*Re: Destruction and reinstatement of coastal hypoxia in the South China Sea off the Pearl River Estuary" by Yangyang Zhao et al.*

March 07, 2021

Dear Editor,

Thank you for your time in handling our paper. Enclosed please find our revised MS entitled "Destruction and reinstatement of coastal hypoxia in the South China Sea off the Pearl River Estuary" by Yangyang Zhao et al.

During the revisions, we have fully considered the comments and suggestions from the reviewers. Briefly, we elaborated the shoreward intrusion of deep shelf waters originating from the coastal current which flows northeastwardly in summer. Following suggestions, we have rephrased or removed statements that were not supported by our observations.

Finally, we would like to take this opportunity to thank the reviewers for their constructive comments and suggestions, which significantly improved the quality of the paper. We sincerely hope that our revision will meet the standards of *Biogeosciences*.

Sincerely,

Minhan Dai
Corresponding author
State Key Laboratory of Marine Environmental Science
Xiamen University
Xiamen 361005, China
Phone: 86-592-218-2132
Fax: 86-592-218-0655
E-mail: mdai@xmu.edu.cn

**Anonymous Referee #1**

**General comments:**

The revisions significantly improved Zhao et al manuscript. The choice of mixing Results and Discussion improves the readability. The drawback is that some of the statements are not supported by observations. This was already the case in the previous version of the manuscript. I encourage the authors to read through their manuscript and remove or rephrase some of their claims that are not supported by their observations. Specific examples are listed in the comments below. For example I would remove the section/paragraph about tidal mixing and future state that are not linked to the current results.

**[Response]**: We appreciate the constructive comments and suggestions from the reviewer. We have further revised the MS accordingly as explained in our responses as of below.

**Specific comments**

L168: Do you have supporting observations for this assumption?

**[Response]**: Yes. This assumption is based on our samples collected at depths of 43-50 m along the ~ 50-m isobaths off the Pearl River Estuary in July 2017. The DO concentrations of these samples were averaged ~180.9 μmol $kg^{-1}$, nearly 16% of oxygen deficit relative to the saturation level for the water mass with a temperature of 22.5°C and a salinity of 34.5, i.e., the upwelled subsurface water of which the endmember values were adopted from Zhao et al. (2020).

L199-200: Mixing Results and Discussion doesn't mean you can extrapolate your results without supporting observations. The wording is important. In this sentence a better wording could be: "The freshwater bulge also featured a relatively weak bloom, with Chl a concentrations of ~10 μg $L^{-1}$ and DO of ~250 μmol $kg^{-1}$ (equivalent to a DO saturation level of ~ 125 %). Similar blooms were previously associated with high nutrient concentrations and a long water residence time in the plume (Lu and Gan 2015)."

**[Response]**: We appreciate the reviewer's comment. Following suggesions, we have revised the sentence as "The freshwater bulge also featured a relatively weak bloom, with Chl *a* concentrations of ~ 10 μg $L^{-1}$ and DO of ~ 250 μmol $kg^{-1}$ (equivalent to a DO saturation level of ~ 125 %). Similar blooms were previously observed to be associated with high nutrient concentrations, a sufficently long water residence time and an abundance of photosynthetically active radiation (Lu and Gan, 2015)." (Page 8, Lines 204-207 of our revised MS).

L201-202: That does not seem like a relevant explanation for the lower water temperature. 1) there is no indication that the lower surface temperature is the direct result of the air temperature, 2) air temperature is lower only at the end of the leg for a short period of time and 2) air temperature could be the same in the other areas.

"during data collection", "at the time of sampling" would be better than "visits".

**[Response]**: We appreciate the reviewer's comment. We plotted the surface water temperature measured at a depth of 1 m for all stations along the cruise track with the air temperature (Figure R1), showing a consistent trend of changes in temperature. Specifically, the air temperature was lower at the end of Leg 1, also in consistence with our observations when we sampled stations to the southwest of Hong Kong. Following suggestions, we revised Figure S1 (Page 2 of our revised Supplement) by adding the surface water temperature and the statement as "Exceptions occurred to the southwest of Hong Kong where the air temperature was 2-3 °C lower at the time of sampling" (Page 8, Lines 208-209 of our revised MS).

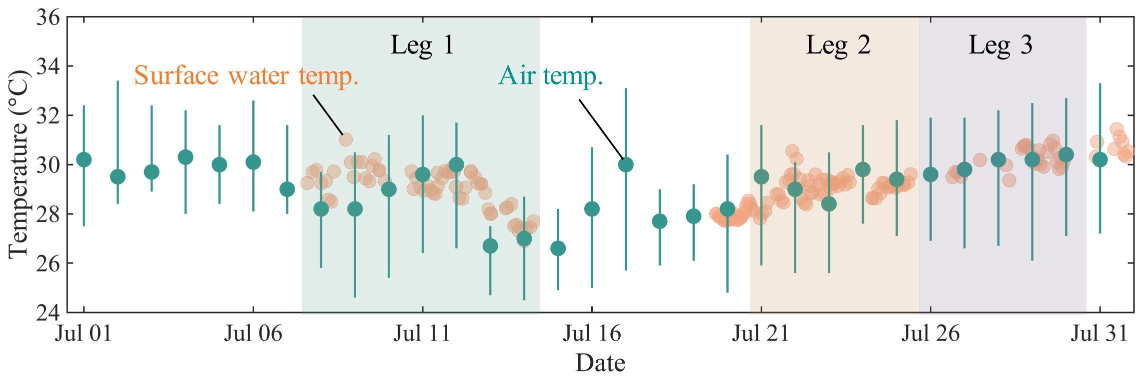


**Figure R1:** Surface water temperature and air temperature in July 2018. Surface water temperature was measured at a depth of 1 m for all stations along the cruise track. Air temperature was recorded at the Hong Kong Observatory. The shaded area indicates the cruise periods for Leg 1 (grey), Leg 2 (pink) and Leg 3 (blue), respectively.

L204: Bottom shelf waters are found in z>10-20m below plume waters. They are not "intruded". The plume is attached to the bottom in the inshore area (0<z<20) according to Figure 4.

**[Response]**: Here "shelf benthic waters" actually indicate deep shelf waters originated from the coastal current over the middle/outer shelf which flows northeastwardly in summer. The coastal current is advected upslope towards the coastal zone off the Pearl River Estuary due to irregular topography (Gan et al., 2009; Liu et al., 2020). This upslope transport prevents the buoyant plume from being bottom-advected over the shelf deeper than 20 m, and, in response to the eastwardly strengthened coastal current, the onshore invasion of deep shelf waters strengthened eastwards (Liu and Gan, 2020). Therefore, we have replaced “shelf benthic waters” by “deep shelf waters” to avoid misleading.

L208-209: please rephrase "a region... measurements"

**[Response]**: Accepted. We have revised the statement as “Additionally, a smaller-scale hypoxic zone appeared beneath the surface bloom near the Huangmaohai sub-estuary, a region where hypoxia was also ever reported but not fully covered by survey measurements.” (Page 8, Lines 214-216 of our revised MS).

L212-213: how did you calculate these areas?

**[Response]**: We interpolated DO concentrations into 0.5’×0.5’ grids over our sampling regions with observed DO data using the Kriging interpolation method. For grids with DO < 63 or 94 μmol $kg^{-1}$, we integrated their spatial area for the hypoxic or oxygen-deficient zones, respectively.

L215-216: please remove this statement. You cannot draw long term conclusions by comparing 2014 and 2018. Also, the sampling area was different.

**[Response]**: Accepted. We have removed this statement accordingly.

L224-225: That is not supported by your observations from Fig S1. Air temperature at the Hong Kong observatory was >28 at this time.

**[Response]**: During the time-series observations from July 19-20, the air temperature at the Hong Kong observatory was ~ 28 °C with a range of 26-31.6 °C (Figure R1).

L229-230: Same comment here, be careful with the wording. The bloom is within the plume and therefore more likely associated with the riverine nutrient input.

**[Response]**: We appreciate the reviewer’s comment. The bloom was indeed within the plume, and the plume waters were a mixture of freshwater and seawater, the latter of which had an elevated nutrient concentration due to the strong vertical mixing during the typhoon period. This relatively high nutrient seawater increased nutrient supplies and fueled the post-storm bloom. Therefore, the post-bloom was potentially fuelled by the nutrients mixed upward from the depth in addition to riverine inputs.

L239-241: "Although... pycnocline": This is not yet supported, please remove.

**[Response]**: During Leg 2, the similar distributions of salinity and temperature at middle and bottom layers (Figure R3, R4) indicate that the subsurface water column remained relatively well-mixed, whilst the discrepancy between the surface layer and the middle/bottom layers (Figure R2, R3, and R4) indicates the revitalization of density stratification due to freshwater buoyancy and weakened winds (Figure R5c). The following sentence also supports that the oxygen decline after the typhoon. Therefore, we would like to keep this statement — "Although the water column remained relatively well-mixed in the subsurface layer, freshwater buoyancy and weakened winds facilitated the revitalization of density stratification and subsequent oxygen decline below the pycnocline" (Page 9, Lines 248-250 of our revised MS).

L249-250: provide supporting observations or remove this statement

**[Response]**: Figure R2c shows that the surface temperature was warmed to over 30 °C during Leg 3, increasing the vertical thermal gradient relative to that during Leg 2 (Figure R2, R3, R4). The increased vertical thermal gradient strengthened the density stratification which was thus mainly driven by the freshwater inputs. We have revised the statement as "The surface layer was warmed up to over 30 °C (Fig. 3c), increasing vertical thermal gradients relative to Leg 2 (Fig. 3 and Fig. 4) and strengthening the stratification (Allahdadi and Li, 2017)" (Page 9, Lines 258-260 of our revised MS).

L265: What is the depth of this subsurface (mid-) layer shown in Fig. S2?

**[Response]**: The depth of the middle layer shown in Fig. S2 depends on the geographical locations of the stations, varying from 3-5 m at nearshoremost stations to ~ 15 m at offshoremost stations.

L265-266: "likely... winds". again, this is not shown

**[Response]**: Figure R5d shows that the southeasterly winds dominated Leg 3, which constrained the plume to the coast and even to penetrate into the subsurface layer (Huang et al., 2019; Li et al., 2021), as shown in Figure R3 and R4. We have revised the statement as "Similar to Leg 1 and Leg 2, the surface waters penetrated into the subsurface layer along the coast (Fig. 4f), likely forced by the downwelling-favourable winds (Fig. 1d) …" (Page 12, Lines 276-278 of our revised MS).

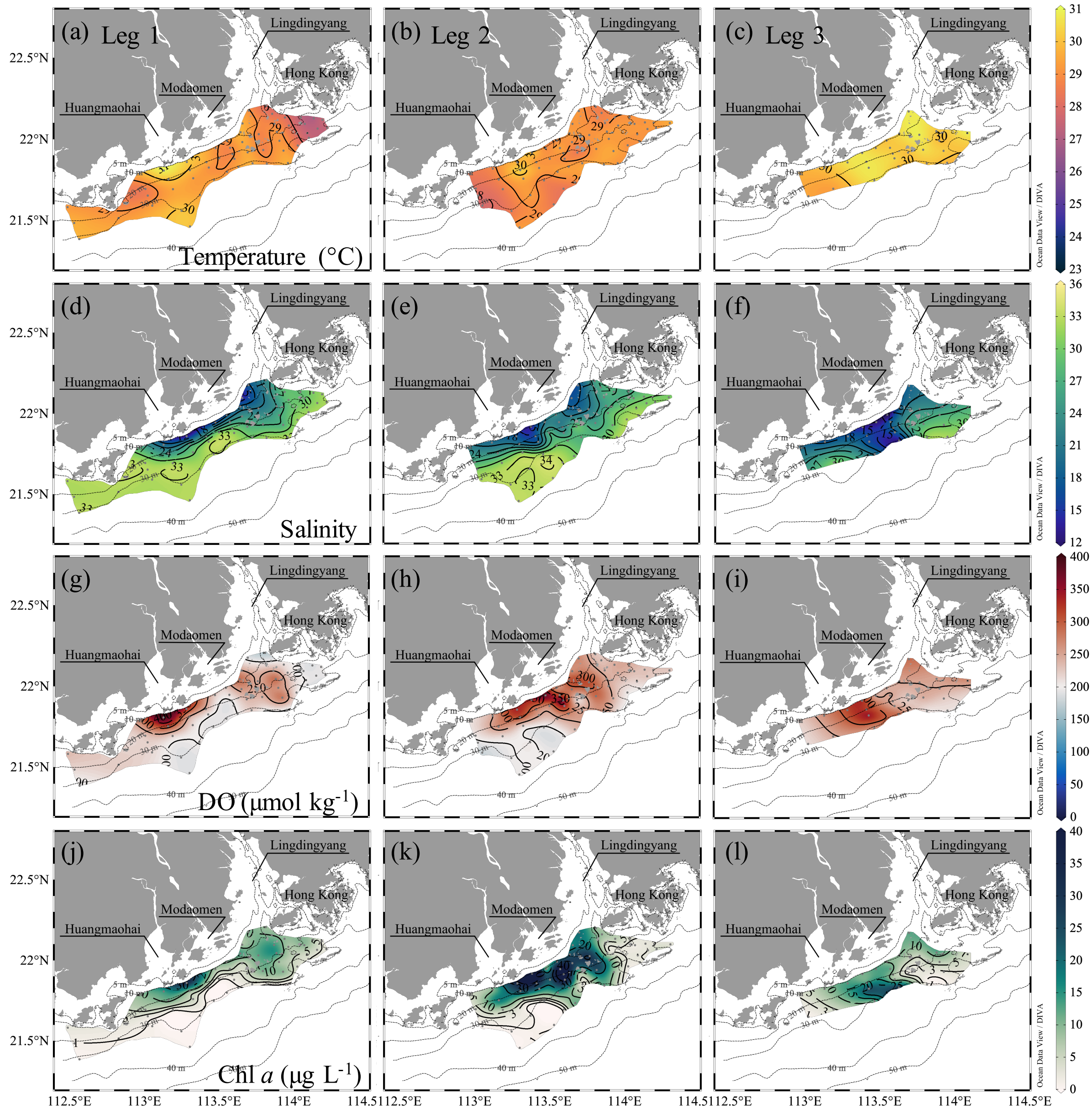


**Figure R2:** Distributions of temperature (°C), salinity, DO (μmol kg$^{-1}$) and Chl *a* concentrations (μg L$^{-1}$) at the surface water layer off the PRE during Leg 1 pre-typhoon, and during Legs 2 and 3 post-typhoon. The white and magenta contours in (g) and (w) show the hypoxic (DO < 63 μmol kg$^{-1}$) and oxygen-deficit (DO < 94 μmol kg$^{-1}$) zones. Figures were produced using Ocean Data View v. 5.3.0 (http://odv.awi.de, last access: 08 June 2020)

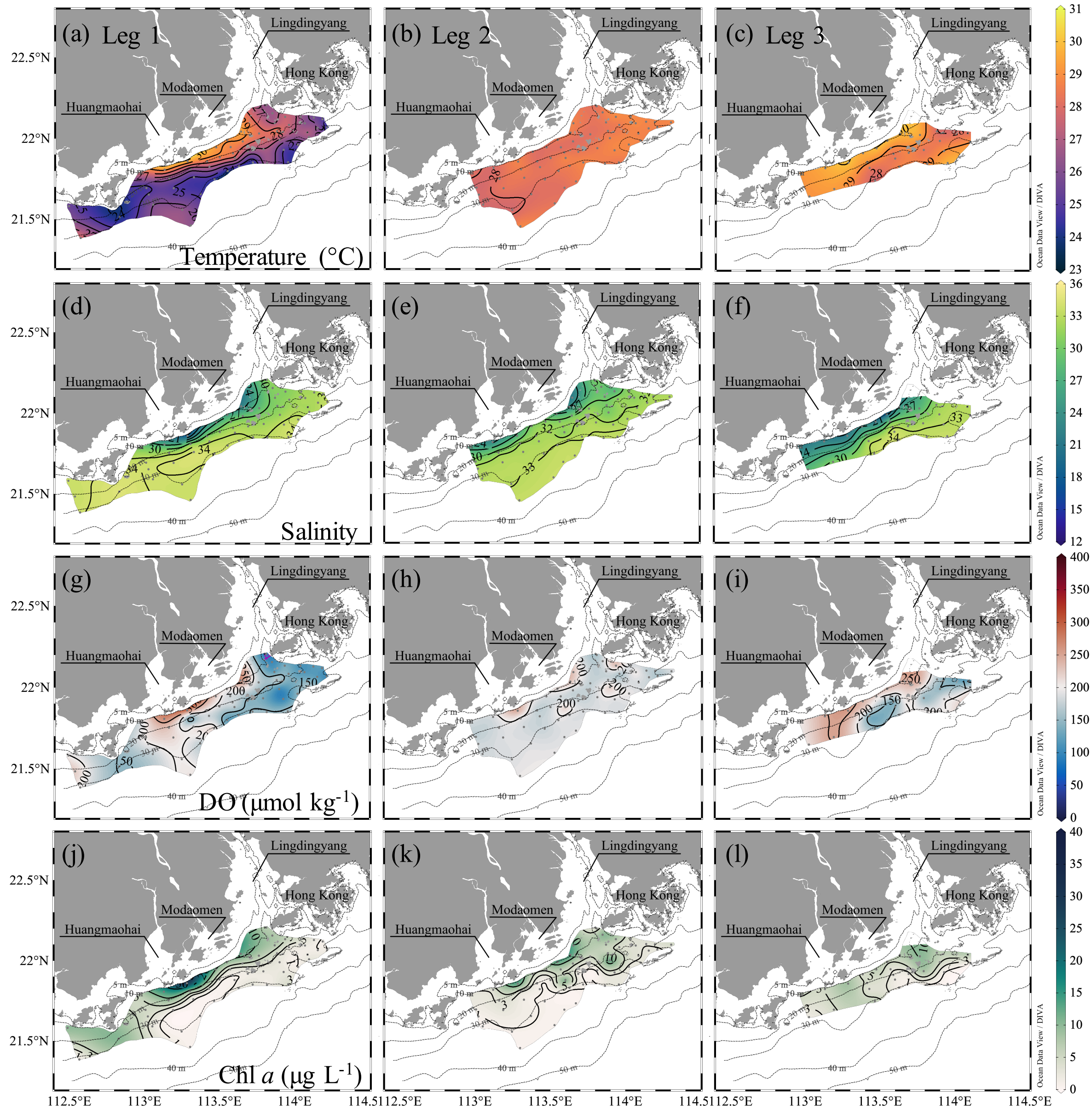


**Figure R3:** Distributions of temperature (°C), salinity, DO (μmol $kg^{-1}$) and Chl *a* concentrations (μg $L^{-1}$) at the middle layer off the PRE during Leg 1 prior to Typhoon, and during Legs 2 and 3 post-typhoon. The almost homogeneous spatial distribution was similar to the bottom layer after being disturbed by the typhoon, and reaeration along the coast in shallow waters was forced by easterly winds in Legs 1 and 3 when hypoxia developed.

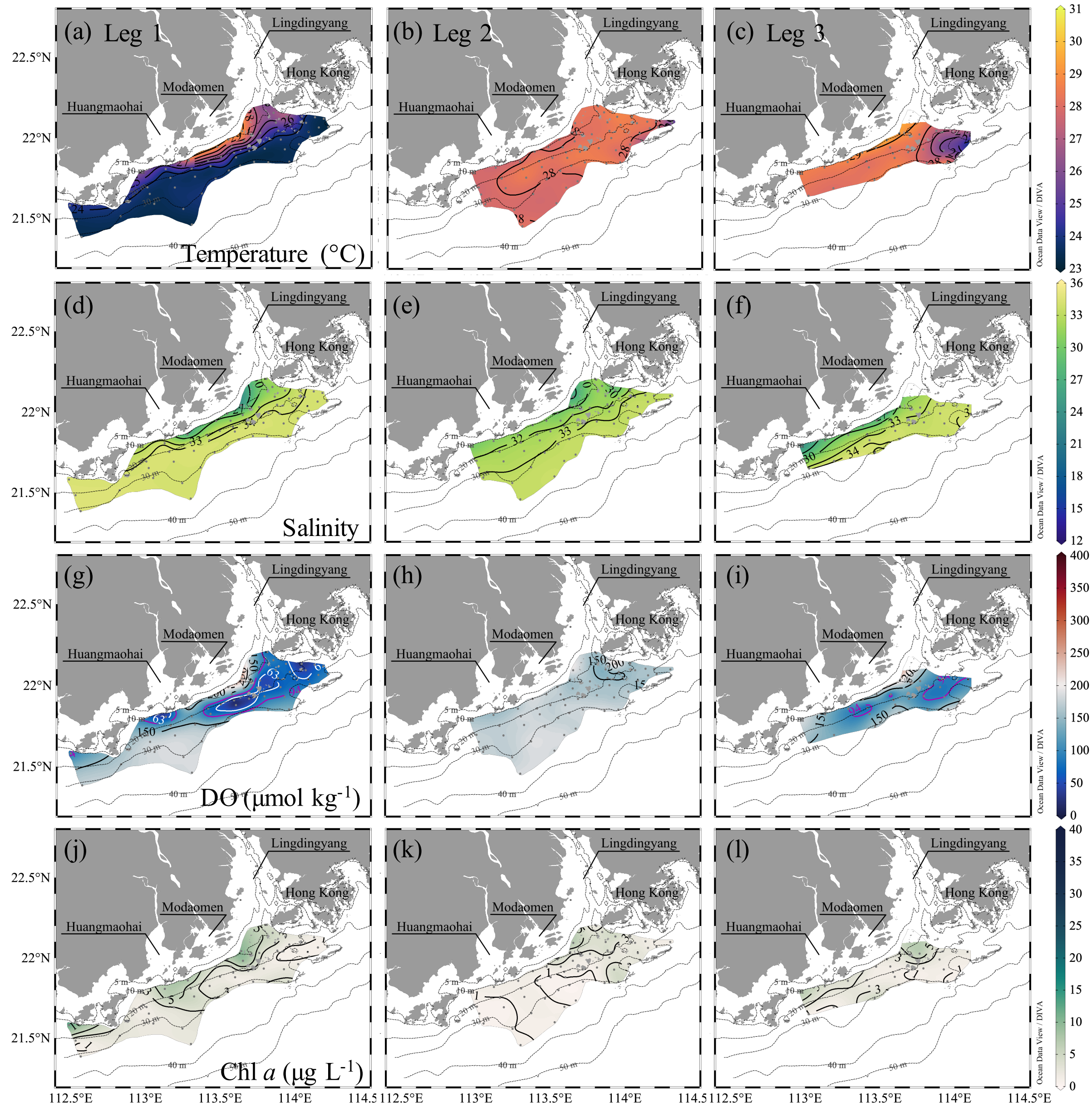


**Figure R4:** Distributions of temperature (°C), salinity, DO (μmol $kg^{-1}$) and Chl *a* concentrations (μg $L^{-1}$) at the bottom water layer off the PRE during Leg 1 pre-typhoon, and during Legs 2 and 3 post-typhoon. The white and magenta contours in (g) and (w) show the hypoxic (DO < 63 μmol $kg^{-1}$) and oxygen-deficit (DO < 94 μmol $kg^{-1}$) zones.

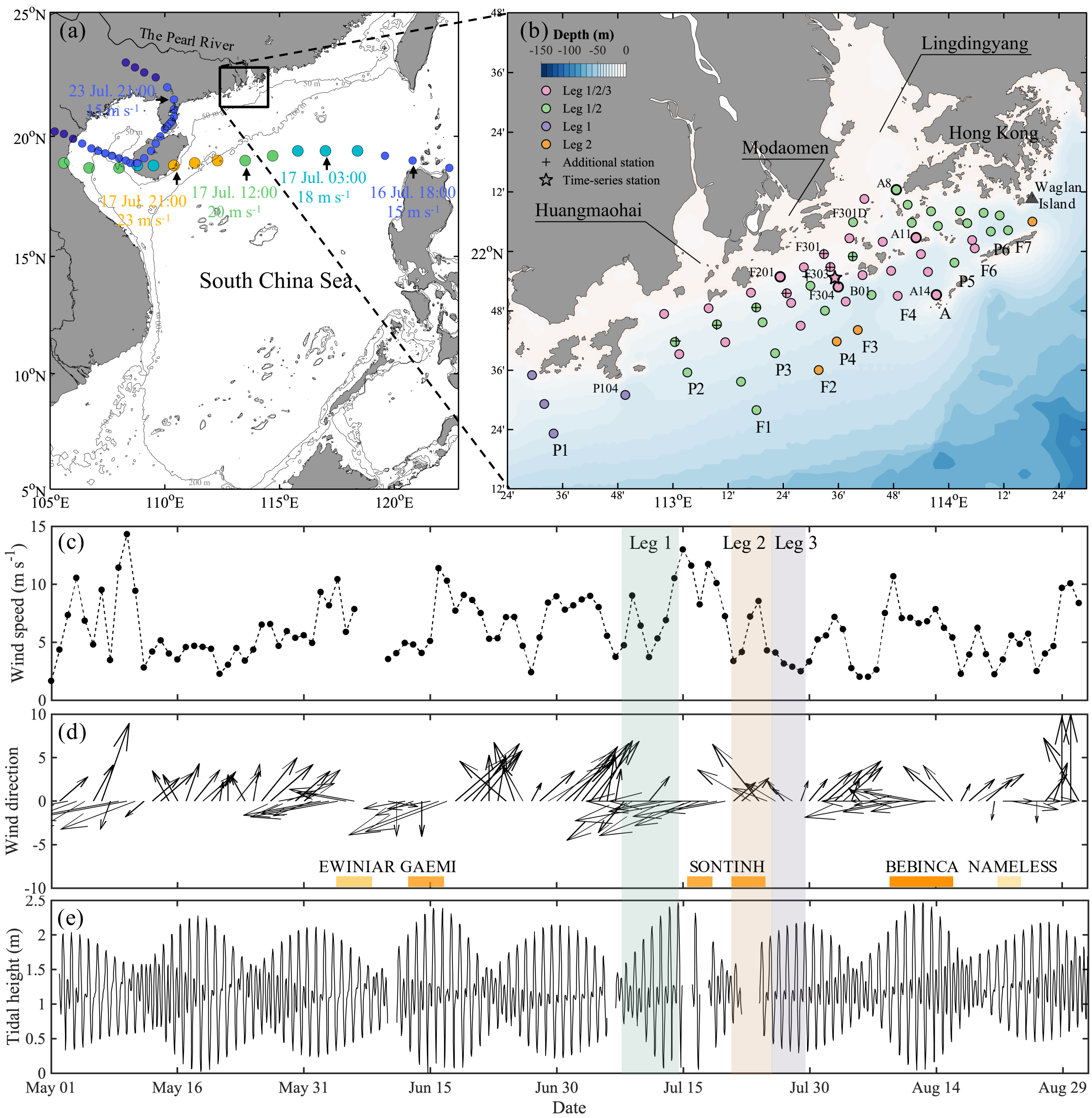


**Figure R5**: (a) Map of the study area on the shelf of the northern South China Sea (NSCS), showing the track of Typhoon SONTIHN (circles) across the NSCS during July 16-24, 2018. The color of the circles represents the magnitude of wind speed. Additionally, the smaller circles denote tropical depression (wind speeds ≤ 17.1 m $s^{-1}$) and the larger circles denote tropical storm (wind speeds within 17.2-32.6 m $s^{-1}$). The arrows denote the locations of the typhoon as marked with time and wind speed. The grey lines are the depth contours at 50 and 200 m. (b) Sampling stations on the NSCS shelf off the Pearl River Estuary in summer 2018. The pink, green, purple and orange circles denote the stations surveyed in all three legs, only both Leg 1 and Leg 2, only Leg 1 and only Leg 2, respectively. Time-series observations were conducted at Station F303 as marked by the star, and vertically high-resolution samplings were conducted at stations marked with bold circles. (c) The wind speed and (d) wind direction at Waglan Island (triangle in (b)) from May to August, 2018. Bars at the bottom of (d) mark times when tropical cyclones impacted the NSCS. (e) The tidal height at the Dawanshan gauge station near Station F303 from May to August, 2018. The shaded area indicates the cruise periods for Leg 1 (grey), Leg 2 (pink) and Leg 3 (blue), respectively.

L272: "expanded... isobath": where is this shown?

**[Response]**: We have removed this statement — "…and expanded along the 20-m isobaths".

L274-277: Again, this is not supported by your observation. It can be discussed (as in a regular discussion) but you cannot make this type of conclusion based on your observations.

**[Response]**: Comparing the bottom distributions of temperature and salinity during Leg 2 and Leg 3 (Figure R4), we found that the low-temperature, high-salinity bottom waters to the southwest of Hong Kong were upslope-invaded deep shelf waters in response to topographical-driven upwelling (Gan et al., 2009; Liu et al., 2020). By further comparing the environment settings associated with the two hypoxic centers, off the Modaomen sub-estuary and to the southwest of Hong Kong, we contend that "the shoreward intrusion of deep shelf waters is not a prerequisite for the initiation of hypoxia formation off the PRE, but it contributes to the reinstatement of hypoxia southwest off Hong Kong" (Page 12, Lines 286-288 of our revised MS).

L282: This section title is a bit redundant with the previous subsection titles. In part 3 you look at the temporal evolution of hypoxia (as stated in the section/subsection headers) and in part 4 you look into the mechanisms that lead to the temporal evolution observed in part 3. This should be reflected in the section headers.

**[Response]**: We appreciate the reviewer's comment. We have revised the section title of part 4 as "Physical and biochemcial controls on the evolution of intermittent hypoxia" (Page 13, Line 293 of our revised MS).

L292: The time series is only 26h long so you shouldn't draw too many conclusions. The end of the time series indicate that the location of the plume varies rapidly in space/time.

**[Response]**: Here we described the phenomenon based on our observations. Figure R6 clearly shows that low-salinity freshwater came along with high Chl *a* and DO concentrations at the surface layer in the second half of the observations. The signal of oxygen decline beneath the freshwater was also observed.

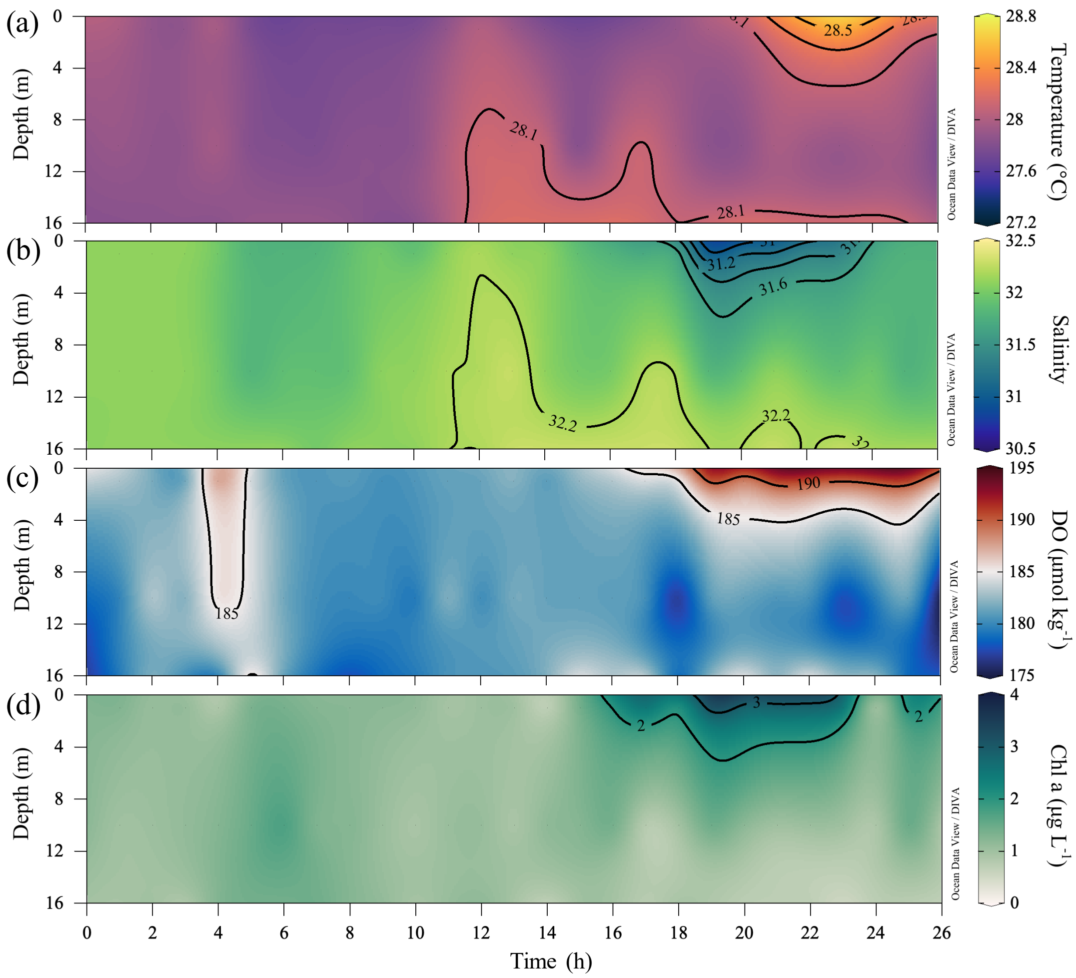


**Figure R6 :** Time-series observations of (a) temperature (°C), (b) salinity, (c) DO (μmol $kg^{-1}$) and (d) Chl *a* concentrations (μg $L^{-1}$) at Station F303 (see Fig. 1b) from July 19-20, 2018 after the typhoon passage, showing the complete destruction and the subsequent rapid development of stratification.

L292-298: all hypoxic centers occur in cold/salty waters during leg 1.

The terminology "intrusion" is misleading as it tend to indicate that offshore bottom waters are advected onshore, whereas it seems that it is the bottom-attached plume that prevents offshore bottom waters to reach the z<20m area.

**[Response]**: As responded above, deep shelf waters were actually advected onshore in the area with depths > 20 m, as the bottom waters originate from the coastal current over the middle/outer shelf which flows northeastwardly in summer. This “intrusion” of deep shelf waters does not conflict with that bottom-attached plume prevents offshore bottom waters to reach the area with depth < 20 m. We have replaced “shelf benthic waters” by “deep shelf waters”.

L317-340: You could shorten this paragraph to avoid redundancy with section 3.

**[Response]**: This paragraph focused on discussing the effect of wind speed and direction on the evolution of hypoxia, differing from the description in section 3. Some observations were referred to support our discussion. Following suggestions, we have shortened this paragraph by removing unnecessary descriptions to avoid redundancy with section 3 (Pages 14-15, Lines 328-348 of our revised MS).

L337: "with a limited spatial extent beneath the surface plume": What do you mean? vertical extent?

**[Response]**: This means that the surface plume overlapped with the bottom hypoxia with a limited horizontal extent due to an offshore or westward shift of hypoxic zones.

L345-360: You speculate here, this paragraph should be reduced to one short sentence where you mention that tide could influence your estimates of hypoxia extent.

**[Response]**: We have shortened the paragraph following suggesions. We are now focusing on effects of the spring-neap tidal oscillations (Page 8, Lines 221-225 of our revised MS).

L362-370: this paragraph is not necessary, you should focus on your results. In general, it is better to start a section by stating your results and then develop.

**[Response]**: We have removed this paragraph and started Section 4.1 by our observed mixing-induced oxygen sinks.

L371: "On the condition of a precedent restoration of density stratification": can you rephrase for clarity?

**[Response]**: This statement means that the density stratification was restored before the oxygen decline from Leg 2 to Leg 3. The restoration of density stratificaiton is also a prepresiquite for oxygen decline. We have revised the statement as "With the restoration of density stratification from Leg 2 to Leg 3,…" (Page 16, Line 356 of our revised MS).

L385-394: The main center of hypoxia off Modaomen occurs where there is no $O_2$ mixing (Figure 8d), but you seem to suggest that this area is influenced by the upwelled waters SW of Hong Kong. The two centers of hypoxia (off Modaomen and off Hong Kong) seem to have different dynamics.

**[Response]**: Although little physical oxygen mixing contributed to the hypoxia formation off Modaomen sub-estuary during Leg 3, the coverage of cold, high-salinity deep shelf waters over this hypoxic zone during Leg 1 (Figure R4) indicates that the hypoxia formation during Leg 1 was influenced by deep shelf waters, which is identical to the upwelled waters SW of Hong Kong.

L405: what do you mean here?

**[Response]**: As deep shelf waters originate from the alongshore shelf current in the low-latitude, high-temperature oligotrophic NSCS and the NSCS shelf is narrower than the East China Sea shelf, they spend a shorter time intruding toward the coastal zone after diverting its direction from the continental slope. We have revised the sentence as "Comparing with these systems, the source water originating from the low-latitude, high-temperature oligotrophic NSCS (Wong et al., 2007) has a higher DO level (AOU ~ 35 μmol $kg^{-1}$). As the NSCS shelf is narrower than the East China Sea shelf, the source water spends a shorter time intruding toward the coastal zone after diverting its direction from the continental slope (Gan et al., 2009; Wang et al., 2014). These might explain the relatively low contribution of coastal upwelling to the oxygen depletion on the inner NSCS shelf off the PRE." (Page 17, Line 381-386 of our revised MS).

L416-418: please rephrase, this was not observed in your study.

**[Response]**: We have revised the statement as "The geographical locations of high-OCR zones at the bottom layer (OCR > 10 μmol $O_2$ $kg^{-1}$ $d^{-1}$) were not fully overlapped with those of surface blooms (Fig. 3l and Fig. 8c)" (Page 17, Lines 394-396 of our revised MS) and removed the statement "even though eutrophication-produced organic matters were primarily responsible for fuelling oxygen depletion in the hypoxic zone (Su et al., 2017; Yu et al., 2020; Zhao et al., 2020)".

L421: "only the western hypoxic centre was located"

This is linked to the comment above (L385-394): it suggests different mechanisms for hypoxia formation between the two hypoxia centers?

**[Response]**: Accepted. We have revised the statement as "In fact, only the west hypoxic centre was located beneath the surface bloom from Leg 2 to Leg 3" (Page 17, Line 399 of our revised MS). As reponsed above, deep shelf waters covered the two hypoxic centres, despite organic matter of different sources and/or forms fueling oxygen decline for hypoxia formation between the two hypoxic centres.

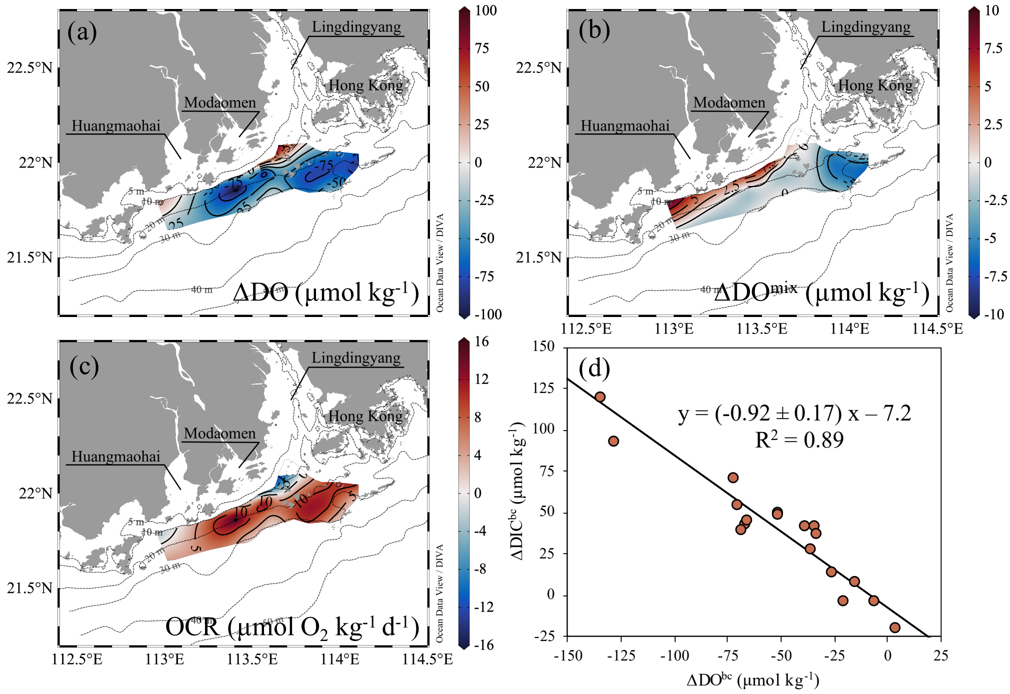


**Figure R7:** Distributions of (a) total DO changes (ΔDO, μmol kg$^{-1}$), (b) mixing-induced DO changes (ΔDO$^{mix}$, μmol kg$^{-1}$) and (c) the biochemical-induced oxygen consumption rate (OCR, μmol $O_2$ kg$^{-1}$ d$^{-1}$) between Leg 3 and Leg 2 on the inner NSCS shelf off the PRE. (d) The biochemical-induced changes in DIC (ΔDIC$^{bc}$, μmol kg$^{-1}$) vs. DO (ΔDO$^{bc}$, μmol kg$^{-1}$) in bottom waters with depths > 10 m from Leg 2 to Leg 3. The black line denotes the slope of ΔDIC$^{bc}$ plotted against ΔDO$^{bc}$ derived from the Model II regression.

L439-441: Is there a reason? it would be interesting to mention it

**[Response]**: As mentioned, "sediment oxygen demand might be significant near the seabed or in its overlying water column in shallow waters (Kemp et al., 1992; Zhang and Li, 2010)", while our sampling at the bottom layer was 4-6 m above the seabed and the water depth of the hypoxic centres was nearly 20 m. We have revised the statement as "Sediment oxygen demand might be significant near the seabed or in its overlying water column in shallow waters (Kemp et al., 1992; Zhang and Li, 2010). However, our sampling at the bottom layer was 4-6 m above the seabed and the water depth of the hypoxic zones was nearly 20 m (Fig. 4). In such sampling area, Cui et al. (2019) found that oxygen losses by sediment oxygen demand (i.e., benthic respiration) were much smaller than the bacterial respiration in the water column based on both incubation experiments and oxygen budget analysis." (Page 18, Lines 415-420 of our revised MS).

L457: See previous comments about intrusions

**[Response]**: As reponsed above, deep shelf waters were actually advected onshore in the area with depths > 20 m, as the bottom waters originate from the coastal current over the middle/outer shelf which flows northeastwardly in summer. We have replaced “shelf benthic waters” by “deep shelf waters”.

L444-462: This paragraph is not very clear and I am not sure that it adds anything to your story.

**[Response]**: This paragraph explains how our estimated OCR differs from that derived from the steady-state budget analysis and how oxygen sources/sinks shift with oxygen decline for hypoxia formation. We have revised this paragraph for clearly elaborating these issues (Pages 18-19, Lines 423-442 of our revised MS).

L472-473/480-481: The hypoxia formation time scale (6-12days) is shorter than the estimate of residence time. Also 15 days in Li et al (2020) is a depth-averaged estimate so residence time in bottom waters could be significantly longer.

**[Response]**: We appreciate the reviewer’s comment. We have revised the statement accordingly as “These estimates of hypoxia formation timescale are shorter than the bottom water residence time (> 15 days, Li et al. (2020)), which favoured the hypoxia formation to the west off the PRE (Su et al., 2017; Zhao et al., 2020)” (Page 19, Lines 452-453 of our revised MS) and “…extend to a larger hypoxic zone within the water residence time of > 15 days” (Page 19, Lines 460-461 of our revised MS).

L475: "shoreward-intruded": same comment as before, "shelf bottom waters" is more appropriate

**[Response]**: As reponsed above, deep shelf waters were actually advected onshore in the area with depths > 20 m, as the bottom waters originate from the coastal current over the middle/outer shelf which flows northeastward in summer. We have replaced “shelf benthic waters” by “deep shelf waters”.

L498-501: rephrase for clarity.

what does that mean: "had the potential to overwhelmingly destroy the stability of the water column"? How is this defined?

**[Response]**: As mentioned in the original MS, “at least four named tropical cyclones impacted the study area from May to August in 2018, most of which … and increased the wind speed up to over 9 m $s^{-1}$, being able to destroy water column stratification and interrupt hypoxia formation (Geng et al., 2019)”, which help understand these follow-up sentences. Annually, about five of the six annual tropical cyclones that travel across the northern South China Sea from May to September (when seasonal hypoxia develops), on average, had the maximum wind speed of > 9 m $s^{-1}$ (Figure R7), which could well vertically mix the water column.

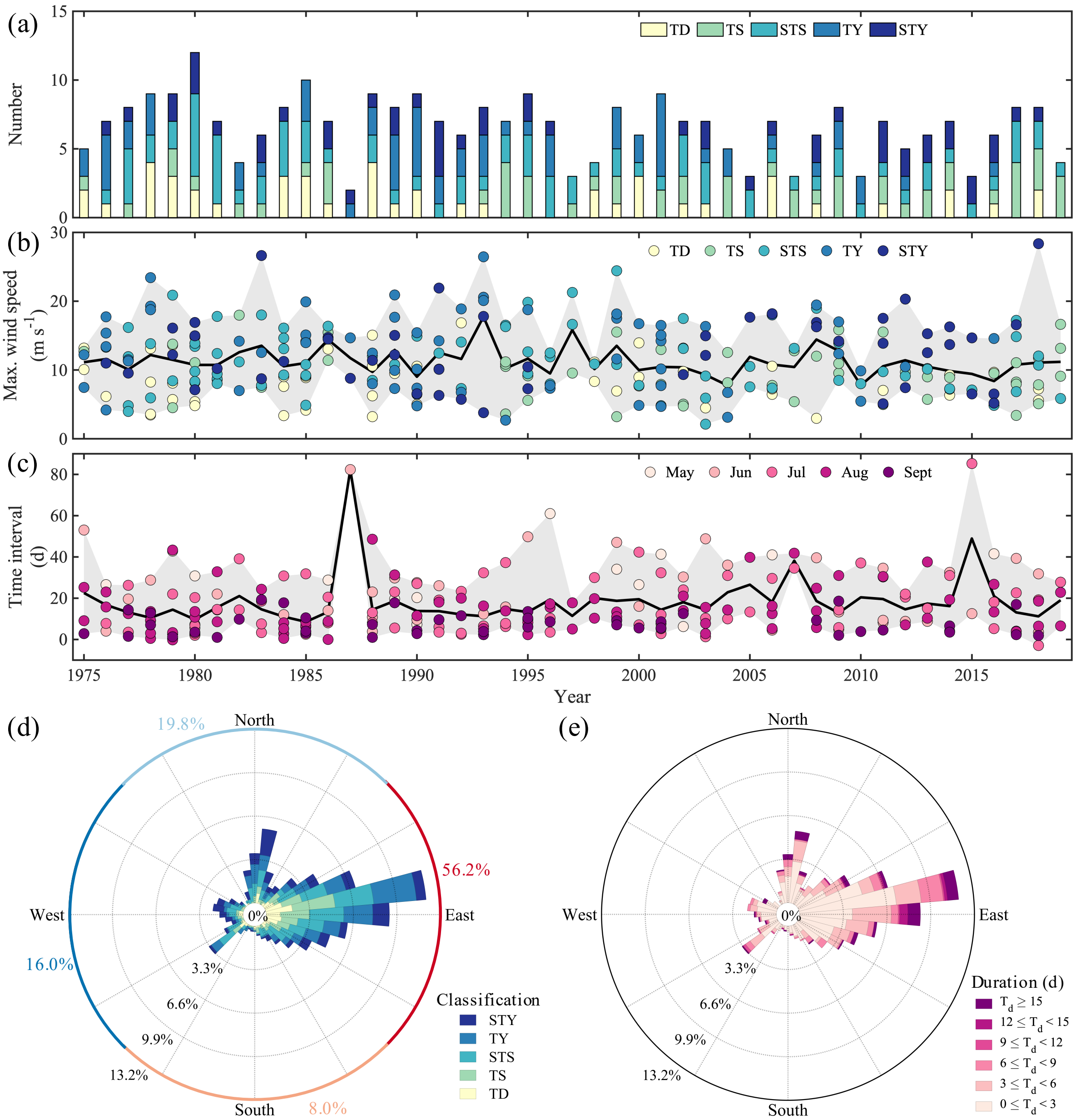


**Figure R7:** Statistics of tropical cyclones passing the northern South China Sea (NSCS) from May to September over 1975-2019. (a) Numbers of tropical cyclones. TD, TS, STS, TY and STY represent tropical depressions (the maximum wind speed near the centre is between 10.8-17.1 m $s^{-1}$ over its lifetime), tropical storms (17.2-24.4 m $s^{-1}$), strong tropical storms (24.5-32.6 m $s^{-1}$), typhoons (32.7-41.4 m $s^{-1}$) and strong typhoons (41.5-50.9 m $s^{-1}$), respectively. (b) The maximum wind speed of each tropical cyclone. The black line and grey shadow denote the annual average and range of the maximum wind speeds. (c) The time interval between two successive tropical cyclones. The black line and grey shadow denote the annual average and range of the time intervals. (d) The wind rose of the intensity of tropical cyclones. (e) The wind rose of the duration of tropical cyclones. The wind speed in (b) and wind direction in (d, e) were recorded at the Waglan Island station.

L508-509: This sentence is odd.

**[Response]**: As the time interval between two successive tropical cyclones was mostly less than 15 days, close to the timescale for hypoxia formation. The number of the time interval < 15 days showed a decreasing trend over 1975-2019 (Fig. R7c). Specifically, this number was averaged 4.1 per year before the year of 2000, in contrast to 2.8 per year after 2000. Therefore, hypoxia was more probably destroyed by tropical cyclones before the year of 2000, resulting in few observations of hypoxia in this study area. We have added the statements "The number of the time interval < 15 days showed a decreasing trend over 1975-2019 (Fig. 9c). Specifically, this number was averaged 4.1 per year before the year of 2000, in contrast to 2.8 per year after 2000." (Page 20, Lines 488-489 of our revised MS) to help clarify why less hypoxia was formed and even observed before the year of 2000 (Yin et al., 2004; Rabouille et al., 2008).

L511: suggestion: "Although strong winds constrain the development of hypoxia, tropical cyclones potentially..."

**[Response]**: Accepted. We have revised the sentence accordingly (Page 20, Line 494 of our revised MS).

L515-516: The reference is in chinese and therefore not accessible to most reader, please remove. You can provide a time series of rainfall in the supporting material if necessary or add it to Figure 1. However, what you mention here is river discharge and it would be more appropriate to show a time series of freshwater discharge in the PRE. This would fit well in Figure 1.

**[Response]**: We appreciate the reviewer's comment and have removed the reference. A time series of freshwater discharge has been shown in Li et al. (2021).

L518: suggested change: "... PRE did not increase significantly". See comment above about the time series of river discharge.

**[Response]**: Accepted. We have revised it accordingly (Page 20, Line 499 of our revised MS).

L521-522: remove "as shown in Fig. 3 that strong blooms occurred in the surface plume along the coast with much higher Chl *a* concentrations during Leg 2 than that during Leg 1."

**[Response]**: Here our observations are to support the statement "Enhanced vertical mixing and/or freshwater discharge supplied large amounts of nutrients to the surface layer to fuel phytoplankton blooms following large storms (Zhao et al., 2009; Ni et al., 2016; Wang et al., 2017)". We would like to keep them.

L526: Figure 4 show that $O_2$ is decreasing in bottom waters but hypoxia did not re-establish yet.

**[Response]**: Hypoxia was actually re-established durng Leg 3 with DO concentrations of ~45 μmol $kg^{-1}$. It was not clearly shown in Figure 4 because of the limited hypoxia area. We have revised the statement as "Off the PRE, we also found that hypoxia re-occurred in the wake of a more extensive freshwater plume and enhanced eutrophication after the passage of typhoon SONTIHN (e.g., ~ 45 μmol $kg^{-1}$ at stations F202 and F302)" (Pages 20-21, Lines 507-509 of our revised MS).

L542: the decreasing frequency is in the tropics but not necessarily further north, e.g. a recent study with similar conclusions: https://advances.sciencemag.org/content/6/51/eabd5109

**[Response]**: The recent study, Chu et al. (2020), showed that "a decreased TC track density over almost the entire tropics and subtropics in response to $CO_2$ doubling. In the 4×$CO_2$ experiment, the reduction in TC density is even more pronounced, extending further into the subtropics. TC track density decreases globally by 7 and 32% in the 2×$CO_2$ and 4×$CO_2$ experiments, respectively". We have revised the statement as "In a changing climate, tropical cyclone features are believed to have a trend with higher intensity but lower frequency" (Page 21, Lines 513-514 of our revised MS).

L551: For clarity you could say that the development of hypoxia depend on a trade-off between between storm intensity and frequency.

**[Response]**: Accepted. We have revised the statement accordingly (Page 21, Lines 522-523 of our revised MS).

L557-568: this is more a summary than conclusions.

**[Response]**: We have revised the section Conclusions beyond a summary (Page 23, Lines 540-554 of our revised MS).

L564: suggested modification: "This hypoxia timescale is shorter than water residence time but comparable to the disturbance of hypoxia..."

**[Response]**: Accepted. We have revised the statement accordingly (Page 23, Line 549 of our revised MS).

L566-568: please remove

**[Response]**: We have removed this statement accordingly.

L572: http://www.geodata.cn: the website doesn't seem to be available on english. Will the data be available to the non-chinese speaking readers?

**[Response]**: Yes. We have applied for the English version and the data will later be available to non-Chinese speaking readers.

Figure 9c: why is there negative time intervals?

**[Response]**: The negative intervals indicate the partial overlaps in time of two successive tropical cyclones impacted the NSCS, that is, the second one starts to impact the NSCS before the dying-out of the first one. We have added an explanation for negative values in the figure title (Page 22, Figure 9 of our revised MS).

**Minor comments/edits:**

L191/217/244: Suggestion: add the leg # for each phase in the header, i.e. "(Leg 1)" for section 3.1

**[Response]**: We appreciate the reviewer's suggestion. Although sub-sections 3.1 and 3.3 well corresponds to Leg 1 and Leg 3, sub-section 3.2 includes both time-series observations and Leg 2. They do not follow a strict relationship. Therefore, we would like not to add the leg # in the headers.

L204 and all occurrences elsewhere: bottom seem more appropriate than benthic

**[Response]**: We appreciate the reviewer's suggestion. "Deep shelf waters" might be more appropriate than "shelf benthic waters" or "shelf bottom waters", as deep shelf waters originate from the alongshore shelf current which flows northeastwardly in summer and invade upslope off the Pearl River Estuary due to irregular topography (Gan et al., 2009; Liu et al., 2020). Therefore, we have replaced all "shelf benthic waters" by "deep shelf waters" throughout our MS.

L209: suggestion: "The general spatial pattern of hypoxic centers..."

**[Response]**: Accepted. We have revised the sentence accordingly (Page 8, Line 216 of our revised MS).

L228: suggestion: Large phytoplankton blooms were identified in the surface plume between...

**[Response]**: Accepted. We have revised the sentence accordingly (Page 9, Line 237 of our revised MS).

L235: remove "however"

**[Response]**: Accepted. We have removed "however" accordingly (Page 9, Line 244 of our revised MS).

L550: remove "enduring"

**[Response]**: Accepted. We have removed "enduring" accordingly (Page 23, Line 522 of our revised MS).

Figure 7: it should be: "Profiles of temperature (°C) (blue dashed lines)"

**[Response]**: Accepted. We have corrected the figure title as "**Figure 7**: Profiles of temperature (°C) (blue dashed lines), salinity (pink solid lines), …" (Page 15, Figure 7 of our revised MS).

Figure S2: DO: the color bar is not complete

**[Response]**: Accepted. We have corrected the color bar for DO in Figure S2 (Page 3 of our revised Supplement).

L311: (e.g., stations A8 and A11, Fig. 7a)

**[Response]**: Accepted. We have added "A11" in the sentence accordingly (Page 14, Line 322 of our revised MS).

**Anonymous Referee #2**

I thank the authors for their extensive work to revise the paper. I suggest a few final clarifications.

**[Response]**: We appreciate the reviewer's affirmation of our revisions.

(1) in the methods where the stratification calculation is described, the authors don't specifically say where and when they applied computations of stratification from their data and why. It is a small thing, but perhaps add a sentence to make clear where this stratification index was calculated.

Stratification – say where and when you calculate it (see methods)

**[Response]**: We appreciate the reviewer's suggestion. We have added the statement in the methods — "CTD temperature and salinity were used to calculate the buoyancy frequency for sampling stations, to indicate the controls of density stratification on the development of hypoxia (Section 4.1)" (Page 4, Line 116-118 of our revised MS).

(2) Line 829 – In the new discussion of tidal forcing oxygen, the authos refer to mg/L units of oxygen, which is different from the rest of the paper. Can this be referred to in umol/kg for consistency? Weight units are also used in the section beginning on 1065.

**[Response]**: We appreciate the reviewer's comment. We have unified the unit for oxygen as μ mol $kg^{-1}$ throughout our revised MS.

(3) "organic matters" should be "organic matter" throughout the manuscript.

**[Response]**: Accepted. We have replaced all "organic matters" by "organic matter" in our revised MS.

(4) Thus authors add some new discussion which says "The oxygen enriched incubation of unfiltered water samples also revealed that the OCR could be significantly enhanced when the initial *in situ* DO concentration was low (e.g., ~ 30 μmol $kg^{-1}$), but changed little when the *in situ* DO concentration was higher than ~ 90 μmol $kg^{-1}$ (He et al., 2014)." It is not entirely clear what is meant by this. Were there experiments performed where the same water sample was incubated at ambient DO (30 umol/kg; "incubation 1") and then another sample of the same water was enriched with oxygen and incubated ("incubation 2)? It seems so because the context of the statement seems to support the idea. If I am right, the sentence should be re-worded, or perhaps slightly expanded to be clear how the "enhancement" was determined.

**[Response]**: This new discussion indicates the OCR varies with the *in situ* DO concentration, that is, when *in situ* DO concentration was higher than ~ 90 μmol $kg^{-1}$, the OCR changed little, while when the *in situ* DO concentration decreased to ~ 30 μmol $kg^{-1}$, the OCR also decreased. The reviewer was right that He et al. (2014) performed the oxygen enriched incubation using two samples of the same water: one with in situ oxygen and another one bubbled with fresh air to enrich the oxygen before incubation. We have revised the statement as “The oxygen enriched incubation of unfiltered water samples also revealed that the OCR changed little when the in situ DO concentration was higher than ~ 90 μmol $kg^{-1}$, but decreased when the in situ DO concentration decreased to ~ 30 μmol $kg^{-1}$ (He et al., 2014).” (Page 18, Line 429-432 of our revised MS).

## References


Allahdadi, M. N. and Li, C.: Numerical Experiment of Stratification Induced by Diurnal Solar Heating Over the Louisiana Shelf, in: Modeling Coastal Hypoxia: Numerical Simulations of Patterns, Controls and Effects of Dissolved Oxygen Dynamics, edited by: Justic, D., Rose, K. A., Hetland, R. D. and Fennel, K., Springer International Publishing, Cham, 1-22, https://doi.org/10.1007/978-3-319-54571-4_1, 2017.

Chu, J.-E., Lee, S.-S., Timmermann, A., Wengel, C., Stuecker, M. F. and Yamaguchi, R.: Reduced tropical cyclone densities and ocean effects due to anthropogenic greenhouse warming, Sci Adv, 6, eabd5109, https://doi.org/10.1126/sciadv.abd5109, 2020.

Cui, Y. S., Wu, J. X., Ren, J. and Xu, J.: Physical dynamics structures and oxygen budget of summer hypoxia in the Pearl River Estuary, Limnol Oceanogr, 64, 131-148, https://doi.org/10.1002/lno.11025, 2019.

Gan, J., Cheung, A., Guo, X. and Li, L.: Intensified upwelling over a widened shelf in the northeastern South China Sea, Journal of Geophysical Research: Oceans, 114, https://doi.org/10.1029/2007JC004660, 2009.

Geng, B. X., Xiu, P., Shu, C., Zhang, W. Z., Chai, F., Li, S. Y. and Wang, D. X.: Evaluating the Roles of Wind- and Buoyancy Flux-Induced Mixing on Phytoplankton Dynamics in the Northern and Central South China Sea, J Geophys Res-Oceans, 124, 680-702, https://doi.org/10.1029/2018jc014170, 2019.

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

Huang, J., Hu, J., Li, S., Wang, B., Xu, Y., Liang, B. and Liu, D.: Effects of Physical Forcing on Summertime Hypoxia and Oxygen Dynamics in the Pearl River Estuary, Water-Sui, 11, https://doi.org/10.3390/w11102080, 2019.

Kemp, W. M., Sampou, P. A., Garber, J., Tuttle, J. and Boynton, W. R.: Seasonal depletion of oxygen from bottom waters of Chesapeake Bay: roles of benthic and planktonic respiration and physical exchange processes, Mar Ecol Prog Ser, 85, 137-152, http://www.jstor.org/stable/24829928, 1992.

Li, D., Gan, J., Hui, C., Yu, L., Liu, Z., Lu, Z., Kao, S.-J. and Dai, M.: Spatiotemporal Development and Dissipation of Hypoxia Induced by Variable Wind-Driven Shelf Circulation off the Pearl River Estuary: Observational and Modeling Studies, Journal of Geophysical Research: Oceans, 126, e2020JC016700, https://doi.org/10.1029/2020JC016700, 2021.

Li, D., Gan, J., Hui, R., Liu, Z., Yu, L., Lu, Z. and Dai, M.: Vortex and Biogeochemical Dynamics for the Hypoxia Formation Within the Coastal Transition Zone off the Pearl River Estuary, Journal of Geophysical Research: Oceans, 125, e2020JC016178, https://doi.org/10.1029/2020JC016178, 2020.

Liu, Z. and Gan, J.: A modeling study of estuarine–shelf circulation using a composite tidal and subtidal open boundary condition, Ocean Model, 147, 101563, https://doi.org/10.1016/j.ocemod.2019.101563, 2020.

Liu, Z., Zu, T. and Gan, J.: Dynamics of cross-shelf water exchanges off Pearl River Estuary in summer, Prog Oceanogr, 189, 102465, https://doi.org/10.1016/j.pocean.2020.102465, 2020.

Lu, Z. M. and Gan, J. P.: Controls of seasonal variability of phytoplankton blooms in the Pearl River Estuary, Deep-Sea Res Pt Ii, 117, 86-96, https://doi.org/10.1016/j.dsr2.2013.12.011, 2015.

Ni, X., Huang, D., Zeng, D., Zhang, T., Li, H. and Chen, J.: The impact of wind mixing on the variation of bottom dissolved oxygen off the Changjiang Estuary during summer, J Marine Syst, 154, 122-130, https://doi.org/10.1016/j.jmarsys.2014.11.010, 2016.

Rabouille, C., Conley, D. J., Dai, M. H., Cai, W. J., Chen, C. T. A., Lansard, B., Green, R., Yin, K., Harrison, P. J., Dagg, M. and Mckee, B.: Comparison of hypoxia among four river-dominated ocean margins: The Changjiang (Yangtze), Mississippi, Pearl, and Rhône rivers, Cont Shelf Res, 28, 1527-1537, https://doi.org/10.1016/j.csr.2008.01.020, 2008.

Su, J. Z., Dai, M. H., He, B. Y., Wang, L. F., Gan, J. P., Guo, X. H., Zhao, H. D. and Yu, F. L.: 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, 14, 4085-4099, https://doi.org/10.5194/bg-14-4085-2017, 2017.

Wang, B., Hu, J. T., Li, S. Y. and Liu, D. H.: A numerical analysis of biogeochemical controls with physical modulation on hypoxia during summer in the Pearl River estuary, Biogeosciences, 14, 2979-2999, https://doi.org/10.5194/bg-14-2979-2017, 2017.

Wang, D. X., Shu, Y. Q., Xue, H. J., Hu, J. Y., Chen, J., Zhuang, W., Zu, T. T. and Xu, J. D.: Relative contributions of local wind and topography to the coastal upwelling intensity in the northern South China Sea, J Geophys Res-Oceans, 119, 2550-2567, https://doi.org/10.1002/2013jc009172, 2014.

Wong, G. T. F., Ku, T.-L., Mulholland, M., Tseng, C.-M. and Wang, D.-P.: The SouthEast Asian Time-series Study (SEATS) and the biogeochemistry of the South China Sea—An overview, Deep Sea Research Part II: Topical Studies in Oceanography, 54, 1434-1447, https://doi.org/10.1016/j.dsr2.2007.05.012, 2007.

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

Zhang, H. and Li, S. Y.: Effects of physical and biochemical processes on the dissolved oxygen budget for the Pearl River Estuary during summer, J Marine Syst, 79, 65-88, https://doi.org/10.1016/j.jmarsys.2009.07.002, 2010.

Zhao, H., Tang, D. L. and Wang, D. X.: Phytoplankton blooms near the Pearl River Estuary induced by Typhoon Nuri, J Geophys Res-Oceans, 114, https://doi.org/10.1029/2009jc005384, 2009.

Zhao, Y., Liu, J., Uthaipan, K., Song, X., Xu, Y., He, B., Liu, H., Gan, J. and Dai, M.: Dynamics of inorganic carbon and pH in a large subtropical continental shelf system: Interaction between eutrophication, hypoxia, and ocean acidification, Limnol Oceanogr, 65, 1359-1379, https://doi.org/10.1002/lno.11393, 2020.