Deep-Sea Research II 100 (2014) 212–220

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Ecosystem functioning in the Mozambique Channel: Synthesis and future research

F. Marsac[a,*], R. Barlow[b,c], J.F. Ternon[d], F. Ménard[e], M. Roberts[f,g]

[a] Institut de Recherche pour le Développement (IRD), UMR 212 EME/ICEMASA, University of Cape Town, Department of Oceanography, Private Bag X3, Rondebosch 7701, South Africa
[b] Bayworld Centre for Research & Education, PO Box 7296, Roggebaai 8012, Cape Town, South Africa
[c] Marine Research Institute, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa
[d] Institut de Recherche pour le Développement (IRD), UMR 212 EME, 16 rue Claude Chappe, 97420 Le Port, La Réunion, France
[e] Institut de Recherche pour le Développement (IRD), UMR 212 EME (IRD/IFREMER/UM2), Avenue Jean Monnet, BP 171, 34203 Sète cedex, France
[f] Oceans & Coasts Research, Department of Environmental Affairs, PO Box 52126, Victoria & Alfred Waterfront, Cape Town 8000, South Africa
[g] Rhodes University, Grahamstown 6140, South Africa

ARTICLE INFO

Available online 20 November 2013

Keywords:
Mozambique Channel
Mesoscale circulation
Bio-physical coupling
Ecosystem approach

ABSTRACT

The MESOBIO programme investigated mesoscale dynamics using an integrated ecosystem approach, linking physical and biogeochemical processes with different trophic levels. Observation and modeling were used in combination to explain the main processes occurring in the mesoscale eddy field. The particular shape of the Mozambique Channel, composed of two basins interconnected through a narrow zone, favours the generation of mesoscale eddies and increases the opportunity for eddy-shelf interactions. Phytoplankton abundance peaked in areas of nutrient enrichment that are often found in the core of cyclonic eddies, as well as on the continental shelf. Grazers in zooplankton communities exhibited high biovolume in cyclonic eddies, but their abundance was lower in fronts and divergence zones, with lowest biovolume in anticyclones. Biovolume was highest at shelf stations, but very variable and similar to phytoplankton. Age of eddies, their subsequent maturation stage and the dynamics of the eddy field played a major role effecting zooplankton abundance. Micronekton presented abundance patterns coherent with zooplankton distribution, however this was only demonstrated by acoustic methods, whereas mid-water trawl collection and predators stomach contents (predators being used as biological samplers) did not reveal significant relationships with mesoscale features. For upper trophic levels, the average density of foraging seabirds was lowest in anticyclones, highest in cyclones and at intermediate levels in divergence, shelf and frontal zones. However, multifaceted behavioral responses were observed in such a highly variable environment. Swordfish was clearly associated with divergence zones, and to a lesser extent with fronts, suggesting that the higher density in divergences was related to the presence of its main prey, essentially large squids. Although tunas tended to be more abundant in areas with weak geostrophic currents, their relationship to mesoscale features was not straightforward as adult tunas caught by longline have the ability to explore different foraging habitats over a broad range of depths. Several suggestions for advancing eddy-related research from the current state of knowledge are proposed in the second part of the paper.

1. Introduction

The MESOBIO programme was designed to study the influence of the mesoscale ocean dynamics on biological productivity. Research cruises and experiments were undertaken in the Mozambique Channel (MC), an extremely dynamic environment where mesoscale eddies are formed continuously throughout the year. MESOBIO was conducted in 2009–2010 by a French–South African multidisciplinary team undertaking quasi-simultaneous observations in physical oceanography, plankton composition and ecology, distribution and habitat of micronekton, large pelagic fish and seabirds. To broaden the knowledge on bio-physical interactions in the MC, however, cruise data collected during 2002–2009 from other projects (ECOTEM, ACEP, SWIOFP and ASCLME) were also utilized in the preparation of the papers presented in this suite (see Table 1 in Ternon et al., 2013a).

This paper is structured in two main parts. In the first section, we summarize the major results produced by the MESOBIO group

* Corresponding author.
E-mail address: francis.marsac@ird.fr (F. Marsac).

0967-0645/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dsr2.2013.10.028

in an ecosystem perspective, where the various disciplines, from physics to biology, through the different trophic levels, are connected in order to depict an integrated picture of the ocean mesoscale environment in the MC. The second part is a prospective exercise where we propose new avenues of research to expand our knowledge of functioning of the ecosystem.

2. Overview of the major results

2.1. Circulation and mechanical effects of eddies

Ship borne and satellite observations during 2003–2010 (Roberts et al., 2013; Ternon et al., 2013b; Hancke et al., 2013; Malauene et al., 2013) and numerical modeling (Halo et al., 2013) were used to depict and understand the mechanisms of formation, propagation of eddies and their subsequent role to entrain and/or uplift nutrient enriched waters into the surface layer. It was shown that horizontal velocity of the eddy-related geostrophic current is underestimated by 20–30% in the altimetry dataset compared to S-ASCP measurements and drifter-derived velocities. This is attributed to smoothed gradients at the space (1/4°) and time (1 day) grid resolution of the altimetry data, in addition to the locally wind-driven component of the current (a-geostrophic Ekman transport) which may episodically override the mesoscale dynamics and mix the water properties at the surface (Ternon et al., 2013b; Hancke et al., 2013).

Previous studies have shown that anticyclonic eddies are the dominant features in the MC, dynamically-speaking, and the notion of a permanent, continuous western boundary current along the Mozambique shelf, directly connected to the Agulhas Current to the south, has been dispelled (Biastoch and Krauss, 1999; Ridderinkhof and de Ruijter, 2003; Schouten et al., 2003; Penven et al., 2006; Lutjeharms et al., 2012). The 82 satellite drifter tracks over the period 2000–2010, analyzed by Hancke et al. (2013), indicated clearly that anticyclonic activity is mostly observed along the western Channel, whereas cyclonic activity is more developed in the northeastern and eastern MC. However, Ternon et al. (2013b) report an anomalously large and well-developed cyclonic eddy in the west of the Channel narrows during the 2010 cruise, indicating that substantial variability may occur in the average picture of the eddy field. Transit durations of drifters from north to south through the Channel ranged from 51 to 150 days (average speed >150 cm s^{-1} along the Mozambique shelf). Continuous northward transport was also observed in several drifter tracks, ranging from 55 to 207 days, but was typically restricted to the eastern side of the Mozambique Channel, east of 40°E (average speed of 33 cm s^{-1}). Other drifters indicated a cross-channel transport between Mozambique and Madagascar and vice versa, with highly variable transit durations (from 15 to 113 days). Strong frontal jets can develop at the periphery of eddies in relation to increased sea-level gradients. These jets have the potential to exchange biological material between Madagascar and the Mozambique shelf.

The spatial structuring of anticyclonic vs cyclonic eddies in the MC is well represented by the two numerical ocean circulation models (ROMS, Shchepetkin and McWilliams, 2005; and HYCOM, Bleck, 2002) developed and assessed against altimetry data (Halo et al., 2013). An eddy detection and tracking algorithm applied to altimetry data and model simulations identified the eddy generation sites and provided general statistics related to each eddy type. Cyclonic eddies were more abundant and of smaller size compared to anticyclonic eddies. They can be formed almost anywhere; however, the eastern part of the MC along the Madagascan shelf was a prominent generation site, and they propagated mostly in a southwesterly direction. Two types of anticyclonic eddies were detected, on a radius size basis, with a cutoff scale of 100 km. They exhibited distinct dynamical properties. The largest anticyclonic eddies (radius ≥ 100 km), named rings by analogy with features described in the North Brazil Current (Castelão and Johns, 2011), had higher sea level height at the core, stronger frontal currents at the edge, stronger (downward) vertical velocity at the core and a sharp reversal to upward velocity (upwelling) at relatively short distances outside the edge. They originated from the northern Mozambique Channel and tended to propagate southwesterly along the Mozambique shelf. Smaller anticyclones (radius <100 km), whose scale is characteristic of baroclinic instabilities, exhibited weaker dynamical properties, which mirrored, in an opposite way, that of cyclones. They were generated to the south of the narrows of the MC at 17°S near the Madagascar coast. The models also reproduced the findings by Chelton et al. (2011) that the larger the amplitude and horizontal scale, the longer the life expectancy of the small anticyclonic eddies. Such relationships did not apply to anticyclonic rings, confirming distinct properties that warrant further investigation (Halo et al., 2013).

As they propagate along the Mozambique shelf, eddies often form a chain of dipole structures, i.e. contra-rotating vortices between anticyclones and cyclones that are separated by a frontal zone. This particular dipole configuration also interacts with the steep shelf slope and activates two sources of biological enrichment from the shelf towards the offshore domain when the cyclone is to the south and the anticyclone is to the north. The first source is the coastal biomass entrained offshore by strong radial transport created at the interface between the contra-rotating eddies. This connection was suggested by Tew Kai and Marsac (2009) using satellite imagery and later demonstrated by Kolasinski et al. (2012) using isotope tracers showing the presence of coastal POM downwelled in the interior of an anticyclonic eddy in a dipole configuration. The second source is the result of intense horizontal divergence caused by the dipole, generating slope upwelling as observed and discussed by Roberts et al. (2013). Elevated chlorophyll-a (Chl-a) on and adjacent to the shelf is then advected offshore for distances of 200–300 km as filament structures along the dipole interface. Such a mechanism was clearly demonstrated off Inhambane (Mozambique) from a combination of ocean color snapshots and drifter trajectory (Roberts et al., 2013). We consider that dipole dynamics is the main mechanism responsible for the formation of filaments near continental shelves and for the exchange of shelf and open waters in the MC. Depending on the number of interacting slope eddies, as many as three filaments can exist in the Channel at the same time. It is suggested that such dipole-slope upwelling and offshore advection of organic matter occurs all along the western slope of the MC and might be a continuous process as the dipole migrates southwards, provided it remains in contact with the slope. Other events, such as the merging of eddies of the same type in the west sector of the MC, form stronger eddies that interact with the shelf to increase offshore transport and generate slope upwelling.

Another case of shelf edge cool, elevated Chl-a events, is presented by Malauene et al. (2013). These events have long been attributed to a semi-permanent lee eddy formed off Angoche (Northern Mozambique) where the continental shelf begins to widen and the coast has a more southwesterly orientation. Whilst the lee eddy was considered to be triggered by passing anticyclonic eddies, Malauene et al. (2013) suggested a more complex mechanism combining initial forcing by the local winds, enhanced both vertically and laterally by passing eddies. However, it is not clear which mechanism might dominate. Deep eddies could raise the thermocline at the shelf, so that deep cool water is readily available to be influenced by favorable, alongshore northeasterly winds, inducing cool, elevated Chl-a waters near, and sometimes at the surface.