Biogeosciences Discuss., 4, S2696–S2702, 2008
www.biogeosciences-discuss.net/4/S2696/2008/

Biogeosciences Discussions

BGD

4, S2696–S2702, 2008

Interactive Comment

Interactive comment on "Influences of initial plankton biomass and mixed layer depths on the outcome of iron-fertilization experiments" *by* M. Fujii and F. Chai

M. Fujii and F. Chai

Received and published: 26 February 2008

First of all, the authors greatly appreciate the constructive review on our manuscript. We have revised our manuscript according to the reviewer's comments, which are described below. Especially we have focused more on the difference in the iron-induced biogeochemical responses between volume and area-based values (such as surface vs. column-integrated chlorophyll) in the revised manuscript.

Responses to general comments

Horizontal (Lateral) mixing or dilution: The authors consider that Tsuda et al. (2007) primarily emphasize great difference of initial zooplankton density between SEEDS and SEEDS II. On the other hand, as the reviewer pointed out several times (both in general and specific comments), difference in the horizontal mixing between the two experiments would be one of other important constraints as well. Although the horizontal mixing cannot be reproduced with a current model framework, we have just started to develop a 3D physical-biological model including explicitly iron cycling that can reproduce realistically the horizontal mixing and the limitation on the photosynthesis by iron concentration (e.g. Chai et al., in prep.). This issue should be solved in the future works, and this statement has been included in the revised manuscript as follows: "Presumably the lateral patch dilution is an important physical factor to control biological responses to iron-fertilization experiments (Assmy et al., 2007) and the effect is examined by using a 3D ecosystem model which can reproduce explicitly the lateral patch dilution (e.g. Chai et al., in preparation)."

Light limitation & Sverdrup: The authors have calculated critical depth (e.g. Sverdrup, 1953; Nelson and Smith, 1991) and found the depth always exceeds substantially the MLD in any cases of Experiment 1. Instead, the authors have compared compensation depth (CD), which is often defined as the depth at which the PAR is equal to 0.1∼1% of the surface PAR (1% in this study). The authors have added a new table (Table 2 in the revised manuscript) to clarify the difference between the MLD and CD. The CD is almost the same as the MLD in Case 1-5, and is shallower and deeper than the MLD in Cases 1-1 through 1-4 and Cases 1-6 through 1-7, respectively. This suggests that phytoplankton in deeper MLD cases (Cases 1-6 and 1-7) are exposed to the light limitation when they are pushed down to deeper layers by the vertical mixing. This statement has been included in the revised manuscript as follows: "The modeled compensation depth, defined as the depth at which the PAR is equal to 1% of the surface PAR, was calculated and compared to the MLD (Table 2). The compensation depth is almost the same as the MLD in Case 1-5, and is shallower and deeper than the MLD in Cases 1-1 through 1-4 and Cases 1-6 through 1-7, respectively. This suggests that phytoplankton in deeper MLD cases (Cases 1-6 and 1-7) are exposed to the light limitation when they are pushed down to deeper layers by the vertical mixing."

The authors have also examined a depth at which diatom grazing rate exceeds total diatom growth rate in Case 1. The model results have been added to Figure 6 ((h) and (i)) and to Table 2, with a paragraph in the text in the revised manuscript as follows: "The modeled diatom total growth rate was compared with the corresponding total diatom grazing rate by zooplankton (ZL and ZP) on the date when the maximum surface chlorophyll appears (Figure 6 (h) and (i)). The total diatom grazing rate by zooplankton has a similar vertical profile to the diatom biomass in any cases, because the grazing rate depends on the diatom biomass (Equation (2)). The total diatom grazing rate by zooplankton exceeds the diatom total growth rate below the depth of 47.5, 32.5, 27.5, 32.5, 32.5, 47.5, and 62.5m in Cases 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, and 1-7, respectively (Table 2). The depth is similar to the modeled compensation depth by 5m in any cases. The higher total diatom grazing rate by zooplankton than the diatom total growth rate means no accumulation or decrease of the diatom biomass at the depth, showing that the diatom growth is regulated by both light limitation and grazing pressure below the compensation depth even during the iron-induced diatom bloom prime, which is irrespective of the mixed layer depth." This result has also been summed up in Abstract and Concluding Remarks as follows: "The iron-induced diatom bloom is severely restricted below the compensation depth due to both light limitation and grazing pressure, irrespective of the mixed layer depth."

Program with Model Design: The reviewer is correct in pointing out the absence of the iron limitation below the MLD may lead to overestimation of the iron-induced primary production in the MLD. This issue is also to be solved in our forthcoming work (e.g. Sato et al., in prep.) by incorporating realistic iron cycling into our 1D and 3D models, and has been described in the revised manuscript as follows: "Notice this merely simulates the role of iron in SEEDS, whereas a dedicated sensitivity analysis to realistic iron concentration is the subject of ongoing studies (e.g. Sato et al., in prep.)."

Area vs Volume: The authors have added a sentence to the main text, emphasizing the importance of the export ratio (and the e-ratio, too) as column-integrated values,

BGD

4, S2696–S2702, 2008

Interactive Comment

as follows: "In assessing the efficiency of iron-fertilization experiments, how much the atmospheric CO_2 is absorbed by the ocean can be a good proxy, and therefore, we should pay much more attention to the export production to the deep water and the ratio of the export production to the net community production (e-ratio)." Following the reviewer's useful comment, the authors have examined column-integrated (area-based) biomass for any of three sensitivity studies, and have found that unlike the surface (volume-based) value, the column-integrated maximum appears with intermediate MLD cases. This is an insight that the reviewer has already anticipated but was not described in the previous manuscript and de Baar et al. (2005), either. The authors have mentioned about this result in Abstract ("The modeled column-integrated chlorophyll, on the other hand, is highest with intermediate mixed layer depth cases, suggesting difference in iron-induced biogeochemical responses between volume and area bases."), in the main text ("Although the surface values have their peaks in Case 1-1 (MLD=7.5m), some of the maximal column-integrated values appear with intermediate MLD cases (Figure 5-1). For example, unlike the maximum surface chlorophyll, the column-integrated chlorophyll is highest in Case 1-3 (MLD=17.5m) (Figure 5-1 (e)"), and in Concluding Remarks ("as is also suggested in this study that unlike the maximum chlorophyll, the highest column-integrated chlorophyll appears with intermediate mixed layer depth cases.") in the revised manuscript.

Other zooplankton studies: The authors found that the two papers introduced by the reviewer (Jansen et al., 2006; Schultes et al., 2006) are very interesting and important, because the papers suggest that the top-down (grazing) control on iron-induced diatom blooms occur relatively earlier than previously considered for cold waters. The papers have been cited and introduced in the main text of the revised manuscript several times.

Responses to specific comments

Bakker et al. (2005) has been cited as a reference for the CO_2 data in EisenEx.

As the reviewer points out, the water temperature in Experiment 1 was given so that

BGD

4, S2696–S2702, 2008

the temperature is uniform in the MLD and the heat content is conserved in the water column. This statement has been added to the revised manuscript.

PAR: Firstly, a sentence in Section 2 (Model Description and Experimental Design) “The MLD and the daily-averaged photosynthetically active radiation (PAR) **in the mixed layer** in a standard experiment are fixed at 12.5m and 75.1 [W m^{-2}] respectively, . . . ” has been modified to ”The MLD and the daily-averaged photosynthetically active radiation (PAR) **at the sea surface** in a standard experiment are fixed at 12.5m and 75.1 [W m^{-2}] respectively, . . . ”. As the reviewer figures out, the mixed-layer-mean PAR is used for discussion in Section 3 (Results and Discussion) and Figure 4 (c), which has been described in the revised manuscript. The PAR used for the comparison is that on the day when the iron-induced surface chlorophyll concentration is maximum, i.e., on Day 11, 12, 13, 13, 14, 16, and 18 in Cases 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, and 1-7, respectively. Following the reviewer’s comment, the authors have calculated the compensation depth and have discussed the difference with the MLD in the main text and in Figure 4 (c) (See also **Light limitation & Sverdrup** above).

In the previous manuscript, the biomass was in terms of nitrogen because nitrogen is a currency in the model and previous modeling studies using the same model have discussed the model results with nitrogen-based biomass. However, the authors now agree with the reviewer’s comment that the biomass may be better to be described in terms of carbon (definitely for growth rate in some figures), and therefore, nitrogen-based units have been converted to carbon-based units by being multiplied by the Redfield ratio of 6.625 in Table 1 and Figures 6, 7-1 and 7-2 in the revised manuscript.

Following the reviewer’s definite comment, Figure 6 in the previous manuscript has been removed.

Figure 6 in the revised manuscript: The day is when the iron-induced surface chlorophyll concentration is maximum, that is, on Day 11, 12, 13, 13, 14, 16, and 18 in Cases 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, and 1-7, respectively. The authors have clarified this by

BGD

4, S2696–S2702, 2008

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

adding a sentence to the revised manuscript as follows: "Figure 6 shows the vertical profiles of Terms 1, 2, 3, 4, and 5 in Equation (1), the diatom specific growth rate (equivalent to the product of Terms 1, 2, 3, and 4), and the diatom total growth rate (equivalent to the product of the diatom specific growth rate and Term 5), on the date when the maximum surface chlorophyll appears (on Day 11, 12, 13, 13, 14, 16, and 18 in Cases 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, and 1-7, respectively)." Similar description has also added to Figure 6 caption.

Other revisions

The following references have been added to the revised manuscript.

Assmy, P., Henjes, J., Klaas, C, and Smetacek, V.: Mechanisms determining species dominance in a phytoplankton bloom induced by the iron fertilization experiment EisenEx in the Southern Ocean, Deep-Sea Res. Part I, 54, 340-362, 2007.

Bakker, D. C. E., Bozec, Y., Nightingale, P. D., et al.: Iron and mixing affect biological carbon uptake in SOIREE and EisenEx, two Southern Ocean iron fertilization experiments, Deep-Sea Res. Part I, 52, 1001-1019, 2005.

Boyd, P. W., Jickells, T., Law, C. S., et al.: Mesoscale iron-enrichment experiments 1993-2005: synthesis and future directions, Science, 315, 612-617, 2007.

Jansen, S., Klaas, C., Kragefsky, S., Von Harbou, L., and Bathmann, U., Reproductive response of the copepod Rhincalanus gigas to an iron-induced phytoplankton bloom in the Southern Ocean, Polar Biology, 29, 1039-1044, 2006.

Schulters, S., Verity, P. G., and Bathmann, U., Copepod grazing during an iron-induced diatom bloom in the Antarctic Circumpolar Current (EisenEx); I. Feeding patterns and grazing impact on prey populations, Journal of Experimental Marine Biology and Ecology, 338, 16-34, 2006.

Table 2 has been created and added to the revised manuscript.

BGD

4, S2696–S2702, 2008

Interactive Comment

Interactive comment on Biogeosciences Discuss., 4, 4411, 2007.

BGD

4, S2696–S2702, 2008

Interactive Comment