Response to Comments (paper # EGUsphere-2022-30)

Variations in dissolved and particulate organic carbon in the lower Changjiang River on time scales from seasonal to decades

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We gratefully thank Reviewer for your time and valuable comments on our manuscript. We have carefully considered these comments and revised the manuscript accordingly. Our response to reviewers' comments point by point is given below. The original comments (in blue text) are also provided followed by our detailed response (regular font size).

Reviewer #3:

Major comments:

This paper presents DOC and POC data at the Xuliujing Station of the Yangtze River over three years. These data are very valuable to explore the seasonal and long-term variations and controls of organic carbon exported by the Yangtze to coastal oceans. However, the analysis is not complete or thorough. Some of the major conclusions are not supported by the presented data.

Response: We appreciate the positive comments and suggestions from Reviewer #3.

(1) The authors conclude that higher ^{13}C-POC in summer was due to autochthonous production in upstream intensified by human activities (e.g., the Three Gorges Dam). However, I am not convinced on this point. The authors should also consider other

factors potentially affecting ^{13}C signals of organic carbon. First, Poyang Lake and Dongting Lake are very important sources of water to the main channel of Yangtze (20-30%). These large lakes also contribute organic carbon to the main channel.

Response: We totally agree and thank you for all the comments. According to CWRC and taking data from 2019 as an example, the outflows from Lakes Doting and Poyang to the Changjiang were 2.87×10^{11} m^3/yr and 1.94×10^{11} m^3/yr, which accounted for about 30.8% and 20.8%, respectively, to the discharge at Datong station (9.33×10^{11} m^3/yr). This conclusion is consistent with those suggested by Bao et al. (2015). At the same time, however, it must be noted that the inflows to the two lakes (2.52×10^{11} m^3/yr and 1.57×10^{11} m^3/yr, respectively) were also very large, which largely reflected the contributions from large tributaries, such as the Xiangjiang River (with discharge of 0.9×10^{11} m^3/yr) to Lake Dongting and the Ganjiang River (with discharge of 1.0×10^{11} m^3/yr) to Lake Poyang.

Wu et al. (2014) suggested that the water retention time of Lake Poyang was relatively low, approximately 10 d, a value that was considerably less than the other two large freshwater lakes in China (i.e., Lake Taihu and Lake Chaohu, with retention times of 264 and 127 d, respectively). Furthermore, the water retention time varied among seasons in Lake Poyang, with low values in the dry (2.7 d) and mid-dry (12.5 d) seasons but a comparatively high value in the wet season (25.5 d). Pan et al. (2009) also suggested that the retention times for Lakes Dongting and Poyang were 18.2 and 10.0 d, respectively. Liu et al. (2016) suggested that the average retention time was less than 10 d along the main flow channels of Lake Poyang; whereas approximately 30 d was estimated in the summer. The short retention times of the two lakes suggested that they were more like a passageway of tributaries rather than a reaction vessel.

The chemical properties in these lake waters were also highly variable and largely depended on the specific locations and the retention times where samples were collected. According to Bao et al. (2014), the chemical parameters (POC (%), PN (%), POC/PN ratio, and $\delta^{13}C$) measured in the two lakes were generally similar to, or within the variation ranges of those measured at stations in the nearby Changjiang River mainstream during the same sampling time period.

Furthermore, the influence of lakes on the water chemistry in the Changjiang River mainstream is very important and complex. Based on data collected during our field sampling in May 2021, the chemical properties showed some differences, although not large, between lake waters and the Changjiang River mainstream (see also Table R1), including DOC concentration, POC (%), $\delta^{13}C$, $\delta^{15}N$, and POC/PN.

Table R1. Comparisons in chemical properties of Lakes Dongting and Poyang and the Changjing River at the Xuliujing station during May 2021 (unpublished data from our group).

Lake or Station	Distance (km)	SPM (mg/L)	POC (μmol/L)	DOC (μmol/L)	POC (%)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	POC/PN (mol/mol)
Dongting	1361	21	126	171	7.2	-26.1	5.2	6.6
Poyang	840	45	169	141	4.5	-25.0	4.7	7.9
Xuliujing	114	40	80	152	2.4	-23.8	6.1	6.0

As suggested by Reviewer #3, the influence of lakes is very important, and we have added these discussions into the revised manuscript.

References:

Bao, H., Wu, Y., and Zhang, J.: Spatial and temporal variation of dissolved organic matter in the Changjiang: fluvial transport and flux estimation, J. Geophys. Res.: Biogeo., 120, 1870-1886, https://doi.org/10.1002/2015JG002948, 2015.

Bao, H., Wu, Y., Zhang, J., Deng, B., and He, Q.: Composition and flux of suspended organic matter in the middle and lower reaches of the Changjiang (Yangtze River)—impact of the Three Gorges Dam and the role of tributaries and channel erosion, Hydrol. Process., 28, 1137-1147, https://doi.org/10.1002/hyp.9651, 2014.

Liu, X., Li, Y.-L., Liu, B.-G., Qian, K.-M., Chen, Y.-W., and Gao, J.-F.: Cyanobacteria in the complex river-connected Poyang Lake: horizontal distribution and transport, Hydrobiologia, 768, 95-110, https://doi.org/10.1007/s10750-015-2536-2, 2016.

Pan, B.-Z., Wang, H.-J., Liang, X.-M., and Wang, H.-Z.: Factors influencing chlorophyll *a* concentration in the Yangtze-connected lakes, Fresen. Environ. Bull., 18, 1894-1900, 2009.

Wu, Z., Lai, X., Zhang, L., Cai, Y., and Chen, Y.: Phytoplankton chlorophyll *a* in Lake Poyang and its tributaries during dry, mid-dry and wet seasons: a 4-year study, Knowl. Manag. Aquat. Ec., 06, https://doi.org/10.1051/kmae/2013088, 2014.

Second, summer features high discharge and high sediment load, which does not favor autochthonous production (authors also stated this point, e.g., in line 287-288). In fact, a lot of studies have shown high phytoplankton activities in the Yangtze in winter or spring when flow and suspended sediment content are low.

Response: Thank you for this comment. Reviewers #1 and #2 also raised similar comments. In the literature, it is generally regarded that higher river discharge in summer should also be accompanied by higher SPM concentrations, largely due to the enhanced soil erosion caused by deforestation (Dai et al., 2016). However, due to recent intensive dam trapping and decreased deforestation in the river basin, the difference in SPM concentration between flood and dry seasons has become much smaller or disappeared (please see Figures D11 and D12, the letter D means the reference of Dai et al. [2016], similarly hereafter). Based on our own data (Figure G4a, and those in Gao et al. [2012]), no clear evidence was found for higher SPM concentrations in flood seasons compared to dry seasons.

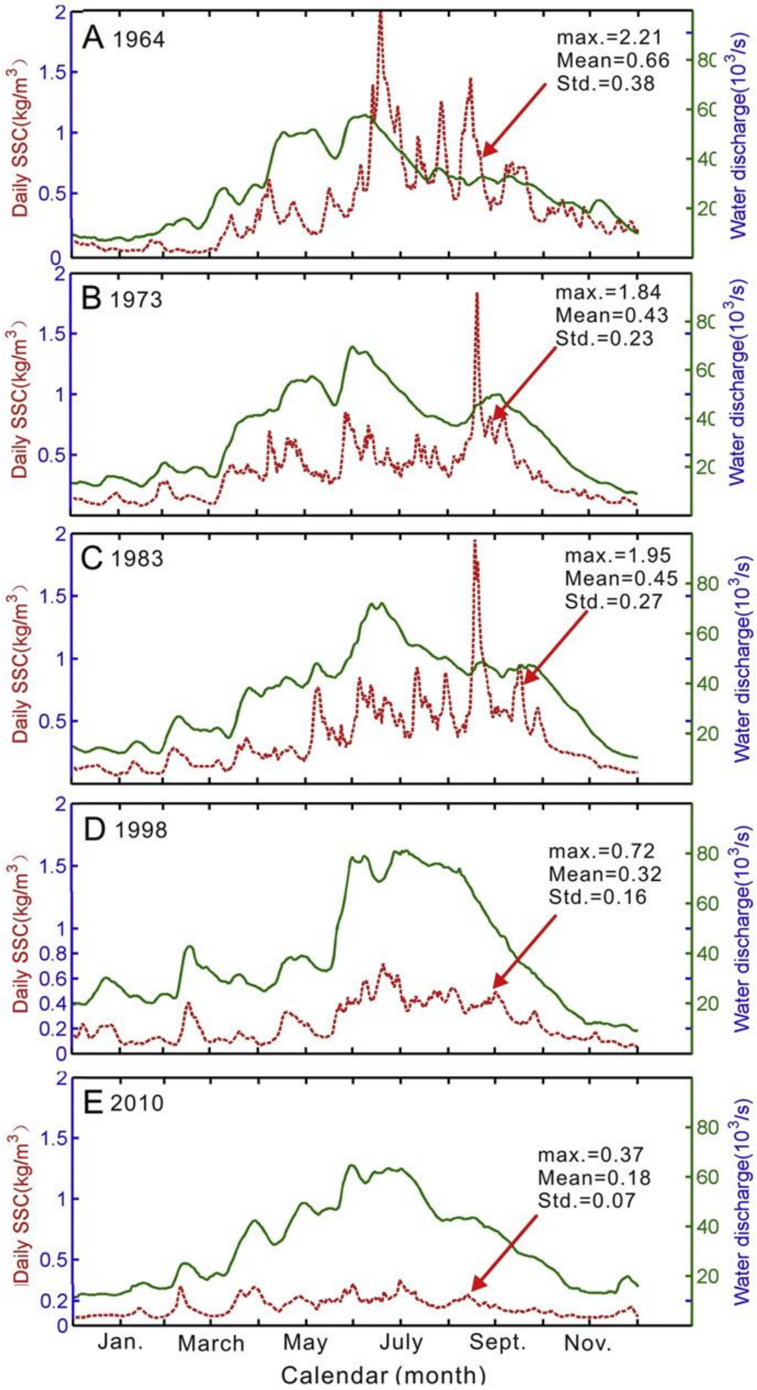

Figure D11. Daily SSC (suspended sediment concentration) and water discharge in different flood years: A) 1964; (B) 1973; (C) 1983; (D) 1998; (E) 2010.

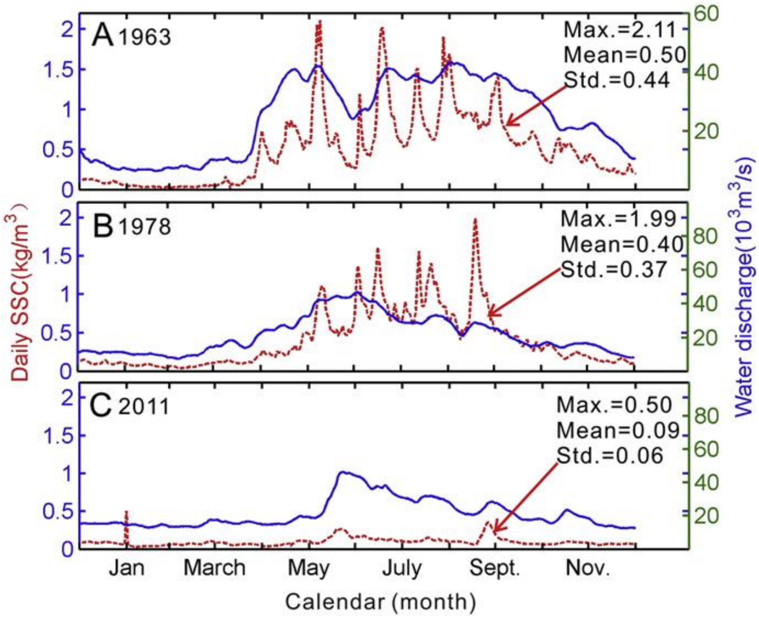

Figure D12. Daily SSC and water discharge during different drought years: (A) 1963; (B) 1978; (C) 2011.

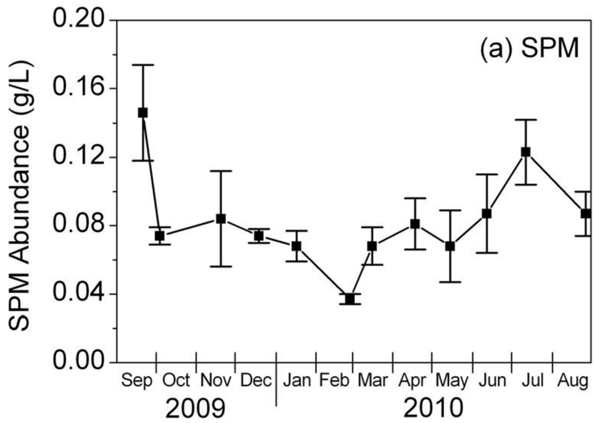

Figure G4a. Variations of the monthly average values (±standard deviation) of SPM abundance measured at station #4 during the sampling period September 2009 to August 2010.

References:

Dai, Z., Fagherazzi, S., Mei, X., and Gao, J.: Decline in suspended sediment concentration delivered by the Changjiang (Yangtze) River into the East China Sea between 1956 and 2013, Geomorphology, 268, 123-132, https://doi.org/10.1016/j.geomorph.2016.06.009, 2016.

Gao, L., Li, D., and Zhang, Y.: Nutrients and particulate organic matter discharged by the Changjiang (Yangtze River): Seasonal variations and temporal trends, J. Geophys. Res.: Biogeo., 117, G04001, https://doi.org/10.1029/2012JG001952, 2012.

Third, Xuliujin is the last station before Yangtze enters the coastal ocean. Hence, the tidal influence is significant. Is it possible that autochthonous production in coastal ocean cause the higher ^{13}C values in summer? How does estuarine process affect organic carbon biogeochemistry of the river?

Response: Thank for the comment. As stated in the original manuscript, the salinity values of all our 35 samples never exceeded 0.2, typical values of river waters. In fact, during the flood season in summer, the greatly enhanced Changjiang River discharge would push the freshwater to a much longer distance and dispense river water to a much larger overlying area. According to our own experience, even in downstream areas with a distance of 50 km or more from Xuliujing station, the salinity there was still generally lower than 0.2 regardless of surface water or bottom water in summer. Thus, at the Xuliujing station, the estuarine and tidal process might influence the water levers there, but no saltwater intrusion or influence on salinity and chemical composition occurs there during flood seasons.

(2) The authors conclude on a significant increase of POC, ^{13}C-POC and ^{15}N-PN over the past decades based on the literature and their own data, which was attributed to increase in the proportion of autochthonous organic components owing to intensified human activities and global warming in the river basin. However, these data are from three different stations (Datong, Nantong and Xuliujing), and the distance between Datong and Xuliujing stations could be as high as > 500 km. In particular, the Xuliujing station is also likely affected by autochthonous production in the estuary. It seems that the increasing trend of POC and isotopes is likely caused by geographic rather than temporal variations. Also, there is a large gap linking the observed variations with human activities and global warming. I think the above problems are critical to the validness of the conclusions.

Response: Thank you for pointing this out. Although the two stations between Datong (for discharges) and Xuliujing (for sampling) are far apart, the total discharges from the several small tributaries between Datong and Xuliujing only accounted for 1.2% of the Datong's annual discharge (Mei et al., 2019). Therefore, the discharge measured at Datong has always been used to represent the ultimate discharge from the Changjiang River.

In terms of the chemical properties, the results from Liu et al. (2003) suggested that the concentrations of all the five nutrients (NO_3^-, SiO_3^{2-}, PO_4^{3-}, NH_4^+, and NO_2^-) were relatively constant over the whole lower reach of the Changjiang River (please see Figure L2 in Liu et al. [2003]).

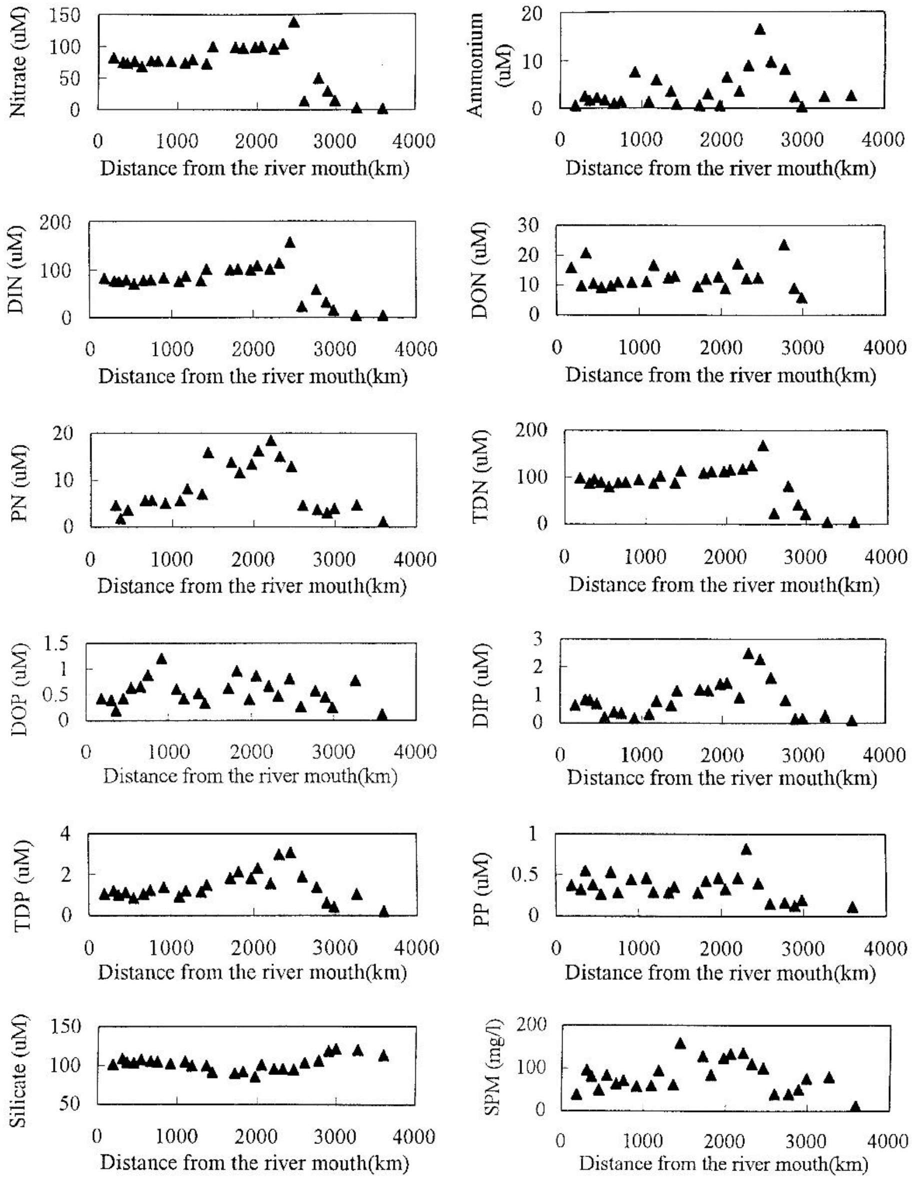

Figure L2. Concentrations of nutrients in the main stream of the Changjiang, which are plotted against the distance from the river mouth.

Bao et al. (2015) carried out two samplings (in October 2009 and July-August 2010) in the middle and lower Changjiang mainstream, and they showed that DOC concentrations between Xuliujing and the nearest upward stations (with distances even longer than that between Datong and Xuliujing) were generally 0.1 mg-C/L (equal to 8.3 μM). Wang et al. (2019) also showed that the DOC and CDOM (quantified by a_{254}) over the distance from Xuliujing to stations about 500 km upward were also relatively stable, especially considering the variation ranges after data from the middle and lower reaches had all been included. Similarly Wu et al. (2018) carried out two sampling cruises in October 2009 and August 2010, and they observed that POC (%), $\delta^{13}C$, and conventional ages were rather stable in the SPM samples over the whole lower reach (see their Table W2). Yu et al. (2011) conducted samplings in April-May 2011 and October-November 2006 in the middle and lower reaches of the Changjiang River, and they also found that POC (%) (0.92 ± 0.06 in 2003, and 1.73 ± 0.23 in 2006) and $\delta^{13}C$ (‰) values (–24.90‰ ± 0.14‰ in 2003, and –24.90‰ ± 0.06‰ in 2006) were rather similar over the whole lower reach (see their Table Y2). Data from our group also suggested that the chemical properties between Xuliujing and Wuhu (close to Datong) in May 2021 were quite similar (Table R2 below).

Table W2. TSM concentrations (TSM samples only), organic carbon contents (POC%), and bulk stable carbon isotope ($\delta^{13}C$, ‰) and radiocarbon compositions (conventional ^{14}C age, years BP) of organic carbon in suspended particulate matter and sediments in the lower reaches of the Changjiang river.

Sampling period	Station	Water depth (m)	TSM (mg/L)	POC%	$\delta^{13}C$	Conventional age (BP)
Oct 2009	Wuhu	0	69.0	1.0	-25.7	2190
		4.5	57.3	0.9	-25.7	2200
		8	61.0	0.9	-25.5	1900
		13.5	55.5	0.8	-25.9	2360
	Xuliujing	0	27.2	0.8	-26.0	2090
		4.5	33.7	0.8	-25.4	2350
		9	36.0	0.8	-25.7	2250

		14.5	40.7	0.8	-25.6	2240
Aug 2010	Jiujiang	0	157.3	1.0	-25.6	1570
		18	173.7	1.2	-25.1	
	Jiangyin	0	136.5	1.2	-25.1	2960

Table R2. Comparison of chemical properties between Xuliujing and Wuhu stations in the Changjiang River mainstream, collected in May 2021 (unpublished data from our group).

Station	Distance (km)	SPM (mg/L)	POC (μmol/L)	DOC (μmol/L)	POC (%)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	POC/PN (mol/mol)
Wuhu	492	33.7	73	155	2.6	-23.9	5.7	7.7
Xuliujing	114	40.1	80	152	2.4	-23.8	6.1	7.0

In the revised manuscript, we have added some sentences into the revised manuscript, explaining that the samples collected between Datong and Xuliujing were generally similar in chemical properties or no systematic differences/changes could be found between samples collected at these two stations. Our further explanation can also be found in the responses below to your specific comment on Section 4.3.

References:

Bao, H., Wu, Y., and Zhang, J.: Spatial and temporal variation of dissolved organic matter in the Changjiang: fluvial transport and flux estimation, J. Geophys. Res.: Biogeo., 120, 1870-1886, https://doi.org/10.1002/2015JG002948, 2015.

Liu, S. M., Zhang, J., Chen, H. T., Wu, Y., Xiong, H., and Zhang, Z. F.: Nutrients in the Changjiang and its tributaries, Biogeochemistry, 62, 1-18, https://doi.org/10.1023/A:1021162214304, 2003.

Mei, X., Zhang, M., Dai, Z., Wei, W., and Li, W.: Large addition of freshwater to the tidal reaches of the Yangtze (Changjiang) River, Estuar. Coast., 42, 629-640, https://doi.org/10.1007/s12237-019-00518-0, 2019.

Wang, X., Wu, Y., Bao, H., Gan, S., and Zhang, J.: Sources, transport, and transformation of dissolved organic matter in a large river system: Illustrated by the Changjiang River, China, J. Geophys. Res.: Biogeo., 124, 3881-3901, https://doi.org/10.1029/2018JG004986, 2019.

Wu, Y., Eglinton, T. I., Zhang, J., and Montlucon, D. B.: Spatiotemporal variation of the quality, origin, and age of particulate organic matter transported by the Yangtze River (Changjiang), J. Geophys. Res.: Biogeo., 123, 2908-2921, https://doi.org/10.1029/2017JG004285, 2018.

Yu, H., Wu, Y., Zhang, J., Deng, B., and Zhu, Z.: Impact of extreme drought and the Three Gorges Dam on transport of particulate terrestrial organic carbon in the Changjiang (Yangtze) River, J. Geophys. Res.: Earth, 116, F04029, https://doi.org/10.1029/2011JF002012, 2011.

Specific comments

Abbreviations (not full name) should be shown in brackets in the text for the first time.

Response: Corrected. Thank you for all the detailed comments.

Line 1-2: the words "variations" and "dynamics" in title are replicate.

Response: Thank you for pointing this out. The title has been modified.

Line 8-10: the abstract did not show research background or scientific questions. Research significance is not shown in the Abstract either.

Response: The Abstract has been revised according to your comment. Thank you for this constructive comment.

Line 19-21: the increasing trend need to be reconsidered based on the same station; contribution of autochthonous component to DOC and POC should consider the influence of estuary phytoplankton dynamics and tidal activities.

Response: Regarding the potential interference caused by different stations, please see our detailed explanations to your comment on Section 4.3 below. As explained earlier, the chemical properties in waters collected at Xuliujing are seldom influenced by the tidal activities and estuarine phytoplankton dynamics, especially in summer when the Changjiang River discharges were elevated.

Line 39-47: authors stated that biogeochemical cycles of carbon in aquatic environments had long been of great interest in the literature, but did not state the existing work on carbon variations under the influences of climate change and anthropogenic activities. And the knowledge gap deducted from existing work is not clear either in this paper.

Response: Thank you for pointing this out. Differentiating the respective influences of climate change and anthropogenic activities is always challenging (Liu et al., 2020;

Lv et al., 2019; Wu at al., 2021). We agree with Reviewer #3 here that a knowledge gap still exists. However, the most important finding of this study was that the significant trends on the decadal time scale are evident and had really occurred over the Changjiang River basin. To the best of our knowledge, the new decadal trends have never been reported for the Changjiang River basin in previous studies. These findings deepened and enriched our knowledge on the ecosystem evolution in the recent decades under the combined effect of global warming and human activities. Unfortunately, based on our current dadaset, we are unable to differentiate the influences of the two factors. Further studies are sorely needed.

References:

Liu, D., Bai, Y., He, X., Chen, C.-T. A., Huang, T.-H., Pan, D., Chen, X., Wang, D., and Zhang, L.: Changes in riverine organic carbon input to the ocean from mainland China over the past 60 years, Environ. Int., 134, 105258, https://doi.org/10.1016/j.envint.2019.105258, 2020.

Lv, S., Yu, Q., Wang, F., Wang, Y., Yan, W., and Li, Y.: A synthetic model to quantify dissolved organic carbon transport in the Changjiang River system: Model structure and spatiotemporal patterns, J. Adv. Model. Earth Sy., 11, 3024-3041, https://doi.org/10.1029/2019MS001648, 2019.

Wu, N., Liu, S.-M., Zhang, G.-L., and Zhang, H.-M.: Anthropogenic impacts on nutrient variability in the lower Yellow River, Sci. Total Environ., 755, 142488, https://doi.org/10.1016/j.scitotenv.2020.142488, 2021.

Line 56-59: these sentences are research methods.

Response: We agree. This sentence has been moved to the Methods section.

Section 4.1: the potential factors influencing organic matter quantity and quality were only discussed using their own data when referring to flushing and dilution effects (e.g., lines 263-265, 267-268), but all the others were repeating the conclusions that have been reported by literatures without discussing the major findings of the present study. Therefore, it is hard to tell whether human activities, global warming and autochthonous production did show their effects in the present study. I suggest that the authors concisely summarize their major findings that directly answer their main research questions and focus on explaining and evaluating what they found.

Response: Thank you for this suggestion. In this section, our main purpose was to list the possible reasons that may have their influence on the seasonal and decadal trends of organic carbon pools. Some factors, such as global warming, cannot be discussed based on our own data. We totally agree with you here and we have revised our discussion focusing on what our data can support and on reducing the overall length of text (more concise).

Section 4.2: I agree that the seasonal variations of POC and its isotopes may be related to the ratios of autochthonous to allochthonous components, but I am reserved on that the autochthonous signal of POC at Xuliujing station is related to the upstream reservoir constructions (e.g., the Three Gorges Dam) which is like >1500 km far away. What about the influences of autochthonous production in upstream lakes (e.g., Dongting and Poyang Lakes)? And is it possible that the POC quantity and quality are influenced by the phytoplankton dynamics in the estuary or coastal ocean where autochthonous production is strong in summer?

Response: There is no dispute that the constructions of more than 50,000 dams over the recent decades, including the Three Gorges Dam, are the main reason that had led to the sharply decreasing SPM concentrations and transport fluxes (Yang et al., 2011). As pointed out by Dai et al. (2016), the river waters were much "cleaner" than before, even in the lower reach of the Changjiang River. Similar phenomenon not only occurred in the Changjiang River but also in the Yellow River in China (Wang et al., 2017). Thus, the river water ecosystems in the lower reach should also have been changed in response to the decreased SPM, largely due to the daming effects.

Regarding the effects of lakes, please see our response to your general comment.

Regarding the possible effect from the estuarine processes, please see our response to your general comment.

References:

Dai, Z., Fagherazzi, S., Mei, X., and Gao, J.: Decline in suspended sediment concentration delivered by the Changjiang (Yangtze) River into the East China Sea between 1956 and 2013, Geomorphology, 268, 123-132, https://doi.org/10.1016/j.geomorph.2016.06.009, 2016.

Wang, H., Wu, X., Bi, N., Li, S., Yuan, P., Wang, A., Syvitski, J. P. M., Saito, Y., Yang, Z., and Liu, S.: Impacts of the dam-orientated water-sediment regulation scheme on the lower reaches and delta of the Yellow River (Huanghe): A review, Global Planet. Change, 157, 93-113, https://doi.org/10.1016/j.gloplacha.2017.08.005, 2017.

Yang, S. L., Milliman, J. D., Li, P., and Xu, K.: 50,000 dams later: Erosion of the Yangtze River and its delta, Global Planet. Change, 75, 14-20, https://doi.org/10.1016/j.gloplacha.2010.09.006, 2011.

Line 309-311: is there any data supporting the source of POC from deep soils? Why are waters from deep flow paths high in DOC concentration? Can belowground water influence DOC concentration?

Response: This sentence has been deleted from the revised manuscript since we do not have relevant data to support this. Thank you for pointing this out.

Section 4.3: authors tried to show the decadal trend of SPM, DOC, POC and their isotope signals using reported data and literature data. This is a great idea, however, these data are from three different stations (Datong, Nantong and Xuliujing), of which the Xuliujing station is likely severely influenced by estuary phytoplankton dynamics and tidal activities. More importantly, the increasing trend of POC, ^{13}C-POC and ^{15}N-PN in Figure 11 is very likely caused by different stations (higher values in Xuliujing station) instead of time. I'm afraid that the decadal trends need to reconsideration.

Response: As we have explained earlier, the chemical properties between Datong and Xuliujing, even over the entire lower reach of the Changjiang River, were generally similar. No systematic changes in chemical property parameters between Datong and Xuliujing could be found, as reported in previous studies. In fact, if the data from Datong were removed from Figure 11 (the two stations of Xuliujing and Nantong are very close), the increasing trends would be still significant and seemed to be even stronger than before (Figure R1), and the decadal trends would not be changed by this modification, again suggesting that the significant decadal trends were not caused by the spatial factor over the distance between Datong and Xuliujing.

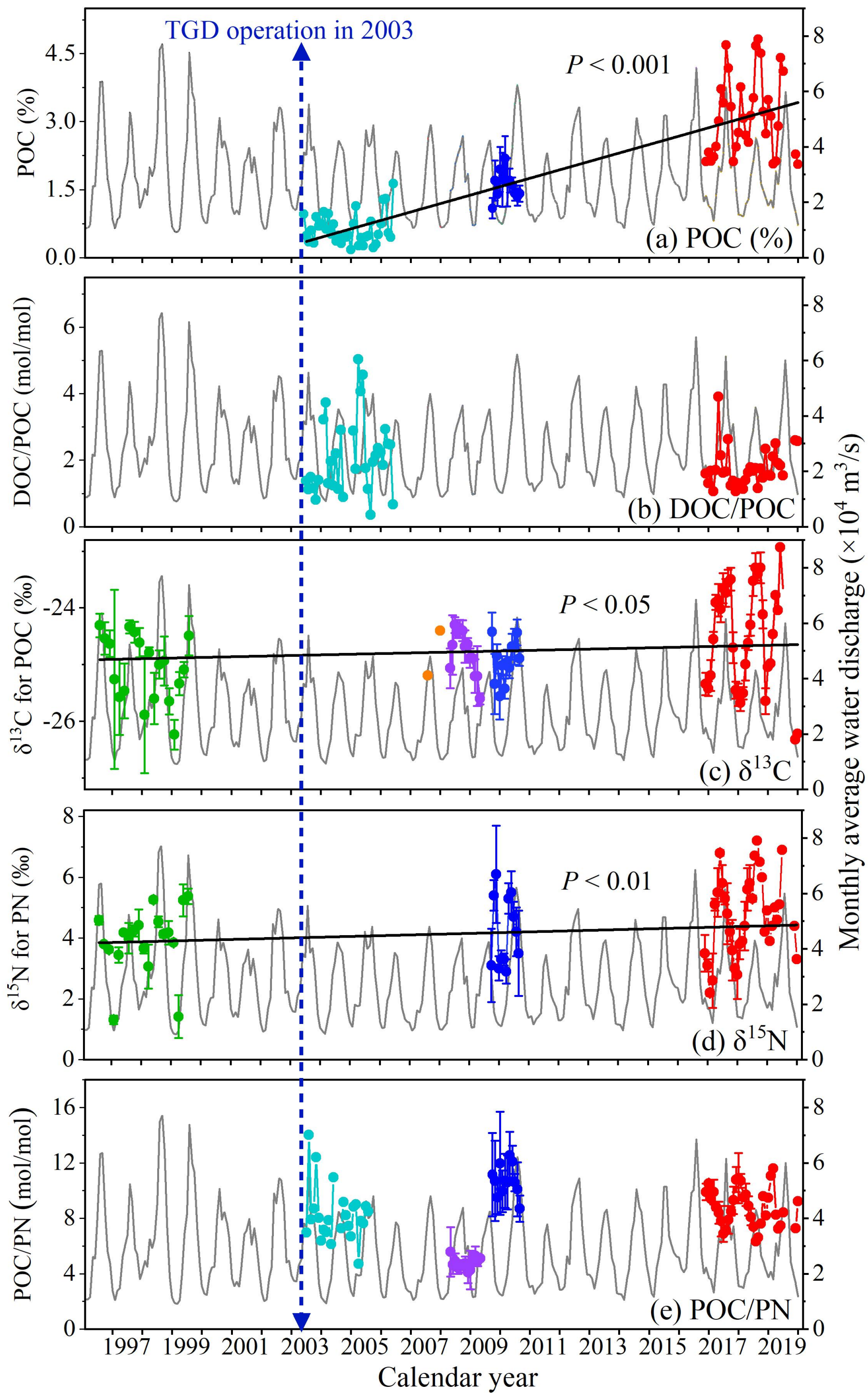

Figure R1. Variations of POC (%), DOC/POC ratios, $\delta^{13}C$, $\delta^{15}N$, and POC/PN ratios in the lower Changjiang River between 1993 and 2019. **In this figure, the data obtained from the Datong station have been removed and only data from Xuliujing and Nantong remain.**

Figure 1: add dam positions.

Response: Done. Thank you for this comment.

Figures 9 and 10: when investigating temporal variations, using data from the same station should be more compellent.

Response: We agree with you here. In order to collect sufficient data and to make our study more representative, using additional data from other stations is a better choice (note that all these stations are restricted in the lower reaches from Datong to Xuliujing). It should also be emphasized that even if we removed the data at the Datong station, our conclusions would still hold and not be altered. Please see our response to previous comments.

Figure 11: add legend of points including station name

Response: Done. Thank you for this comment.

Again, we appreciate the Reviewer for the constructive and insightful comments and time spent on our manuscript. The comments have greatly improved our manuscript. We hope that our revised manuscript now meets the standard set by *Biogeosciences*.