

Interactive comment on “Photosynthetic production in the Central Arctic during the record sea-ice minimum in 2012” by M. Fernández-Méndez et al.

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The authors would like to thank Referee #2 for the kind words and the useful comments that will improve the manuscript. Please find below the comment followed by our answer starting with an “A:”

General comments

The manuscript presents a comprehensive view of primary production (PP) in the Central Arctic Ocean. This study provides measurement of PP during August and September 2012 for sea-ice, melt ponds and water column. The authors suggest that sub-ice algae are an important component of total PP and may represent up to 60% of the

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Central Arctic PP. Overall, this manuscript is of high quality, well focus and its content is scientifically truly relevant. As acknowledge by the authors the Central Arctic is one of the least-well understood regions of the world, partly due to its remote and extreme environment which made it barely inaccessible. Therefore, this manuscript, as a part of a larger scheme, is leading to a better understanding of regional and temporal this remote area. The authors are also using complementary approaches in order to assess the impact of a decreasing ice-cover environment, but they could go further with these approaches. I also have minor comments about the manuscript (list below). Nevertheless, I'm confident that the manuscript, after revision, will make a significant contribution to the field.

A: Yes, we would have liked to expand our model calculations to an entire season, but we decided not to do it as we are aware of the high seasonal variability of photosynthetic parameters and biomass concentrations for which no data is available. We hope to improve the model and its predictive power in the future by adding seasonal data from sea-ice algae and phytoplankton.

Specific comments

Abstract

P. 2898 L15 - What do you mean by “end of the season”. Please define the “season” here or in the introduction.

A: End of the productive season in the Central Arctic refers to August-September. This has been clarified in the text.

Introduction

P. 2901 L18-20 – These approaches should be more developed throughout the manuscript.

A: We added such information where necessary to explain each approach properly.

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Method

P. 2902 Section 2.1 – What were the sampling depth for the water in ice-free area? Is only one depth was sampled for PP measurement? What was the method use for the taxonomy data (or cited the study where these data where coming from)?

A: The sampling depth for the ice-free area was 2-5 m depth. The phytoplankton sampled at this depth is supposed to be representative of the phytoplankton present in the mixed layer (5-15 m during summer), so yes, only one depth was sampled and then incubated at different light intensities mimicking different depths. No real taxonomy data is presented in this study. The few descriptions of community composition are based on light microscopy as explained in 2907 L19-23.

Results

P. 2909 Section 3.1 – Is ammonia data are available from the cruise? It could be interesting to add ammonia data to the nutrient overview.

A: Unfortunately ammonia was not part of the main set of parameters measured, there are only a few values from samples of water below the ice at certain stations around 0.5, in rare cases 2 μM . Therefore, these data was not included in this manuscript. We do agree that it would be interesting to have full ammonia data for all stations and environments, but we did not have the manpower to complete them on board.

P.2910 L 1-6 – What is the criteria (concentration's threshold) used to determined nutrient depletion for nitrate and silicate?

A: Nutrient depletion is defined here as concentrations lower than 1 $\mu\text{mol L}^{-1}$ nitrate, 0.2 $\mu\text{mol L}^{-1}$ phosphate, and 1.5 $\mu\text{mol L}^{-1}$ silicate.

P.2910 L 15-25 – What is the sampling depth for “under-ice” and “ice-free” water phytoplankton?

A: 2-5 m depth for both. The exact depth depended on the station and is specified in

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the Pangaea dataset.

P.2911 L 6 – Why a depth of 25 m was chosen for the nutrient addition experiment?

A: Because the fluorometer of the CTD during the downcast showed that the Chl a max was at that depth.

P.2914 L 21-28 – Please elaborate here. The model proposed is really interesting, but it should be more developed in this section. Is it possible to assess the contribution of melt pond, sea-ice and under water to total PP with the model? Is the change in the dynamic of the ice cover lead to significant change in the contribution of each group?

A: Yes, in the previous paragraph we discuss the contribution of melt pond and sea-ice under sea-ice. These results are shown in Fig. S8 (Fig. 12 in the revised version).

P.2914 L 21, 25 and 27 – Please add absolute data to relative data presented here.

A: Table S2 containing the absolute data is now included in the main text as Table 5.

P.2914 L 26 – I understand that the ice-free scenario represent September 2050 conditions?

A: Yes, this has been added for clarification.

Discussion

P.2916 L 5-15 – I'm getting a bit lost in here. Please rephrase in order to clarify the meaning of these three sentences.

A: The sentences have been rephrased as follows to improve clarity: “If we assume that the sinking algae had previously contributed to NPP at the surface, and that they occurred throughout the entire Eurasian Basin north of 78°N (1.8x10¹² m²), the average 9 g C m⁻² (range:1-156 g C m⁻²) of sub-ice algae found deposited at the seafloor would have contributed an additional 16 Tg C to INPP. From the nitrate annual drawdown, we calculated a total carbon uptake of 17 ± 7 Tg C yr⁻¹ in the Eurasian Basin north of

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78°N. However, this calculation does not take into account lateral scavenging of nutrients by sub-ice algae such as *Melosira arctica*. Algal filaments hanging from the sea ice are transported along the Transpolar drift, from the Siberian shelves where ice is formed, to the Central Arctic Ocean. Hence they may have a better access to nutrients than phytoplankton. This lateral scavenging of nutrients by the sub-ice algae should be added to the nutrient drawdown calculated from vertical profiles. Accordingly, when adding the nutrients taken up by the sub-ice algae, the total new production could be $17 + 16 = 33 \pm 7 \text{ Tg C yr}^{-1}$ in the deep basins of the Eurasian Basin.”

P.2918 L 6 – What was the depth of the phytoplankton community sampled?

A: 2-5 m depth

P.2918 L 16 – What about ammonia?

A: See answer above

P.2921 L1-8 – Palmer 2011 (*Polar Biol.*, 34, 1915–1928) also observed that change in photosynthetic parameters can be very quick in the Arctic (within few days).

A: This is correct and has been added to the discussion.

P.2922 L 3-4 – Are you referring to the September 2050 model?

A: Yes. We made this more explicit in the text.

P.2922 L 1-17 – What about the September 1982 model? What is the response in PP to 1982 conditions? Plus, some references about effect of ice reduction on PP should be added and discussed in this section.

A: This section has been modified to add information about the 1982 model run. “The relationship between sea ice decrease and INPP increase also arises when comparing the model results of 1982 and 2012. In this case, for the entire Eurasian Basin, a 45% decrease in the ice cover leads to a doubling in the September INPP.” Also, more references, such as Kahru et al 2011, Ardyna et al 2014 and Bhatt et al 2014, have

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been added and discussed.

P.2922 L 18-21 – Why is the community will shift? Some more explanation are need to this conclusion.

A: The paragraph has been modified to explain this better. “The phytoplankton community will probably shift from diatoms towards small picoplankton due to the freshening of the upper layers (Li et al., 2009), especially in the silicate limited area of the Eurasian Basin, where small picoplankton is already present (Kilias et al., 2013) and would be more nutrient efficient at low silicate concentrations (Bhatt et al., 2014; Kilias et al., 2014; Li et al., 2009), with This shift in the phytoplankton community together with the disappearance of the sea-ice communities could have potentially detrimental consequences for the Arctic food web (Bhatt et al., 2014).”

P.2922-2923 Section 4.4 –There is also vertical variability to photosynthetic parameters in the water column. I think this should be addressed in this section. I also think that new versus regenerated production should be briefly discussed there.

A: The vertical variability of photosynthetic parameters both in the water column and in the sea ice is now mentioned in this section. A short discussion of new vs regenerated production has also been included: “In addition, nitrate vs ammonium uptake rates should be included in such studies to estimate the importance of new versus regenerated production at each period of the productive season (Dugdale and Goering, 1967; Tremblay and Gagnon, 2009). With our approaches, the in situ measurements in late summer were probably mainly measuring regenerated production, while the annual estimates of production based on nutrient drawdown is only taking into account the new production.”

Figures

Figure 1 – Please explain what the red number on figure is. The orange line is very difficult to see. A: The explanation of the red numbers is now explained in the figure

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caption and the orange line has been modified by a darker colour. Figure 5 – “Sea-ice” should be rescale in order to increase the contrast for NPP. The unit should also appear in the caption. The authors should add a note to notice the different scales with the panels. A: All changes have been done. Supplement Figure S7 – Maybe try a log scale in order to increase contrast. A: Since all other plots are in linear scale we decided to keep it consistent to avoid confusion. Figure S8 – The different scales are confusing. Please try something else (maybe log scale) or make sure to notice the reader about it. A: A note in the figure caption has been added.

Interactive comment on Biogeosciences Discuss., 12, 2897, 2015.

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