Evidence of ice shelf melt in the Bellingshausen Sea from seal-borne observations

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Introduction

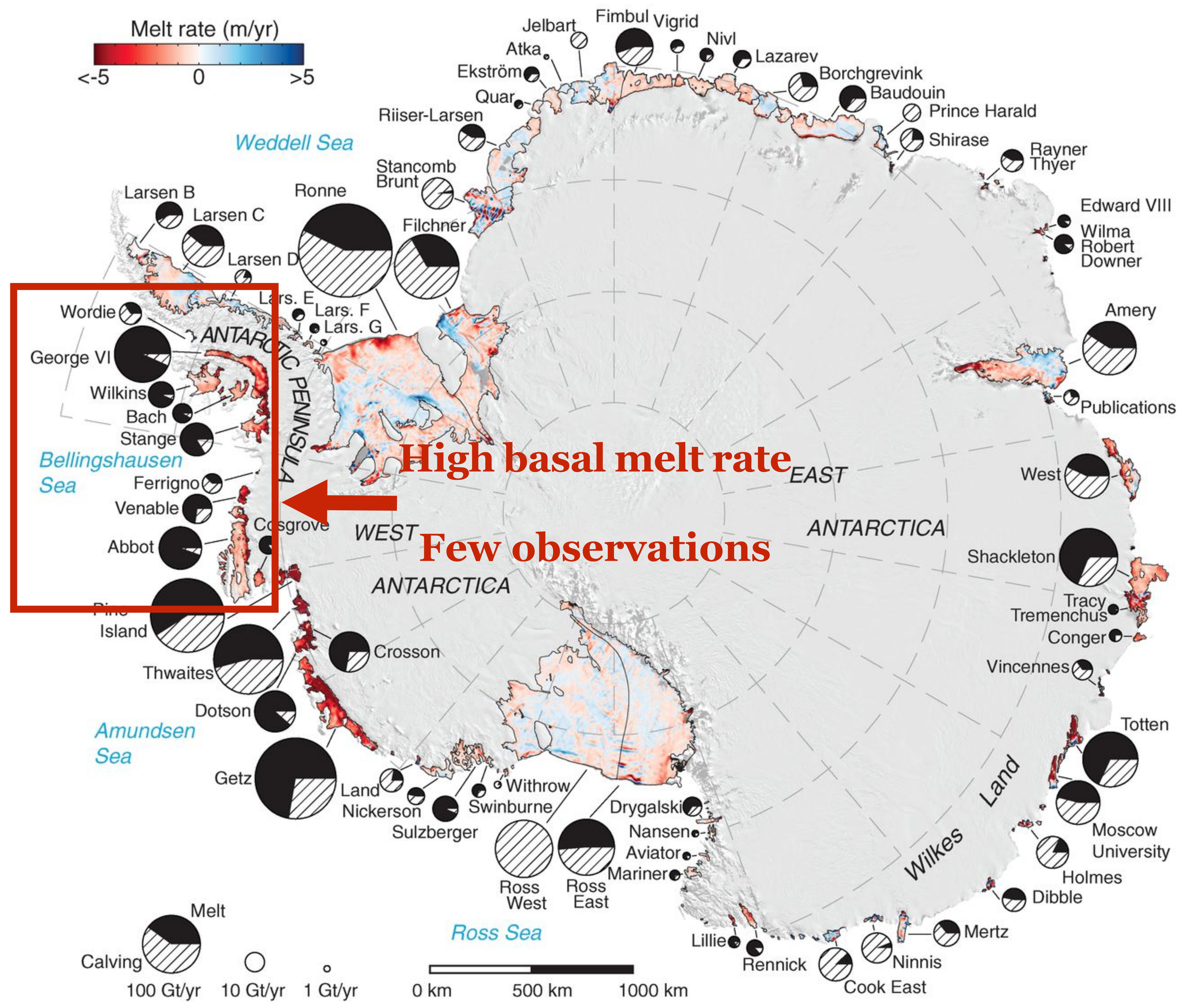


Figure 1. Ice shelf basal melt rate from Rignot et al. (2013). The circles show the fraction of mass loss by basal melting (black) for each ice shelf. Colors show the basal melt rate. Red means losing mass.

- Observations indicate a warming and freshening of the Southern Ocean (Gille 2008; Rintoul 2007)
- The link between oceanic changes and increased ice shelf basal melt is less clear

In the Amundsen Sea observations show:

- Intrusions of Circumpolar Deep Water (CDW) onto the continental shelf (Arneborg et al. 2012; Walker et al. 2013)
- Evidence of mixture of ice shelf melt water and modified CDW on shelf (Wåhlin et al. 2010)

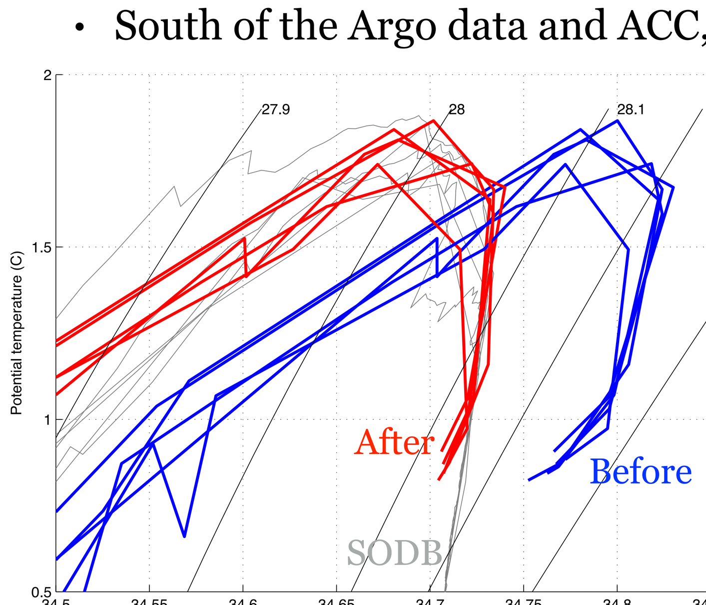
We use hydrographic data in the western Bellingshausen Sea to detect changes of water properties as a result of increased ice shelf basal melt.

Data descriptions

Data type	Time	# of profiles	Reference
Seal 8	Apr — Aug 2010	432	Bornemann et al. 2012
MEOP-CTD database	2006-2010	507	Roquet et al. 2013
Southern Ocean Database (SODB)	Mar 1994	14	Orsi & Whitworth III

Data collected by Southern elephant seals

- Instrumented with CTD-SRDLs
- South of the Argo data and ACC, some beneath sea ice



Salinity calibration:

- Argo float data in nearby regions as reference
- Linear pressure correction
- Salinity offset based on the lower CDW

(Roquet et al. 2011; Roquet, personal communication)

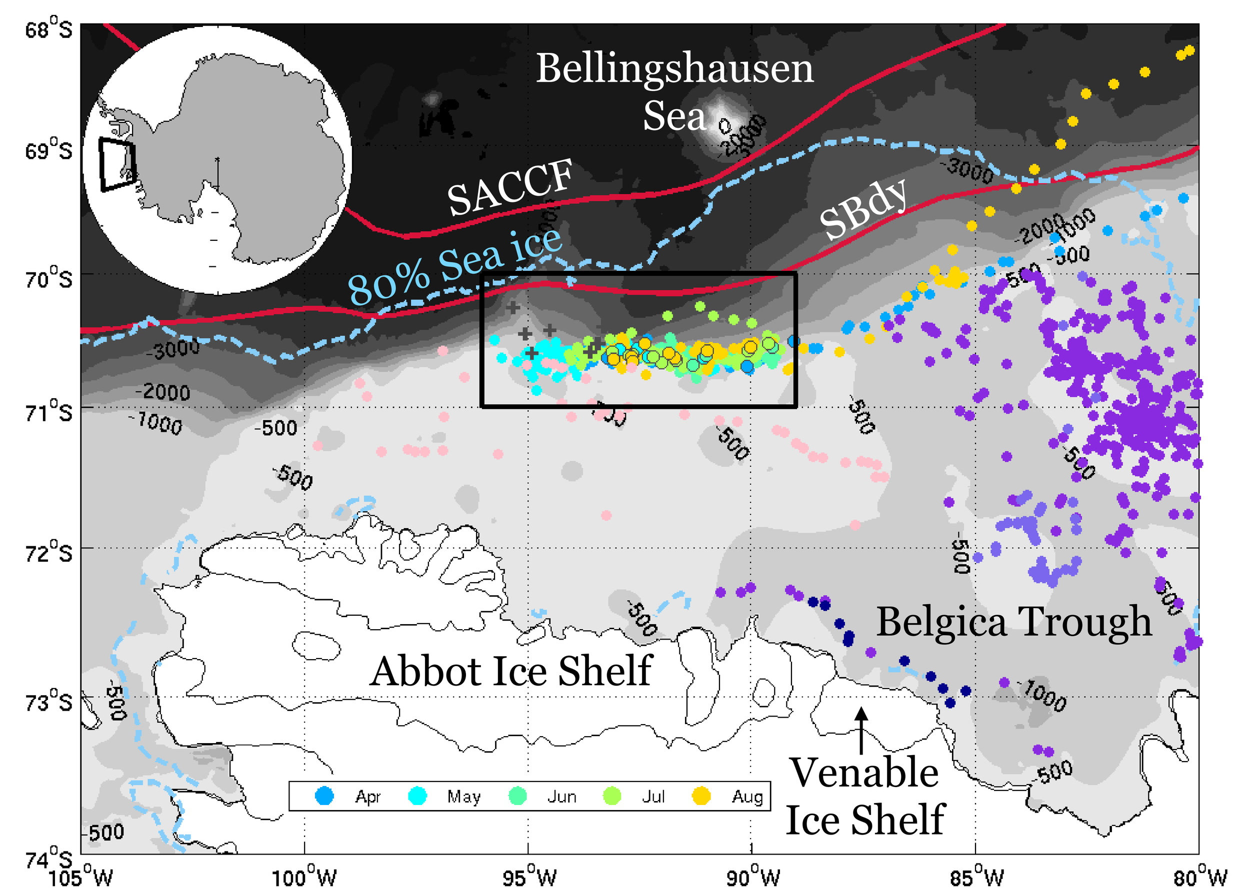


Figure 2. Map of the western Bellingshausen Sea. Dots show the locations of seal dives. Dots colored by months. The rest (pink, purples) are from the MEOP database (Roquet et al. 2013). The crosses are from SODB. The grey shading show IBCSO bathymetry (Arndt et al. 2013). The red lines show the climatological ACC fronts (Orsi et al. 1995). The dashed light blue line shows the 80% contour of mean April to August sea ice concentration in 2010 from AMSR-E (Spreen et al. 2008).

Results

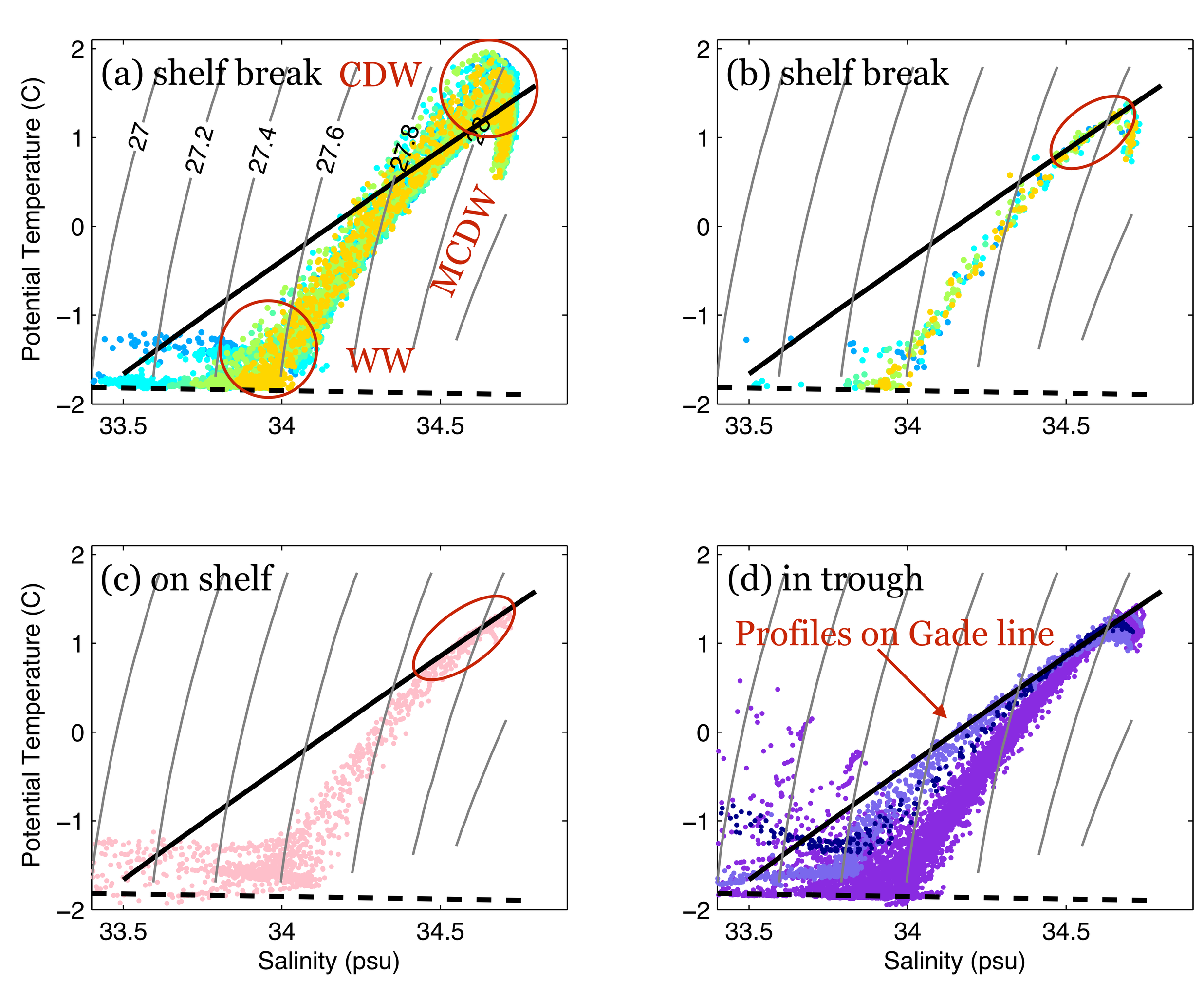


Figure 3. Potential temperature—salinity diagrams of seal data shown in Figure 2. The dashed lines show the freezing temperatures of sea water at the surface. The solid black line shows the Gade line. Gray contours show neutral density surfaces. (a) All data from the seal in 2010. (b) Profiles that lie on the Gade line, with the locations shown on Figure 2 as grey circles. (c) MEOP data on the continental shelf that fall on the Gade line. (d) MEOP data in Belgica Trough that fall on the Gade line. Three different families (light purple, navy, violet) are identified with their locations shown on Figure 2.

The Gade line (Gade 1979; Jenkins 1999) is calculated by

$$T_P(S_P) = T_{\mathrm{OCEAN}} + \frac{L_F}{C_P}\left(1 - \frac{S_{\mathrm{OCEAN}}}{S_P}\right)$$

T_{OCEAN} and S_{OCEAN} are the properties of the water that mixes with the melt water, in our case we take $T_{\mathrm{OCEAN}} \approx 1.1$°C, $S_{\mathrm{OCEAN}} \approx 34.6$ psu, which represents the modified CDW (MCDW) on shelf.

Ice shelf melt water and MCDW mixture (**Fig 3**):

- Data in Belgica Trough show ice shelf melt water mixture (light purple and navy, **Fig 3d**)
- Seal 8 profiles show similar shape to the on shelf profiles and most profiles in the Belgica Trough (violet, **Fig 3b, c, d**)
- Insufficient data coverage to pin down the melt water source, but possibly from Venable or/and Abbot Ice Shelf.

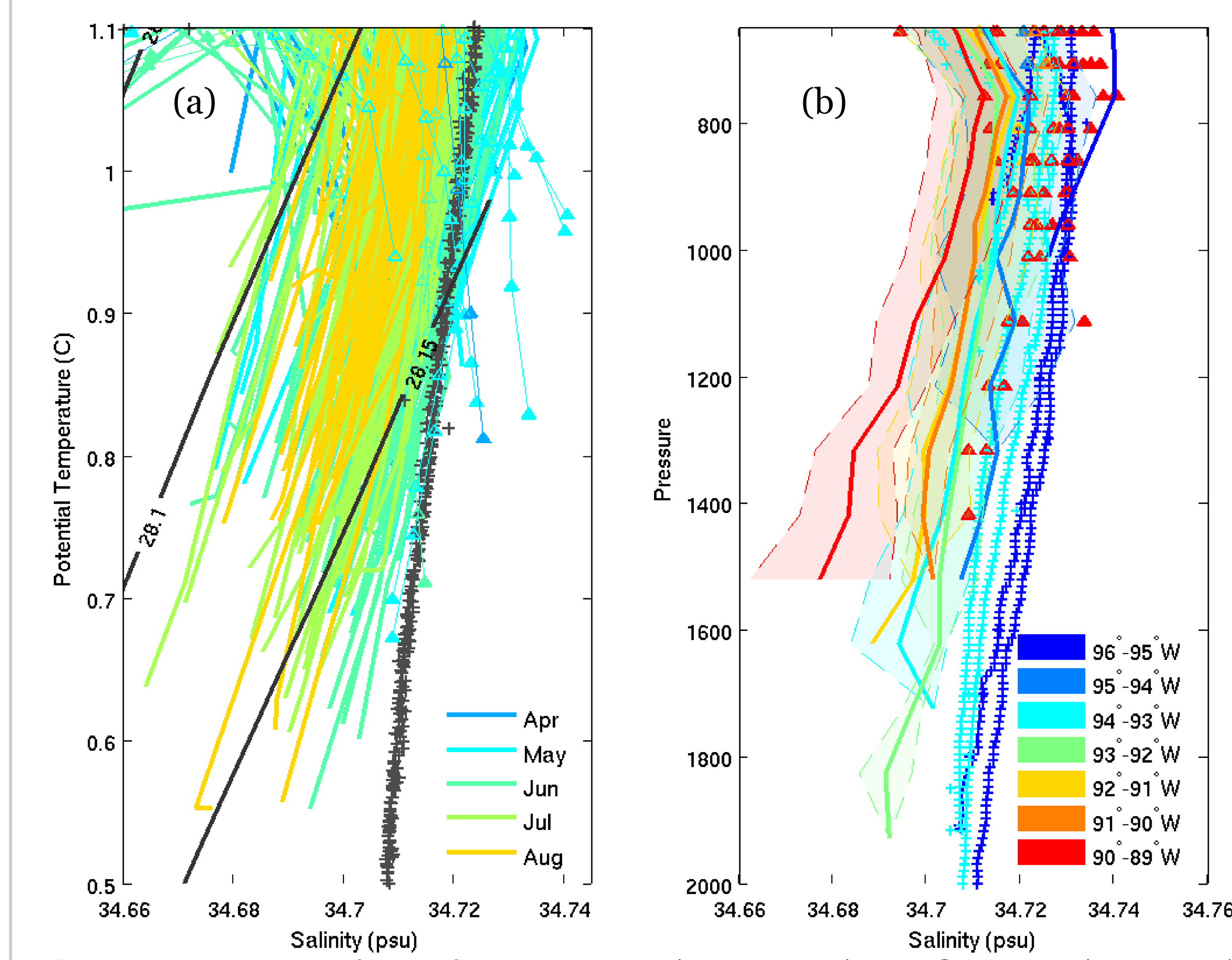


Figure 4. Deep profiles of seal 8 data (solid lines), MEOP data (triangles), and SODB data (gray crosses). (a) Potential temperature—salinity diagram of the boxed region on Figure 2. Data colored by months. Gray contours show neutral density surfaces. (b) Vertical profiles of salinity data in the boxed region on Figure 2. Different colors indicate longitude bins. Solid lines show the mean salinity profile in each bin with one standard deviation shown in the shades.

Deep water trends (**Fig 4**):

- Freshening of MCDW compared to historical data
- Data in recent years have lower salinity (**Fig 4b**)
- Weak seasonal variability in deep water (**Fig 4a**)
- Longitudinal trend in salinity with fresher water on the east, closer to the trough, and saltier water on the west, further from the trough (**Fig 4b**)

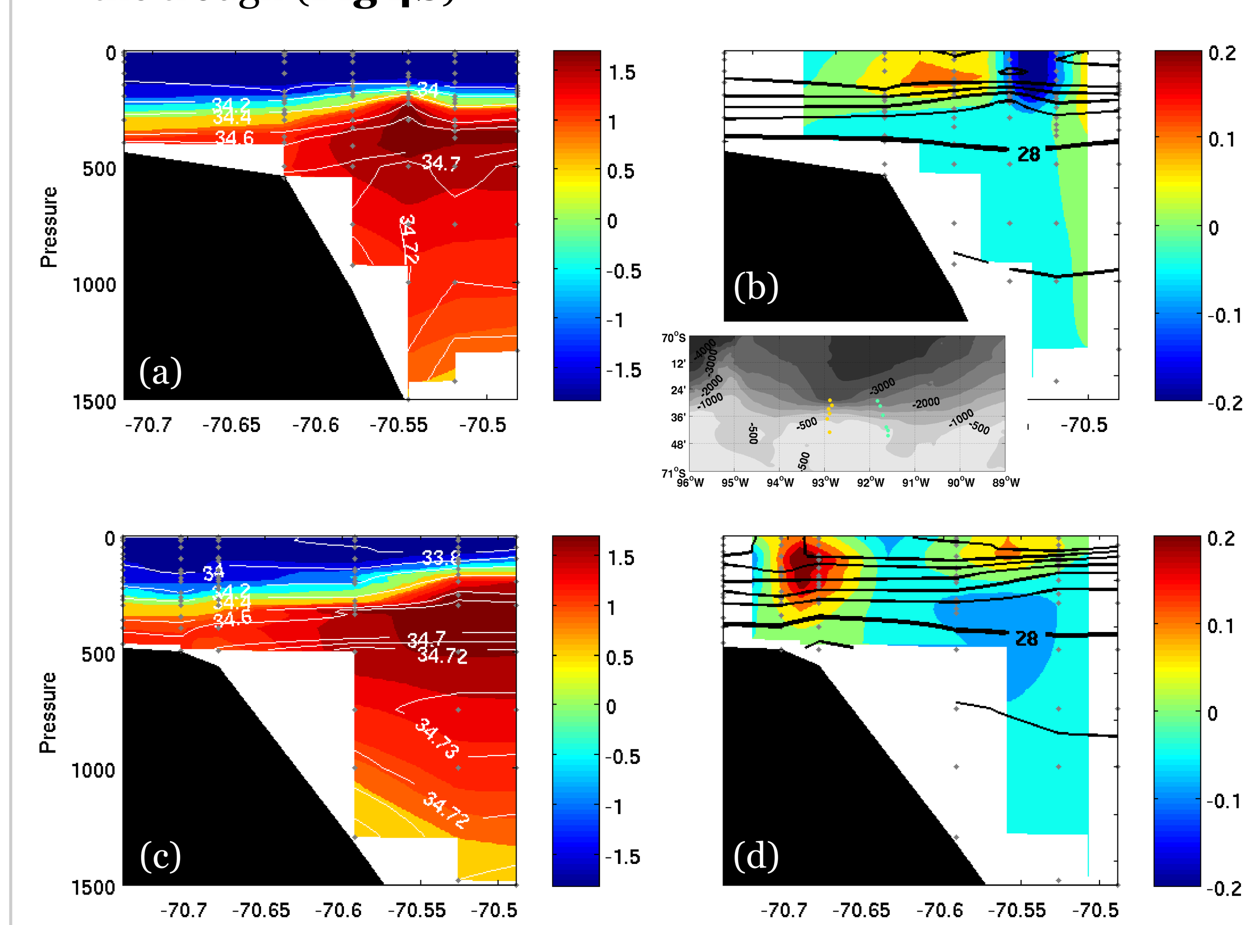


Figure 5. Cross-shelf sections from profiles shown on the small map. Potential temperatures are in colors and salinity on white contours in (a) and (c), geostrophic velocity referenced to bottom are in colors and neutral density on black contours in (b) and (d). Positive velocity means westward flow.

Cross-slope sections on the shelf break show (**Fig 5**):

- CDW (UCDW θ>1.7°C, LCDW S>34.7 psu) sits right next to the shelf break (**Fig 5a, c**)
- Modified CDW ($\gamma^n \geq 28.0$ km m^{-3}, Whitworth et al. 1998) on shelf is more than 3 degrees above the freezing temperature
- Baroclinic shelf break current is present on both sections (**Fig 5b, d**)
- Westward shelf break current suggests the existence of Antarctic Slope Current in the region

Discussion

Ice shelf melt water is detected, potentially coming from the base of Venable or Abbot ice shelf. The ice shelf melt water mixture can enter the shelf break through the western boundary current in the trough or via small channels on the continental shelf. Ice shelf melt water from upstream ice shelves is likely the cause of the deep water freshening.

The modification of CDW is caused by the presence of Antarctic Slope Front (ASF), where mixing between Antarctic Surface Water (AASW), dense shelf water, and CDW occurs (Whitworth III et al. 1998; Jacobs and Giulivi, 2010). West of the Belgica Trough, we do not observe shelf water that is cold enough to modify CDW, which means the modification happens upstream.

Summary

We use hydrographic data collected by elephant seals near the shelf break in the western Bellingshausen Sea, and find:

- presence of the MCDW on the continental shelf;
- presence of ice shelf melt water mixture at the shelf break that may come from the trough or via the shelf;
- freshening of deep water compared to historical data that is likely due to increased ice shelf basal melt;
- evidence of baroclinic shelf break current suggesting the presence of the ASC.

Acknowledgement and references

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