

Review of “The vertical structure of mesoscale eddies in the Azores Current corridor: a combined altimetry-ARGO analysis” by Silva-Fernandes and Peliz

This manuscript investigates the characteristics and vertical structure of mesoscale eddies in the Azores Current corridor of the North Atlantic Ocean using satellite altimetry and Argo observations.

It describes regional differences in eddy propagation and in the composite temperature and salinity anomaly structures within the AzCC. The study further suggests that most eddy-induced anomalies arise from eddy pumping, manifested as vertical deflections of isopycnal surfaces. While the manuscript presents potentially important results on mesoscale eddies along the AzCC, substantial revision is required before it can be considered for publication.

My major concerns and suggestions are outlined below.

We greatly appreciate all the comments and suggestions, as we believe they have helped improve the quality of the manuscript. We hope we have addressed all of them as thoroughly as possible.

Main Comments

1. How does the strength of eddies vary spatially across the study area?

Do mesoscale eddies exhibit similar magnitudes in regions R1-R3? Including a discussion supported by spatial maps of eddy amplitude would strengthen the manuscript.

In our previous study of this region (Silva-Fernandes and Peliz, 2020), the surface eddy field was analysed using a different eddy-tracking product, and the kinematic properties of eddies were examined spatially. Although the product used in that study differs from the one used here, the overall results are consistent.

Figure R1a) to c) corresponds to part of Figure 7 from Silva-Fernandes and Peliz (2020). It shows that west of the ridge (i.e., west of 40° W), eddies exhibit not only higher amplitudes but also larger radii and stronger swirl velocities. Furthermore, these properties decrease progressively eastward. In Figure R1 d), we present the same spatial distribution for eddy amplitude, computed using the properties of the sampled eddies in the present study. The results confirm that eddies in region R3 are indeed more intense than those located further east.

As the surface eddy field in this region has already been thoroughly characterised in our previous study, we chose to include a concise paragraph in the Introduction summarising

the spatial differences in kinematic properties across the AzCCo, rather than repeating the same analysis.

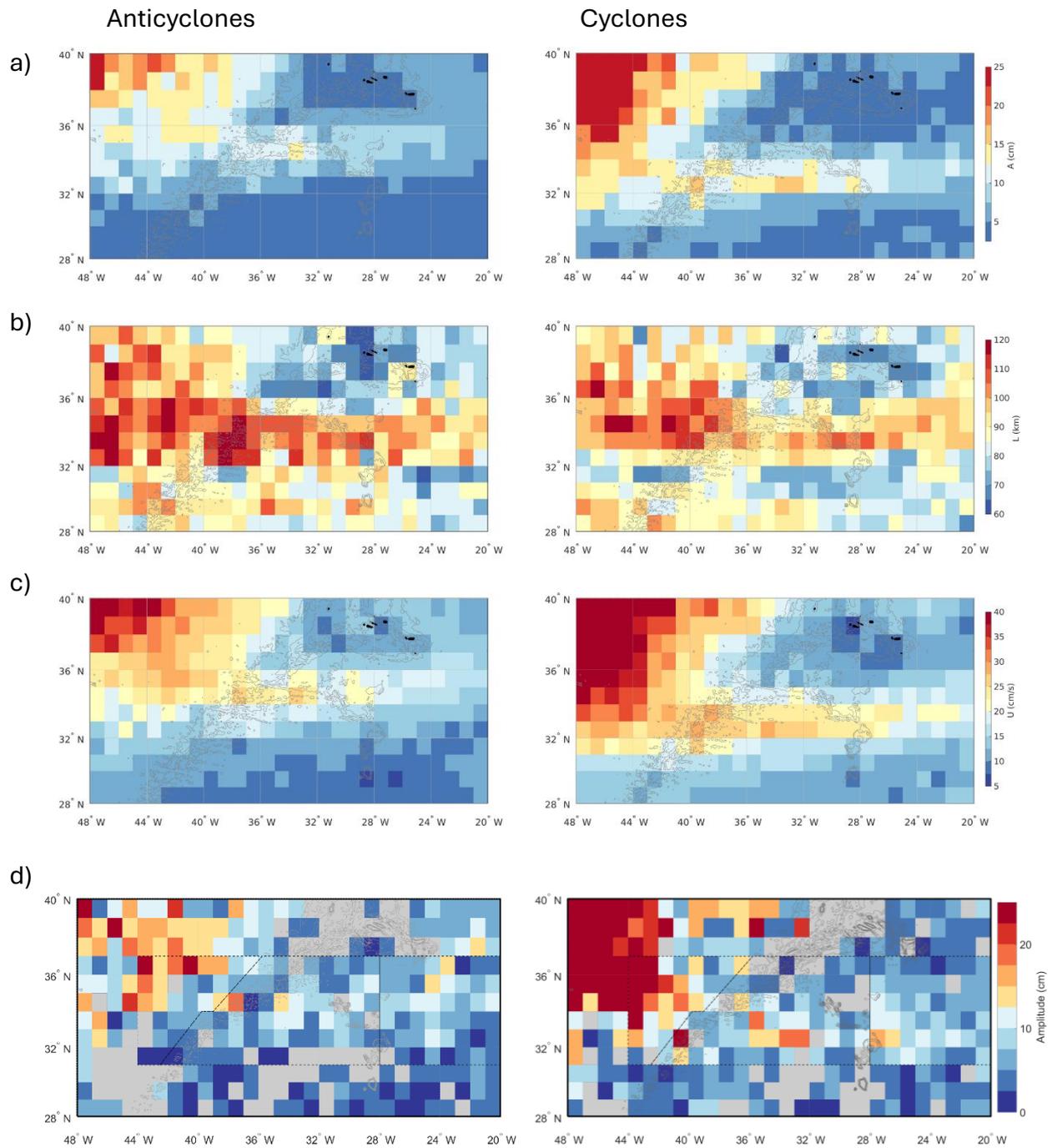


Figure R1 – Spatial distribution of the Eddy Kinematic Properties: (a) amplitude A (cm), (b) radius L (km) and (c) swirl velocity U (cm/s), adapted from Silva Fernandes and Peliz, 2020. d) Spatial distribution of amplitude (cm) of eddies sampled by Argo in this work.

The second paragraph of the manuscript was altered to: “The Azores current (AzC) is a highly turbulent zonal jet located around 34° N, east of the Mid-Atlantic ridge (MAR), with mean eddy kinetic energy (EKE) values above $200 \text{ cm}^2 \text{ s}^{-2}$ (Figure 1), the highest of the

eastern subtropical North Atlantic. The current system and its associated frontal zone have been revisited several times over the last decades (e.g., Gould, 1985; Juliano and Alves, 2007; Frazão et al., 2022). The latitudinal band surrounding the jet, which we will loosely refer to as the Azores Current Corridor (AzCCo) is characterised by coherent eddies, meanders, and filaments, mostly evolving from baroclinic instability of the jet (Klein and Siedler, 1989; Alves and De Verdière, 1999), as well as several other types of structures propagating into the corridor. Different zonal sectors with distinct characteristics have been identified within the AzCCo, characterised by a decrease in EKE values from west to east. These sectors approximately coincide with the locations of two main topographic features in the region. Furthermore, as the Mid-Atlantic Ridge (MAR) acts as a partial barrier between the basins west and east of the ridge, eddies west of the MAR are not only more energetic but also exhibit larger amplitudes, greater radii, and stronger swirl velocities (see Silva-Fernandes and Peliz, 2020, their Figure 7b), c) and d)). East of the MAR, Barbosa Aguiar et al. (2011) identify three main sectors: (i) the western sector between the MAR and the Seewarte Seamount Chain (SWSM) (~28° W); (ii) the central sector between 28° W and 20° W; and (iii) the eastern sector extending toward the Gulf of Cádiz.”

The text regarding the spatial magnitude variation of the eddies kinematic properties is underlined.

2. The composite structure indicates an elongated vertical structure for anticyclones in region R2. While I acknowledge that the number of Argo profiles within eddies in R2 is small and that many profiles are concentrated near the southwestern corner, close to the boundary with R3 (L312), it is unclear whether this alone justifies the interpretation. Such a conclusion should be supported by additional analysis.

I therefore suggest recalculating the vertical structure after excluding profiles located near the regional boundary to substantiate this argument.

To test the hypothesis that eddies near the R2–R3 boundary influence the vertical structure of anticyclones, we shifted the R2–R3 boundary eastward, approximately following the ridge axis (red box R2_a in Figure R2, top panel). In this configuration, eddies located along the western flank of the ridge are excluded.

Although Figure R2 presents CT anomaly composites for both cyclones and anticyclones, our analysis focuses exclusively on the vertical structure of the anticyclones.

Inspection of Figure R2a and R2b (left panel) shows that excluding the western flank of the ridge results in a vertical structure with a shallower core and an elongated vertical extent reaching approximately 1500 dbar. This supports our hypothesis that eddies located near the R2–R3 boundary influence the vertical structure of anticyclones in R2.

When initially defining the boxes representing the different dynamical regions of the Azores Corridor, we considered a region (R4 in Figure R2, bottom panel) encompassing the longitudinal extent of the ridge. In this configuration, R2 was subdivided into two regions: R4 and R2_wr, the latter representing only the area east of the ridge. The objective was to assess differences in the mesoscale vertical structure east and west of the ridge, as well as directly above it.

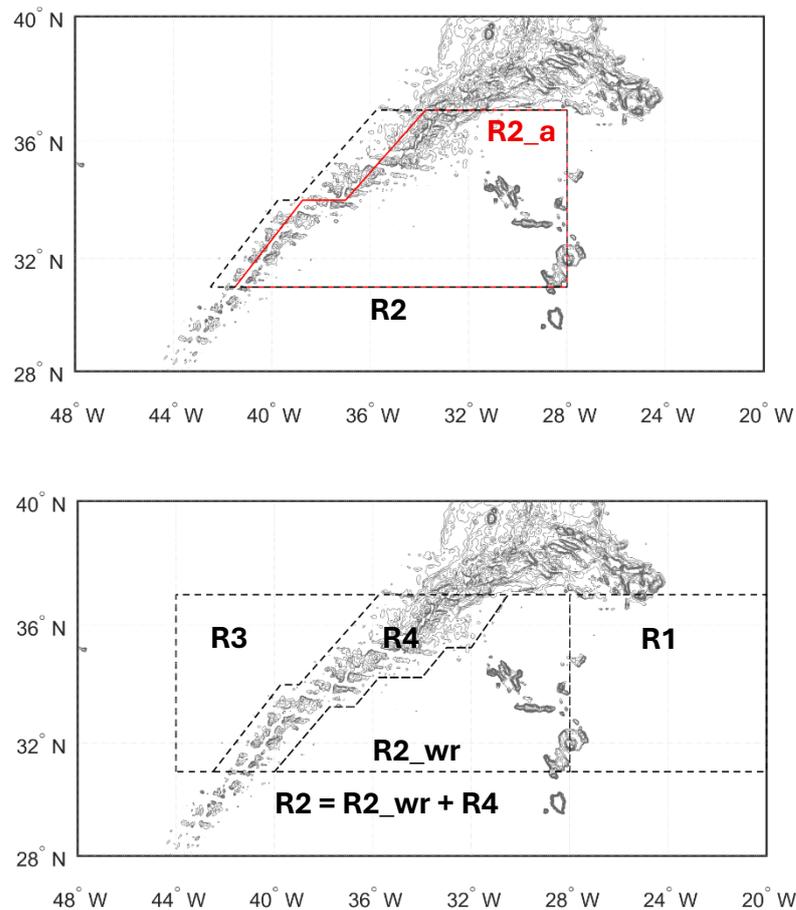


Figure R2 – Boxes used to compute the composites along the Azores corridor. top - excluding the western flank of the ridge. bottom - excluding the ridge itself.

Composites for R4 and R2_wr were computed and analysed. However, because the number of Argo profiles in R4 was limited and their spatial distribution within the box was sparse and radially asymmetric after normalization, we decided to merge R2_wr and R4 into a single region (R2) as described in the manuscript.

Nevertheless, inspection of Figure R3b (centre and right panels) shows that R4 exhibits a deeper core, whereas R2_wr presents core depths similar to those of region R2_a. These results suggest that the vertical structure in R4 may be biased by eddies sampled along the western flank of the ridge, where deeper cores are observed, while the cores in R2_wr and R2_a remain comparatively shallower.

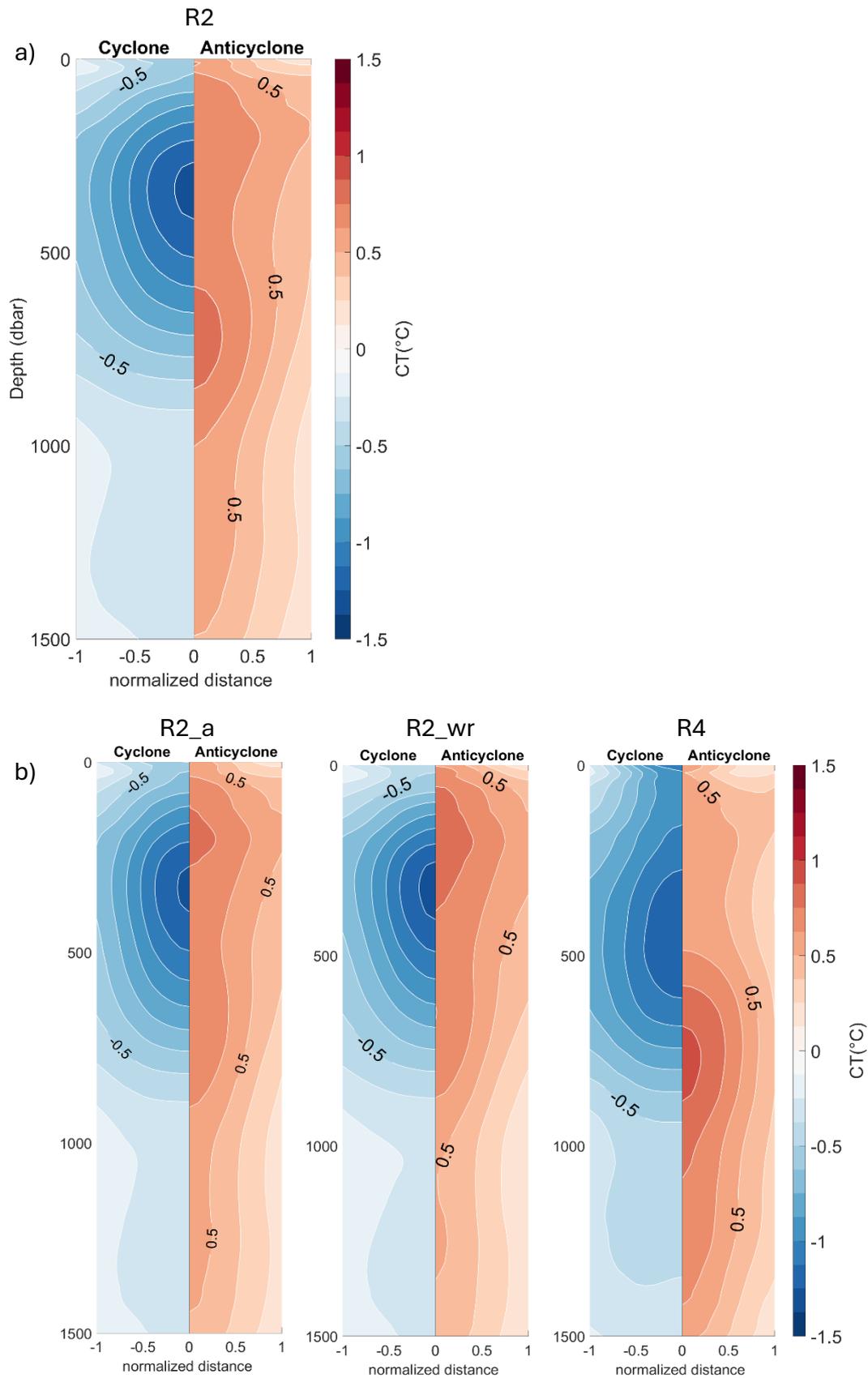


Figure R3 – CT anomaly composite in a) original R2, b-left) R2_a, b-centre) R2_wr and b-right) R4.

In conclusion, the elongated CT vertical structure of anticyclonic eddies in R2 appears to be influenced by eddies sampled near the boundary between R2 and R3.

3. Large IVD coincides with the temperature/salinity anomaly core in regions R1 and R2; however, in region R3, it extends down to 1500 dbar with little variation, whereas the CT/SA anomaly core remains confined to around 500 dbar.

What physical processes could explain this discrepancy?

We understand your comment.

In regions R1 and R2, the largest IVD values do not exactly coincide with the temperature and salinity anomaly cores but are instead located slightly deeper in the water column. Regarding R3, we do not agree that the CT and SA anomaly cores are confined to approximately 500 dbar. Instead, the anomalies extend to greater depths: in the cyclonic case, CT (SA) anomalies reach approximately 1000 dbar (750 dbar), and in the anticyclonic case, CT anomalies extend down to about 1500 dbar. Since IVD represents the vertical displacement of isopycnal surfaces, it reflects the combined influence of CT and SA variability. In R3, the IVD maximum occurs at approximately 1000 dbar, below the depth of the strongest CT anomalies. A similar vertical offset between the thermohaline anomaly cores and the IVD maximum is also observed in R1 and R2 for cyclonic structures. Furthermore, in the anticyclonic case in R3, the maximum IVD contour is closed near 1500 dbar at the centre of the composite, indicating that the largest vertical displacements occur deeper in the water column and that the eddy structure exhibits a pronounced vertical extent.

Because eddies in R3 are generally larger and more energetic, with higher amplitudes, they are expected to induce stronger and deeper isopycnal displacements. In our view, the observed differences in vertical structure are therefore primarily related to differences in eddy characteristics and origin between the regions (mainly between the east and the west of the ridge), rather than to an additional distinct mechanism.

Providing estimates of the mean water depth in each region would help place the vertical structure in context.

A new figure showing the bathymetry of the study region has been added to the manuscript (Figure R5a; Figure 1a in the revised version). From this figure, it can be observed that R2 and R3 present maximum depths of approximately 4000 m, whereas R1 includes deeper areas exceeding 5000 m.

Since the overall depths in R2 and R3 are comparable, we do not consider differences in bottom depth to be the primary factor controlling the contrasting vertical structures observed east and west of the ridge. Instead, as discussed previously, we interpret these differences as being mainly associated with the distinct characteristics and origins of the eddies in each region.

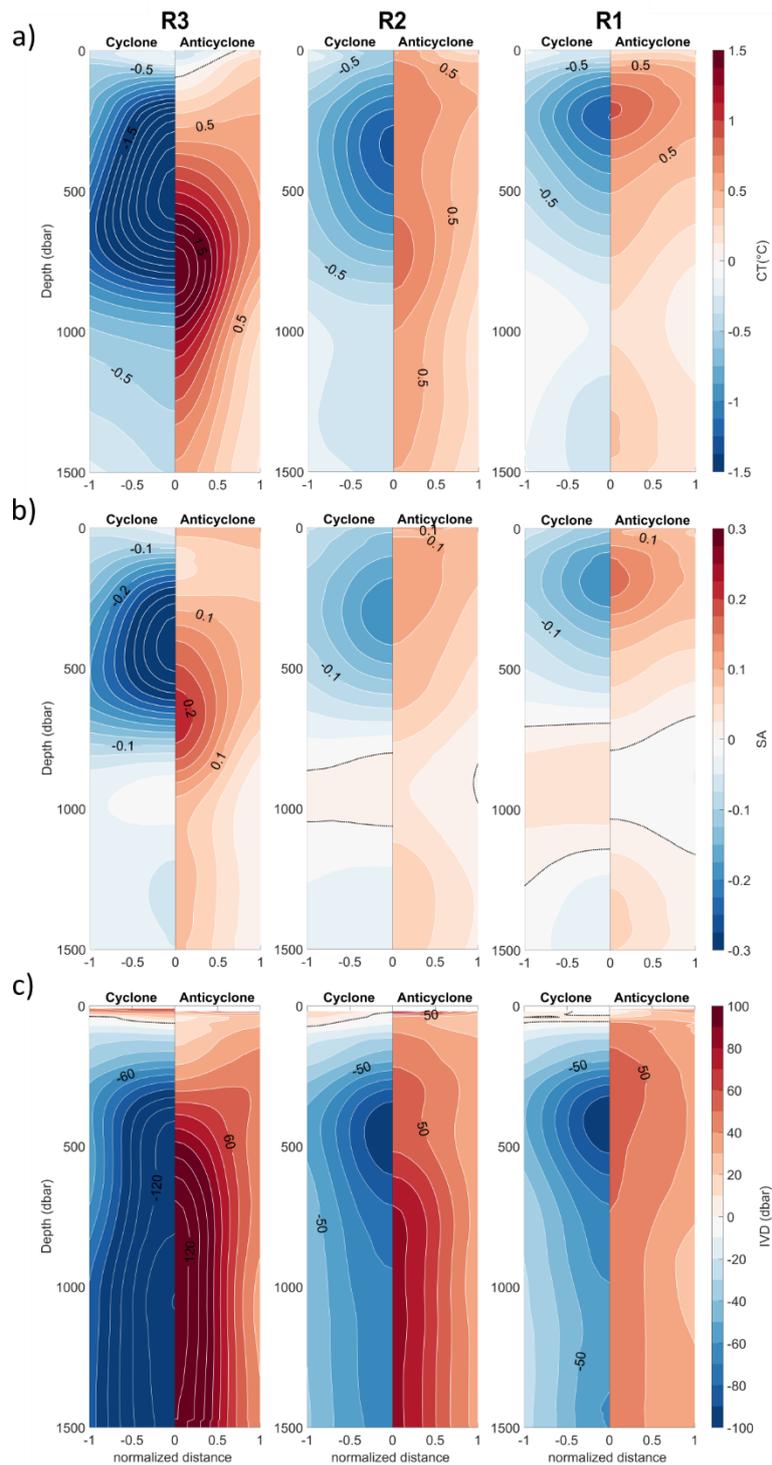


Figure R4 - (Figure 8 of the manuscript): ISOD decomposition: radial vertical structure composite for sampled eddies inside R1, R2 and R3 for both anticyclonic and cyclonic structures. (a) CT anomaly, (b) SA anomaly, (c) Isopycnal Vertical Displacement (IVD). The dotted black line contour represents zero for that variable.

In addition, why do eddies appear to penetrate deeper layers in R1 compared to the other regions?

We understand from our results that eddies penetrate deeper layers in R3 rather than in R1. If the reviewer was referring to R3, this deeper penetration is discussed above and is

consistent with the stronger and more vertically developed structure of eddies in that region. If a different interpretation was intended, we would appreciate clarification so that we may address it appropriately.

4. Many of the references to regional bathymetric features (e.g., plateaus, ridges, and islands) are confusing and are not clearly represented in the figures.

I suggest revising Figure 1 to include a broader map of the Atlantic Ocean showing bathymetry, the location of the Azores Current, the Mid-Atlantic Ridge (MAR), and the names of the major islands and island chains.

Regions R1, R2, R3, and the Seewarte Seamount Chain should also be clearly marked in Figure 1.

A new Figure 1 was made (Figure R5). The boundaries were extended, and the figure was divided into: Figure 1a: which highlights the main geographic and bathymetric features present in the study region; Figure 1b: which shows the mean EKE distribution. In both panels, is represented not only the study region and the AzCCo, but also the mean axis of the current between 20° W and 40° W, following Silva-Fernandes and Peliz, 2020.

In addition, the bathymetric contours are difficult to discern in the current figures. Plotting the contours in a contrasting colour (e.g., black) would help highlight the bathymetric features in all spatial maps.

The colour of the bathymetry was changed to a darker one in all figures where bathymetric lines were present.

5. The manuscript does not adequately address the seasonal variability of the background circulation and its potential influence on eddy trajectories and vertical structure.

We understand and agree with your comment. The seasonal variability of the background circulation is indeed important, and further investigation is needed in this region given the current scarcity of studies.

Even though we did not make a thoroughly characterisation of the variability in this region, a superficial analysis of the inter-annual and seasonal eddy kinetic energy (EKE) and the geostrophic kinetic energy (GKE) variability was made.

The differences presented were not very significative in terms of seasonal variability. A first analysis indicated that the inter-annual variability could play a more important role in this region, since years with lower values of EKE or even in the GKE will reflect less instability of the AzC and consequent generation of eddies.

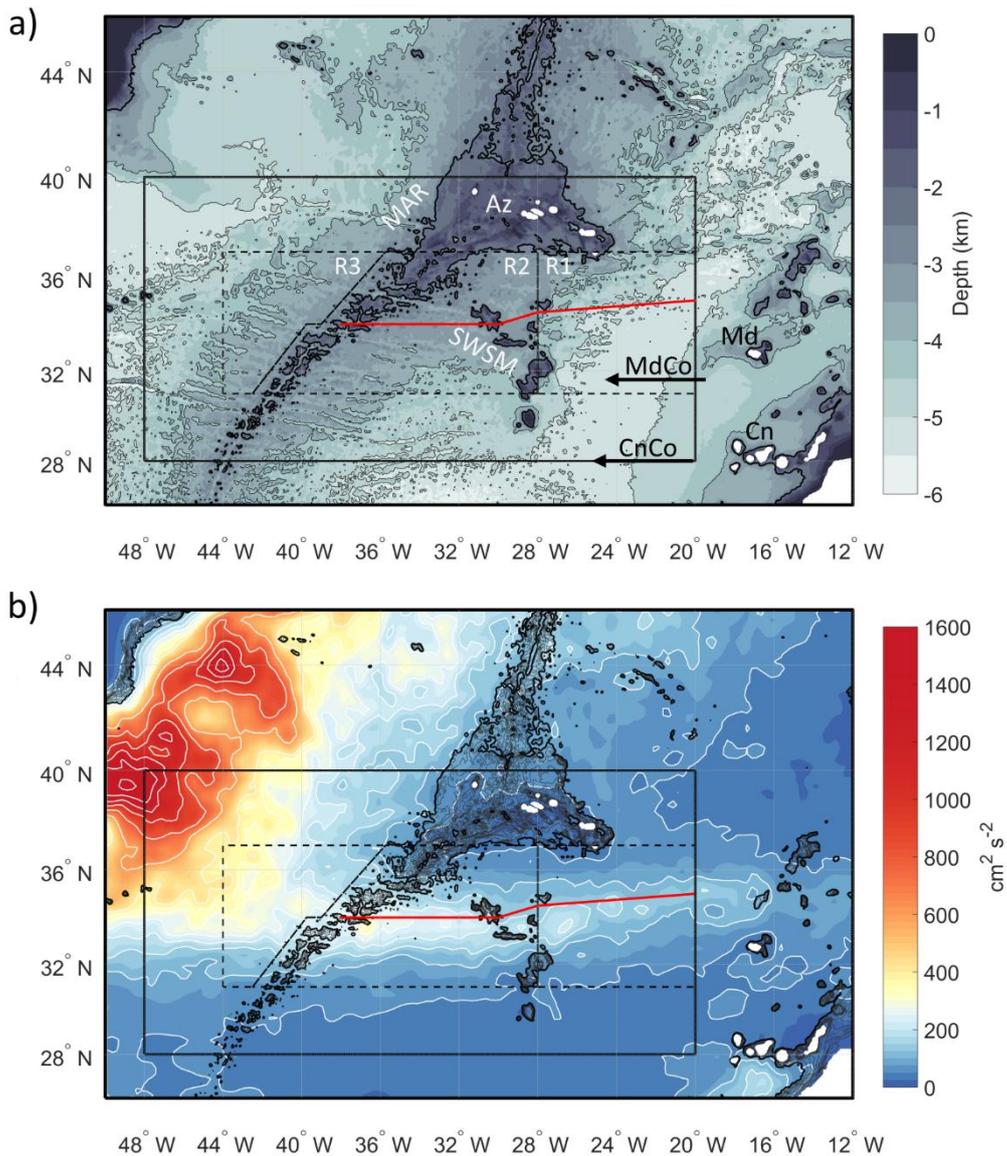


Figure R5 - (Figure 1 in the revised manuscript) (top – Figure 1a in the revised manuscript) Bathymetric map. The thick black contour represents the 2.5 km bathymetric and the black thin ones the 4 and 5 km bathymetric (bottom – Figure 1b in the revised manuscript) Mean EKE for the period 2005-2017. The contours are highlighted in white every 50 cm^2/s^2 until the 400 cm^2/s^2 level and then every 200 cm^2/s^2 . The thick black contour represents the 2.5 km bathymetric. On both figures the black box represents the study region and the black dashed boxes the 3 regions of the AzCCo; the dotted line represents approximately the current axis between 20 °W and 40 °W following Silva-Fernandes and Peliz, 2020. Land areas are represented in white.

We understand and agree that seasonal variability of the background circulation could influence eddy trajectories and vertical structure. In the present study, we did not analyse eddy trajectories seasonally or inter-annually, so we cannot quantitatively assess these effects. However, our results focus on eddy composites constructed from a multi-year dataset, which integrates a range of conditions. Therefore, the composite structures are expected to reflect the general characteristics of anticyclones and cyclones in the region.

Furthermore, since the number of Argo floats emerging inside eddies in each season is relatively low (see Table R1), seasonal composites would be based on very few profiles and would therefore not provide a statistically robust representation of the eddy structure. As a result, good seasonal composites cannot be reliably produced from the available dataset.

In addition, the study does not discuss the monthly distribution of Argo profiles sampled within eddies in each region. Any potential bias arising from uneven sampling or oversampling during particular months should be evaluated and discussed.

Table R1- Number of Argo floats by season emerging inside eddies.

Wi – Winter, Au – Autumn, Sp – Spring and Sm- Summer

Anticyclones	R1	R2	R3
Wi	76 (31%)	60 (25%)	21 (16%)
Au	46 (19%)	59 (24%)	21 (16%)
Sp	81 (33%)	41 (17%)	39 (30%)
Sm	41 (17%)	82 (34%)	50 (38%)
Total	244	242	131

Cyclones	R1	R2	R3
Wi	57 (21%)	45 (22%)	39 (34%)
Au	74 (28%)	32 (15%)	27 (23%)
Sp	60 (22%)	72 (34%)	22 (19%)
Sm	77 (29%)	60 (29%)	28 (24%)
Total	268	209	116

In Figure R5a and R5b, the number of eddies per month is shown for both anticyclones and cyclones. Overall, there is no evident bias in the monthly sampling. Some exceptions exist, such as the low number of sampled anticyclones in September–October in R1 (Figure R5a) and of cyclones in November–December in R2 (Figure R5b), but in general, the number of sampled eddies is well distributed across all months in all regions for both anticyclones and cyclones.

The manuscript includes an excessive description of the figures that reiterates information already evident from the visuals. I recommend reducing these descriptive passages as well as repetition and instead focusing on the key results and their underlying physical interpretations.

We appreciate your comment. This issue has been addressed in the revised version, which has been shortened by approximately four pages.

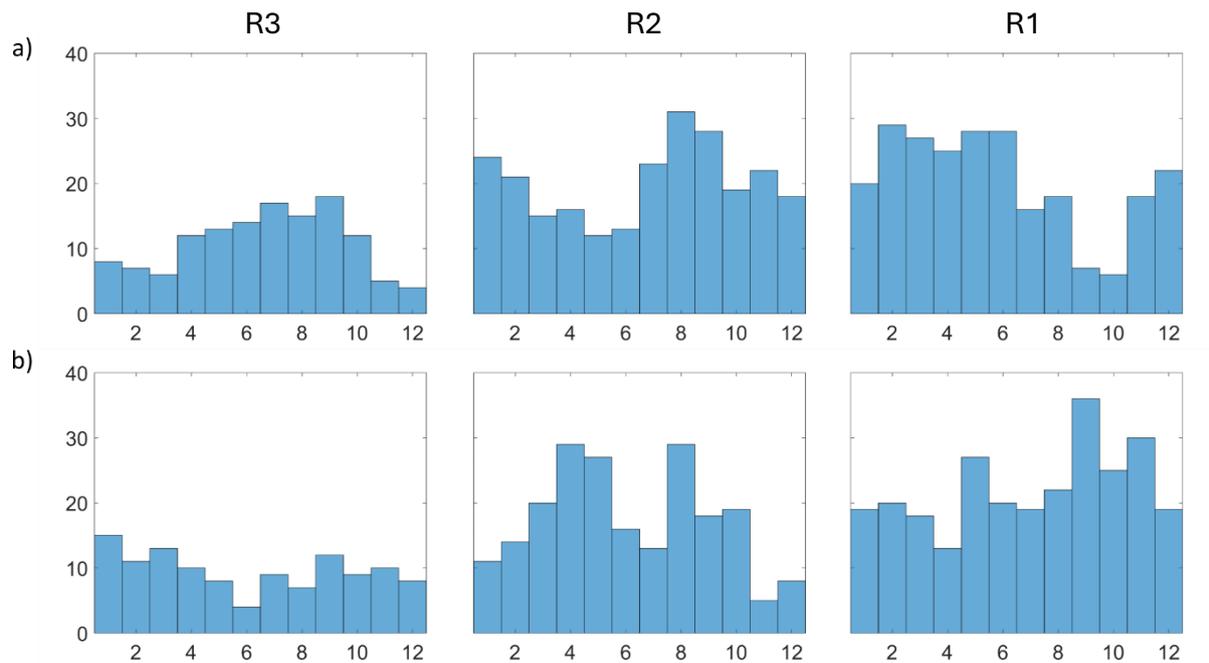


Figure R6 – Number of Argo per month inside eddies: a) anticyclones and b) cyclones.

Minor Comments

. L39: MAR is not defined in the manuscript except in the abstract.

MAR is now defined in the line 40 of the revised manuscript.

. L80: The order of the main research questions presented here does not match the current structure of the manuscript.

We appreciate or comment. The order of the questions in the introduction was changed to match the structure of the manuscript.

. L108: Extra parentheses.

Corrected.

. L134: Repeated sentence.

Corrected.

. L162: The method is not clear.

What we meant was: An eddy was considered to belong to a region if the Argo float sampling that eddy was located within that region, meaning that we used Argo locations rather than eddy centroid positions. This approach was adopted because, given an eddy's spatial extent, it can span multiple regions; even if its centroid falls within one region, the Argo sampling it could be located in another. Therefore, we assigned eddies to regions based on the location of the Argo float sampling them.

The text was changed to: “To avoid ambiguities when eddies extend across regional boundaries, regional attribution was based on the location of the Argo float sampling the eddy rather than on the eddy centroid position.”

. L214: Grammatical error. Provide the latitude of the current axis for clarity. The north-south difference in sampled eddy trajectories is not evident in Figure 4.

The error was corrected. The latitude of the current axis is provided in Line 32 of the revised manuscript, and a red line was added in Figure 1 to represent the current axis.

Regarding the north-south difference, that is more evident in region 2 We added this detail in the text: “Along the AzCCo, the highest trajectories numbers are located north (south) of the current axis ($\sim 34^\circ$ N) for anticyclones (cyclones) in R2, whereas other areas show a more even distribution.”

. L226: Madeira Island is difficult to locate and is not denoted in the study area.

Its location was added in Figure R4a (Figure 1a of the revised manuscript).

. L241: Region 2(b) is missing in the figure caption.

Corrected.

. L256: Figure caption is unclear (“shown in Figure CT (left) and SA (right)”).

We were referring to Figure 6. The number of the figure was added to the text.

. L307: Figure 7a does not show the anomaly. Check the figure reference.

The figure is 8a not 7a. It was corrected in the text.

. L334: The nearly uniform magnitude of isopycnal vertical displacement does not constitute a barotropic eddy structure. Consider using alternative terminology to avoid confusion.

We understand your comment. In the revised manuscript, we have replaced the terms “more barotropic/baroclinic”: “more uniform” instead of “more barotropic”, and “with a well-defined subsurface maximum” instead of baroclinic.

. L410: Figure reference is not correct. Figure 10 is not referred to in the manuscript.

The Figure 9 in lines 410 to 411 is in fact Figure 10. It was corrected in the text.

. L380-382: These details are part of the figure caption. Why discuss it as a result?

We appreciate your comment. Those details were deleted.

Correct the reference Frenger et al. (2015).

Corrected.

Figures

Figure 3: Use the same sequential colour scale in panels (a) and (c) for easier comparison of the number of profiles inside cyclonic and anticyclonic eddies.

We chose to use the same colour as panel (e) - green

Add tick marks on the axes. The minimum and maximum of the whiskers are not clear.

We re-did the boxplots with thicker ticks and whiskers.

Figure 5: Eddy trajectories are not clearly visible.

The figure was re-done with a thicker line for the trajectories.

References

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