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Hydrodynamics of the Indian Ocean sector of coastal Antarctica

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ABSTRACT

The report addresses preliminary results from the temperature and salinity profiles recorded by using XCTD probes deployed along the ship track from Prydz bay (68.69°S, 75.29°E) to India bay (69.26°S, 12.94°E) during the 28th Indian Scientific Expedition to Antarctica. The data was collected during 11th - 17th February, 2009,onboard M. V. Emerald Sea. In the Prydz bay region, cold Antarctic Surface Water sinks to deeper depth near 70°E. This region is dominated by closed cyclonic gyre adjacent to the Amery Ice Shelf. Being a closed circulation, there is inflow of cold water from the east near the West Ice Shelf and outflow near Cape Darnley and due to its confined nature waters tend to be more salty in this region. In the India Bay region, high salinity is encountered with salinity range of 34.5 and above in regions where Circumpolar Deep Water is present. Isohaline at this site suggest upwelling of warm waters towards the subsurface. At the surface some regions show less saline water, with salinity ranging from 33 to 33.5, due to presence of fresh water from melting of ice.The T-S diagram shows the presence of Circumpolar Deep Water, Antarctic Bottom Water, Antarctic Surface Water, Continental Shelf Water and signatures of Winter Water.At 70°E an eastward transport of 2.5Sv is associated with high geostrophic velocity of ~15cms^{-1} at surface, while at 50°E southward transport of 1.2Sv is associated with a poleward velocity of 2.5 cms^{-1}.Comperatively high values of heat and salt content are observed at at 60°E, 40°E and 20°E, which could be attributed to warm and saline Circumpolar Deep water.

Keywords: XCTD data, thermohaline structure, heat content, geostrophic currents

INTRODUCTION

The coastal Antarctic circulation has been poorly understood and documented because of lack of hydrographic data, which is due to requirement of expensive logistics (research vessel and operating costs) and inclement weather. Very few historical (bottle and CTD casts) ship transects with high spatial resolution hydrographic data are available in gaps in this sector.The most important feature of this sector is the Antarctic Coastal Current which is the southernmost current of the southern Ocean. It flows westward parallel to the Antarctic coastline. The current is an important component of the very active air-sea exchange in this area that leads to deep convection and production of deep ocean water masses. The Antarctic Bottom Water and Antarctic Intermediate Water obtain their fundamental characteristics (Tchernia and Jeannin, 1980) in this region. A large horizontal pressure gradient in the frontal zone over the continental slope intensifies the wind-driven flow and produces the high velocity core of the Antarctic Coastal Current.

Fahrbach et al. (1994) reported that freshening of the upper one kilometer of near-surface coastal/ocean waters increases the sea surface height near the coast thereby, leading to the onshore pressure gradient. The resulting geostrophic flow is in the same direction as the wind-driven flow and this leads to the intensified Antarctic Coastal Current. Tchernia and Jeannin (1980) found that in the areas of the current closest to shore, it exhibited small loops of 4 to 6 km diameter that lasted 4 to 8 days. The loops became larger, more frequent, and of longer duration. They hypoth-esized that the southernmost areas of the current are steered on the left by the continental margin, providing stability. When the current flows farther offshore at greater depths and turns to the east on account of the Coriolis force. This causes the circulation to become more unstable, leading to large amplitude meanders of the Antarctic Coastal Current which pinch off ed-dies which eventually drifts offshore and enters the cyclonic circulation. The modern approach to understanding the complex role of convective mixing, deepening of the mixed layer through action of polar easterlies, and transport of the water characteristics by eddies and Antarctic Coastal Cur-rent is through a combination of field measurements like the one proposed here, long-term microwave measurements from space and numerical mod-eling.

OBJECTIVES

Repeated hydrographic observations are required to compare and quantify changes in the hydrodynamics over a period of many years; how-ever, such observations are impractical because of the high costs of char-tering research vessel. To overcome this problem, we have initiated a project to record hydrographic data in the Indian Ocean sector of coastal Antarc-tica by deploying expendable temperature, conductivity and depth probes (XCTDs) which are launched from a moving ship. The major objectives of this study are to (1) study interannual variability in thermohaline changes during the austral summer, (2) quantify the thickness of melt water associ-ated with melting of ice, (3) identify the water masses to characterize mix-ing, and (4) quantify the heat and salt content of the ocean. We attempt to address these by deploying expendable temperature, conductivity and depth probes (XCTDs) along the ship route between Prydz bay and India bay.

The data were collected aboard M. V. Emerald Sea chartered for the 28th Indian Scientific Expedition to Antarctica during the period 11th to 17^{t}h February, 2009.

DATA AND METHODS

The vertical profiles of temperature and salinity (symbol • in Fig. 1) were recorded using XCTD manufactured by Tsurumi Seiki Company Limited (model: XCTD-3; terminal depth: 1000 m; temperature accuracy: ±0.02°C and salinity accuracy: ±0.03 $mScm^{-1}$). The XCTD probes were deployed at every longitude to record temperature and salinity in the upper 1000 m of the ocean. Our earlier comparison of XCTD-3 and Sea Bird CTD profiles reveal that the former is consistent with temperature and salinity accuracy specified by the manufacturer, and the fall rate for the XCTD probes showed no systematic bias in the fall equation provided by the manufacturer. The quality control for the profiles was carried out by adopting the following procedure (Bailey et al., 1993). (1) The geographic coordinates and the launch time of each XCTD were checked against the sampling logs. (2) Each profile was examined to eliminate readily visible malfunctions, such as broken wire and obvious bad profiles due to faulty probes were rejected. (3) Each profile was inspected for spikes caused by external electromagnetic interference and insulation penetration, temperature inversion due to wire stretch and leakage etc. (4) Profiles with high frequency spikes and temperature inversions greater than 0.2°C were rejected. (5) Waterfall plots for each track were generated to evaluate further consistency of the profiles, and those profiles with temperature offset greater than 0.5°C were rejected in this process. (6) High frequency noise in the salinity profiles was minimized by applying a median filter with a 15 m window (Xiaojun et al., 2004).

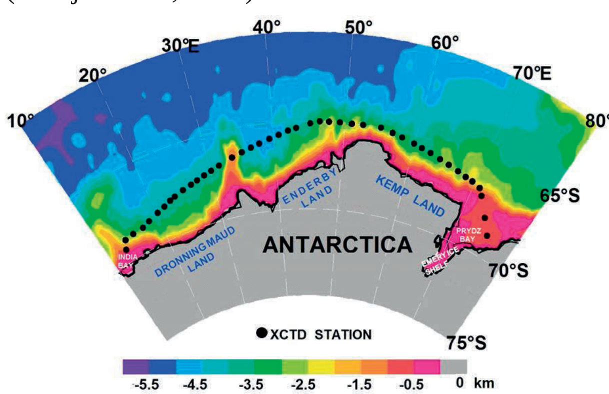

Figure 1. Bathymetry from TOPEX/Poseidon (light gray contours, km; Smith and Sandwell, 1997) overlaid with XCTD (•)stations occupied during 11th to 17th February 2009.

The geostrophic velocity across a pair of stations was calculated relative to the deepest common level (1000 db) available from the XCTD data using the following the method (Pond and Pickard, 1993):

$$Tg=\frac{1}{f}\int_{-1000}^{0}\Delta\Phi dz \quad (1)$$

where f is the Coriolis parameter (s^{-1}) at a mean latitude, dz is depth interval (m) and $\Delta\phi$ is geopotential anomaly (m^2s^{-2}) between the adjacent pair of XCTD stations.

Heat content (Jm^{-2}) and salt content (kgm^{-2}) of the region for the layer 0 - 750m has been computed from the temperature and salinity values, by using the equation suggested by Bathen (1971).

$$HC= \; C_p \;{}_{0}^{750} Tdz. \quad 2$$

Where, p is the seawater density (kgm^{-3}), Cp is the specific heat of seawater at constant pressure ($Jkg^{-1}\,°C^{-1}$) and T is the depth averaged temperature. Salt content along the transect was computed using the equation

$$SC=0.001*\rho\int_{0}^{750} Sdz, \quad (3)$$

where S in the depth averaged salinity.

RESULTS AND DISCUSSION

Figure 2 depicts vertical structures of temperature and salinity prepared from the data collected from 44 stations at each longitude which were occupied from Prydz bay (68.69°S, 75.29°E)to India bay (69.26°S, 12.94°E). From the temperature section it is clearly seen that the winter water layer of temperature below -1.98°C is well developed over entire section. Between 40° and 60°E, signature of warmer Circumpolar Deep Water extends up to the surface. This may possibly be due to the upwelling of subsurface waters promoted by wind and the local topography as this region is closer to the Antarctic subcontinent. Circumpolar Deep Waters with temperature range of 0.1-2°C and salinity ranging from 34.62-34.73 are one of the major source of heat being transferred from sub-Antarctic regions to the Antarctic region which is one of the mechanisms for melting the sea ice during summer season.

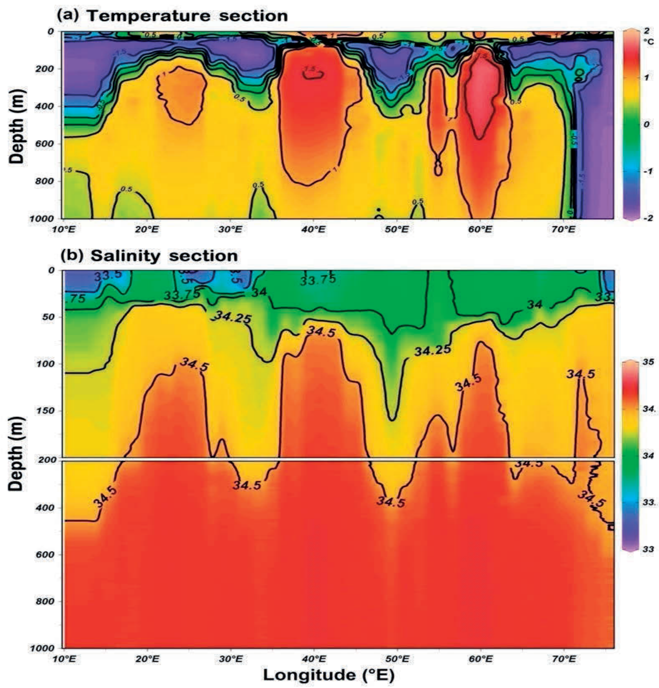

Figure 2.Vertical structure of: (a) temperature (°C) and (b) salinity,along the ship track. The salinity section is enlarged in the vertical to focus on close salinity contours in the upper 200 m.

In the Prydz bay region, the cold Antarctic Surface Water sinks to deeper depth near 70°E. This region is dominated by closed cyclonic gyre adjacent to the Amery Ice Shelf. Being a closed circulation, there is inflow of cold water from the east near the West Ice Shelf and outflow near Cape Darnley and due to its confined nature waters tend to be more salty in this region. Being in the proximity of cyclonic gyre, the Antarctic Divergence (AD), between 60° and 100°E, the eastward-moving ACC, driven by the prevailing westerlies, meets the westward flowing Antarctic Coastal Current which sums up to the circulation pattern in this region, resulting in the typical thermohaline structure.

In the India Bay region, Weddell Sea gyre plays a dominant role in the evolution of the temperature and salinity pattern. Previous studies have showed that Circumpolar Deep Waters tend to bypass the Antarctic Circumpolar current and enter the gyre. This mixed saline Circumpolar Deep Water along with the cold shelf waters of the Antarctica makes it one of the Deep water formation region. Salinity section reveals high salinity with salinity range of 34.5 and above in regions where Circumpolar Deep Water is present. Isohaline at this site suggest upwelling of warm water towards the subsurface. At the surface some regions show less saline water with salinity ranging between 33 to 33.5 which is basically due to fresh water generated from melting of ice.

Figure 3 shows θ-S scatter diagrams of all the profiles collected along the coastal track. The T-S diagram shows the presence of Circumpolar Deep Water (temp: 0.1-2°C, sal: 34.62-34.73), Antarctic Bottom Water (temp: 0.9-1.7°C, sal:34.64-34.72), Antarctic Surface Water (AASW) (temp: -1 to 1°C, sal: 34.0-34.6), Continental Shelf Water (temp: ~ –1.85°C, sal: ~34.56) and Winter Water (temp:-1.9°C, Sal: 34.34). Super Cooled Water having temperature below -2°C as documented in previous studies is missing during 2009.

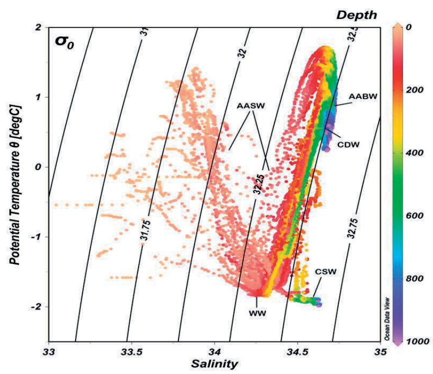

Figure 3.T-S scatter diagrams of all the profiles collected along the coastal track.

Figure 4 depicts geostrophic velocity (Tg) for the entire section and varies between -5 to 5 cms^{-1}. At 70°E an eastward transport of 2.5Sv is associated with high geostrophic velocity of ~15cms^{-1} at surface. This is the same location in Prydz Bay region where downwelling of cold waters from the surface occurred. At 50°E southward transport of 1.2Sv is associated with a poleward velocity of 2.5 cms^{-1}.

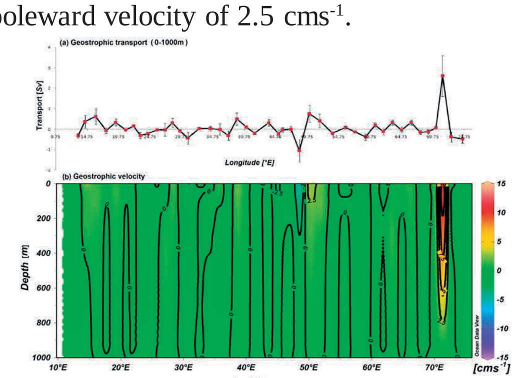

Figure 4. Geostrophic transport (1 Sv=10^6 m^{3}s–1) for the 0-1000 m slab relative to the deepest common level between the XCTD stations.

Heat content and salt content for 0-750 m is seen higher in the regions where signatures of Circumpolar Deep Water were detected (Figure 5). Comperatively high values of heat and salt content are observed at 60°E, 40°E and 20°E with values 844x10^9 Jm^{-2}, 2.66 x10^4 kgm^{-2}, 843 x10^9 Jm^{-2}, 2.66x10^4 kgm^{-2} and 842 x10^9 Jm^{-2}, 2.66 x10^4 kgm^{-2} respectively. At 60°E heat content is seen higher than at 40° and 20°E because temperature profile shows warm water of Curcumpolar Deep Water extendsupto 1000 m at this longitude. Lower values of heat and salt content, 834 x10^9 Jm^{-2}, 2.65 x10^4 kgm^{-2} at 75°E and 838 x10^9 Jm^{-2}, 2.645x10^4 kgm^{-2} at 10°E are observed in the western Prydz bay and eastern India Bay due to characteristics vertical density patterns depicted in Fig. 2.

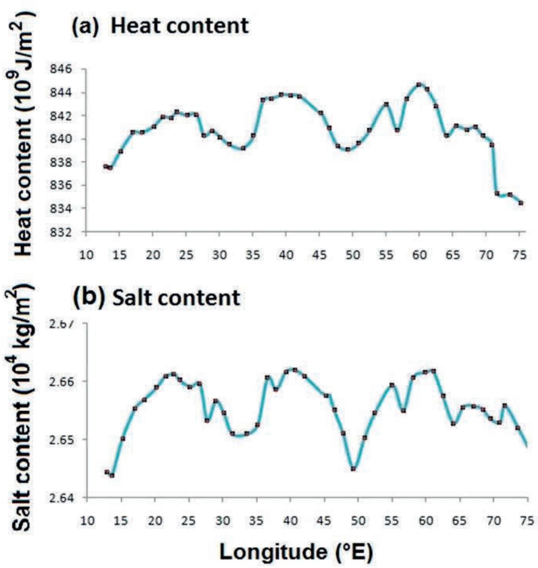

Figure 5. Variation of heat and salt content (0-750 m) along the ship track from Prydz bay to India bay.

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