

# ocean**iron**fertilization

come to listen

learn

debate

explore



## Ocean Fertilization Ironing Out Uncertainties in Climate Engineering

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Woods Hole Oceanographic Institution

**Elisabeth and Henry Morss Jr. Colloquium**

*"there is not a living cell that will remain unaffected in the next century by what humans do and fail to do"*



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## Outline

Rising carbon dioxide ( $\text{CO}_2$ )

Ocean iron fertilization- background & history

Science results from prior experiments

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

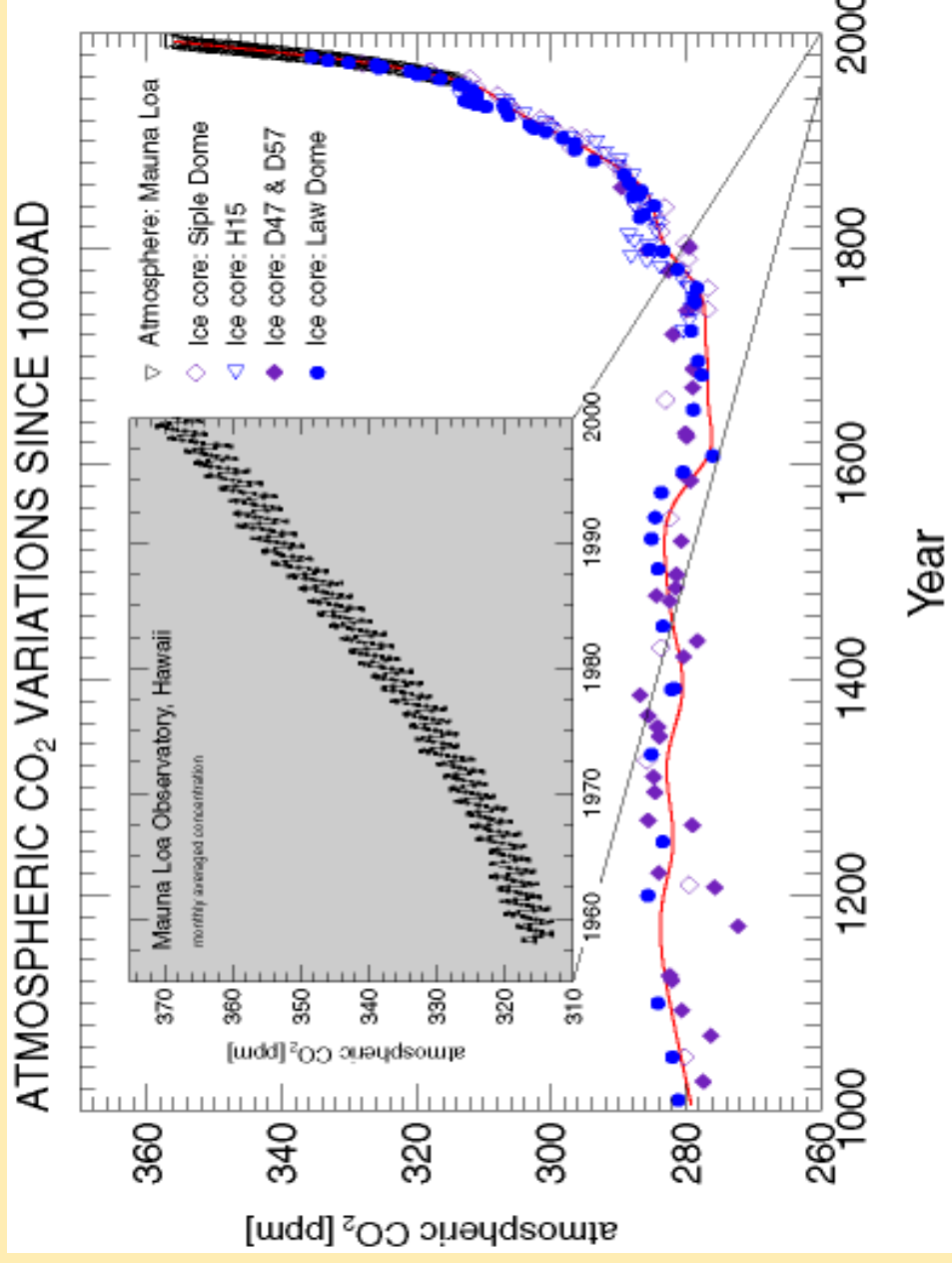
September 26-27, 2007

Legal, economic issues coming out of the meeting

*After talk- Q&A/Panel: Doney, Kite-Powell, KB*



# Atmospheric CO<sub>2</sub> is rising due to human activities



CO<sub>2</sub> is a greenhouse gas,  
so rising CO<sub>2</sub> will impact climate

# Can we stabilize atmospheric carbon dioxide?

No single "silver bullet"

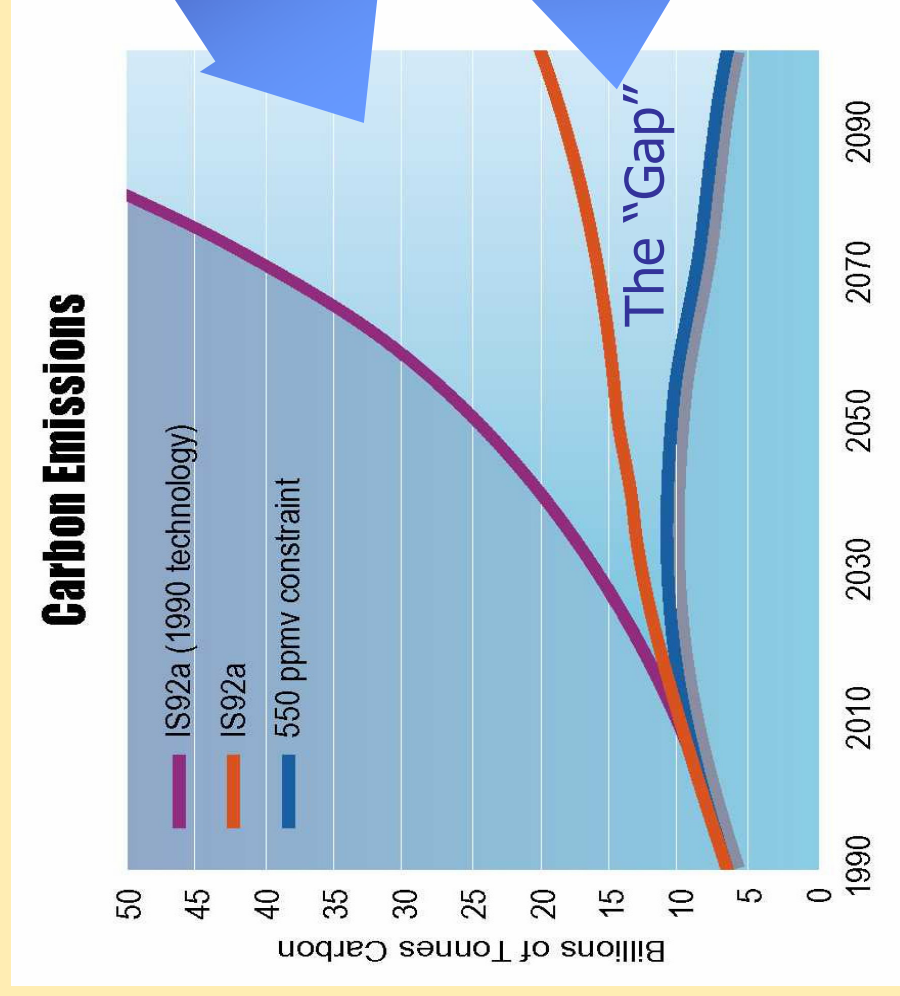
Need to consider reducing sources and enhancing sinks

## Assumed advances in familiar technologies

- Fossil fuels
- End use energy
- Nuclear
- Renewables

## Less familiar technologies

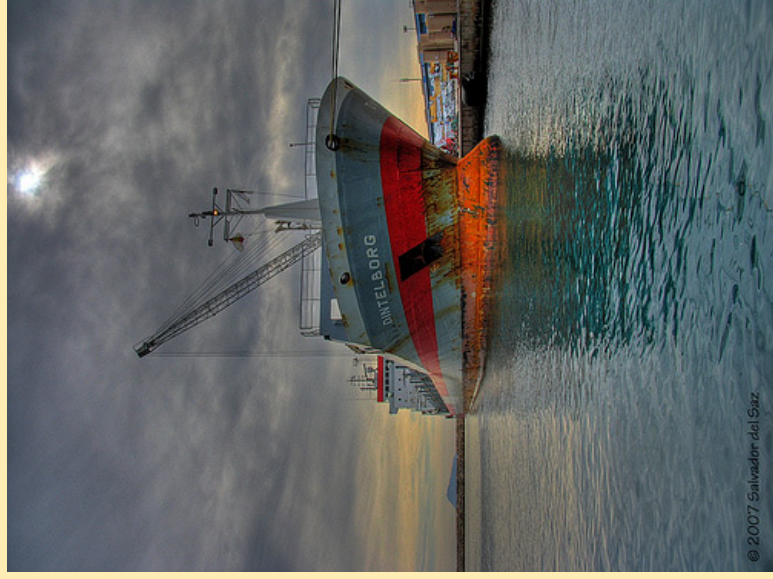
- Carbon capture & disposal
- H<sub>2</sub> and adv. transportation
- Biotechnologies
- Soils, Bioenergy, adv. Biological energy
- Land/**ocean carbon sequestration**



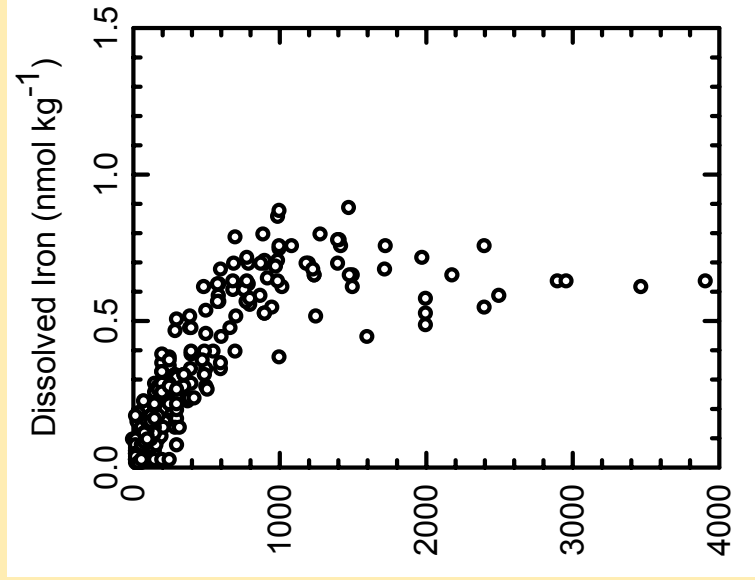
# What is ocean iron fertilization?

## History

Challenge-  
measuring iron on a rusty ship!



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



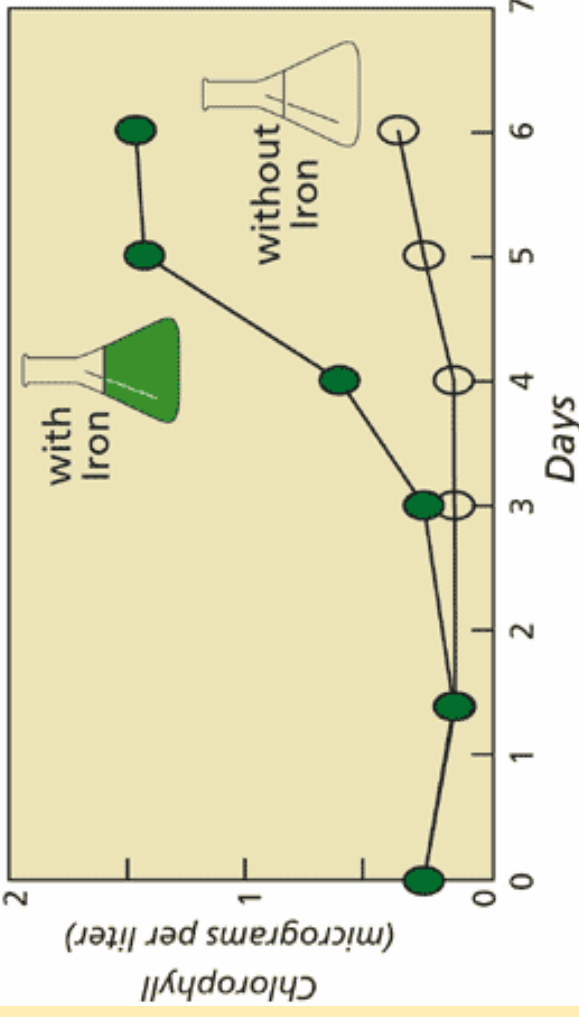
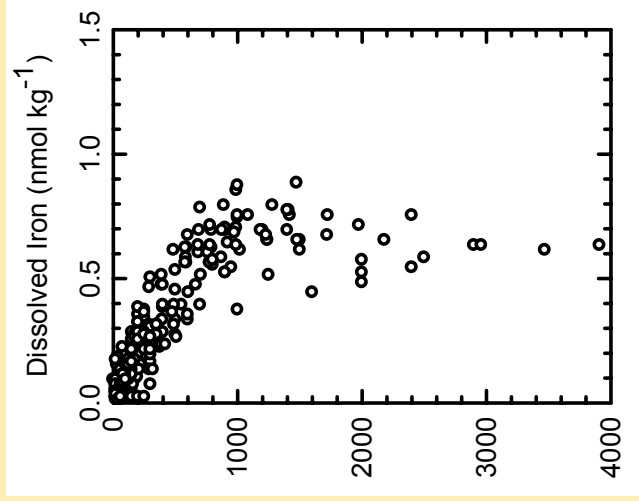
*(regional differences)*

# What is ocean iron fertilization?

## History

extremely low iron in surface ocean

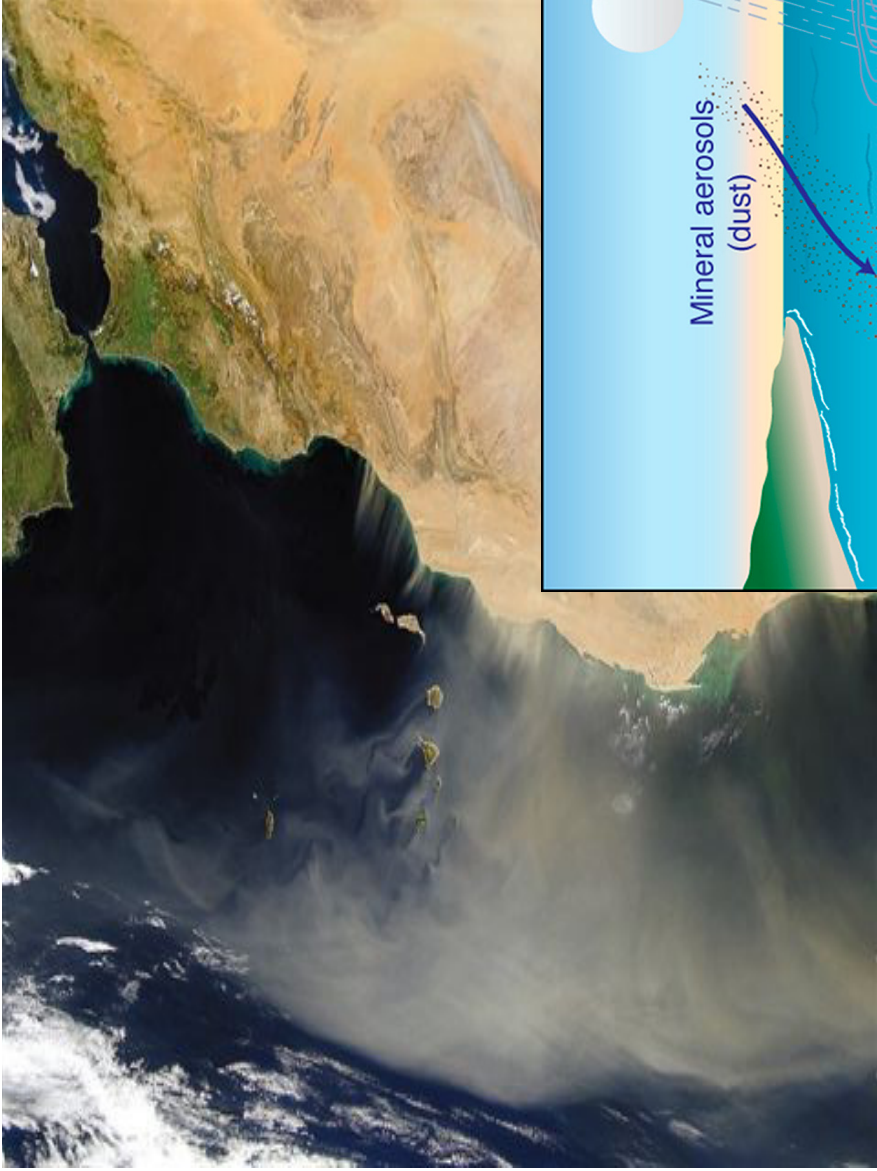
& adding iron can stimulate phytoplankton growth



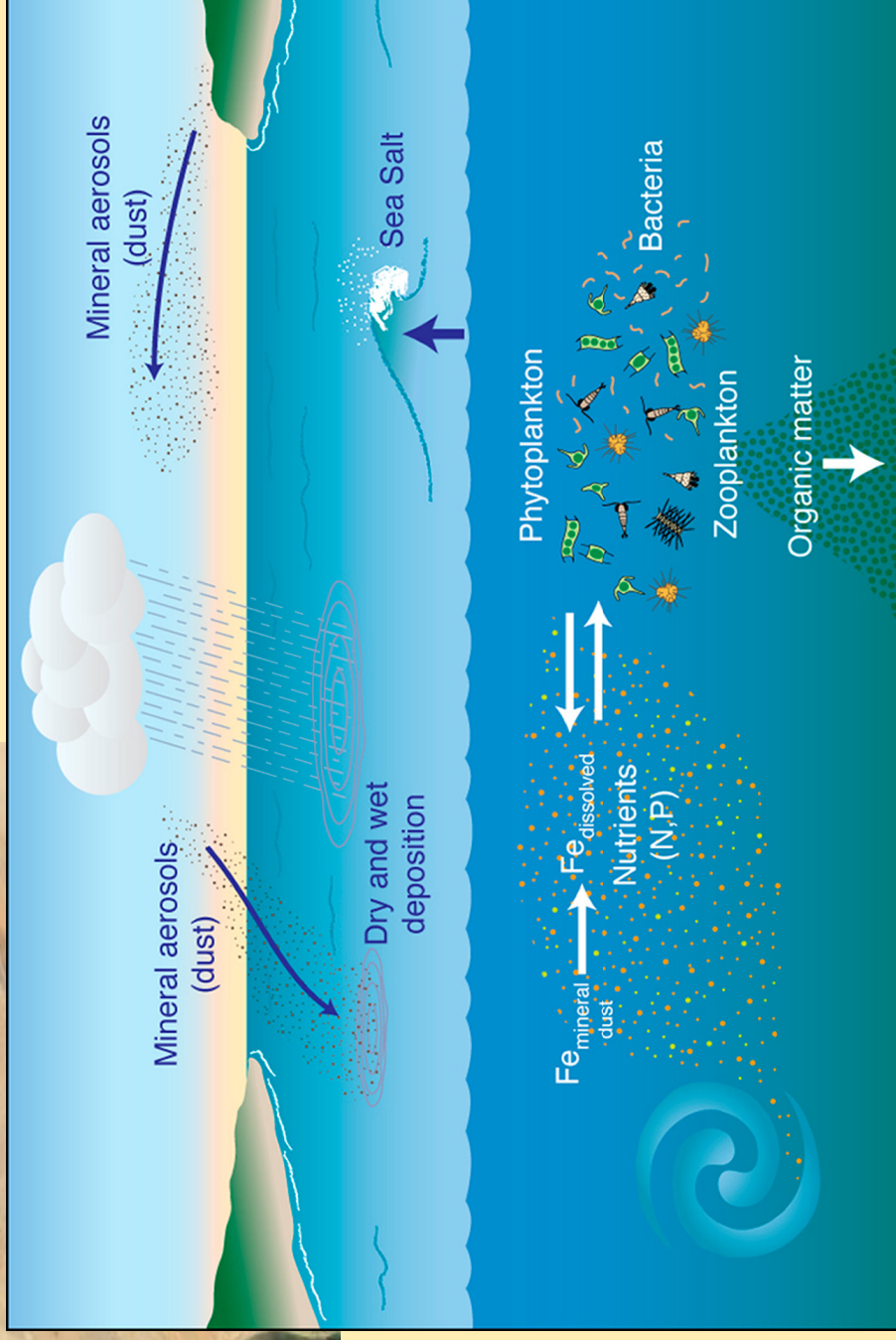
*A little iron goes a long way!*

**Dust is a  
major  
source of  
iron to the  
ocean**





**Dust is a major source of iron to the ocean**



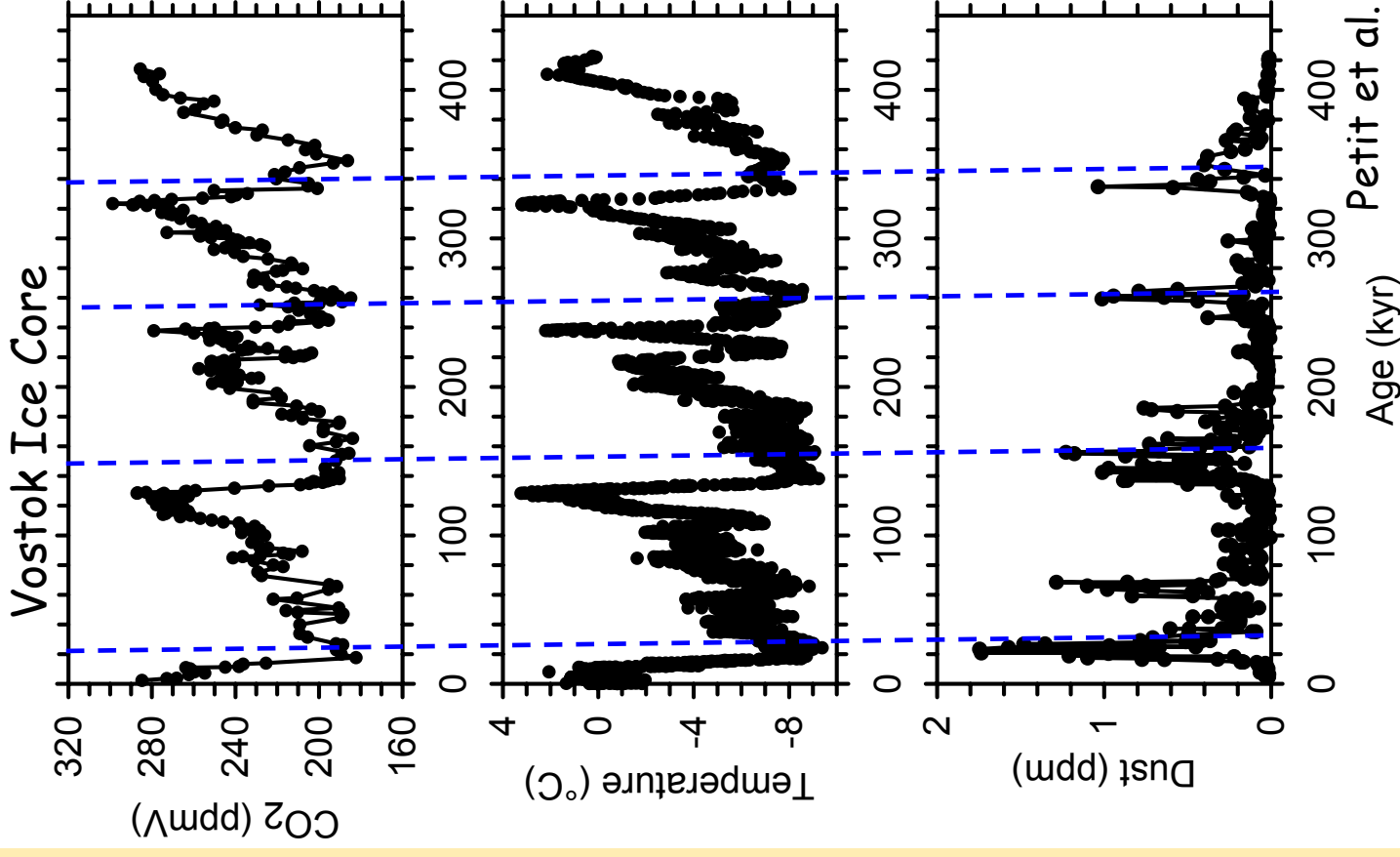
**Dust born iron stimulates marine plankton growth and carbon flux to the deep sea**

The Iron Hypothesis-  
"Give me half a tanker  
of iron and I'll give you  
the next ice age"

John Martin



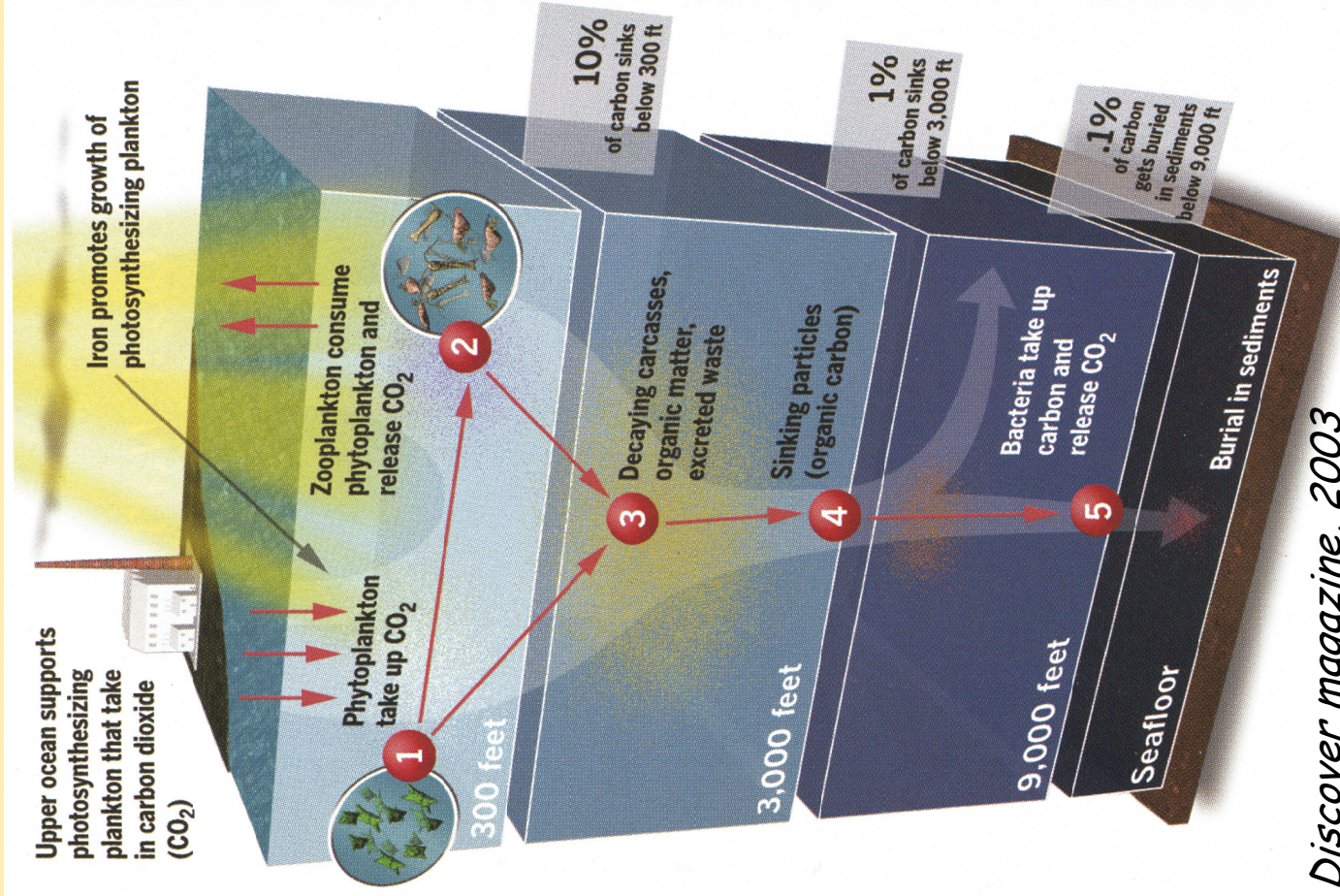
High dust (high Fe) = low CO<sub>2</sub>  
& low Temp.



Can we geengineer the ocean to become a larger C sink by adding iron "fertilizer"?

Two processes are needed to impact atmospheric CO<sub>2</sub> via iron additions

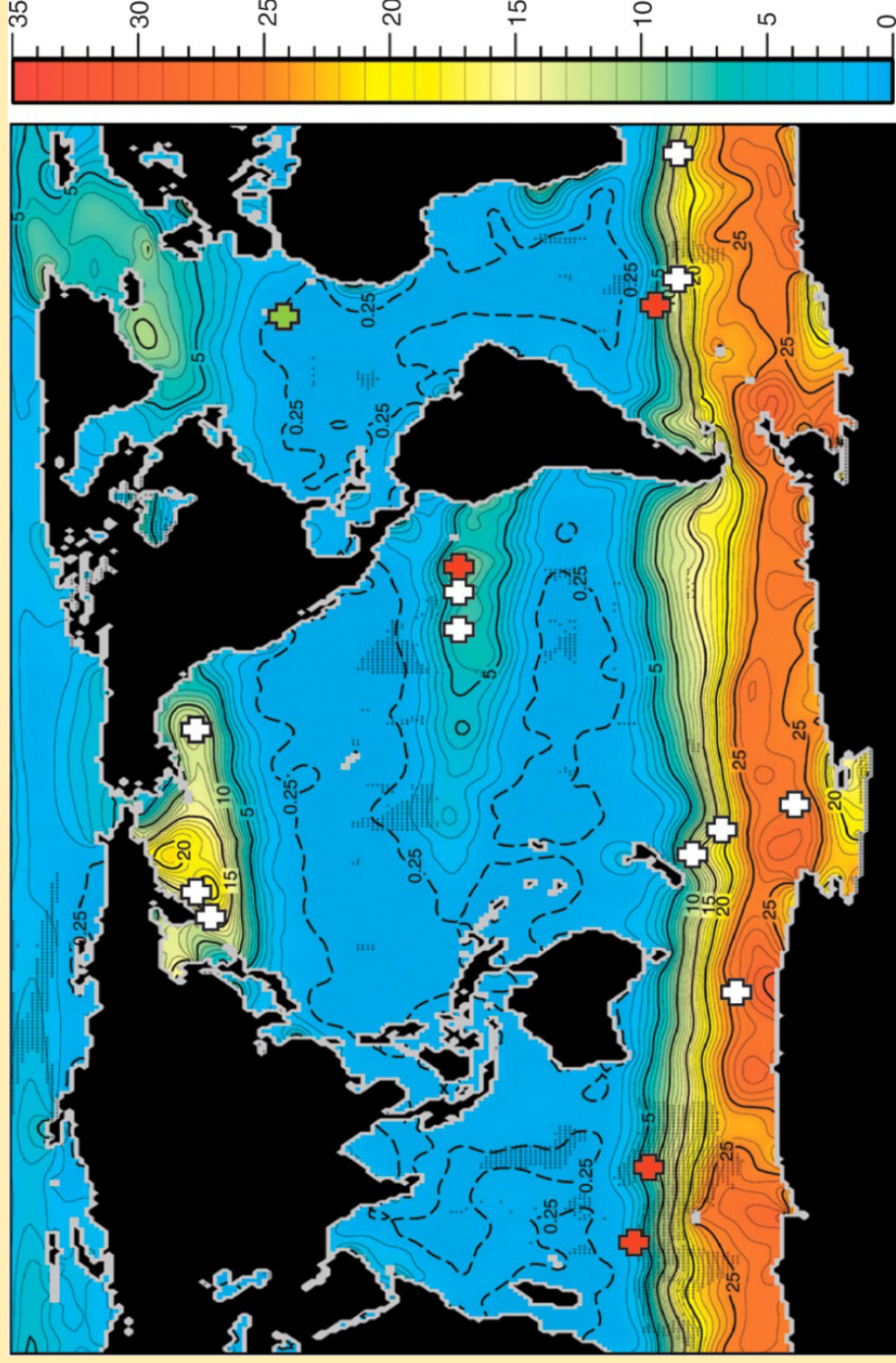
1. Stimulate algal growth
  - relatively well known
2. Enhance carbon flux to the deep-sea
  - little known, hard to measure, key to C credits



Discover magazine, 2003

GRAPHIC BY DON FOLEY

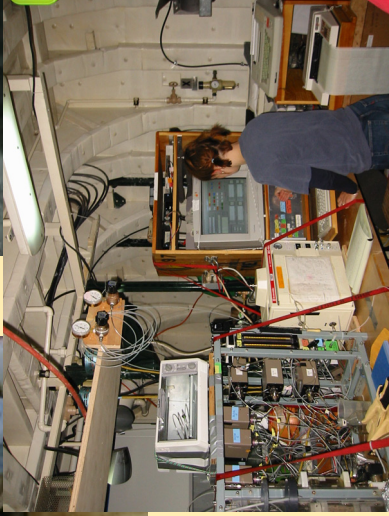
# 12 major iron fertilization experiments & studies of natural Fe sources



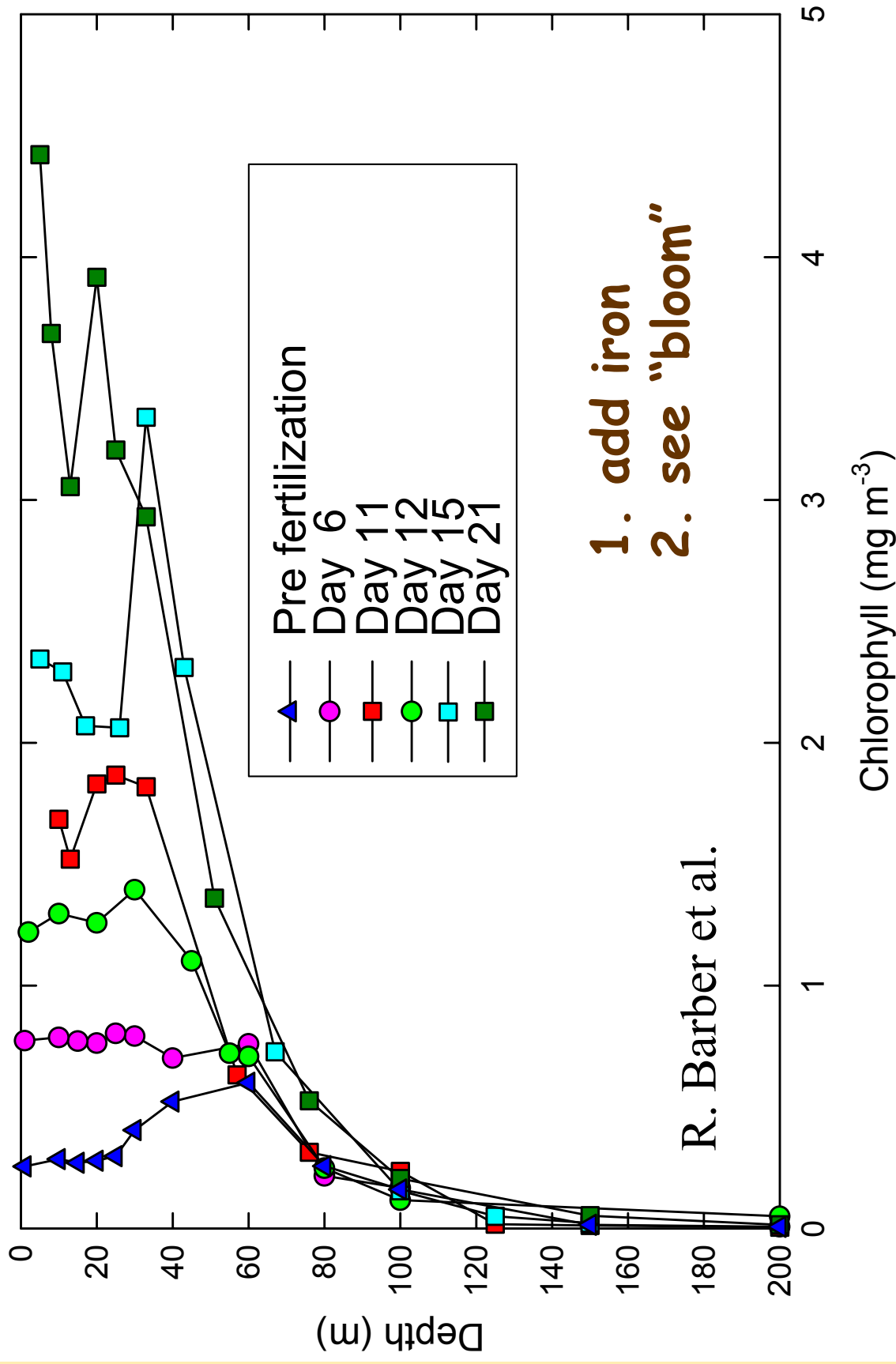
P. W. Boyd et al., Science 315, 612-617 (2007)

Map of surface ocean nitrate

12 major field experiments- take a lot of effort!



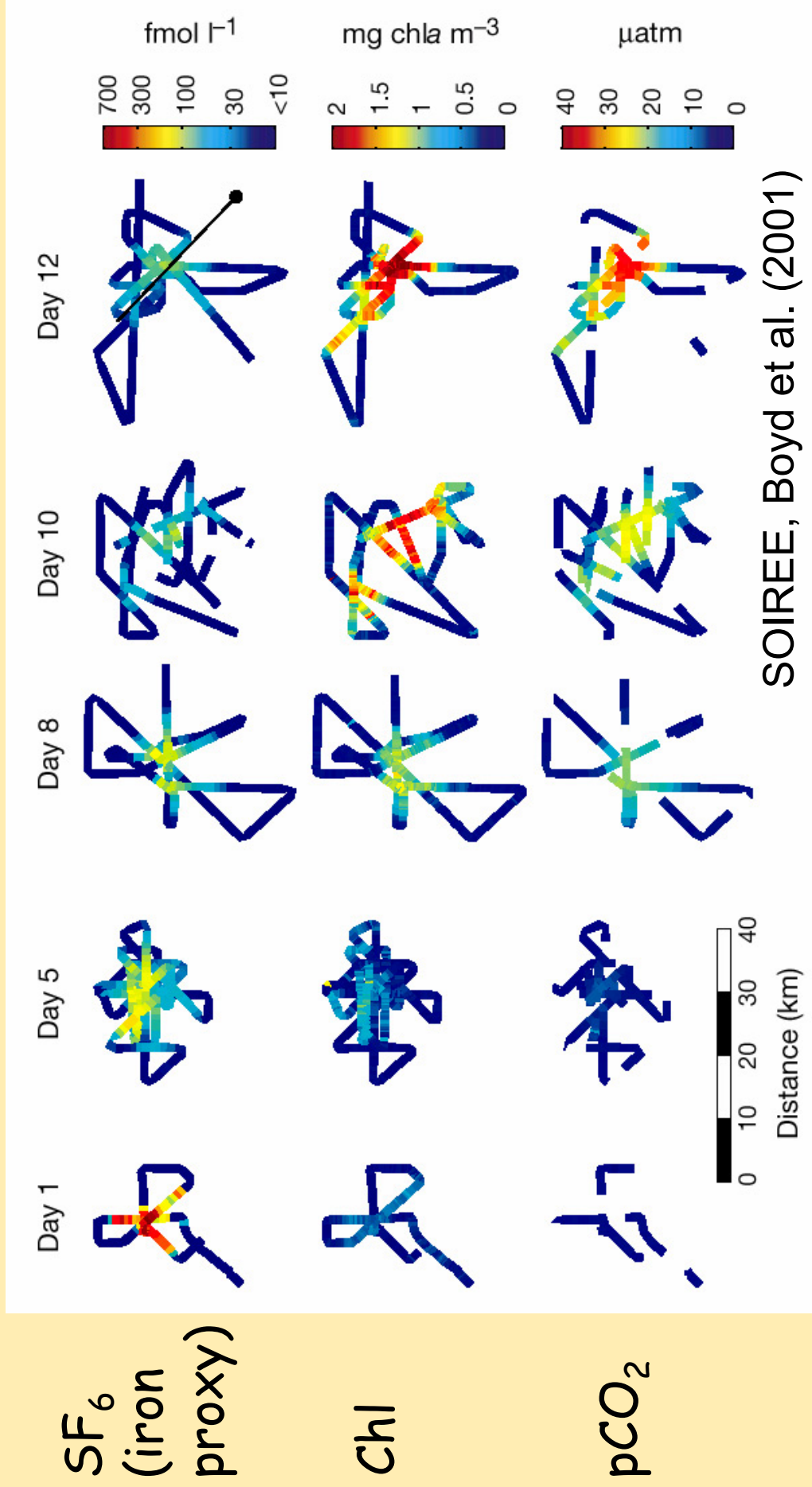
# Increase in phytoplankton seen after iron addition



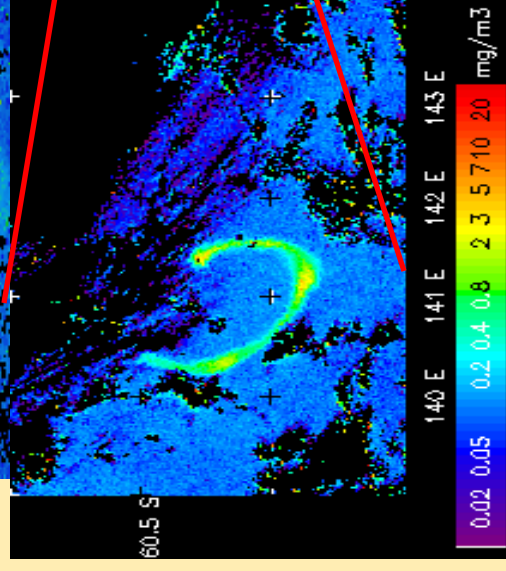
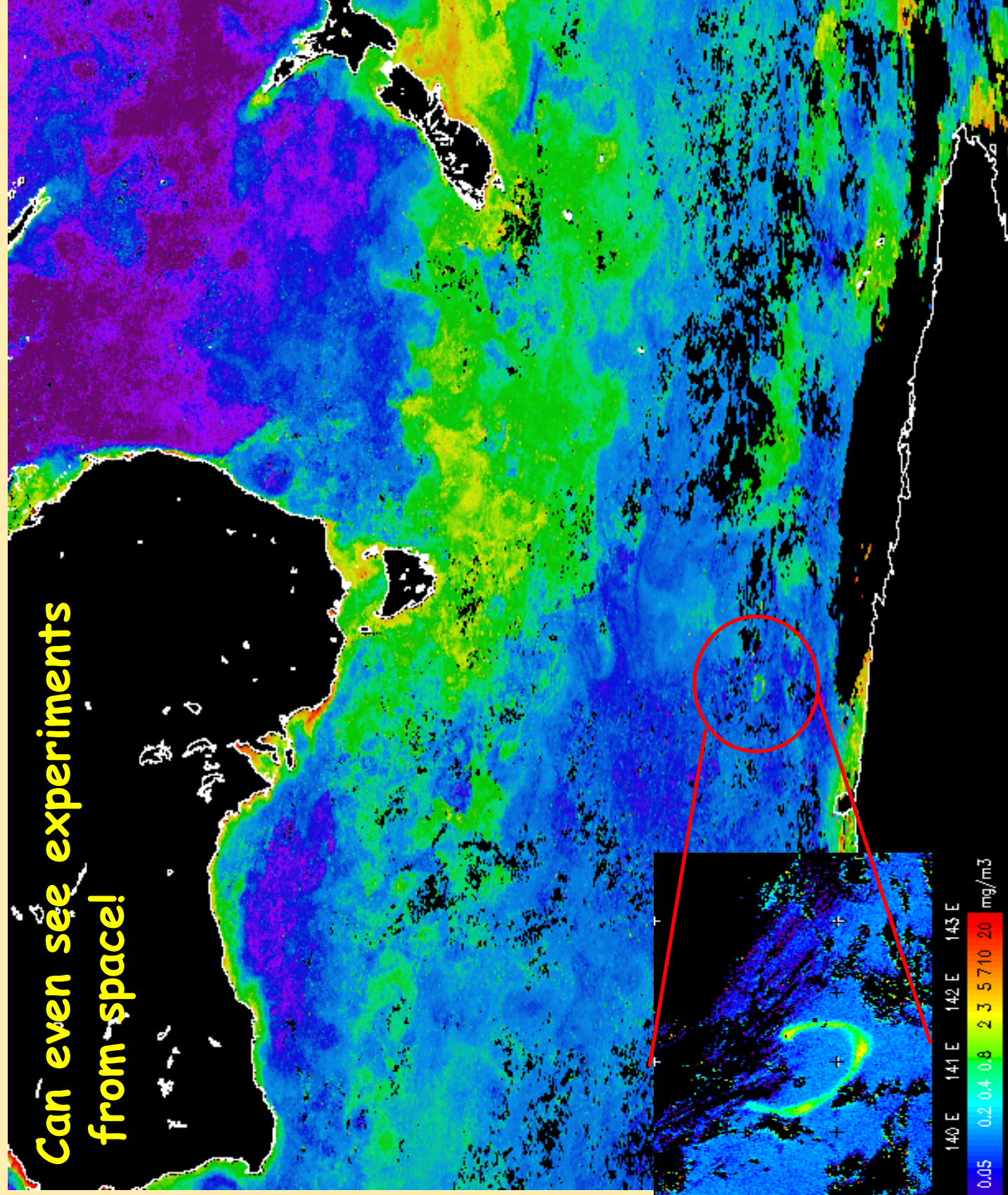
R. Barber et al.

1. add iron
2. see "bloom"

# Multiple iron experiments succeeded in showing surface biological response and CO<sub>2</sub> decrease after iron additions

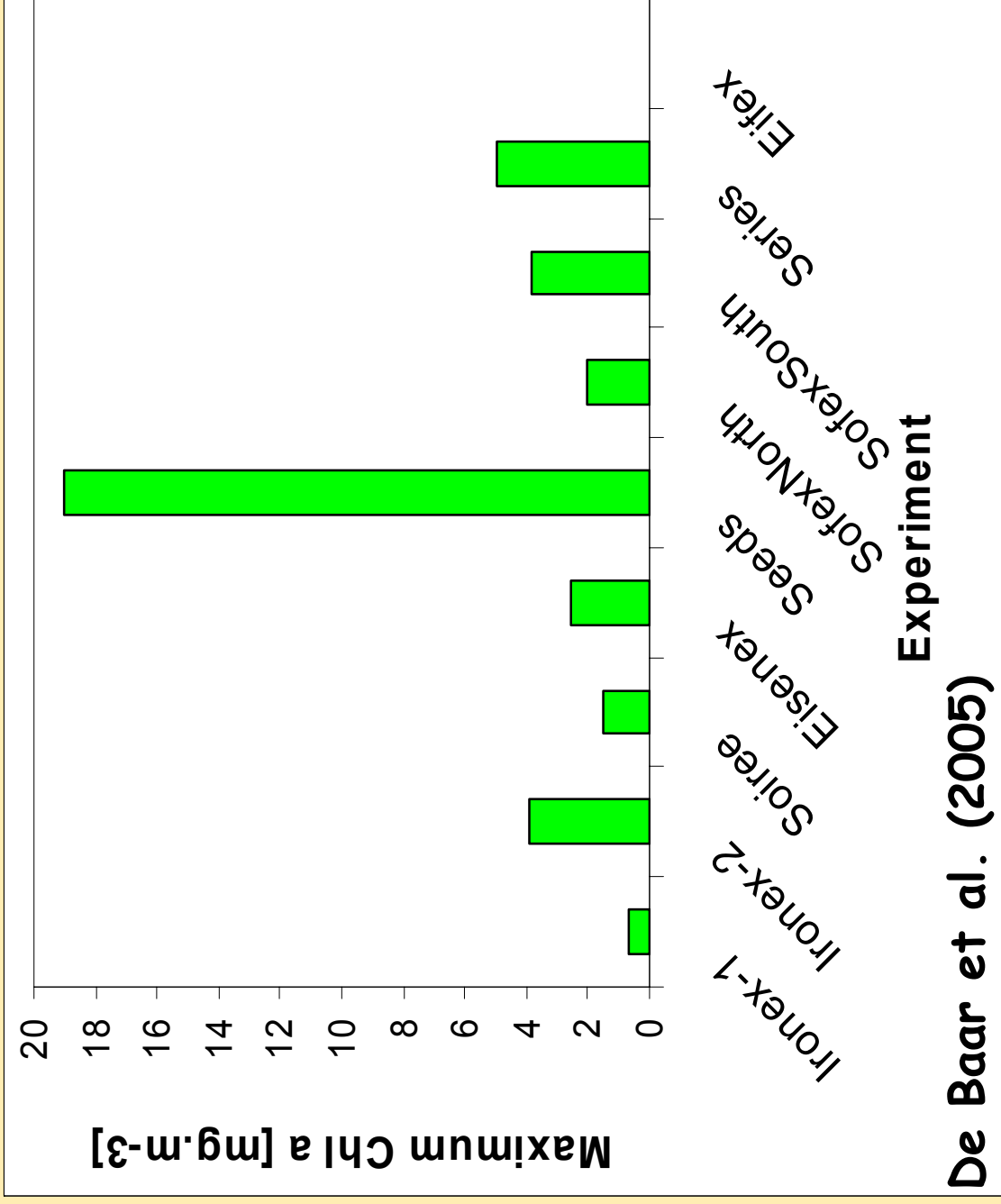


Can even see experiments  
from space!



# Location, location, location....

[Phil Boyd- U. Dunedin, NZ]

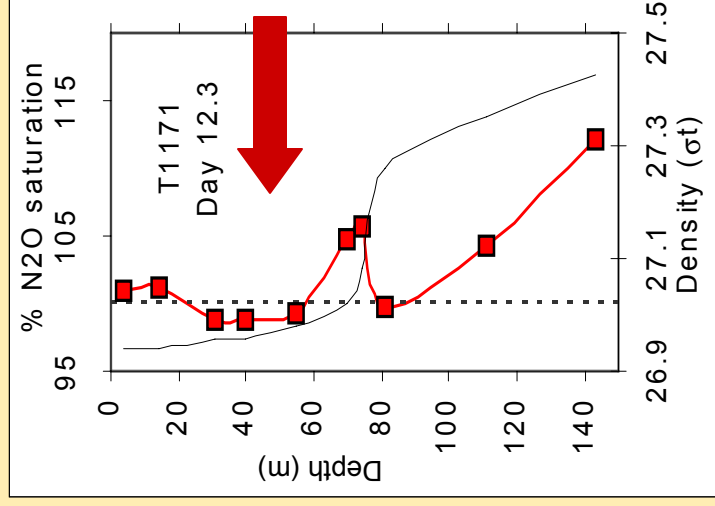


Impact of  
initial  
conditions  
- light  
- temp.  
- season  
- winds  
- biota  
- currents  
etc.

De Baar et al. (2005)

# Multiple iron experiments resulted in variable biomass & CO<sub>2</sub> uptake

- biomass increase is an intended ecological response
- what about other consequences?



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

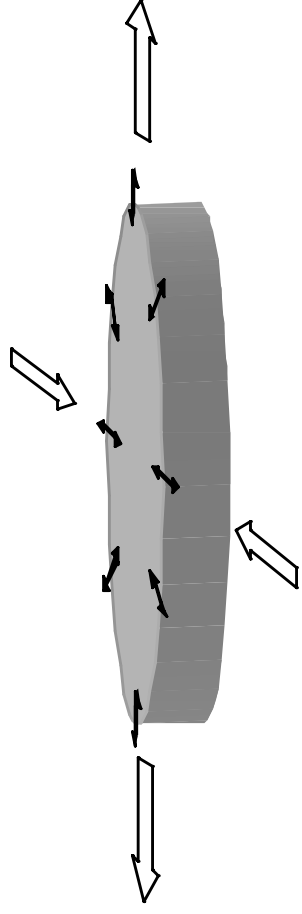
*[Andrew Watson- Univ. East Anglia]*

- other greenhouse gases (DMS, CH<sub>4</sub>, N<sub>2</sub>O)
- biophysical effects (light)

**Law & Ling (2001)**

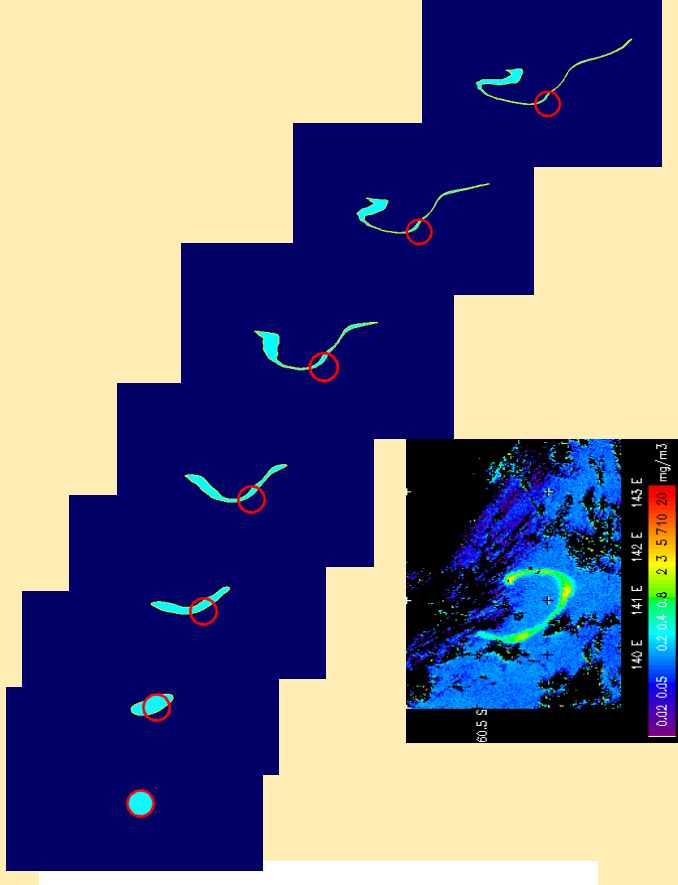
# Multiple iron experiments resulted in variable responses

## 1. unresolved issues related to ocean mixing & dilution



↔ Stretching via horizontal flows

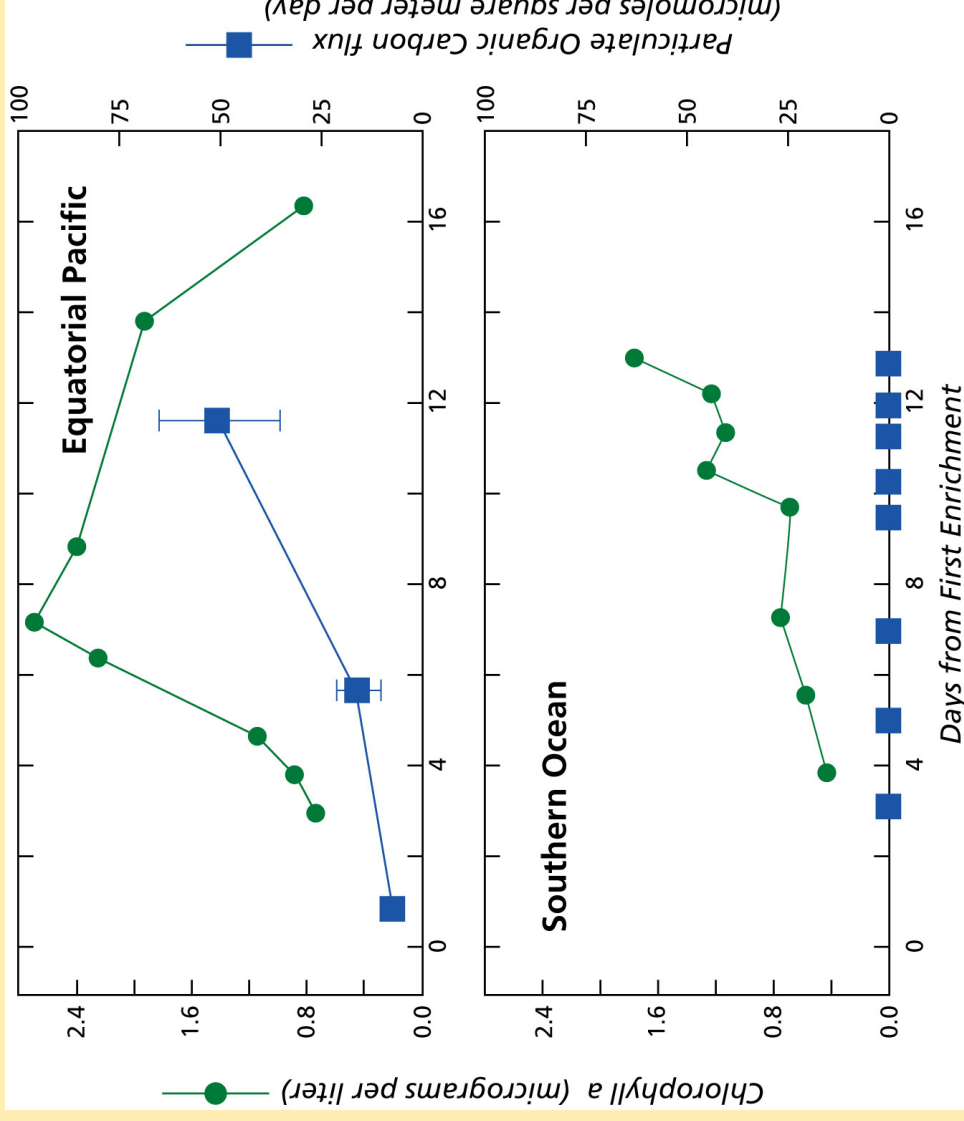
↔ Mixing of water by horizontal diffusion



## 2. experiments were short relative to natural ocean blooms

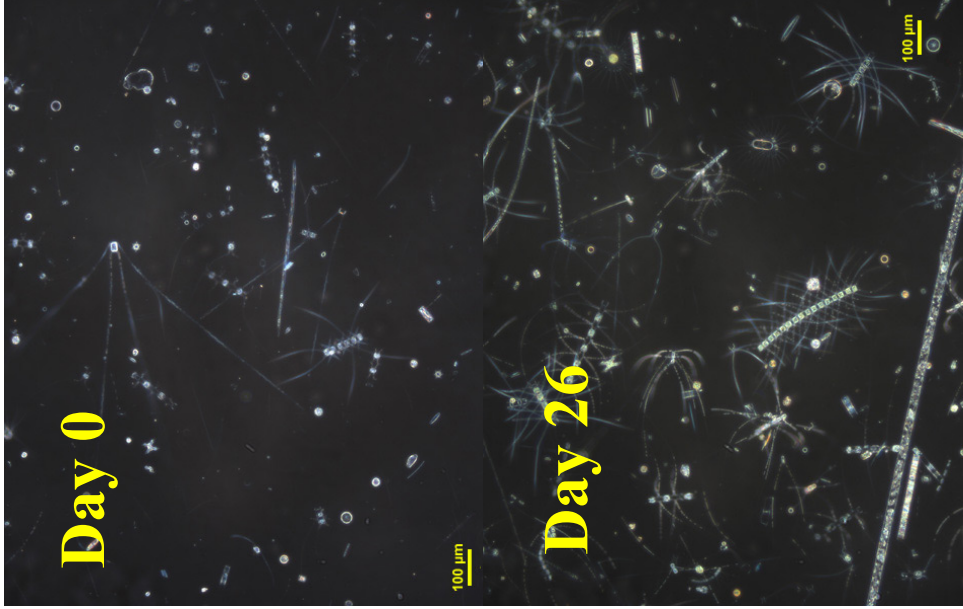
- important for carbon export to deep sea

**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**

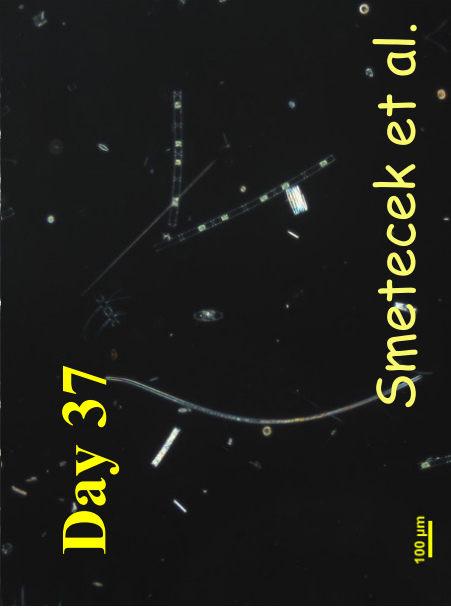
**Day 0**



**Day 26**



**Day 37**



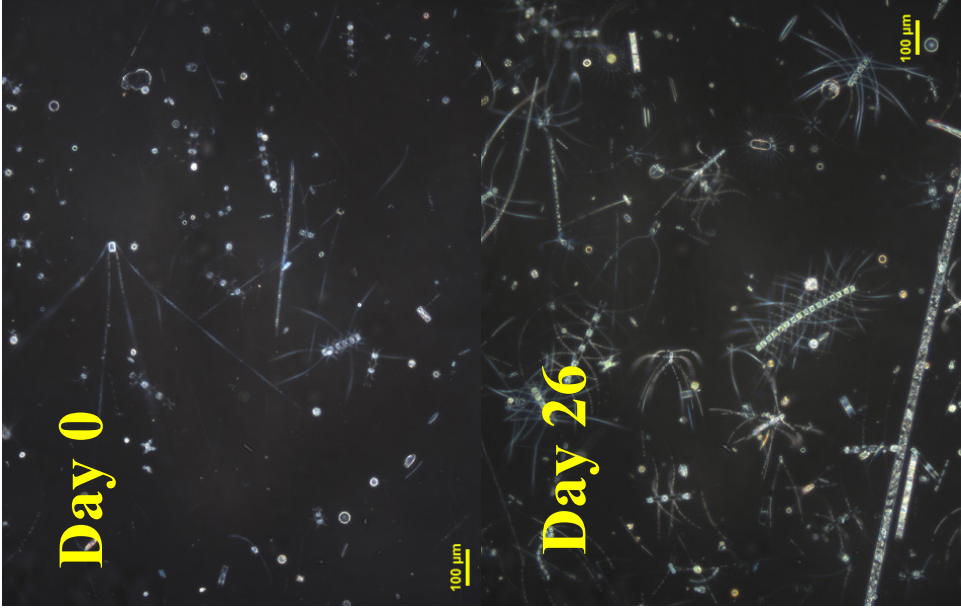
Smetceck et al.

**Longer experiments are needed**

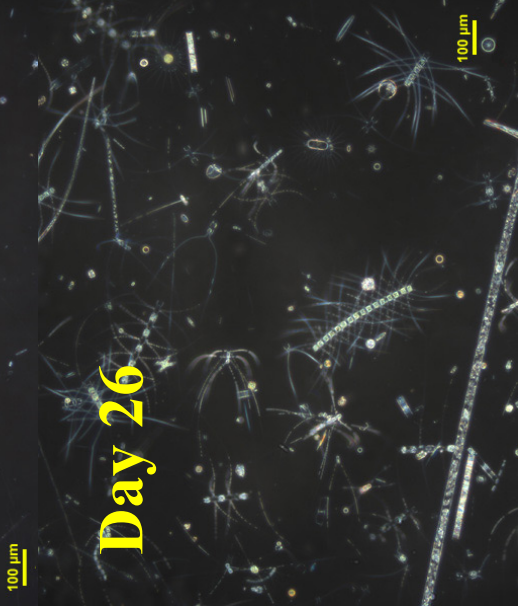
See build up and decline of  
diatom bloom in surface waters  
after 35 days- So. Ocean



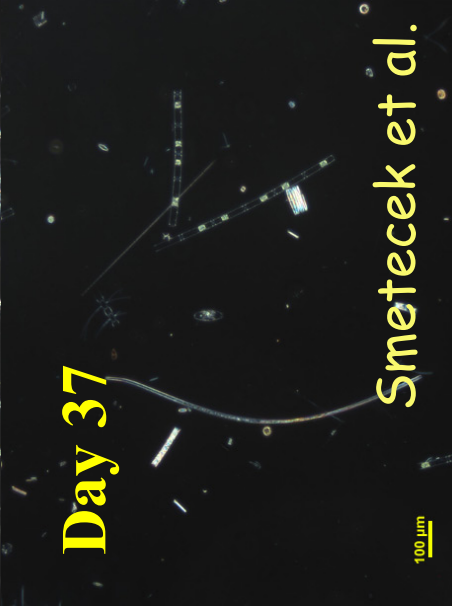
Day 0



Day 26



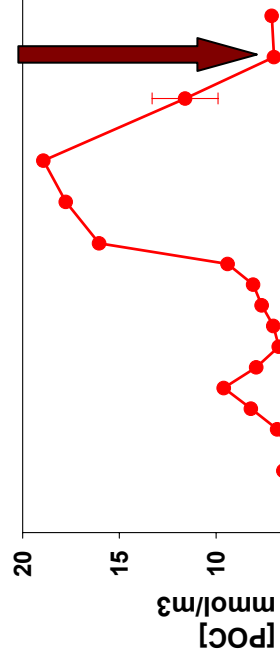
Day 37



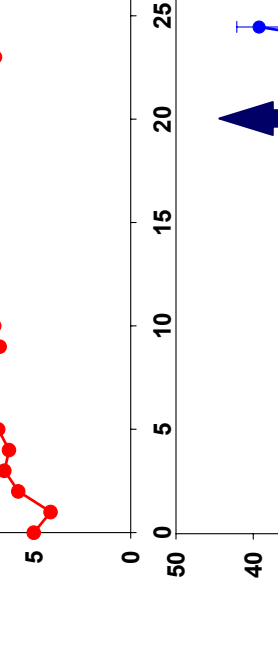
Smettecek et al.

Longer experiments are needed

See build up and decline of diatom bloom in surface waters after 35 days- So. Ocean



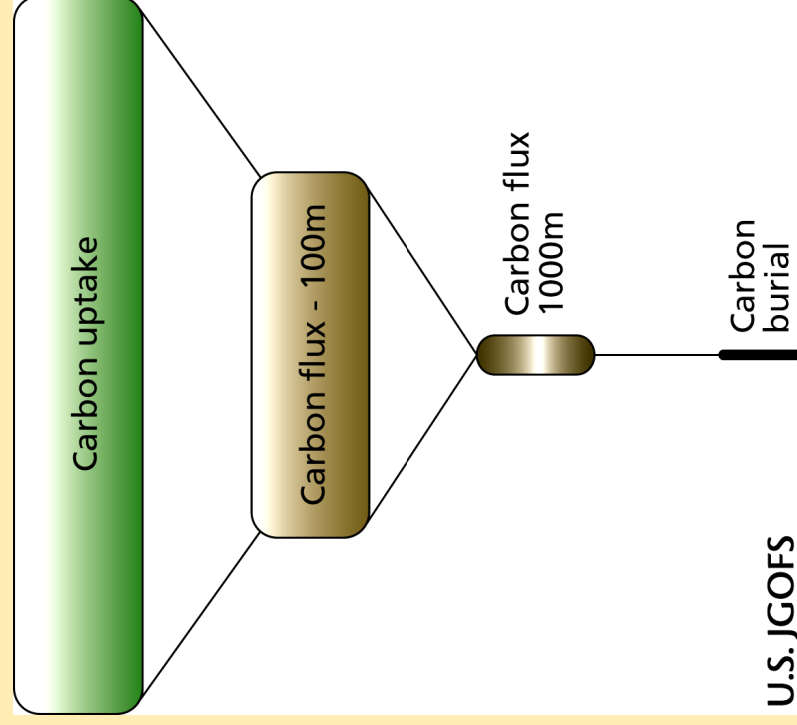
N. Pacific C stocks decrease



C flux increases after 20 days

Boyd et al.

**Most algal carbon does not reach the deep sea**  
**Carbon sequestration efficiency low (<10%?)**



**Primary Production ( $\text{CO}_2$  uptake)**

**Export flux on sinking particles**  
**<2 to >50% (decades)**

***~1 - 10% (centuries)***

***~0.1% (millennium)***

# What are possible\* ecological consequences?

- scaling is key  
tragedy of the commons
- oxygen depletion?
- ecological shifts to harmful algae?
- disruption/changes to higher trophic levels?
- many unknowns- watch out for bold claims!  
Negative impacts- dead fish, harmful algal blooms  
Positive impacts- enhanced fisheries, support whales

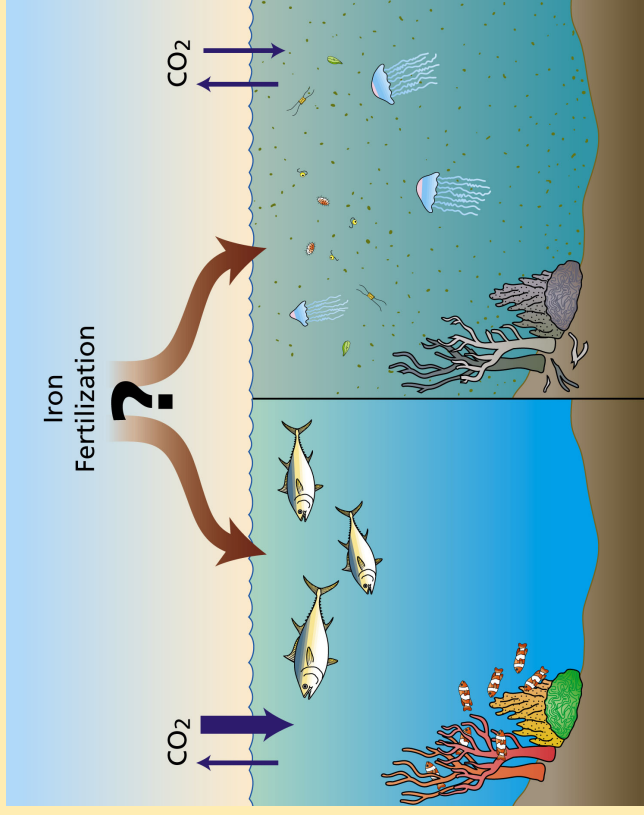
\* by design, ocean fertilization changes ecology



**Science is clear** - iron can stimulate C uptake by plankton

**However, we still cannot adequately assess/predict-**

1. will it work? (to sequester atmospheric C into mid-waters)
2. what are ecological consequences? (intended & unintended)
3. what is variability/predictability? (esp. at larger scales)



**But, the ocean is already changing**

- acidification, temperature, stratification...

# Commercialization of Ocean Iron Fertilization

- here already



*"option to own one ton CO<sub>2</sub>  
equivalent = \$4  
(15 tons per US household  
to offset typical  
contributions)"*

Anyone can sell voluntary C offsets

Planktos- "ecorestoration" planned off  
of the Galapagos

Climos- "code of conduct", academic  
partners, methodologies,  
3rd party verification

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

*September 26-27, 2007*

### **Goal**

To present the state of the science and discuss remaining uncertainties regarding the impacts and efficacy of ocean iron fertilization and issues that arise with the commercialization of this process

**Brought together ~100: science, policy, commercial, legal experts, NGO's, agencies, students, media....**

**<http://www.whoi.edu/conference/OceanIronFertilization>**

**-video, slides, resources, links, press, Oceanus (end Nov.)**

## Ocean Iron Fertilization- key issues discussed

Will it work?

- efficacy: how much? how long?

What are the **environmental consequences**?

- intended and unintended
- scaling is important

Can **carbon offsets be verified**?

- measure Fe added and C uptake and loss
- downstream impacts/additionality

What is **legal/policy framework**?

- London Convention, US EPA

What are **economic considerations**?

- value of markets vs. addressing uncertainties

What **comes next**?

- privately funded larger/longer "experiments"

## Key International Legal Issues

- Can ocean iron fertilization be regarded as pollution ?
- Should it be regarded as dumping ?
- Are ocean iron projects eligible for certification under the Kyoto Protocol?

## Conclusions

If an activity is likely to “result in such deleterious effects as harm to living resources and marine life” then it is “pollution”

States have an obligation to prevent, reduce and control pollution

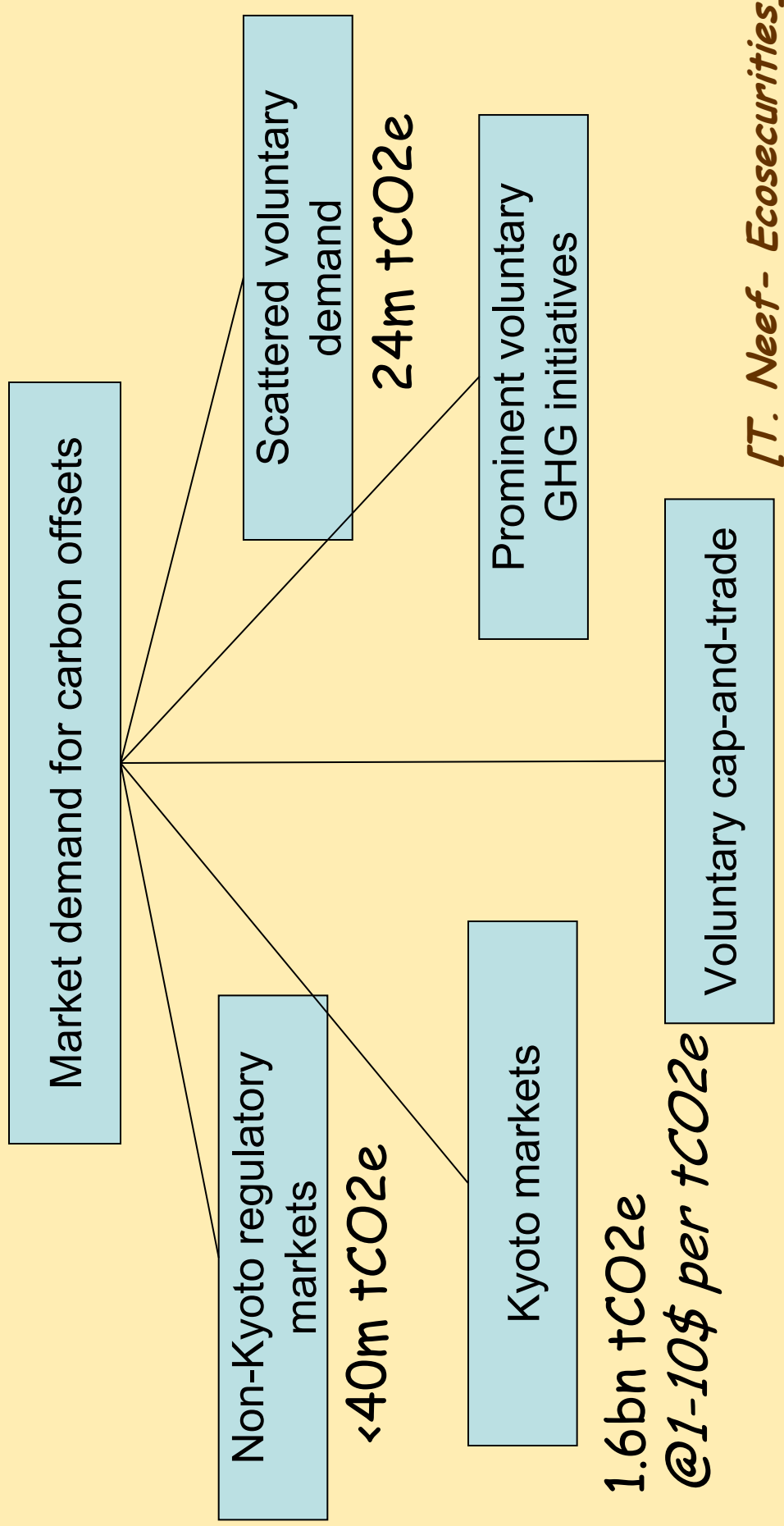
Deliberate dispersal of iron is probably not dumping (ie not disposal) but may come within the general mandate of the London Convention and its 1996 Protocol

(US EPA regulates ocean dumping/London Convention)

*[David Freestone - World Bank]*

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*[T. Neef- Ecosecurities]*

Potential value of ocean iron fertilization may be \$100b under an economically optimal climate policy *[H. Kite Powell- WHOI]*

## “Moving ahead with uncertainty”

### Science

End of an era wrt Ocean Iron Fertilization expt's

See variability & gain understanding

Next? Field experiments with models & new techniques

Funding from commercial sources likely (& others?)

### Economics

Value of C market & Value of science to market are apparent

Cost/ton & cost/impacts still debated

### Law

London Convention may be used to regulate?

### Policy

Impact assessments needed? & post-Kyoto regulation of C credits



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

<http://www.whoi.edu/conference/OceanIronFertilization>

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