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On the ventilation of Bransfield Strait deep basins

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ABSTRACT

The deep basins of the Bransfield Strait (BS) are ventilated by Weddell Sea (WS) waters from different origins. Depending on the source and density, these water masses follow different routes across the complex topography near the tip of the Antarctic Peninsula and thus into the Bransfield Strait abyss.

Using a global setup of the Finite Element Sea-ice Ocean Model (FESOM) we show that the WS waters found at the western WS continental shelf break have a higher influence on the short period variability of BS bottom waters than the waters present over the continental shelf.

Adding passive tracers to the glacial melt water (GMW) from two different origins, Larsen Ice Shelf (LIS) and Filchner-Ronne Ice Shelf (FRIS), we show that the GMW from FRIS has a larger influence on BS bottom waters than the GMW from LIS. FRIS GMW has a higher concentration in the BS eastern basin, while LIS GMW is more abundant in the BS central basin. This duality mainly leads to the difference between BS central and eastern basins seen on the observations. This is a novel result and we believe is a significant contribution to the understanding of the BS-WS circulation and interactions.

1. Introduction

The Bransfield Strait (BS) is located at the tip of the Antarctic Peninsula limited to the north by the South Shetland Islands (Fig. 1). It is divided into three deeper basins, western, central and eastern, which are separated by relatively shallow sills (Fig. 1)and filled with waters from the Weddell Sea (WS) and Circumpolar Deep Water (CDW) originating from the Antarctic Circumpolar Current (ACC) (e.g. Dotto et al., 2016). CDW enters BS through the deep passages between the South Shetland Islands and is carried northeast along the southern slope of the South Shetland Islands by the Bransfield Current (BC) (Fig. 1).

In the western WS, the Antarctic Coastal Current (ACoC) flows northwards. It carries approximately 1 Sv (1 Sv $= 10^6\ m^3\ s^{-1}$) of WS shelf waters around the tip of the Antarctic Peninsula and into BS (Heywood et al., 2004), feeding the southern branch of the cyclonic gyre that dominates the BS circulation (e.g. Sangrà et al., 2011) (Fig. 1). A significant flow from WS to BS through the Antarctic Sound seems unlikely (Huneke et al., 2016). In the southern BS, a southwestward current flows along and over the continental shelf as a continuation of the ACoC. The current recirculates in the western basin of the BS thus initiating the BC. The latter is a coastal current with maximum surface velocities of approximately $0.4\ m\ s^{-1}$ and an almost linear velocity decay towards the bottom (Poulin et al., 2014).

The water coming from the WS is relatively denser and sinks into the deeper layers of BS while mixing with ambient waters (e.g. Whitworth et al., 1994; Gordon et al., 2000). Applying an Optimum Multiparameter Analysis to temperature, salinity and oxygen data, Dotto et al. (2016) showed that BS deep waters can be well represented by three source water types: CDW, Low Salinity Shelf Water, and High Salinity Shelf Water (HSSW). The inflow of waters from the WS is controlled, at least to some extent, by the Southern Annular Mode (e.g. Youngs et al., 2015; Dotto et al., 2016) and leads to changes in the mixture proportion and thus salinity of BS deep waters.

Applying the same technique but using noble gas measurements (Helium, Neon and δ^3 He) instead of oxygen, Dorschel et al. (2016) considered four source water types to depict the bottom waters of BS and the northwestern WS. They used Surface Water, a mixture of CDW and modified Warm Deep Water, HSSW, and pure Glacial Melt Water (GMW) as source water types to analyze data from 2013. HSSW originating from the southwestern WS has a higher concentration over the continental shelf and upper part of the continental slope in the WS and the Central Basin in the BS. Despite the relatively high sampling resolution the path of HSSW into the BS is not clearly resolved. The concentration of GMW is higher on the WS continental shelf, and fractions are larger south of 64°S, reflecting its origin from the ice shelves in the western WS (Dorschel et al., 2016). Despite small concentrations, the presence of GMW is an ideal indicator for the origin of the water mass and its pathway. Nevertheless, existing methods cannot

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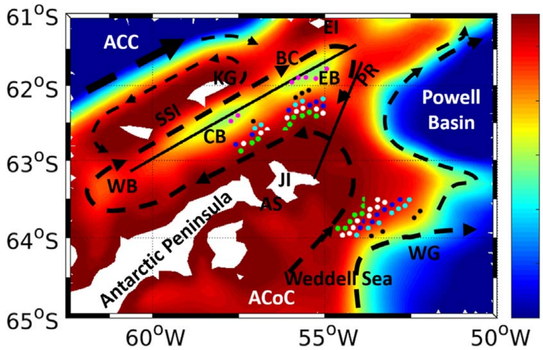

Fig. 1. Regional map of the northwestern Weddell Sea and Bransfield Strait showing a schematic representation of the local circulation (arrows) and important geographic features. The stations used for the correlation analysis in Section 3 are shown as points, the colors correspond to different isobaths: green 300 m, white 400 m, blue 500 m, cyan 650 m, black 1000 m, magenta 1500 m. The line between Joinville Island (JI) and King George Island (KG) marks the position of the section shown in Fig. 5, and the line between JI and Phillip Ridge (PR) is shown in Fig. 3. The background colors depict the bathymetry as represented in the model. Other abbreviations are: ACoC Antarctic Coastal Current, WG Weddell Gyre, AS Antarctic Sound, WB Bransfield Strait Western Basin, SSI South Shetland Islands, CB Bransfield Strait Central Basin, ACC Antarctic Circumpolar Corrent, BC Bransfield Current, EI Elephant Island, EB Bransfield Strait Eastern Basin. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

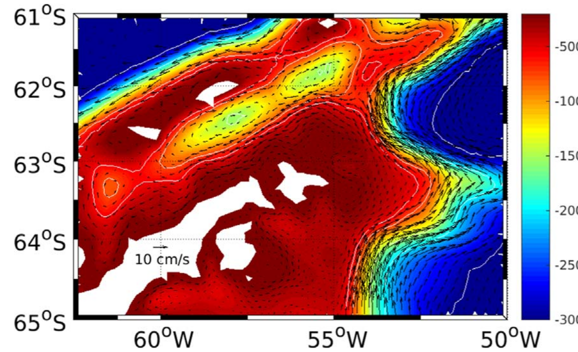

Fig. 2. Regional map of the northwestern Weddell Sea and Bransfield Strait showing the model mean (1999–2010) bottom currents. The colors depict the model bathymetry, white lines are the isobaths of 550, 750, 1500, 2000, and 3000 m.

distinguish between GMW from different ice shelves, therefore, its origin remains somewhat speculative.

In the present study, we use results from a global model to investigate (a) the pathways of waters, found close to the bottom of the continental shelf and slope, from the WS into BS and (b) the origin of these waters. Understanding the sources of BS deep waters is crucial to assess the reasons and implications of its freshning (Dotto et al., 2016). In addition, our results support observations in the deep BS, which might identify changes in the characteristics of the shelf waters forming Weddell Sea Deep Water, the precursor of Antarctic Bottom Water.

2. Model

2.1. Description

The model results used in this study were generated using the Finite Element Sea-ice Ocean Model (FESOM) (Timmermann et al., 2009; Wang et al., 2014). FESOM is a fully-coupled combination of a finite element ocean circulation model, which includes the ice shelf cavities, and a dynamic-thermodynamic sea-ice component. The ocean component solves the hydrostatic primitive equations and was extensively described in Danilov et al. (2004); Timmermann et al. (2009); Wang et al. (2014). The ocean-ice shelf interaction is included, based on the three equation approach proposed by Hellmer and Olbers (1989).

Ice shelf cavities have a constant geometry, and the model accounts for the ocean heat loss and represents the Glacial Melt Water (GMW) input by changes in the salinity. The sea-ice is represented by a two-layer model, one layer of snow and one layer of ice with the internal heat capacity of ice neglected (Parkinson and Washington, 1979), and was presented by Timmermann et al. (2009). Ice and snow volume are advected using the velocities obtained from the elastic-viscous-plastic solver described by Danilov et al. (2015).

Ice and ocean components are resolved for an unstructured surface triangular grid that was prepared for the study of dense water formation in the western WS (van Caspel, 2016). It is a global mesh with the number of surface nodes per unit area increased in the Southern Ocean, and an additional focus in the southern and western WS. The grid length scale (resolution) varies between 4 km and 73 km in the WS (Fig. 3.1 in van Caspel, 2016). In the vertical, the model uses a hybrid grid with 25 terrain-following (sigma) layers extending from the Antarctic continent down to the 3000-m isobath, and 36 horizontal (z) layers in all other regions (Fig. 3.2 in van Caspel, 2016).

The model results used in this study were validated and considered to be appropriate for WS studies (van Caspel, 2016). Although the mesh is not designed for BS studies, this region is represented with a resolution higher than 20 km, and the model is capable of resolving the main circulation characteristics like the inflow of WS waters and the BS cyclonic gyre (Fig. 2). Nevertheless, due to the smoothing, applied to the bathymetry to keep the model stable, the deep basins in the BS are shallower in the model; BS central and eastern basin have maximum depths of 1700 and 2700 dbar (e.g. Gordon et al., 2000), respectively, but both reach only 1500 m in the model. This discrepancy could have an impact on the amount of dense water accumulated in the BS over longer simulation periods, but we strongly believe that it has no major implications for this study since we focus on the source of dense water rather than on its total volume.

The current experiment started in 1979 and was integrated for 32 years, until 2010, using 6-hourly fields from the National Centers for Environmental Prediction Climate Forecast System Reanalysis (NCEP-CFSR, Saha et al., 2010); the atmospheric forcing parameters are: air temperature, longwave and shortwave radiation, zonal and meridional wind, humidity, precipitation, and evaporation. After 20 years, i.e. in 1999, until the end of the simulation, a passive tracer proportional to the glacial melting was added to the GMW from the Filchner-Ronne Ice shelf (FRIS) and another one to the GMW from Larsen Ice Shelf (LIS). The tracers are used to distinguish between the area of influence of the two sources of dense water. To keep the study consistent, all analyses were done for the 'tracer' period, i.e., between 1999 and 2010.

2.2. Validation

van Caspel (2016) showed that the modeled waters on the WS continental slope are colder and fresher than the observations but with similar density and, therefore, the interaction between water masses was well depicted. The thermohaline bias is carried into BS leading to a misrepresentation of the basin water mass characteristics (not shown), i.e, deep temperature and salinity values in the model are different from observations. Due to this issue, our study is focused on the correlation between properties rather than the absolute values and on the tracer concentrations to study the dynamical pathways of WS bottom waters into BS.

In addition to the validation performed for the WS (van Caspel, 2016) we evaluate the representation of (1) the bottom circulation in the BS and (2) the transport of water masses from WS into BS:

(1) The model reproduces important features of the bottom circulation in the BS and surroundings: 1999–2010 mean bottom velocities (Fig. 2) show a strong current along the continental slope present in the WS and Powell Basin, namely the Antarctic Slope Current; the