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<Manuscript Title> Integrated Observation of an Asymmetric Eddy Dipole in the South China Sea

Dear Editors and Reviewers,

We highly appreciate the detailed and valuable comments of the referees on our manuscript entitled "Integrated Observation of an Asymmetric Eddy Dipole in the South China Sea (MS No. essd-2025-276)". These comments are all valuable and helpful for revising and improving our paper, as well as providing important guidance for our research. In the past few days, we have referred to the comments and improved the paper.

As follows, we would like to clarify some of the points raised by the Associate Editor and Reviewers. The original comments begin with "**Questions and Comments**" and are quoted in normal font, the replies are in blue letters, the revised sentences and phrases are in red letters, and the line number in the revised manuscript is highlighted in yellow. We appreciate the Editors/Reviewers' warm work and taking the time to review the manuscript, and we hope that the corrections will meet with approval.

Yours Sincerely,

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2025-12-01

1. Questions and Comments: More observations on eddy dipoles and the results are very important for knowing their 3D structures and the couplings (or interactions) between them. In this paper, Argo, gliders, drifters, and research vessel were used to observe an eddy dipole which may be associated with Kuroshio intrusion in the South China Sea, the relevant data obtained in this cruise are presented, and a gear-like process associated with the dipole is suggested. However, the integrated observation scheme proposed in this paper is not very effective, at least, the argos, gliders and so on didn't provide very significant data, and accordingly it is not sure that "the gear-like process" is appropriate for the couplings for eddy dipole. Maybe there is no gearing effect between AE and CE.

Answer: Thanks for your comments. Our previous work revealed the "gear-like" process of asymmetric dipole based on global analyses. Its distinctive feature is that stronger dipole eddies generally drive weaker ones to move around, resulting in a reduction of discrepancies in their kinematic properties via eddy-eddy interaction, such as rotational speed, amplitude, and eddy kinetic energy. Therefore, this manuscript first confirmed the observed dipole eddies exhibit "gear-like" process during their first coupling process according to their kinematic properties and eddy shape derived from satellite altimetry data (Section 3 in this manuscript). Subsequently, we further analyzed their evolution of vertical structure from floats and survey vessel observations and found that the vertical structure of the asymmetric dipole eddies responses to their changes in surface feature.

2. Questions and Comments: "anomalies" presented in this paper are not the original data. How they are derived should be clarified. Why are there blank in Argo data (No. 897875) on 16-April? And, accordingly, will the anomalies in temperature and salinity be altered?

Answer: Thank you for pointing this out. The text regarding "anomalies" was added in Line 175-180 as "This work utilized the annual statistics of WOA23 dataset with a grid size of 1/4° to characterize the typical northern SCS water and Kuroshio water and calculate the T/S anomalies from the observations of Argo floats, gliders, and RBRmaestro3. The annual and observed T/S profiles were first resampled at the same depth through linear interpolation. The T/S anomalies were then obtained by subtracting annual T/S profiles from the observed T/S profiles." Therefore, the "blank" Argo data (No. 897875) does not influence the T/S anomalies. The Argo was artificially set to hover at about 120 m depth.

3. Questions and Comments: The RBRmaestro3 seems to provide more reliable data for the eddy dipole presented. The salinity anomaly in the transitional zone between AE and CE gives pronouncing signal of interaction between AE and CE, however, there is no adequate support for "gearing" process. The same is with the Chl-a.

Answer: Thanks for your comments. The "gear-like" process of asymmetric dipole was proposed based on the eddy surface feature. Therefore, this manuscript first confirmed the observed dipole eddies exhibit "gear-like" process during their first coupling process according to their kinematic properties and eddy shape derived from satellite altimetry data (Section 3 in this manuscript). The profiles from floats and survey vessel observations provide pronouncing signal of eddy-eddy interaction during the 10-day coupling process, especially the deeper contours of T/S profiles and dissolved O_2 saturation sections on 17 April responses to the increase in eddy kinematic properties on 16-17 April in Fig.3. This indicates the response between changes in surface feature of dipole eddies and changes in vertical structure via eddy-eddy interaction.

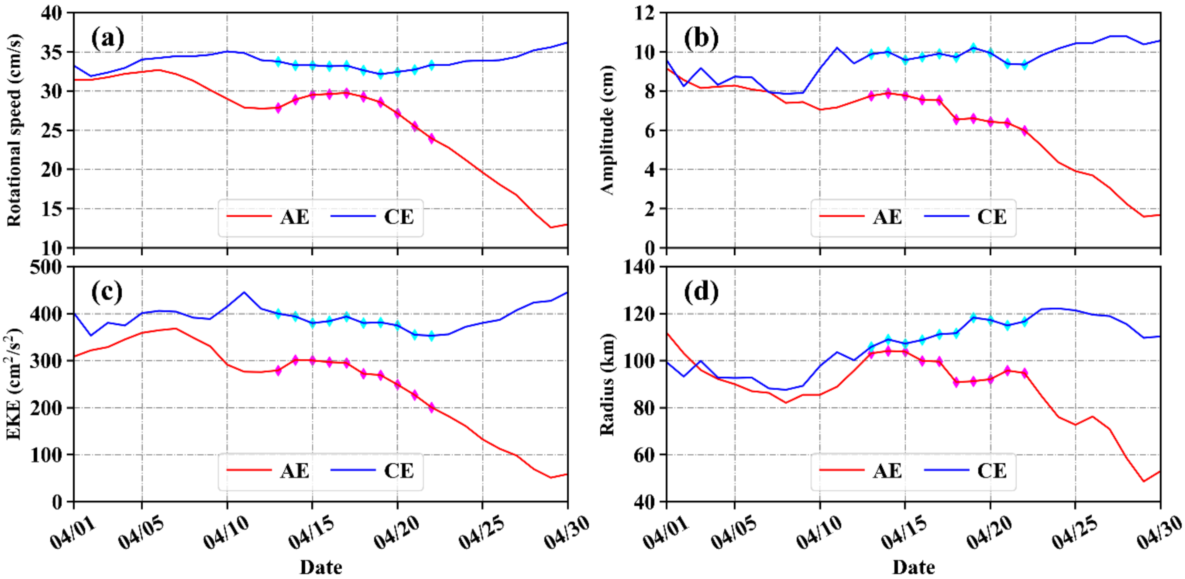

Figure 3: The temporal evolution of (a) rotational speed, (b) amplitude, (c) EKE, and (d) radius for the dipole AE and CE. The diamonds mark the continuous coupling process from 13 to 22 April.

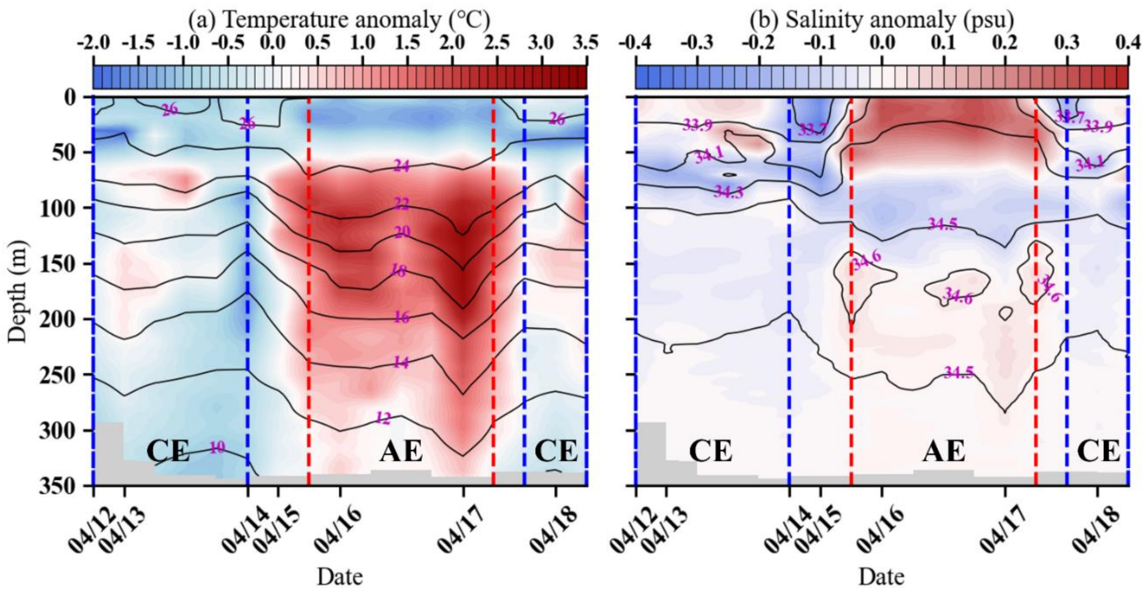

Figure10: (a) Temperature (black lines) and corresponding temperature anomaly (colored shadow), and (b) salinity (black lines) and corresponding salinity anomaly (colored shadow) crossing the dipole eddy centers. The profiles between two dashed blue (red) lines indicate stations are located within the CE (AE), and the profiles between a dashed red line and a dashed blue line indicate stations are located at the contact zone. The gray in each plot indicates missing values.

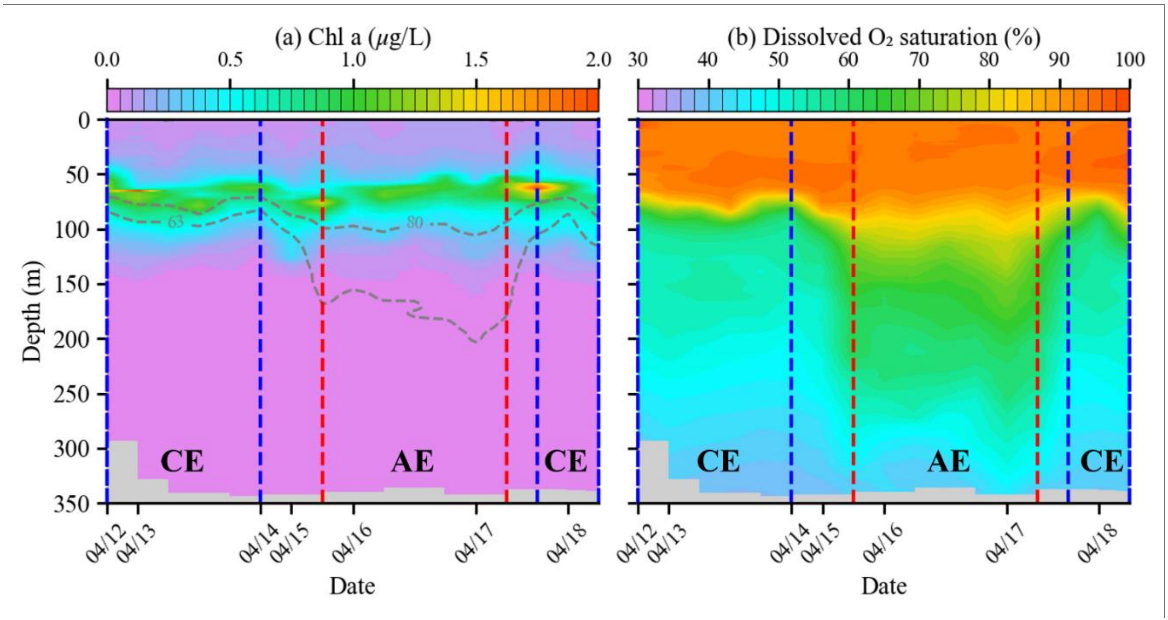

Figure11: (a) Chl *a* concentration and (b) dissolved O_2 saturation crossing the dipole eddy centers. The dashed gray lines in (a) are the dissolved oxygen (O_2) saturation. The dashed red and blue lines have the same meaning as Fig.8. The gray in each plot indicates missing values. It is noted that the 2.0 μg/L of the color bar is the value exceeding 2.0 μg/L.

4. Questions and Comments: Other indexes by microorganisms and zooplanktons as shown by Fig.12, give no signal of AE and CE. More observations from other cruises or from other published documents rather than a case, may be necessary.

Answer: Thanks for bringing this to our attention. We had updated the Fig.12 on a logarithmic scale. It now provides pronouncing signal regarding the diel vertical migration of zooplankton. The related text was added in Line as "Furthermore, the observed eddies are found to exert a significant influence on the vertical distribution of small zooplankton. A secondary subsurface maximum of small zooplankton occurs at approximately 75 m depth in close proximity to the CE core. In contrast, abundances are significantly suppressed within the AE core, especially at the 80–160 m depth, but exhibit elevated values within the AE–CE transition zone. This finding is consistent with Guidi et al. (2012) that concentrations of buoyant particles increase within the mesoscale frontal zone of AE-CE dipole." Please see Line 405-410 in the revised manuscript. Other research well demonstrated the eddy-eddy interaction on the diel vertical migration of zooplankton (Guidi et al., 2012.), and this manuscript more evidence to support the findings.

Guidi, L., Calil, P. H., Duhamel, S., Björkman, K. M., Doney, S. C., Jackson, G. A., ... & Karl, D. M. (2012). Does eddy-eddy interaction control surface phytoplankton distribution and carbon export in the North Pacific Subtropical Gyre?. Journal of Geophysical Research: Biogeosciences, 117(G2).

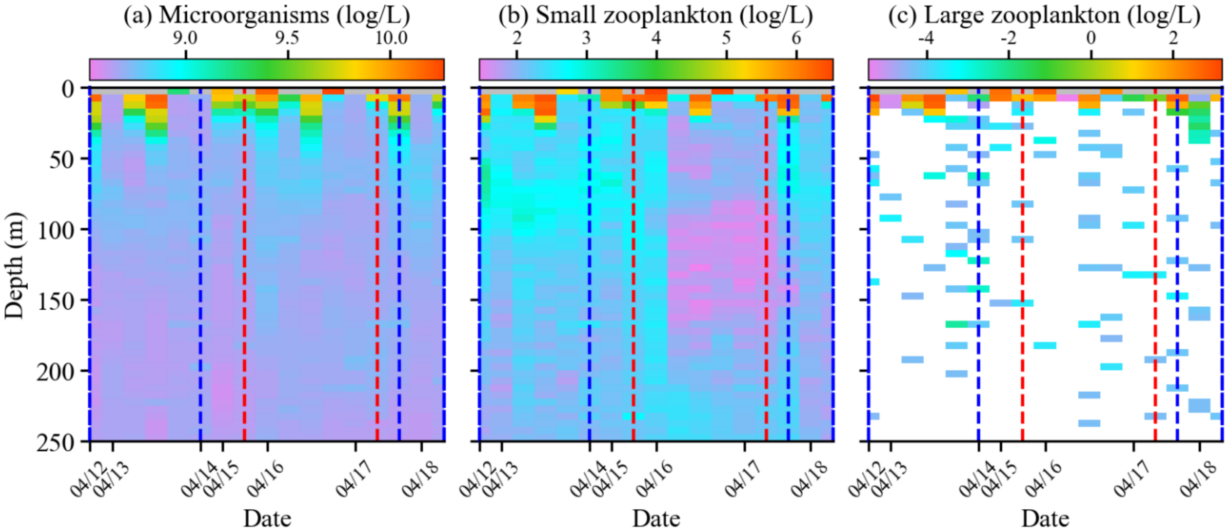

Figure 12: The particle concentrations of (a) microorganisms, (b) small zooplankton, and (c) large zooplankton crossing the dipole eddy centers. The dashed red and blue lines have the same meaning as Fig.8. The gray in each plot indicates missing values. Blanks in (c) mean there is no large zooplankton.

5. Questions and Comments: How does the Kuroshio intrusion cause AE, CE or eddy dipole?

Answer: Thanks for your comments. Nan et al. (2011) summarized three paths of Kuroshio intrusion through Luzon Strait: looping path, the leaking path, and the leaping path. Looping path is related to the Kuroshio Loop Current eddy shedding event. It results in high-salinity or high-temperature water. Based on the T-S plot from Argo floats and climatological WOA23 data (in Fig. 2(c)), the water mass within the target eddies is evidently similar to the northern SCS water compared to the typical Kuroshio water. Since this manuscript pays more attention to the evolution of coupling process, the impact of Kuroshio intrusion on the generation of dipole eddies will be further studies in the future work.

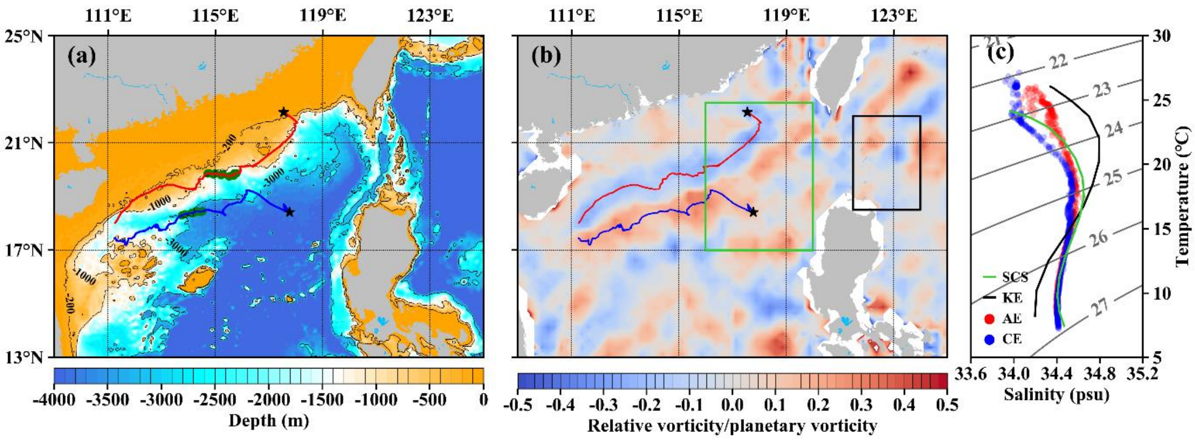

Figure 2: (a) Bathymetry of the northeastern SCS. The 200, 1000, and 3000 m isobaths are marked with thin black lines. (b) The vorticity maps that the relative vorticity is divided by planetary vorticity at each grid point. The red and blue lines denote the trajectories of AE and CE revealed in this study, respectively. The black stars represent the eddy origins. (c) The T-S diagrams of Argo profiles within the dipole eddies. The green and black lines are the averaged T-S curves for the northeastern SCS (green box, 116 °E–120 °E, 17 °N–22.5 °N) and Kuroshio area (black box, 121.5 °E–124 °E, 18.5 °N–22 °N), respectively, based on World Ocean Atlas 2023 climatological data.

Nan, F., Xue, H., Chai, F., Shi, L., Shi, M., and Guo, P.: Identification of different types of Kuroshio intrusion into the South China Sea, Ocean Dyn., 61, 1291-1304, 10.1007/s10236-011-0426-3, 2011.