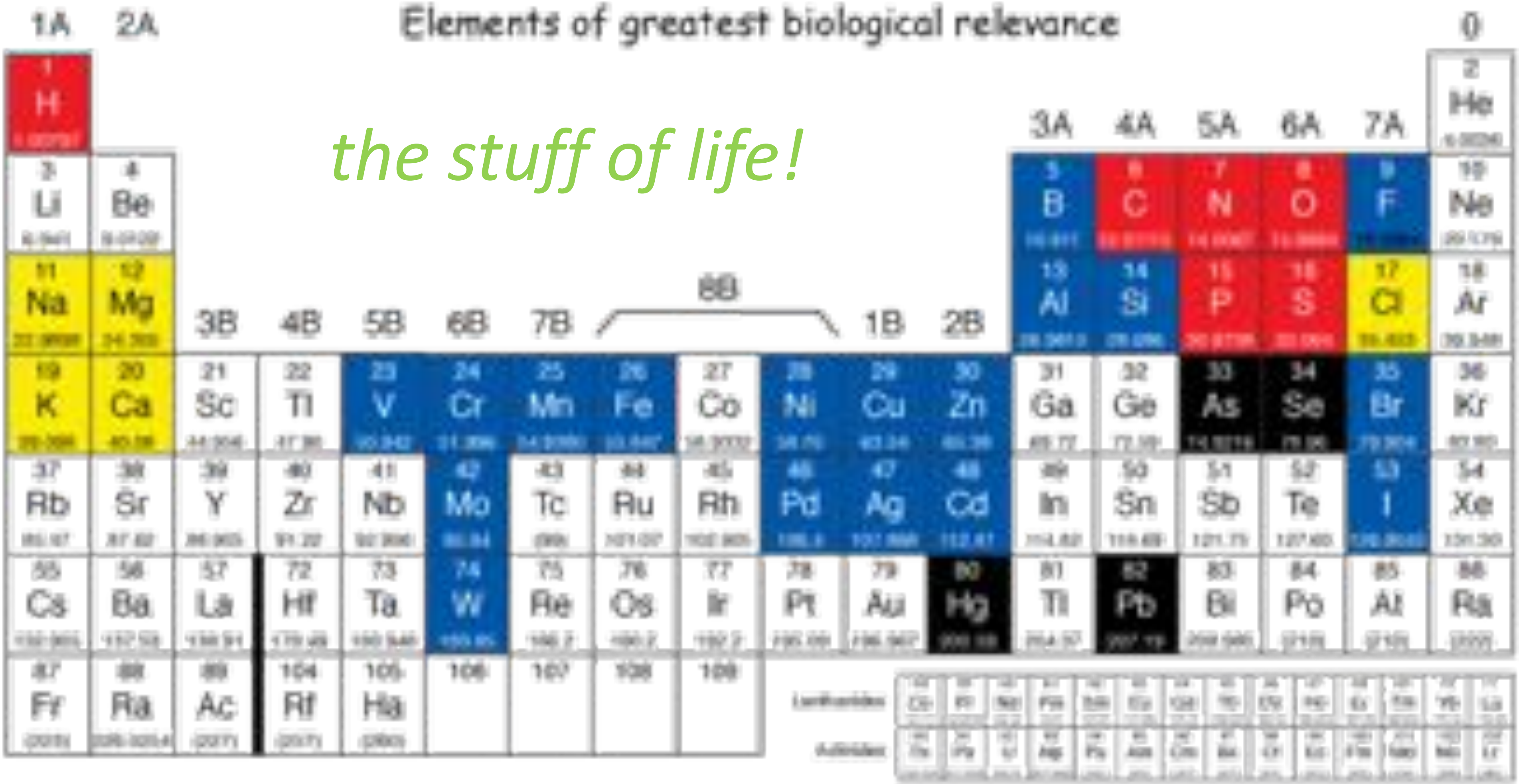
Trace metals, climate, and ocean iron fertilization (OIF)

Ben Twining

17 September 2018



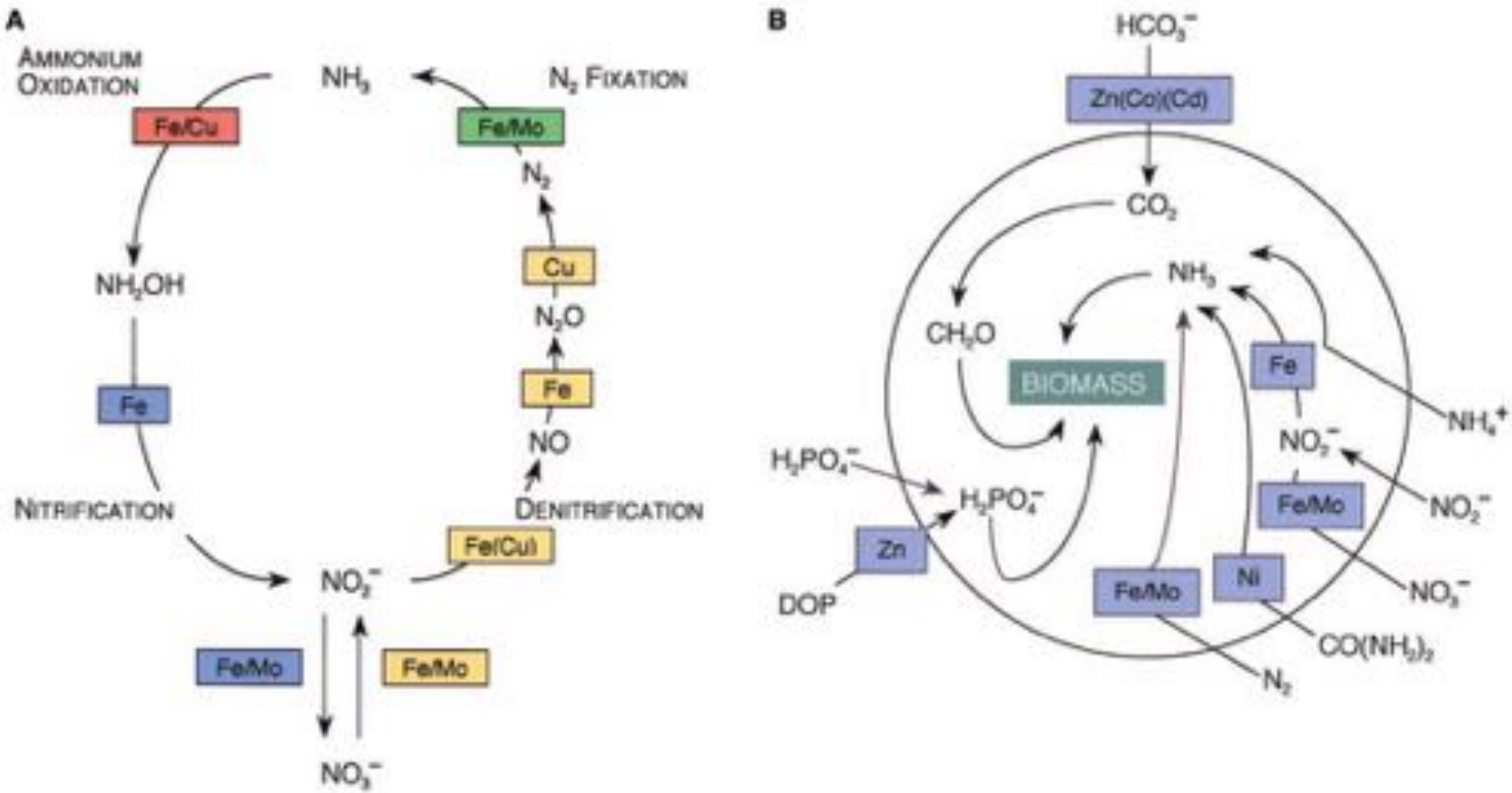
Major building blocks of biomolecules

Metals and other trace components of biomolecules

Important ions

Significant bio-toxins

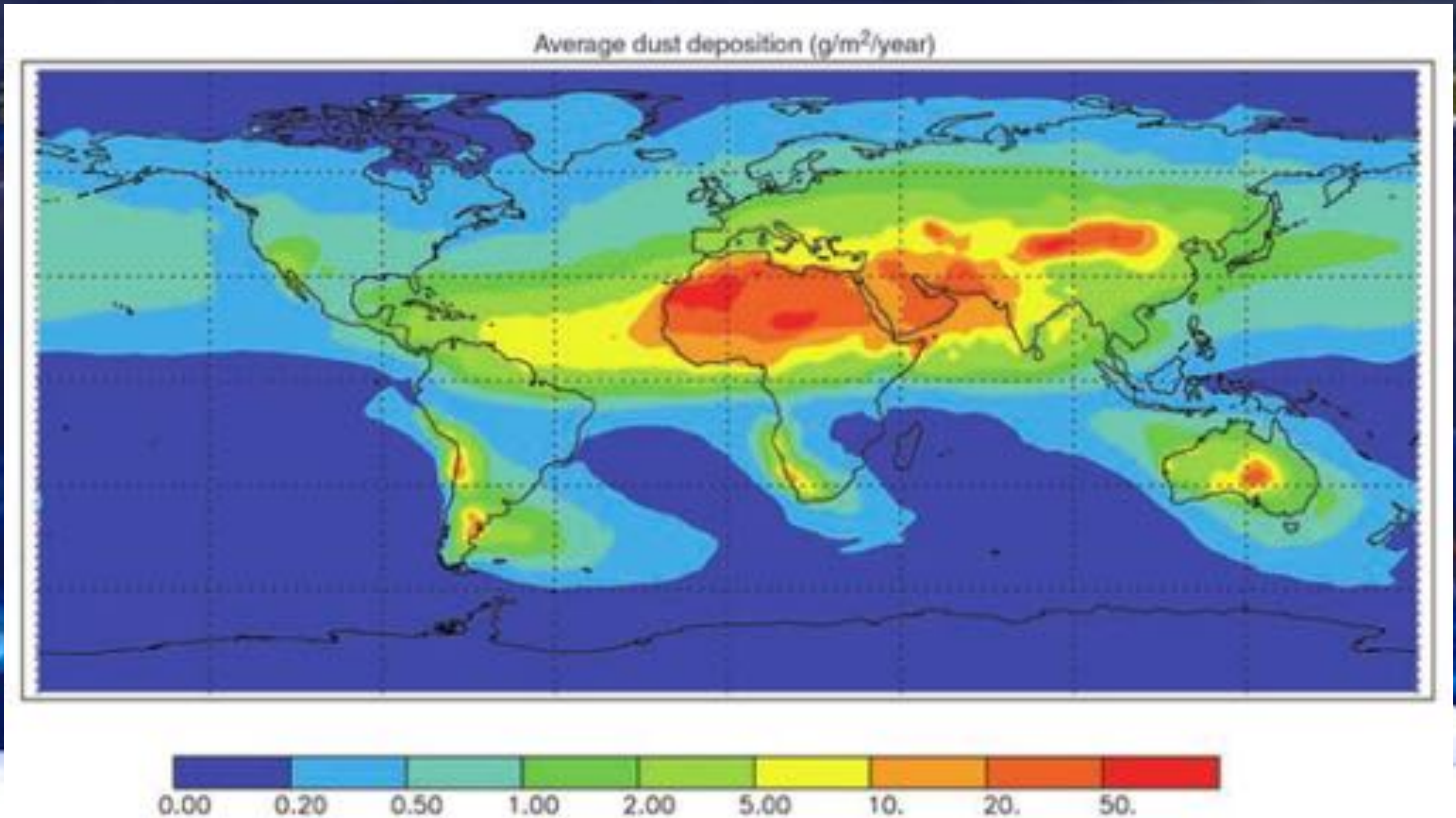
Uses of metals in cells



(Morel and Price 2003)

Importance of iron

How does iron get into the ocean?



Jickells et al. 2005

William Putman, NASA/Goddard

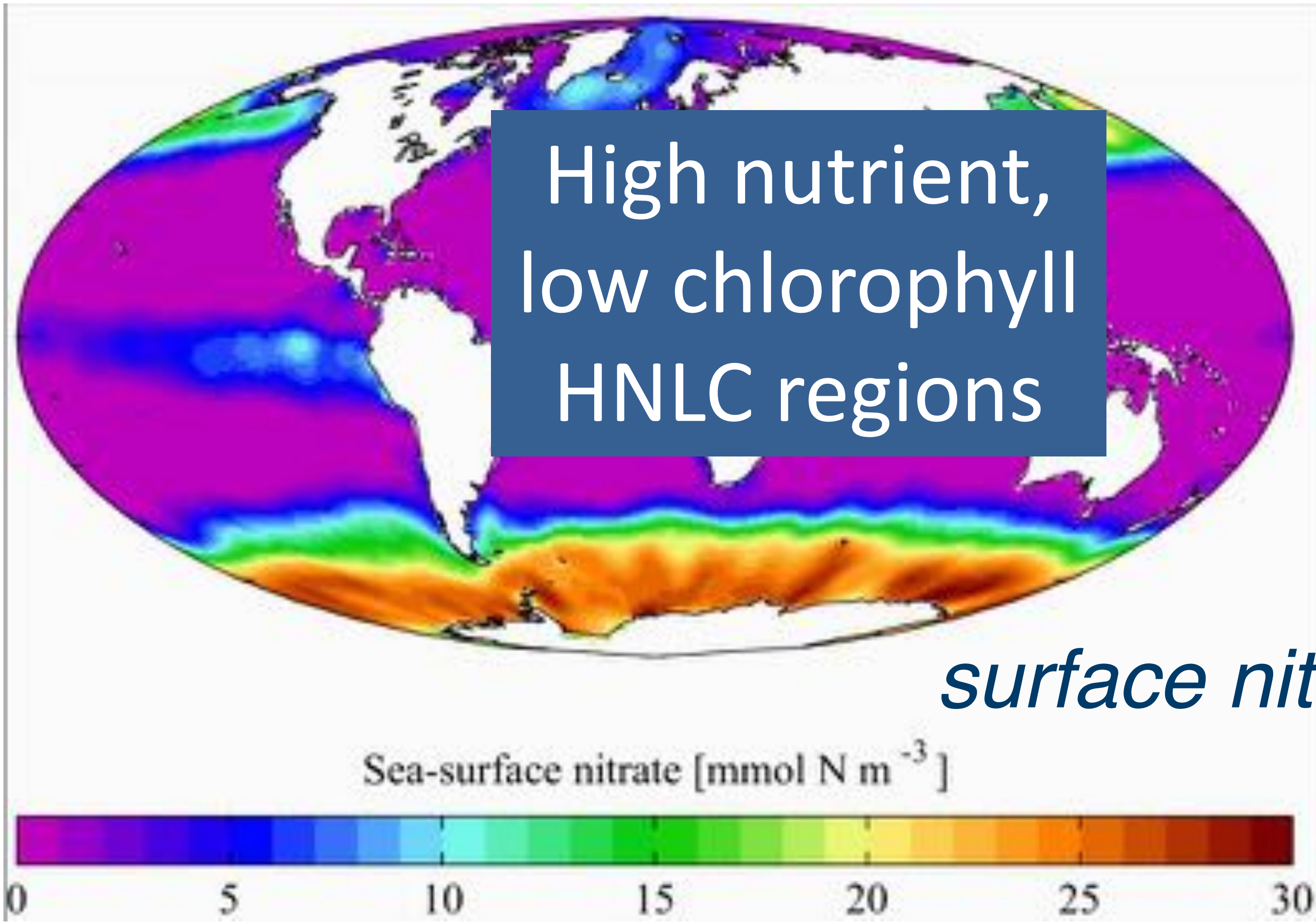
Ice rafted debris (dirt) in icebergs

HNLC Regions, Grazing and Iron

John Martin (1935-1993)

Colby '62

High nutrient,
low chlorophyll
HNLC regions

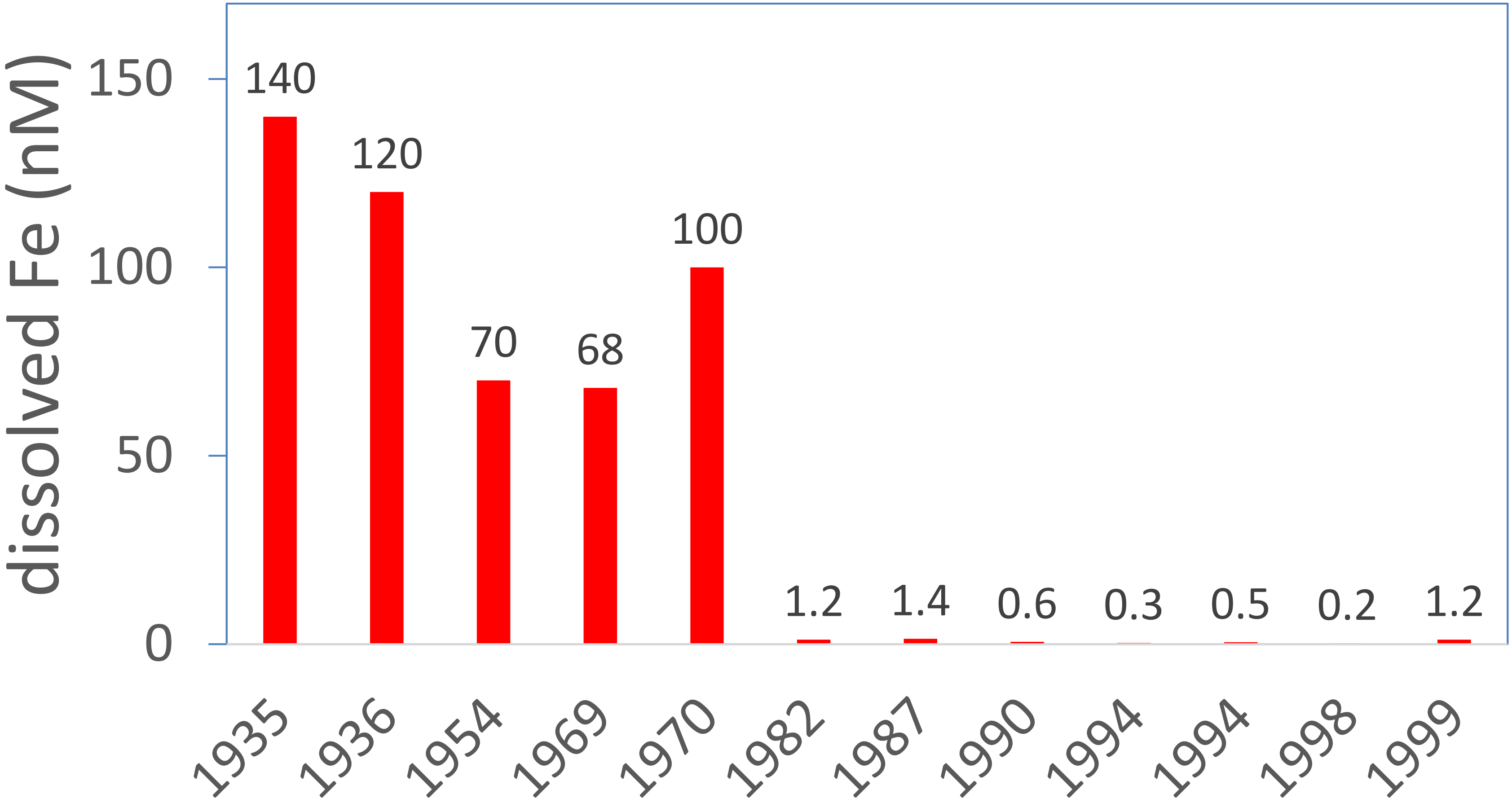


surface nitrate

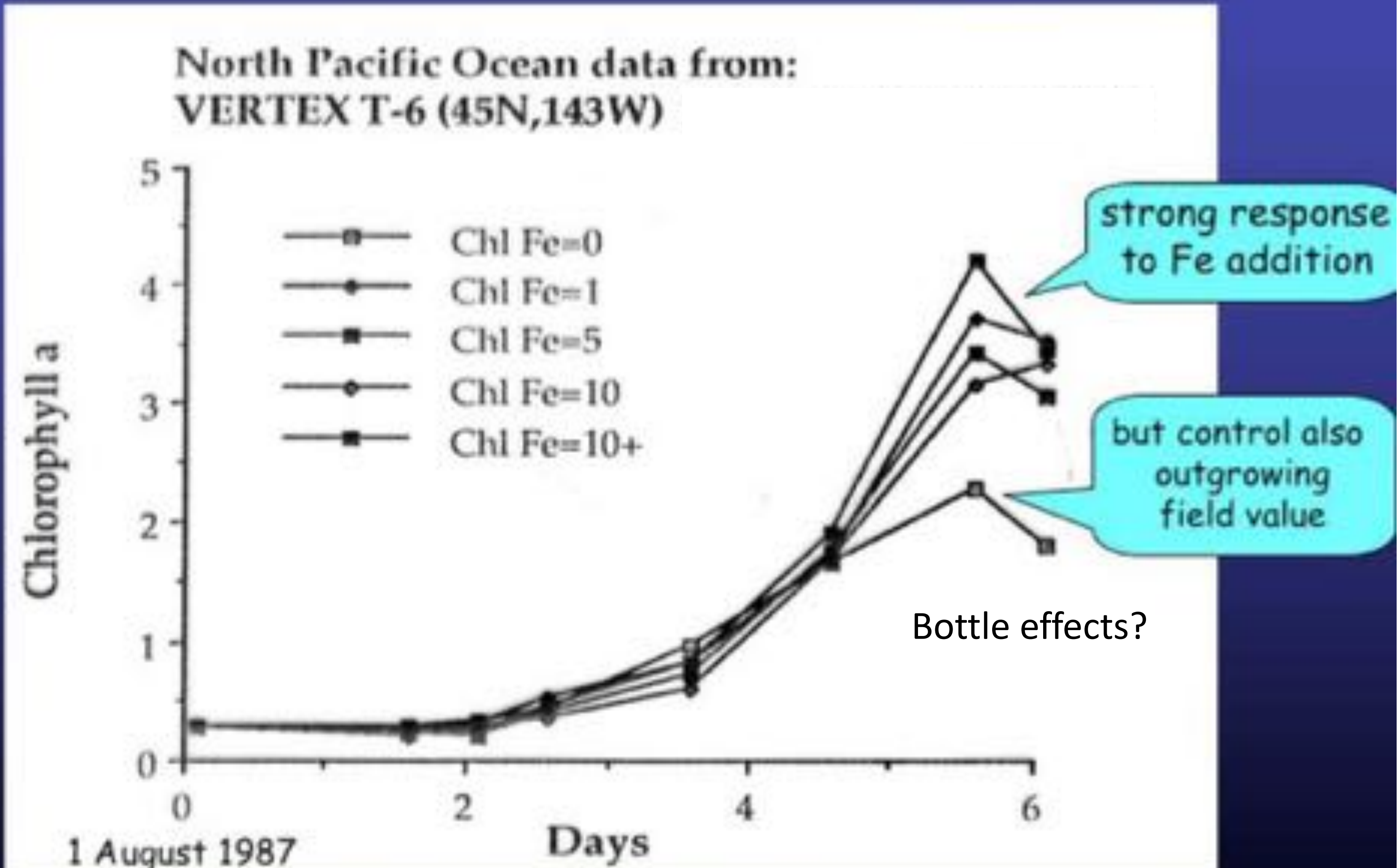
Claire Patterson

1922-1995


Ocean iron concentrations through time…



Subarctic North Pacific, August 1987

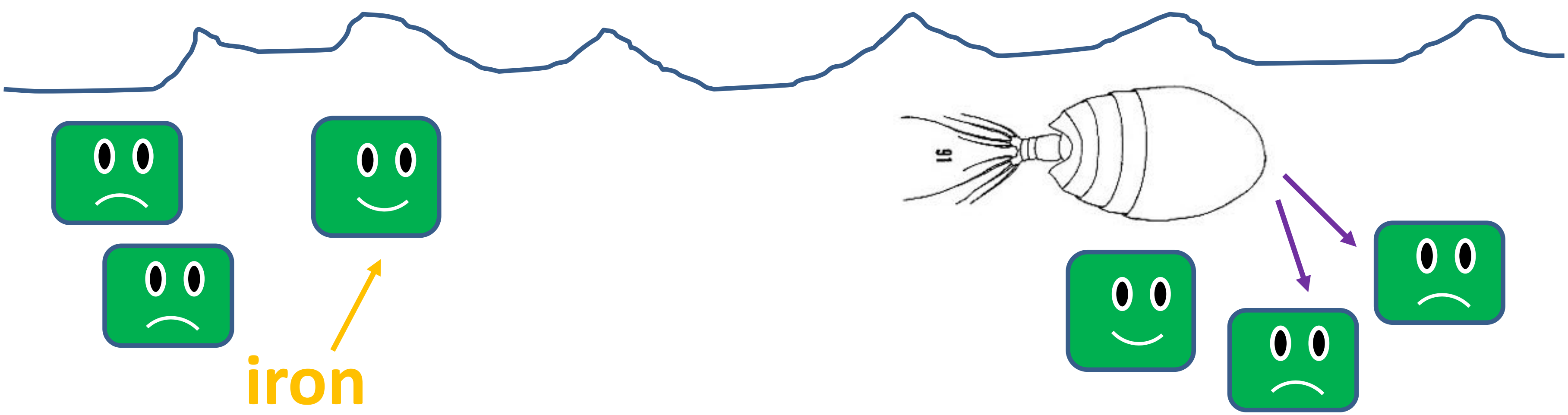


....as shown in Paris by John Martin in September 1987

Oscar Schofield - Rutgers Martin and Fitzwater (1988) *Nature*, **331**, 341-343.

Why are nutrients not depleted in HNLC regions?

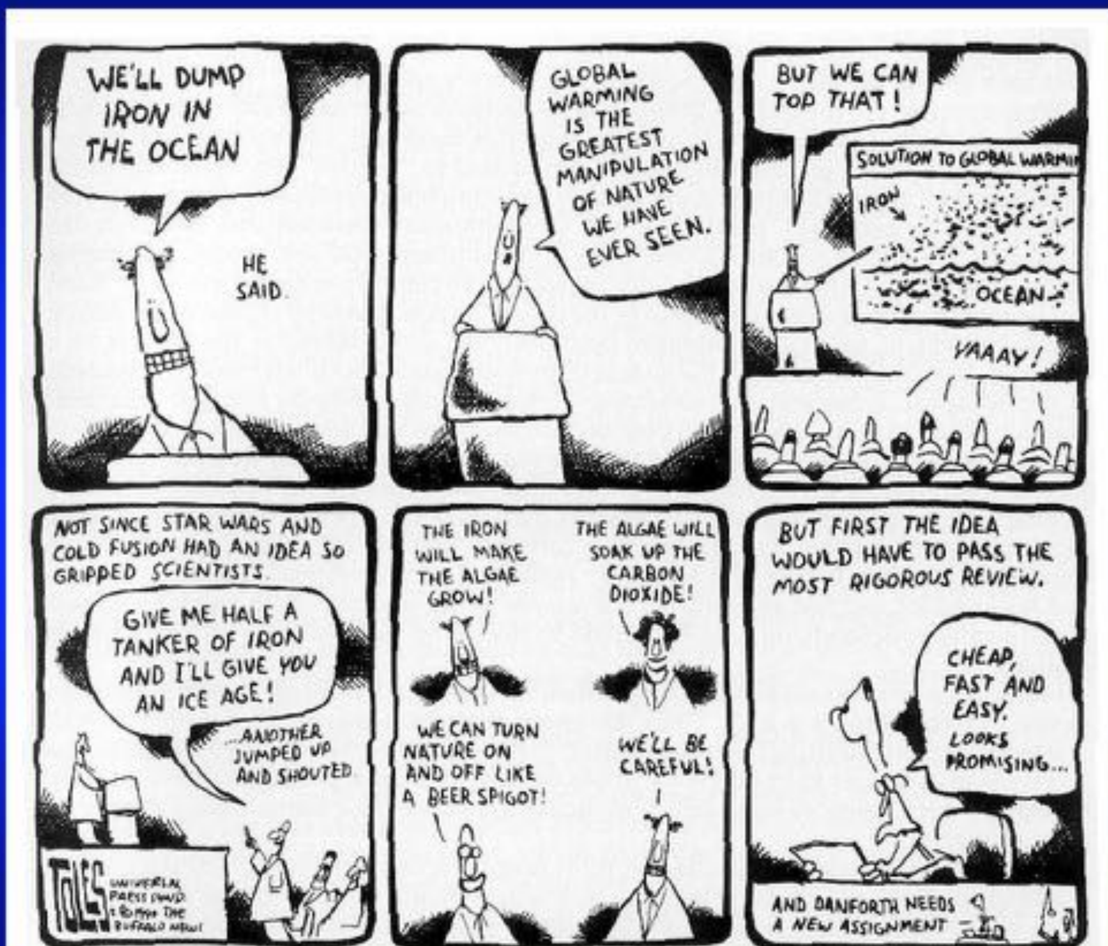
Iron hypothesis *vs.* *Grazing hypothesis*



"give me half a tanker of iron, and I will give you the next ice age"

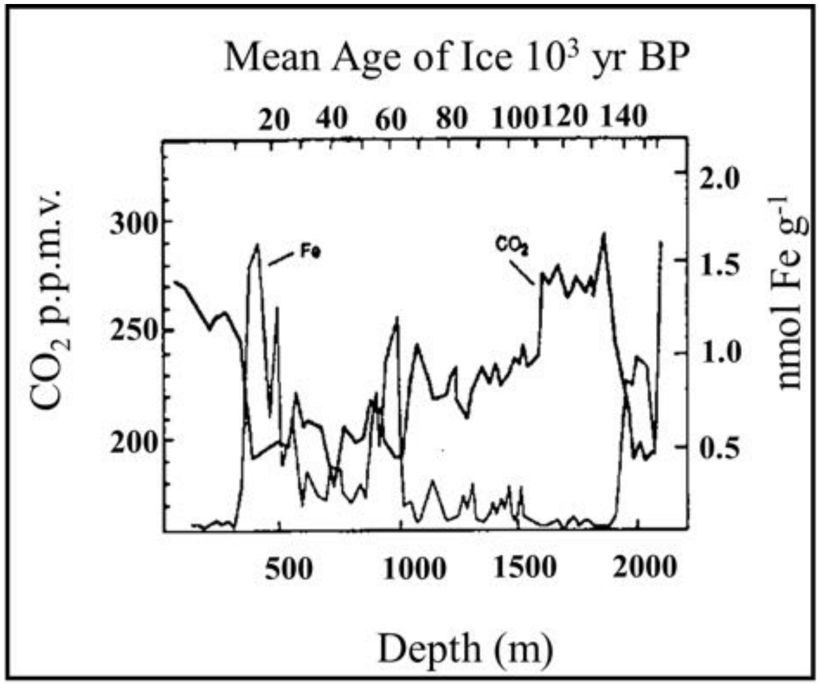
... John Martin

(Colby '62)

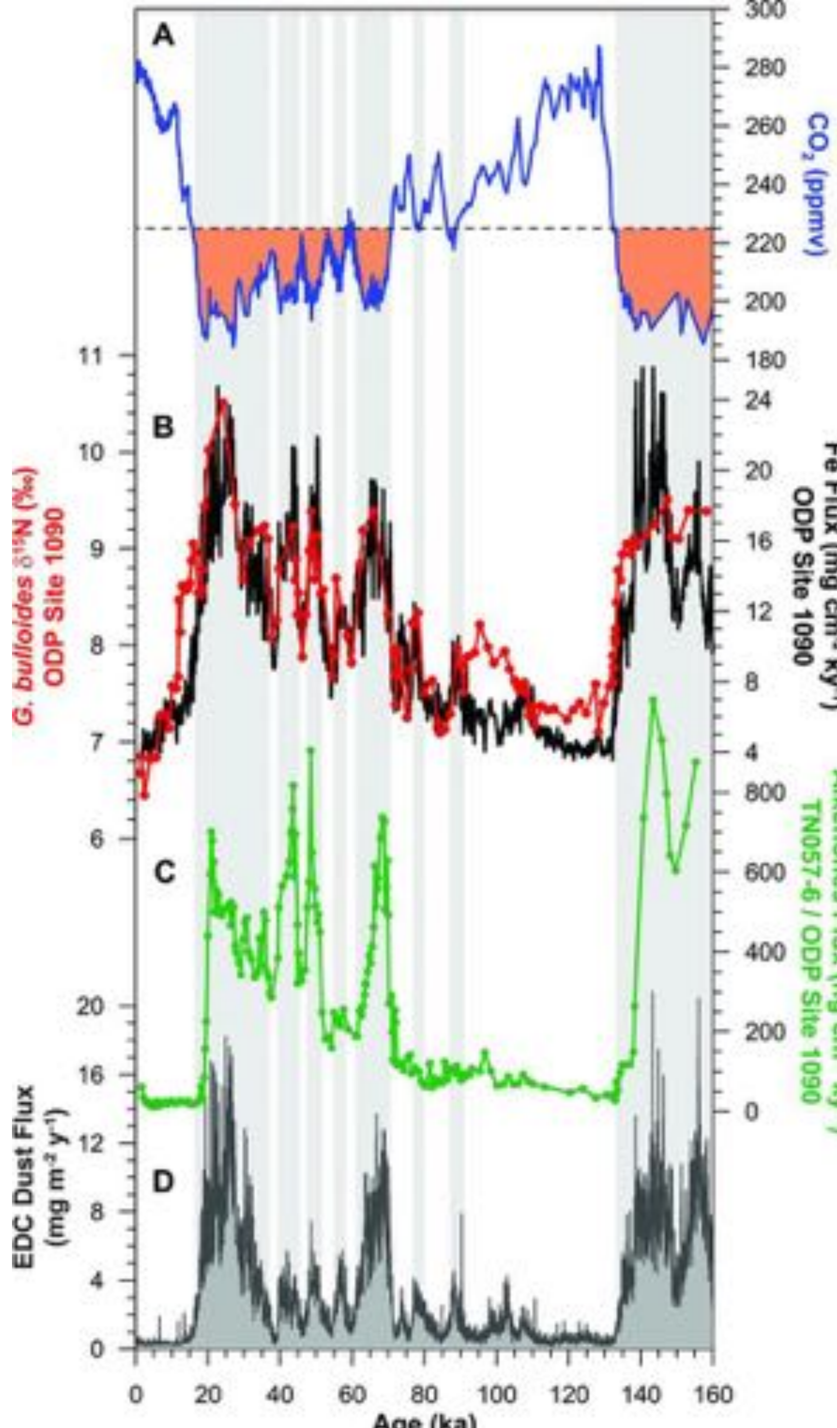


Over beer, on the Redfield patio, Woods Hole Oceanographic Institution, July 1988

Iron and atmospheric carbon dioxide

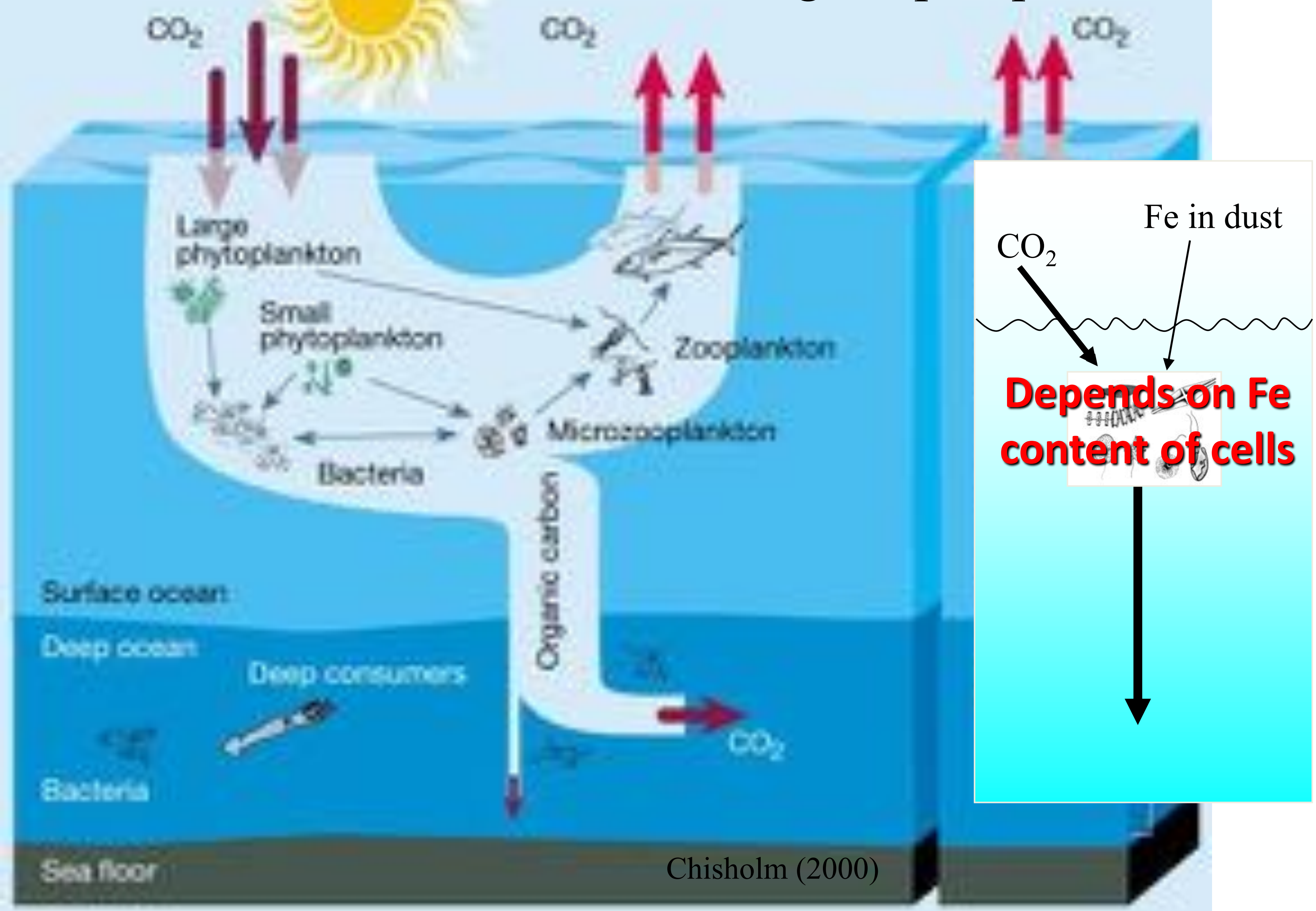


(Martin 1990)



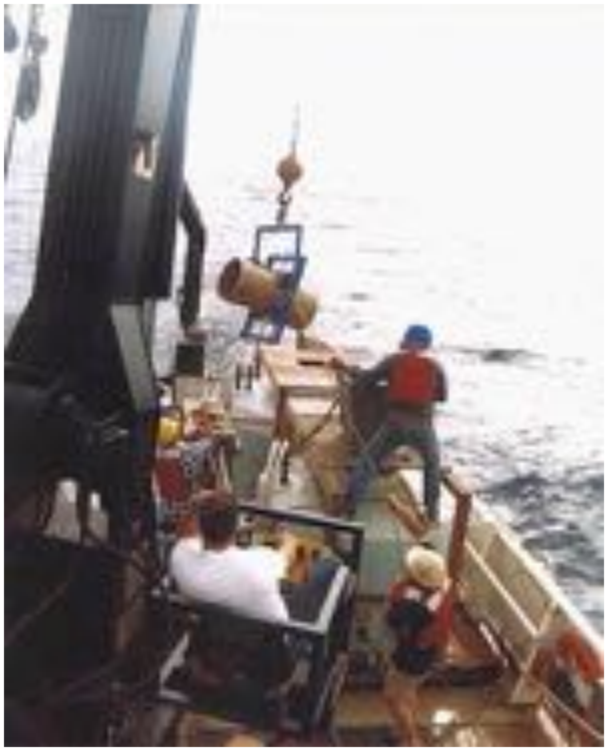
(Martinez-Garcia et al. 2014)

Iron may prime the biological pump

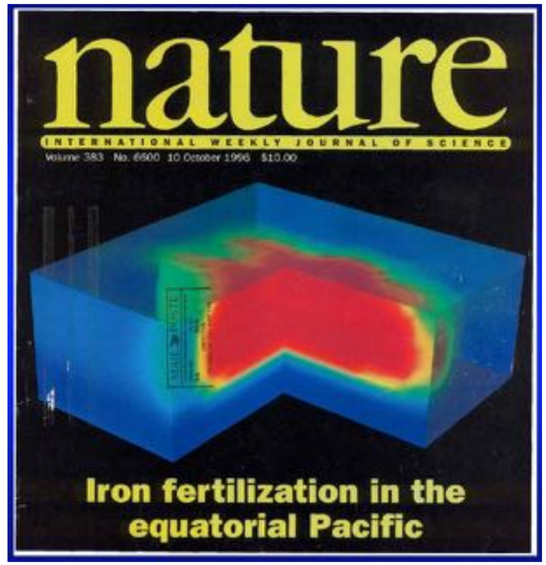


Chisholm (2000)

In situ iron addition experiments

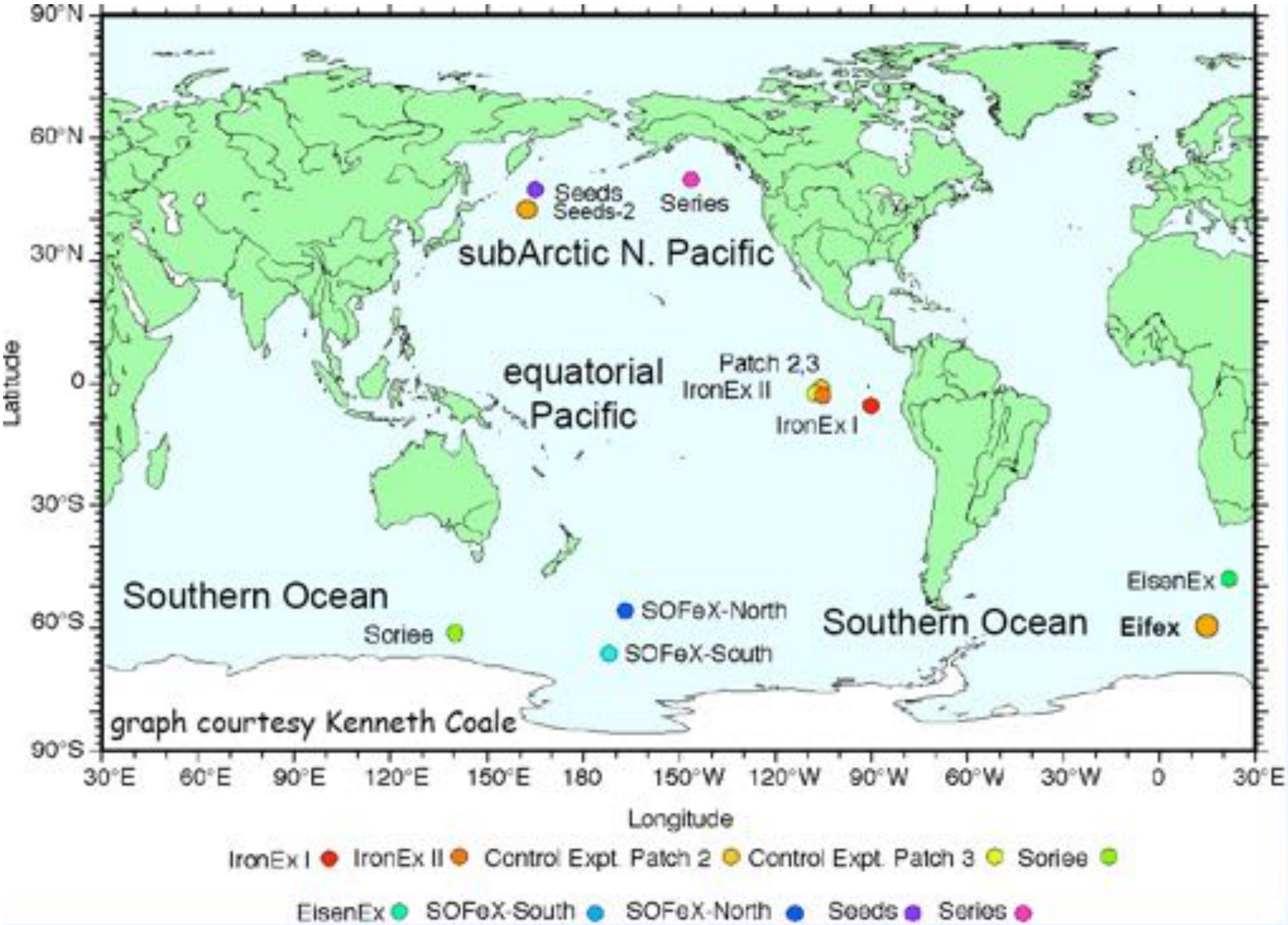


IRONEX, 1993



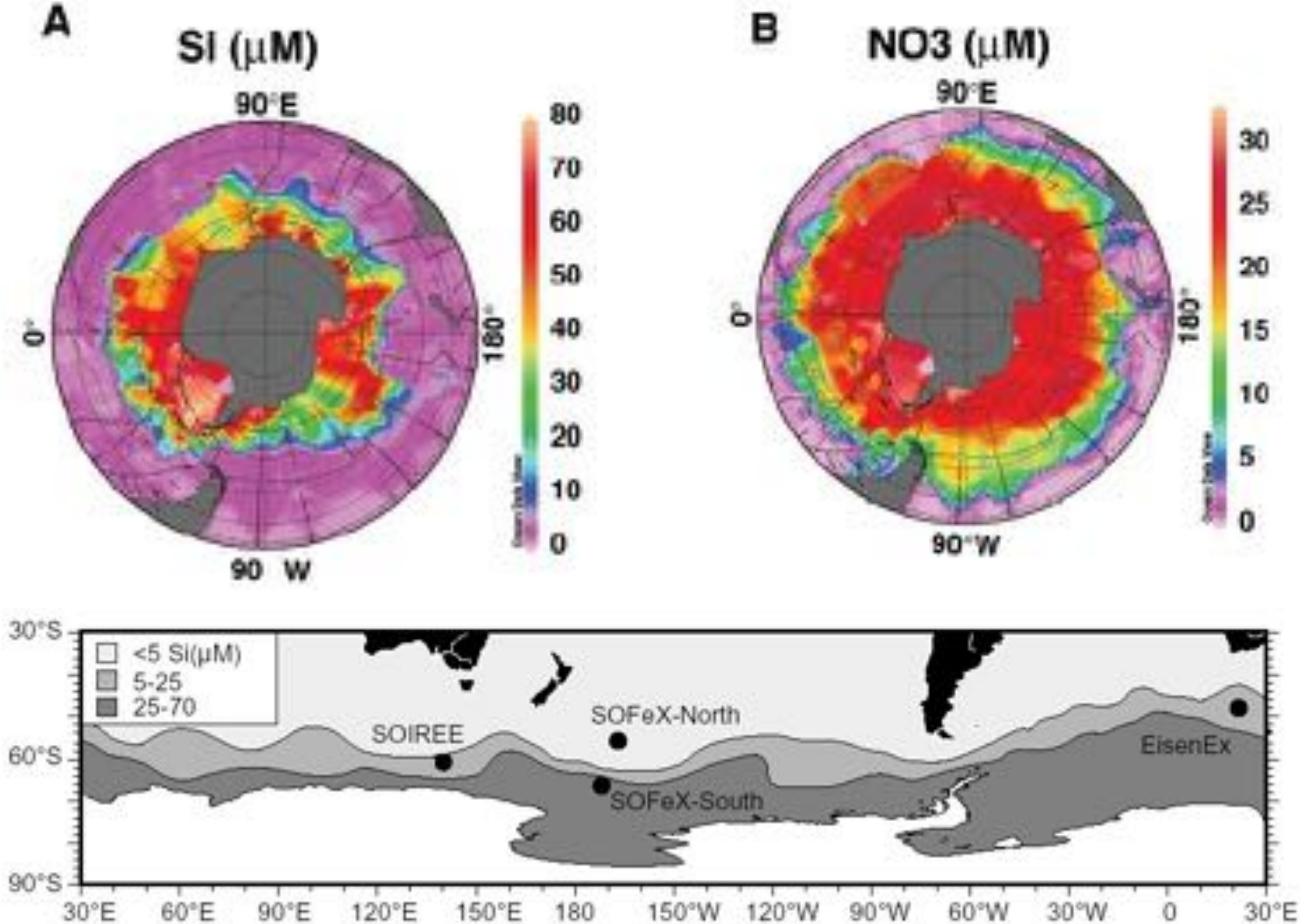
IRONEX II, 1995

SOFEX, 2002



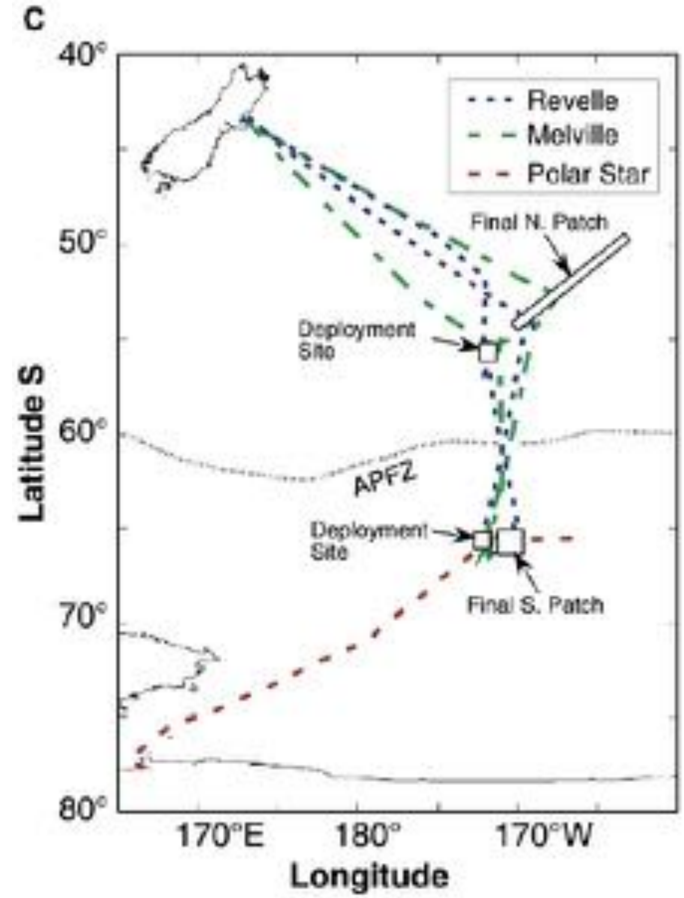
90°N
60°N
30°N
0
30°S
60°S
90°S
Latitude
Seeds
Seeds-2
Series
subArctic N. Pacific
equatorial Pacific
Patch 2,3
IronEx II
IronEx I
Southern Ocean
Soriee
SOFeX-North
SOFeX-South
Southern Ocean
EisenEx
Eifex
graph courtesy Kenneth Coale
30°E 60°E 90°E 120°E 150°E 180 150°W 120°W 90°W 60°W 30°W 0 30°E
Longitude
IronEx I IronEx II Control Expt. Patch 2 Control Expt. Patch 3 Soriee
EisenEx SOFeX-South SOFeX-North Seeds Series

Southern Ocean Iron Experiment

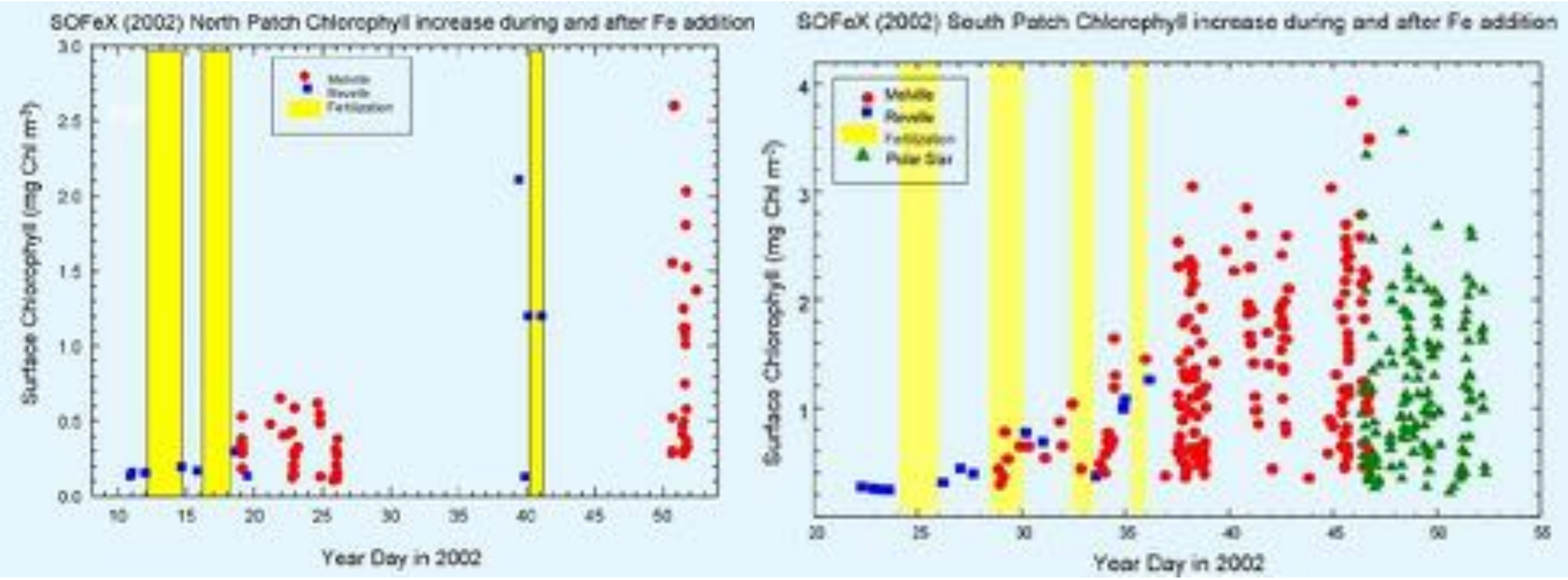


SOFeX cruise plan

- Austral summer: Jan-Feb
- Fertilized two patches of water:
    - North: high N, P; low Si
    - South: high N, P, Si
- Plankton samples collected inside and outside each patch for x-ray fluorescence analysis

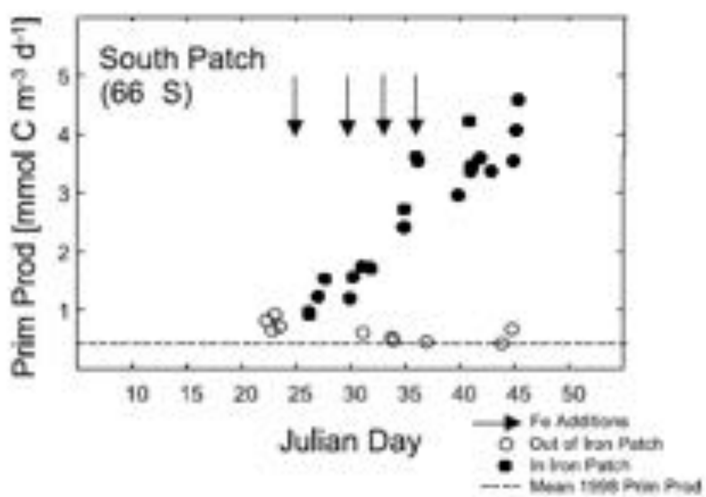


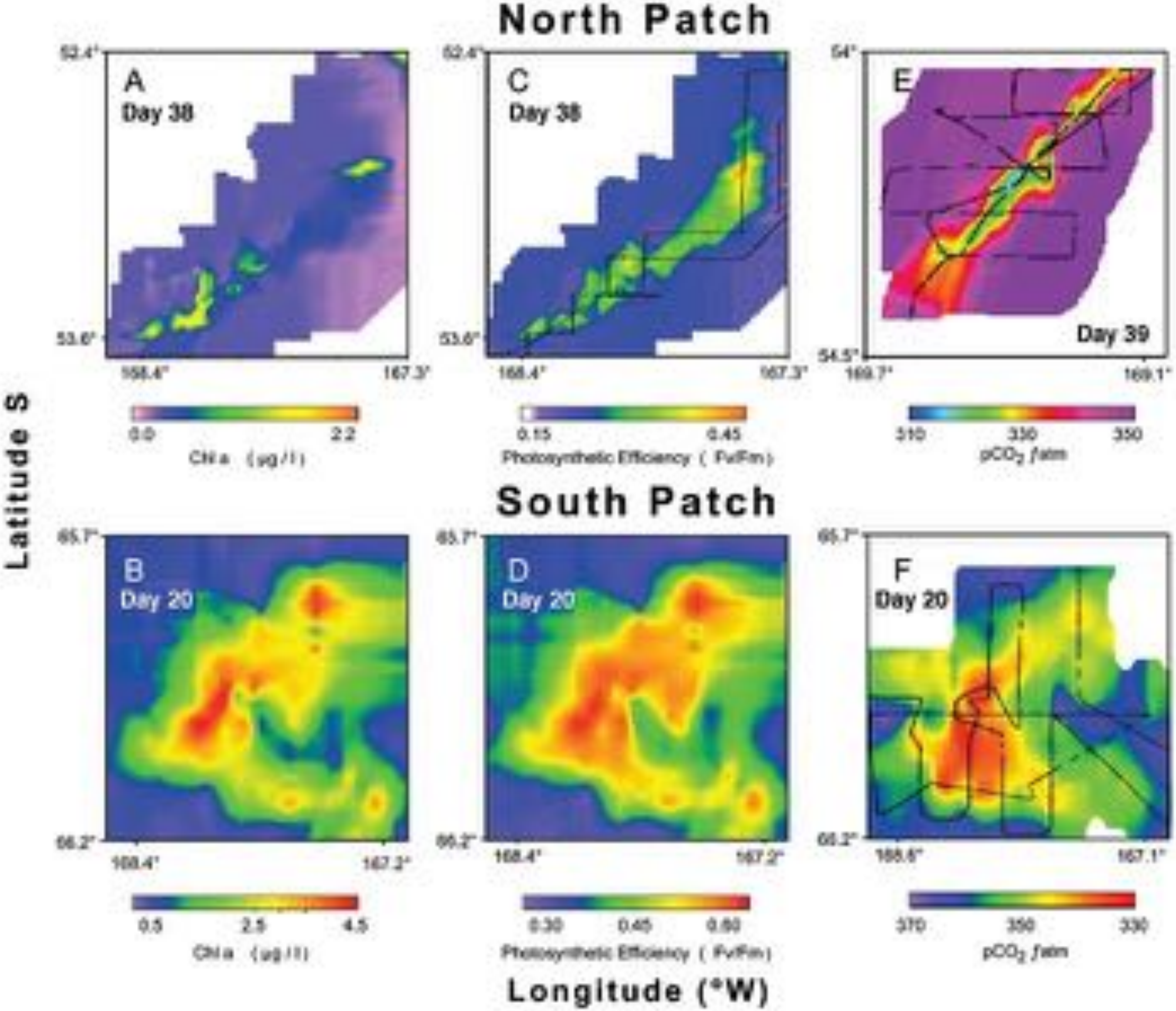
Response of phytoplankton community



North

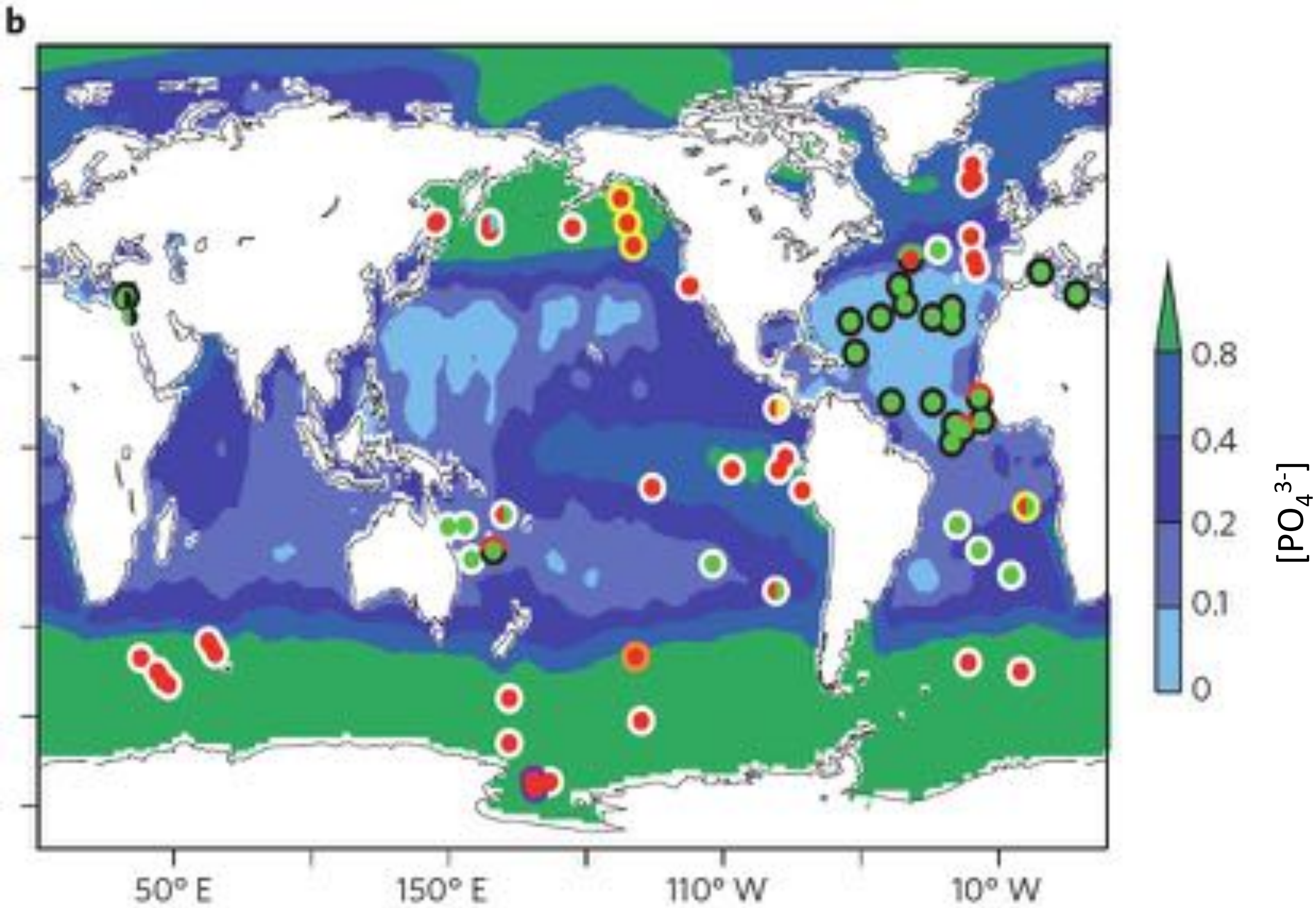
South





North Patch
South Patch
Latitude S
Longitude (°W)
A
Day 38
C
Day 38
E
Day 39
B
Day 20
D
Day 20
F
Day 20
Chl a (µg / l)
Photosynthetic Efficiency (Fv/Fm)
pCO2 µatm

Metal limitation of primary production



Limiting nutrient: N P Fe Co Si

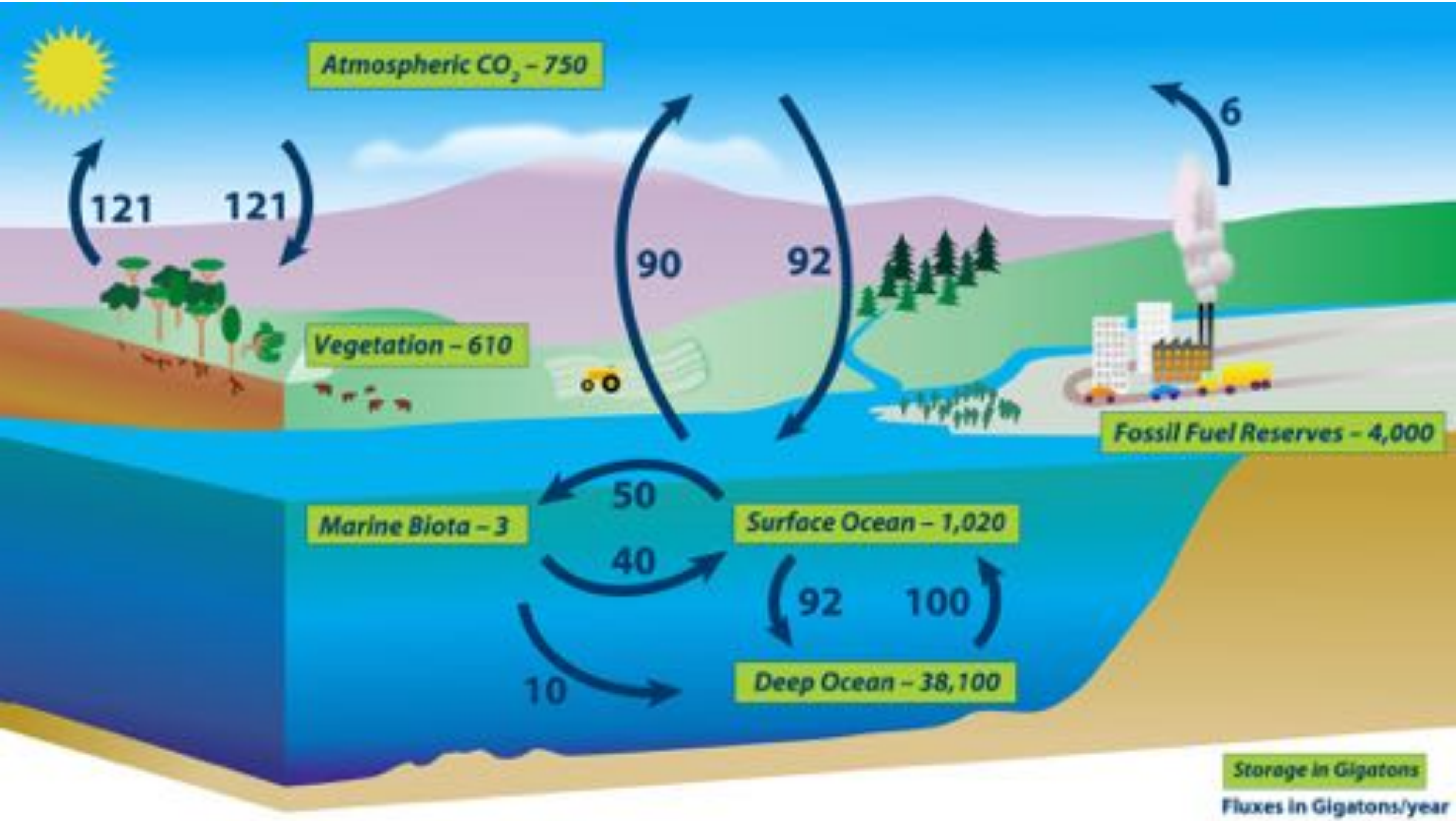
(Moore et al. 2013 *Nature Geo.*)

Climate geoengineering

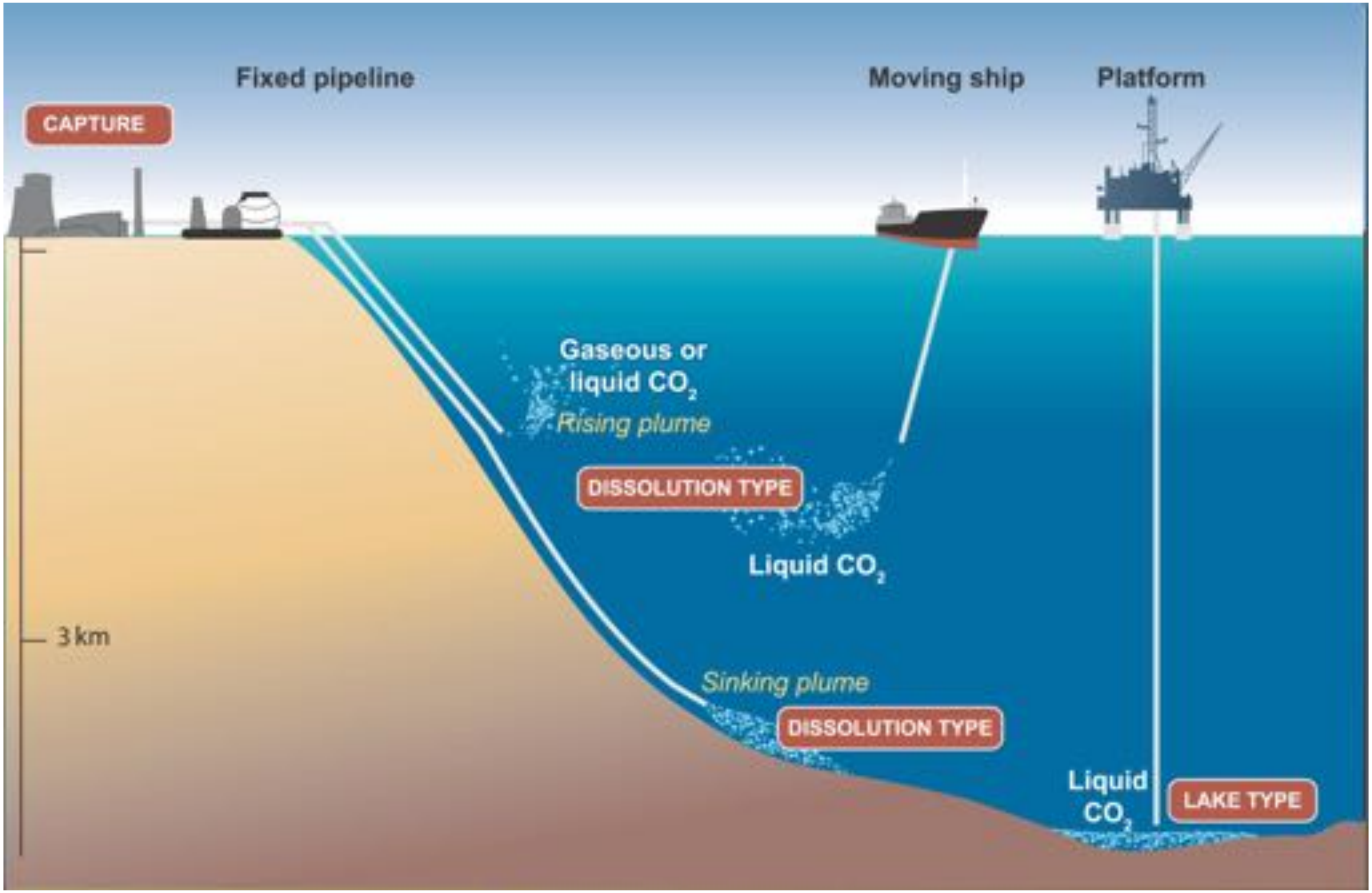
- National Academy of Sciences: “climate intervention”

- Albedo modification
- Carbon sequestration

The Global Carbon Cycle

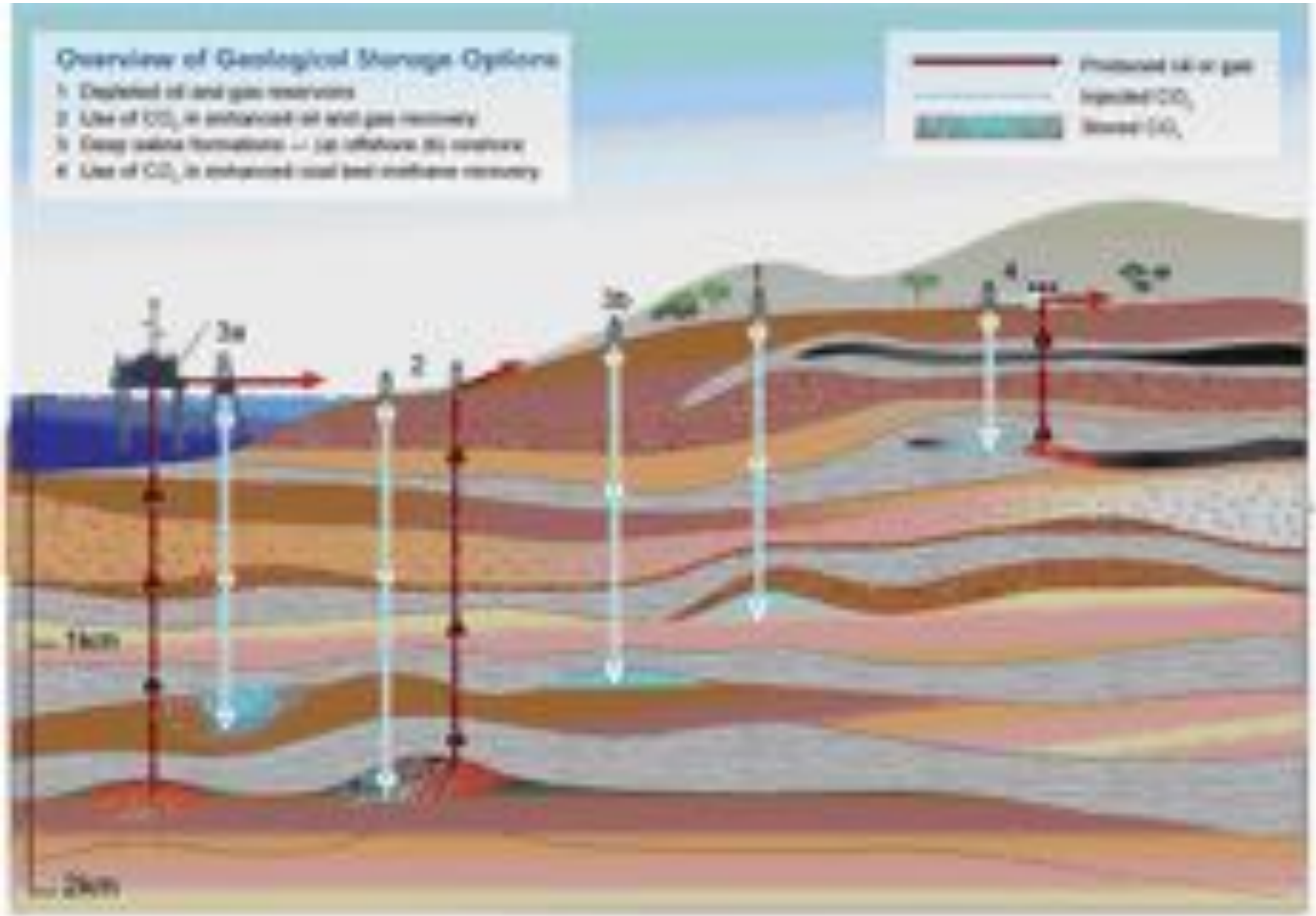


Direct oceanic CO_2 sequestration



Potential impacts: 1) change in ocean pH at location of input; 2) benthic kills / other ecosystem impacts; 3) eventual release of CO_2 back to atmosphere due to MOC

Geological CO_2 sequestration



Mineral carbonation

$$CO_2 + MgO \rightarrow MgCO_{3(s)}$$

$$CO_2 + CaO \rightarrow CaCO_{3(s)}$$

Then store resulting salts on seabed (above calcium carbonate compensation depth)

Enhance chemical weathering

$$\text{Igneous rocks}_{(s)} + H_2CO_{3(aq)} + H_2O_{(l)} \rightarrow$$
$$HCO_3^-{}_{(aq)} + H_4SiO_{4(aq)} + \text{Cations}_{(aq)} + \text{Clay minerals}_{(s)}$$

Generate acid from seawater using solar energy and spray on coastal volcanic rocks. Uses CO_2; generates HCO_3^-

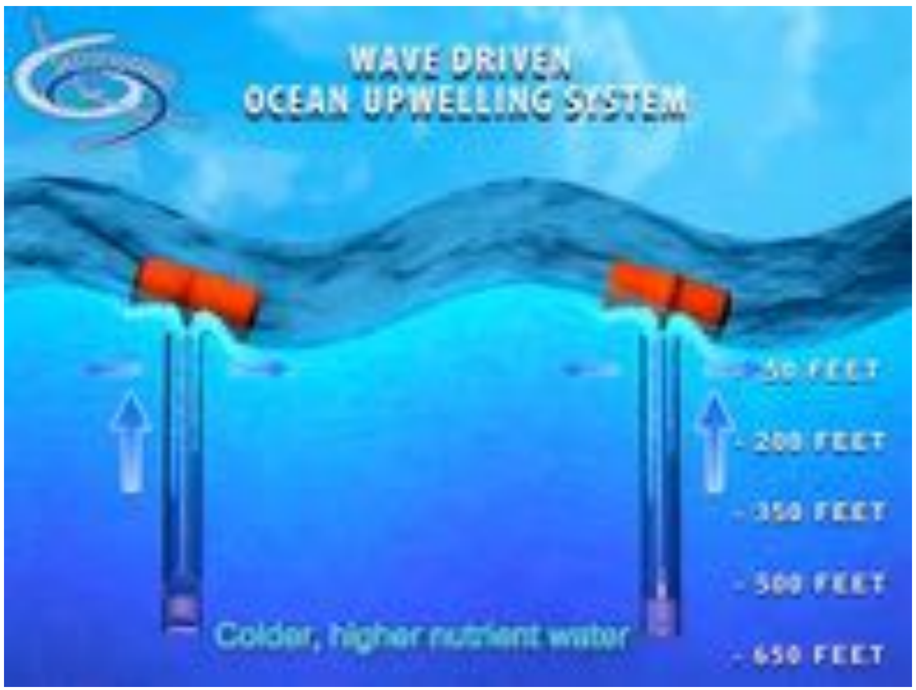
Ocean iron fertilization motivations

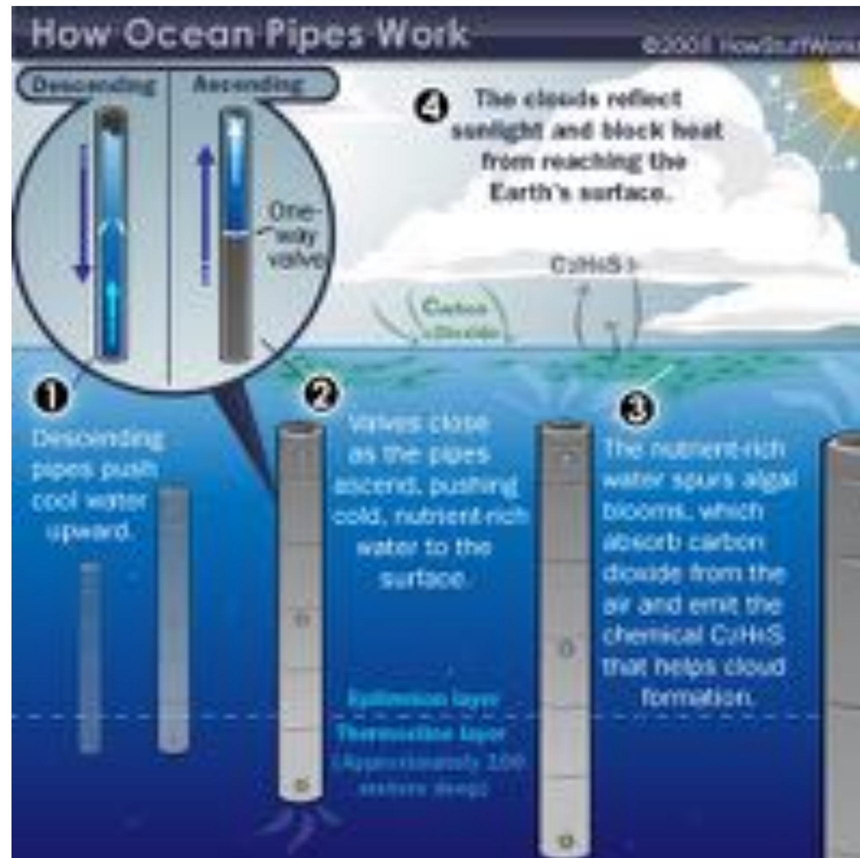
- Mitigate atmospheric CO_2 emissions by using the ocean to store carbon
- Increase fisheries productivity

Ocean fertilization

Ocean Nourishment Corporation: fertilization of surface ocean waters with urea and other N compounds

Atmocean, Inc.: “wave energy sequestration technology”





Ocean iron fertilization

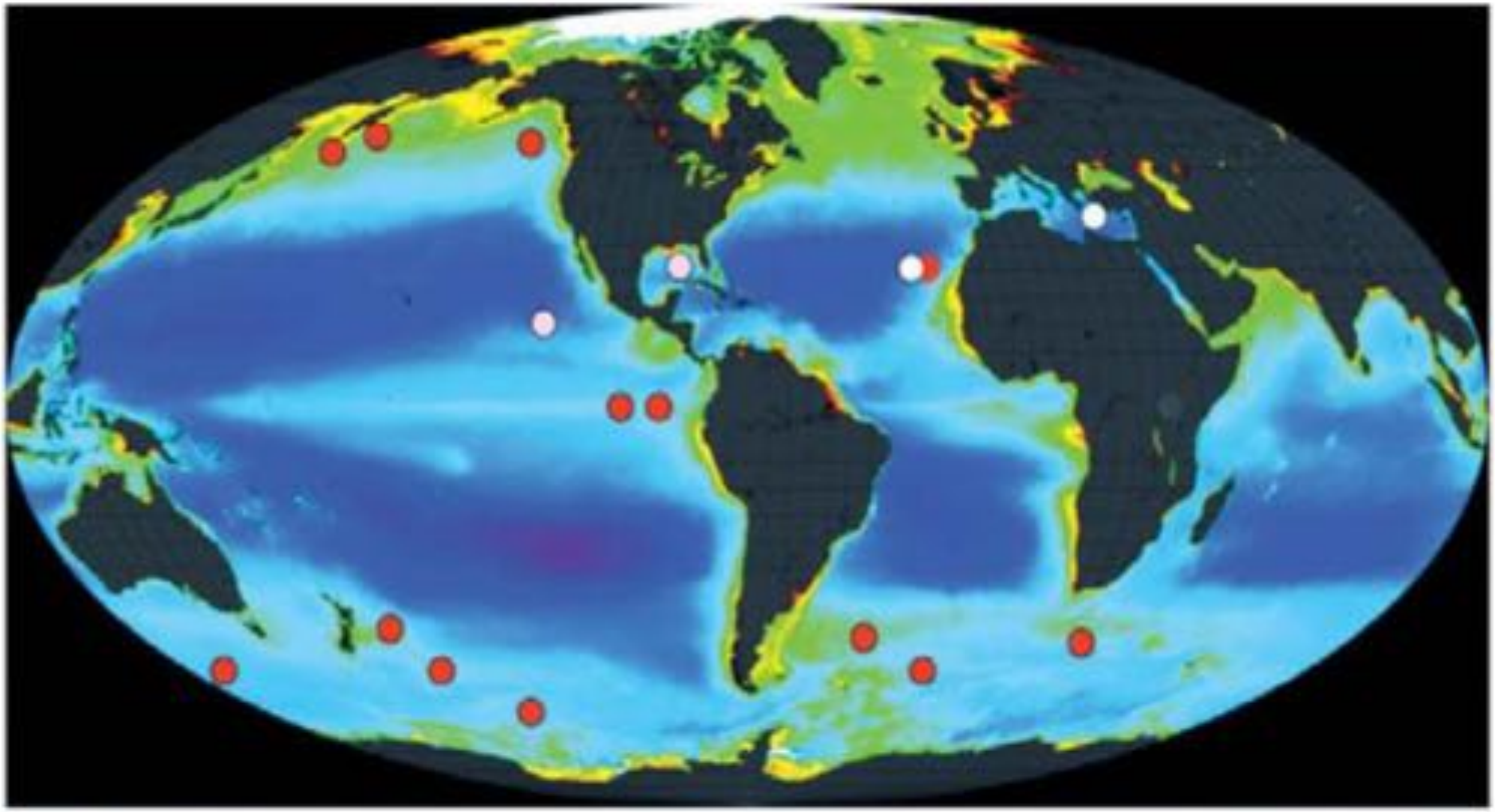
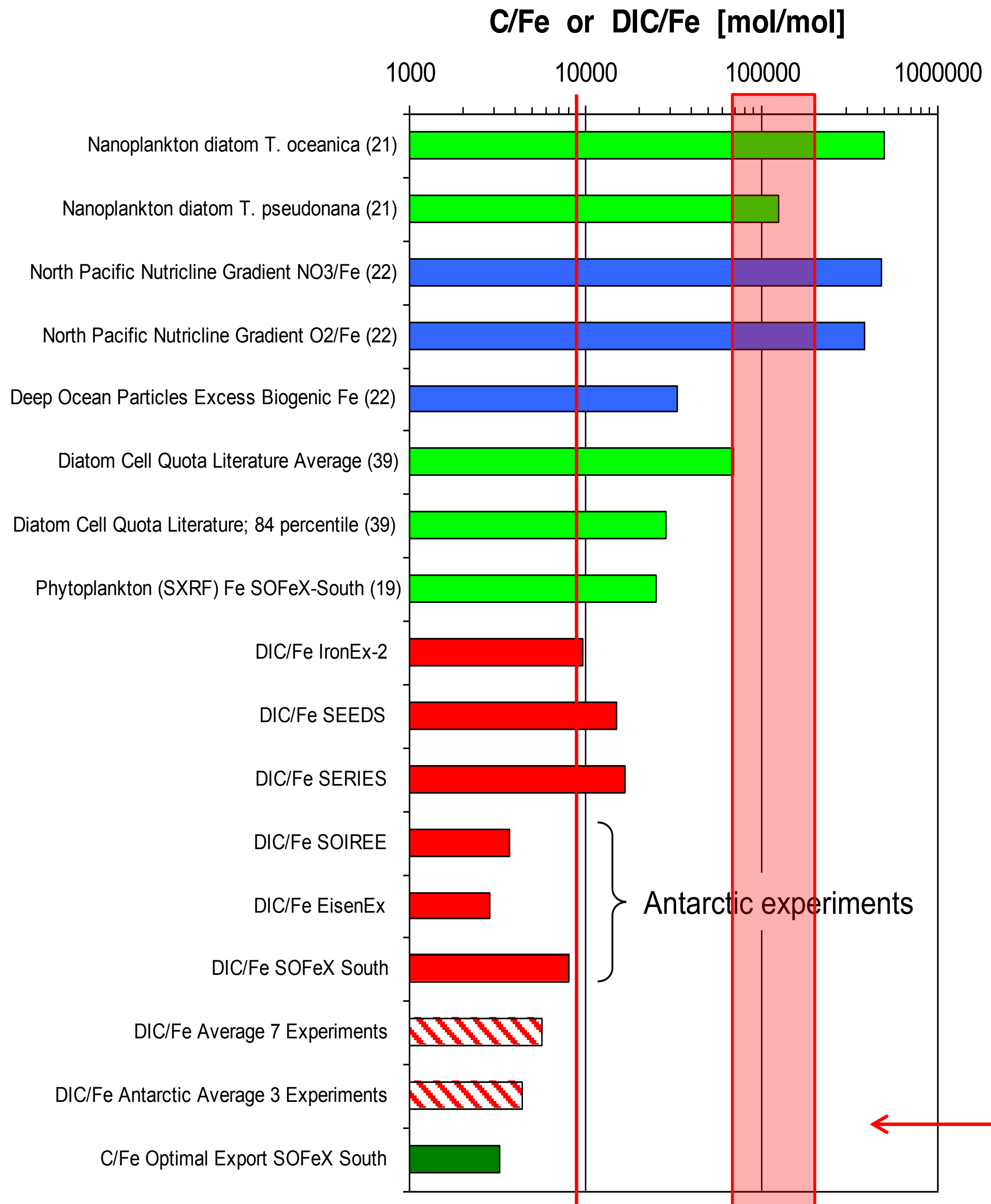


Fig 2. *Sites of the 13 iron fertilization experiments (red), two commercial trials using iron (pink) and two phosphate addition studies (white) carried out to date, on map of satellite-based ocean primary production (yellow/green, high; dark blue, low).*

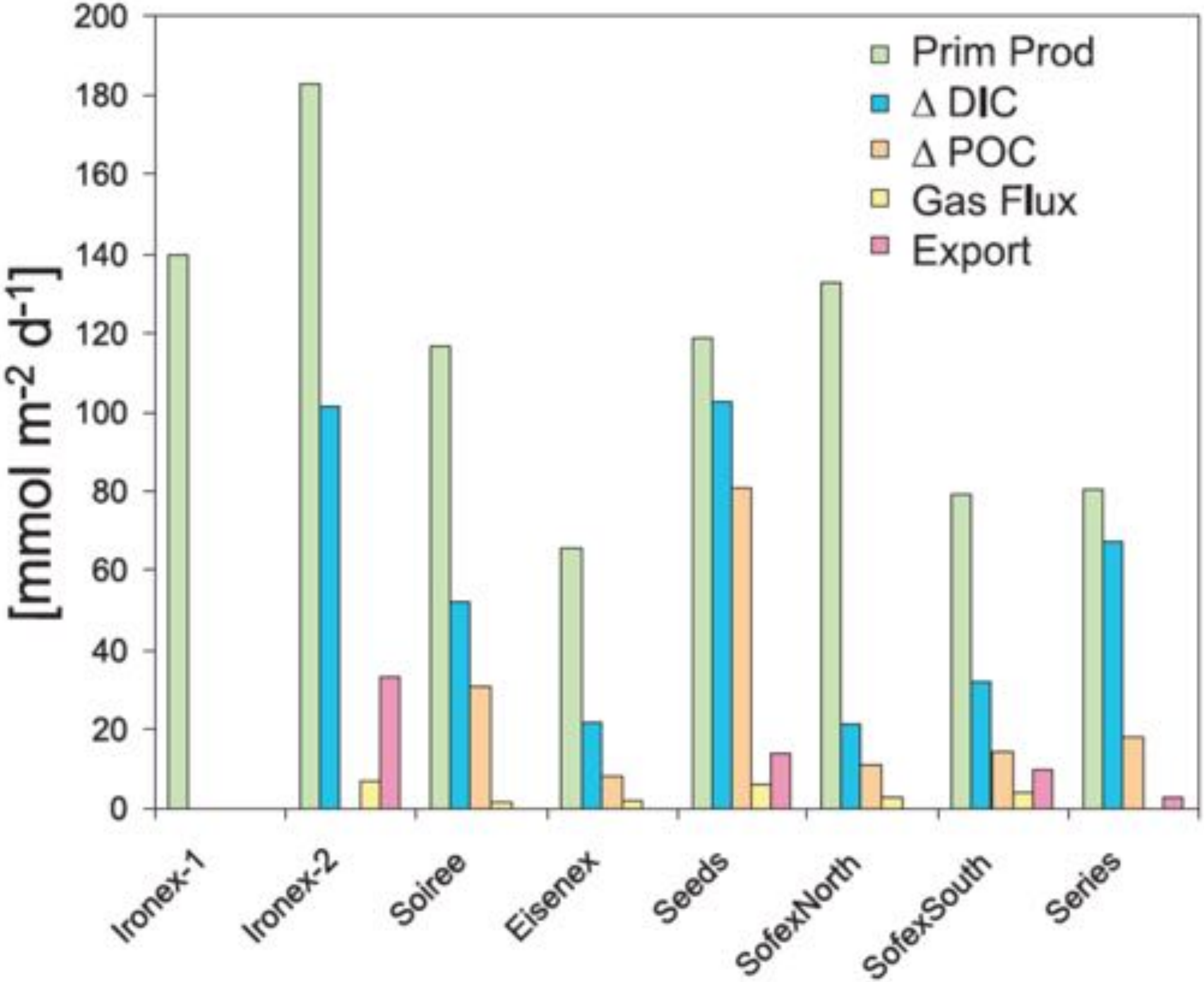


Sequestration efficiency

(C removed per mole Fe added)

Red lines are natural OIFs (Crozet and Kerguelen archipelagos)

So will it work?



Modeling effects of OIF

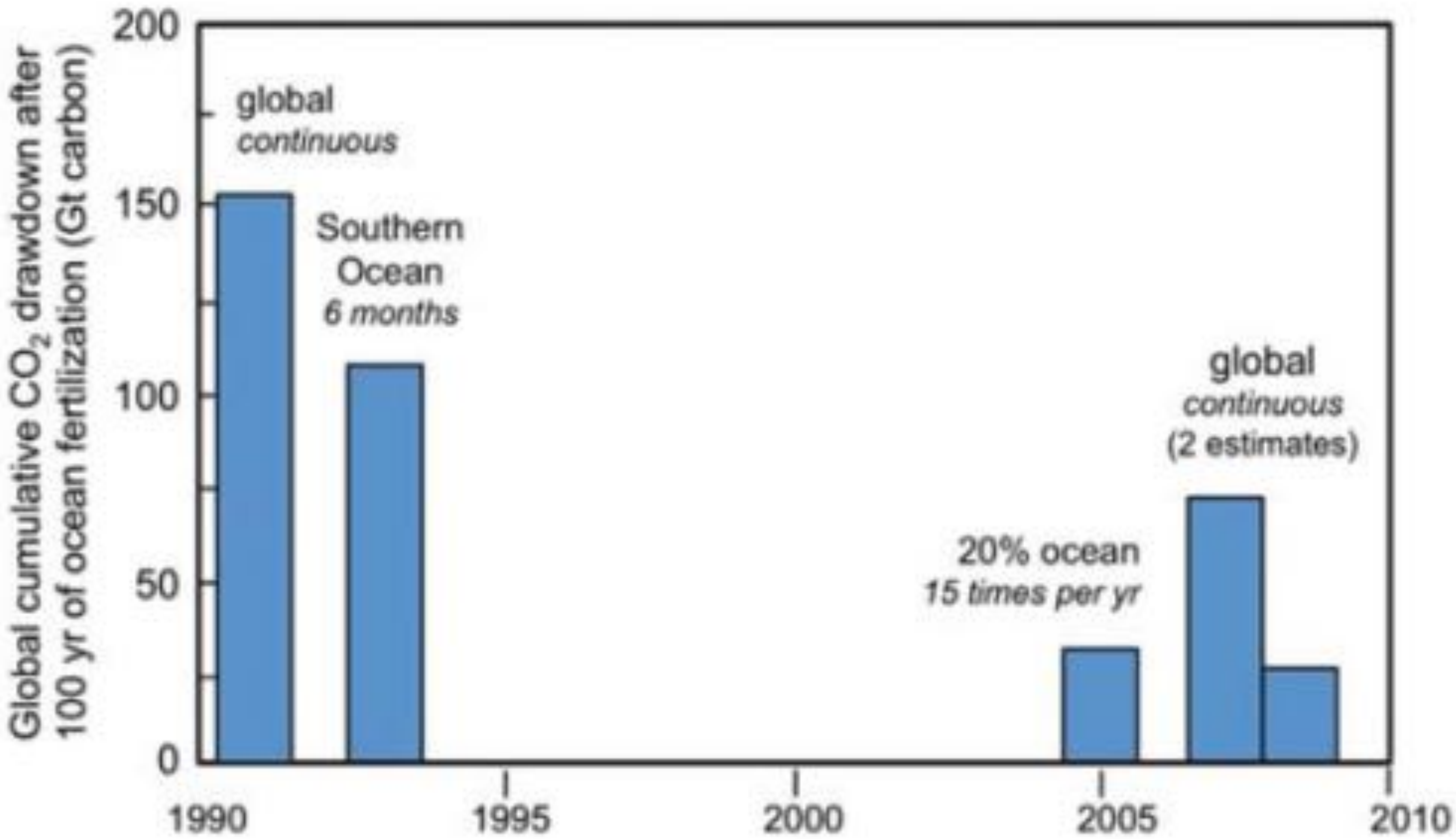
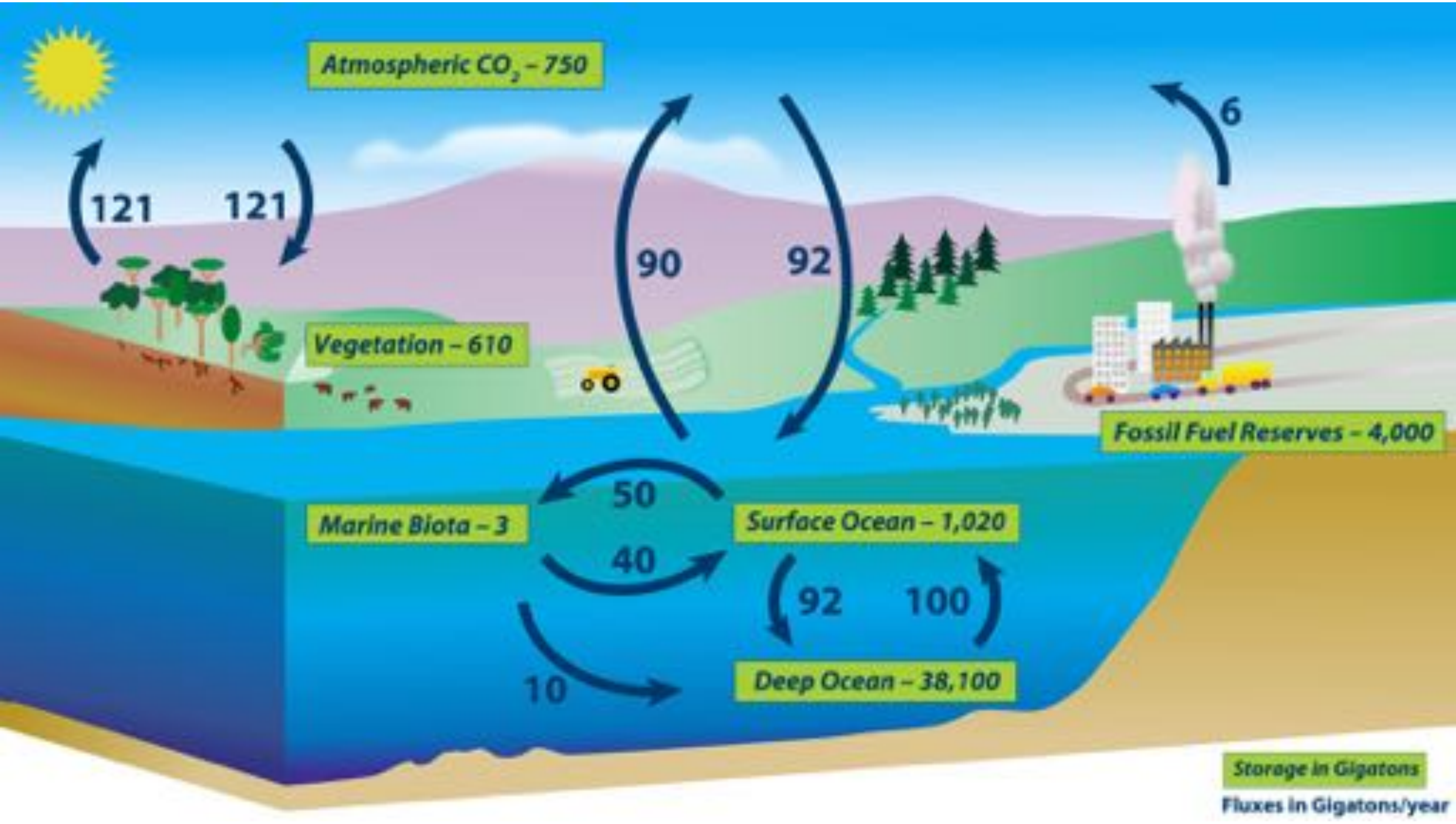
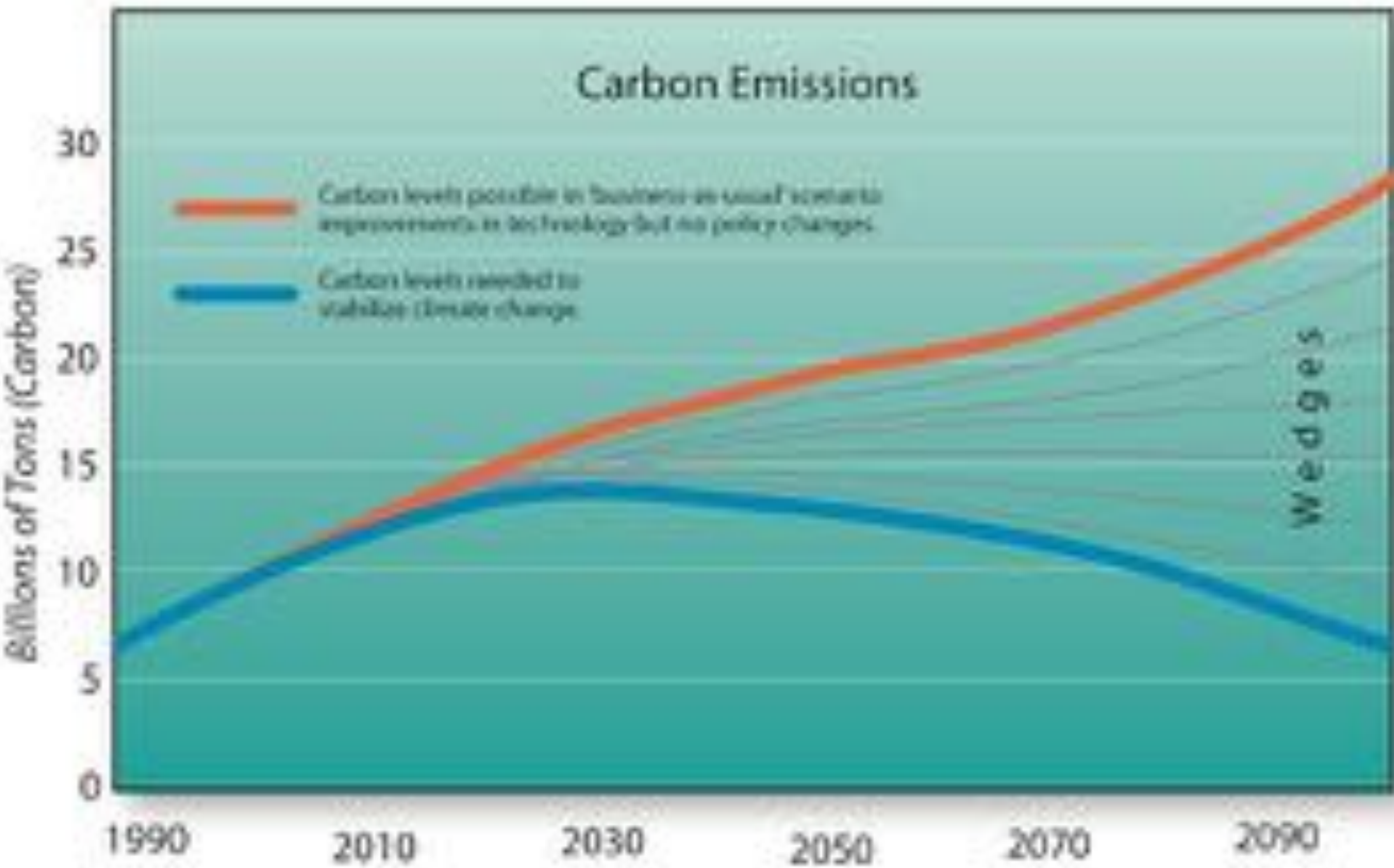


Fig 4. *Model-based estimates of the effectiveness of carbon sequestration (cumulative drawdown over 100 yr) for large-scale, iron-based ocean fertilization. Dates relate to year of publication.*

The Global Carbon Cycle



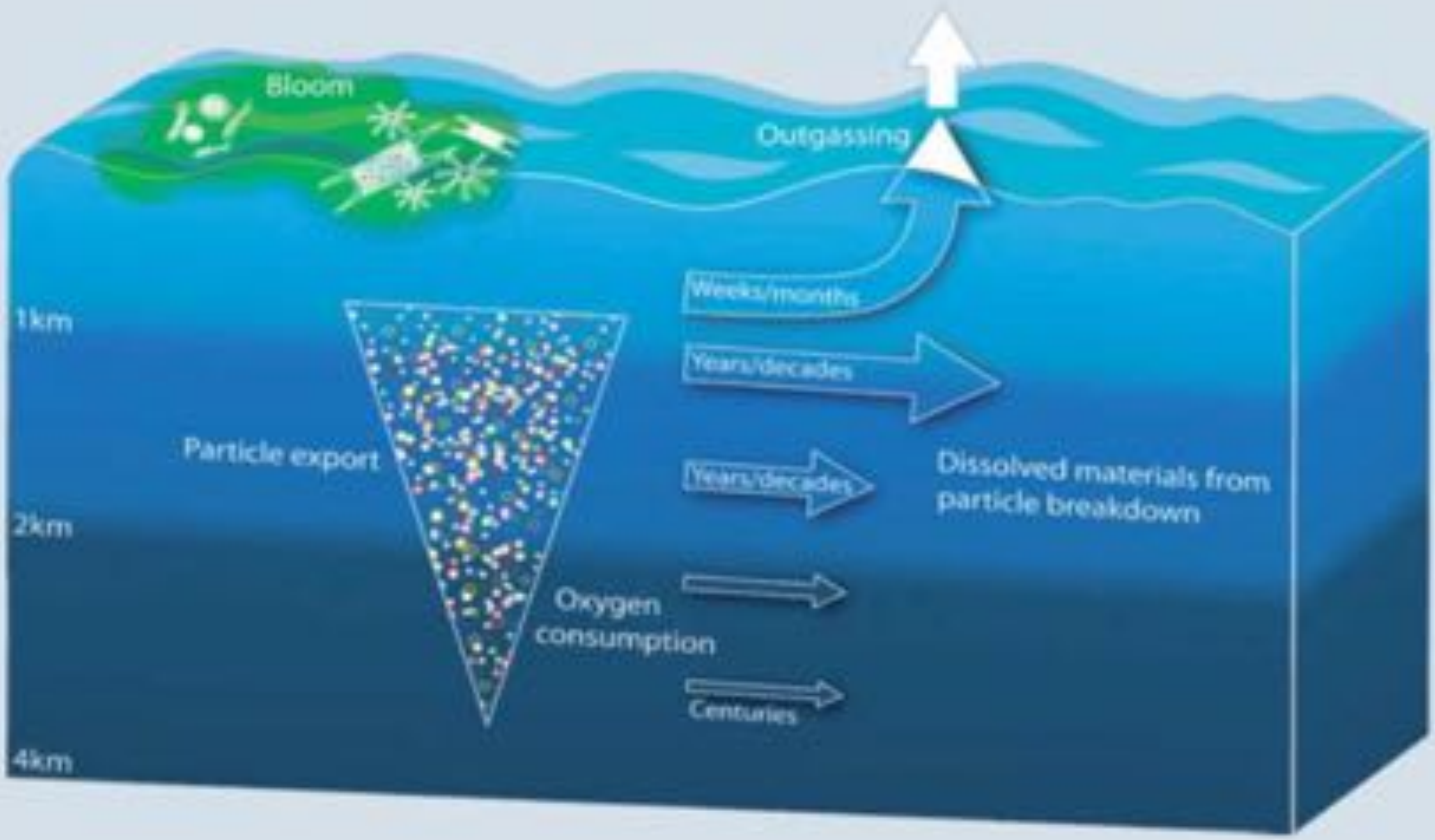
A ‘stabilization wedge’?



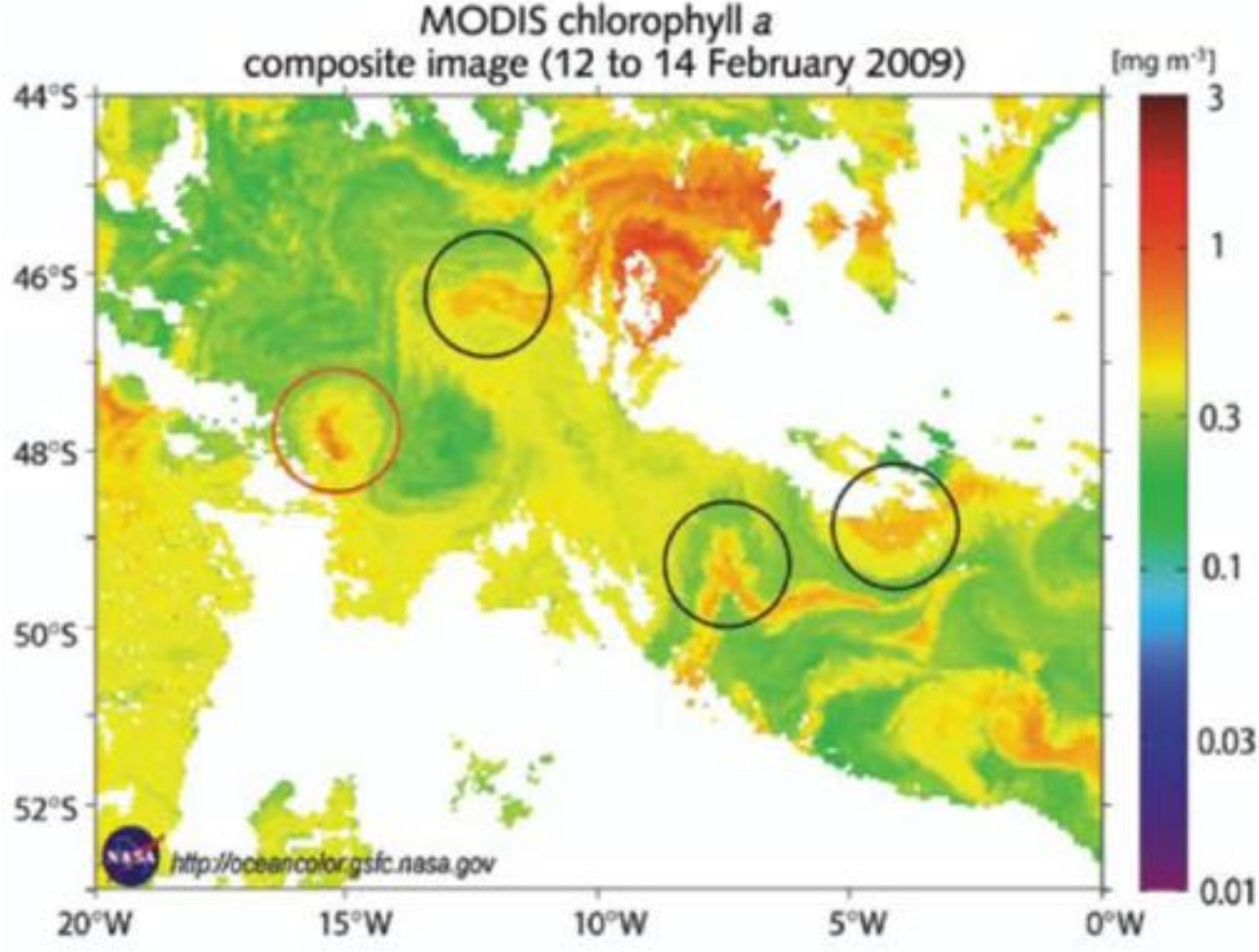
Potential negative effects

- Removal of oxygen at depth
- Generation of N_2O and methane
- ‘nutrient robbing’ from other regions
- Changes in food webs
- Difficult to verify C export

The importance of transport and timescales



Vertical and horizontal transport processes over a range of timescales affect the fate of biologically-fixed carbon in the ocean


MODIS chlorophyll a
composite image (12 to 14 February 2009)
[mg m⁻³]
3
1
0.3
0.1
0.03
0.01
44°S
46°S
48°S
50°S
52°S
20°W
15°W
10°W
5°W
0°W
http://oceancolor.gsfc.nasa.gov

Carbon Dioxide Removal proposals…	Albedo Modification proposals…
… address the cause of human-induced climate change (high atmospheric GHG concentrations).	…do not address cause of human-induced climate change (high atmospheric GHG concentrations).
…do not introduce novel global risks.	… introduce novel global risks.
…are currently expensive (or comparable to the cost of emission reduction).	…are inexpensive to deploy (relative to cost of emissions reduction).
…may produce only modest climate effects within decades.	…can produce substantial climate effects within years.
…raise fewer and less difficult issues with respect to global governance.	…raise difficult issues with respect to global governance.
…will be judged largely on questions related to cost.	…will be judged largely on questions related to risk.
…may be implemented incrementally with limited effects as society becomes more serious about reducing GHG concentrations or slowing their growth.	…could be implemented suddenly, with large-scale impacts before enough research is available to understand their risks relative to inaction.
…require cooperation by major carbon emitters to have a significant effect.	…could be done unilaterally.
…for likely future emissions scenarios, abrupt termination would have limited consequences	…for likely future emissions scenarios, abrupt termination would produce significant consequences

Recommendation 1: Efforts to address climate change should continue to focus most heavily on mitigating greenhouse gas emissions in combination with adapting to the impacts of climate change because these approaches do not present poorly defined and poorly quantified risks and are at a greater state of technological readiness.

United States Patent [19]

Markles, Jr.

[11] **Patent Number:** 5,433,173

[45] **Date of Patent:** Jul. 18, 1995

[54] METHOD OF IMPROVING PRODUCTION OF SEAFOOD

[76] Inventor: **Michael Markles, Jr.**, [illegible] Drury La., Alexandria, Va. [illegible]

[21] Appl. No.: [illegible]

[22] Filed: **Apr. 28, 1994**

[51] **Int. Cl.** **A01K 61/00**

[52] **U.S. Cl.** **119/230**

[58] **Field of Search** .... [illegible]

[56] **References Cited**

U.S. PATENT DOCUMENTS

[illegible]	[illegible]	Ellis	
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible] et al.	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible] et al.	[illegible]

FOREIGN PATENT DOCUMENTS

[illegible]	[illegible]	U.S.S.R.	[illegible]

OTHER PUBLICATIONS

Elements of Dynamic Oceanography, D. Tolmazin, 1985, pp. 22-23.

"Testing the Iron Hypothesis in Ecosystems of the Equatorial Pacific Ocean", J. H. Martin et al., Nature, vol. 371, pp. 123-129 (Sep. 8, 1994).

Primary Examiner—Todd E. Manahan

Attorney, Agent, or Firm—Bacon & Thomas

[57] **ABSTRACT**

A method of improved production of seafood comprises (1) testing the water at the surface of the ocean in order to determine the nutrients that are missing, (2) applying a fertilizer that contains the missing nutrients to fertilize the surface of the ocean, and (3) harvesting the increased production of seafood that results from the fertilization.

[illegible] Claims, No Drawings

US Patent Application for PROCESS AND METHOD OF SUSTAINABLE IMPROVEMENT OF SEAFOOD PRODUCTION IN OCEAN WATERS (#20170360065)

PROCESS AND METHOD OF SUSTAINABLE IMPROVEMENT OF SEAFOOD PRODUCTION IN OCEAN WATERS

Dec 8, 2015

Disclosed is a method and process for manifesting sustainable improvement in fisheries productivity in Ocean waters. This method and process includes (1) selecting a location of the Ocean that is considered both High Nutrient Low Chlorophyll (HNLC), (2) that the location is within proximity to fisheries feeding grounds or migratory routes or within areas that are considered to be fish feeding areas, (3) within this location, a


R/V WEATHERBIRD II
PLANKTOS

GEOENGINEERING

Ocean-fertilization project off Canada sparks furore

Bid to boost salmon stocks relied on hotly debated science and dubious carbon credits.

BY JEFF TOLLEFSON

When a chartered fishing boat strewed 100 tonnes of iron sulphate into the ocean off western Canada last July, the goal was to supercharge the marine ecosystem. The iron was meant to fertilize plankton, boost salmon populations and sequester carbon. Whether the ocean responded as hoped is not clear, but the project has touched off an explosion on land, angering scientists, embarrassing a village of indigenous people and enraging opponents of geoengineering.

The first reports about the project, which appeared in British newspaper *The Guardian* on 15 October, presented it as a rogue geoengineering scheme — the largest in history — in "blatant violation" of international treaties. Critics suggested that Russ George, a US

Workers on a Haida Salmon Restoration Corporation boat release iron sulphate into the Pacific Ocean.

October 25, 2012 *Nature*