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Eddy Surface properties and propagation at Southern Hemisphere western boundary current systems

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Abstract

Oceanic eddies occur in all world oceans, but are more energetic when associated to western boundary currents (WBC) systems. In these regions, eddies play an important role on mixing and energy exchange. Therefore, it is important to quantify and qualify eddies occurring within these systems. Previous studies performed eddy censuses in Southern Hemisphere WBC systems. However, important aspects of local eddy population are still unknown. Main questions to be answered relate to eddies' spatial distribution, propagation and lifetime within each system. Here, we use a global eddy dataset to qualify eddies based on their surface characteristics at the Agulhas Current (AC), the Brazil Current (BC) and the East Australian Current (EAC) Systems. We show that eddy propagation within each system is highly forced by the local mean flow and bathymetry. In the AC System, eddy polarity dictates its propagation distance. BC system eddies do not propagate beyond the Argentine Basin, and are advected by the local ocean circulation. EAC System eddies from both polarities cross south of Tasmania, but only anticyclonics reach the Great Australian Bight. Eddies in all systems and from both polarities presented a geographical segregation according to size. Large eddies occur along the Agulhas Retroflection, the Agulhas Return Current, the Brazil-Malvinas Confluence and the Coral Sea. Small eddies occur in the systems southernmost domains. Understanding eddies' propagation helps to establish monitoring programs, and to better understand how these features would affect local mixing.

1 Introduction

Oceanic mesoscale eddies are defined by a closed circulation (Cushman-Roisin and Beckers, 2006), having an internal water parcel with different characteristics from the surrounding fluid (Flierl, 1979). Due to eddies' advective properties, they play an important role in ocean circulation. Eddies redistribute heat, salt, and momentum between different regions, as well as act on mixing and energy exchanges with the mean flow (e.g. Stammer and Wunsch, 1999; Lee et al., 2007). Despite being found in all oceans, eddies are most intense when associated with western boundary currents (WBC) (Chelton et al., 2011). In these highly energetic regions, eddies often originate from mean flow instabilities, being shed by the currents meanders.

WBCs that close Southern Hemisphere subtropical gyres are the Agulhas Current (AC) the Brazil Current (BC), and the East Australian Current (EAC). These currents separate from the coast abruptly, in a process normally associated with the formation of a quasi-stationary retroflection meander (da Silveira et al., 1999; Fig. 1). This meander may occlude and shed a large anticyclonic eddy, in a process forced by continental geography, bathymetry and wind patterns (e.g. Nilsson and Cresswell, 1981; Olson, 1991; Matano, 1993; De Boer et al., 2013). These large anticyclonic retroflection eddies are not the only ones contributing to the energy within WBC systems. Smaller cyclonic and anticyclonic eddies also participate on the complex WBC's energetic eddy field; therefore, being an important part of the local circulation (e.g. Boebel et al., 2003; Bowen et al., 2005; Mata et al., 2006). Previous studies performed eddy censuses in these three systems. However, important aspects of local eddy fields are still unknown. Main questions to be answered relate to eddies' spatial distribution and propagation within each system.

In the AC System, censuses of anticyclonic eddies were extensively performed after sea surface temperature (Lutjeharms and Van Ballegooyen, 1988) and single-satellite altimetry (e.g. Byrne et al., 1995; Goni et al., 1997; Schouten et al., 2000). Cyclonic eddies censuses in the region were performed after merged altimetry products (e.g. Boebel et al., 2003; Halland Lutjeharms, 2011). These censuses show that large retroflection anticyclonic eddies propagate beyond Cape Basin, while cyclonic eddies remain trapped within it. The propagation of smaller anticyclonic and cyclonic eddies has not been fully reported.

In the BC System eddy censuses were performed after sea surface temperature data (Legeckis and Gordon, 1982; Lentini et al., 2002) and single-satellite altimetry data (Lentini et al., 2006). These early studies have reduced temporal and spatial res-

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olutions; therefore, the eddies' sample is biased towards large, persisting features. The 67 eddies considered in these studies propagate in an unorganized manner, close to the Brazil-Malvinas Confluence (BMC), being later reabsorbed by their parent current. A census using merged altimetry was also performed on the Argentine Basin, the bathymetric feature in which the BC retroflection and the BMC are located. There, eddy shedding is associated with meandering of the local anticyclonic flow, called the Zapiola Drift (Saraceno and Provost, 2012). It is still unknown if eddies shed by the BC, the BMC or the Zapiola Drift propagate beyond the Argentine Basin. Their mean lifetime and surface properties also require further assessment.

In the EAC only one eddy census was performed to date. Everett et al. (2012) studied eddies with a global eddy dataset (Chelton et al., 2011), built after altimetry data. The authors show that a large number of eddies occur close to the Australian shelf break between the retroflection region ($\sim 31^{\circ}$ S) and the east coast of Tasmania ($\sim 40^{\circ}$ S). However, they do not investigate eddies' lifetime or propagation.

Here, we qualify AC, BC and EAC System eddies based on their surface properties, and investigate eddy propagation and lifetime. We show that a global eddy dataset built after gridded altimetry data (Chelton et al., 2011) is a valuable tool to quantify eddies regionally. Eddies mean surface properties and propagation presented here helps us to further understand eddies' interaction with the local ocean circulation. Identifying eddies' propagation patterns allows us to establish monitoring programs. Also, it helps us to better understand eddies' contribution to oceanic heat and salt transports and how eddies affect local mixing.

The next section describes the global eddy dataset used in this study, as well as our investigation methods. In Sect. 3 we present eddies propagation and lifetime in the AC, BC and EAC systems, followed by eddies' surface properties (e.g. amplitude, rotation speed and radius). In Sect. 4 we discuss the results, and in Sect. 5 we summarise our main findings.

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2 Data and methods

We use version 3 of Chelton and Schlax global eddy dataset (Chelton et al., 2011; available at http://cioss.coas.oregonstate.edu/eddies/). This dataset provides eddy tracks identified in global merged Sea Surface Heigh (SSH) maps between October 1993 and April 2012. Eddy radius, amplitude and rotation speed are also provided at each time-step of the eddy lifetime. The SSH maps used to built this global eddy dataset have weekly temporal resolution and, after filtering, 1/4° spatial resolution (see Chelton et al., 2011 Appendix A); therefore, most of the mesoscale spectrum is resolved. The eddies are identified using a SSH-based method and tracked using the same approach as Chelton et al. (2007). We refer the reader to Chelton et al. (2011) for further information on the identification and tracking method.

Here, we select eddies with first occurrences (i.e. first detections) in (a) the Agulhas Retroflection and the ARC (33–46° S and 5–70° E) hereafter defined as the AC System (Fig. 1a); (b) the Argentine Basin, associated with the BMC and the BC retroflection (35–50° S and 60–30° W), hereafter defined as the BC System (Fig. 1b); and (c) the EAC, flowing through western regions of the Coral and the Tasman Seas, and its retroflection (25–45° S and 147–164° E), hereafter defined as the EAC System (Fig. 1c). In the AC System we do not include eddies from the Mozambique Channel (upstream of the study region) and from the East Madagascar Current (to the east of the study region). These eddies may affect eddy shedding by the Agulhas Retroflection (Lutjeharms, 2006). However, in the dataset used here, no eddy formed in these regions reach either the Cape Basin or the ARC (not shown) and seem to belong to different highly energetic systems.

To calculate an eddy mean surface property along its lifetime we first multiply the property mean between two subsequent time-steps by the distance the eddy propagates in this time period (i.e. 7 days). Then, these adjacent time-steps products from the entire eddy lifetime are summed. This sum is then divided by the total distance that

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the eddy covered along its lifetime. We repeat this procedure for all eddies within the same system.

We must consider particularities of the global eddy dataset when investigating highly energetic regions. One particularity relevant for our study is the premature eddy dissipation due to detection inaccuracies. Eddies can escape detection in sparsely sampled regions (i.e. between satellite ground tracks), where the gridded altimetry dataset has reduced spatial resolution. Eddies can also escape detection after merging, splitting, and interaction with other eddies, the mean flow and local bathymetry. These events can distort the eddy, failing to satisfy the algorithm identification criteria. An eddy can be later re-identified and considered as a new eddy. Therefore, detection inaccuracies can lead to the underestimation of eddies' lifetime and overestimation of eddies first identification.

A second particularity to be considered are meanders being identified as eddies. According to (Chelton et al., 2011), Aviso's SSH time-averaged removal to obtain Sea Level Anomaly (SLA) maps also removes mean currents. This removal may convert meander signals into apparent closed contour eddy signals, which would be identified by the algorithm. Considering that meanders are more transient than eddies, we apply a lifetime-cutoff filter to separate these mesoscale features as in Chelton et al. (2011). The optimal value for this cutoff varies geographically. After running several tests in the three systems, we define 10 weeks as an appropriate value to distinguish eddies and meanders identified as eddies. Therefore, only eddies originated in our study regions with lifetime larger than 10 weeks are considered.

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3 Results

3.1 Eddy propagation

3.1.1 Agulhas current system

At the AC System 2740 eddies are identified, being 48 % cyclonic and 52 % anticyclonic. Both cyclonic and anticyclonic eddies occur over the entire domain (Fig. 2).

Most cyclonic eddies propagate within the system boundaries, covering 732 km on average (Table 1). However, three cyclonic eddies overcome the Walvis Ridge, with one propagating 5000 km across the South Atlantic. This cyclonic eddy reaches the Rio Grande Rise, at ~ 40° W, before dissipating (i.e. being lost by the algorithm). AC System cyclonic eddies have an average lifetime of 6.5 months (Table 1), and propagate faster than anticyclonic eddies in this system (4 vs. 3.8 km day^{-1}, respectively; Table 1).

As expected, a higher number of anticyclonic eddies propagate beyond the AC System into the South Atlantic, with 24 eddies reaching the Brazilian continental shelf break. These eddies originate in the Cape Basin (Fig. 2b, inset). With some eddies overcoming the Walvis Ridge and others not, their propagation distance standard deviation is higher than their mean propagation distance (Table 1). AC System anticyclonic eddies have an average lifetime of 9 months (Table 1), with maximum lifetime of 3 years.

AC System's eastward propagating eddies (34 % of total AC System eddies; Fig. 2c) are advected by the ARC. Here, eddies follow the local bathymetry, as can be seen in the Agulhas Plateau (25° E; 40° S). Both cyclonic and anticyclonic eddies are deflected northwards when encountering the plateau.

3.1.2 Brazil current system

At the BC System 1119 eddies are identified, being 56 % of them cyclonic and 44 % of them anticyclonic. Both cyclonic and anticyclonic eddies propagate strictly within the

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Argentine Basin (Fig. 3), and eddy numbers are small where the Zapiola Drift is most intense. The Zapiola Drift is an anticyclonic flow that dominates the Argentine Basin circulation (De Miranda et al., 1999). It flows around the Zapiola Rise, a bathymetric feature of 2000 m in the centre of the 4000 m basin (45° W, 45° S; Fig. 1b).

Cyclonic eddies cover 523 km, on average, with a 4.4 km day^{-1} mean propagation speed (Table 1). These eddies occur over the entire basin, also dominating the inner portion of the Zapiola Drift (Fig. 3a). There, 23 cyclonic eddies display an anticlockwise propagation around the Zapiola Rise, entering the drift on its eastern flank. Two cyclonic eddies, on average, enter the drift per year between 1998–2011; however, none is detected after this period. BC System cyclonic eddies have an average lifetime of 4 months, with maximum lifetime of 1.5 years (Table 1).

Anticyclonic eddies cover 514 km, on average, with a 4.6 km day^{-1} mean propagation speed (Table 1). BC System anticyclonic eddies have an average lifetime of 4 months, with maximum lifetime of 1.3 years (Table 1).

Despite most eddies of the BC System eddies in the basin's western domain propagate southward, 22 eddies in this domain propagate northward. They occur along the continental slope, where northward coastally trapped waves have been reported (Vivier et al., 2001). These local coastally trapped waves result in 10-week period intraseazonal variability, seen in SSH fields, with a phase speed of 1.4–3.6 m s^{-1}. The northward eddies have a lifetime of 10–19 weeks and propagate at 0.05 m s^{-1}. It is unclear if these northward eddies are advected by the northward Malvinas Current or are coastally trapped waves not removed by the 10 week cutoff filter. We look for these eddies signature in sea surface temperature (SST) data (AVHRR Pathfinder version 5.0, available at http://www.nodc.noaa.gov/sog/pathfinder4km/), but none can be seen. This absence of SST signature means that (a) the eddies are identifiable in SSH fields but not in SST fields, or (b) the eddies are false closed contours not eliminated by the 10 week cutoff filter.

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3.1.3 East Australian current system

At the EAC System 1050 eddies are identified, being 51 % of them cyclonic and 49 % of them anticyclonic. The eddies occur over the entire domain, but cluster off the continental slope (Fig. 4). This eddy cluster is due to eddies shed by the EAC retroflection and to eddies travelling westward from the Tasman Sea. Regardless their origin, they propagate southward along the Australian coast, dissipating before 40° S (not shown). Eddies occurring at the Tasman Sea (i.e. south of the Tasman Front, at ∼ 31° S) display no clear propagation pattern. Roughly 88 % of the EAC System eddies propagate westward.

Cyclonic and anticyclonic eddies from the EAC System do not differ in terms of lifetime, propagation distance or speed (Table 1). Cyclonic eddies cover on average 521 km at the EAC System, with a 3.2 km day^{-1} mean propagation speed, and an average lifetime of 6 months. Antiyclonic eddies, in turn, cover on average 522 km at the EAC System, with a 3.1 km day^{-1} mean propagation speed. These eddies have an average lifetime of 6 months, with maximum lifetime of 5 years. This 5-year-lasting eddy propagates from the EAC System into the Great Australian Bight.

EAC System eddies can cross south of Tasmania and reach the Great Australian Bight (Fig. 4a in cyan and b in pink). However, the origin of these eddies is not linked to the EAC retroflection region, with their first occurrence being east of Tasmania. The 10 anticyclonic eddies that cross south of Tasmania have a mean radii of 70 km and mean lifetime of 1.5 years.

3.2 Eddy surface properties

We now look at eddies surface properties: amplitude, rotation speed and radius. We then focus on eddy radius spatial distribution within each basin.

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3.2.1 Eddy amplitude and rotation speed

Agulhas System eddies' amplitudes range from 1.5 to 64.1 cm, with cyclonic eddies having a larger mean amplitude than anticyclonic ones (Table 1). Most of cyclonic and anticyclonic eddies have amplitudes smaller than 10 cm, with their distribution being positively skewed (Fig. 5a). This skewed distribution is also reflected on eddies' rotation speed (Fig. 5d), with most eddies rotating slower than 25 $cm\,s^{-1}$. Here, cyclonic eddies spin faster than anticyclonic eddies (Table 1).

BC System eddies' amplitudes range from 1.8 to 56.7 cm, with cyclonic eddies also having larger mean amplitude than anticyclonic ones (Table 1). At this system, the amplitude distribution is less skewed and closer to a normal distribution (Fig. 5b). Here, most cyclonic and anticyclonic eddies have amplitudes between 2 and 30 cm. As expected, the eddies' rotation speed distribution also follows the amplitude distribution (Fig. 5e). Rotation speeds between 1 and 50 $cm\,s^{-1}$ are recurrent and, as in the AC System, cyclonic eddies rotate faster (Table 1).

EAC System eddies' amplitudes range from 1.5 to 41.9 cm. As in the previous systems, EAC System cyclonic eddies have larger mean amplitude than anticyclonic ones (Table 1). This property distribution resembles more the AC System eddies' distribution than the BC System one (Fig. 5c). Here, eddies' amplitude distribution is positively skewed, with most eddies presenting values smaller than 7 cm (Fig. 5f). EAC System eddies' rotation speed distribution is positively skewed, with most speeds smaller than 15 $cm\,s^{-1}$. Cyclonic and anticyclonic eddies from the EAC system have similar rotation speeds (Table 1).

3.2.2 Eddy radius

In all three systems, cyclonic and anticyclonic mean radii are similar between each other (Table 1). However, differences between both types of eddies arise when we look at radius' histograms. Also a spatial pattern emerges when we look at eddy radius' spatial distribution in each system (Fig. 6). For this spatial analysis we grid each do-

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main onto 1° × 1° cells. We then consider the radius of all eddy-like features (lifetime > 4 weeks) that occur in each cell to calculate a mean value for that cell. To test for significance we perform a *z* test with 0.05 significance level. Cells with eddies significantly larger than cells within that system (mean radius > 112, 117 and 109 km at AC, BC and EAC Systems, respectively) are marked by white dots in Fig. 6. Cells with eddies significantly smaller than cells within that system (mean radius < 58, 62 and 56 km at AC, BC and EAC Systems, respectively) are marked by black stars.

AC System cyclonic eddies have a close to normal distribution, with most eddies having radius between 70 and 110 km (Fig. 5g). Anticyclonic eddies, in turn, present two modes in their distribution: one at 75 km and other at ~ 90 km. Here, significantly large eddies occur at the Agulhas Retroflection and along the ARC path, while significantly small eddies occur to the south of the ARC. This large and small radii pattern is seen for both cyclonic and anticyclonic eddies; however, it is more pronounced for anticyclonic eddies.

BC System cyclonic and anticyclonic eddy radius distributions are close to normal, with most eddies having radii between 60 and 120 km (Fig. 5h). Here, significantly large eddies occur in Argentine Basin's northern domain, associated with the BMC, while small eddies fill the basin's southern domain and the inner portion of the Zapiola Drift.

EAC System eddies radius distribution is more positively skewed than in the other systems (Fig. 5i), with most eddies' radius being smaller then 90 km. Here, significantly large eddies occur in the northern domain of the study region (i.e. at the Coral Sea), and off the eastern Australian coast (Fig. 6). Significantly small eddies occur in the Tasman Sea south of 35° S. This radius differences between Coral and Tasman Seas is more evident for anticyclonic eddies.

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4 Discussion

At the AC System some eddies overcome the Walvis Ridge and others do not. de Steur and van Leeuwen (2009) showed that eddies with a strong barotropic component, when encountering the ridge, tend to slow down or deflect until adjusted to a less barotropic state. Therefore, barotropic eddies are less likely to overcome the ridge. Eddies with a strong baroclinic component, in turn, are stabilised by the ridge, which reduces their decay and supports their South Atlantic crossing. These South-Atlantic crossing eddies will eventually fade close to the Brazilian continental shelf break (Azevedo et al., 2012). Eddies' meridional drift is seen in these eddies and, to a smaller extend, in eddies within the Cape Basin. This drift occurs due to interactions between eddies and the vorticity field of surrounding water parcels (Morrow, 2004; Cushman-Roisin and Beckers, 2006), resulting in an equatorward (poleward) drift of anticyclonic (cyclonic) eddies, regardless their hemisphere.

BC System eddies do not propagate beyond the Argentine Basin. Rykova et al. (2015) showed that eddies occurring at the BMC are essentially barotropic and displace isopicnals up to 500 m. These eddies are the second deepest eddies of all WBC, losing only to the Agulhas Rings. Since the vertical extension of eddies shed by the Zapiola Drift is unknown, we can only especulate that BC System eddies' strong barotropic component confines them in the basin, similarly to barotropic AC System eddies in the Cape Basin.

The cluster of cyclonic eddies inside the Zapiola Drift was previously reported by Saraceno and Provost (2012). The authors suggest that the Zapiola Drift sheds eddies through a mechanism similar to the Gulf Stream: the drift forms anticyclonic meanders to its outer portion and cyclonic meanders to its inner portion. These meanders may occlude and shed eddies, justifying the larger number of cyclonic eddies in the inner part of the flow.

EAC System eddies clustering along the Australian slope were previously shown by Everett et al. (2012). Here, we show that these eddies are not only shed by the EAC

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retroflection, but also come from the Coral Sea. Yang et al. (2013) came to a similar conclusion, showing that the intensification of eddy variability in the Northwestern Pacific is not caused by increase in the Kuroshio Current eddy shedding, but by westward eddies clustering along the continental shelf break.

Eddies formed in the Tasman Sea can cross south of Tasmania and propagate beyond the EAC system, reaching the Great Australian Bight. As in the AC System, EAC System eddies also display meridional drift, with anticyclonic eddies propagating northwestward along the Bight and cyclonic eddies propagating southward. As previously reported by Baird and Ridgway (2012), these eddies that cross south of Tasmania may advect Bass Strait coastal waters to the open ocean south of Australia. Therefore, they act on heat and biogeochemical budgets between different oceanic regions.

When analysing eddies' lifetime in this study we must keep in mind the 10 week cutoff lifetime filter applied here. AC System eddies in the literature have a 7 months mean lifetime, with Agulhas Rings lifetime ranging from 2.5 to 3.5 years (Schouten et al., 2000). These values are comparable to our 8-months mean eddy lifetime and maximum Agulhas Rings lifetime of 3.8 years. BC System anticyclonic eddies lifetimes reported in the literature range from 3 (Lentini et al., 2006) to 9 weeks (Souza et al., 2006) while our values range from 10 weeks to 1.5 years. In this system, we must consider that only 41 robust anticyclonic eddies shed by the BC retroflection were considered in previous studies, biasing the sample. We attribute this lifetime difference due to different tracking methods and datasets used in previous studies. No census of cyclonic eddies has ever been reported; therefore, no comparison on eddy properties can be made. Everett et al. (2012) recently performed an eddy census at the EAS System after the same dataset used in our current study. This system eddies' properties are, therefore, comparable to the properties shown in Everett et al. (2012).

BC System eddies' have amplitude and rotation speed values distribution different than in the other systems. While these distributions are close to normal for BC System eddies, they are positively skewed for AC and EAC System eddies. Also, BC System eddies have a larger mean amplitude (27 cm) than the other systems (~9 cm). The

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outnumbering of smaller amplitude and reduced speed eddies in the AC and EAC System can be explained by the larger mean eddies' lifetime in these systems when compared to the BC System. AC and EAC System eddies lose their amplitude as they live and propagate across long distances (e.g. Souza et al., 2014, for the Agulhas Rings), adding smaller amplitude and rotation speed values to the histograms.

In all three systems, anticyclonic eddies with radius larger than 115 km occur close to the currents retroflections. This value corroborates with retroflection eddies radii of the AC current (120–324 km; Lutjeharms, 1981), the BC current (35–150 km; Lentini et al., 2006), and the EAC current (100–150 km; Nilsson and Cresswell, 1981; Bowen et al., 2005). The mechanisms responsible for eddies' segregation according to radius size seem to act similarly in both cyclonic and anticyclonic eddies. These mechanisms are more complex than would be expected based only on the relation between latitude and the first baroclinic Rossby radius of deformation.

5 Summary

Previous eddy censuses were performed in the systems associated with Southern Hemisphere WBCs: the AC, the BC and the EAC. However, some questions regarding eddies' propagation and lifetimes remained unanswered. In this sense, and taking advantage of a longer altimetry dataset, we use a global eddy dataset to investigate eddies' propagation, lifetime and surface characteristics within these systems.

While most of the AC System eddies' are restrained within the Cape Basin, some overcome the Walvis Ridge and reach the South Atlantic. Three of these eddies are cyclonic and 24 are anticyclonic (i.e. Agulhas Rings). The Agulhas Rings propagate along the expected path between 20–30° S, living up to 3 years. AC System eastward eddies' are mainly advected by the ARC. These eddies' tracks follow isobaths, contouring the Agulhas Plateau to the north.

We show that BC System eddies' do not propagate beyond the Argentine Basin and suggest that this behaviour may be associated to these eddies' vertical extend and

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barotropicity showed by Rykova et al. (2015). BC System eddies are the shortest living of all systems investigated, and also the ones with larger mean amplitude.

EAC System eddies occur all over the study region, from the southern domain of the Coral Sea to the Tasman Sea. Coral Sea eddies propagate westward until reaching the Australian continental slope, where they acquire a southward route following the Australian coastline. Tasman Sea eddies, in turn, propagate in an unorganised manner. EAC System eddies live in average 6 months, but can live up to 5 years after crossing the south of Tasmania and reaching the Great Australian Bight. Both cyclonic and anticyclonic eddies identified in the Tasman Sea cross south of Tasmania and, beyond this point, they display meridional drift.

Eddies from all three systems exhibit a spatial segregation according to their radius. At the AC System, large eddies occur along the ARC and at the Agulhas Retroflection, while small eddies occuring in the southern domain of this system. At the BC System, large eddies follow the high Eddy Kinetic Energy pattern, occurring in the northern domain of the basin; small eddies occur in the southern and inner part of the Argentine Basin. At the EAC System large eddies occur at the Coral Sea and off the Australian east coast, while small eddies occur in the Tasman Sea. In all three retroflection regions, anticyclonic eddies have radii larger than 115 km. The segregation mechanisms seems to be the same for both cyclonic and anticyclonic eddies, although the segregation pattern is more evident for anticyclonic ones.

The analysis presented here increases our knowledge on how the local circulation can force eddy behaviour. This knowledge acts as a starting point for future, more specific studies. Nevertheless, we seem to be one step closer for understanding eddies interactions with the mean flow.

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Table 1. Mean (and SD) properties and characteristics of cyclonic and anticyclonic long-lived eddies. See text for description of mean calculation.

	Mean (SD)					
	AC System		BC System		EAC System	
	Cyc	Anti	Cyc	Anti	Cyc	Anti
Propagation Distance (km)	732.8 (640.5)	1050.4 (1258.0)	523.4 (282.6)	513.8 (263.9)	521.5 (374.9)	522.2 (427.1)
Propagation Speed (km day^{-1})	4.0 (1.3)	3.8 (1.3)	4.4 (1.5)	4.6 (1.7)	3.2 (1.2)	3.1 (1.1)
Lifetime (weeks)	26.3 (21.6)	37.2 (38.6)	17.3 (8.3)	16.3 (7.5)	22.9 (14.9)	24.6 (19.8)
Amplitude (cm)	8.9 (8.1)	7.9 (6.0)	18.7 (9.0)	15.9 (7.8)	9.2 (7.1)	8.6 (6.4)
Rotation Speed (cm s^{-1})	19.5 (13.9)	17.5 (9.9)	31.7 (12.0)	29.4 (11.4)	21.1 (13.7)	20.1 (12.5)
Radius (km)	87.0 (13.9)	89.0 (14.5)	87.6 (17.1)	90.7 (16.5)	83.4 (15.4)	82.7 (16.5)

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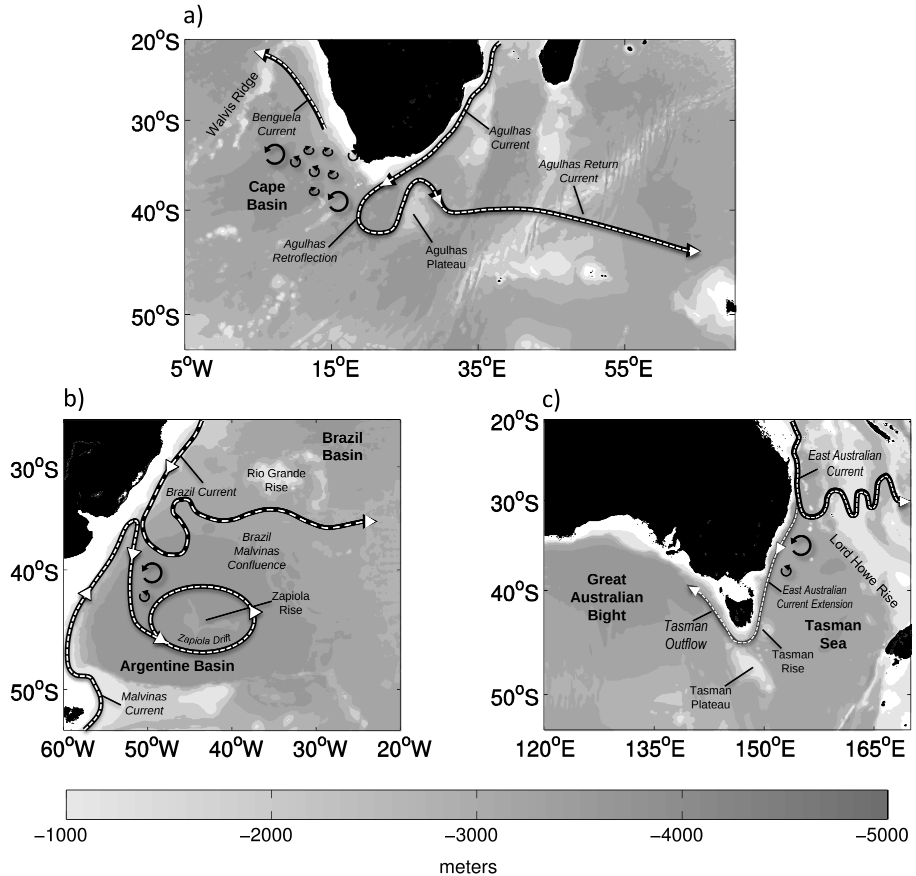

Figure 1. Main bathymetric features and circulation patterns of the **(a)** AC System, **(b)** BC System and **(c)** EAC System (Adapted from Peterson and Stramma, 1991; Cresswell, 2000; Tilburg et al., 2001; Mata et al., 2006; Matano et al., 2010).

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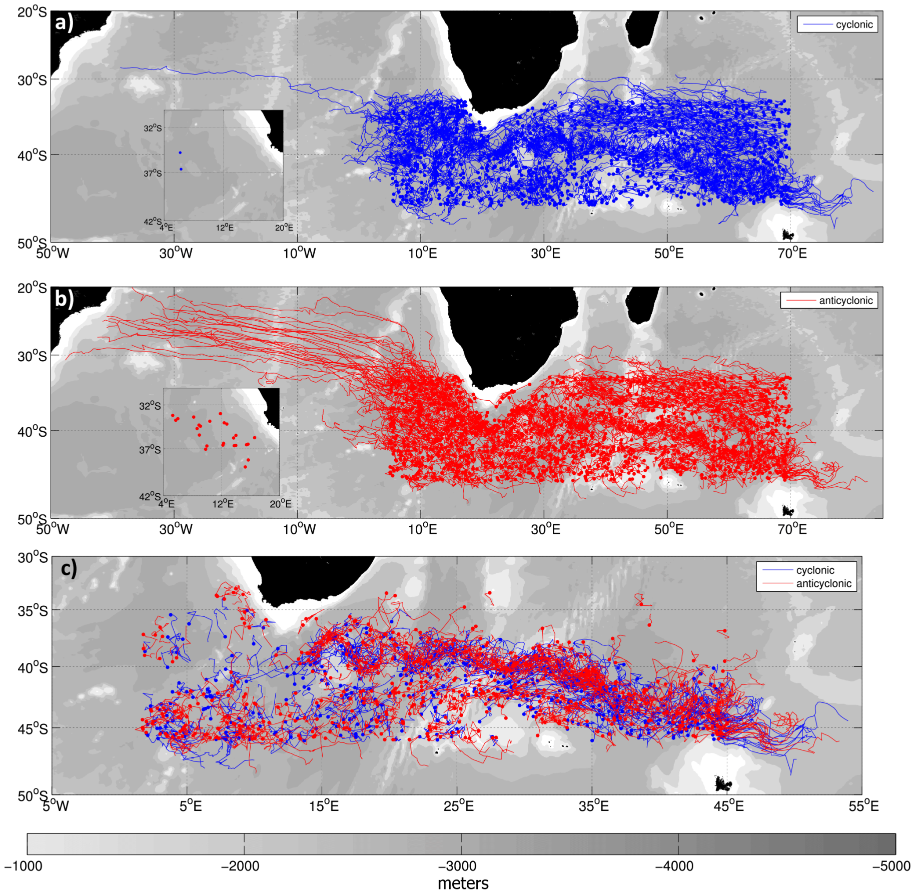

Figure 2. Trajectories of **(a)** cyclonic, **(b)** anticyclonic, and **(c)** eastward eddies first identified in the AC System between October 1992 and April 2012. Insets in **(a)** and **(b)** show South Atlantic crossing eddies' first locations.

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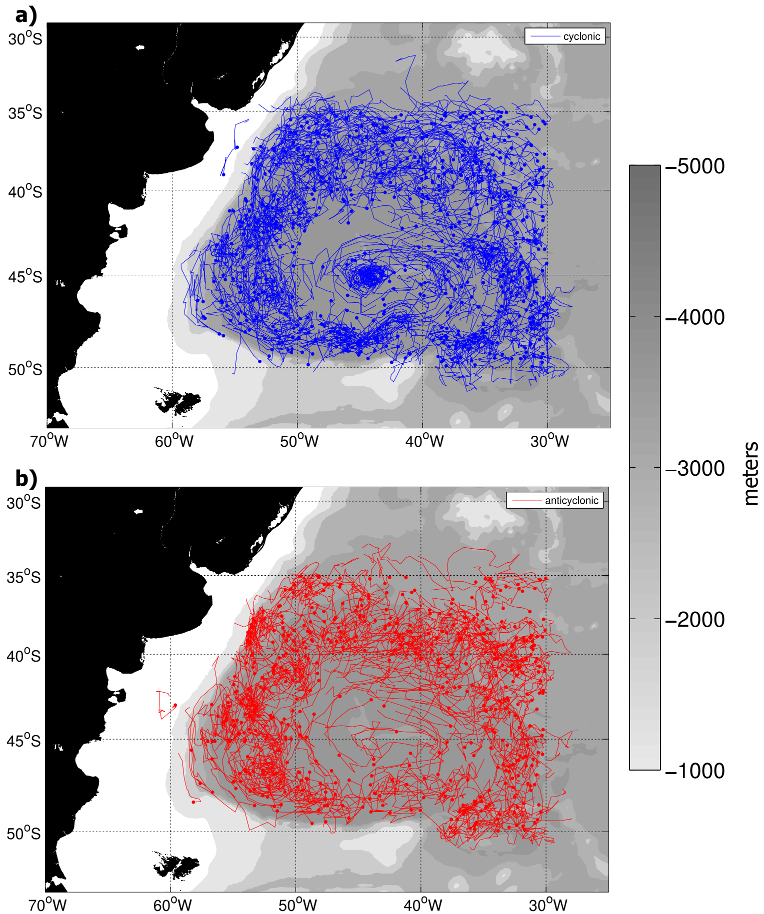

Figure 3. Trajectories of **(a)** cyclonic and **(b)** anticyclonic eddies first identified in the BC System between October 1992 and April 2012.

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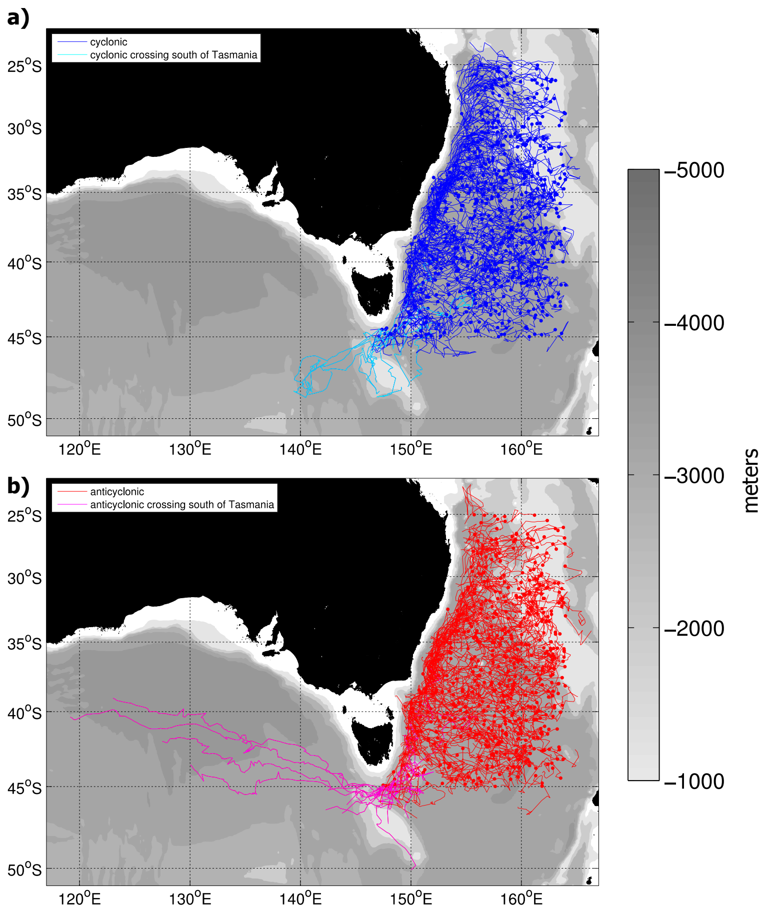

Figure 4. Trajectories of **(a)** cyclonic and **(b)** anticyclonic eddies first identified in the AC System between October 1992 and April 2012. Eddies' tracks that cross south of Tasmania are shown in pink and cyan.

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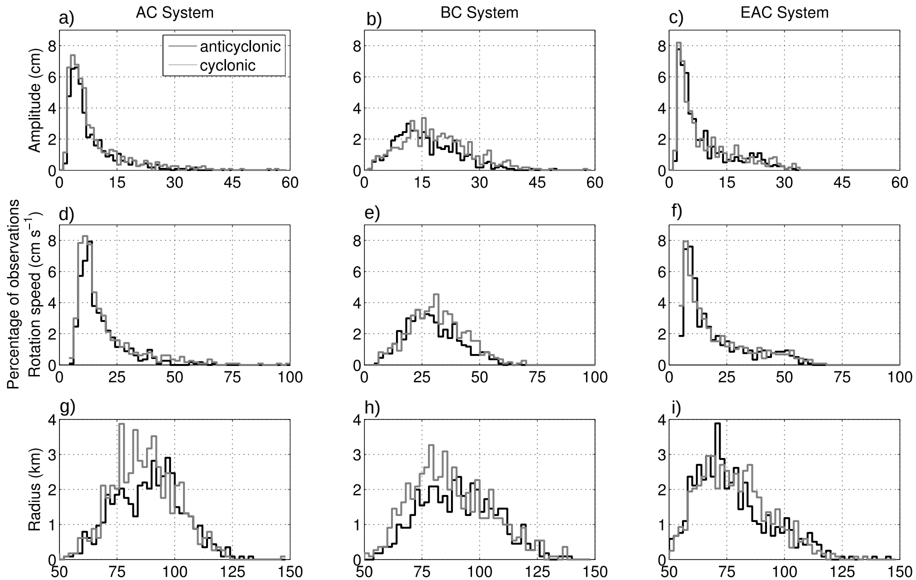

Figure 5. Histograms of amplitude **(a)–(c)**, rotation speed **(d)–(f)** and radius **(g)–(i)** for AC, BC and EAC System eddies.

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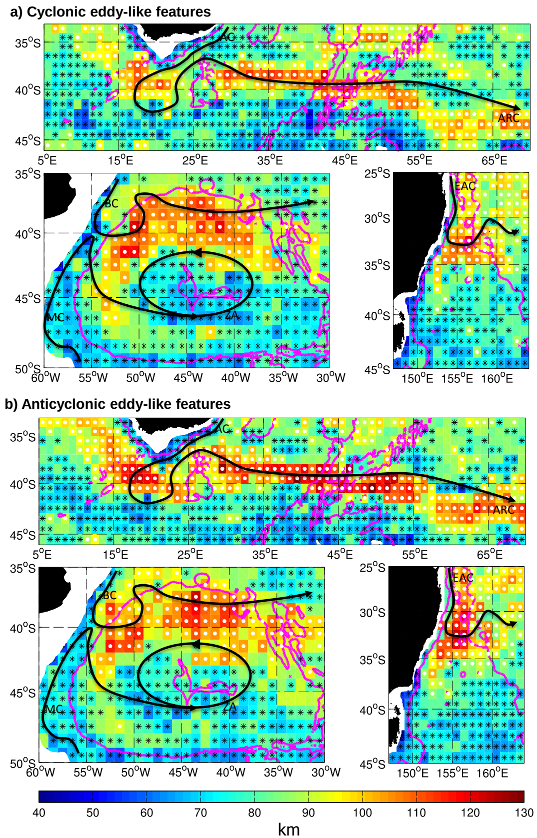

Figure 6. Mean radii (km) of **(a)** cyclonic and **(b)** anticyclonic eddy-like features (lifetime > 4 weeks) in the AC, BC and EAC Systems in a 1° × 1° grid. White dots (black stars) indicate cells with values significantly higher (smaller) than the system mean. Heavy black lines indicate the mean flow of the primary currents and magenta lines indicate the 4000, 3000 and 2000 m isobaths.

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