Response to Anonymous Referee #3

We have copy-pasted the original review comments below to allow for a one-by-one reply. The reviewer's text is underlined, while our response follows as plain text (no underline).

Review for Biogeosciences manuscript bg-2021-181

"Regional-scale phytoplankton dynamics and their association with glacier meltwater runoff in Svalbard"

By Dunse et al.

General comments:

It has been several years now that the subject of glacial run-off enhancing primary production in adjacent fjords has been a "hot topic" in Arctic marine research. In recent years, there have been many research papers investigating the subject, most of them featuring in situ observations. However, in situ observations are often lacking spatial and temporal resolution which is needed to extrapolate observed patterns. Further, many prior studies on the subject left the question of how far reaching these effects of enhanced primary productivity would be. Would they extend outside of fjord and onto the shelves? Or would the effects be more local? This manuscript if the first I am aware of to address both of those knowledge gaps. While there are many limitations of using satellite data, which the authors have discussed and acknowledged, their effort is truly a first step in resolving the multiple drivers for enhanced primary production in glacially influenced coastal regions and the first to empirically show the limits of run-off derived productivity enhancement. Furthermore, the paper is well written and their conclusions are well reasoned and supported by their analyses and results. This article is an appropriate fit for Biogeosciences, where many of the prior research on the same topic has been published and it will likely be highly cited in the discipline. I recommend this manuscript to be published with minor revisions. See attached document for further comments.

We are very glad to read this positive feedback by the reviewer, highlighting the contribution of our study in the field of glacially influenced marine ecosystems. Thank you so much!

Line 3: I would temper this statement—"provide…essential nutrients". As the authors point out later on, glacier run-off often act to dilute surface nutrient concentration, and this sentence makes it seem like the freshwater directly provides the nutrients. I would rather say ",but glacier run-off may indirectly aid in supplying the surface ocean with essential nutrients" or something similar…

Ok: will change this to ", but may also AID TO provide surface"

Introduction: The second 2 paragraphs read very much like a text book covering very basic topics. The authors could condense this section (e.g. most readers will understand what primary production is or the concept of stratification without so much explanation).

We want to make this paper easily accessible for a diverse audience. We have therefore chosen to explain some terms that seem basic from the perspective of for example, a marine biologists but not necessarily a glaciologist. Nevertheless, we will go through the introduction and try to condense it.

Also, the same citations are repeated over and over again often without very clear links to the articles. The introduction could use more diversified and more recent citations and there are many that are also more relevant to Svalbard. For example, Cantoni et al. (2020) shows, among other things, a negligible amount of nutrients entering with run-off from varying types of run-off sources in Svalbard fjords. McGovern et al. (2020) gives a nice seasonal perspective showing varying amount of nutrients entering with run-off depending on the season in Svalbard. There are few citations focusing on land terminating glacial fjords, Holding et al. (2019) for example shows season patterns of primary production in a land terminating glacier fjord in Greenland, highlighting influences of stratification (MLD) and light limitation. Also, Sakshaug (2004) is used a lot as a general citation for just about everything. While it is a seminal book in the field, it is now, unfortunately, pretty outdated (e.g. there is no longer much sea ice in the Barents Sea) and only about the Barents Sea. I suggest citing a more recent review on the basics of Arctic Ocean ecology from a Pan-Arctic perspective (Wassmann et al. 2020)

Thanks for making us aware of these relevant recent publications! We will update existing references and/or add these new ones in the revised manuscript, where appropriate.

Lines 41-42: These citations are not appropriate it you are discussing the general Pan-Arctic seasonality. Rather use Wassmann et al. (2020). Juul-Pedersen and Meire show different patterns more typical of fjord ecosystems (without much sea ice), the pattern they show are similar to your seasonal patterns and you cite them properly further down in the introduction and in the discussion section in that context.

Ok – thanks for making us aware of this new and more appropriate reference in the context of pan-Arctic seasonality.

Lines 42-43: Remove Sakshaug (2004) citation here. Also, on the other hand, the lack of sea ice cover can delay stratification and may also delay the spring bloom (see Song et al. 2021)

ok

Line 50. Juul Pedersen and Meire don't show the influence of grazing that I am aware of, perhaps they discuss it, but you should cite the original articles, not their discussion of it. But again, you are phrasing this in the context of general Pan-Arctic and I'm sure there is a more appropriate citation of this for that context.

Ok – we will add a new references concerning the statement on grazing pressure: Rysgaard et al., 1999, mentioned by the reviewer (see reference below) as well as Calbet et al. 2011. We will leave the reference to Juul-Pedersen et al., 2015 in the context of nutrient depletion.

Calbet, A.; Riisgaard, K.; Saiz, E.; Zamora, S.; Stedmon, C. & Nielsen, T. G. Phytoplankton growth and microzooplankton grazing along a sub-Arctic fjord (Godthabsfjord, west Greenland). MARINE ECOLOGY PROGRESS SERIES, **2011**, 442, 11-22

Methods/ Results: How do you deal with covariance in your model? Surely MLD covaries with RUNOFF for example?

By doing the model selection in two steps, first selecting other covariates than RUNOFF, and then adding RUNOFF if leading to lower AICC and having a P-value <0.05, we took a conservative approach. That is, RUNOFF would only be added to the model if it explained more of the variation than the correlated variables did. Covariance between predictors may hence have reduced the power of the analysis of RUNOFF effects, and may also have contributed to broad confidence intervals for some of the effects.

You don't really present a final model(s) with all the contributing variables, their coefficients and their goodness of fit values. I think it could be interesting to see this in an AIC table for example. I realize this would be a huge table if you did it for each region separately, but is there a way to summarize it? Or show only the significant models? Can you make one model for the overall data or is it not significant due to the variability in regions?

We can add tables with coefficient values, R2 and AICC of, e.g. a null model with no covariates, an environmental model without RUNOFF, and the final model with potentially RUNOFF included.

We did not use a global model for all regions for several reasons. Firstly, different environmental variables were expected to be important in different regions and different distances from shore. Selection of region-specific effects would be complex, and a model with too many environmental variables would easily be overparameterised. Secondly, we would have to take into account possible spatial correlations and differences in error variance (heteroscedasticity), which would further add to the complexity of the analysis. Thirdly, we considered the simpler region-specific approach sufficient to the question, transparent and relatively straightforward to interpret.

Line 125: Starting a sentence with a number is usually not ideal. I suggest either spelling the number out or altering this sentence so this does not occur

We split the sentence up in to and reformulate it to: Glaciers and ice caps cover 57% (34000 km2) of the total land 125 area in Svalbard. Tidewater glaciers drain 68% of the glacierized area and have a combined total calving-front length of ~740 km (Nuth et al., 2013).

Line 254-255: What about the difference variable for SIF? You should indicate that these difference variables are denoted by dt in the figures because it took me a while to realize this when interpreting figure 2.

OK – will be clarified both in text and figure caption

Line 354-357: What about sills and upwelling at the sills? Also, fjord geometry and narrowing regions enhancing turbulent mixing … I think this should also be mentioned.

We will add a statement about individual fjord geometry and the presence of sills further down, when discussing the estuarine circulation (presently Lines 373-383).

Line 430: I think there is a typo, maybe should be 2013?

Yes, indeed 😉

Line 440-445: It could be nice here to give an alternate view comparing also to a land terminating glacier fjord. See Holding et al. (2019) There, there is measurable production across the whole season well into fall. Also, in reference to your data I think you can point out the deepening of the MLD in September coinciding with the cessation of RUNOFF, however there is still sustained CHL. My interpretation of this

is a re-deepening of the ML may allow for greater turbulent nutrient flux into the photic zone, combined with increasing fall wind mixing before sea ice reforms, allowing for sustained CHL well into the fall. This is shown in the Greenland fjord presented by Holding et al.

We will look into the study by Holding et al., 2019 and implement their findings on low, but persistent primary production in the discussion to achieve a more balanced view with regards to land-terminating glaciers.

Thank you also for your interpretation of the data presented in Figure.3. We will mention wind-induced mixing as a potential player for deepening of the MLD in September in the discussion of the seasonal cycle of phytoplankton dynamics.

Figure 1 could show more of the currents, especially in the northern region. See Hop et al (2019) figure 1 for example.

OK – thanks. We will refine the representation of currents in our map figure 1, in particular to highlight pathways of overflow onto the shelf and into the major fjord systems.

References

Cantoni, Carolina, et al. "Glacial drivers of marine biogeochemistry indicate a future shift to more corrosive conditions in an Arctic fjord." Journal of Geophysical Research: Biogeosciences 125.11 (2020): e2020JG005633.

Holding, Johnna M., et al. "Seasonal and spatial patterns of primary production in a high-latitude fjord affected by Greenland Ice Sheet run-off." Biogeosciences 16.19 (2019): 3777-3792.

Hop, Haakon, et al. "Pelagic ecosystem characteristics across the Atlantic water boundary current from Rijpfjorden, Svalbard, to the Arctic Ocean during summer (2010–2014)." Frontiers in Marine Science 6 (2019): 181.

McGovern, Maeve, et al. "Terrestrial Inputs Drive Seasonality in Organic Matter and Nutrient Biogeochemistry in a High Arctic Fjord System (Isfjorden, Svalbard)." Frontiers in Marine Science7 (2020): 747.

Rysgaard, Søren, Torkel Gissel Nielsen, and Benni Winding Hansen. "Seasonal variation in nutrients, pelagic primary production and grazing in a high-Arctic coastal marine ecosystem, Young Sound, Northeast Greenland." Marine Ecology Progress Series 179 (1999): 13-25.

Song, Hongjun, et al. "Strong and regionally distinct links between ice-retreat timing and phytoplankton production in the Arctic Ocean." Limnology and Oceanography (2021).

Wassmann, Paul, et al. "Towards a unifying pan-Arctic perspective: a conceptual modelling toolkit." Progress in Oceanography (2020): 102455.

Thanks for making us aware of these relevant recent publications. We will have a close look at all and implement them in our revised manuscript where appropriate.