Response to reviewer RC3

We would like to thank the Editor and the reviewer for their careful reading of the manuscript and for their constructive comments. We believe that their suggestions have significantly improved the quality and clarity of the paper.

In the following document, reviewer comments are reproduced in black and our responses are given in blue. For transparency, each substantive modification is accompanied by a screenshot of the revised manuscript with track changes enabled. Additions and modifications are highlighted in red, whereas removed text appears as strikethrough text.

Dear Editor,

Thank you for inviting me to review this manuscript. This paper presents a new global mesoscale eddy network atlas, META4.0. Its main innovation lies in explicitly identifying eddy merging and splitting events on the basis of conventional single-trajectory eddy tracking, and in organizing related eddy trajectories into interconnected network structures. The authors present diagnostic tools for eddy networks, global statistical results, the spatiotemporal distribution of merging/splitting events, changes in eddy properties, qualitative validation with external data, and particle-advection-based coherence analysis.

Overall, this dataset has potential application value. However, the current manuscript still has several issues related to methodological definitions, parameter selection, independent validation, reproducibility information, and the interpretation of some figures and tables. In particular, the abstract is inconsistent with the validation presented in the main text; the definition of normalized overlap used for trajectory tracking is insufficiently clear; the 10% overlap threshold and the five clustering categories lack adequate objective justification; the external CHL validation is closer to a qualitative consistency check based on a small number of typical cases than to a truly independent validation of eddy boundaries; and some figures and case descriptions do not provide sufficient information for reproducibility and deeper interpretation.

For these reasons, I recommend that the manuscript undergo major revision before publication.

Major comments

1. The statements in the abstract regarding independent validation using SST and CHL are inconsistent with the main text

The abstract states that the study uses independent datasets, including sea surface temperature and chlorophyll concentration, to qualitatively validate selected events. However, in Section 3.3.5 of the main text, the external validation that is actually presented and discussed uses only CHL data, with no validation procedure or conclusions based on SST.

This creates an inconsistency between the abstract and the main text. I suggest that the authors either add validation results for typical merging/splitting events using SST data, including the data source, processing procedure, diagnostic criteria, and corresponding figures, or revise the abstract and related conclusions to avoid claiming that SST was used for qualitative validation.

This comment raises the same issue as Comment 1 of Reviewer RC2. Our response is therefore identical and is reproduced below for completeness.

We thank the reviewer for pointing out this inconsistency.

The manuscript has been revised to ensure consistency between the abstract and the validation section:

reveal recurrent interaction patterns and identify regions where eddy networks are particularly active. ~~Independent datasets, including sea surface temperature and chlorophyll concentration, are used~~ An independent dataset of surface chlorophyll concentration is used for qualitative validation of selected events. Finally, Lagrangian advection of synthetic particles highlights

2. Justify the use of 1/4° ADT data and discuss resolution sensitivity

This study uses global daily ADT data from the DT2021 reprocessing product at a spatial resolution of 1/4°. However, higher-resolution global L4 reprocessed products for sea level and derived variables are now available, such as the 1/8° × 1/8° product provided by Copernicus Marine. In addition, when discussing the spatial distribution of lonely eddies, the authors also note that some regions with a high occurrence of isolated eddies may be related to limitations in altimetric resolution.

Therefore, I suggest that the authors further justify why the 1/4° product is still used as the primary input dataset. Considering the large workload required to recompute a 30-year global atlas, the authors do not necessarily need to reconstruct the entire dataset. However, it would be useful to add a resolution-sensitivity experiment for representative regions or representative years. For example, several cases could be selected from western boundary current regions, the Southern Ocean, coastal regions, or equatorial regions, and the results obtained from the 1/4° and 1/8° products could be compared in terms of the number of detected eddies, the number of lonely eddies, the number of networks, the number of segments, and the number of merging/splitting events.

This comment raises the same issue as Comment 4 of Reviewer RC2. Our response is therefore identical and is reproduced below for completeness.

We thank the reviewer for this important comment. Performing such a comparison is beyond the scope of the present data paper which aims to present the META4.0 dataset, but this limitation is now discussed in the manuscript by expanding the discussion regarding the limitations imposed by the effective resolution of altimetric products. We now explicitly acknowledge that some small-scale interactions may remain unresolved and that higher-resolution future products may improve the representation of such events.

Moreover, as mentioned in the revised manuscript, we are currently working on a new version of META based on the DUACS DT2024 1/8° products. We believe that this forthcoming dataset will provide a more appropriate framework for assessing the sensitivity of network properties and interaction statistics to the resolution of the underlying altimetric fields.

(MDT), and would therefore be partially masked in SLA fields. The ADT fields used here are the global daily products from the DT2021 reprocessing (Faugère et al. (2022)), with a 1/4° grid resolution and corresponding to the all-satellite (all-sat) configuration.. The effective resolution of the altimetric product influences the detection of eddies and their interactions, with smaller and shorter-lived features being more difficult to resolve and therefore potentially underrepresented in the resulting networks. Consequently, some merging and splitting events involving small-scale structures may not be fully captured. The present atlas is based on the DT2021 1/4° reprocessing in order to ensure consistency with the META3.2 atlas and to perform comparisons of the tracking methodology (see Section 3.2.2). A new version based on the DT2024 reprocessing at 1/8° resolution is currently under development and is expected to improve the representation of smaller-scale eddies and their interactions.

3. The area-overlap-based tracking method relies on a subjective threshold

The network grouping in this study mainly relies on the overlap between eddy polygons at adjacent time steps, with 10% set as the connection threshold. This threshold directly affects whether eddies are connected into the same network, and thus influences the number of networks, the number of segments, the number of merging/splitting events, and the resulting eddy lifetime statistics.

At present, the manuscript does not explain the rationale for choosing the 10% threshold, nor does it demonstrate the stability of the results under different threshold values. I suggest adding a threshold-sensitivity experiment.

In addition, I suggest that the authors compare the geometric-overlap tracking method used in this study with existing Lagrangian eddy tracking methods in the Discussion. The discussion could address the practicality of a geometric overlap threshold for constructing long-term global eddy networks, as well as its advantages and limitations relative to particle-advection methods in terms of physical constraints, computational cost, and parameter sensitivity. Relevant studies include Jones-Kellett A. E. and Follows M. J., "A Lagrangian coherent eddy atlas for biogeochemical applications in the North Pacific Subtropical Gyre," Earth System Science Data, 2024, 16(3): 1475–1501; and Tian F., Zhao Y., Qin L., et al., "A Black Hole Eddy dataset of North Pacific Ocean based on satellite altimetry," Earth System Science Data, 2025, 17(12): 7119–7145.

This comment raises the same issue as Comment 2 and Comment 5 of Reviewer RC2. Our response is therefore almost identical and is reproduced below for completeness.

We thank the reviewer for this comment. We agree that the methodological description was not sufficiently detailed in the original version. The revised manuscript now provides additional explanations regarding the choice of the 10% overlap threshold and the 7-day search window, and a clearer description of the network construction procedure.

> To account for occasional missing detections, resulting from mapping limitations or temporary detection failures, the search is extended up to seven days forward~~, provided that eddies remain geographically consistent~~. This allows eddies belonging to the same trajectory to be reconnected when intermediate detections are missing. No constraint is imposed on radius or ampli-

> tude variations, allowing the detection of rapid size changes associated with merging or splitting. These tracking parameters were selected empirically based on extensive expert evaluation of trajectory continuity and network consistency. They build upon the methodology developed for previous versions of the META atlas Pegliasco et al. (2022), while being adjusted to improve the identification of merging and splitting events in the network framework. In particular, the temporal search window was extended from 5 days in META3.2 to 7 days in META4.0. Indeed, merging and splitting events are often associated with deformations of the eddy contours and rapid changes in their properties (see Section 3.3.3), which can increase the occurrence of temporary detection gaps. A longer temporal window therefore improves the reconnection of eddies belonging to the same network while remaining short enough to limit spurious associations. In should be added that the complete workflow is implemented in the open-source `pyeddytracker` library, which allows users to modify the tracking parameters and generate customized eddy trajectories, networks, and associated statistics according to their specific applications.

We also added a short discussion comparing the present geometric-overlap framework with alternative approaches based on Lagrangian coherence, together with the references suggested by the reviewer.

However, the objective of the present manuscript is not to compare Eulerian and Lagrangian tracking methodologies, but rather to describe the construction and validation of the META4.0 network atlas.

> The coherence of eddy segments and their associated networks is assessed using Lagrangian particle advection experiments. Lagrangian approaches based on particle trajectories and Lagrangian coherent structures have been widely used to characterize
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> 25
>
> eddy transport and coherence properties (e.g. Abernathey and Haller (2018); Jones-Kellett and Follows (2024); Tian et al. (2025).
>
> Approaches based directly on Lagrangian coherent structures or particle trajectories characterize eddy coherence using explicitly Lagrangian criteria. In contrast, META4.0 relies on an Eulerian detection and tracking framework based on contour geometry and overlap criteria. The purpose of the particle-advection experiments presented here is therefore not to reproduce such Lagrangian tracking methodologies, but rather to assess whether the reconstructed network topology is consistent with the transport properties implied by the velocity field.

> It should be noted, however, that the velocity fields used for particle advection are derived from the same altimetric product as that employed for eddy detection. As a result, the coherence assessment is not fully independent of the detection methodology, unlike diagnostics based on external tracers such as chlorophyll or sea surface temperature. ~~Nevertheless, the particle-based analysis remains semi-independent, as it probes the Lagrangian behavior of the flow rather than the Eulerian properties of the eddy contours themselves.~~ Nevertheless, the particle-based analysis evaluates a different aspect of the dataset. While the detection and tracking procedures are based on Eulerian contour geometry, the advection experiments assess the Lagrangian transport properties implied by the same velocity field. The analysis therefore provides a consistency check of the reconstructed networks rather than an independent validation of the underlying eddy detections.

4. The definition of normalized overlap is insufficiently clear

The manuscript mentions normalized overlap around lines 125 and 135 and uses 10% as the network connection threshold, but it does not provide an explicit mathematical definition. It is therefore unclear how the overlap area is normalized. Different normalization schemes may substantially affect the identification of merging and splitting events.

I suggest that the authors provide a clear formula for normalized overlap before introducing this threshold, and explain how this definition affects the identification of the main eddy and secondary eddies in merging and splitting scenarios.

This comment raises the same issue as Comment 2 of Reviewer RC2. Our response is therefore identical and is reproduced below for completeness.

We thank the reviewer for this comment. We agree that the methodological description was not sufficiently detailed in the original version. The revised manuscript now explicitly provides the mathematical definition of the normalized overlap area.

The grouping step links daily detections into spatio-temporal networks based on their geometric overlap across consecutive days. Two eddies are connected if their ~~normalized overlap area~~ intersection-over-union (IoU) overlap score O exceeds 10% , as defined (Pegliasco et al., 2022):

$$O(eddy_{ref}, eddy_{study}) = \frac{\text{Area}(eddy_{ref} \cap eddy_{study})}{\text{Area}(eddy_{ref} \cup eddy_{study})}. \quad (1)$$

5. Table 1 lacks specific information needed to reproduce the representative network case

Section 3.1 introduces a representative anticyclonic network case and reports its number of observations, number of segments, number of merging/splitting events, lifetime, and longitude–latitude range. However, the manuscript does not provide the specific start and end dates of this case.

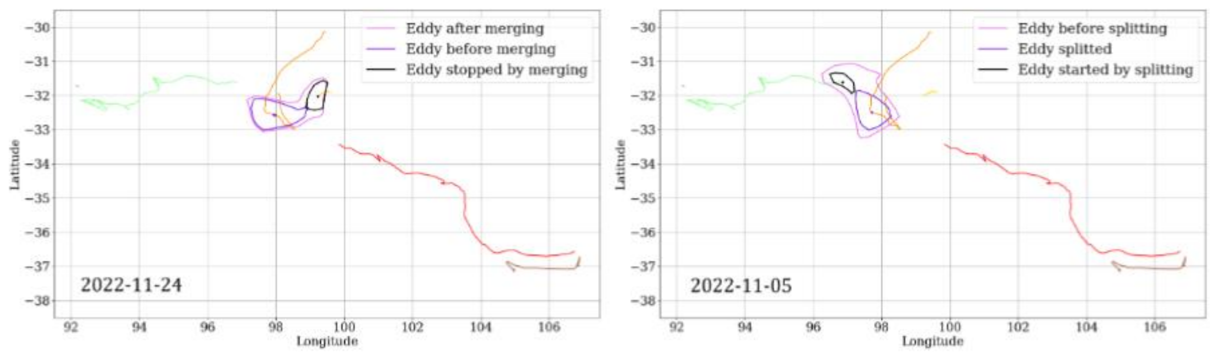
For a dataset paper, representative cases should be as reproducible as possible. I suggest that the authors add the start and end dates, as well as the specific data files corresponding to Figures 2–4. This would help readers verify the exploratory tools proposed by the authors.

We thank the reviewer for this suggestion. We agree that providing additional information on the representative network improves reproducibility. The covered period of the example network have been added to the manuscript as well as the date of the events show in Figure 3.

The chosen network characteristics are summarized in Table 1.

Characteristics	Number of observations	Number of segments	Number of merging events	Number of splitting events	Lifetime (days)	Longitude/latitude range	Time range
Values	601	6	3	2	445	(92.15°;106.90°) (-37.14°;-30.15°)	2022-05-06 to 2023-07-04

Table 1. Internal characteristics of the demo network.



(a) Segments' tracks and one example of merging event. (b) Segments' tracks and one example of splitting event.

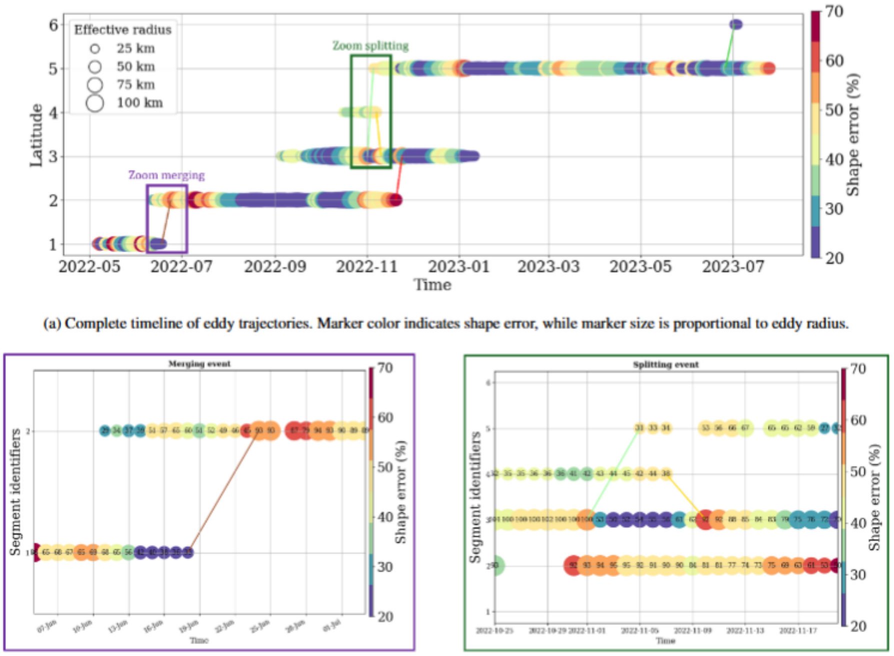
6. Add local zoom-in panels for key interaction nodes in Figure 4

Figure 4 shows the temporal evolution of effective radius and shape error within the network, using marker size and color to represent eddy properties. Based on this figure, the authors interpret phenomena such as an increase in radius after merging, an enlarged radius before splitting, and elevated shape error near interaction events.

However, the current figure contains relatively dense data points, and the local changes before and after key merging and splitting events are not sufficiently intuitive. I suggest adding local zoom-in panels to

Figure 4 to show the changes in eddy properties before and after typical merging and splitting events. This would provide more direct support for the interpretation that eddy interactions are accompanied by structural reorganization and morphological deformation.

We thank the reviewer for this suggestion. We added zoom-in panels as suggested.



(a) Complete timeline of eddy trajectories. Marker color indicates shape error, while marker size is proportional to eddy radius.

(b) Zoom on the merging event.

(c) Zoom on the splitting event.

Figure 4. Timeline representation of the selected network. (a) Complete network evolution. (b) Detailed view of the merging event between segments 1 and 2. (c) Detailed view of the splitting event occurring later in the network evolution. A merging event is also visible. Marker size is proportional to the effective radius (also indicated numerically in kilometers) and color indicates the shape error.

7. Report network characteristics separately for cyclonic and anticyclonic eddies in Table 2

The manuscript states that network construction is performed separately for anticyclonic and cyclonic eddies. However, Table 2 only provides overall statistics for the META4.0-Networks dataset.

Since the construction procedure is polarity-specific, I suggest that Table 2 report statistics separately for anticyclonic and cyclonic eddies. These should include the number of observations, networks, segments, merging events, splitting events, and lonely eddies for each polarity, as well as the mean segment lifetime and network lifetime. This would help readers assess whether the two eddy polarities exhibit systematic differences in network complexity and interaction frequency.

We thank the reviewer for this suggestion. Following the reviewer's recommendation, Table 2 now reports the main statistics separately for cyclonic and anticyclonic eddies, including the numbers of observations, networks, segments, merging and splitting events, lonely eddies, and lifetime-related diagnostics.

Properties	Number of observations	Number of networks	Number of segments	Number of merging events	Number of splitting events	Number of lonely eddies
AC	29,353,140	934,475	1,098,337	91,034	89,127	491,378
C	31,338,295	1,004,983	1,183,206	97,226	97,483	506,599
AC+C	60,691,435	1,939,458	2,281,543	188,260	186,610	997,977

Table 2. Global characteristics of the META4.0~~-Networks~~ dataset. AC: Anticyclonic eddies global atlas. C: cyclonic eddies global atlas. AC+C: META4.0~~-Networks~~ global atlas.

8. The reason why segment lifetimes in Figure 9a are longer than META3.2 single trajectories is insufficiently explained

The central improvement of this study is that the network formalism connects multiple segments before and after merging and splitting events, thereby reducing artificial births/deaths in traditional single-trajectory methods and extending the effective lifetime of eddy systems. This conclusion is clearly reflected in Figure 9b.

However, Figure 9a shows that the lifetime distribution of META4.0 network segments is also longer than that of META3.2 single trajectories. This result is not intuitive. I suggest that the authors further explain why the segment lifetimes in Figure 9a are longer.

We thank the reviewer for pointing out this aspect. Although the increase in network lifetime is expected because several segments may be connected through merging and splitting events, the increase in segment lifetime deserved additional clarification. A sentence has been added to complete the Figure 9 analysis.

> Although trajectories are divided into segments, segment lifetimes are slightly longer on average. The network framework better preserves continuity around interaction events and short detection gaps, notably through its 7-day search window.

9. The diagnostic criteria for CHL-based external validation in Section 3.3.5 are unclear

Section 3.3.5 uses CHL fields to qualitatively validate merging and splitting detections, and Figures 18 and 19 show ADT and CHL background fields. The authors argue that these examples indicate that the merging/splitting events detected from altimetry can also be observed in an independent field.

However, the manuscript does not currently explain how CHL is used to diagnose interaction events. The eddy contours shown on the ADT and CHL panels in Figures 18 and 19 appear to be identical, suggesting that these contours are likely still eddy boundaries detected from ADT and merely overlaid on the CHL background field. If this is the case, CHL does not independently identify the same eddy boundaries, but instead provides a tracer-background response that is consistent with the ADT-based detection results.

I suggest that the authors clearly state whether all eddy contours in the figures come from ADT/META4.0, whether CHL data participate in boundary identification, or whether CHL is used only as a background tracer field. The authors should also specify the concrete criteria by which CHL is considered to support the merging/splitting detections.

In addition, the information in the corresponding network timelines in Figures 18 and 19 is rather crowded. I suggest retaining only the segments involved in the current interaction to improve readability.

We thank the reviewer for this comment. We agree that the role of chlorophyll data was not sufficiently explicit in the original manuscript. The revised manuscript now clarifies that all eddy contours displayed in the figures originate from the altimetry-based META4.0 detection and are simply superimposed on chlorophyll fields. CHL does not participate in eddy contours identification but is used as an independent tracer field to assess whether the filamentary structures observed around detected merging and splitting events are consistent with the altimetric interpretation. Additional explanations on the scope and limitations of this validation approach have been added to the manuscript.

~~Finally, a qualitative validation of merging and splitting detections is provided using independent chlorophyll concentration (CHL) fields. The CLS CatSat chlorophyll product is used to cross-check the occurrence of interaction events. One representative example of each interaction type is shown.~~ Finally, the plausibility of some selected merging and splitting events is assessed using an independent chlorophyll concentration (CHL) product. The CLS CatSat chlorophyll fields (data courtesy of CLS) are not used to detect eddies or interaction events but provide an independent tracer field against which the altimetry eddy detections can be qualitatively compared.

These figures are not intended to provide an exhaustive validation of merging and splitting detections. However, they offer additional qualitative evidence that the interaction events reconstructed from altimetric observations are associated with identifiable tracer structures across multiple regions of the global ocean.

Minor comments

1. The two subpanels in Figure 10 are not fully aligned.
2. It is reasonable to use normalized radius and normalized shape error in Figures 13 and 14 to analyze life-cycle stages before and after interactions. However, the normalized results cannot directly reflect absolute scale changes between parent eddies and resulting eddies. I suggest that the authors add corresponding statistics and figures for absolute effective radius and absolute shape error to support the statement that "merging leads to larger structures and splitting to smaller ones."
3. In the multi-panel composites of Figures 18 and 19, some subpanels are slightly misaligned, and the overall layout is not sufficiently tidy.
4. In Figure 20, the colorbar labels in some subpanels are partially obscured or not fully displayed, and there are also alignment issues among different subpanels.
5. French labels appear in Figure 23b and should be unified into English.

We thank the reviewer for these suggestions. All minor comments have been addressed in the revised manuscript. This includes figure alignment improvements, harmonization of terminology and language, correction of formatting issues, replacement of French labels by English labels, and the addition of absolute-radius and absolute-shape-error diagnostics in Appendix B.

In summary, I consider the META4.0 eddy network dataset proposed in this manuscript to have scientific value and application potential. However, the current version still requires further improvement in several respects, including key methodological definitions, parameter selection, robustness of results, sufficiency of external validation, and reproducibility information for representative cases. Therefore, I recommend that the manuscript be considered for acceptance only after major revision. I hope the authors will further strengthen the transparency of the methodology, the robustness testing of parameters, and the experimental framework, thereby improving the reliability, reproducibility, and practical value of the dataset. Thank you again for inviting me to review this manuscript. I also hope that the comments above will be helpful for the authors in revising and improving the paper.

Sincerely,

Reviewer

Sincerely,

The authors