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 #2

[General Comments]

This manuscript is relevant to be published by the Geoscientific Model Development due to the approach of present a single-column ocean biogeochemistry model, GOTMTOPAZ,as a tool for developing and test new methods to improve the ocean biogeochemistry models. As these models are essentials components in the Earth System Models, the development of tools to improve these models is necessary. Developments and improvements in the ocean biogeochemistry representation by the models are crucial for a better representation of all earth system dynamics. The work is also interesting to be published because there were modifications in the marine biogeochemical model TOPAZ, as the insertion of a module to reproduce upwelling and also the representation of the air-sea gas transference for O2 and CO2.

The paper is consistent because there was presented an evaluation of the performance of GOTM-TOPAZ by comparisons with observations. Another interesting point of this paper is that, as the model TOPAZ was separated from the MOM model this paper can inspire others studies testing TOPAZ with others OGCM models. Also, others applications with this single-column model could be done in the future.

In summary, I believe that this manuscript is important and deserves to be published. However, I suggest here some points that should be revised aiming to produce a final version in a better condition to be published.

: Thank you for positive review and helpful comments. We addressed each of specific comments and separately responded in next page.

[Specific Comments]

1. “Page 3, Line 10: The phrase “we selected points in the East/Japan Sea” is wrong, because in the paper there were just analyzed results for one point. At the page 7 line 22 it is said: “To verify GOTM-TOPAZ, we selected a point : : :”.”

: Thank you for your observation. Following the suggestion in the comments below, we have added two points to the revised manuscript.

2. “About this item, I believe it would be necessary to show results for more points. The study would be more robust if there were analyses for more points located in areas with different characteristics. For instance, it would be selected at least more two points to verify the model performance, one would be located in the East Korean Warm Current and other in the North Korea Cold Current. This approach would be more interesting, instead of just to select a point where the two currents meet, as was presented in this paper.”

: Thank you for your valuable suggestion. Based on it, we ran our model on points 104 (131.3E, 37.1N) and 102 (103.6E, 36.1N), as well as at point 107 (130.0E, 38.2N), to verify it. Points at which the NKCC flows are located in North Korea and available observation values do not exist. Therefore, we selected a point where the EKWC is dominant (point 102) and a point in the middle of the warm eddy caused by the EKWC (point 104). The selections were centered on points for which nutrient observation values exist, and which have enough continuity to be used for verification. The images resulting from the analyses of the two new points are not very different from that from point 107. Therefore, they were added to the supplementary material and not to the main manuscript. Please refer to the revised paper for more.

3. “Page 4, Line 3: The section that explains the optical feedback is Section 4.4.”

: Done, accordingly.

4. “Page 5, Line 2: It is said that the MOM version is 5, however in Figure 4 in the legend it is written that it is analyzed results from MOM4p1_SIS_TOPAZ. Which is the correct MOM version used in this paper?”

: We used MOM version 5 in our study. A revised Fig. 4 is attached below. Thank you for your observation.

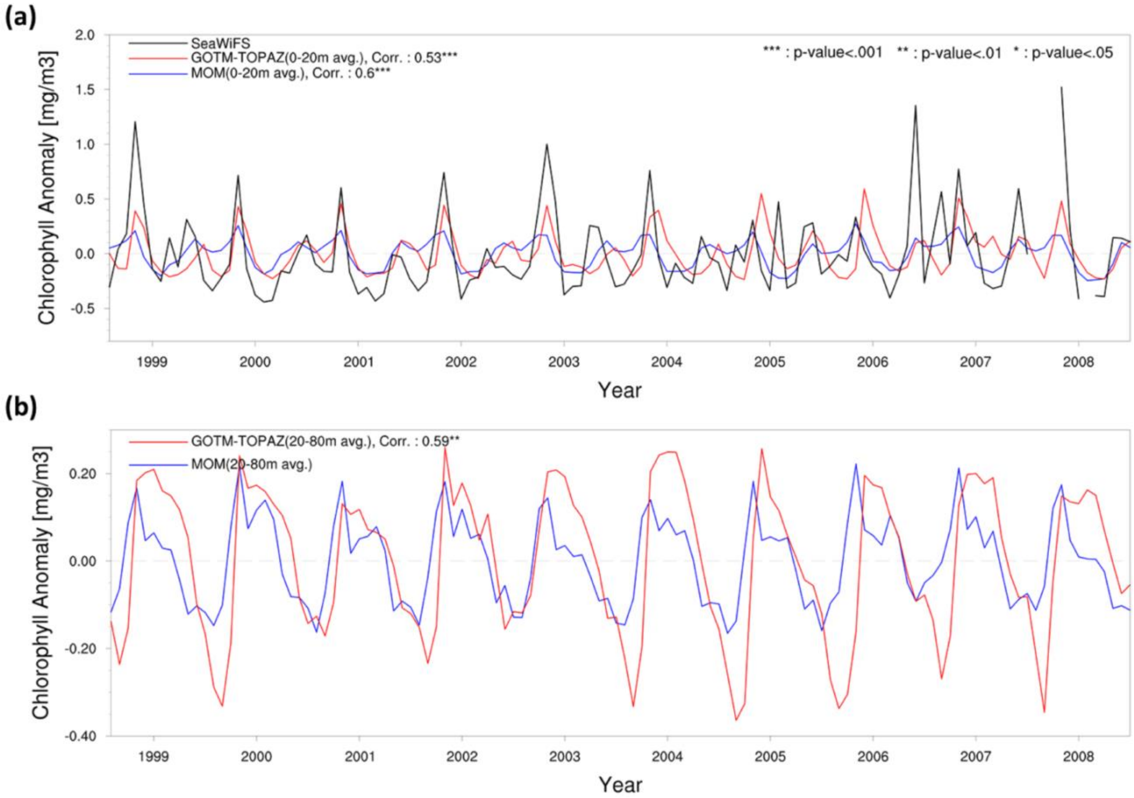

Figure 4: Chlorophyll anomaly time series and correlation values for observational data (black lines), MOM5_SIS_TOPAZ resuts (blue lines), and GOTM-TOPAZ resuts (red lines) at point 107 for the 10-year period 1999–2008; (a) the mean value atdepths $\geq$ 20 m and the correlations between the observations and each model; (b) mean values at depths of 20– 80 m and the correlation between the two models.

5. "Page 8, Line 12: It is necessary to describe which are the data used for initializing the biogeochemical tracers in TOPAZ. Which are the data sets and sources?

: We used the tracer input data provided by the Australian Research Council's Centre of Excellence for Climate System Science (http://climate-cms.unsw.wikispaces.net/Data). Global data were interpolated for each point to create the input data. Following your suggestion, we used data for which a 14-year spin-up was been performed for each point. Thank you for the suggestion.

"For the initial data on prognostic/diagnostic tracers in TOPAZ, we used the data provided by ARCCSS for use with MOM5 (http://climate-cms.unsw.wikispaces.net/Data). This initial tracer data was interpolated for each location, and a spin-up was applied over 14 years for use in the experiments."

6. "Page 8, Line 27: Just 4 years of spin up for a biogeochemical model is enough? Most of the applications with biogeochemical modeling are based in long spin up periods."

: Thank you for the good suggestion. As you suggested, we applied 14 years of spin-up to the initial data for each point and used it in the experiments. Please refer to the answer to specific comment #5.

7. “Page 8, Line 30: This similarity between GOTM-TOPAZ and observations is just on the first 40 meters for temperature. The difference in deeper regions must be discussed in this point.”

: We have revised the text as you suggested. The water temperature at point 107 as simulated by GOTM-TOPAZ showed a cold bias in the upper layer and a warm bias in the lower layer at a depth of around 120 m. We believe that this is an effect of the large-scale forcing (EKWC, ESIW) that is affecting this point. Thank you for the suggestion.

“Figure 3 shows the results of the GOTM-TOPAZ simulation and observational data (EN.4.2.1) as vertical distributions of the water column over time. 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).”

8. “Page 9, Line 5: Similarly to the latest comment, it is necessary to be clear in the text that this correspondence in seasonality between the model GOTM_TOPAZ and observation are just in the initial 40 meters.”

: Thank you for the suggestion. We have deleted this text and analyzed the reason for the difference in water temperature between GOTM-TOPAZ and the observations. Please refer to the response to specific comment #7 for more details.

9. “In Figure 3, there is no figure for observation to chlorophyll. In this case, I do not see a reason for this variable to be included in this figure.”

: We agree. We deleted the figure showing the results from MOM (water temperature and chlorophyll) from Fig. 3 and added a figure to show the difference in water temperature and salinity between the observations and the model. The revised figure is shown below.

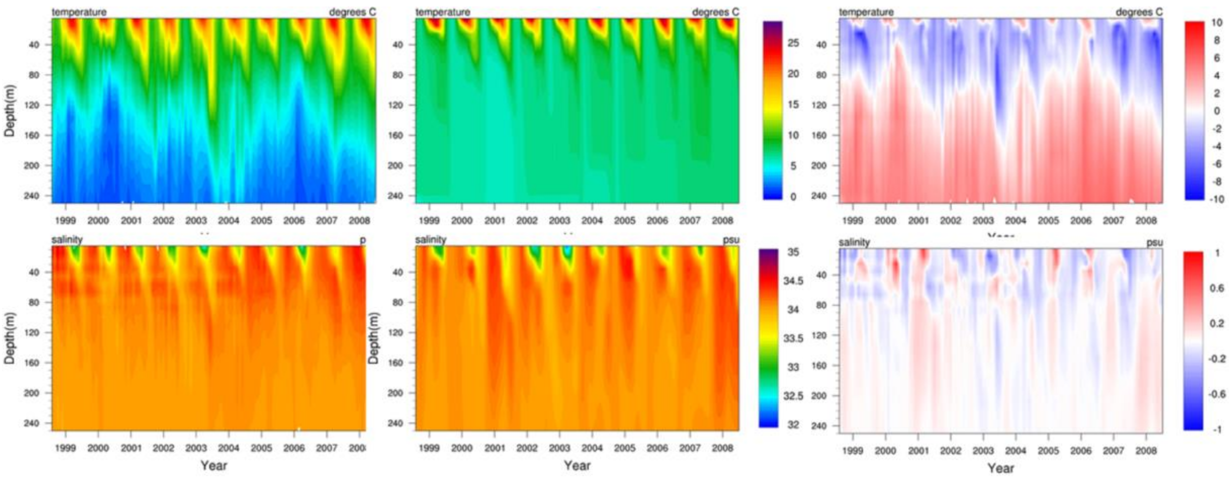

Figure 3: Comparison of the vertical distribution over time for water temperature [℃], salinity [psu] and the difference between the two (GOTM-TOPAZ results minus observational data) at point 107 for the 10-year period from 1999–2008.

10. “Page 9, Line 13: These correlation coefficients are statically significant?”

: We described the statistical significance levels of the correlations in this paper.

“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 ($p < 0.001$).”

11. “Page 9, Line 6: It would be interesting here to discuss why the model GOTM-TOPAZ does not represent well the temperature in deeper regions, especially below 80 m. This discussion would be more interesting with the inclusion, in Figure 3, of a figure with the biases between models (MOM and GOTM-TOPAZ) and observations. Maybe this deficiency in the deeper regions is related with a short spin up period.”

: As you suggested, we used the results of 14 years of spin-up as the initial data for GOTM-TOPAZ. However, despite this, there was still a warm bias in the water temperature below a depth of 80 m (Fig. 3). We examined the difference between the observations and the simulated results for water temperature at points 107, 104, and 102 for a 22-year period 1987 to 2008. Fig. review 1 shows a cold region similar to the observations during the integral initial time at all three points; however, as time passed this region disappeared and the error increased. Therefore, we assumed that the difference in water temperature below 80 m between the model and the observations was caused by large-scale forcing in the ESIW. Of course, there will clearly be errors related to the spin-up, and we think that in the future it will be necessary to research the amplification of error as the integral time passes in a single-column model.

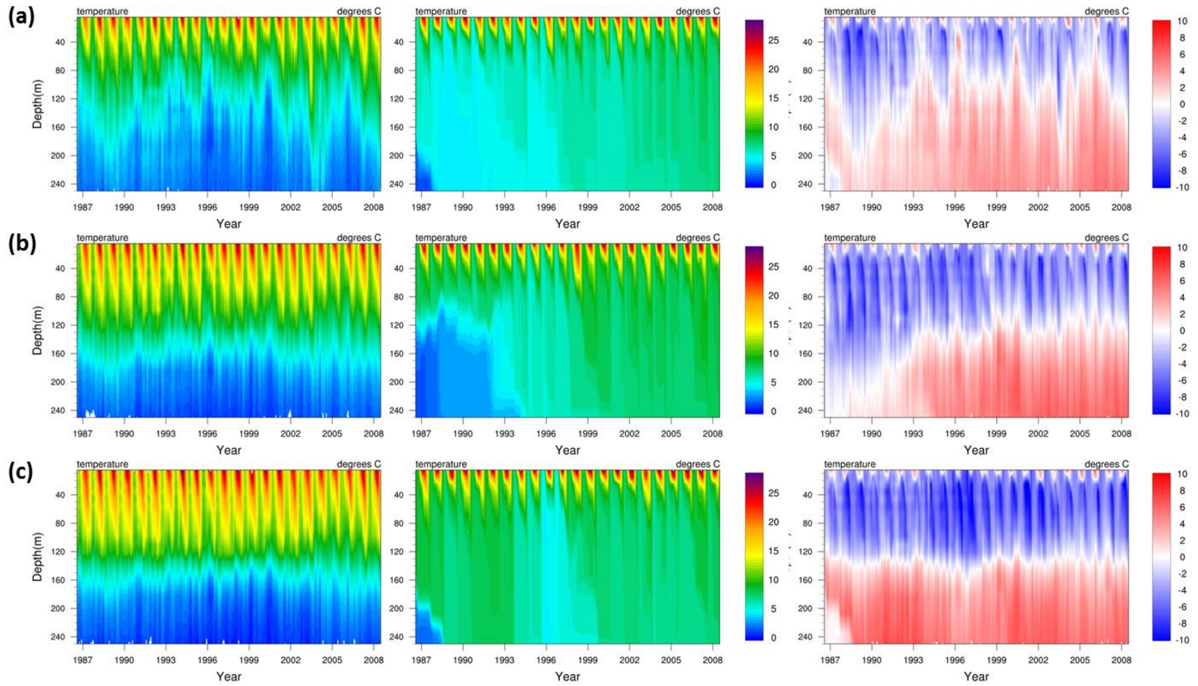

Figure review 1: Comparison of the vertical spatial distribution over time for water temperature [℃] and difference (GOTM-TOPAZ minus obs.) for the period from 1987 to 2008; (a), (b), and (c) represent point 107, 104, and 102, respectively.

12. “Page 9, line 30: The phrase ”These results can be viewed as validating the gas flux equation reproduced in GOTM-TOPAZ” does not make much sense, once the correlation coefficient for GOTM-TOPAZ was worse than for MOM. Again, the correlation coefficients presented in Figure 5 are statically significant? In this paper, there was no evaluation of the fluxes. It is possible to evaluate the CO2 flux based on observational data, for instance, from SOCAT database.”

: Following your suggestion, we have mentioned the statistical significance levels of all correlation coefficients, which we verified by comparing the CO_2 concentrations at the sea surface calculated by GOTM-TOPAZ with the SOCAT data. A scatterplot of the sea surface CO_2 concentrations calculated by GOTM-TOPAZ and SOCAT was added to the paper (Fig. 7). This figure shows that our model predicted CO_2 concentrations similar to the observations. Thank you for the useful comment.

“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).”

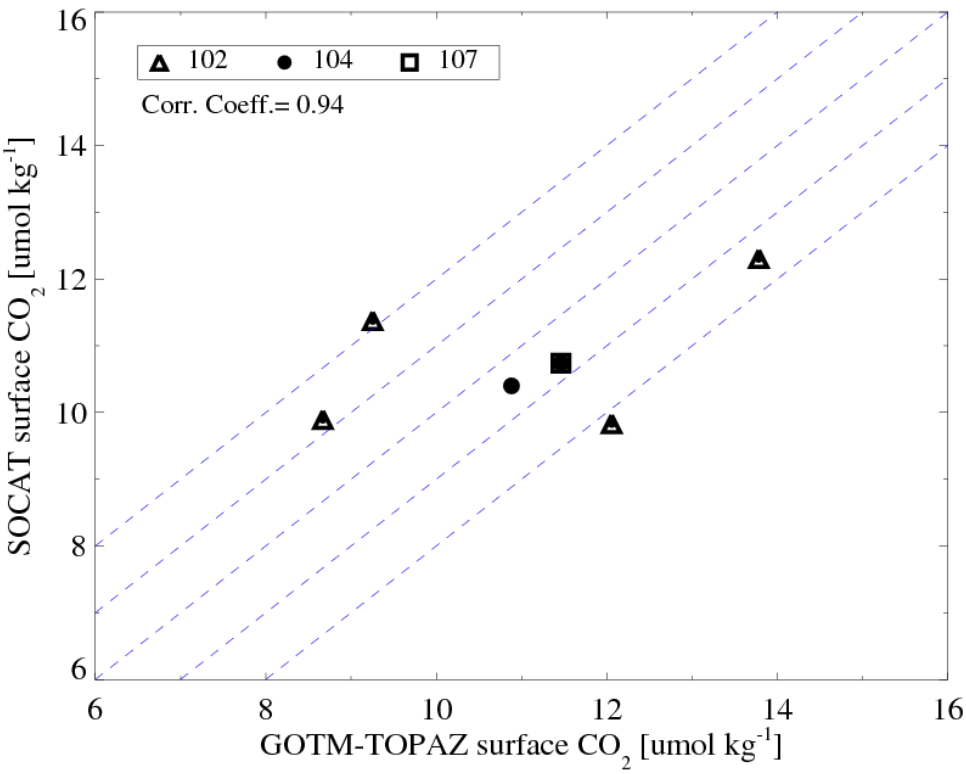

Figure 7: Scatterplot of mean monthly sea surface CO2 concentration as observed by the Surface Ocean CO2 Atlas and modelled by GOTM-TOPAZ. The thin dotted lines around the 1-to-1 line represents ±1 and 2 μmol kg^{-1}.

13. “Page 9, Line 21: The phrase: “In this paper, we have explained the major models that comprises GOTM-TOPAZ and the ocean biogeochemical process reproduced within the models” is not appropriated because you do not have made this on this paper. The model TOPAZ and the ocean biogeochemical process reproduced in this model was not explained on details on this paper. Actually, this explanation was not the main objective of this paper. To start the item discussion, I believe it would be more relevant to mention the main contributions of this paper, as a study about the development of a single-column ocean-biogeochemistry model.”

: Thank you for this correction. We revised the relevant section of the text. We have added a description of the fields of research that can use GOTM-TOPAZ to the Discussion section.

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

“ 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.

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 clearly a possibility that aerosols affect oceanic biogeochemical processes as deposition occurs in 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 CO2 in the atmospheric change. 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). Phytoplankton of TOPAZ is divided into two-types depending on their size, so it is expected to be useful in above mentioned research.

In addition, GOTM-TOPAZ can be used in studies on feedback mechanisms in the biogeochemical and physical environment of the ocean.”

14. “Page 10, Line 28: In this paper was not presented results about this sensitive experiments that are exemplified, how can you affirm that GOTM-TOPAZ will be good in this kind of applications? In the discussion topics, you should dedicate to discuss based on the results found in the paper.”

: We agree. We have deleted this text and added a description of the fields of research in which GOTM-TOPAZ can be applied, as mentioned in the answer to specific comment #13. Thank you for the useful suggestion.

15. “Finally, in the discussion, there was no evaluation about the upwelling representation. I believe that would be important to include in the paper the evaluation of the upwelling representation. How the module related to w-advection impacted the results? A comparison of the vertical movements reproduced by the model with observations would be interesting.”

: 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 2 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 3). 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 4). The effect of the upwelling is also seen in the vertical profile of dissolved oxygen. Fig. review 4 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.

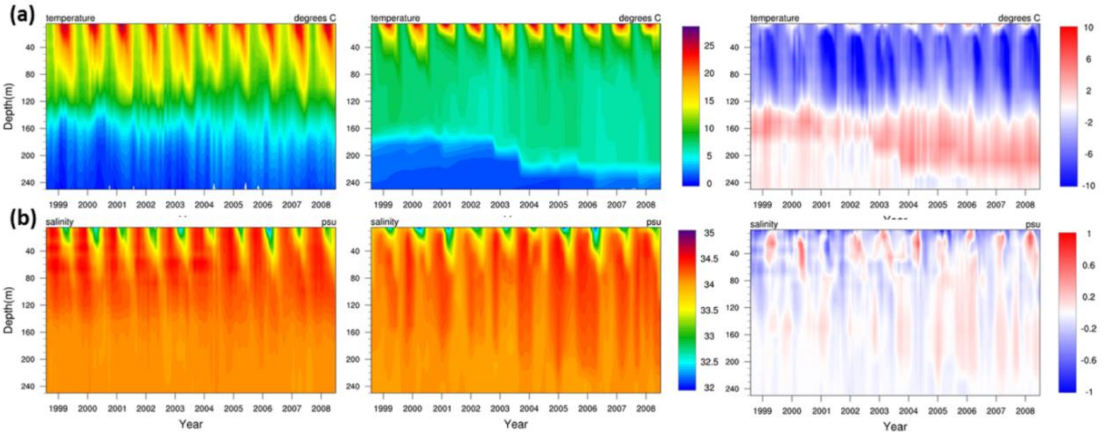

Figure review 2: Comparison of the vertical distribution over time for water temperature [℃] (a), salinity [psu] (b) and the difference between the two (GOTM-TOPAZ minus obs.) at point 102 for the 10-year period from 1999–2008. The upwelling is prescribed to the GOTM-TOPAZ.

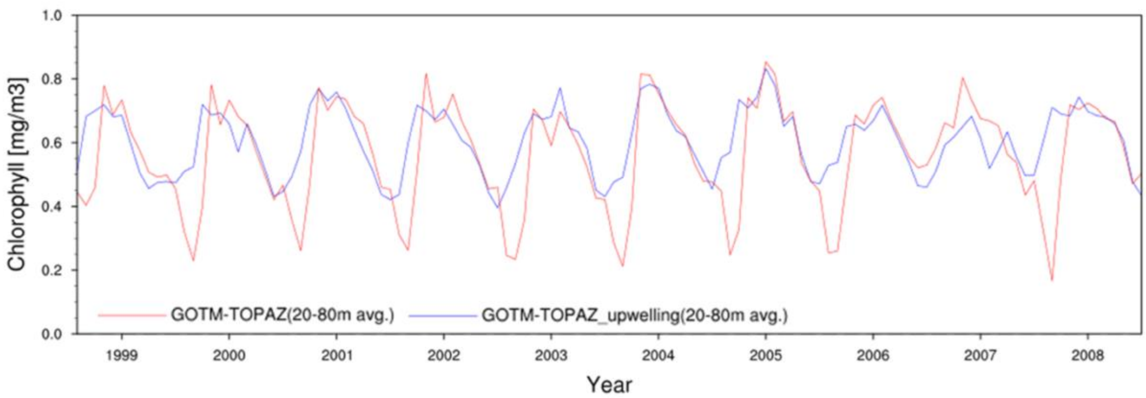

Figure review 3: Chlorophyll time series from GOTM-TOPAZ (red lines) and upwelling case (blue lines) at point 102 for the 10-year period from 1999–2008. Chlorophyll concentration is averaged between 20 to 80m depth. The upwelling is prescribed to the GOTM-TOPAZ.

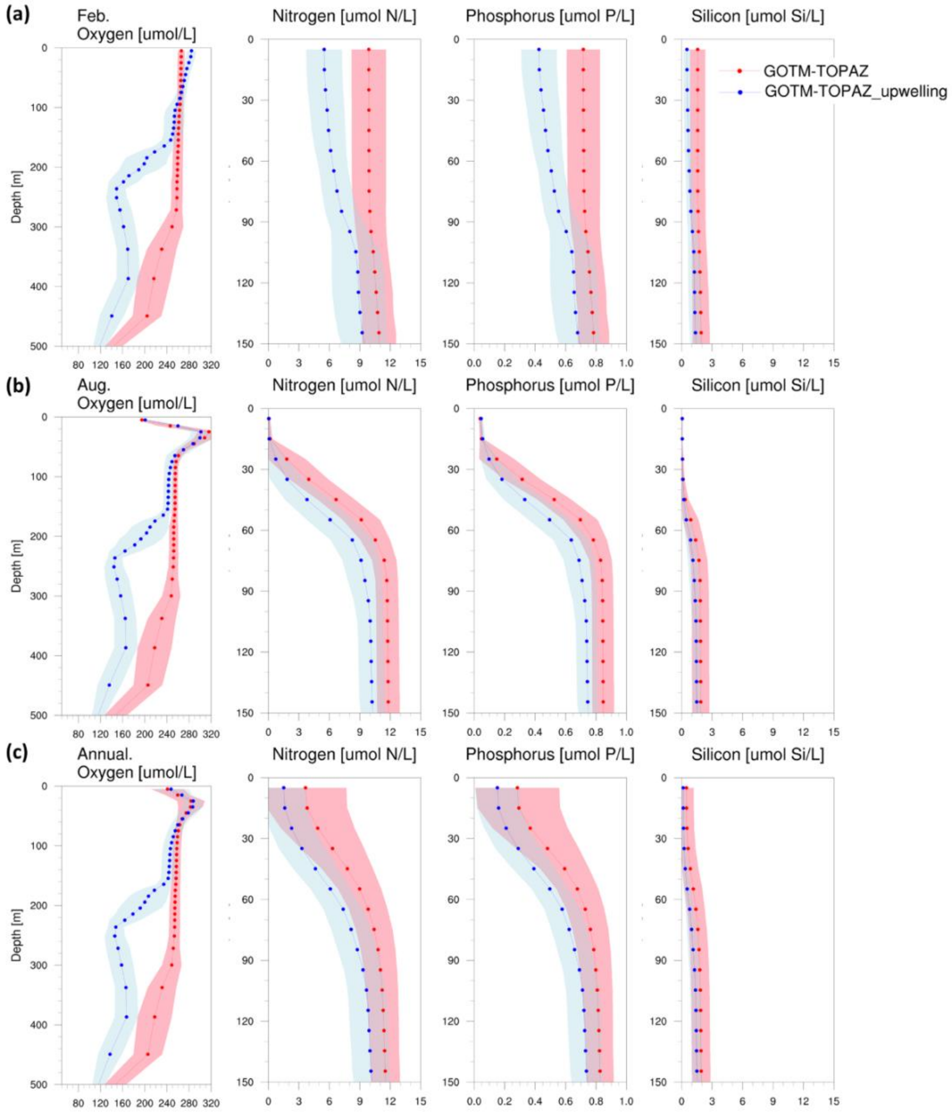

Figure review 4: Vertical profile from the GOTM-TOPAZ (red dots) and upwelling case (blue dots) with respect to dissolved oxygen, nitrogen, phosphorus, and silicon averaged from 1999 to 2008; (a) for February; (b) for August; and (c) annually. The shaded area represents 1 sigma. In this figure, nitrogen, phosphorus, and silicon include NO3, PO4, and SIO4, respectively.