Moored Measurements of Antarctic Bottom Water at the Equator

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Antarctic Bottom Water (hereafter, AABW) lies below roughly 4000 metres depth in the western Atlantic Ocean, and is therefore highly constrained by topography as it flows from one deep basin to the next. Near the equator, it flows through a tortuous interconnecting passageway from the Brazil Basin in the western South Atlantic to the Guiana Basin in the tropical western North Atlantic. This topography forces the water to flow westward through an east-west trending gap that spans the Equator (Figure 1). The gap is approximately 230 km wide, and is bounded to the north by extensions of St. Paul's Fracture Zone, and to the south by the Parnaiba Ridge extending from the South American continent. Previous estimates of the magnitude of cross-equatorial flux of AABW range from approximately 1 to 4 Sv. For example, McCartney and Curry (1993) have made a geostrophic estimate of the volume flux of the AABW through this gap of 4.3 Sv. Rhein *et al*. (1994) measured the velocity distribution in this gap at three times with current profilers, and found, in addition to considerable variability, that the westward flowing bottom water current is greatest near the southern end of the gap, with an estimated transport of 2.6 Sv. They also observed a strong core, or jet, of eastward flowing North Atlantic Deep Water (NADW), centred at about 3800 m, between roughly 1° and 2°S.

In order to provide an accurate estimate of AABW transport (westward) out of the Brazil Basin at this location, as part of the WOCE Deep Basin Experiment, an array of six moorings with a total of 24 instruments was deployed from the RV Iselin, between 28 September and 2 October 1992. Moorings were deployed approximately every 30 minutes of latitude between 1°N and 1.5°S, along 36°W (see Figure 1). These locations not only filled the gap evenly from north to south, but also put the array at approximately the east-west centre of the almost perfectly zonal gap. All six moorings had at least three instruments (vector averaging current meters (VACM) with temperature sensors) at depths of 3900, 4100, and 4300 m. One mooring was placed almost exactly on the equator and had additional current meters at shallower levels of 3600, 3300 and 3000 m, and deeper, at 4450 m. These, as well as additional instruments at 3300 m on the moorings at 1°N

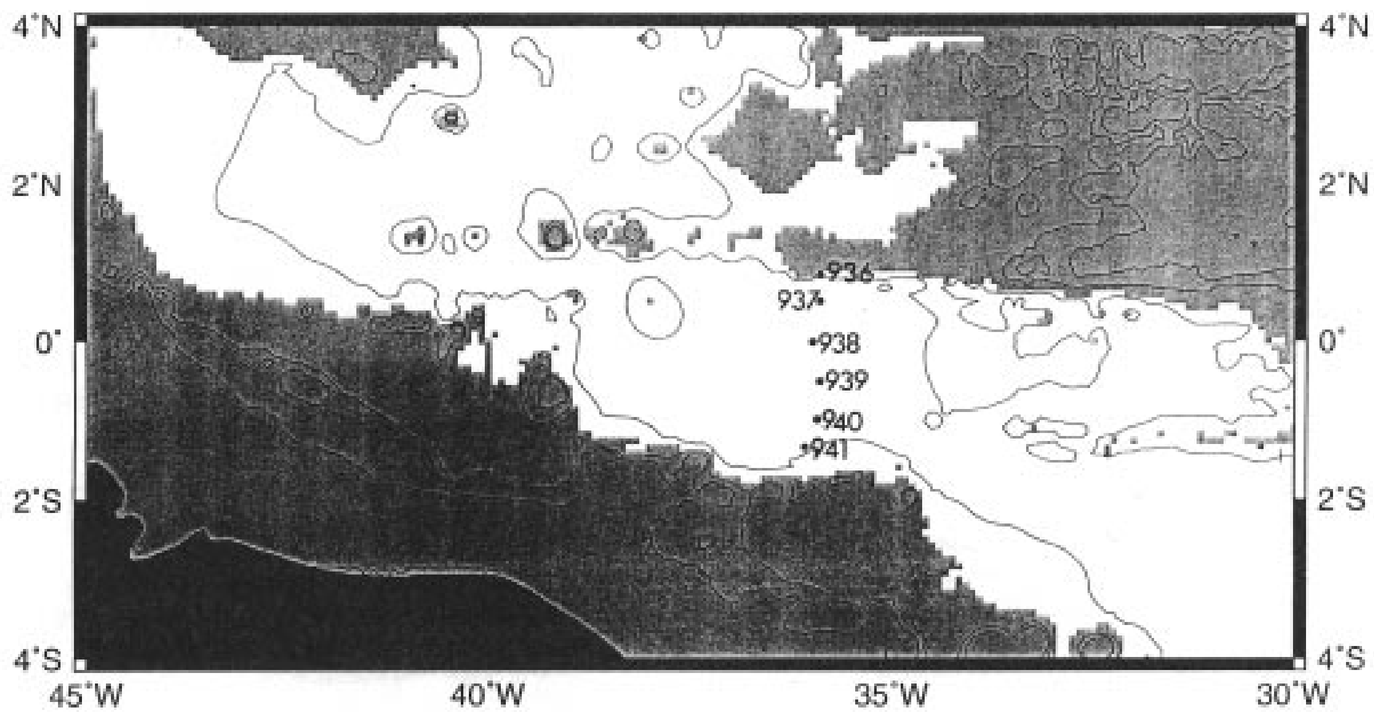

Figure 1. Local topography in the vicinity of the moored array, with mooring positions designated as dots. The shaded area is depths less than 4000 m, with the 3000 and 3500 m contours superposed. In the unshaded area, the 4250 m contour is shown. Water depth in the vicinity of the array just exceeds 4500 m at some locations.

and S, are intended to supply information about the levels of no motion. The recovery cruise took place aboard the RV Knorr, from 27 May to 13 June 1994. Data return from the roughly 610 day deployment was 98%, and a preliminary calculation for the mean AABW transport through the array yielded an estimate of 2.1 Sv. To supplement the velocity and temperature data from the moorings, 11 CTD stations were taken during both the deployment and recovery cruises, with stations located both at and between the mooring locations. Figure 2 displays potential temperature, salinity, and σ_4 (potential density referenced to 4000 dbar), from 1994, for depths below 3600 dbar, with dots representing the positions of the VACMs. So far these data have been used only to aid in calculating time series of potential temperature from the temperatures recorded by the VACMs.

Several striking qualitative features of the moored data are worth noting. First, the time series of velocities confirms Rhein *et al.*'s results, that the AABW flow is concentrated in the southern portion of the channel. To illustrate this, Figures 3 and 4 show the vector velocity time series for the northernmost and southernmost moorings, respectively. At 1°N (Figure 3), although flow at 4300 m is weakly westward in the mean, maximum velocities rarely exceed magnitudes of 5 cm s^{-1}. In contrast, at 1.5°S (Figure 4), zonal velocity is almost always westward, with a mean of -4.9 cm s^{-1}, and maximum westward velocities of 18.6 cm s^{-1}. The data also demonstrate that eastward flow of lower North Atlantic Deep Water (NADW) occurs in a narrow jet evidently confined between the equator and 1°S. This flow is seen at 3900 m in Figure 4; vector velocities at mooring 940 (not shown; near 1°S) have a similar vertical structure (though westward flow at 4300 m there is less intense), while those at 939 (~0.5°S) are strongly westward at all depths. Figure 5 shows velocities for the 7 instruments on the equatorial mooring 938 (3000, 3300, 3600, 3900, 4100,

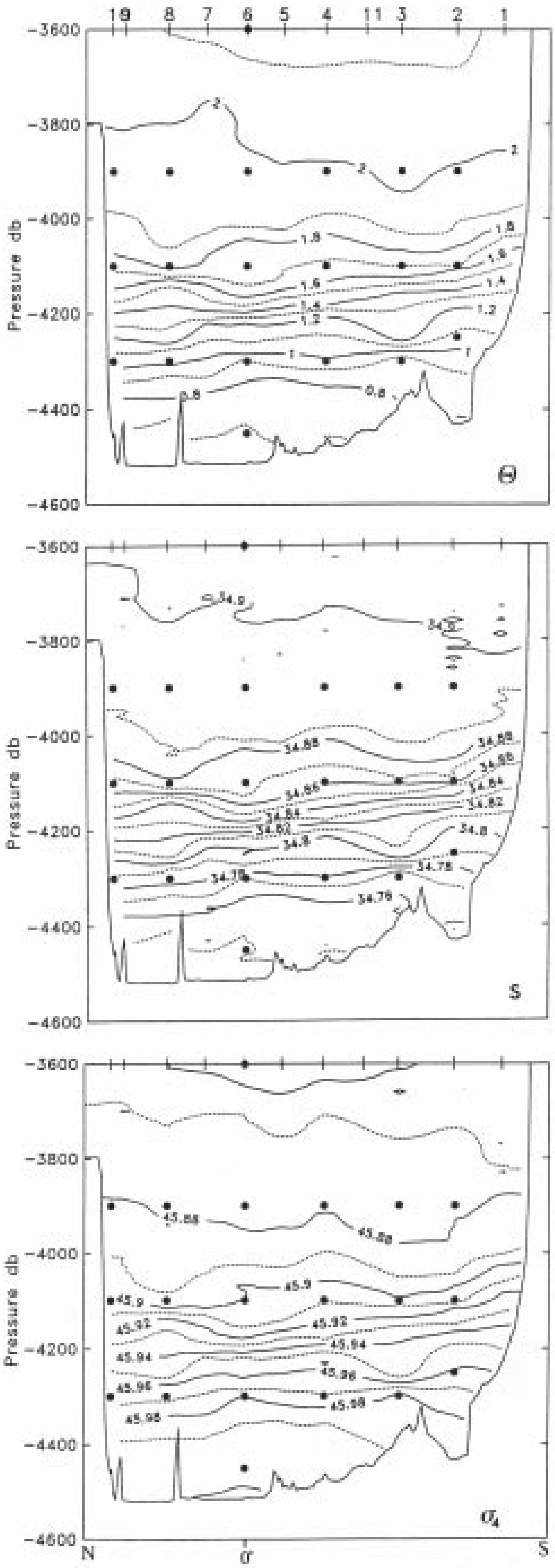

Figure 2. Potential temperature, salinity and σ_4 from the 1994 CTD data across the gap, plotted vs. pressure, at pressures greater than 3600 dbars. CTD station numbers are indicated at the top of the plot. There is an inconsistency between dbars and metres in the figure, so that relative to the vertical axis, bottom depths and instrument locations (shown by dots), plotted in metres, should appear 50–70 dbars deeper than shown. North is to the left; south is to the right.

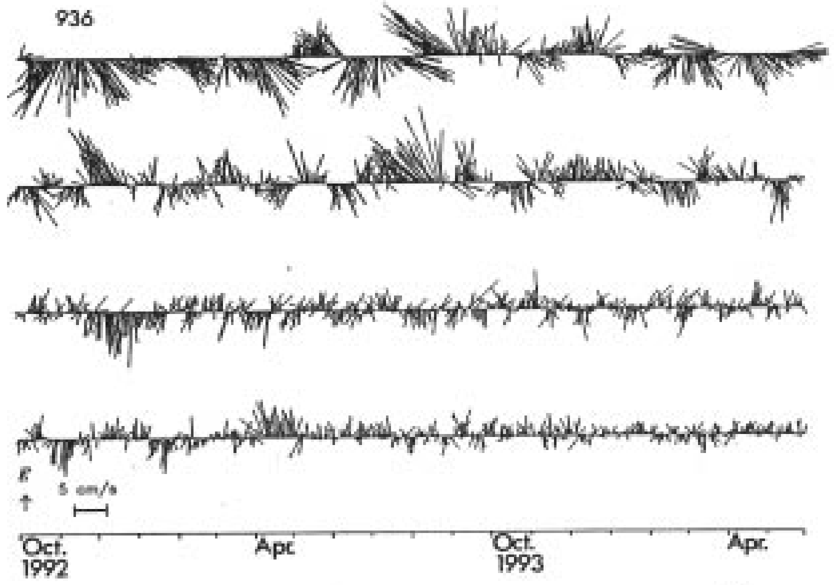

Figure 3. Vector velocity time series for mooring 936, at approximately 1°N. Eastward velocities are up, and the 5 cm s^{-1} scale is shown on the plots. Depths of instruments are (top to bottom) 3297 m, 3896 m, 4096 m, and 4297 m.

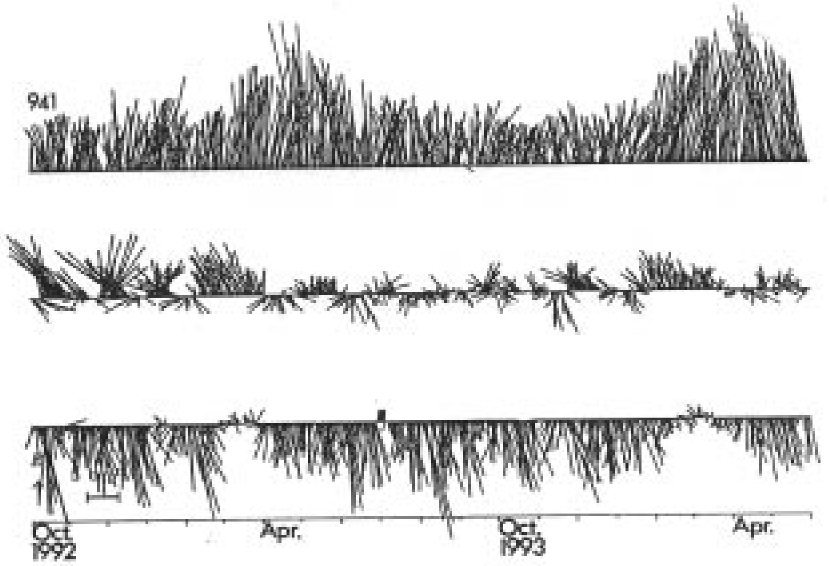

Figure 4. As in Figure 3, but for mooring 941, near 1.5°S. Depths of instruments are 3899 m, 4099 m, and 4300 m.

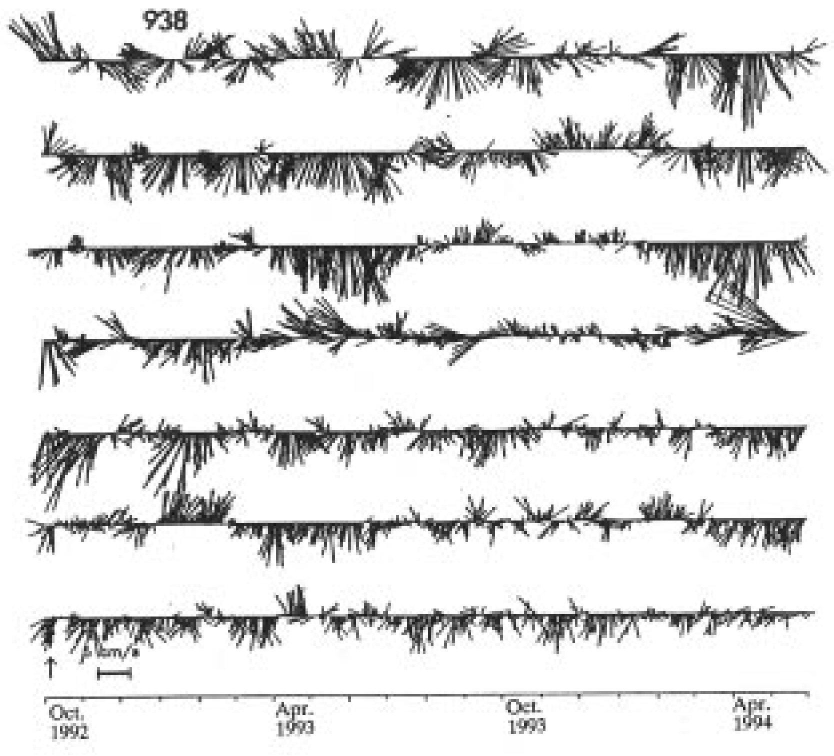

Figure 5. As in Figure 3, but for mooring 938, on the equator. Depths of instruments are 2993 m, 3293 m, 3593 m, 3892 m, 4093 m, 4292 m, and 4485 m.

4300, and 4500 m). What is interesting here is that there appears to be vertical coherence of the flow throughout the water column between 3000 and 4450 m at times. As at mooring 939, mean zonal velocities at 938 are all westward, confirming that eastward flow of NADW is confined south of the equator.

Temperature variance from the moored data at all locations was 2–10 times greater at 4100 m than at other depths, and these records all showed a linear warming trend. The high variance at the 4100 m instruments suggests that they were located near the interface between AABW and NADW, which is characterized by the strong vertical gradient of potential temperature between the two layers. It is not yet clear whether this interface receded downward during the deployment period, or whether the deep and bottom water properties underwent a long time scale change during the time of deployment. Figure 6 shows lowpassed time series for potential temperature at 4100 m (smoothed with a 15-day boxcar filter): the visual coherence between different locations is confirmed quantitatively as well. In fact, cross-correlations between records at 4100 m are significantly higher than either correlations between temperatures at different depths on the same mooring, or cross-correlations between temperature time series at either 3900 or 4300 m.

In summary, preliminary conclusions based on the moored data (presented by J. Whitehead at the South Atlantic Symposium in Bremen, August 1994) include the following:

1. A relatively steady westward (from southern to northern hemisphere) flux of Antarctic Bottom Water exists. The current is strongest in the southern half of the gap, as found by Rhein *et al*.
2. A preliminary estimate of this cross-equatorial flux is about 2.1 Sv.
3. A strong long-lived jet of North Atlantic Deep Water is present above the Antarctic Bottom Water, but is confined south of the equator, in agreement with Rhein *et al.*
4. A warming of about 0.25–0.35°C occurred at 4100 m during the deployment (equivalent to about 0.5°C per 1000 days), accompanied by strong high frequency variability. Neither the warming nor this strong variance occurred at any other depth in the array.

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References

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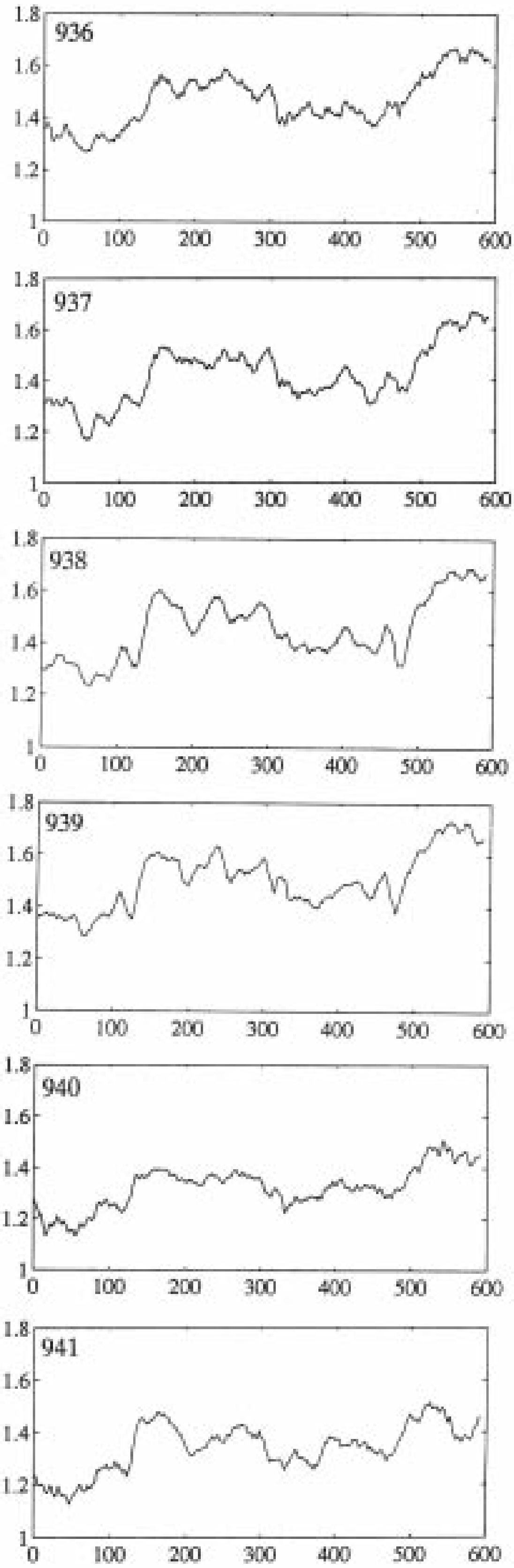

Figure 6. Lowpassed time series of potential temperature at 4100 m from the six mooring locations, for the common time period. The abcissa is sequential days, beginning with 1. The ordinate is °C. The 15-day boxcar filter yields time series that are 590 days in length.