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The vertical structure of mesoscale eddies in the Azores Current corridor: a combined altimetry-Argo analysis

Silva-Fernandes and Peliz

The manuscript is improved from length and directness perspectives, and my previous comments have been addressed, but issues still remain. Added detail should be provided on the heave and spice decomposition and composite eddy structure calculations. Results are often confusingly worded with grammatical mistakes, making interpretation more difficult. I do think the results are interesting, but they could still be presented in a more concise manner.

We greatly appreciate your comments and suggestions again, as we believe they have helped improve the manuscript's quality. We hope that we have addressed all comments as thoroughly as possible. We also performed a final, careful proofreading of the manuscript after acceptance of all tracked changes to ensure consistency and to remove any remaining typographical and formatting errors.

Main comments (referencing the track changes line numbers):

- Introduction - this section is improved, but additional synthesis of previous results is still needed. At present it reads as a list of past studies characterizing some aspects of eddies in the region of interest. What is missing from these studies? Collectively what do their results suggest as a next topic of research? Line 57-59 is good context, maybe more of this is needed at the end of the summary of previous results?

We thank the reviewer for this helpful suggestion. We have revised the Introduction to include a clearer synthesis of previous studies. In particular, we now emphasise the common findings from earlier work, including regional variability in eddy properties and the distinction between locally generated eddies and remotely generated structures. At the same time, we highlight the main limitations of these studies, namely the lack of a unified three-dimensional characterisation of eddies and the limited understanding of their vertical structure across the AzCCo.

While previous studies have described aspects of eddy dynamics and thermohaline structure, fewer have addressed their vertical structure in a systematic way or examined the relative roles of different mechanisms shaping these anomalies. We have therefore clarified how these gaps collectively motivate the need for a more comprehensive analysis of eddy vertical structure and variability, which is the focus of this work.

The text was corrected to:

“Mesoscale eddies play a fundamental role in redistributing heat, salt, and momentum in the ocean (e.g., Chelton et al., 2011; Treguier et al., 2012; Frenger et al., 2015). Part of this transport occurs through the advection of water masses with distinct thermohaline properties within coherent eddy cores (eddy trapping). However, recent studies have shown that this mechanism accounts for only a limited fraction of the total transport, with a significant contribution arising from stirring and filamentation surrounding the eddies (e.g., Abernathey and Haller 2018). In addition, vertical motions induced by mesoscale structures (eddy pumping) influence the nutrient transport, while their rotation modulates the horizontal distribution of biogeochemical tracers (e.g., Martin and Richards, 2001; Gaube et al., 2011; Mahadevan, 2016; Keppler et al., 2024).

The Azores current (AzC) is a highly turbulent zonal jet located around 34° N, east of the Mid-Atlantic ridge (MAR), characterised by high eddy kinetic energy (EKE) values exceeding 200 $cm^2\ s^{-2}$ (Figure 1), the highest in 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, hereafter referred to as the Azores Current Corridor (AzCCo), is characterised by a combination of coherent eddies, meanders, and filaments, mostly generated by baroclinic instability of the jet as well as by remote eddy propagation into the region (Klein and Siedler, 1989; Alves and De Verdière, 1999). Different zonal sectors with distinct mesoscale activity have been identified within the AzCCo, with a general decrease in EKE values from west to east. These patterns are strongly influenced by topography, particularly the MAR, which acts as a partial barrier between the eastern and western basins. West of the MAR, eddies 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 sub-regions: (i) western sector between the MAR and the Seewarte Seamount Chain (SWSM) (~28° W); (ii) central sector between 28° W and 20° W; and (iii) eastern sector extending toward the Gulf of Cádiz.

While the surface expression and statistical properties of eddies in this region are relatively well documented (e.g. Barbosa Aguiar et al., 2011; Silva-Fernandes and Peliz, 2020), a systematic study of their internal structure and impact on the water column is still missing. Existing studies comprise mainly isolated events derived from in situ data (e.g., Pingree et al., 1996; Pingree and Sinha, 1998; Mouriño et al., 2002; Mouriño et al., 2003), with most of these studies focusing on the large cyclonic eddies along the “Storm Corridor” (~ 34° N; Pingree, 2002). These large cold-core cyclones are characterised by horizontal temperature anomalies of ~2.5° C between 200 and 600 dbar. Pingree et al. (1996) also reported isopycnal displacements of ~200 dbar, extending from the surface to near the seafloor (~4000 m).

More recently, Pegliasco et al. (2015) characterised the vertical structure of two clusters of eddies using Argo floats originating from the Canary upwelling system, partially overlapping the southern flank of the AzCCo (west of 20° W). A shallow cluster (cores at ~0–200 m), dominated by anticyclones, exhibits weak positive anomalies and short propagation pathways, forming part of the Canary Corridor (CnCo). In contrast, a deeper cluster (maxima between 200 and 600 m), dominated by cyclones, shows negative temperature and salinity anomalies (~−0.5 °C and −0.07) and extends to depths of 600–800 m. This latter group propagates as far as 40°W, near the MAR, and is associated with the Madeira Corridor (MdCo; Sangrà et al., 2009). Similarly, Amores et al. (2017used composites of Argo floats and altimetry (Sea Level Anomaly - SLA), covering part of the AzC southern flank (~32°N). They reported peak anomalies at ~150 m for anticyclones and 400–800 m for cyclones, with potential temperature anomalies exceeding 1 °C and salinity anomalies of ~0.2, the latter being slightly stronger in cyclones. Anticyclonic (cyclonic) eddies are generally characterised by warm and salty (cold and fresher) cores, with signals extending down to ~1200 m. West of the ridge, based on the analysis of SOFAR float trajectories launched on both sides of the MAR, Ollitrault and Colin de Verdière (2002) reported that eddies in this region exhibit a southward flow south of 38° N and generally migrate along the western flank of the ridge. Furthermore, their analysis showed that cyclones (anticyclones) are characterised by cold (warm) cores at approximately 770 dbar.

In addition to locally generated eddies, Mediterranean water eddies (meddies) are also present in the region, particularly east of the MAR (east of the SWSM and the Azores Plateau (AzP)) (Bashmachnikov et al., 2015). These structures transport Mediterranean water (MW) with strong thermohaline contrasts relative to the surrounding ocean, generating pronounced temperature and salinity anomalies at intermediate depths (~800–1200 dbar), with values exceeding 0.5 °C and 0.2 in salinity over vertical scales of several hundred meters (Richardson et al., 1991; Bashmachnikov et al., 2015). Meddies are predominantly anticyclonic, although cyclonic meddies have also been reported, exhibiting positive temperature and salinity anomalies and vertical extensions from approximately 500 to 1300 dbar (Richardson et al., 2000; Barbosa Aguiar et al., 2013). In contrast to locally generated eddies, meddies are expected to exhibit higher thermohaline anomaly values, offering a useful contrast with respect to different mechanisms of eddy-induced anomalies.

Collectively, previous studies have provided a detailed description of the surface eddy field and documented a number of isolated subsurface structures, but they lack a unified three-dimensional characterisation of eddies across the AzCCo. In this work, we address these gaps by analysing more than 10000 Argo profiles combined with 20 years of altimetric data and an eddy atlas (AVISO+, Sect. 2.3). We characterise the vertical structure of composite mesoscale eddies in the AzC corridor (AzCCo) and explore the concepts of Spice (SPI) and Heave (HEV), relating the observed variations in climatological temperature and salinity fields to eddy trapping, associated with the advection of distinct water masses, and eddy pumping, manifested as the deflection of isopycnal surfaces driven by the internal structure of anticyclonic and cyclonic eddies.

The main research questions addressed in this study are as follows: 1) What is the typical vertical structure of eddies in the Azores Current corridor? 2) Which mechanisms - reflected by HEV and SPI anomaly signatures - dominate the generation of internal temperature and salinity anomalies within eddies? 3) How does the presence of mesoscale turbulent structures affect the water column in our study region?"

- If defining anomaly profiles as the difference between Argo and WOA, potential biases or offsets between the two products need to be assessed. L131 references "this bias", but no bias has been quantified?

We thank the reviewer for this comment. We clarify that the climatology used for computing anomalies is restricted to the Argo period (2005–2017), in order to ensure consistency between the reference state and the observational coverage. The term "bias" in the original text was misleading and has been removed. Our intention was not to quantify or correct a bias between datasets, but rather to avoid differences arising from the inclusion of earlier, sparsely sampled periods in the climatology. The paragraph has been revised to improve clarity:

"All variables were interpolated to 10 dbar levels, and anomalies were computed relative to the World Ocean Atlas 2018 climatology (Boyer et al., 2018; WOA2018; https://www.ncei.noaa.gov/archive/accession/NCEI-WOA18), for the Argo period (2005–2017). The climatological fields were interpolated in space and time to each Argo profile location and standard depth levels. In time, the interpolation consisted of selecting the climatological profile corresponding to the appropriate day of year, using a 12-month spline interpolation. The choice of the Argo period climatology ensures consistency between the climatological reference and the Argo-era sampling period, thereby avoiding differences arising from the inclusion of earlier, sparsely sampled periods in the climatology."

- The methodology section is improved (L149-160), but more detail is needed. The step-by-step procedure described could be improved by incorporating some spice and displacement units? It feels a bit too descriptive. In step three, these differences being referenced need to be more clearly defined. For a given neutral surface, Is IVD derived as the difference in pressure between an Argo and climatological profiles? It should be stated that heave is calculated in units of CT or SA … as heave is more commonly defined as a vertical distance?

We thank the reviewer for this helpful comment. We have revised the methodology section to improve clarity and explicitly define the SPI and IVD contributions, including their units and physical interpretation. We now clarify that SPI and HEV are expressed in the same units as the corresponding tracer anomalies (CT and SA), while IVD represents the vertical displacement of neutral surfaces and is expressed in pressure coordinates (dbar).

We also clarify that IVD is computed as the difference in pressure between Argo and climatological profiles for the same neutral isopycnal surface and therefore represents isopycnal vertical displacement (heave) in pressure space. Finally, step 3 has been rewritten to explicitly define that SPI and IVD are computed as Argo–climatology differences evaluated on the same neutral surfaces.

The text was corrected to:

"The vertical isopycnal decomposition (hereinafter ISOD) has been applied not only to investigate the warming and/or freshening of specific water masses (e.g., Desbruyères et al., 2022) and ocean heat content variability (Zhang and Yan, 2017), but also to examine the vertical structure of mesoscale eddies and the mechanisms responsible for their internal physical and biogeochemical anomalies (e.g., Frenger et al., 2015; Gaube et al., 2014; Keppler et al., 2024). ISOD separates the contributions of two distinct processes to the generation of CT and SA anomalies: eddy trapping, associated with advection along isopycnal surfaces and quantified by SPI, and eddy pumping, associated with the vertical displacement of isopycnal surfaces and quantified by HEV. HEV is positive (negative) for downward (upward) displacement of isopycnal surfaces.

In this study, all anomalies are defined as differences between Argo profiles and the climatological fields projected onto neutral isopycnal surfaces. Following Bindoff and Mcdougall (1994) and later Han and Yan (2018), the ISOD equation can be written as:

$$\Delta X|_p \cong X_{SPI} + (-X_{HEV}) + residue \cong \Delta X|_n + (-\Delta p|_n \nabla X) + residual \quad (1)$$

Where $\Delta X|_p$ represent the total anomaly at a pressure level, $\Delta X|_n$ the anomaly along a neutral isopycnal surface (NIS), $-\Delta p|_n$ the vertical displacement of neutral surfaces is expressed in pressure coordinates (dbar) and defined as the difference in pressure between Argo and climatological profiles for the same NIS, and $\nabla X$ is the vertical gradient of the climatological field. HEV and SPI are expressed in the same units as the corresponding variables (CT and SA anomalies). The residual (RES) term accounts for unresolved processes such as mixing and diffusion and is expected to be small in a well-stratified ocean.

The ISOD of CT and SA was computed as follows. NIS were calculated using TEOS-10 routines (http://www.teos-10.org/preteos10_software/neutral_density.html, Jackett and McDougall, 1997) and interpolated onto a fixed grid. CT, SA, density, and pressure were then mapped onto each NIS. SPI and IVD were computed as differences between Argo and climatology along each NIS and subsequently interpolated back to pressure coordinates. The HEV component was calculated as $-\Delta p|_n \nabla X$. Total anomalies ($\Delta X|_p$)

were obtained in pressure space as Argo minus climatology, and the residual was defined as the difference between the total anomaly and the sum of SPI and HEV.

In summary, each Argo profile was converted into profiles of CT and SA anomalies, as well as IVD, HEV, and SPI (for both CT and SA). These metrics were then used to construct the eddy composites, which are analysed to assess how mesoscale structures affect the water column in our study region."

- I'm still a bit confused about composite construction. I understand the normalized distance from the eddy center, but how are amplitudes normalized? Are they? As there is a strong meridional gradient in mean CT/SA structure do we expect eddies to be radially symmetric?

We thank the reviewer for this question. In our composite analysis, only the radial distance from the eddy centre was normalised by the eddy radius, while no amplitude normalisation was applied. Temperature and salinity fields were composited in physical units after removal of the background climatological structure.

Zonal and meridional composite sections were initially computed and were found to be very similar. As stated in the manuscript: "Further, to build the composites, we have assumed azimuthal symmetry (i.e., that eddies are circular structures and depend only on depth and distance from the centre). Although this is not verified for all eddies, a first decomposition into zonal and meridional mean sections revealed similar vertical structures (not shown)."

For clarity and to avoid redundancy, only radial composites are presented. This choice is further supported by the fact that eddies are often deformed and not perfectly axisymmetric, so directional (zonal or meridional) sections may not be consistently aligned with their structure. As a result, radial composites provide a more robust statistical representation of the mean eddy structure.

- Significant grammatical issues remain (in some cases the original draft was better) - see line by line comments

We thank the reviewer for this remark. We have carefully revised the manuscript and conducted a detailed language review, considering all line-by-line comments. Where appropriate, we have also restored or adjusted original phrasing when it improved clarity and readability.

- Additional synthesis/interpretation of heave and spice figures is needed.

We thank the reviewer for this comment. Additional synthesis and interpretation of the HEV and SPI components have been added in section 3.4 of the results and 4.2 of the discussion.

The text was corrected to:

Section 3.4

“The isopycnal decomposition reveals the respective contributions of heave (HEV), spice (SPI), and residual (RES) components to the vertical structure of CT and SA anomalies along the AzCCo, for both anticyclonic and cyclonic composites (Figure 8).

A clear asymmetry between anticyclones and cyclones appears in both CT (Figure 8a) and SA (Figure 8b) anomaly structures, including differences in magnitude, vertical extent, and sign. Cyclones display a well-defined core, whereas anticyclones show a more vertically distributed structure throughout the water column, particularly in R2.

A systematic deepening of eddy cores is observed from east to west, with depths ranging from approximately 250–500 dbar for cyclones and 250–750 dbar for anticyclones. However, a reversal in polarity is evident: east of the MAR, cyclones are deeper than anticyclones, whereas in R3 the opposite pattern occurs, with anticyclones reaching the greatest depths (Figures 8a and 8b). Anticyclones are characterised by warmer and saltier cores (> 0.75° C and 0.1 salinity), while cyclones exhibit colder and fresher cores (< −2° C and −0.3 salinity). In R1 for both structures, and in R2 for cyclones, a CT anomaly minimum occurs near 1000 dbar. At similar depths, SA anomalies reverse sign, reflecting depth-dependent changes in the background thermohaline structure linked to isopycnal displacement and highlighting the strong influence of stratification. In R2, anticyclones combine features of R1 and R3, forming a vertically stretched structure from the surface to about ~1000 dbar. This reflects sampling above the ridge near the R3 boundary, indicating a transition in vertical structure along the AzCCo.

Anticyclones (cyclones) exhibit positive (negative) IVD (Figure 8c), corresponding to the isopycnal surface deflection (elevation). This signal is stronger and more defined in cyclones (below −90 dbar in R1–R2 and −130 dbar in R3). In R1 and R2, the cyclonic IVD structure is similar, with a slight deepening of the maximum, while in R3 it becomes more vertically uniform between 400 and 1500 dbar. Anticyclones show comparable patterns across regions, more pronounced in R2 (>80 dbar) and R3 (120 dbar). In all regions, IVD remains non-zero at 1500 dbar, indicating a deep-reaching, vertically coherent eddy signal.

HEV (Figures 8d and 8g) dominates over SPI (Figures 8e and 8h) in shaping CT and SA anomalies. HEV maxima occur slightly deeper than anomaly maxima and follow the same westward deepening trend. Furthermore, HEV shows the same sign as CT anomalies, while SA shows sign inversion due to reversal of the climatological gradient ($\nabla pX$; Equation 1) around 750 dbar, limiting the vertical extent of SA IVD. As for IVD, HEV remains non-zero at depth, supporting the presence of eddies extending below 1500 dbar.

The SPI structure (Figures 8e and 8h) is more complex and confined to shallower depths. CT SPI shows higher eastern values restricted to the upper 250 dbar, with a sign inversion at depth and broader vertical extension. West of the MAR, anticyclones maintain consistent CT and SA sign, while cyclones exhibit a sign reversal near 1000 dbar. A similar pattern appears in SA SPI. This shallow confinement indicates that along-isopycnal variability is primarily surface-intensified in this region.

Although not a primary focus, ISOD residuals (Figures 8f and 8i) are comparable in magnitude to SPI, suggesting contributions from diffusivity, diapycnal mixing, or processes such as eddy stirring not captured by HEV or SPI. This component is stronger in cyclones and west of the MAR.

Overall, the ISOD decomposition reveals a vertically structured eddy field dominated by heave-driven variability at depth and weaker, surface-intensified spice contributions, with clear regional and eddy-type asymmetries along the AzCCo. This highlights a vertical partitioning of thermohaline variability between deep and surface layers."

Section 4.2

"HEV dominates the vertical structure of both CT and SA anomalies on both sides of the MAR throughout most of the water column, with SPI exhibiting higher values in the upper ~250 dbar east of the MAR and a larger vertical extension west of the ridge. In R1 and R2, HEV presents well-defined maxima for anticyclonic (cyclonic) structures around the 400 dbar (500 dbar) level, indicating that the observed anomalies are primarily driven by the vertical displacement of isopycnal surfaces. This mechanism leads to the depression (elevation) of isopycnal surfaces and the associated downwelling (upwelling) of warmer (colder) waters, resulting in warm (cold) anomalies. West of the MAR, the same dynamical behaviour is observed, but with stronger amplitude and greater vertical extent, consistent with larger IVD values in this region. This dominance of HEV indicates that eddy-induced thermohaline anomalies along the AzCCo are primarily governed by vertical redistribution processes (eddy pumping), rather than by lateral transport of distinct water masses along isopycnal surfaces.

The generally low SPI values observed across the AzCCo suggest that thermohaline anomalies are not primarily driven by contrasts along isopycnal surfaces within most eddies. This can be explained by the fact that many eddies evolve within the corridor, where background CT and SA gradients are relatively smooth in the zonal direction. As a result, advection along isopycnal surfaces introduces only minor deviations from the background state. An exception is found for meddies (not shown), which advect MW, leading to significantly higher SPI values. Furthermore, the weak SPI signal implies a limited efficiency of these eddies in transporting tracers over long distances, reinforcing the view that their primary role is the vertical redistribution of properties. In this sense, the AzCCo can be viewed as a regime where the surface intensified mesoscale variability is dominated by deformation of the background stratification rather than by the advection of thermohaline properties.

These results are consistent with the conceptual framework of eddy-driven transport mechanisms. Four main processes are typically identified: eddy pumping, eddy trapping, eddy-induced Ekman pumping, and eddy stirring. At a global scale, He et al. (2024) show that temperature anomalies are primarily controlled by eddy pumping, consistent with the dominance of HEV in our results. In contrast, eddy trapping becomes relevant in regions with strong horizontal property gradients, as highlighted by Frenger et al. (2015). In our study area, this mechanism is most clearly expressed in meddies, where sharp zonal gradients in temperature and salinity lead to enhanced SPI values. Regional studies further support this interpretation. Keppler et al. (2018) and He et al. (2023) show that eddy trapping tends to dominate near the surface, whereas eddy pumping becomes increasingly important at depth. Similarly, Amores et al. (2017) found that temperature and salinity anomalies are mainly driven by advection in the upper ~200 m, while vertical displacement of isopycnal surfaces dominates below ~300 m. Their reported signal extending down to ~1200 m is consistent with the non-vanishing HEV, and the high IVD values observed throughout the AzCCo east of the MAR. In situ studies by Pingree et al. (1996) and Mourino et al. (2003) also report deep-reaching eddy signatures extending from several hundred meters to full water column depth, supporting the presence of vertically coherent eddy structures in the region.

The westward intensification of HEV reflects a transition between two dynamical regimes separated by the MAR: an eastern region more influenced by local stratification and horizontal gradients, and a western region characterised by deeper, more energetic eddies with a capacity to redistribute properties throughout a larger fraction of the water column.

Finally, the dominance of HEV has important implications for vertical exchanges in the region. Cyclonic eddies, through isopycnal upwelling, are likely to enhance the upward transport of colder, nutrient-rich waters, while anticyclones promote downwelling and subduction of surface waters. Given the deep vertical extent of HEV observed here, these processes are not confined to the upper ocean but may contribute to the ventilation and redistribution of properties down to at least 1500 dbar along the AzCCo."

- The conclusion section summarizes nicely a long list of results (but grammatical mistakes remain)

We thank the reviewer for this remark. The Conclusion section has been revised to correct remaining grammatical issues and improve readability, while preserving the scientific content and structure of the summary.

The text was corrected to:

"In this study, we analysed the CT and SA profiles of Argo floats emerging within tracked eddies (both anticyclones and cyclones) identified on ADT maps. From the total of individual sampled eddies, 617 anticyclones and 593 cyclones were profiled in the

AzCCo. The main objective was to characterise the vertical structure of mesoscale turbulence along the AzCCo and to understand its impact on the water column. Our findings can be summarised as follows.

The vertical structure differences found between the eastern and western sides of the ridge are associated with the origins of the sampled eddies: while in the east, most eddies originate locally, in the west, the majority originate outside R3, representing a combination of eddies propagating from the east and from the northwest, the latter being associated with Gulf Stream eddies. This results in more intense anomalies in the westward composites.

When analysing the HEV and SPI signatures and intensities, we concluded that: 1) The HEV component is the main contributor to the formation of the CT and SA anomalies, as it exhibits the highest values along the AzCCo. 2) This dominance indicates that most eddy anomalies are generated through an eddy pumping mechanism, producing warm and saltier (cold and fresher) anomalies due to the downwelling (upwelling) of the shallower (deeper) isopycnal surfaces in the anticyclonic (cyclonic) eddy interior. 3) SPI shows lower values across the domain, although slightly higher values are found in the upper 250 dbar east of the MAR, reflecting the tendency of eddies to trap different water masses.

Regarding the influence of mesoscale turbulence on the water column, this work shows that: 1) From east to west, the absolute maximum values of both CT and SA anomalies occur at increasing depths, from 250 dbar to ~750 dbar. 2) Anticyclones exhibit a more uniform structure while cyclones display a well-defined subsurface maximum. 3) IVD absolute values exceeding 50 dbar down to 1500 dbar confirm the deep-reaching influence of both anticyclonic and cyclonic eddies. 4) High IVD absolute values (above 150 dbar) across the AzCCo further indicate that these structures could have the potential to enhance vertical advection not only of heat and salt, but also of biogeochemical properties.

Overall, this study confirms that mesoscale eddies along the AzCCo exert a deep influence on the water column, with differences in their vertical structure linked to eddy origins and dynamical properties. Taken together, these results depict the AzCCo as a vertically driven mesoscale regime in which eddies primarily act through isopycnal displacement, redistributing thermohaline properties over a large fraction of the water column rather than through lateral transport. This has important implications for regional ocean dynamics, suggesting that mesoscale processes in this corridor may play a key role in deep ventilation and in the vertical redistribution of heat, salt, and biogeochemical tracers."

Line-by-line (referencing the track changes line numbers):

L33-35: I think it is still worth reconciling this statement with the findings of Abernathy and Haller 2018, namely that eddy trapping is responsible for only a small fraction of heat/salt/momentum redistribution.

We thank the reviewer for this suggestion. As we revised the Introduction, we now included the findings of Abernathey and Haller 2018. In particular, we now clarify that, although eddy trapping contributes to the transport of heat, salt, and momentum, it represents only a limited fraction of the total redistribution, with a substantial contribution arising from stirring and incoherent motions. This distinction is now clearly stated to provide a more balanced description of the mechanisms involved.

"However, recent studies have shown that this mechanism accounts for only a limited fraction of the total transport, with a significant contribution arising from stirring and incoherent motions surrounding the eddies (e.g., Abernathey and Haller 2018)."

L64: replace "bottom" with "seafloor"

Corrected

L75-76: this sentence belongs in the preceding paragraph

Corrected

L83: easily tracked in what sense? By a specific instrument?

We meant that meddies have a pronounced signature in temperature and salinity (high anomalies), which allows them to be easily identified in hydrographic measurements, as in Argo float profiles.

L90: should spice and heave be capitalized?

Was a misspelling. Corrected.

L106: bathymetric contour?

We meant bathymetric contour. We added contour.

L116: "completed inside"

We couldn't understand what is meant by "completed inside".

L119-120: replace first with shallowest and last with deepest

Corrected

L125: state which MLD definition is used

The text was corrected to: "The Gibbs SeaWater oceanographic toolbox (GSW-OT; www.TEOS-10.org) was used to compute conservative temperature (CT), absolute salinity (SA), density anomaly (RHO), and mixed layer depth (MLD), defined following de Boyer

Montégut et al., 2004 as the depth at which potential density increases by 0.03 kg $m^{-3}$ relative to the surface. "

L145-146: delta p_n definition does not make sense. It seems to be defined as a difference in pressure, but I assume displacement is in units of meters? Additional detail is needed.

In our formulation, $-\Delta p|_n$ represents the vertical displacement of neutral isopycnal surfaces and is computed as the difference in pressure between Argo and climatological profiles evaluated on the same neutral surface. This quantity is therefore expressed in pressure coordinates (dbar) and is used as a proxy for vertical displacement (heave).

We clarify that although vertical displacement can be equivalently expressed in meters, we use pressure coordinates throughout the analysis for consistency with the vertical coordinate system of the dataset and the decomposition framework. The manuscript has been revised to make this definition and its interpretation more explicit.

L149: why are you performing this decomposition on climatology? I thought displacements were computed with respect to climatology?

The isopycnal decomposition is performed using the climatology as the reference state. In this framework, all anomalies and vertical displacements (IVD) are computed as differences between Argo profiles and the climatological fields evaluated on the same neutral isopycnal surfaces.

We have clarified in the revised manuscript that the climatology is not independently decomposed but instead serves as the reference state against which both SPI (along-isopycnal anomalies) and IVD (isopycnal vertical displacements) are computed. This ensures that displacements are consistently defined with respect to the climatological neutral surfaces.

L177: what is the geometric method?

The "geometric method" refers to the eddy tracking approach used in META 3.2, which links eddy detections between successive time steps based on the spatial proximity and overlap of eddy contours identified in absolute dynamic topography fields. The trajectories are constructed by minimising spatial displacement and ensuring continuity of eddy features through time. The text was corrected to: "The mesoscale eddy trajectory atlas product version 3.2 (hereinafter META2022), produced by SSALTO/DUACS and distributed by AVISO+ (https://www.aviso.altimetry.fr/en/data/products/value-added-products/global-mesoscale-eddy-trajectory-product.html), was used to identify and track eddies in absolute dynamic topography (ADT) maps using a geometric tracking method based on spatial proximity and contour overlap between successive time steps. Only eddies with a tracking duration longer than 10 days were retained in this study."

L184: delete "the values of"

Corrected

L188: “used to superimpose the atlas” I’m not sure what this means

We have clarified the wording in the manuscript. The mesoscale eddy atlas trajectories and associated eddy contours are overlaid onto the ADT fields in order to provide a visual representation of the spatial evolution of the tracked eddies relative to the sea level anomaly field. The text was corrected to: “These maps were used as a background onto which the mesoscale eddy atlas trajectories were overlaid.”

L195: “eddy turbulent energy” if referencing EKE, it needs to be defined (with respect to what mean?)

The EKE was estimated as $U^2/2$, where $U$ is the swirl velocity given by the META 3.2 product. Therefore, it represents an instantaneous measure of the kinetic energy associated with the eddy circulation, rather than EKE defined relative to a temporal mean flow.

L220: “each Argo profile”?

Yes. Corrected.

L221: “independent”

Corrected

L272: what is an “argo sampled eddy trajectory”? Does this mean an altimeter identified eddy track for an eddy that an Argo float profiled?

We refer to an eddy track for which, at least at one time step, the eddy was sampled by an Argo float.

L274: “sampled”

Corrected

L280: “highest trajectory numbers”?

Corrected

L304: missing space between R2 and which … this occurs in many places and makes me think proofreading was not adequately carried out.

Corrected

L306: the region numbers appear incorrect? They do not match those described in figure 1 caption

They were in reverse. Corrected

L313: “it could hypothesize” this is incorrect grammar

It was corrected to: “it could be hypothesised that the”.

L324: “spans to depths” grammatical error

It was corrected to: “Its signature reaches depths of approximately”.

L344: in general you do not have to state “results are presented in figure X”. rather the result should stated and the figure referenced.

We thank the reviewer for this comment. We have revised the text throughout the manuscript to state the results directly and reference the corresponding figures, rather than introducing them with phrases such as “results are presented in Figure X.”

L405: “a deepening of eddies’ core is observed from east to west (), being the anticyclones core deeper in R3” this makes no sense and is a bit frustrating to try and make sense of these sections contain many grammatical mistakes.

We thank the reviewer for this comment. The text was corrected to:

“A systematic deepening of eddy cores is observed from east to west (approximately 250–500 dbar for cyclones and 250–750 dbar for anticyclones). However, cyclones exhibit a deeper core in the eastern region compared to the west, whereas anticyclones reach their deepest cores in R3 (Figures 8a and 8b).”

L452: “west of MAR, anticyclones present the same sign throughout the water column for anticyclones while the cyclones change signal” again this is difficult to make sense of. The same sign of what? What does change signal mean?

We meant the same sign of temperature and salinity spice values throughout the water column. The word signal is a misspelling of the word sign. The text was corrected to: “West of MAR, anticyclones present the same sign of CT and SA spice throughout the water column near their centre, while the cyclones show a sign inversion at 1000 dbar.”

L474: “mean direction of the sampled eddies”? Do you mean their direction of translation? (L475: “cyclones have mostly westward directions” …)

Yes, we meant translation direction. The text was corrected to: “The 10-day mean translation direction of the sampled eddies along the AzCCo is presented in Figures 9, where some preferred directional paths emerge.”

L601-621: This appears a summary of past results with few physical/dynamical links to the results presented here? I suggest a bit more synthesis between new and old results.

We thank the reviewer for this helpful suggestion. We agree that this section initially read as a summary of previous literature with insufficient connection to the results of this study. We have therefore revised the text to improve the synthesis between existing studies and our findings. We now more clearly relate previously identified eddy transport mechanisms to our HEV and SPI results and highlight how our observations support and extend earlier work on eddy pumping and eddy trapping in the AzCCo region.

The text was corrected to:

“HEV dominates the vertical structure of both CT and SA anomalies on both sides of the MAR throughout most of the water column, with SPI exhibiting higher values in the upper ~250 dbar east of the MAR and a larger vertical extension west of the ridge. In R1 and R2, HEV presents well-defined maxima for anticyclonic (cyclonic) structures around the 400 dbar (500 dbar) level, indicating that the observed anomalies are primarily driven by the vertical displacement of isopycnal surfaces. This mechanism leads to the depression (elevation) of isopycnal surfaces and the associated downwelling (upwelling) of warmer (colder) waters, resulting in warm (cold) anomalies. West of the MAR, the same dynamical behaviour is observed, but with stronger amplitude and greater vertical extent, consistent with larger IVD values in this region. This dominance of HEV indicates that eddy-induced thermohaline anomalies along the AzCCo are primarily governed by vertical redistribution processes (eddy pumping), rather than by lateral transport of distinct water masses along isopycnal surfaces.

The generally low SPI values observed across the AzCCo suggest that thermohaline anomalies are not primarily driven by contrasts along isopycnal surfaces within most eddies. This can be explained by the fact that many eddies evolve within the corridor, where background CT and SA gradients are relatively smooth in the zonal direction. As a result, advection along isopycnal surfaces introduces only minor deviations from the background state. An exception is found for meddies (not shown), which advect MW, leading to significantly higher SPI values. Furthermore, the weak SPI signal implies a limited efficiency of these eddies in transporting tracers over long distances, reinforcing the view that their primary role is the vertical redistribution of properties. In this sense, the AzCCo can be viewed as a regime where the surface intensified mesoscale variability is dominated by deformation of the background stratification rather than by the advection of thermohaline properties.

These results are consistent with the conceptual framework of eddy-driven transport mechanisms. Four main processes are typically identified: eddy pumping, eddy trapping, eddy-induced Ekman pumping, and eddy stirring. At a global scale, He et al. (2024) show that temperature anomalies are primarily controlled by eddy pumping, consistent with the dominance of HEV in our results. In contrast, eddy trapping becomes relevant in regions with strong horizontal property gradients, as highlighted by Frenger et al. (2015). In our study area, this mechanism is most clearly expressed in meddies, where sharp zonal gradients in temperature and salinity lead to enhanced SPI values. Regional studies further support this interpretation. Keppler et al. (2018) and He et al. (2023) show that eddy trapping tends to dominate near the surface, whereas eddy pumping becomes increasingly important at depth. Similarly, Amores et al. (2017) found that temperature and salinity anomalies are mainly driven by advection in the upper ~200 m, while vertical displacement of isopycnal surfaces dominates below ~300 m. Their reported signal extending down to ~1200 m is consistent with the non-vanishing HEV, and the high IVD values observed throughout the AzCCo east of the MAR. In situ studies by Pingree et al. (1996) and Mourino et al. (2003) also report deep-reaching eddy signatures extending from several hundred meters to full water column depth, supporting the presence of vertically coherent eddy structures in the region.

The westward intensification of HEV reflects a transition between two dynamical regimes separated by the MAR: an eastern region more influenced by local stratification and horizontal gradients, and a western region characterised by deeper, more energetic eddies with a capacity to redistribute properties throughout a larger fraction of the water column.

Finally, the dominance of HEV has important implications for vertical exchanges in the region. Cyclonic eddies, through isopycnal upwelling, are likely to enhance the upward transport of colder, nutrient-rich waters, while anticyclones promote downwelling and subduction of surface waters. Given the deep vertical extent of HEV observed here, these processes are not confined to the upper ocean but may contribute to the ventilation and redistribution of properties down to at least 1500 dbar along the AzCCo."

The following text does not appear in the tracked-changes document but is present in the revised manuscript.

L393: “eddy’s” implies there is a single eddy being referenced?

It was a misspelling. Corrected.

L403-404: “demonstrate directions” what does this mean? Do you mean to say something about direction of propagation as implying an origin site?

Yes, we meant direction of translation. The text was corrected to: “In R3, the sampled trajectories indicate translation from the north and east, primarily in the cyclonic case.”