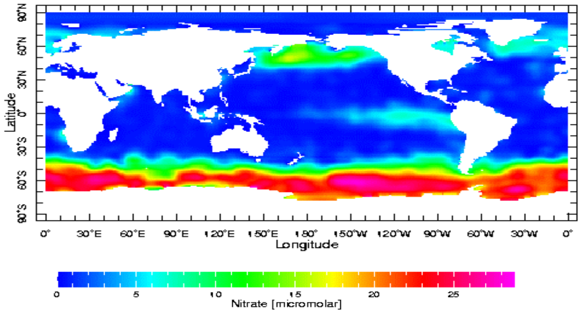
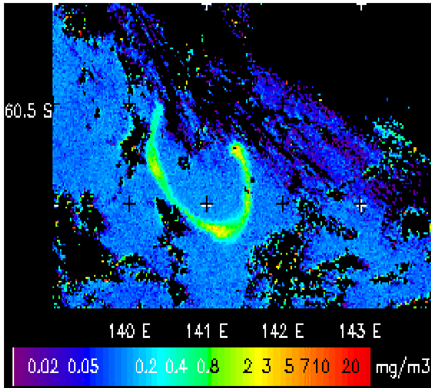
Iron studies during JGOFS

Philip Boyd



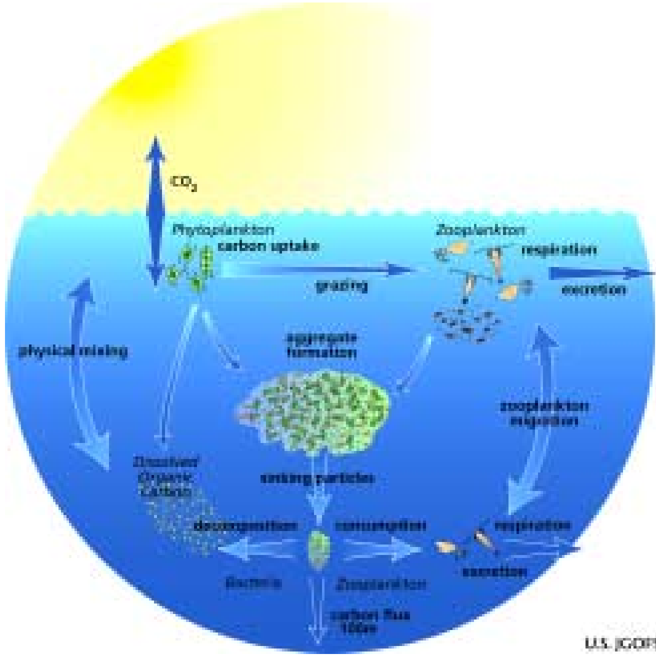
- Fe and JGOFS - historical perspective
- Fe limitation and the Biota
- Biogeochemical cycling of Fe
- Reappraisal - Fe supply and the global C cycle?

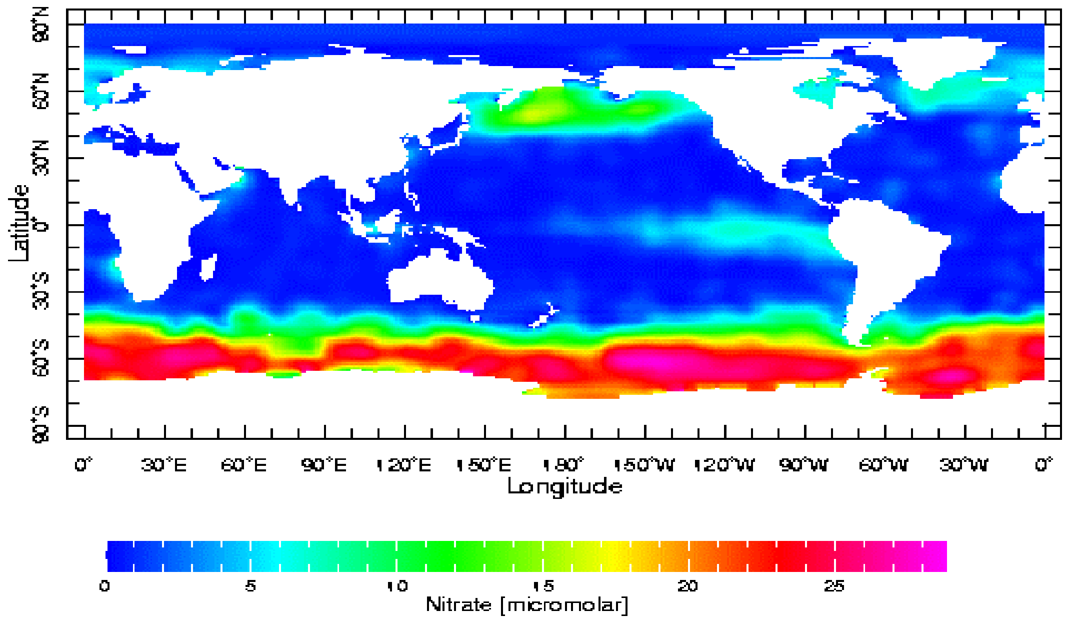


IRON and CLIMATE

Marine biota play a key role in climate by regulating atmospheric CO_2 levels

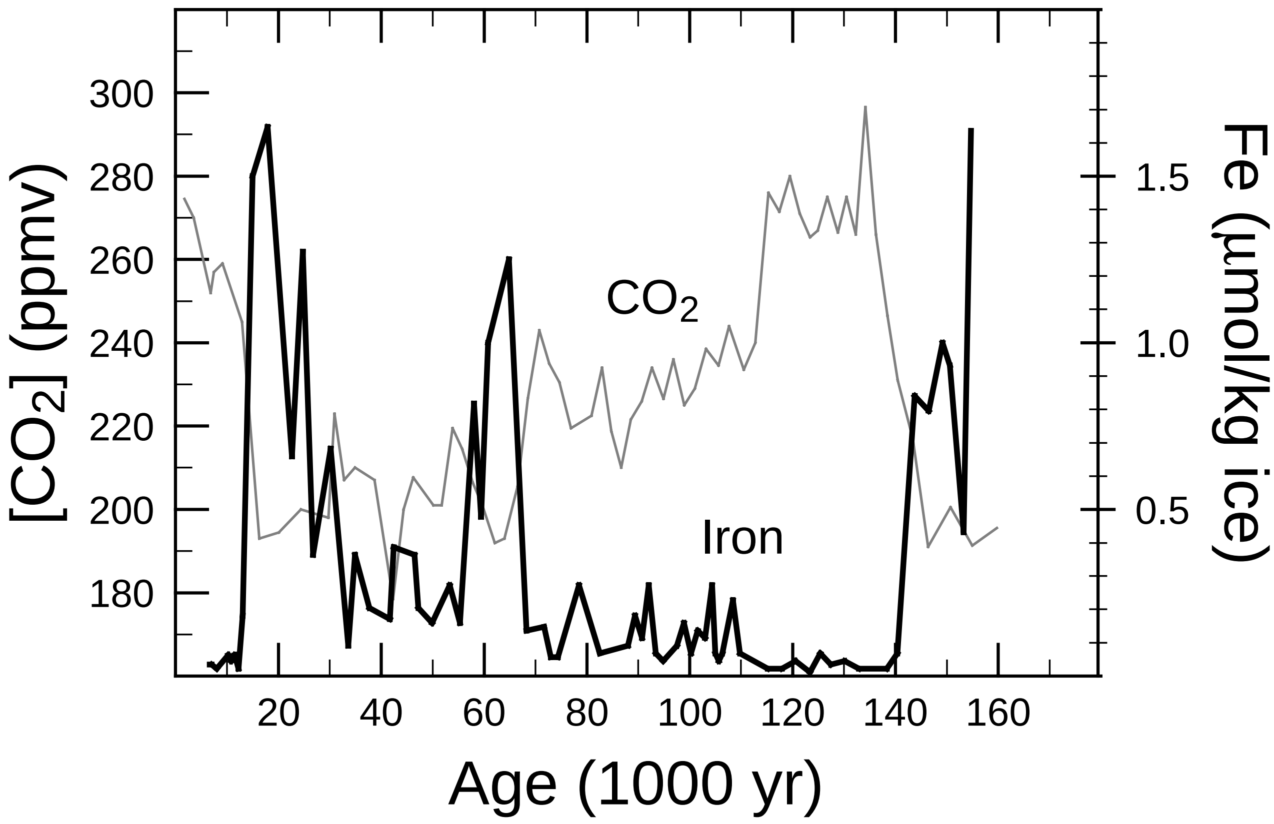
One means of regulation is via the BIOLOGICAL PUMP



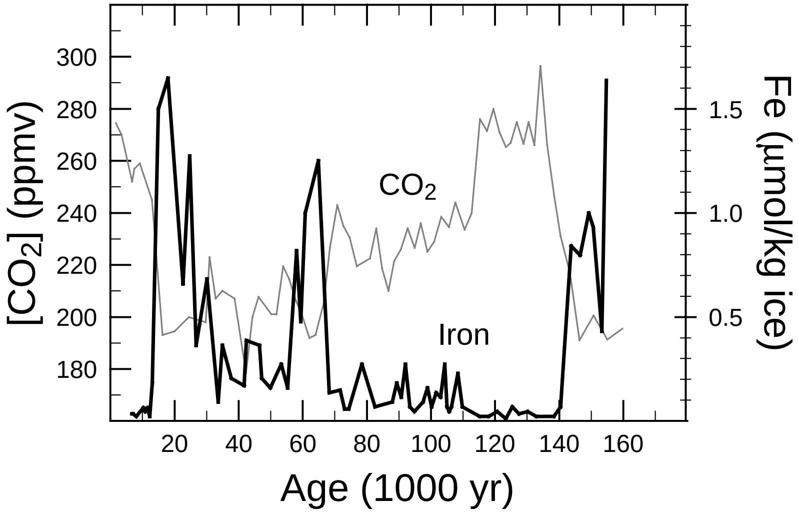


The PUMP works most efficiently when all of the available nutrients are utilised

The Vostok ice core provided tantalising evidence of the impact of changes in Fe supply on atmospheric CO2 (Martin, 1990)



Historical perspective

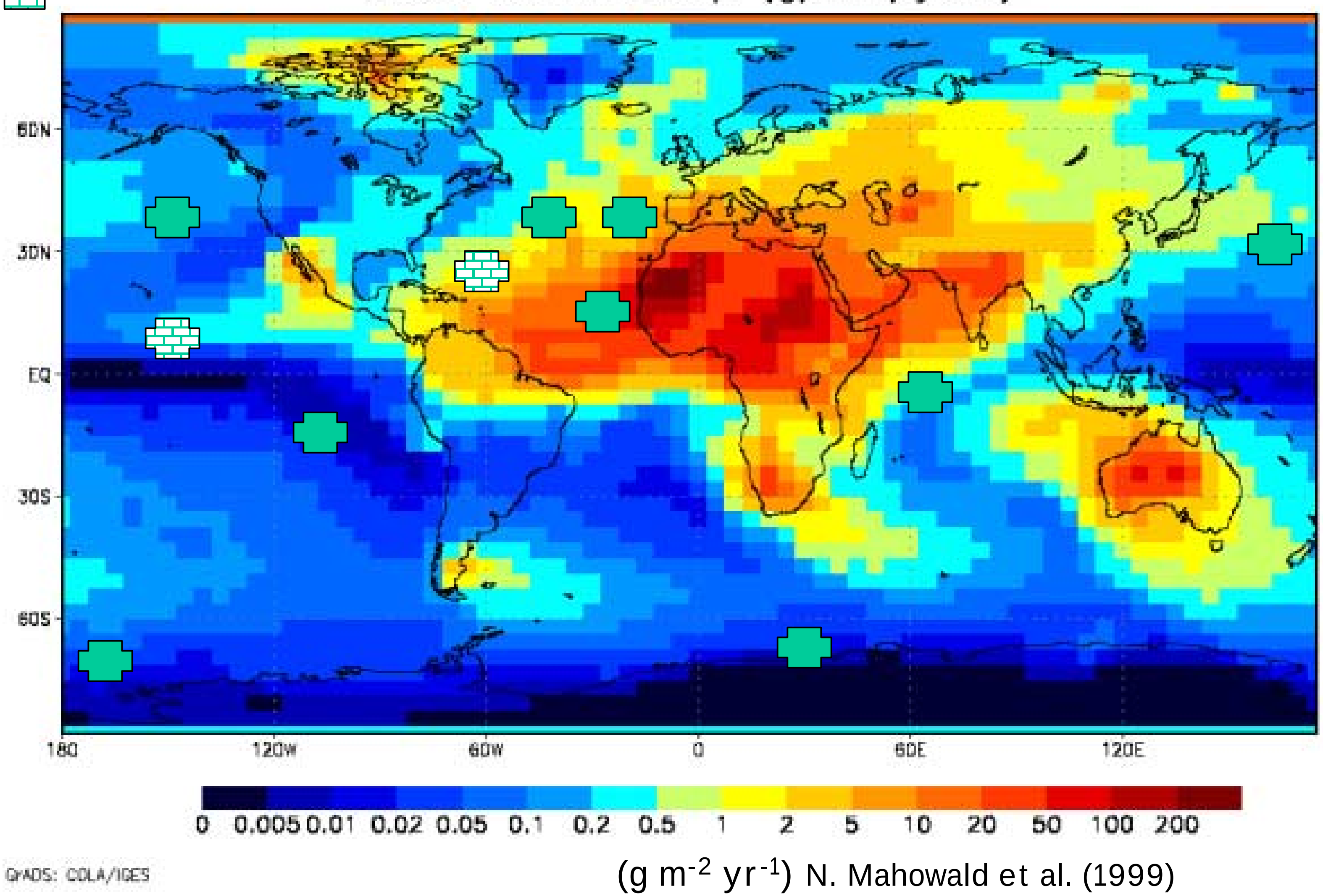


- **S. Ocean Paradox - Gran, Hart**
- **Trace metal chemistry and contamination (Patterson, Bruland, Martin) - improved techniques**
- **Shipboard Fe enrichments - Martin, de Baar**
- **The link to climate - Fe Hypothesis - Martin**
- ***In situ* Fe enrichments - SF_6 - Watson, Duce, Liss, Martin**

JGOFS Sites in relation to (modelled) dust deposition

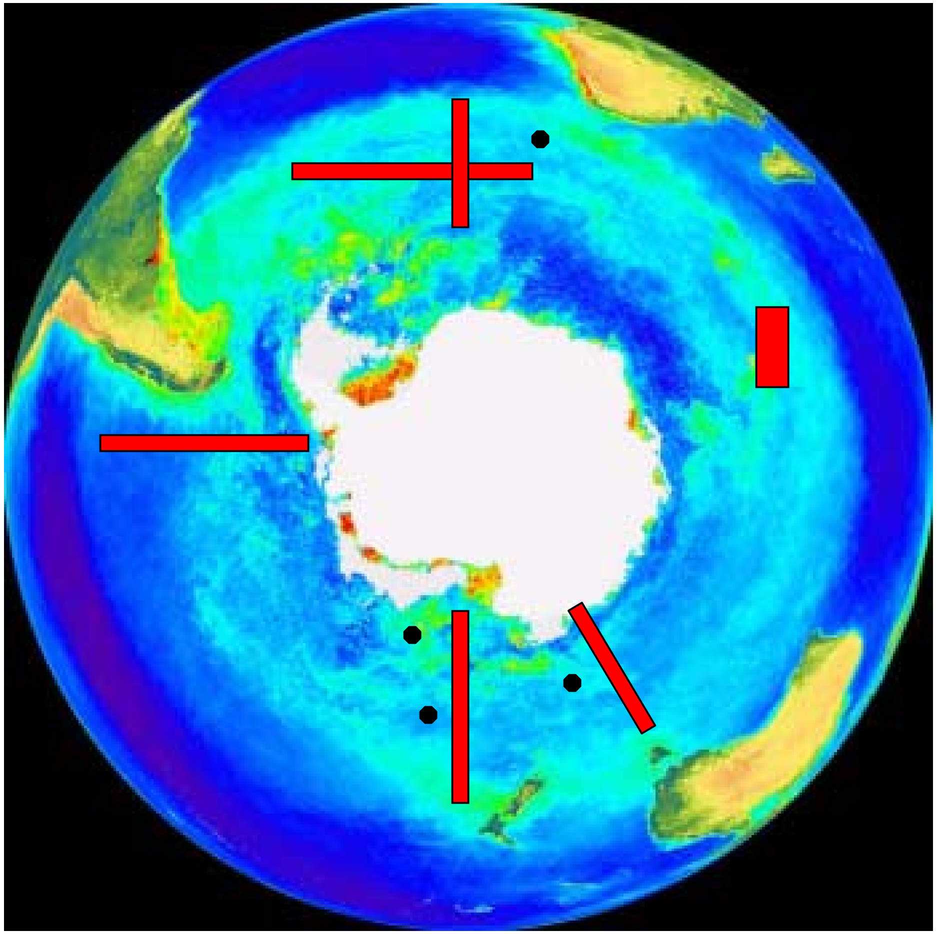
Field studies/surveys

Time-series



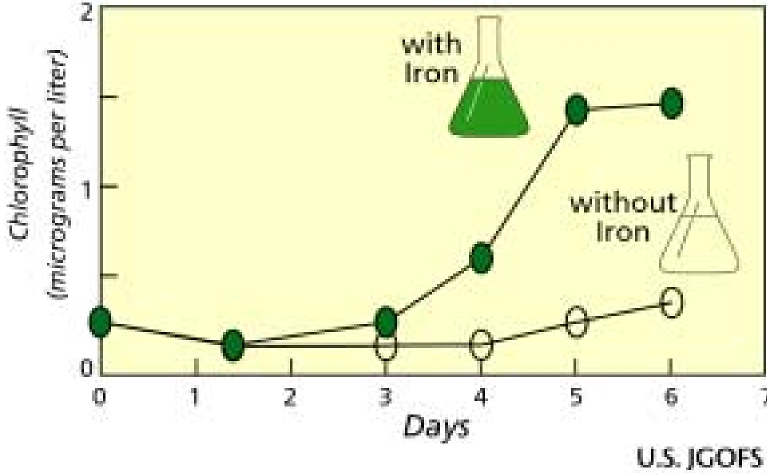
(g m^{-2} yr^{-1}) N. Mahowald et al. (1999)

JGOFS STUDIES IN HNLC POLAR WATERS



There were also major studies conducted in tropical (EQPAC) and subpolar (N PACIFIC) HNLC waters

Fe limitation and the biota

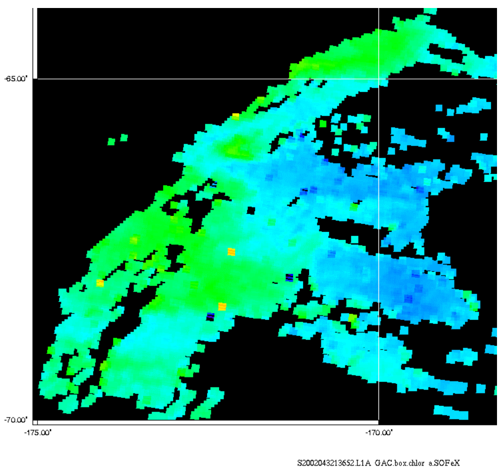


1) Shipboard Fe enrichments

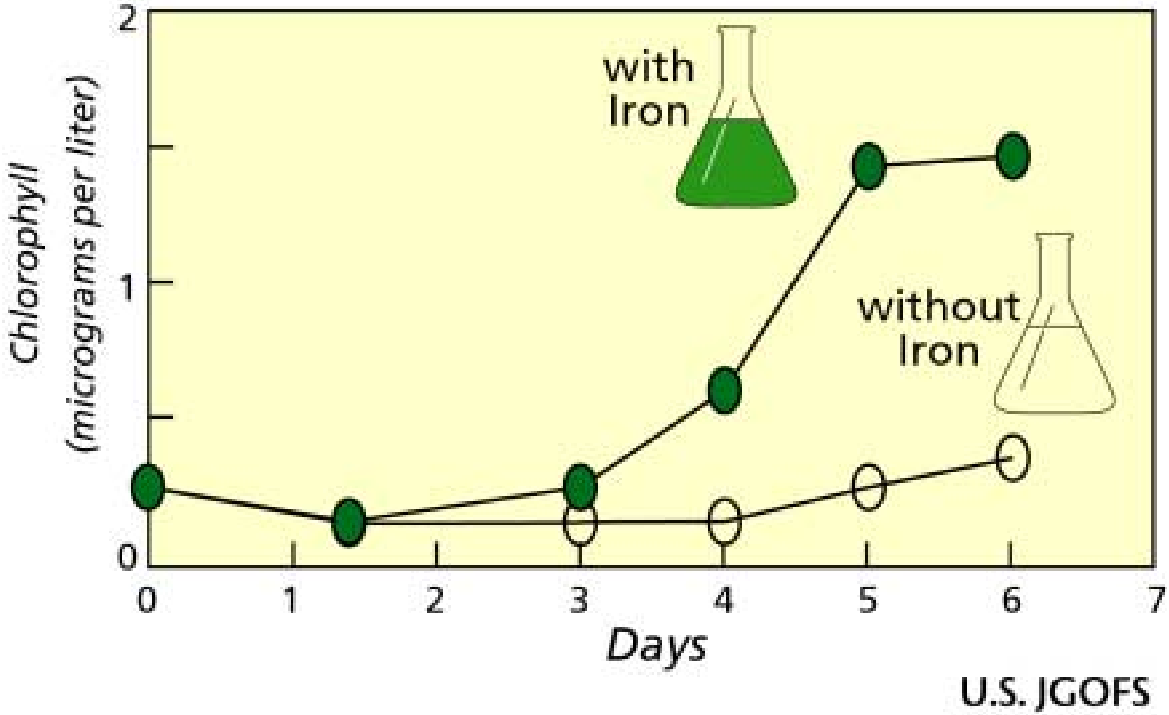
2) Oceanic surveys - spatial relationships

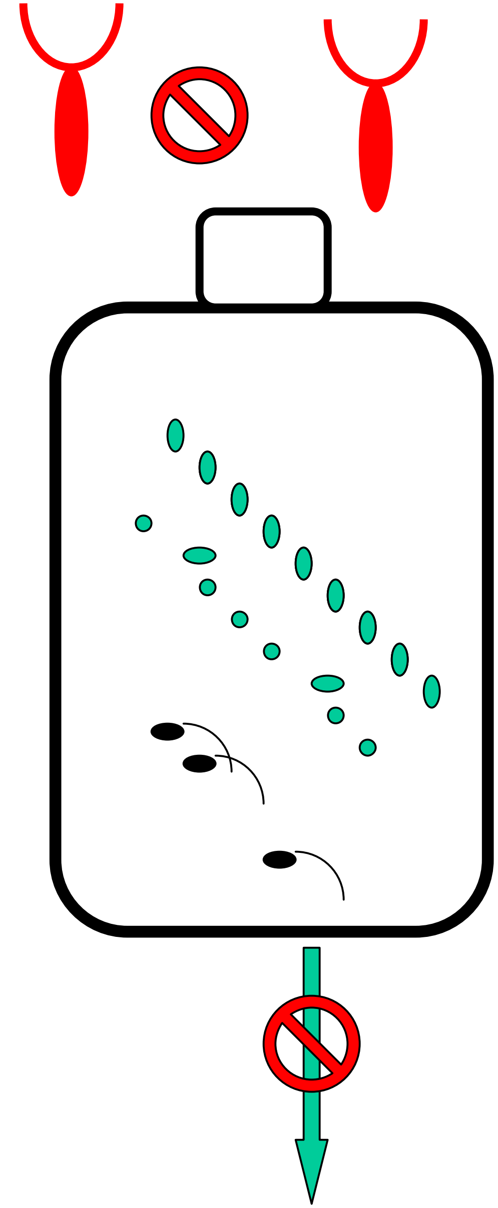
3) Molecular and other proxies of Fe stress

4) *In situ* mesoscale Fe additions



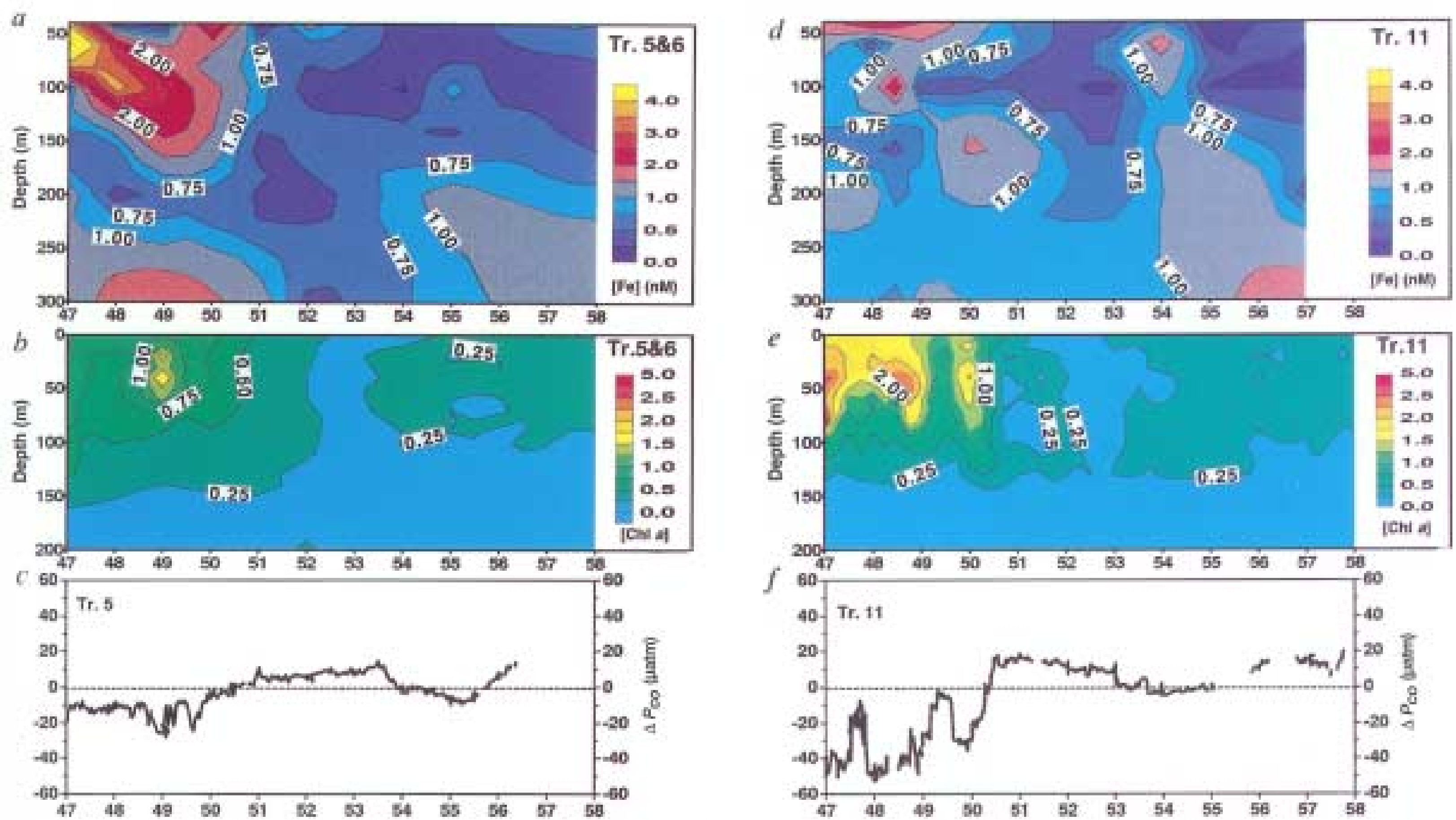
Shipboard Fe Enrichments





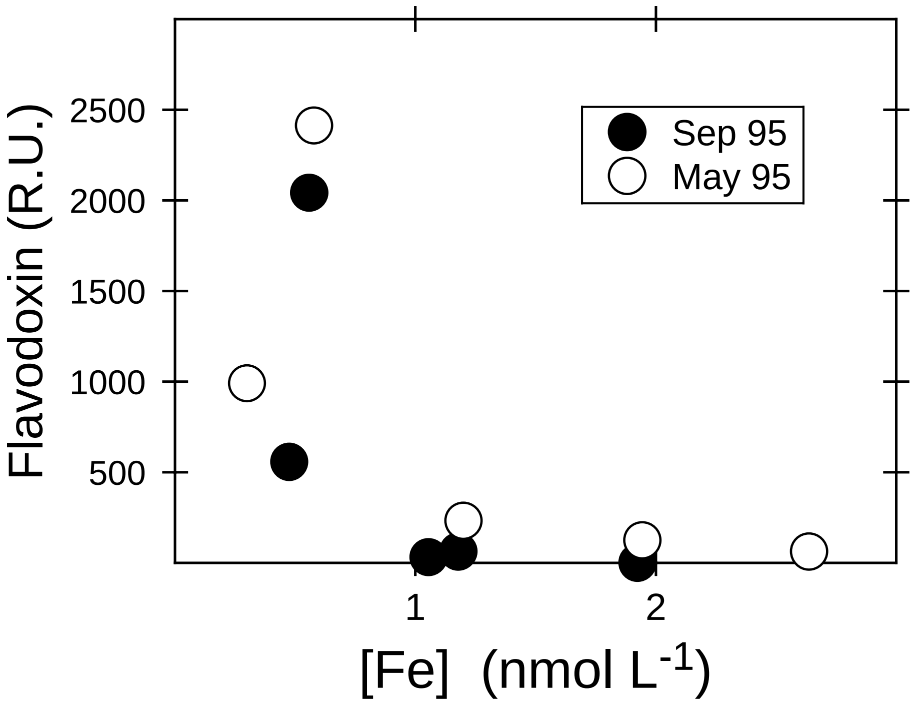
S. Ocean - Martin, de Baar…...
EqPac - Coale, Price…..
NE Pacific - Martin, Coale…….

Oceanic surveys - spatial relationships



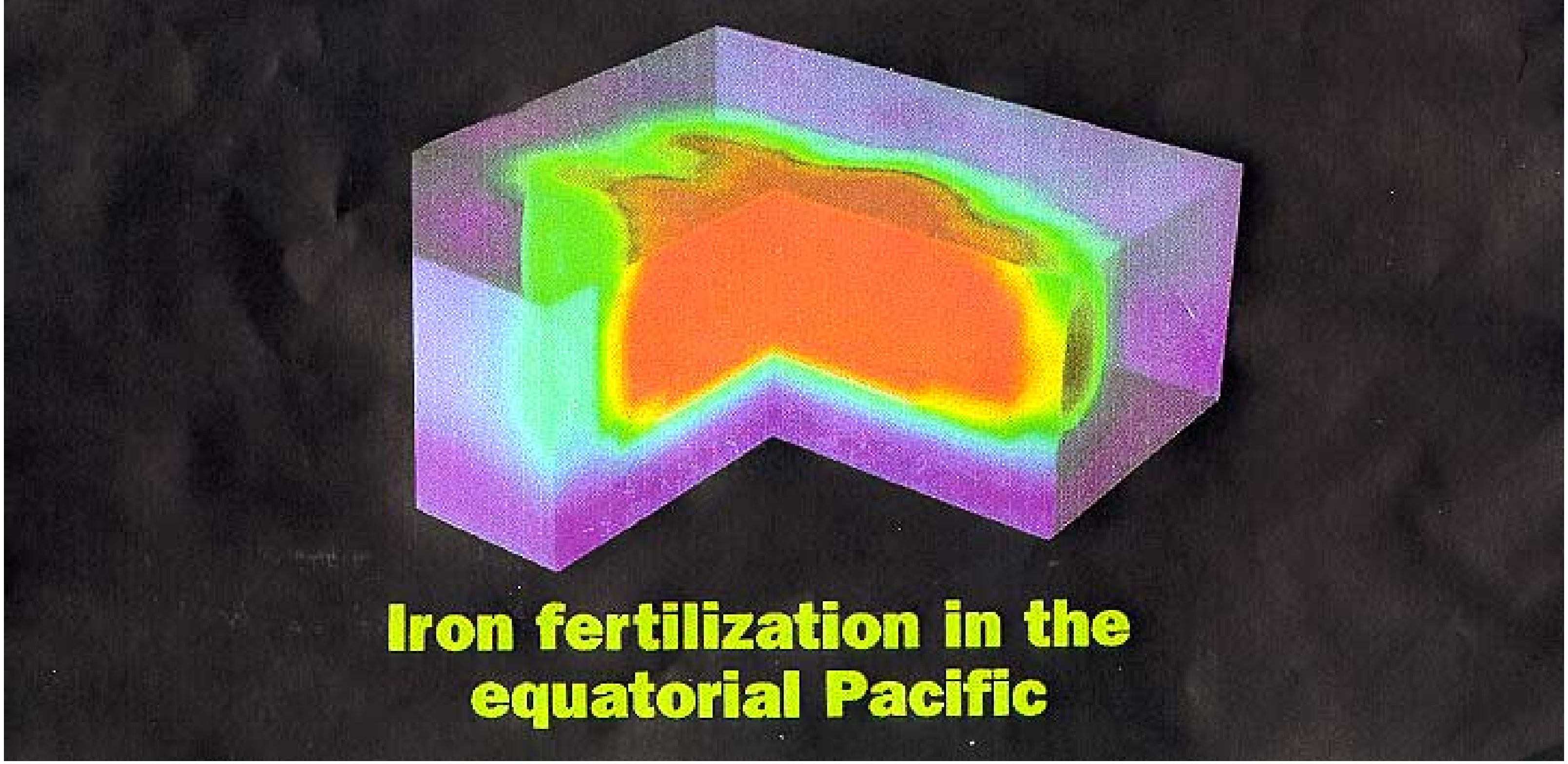
de Baar et al. (1995) - Polar Front (Atlantic sector)
Iron, chlorophyll and CO_2 drawdown

Molecular and other proxies of Fe Stress



LaRoche et al. (1996)
NE Pacific
Flv can substitute for Fd to alleviate iron stress by reducing the cell's Fe requirements

Other proxies
FRRF - biophysical (Falkowski….)
Nutrient uptake kinetics (Coale, Timmermans….)



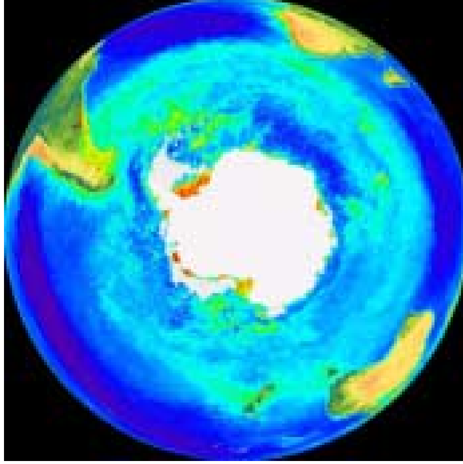
Behrenfeld et al. (1996)

***In situ* Fe enrichments - (10 km length-scale)**

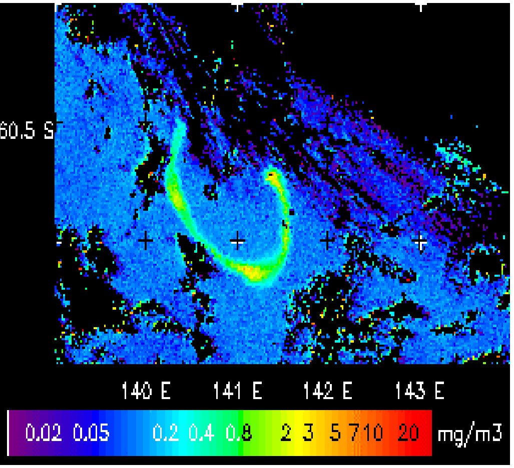
IronEx I - subducted after 3-4 days, increase in F_v/F_m

IronEx II - chlorophyll 0.3 to > 3 mg m^{-3}, CO_2 and DMS

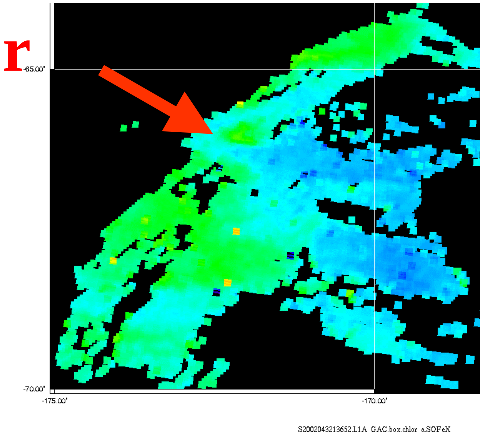
Fe limitation and mesoscale Fe enrichments in the S. Ocean



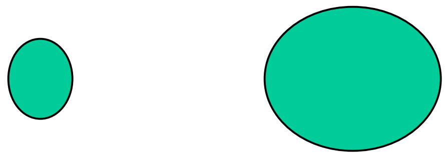
Largest inventory of unused nutrients
Deep-water formation
Other limiting factors? Mixed layers, Si, Krill?



SOIREE Summer, Pacific sector
Eisenex - Spring, Atlantic sector
SOFEX - Summer - Pacific sector



In situ experiments have yielded similar trends



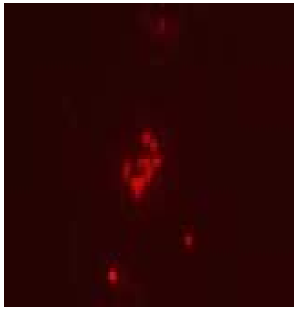
Cell size

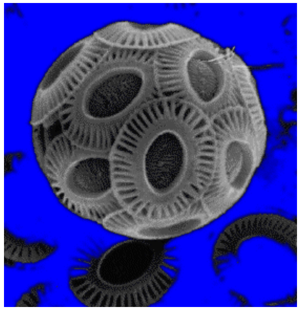
Cellular chlorophyll

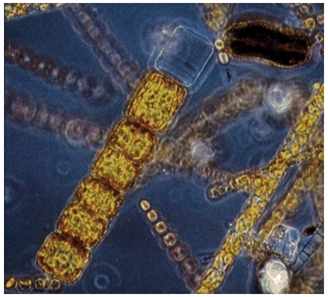
Increased growth rate, C fixation, F_v/F_m……….

Altered Si:C uptake ratio's

Floristic shifts



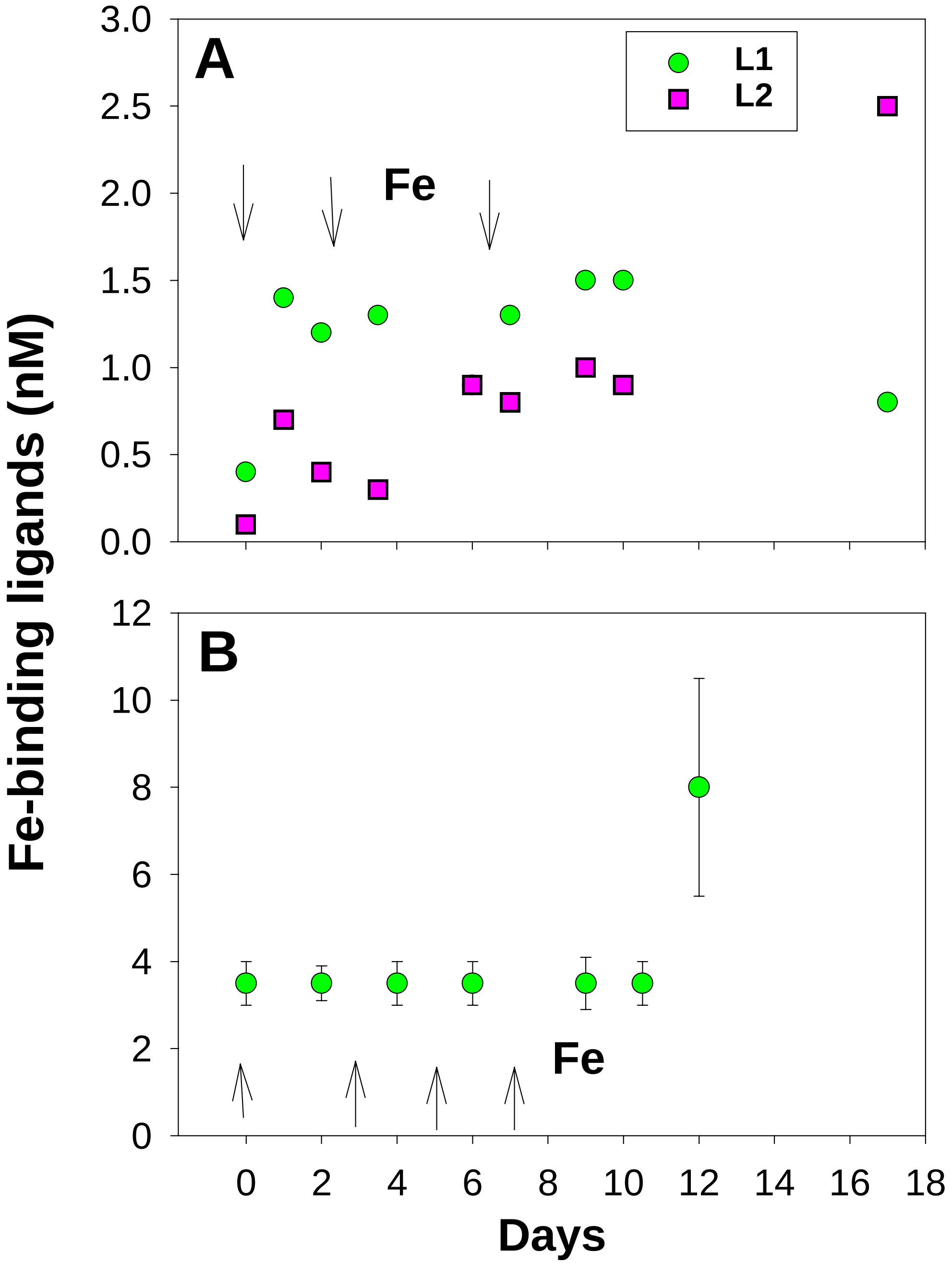




DMSP

C fixation

But there have also been different trends between tropical and polar HNLC *in situ* experiments

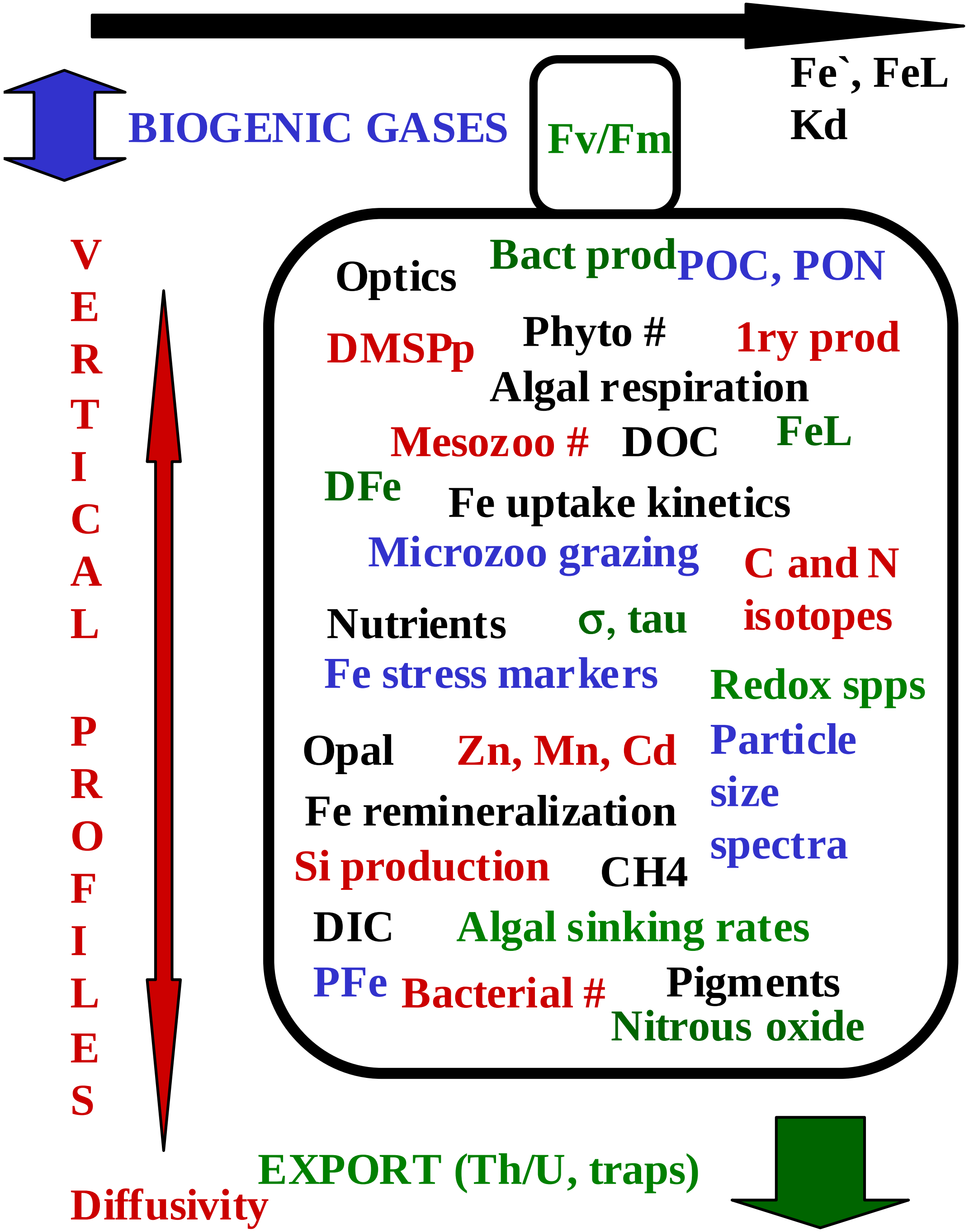


Iron-binding ligands and their production

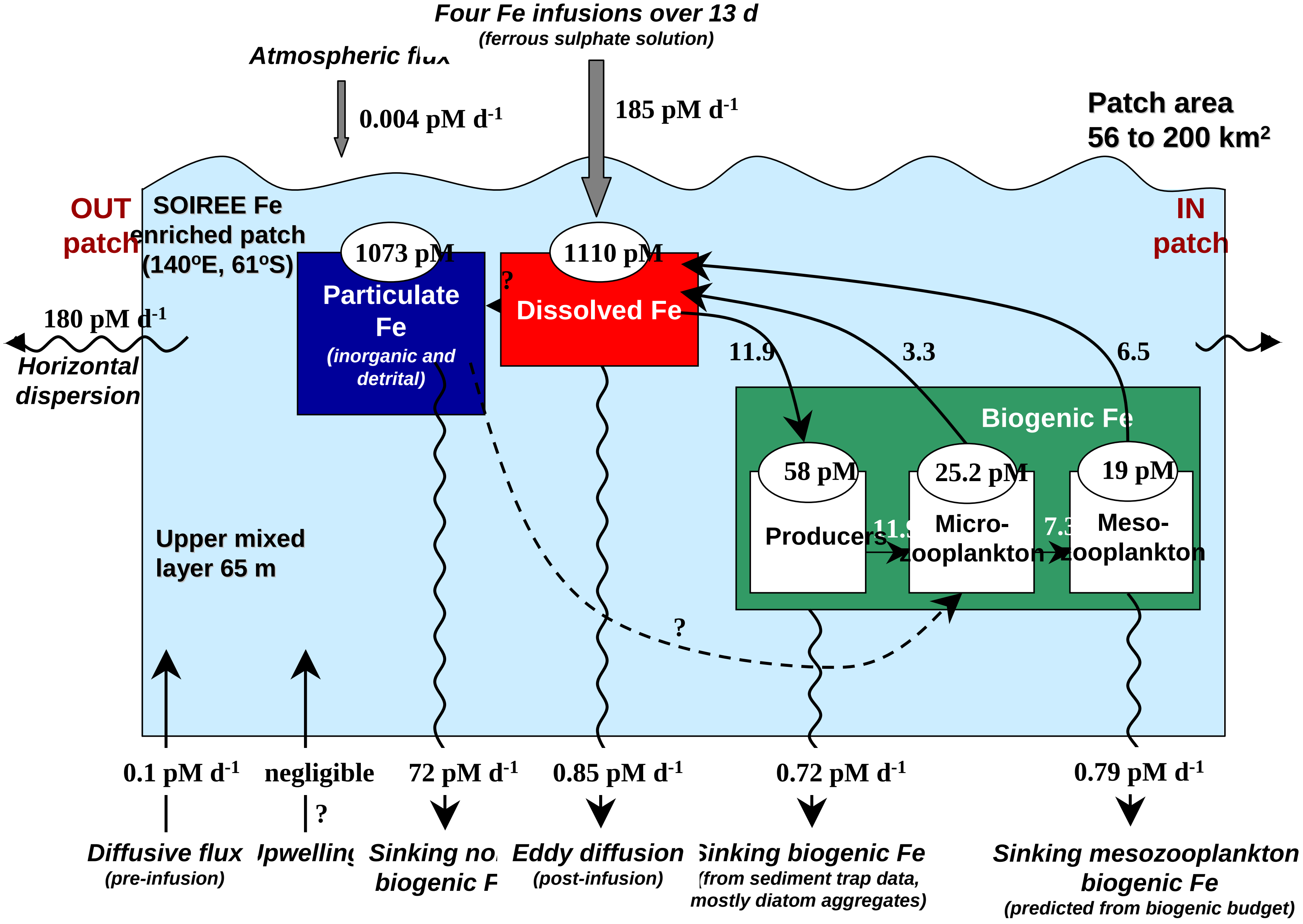
In situ experiments permit the concurrent examination of many parameters

permitting the construction of Fe budgets

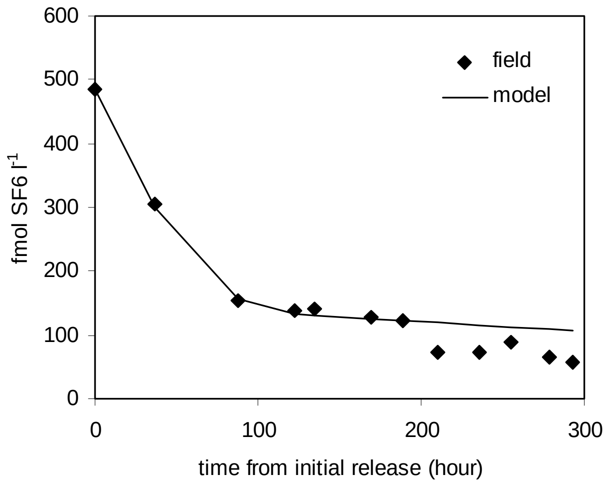
and validation data for models

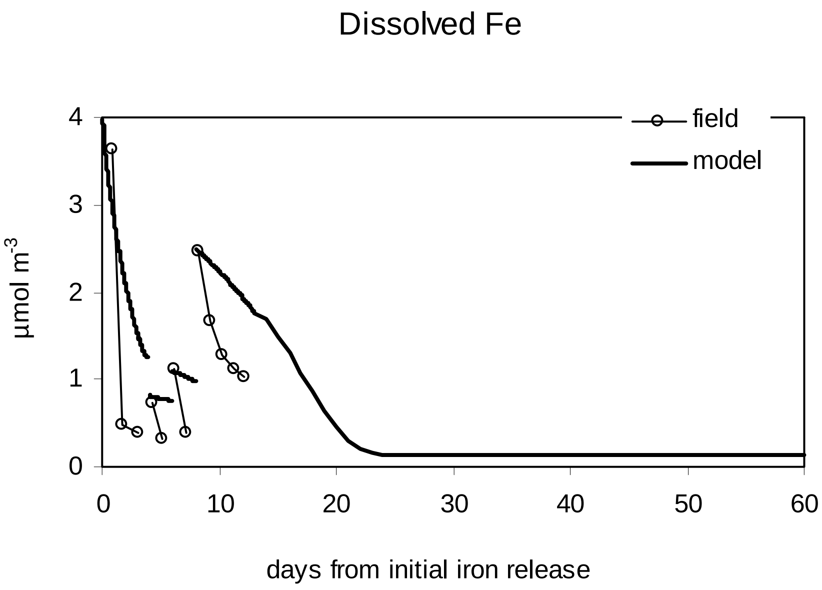


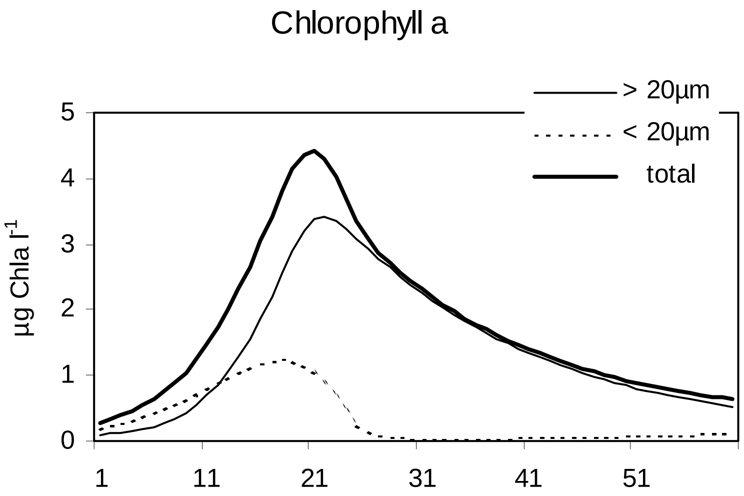
Fe budget from SOIREE (Bowie et al. 2001)

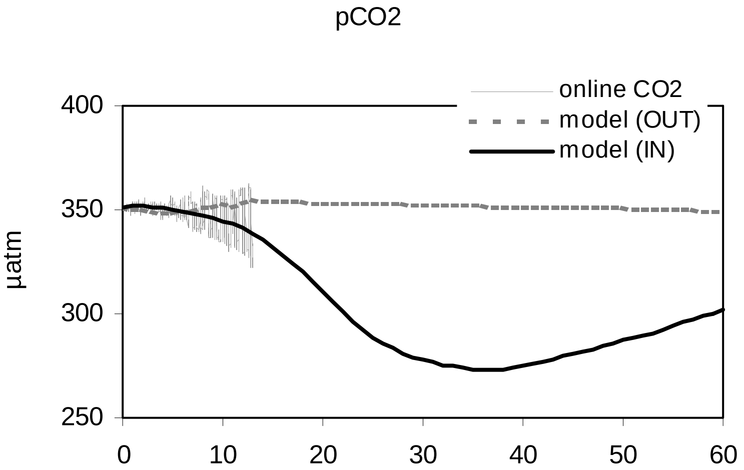


Numerical modelling of SOIREE (Hannon et al., 2001)

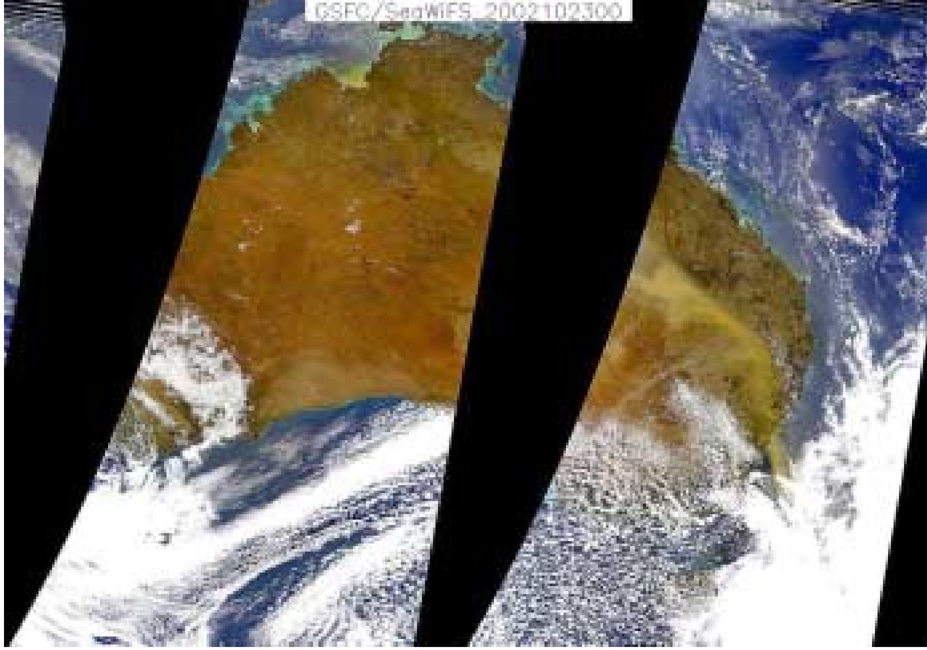








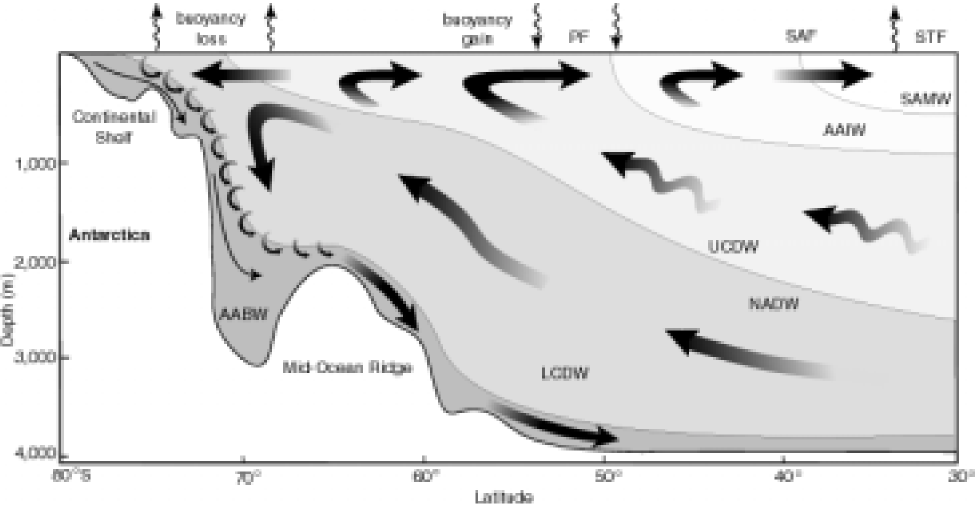
Biogeochemical cycling of Fe



What are the relative contributions of

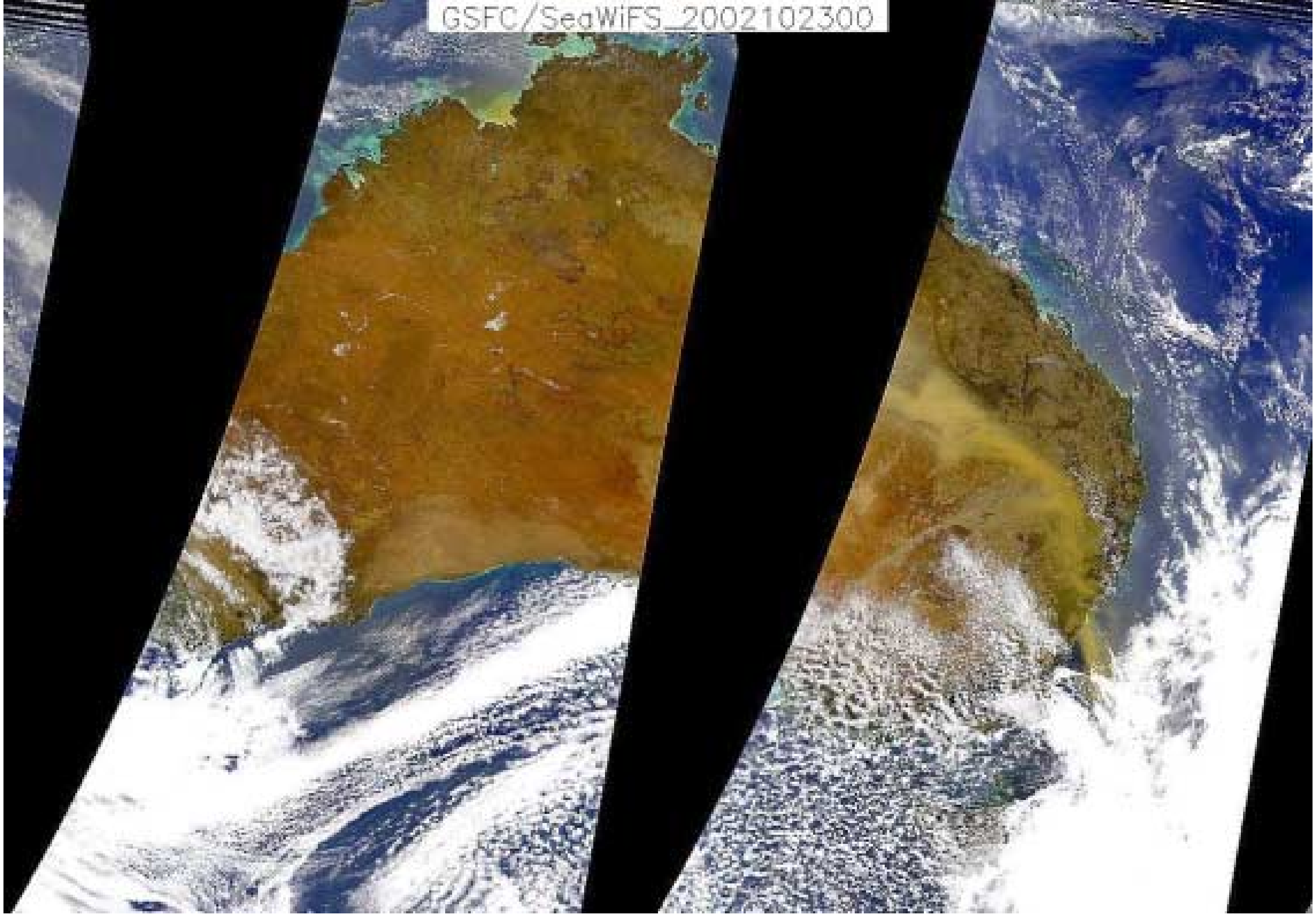
Atmospheric inputs

Upwelling



Martin
Dust deposition is dominant in the NE Pacific

de Baar; Measures
Upwelling is the dominant driver in the S. Ocean

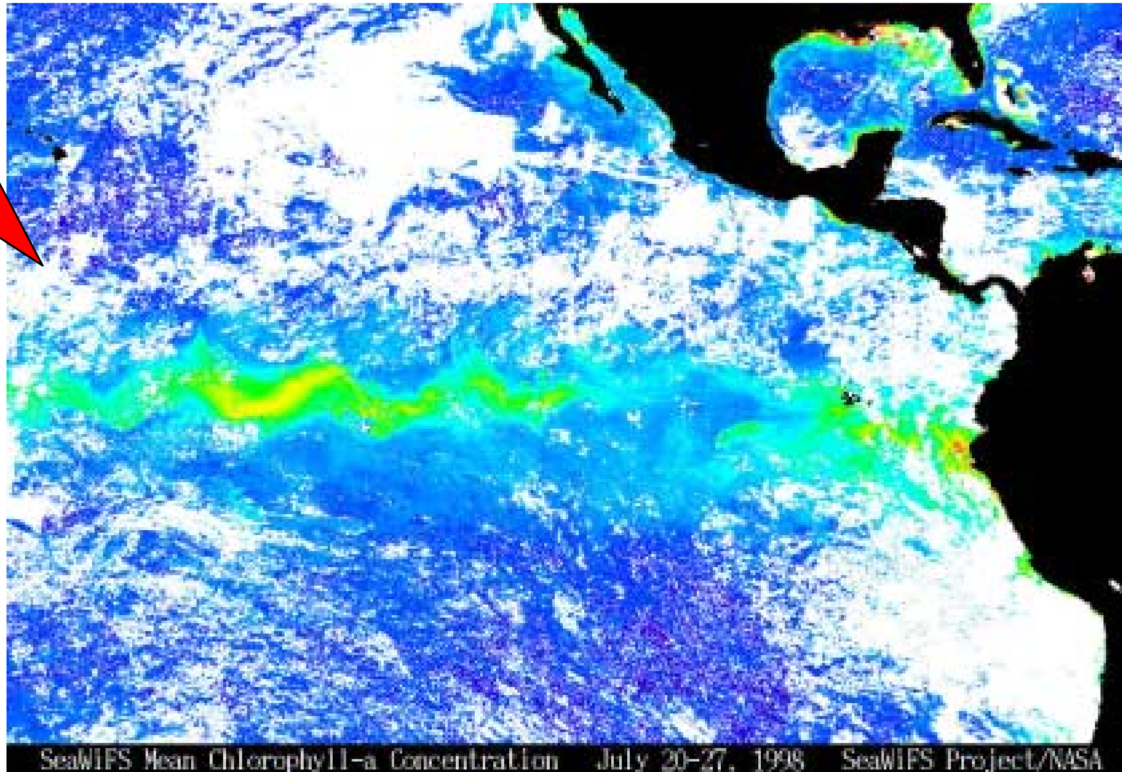


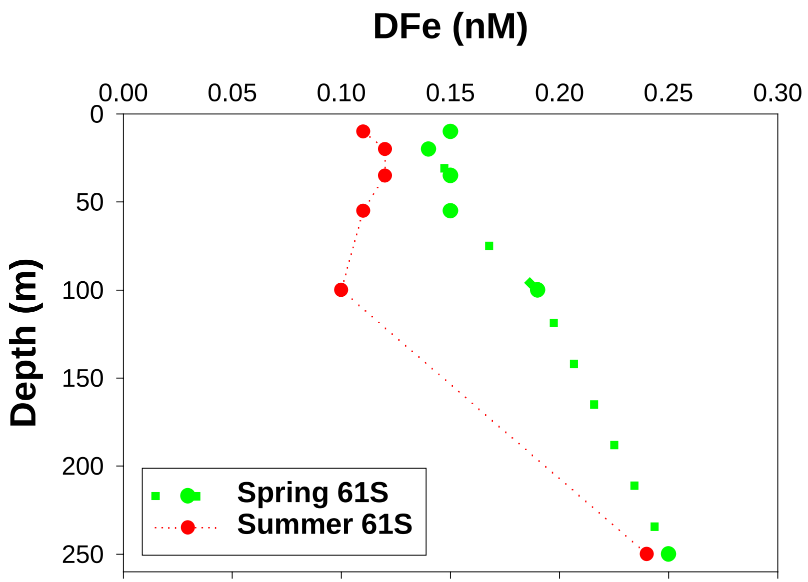
Remote-sensing (TOMS, SeaWiFs) has enabled us to monitor episodic dust events from source to sink

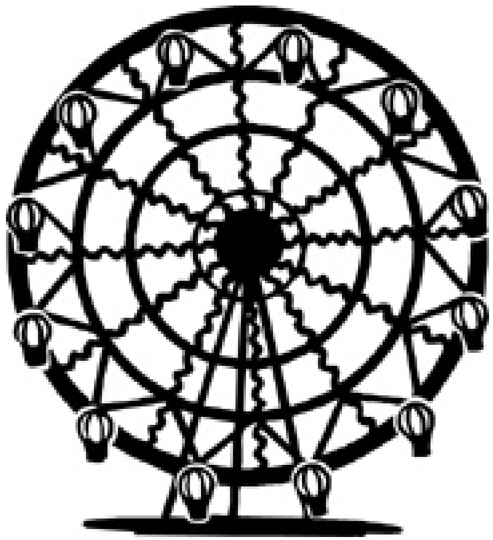
Other iron supply mechanisms

Ice melt (Sedwick, DiTullio)
Offshore transport of Fe in eddies (Crawford, Whitney)
Coastal ocean - geomorphology (Bruland, Hutchins)

Upwelling - Cromwell undercurrent (Coale, Chavez)







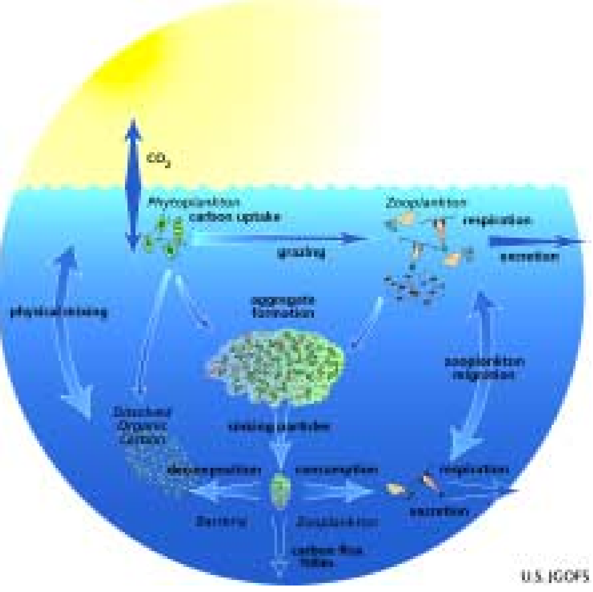
THE 'FERROUS' WHEEL (Kirchman, 1997)

(Measures & Vink, 2001) Dissolved Fe profiles: little decrease in DFe during the 'growth season'

Relatively flat profile compared to macro-nutrients

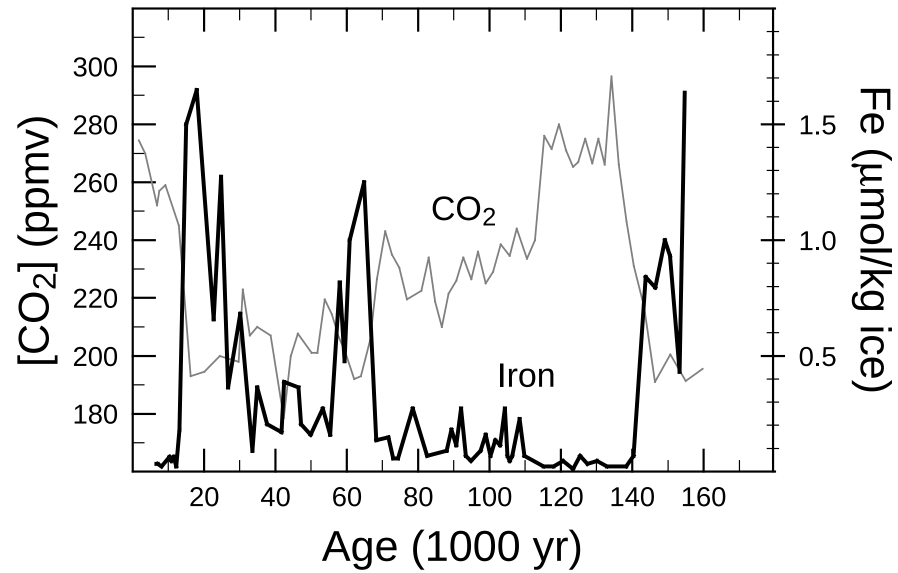
Evidence that the microbial loop rapidly recycles Fe

Heterotrophic bacteria
Heterotrophic nanoflagellates
Viruses ??



IRON AND THE OCEANIC C CYCLE

What has been learnt during JGOFS



The Fe Hypothesis

Tenet 1 - Fe would increase phytoplankton growth

Tenet 2 - Fe would increase C sequestration ?

Modelling - yes, Field data ??

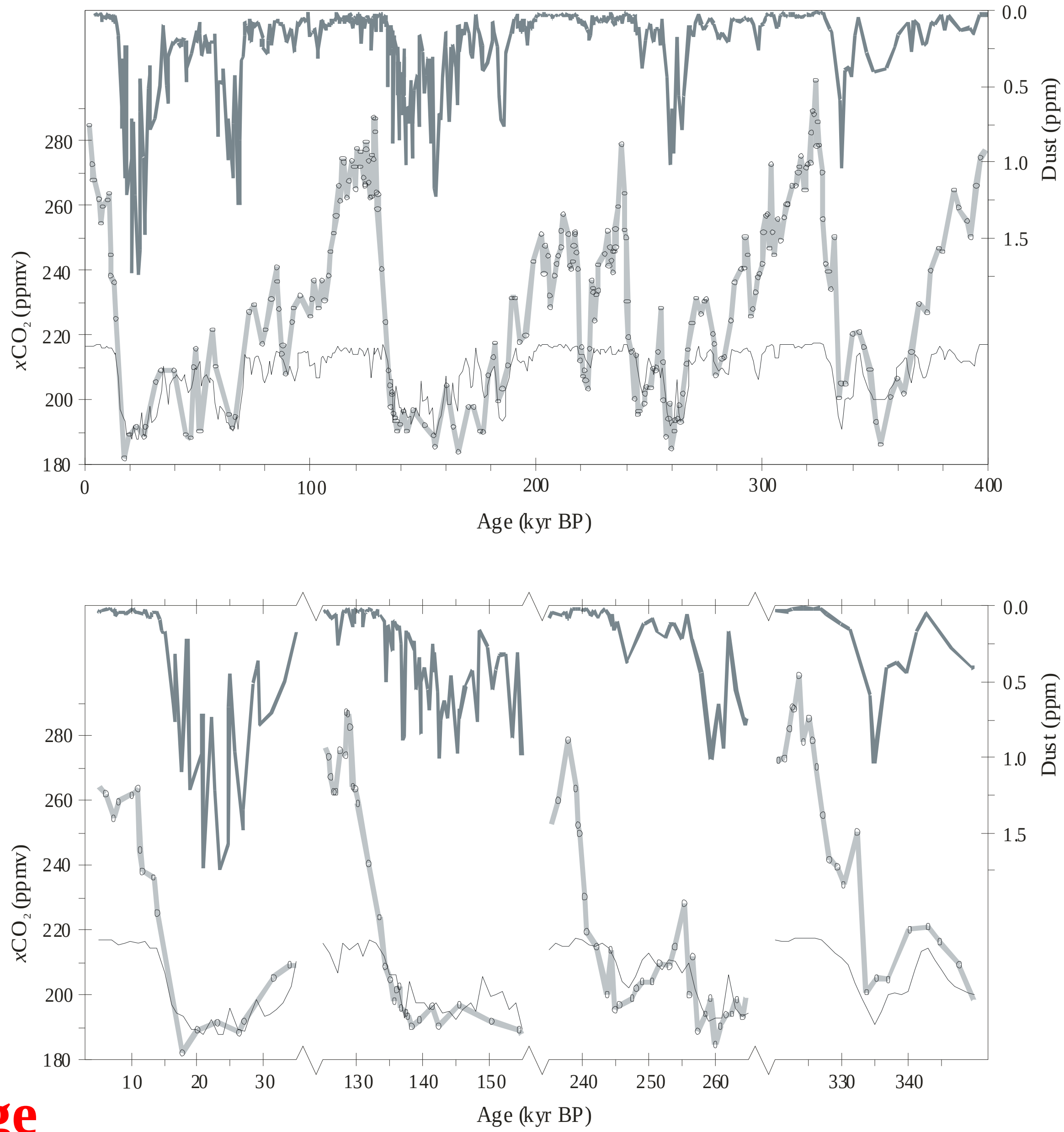
Modeling

Watson et al. (2000)

SOIREE
CO2 drawdown
Si:C uptake ratio's

Glacials predicted timing and magnitudes match records well

Glacial terminations
Fe supply - 50%
of 80 ppm CO_2 change



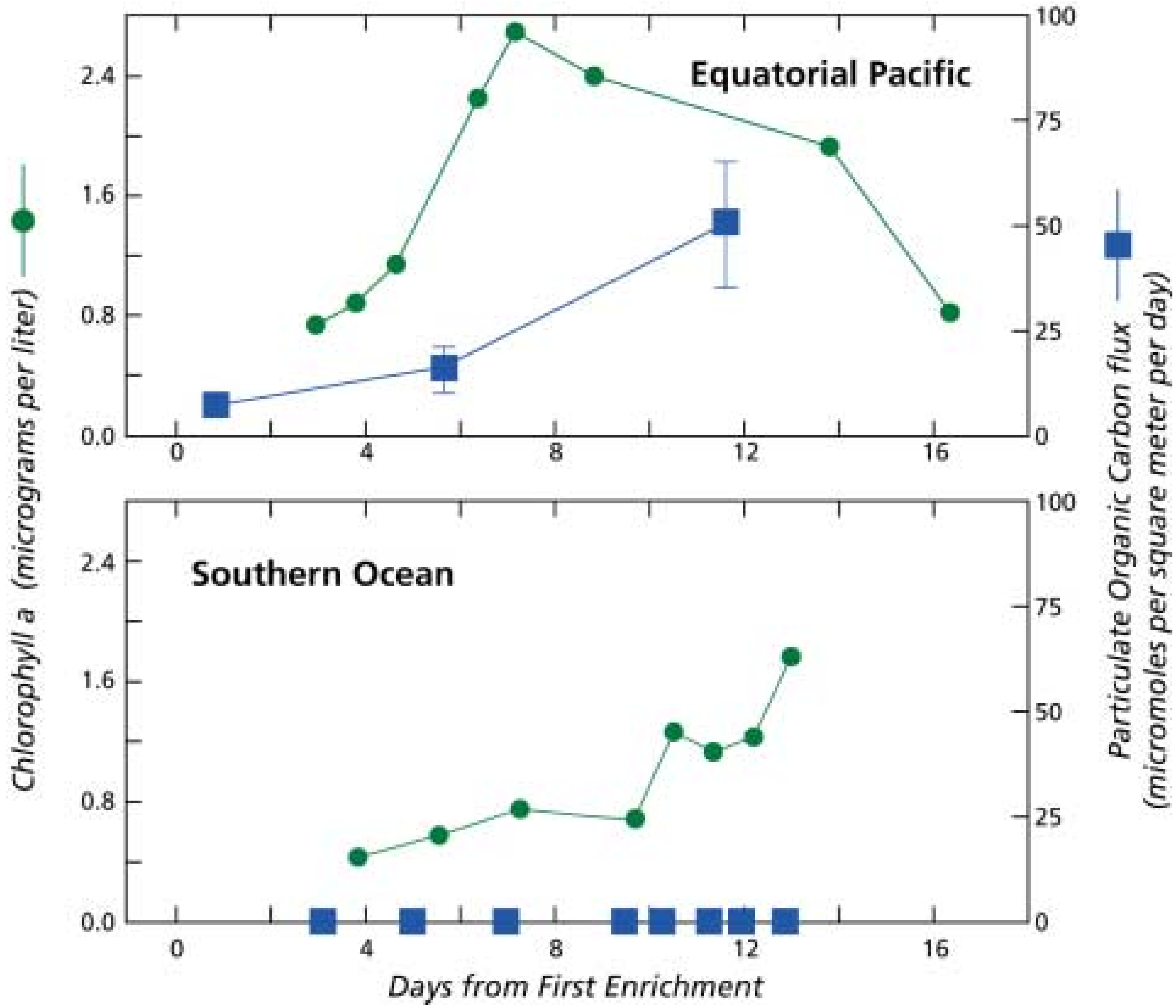
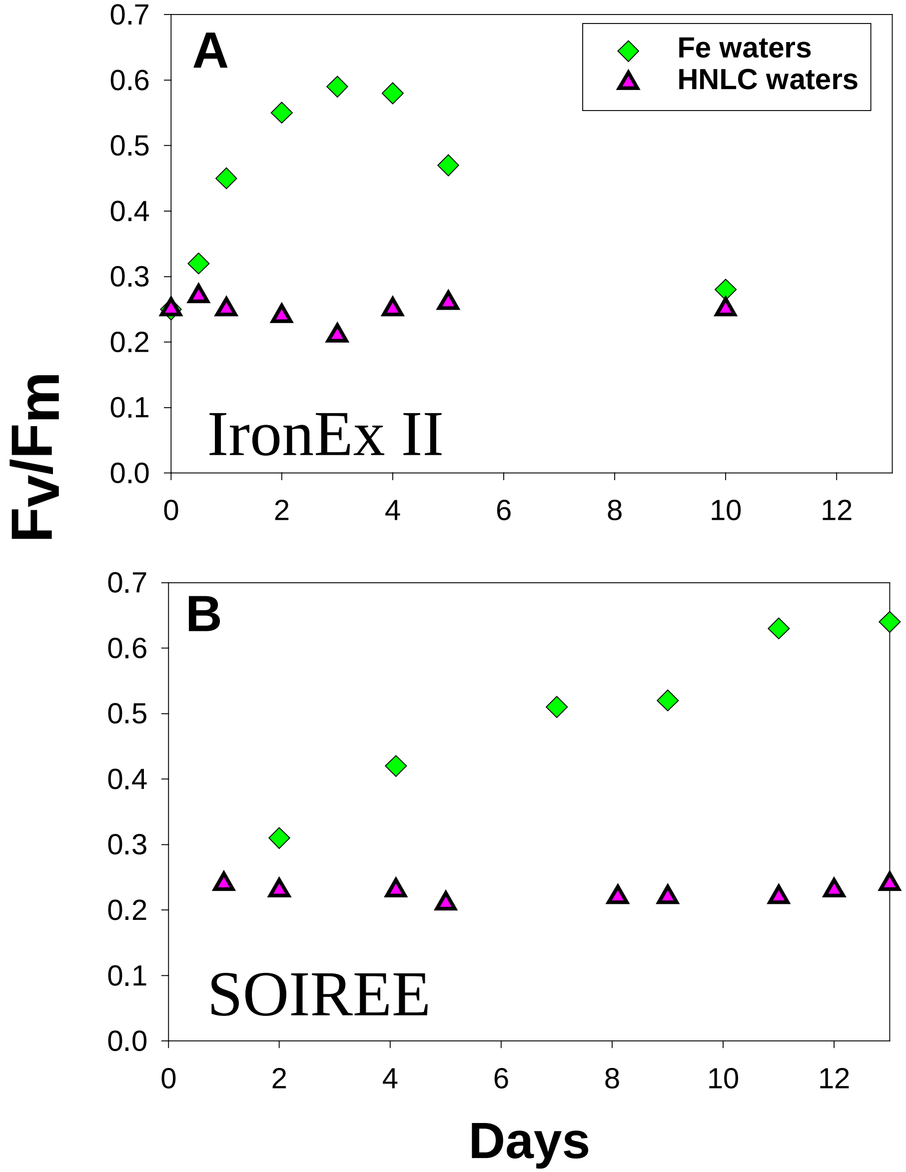
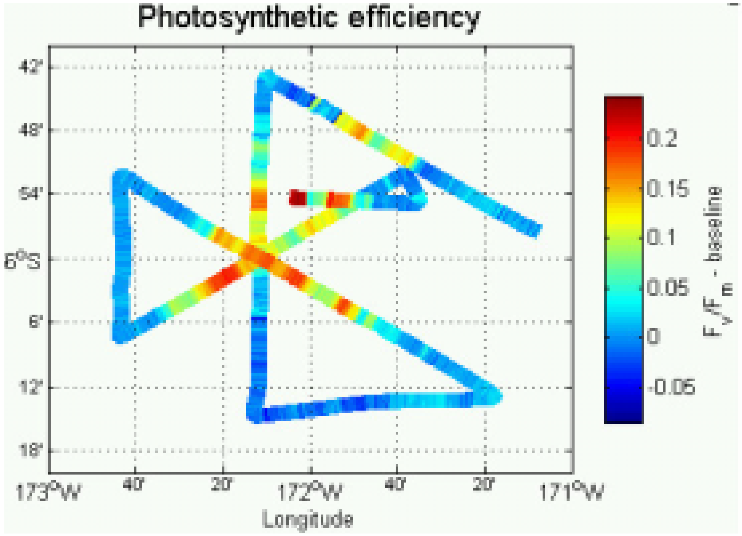


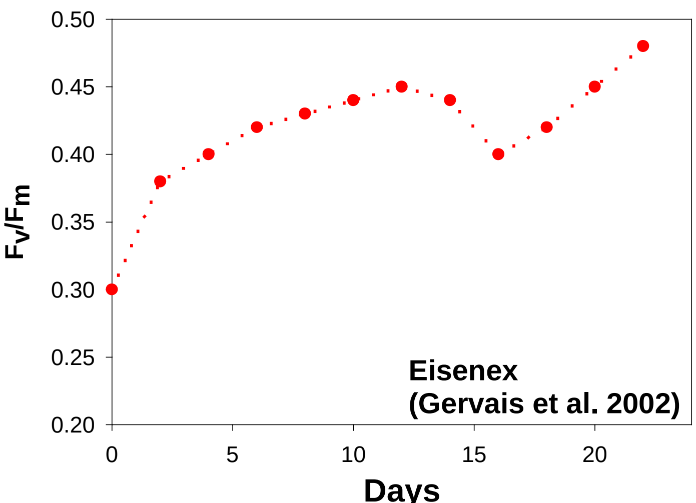
Fig. Courtesy K. Buesseler

***In situ* experiments display increases in chlorophyll, but not always increases in export - WHY?**





SOFEX



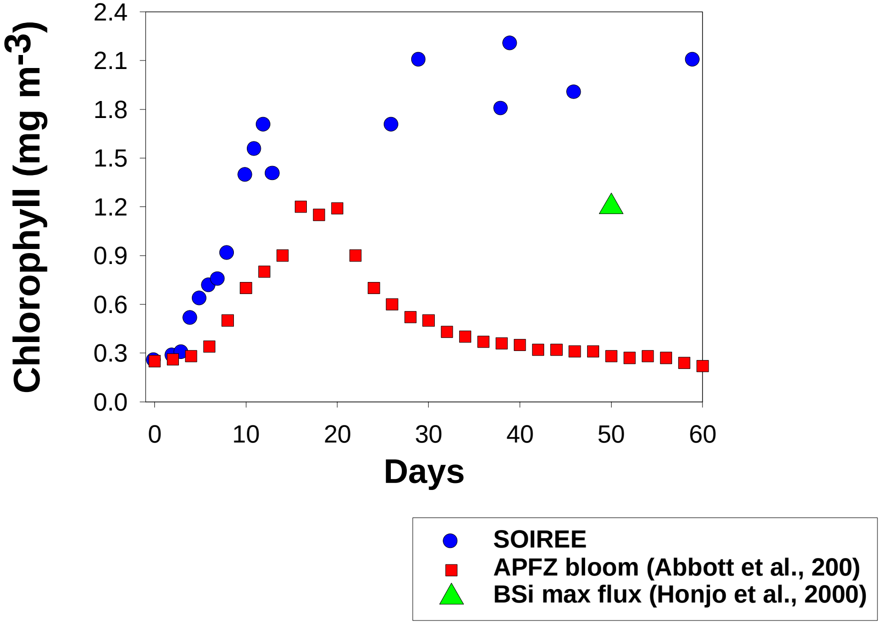
Eisenex

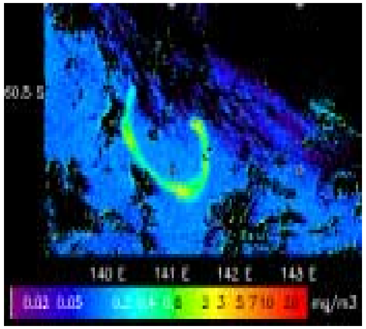
Time-series of Photosynthetic competence provides some clues

SOIREE vs. polar blooms

Few data available on the temporal evolution of polar blooms

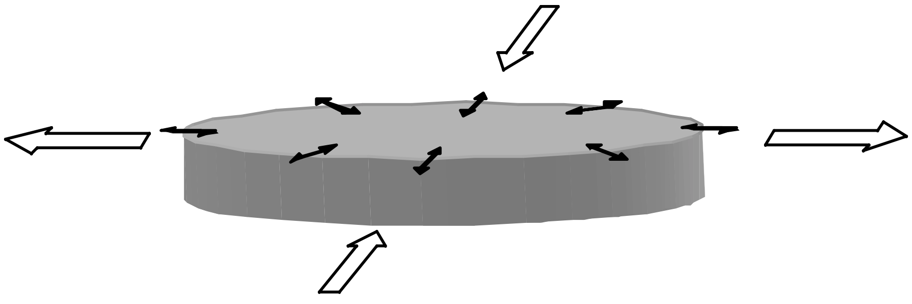
Mooring data in the vicinity of the APFZ (60S, 170W) from 10 bio-optical arrays provides excellent coverage





Why the exceptional longevity of SOIREE?

Fe Patch increased from 50 to 1100 km^2



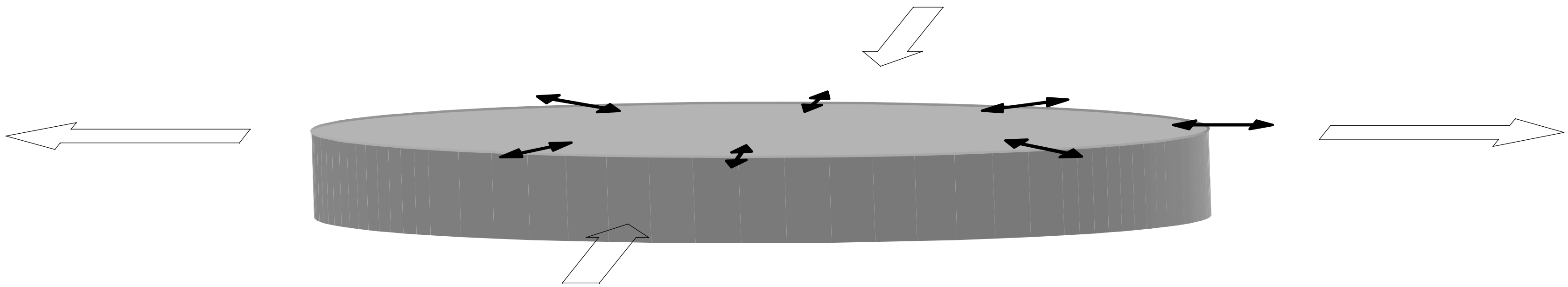
Stretching via horizontal flows

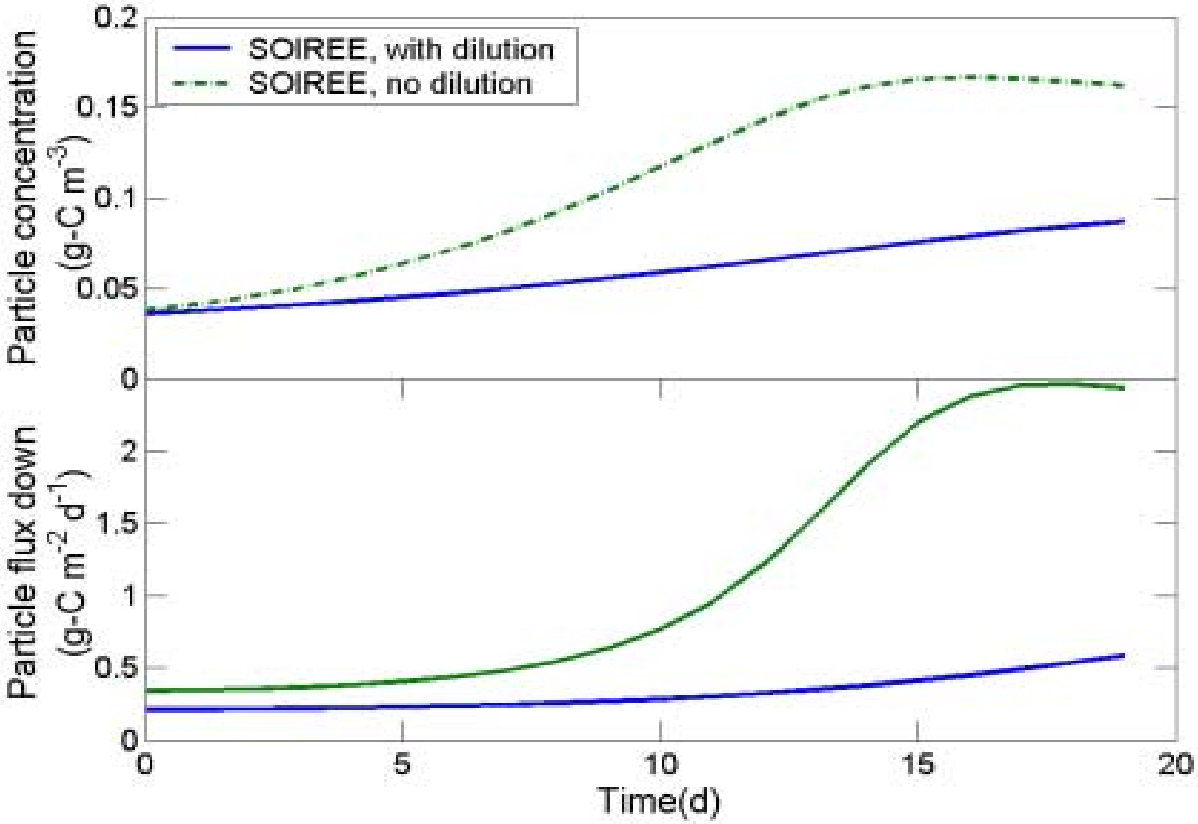
Mixing of water by horizontal diffusion

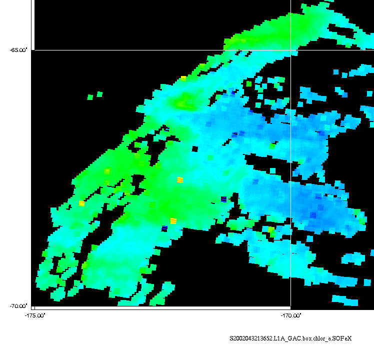
IN
HNLC waters
hi Si
low Fe
low diatoms
low Chl

OUT
low Si
hi Fe*
hi chla
hi diatoms

DOES 'DILUTION' OF CELLS PREVENT AGGREGATION

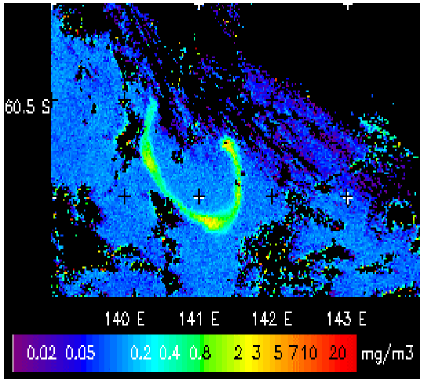






The Future

- Improved global/seasonal coverage of DFe profiles
- Better understanding of Fe biogeochemistry - Fe:C ratios, scavenging, remineralisation length scales
- More data to explore the links between Fe supply, bloom termination and export (and C sequestration)
- Use of SF_6 approach for other manipulations - DISCO, FeCycle
- The Fe-phytoplankton link is an example of what can be achieved for other key groups - N Fixers, Calcifiers...



Conclusions

- **During JGOFS *in situ* mesoscale expts have confirmed the key role that iron plays in the ocean C Cycle**
- **Expts have placed JGOFS field studies into context - IronEx II and EQPAC**
- **Iron supply results in similar trends in tropical - polar HNLC waters**
- **Some divergences remain - Fe-L production**