Reply to Reviewer's Comments and Suggestions

Manuscript number: gmd-2018-200
Title: A single-column ocean-biogeochemistry model (GOTM-TOPAZ) version 1.0

We appreciate your considered comments and suggestions, which have proven very helpful in improving our manuscript as well as very valuable in guiding our future research. We have made some revisions to the manuscript in accordance with your comments. The revised portions of the manuscript are marked in red, while our detailed responses below are given in blue.

We greatly appreciate the time and effort you have given to assessing our work and, once again, we thank you very much for your kind comments and suggestions.

Reviewer #1

[General comments]

1. "Innovation. The manuscript only describes the model and a comparison with observations and with a 3D model. None of the broad-brush statements about the potential use and usefulness materialises."

: The SCM (1D model) includes important physical processes and has a much lower computation cost than 3D models; therefore, it can be used to perform a variety of experiments repeatedly. Because of this advantage, 1D models can be useful to track mechanisms that are difficult to understand using 3D models. In particular, we think that TOPAZ, which includes complex biogeochemical mechanisms, can be used to obtain insights into the interactions between the chemical makeup of and organisms living in the ocean. In addition, the key processes which are studied via TOPAZ can later be implemented into 3D models. We added content on this to the discussion section.

"The SCM (1D model) includes important physical processes and has a much lower computation cost than 3D models; this means that a variety of experiments can be performed repeatedly. With this advantage, 1D models can be useful to track mechanisms that are difficult to understand using 3D models. We believe that TOPAZ, in particular, can be used to obtain insights on the interactions between the chemical makeup and organisms in the ocean because it accounts for complex biogeochemical mechanisms. In addition, the key processes which are studied via TOPAZ can be implemented later into 3D models."

"For example, the aerosol concentrations are continuously increasing in the over the East Asia region and are known to affect precipitation and atmospheric circulation. Thus, there is a possibility that aerosols affect oceanic biogeochemical processes as deposition occurs into the ocean, and this cannot be ignored. A variety of numerical experiments are necessary to understand this process, but they are difficult to perform using 3D models due to limitations in computing resources. However, as previously noted, GOTM-TOPAZ is fast; as such, it is useful for understanding the biogeochemical changes that occur in the ocean when the concentration of aerosols or CO_2 in the atmosphere changes. In addition, recent studies have reported that the distribution of fisheries is changing due to changes in phytoplankton size structure, caused by upwelling intensity on the coast of the East/Japan Sea (Shin et al., 2017). Phytoplanktons of TOPAZ are divided into two-types depending on their size, so it is expected to be useful in above mentioned research."

Shin, J.-W., Park, J., Choi, J.-G., Jo, Y.-H., Kang, J. J., Joo, H. T., and Lee, S. H.: Variability of phytoplankton size structure in response to changes in coastal upwelling intensity in the southwestern East Sea, J. Geophys. Res. Oceans, 122, 10, 262–10, 274, doi:10.1002/2017JC013467, 2017.

2. “Innovation. Other 1D ocean-biogeochemical models already exist. Why create another one? What can this one do that others can’t? What can you do with this one that you can’t do with others? How does the performance of this one compare with others?”

: You are correct that other 1D ocean biogeochemical models exist; one such model is included in the GOTM that we used (Burchard et al., 2006). However, most of these 1D ocean biogeochemical models include very simple processes and only predict limited oceanic biogeochemical variables. Furthermore, in most cases, they do not take the gas transfer between the atmosphere and ocean into account, or they simply calculate it as a constant. However, TOPAZ distinguishes three kinds of phytoplankton (which are important in ocean biogeochemistry) by size (small and large) and characteristics (diazotrophs), and also accounts for more than thirty biogeochemical variables. It also considers the atmospheric and oceanic environment and calculates the oxygen and carbon dioxide exchange fluxes for each time step. Iron and lithogenic particle deposition and NH4 and NO3 wet/dry deposition from aerosols are described. Since TOPAZ includes this kind of sophistication, we believe that researchers can use it to perform the following various kinds of experiments:

1. Examine changes in the marine environment according to changes in aerosols
2. Examine changes in oceanic biogeochemistry according to changes in the gas flux
3. Examine changes in the phytoplankton size structure according to upwelling

In addition, MOM and other OGCMs only consider temperature changes caused by the absorption of solar radiation by chlorophyll. However, Sonntag and Hense (2011) used a simple 1D ocean biogeochemical model to show that the effect of chlorophyll in a marine environment not only changes water temperature through photosynthesis but also changes the viscosity and albedo of the ocean, which affects the mixed layer depth. In the future, we plan to use GOTM-TOPAZ to perform experiments on changes in viscosity and albedo caused by chlorophyll and also apply this to a 3D model. We added content on this to the discussion section.

“A variety of single-column ocean biogeochemical models have already been developed. However, GOTM-TOPAZ includes complex biogeochemical processes and models over 30 kinds of tracers; the other models, which have only simple structures, do not (Dunne et al., 2012b). Furthermore, GOTM-TOPAZ considers the gas transfer caused by changes in the atmosphere and the physical environment of the ocean, depicting the deposition of dissolved iron, lithogenic aluminosilicate, NH4, and NO3 due to aerosols. We believe that the sophistication of TOPAZ provides researchers with the opportunity to perform a variety of experiments.”

Sonntag, S., and Hense, I.: Phytoplankton behavior affects ocean mixed layer dynamics through biological-physical feedback mechanisms, Geophys. Res. Lett., 38, L15610, doi:10.1029/2011GL048205, 2011.

3. “Observations. No information about the observational data set is given. How was it collected? Where, and at which time/depth intervals? How was it processed?”

: The observational data provided by the NIFS (http://www.nifs.go.kr/kodc) (water temperature, salinity, and dissolved oxygen, nitrogen, phosphorus, and silicon concentrations) were measured from vessels at 52, 54, and 69 specific points in the West, South, and East seas. Water temperature, salinity, and dissolved oxygen concentrations were measured every 15 m from 0 m to 500 m, while the nutrient concentrations were measured at intervals of 0, 20, 50, and 100 m. They were measured once every February, April, June, August, October, and December from 1961 to date. The specific measurement dates and times were not fixed and varied according to weather, vessel, and observation device conditions. Therefore, we viewed the measurement data as values that represented each month and used them as such in the model verification. We used the observational data in Fig. 6, the February (winter) and August (summer) mean from 1999 to 2008, and the mean data for the entire period. This information was added to the Experimental Setup section.

"The water temperature and salinity data from the NIFS was measured at 15 m intervals at depths of 0 m to 500 m. They were measured once in February, April, June, August, October, and December every year from 1961 to date."

"these data were measured once every year, in February, April, June, August, October, and December, at depths of 0, 20, 50, and 100 m. Specific measurement dates and times were not fixed, so we viewed the measurement data as values that represented each month and used them to verify the model."

4. "Validation. The comparison with observations is mostly visual, and involves statements such as 'similar'. This must be made quantitative."

: According to your advice, we have revised the text in the Abstract and the Results regarding the evaluation of the model and the observational data to make it quantitative. The text was revised to mention the p-values and correlation coefficients of the model results and the observational data shown in a time series figure. Thank you for the valuable suggestion.

"The temporal variability of observed upper-ocean (0-20m) chlorophyll is well captured by GOTM-TOPAZ model with a correlation coefficient of 0.51."

"The surface correlation coefficients between the GOTM-TOPAZ oxygen, nitrogen, phosphorus, and silicon are 0.47, 0.30, 0.16, and 0.19, respectively."

"The mean chlorophyll concentration at depths of 0–20 m, as simulated by GOTM-TOPAZ and MOM, had similar inter-annual variabilities; their correlation coefficients versus the observational data were 0.53 and 0.60, respectively (Fig. 4a), which is statistically significant ($p < 0.001$)."

"the two models had a correlation coefficient of 0.59 ($p < 0.01$) and a similar inter-annual variability (Fig. 4b)."

"The sea surface dissolved oxygen levels simulated by GOTM-TOPAZ and MOM had correlation coefficients of 0.47 ($p < 0.001$) and 0.50 ($p < 0.001$), respectively, versus the observed data (Fig. 5a)."

"The GOTM-TOPAZ correlation coefficient versus the observed data was 0.31 ($p < 0.001$) for nitrogen, 0.16 ($p < 0.10$) for phosphorus, and 0.19 ($p < 0.05$) for silicon; these were lower than the correlation coefficients between MOM and the observed data (0.36, 0.24, and 0.33, respectively; $p < 0.001$). However, GOTM-TOPAZ seemed to depict the inter-annual variability of nutrients at the sea surface well (Fig. 5b–d)."

5. "Validation. The text often contradicts the information in the figures, and suggests that the results are better than they really are."

: Thank you for pointing this out. After reading your comment, we realized that the text overstates the modeling capabilities of the model in many places, in contrast to what the figures show. We removed or revised the overstated text and made revisions to evaluate the model using objective numerical values. We also revised the parts where this problem was pointed out in specific comments.

"The vertical distributions of salinity are well simulated and are comparable to the observations, although this could also be because relaxation was applied. The water temperature simulated by GOTM-TOPAZ showed a cold bias in the upper layer at a depth of around 120 m. This appears to be the effect of large-scale forcing (from the EKWC) that GOTM-TOPAZ could not resolve. Similar differences in water temperature also appeared at points 104 and 102 (Supplementary Figure 1)."

"GOTM-TOPAZ well simulated dissolved oxygen (surface to 250 m) and nitrogen (surface to 100 m) concentrations during that season (Fig. 6a). However, for phosphorus and silicon at the same depths, there was a difference between the GOTM-TOPAZ results and the observational data."

"During this season, the oxygen concentration simulated by GOTM-TOPAZ, unlike that in the observational data, increased sharply from depths of 20–60 m. This seems to have been caused by the creation of oxygen from photosynthesis by phytoplankton (Fig. 6b)."

"Nonetheless, the results demonstrated that dissolved oxygen at 80–250 m, nitrogen, and phosphorus are well simulated over 10 years using GOTM-TOPAZ (Fig. 6c)."

6. "Validation. Why are only anomalies presented in the time series? Anomalies compared to what? Does this mask biases?"

: We used anomalies to check if GOTM-TOPAZ depicted the inter-annual variability of the biogeochemical tracers well. Time series images of the concentrations of chlorophyll, dissolved oxygen, nitrate, phosphorus, and silicon (which are not depicted as anomalies) at the three points are given below for your reference.

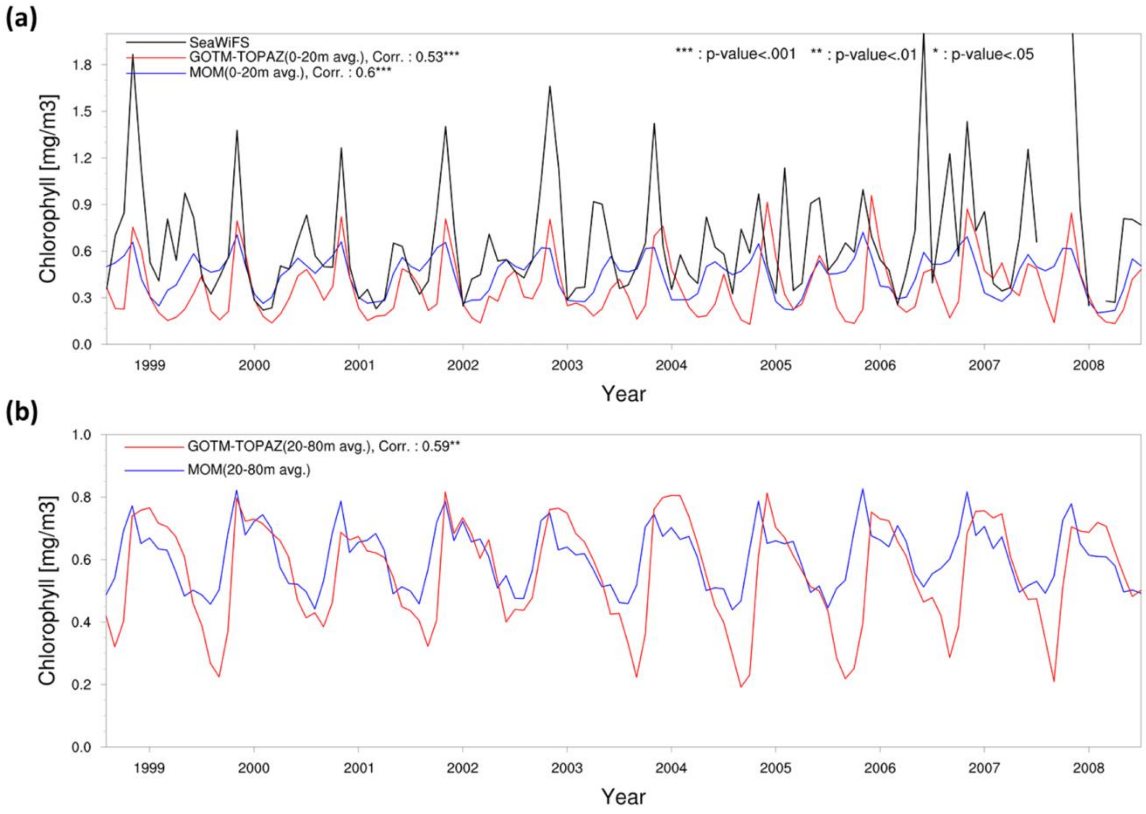

Figure review 1: Chlorophyll time series and correlation values for observational data (black lines), MOM5_SIS_TOPAZ results (blue lines), and GOTM-TOPAZ results (red lines) at point 107 for the 10-year period 1999–2008; (a) the mean value at depth ≥ 20 m and the correlations between the observations and each model; (b) mean values at depths of 20–80 m and the correlation between the two models.

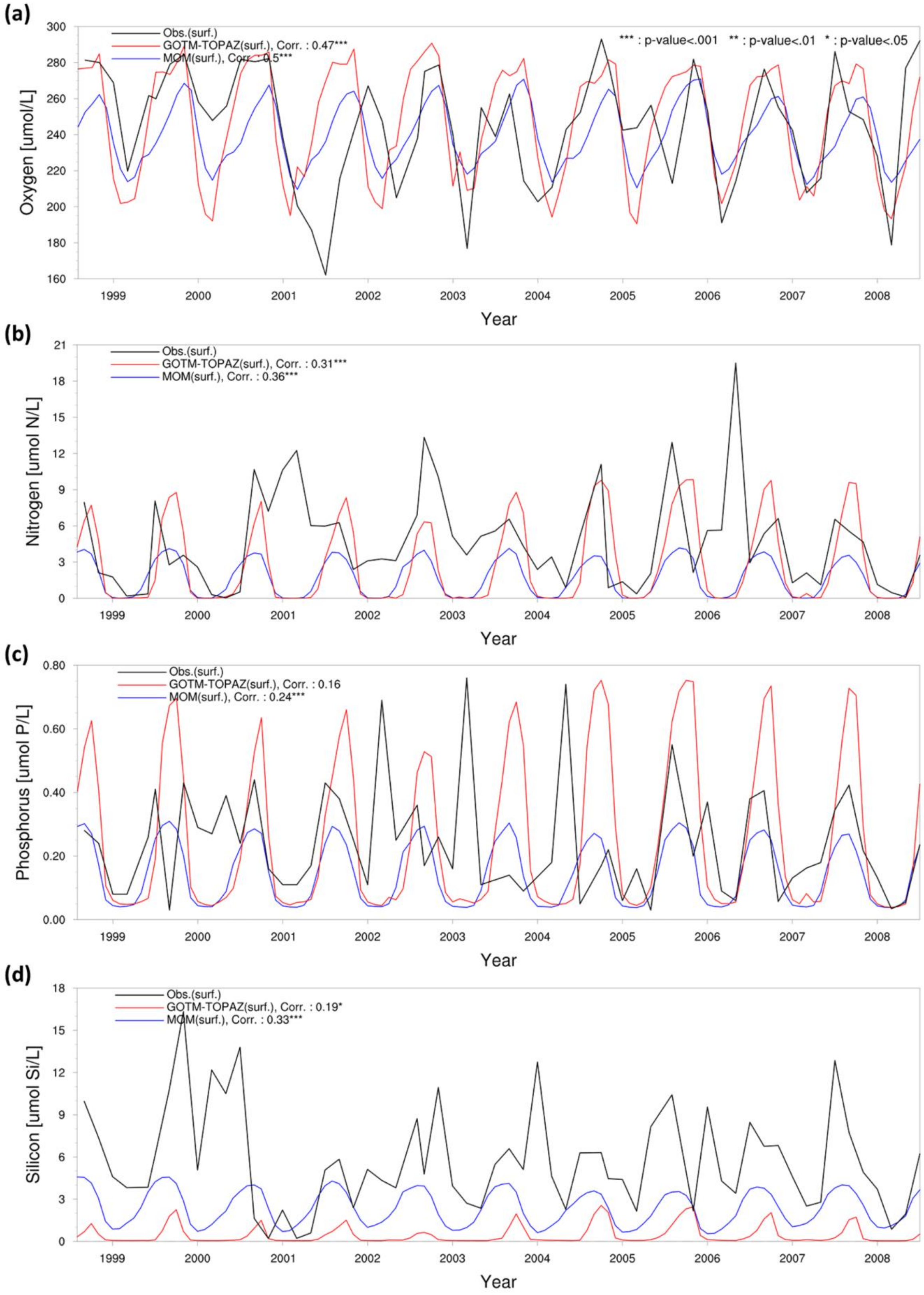

Figure review 2: Time series and correlation values from observational data (black lines), MOM5_SIS_TOPAZ results (blue lines), and GOTM-TOPAZ results (red lines) for concentrations of (a) dissolved oxygen, (b) nitrogen, (c) phosphorus, and (d) silicon at point 107 for the 10-year period 1999–2008; in this figure, nitrogen, phosphorus, and silicon include NO3, PO4, and SIO4, respectively.

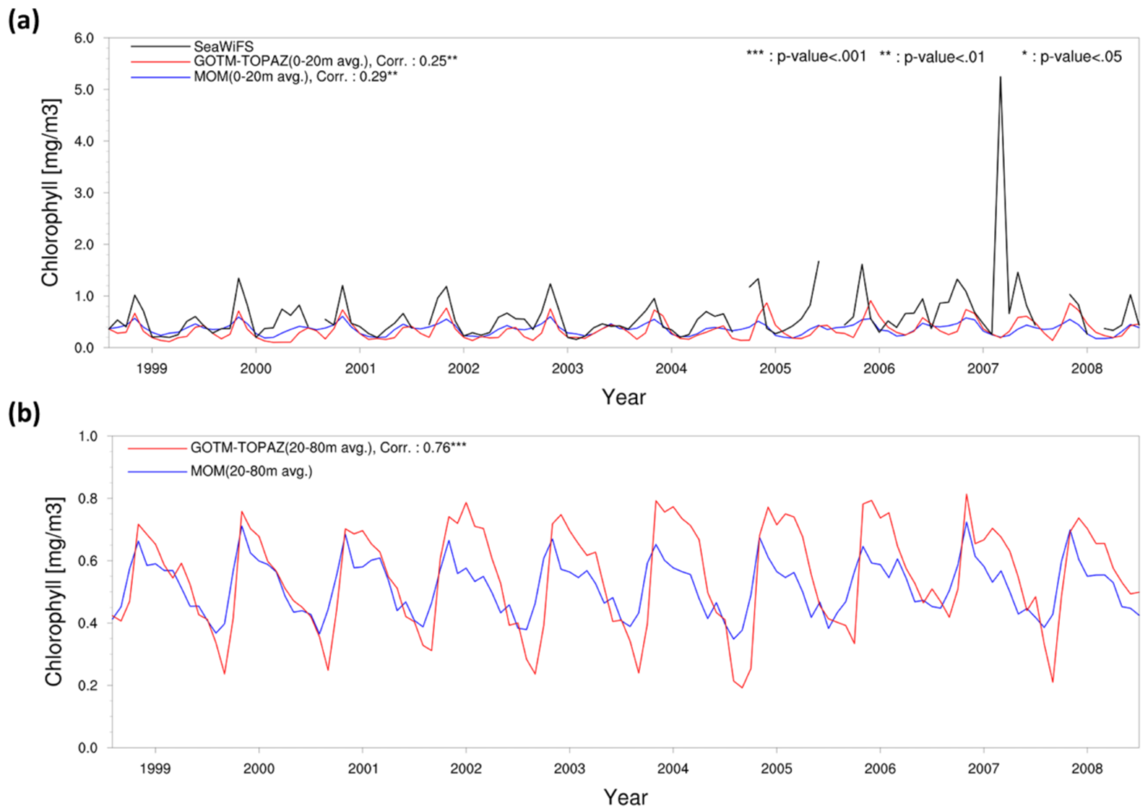

Figure review 3: Same as in Fig. review 1 except for 104 point.

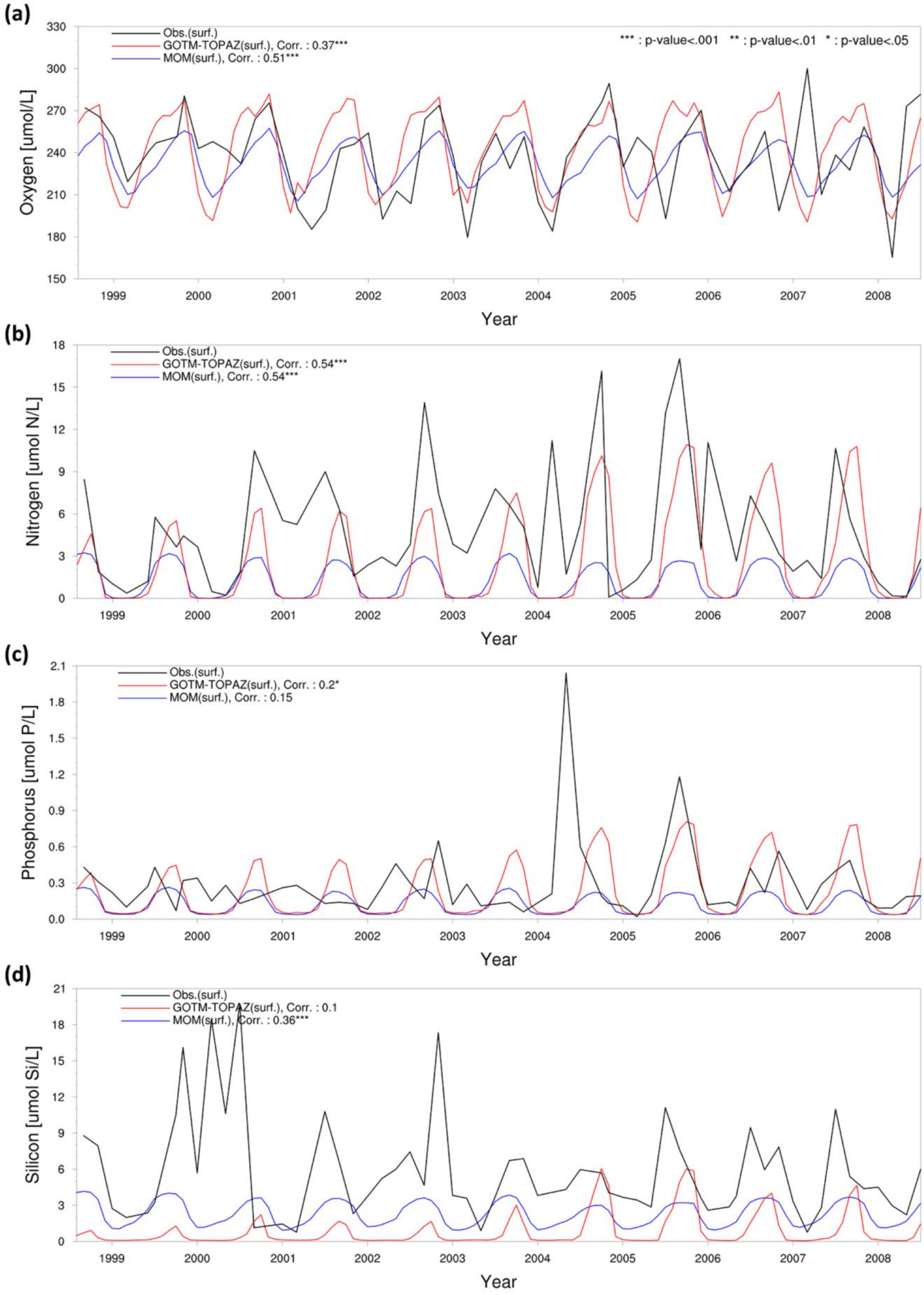

Figure review 4: Same as in Fig. review 2 except for 104 point.

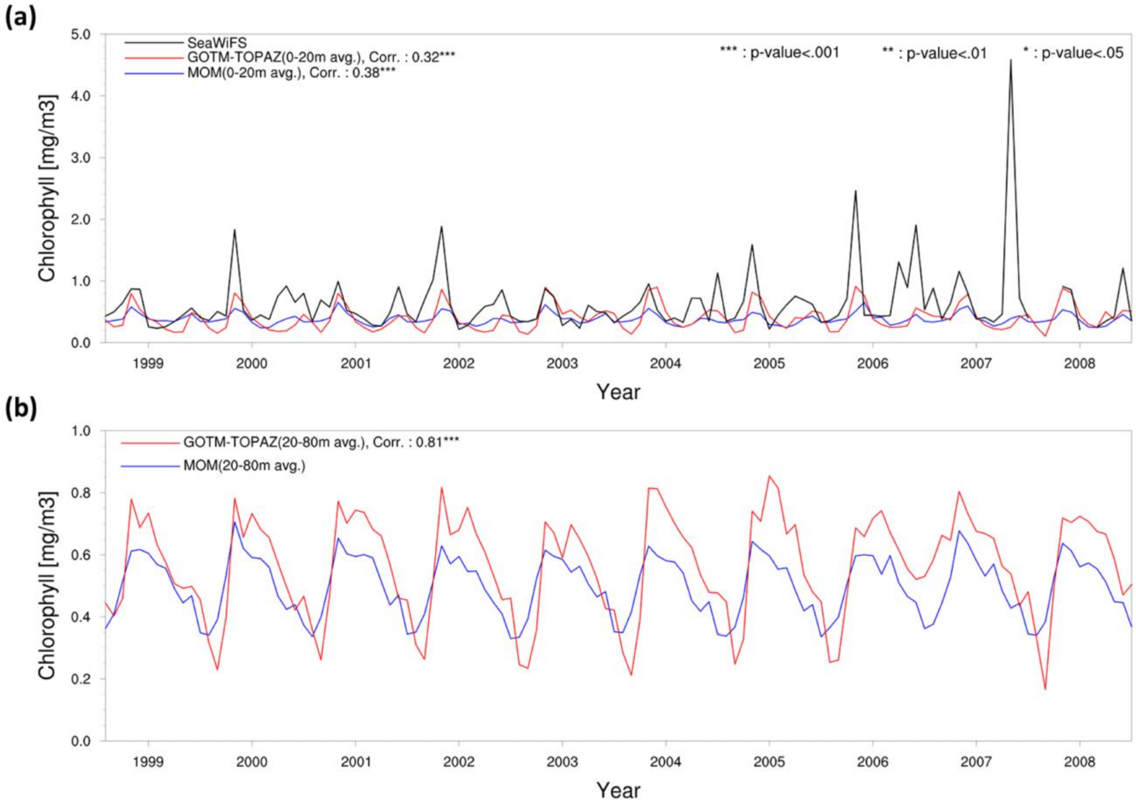

Figure review 5: Same as in Fig. review 1 except for 102 point.

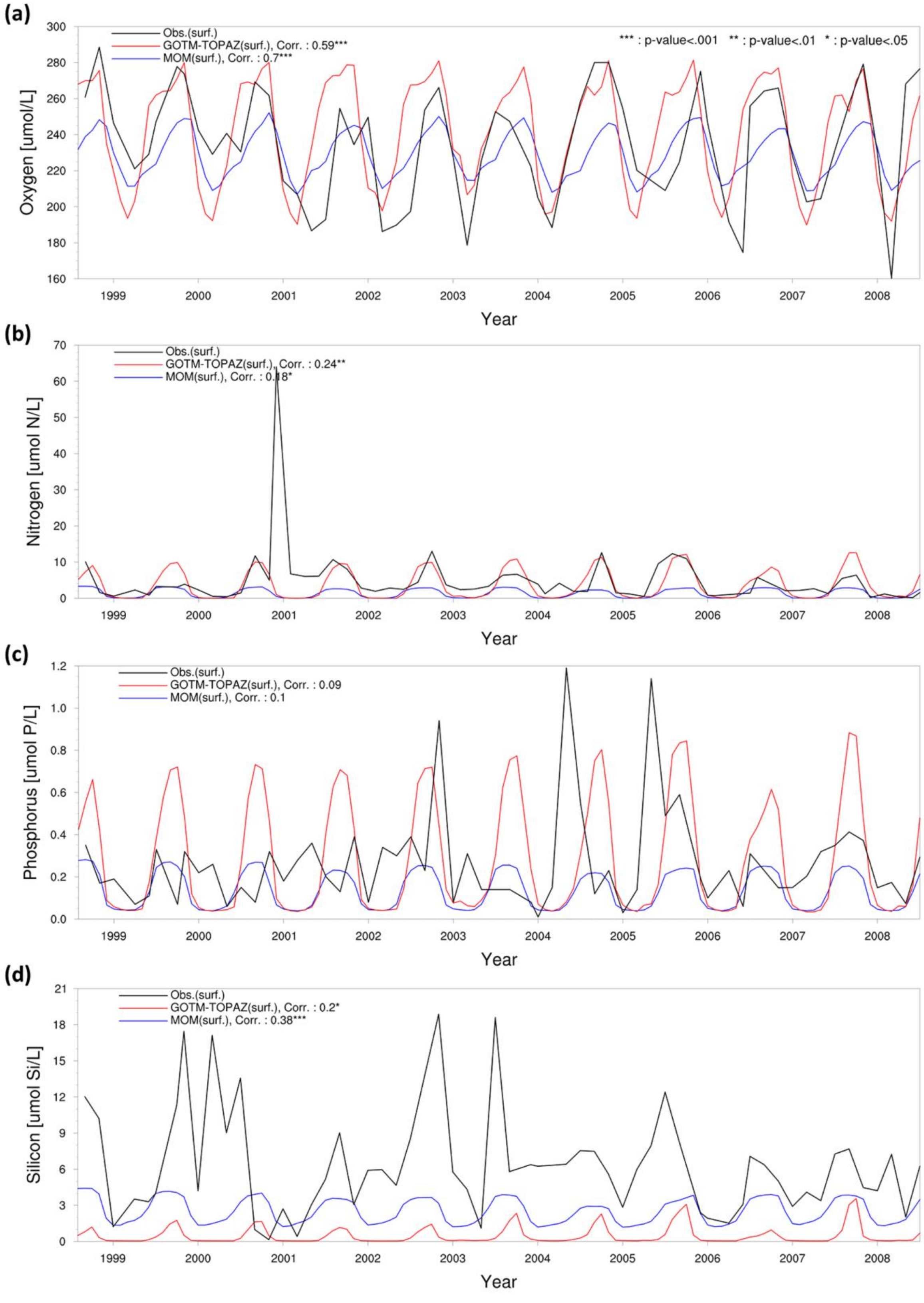

Figure review 6: Same as in Fig. review 2 except for 102 point.

7. “Location. The location for application/validation was chosen because of its advective properties at the confluence of two ocean currents (p. 8, l. 8-9). This baffles me, as a water-column model can not (as the authors acknowledge) deal with horizontal advection. How can this site be used to reliably evaluate the model’s performance? It’s absolutely unsuitable. And indeed, most of the arguments given for mis-matches with the observations are related to advection...”

: Thank you for your observation. The point that we selected was chosen not just because it is a place where two currents with different properties meet, but because this means it has other important oceanographic and biogeochemical significance. This region is being studied with regard to changes in the major fish species and the total catch based on the type of phytoplankton (size and toxicity) (Joo et al., 2014; Shin et al., 2017). Furthermore, when we considered the continuity and quality of the nutrient observation data mentioned in general comment #3, we determined that point 130E/38N was the best sampling site. As GOTM-TOPAZ handles phytoplankton subdivided into small-sized, large-sized, and diazotrophs, we think that it can be used in such studies. Of course, this region does have strong horizontal advection, which is disadvantageous for testing a 1D column model; despite this, we believe that if the analysis results show some degree of significance, they indicate that GOTM-TOPAZ can be used to test a variety of points. Based on your suggestion, we believe that the content in the paper regarding the site selection was inadequate and have thus added related content. In addition, we selected different points in the East/Japan Sea and performed additional tests.

“We selected three points that have features typical of the East/Japan Sea and for which observation data suitable to use for verification exists (Fig. 2): point 107, where the EKWC and NKCC meet (130.0° E, 38.0° N); point 104, which is an important location along the EKWC (131.3° E, 37.1° N); and point 102, which is in the middle of a warm eddy created as the EKWC moves north (130.6° E, 36.1° N). As noted previously, these points are in regions with strong advection and thus may not be suitable for testing GOTM-TOPAZ, which is an SCM. However, since the results obtained using GOTM-TOPAZ were significant when compared to the observations, we think that this shows that it is possible to perform sensitivity experiments using GOTM-TOPAZ at several kinds of locations.”

Joo, H. T., Park, J. W., Son, S. H., Noh, J.–H., Jeong, J.-Y., Kwak, J. H., Saux-Picart, S., Choi, J. H., Kang, C.-K., and Lee, S. H.: Long-term annual primary production in the Ulleung Basin as a biological hot spot in the East/Japan Sea, J. Geophys. Res. Oceans, 119, 3002–3011, doi:10.1002/2014JC009862, 2014.

Shin, J.-W., Park, J., Choi, J.-G., Jo, Y.-H., Kang, J. J., Joo, H. T., and Lee, S. H.: Variability of phytoplankton size structure in response to changes in coastal upwelling intensity in the southwestern East Sea, J. Geophys. Res. Oceans, 122, 10, 262–10, 274, doi:10.1002/2017JC013467, 2017.

8. “Generality. The model is intended to serve very general purposes. However, it is applied only to a single (unsuitable) site. How can we know that it is generally applicable to the purposes for which it was intended?”

: 3D models are generally compared to observations, verified, and used to predict future states. However, 3D models are large, very complex, and take up significant computing resources. As such, they are difficult to use to understand key earth systems processes. In contrast, single-column models are used mainly in sensitivity tests such as mutual comparisons of model results regarding changes to the parameterization method or to external forcing. Many parts of various ocean biogeochemical processes are depicted empirically, and these equations are fitted mainly to observations on the open sea, such as those from the Pacific or Atlantic oceans. However, the biogeochemical results simulated by current climate models vary depending on the model used, and projects are being conducted to compare and evaluate these results (Orr et al., 2017). We think that the GOTM-TOPAZ model we developed can be used to better understand the characteristics of these global models and improve the parameterization of biogeochemical processes.

Orr, J. C., Najjar, R. G., Aumont, O., Bopp, L., Bullister, J., Danabasoglu, G., Doney, S. C., Dunne, J. P., Dutay, J.-C., Graven, H., Griffies, S. M., Joos, F., Levin, I., Lindsay, K., McKinley, G. A., Oschlies, A., Romanou, A., Schlitzer, R., Tagliabue, A., Tanhua, T., and Yool, A.: Biogeochemical protocols and diagnostics for the CMIP6 Ocean Model Intercomparison Project (OMIP), Geosci. Model. Dev., 10, 2169-2199, doi:10.5194/gmd-10-2169-2017, 2017.

[Specific comments]

9. "p. 1, l. 20. reliably: requires quantification."
: As suggested, the correlation coefficients of the model and the observational data have been added to the abstract.

"The temporal variability of observed upper-ocean (0-20m) chlorophyll is well captured by GOTM-TOPAZ model with a correlation coefficient of 0.51. The surface correlation coefficients between the GOTM-TOPAZ oxygen, nitrogen, phosphorus, and silicon are 0.47, 0.30, 0.16, and 0.19, respectively."

10. "p. 1, l. 28-29. Requires reference."
: We have added these four citations.

Dirmeyer, P. A., Cash, B. A., Kinter III, J. L., Stan, C., Jung, T., Marx, L., Towers, P., Wedi, N., Adams, J. M., Altshuler, E. L., Huang, B., Jin, E. K., and Manganello, J.: Evidence for enhanced land-atmosphere feedback in a warming climate, J. Hydrometeorol., 13, 981-995, doi:10.1175/JHM-D-11-0104.1, 2012.
Friedlingstein, P., Cox, P., Betts, R., Bopp, L., von Bloh, W., Brovkin, V., Cadule, P., Doney, S., Eby, M., Fung, I., Bala, G., John, J., Jones, C., Joos, F., Kato, T., Kawamiya, M., Knorr, W., Lindsay, K., Matthews, H. D., Raddatz, T., Rayner, P., Reick, C., Roeckner, E., Schnitzler, K. G., Schnur, R., Strassmann, K., Weaver, A. J., Yoshikawa, C., and Zeng, N.: Climate-Carbon Cycle Feedback Analysis: Results from the C4MIP Model Intercomparison, J. Clim., 19(14), 3337-3353, doi:10.1175/JCLI3800.1, 2006.
Randerson, J. T., Lindsay, K., Munoz, E., Fu, W., Moore, J. K., Hoffman, F. M., Mahowald, N. M., and Doney, S. C.: Multicentury changes in ocean and land contributions to the climate-carbon feedback, Global Biogeochem. Cycles, 29, 744-759, doi:10.1002/2014GB005079, 2015.
Soden, B. J., and Held, I. M.: An assessment of Climate Feedbakcs in Coupled Ocean-Atmosphere Models, J. Clim., 19(14), 3354, doi:10.1175/JCLI3799.1, 2006.

11. "p. 2, l. 1. Requires reference."
: We have added these four citations.

Dunne, J. P., John, J. G., Adcroft, A. J., Griffies, S. M., Hallberg, R. W., Shevliakova, E. N., Stouffer, R. J., Cooke, W., Dunne, K. A., Harrison, M. J., Krasting, J. P., Malyshev, S. L., Milly, P. C. D., Phillipps, P. J., Sentman, L. A., Samuels, B. L., Spelman, M. J., Winton, M., Wittenberg, A. T., and Zadeh, N.: GFDL's ESM2 global coupled climate-carbon Earth System Models Part I: Physical formulation and baseline simulation characteristics, J. Clim., doi:101175/JCLI-D-11-00560.1, 2012a.
Dunne, J. P., John, J. G., Shevliakova, E., Stouffer, R. J., Krasting, J. P., Malyshev, S. L., Milly, P. C. D, Sentman, L. T., Adcroft, A. J., Cooke, W., Dunne, K. A., Griffies, S. M., Hallberg, R. W., Harrison, M. J., Levy, H., Wittenberg, A. T., Phillips, P. J., and Zadeh, N.: GFDL's ESM2 global coupled climate–carbon earth system models. Part II: carbon system formulation and baseline simulation characteristics, J. Clim., 26, 2247–2267, doi:10.1175/jcli-d-12-00150.1, 2012b.
Jones, C., and Sellar, A.: Development of the 1st version of the UK Earth system model, UKESM newsletter no. 1 – August 2015, available at: https://ukesm.ac.uk/ukesm-newsletter-no-1-august-2015/ (last access: 4 November 2018), 2015.
Sokolov, A., Kicklighter, D., Schlosser, C. A., Wang, C., Monier, E., Brown-Steiner, B., Prinn, R., Forest, C., Gao, X., Libardoni, A., and Eastham, S.: Description and Evaluation of the MIT Earth System Model (MESH), J. Adv. Model. Earth. Sy., 10(8), 1759-1789, doi:10.1029/2018MS001277, 2018.

12. “p. 2, l. 10. for differentiating. I’m not sure what’s meant here. Probably not mathematical differentiation?”

: You are correct. We have revised the text to convey our intended meaning more precisely. The revised text is shown below. Thank you for the useful advice.

“There are still no accurate methodologies with which to distinguish biogeochemical variables and to represent biogeochemical processes as formulas (Sauerland et al., 2018)”

13. “p. 3, l. 25. Please finish explaining all the variables before going into the equations.”

: We have added descriptions of all variables included in Eqs. (1)–(4). We revised the text as shown below.

“In Eqs. (1) and (2), u, v and w represent the mean velocities in the spatial directions x (eastward), y (northward), and z (upward), respectively; ν represents the molecular diffusivity of momentum; ρ_0 represents a constant reference density; p represents pressure; and f represents the Coriolis parameter. In Eq. (3), the temperature (T) equation, ν' represents the molecular diffusivity due to heat; c_p represents the heat capacity; and I represents the vertical divergence of short-wave radiation. The effect of solar radiation absorbed by seawater is included in this equation; thus, Eq. (3) is closely associated with the radiation parameterization method. Moreover, a coupled ocean biogeochemistry model must contain an additional short-wave absorption process associated with chlorophyll synthesis distributed throughout the upper-ocean layer (Morel and Antoine, 1994; Cloern et al., 1995; Manizza et al., 2005; Litchman et al., 2015; Hense et al., 2017). Based on the methodology of Manizza et al. (2005), we applied a visible light absorption process due to chlorophyll synthesis, explained in detail in Sect 4.4, to the coupled model. Equation (4) explains the vertical distribution of salinity (S). In this equation, ν'' represents the molecular diffusivity of salinity; τ_R represents the relaxation time scale; and S_R represents the observed salinity distribution. In other words, the terms on the right side of this equation express the “relaxation” process based on observations.”

14. “p. 4, l. 25-26. empirical formulas derived from observations. Please expand. Formulas of what kind? Which observations? How were the formulas derived? Are they generally applicable, or (more likely?) specific to the location(s) where the observations were taken? How does this relate to the location used here? There’s no need to repeat the Dunne et al. paper, but a summary is required here.”

: As per your advice, we added more information on the main processes of the ocean biogeochemical process implemented by TOPAZ and added a reference (de Baar, 1994; Redfield et al., 1963). The Redfield ratio (C:N:P found in phytoplankton is 106:16:1), Leibig’s law of the minimum (which states that growth is controlled by the limiting nutrient), and size considerations (large organisms feed on small ones) were mentioned. The revised text is shown below. Thank you for the useful advice.

“The biological processes of TOPAZ were reproduced with a focus on phytoplankton growth, nutrient and light limitations, the grazing process, and empirical formulas derived from observations. These are followed by the Redfield ratio (Redfield et al., 1963), Liebig’s law of the minimum (de Baar, 1994), and size considerations (large organisms feed on smaller ones), which were used to establish the ocean ecosystem model (Dunne et al., 2012b).”

15. “p. 5, l. 11-12. we used: How?”

: The “SUBROUTINE adv center,” which calculates tendencies caused by w-advection and applies them to tracers in GOTM, was applied to TOPAZ. The “SUBROUTINE topaz_w_adv” module, in particular, was created within TOPAZ and the “SUBROUTINE adv_center” was linked to it. The text was revised to demonstrate this better, and the revised text is shown below. Thank you for the useful comment.

“We connected the w-advection module in GOTM to TOPAZ so that the upwelling was reproduced in TOPAZ.”

16. “p. 5, l. 17. were determined: how? What was the source of the data?”

: Thank you for making this suggestion. We have revised the text as follows to convey our intended meaning. We also added text to the Experimental Setup section to describe the source of the initial GOTM data.

“The observed data such as seawater temperature and salinity was used to initialize and relax vertical structures in the GOTM throughout the simulation. This data was provided by the National Institute of Fisheries Science (NIFS; http://www.nifs.go.kr/kodc).”

17. “p. 5, l. 26. process for calculating: please specify.”

: TOPAZ includes calculations for sediment calcite cycling and the external bottom flux of O2, NH4, PO4, and alkalinity. We revised the relevant text as shown below.

“TOPAZ includes processes for variables include sediment calcite cycling and the external bottom fluxes of O2, NH4, PO4, and alkalinity (Dunne et al., 2012b).”

18. “p. 5, l. 31. monthly average climate values. From which source? How can this be done without systematically enriching the system during the simulation?”

: We used MOM’s initial data, which was provided by the Australian Research Council’s Centre of Excellence for Climate System Science (ARCCSS; http://climate-cms.unsw.wikispaces.net/Data). The text added to the manuscript is shown below. TOPAZ’s internal mechanism is shown in Fig. review 7. The material provided from the atmosphere is consumed by phytoplankton, decomposes, and sinks; as the material cycles through this process, it does not seem to accumulate.

“These surface flux data are provided by the Australian Research Council’s Centre of Excellence for Climate System Science (ARCCSS; http://climate-cms.unsw.wikispaces.net/Data).”

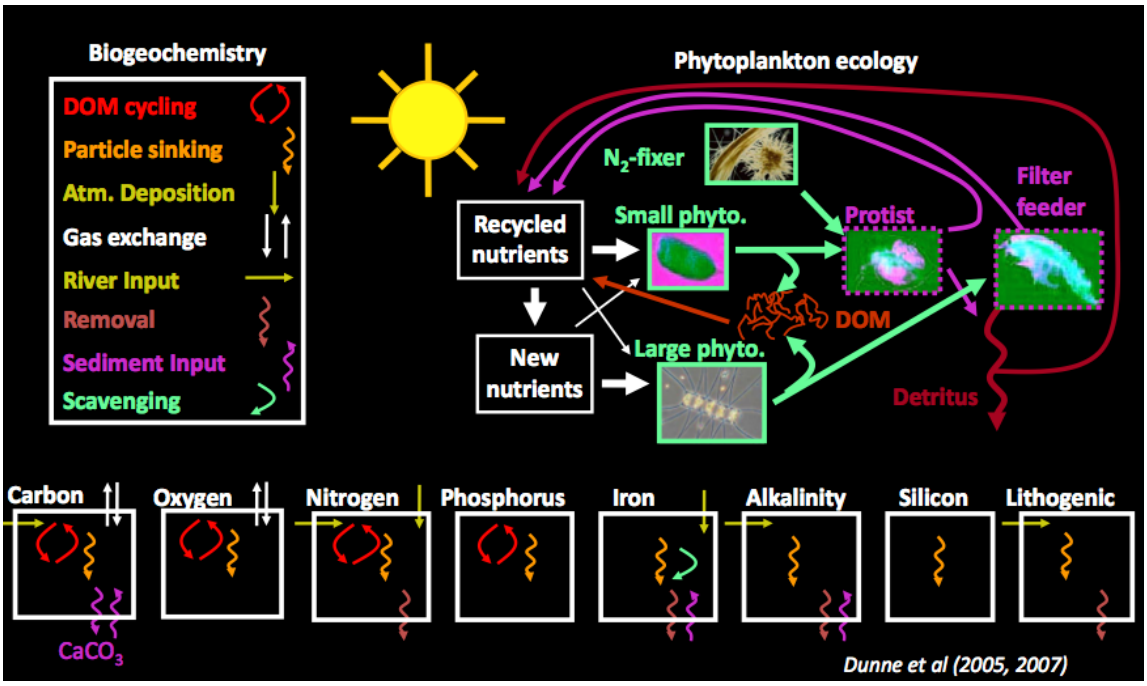

Figure review 7. Ocean biogeochemical process represented in TOPAZ.

19. "p. 6, l. 7. [A]: please provide values and reference(s)."

: In eq 6, [A] is the surface ocean concentration of gas A as predicted by the model. Concentrations are indicated throughout with [] and are in units of μmol of the chemical species per kg of seawater. The information related to air-sea gas transfer is referenced in Najjar and Orr (1998). We revised the text which describes Eq. 6 as shown below.

"Here, F is the upward flux of gas A and k_w is its gas transfer velocity, which can be calculated as a function of the Schmidt number and wind speed at 10 m (Wanninkhof, 1992). ρ is the density of surface seawater, [A] is the concentration [μmol kg^{-1}] of gas A at the surface of the ocean, and $[A]_{sat}$ is the corresponding saturation concentration of gas A in equilibrium with a water vapor-saturated atmosphere at total atmospheric pressure (Najjar and Orr, 1998). [A] is predicted by the model. Please see Najjar and Orr (1998) for further detailed information related to Eq. (6)."

20. "p. 7, l. 2,3: please explain what XI(lambda) and e(lambda) are."

: $\chi_{(\lambda)}$ represents the pigment absorption and $e_{(\lambda)}$ represents the power law for absorption. We have modified the sentence as follows.

"In these bands, the values of the pigment adsorption $\chi_{(\lambda)}$ are 0.037 and 0.074 m^{-2} mg Chl m^{-3}, respectively; $e_{(\lambda)}$, the power law for absorption, has values of 0.629 and 0.674 [no units], respectively."

21. "p. 7, l. 1-4: are all these parameter value settings from Manizza et al?"

: Yes, we used all parameter settings from Manizza et al. (2005).

22. “p. 6, eqn 7. Why are contributions to the light-extinction coefficient by CDOM and suspended particulate matter not taken into account? These can be dominant in many locations.”

: As you have noted, light extinction due to CDOM and suspended particulate matter are certain items that must be considered in the model. However, as far as we know, there is currently no earth systems model in existence that considers all of these mechanisms. We can use GOTM-TOPAZ to perform experiments that consider changes in light-extinction due to chlorophyll, CDOM, and suspended particulate matter. We can perform a study that first uses a 1D column model to test the stability of this kind of parameterization, and then apply it to a 3D model. We are grateful to the you for your providing helpful suggestions regarding the improvement of our model.

23. “p. 7, section 4.5. How was this used for the test case?”

: Thank you for drawing our attention to this. We added tests for new points in the East/Japan Sea and included the results in the supplementary material.

In the experiment at point 102, we prescribed the upwelling as decreasing linearly in the upward and downward directions at maximum value of 0.0000005 m/s, based on a depth of 100 m. The water temperature from GOTM-TOPAZ shown in Fig. review 8 demonstrates that a cold region exists due to upwelling at a depth of around 200 m. However, this cold region, which actually exists at point 102, is due to cold advection, and its mechanism is different from the upwelling experiment. Nonetheless, we performed experiments to verify the implementation of upwelling in the model. The mean chlorophyll concentration at depths of 20–80 m show that there is a rapid increase in upwelling during winter (Fig. review 9). Because of the effect of this upwelling, the nutrients below a depth of 200 m were supplied to the upper layer during the previous period. The supplied nutrients are consumed and thus have an effect on the increase in chlorophyll concentration around at 20–80 m in the winter (Fig. review 10). The effect of the upwelling is also seen in the vertical profile of dissolved oxygen. Fig. review 10 shows that the middle layer of seawater, which is deeper than 300 m (where there is little dissolved oxygen), was supplied to the upper layer, and the concentration of dissolved oxygen below a depth of 150 m decreased sharply. We still do not have adequate data to implement upwelling that is similar to reality. In the future, we plan to collect observational data related to this and perform a study on upwelling on the eastern coast and changes in the ocean biogeochemical environment.

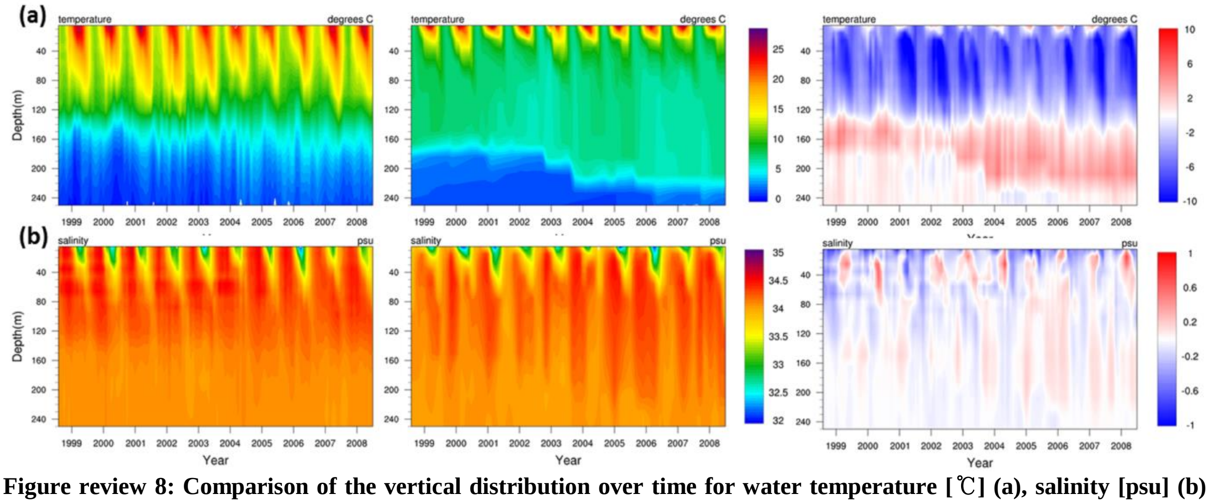

Figure review 8: Comparison of the vertical distribution over time for water temperature [℃] (a), salinity [psu] (b) and the difference between the two (GOTM-TOPAZ minus obs.) at point 102 for the 10-year period from 1999–2008. The upwelling is prescribed to the GOTM-TOPAZ.

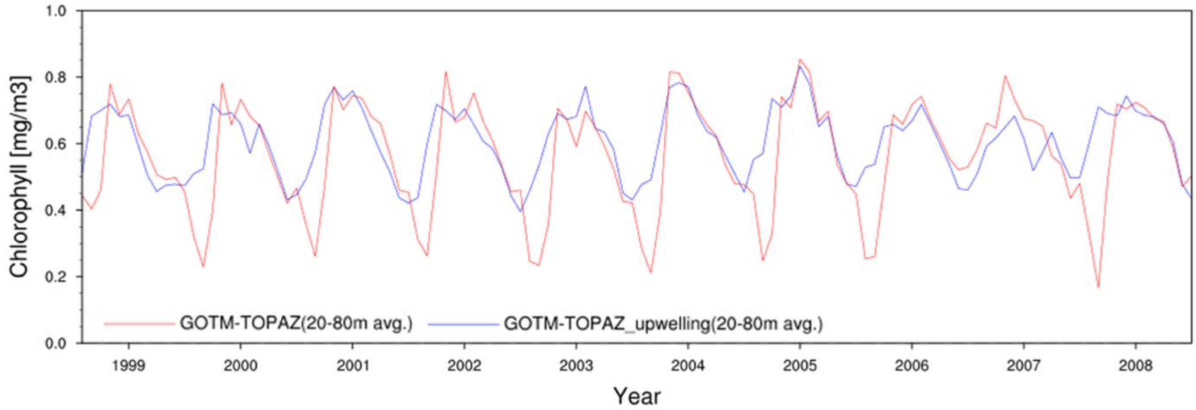

Figure review 9: Chlorophyll time series from GOTM-TOPAZ (red lines) and upwelling case (blue lines) at point 102 for the 10-year period from 1999–2008. Chlorophyll concentration is averaged between 20 to 80m depth. The upwelling is prescribed to the GOTM-TOPAZ.

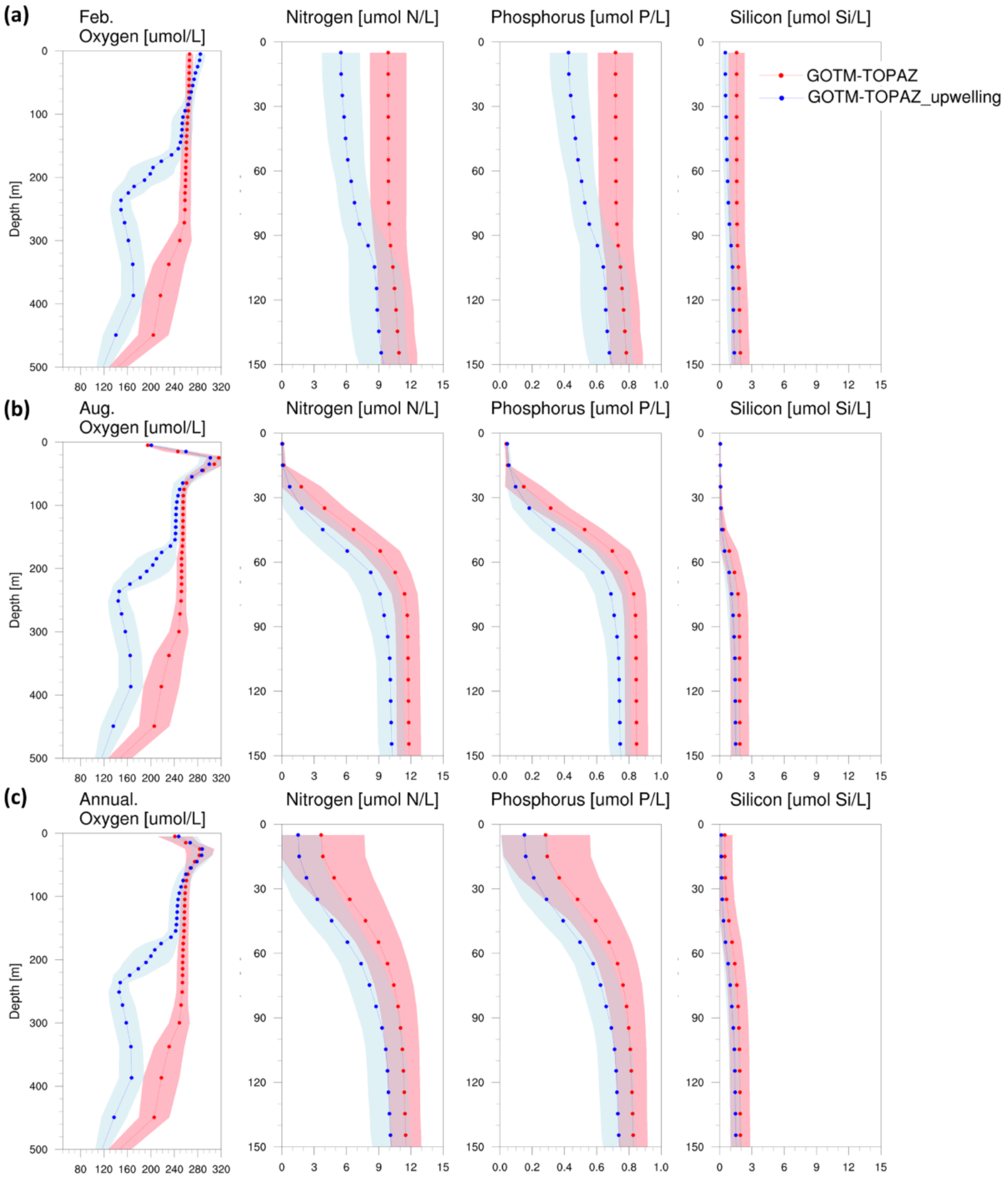

Figure review 10: Vertical profile from the GOTM-TOPAZ (red dots) and upwelling case (blue dots) with respect to dissolved oxygen, nitrogen, phosphorus, and silicon averaged from 1999 to 2008; (a) for February; (b) for August; and (c) annually. The shaded area represents 1 sigma. In this figure, nitrogen, phosphorus, and silicon include NO3, PO4, and SIO4, respectively.

24. “p. 8, l. 2. they: what does this refer to?”
: In this text “they” refers to the East/Japan Sea. We revised the text as follows to convey our intended meaning more precisely. Thank you for this comment.

“The East/Japan Sea is divided into warm and cold regions relative to the 40° N parallel, and, since the current pattern and characteristics of the East/Japan Sea vary spatially and seasonally, this region is very important to oceanographic studies.”

25. “p. 8, l. 23. aforementioned observational data. Requires description of the data set.”
: Thank you for this suggestion. As mentioned in the answer to general comment #3, we have added detailed information on the water temperature, salinity, dissolved oxygen, and nutrient observation data provided by the NIFS to the paper. Please refer to our answer to general comment #3.

26. “p. 8, l. 30. similar. Please quantify. There are many occurrences of this kind of terminology, please find and address all.”
: Thank you for this suggestion. We revised most of the sentences in the paper that evaluated the model so that they included quantitative values (e.g., coefficients of correlation) rather than the term “similar.” Please refer to our answer to general comment #4.

27. “p. 9, East Sea Intermediate Water. Should have been introduced in the description of the study area.”
: Based on your suggestion, we moved the text that introduces the East Sea Intermediate Water to the Experimental Setup section.

28. “p. 9, l. 13-15: what do we learn from this?”
: MOM is a low-resolution model with a grid size of about 1° by 1°. Therefore, because TOPAZ is connected to MOM, the atmospheric forcing or ocean physical environment is transferred as a mean value of the grid. Thus, the biogeochemical results also generate smoothed results. However, GOTM-TOPAZ uses detailed data from a single point as input and can therefore show extreme values well.

29. “p. 9, l. 16. Chlorophyll at 40 m. How do we know this is real? This is based solely on results of the current model.”
: The fact that chlorophyll is mainly distributed around 40 m at the point in the East/Japan Sea sampled in this study is a result generated by the model. However, because there is no observational data on this, it is difficult to confirm whether it is true or not. Therefore, we removed the chlorophyll figure in Fig. 3 and to add a reference. The revised Fig. 3 is shown below. Thank you for your suggestion.

“Phytoplankton in the East/Japan Sea are generally present in the highest concentrations at depths of around 10–60 m (Rho et al., 2012).”

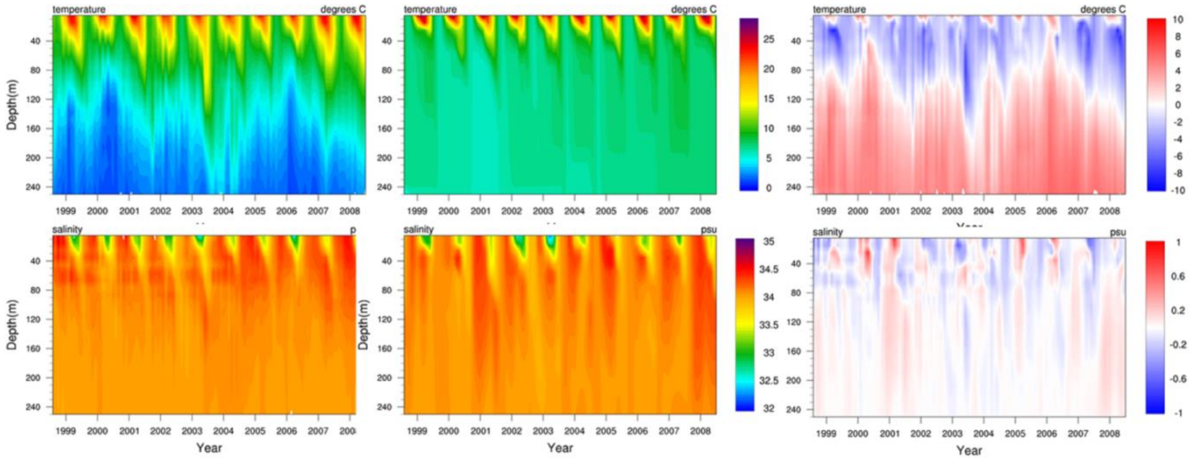

Figure 3: Comparison of the vertical distribution over time for water temperature [℃], salinity [psu] and the difference between the two (GOTM-TOPAZ results minus observational data) at point 107 for the 10-year period from 1999–2008.

30. "p. 9, l. 24-25. attributed to horizontal advection. How do you know?"

: As you noted, the analysis of the difference in chlorophyll concentrations in the paper, as simulated by the two models, is excessive. Not only are the transport tendencies of the MOM-TOPAZ and GOTM-TOPAZ different, but so are the atmospheric forcing data described by these models. They also model the ocean physical environment in different ways; therefore, the reason that the results from the two models are different is complex. We deleted the text on the analysis of direct reasons. Thank you for the useful suggestion.

"In the TOPAZ module in MOM, the transport tendencies of each tracer were calculated in the ocean model; however, this process was not carried out in GOTM-TOPAZ. In addition, MOM and GOTM-TOPAZ are not only just different models of the marine physical environment; the atmospheric forcing data they each use are also different. Therefore, there are complex reasons for the differences in the results of the two models, and further detailed experiments and analysis are required."

31. "p. 9, l. 25-27. I don't see the logic. The 3D model has an influx of nutrients, but the 1D model has higher chlorophyll. How can this influx explain the difference? I would expect the reverse."

: Thank you for making a good point. As mentioned in the answer to specific comment #30, the reasons for the difference in chlorophyll simulated by the 3D model (MOM) and the 1D model (GOTM-TOPAZ) are not limited to one or two items but are complex. We determined that the text that you referred to could be a problem and have deleted it from the paper. Regarding the reason for the higher chlorophyll in the 1D model compared to the 3D model, please refer to the answer to specific comment #28.

32. "Figure 5 b,c. The model appears to be getting enriched with N and P during the simulation. Why? How does this affect the applicability of the model for the intended purposes?"

: Currently, we assume that this problem occurs due to differences in the amounts of nutrients used during the non-implemented advection and sinking processes, and this is considered a limitation of the single-column model. Furthermore, in Fig. 5, this increasing trend occurs in the latter five years of the modeling period. This problem must be considered during any long-term experiments using this model.

33. “p. 10, l. 1-2. Why February, August and ’the entire period’?”
:	As mentioned in general comment #3, the NIFS conducts observations once every February, April, June, August, October, and December. Therefore, February was chosen to represent winter and August was chosen to represent summer. The model results for the entire period were verified to confirm its reliability.

34. “p. 10, l. 3. accurately simulated ... nutrient concentrations. I disagree. The averages of phoshorus and silicon near the surface are outside the standard deviation of the observations.”
:	Thank you for the useful comment. As mentioned in the response to general comment #5, we have revised the parts in which the performance of the model was overstated to make them objective.

“GOTM-TOPAZ well simulated dissolved oxygen (surface to 250 m) and nitrogen (surface to 100 m) concentrations during that season (Fig. 6a). However, for phosphorus and silicon at the same depths, there was a difference between the GOTM-TOPAZ results and the observational data.”

35. “p. 10, l. 3. upper layer: how is this defined?”
:	We have revised “upper layer” to “surface to 100 m.”

36. “p. 10, l. 4-5. phytoplankton at 40m. No observational proof of this is presented.”
:	We deleted the chlorophyll figure from Fig. 3 and also deleted the text that referred to it. Thank you for this suggestion.

37. “p. 10, l. 7. each layer: which? how many? Please define all layers clearly.”
:	Based on your suggestion, we revised the text to clearly present the information on the layers , and the amounts reduced, as shown below.

“The concentrations of nitrogen, phosphorus, and silicon simulated by GOTM-TOPAZ from the surface to 60 m decreased during August, and these concentrations were clearly distinguishable from the surface to 60 m due to strong stratification in the summer (Fig. 6b).”

38. “p. 10, l. 8. properly simulated. I disagree, O2 in the model is substantially higher than observed in the upper 80 m.”
:	We agree. We have revised the text as shown below.

“During this season, the oxygen concentration simulated by GOTM-TOPAZ, unlike that in the observational data, increased sharply from depths of 20–60 m. This seems to have been caused by the creation of oxygen from photosynthesis by phytoplankton (Fig. 6b).”

39. “p. 10, l. 13. subsurface layer. How defined?”
:	We have revised the text according to specific comment #40, and the relevant text was deleted. Please refer to the answer to specific comment #40 for more details.

40. “p. 10, l. 13. since. I don’t follow the logic here. Were the model results and the observations not processed in the same way?”
:	Thank you for the useful comment. We have revised the text. Please refer to the appropriate section of the revised paper.

"However, a highly concentrated dissolved oxygen concentration is not apparent in the observational data, because the low dissolved oxygen is transported by the EKWC (Rho et al., 2012)."

41. "p. 10, l. 13-14. not in figure 6b between 0 and 80 m."
: You are correct; thank you for your careful observation. The interval in which the dissolved oxygen in GOTM-TOPAZ and the observational data was similar was revised to 80–250 m. The revised text is as follows.

"The concentrations of dissolved oxygen from 80–250 m were similar in both the results from GOTM-TOPAZ and in the 10-year observational data (Fig. 6c)."

42. "p. 10, l. 17. excellent. I disagree."
: We revised the sentence that includes the term "excellent," as shown below. Thank you for the suggestion.

"Nonetheless, the results demonstrated that dissolved oxygen at 80–250 m, nigrogen, and phosphorus are well simulated over 10 years using GOTM-TOPAZ (Fig. 6c)."

43. "p. 10, l. 14. all within range. No. O2 is outside the standard deviation below 300 m, and silicon over the entire profile."
: Thank you for this observation. We revised the parts that overstate the level of modeling. Please refer further to the response to specific comment #42.

44. "p. 10, l. 22. reproduced. Well, it doesn't really, does it?"
: You are correct. We have revised the term "ocean biogeochemical processes" to "biological-physical feedback" in the text.

"In this paper, we explain the major models that comprise GOTM-TOPAZ and the biological-physical feedback loop that they reproduce."

45. "p. 10, l. 26. consistent. I disagree."
: We have deleted this text.

46. "p. 10, l. 23. sensitivity experiments. Why were these not done here?"
: We invested a period of over one year to the process of separating TOPAZ from MOM and combining it with GOTM. As such, we needed to present the results obtained from these processes before performing experiments using the model, and we submitted a development and technical paper on this to GMD. We plan to perform sensitivity experiments using the model soon. Thank you for the suggestion.

47. "p. 10, l. 30. excellent tool. Please elaborate how."
: Thank you for your suggestion. We did not perform sensitivity experiments related to this text in this paper. Therefore, we deleted this text and have referred to research fields in which GOTM-TOPAZ can be used in the Discussion section. Please also refer to the answers to general comments

#1 and #2 for more.

48. “p. 10, l. 31. parameterisation improvements. How? I don’t quite see how this model, which has its own (unexplained, at least here) parameterisations, can be used to improve parameterisations of other models, which may well be incompatible.”
: As mentioned in the response to specific comment #47, we have not performed an experiment which can prove the content for this text. Therefore, the text was deleted and a description of the fields in which the model can be used was added to the paper. Please refer to the answers to general comments #1 and #2 for more.

49. “p. 11, l. 1. many issues. Please specify. Should these not be sorted out first?”
: We deleted this text and instead clearly described the research fields in which GOTM-TOPAZ can be used. Please refer to the answers to general comments #1 and #2 for more.

50. “p. 11, l. 5. This: refers to what?”
: In this section, “This study” refers to “Sonntag and Hense (2011).” Following your advice, we have revised the text as shown below to convey our meaning clearly. Thank you.

“Sonntag and Hense (2011) provided us a better understanding of the needs and direction to focus on with GOTM-TOPAZ, and we plan to apply various climate-ocean biogeochemistry feedback mechanisms to it in future research.”

51. “p. 11, l. 11. coupling ... more easily. How/why?”
: We separated TOPAZ from MOM and divided it into modules that manage initialization, optical feedback, and column physics to create a stand-alone version of TOPAZ. Of course, this version was created in the form of a static library. Other researchers can try combining this library with a variety of ocean models. As mentioned in the Introduction, ocean biogeochemical processes in current earth systems models have a large bias and inter-model diversity based on the type of model. As such, we believe that the separated TOPAZ modules can not only be used to develop new earth systems models, but also that it can help reduce the uncertainty in current models via a comparative analysis of various model results.

52. “Figure 3: why not include the nutrients and oxygen here? The data from Fig 6 can be plotted in the first column as well; if sparse as coloured circles?”
: As mentioned in the response to general comment #3, the observational data on oxygen and nutrients provided by the NIFS are measured at depths of 0, 20, 50, and 100 m six times a year (February, April, June, August, October, and December). The continuity of this data is not good and missing values exist. Therefore, to reduce the limitations of the observational data, we decided that it would be better to take their averages when performing a comparison, as in Fig. 6, rather than to use the image format in Fig. 3. Thank you for your suggestion.

53. “Figure 6: I’m a bit surprised that chlorophyll/fluorescence was not measured as well? If so please use?”
: The NIFS data that we used did not include chlorophyll/fluorescence measurements.

[Technical corrections]

54. “p. 7, l. 16. anthropogenically. Remove this word.”
: This has been done.

55. “p. 7, l. 29. Refer to Figure 2 here.”
: This has been done.

56. “p. 7, l. 23 to p. 8, l. 24. This section is Methods, not Results.”
: Thank you for this important suggestion. We have moved this text to the section “5. Experimental Setup”.

57. “p. 8, section 5.1. header can be removed.”
: Thank you for the suggestion. As you suggested, we deleted the header for section 5.1.

58. “p. 8, l. 27-28. This is Methods, not Results.”
: As you suggested, we moved this content to the Experimental Setup section.

59. “Abbreviations. There are so many abbreviations that the manuscript would benefit from a tabulated list.”

: We have added the following table, which shows the abbreviations used in the paper, to our manuscript. Thank you for the valuable suggestion.

Table 1: List of abbreviations

Abbreviation	Full form
ESM	Earth System Model
SCM	Single Column Model
OGCM	Ocean Global Circulation Models
CMIP5	Coupled Model Intercomparison Project 5 (fifth phase)
GFDL	Geophysical Fluid Dynamics Laboratory
ARCCSS	Australian Research Council Centre of Excellence for Climate System Science
NIFS	National Institute of Fisheries Science
ESM2M	Earth System Model version 2, with Modular Ocean Model Version 4.1
ESM2G	Earth System Model version 2, with General Ocean Layer Dynamics
ECMWF	European Centre for Medium-Range Weather Forecasts
GOTM	General Ocean Turbulence Model
TOPAZ	Tracers of Phytoplankton with Allometric Zooplankton
MOM5	Modular Ocean Model version 5
NEMO	Nucleus for European Modelling of the Ocean
MEDUSA	Model of Ecosystem Dynamics, Nutrients Utilization, Sequestration and Acidification
PISCES	Pelagic Interactions Scheme for Carbon and Ecosystem Studies
SOCAT	Surface Ocean CO_2 Atlas
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
CORE-II	Coordinated Ocean-ice Reference Experiments II
PAR	Photosynthetically Active Radiation
TWC	Tsushima Warm Current
EKWC	East Korea Warm Current
NKCC	North Korea Cold Current
NB	Nearshore Branch
OB	Offshore Branch
ESIW	East Sea Intermediate Water