Final response to all three anonymous reviewers of our paper:

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

by Thorben Dunse, Kaixing Dong, Kjetil Schanke Aas, and Leif Christian Stige

MS No.: bg-2021-181 MS type: Research article

We would like to thank all three referees for their detailed and constructive feedback, which helped to improve both the content and clarity of this paper. We have considered all comments in the revised version of the manuscript. All minor comments and most of the major comments and suggestions are now accommodated in the updated version, in line with our previous response to all reviews, published in the interactive discussion.

In addition to the revised manuscript, we provide a marked-up version of the paper highlighting all track-changes since the initial submission. For reference, we have also copied our point-by-point reply to all referees, adding and highlighting recent "**UPDATEs**". At the end of the document, we list some additional changes, not requested by the reviewers.

Again, many thanks for your time and good feedback – also to the handling editor, Jean-Pierre Gattuso!

Kind regards,

Thorben Dunse - on behalf of all authors

Response to Anonymous Referee #1

The reviewer's original statement is copied below and highlighted by underline. Our response follows in plain text (no underline).

General comments

This paper describes a study relating glacier meltwater with chlorophyll concentrations around Svalbard. The authors use most (if not all) of the relevant bibliography in a study focused on an important theme in these times of rapid warming of the Arctic regions. Their methods combine coupled atmospheric and glacier runoff modeling and, satellite derived ocean data, which are appropriate methods to the spatial scale of the study. They conclude about a positive association between glacier runoff and chlorophyll concentration in 7 out of 14 hydrological regions within ~10 km from the shore. This conclusion is in line with related studies in Greenland and emphasizes the potential role of glacier runoff in stimulating primary production in adjacent coastal areas and it further contributes to the capacity of the scientific community to foresee the impacts of warming on the Arctic and Antarctic marine ecosystems.

The is an excellent and well written paper about an important topic. Therefore, I believe it should be accepted for publication after a minor revision. I made some suggestions directly on the pdf manuscript file which I attach. Please note that these suggestions should not be seen from my side as a necessary condition for paper acceptance.

Reviewer 1 spotted several typos and highlighted some text passages that would benefit from clarifications.

UPDATE: All typos and suggested text clarifications have been accounted for in the revised manuscript.

Specific suggestions by reviewer 1 (see annotated pdf file) that will be addressed, include:

- **UPDATE**: We have added a direct link to the CHL a dataset in the data-availability section, i.e.

https://resources.marine.copernicus.eu/product-detail/OCEANCOLOUR_ARC_CHL_L4_REP_OBSERVATIONS_009_088/INFORMATION

o please note that this is an updated version (after Dec 2019) of the original 8-day dataset used in our study

- "Perhaps it would be informative to compare regions with and without a significant runnof effect based on the tide water associated specific-runnofs?"

o This would be an interesting point to follow up. However, our timeseries of regional glacier runoff does not distinguish between runoff from land or marine-terminating glaciers.

- Fig.2 could include contour lines of 10, 20 and 50 km distance to coast

o **UPDATE**: The various marine zones (depending on distance from the coast) are already visualized through the colour-shaded polygons. We agree that additional contour lines would have been nice, but not essential. Due to time constrains during this revision (fig. 2 is composed of 12 individual figures), we decided to leave the figure as it is.

Response to Anonymous Referee #2

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

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

Author(s): Thorben Dunse et al. MS No.: bg-2021-181 MS type: Research article

General comments:

The manuscript examines summer phytoplankton bloom in the fjords of Svalbard region and its association with glacier meltwater runoff, sea ice and ocean variables- MLD and SST for the period 2003-2013. Satellite derived surface CHL data and model simulation data is used for getting RUNOFF, SEAICE, SST and MLD. The manuscript shows correlation of summer bloom (CHL data) with the model variables. And reports that 50% (7 of 14) hydrological regions of Svalbard showed CHL increase in summer when RUNOFF increases. But the correlation was limited only up to 10 km distance from the coast. The manuscript suggests that the association can be due to subglacial plume upwelling and estuarine circulation. For other 50% hydrological regions that do not follow the correlation between summer bloom and glacial melt, role of other players, including land terminating glaciers and sea ice, is attributed.

The manuscript also discusses phytoplankton dynamics of the fjords of Svalbard in the productive season from April to August, and compares it with other Arctic fjords.

One of the purposes of the manuscript is to explore the feasibility of regional scale monitoring of phytoplankton. And it shows that indeed monitoring by satellites can be useful where in-situ monitoring is not possible or data is not available, though satellites have limitations such as cloud cover, sea ice and lack of sub surface overview.

In literature, such studies are mainly reported for Greenland fjords with limited information on Svalbard fjords. Thus, the gaps identified are valid and the manuscript has attempted to fill the gap.

Thank you for summarizing our study and for highlighting the knowledge gaps it aims to address.

Good points:

The study adds key data to existing literature. It combines regional physical oceanography with biogeochemistry of phytoplanktonic bloom of an important region of the Arctic- Svalbard. Though the study is regional, the factors discussed are universal in nature and may apply to any similar setting.

The manuscript is well written considering the literature search and identifying the gaps. The study region, and material and methods are defined elaborately.

We appreciate this general positive feedback by the reviewer – thank you!

Limitations:

There are some limitations that the authors can perhaps rectify.

We will try our best 😉

How is the association with other variables accounted for while discussing the partial effects of chl with each predictor variable?

We now explain this better by adding a sentence to the first paragraph of the Results. After "Note that the associations that we hereafter discuss are partial effects, i.e. the association of CHL with each predictor variable, while accounting for all other predictor variables selected in the model.", we add: "Specifically, the statistical model estimates the joint effects of all selected predictor variables on CHL, and the partial effect of a variable represents the expected effect of that variable if all other variables are kept constant."

What could be the reasons for 50% of the fjords not complying with the said pattern? It would be good to add a paragraph in discussion related to this point?

We will extent the discussion of this point.

We already stated that the seven regions with runoff-effects on CHL, encompass the major fjord systems of Svalbard, whereas the remaining seven regions are characterized by open coastal conditions. In open coastal regions, other environmental factors dominate, such as SST, MLD and sea-ice fraction, while there is no significant association of CHL with runoff - neither positive or negative. In other words, the observed CHL is sufficiently explained by the other environmental factors.

It is worth mentioning in the revised manuscript that the potential enhancement of the estuarine circulation applies for the fjord systems, but not for the open coastal regions. Furthermore, we expect that residence times of water masses to be higher inside the fjords than along the open coast. Potential direct and indirect enhancement of nutrient availability through glacier runoff may thus be of lower magnitude and/or attenuate more quickly, so that no effect on primary production is revealed at the spatiotemporal scale used in our study.

Furthermore, we will also better highlight that we haven't found significant negative effects of runoff on CHL on a regional scale, as would be expected by increased turbidity associated with glacier runoff.

UPDATE: We added the following paragraph at the end of Sec. 5.1
"To this end, we can highlight some differences between regions with significant positive associations between CHL and RUNOFF namely the major fjord-systems in Svalbard, and regions without such association, i.e. regions characterized by open ocean conditions. While our method does not reveal the specific mechanism(s) by which the association is achieved, the fjord systems receive more freshwater per marine area, compared to open coastal regions, as evident in their specific runoff rates (Tab. 1). Furthermore, enhancement of estuarine circulation would only apply within the fjords, but not at the open coast. We expect that residence times of water masses are higher inside the fjords than along the open coast. Potential direct or indirect enhancements of nutrient availability through glacier runoff may thus be of lower magnitude and/or attenuate more quickly, so that no effect on primary production is revealed at the

spatiotemporal scale used in our study. With the exception of a single weak negative association between CHL and RUNOFF off the coast off Southern Spitsbergen (region 12 at 20–50-km distance from the coast), and two weak negative delayed associations for Wijdefjorden (16; 0–10 km) and north off Nordaustlandet (25; 20–50 km), we generally find significant positive associations between CHL and RUNOFF. This indicates that on a regional scale, positive effects of glacier runoff on primary production may outweigh negative local impacts such as reduced light availability and strong stratification."

Estuarine circulation fuelled by downfjord winds is mentioned as an alternative mechanism. Winds are an important parameter as they can mix the water column irrespective of glacier meltwater runoff. Checking surface winds can perhaps explain some of the cases which did not follow the pattern.

We agree that studies of wind-induced vertical mixing and their effect on estuarine circulation in glacier fjords are needed. However, this task is beyond the scope of the present paper.

In our study, the relationship between surface wind and mixed-layer depth (MLD) is of particular interest. The ocean model used to calculate MLD, relies on wind fields as input. Unfortunately, it has a low horizontal resolution of 12.5 km. This is sufficient at a regional scale, but not local scale, i.e. it cannot resolve local wind fields, which are to a large degree steered by local topography. For this, local observations are needed, and these are only available for individual fjords.

Also, checking turbidity data from satellite products can add information about the dominant character of runoff in a region. It will again help in explaining the other 50 % cases that did not follow the pattern.

The reviewer probably suggests that turbidity data could help us to identify regions where glacier meltwater severely impacts light availability in surface waters, and thereby limiting primary production.

A problem with such analysis would be that the satellite derived turbidity data is also influenced by chlorophyll and is thus not independent from the CHL data. The analysis could then become a bit circular. We have chosen to use an available CHL product which accounts/corrects for turbidity in coastal waters.

Further, though limitations of satellite data are discussed, limitation of the model data (if any) may also be included.

This comment probably relates to the coupled atmosphere-glacier model!?

Model performance was extensively validated by meteorological observations from weather stations and in-situ observations of seasonal glacier mass balance (see Aas et al., 2015 and 2016) – and generally found reasonably good.

Some model limitations are already acknowledged in our manuscript, such as the lack of runoff routing and hence, lack of knowledge of where exactly the water is injected into the fjord. We also mentioned the lack of knowledge of the exact delay time between meltwater production and runoff into adjacent seas. Both factors are not considered serious limitations, giving our regional scale study and 8-day temporal resolution (+ including runoff from previous 8-day time period).

In addition to the above, we could mention in the revised paper, that refreezing of meltwater is accounted by the model, but that this process is associated with somewhat larger uncertainty. We will also highlight that we have no information with regards to the fraction of meltwater discharged though supraglacial, englacial or subglacial routing.

When it comes to the ocean model, we believe that the MLD product has considerable uncertainty, particularly with respect to resolution.

UPDATE: We consider limitations of the satellite-born CHL product as the most important aspect of uncertainty in our study. We had therefore dedicated a specific section in the discussion to this topic, i.e. section 5.4. Limitations of other data were already included within the material and method section. We have added a point concerning the timeseries of glacier runoff ->"… the glacier model does not distinguish between surface runoff and subglacial discharge."

A general quality assessment of the TOPAZ4 data set, including uncertainties in the mixed-layer depth, is beyond the scope of this paper. However, we now advice the reader towards an appropriate work and have added the following sentence to the end of section 3.2: "A rigorous quality assessment of the TOPAZ4 data set can be found in Xie et al. (2017)." For the general description of TOPAZ4, we have changed the reference from Xie et al., 2017 to Sakov et al., 2012.

Sakov, P.; Counillon, F.; Bertino, L.; Lisæter, K. A.; Oke, P. R. & Korablev, A.
TOPAZ4: an ocean-sea ice data assimilation system for the North Atlantic and Arctic
Ocean Science, 2012, 8, 633-656

How modelling approaches and satellite remote sensing are going to up-scale in-situ observations in the present context? Does it imply identification of hotspots to be studied or suitable time to access the locations?

We find significant positive association of CHL with runoff mainly within the fjord systems of Svalbard, but generally not for open coastal regions. This implies that glacier fjords are generally suitable locations for detailed in-situ studies. Our regional-scale analysis does not allow us to pinpoint specific fjords or fjord arms. Our seasonal analysis shows that runoff from glaciers in Svalbard, and its effects on primary production, peaks in the months July and August. In-situ studies should extent throughout this time period and ideally several weeks beyond the onset and cessation of glacier runoff.

UPDATE: We have rearranged and reformulated the final paragraph of the conclusions to highlight how satellite remote sensing helps to up-scale in-situ information. Most important, our method allows to identify and quantify significant associations between CHL and Runoff, as well as other environmental variables. While in-situ studies are typically spatial constrained, satellite remote sensing provides regional coverage and can thus be used to infer the overall regional effect, which may differ from the local effect, measured in-situ.

"To our knowledge, this study is the first to link large-scale chlorophyll a from satellite ocean colour, an indicator of phytoplankton biomass, with glacier runoff from glacier mass balance modeling. Statistical analysis allowed us to identify and quantify significant associations between glacier runoff and regional chlorophyll a. We empirically show that glacier runoff effects on primary production in Svalbard are mainly restricted to the major fjord-systems, and do not extent far outside the mouth of the fjords and onto the shelves. As we also consider physical-ocean and sea ice variables in our statistical analysis, we are able to identify other environmental factors controlling regional summertime chlorophyll a dynamics in Svalbard. […] Our method can be applied on a regional to pan-Arctic scale, thereby complementing

valuable in-situ observations which are only available from a few sites and often of short duration, thus not capturing inter-seasonal to inter-annual variability."

Minor remarks:

Abstract

Line 3: Replace 'loads' with 'load'

ok

Line 4 and line 478: See the usage of counteracting. At places it is written with a hypen '-'. Keep it consistent throughout. 'Counteracting' should be ok.

ok

Line 20: Replace 'Pan-Arctic' with 'pan-Arctic'

ok

Introduction

Line 38: Correct quote marks

ok

Line 58: may add silicate to the list with suitable reference as it is one of the nutrients contributed by runoff

Changed sentence "Glacier runoff may be a direct source of nutrients to downstream ecosystems, for example bioavailable iron, nitrate or phosphate (Hodson et al., 2005; Bhatia et al., 2013; Hawkings et al., 2015; Meire et al., 2016; Dubnick et al., 2017; Milner et al., 2017; Hopwood et al., 2018)." to

"Glacier runoff may be a direct source of nutrients to downstream ecosystems, for example bioavailable iron, NITROGEN, PHOSPHATE OR SILICATE (Hodson et al., 2005; Bhatia et al., 2013; Hawkings et al., 2015; Fransson et al., 2015; Meire et al., 2016; Dubnick et al., 2017; Milner et al., 2017; Hopwood et al., 2018)."

Corrected nitrate to nitrogen and added silicate, along with a new reference "Fransson et al., 2015".

Fransson, A., Chierici, M., Nomura, D., Granskog, M. A., Kristiansen, S., Martma, T., and Nehrke, G.: Effect of glacial drainage water on the CO2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years, Journal of Geophysical Research: Oceans, pp. n/a–n/a, https://doi.org/10.1002/2014JC010320, 2015.

Line 88: Replace 'On Svalbard' with 'In Svalbard'

ok

Research region

Line 152: “Svalbard fjords can be regarded as broad fjords, i.e. fjord circulation is influenced by rotational dynamics or ‘Coriolis’ effects (Svendsen et al., 2002; Cottier et al., 2010).” The sentence comes abruptly and doesn’t flow with the last sentence and with the paragraph in which it is mentioned.

Agree – we move this sentence upwards to directly follow the statement on wind-driven, estuarine circulation in fjords and reformulate it slightly: “In addition to wind-stress, the circulation in broad fjords, such as found in Svalbard, is influenced by rotational dynamics or `Coriolis' effects (Svendsen et al., 2002; Cottier et al., 2010).”

Material and methods

Both present and past tense are used in the material and methods section. Past is preferable. Please make it consistent throughout the section.

Our intention was to use present tense whenever describing processes, configurations of the model(s) or data, which are still considered valid, today. We used past tense when, for example, referring to past applications of material and methods, or for preparation of data which had been completed prior to our study.

We went through the material and method section, as well as through the introduction and study-region sections, to make sure that tenses are used consistently.

Line 233 and 234: replace ‘time-series’ with ‘timeseries’. Keep it consistent throughout.

ok

Line243, 258, 261, 262, 265: Replace ‘normal distributed’ with ‘normally distributed’. Please make the same change throughout the manuscript.

ok

Line 249: “Variables were selected by step-wise adding terms if leading to lower value of the Akaike Information Criterion corrected for small sample size, AICC “The sentence needs revision to make it clearer.

Will be changed to “Variables were selected by step-wise adding terms if leading to lower value of the information criterion AICC, i.e. the Akaike Information Criterion corrected for small sample size"

Line 263: Replace ‘indications’ with ‘indication’

UPDATE: We exchanges “The final model…” with “The residuals from the final model…”, thus, we kept “…showed indications…”

Line 266: “If outliers were identified, we refitted the model with the outliers removed and report significant changes in results, but kept the outliers in the presented model.” The sentence needs revision. Maybe you can split it into two.

UPDATE: We have reformulated this section and deleted the specific sentence: “Outliers were identified as residuals more than 3.3 standard deviations away from zero, which is expected to occur by chance for 1 out of 1000 normally distributed cases, i.e. for about 2–3 of the >2000 observations analysed. Within 10-km distance from the coast, 13 residuals distributed among 10 regions were identified as outliers. A similar number of outliers existed for the distances from the coast. If outliers were identified, we refitted the model excluding the outliers. Since the removal of outliers had little influence on parameter estimates for RUNOFF effects, we kept them in the present model (all the coefficients remained statistically significant at P < 0:05).”

Results

Line 280: Replace “The model reveals significant positive association in all regions and regardless of distance from the coast, as expected.” With “The model reveals significant positive association in all regions regardless of distance from the coast, as expected.”

ok

Line 295: Replace ‘association’ with ‘associations’

ok

Line 311: Replace “There are both negative and positive associations with CHL and any of the physical ocean and sea ice variables, although only for a limited number of regions.” with “There are both negative and positive associations of CHL with any of the physical ocean and sea ice variables, although only for a limited number of regions.”

ok

Discussion

Line 339: Replace ‘tidewater-glacier drained area’ with ‘tidewater glacier-drained area’

ok

Line 340: Replace ‘less, than’ with ‘less than’

ok

Line 361: Replace ‘productions’ with ‘production’

ok

Line 370: Replace ‘timeperiod’ with ‘time period’

Simplified this instance of “timeperiod” to “present for a long period during summer”, and did the same for all instances of “per 8-day timeperiod” -> “per 8-day period”; for two other instances, we replaced “timeperiod” with “time period”, i.e. Line 101: “…for the time period 2003–2013…”

Line 387: As the authors have not checked the estuarine circulation in the methods, perhaps it is better to say that it may contribute to the positive association.

So, replace “plumes, we cannot exclude that also the enhancement of the general estuarine circulation contributes to the observed positive effect of glacier runoff on marine primary productivity.” with “plumes, we cannot exclude that enhancement of general estuarine circulation may also contribute to the observed positive effect of glacier runoff on marine primary productivity.”

Or otherwise, authors may check that component and can then give a quantitative or specified mention.

We have chosen to “moderate” our statement, as suggested above, as a proper analysis of the wind field and estuarine circulation is beyond the scope of our study (see response above).

Line 424: Replace ‘will discuss’ with ‘discuss’

ok

Line 430: Replace ‘2003-1013’ to ‘2003-2013’

Ok :-D

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.

UPDATE: We removed, for example the sentence about basic introduction of the term stratification, as well as some redundant and detailed definition of the euphotic zone.

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.

UPATE: We have been including the recommended recent publications, as well as a few other publications in the introduction (as well as discussion). We made an attempt to have a more direct link between statements and references, avoiding unnecessary repetitions of the same reference.

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.

UPDATE: We added three tables to the appendix, containing the regional models and associated statistics, including AICC and added the following sentence in the section describing the statistical model: "A summary of all regional models, including model equations, parameter estimates with standard errors and statistical significance can be found in the appendix (Tabs. A1–A3)."

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).

UPDATE: now mentioning sills, specifically in the introduction as part of the following sentence: "In-situ studies across the Arctic show a large variability in marine primary production in response to glacier runoff for individual fjord systems, due to distinct fjord geometry, **presence and depth of an entry sill,** glacier configuration of marine and land-terminating glaciers, oceanographic and climatic setting (Hopwood et al., 2018, 2020)."

… and added this sentence to sec 5.2.2: "[The importance of warm saline Atlantic water for fjord and shelf water masses and the marine ecosystem was previously reported by Hegseth et al., 2013 and Nilsen et al., 2016.] Variations in the correlation between CHL and SST for different fjord systems may at least partly be explained by the presence and depth of entry sills, which regulate the exchange of water masses between the shelf and the fjords (Cottier et al., 2010)."

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.

UPDATE: added the following text to Sec. 5.3:

"There are only few studies of primary production in glacier fjords dominated by land-terminating glaciers. Holding et al. (2019) found low, but persistent primary productivity in a northeast Greenland fjord, throughout the ice-free season well into autumn. The relatively low productivity was attributed to glaciers runoff causing low light availability and a strong stratification, thereby limiting the nutrient supply to the photic zone. Holding et al. (2019) showed that plankton communities had adapted to the low light regime in glacier influenced waters, similar to findings from northern Svalbard (Hop et al., 2019)."

"Glacier runoff terminates in September, which may lead to the observed increase in the MLD, along with the recession of solar insulation and, possibly, initiation of wind-induced autumn mixing. Vertical mixing, as evident in a re-deepening of the MLD may supply the photic zone with limiting nutrients, which could explain sustained CHL well into autumn, as observed in a northeast Greenland fjord (Holding et al., 2019)."

In addition, we also include the study by Holding et al., 2019 in the introduction, in order to balance the statement with regards to marine-terminating glaciers: "[Glacial fjords dominated by tidewater glaciers appear to have a higher productivity than those dominated by land-terminating glaciers…] A study by Holding et al. (2019) revealed low primary production in a NE Greenland fjord dominated by land-terminating glaciers, as glacier runoff limited light availability and enhanced stratification. Nevertheless, this low productivity was sustained throughout the ice-free season, well into fall."

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.

Additional changes

- We have moved some statements discussion regional glacier characteristics from the result section 4.1 to the discussion section 5.1. These changes are highlighted in the marked-up version of the revised paper.

- We have added a paragraph to section 5.1 “Glacier runoff effects on marine primary production” discussing possible impacts of a widespread transition from marine to land-terminating glaciers on primary production in Svalbard:
  “The strong climatic warming trend which is currently observed in Svalbard (Hanssen-Bauer et al., 2019) is expected to lead to a widespread transition from marine to land-terminating glaciers. Glacier runoff from land-terminating glaciers may still promote estuarine circulation and constitute a potential, although limited source of nutrients. On the other hand, freshly exposed glacier forelands may supply arctic fjords with nutrients mobilized by aeolian or fluvial processes (Hodson et al., 2016; McGovern et al., 2020). Nevertheless, widespread tidewater-glacier retreat would lead to a reduction and eventually loss of subglacial
  plume dynamics, with significant implications on fjord circulation and biogeochemistry, possibly rendering Svalbard fjords less productive (Torsvik et al., 2019).”

  New references:

  Torsvik, T., Albretsen, J., Sundfjord, A., Kohler, J., Sandvik, A. D., Skarohamar, J., Lindback, K., and Everett, A.: Impact of tidewater glacier retreat on the fjord system: Modeling present and future circulation in Kongsfjorden, Svalbard, Estuarine Coastal and Shelf Science, 220, 152–165, https://doi.org/10.1016/j.ecss.2019.02.005, 2019.

  Hodson, A., Nowak, A., and Christiansen, H.: Glacial and periglacial floodplain sediments regulate hydrologic transfer of reactive iron to a high arctic fjord, Hydrological Processes, 30, 1219–1229, https://doi.org/https://doi.org/10.1002/hyp.10701, 2016.