Anonymous Referee #1

We wish to thank the referees for the constructive comments and suggestions which are helpful to the revision of our manuscript. Detailed response to all comments are given below (responses are shown in blue)

General Comments

Hu and his/her colleagues use 1976-2017 pearl river estuary monitoring data to present a analysis of PRE oxygen depletion history assessment work. The strength of this work, in my eye, includes two points. One is the 42 years of historical data itself, and the other is fig.7b, namely the statistics of hypoxic sites. The weakness of current work is also very apparent. There is a lack of deep exploration for the mechanism of the occurrence of the hypoxia, or oxygen depletion. Also, I think authors can go even further in the ststistics job. To improve the current work, I have the following comments and suggestions.

Response: Thank you for providing these comments. First of all, we would like to emphasize the significance of our study and its implication. For a long period of time, the problem of low oxygen and hypoxia in the Pearl River estuary (PRE) has attracted great attention. There have been a large number of observational and modeling studies on the low-oxygen conditions in the region, but most of them focused on short-term hypoxic events with limited data span, and there is still a lack of understanding of the long-term temporal and spatial variability of low-oxygen conditions in the PRE. Therefore, the contribution of this work is not merely on collecting the historical oxygen data itself, but more importantly, is on synthesizing these field observations during 1976-2017, for the first time (to the best of our knowledge) to attempt to elucidate the long-term evolution of low-oxygen conditions in terms of areal extents for the PRE. Specifically, our study explored the seasonal and interannual variations of oxygen status and their changes over the past 4 decades, and have revealed several important aspects on the low oxygen and hypoxia, such as the hotspot area prone to subsurface low-oxygen events, the exacerbation of summertime low-oxygen conditions, the potential transition of the PRE from a system characterized by episodic, small-scale hypoxic events to a system with seasonal, estuary-wide hypoxic conditions, etc. We believe that this work is an important supplement to the understanding of decadal changes in low-oxygen conditions in river-dominated coastal systems (like the PRE) in the context of global oxygen declines. Furthermore, this study also reported prominent hypoxic events in the early autumn of the PRE and would serve as a critical reminder for the community to realize the importance and severity of the low-oxygen problem in this period, which has long been ignored.

Secondly, it is also one of our main objectives to clarify the mechanisms and key factors controlling the occurrence of low-oxygen conditions and their expansions over recent years. We have provided some proper discussions on this by utilizing the data available to us so far and incorporating relevant findings from previous studies as well. However, to fully utilize the sparse observations, it is inevitable to use data collected from independent field surveys conducted by different institutions with different research purpose. Some problems inherent in the observational data used limit us to make more direct comparisons and quantitative analysis. For example, as we mentioned in section 4.4 of our manuscript, there existed data gaps in certain years and lack of conformity in observational coverage, and the observations were under sampled in some years, especially before the 2010s. Besides, the available amounts of different data types are also different; for instance, the historical data on dissolved oxygen (DO), nutrient concentrations, temperature, and salinity are relatively abundant, while the long-term data on chlorophyll and nutrient loadings are lacking for us. Currently, we only have chlorophyll data in July 1999 and September 2006 on hand (as listed in Table 1 of our manuscript). Therefore, while maximizing the use of available data for analysis, we are also very cautious about its results and try to avoid the over-interpretation of these results, including the quantification of the estimated low-oxygen areas and its long-term trend. Despite the data limitations, the long-term observations show that the DO content in the PRE had significant temporal variability and spatial heterogeneity. A distinct exacerbation of low-oxygen conditions in summer could be evidenced by the increased susceptibility to large-scale low-oxygen events, be coincident with the major environment changes, and be supported by previous similar findings. These results emphasize the importance of conducting estuary-wide surveys to collect extensive data on DO and its related factors in a consistent way. In addition, this work will initiate our further studies to quantify the long-term oxygen changes and the associated mechanisms by collecting more observations to fill the data gaps as well as combining them with numerical models and/or machine learning techniques in the future.

Lastly, we agree with the reviewer's comment on providing additional statistical analysis that could be useful for linking the long-term expansion of low-oxygen conditions with the environment changes in the Pearl River region. Based on the reviewer's suggestions, we will incorporate the estimated areas of low-oxygen conditions in the PRE and the changes in nutrient concentrations along with anthropogenic activities, river discharge, and sediment load into the same figure (i.e. Figure 11 in our manuscript), and also add new scatter plots of the oxygen data versus suspended sediment concentrations (SSC). Please see our responses below for details.

Major comments:

1. what is the scientific question of this work?

Response: It is clearly denoted by the title of our manuscript as well as in the abstract and introduction sections that the main scientific question for our study is on the long-term spatiotemporal variations and expansion of low-oxygen conditions in the PRE and the associated key factors. Specifically, this work highlights (1) an apparent expansion of the areas affected by low oxygen in the bottom waters of the PRE during summer, which is primarily attributed to the exacerbated eutrophication associated with anthropogenic nutrient inputs and sharp decline in sediment load, (2) prominent low-oxygen events in the early autumn of the PRE, which were comparable to the most serve ones observed in summer and formed by unique mechanisms from the summer (please see our response to the Minor Comment 1 for details of the mechanisms) , and

(3) the potential transition of the PRE from a system characterized by episodic, small-scale hypoxic events to a system with seasonal, estuary-wide hypoxic conditions in summer.

As we mentioned in our response to the General Comments, we are fully aware of the limitations of the observational data in use, which largely limits our ability to quantify the long-term oxygen changes. Nevertheless, inferring from the available data, our findings on the declining trend of bottom-water DO and spatial expansion of low-oxygen conditions in the PRE are reliable from a qualitative point of view and have also been supported by previous studies (Ye et al., 2012; Qian et al., 2018). Please see lines 347-355 of our manuscript for further details.

2. Why use a very old equation (Hyer et al 1971) to calculate DOsat? (line 120). Why not try the newer one? See Garcia and Gordon 1992.(Garcia and Gordon, 1992)

Response: Thank you for the comment. As suggested, we used the newer equation proposed by Garcia and Gordon (1992) to re-calculate the oxygen saturation concentrations (DOsat). The new results (shown in Figure r1 below) are close to the original ones (their relative differences are mostly within 2%). The main findings remain solid. We will revise the equation, the figure and related numbers in our manuscript accordingly.

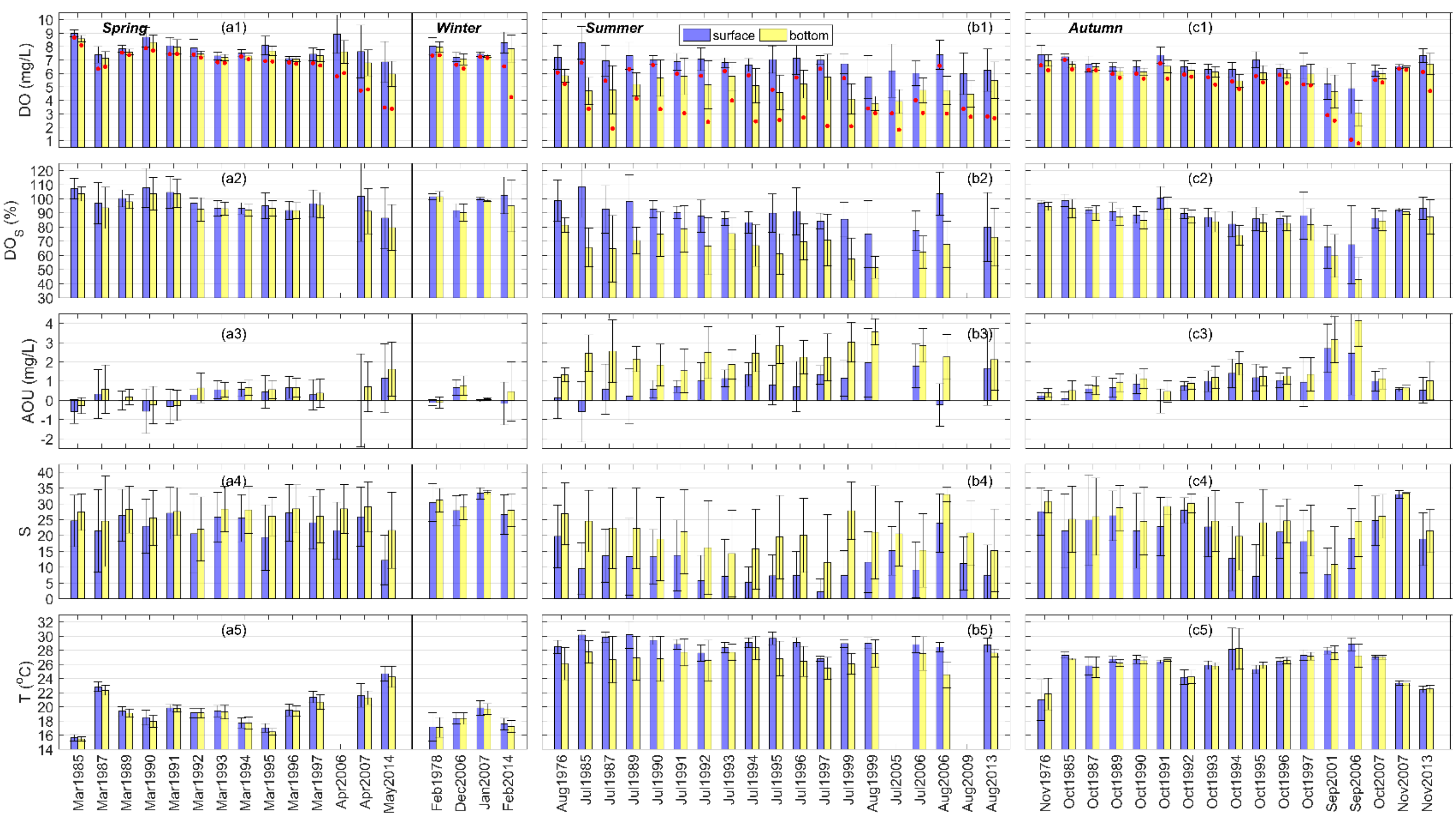

Figure r1. Spatial means and standard deviations of DO concentrations, DO saturation (DOs), apparent oxygen utilization (AOU), salinity (S), and temperature (T) in the surface and bottom waters of the PRE in (a) spring (March-May) and winter (December-February), (b) summer (June-August), and (c) autumn (September-November) during 1976-2014. Note that the red dots in the first row of the figure represent the lowest DO values measured in each time period.

3. Authors use several independent field investigation results., but without indicating the data quality control result. Can these data be directly compared? What is the offset between variouis data set? How the water sample was collected on board? In lab what is the DO measuring method and corresponding quality control?

Response: As we mentioned in our response to the General Comments, the spatiotemporal variations and long-term evolution of low-oxygen conditions in the PRE are poorly understood at the current stage. One major reason is the lack of accessible continuous observations for oxygen and a synthesis of relevant historical data (note that the previous studies on low oxygen and hypoxia in the PRE mostly focused on short-term events with limited data span). For us, with the aim to advance the research progress on the long-term oxygen changes in the PRE, our strategy is to make full use of a variety of data sources to integrate all available observations as far as possible. Thus, it is inevitable to use data collected from independent field surveys conducted by different institutions. We totally understand the reviewer's concern about the data quality control and their comparability. In fact, in order to minimize the uncertainties of the data, we selected data only from reliable sources with formal publication and usage records, which would ensure the reliability and quality control of the data.

The observational data we collected involve five datasets compiled from different sources. Specifically, as denoted in Table 1 of our manuscript, the first dataset (Dataset 1) includes water quality observations from 42 cruises during 1976-2006 conducted by the South China Sea Environmental Monitoring Center. Part of the data were also used for analysis by Li et al (2020), in which the methods of sampling and chemical analysis were described in their section 2.1. The sample collection, storage and transportation, seawater analysis, and data processing and quality control were strictly operated in accordance with the specifications of oceanographic survey (e.g., GB/T 12763-1991 and GB/T 12763-2007) and the specifications for marine monitoring (e.g., GB 17378-1998 and GB 17378-2007) issued by the National Standard of P.R. China. By following these specifications, three-point samples were collected from the surface (0.5 m below the sea surface), half depth, and bottom (0.5-2 m above the sea bed) when the water depth was > 10 m; two-point samples were collected from the surface and bottom when the depth was between 5 and 10 m; and only surface sample was collected when the depth was < 5 m. Temperature was measured on board using a thermometer, and salinity was measured with an induction salinometer in the laboratory. Ammonia (NH_4), nitrate (NO_3), and phosphate (PO_4) were analyzed using the indophenols blue spectrophotometric, Cd reduction, and phosphorus molybdenum blue spectrophotometric methods, respectively. Suspended sediment concentrations (SSC) were measured by the gravimetric method, and chlorophyll *a* was measured using a spectrophotometer after the acetone extraction. As for DO, water samples were collected in brown frost-mouth bottles, immediately fixed with solutions of $MnCl_2$ and KI on board, and were analyzed using the Winkler titration method (Parson et al., 1984). According to the requirements of data quality control, double-parallel samples were obtained to ensure the accuracy and comparability of the sample measurements.

The third dataset (Dataset 3) with observations for 4 seasonal cruises during 2006-2007 and the fourth dataset (Dataset 4) with observations for 4 seasonal cruises during 2013-2014 both followed the same specifications as for Dataset 1 in terms of sampling procedures and chemical analysis. It is important to note that although the specifications issued by the National Standard of China have changed over time, the methodology and fundamental principles for analyzing salinity, DO, nutrients, and chlorophyll involved in this work have not changed, ensuring the accuracy and comparability of the data.

With respect to Dataset 2, the observations were collected from a summer cruise conducted by the Pearl River Estuary Pollution Project in July 1999 (Chen et al., 2004). The vertical profiles for temperature, salinity, turbidity, DO, and chlorophyll *a* were measured using a YSI-6600 multi-parameter automatic water quality sensor. The instrument was calibrated twice with standard samples. The chlorophyll *a* data obtained were compared with those obtained from 169 water samples measured by Turner Designs 10-005R fluorescence method, and the DO content was calibrated against the saturation level prior to each profile measurement (Yin et al., 2004). As for nutrients, samples were collected by Go-flo water samplers from the surface, middle, and bottom, and were measured on board with traditional standard methods following the same specification as for the datasets mentioned above. The physical and biochemical parameters of Dataset 2 have been used in multiple observational studies (e.g., Yin et al., 2004; Yang et al., 2011) and modelling studies (e.g., Hu et al.,2009; Luo et al., 2009).

Regarding Dataset 5, it was comprised of recent observations on bottom-water DO data collected in July of 2014, 2015, and 2017 reported by Su et al. (2017), Lu et al. (2018), and Shi et al. (2019), respectively. All these DO data were measured on board using the classic Winkler titration method (Parson et al., 1984). Please see the Materials and methods sections in the corresponding literatures for more details.

Based on the reviewer's comments, we will provide supplementary details of the corresponding sampling procedures and chemical analysis involved in the five datasets. Also, we will provide further explanations on the quality control of the data in use and their comparability. It should be mentioned that although we cannot fully eliminate the potential data inconsistences, which is inevitable, this work has a significant contribution to advancing our understanding on the long-term variability and expansion of low-oxygen conditions in the PRE, and it also serves as an important reminder for the community to conduct estuary-wide field investigations in a consistent way.

4. Why the surface water can be low in DO? Sometimes surface water can be hypoxic (line 280-285). Why? There is some work talking about this feature (surface water hypoxia) and authors

should cite. Search for work by MH Dai, and /or WD Zhai.

Response: Based on the long-term observations, we found that the low-oxygen water frequently appeared in the surface waters of the inner Lingdingyang Bay in recent years, as also reported by previous studies (Zhai et al. 2005; He et al., 2014; Li et a., 2020). This phenomenon was primarily attributed to the influence of low-oxygen inflows from the upstream reaches as a result of intense nitrification and aerobic respiration of organic matter from direct anthropogenic inputs (He et al., 2014 - a work conducted by Dai's lab). Please see detailed discussions in our manuscript (lines 178-183 and lines 367-370). We will add the citations of Zhai et al. (2005) and He et al. (2014) as suggested.

5. Go deeper in statistics: authors should compare pearl river discharge history, pearl river basin GDP or fertilizer ultilization history, or any other available anthropogenic data, with their oxygen data for the period 1976-2017.In someplace in the main text authors mentioned a few about this (e.g., line 355), but that's not quantitative, instead very shallow. Try compare oxygen and anthropogenic activities by numbers, and present readers by scatter plots. That would be more strong, straightfoward, and perswasive. I see authors already show some historical data (fig. 11)along. That's good. I encourage authors further incorporate oxygen data into the same plot and seek for some pattern or relation. In the main text, authors repeatedly mentioned about some threshold time point (sediment load 1999 at line 378; nutrients 2000 at line 363 et al), so I suggest try compare the oxygen data and corresponding historical data if possible.

Response: We agree with the reviewer that it will help us to further explore the link between the long-term expansion of low-oxygen conditions and the environment changes in the Pearl River region by incorporating the oxygen data, anthropogenic activities, river discharge, and sediment load into the same figure. Accordingly, we added the estimated areas of low-oxygen conditions in the bottom waters of the PRE during 1985-2017 and the nutrient concentrations near the eastern four river outlets along with the wastewater discharge to reflect the pressure of anthropogenic pollutant inputs (please note that the long-term nutrient loadings are not available) into Figure 11 of our manuscript. Please see the revised figure (Figure r2) below.

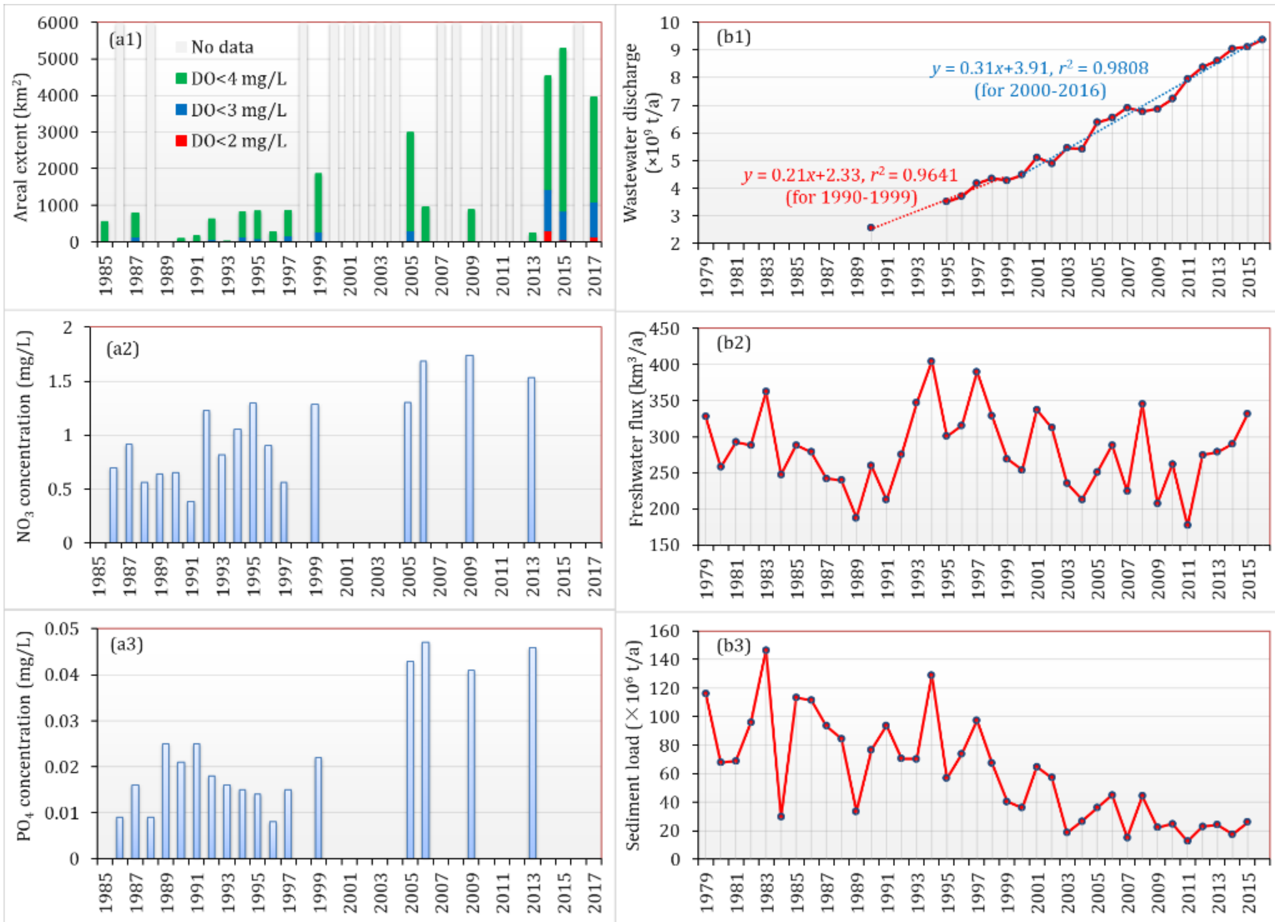

Figure r2. (a1) The estimated area extents of low-oxygen conditions in the bottom waters of the PRE and the (a2) NO_3 and (a3) PO_4 concentrations near the eastern four outlets in summer during 1985-2017. (b1) Annual wastewater discharge in Guangdong Province during 1990-2016. The data before 1998 were taken from Li et al. (2020), and the remaining data were obtained from the Environmental Statistics Bulletin published by the Department of Ecology and Environmental of Guangdong Province (http://gdee.gd.gov.cn/tjxx3187/index.html). (b2) Freshwater discharge and (b3) sediment load of the Pearl River from 1979 to 2015, adopted from Wu et al. (2020).

The above figure clearly shows a distinct exacerbation of summertime low-oxygen conditions as the increased frequencies in extremes, and an increasing trend in the nutrient concentrations along with the wastewater discharge. Although there existed data gaps in certain years, it is still clear that the nutrient concentrations after 2000 are higher than those before. This finding is also supported by Li et al. (2020), which found that the nutrient concentrations in the upstream reaches mostly exceeded 50 μg/L for NH_4, 1000 μg/L for NO_3, and 30 μg/L for PO_4 since 2000 by analyzing the 24-year time series data obtained during 1988-2011.We have cited their findings regarding the changes in nutrients in our manuscript (lines 361-364). In addition to the rise in nutrients, the sediment load of the Pearl River (data adopted from Wu et a. (2020)) experienced a significant decline from 1979 to 2015, while the freshwater discharge only showed a slight declining trend. This is consistent with the findings by Wu et al. (2020); they investigated the sediment load of the nine major rivers in China (including the Yangtze, Pearl, and Yellow rivers) and found that the sediment load has dramatically dropped by 85% over the past 6 decades, and they also found from the statistical analysis that the year 1999 was one of the important time nodes for the sediment decline. We have also cited their findings regarding the changes in the sediment load in our manuscript (lines 376-378). Based on our calculation, the sediment load of the Pearl River was approximately dropped by 63% between 1979-1998 and 1999-2015. Such an abrupt change, superimposed with the changes in nutrients, would act on the expansion of low-oxygen conditions in the PRE. Nevertheless, further studies are needed to clarify the role and relative contributions of these changes in the long-term trend of low-oxygen conditions in the PRE by combining the observations with numerical models.

Finally, we would like to emphasize that cautions should be kept when interpreting the changes of the low-oxygen areas as shown in Figure r2. These results, estimated from the available data so far, should not be directly used to quantify the long-term deoxygenation trend due to the data limitations as we pointed out in our response to the General Comments. In order to avoid the potential misleading or over-interpretation from the figure, we will provide necessary explanations on this issue in the figure caption and the text of our manuscript.

6. Instead of showing grid contour maps, it is clearer by using scatter plot to show readers how the oxygen minimum value, as well as hypoxic (or low oxygen) area and oxygen depletion amount, varied from year to year.

Response: Compared with the northern Gulf of Mexico and the Yangtze River estuary, the low-oxygen zone in the PRE shows relatively significant temporal and spatial variability, with locations and severity varying greatly from year to year (Figures 3-6 in our manuscript). Therefore, in order to comprehensively present the occurrence and spatial patterns of the low-oxygen conditions in different years, we chose to use the contour maps. In addition, we did use scatter plots to show the oxygen minimum values (please see the red dots in the first row of Figure 2 of our manuscript) and the oxygen saturation state (DOs). Please note that we have added new subplots of apparent oxygen utilization (AOU, indicating the oxygen depletion amount) into the same figure (please see Figure r1 above) as suggested by the reviewer #2.

7. The autumn oxygen depletion event is highlighted by the authors. But how that came into being? I am curious that authors mentioned a 'distinct mechanisms' for this autumn oxygen depletion. So, what is the mechanism? In the main text it explained as 'intricate coupling of physical and biogeochemical processes', that does not quench readers' thirst. Oxygen depletion occurs under stratification and organic matter decay. What do authors mean by saying 'intricate coupling of physical and biogeochemical progress'? Some noval mechanisms identified in this autumn event, rather than stratification and organic matter decay? I would like to know that.

Response: As we discussed in our manuscript (section 4.2, lines 276-325), we speculate that the hypoxic and low-oxygen events in early autumn were caused by (1) the inflows of low-oxygen waters from the upstream reaches and (2) enhanced oxygen depletion driven by an intricate coupling of physical and biogeochemical processes. Firstly, in early autumn the freshwater discharge has decreased to about 60% of the summertime discharge (10,000 m^3/s). This would reduce the intensity of two-layers gravitational circulations in the Lingdingyang Bay, i.e. the weaker offshore extension of fresh water at the surface layer and milder onshore intrusion of saline water at the bottom layer (Figure 10 in our manuscript). As a result, the low-oxygen freshwater from the upstream reaches could be transported further into the Lingdingyang Bay at the bottom layer. This can be supported by the high correlation between the oxygen and salinity as shown in Table 2 of our manuscript. Secondly, the reduced freshwater discharge would also facilitate the settling down of terrestrial organic carbon within the Lingdingyang Bay. The thereafter respiration of these organic carbon could also maintain the low oxygen and even hypoxic levels within the bay. In addition, the light availability would be largely improved, which in combination with the prolonged residence time would favor the primary production and ultimately the oxygen consumptions due to locally produced organic matter.

The intricate coupling of physical and biogeochemical processes is a summarization of all the processes that we have discussed above in the same section of our manuscript (section 4.2). Specifically, they include the facilitated deposition of terrestrial organic carbon, the increased light availability, the prolonged residence time, the enhanced primary production, and etc.

In a summary, the mechanisms of early-autumn hypoxia appear to be different from that of the summer one. The inflow of low-oxygen freshwater is the first-order mechanism and the organic matter decay can maintain the hypoxia within the Lingdingyang Bay. With respect to stratification, as we mentioned in this section of the manuscript (lines 292-296), it is not as important as in the summer because there is no significant correlation between the bottom oxygen and the vertical density gradient (Table 2 in our manuscript).

8. Authors suggest the peal river decreased its sediment load in recent years. And a decrease in riverine sediment load result in better light condition in the PRE, so better phytoplankton grwoth and hence worsen bottom hypoxia. While the logic sounds good, authors are suggested to do some quantitative explorations. For example, I see that authors have the suspended sediment concentration (ssc) data for dataset 1 (table 1). So what is the contour distribution patter of ssc in PRE? Maybe it matches well with the surface DO or bottom DO? What is the scatter plot if plot ssc with oxygen data?

Response: With respect to the impact of the sediment decline on the oxygen changes, please see our response to the Major Comment 5 for detailed discussions. In brief, the sediment load of the Pearl River experienced a significant decline from 1979 to 2015, which is consistent with the findings by Wu et al. (2020). It was approximately dropped by 63% between 1979-1998 and 1999-2015. We have shown the distributions of SSC in the PRE during July 1999 and September 2006

(Figure 10 in our manuscript), and the different patterns of SSC and its effects on the growth of phytoplankton in different seasons can be observed. For the rest of the years with available SSC data, the distributions of SSC are given in Figure r3 below. It can be seen that the SSC shows a spatial pattern of being high at the nearshore and low in the offshore waters. Besides, the averaged values of SSC in the 2000s-2010s were generally lower than those in the early 1990s, which is consistent with the declining trend of the sediment load of the Pearl River.

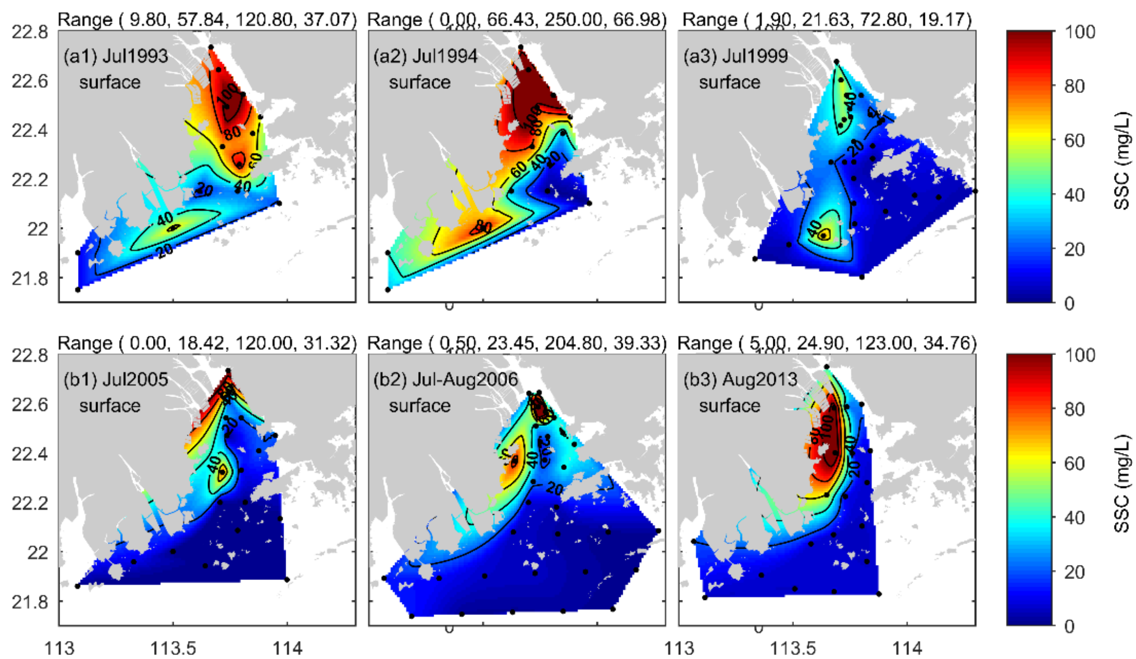

Figure r3. Spatial distributions of suspended sediment concentrations (SSC) at the surface of the PRE in summer.

As suggested by the reviewer, we also plotted the SSC with oxygen data for the surface and bottom waters (please see Figure. r4 below). There is no obvious relationship between these two variables at the bottom, but there is a negative correlation at the surface, that is, the higher SSC, the lower oxygen. On the one hand, this implies that the physical transport and dynamic processes of suspended sediments (e.g., flocculation, deposition, suspension caused by erosion at the bottom layer), in combination with the joint effects of various physical and biochemical processes on oxygen, complicates the intrinsic linkage between suspended sediments and oxygen in the bottom waters. On the other hand, the negative correlation between SSC and oxygen at the surface suggests that with the decrease in SSC, water transparency greatly improves and thus favors the growth of phytoplankton, and thereby the surface oxygen increases as a result of the oxygen release via photosynthesis.

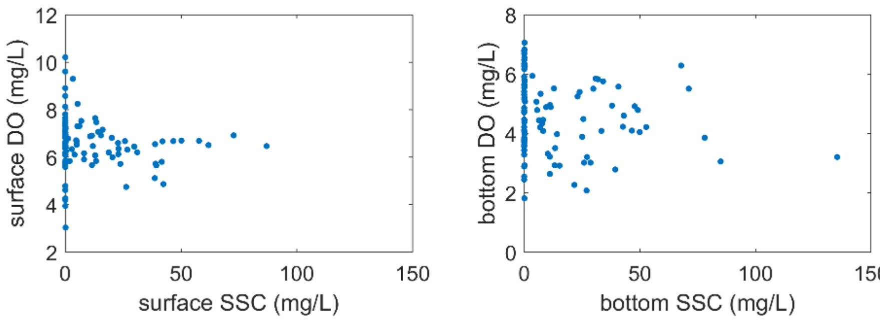

Figure r4. Oxygen versus SSC at the surface and bottom of the PRE in summer

The significant decline of the sediment load of the Pearl River, superimposed with the changes in nutrients, would act on the expansion of low-oxygen conditions in the PRE. However, we realized that the data available so far are not able to clarify the role and relative contributions of these changes in the long-term trend of low-oxygen conditions in the PRE. Therefore, further studies by combining the observations with numerical models are needed to address these important questions in the future.

According to the reviewer's suggestions, we will add the above discussions regarding the effect of SSC on oxygen in the main text of our manuscript and add the distribution patterns of SSC in different years and scatter plots of oxygen versus SSC in the supplementary materials of our manuscript.

Minor comments:

(1) Hard to follow: line 27-29. What is the meaning of this sentense saying low oxygen area? If only read abstract, readers have no idea what is low oxygen. 3mg/L? 2mg/L? 4mg/L? and what is 'distinct mechanisms'?. If readers only read abstract, it is confusing.

Response: In this study, we refer the oxygen concentrations below 2, 3, and 4 mg/L to as hypoxia, oxygen deficiency, and low oxygen, respectively. We will make these definitions clear earlier in our revised manuscript. As for the 'distinct mechanisms', please see our response to the Major Comment 7. Here we mean that the mechanisms for the early-autumn low oxygen events are different from that in the summer. We will change this sentence in our revised manuscript into: *A large area affected by low oxygen (DO<4mg/L) was found in September 2006, where the low-oxygen conditions were comparable to the most severe ones observed in summer. It was formed by the inflows of low-oxygen waters from the upstream reaches and enhanced oxygen depletion driven by an intricate coupling of physical and biogeochemical processes.*

(2) Again, 'low oxygen' is mentioned in the main text (introduction line 86-87, without definition. It is really confusing to say low oxygen in a hypoxia work. Withou definiation, water beneath pycnocline can always be called low oxygen, as it is not saturated. If this is the case, then the 'low oxygen' means nothing serious in the PRE, since it is very common in many places

worldwide. I see in line 99-100 there seems a low oxygen definition, it comes a little late than expected. Also I have no idea if this definiation at line 99 can be applied to term ‘low oxygen’ prior to this line.

Response: Thank you for the comment. The ‘low oxygen’ in this study was defined as the oxygen concentrations below 4 mg/L. We will move this definition earlier in our revised manuscript to make it clearer.

(3) Changjiang diluted water, instead of Yangtze river diluted water, is recommended. Line 63.

Response: We will revise it as suggested.

(4) I am not a physical oceanographer, but for salinity, usualy no unit is needed. See line 121, line 128 and et al.

Response: We will revise it as suggested.

(5) Section 3.1: What is the depth of ‘bottom’? what is the sampling stratigy for the cruises during 1976-2017? How the water was collected, via what sampler? How the DO was measured?

Response: Bottom samples were collected at the waters 0.5-2 m above the sea floor. Please see our response to the Major Comment 3 for details. We will provide supplementary information on the sampling procedures and chemical analysis involved in the five datasets we used. Also, we will provide further explanations on the quality control of the data in use and their comparability.

(6) Line 240 temperature also enhance stratification.

Response: Yes, we agree. However, in many coastal hypoxic systems (e.g., the Yangtze River estuary, Chesapeake Bay, and the northern Gulf of Mexico), salinity has a much stronger effect on stratification compared to temperature (Fennel and Testa, 2019). This is also the case for the PRE, in which the stratification is mainly determined by salinity due to large freshwater discharges (Wong et al., 2003; Hu et al., 2011).

(7) Fig2-8，fig10. Too hard to read. Too small fonts.

Response: We will revise these figures to make their fonts clearer in our revised manuscript.

(8) Fig7a is confusing. It is surface or bottom? What is the meaning of color bar? Why the dots color conflicts with color bar?

Response: It is bottom. It shows the stations where the low oxygen conditions (DO < 4 mg/L) and oxygen deficiency (DO < 3 mg/L) have been observed during July and August. The dots color represents the observed minimum oxygen concentrations, where the dark blue represents the lower oxygen concentrations and the yellow represents the relatively higher oxygen concentrations. Please note that the dots color is consistent with the color bar.

(9) Data availability: it is better to upload authors data into a public data storage, instead of share upon request. But that also depends on the data policy of the local government I guess.

Response: Please see our response to the Major Comment 3 for details on the data sources of all five datasets we compiled. Among these datasets, Datasets 1 and 3 are copyrighted and not allowed to be released in their original forms according to the administrations' data policy. As for Datasets 2 and 4, there is no such restriction and thus we will share these data through public data storage. Dataset 5 was derived from the literatures (Su et al., 2017; Lu et al., 2018; Shi et al., 2019) and can be downloaded directly via the links provided in the corresponding literatures.

References

Chen, J. C., Heinke, G. W., and Zhou, M. J.: The Pearl River Estuary Pollution Project (PREPP), Continental Shelf Research, 24, 1739-1744, https://doi.org/10.1016/j.csr.2004.06.004, 2004.

Fennel, K., and Testa, J. M.: Biogeochemical Controls on Coastal Hypoxia, Annual Review of Marine Science, 11, 105-130, https://doi.org/10.1146/annurev-marine-010318-095138, 2019.

Garcia, H. E., and Gordon, L. I.: Oxygen solubility in seawater: Better fitting equations, Limnology and Oceanography, 37, 1307-1312, https://doi.org/10.4319/lo.1992.37.6.1307, 1992.

He, B., Dai, M., Zhai, W., Guo, X., and Wang, L.: Hypoxia in the upper reaches of the Pearl River Estuary and its maintenance mechanisms: A synthesis based on multiple year observations during 2000–2008, Marine Chemistry, 167, 13-24, https://doi.org/10.1016/j.marchem.2014.07.003, 2014.

Hu, J., and Li, S.: Modeling the mass fluxes and transformations of nutrients in the Pearl River Delta, China, Journal of Marine Systems, 78, 146-167, https://doi.org/10.1016/j.jmarsys.2009.05.001, 2009.

Hu, J., Li, S., and Geng, B.: Modeling the mass flux budgets of water and suspended sediments for the river network and estuary in the Pearl River Delta, China, Journal of Marine Systems, 88, 252-266, https://doi.org/10.1016/j.jmarsys.2011.05.002, 2011.

Li, X., Lu, C., Zhang, Y., Zhao, H., Wang, J., Liu, H., and Yin, K.: Low dissolved oxygen in the Pearl River estuary in summer: Long-term spatio-temporal patterns, trends, and regulating factors, Marine Pollution Bulletin, 151, 110814, https://doi.org/10.1016/j.marpolbul.2019.110814, 2020.

Lu, Z., Gan, J., Dai, M., Liu, H., and Zhao, X.: Joint Effects of Extrinsic Biophysical Fluxes and Intrinsic Hydrodynamics on the Formation of Hypoxia West off the Pearl River Estuary, Journal of Geophysical Research: Oceans, 123, 6241-6259, https://doi.org/10.1029/2018JC014199, 2018.

Luo, L., Li, S., and Wang, D.: Hypoxia in the Pearl River Estuary, the South China Sea, in July 1999, Aquatic Ecosystem Health & Management, 12, 418-428, https://doi.org/10.1080/14634980903352407, 2009.

Parsons, T.R., Maita, Y., Lalli, C.M.: A Manual of Chemical and Biological Methods for Seawater Analysis, Pergamon Press, Oxford, https://doi.org/10.1016/C2009-0-07774-5, 1984.

Qian, W., Gan, J., Liu, J., He, B., Lu, Z., Guo, X., Wang, D., Guo, L., Huang, T., and Dai, M.: Current status of emerging hypoxia in a eutrophic estuary: The lower reach of the Pearl River Estuary, China, Estuarine, Coastal and Shelf Science, 205, 58-67, https://doi.org/10.1016/j.ecss.2018.03.004, 2018.

Shi, Z., Liu, K., Zhang, S., Xu, H., and Liu, H.: Spatial distributions of mesozooplankton biomass, community composition and grazing impact in association with hypoxia in the Pearl River Estuary, Estuarine Coastal & Shelf Science, 225, 106237.106231-106237.106210, https://doi.org/10.1016/j.ecss.2019.05.019, 2019.

Su, J., Dai, M., He, B., Wang, L., Gan, J., Guo, X., Zhao, H., and Yu, F.: Tracing the origin of the oxygen-consuming organic matter in the hypoxic zone in a large eutrophic estuary: the lower reach of the Pearl River Estuary, China, Biogeosciences Discussions, 14, 4085-4099, https://doi.org/10.5194/bg-14-4085-2017, 2017.

Wong, L. A., Chen, J., Xue, H., Dong, L. X., Su, J. L., and Heinke, G.: A model study of the circulation in the Pearl River Estuary (PRE) and its adjacent coastal waters: 1. Simulations and comparison with observations, Journal of Geophysical Research-Oceans, 108, https://doi.org/10.1029/2002jc001451, 2003.

Wu, Z., Zhao, D., Syvitski, J. P. M., Saito, Y., and Wang, M.: Anthropogenic impacts on the decreasing sediment loads of nine major rivers in China, 1954–2015, Science of the Total Environment, 739, 1-21, https://doi.org/10.1016/j.scitotenv.2020.139653, 2020.

Yang, W., Luo, L., Gao, Y., Zu, T., and Wang, D.: Comparison of environmental constituents in the Pearl River Estuary during summer of 1999 and 2009, Journal of Tropical Oceanography, 30, 16-23, 2011. (in Chinese with English abstract)

Ye, F., Huang, X., Zhang, X., Zhang, D., Zeng, Y., and Tian, L.: Recent oxygen depletion in the Pearl River Estuary, South China: geochemical and microfaunal evidence, Journal of Oceanography, 68, 387-400, https://doi.org/10.1007/s10872-012-0104-1, 2012.

Yin, K., Lin, Z., and Ke, Z.: Temporal and spatial distribution of dissolved oxygen in the Pearl River Estuary and adjacent coastal waters, Continental Shelf Research, 24, 1935-1948, https://doi.org/10.1016/j.csr.2004.06.017, 2004.

Zhai, W., Dai, M., Cai, W. J., Wang, Y., and Wang, Z.: High partial pressure of CO2 and its maintaining mechanism in a subtropical estuary: the Pearl River estuary, China, Marine Chemistry, 93, 21-32, https://doi.org/10.1016/j.marchem.2004.07.003, 2005.