Studying the impact of ocean eddies on the ecosystem of the Prince Edward Islands: DEIMEC II

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THE *Dynamics of Eddy Impacts on Marion's Ecosystem Study* (DEIMEC) programme was begun in 2002 with the aim of understand the importance of the oceanic, upstream environment to the ecosystem of the Prince Edward Islands.[1] This island group consists of two small volcanic islands and provides many opportunities for studying ecological and evolutionary processes, for monitoring ecological changes in relation to global climate change and for conserving a unique component of the planet's biological diversity.

Surrounded as they are by vast tracks of ocean, it is reasonable to expect that the ecosystem of the Prince Edward Islands would be dominated by marine influences. Marked changes in offshore conditions should therefore also be noticeable on the islands. Previous studies[2,3] have shown that the immediate marine environment is very turbulent, consisting largely of mesoscale eddies, both cyclonic and anti-cyclonic. Recent work[4,5] has demonstrated that these eddies originate at a gap in the South-West Indian Ridge, through which the Antarctic Circumpolar Current (ACC) is forced to pass. The eddies generated here drift towards the islands, roughly following the bottom topography.

It has been postulated that the eddies have a profound effect on the physical and biological environment of the islands, thus affecting the whole ecosystem.[5] Furthermore, it has recently been documented that a number of bird species and seals on the islands preferentially use the upstream anomalies/eddies as foraging grounds.[6] Little is known about the physical properties of eddies shortly after their spawning, nor of the manner in which they change with time as they spin down. Nothing is known also about temporal changes in biological characteristics or the primary productivity as eddies move northeastwards.

The research aims of the DEIMEC ll cruise, the second in the series, were threefold: first, to carry out underway measurements between Cape Town and the Prince Edward Islands; second, to conduct an inter-island survey to study the feeding ecology of selected species of shallow demersal fish, to collect data on the demography of the swimming prawn *Nauticaris marionis* and to establish the importance of kelp carbon sources for the inter-island ecosystem. Finally, the main objective of the offshore cruise component was to investigate the exact nature of eddies in the region between the South-West Indian Ridge and the islands, and to study changes in their physical and biological characteristics after their advection into the vicinity of the islands. This report serves as a brief overview of the preliminary findings of the expedition.

To accomplish the above objectives, research teams from the University of Cape Town, the University of Fort Hare and Rhodes University participated in the annual relief voyage to Marion Island (voyage 110) on board the supply and research vessel *SA Agulhas*, from 25 March to 30 April 2003 (Fig. 1). The cruise consisted of three main segments: a transect between Cape Town and Marion Island during which only surface physical and biological conditions were recorded, an inter-island study consisting of surface sampling and dredging over the shelf between Prince Edward and Marion islands, and an upstream, multi-disciplinary oceanographic survey to investigate the physical and biological characteristics of a number of mesoscale anomalies (Fig. 1). Using TOPEX/Poseidon products available on the Internet made it possible to locate anomalies for potential study prior to the cruise.

In total, 212 oceanographic stations, including XBT (expendable bathythermograph) and CTD (conductivity-temperature-depth) stations, as well as 13 RMT-8 (rectangular-midwater-trawl) trawls and 23 bottom dredges, were completed during the expedition. Sippican T7 XBTs were deployed to a maximum depth of 760 m. At each CTD station vertical profiles of salinity, temperature and density were obtained with a Neil Brown Mark IIIc WOCE upgrade underwater unit to a

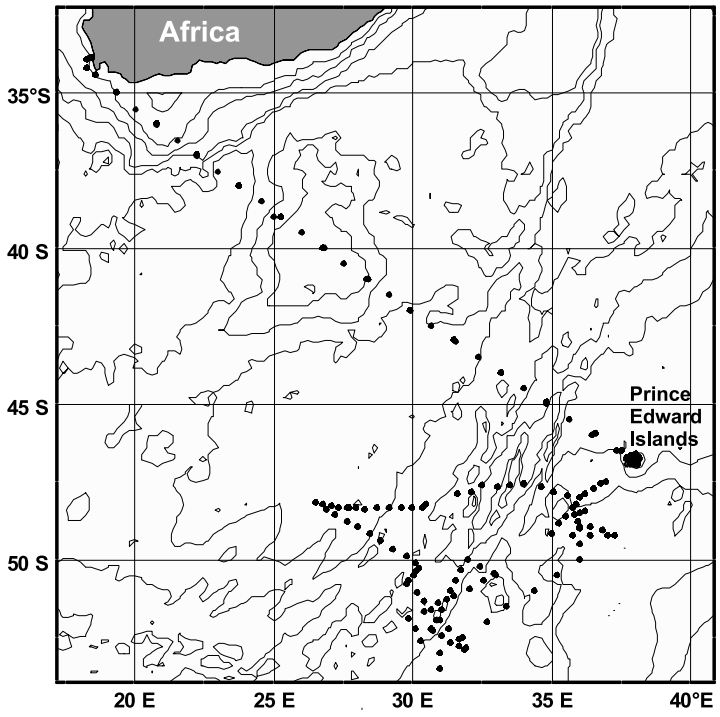

Fig. 1. Station positions occupied during the DEIMEC II expedition in March and April 2003.

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maximum depth of 1000 m. Water samples were collected on average at 9 standard depths and analysed for dissolved oxygen, salinity, and nutrient (silicate, phosphate, nitrate and nitrite) concentrations. Total chlorophyll-*a* (Chla) concentration was determined at six depths in the upper 250 m of the water column at each CTD station. In addition, size-fractionated (<2, 2–20 and 20 μm) Chla concentrations were determined using surface water samples at each oceanographic station. Two ARGO floats were deployed within the survey area at 48°18′S, 26°30′E and at 50°S, 30°E. These are profiling CTD floats capable of measuring temperature, salinity and density during a 10-day cycle between surface and 2000 m.

Underway sampling between Cape Town and Marion Island

The surface position of the Subantarctic Front (SAF) *en route* to Marion Island was recorded at ~ 45°S, as expressed by the 7°C isotherm. It had shifted farther south by the time of the return leg, when it was found near the islands at 46°15′S (Fig. 2). The locations of this and other fronts are consistent with previous observations.[7,8] Total Chla concentrations ranged from 0.2 to 1.7 mg m^{-3} and from 0.2 to 3.4 mg m^{-3} *en route* to Marion Island and on the return trip to Cape Town, respectively. The Chla levels exceeding 1 mg m^{-3} were recorded at stations occupied south of the SAF and on the shelf of the Prince Edward Islands (Fig. 3). In addition, during the return leg, enhanced Chla values were found at the southern and northern boundary of the joint frontal feature created by the Agulhas Return Current[9] and the Subtropical Convergence (ARC/STC; Fig. 3B). At these stations, microphytoplankton (cells >20 μm) accounted for ~70% (ARC/STC and SAF) to >80% (island shelf) of total pigments. At the remaining stations during both legs, Chla concentrations usually did not exceed 0.5 mg m^{-3} and nano- and picophytoplankton (<20 μm) contributed up to 80% of the total Chla.

Phytoplankton bloom dynamics near Marion Island

The inter-island survey that was conducted immediately after arrival at Marion Island (29–31 March) showed that surface temperatures ranged from 6.7 to 7.7°C with the highest values recorded in the eastern part of the survey area (Fig. 4A). A cold-water region was evident in the western part of the survey area. There was a very distinct pattern in surface Chla distribution. The highest Chla values (1.6–2.1 mg m^{-3}), indicative of a phytoplankton bloom, were found in the eastern part of the survey region on the lee sides of both Prince Edward and Marion islands (Fig. 4B). The lowest Chla concentrations (<0.3 mg m^{-3}) coincided with the region of cold water and with offshore stations in the southwestern and northwestern parts of the survey area (Fig. 4B). Three weeks later (20–21 April), surface temperatures were lower, lying between 6.1 and 6.8°C, with the coldest water found between the islands (Fig. 4C). The highest Chla concentrations, reaching 3.4 mg m^{-3}, were found northeast of Marion Island and were confined to the island shelf (Fig. 4D). The bloom previously found behind Prince Edward Island may have been advected downstream, as the Chla concentrations to the north of

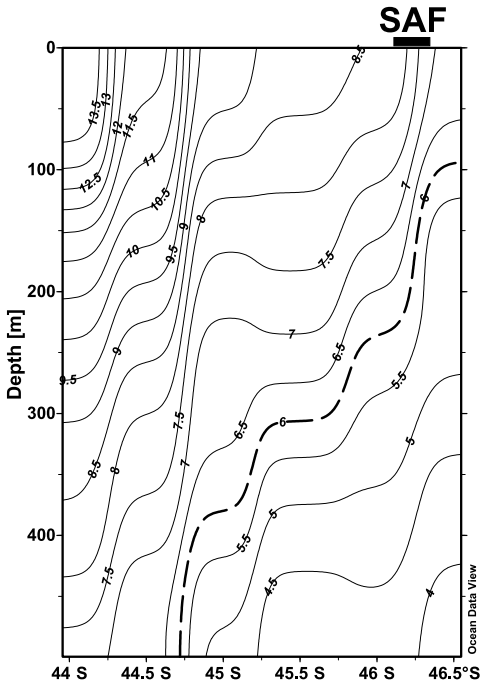

Fig. 2. Vertical temperature section during the return leg to Cape Town showing the position of the Subantarctic Front (SAF), which is indicated by the thickening of the upper axis.

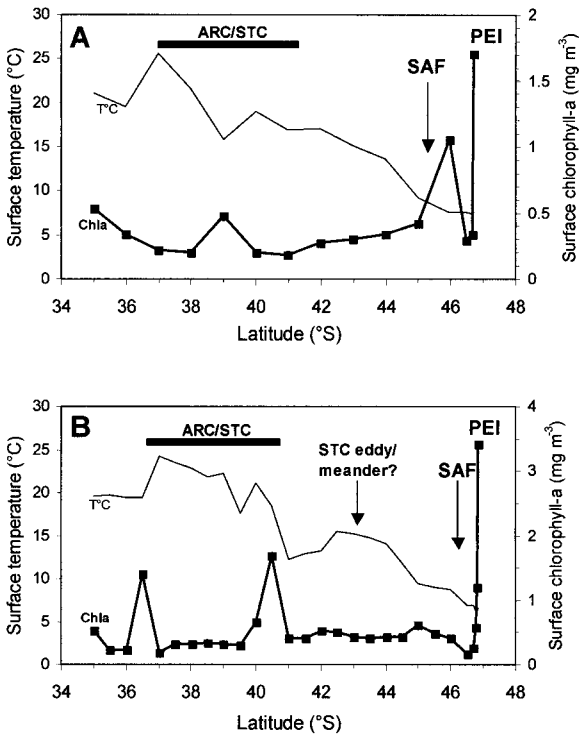

Fig. 3. Changes in surface temperature and total chlorophyll-*a* distribution along transects *en route* to Marion Island (**A**) and return to Cape Town (**B**) during March and April 2003. ARC, Agulhas Return Current; STC, Subtropical Convergence; SAF, Subantarctic Front; PEI, Prince Edward Islands.

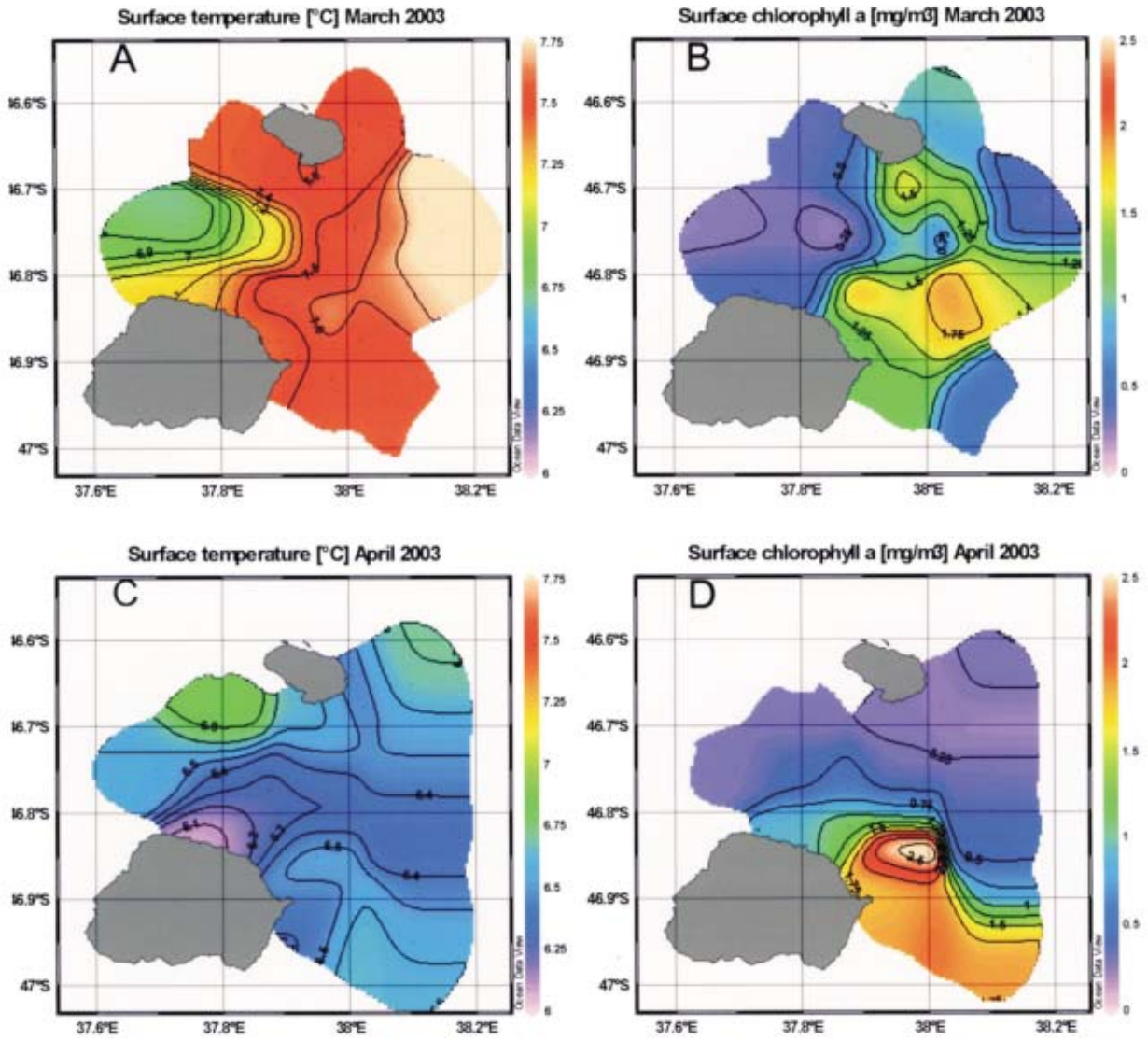

Fig. 4. Distribution of surface temperature (**A** , 29–31 March; **C**, 20–21 April) and total chlorophyll-*a* (**B**, 29–31 March; **D**, 20–21 April) between Prince Edward and Marion islands.

Marion Island did not exceed 0.4 mg m^{-3} during this period (Fig. 4D). During both surveys, the micro-size fraction dominated at bloom stations, accounting for >80% of total pigments, while nano and pico size fractions made up the bulk of pigment concentrations at stations with low Chla values.

During the last seven years, a phytoplankton bloom of such magnitude has been observed on only two occasions, in 1996 and 2003.[10] During both years, the SAF was located far to the north of the islands, at approximately 45°S. It has been postulated that in such conditions the water masses approach the island plateau at a reduced speed and as a consequence the inter-island environment is conducive to water retention and phytoplankton bloom development.[10,11] Alternatively, during situations when the SAF is found to lie in close proximity to the islands, a through-flow regime appears to dominate in the inter-island region.[10,11] This was the case during the second (20–21 April) inter-island survey as a few days later the SAF was recorded close to the islands (see underway section and Fig. 2). An interesting finding is that the bloom may not have been entirely swept downstream from the inter-island region and indeed may have intensified over the shelf to the east of Marion Island. This implies that a retention mechanism, as yet unknown, persists over the shelf. The same mechanism is likely to play an important role in the retention of the bottom-dwelling shrimp and fish larval populations and could limit the penetration of oceanic species onto the shelf areas of both islands.

The DEIMEC II survey

Altimetric data, obtained prior to the cruise, revealed the presence of an intense (first anomaly, >35 cm), positive anomaly in sea-surface height lying between 50–52°S and 29–33°E, while immediately to the north a negative anomaly (second anomaly, >–35 cm) between 47–49°S and 28–30°50′E was evident (Fig. 5A). Since such anomalies may represent eddies, this information was used to plan the rest of the cruise. Satellite altimetry has also shown that these anomalies exhibit specific trajectories beyond their generation region, so it was assumed that the first anomaly (Fig. 5) may have represented a fairly new, anti-cyclonic eddy and the third anomaly, centred at 48°30′S and 35°E, was a predecessor of more advanced age.

Analysis of preliminary hydrographic data shows that there was a good correlation between anomalies in sea-surface height observed using altimetry and the intensity of eddies (Fig. 5). Some of the eddies had moved and were not found in the same locations where they had been

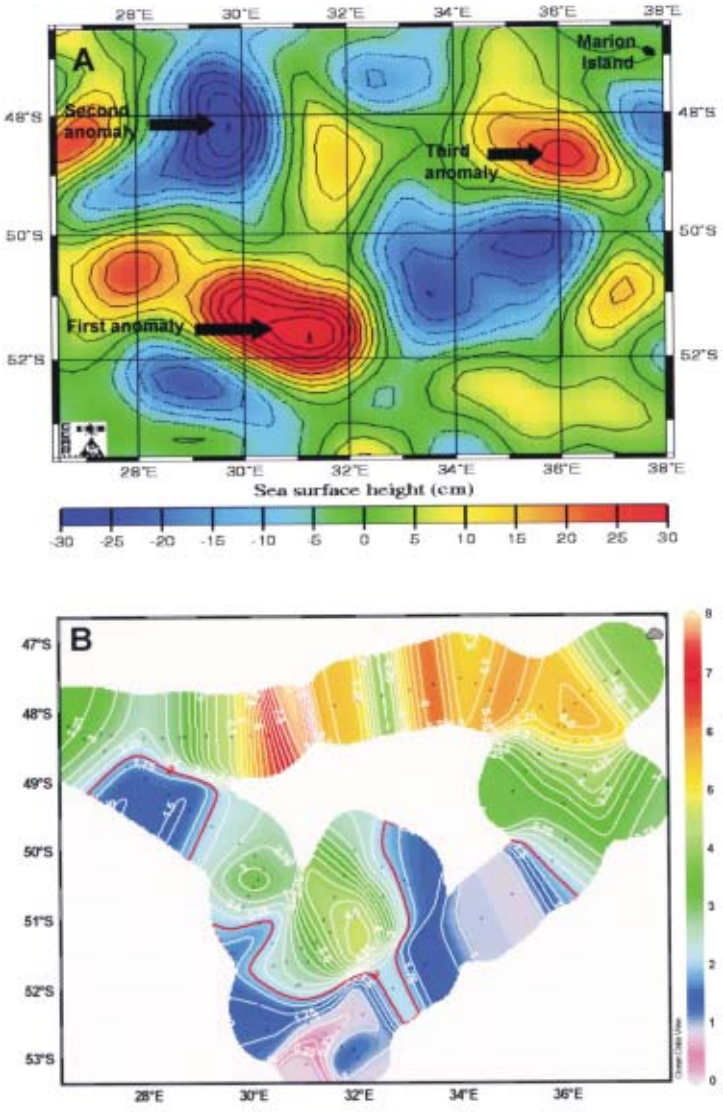

Fig. 5. Average sea-surface height anomalies (**A**) from blended TOPEX/ERS altimetry data and subsurface (200 m) water temperatures (**B**) in the upstream region of the Prince Edward Islands during April 2003. Anomalies are marked as indicated in the text. The position of the Antarctic Polar Front (APF) is highlighted in red at the 2°C isotherm.

two weeks before, according to the altimetric data. Water masses corresponding to Subantarctic Surface Water (>5°C, >33.85 psu) were identified in the central core of both anti-cyclonic eddies. By contrast, water masses associated with the cyclonic eddy tended to be fresher (<4°C, <33.70 psu) and more consistent with that of Antarctic Surface Water. The subsurface expression of the SAF was identified by its 6°C axial value and was found at various places along the northern boundary of the survey area between 48°15′S–30°E and 48°S–32° 15′E. Of greater interest is the subsurface expression of the APF (identified by the northern limit of the temperature minimum of 2°C), which was found extensively across the survey area between 48°45′S, 28°E; 52°S, 30°E; 52°S, 33°E and 50°15′S, 35°50′E (Fig. 5B). It may have displayed meandering in the front, or its expression in a number of eddies. Comparison of the two anti-cyclonic eddies shows a weaker hydrodynamic structure for the one closer to the islands and farther from its source. This suggests a greater age than the other, but this will have to be confirmed by a more extensive altimetric investigation.

During the DEIMEC ll survey, Chla concentrations were low, lying between 0.1 and 0.4 mg m^{-3}. There was no distinct pattern in the Chla distribution. Preliminary results of RMT-8 trawls showed that at stations north of the APF, the tunicate *Salpa thompsoni* numerically dominated macroplankton samples, accounting for >70% of total abundance. By contrast, its contribution never exceeded 30% of total density at stations occupied south of the APF. There was a sharp change in euphausiid community structure, as *Euphausia longirostris* and *Euphausia similis* dominated in Subantarctic Surface Waters, whereas *Euphausia triacantha* were associated with Antarctic Surface Waters. A similar correlation was evident in the lantern fish community structure. Average densities of lantern fish and squid were found to be significantly higher within the first anomaly (50–52°S, 29–33°E) compared to the third anomaly (48°30′S, 35°E). There was a visible south–north downscale trend in mesopelagic fish and squid densities.

Hydrographic and biological data collected during the DEIMEC ll survey thus provide a first multi-disciplinary contribution to an understanding of the manner in which the generation of mesoscale eddies at the South-West Indian Ridge may affect the ecosystem of the Prince Edward Islands. It is hoped that this investigation can be extended next year to include cyclonic eddies in a more detailed and rigorous way.

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