Response to minor review of **“Evaluation of CMIP6 Models Performance in Simulating Historical Biogeochemistry across Southern South China Sea”**

Manuscript egusphere-2024-72

Response to Anonymous Referee #2:

We sincerely appreciate the time and effort invested by both the reviewer and the editor in re-evaluating our paper titled **"Evaluation of CMIP6 Models Performance in Simulating Historical Biogeochemistry across Southern South China Sea"** submitted for publication in Biogeosciences. We are grateful for the positive feedback and the insightful comments provided, which is detailed in this report and also in the revised manuscript. The line numbers **(L)** mentioned in the response refer to the line numbers in the revised manuscript. The newly added figures and tables in the revised manuscript or supplementary materials are also included in this report for the convenience of the reviewer and editor to refer.

*This report contains point-by-point detailed responses to each comment from the reviewer.

REVIEWER GENERAL COMMENTS

Comment 1:

The paper has been improved by incorporating a more in-depth discussion on the model structure, resolution, and physical processes. However, I still have some concerns regarding the datasets used in the model. If this study aims to conduct an evaluation, it should consider actual observations such as satellite products.

I understand that CMEMS datasets have been evaluated and shown good agreement with the World Ocean Atlas and ocean colour data. Nevertheless, I am curious as to why the authors did not use the available observations that was mentioned in the author's response (i.e. in-situ measurements taken from the Southern South China Sea). If these datasets are not available for the entire time series (1993-2014), could the authors consider using the specific years where observations are available?

Response:

Thank you for your comment regarding evaluating the CMEMS dataset with available observation and satellite data. Accordingly, we have presented the evaluation results in supplementary. **Table S1** and **Figs S1 & S2** shows the statistical test results of CMEMS vs observation from WOA18 and satellite data from GlobColour. The validation results demonstrated good agreement, with region-wide differences less than ±5% for chlorophyll and phytoplankton, and less than ±10% for nitrate and oxygen. The spatial pattern comparison indicates that the largest differences between the CMEMS and WOA observation data occur in coastal areas. These differences may be attributed to the insufficient number of WOA observation data in our study region **(see Fig. A below this response)** and the coarse resolution of WOA (~111 km). However, the small differences between their climatology (less than ±10%) give us confidence that CMEMS is reliable. Therefore, given that CMEMS has all the required parameters, and our analysis established the reliability of the CMEMS in our study region, we believe that using CMEMS as a reference data allows for a fair performance assessment of the CMIP6 ESMs across all the parameters evaluated.

This is also mentioned in the revised manuscript in **L152–L163** as:

"Furthermore, we have assessed the CMEMS product using observation data from the World Ocean Atlas 2018 (WOA18) for nitrate and oxygen, and satellite data from GlobColour (Product ID: OCEANCOLOUR_GLO_BGC_L4_MY_009_104) for chlorophyll and phytoplankton. The validation results are presented in supplementary ***Table S1****, with the spatial percentage bias detailed in supplementary* ***Figs. S1 – S2****. The validation results demonstrated good agreement, with region-wide differences less than ±5% for chlorophyll and phytoplankton, and less than ±10% for nitrate and oxygen. The spatial pattern comparison indicates that the largest differences between the CMEMS and WOA observation data occur in coastal areas. These differences may be attributed to the insufficient number of WOA observation data in our study domain and the coarse resolution of WOA (~111 km). However, the small differences between their climatology (less than ±10%) give us confidence that CMEMS is reliable. Therefore, given that CMEMS has all the required parameters, and our analysis established the reliability of the CMEMS in our study region, we believe that using CMEMS as a reference data allows for a fair performance assessment of the CMIP6 ESMs across all the parameters evaluated."*

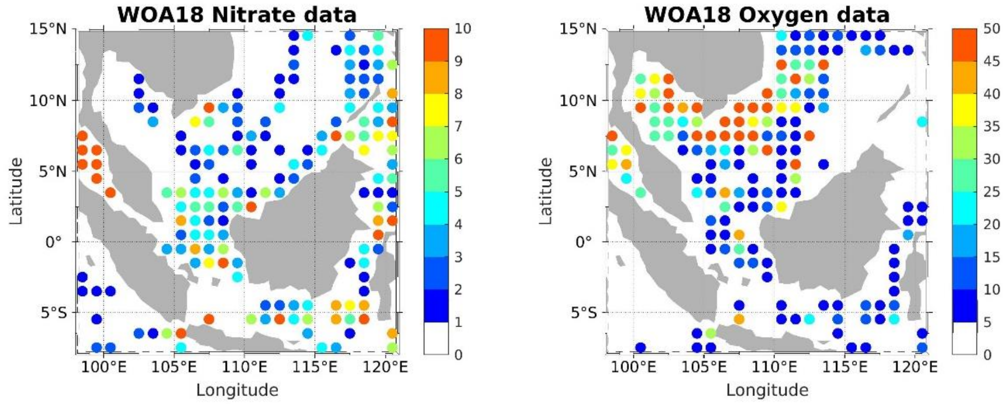

Figure A. Number of WOA observation data and their distribution annually from 1960 to 2017 in southern South China Sea region. (This figure is not included in the manuscript or in supplementary).

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Comment 2:

Additionally, the manuscript could benefit from further clarity. Some sections are challenging to follow due to long paragraphs that are lacking a specific point, especially some parts of the introduction as well as the results and discussion section (chlorophyll and phytoplankton carbon, nitrate, oxygen, and the entire section 4.2). I recommend having someone outside the research group to review the manuscript for readability.

Response:

Thank you for your feedback. We tried our best to use simple words and phrases in this manuscript to ensure clarity for our readers. We have also asked some of our colleagues and students from different field to read the manuscript for comprehensibility, and it was found to be understandable.

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REVIEWER SPECIFIC COMMENTS

Comment 1:

Line 17: The authors mostly refer southwest monsoon as JJA and northeast monsoon as DJF, so this is not representative of the text, please change to June-August and December-February

Response:

Thank you for your feedback. We have made the changes according to your suggestion **L16**.

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Comment 2:

Line 133-134: Can you provide a reference for this sentence

Response:

Thank you for your feedback. After a thorough review, we found that (Pinkerton et al., 2021 and Yuwono & Rendy, 2023) are suitable references for the statement **L126-L128.**

Pinkerton, M. H., Boyd, P. W., Deppeler, S., Hayward, A., Höfer, J., & Moreau, S. (2021). Evidence for the Impact of Climate Change on Primary Producers in the Southern Ocean. Frontiers in Ecology and Evolution, 9. https://doi.org/10.3389/fevo.2021.592027

Yuwono, F. S., & Rendy. (2023). Seasonal response of coccolithophores and its potential to reconstruct paleomonsoon in the eastern Indonesian seas: An overview. In IOP Conference Series: Earth and Environmental Science (Vol. 1163). https://doi.org/10.1088/1755-1315/1163/1/012003

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Comment 3:

Line 148: I disagree, there are satellite products which count as an observation for chlorophyll (even primary production).

Response:

Thank you for your suggestion. We agree with your assessment and have included satellite observations in our study for the evaluation of the chlorophyll and phytoplankton data from CMEMS in supplementary **Table S1** and **Figs S1 & S2**.

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Comment 4:

Line 153: Wahyudi et al., 2023 is missing from the reference list
Line 155: Triana et al., 2021 is missing from the reference list
Line 157: Chen et al., 2023 is missing from the reference list

Response:

Thank you for bringing up this. We apologize for our oversight in this matter. Accordingly, we have provided the following reference.

Chen, Q., Li, D., Feng, J., Zhao, L., Qi, J., & Yin, B. (2023). Understanding the compound marine heatwave and low-chlorophyll extremes in the western Pacific Ocean. Frontiers in Marine Science, 10. https://doi.org/10.3389/fmars.2023.1303663.

Triana, K., Wahyudi, A. J., Murakami-Sugihara, N., & Ogawa, H. (2021). Spatial and temporal variations in particulate organic carbon in Indonesian waters over two decades. Marine and Freshwater Research, 72(12). https://doi.org/10.1071/MF20264.

Wahyudi, A. J., Triana, K., Masumoto, Y., Rachman, A., Firdaus, M. R., Iskandar, I., & Meirinawati, H. (2023). Carbon and nutrient enrichment potential of South Java upwelling area as detected using hindcast biogeochemistry variables. Regional Studies in Marine Science, 59. https://doi.org/10.1016/j.rsma.2022.102802.

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Comment 5:

In figures with maps, the authors show the model ensemble bias, but there are no specific comments about it in the text. Some of the figures and subfigures are also not referenced in the text.

Response:

Thank you for your feedback. The main goal of our study is to assess the skill of individual models. We included the model ensemble as an additional data. To avoid any potential confusion for future readers, we better remove the model ensemble from all the figures.

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Comment 6:

In line 227-229, the authors mentioned that errors larger than +0.1 mg/m3 indicates a notable discrepancy, but in line 236-238, the authors said that >0.15 mg/m3 is within acceptable range – so the three models mentioned earlier are still within acceptable range?

Response:

Thank you for bringing this to our attention. We apologize for the oversight. The acceptable range should be less than 1 mg/m^3. This has been corrected in **L232** of the revised manuscript.

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Comment 7:

Line 241-242: Do you mean: does not overestimate?

Response:

Thank you for bringing this to our attention. YES, we mean does not overestimate. We rephrase the statement *"UKESM1-0-LL model not overestimating chlorophyll"* to "*UKESM1-0-LL model does not overestimate chlorophyll"* in **L236.**

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Comment 8:

Line 253-268: great discussion!

Response:

Thank you very much for your appreciation.

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Comment 9:

Line 308-309: Do you mean: ranging from?

Response:

Thank you for bringing this spelling mistake to our attention. We have corrected accordingly in **L294** as *"rang"* to *"range"***.**

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Comment 10:

Perhaps the authors can show the ESM's nitrate profiles to show whether ESM can capture where the nitracline is during diberent season? (is this the dissolved inorganic nitrogen?)

Response:

Thank you for your feedback. Accordingly, we have provided both ESM's nitrate and oxygen profile for both seasons (DJF & JJA) in the supplementary **Figs. S3-S4** for nitrate and **Figs. S5-S6** for oxygen**.** This is also mentioned in the revised manuscript in **L290** for nitrate and in **L315** for oxygen.

YES, the nitrate utilized in our study is a type of dissolved inorganic nitrogen.

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Comment 11:

Line 338: is this DJF?

Response:

Thank you for your feedback. Yes, it is DJF.

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Comment 12:

Line 348-350: Can you provide reference for this?

Response:

Thank you for your feedback. After a thorough review, we found that Séférian et al., 2020 is suitable references for this statement in **L335**.

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Comment 13:

Line 434: you mean all the biogeochemistry variables? Because some models can reproduce the pattern of at least one of the variables.

Response:

Thank you for your feedback. We agree with your statement and have articulated a similar viewpoint. In the subsequent line **L400**, we already elaborated on this matter by stating, *"While some ESMs can effectively reproduce the reference pattern for individual variables, there remains significant uncertainty regarding the reasons why some ESMs outperform others in this respect."*

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Comment 14:

Section 4.2.2 – can you also make some comments on using a better phytoplankton parameterisation such as the nutrient quota? (or flexible N:C ratio of phytoplankton).

Response:

Thank you for your suggestion. Accordingly in **L474-L482,** we provided a short comment bases on your suggestion as:

"Furthermore, this analysis highlights significant variability in phytoplankton-nutrient correlations across CMIP6 models, the observed discrepancies underscore the potential benefits of employing more advanced phytoplankton parameterizations, such as nutrient quota or flexible N:C ratios. These approaches could provide a more nuanced representation of phytoplankton response to nutrient availability. Models like UKESM1-0-LL, which utilize nitrogen as their primary currency for phytoplankton biomass, demonstrate good correlations with nitrate, suggesting that explicit consideration of nutrient stoichiometry may enhance model accuracy. Similarly, integrating phosphorus cycles, as seen in MIROC-ES2L, could better capture phosphorus limitations affecting phytoplankton growth. Future model developments should prioritize these parameterizations to improve the fidelity of biogeochemical simulations and better understand ecosystem responses to environmental changes."

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Comment 15:

Line 520 – Taylor's diagram or Taylor diagram? Please be consistent.

Response:

Thank you for pointing this out. We have corrected this error to align consistently with the Taylor diagram.

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Comment 16:

Line 580-581 – You are repeating line 579 – 580.

Response:

Thank you for pointing this out. We have revised and corrected this error in **L541-L543 from** *"In addition to the qualitative analysis presented in the Taylor diagram above, a skill score is calculated using Equation (5) to further validate the models' proficiency in reproducing biogeochemical variables. The Taylor skill score, derived from Equation (5), serves as a quantitative summary of the information conveyed by the Taylor diagram, providing a synthetic measure of the models' performance."* **to** *"In addition to the qualitative analysis presented in the Taylor diagram, a skill score is calculated using Equation (5) to further validate the models' proficiency in reproducing biogeochemical variables, serving as a quantitative summary of the information conveyed by the Taylor diagram."*

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Comment 17:

Line 618 - Perhaps i am missing something but the authors have not mentioned about annual scales at all in the first half of the results and discussion; and is only touched in the Taylor diagram part

Response:

Thank you for your comment. The initial part of our analysis involves evaluating the models' ability to simulate the climatology of biogeochemical parameters in the study area, i.e., southern South China Sea (SSCS). This region is significantly influenced by two monsoon regimes: the boreal summer (JJA) and boreal winter monsoon (DJF). Therefore, it is important for the models to have a high skill in capturing the seasonal climatology, even though our primary focus is on how biogeochemical parameters will be affected by climate change on an annual time scale. Evaluating model performance solely on an annual basis could lead to selecting models that may not perform well seasonally, yet at annual scale they might look fine. Thus, for the first part of the evaluation, we assessed the models on a seasonal scale. This approach ensures confidence in our later future projection assessments, which focus on annual time scale changes of biogeochemical parameters in our study area.

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Comment 18:

Line 620 – is this only at the surface? Perhaps also consider the deeper depths as well because this is the conclusion section.

Response:

Thank you for your suggestion. Accordingly, we have presented the statistical results for nitrate and oxygen at deep layer of 1000m in **L581-L585** as *"Similarly, at the depth of 1000m, GFDL-ESM4 and MRI-ESM2-0 models alone shows positive correlation of 0.02 and 0.46, respectively and the remaining* *models showed negative correlation ranging -0.77 to -0.08. At the depth of 1000m for oxygen, ACCESS-ESM1-5, GFDL-ESM4 and UKESM1-0-LL alone showed negative correlation of -0.2, -0.26 and -0.06, respectively and the remaining models showed positive correlation ranging 0.05 to 0.6."*

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Comment 19:

Line 634 – do not use etc.

Response:

Thank you for suggestion. We have rectified this.

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FIGURE & TABLES:

Table S1 Validation results of CMEMS (1993 - 2014) climatology against the Observation climatology of WOA18 data (1960 – 2017) and Satellite data (GlobColour: 1997 - 2014) across the study domain (southern South China Sea). Satellite provides chlorophyll and phytoplankton data and WOA18 provides nitrate and oxygen data. Correlation Coefficient (CC), Root Mean Square Difference (RMSD), Mean Bias Error (MBE) and Mean Percentage Bias (MPB).

Variables	CC		RMSD		MBE		MPB (%)	
	DJF	JJA	DJF	JJA	DJF	JJA	DJF	JJA
chlorophyll (mg m^{-3})	0.69	0.68	0.19	0.2	-0.18	-0.21	-3.5	-4.8
phytoplankton (mmol m^{-3})	0.68	0.7	1.19	1.27	0.55	0.54	3.25	3.17
nitrate (mmol m^{-3})	0.33	0.31	0.33	0.36	-0.1	-0.1	-0.96	-0.97
oxygen (mmol m^{-3})	0.47	0.68	8.4	6.7	1.9	0.4	2.79	1.2

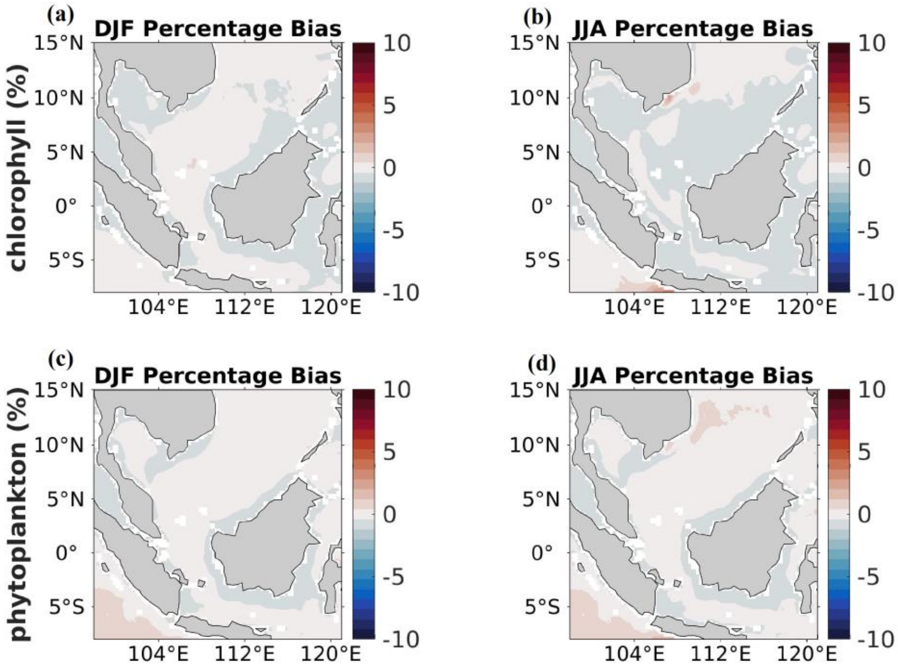

Figure S1 Seasonal Percentage Bias of chlorophyll (a-b) and phytoplankton (c-d) from CMEMS against Satellite data (GlobColour).

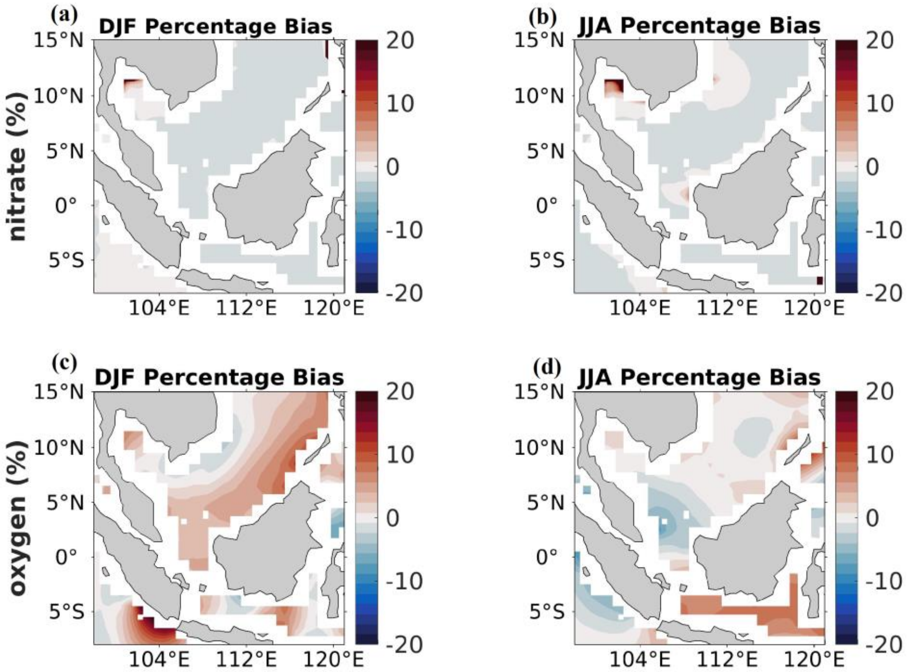

Figure S2 Seasonal Percentage Bias of nitrate (a-b) and oxygen (c-d) from CMEMS against observation data (WOA18).

Table S2 Spatial statistics of nitrate and oxygen at depth of 1000m for the selected 13 CMIP6 ESMs.

CMIP6 ESMs	nitrate 1000m			oxygen 1000m		
	CC	NSD	NRMSD	CC	NSD	NRMSD
ACCESS-ESM1-5	-0.20	7.01	7.27	-0.21	5.70	5.99
CanESM5	-0.08	1.77	2.10	0.44	1.27	1.22
CanESM5-CanOE	-0.20	2.45	2.82	0.22	2.12	2.14
GFDL-ESM4	0.02	3.86	3.96	-0.26	3.04	3.43
MIROC-ES2H	-0.77	0.18	1.14	0.30	0.69	1.03
MIROC-ES2L	-0.27	0.12	1.04	0.34	0.31	0.94
MPI-ESM1-2-HR	-0.79	1.62	2.49	0.61	2.91	2.43
MPI-ESM1-2-LR	-0.77	0.89	1.78	0.05	1.89	2.10
MPI-ESM-1-2-HAM	-0.74	0.60	1.49	0.19	1.73	1.82
MRI-ESM2-0	0.46	2.10	1.86	0.25	1.66	1.71
NorESM2-LM	-0.14	0.34	1.10	0.49	1.11	1.07
NorESM2-MM	-0.21	0.43	1.17	0.53	1.38	1.20
UKESM1-0-LL	-0.43	1.93	2.53	-0.06	2.65	2.89

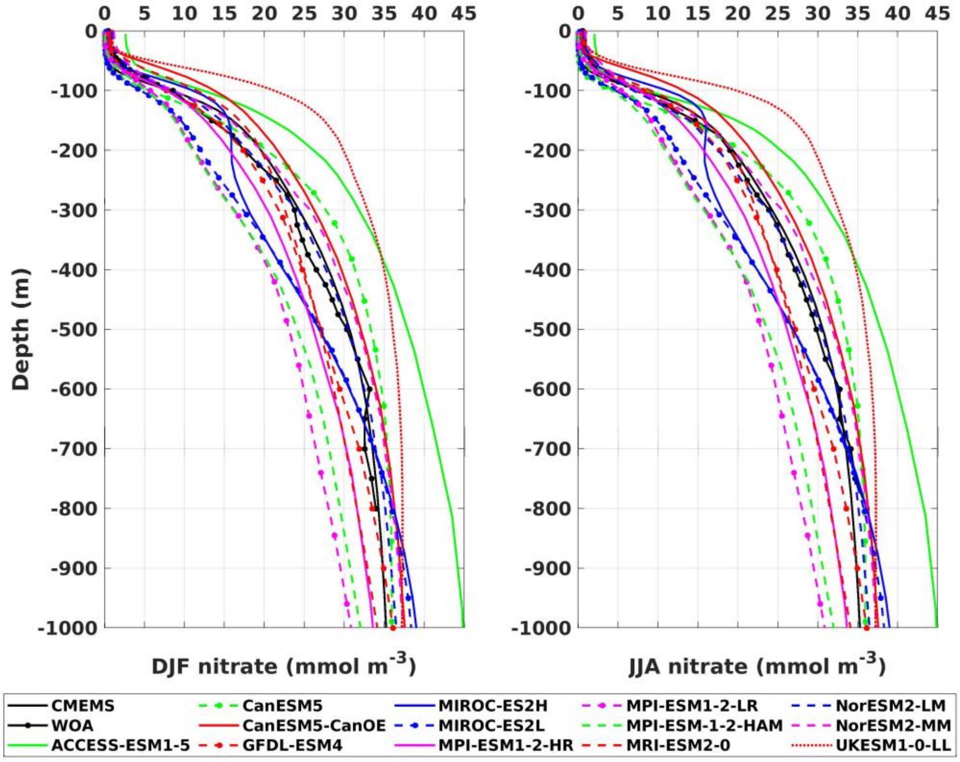

Figure S3 Depth profile of nitrate up to 1000 meters for reference (CMEMS) and observation (WOA18) data with 13 selected CMIP6 ESMs

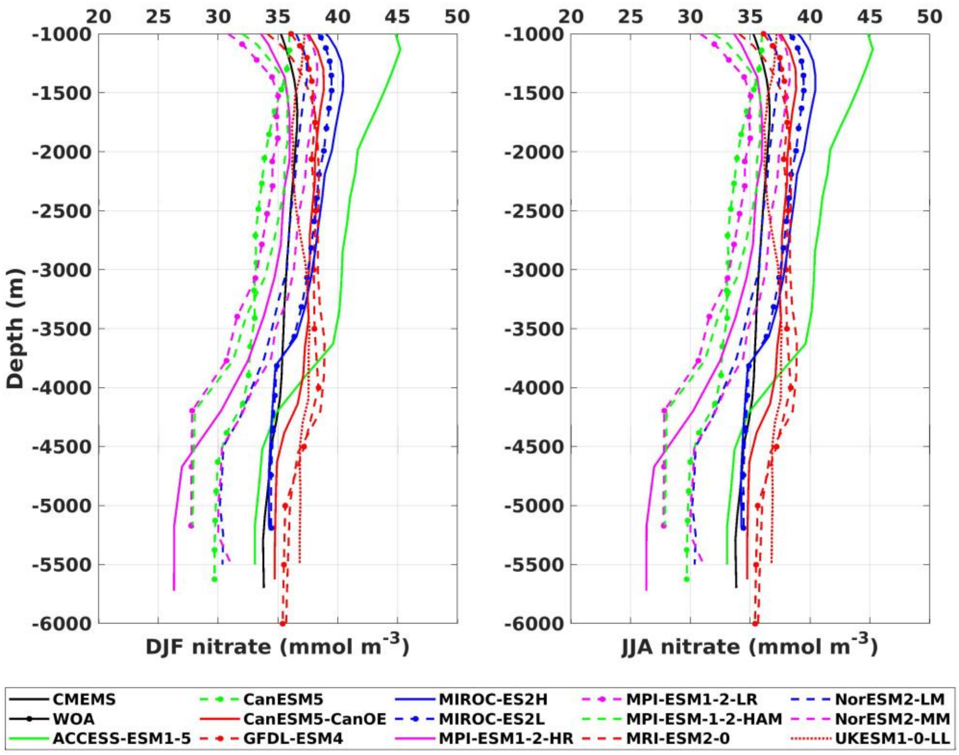

Figure S4 same as Figure S3 but for depth from 1000 to 6000 meters.

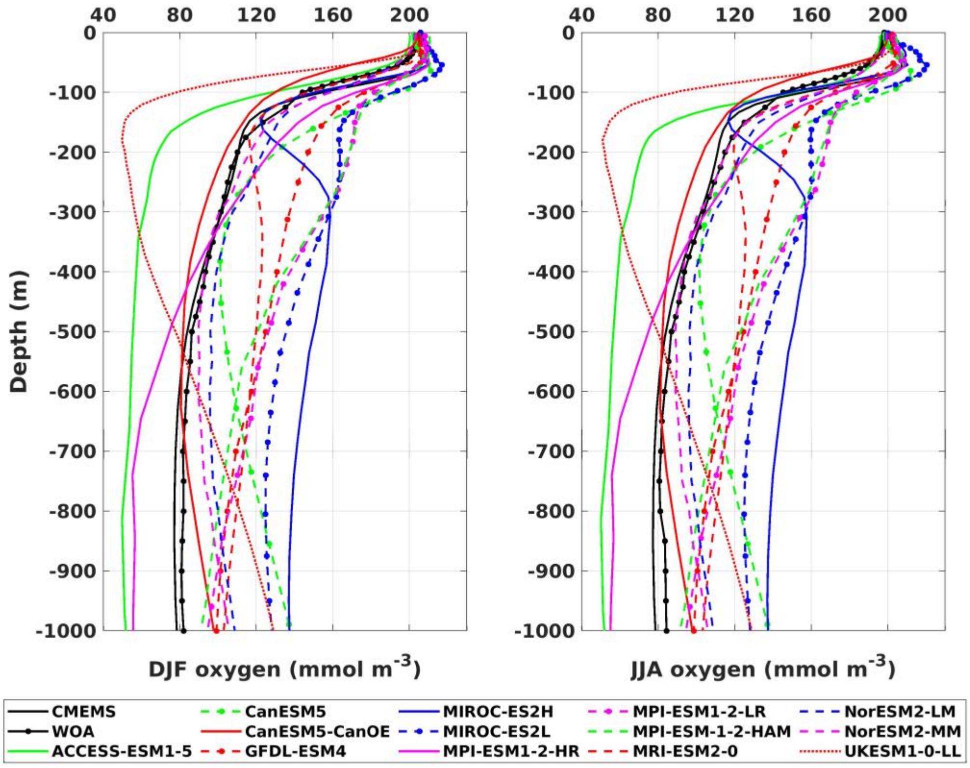

Figure S5 Depth profile of oxygen up to 1000 meters for reference (CMEMS) and observation (WOA18) data with 13 selected CMIP6 ESMs

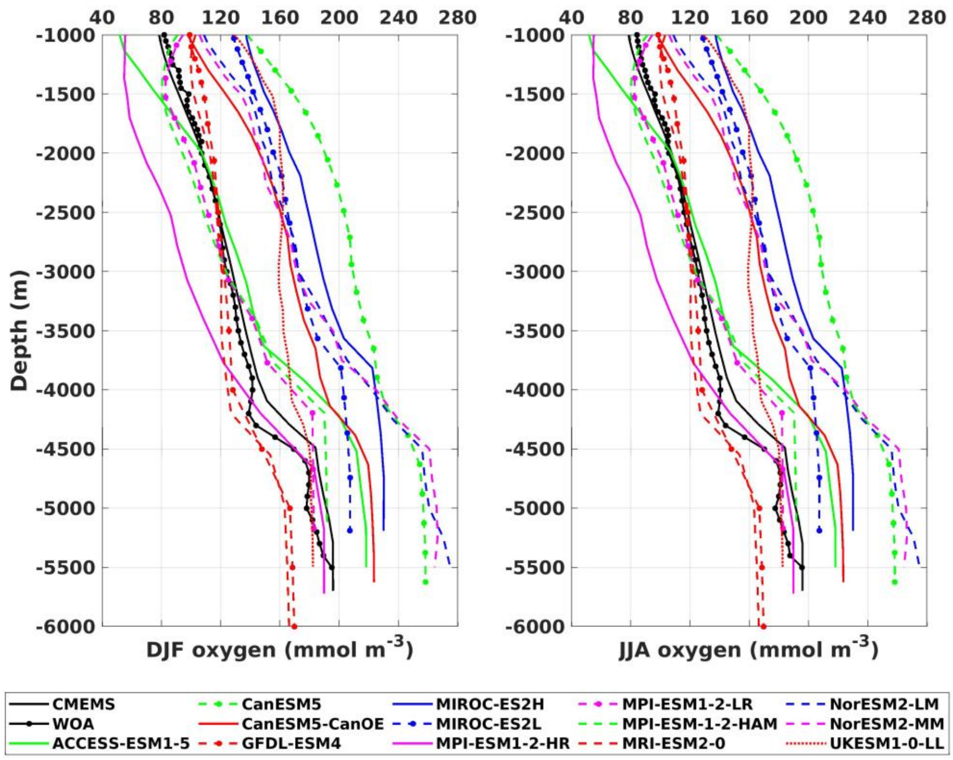

Figure S6 same as Figure S5 but for depth from 1000 to 6000 meters.