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Biogeosciences Discussions

Interactive comment on "Variable phytoplankton size distributions reduce the sensitivity of global export flux to climate change" *by* Shirley W. Leung et al.

Anonymous Referee #3

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Leung et al. present an interesting study in which they thoroughly analyse the "particle size remineralization" (PSR) feedback in a simple 3D biogeochemical model. The PSR feedback is described by decreased circulation leading to increased nutrient limitation at surface, which in turn leads to plankton communities with smaller sizes producing smaller sinking particles, leading to a slower sinking speed and hence remineralization at shallower depths. This chain of mechanisms increases nutrient concentration at these shallower depths, dampening the decreased nutrient supply to the surface. Their results show that the PSR feedback dampens projected decrease in export production by 14% globally and also details the dampening in different regions. In particular the detailed regional analysis is very informative, suggesting that changes in particle sink-

ing speed in the Southern Ocean have only a small impact on carbon export. Overall I find this an important and interesting study, well written and clearly presented and I recommend a speedy publication after the following comments have been addressed.

Main comments:

- I like that the PSR feedback has been thoroughly analyzed, but it should be discussed or mentioned earlier that there are several other processes potentially affecting the nutrient supply to the surface (varying stoichiometry, temperature dependence of remineralization, ballasting, aggregation/fragmentation etc) that are ignored in this study. There is a good discussion of the caveats at the very end in the conclusions, but I think it would help to mention early on that this paper analyses the PSR feedback in isolation of the other feedbacks.

- The proposed PSR feedback has been analysed for carbon export through 100m depth, however I would expect that there is a decrease in POC flux at deeper layers in the ocean (as the PSR feedback mainly acts in the first few 100m? My interpretation of course). For instance for the question how much carbon is sequestered from the atmosphere or how much food supply is available for mesopelagic organisms, the carbon flux below 100m depth might be of higher relevance. It would be very interesting to see how much the carbon flux at deeper layers is dampened by the PSR feedback.

- There are models participating in CMIP5/CMIP6 that parameterize two different particle size classes with different sinking speeds (I have written a bit more in the line-by-line comments). Is the full particle size spectrum really needed for the PSR feedback, or is it also possible to use just two particle size classes?

- I think some aspects of the model should be described in more detail, in particular the PRiSM component used to estimate particle flux (see line-by-line comments)

Line-by-line comments:

L 9: Please write something like "This decline is mainly caused by. . .", as there are

other mechanisms projected as well, for instances stronger grazing pressure due to higher temperatures

L 11: But there are some Earth System Models that simulate changes in remineralization depth, due to e.g. changes in phytoplankton community composition? For instance CESM-BEC, IPSL-PISCES and GFDL models all simulate changes in formation and sinking of particles under climate change. It is true that most models don't have a dynamic particle size spectrum though. (I am also wondering, do the Earth System Models that already have particles with different size classes also predict lower export decrease? But this is probably impossible to disentangle from other effects such as a temperature-dependent remineralization or varying stoichiometry etc.)

L 45/46 Maybe cite Laufkotter et al. 2015 for drivers of future declines in primary production as well

Introduction: I miss a discussion or mentioning of other drivers of sinking speed/particle remineralization, such as particle density/porosity and ballasting, also fragmentation and aggregation which potentially change the particle size over time

L 67/68 "parameters and processes in most previous models are not constrained by observations of particle size distributions" - Yes! Nice!

L74/75 Are there more recent references for the particle size distribution?

L 99 Just a small comment: I think the "shallowest" can be removed?

L 117 I think the decreased nutrient supply causes the decrease in phytoplankton/particle size, not the decrease in export?

The introduction reads slightly redundant to me and could be streamlined a bit, particularly part 1.2 (PSR feedback). However, I acknowledge that other reviewers seem to particularly like it and find it "very clear", so maybe for readers with little background in particle export it is better the way it is.

L 164 Does the plankton not become small plankton, or does the small plankton not produce small particles? Oh I see, plankton community isn't explicitly represented, correct?

I don't understand where Prism has the microbial respiration rates from, and whether they increase due to temperature in a warmer ocean? Is there an oxygen dependence? Is there aggregation/fragmentation? Can the sinking speed change over depth? Given that these questions are essential to this study, please explain Prism in more detail.

L173/174 wouldn't it make sense to also increase the production of DOC when changing the beta of the particle size spectrum?

Fig 3: That's probably only my personal preference, but I generally prefer mapping data using a log scale, instead of plotting log(data) and using a linear scale.

L 233/234 The NPP estimates you are using are significantly biased in the Southern Ocean. This should probably be discussed here, or you could use an NPP estimate that has been specifically created for the Southern Ocean (for instance Johnsson et al. 2013).

L254 How sensitive are your results to this simplified representation of future ocean circulation?

L 282 In light of these "counterintuitive" relationships I think it would be really interesting to use an NPP algorithm that's been developed for the Southern Ocean, as mentioned above (the result might stay the same of course, and I like how it is discussed/explained with the Lam&Bishop findings)

L 346: Is this a conclusion from the correlation between P200m and E or something that is actively diagnosed in the model?

L 355 ff The considerations up to this point hold for the nutrient-limited low and mid latitudes. But here you discuss a global uniform decrease of circulation rates. I found the jump from regional to global a bit confusing. Wait, I see now that in line 349, eq 3

is meant to hold at any given location, including regions in which eq. 2 does not hold, yes? Is that mathematically sound??

L 358 “This decrease in P200m is ..” - Is this your interpretation or has this been diagnosed in the model?

L 404 - Is eq. 2 a close approximation in the low latitudes or globally? Is it possible to show on a map how well Eq 2 holds regionally?

L 484 is this a typo “1.16 times”? Otherwise, I don’t understand, why 1.16 times? 1 - 16%? But I wouldn’t understand that, either. Sorry if I am missing something obvious.

L 485 I believe the Pisces models used in the Bopp et al. study implements two different particle sizes, so it’s possible that the PSR feedback is at least partly included? Please check

L 507/508 “PSR Âăfeedback strength remains relatively constant whether circulation rates are increased/decreased by 10% or 50% “ - That is very surprising to me. Why would that be? Are you reaching a maximum/minimum particle size distribution such that a further decrease in nutrient supply does not affect the size distribution anymore? Please discuss this a bit more. I also think this sensitivity test should be mentioned in the results already.

L 528 I think the study by Briggs et al. 2020 is good recent reference for fragmentation

L 545 The effect of temperature increases and oxygen decreases on future carbon export has been analyzed in Laufkotter et al 2017, maybe good to cite here

Conclusion: If I understand everything correctly, your results suggest that changes in particle size/sinking speed in the Southern Ocean have only a small impact on carbon export regionally and globally. This could be interpreted as a justification for modelers to give implementation of particle size a low priority in this region - would you agree?

Anyway. I hope this review helps, and my apologies that it took me so long!

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