Impact of Sea Ice Variability on the Ross Sea Water Masses

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Abstract

Results from the 20th century and SRESA1b CCSM3/NCAR simulation (1870 to 2100) were analyzed using the Optimum Multiparameter Analysis (OMP) to separate water masses. Three water masses were identified in the Ross Sea: Circumpolar Deep Water (CDW); Ice Shelf Water (ISW); Low Salinity Shelf Water (LSSW). Simulation results have shown that the ISW gets shallower during the 20^{th} century and then, during the 21^{st} century, it gets deeper and occupies the deepest layer by 2100 while it flows towards higher latitudes as AABW. Much closely to what has been shown by observational studies, water masses formation in the Southern Ocean is intrinsically linked to atmospheric vaiability modes, such as the southern annular mode–SAM, and to sea ice variation.

1 Introduction

It has been known for a long time that the ocean plays the most important role on Earth's heat budget, what turns it into a major component of the global climate system. Therefore, many studies have been made to assess whether features of climate processes are changing and how may climate itself be affected by these changes. In that sense, the Southern Ocean (SO) is recognized as a key region, since water mass transformations and unique exchanges of heat and freshwater with the rest of the World Ocean take place on the Antarctic continental margins (*Baines and Condie*, 1998; *Orsi and Wiederwohl*, 2009). The densest Antarctic Bottom Water (AABW) will not spread along with the lower limb of the "Global Thermohaline Circulation" (THC) to ventilate the deepest world oceans without first mixing into overlying deep water around Antarctica (*Orsi and Wiederwohl*, 2009; *Jacobs*, 2006). According to *Schmitz* (1996), the THC can be taken as a "*buoyancy-driven flow-field associated with water cooled (or heated) by contact with cold (warm) air, or modified by sources and sinks of fresh water. [It] may also include flows whose characteristics are significantly altered by upwelling and/or mixing. Water sinking at high latitudes tends to return equatorward in relatively strong, narrow deep western boundary currents*", where the SO takes part as the source for dense waters which produce the AABW (*Gordon et al.*, 2004).

The primary source of deep waters in the SO are the Weddell and Ross seas, and the last one is the formation site of the main AABW harbingers: the High Salinity Shelf Water (HSSW) and the Ice Shelf Water (ISW) (*Jacobs et al.*, 1985; *Bergamasco et al.*, 2003). Formed in the southwestern RS due to extensive brine rejection in the RS polynya, the saltiest HSSW flows into the RS continental shelf and under the Ross Ice Shelf (RIS), where ISW is formed by means of melting at the base of the ice shelf to be the densest SO water mass. Both waters flow then, towards the shelf break to interact with the Circumpolar Deep Water (CDW), captured from Antrctic Circumpolar Current (ACC) by the ciclonic Ross Gyre, producing the AABW (*Jacobs et al.*, 1985; *Assmann et al.*, 2003; *Bergamasco et al.*, 2004). Many factors have direct influence on deep waters formation in the SO, such as sea ice concentration and the Southern Annular Mode (SAM), the most prominent atmospheric mode of variability at high latitudes in the Southern Hemisphere (SH) (*Gille*, 2002; *Hall and Visbeck*, 2002). To assess wether may global warming impact the ocean heat transport, this work aims to look at the ISW/HSSW variability as an outcome of climate changes to deep water masses formation in the SO, on a simulation by the CCSM3/NCAR numerical model for the 20c3m and SRESA1B IPCC scenarios.

2 Methodology

2.1 Experimental design

The Community Climate System Model version 3 (CCSM3)/National Centre for Atmospheric Research (NCAR) is a global coupled climate model which has been used to conduct multimember ensemble simulations for the 20^{th} century climate and the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A1B scenario for the 21^{st} century. For the 20^{th} century simulations, concentrations of Green House Gasses (GHGs; $C0_2$, CH_4, N20) from the IPCC Third Assessment Report (TAR; $C0_2$ from the Integrated Science Assessment Model (ISAM)) were used. The 20^{th} century experiments provided the starting point for the A1B scenario simulations, which considered an increase of atmospheric $C0_2$ concentration from 386 ppm in year 2000 to 690 ppm by 2100. The simulation period embraces 230 years, from 1870 to 2100.

2.2 Data

Salinity (S), Temperature (θ), ocean velocity components (U and V), Sea Level Pressure (SLP) and Sea Ice Concentration (SIC) annual mean data from the CCSM3 simulations results were used to assess the water mass distribuition and variability as well as the sea ice and SAM impact on the deep water formation. According to *Gong and Wang* (1999), the SAM index was computed as the difference of zonal mean sea level pressure between 40ºS and 65ºS. SIC time series from two points in the RS were assessed; one point closer to the RIS (79ºS) and a northern one at 72ºS. U and V velocity componentes were used to investigate subsurface circulation at 200m depth. Decadal means of S and θ data were used to perform the OMP and indentify the ISW distribuition and variability.

2.2.1 OMP analyis

Described in various papers, OMP analysis is an inverse modelling technique which determines the relative contributions of various water masses to a water sample (*Tomczak and Large*, 1989; *Poole and Tomczak*, 1999). It is an inversion method applied to a system of linear equations, which is solved for every individual data point, assuming that all hydrographic parameters are conserved. In abbreviated form it can be written as $Gx = B + R$ (where G is the matrix of source water types (SWTs), B is the vector of observations, x is the solution vector and R is the vector of residuals), or in matricial form Equation 1:

$$\begin{aligned} x_1\theta_1 + x_2\theta_2 + x_3\theta_3 + 0 &= \theta_{Obs} + R_\theta \\ x_1S_1 + x_2S_2 + x_3S_3 + 0 &= S_{Obs} + R_S \\ x_1 + x_2 + x_3 + 0 &= 1 + R_{CMass} \end{aligned} \quad (1)$$

To make the parameters measured in different units comparable the equations are normalised and weighted to account for differences in measurement accuracy or environmental variability between parameters (*Leffanue and Tomczak*, 2004).The present study investigated three water masses which SWTs determined through TS diagrams analysis are shown in Table 1: CDW, ISW and Low Salinitity Shelf Water (LSSW). OMP was performed over S and θ data from a meridional section across the RS from under the RIS at 80°S to 55°S along the 180°E longitude.

3 Results and Discussion

All three water masses were identified in the Ross Sea: CDW, ISW and LSSW. ISW showed a greater variability (Figure 1). The maximum contribuition core located at 2000–2500m depth in 1870 (Figure 1a), gets shallower by the year 2000 assuming a maximum contrituition at 1500–2000m depth (Figure 1b). During the 21st century starts to sink again placing its core at 2500–3000m depth in 2100 (Figure 1c). Many factors may have acted together to procuce such a vertical variation.

Subsurface circulation shows that de Ross Gyre got weaker at the end of 20th century, diminishing the transport of CDW to RS, narrowing the upper warm layer and so pulling up the isopycnals, as a mass-

Table 1: SWTs and Weigths for water masses in the Ross Sea

	CDW	ISW	LSSW	Weigths
θ	0,25	-0,60	-1,72	8,65
S	34,733	34,761	34,415	3,69
C. Mass	–	–	–	8,84

conserving feedbak. In contrast, during the 21^{st} century the Ross Gyre strength increases, enhancing the CDW transport to the RS. The same mecanism acts in the opposite way, lowering the isopycnals and pushing ISW down, back to deeper layers.

SAM index shows positive trends during the entire 21^{st} century. That makes the polar atmospheric meridional cell stronger, increasing surface winds velocity and advecting sea ice northward at higher rates. Confirmed by negatives SIC trends close to RIS and positive SIC trends in the northern RS, a greater sea ice production will lead to higher brine release making water saltier and denser. Besides that, enhanced sea ice transport leaves more ocean surface in contact whith the atmosphere, which allows more ocean heat loss, also increasing water density in the 21^{st} century. As a result, there is more water sinking and deep water formation.

4 Conclusion

Simulation results have shown that the ISW gets shallower during the 20^{th} century and then, during the 21^{th} century, it gets deeper and occupies the deepest layer by 2100 while it flows towards higher latitudes as AABW. Much closely to what has been shown by observational studies, water masses formation in the Southern Ocean is intrinsically linked to atmospheric variability modes, such as the Southern Annular Mode–SAM, and to sea ice variation.

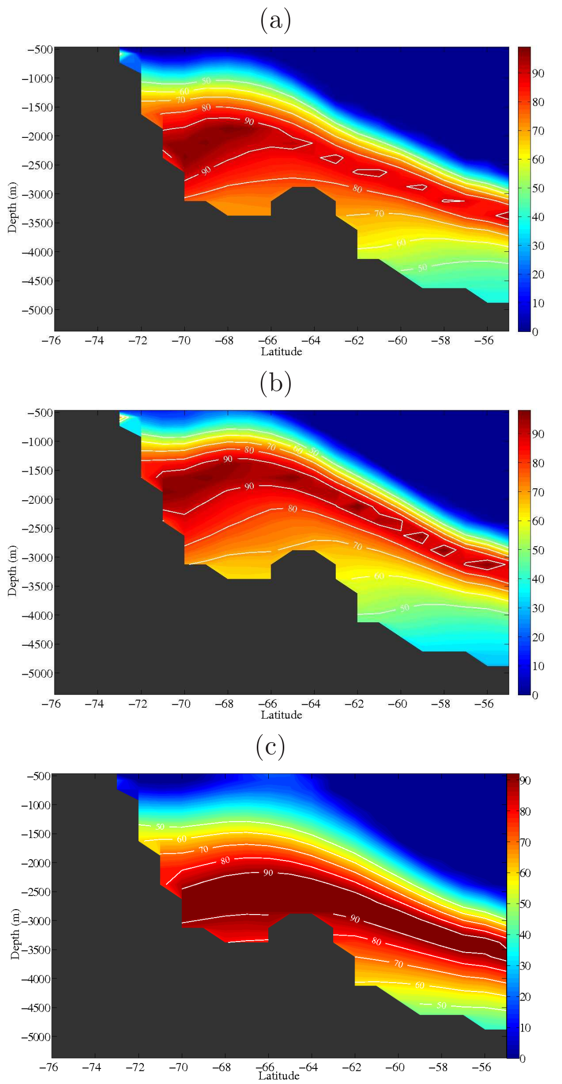

Figure 1: (a) Contribuition (%) of ISW in 1870; (b) 1990; (c) 2090.

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