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Structure and evolution of the abyssal jet in the Vema Channel of the South Atlantic

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ABSTRACT

The Vema Channel represents the only major conduit through which the deepest and coldest (< 0.2 °C potential temperature) Antarctic Bottom Water (AABW) flows from the Argentine into the Brazil Basin. From 2003 to 2007 two current meter moorings were present on each side of the Vema Sill, close to the narrowest spot of the Vema Channel. The data from the moorings are compared with earlier current and temperature observations. On average the maximum current core lies ~100 m above the bottom of the sill with a mean northward speed of 0.3 m s^{-1}. Farther up in the water column where Lower Circumpolar Deep Water and North Atlantic Deep Water prevail, one finds a level of sluggish currents with a southward tendency in the sub-centimeter-per-second range. The lower boundary of a layer of 'no' motion was observed at ~3700 m depth where the mean potential temperature amounts to 1.5 °C.

The evolution of the abyssal warming phenomenon over the last decades with notable fluctuations at the choke point between the Argentine and the Brazil Basin differs from the more stable attitude of deep horizontal currents. Starting with CTD observations in 1972 we find a steady increase of temperatures of the coldest AABW in the Vema Channel. This general trend of rising abyssal potential temperatures of almost 2 mKelvin per year is based on mostly annual CTD observations. The overall warming trend is fully compatible with our three-year moored temperature series in agreement with earlier records with high temporal resolution.

Distinct frequently fluctuating horizontal current shear between the western and eastern sides of the Vema Sill may be explained by two different catchment areas for AABW at the mouth of the Vema Channel. One pathway originates at the American continental rise and advects bottom water in form of the deep western boundary current. A second pathway is supplied by an eastern boundary current along the Mid Atlantic Ridge in the Argentine Basin. Both source waters merge at the channel entrance, mix, and their respective strengths can alternate within the sill area.

1. Motivation and background

In recent years the public and scientific interests in the ocean's role in climate change have grown enormously. One of the key aspects is the global heat transport of the ocean and particular its thermohaline circulation. It is quite obvious that in the conception of a global three dimensional circulation scheme, bottom water flows represent a fundamental limb for transports of mass, heat, and freshwater. Their origins in the Atlantic Ocean lie in subpolar North Atlantic and Antarctic coastal regions. In the southern hemisphere the formation and spreading of Antarctic Bottom Water (AABW, Orsi et al., 1999; Wüst, 1933) is believed to play an important role with respect to decadal to secular oceanic climate variability. AABW is characterized by potential temperatures below 2 °C (Orsi et al., 2001) and flows as the densest of all global water masses from its source in the Weddell Sea and partly in the Ross Sea and along the Adelie Coast and Prydz Bay region, equatorward through the western basins of the South Atlantic (cf. Johnson, 2008). In fact, the abyssal branch of the ocean-wide meridional overturning circulation fills several deep basins far north of the equator with modified AABW.

After leaving the Southern Ocean AABW is believed to approach subtropical regions (~30°S) in the Atlantic along two pathways (Fig. 1). A well-recognized continuous deep western boundary current hugs against the continental rise north of the Scotia Arc and off the Patagonian Shelf edge (cf. Coles et al., 1996; Morozov et al., 2008). A secondary less confined route was first documented west of the Mid Atlantic Ridge indirectly in bottom photographs (Flood and Shore, 1988). These authors found strong evidences for dispersed mud waves and underwater dunes attributed to the integrated impact of bottom currents. Also Coles et al. (1996) allude to the possibility that a "significant fraction of the flow out of the Argentine Basin to the north originates in the eastern part of the Argentine Basin". At the southern banks of the Rio Grande Rise both branches can merge, before they are drained from the Argentine Basin either through the Vema or the Hunter Channel. The sill depths

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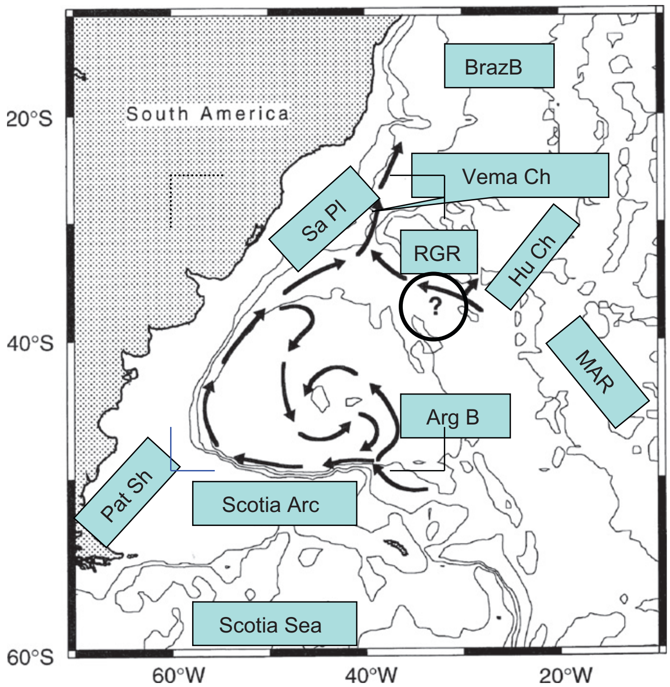

Fig. 1. Large scale topography of the Argentine Basin with the Vema Channel of the South Atlantic (after Coles et al., 1996, modified with permission from the American Geophysical Union). The Santos Plateau (Sa Pl), and the Vema and Hunter Channels (Hu Ch) interconnect the abyss of the Argentine Basin (Arg B) with the Brazil Basin (Braz B). According to Coles et al. (1996) Antarctic Bottom Water can reach the mouth of the Vema Channel via the deep western boundary current system *and* most probably along the western flank of the of the Mid Atlantic Ridge (MAR). The circled question mark close to the Hunter Channel is reproduced from the original image by Coles et al. Other abbreviations: Pat Sh—Patagonian Shelf; RGR—Rio Grande Rise. The over-plotted thin right angles indicate the frame of Fig. 17.

and the outflow paths to the adjacent Brazil Basin in the north differ substantially in both deep conduits.

Flow observations made in the 1990s during the World Ocean Experiment (WOCE) document major modifications of mixing rates in abyssal channels (Hogg, 2001). The resilient determination of mass, heat, and freshwater fluxes across the Rio Grande Rise as the barrier between the American continent in the west and the Mid Atlantic Ridge to the east of the northern Argentine Basin belonged to the core project Deep Basin Experiment (DBE) of WOCE (Hogg et al., 1996). A decade later Morozov et al. (2010) compiled and reviewed the present base of our observational understanding of abyssal channels with emphasis on the South Atlantic. Their most extended book chapters deal with the history and flow conditions of AABW entering and passing the Vema Channel. Their publication also offers a comprehensive overview about volumetric transports of bottom water across the Rio Grande ridge published between 1982 and 2008. In addition it includes some new transport estimates from moorings introduced in Section 2 of this paper.

Since November 2002 international en-route measurements at the Vema Sill are still ongoing from board research vessels bound to Antarctica (Zenk and Naggar, 2010; Zenk and Visbeck, 2011). Every year these incoming new data allow an update of the hydrographic time series from the coldest AABW core in the Vema Channel. The analysis from over 80 conductivity–temperature–depth (CTD) stations from 22 revisits shows a robust temperature rise of order 2 mK/year in the abyssal (Zenk and Morozov, 2007). Since 2005 the Russian CTD observations are supplemented by lowered Doppler current meters (Morozov et al., 2010).

This paper presents observations pertinent to properties of abyssal flows through the Vema Channel. They are based on long-term current meter and temperature records that were primarily collected at the Vema Sill from 2005 to 2007 as a German contribution to CLIVAR ((CLImate VARiability and predictability), cf. Hurrell et al., 2006). Where opportune we consider older moored data from WOCE (Hogg et al., 1999) and from earlier observations (Schmitz and Hogg, 1983). A description of the moored array and the resulting data set, along with some limited previous analyses is given in Section 2. In Section 3 we discuss the structure and variability of the deep and near-bottom currents, together with their evolution during the last decades. A summary of results and some concluding remarks can be found in Section 4.

2. Current meter arrays and data sets

The funnel shaped entrance of the Vema Channel supports a robust local intensification of the flow. The topographical condition represents an obvious location for sustained observations with moored current meters in search for the interbasin exchange and mixing across the Rio Grande Rise. Pioneering measurements were conducted by Hogg et al. in 1980/81. They delivered the first exploratory estimates of the vertical energy distribution and transport of AABW in the region (Hogg et al., 1982). Based on their results an ambitious joint current meter array in quasi-zonal direction between the continental rise off Santos, Brazil, and the Hunter Channel was implemented as a major contribution to WOCE from the former *Institut für Meereskunde*[1] Kiel and the Woods Hole Oceanographic Institution. From 1991 to 1992 19 moorings were deployed in the sub-thermocline water column with increasing coverage towards the bottom (WOCE code ACM 12). At the mouth of the Vema Channel, or more precisely from the western wall of the Vema Sill five almost two-year long records[2] (#1–5) could be collected. From the channel outlet at the southern end of the Brazil Basin, called Vema Extension two additional series (#71, 72) were obtained within the AABW level.

Due to limited resources some deployments of current meters had to be handled successively, constrained by revisits of research vessels. In our discussion we also refer to the main conduit in the Hunter Channel (WOCE code ACM13) where comparably stable, though less vigorous northwestward near-bottom currents were observed as compared with the Vema Sill (Zenk et al., 1998).

In the post-WOCE phase, i.e. in the beginning of CLIVAR a further experiment with moored current meters and two vertical thermistor chains was conducted on the Vema Sill (1998–2000). Again two stacked current meters (#52, 54) were deployed in the cold core of AABW close to the eastern wall of the sill (Zenk, 2008). Finally several 3.4-year-long records from two mooring sites on opposite sides of the Vema Sill were gathered between 2003 and 2007. The rational for the synoptic twin moorings Vema West and East was that they would provide some insight into the cross-channel structure and variability of the contour current and its topographic steering by the constraining walls on both sides of the channel.

The two moorings were positioned 12.4 km apart. The records are interrupted only by a three-day service interval in the middle of the time series (phases I (east: #11–14, west: #21–23) and II (east: #30–35, west: #42–44)). The coverage with instruments was concentrated on the depth range within North Atlantic Deep Water (NADW) and Weddell Sea Deep Water (WSDW), the deepest subsample of AABW. During the second phase two brand new acoustic current meters (RCM11) with a burst sampling scheme supplemented the eastern rig (#31, 35). In addition to Aanderaa current meters with rotors

[1] Now: GEOMAR.
[2] All times series in this contribution are identified by a number sign (#).