The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-326-RC2, 2021


The Cryosphere Discussions
Open Access
EGU



# *Interactive comment on* "Subglacial upwelling in winter/spring increases under-ice primary production" *by* Tobias Reiner Vonnahme et al.

**Anonymous Referee #2**

Received and published: 7 January 2021

Subglacial upwelling in winter/spring increases under-ice primary production

Summary: This paper aims to explore the role of the release of subglacial meltwater in the winter and spring on under-ice primary production. The premise of the study is that though subglacial upwelling of nutrient rich deep marine waters has been shown to be a viable mechanism for stimulating primary production in the summer, very few studies have examined this topic with regards to spring under-ice primary production. The study is an interesting, under-explored topic, which is only likely to become more important with global warming and prolonged glacial melt seasons, and thus, worthy of eventual publication in this journal.

However, I think there are number of improvements that could be made to aid the study, which I outline below. Apart from issues with over-interpretation of the data



Printer-friendly version

Discussion paper

(detailed below), the writing is often disorganized and unclear. Also, there often a lack of consideration of the on-ice processes that are occurring that could be affecting the authors interpretations – i.e. enrichment of the glacial meltwater itself that has been stored at the bed overwinter and is released in the spring. The fact that the submarine discharge in the spring is likely quite different to the dilute discharge characteristic of summer drainage is a fact that makes this difficult to compare to previous summer studies of glacial discharge into the ocean. To this end often the authors seem to have a pre-ordained conclusion – i.e. that the mechanism of nutrient addition was via upwelling of "deep" bottom waters by the submarine discharge, but this seemed at odd with the shallow depth of this discharge (20-m). Finally, there is also a lack of clarity with how some of the calculations are made – this needs to be rectified for these calculations to be understood. I would urge the authors to address these points, and indeed try to focus their story on the novel spring measurements they have, to maximize the potential readership of this interesting study.

Title: Given the confusion regarding subglacial upwelling (see below) – do you mean submarine discharge or upwelling of deeper marine waters? – I would suggest a title change.. Perhaps: Spring submarine discharge plumes fuel under-ice primary production ?

Abstract: L25: "retreat of tidewater glaciers could lead to decreased under-ice phytoplankton primary production" when? in the spring? In winter? Or both?

My comment on the line above points to a broader problem which is evident in the title.. which is that I think by the lack of specificity regarding the timing, winter or spring is determinantal to the paper. Presumably if the focus is on spring primary production then the authors are speaking about subglacial upwelling in the spring?

*A minor point, but line numbers every line would be really very helpful*

Introduction: L37: unclear what "it" is referring too L39: "close to the glacier front".. meaning what? Suggest specifying. Also a reference would be helpful here. The

ranges of increased primary production in front of tidewater glaciers is quite variable so specification would be good. L41: “at some distance” .. again suggest specifying here. L46: I’m not sure I would necessarily agree that the lack of studies of subglacial discharge in the winter / spring is due to the perception of a lack of freshwater outflow. I think it’s well known from a glacier hydrological perspective that temperate and even polythermal ice masses likely have winter / spring discharge. More likely it’s due to a lack of opportunity given the challenge of Arctic field conditions and the difficulty in locating such an outflow which would presumably be of low flux. L52-53: Suggest defining what you mean by “Glacier terminus melt rates” L54: Svalbard glaciers are shallower compared to what? L55-56: Phrase “can persist throughout winter and specifically in early spring” is unclear. Are you suggesting that outflow persists through winter and into spring? L57: add phrase “ various other mechanisms such as:” between the words “through” and “constant”. Also suggest making the part re: temperate parts of the glacier” a discrete sentence. Presumably, with regards to winter / spring discharge you are speaking about polythermal glaciers? I think this section in general needs more specifics regarding the types of glaciers that typically have winter/spring discharge and the typical fluxes and chemical composition of this discharge. I would think that all of these points are worth mentioning to set-up the discussion of this paper. The point regarding chemical composition in particular has been glossed over as being sourced from meltwater stored from the previous melt season but this meltwater having been stored at the bed over winter would have a significantly different chemical character than dilute snow and ice-melt passing quickly through the system at the height of summer. Also, what about the possibility of basal ice melt? L59-60: “Even low rates of subglacial outflows can be sufficient to supply nutrients to the surface”.. why? How? Is it because they would be sufficiently deep enough in the water column? Are you speaking of supplying nutrients via upwelling or via direct addition of nutrients in the subglacial discharge itself? If only the former, how can the latter be discounted since subglacial discharge in the spring would likely be more chemically enriched from greater contact times with the glacier bed or being sourced from basal ice melt? L60:





Printer-friendly version

Discussion paper

Why would spring subglacial discharge contain less sediment.. b/c of the low fluxes? Suggest specifying why. L63: Suggest setting up this argument a bit more progressively. Explain first what nutrients are generally fueling the under-ice spring bloom initially, and then go into the timing of glacial discharge and how that might positively affect under-ice primary production. As of now, the timing of the discharge and the initial bloom and end of bloom period are all not clearly laid out and this is problematic (in my opinion). L67: delete "the" before "primary" and add "in front of tidewater glaciers" after the word "production" L70: Re-arrange /re-write sentence to: Once sufficient light penetrates the snow and ice layers, ice algae start growing within sea ice between March and April.... Etc" L73: "nutrient additions from the water column" .. via what? How? Suggest specifying. L74: "subglacial upwelling" .. does this refer to spring subglacial upwelling? Suggest specifying. Again, I find the timeline within the year confusing with regards to glacial meltwater discharge and effect on bloom dynamics. Suggest more clearly spelling all of this out above. L78: "or at the ice edge related to ice edge induced upwelling" .. can you define this upwelling without using the words "ice edge"? L79: suggest replacing "coverage also" with "accumulates" L81: suggest replacing "Once" with "After" L83: suggest replacing "related" with "induced" L86: suggest deleting "to" and replacing "fuel" with "fueling" L87: the word "slow" is curious .. why is the subglacial upwelling slow? How do you know it's slow vs fast or continuous vs intermittent? Suggest deleting this word as it opens up a range of topics that haven't been discussed in enough detail above to warrant the use of this adjective here. L86-88: This pivot in this last sentence doesn't make a lot of sense to me as it seems to not really address the points brought up by the sentences immediately preceding it... i.e. namely reduced algal biomass due to brackish ice conditions .. suggest rectifying this last sentence. L90-91: How are the 2 freshwater inputs different? Suggest specifying versus keeping your reader in the dark here.. L92: "to investigate the effect of the glacier terminus" .. this is a big vague. Suggest specifying. L94: "nutrient rich meltwater".. I'm unclear what you are referring to here.. presumably since this phrase is followed by "bottom water to the surface" I think by nutrient-rich meltwater you are





Printer-friendly version

Discussion paper

referring to the subglacial discharge being enriched itself in nutrients versus upwelling of bottom waters but this has not been addressed above (though I suggest doing so) L95: suggest adding “under ice” before the words “primary production” if this is indeed what you are referring too? L95: “near the glacier front”.. phrase is vague. Suggest specifying. L95-96: “low permeability of sea ice” .. phrase is also vague. Suggest specifying.

As noted above I think the introduction would benefit from some more specificity, especially regarding the types of glaciers where winter / spring discharge might occur, a timeline of how this discharge evolves from end of the season to the winter and spring, and how this discharge might affect spring bloom under-ice dynamics – considering both the possibility of upwelling of bottom waters and also addition of nutrients directly from the glacial meltwater itself as alluded to in the last paragraph. One thing that should also be likely addressed is that any spring discharge will presumably be of quite low flux.. given this how likely / effective will any upwelling be?

Methods: L120: “.. were melted in 50% vol/vol sterile filtered seawater. . .” what was the reasoning for this? L155-157: Estimates of bottom water fractional contributions based on conservative mixing of nitrate.. can you rule out nitrate addition from the glacial meltwater itself? Other studies have found this (see, Beaton et al., 2017 in ES&T: https://pubs.acs.org/doi/abs/10.1021/acs.est.7b03121), especially in the early season meltwater from a distributed subglacial drainage system. L215: I’m confused by the words “reciprocal transplant experiment” .. I don’t think a “transplant experiment” is described above.. just primary production incubations. I also find the description of this experiment (L215-218) unclear and thus the overall purpose of the experiments to the study also unclear. As written, I cannot assess these experiments so I’d suggest a re-write of this paragraph. L225: Unclear what map you are referring to in sentence starting with “The map..” L232: I’m wondering why you chose to you swarm to cluster versus amplicon sequence variants (see Callahan et al., 2017: https://www.nature.com/articles/ismej2017119) L235: Was the data trans-





Printer-friendly version

Discussion paper

formed in anyway before making the dissimilarity matrix? I'm only asking because it seems doing some type of transformation (e.g. Hellinger) is increasingly common.

Results: L243: replace "were having" with "had" L244: why is Fig 2 c, d referenced before Fig 2 a, b.. did I miss the reference to a, b somewhere? L265: Are there any photos of the subglacial outflow described in L267-268? Since there is a lack of field data at this time of year I think that these would be of value. L283: When reading about the very high nitrate+nitrite and silicate concentrations below the ice at SG I found myself really wondering if this could be coming from the subglacial meltwater itself versus upwelling of deeper marine waters. I believe you have data of the glacial meltwater itself? You mention these samples in lines 101-102 .. and I see further on that you present this data in L295. I'd suggest re-organizing so that this comes before the marine data. L295: missing units for silicate in the outflow water L300: The definition of conservative mixing is not quite right. The sentences in lines 300-302 are especially problematic. I see that the other reviewer has already adequately commented on this so I will defer to those comments. In the rest of the paragraph I would avoid the words "positive mixing patterns" and "positive relations". I also found the color scheme in Fig 5 (red and pink) challenging to interpretation. L310: I echo the other reviewer that these calculations of nutrients supplied via upwelling vs the glacial meltwater should be shown.. how were these calculated? What is the error on these calculations? This paragraph needs more explanation for these values to be believed especially considering (as pointed out by the other reviewer) the single outlier values that are driving the gradient in SG samples. Also, at SG, it seems, at least from Fig 5 d-f, that the lower salinity water had higher silicate concentrations but these concentrations were much higher than those reported for the glacial meltwater above. What is the source of this silicate? L333: Like the other reviewer I'm confused by the term "vertical export of Chl" – what it means, how it was estimated, and what the errors on this estimate are. L337: "assuming absence of grazing".. this doesn't really seem realistic? L348: I'd suggest explaining more fully again the goal of the "reciprocal transplant experiment" before giving the results. Fig 6: The quality of this

figure should be improved. The numbers in the parentheses are very difficult to read. Fig 7: The x-axis with the experiment name are not clear. What does “com” stand for? Fig 8: Define UIW in the legend as you have for the other abbreviations L355-356: “The first [NMDS1] axis separated sea ice from water communities with no overlapping samples”.. this really isn’t evident in Fig 8a.. sea ice is the square and what water and under ice water samples are the triangles. These regularly are in the same ellipses, unless I’m missing something? Also, is the glacier outflow sample actually a under ice water sample? What is the salinity of this sample? I guess I’m wondering if this is a true non-marine glacial outflow sample or one that could be diluted by marine water? I think this is an important point that needs to be clarified above. L358-360: What was the stress on this NMDS? How robust is this ordination you show? I’m always weary of interpreting the axes in this manner, i.e. axes one shows X and axes 2 shows Y .. i.e. similar to how one might view a PCA. I agree that looking at Fig 8a your communities are different but I don’t think you can go as far to say that axis 1 is separating ice vs water and axis 2 is separating glacial vs marine. The ordination of this NMDS would likely change each time you ran it.. maybe something to consider? L371: “Overall the same NMDS clustering has been found as for the 16S rRNA sequencing” .. but in the 18S plot (Fig 8b) no ellipses are drawn.. does this indicate that these group divisions were not significant? The written text doesn’t seem to match the figure. Fig8c – the separation in the samples is quite striking on this NMDS. How come there are no ellipses on this plot? Were the differences shown in the NMDS not significant? Could try a perMANOVA to test the significance of differences between the groups perhaps?

Discussion: L388-391: These first few lines are a great summary and really the abstract and introduction needs to be better set-up to frame these important points: (1) evidence for subglacial upwelling at a shallow tidewater glacier under sea ice and (2) that this upwelling persists in the winter / spring and supplies nutrient-rich glacial meltwater and upwelling of bottom water. . . I actually think part of the confusion is the use of the term “upwelling” to describe the release of submarine discharge into the ocean and also the upwelling of bottom water. Perhaps a change of language throughout would be helpful





Printer-friendly version

Discussion paper

– i.e. saying “submarine discharge” vs “subglacial upwelling”. And as per points above the case about nutrient-rich glacial meltwater needs to be set-up and made earlier as it’s really a central finding. L406: The phrasing “which does not allow basal glacial ice to melt” is unclear. The whole sentence is too long and should be made into 2, but are the authors saying that because there is not Atlantic inflow water there can be no basal ice melt? Basal ice melt can result from geothermal heat flux, overburden ice pressure, and sliding friction. Warm ocean water is not the only mechanism. I suggest looking at a textbook (e.g. the physics of glaciers) and reviews on this topic: e.g. Hubbard and Sharp, 1989 L407: “Subglacial meltwater itself is unlikely to lead to basal ice melting due to its low salinity”. This sentence is very unclear to me. I’m not sure what this sentence is saying or trying to say. L407-408: ”However, basal ice melt is likely more important in systems with Atlantic water inflows. . .” as per above this seems to ignore the possibility of basal ice melt underneath temperate and polythermal glaciers. This may not be what the authors mean but as written it reads this way. L420: “remains from the previous melting season” is unclear. Can you specify what you mean by remains. L433: Can you specify what data you are referring to when you say “estimated bacterial growth rates”. I searched for this term in the paper and did not see it previously defined. It really should be so that the basis for this calculation of doubling time is clear. L442: Why does the supply have to be “constant” ? It seems like (from the methods) that samples for community analyses were only taken once at each station? How does a single-time point sample give an indication of the timescale of submarine discharge into the fjord? This might be a bit of a reach based on the community data alone – suggest tempering this statement. L442-444: When you say the “southern part of the glacier” is this part on land or in the ocean? If it’s on land you should specify. I also think that this assumption that this outflow is being released under the marine-terminating portion can be backed up by your marine data? This sentence seems out of place here. L445- to end of paragraph: This explanation of glacier hydrology really needs to come earlier. As written this whole section on the potential magnitude of upwelling is poorly organized. Suggest first setting it up by talking about processes on the ice and then





Printer-friendly version

Discussion paper

what's happening in the ocean. L456: "Our mixing calculations estimate".. where are these calculations described? L457: At what depth is the submarine discharge exiting the glacier? I find myself wondering at what depth these different water masses occur (can you specify this) and how deep the DLAW is being entrained from? Is it sufficiently below the nutricline to be replete in nutrients? Also the calculated entrainment factor of 1.6, how was this calculated exactly? And you state "which pulled 1.6 times more DLAW" .. more than what? This is not clear. L458-459: "Fransson et al. (2020) found that 30-60% of glacier derived meltwater was incorporated in the bottom sea ice ... again indicating that it is a widespread process at marine terminating glacier fronts" .. what is a widespread process? The release of submarine discharge and its incorporation into bottom sea ice OR the entrainment of different water masses (i.e. DLAW) as the plume rises (as discussed in the previous sentence). Again, this is a case in point of the organizational structure and lack of specificity of terms "submarine discharge" vs "upwelling of bottom waters" to be a source of confusion. L461: "Compared to the massive subglacial plumes of summer systems" .. where? This should be specified .. different glaciers have widely different discharge fluxes. The citation seems to be from Greenland but these glaciers will bear little resemblance to Svalbard, perhaps citing summer discharge fluxes from Svalbard glaciers too would be useful – particularly from your study site if the intent of this sentence is to contrast with spring discharge fluxes as seems to be the case. L462: "subglacial upwelling in spring is a small volume transport".. where is this data from? This study? This should be explicitly stated. Suggest re-writing this entire sentence. Also, the last part of the sentence regarding upwelling needed to maintain primary production should be a new sentence as this is a different point then the discharge flux. L464: "This careful estimate".. I'd remove the word "careful".. the more so because the sentence before this one is unclear! Is this estimate of freshwater input for Billefjorden in the summer or spring? It's unclear. The estimate from the Halbach paper is I believe from the summer so you want to make sure you are comparing like with like. L465-466: The fact that you have less entrainment than the Hopwood study is really not surprising at all considering the depth of





Printer-friendly version

Discussion paper

discharge and flux of discharge at the much deeper, larger glaciers in that study. I'm not sure what the purpose is of this statement? As written now it's failing to provide relevance to this study. L466-467: "each volume of SGO water pulled about the same volume of DLAW with it to surface".. this is unclear.. do you mean each volume over a certain timeframe (a day? A week? A month?) .. what is the volume exactly? What was the volume of DLAW entrained? This should be stated if you are speaking about volumes here. And again the comparisons to the Hopwood study don't' seem relevant if you are comparing to large Greenland glaciers. You should specify where and what type of glaciers in the Hopwood review you are comparing too. L470: This is the first mention of the depth of the discharge. As you say, 20-m is quite shallow. Are nutrient concentrations sufficiently high enough here to augment surface concentrations? In other words, is this depth below the nutricline. L473-to end of paragraph: This seems to directly contradict previous statements regarding the glacial meltwater discharge being enriched in nutrients (e.g. silicate?). Also many of the comparisons you are making are to summer discharge fluxes and summer entrainments.. the spring discharge will of course be lower but more chemically enriched from the glacial meltwater discharge? I think if you are going to use the summer values to compare, which you might have to do out of necessity and lack of other comparisons, you need to state so explicitly, and the limitations of such comparisons. L480: The word "Surprisingly" seems to not be the right word choice here. L438: "Substantial subglacial upwelling" .. I'm unclear was to what you are referring to here – is this submarine discharge of glacial meltwater or upwelling of bottom waters? In either case the word "substantial" seems ill-advised here given the preceding discussion and should be removed. Could it be that you didn't observe much light limitation because the plumes were not that "massive" (compared to summer).. i.e. you just have a much smaller discharge flux and therefore plume in the spring? This seems likely and unsurprising. L485-86: Unclear what the phrase "where light is not considered limiting" is referring too. Line 511: "rations" should be "ratios"? L515: Can you really call it "deep water upwelling" if the water is being entrained from only 20-m? This is problematic (at least for me) and needs to be clearly





Printer-friendly version

Discussion paper

addressed I think. L517-519: The discussion on iron seems unrelated and as written is unconvincing. L520: “nutrient concentrations may simply be higher due to the shallower depth at SG” .. why? It’s unclear what you are trying to say. Suggest re-writing with more detail and explicity. L529: Was the Frasson study done at this same site? L530: “The values” .. vague.. specify what kind of values you are referring to. L535: Paragraph ending here is rambling and needs to be re-written. Suggest taking out the iron since you have no data on this to compare. L536: “related”.. what do you mean by this word? Specify. L538: Were are you proposing this nitrification is occurring? In the ocean or in the glacial meltwater? Could the high nitrate come from the subglacial waters itself? See papers by Beaton et al. in Greenland, Jemma Wadham, Boyd et al., 2011 (AEM) and Wynn et al., 2007 (Chemical Geology). Do you have measurements of the outflow un-diluted by seawater so you can rule this possibility out? L566: Were you able to resolve any low-light level species in your molecular community composition data to back this statement up? L581: “their” .. unclear what this is referring to. L646: “In winter and spring, this would result in the lack of subglacial upwelling”.. but with more melt there would be longer melt seasons and presumably more submarine discharge and associated upwelling – at least in the shorter term?

---

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2020-326, 2020.





Printer-friendly version

Discussion paper