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Eddy properties in the Mozambique Channel: A comparison between observations and two numerical ocean circulation models

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ABSTRACT

Analysis of satellite altimetry observations, transports estimates from a mooring array, as well as output from two different numerical ocean circulation models (ROMS and HYCOM), have been used to investigate the mesoscale eddy properties and transport variability in the Mozambique Channel. The power spectral density of model transports at 17°S indicates the models ability to represent the transport variability at mesoscale frequencies (range between 3 yr^{-1} and 10 yr^{-1}). The models have shown an exaggerated representation of the lower frequencies ($\sim\ < 3\ \text{yr}^{-1}$), while underestimating the higher frequency signals ($\sim\ > 10\ \text{yr}^{-1}$). The overestimation of the seasonal cycle appears in our case not to be related to a misrepresentation of the mesoscale variability. The eddies were identified using an automatic eddy tracking scheme. Both anticyclonic and cyclonic eddies appeared to have a preferred site of formation within the channel. The density distribution showed that the anticyclones exhibited a bi-modal distribution: the first mode was associated with the typical scale for the oceanic mesoscale turbulence, while the second mode was related to the passage of large rings at a frequency of about 4–7 per year. On the other hand, cyclonic eddies had a single mode distribution that follows the first baroclinic Rossby radius of deformation, which is a typical scale for the oceanic mesoscale surface eddy variability, suggesting that their formation is associated with baroclinic instability. Eddy mean amplitudes per class of radius (< 100 km), increase linearly with increasing radius, while no linear relationship exists for the rings. Different from the rings, the increase in the amplitude of the eddies was consistent with the increase of their life expectancy and travelling distances.

1. Introduction

The Mozambique Channel forms part of the greater Agulhas Current system, which extends from north of Madagascar to the southwestern extremity of South Africa (Lutjeharms, 2006). The greater Agulhas Current system is an important link in the exchange of heat and salt between the Indian and the Atlantic Oceans (Gordon, 1986; Weijer et al., 1999). It has been shown that the flux of warm and salty waters into the Atlantic Ocean via the Agulhas retroflection region plays a decisive role in maintaining the stability of the global meridional overturning oceanic circulation (de Ruijter et al., 1999), and hence the global climate (Beal et al., 2011).

An important way in which warm and salty waters from the Agulhas are transported into the South Atlantic is through the shedding of Agulhas Rings from the Agulhas retroflection south of Africa Lutjeharms and van Ballegooyen (1988); Reason et al., 2003). This mechanism has been termed the Agulhas leakage, and studies have shown that the frequency of Agulhas Ring shedding and thus the inter-ocean leakage is modulated by mesoscale perturbations originating upstream of the retroflection area, in the Mozambique Channel and South of Madagascar (Schouten et al., 2002; Penven et al., 2006; Biastoch et al., 2008b).

The flow through the Mozambique Channel is characterised by intense mesoscale eddy activity (Fig. 1), dominated by large anticyclonic eddies (Biastoch and Krauss, 1999; Ridderinkhof and de Ruijter, 2003; Schouten et al., 2003). These eddies play a significant role in the dynamics of the local marine ecosystems (Weimerskirch et al., 2004). It has been observed that these eddies trap anomalous water masses with higher nutrient and lower oxygen (Swart et al., 2010), and also advect coastal waters with high phytoplankton biomass into the offshore oceanic environment (Quartly and Srokosz, 2004; Omta et al., 2009; Tew-Kai and Marsac, 2009).

Mozambique Channel eddy characteristics have been determined from a number of measurements (Ridderinkhof et al., 2001; de Ruijter et al., 2002). Observations from a current metre mooring

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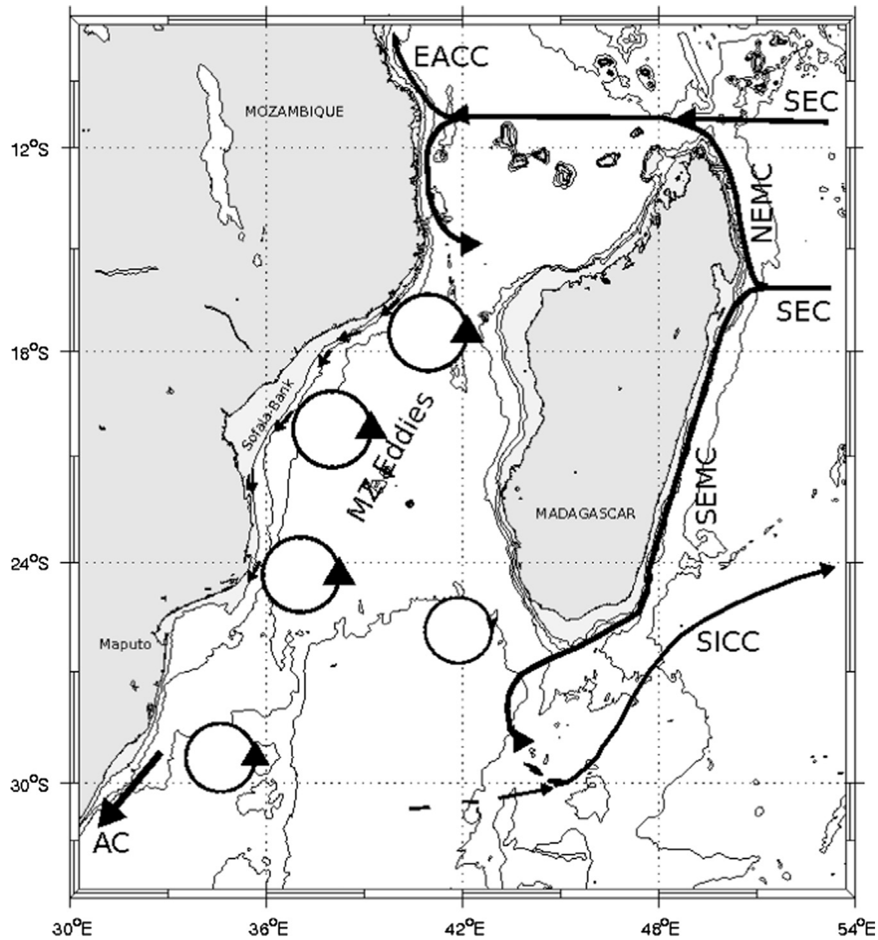

Fig. 1. Main oceanographic features of the circulation system in the Mozambique Channel, and region around Madagascar. South Equatorial Current (SEC), North East Madagascar Current (NEMC), South East Madagascar Current (SEMC), East African Coastal Current (EACC), South Indian Countercurrent (SICC), the Agulhas Current (AC) and Mozambique Channel eddies (MZ-Eddies). The arrows indicate the direction of the flow. The cyclic features represent the eddy field, being clockwise for cyclonic eddies and anticlockwise for anticyclonic eddies. The background contours show the isobaths at 200, 1000, 2000 and 4000 m. The grey shaded bathymetry is shallower than 200 m.

array at $\sim 17^\circ$S (Ridderinkhof and de Ruijter, 2003) have shown that these eddies are up to $\sim$300 to 350 km wide, can reach all the way to the bottom of the Channel (over 2000 m deep), and have a strong barotropic component (de Ruijter et al., 2002; Ridderinkhof and de Ruijter, 2003; Schouten et al., 2003).

These eddies have been shown to be surface intensified, propagating southward, parallel to the western boundary of the Channel, with speeds of $\sim 6\ \mathrm{km\,d^{-1}}$. Interestingly, between 18° and 21°S, their propagation speed reduces to 3–4 $\mathrm{km\,d^{-1}}$ (Schouten et al., 2003), but further to the south, at 24°S, analysis of the eddy properties by Swart et al. (2010), revealed that the eddy propagation velocities increase to $> 6\ \mathrm{km\,d^{-1}}$, with tangential velocities of about 0.5 $\mathrm{m\,s^{-1}}$, while maintaining their large diameters (over $\sim$200 km). On average, these eddies transport heat and salt of about 1.3×10 J and 6.9×10 kg, considered to be sufficient to modify the water masses downstream (Swart et al., 2010).

The frequency of occurrence of eddies is quite regular, observed to be about 4–5 per annum at 17°S (Schouten et al., 2003). Their passage induces fluctuations in the volume transport, ranging from approximately 20 Sv northward to 60 Sv southward. The mean poleward transport has been estimated to be 15 Sv (de Ruijter et al., 2002). However, this quantity seems highly variable: a lower transport of 8.6 Sv was found by Harlander et al. (2009), for the period 2003–2006, but using a longer time series, from the end of 2003 to early 2008, Ridderinkhof et al. (2010) estimated a transport of 16.7 Sv.

Due to the overwhelming signature of the anticyclonic eddies in the central Mozambique Channel, there is no conclusive evidence in the literature regarding the origin of cyclonic eddies in this region. Both cyclonic and anticyclonic eddies are important dynamical features for marine ecosystems (Robinson, 1983; Lathuiliere et al., 2011). They usually bring deep nutrient-rich waters into the upper ocean, thereby enhancing primary production. Currently, the role of the Mozambique Channel eddies in the local ecosystem is being investigated by hydrographic surveys, carried out as part of the MESOBIO programme (Ternon et al., 2013). However, despite their important role, little is known about their abundance and characteristics. For example, de Ruijter et al. (2002) found no cyclonic eddies in the Channel. The apparent cyclonic anomalies observed from altimetry in their study were attributed to artifacts in the data processing, and an inaccurate knowledge of the mean dynamic topography. They concluded that the cyclonic features are misrepresented simply because of the absence of anticyclonic eddies (de Ruijter et al., 2002). Thus, the present knowledge states: *"the frequent passage of positive anomalies through the Mozambique Channel leaves a signal in the mean SSH field, leading to a negative anomaly when no anticyclone is present"* (Schouten et al., 2003). Previous studies have identified cyclonic eddies in the Mozambique Channel Gründlingh (1995). However, their generation site was uncertain, and later studies (Schouten et al., 2003; de Ruijter et al., 2004) have suggested that these transitory features were generated at the southwestern edge of Madagascar, and not within the channel.