

## ***Interactive comment on “Arctic (Svalbard Islands) Active and Exported Diatom Stocks and Cell Health Status” by Susana Agustí et al.***

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Actions taken to accommodate the comments of reviewer #1.-

Reviewer#1- The manuscript describes the health status of diatoms during the course of the bloom in the Arctic. The main finding is that when diatoms are dying they sink out of the photic zone. Two main types of results are described here. First a clear and complete description of the diatoms in 8 stations around svalbard, and second an experiment testing the decay of diatoms in the dark, while comparing the sinking of living versus dead diatoms. While I feel that these data are very interesting, the findings are not new and should have been presented with others in order to give a valuable manuscript.

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Authors: We thank you the reviewer for the useful comments and the time devoted to revising the manuscript. We carefully followed the reviewer's comments to improve the revised manuscript. We added more data to the manuscript as detailed below, which are now shown in the Table and in three new plots. We agree that our results are relevant, as indicated by the reviewer, but also wish to point out, that they are also original and new, as clearly stated also by Reviewer #2. There are no similar data published before, so the novelty of the results presented cannot be disputed. Whereas the patterns found here could be hypothesized or expected, such expectations cannot replace empirical demonstrations or observations. During the cruise, we used a new oceanographic device, the Bottle-net, which we described in a recent paper (Agusti et al. 2015, Nature Communications), that allows sampling of microplankton at the desired depth layers. Indeed, the system used here is advanced relative to that used by Agusti et al. 2015, and allowed sampling strategies that were not possible with the original system. Hence, no data similar to that presented here has been reported anywhere for the ocean (neither the Arctic nor anywhere else). We used this new device to sample the phytoplankton populations present in the photic and aphotic layers, separately. We obtained fresh samples from below the photic layer, and from the photic layer, and were able to test the cell health status of the cells at both layers. The number of studies quantifying diatoms health cell status of natural samples remains minimal, particularly for populations below the photic layer, which have never before been reported for the Arctic Ocean.

Action: We followed the reviewer's advice and added more data to the revised manuscript: -We included data of the upper mixed layer depth (UPM), as suggested by the reviewer, to improve the description of the environmental conditions. In pg. 3, lines 8-10, methods section we indicated: "We calculated the upper mixed layer (UPM), an index of the stability of surface water column, as the shallowest depth at which water density ( $\sigma_t$ ) differs from surface values by more than 0.05 kg m<sup>-3</sup> (Mura et al. 1995)". In pg. 5, lines 5-17, we added information about the UPM in the results sections, together with other environmental parameters: "The stations sampled en-

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compassed a broad diversity of conditions, including a station where the spring bloom had not yet occurred (station 4, off the Western Svalbard shelf), as indicated by low diatom stocks and high dissolved inorganic nutrient concentrations (photic layer concentrations  $\text{Si(OH)}_4 = 4.15 \pm 0.04 \mu\text{mol Si L}^{-1}$ ,  $\text{NO}_3 = 9.43 \pm 0.09 \mu\text{mol N L}^{-1}$ , Table 1) with lower stratification (Table 1). All other stations sampled were characterized by comparatively depleted nutrient concentrations (photic layer concentrations  $\text{Si(OH)}_4 = 0.99 \pm 0.30 \mu\text{mol Si L}^{-1}$ ,  $\text{NO}_3 = 1.93 \pm 0.76 \mu\text{mol N L}^{-1}$ , Table 1), thereby representing communities that were either in advanced blooming stages or were senescent after blooming. Stations 6 (SW Svalbard shelf) and 8 (E Svalbard shelf) supported actively blooming diatom populations, with the highest chlorophyll a concentration ( $10.5 \mu\text{g Chl a L}^{-1}$  for station 8), and a large fraction of living diatom cells (about 70%, Table 1). Both stations showed the highest stratification among the stations sampled, as indicated by their lower UPM values (Table 1). In contrast, Station 9 (Polar Front) supported a senescent diatom population in post-bloom phase, as indicated by depleted nutrient pools and a low percentage of living diatom cells (46.0 %, Table 1). The highest mixing was observed at the station sampled at the Barents Sea (Table 1).”

-We added a new Figure (now Figure 4), to the revised manuscript where we show the composition of the diatom community in the photic and aphotic layers. In pg. 5-6, lines 33-38, 1-4, we indicated: “The diatom community at the beginning of the cruise was dominated by *Fragilariopsis* spp. and *Chaetoceros* spp., and changed at stations 6-7-8 to communities dominated by *Fragilariopsis* spp. and *Thalassiosira* spp. that dominated the biomass where the largest diatom bloom was found (station #8, Fig. 4). Community composition changed at the Polar Front and Barents Sea stations (Fig. 4) with a larger contribution of *Navicula pelagica* (included in “Other”, Fig. 4). The diversity of the diatoms found at the aphotic zone differed in several stations from that found at the photic layer (Fig. 4). The large celled *Thalassiosira* sp. colonies dominated the aphotic community in several stations although they were not dominant at the photic community (Fig. 4). At station #4, the community sampled was more diverse at the aphotic than at the photic layer (Fig. 4) indicating high sinking despite the low biomass.”

- We replaced the old Figure 4 to now show two panels in the new Figure 5. Panel (a) shows the proportion (mean  $\pm$  SE) for the different diatom taxa of the water-column population stock found in the aphotic zone. Panel (b) shows the relationship between the percentage of living diatoms cells in the photic layer and the proportion of the water-column population stock found in the aphotic zone for all the dominant taxa. The new figure is more informative and more significant ( $p < 0.001$ ) than the previous one showing mean data values, which aggregated variability among populations. - In pg. 6 lines 4-16, in the results section, the revised text was modified to describe the new results shown, as follows: “The stock of diatoms that had sunk below the photic layer comprised, on average,  $24.2 \pm 6.7$  % of the total water column stock, with this fraction ranging considerably between groups (Fig. 5). The proportion of biomass of the large celled *Thalassiosira* colonies that had sunk below the photic layer was the largest, and that of *Chaetoceros* spp. the smallest (Fig. 5). Station #4 in pre-bloom status showed the largest proportion of the biomass below the aphotic layer and station #8, supporting the largest diatom bloom, the lowest. At station #8, however, the population of the dominant *Thalassiosira* species contained 54.8 % of living cells and was paralleled with a significant contribution of dead cells at the aphotic layer (Fig. 4), suggesting the initiation of the collapse of the bloom, despite the considerable biomass standing in the photic layer. Similarly, *Fragilariopsis* senescence at station #3 (only 35.1 % of cells were alive at the photic layer) helps explain its larger contribution at the aphotic zone (Fig. 4). There was a significant negative relationship between the percent of the diatom stock population that had sunk below the photic layer and the percent of living cells in the photic layer ( $R^2 = 0.39$ ,  $P < 0.001$ , Fig. 5b), indicating that healthy, actively growing populations largely remain on the surface, whereas senescent ones sink out of the photic layer. “

Reviewer#1- The discussion is a little weak and rely a lot on the paper by Krause et al. For example, the discussion starts saying that diatoms in Arctic are limited by silicates and that silicates depletion is the driver of diatom death and sinking which is a result from the study by Krause et al. 2018. Why didn't you use the results of this study

regarding the survival of diatoms in the dark? Can't it be one of the trigger if the mixing increase? The paper states that the average life of the diatoms in the dark is slightly superior than a day. In this part of Arctic I guess that there is strong mixing. How long are the diatoms kept in darkness due to mixing? The data from station 9 (polar front) showed indeed that there is an effective mixing (similar diatom concentrations and % of living cells in photic and aphotic samples), however, the % of living cells is still high. How do the authors explain that?

Authors: We revised and implemented the manuscript and the discussion in the aspects indicated by the reviewer. However, Krause et al. (which includes all of us), did not conclude that "silicates depletion is the driver of diatom death and sinking", simply because diatom death was not measured or reported in the experiments reported in Krause et al. [which were conducted at different stations as those reported here]

Actions: The actions made to improve the manuscript discussion included: - Mixing conditions, as UPM included in Table 1, are now used to interpret and discuss the results at the different stations. However, mixing was not as high as suggested by the reviewer as the UPM ranged from 3 m at station 8, to 75 m at station 10. In contrast to the Southern Ocean, where mixing depths often exceed 100 m, the sector of the Arctic where we worked is characterized by shallow UPMs, as the water column is often established by ice melting or density differences between Arctic water and the underlying saltier Atlantic water. Hence, the average UPM across the study was 32.7 m, which did not extend significantly below the photic layer (average photic layer depth 40 m), implying that cells being mixed within the UPM largely experienced photic conditions. - Station #9, at the polar front, showed, however, a moderate UPM of 35 m, so we could not relate the % of living cells observed in the two layers (photic and aphotic) to mixing below the photic layer. We can however relate diatom sinking at the polar front to the bloom-stage, and to the limitation by nitrate and Si. We now include in the discussion the statement (pg. 7 lines 18-21): "A post-bloom situation was identified at the polar front community, with similar percentages of living cells at the photic and aphotic zones as a result of high sinking induced by Si and nitrogen limitation." - In re-

lation to the dark experiments, Reviewer #2 noted that the experiments did not include a light treatment, so we could not extrapolate the decay rates solely to darkness. In the revised manuscript, we indicated that those experiments are representative of the environmental conditions in the aphotic layer, i.e darkness and other conditions, and the experiments are now referred as “aphotic conditions” instead of “darkness” alone.

Reviewer#1- The different stations are ideally located and sampled to describe the diatom bloom from the initiation to the decline, but these could be more interestingly discussed in the paper. What can be brought to light from the results of this paper? What is the bloom status at each station at the sampling time? this could be a lot more discuss using diatom cell concentrations in photic and aphotic zone, % of living cells, nutrients concentrations.... How are the nutrient concentrations compared to the winter concentrations ? that may give an idea of the bloom advancement. How is the bloom terminate? Authors: We revised this aspect in the discussion. In pg. 7 lines 10-20, the new paragraph reads: “Quantification of the % of living cells helped identify the different stages of the arctic spring bloom at the stations sampled. A pre-bloom situation, characterized by low cell abundance and a small percentage of living cells, was found at station #4, located further west off Svalbard Islands, where silicic acid and nitrogen concentrations were high and the UPM was deeper than in other arctic stations. The healthiest diatom community was observed at station #5, where the high stratification and Si(OH)<sub>4</sub> concentration above the half saturation constant (K<sub>s</sub>) of 2 μM (from kinetic experiments in the same region by Krause et al. 2018) helped the diatoms support active growth. The highest cell abundance was observed at station #8, but the lower % of living diatoms and the Si(OH)<sub>4</sub> concentration well below the K<sub>s</sub> value indicated that the bloom was reaching the maximum capacity, although diatom sinking was still low. A post-bloom situation was identified at the polar front community, with similar percentages of living cells at the photic and aphotic zones as a result of high sinking induced by Si and nitrogen limitation.”

Reviewer#1- Why these data are not in the paper by Krause et al if it uses so much

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of the conclusions issued from it? Alone I feel that these data even if very interesting are too poor. Authors: In the manuscript, we reported original data based on the new methodology, and both the goals addressed and the results obtained are not the same as those described on the manuscript by Krause et al. As indicated above, we included more data in the revised manuscript and we followed the reviewer suggestions and improved the discussion to deviate from Krause et al. manuscript discussion on Si limitation. Note, that the stations sampled in Krause et al. and those we sampled often did not match due to operational limitations of cable time and water budgets available, so Krause et al. used a sampling and experimental strategy completely different from that used here (as well as variables and processes resolved). Hence, any attempt to combine Krause et al. results, which focus on Si uptake kinetics resolved through experimental additions of Si, with those presented here would have been lead to high inconsistencies. We used the conclusions by Krause as a starting point, whereas our conclusions are self-standing and do not depend on results presented in Krause et al.

Action: As indicated above, we added more data and detail on the community composition described in three new plots (new Figs 4 and 5).

Reviewer#1- What are the limitations there? Why do the authors state that there is only silicate limitations and not nitrate while nitrate are also very depleted in some zone (station 6, 7 and 8) Authors: We revised the manuscript to increase clarity on this aspect. The high requirements of diatoms for Si imply that silicon limitation could led to diatom bloom collapse before nitrogen would be exhausted. Kinetic experiments by Krause et al 2018), indicated that the half saturation constant ( $K_s$ ) of  $\text{Si(OH)}_4$  was above of  $2 \mu\text{M}$  (from kinetic experiments in the same region by Krause et al. 2018) for most communities which was above the  $\text{Si(OH)}_4$  concentration in the water. In any case, we revised this aspect in the manuscript because other drivers, as mixing and other nutrients (nitrogen), would contribute to the variability described in the study, and we now acknowledge the role of depleted nitrate pools as well. Action: The actions made included: -In the abstract, pg 1, lines 35-37. We corrected the paragraph that

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now reads: “The results conform to a conceptual model where diatoms grow during the bloom until resources are depleted, and support a link between diatom cell health status and sedimentation fluxes in the Arctic”. - In pg 7 lines 18-20, we modified the paragraph as follows: “A post-bloom situation was identified at the polar front community, with similar percentages of living cells at the photic and aphotic zones as a result of high sinking induced by Si and nitrogen limitation, as suggested by the lower Si(OH)<sub>4</sub> KS of 0.8  $\mu$ M (Krause et al. 2018). “ -pg 7, lines 24-30. We modified the paragraph at the end of the discussion as follows: “When compared across the contrasting stages of bloom development represented in the data set analyzed here, the results presented conform to a conceptual model where nutrients, including Si (Rey 2012; Krause et al., 2018), and mixed layer drives the growth of diatoms during the Arctic spring bloom (Wassmann et al., 1997; Reigstad et al 2002). For diatoms, Si depletion results in two potential physiological issues: yield limitation (i.e. diatom standing stock is too high to be supported by the available silicic acid) and intense kinetic/growth limitation (i.e. depleted silicic acid silicic acid limits diatom Si uptake to such a degree that growth must slow, Krause et al., 2018)”.

Reviewer#1- It would have been great to discuss them in light with production rates, limitations or sinking fluxes of bSi or POC from sediment traps data. Authors: We agree that these comparisons would be relevant, but despite our great interest, these data sets did not match due to logistic requirements of the operation of the Bottle-nets and CTD sampling and sediment trap operations, so these data sets are largely disjoint for the cruise, with measurements conducted in different stations. This is, as explained above, one of the rationales why these results and those reported in Krause et al. (2018) could not be integrated onto a single paper. For example, the number of sediment traps deployed was low, only two of them were deployed in the same area sampled by Bottle-Nets (Hornsund and Erik Eriksen strait), but not at the same position and were deployed on a Lagrangian, drifting, mode, with the depths of deployment more shallower than the stations, further offshore, where bottle nets were deployed. In any case, in the revised version we now refer to results obtained by the sediment traps

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deployments during the study (reported in Krause et al. 2018).

Action: In the revised manuscript, at pg. 7, lines 20-23 we added the following paragraph: “The diatom community captured by the bottle net below the photic layer was consistent with the limited but comparable data obtained with results obtained from sediment traps deployed in the area, which also indicated *Fragilariopsis* and *Thalassiosira* species to be the dominant contributors to Si and biomass export (Krause et al. 2018). “

New references: Mura, M.P., M. P. Satta and Agustí, S.: Water-mass influences on summer Antarctic phytoplankton biomass and community structure, *Polar Biology*, 15 (15-20), 1995.

Reigstad, M., Wassmann, P., Riser, C. W., Øygarden, S., and Rey, F.: Variations in hydrography, nutrients and chlorophyll a in the marginal ice-zone and the central Barents Sea, *J. Marine Syst.*, 38, 9–29, 2002.

New Figures are copied below

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Interactive comment on Biogeosciences Discuss., <https://doi.org/10.5194/bg-2018-459>, 2018.

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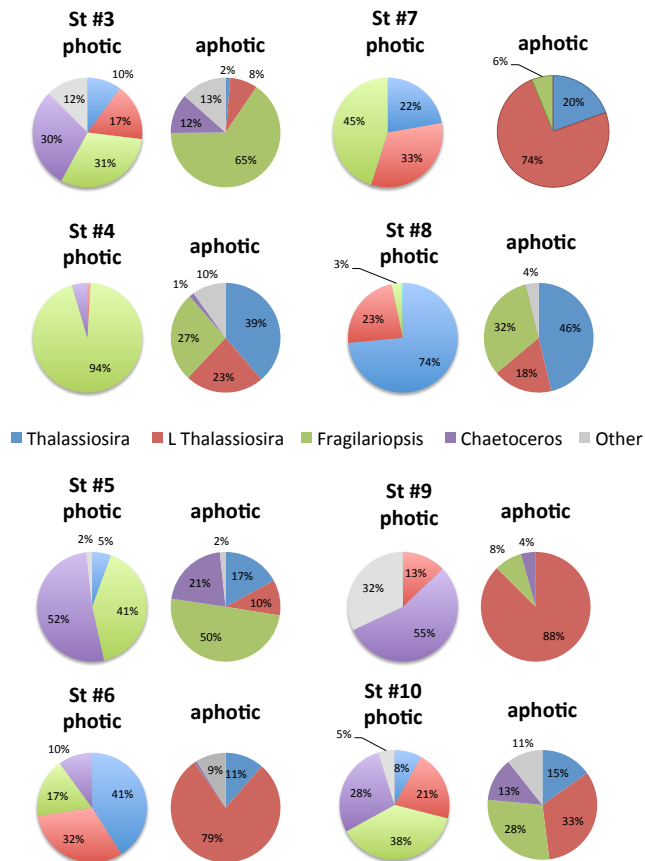
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**Fig. 1.** New Figure 4: Pie charts showing the diatom community at the photic and aphotic zones. The colors correspond to different taxa

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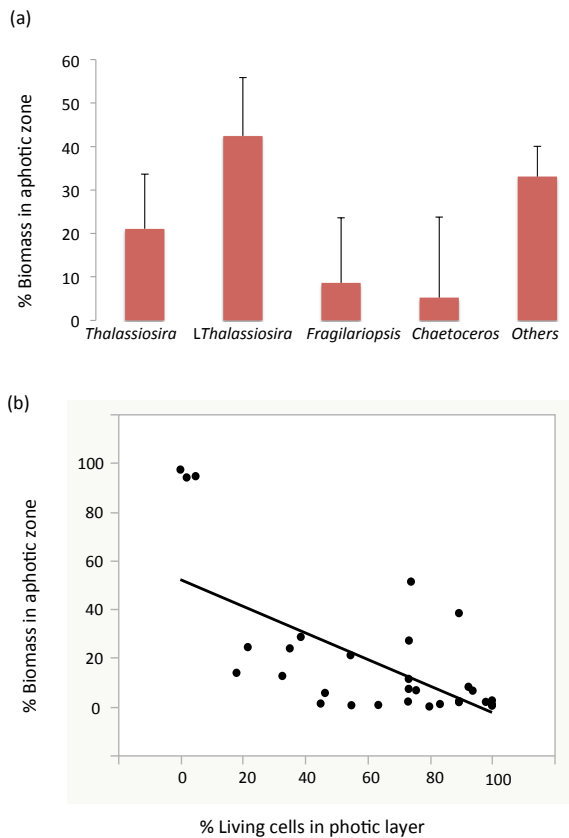


Fig. 2. New Figure 5: with new plots (a) and (b)