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The Cryosphere Discussions

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

Anonymous Referee #1

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Vonnahme et al., conduct spring-time measurements in a tidewater glacier fjord and provide evidence that entrainment of subsurface-fjord waters by early season freshwater discharge is a measurable nutrient source to under-ice phytoplankton blooms which would otherwise be nutrient-limited at this time of year. The hypothesis and general idea is quite novel, supported by some in situ data as well as incubation studies, and I think it is an interesting addition to the field. I have no specific expertise in sea-ice or in the analysis of algae community composition- I defer to a more appropriate reviewer on these aspects. I do have quite a few comments throughout the text, but nevertheless found the discussion paper an interesting read suitable for the journal. Most of my comments are minor, or simply requests for a little more clarity.

12 in some Arctic fjord systems, many don't have this and some of the few available

case studies don't have high primary production.

25 You do briefly comment on this once, but considering the timescale required to get significant shifts in the groundling line of these glaciers, could you also think about trends in sea-ice loss as well. Could the timing of sea-ice loss from some of these fjords shift, or could sea-ice even completely disappear, before significant changes in grounding line are evident?

35 "During summer" Here I think the reference you mean is a similar paper by the same author that deduces the 'upwelling' effect in summer has a measurable impact on silicic acid availability1, the paper cited is from the same area but concerns the spring bloom in the same fjord (which has some sea-ice cover in spring)2. I think you could be a little more precise here.

39 Is time not also important here? If you didn't have any sediment close to the glacier front, the nature of the upwelling followed by outflow at the surface would surely lead to relatively low primary production at the glacier front anyway, because the freshly upwelled water is being laterally advected away from the front i.e. I assume you would never see the highest cell counts here even in the absence of high turbditity? Looking specifically at the system studied by Meire et al., the bloom also seems to peak a fair way downstream of the large glaciers, even though there isn't much turbidity in the inner fjord.

46 I don't think there's a perception of no freshwater release from these systems overwinter, there are several papers demonstrating this (for a good recent Arctic example3), although I agree there is a big problem with bias in the distribution of data towards the peak meltwater season, and model discharge curves do I think include a little early/late season discharge comparable to that observed here4. I think a more accurate statement would be that whilst it's known that a little discharge occurs early/late season there simply isn't much data to quantify it.

48 I think you should distinguish 3 sources here, as written icebergs and terminus melt,

but also subglacial discharge at the grounding line

51 in summer. (Reference?)

61 "while at the same time entrapping considerably less light absorbing sediments" I'd be genuinely interested to know if you can provide data/refs to support this. I'm not sure we know what turbidity looks like in these sub-surface plumes and to what extent it represents particles from the ice melt/basal erosion, or resuspension, and how this changes through the year, although I would agree it would be expected to be low in this environment given the description of the fjord

63 "this spring upwelling mechanism could be the primary mechanism to significantly increase primary production" does not read well, try "could be a mechanism via which primary production is increased in tidewater fjords compared to similar fjords without these glaciers. . ." or similar.

65 I think you need a reference here. Retreat may generally co-occur with shoaling of the grounding line, but not always, and there may also be an increase in discharge which could offset shoaling to some extent as entrainment also depends on freshwater discharge volume. Also, you comment on upwelling being eliminated, but wind-driven upwelling will remain, so maybe be a bit more precise.

107 'shallow' Do you know the approximate depth?

120 "were melted in 50 % vol/vol sterile filtered" Is there a reason for this?

131 One metre or 1 m

140 Does the exact salinity you use for your inflowing seawater have a large impact on your calculations, can you state what the value of 34.6 refers to? Also, can you clarify to what extent small changes in this would matter (you may want to calculate the saline endmember uncertainty and propagate it?

197 What does 'net haul' refer to?

285 "where NOX (10 μmol L-1) and silicate (19 μmol L-1) levels were exceptionally high (Fig. 4)." Am I right that this is basically driven by one data point? If so, how do you explain such high NOx concentrations? Is it possible that this value is an anomaly? And what are the implications of this? From your profile, and from the range of the other samples I guess that this is an outlier for both NOx and Si, with the NOx harder to explain from environmental processes. If this is an outlier, I think the calculations throughout need amending or flagging to reflect this, noting that there is a large difference depending on whether or not this data point is included.

291 "N:P ratios were generally highest. . ." Somewhere it would be interesting to comment on what drives this trend? Is it a source of N, or a sink/dilution of P? If saline water inflow dominated the N and P supply, would you expect such strong shifts? I suspect you need some sort of local process leading to a net accumulation of N or loss of P to get these ratios (you do comment on this for NH4 briefly), and whilst there are no other spring studies I can think of looking at this, I think a few papers have commented on some not particularly well explained P loss in similar environments in summer 5,6.

300 "Nutrient versus salinity profiles give indications of the endmembers (sources) of the nutrients (Fig. 5). A positive correlation for example would indicate conservative mixing (assuming high salinity Atlantic water endmember had higher concentrations than melt water). Biological uptake and remineralisation as well as physical processes, such as external inputs by meltwater could inverse or eliminate the correlation." This isn't quite right and needs a bit more clarity, you will find a lot of literature on this in marine chemistry or in a good textbook. In simple terms, a linear correlation shows conservative mixing, the absence of a non-linear correlation suggests non-conservative processes (although there are some subtleties to this, some physical factors can also lead to non-linearity). The gradient, not the strength of the correlation, indicates whether fresh, or saline, endmembers have a higher concentration, i.e. an increasing nutrient concentration with salinity (positive gradient) suggests saline inflow has higher nutrient concentrations, whereas a decrease with salinity suggests (negative gradient) a higher

freshwater concentration.

310 “The contribution of nutrients by upwelling as well as freshwater inflow from glacial meltwater was estimated by linear mixing calculations”. Can you show these, maybe in the supplement, I am a little confused mainly because of the unclear description above. Similarly for the % nutrient values, please clarify how these were calculated and consider the error on them – especially if it is the case that the single SG value with very high NOx and Si is basically dominating the trend and an outlier.

333 Can you clarify what you mean by the vertical export of Chl a and how this was calculated please

462 These values are hard to compare as written because the first (250-500) refers to the vertical plume volume, whereas the second (1.1) refers to the volume transport over the fjord surface, with different units and spatial scales, it would be better to calculate a set of numbers with the same units for comparison.

462 ‘careful’ implies errors/uncertainties are quantified, at the moment I would say it was a little crude.

465-468 There are 2 sentences here basically saying the same thing

469 ‘depth of glacier front’ it would be better to cite the physical studies which specifically show this rather than a review

470 It would be useful to mention the grounding line estimate earlier in the text

486 required for photosynthesis or something more specific (primary production can occur in the dark)

519 Yes I would agree, but I don’t think the review cited explicitly shows this. You can however find a lot of work that suggests most of the Arctic is basically nitrate limited based on observed macronutrient distributions in summer7, and I think this has been explicitly tested closed to Svalbard showing no significant effect of Fe additions8.

520 I’m not sure what you mean by nutrient concentrations are higher at shallower depths, something due to relatively more evident benthic input as you mentioned for NH4 briefly?

523 As above, I think this is not quite right. Non-conservative silicic acid behavior (but conservative N/P behavior) would suggest glacier associated input from dissolution of glacier-derived particles either directly into the water column or from sediments into the water column, although conservative silicic acid behavior is also equally often observed downstream of glaciers so this is not really a clear universal meltwater signature9. I think the only generalizations you could make would concern concentrations that melt is generally expected to be a low or not significant source of nitrate/phosphate, and a more important source of silicic acid, see Ref1 and the supplement for a summary.

530. I’m not sure these values are low compared to Greenland work if you compare to the dissolved values in freshwater. See the supplement for Ref for a summary1, I suspect if you calculate mean/median for data available for Greenland or Svalbard your values are likely not atypical (for silicic acid especially, I think the mean and range is high because 1 or 2 catchments have exceptionally high concentrations, but median concentrations are likely a few micromolar.) Note spelling Hawkings (I assume).

533 This is curious, do you have any idea why? Based on the Ref10 cited, this source would be expected to be quite large (i.e. silicic acid entering solution from glacier derived particles) compared to direct glacier inputs of dissolved silicic acid, but I’m not sure how much evidence there is for this, elsewhere around Svalbard I think the same summary can be made as herein that there doesn’t seem to be strong evidence for a significant silicic acid source from glacier sediments6.

534 Besides. . . This is repetition, I don’t think it’s particularly controversial to assume NOx as the limiting nutrient in this environment11,12, I think a very brief comment about Fe would suffice, there is more than ample evidence for really high Fe inputs in and around Svalbard13,14 and low nitrate levels through most of the growing season.

539 Given the lack of relevance for atmospheric inputs to under-ice blooms, I don't think you need to discuss this, unless you are writing about incorporation of such nutrients into sea-ice

549 I'm not sure which value in the cited review you're referring to here, it would be more useful to cite the specific studies that measured primary production (there are many studied on primary production for Svalbard including values specifically for spring which are presumably the best comparison)12,15,16.

570-575 As written this is fine, but please note I think the 'seed' hypothesis specifically referring to inner-fjord communities seeding outer-fjord/shelf areas is not particularly well supported by literature, especially since in the context of sea-ice covered fjords, I think the bloom generally occurs earlier outside the fjord than it does inside (I'm not sure if that is the case here). Elsewhere on seasonal timescales there is evidence of marine inflow changing the in-fjord bloom and not really of the opposite17,18.

585 These are averages you're referring to? It may be worth commenting on the variability, I expect there's a huge range when you're writing about all Arctic glacier-fjords

589 'limited by phosphate' do you actually show this, or do you mean than based on measured concentrations, there was a deficiency of phosphate?

595 This appears very speculative, because I think you are comparing broad regional averages to a spot measurement?

599 -8.3 above average doesn't make sense

644 Here, in this section, I think you need to consider where sea-ice cover occurs and also how that and the timing of its breakup may also change in the future.

650 "the seed material from the deeper sediments would not reach the water column, leading to a reduced and delayed phytoplankton summer bloom" Whilst I've read this hypothesis in a few places, I'm not sure there's much evidence for this, can you cite studies specifically showing this does affect the summer bloom?

650-660 There are a lot of ideas in these paragraphs which are not extensively developed. I think it would be good to either develop these a bit more, or remove them. For the later comment, Holding et al., is probably the best ref I can think of – you also need to think about stratification19 if you want to write about changes in summertime, but I generally suggest you cut this given the spring focus of your manuscript. The writing concerning spring is much better developed and the comments concerning changes in summer bloom lack discussion of the many factors (changing discharge, stratification, circulation) that change seasonally and are generally beyond the scope of the manuscript.

In your comments about how significant/important this process is, maybe you could think about how it works with respect to the availability of nutrients and timing. If I understood correctly, the entrainment occurs from only 20 m depth, so if it started slightly later in the season it would be presumably much less effective as nitrate would already have been drawdown and meltwater would just be mixing into an already nutrient deficient top 20 m layer? Presumably this means the relative timing of bloom onset, and early discharge is an important feature to think about in determining when/when this is important? (And, also sea ice break up, the dates of which presumably are also changing?)

Data files: These are generally well organized but I could not find the nutrient data in the file which the readme says it is in, did I miss something?

Fig. 3 The blue line doesn't quite display properly in my version

Fig. 4 There are a couple of suspect anomalies here, along the line that represents the ice boundary there are a few nutrient concentrations that appear well above the trend for either ice or water column concentrations, are you sure these are real?

Fig. 5 As in text, the description of 'conservative mixing' isn't quite right. "Conservative mixing shows as a positive correlation, non-conservative mixing as a negative correlation". The strength of the correlation indicates roughly how conservative it is. The sign of the gradient indicates whether the concentrations are increasing or decreasing with salinity i.e. whether freshwater or saline water has the higher concentration. It would be useful to have the actual p values written somewhere.

Fig. 6 This took a while to read, there are a lot of abbreviations.

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