

Limits of iron fertilization:

Why simple models of iron fertilization may give misleading answers

Anand Gnanadesikan

NOAA/GFDL Princeton, NJ

Irina Marinov, Jorge L. Sarmiento and Richard D. Slater

AOS Program, Princeton University



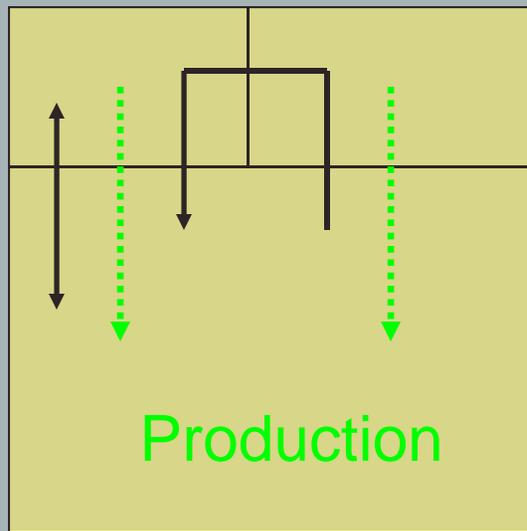
Chisholm et al. (2001) characterize the argument for iron fertilization as being

...an easily controlled, verifiable process that mimics nature; and that it is an environmentally benign, long-term solution to atmospheric CO₂ accumulation.

(Claims are directly drawn from US Patent by Markels). Chisholm et al. (2001) then attack each of these claims.



A simple model of fertilization



Start with box model of Sarmiento and Toggweiler (1984).

Add iron cycle.
(Surface deposition,
deep ocean removal)

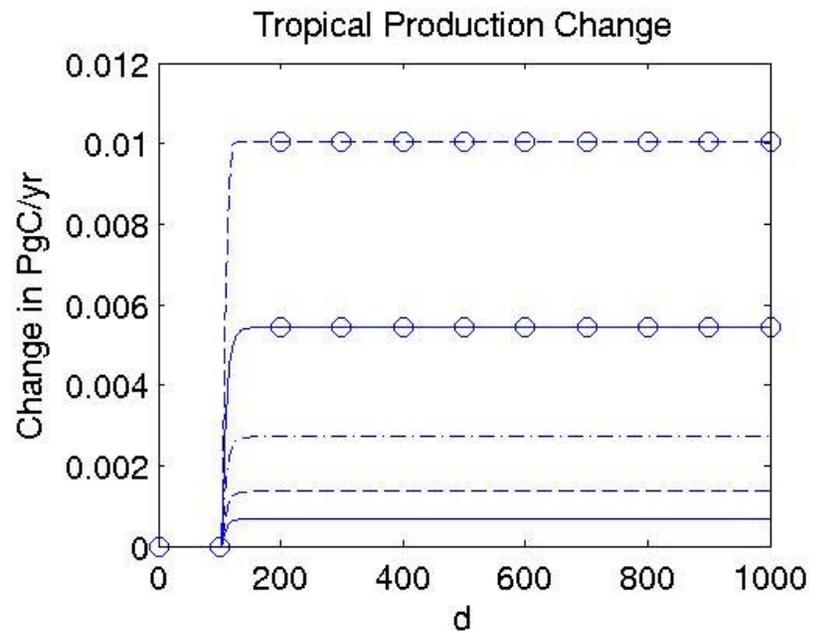
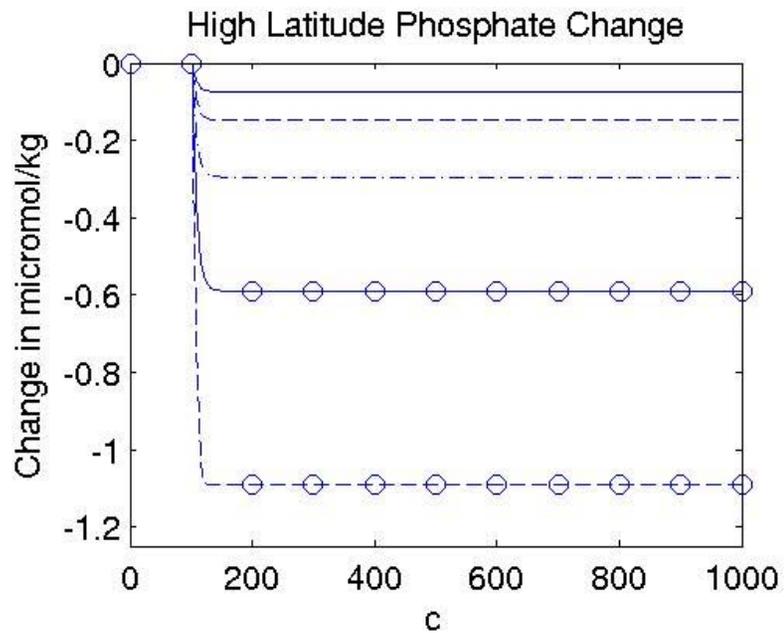
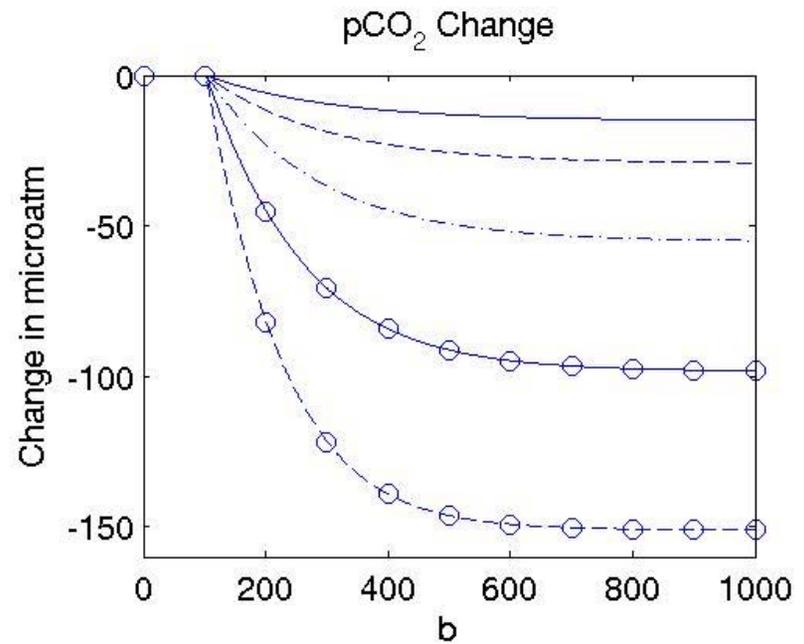
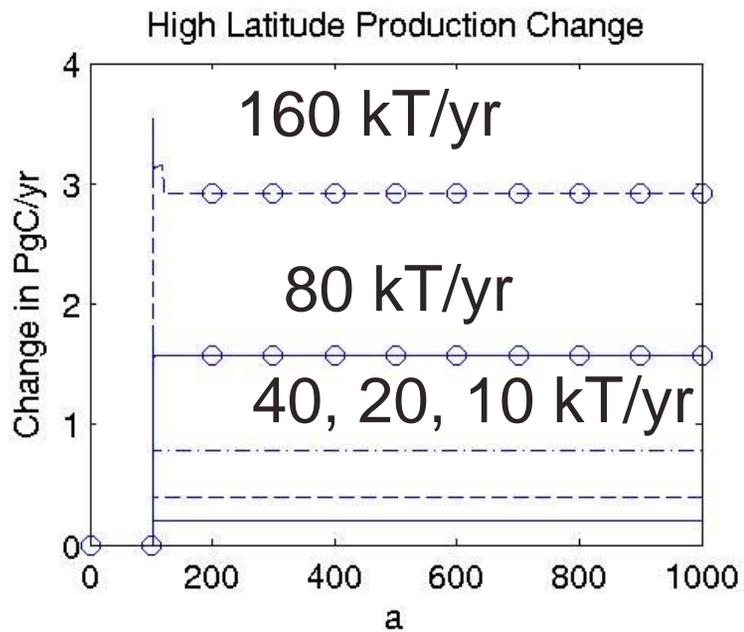
$$\text{Let } \gamma = \gamma_{\max} \text{Fe} / (\text{Fe} + \text{Fe}_c)$$

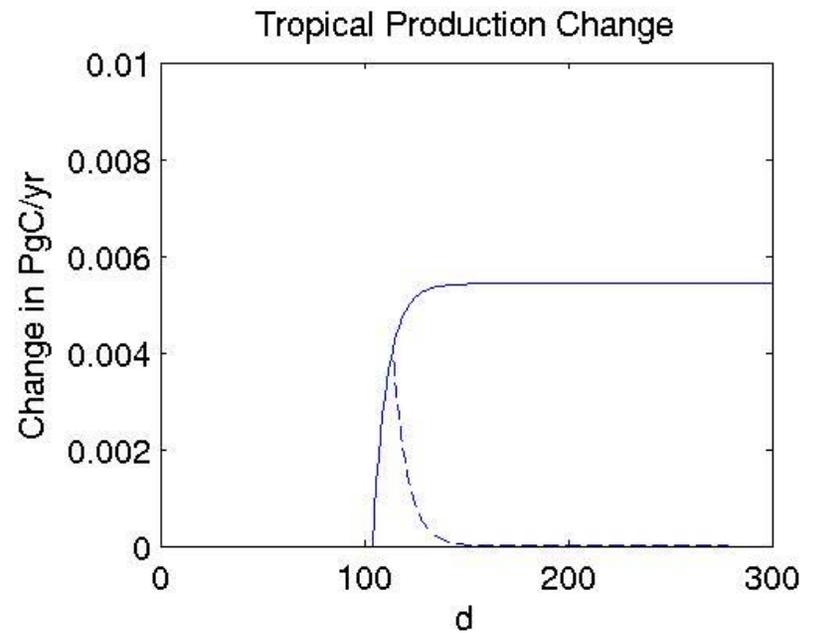
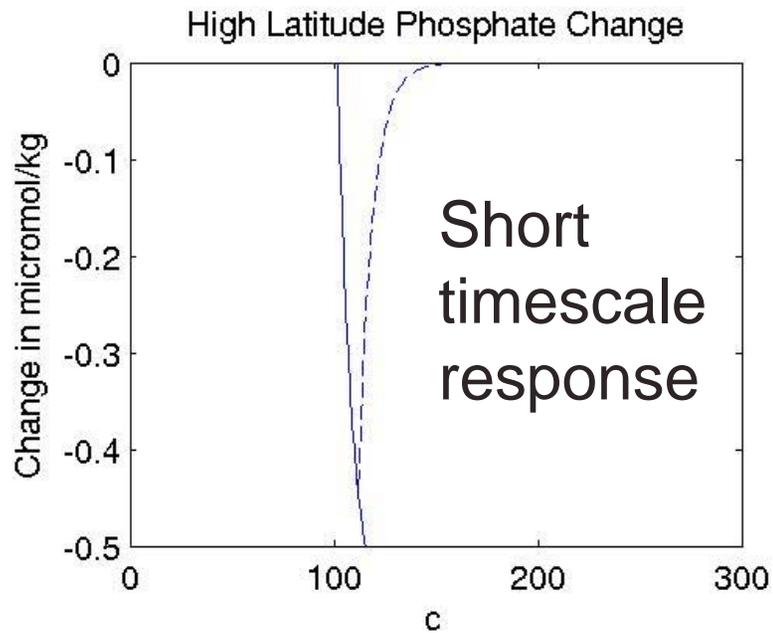
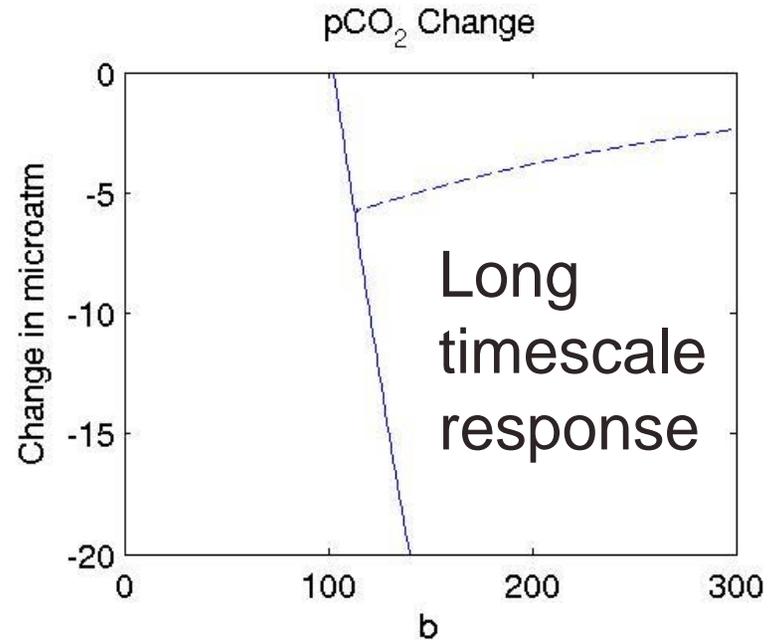
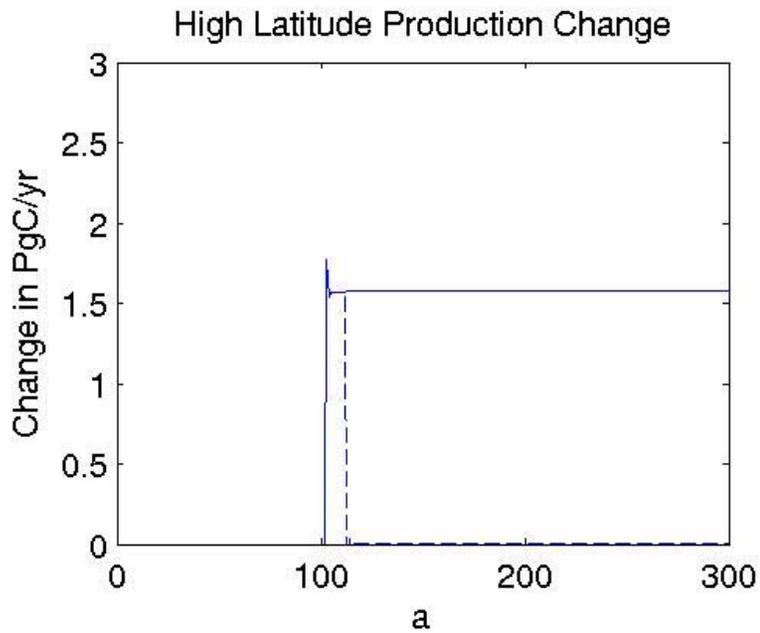
$$\text{Fe}_c = 0.6 \text{ nM.}$$

$$\text{Fe:P} = 500 \quad \text{Fed}_h = 7 \text{ kT/yr} \quad \text{Fed}_L = 173 \text{ kT/yr}$$

Deep ocean iron restored strongly to 0.6 nM.







Basic picture that emerges from box models:

Iron fertilization is **controllable**- change the fertilization, it stops quickly.

Iron fertilization is **verifiable**- it is tightly linked to production and iron input.

Iron fertilization is **environmentally benign**- no long-term, long-distance effects on productivity.

Sequestration is **long-term**, hundreds of years, determined by ocean overturning timescale.

Do more realistic circulation models support this?



Consider results from a suite of ocean general circulation models

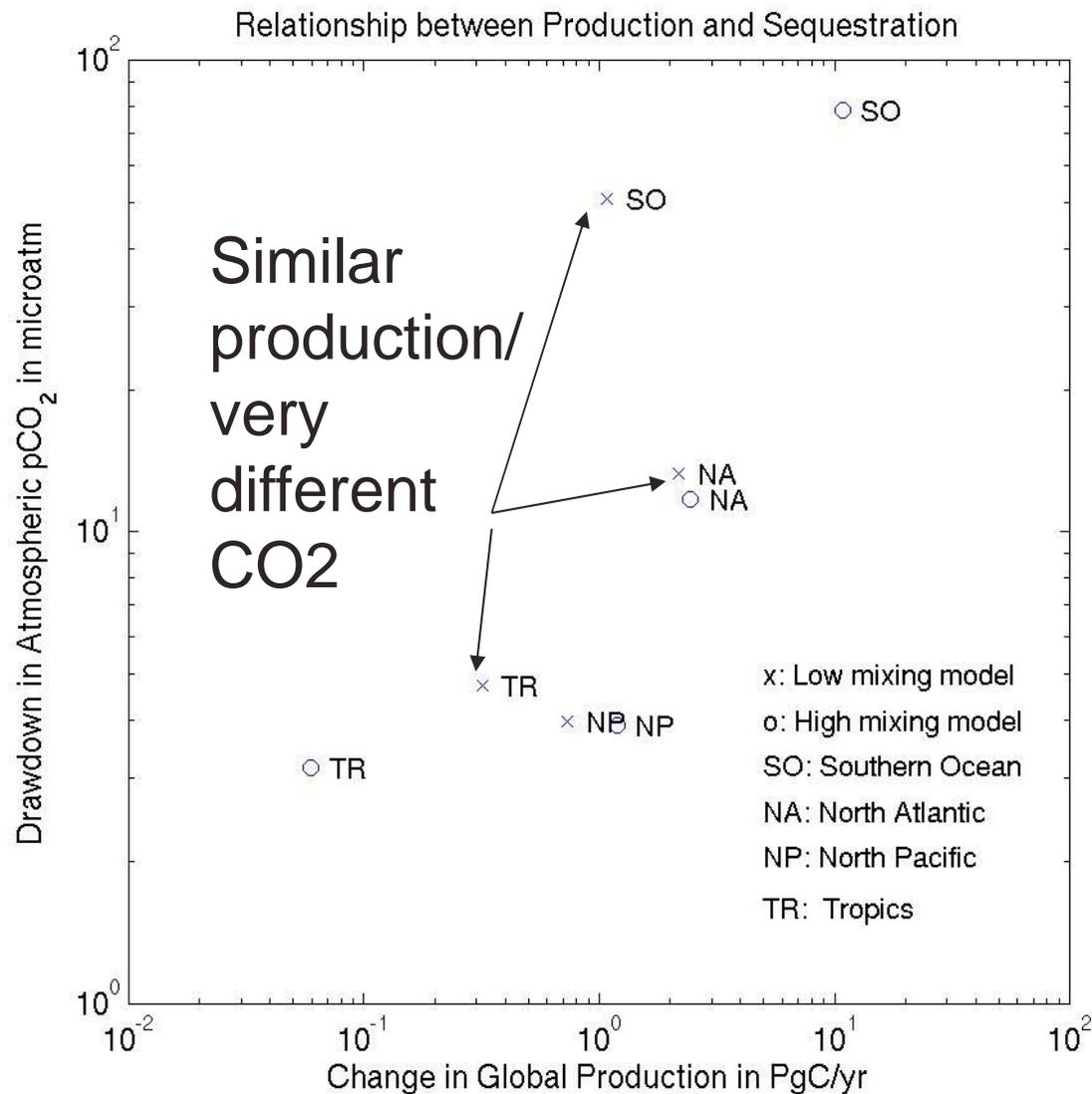
4-degree ocean with realistic topography

Basic question: If you take all the physics you learned in Introductory Physical Oceanography, how well could you explain the ocean circulation?

Two models, a model with high vertical and lateral mixing and a model with low vertical and lateral mixing.



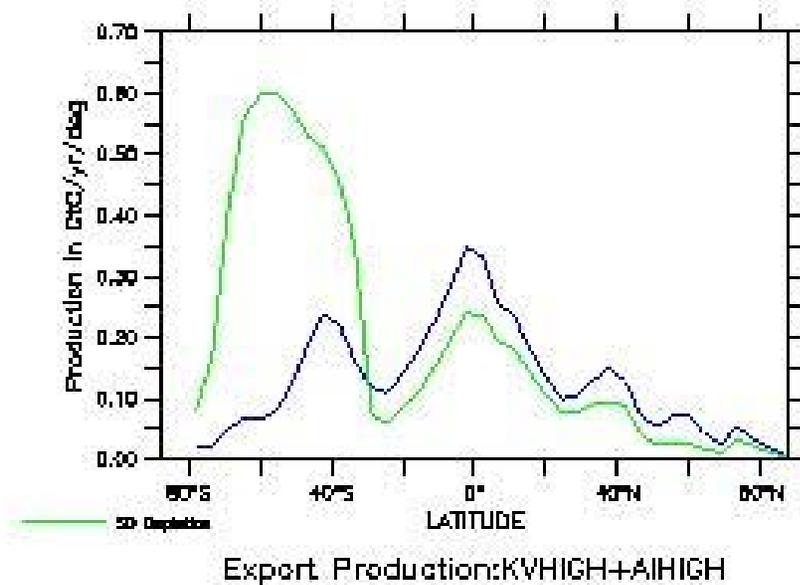
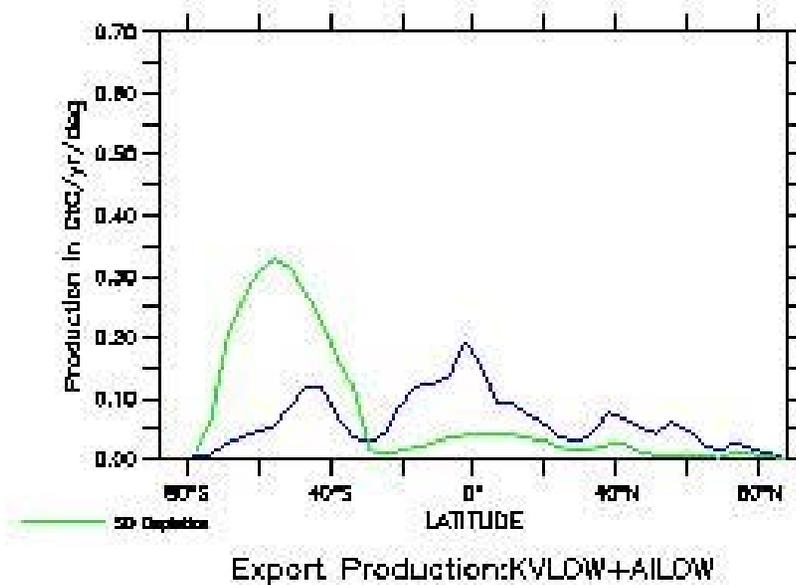
A suite of models was run with long-term fertilization. What is relationship between fertilization and production?



There is no robust relationship between export and CO2!

Drawdown is much lower than in box models!

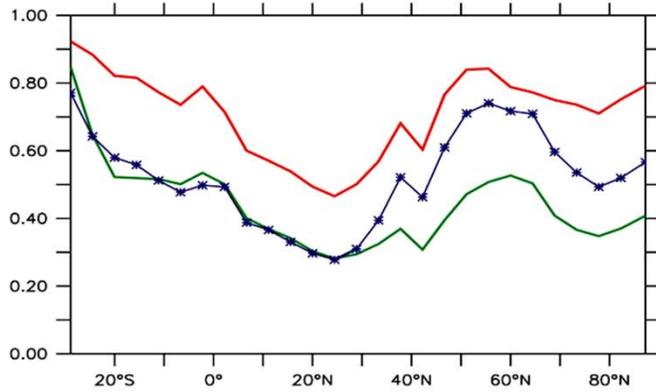
Results mask fact that Southern Ocean fertilization causes a reduction in tropical export production.



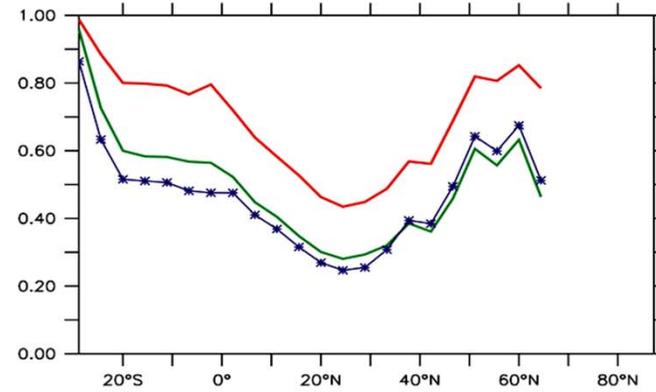
Fractional Change in Export Production following Nutrient Depletion

South of 30S (red), N of sigma 27.1 (green), S of sigma 27.1 (blue)

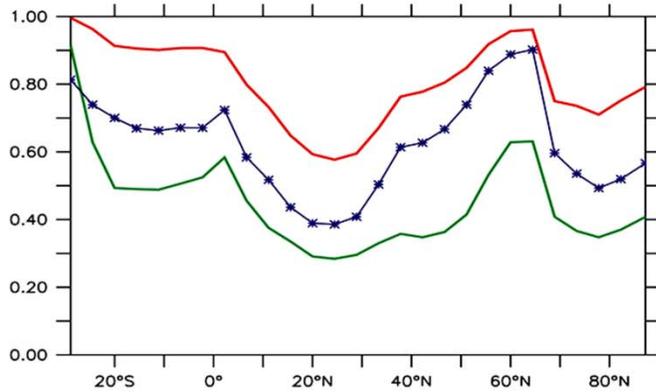
Whole Ocean



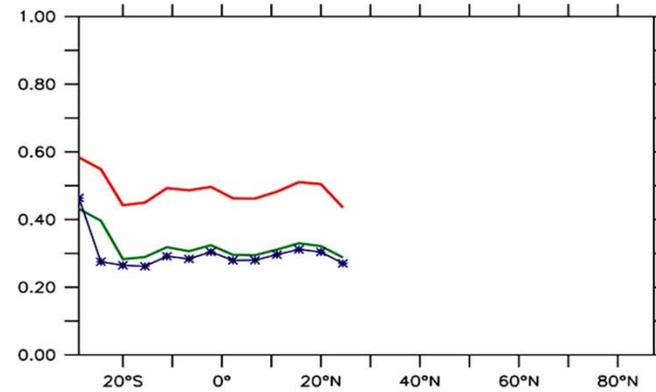
Pacific Ocean



Atlantic Ocean

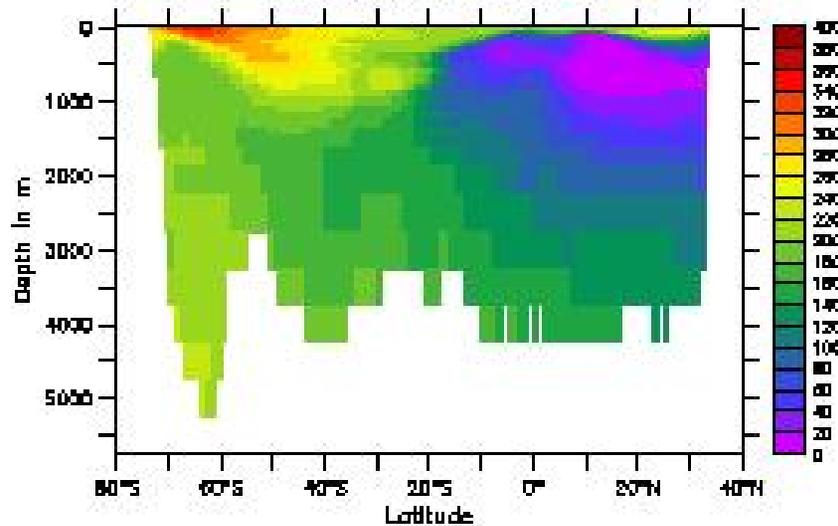


Indian Ocean

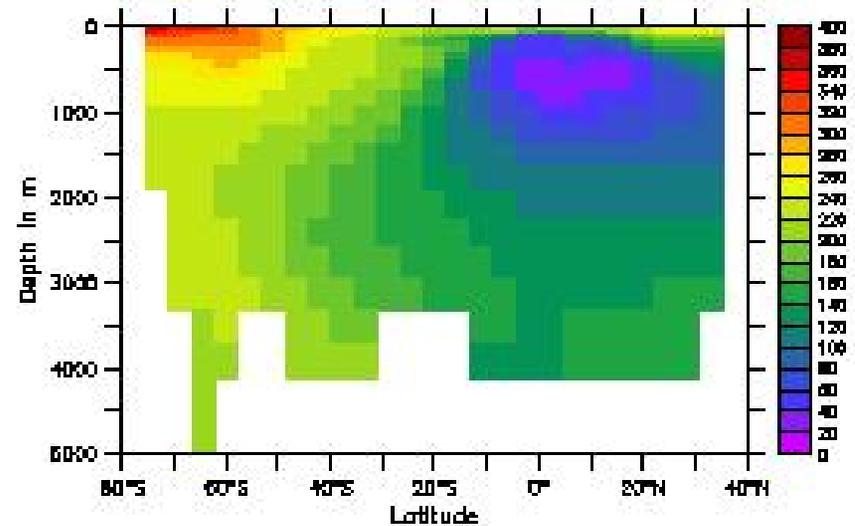


Fertilization can result in a massive increase in anoxia

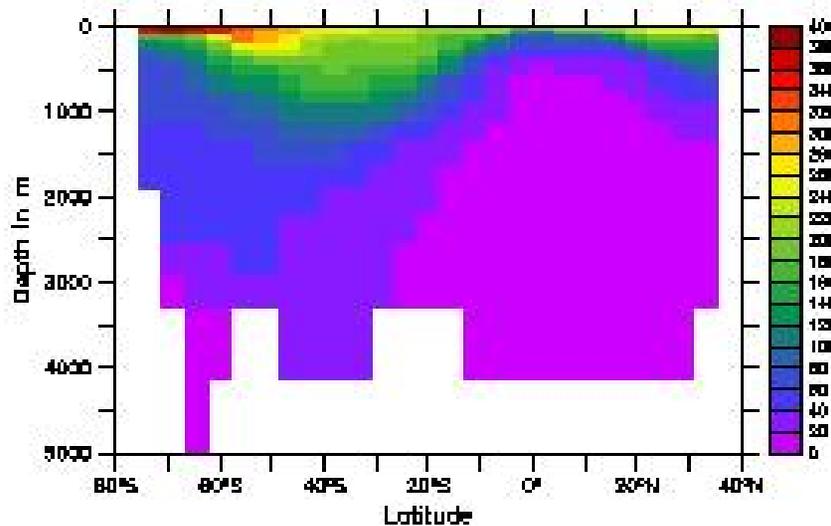
Oxygen: 120W, Data



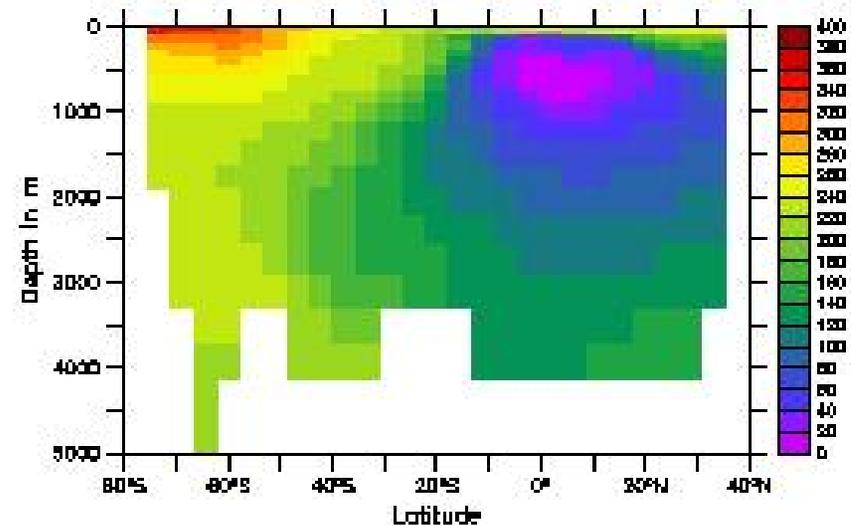
Oxygen: 120W, Modelled



Oxygen: 120W, SO Fertilization



Oxygen: 120W, Tropical Fertilization



Additional results of patch fertilization:

Fraction of carbon remaining in ocean depends critically on depth scale of remineralization.

If remineralization is shallow there is significant leakage.

All PO₄ goes to bottom: 9.7% comes from atmosphere after 100 years.

PO₄ remineralizes exponentially: 2.0% comes from atmosphere.



Results of comparison

Box models tend to **overestimate impact of fertilization** (Archer et al., 2000).

Reasons include gas exchange (Toggweiler et al. 2003) and shallow recirculation of nutrients.

Shallow recirculation means **verifying fertilization could be difficult**, patch fertilization **unlikely to be “long-term”**.

Both patch and large-scale fertilization show long-term reduction of production in tropics. **Fertilization is not environmentally benign or “controllable”**.

