

Response to RC4

Title: “Biogeochemical Layering and Transformation of Particulate Organic Carbon in the Tropical Northwestern Pacific Ocean Inferred from $\delta^{13}\text{C}$ ”

In this document, we present the response to Referee’s comments repeated in [blue](#).

We sincerely appreciate the thorough review of our revised manuscript by you and the reviewers. We have carefully addressed all the remaining comments and further refined the manuscript, with particular attention to enhancing the discussion of inter-station variability and clarifying the description of process rates. Below we provide point-by-point responses to your specific comments along with detailed explanations of the corresponding revisions.

1. This is a study with valuable data of POC, DIC and their isotopes for an important region around the equator. This is a review of the revised version of the manuscript. I think most of the comments by the two referees of the first version of the manuscript were satisfactorily accounted for. The vertical profiles of POC and DIC are now more connected to the horizontal currents, which was a major critique. What could be more emphasized and discussed is the changes between the different stations. In their analysis, often all stations are taken together, for example in Figures 4 and 6. There might be interesting differences between the stations, as they are also influenced by different water masses.

We thank you for this insightful suggestion. In the revised manuscript, we have now expanded the discussion of inter-station variability in Section 3.2 and provided a new figure (Figure 1/Revised Manuscript Figure S1) to highlight differences between $\delta^{13}\text{C}$ -POC, POC concentration, and C:N ratios across stations (Revised Manuscript Line 265-292): *“However, significant differences were observed among sampling stations in the relationships between $\delta^{13}\text{C}$ -POC value and POC concentration, as well as between $\delta^{13}\text{C}$ -POC value and C:N (Fig. S1). Among them, the EQ-6 station exhibited the most distinct regression trends. Located within the South Equatorial Current regime, where the water column is stable and strongly stratified, this station showed strong correlations ($p < 0.05$) between $\delta^{13}\text{C}$ -POC value and both POC concentration and C:N, indicating that degradation-dominated isotopic fractionation processes are prominent in this region (Tuchen et al., 2024). At station E142-13, under the influence of the Equatorial Undercurrent,*

continuous nutrient supply and an active biological pump created a marked gradient in POC content and composition between surface and subsurface waters (Brandt et al., 2021). As a result, significant correlations ($p < 0.05$) were also observed between $\delta^{13}\text{C}$ -POC value and both POC concentration and C:N. In contrast, at station E142-19, located in the Mindanao Dome upwelling region, the correlation between $\delta^{13}\text{C}$ -POC value and POC concentration was not significant ($p > 0.05$). This may be attributed to the upward transport of deep nutrients and the resuspension or entrainment of aged POC, leading to heterogeneous POC sources and ages in the water column, which diluted the isotopic fractionation signal associated with degradation (Gao et al., 2021). Nevertheless, $\delta^{13}\text{C}$ -POC at this station still exhibited a significant negative correlation with C:N ($p < 0.05$), indicating the persistence of $\delta^{13}\text{C}$ enrichment resulting from organic matter degradation (Guo et al., 2023b). Moreover, although stations E142-3, E142-7, and E142-11 are located within the same water mass regime (Fig. 2), their $\delta^{13}\text{C}$ -POC value correlations with POC concentration and C:N differed. At station E142-7, no significant correlation was found between $\delta^{13}\text{C}$ -POC value and C:N ($p > 0.05$). In contrast, stations E142-3 and E142-11 exhibited significant negative correlations between $\delta^{13}\text{C}$ -POC value and C:N ($p < 0.05$), likely due to stepwise degradation processes driven by water column stratification. These two stations are probably situated at the edges or transition zones of the water mass, where pronounced stratification limits vertical mixing, thereby creating stronger vertical gradients in POC degradation and leading to the observed negative correlations (Close et al., 2014; Häggi et al., 2021). In comparison, station E142-7 may be located near the water mass core, where enhanced mixing results in a narrower vertical range of C:N (Fig. S1), suggesting a more uniform POC composition throughout the water column. This homogeneity reduces spatial variability in degradation, thus weakening the coupling between $\delta^{13}\text{C}$ -POC value and C:N (Meyers, 1997)."

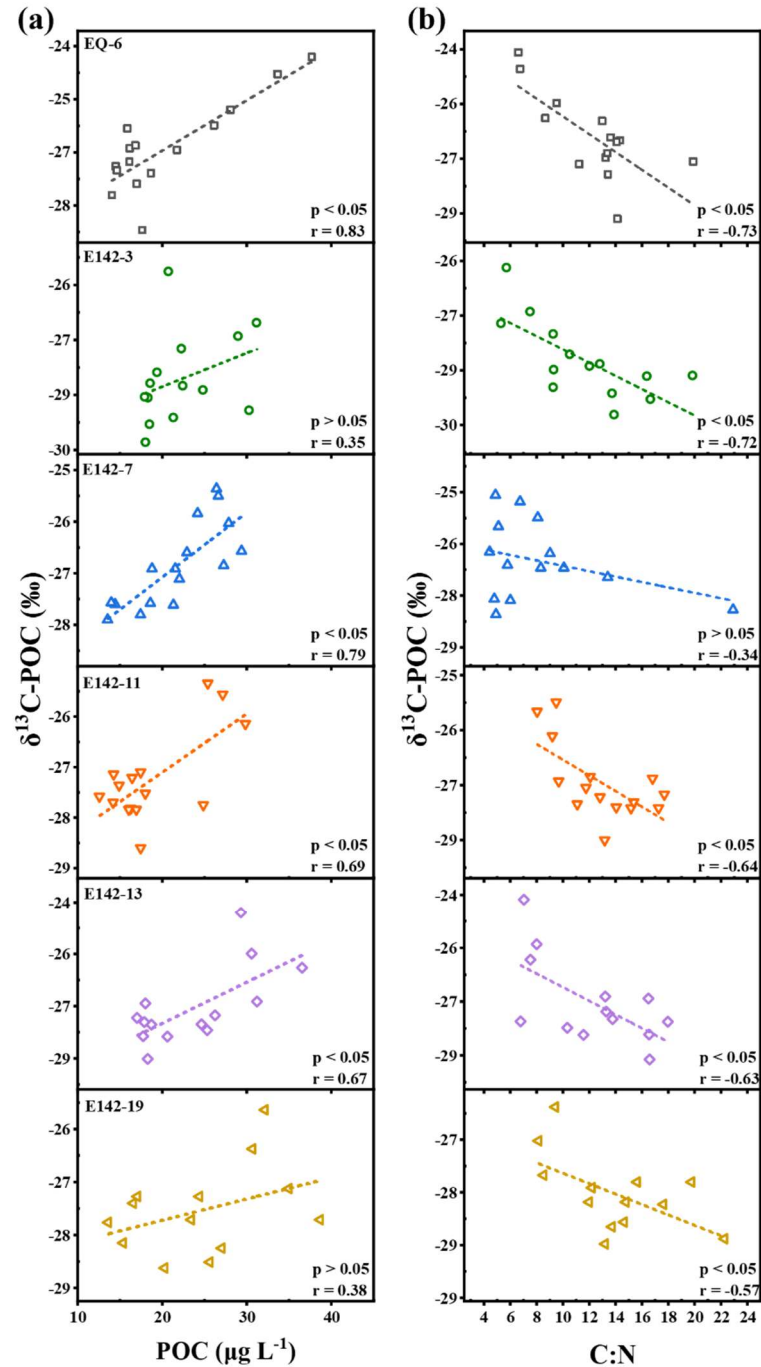


Figure 1. /Revised Manuscript Figure S1. Relationships between $\delta^{13}\text{C-POC}$ and (a) POC concentration and (b) C:N across sampling stations.

References

- Tuchen, F. P., Perez, R. C., Foltz, G. R., McPhaden, M. J., and Lumpkin, R.: Strengthening of the Equatorial Pacific Upper-Ocean Circulation Over the Past Three Decades, *J. Geophys. Res. Oceans*, 129, <http://doi.org/10.1029/2024jc021343>, 2024.
- Brandt, P., Hahn, J., Schmidtke, S., Tuchen, F. P., Kopte, R., Kiko, R., Bourlès, B., Czeschel, R., and Dengler, M.: Atlantic Equatorial Undercurrent intensification counteracts warming-induced deoxygenation, *Nat. Geosci.*, 14, 278-282, <http://doi.org/10.1038/s41561-021-00716->

1, 2021.

Gao, W., Wang, Z., Li, X., and Huang, H.: The increased storage of suspended particulate matter in the upper water of the tropical Western Pacific during the 2015/2016 super El Niño event, *J. Oceanol. Limnol.*, 39, 1675-1689, <http://doi.org/10.1007/s00343-021-0362-0>, 2021.

Guo, J., Achterberg, E. P., Shen, Y., Yuan, H., Song, J., Liu, J., Li, X., and Duan, L.: Stable carbon isotopic composition of amino sugars in heterotrophic bacteria and phytoplankton: Implications for assessment of marine organic matter degradation, *Limnology and Oceanography*, 68, 2814-2825, <http://doi.org/10.1002/lno.12468>, 2023b.

Close, H. G., Wakeham, S. G., and Pearson, A.: Lipid and ^{13}C signatures of submicron and suspended particulate organic matter in the Eastern Tropical North Pacific: Implications for the contribution of Bacteria, *Deep Sea Res. Part I Oceanogr. Res. Pap.*, 85, 15-34, <http://doi.org/10.1016/j.dsr.2013.11.005>, 2014.

Häggi, C., Pätzold, J., Bouillon, S., and Schefuß, E.: Impact of selective degradation on molecular isotope compositions in oxic and anoxic marine sediments, *Org. Geochem.*, 153, <http://doi.org/10.1016/j.orggeochem.2021.104192>, 2021.

Meyers, P. A.: Organic geochemical proxies of paleoceanographic, paleolimnologic, and paleoclimatic processes, *Org. Geochem.*, 27, 213-250, [http://doi.org/10.1016/s0146-6380\(97\)00049-1](http://doi.org/10.1016/s0146-6380(97)00049-1), 1997.

2. Something that was not always corrected as a response to the previous review is the mentioning of rates of change by the authors. The present study did not measure any rates, but still at some places in the manuscript rates are suggested. I have the impression that in some cases the authors mean the general processes that occur and are well-known. In that case they should not use the past tense as this would suggest that they measured it. If it is general knowledge, one should use the present tense. I have touched upon that in the below comments.

Thank you for pointing this out. To avoid confusion,

① We have removed all implicit rate suggestions (e.g., “rapid”) unless citing published rate measurements.

② Clearly distinguished between our observations and established knowledge (now using present tense for the latter).

3. There are too many abbreviations of currents, regions, etc. in the text. Please use less of those for enhancing the readability. Only generally accepted and well-known abbreviations such as SST, POC, CTD are useful. Even when not using those abbreviations increases the length of the text, this is not an issue in online publishing.

We appreciate this suggestion. To improve readability, we revised the manuscript to reduce the use of abbreviations, especially for regional currents and zones. Full names are now provided in the main text and figure/table captions. Furthermore, to maintain the clarity and visual appeal of the figures, we have opted to retain the abbreviations for the relevant water masses.

List of comments:

1. L34 Define POC here, as it is used for the first time. Even when it has been defined in the abstract, this must be done in the main text, because abstract and main text are considered separate.

Thank you for catching this oversight. We have now explicitly defined particulate organic carbon (POC) at its first mention in the main text for clarity.

2. L34 delete: Despite being in minimal quantities (Because this has no relation with the following part of the sentence)

We agree this phrase was unnecessary and have deleted it to improve the flow of the sentence.

3. L38 in instead of: from

We appreciate this correction. The text now reads (Revised Manuscript Line 37-38): “*Organic matter produced in the euphotic layer...*”

4. L39 add “may”: ... microorganisms MAY rapidly utilize it ...

Thank you for this suggestion. We have added “*may*” to reflect that rapid utilization of POC by microorganisms is a potential process rather than a measured result.

5. L50-52 I think the beginning of the sentence with “Although” is confusing. Both parts of the sentence are equivalent.

This is a helpful point. The sentence has been restructured to clarify the parallelism (Revised Manuscript Line 50-52): “*The vital activities of the microbial community in the dark ocean are predominantly driven by heterotrophic respiration (Herndl et al., 2023), while many autotrophic organisms also use chemical energy to synthesize POC.*”

6. L53 change to: There is compelling evidence that ...

We have adopted this more precise phrasing (Revised Manuscript Line 53): “*There is compelling evidence that ...*”

7. L54 oxygen minimum zone (as the abbreviation already indicates)

Apologies for the typographical error in the terminology, which has been corrected to “*oxygen minimum zone*” Additionally, since this term appears fewer than three times in the text, the abbreviation “OMZ” has been removed to enhance readability.

8. L58 delete primarily (there are only those four forms)

Thank the you for noting this redundancy. The word “primarily” has been removed.

9. L66 $\delta^{13}\text{C}$ value

Thank you. To ensure clarity, “ $\delta^{13}\text{C}$ ” has been changed to “ $\delta^{13}\text{C}$ value”.

10. L67 delete significantly

We agree this modifier was unnecessary and have deleted it.

11. L94 delete at the end of the sentence: process

Thank you for the suggestion. We have removed “process” to improve conciseness.

12. L96 Please be more specific about the dates of the expedition. Is there a cruise report that can be cited?

We have added the exact dates (Revised Manuscript Line 95-96): “*The samples were collected in the TNPO during an expedition on R/V Kexue from 16 February to 12 April 2022.*” We regret that the cruise report is not publicly available, so we did not cite it.

13. L104 Please give precision and/or accuracy of temperature and salinity

Thank you for the suggestion. We have supplemented the relevant information in the Methods section (Revised Manuscript Line 104-105): “*The temperature and salinity were measured by CTD in situ, with accuracies of ± 0.001 °C and ± 0.0003 S/m, respectively (Ma et al., 2024).*”

References

Ma, J., Wen, L., Li, X., Dai, J., Song, J., Wang, Q., Xu, K., Yuan, H., and Duan, L.: Different fates of particulate matters driven by marine hypoxia: A case study of oxygen minimum zone in the Western Pacific, Mar. Environ. Res., 200, 106648, <http://doi.org/10.1016/j.marenvres.2024.106648>, 2024.

14. L106-107 The precision for the DO determination is given as 0.0022 µmol/L. I do not know any method of DO determination with such a precision. This must be a mistake. Please explain and correct.

We sincerely apologize for this error. The text now reads: (Revised Manuscript Line 106-107): “*DO was determined in situ using the manual Winkler titration method, with a measurement precision of 0.22 µmol/L.*”

15. L106 and further: Is this an automated Winkler method or titration by hand?

We employed the manual Winkler titration method for DO determination, and the corresponding text has been revised accordingly (Revised Manuscript Line 106-110): “*DO was determined in situ using the manual Winkler titration method, with a measurement precision of 0.22 µmol/L. At each depth, we collected samples in 50 mL brown bottles, added manganese sulfate and alkaline potassium iodide to fix the oxygen, then manually titrated the released iodine with sodium thiosulfate using a calibrated burette to calculate DO concentrations (Bryan et al., 1976; Zuo et al., 2018).*”

16. L115-117 Three variables are given at the beginning of the sentence, but at the end only two accuracies are given. Please correct

We apologize for the omission. The sentence now states (Revised Manuscript Line 116-118): “*POC, PN concentration, and $\delta^{13}\text{C}$ -POC value were analyzed using an elemental analyzer and an isotope mass spectrometer (Thermo Fisher Scientific Flash EA 1112 HT-Delta V Advantages, United States) with an accuracy of $\pm 0.8\%$, $\pm 3\%$ and $\pm 0.2\%$ ”*

17. L11 and further: In the response to reviewers the authors described how blank corrections were treated. As these blanks may play a large role, in particular at low concentrations for

example for samples below the euphotic zone, this is information that should also occur here in the methods section. Please add this.

We appreciate this suggestion and have added the following statement (Revised Manuscript Line 119-120): *“Blank filters were analyzed alongside samples and exhibited negligible background levels for POC, PN, and $\delta^{13}\text{C}$ -POC value.”*

18. L145-148 Please give the full names of the currents as shown in the figure in the caption. All these different current names are confusing to the reader.

We agree this improves clarity. The caption now lists (Revised Manuscript Line 153-158): *“...blue represents the ocean currents from the surface to the bottom of the thermocline, mainly Subtropical Countercurrent, North Equatorial Current, North Equatorial Countercurrent, and South Equatorial Current; green represents the ocean currents in the subthermocline, mainly North Equatorial Undercurrent; purple represents the ocean currents from the bottom of the thermocline to the subthermocline, mainly Equatorial Undercurrent.”*

19. L164 Please add the full names of the abbreviations used in the table in the caption

Thank you for your suggestion. We have expanded the caption (Revised Manuscript Line 174-176): *“Table 1. Water depth (WD), primary production zone depth (PPZD), mixed layer depth (MLD), deep chlorophyll maximum layer depth (DCMD), and the chlorophyll-a (Chl-a) concentration at DCMD for each station.”*

20. L166 As to the water masses of the region, please add a reference.

We appreciate the suggestion. A supporting reference has been added:

Sun, C., Xu, J., Liu, Z., Tong, M., and Zhu, B.: Application of Argo Data in the Analysis of Water Masses in the Northwest Pacific Ocean, Marine Science Bulletin, 10, 2008

21. L175 “The representative water mass in the middle ocean” change to: “The representative water mass at intermediate water depths ...”

We sincerely appreciate this suggestion for improved precision in terminology. To maintain terminological consistency with subsequent sections, we have revised *“middle ocean”* to *“intermediate ocean”* throughout the manuscript.

22. L178 variations instead of changes

Thank you for this suggestion. *“Changes”* has been replaced with *“variations”* to better describe the context.

23. Figure 2: In the response to reviewers, in the caption of this figure, Tian et al 2025 manuscript under review is shown. Please discuss in the main text what the theme of that manuscript is and where it differs from the present manuscript.

We greatly appreciate the opportunity to clarify this point. After careful consideration, we have removed the mention of Tian et al. (2025) from the figure caption to maintain focus on the current study. That work examines TEP (transparent exopolymer particles) biogeochemistry in the same region but uses different datasets and has distinct objectives. Additionally, the manuscript under

review will cite the present study instead.

24. L190-192 Please refer to Fig. 1 here.

Thank you for catching this oversight. We have added the appropriate reference to Figure 1 in this section.

25. L218 leads instead of: led

We appreciate this correction regarding verb tense. The text now uses present tense ("leads") to properly describe this general biogeochemical relationship.

26. L219 and further: Which change and acceleration do you mean? You did not measure changes, right? Please reformulate if you mean something different.

We sincerely appreciate this important critique. We have carefully revised this section to remove any implication that we measured rates of change. The text now reads (Revised Manuscript Line 229-231): *"The aerobic degradation of POC significantly consumed DO, leading to decreased DO levels and the formation of an oxygen cline (Fig. 3)."*

27. L222 cannot instead of: could not

Thank you for this suggestion. *"Could not"* has been replaced with *"cannot"* for grammatical precision.

28. L223 exists instead of: emerges

We appreciate your careful attention to precise language. We have revised *"emerges"* to *"exists"* to enhance clarity.

29. L232 Referring to Fig. 2 is not correct here and Fig. 3 does not have 3a.

We apologize for this error and thank you for identifying it. The reference has been corrected to (Figs. 3, 4a).

30. Figure 4: At the bottom left a correlation coefficient is given and a probability. In both panels $p < 0.001$. However, at the bottom right another p is shown, bigger or smaller than 0.05. Please explain how the statistics work here and how the significance was calculated.

We are grateful for this suggestion to improve methodological transparency. We have added this explanation to the Methods section (Revised Manuscript Line 147-151): *"Data analysis was conducted using OriginPro 2021 (v9.8.0.200). Inter-group differences were assessed using t-tests, with statistical significance defined as $p < 0.05$. Linear relationships between variables were examined using least-squares regression, and correlation strength was reported as the Pearson correlation coefficient (r). An $r > 0$ denotes a positive correlation, $r < 0$ a negative correlation, and $|r|$ closer to 1 indicates a stronger linear relationship."* Additionally, we have redrawn Figure 4 to improve its clarity and readability (Fig. 2/ Revised Manuscript Fig. 4).

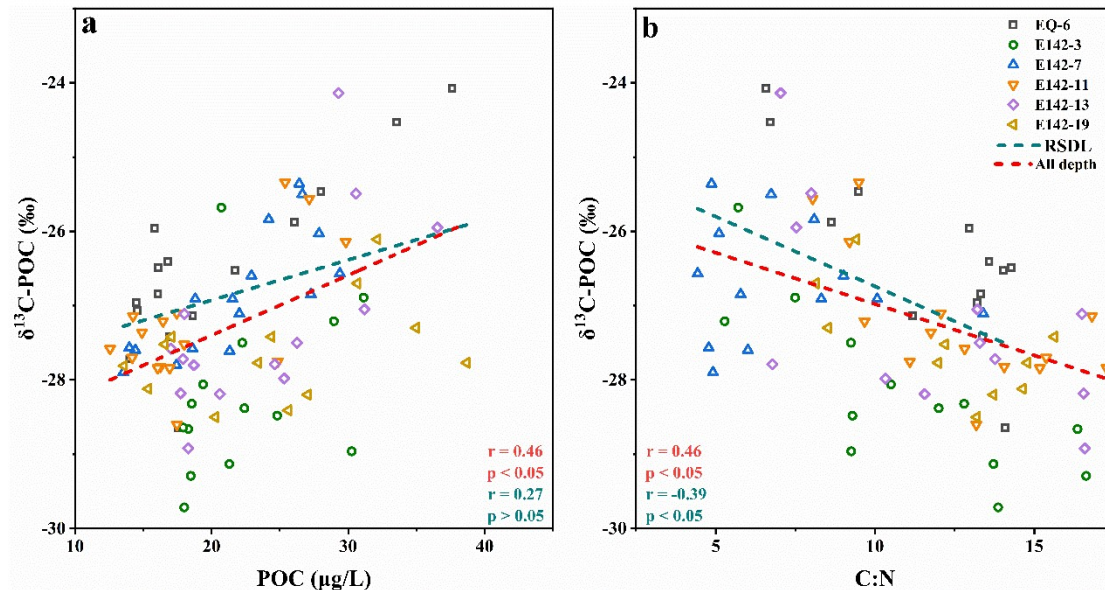


Figure 2. / Revised Manuscript Figure 4. a. Relationship between $\delta^{13}\text{C}$ -POC values and POC concentration; b. Relationship between $\delta^{13}\text{C}$ -POC values and C:N. Red and green lines indicate regressions for the full water column and the rapid synthesis-degradation layer, respectively.

31. L279 intermediate instead of middle, L280 intermediate -depth instead of: mid-layer, L283 again: intermediat”

Thank you for this suggestion. We have systematically replaced all instances of “*middle ocean*” and “*mid-layer*” with “*intermediate ...*” throughout the manuscript to maintain terminological precision.

34. L285-286 “Affected by photosynthesis, DIC increases gradually in the upper ocean.” This is not correct. Photosynthesis utilizes CO_2 and thus reduce DIC in the surface layer. In the deeper layers the DIC values are thus higher. Please change to wording so that more detail for this contention is conveyed.

We sincerely appreciate this important correction. The revised text now accurately states (Revised Manuscript Line 324-325): “*In the upper ocean, DIC concentrations are lower due to photosynthetic uptake...*”

35. L286 intermediate depths

L286, 287 delete rapid, unless you give a reference that this process is rapid

L286-287 Change to: ... the decomposition of POC releases inorganic carbon, causing elevated DIC throughout the intermediate water column ...

L288 Change to: ... a small amount of POC may still degrade ...

We are grateful for this opportunity to clarify. The text now reads (Revised Manuscript Line 325-328): “*...the decomposition of POC at intermediate depths releases inorganic carbon, causing elevated DIC levels with depth. In the deep ocean, a small amount of POC may still degrade, and, along with the release of DIC driven by decreasing carbonate saturation, contributes to a gradual further increase in DIC concentrations.*”

36. L293 delete: as atmospheric CO₂ concentrations have increased

We agree this phrase was unnecessary. “~~As atmospheric CO₂ concentrations have increased~~” has been removed to improve conciseness.

37. L295 delete: among the six stations

Thank you for this suggestion. “~~Among the six stations~~” has been deleted to avoid redundancy.

38. L303, 304, 306 A rapid decrease and a rapid decline is mentioned. What decreases and decline is meant here (how were these determined) and how can you know it is rapid without having measured the rates?

We appreciate this important critique. “*Rapid*” has been replaced with “*pronounced*” to describe the observed trend without implying a quantified rate (Revised Manuscript Line 341-345): “*In analyzing the vertical distribution of $\delta^{13}\text{C-DIC}$, the findings revealed a pronounced decrease in $\delta^{13}\text{C-DIC}$ values at each station (Fig. 5), consistent with the $\delta^{13}\text{C-POC}$ variations observed in the upper ocean (Fig. 6d). Within this depth range, the average decrease in $\delta^{13}\text{C-POC}$ values was 2.23‰, while the average decrease of $\delta^{13}\text{C-DIC}$ values was 0.30‰, with $\delta^{13}\text{C-DIC}$ reaching its minimum value in the subsurface.*”

39. L305 Figures 4 and 5d are referred to. Is that correct? There are no subpanels a,b,c,d in Figure 5.

We apologize for this error. The text now correctly references Figure 5 and Figure 6d (Revised Manuscript Line 341-343): “*In analyzing the vertical distribution of $\delta^{13}\text{C-DIC}$, the findings revealed a pronounced decrease in $\delta^{13}\text{C-DIC}$ values at each station (Fig. 5), consistent with the $\delta^{13}\text{C-POC}$ variations observed in the upper ocean (Figs. 6d).*”

40. L326 “POC was rapidly degraded while being synthesized” How do you know? You did not measure that, did you? Is this a contention based on the literature? If yes, then the present tense should be used.

Thank you for this suggestion. A literature citation (Calbet & Landry, 2004) has been added to support the statement. The sentence was revised to the present tense (Revised Manuscript Line 362-363): “*Within the RSDL, POC undergoes concurrent synthesis and degradation (Calbet and Landry, 2004).*”

Calbet, A. and Landry, M. R.: Phytoplankton growth, microzooplankton grazing, and carbon cycling in marine systems, *Limnology and Oceanography*, 49, 51-57, <http://doi.org/10.4319/lo.2004.49.1.0051>, 2004.

41. L330 Again rapid decrease. How was that determined?

We have deleted “~~rapid~~” and revised to (Revised Manuscript Line 367-368): “*Therefore, the decrease of $\delta^{13}\text{C-POC}$ values in this layer was dominated by...*”

42. L331 ... and by photosynthesis (add: by, because as it is now it may be ambiguous)

Thank you for this helpful comment. We have revised the sentence to (Revised Manuscript Line 367-368) “*...the decrease of $\delta^{13}\text{C-POC}$ values in this layer was dominated by the selective*

degradation of POC and by photosynthesis.” to clarify the relationship and avoid ambiguity.

43. L337 tend instead of tended

Thanks for pointing out the tense issue. We have revised it as suggested.

44. L338 ... of the near surface ocean ... (because the layer concerned is more than the just the surface)

We appreciate this suggestion for precision. We have clarified the sentence by using “...*of the near surface ocean...*” to reflect the accurate depth range.

45. L341 I think you mean declined with depth, right? If yes, then this should be mentioned.

Thank you for this suggestion. The sentence has been revised to (Revised Manuscript Line 378): “*Consequently, the $\delta^{13}\text{C}$ -DIC values in this layer steadily declined with depth (Ge et al., 2022).*”

46. L352 ... activity may explain the observed ... (add: may, because you did not measure it)

Thank you for your suggestion. We have added this important qualifier (Revised Manuscript Line 389): “*This microbial activity may explain the observed increase...*”

47. Figure 6: How was the significance of the relationships determined? Please explain.

We appreciate this comment and have addressed it by adding detailed descriptions of the statistical methods, as outlined in our response to Comment #30.

48. L530 Please delete strange symbols

We apologize for this formatting issue. The strange symbols in references have been verified and corrected. (Revised Manuscript Line 570-572): “*Schmittner, A., Gruber, N., Mix, A. C., Key, R. M., Tagliabue, A., and Westberry, T. K.: Biology and air-sea gas exchange controls on the distribution of carbon isotope ratios ($\delta^{13}\text{C}$) in the ocean, Biogeosciences, 10, 5793-5816, <http://doi.org/10.5194/bg-10-5793-2013>, 2013.*”

We are truly grateful for the valuable suggestions provided during this final pre-acceptance stage, which have helped strengthen the rigor and clarity of our conclusions. We have meticulously addressed all remaining issues and ensured the revised version meets the journal's standards. Should any additional minor adjustments be required, we stand ready to make them promptly. We look forward to the final publication of our work.