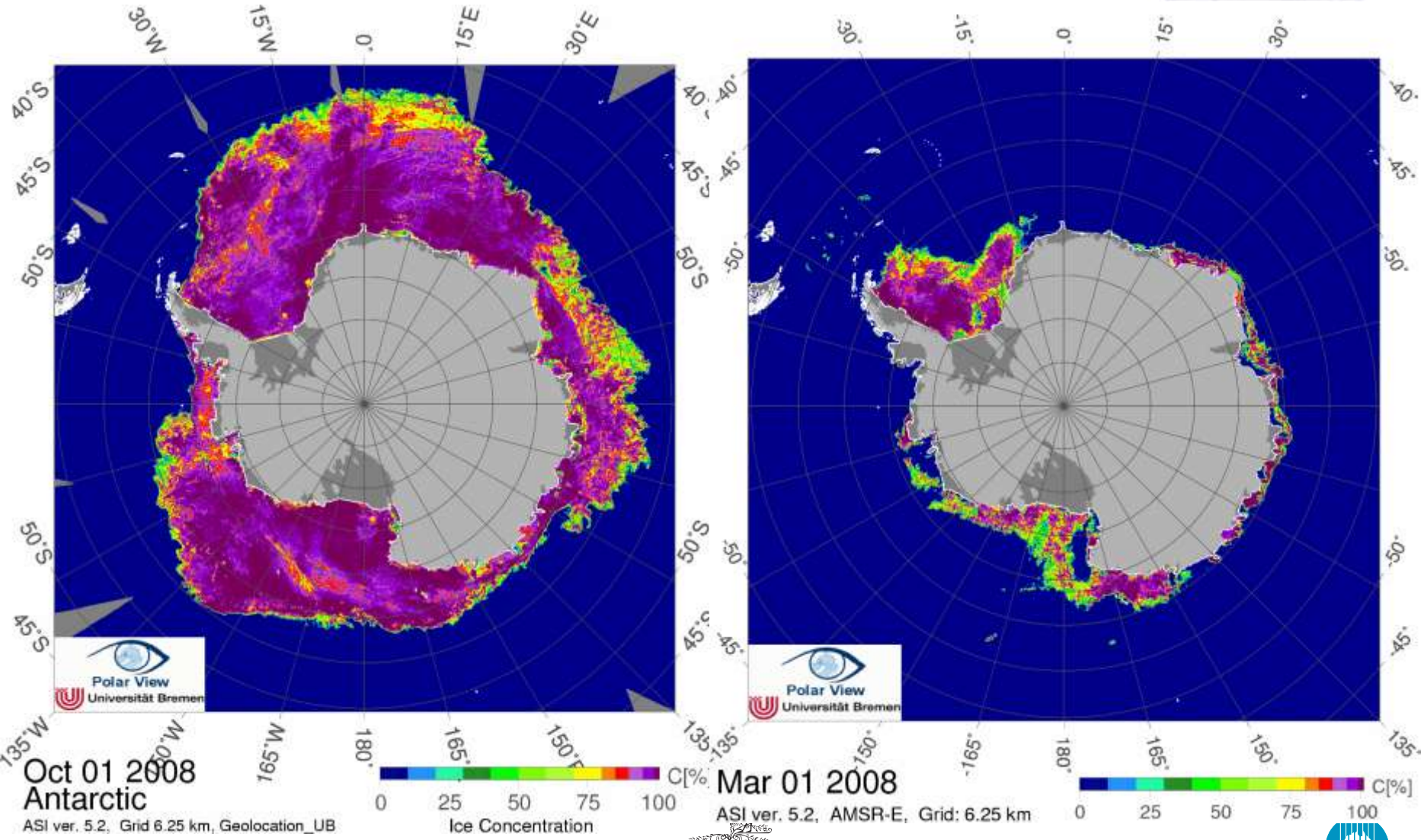
Ekman + eddies (residual mean)



Southern Ocean buoyancy flux determines upwelling pattern, hence nutrient supply and community structure.

Ito et al., 2005

Antarctic sea ice

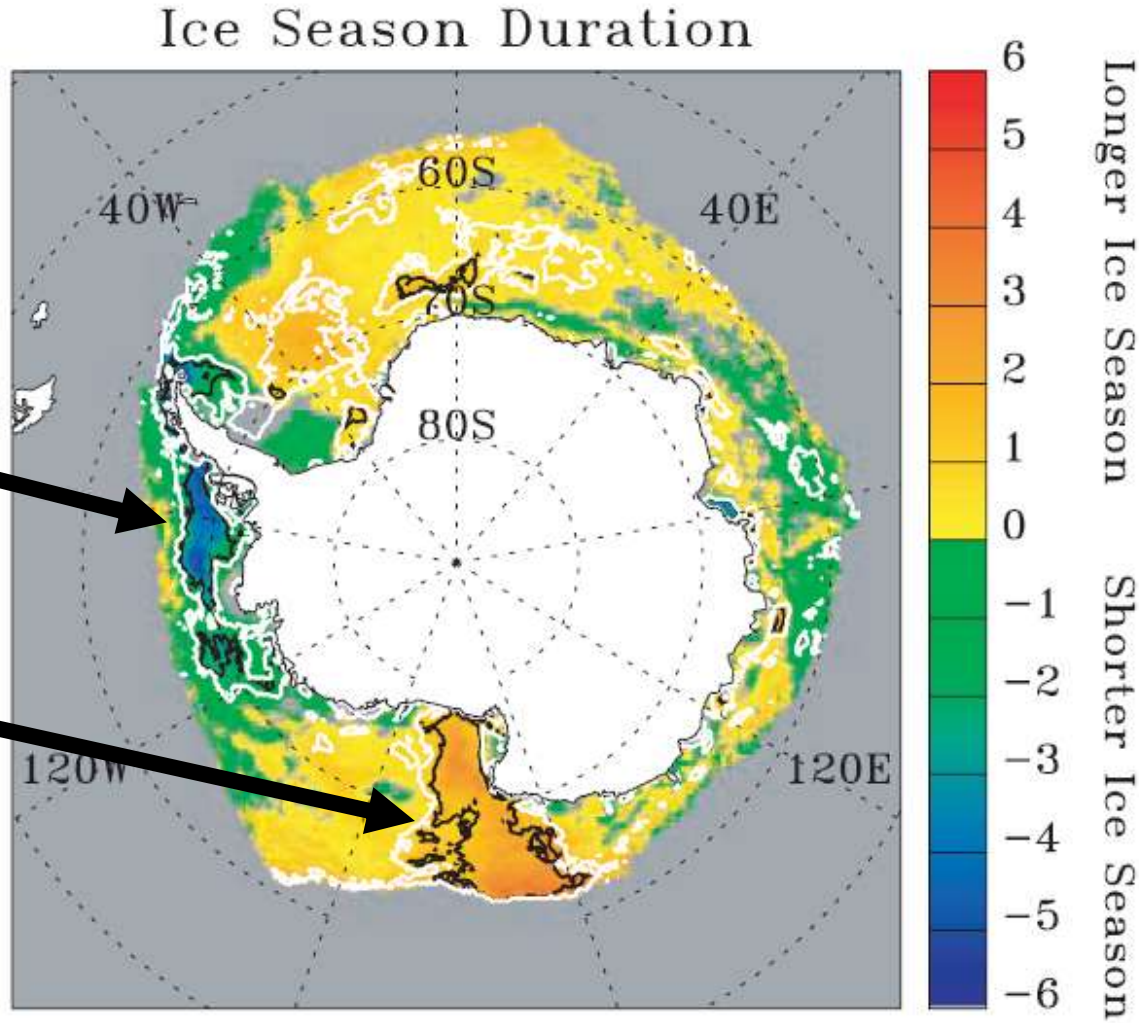


Large regional changes in Antarctic sea ice

Changes in sea ice duration: 1979 – 2006

-83 ± 23 days

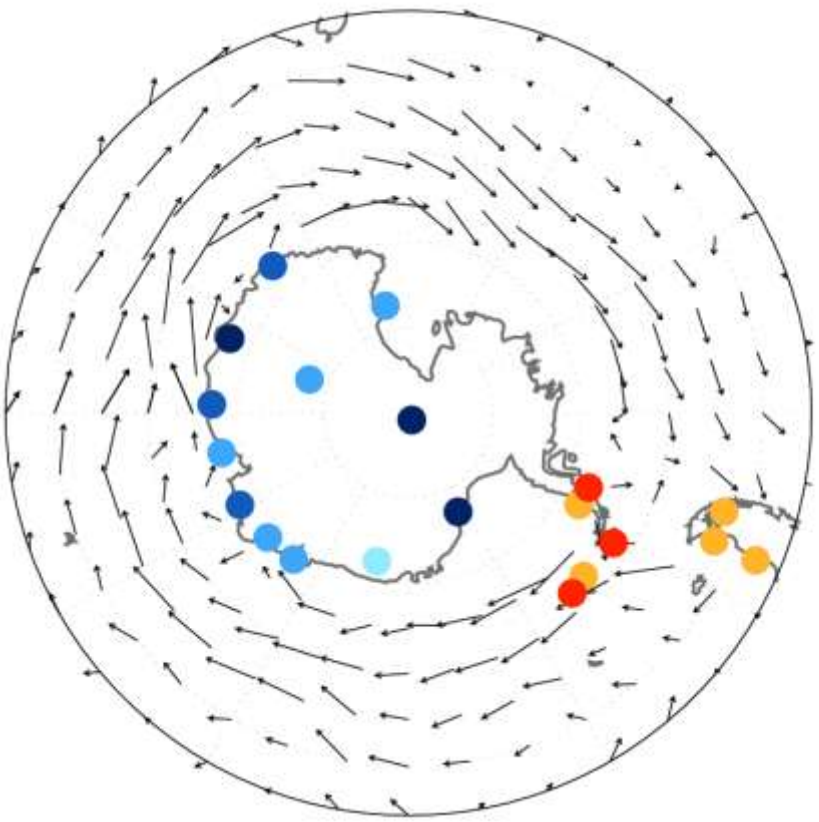
57 ± 13 days



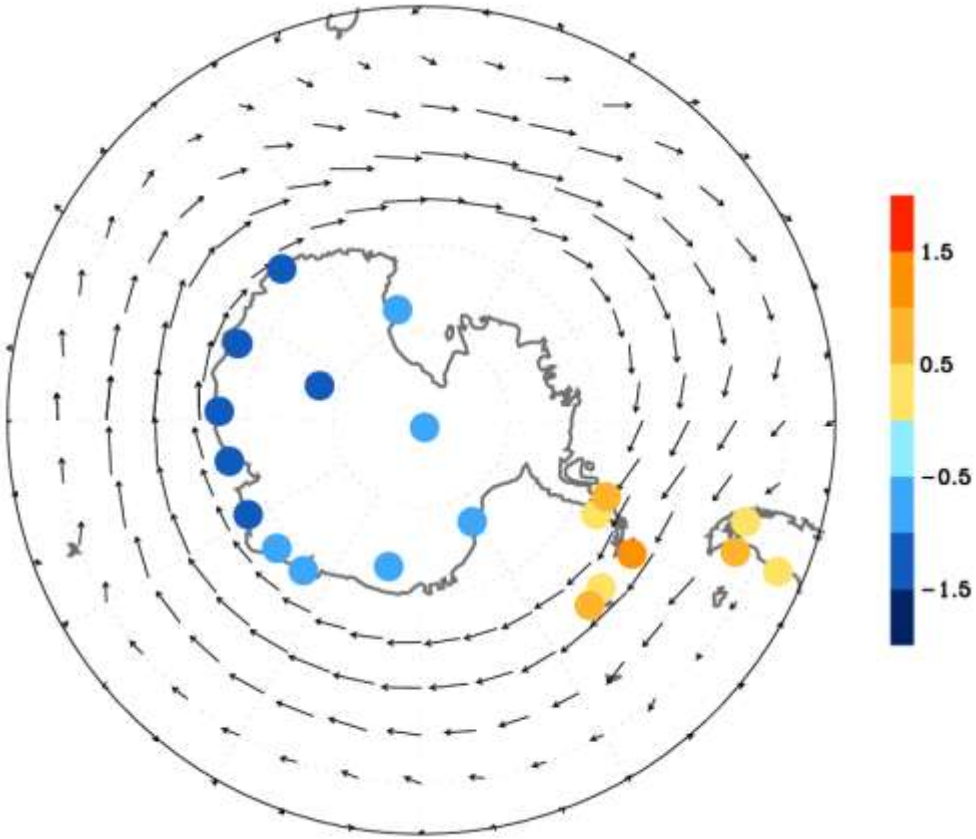
Stammerjohn et al. (2008)

Changes in SO winds: Southern Annular Mode

TREND



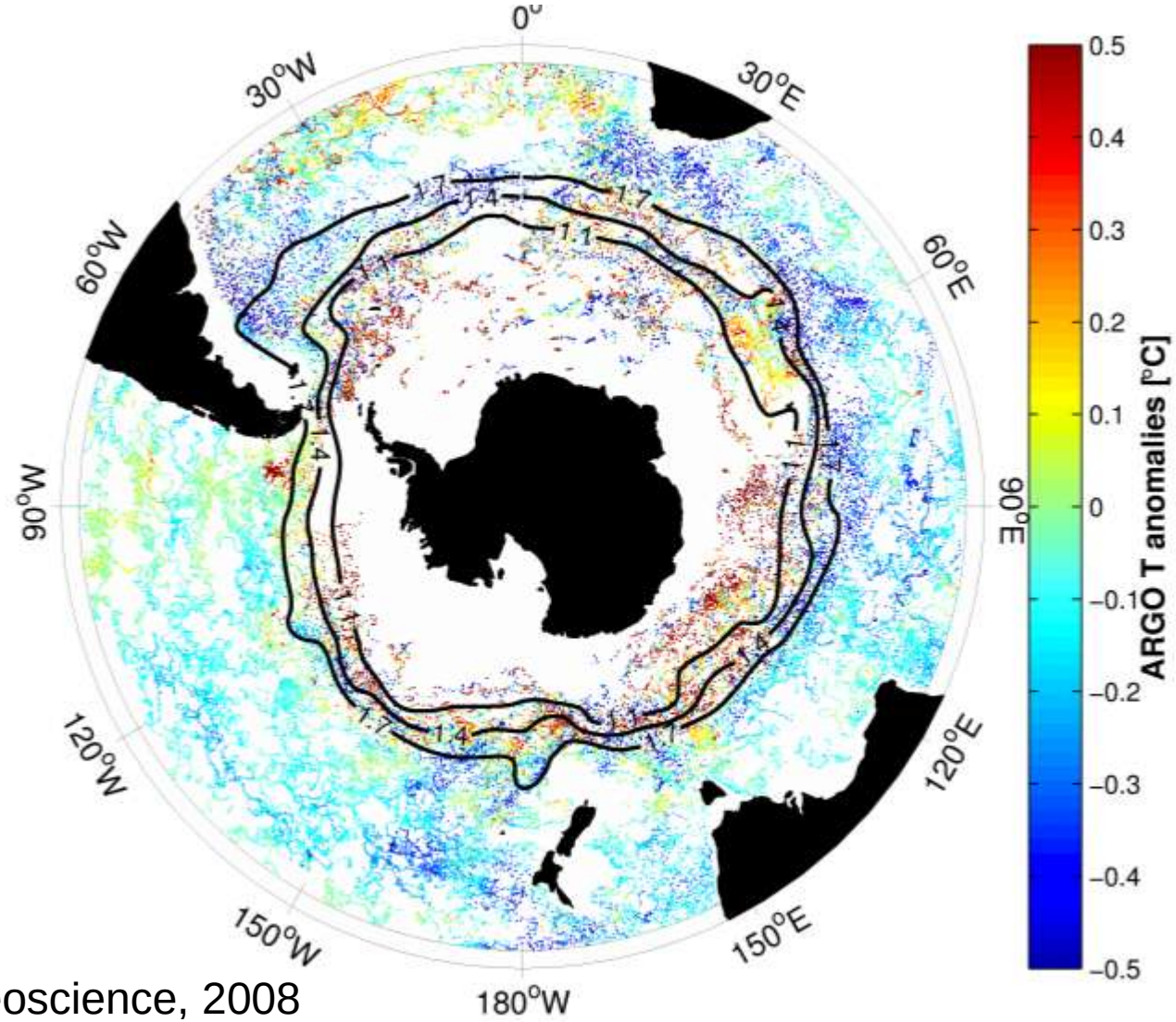
CONGRUENT WITH SAM



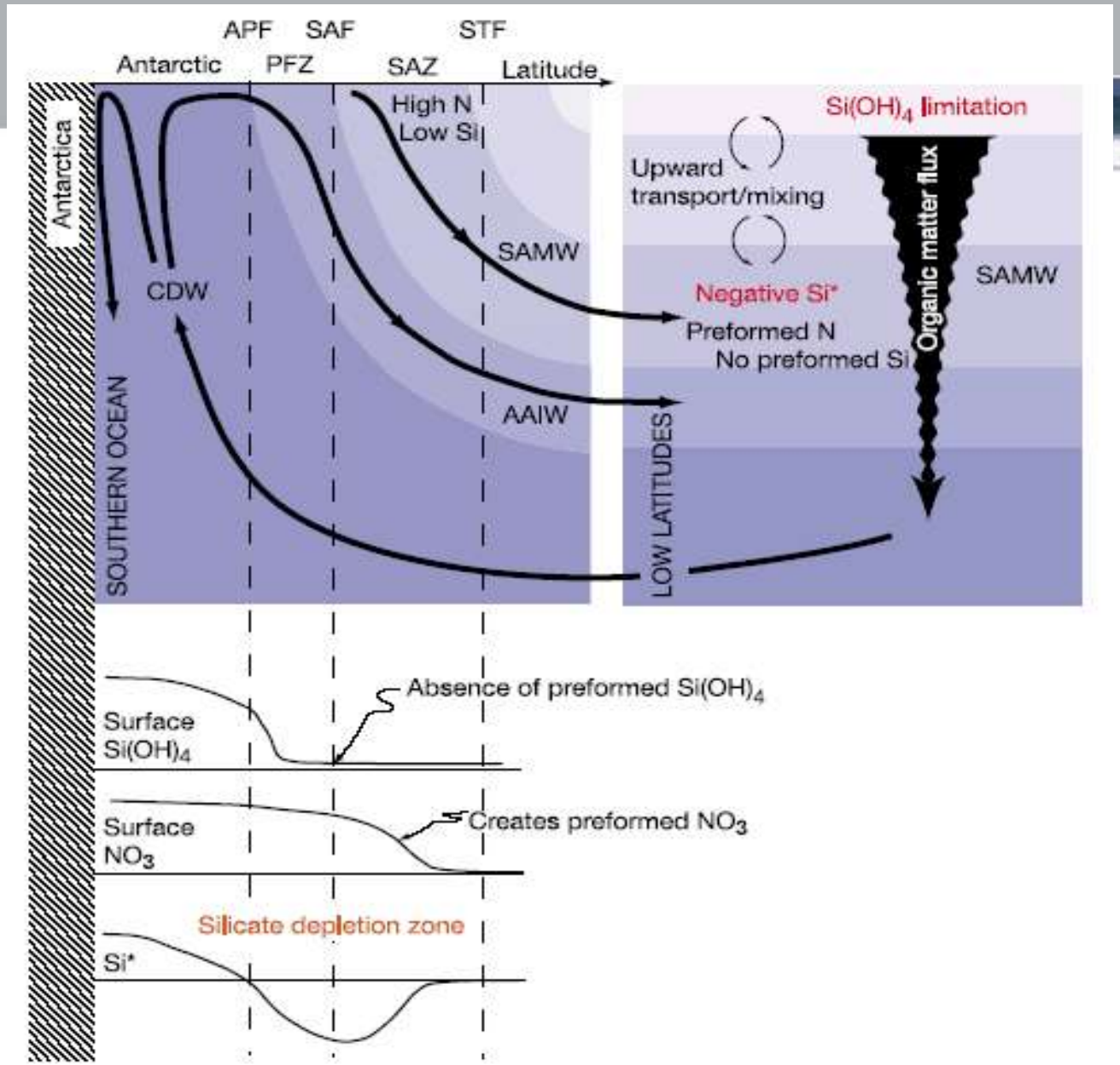
Thompson and Solomon (2002)

Warming of the ACC belt

Change in temperature (Argo – CARS climatology, γ_n = 26.9 – 27.7)



Böning et al., Nature Geoscience, 2008



Sarmiento et al., 2004

Summary

Southern Ocean has warmed and freshened through full ocean depth. Overturning change?

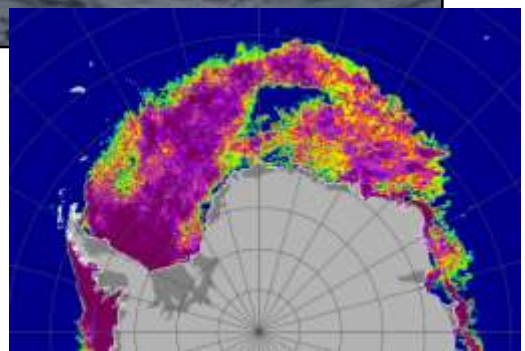
Changes reflect both water mass changes caused by changes in forcing (warming, precipitation, ice melt) and poleward shift of currents.

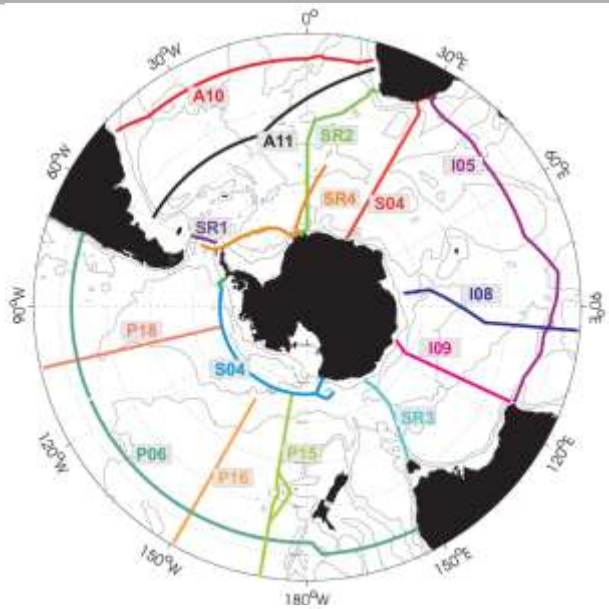
Southern Ocean changes may result in climate feedbacks driving further change (overturning, carbon cycle, sea ice).

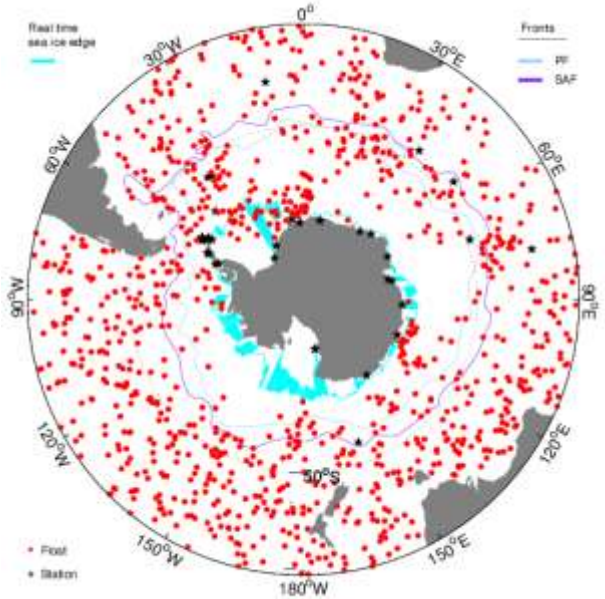
Attribution of the causes of observed changes remains a challenge, due to short records and incomplete understanding. Changes likely linked to changes in wind as well as warming, in turn caused by human activities and natural variability.

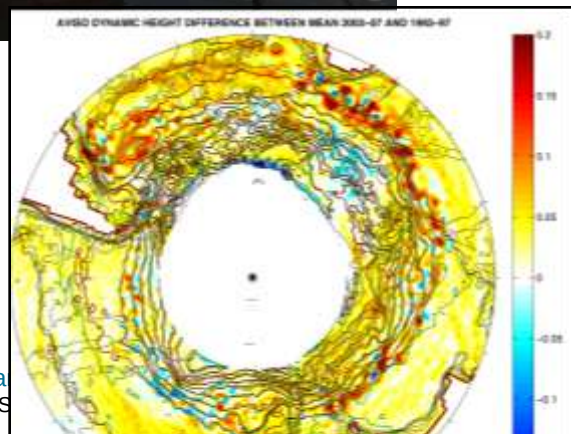
To detect, interpret and respond to change, a Southern Ocean Observing System is needed to provide sustained, multi-disciplinary measurements.

Southern Ocean Observing System









r Australia
between CS

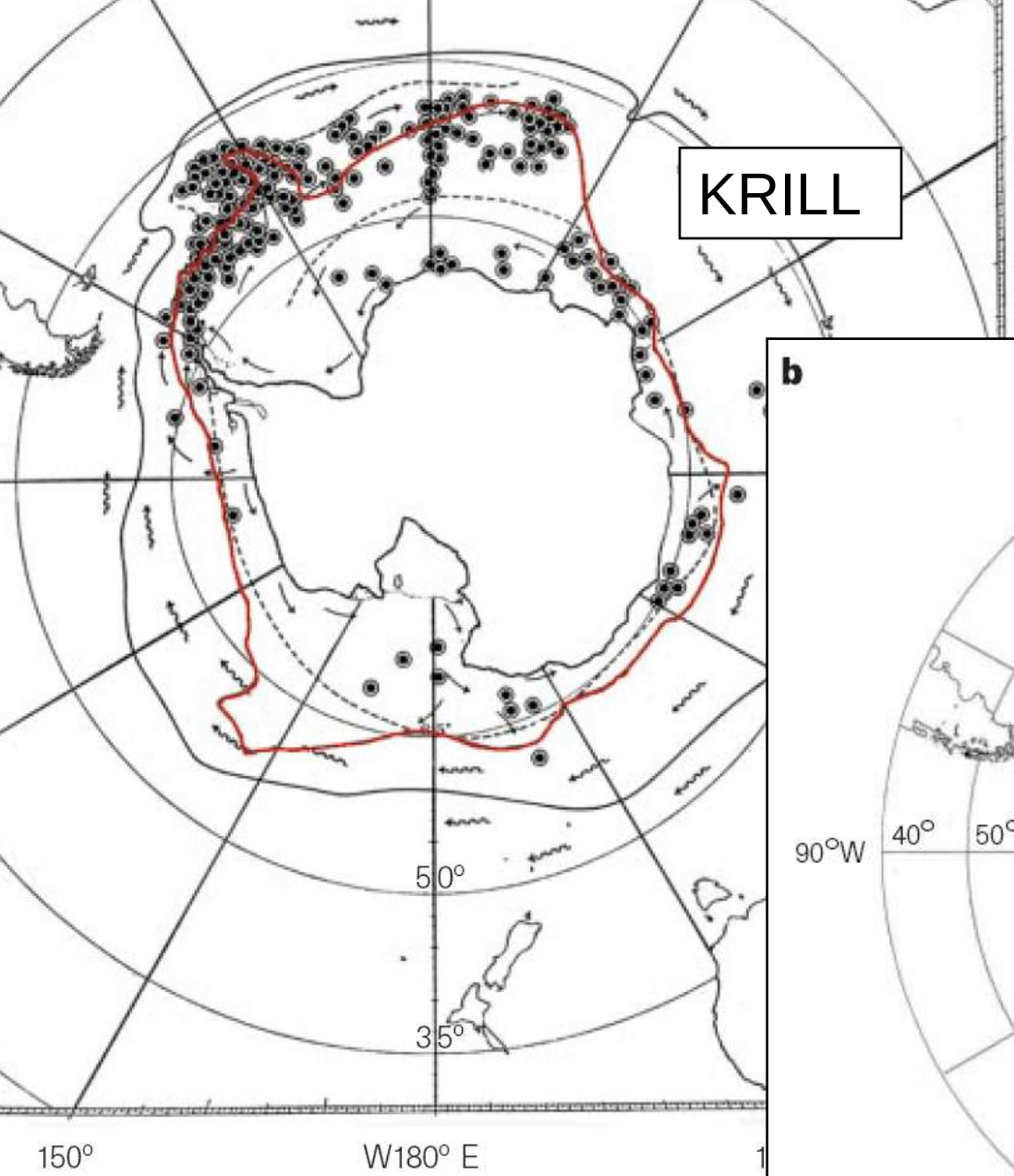
Drivers of change in the Southern Ocean

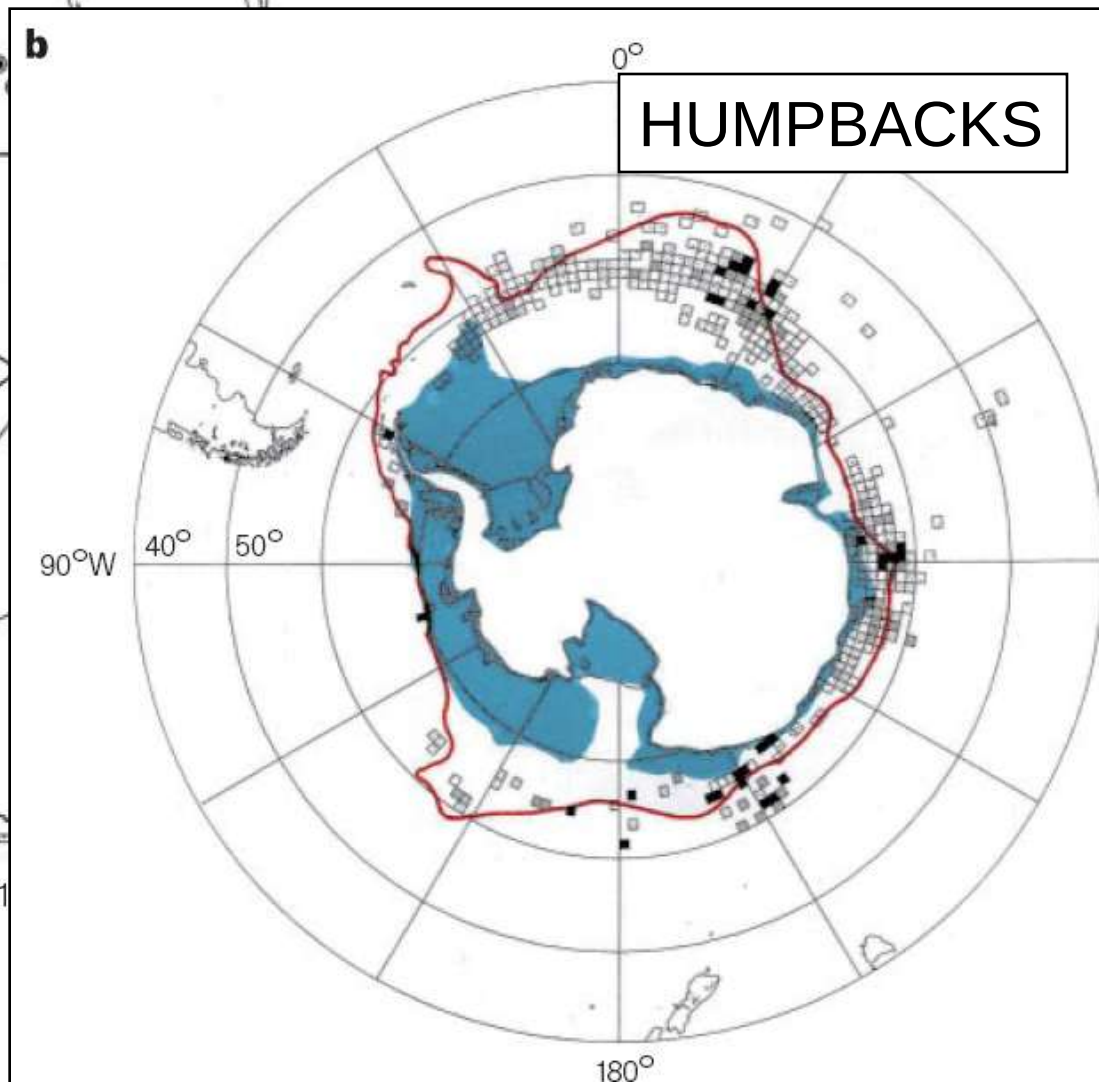
- Warming of the surface ocean, and transport into ocean interior
- Increased vigour of the hydrological cycle (more precip at high latitude)
- Increased supply of glacial ice melt
- Changes in wind-driven circulation
- Changes in sea ice

Are we seeing evidence of climate change?

- Pattern of warming and freshening is broadly consistent with climate model projections under enhanced greenhouse forcing
- But climate models project a change in ACC transport and overturning that we do not see in observations

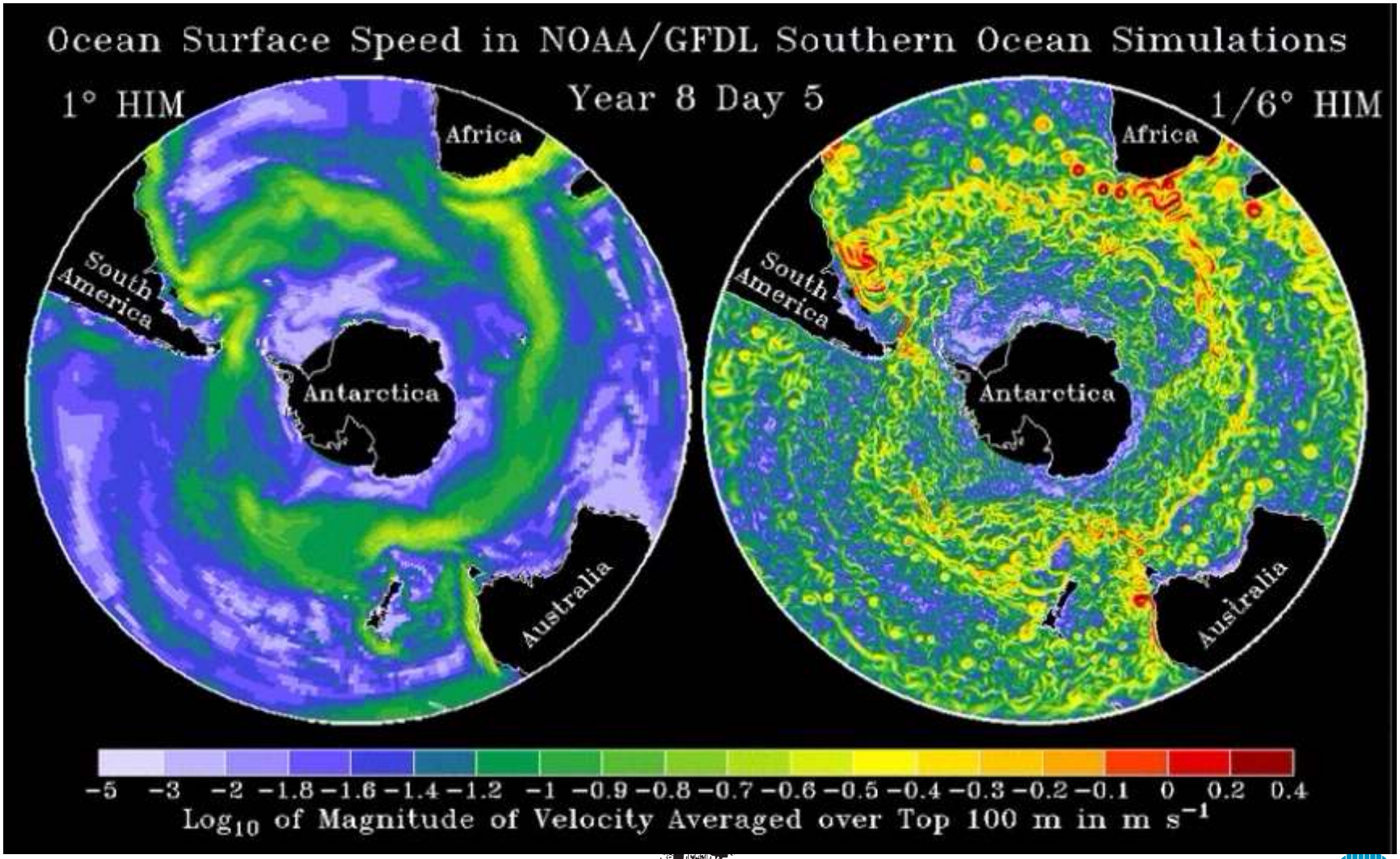
Observed signal is a response to multiple drivers (ozone depletion, greenhouse forcing, ENSO) and internal variability. Lack of observations makes attribution of change a challenge





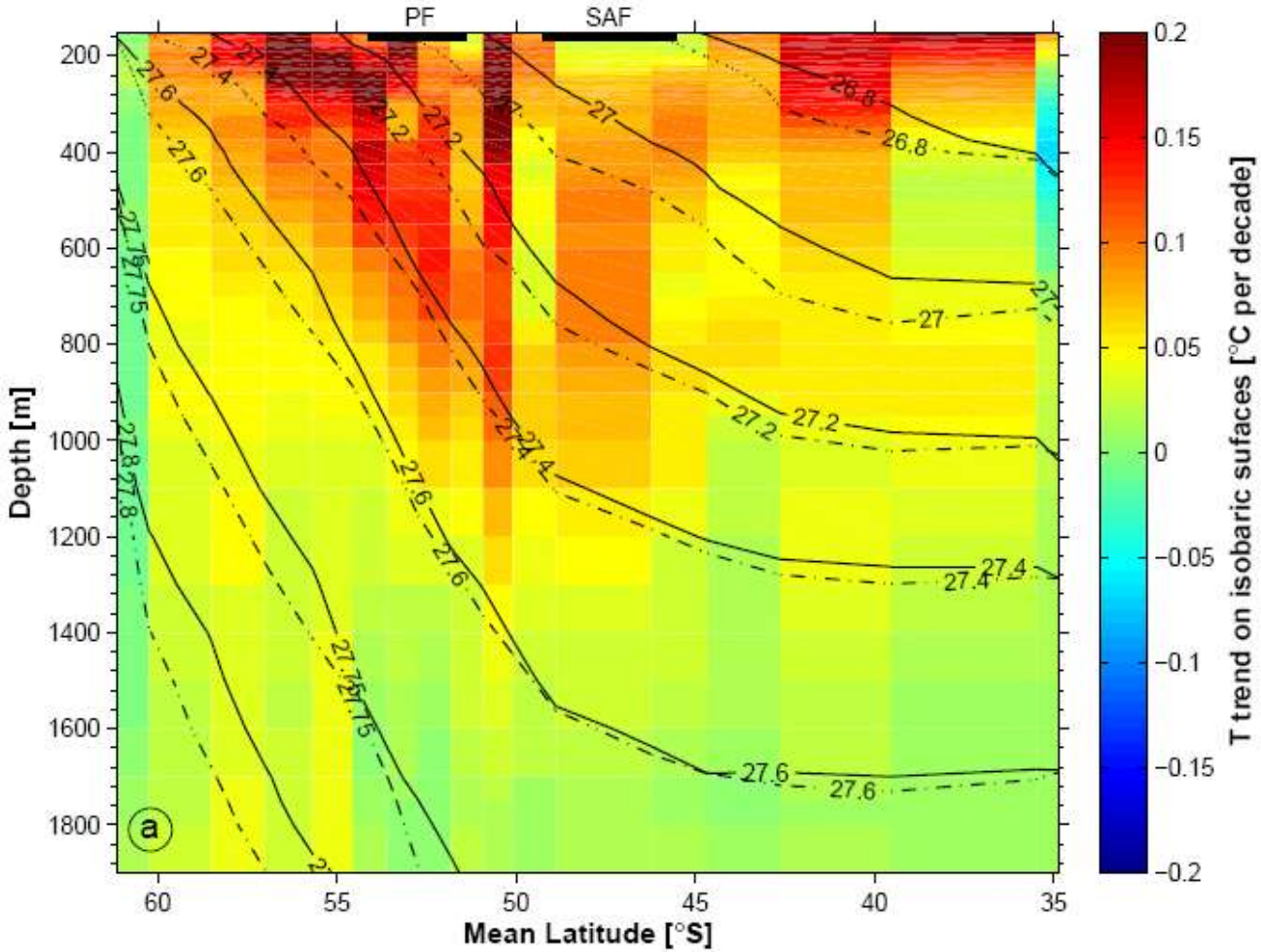
Tynan, 1998

Small scale motions (eddies) are important



Southward shift contributes to warming of ACC

Temperature trends on pressure surfaces, along mean streamlines of the ACC

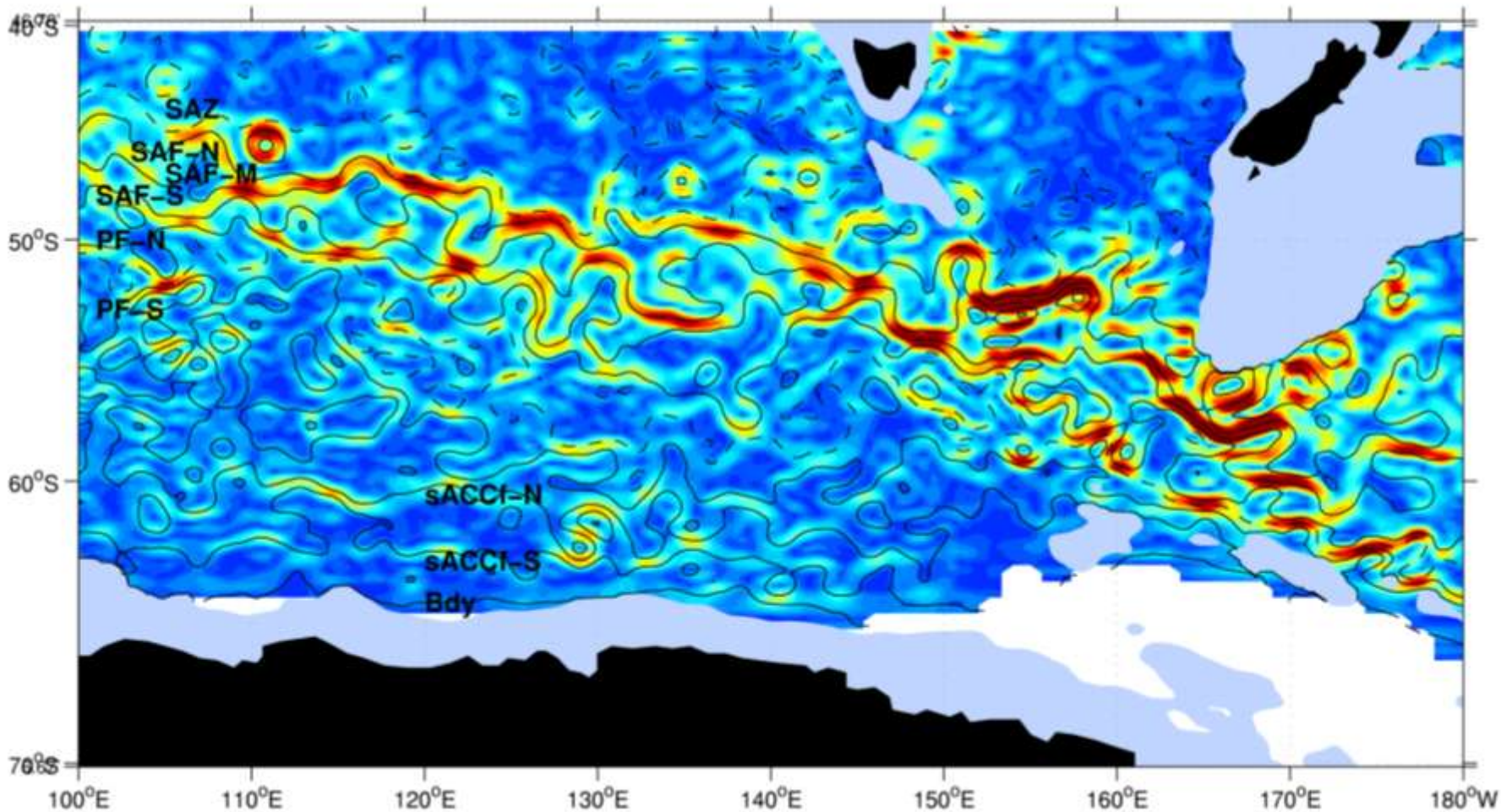


Böning et al., Nature Geoscience, 2008

Summary 2

- Changes are occurring in the Southern Ocean.
- In most cases, can be attributed to changes in winds, in turn associated with human activities (mostly ozone now, greenhouse more important later?).
- Strong forcing anomaly associated with ozone-driven change in winds means SO is not “pristine”: while remote from many human drivers, our observations span a period where the SO is heavily impacted by pollution.
- Models suggest changes in the open Southern Ocean may be subtle and indistinguishable from natural variability for decades.
- Shifts of biomes may be an exception.
- A process understanding of short-term variability may allow interpretation of short and incomplete records.
- A sustained Southern Ocean Observing System is essential, feasible, and needs to start now. We need your help.

Frontal structure of the Circumpolar Current



Sokolov and Rintoul, 2007a,b; 2009a,b