Reply to reviewers' comments

Title: "Reviews and syntheses: Assessment of Biogeochemical Models in the Marine Environment"

To the reviewer

> *The authors would like to thank the reviewer for his useful comments that help to improve the manuscript. The authors have considered all suggestions and addressed the raised issues trying to provide necessary clarifications and improvements in the revised manuscript. Based on the reviewer's comments, the authors have started rewriting the three sections (introduction, model approaches, applications of biogeochemical models in the global oceans) as per the reviewers' suggestion and requests.*
>
> *Below are given point by point answers to the comments (Reviewers comments in normal fonts, response in italic fonts). All the changes will be implemented in the revised manuscript.*

Comments from the editors and reviewers:

Reviewer Comments:
Reviewer 2

I do not think that this paper meets the expected standard for a Reviews and Syntheses paper in this journal. The Abstract, the Introduction and the Conclusion mostly fail to explain to the reader what the authors' overall purpose is. The Results are a rather verbose and poorly organized recitation of many details without much of an overall coherent structure. First, one might want to step back and ask why another review on this topic is needed and what differentiates it from existing ones. Ideally this question should be addressed in the first paragraph of the Introduction. This paper never addresses it at all. Secondly, why a review rather than a primary research contribution? There are today a great variety of ocean biogeochemistry data products that are in the public domain and available to anyone with an internet connection. Why not attempt some systematic evaluation of a set of biogeochemistry models against one or more of these, similar to past experiments in the cited literature (e.g., Friedrichs et al, 2007; Kwiatkowski et al, 2014). Instead, this review offers a subjective and meandering assessment of the existing literature and various authors' conclusions regarding how well their models simulate various observables (e.g., in Section 3.1). If the paper were clearly organized around a set of questions or metrics I might be more charitable, but it is not.

> *The authors would like to thank the reviewer for his comments. The authors believe that an updated review on the biogeochemical models is highly needed and would be very useful for the community. Indeed, there is still a critical need to identify the biogeochemical models that are geographically portable and can be applied across diverse ecosystems. Thus, introducing an updated general review on the biogeochemical modeling is also important to review the state of art and help in improving the uncertainties of the existing biogeochemical models.*
>
> *Therefore, the authors have updated all the sections, especially section 3. They have added more discussions on the applications of the biogeochemical models. The authors have also divided the regions into four zones including: the tropical zone, subtropical zone, seasonally stratified and High Nutrient and Low Chlorophyll (HNLC) zone. The authors have discussed the reasons for the models to perform well in diverse regions and the corresponding physical settings. In the discussion, the authors emphasized that the complex models are not necessarily more accurate*

than simpler PFTs or NPZD models. For example, both simple NPZD (e.g. Fasham-ROMS) and more complex models (e.g. Darwin and other PFTs) can provide closer estimates for nutrients (e.g. nitrogen) to observations in subtropical and tropical seas as the coastal and continental shelves in these regions are nutrients enriched with organic matter. However, the NPZD-Fasham model is unable to represent the diverse PFTs observed in regions such as the HNLC and the seasonally stratified (Arctic) regions. Therefore, PFTs-based models such as PISCES and TOPAZ coupled to NEMO give better chlorophyll estimates as compared to BLING-NEMO in the seasonally stratified (Arctic) and HNLC (Southern Ocean) zones. Together with PISCES and TOPAZ, PlankTOM also provides a good estimate of chlorophyll in the HNLC zone (Southern Ocean).

Section 3 includes extended discussions about the applications of biogeochemical models across diverse ecosystems and Table 1 (attached at the end) is added to support the discussions.

The classification of models seems very subjective and arbitrary. Why can not a carbon-cycle model incorporate either an NPZD model or a PFT model? Indeed, most modern ones do. The history of the field is the gradual replacement of simple HamOCC or OCMIP type approaches to parameterizing uptake and remineralization of carbon and nutrient (usually P) with explicit biology models. The question is which biology model, and how much complexity is justified and useful? I do not believe that this review sheds much light on this history or offers new and useful information that could help to guide such choices in the future.

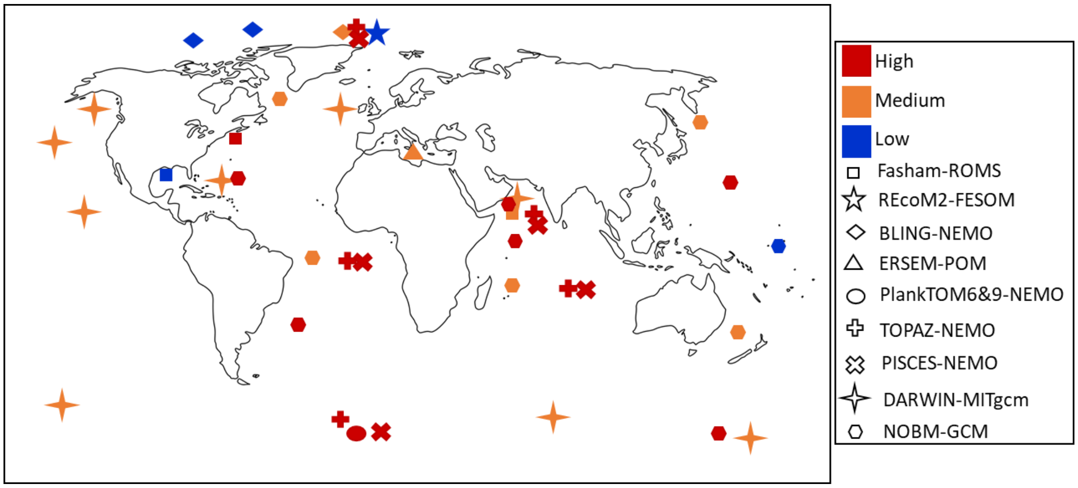
The authors highly appreciate the reviewer's comments. The subsections of the model approaches have been updated to include: 1. Classical NPZD Approach, 2. Adding more elements (other nutrients, and carbon, 3. Increasing the biological complexity and 4. The addition of several classes of organic matter and bacteria as suggested by reviewer 1.

The only part of this paper that really contains anything new is Table 5. This Table contains a huge amount of information. The only way I can see to salvaging this effort is to reorganize this information around some kind of coherent structure. The nearest historical precedent I can think of is Totterdell (1993, in Evans and Fasham, eds, "Towards a Model of Ocean Biogeochemical Processes") (10.1007/978-3-642-84602-1_15). But the current version seems more like a "data dump". The authors have gleaned a great deal of information from the existing literature. But to justify publication of such a review they need to present it in a way that is useful to the reader.

The authors highly appreciate the reviewer's comments. They have updated the text of section 3 in which the applications as well as assessment of the models have been discussed. The table has been also updated and it is attached at the end of this document. A figure that shows the statistical performance of the biogeochemical to estimate the Chl-a in the regional oceans has been also added. The table has been also discussed in term of the structure of the biogeochemical models along with the physical settings, elements, living/non-living components, regions and applicability.

On a personal note, I will tell the authors that early in my career I had a similar paper rejected by a journal editor. It is never a pleasant experience, but we can learn from it.

The authors thank the reviewer for his advice and comments which help the authors to make substantial changes and improvements in the manuscript.



The coupled biogeochemical-physical models applied in the regional seas to reproduce the surface chlorophyll-*a* concentrations along with their statistical performance. Red color represents high statistical correlation (r> 0.8), orange color represents medium statistical correlation (0.5 < r < 0.8, and blue represent low statistical correlation (r <0.5).

Table 1. Overview of the biogeochemical models reviewed in this work showing the model approach, physical model, resolution, Nutrient/element cycling and the number of the living/non-living components.

Ocean	**Zone**	**Model approach**	**Physical model**	**Resolution**		**Nutrient/element cycling**						**Living/non-living components**				**Ref.**
				Vertical layers	Horizontal resolution	Fe	N	P	Si	O_2	C	#of phytoplankton	# of zooplankton	# of detritus	# of Bacteria	
Global		NOBM	GCM			+	+		+			4	1	2		(Gregg et al., 2003)
Global		HAMOCC5	LSG			+	+	+	+			2	2	1		(Aumont et al., 2003)
Global		ERSEM	GOTM			+	+	+	+	+	+	4	3	1	1	(Blackford et al., 2004)
Global		Moore	CCSM			+	+	+	+	+	+	4	1	1		(Moore et al., 2004)
Global		Moore	CCSM			+	+	+	+	+	+	4	1	2		(Moore & Doney, 2007)
Global		PlankTOM	NEMO			+	+		+	+	+	5	2	2		(Buitenhuis et al., 2013)
Global		PISCES	NEMO			+	+	+	+	+	+	2	2			(Aumont et al., 2015)
Global		DARWIN	MITgcm				+	+	+	+	+	9	2	2		(Dutkiewicz et al., 2015)
Global		PlankTOM	NEMO				+			+	+	6	3		1	(Andrews et al., 2017)
Global		PISCES	NEMO			+	+	+	+			2	2	2		(Aumont et al., 2017)
Global		Moore	NCAR-CSM1			+	+	+	+	+	+	4	1	2		(Pant et al., 2018)
Global		TOPAZ/PISCES	NEMO			+	+	+	+	+	+	TOPAZ:3 PISCES: 2	PISCES:2			(Jung et al., 2019a)
Atlantic	Tropical	Fasham	MOM				+					1	1	1		(Oschlies and Garçon, 1999)
Atlantic	Subtropical	Fasham	ROMS				+				+	1	1	1		(Fennel et al., 2008)
Atlantic	Subtropical	Fasham	ROMS				+				+	1	1	2		(Druon et al., 2010)
Atlantic	Subtropical	Fasham	ROMS				+					1	1	2		(Xue et al., 2013)
Atlantic	Subtropical	ERSEM	OGCM-MED16				+	+	+	+		4	4	1	1	(Lazzari et al., 2016)
Atlantic	Subtropical	ERSEM	POM				+	+	+	+	+	4	3	2	1	(Kalaroni et al., 2019)
Atlantic	Subtropical	ERSEM	POM				+	+	+	+	+	4	3	2	1	(Kalaroni et al., 2020)
Indian	Tropical	Fasham	OGCM				+					1	1	1	1	(Ryabchenko et al., 1998)

Indian	Tropical	ERSEM	Princeton/Mellor –Yamada	▓	▒		+		+			4	2	2	1	(Blackford and Burkill, 2002)
Indian	Tropical	McCreary	Four-layer model	░	░		+					1	1	1		(Hood et al., 2003)
Indian	Tropical	Fasham	MOM	▓	░		+					1	1	1		(Kawamiya and Oschlies, 2003)
Indian	Tropical	PISCES	NEMO	▓	▓	+	+	+	+			2	2	3		(Koné et al., 2009)
Indian	Tropical	PISCES	NEMO	▓	▓		+		+			2	2	3		(Resplandy et al., 2011)
Indian	Tropical	McCreary	Six-layer model	░	░		+			+		1	1	2		(McCreary et al., 2013)
Indian	Tropical	Fasham	ROMS	▓	▓		+			+		1	1	1		(Lachkar et al., 2017)
Indian	Tropical	ERSEM	GOTM	█	░		+	+	+	+		4	3	1	1	(Sankar et al., 2018)
Indian	Tropical	Fasham	ROMS	▓	█		+			+		1	1	1		(Lachkar et al., 2019)
Indian	Tropical	PISCES	ROMS	▓	▓	+	+	+	+			2	2	3		(Guieu et al., 2019)
Indian	Tropical	NOBM	OGCM	░	░		+					4	1	3		(Das et al., 2019)
Indian	Tropical	TOPAZ	MOM	▓	░	+	+	+	+			3		2		(Sharada et al., 2020)
Indian	Tropical	Fasham	ROMS	▓	▓		+			+		1	1	1		(Lachkar et al., 2020)
Southern	HNLC	PlankTOM	NEMO	▓	░		+	+	+	+	+	6	3	3	1	(Le Quéré et al., 2016)
Southern	HNLC	NOBM	OGCM	░	░		+		+		+	4	1	3		(Trull et al., 2018)
Southern	HNLC	DARWIN	MITgcm	█	█	+						2	2			(Uchida et al., 2019)
Southern	HNLC	PISCES	NEMO	█	░	+	+	+	+			2	2	2		(Person et al., 2019)
Sothern	HNLC	DARWIN	MITgcm	▓	▓		+	+	+		+	6	2			(Lo et al., 2019)
Southern	HNLC	Chai	ROMS	▓	█	+	+		+			2	2	3	1	(Jiang et al., 2019)
Southern	HNLC	TOPAZ	ESM2M	▓	░		+				+	3		2		(Bronselaer et al., 2020)
Arctic	Seasonally stratified	PISCES	MITgcm	▓	▓						+	2	2	2		(Manizza et al., 2011)
Arctic	Seasonally stratified	21 biogeochemical models $^{c)}$	-													(Babin et al., 2016)

Arctic	Seasonally stratified	REcoM2	FESOM	▒	░	+	▒ +		▒ +		+	2	1			(Schourup-Kristensen et al., 2018)
Arctic	Seasonally stratified	BLING	NEMO	▒	▒	+		+		+						(Castro de la G uardia et al., 2019)
Arctic	Seasonally stratified	DARWIN	MITgcm	▒	▒	+	+	+	+		+	5	2			(Manizza, 2019)
Pacific	Tropical	Leonard	OGCM	░	▒	+	+					1	1	1		(Christian et al., 2001)
Pacific	Tropical	Chai	ROMS	▒	▒		+		+			2	2	2		(Xiu and Chai, 2011)
Pacific	Subtropical	Fasham	ROMS	▒	▓		+	+				1	1	2		(Gan et al., 2014)
Pacific	Tropical	Fasham	ROMS	▒	▓		▓ +			▓ +	+	1	1	2		(Ji et al., 2017)
Pacific	Tropical	PISCES	ROMS	▒	▓	▓ +	+	+	+			2	2	3		(Vergara et al., 2017)
Pacific	Tropical	TOPAZ	GOTM	░	░		░ +	░ +	░ +	░ +	▓ +	3		1		(Jung et al., 2019b)
Pacific	Tropical	Chai	ROMS	▓	░		+	+	+	+	+	2	2	3		(Ma et al., 2019)
Pacific	Tropical	Fasham	ROMS	▒	▓		▓ +	▓ +				1	1	2		(Lu et al., 2020)
Pacific	Tropical	Kearney	Bering 10K ROMS	▒	▒	+	+					2	5	2		(Kearney et al., 2020)

*For the nutrients: dark orange: 0.8<r<1; Bias: < 0.5; RMSD <0.2, Medium orange: 0.5 <r <0.8; 0.5<Bias< 1; 0.5< RMSD <0.2 and Light orange: r <0.5; Bias > 1; RMSD >0.5. For the vertical resolution: dark blue: > 50 layers, medium blue: 20<layers< 50, light blue: < 20 layers. For the horizontal resolution: dark blue: < 0.1degrees, medium blue: 0.1<degrees<0.5 and light blue: >0.5 degrees.