

Review of “**Reviews and syntheses: Assessment of Biogeochemical Models in the Marine Environment**” by Kaltham A. Ismail and Maryam R. Al-Shehhi

Summary

The authors have written a review of marine biogeochemical models. An updated review on this topic is highly needed and would be very useful for the community. The authors have structured the paper into an introduction, a section on the structure of biogeochemical models, and a section where they evaluate the performance of BGC models in various parts of the ocean. I think this structure would work well, however there are many important aspects, and details, of marine biogeochemical modeling that are lacking in the manuscript (please see my comments below for more details). Apart from my comments below, one additional major detail that needs to be thought about is whether the authors want to focus on a specific type of biogeochemical models (for instance, global, regional, or biogeochemical models used within the CMIP framework), or if they want to write a general review on biogeochemical modeling. This is not very clear in the current manuscript. Overall, the manuscript needs an overall major revision, both with respect to scientific content and writing/language, to reach the level that I would expect from a review paper on marine biogeochemical models.

Major Comments

Introduction

The introduction is difficult to read. There is no well defined structure (i.e., no red line) and the language needs some work (at the moment it is very much spoken language). Also, the scientific content needs to be worked on. In a review of marine biogeochemical modeling I would expect something like the following content:

1. Some introductory text on ocean biogeochemistry, why it is important (for example for global carbon cycle, marine ecosystems), and its most important components. The authors have written some text on this on lines 28-36, but it is very short and not very informative. Try to make a link between the different components instead of just mentioning them one by one. Maybe a figure with an illustrative scheme could be useful.
2. Some information on the history of marine biogeochemical models: The authors mention the model of Fasham et al., 1990. Some more references to possibly earlier and later models would be highly valuable, and how the models are connected through history. Maybe you could create a flow diagram showing how the models have developed? You could also mention their inclusion in ocean circulation models and Earth System Models.
3. Some examples on why these models are important: You could mention some major findings that have been made by the use of marine biogeochemical models, and the role they play for example in assessments of the global carbon budget and in the IPCC reports.

Section 2: Biogeochemical modelling approaches

It is unclear to me why you have chosen these three types of classes for biogeochemical models, specifically? In my opinion the classes are not that distinct, and with this classification you are missing several important aspects of biogeochemical models. I would suggest you have the following subsections under section 2:

2.1 Classical NPZD models

I like that you start with this section. It is important as it explains the most simple biogeochemical model possible.

2.2 Adding more elements (other nutrients and carbon)

Here it would be interesting if you could describe the rationale behind including other elements, including carbon, phosphorus, iron, oxygen. You should describe that the most common way to represent the content of the different elements in plankton is by using the Redfield ratio, and what implications this has for the representation of biogeochemical cycling. You should also describe that there are models that use a flexible stoichiometry approach. In relation to this you can discuss the Droop-papers. Why do some models take into account chlorophyll?

Here (or in the introduction) you can also mention that all BGC models have not been developed from plankton models, and that HAMOCC initially was a pure inorganic carbon cycle model and was utilised to evaluate both the ^{12}C cycle and the ocean model residence time properties.

2.3 Increasing the biological complexity

Here you can describe the approaches used to represent several types of plankton, i.e. functional types. What functional types are the most common ones to include? What traits do they have? In relation to this you should discuss the inclusion of silicate (and diatoms). It would also be useful to take up nitrogen fixers here, and the process of nitrogen fixation.

2.4 The addition of several classes of organic matter and bacteria

Many biogeochemical models have several classes of organic matter (of different lability). An overview of these would be useful.

2.5 Sediment interactions

It would be useful with some text on the representation of sediment biogeochemistry in a review paper on biogeochemical models. Some biogeochemical models lack a sediment model. Does this matter?

Section 3: Determination of the biogeochemical parameters

I have several remarks on this section:

- 1) The title is very vague. I would suggest something like "Applications of biogeochemical models".

- 2) The content of this section needs a major revision. In a review paper on marine biogeochemical models, I would expect a section discussing the ability of these models to represent marine biogeochemical cycles. This includes several aspects; i) spatial variations (both vertical and horizontal), ii) temporal (including seasonal, interannual, decadal) variations. You do not necessarily have to discuss this for all state variables, but you can pick out important examples from the literature. At the moment you are mostly discussing the models' abilities to simulate spatial (?) variations by mentioning correlation coefficients and bias, but this does not tell the reader much. Please be more precise in your description. For example, do the models reproduce the deep oxygen minimum zones, and the high chlorophyll concentrations in the North Atlantic? Do they simulate the observed interannual variations in seawater pCO₂? You can divide the section into some major zones that you discuss, for example the tropical, subtropical, seasonally stratified seas/oceans/high nutrient-low chlorophyll zones/ etc... If you want to bring in examples from smaller seas, as you do, this could also be very useful, but please structure the text better. At the moment it is jumping forth and back between regions, making it difficult to follow.

You have to provide a deeper discussion on the fact that the performance of biogeochemical coupled to ocean circulation models highly depends on the performances of the physical models. Therefore, you should be careful when you compare different models with different biogeochemical structure, and also different physical models. If they have different physical models, you cannot attribute the differences to the biogeochemistry.

- 3) Within this section I would recommend you not to only discuss the performance of the biogeochemical models, but also their applications, i.e., some examples of what scientific questions that can be answered with these models. Some examples are process studies, future projections, near-time predictions and forecasts, and reconstructions. In your manuscript you do not mention paleo-oceanography and future projections. I think that these are important applications that should be mentioned. If you want to specialize your review on "present days", please state so clearly somewhere in the beginning of the manuscript.
- 4) In this section, I would also expect a discussion on major issues and uncertainties related to these models, and a paragraph on their future development.
- 5) Please carefully revise the language and your formulations.

Equations

I think that it is enough that you show equations 1-4 in your paper. These give the basic idea of biogeochemical models. For more complex formulations, you can refer to model description papers. In other words, you can remove equations 5-14.

Figures

I cannot see that you refer to figure 1?

Table 5

This table is very difficult to read. How do you determine what are key biogeochemical variables? Moreover, I do not think that it is fair to determine their performance just by mentioning numbers representing correlation or bias. It does not say much (see my

comments above). I would completely remove the column on performance, and rather include some figures showing the performance of various models.

Maybe you could consider having a table like Table 1 in Seferian et al., 2020..

Minor Comments

L11-12: Replace “Therefore, this review...” with “This review ...”

L13: Replace “Then, applications of these ...” with “Applications of these...”

L16: Replace “models based on functional group approach when coupled to high-resolution physical models” with “models with a functional group approach coupled to high-resolution physical models”

L17: With “good estimates of surface nutrients” I guess that you mean “good spatial distribution of surface nutrients”? Please clarify this in the text.

L19: I suggest to remove “suitable”

L17-20: why do you mention correlation coefficients for the functional group models, and coefficients of determination for the NPZD models?

L16 & L19: On line 16 you write functional group models coupled to high resolution models, but on line 19 when you write about the NPZD models, you do not mention anything about the resolution. From this the reader get the impression that you only look into high resolution models in the first case, but not in the second. I would suggest just to remove the “high resolution”

L25-26: I do not agree with this: NPZD models are also commonly used for studying biogeochemical cycling. Rather, models with functional groups have been developed for questions more oriented towards ecosystems (Baird et al., 2022).

L39: Models that include fishes and whales are not biogeochemical, but ecological models. Please remove fishes and whales.

L127-140: This text does not fit under this subsection. I would suggest you to distribute it under the other subsections of section 2 that I suggested you to include.

L127-130: I get the impression that this part describes the introduction of nitrogen fixation, but you do not mention it explicitly.

L146: replace “which is a pure inorganic carbon” with “which initially was a pure inorganic carbon” (today HAMOCC includes biology)

L281-283: Are you sure that a better representation of chlorophyll is a result of the inclusion of several functional types? There are many other parameters that may differ between these models (as you for example write on L286-289)

L418-419: pCO₂ is not a form of carbon, please remove

L418-421: I would suggest you to include this in the subsection on organic matter that I suggested you to include

References:

Baird, M., Dutkiewicz, S., Hickman, A., Mongin, M., Soja-Wozniak, M., Skerratt, J., & Wild-Allen, K. (2022). Modeling phytoplankton processes in multiple functional types. In *Advances in Phytoplankton Ecology* (pp. 245-264). Elsevier.

Séférian, R., Berthet, S., Yool, A. *et al.* Tracking Improvement in Simulated Marine Biogeochemistry Between CMIP5 and CMIP6. *Curr Clim Change Rep* 6, 95–119 (2020). <https://doi.org/10.1007/s40641-020-00160-0>