Why dump iron in the oceans?
Lessons learned from ocean iron fertilization experiments

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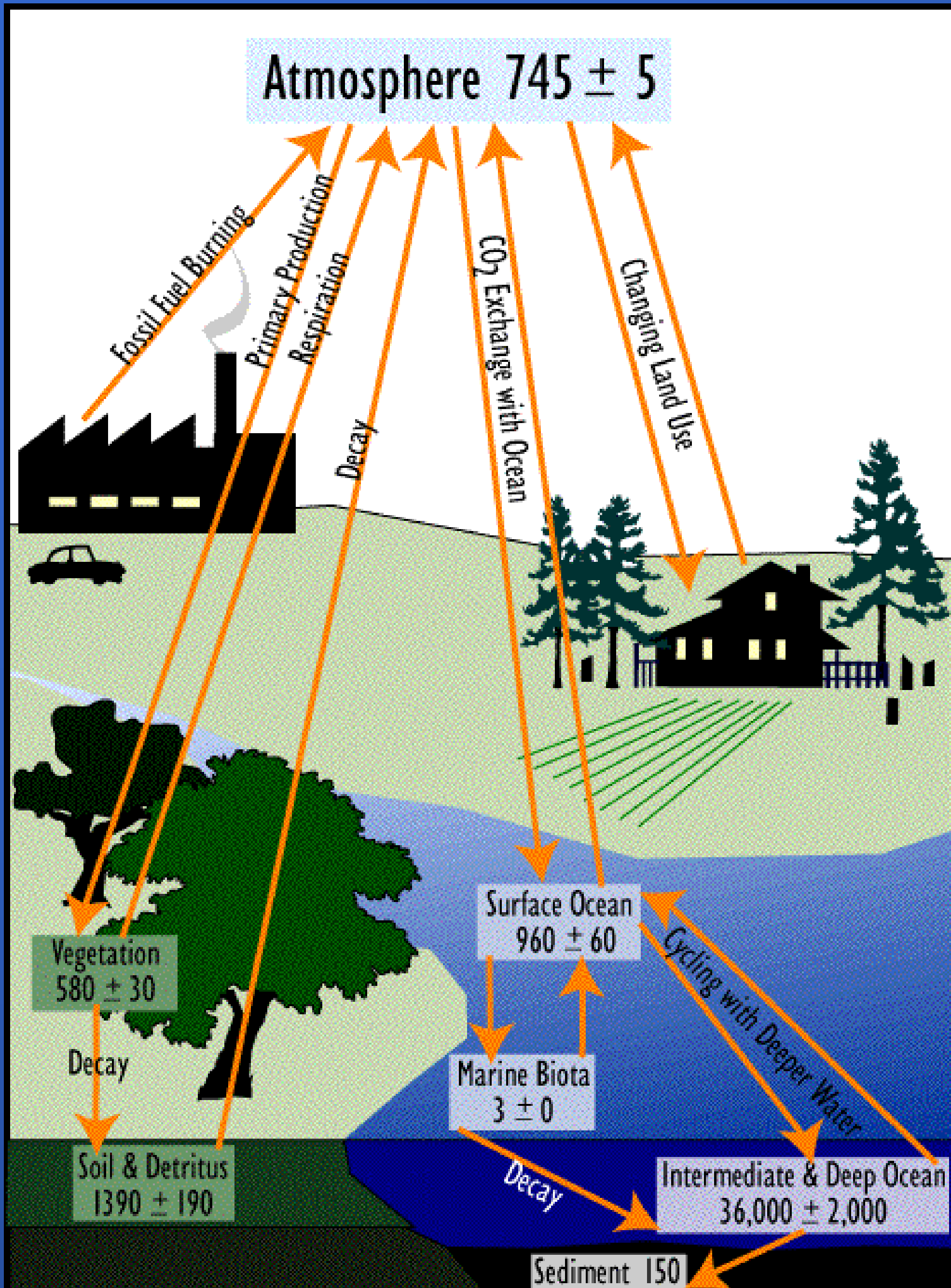
Outline

- Oceans Role in the Global Carbon Cycle
  & iron's role in ocean C cycle

- Ocean Iron Fertilization Experiments
  - lessons learned

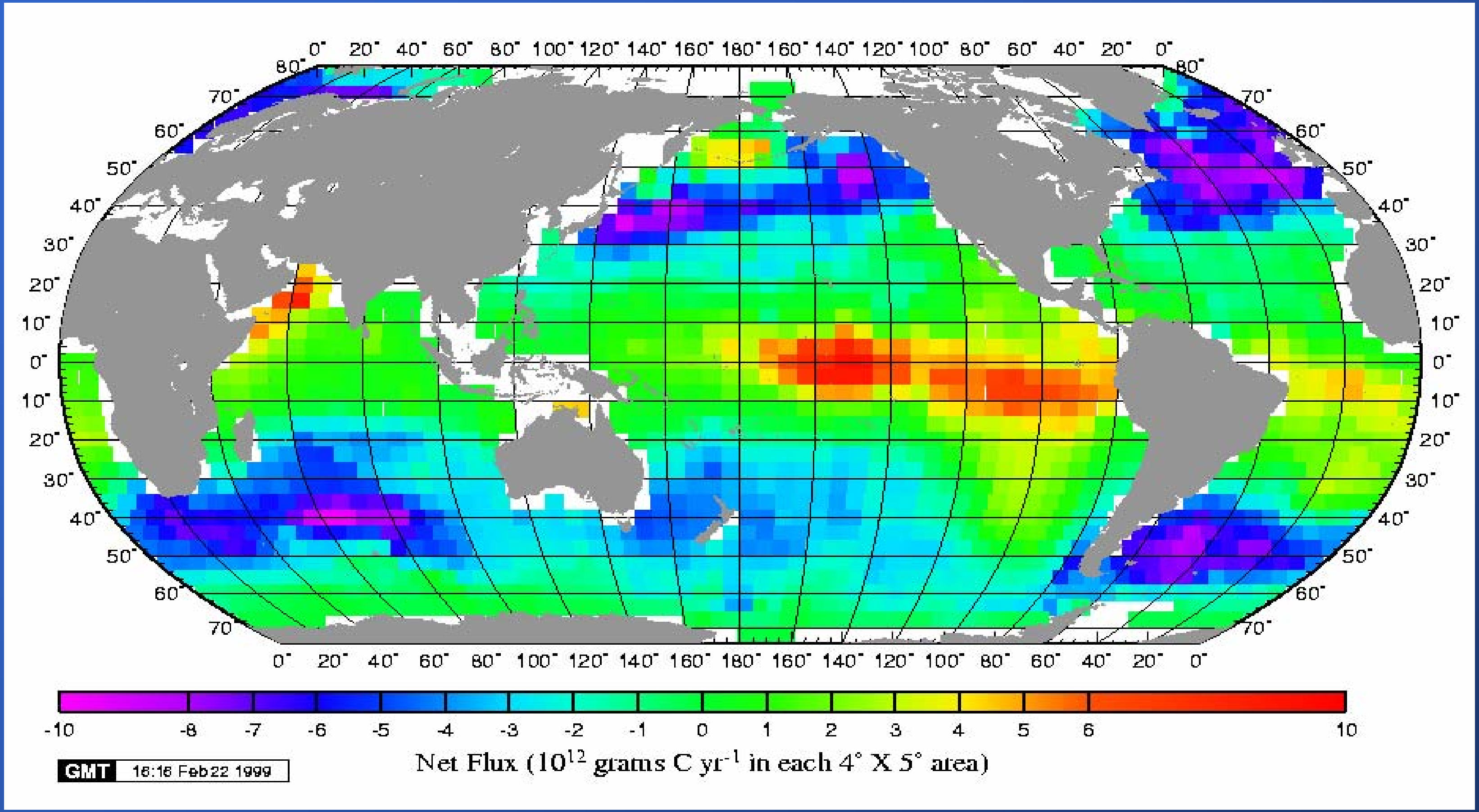
- Can we engineer an enhanced ocean C sink?
  - will it work?
  - what are the consequences?
  - current commercial interests
  - remaining uncertainties



Global Carbon Cycle

- human activities release 6.5 billion metric tons C as CO_2
- marine biota <1% of terrestrial C stocks
- marine biota 50% of global primary production
- deep ocean 50x more C than atmosphere

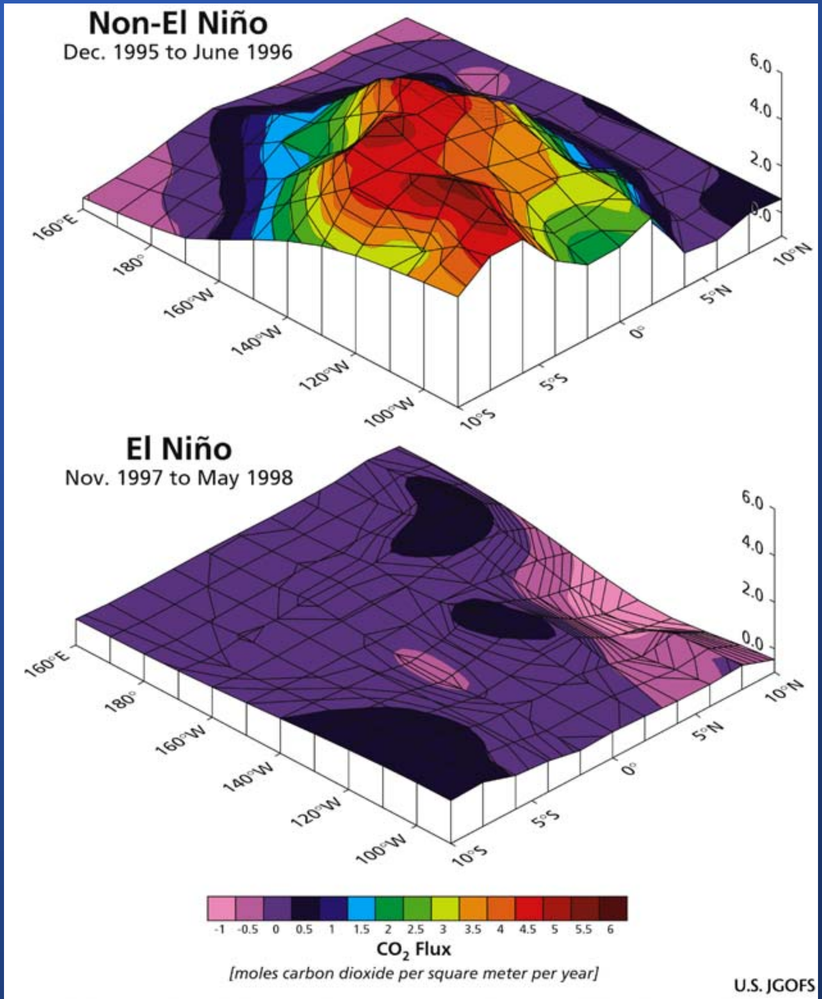
How the ocean "breathes"



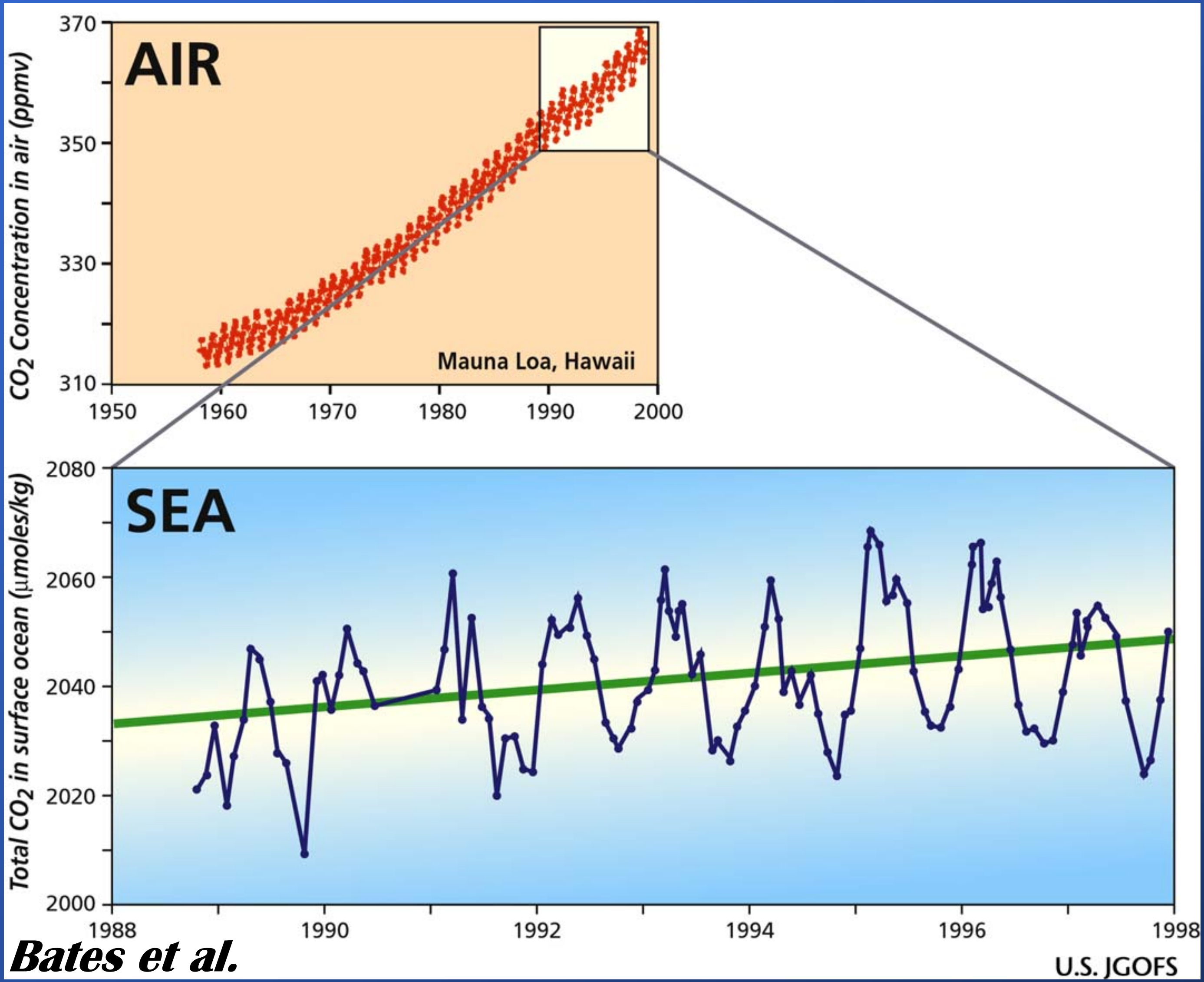
- >500,000 surface CO_2 measurements
- Ocean acts as both source and sink for CO_2
  - Biological pump- Marine plants take up CO_2
  - Solubility pump- cold water has higher CO_2

The "Solubility Pump"

- Gas exchange allows CO_2 to enter ocean
  - flux depends upon air-sea CO_2 difference
  - Solubility increases in cold waters (polar regions are sinks, equatorial sources)
- El Nino reduces equatorial Pacific CO_2 release by 75%
  - 10% of global budget

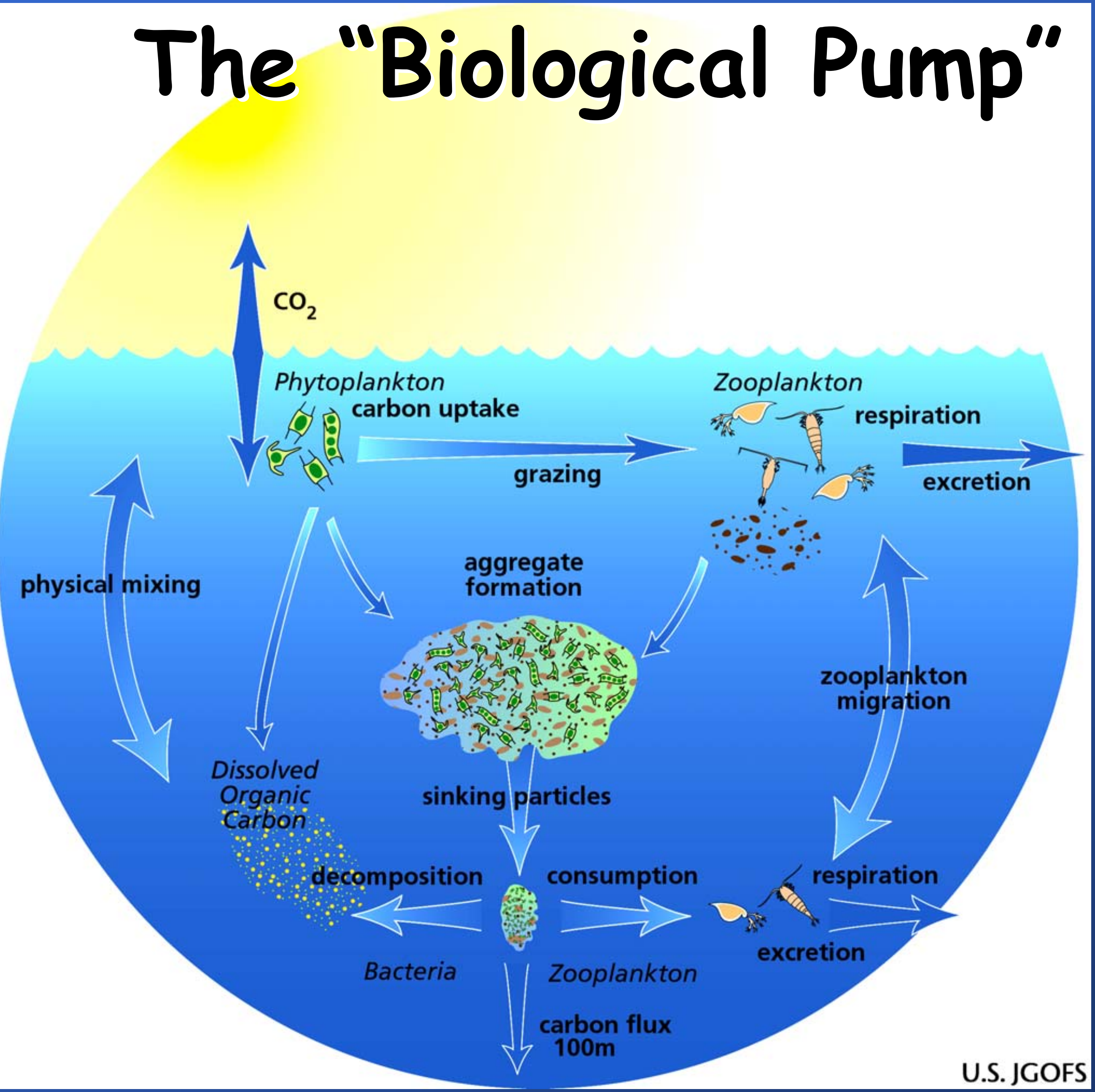


Atmospheric and ocean CO_2 are rising



Bates et al.

The "Biological Pump"



Combined biological processes which transfer organic matter and associated elements to depth

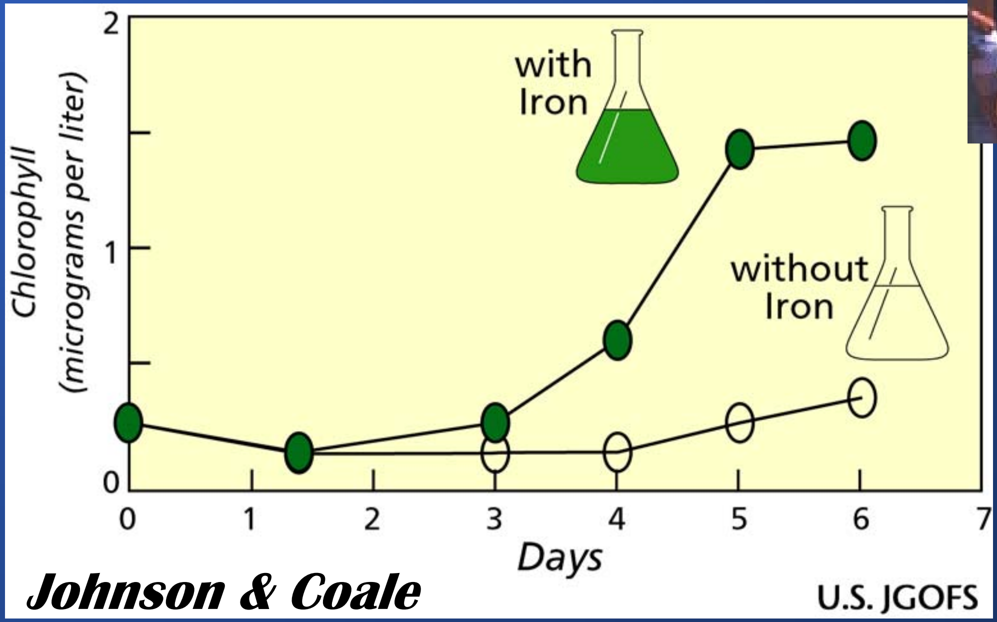
- pathway for rapid C sequestration

Quickly remove C from surface ocean & atm.

- turn off bio pump and 200 ppmv increase atm. CO_2

What controls carbon uptake by algae?
i.e. primary productivity

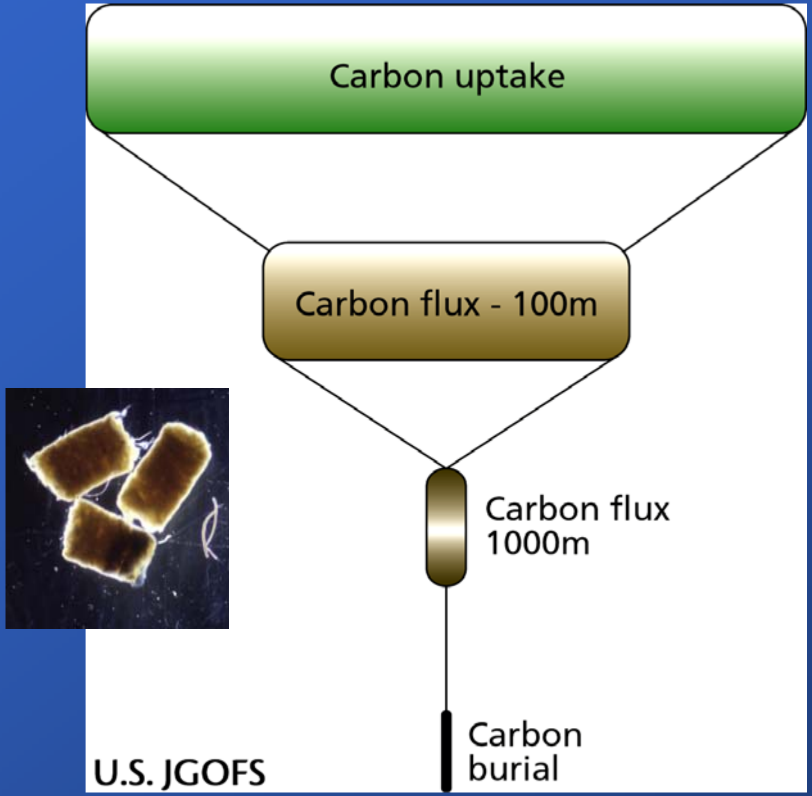
- Light, temperature, mixing
- Major nutrients (N, P, Silica)
- Grazing
- Micro-nutrients (Iron, Zinc)



What controls carbon export?

i.e. efficiency of biological pump

Biological pump and
the ocean C sink-
an inverted pyramid



Primary Production

Export flux on sinking particles

<5 to >15% (decades)

~1% (centuries)

~0.1% (millennium)

Why this variability?

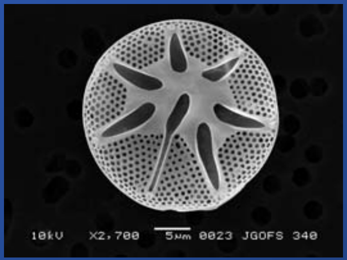
- Food-web controls efficiency of biological pump

High latitudes &
Spring blooms

High efficiency

Blooms of large diatoms (role of silica- ballast; lack of grazing)

High iron requirements

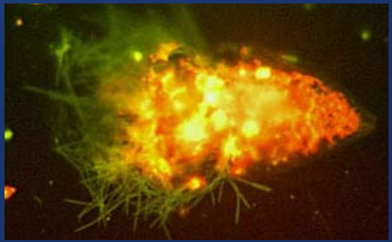


Equatorial regions &
oligotrophic regions

Low efficiency

Tightly coupled food web characterized by smaller cells & efficient grazers

Low iron requirements

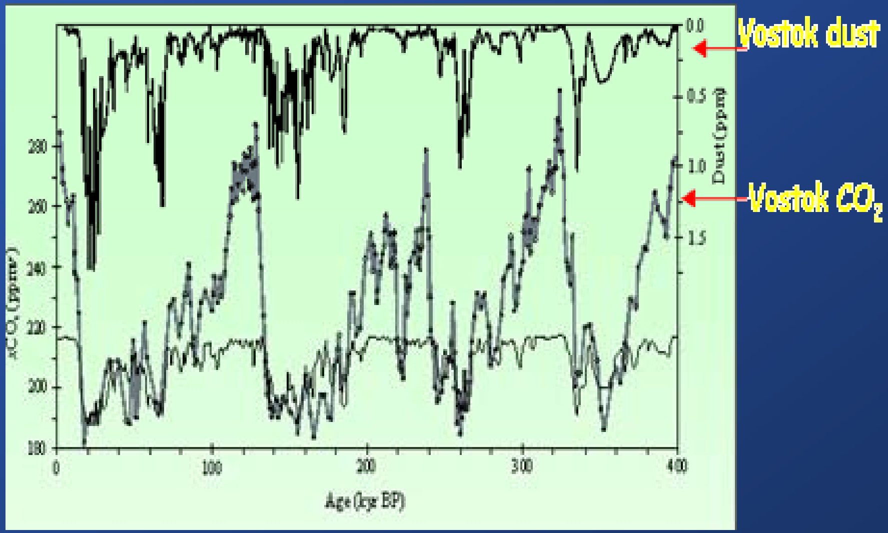


Iron Hypothesis

- 40% of ocean "HNLC"
- high nutrient, low chlorophyll & low Fe

Past climate shows correlations to support

- high dust & iron
- lower CO_2 & temp.



"Give me half a tanker of iron and I'll give you the next ice age" - J. Martin, 1990

So, could we add Fe to “fertilize” ocean & thus ameliorate greenhouse CO_2 build-up?

1. Will it work?

2. What are the ecological consequences?

Oct. 2000

Just Add Iron
ABCnews.com, Amanda Onion 10/11/00

How algae may slow warming
By Gareth Cook, Boston Globe Staff, 10/12/2000

Helping ocean algae could beat greenhouse effect
LONDON (Reuters), WIRE:10/11/2000

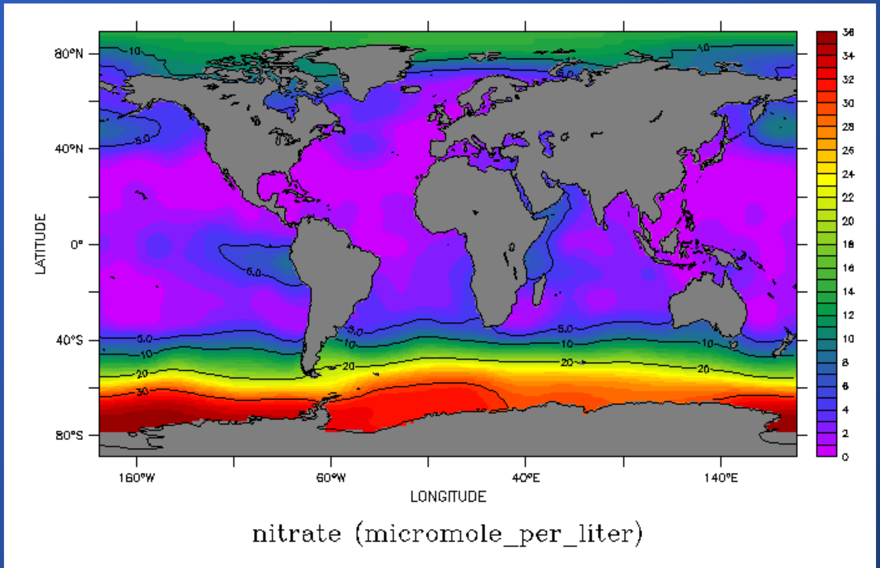
Global Warming
NPR Morning Edition- John Nielsen, 10/11/00

Iron-Fed Plankton Absorbs Greenhouse Gases
By ANDREW C. REVKIN, NY Times, 0/12/00

Iron May Increase Gas - Eating Algae
By THE ASSOCIATED PRESS, 10/11/00

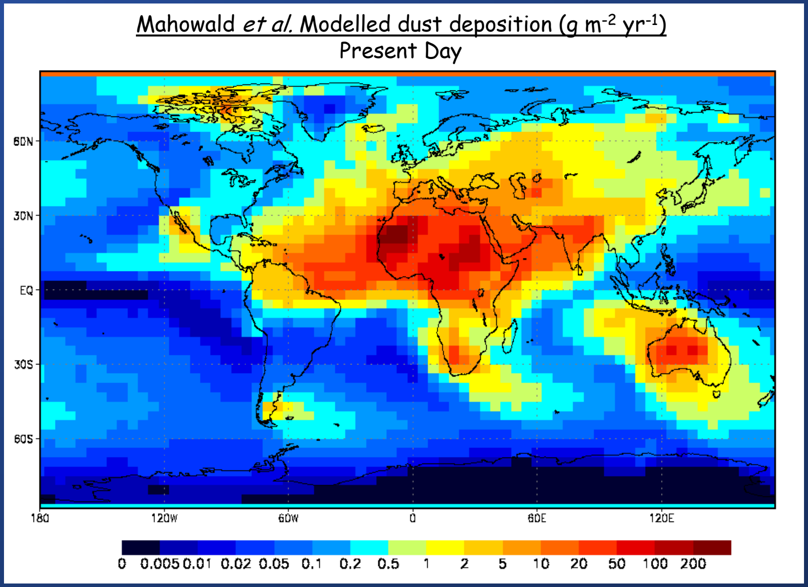
Ocean Fertilization Models

- focus on Southern Ocean
- high nutrients
- low dust, low iron



Remove all So. Ocean nitrate

- 100-200 Gt C sequestered
- Double atmospheric CO_2 = 1000 Gt C so ocean "solves" 10-20% of CO_2 problem
- time scale of removal 100-300 years
- lower production in tropics?




U.S.
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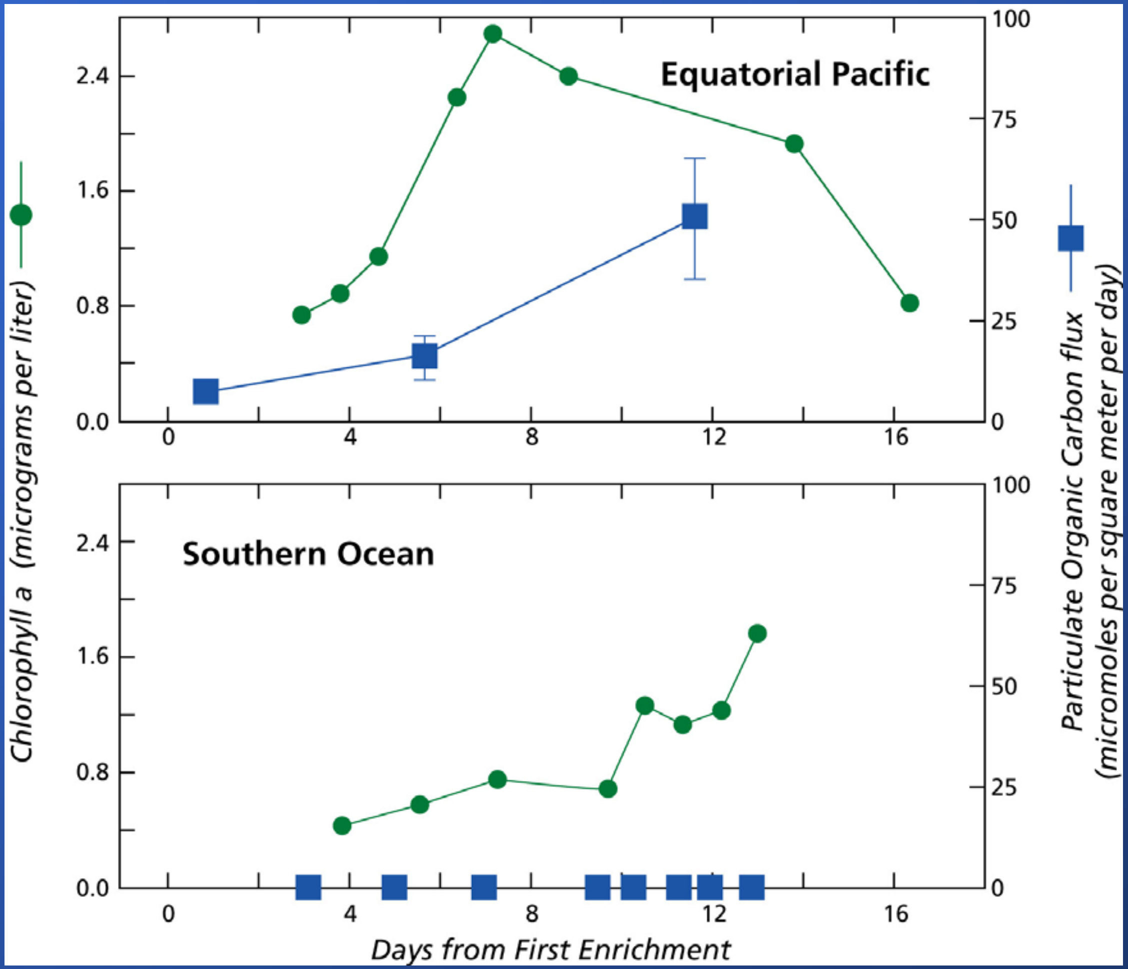
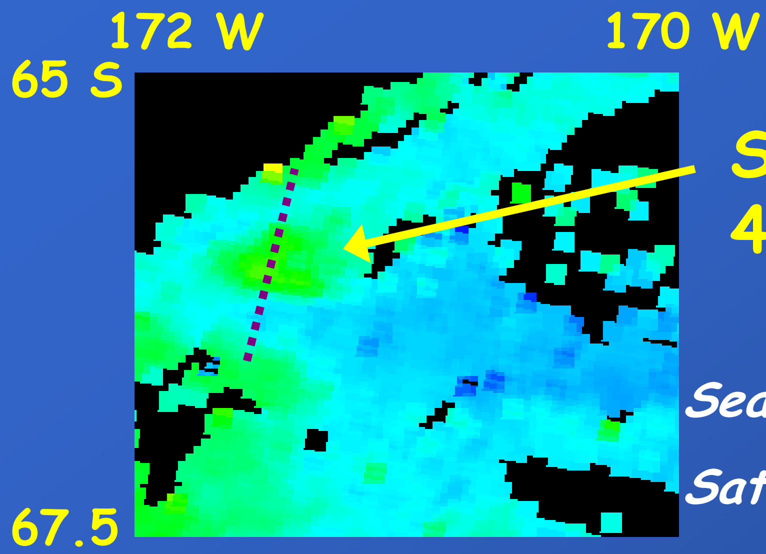
Ocean Fertilization Experiments



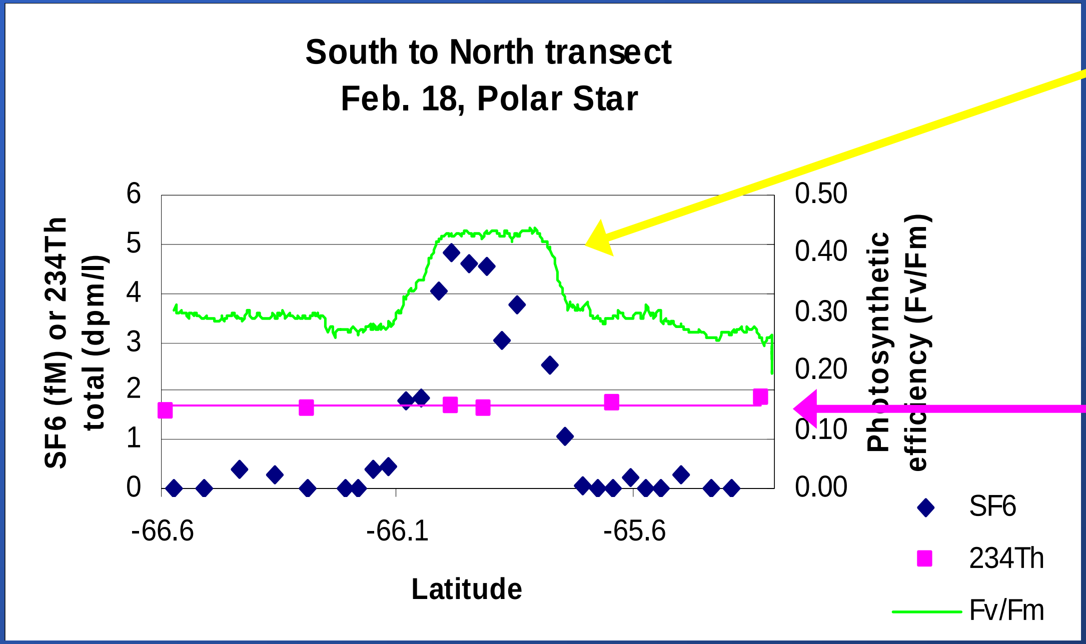
If you add iron, you observe more phytoplankton (chlorophyll), but not necessarily enhanced sequestration (biological pump can have low efficiency)



SOFeX patch as seen from space 4 weeks after iron fertilization

SeaWiFS ocean color

Satellite image- Feb. 12, 2002, F. Chavez et al.



SOFeX patch seen as SF6 peak & Fv/Fm peak

Thorium-234 indicates similar particle flux in & out of patch (C flux may be elevated, but didn't see diatom crash)

What is impact of the biological pump on C sequestration potential as a result of Fe addition? *Example from "SOIREE"*

So. Ocean Feb. 1999	Low	High
C uptake* (8.7 tons Fe added)	400 tons	3000 tons
C flux @100m*: 1%	4	30
50%	200	1500
C flux @500m*: 10%	0.4-1.6	3-12
(100m/500m) 40%	20-80	150-600

** Observed from DIC & C stocks*

** Range of export ratios*

** Range of deep ocean flux data*

The effectiveness of Fe on C sequestration is controlled by the type of plankton community that responds

If one "SOIREE" leads to 1-600 tons C sequestration, can ocean fertilization impact atmospheric CO_2?

Human impact atmospheric CO_2 = 6.5×10^9 tons/yr
-to remove 10% need $1\text{-}650 \times 10^6$ "SORIEES"

In other units-

1 SOIREE = 10^3 km^2

so 10^6 "SOIREES" = 10^9 km^2

note area ocean = 0.36×10^9 km^2

1 SOIREE = 8.7 tons Fe

so need $8.7 - 5{,}600 \times 10^6$ tons Fe

= 220 – 141,000 ships w/40,000 ton load

What would be needed to increase impact of ocean fertilization?

Higher yield per ton Fe-

C:Fe of 3×10^5 possible in uptake experiments
1 "SOIREE+" = 2.6×10^6 tons C
250 "SOIREE+" = 10% annual CO_2 human input

Need high efficiency biological pump

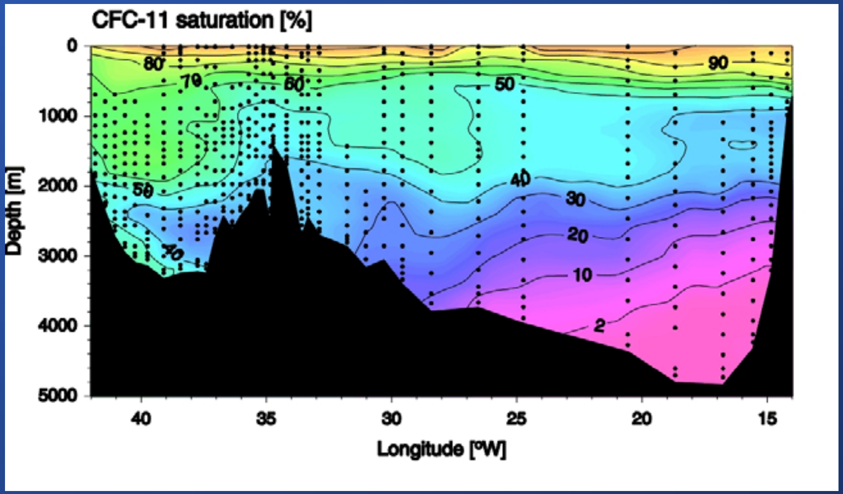
100m C flux/uptake efficiencies as high as 50%
midwater transfer of 10-40% into deep ocean
- select for blooms of large diatoms?

Need enough nutrients

not just Fe, or N or P, but
Si would become limiting in So. Ocean blooms

Could we monitor Fe induced C sequestration?

- Technology exists
  - tracers (thorium-234)
  - traps, optical methods
- Need to consider C sequestration relative to depth of seasonal mixing
  - C must reach depths that are slowly ventilated



What are possible ecological consequences?

- oxygen depletion

- ecological shifts to harmful algae

- microbial shifts result in production of other greenhouse gases (methane, nitrous oxide) or DMS (cloud nucleation & aerosol scattering)

- disruption/changes to higher trophic levels

- many unknowns (scaling; duration; higher trophic levels)
  Negative impacts- "blue ocean turned green"
  Positive impacts- enhanced fisheries?

- by design, ocean fertilization changes ecology

Commercialization of Ocean Iron Fertilization - here already

"option to own one ton CO_2 equivalent = $4 (15 tons per US household to offset typical contributions)"

"One of our eco-solution notions is to create a combined technology/methodology for Ocean Biomass Carbon Sequestration OBCS™"

Patent applications-
Fe nutrient delivery systems; application patterns

Field plans-
Marshall Islands; Chilean coast; Equatorial Pacific

Key unknowns:

- extrapolation of results/scaling
- verification of carbon sequestration
- ecological consequences

Knowns:

- at best, ocean fertilization partial solution & not permanent

similar to many other sequestration options

- low "cost" option buys time

is it worth it?

- Oceans already taking up 100 Gt fossil fuel C
- doing nothing results in changes to ocean temperature, circulation, stratification, pH and ecology

What is needed?

Experimental data is sparse & expensive

- *scaling issues*
- *C flux monitoring & biogeochemistry*
- *ecological consequences*
- *modeling: 3D transport issues; max. impact*

Dialog is lacking

- *not just ocean fertilization, but wrt other C sequestration & reduction options*
- *truth in advertising*

Where will this lead?