Oceanography at the Antarctic Margins

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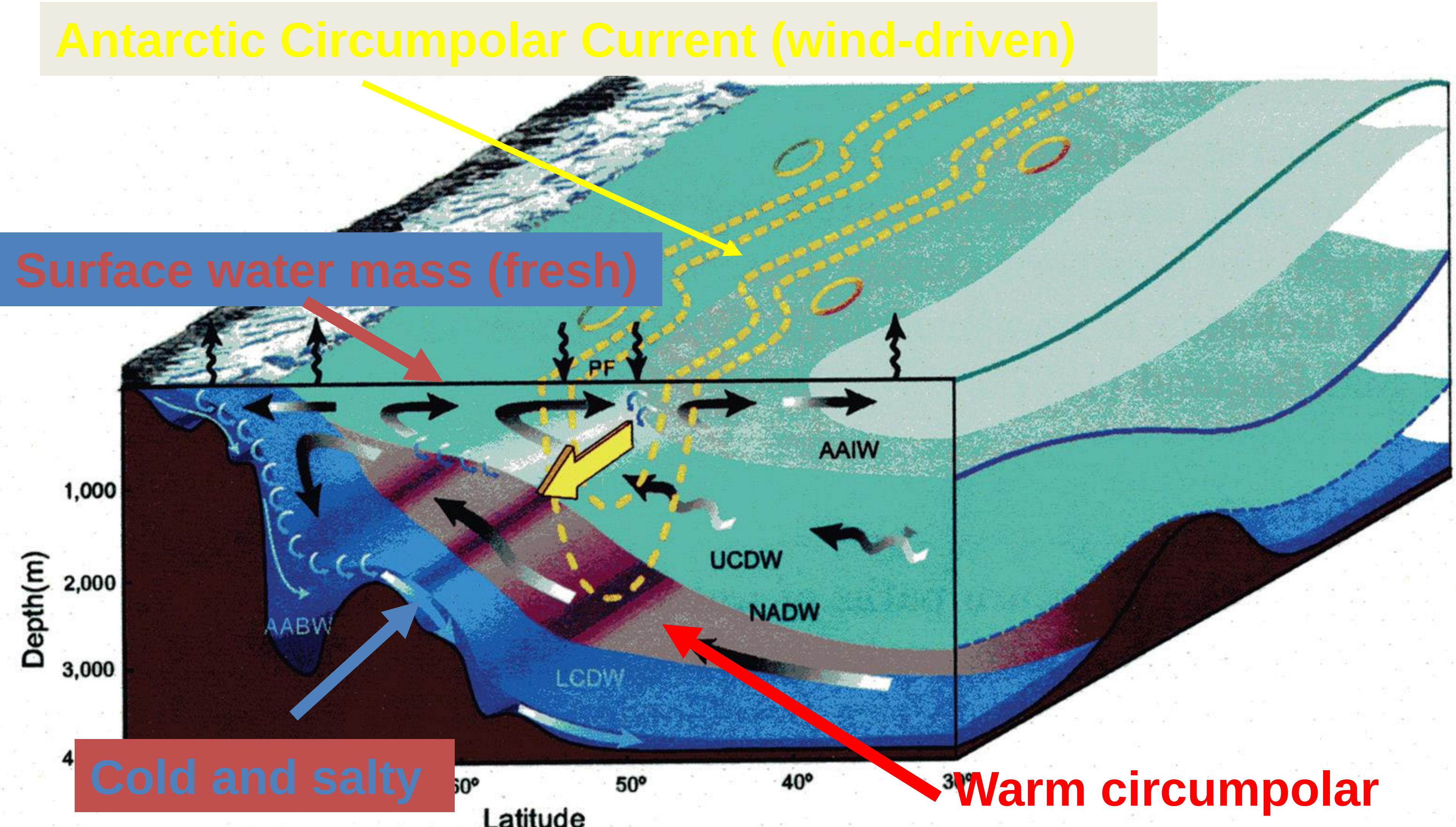
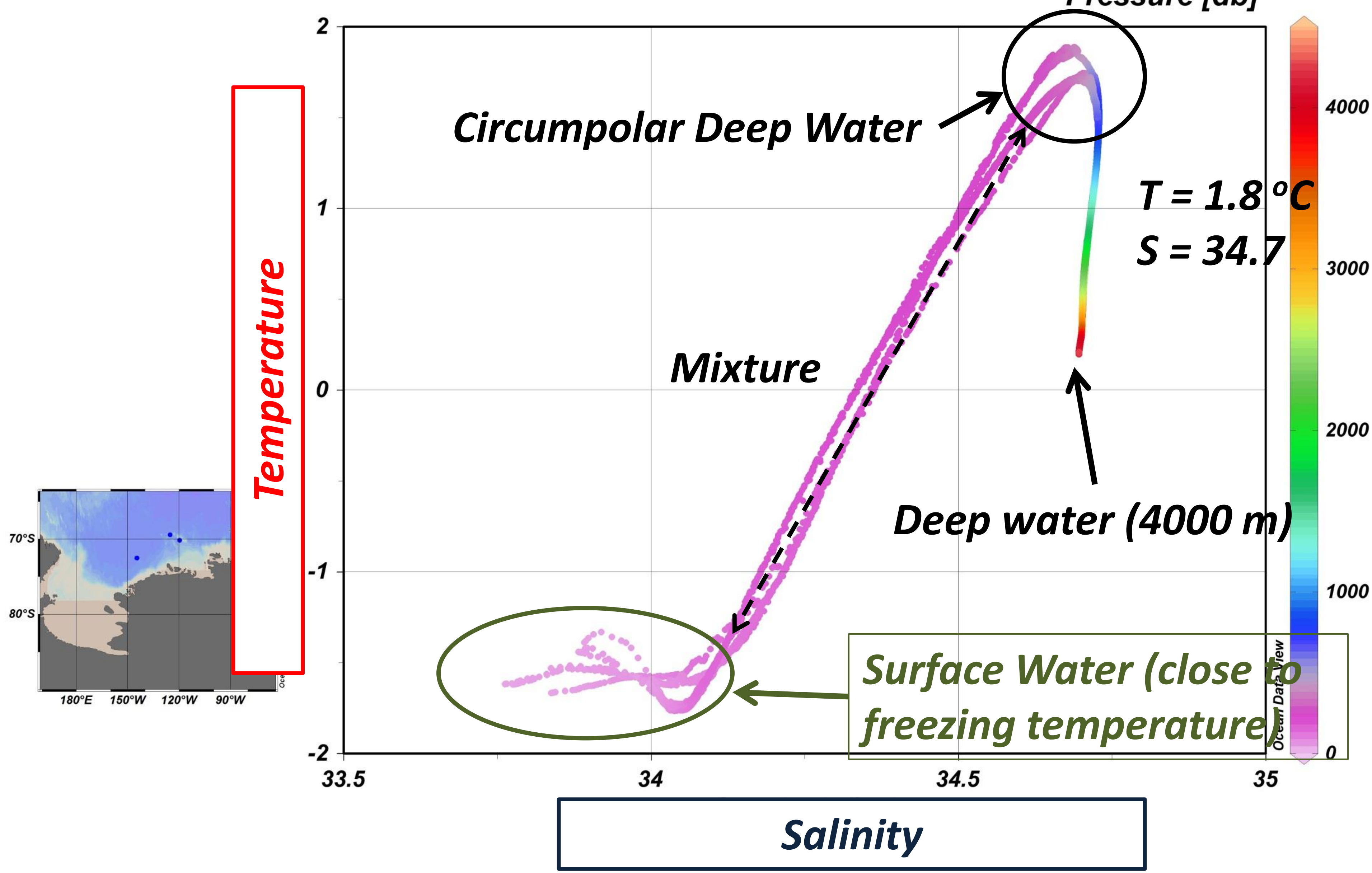
- 1) Shelf seas water mass modification. Some examples in TS diagrams
- 2) Mechanisms for cross-shelf flow: Eddies and buoyancy driven
- What we know
- What we do not know
- What we should focus on measuring

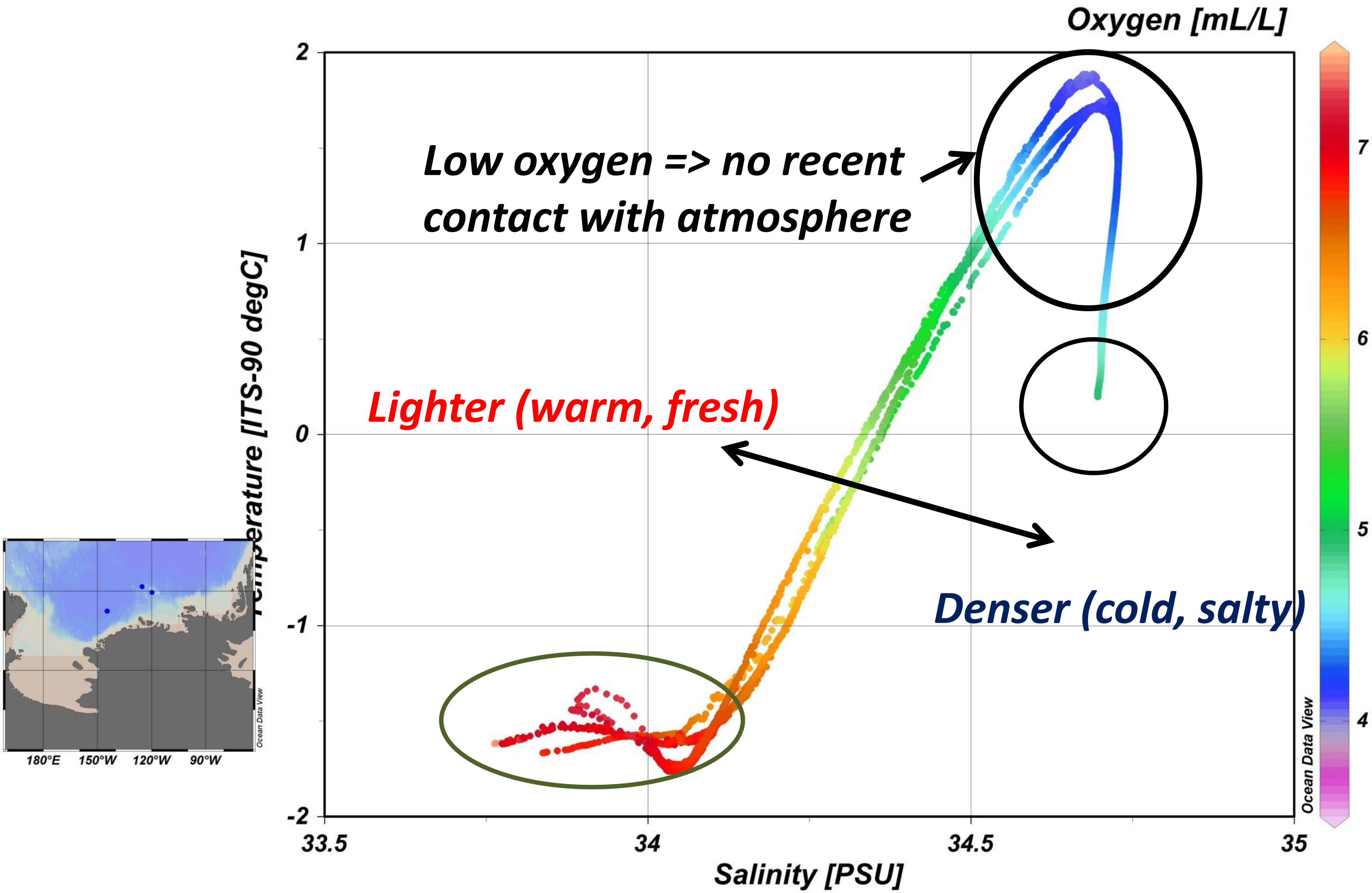
Water masses in the Southern Ocean



From Olbers et al. (2004), redrawn from a f igure from Speer et al. (2000)

Temperature- salinity properties of water masses

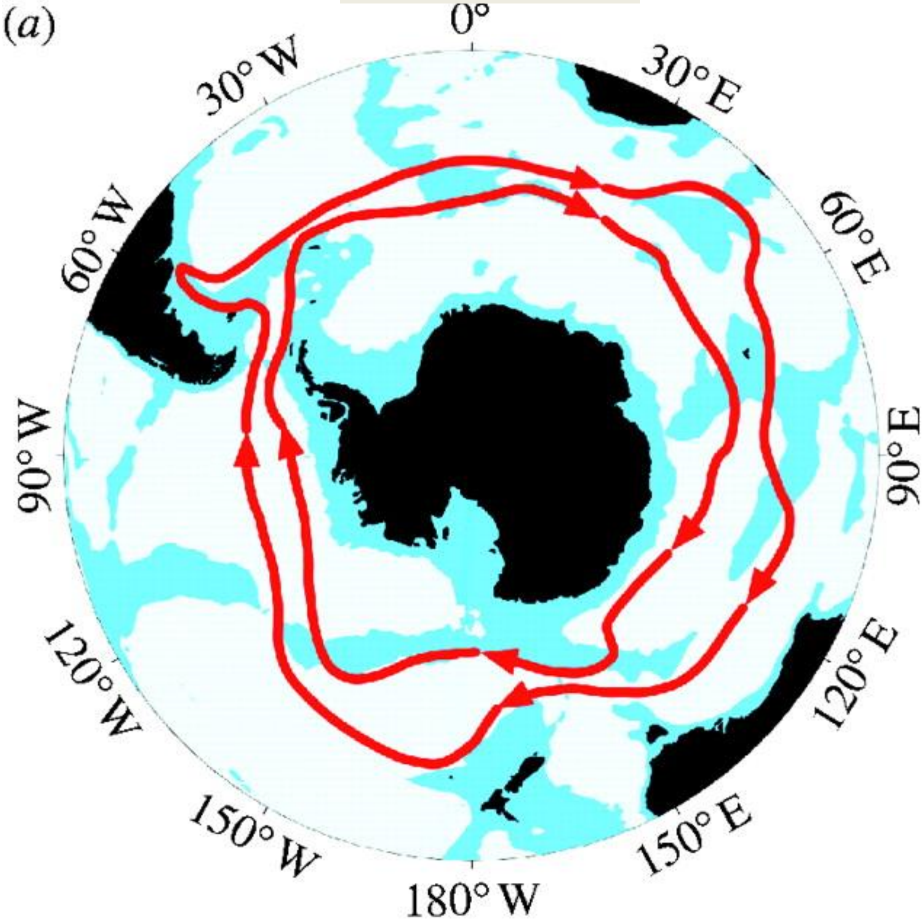




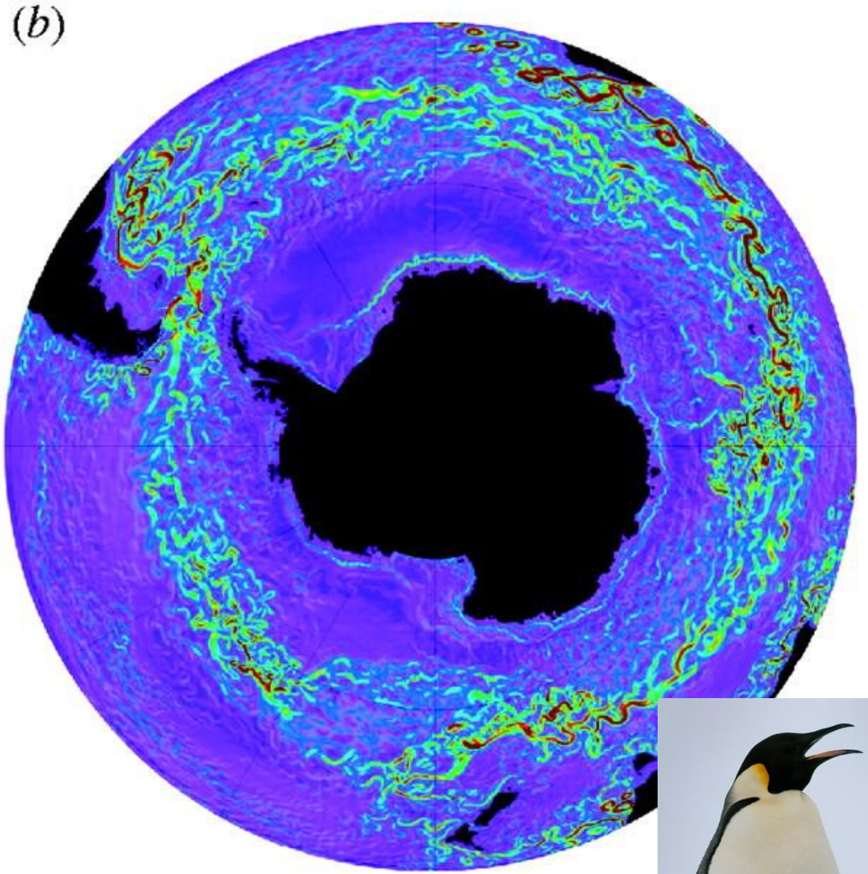
Oxygen [mL/L]
Low oxygen => no recent contact with atmosphere
Lighter (warm, fresh)
Denser (cold, salty)
Temperature [ITS-90 degC]
Salinity [PSU]
2
1
0
-1
-2
33.5
34
34.5
35
7
6
5
4
Ocean Data View
180°E
150°W
120°W
90°W

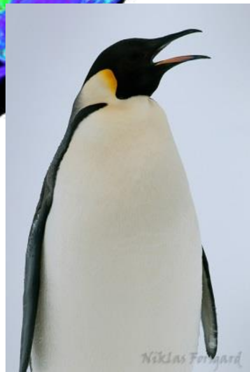
ACC: Unbroken path around the globe. Transport of water northward/southward due to eddies

Average flow



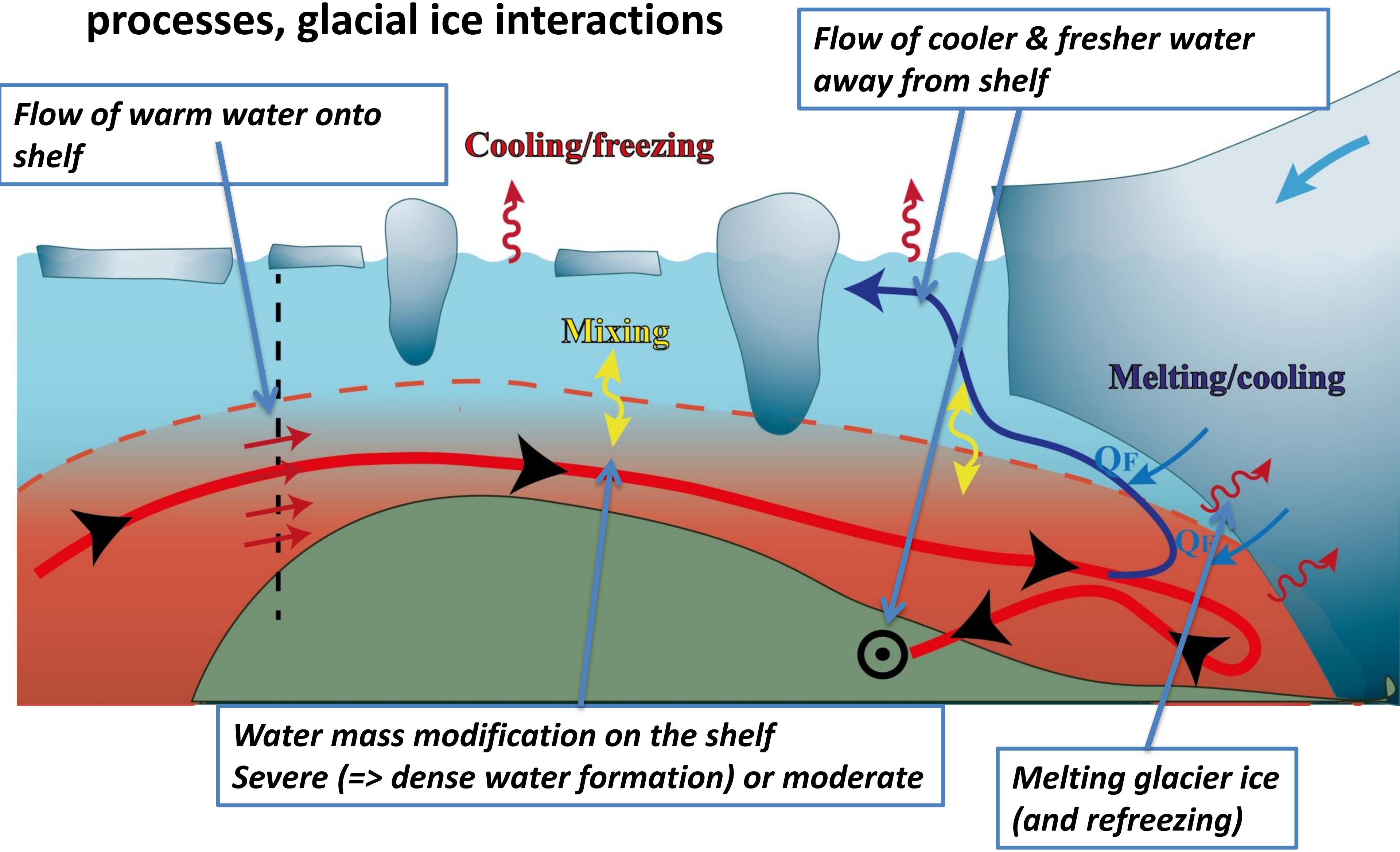
Snapshot



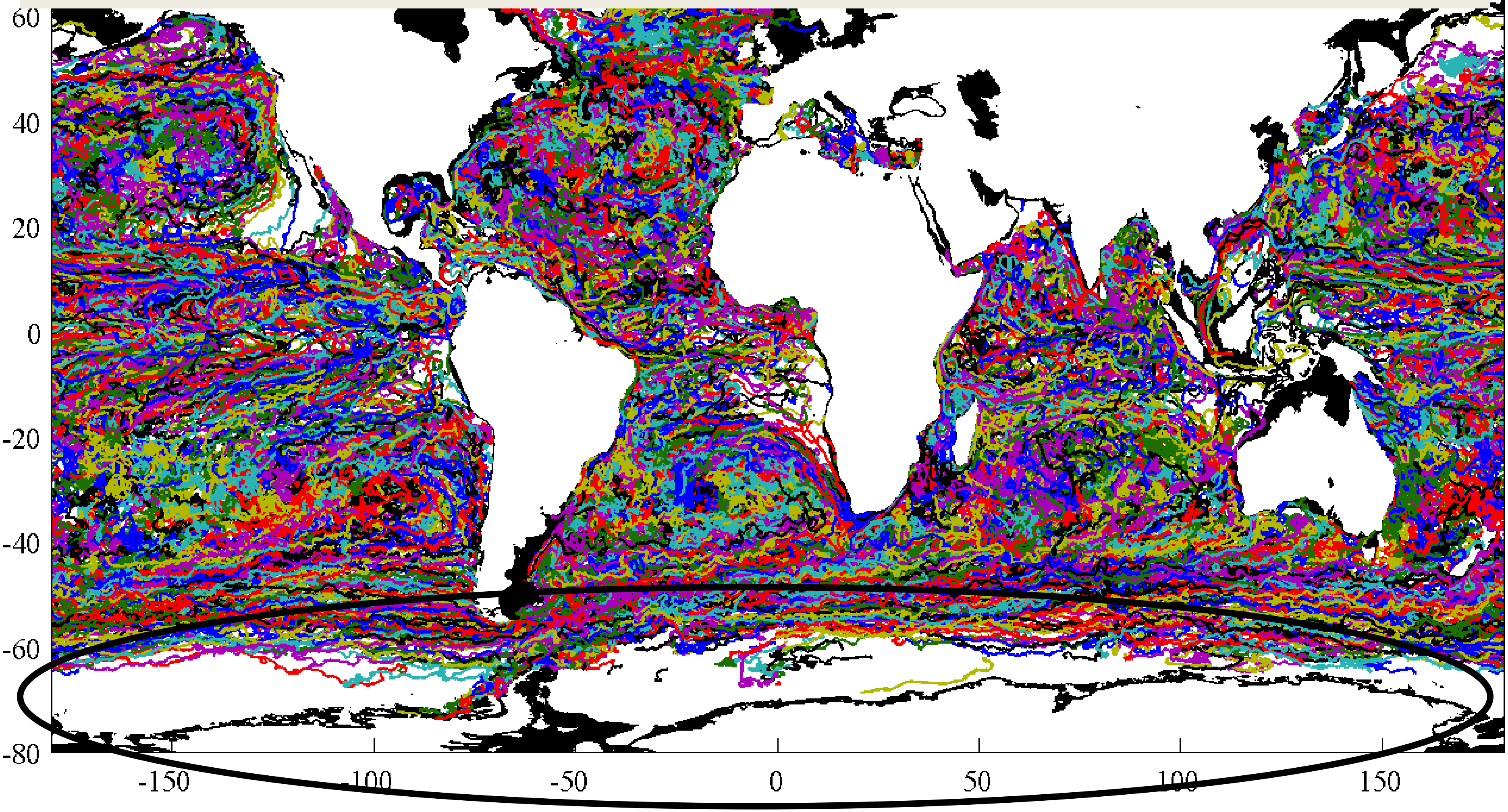


Thompson A F Phil. Trans. R. Soc. A 2008;366:4529-4541

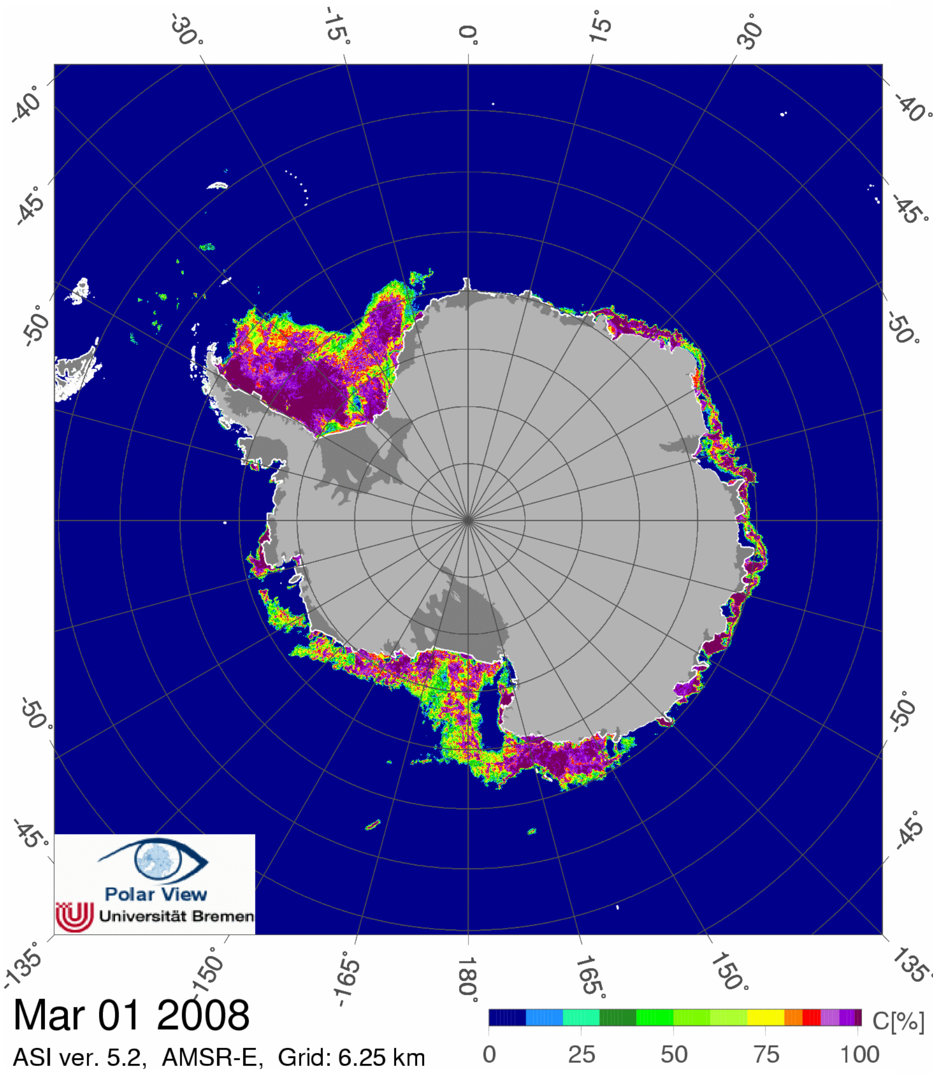
Processes on the shelf: Atmospheric cooling and sea ice processes, glacial ice interactions

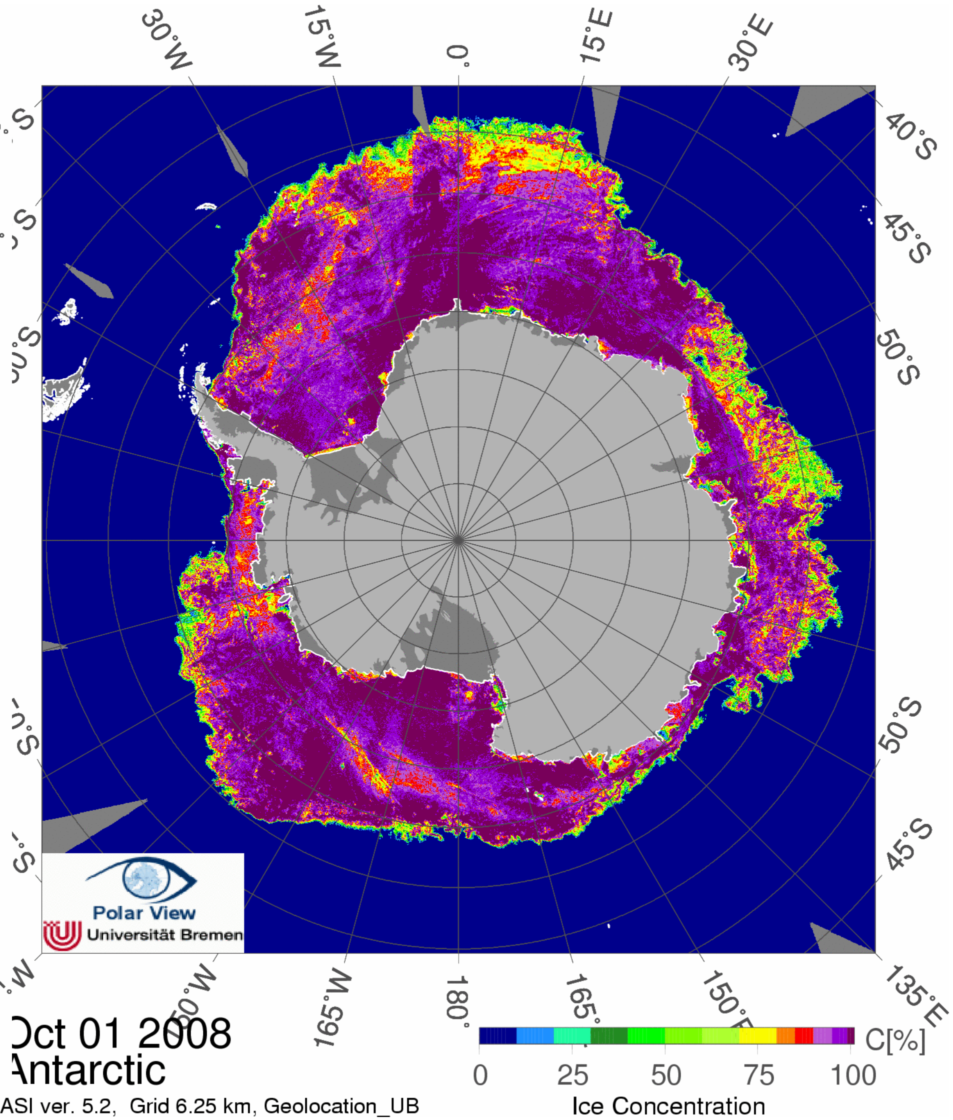


The Southern Ocean shelf seas are essentially a blind spot. Like picking 100 grains of sand from a football field and trying to analyze the field from that. For example Argo buoy tracks



Remote sensing: Sea ice 19 million km^2 in winter



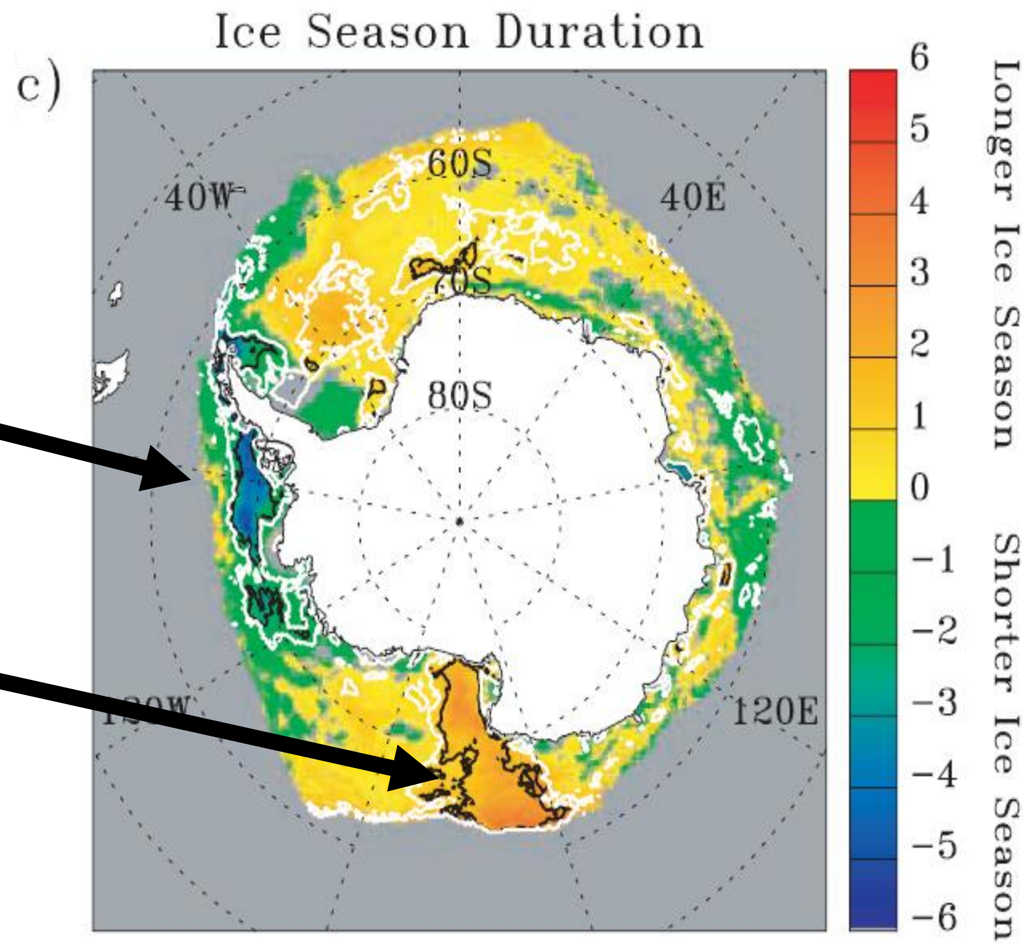


Large regional changes in Antarctic sea ice

Changes in sea ice duration: 1979 – 2006

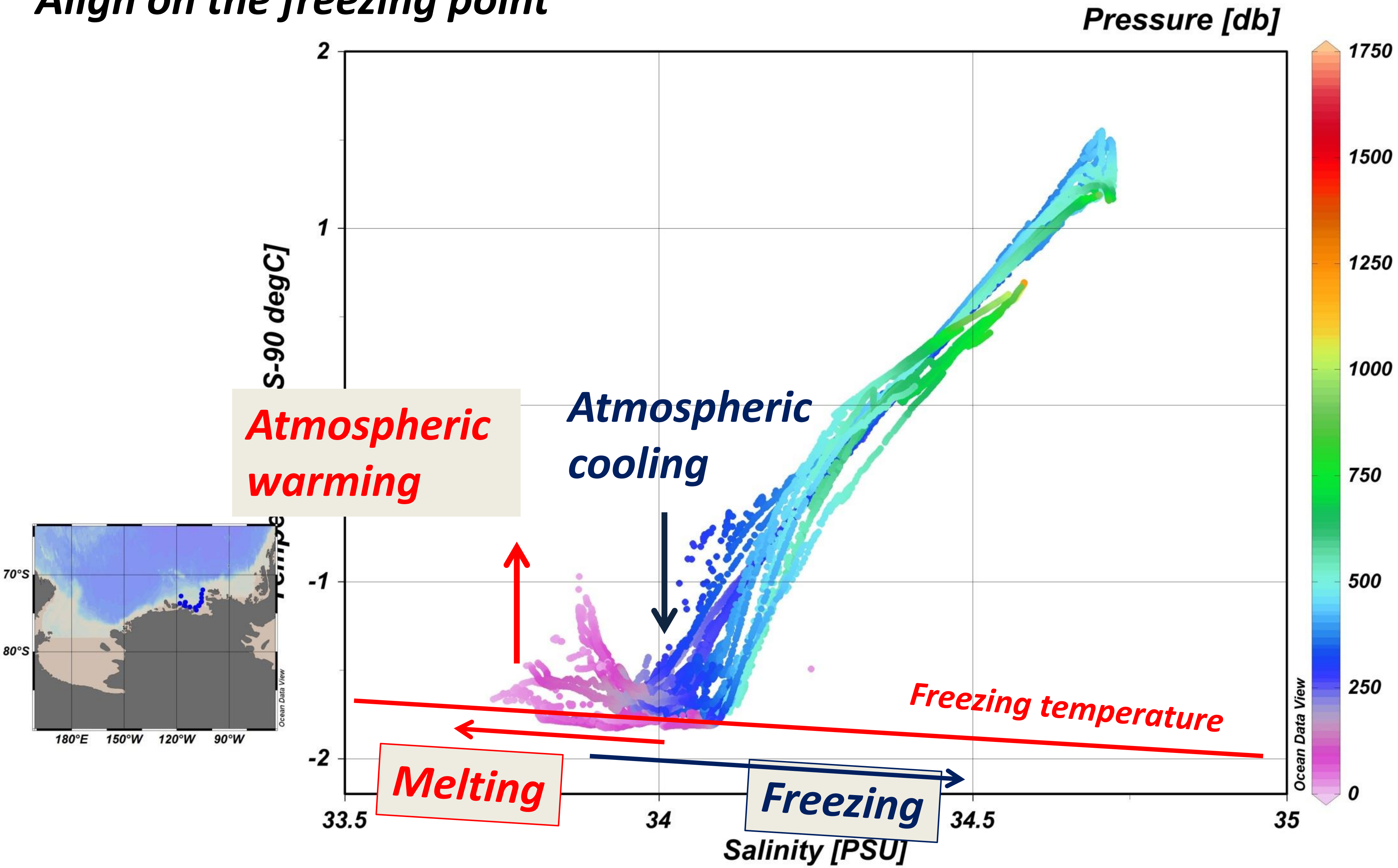
-83 ± 23 days

57 ± 13 days

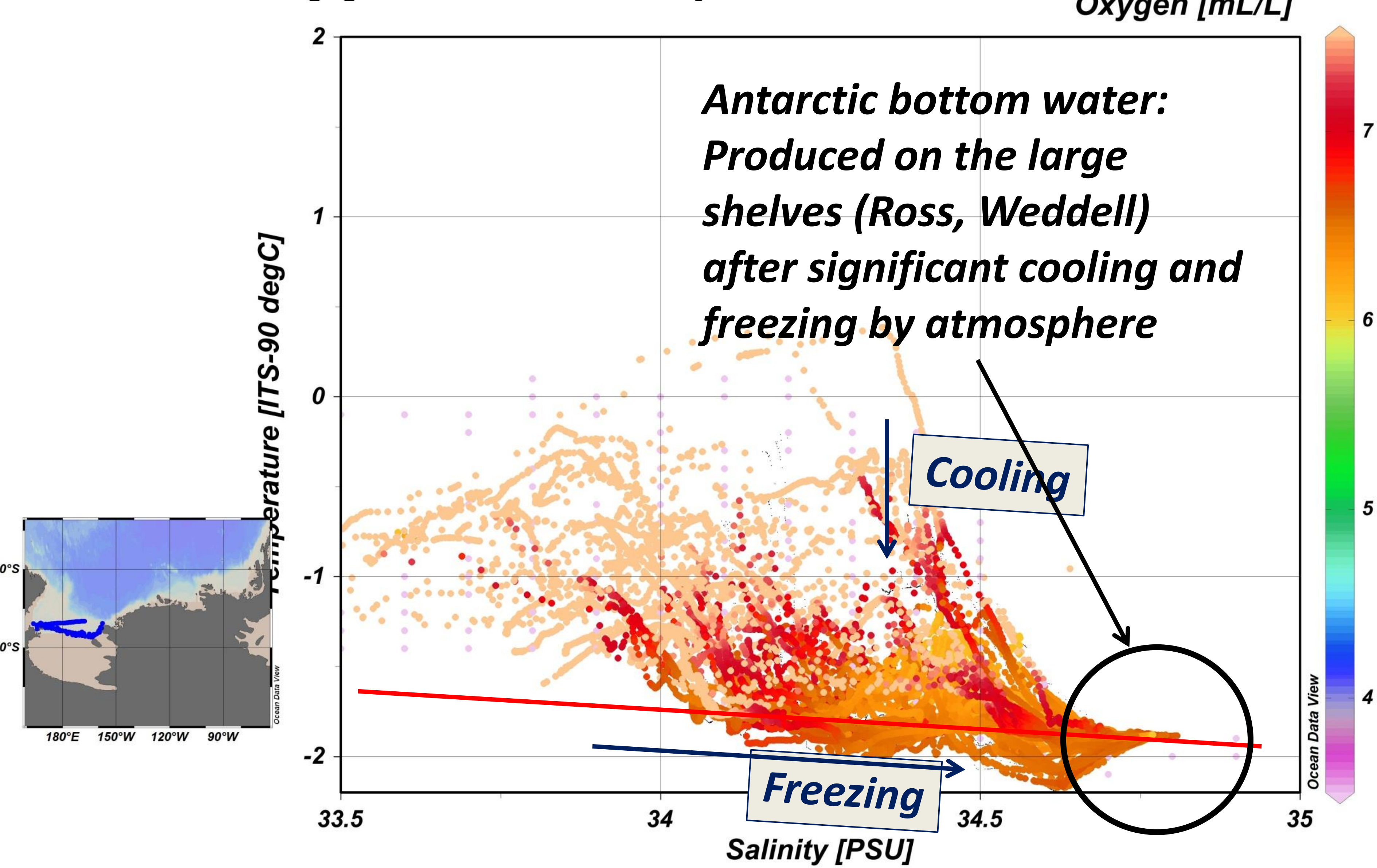


Stammerjohn et al. (2008)

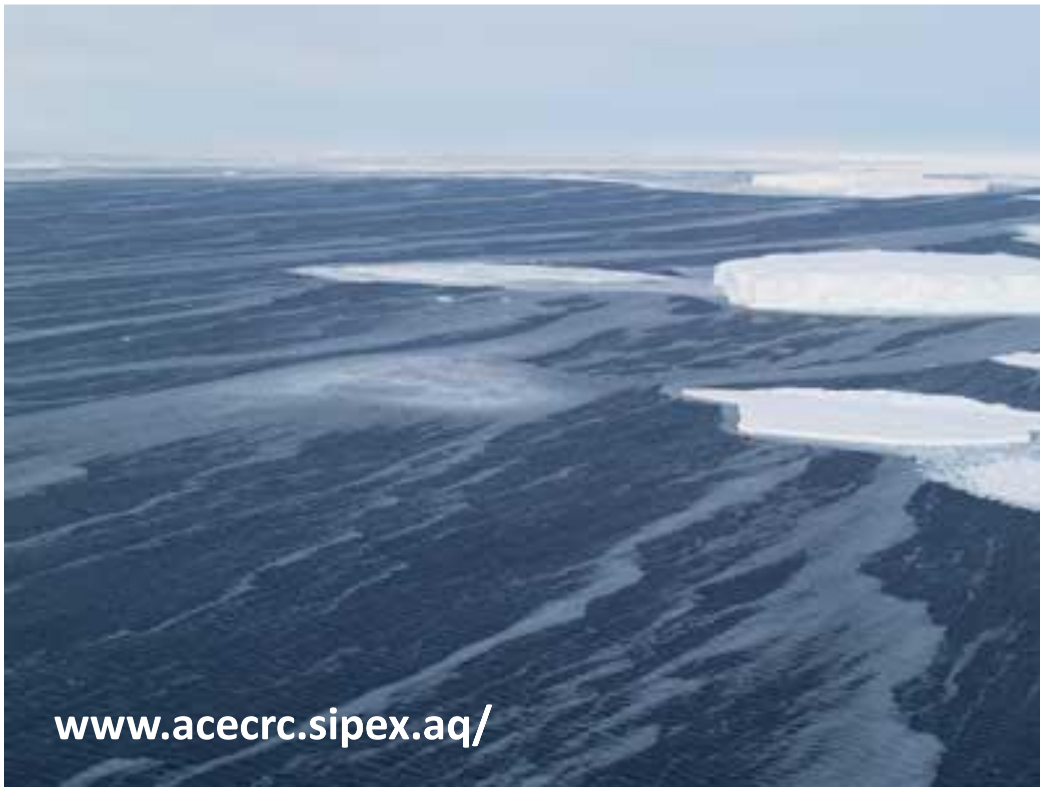
Effects of atmospheric cooling in the water mass:
Cooling (warming)
Align on the freezing point

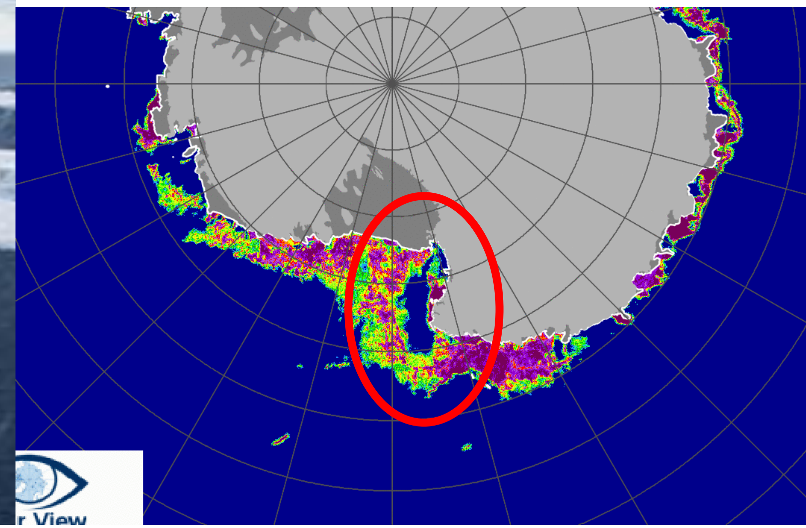


Severe cooling gives dense water formation

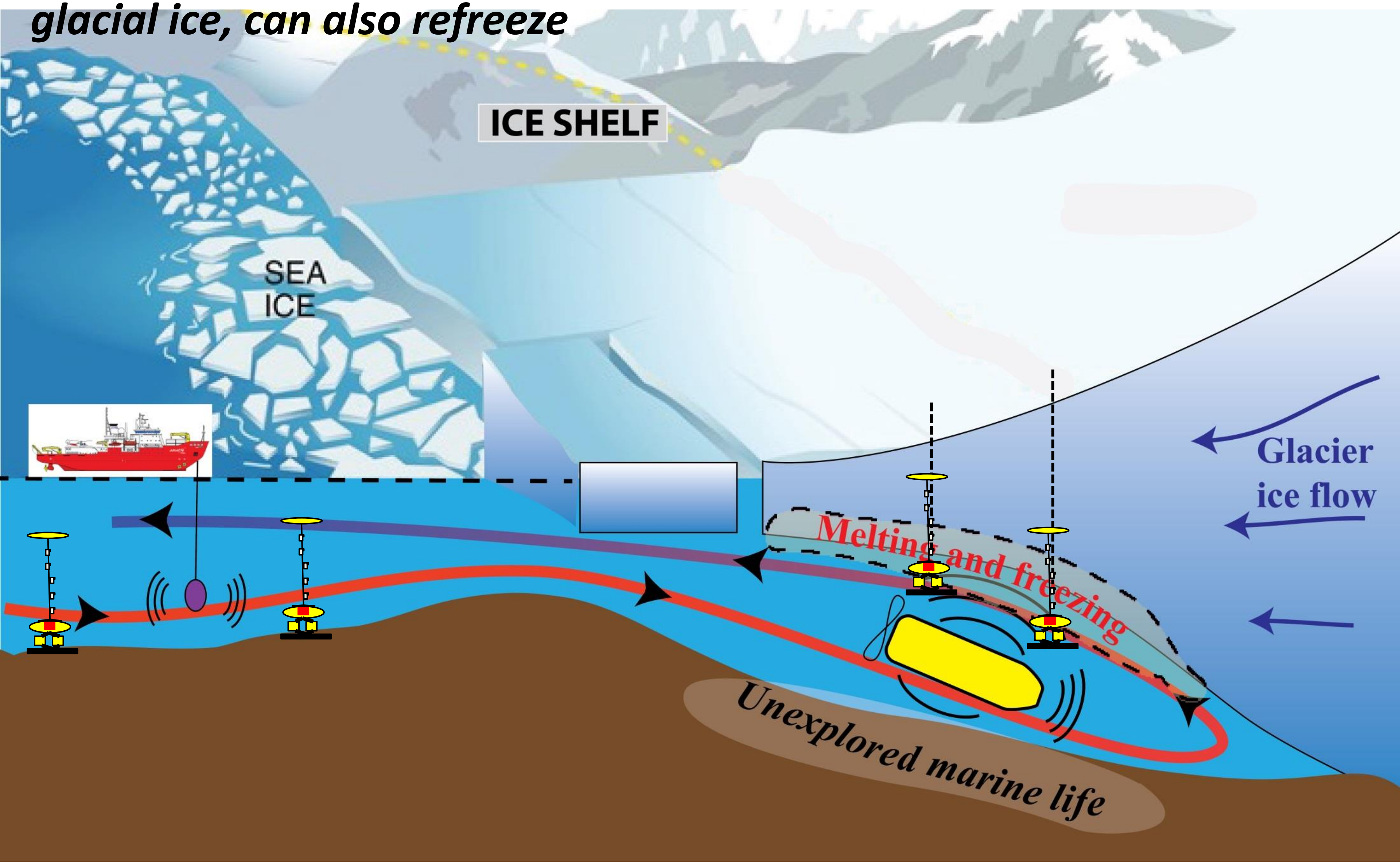


Strong ice formation in polynyas, held open by catabatic winds and/or tides

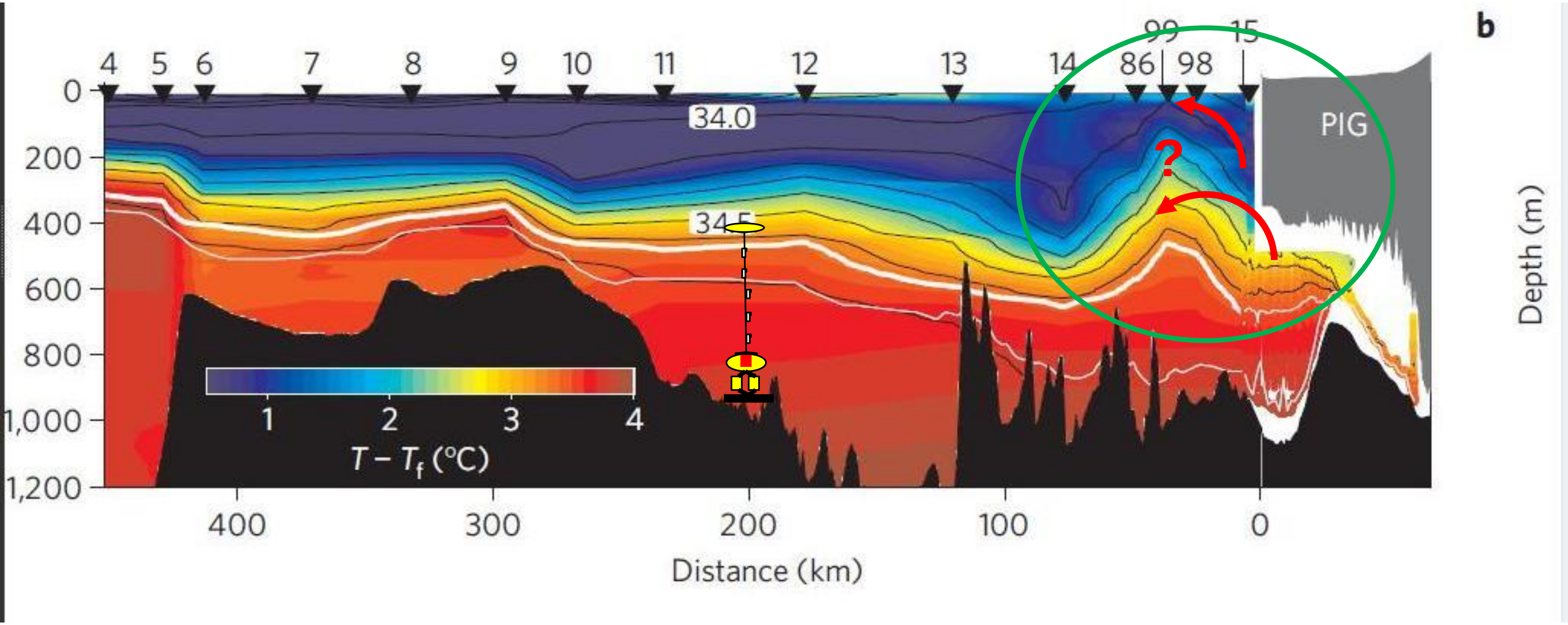




CDW circulating below floating glaciers. Very little known. Melts glacial ice, can also refreeze

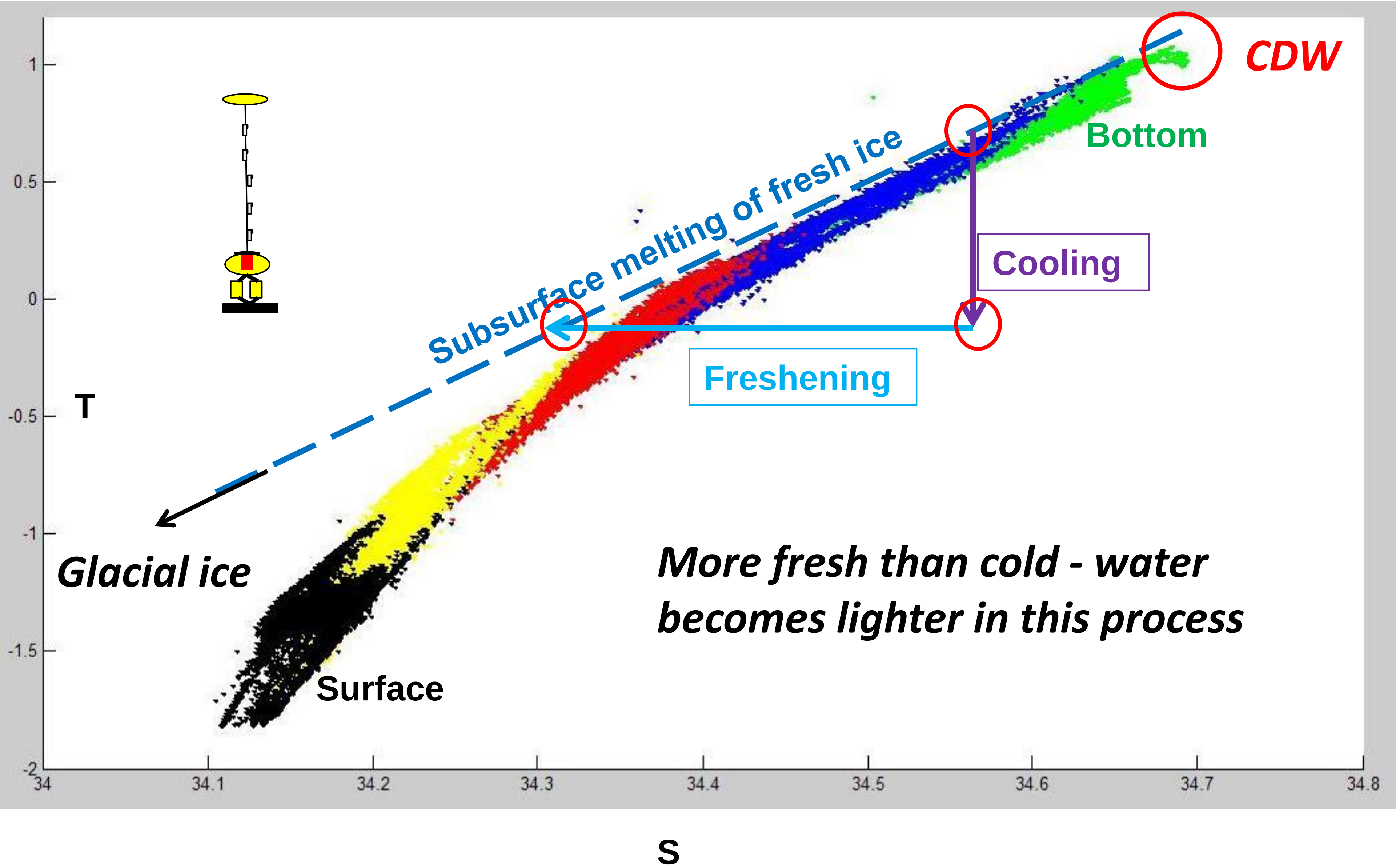


First measurements of ocean water circulating below glacier (2011).
Very irregular ice 'roof'
Found warm ocean water below glacier

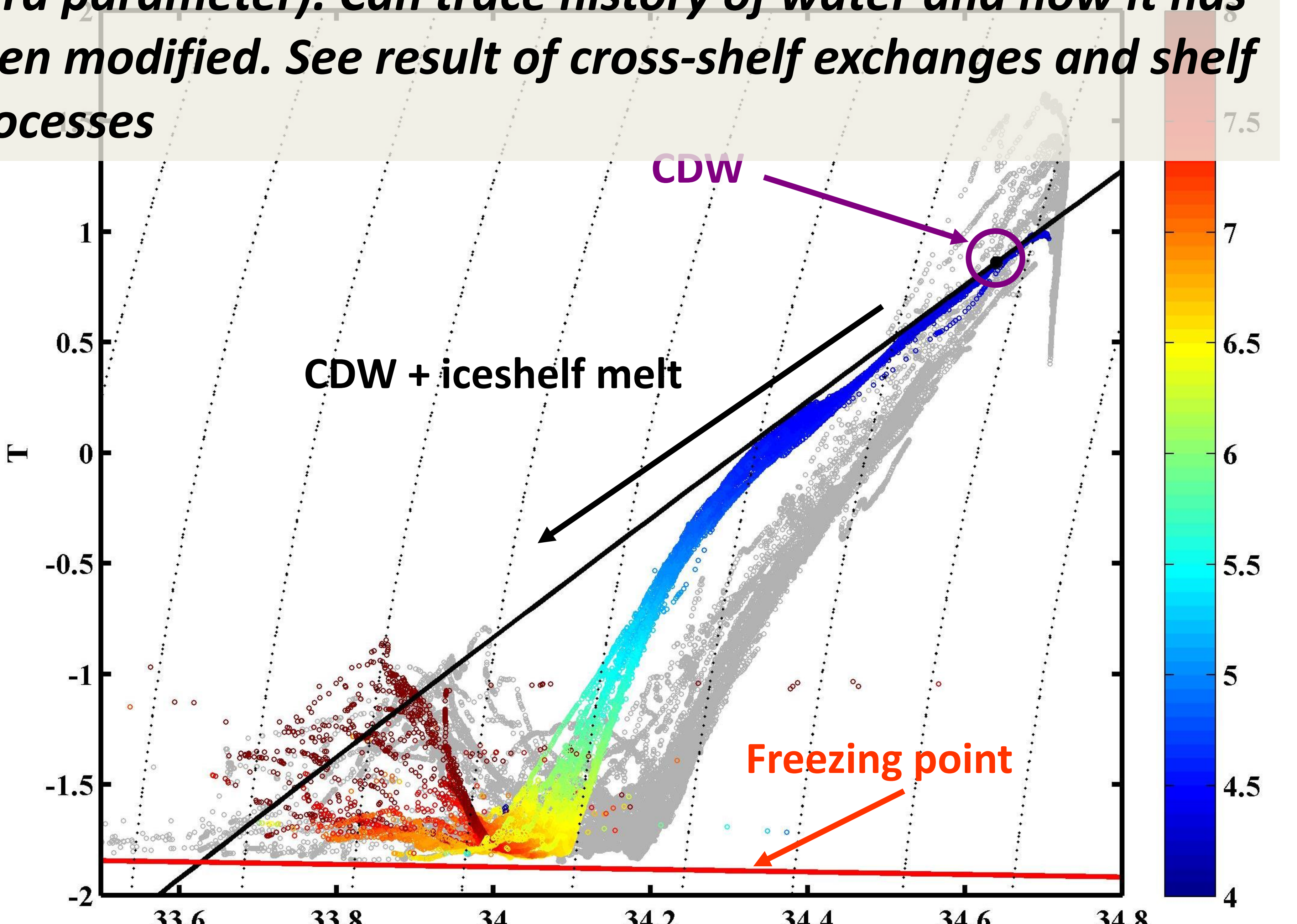


Jacobs et al, Nature Geoscience, 2011

Glacial ice melting: Freshening and cooling (latent heat loss)



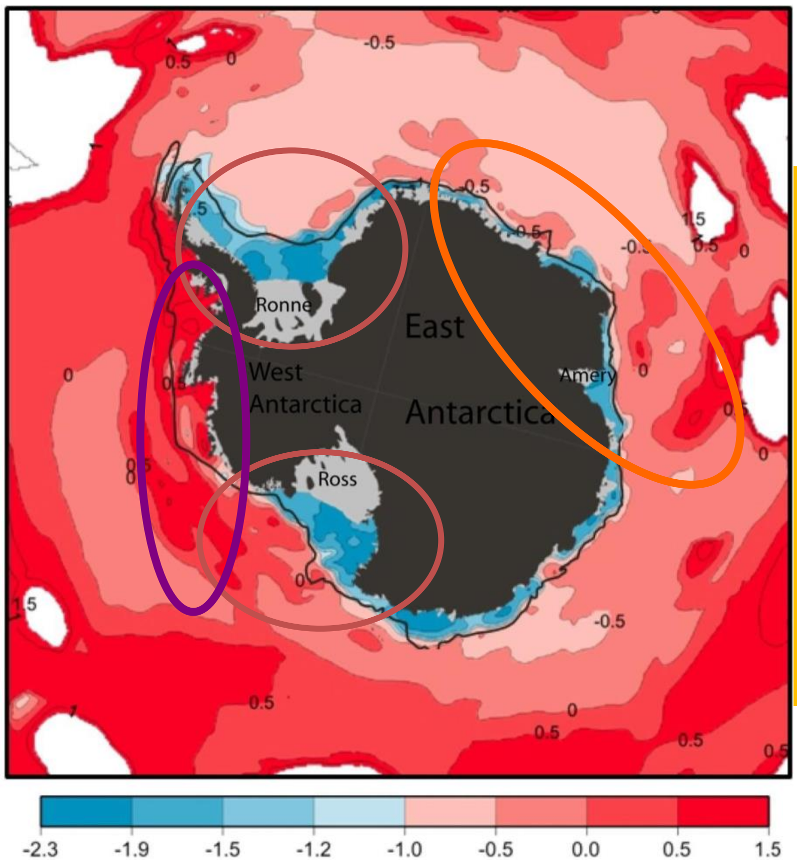
Use TS diagram to identify glacial melt (also use oxygen, third parameter). Can trace history of water and how it has been modified. See result of cross-shelf exchanges and shelf processes



Depending on strength of atmospheric processes, mixing on the shelf, and cross-shelf transports, the shelf areas can be sites for deep water production, flooded by warm water melting glaciers, or a combination

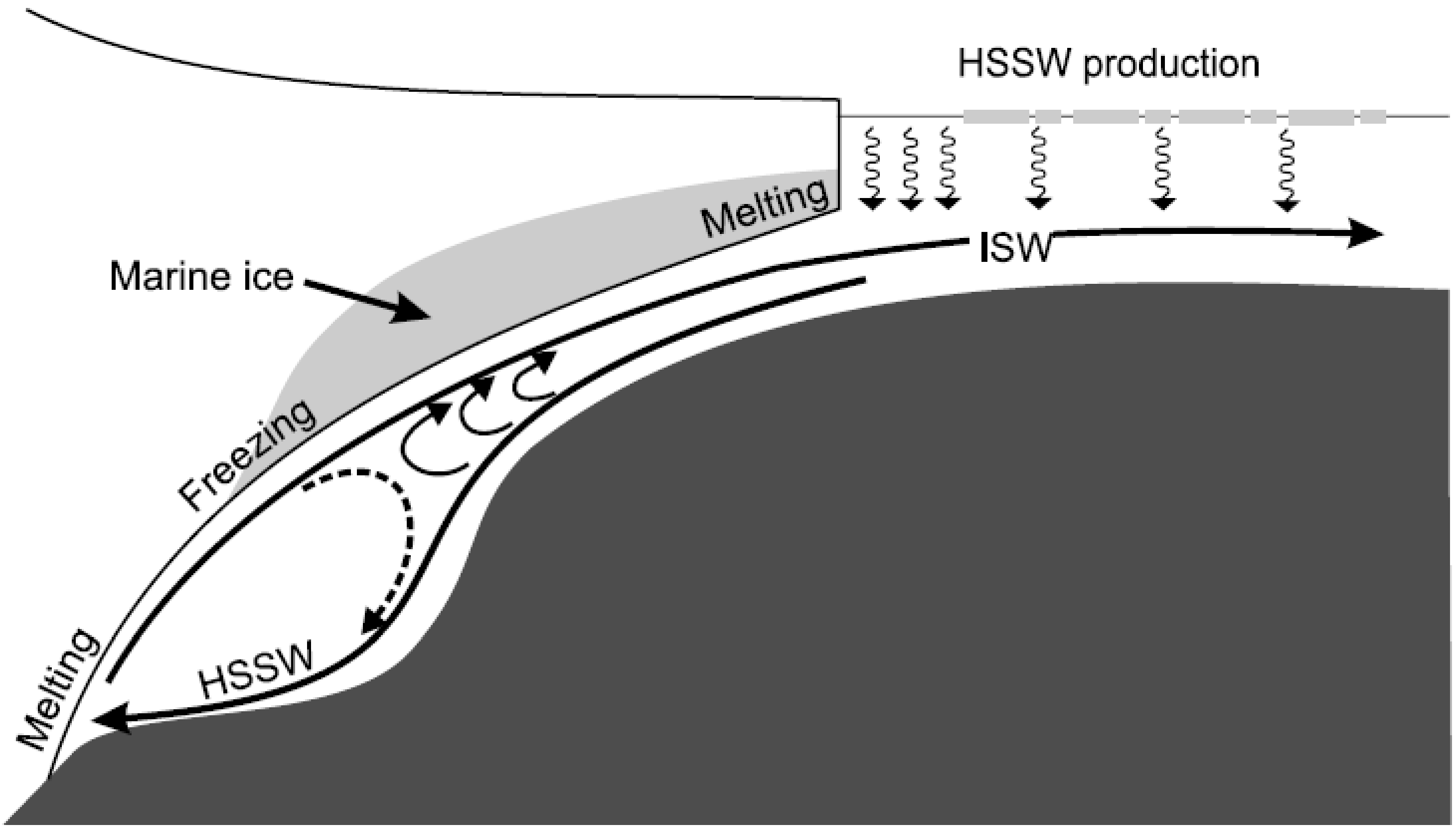
Weddell & Ross Seas: Large continental shelves and dense water formation. Modified Circumpolar Deep Water (CDW) flows towards the ice shelves.

Amundsen & Bellingshausen Seas: Nearly pure CDW flows onto the continental shelf and into the ice shelf cavities. No strong barriers



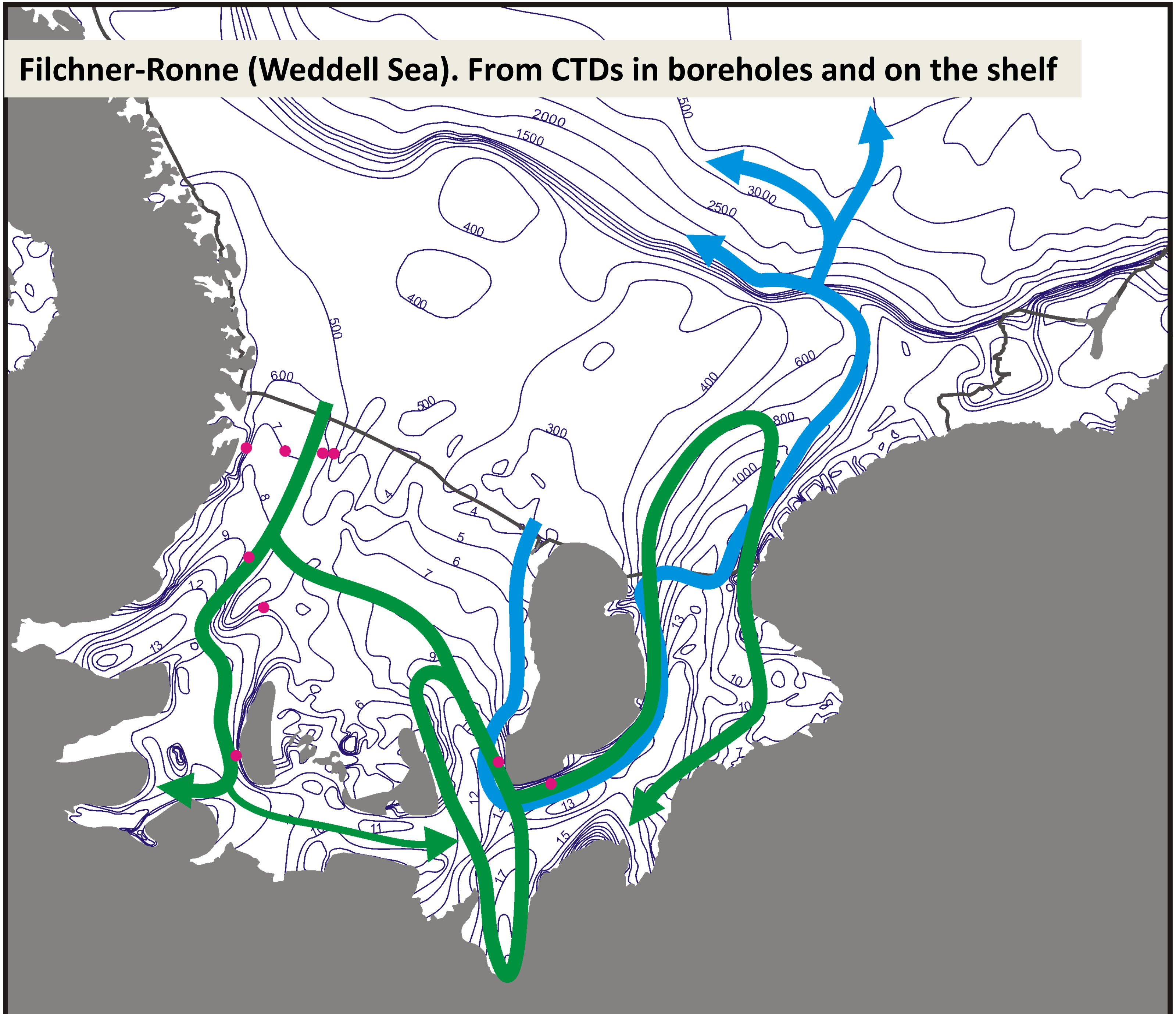
East Antarctica: Onshore surface Ekman flux creates a strong Antarctic Slope Front which acts as a barrier between the CDW and the ice shelves. Some modified CDW flows onto the shelf.

Filchner-Ronne (Weddell Sea): Atmospheric cooling on shelf makes the water entering the cavity very cold - refreezing and marine ice formation

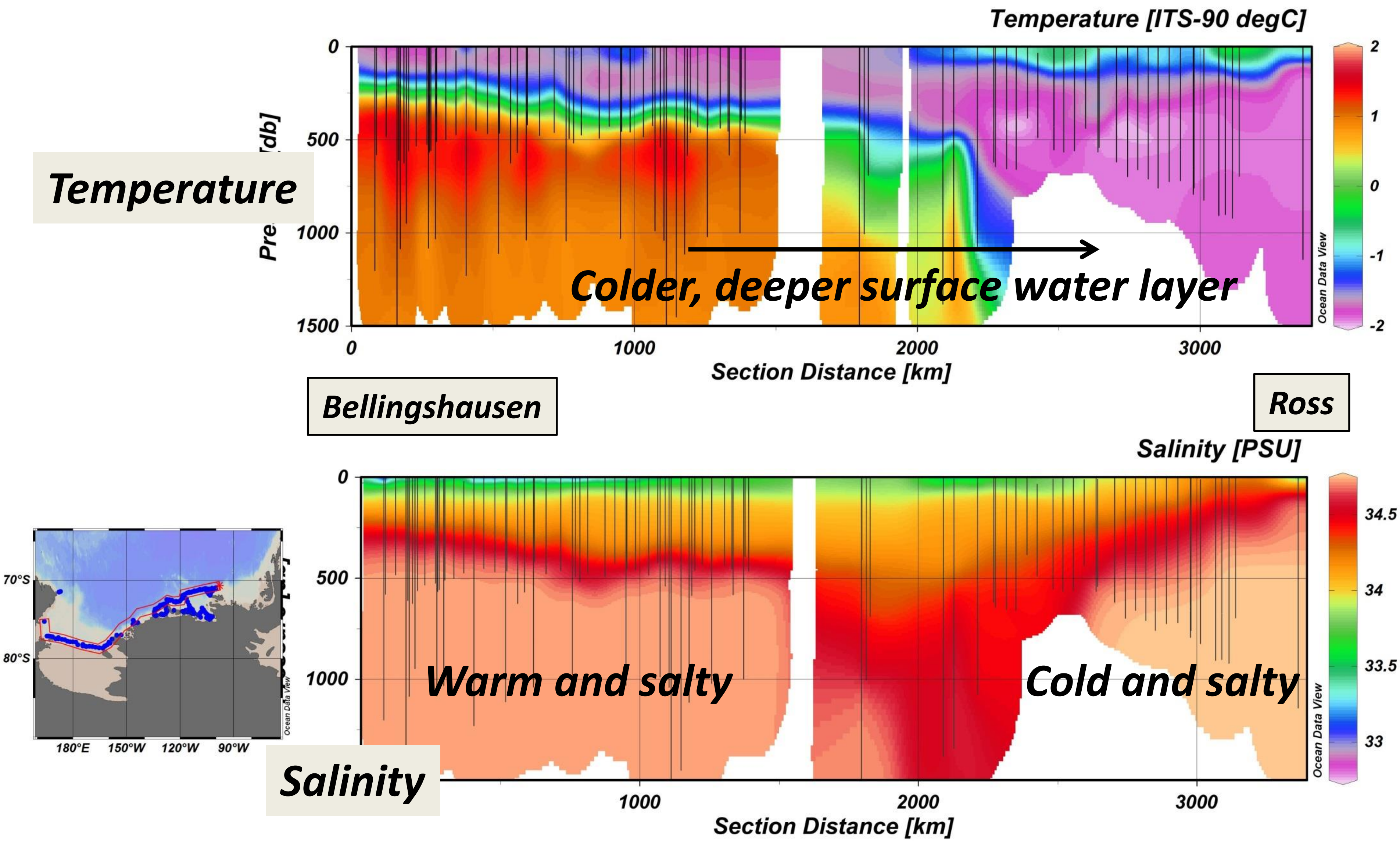


Nicholls et al, 2009

Filchner-Ronne (Weddell Sea). From CTDs in boreholes and on the shelf



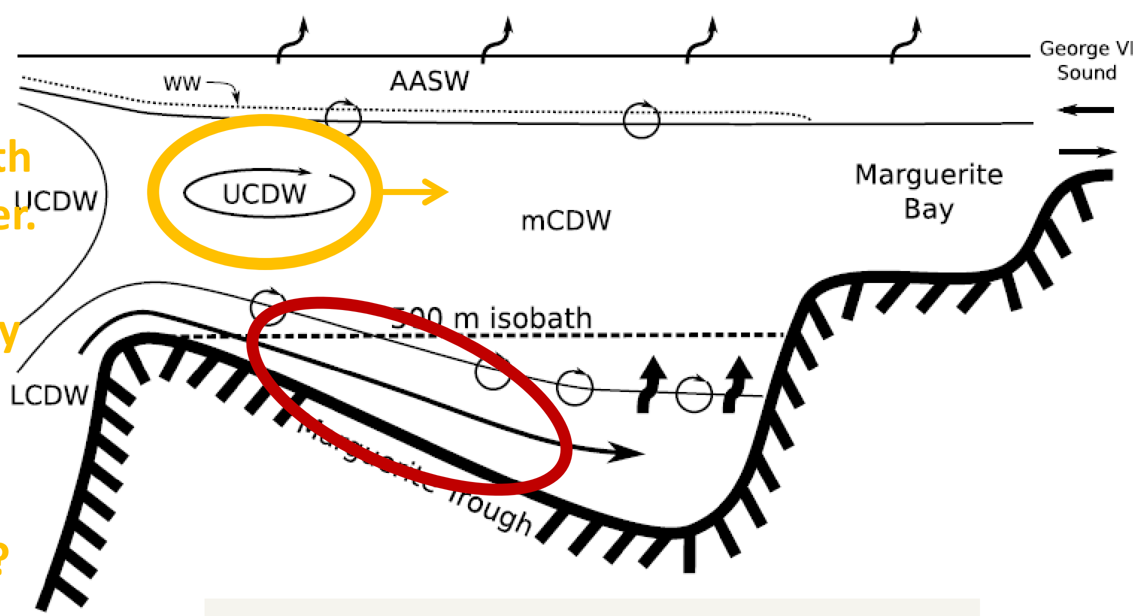
Transect along outer shelf from Bellingshausen to Ross Seas:



Mechanisms for cross-shelf flow of warm water: On-shelf flow of dense or intermediate water masses. We know very little!

Models (e.g. Dinniman et al, 2011 & 2009) and observations (e.g. Moffat et al, 2009) from the Antarctic Peninsula shows two types of warm inflow: Upper CDW through intermittent 'eddies', and lower CDW more steady:

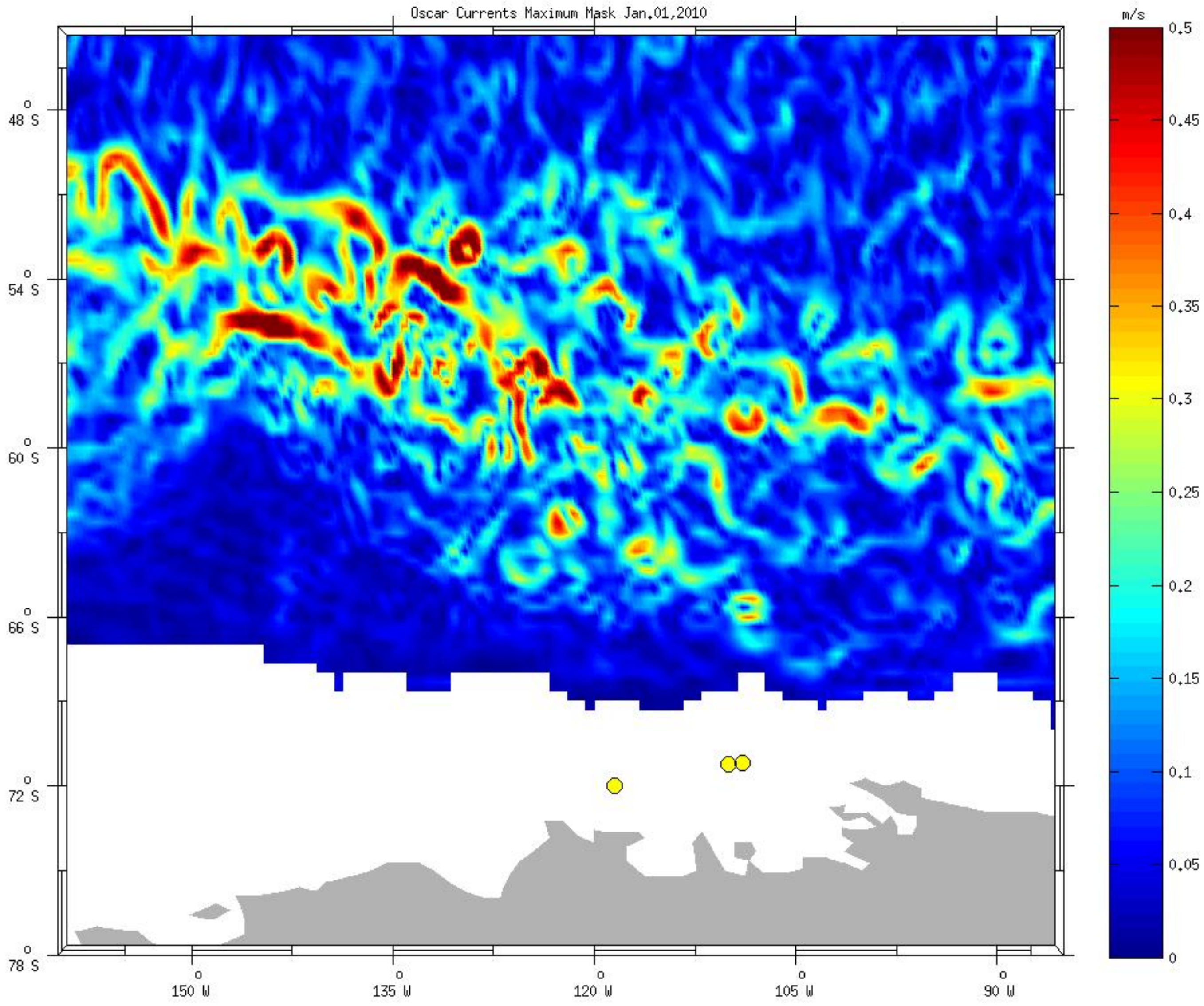
C05017 MOFFAT ET AL.: CDW INTRUSIONS TO WAP CONTINENTAL SHELF C05017



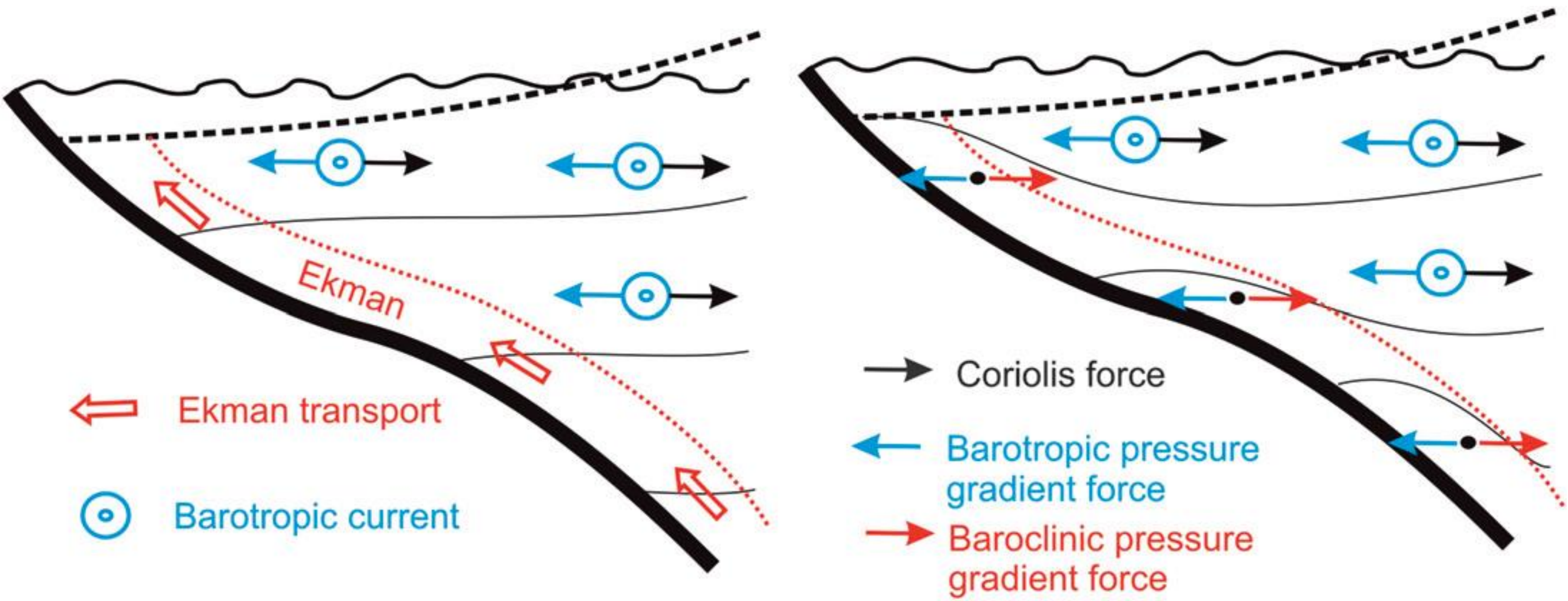
UCDW: Moves with intermediate water. Eddies
Primarily driven by velocity shear
Needs external forcing to uphold velocity shear....??

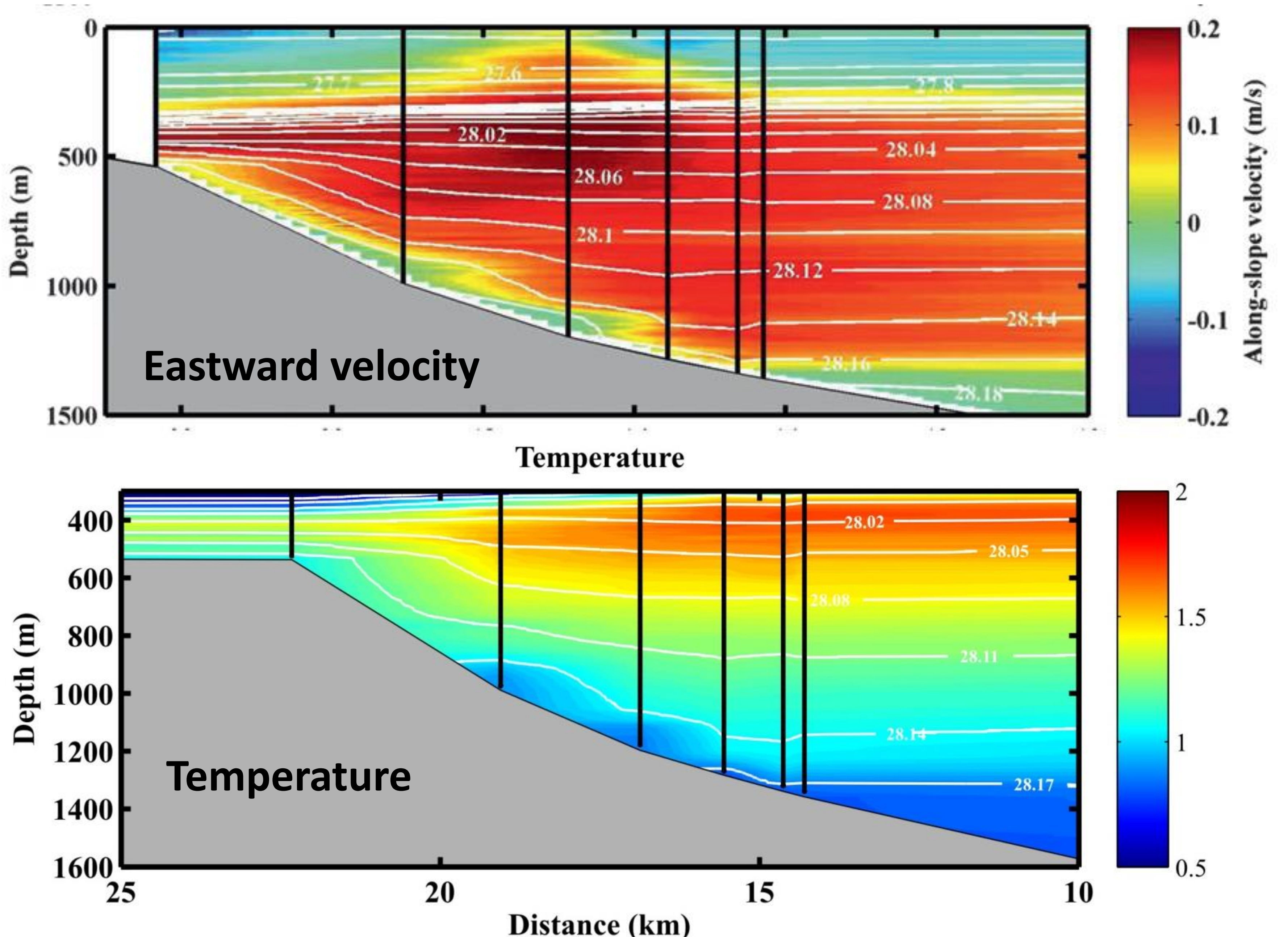
LCDW:
More or less constant
Buoyancy driven (once on shelf)
Needs external forcing to get onto shelf

ACC (from altimetry + winds OSCAR data) in the vicinity of the shelf. High variability and eddies

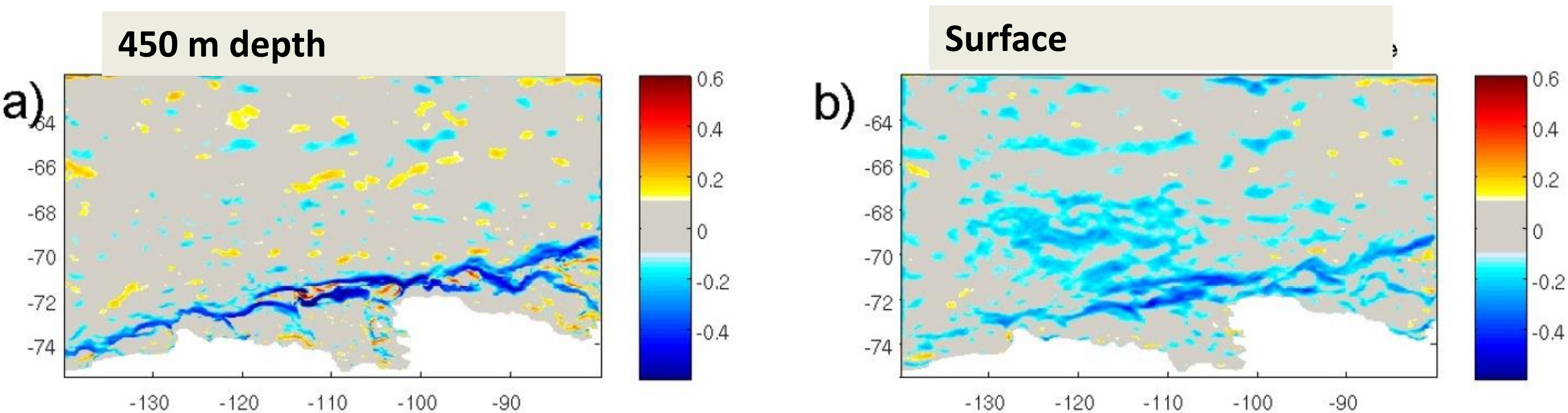


How does the water get onto the shelf (lifted from depth)?
Ekman dynamics: Transport of deep water up the slope due to alongslope (eastward) current at shelf break

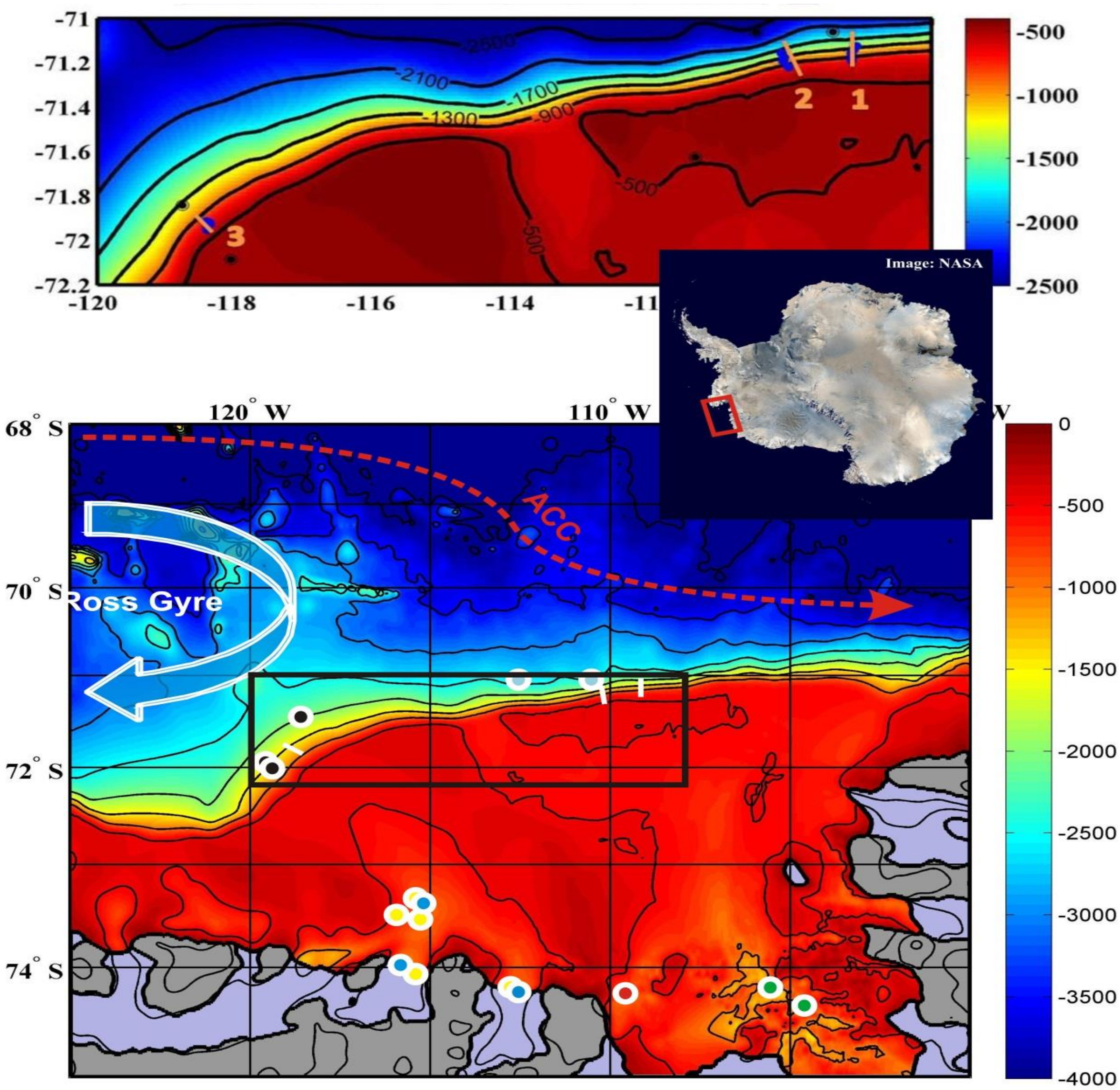



Eastward velocity
Depth (m)
0
500
1000
1500
27.7
27.6
27.8
28.02
28.04
28.06
28.08
28.1
28.12
28.14
28.16
28.18
Along-slope velocity (m/s)
0.2
0.1
0
-0.1
-0.2
Temperature
Temperature
Depth (m)
400
600
800
1000
1200
1400
1600
28.02
28.05
28.08
28.11
28.14
28.17
2
1.5
1
0.5
25
20
15
10
Distance (km)

Model study: High correlation between along-slope current at shelf break and inflow in deep trough.



From Assmann et al, in press

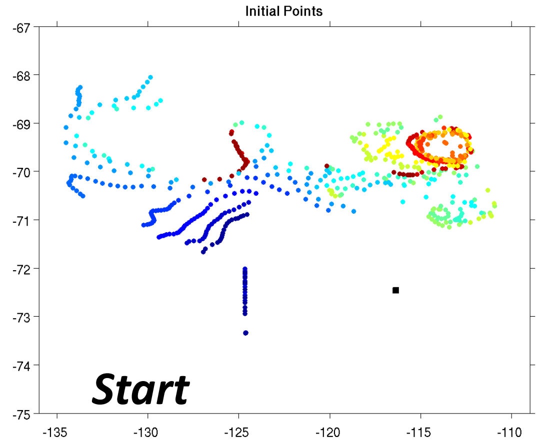


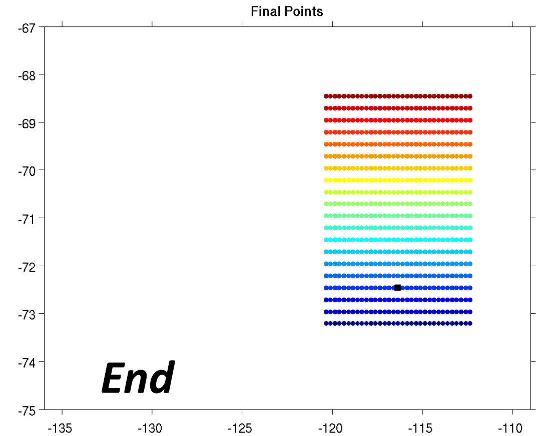
If it is true that along-shelf currents in deep water forces on-shelf flow of warm deep water, then what is the role of clockwise gyres? (Ross, Weddell)

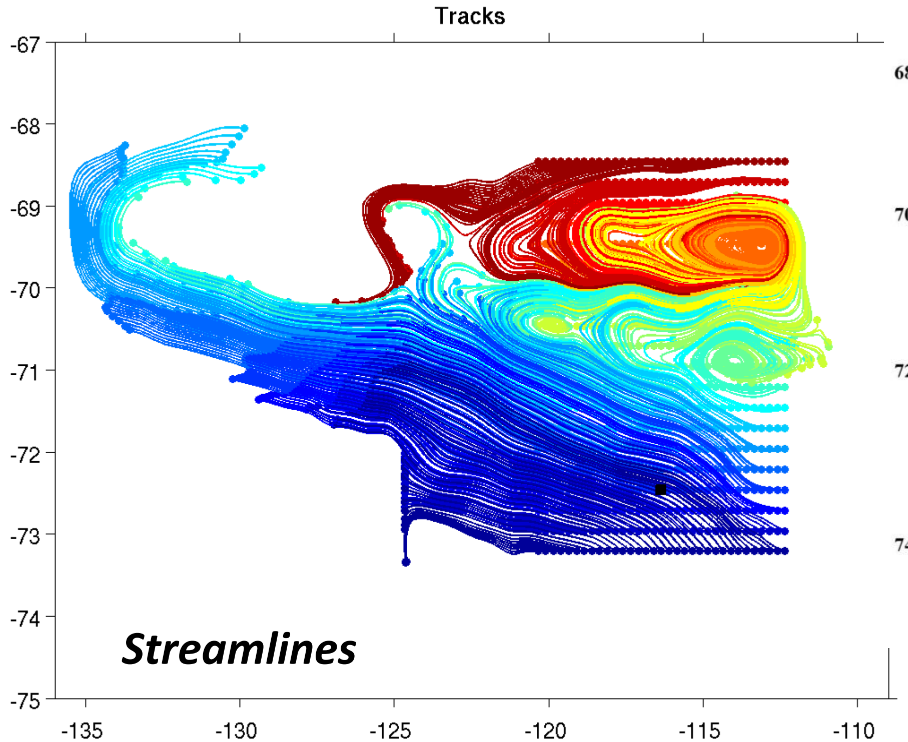
Do they prevent warm water flooding? Or are they an artefact of strong shelf modification, blocking the warm water and setting up a geostrophic circulation?

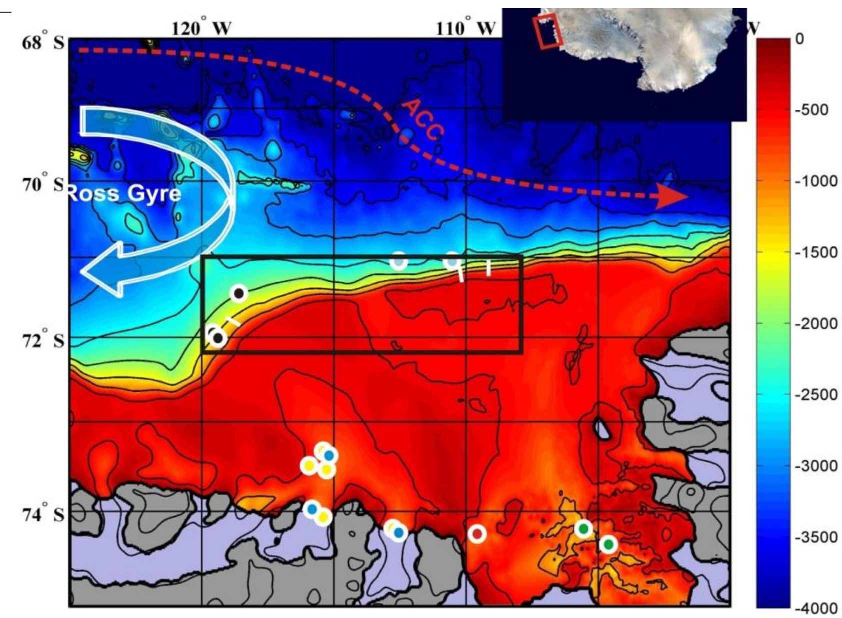
How persistent are they? Need more observations!

Start points, end point, and streamlines of surface currents in the Amundsen Sea





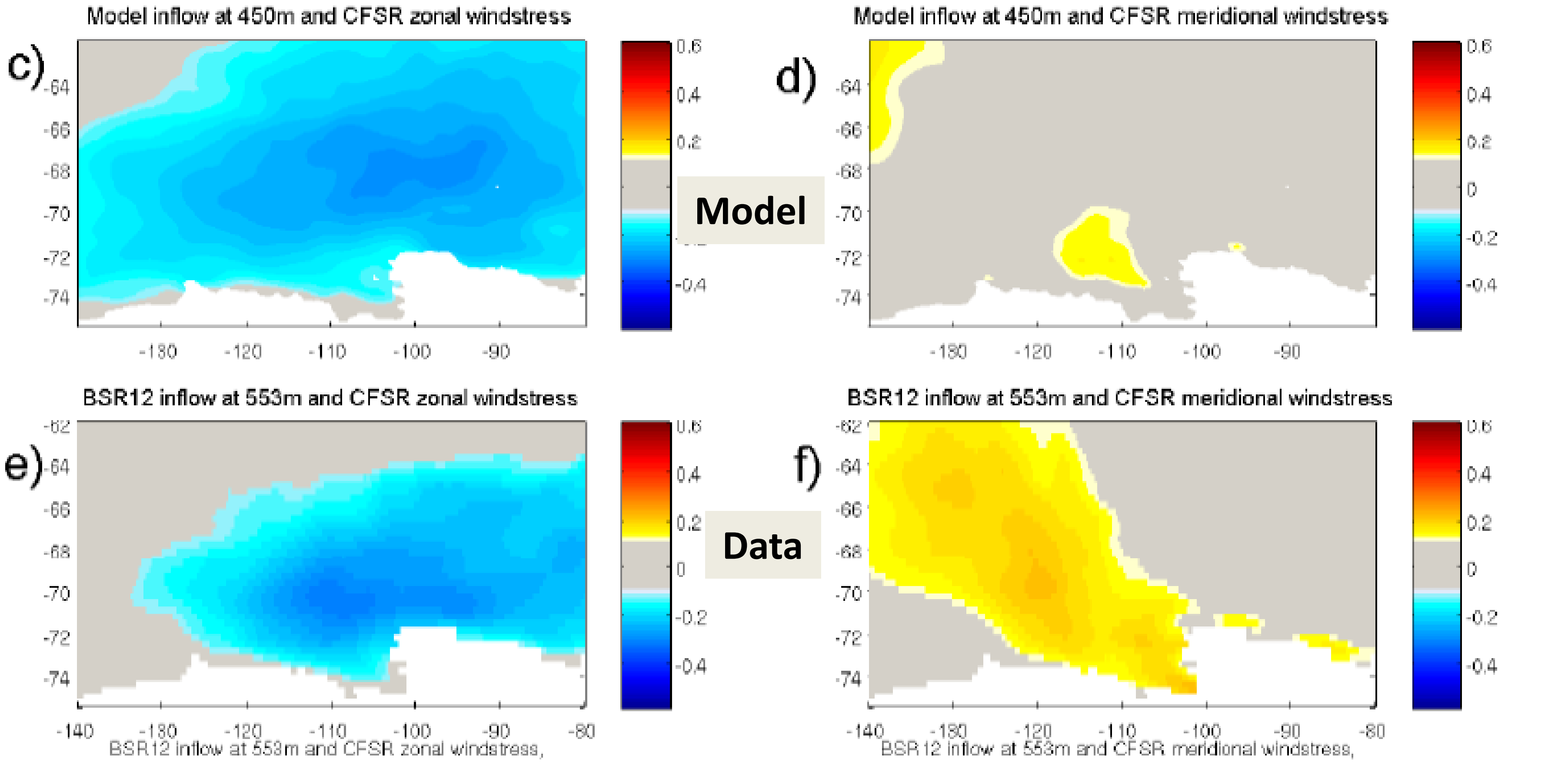




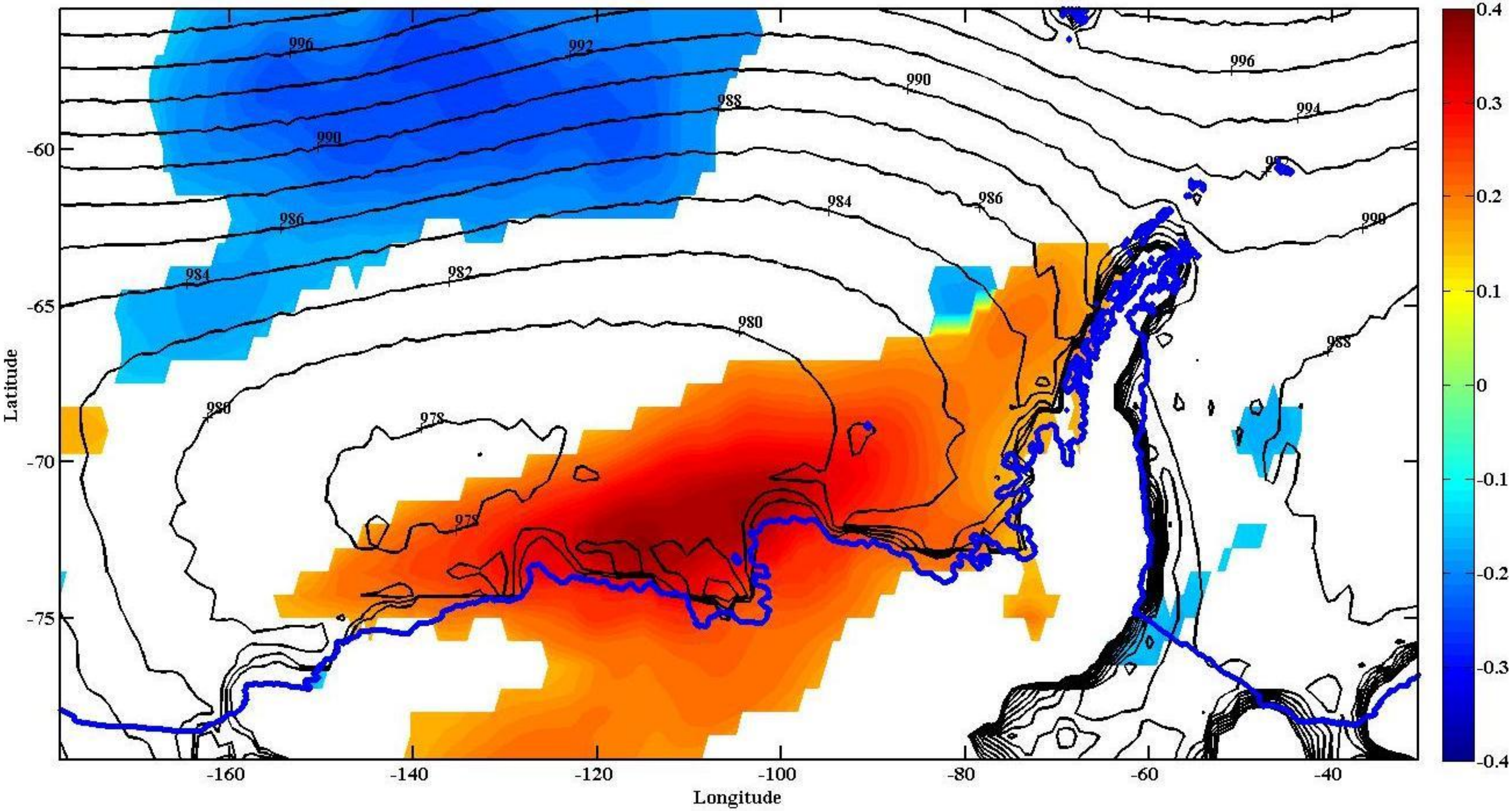
Dohan et al, in prep

Correlation wind and Pine Island trough

Upwelling by wind responsible for on-shelf flow? (Also, wind can force along-slope currents => Ekman transport uphill)

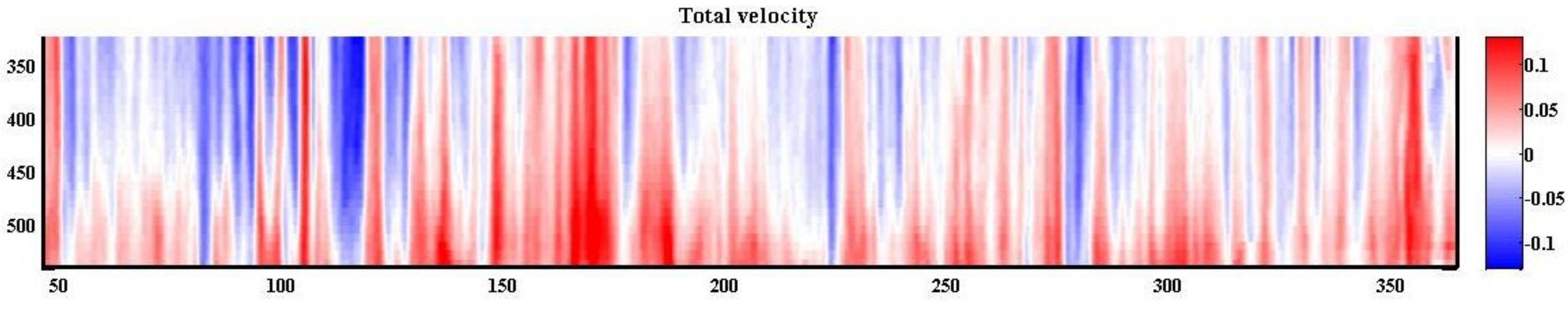


Upwelling: Correlation map showing that eastward wind correlates to along-trough flow



Wåhlin et al (in press)

Along-channel velocity (red = towards iceshelves) 2010

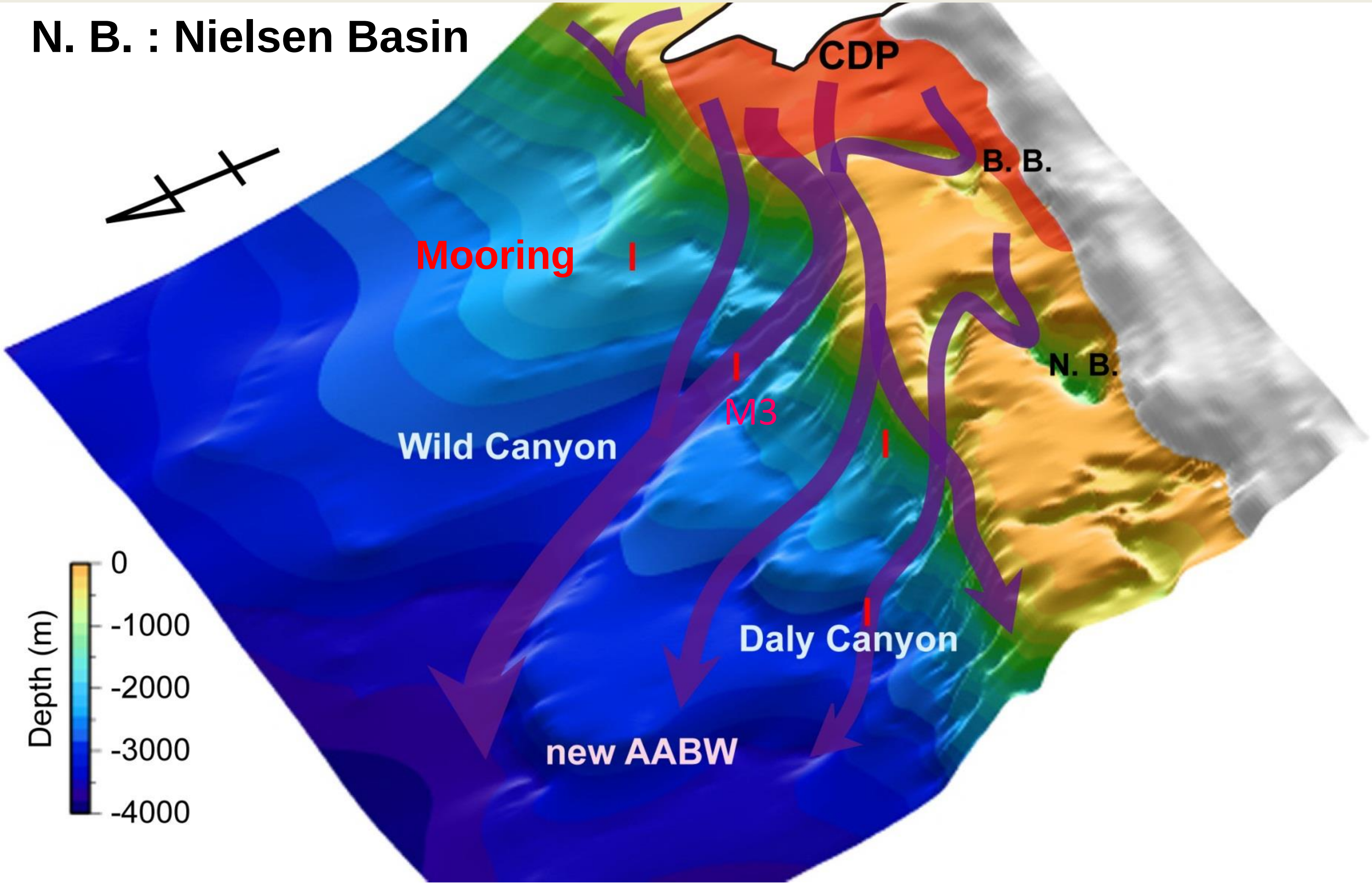


However: Strong component of the flow velocity is short-term fluctuations. They correlate with wind, but not clear how much they contribute to transport of warm water. No correlation between wind and temperature, no correlation between wind and velocity on monthly time scales

From Arneborg et al, 2012

Dense water moving down from the shelf have difficulty crossing depth contours (due to Earth's rotation). Small-scale topography acts as conduits and steer the water downhill. Channels, canyons, corrugations, sometimes with sills over which the water spills (Filchner-Ronne). Picture from Cape Darnley

N. B. : Nielsen Basin



Offshelf transport of dense water depend on bathymetry. Small-scale topography towards the deep sea, e.g. channels, greatly enhance the flow. There are a number of ways to estimate the flow capacity given a certain geometry (hydraulic control, canyon capacity, etc). They are all equal to some fraction of the density difference between ambient water and dense current, i.e.

$$Q_C \sim g'\beta$$

The theoretical max transport for any geometry of channel/sill is given by

$$Q_C \sim \frac{g'H^2}{2}$$

This means that denser water can leave shelf more easily. If there is a block anywhere, the water will become denser until it fits through the transport capacity

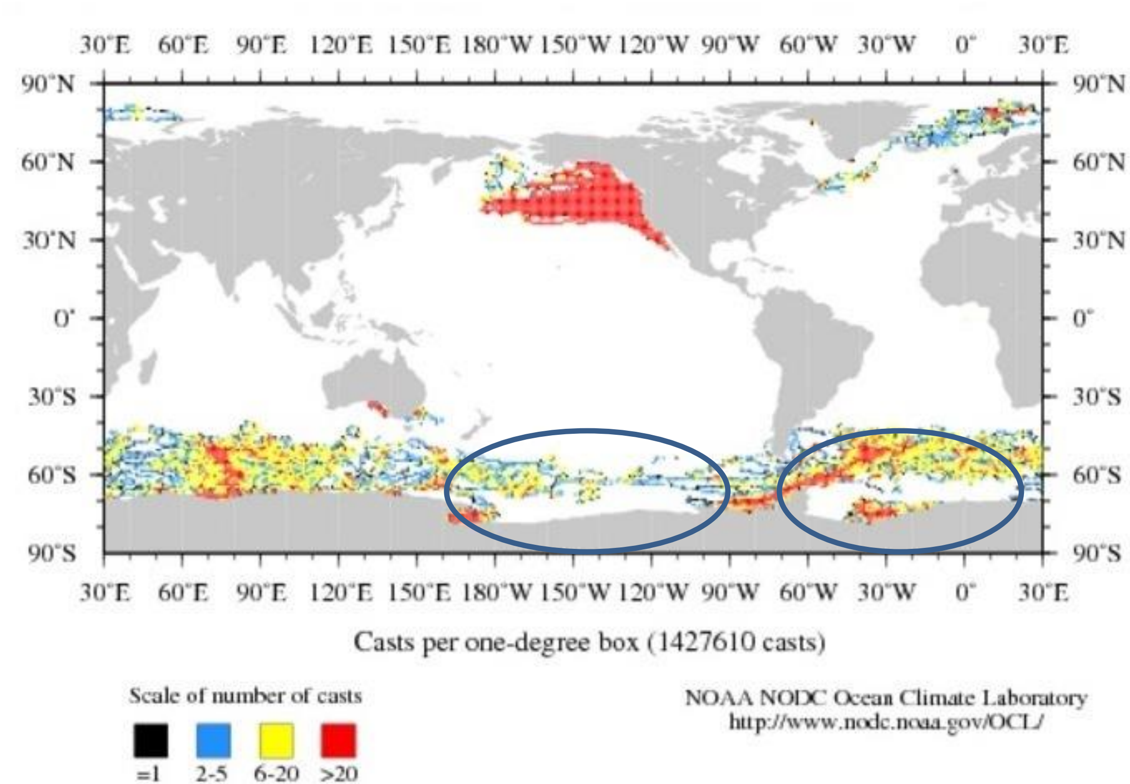
Gaps in knowledge:

1) Strong summertime bias

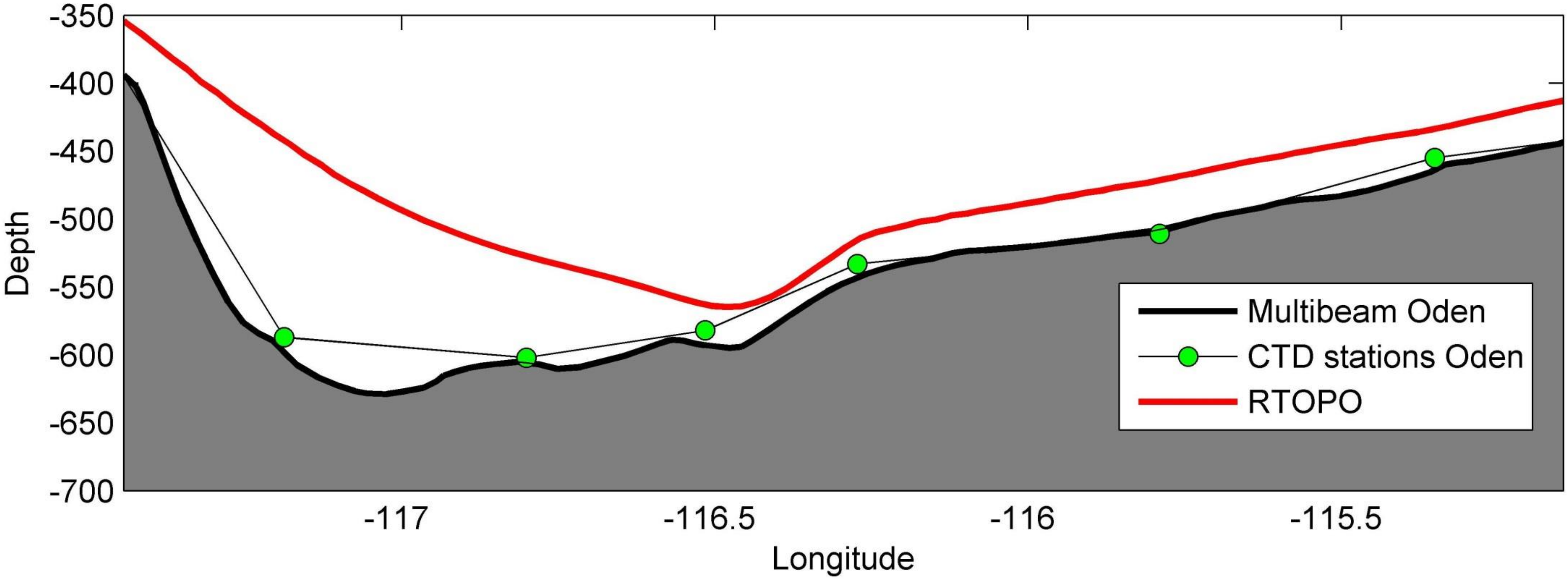
2) Lack of long time series

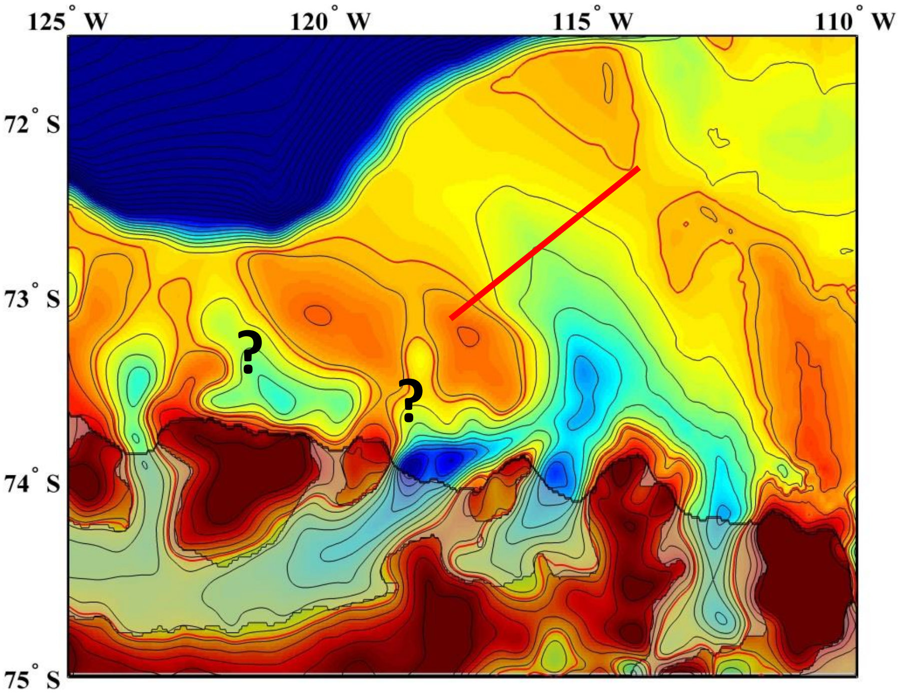
3) Some areas very poorly known (bathymetry, CTD, etc)

4) Measurements of basal melt and the grounding line



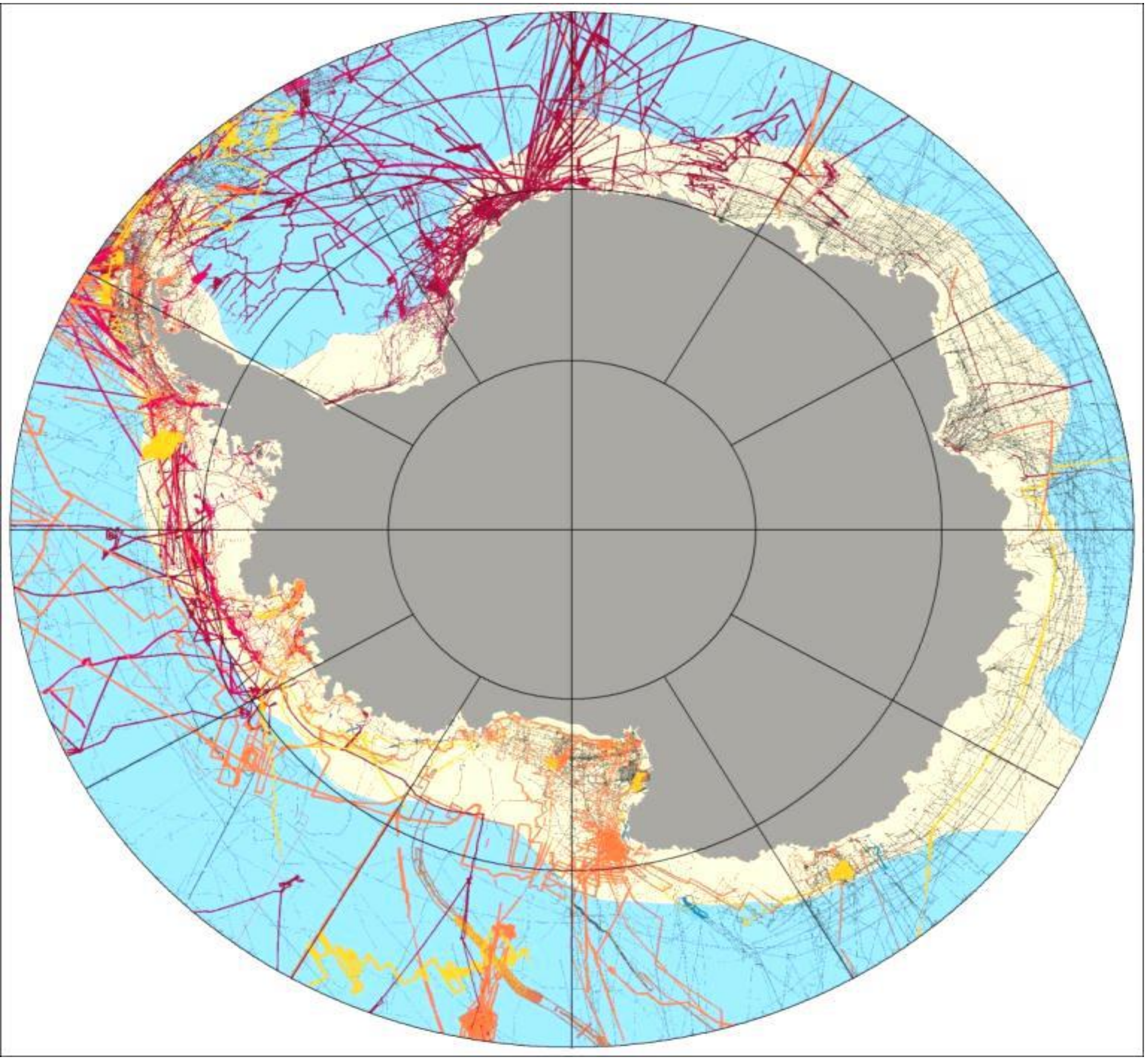
Animal sensors (NODC)
Where gaps => very strong summertime bias





Need to know bathymetry! Don't know sill depths and channel axis of troughs, don't know bathymetry below ice shelves

IBCSO ship tracks



Simple measure for bathymetry: Look at ship tracks, chose slightly different route.
www.ibcso.org

Outstanding questions:

* **Why are some continental shelves flooded by warm CDW while others only have modified (colder) versions of it?**
* **What forces the warm water onto the shelf?**
* **We can not predict the melt rate (big uncertainty in IPCC)**
* **How does temperature, melt rate, grounding line location change with climate (decadal timescales)?**

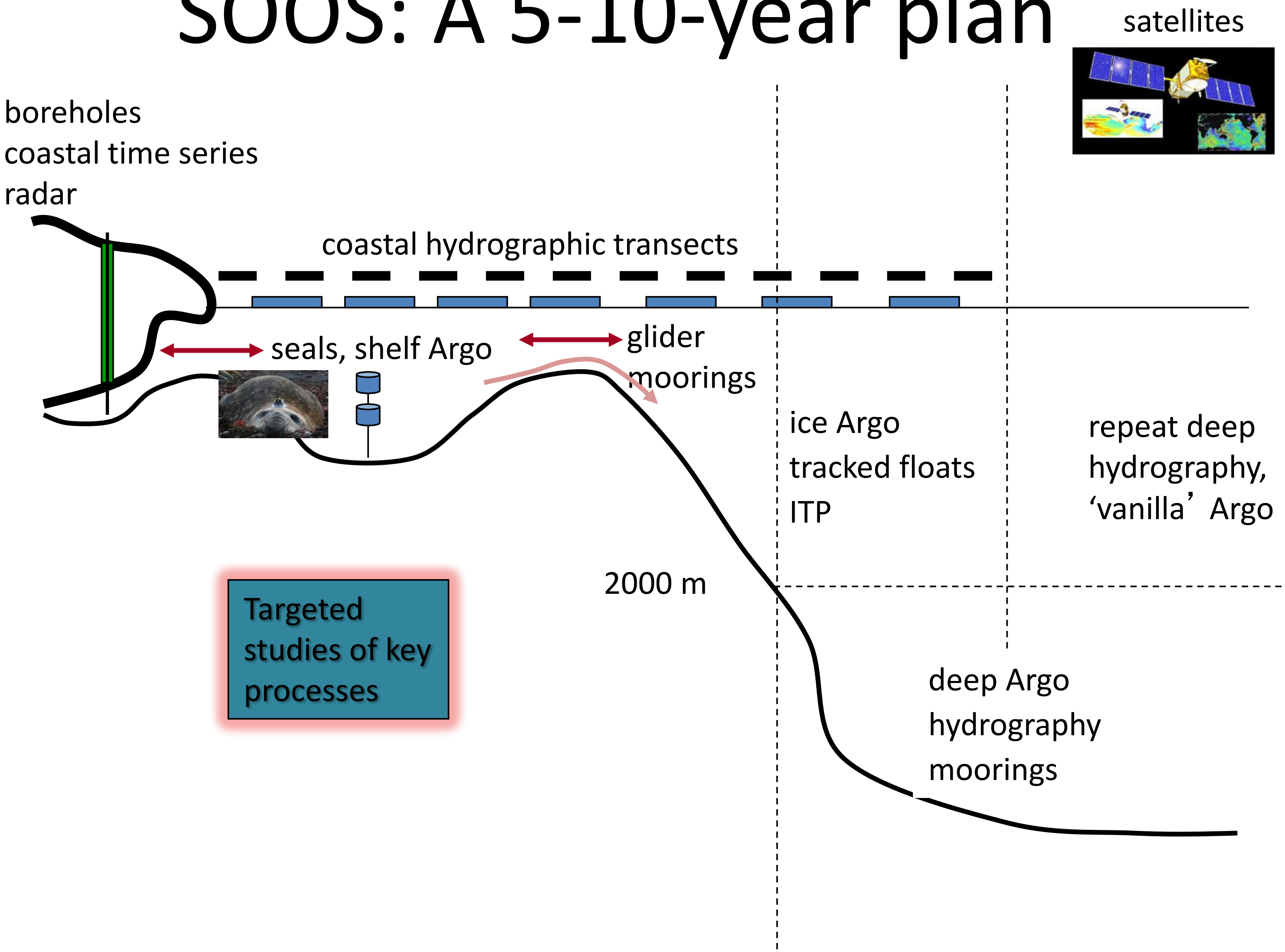
SOOS Science Themes

Key science challenges identified as the most pressing issues - both scientifically and societally - to be addressed by the SOOS:

1. **Role of Southern Ocean in global freshwater and heat balance**
2. **Stability of Southern Ocean overturning circulation**
3. **Stability of Antarctic ice sheet and future contribution to sea-level rise**
4. Future of Southern Ocean carbon uptake
5. **Future of Antarctic sea ice**
6. Impacts of global change on Antarctic ecosystems

Ongoing activities and gaps

SOOS: A 5-10-year plan

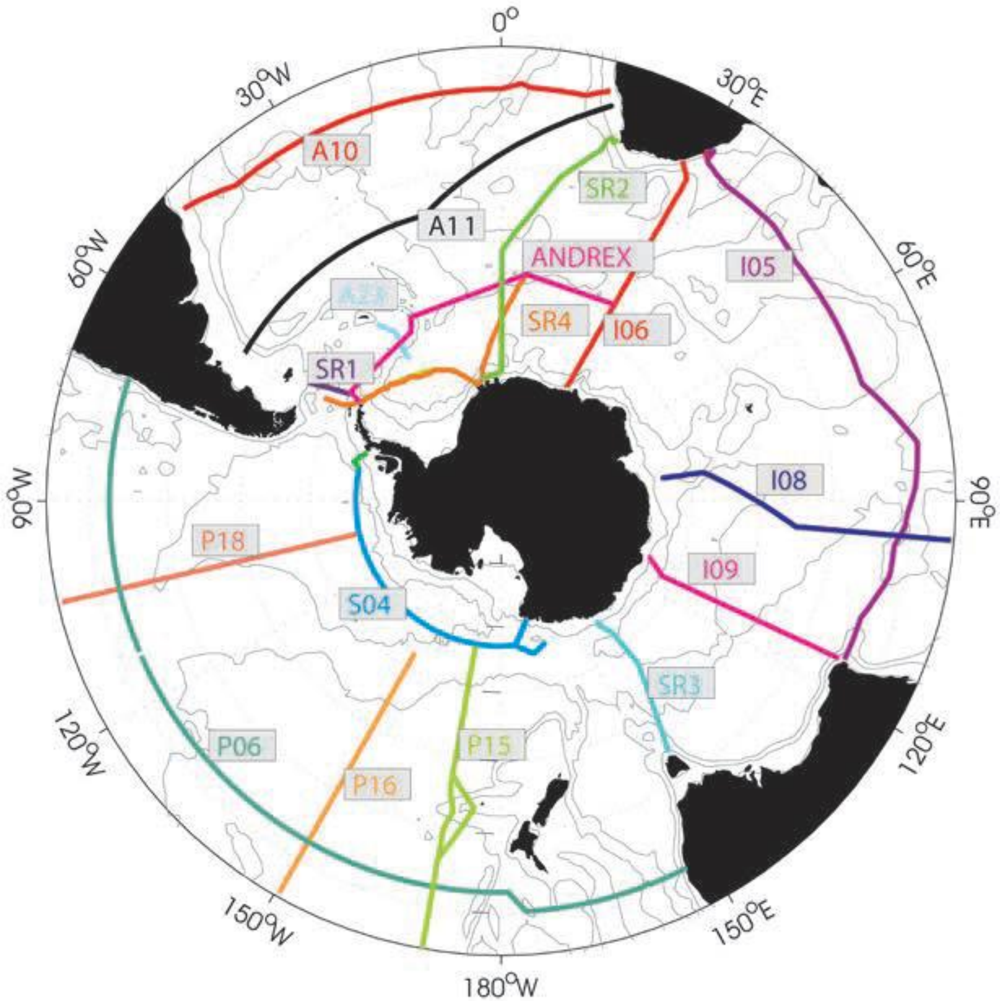


www.soos.aq

The most important activities for sustained physical oceanography observations of the Southern Ocean today include:

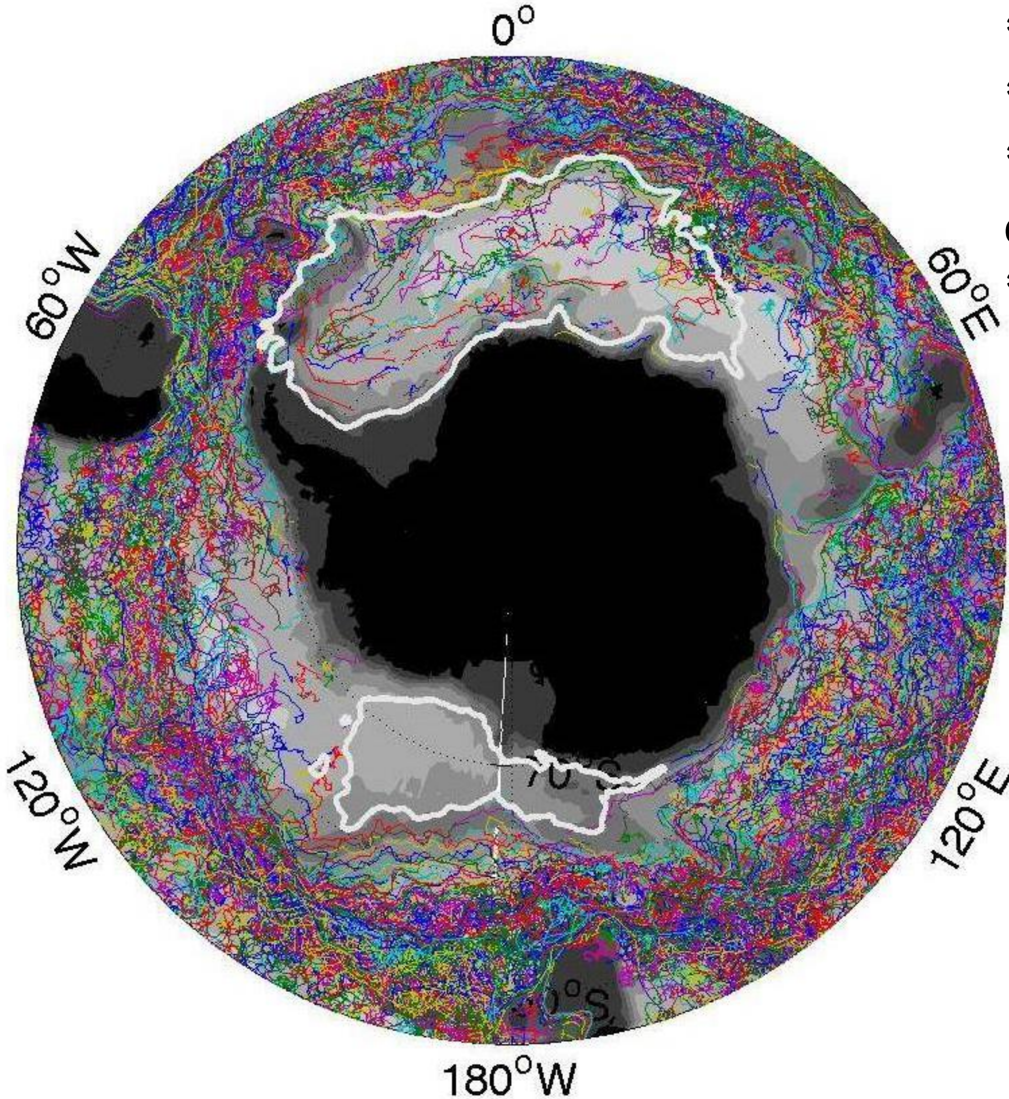
- Repeat hydrographic sections
- Argo floats
- Instrumented sea mammals (seals, whales)
- Moorings
- Automated underwater vehicles (including gliders)
- Boreholes and radar techniques for measuring the circulation and melt of the ice shelves

WOCE sections: Coordinated by GO-SHIPS



WOCE and CLIVAR sections

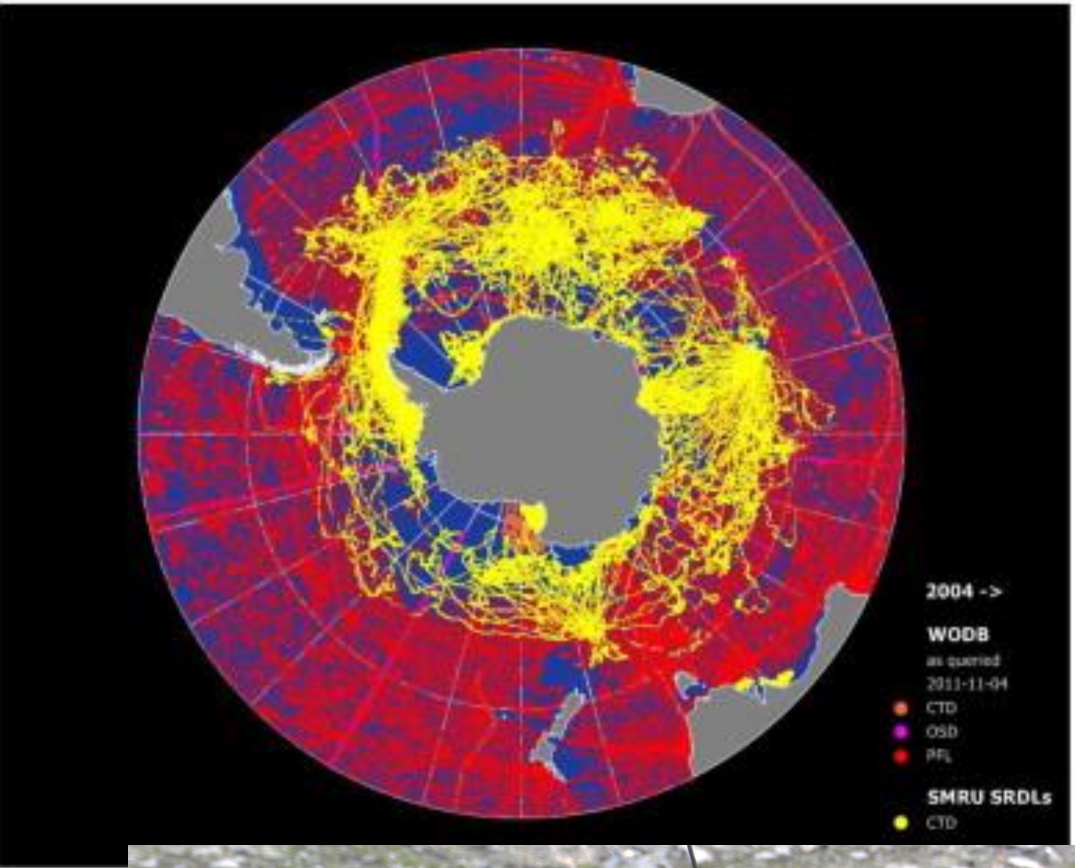
- Do not extend onto shelf
- Significant gaps in important areas
- Needs to be complemented by additional sections undertaken by national Antarctic programs
- an important SOOS task is to coordinate and provide help prioritizing: Where, what and how often additional sections are needed in order to address the science questions



Argo float trajectories as of 2012

* Floats are filling a lot of the gaps
* Coordinated by ARGO
* The ice covered regions are essentially blank
* Under-ice ARGOs being developed

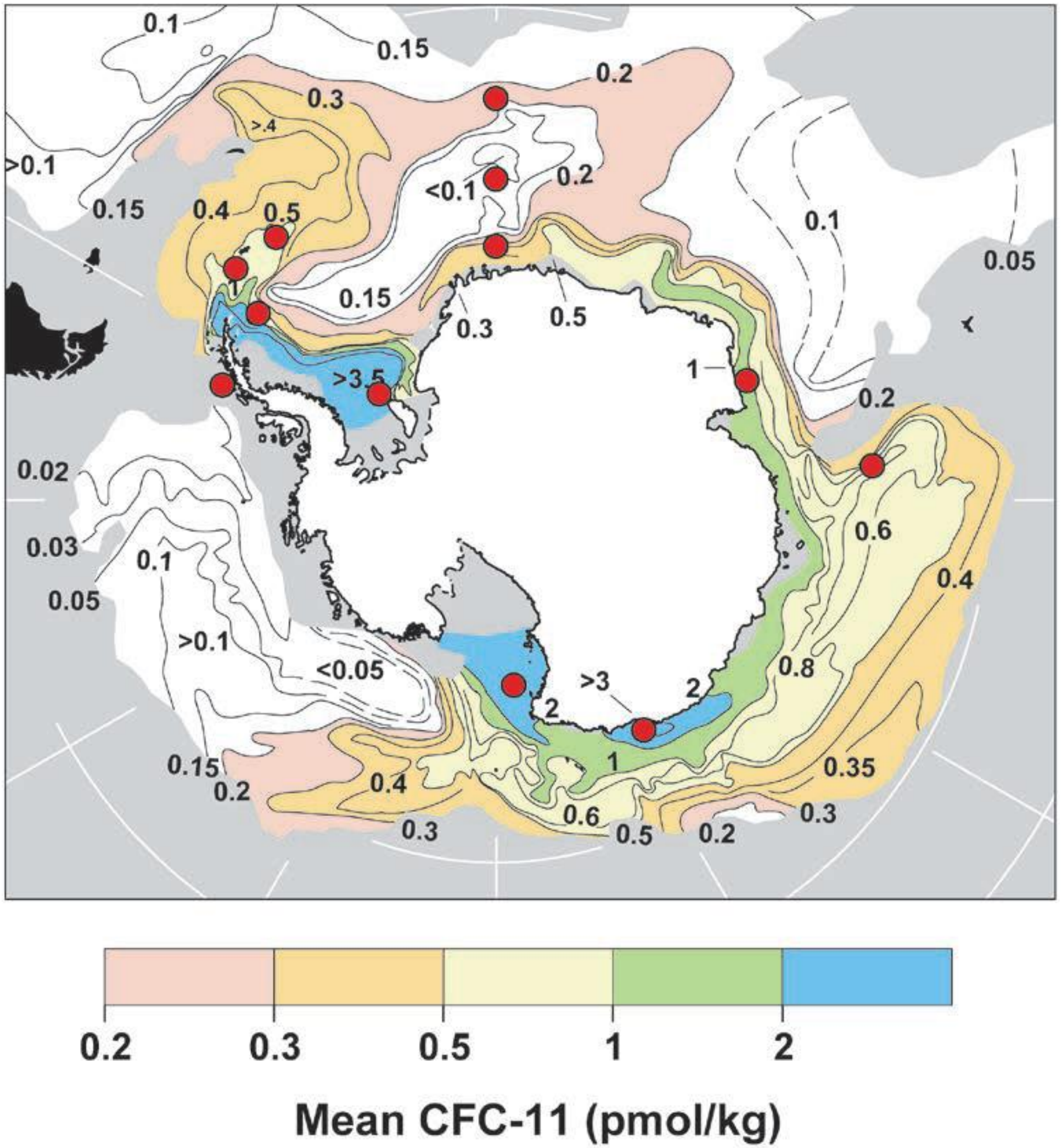
Marine mammal tagging are excellent complement to floats - cover the winter, measures under sea ice. Information about the mammals as well as physical oceanography



Yellow: Seal tags
Other colors: CTD, floats, moorings

Marine mammal tagging:
* Not presently coordinated internationally
* Still depends on individual projects
* Problems getting funding since it is not recognized as part of an ongoing international program, have to be motivated in every application

Moorings: Year-round, high temporal coverage. Needs to be complemented with sections (only point measurements)



Map showing some sites recently occupied by moorings.
Not up to date, not complete.

*** Moorings are not coordinated internationally**
*** Important task for SOOS: provide information and coordination of mooring sites and instrumentation**

Example: Filchner/Ronne, multi-national joint effort. Several years of mooring data in few positions, combined with intense short-term process studies - CTD, AUV, gliders, floats, moorings. BAS, AWI, Norway, APL-UW