LIMITS OF IRON FERTILIZATION

Anand Gnanadesikan[1], John P. Dunne[1] and Irina Marinov[2]

1: *NOAA Geophysical Fluid Dynamics Laboratory, PO Box 308, Princeton, NJ 08542*
Anand.Gnanadesikan@noaa.gov, John.Dunne@noaa.gov

2: Department of Earth, Atmosphere and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, imarinov@mit.edu

ABSTRACT
Iron fertilization has been proposed as a cheap, controllable, and environmentally benign method for removing carbon dioxide from the atmosphere. While this is in fact the case in simple, 3-box models of the carbon cycle, more realistic models show that these claims fall short of reality. The fact that the efficiency of iron fertilization depends on the long term fate of the added iron and on the carbon associated with it makes tracking the effects of iron fertilization much more difficult and expensive than has been asserted. Additionally, advection of low nutrient water away from iron-rich areas can result in lowering production remotely, with potentially serious consequences.

INTRODUCTION
The idea of offsetting anthropogenic carbon dioxide emissions by fertilizing the ocean with iron has a number of superficially attractive features. A host of iron fertilization experiments have demonstrated that adding iron to surface waters leads to a local increase in productivity [see for example *Coale et al*., 1996]. Our own survey of the literature [*Dunne et al*. subm.] shows that this should be expected to lead to a local increase in particle export. It is claimed however, that this local increase in particle export would necessarily lead to an easily verifiable drawdown in atmospheric carbon dioxide. It is further claimed that the increase in export is controllable and environmentally benign, implying that the effects cease as soon as the fertilization stops. We show that while simple three-box models do exhibit such behavior, more realistic models do not.

MODEL RESULTS
We constructed a simple three-box model of the ocean circulation, similar to that developed by *Sarmiento and Toggweiler* [1984] with high and low-latitude surface boxes and a single well-mixed deep box. We added a simple model of the iron cycle to this model, such that the iron delivery determined the production. We found that the impact of adding iron in this model was very similar to that predicted by proponents of iron fertilization. Adding iron to the high-latitude surface ocean produced a pulse of production which drew down atmospheric CO_2, the effect of this lasted for a significant time, and remote effects were small.

However, when we make the model more realistic, the picture becomes less clear. Including the transport of nutrients from high to low latitudes results in high latitude nutrient depletion producing a significant drop in tropical production. Adding vertical resolution to the model results in making the sequestration of carbon strongly dependent on the vertical scale of remineralization.

DISCUSSION
The more complicated box model results move the box models towards more realistic general circulation model results. *Gnanadesikan et al.* [2003] suggest that the efficiency of fertilization is strongly dependent on the vertical scale of remineralization when iron is rapidly lost to the system. This implies that the impact of iron fertilization will not be easily verifiable. *Marinov et al.* [subm.] demonstrate that when iron fertilization is applied to the Southern Ocean, the result is a substantial drop in the productivity of the tropics and an increase in deep ocean anoxia. Both *Gnanadesikan et al.* [2003] and *Marinov et al* [2005]

suggest that the decreases in tropical production are large in comparison with the carbon sequestered by fertilization. In summary the complexity of ocean circulation means that iron fertilization is not controllable, benign or easily verified.

REFERENCES

Coale, K. et al., (1996) A massive phytoplankton bloom induced by an ecosystem-scale iron fertilization experiment in the equatorial Pacific Ocean, Nature, 383: 495-501.

Dunne, J.P., R.A. Armstrong, A. Gnanadesikan, and J.L. Sarmiento, (subm.) Empirical and predictive models of particle export, submitted to Global Biogeochemical Cycles.

Gnanadesikan, A., J.L. Sarmiento, and R.D. Slater, (2003) Impact of patchy ocean fertilization on atmospheric carbon dioxide and oceanic biological production, Global Biogeochem. Cycles, 10.1029/2002GB001940.

Marinov, I., A. Gnanadesikan, J.R. Toggweiler and J.L. Sarmiento (2005) The Southern Ocean Biogeochemical Divide, subm. Nature.

Sarmiento, J. L. and J. R. Toggweiler, (1984) A new model for the role of the oceans in determinine atmospheric pCO2, *Nature* 308, 621-624.