THE EFFECTS OF PATCH SIZE AND DURATION ON THE EFFICIENCY AND CONSEQUENCES OF IRON FERTILIZATION---RESULTS FROM AN EDDY-PERMITTING MODEL

X. Jin, N. Gruber, and H. Frenzel

IGPP & Dept. of Atmospheric and Oceanic Sciences, UCLA, Los Angeles, CA 90095-1567, USA; xjin@igpp.ucla.edu, ngruber@igpp.ucla.edu, and hfrenzel@igpp.ucla.edu

ABSTRACT

By coupling an ecosystem model to a Pacific Ocean setup of ROMS (the Regional Oceanic Modeling System) at eddy-permitting resolution and performing experiments in scale ranging from the patch size of *in situ* experiments to the several 100km size of coarse resolution models, we aim to establish a connection between large-scale global model studies and the many insights emerging from the very small-scale patch fertilization studies. Our research will be guided by three hypotheses, which state that the export efficiency of fertilization, i.e. the amount of carbon that is being exported from the surface ocean per unit of iron applied to the ocean, will depend critically on the size and duration of the experiment.

INTRODUCTION

Ocean iron fertilization has been considered as a means to enhance the net oceanic uptake of CO_2 from the atmosphere to slow down the buildup of CO_2 in it [see e.g *Buesseler and Boyd*, 2003]. Field experiments in which high iron concentrations are maintained in a relatively small patch of surface water have resulted in increases in biomass and drawdown of surface nutrients and CO_2 [Boyd et al., 2000]. Yet little is known about the increase in export and the net effect of the air-sea CO_2 flux [*Buesseler et al.*, 2004]. The sizes of these *in situ* experiments were small, typically 10 by 10 km, and they usually lasted only a few weeks. How can insights from these studies provide guidance for large-scale experiments? For example, in order for iron fertilization to have any substantial impact on atmospheric CO_2 they would need to be scaled up by a factor of at least 1000. Most fertilization experiments with models have been done at coarse resolution, creating a gap between *in situ* and global scale model studies. We plan to bridge this gap in our research. The efficiency of fertilization can be divided into two terms, one related to export efficiency and the other one related to CO_2 efficiency, where the first describes how much carbon gets exported per unit Fe applied, whereas the second one says how much atmospheric CO_2 changes per unit carbon exported. We will be focusing here primarily on the first part, i.e. export efficiency. Our studies will be guided by three hypotheses.

HYPOTHESES

Hypothesis 1: Mid-size patches will be most efficient at exporting carbon from the surface ocean in response to iron fertilization, as they are llarge enough to reach critical algal densities for algal aggregation to dominate the loss terms, but small enough to be efficient in entraining new nutrients laterally.
Hypothesis 2: Intermittent application of iron will be more efficient at exporting carbon than singular massive applications as the iron will be better retained in the surface ocean and because macronutrients will be resupplied more quickly.
Hypothesis 3: Differences in the export efficiency between different sites are primarily determined by differences in the available light, which, in the summer season, is mostly controlled by the depth of the surface mixed layer.

MODEL

In order to establish the connection between global-scale coarse-resolution studies and the many insights emerging from the patch-scale and short-term fertilization studies and to be able to compare and evaluate our results with the observations, we need to resolve the highly turbulent nature of the oceanic environment. As the resolution of global models cannot be increased much beyond about 1 to 2 degrees, and therefore stay well above the resolution necessary to resolve mesoscale phenomena, we instead use a high-resolution model. The modeling framework that we use is ROMS [*Haidvogel et al.*, 2000; *Shchepetkin and McWilliams*, 2005]. ROMS is configured for a whole Pacific domain (north of 45^{o}S). We performed calculations at intermediate resolution (0.5^o) over the period 1970-2000, using NCEP reanalysis surface forcing.

The ecosystem-biogeochemical model, based on the global ecosystem model of Moore et al. [2002], includes multiple nutrient limitation (N, P, Si, Fe), four phytoplankton functional groups (picoplankton, diatoms, coccolithophores, diazotrophs (*Trichodesmium spp.*), an adaptive zooplankton class, dissolved organic matter and sinking particulate detritus. Phytoplankton growth rates are limited by available nutrients, temperature, and light.

The diazotrophs get all required nitrogen from N_2 gas with growth limited at temperatures below 15^{o}C. Calcification is parameterized as a variable fraction of small picoplankton production. Iron is modeled explicitly with inputs from atmospheric dust deposition. The sinking of dust particles is modeled so that there is dissolution of iron below the surface as well. In order to facilitate our analysis, we add two additional tracers to our model. One is a passive dye tracer that is added as the iron is added. This tracer is analogous to the SF_6 tracers that is usually added in the experiments and permits us to track the dilution and expansion of the patch. The second tracer is a labeled iron tracer that permits us to track the fate of the additionally added iron.

An initial evaluation of the simulated fields with *in situ* and remotely sensed physical, biogeochemical properties suggests that the model captures the large-scale, time averaged pattern very well (e.g. see Fig. 1). The model also captures the structure and dynamical mechanisms of regional and mesoscale variability, for example, the upwelling system along the U.S. West Coast, which is not represented well in large scale global models.

EXPERIMENTS

Iron fertilization is simulated in the areas where *in situ* iron fertilization experiments have been conducted so far. These regions are the northeastern Pacific (SERIES experiment), the northwestern Pacific (SEED, the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study), and the eastern equatorial Pacific (IronEx I and IronEx II experiments). We undertake a series of patch fertilization simulations, ranging in size from those typical of field experiments (i.e. a couple tens of kilometers) to the size of grid boxes in large-scale coarse resolution GCMs (i.e. a couple hundred of kilometers) for each of these sites.

RESULTS

As the experiments are still running, we provide here only an outline of our planned analyses: In addition to addressing the three hypotheses that we put forward above, our analyses focus on the export efficiency. For example, how will the duration and size of the patch impact the export efficiency? Are the differences between different sites primarily determined by the depth of the mixed layer, i.e., by light limitation?

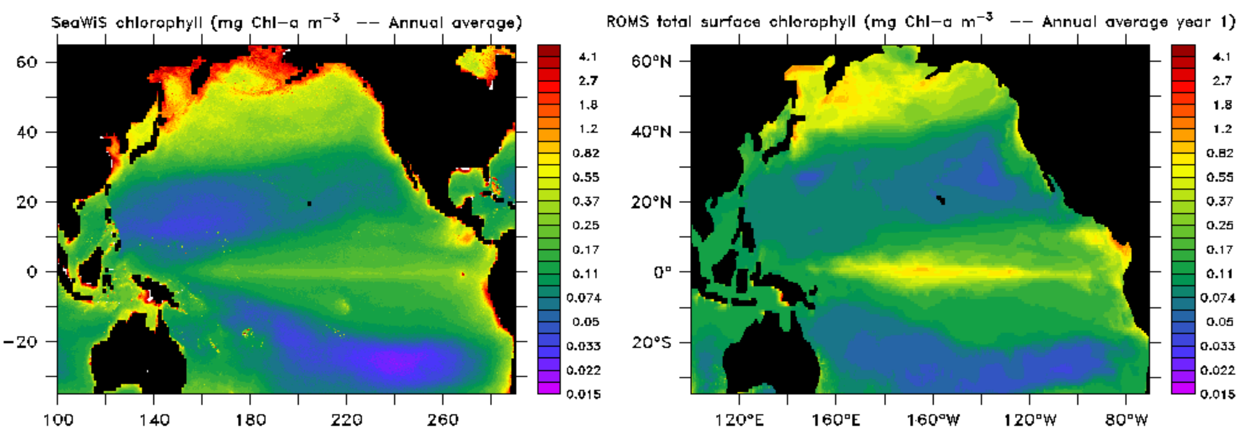

Fig. 1. A comparison of annual mean surface chlorophyll in the ROMS model and from remote observations with SeaWiFS.

REFERENCES

Boyd, P. W., et al. (2000), A mesoscale phytoplankton bloom in the polar Southern Ocean stimulated by iron fertilization, Nature, 407 (6805), 695-702.

Buesseler, K. O. and P.W. Boyd (2003), Will ocean fertilization work? Science, 300, 67-68.

Buesseler, K.O., et al. (2004), The effects of iron fertilization on carbon sequestration in the Southern Ocean, Science, 304, 414-417.

Haidvogel, D. B., et al. (2000), Model evaluation experiments in the North Atlantic Basin: Simulations in non-linear terrain-following coordinates. Dyn. Atmos. Ocean. 32, 239-281.

Moore, J. K., et al. (2002), An intermediate complexity marine ecosystem model for the global domain, Deep Sea Research II, 49, 403-462.

Shchepetkin, A. F., and J. C. McWilliams (2005), The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean Modeling, 9, 347-404.