

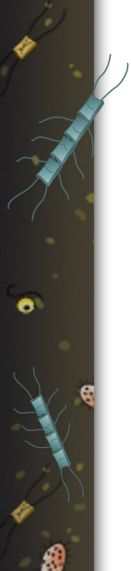
ocean**iron**fertilization

come to listen

learn

debate

explore



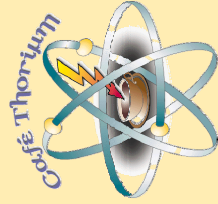
Advances in Our Understanding of Ocean Iron Fertilization: What comes next?

Ken Buesseler

Marine Chemistry and Geochemistry Department
Woods Hole Oceanographic Institution

*Ocean Iron Fertilization & Carbon Sequestration:
Can the Oceans Save the Planet?*

AAAS Annual Meeting, Feb. 18, 2008



The Iron Hypothesis-

**“Give me half a tanker
of iron and I’ll give you
the next ice age”**

-John Martin, 1988



Outline

The history of ocean iron fertilization

- **Connections between iron and ocean carbon cycle**

What we have learned so far

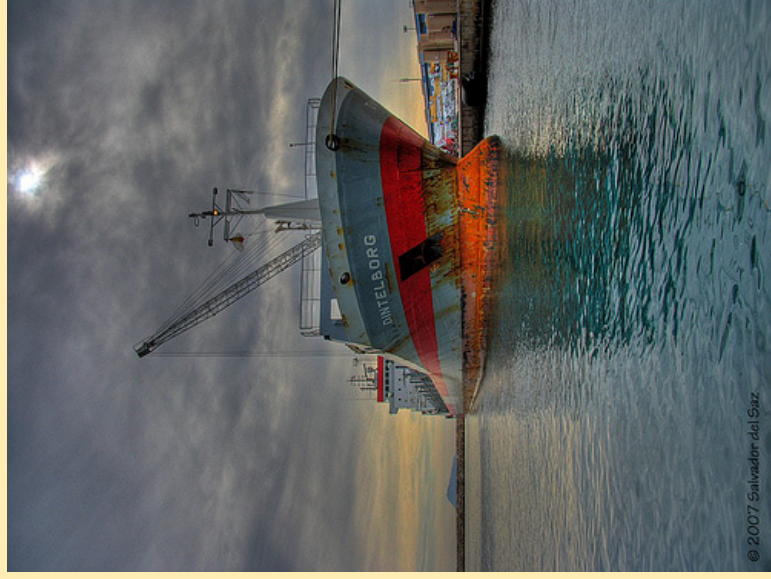
- **Ocean response to iron fertilization**

What's next?

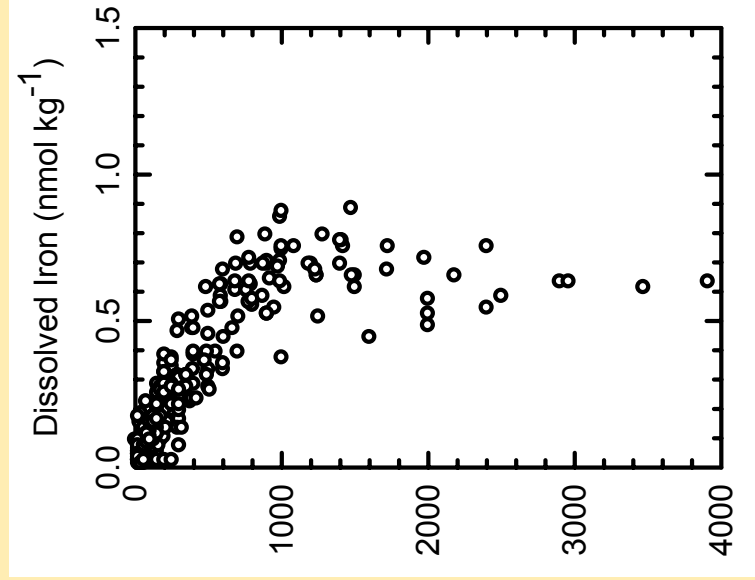
What is ocean iron fertilization?

History

Challenge-
measuring iron on a rusty ship!



Late 80's-
measured extremely low
iron in surface ocean

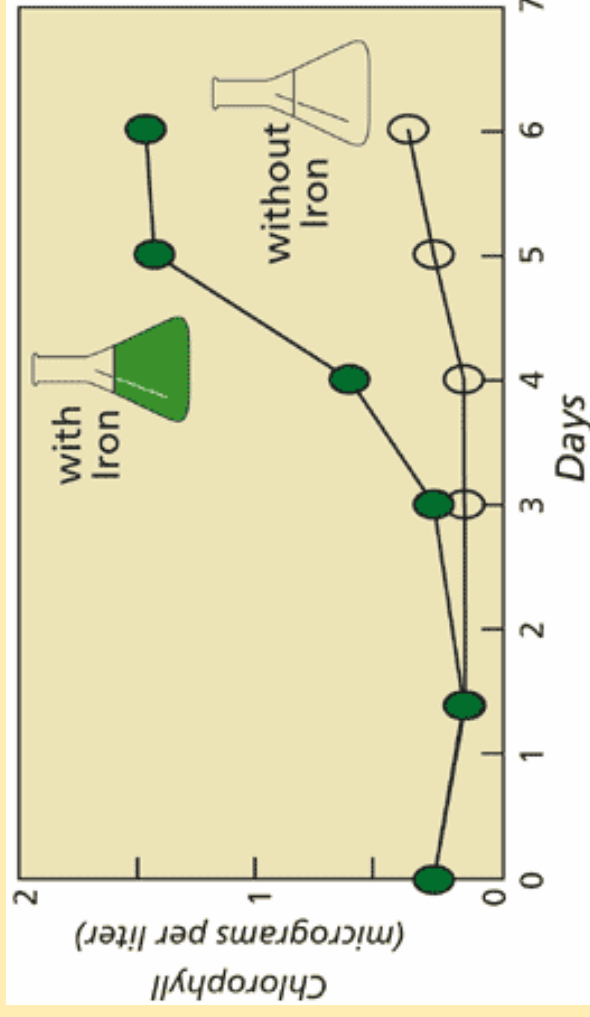


(regional differences)

What is ocean iron fertilization?

History

1. Adding iron can stimulate phytoplankton growth
= carbon uptake



2. A little iron goes a long way!



3. How does this work in nature?

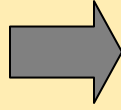
The natural iron cycle



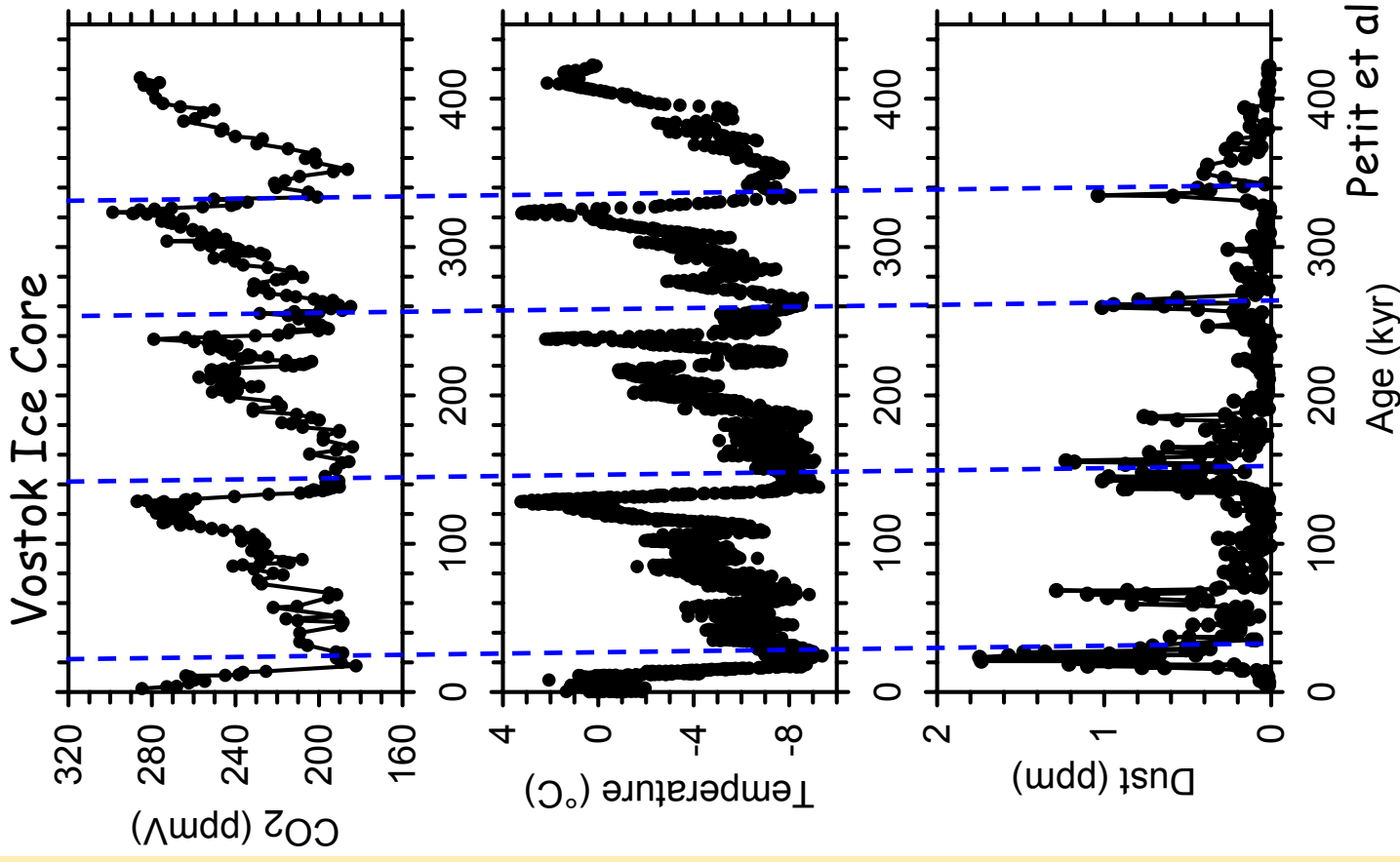
Dust is a
major
source of
iron to the
ocean

Evidence of past global climate change led to the iron hypothesis

High dust (high Fe)



low temperatures
and low CO₂



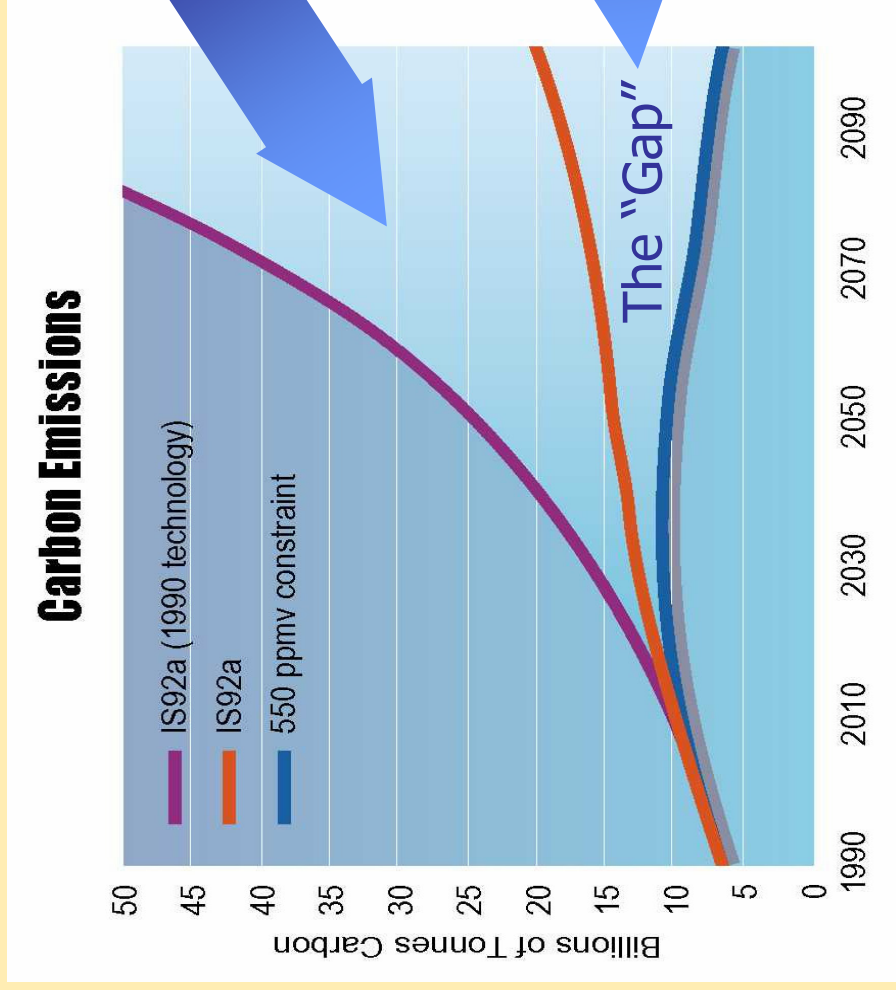
How can we stabilize rising CO₂?

Reducing CO₂ sources

- Higher efficiency
- Renewables
- Nuclear, alt. energy

Enhancing CO₂ sinks

- Carbon capture & disposal
- Land/ocean carbon sequestration



Can we geoengineer the ocean to increase C sequestration?

Two processes are needed to impact atmospheric CO_2 via iron additions:

1. Stimulate phytoplankton growth

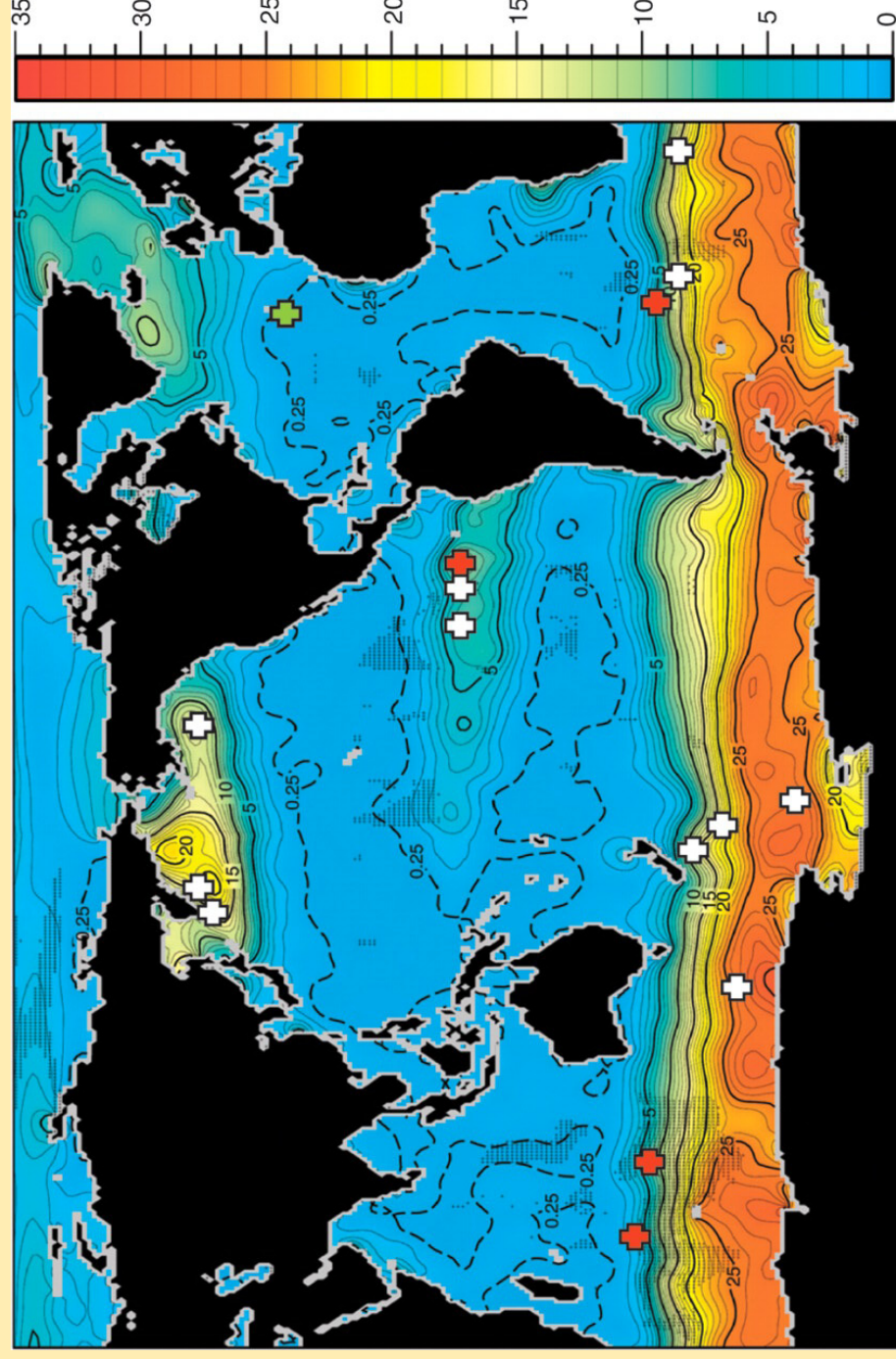
- relatively well known

2. Enhance carbon transport to the deep-sea

- little known,
hard to measure,
but key to C credits



12 major iron fertilization experiments since 1993 & studies of natural Fe sources



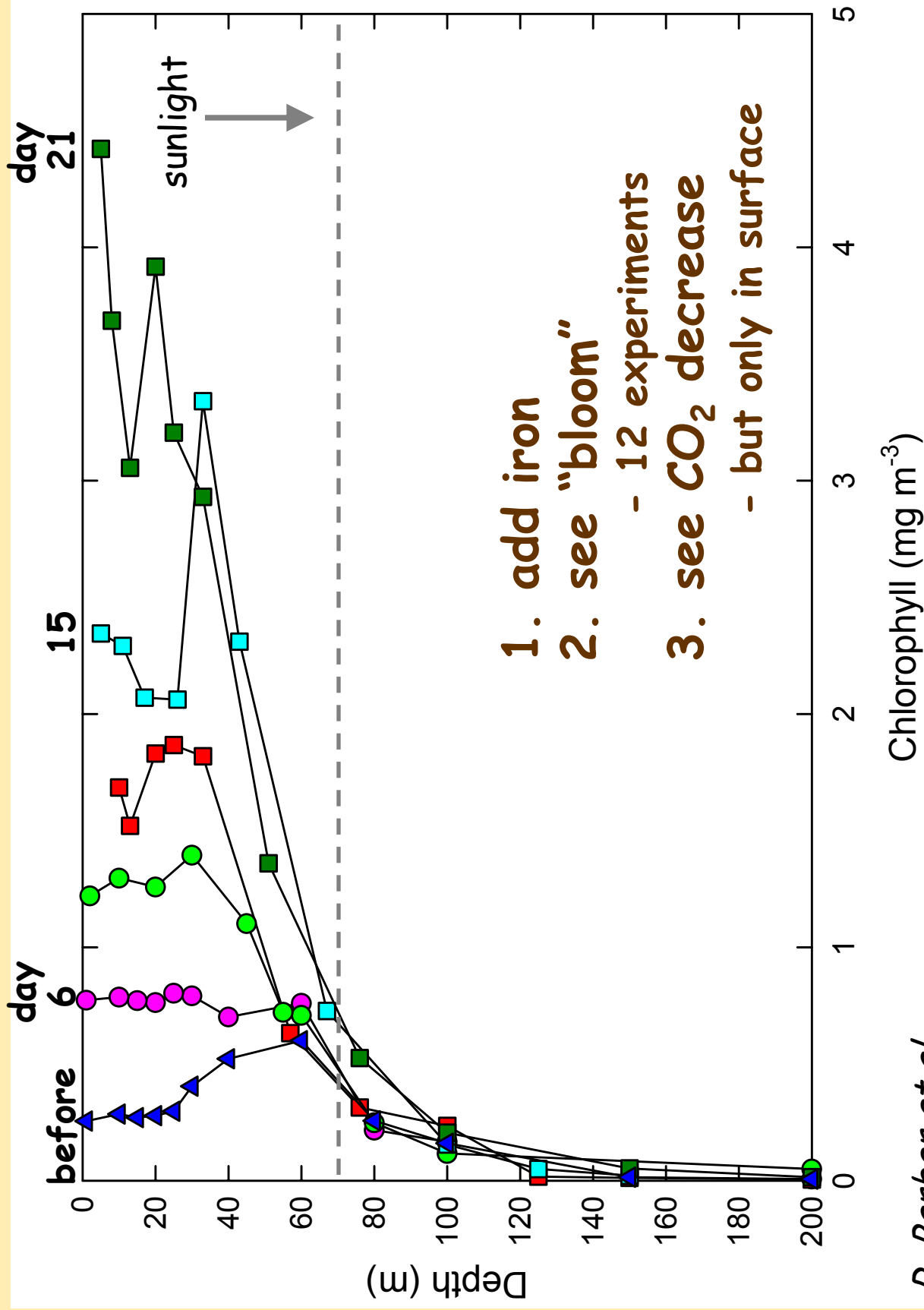
P. W. Boyd et al., *Science* 315, 612-617 (2007)

Map of surface ocean nitrate

Science

AAAS

Increase in phytoplankton seen after iron addition

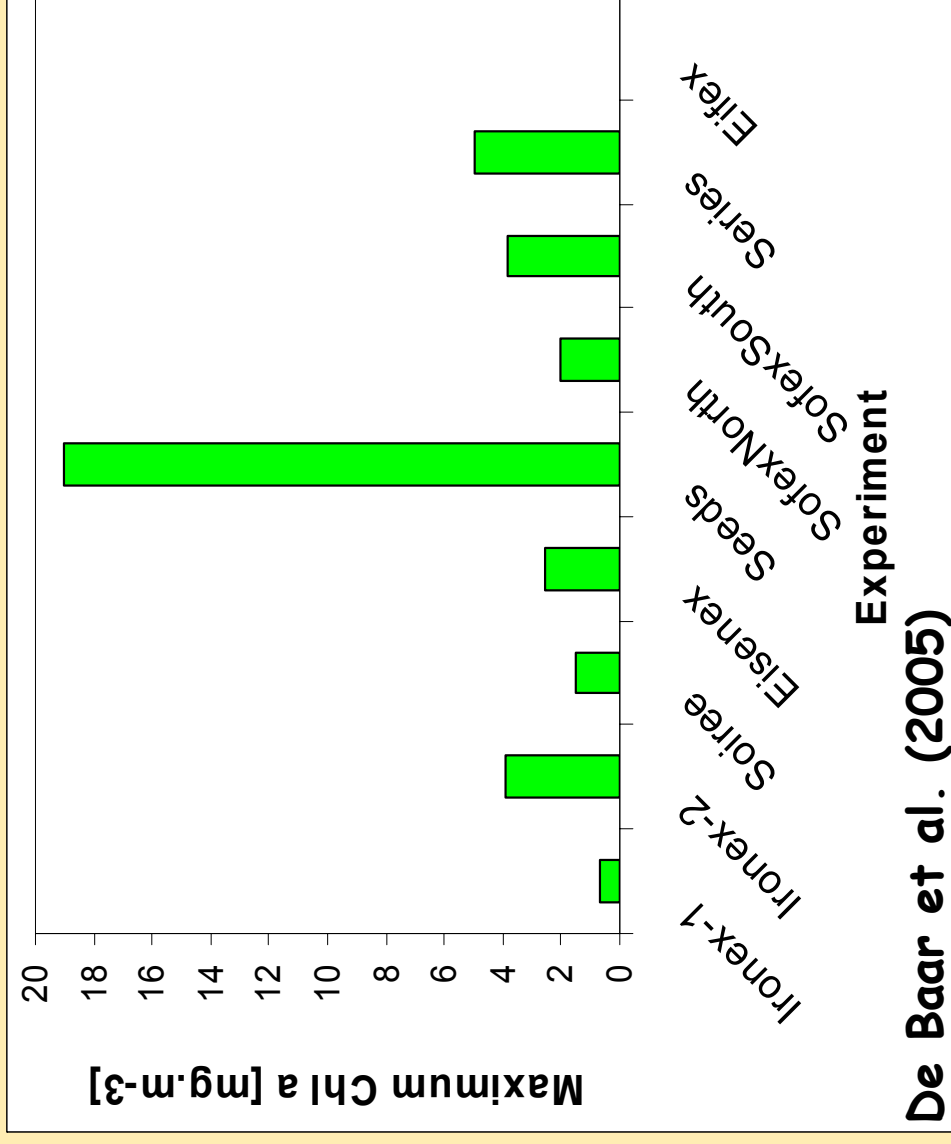


1. add iron
2. see "bloom"
 - 12 experiments
3. see CO₂ decrease
 - but only in surface

R. Barber *et al.*

What controls the ocean response to iron? Location, location, location...

[Phil Boyd- U. Dunedin, NZ]



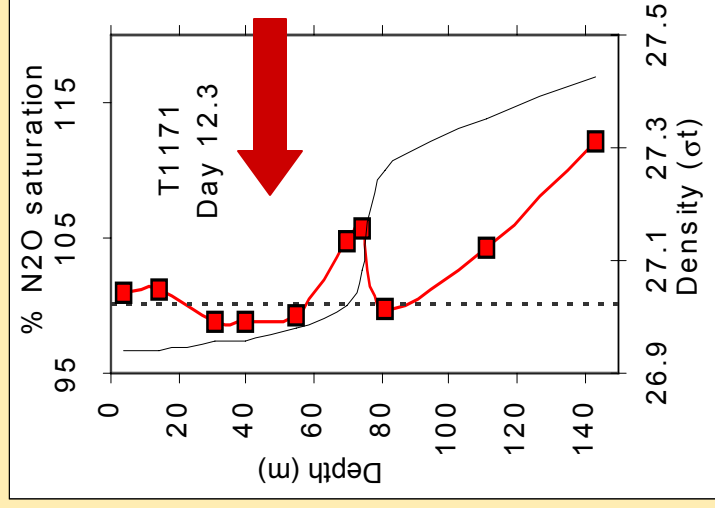
Initial conditions
matter both for
C uptake and
C sequestration

- light
- temperature
- season
- winds
- biota
- currents etc.

De Baar et al. (2005)

Multiple iron experiments resulted in variable biomass & CO₂ uptake

- what about other consequences?



Numerous biogeochemical and biophysical "side effects". Some may help combat climate change, some exacerbate it

[Andrew Watson- Univ. East Anglia]

- other greenhouse gases (DMS, CH₄, N₂O)
- biophysical effects (light)

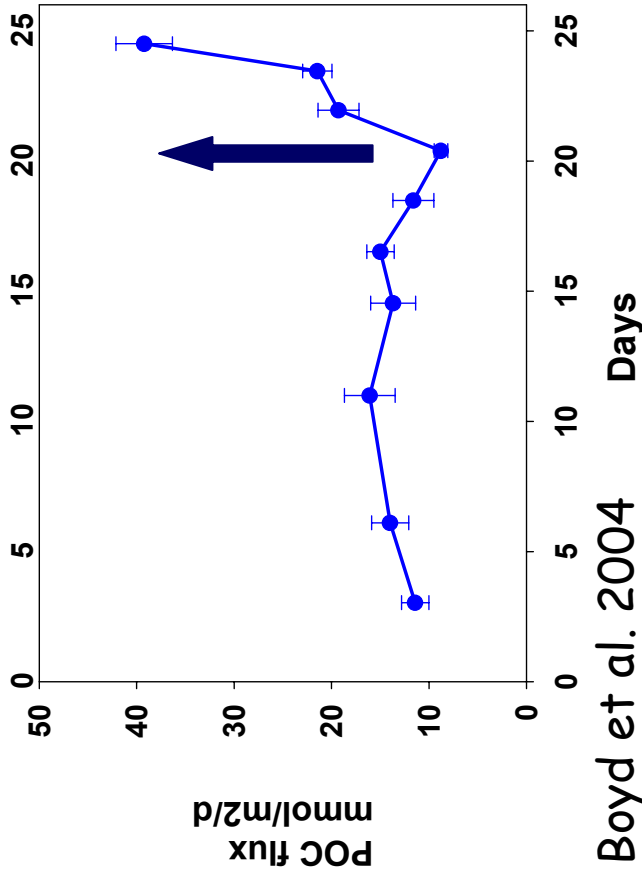
Law & Ling (2001)

What happens below the surface?

Add iron
here

Collect C
on sinking
particles
here

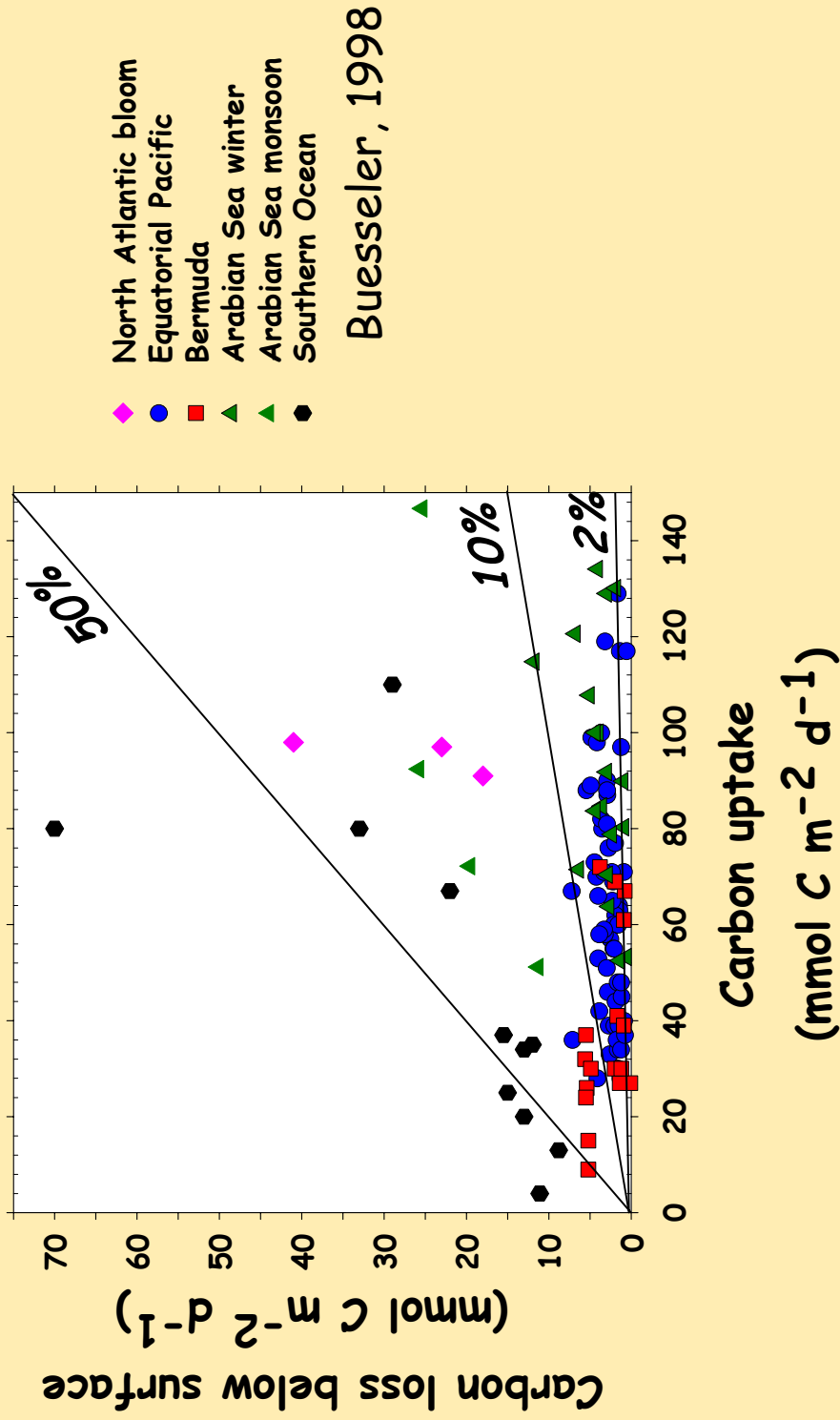
Surface
Tethered
Trap



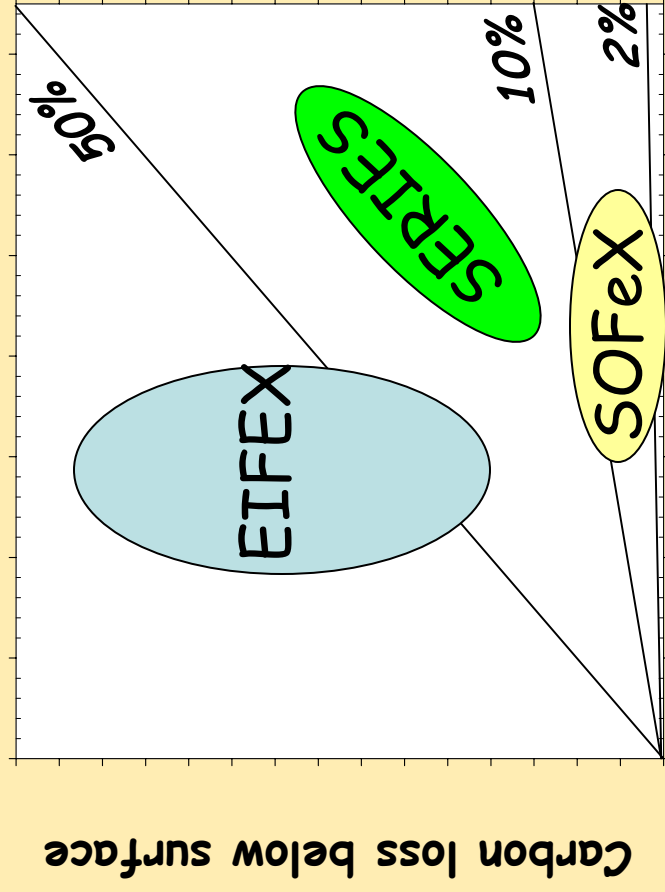
Boyd et al. 2004

- not so easy to measure
- need longer experiments

But, not all carbon
sinks out of the surface ocean

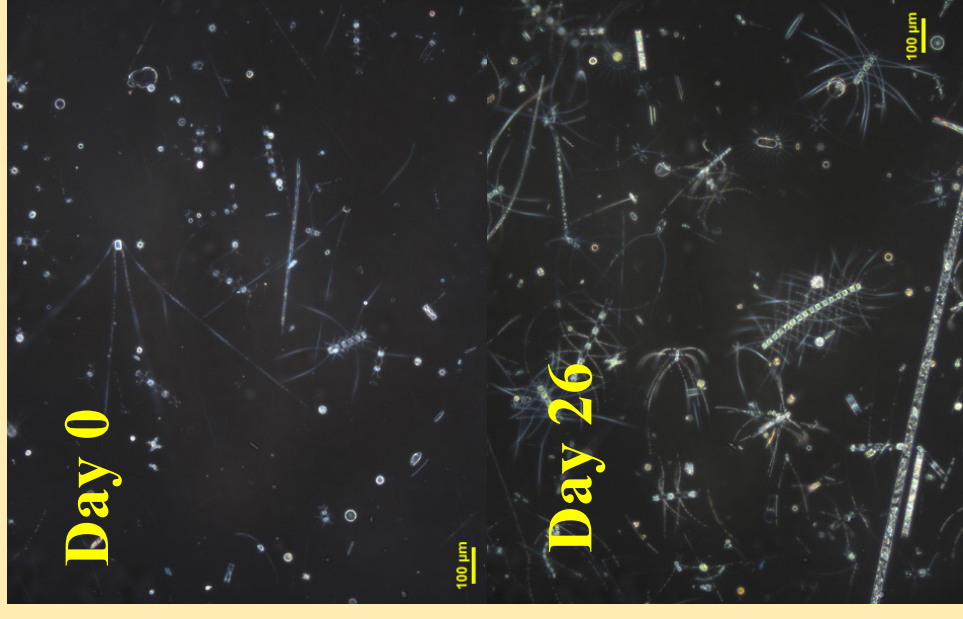


Same would apply to ocean iron fertilization

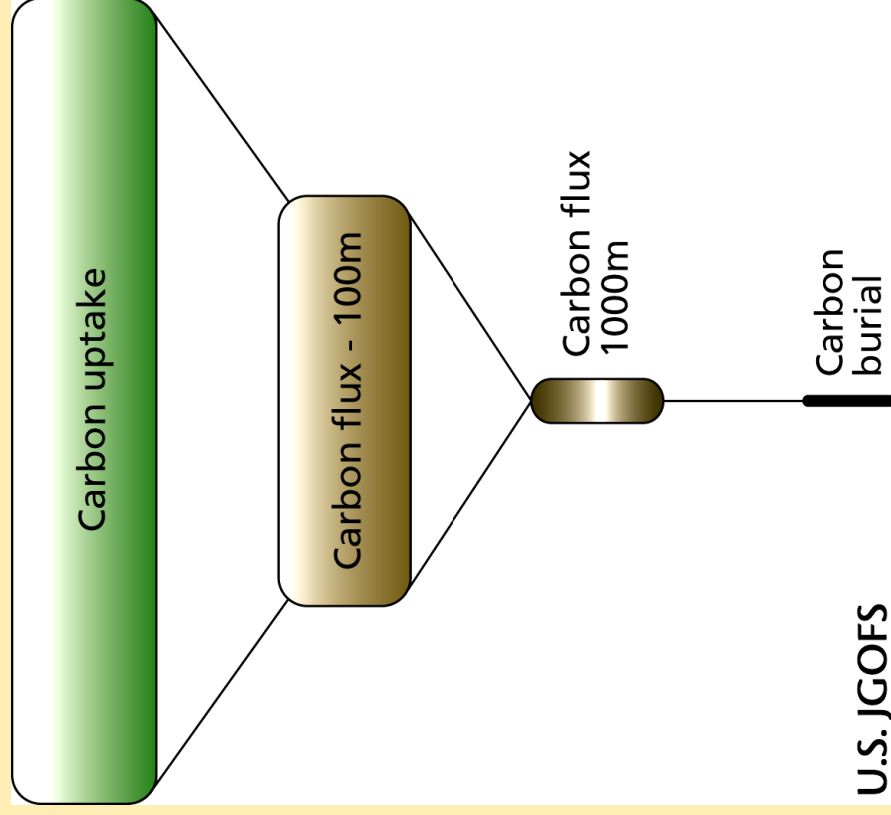


Carbon uptake

C loss from surface is variable & time matters



And not all C reaches the deep sea as required for C sequestration



CO₂ uptake

Carbon transport

below 100m

<2 to >50% (decades)

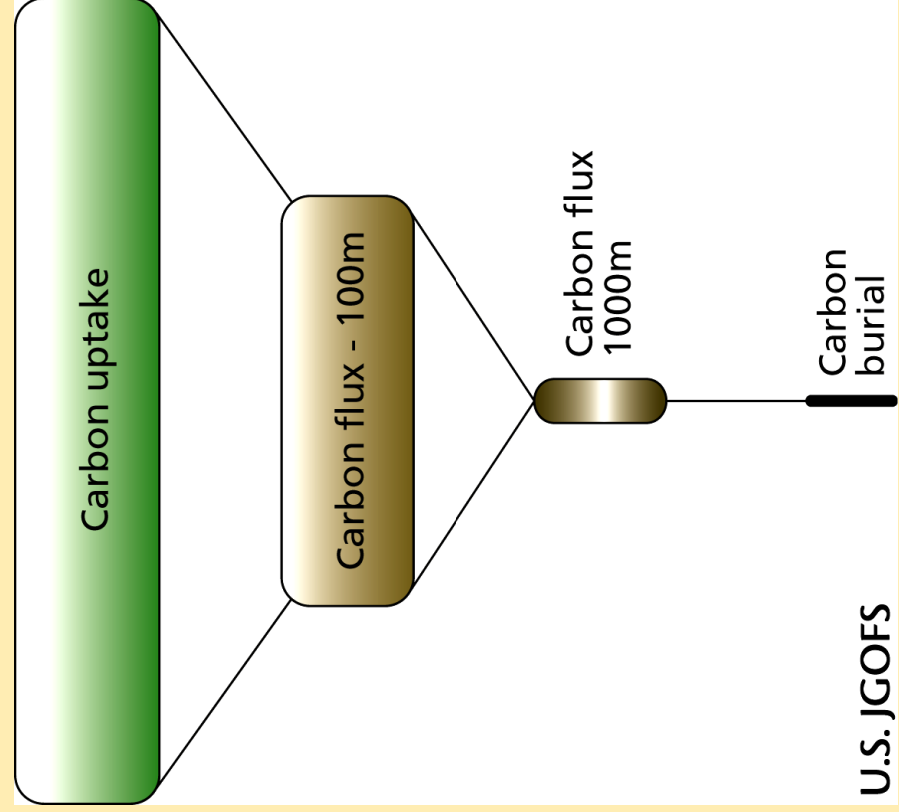
below 1000m

~1-10% (centuries)

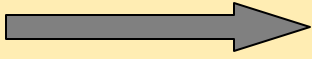
to sediments

~0.1% (millennia)

Does iron enhance carbon sequestration?



CO₂ uptake



<2 to >50% (decades)



~1-10% (centuries)

~0.1% (millennia)

**Need to stimulate both C uptake
& C transport to deep ocean**

What comes next?

Commercialization of Ocean Iron Fertilization

- here already
- Potential value of OIF may be **\$100b**



Climos- "code of conduct" & academic partners

Eli Kintisch, Oct. 11, 2007 **Science**

Planktos- "ecorestitution" claims

Feb. 13- indefinitely postponed new OIF work

Due to "highly effective disinformation campaign"

Who will regulate & validate?

What comes next?

POLICYFORUM

ENVIRONMENT

Ocean Iron Fertilization—Moving Forward in a Sea of Uncertainty

Ken O. Buesseler,^{1*} Scott C. Doney,¹ David M. Karl,² Philip W. Boyd,³ Ken Caldeira,⁴ Fei Chai,⁵ Kenneth H. Coale,⁶ Hein J. W. de Baar,⁷ Paul G. Falkowski,⁸ Kenneth S. Johnson,⁹ Richard S. Lampitt,¹⁰ Anthony F. Michaels,¹¹ S. W. A. Naqvi,¹² Victor Smetacek,¹³ Shigenobu Takeda,¹⁴ Andrew J. Watson¹⁵

It is premature to sell carbon offsets from ocean iron fertilization unless research provides the scientific foundation to evaluate risks and benefits.

11 JANUARY 2008 VOL 319 SCIENCE www.sciencemag.org
Published by AAAS

What comes next?

POLICYFORUM

ENVIRONMENT

**Ocean Iron Fertilization—Moving
Forward in a Sea of Uncertainty**

Research priorities are clear

- **Larger & longer experiments**
- **High and low nutrient regions**
- **Subsurface fate of C**
- **Other gases- O₂, N₂O, CH₄, DMS**
- **Downstream effects**
- **Improved modeling**
- **Compare costs, benefits and impacts to other
climate and carbon mitigation schemes**

What comes next?

POLICYFORUM

ENVIRONMENT

Ocean Iron Fertilization—Moving Forward in a Sea of Uncertainty

Organization of OIF projects is critical

- **Ocean scientists need to be involved**
- **Wide distribution of data and peer-review articles**
- **Abide by London Convention**
- **Multiple sponsors possible**
 - national agencies, philanthropies, commercial**
- **Clear and explicit statements of conflict of interest**
- **Premature to sell carbon offsets**

“unless there is better demonstration that OIF removes CO₂ and retains C in the ocean for quantifiable amounts of time, and with acceptable and predictable environmental impacts”

Can the oceans save the planet?

1. philosophical opposition to C offsets & use of ocean
2. scaling is key
 - single "large scale" projects (100x100 km) are small and transient relative to natural ocean C cycle
 - would need to regulate or expect tragedy of the commons
3. other climate mitigation options, including no action,
 - sea level rise, acidification, temperature, UV

boston.com

US corn boom threatens sea life Fertilizer runoff polluting Gulf

By Henry C. Jackson, Associated Press | December 18, 2007

JEFFERSON, Iowa - Because of rising demand for ethanol, American farmers are growing more corn than at any time since the Depression. And sea life in the Gulf of Mexico is paying the price.

THIS STORY HAS BEEN FORMATTED FOR EASY PRINTING

The Boston Globe

Can the oceans save the planet?

1. philosophical opposition to C offsets & use of ocean
2. scaling is key
3. other climate mitigation options, including no action, have an impact on the oceans
4. markets moving ahead with or w/o good science
 - small C offset projects are big business
5. watch out for bold claims on both sides!
 - + enhanced fisheries & food for whales
 - harmful algal blooms, anoxia and dead fish

Ocean Iron Fertilization

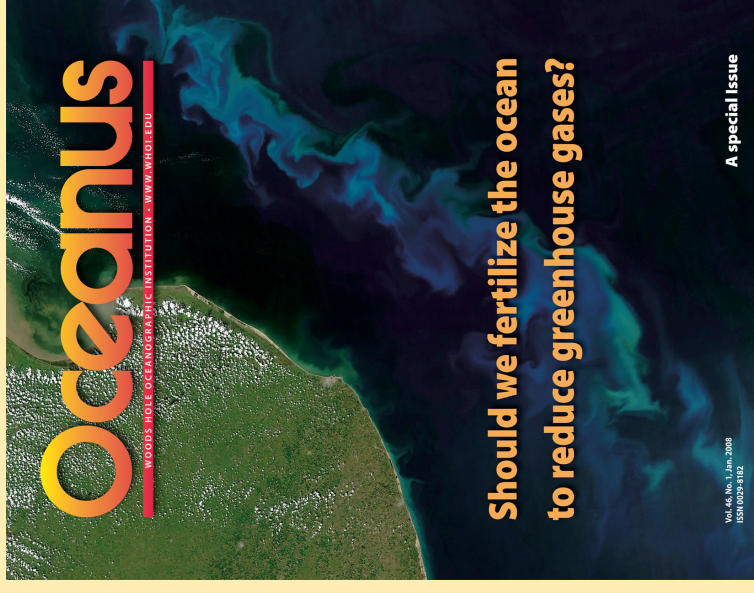
Science is *clear* regarding-

1. iron can stimulate plankton blooms

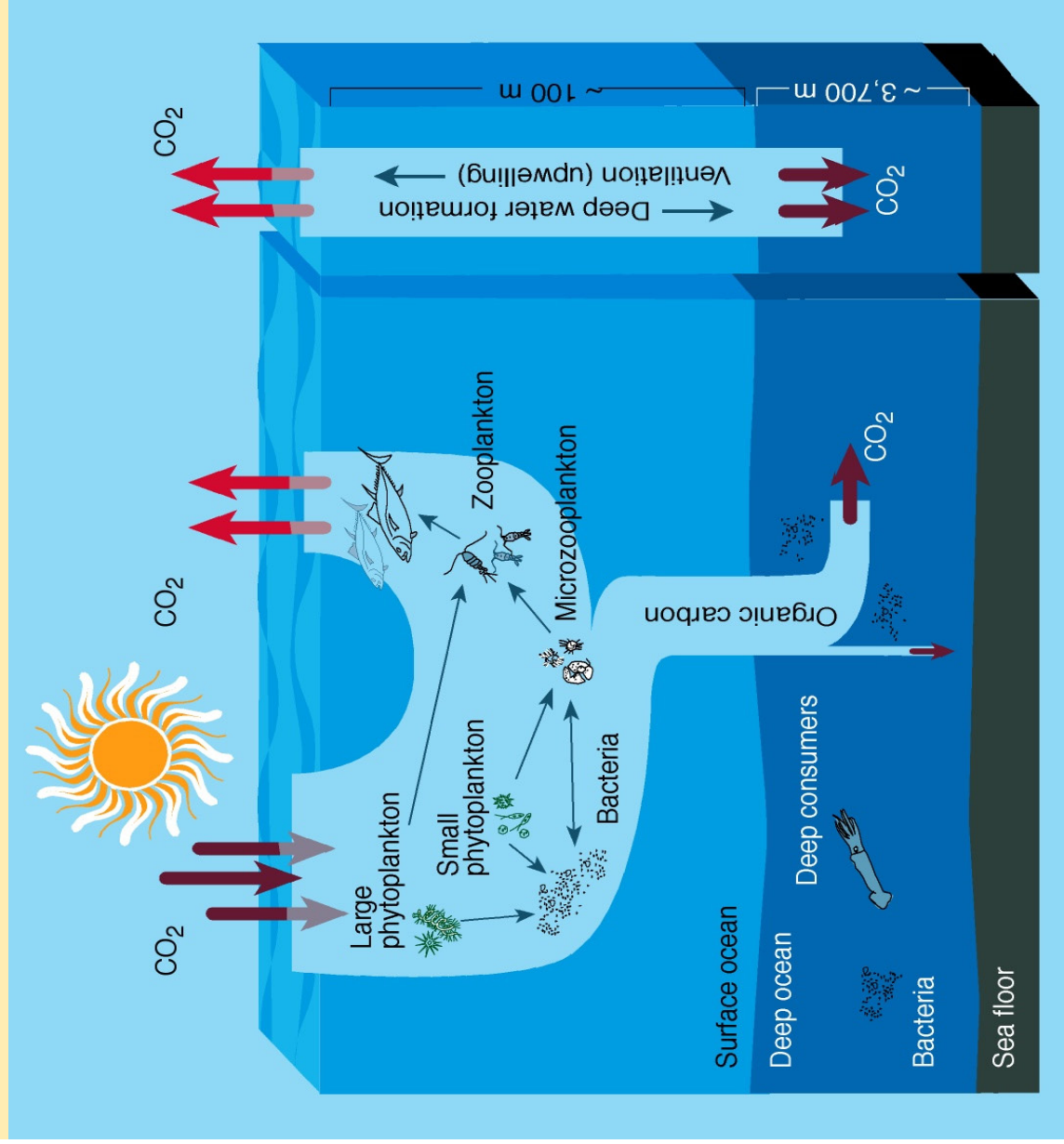
Science is *unclear* regarding-

1. will it work?
 - to sequester atmospheric C into deep ocean
2. what are the ecological consequences?
 - intended & unintended
3. what is variability/predictability?
 - especially at larger & longer scales

*** New *experiments* would answer some of these questions**



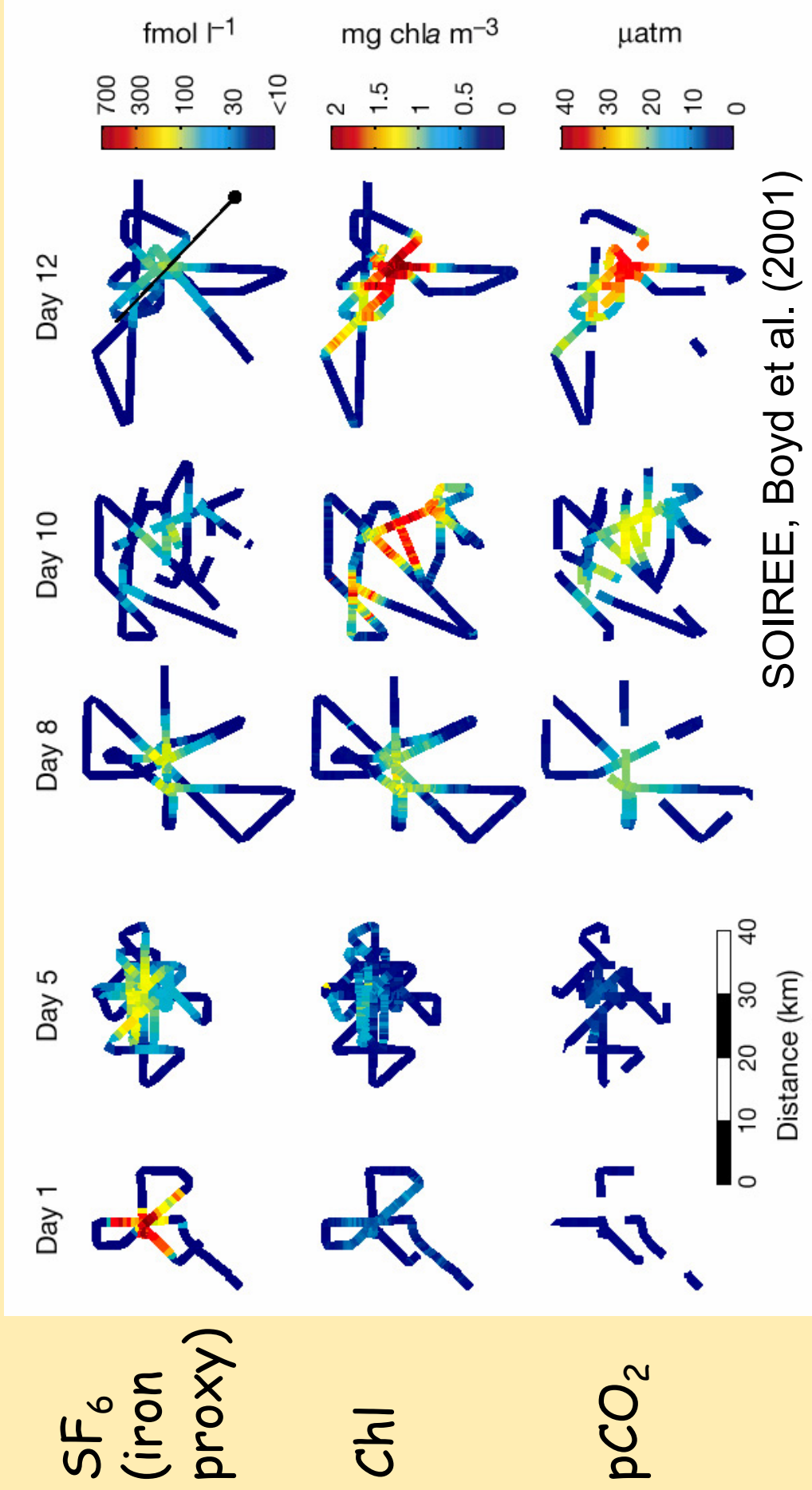
Can iron (dust) enhance ocean's "biological pump"?



- natural pathway for rapid C sequestration in deep sea

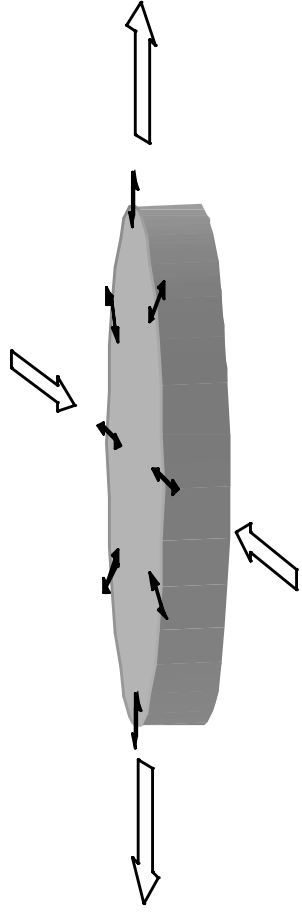
- turn off biological pump and expect 200 ppmv increase atm. CO₂

Multiple iron experiments succeeded in showing surface biological response and CO₂ decrease after iron additions



Multiple iron experiments resulted in variable responses

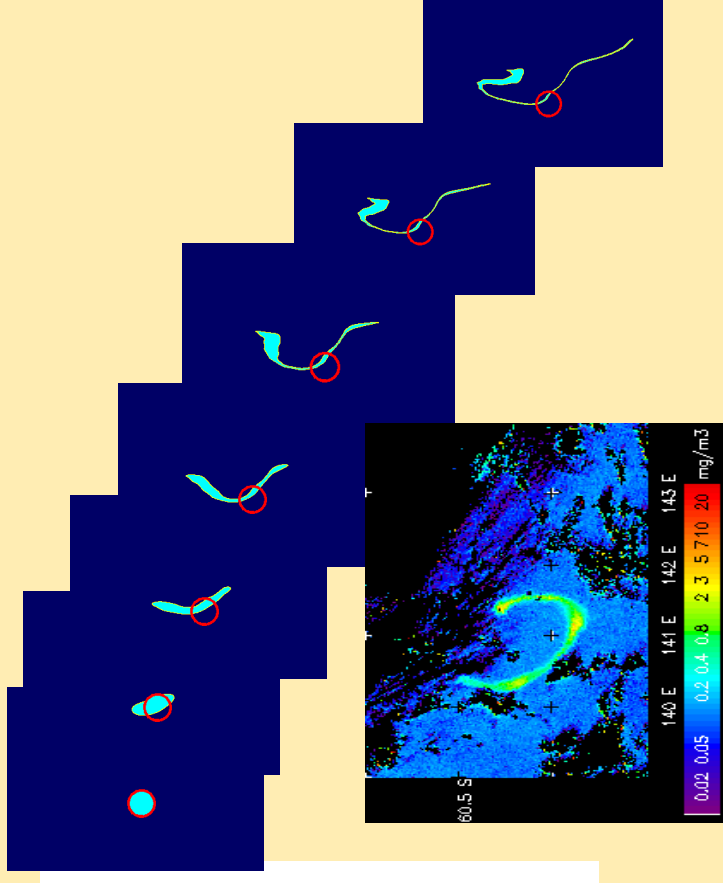
1. unresolved issues related to ocean mixing & dilution



↔ Stretching via horizontal flows

↔ Mixing of water by horizontal diffusion

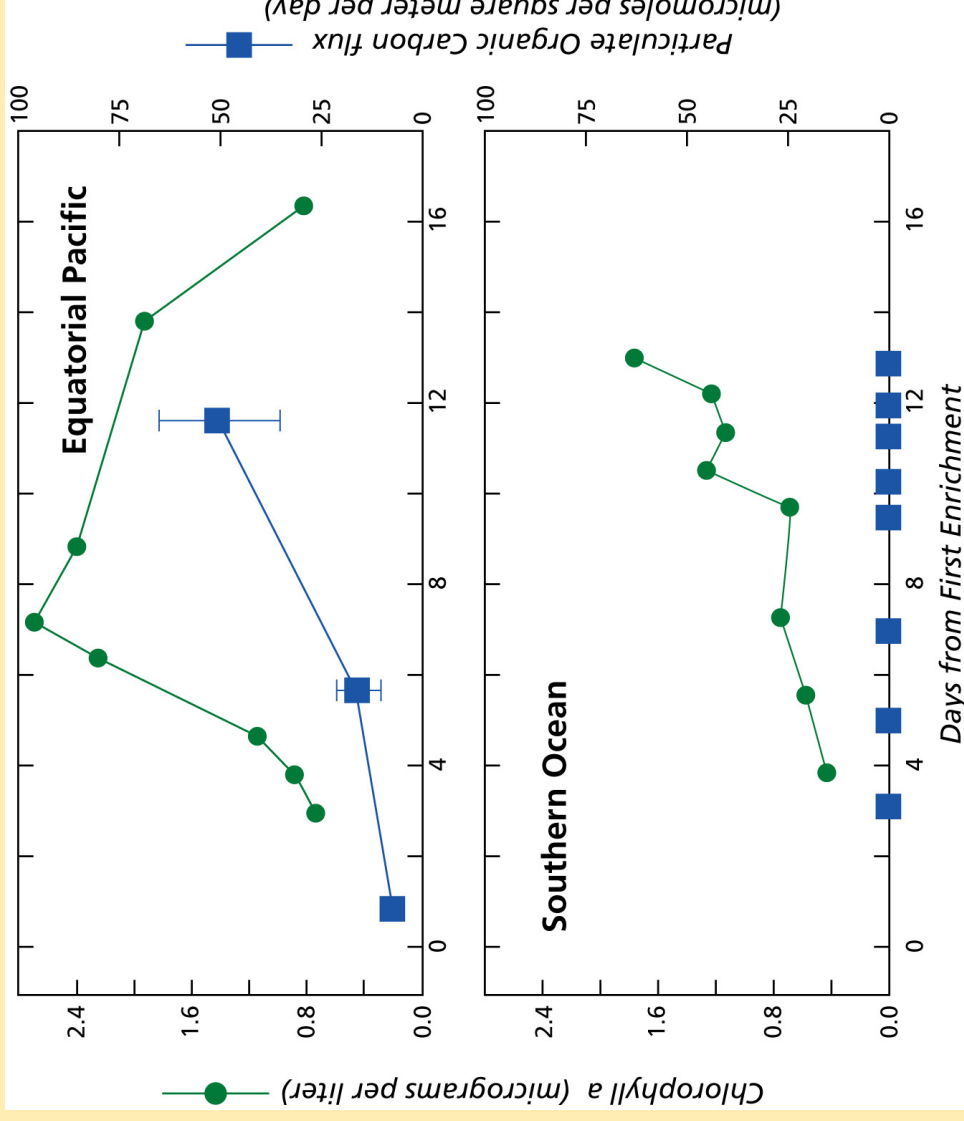
Abraham, Boyd, Laws & others



2. experiments were short relative to natural ocean blooms

- important for carbon transport to deep sea

Add iron - more phytoplankton biomass (chlorophyll)
- but not necessarily enhanced C sequestration (C flux)



Varies - w/season, w/ecosystem, w/depth
& duration of observations is key

Exploring Ocean Iron Fertilization: the scientific, economic, legal and political basis

Woods Hole, MA September 26-27, 2007

Will it work?

What are the environmental consequences?

Can carbon offsets be verified?

What is legal, policy, economic framework?

What comes next?

**<http://www.whoi.edu/conference/OceanIronFertilization>
- video, slides, resources, links, press, articles**