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Cyclonic eddies identified in the Cape Basin of the South Atlantic Ocean

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ABSTRACT

Inter-ocean exchange south of Africa takes place largely through the movement of Agulhas Rings into the Cape Basin. Recent observations have shown that the highly energetic flow field in this basin consists of anti-cyclonic rings as well as cyclonic eddies. Very little is known of the characteristics of the cyclonic eddies. Using altimetric data, this study determines the location, frequency and seasonality of these cyclonic eddies their size, trajectories, life spans and their association with Agulhas Rings.

Cyclonic eddies were seen to split, merge and link with other cyclonic eddies, where splitting events created child cyclonic eddies. The 105 parent and 157 child cyclonic eddies identified over a decade show that on average 11 parent and 17 child cyclonic eddies appear annually in AVISO merged absolute dynamic topography data along the continental slope. Thirty-two percent follow an overall west south-westward direction, with 27% going west north-westward. Average translocation speeds are 2.2 ± 0.1 km/day for parent and 3.0 ± 0.2 km/day for child cyclonic eddies. Parent cyclonic eddy lifespan averaged 250 ± 18 days; whereas child cyclonic eddies survived for only 118 ± 11 days. A significant difference in lifespan for parent and child cyclonic eddies identified in the north and south region of the study area was detected. Seventy-seven percent of the northern and 93% of the southern cyclonic eddies were first detected directly adjacent to passing Agulhas Rings, suggesting a vital interaction between these mesoscale eddies within the region. Topographical features appeared to affect the behaviour and lifespan of these deep cyclonic eddies.

1. Introduction

The Atlantic is the only ocean where there is a net heat flux from the southern to the northern hemisphere. Therefore the physical and chemical properties of the waters that flow into the Atlantic Ocean are crucial (Gordon et al., 1992) in their effect on the density of the waters reaching the formation region of North Atlantic Deep Water (NADW) and therefore ocean circulation. The region south of the African continent is thought to be one of the main inflows into the Atlantic and has been studied intensely (Biastoch et al., 2008a,b; Broecker, 1991; Gordon, 1985, 1986; Gordon and Piola, 1983; van Sebille et al., 2010a,b). Many reports have confirmed the presence and nature of anti-cyclonic Agulhas Rings (e.g. Byrne et al., 1995; de Ruijter et al., 1999; Duncombe Rae et al., 1992; Garzoli et al., 1999; Lutjeharms and van Ballegooyen, 1988; etc.) and individual Agulhas Rings have been observed via altimetry and surveyed hydrographically (e.g. Baker-Yeboah et al., 2010; Garzoli et al., 1999; Richardson, 2007; van Aken et al., 2003).

However, these are not the only vortices to be found within this region. Data collected during the Cape of Good Hope Experiment (KAPEX) unequivocally showed the prevalence of cyclonic eddies of unknown origin (vide Fig. 1). Boebel et al. (2003) have compared sea surface height data with in-situ Lagrangian velocity measurements at intermediate depth for these features. They found that the presence of most cyclonic eddies was limited to the south-eastern Cape Basin. Between 1997 and 1999 they recorded 62 cyclonic eddies and only 29 anti-cyclonic Agulhas Rings. The Rings were observed to drift in a north-westward direction at an average rate of 3.3 ± 1.0 kilometres per day (km/day); the cyclones drifted in a west south-westward direction at approximately 3.1 ± 0.5 km/day (Boebel et al., 2003). Boebel et al. (2003) reported that the average lifespan of cyclones was, in general, shorter than that of anti-cyclonic eddies. However, their study only identified those eddies with life spans over two months, possibly filtering out equally prominent eddies with a shorter lifespan. Having left the Cape Basin these cyclones may conceivably last longer than the anticipated 2–3 months. Boebel et al. (2003) stated that these cyclones reach a diameter of 120 km and may form with higher frequency than Agulhas Rings and in some cases, exhibit greater circular velocity.

Using altimetric observations in a study of the global prevalence of eddies, Chelton et al. (2007) noted a general westward propagation of eddies, where 'the percentages of eddies that propagated with equatorward deflection, purely zonally ($0° \pm 1°$), and with poleward deflection, respectively, were 34%, 8% and 58% for the cyclonic eddies and 60%, 9% and 31% for the anti-cyclonic eddies'. Morrow et al. (2004) investigated eddy characteristics in four eastern boundary current regions. They showed that in the Cape Basin, 66% of the cyclones travelled in a west-south-westward direction at approximately 0.3 km/day.

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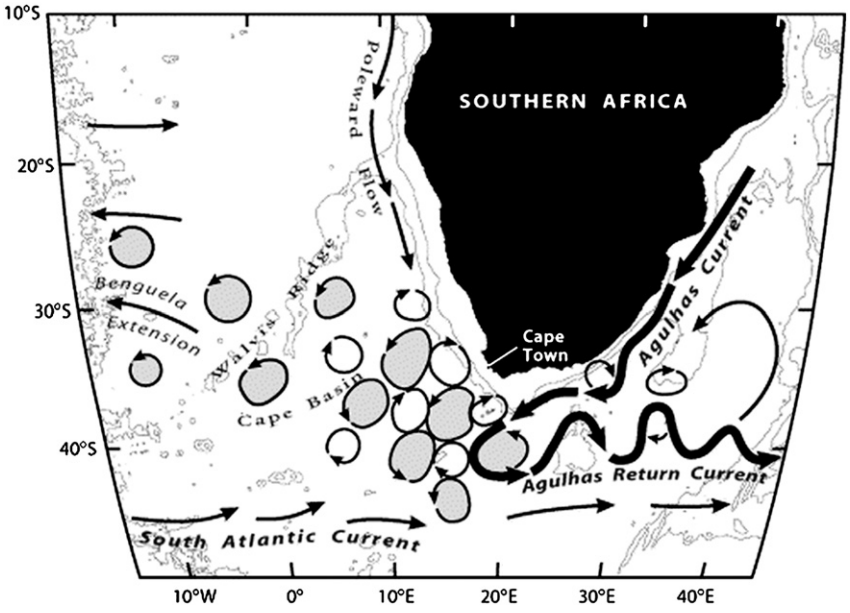

Fig. 1. Schematic map of the circulation of intermediate water south of Africa based on float trajectories (Richardson et al., 2003). The Cape Basin is seen to be populated by numerous anti-cyclonic Agulhas Rings as well as cyclonic eddies.

Giulivi and Gordon (2006) have used hydrographic data to study the displacement of the thermocline in the Cape Basin. They have identified a ratio of 2:1 between positive and negative sea level anomalies (SLAs), representing anti-cyclonic and cyclonic eddies. Simulated cyclonic eddies are clearly evident in numerical models for the Cape Basin with high spatial resolution (e.g. Biastoch et al., 2008a, c; van Sebille et al., 2010b).

The discovery of these cyclonic eddies in the Cape Basin implies that the origins of the region's eddy turbulence, previously attributed solely to Agulhas Rings, may have to be reconsidered. Interaction between the cyclonic and anti-cyclonic eddies could furthermore result in enhanced mixing (Boebel et al., 2003; Matano and Beier, 2003; Richardson and Garzoli, 2003; van Sebille et al., 2010b) diffusing the warm, salty water of Agulhas Rings into the background water more efficiently than was previously thought to happen by natural degradation. Richardson (2007) conducted a thorough investigation into leakage from the Agulhas Current into the Cape Basin by considering the trajectories and speeds of surface drifters and subsurface floats. These instruments were entrained into cyclonic and anti-cyclonic eddies as they entered the Atlantic Ocean. However, few instruments were inducted into cyclonic eddies that are identified in the northern region discussed here, although Richardson (2007) did identify cyclones that formed further north than those near the Agulhas Retroflection.

Baker-Yeboah et al. (2010), have proved that the collision of Agulhas Rings with the continental slope and other topographical features may result in eddy splitting. Should this be the case, then of question is the behaviour and appearance of cyclonic eddies in the northern part of this study area, away from the Agulhas Ring Corridor. Furthermore, little is known about the timing and frequency of cyclonic eddy formation, their dimensions, trajectories or life spans. This paper aims to chronicle a descriptive, pilot study undertaken to investigate these aspects of cyclonic eddies initially detected between the latitudes of 24 ° and 35 °S. It attempts to form a basis for future research into their thermohaline dynamics and potential role in the meridional transfer of heat and salt to the northern Atlantic Ocean and therefore the forcing of NADW formation on global ocean circulation.

2. Methods and data

Detecting cyclones and following them in the highly turbulent Cape Basin is certainly not without problems. However, Agulhas Rings have been studied very efficaciously using altimetry (e.g. Arhan et al., 1999; Byrne et al., 1995; Garzoli et al., 1999; Gründlingh, 1995), as have the smaller cyclones (Baker-Yeboah et al., 2010; Boebel and Barron, 2003; Chelton et al., 2007; Lutjeharms et al., 2003; Morrow et al., 2004), proving the effectiveness and the adequate spatial resolution of current satellite altimetry. Nevertheless, these satellite altimetry data are useful only if there is conclusive proof that the negative SLAs truly represent eddies in this region. Fortuitously available hydrographical data were compared with simultaneous altimetric observations. Multiple comparison results, in conjunction with previous investigations, give us confidence that altimetric data represent a reliable source of information on Cape Basin cyclones.

Ten years of altimetric data (1992–2002) were used for this investigation. SLAs were calculated from gridded 1/3° x 1/3° Mercator grid, 100 kilometre resolution TOPEX/Poseidon and ERS1-2 sea level anomaly data produced by Ssalto/Duacs and distributed by Archivage, Validation et Interprétation des données des Satellites Océanographiques (AVISO), with support from CNES (www.aviso.oceanobs. com/en/altimetry/multi-satellites/index.html, 2010). The following webpage describes the AVISO data processing applied to the raw data before dissemination: www.aviso. oceanobs.com/en/data/product-information/processing-steps-and-data-levels/index.html (2010). Errors associated with these data are detailed in Baker-Yeboah and Watts (2009).

Due to the parameters investigated within this study, attention was focused exclusively on cyclonic eddies that were first identified as near-shore SLAs until they were no longer visible in the AVISO merged absolute dynamic topography data. This approach restricted cyclonic eddy identification to those first detected between the latitudes of 24 ° and 35 °S, and not cyclonic eddies entering into the study area (Fig. 2). Therefore this study focuses on cyclonic eddies first identified further north than other research on cyclonic eddies found near the Agulhas Retroflection.

Agulhas Rings can be legitimately tracked until they are a minimum of 10 cm above mean sea surface height (Byrne et al., 1995). Therefore a +10 cm depression is used as a criterion for the first detection of a cyclonic eddy. This criterion may be on the conservative side but is largely subjective since few target in-situ hydrographic data are available to confirm or deny this value. Cyclonic eddy centres were defined as the most intense portion of the depression. The outer ring