

## ***Interactive comment on “Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models” by L. Bopp et al.***

**Anonymous Referee #2**

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Recommendations: Major Revisions

General Comments

The title of the manuscript had me expecting to find a discussion of the combine impacts of climate change and ocean acidification on marine ecosystems. The title is misleading and the study really only presents the environmental changes projected by 10 CMIP5 models for a range of RCP scenarios for 4 key environmental variables (T, pH, mid-depth Dissolved Oxygen (DO) and Primary Productivity (PP) ).

The study sets out to investigate multiple stressors for marine ecosystems. However, the chosen fields (like pH ) are not ideally suited for demonstrating marine ecosystem impacts. Second, many of the stressors are not coincident (located in different parts

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of the water column). If the study wants to discuss multiple stressors of environmental change they should present the stressors in coincident domains (e.g. for: 1) ocean surface and 2) ocean interior between 200-600m). In the latter domain, a case must be made for why this depth range can be considered one habitat, Further, in the ocean interior the coincident DO, CO<sub>2</sub> and Temperature changes should be given.

In choosing the fields to present, the authors need to clearly motivate why these environmental changes are ecosystem stressors. Further, they must provides some context on what is a significant change (may be a threshold change) and discuss in a more quantitative manner why RCP26 significantly less stressful than RCP85.

To address the questions identified, the paper needs to discuss environmental stressors relevant to marine ecosystems and in a manner that makes it clear the changes are coincident thus justifying calling them multi-stressors.

Specifics (I'm working of the discussion paper and I have attached it to make the link to my comments clear. While the pdf has notes all the important issues are listed below)

pg 3629 line 9 - cite the original references or preferably use some more recent references line 10 - 11 - add citation for the first part of this sentence line 13 - Thomas reference seems out of place since the example you give more reflective of high latitude ecosystems line 23 - their several more recent studies of anthropogenic CO<sub>2</sub> concentrations (e.g. Khatiwala et al., 2009)

pg3630 line 8 - add citation for 50-80 threshold and what organisms have such a high oxygen threshold? line 28 - add citation for importance of T, DO, pH and NPP and it possible give key threshold changes line 29 - the sentence is not clear - will they be discussed here or later

pg 3631 line 3-8 - should comment on the difference between is92a and RCP8.5, since for CO<sub>2</sub> the latter has much greater concentrations by 2100 then IS92a. line 6 - a better reference for the emergence of under-saturation in the Southern Ocean in the McNeil

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and Matear (2008).

line 9-14, The overall decline in DO as you stated earlier in the introduction is probably not important, rather it is whether the volume of low oxygen water (you stated 50 -80  $\mu\text{mol/l}$  or less) changes. You should discuss this feature in previous modelling studies since there are many studies which have look at this issue (e.g. Cocco et al 2012, Keeling et al 2010, Schmittner et al 2008, Oschlies et al 2008, Matear and Hirst 2003). For this ocean field there are important physical, solubility and biological interactions

line 20, why do you focus on pH rather than saturation state? there is a much clearer biological link with aragonite saturation state than pH

line 23 - The statement is confusing As I read it, it sounds like from a biological perspective there a debate whether ocean acidification and deoxygenation have a synergistic impact on marine biota (if this what you are trying to say then add citations for this debate). What you go on to discuss is the change in C/N of exported organic matter with rising  $\text{CO}_2$ , which is a feature that is also being debated. The synergist impacts are on BGC cycling rather than marine ecosystems.

pg 3636 line 12 - this statement is provocative and make me ask what is the point of the study. I suggest you just state what you will focus on.

line 24-25 - the ability of the models to represent the surface pH and NPP variability is poor - why should I believe the projections of such poor models. Justify using these models for looking at pH and NPP changes.

pg 3638 line 4-8 - Confusing you start by mentioning differences in radiative forcing but then give an example of different climate sensitivity - what causes the differences?

line 20-24 - Aragonite would be a better biological stress variable particularly in the upper ocean where the undersaturation provides a nice threshold to discuss. Is92a scenario has less  $\text{CO}_2$  atmosphere in 2100 than rcp 8.5. This difference should be discussed because it changes the acidification of the ocean. Further, I don't follow the

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range given for pH ( pH range should be  $0.12 \times 4 = 0.48$ ). Where do you get 0.1 from?

pg 3639 line 24 - I don't see why global decline is relevant for the discussion of multi-stressors on the marine ecosystem.

pg 3644 line 10 -14 - explain why you think they are decoupled

pg 3647 line 4 - Looking for synergies at a global scale is inconsistent with the concept multiple stressors impacting ecosystems line 9 - why is global DO changes important? you need to focus on biologically relevant variables

For the results section I also included my comments on the figures

figure 2 -you could just use numbers for model and colours for variable to make the figure easier to read - Models have no skill for ph. Why? - What are the values for RMS error lines? - what is the bias between obs and models? - Include in the plot the multi model mean perhaps a shown as a circle to represent the variance in the multi-model mean - what years are used for models? - for the PP observations they are really just another model. This should be clearly stated.

Figure 3 -No variability in ph - state why

Figure 4 -Why show individual models? The only new info is in c) where one model has strange increase in DO in first 50 y drift? What causes this?

Figure 5 -Define stress intensity - Missing arctic in figs a and b -Missing shade key -pH change is not a significant stress? All the models have the same ph change but present day pattern was shown to be bad for all models. Why should I believe the projected change?

Figure 6 -define stress intensity

Figure 7 -Need to convince me the pH projections can be used when they so poorly represented in the observed fields. - why show pH since it affect as a marine ecosystem stressor is less clear - what is a significant pH change for marine biota?

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Figure 8 -Would be nice to know the actual change too

Figure 9 -D. Only one model? But it is not shown in b and c? Therefore, no model meets the good criteria for 3 selected volumes! Justify the use of model projections.

Figure 10 - panels a) and d) Useful comparison? Why should they be related? Good correlation does mean causality. This analysis would be more useful if done regionally rather than globally

- b) and c) How do the model compare to the observed heat content changes?

Figure 11 -Should assess models present day representation of these fields before looking at changes - Why the multiple plots per water mass? - By 2100 you can see and detectable changes in the averaged deep and bottom water properties?

Figure 12 -As stated in previous fig I'm surprise you can see a detectable change in deep and bottom water - for marine ecosystems why are these change important - they are small - Need to convince me that the pH and DO changes are believable for these water masses

Figure 13 - selection of the thresholds - should assess the model less than 50 mmol/m<sup>3</sup> area in the present-day - the DO decline in the intermediate water is not located where the SST and surface pH change occur - how can referred to as multiple stresses?

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line 24-27 - you really only presented and assess SST. There are no clear analysis of the change in Temperature within the ocean. For example how does the observed change in heat content compare to the modelled fields? For marine biota, why should I care about T changes in the deep water?

pg 3650 line 15-17 DO values are high, are the DO changes in the Southern Ocean really a stressor for marine ecosystems?

line 18- next page - As you stated you did not do attribution analysis therefore you need

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to cite the previous work to back up your statements about the mechanisms responsible for the projected changes

pg 3651 line 3-5 - How do pH biases affect the projections? This is especially important for regional and water masses changes.

line 6-15 Why is this important ? For most of the variables chosen (e.g. T, pH, DO) the biological parameterization are of second order importance. The base state is where you would expect to see the largest impact of the chosen parameterization and for fields like pH and DO there are problems with most of the models.

The paper switches between surface and interior, but for the interior fields (other than DO) there was no assessment of present day fields. For ocean interior changes in heat content and anthropogenic carbon are two fields that could be used to assess the simulations.

Please also note the supplement to this comment:

<http://www.biogeosciences-discuss.net/10/C1994/2013/bgd-10-C1994-2013-supplement.pdf>

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Interactive comment on Biogeosciences Discuss., 10, 3627, 2013.

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