Responses to Comments

General comments:

The revised manuscript is somewhat refocused toward nutrient limitation, plankton community dynamics and their effect on hypoxia. The study concludes that Si and P are the most limiting nutrients in the region. Although this is a legitimate conclusion based on their model results, I am not convinced that this is a good representation of the system.

The model indicates widespread P limitation in PS and widespread Si limitation in PL, with N limitation found sometimes on the western shelf. Does this agree with our current understanding of nutrient dynamics in this area? Si limitation patterns do not seem to agree with the literature cited in the manuscript.

My worry is that the model is not well tuned and constrained by observations, including resource limitation data. The authors mention the importance of having more complexity in the model to better represent resource limitation and oxygen dynamics. However, more complexity results in more nonlinearities, which may not be real if the model is not well constrained by observations. The fact that N mitigation results in less oxygen in bottom waters may be one on these unconstrained nonlinearities.

Another issue is that results are interpreted in length but not discussed. The Discussion section presents new results about nutrient mitigation experiments but those are not discussed in light of the literature. Results presented in section 4 are not discussed later on. The lack of discussion limits the amount of trust the reader has regarding the model results.

Overall, model results should be more supported by observations and by a mechanistic understanding of resource limitation in the region.

Responses to the general comments:

After carefully double-checking the parameterization of our biogeochemical model, we found that the half-saturation coefficients for PO_4 (KPO4S and KPO4L) needed to be appropriately designed. We updated the half-saturation coefficients for PO_4 to be 0.03125 mmol P m^{-3} for the PS and 0.1875 mmol P m^{-3} for the PL, 1/16 of the corresponding half-saturation coefficients for NO_3. This parametrization method was also applied by Laurent et al. (2012) to discuss the effects of P limitation on the LaTex shelf. We reran the 2006-2020 hindcast and updated all the results accordingly.

According to the new results, P limitation usually occurs around the river outlets, while N and Si limitations are found in the middle and west LaTex shelf. We added section 3.3 for nutrient limitation validation in the updated manuscript. Our N and P limitation patterns align well with previous bioassay studies. While we could not find any bioassay studies in the west shelf (<-92°W) in the recent two decades related to the discussion of Si limitation, indirect evidence from concentration measurements (Dortch and Whitledge, 1992) suggested that Si limitation could overwhelm the N limitation in the deep gulf waters (depth > 50 m). Our model studies show that the Si limitation is most induced by the intrusion of open ocean water to the western shelf (Figures 11 f and g). Recent studies also pointed out that marine diatoms require a lower N:P:Si (=16:1:20) ratio (Billen and Garnier, 2007; Royer, 2020), indicating that Si limitation is highly possible even if Si concentration is higher than N concentration. We posted the discussion on Si limitation in sections 3.3 and 4.1.

We tried to illustrate the impacts of plankton complexity on productions and DO dynamics, starting with intensive validation and ending with analysis based on multiple snapshots from the model results. Our model successfully reproduced a bi-peak primary production pattern in spring and early summer, aligned with the pattern from satellite-derived chlorophyll *a* concentration (see section 4.2 and Fig. 12 in the manuscript). This pattern was attributed to the competition of different phytoplankton functional groups for nutrients and grazing pressure from the zooplankton groups. The combined effects can lead to spatial differences in PS and PL distribution and further the bi-peak total primary production in the LaTex shelf. We found direct evidence of the spatial difference of the dominated phytoplankton species from a cruise study in 2013 and 2014 (Anglès et al., 2019). Our results (Fig. C4–C5) aligned well with their findings. We further sampled multiple snapshots of different DO contribution terms (Fig. 16–17) and demonstrated that different planktonic groups contributed differently to DO changes in the upper water column and further affected the DO gain/loss patterns in the bottom layer through physical transport processes (e.g., vertical diffusion).

In the revised one, we merged the results and discussion in section 4, which were divided into three parts focusing on (1) nutrient limitation, (2) plankton community interactions, and (3) DO dynamics. In each subsection, we posted our findings, followed by a discussion, including a comparison against previous studies, more observational evidence supporting our findings, and suggestions on further observational studies and model development.

Specific comments:

L28: it is odd to associate the timing of hypoxia with mid summer cruises (which do not provide temporal information)

Responses: This conclusion was based on monthly observational data and continuously recorded data from earlier hypoxia research (Rabalais et al., 1991; 2002). We cited these works in our revised manuscript on L26–27.

L76: doesn't that contradict the previous sentences?

Responses: This statement was based on the McCarthy et al.'s (2013) results where the SOC was measured 7-fold greater than the respiration rate at water overlaying the sediment. Then we calculated the ratio of SOC/(SOC+overlaying respiration)=0.87 to emphasize the importance of SOC in changing the bottom DO. We removed this sentence in the revised manuscript to avoid confusion.

L86-87: It is the other way around, at the peak of the bloom there is more SOC because more deposition and less SOC in the subsequent months.

Responses: Thanks. We have corrected this statement in L48–49.

L174-178: This is weak evidence of the importance of Si limitation in this system

Responses: We kept this part in the introduction and added more observational evidence by Quigg et al. (2011), seeing L75-76.

We added more evidence in section 3.3 (validation of nutrient limitation) and section 4.1 (results and discussion of nutrient limitation). In section 3.3, Si limitation is supported by bioassay studies by Nelson and Dortch (1996), Quigg et al. (2011), and Smith and Hitchcock (1994). Although we did not find bioassay studies related to Si limitation over our analysis period (2007–2020), strong clue of Si limitation has been documented and should not hinder model development.

In section 4.1, we discussed that Si limitation is possible as the riverine N:Si is near 1:1 and marine diatoms require a lower N:P:Si ratio (16:1:20, Billen and Garnier, 2007; Royer, 2020) than the Redfield ratio (16:1:16). As riverine Si:P is larger than 16:1 and 20:1, P limitation is more pronounced around the river mouths as evidenced by observations and our model results (Fig. 4–5). However, in waters far from the mouths, P limitation is usually replaced by N or Si limitation. Accordingly, although Si is excessive over P around the river mouths, Si can be more limited than N in other shelf regions as the uptake efficiency of Si by phytoplankton is somewhat higher than that of N. Our model results show that Si limitation develops as currents turn eastward in summer, allowing intrusion of waters with a higher N:Si ratio than 1:1 (Fig. 11 and C3). This mechanism has not yet been discussed in previous studies.

L180: That is not true. What observations that emphasize N and P limitation? There is no biology in Hetland and DiMarco (2008) so unless you refer to oxygen data your statement does not apply to this study. For the other cited studies, the models were validated against these observations.

Response: We rewrote this statement and removed the citation of Hetland and DiMarco (2008). Please see L82–83 in the revised manuscript.

L183-187: You need to provide more support for your study, saying that previous models are based on misleading observations and oversimplified is not enough to justify

your study. Why and how do you think Si is an important limiting nutrient on the shelf? Why and how do you think multiple plankton groups help to better characterize hypoxia?
Responses: We done a throughout literature research and listed supports of Si limitation by previous observational studies in L73–80. We added statements about the bi-peak primary production pattern that is captured in satellited-estimated chlorophyll *a* and Gomez et al.'s (2018) model (two phytoplankton + three zooplankton function groups) study but is not captured in the models with a less complex planktonic community (L87–91). We highlighted our objective to investigate the possible Si limitation and to assess the impacts of the complexity of the plankton community on DO dynamics and bottom hypoxia development (L92–94).

L286-287: what do you mean?
Responses: We would like to address the biological concentration (e.g., PS, PL, ZS) and organic matter concentration are represented by N (i.e., in mmol N m^{-3}) rather by P or Si. We rewrote this sentence to avoid confusion (see L129–130).

L339: other way around, see earlier comments
Responses: Have corrected. Please see L168–169.

L495-496: why only 2.5 years?
Responses: We only found 2.5-year WOD records (https://www.ncei.noaa.gov/products/world-ocean-database). To expand our observation dataset for nutrient validation, we also incorporated the shelf-wide cruise measurements of nutrients (please see the updated section 3.2).

L508: but this is average in space and time over 2.5 years right? Also, as previously mentioned, validating by looking only at means is misleading.
Responses: We updated section 3.2, focusing on validating surface nutrient concentration. In the revised section, we performed one-to-one comparisons between modeled hindcast and observed records from the WOD and shelf-wide datasets. Bar graphs showing the percentages of concentration differences within specific concentration intervals and concentration differences against the distances between the Mississippi River mouths and the sampled locations illustrated the summarization of the model-observation misfits (Fig. 3).

L509-510: I don't think these levels qualify as oligotrophic
Responses: We updated this section and this statement has been removed. Please see the updated section 3.2 from L288 to L304.

L510-511: You cannot say that from Figure 3
Responses: We updated this section, and this statement has been removed. Please see the updated section 3.2.

Figure 3: the bias is quite large in some regions and the sign of the bias (positive for NO3, negative for PO4, Si) may favor the development of Si or P limitation.
Responses: We updated this section after we re-parametrized and reran our model. New results suggested that one-to-one biases were acceptable. Please see the updated section 3.2.

L588: "reasonably well" would be a better statement

Responses: We have updated this section and removed this statement. In the revised section 3.4, we first provided more detailed information about how we performed the model-observation comparison than we did in the previously submitted manuscript. Second, we found a better alignment between hindcast and measurements than in the last version after reparameterizations.

L665: Figure 3 shows well that although there is a good agreement between mean profiles, 1 to 1 comparisons indicate large biases.
Responses: As for the validation of DO profiles against the SEAMAP and shelf-wide cruise measurements, we provided a one-to-one comparison in our revised manuscript. Similar to the validation of diatom ratios, in section 3.6, we first provided a detailed description of how we performed the model-observation comparison. That is, observed DO profiles were interpolated to the modeled layers using the nearest interpolation method as the number of observed layers is close to or even more than that of the modeled layers. We then plotted the vertical profiles of mean, median, and 25–75th percentile ranges of the one-to-one model-measurement differences. We argued that our model results provided a better representation of measured DO profiles than previous numerical studies (e.g., Yu et al., 2015). Please see the updated section.

L678: As mentioned in a previous review, in Figure 5 you compare regional mean profiles, which is not a very good comparison, especially along such a large longitudinal range. Also I believe Yu et al compared actual profiles, which is a different level of validation. Point to point comparison might show large biases, cf Figure 3
Responses: Please see our previous responses.

Table 2 (0.02): this is odd. I am not sure I believe the explanation for the mismatch
Responses: We updated Table 2 according to our new experiment results and performed 10-year running correlation coefficients (CCs) between hindcast and shelf-wide measurements. The 10-year running CCs should be more statistically meaningful than the 5-year running CCs. We also provided significant tests for these CCs and found they all significantly showcased the model's accuracy in reproducing year-to-year variations of hypoxic areas.

L785: I am not sure that it is pertinent to use shelf and depth averaged nutrient ratios to discuss growth limitation.
Responses: We rewrote the entire section 4.1 to discuss nutrient limitation as we agreed with the reviewer's doubts that using shelf and depth-averaged nutrient ratios may be problematic.

In the revised section 4.1, we first addressed the possible types of limited nutrients based on the ratios of riverine nutrient supplies. We found that P can be more limited than N and Si around the river mouths, while N and Si limitations may vary in other shelf waters. Si limitation is possible that riverine N:Si was near 1:1 and, during some summers, was greater than 1:1 and that marine diatoms require a lower N:P:Si ratio (16:1:20, Billen and Garnier, 2007; Royer, 2020).

Secondly, we moved the discussion of half-saturation of $Si(OH)_4$ uptake by PL (K_{SiOH4}) from section 5.1 in previous submission to here in this revised manuscript. We would like to address that our selection of K_{SiOH4} is reasonable as it was based on multiple bioassay studies.

Finally, we tried to illustrate the Si limitation, its causes, and its impacts on the plankton distribution and PON_{sed} (directly related to SOC) distribution. We further argued that N and P limitations were reported more frequently than Si limitations along the shelf because samples collected in previous studies were mainly from the eastern shelf. Yet a lack of data on the western shelf should not hinder our attempt to perform numerical investigation and suggest possible Si limitation in the LaTex shelf and low-Si waters in the deep gulf. Please see the updated section 4.1 for more details.

Figure 8: nutrient ratios indicate the potential for growth limitation but this limitation does not occur until one of the nutrients runs out.
Responses: We updated this figure and this section. Nutrient limitation can occur even if such nutrient has yet to run out. We found evidence in many bioassay studies that addressed co-limitation conditions. For example, in Quigg et al. (2011) (we pasted Table 2 in their work here), N, P, and Si limitations were found to coexist in one sample even though when the background nutrients were still detectable.

Table 2 Resource limitations assays conducted across the Louisiana shelf during three research cruises in 2004 at locations shown on Fig. 1

Cruise	RLA #	Lat	Long	Salinity	Temp (°C)	DIN (μmol L^{-1})	P_i (μmol L^{-1})	Si (μmol L^{-1})	DIN/P_i	DIN/Si	Chl a (mg m^{-3})	APA (nmol L^{-1} h^{-1})	SPP (mgC mg Chl^{-1} h^{-1})	Primary limiting resource
March	M1	28.78	89.83	30.2	19.1	2.73	0.21	7.41	13.0	0.37	3.5	64.4	5.12	NP_iSi
	M2	28.77	90.77	28.0	18.8	1.18	0.09	6.81	13.1	0.17	1.1	112	2.78	NP_iSi
	M3	28.84	91.59	32.3	19.4	0.14	0.11	0.91	1.27	0.13	1.6	85.6	3.66	N
May	Y1	28.78	89.43	28.0	27.0	0.29	0.08	1.38	3.63	0.21	0.2	nd	nd	No growth
	Y2	29.08	90.04	23.2	27.6	12.3	0.05	23.2	246	0.53	2.4	55.7	9.02	P
	Y3	28.97	91.03	24.8	28.2	8.20	0.07	18.3	117	0.45	0.9	30.6	7.69	P
	Y4	29.14	91.96	24.8	28.6	3.76	0.03	bdl	125	–	3.9	440	8.09	NP_iSi
July	J1	28.93	89.86	23.3	26.2	0.50	0.04	bdl	12.5	–	5.0	664	nd	P + DGlu
	J2	28.88	89.43	33.0	27.6	32.6	1.49	38.4	21.8	0.85	0.2	44.8	nd	L
	J3	29.11	89.83	21.7	30.8	5.66	0.18	1.31	31.4	4.32	2.7	28.6	8.24	NP_iSi
	J4	28.89	90.57	25.9	29.5	bdl	bdl	bdl	bdl	–	1.3	16.9	18.0	L
	J5	28.56	91.45	23.9	28.9	4.59	0.28	12.7	16.4	0.36	0.2	3.53	19.0	L

All water quality, nutrient, Chl *a*, and APA values presented were measured on the initial bulk water sample used to start each RLA. During the July cruise only, two additional treatments (+phosphono-acetic acid and +D glucose-6-phosphate) were added to examine the potential role of organic P (vs P_i) on phytoplankton productivity (see methods section for specific details)

DIN dissolved inorganic nitrogen, P_i dissolved inorganic phosphate, *APA* alkaline phosphatase activity, *SPP* surface primary productivity (=P_m^B defined in methods), *L* light limitation, *bdl* below detection limit, *nd* no data, *DGlu* D glucose-6-phosphate

L931-933: This is very surprising. Offshore waters should be N limited. P limitation does not typically occur there, but the model indicate the opposite.
Responses: According to our new results, offshore waters were limited by N or Si (depending on current patterns), and P limitation occurred around the river mouths (Fig. 11 and C3). Please see the updated section 4.1 for more details.

L941-945: I don't think the results from Quigg et al support your findings.
Responses: In our new results, P limitation occurred around the river mouths, and Si limitation was also detected when the dominated current turned eastward or northward in the shelf. Quigg et al. (2011) suggested the P limitation regime and also the potential of Si limitation. Please see the discussion of Si limitation from L526 to L542.

Figure 9: does your model reproduces the seasonal cycle on resource limitation? Caption: can you indicate that this is at the surface?
Responses: We have removed Figure 9. The revised manuscript discussed nutrient limitation based on multiple surface snapshots sampled from the hindcast results. Please see the updated section 4.1 for more details.

L967-977: are these patterns supported by observations?
Responses: We re-wrote the section 4.2. We tried to demonstrate and validate the bi-peak production pattern by comparing the daily time series of model primary

production (PS+PL; Fig. 12) and monthly time series of chlorophyll concentration from satellite products. In the satellite-derived chlorophyll *a* concentration, a bi-peak pattern was also found in spring and summer. Quigg et al. (2011) also found two chlorophyll peaks in May and July in cruise observation. Please check the L551–L562 in the revised manuscript.

L976: can you explain mechanistically why there is a lag for PS and not PL
Responses: We removed this part.

Figure 10a: do you believe these oscillations?
Responses: We removed this part.

L1010-1023: you can remove this paragraph and keep the last sentence. The rest is confusing and not necessary.
Not sure I believe these results, is this supported by earlier studies? It seems that rather than sinking PL is eaten up and then Z sinks and contribute to PONsed, wheras PS sinks rather than being eaten. This dynamics needs to be supported by observations
Responses: We have removed this part. We tried to demonstrate two mechanisms (bottom-up and top-down) that alternate the PS and PL variations using snapshots sampled from the model hindcast. Please see the brief description in the general responses above and the detailed one in the revised section 4.2.

L1025-1035: I do not understand this paragraph. Also, there is a lot of discussion here but the data are not shown to support it.
Responses: We have removed this part.

1058-1067: similar to section 4.3, I get lost here.
Responses: We have removed this part.

L1063-1067: this is not shown in your results.
Responses: We have removed this part.

L1072: the results presented in section 4 are not discussed. Below you introduce new analyses (nurient load reduction experiments), without much discussion.
Responses: We removed all sensitivity tests and reshaped section 4, merging results and discussion. Please see the brief description in the general responses above and the detailed one in the revised manuscript.

L1067: "while simulated N:Si"
Responses: We have removed this part.

L1231: "ZS biomass increase..."
Responses: We have removed this part.

L1243: this is hard to follow. Can you start your paragraphs by a sentence that summarizes your main point?
Responses: We have removed this part. And by following the review's suggestion, in the revised manuscript, we tried to start our paragraphs by a leading sentence that summarized the main points.

L1260: you are not showing these results
Responses: We have removed this part.

L1270: "Reductions in Si supplies lead"
Responses: We have removed this part.

L1277: this response is the direct result of more complexity in the model and therefore more nonlinearities. But are those real? Is the model well constrained by observations?
Responses: We have removed this part. To discuss the impacts of complexity on bottom DO and hypoxia, in the updated manuscript, we started with the validation of various factors from nutrient dynamics (concentration and limitation types) to phytoplankton composition (diatom ratio and temporal variations in total primary production) and oxygen variables (SOC, DO profiles, and hypoxia patterns). Then, we organized our discussion from nutrient to plankton and DO based on hindcast snapshots of various physical and biogeochemical metrics. During each part, we post observational evidence and related discussions to support our findings.

L1392: I don't think that meets the BG requirement
Responses: The model data is big (in several TBs); we will, of course, share all hindcast results online via a valid link.