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A model for the structure of the Antarctic Slope Front

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ABSTRACT

The Antarctic Slope Front is an oceanic front that appears to be a semi-permanent feature situated above or near long sections of the shelf break of the Antarctic continental shelf. These sections include the shelf break of the Ross and Weddell Seas. It is distinguished by a V-shaped structure, unique to coastal Antarctica, in which isopycnals slope downward from near the surface on both the shallow (continental shelf) and the deep (continental slope) sides, toward the bottom near the upper part of the slope. In the regions where it is observed, the overflow of dense water from the shelf down the slope is observed or presumed to occur. Such overflows entrain fluid from the overlying stratified environment into the downflow, and this entrainment acts as a distributed sink of the overlying fluid. A model of this frontal structure is constructed here, consisting of the downslope flow modelled as a plume, and the overlying fluid governed by quasi-geostrophic dynamics, with the effect of the plume on the latter being represented by a suitable distribution of sinks. The alongslope currents follow from geostrophy and potential vorticity conservation. Two distinct flow regimes are found. In the first regime, a realistic depiction of the two-sided V-shaped structure is obtained, where most of the fluid flowing off the shelf enters the downflow at the top of the slope constituting the shallow side of the V, and fluid from offshore enters the deep side of the V. Alongslope flow in this region is mostly eastward. In the second regime, where most of the fluid flowing off the shelf passes over the downflow, only the shallow side of the V is present, and alongslope flow is westward near the shelf break and eastward further offshore.

1. Introduction

The Antarctic Slope Front (ASF) constitutes a boundary between the Circumpolar Deep Water over the continental slope around Antarctica, and water over the continental shelf. It is a unique phenomenon in the world's oceans, in a unique environment. It has a characteristic V-shaped density structure, in which the isopycnals slope downward toward the upper part of the continental slope (in an onshore–offshore section) from both the shelf water and the water over the slope, although in some locations only the seaward half of the "V" is observed. It has been observed in many locations along the edge of the continental shelf, particularly in the Ross and Weddell Seas, and is assumed to exist at most longitudes to varying degrees, though it appears to be weak or absent in the sector in the South-East Pacific, on the western side of the Antarctic Peninsula as far as the Ross Sea. The ASF is often observed or inferred to occur in conjunction with the overflow of dense water off the shelf and down the continental slope. The surface signature of the ASF is weak, with most of its structure below about 200 m or more. Its presence is generally thought by many to be related to the process of the overflow of dense shelf water, which results in Antarctic Bottom Water, and this is the basis of the dynamical model described here.

The dense overflow water is formed from a mixture of three water masses (Gill, 1973). A model of the ASF has been described by Ou (2007), which assumes three homogeneous water masses: shelf water, Circumpolar Deep Water and "surface water", for which the junctions form a V-shaped structure capped on the surface by a layer of ice. This model is two-dimensional and steady state, and balances in fluxes of mass, heat and salt are evaluated. The flux of shelf water down the slope is balanced by a conversion of Circumpolar Deep Water (CDW) to surface water over the shelf. Some useful relationships and constraints on heat and salt fluxes are obtained, but the model does not attempt to explain the observed dynamical structure of the ASF.

Observations in the Weddell and Ross Seas have described the incipient formation of Antarctic Bottom Water by mixing of dense shelf water with lighter water over the continental slope (Muench and Gordon, 1995; Gordon et al., 2004). Such downflows into density-stratified environments are known from laboratory studies to entrain ambient fluid into them from above under suitable dynamical conditions, notably that the slope is steep enough (Turner, 1973; Baines, 2001, 2005). Such entrainment is

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also observed in the oceanic downflows around Antarctica, and in others such as the Denmark Strait overflow in the North Atlantic (Baines, 2008). This entrainment increases the flux of the downflow, and is a local small-scale mixing process that is well parametrised by an entrainment coefficient that is dependent on a bulk local Richardson number (Ellison and Turner, 1956; Turner, 1986; Baines, 2002, 2005). The effect of this entrainment on the ambient fluid above the downflow may be represented by a distributed array of sinks that removes fluid from the local environment and transfers it to the downflow.

The model of the ASF presented in this paper divides the fluid region into two parts with different dynamics, but with interactions between them. The first part consists of the downflow region, modelled as a plume with nonlinear rotating hydraulic dynamics, entraining the environment above. The second part consists of the overlying rotating stratified environmental fluid, modelled with quasi-geostrophic or semi-geostrophic dynamics. This division of a fluid region into different parts with different dynamics is common in fluid dynamics, with boundary layers in general and Ekman layers in particular being good examples.

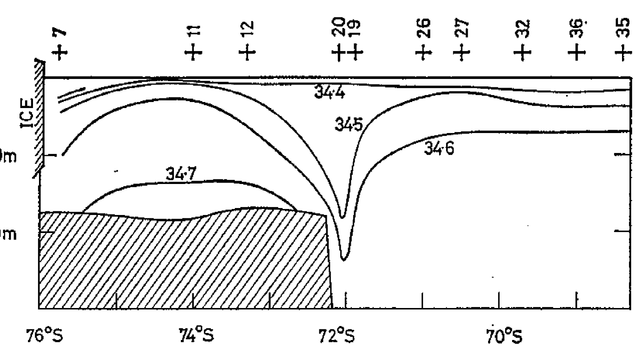

Fig. 1. Salinity field near 50°W in the Weddell Sea, taken by *Glacier* in 1968 (from Gill, 1973).

2. Observations and description of the Antarctic Slope Front

The ASF was first identified and described by Gill (1973) from an analysis of observations accumulated by previous workers in the Weddell Sea. Fig. 1 shows a North–South (approximately) section of salinity taken across the shelf break in the southwest part of the Weddell Sea at the longitude 50°W by the *Glacier* in 1968. Though the effects of both temperature and salinity on density are significant, this salinity pattern is qualitatively representative of density, and the V-shaped pattern is evident, with a region that is approximately homogeneous (in salinity) inside the V. This structure is more pronounced here than in sections further east. Fig. 2 shows a section in the central part of the Ross Sea, taken from Jacobs (1991), which is another main reference for observational details of the ASF, and appears to deserve the credit for coining the name. This figure shows data taken at (approximately) 175°W in December 1976, depicting temperature, salinity and net density. From the dynamical viewpoint the density section is the most significant, and is perhaps the most revealing of the V-shaped structure. The contrast between the shelf waters and the Circumpolar Deep Waters over the slope is stark and clear, and the ASF is seen as relatively narrow and sharp in comparison with the length scales of variation in the shelf and deep waters.

Fig. 3 (from Jacobs, 1991) shows sections of temperature and salinity from the *Ilas Orcadas* at 10 °W in the eastern Weddell Sea

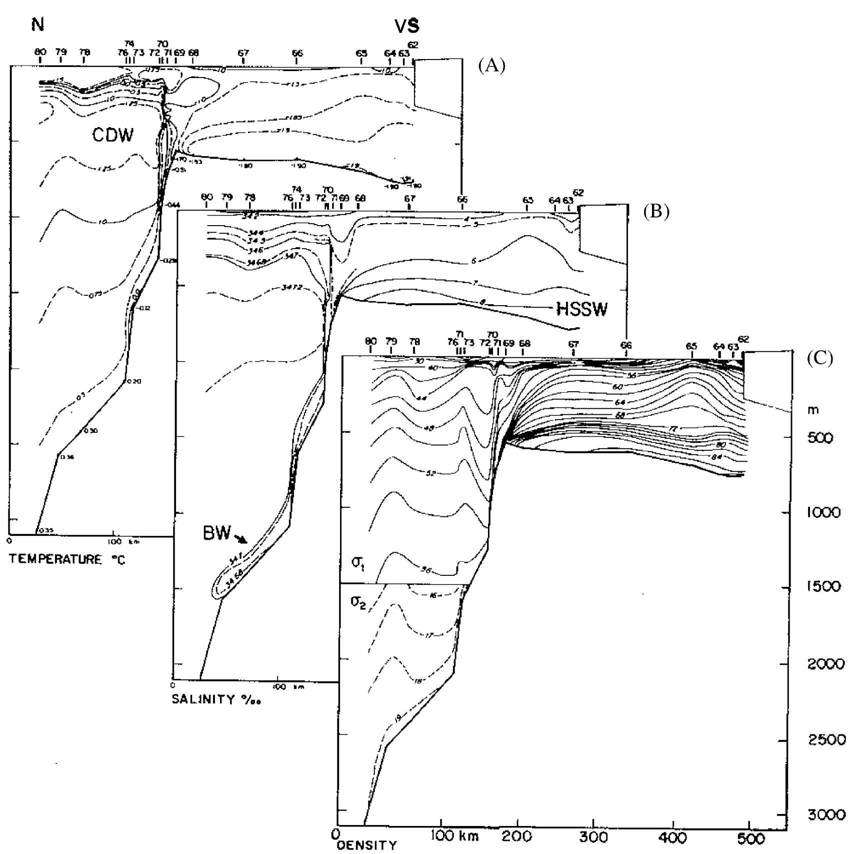

Fig. 2. Vertical sections of (A) temperature, (B) salinity and (C) density taken across the continental slope and shelf in the Ross Sea at approximately 175°W in December 1976 (from Jacobs, 1991).