We wish to thank the editor and 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 below the questions).

Anonymous Referee #2

General Comments

1. The manuscript by Chen et al. provides data analysis (mostly statistical) of the water quality observations in the southeastern part of the Pearl River Estuary (PRE). Several recent studies, such as Hu et al., 2021, and Li et al., 2021, about the de-oxygenation problems in this region, provide background and justification of hypoxia-related study in PRE. Nevertheless, I feel this manuscript fails to connect the new data with the findings of these existing studies and covers only a small portion of the PRE; thus, its potential to convey what can be learned from a regional study to a broader audience is limited.

   A critical flaw of this study is the representativeness of the stations that all statistical analyses are built upon. I acknowledge these are valuable (30 yr) monthly data covered by these stations, yet their spatial coverage is mainly surrounding the Hongkong island; it is a challenge to draw any solid conclusion regarding the PRE, even the east part, without a throughout cross-reference with the model and data by the previously mentioned two studies. Instead of using these stations to refer to east PRE, I would say the author should do the opposite—to provide a possible water quality study of the Hongkong coast with impacts from the PRE.

   Built on the above point, I see in line 103 (page 4), "the observed DO profiles were interpolated by MATLAB along with the three subregions with a grid resolution of 600 m (length) and 0.3 m (depth)." But take a look at the distribution of the stations; they are concentrated mainly in the nearshore area surrounding Hongkong; I doubt they can be representative of the condition in the east part of the PRE (e.g., the ECTZ defined by Li et al., 2021). And any conclusion based on such "hypoxia area" analysis (e.g., Fig. 4) is thus questionable.

Response: Thank you for the comments. As the reviewer pointed out, there have been many observational and modelling studies on hypoxia in the PRE over recent years. However, most of these studies focused on short-term oxygen dynamics (Li et al., 2021), whereas the long-term oxygen pattern was less investigated. Hu et al. (2021) had an attempt to elucidate the long-term evolution of low-oxygen conditions in the PRE using observations during 1976-2017 collected from multiple datasets; however, as they mentioned, there existed data gaps in certain years and lack of conformity in observational coverage, and the observations compiled were under sampled in several years, which brought out great obstacles for quantifying the long-term oxygen changes due to the data limitations (Hu et al., 2021). Given this situation, we decided to utilize the monthly data collected in the coastal waters off Hong Kong, which have significant merits in terms of temporal coverage (over three decades) and consistency of sampling locations. These coastal data with good spatiotemporal continuity enabled us to better estimate the long-term and interannual variations in low-oxygen conditions without concerns on the uncertainties that would arise from the usage of different data sources. Besides, various oxygen-related parameters (e.g., chlorophyll-*a* concentrations) were measured as well and could be used to discern the key factors controlling the long-term oxygen changes. It should be mentioned that several previous studies have also used data from the same source (e.g. station SM18) to represent water quality conditions in the eastern PRE (Lui et al., 2020). Therefore, we considered that our data selection was reasonable.

Moreover, based on in-situ observations in the PRE, low-oxygen conditions exhibited large spatial variations. Low-oxygen conditions were observed in the upstream zone (Li et al., 2020) and western shelf (Wang et al., 2016; Yin et al., 2004; Cui et al., 2018; Shi et al., 2019). Also, in the eastern PRE, prominent low-oxygen conditions at the bottom together with surface phytoplankton blooms have been frequently reported (Li et al., 2021; Li et al., 2020; Qian et al., 2018; Lu et al., 2018). Observational data from the coastal sites off Hong Kong (e.g. station SM18), which were close to a hotspot area of low-oxygen conditions in the eastern PRE (Hu et al., 2021), were often adopted as a representative to depict the water quality and oxygen conditions in the region (e.g. Qian et al., 2018 and Lui et al., 2020). Besides, dominant deoxygenation mechanism varied among subregions in the PRE. While the western coastal transition zone (CTZ) (Li et al., 2021) was more heavily influenced by terrestrial organic matter (Wang et al., 2016; Wang et al., 2018), low-oxygen events in the Hong Kong waters were largely regulated by the joint effect of physical and eutrophic processes (Li et al., 2021; Qian et al., 2018). What's more, we found that the deterioration trend of low-oxygen in the Hong Kong waters was consistent with the whole PRE (Hu et al., 2021), revealing that the Hong Kong data could reflect some characteristics of the long-term deterioration of low-oxygen conditions in the PRE. Collectively, although the stations selected in our study couldn't cover the whole area of the eastern PRE, we considered that these stations could grasp the long-term deoxygenation trend in the low-oxygen hotpot area in the eastern PRE. In addition, by utilizing this valuable dataset from Hong Kong waters, we could also provide a better insight into the long-term oxygen changes and the underlying mechanisms in the eastern PRE from a quantitative perspective, which could be a significant part of low-oxygen researches for the whole estuary.

Based on the reviewer's comment, we will revise the manuscript by 1) adding more descriptions of water quality and oxygen background information in different subregions (including the upstream regions and the western and eastern CTZ) in section 1 to better justify the representativeness of our analysis using the Hong Kong data, and enhancing the descriptions regarding the current status and existing problems in the long-term low-oxygen research in the PRE to emphasize the significance of our work; 2) adding more discussion on the effects of wind, freshwater discharge, and nutrient load on deoxygenation in combination with the relevant findings of the previous studies, and enhancing the analysis on differences of key deoxygenation mechanism in different subregions of the PRE to improve the implication of our work; and 3) further clarifying the selection on the external variables (e.g. wind speed and direction) in the Methods section. Overall, we hope to emphasize our aim in exploring the long-term low-oxygen change and its important drivers for a significant part of the PRE, in which our analysis methods exhibited general applicability for further studies.

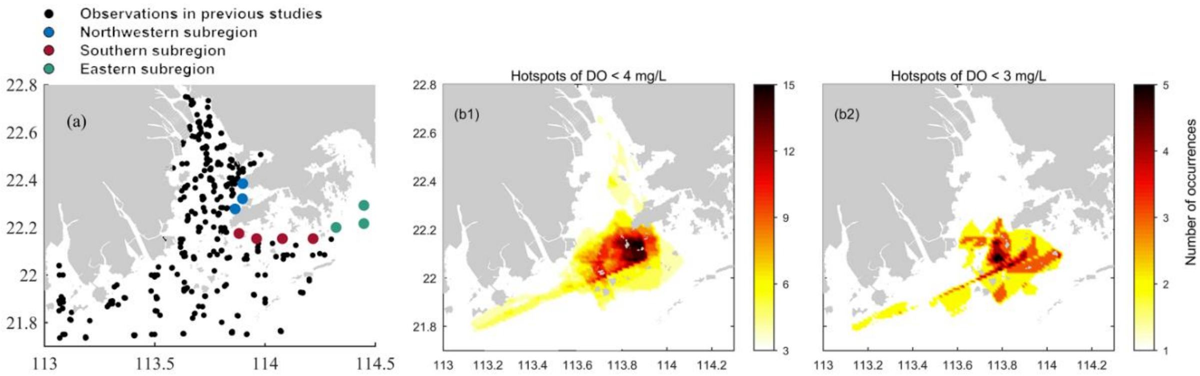

Figure r1 Observation sites during 1976-2014 in the PRE in previous studies (Hu et al., 2021) and station sites in our work (a). Note that black dots represent observation sites in previous studies and blue, red, green dots represent station sites in the northwestern, southern, and eastern subregions of Hong Kong waters, respectively. The incidence of low-oxygen (b1) and oxygen-deficiency (b2) conditions at the bottom of the PRE in summer during 1976-2014 (Hu et al., 2021).

2. In addition, the water depth of these stations varies from 5 m to more than 30m, and the analysis in this manuscript concentrated mostly surface and bottom, which impair the reliability of such analysis in the de-oxygenation study, which is very sensitive to water depth and vertical distribution of variables.

Response: We agreed that the analysis of deoxygenation and its related processes was sensitive to water depth and vertical distribution of variables. In fact, we did concern with this issue, especially for DO. That is exactly the reason why we used several vertical-profile-based metrics (e.g. the cross-sectional area and the layer thickness of low-oxygen conditions) to depict the long-term oxygen changes in the region (please see detailed descriptions in the Methods section 2.2). For example, as for the spatial extent of low-oxygen conditions, we estimated the vertical low-oxygen area and thickness by interpolation using the data at the surface, middle, and bottom layers according to the depth of each station. In addition, we have also investigated the occurrence of low-oxygen and hypoxic events at the surface, middle, and bottom layers (please see Figure A1 in the manuscript), which indicated that low-oxygen events mainly appeared in the bottom waters of summer. Vertical distributions of DO in summer was provided as well (please see Figure A2 in the Appendix). For other variables, we also performed a thorough analysis on their spatial (surface, middle, bottom layers) and temporal patterns. We found that the key problems were concerned mostly in the surface and bottom waters. For instance, while low DO mostly occurred at the bottom, high Chl *a* concentrations frequently occurred at the surface. Therefore, in order to embody the compactness of analysis and data display, we decided to focus on the surface and the bottom when showing part of the results on the long-term variations in water quality constituents and DO concentrations (e.g. results shown in Figures 2-3). Nevertheless, we would like to emphasize that several oxygen-related metrics incorporating information of vertical DO distributions were analyzed and discussed throughout the manuscript, including the Low-Oxygen Index (LOI as defined in section 2.2) and the cross-sectional area of low-oxygen conditions.

3. In the abstract, the author indicated that "there is still a lack of quantitative understanding of the long-term trends and interannual variabilities in oxygen conditions in the PRE as well as the driving factors, which was comprehensively investigated in this study," which I could not agree, I think Hu et al. and Li et al. provided good studies about the mechanism of oxygen dynamics in the PRE. Yet, this manuscript fails to connect what is observed by the stations surrounding Hongkong to what has been reported in a larger geospatial content (PRE and coastal/shelf water).

Response: Thank you for your comments. For the sentence *"there is still a lack of quantitative understanding of the long-term trends and interannual variabilities in oxygen conditions in the PRE as well as the driving factors, which was comprehensively investigated in this study"* that we mentioned in manuscript, we would like to provide some explanations. As we mentioned earlier (please see our response to Comment 1), there were indeed many studies about the mechanism of hypoxic generation and development in the PRE, but most of them focused on short-term oxygen dynamics (Li et al., 2021), while the long-term mechanism received less attention. Hu et al. (2021) had an attempt to elucidate the long-term evolution of low-oxygen conditions. However, as mentioned in their analysis, more quantitative perspective on hypoxic mechanism was needed, limited by the lack of accessible continuous observations. Therefore, the long-term analysis of Hong Kong data could make up for these problems to some extent as mentioned earlier (please see our response to Comment 1).

With respect to the connection of our analysis with previous studies, we also believed that it was vitally necessary. Although most of researches of low-oxygen focused on the whole PRE, we tried to compare their results involved in the eastern CTZ with ours (please see section 4.1 and 4.2). For example, as for the effect of wind (in section 4.1), we have explained our results by combining the findings of previous studies (please see details in Line 55-58). We agreed that this part of discussion should be enhanced. As we mentioned earlier (please see our response to Comment 1), we will provide more detailed discussions in this part. For instance, in section 4.1, we will improve the reference on the effect of wind on the circulation and material fluxes (Li et al., 2021) in the eastern PRE and make clearer explanation on our focus on wind speed. Also, we will add more comparison about key low-oxygen driving factors among different subregions of the PRE in our revised manuscript.

4. The author uses wind speed in their statistic analysis which is also questionable. How about wind direction, and does the wind play the same role in low oxygen development over a year? I am asking because Li et al. (2021) indicated that both wind direction and intensity influenced the circulation nutrient flux, detritus, and vertical mixing. Also, as suggested by Li et al., 2021, what is the role of shelf circulation in physics (mixing, etc.) and nutrient and sediment delivery? Li et al. (2021) and Feng et al. (2014) show that the upwelling and downwelling favorable wind condition has different impacts on the low-oxygen development in this area. It is problematic to use the monthly mean wind speed as a predictor without looking into wind's detailed role in this environment.

Response: In fact, during the preparation of our study, we have also tried to examine the effect of wind direction since the transport of nutrient and detritus, vertical mixing, and residence time could be regulated by wind-driven circulation (Li et al., 2021). Previous studies have revealed that the southwestward (upwelling-favorable) wind could enhance hypoxia in the eastern PRE (Li et al., 2021). Therefore, we processed the daily data of wind speed and direction into monthly average wind speed (WS), southwestward wind duration (SWWD), southwestward wind cumulative stress (SWCS), and southeastward wind cumulative stress (SECS) in summer (please see Figure r2 below), and then we carried out a suite of multiple regressions to fit the Low-oxygen Index (LOI) for each wind-related variable. As shown in Table r1 below, the fitting effect of LOI was better using WS, which also has the highest correlation with LOI among the wind-related variables. We considered that WS was the most significant explanatory wind-related factor for the interannual variations in LOI, and thus we eventually selected WS to be the wind-related input variable in the multiple regression. Besides, we noted that the long-term trends of direction-related variables (i.e. SWWD, SWCS, and SECS) were not as significant as WS (please see Figure r2 below). This probably suggested that the wind direction-related processes played vital important roles in short-term low-oxygen events, but the decline in wind speed has a more significant contribution from a long-term perspective. Based on the reviewer's concern on the wind direction, we will provide more discussion (as mentioned above) on this issue in our revised manuscript.

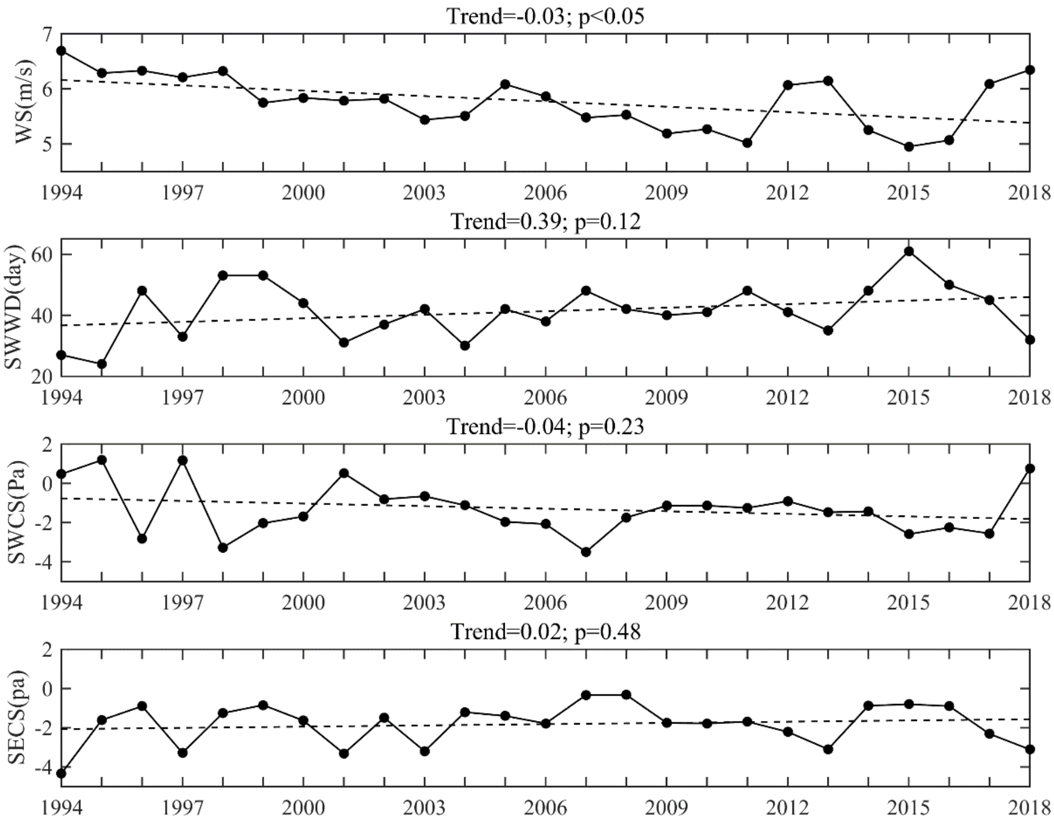

Figure r2. Average wind speed (WS), Southwestward wind duration (SWWD), Southwestward wind cumulative stress (SWCS), Southeastward wind cumulative stress (SECS) in summer and their long-term trends during 1994-2018. Note that the negative value of SWCS and SECS represent southwestward and southeastward wind respectively. The trend and significant p value were texted on the top of each subgraph.

Table r1 R^2 of Average wind speed (WS), Southwestward wind duration (SWWD), Southwestward wind cumulative stress (SWCS), Southeastward wind cumulative stress (SECS) participating in fitting LOI; Pearson correlation coefficient of WS, SWWD, SWCS, SECS with LOI. Note that the symbols * and ** represents the significant level at $p < 0.05$ and $p < 0.01$, respectively.

	R^2 of fitting LOI		Correlation with LOI
WS+flow+T+DIN	0.61	WS	-0.67**
SWWD+flow+T+DIN	0.55	SWWD	0.48*
SWCS+flow+T+DIN	0.55	SWCS	-0.33
SECS+flow+T+DIN	0.57	SECS	0.25

5. The author’s conclusion that the eastern PRE would “develop into a severe hypoxic state within the next two decades” is too strong to be supported by the analysis provided by this study. For

instance, what do the wind, large-scale circulation (cause it affects lateral delivery of water and nutrient, etc.), and river (Pearl plus wastewater from the city) look like in the next two decades? The Pearl River discharged into the PRE from the north, yet if we focus on the spatial scale covered by the stations in this study, what is Pearl River's role in MM stations? Also, what is the impact of overland runoff from Hongkong, such as wastewater discharge, which is also indicated by Hu et al. (2021), and the author briefly mentioned this in Line 250 of page 8.

Response: Based on the observational data and the multiple regression model, we have discerned the contributions of wind speed, freshwater discharge, water temperature, and DIN to the long-term deoxygenation, in which wind speed and DIN contributed the most. Based on the wind data, the wind speed was expected to decrease at a rate of 0.6 m/s within two decades, which would contribute to longer water residence time and nutrient accumulation (Li et al., 2021) in combination with wind-driven circulation, favoring the generation and development of low-oxygen conditions. Likewise, DIN was expected to increase by 0.2 mg/L in two decades according to the observed growth trend, which would enhance eutrophication and subsequent low-oxygen condition within the region. Overall, based on the long-term trends of each influential variable and the proposed regression model, we made the judgement that low-oxygen conditions would develop into a severe hypoxic state. Certainly, this inference was laid on the assumption that wind speed, freshwater discharge, water temperature, and DIN would keep increasing/decreasing at the rate in the next two decades.

We totally understood the reviewer's concern. It should be mentioned that the long-term changes in low-oxygen conditions were ultimately driven by the long-term changes in physical factors (e.g. wind and circulation) and biogeochemical factors (e.g. nutrients), and the proposed regression model (fitting the LOI) actually implicitly incorporated the influence of physical-biogeochemical processes on DO to some extent. We have also tried to discuss the effects of wind, freshwater discharge, and DIN in combination with the circulation and nutrient fluxes in section 4.1 and 4.2, but we realized that it was hard to explore the detailed changes in mechanic processes clearly based on observational data and statistic methods only. To this end, further studies such as numerical simulation are needed in the future. Also, we would like to point out that although prediction with the multiple regression would bring out uncertainties by losing some non-linear physical-biological processes, the long-term deoxygenation trends revealed by the regression model could provide implication for scientific research and management of low-oxygen conditions in the region. Based on the reviewer's comment, we will improve this part of discussion in our revised manuscript. Specifically, in section 5 we will add the rationale of our prediction on the deterioration of low-oxygen conditions. Moreover, we will enhance the discussion on the combined effects of mechanic processes as mentioned above in the revised manuscript, and we will also discuss the limitation of our statistic methods to have a clearer implication of our work.

For the effect of wastewater, we didn't distinguish the influence from the Pearl River and Hong Kong local pollution in our study as we aimed to investigate the effect of the long-term variations in physical conditions and nutrient levels within the region from a general perspective. As for the role of the Pearl River, there were indeed differences among stations, which were also shown by different correlations of DO with other external variables in each station. It might be interesting to dig into this issue, but our present work mainly focused on the whole status of low-oxygen conditions in the selected region, rather than dealing with the spatial differences.

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