Response to Anonymous Referee #2

Subject

Wang and co-authors investigate the impacts of physical supply and biological consumption of dissolved oxygen (DO) on the dynamics and asymmetry of the OMZs in the tropical Pacific. They perform 4 numerical experiments to evaluate the sensibility of the mid-depth oxygen concentration to these aspects in their model, OGCM-DMEC v1.0. The physical supply is evaluated through the background diffusion parameterization (that the authors test by changing a partial mixing parameter) and the effects of biological consumption on oxygen are tested by changing the C:O utilization ratio. The final aim is to advance their model capacity to simulate the oceanic oxygen cycle, and to explore the mechanisms driving the asymmetric OMZs in the tropical Pacific (introduction, l.67-68).

Relevance of the subject

To understand the physical and biological processes responsible for the asymmetry of tropical Pacific OMZs is a topic of great interest for climate modelers, which has currently not been solved.

General comments

However, in its present form, the conclusions of this study bring no new clues of understanding, and do not explore any mechanisms. The authors conclude that both physical supply and biological consumption impact the OMZs extend and vertical structure, which, according to them, has been the subject of numerous previous papers (see l.188-190 or l.219-220).

Response: Thank you for the constructive comments. We have made major revisions, including some new experiments and analyses, and rewriting of some sections (e.g., model description, sensitivity experiment, model validation, results and discussions).

While it is a promising approach to explore the DO budget term by term, I recommend to enlarge the analyses to other variables (by characterizing the tropical ocean dynamics with vertical sections of horizontal currents for example, and by giving insights of plankton and nutrients mean-state and variability) in order to explore the mechanisms at play when increasing the background diffusion or decreasing the biological consumption.

Response: Thank you for the constructive comments. This basin-scale model was developed to study the upper ocean dynamics for the tropical Pacific, which includes the spatial and temporal variabilities of physical and biogeochemical fields. We have analyzed/validated many physical and biogeochemical variables in our previous studies, e.g., SST (Wang et al., 2006), chlorophyll (Wang et al., 2009a; Wang et al., 2013), nitrogen cycle (Wang et al., 2009b) and carbon cycle (Wang et al., 2015). In this paper, we have added the comparisons of DON and oxygen consumption, which have a direct link to the mid-depth DO dynamics.

Besides I have some reservations about the use of a basin-scale model of the Pacific limited at 20 S and 20 N to study the Pacific OMZs. It seems not very appropriated to model OMZ borders, as these latter are found far north of 20 N. If the aim of the study is to investigate the importance of

DO physical supply, one may not ignore the ventilation processes at play in the OMZ borders (Bettencourt et al., 2015). And even in a case of tropical study (as reflected by the analyses restricted to 15 S-15 N), one may not ignore the critical representation of the equatorial undercurrent (EUC) to model the tropical OMZ structure (Busecke et al., 2019). As both processes are highly resolution dependent (see for example Fig. 16 in Berthet et al., 2019), I am surprised to find no discussion and no bibliography on the questions of the appropriate model resolution needed to get a realistic OMZ structure.

Response: Thank you for your constructive comments. This basin-scale model was developed to study the upper ocean dynamics for the tropical Pacific, with a domain of 30°S-30°N. We have changed to "sponge area" to 25°-30°, and re-done all model simulations and reproduced all figures covering 25°S-25°N. We have added some discussion regarding the impacts of horizontal resolution of the model on the OMZ structure.

Results

Model description: The parameterization of the oxygen cycle needs to be described with more details. It would help the reader to analyze the results.

Response: Thank you for the suggestion. We have added more details for model description, including model equations and parameters (as appendix A and B).

Validation: In its present form, the model validation may be completed by showing physical currents and temperature/salinity mean state and variability (at the surface and with a vertical section along latitudes), OMZ inter-annual variability, ventilation at the OMZ boundaries (as mesoscale activity has been shown to shape the OMZ) …

Response: We agree with that more model validation should be carried out. Since our previous studies have reported the evaluations of physical (including mesoscale and sub-mesoscale structures) and many biogeochemical fields (see responses above), this paper mainly reports the calibration and validation of oxygen related fields (e.g., consumption and DON). We have analyzed the temporal variability of OMZ in another paper.

As stated l.70, the OGCM-DMEC V1.0 has shown a good model-data agreement in the carbon cycle for the tropical Pacific Ocean (Wang et al., 2015). This is a good point if the model was validated on carbon cycle, but the paper needs a true validation on oxygen.

Response: We have added more model-data comparisons, using cruises' data for the distribution of DO.

Specific comments

l.14: 'DO' is used in the abstract, but not defined

Response: We have defined DO.

l.53: I would recommend to add the following study to justify that circulation play a dominant role in regulating the dynamics of tropical OMZs: Busecke, J. J. M., Resplandy, L., & Dunne, J. P.

P. (2019). The Equatorial Undercurrent and the oxygen minimum zone in the Pacific. Geophysical Research Letters, 46. https://doi.org/10.1029/2019GL082692

Response: We have added this reference in the introduction section.

l.54-57: And what about the horizontal resolution of the model ? Using an ESM with a high-resolution ocean (1/10), Busecke et al. (2019) show that a realistic representation of the Equatorial Undercurrent (EUC) dynamics is crucial to represent the upper OMZ structure and its temporal variability. They demonstrate that coarser ESMs commonly misrepresent the EUC, leading to an unrealistic "tilt" of the OMZ (e.g., shallowing toward the east) and an exaggerated sensitivity to EUC changes overwhelming other important processes like diffusion and biology. This last aspect would be interesting for your discussion.

Response: Thank you for your constructive comments. We have added some discussion regarding the impacts of model's horizontal resolution on the OMZ structure.

l.61: "A fully coupled basin-scale physical-biogeochemical model (OGCM-DMEC V1.0) was developed for the tropical Pacific (Wang et al., 2008; Wang et al., 2015; Wang et al., 2009)." –> are you using a regional configuration centered on the Pacific ocean ? Or is it a global model ?

Response: Our model is a regional model, with a domain of 30°S-30°N.

l.78: "The model domain is between 30 S and 30 N" –> thus it is not "global". This has to be clarified, as OGCM generally means ocean GLOBAL circulation model.
Moreover if your domain extends between 30 S-30 N: why did you crop your horizontal maps at 15 N while Fig. 2b clearly not catch OMZ northern border between 200-600m (which seems far north) ? I would suggest to enlarge the northern border up to 20 N (at least, as your sponge layers are in the 20 -30 bands). "and zonal resolution is 1." –> have you checked how your EUC behaves ?

Response: Our model is a basin-scale OGCM, and we have used such name/definition in many our previous publications. Others have also used "OGCM" for a regional ocean model (e.g., Sofianos and Johns, 2003).

We have changed to "sponge area" to 25°-30°, and re-done all model simulations and reproduced all figures covering 25°S-25°N. We believe that our model does a good job in simulating physical fields including EUC because we have validated many physical and biogeochemical variables in our previous studies, e.g., TIW (Zhang, 2016; Zhang and Busalacchi, 2008), SST (Wang et al., 2006), nitrogen cycle (Wang et al., 2009b) and carbon cycle (Wang et al., 2015).

l.86-87: precipitation (gpcp) and wind stress (NCEP) forcings are not consistent ?

Response: We have changed to "Precipitation is from ftp://ftp.cdc.noaa.gov/Datasets/gpcp. Wind stresses are from the National Centers for Environmental Prediction (NCEP) reanalysis (Kalnay et al., 1996)".

l.90: “an interannual simulation for the period of 1978-2000, and analyze model output for the period of 1981-2000.” –> could you give some insights about the interannual behaviour of your OMZs ?

Response: We have analyzed the temporal variability of OMZ in another paper. This paper has a focus on the spatial pattern, with a particular interest in the asymmetry of OMZ.

l.96: DON is not defined

Response: We have defined DON.

l. 107-109: please clarify your computation of the vertical mixing term: “the vertical mixing term that is calculated by three subroutines (Chen et al., 1994).” –> I guess that to be splitted in 3 subroutines is not the main characteristic of the hybrid scheme of Chen et al. (1994). It would be interesting to mention why you add this mixing scheme in your model from a physical point of view. Following the abstract of Chen et al. (1994), this hybrid vertical mixing scheme “helps to produce more realistic velocity profiles in the eastern and central equatorial Pacific. This is mainly due to the improved parameterization of interior mixing related to the large shears of the Equatorial Undercurrent”, which seems to me an important aspect when modelling the OMZ. Or it would be important to tell the reader (still from their abstract) that this scheme “is capable of simulating the three major mechanisms of vertical turbulent mixing in the upper ocean, that is, wind stirring, shear instability, and convective overturning.” l. 137: as you aim to determine the respective roles of physics and biogeochemistry in the oxygen biases, it would be helpful to have some basic validations on horizontal / vertical circulations (for example, a vertical section of zonal jets along the latitudes) and nutrients affecting the oxygen budget in your model (phyto- and zoo-plankton, detritus, DON, ammonium, nitrate).

Response: Thank you for your constructive comments. You are correct about the “3 subroutines” and Chen mixing scheme. We have made a correction, i.e., delete “(Chen et al., 1994)” in that sentence. We have added some more information about the Chen scheme, as suggested.

l.142-145: Regarding your sensitivity experiments, it would be helpful to clarify how the initial DON remineralization constant and O:C utilization ratio were determined.

Response: Thank you for your suggestion. We have added more information about the model and parameters, e.g., “The equations for biogeochemical processes and model parameters are described in Appendix A and B. There have been changes in some parameters comparing with those in Wang et al. (2008), which were based on our model calibration and validation for chlorophyll (Wang et al., 2009a, Wang et al., 2013), nitrogen cycle (Wang et al., 2009b) and carbon cycle (Wang et al., 2015)”. Note: we have deleted the modified O:C simulation because there was no good reason to change the O:C ratio.

Moreover, are you increasing the oxygen supply through mixing only in the OMZ region or in the whole Pacific basin? Could you justify your choices ? Could you elaborate on your “variable Pm” ? How does it vary?

Response: All the experiments with enhanced mixing are in the whole basin. We have added more information to justify our choices (see responses above). We have deleted the “variable Pm” experiment.

l.179-180: “We first compare the distribution of DO over 300-500 m between reference run and Exp3. The reference run produces much large volume of suboxic waters (<20 mmol m-3) in both the ETNP and ETSP where the two OMZs are merged (Figure 6a).” The reader would appreciate if the oxygen average for your “ref” experiment in Fig. 6 may be comparable with observations: Fig. 2 (right column) shows the 200-600 m mean, and Fig. 6 the 300-500 m mean. These 2 averaged layers (200-600 vs 300-500 m) are quite different in terms of volume of equatorial suboxic waters, so, please, could you add a 3rd column in Fig. 2 with the 300-500 m mean in WOA ?

Response: We have made major revisions, with all figures showing the comparison/analyses over 200-400 m, 400-700 m, and 700-1000 m.

l. 181: “Exp3 performs well in reproducing the sizes and locations of two asymmetric OMZs” –> the use of quantitative metrics (OMZ volume, maximal horizontal extent) would reinforce this conclusion.

Response: Thanks for the suggestion. We have added a new table to show the quantitative metrics for model-data comparison (see below).

Table 3. Comparisons of OMZ volume (10^{15} m^3) between WOA2013 and model experiments

Regions	Waters	WOA2013	Reference	CD0.5	CD0.5 PM0.1	CD0.5 PM0.3	CD0.5 PM0.5	CD0.5 PM1.0
North Pacific	Suboxic	5.97	10.47	8.87	8.29	7.36	6.61	5.23
	Hypoxic	19.98	21.21	20.48	20.35	20.01	19.62	18.74
South Pacific	Suboxic	1.43	3.49	2.42	2.20	1.85	1.56	0.93
	Hypoxic	7.12	9.90	8.73	8.35	7.70	7.13	5.96

Suboxic: DO <20 mmol m^{-3}; Hypoxic: DO <60 mmol m^{-3}.

l.195: regarding the small decrease you detect in the ETNP-OMZ in exp3 (Fig. 7c): what do you obtain with exp4 ? Is this decrease linked with coastal processes ? If yes, how ?

Response: The small decrease of physical supply in the ETNP-OMZ is detected in all the experiments with enhanced background diffusion. We think that this decrease is not linked with coastal processes, but is due to the redistribution of DON, which causes non-uniform changes in consumption over depth, and thus alters the vertical gradients of DO (see figure below).

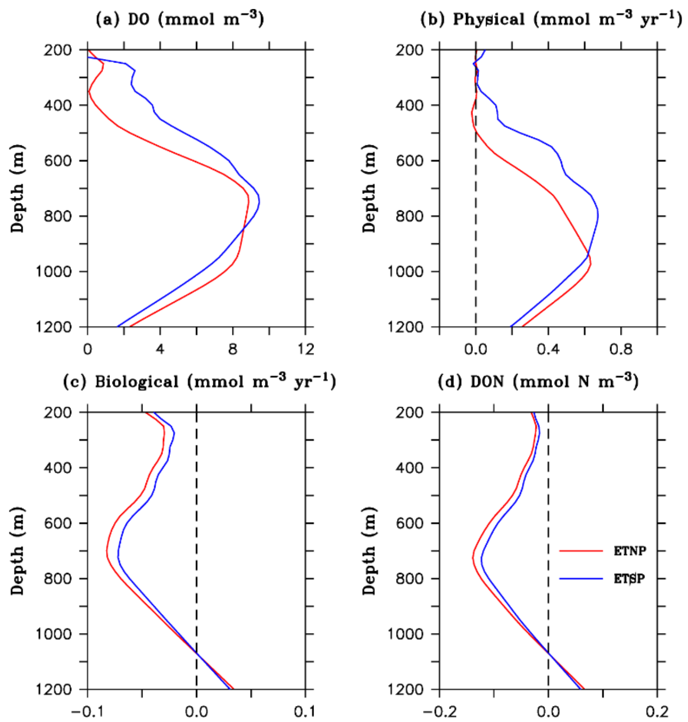

Figure 10. Changes due to enhanced background diffusion (CD0.5PM0.5 minus CD0.5) for (a) DO, (b) physical supply, (c) biological consumption, and (d) DON. Red lines (ETNP: 165°W-90°W, 5°N-20°N) and blue lines (ETSP: 110°W-80°W, 15°S-5°S).

Figures

Figure 1: legend of Ps, PL, Zs, ZL, Ds, DL is missing.

Response: We have redrawn the ecosystem diagram (see figure below).

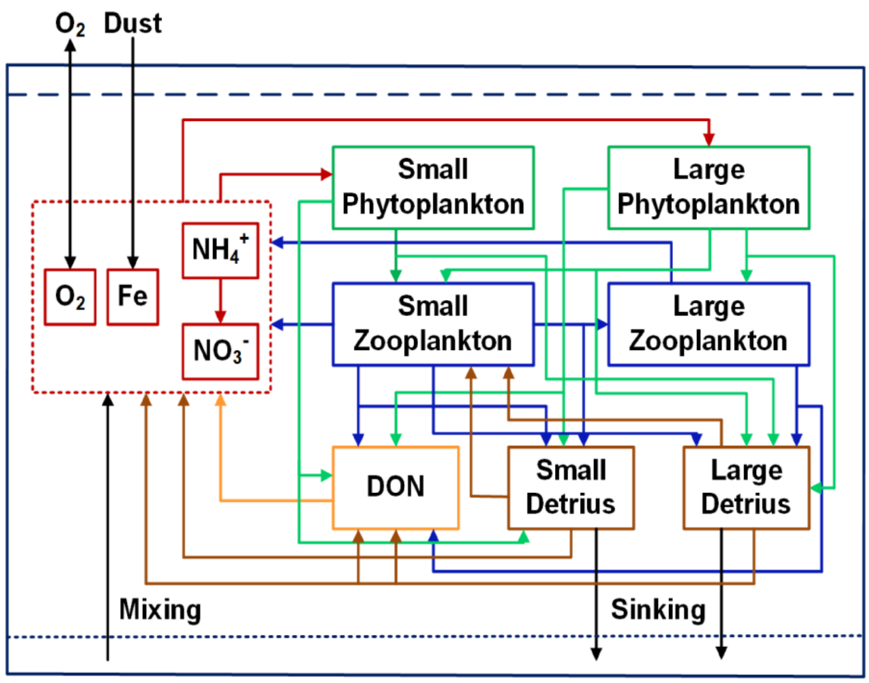

Figure 1. Flow diagram of ecosystem model. Red, green, blue, yellow and brown lines and arrows denote fluxes originating from inorganic forms, phytoplankton, zooplankton, DON and detritus, respectively.

Figure 2: it seems weird to me to study the Pacific OMZ but to not catch its spatial extend entirely: why don't you extend your simulated regions at least to 25 S and 25 N (shifting your sponge layers between 30 and 35 for example), and to the coasts of America (70W to get both northern and southern parts of the Pacific OMZ) ?

Response: Thank you for the suggestion. We have extended simulated region to 25°S and 25°N, and to the coasts of America (see figure below).

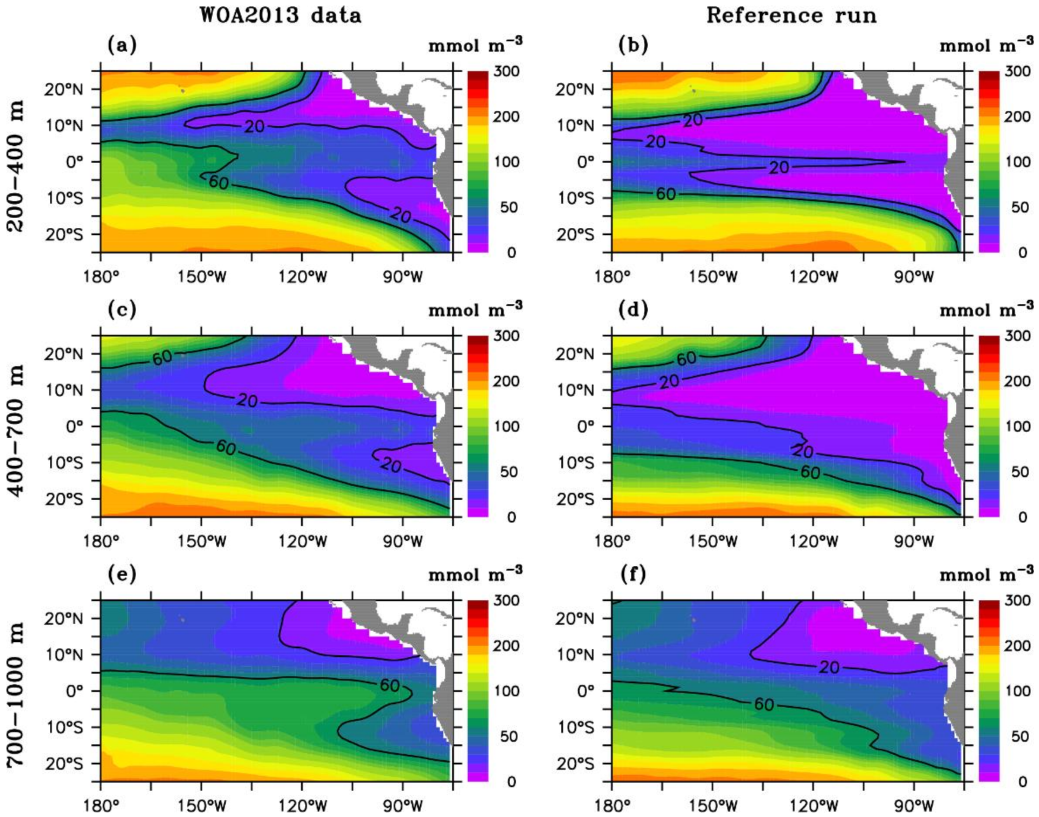

Figure 2. Comparisons of DO concentration between WOA2013 (left panel) and reference run over 1981-2000 (right panel).

Figures 3 (and 10): as the paper focus on the asymmetry between the northern and southern part of the Pacific OMZ, and as its aim is to show how they differ, the meridional means between 10S-15N seem not appropriate. I would recommend to split the analyse in two, one for each OMZ (south and north). As it is, Fig. 3 does not allow to properly evaluate how the model reproduces the vertical structure of the OMZ against observations. Same comment for Fig. 10 (left column), and this analyse does not allow to investigate any mechanisms.

Response: Thank you for your suggestion. We have made major revisions, which include the deletion of previous Figure 3 because we think that Figure 4 (see below) is sufficient to show the asymmetric OMZs. Regarding Figure 10 (now Figure 9), we have split the zonal distribution into two as suggest (see below).

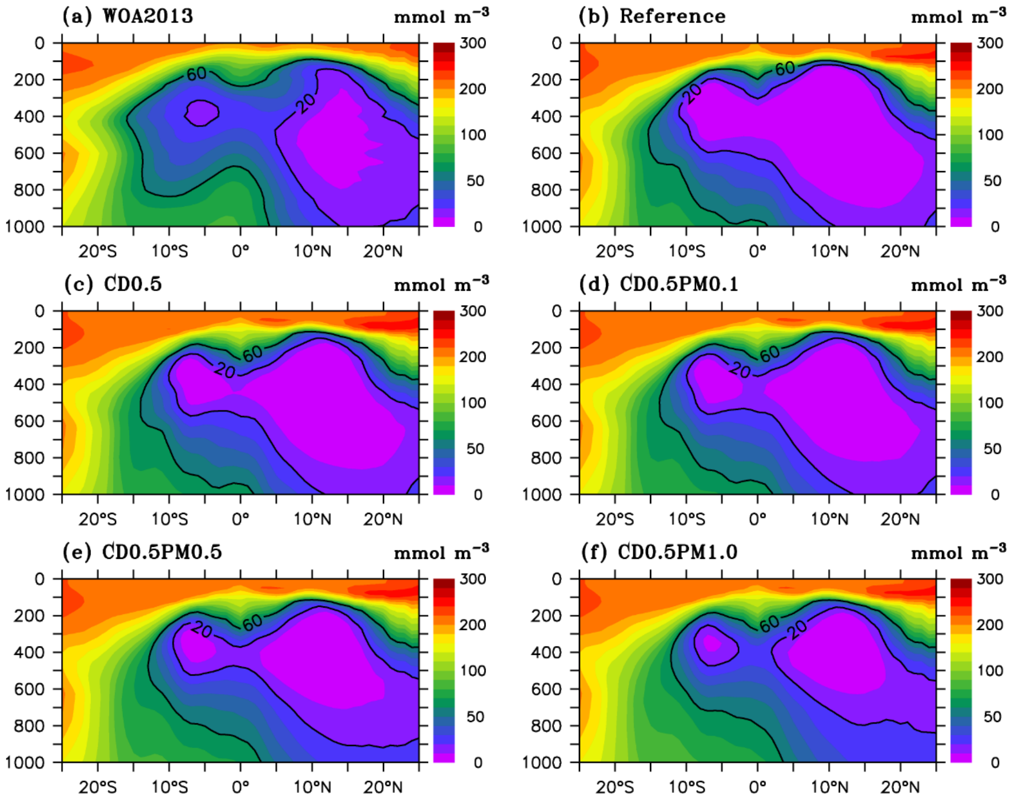

Figure 4. Observed and simulated DO from model experiments over 130°W-90°W. (a) WOA2013, (b) reference run, (c) CD0.5, (d) CD0.5PM0.1, (e) CD0.5PM0.5, and (f) CD0.5PM1.0 over 1981-2000.

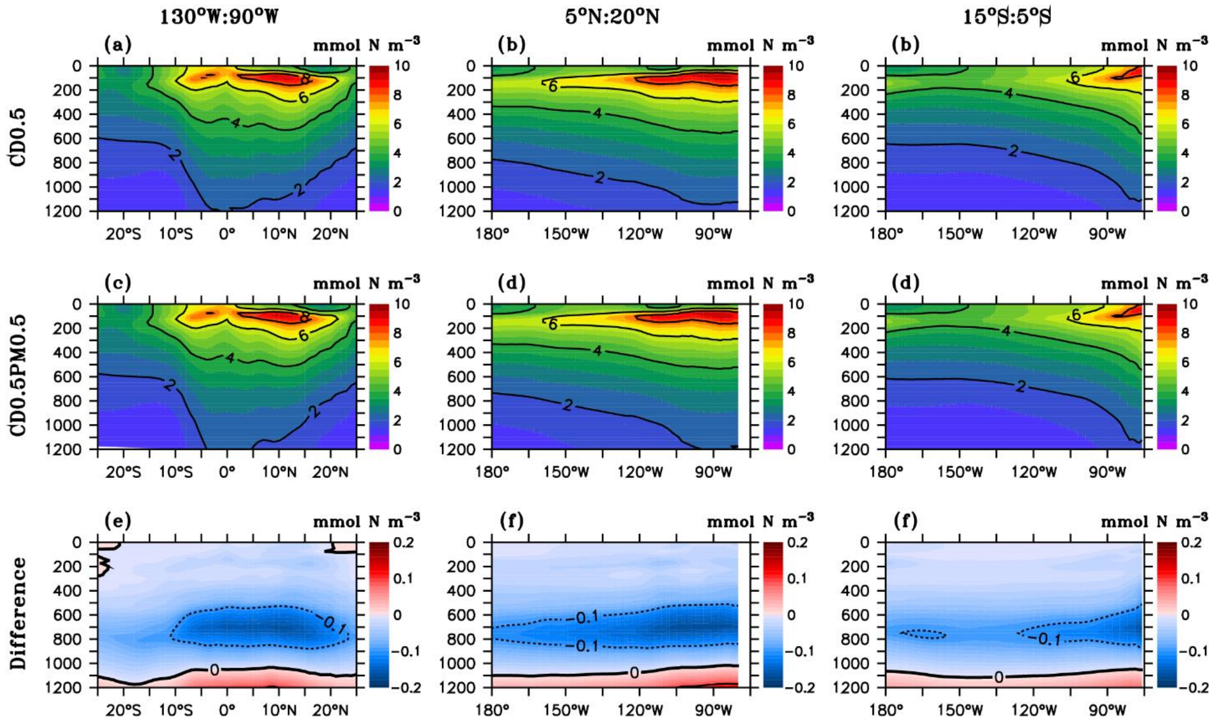

Figure 9. Distribution of DON over 130°W-90°W (left), 5°N-20°N (middle), and 15°S-5°S (right) from (a-c) CD0.5, (d-f) CD0.5PM0.5, and (e-f) differences (CD0.5PM0.5 minus CD0.5).

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