The flow of dense water plumes in the western Weddell Sea simulated with the Finite Element Ocean Model (FEOM)

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Abstract

Ocean simulations performed with the Finite Element Ocean Model (FEOM) were used to show the relevance of the location of the dense water plume source on the western Weddell Sea continental shelf. When the plume starts close to the tip of the Antarctic Peninsula it flows into Bransfield Strait, but if it is found further south it can flow down the slope and contribute to Weddell Sea Deep Water (WSDW). The influence of density on the spreading was also tested indicating that a denser plume reaches greater depths while lighter plumes do not interact with the WSDW.

Keywords: Plume, Larsen Ice Shelf, Weddell Sea Deep Water, Ocean Modelling, Bransfield Strait

Introduction

The shelf waters from the northwestern Weddell Sea contribute to the production of Weddell Sea Deep Water (WSDW) (e.g. Absy et al., 2008), which is one important source of the water mass that fills most of the world ocean abyss, the Antarctic Bottom Water (AABW) (e.g. Orsi et al., 1999). Besides of this global relevance, part of the water contours the Antarctic Peninsula (AP) and enters the Bransfield Strait, playing an important role for the circulation of this region (e.g. Gordon et al., 2000; García et al., 2002).

WSDW is transported by the clockwise circulation of Weddell Gyre and is formed by the mixture of Weddell Sea Bottom Water with Warm Deep Water (WDW) or by the interaction of shelf waters with WDW (e.g. Nicholls et al., 2009). As the current flows north along the isobaths, dense waters observed on the continental shelf in front of the Larsen Ice Shelf (LIS) flow down the slope mixing with the ambient waters and increasing the volume of WSDW (e.g. Absy et al. 2008).

As the current reaches the tip of the AP it turns east along the South Scotia Ridge and forms the northern branch of the gyre. Through a passage in the Powell Basin, the Philip Passage, or one of the deep gaps in the South Scotia Ridge, Orkney Passage, Bruce Passage, and Discovery Passage, the WSDW escapes from the Weddell Sea to form AABW (e.g. Naveira Garabato et al 2002).

As mentioned before, part of the shelf water is deviated to the west and enters the Bransfield Strait. There, the relatively cold and salty Weddell See waters mix with water masses from the Antarctic Circumpolar Current and from the Bellingshausen Sea, filling almost the entire Strait. One assumes that the Bransfield Deep Water is a mixture of Weddell shelf waters with WDW modified by in-situ winter conditions (García et al, 2002).

In the present work we investigate how changes in the characteristics of the dense shelf waters observed off LIS may impact the neighboring basins. To reach this goal we used numerical simulations performed with the Finite Element Ocean Model (FEOM).

Model setup and experiments

FEOM is a 3D finite-element primitive equation ocean circulation model based on an unstructured horizontal mesh. The version used in this study is fully described by Wang et al. (2008a). For our experiments a triangular grid that goes from 25°S to 80°S and encircles the Antarctic Continent was created. The surface mesh resolution varies from 1/15° (approx. 3.3 km) in the area of investigation, i.e. the western Weddell Sea, to 2° in the remaining areas. 21 terrain-following (σ) vertical levels with increased resolution close to the bottom and in the surface mixed layer were used (Wang et al., 2008b). The bathymetry was derived from the 2-Minute Gridded Global Relief Data (ETOPO2, 2001).

To the south the continent limits the domain, and for the northern open boundary a restoring of temperature and salinity to climatological values from the World Ocean Atlas 1994 (WOA01) (Levitus and Boyer, 1994) was used along 15° of latitude. The model was initialized with mean temperature and salinity fields extracted from WOA01 and forced with the wind stress from the National Centers for Environmental Predictions (NCEP) reanalysis (see e.g. Trenberth et al., 1990), and sea surface temperature and salinity were relaxed to the WOA01 values. After 4.5 years of integration the model was stable and we initialized the outflow experiments.

Two sensitivity tests were performed: task (a) to assess the importance of the latitude were the dense water plume is formed and task (b) to study the effects of initial density on the spreading of the plume. All simulations start on the first day of June and run for 8 months with a 6-minutes time-step. In each case, a plume source occupying half of the water column was placed on the continental shelf for two months. Afterwards the integrations continued without any further adjustments. The plumes were marked with a passive tracer.

For the first task two experiments were carried out: the dense water source was placed where (a) the former LIS A and B were located (experiment L1) and (b) in front of LIS C (L2). The temperature (-1.92°C) and salinity (34.64) values used were obtained from observations (station 301 in Absy et al. 2008).

The second task consisted of two experiments with the plume starting at the same position of L2. In the first run, the density of the water (σ_0) was reduced from 27.89 Kg/m^3, L1 and L2, to 27.73 Kg/m^3 using an increased temperature (-1.69°C) and lower salinity (34.45) (S1). In the second simulation the density was raised to 27.97 Kg/m^3 by increasing the salinity to 34.75 (S2).

Results

The plume starting at L1 leads to a major flow into Bransfield Strait (BS) (Fig. 1). The spreading path bifurcates at the tip of the AP. The southern branch flows southwest along the Strait southern slope of BS and then turns north-northeast to spread along the opposite margin. This path agrees well with the circulation scheme proposed for this region (e.g. García et al 2002). The other branch flows along the northern rim of Powell Basin, leaving the Weddell Sea at the western margin of Philip Passage.

In L2, part of the plume flows down the slope and is carried by the Weddell Gyre, while the water that remains on shelf flows north with smaller velocities (Fig. 1). The portion transported by the gyre enters Powell Basin, flows around South Orkney Island and leaves the Weddell Sea through the South Orkney Passage, with some leakage of dense water through Philip Passage. The waters remaining on the continental shelf follow the same path as described in L1.

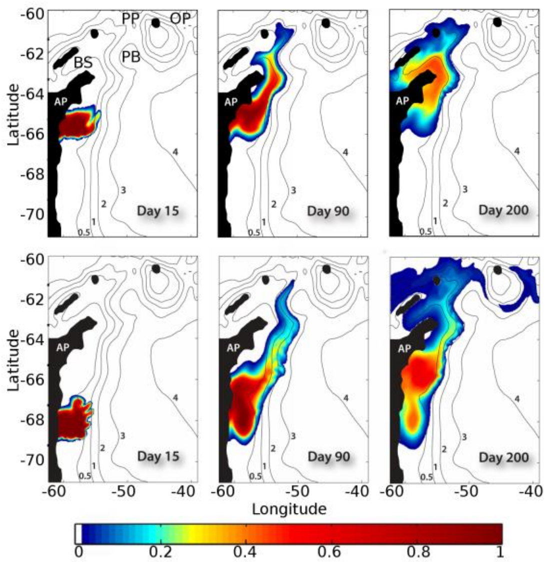

Figure 1: Tracer concentration in simulations L1 (upper panels) and L2 (lower panels) after 15 (left), 90 (middle) and 200 (right) days. The abbreviations in the upper left panel represent Bransfield Strait (BS), Orkney Passage (OP), Powell Basin (PB), and Philip Passage (PP).

In simulation S2 the spreading paths are similar to L2, but the dilution by the surrounding ambient takes a longer time (distance) and the plume water reaches greater depths than in the other runs. When lighter water is prescribed (S1), the northward flow is restricted to the continental shelf and the upper part of the slope, and the dilution below the shelf break is higher. When the traced water gets closer to the tip of the AP a behavior analogous to the first 90 days of L1 is observed, but the simulation period ends before the southwestward flow into BS can occur.

Summary and conclusions

Our experiments have shown that dense water found close to the tip of the Antarctica Peninsula flows mainly into Bransfield Strait, while if it is located further south, it can flow down the slope and contribute to the WSDW that might be converted into AABW. The importance of the waters from the northwestern Weddell Sea for the fringing basins is already known, but we showed that the location where the plume starts defines whether it will flow into Bransfield Strait or into the Scotia Sea.

This result support the idea that the freshening of the deep waters from BS (Garcia and Mata, 2005) is associated with the freshening observed on the northwestern Weddell Sea (Hellmer et al., 2011). Further investigation of this subject will be carried out using the Finite Element Sea Ice-Ocean Model (FESOM) (Wang et al. 2014), a model that simulate sea-ice formation and the interaction with the fringing ice shelf, both crucial for the dense water production.

Another crucial factor for the spreading of the LIS plume is its initial density. Lighter water mixes faster with the ambient waters and does not influence the WSDW while denser water sinks to greater depth. Due to the lack of data, the variability of the plume is not known. Modelling attempts will be made to illuminate this issue, but in-situ measurements are indispensable for understanding this region, its influence on the fringing basins, and its importance for the World Ocean.

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