Biogeosciences Discussions

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Reply on RC1

Jenny Hieronymus et al.

Author comment on "Modeling cyanobacteria life cycle dynamics and historical nitrogen fixation in the Baltic Proper" by Jenny Hieronymus et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-156-AC1, 2021

Author replies in italics.

The Hieronymus et al., have done through approach toward modeling phytoplankton and N2 fixation in Baltic Sea. The model seems to be well constructed developed upon the accumulated bodies of modeling and certainly provides new aspects of the regional modeling targeting this area. One challenge I had was to see how the cyanobacterial life cycle is simulated. A schematic and narrative would be useful. That said, I like how explicitly the filamentous bacteria is simulated, which is the unique feature of Baltic Sea. The manuscript is suitable Biogeosciences. The following are my comments hoping to improve the manuscript.

Authors: Thank you for your thorough review and for pointing out that we need to be more clear in explaining the life cycle part of the model. We will include a detailed schematic figure of the CLC model in parallel to current figure 2 in the revised version of the manuscript and clarify the description of it where needed (see the enclosed New Figure 2 for a first version).

Main text:

L20: in timing of -> in the timing of

Authors: This will be corrected in the revised version of the manuscript.

L21: runs we -> runs, we

Authors: This will be corrected in the revised version of the manuscript.

L28: of its -> of their

Authors: This will be corrected in the revised version of the manuscript.

L30: nitrogen fixing -> nitrogen-fixing (there are other cases below, which I would not mention)

Authors: This will be corrected in the revised version of the manuscript.

L46: in bloom formation -> in the bloom formation

Authors: This will be corrected in the revised version of the manuscript.

L46: e.g. -> e.g., (there are other cases below, which I would not mention)

Authors: This will be corrected in the revised version of the manuscript.

L54: In the model growing -> in the model, growing (for clarity)

Authors: This will be corrected in the revised version of the manuscript.

L66: in abundance -> in the abundance

Authors: This will be corrected in the revised version of the manuscript.

L73: gain understanding -> gain an understanding

Authors: This will be corrected in the revised version of the manuscript.

L81: which has -> that has

Authors: This will be corrected in the revised version of the manuscript.

L83: three dimensional -> three-dimensional

Authors: This will be corrected in the revised version of the manuscript.

L88: the northern -> northern

Authors: This will be corrected in the revised version of the manuscript.

L101: tense should be consistent

Authors: This will be corrected in the revised version of the manuscript.

L112: remove ‘a’ or make it to ‘the’

Authors: This will be corrected in the revised version of the manuscript.

L144: for the entire period -> for the entire period of (or put 1850 – 2008 in parenthesis)

Authors: This will be corrected in the revised version of the manuscript.

L150: by very large burial -> by a very large burial (or ‘the’ very ...)

Authors: This will be corrected in the revised version of the manuscript.

L175: For this work -> For this work,

Authors: This will be corrected in the revised version of the manuscript.

L176: post processed -> post-processed

Authors: This will be corrected in the revised version of the manuscript.

L186: includes also -> also includes

Authors: This will be corrected in the revised version of the manuscript.

L189: true also -> also true

Authors: This will be corrected in the revised version of the manuscript.

L193: A -> The (or remove ‘A’)

Authors: This will be corrected in the revised version of the manuscript.

L197-210: There are different modeling experiment. I wonder which one is considered as default. Is there a model run that includes all the factors, which could be considered as default? I think it was done in the previous study? In any case, it would be useful to compare these sensitivity analysis to be compared with the default, so I suggest putting

the results from the default along with these simulations.

Authors: There is no default in the original model. Since there has not been any previous 3D modeling efforts of the Baltic sea where the CLC model has been included, and the original model had unlimited P availability, we needed to evaluate P dependency before estimating nitrogen fixation and cyanobacterial biomass. Therefore, several runs using different settings were performed with the aim of producing the best fit to observations and in order to understand the CLC in the Baltic Sea and its effect, and depence on, the nutrient composition. From these sensitivity runs, one was chosen as the best fit (weak P limitation) and used in the estimates. This will be clarified in the revised version of the manuscript, starting with background about P limitation in the Baltic Sea and the lack of P dependency as a setting in the model already in the introduction.

L220: which -> ,which

Authors: This will be corrected in the revised version of the manuscript.

L225: in this case -> in this case,

Authors: This will be corrected in the revised version of the manuscript.

L227: generating -> , generating

Authors: This will be corrected in the revised version of the manuscript.

L228: faster growing -> faster-growing

Authors: This will be corrected in the revised version of the manuscript.

L240: we -> , we (for clarity and improving readability)

Authors: This will be corrected in the revised version of the manuscript.

L245: I am having a hard time understanding what is meant by the life cycle model. Is that the diurnal cycle or is that longer cycle? A schematic (in addition to figure 2) and additional explanation (model summary with a few sentences) would be useful. I am suspecting it is a seasonal cycle, so it would be nice if it is clearly defined here.

Authors: The life cycle model is seasonal. This will be clarified in the method section as well in the new schematic image that will be included in the revised version of the manuscript (please see reply above).

L268: release -> the release

Authors: This will be corrected in the revised version of the manuscript.

L301: we -> , we (for clarity and readability)

Authors: This will be corrected in the revised version of the manuscript.

L301: seasonality of -> the seasonality of

Authors: This will be corrected in the revised version of the manuscript.

L314: bloom forming -> bloom-forming

Authors: This will be corrected in the revised version of the manuscript.

L320: however -> however,

Authors: This will be corrected in the revised version of the manuscript.

Figure 2: Many different shapes are used. I wish to have a list of explanations for different shapes. Also, It is less clear where and how phytoplankton are represented. There seem to be multiple functional types of phytolankton but it is hard to see from the figure. I suggest another figure or panel to focus on phytoplankton functional types, as well as the life cycle of them since they seem to be key in the paper.

Authors: We agree that this figure is a bit difficult to follow and will revise it to become more clear. In a revised version of the figure, the colours of the parts belonging to the CLC-model will be changed (see first version enclosed, New Figure 3). These colours will in the revised manuscript match the new figure of the CLC (described above). It is also described in the figure legend that the red lines are indicating the flow between the CLC components. We will also, along with the figure, have a table with all the abbreviations (e.g., AKIW, AKIB) so it is easier for the reader to look back when needed, as well as explain the most important ones in the figure legend. We will however not describe the life cycles of the other phytoplankton groups in more detail since this is not the focus of the paper. There is a description in the figure legend that A1 and A2 stand for the functional groups "diatoms" and "flagellates and others", respectively.

Figure 3: Model seem to show much higher values than observations. I wonder what are the reasons.

Authors: This difference will be further discussed in the revised manuscript. Figure 3 shows all different sensitivity runs and therefore also the runs with very high biomass values. However, the wPlim that we chose for the model results is not very far from the observations. We will provide a more detailed comparison in the revised version of the manuscript, where we provide mean values of the summer biomass peak as well as the

seasonal span in a table so that it is easier to evaluate the runs to the observations. Also, observations have a maximum frequency of once every two weeks. This means that much information about peak biomass and variance is lost, and the highest values can sometimes be missed.

Figure 4: I am personally curious about how the population of N2 fixers change.

Authors: We are a bit uncertain about this comment. Is it regarding how the community composition changes? Because the current figure, the upper panel, demonstrates how the whole population changes over time. Since the model only includes one group of cyanobacteria we can unfortunately not demonstrate how each taxa changes over time.

Figure 5: The rate of nitrogen fixation seems to match despite the difference in biomass shown in Figure 3. I wonder what explains this. Also, I wish to see discussion on how Heterotrophic N2 fixation may alter the result.

Authors: The strong coherence between model results and observed nitrogen fixation is somewhat surprising given the larger cyanobacteria biomass displayed by all model experiments compared to observations (Fig. 3). There are several potential causes for the deviation in carbon biomass estimations from the model and observations. The cyanobacteria biovolume from observations was used with different presumptions to estimate the nitrogen fixation rates and to calculate carbon concentrations, respectively. The modelled nitrogen fixation is calculated during the run from the growth of HET in the CLC model while the carbon content of cyanobacteria is calculated by the Redfield ratio between nitrogen and carbon in HET with a minor contribution also from REC. Hence, there are uncertainties in the calculations of carbon biomass from both observations and from model results. It is not easy to change the Redfield C:N:P ratio that is used in the model since the results from the entire biogeochemical cycle including the oxygen consumption in the model is dependent on this ratio. There are other biogeochemical models with variable C:N:P ratios that might be used to analyze the impact from these processes further. Uncertainties in the comparison of models and observations stem also from the fact that observations are done on small water samples from an area that is covered by an average value from a 3.7 km x 3.7 km grid in the model.

Heterotrophic N2 fixation is extremely low in the Baltic Sea (e.g., Farnelid et al. 2013) and is therefore not included here. It has been demonstrated in the Baltic Sea that its three taxa that dominate the N2 fixation (Klawonn et al. 2016). Heterotrophic N2 fixation is neither included in the observations nor the model, and would probably not make any notable difference since it is so small.

We will enhance the discussion of this in the revised manuscript.

Figure 6: How do these compare to the model simulation?

Authors: These are from model simulations.

Figure 8: Could this be compared with observation?

Authors: The data in red is from the model simulation wPlim and in black from observations. This will be better clarified in the revised version of the manuscript both in the text and the figure legend.

Supplementary material:

I wish to get the explanations behind (8). Why is it power of 4? Is that based on some previous studies?

Authors: The equations for light and temperature limitation are adapted to RCO-Scobi from the original model by Beckmann and Hense (2004) and Hense and Beckmann (2006).

I wish to get the reasoning behind (9). What is it formed with the addition of square termed in square root instead of the simple additions? Is that based on some previous studies?

Authors: See previous answer.

I wish to get some explanations behind equation (10) and (11), especially the reasoning of the mathematical formulas and qualitative interpretation of them.

Authors: Eq. (10) describes the transition from the recruiting and vegetative state (REC) to the diazotrophic state (HET). The maximum growth rate (s-1) of REC is larger than that of HET but the growth (mmol m-3 s-1) is, in the previous state, also dependent on nitrogen. When the growth of HET is larger than that of REC a transition to HET occurs.

Eq. (11) describes the transition of HET to pelagic akinetes (AKIW). If the growth of HET is below a critical value, a transition to AKIW occurs.

We will deepen the model description and include a schematic of the CLC model in the revised manuscript.

Other points for discussion:

There are studies suggesting that heterotrophic bacteria may contribute to N2 fixation. I suggest considering discussing their effect on the overall N2 fixation in the Baltic Sea. The following papers may be useful: (Bentzon-tilia et al., 2015; Farnelid et al., 2013; Bentzon-Tilia et al., 2014; Chakraborty et al.; Pedersen et al., 2018).

Authors: We agree that heterotrophic N2 fixation should be mentioned and it will be included in the discussion in the revised version of the manuscript. However, since the N2 fixation rates by heterotrophic bacteria are extremely low in the Baltic Sea it would not affect the overall input of N2 fixation in the studied region (heterotrophic bacteria: 0.44 nmol l-1 d-1 in Farnelid et al. 2013 as compared to up to 800 nmol l-1 d-1 by filamentous cyanobacteria in Klawonn et al. 2016).

N2 fixers (or nitrogenase) are known to be sensitive to O2. However, heterocysts have glycolipid layer which may protect them from O2. I think the hidden assumption in the model is that O2 does not matter to heterocysts. To support the assumption, the authors may consider citing (Inomura et al., 2017), as it shows that respiratory protection is not required for heterocysts; otherwise the rate of N2 fixation would be O2 dependent.

Authors: We agree that heterocysts are designed to protect them from O2 and therefore is this model assumption correct. The suggested paper includes a totally different species (soil bacterium) so if needed we prefer to cite something closer to our study organisms. However, since the filamentous cyanobacteria in our study are photosynthetic they produce their own oxygen, and therefore always have O2 present around their cells, and why changes in O2 concentration does not affect the nitrogen fixation rates.

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Please also note the supplement to this comment:
https://bg.copernicus.org/preprints/bg-2021-156/bg-2021-156-AC1-supplement.pdf