1. Introduction

The global ocean ecosystem is controlled by biological production, which is governed by the physical constraints of temperature, light, and nutrient availability on oceanic phytoplankton. It is common to assume a single macronutrient as globally limiting, which makes it possible to build simple models that capture the major nutrient cycles surprisingly well. However, it has been shown that complex competition processes are at play in global biogeochemical cycles. For example, the existence of HNLC regions is attributed to iron limitation [e.g., Boyd et al., 2007; Landry et al., 1997]. To understand how the global ocean ecosystem responds to climate-driven changes in the iron supply, it is therefore crucial to have a model that couples the major nutrient cycles to the iron cycle. This allows us to investigate how the global-scale teleconnections of the marine ecosystem respond to changes in micronutrients under various scenarios.

2. The FePSi model

The tracer equations for the nutrient concentrations are given by:

\[ \frac{\partial N}{\partial t} + \nabla \cdot (r N - D \nabla N) = 0 \]

where

- \( N \) is the nutrient concentration in the model.
- \( r \) is the nutrient supply rate.
- \( D \) is the nutrient diffusion coefficient.

3. Climatological base state

Phosphate and silicate including, mismatch with observations

4. Aeolian iron perturbations

Phosphorus and opal export responses

5. Aeolian iron perturbations: Transient response

Response to sudden SO +1 perturbation

6. Conclusions

We constrained the biogeographical parameters of the coupled Fe, P, Si cycle using a numerically highly efficient inverse model to minimize the mismatch with observed concentrations and chlorophyll. The model is then used to explore the effects of perturbations on the global nutrient cycling of phosphorus and silicon:

- The FePSi model captures the observed macronutrient concentrations (Diatom > 10%) and [Si(OH)₄] ≈ 11% and produces a qualitatively realistic field. The implied chlorophyll concentration matches satellite data in the mean, but still underestimates lateral chlorophyll asymmetries in strength and sign.
- The Small plankton class has spatially well separated regions, due to lower half-saturation rates compared to the Large and Diatoms. The Small and Large classes are mostly iron-limited especially in HNL C regions, and Diatoms are Si-limited in the sub-tropical gyres (Fig. 4).
- The response to aeolian iron perturbations differs for the iron, phosphate, and silicate cycles (Figs. 5-8):
  - Globally uniformly increased aeolian input (GBl +10%) increases P and Si exports at high latitudes (e.g., SO) but export reduces (5% and 8%) for SO uniformly increased aeolian input (GBl +10%).
  - Concentrally, globally uniformly increased silicic acid export (GBl +10%) increases Si-trapping globally. It decreases Si-export in the SO (50%), which releases previously SO-trapped silicon, increasing Si-export out of the SO.
  - For GBl +0.1, there is a strong decrease (+14%) in the rest–rest (rest not SO) thermocline regenerated phosphorus (Preg) path and Si export increases (30%) in the deep diffusive rest–rest SO Preg path, while the same Si paths are moderately increased (+15% and 35%).
  - Conversely, for GBl +0.1, there is only a weak increase in the same Si paths (+15% and 35%), but a stronger decrease in the same Fe paths (+4% and 8%).
  - The (Si/P) export ratio and the global biomass fraction of Diatoms \( f_D \) are reduced (+5% and -8%) for SO uniformly increased silicic acid input (SO +10%), and are hardly increased (+3% and +2%) for SO uniformly increased silicic acid input (SO +10%), due to the SO iron deficiency. Because of the asymmetry in strength and sign of the P and Si export responses, the (Si/P) export ratio and \( f_D \) are largely increased (+105% and +43%) for GBl +1.1 and decreased (-11% and -11%) for GBl +10 (Figs. 8-10).
  - Again, because the SO is iron deficient, SO +0.1 has little effect on the global biogeochemical cycle efficiency (+1%), while SO +10 increases it (+8%). However, it responds strongly to global perturbations (+17% for GBl +10 and -40% for GBl +0.1) (Fig. 10).
  - Two timescales can be distinguished in the transient response for an abrupt aeolian input reduction: -50yr for the SO export, and -200yr for SO releases and Si increase export outside the SO (Fig. 11).

References