Review of **"A missing link in the carbon cycle: phytoplankton light absorption under RCP emissions scenarios"**
by Rémy Asselot, Philip Holden, Frank Lunkeit and Inga Hense

General comments

Following the conclusions of Asselot et al (2022) who demonstrate that phytoplankton light absorption (PLA) mainly affects the climate system via air-sea CO2 exchange, the present study of Asselot and co-authors analyse the effect of activating the PLA in an earth system model (ESM) of intermediate complexity under emissions-driven (for CO2) scenarii of climate change.

Thanks to their framework with freely-evolving atmospheric CO2 concentrations, the authors show that the consideration of the PLA is critical, as it leads to an enhanced greenhouse gas effect in climate forecasts. Indeed it increases by 8 to 20% the global atmospheric CO2 concentrations. This result has great implications for climate forecasts: it highlights the importance of PLA-induced climate changes that a large proportion of current ESM do not consider, and proposes a quantification of this missing part of the atmospheric CO2 content under different climate scenarii (it identifies the PLA-induced changes as a function of climate change itself).

However, two points need clarifications from my perspective:

- What implications has the use of an EMIC compared to a classical ESM in terms of feedbacks between the ocean and atmosphere ? This would give some clues on how your main results are generalizable.
- One of the main result of this study is that PLA increases the surface net primary production in mid-latitude and upwelling regions due to a higher availability of nutrient concentrations, which is in turn driven by a higher remineralization at the ocean surface (and a reduced export efficiency). While this result is important, I would expect to understand to what perturbations of the oceanic physical conditions the higher remineralization is due.

Specific comments by section

Abstract

L.9 "This biogeophysical mechanism increases the surface chlorophyll": based on your Table 2, your net primary production (globally integrated) in 2500 increases by less than 2% for all RCPs when activating the PLA. Of course this is not comparable with the order of changes you cited in your introduction part (e.g. "chlorophyll concentration has declined over more than 62% of the ocean surface from 1890 to 2010", "between 1998 and 2006, low surface chlorophyll areas have expanded by 15%"...), but I would highlight that point in the abstract by giving the percentages of changes, because your results show that, by triggering NPP changes of less than 2%, the PLA may perturb the global atmospheric CO2 content by 8 to 20%.

L.15 "that *may be*" or "that *are maybe*" ?

2 Methods

From the **legend of figure 1**, I understood that what differentiates your EMIC from what you call an "ESM of high complexity" here is mainly the use of a simplified atmospheric module ("EMBM") which is not a fully 3D atmospheric model…? Please, could you clarify that aspect in the text of section 2, and explain with one sentence what is EMBM: if not a 3D model, is it a slab layer of atmosphere ?

l.72-74 the authors wrote “EcoGEnIE is an ESM of intermediate complexity (EMIC) (Claussen et al., 2002) and due to the limitations of such a model, we focus on the quantification of the large-scale impacts of phytoplankton light absorption but we do not quantify the components or drivers of those large-scale impacts”.
I am wondering how could we trust the large-scale impacts of PLA analyzed here if we do not trust what cause them ? I understand from this sentence that, due to the limitations inherent to an EMIC, the authors do not trust the drivers of the PLA large-scale impacts. Please reformulate.

l.75-77 “We chose to conduct our study with an EMIC because we are interested on the effect on particular climate mechanism (e.g. phytoplankton light absorption) and it would have been difficult to isolate this effect with an ESM of high complexity, due to numerous climate feedbacks implemented in high complexity ESM.”
In their analysis of many ESM “of high complexity”, Séférian et al (2020) decomposed the Earth system interactions represented in ESM involving marine biogeochemistry into 4 main feedbacks: climate-carbon cycle feedbacks (F1), biogenic aerosol-cloud feedbacks (F2), non-CO2 biogeochemical cycle feedbacks (F3) and phytoplankton-light feedbacks (F4). It is not straithforward to me to see how climate feedbacks F1 to F3 would have perturb your analyses of the PLA-induced effects. Please, be more specific : give examples of the numerous feedbacks that would hinder the identification of PLA-induced effects. Don’t you mostly think here to ocean-atmosphere interactions (not existing in your case due to the use of a simplified atmosphere with EMBM) ? If true, please mention it.

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

2.1 Ocean, atmosphere and sea-ice representation

l.95 “However, on a global scale, Marsh et al. (2011) show that the model simulates realistic upwelling.”
With an horizontal resolution smaller than 3° in latitude (and not specified in longitude... but Ward et al., 2018 declare that they have 10° of longitudinal increments: what about yours ?…) and a minimum vertical spacing of 29 m, I guess “upwelling” refers to equatorial convergence, and not to coastal upwelling regions which have widths < 100 km, associated to very specific coastal dynamics needing quite fine horizontal and vertical resolutions to be represented. But even for equatorial regions, I find a bit inappropriate the expression “the model simulates realistic upwelling” as we know that your model represents only the very large-scale ocean dynamics. Could you describe in the text the dynamical conditions favoring these “realistic” upwellings in your model ?

l.96-107 Again, could you clarify why this 2D atmospheric model was a more suitable choice than the fully 3D atmospheric model PLASIM in your framework ? Could you add a sentence explaining how the use of this simplified atmosphere may help revealing the PLA effects ?

2.3 Ecosystem community component

l.126 “messy feeding” ?
l.145 “so the rate”

2.8 Model inter-comparison

l.225 comparison with an other EMIC ("an ESM of intermediate complexity") model: but more generally the reader is curious to know what would give the comparison with a high-complexity ESM ?

More generally, I understand that this first comparison focused on surface atmospheric temperature (SAT) because it allows to validate the use of a simplified atmospheric model in this study...? But back to the main goal of this study (effect of the PLA), I would expect here some elements characterizing how the ocean compartment absorbs heat without PLA (ocean heat content or at least ocean temperature). This would allow to discuss later the true PLA effect added by your equation (3). If Zickfeld et al (2013) have no ocean heat data, I suggest you to insert a small paragraph (and figure) characterizing the ocean heat content changes (or time series: see for example Figure 1 of Berthet et al, 2023) for each of your RCPs without and with PLA. Based on eq. (3), the first effect PLA will have on climate before any feedbacks on the biological pump/CHL/atmospheric CO2/SAT, will be to perturb the oceanic temperature, no ? So the first question for me is: how much ocean heat content is altered by the activation of your PLA parameterization ? Could you elaborate a bit on that point ?

Berthet, S., Jouanno, J., Séférian, R., Gehlen, M., and Llovel, W.: How does the phytoplankton–light feedback affect the marine N_2O inventory?, Earth Syst. Dynam., 14, 399–412, https://doi.org/10.5194/esd-14-399-2023, 2023.

3 Results
3.1 Oceanic properties

l.240 I would suggest to reformulate: "when PLA is activated" or "represented", rather than "simulated" ; this is only a suggestion, as my english is for from being perfect.

L.241 How is the spatial pattern of this POC flux reduction ? Do you observe a reduction over the entire globe ? Or is it consistent with the patterns you described for the chlorophyll (l.266-270), i.e. mainly marked in upwelling and mid-latitude regions ?

L.242 "independently of the RCP scenario": by activating the PLA, the oceanic temperature increases in sub-surface in all scenarii, but with different intensities, no ?

l.245 "Indeed, the surface net primary production increases with phytoplankton light absorption": could you explain why ? To what perturbations of the physical conditions is it due (see my general comment on section 2.8) ? Please elaborate on that.

3.1.2 Surface chlorophyll

L.266 Unlike the results of Paulsen (2018), who reports a decline in chlorophyll concentrations in the upwelling regions with PLA (**L.46**), you find a higher chlorophyll (CHL) concentration in the upwelling and mid-latitude regions with PLA in your model and framework: could you explain why Paulsen obtained an opposite feedback with its "Earth system model of high complexity" ? By which mechanism ? Does your EMIC represent this mechanism ? Or is this different behaviour attributable to the fact that Paulsen run its ESM under prescribed future atmospheric CO2 concentrations rather than freely-evolving emissions: in this case could you explain by which mechanism the atmospheric CO2 concentration may constrain the CHL to decrease locally in upwelling regions ?

3.1.3 Sea surface temperature

L.273 "Due to changes in surface chlorophyll, we expect variations in SST".
What do you mean exactly here ? Due to changes in 1) surface chlorophyll *concentration* or 2) *in absorption properties* of surface chlorophyll ? This does not imply the same chain of causality:

– case 1) describes the fact that PLA activation directly affects CHL concentration and, then, indirectly affects the SST due to the CHL concentration changes. However, in this case, could you clarify what mechanism triggers the initial perturbation of your CHL concentration ? In other words, how the PLA activation affects your CHL concentration ?
– case 2) describes the fact that activating PLA has first a direct effect on ocean temperature. And that the other effects on CHL/export/remineralization arise from that one.

3.2.1 Atmospheric CO2 concentration

L.293 I am a bit puzzled about these runs driven by CO2-emissions that do not match the target. I am not sure to fully understand the implications that could have on your analyses. Could you elaborate on it ?

L.302 "For the RCP8.5 scenario, the atmospheric CO2 concentration increases by 8% only, which is due to the lower increase in chlorophyll and SST".
To demonstrate this assertion it would be interesting to see maps of atmospheric and oceanic CO2 partial pressure, as well as DpCO2 for all RCPs. Because in the current state I am not sure you have enough elements to directly conclude what you wrote. For me, you need to disentangle here 1) how the PLA activation changes your ocean CO2 content, from 2) how the CO2 atmospheric content in RCP8.5 allows to absorb new oceanic outgassing compared to the other RCPs. Your results in figures 7 and 8 show a non-linear behaviour of RCP8.5 compared to the other three RCPs, which is most likely attributable to a non-linear effect of the increased atmospheric CO2 concentrations.

From my perspective you did not dig deep enough into this aspect, because it was one of the main conclusions of your work: the effect of PLA activation is not linear and depends on the climate scenario. You may show that RCP8.5 crossed a tipping point (due to an extensive ice melt and other effects) what changes the way the ocean-atmosphere system manages the CO2 exchanges and finally, modulates the effect/amplitude the PLA activation may have on climate.

4.1 General discussion

L.334 "Our results show that phytoplankton light absorption affects water temperature and nutrient concentrations."
Please see my related comment in section 3.1.3.

L.335 "The increase in surface nutrient concentrations (Appendix D1) is driven by a reduced export efficiency of organic matter and enhanced remineralization at the ocean surface (Table 2)."
While I found the result of more remineralization in surface very interesting, I still have the feeling that something is missing in your analyses. You did not explain (or I missed it, so maybe it would be great to clarify it) by what mecanisms does the PLA activation affect your modelled remineralization and export ? This will possibly also help understand why RCP8.5 does not react proportionnally to the other RCPs when activating the PLA.

L.336 "The increased surface nutrient concentrations leads to higher surface chlorophyll, which in turn leads to a warming of the ocean surface."
Here I interpreted that you choose the case (1) of my comment in section 3.1.3.

4.2 Limitations

L. 384 "Our results highlight that phytoplankton light absorption itself increases chlorophyll leading to more heat being trapped in the ocean surface."
My guess is that PLA *promotes environmental conditions in ocean surface temperature* that allow an increase in remineralization in surface, what triggers an increase in nutrients concentrations and, thus,

an increase in CHL concentrations allowing more heat to be trapped: is that what you mean ? Please clarify.