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Preface

Southern Ocean shelf slope exchange

1. Introduction

Cold, dense water masses generated over the Antarctic continental shelves make a major contribution to the global thermohaline circulation. The volume flux and properties of these waters are constrained by cross-slope exchange and mixing of shelf and offshore water masses along the Antarctic shelf break. Two national programs, the US Antarctic Slope ("AnSlope") experiment and the Italian Climate Long-term Interaction of the Mass balance of Antarctica ("CLIMA") program, have significantly advanced our understanding of processes through intensive measurements in the northwest Ross Sea. This issue contains a collection of four papers that describe the oceanographic environment of this region, and another four papers that report theoretical and numerical models of the Antarctic Slope Front and the contribution of tides. These papers reveal a complex environment in which energetic variability at small spatial and temporal scales has a significant impact on the contribution of Antarctic shelf seas to the circulation of deep water in the global ocean.

2. Background

Water masses on the Antarctic continental shelf are cooled by heat loss to the cold polar atmosphere in the austral fall and winter, and by contact with the base of the floating ice shelves that fringe much of the continent. The density of shelf-resident water masses is further increased by brine rejection during sea ice formation. The resulting cold, dense water escapes the continental shelf, and its signature can be traced throughout much of the deep global ocean as Antarctic Bottom Water (AABW). The total production rate of AABW and related dense water types is comparable to that for North Atlantic Deep Water.

The mechanisms by which water masses are modified on the shelf by buoyancy fluxes including ocean/ice interactions are relatively well-known, even if still difficult to quantify. In contrast, the processes that determine the flux of new waters onto the shelf and the export of recently modified cold, dense water into the deep ocean are poorly understood. In the last decade, significant progress has been made in identifying the primary locations of cross-slope exchange, including the onshore flux of water originally derived from the Antarctic Circumpolar Current and the offshore flux of shelf-modified waters.

The US Antarctic Slope ("AnSlope") experiment and the Italian "CLIMA" program generated an extensive data set for one of these locations, the northwest Ross Sea (Fig. 1). Preliminary results have been reported by Gordon et al. (2004), Erofeeva et al. (2005) and Whitworth and Orsi (2006). The most dramatic oceanographic feature observed during the first year of the AnSlope field program was an intense outflow of cold, salty shelf water from the Drygalski Trough (Gordon et al., 2004). The velocity of the outflow was about 0.6 m s^{-1} at about a 35° angle downslope of the local isobaths, and the benthic layer thickness was of order 100 m. Export of less saline shelf water is also found to the east of Drygalski Trough (Bergamasco et al., 2002). Whitworth and Orsi (2006) analyzed temperature, salinity and current data from moorings over the outer shelf, finding that the energetic tides in this region were critical to both the cross-slope transport of the outflowing high salinity shelf water (HSSW) and the mixing experienced by the HSSW before it reached the shelf break. Erofeeva et al. (2005) improved the accuracy of tidal models for this region by assimilating current data measured with the hull-mounted acoustic Doppler current profiler (ADCP) during the first AnSlope cruise on the *RVIB Nathaniel B. Palmer*. Interpretation of mooring measurements and the new tide model showed that tidal currents sometimes exceed 1 m s^{-1} over the outer shelf and upper slope. These strong currents explain the rapid, intermittent downslope benthic flows of almost pure HSSW observed at a mid-slope mooring (Gordon et al., 2004) north of the Drygalski Trough sill.

The variation of hydrography and velocity at short (tidal) time scales combined with a short internal Rossby radius of deformation ($\sim$5 km) and steep bottom slopes (up to 1:6) place significant constraints on our ability to measure specific processes and to interpret data obtained in this region. Nevertheless, various factors that contribute to cross-slope exchange processes and mixing have been identified as being worthy of further study. These processes include the dynamics of the Antarctic Slope Current (ASC) associated with the Antarctic Slope Front (ASF), tides, local and regional wind forcing, sea ice, and icebergs. The AnSlope data set also has inspired new ways to think about the fate of the dense shelf water outflows, whose properties vary with the texture of the Ross Sea bathymetry and temporally on times scales from tidal to interannual.

3. The US AnSlope experiment

The US AnSlope program, funded by the Office of Polar Programs of the US National Science Foundation, began its field phase in early 2003, with final mooring recovery in early 2005. The program involved three cruises on the *RVIB N.B. Palmer* (Fig. 2)

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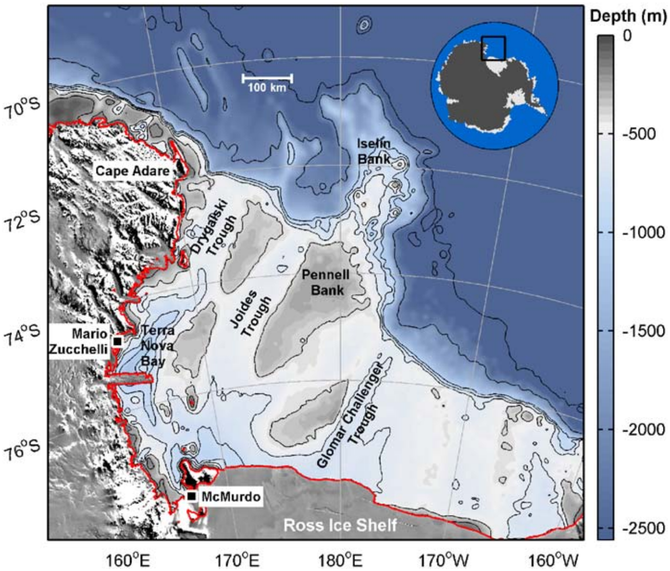

Fig. 1. The Ross Sea continental shelf and adjacent regions, identifying various geographic features referred to in the special issue. The region shown is indicated on the inset map of Antarctica, upper right. Water depths are shaded (color scale on right), with black contours indicating the 200, 400, 600, 800, 1000, 2000 and 3000 m isobaths. Locations of the US McMurdo Station on Ross Island and the Italian Mario Zucchelli Station at Terra Nova Bay are indicated.

NBP03-02, NBP04-02 and NBP04-08, during which full-depth profiles of temperature (*T*), salinity (*S*), dissolved oxygen (O_2), velocity (**u**) and microstructure were collected at several hundred station locations from the shelf to the adjacent deep ocean. Water samples were collected for tracer geochemistry studies. Several moorings were deployed, for two-year-long periods, to measure time series of *T*, *S* and **u**.

The main research question motivating the AnSlope program was: *What is the role of the Antarctic Slope Front (ASF) and continental slope morphology in the exchanges of mass, heat, and freshwater between the shelf and oceanic regimes, in particular those leading to outflows of dense water into intermediate and deep layers of the adjacent deep basins and world ocean circulation?* As it is impractical to investigate the total ~18,000 km length of the ASF, a site was selected based on evidence in archived data that the major processes of interest were all present. The northwest Ross Sea exhibits a well-developed ASF and associated ASC, is well known as a source of dense water outflows via the complex of submarine troughs cutting across the Ross Sea shelf from the Ross Ice Shelf to the shelf break, and has strong tidal currents. Moreover, the region is much more accessible all year than the suspected primary ventilation site for AABW in the southern and western Weddell Sea. As the previously cited papers and those in this volume attest, the program was successful in measuring each of these features previously deemed to be relevant to addressing the program goals.

4. The Italian CLIMA program

The Italian CLIMA program in the Ross Sea has provided the general framework in which physical oceanographic activities within the Italian National Program for Antarctic Research have been carried out since 1994. The CLIMA program, utilizing the *Research Supply Vessel Italica* (Fig. 3), has studied various aspects of the Ross Sea continental shelf, with a focus on the Terra Nova Bay region. CLIMA obtained CTD data over the Ross Sea shelf, including along the shelf ice margin and within Terra Nova Bay

Fig. 2. The Research Vessel Ice Breaker Nathaniel B. Palmer used during AnSlope.

Fig. 3. The Research Supply Vessel Italica used during the CLIMA Program.

(Budillon and Spezie, 2000) and over the continental slope (Bergamasco et al., 2002). CLIMA current meter moorings extend the coverage of the AnSlope program's arrays.

5. The collection

The following collection includes four papers describing ship-based and mooring observations from the AnSlope and CLIMA programs. Orsi and Wiederwohl provide a detailed account of the circulation and structure of the water masses of the Ross Sea and adjacent area. Gordon et al. discuss the regional view of the gravity current descent into the deep ocean. Visbeck and Thurnherr describe lowered ADCP data that demonstrates the intense small-scale fluctuations of the velocity field associated with the gravity current over the upper continental slope. Capello et al. relate the presence of turbidity or nepheloid layers to the thermohaline stratification of the benthic layer over the outer shelf and slope.

Four modeling studies provide a complementary view of AnSlope, CLIMA and related observations along the Antarctic shelf break. Padman et al. show that the tidal currents near the shelf break have a significant impact on the mean outflow of dense shelf water. Ou et al. describe an analytical model for investigating the spread and descent of dense water. Guan et al. explore the effect of tidal mixing on the gravity currents. Baines presents a model for the Antarctic Slope Front.

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