Antarctic Bottom Water formation and variability of Antarctic water masses

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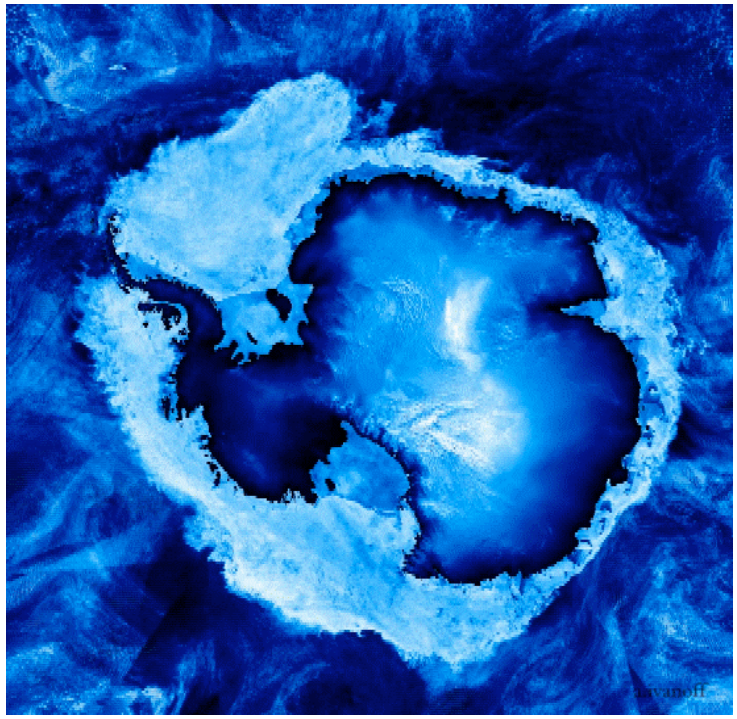
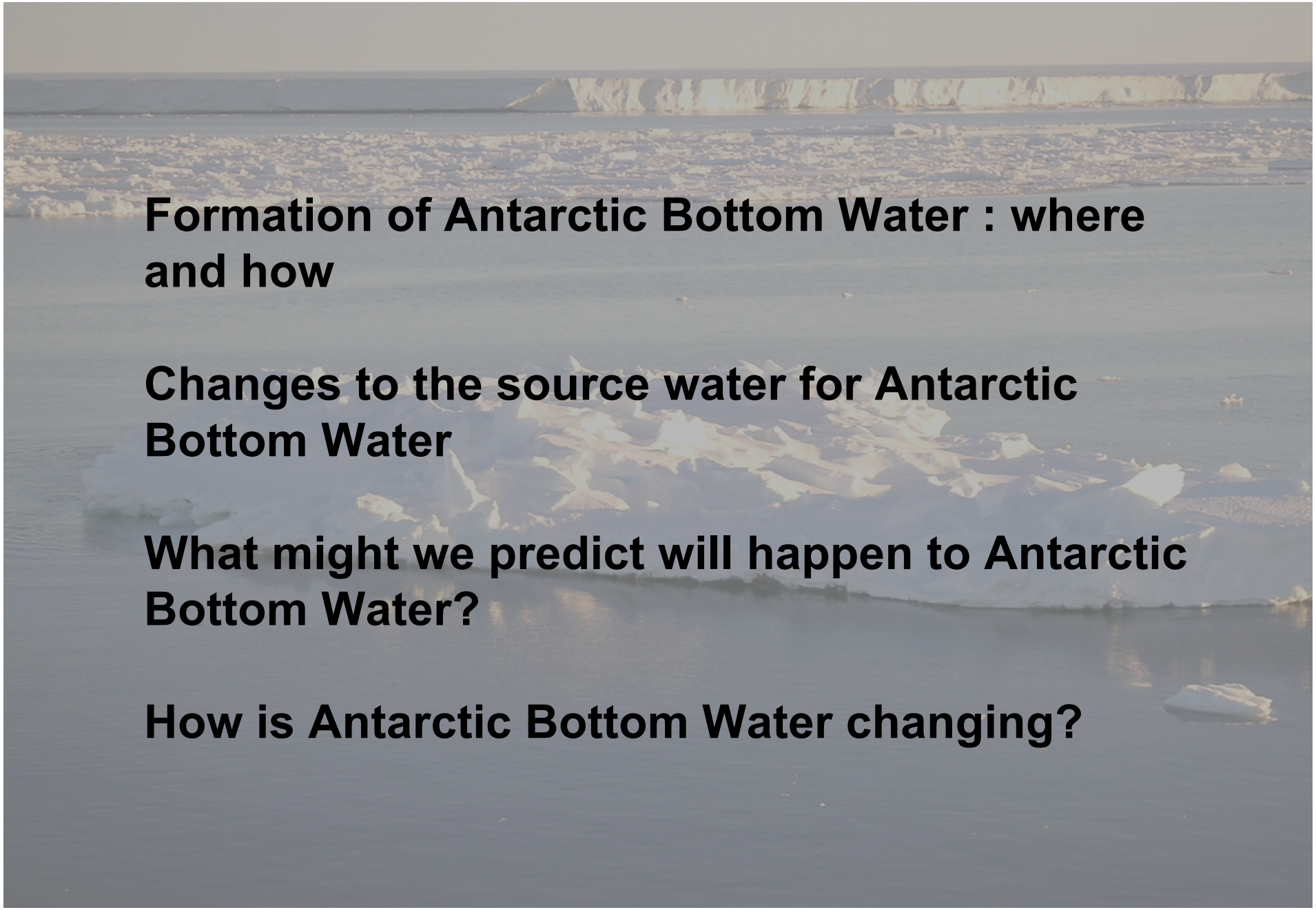


Courtesy of Nick Owens, BAS

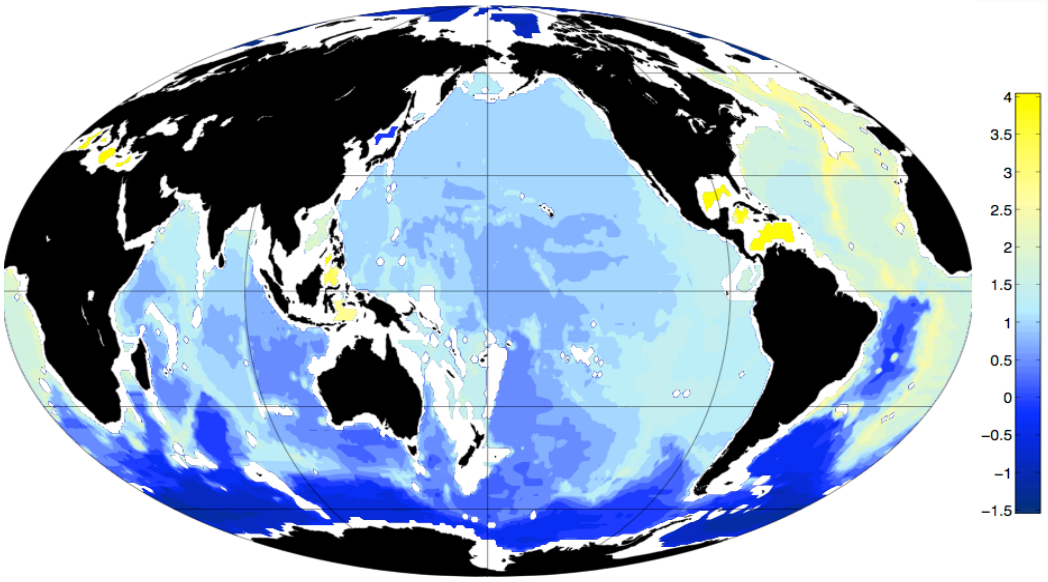


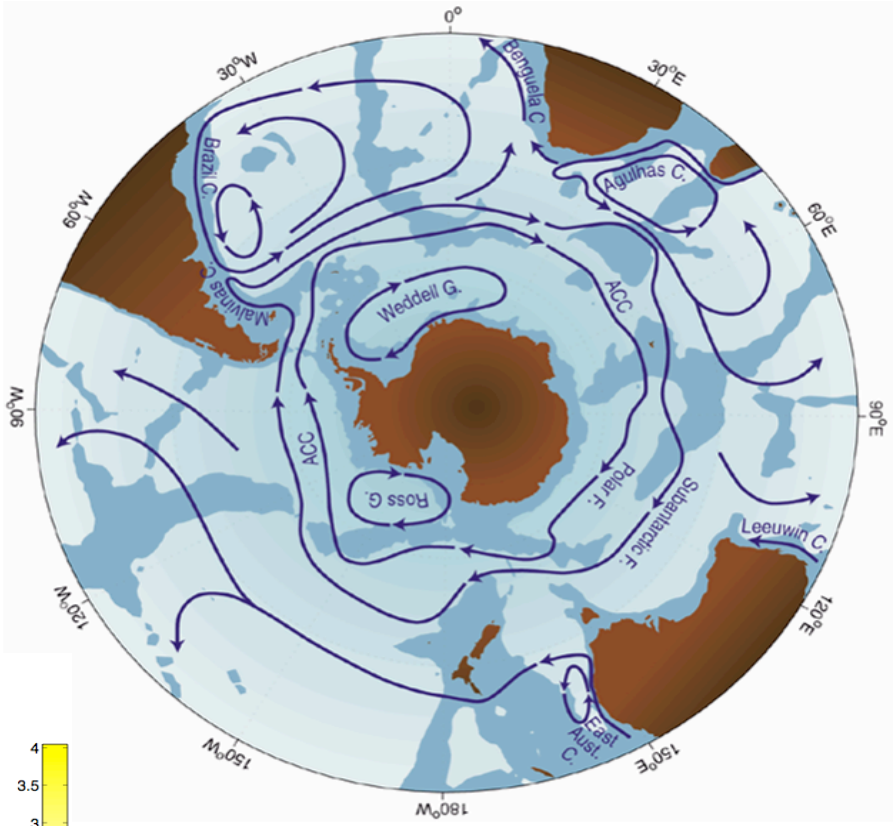
Formation of Antarctic Bottom Water : where and how

Changes to the source water for Antarctic Bottom Water

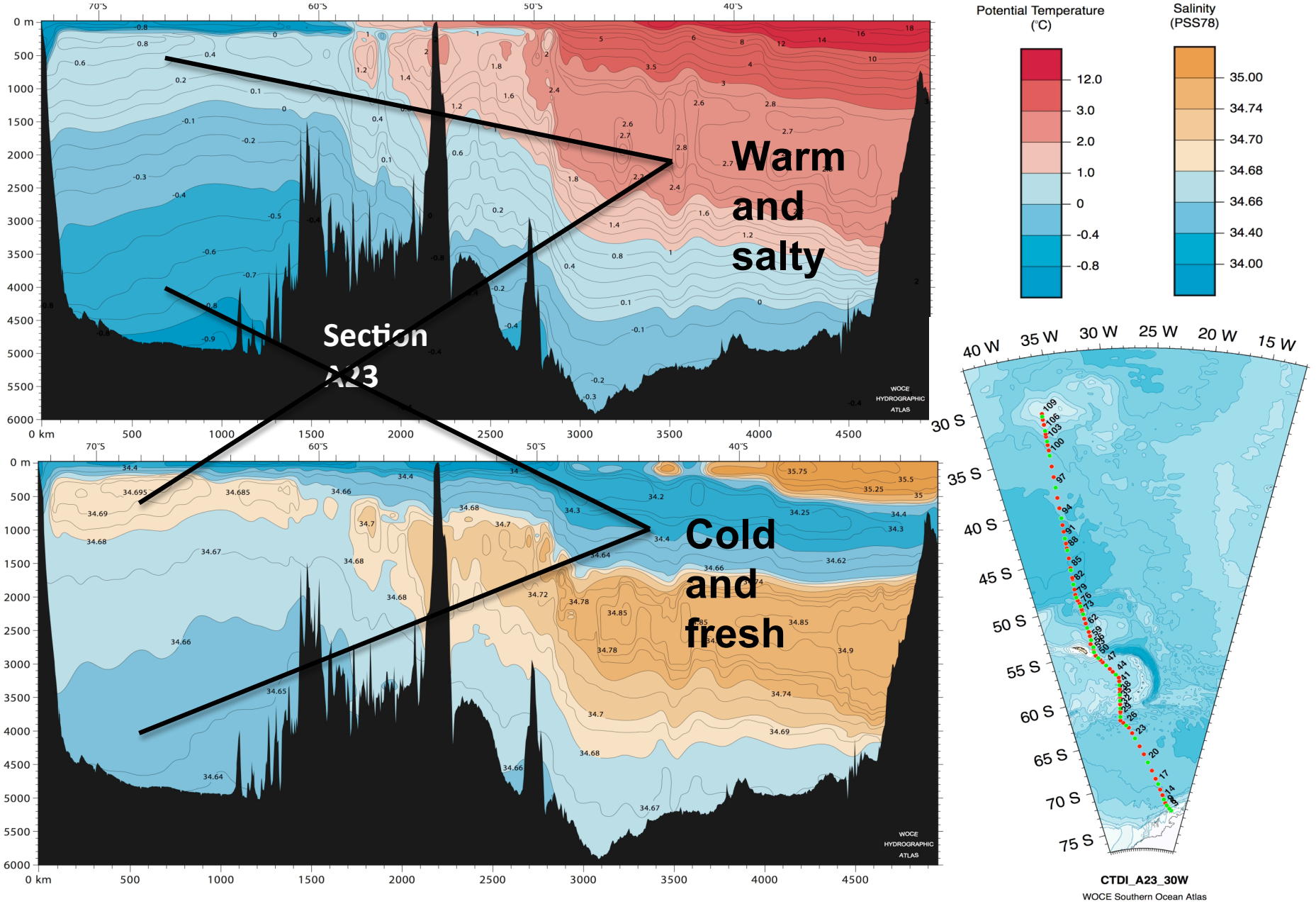
What might we predict will happen to Antarctic Bottom Water?

How is Antarctic Bottom Water changing?

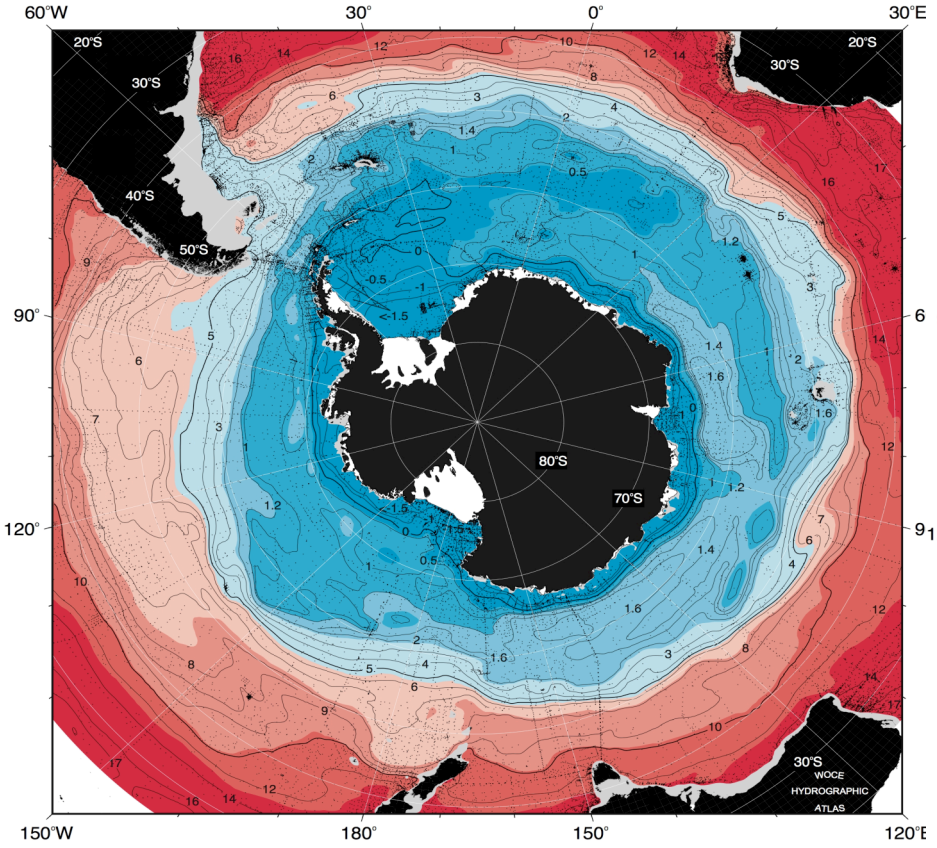


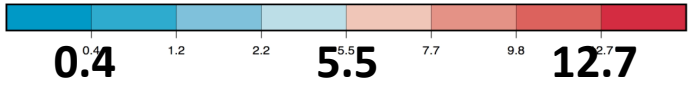


The Southern Ocean is the source of cold dense water at the bottom of most of the world ocean.

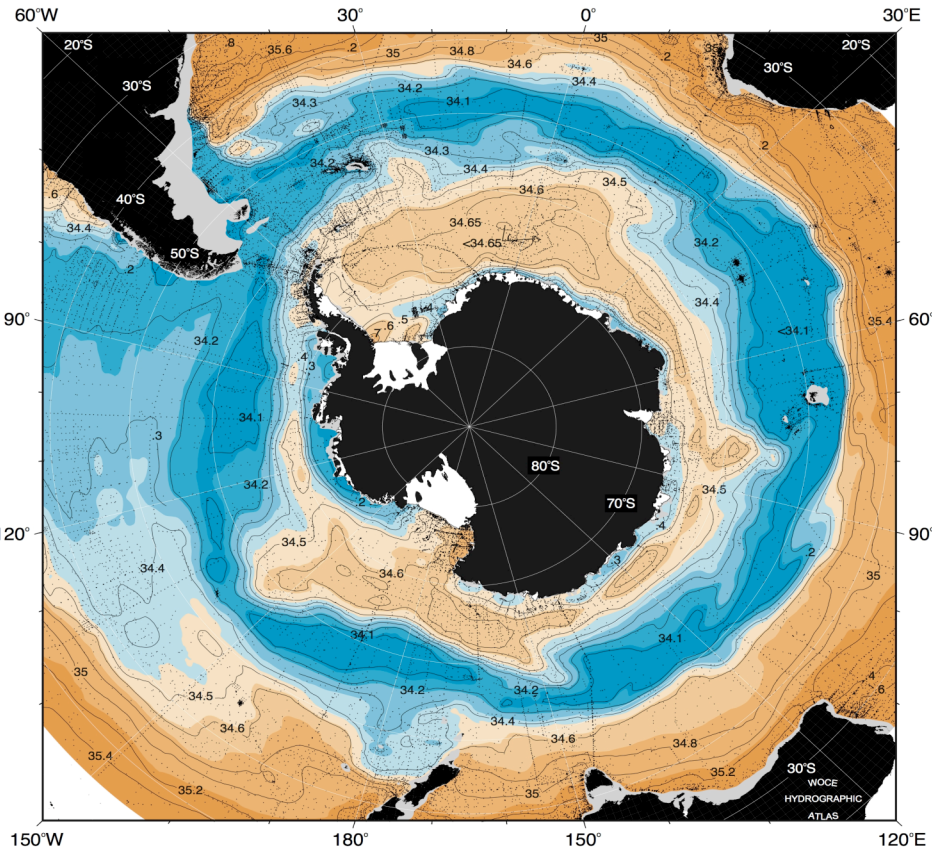

Potential Temperature (°C)
12.0
3.0
2.0
1.0
0
-0.4
-0.8
Salinity (PSS78)
35.00
34.74
34.70
34.68
34.66
34.40
34.00
Warm and salty
Cold and fresh
Section A23
70°S
60°S
50°S
40°S
0 m
0 km
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
WOCE HYDROGRAPHIC ATLAS
40 W
35 W
30 W
25 W
20 W
15 W
30 S
35 S
40 S
45 S
50 S
55 S
60 S
65 S
70 S
75 S
CTDI_A23_30W
WOCE Southern Ocean Atlas

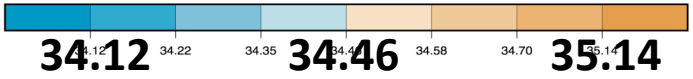
Potential temperature at 200 m.



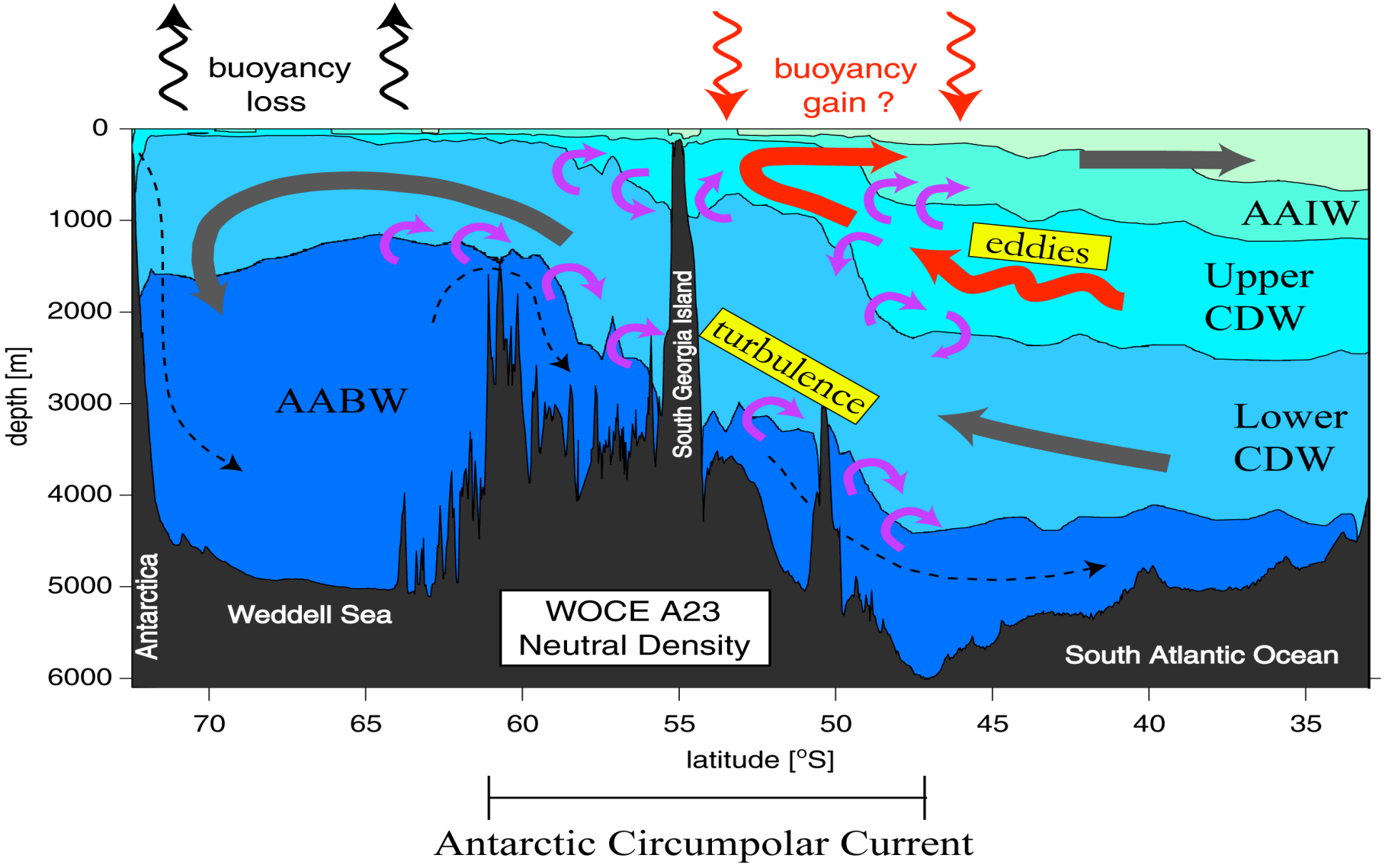


Salinity at 200 m.



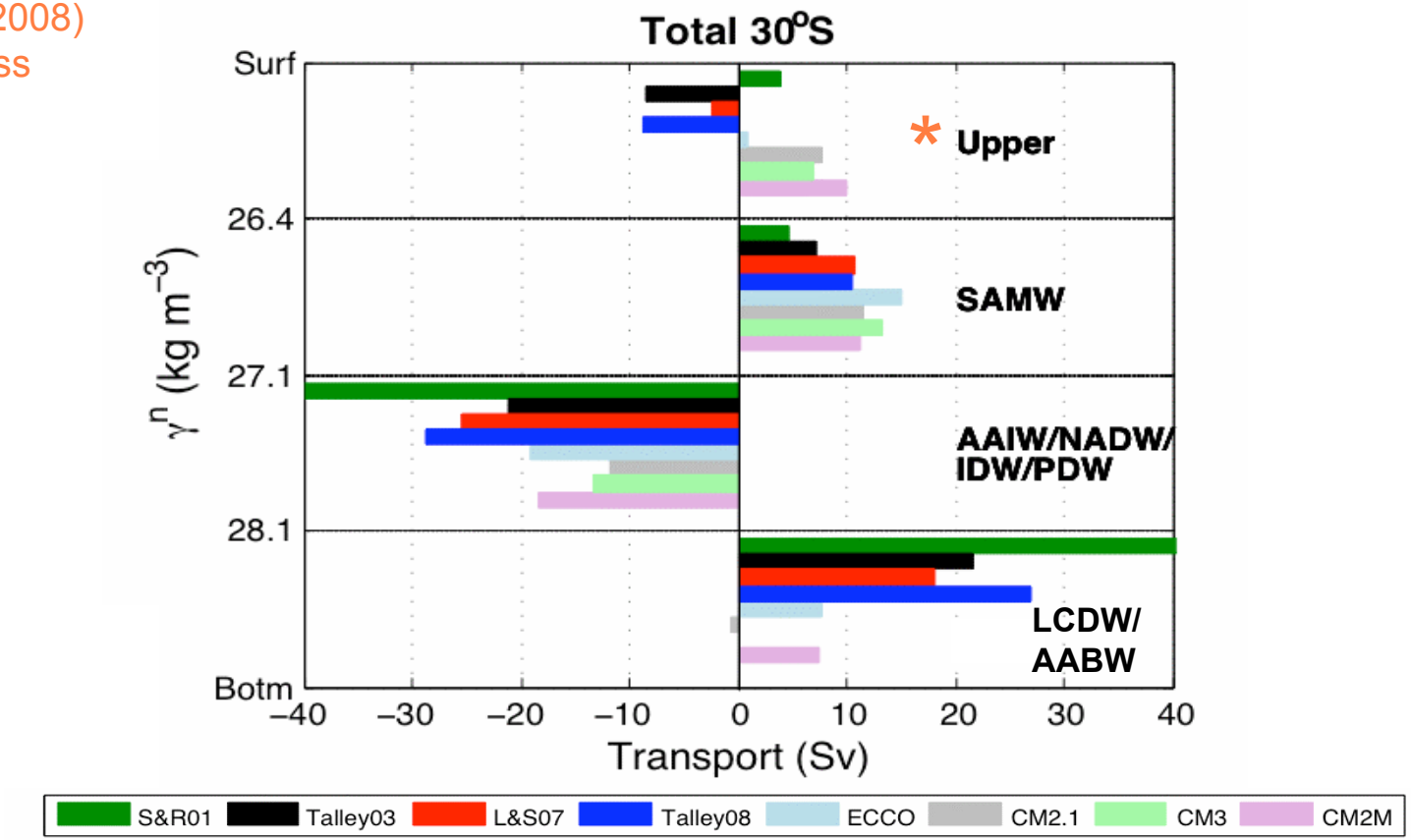


Elements of the Southern Ocean overturning circulation



Transport across 30°S from Observations and Climate models

* Talley (2008) water mass classes

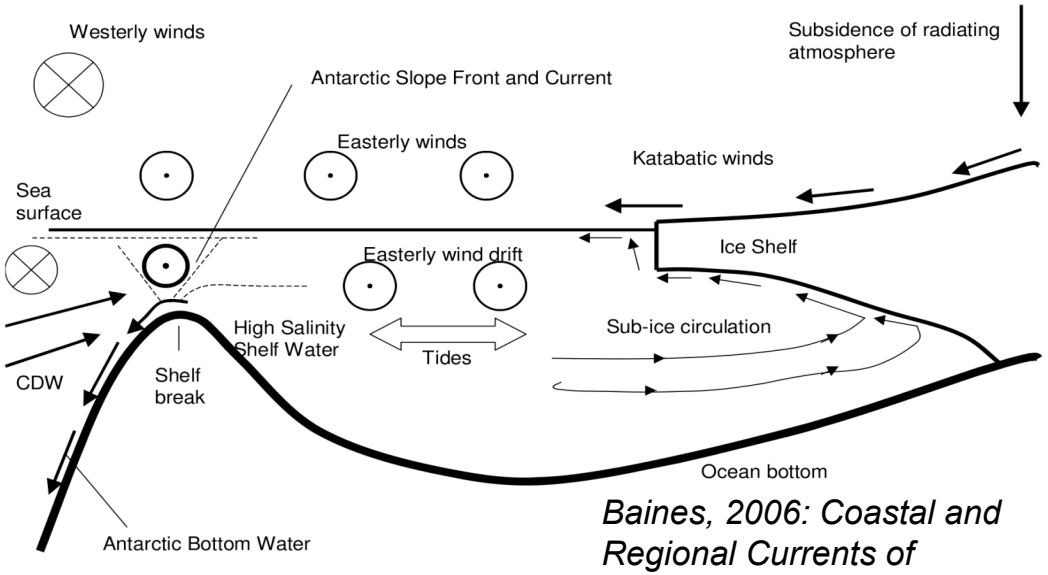


Slide courtesy of Stephanie Downes, Princeton

Recipe for Antarctic Bottom Water

Ingredients:

- A ready supply of source water ('Warm Deep Water')
- A broad continental shelf
- A cold atmosphere
- An abundance of ice shelves



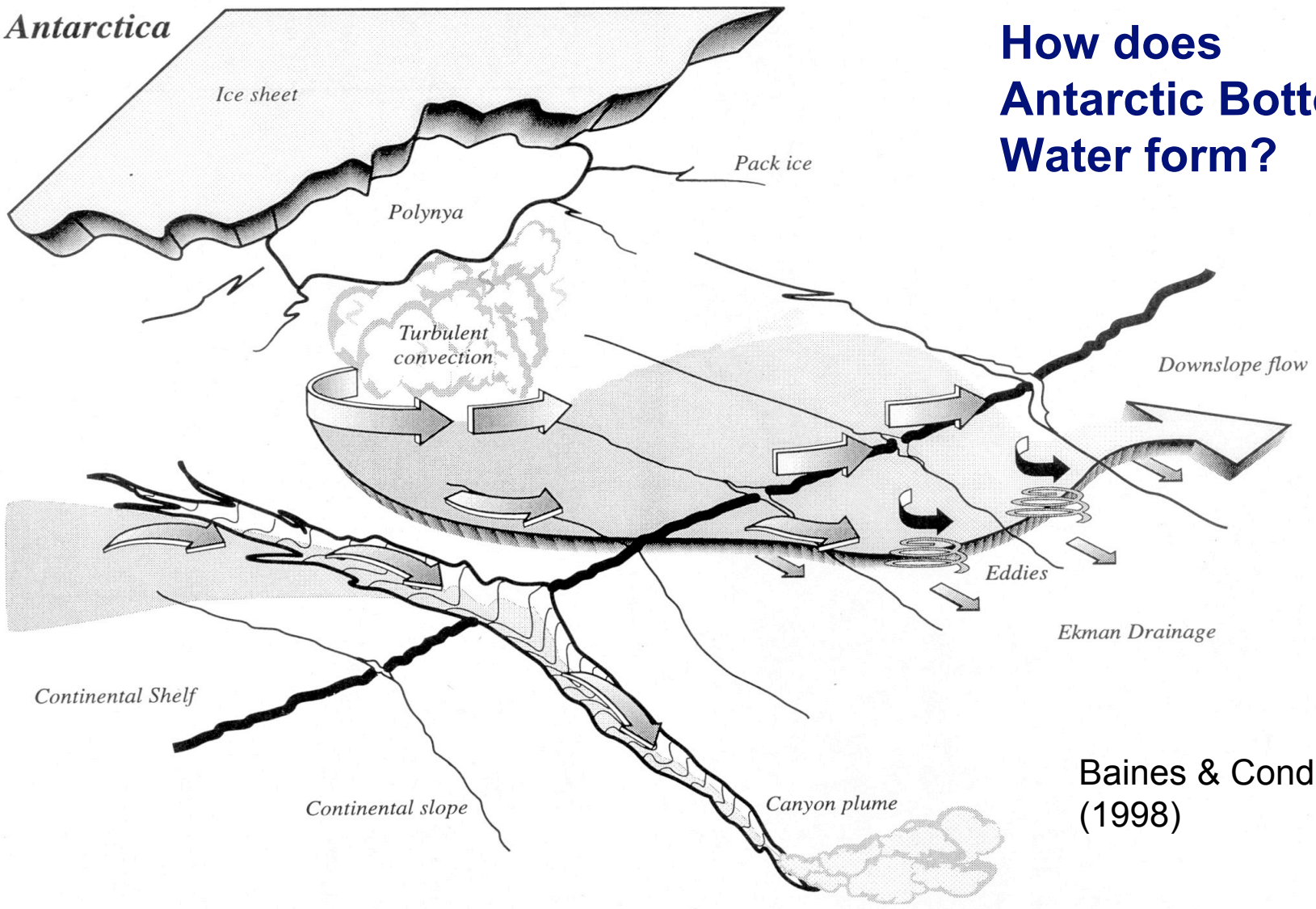
Baines, 2006: Coastal and Regional Currents of Antarctica. In Encyclopedia of the Antarctic, ed. Riffenburgh, 269-272.

Instructions:

- Take Warm Deep Water
- Freshen it by adding ice melt
- Transport it westward to regions of wide continental shelf
- Cool it by latent and sensible heat fluxes in polynyas
- Season to taste with ice shelf meltwater
- Keep cooling until sea ice forms and releases brine to make it salty again
- When it's dense enough to spill off the shelf by itself, it's ready!

But…….many climate models form Antarctic Bottom Water by deep convection in the open ocean!

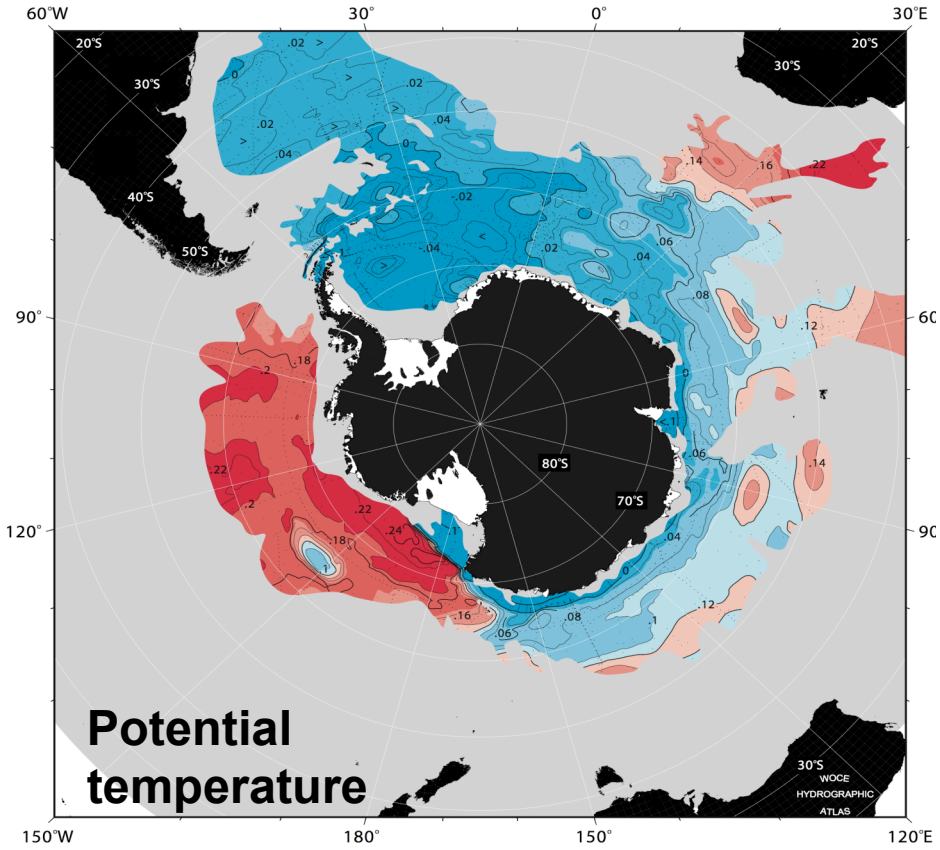
How does Antarctic Bottom Water form?

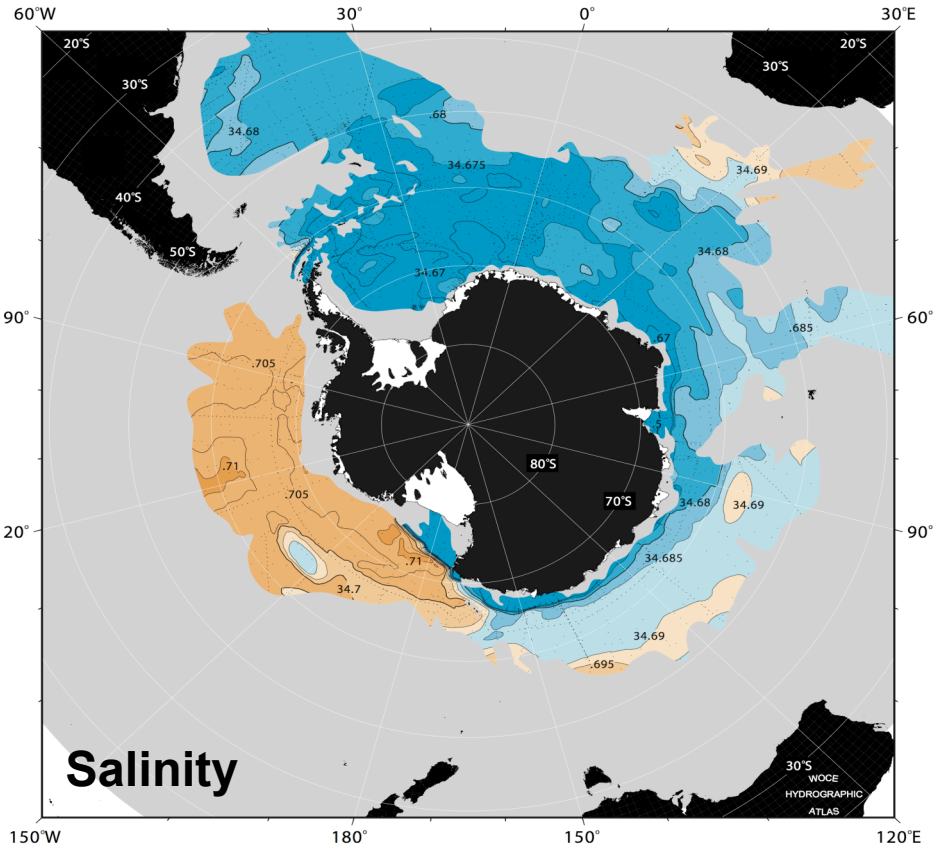


Baines & Condie (1998)

All these processes are too small-scale to be represented in climate models and so must be parameterised.

Properties of 28.27 kg m^{-3} neutral density layer: Antarctic Bottom Water





Antarctic Bottom Water formed in the Ross Sea is historically saltier and warmer on isopycnals than that formed in the Weddell Sea.

WOCE Southern Ocean atlas

Synoptic Antarctic Shelf-Slope Interactions (SASSI)

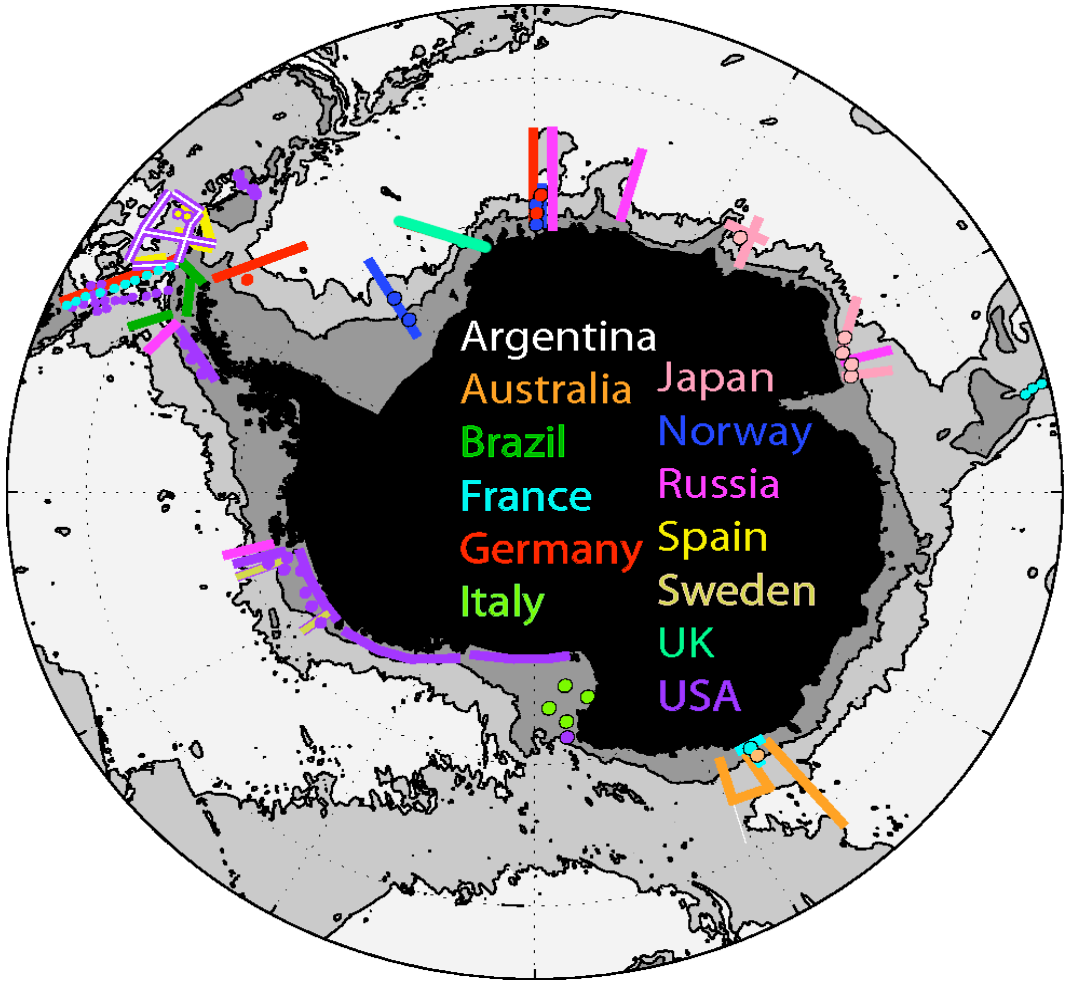
Project for the International Polar Year coordinated by iAnZone

Hydrographic sections ('hedgehog')

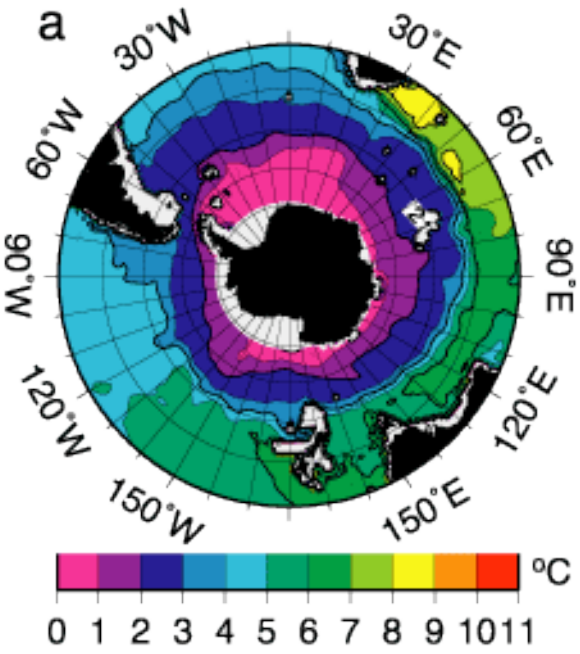
Moorings on continental shelf and slope

Quasi-circumpolar

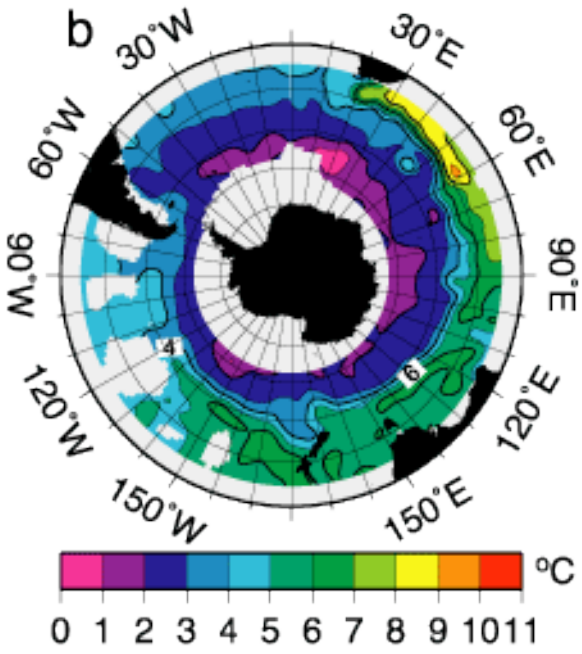
We do now have datasets to compare with climate models.



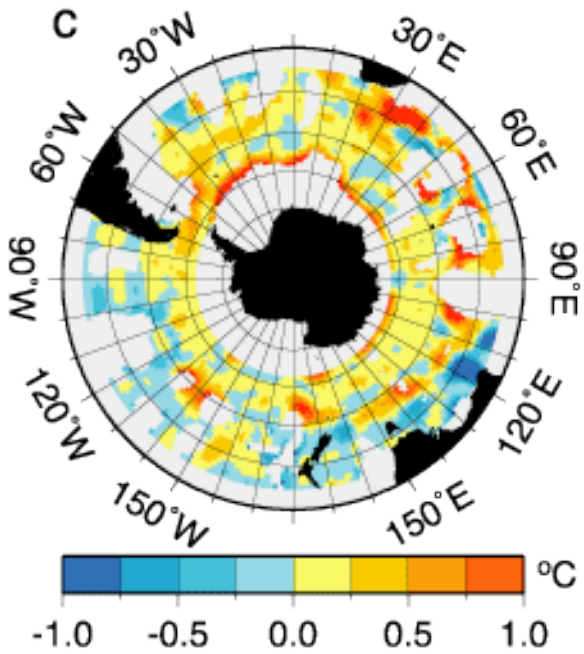
Warming at 900 m depth in the Southern Ocean



Historical data, prior to 1990

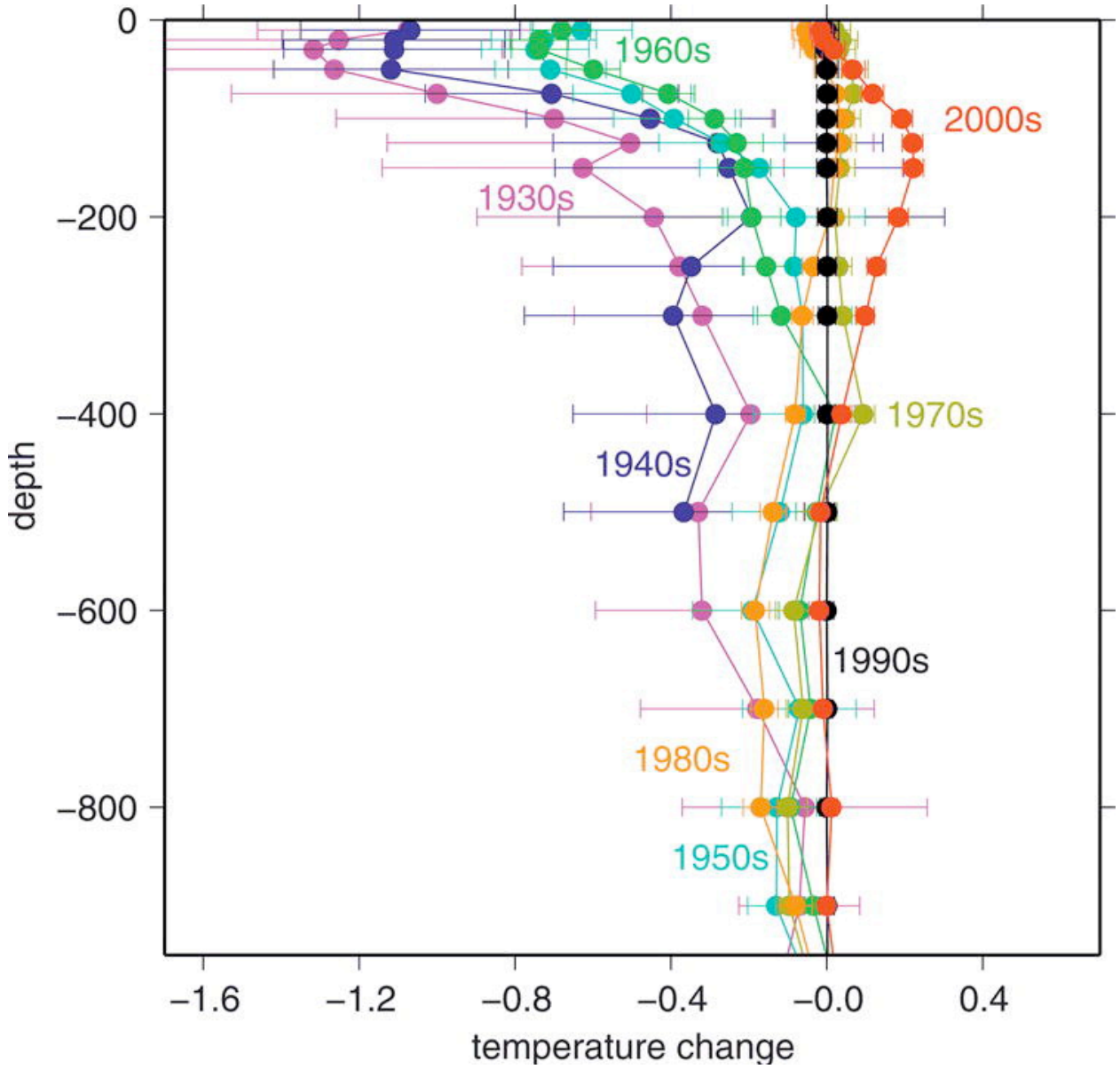


Freely drifting floats, after 1990



Floats minus hydrography, showing warming in Antarctic Circumpolar Current

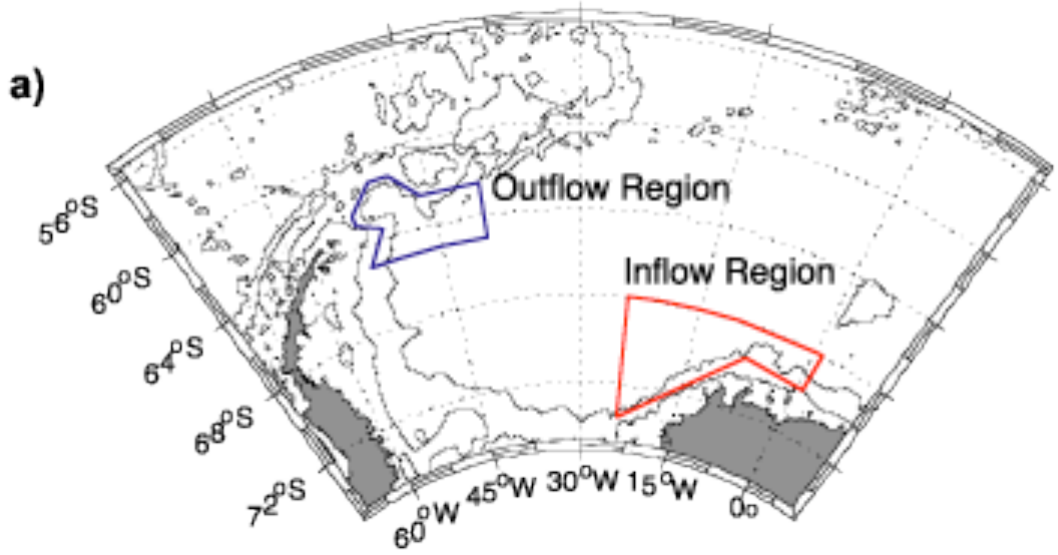
Gille (2002) *Science*.

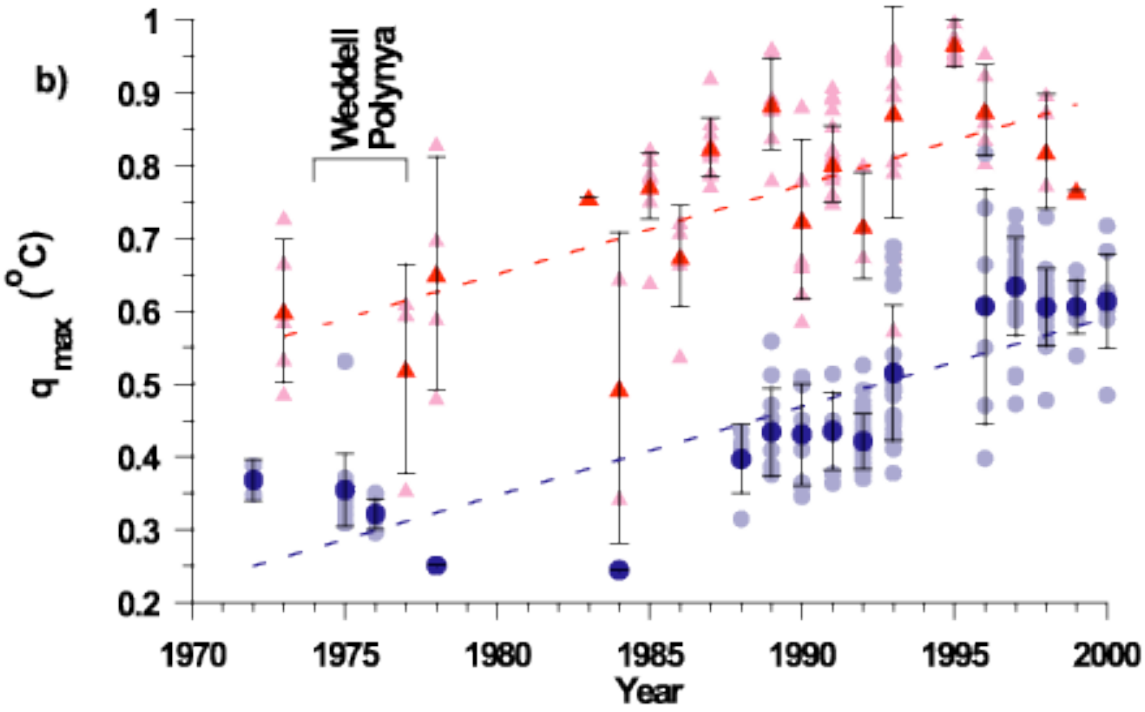


Temperature differences from 1990s for summer data (November to March), averaged first by latitude band.

Gille 2008 J. Climate

Long term warming of deep waters of the Weddell Sea





Maximum potential temperature values of Warm Deep Water (the temperature maximum layer) in the Weddell Sea.

Robertson *et al*., 2002

Some Speculation:

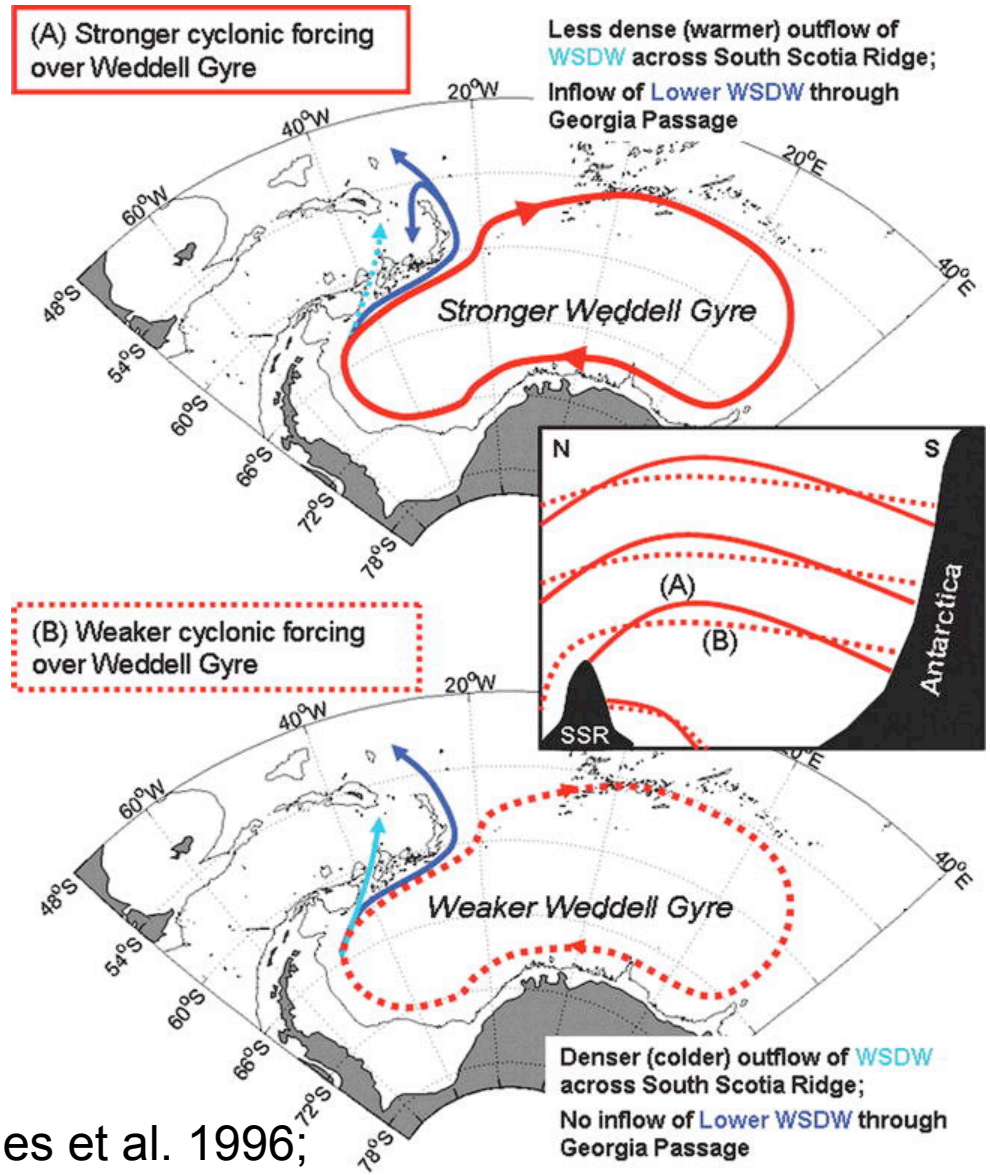
Warmer source water (Warm Deep Water) might lead to:

(i)Overspilling water entraining warmer-than-usual water above it, so exported water might be warmer and less dense?

(ii)Warmer waters penetrating onto the continental shelves and melting more ice?

So shelf water is fresher, so is the water spilling off the shelf colder to compensate, keeping the same density?

Or is the outflow water less dense?



Coles et al. 1996;
Meredith et al., 2008

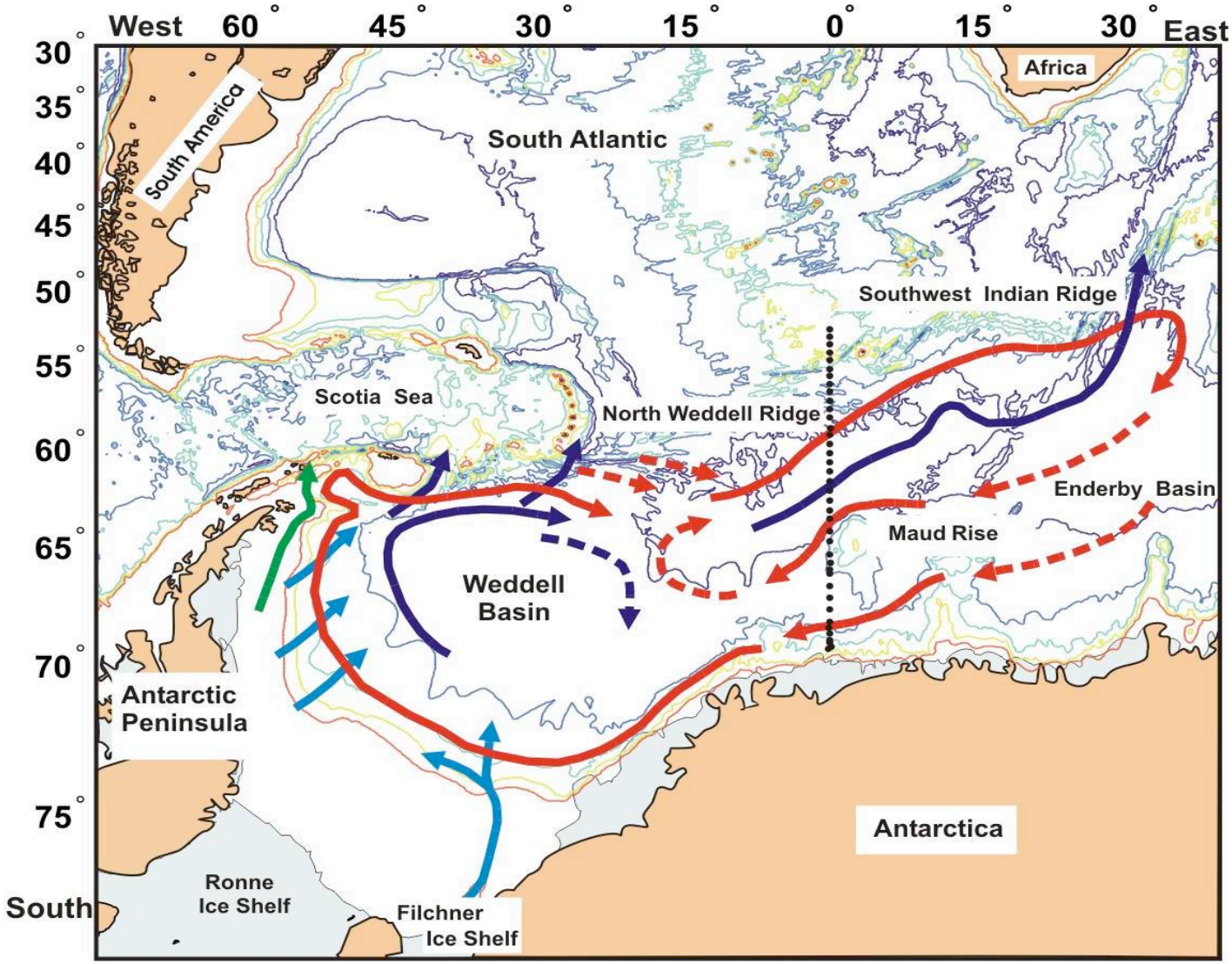
Impact of changing atmospheric cyclonic forcing on Weddell Gyre intensity and the consequences for the export of AABW across the South Scotia Ridge.

Steepening (A) or slumping (B) of isopycnal surfaces in the Weddell Sea in response to gyre spinup/down.

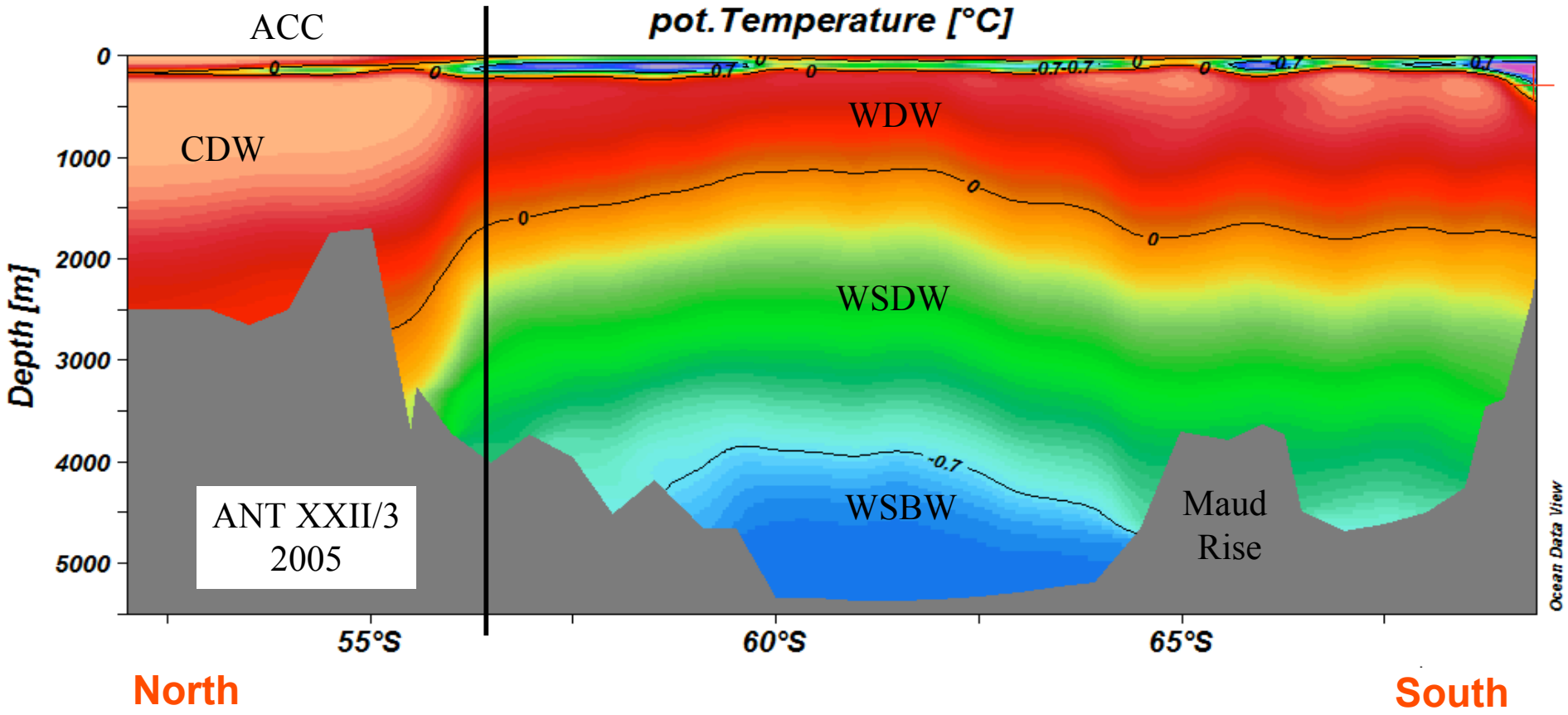
Stronger Weddell Gyre leads to less dense (warmer) WSDW crossing the ridge.

Weaker Weddell Gyre leads to denser (colder) WSDW exported.

The Weddell gyre circulation and the area of observations carried out during WECCON



Water mass and temperature distributions at the Greenwich meridian

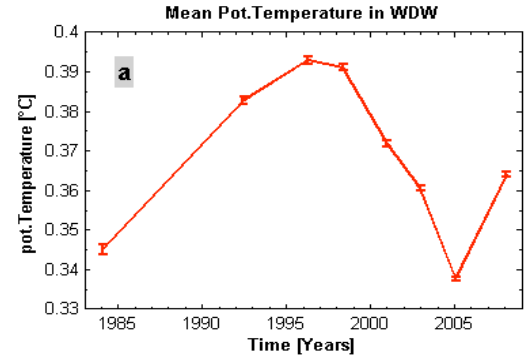


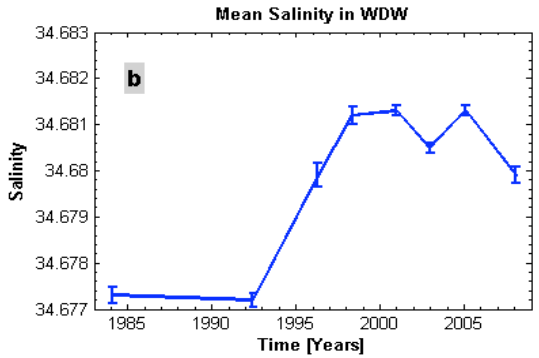
Mean temperature and salinity in the deep water masses of the Weddell gyre at the Greenwich meridian

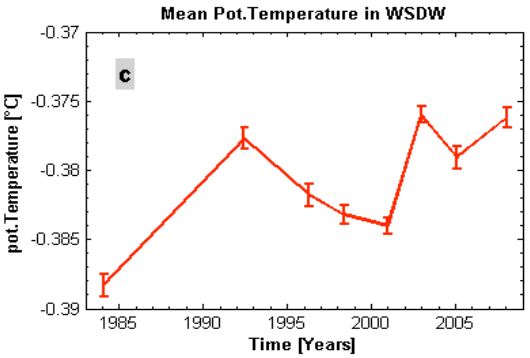
WDW temperature increased until 1996 and decreased until 2005 and is increasing since.

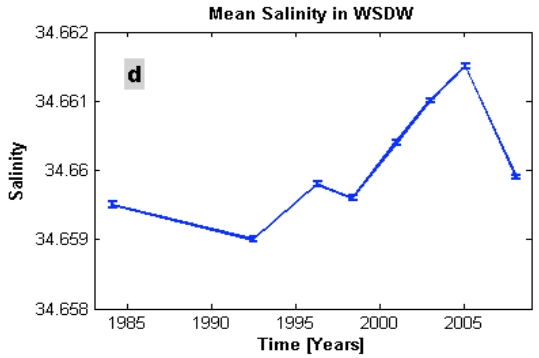
WSBW temperature is increasing since 1992.

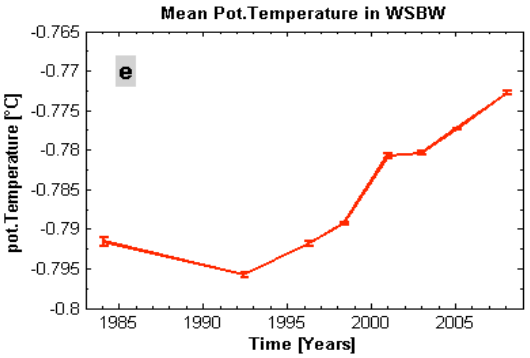
Potential temperature

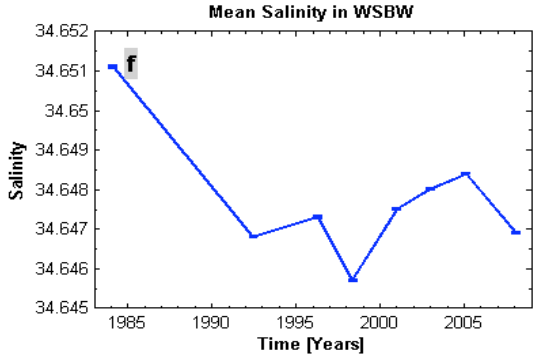








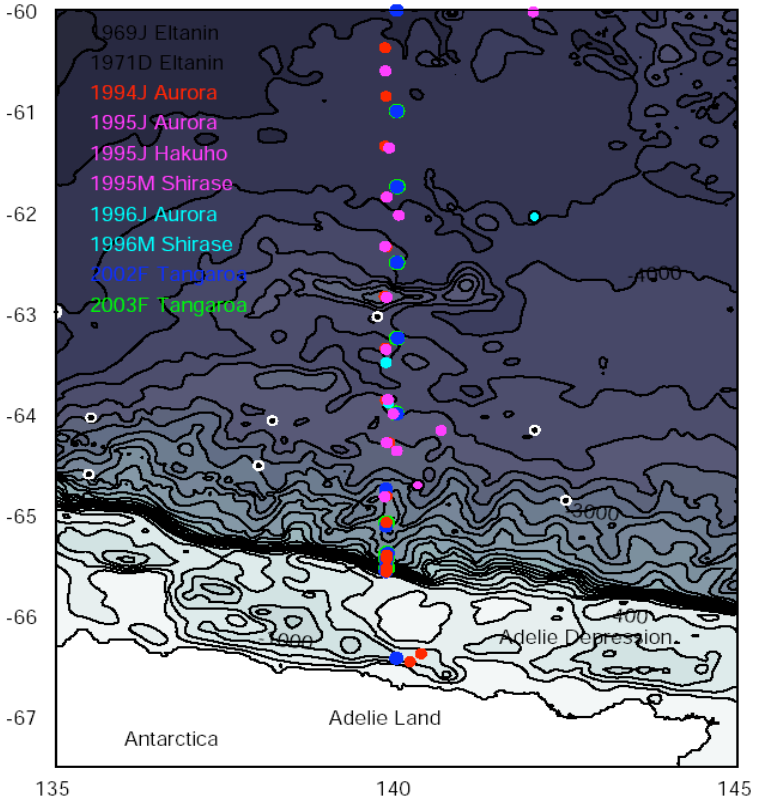


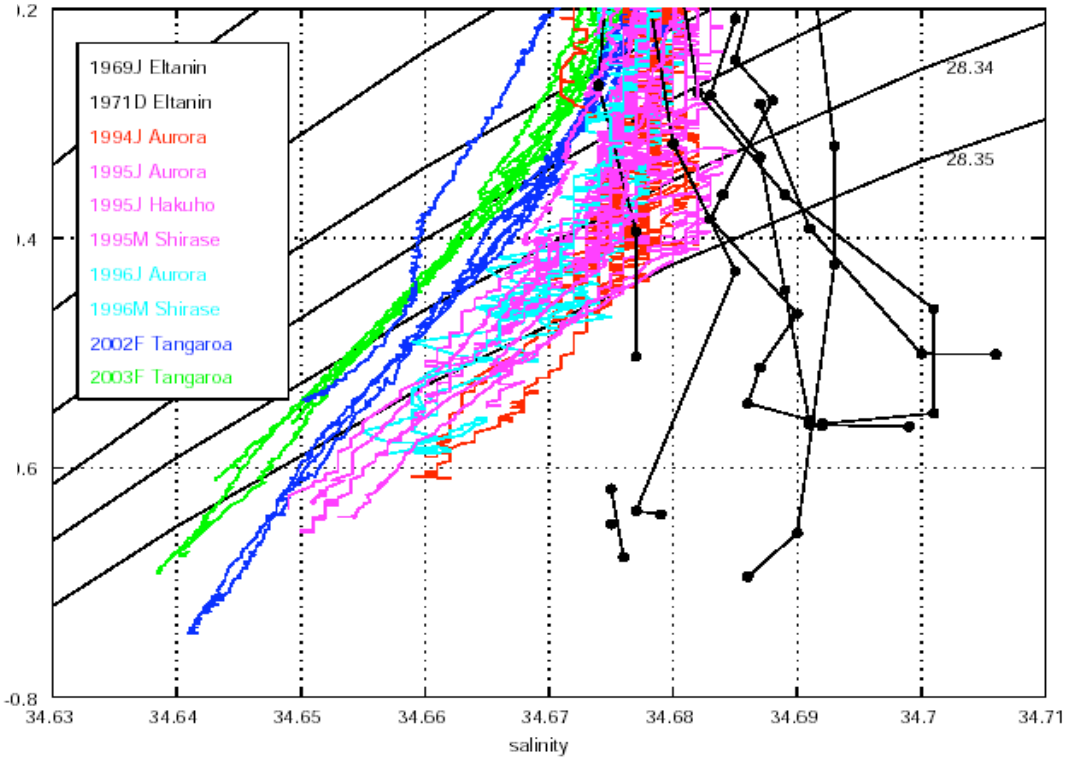


Courtesy of Eberhard Fahrhach, AWI

Salinity

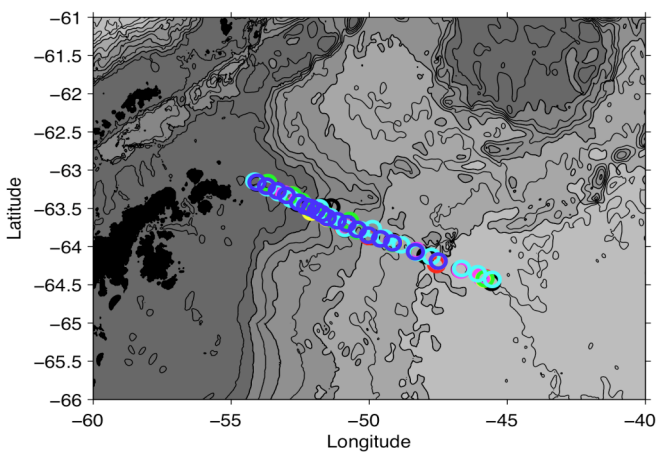
Long term freshening of Adelie Land Bottom Water : the variety of Antarctic Bottom Water found in the Australian-Antarctic Basin.

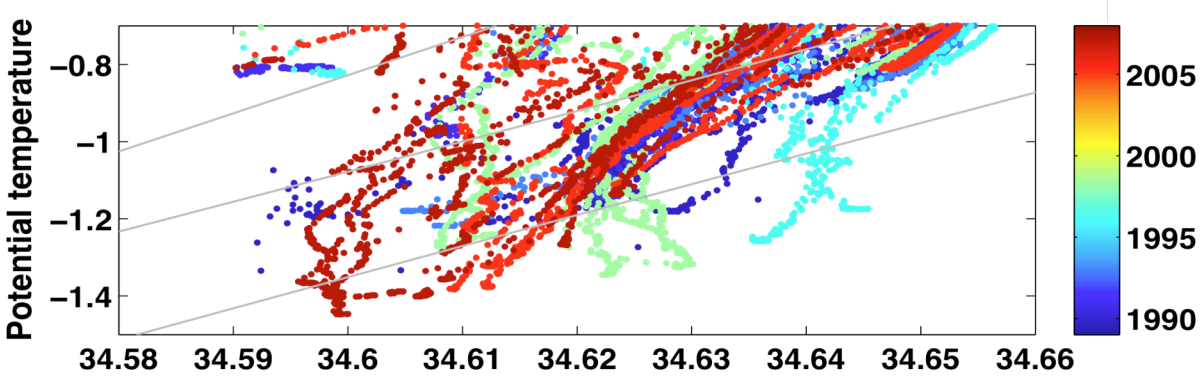




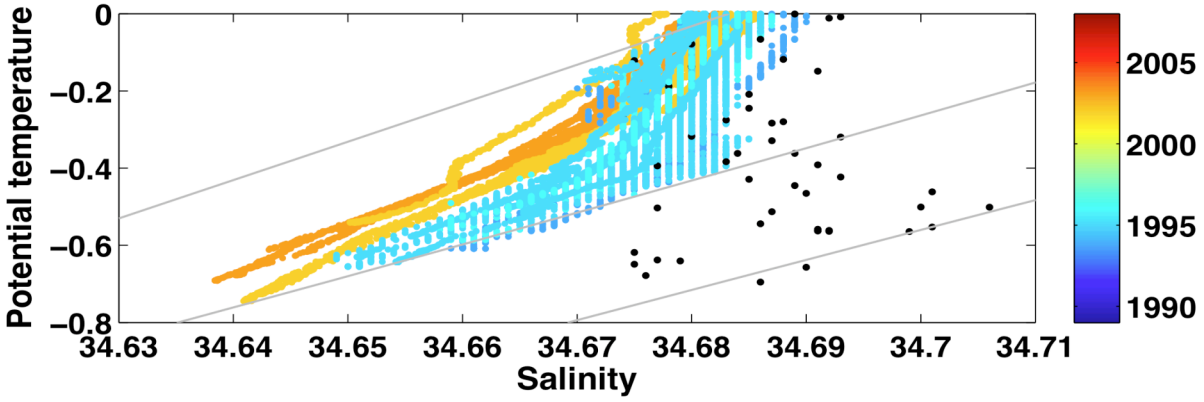
Aoki *et al.*, 2005, *GRL.*

Increasing evidence for freshening of AABW at the exit of the Weddell Sea too



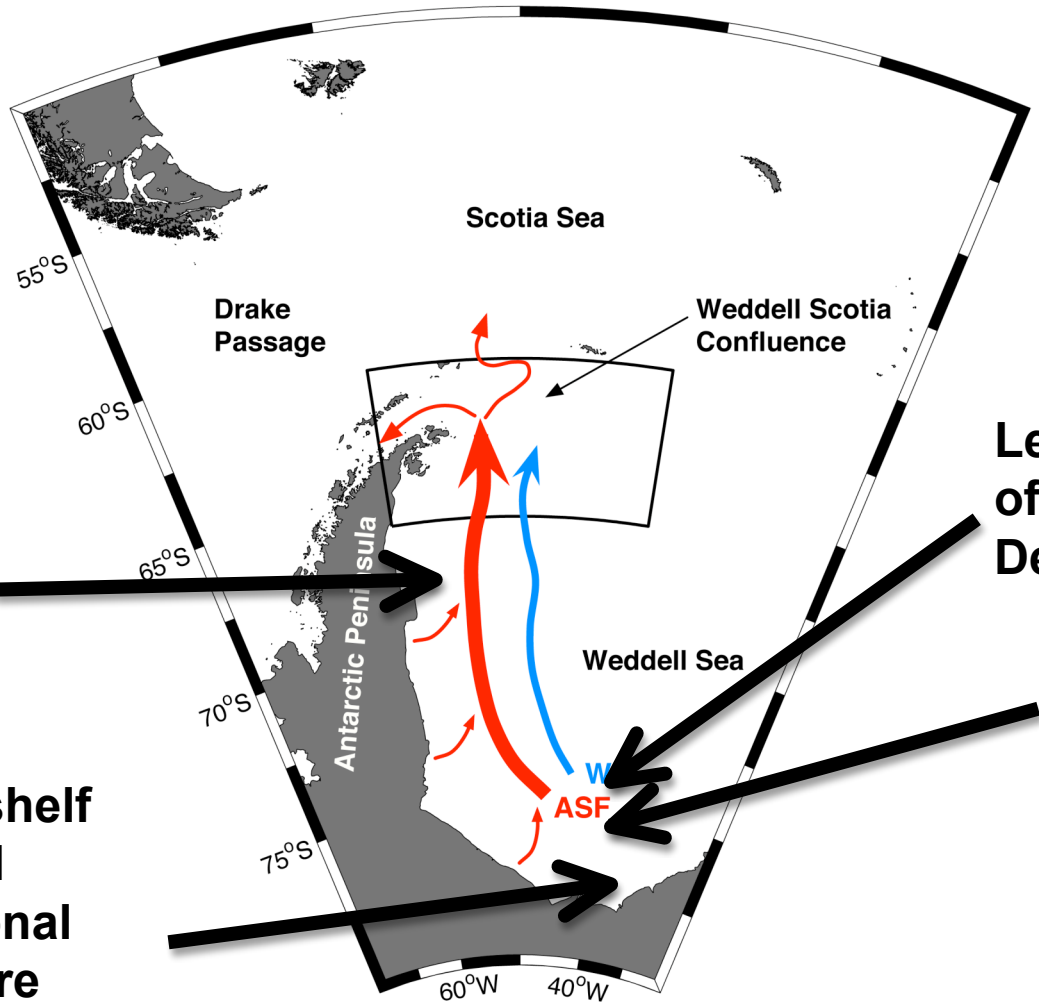


Northwest Weddell Sea



140E
Aoki et al. 2005

What is causing any freshening and cooling?

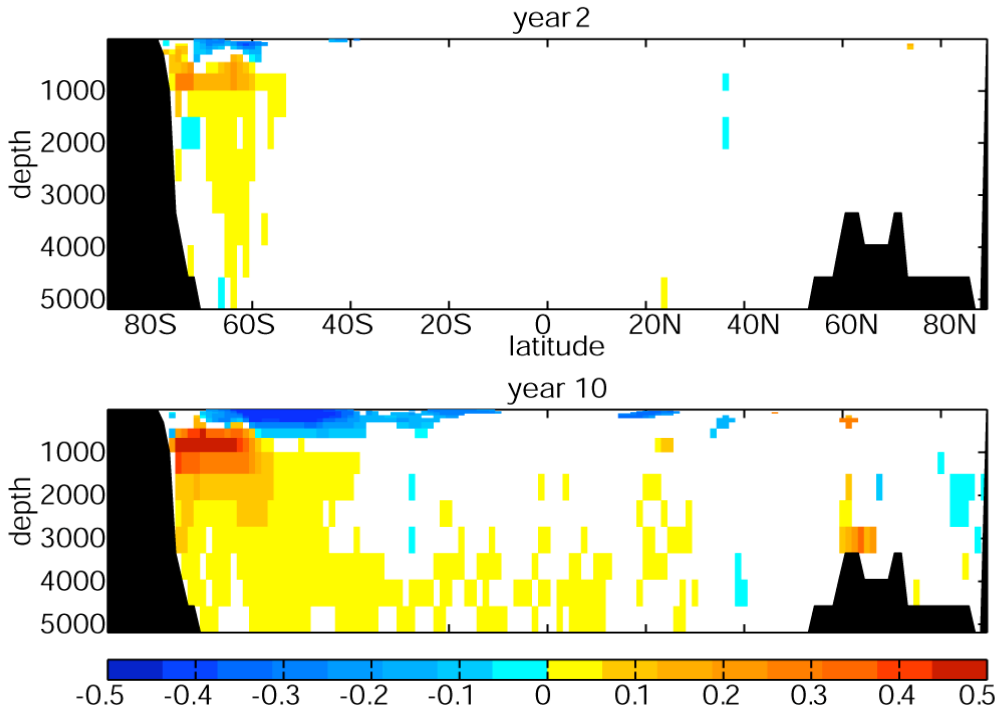


Larsen now provides additional dense water source ?

Less entrainment of salty Warm Deep Water?

Less new sea ice formation each year?

Properties of shelf water changed though additional ice melt or more precipitation ?



Do we care about increased freshwater? Climate models suggest we should.

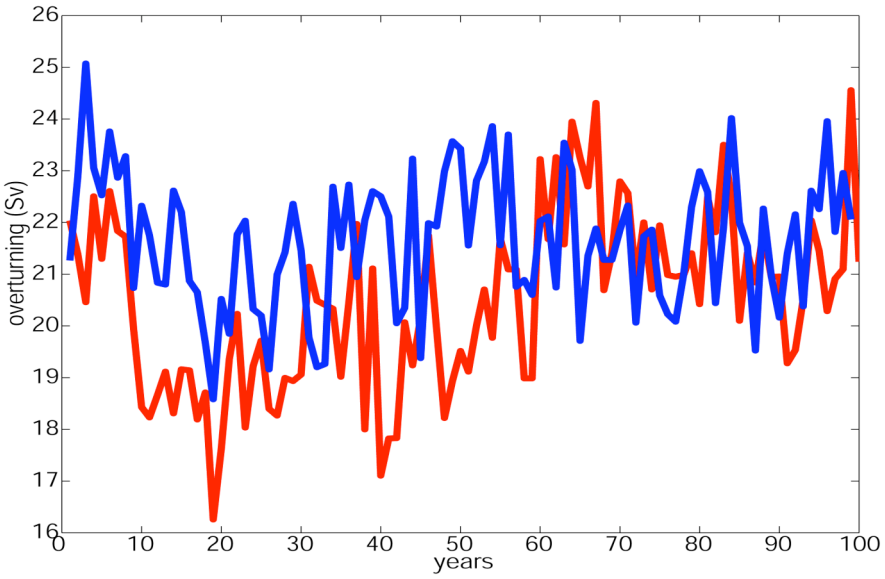
Effects of perturbation experiment in HadCM3, adding surface freshwater layer that prevents convection.

(Richardson et al., GRL, 2005)

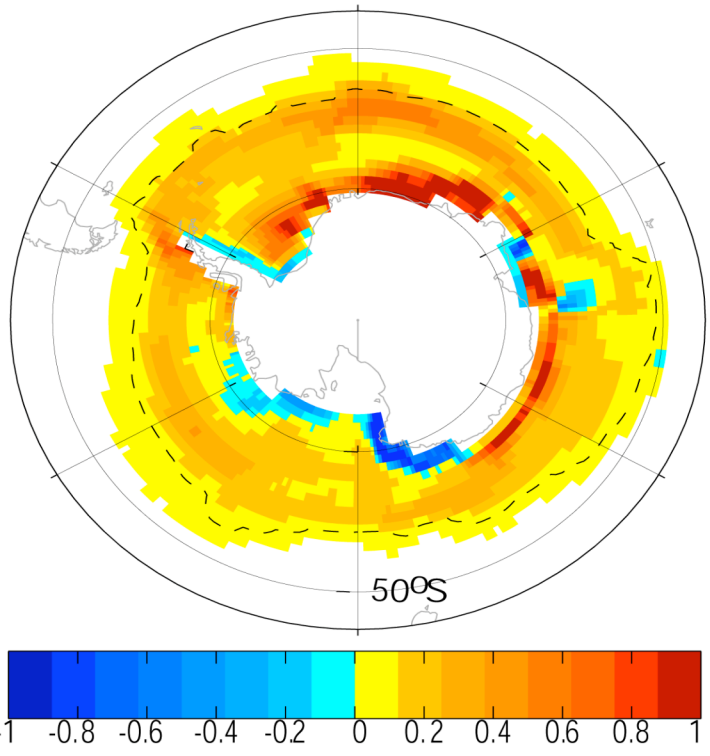
Causes significant zonal mean ocean temperature anomalies (°C).

Heat that is normally vented to the atmosphere is trapped in the ocean.

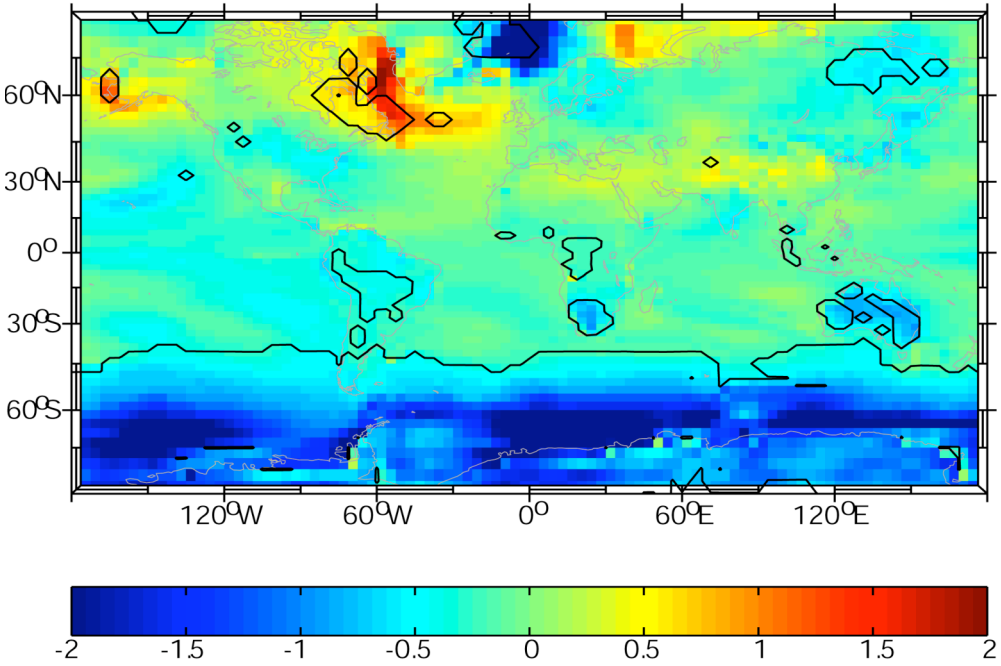
Strength of the Antarctic overturning circulation over 100 year run (without freshwater dump, with freshwater dump)



Climate impacts



Anomalies in Antarctic sea ice thickness (m), 6-10 years after dumping freshwater around Antarctica. Dashed contour shows maximum extent in model normally.



Surface air temperature differences, 6-10 years after dumping freshwater around Antarctica.

Richardson et al., GRL, 2005

Conclusions

The processes driving Antarctic Bottom Water are complex, and generally too local to be represented in climate models – we need better parameterisations.

The source waters for Antarctic Bottom Water seem to have warmed in recent decades, and the waters on the Antarctic continental shelf have freshened.

Close to Antarctica, Antarctic Bottom Water has in many places cooled and/or freshened.

Until we better understand the processes, it is difficult to predict what will happen to the Antarctic Bottom Water overturning cell.