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Interactive Comment

Interactive comment on "Plankton ecosystem functioning and nitrogen fluxes in the most oligotrophic waters of the Beaufort Sea, Arctic Ocean: a modeling study" *by* V. Le Fouest et al.

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We gratefully thank referee #1 for her/his constructive comments with respect to our manuscript results, discussion and conclusion. In order to improve the manuscript with respect to these comments, we amended the manuscript as suggested by the referee wherever it was possible.

1. "A steady state approach is used, however no consideration is given as to whether the steady state is meaningful. It is achieved (if the axes on Figure 4 are correct) after 2-3 years of integration. Such a long time scale in a system with a strong annual signal means that the system never has a chance to reach or even approach it, if forced by

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the variable seasonal forcing! You initialise from observed distributions, so to make the approach valid you have to achieve near-equilibrium as soon as possible (ideally on a time scale of a month) with a minimum deviation from the initial conditions."

We introduced a discussion in the text as follows:

Page 14759 (line 3): "The coupled model was run in steady state mode so that the diffused state variables reached a near equilibrium state (Fig. 4) ("standard" run). Our steady-state approach was taken from the previous studies of Zakardjian and Prieur (1994, 1998). It aimed at using the best set of biological functions and parameters to get as close as possible from a theoretical equilibrium state of nitrogen fluxes between the biogeochemical compartments independently of the pre-set initial conditions. The ecosystem model tended towards this near equilibrium state given the imposed environmental conditions. The integration time required to reach such equilibrium in biogeochemical models is first dependant on vertical mixing and vertical velocities that constrain the timescale required for the numerical adjustment of the scalar gradients. Strong physical forcings (e.g. high turbulence or significant vertical velocities) lead to relatively short steady-state time integration (several weeks), whereas weaker forcings lead to longer steady-state time integration (several months). Initial conditions far or close to the final equilibrium state only affect the initial response of the model and the way the model reaches the simulation asymptotic. The present physical-biological coupled model was run for the summer period, when the water column at the Malina sampling site was highly stratified and, as a consequence, vertical turbulent fluxes were very low. This physical setting explains the relatively long time needed by the model to reach near equilibrium within the photic zone. The hypothesis stated is that the ecosystem would never be far from this near equilibrium state as the time scale required continuously changes in response the environmental conditions. Rapid environmental changes are generally driven by strong physical forcings hence implying a rapid ecosystem response. A contrario, highly stratified conditions as observed at the Malina sampling site generally result from physical processes associated to a time scale of several weeks and to which the ecosystem generally has enough time to adjust to. Finally, the initial conditions of the model were principally defined from observations, which the simulated steady-state did not depart too much from. This result supports the stated hypothesis of a near-equilibrium plankton ecosystem under vertically stratified conditions and slowly varying environmental conditions as observed during the Malina cruise. The model outputs at steady-state were then compared with the time coincident multiparametric measurements (10:00AM local time for all variables, except for downwelling PAR measured at 11:00AM local time) (Figs. 5 and 6). The profiles of measured NO3, NH4, size-fractionated Chl, PON, LZ and bacterial biomass used for the comparison were same as those used to initiate the model state variables. This approach permits to assess the model ability to reproduce the observed concentrations and rates."

2. "You can substantially shorten equilibration timescale if you sort out your LP-LZ-NO3 behaviour in the upper part of the water column. It appears that your large zooplankton grazing term does not work well at very low concentrations and need either adjustment of the parameters or even change of the functional form. I suggest that additional experiments to achieve steady non-zero level at the surface are needed."

To prevent large phytoplankton (LP) to depart too much from initial conditions and to tend towards near zero values, we slightly modified three biological parameters in equations related to the LP and large zooplankton (LZ) compartments. The grazing pressure on LP was decreased by assigning a lower Ivlev coefficient in the LZ grazing function (0.35 (mmol m-3)-1). The LP sinking rate was also reduced to 0.075 m-1, and the LP initial slope of the photosynthesis-irradiance curve set to 2 mgC (mgChl)−1 (Ein m−2 d−1)−1 in better accordance with surface measurements (2.2 mgC (mgChl)−1 (Ein m−2 d−1)−1). A non-zero steady state was achieved for LP at the surface, as well as an overall closer match with observations for all variables. New figures 4-6 are given in the file providing supplementary material.

3. "You are discussing *very* low concentrations near the surface. Are they above

BGD

9, C8429–C8434, 2013

detection limits? I would like to see detection limits and error bars for all measured variables."

We added standard deviations for measured variables for which replicates were available, i.e. for primary and bacterial production. For most of the remaining variables, we give in the text the coefficients of variation. We modified the text as follows:

Page 14756 (line 1): "Ammonium concentrations (NH4) were determined on board by fluorometer according to Holmes et al. (1999). Nitrate concentrations (NO3) were quantified at laboratory using an automatic colorimetric procedure (Raimbault et al., 1990). The coefficient of variation (CV) is 5% for both NH4 and NO3. Rates of primary production, NH4 and NO3 uptake (CV 20-25%), and NH4 regeneration (CV 20-25%) and nitrification were measured using a dual 13C/15N isotopic technique (Raimbault et al., 1999) applied during 24 hours in-situ incubation. Size-fractionated Chl concentrations measured during the Malina cruise following the methodology described in Ardyna et al. (2011) were used (S. Bélanger, unpublished data) (CV ca. 10%). Particulate organic carbon (POC) measurements (Doxaran et al., 2012, this issue) were used to compute POC:Chl ratios. Bacterial biomasses were derived from the product of the measured cell counts with the measured mean carbon content per cell (15.2 fg; Ortega-Retuerta et al., 2012a, this issue) (CV ca. 10%). Production rates estimated in pmol Leu L-1 h-1 were converted into carbon equivalent using a conversion factor of 1.5 Kg C (mol Leu)-1 (Kirchman et al., 2009)."

4. "You assume that the steady state can be achieved in the system ignoring horizontal advection. Arctic is a very "advective" system. Are you sure that your resulting ammonium concentration (triple of what was observed) is not an artefact of missing advection? You probably cannot constrain its effect, but at least some discussion on possible consequence of omitting advection should be presented."

We modified the text as follows:

Page 14759 (line 23): "The omission of lateral advection, which can be significant in late summer near the slope of the Mackenzie plateau (Griffith et al., 2012), and overestimated biological sources of ammonium from the ecosystem model likely explain the high simulated ammonium concentrations relative to measurements within the DCM."

Relatively minor points:

L3. "What are your evidence of "greater stratification" in the AO? This is a controversial topic. Retreat of the ice can promote both types of factors (increasing and decreasing stratification). Please substantiate."

We modified the text as follows:

Page 14753 (line 2): "In some areas of the Beaufort Sea, the stronger haline stratification observed in summer alters the plankton ecosystem structure, functioning and productivity promoting oligotrophy (Li et al., 2009)."

Page 14754 (line 2): "In the Hudson Bay, Foxe Basin, Baffin Sea, off the coasts of Greenland, in the Kara Sea and around Novaya Zemlya, earlier blooms are observed in response to earlier light exposure caused by sea ice retreat (Kahru et al., 2011). In some areas of the Beaufort Sea, the stronger haline stratification recently observed mediates the growing contribution of small phytoplankton cells to the planktonic community in summer (Li et al., 2009) suggesting oligotrophy is expanding in this part of the AO."

L25. "This is a very strong statement made on a basis of a single modelling example in the Bering Sea. A lot of effort has been made recently on modelling of AO production (see independent papers of the following authors: Jin, Zhand, Deal, Popova, Wassmann, Slagstad, Dupont). Such a criticism (even if correct) must be substantiated."

We modified the text as follows:

Page 14754 (line 9): "The ability of coupled physical-biogeochemical models applied to the AO to simulate realistic plankton dynamics and production rates relies on both the simulated physics (e.g. Popova et al., 2012) and elemental biogeochemical fluxes (e.g. Le Fouest et al., 2011). In summer, nutrients within the upper mixed layer are mostly issued from the remineralization of freshly produced organic matter. Hence biogeochemical equations driving the simulated elemental fluxes between the ecosystem compartments play a pivotal role. The representation in models of key biogeochemical processes and their comparison with measurements is generally limited in the AO by the lack of joint multiparametric measurements, especially nutrients turnover rates and light-related parameters."

Figure 3. "You are missing arrow between DON and NH4 (especially in a view of its importance!)"

The arrow has been added to Figure 3 given in the file providing supplementary material.

Figure 4. "Please show days instead of hours."

Figure 4 has been modified accordingly. It is given in the file providing supplementary material.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/9/C8429/2013/bgd-9-C8429-2013-supplement.pdf

Interactive comment on Biogeosciences Discuss., 9, 14751, 2012.