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UND MEERESFORSCHUNG

Ocean iron fertilization: Overview and perspectives

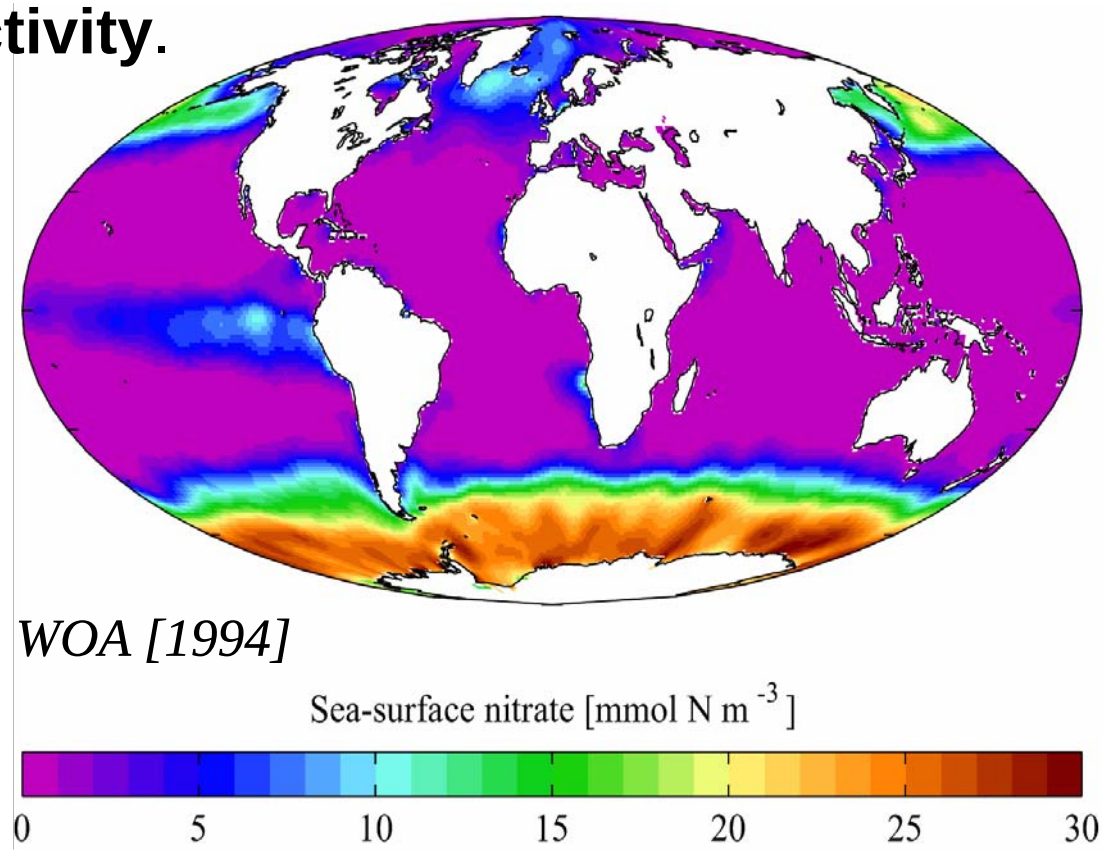
Christine Klaas

IMO, London 2015

MOTIVATION

Large areas of the ocean were biomass is low and nutrients are high all year round (not used): **High Nutrient Low Chlorophyll areas**.

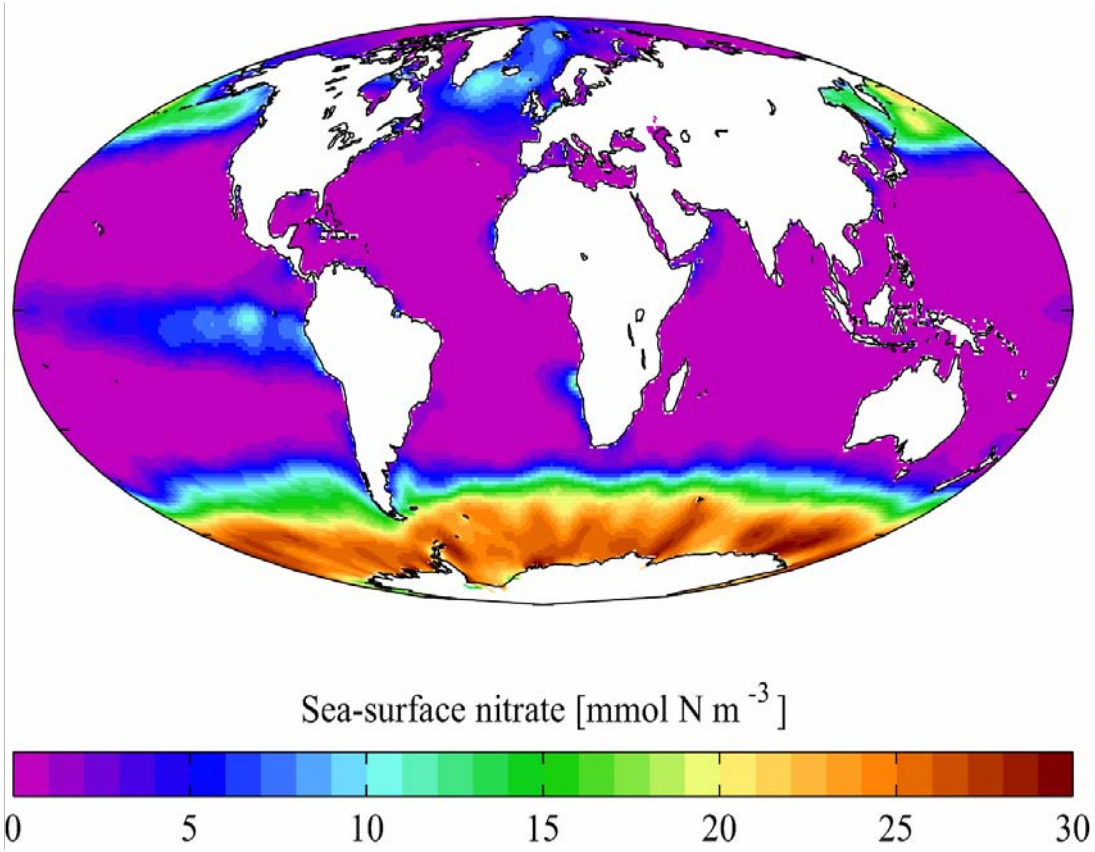
Prominent among them is the Southern Ocean. Further, models show **high sensitivity of atmospheric CO_2 to changes in Southern Ocean productivity**.



WOA [1994]

IRON HYPOTHESIS *(Martin,1990)*

- HNLC areas are iron limited.
- Glacial/interglacial pCO_2 variations are due to changes in biological activity due to changes in dust input in the Southern Ocean



PALEOCEANOGRAPHY, VOL. 24, PA1207, doi:10.1029/2008PA001657, 2009

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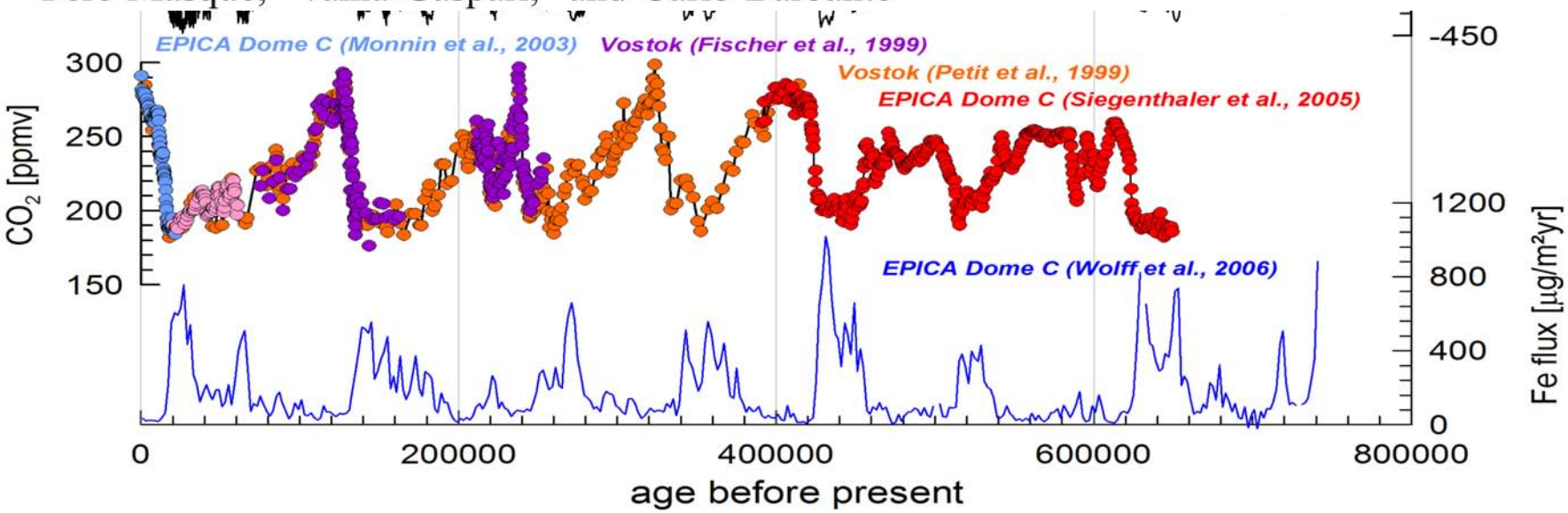
Links between iron supply, marine productivity, sea surface temperature, and CO_2 over the last 1.1 Ma

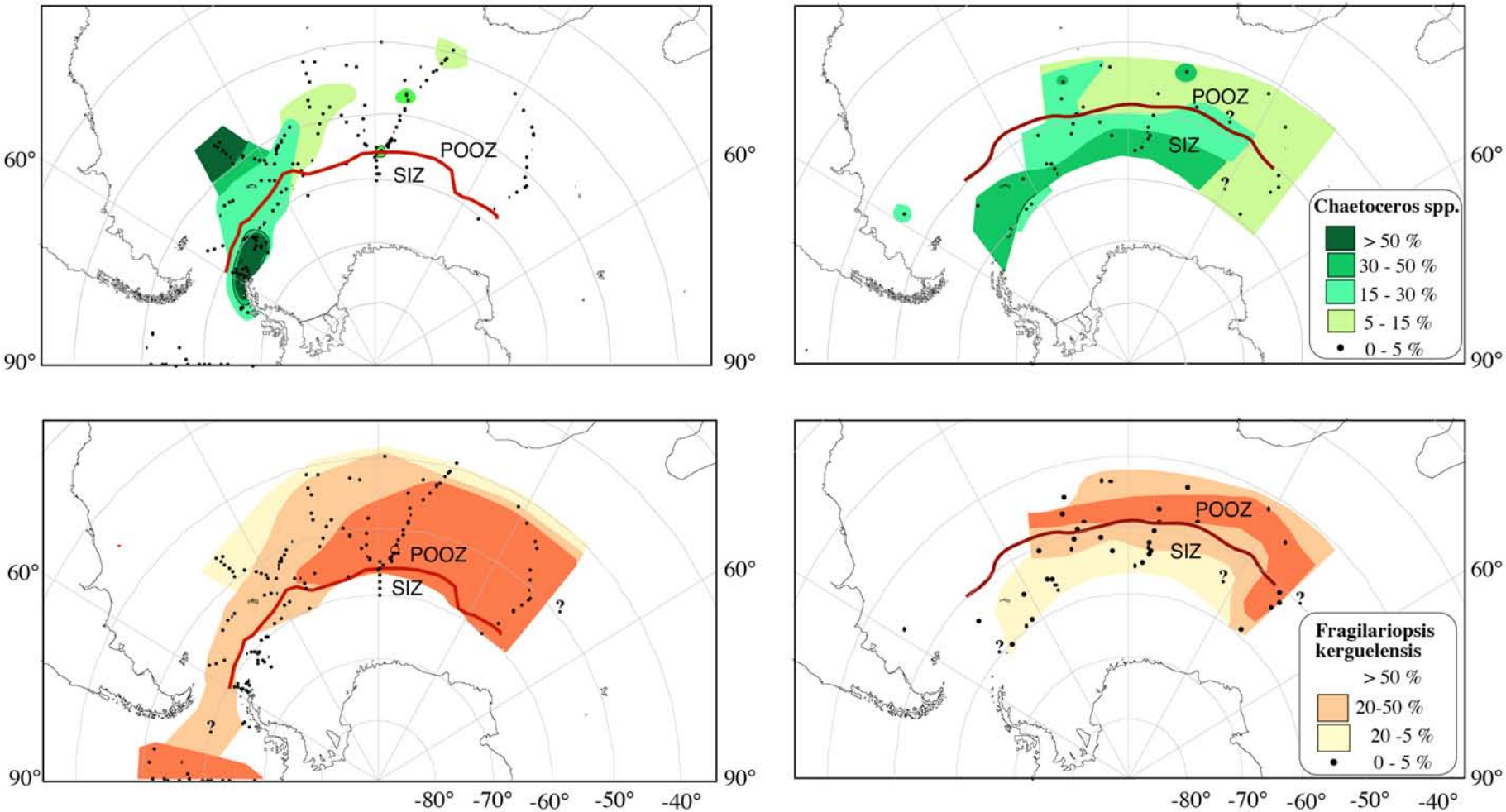
Alfredo Martínez-Garcia,[1] Antoni Rosell-Melé,[1,2] Walter Geibert,[3,4,5] Rainer Gersonde,[6] Pere Masqué,[1] Vania Gaspari,[7] and Carlo Barbante[7,8]



Diatoms in the sediments

Interglacial

glacial



Abelmann et al. 2006

WHY IRON?

. Carbon fixation (PHOTOSYNTHESIS):

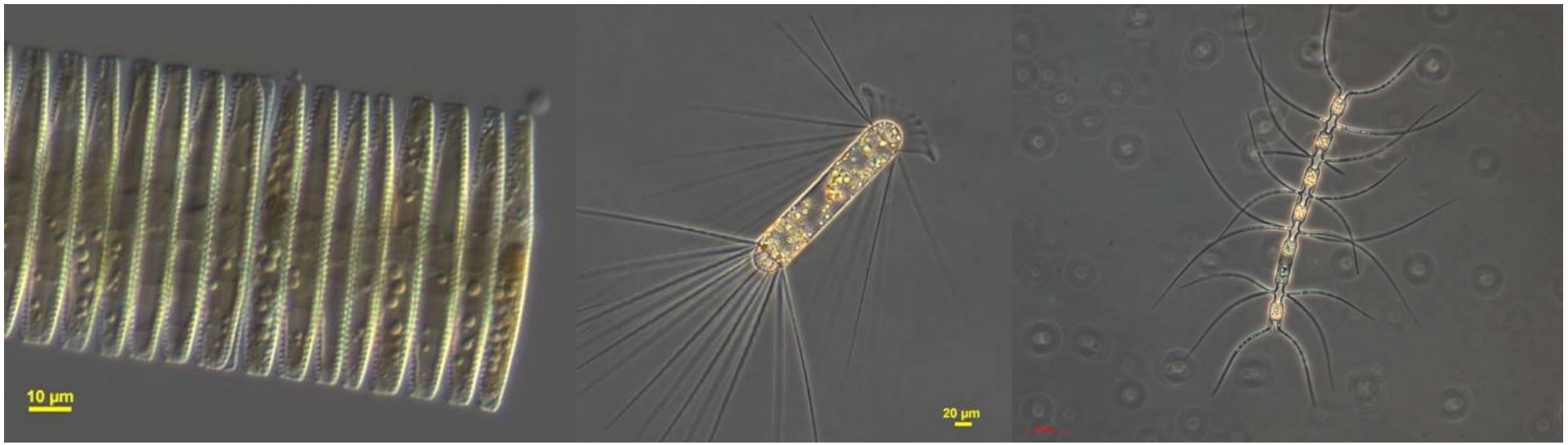
-> $n CO_2 + n.H_2O \rightarrow (CH_2O)n + nO_2$

. Nitrate assimilation:

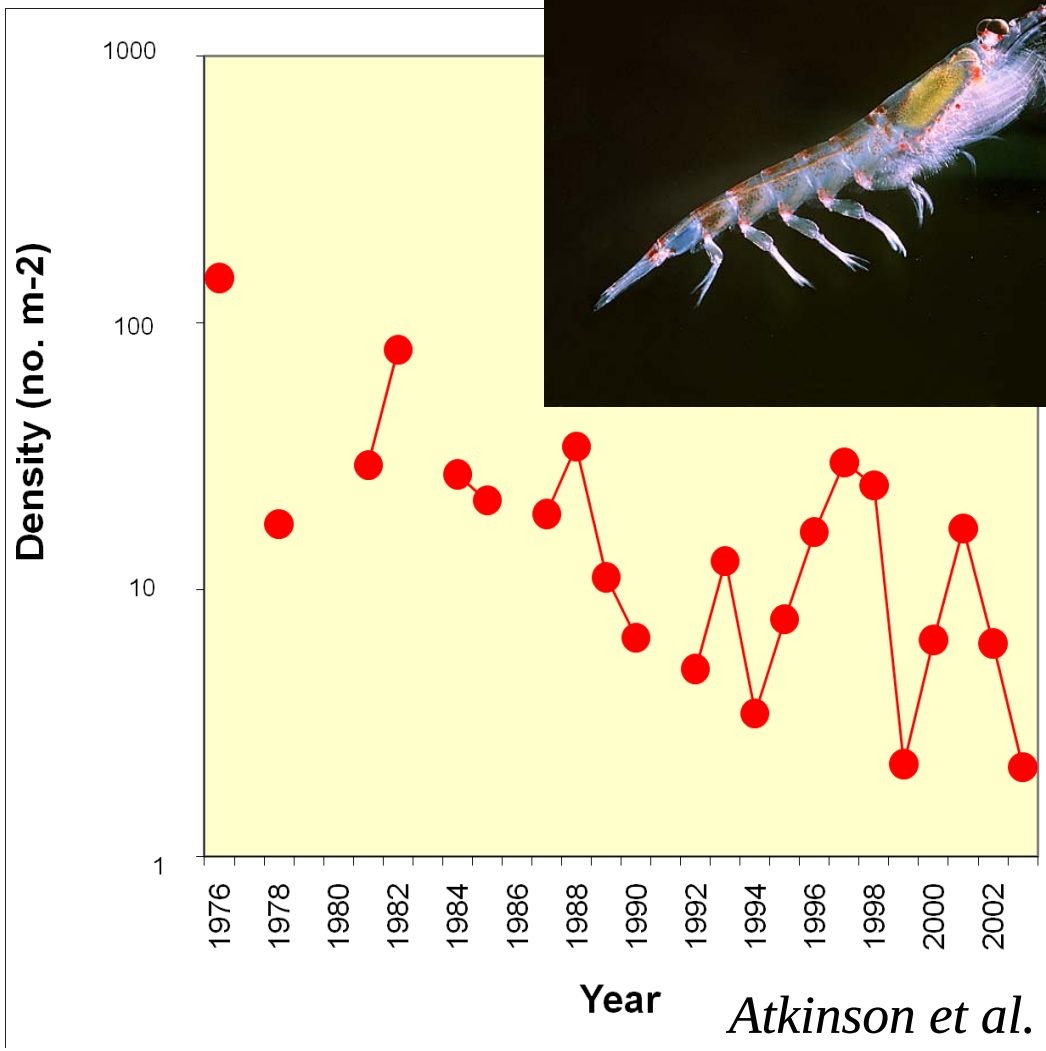
-> Conversion of NO_3^- to NO_2^- to NH_3

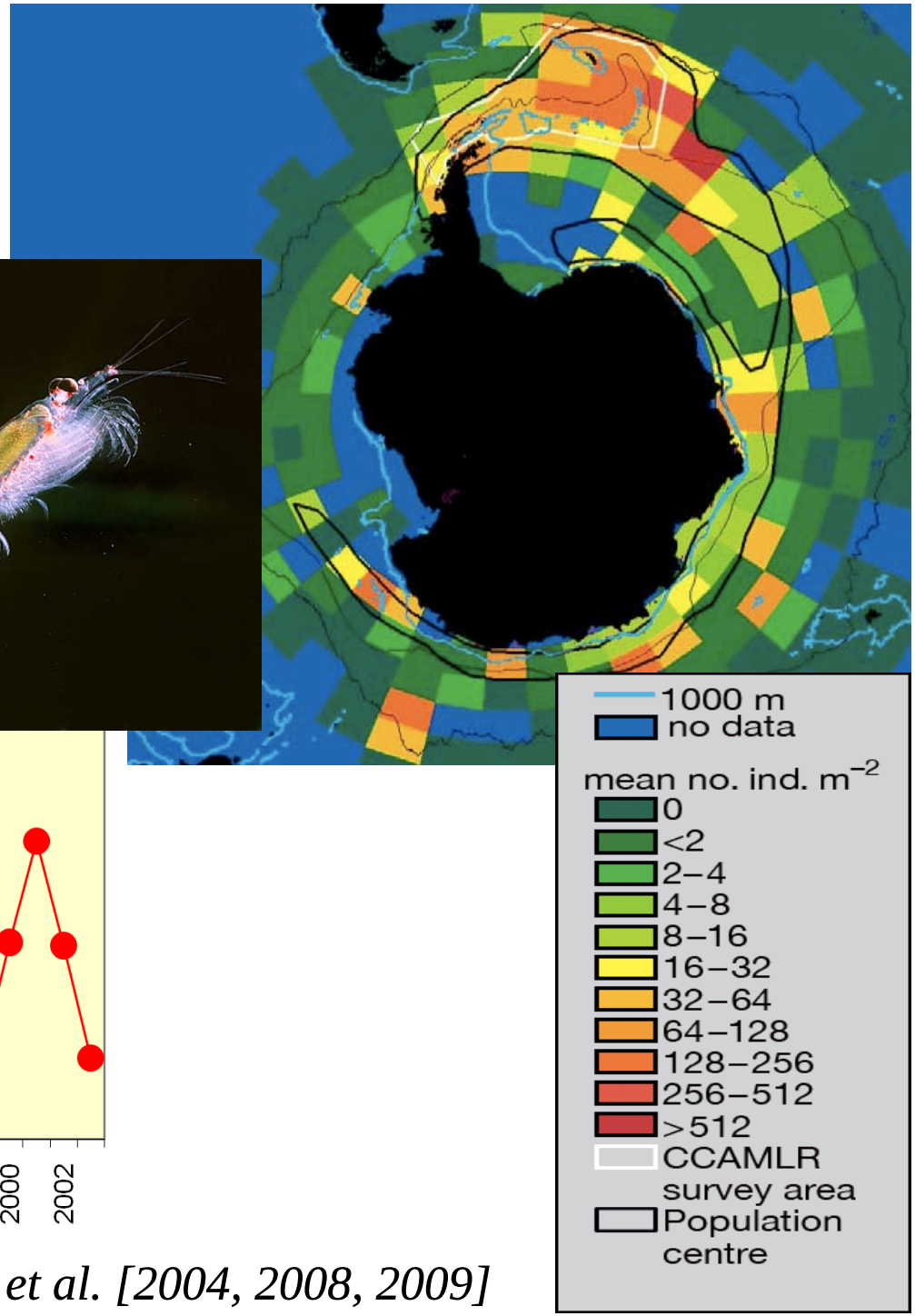
. Iron has very low solubility (sub-nanomolar) in oxygenated ocean waters

. Particularly important for diatoms (main drivers of biological C sequestration in the ocean)



80% decrease in krill stocks (Atlantic sector)





Atkinson et al. [2004, 2008, 2009]

Blue whales 300’000
Fin whales 700’000

FISH and FISHERIES

Southern Ocean iron fertilization by baleen whales and Antarctic krill

Delphine Lannuzel[2,4], *Klaus M Meiners*[2] &

he Arts, Australian Antarctic Division, 203 Channel Highway,
Ecosystems Cooperative Research Centre, University of Tasmania,
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03 Channel Highway, Kingston, Tas. 7050, Australia; [4]Centre for
, Hobart, Tas. 7001, Australia; [5]Institute for Antarctic and
7000, Australia

ern Ocean and experiments have
ce waters results in phytoplankton
rill (*Euphausia superba*) eat diatoms
ıg. Baleen whales eat krill, and,
ave been a major mechanism for
ıuantities of iron. We analysed the
ecies of baleen whale. Faecal iron
ately ten million times that of
as a fertilizer. Furthermore, we
l of muscle tissue of two species of
Using these figures, together with
ve calculate that the Antarctic krill
surface waters in its range. Thus,
ntarctic surface waters, by storing
ulations of whales and krill must
have also recycled more iron in
ivity through a positive feedback
might actually increase Southern
in the surface layer.

Southern Ocean

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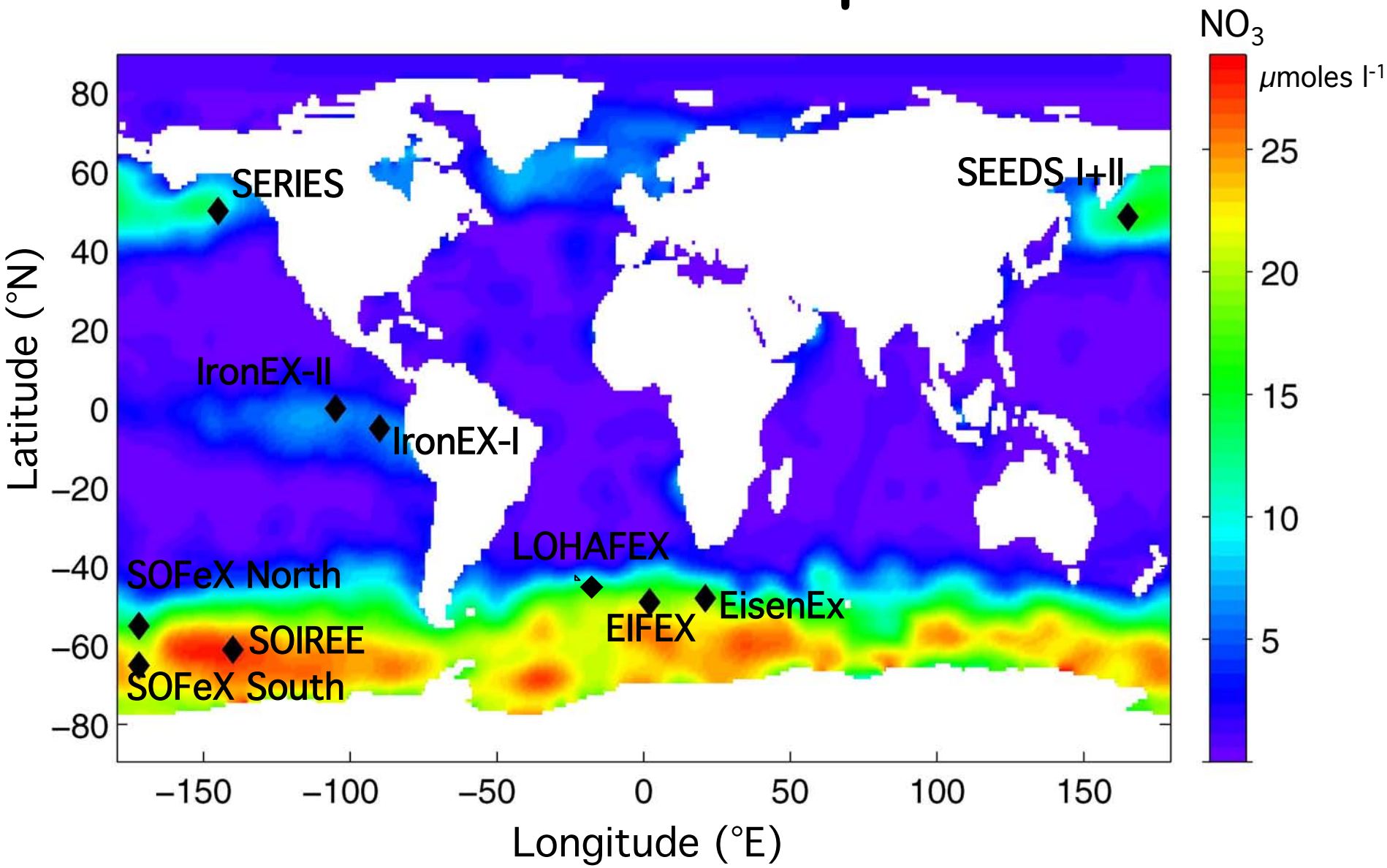
cells, w

BIOGEOCHEMISTRY

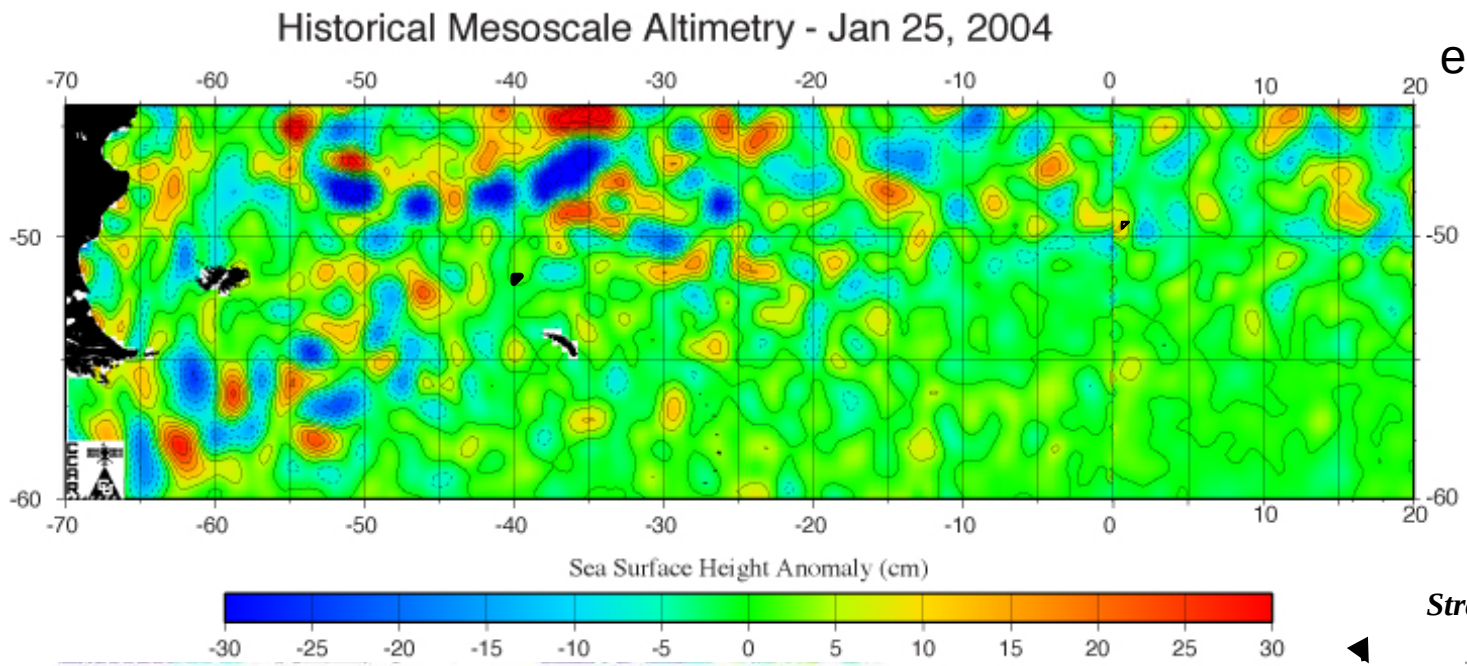
Faecal fertilization

Proc. R. Soc. B doi:10.1098/rspb.2010.0863 (2010)

Iron fertilization experiments

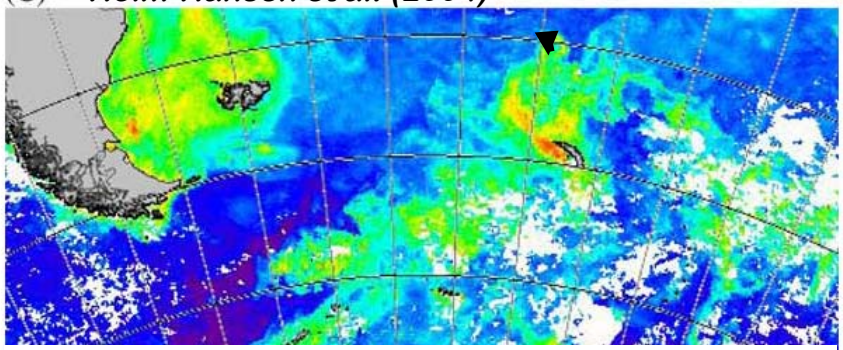


Ocean surface elevation anomaly



Strass & Cisewski (pers. com.)

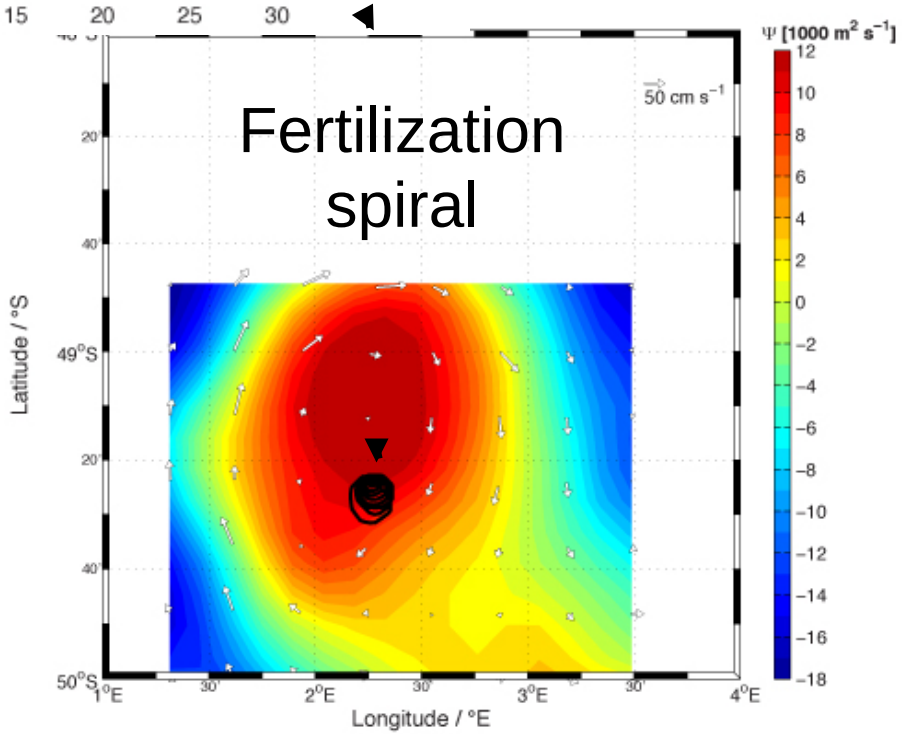
(C) ***Holm-Hansen et al. (2004)***



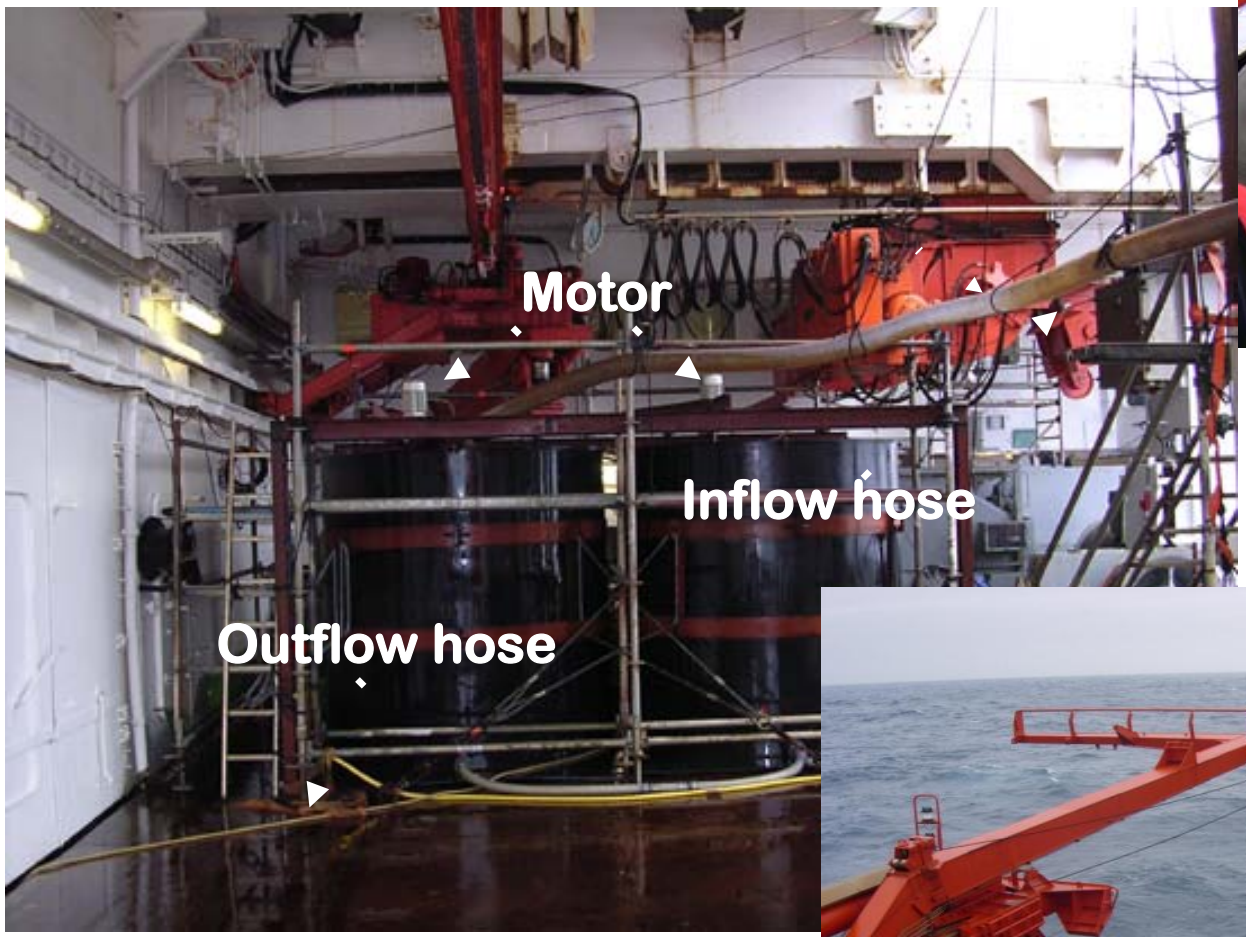
Natural fertilization by terrestrial input of iron

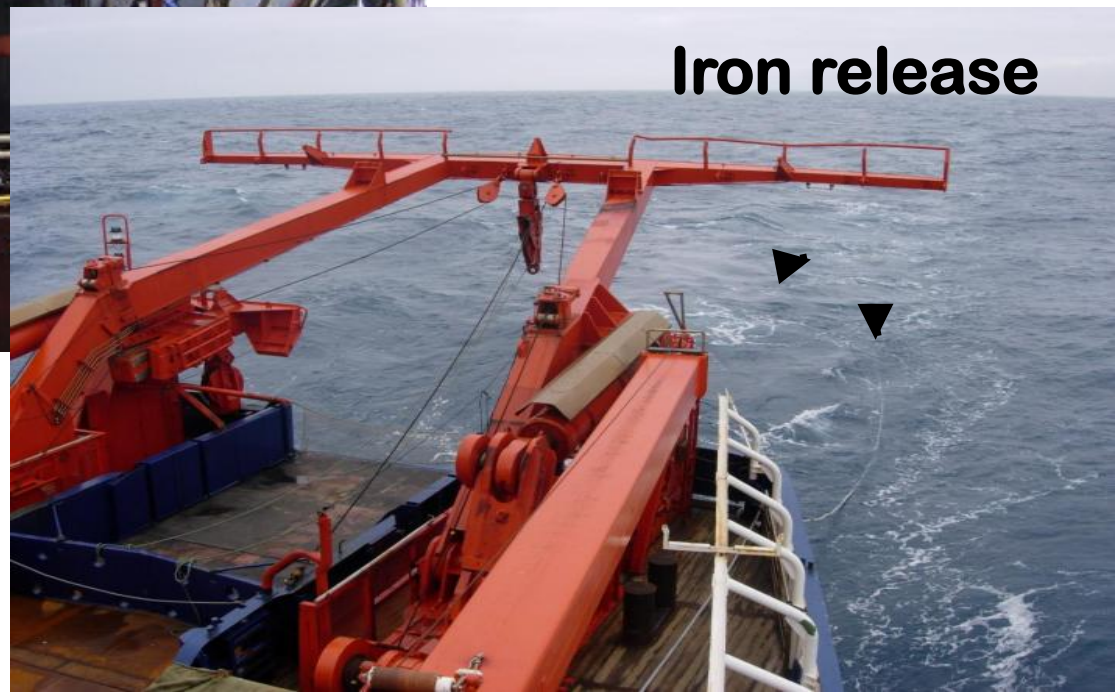
Chl *a* (mg m^{-3})

0.1 0.5 1 2 5 10 28



Iron sulfate (used as lawn conditioner)
not toxic but makes very dusty!





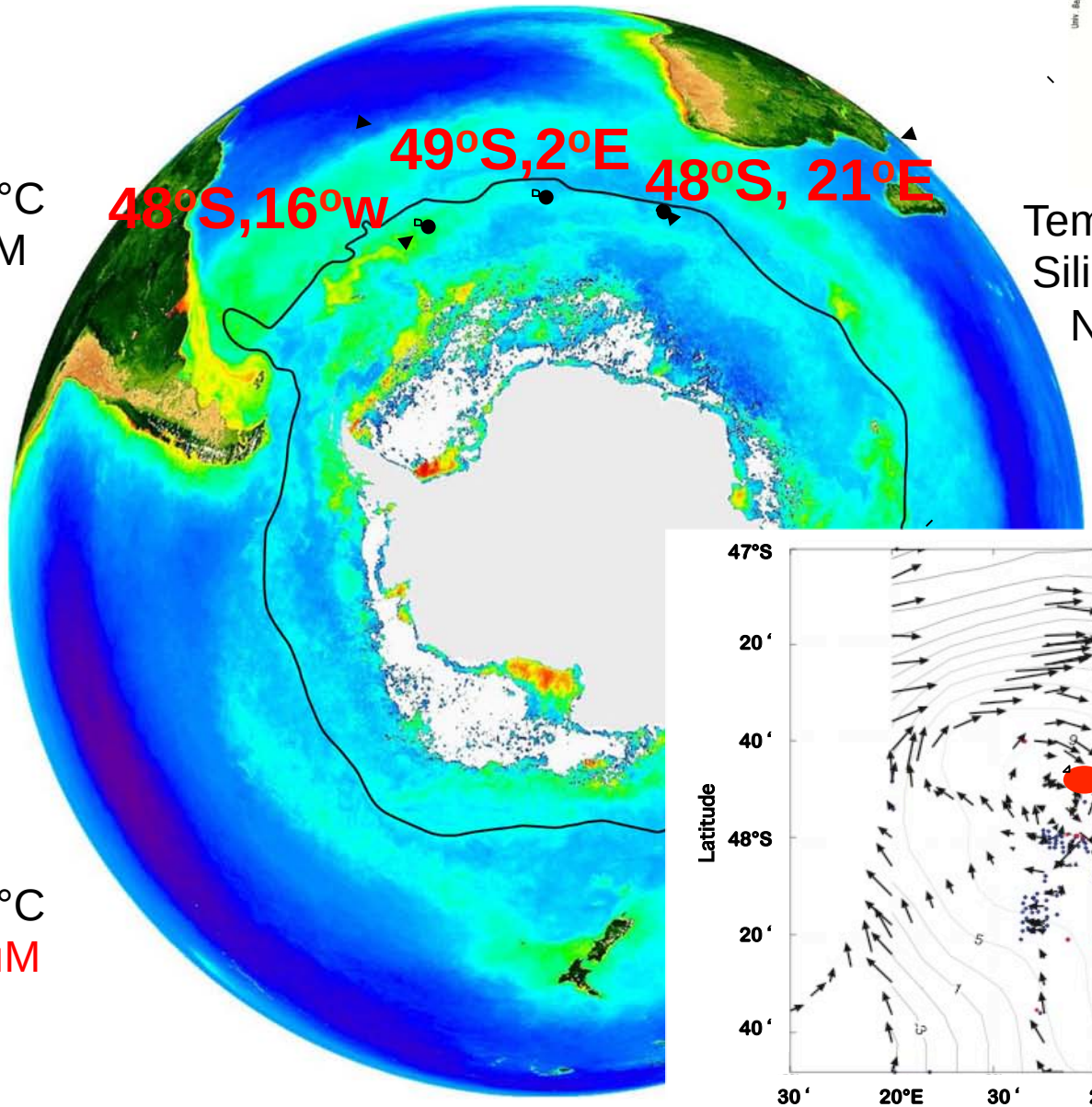
Final concentration:
~ 1.2 nmol L^{-1} (67 ng L^{-1})
Conc. in drinking water:
100-1 000 times higher!

Eisenex, EIFEX & LOHAFEX eddies

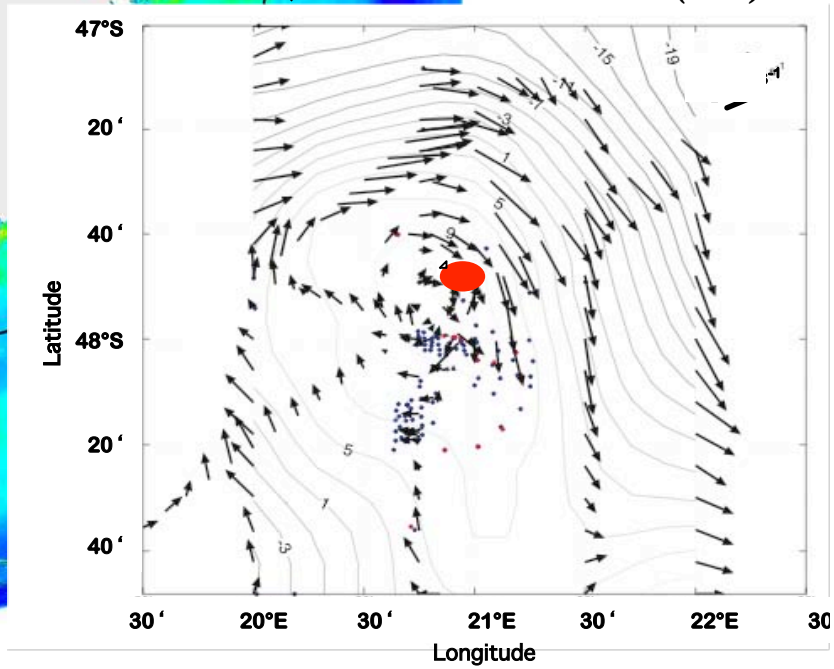
Temperature: ~4°C
Silicic acid: 19 µM
Nitrate: 25 µM

Temperature: ~4°C
Silicic acid: 14 µM
Nitrate: 24 µM

Temperature: ~7°C
Silicic acid: ~ 2 µM
Nitrate: 20 µM

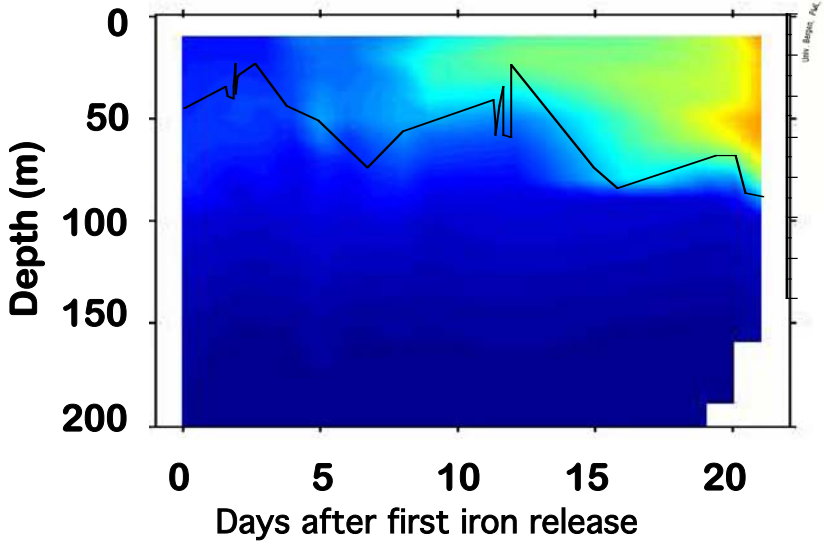


Cisewksi et al. (2005)

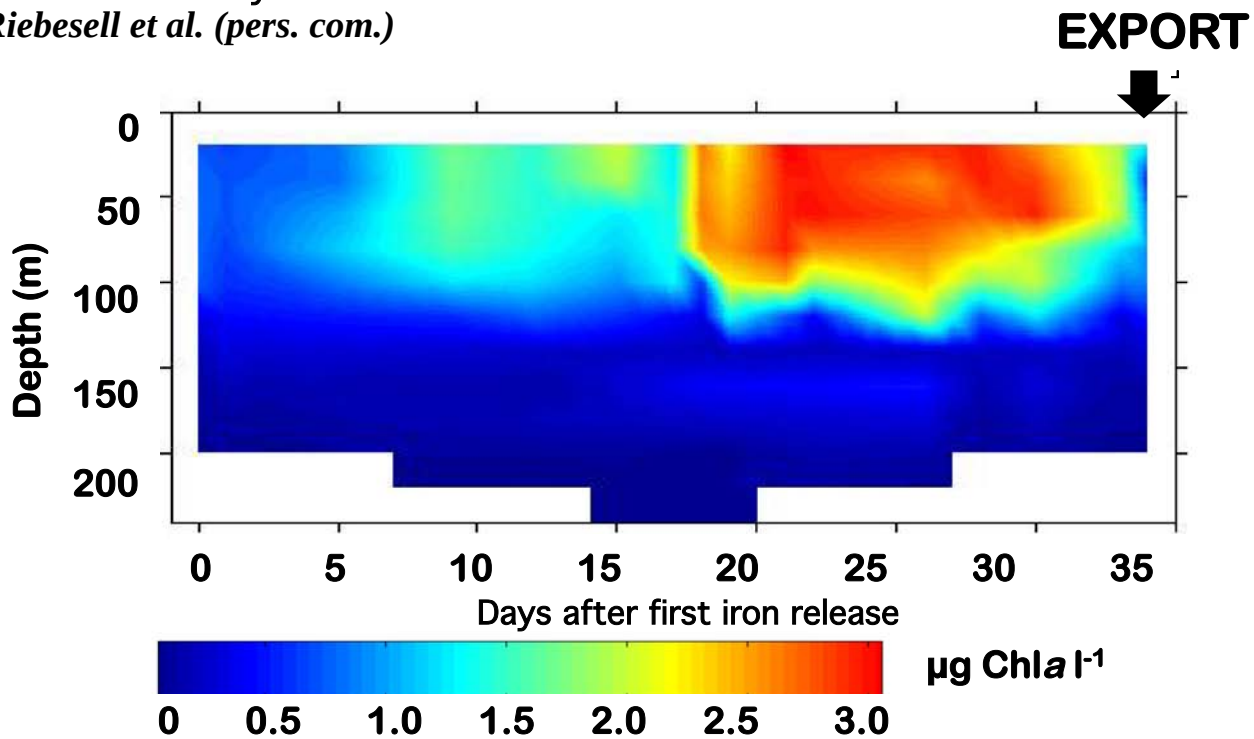


Chlorophyll *a*

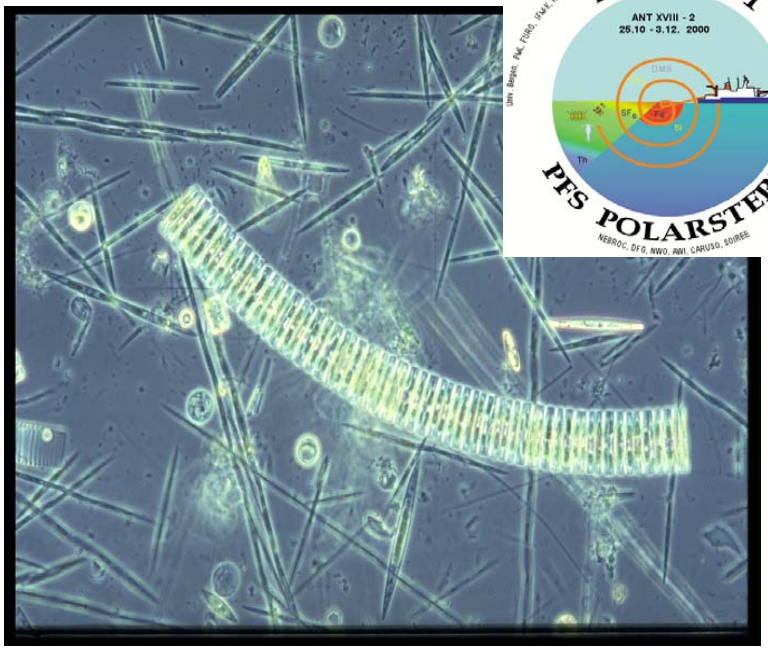
~ plant biomass

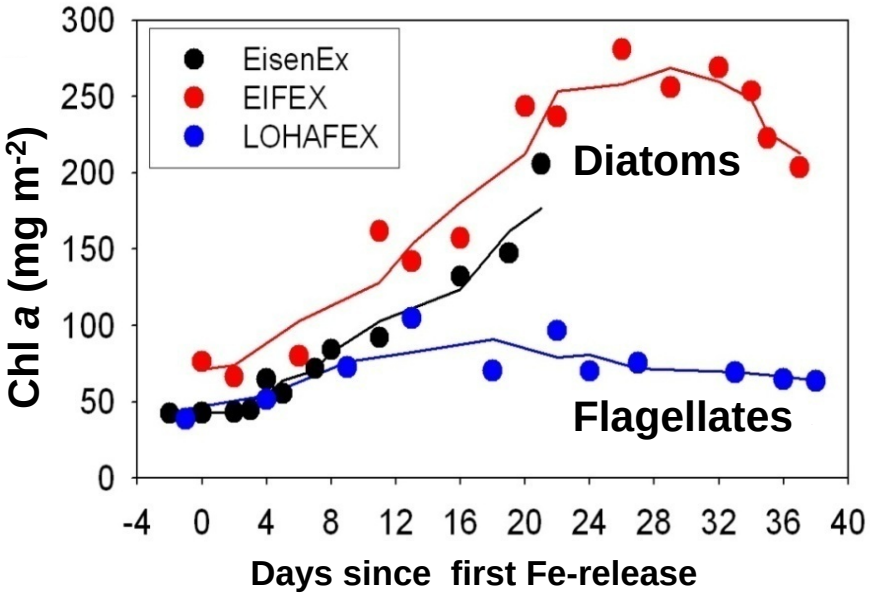


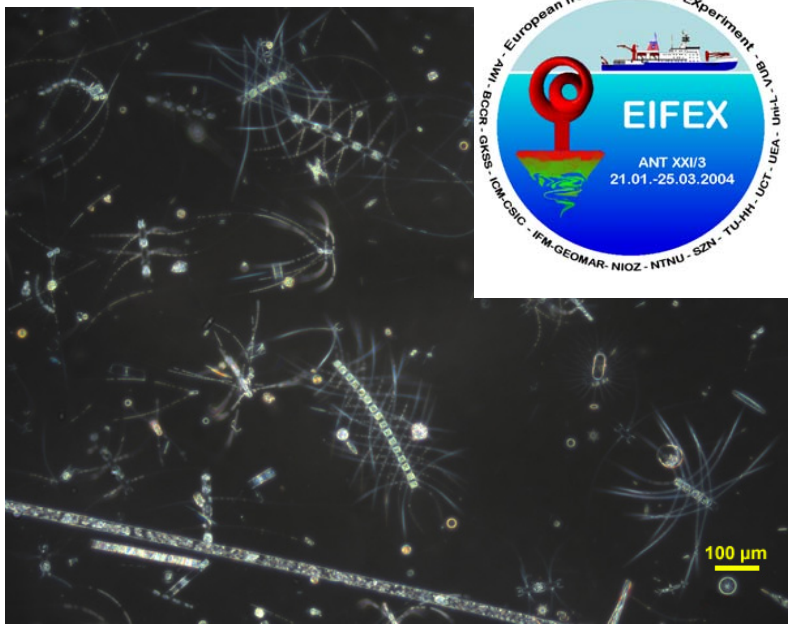
Riebesell et al. (pers. com.)

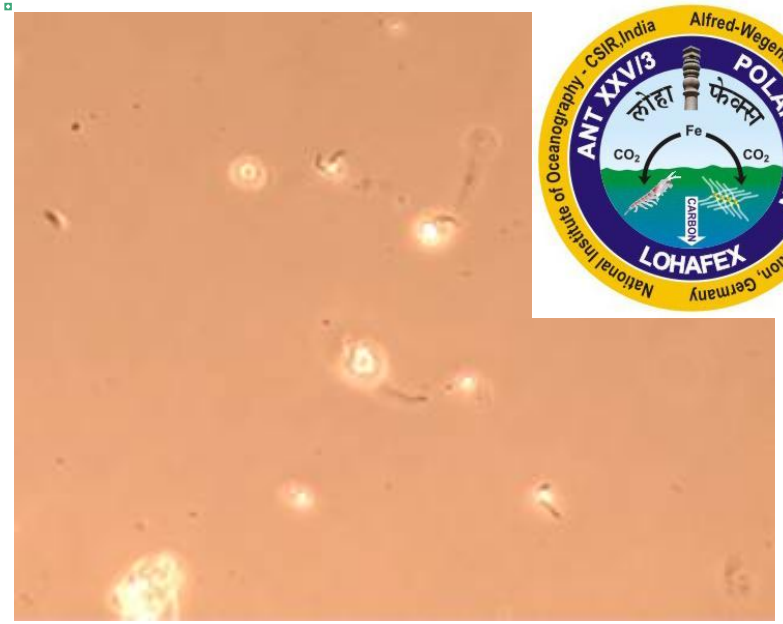


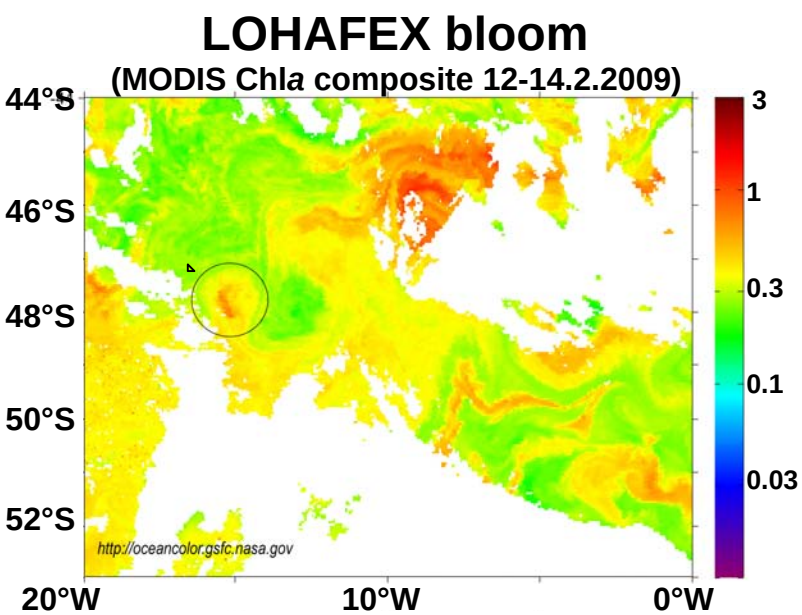
Smetacek et al. (2012)

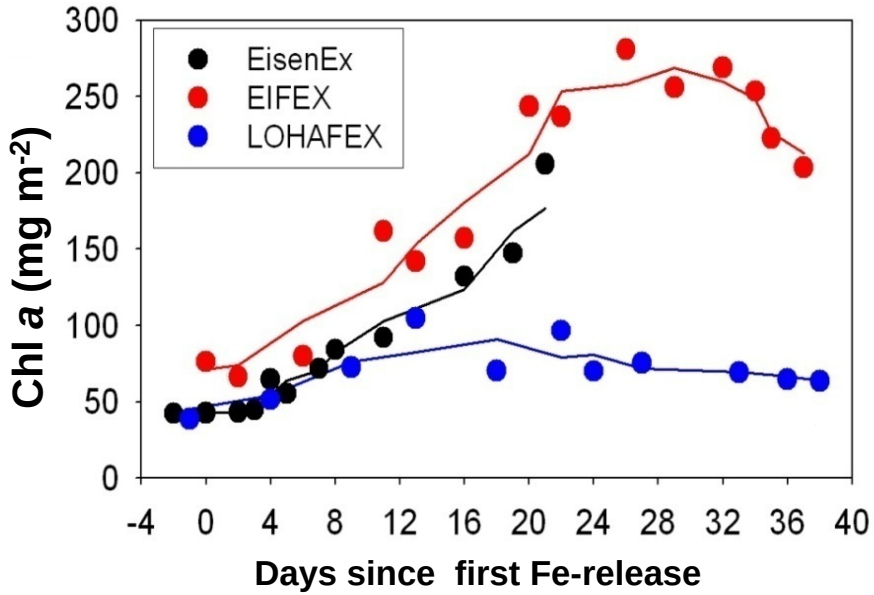


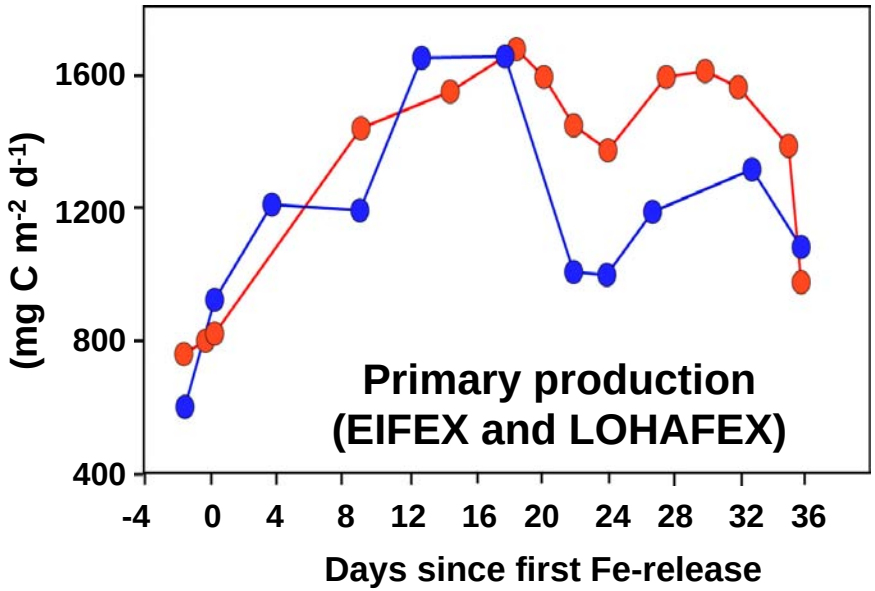

EisenEx
EIFEX
LOHAFEX
Diatoms
Flagellates
Chl a (mg m-2)
Days since first Fe-release
300
250
200
150
100
50
0
-4
0
4
8
12
16
20
24
28
32
36
40


100 µm







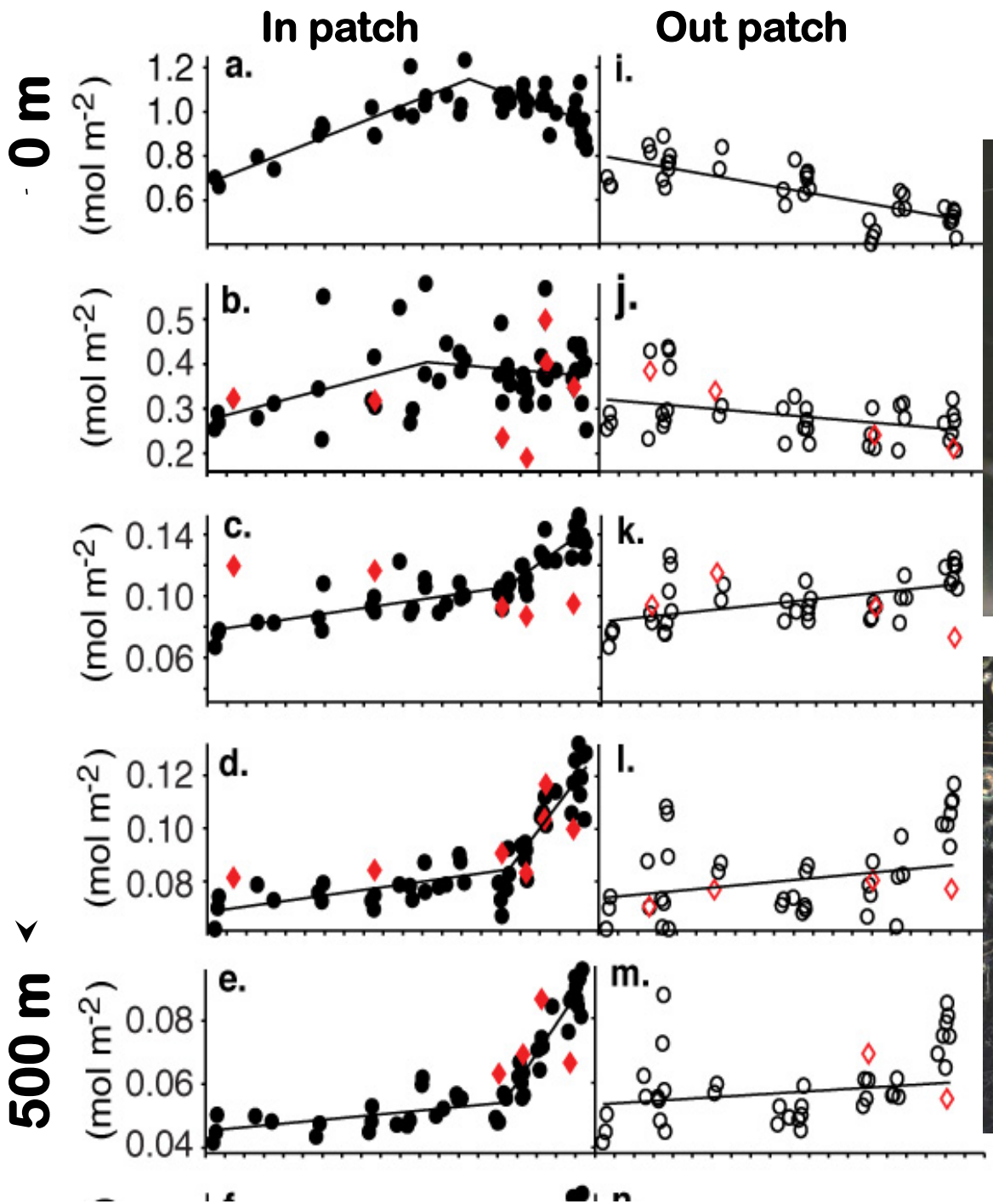


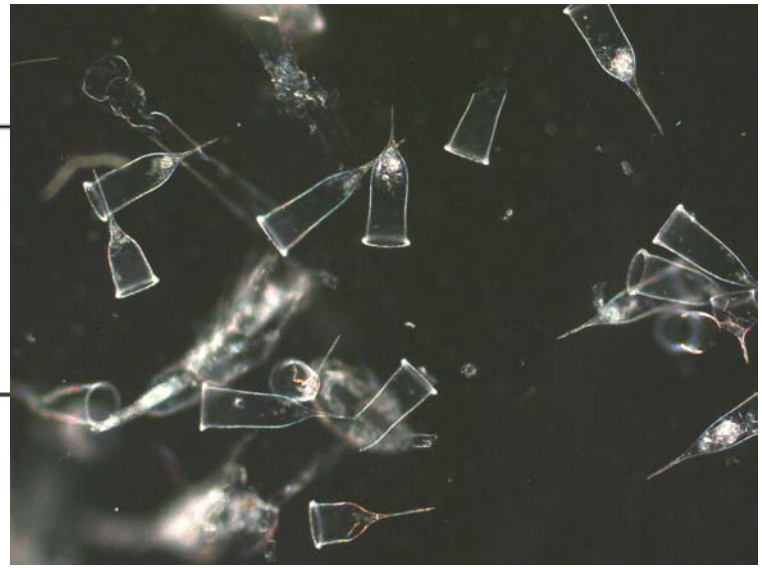
Peeken [pers. com]

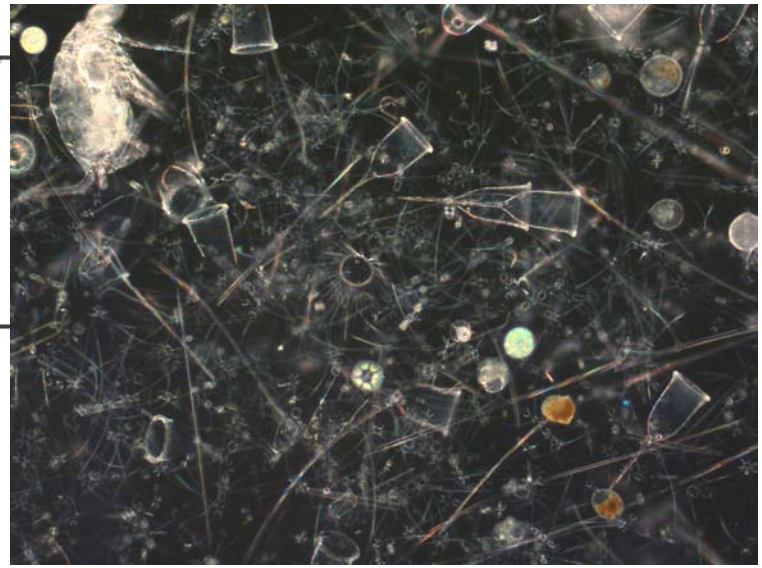
Gauns M. and Naqvi SWA [pers. com]

Carbon export

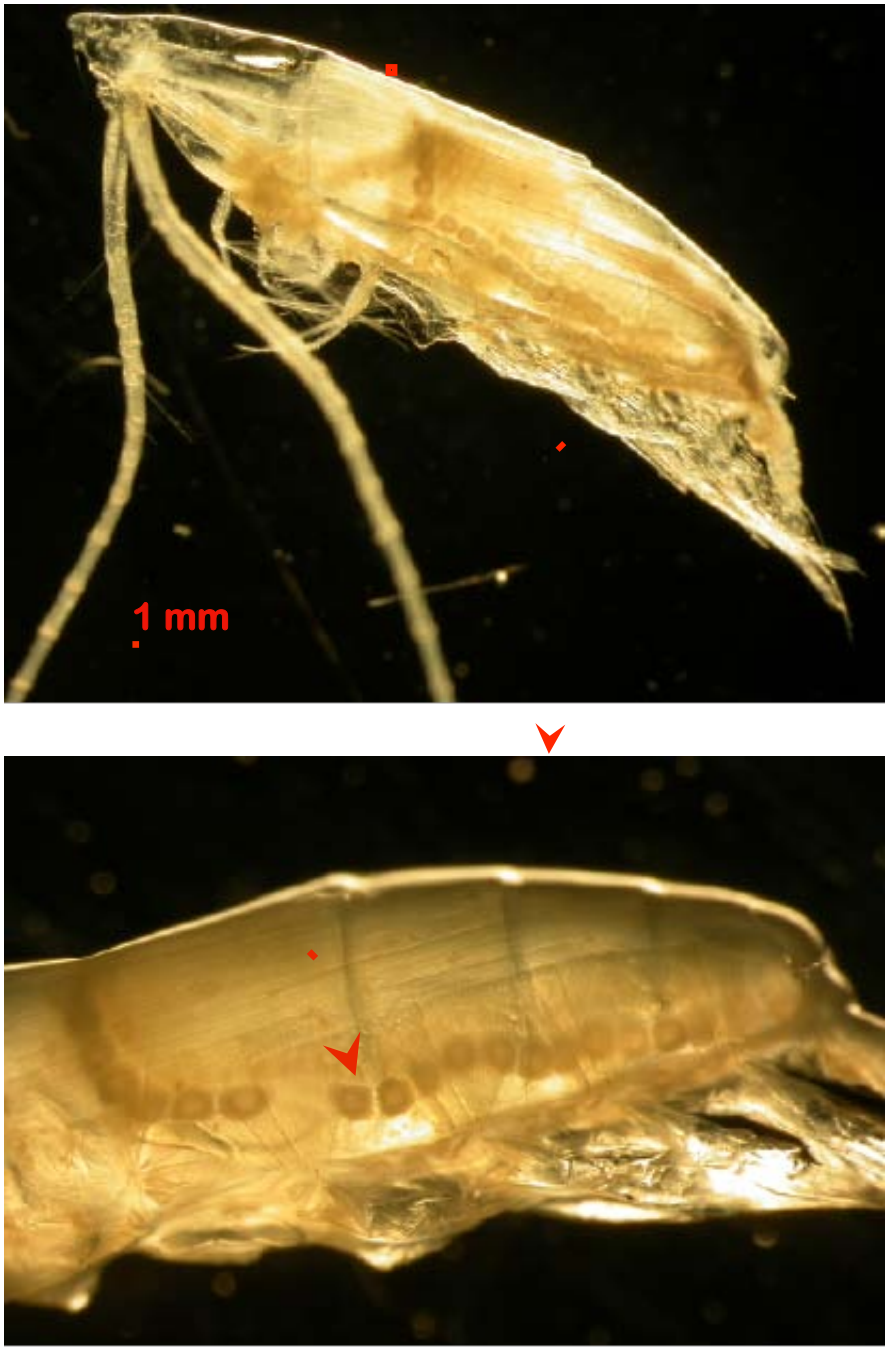
Smetacek et al. [2012]

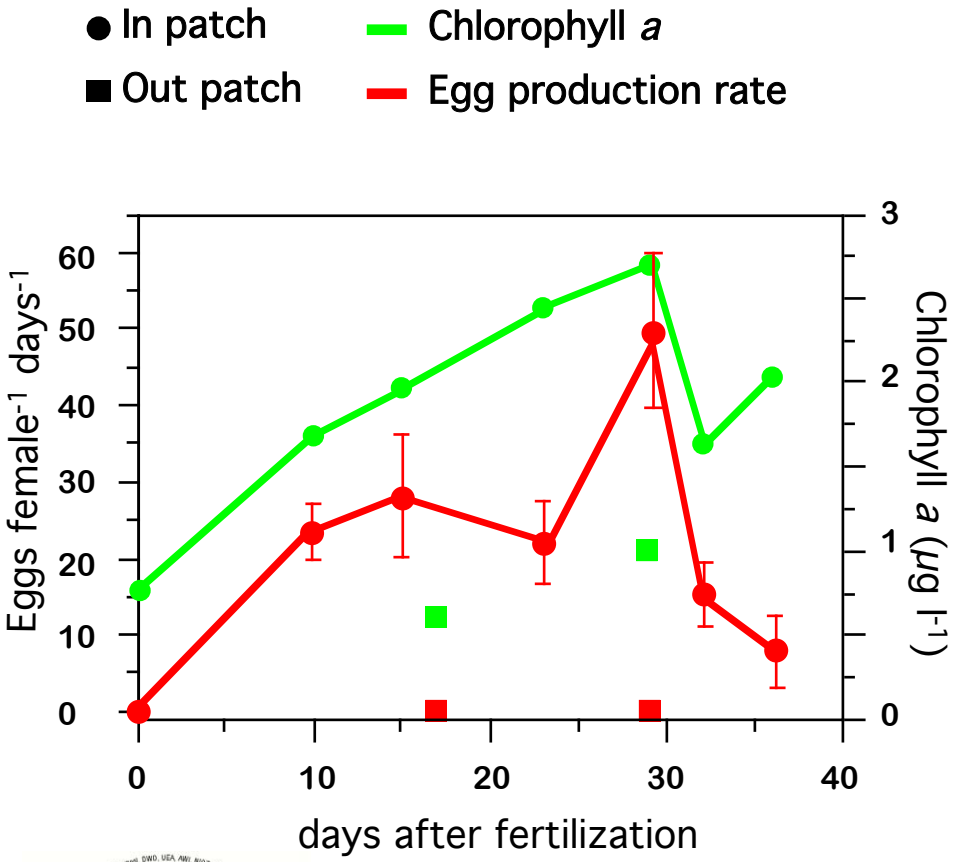






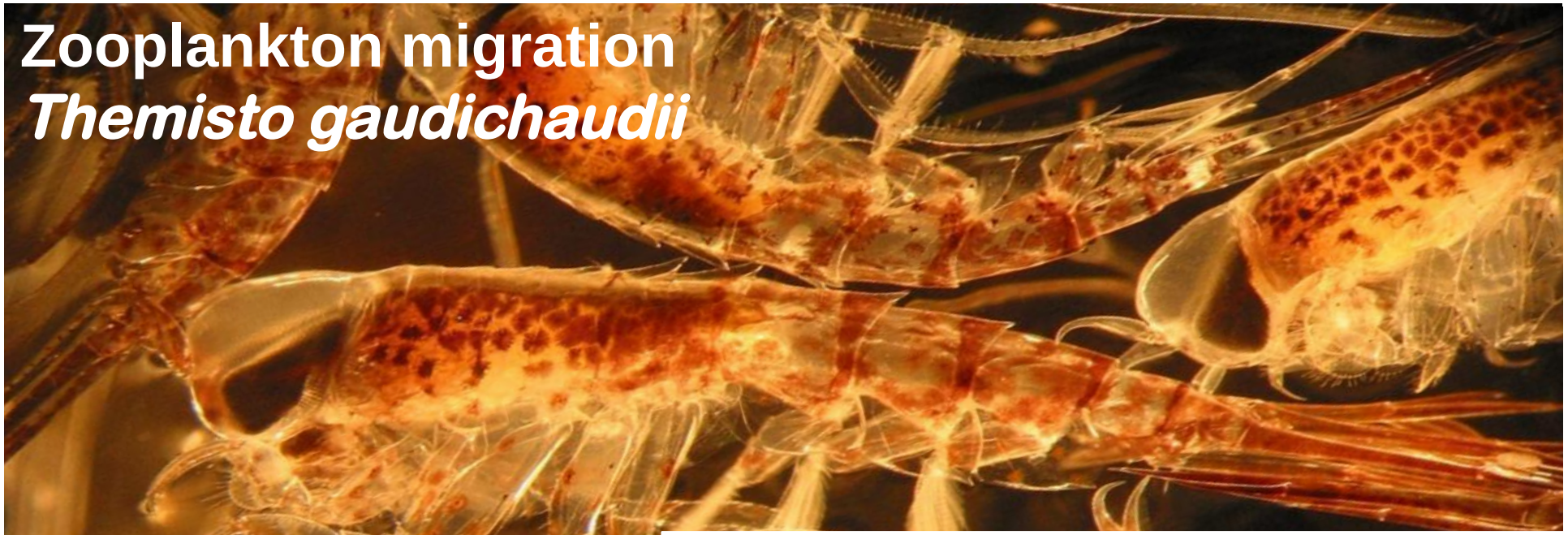
EisenEx: reproductive response of *Rhincalanus gigas*

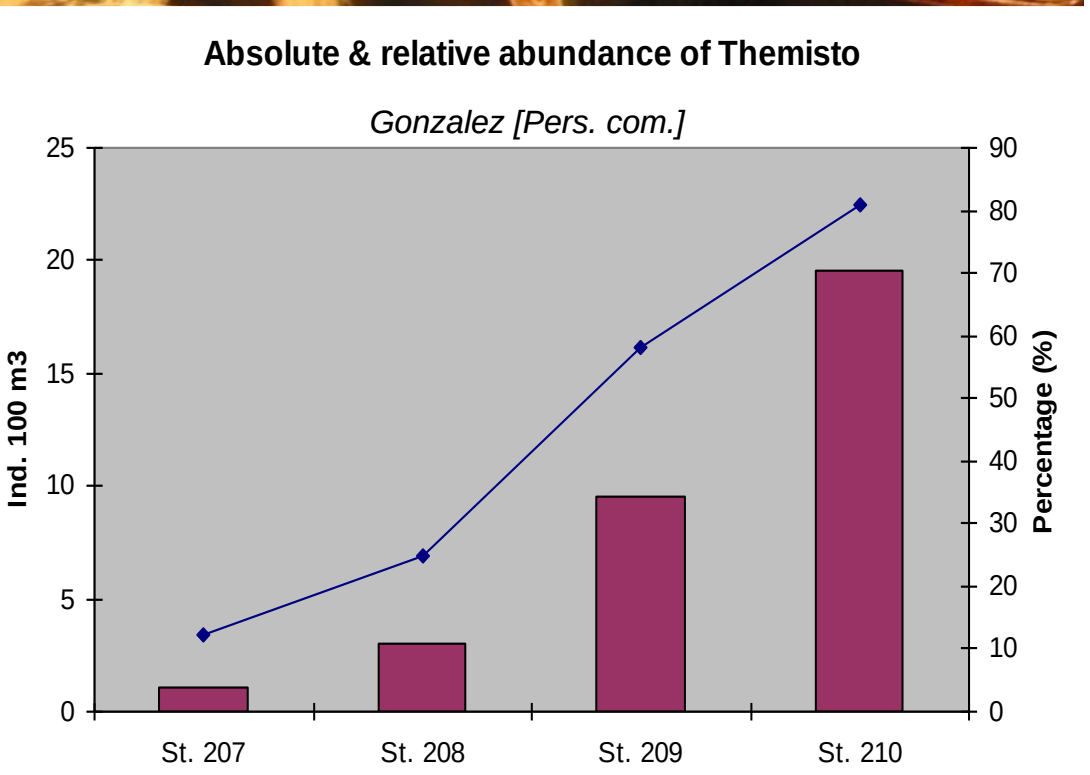




Jansen et al. [2006]

Zooplankton migration
Themisto gaudichaudii





Carbon export

Effect of iron addition:

(1)SOIREE	0-9 mmol C m^2 d^{-1}
(2)EISENEX	~0
(3)SOFEX South	~12 mmol C m^2 d^{-1}
(4)Natural (KEOPS)	~23 mmol C m^2 d^{-1}
(5)EIFEX	75 mmol C m^{-2} d^{-1}
(6)LOHAFEX	6 mmol C m^{-2} d^{-1}

C/Si of export - in patch ~ 3 - out patch ~ 1

(1) Charette and Buesseler (2000); Nodder et al. (2001)

(2) Rutgers van der Loeff et al. (unpublished data)

(3) Buesseler et al. (2005)

(4) Blain et al. (2007)

(5) Smetacek et al. (2012)

(6) Martin et al. (2013)

CONCLUSIONS

- Phytoplankton production stimulated by all iron additions (small influence of mixed layer depth)

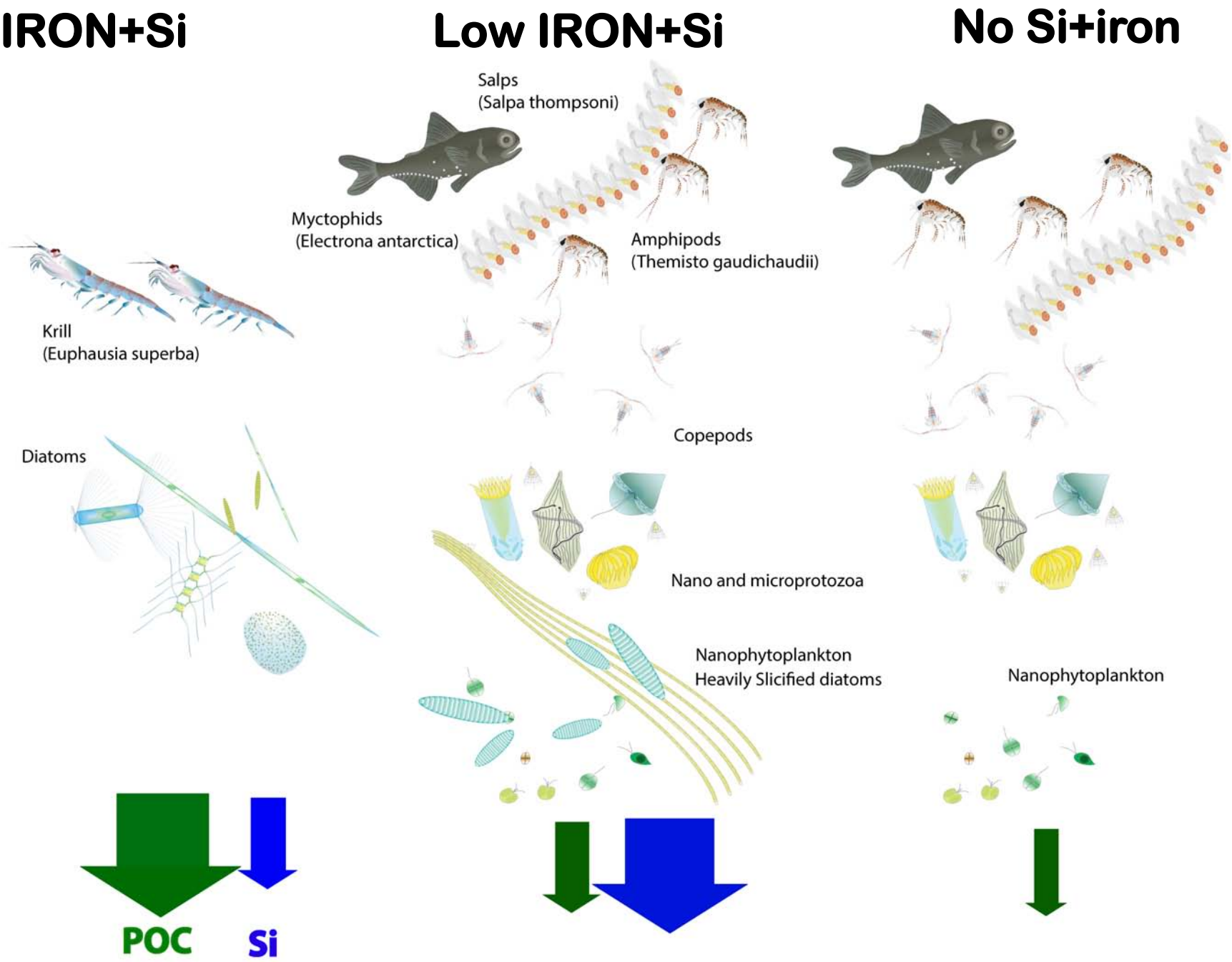
- Iron fertilization can lead to significant carbon export provided there is silicic acid for diatom growth

=>**Ultimately Si and not N supply would limit export**

- Zooplankton also respond to fertilization

⇒ Food limited (KRILL ???)

-> long term effects on/of food webs


IRON+Si
Low IRON+Si
No Si+iron
Salps
(Salpa thompsoni)
Myctophids
(Electrona antarctica)
Amphipods
(Themisto gaudichaudii)
Krill
(Euphausia superba)
Copepods
Diatoms
Nano and microprotozoa
Nanophytoplankton
Heavily Slicified diatoms
Nanophytoplankton
POC
Si

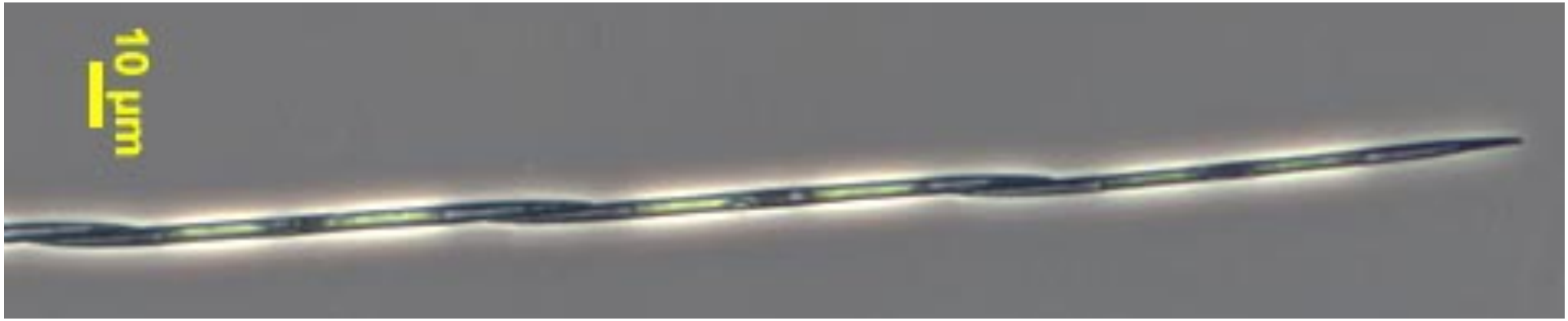
Local risks

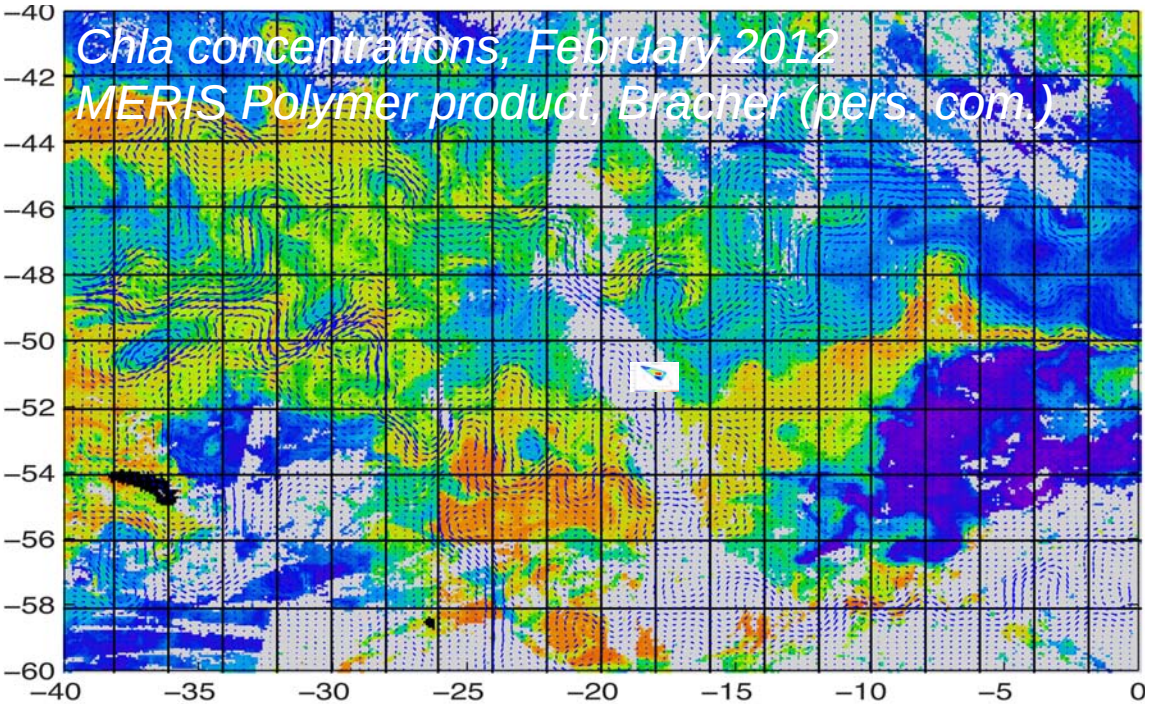
- Toxic blooms*

*In the SO: One potentially toxic diatom genus *Pseudo-nitzschia* (*P. lineola*) produces domoic acid.

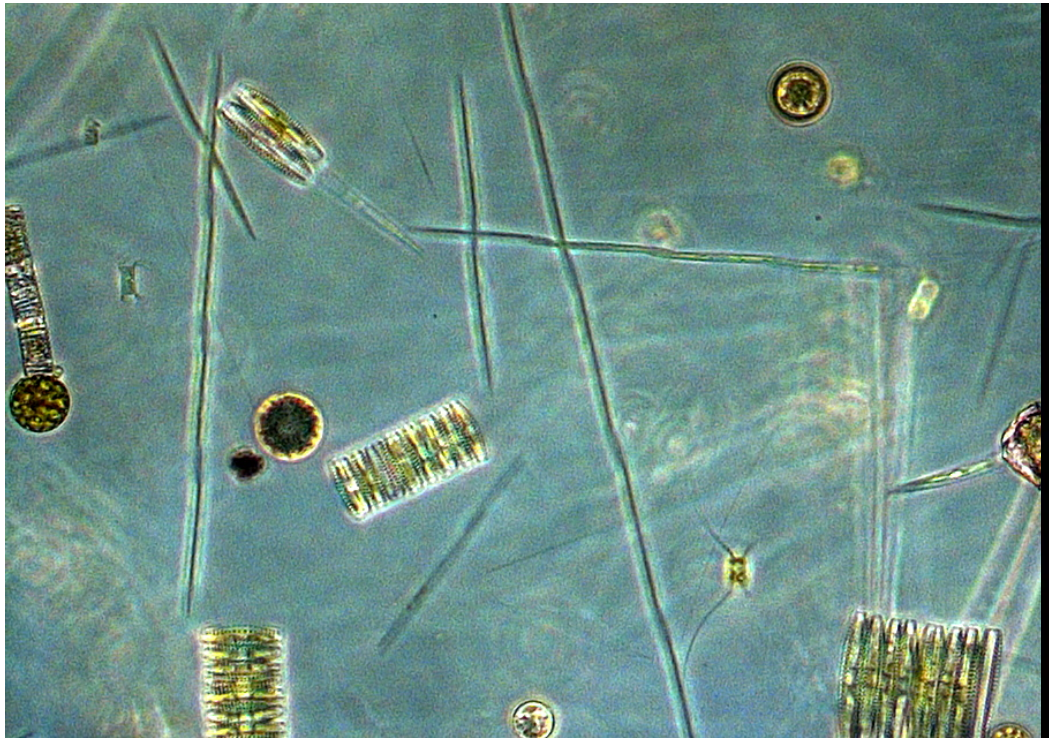
P. lineola dominated phytoplankton during Eisenex but no significant increase in domoic acid observed.

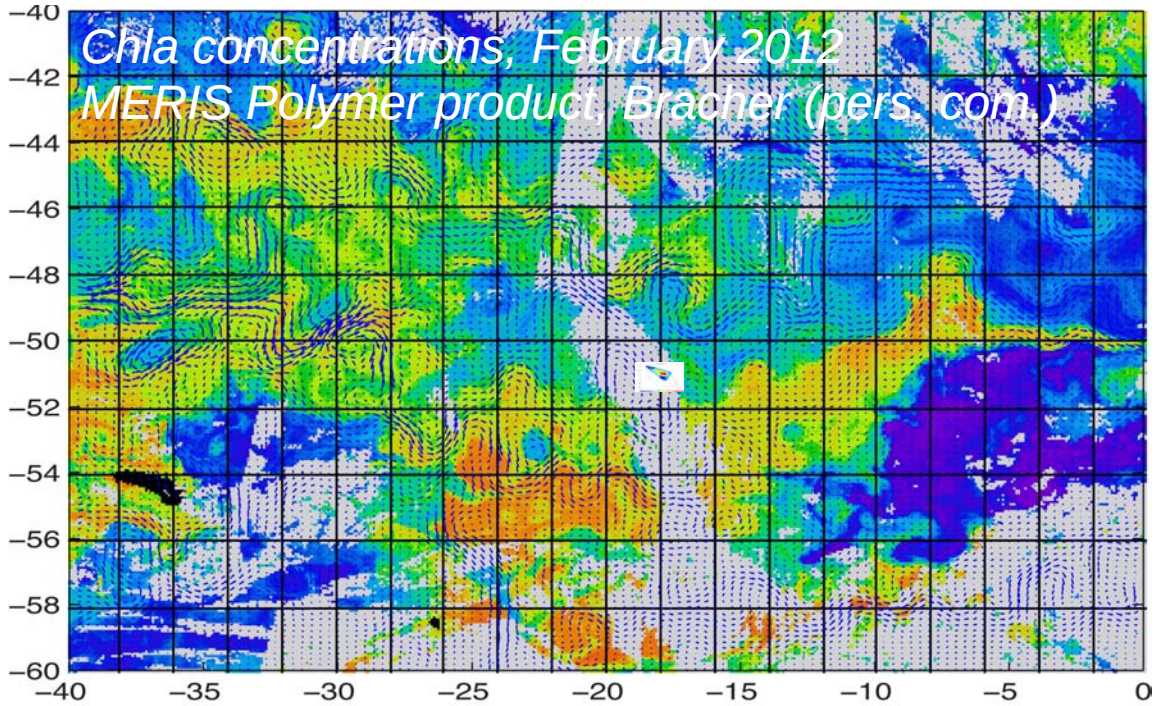
During SOFEX elevated domoic acid values were measured *(Silver et al., 2010)*





Pseudo-nitzschia (*P. lineola*) occur naturally in the SO.





Diatom bloom composition was different for each experiment and no different than naturally occurring blooms in the SO.

Problem: We are as yet unable to predict what the species composition of blooms is/will be (i.e. *Pseudo-nitzschia* or not) + domoic acid production or not.

Local risks

- Dead zones**-> NOT APPLICABLE TO OIF IN THE SOUTHERN OCEAN**
- Reduction in oxygen concentration at depth
  not significant (but would occur under long term, large scale OIF and business as usual scenario *(Keller et al., 2013)*
- Production of other greenhouse gases
  CH_4 observed but lower than natural blooms in the SO
  N_2O no significant increase
- Production of climate relevant gases (**DMS**, **Isoprenes** CH_3I, CH_3Br), can be higher but not higher than natural blooms *(Wingenter et al., 2004; Hepach et al, 2015)*

Global impacts
(long term large scale fertilization)

- Reduction in oxygen concentration at depth
- Partly offset by decreased productivity in other areas
- Production of other greenhouse gases (CH_4, N_2O)

(Jin and Gruber, 2003; Aumont and Bopp,2006; Oschlies et al., 2010)

offsetting 10~20% of increase in C uptake in the SO

- long term effects on/of food webs unknown

- RISKS BUT ALSO BENEFITS OF LARGE SCALE FERTILIZATION BOTH LOCALLY AND GLOBALLY ARE POORLY CONSTRAINED.

IRON FERTILIZATION & CARBON SEQUESTRATION

Realistic estimates (model studies based on **CONTINUOUS** fertilisation over 100 years)
-> ~ 0.4-1 Gt yr^{-1}
(ex.: *Aumont and Bopp, 2006; Oschlies et al., 2010*)

With large uncertainties in the magnitude and time Scales!

- CO_2 emissons *(Le Quéré et al. 2009)*:
9.9 Gt yr^{-1} of which 2.3 Gt yr^{-1} taken by the ocean

IRON FERTILIZATION CANNOT REPLACE EMISSIONS REDUCTION

WHY IRON FERTILIZATION EXPERIMENTS?

- Mimics natural processes (occurring or occurred in the past)
- Fantastic research tool to improve basic understanding of the biogeochemistry of the oceans including impact and response to past and future climate change.
- Risks of large scale fertilization both locally and globally are poorly constrained.
- Understanding those risks is inherent to understanding how changes in productivity have affected earth's system in the past and in the future

Thank you for your attention!

With pictures and data from EISENEX, EIFEX and LOHAFEX participants.

Captain and crew RV Polarstern

Cruise leaders: Victor Smetacek, SWA Naqvi