Reply to Anonymous Referee #1 regarding the paper submitted to Ocean Science entitled " Eddy Surface properties and propagation at Southern Hemisphere western boundary current systems"

G. S. Pilo et al.

June 29, 2015

This manuscript analyzes a satellite altimetry derived global eddy data base with the aim of characterizing the mean lifetimes, radius, rotational speed and propagation in the neighborhood of the Southern Hemisphere western boundary currents. Though the scope of the analysis is straightforward and the manuscript is well organized and generally well written, there are several issues that require a more in-depth analysis as indicated below. Though there are parts of the analysis that justify its publication in Ocean Science I cannot recommend acceptance until the authors address the following issues.

R: We greatly appreciate the detailed review by Referee #1. His/her suggestions were incorporated to the new version of the manuscript, certainly improving its quality. The referee's specific comments are in **bold** font, while our reply is in normal font. New paragraphs added to the manuscript are shown here in *italic*.

1) The study must include distributions of sea surface height variance or eddy kinetic energy as well as eddy density in the three WBCs. Thus, one wonders to what extent are the statistics representative of specific sub-regions where

eddy properties are so distinct. It is also relevant that south of about 40^{o}S the western slope of the Argentine basin presents very low eddy kinetic energy (10 cm2/s2) and rms sea surface height (<4 cm) (Goni et al., JGR, C10037, 2011; Saraceno and Provost, DSR, 62-69, 2012), indicating small mesoscale variability and presumably very few eddies.

R: As suggested, we calculated the Eddy Kinetic Energy (EKE) between 1993 and 2010 after Aviso's geostrophic velocity fields (Figure 2a). We also built maps of eddy density in all three regions, by summing the amount of eddies occurring within 1^{o}x1^o cells (Figure 2b). The datasets used and the applied methods are described in the revised manuscript Data and Methods section as follows:

" Eddy density maps are built by considering how many eddies with lifetime > 10 weeks are identified within each 1^o×1^o grid cell. These maps relate to individual observations of eddies, instead of individual eddies. For example, if an eddy is stationary within a cell for three weeks, it will account as three eddy observations within that cell. "

*"Mean EKE maps are built using Aviso's Reference Series Maps of Absolute Geostrophic Velocities between Jan/1993 and Dec/2010 (`http://www.aviso.altimetry.fr/duacs/`).
"*

We see that regions of high mean EKE are not necessarily associated with regions of high eddy density. High mean EKE is, in turn, associated with eddies' amplitude (Figure 1, edited after requests from the review group leaded by J. Williams; this figure is now Figure 3 in the manuscript). A clear example is the EAC System, where high number of eddies (∼90 eddies per cell; Figure 2b) occur over the entire domain and specially high values (>140 eddies per cell) along the southeast Australian coast. However, the high EKE occurs close to the EAC retroflection regions, due to the retroflection itself, its meanders and eddies.

There, we find eddies with significantly higher amplitude ($\sim$25 cm).

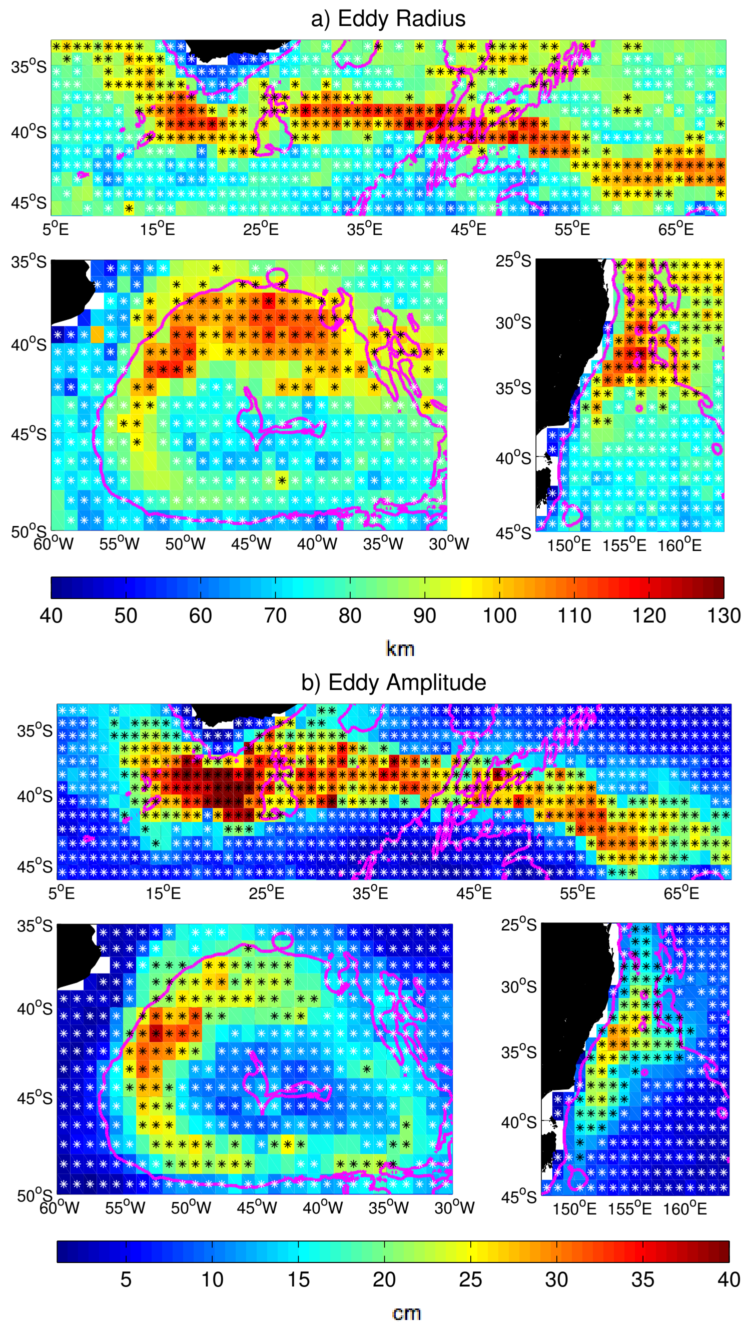

Figure 1: Mean a) radii (km) and b) amplitude (cm) of eddy-like features (lifetime $>$ 4 weeks) in the AC, BC and EAC Systems in a 1^o x 1^o grid. Magenta lines indicate the 4000, 3000 and 2000 m isobaths, respectively. White (black) dots indicate cells with values significantly smaller (higher) than the system mean. (Figure requested by J.Williams et al in their review process during the open discussion period of the original manuscript.)

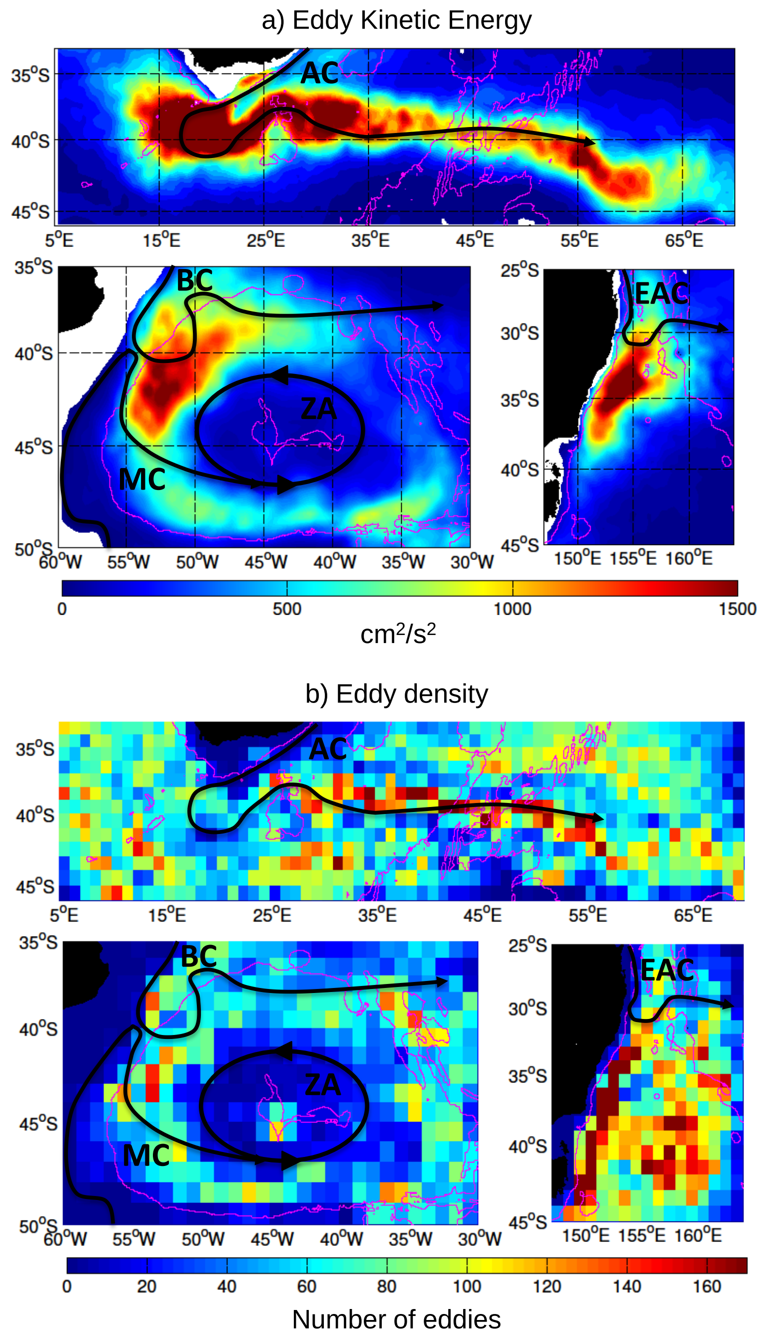

Figure 2: a) Map of Eddy Kinetic Energy built after Aviso's Sea Surface Height dataset (1993-2011), and b) map of eddy density built after Chelton et al (2011) global eddy dataset.

Maps of eddy density for both polarities (not shown) display similar patterns at the AC and EAC System. In the BC System polarity differences occur mainly in the inner part of the Zapiola Drift. Here, a high number of cyclonic eddies ($\sim$ 100 eddies) occur over the Zapiola Rise. This polarity difference has already been reported by Saraceno et al. (2009). Therefore, considering overall similarities between cyclonic and anticyclonic density distribution we decided to merge polarities and add only one figure to the manuscript(Figure 2b).

The maps of mean EKE and eddy density were added to the manuscript as Figure 2. We added two new subsections to the Results section of the manuscript, where we describe EKE and eddy density distribution, and eddy radius and amplitude distribution, allowing the reader to compare these figures together. The text added to the first subsection is as follows:

" The EKE is a measurement of mesoscale activity within a region. Therefore, one would expect regions with high EKE to be associated with an increased number of eddies. With that in mind, we look at both mean EKE maps and eddy density maps of the three systems (Figure 2a and 2b, respectively). While high mean EKE is associated with the WBCs retroflection regions, high eddy density seems not to be the case.

In the AC System high mean EKE values occur in the AC retroflection (~17ºE, 37ºS) and expand further west, reaching the Cape Basin. In this system the ARC also displays high EKE values along its path. Here, the meandering performed by the current when encountering the Agulhas Plateau (26ºE, 40ºS) becomes evident. High eddy density patterns do not agree with the EKE distribution in this system, with eddies occurring over the entire region. Cells with low eddy density occur both to the north and to the south of the ARC.

In the BMC System high mean EKE values occur in the BC retroflection (~52º W, 40º S) and contouring the Argentine Basin, as previously shown by Fu (2006). High eddy density patterns do not agree to the mean EKE distribution in this system. High density cells occur in the outer portions of the basin and over the Zapiola Rise, a bathymetric feature in the centre of the Argentine Basin (45º W, 45 ºS) that rises 4700 m below the surface (Ewing, 1964). This Basin has depths exceeding 6000 m in its southwestern part (Saunders and King, 1995). This high eddy density over the Zapiola Rise was previously shown by Saraceno and Provost (2012) to be due to the presence of cyclonic eddies that enter the Zapiola Drift. This drift is an anticyclonic flow that dominates the Argentine Basin circulation (Miranda et al., 1999), flowing around the Zapiola Rise.

In the EAC System high mean EKE values occur to the south of the EAC retroflection (~157º E, 31º S) extending to the southern end of Australia's mainland. However, a band of high eddy density cells expand further south, reaching Tasmania. Eddies also occur over the entire Tasman Sea, and not only close to the eastern Australian shelf break, as suggested by the mean EKE map. "

And the discussion of maps of EKE, and eddy density, radius and amplitude distribution was added to the Discussion section as follows:

"While eddy density maps are valuable to show locations of major eddy activity, they can be misleading. Eddy density maps consider the numbers of eddies identified within each grid cell along the entire time period. However, they do not consider if an identified eddy is still the same eddy or not. Therefore, a stationary eddy can be counted more than once, evasively suggesting a higher abundance of eddies in that particular grid cell. The fact that a group of grid cells has a high density does not necessarily means that it is a significant region of eddy formation. In the case of the EAC retroflection region, despite the local shedding and

meandering, eddies also remain "trapped" for long periods of time, interacting with each other (Mata et al., 2006), and therefore increase eddy density per cell. This could also be the case for the BC System, considering eddies seem to be retained within the Argentine Basin boundaries.

In all three systems, eddies with radius larger than 115 km occur close to the WBCs 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.

We show that high mean EKE regions in all systems are more related to eddies' amplitude than to eddies' abundance. In the AC System, eddies with large radius and large amplitude occur in the same regions of high mean EKE (i.e. the AC retroflection and the ARC). Conversely, in the BC and the EAC Systems large radius eddies are not necessarily spatially distributed as the mean EKE field . In these systems, eddies with significantly large radius occur in the northern domains (BMC region and Coral Sea, respectively), while high mean EKE concentrates in the currents' retroflection regions. Furthermore, in these systems high mean EKE values are associated with large amplitude eddies. Hence, large radius' eddies are not necessarily the most energetic ones. "

On a further note on the referee's comment regarding EKE and eddy density south of 40^{o}S on the western slope of the Argentine Basin: Figure 2a shows that higher mean EKE values in the BC System extend from 37^{o}S to 45^{o}S - where the BC retroflects. Eddy density does not seem to be the main driver for this increased mean EKE. The EKE spatial distribution in this system seems more related to eddies' mean amplitude at that location, as previously mentioned.

2) The observations that most eddies of the western BC system propagate southward, but some eddies propagate northward (p. 142, line 15) must be documented. The authors go on referring to coastal trapped waves with phase speeds 3-fold larger than the eddy propagation speeds and that it is unclear whether the northward propagating eddies are advected by the Malvinas Current. What is clear is that the issue demands a more in-depth analysis.

R: This matter can be further addressed when looking at BC System eddies' mean propagation maps shown in the next item of this manuscript (Figure 3b). We thank the referee for that suggestion, and we will approach the matter in its extension in the next item, using these new results. For now, we will focus on the northward-propagating BC System eddies.

By calculating eddies' mean velocity propagation we show that eddies over the continental slope can propagate northward from 4 to 20 cm/s, instead of the 5 cm/s we reported on the discussion manuscript. Now, we are able to determine the speed range, instead of focusing on a few case study eddies. The Malvinas Current in this region flows at 40 cm/s (Peterson, 1992), and the previously mentioned coastally trapped waves propagate at 140-360 cm/s. It does sound suspicious that these slow eddies could be meanders of the fast moving trapped waves erroneously identified as eddies. After we performed this in depth analysis, it is much more likely that the northward eddies along the Argentinian Shelf slope are being advected by the Malvinas Current. We suggest that the slow eddy speed compared to the current is due to the eddies' intrinsic westward propagation. This westward propagation could be slowing the eddies down. We correct the text on the original manuscript, replacing the original paragraph between lines 15 and 27 for the following:

"Eddies located along the Argentinian continental shelf break propagate northward, with mean speeds between 3 and 7 cm/s (Figure 8; ∼55^{o}W, 47^{o}S). These northward eddies are probably being advected by the Malvinas Current. This current flows northward along the slope at 40 cm/s (Peterson, 1992), therefore, with higher speeds than the eddies' mean speed at that location. However, the intrinsic westward propagation of eddies might be slowing the Malvinas Current advection down. The effect of the Zapiola Drift in the remaining BC System eddies is clear. "

3) The study lacks a quantitative measure of eddy propagation. It is stated that EAC eddies propagate southward (p.143), but no evidence is presented to support this observation. An analysis similar to Fu's (GRL, L14610, 2006 and Fu, JGR, C11017, 2009) seems suitable. In fact, the later reference is relevant to the eddy propagation in all three regions and must be carefully considered in the discussion.

R: We agree that a quantitative measure of eddy propagation was missing. Following referee's suggestion we calculated mean eddy propagation maps for all three systems. To accomplish that we gridded the systems into 1^{o}x1^o cells and considered the eddies occurring in each cell. This approach is the same as the one used to built eddy density maps and eddy radius maps. Then, we averaged eddies' speed within each cell that contained more than 20 eddies. We performed several tests to establish an optimum number of eddies per cell, and 20 eddies proven itself as a large enough sample to show robust results.

The mean propagation speed seen in Figure 3 only considers the eddies selected for this study (i.e. originated within the systems and with lifetime >10 weeks). The paper by

Fu suggested by the Referee enriched our discussion regarding eddy mean propagation. However, we could bot use the same approach as the author due to the different nature of Chelton et al. (2011) dataset used in our study.

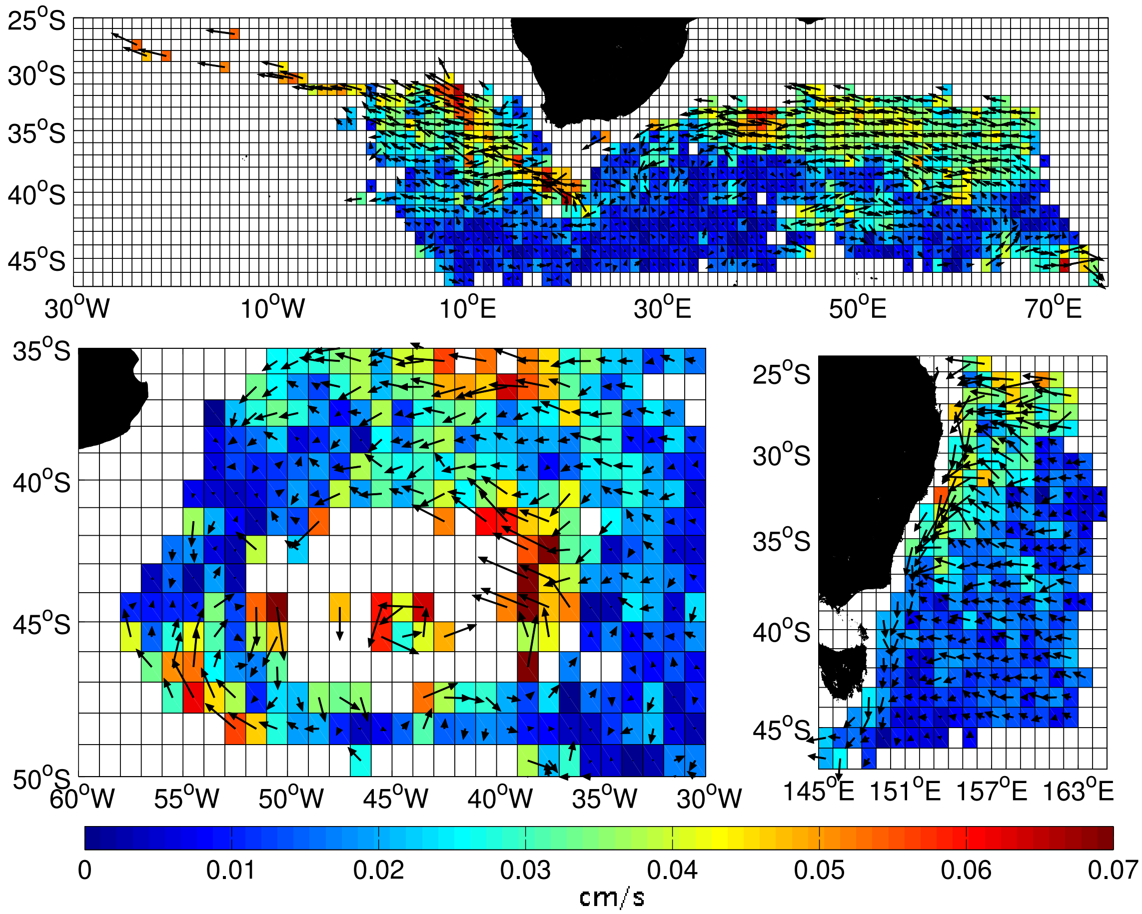

Figure 3: Eddies' mean propagation speed (colours) and direction (arrows) for 1^ox1^o cells containing more than 20 eddies in the AC, BC and EAC Systems.

These mean propagation maps show, more clearly, what was seen in the eddy track figures (Figures 2, 3 and 4 from the original manuscript). We added these maps to the manuscript, and incorporated Fu's 2006 paper on the discussion, as follows:

When looking at the mean propagation of eddies in the AC System two westward patterns are dominant (Figure 8): in the Cape Basin and north of the ARC. In the Cape Basin eddies propagate as fast as 7 cm/s. Here, the "eddy corridor" is well defined by higher propagation speeds. After leaving the Cape Basin, eddies still present high mean propagation in the South Atlantic. North of the ARC, in the Indian Ocean, eddies propagate at ~ 4 cm/s. Two smaller patches of eastward mean velocities are centred at 47^oE,47^oS and at 70^oE,45^oS. The northern one is caused by ARC advection, and the southern by Antarctic Circumpolar Current advection.

AC System eddies propagate along the "eddy corridor" in the Cape Basin at 4 cm/s, on average, and up to 7 cm/s. Reported mean eddy propagation speed within the Cape Basin range from 6 cm/s (Garzoli et al., 1996) to 11 cm/s (Goni et al., 1997). Therefore, our mean value falls in the smaller end of the reported mean speed range. Still in the Cape Basin, eddies propagate northwestward. This propagation pattern does not match the one shown by Fu (2006) for that region. The author reports a mainly westward propagation. We believe these differences to be attributed to differences in methods and also to the fact that in Fu (2006) "eddies" are defined as all mesoscale current variability (i.e. eddies, fronts, planetary waves, and current meanders).

BC System eddies' mean propagation is mainly dictated by the Zapiola Drift. However, there are some exceptions. In the northern section, eddies propagate according to their induced westward propagation and in the western section, advection by the Malvinas Current takes place. Fu (2006) also shows the mean propagation of mesoscale features in this region. While we show small propagation speeds in the BC retroflection region ($<$ 20 cm/s, 38^oS), the authors show higher local values ($>$ 35 cm/s). Again, we attribute this difference to the fact that the latter authors include all mesoscale features (such as eddies, fronts and meanders) in their work. Nevertheless, as in here, Fu (2006) also finds the Zapiola Drift *to be the dominant feature in the Argentine Basin.*

Over most of the EAC System, eddies propagate westward (Figure 8) and, when encountering the Eastern Australian shelf slope, they turn southward. Higher propagation speeds (∼3–6 cm/s) are found in the Coral Sea and close to the EAC retroflection region. In the Tasman Sea eddies propagate slower (1–2.5 cm/s). It is relevant to say that these propagation speeds within each cell do not denote eddy tracks continuity, but denote a mean pattern of propagation for eddies occurring at each location.

4) Inspection of Figs. 2, 3 and 4 indicates that eddies do not form nor drift over the continental shelves. There are a number of dynamical reasons for this, but why is this particular behavior pointed out in the EAC eddies (p. 143) and not in the AC and BC systems?

R: The Referee is correct and, considering the lack of eddies propagating over continental shelves, we added the following sentences on the manuscript's result section:

Results: Eddy propagation on the AC System: *"... entire domain, except over the continental shelf (Fig. 4)."*

Results: Eddy propagation on the BC System: *"Here, we see three eddies identified over the continental shelf. These eddies should be considered with caution. According to Saraceno and Provost (2012) altimeter data on the Patagonian shelf are usually unreliable due to intrinsic difficulties on corrections applied to data, especially related to tides. In their study, where they perform an eddy census in the Argentine Basin using gridded altimetry data, they only consider eddies identified offshore (i.e. depths greater than 200 m). "*

Also, we added a discussion on the dynamical reasons for eddies not propagating over continental shelves on our Discussion section, as follows:

In all three systems, eddies do not propagate into the continental shelf, being retained at the slope. This behaviour can be explained by a) the shallow depths of shelves compared to eddies depths, b) the presence of WBCs, and c) the propagation of eddies along lines of same potential vorticity. First, as previously shown, the mean eddy radius considering all the systems is 86.7 km. If we consider this 86.7 km radius eddy to be a lense type we can estimate its depth, as the following (Nof, 1981):

$$H = \frac{f_0^2 r_0^2}{8g'} \tag{1}$$

where

$$g' = g\frac{\rho_2 - \rho_1}{\rho} \tag{2}$$

Considering the eddy is in a 1,5 layers model and having $\rho_1 = 1025 kg/m^3$ *and* $\rho_2 = 1027.4\ kg/m^3$ *(Rykova et al., submitted; considering mean densities for AC, BC and EAC canonical eddies), we have an approximate eddy mean depth of 360.4 m. This means that eddies would not drift to regions shallower than that depth (i.e. continental shelves). Second, westward propagating eddies approaching a western boundary will only reach the continental slope if their Rossby radius is larger than the local WBC's Rossby radius (Azevedo et al., 2012). If not, the eddy might be advected poleward by the current. Third and last, eddies propagate along lines of same potential vorticity, established by local bathymetry. In the EAC System the eddy propagation along the 3000 m isobath, but never crossing to shallow regions, had been previously reported by Mata et al. (2006), but never crossing this isobath to shallow regions.*

5) It appears that class intervals for amplitude, rotation speed and radius are 1cm, 2cm/s and 2km, respectively. You must explain how were these values

selected. The spatial resolution of satellite altimetry, even with multi-mission data, is too gross to justify the 2km radius binning. Perhaps this is why those histograms are considerably nosier. Also note the % of observations is about half of those for speed and amplitude.

We thank the referee for this observation. We re-plotted the histograms (Figure 4) considering more appropriate intervals: 5 cm for eddy amplitude and 20 km for eddy radius. We also removed the Rotation Speed histogram, which was redundant considering it is a measurement obtained after amplitude, as pointed by Referee #2.

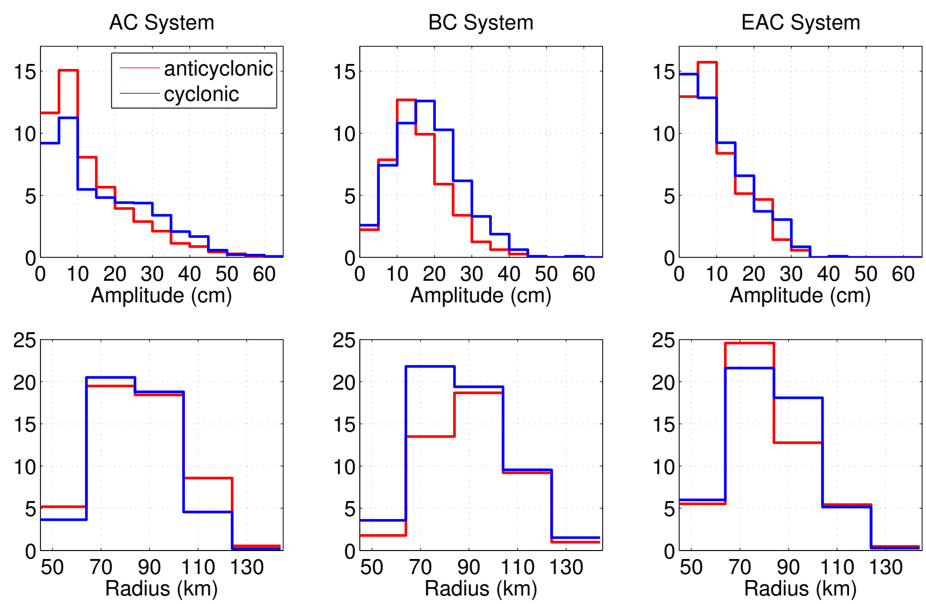

Figure 4: Histograms of amplitude and radius for AC, BC and EAC System eddies.

However, on their review of the discussion manuscript, J. Williams *et al.* suggested the addition of amplitude 2D contour plots. We agree with the reviewers that such plots are more meaningful than the histograms. Therefore, we chose to omit the histograms and add the amplitude spatial distribution to the manuscript. The final figure (Figure 1) shows the spatial distribution of radius (a) and amplitude (b), combining cyclonic and anticyclonic eddies. We chose to merge cyclonic and anticyclonic eddies because the general distribution pattern is the same for both polarities (Figure 6 of discussion manuscript and Figure 2 in our reply to J. Williams' review).

6) The poleward extensions of WBCs are characterized by some of the sharpest SST fronts in the world ocean. Eddies formed in the southwest corner of the subtropical gyres (in the SH) are therefore expected to present strong SST signals. It was therefore rather disappointing to see "surface properties" did not include SST anomalies. In addition to SST anomalies these data would provide independent information on the eddy radius at better space-time resolution than the original SSH data.

We agree with the reviewer that eddies' SST anomalies in WBC systems are an interesting matter. However, we aimed to use Chelton et al. (2011) global eddy dataset built after altimetry to perform an eddy demographic study. Also, altimetry datasets have been proven more efficient on eddy tracking than SST datasets because the contrast in SST between eddies and surrounding waters decreases as eddies propagate (Olson, 1991). Identifying and tracking eddies in SST datasets was out of the scope of out study, however, it is indeed an interesting analysis to be revisited in a future study.

WBC Systems are regions of steep temperature gradient, due to the encounter of warm WBC and cooler subantartic waters. Therefore, in those regions eddies' SST signatures are more enhanced than in other oceanic regions. At the AC System one anticyclonic eddy sampled within the Cape Basin displayed a SST of 19^{o}C during the summer, colling to 17^{o}C during the winter (Schmid et al., 2003). This SST loss was attributed to eddy mixing with Antartic Intermediate Water. As anticyclonic AC System eddies propagate into the South Atlantic they change their SST signature. Souza et al. (2014) shows a persistent pattern of negative SST anomaly in the eddy core and positive SST anomaly in the eddy boundary, explained by Ekman pumping. Not much is know on cyclonic eddies' SST signature on the AC System. However, it is known that these eddies, together with anticyclonic ones, transfer subtropical and alongslope waters into the Subantartic Zone (Arhan et al., 2011). Also, anticyclonic AC System eddies participate on the Termohaline circulation, as an important aspect of the Agulhas Leakage (e.g. Beal et al., 2011). At the BC System anticyclonic (cyclonic) eddies display a SST anomaly of 5.1^{o}C (Lentini et al., 2006) (-5^{o}C; Gordon, 1989) when compared to waters in their exterior. These eddies are known to act in water mass formation and modification (Gordon (1989), Lentini et al. (2006)). In this study, we showed that the amount of eddies occuring in the BC System is larger than previously reported, as well as these eddies horizontal length. Therefore, these temperature signatures can be even more important than currently thought. At the EAC System anticyclonic (cyclonic) eddies display a SST anomaly of 0.32^{o}C (-0.62^{o}C; Everett et al., 2012) when compared to waters in their exterior. These eddies are known to act in meridional heat distribution (Rykova et al., 2015) and alter coastal water temperatures (Oke and Griffin, 2011).

We added the following note on the matter on the Discussion section of the manuscript:

"In this study we do not approach eddies' SST signatures, but we recognise the importance of revisiting this matter in future studies, specially with new SST datasets available. "

7) I am not a marine geologist but something seems wrong in the bottom topography. In p. 142, line 3 the authors state:"It flows around the Zapiola Rise, a bathymetric feature of 2000 m in the centre of the 4000m basin (45^{o}W, 45^{o}S; Fig. 1b)."This gives the impression that the rise is about 2000 m higher than

the surrounding waters, which are 4000 m deep. However, available bathymetric maps and data bases show that the Argentine Basin is mostly deeper than 5000 m around the Zapiola Rise, and that the rise itself is only about 1000 m shallower than the abyssal plane, which is 6000 m deep, and 500 m shallower than the waters farther east (e.g. Fig. 2 in Saunders and King, JPO, 1942-1958, 1993). The gray shading in Fig. 2b indicates the rise is shallower than 3500 m, whereas it should be around 4900 m! The error does not appear to have an impact on the AC and EAC regions, but this needs to be carefully checked in all figures that present a bottom topography background. In addition, according to Exon et al. (Austr. J. Earth Sci., 561-577, 1997) the names of the bathymetric features south of Australia are incorrect, the feature labeled as Tasman Plateau is the South Tasman Rise and the feature labeled Tasman Rise is the East Tasman Plateau.

R: We thank the referee for the correction. We checked isobaths for all regions, and they seem to be correct. However, our text regarding the Zapiola Rise was indeed incorrect. The corrections are copied below:

"... the Zapiola Rise, a bathymetric feature in the centre of the Argentine Basin (45^{o}W, 45 ^{o}S) that rises 4700 m below the surface (Ewing, 1964). This Basin has depths exceeding 6000 m in its southwestern part (Saunders and King, 1995)."

Also, names of Australian region bathymetric features were corrected accordingly.

8) In the Discussion the authors point out that EAC eddies are also derived from the Coral Sea, which is clear from the eddy tracks in Fig. 4. However, the study of Everett et al. shows that both, cyclonic and anticyclonic eddies are a lot more frequent south of 32- 33^{o}S. This suggests that eddy shedding near

the EAC retroflection is a more significant eddy source. This could be tested quantitatively based on the analysis of eddy density distributions suggested earlier.

R: We agree that the EAC retroflection region is an important source of EAC eddies in that system. We also agree that eddy density maps are relevant for the current study and we added them to the new version of the manuscript, as shown above (Figure 2). These maps are valuable to show locations of major eddy activity. However, eddy density maps, as well as the ones from Everett et al. (2012), can be misleading. We added a discussion on this matter on the Discussion section of the manuscript, as follows:

"While eddy density maps are valuable to show locations of major eddy activity, they can be misleading. Eddy density maps consider the numbers of eddies identified within each grid cell along the entire time period. However, they do not consider if an identified eddy is still the same eddy or not. Therefore, a stationary eddy can be counted more than once, evasively suggesting a higher abundance of eddies in that particular grid cell. The fact that a group of grid cells has a high density does not necessarily means that it is a significant region of eddy formation. In the case of the EAC retroflection region, despite the local shedding and meandering, eddies also remain "trapped" for long periods of time, interacting with each other (Mata et al., 2006), and therefore increase eddy density per cell. This could also be the case for the BC System, considering eddies seem to be retained within the Argentine Basin boundaries. "

Further discussion regarding eddy density and EKE was presented in our reply for comment 1 on the current document, together with the eddy density maps.

9) The authors claim that the eddies that cross south of Tasmania may "...act on heat and biogeochemical budgets between different oceanic regions." Given

that only very few eddies were observed in a 20 year period, I wonder how significant these fluxes are. It seems that eddy fluxes must be more relevant within the Tasman Sea. A combination of maps of eddy density and eddy kinetic energy would be more useful in this regard than just the trajectories.

R: The referee is correct. Based on the current study the number of eddies crossing south of Tasmania is small to account for significant fluxes. On that subject, van Sebille et al. (2012) show that 46% of the Tasman Leakage, connecting the South Pacific to the South Indian south of Tasmania, is carried by eddies. However, despite of this large percentage, the authors suggest that eddies are not important for the leakage. We do not completely agree on that. The number of eddies propagating from the EAC retroflection region towards the Great Australian Bight seems to be larger than previously thought (Pilo et al., submitted).To remove inconsistencies on our revised manuscript, we changed the focus of our discussion. As the referee stated, we can, indeed, assert that EAC eddies propagating southward along the eastern Australian coast do affect Tasman Sea biogeochemical properties. Now, we focus on the Tasman Sea, as added to the Discussion section and copied below:

" When propagating southward within the Tasman Sea, eddies can act on heat and biogeochemical budgets between two different oceanic regions (i.e.northern tropical waters and southern temperate waters). Eddies have been shown to impact coastal water nutrient enrichment (Tranter et al., 1986, Oke and Griffin, 2011), increase chlorophill-a concentrations (Everett et al., 2012), and alter zooplankton communities (Baird et al., 2011). Actually, the impact of EAC System eddies can extend beyond the Tasman Sea. Baird and Ridgway (2012) report Tasman Sea eddies entrapping Bass Strait coastal waters and suggest that these eddies could advect this water mass to the open ocean south of Australia. [...] "

10) It is argued that AC and EAC System eddies present smaller amplitudes because they live longer than BC eddies. To test this hypothesis the authors must determine the statistics of young AC and EAC eddies and compare them with those of BC eddies.

R: We thank the referee for the suggestion of looking into young AC and EAC eddies amplitude values. The results are shown in Table 1. We only considered AC and EAC eddies with lifetime smaller than 17 weeks, which is the mean lifetime of BC eddies to calculate eddies' amplitudes.

	Amplitude All eddies	**Amplitude young eddies (Lt $<$17 weeks)**
BC cyc	18.7	-
AC cyc	8.9	15.1
EAC cyc	9.2	10.3
BC anti	15.9	-
AC anti	7.9	12.6
EAC anti	8.6	9.4

We can see that young AC and EAC eddies' amplitudes have similar values than BC eddies' amplitudes, confirming our previous statement. We added this discussion in the paper as follows:

"We draw attention to BC System eddies' shorter mean lifetime and larger mean amplitude when compared to the other systems. These differences occur because 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). This is evidenced if we calculate AC and EAC System eddies amplitudes considering only eddies with lifetime shorter than 17 weeks (being 17 weeks the mean lifetime of BC System eddies). Young AC System eddies have a mean amplitude of 13.8 cm compared to 8.4 cm for all eddies; and young EAC eddies have a

mean amplitude of 11.5 cm compared to 8.9 cm for all eddies. The mean amplitudes of these young AC and EAC eddies are more comparable to the 17.3 cm mean amplitude of BC eddies. "

11) Last but not least, in the summary section the authors state that Agulhas rings propagate into the Atlantic "along the expected path between 20^o-30^{o}S". I wonder why is this path expected? Interestingly, the band of high SSH variability extending from the Agulhas Retroflection maximum into the subtropical South Atlantic, is clearly located south of 30^{o}S (e.g. Fu, GRL, 2006). However, the results presented here show that west of 10^{o}W all AC eddies follow paths to the north of that high variability band. Thus, the high EKE band does not match the AC eddy path. Given the small number of eddies observed in a 20 year period this is not too surprising, but it also warns us about the interpretation of SSH variability distributions and Agulhas eddies. The authors should delve deeper in these issues as the results perhaps are not "as expected" as they may first appear.

R: We have removed the "as expected" affirmative from the sentence, as it was also suggested by a previous reviewer on the manuscript interactive discussion. We thank the referee for suggesting the paper by Fu (2006), which improved our discussion, as previously mentioned in item 3 of this document. As shown by Fu (2006), northwestward propagating mesoscale features (which are not necessarily eddies) in the Atlantic occur north of $\sim$30^{o}S, instead of $\sim$30^{o}S south of as stated by the referee (Figure 5). Also, we add two other figures of Agulhas rings propagating in the Atlantic (Souza et al., 2011 and Azevedo et al., 2012), which shows the propagation corridor between the same latitudes as the eddies in our study propagate (Figures 6 and 7).

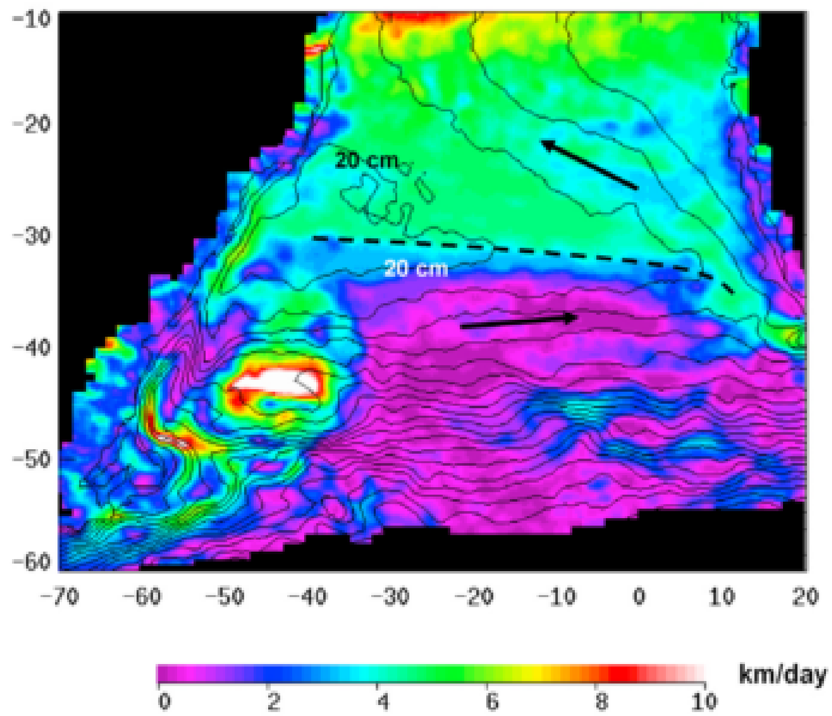

Figure 3. The color shading displays the speed of eddy propagation in km/day. The contours represent the surface dynamic topography. The contour intervals are 10 cm. The highest values are in the center of the subtropical gyre enclosed by the 20 cm contour. The dashed line is a schematic representation of the ridge of the subtropical gyre with northwestward mean flow in the north and eastward mean flow in the south as indicated by the arrows.

Figure 5: Figure copied from Fu (2006)

J. M. A. C. Souza et al.: Comparison between three implementations of automatic 319

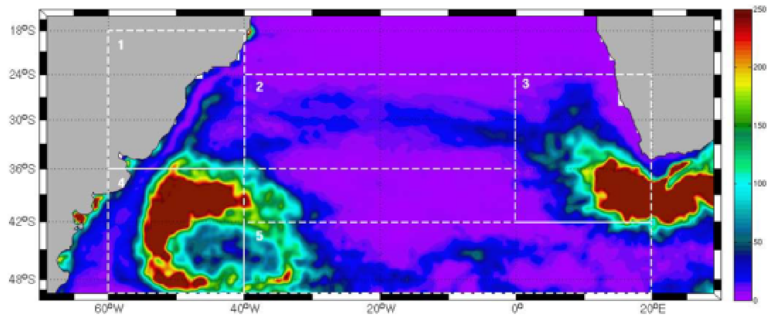

Fig. 1. Variance (cm^2) of the SLA from AVISO over the years 2005 to 2008. Five areas of particular eddy dynamics are highlighted in white boxes: (1) The Brazil Current; (2) the corridor of propagation of Agulhas Eddies; (3) The Agulhas Current retroflection region; (4) the Brasil-Malvinas confluence zone and (5) the northern branch of the Antarctic Circumpolar Current.

Figure 6: Figure copied from Souza et al. (2011)

AZEVEDO ET AL.

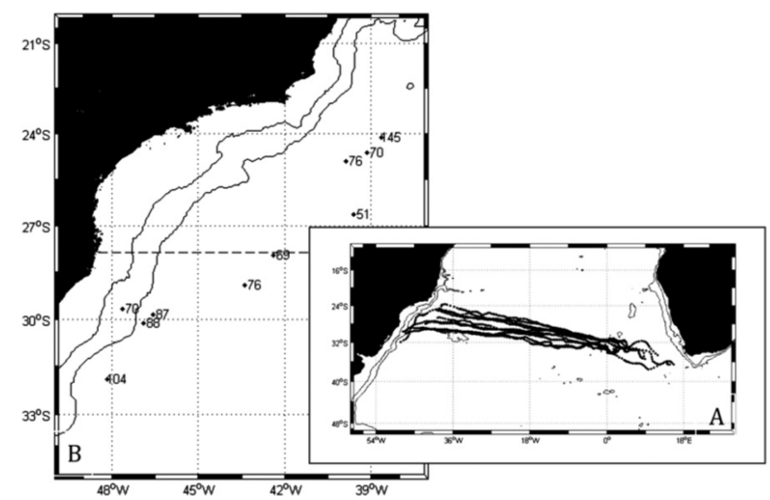

FIG. 1. (a) Anticyclonic eddy trajectories that began near the Agulhas retroflection zone and ended west of 38.5°W, as tracked between 14 Oct 1992 and 31 Dec 2008. (b) Final eddy position and radius (km) for each trajectory. The dashed line shows the average latitude at which these eddies approach the South American continental boundary (27.9°S). The 200- and 2000-m isobaths are shown in both figures. Eddy data are available online (from http://cioss.coas.oregonstate.edu/eddies/) (Chelton et al. 2011).

Figure 7: Figure copied from Azevedo et al. (2012)

To avoid confusion and aiming for clarity, we modified our discussion on this matter, copied below:

"AC System eddies propagate along the "eddy corridor" in the Cape Basin at 4 cm/s, on average, and up to 7 cm/s. Reported mean eddy propagation speed within the Cape Basin range from 6 cm/s (Garzoli et al., 1996) to 11 cm/s (Goni et al., 1997). Therefore, our mean value falls in the smaller end of the reported mean speed range. Still in the Cape Basin, eddies propagate northwestward. This propagation pattern does not match the one shown by Fu (2006) for that region. The author reports a mainly westward propagation. We believe these differences to be attributed to differences in methods and also to the fact that in Fu (2006) "eddies" are defined as all mesoscale current variability (i.e. eddies, fronts, planetary waves, and current meanders). "

12) Specific comments

We thank the referee for the thorough review of the paper. Below, we copy the referee's **specific comments**, followed by our response in regular font.

- **Page 137, line 23, "Hall and Lutjeharms, 2011", insert blank Line 26, "has not been fully reported." too vague. If there are previous reports, what are their main conclusions?**

  "In the AC System censuses of large anticyclonic eddies were extensively performed using sea surface temperature data (Lutjeharms and Van Ballegooyen, 1988) and single-satellite altimetry data (e.g. Byrne et al., 1995; Goni et al., 1997; Schouten et al., 2000). Censuses of large cyclonic eddies in the region were performed using merged altimetry products (e.g. Boebel et al., 2003; Hall and Lutjeharms, 2011). These studies show that large retroflection anticyclonic eddies propagate beyond Cape Basin, while cyclonic eddies remain trapped within it. These censuses, while present-

ing insightful results for eddies in the Cape Basin and AC retroflection region, omit the ARC region. "

One of the main differences between this study and the one performed by Hall and Lutjeharms (2011) is the fact that we use the output from an eddy identification algorithm and they follow a manual identification process.

- **Page 137, Line 30, "These early studies were based on data with reduced temporal and spatial resolution..."**

  We thank the referee and corrected the sentence.

- **Page 138, line 15, "Here, we qualify AC, BC and EAC System eddies based on their surface properties, and investigate eddy propagation and lifetime." Spell out the surface properties being analyzed.**

  We thank the referee and corrected the sentence to *"In that sense, the goal of this research is to qualify AC, BC and EAC System eddies based on their surface properties (i.e. amplitude, radius, rotation speed), and investigate eddy propagation and spatial distribution. "*

- **Page 138, Line 18, "presented here help..." delete "s"**

  We thank the referee and corrected the sentence.

- **Page 138, Line 19, "Identifying eddies' propagation patterns allows us to establish monitoring programs." First identify the propagation patterns and then be specific, what kind of monitoring programs? For what purpose?**

  We thank the referee and corrected the sentence to *Identifying eddies' mean propagation patterns helps us to establish monitoring programs (i.e. moorings location,* *hydrographic sampling). ...*

- **Page 139, lines 13-17 indicate the selected regions in Fig 1.**

  We thank the referee for the suggestion. To avoid cluttering Figure 1 with more information we leave it clear in the text that the areas in Figure 2 comprise the study region (e.g. *... the Agulhas Retroflection and the ARC (33ºS–46ºS and 5º–70ºE) hereafter defined as the AC System (the region comprised in Figure 2a)...*).

- **Page 140, line 3, unclear what the authors mean by "particularity", is it inaccuracies? Why are these more relevant in the regions of interest?**

  We corrected the term "particularities" to the more correct term "aspects". Also, these aspects are not only relevant to our study regions, but to the global ocean in general. We corrected the sentence to *"We must consider aspects of the global eddy dataset when investigating its output."*

- **Page 140, line 4-5 (actually, line 10-11), Detection inaccuracies may lead to premature dissipation but also to late detection and, more importantly, tagging of "old" eddies as new ones.**

  We thank the referee and corrected the sentence.

- **Page 141, line 11, are 3.8 and 4 km/day significantly different?**

  Not really. We removed general comments on the table, leaving it just for completion purposes. More on that is mentioned below.

- **Page 141, Line 12, why is the propagation of a higher number of anticyclonic rings beyond the AC system expected?**

  We use the term "as expected" based on previous studies that report the propagation of AC rings across the South Atlantic, as an important part of the Thermohaline Circulation (e.g. Beal et al., 2011). There are no studies, as far as we are aware, reporting AC System cyclonic eddies propagating into the South Atlantic Ocean. In our study, we show the two cyclonic eddies from the global eddy dataset that do. To avoid conflict, we removed the "as expected" expression. The new sentence is: *More anticyclonic eddies propagate beyond the AC System into the South Atlantic than cyclonic ones.*

- **Page 141, Line 21, it is very difficult to observe the eddy deflection in the Agulhas Plateau in Fig. 2, perhaps using bold lines for selected trajectories would help.**

  We agree. It is indeed difficult to see the trajectories. Also, the mean propagation map (Figure 3) does not make the pattern clearer. We plotted some of those trajectories in black (Figure 8), to facilitate viewing. However, we chose not to use this figure for simplicity. We also removed mentioning to tracks deflection at the Agulhas Plateau.

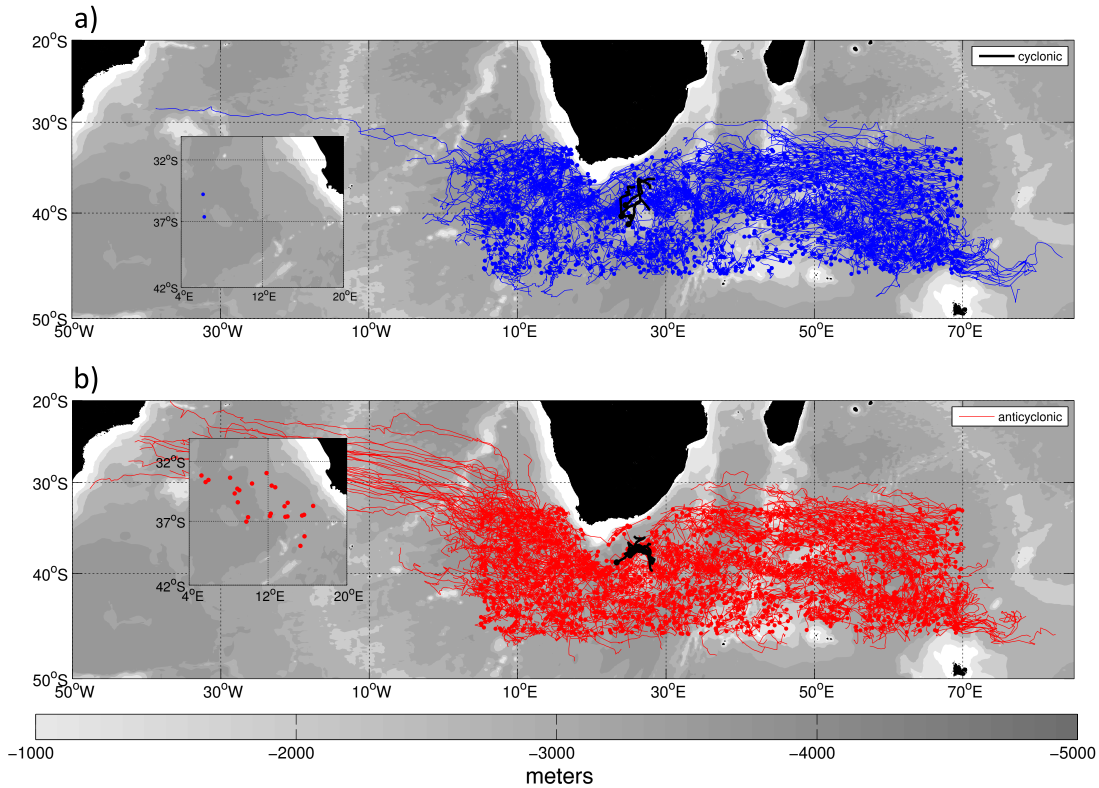

Figure 8: Trajectories of a) cyclonic, and b) anticyclonic eddies first identified in the AC System between Oct/1992 and Apr/2012. Insets in a and b show South Atlantic crossing eddies' first locations. Trajectories in black show eastward eddies deflected by the Agulhas Plateau.

- **Page 142, line 15: "Despite most eddies of the BC System eddies in the basin's western domain propagate..."**

  We thank the referee and corrected the sentence.

- **Page 142, line 18: " intraseasonal"**

We thank the referee for the correction. That section was removed from our manuscript, as reported in reply for comment 2 in this document.

- **Page 143, line 5: "Regardless of their origin,..."**

  We thank the referee for the correction. This sentence was edited out in the new version of the manuscript.

- **Page 144, lines 6-9: Statements such as " ... cyclonic eddies spin faster than anticyclonic eddies" and "... cyclonic eddies also having larger mean amplitude than anticyclonic ones" must be supported by a significance test.**

  We agree that the differences between cyclonic and anticyclonic eddies both in the histogram and in Table 1 are not significant. As mentioned above we removed the histograms. We also narrowed our discussion on Table 1. The next paragraph, related to Table 1, was added to the Results section:

  "For completion purposes we show eddies' mean properties in Table 1. Differences in eddy properties are not significant between cyclonic and anticyclonic eddies in all three systems (with some standard deviation values as large as the mean values). The similarities between cyclonic and anticyclonic eddies is due to the large range of eddies investigated. Eddies with radii spanning from 40 km to 130 km were included in the analysis.

  Anticyclonic eddies from the AC System are the longer lived ones from all systems, due to their propagation across the South Atlantic. The small number of eddies propagating south of Tasmania do not increase the mean lifetime of EAC System anticyclonic eddies.

We draw attention to BC System eddies' shorter mean lifetime and larger mean amplitude when compared to the other systems. These differences occur because 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). This is evidenced if we calculate AC and EAC System eddies amplitudes considering only eddies with lifetime shorter than 17 weeks (being 17 weeks the mean lifetime of BC System eddies). Young AC System eddies have a mean amplitude of 13.8 cm compared to 8.4 cm for all eddies; and young EAC eddies have a mean amplitude of 11.5 cm compared to 8.9 cm for all eddies. The mean amplitudes of these young AC and EAC eddies are more comparable to the 17.3 cm mean amplitude of BC eddies. "

- **Page 146, line 9: "... to a smaller extent."**

  We thank the referee and corrected the sentence.

- **Page 146, line 16: isopycnals**

  We thank the referee and corrected the sentence.

- **Page 146, line 17: the vertical scale**

  We thank the referee and corrected the sentence.

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