13/02/2014

Il mare di Ross

Masse d’acqua e Circolazione

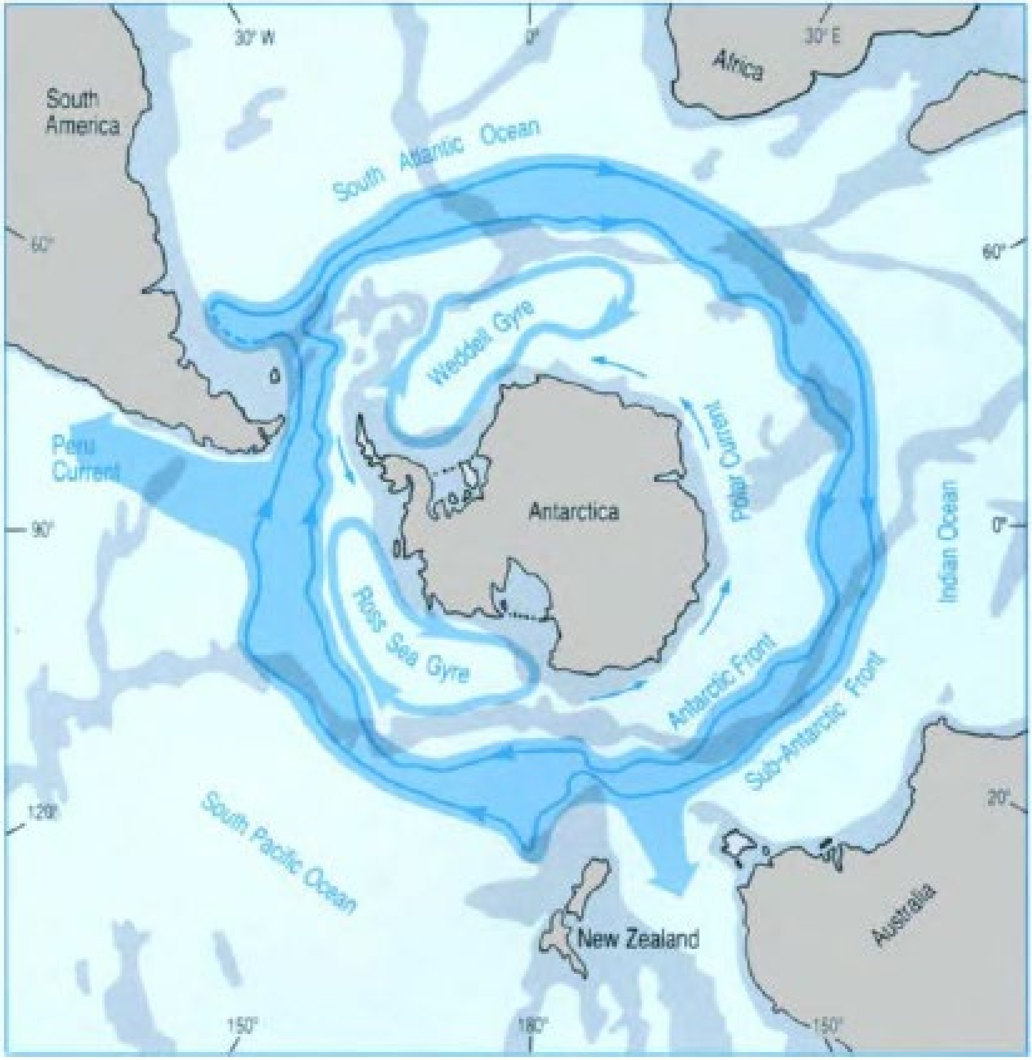
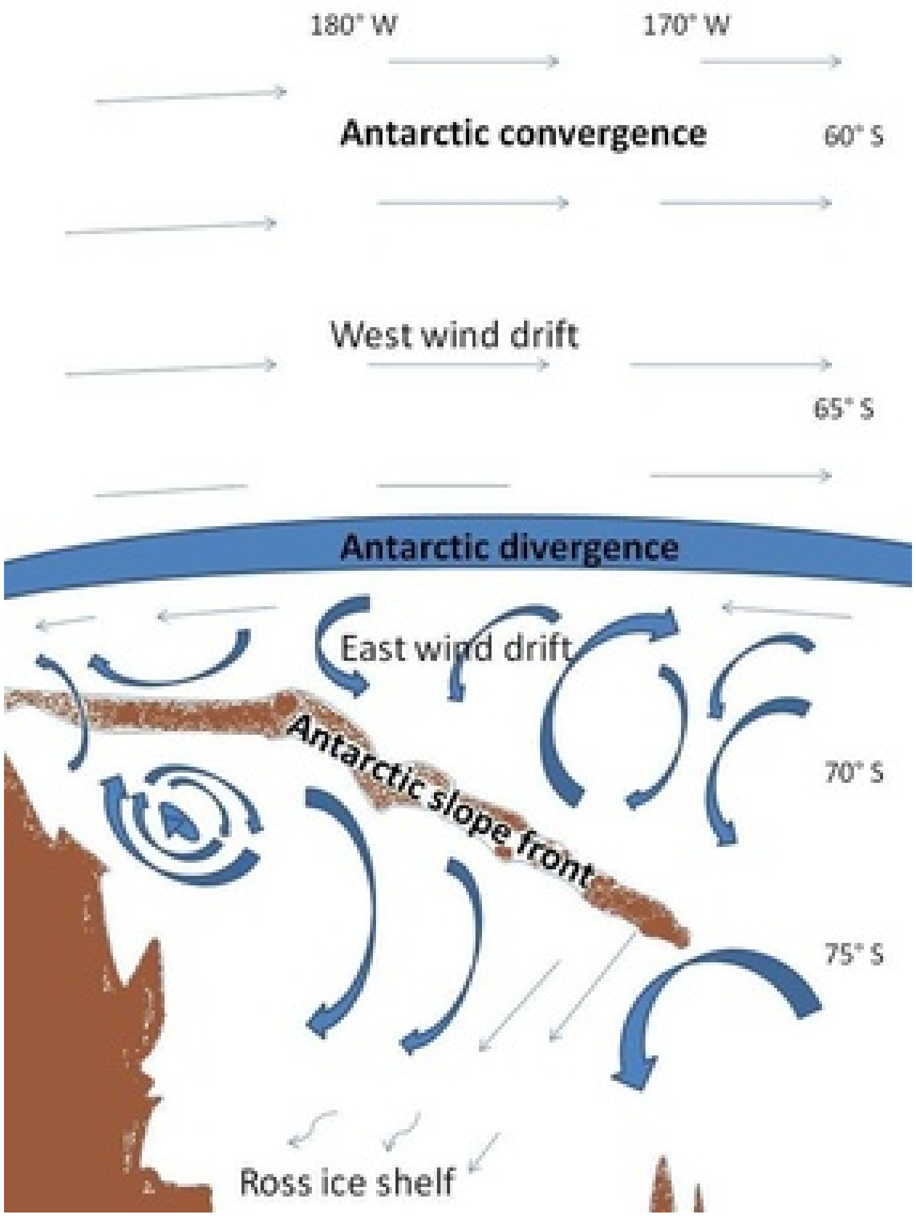


Figure 5.30 Schematic map showing the mean path of the Antarctic Circumpolar Current (blue tone); the two dark blue lines represent the average positions of the Antarctic Front and the Sub-Antarctic Front, and the jets which flow along them (discussed in the text). Note that a significant part of the current branches northward and flows up the west coast of South America as the Peru Current; there is also a branch of the current flowing northwards below the surface between Australia and New Zealand. The approximate positions of the gyres in the Weddell Sea and Ross Sea are also shown, as is the path of the Polar Current. The Antarctic Divergence is between the Polar Current and the Antarctic Circumpolar Current. Blue–grey shading indicates water depths less than 3000 m.

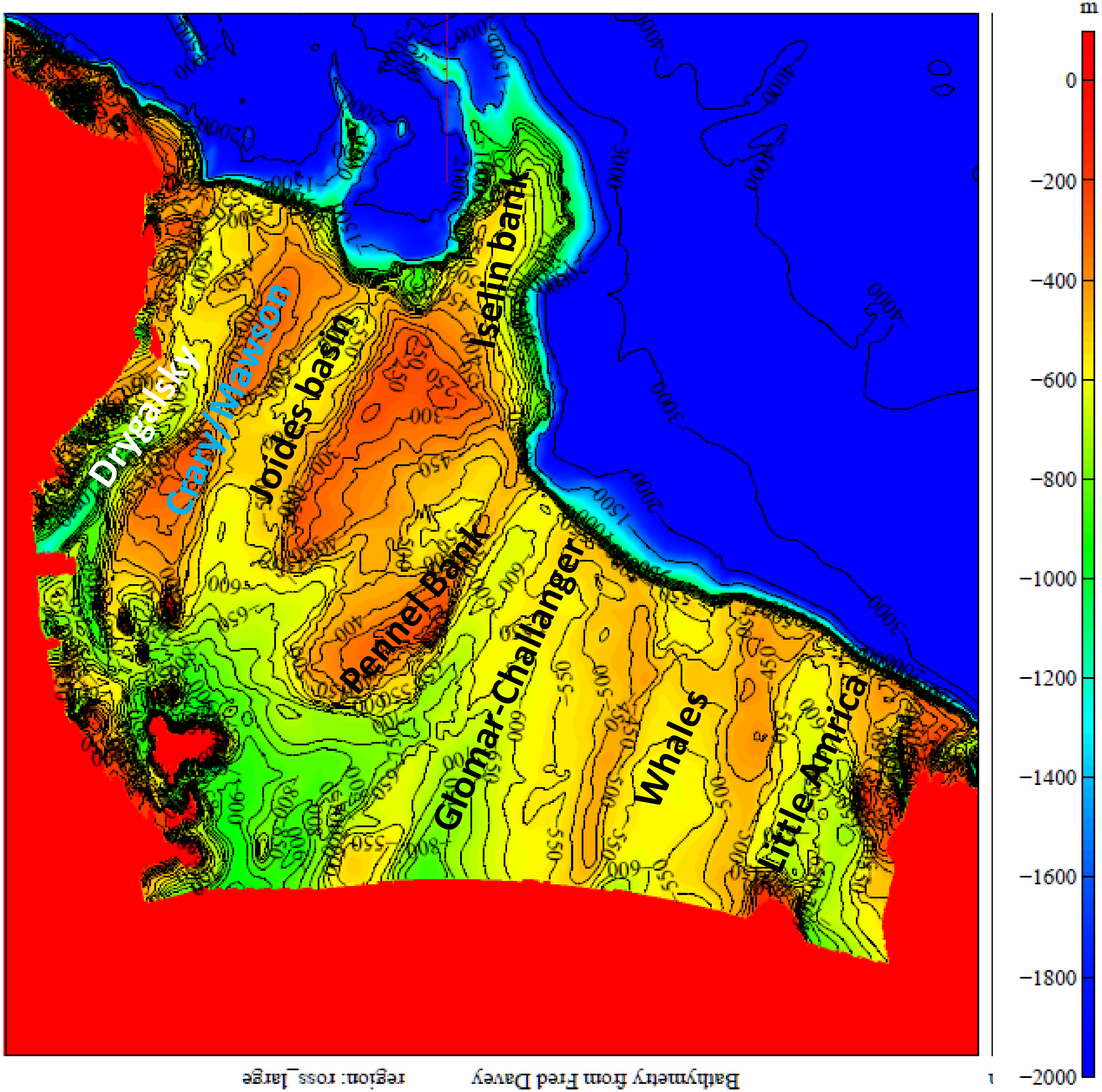


-La CDW che procede verso Sud, entra nella circolazione ciclonica del Ross Gyre

-La sua densità è tale da posizionarla sotto la AASW (o ASW più fredda) e sopra le AABW

-La risalita in superficie della CDW avviene seguendo approssimativamente la batimetrica dei 700 m

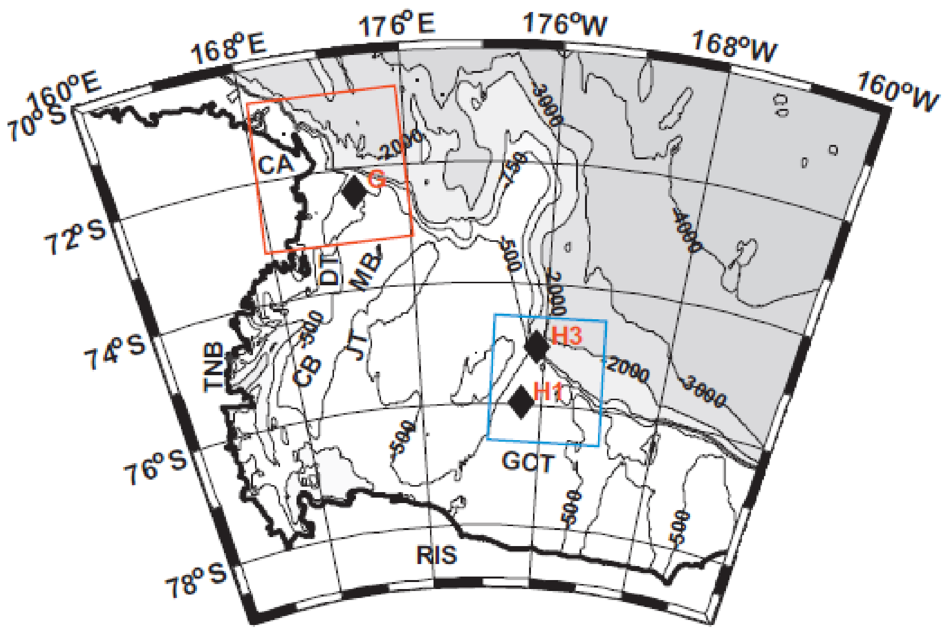
-Processi diapicnici nella zona del ASF determinano, più a sud, una massa d'acqua nota come Modified CDW (MCDW)



Drygalsky
Crary/Mawson
Joides basin
Iselin bank
Pennel Bank
Glomar-Challanger
Whales
Little Amrica
m
0
−200
−400
−600
−800
−1000
−1200
−1400
−1600
−1800
−2000
Bathymetry from Fred Davey
region: ross_large

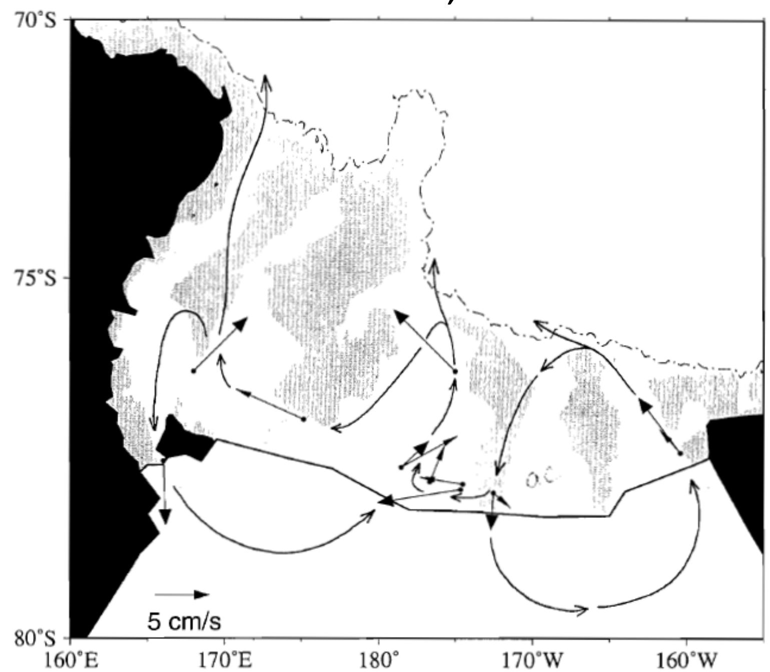
Topografia e circolazione nel MdR

Fig. 1. (a) General map of the Ross Sea with bottom topography in meters and locations of moorings G, H1 and H3 discussed in text. Locations of geographic features discussed in the text are indicated: Terra Nova Bay (TNB), Ross Ice Shelf (RIS), Cape Adare (CA), Drygalski Trough (DT), Glomar-Challenger Trough (GCT), Joides Trough (JT), Mawson Bank (MB) and Crary Bank (CB). CTD/LADCP casts (1994/95 Green, 1997/1998 blue, 1999/2000 black, 2000/01 cyan, 2002/03 yellow, 2003/04 magenta, 2005/06 red) in (b) Drygalski Trough (DT) and (c) Glomar-Challenger Trough (GCT). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



Da Budillon et al., 2011

Da Locarnini, 1994



Sketch of the subsurface circulation in the Ross Sea. Wide (thin) arrow heads represent current-measurements obtained at the bottom (between 250 m and 450 m). Depths less than 500 m are shaded, and the dash-dot line indicates the 1-km isobath.

Climatologia del mare di Ross

A.H. Orsi, C.L. Wiederwohl / Deep-Sea Research II 56 (2009) 778–795 779

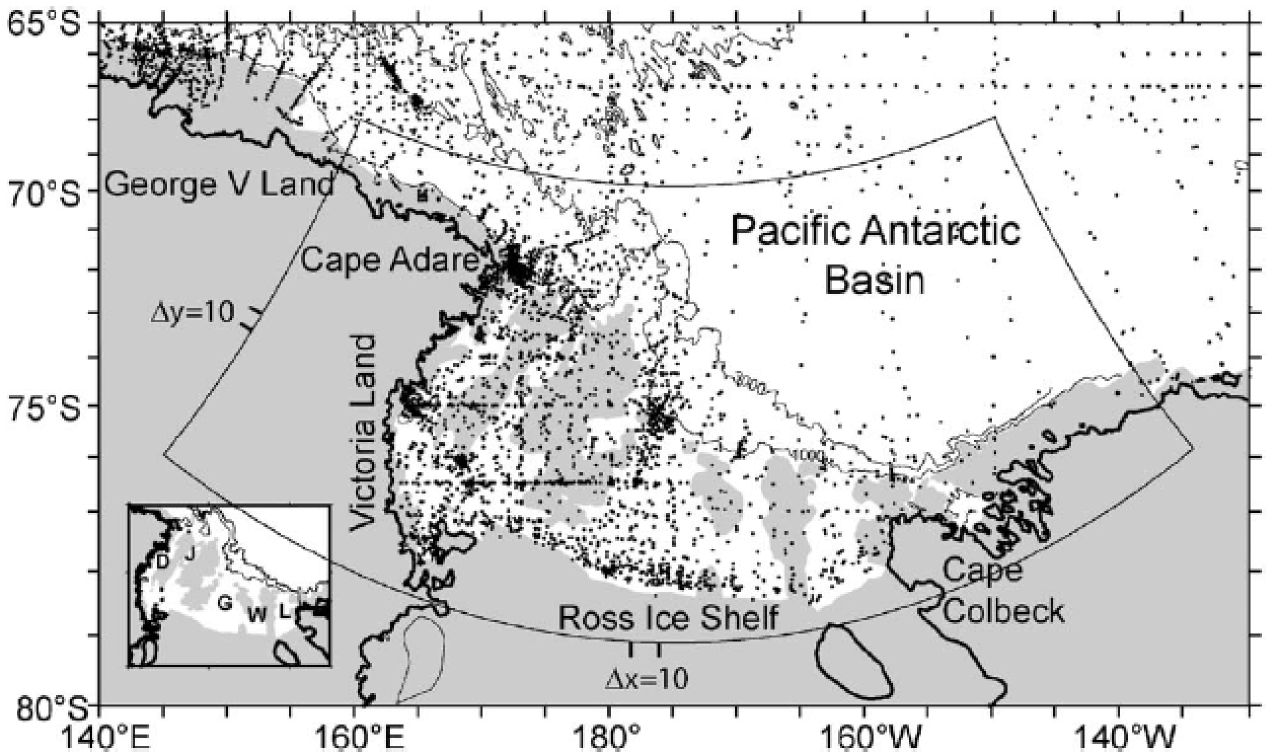


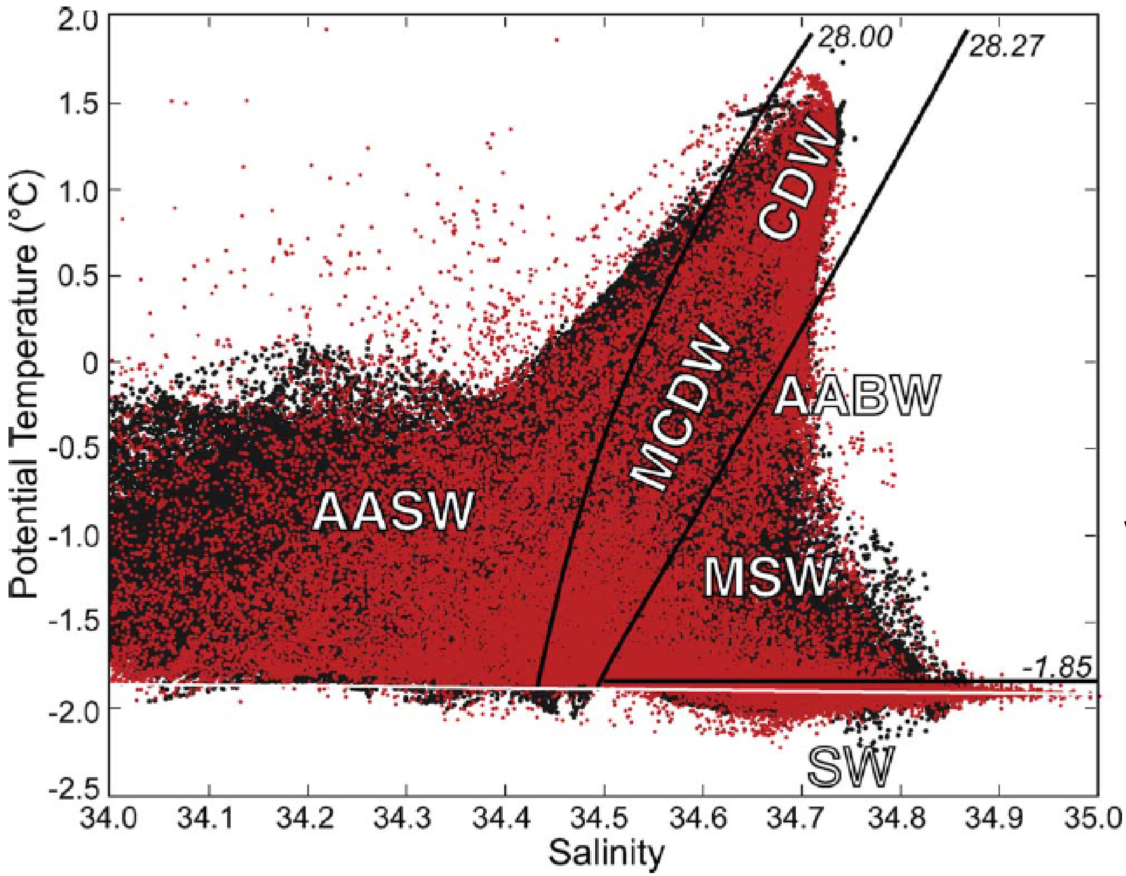
Fig. 1. Base map of the study area. Depths less than 500 m are lightly shaded, and the thin lines show the 1000 and 3000 m isobaths. Small dots show all stations (4364; mostly from the austral summer) used in this study. Meridional (zonal) grid spacing is indicated for 10 adjacent grid points aligned at the western (southern) edge of the grid. Major troughs are labeled in the inset: (D) Drygalski, (J) Joides, (G) Glomar Challanger, (W) Whales, and (L) Little America, separated by the Crary/Mawson, Ross/Pennell/Iselin, Whales, and Little America banks. Bathymetry derived from satellite radar altimetry data (Smith and Sandwell, 1997) and GEBCO-1997 digital isobaths (IOC et al., 1997).

Classificazione della masse d’acqua

- Suddividiamo la verticale in tre livelli individuati da due isopicne di densità neutrale γ_N
- Strato superficiale (L1), ovvero lo strato occupato dalla AASW, limite inferiori $\gamma_N = 28.00$ Kgm^{-3}
- Strato di fondo (L3) al di sotto di $\gamma_N = 28.27$ Kgm^{-3} che separa la AABW dalla soprastante CDW
- Lo strato (L2) compreso tra 28.00 $Kgm^{-3} < \gamma_N < 28.27$ Kgm^{-3} è dove si posiziona la CDW e la MCDW che si trovano a nord e a sud della scarpata continentale

Water mass definitions. Shelf/slope 700 m demarcation refers to water depth.

γ^n layer (kg m^{-3})	Slope (> 700 m)	Shelf (< 700 m)	Properties
Top (L1: < 28.0)	AASW	AASW	
Middle (L2: 28 < γ^n < 28.27)	CDW	MCDW	
Bottom (L3: > 28.27)	AABW	MSW	$\theta > -1.85$ °C
		SW	$\theta < -1.85$ °C
		HSSW	$S > 34.62$
		LSSW	$S < 34.62$
		ISW	$\theta < -1.95$ °C



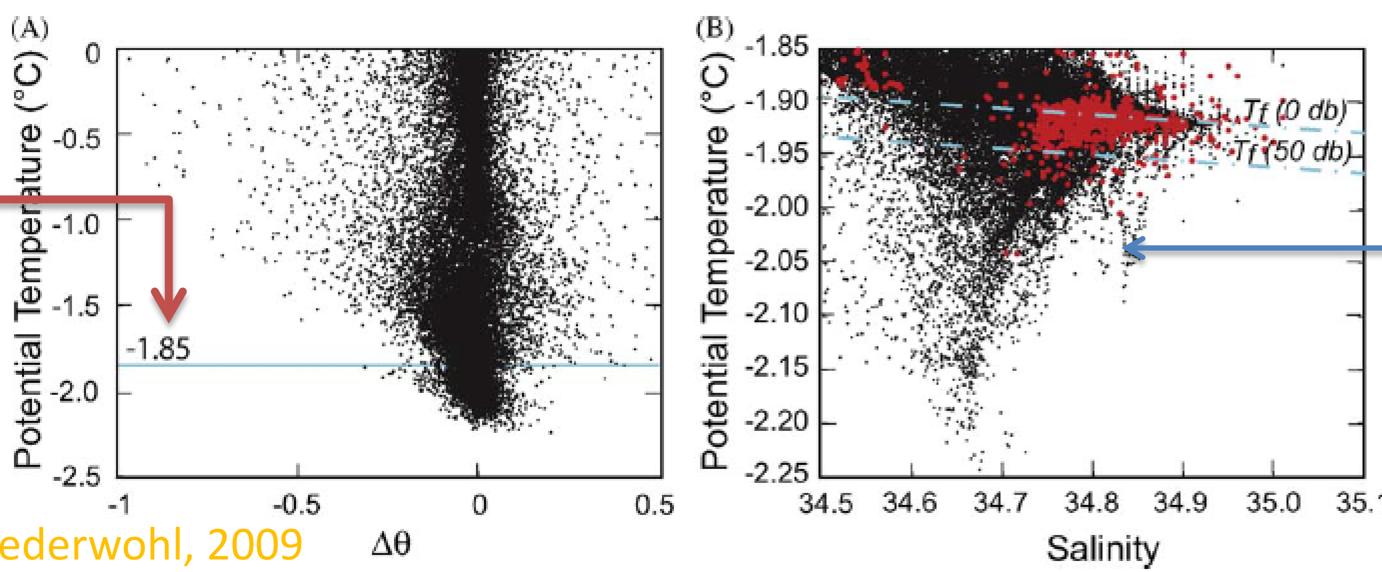
Da Orsi e Wiederwohl, 2009

Fig. 2. θ–S scatter plot for Ross Sea stations (red) and climatology (black) at water depths shallower than 2000 m. Solid traces show the 28.00 and 28.27 kg m^{-3} neutral density γ^n surfaces. The white horizontal line shows the surface freezing point of seawater. Major water masses are labeled: Antarctic Surface Water (AASW), Modified Circumpolar Deep Water (MCDW/CDW), Modified Shelf Water (MSW/SW), and Antarctic Bottom Water (AABW). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Shelf Water(SW) e Modified SW

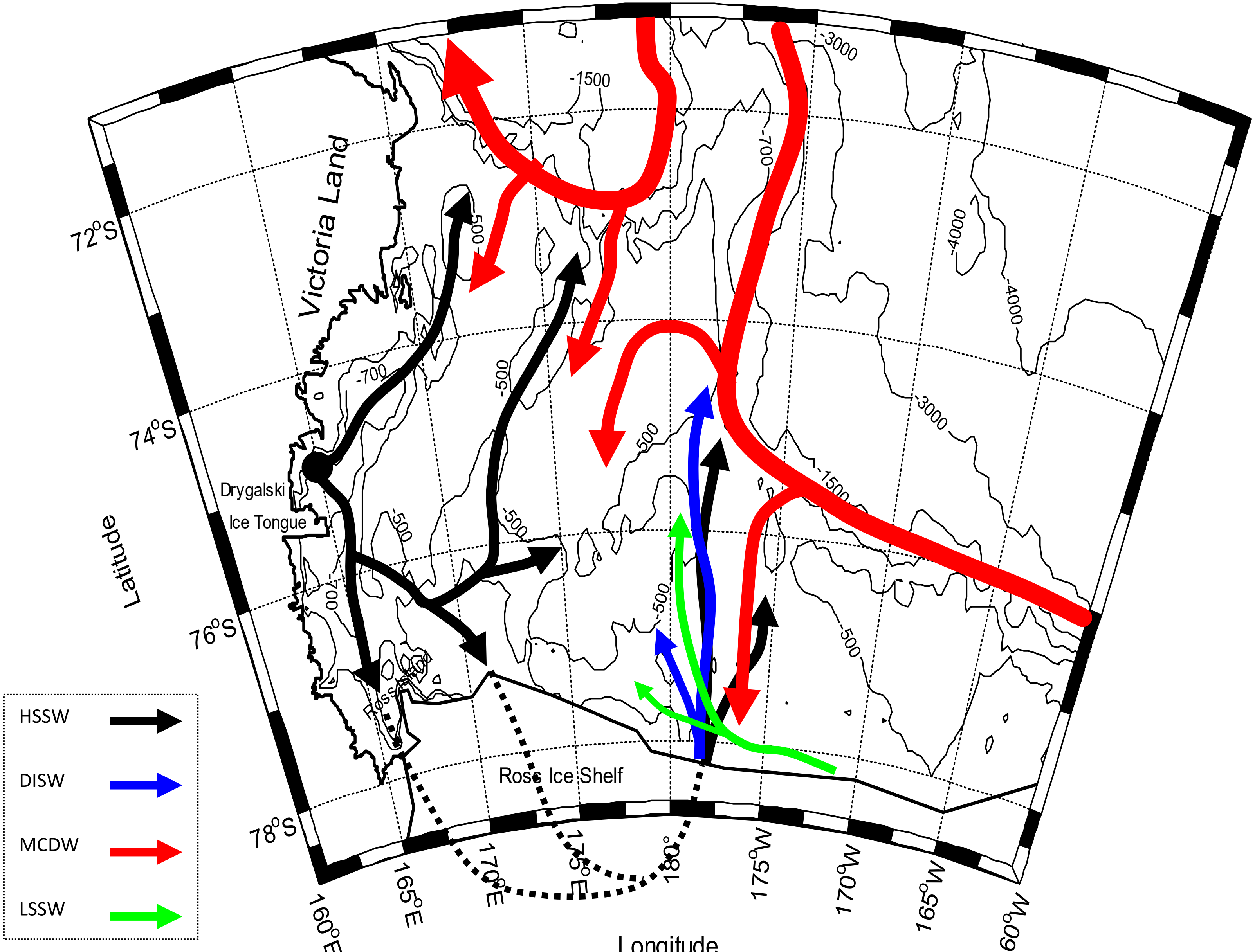
- Le SW hanno origine quando il ghiaccio formandosi, converte le acque superficiali (sia le fredde AASW che le più calde MCDW) nelle acque più dense che si trovano in Antartide
- Le MSW nascono dalla continuo mescolamento che subiscono le SW nel loro percorso all'interno del mare di Ross
- Forzanti che favoriscono il mescolamento (come le correnti di marea) determinano la transizione tra SW in MSW con caratteristiche intermedie tra le masse acqua che partecipano al processo di formazione

- Limite superiore (isoterma) delle SW : **θ= -1.85°C**
- **⇒ SW si hanno quando θ < -1.85°C** con salinità che compresa in un range abbastanza ampio (S> 34.50 psu)
- Se **θ > -1.85°C** (nello strato di fondo) ⇒ **MSW**
- Acque superfredde che <u>non</u> derivano da interazioni superficiali (sono sotto la temp di cong a 50 db) sono effetto di interazioni con il ghiaccio
- **θ < -1.95°C è il limite dell Ice Shelf Water (ISW)**



Da Orsi e Wiederwohl, 2009

Fig. 3. (A) Scatter plot of 10 m vertical thermal gradient at $\gamma^n > 28.10\,kg\,m^{-3}$ against temperature from CTD data in the Ross Sea. (B) θ–S Scatter for SW with red dots showing bottom values deeper than 500 m. Dashed lines show freezing temperatures at the sea surface and at 50 db. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

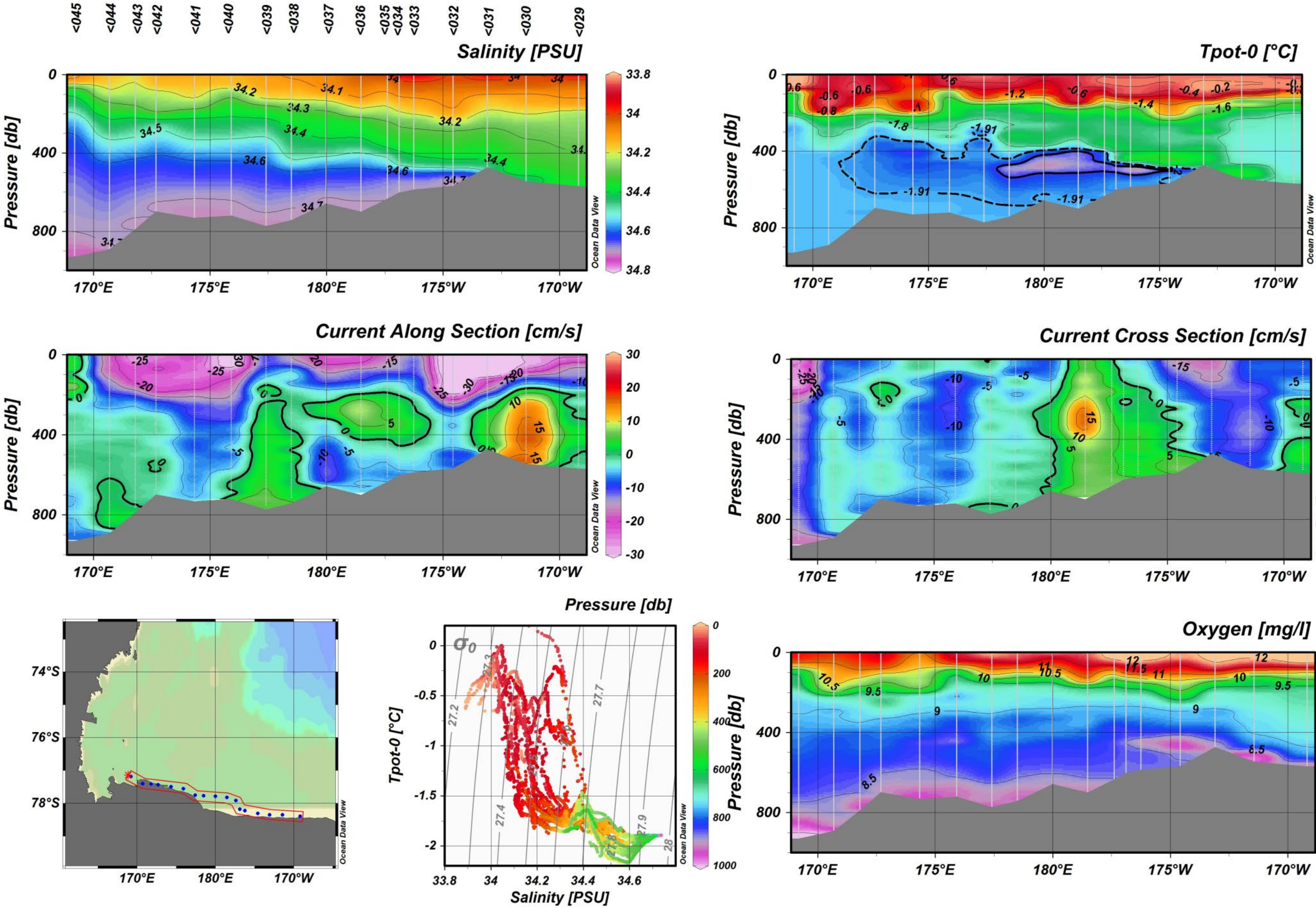


From Budillon et al., Antarctic Science 2003

High Salinity Shelf Water (HSSW)

- Il ghiaccio marino è meno salato rispetto all’acqua che lo genera
- Nella fase di formazione, la parte in “eccedenza” rimane in acqua aumentando la salinità degli strati superficiali
- Si forma così la HSSW.
- La produzione di ghiaccio durane l’inverno è maggiore nelle aree di polynya
- Questo crea un gradiente di salinità E-W

- Si distinguono pertanto una HSSW ed una Low SSW (LSSW)
- La prima è presente nel settore occidentale del mare di Ross, si diffonde in profondità seguendo l'asse del Drygalsky basin sia verso nord che verso sud.
- Verso nord, raggiunge la shelf break dove, per mescolamento, crea con CDW acque dense e di fondo
- Verso Sud si ha "*ragionevole*" convinzione che fluisca sotto il Ross Ice Shelf dal quale (per interazione con la base del ghiaccio) uscirà più fredda, meno salata e densa come ISW.
- Il segnale di ISW si osserva a quote intermedie (300-500m

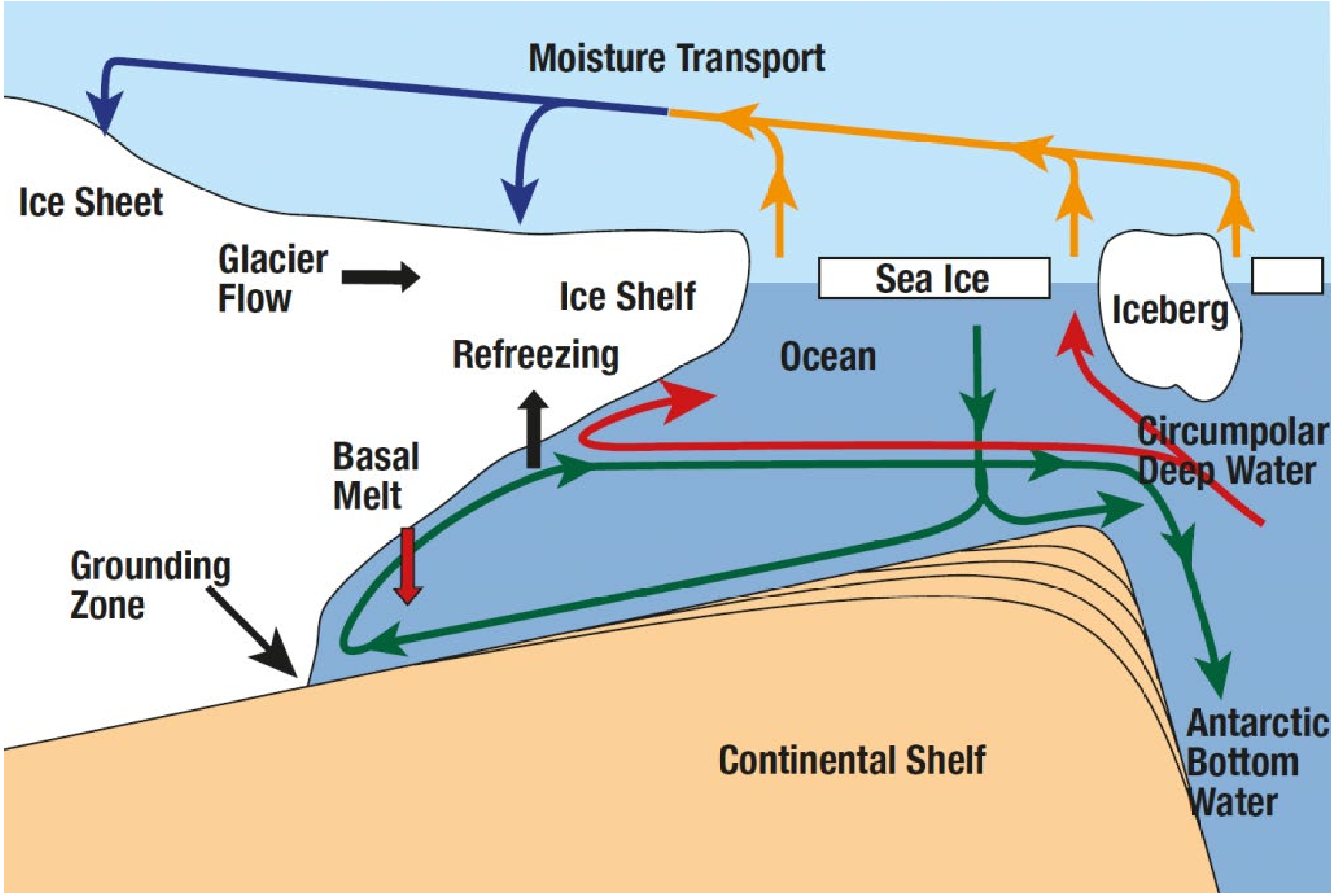


PNRA – XXVII sped – Dal report di campagna - Spezie et al., 2012

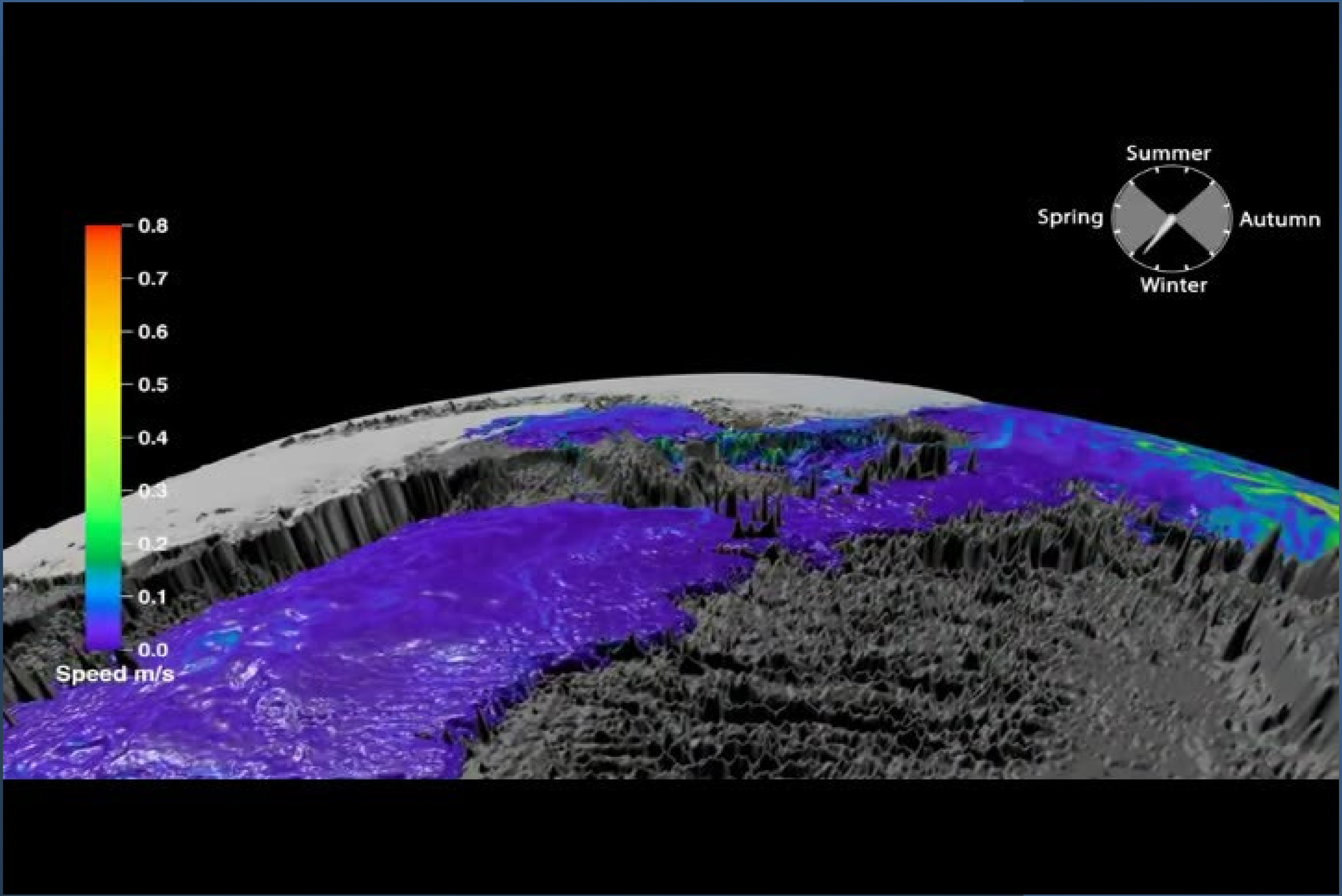
- La ISW procede verso lo shelf break dove per mescolamento con la MCDW contribuirà a produrre ancora acqua densa e di fondo
- La LSSW, si osserva nel settore centro- orientale del mare di Ross ed è il prodotto di processi di modifica della AASW
- I continui cicli di raffreddamento, scioglimento e congelamento della superficie determinano valori relativamente variabili della AASW con conseguente impatto sulla LSSW.

Sea water type	LSSW	HSSW
Parameter		
Potential Temperature (°C)	-1.80	-1.92
Salinity	34.47	34.88
Oxygen (μmol dm^{-3})	300	298
Phosphate (μmol dm^{-3})	2.1	2.2
Nitrate (μmol dm^{-3})	29.0	31.0
Silicate (μmol dm^{-3})	76.0	80.0
Potential vorticity (m^{-1} sec^{-1}) x 10^8	0.075	0.001
Mass conservation	-	-

Formazione delle AABW



Jacobs et al., 1992


Summer
Spring
Autumn
Winter
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Speed m/s

Circolazione in L1 (AASW)

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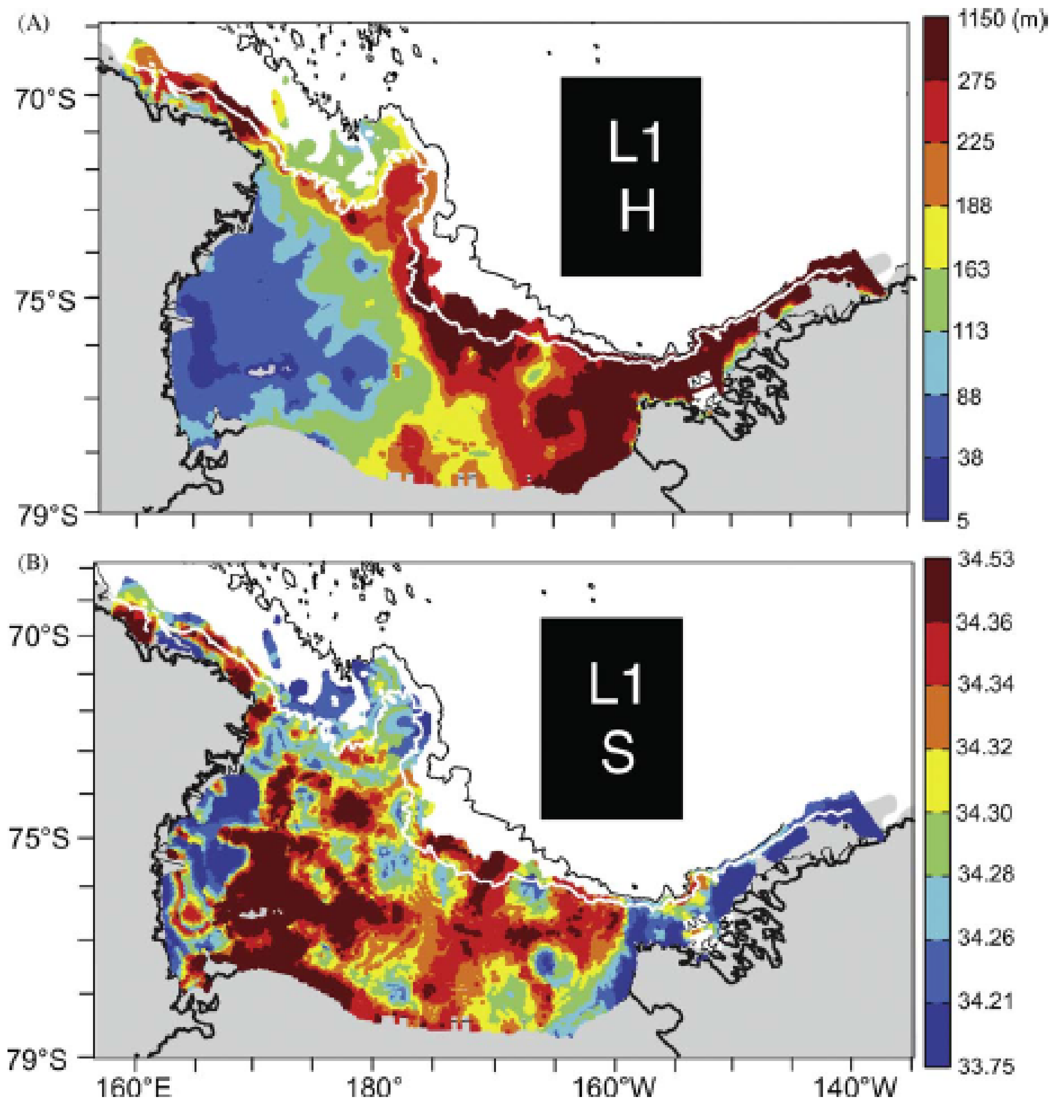

Fig. 5. (A) Thickness (m) and (B) salinity average for the top density layer (L1: $\gamma^n < 28.00\,kg\,m^{-3}$) spanning AASW. The white (black) line shows the 1000 m (3000 m) isobath. Areas shown with the same color extend over 1/8 of the total spatial domain mapped at water depths shallower than 2000 m.

- Circolazione ciclonica nell'area del mare di Ross
- Flusso verso W allo shelf break come ASC
- Fronte alino (ASF)
-Oltre al flusso verso W si osserva una deflessione verso S, passato capo Colbeck,
-Tale flusso si osserva anche a 300 m e rappresenta la Antarctic Coastal Current.
- Ancora più a S la AASW si incunea sotto il RIS, dove per interazione con la base del ghiaccio, si "osserva" una riduzione della sua T fino a quella di congelamento.
-La polynya del RIS produce la AASW più salata e fredda

Input oceanico

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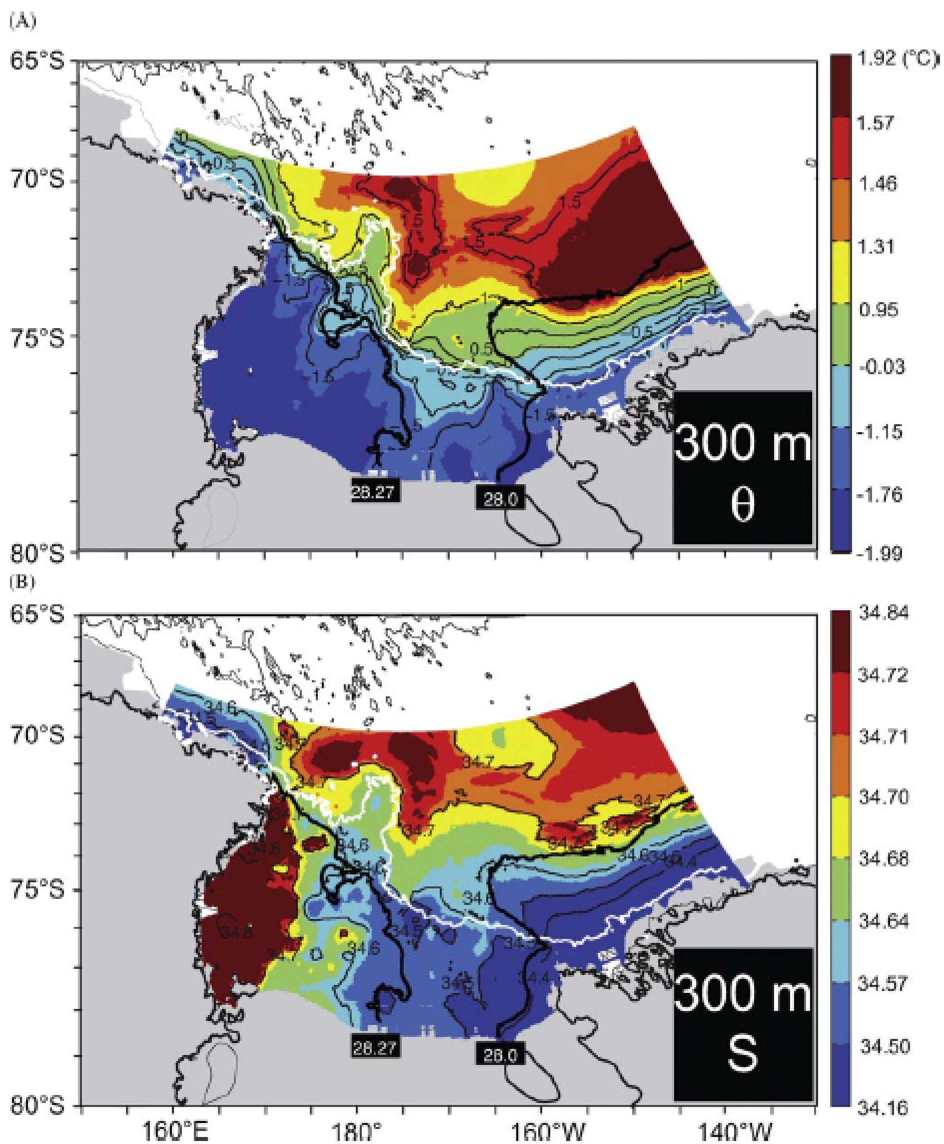
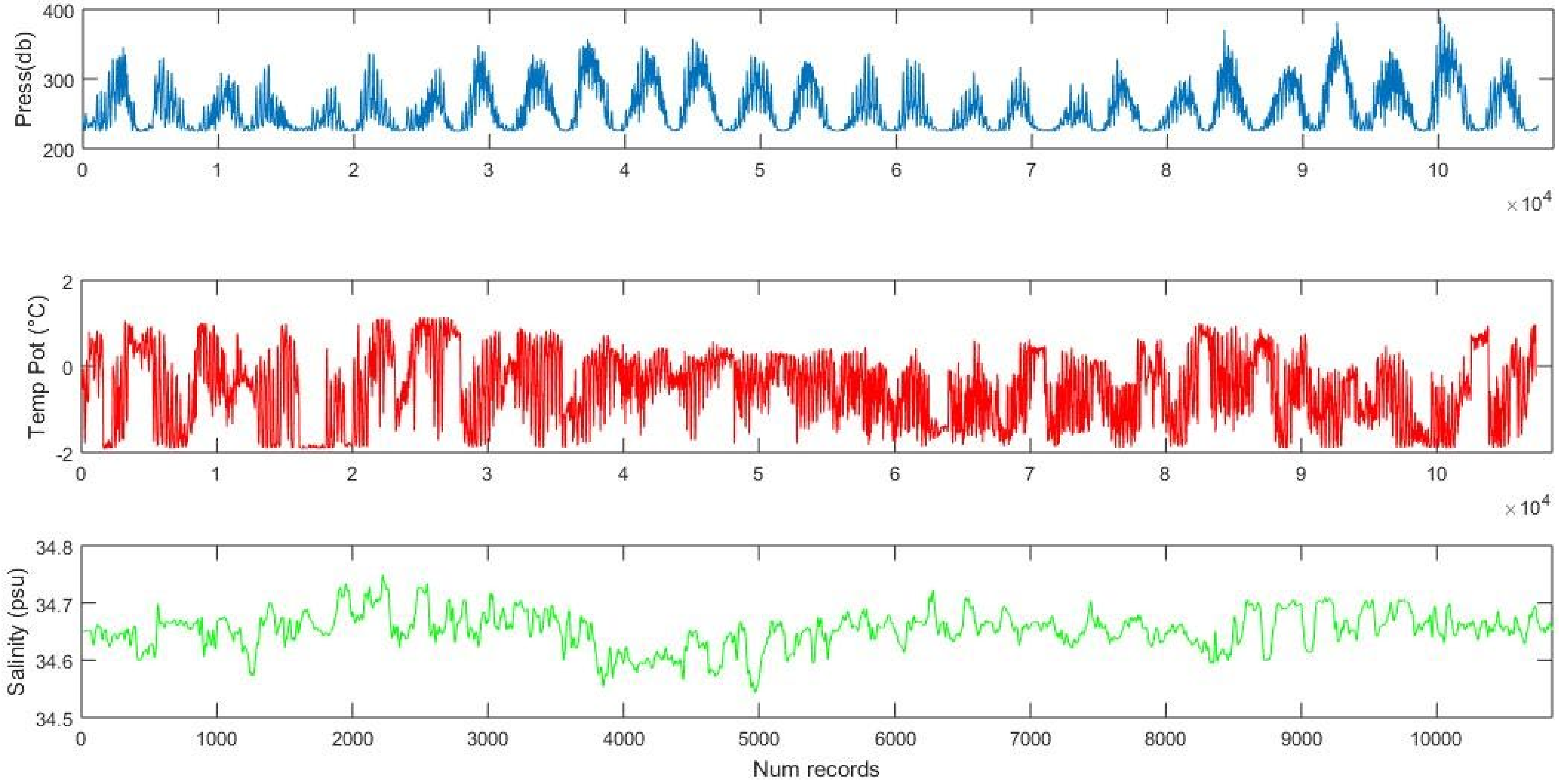


Fig. 6. (A) Potential temperature (°C) and (B) salinity at 300 m. The white line shows the 1000 m isobath; black contours show the traces of the γ^n = 28.00 and 28.27 kg m^{-3} isopycnals at 300 m. Areas shown with the same color extend over 1/8 of the total spatial domain mapped.

- La CDW entra nel Ross gyre dal margine orientale
- Come la AASW anche la MCDW allo shelf break è trasportata verso W con caratteristiche che si attenuano
- Lungo lo shelf break a prof > 700 m si osserva una stato spesso circa 1000 metri di CDW con T≅ 0.6°C

Mooring G T,S and P time series



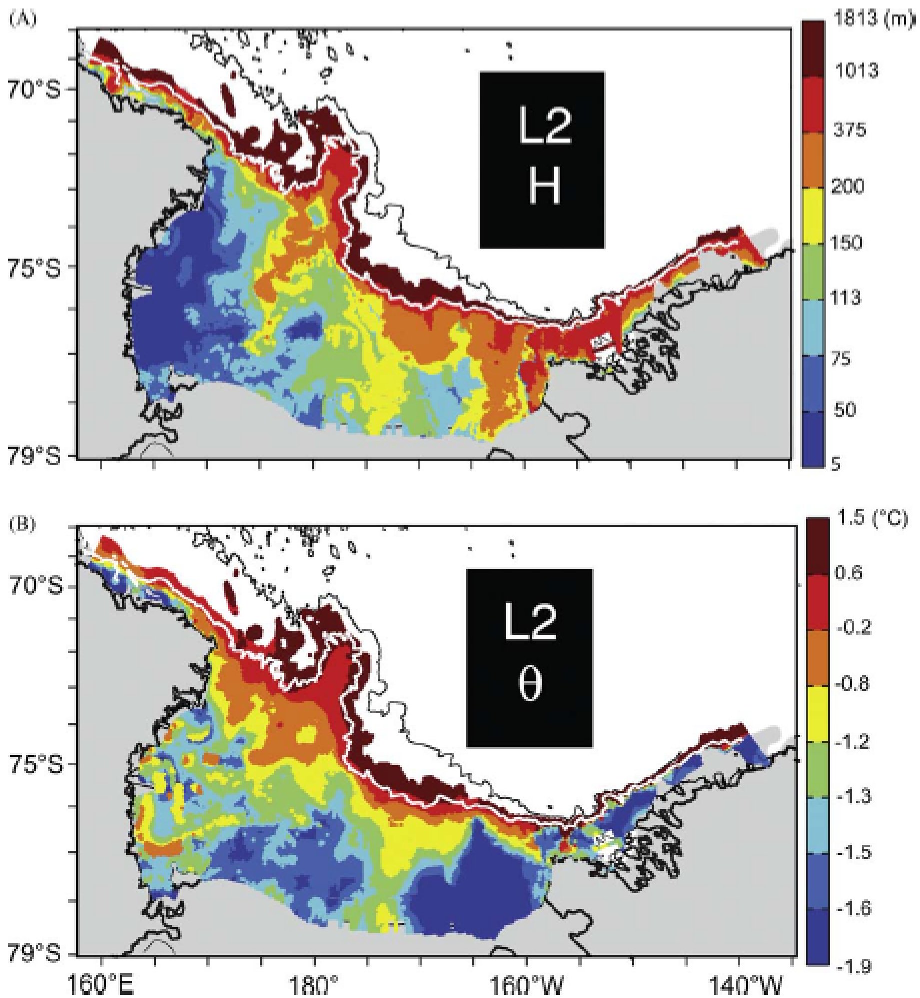


Fig. 7. (A) Thickness (m) and (B) potential temperature (°C) for the middle density layer (L2: 28.00 kg m^{-3} < γ^n < 28.27 kg m^{-3}) spanning MCDW and CDW. The white line shows the 1000 m isobath. Areas shown with the same color extend over 1/8 of the total spatial domain mapped at water depths shallower than 2000 m.

-Intorno ai 170 W nel Glomar basin si osserva l'intrusione di acqua oceanica : MCDW con θ > -1.2°C e S > 34.5

-Si nota anche in questo caso una intrusione sotto il RIS dove la MCDW contribuirà alla formazione di ISW

-Anche dal Drygalsky e dal Joides basin giungono input relativamente calda che si estendono verso il RIS.

Shelf outflow

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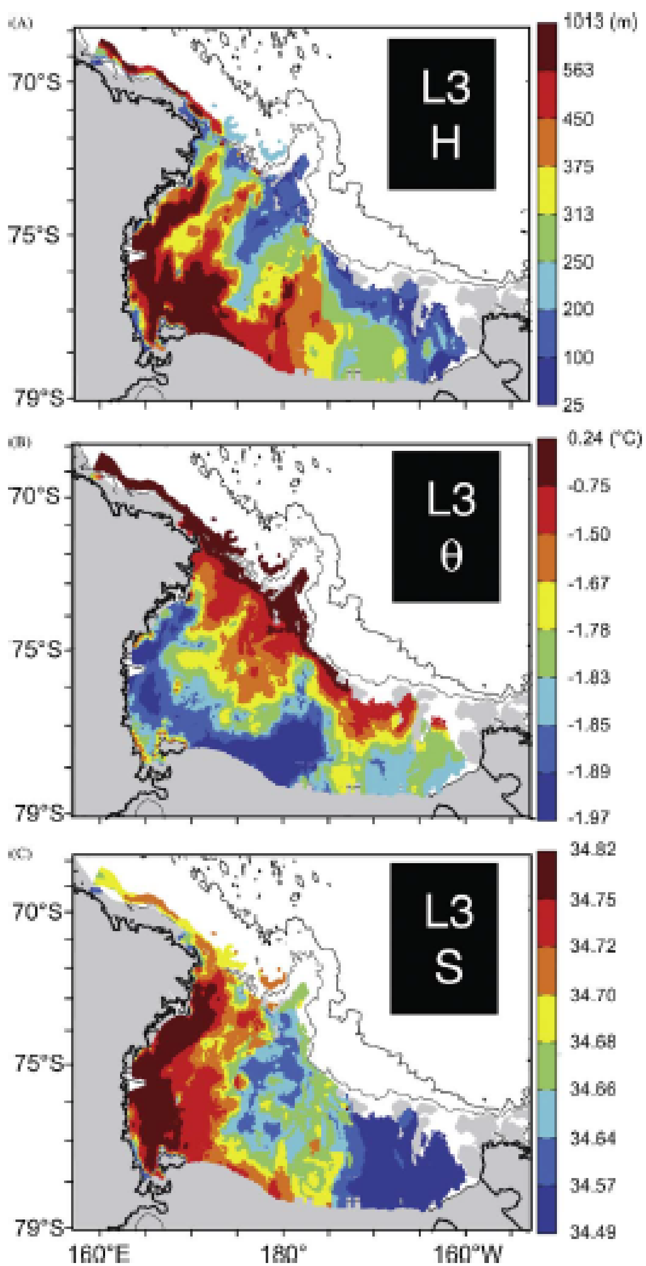

Fig. 8. (A) Thickness (m), (B) potential temperature (°C), and (C) salinity averages for the bottom density layer (L3: $\gamma^n > 28.27$ kg m^{-3}) spanning SW, MSW, and AABW. Depths less than 500 m are lightly shaded, and the thin lines show the 1000 and 3000 m isobaths. Areas shown with the same color extend over 1/8 of the total spatial domain mapped at water depths shallower than 2000 m.

- Lo strato di fondo è occupato da AABW a prof>700 m e da SW e MSW sulla piattaforma
- Nessuna di questa masse d'acqua si osserva a E di 160 °W (topografia)
- In questo caso i volumi maggiori di acqua si trovano nel settore orientale
- Due tipi di ISW si osservano in uscita una dal Glomar (θ<-1.937 °C) e l'altra dal Drygalsky (θ<-1.910 °C)
- Il segnale di O2 può essere utilizzato per individuare le regioni di formazione ed il percorso successivo

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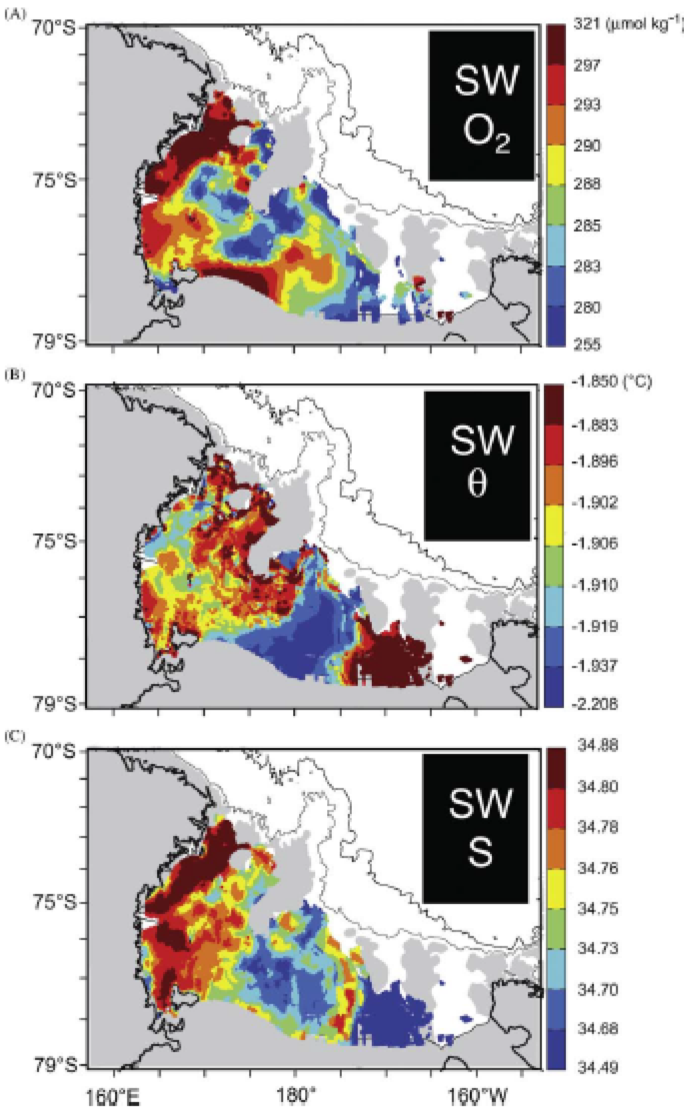
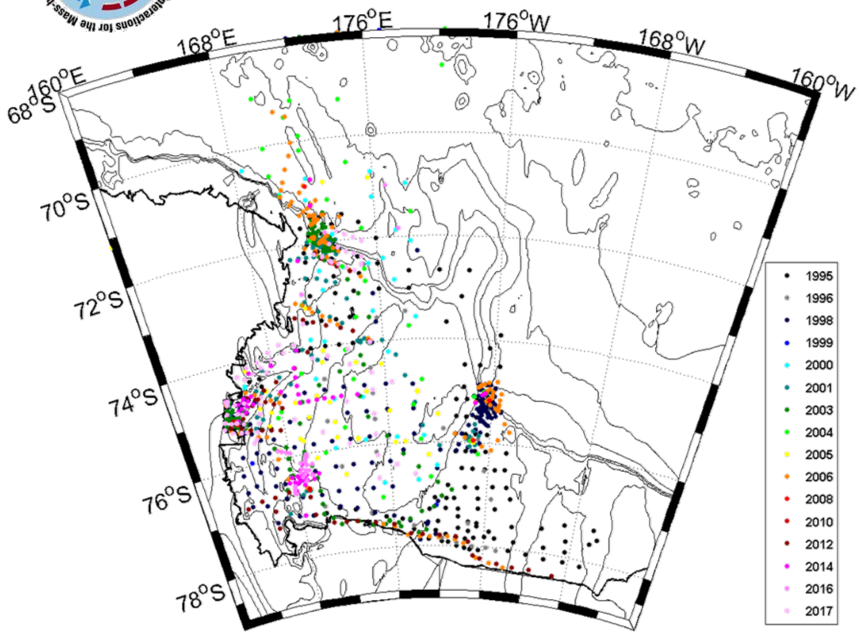


Fig. 9. (A) Dissolved oxygen (µmol kg^{-1}), (B) potential temperature (°C), and (C) salinity averages for the bottom layer of SW (γ^n>28.27 kg m^{-3} and $\theta < -1.85$ °C). Depths less than 500 m are lightly shaded, and the thin lines show the 1000 and 3000 m isobaths. Areas shown with the same color extend over 1/8 of the total spatial domain mapped at water depths shallower than 2000 m.

- La distribuzione di O2 mette in evidenza due siti di formazione : 1) la polynya di Baia Terranova (più salata S> 34.8) e 2) la polynya del RIS (S<34.76)
- RIS-SW ⇒ ISW (non di fondo)
- Anche nei θ-S si osserva un modo di acqua più fredda (θ< -2°C) e meno salata (34.6<S<34.75)
- "Nuova" AABW (-0.75<θ< 0.24°C e 34.68<S<34.25) si osserva in corrispondenza di capo Adare

Data Set: 19 summer cruises over 23 years



CTD (SeaBird SBE 911 + system):

- **pressure**
- **Temperature**
- **Salinity**
- **……**

Hydrographic surveys (Dec-Feb):

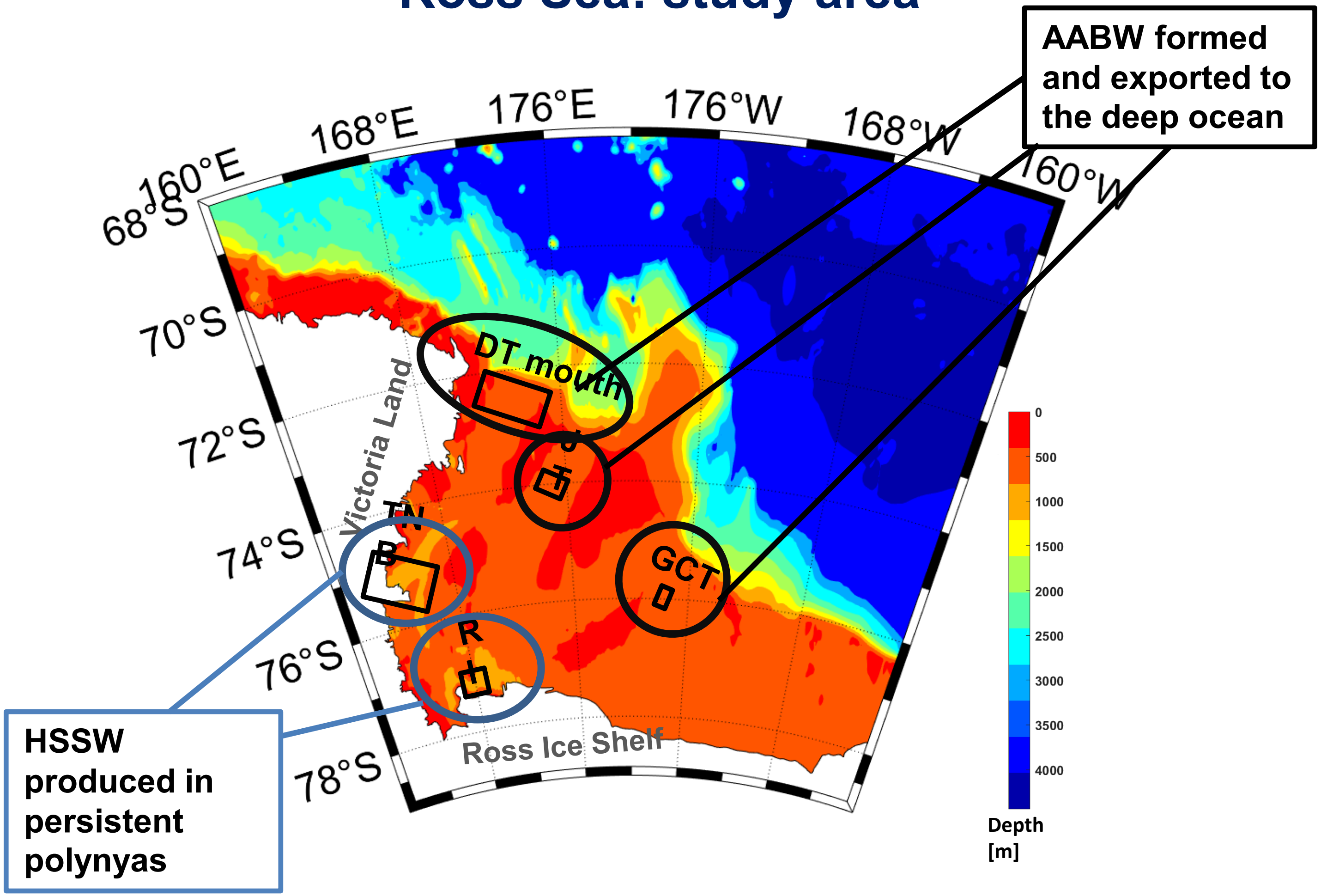
Italica (PNRA):

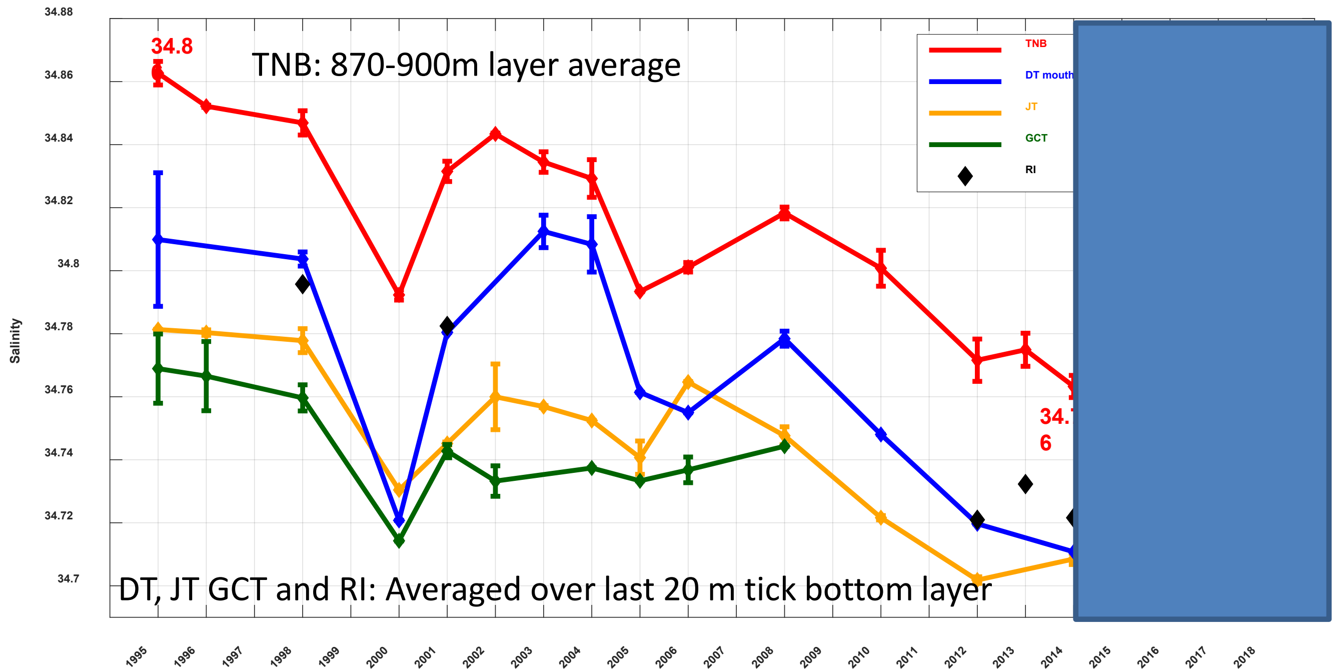
1995
1996
1998
1999
2000
2001
2003
2004
2005
2006
2008
2010
2012
2014
2016
2017

Palmer (NSF):

2005
2013
2018
ANSLOPE, TRACERS and CICLOPS projects.

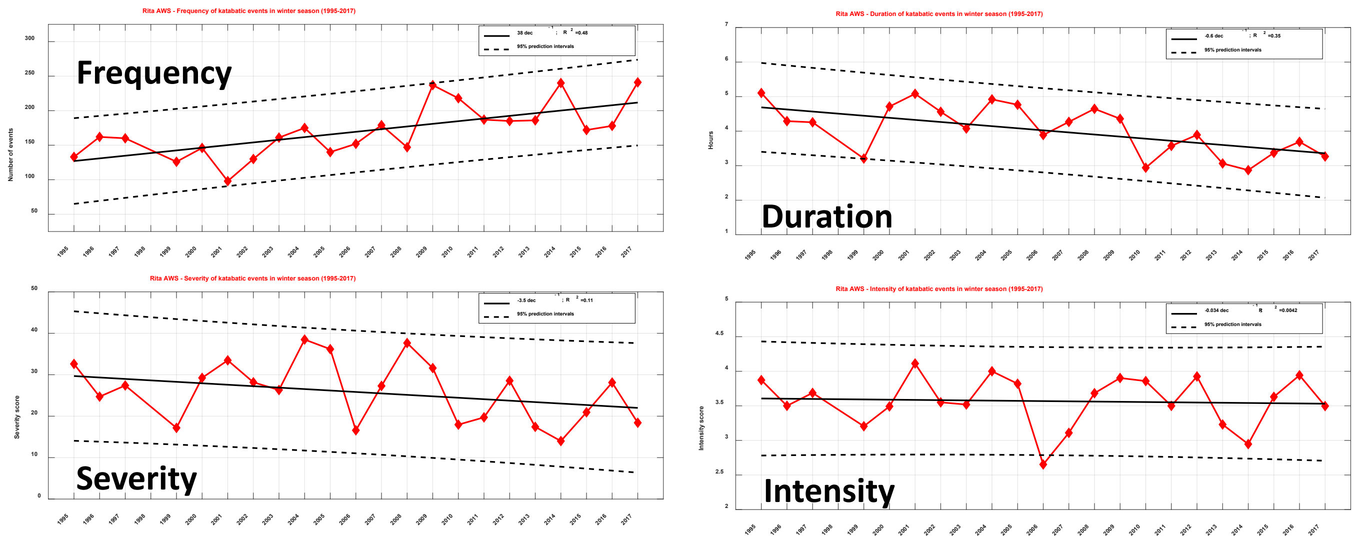
Ross Sea: study area





- **In each region, we average profiles on pressure surfaces to obtain a mean profile for each austral summer**
- **Between 1995 and 2014 HSSW salinity decreased at similar rate (-0.04 dec^{-1} in TNB, -** 0.03 dec^{-1} at DT and -0.04 dec^{-1} at JT) **of previous observed freshening** (Jacobs & Giulivi 2010 and Budillon et al., 2011).
- **After 2014 HSSW salinity rebounded sharply, with values in 2018 similar to those observed in the mid-1990s.**

Variability of the TNB polynya activity



- **Changes in the intensity, duration or frequency of katabatic wind events cannot explain the observed changes in salinity.**
- **Sea ice production in the TNB polynya has changed little with time (Tamura et al., 2016)**
- **Near-synchronous variability at five locations on the shelf also suggests that local factors in TNB cannot explain the observed salinity variability**

Trends and fluctuations can't be explained by local changes in Terra Nova Bay polynya, suggesting "preconditioning" influences the salinity of dense water formed on the shelf.

Factors influencing the salt budget of Ross Sea shelf waters

- Inflow of relatively fresh water from the Amundsen Sea (reducing salinity)
- Net export of sea ice (increasing salinity)
- Inflow of CDW
- Precipitation
- Basal melt of the Ross Ice Shelf

Salinity field pre-conditioning

Salinity anomalies at each site extend throughout the water column, with fresh (salty) HSSW associated with fresh (salty) upper ocean waters and a deeper (shallower) halocline

Salinity from sea ice formation

- A crude estimate of the change in salt or freshwater input needed to account for the salinity increase between 2014 and 2018 can be used to assess possible drivers.
- The salinity increase between 2014 and 2018 requires an addition of

$$\rho V \Delta S = 6.322 \times 10^{15} \text{ kg of salt}$$

ρ=1027 kg m^{-3}, **ΔS = 0.086**, **V = 7.158 x 10^4 km^3** is the mean volume of HSSW (Orsi and Wiederwohl, 2009)

- The mass of salt added to the water column during sea ice formation is

$$\rho_{ice} V_{ice} f\, S_{surf}$$

ρ_{ice}= 920 kg m^3, V_{ice} is the volume of sea ice formed, **f= 0.79** (Skogsethet al, 2004) is the fraction of salt released during freezing, **S_{surf} = 34.0** is the SSS

Salinity from sea ice formation

- If the salinity change reflected only a change in sea ice formation, the observed increase in salt content would require formation of an additional

255 km^3 of sea ice

or an average annual anomaly of about

64 km^3 yr^{-1}

- The mean (1992-2013) cumulative sea-ice production of the Ross and TNB polynyas is 438 ± 64 km^3 yr^{-1} (Tamura et al.,2016)
- The increase in salinity of HSSW between 2014 and 2018 could therefore be accounted for by an increase in annual sea ice formation by the Ross and TNB polynyas of about 15% of the 1992-2013 mean value, sustained over four years.

Role of the Fresh water Inflow from West Antartica

- **Upstream preconditioning:** Jacobs and Giulivi (2010) **observed that the freshening of the westward coastal and slope front current (entrained in the formation of MCDW) from 1964-2007, was sufficient to account for the HSSW salinity decline and was consistent with the increased melting of the continental ice upstream in the Amundsen Sea.**

- A decrease in freshwater input to the HSSW layer could also contribute to the observed increase in salinity.
- Assuming the salt content of the HSSW remains unchanged

$$\rho_o V_o S_o = \rho_o V_f S_f,$$

where the subscripts refer to initial (2014) and final values (2018)

- **A reduction in volume of 0.018 x 10^4 km^3 would be needed to explain the observed increase in salinity.**
- This corresponds to a **reduction in freshwater input of 180 km^3 between 2014 and 2018, or about 45 Gt yr^{-1} sustained over four years**.
- **However, <u>freshwater input to the ocean from West Antarctica has generally increased in recent decades</u> (Rignot et al., 2019), counter to the recent trend of increased HSSW salinity***