Optimum Multiparamenter Analysis of the Weddell Sea Water Mass Structure

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1. Introduction

The Southern Ocean plays an important role in global climate as a result of complex interactions between ocean/atmosphere/ice, which eventually influence the global ocean circulation at different levels (e.g. Fahrbach et al., 1994; Orsi et al., 1999). One of the key regions of the Southern Ocean with respect to climate is the Weddell Sea (WS) as most of the bottom water that occupies the world ocean is likely to originate from this region (Orsi et al., 1999). Furthermore, those water masses acquire their signatures from air-sea processes and are therefore excellent indicators of alterations in climatic conditions.

Generally, four water masses occupy the water column in the Weddell Sea. The Surface Water (SW) is present in the top 200 m and experiences strong and variable atmospheric influences at different timescales. The Warm Deep Water (WDW) occupies the intermediate layer between 200-1000m and is derived from the modification of Circumpolar Deep Water (CDW) as it enters the Weddell Gyre around 20-30^{o}E (Gouretski and Danilov, 1993). Moreover, the WDW is a source water mass for deep and bottom waters in the region. The Weddell Sea Deep Water (WSDW) occurs in the layer between 1000-4000m and is the main water mass exported from the WS, an important constituent of Antarctic Bottom Water (AABW) outside the Weddell gyre. Finally, the Weddell Sea Bottom Water (WSBW) is found near the ocean floor below 4000 m.

In this study, we address the distribution, mixing and some aspects of the variability of many of the water masses mentioned above. We dedicate special attention to 1990 and 1996, when positive (and negative) extremes of WSBW distribution were observed.

2. Methodology and data

An Optimum Multiparameter (OMP) analysis (e.g Tomczak and Large, 1989) is used to quantify the mixing between the major water masses present in the WS. The field data used was collected during the WOCE repeat line SR04 (in 1989, 1990, 1993, 1996 and 1998), which covers the WS central region from approximately 63^{o}S to 71^{o}S (Figure 1). The whole dataset is available at the WOCE Hydrographic Database (http://www.woce.org). Further details on the cruise data as well as many more references can be found in Fahrbach et al. (1994, 2004).

Due to strong seasonal variability we discarded the surface layer and only the following water masses were considered for the analysis: WDW, WSDW and WSBW. Table I shows the water mass definitions and weights utilized for model input (based on Robertson et al., 2002):

Table 1 - SWTs and paramet for model output

SWT/ Parameter	WDW	WSDW	WSBW	Weight
θ (^{o}C)	0.5	-0.3	-0.9	11.5
Salinity	34.70	34.66	34.64	11.5
DO (M)	212	234	263	11.9

3. Results and discussion

The general results (Figure 2, 1st column) show the presence of WDW in the intermediate layers up to 1000m, contributing 50-100% to mixing. The WDW reaches around 1500m deep with a contribution of about 30%. The deep layer shows the WSDW present between 1000-4000m, contributing around 50-100% to the mixing (Figure 2, 2nd column), while WSBW has more than a 60% contribution below 4000m along the deep basins (Figure 2, 3rd column).

With respect to the latter, the results from the OMP analysis show the same levels of contribution of WSBW hugging the northwestern slope, indicating the recently formed water mass, especially during 1990.

The WDW has an increased contribution during the years analyzed (not shown) and significant variability in its thermohaline properties as documented in the literature (Robertson et al., 2002; Farhbach et al, 2004), indicating a warming trend in this period that might be related to processes originating outside the Weddell Gyre. Fahrbach et al. (2004) suggest the possible factors that cause the WDW variability. They further argue that WDW temperature and salinity increase may explain the observed variability in WSBW.

The WSDW has a consistent distribution along the section during the years analysed. The core is shallower in the northwestern side of the section with the maximum (~100%) positioned between 2000-2500 m. An extreme event took place in 1990, when an anomalously vigorous decrease (increase) in WSDW (WSBW) contribution occurred. For that year, the analysis of the anomalies (not shown) indicates a decrease of about 30%, with respect to the average of all cruises, in the WSDW contribution to the mixing at the 3000 m layer. At the same time and depth, the WSBW contribution to the mixing increased by ~20%.

The peak contribution of WSBW to the water column in 1990 agrees with the Fahrbach et al (2004) analysis. They argue that during 1990 the atmospheric low-pressure centre was weaker and situated further to the east (see their figure 9). As a result, the wind regime changed and modified the Weddell Gyre structure and intensity. This anomaly significantly altered the Circumpolar Deep Water intrusions (source water mass for WDW). Here we add to the analysis of Fahrbach et al, showing that the anomaly signal also propagates to the WSDW layer and, in fact, the entire water mass structure of the Weddell Sea is changed. In 1990, for example, the core of WSDW is about 700 m shallower in the northwestern side of the gyre than observed in other years. We appreciate that the observed changes can be the result of alterations in the source water types. Nevertheless, those anomalies are felt throughout the water column in a single event, which is an important result.

The opposite was found during 1996, with a significant decrease in the contribution of WSBW. This event is matched with an increase in the positive anomaly of WSDW contribution, especially towards the bottom layers. Furthermore, the WSBW showed a decreasing trend during 1990s, with a small signal increase observed in the northwestern slope during the 1998 cruise.

Several mechanisms (remote and local) may be responsible for driving the deep and bottom water variability in the region. For example, Beckmann and Timmermann (2001) showed that seasonal, interannual and longer timescale variations in dense water volume in the WS are related to the frequencies of the Antarctic Circumpolar Wave. Atmospheric patterns of variability, like the Southern Annular Mode (Thompson and Solomon, 2002), probably also affect the WS deep and bottom water variability. For example, the strongest positive SAM index since 1950 was observed about 18 months before the 1990 positive anomaly of WSBW, but further investigation is needed to quantify that relationship. Furthermore, factors inside the Weddell Gyre may also be contributing to the observed variability as well. For example, a decrease in surface source waters (High Salinity Shelf Water or Ice Shelf Water) impacts the formation and hydrographic characteristics of WSBW (Fahrbach et al, 2004).

4. Summary

In this study we address the Weddell Sea water mass structure and variability based on an OMP analysis. The results identify two opposite extremes in the deep and bottom water mass distribution. The positive WSBW phase was observed during 1990, when a maximum concentration and distribution of this water mass was observed. This event occurred in conjunction with a significant decrease of the WSDW layer, showing that the anomaly was felt in the entire water column considered. The opposite phase was observed in 1996, when the minimum (maximum) of the WSBW (WSDW) contribution to the mixing was registered.

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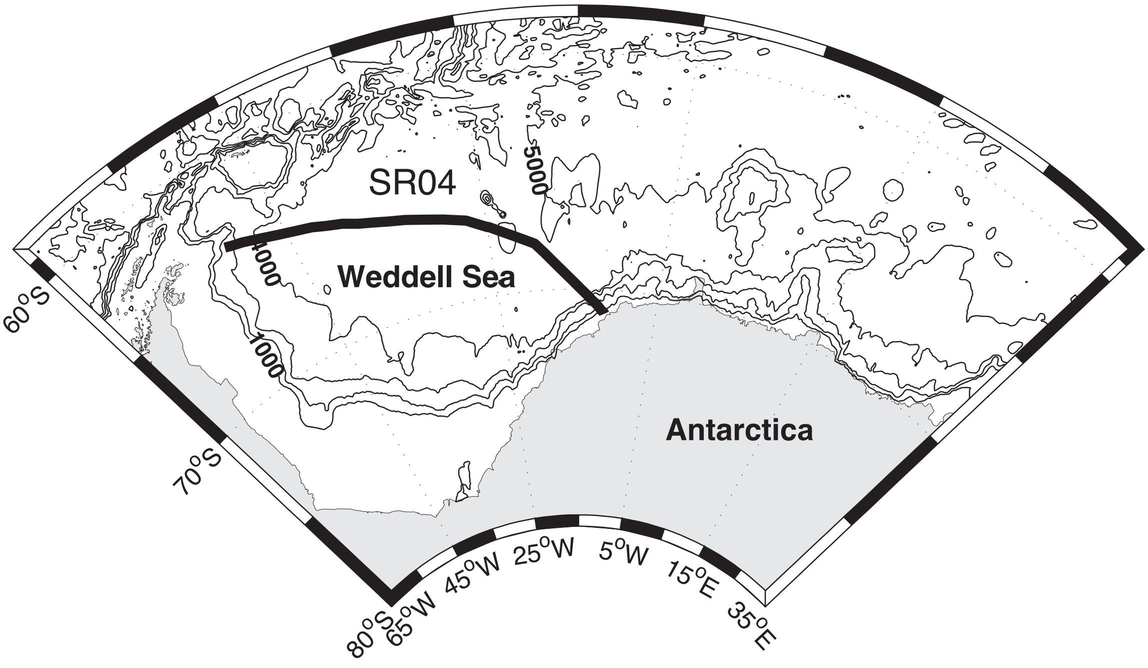

Figure 1 – Location of WOCE SR04 repeat hydrographic section.

Figure 2 – Weddell Sea Water Masses concentration (%): WDW (left column), WSDW (centre column) and WSBW (right column). Each line corresponds to a particular year which is indicated in the first box. Latitude limits vary slightly from cruise to cruise.