THE FAWN TROUGH: A MAJOR PATHWAY FOR THE ANTARCTIC CIRCUMPOLAR CURRENT ACROSS THE KERGUELEN PLATEAU

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Introduction to the circulation around the Kerguelen Plateau

Owing to its large meridional extent (~18° in latit ude) and relatively shallow depths, the Kerguelen Plateau constitutes a major barrier to the eastward flowing Antarctic Circumpolar Current (ACC) in the Indian sector of the Southern Ocean (Figure 1). Previous work showed that most (~100 Sv, 1 Sv = 10^6 m^3 s^{-1}) of the ACC transport is deflected north of the Kerguelen Islands (Park et al., 1993), which implies that a substantial remainder (~50 Sv) has to cross the plateau through two deep passages: the Fawn Trough (56°S, 2650 m) in the middle part, and the Princess Elizabeth Trough (64°S, 3650 m) close to Antarctica. Using two hydrographic WOCE sections (I8 and I9), McCartney and Donohue (2007) suggested a transport of about 40 Sv across the Fawn Trough. Yet, this estimation was only indirect, because the two WOCE sections did not cross optimally the Fawn Trough and Princess Elisabeth Trough areas. These authors also suggested a powerful Australian-Antarctic cyclonic gyre with an unprecedented transport (~100 Sv) in this basin, while the traditional view barely mentions the possibility of such a subpolar gyre. This gyre is associated with a powerful western boundary current strongly concentrated along the eastern flank of the southern Kerguelen Plateau.

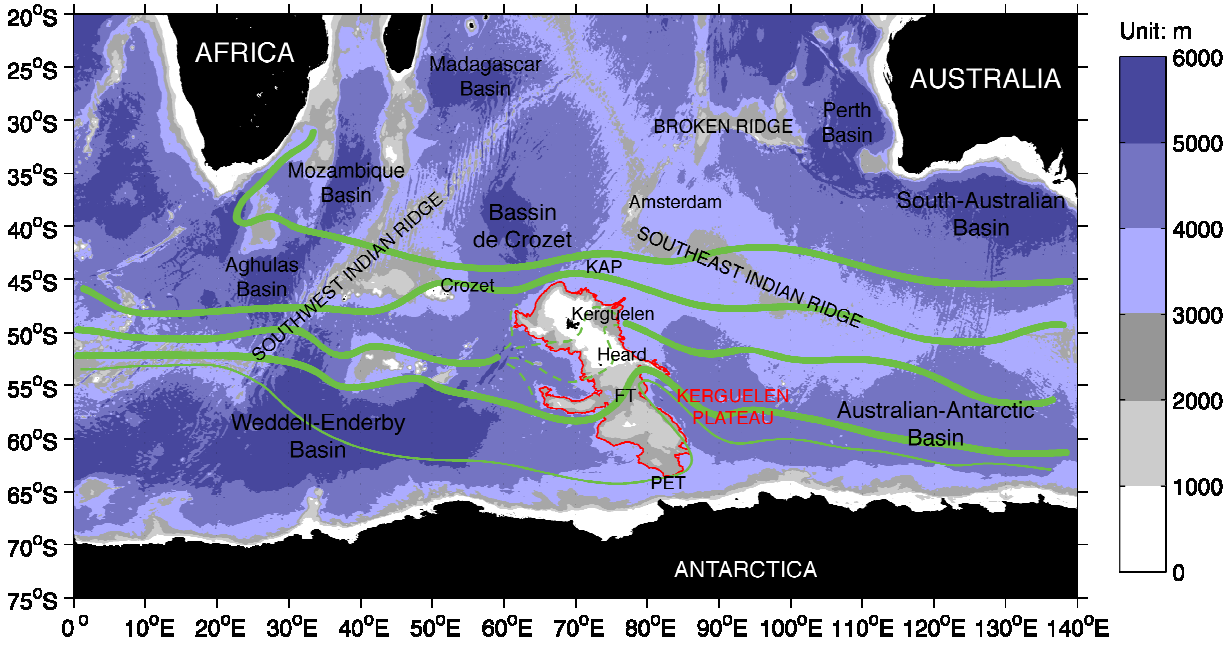

Figure 1

Bathymetry (meter) of the South Indian Ocean. The Kerguelen Plateau is highlighted using the 3000 m contour line. The Fawn Trough (FT) lies in the middle of the Kerguelen Plateau, while the Princess Elizabeth Trough (PET) lies to its south. Also, main ACC pathways are indicated (blue lines): from north to south, the Agulhas return current, the Sub-Antarctic Front, the Polar Front (splitted over the shallow Northern Kerguelen Plateau), the Southern ACC Front, and the Southern Boundary. Adapted from Roquet (2009b).

The analysis of hydrographic data collected by instrumented elephant seals has recently confirmed the existence of a strong northeastward current across the Fawn Trough (Roquet et al., 2009a). The Fawn Trough appeared to act as a veritable bottleneck, channeling the quasi-totality of the cold Antarctic Surface Water found south of the Ice Limit (58°S) and the Circumpolar Deep Water transiting the Enderby Basin toward the Australian-Antarctic Basin. Other more conventional datasets (hydrography, satellite and floats) together with oceanic general circulation models have consistently provided additional clues supporting the existence of the Fawn Trough current (Roquet, 2009b). Yet, a quantitative knowledge of the transport across the plateau was still missing due to the lack of ship-based observations over the plateau.

The TRACK project

This knowledge gap has been largely filled thanks to finely resolved hydrographic data and direct current measurements made in the Fawn Trough area during the two legs of the TRACK project (TRACK1 in January-February 2009 and TRACK2 in January 2010) on board the R/V Marion Dufresne II. TRACK (TRansport ACross the Kerguelen plateau, PI: Y.-H. Park) aimed at quantifying the ACC transport through the Fawn Trough and its variability. The field program of the project also included a 1-year-long deployment of three mooring lines of current meters across the passage, and the deployment of 12 ARGO floats. We will now present some results based on hydrographic and current measurements obtained during the two surveys.

During TRACK1, 60 CTD-O2 casts have been sampled, along 7 sections (Figure 2, black dots). TRACK2 has been designed to complement efficiently the first leg, redoing the sections crossing the Fawn Trough and the Deep Western Boundary Current. A transect between Heard and Kerguelen Islands has also been added. Finally, 57 casts have been sampled during TRACK2 (Figure 2, red dots). For each cast, direct current measurements have been performed simultaneously using two LADCPs and the Marion Dufresne SADCP.

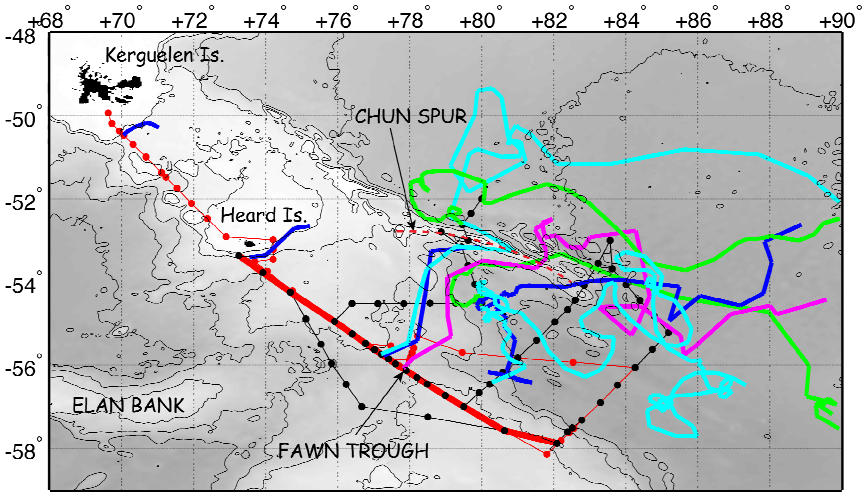

Figure 2

Cruise map of TRACK cruises, showing the leg 1 (Feb-March 2009, black dots) and the leg 2 (Jan 2010, red dots). The trajectories of ARGO floats deployed during TRACK are also shown. The thick red line indicates the stations used to plot the properties across the Fawn Trough in Figure 3.

Hydrography and transport across the Fawn Trough

The Fawn Trough section sampled during TRACK1 is presented in Figure 3. This section shows clearly the powerful and deep-reaching 50-km wide jet (stations 17-22), associated with a 43 Sv transport according to LADCPs. A strong baroclinic structure is observed in the temperature and salinity fields. Consequently, velocities are largest at the surface (up to 70 cm/s), then decreasing gradually to a yet non-negligible 15 cm/s bottom velocity (2600 m). The two hydrographic markers of the Fawn Trough current proposed by Roquet et al. (2009a) are well observed in this section: the crossing of the 0ºC isotherm in the subsurface minimum temperature layer, and of the 2ºC isotherm in the deep maximum temperature layer.

The coldest and freshest bottom water is not observed at the deepest part of the Fawn Trough sill, but further south along the southern flank of the sill (station 23). This bottom water, carried northward by the Deep Western Boundary Current, is meandering westward across the Fawn Trough section, before returning eastward and then southward in the Australian-Antarctic Basin. A 6 Sv branch is also detected just south of Heard Islands, which is thought to be the main pathway of water masses flowing over the shallow Northern Kerguelen Plateau (Park et al., 2008).

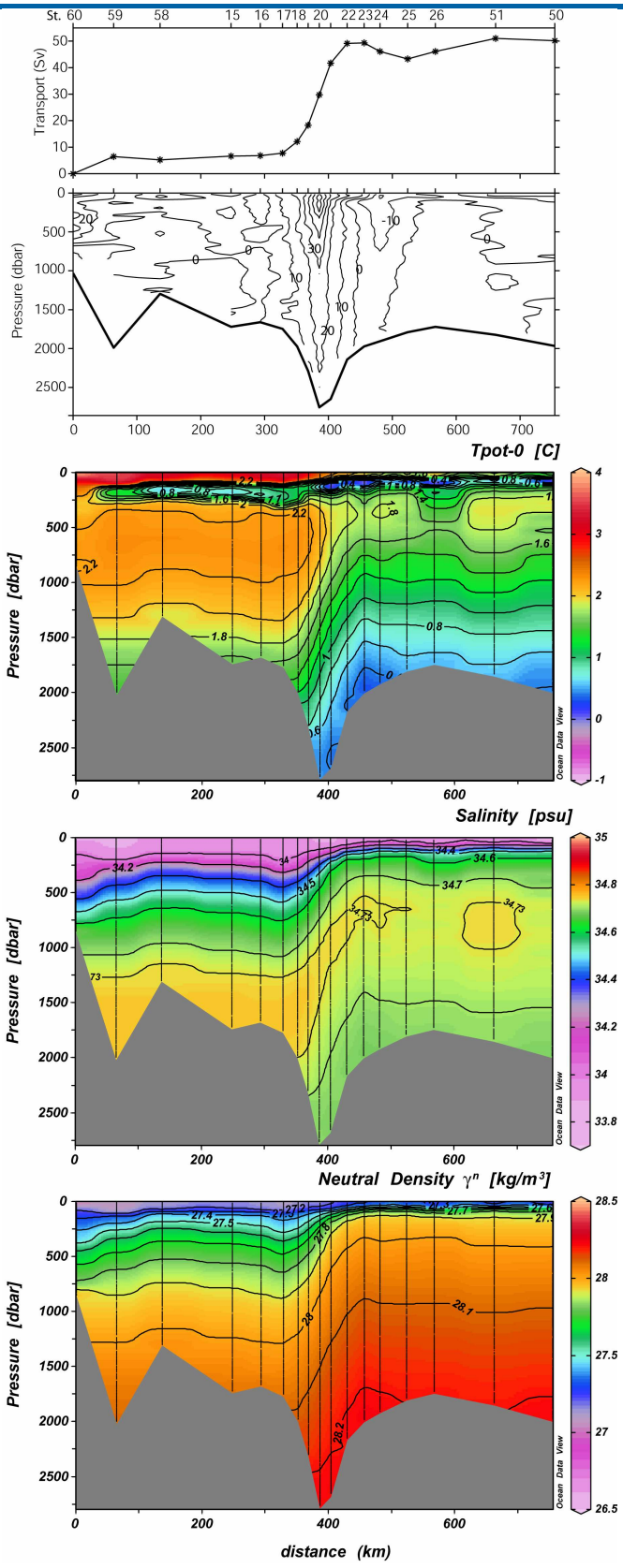

Figure 3 - Properties across the Fawn Trough (see thick red line in Figure 2 for casts position), as measured during the first leg of TRACK. From top to bottom, cumulative transport (Sv), LADCP speeds (cm/s), potential temperature (ºC), salinity (PSU) and neutral density (kg.m-3). The Fawn Trough current is clearly seen between stations 18 and 22 as an intense jet associated with enhanced meridional gradients of hydrographic properties. From Roquet (2009b).

A more thorough analysis of LADCP data obtained during TRACK1 revealed a net eastward transport of 58 Sv south of the Kerguelen Islands, which represents ~40% of the regional ACC transport (~150 Sv) (Park et al., 2009). The 43 Sv of the Fawn Trough current thus represents ~30% of the ACC transport, demonstrating the major importance of this ACC branch. The Princess Elizabeth Trough, south of the Kerguelen Plateau, originally thought to be a major passage for the ACC flow (Orsi et al., 1995), was finally found to be only minor (7 Sv). Although substantially weaker than in the McCartney and Donohue (2007) study, the Australian-Antarctic Gyre is well detected along the eastern flank of the Southern Kerguelen Plateau with a substantial 36 Sv transport.

ARGO deployments

A total of 12 ARGO floats have been deployed in the cruise area to obtain a better coverage of the hydrographic sampling. During TRACK1, we deployed 5 PROVOR and 2 ARVOR around the Fawn Trough. During TRACK2, 5 additional PROVOR have been deployed. A total of 717 profiles were logged on the 15th of February 2010, including more than 200 profiles in the TRACK cruise area. A delayed-mode procedure based on comparison of deep T/S correlations between the different ARGO floats and the TRACK data showed an overall satisfying quality of ARGO data, with salinity accuracy within the standard range ±0.01 psu. The trajectory of these floats revealed two interesting features of the fine-scale circulation between the Fawn Trough and the Chun Spur (Figure 2). Firstly, it could be clearly seen that the Chun Spur blocks efficiently most of the circulation, inducing a southward deflection of the flow along its western edge. Only a rather small surface flow is allowed around 53ºS, 78ºE. Secondly, 3 ARGO floats remain still during several months in a limited area lying at the centre of the circle formed by the cyclonic trajectory of the Fawn Trough current (54ºS, 80ºE), associated with subpolar waters carried by the Deep Western Boundary Current (see also Figure 4).

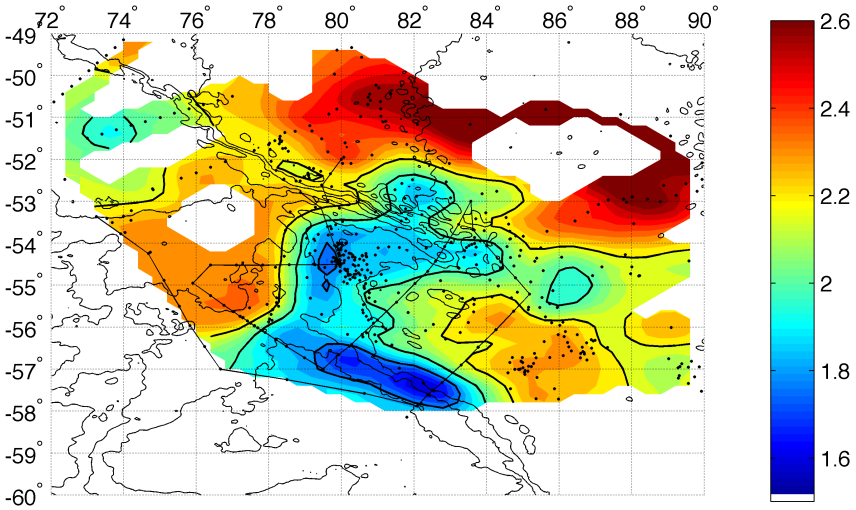

Figure 4

Map of the potential temperature (ºC), within the deep maximum temperature layer characterizing Upper Circumpolar Deep Water.

The combination of these several sources of profiles allowed us to map hydrographic properties at fine-scale for the first time in the Fawn Trough area. In Figure 4, we present a map of temperature taken in the maximum temperature layer characteristic of the Upper Circumpolar Deep Water south of the Polar Front. This map has been obtained by combining data from TRACK1, TRACK2, the 12 ARGO floats, and KEOPS data (see Park et al., 2008) to complete the picture over the Northern Kerguelen Plateau. We remark that the ARGO profiles complemented very efficiently the coverage of the two TRACK surveys, especially in the area along the Chun Spur. The Fawn Trough current can be accurately followed by the 2.2ºC and 2ºC isotherms in the maximum temperature layer. A tongue of cold water (<1.8ºC), characteristic of subpolar regions, is also seen along the eastern flank of the southern Kerguelen Plateau, gradually fading out while forming a U-turn in the area between the Fawn Trough and the Chun Spur, thus indicating the presence of mixing with surrounding warmer waters.

Discussion

So far, TRACK has fulfilled several of its objectives. The transport across the Kerguelen Plateau has been measured directly for the first time, demonstrating the major path across the Fawn Trough, and its jet-like structure. The CTD-O2 profiles obtained during the two surveys complement very efficiently the oceanographic database in a key area that was still so badly sampled. It is

now confirmed that the area upstream the Fawn Trough sill is a major convergence area between ACC and subpolar waters, and thus should be regarded as a possible key area for monitoring the southern ocean variability. The on-going analysis of mooring data in combination with satellite altimetry and models should allow us to quantify the transport variability across the Kerguelen Plateau, and hopefully to determine what sets this variability.

Acknowledgments

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