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Recent decadal warming and freshening of Antarctic-derived abyssal waters

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Waters of Antarctic origin play a large role in the global meridional overturning circulation (Lumpkin and Speer, 2007). These waters dominate the abyss and ventilate a significant fraction of the entire global ocean (Johnson, 2008). Here we review evidence of recent decadal warming of these Antarctic-derived abyssal waters around much the global oceans, and recent freshening of these waters in some basins near their source regions. We also attempt to assess the potential contribution of these changes to global heat and sea level budgets. Hydrographic sections occupied mostly in the 1990's during the World Ocean Circulation Experiment (WOCE) provided a high-accuracy near-global survey of ocean water properties. A subset of these sections has been reoccupied in the current decade by international repeat hydrography programs in support of CLIVAR and CO2 studies. Comparison of these repeat sections have revealed statistically significant warming in abyssal waters around various parts of the globe over the past decade. Abyssal freshening has also been observed with repeat section data in more limited regions around Antarctica over the past few decades. In the Atlantic sector of the Southern Ocean, deep and bottom waters have been warming over recent decades in the Weddell Sea (Fahrbach et al., 2004), although that trend appears to have been partially reversed in the last several years. Repeat hydrographic sections show that abyssal waters derived from Antarctica have warmed considerably over the last few decades in all the deep western basins of the South Atlantic (Coles et al., 1996; Johnson and Doney, 2006) and their signatures appear to be weakening in the western basins of the North Atlantic as well (Johnson et al., 2008b). More frequent bottom temperature data in a few deep passages such as the Vema Channel (Zenk and Morozov, 2007) and the equatorial Atlantic (Andrie et al., 2003) also show warming over the past few decades. The Indian Ocean has not yet been extensively resurveyed since WOCE, but the Australian-Antarctic Basin and the Princess Elizabeth Trough both shows signs of significant abyssal freshening and warming in recent decades (Rintoul, 2007; Johnson et al., 2008a). However, the eastern Indian Ocean Basins to the north of the Southeast Indian Ridge show no such changes (Johnson et al., 2008a). Recent and upcoming repeat sections should be useful in exploring for abyssal changes in much of the rest of the Indian Ocean west and north of the Australian-Antarctic Basin. In the Pacific Ocean, warming has been observed over recent decades in the relatively vertically and laterally homogenous abyssal layers throughout much of the main basins of the Pacific, from Antarctica all the way to the Aleutian Islands (Fukasawa et al, 2004; Kawano et al., Johnson et al., 2007). The rate of warming is generally larger in the south and smaller in the north, consistent with two known factors. First, abyssal waters of Antarctic feed into the Pacific from the south, and changes in properties might be expected to be largest near the source. Second, lateral temperature gradients generally decrease to the north, so velocity changes working on these gradients would produce smaller temperature anomalies in the north. Similarly to the Indian Ocean, in the deep Pacific basins closest to Antarctica, there are also indications of abyssal freshening, consistent with freshening in some of the Antarctic source regions for these waters (Jacobs 2004). The large distances between hydrographic sections, and the fact that they are reoccupied only from decade to decade makes quantification of the contribution of the observed recent abyssal warming to the global heat budget difficult. Quantification of the contribution of the warming and freshening observed to the global sea level rise budget is difficult for the same reasons. However, we can attempt to quantify the local contributions for each section. For the heat budget, these range from 0.9 W m-2 applied along the portion of a section with bottom depths exceeding 3000 m in the Australian Antarctic Basin of the Indian Ocean (Johnson et al., 2008a), to 0.5 W m-2 along the western S. Atlantic (Johnson and Doney, 2006), to 0.06 W m-2 in the western S. Pacific and 0.01 W m-2 in the far N. Pacific (Johnson et al., 2007). These numbers can be compared with a recent global upper ocean decadal heat gain estimate of 0.6 W m-2 (Willis et al., 2004). However, the latter number is normalized to the surface area of the Earth, but the deep ocean estimates are made in terms of local heat gains. Similarly, the warming and freshening below 3000 m in the Australian-Antarctic Basin contributes to a local sea level rise of 4 cm over 12 years in the deepest portions of that basin (Johnson et al., 2008a), compared with a global average sea level rise of 3.1 mm yr-1 since 2003 (Nerem et al., 2006). Changes in other regions are much smaller. Nevertheless, this qualitative analysis suggests that abyssal changes may play some role in global heat and sea level rise budgets.

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