Response to reviewer RC2

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 giving me the opportunity to review the manuscript by Gamot et al., titled "META4.0: a new mesoscale eddy network atlas derived from altimetry" This study attempts to extend mesoscale eddy tracking from a single-trajectory representation within the existing META framework to an explicit network representation that includes merging and splitting events, and provides corresponding global statistical analyses and validation results. In terms of topic selection, the work has certain potential value, especially its focus on eddy interaction processes, which is meaningful for improving existing mesoscale eddy data products.

However, I believe the manuscript is not yet suitable for direct publication and requires major revision before further consideration. The main reasons are: the tracking method is highly subjective, particularly lacking sufficient explanation of parameter definitions, threshold bases, time window settings, and event determination logic; the interpretation of results somewhat exceeds the support of existing evidence, especially regarding the physical interpretation of merge/split events remains inadequate; the validation section is not yet adequate in terms of independence, statistical representativeness, or generality; furthermore, although the paper claims that the network method can reduce artificial breaks and extend eddy lifetimes, it has not sufficiently demonstrated that these extended connections are physically more realistic and reliable. For ESSD, the parameter robustness of data products and the validation framework should be more thoroughly supported, which is a weak point in the current version of this manuscript.

Overall, I suggest the authors systematically supplement and substantially revise the manuscript, focusing on parameter sensitivity, the objectivity of event identification, and the completeness of the validation framework. Until these core issues are adequately addressed, I do not recommend acceptance of the manuscript in its current form.

We thank the reviewer for the detailed and constructive comments. We agree that the first version of the manuscript lacked some methodological clarifications and that several aspects deserved further discussion. The manuscript has been substantially revised accordingly. All comments have been carefully considered and are addressed below.

Major Comments:

1. Inconsistency between Abstract and Validation Section

The abstract states that independent datasets, including sea surface temperature (SST) and chlorophyll concentration (CHL), were used for qualitative validation of selected events, implying that both SST and CHL are part of the external validation framework. However, in Section 3.3.5, the manuscript only presents validation based solely on chlorophyll concentration (CHL), including one representative merging event and one representative splitting event. I could not find corresponding SST validation content in the current manuscript. Additionally, the geographic context of the selected validation cases is not clearly described. This inconsistency should be corrected. The authors should: (1) Add SST validation consistent with the abstract; or (2) revise the abstract and related statements to align with the actual content of the main text. It is recommended that the manuscript clearly specify where these validation cases are located and explain why these regions were chosen, which would further enhance the paper's persuasiveness.

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. Unclear Parameter Definitions and Subjective Selection; Suggest Adding Parameter Basis and Sensitivity Tests

The authors propose that two eddies are considered connected if their normalized overlap area exceeds 10%, and they allow the search window to be extended forward by 7 days under the premise that the eddy remains "geographically consistent." This part is not clearly described. The manuscript does not explicitly define the mathematical expression of normalized overlap area, nor clearly explain the specific criteria for "geographically consistent." Moreover, the basis for choosing the 10% overlap threshold and the 7-day time window is insufficient. It is recommended to evaluate the impact of these parameter settings on event identification results through sensitivity tests. Therefore, the authors should supplement clearer methodological descriptions, including:

- The mathematical expression of normalized overlap area;

- The specific meaning and criteria of "geographically consistent";

- The rationale for selecting a 10% overlap threshold and a 7-day window.

It is suggested to add parameter sensitivity analyses, for example, comparing overlap thresholds of 5%, 10%, and 15%, and time windows of 3, 5, and 7 days, to assess their effects on event counts, lifetime distributions, proportions of long-lived networks, and spatial distributions of merge/split events. Currently, the robustness of conclusions against parameter variations is not sufficiently demonstrated.

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

- modification of the part using “geographically consistent” terms;

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-

- additional explanations regarding the choice of the 10% overlap threshold and the 7-day search window.

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.

These additions were intended to improve both the transparency and reproducibility of the method.

3. The Parameters Defining Tracking and Merge/Split Events Are Highly Subjective

The network grouping adopts a relatively loose design: analysis is limited to same-polarity eddies; a connection is established when the normalized overlap area exceeds 10%, an overlap-based association approach previously reflected in Liang Sun et al. (2016, GEM: a dynamic tracking model for Mesoscale Eddies in the ocean); the search can be extended forward up to 7 days; and no constraints imposed on radius or amplitude changes. In the segmentation stage, successors and predecessors are mainly selected based on maximum polygon overlap, while merge/split events are topologically defined from these connections. From a data product perspective, this design is understandable, but event identification mainly relies on geometric continuity rather than stronger dynamical or material coherence constraints, and the criteria remain largely empirical. This is important because a pair of overlapping contours alone does not necessarily prove a physically meaningful merge or split event. The particle advection analysis provided later is helpful but is conducted after the network has been constructed to assess coherence. As the authors themselves admit, the particle advection uses the same altimetry product as the eddy detection, so this validation is not fully independent of the detection method; furthermore, topological continuity based on contours and material coherence are related but not equivalent. Therefore, I suggest that the authors:

- More explicitly discuss these limitations more explicitly and appropriately moderate the term “physical validation” where necessary.

- More directly compare this framework with tracking methods based on particle advection or other Lagrangian criteria that have stronger objectivity.

- At a minimum, clarify precisely what exactly the current coherence experiments validate and what they do not. In addition, recent studies have explored more objective particle advection-based tracking strategies, such as Alexandra E. Jones-Kellett et al. (2024, A Lagrangian Coherent Eddy Atlas for Biogeochemical Applications in the North Pacific Subtropical Gyre), Tian et al. (2025, A

Black Hole Eddy Dataset of North Pacific Ocean based on satellite altimetry), and Tian et al. (2022, SLA-Based Orthogonal Parallel Detection of Global Rotationally Coherent Lagrangian Vortices). The authors are encouraged to refer to these papers and the more objective tracking methods they mention.

We thank the reviewer for this suggestion and for pointing out these recent studies. The objective of the present manuscript is not to compare the Eulerian and Lagrangian methodologies, but rather to describe the construction and validation of the META4.0 network atlas, which extends the existing META framework. A comprehensive comparison between geometric-overlap and Lagrangian approaches would require dedicated analyses and evaluation metrics beyond the scope of this data description paper.

However, to address the reviewer's concern, we now explicitly state that the particle-advection experiments should not be interpreted as a fully independent validation of the detection framework, since they rely on the same altimetric product. Their purpose is instead to assess whether the detected networks are associated with enhanced Lagrangian coherence and transport continuity. We also acknowledge the relevance of alternative tracking approaches based on Lagrangian coherence and added the corresponding references suggested by the reviewer.

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

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 Choice of Resolution for Analyzing Merge and Split Events Deserves Further Discussion

The manuscript uses the DT2021 global daily ADT field with a spatial resolution of 1/4°, explicitly choosing to retain the full, unfiltered ADT signal. This choice is reasonable and clearly documented.

However, merge and split events are highly sensitive to small-scale deformations and transient structural changes. Since the paper emphasizes interaction processes rather than just long-lived trajectories, I believe the manuscript should more fully discuss whether the current spatial resolution is sufficient to robustly identify these events, especially in energetic western boundary currents and coastal regions. The authors are advised to:

- Evaluate whether utilizing higher-resolution full-satellite products (e.g., SEALEVEL_GLO_PHY_L4_MY_008_047) affects the inferred statistics of merge and split events. Even if such experiments are beyond the scope of this paper, the manuscript should more clearly explain how the effective resolution of the dataset affects the detection of interaction events and whether certain event types might be under-resolved or over-fragmented.

We thank the reviewer for this remark. Performing such a comparison is beyond the scope of the present data paper, 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.

> (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.

5. The paper demonstrates that the Network Method "Extends Lifetimes" but Has Not Fully Proven That the "Extended Lifetimes Are More Realistic"

The manuscript clearly shows in comparison with META3.2, that the network-based approach reduces the number of birth/death events, indicating that the new method technically reduces "artificial breaks" within the single-trajectory framework, which is an important contribution. However, the current issue is that while the paper sufficiently demonstrates that the network method reduces trajectory fragmentation and extends lifetimes, it has not adequately proven that these additional connections correspond to more realistic physical evolution rather than simply resulting from looser connection rules. The authors should strengthen the argument in this part, possibly by checking the credibility of new connections using in situ observational data or other means.

We thank the reviewer for this important comment. We agree that extending trajectories alone does not demonstrate that the additional connections correspond to more realistic physical evolution. The objective of the validation analyses presented in the manuscript is therefore not simply to show that the network framework increases eddy lifetimes, but rather to evaluate whether the newly identified connections are consistent with complementary dynamical and observational evidence. Several diagnostics support the physical relevance of the reconstructed connections. In particular, the spatial distribution of interaction events is concentrated in dynamically energetic regions where eddy interactions are expected to occur, while Lagrangian particle-advection experiments show that many detected interactions are associated with coherent transport patterns and exhibit the expected asymmetry between forward and backward coherence. We acknowledge that these analyses do not provide direct proof that every additional connection corresponds to a physical interaction. That is why we added comparisons with independent chlorophyll concentration field. However, we agree that this validation is qualitative and focuses on a few number of cases. Future work will therefore focus on developing quantitative validation strategies for merging and splitting events using independent observations, including biogeochemical tracers and in situ measurements. We have added a corresponding perspective in the conclusion of the manuscript.

> Particular attention will be devoted to the development of quantitative validation approaches for merging and splitting events based on independent observations, including biogeochemical tracers and in situ measurements. Such analyses will help constrain the physical realism of reconstructed eddy interactions and further improve the characterization of mesoscale connectivity.

6. Adding More Regionally Diverse Event-Level Cases Would Help Strengthen the Paper's Persuasiveness The manuscript includes a demo network in Section 3.1 and one representative merge case and one representative split case in Section 3.3.5. While these examples are helpful, but for a paper focused on eddy networks and event identification, the event-level presentation still lacks regional diversity. Global distribution maps are useful but cannot fully replace detailed regional cases. The authors are encouraged to:

- Add at least 2 to 3 representative cases from dynamically distinct regions, such as western boundary current areas. This would help readers assess the method's applicability under different eddy dynamic environments and make the paper more convincing at the "network event" level.

We thank the reviewer for this suggestion.

Additional examples from distinct dynamical regions (i.e., Aghulas and Gulf Stream regions) have been added to the manuscript in Appendix A.

> To illustrate the applicability of the approach in different dynamical environments, Appendix A presents two additional pairs of examples (one merging event and one splitting event in each region) extracted from the Agulhas and the Gulf Stream areas.

> **Appendix A: Additional chlorophyll-based qualitative validation examples**
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> To complement the examples presented in Section 3.3.5, additional merging and splitting events are shown in two other dynamically active regions: the Agulhas and the Gulf Stream zones. As in the main text, ADT-derived eddy contours are superimposed on surface chlorophyll concentration fields.
>
> Figure A1 and Figure A2 present one merging event and one splitting event observed in the Agulhas region. Figure A3 and Figure A4 show equivalent examples in the Gulf Stream system. In all cases, the chlorophyll fields exhibit coherent structures whose evolution is qualitatively consistent with the interaction events inferred from the altimetric network.
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> 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.

7. CHL Validation Is a Valuable Supplement but Currently Mainly at the Case Study Level; Suggest Further Adding More General Statistical Validation

The authors use CHL data to show one merge case and one split case, which is valuable as it provides independent visual evidence beyond altimetry-based geometric identification. However, the validation remains mainly at the case study level, with evidence strength closer to illustrative examples rather than quantitative global-scale validation. Two cases are insufficient to support judgments on 30 years of global merge/split identification or to demonstrate that these events have similar reliability across different ocean regions, dynamic environments, and seasons. Therefore, the authors should further generalize the existing cases into more universal statistical results. Therefore, the authors are encouraged to:

- Randomly sample a certain number of merge/split events in several typical regions and statistically assess the proportion that show corresponding structures in CHL or SST;
- Providing recognition rates by region, eddy type, and event type.

We thank the reviewer for these valuable suggestions. We agree that this section relied mainly on one illustrative example. To strengthen this aspect, an appendix has been added including two additional case studies from dynamically distinct regions, namely the Gulf Stream and the Agulhas Current systems. Moreover, the manuscript now clarifies that the CHL and SST examples should be regarded as independent illustrations of the detected events rather than as a quantitative global validation framework. As also indicated in the revised conclusion, work is currently in progress to develop such a framework based on independent observations.

We note, however, that designing a quantitative validation methodology for merging and splitting events on chlorophyll or sea surface temperature fields is not straightforward. The detection or particle-advection tools used in pyeddytracker are not directly applicable to tracer fields such as SST or CHL, because satellite SST and CHL are intrinsically filamentary tracers and frequently affected by data gaps caused by clouds, and merging and splitting events generally occur over periods ranging from several days to several weeks rather than at a single instant. As a consequence, appropriate metrics and global quantitative validation procedures still need to be developed. We therefore consider this effort as a dedicated study and have added this perspective to the manuscript.

Minor Comments.

- Section 3.4 uses clustering to propose eddy network type classification. I think the internal presentation logic of this section can be improved. Since Figures 21 and 22 summarize the average properties and distributions defining these clusters, it might be clearer to present and discuss Figures 21 and 22 first, then show Figure 20 (which gives the spatial distribution of the final categories).
- Figure 4: It is recommended to use a continuous colorbar to better show the variation pattern of shape error. There are still several issues related to grammar, clarity of expression, redundant wording, and terminology consistency throughout the manuscript. The authors are advised to carefully proofread the entire text and further improve language clarity. Some specific suggestions:
- Page 3: The product name is not consistent throughout the manuscript. The text alternates between "META4.0," "META4.0-Networks," "META4.0 network dataset," and "META4.0 networks." It is recommended to unify the product name throughout the manuscript, and if necessary, introduce an abbreviation only at first occurrence.
- Line 143: "...https://py-eddy-tracker.readthedocs.io/en/latest/python_module/..." contains formatting errors.

- Line 148: In the sentence describing the network schematic, the phrase “splits and give birth” contains a grammatical error. It should be corrected to “splits and gives birth.”

- Line 148: The term “observations” is ambiguous and should be further clarified in the methods and figure captions. Near Line 148, the authors write “The first segment is composed of four observations represented by the dots.” The meaning of “observations” is unclear. For readers unfamiliar with the data structure, do these dots represent: (1) Eddy centroid positions; (2) Feature points extracted from contours; (3) Or some kind of seed points/representative points? Since the figure uses dots to represent observations within a segment, the correspondence between the contour structure and the dots is not explained, which may cause confusion. If the dots are only for visualizing temporal order within the segment, it is recommended to state this explicitly in the Figure 1 caption to avoid readers mistaking them for seed points or other internal algorithm nodes.

- Lines 203-204: The shape error definition has already been given earlier and does not need to be repeated here.

- Line 205: Shape error and ellipticity seem to be conflated here. The authors should clarify whether these are equivalent and unify terminology throughout the manuscript.

- Line 383: The phrase “Performing particle advection both forward and backward in time allows to characterize the directionality of coherence…” is grammatically incorrect. It should be revised to “allows characterization of.” In summary, I believe this manuscript presents a promising and potentially valuable dataset, but it would be improved by a more rigorous validation framework, a more objective tracking method, and more regionally representative event-level evidence. I hope these comments will help the authors revise and improve the manuscript.

We thank the reviewer for these suggestions. All minors comment have been taken into consideration in the revised manuscript.

Sincerely,

The authors