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Extended abstract

Ocean circulation and frontal structure near the southern Kerguelen Plateau during the Kerguelen Axis marine ecosystem survey

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A relatively large research effort has historically focused on the northern part of the Kerguelen Plateau, providing an improved view of the ocean circulation at regional (McCartney and Donohue, 2007; Park et al., 2008; Roquet et al., 2009) and more local scales (Park et al., 2009; van Wijk et al., 2010; Vivier et al., 2015). Here we focus on the ocean circulation and frontal structure between the southern section of the Kerguelen Plateau and the Antarctic margin (Heywood et al., 1999; McCartney and Donohue, 2007).

A regional-scale marine ecosystem study was undertaken in January–February 2016, to survey the southern part of the Kerguelen Axis (KAXIS, Figure 1). The RV *Aurora Australis* voyage was primarily designed to determine the spatial differentiation of the marine food webs (i.e. krill-based and fish-based) and assess the biophysical drivers underlying these ecological transitions. A comprehensive multidisciplinary program covered physical oceanography, trace metals (iron and other micronutrients), active acoustics, carbon, genetics, primary and bacterial production, zooplankton communities (with particular focus on krill, copepods, salps and pteropods), and mesopelagic fishes and squid (via depth-stratified net sampling).

This abstract summarise the oceanographic circulation and frontal structure observed during the KAXIS voyage (Figure 1). These results are reported in full in Bestley et al. (2018), which provides the physical context for the KAXIS ecological program. Hydrographic data were collected at 47 conductivity-temperature-depth (CTD) stations (Rosenberg and Eriksen, 2016) and water properties used to describe key water masses and infer frontal locations. These observations were combined with environmental and satellite data products to provide a broader regional perspective including bathymetry, sea-ice concentration, sea-surface height, temperature and colour as well as 334 compiled Argo float trajectories (Figure 2). Our results are generally consistent with previous hydrographic studies (Bindoff et al., 2000; Heywood et al., 1999; McCartney and Donohue, 2007; Meijers et al., 2010; Orsi et al., 1995; Sokolov and Rintoul, 2009a, 2009b; Sparrow et al., 1996; Williams et al., 2010) and show the steering of currents by topography dictates both the southern extent of the Antarctic Circumpolar Current (ACC) influence and the northern limit of subpolar waters.

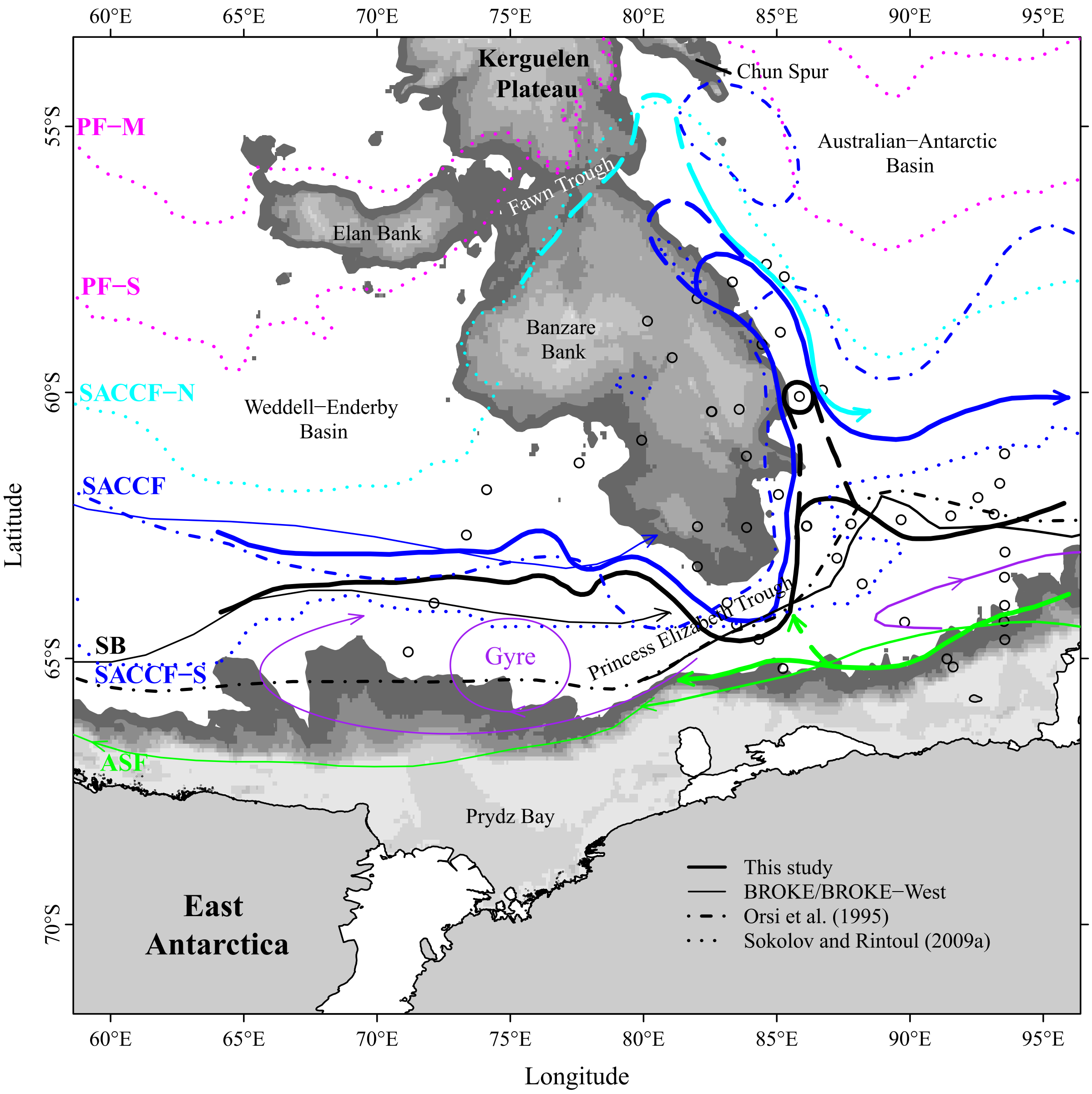

Figure 1: Location of oceanic features around the southern Kerguelen Plateau compiled from this and previous studies. Major fronts shown include: the Antarctic Slope Front (ASF), the Southern Boundary (SB), the Southern ACC Front (SACCF) and its northern branch (SACCF-N), as well as the southern (PF-S) and middle (PF-M) branches of the Polar Front. Fronts are grouped by colour with the line styles indicating associated references (bold lines – this study; solid lines east of 80°E: BROKE survey – Bindoff et al., 2000; solid lines west of 80°E: BROKE-West – Meijers et al., 2010; Williams et al. 2010; dashed lines – Orsi et al., 1995; dotted lines – Sokolov and Rintoul, 2009a). Subpolar gyres are also shown: the Prydz Bay Gyre in the west and the recirculation within the Australia-Antarctic basin in the east (purple). CTD station locations are shown as open circles (n = 47). Background displays bathymetry (Weatherall et al., 2015) at 500 m intervals to 3 000 m. Major geographical features are named, with the Antarctic continent and major ice features shown in grey and white, respectively (reproduced from Bestley et al., 2018).

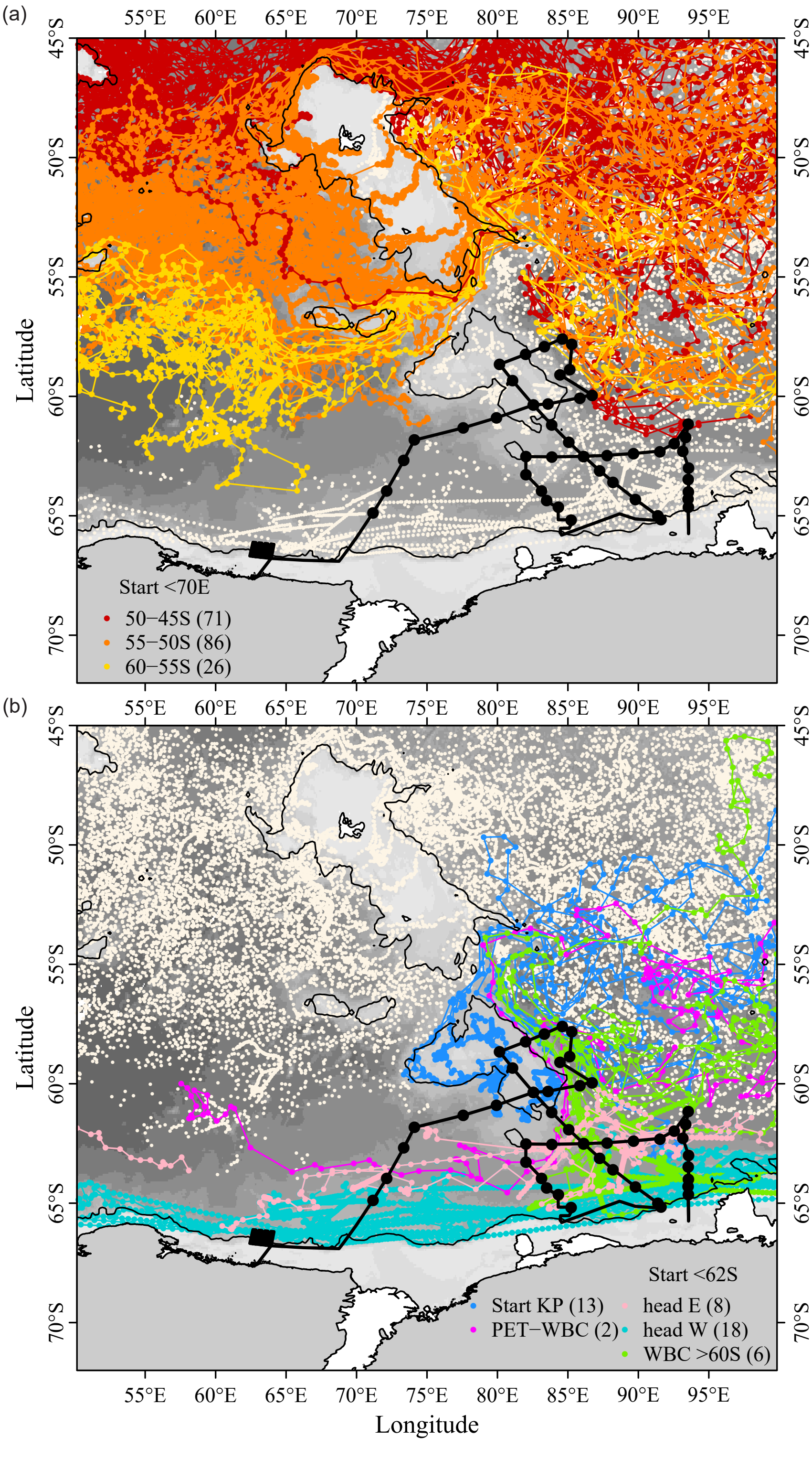

Figure 2: Historical Argo float trajectories (n = 334 floats, N = 23 920 profiles) within the greater Kerguelen Plateau region. Coloured trajectories highlight floats with (a) northwestern (i.e. west of 70°E), and (b) southern (i.e. south of 62°S) origins. In (b) the turquoise and green floats originate to the east of PET, the pink and magenta floats originate to the west of PET and the blue floats are of southern Kerguelen Plateau origin. Number of floats indicated in parentheses. Argo float data were obtained from the US GODAE Global Data Access Centre (GDAC) Data Browser (www.usgodae.org/cgi-bin/argo_select.pl) and the Australian Ocean Data Network (AODN) Portal (IMOS, 2017) as part of the Argo data distribution network. Argo trajectories predominantly reflect velocity conditions at the drift depth (typically 1 000 m). However, floats may also be subject to transport by surface currents and winds during surfacing. Note that Argo linearly interpolates trajectories when floats are under sea-ice and unable to surface and transmit locations, therefore many of the winter turquoise trajectories appear to be located farther north than they are in reality. Abbreviations are KP – Kerguelen Plateau; PET – Princess Elizabeth Trough; WBC – Western Boundary Current. KAXIS cruise track and CTD stations are indicated (bold black line and circles). Background displays bathymetry at 500 m intervals, with 2 000 m isobath highlighted (black contour) (reproduced from Bestley et al., 2018).

Combined oceanographic observations (ship-based, Argo floats and satellite remote sensing) show the flow of the ACC to be largely zonal upstream of the Kerguelen Plateau. The southern branch of the Polar Front and the northern branch of the southern ACC front (SACCF) are deflected to the north by the topography and cross the plateau through the Fawn Trough. The southern branch of the SACCF and the southern boundary of the ACC pass to the south of BANZARE Bank, through the Princess Elizabeth Trough (PET). These fronts turn sharply to the north on the eastern flank of the plateau in the Western Boundary Current (WBC) (Aoki et al., 2008; Fukamachi et al., 2010; McCartney and Donohue, 2007), then retroflect to the south before continuing eastward. Satellite altimetry and float trajectories (Figure 2) suggest the ACC regime to the east of the plateau is eddy-rich and characterised by extensive meandering of the ACC fronts, in contrast to the low eddy energy and zonal flow observed west of the plateau. The Antarctic Slope Current flows west along the upper continental slope, with hydrographic data indicating some of the flow turns offshore and feeds the Southern Boundary flow in the WBC. Flow over the plateau itself is relatively quiescent (<3 cm s^{-1}) and floats in this region have a long residence time (>1 year).

The regional circulation is closely associated with the distribution of biological productivity in surface waters, as revealed in satellite measurements of ocean colour (Figure 3), including high chlorophyll-*a* in subpolar waters, along the eastern edge of the plateau within the WBC (Rintoul et al., 2008) and over the Antarctic continental shelf. Moderately high surface chlorophyll concentrations are maintained over the southern plateau where it is likely that the sluggish circulation assists in retaining phytoplankton. In contrast, productivity is low in ACC waters north of the SACCF, particularly in the ‘low zone’ to the northwest of the southern plateau (see also Roquet et al., 2009). Here the ACC flow is channelled, and high geostrophic velocities appear to rapidly advect phytoplankton through the Fawn Trough (e.g. surface flows of up to 60 cm s^{-1} reported by Park et al., 2009) resulting in low concentrations in this region.

The region southeast of the southern Kerguelen Plateau is a well-recognised area of biological activity, with observations of phytoplankton abundances well above Southern Ocean background concentrations. A number of interplaying mechanisms may support this sustained productivity, including topographic upwelling, ice edge blooms, the advection of biomass and/or nutrients from the south, and potentially gyre retention (see discussions in Rintoul et al., 2008; Sokolov and Rintoul, 2007). Schallenberg et al. (2018) link the KAXIS dissolved iron measurements with in situ and satellite chlorophyll-*a* data, within the regional oceanographic context, and attempt to evaluate the possible mechanisms providing the dissolved iron to support this productivity. They found upwelling of subsurface iron (most likely originating from Antarctic shelf sediments), in connection with major fronts in the area, to be the most likely mechanism supplying iron to the phytoplankton blooms in this region.

Our survey results, combined with other regional research efforts, provide an enriched understanding of the complex circulation in the area. A relatively detailed picture is emerging which consists of distinct regimes: zonal flow and low eddy energy in the ACC upstream of the plateau; quiescent flow and moderate productivity over the plateau itself; intensified flow channelled to cross the plateau through the Fawn Trough; convergence of the southern fronts of the ACC and eastward flow in the northern PET, with a sharp northward turn and retroflection of the fronts in a western boundary current on the eastern edge of the plateau; complex meandering of the ACC fronts in an eddy-rich region downstream of the plateau; and westward flow in the ASC over the Antarctic continental slope. These circulation features likely play a role in shaping the distribution and productivity of marine ecosystems at multiple trophic levels.

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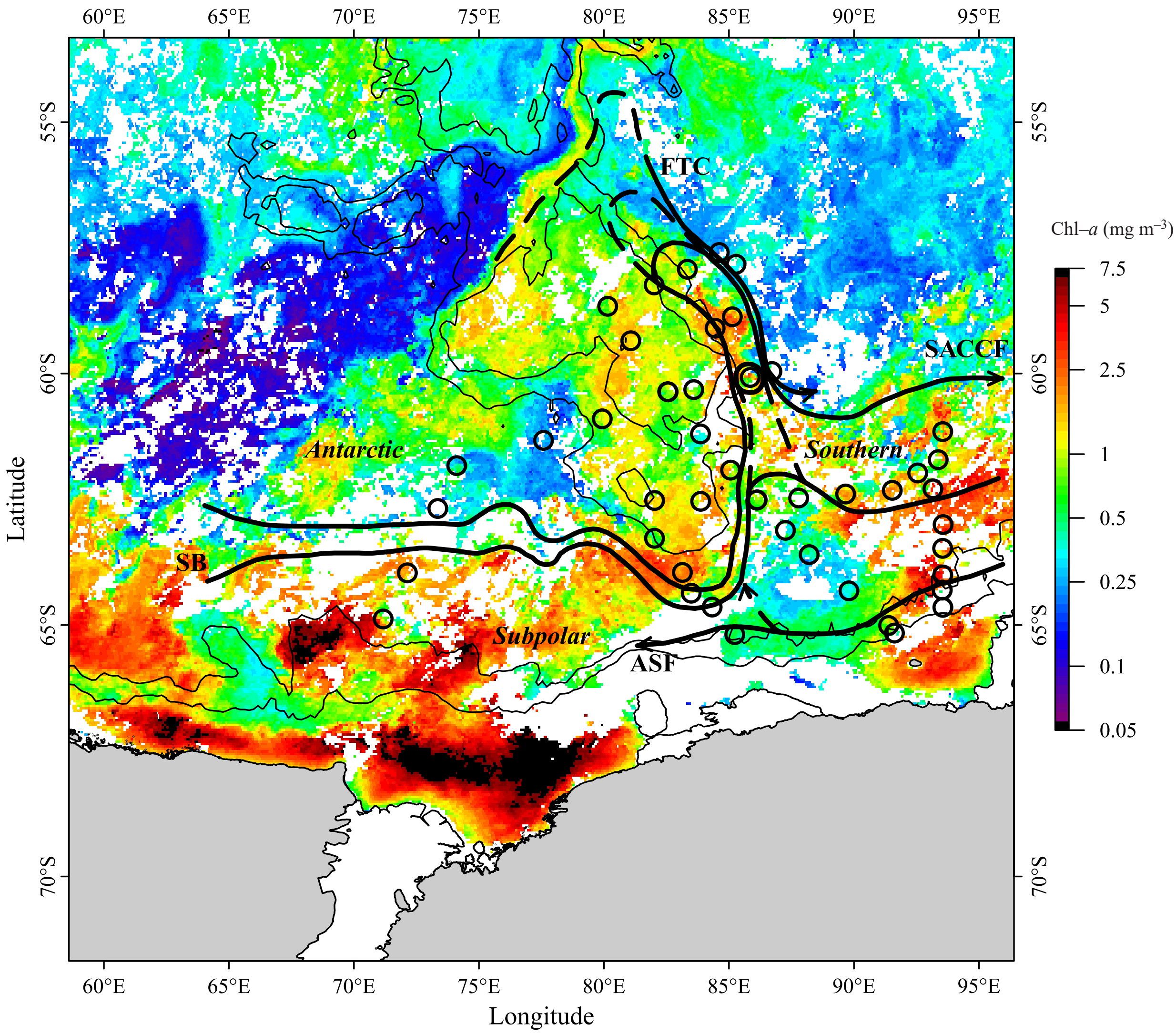

Figure 3: Major circulation features around the southern Kerguelen Plateau overlaid on the mean sea-surface chlorophyll-*a* during the KAXIS survey. Daily L-3 binned 4.6 km satellite Remote Sensing Reflectance data (NASA, 2014) was obtained from the MODIS-Aqua satellite as distributed by NASA (https://oceandata.sci.gsfc.nasa.gov/MODIS-Aqua/L3BIN/). Surface chlorophyll-*a* concentration (mg m^{-3}) was calculated from reflectance wavelengths using the Johnson et al. (2013) Southern Ocean algorithm and compiled for 18 January – 18 February 2016 to produce a regional average image. Note the colour bar is on a natural log scale in mg m^{-3}. Circulation features inferred from this study are from Figure 1. Nomenclature of the three main oceanic zones (italics) follows Orsi et al. (1995) as Antarctic, Southern and Subpolar (reproduced from Bestley et al., 2018).

References

Aoki, S., N. Fujii, S. Ushio, Y. Yoshikawa, S. Watanabe, G. Mizuta, Y. Fukamachi and M. Wakatsuchi. 2008. Deep western boundary current and southern frontal systems of the Antarctic Circumpolar Current southeast of the Kerguelen Plateau. *J Geophys. Res.-Oceans*, 113: C08038.

Bestley, S., E. van Wijk, R. Coleman, S. Corney, R. Eriksen, M. Rosenberg, K. Tattersall and S. Rintoul. 2018. Ocean circulation and frontal structure near the southern Kerguelen Plateau: the physical context for the Kerguelen Axis ecosystem study. *Deep-Sea Res. II*: doi: 10.1016/j.dsr2.2018.07.013.

Bindoff, N.L., M.A. Rosenberg and M.J. Warner. 2000. On the circulation and water masses over the Antarctic continental slope and rise between 80 and 150 degrees E. *Deep-Sea Res II*, 47: 2299–2326.

Fukamachi, Y., S.R. Rintoul, J.A. Church, S. Aoki, S. Sokolov, M.A. Rosenberg and M. Wakatsuchi. 2010. Strong export of Antarctic Bottom Water east of the Kerguelen plateau. *Nature Geosci*., 3: 327–331.

Heywood, K.J., M.D. Sparrow, J. Brown, R.R. Dickson. 1999. Frontal structure and Antarctic Bottom Water flow through the Princess Elizabeth Trough, Antarctica. *Deep-Sea Res. I*, 46: 1181–1200.

IMOS, 2017. IMOS – Argo Profiles, catalogue-imos.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=8cc13f98-9897-4193-8ba6-d1f05356d3f2 (accessed 27 April 2017).

Johnson, R., P. Strutton, S. Wright, A. McMinn and K. Meiners. 2013. Three improved satellite chlorophyll algorithms for the Southern Ocean. *J. Geophys. Res.-Oceans*, 118: C20270.

McCartney, M.S. and K.A. Donohue. 2007. A deep cyclonic gyre in the Australian–Antarctic Basin. *Prog. Oceanogr.*, 75: 675–750.

Meijers, A.J.S., A. Klocker, N.L. Bindoff, G.D. Williams and S.J. Marsland. 2010. The circulation and water masses of the Antarctic shelf and continental slope between 30 and 80°E. *Deep-Sea Res. II*, 57: 723–737.

NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. 2014. Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua Remote-Sensing Reflectance Data; 2014 Reprocessing. NASA OB.DAAC, Greenbelt, MD, USA, doi: 10.5067/AQUA/MODIS/L3B/RRS/2014 (accessed 24 May 2017).

Orsi, A.H., T. Whitworth and W.D. Nowlin. 1995. On the meridional extent and fronts of the Antarctic Circumpolar Current. *Deep-Sea Res. I*, 42: 641–673.

Park, Y.-H., F. Vivier, F. Roquet and E. Kestenare. 2009. Direct observations of the ACC transport across the Kerguelen Plateau. *Geophys. Res. Lett.*, 36: L18603.

Park, Y.H., F. Roquet, I. Durand and J.L. Fuda. 2008. Large-scale circulation over and around the Northern Kerguelen Plateau. *Deep-Sea Res. II*, 55: 566–581.

Rintoul, S.R., S. Sokolov and R.A. Massom. 2008. Rapid development and persistence of a massive Antarctic sea ice tongue. *J. Geophys. Res.-Oceans*, 113: C07045.

Roquet, F., Y.H. Park, C. Guinet, F. Bailleul and J.B. Charrassin. 2009. Observations of the Fawn Trough Current over the Kerguelen Plateau from instrumented elephant seals. *J. Mar. Syst.*, 78: 377–393.

Rosenberg, M. and R. Eriksen. 2016. Aurora Australis Marine Science Cruise AU1603 – Oceanographic Field Measurements and Analysis. Antarctic Climate and Ecosystems cooperative Research Centre, Hobart, Australia: 1–33.

Schallenberg, C., S. Bestley, A. Klocker, T.W. Trull, D.M. Davies, M. Gault-Ringold, R. Eriksen, N.P. Roden, S. Sander, M. Sumner, A.T. Townsend, P. Merwe, K. Westwood, K. Wuttig and A. Bowie. 2018. Sustained upwelling of subsurface iron supplies seasonally persistent phytoplankton blooms around the southern Kerguelen plateau, Southern Ocean. *J. Geophys. Res.-Oceans*, 123 (8): doi: 10.1029/2018JC013932.

Sokolov, S. and S.R. Rintoul. 2007. On the relationship between fronts of the Antarctic Circumpolar Current and surface chlorophyll concentrations in the Southern Ocean. *J. Geophys. Res.-Oceans*, 112, C0703.

Sokolov, S. and S.R. Rintoul. 2009a. Circumpolar structure and distribution of the Antarctic Circumpolar Current fronts: 1. Mean circumpolar paths. *J. Geophys. Res.-Oceans*, 114: C11018.

Sokolov, S. and S.R. Rintoul. 2009b. Circumpolar structure and distribution of the Antarctic Circumpolar Current fronts: 2. Variability and relationship to sea surface height. *J. Geophys. Res.-Oceans*, 114: C11019.

Sparrow, M.D., K.J. Heywood, J. Brown and D.P. Stevens. 1996. Current structure of the south Indian Ocean. *J. Geophys. Res.-Oceans*, 101: 6377–6391.

van Wijk, E.M., S.R. Rintoul, B.M. Ronai and G.D. Williams. 2010. Regional circulation around Heard and McDonald Islands and through the Fawn Trough, central Kerguelen Plateau. *Deep-Sea Res. I*, 57: 653–669.

Vivier, F., Y.-H. Park, H. Sekma and J. Le Sommer. 2015. Variability of the Antarctic Circumpolar Current transport through the Fawn Trough, Kerguelen Plateau. *Deep-Sea Res. II*, 114: 12–26.

Weatherall, P., K.M. Marks, M. Jakobsson, T. Schmitt, S. Tani, J.E. Arndt, M. Rovere, D. Chayes, V. Ferrini and R. Wigley. 2015. A new digital bathymetric model of the world's oceans. *Earth Space Sci.*, 2: 331–345.

Williams, G.D., S. Nicol, S. Aoki, A.J.S. Meijers, N.L. Bindoff, Y. Iijima, S.J. Marsland and A. Klocker. 2010. Surface oceanography of BROKE-West, along the Antarctic margin of the south-west Indian Ocean (30–80 degrees E). *Deep-Sea Res. II*, 57: 738–757.