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Circulation, stratification and seamounts in the Southwest Indian Ocean

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ABSTRACT

Circulation in the vicinity of six seamounts along the Southwest Indian Ridge was studied as part of a multidisciplinary survey in November 2009. Examination of altimetric data shows that several of the seamounts lie in the area of slow mean westward flow between the southern tip of Madagascar (25°S) and the Agulhas Return Current (ARC) flowing eastward between 37°S and 40°S. The mean westward drift of mesoscale features was 4.1 ± 0.9 cm s^{-1}. Integrated between Madagascar and 37°S, this westward drift can account for 50 Sv (1 Sv $= 10^6$ m^3 s^{-1}), which, added to 25 Sv of southward flow past Madagascar, is sufficient to account for the total Agulhas Current transport of 70 ± 21 Sv. The transport of the ARC was also measured, at two longitudes, down to 2000 m. Combined with earlier crossings of the ARC in 1986 and 1995, the full depth transport of the ARC is estimated at 71–85 Sv at longitudes 40–50°E, indicating that the Agulhas Current then ARC transport continues unreduced as far as 50°E before beginning to recirculate in the Southwest Indian Ocean subtropical gyre. The primary control on the circulation near each seamount was its position relative to any mesoscale eddy at the time of the survey. Melville lay on the flank of a cyclonic eddy that had broken off the ARC and was propagating west before remerging with the next meander of the ARC. Nearby Sapmer, on the other hand, was in the centre of an anticyclonic eddy, resulting in very weak stratification over the seamount at the time of the survey. Middle of What lies most often on the northern flank of the ARC, in strong currents, but was at the time of the survey near the edge of the same eddy as Sapmer. Coral, in the Subtropical Front south of the ARC, was in waters much colder, fresher, denser and more oxygenated than all the other seamounts. Walter was close to the path of eddies propagating southwest from east of Madagascar, while Atlantis, the furthest east and north seamount, experienced the weakest eddy currents.

1. Introduction

In late 2009, the research vessel *Dr. Fridtjof Nansen* carried out a 6-week multi-disciplinary survey of six seamounts in the Southwest Indian Ocean (Fig. 1). The purpose of this paper is to summarize the mean circulation and the role of mesoscale eddies in modifying the circulation and stratification at each seamount at the time of the cruise.

Six seamounts were surveyed (Table 1), five of which lay along the line of the Southwest Indian Ridge (Fig. 1), which is split by deep fracture zones. Atlantis, Melville and Coral seamounts were situated on ridges just east of the Atlantis, Indomed and Discovery II Fracture Zones respectively; Sapmer was just west of the Gallieni Fracture Zone; Middle of What (MoW) was a deeper feature on the ridge between Melville and Sapmer. Walter was another deep feature situated on the west side of the Madagascar Ridge, and northwest of the Walter's Shoals, the shallowest part of the Ridge.

A limited number of physical oceanographic observations were made at each seamount, including a short CTD section and a 24-h CTD yoyo. A few CTD stations were also occupied on passage and two CTD sections across the Agulhas Return Current (ARC) were worked. Shipboard acoustic Doppler current profiler (ADCP) data were acquired throughout the cruise. Shipboard data have been supplemented with Maps of Absolute Dynamic Topography (MADT) (Fig. 2), obtained from the Segment Sol multimissions d'ALTimétrie, d'Orbitographie et de localisation precise/Developing Use of Altimetry for Climate Studies (SSALTO/DUACS) multimission altimeter data processing system, distributed by Collecte Localis Satellites/Archivage, Validation, Interprétation des données des Satellite Océanographiques (CLS/AVISO). Fig. 2a shows the synoptic surface circulation on 18 November 2009, when the first seamount, Atlantis, was being surveyed. Four weeks later (Fig. 2b), the survey of the final seamount, Walter, had just ended.

The best known current in the Southwest Indian Ocean is the Agulhas Current (Lutjeharms, 2006), running to the southwest down the east coast of South Africa (Fig. 2). To the south of Africa,

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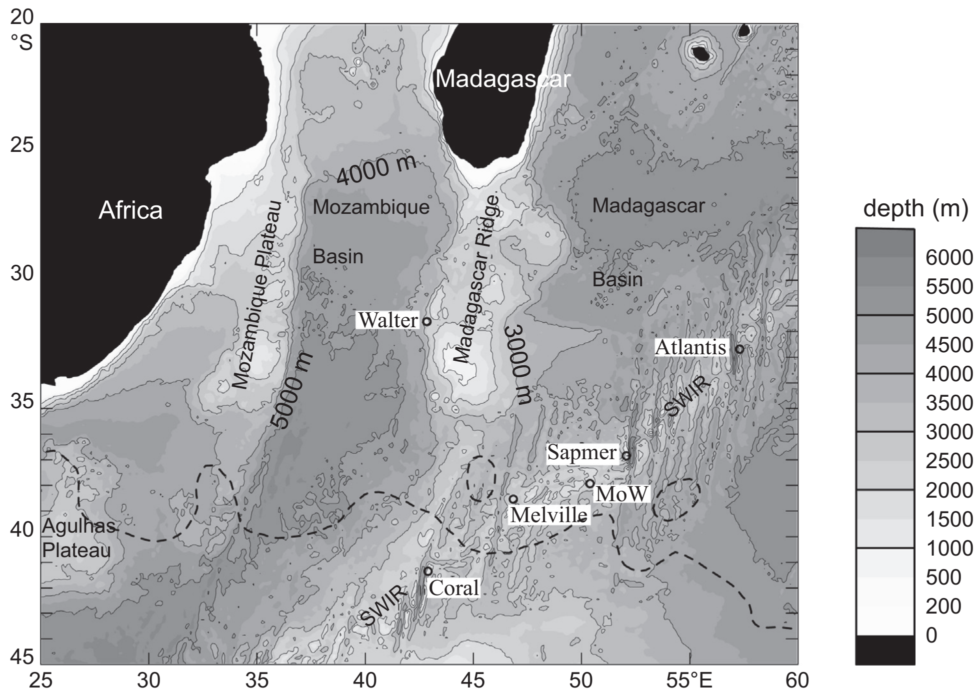

Fig. 1. The positions of the six seamounts surveyed during the Nansen cruise are shown relative to the bathymetry of the Southwest Indian Ocean and a streamline of the Agulhas Return Current (dashed, see Fig. 2). Five of the seamounts – Atlantis, Sapmer, Middle of What (MoW), Melville and Coral – lay along the SouthWest Indian Ridge (SWIR) and Walter was on the west side of the Madagascar Ridge. Sapmer, MoW, Melville and Coral all lay close to the path of the Agulhas Return Current.

Table 1
Seamounts surveyed.

Seamount	Atlantis	Sapmer	Middle of What	Coral	Melville	W of Walters Shoal
Latitude (°S)	32.6–32.9	36.7–37.0	37.8–38.1	41.3–41.6	38.3–38.6	31.5–31.8
Longitude (°E)	57.1–57.5	51.9–52.3	50.2–50.6	42.7–43.1	46.5–46.9	42.65–43.05
Minimum depth (m)	750	350	1100	200	100	1250
Depth of CTD yoyo (m)	700	500	900	400	500	1200
Dates occupied	17–19 November	22–24 November	25–27 November	2–4 December	7–10 December	12–13 December
Days of year occupied	321–323	326–328	329–331	336–338	341–344	346–347

the Agulhas Current retroflects to the east, meandering between 37°S and 41°S in the Agulhas Return Current (ARC). The ARC weakens to the east as transport peels off to the north (Lutjeharms, 2007; Stramma and Lutjeharms, 1997) to close the anticyclonic (anticlockwise) Southwest Indian Ocean Subtropical Gyre.

South of the ARC, two areas of closely spaced sea surface height (SSH) contours can be identified (Fig. 2), marking the South Subtropical Front (SSTF) (Belkin and Gordon, 1996; Read et al., 2000) and the Subantarctic Front (SAF). The SAF is marked by the tightening of SSH contours just east of Coral (Fig. 2, transition from green to yellow), and is the northern edge of the Antarctic Circumpolar Current (ACC), which reaches it northernmost circumpolar excursion at 50°E (Pollard and Read, 2001; Pollard et al., 2007). Thus Coral seamount lies just north of the ACC but in the path of the STF and, on occasion, the ARC (Boebel et al., 2003).

2. Eastward transport along the southern boundary of the Subtropical Gyre

Two closely spaced hydrographic sections (Fig. 2), between Coral and Melville (33 km station spacing) and south of MoW (28 km spacing), allow us to identify the ARC, STF and SAF and estimate their boundaries and separate eastward transports. Using temperature and salinity range criteria for these fronts at several depths (Belkin and Gordon, 1996) and the 300–800 m depth range for the 10 °C isotherm to identify the ARC (Belkin and Gordon, 1996), we have identified the CTDs nearest to the boundaries between the ARC, STF and SAF and overlaid them on the sea surface height contours of Fig. 2b (Fig. 3). The bold dashed lines in Fig. 3 connect these CTDs following sea surface height contours. There are only small offsets between the estimated frontal boundaries and the sea surface height contours on each section, so our choice of frontal boundaries is consistent between the two sections.

Geostrophic transports for adjacent station pairs (Fig. 3) have been calculated down to 1500 m relative to 1500 m for comparison with other estimates (Lutjeharms and Ansorge, 2001). Note the transport minimum between the ARC and STF on each section (2.9 and 3.0 Sv on west and east sections, respectively), which indicates a separation between the ARC and STF transports. However, there is no minimum between STF and the SAF (seen only on the eastern section) so we cannot reliably apportion the transport between the two.

Transports for the ARC are 44 and 51 Sv for the 45°E and 50°E sections, respectively (Fig. 3). The difference between these estimates could have several explanations. The anticyclonic eddy around Sapmer and the large gap between MoW and the next station to the south could have increased the transport for the eastern section. Transports could have changed during the week that elapsed between the occupations of the two sections. For comparison, the transport of the Agulhas Current was observed to change from its minimum 9 Sv to its maximum 122 Sv in only 24

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