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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

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. The authors found the reviewer's reference to Sverdrup's critical depth model very useful. More discussions about relations between the mixed layer depth and compensation depth (instead of critical depth) in terms of iron-induced diatom bloom regulation in deep layers (mainly light limitation vs. grazing pressure) have been added to the revised manuscript.

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Responses to general comments

Concentrations vs. stocks: The authors agree with the reviewer's suggestion that results should be compared not only with the concentrations (mmol m^{-3}) but also with the stocks (mmol m^{-2}). A couple of rates (primary production and export production) have been examined for all of three sensitivity studies and have been presented in the previous manuscript. 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, 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 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 comment, the authors have examined a column-integrated biomass stock for any of three sensitivity studies, and have found that unlike the surface concentration, 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 considerations."), 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.

A biological reason for bloom failure (also as a response to one of the reviewer's specific comments): The reviewer's reference to Sverdrup's critical depth model re-

minds the authors of calculating the critical depth (e.g. Sverdrup, 1953; Nelson and Smith, 1991) in this study. The authors have calculated critical depth 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 main 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."

Responses to specific comments

Zooplankton classification:

The ecosystem model used in iron fertilization model work was developed for the purpose of simulating the observed biological characteristics in the North Pacific, primarily focusing on two key plankton species, diatoms (PL) and diatom-grazing copepods with ontogenetic vertical migration (part of ZL). The model has been evaluated with the observed seasonal and interannual biogeochemical variations in this oceanic region by many previous modeling studies (e.g. Kishi et al., 2001; Fujii et al., 2002 and 2007; Yoshie et al., 2003; Yamanaka et al., 2004), and the observations suggested that copepods basically feed on diatoms when they are in the upper layers. The authors have kept the model structure and the parameter values to the same as used in Fujii et al. (2005) with which the model can reproduce realistically both seasonal characteristics and responses to the iron fertilization (SEEDS) of the biogeochemistry.

The reviewer is correct in recommending to separate diatom-feeding unicells (heterotrophic protests) from the diatom-feeding copepods. This recommendation is also justified by the observational result that heterotrophic dinoflagellates (HDF) *Gyrodinium* sp. phagotrophically feed on the diatoms up to 12 times their length during SEEDS (Saito *et al.*, 2006). However, such biological mechanisms have not been elucidated as sufficiently as to be incorporated into ecosystem models yet.

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The current model has three zooplankton functional groups. The model is categorized as one of the most sophisticated marine ecosystem models at present with regard to zooplankton functional groups. Recent marine ecosystem model inter-comparison project (in which the model used in this study is also involved) has revealed that models with sophisticated plankton functional groups can reproduce measurements better than more simplified ones, but at the expense of the model uncertainties and unconstrained parameters (Friedrichs et al., 2007). Therefore, the authors have chosen the existing zooplankton functional group configuration while still maintain defining characteristics. Considering the SEEDS observational results that reports copepods in the oceanic region feed mainly on diatoms (e.g. Tsuda et al., 2007), copepods have been kept to be included in the ZL. As for the case of HDF, we have put the diatom-grazing *Gyrodinium* sp. and a non-diatom grazing *Gyrodinium fusiforme* s.l. into ZL and ZS, respectively.

Absense of fast-growing species: The reviewer wonders if absence of fast-growing species such as Chaetoceros debilis in the SEEDS II water column was the reason why no bloom developed. The authors think this may affect the difference of iron-induced biological responses between SEEDS and SEEDS II, but may not act as a major trigger. Comparison of two modeling studies which applied a similar model to SEEDS between Fujii et al. (2005) and Yoshie et al. (2005) reveals that the model results can be more realistic by splitting diatoms into two species, especially for the start of iron-induced diatom bloom, but that the two results are qualitatively similar. From the observational point of view, Tsuda et al. (2007) consider that the absence of neritic diatoms had some effect on the responses in SEEDS II, especially the magnitude and timing of the bloom, but not enough to explain the differences. Therefore, so far the authors have kept a single diatom species in this study, but possibly multiple diatom species modeling will be preferable in future studies with more validation data for both phytoplankton and zooplankton.

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.

Figure 6 in the previous manuscript has been removed.

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

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Redfield ratio of 6.625 in Table 1 and Figures 6, 7-1 and 7-2 in the revised manuscript.

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

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