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Biogeosciences
Discussions

Interactive comment on "Climate change impacts on net primary production (NPP) and export production (EP) regulated by increasing stratification and phytoplankton community structure in CMIP5 models" *by* W. Fu et al.

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1 General Reply to Reviewers

We thank the reviewers for their comments and suggestions on this manuscript. We present some general comments first and then address specific comments below. We were unaware of the Cabre et al. (2015) paper at submission, but we will compare many aspects of our results with this work in a revised manuscript. Both Cabre et al.

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(2015) and Bopp et al. (2013) examined the same group of CMIP 5 ocean biogeochemical models as this work. We feel this work strongly complements these two excellent papers. Bopp et al. (2013; and to some extent Cabre et al., 2015) focus more on model-mean responses, and model trends normalized to 1990s values, emphasizing similarities in the model responses to climate change. Cabre et al. (2015) also include detailed analysis of key ocean biomes and changes between the beginning and end of the century under RCP 8.5.

The emphasis in our work is partly on illustrating the wide spread across models for key biogeochemical and physical metrics from the current era, and understanding how that impacts the responses to climate change. Secondly, we wanted to identify, at the global scale, what drives the climate change responses in NPP and sinking export production. The CMIP5 ocean biogeochemical models are an increasingly important component of our climate projections (i.e. Randerson et al., 2015). Considering the vast resources committed (both human and computational), and the societal importance of predicting how the Earth system will respond to climate change, we agree with Reviewer #1 that there needs to be much more study of these models, from different perspectives. CMIP5 marks the first time ocean biogeochemistry has been included in most of these Earth System Models, and detailed documentation of model performance and results is necessary. Quantifying each model's performance relative to current-era observations, also allows for objective evaluation over time as to whether these models are improving. The target audience for this work includes the oceanographic and broader climate communities.

There are a number of new results and perspectives presented here, that are not found in previous works. Both reviewers note our novel finding that the models with the strongest positive biases in stratification for the 1990s, also show the strongest increases in stratification and the largest decreases in export production and NPP with climate change.

We present times series of the absolute values (not normalized to each model mean

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for some period) key physical and biogeochemical variables, illustrating the wide inter-model spread (and comparison to observed values) in surface nutrient concentrations (Figure 5), productivity and export (Figure 8), and sea surface temperature, salinity, and surface stratification (Figure 1). We also show 2-D maps of surface nitrate for the 1990s from all the models compared with the World Ocean Atlas (Figure 7). These figures thus allow readers to examine each model's fidelity to observations for the current era, and illustrate the large spread across the models. No plots like these have appeared in prior works. Similarly, we show the 2-D spatial patterns for diatom contribution to NPP and the particle export ratio (Figures 11 and 13), and the 2d patterns of how these change with climate (Figures 12 and 14). This complements the biome by biome analysis of by Cabre et al. (2015), and illustrates the links between plankton community composition and export efficiency.

We emphasize comparing the biogeochemical variables with stratification as a key driver, as this metric better captures high-latitude, salinity-driven climate impacts than SST alone. We also present 2D plots showing where warming and salinity changes dominate the stratification changes for each model (Figure 3), and show the spatial patterns of stratification change by the end of the century (Figure 4). Previous works have focused on the model-mean response, we highlight the similarities and the disagreements across the models in the spatial patterns of stratification change and in the dominant process driving stratification changes (temperature vs. salinity).

Our analysis of the impacts of changing stratification on biogeochemical variables utilizes the full time series from each model, rather than just comparing the beginning and end of the century. We examine how stratification impacts biogeochemistry, phytoplankton community structure, and export efficiency using 150 data points for each model (Figure 10). Rather than just one or two points per model, based on beginning and end of century, decadal time-scale means. Thus our regressions and illustrations of the similarities and differences across the models are more robust, and are more easily visualized in the plots for each model, than in previous analyses (Figure 10).

2 Anonymous Referee #2

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The paper compares 9 CMIP5 ESM in terms of NPP, EP, surface nutrients, and stratification. There is some very detailed comparison of these various fields. Several recent studies have done similar comparisons (e.g. Bopp et al 2013, Cabre et al 2013) and there have been numerous studies that have considered projected NPP, EP and nutrient changes as function of warming and stratification (e.g. Bopp et al 2001, Bopp et al 2005, Dutkiewicz et al 2013, Marinov et al., 2010; Taucher and Oschlies et al 2012), and several that have also considered changes in phytoplankton community structure (e.g. Bopp et al 2005, Dutkiewicz et al, 2013, Cabre et al, 2015). Thus almost everything this manuscript addresses has been discussed before. This manuscript has some more specific numbers for the variability between models (though similar comparison also have noted this variability though the numbers are a bit different depending which models they included). I struggled therefore the find something new (and useful) in this manuscript. The pieces I did find were:

1) models with largest increases in stratification have strongest changes in NPP and EP (Bopp et al, 2013 had something similar but using changes in SST rather than stratification).

2) models with largest increases in stratification also showed the largest biases for the contemporary period (suggesting potential overestimating climate impacts).

3) Models with dynamic phytoplankton communities show larger decline in EP than NPP (but this could be anticipated any of the previous work that has suggested shifts from large to small phytoplankton and if they parameterize large as having larger impact on export).

We agree that these are three important results, but as noted previously, there is much more new and novel in our paper than these three items.

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The second point is potentially exciting. A careful analysis of the differences in stratification helped identify this. I recommend rewriting a significantly shortened paper which highlights this aspect over a long-winded summary of the detailed comparisons. For instance, the current discussion makes no mention of the point on this stratification/bias issue, but includes a long list of numbers (not particularly useful as it depends on which set of models one looks at – see e.g. Bopp et al 2013, Cabre et al 2015) and focuses on things that have already been addressed elsewhere in the literature (NPP varies more than EP – Bopp et al 2013; shifts in community structure – Bopp et al 2005 (and many others)).

The Bopp et al. (2013) paper mainly focuses on temperature-related factors as driving the different patterns of NPP response to climate change. Cabre et al. (2015) discuss community composition as a relevant factor, but not with the same emphasis or focus as this work. The fact that community structure, and its implementation in the models, determines the NPP response to climate change has not been emphasized previously. The relationship between community composition and export efficiency in these models is familiar to ocean biogeochemical modelers, but less so to the larger oceanographic community and is likely unknown to the climate community.

A long discussion about how CMIP5 models are far from perfect seems irrelevant in the face that several other studies have said similar things.

Previous studies did not highlight the imperfections in the CMIP5 models in the same manner as our paper, but in fact downplayed these large differences by focusing on model-mean results and trends normalized to the mean 1990s values from each model. Both approaches have merit, and as mentioned above, we believe what is needed is more analysis of the CMIP5 models, not less. But our perspective is very different, in part, precisely to highlight the large inter-model differences. We show large variations in the simulated surface nutrients across the CMIP5 models (by a factor of 1.5-2.5 for no3, po4 and sio4; a factor of 5 for

dissolved iron). This has not been discussed in detail or illustrated in this manner previously. In the context of the large model spread, we tried to find robust connections between physics and biogeochemistry. The change of stratification was highlighted as a primary driver to NPP and EP changes throughout the multi-century simulations. On a global scale, we identified a closer relationship between stratification and NPP/EP changes over the period of 1850-2100, than with other factors such as SST or SSS changes across the models.

I suggest shorting to less figures and removal of details that can be referenced to other studies. Details of the nutrient changes I found somewhat less interesting – nutrient supply rate changes are what is important. I was convinced that there was useful information that came from this part of the analysis. This also applies to Fig 3.

We think it is important to include these figures showing the large spread in surface nutrient concentrations relative to observations, etc... These have not been included in prior studies and are of interest and value. It is insightful to see, for each model, the biases present for the current era, and as we show, it helps to interpret the varied responses to climate change. In our paper, we quantify the relations between stratification and biogeochemical variables over the entire time period of 1850-2100. Cabre et al (2015) examined the relations between variables across CMIP5 models by 100-year time-scale changes (difference between 2080–2099 and 1980–1999). Bopp et al. (2013) largely followed a similar approach. Both approaches have merit, but they are different analyses.

Besides a much shorter paper, I suggest much greater care on the discussion which I found to delve into speculation and grandiose statement that I do not feel are supported by (or even relevant to) the paper. For instance: Pg 12870: lines 10-20. I find this discussion potentially dangerous. I will agree that changes in EP is a better metric for climate impacts on carbon cycle; but disagree that it is best metric for “marine ecosystems” or food chains and fisheries. Community structure changes are also very important for marine systems and can potentially not be captured in EP. Additionally

EP is possibly worse in parameterization than NPP in models. Before arguing this too fully it would be worth looking at how each of the models determines EP (Martin curve, explicit particle sinking) and how they parameterize how much is exported relative to community structure.

Our main point here was that the community shifts minimize the declines in NPP as export efficiency declines and regenerated production increases in the more complex models. This can be misleading, and we would argue that export production does have strong relevance for higher trophic levels, but perhaps this was worded too broadly. We agree with the reviewer that improved representation of community structure is needed in this class of models, precisely to improve model predictions of export and export efficiency. Indeed this is one of our key conclusions, which we will bring out more clearly in the revised manuscript.

Could models have more similar changes in EP because they are all so crude in how they parameterize EP? Since the models are so crude in parameterizing the complex processes involved in EP (role of bacteria, Archea etc etc): should EP be sold as a best" metric for any impact of climate change? This goes back to my point (3) above.

It is not the crudeness of the parameterization of the remineralization curve that gives the models a more similar response in EP, but simply the fact that over large enough time and space scales, the total EP must equal the input of new nutrients from circulation and mixing (plus other sources atmospheric, N fixation, etc..). Thus, as stratification increases and nutrient inputs decline, EP declines. What we argue is more uncertain (and less constrained by observations) is the levels of regenerated production in each model, which are not constrained by the physics, but the export efficiency built into each model.

On a final note to the community at large: How much more useful (as opposed to “details” on models we know are flawed) information can be wrung out of CMIP5 comparisons?

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This comment has been addressed in previous sections.

3 References

Bopp, L., and Coauthors, 2013: Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models. Biogeosciences, 10, 6225-6245.

Cabré, A., I. Marinov, R. Bernardello, and D. Bianchi, 2015: Oxygen minimum zones in the tropical Pacific across CMIP5 models: mean state differences and climate change trends. Biogeosciences, 12, 5429-5454.