# Oceanographic processes near the Filchner Sill – plans for fieldwork in 2007

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## Introduction

Over the Antarctic continental shelves, the focus of attention has been on the export of cold dense shelf waters to the world's deep ocean and their contribution to Antarctic Bottom Water (AABW) production. Far less attention has been given to the import, onto the continental shelves, of surface and warm deep waters, which are key components of the heat, salt and mass budgets for the shelf seas. In order to quantify these budgets, mechanisms that control the rate of cross-shelf exchange need to be identified if we are to better understand the interactions between the Antarctic shelf seas and adjacent oceans.

In the southeastern Weddell Sea, east of 26°W, the water masses over the narrow continental shelf are separated from the deep ocean by a series of fronts and associated currents. During winter, cooling leads to the formation of Winter Water (WW), while over the continental shelf water masses are freshened by glacial melt from the ice shelves that fringe the region [*Fahrbach et al.*, 1994]. This cross-shelf density gradient supports a westward slope front current. In addition, the prevailing easterly winds produce a surface Ekman transport, leading to an increase in sea surface elevation toward the coast and a downwelling of the isopycnals that both deepens the interface between the WW and the underlying Weddell Deep Water (WDW) and supports a westward coastal current. In the southeastern Weddell Sea where the open shelf is very narrow, these currents effectively merge and are referred to as the Antarctic Coastal Current [*Fahrbach et al.*, 1992].

Once the coastal current passes the Stancomb-Wills Ice Stream, which overhangs the shelf break, the continental shelf broadens and the current separates into coastal and slope components [*Foster and Carmack*, 1976]. The coastal component heads south towards Brunt Ice Shelf while the slope component flows west towards the Filchner Sill. North of Helmert Bank, WDW is found below the depth of both the shelf break and the troughs that cut some 200 m deeper into the surrounding shelf. Nevertheless, despite the physical and dynamic barriers associated with the shelf break, WDW is able to upwell and access the continental shelf in a modified form. These intrusions of Modified Weddell Deep Water (MWDW) occur at various locations along the shelf break, although only two persist beyond the shelf break region and extend southwards toward Filchner Ronne Ice Front. The aim of the forthcoming cruise in early 2007 is to identify the shelf break processes that control the upwelling of MWDW onto the shelf, and determine the flux of heat, salt and mass across the continental shelf break around the Filchner Sill region and along the Luitpold Coast (Figure 1).

## Observations

Over the southern Weddell Sea, perennial sea ice usually restricts ship access to all but the eastern shelf region, Filchner Depression, and ice front polynyas, with very few observations from the continental shelf region west of Filchner Depression [*Nicholls et al.*, 2003]. The CTD

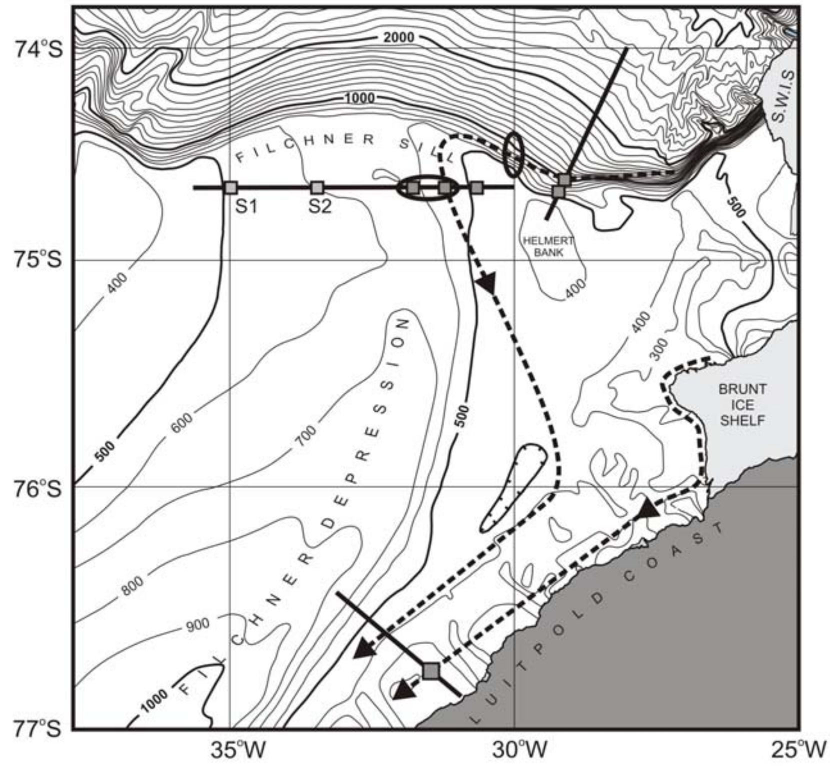



**Figure 1.** Map showing the region around the Filchner Sill in the southern Weddell Sea. The contours are of bathymetry with a separation of 100 m and the arrows show the principal inflows across the shelf. The squares indicate mooring locations planned for deployment in early 2007 and the thick lines across Filchner Sill and the shelf break show planned CTD sections. The southern most line shows the location of the temperature section shown in Figure 3 and the ovals highlight the locations of the CTD profiles shown in Figure 2.

sections used in this paper were obtained in early 2003 and 2005 (Figure 1), although sections across Filchner Sill have been obtained on numerous occasions. Focusing on the accessible eastern shelf region and continental slope, observations over the shelf break along 30°W and further to the east, show the WDW temperature maximum located around 800 m over the continental slope with a broad thermocline separating the WDW from the colder (–1.8°C) Winter Water (WW) (Figure 2, stn. 64). The slope current continues eastward following the continental slope before a proportion turns south, crossing the Filchner Sill and introducing MWDW onto the continental shelf around 31°W. The numerous Conductivity-Temperature-Depth (CTD) sections across the Filchner Sill show this persistent core of MWDW on the eastern flank, centred around 400 m depth during the months of January and February (Figure 3). The distance between the slope and sill observations, following the 500 m contour, is less than 50 km. Assuming the MWDW on the slope undergoes no further modification over this distance, it must rise at least 200 m in 50 km between Stn 65 and Stn 32 (Figure 2), as it negotiates the 120° turn onto the eastern flank of Filchner Sill. To date, no current meter or wintertime measurements have been obtained from this MWDW core, though CTD observations show its summertime evolution as it flows southward across the continental shelf roughly following the 400 m contour (Figure 3), until losing its characteristics before reaching Filchner Ice Front.

Over the central and western part of the Filchner Sill (Figure 3a, stations 33-41), the upwelling is over 100 m greater and presumably the result of other upwelling mechanisms. These MWDW intrusions are frequently observed around 300 m, although they appear erratic in their size and lateral position, unlike the deeper eastern core, which appears to follow the slope topography (Figure 3a, stations 31-32). From existing observations it is clear that MWDW upwells in the

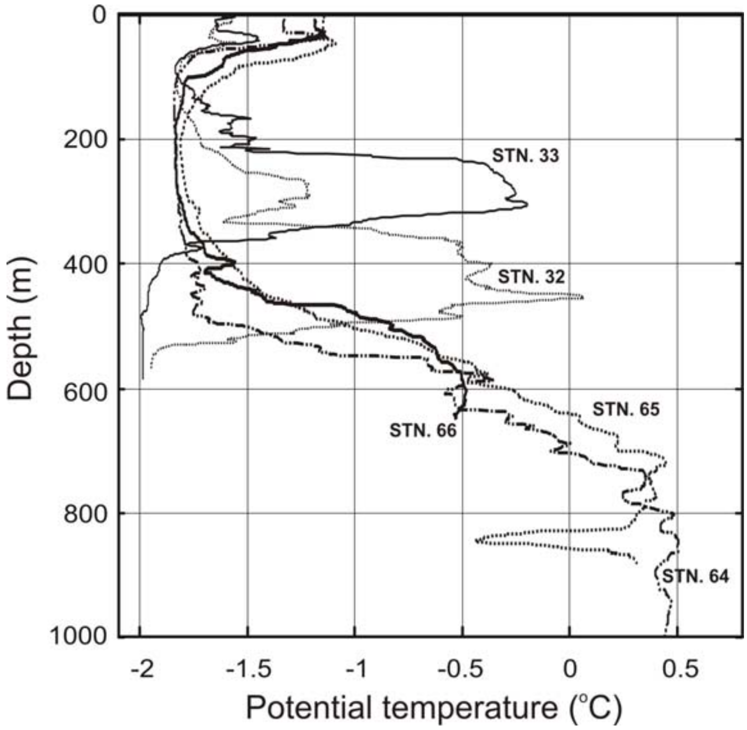


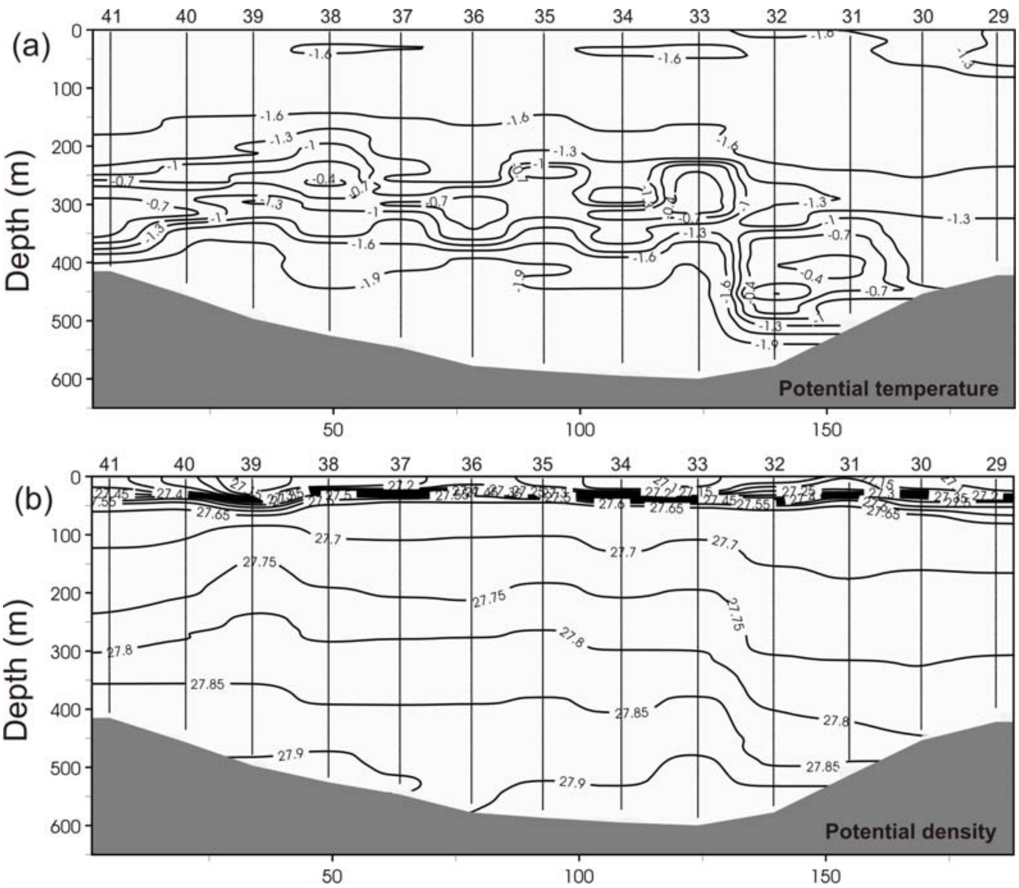

**Figure 2.** Vertical profiles of potential temperature for Filchner Sill (stations 32 and 33 in Figure 2) and the continental slope (stations 64, 65, and 66 along 30°W). The profile locations are within the ovals shown in Figure 1.

region around Filchner Sill and that the processes governing this shelf-ocean exchange are likely to be numerous and complex. Further to the west, a persistent core of MWDW is observed throughout much of the year, mid-way along Ronne Ice Front [*Foldvik et al.*, 2001], having crossed the 400 km wide shelf. Close to the shelf break around 44ºW, bathymetric data obtained during the ROPEX98 cruise shows a 200 m deep trough cutting through the shelf, very similar in cross-section to the Filchner Sill. Presumably, the MWDW reaching Ronne Ice Front accesses the shelf via this trough, suggesting that persistent flows of MWDW crossing the shelf break are topographically steered, although it remains uncertain which dynamic processes are responsible for the upwelling.

In addition to deep upwelling and southward flow of MWDW toward Filchner Ronne Ice Front, a shallow coastal flow is observed during summer bringing relatively warm, low-salinity water around Brunt Ice Shelf and along the Luitpold Coast toward Filchner Ice Front [*Abrahamsen et al.*, 2003; *Nicholls*, 2005] (Figures 1 and 3). This coastal flow is likely to be the southward branch of the coastal current surface waters originating west of Stancomb-Wills Ice Stream [*Foster and Carmack*, 1976]. With no direct or year-round measurements of this current, its seasonal variability in both properties and flux are unknown as are its contribution to the heat, salt, and mass budgets of the shelf region east of Filchner Depression.

## Potential upwelling and mixing mechanisms

The Antarctic continental shelf break presents both a physical and a dynamic barrier to the exchange of water masses between the deep ocean and the shelf seas. Nevertheless in the southern Weddell Sea, MWDW is clearly able to access the shelf region via Filchner Depression for example, with water masses upwelling over 200 m in only 50 km. How this MWDW accesses the continental shelf is currently unknown although several mechanisms may be relevant in this region.



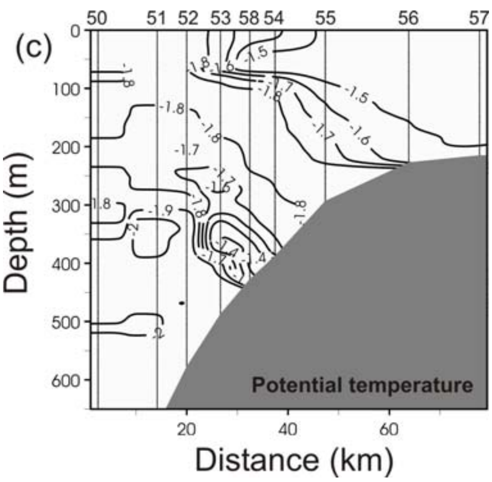




**Figure 3.** Contour plots of (a) potential temperature and (b) potential density for the section across Filchner Sill at 74°40´S [*Abrahamsen et al.*, 2003] and (c) the potential temperature section from around 76.7°S [*Nicholls*, 2005] (See Figure 1). The vertical lines show the location of the CTD profiles.

Using a numerical model, *Williams et al.* [2001] investigated the adjustment of an along-shelf barotropic shelfbreak jet to cross-shelf channel topography, in a scenario almost identical to that found in the southern Weddell Sea. Parameterising the channel topography in terms of the shelf and channel depth together with the speed of the coastal current and the Coriolis parameter, gives a measure of whether the flow is expected to follow the topography. Applying this parameterisation to the weakly stratified water column, with a density contrast of $<0.2$ kg m$^{-3}$ below the surface mixed layer, suggests that the topographic control on the flow is likely to be significant at the shelf break and Filchner Sill. In addition to providing a mechanism for turning the shelf break flow into Filchner Depression, *Williams et al.* [2001] also offer a mechanism for the upwelling of WDW onto the shelf. As the flow along the shelf break turns through 120° into the Filchner Depression because of the topographic control, it must change its relative vorticity. In order to conserve potential vorticity as the flow negotiates the corner, it must shoal, thus effectively bringing deeper waters up onto the Filchner Sill. Once at the sill, other mechanisms take the MWDW across the shelf toward Filchner Ice Shelf.

Another possible upwelling mechanism is that proposed by *Kampf* [2005], who used numerical simulations and laboratory experiments to show that dense water cascading down a broad submarine channel that cuts through the shelf break, induces localized upwelling of deep water into the channel and up onto the shelf. This upwelling is associated with the cascading process and the geostrophic adjustment of a density front that establishes along the channel axis, helping to drive deep waters up into the channel. This situation is similar to that found at the Filchner Sill. Between stations 32 and 33, a weak front separates the outflowing ISW from the inflowing MWDW (Figure 2b) that will help drive both the upwelling and the flow onto the shelf.

Although not strictly applicable to the southern Weddell Sea, a study by *Carmack and Chapman* [2003] showed that upwelling-favorable coastal winds generate downwelling at an offshore sea ice edge. When the downwelling region was situated over the shelf, almost no upwelling of deeper waters occurred, however when the downwelling region moved beyond the shelf break there was an abrupt change and deep water upwelled onto the shelf. This downwelling region could be analogous to the low-density V-shaped coastal current situated over the shelf break, which blocks the passage of WDW onto the shelf. Where the coastal current moves over the deep waters of the shelf break this may lead to a more favourable upwelling region. Equally, as the coastal current follows the shelf break, changes in the shelf break gradient may cause a dynamic response, with the current narrowing and deepening over steep topography preventing or restricting upwelling, while broadening and shoaling of the coastal current over more gentle topography may providing favourable upwelling conditions.

Other mechanisms that may influence the modification of WDW and its flow onto the shelf include tidal processes. Tides are likely to play a significant role in water mass modification at the shelf break as a result of strong mixing in the thick benthic boundary layer (150 m) that develops due to the proximity of the $M_2$ critical latitude [*Foldvik et al.*, 1990; *Pereira et al.*, 2002; *Robertson*, 2001]. In addition to vertical mixing, lateral mixing may also be relevent in some areas of the continental shelf [*Beckmann and Pereira*, 2003], with numerical models showing that tidal mixing is not uniformly distributed along the shelf break. In the troughs along the shelf break, tidal currents and the associated mixing are relatively weak and correspond to areas where significant flows of MWDW access the continental shelf. In the shallower regions, which act as a physical barrier to the flow of MWDW onto the shelf, strong tidal currents lead to greater mixing and the loss of water mass characteristics. This stronger tidal mixing will also help maintain any frontal structures along the shelf break, thus providing an additional dynamic barrier to on-shelf flow. In the shallower area to the east of the Filchner Sill, *Foster et al.* [1987] found that MWDW upwelled onto the shelf as a result of barotropic continental shelf waves, though the mixing with shelf waters led to deep water formation rather than significant flows of MWDW across the shelf.

## Preliminary cruise plan

During early February 2007, RRS Ernest Shackleton will be used to deploy a series of moorings and undertake CTD sections over the continental slope, across the Filchner Sill, and close to the Luitpold Coast (Figure 1). Water samples will be collected for isotopic analysis and moorings will provide the first direct year-round measurements of the two primary flows across the continental shelf, on the eastern side of Filchner Depression. In total, six new moorings are planned and their locations are shown in Figure 1. On the continental slope, two moorings will monitor the depth and strength of the thermocline between the WW and WDW, while three moorings on the eastern flank of the Filchner Sill will monitor the flow and properties of the MWDW core as well as its horizontal and vertical extent. To the south, a mooring will monitor the flow and water mass properties of the current along the Luitpold Coast. Also, mooring S2 will be maintained and mooring S1 may be re-established; both will monitor the flow of ISW out of Filchner Depression. Combined with CTD observations, the mooring data will help identify the mechanisms that control the rate of cross-shelf exchange, the upwelling of MWDW onto Filchner Sill, the spatial and temporal variability of these inflows, as well as potentially providing a useful analogue for the normally inaccessible trough around 44°W. These data will also allow a determination of the heat, salt, and mass fluxes across the Filchner Sill and the continental shelf east of Filchner Depression, thus providing an estimate for the magnitude of the MWDW inflow associated with the 44°W trough. In addition, five Weddell seals will be tagged with miniature CTD units and Argos transmitters; these data will be the first winter CTD measurements over this shelf region, complimenting the data from the conventional moorings and CTD sections.

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