Response: Thank the reviewer for the time spent on our manuscripts. The comments and suggestions by the reviewer are of great helps for us to improve our manuscripts significantly. We have addressed all the comments one by one very carefully.

- Eddy census/analysis strongly depend on the criteria used to define/detect eddies: the method used and field used as well as the value of any threshold used.

Response： Thank you for your comments. We agree with your perspective. The fundamental issue in studying eddy activity lies in the proper definition of eddies and the achievement of automatic identification and tracking for mesoscale and submesoscale eddies. The detection method employed in this study is a vector geometry-based automatic eddy detection algorithm. Detailed description of this detection method can be found in the following reference, which we have now cited in the manuscript.（L160）

“Nencioli, F., Dong, C., Dickey, T., Washburn, L., & McWilliams, J. C. (2010). A vector geometry–based eddy detection algorithm and its application to a high-resolution numerical model product and high-frequency radar surface velocities in the Southern California Bight. Journal of atmospheric and oceanic technology, 27(3), 564-579.”

– The identification tool iused is not sufficiently descrived in the text, leaving ‘the fourth constraint’ a mystery.

Response： Thank you for your comments. We have redescribed the detection method (L173-180).

The constraints require the specification of two parameters: parameter a applies to the first, second, and fourth constraints, while parameter b corresponds to the third constraint. Parameter a defines the spatial range, expressed in number of grid points, over which the increase in the magnitude of v along the east-west axis and of u along the north-south axis is examined. It also specifies the closed contour around the eddy center along which changes in the direction of velocity vectors are evaluated. Parameter b determines the size of the region, also measured in grid points, that is used to identify the local velocity minimum (Nencioli et al., 2010). To ensure global applicability, the parameters are set to a=4 and b=3 based on empirical optimization.

– Are the differences observed using the two different balances larger than differences that would be obtained using the same balance but different eddy detection tool?

Response：Thank you for your comments. Different detection algorithms exhibit variations in eddy identification. For instance, You et al. (2022) show that the total number of eddies in the GOMEAD dataset is 8% lower than that in the META dataset. This study focuses on exploring the differences between cyclogeostrophically corrected altimetry data and original altimetry data in the statistical analysis of eddies.

– The inclusion of the centripetal acceleration (which has the same sign regardless of the orientation of the eddy rotation) induces an asymmetry between cyclones and anticyclones which is not present in the geostrophic balance. Can the authors explain some of the differences observed by this?

Response: Thank you for your thoughtful comments. For a more comprehensive theoretical discussion, please refer to the two earlier publications by the corresponding author (listed below). Here, we provide only a concise analysis on this point.

References：

1. Cao, Y., Dong, C., Qiu, Z., Bethel, B. J., Shi, H.; Lv, H., & Cheng, Y. Corrections of Mesoscale Eddies and Kuroshio Extension Surface Velocities Derived from Satellite Altimeters. Remote Sensing, 2023a, 15(1): 184.

2. Cao, Y., Dong, C., Stegner, A., Bethel, B. J., Li C., Dong J., Lü H., & Yang, J. Global Sea Surface Cyclogeostrophic Currents Derived from Satellite Altimetry Data. Journal of Geophysical Research: Oceans, 2023b, 128(1): e2022JC019357.

The classical geostrophic balance theory ignores the effect of centrifugal force on the real sea motion, which makes the flow field, especially true for curved flow in mesoscale ocean eddies, measured by the altimeter has certain errors under the assumption of geostrophic balance. The curvature effect of streamlines makes the geostrophic balance between the pressure gradient force and Coriolis force be corrected as the balance between pressure, Coriolis and centrifugal forces (Figure 1).

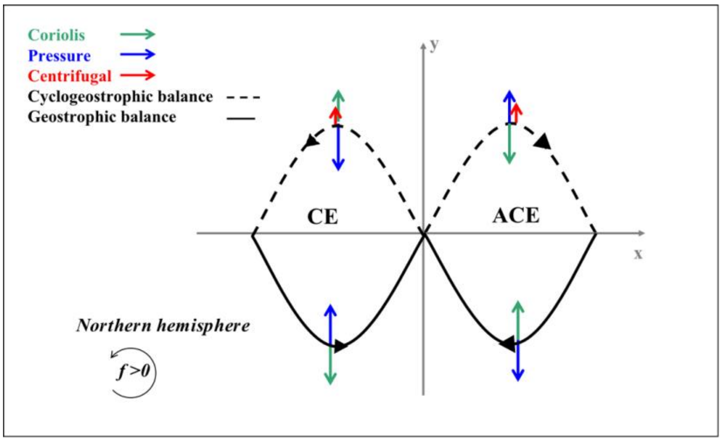

Figure 1. The force diagram of cyclonic eddy (CE) and anticyclonic eddy (ACE) under geostrophic and cyclogeostrophic conditions.

For surface currents, introducing geostrophic velocities, the cyclogeostrophic current equation in cartesian coordinates can be transformed as:

$$\begin{cases} u\dfrac{\partial u}{\partial x}+v\dfrac{\partial u}{\partial y}-fv=-g\dfrac{\partial \eta}{\partial x} \\ u\dfrac{\partial v}{\partial x}+v\dfrac{\partial v}{\partial y}+fu=-g\dfrac{\partial \eta}{\partial y} \end{cases} \Rightarrow \begin{cases} u\dfrac{\partial u}{\partial x}+v\dfrac{\partial u}{\partial y}-fv=-fv_g \\ u\dfrac{\partial v}{\partial x}+v\dfrac{\partial v}{\partial y}+fu=fu_g \end{cases} \tag{1}$$

where u_g and v_g are the geostrophic velocity anomalies of zonal and meridional currents, u and v are surface velocities of zonal and meridional currents, η and g are the sea surface height and gravitational acceleration parameter, respectively. In order to give the solution of the cyclogeostrophic velocity components to Eq.1 for mesoscale eddies and strong surface mean currents with different shapes, this study uses an iterative method. The method was applied to solve the momentum equation of ocean currents under cyclogeostrophic equilibrium conditions. This iterative scheme is given by

$$\vec{u}^{(n+1)} - \frac{\vec{k}}{f} \times \left(\vec{u}^{(n)} \cdot \nabla \vec{u}^{n} \right) = \vec{u}_g \quad (2)$$

where $\vec{k}$ is the vertical unit vector, $\vec{u}$ is the surface velocity vector, and $\vec{u}_g$ is the geostrophic velocity vector. The specific iterative method is as follows:

$$\begin{aligned}
&u^{n+1} = u_g - \frac{1}{f}(u^n \frac{\partial v^n}{\partial x} + v^n \frac{\partial v^n}{\partial y}) \\
&v^{n+1} = v_g + \frac{1}{f}(u^n \frac{\partial u^n}{\partial x} + v^n \frac{\partial u^n}{\partial y}) \\
&n = 0, \\
&u = u_g, \quad v = v_g \\
&n = 1, \\
&u^{(2)} = u_g - \frac{1}{f}(u_g \frac{\partial v_g}{\partial x} + v_g \frac{\partial v_g}{\partial y}) \\
&v^{(2)} = v_g + \frac{1}{f}(u_g \frac{\partial u_g}{\partial x} + v_g \frac{\partial u_g}{\partial y}) \\
&\ldots\ldots
\end{aligned} \quad (3)$$

- Section 3 organises the discussion by physical quantities and analyses there each region while the discussion (section 4) organises the discussion by region. This change is organisation somehow breraks the flow of reading. Is it necessary?

Response：Thank you for your comments. Section 3 lays a systematic and quantitative foundation by organizing results according to key physical quantities — such as EKE, radius, and amplitude — to first establish statistical differences between the GEO and CGEO datasets. This part addresses the “what,” namely the overarching effects introduced by the cyclogeostrophic correction. As is well known, the generation and dissipation mechanisms of eddies are highly complex. Section 4 focuses on the dynamical differences of individual eddies across five specific regions, examining their detailed evolution under varying conditions of background flow curvature and latitude (i.e., Coriolis parameter). To enhance the flow of the manuscript, we have rewritten this section and integrated the Results and Discussion sections.(L555-575)

- **Specif comments**

1)Throughout the paper ‘curvature effect’ is ambiguous and too vague. I suggest the authors use ‘centrifugal force’ or ‘centripetal acceleration’. Curvature effects could refer to the Earth’s curvature. i.e. the latitudinal variation of the Coriolis parameter.

Response：Thank you for your comments. First, the relationship between streamline curvature and centrifugal force is explained here. From a dynamical perspective, when an object moves relative to another at a variable velocity, curvature arises due to the warping of spacetime. In accordance with the principle of equivalence in general relativity, the properties of spacetime in a gravitational field depend on the distribution of mass. The distribution of mass causes spacetime to become inhomogeneous, leading to its curvature. When an object possesses mass (and thus velocity), it bends spacetime; the more massive the object, the greater the curvature of spacetime. The streamline curvature theorem states that in a fluid flow with curved streamlines, the pressure on the convex (outer) side of the curve is higher than on the concave (inner) side. This resulting pressure difference provides the centripetal force that acts on the fluid.

To clarify the terminology in the manuscript, we have replaced the ambiguous term "curvature effect" with the more precise expressions: "streamline curvature effect," "centrifugal force," and "cyclogeostrophic correction." (e.g., L659, 665, 644,691...)

2)L27: '... vorticity is more stable' vorticity is a quantity. It cannot be stable or unstable. An eddy can.

Response： Thank you for your comments. To enhance the flow of the manuscript,we have re-written the abstract. (L11-25)

3)L30: The statement 'translate faster' is more than surprising. I understand eddies can have slightly different characteristics if analysed using two different balances but the statement suggests they are not even at the same location... Surely the two analysis analyse the same SSA and the latter itself would give the location of eddies.

Response： Thank you for your valuable feedback. You are absolutely right that the phrasing "translate faster" is ambiguous. To enhance the flow of the manuscript, we have re-written the abstract.we have corrected the phrase "anticyclonic eddies translate faster" to "anticyclonic eddies exhibit more intense evolution under streamline curvature effects ".(L24-25)

4) L44: The authors mention the 3D structure of eddies, but only analyse SSA so do not have access to the 3D strucuture (unless they make further assumptions).

Response： Thank you for your suggestion. You are correct that the mention of the 3D structure was only conceptual, as the analysis is indeed based on SSA data. We have revised this section accordingly.(L35)

5) L46-49: It would be mnuch simpler (and clearer and shorter) to state that cyclones rotate in the same direction as the Earth and anticlyone in the opposite direction.

Response： Thank you for your valuable suggestion. We agree on the importance of clear and precise expression. We have carefully revised the relevant section to ensure the language is both concise and unambiguous, thereby improving the overall clarity of the manuscript.(L38-40)

"In each hemisphere of the Earth, cyclones rotate in the same direction as the planet's rotation (counterclockwise in the North, clockwise in the South), while anticyclones rotate in the opposite direction. "

6) L78: what is meant by 'significant periods'

Response： Thank you for your valuable comment. We acknowledge that the phrase "significant periods" could be ambiguous, as it might be misinterpreted in a strict statistical sense.To enhance the flow of the manuscript, we have rewritten this section.(L65-69)

The Hawaiian Islands region is recognized as an area of frequent eddy occurrence (Calil et al., 2008). Using available datasets of sea surface height, sea surface temperature, and surface wind stress, Yoshida et al. (2011) further investigated the interannual-to-decadal variability of eddies within the Hawaiian Lee Countercurrent (HLCC) band.

7) L89-90: the statement 'These biases... wind stress' must be further explained.

Response： Thank you for raising this important point. We agree that the statement regarding biases requires clarification. In the revised manuscript, we will expand the explanation to explicitly distinguish between the two types of biases mentioned. (L80-82)

These biases are distinct from the ageostrophic velocity components induced by surface wind stress, and it is mainly caused by the nonlinear term induced by the local curvature of the streamline.

8) L91-92: is somehow a trivial statement as cyclongeosptrophic balance is more accurate. Is it needed (at least in this form)?

Response: Thank you for this insightful comment. We have revised the sentence to eliminate the redundant phrasing, and now state more directly the essential role of the cyclogeostrophic balance in these regions. (L82)

9) L95-96: what is meant by 'theoretical'?

Response：Thank you for your question regarding the term "theoretical frameworks." We agree that this phrasing was ambiguous in the original manuscript.In the context of our introduction, "theoretical frameworks" specifically refers to the cyclogeostrophic balance theory. The intended meaning of the sentence is that while this theory has been successfully applied in several well-defined western boundary current regions (as cited), its practical implementation and validation in the more complex and variable flow environment of the North Pacific—the focus of our study—have not been extensively reported. This gap motivates our research. We have revised the text to clarify this point. (L87-88)

10) L120: velocity anoalies: these have not been defined. Why 'anomalies'? Also EKE is not an energy (only its voluem integral - including multiplying by density - is). It is an EKE density (assuming it is measured on a isopycnal and the density is ignored for simpicity)

Response：Thank you for raising these important methodological points. Please find our detailed responses and the corresponding revisions below.The relevant explanations have been added to the manuscript. (L132-137)

The eddy kinetic energy (EKE) is computed at each point in space and time as::

$$EKE=\frac{1}{2}\times\left[(u')^2+(v')^2\right] \quad (6)$$

where u' and v' are the surface velocity anomalies of zonal and meridional currents. The geostrophic eddy kinetic energy is obtained by the current components computed from the sea surface height anomalies (SSHA) of AVISO/DUCAS. For each component, the calculations are as follows:

$$u'=-\frac{g}{f}\left(\frac{\partial h'}{\partial y}\right) \quad (7)$$

$$v'=\frac{g}{f}\left(\frac{\partial h'}{\partial x}\right) \quad (8)$$

where h' is the SSHA. The cyclogeostrophic eddy kinetic energy is obtained by the cyclogeostrophic surface currents.

11) Equation (2) does not define a percentage (unless it is multiplied by 100).

Response：Thank you for your suggestion. We have corrected Equation (9) to properly represent the result as a percentage.

12) l 123-125: The authors can simplify by simply stating that the index i refers to quantities obtained through cyclogeostrophic balance and g by geostrophic balance.

Response：Thank you for your suggestion. We have noted your point. For consistency with the terminology established in our equations and the broader literature we are aligning with, we prefer to retain the original phrasing in the text. (L140-141)

13) l 127-128 Explain the statement 'Entrophy...' and how it 'account for dissipative effets'. This seems incorrect.

Response: Thank you for your comment. Enstrophy is closely linked to the dissipation of turbulent kinetic energy and represents a fundamental variable in turbulence theory. Regions of high enstrophy typically correspond to intense eddy activities, shear instabilities, or turbulent dissipation processes. In oceanographic and atmospheric dynamics, it is commonly employed to analyze the generation, evolution, interactions, and dissipation of eddies. We have re-defined this parameter. (L144-147)

Enstrophy is defined in fluid dynamics as half the square of the vorticity (Weiss, 1991). It serves as a key dynamical parameter that quantifies the local concentration of rotational intensity or eddy strength in the current. On each grid cell, the eddy enstrophy is given by:

$$ENS = \frac{1}{2}\left(\frac{\partial v'}{\partial x} - \frac{\partial u'}{\partial y}\right)^2 \qquad (10)$$

where the x- and y-axis represent the zonal and meridional lengths of the grid point.

14) L169: I assume the authors mean geostrophic velocities not satellite altimetry data (same l84 etc...).

Response： Thank you for your comment. You are right to point out the need for clarity regarding the geostrophic balance context. We have revised both sections to explicitly state this and improve overall readability. (L202-206, L214-218)

15) L75-176 'due to wind stress and current shear': what is the link with cyclogeostrophic balance?

Response: Thank you for your comment. wind stress curl and shear create background flow curvature, which amplifies geostrophic balance error and thus affects the cyclogeostrophic correction magnitude. We have clarified this in the text.(L211-212)

which enhance flow curvature and velocity gradients, the limitation of the geostrophic balance becomes more pronounced. Consequently,

16) L330-333: There are many mechanisms which can lead to the destruction of an eddy: instability, interaction with nathymetry, coast, other eddies and currents. Why is (turbulent) dissipation the only mechanism singled out?

Response：Thank you for this insightful and absolutely correct comment. We agree that singling out turbulent dissipation as the sole mechanism was an oversimplification. As you rightly point out, eddy destruction involves multiple processes.In the revised manuscript, we have modified the sentence (Lines 328-329) to reflect this complexity.

17) Fig 8 and text: explain how the age is normalised

Response：Thank you for your comment regarding the normalization of eddy age. The eddy age in Figure 8 (and related analysis) is normalized. Specifically, we normalize the surface eddies that have a lifespan longer than 7 days,the X-axis is divided by the lifespan of each individual eddy, while the Y-axis variables are normalized by dividing each variable by its corresponding maximum value throughout the entire lifespan process, the entire lifespan of each individual eddy is normalized to 1. Each life stage is then defined based on intervals of this normalized age: generation (~0-0.1), intensification (~0.1-0.3), maturation (~0.3-0.8), and decay (>0.8). This method allows for the compositing and comparison of eddy properties across eddies with different absolute lifespans.We have added the requested explanation to the manuscript text (and/or figure caption) as suggested. (Lines 363-369，Lines 412-413)

We normalize the surface eddies that have a lifespan longer than 7 days. The X-axis is divided by the lifespan of each individual eddy, while the

Y-axis variables are normalized by dividing each variable by its corresponding maximum value throughout the entire lifespan process. Each life stage is defined by normalized age: generation (~0-0.1), intensification (~0.1-0.3), maturation (~0.3-0.8), and decay (>0.8).

18) l 537: include ‘local’ before ‘rotation’ otherwise the statement is incorrect. Does the eddy description that follows agree with the criteria used to detect eddies (I don’t think so). Moreover, it is questionable. For example. one would most likely to identify eddies using potential vorticity, not (the vertical component of) the (relative) vorticity.

Response: Thank you for your valuable comment. We have re-written this part. (L512-516)

For understanding vorticity, we referred to the following books.

Batchelor, G. K.: An introduction to fluid dynamics, Cambridge Univ. Press, https://doi.org/10.1017/CBO9780511800955, 2000.

Minor points

l 11: ‘among’ → between

Response: Thank you for your comment.To enhance the flow of the manuscript, we have rewritten this section.(L11-13)

l 12: ‘induced owing to’ → ’induced by’

Response: Thank you for your comment.We have corrected “induced owing to” to “ induced by”. (L14)

l 15: remove ‘their’ before ‘cyclogeostrophic’

Response: Thank you for your valuable comment. To enhance the flow of the manuscript, we have re-written the abstract.

l 19: ‘cyclogeostrophic correction’ → ‘cyclogeostrophic balance’ (as cyclogeostrophic includes both the ‘correction (centripetal acceleration) and the leading order geostrophic balance)

Response： Thank you for your comment.To enhance the flow of the manuscript, we have re-written the abstract and corrected “cyclogeostrophic correction” to “ cyclogeostrophic balance”. (L20)

l 24: ‘exhibiting opposite biases’ is too vague to be informative

Response：Thank you for your valuable comment. To enhance the flow of the manuscript, we have re-written the abstract.

l 44: ‘evolutionary behavior’ → ‘evolution’

Response：Thank you for your comment.We have corrected “evolutionary behavior” to “ evolution”. (L35)

l 58-59: ‘a region of highly active mesoscale eddy activity’ deos not read well (and acticity is unexplained/undefined - same l 70)

Response：Thank you for your comment. We have removed the phrase "a region of highly active mesoscale eddy activity" and revised both sections accordingly. (L48 and L59-60) a region of highly active mesoscale eddies.

l 84: remove ‘assumption’

Response：Thank you for your valuable comment. To enhance the flow of the manuscript, we have rewritten this section. (L74-76)

The application of satellite altimetry data (e.g., AVISO/CMEMS) under the geostrophic (GEO) balance has enabled considerable progress in identifying and tracking eddies, as well as analyzing their dynamical characteristics.

l 86: ‘classical’ is unnecessary

Response：Thank you for your comment. As suggested, we have removed the word "classical" in the manuscript. (L77)

Eq (5) Ro is undefined. Is f constant or measured locally?

Response： Thank you for your comment. We have added the necessary definitions directly after Eq. (5): Ro is rossby number，and f is defined as the local Coriolis parameter, calculated at the relevant latitude. (L155-156)

The eddy Rossby number, which is related to the maximum eddy radius (R_{max}) and velocity (V_{max}), is calculated by:

$$Ro = \frac{V_{\max}}{fR_{\max}}, \tag{13}$$

l 190: ‘pronounced’ → ‘larger’

Response: Thank you for your comment.We have corrected “pronounced” to “ larger”. (L218)

l 191: remove ‘percentage’ (unnecessary)

Response: Thank you for your comment. As suggested, we have removed the word "percentage" in the manuscript. (L219)

l 198: ‘ pronounced divergence’ → ‘larger difference’ (divergence should be reserved for the mathematical oerator in an oceanogrphic paper)

Response: Thank you for your comment.To enhance the flow of the manuscript, we have rewritten this section.

l 224: ‘evolutionary pattern’ → ‘evolution’

Response: Thank you for your comment. We have corrected “ evolutionary pattern ” to “ evolution”. (L248)

l 237: What is the ‘mature phase’. ‘close’ → ‘close to each other’

Response： Thank you for your comment.To enhance the flow of the manuscript, we have rewritten this section.(L250-254)

In the SCS region (Fig. 2a), the normalized cyclogeostrophic EKE of cyclonic eddies consistently exceeds the geostrophic EKE throughout their entire lifecycle, with opposing trends in growth and decay rates across different phases. For anticyclonic eddies, the variation in cyclogeostrophic EKE is smaller, and dissipation occurs more slowly during the decay phase.

l 238: ‘decline’ → decrease

Response：Thank you for your comment.Thank you for your comment.To enhance the flow of the manuscript, we have rewritten this section.(L250-254)

l 241: ‘lower than’ → less than

Response：Thank you for your comment.Thank you for your comment.To enhance the flow of the manuscript, we have rewritten this section.(L250-254)