

Ocean Fertilization

Ironing Out Uncertainties in Climate Engineering

Ken Buesseler

Senior Scientist

Marine Chemistry and Geochemistry Dept.

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"



ocean**iron**fertilization

come to listen

• learn

• debate

• explore

Outline

Rising carbon dioxide (CO_2)

Ocean iron fertilization- background & history

Science results from prior experiments

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

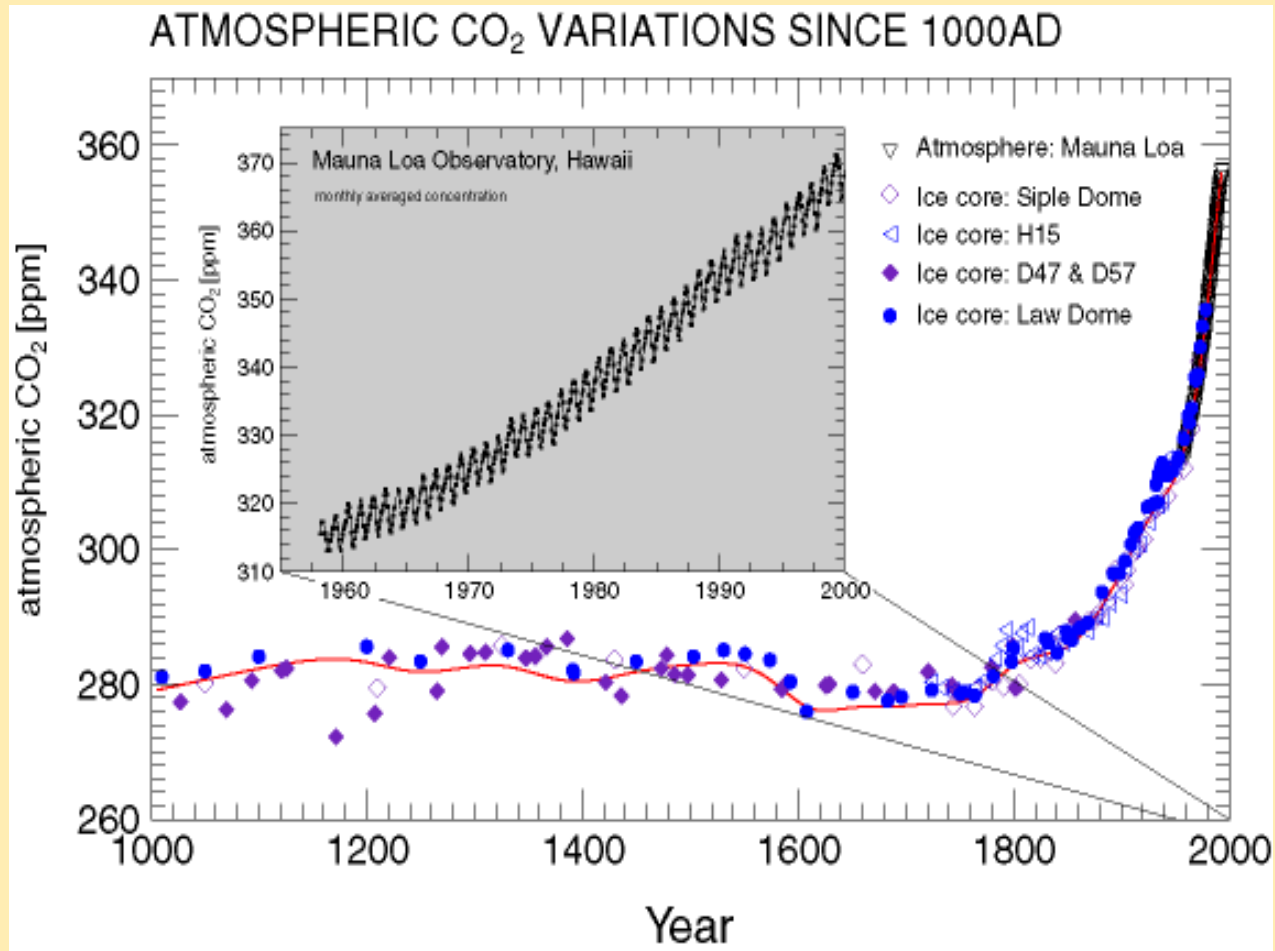
September 26-27, 2007

Legal, economic issues coming out of the meeting

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



Atmospheric CO_2 is rising due to human activities



CO_2 is a greenhouse gas,
so rising CO_2 will impact climate

Can we stabilize atmospheric carbon dioxide?

No single "silver bullet"

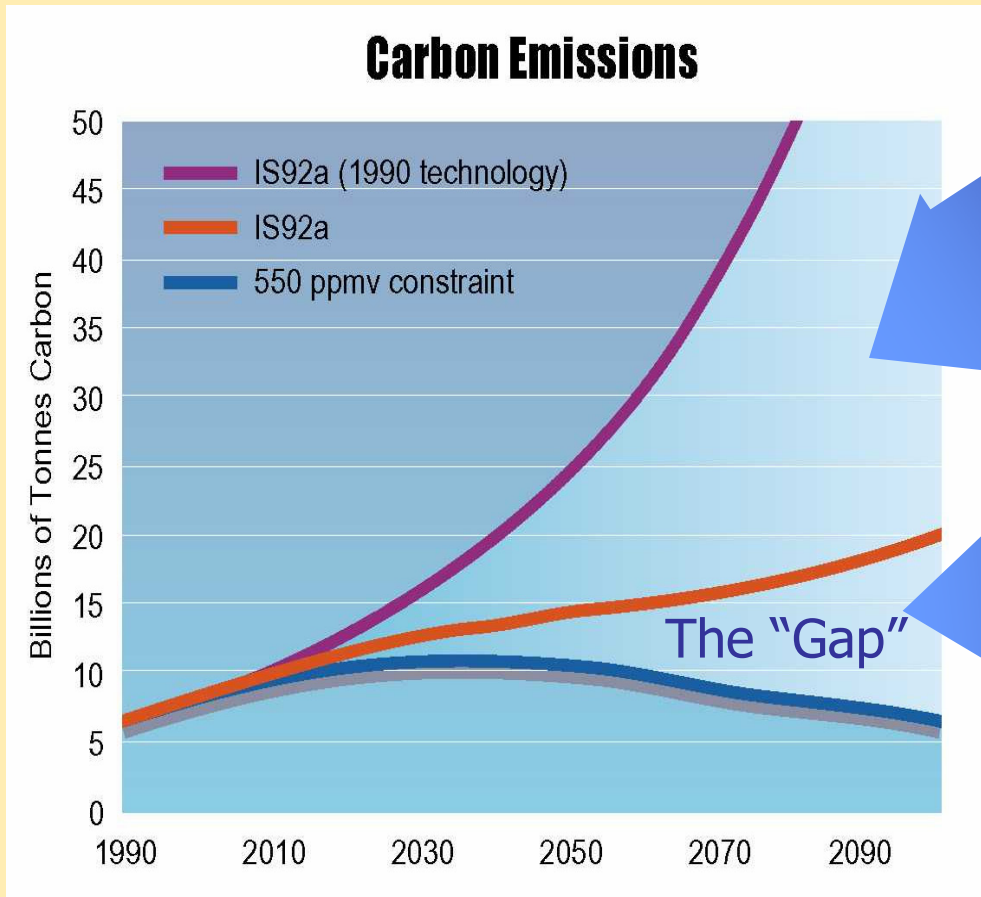
Need to consider reducing sources and enhancing sinks

Assumed advances in familiar technologies

- Fossil fuels
- End use energy
 - Nuclear
- Renewables

Less familiar technologies

- Carbon capture & disposal
 - Adv. fossil
- H₂ and adv. transportation
- Biotechnologies
 - Soils, Bioenergy, adv. Biological energy
- Land/**ocean carbon sequestration**



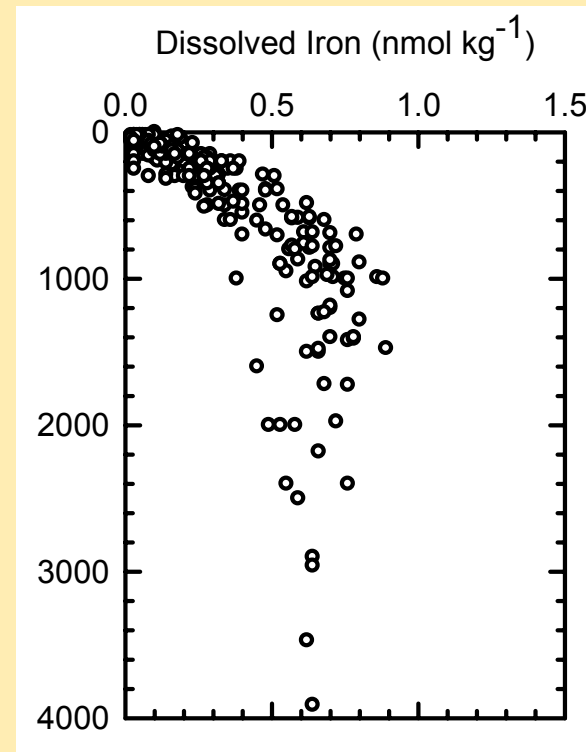
What is ocean iron fertilization?

History

Challenge-
measuring iron on a rusty ship!



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

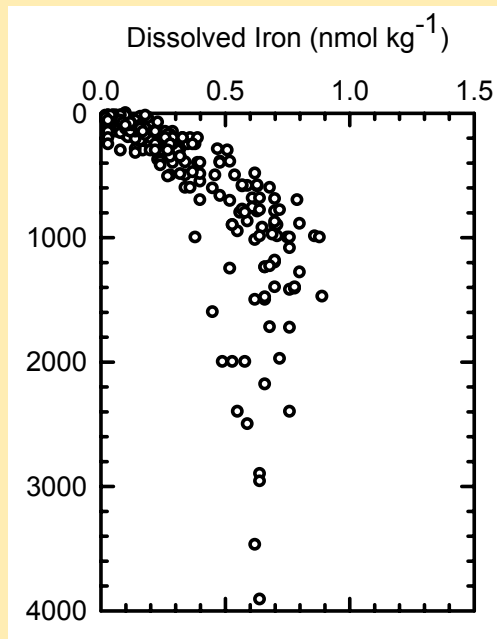


(regional differences)

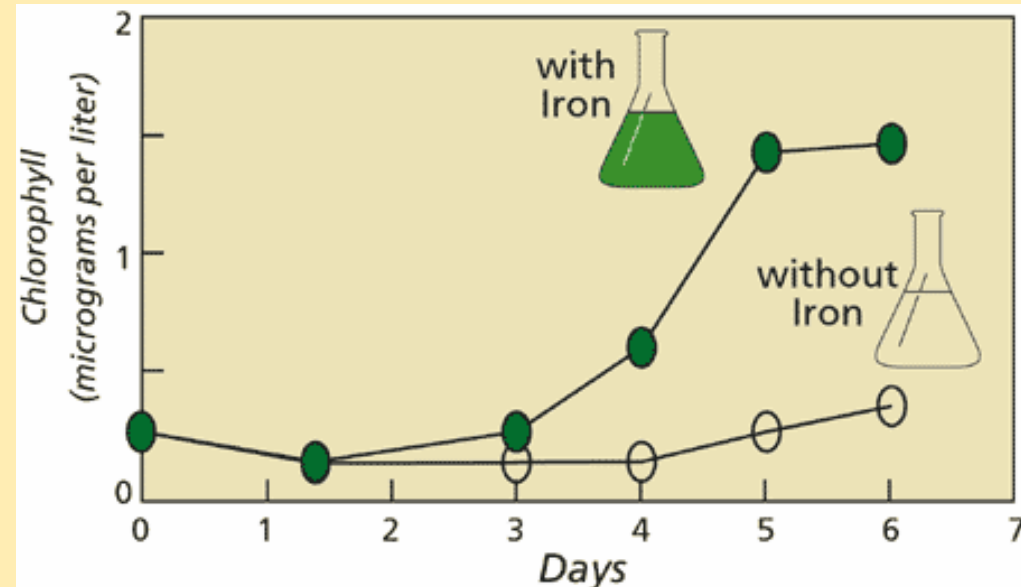
What is ocean iron fertilization?

History

extremely low iron in surface ocean



& adding iron can stimulate phytoplankton growth

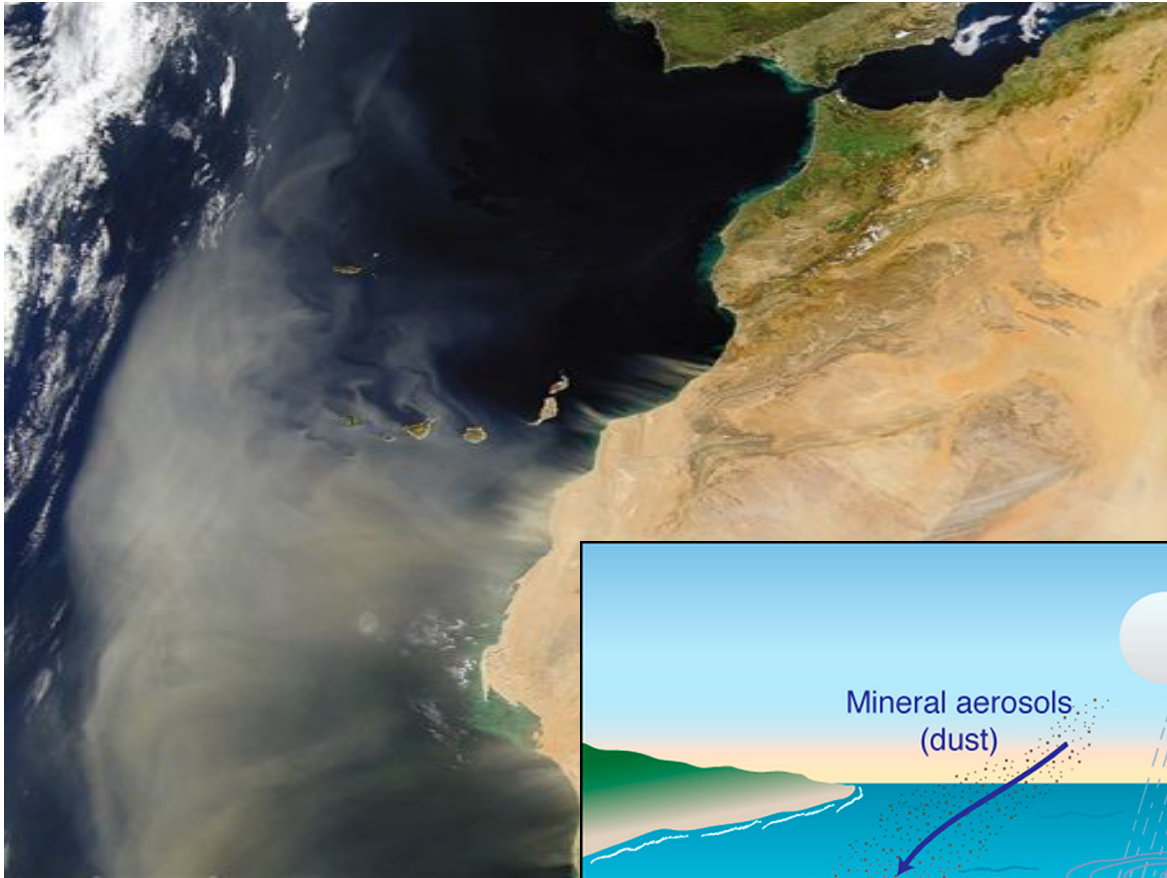


A little iron goes a long way!



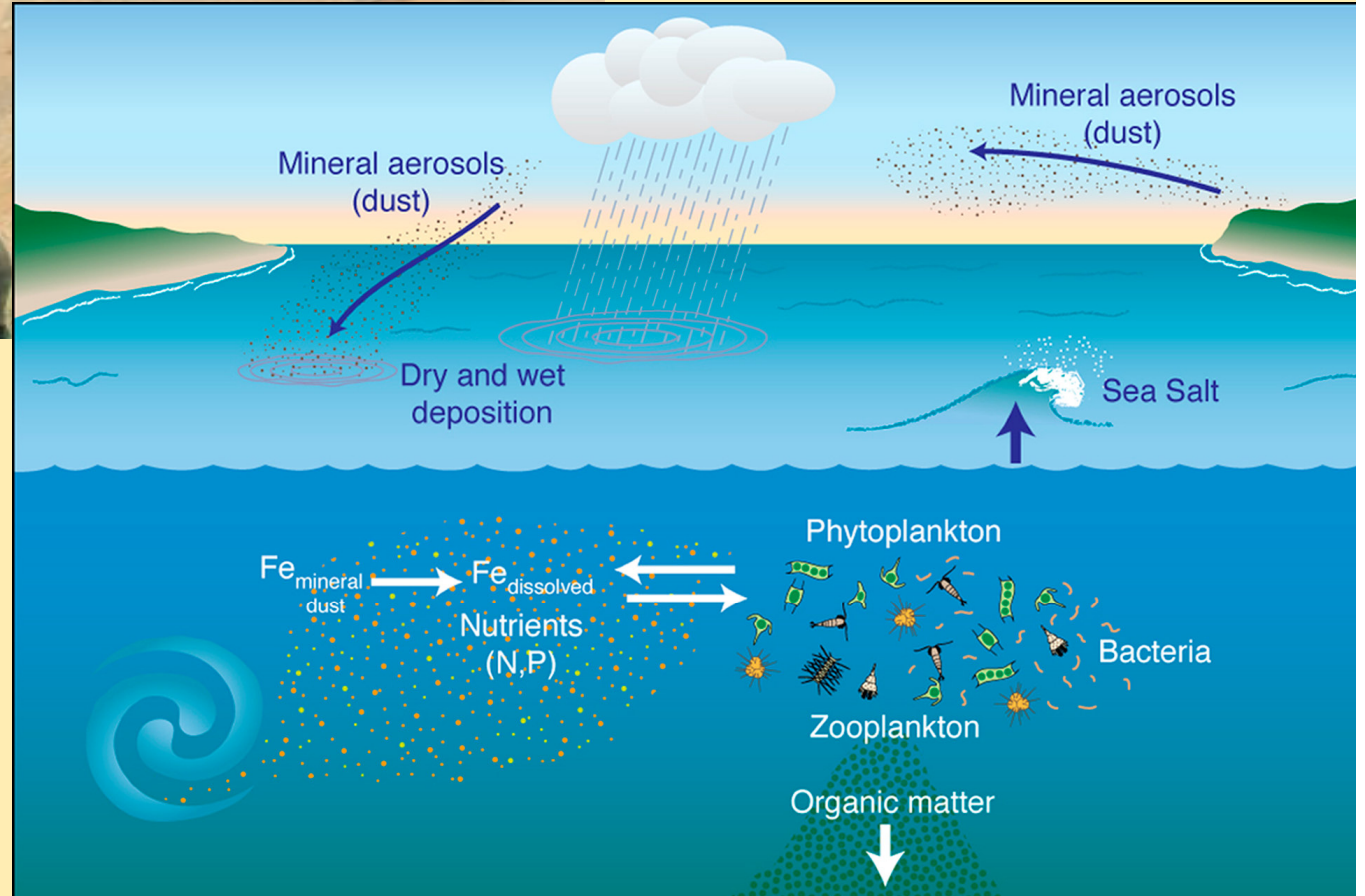


**Dust is a
major
source of
iron to the
ocean**



Dust is a major source of iron to the ocean

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



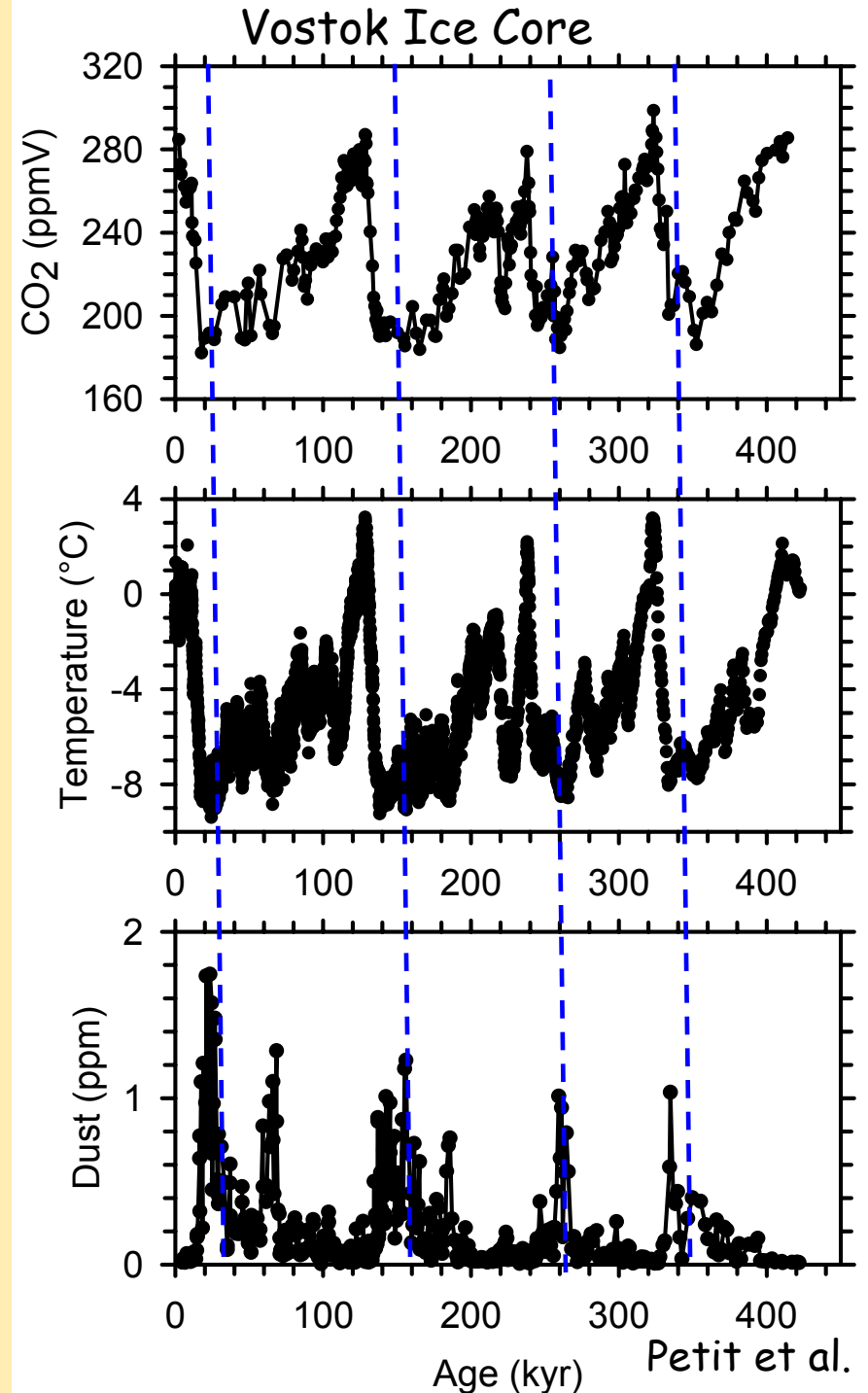
The Iron Hypothesis-

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

John Martin



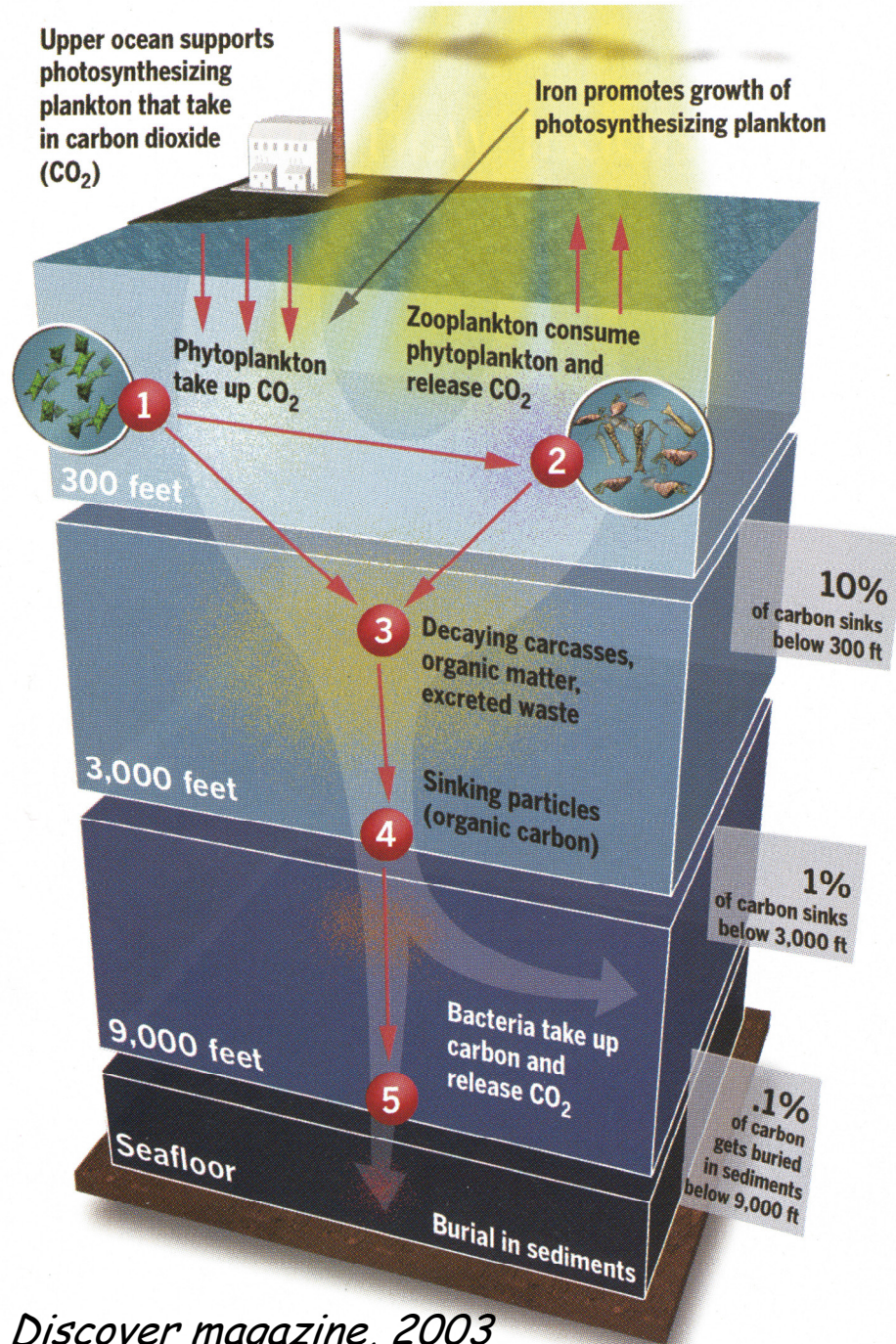
High dust (high Fe) = low CO_2
& low Temp.



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

Two processes are needed to impact atmospheric CO_2 via iron additions

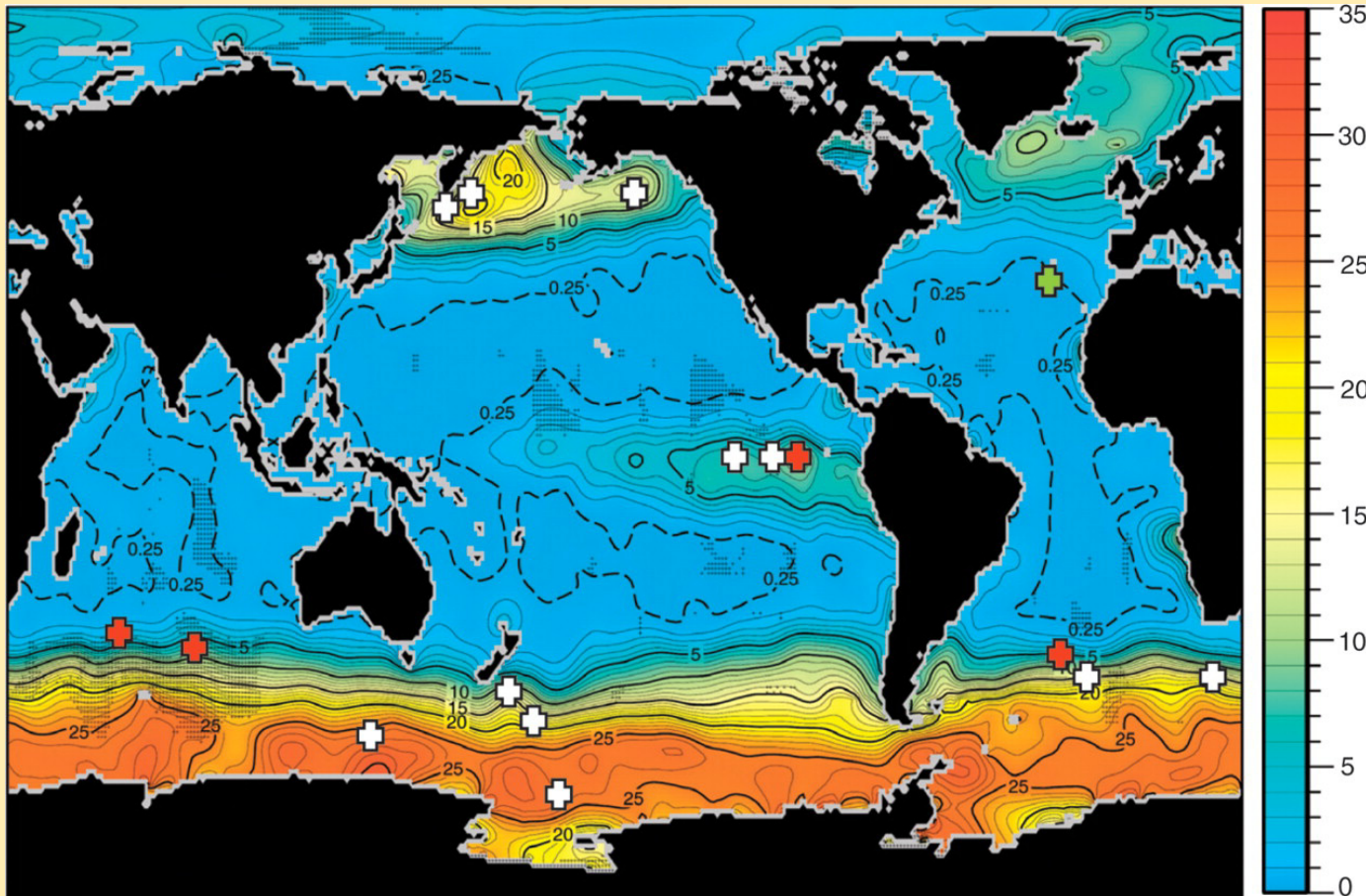
1. Stimulate algal growth - relatively well known
2. Enhance carbon flux to the deep-sea - little known, hard to measure, key to C credits



Discover magazine, 2003

GRAPHIC BY DON FOLEY

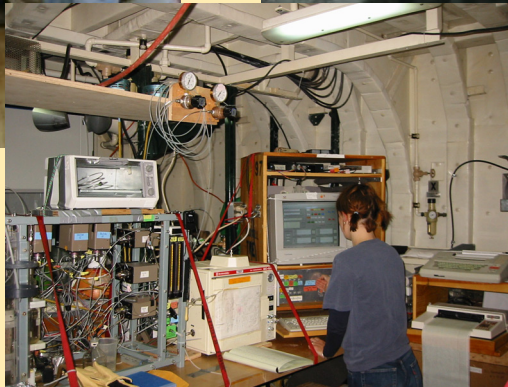
12 major iron fertilization experiments & studies of natural Fe sources



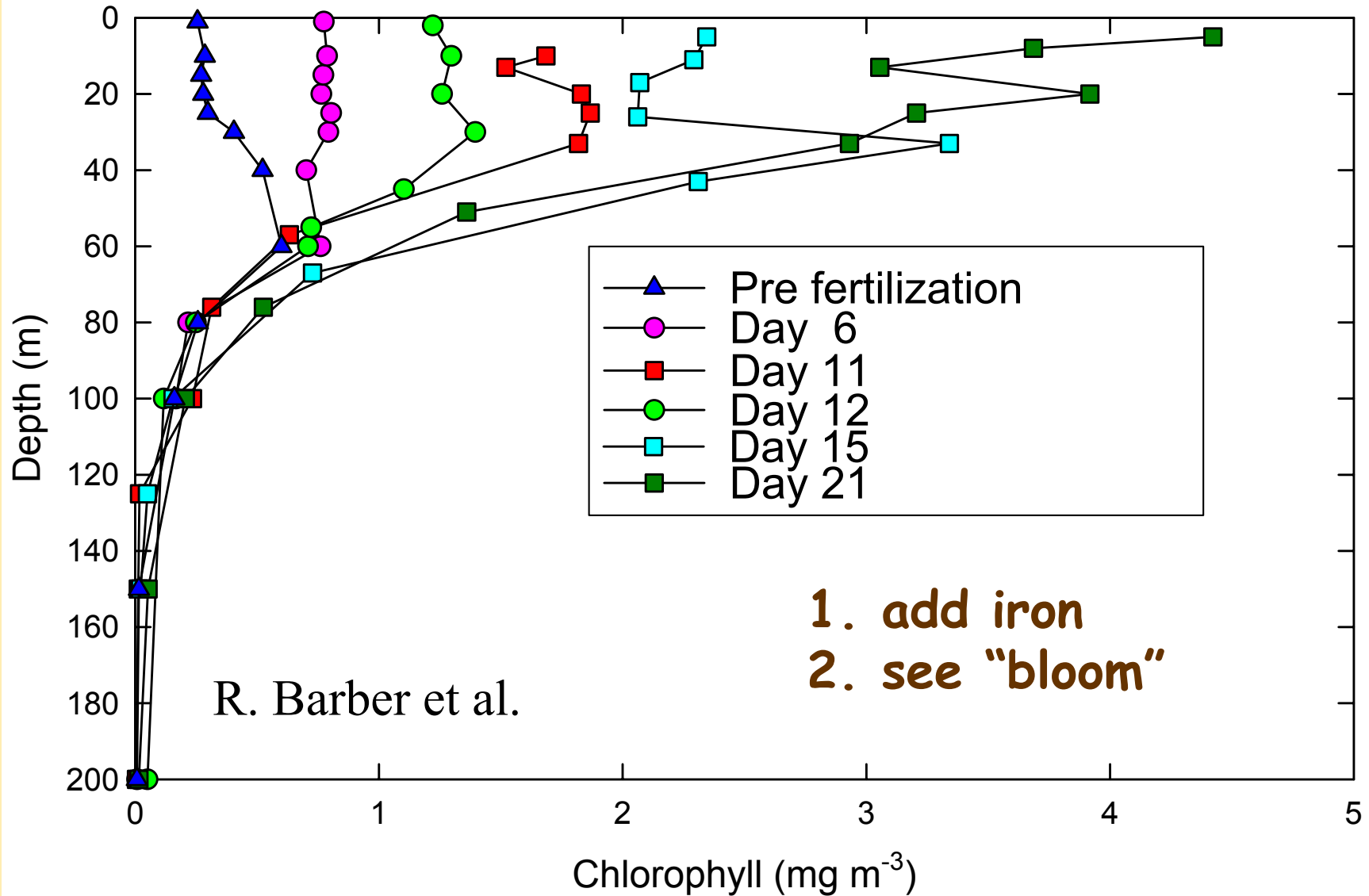
P. W. Boyd et al., Science 315, 612 -617 (2007)

Map of surface ocean nitrate

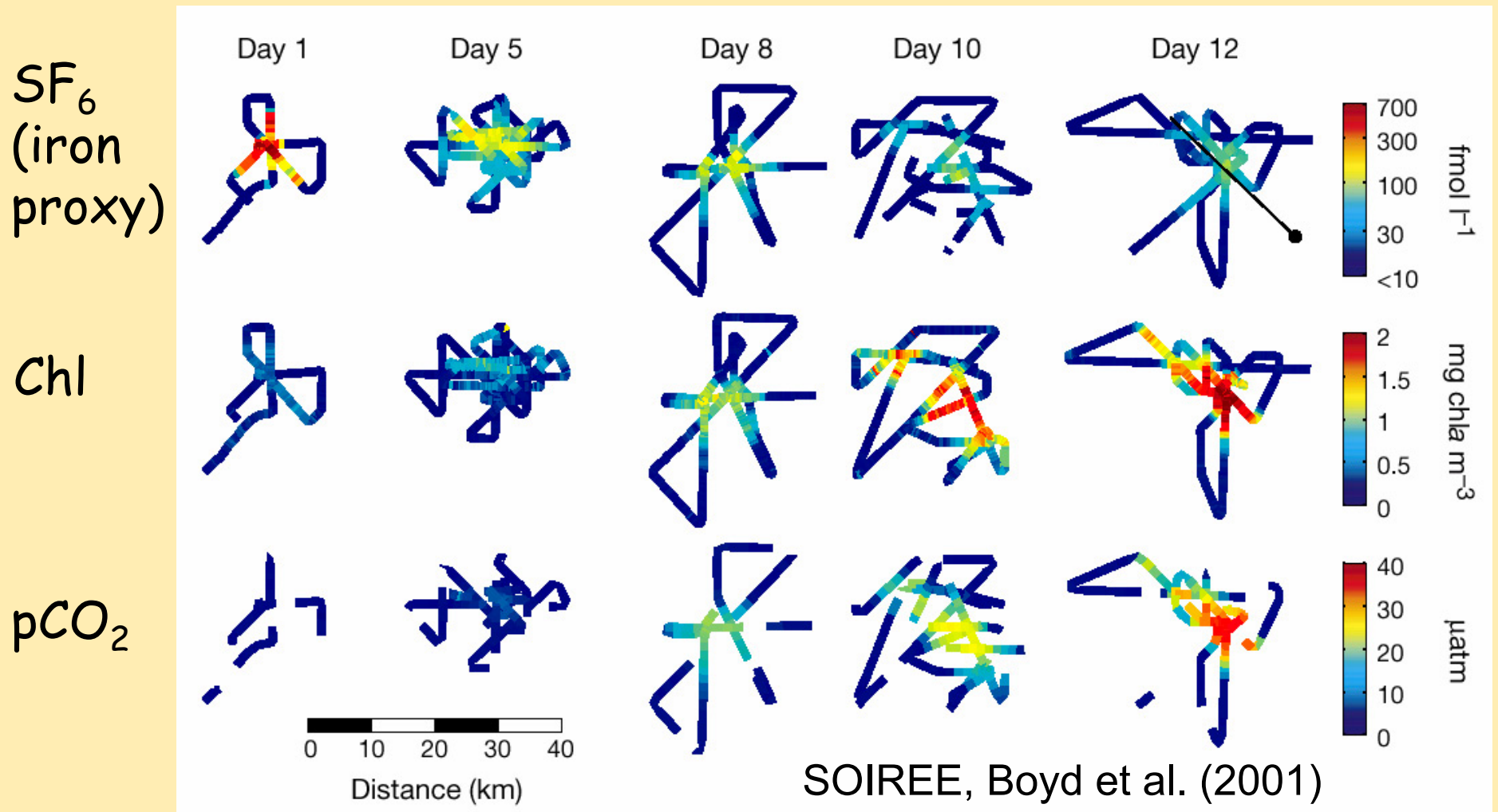
12 major field experiments- take a lot of effort!



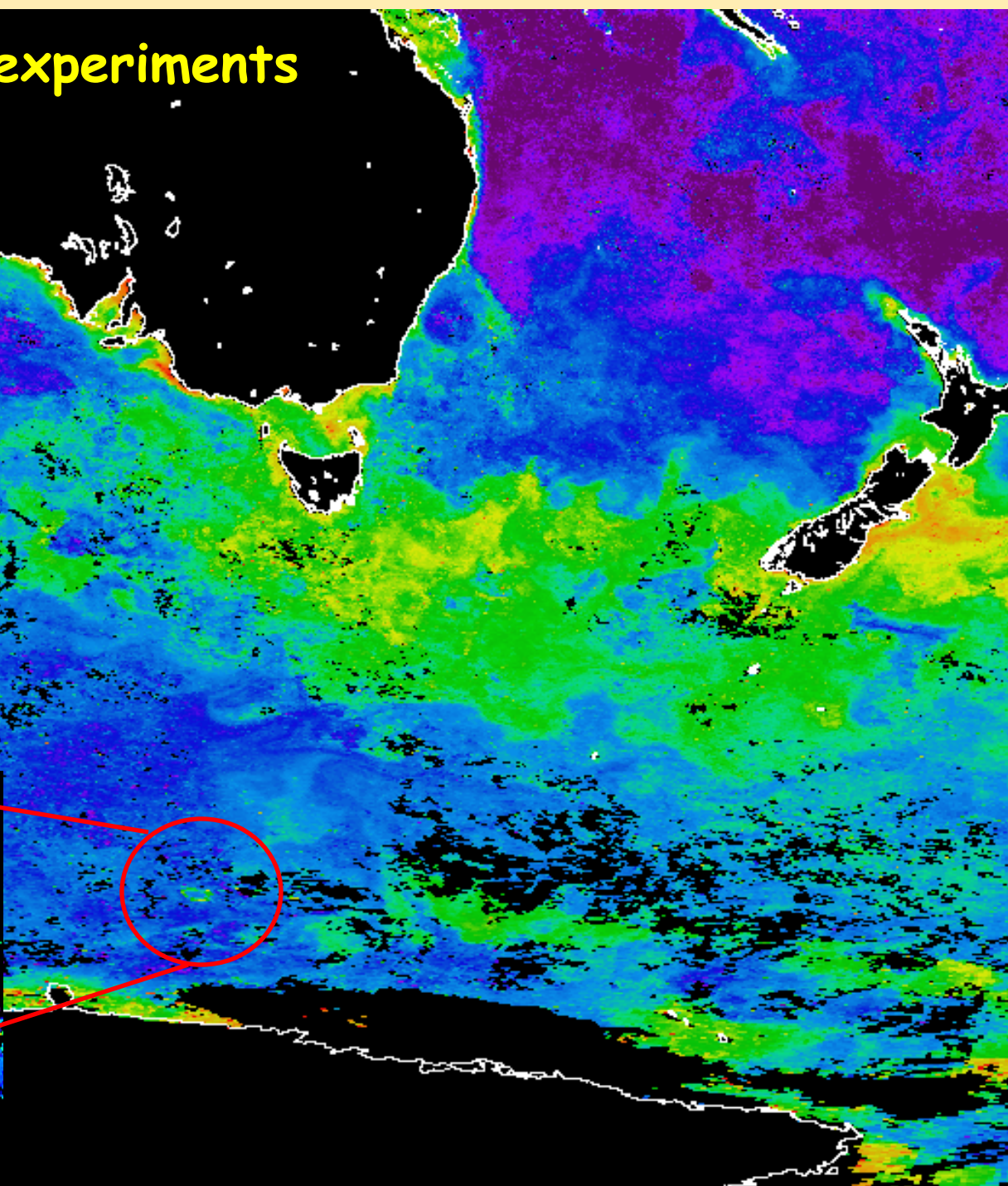
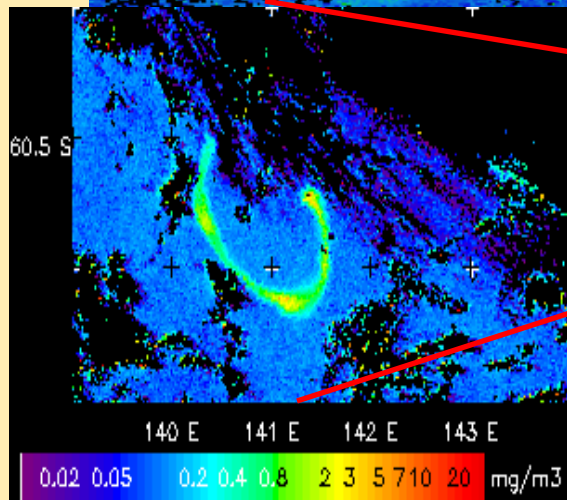
Increase in phytoplankton seen after iron addition



Multiple iron experiments succeeded in showing surface biological response and CO_2 decrease after iron additions

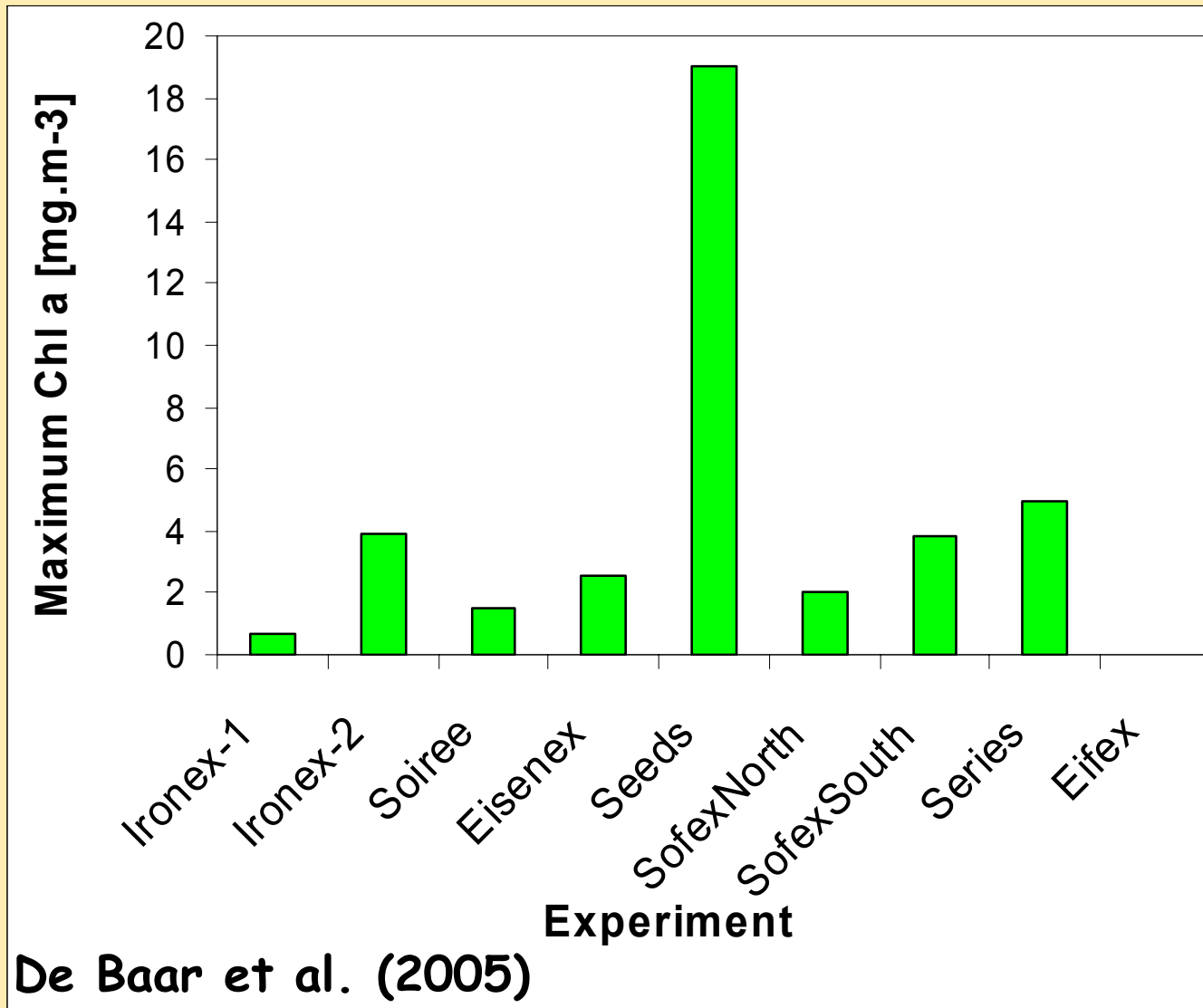


Can even see experiments
from space!



Location, location, location...

[Phil Boyd- U. Dunedin, NZ]



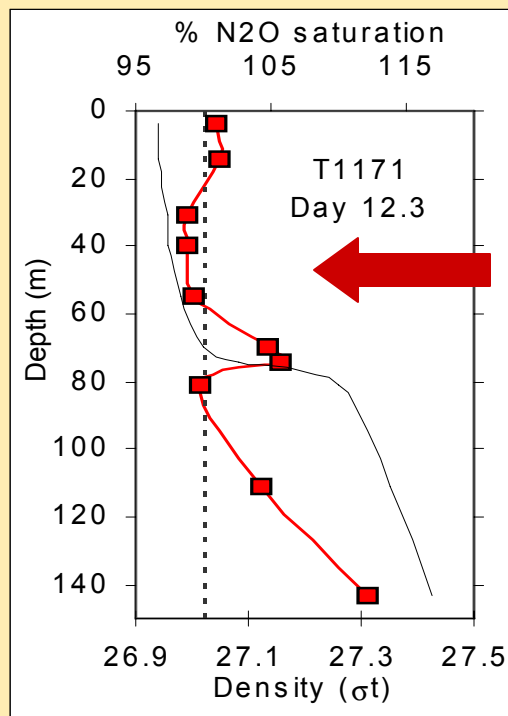
Impact of initial conditions

- light
- temp.
- season
- winds
- biota
- currents

etc.

Multiple iron experiments resulted in variable biomass & CO₂ 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

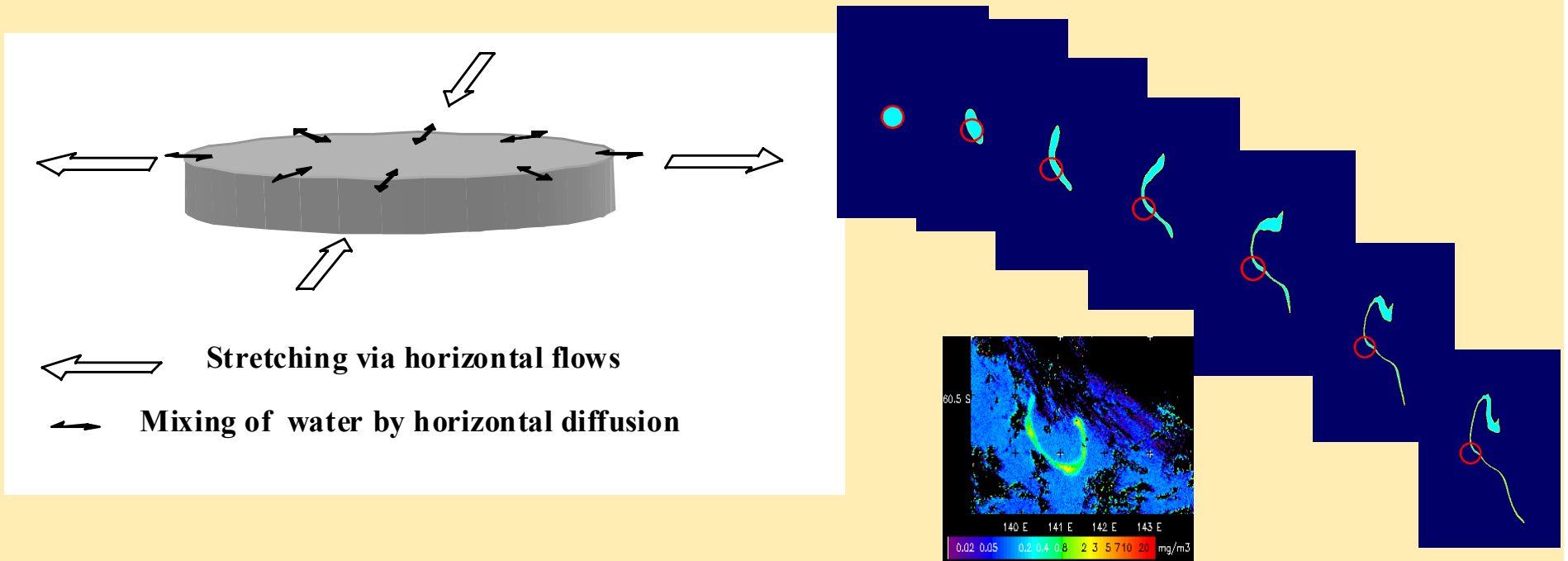
[Andrew Watson - Univ. East Anglia]

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

Law & Ling (2001)

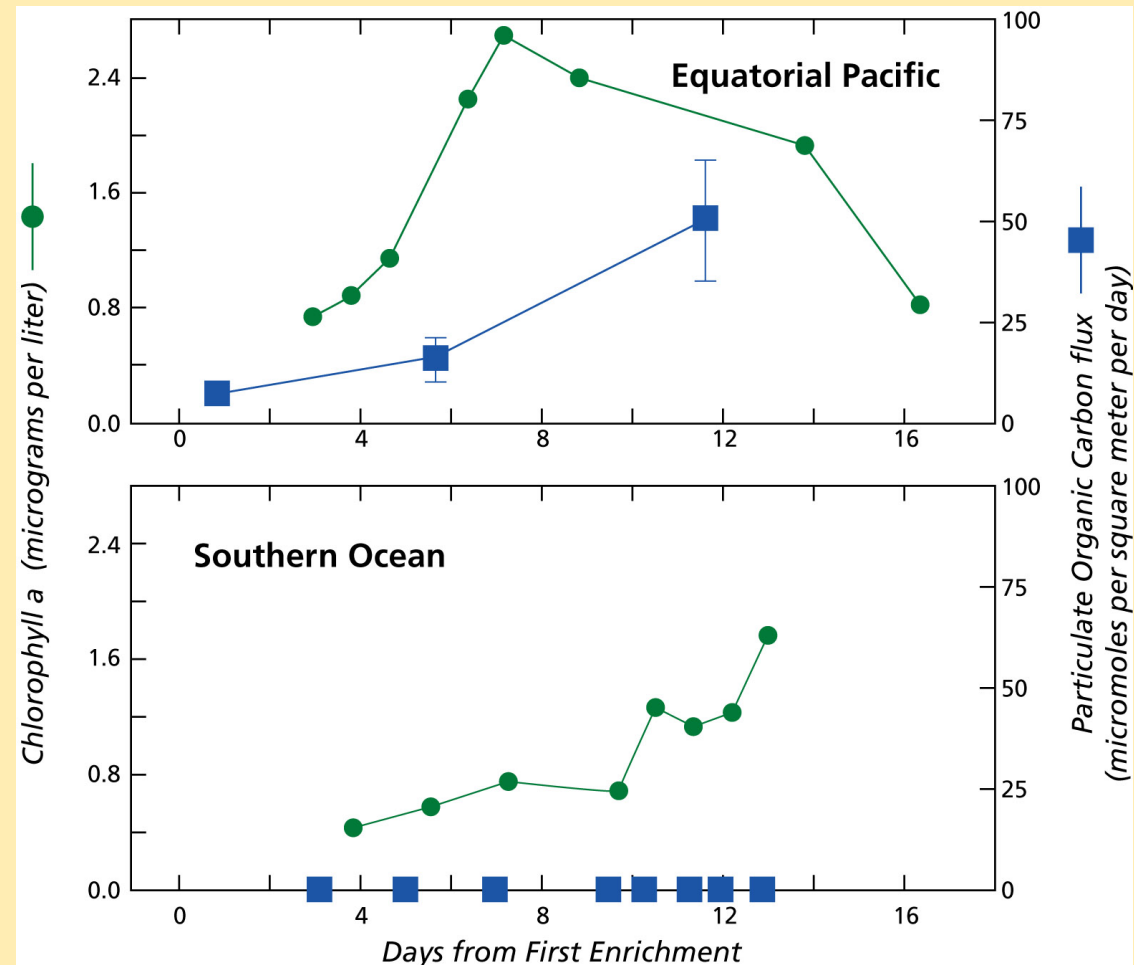
Multiple iron experiments resulted in variable responses

1. unresolved issues related to ocean mixing & dilution



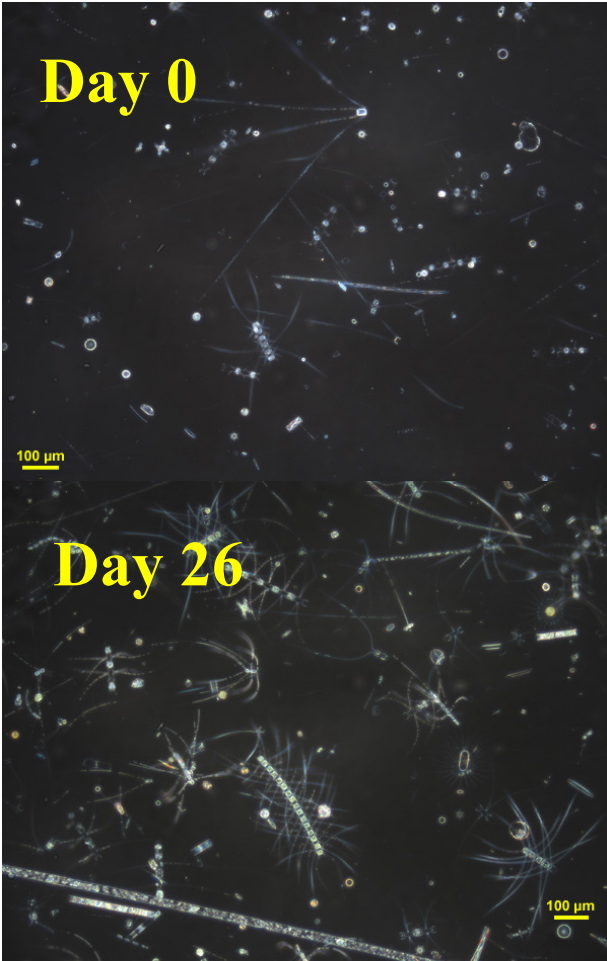
2. experiments were short relative to natural ocean blooms - important for carbon export to deep sea

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

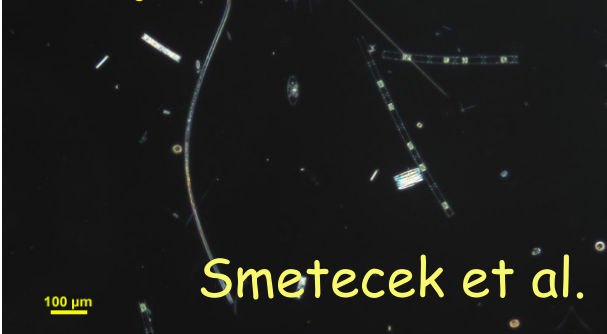
Day 0



Day 26



Day 37

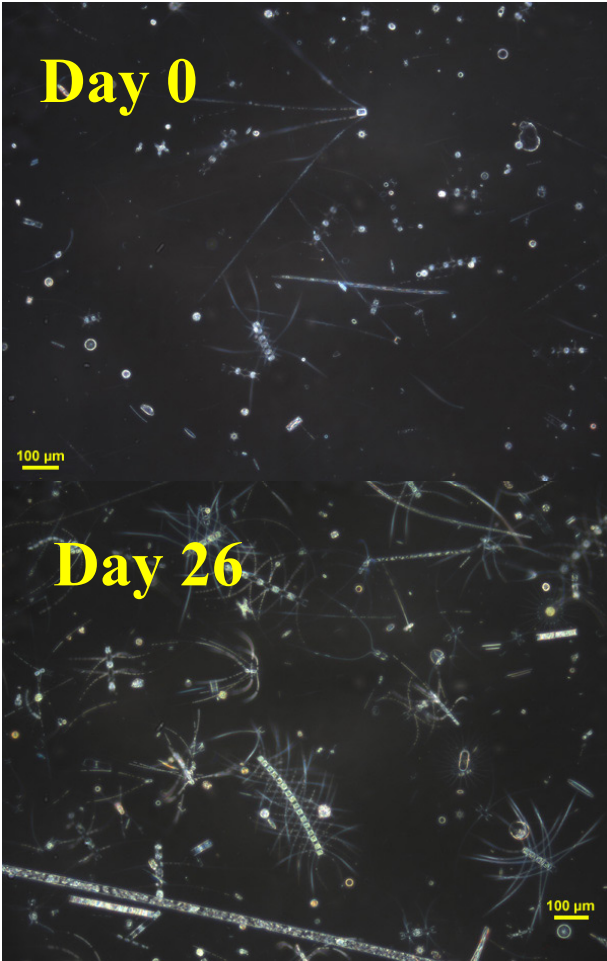


Smetceck et al.

Longer experiments are needed

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

Day 0



Day 26



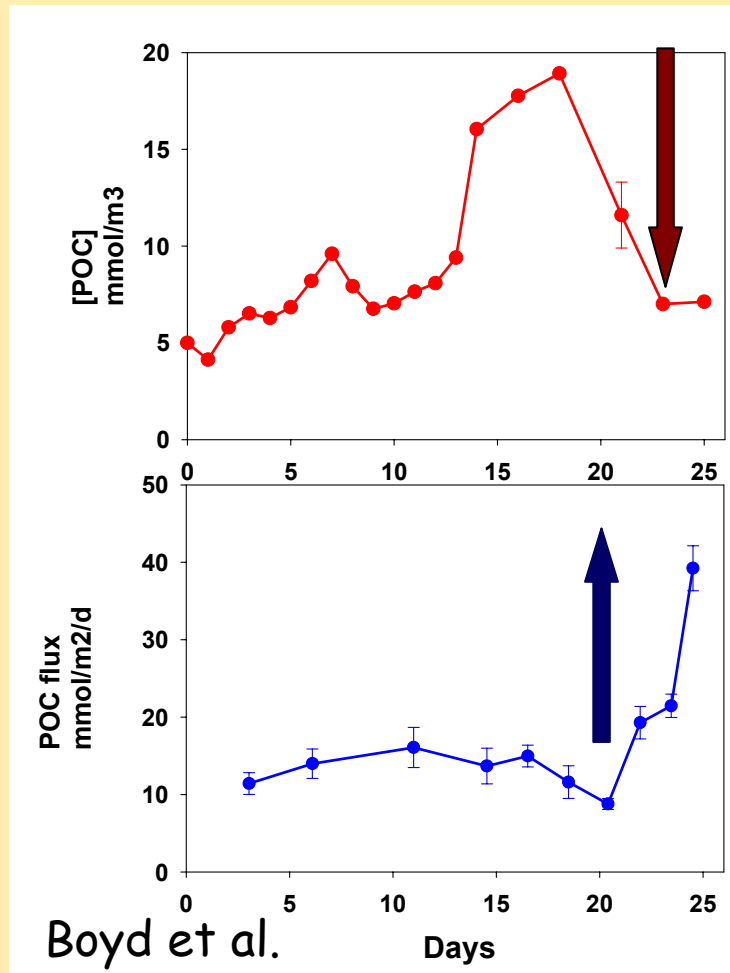
Day 37



Smeteczek et al.

Longer experiments are needed

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



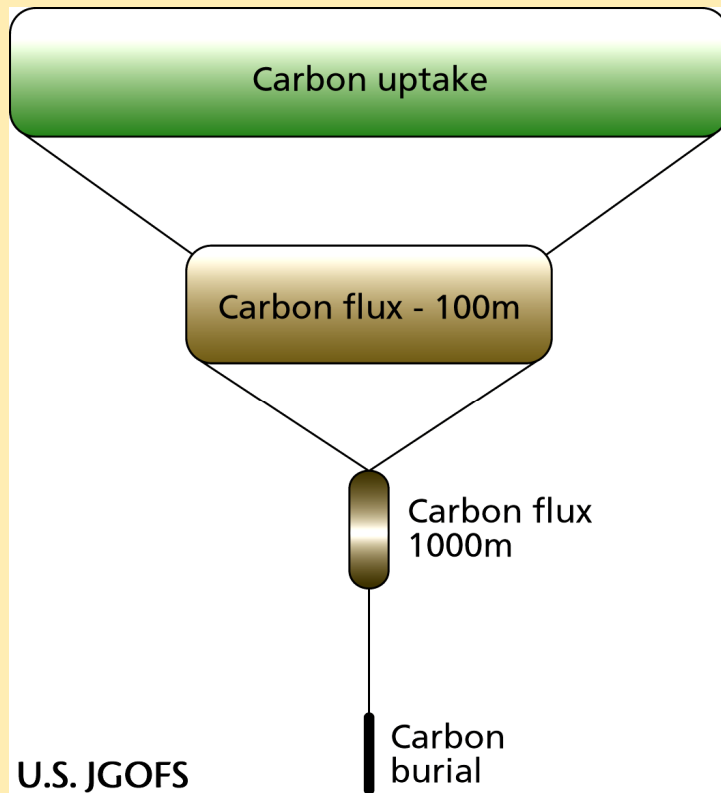
N. Pacific C stocks decrease

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 (CO_2 uptake)

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

~1-10% (centuries)

~0.1% (millennium)



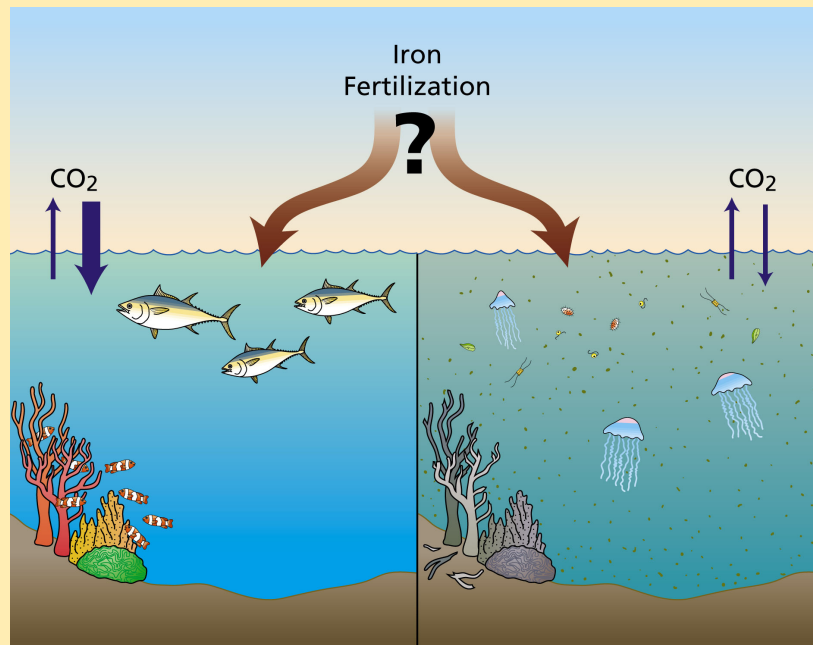
What are possible* ecological consequences?

- 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 CO₂ 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

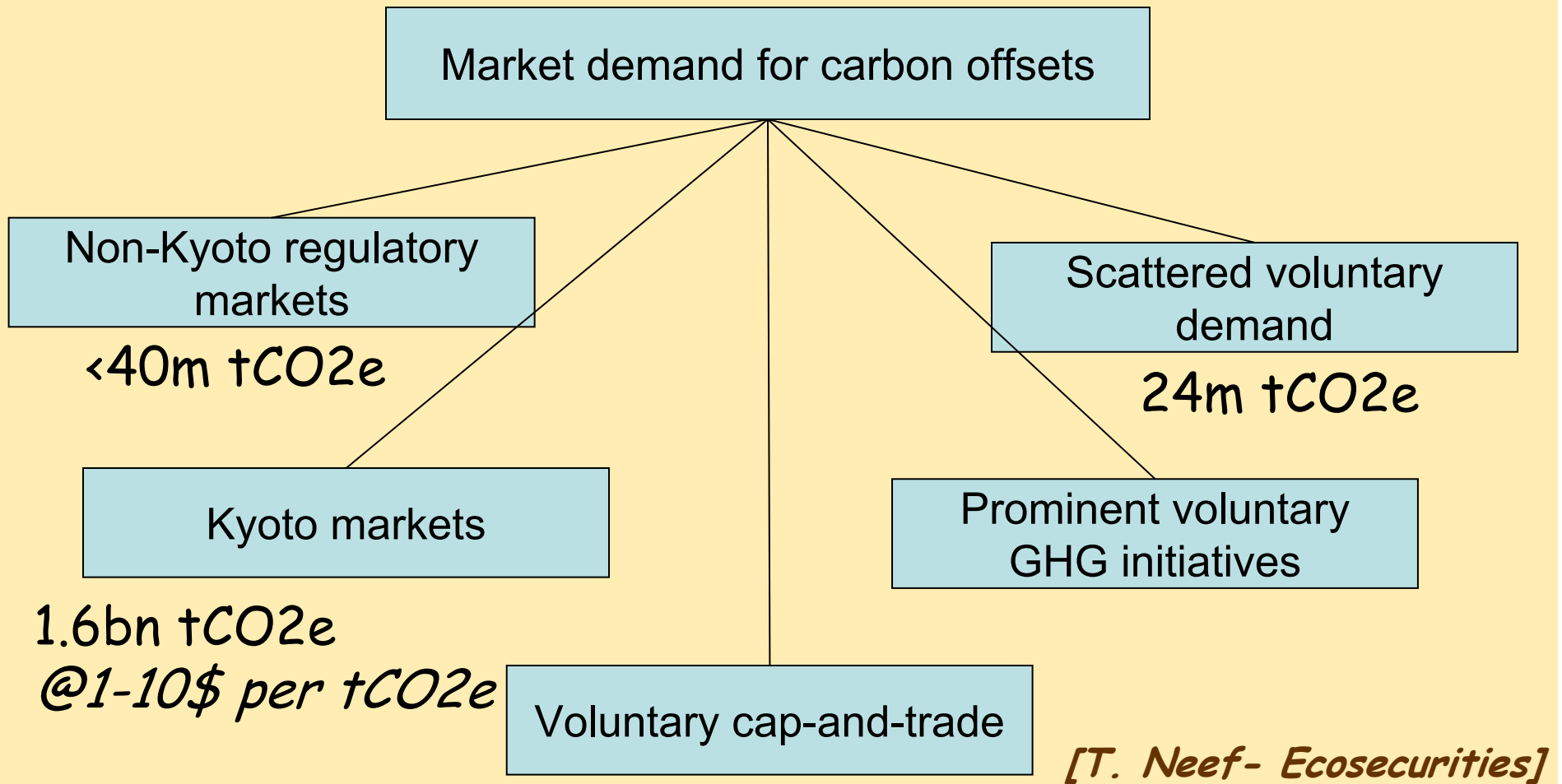
If an activity is likely to “result in such deleterious effects as harm to living resources and marine life” then it is “pollution”

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]



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

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

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

Thanks to sponsors- all from Woods Hole Oceanographic Institution

Morss Colloquia

Ocean and Climate Change Institute

Cooperative Institute for Climate Research (CICOR)

Marine Policy Center

WHOI Sea Grant

Ocean Life Institute