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.

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.

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.

We will include such a statement in the conclusions of the revised manuscript.

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, PHOSEPHATE 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, or configurations of the model(s), which are still considered valid, today. We used past tense when, for example, referring to past applications of material and methods.

We will go through the section and 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’

ok

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.

Split into two sentences: “If outliers were identified, we refitted the model with the outliers removed. We report significant changes in results but kept the outliers in the presented model.”

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