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Biogeosciences Discussions

Interactive comment on "Side effects and accounting aspects of hypothetical large-scale Southern Ocean iron fertilization" *by* A. Oschlies et al.

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We thank the reviewer for his very positive evaluation of our manuscript.

Response to point 1 (Marinov et al., 2006, biogeochemical divide paper):

Meanwhile we have performed a number of sensitivity experiments with simulated fertilization restricted to various surface density classes with the aim to isolate fertilization effects north and south of the biogeochemical divide. The results of these experiments will be discussed in the revised version of the manuscript.

Response to point 2a (seasonality):

A new figure will be added showing the seasonal cycle of surface nutrients in the control run and the fertilization experiment.

Response to point 2b (comparison of 10/day sensitivity study to standard model results of Sarmiento and Orr, 1991):

For about the same absolute reduction of atmospheric pCO2, the model of Sarmiento and Orr had to export more than 3 times as much organic carbon from the surface layer than the model used in our study.

Sarmiento and Orr initialized their model at pre-industrial atmospheric pCO2 of 280ppm and use a linear perturbation approach to compute the relationship between delta(pCO2) and delta(DIC) assuming equilibrium at pCO2=280ppm. One explanation for the differences in pCO2-sensitivity to changes in export production is the non-linearity of the marine carbonate system. To investigate this, we analyse a sensitivity experiment with a 10/day maximum growth rate mimicking iron fertilization in the Southern Ocean, but started at pre-industrial pCO2 of 280ppm (Oschlies, 2009, Biogeosciences, 6, 1603-1613, section 4.2, Fig.8+9), in contrast to the simulations of the current study that start in year 2010 at an atmospheric pCO2 of about 386ppm with rising CO2 emissions.

The sensitivity experiment started (with fully non-linear carbonate chemistry) at 280ppm showed an increase in cumulative export production of 484GtC during the first 100 years of fertilization. This fertilization-induced enhancement of export production is 27% higher than our value of 382GtC obtained by starting in year 2010 and with ocean circulation and export production slowing down because of global warming. The simulated fertilization-induced drawdown in atmospheric pCO2, however, amounts to only 32.7ppm over the first 100 years after fertilization was started at 280ppm, i.e. less than half of the 73.3ppm drawdown obtained when fertilization is started in year 2010. The magnitude of this difference is, at first sight, surprisingly large and can partly be explained by non-linearities in the carbonate system:

The ∼100ppm rise of atmospheric pCO2 since pre-industrial times has already increased the sensitivity of surface water pCO2 to changes in DIC by about 10% (Revelle buffer factor increase from about 10 to about 11 in the Southern Ocean) and is expected to rise more substantially under expected future CO2 emissions (Goodwin et al., 2007). As a result, any removal of DIC from the surface waters (e.g. by iron fertilization) generates an approximately 10% larger pCO2 drawdown today than it would have done under pre-industrial conditions. However, the same air-sea flux of CO2 (i.e. addition of DIC) also leads to a larger pCO2 increase when the Revelle buffer factor is larger. For complete gas exchange, the fertilization-induced carbon uptake should therefore be relatively insensitive to the background value of atmospheric pCO2. The situation is different for incomplete gas exchange due to a rapid subduction of unequilibrated surface waters (e.g. Ito and Follows, 2005), where a larger delta(pCO2) can lead to a larger CO2 uptake.

This is consistent with our observation that the model integration started at 280ppm has a much lower ratio of cumulative air-sea carbon flux to cumulative export production (Figure 9c of Oschlies, 2009), amounting to 0.32 in the fully coupled run and to 0.22 when the terrestrial vegetation was held constant (as implicitly assumed in the model of Sarmiento and Orr, which did not include vegetation). At the higher CO2 values used in the global warming run started in year 2010, this ratio is 0.44 (our Table A1). The same phenomena can presumably explain the lower pCO2 reduction in response to iron fertilization in experiment KVHISOUTH of Sarmiento et al. (2010), run at atmospheric pCO2 of 280ppm.

A rough (linear) estimate for a drawdown from 280ppm to 206ppm in the experiment started at 280ppm would require an export production enhanced by about 1085PgC, which is already close to the 1400PgC of the simulation by Sarmiento and Orr (1991). The remaining discrepancy can probably be attributed to the limitation of phytoplankton growth by light in our model and its absence in the earlier simulation by Sarmiento and Orr. Our model does not simulate any fertilization-induced export during the winter

season, whereas Sarmiento and Orr (1991) restored Southern Ocean surface nutrients to zero all year round. We expect the year-round enhancement of export production in the annual mean circulation and mixing field of Sarmiento and Orr to be less efficient in drawing down pCO2 than the enhanced export simulated by our model only over summer when mixed layers are relatively shallow and there is little sea ice.

In the revised version we will provide a more detailed discussion of both the sensitivity of the atmospheric pCO2 drawdown to the level of atmospheric pCO2, and also of the role of seasonality in our iron-fertilization experiments. This should help to further elucidate the difference with respect to the earlier simulations by Sarmiento and Orr.

oxygen changes already reported Sarmiento and Orr (1991)

Sorry for having overlooked this. In the revised version we will mention that an oxygen increase in thermocline waters had already been reported by Sarmiento and Orr (1991).

References:

- Goodwin, P., R. G. Williams, M. J. Follows, and S. Dutkiewicz (2007), Ocean-atmosphere partitioning of anthropogenic carbon dioxide on centennial timescales, *Global Biogeochem. Cycles, 21*, GB1014, doi:10.1029/2006GB002810.
- Ito, T., and M. Follows (2005), Preformed phosphate, soft tissue pump and atmospheric CO_2, *J. Mar. Res., 63*, 813–839.
- Marinov, I., A. Gnadadesikan, J. R. Toggweiler, and J. L. Sarmiento (2006), The Southern Ocean biogeochemical divide, *Nature, 441*, 964–967.
- Oschlies, A., (2009), Impact of atmospheric and terrestrial CO_2 feedbacks on fertilization-induced marine carbon uptake, *Biogeosciences, 6*, 1603–1613.
- Sarmiento, J. L., R. D. Slater, J. Dunne, A. Gnanadesikan, and M. R. Hiscock

(2010), Efficiency of small scale carbon mitigation by patch iron fertilization, *Biogeosciences*, *7*, in press

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