

## ***Interactive comment on “Impacts of anthropogenic inputs on the hypoxia and oxygen dynamics in the Pearl River Estuary” by Bin Wang et al.***

### **Anonymous Referee #2**

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Review of “Impacts of anthropogenic inputs on the hypoxia and oxygen dynamics in the Pearl River Estuary” by Wang, Hu, Li, Yu and Huang

#### **Summary:**

In this manuscript the authors use a physical-biogeochemical model to examine a hypoxic event in the Pearl River Estuary (PRE) in July and August 2006. They conduct several numerical experiments in order to determine the relative impact of riverine inputs of oxygen, nutrients and organic matter on hypoxia in the PRE. They specifically examine three processes that affect oxygen dynamics: re-aeration due to air-sea oxygen flux, sediment oxygen demand, and all remaining processes which together is

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referred to as WCP (water column production). This is a well-written manuscript with some very interesting results, but some clarifications, some more discussion, and a few additional experiments should be performed before publication. The comments below are lengthy, but if addressed fully the resulting paper would be a very valuable contribution to Biogeosciences.

Major comments:

As I understand it, all results shown in the manuscript are for July and August 2006. This should be made clearer in the abstract, which is written more like this is the “general” case for the PRE. I understand that the model has only been evaluated for July and August 2006, so we don’t really know whether the oxygen concentrations at other times of the year are correct or not; however, as a reader I was very interested to see results for the whole summer (May to September), or even for the whole year, rather than just for two months of one year. How does the temporal variability of hypoxia change in the numerical experiments? This analysis does not seem complete without this addition.

As a reader, I was also wondering whether July and August 2006 was a typical year. Was 2006 a particularly dry July/August? Or wet time period? Are the results of the sensitivity experiments conducted here likely to hold in other years?

One of the main results of this manuscript was that hypoxia in the PRE is not sensitive to nutrient concentrations of the river water entering the region (unlike the Chesapeake Bay and the Gulf of Mexico, for example). This result, however, has to be at least slightly dependent on what value is used for the nutrient concentrations in the eight rivers. What concentrations are used and are they realistic? Where do these concentrations come from? A terrestrial-biogeochemical or watershed model? More detail is needed here. Also, it sounds as if only the nutrient concentrations were changed in the largest river, not all eight rivers. The authors need to show results of changing the concentrations in all eight rivers, not just the largest, since the smaller ones closest to the

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hypoxic zone might impact the hypoxia zone more than the large river, which is farther from the region of hypoxia. (The same is true for the oxygen and POC experiments.)

This analysis compares the impact of sediment oxygen demand, re-aeration and WCP on hypoxia. However, this is misleading since WCP is the sum of multiple positive and negative terms. Thus this term is likely smaller than its components. For a more complete analysis, the authors need to separate out the various components of WCP, including respiration, nitrification, water column remineralization etc. . . This is particularly important because in the discussion they state that in the PRE water column respiration/remineralization is not as important as it is in places such as the Chesapeake Bay. But we cannot see this (truly interesting!) result unless the authors isolate these terms.

It is not completely clear why the “physical modulation” method is needed. If this is a fully coupled physical-biogeochemical model (as is stated), then why can’t the authors simply save each of the oxygen flux terms in the oxygen budget? Presenting results in units of DO per unit time (as is done in Figure 7) would be much more helpful for the reader. The idea of different “species” of oxygen seems a bit convoluted. Clearly REA, WCP and SOD have units of oxygen per unit time (see equation 1). Showing figures of these quantities, rather than DO\_REA, DO\_WCP and DO\_SOD would make the manuscript more clearly understandable to readers.

I really like the idea that re-aerated surface waters can penetrate to the bottom water and offset the changes in DO caused, for example, by increased nutrient, DO, or OM riverine inputs. The authors discuss that this is not the case on the Gulf of Mexico shelf, where hypoxia occurs as a very thin layer near the bottom. The comparison and emphasis on the Gulf of Mexico seems a bit out of place, since the PRE seems to be more similar to the Chesapeake Bay in many ways. The discussion could be strengthened by making a three way comparison between the Chesapeake, Gulf of Mexico and the PRE. Isn’t the re-aeration process described here similarly important in the Chesapeake Bay, where hypoxia occurs as a thick layer, which is not far from the

surface in a typical July/August?

There is some considerable overlap with the authors' previous publication (Wang et al., 2017, BG). For instance, it appears to me that one of the main points in the abstract of the current manuscript: "Model results showed that hypoxia in the Pearl River Estuary was confined to the shelf off the Modaomen sub-estuary with a hypoxic area of ~200 km<sup>2</sup> mainly due to the combined effect of re-aeration and sediment oxygen demand" was actually a primary result of this previous publication. This should be made clearer in the abstract and introduction. Clearly this study builds off the previous study. Although the previous study is mentioned in the abstract, the differences between the current study and the previous study should be made clearer to the readers.

Minor Comments:

Abstract last sentence – suggest changing this to: "This study highlights the importance of re-aeration in determining the hypoxic extent and in reducing hypoxia variability in shallow estuaries."

Abstract – Define here (and in introduction) that by re-aeration you mean a flux of oxygen across the air-sea interface. (Currently this doesn't occur until page 6).

Introduction – Authors could mention climate change as another anthropogenic impact, since recent studies are showing that increasing temperatures have a large impact on increasing hypoxia.

P2, line 7: Why is there a ten-year lag? Does this occur in an estuary like the PRE? Or maybe it's not relevant here.

Page 4, line 11: This paragraph is talking about how nutrient inputs to the Pearl River Estuary can impact hypoxia, but this line is about particulate organic carbon, which could be moved to the following paragraph talking about organic matter.

Page 4, line 16: What is the organic matter? Is it only POC mentioned in line 11? Or does it include PON (nitrogen) and dissolved organic matter? Which type of organic

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matter primarily contributes to hypoxia?

P4, line 20: How are these models dynamically coupled? If these were dynamically coupled, the estuarine model would provide feedbacks to the riverine model. Is that the case? Also, the model set up seems to assume that there are no freshwater or nutrient sources (from the land) into Mirs Bay, Daya Bay or Honghai Bay. Is there evidence to support this assumption?

P5, “Water quality model” section: In this section the authors need to describe more clearly where their riverine biogeochemical concentrations are derived from, since these are at the very heart of their numerical experiments. Do concentrations of the 26 state variables all come from the riverine model described above? If so, more information regarding the details of the biogeochemistry of the riverine model is needed. Where do the outer boundary conditions come from, for the estuarine model? How about atmospheric deposition of nutrients, like nitrate and phosphate? Are all these assumed to be negligible? How realistic is this assumption?

P6, line 1: Since one of the conclusions of the manuscript is the relative importance of SOD compared to WCP (see abstract), here the terms making up “WCP” need to be written out explicitly.

P6, line 7: Please provide the equations for photosynthesis, respiration, nitrification and oxidation (potentially in an appendix), and provide values of all parameters used. (The reference used here for the model is a white paper from 14 years ago. The model has been adjusted since then. Are the authors really using those original parameters and equations? Please include information on the version of the model that is being implemented.)

P6, line 12: Define what is meant by “dissolved matter”. Is this dissolved organic matter, i.e. DON and DOC? Or dissolved nutrients, i.e. ammonium? Or both?

P6, line 18: As above, please provide values of these parameters within this paper

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(possibly in an appendix.)

P6, line 27: As above, please provide equations and parameter values for DO<sub>sed</sub> (possibly in an appendix)

P7, line 2: Earlier the authors stated that this is a dynamically coupled model, but here it sounds as if the water quality model is being run offline from the physical model, which would indicate that there is no dynamic coupling, and the biological simulation cannot impact the physics. Please make it clearer in the text as to whether the models are truly dynamically coupled, or simply run offline.

P 7 line 4: What data is being referred to here and how was it used? Data assimilation? Forcing? Validation?

P7, line 7: There are actually very few observations of DO presented in Wang et al. (2017). Are these really the only observations available of DO in the PRE region? Is nothing more available since 2006? It also looks like the oxygen data shown in Wang et al. rarely, if ever, actually go hypoxic?

P8, line 3: Because the authors have only evaluated model results for oxygen in July and August 2006, does this mean these results only are valid for that year? Is that a particularly wet year or a dry year? Or an average year? Can you put this year in perspective? (Perhaps in the discussion?)

Page 8, line 13: This sentence seems to indicate that this estimation is not straightforward only in river dominant estuaries. How about tide dominant estuaries, which can also be impacted by local and remote source and sink processes?

P9, line 8: What does “Cont” stand for? Continuous? I would think “Base” or “Reference” or “Realistic” might be better descriptions of this simulation.

Section 2.3: The text is not clear here. Are the concentrations of DO and nutrients reduced in all 8 rivers, or only the Humber? Also it is not clear whether the concentrations of DO and nutrients in the experiments are set to what is predicted in 2050, or are

simply increased by 50%. In reality, the concentrations in 2050 will depend on management decisions which are very difficult to predict. I think it's best to state here that you increased/decreased the concentrations by 50%, and if you want to convince the reader that these are representative of 2050 and 1970 respectively, then bring this up in the discussion. Please provide the concentrations of DO and nitrate (as an example nutrient) used in each of these experiments. More detail is needed here. If freshwater flows stay the same, this should be stated.

P11, line 19: Remove HFZ acronym since it is not used elsewhere. Please define the hypoxic frequency zone more quantitatively since this is used throughout the text. Where exactly is this? It's hard for the reader to know. Does it change in time?

P11, line 23: The word "additionally" should come before "occurs" since hypoxia also occurs on the shelf.

P13, line 9: Also list percent changes in hypoxia area and volume, as was done above.

P13, line 22: Considering using PRE acronym earlier. (It hasn't been used much since very early in the manuscript.)

P14, line 14: Aren't there two POC simulations/experiments, not three?

P14, line 24: In the results, it would make sense to discuss Figure 7 (the "Cont" results) before the sensitivity experiment results, rather than inside the section 2.3 sensitivity experiment section.

P14, line 25: The figure shows 0.53, not 0.55?

P15, line 1: How does the reader compute 0.13 from Figure 7?

P15, line 2: Based on equation 8, I would think the dark blue DO bar would equal the sum of all the other bars, but this doesn't seem to be the case? Why is this?

P15, line 11: It is important to qualify the 217km<sup>2</sup> statistic by saying that this is true only for a July/August average in 2006. This is not true for other months of the year,

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and we don't know whether this is true for other years.

P15, line 15: DO\_REA is not a term that your readers will be familiar with (unless they have read this paper carefully). This paper will have a greater impact if this could be reworded such that processes are mentioned, i.e. discuss the re-aeration of surface water via air-sea flux (in units of oxygen per unit time), rather than DO\_REA.

P15, line 19: Again where is the hypoxic frequency zone? Where is “the west of the lower estuary”? Also, make it clearer that this is a result of Wang et al. (2017) and not of this paper.

P15, lines 4-8: This is a very interesting result! But unfortunately this paper does not show any statistics on water column respiration, so this is not clear. Please separate out the various terms inside WCP so the reader can see specifically that water column respiration is not large here.

P16, line 15: I don't think the authors mean the residence time of the Mississippi River, which extends a great distance, well up into the continent of North America. Do you mean the shelf plume area? This section would be much stronger if the authors compared all three systems mentioned here: the GoM, Chesapeake Bay and the PRE.

P16: Rather than discussing terrestrial vs. marine POC, I think it would be clearer to discuss autochthonous vs. allochthonous POC. “Marine POC” sounds as if it comes from outside the hypoxic zone from the ocean, but I don't think this is what is meant?

P16, line 22: Is July-August a wet or dry season?

Section 4.1: This section needs to describe more completely the difference in marine vs. terrestrial POC in the PRE vs. Gulf of Mexico. Why does terrestrial POC not impact hypoxia? Just because that the POC entering from the river is relatively small and sinks out before making it all the way to the shelf? Or is there something specifically different about the terrestrial matter entering from the Mississippi compared to that being delivered to the PRE? Is this a residence time issue? Is the terrestrial source more



important in the PRE because the nutrient inputs are quite low, compared to what they are in the Gulf of Mexico? What about in the Chesapeake Bay?

P17, line 17: Isn't the same likely to occur in Chesapeake Bay? This might be a very interesting discussion point here.

Figures:

Figure 1: The figures do not look to be italicized (as it says in the caption). Fig 1b does not add any significant information to what appears in Fig 1a. In Fig 1c "grids" should be "grid". The Fig 1a caption should note that this is a bathymetric map.

Figure 3: The text refers to 3a and 3b, but the left panel is not marked (b), and there is no reference to (b) in the caption.

Figure 5: The y-axes in (b)-(d) should specify that these are "Changes in concentration", not concentrations themselves. Also, (b)-(d) should have same y-range to make it easier for the reader to compare all three figures.

Figure 6: Please label figures (a)-(e) and provide captions for each. What is the white line? Axes are not labeled.

Figure 7: This figure is a little confusing, because one would expect that the vertical diffusion out of box 1 would represent the vertical diffusion into box 2. I gather the net diffusion arrows are shown, but maybe it would make more sense to show the middle layer as having a +0.02 diffusion into the middle layer at the top, and a -0.17 diffusion out of the middle layer at the bottom? But why doesn't this equal 0.48? Maybe I'm confused because this is only DO\_SOD, and not total oxygen? Wouldn't this be a more enlightening figure if all the DO fluxes were shown here?

English language comments:

Throughout, "organic matters" should be changed to "organic matter". And similarly "dissolved matters" should be "dissolved matter".

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P 4, line 12 – processes should be process

P6, Line 26 – transportation should be transport

P7, line 7 – delete “here” and “as”

P8, line 16 – should be “interacting”

Page 12, line 1: “further” should be “farther”

P14, line 17: should be “layer, exerting a strong constraint”

P15, line 14: supply should be supplies

P15, line 24: most should be “more”

P16, line 5: should be “are the most important processes”

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