BICEP

CROZEX

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Oceans 2025

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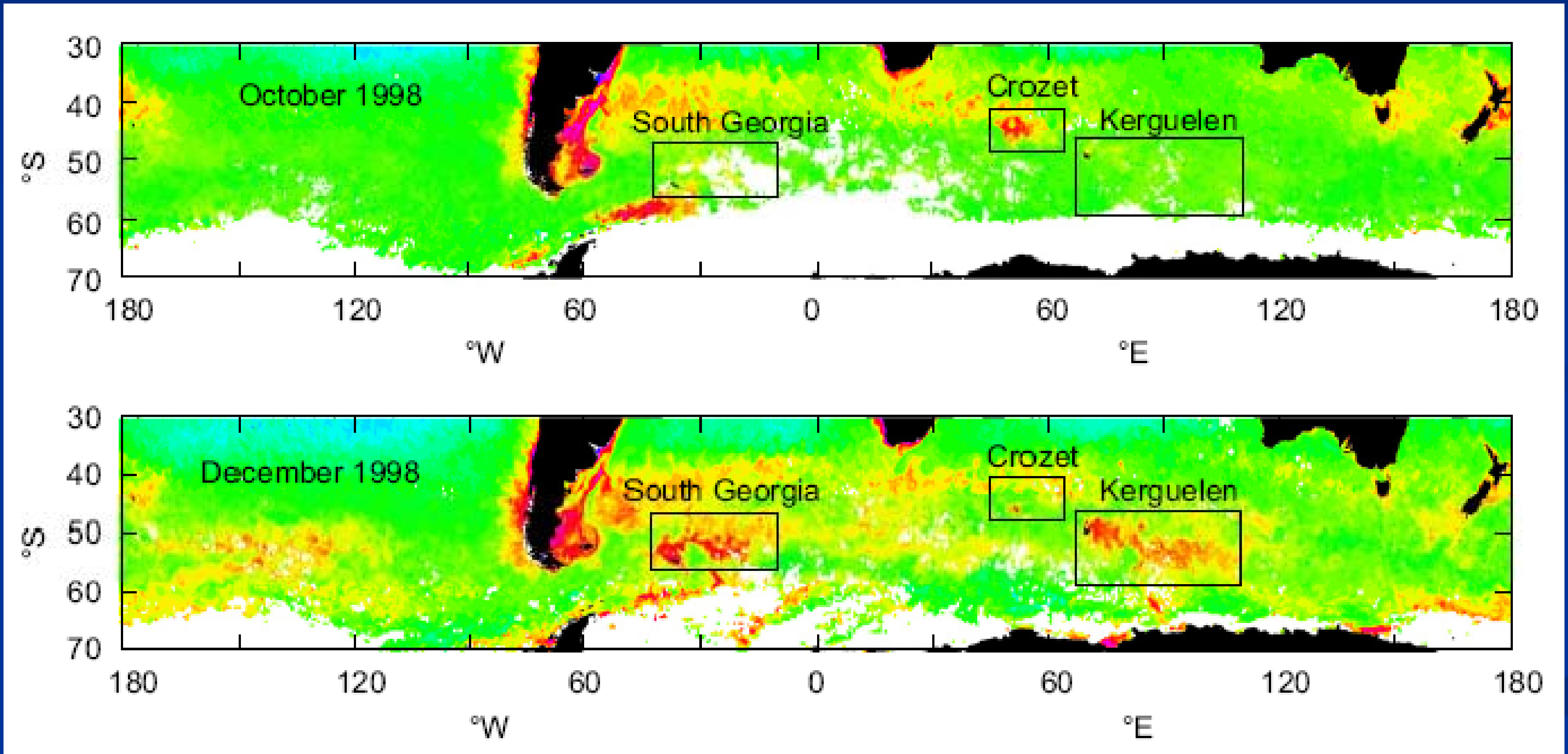
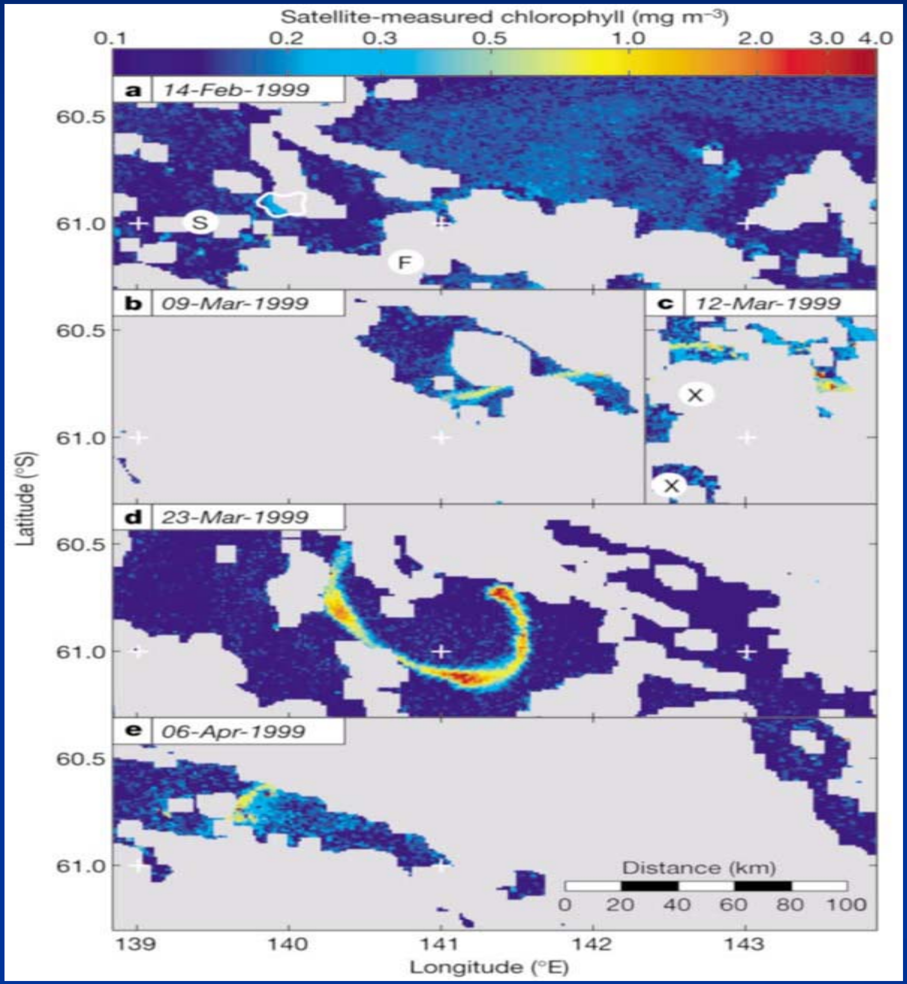
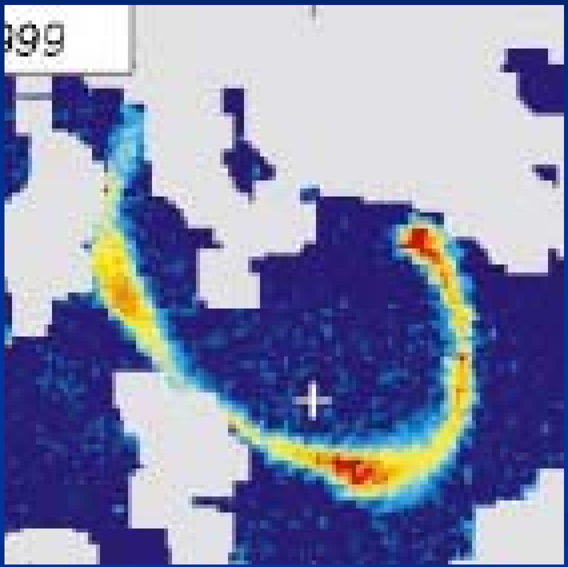
Natural Iron Fertilisation Experiments



Why did we do these natural experiments?





In 2003 we were asking

Are the conclusions from mesoscale experiments valid?

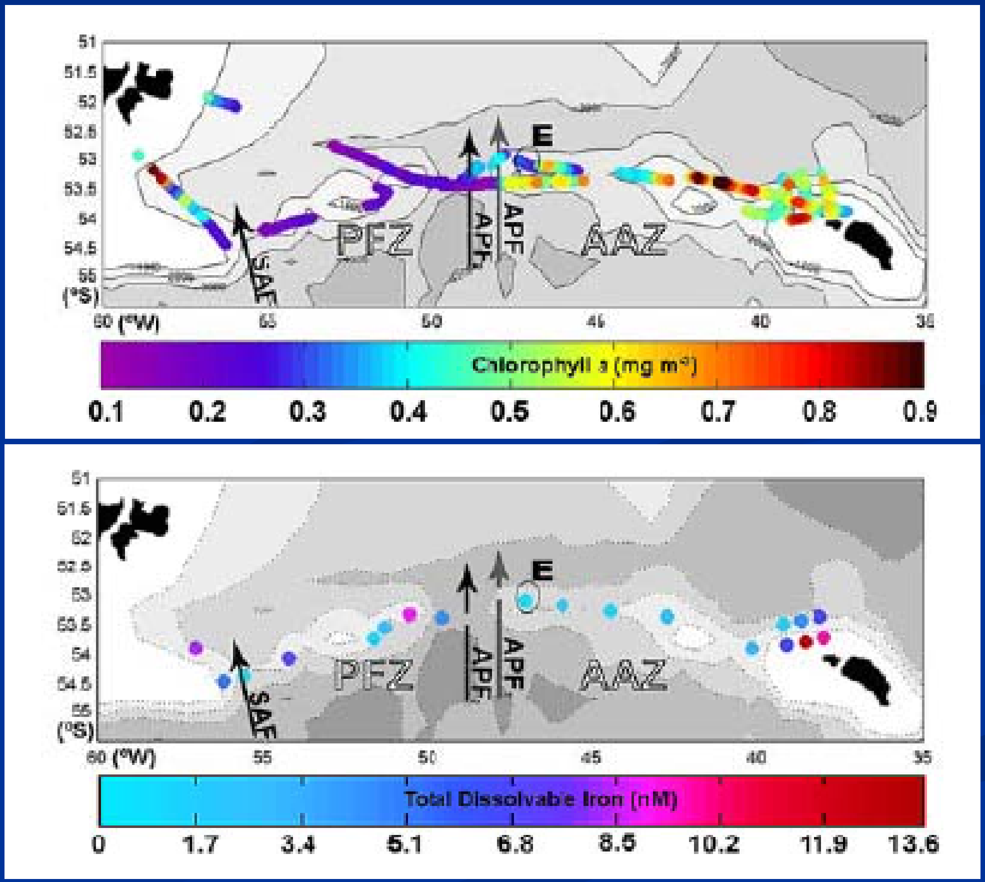
Do they apply to the real world?

Does enhanced export occur?

Abraham et al., Nature

Natural iron fertilisation Experiments - Why did we do them?

- Perceived to be a need for longer bigger more 'realistic' studies
- Very high biomass at South Georgia
- Suspicion that this was due to iron release
- Role of iron in regulating CO_2



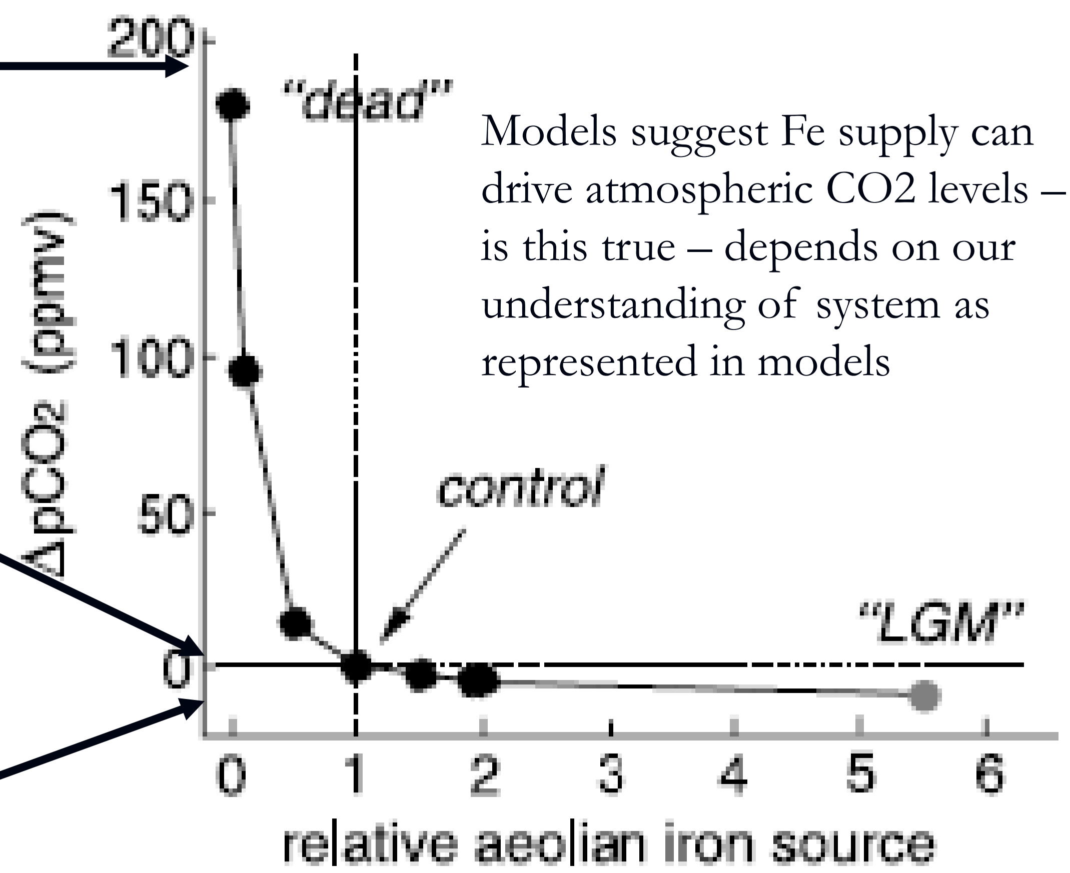
Holeton *et al.*, 2005

Iron Control of CO_2

No Iron

Current Iron

LGM Iron



Models suggest Fe supply can drive atmospheric CO2 levels – is this true – depends on our understanding of system as represented in models

Parekh et al., 2006, GRL

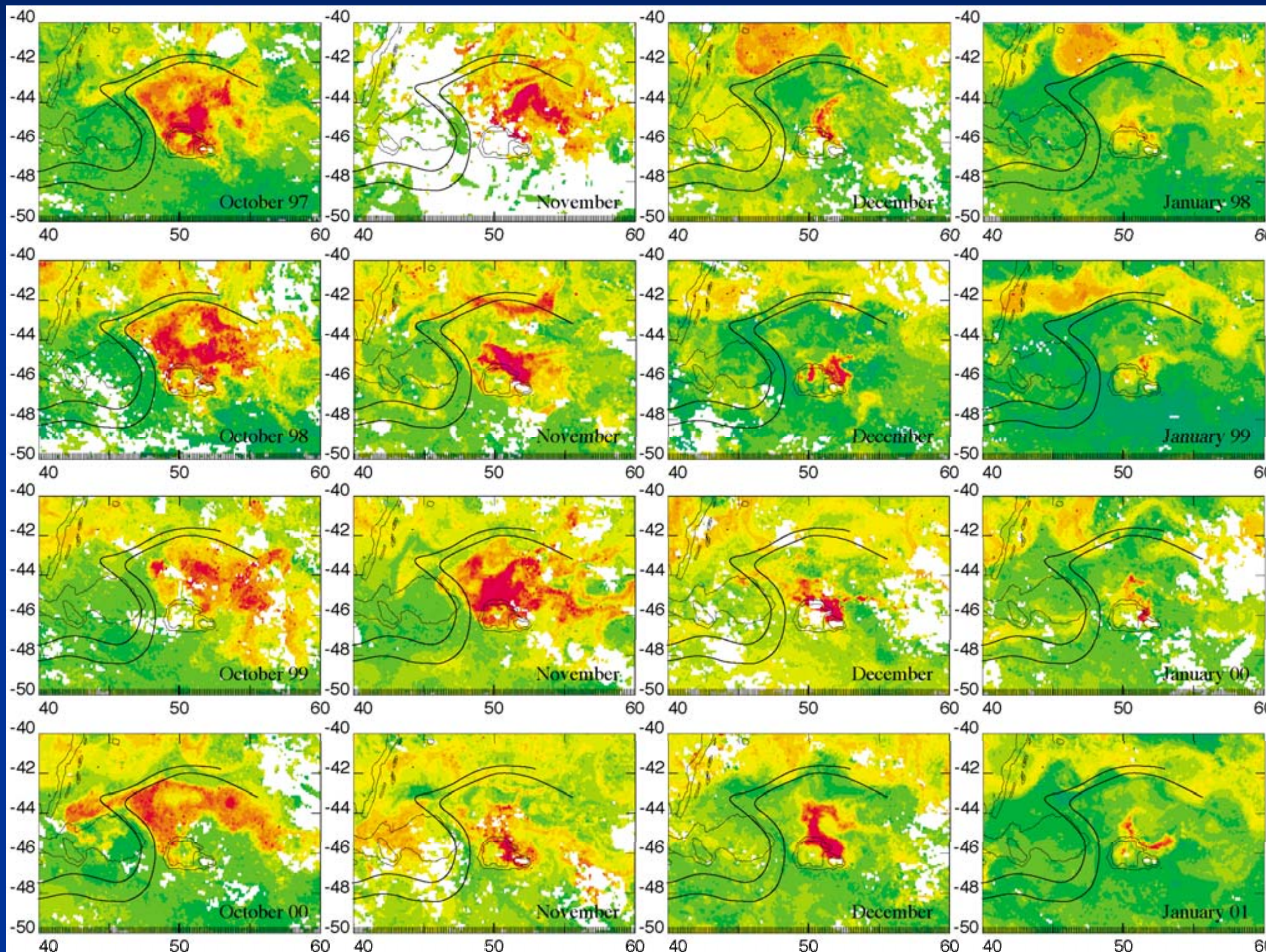
Why CROZEX – Regular, Repeatable bloom

97-98

98-99

99-00

00-01



October November December January

Why CROZEX – Constraint of bloom by circulation and topography

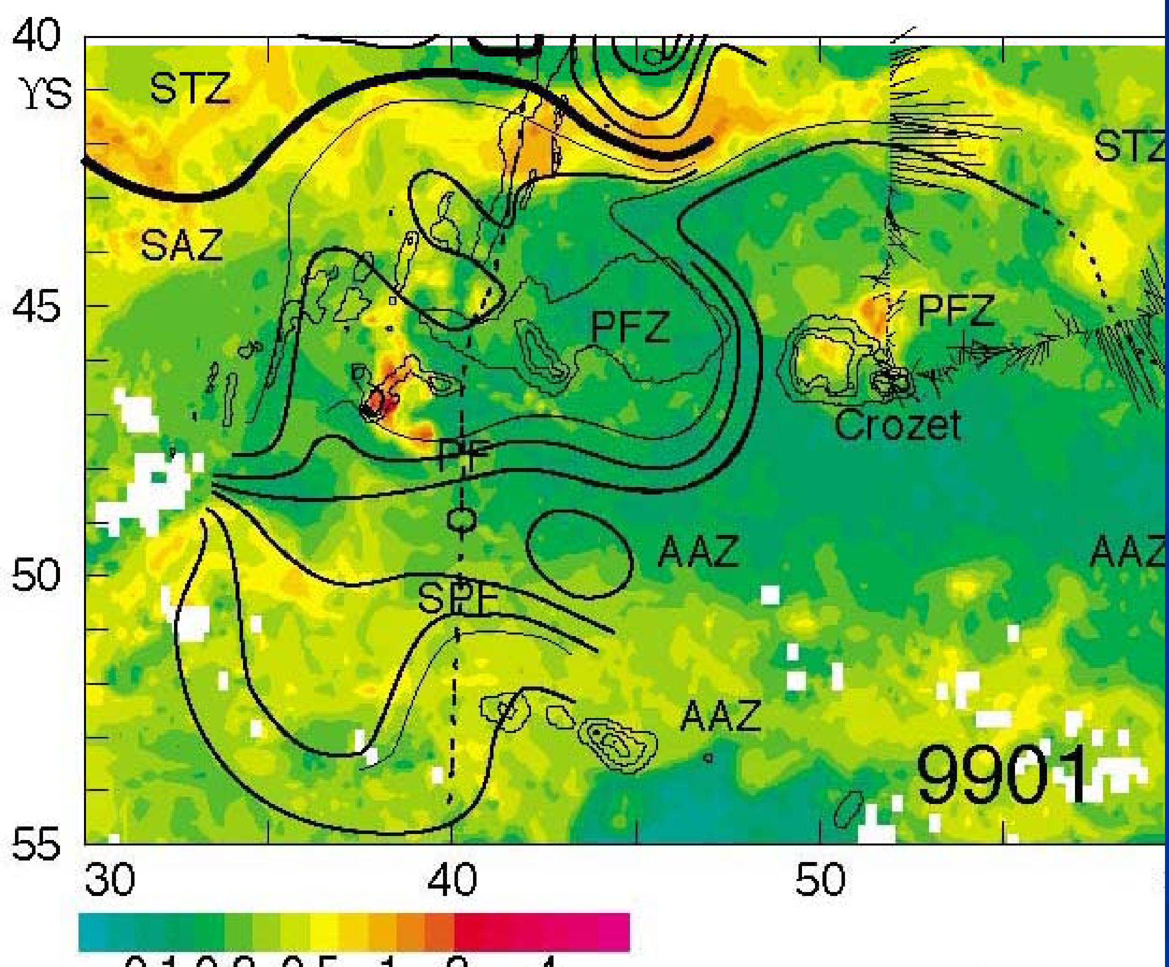
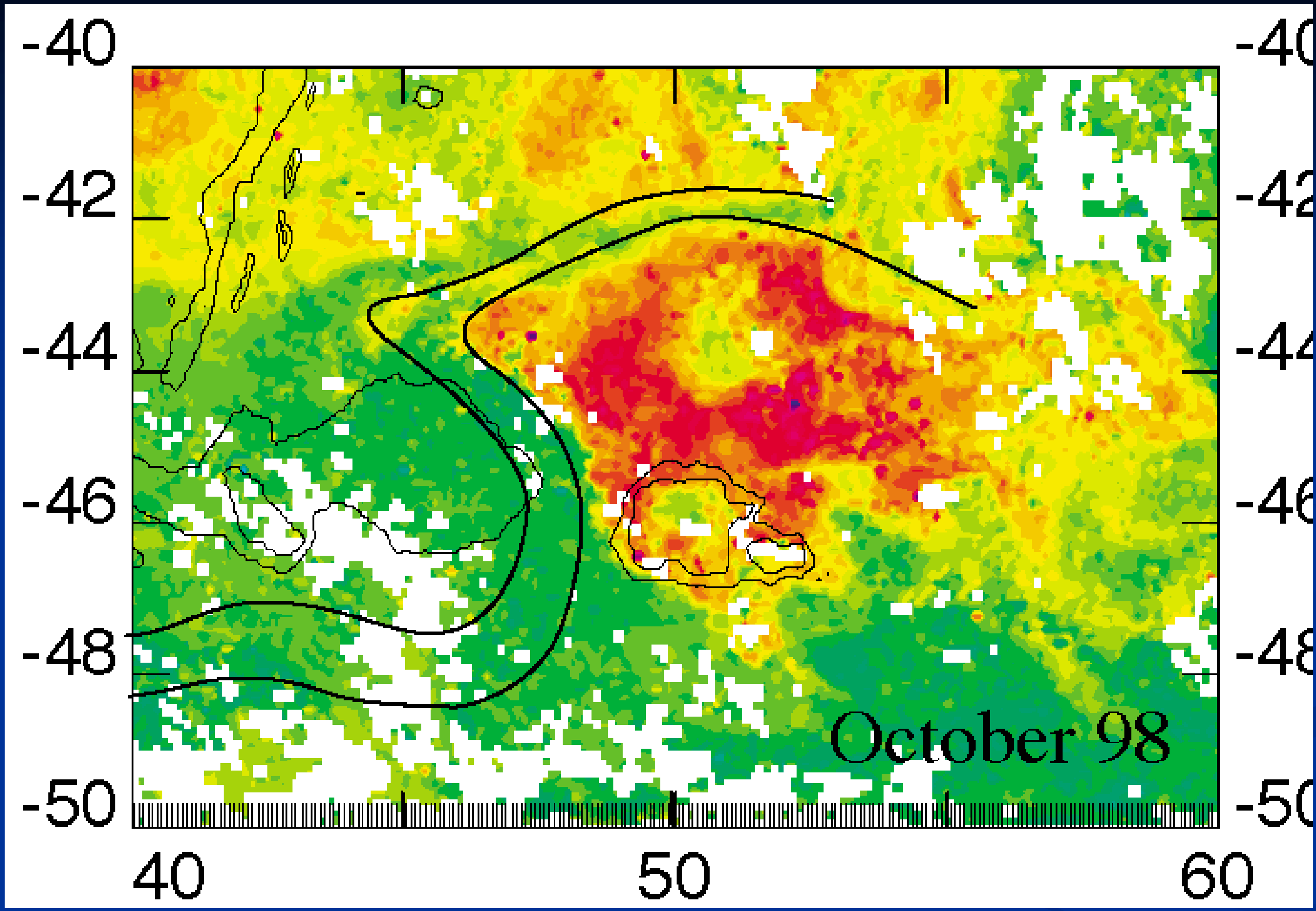


Fig. 5



By early 2000s we had a mental picture of

1) biomass distribution being driven by low Fe water sweeping North across the plateau and becoming iron fertilised and

2) timing being due to mixed layer establishment

CROZEX

Planned in 2002 – 3, executed in 2004 – 5, worked up in 2005 – 7, main

results published 2009

7 Sub projects

Circulation, trace metal chemistry, plankton biology (zoo, phyto, bacterio), carbon export, modelling, benthic biology, paleoceanography

2 Cruises

October - December 2004, December 2004 - January 2005

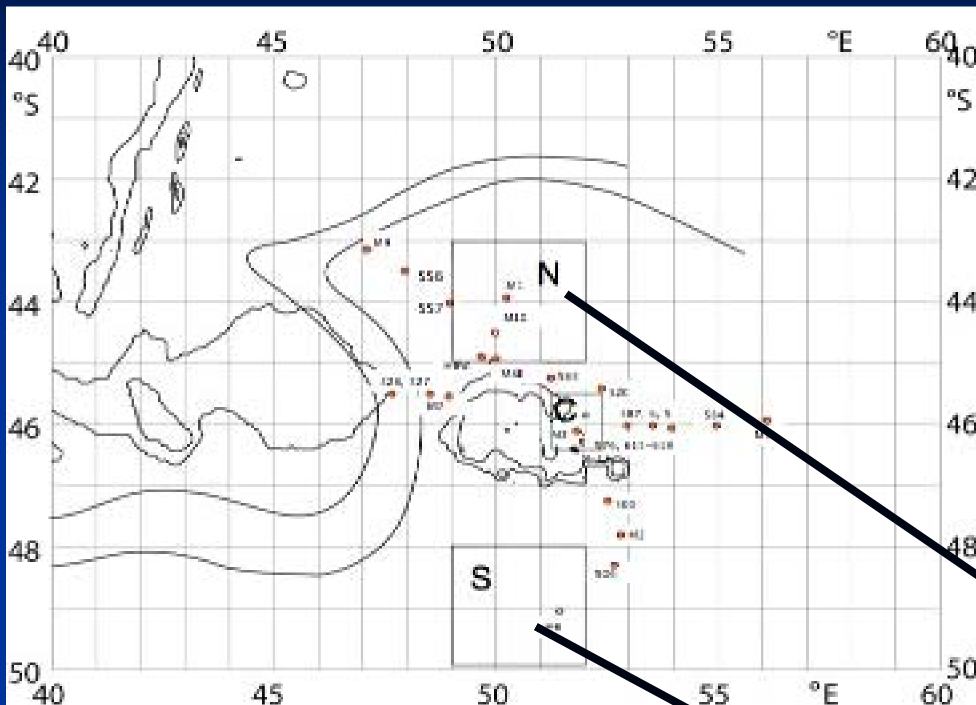
EVEN WITH TWO CRUISES WE COULD NOT CAPTURE THE WHOLE SEASONAL CYCLE BOTH N AND S OF ISLANDS

MADE DECISION TO TARGET END OF BLOOM WHEN EXPORT WOULD OCCUR

Results from Crozex

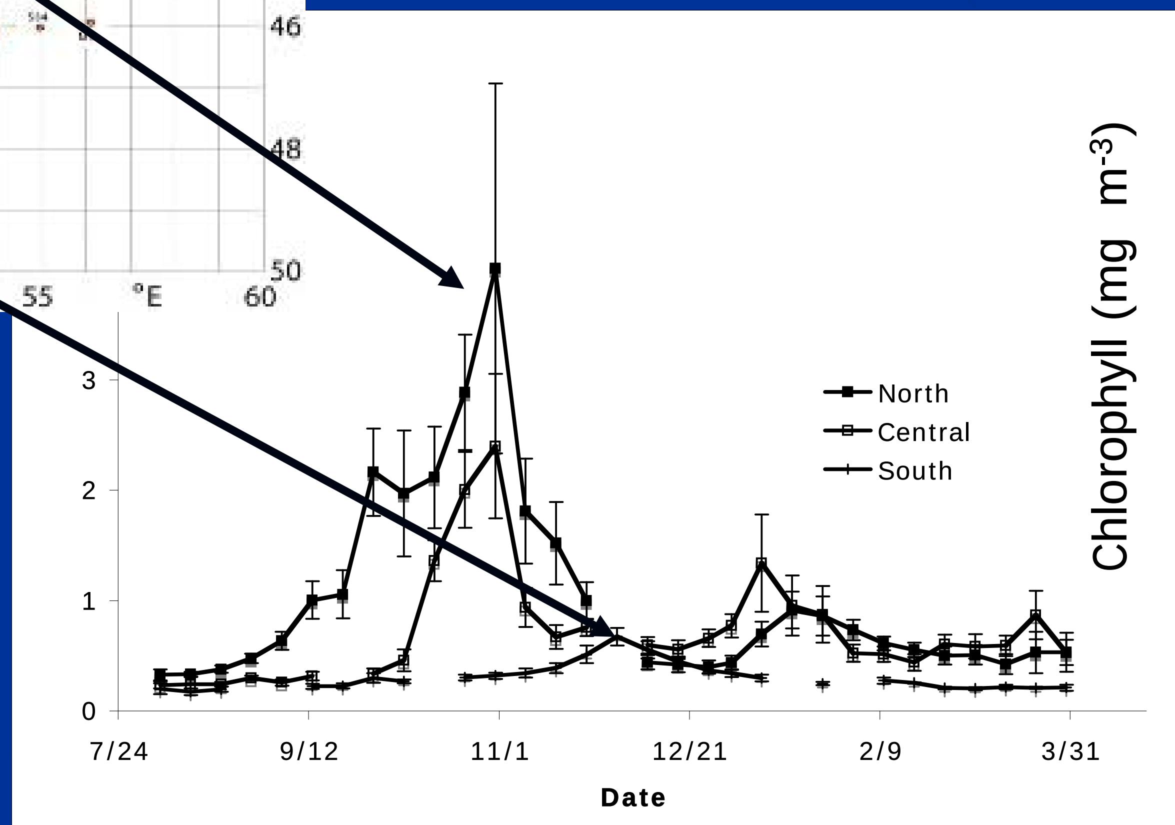
- 1. Chlorophyll
- 2. Iron Supply
- 3. Carbon Export

Time series of chlorophyll, Venables *et al.*, 2007



Large Long Early bloom in N

4 mgChl/m3

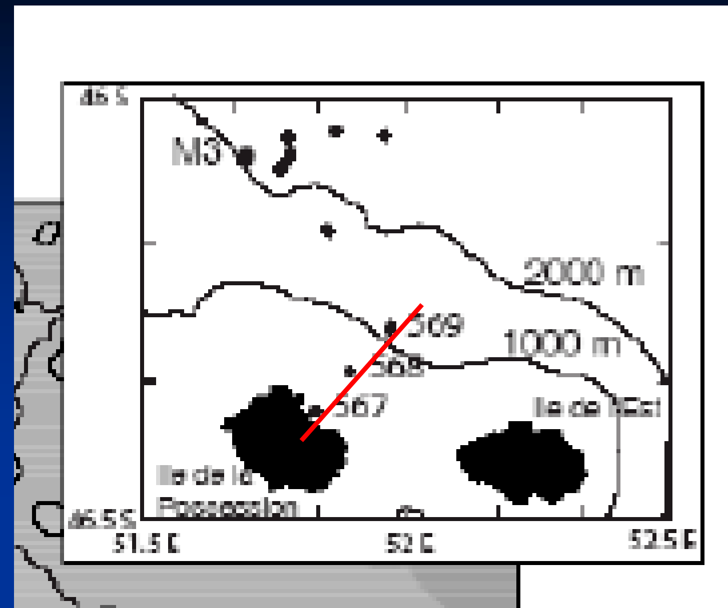


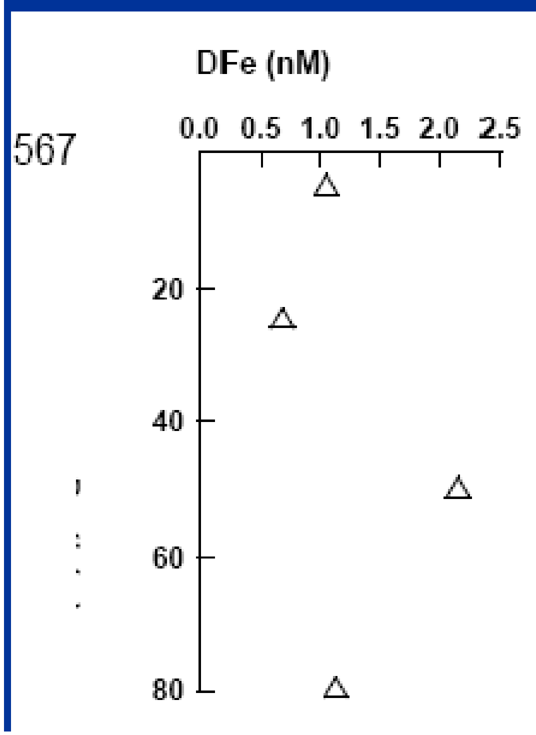
Small Short Late bloom in S (after 1st leg)

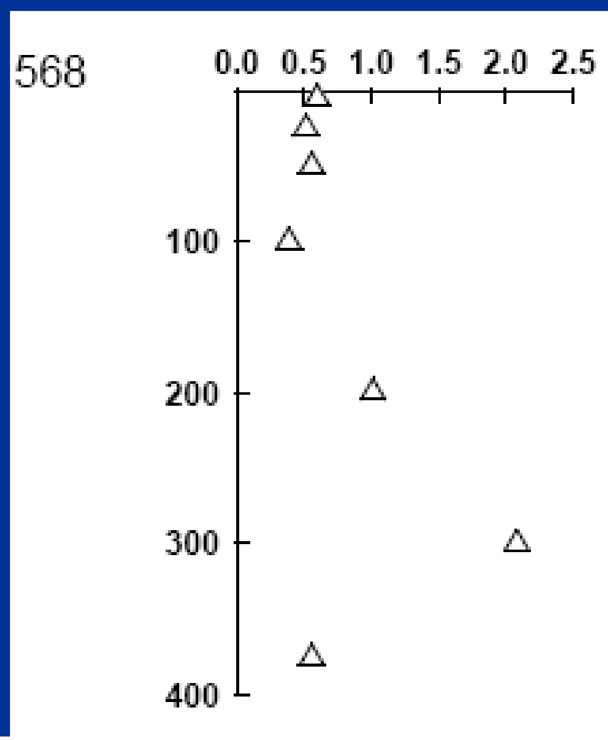
0.5 mgChl/m3

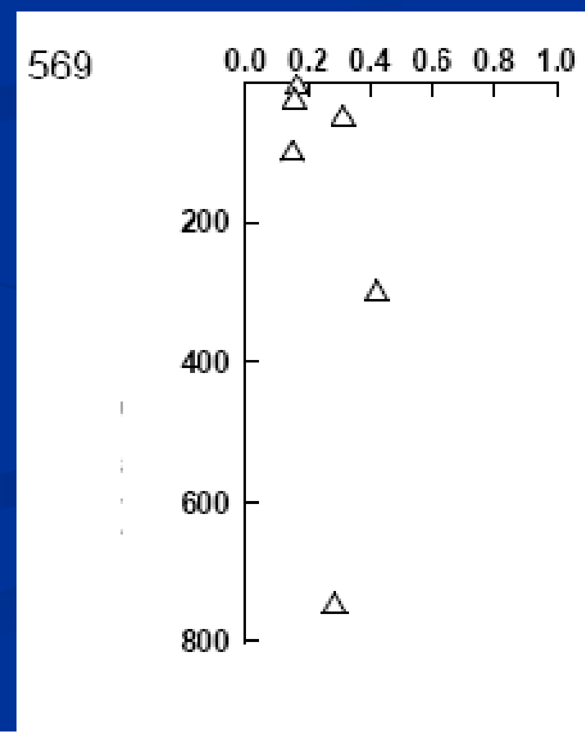
Fe observations

Planquette *et al.*, 2007

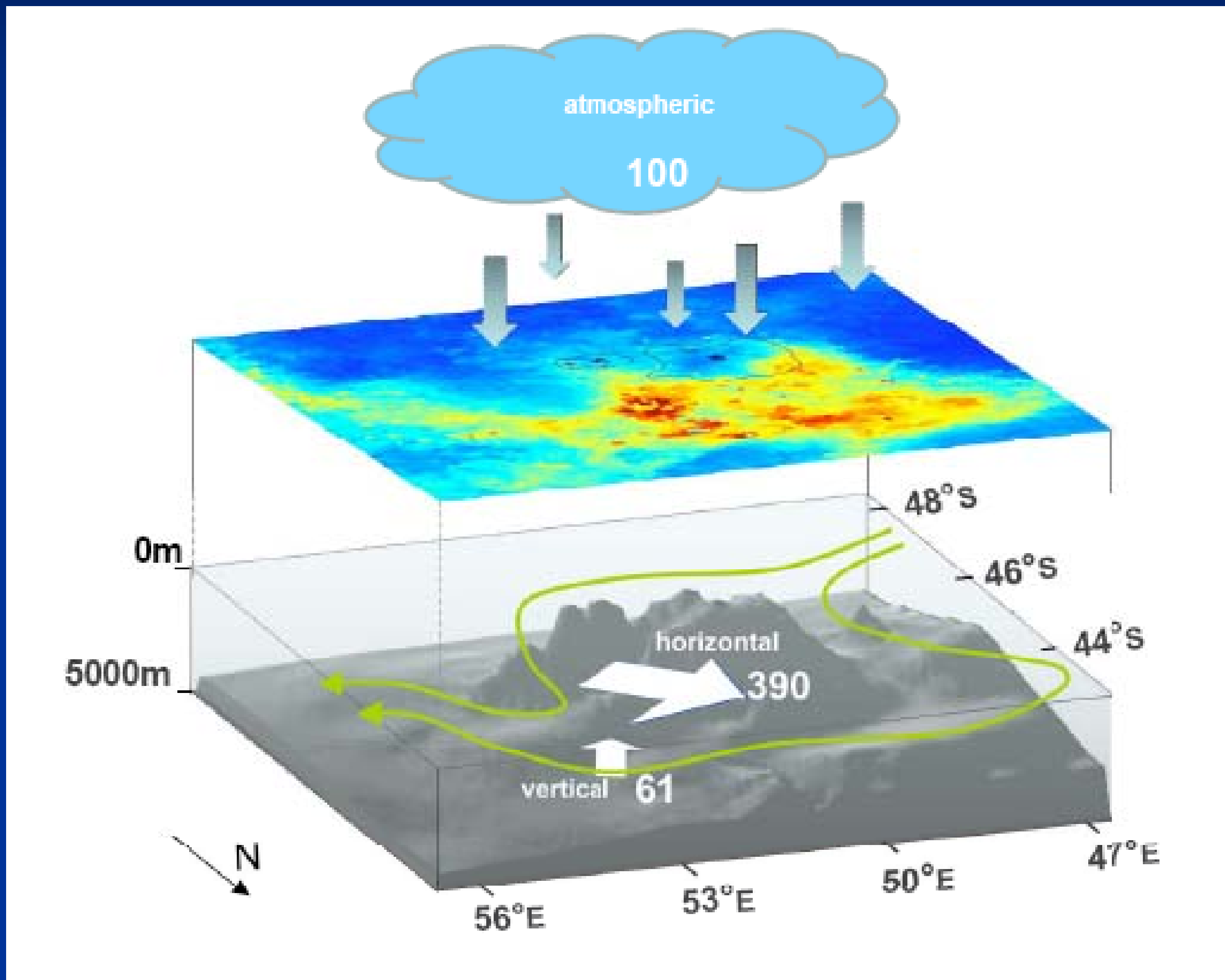






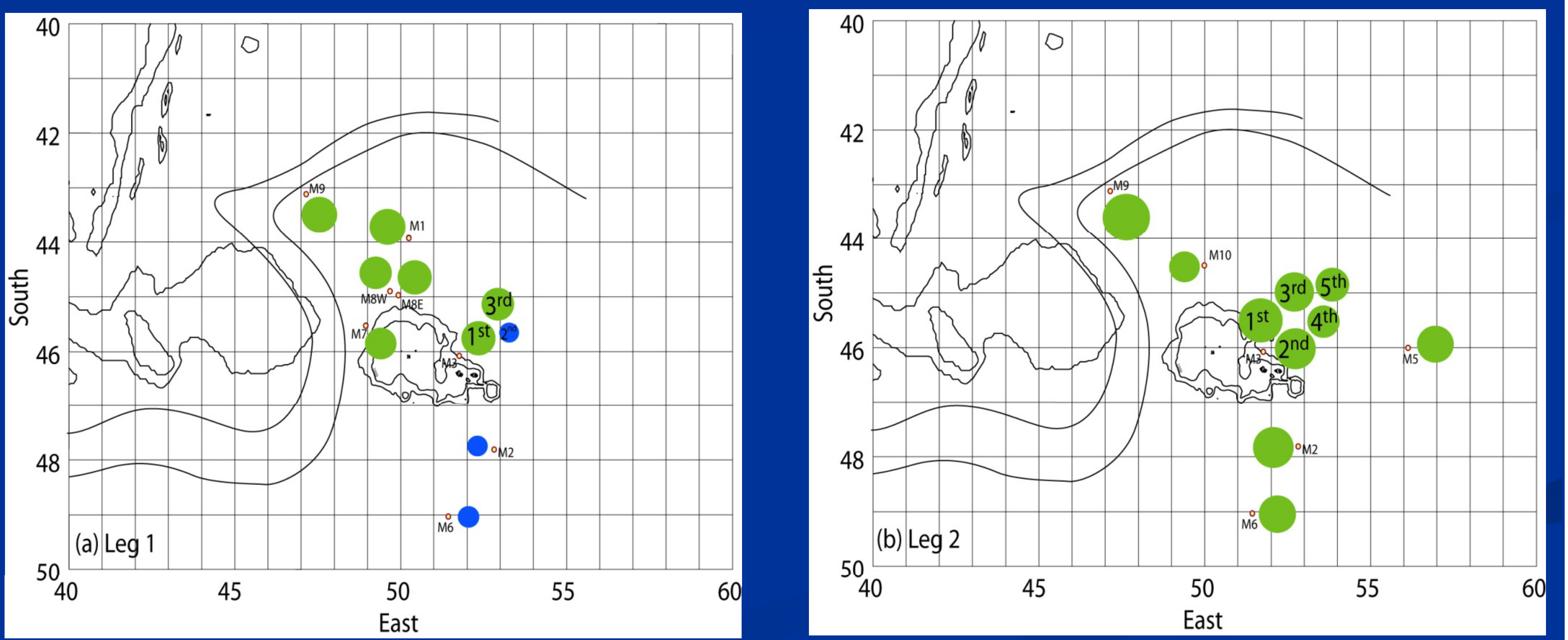


Iron budget for Crozet system (nmol m^{-2} d^{-1})
Planquette *et al.*, 2007

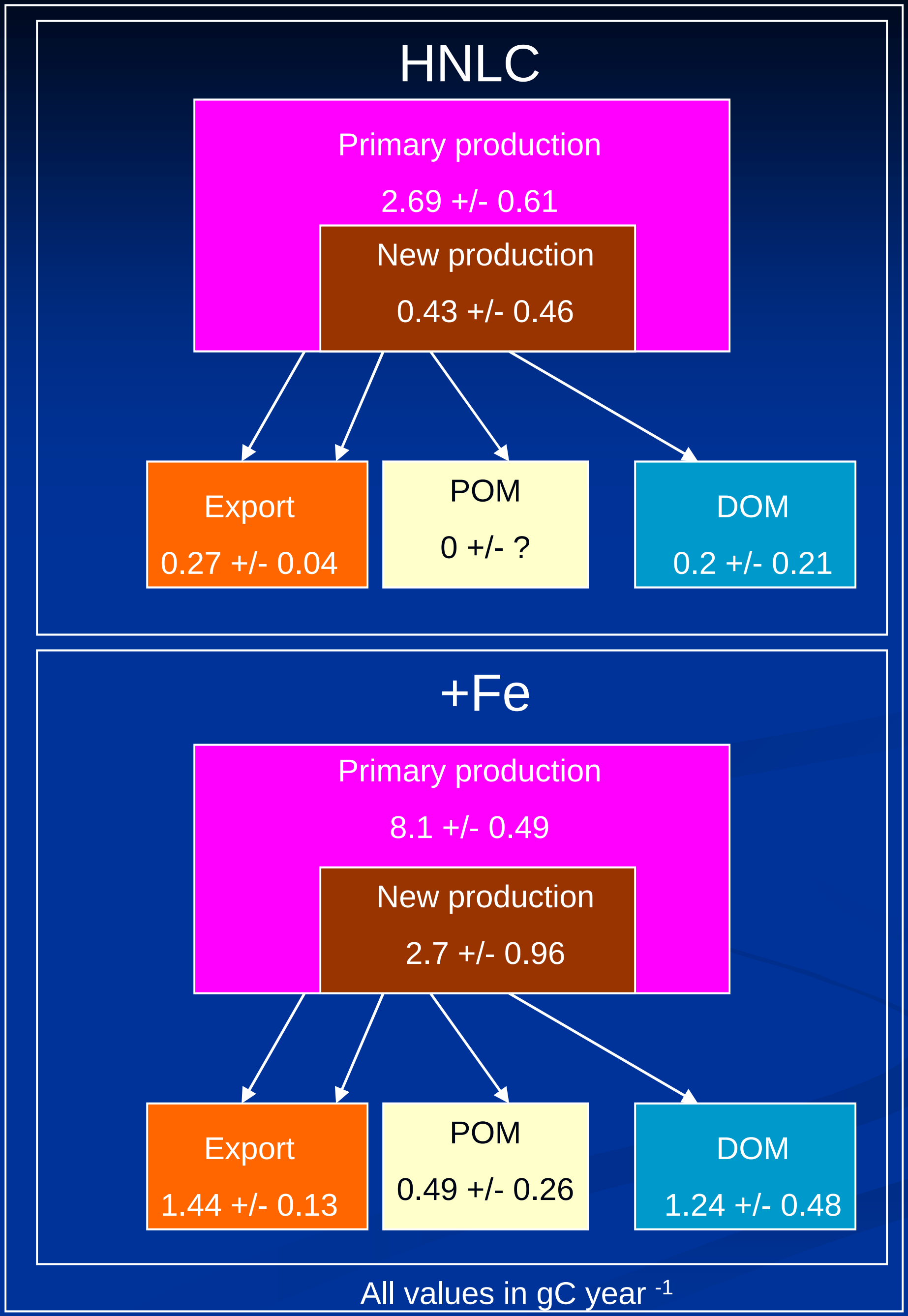


^{234}Th derived export rates

- Leg 1 High N, low S - but S bloom had not occurred
- Leg II High everywhere
- Post bloom export rate is insensitive to size of bloom



Morris et al., 2007



Morris and Sanders, in press

Flux at 100m extrapolated to 200m using b = 0.99

	Carbon (mmol m^{-2} y^{-1})		C/Fe‖ (mol mol^{-1})
	+Fe (fertilized)	−Fe (HNLC)	
^{234}Th via Si* at 100 m	960	290	17,190
Range	626–1,252	166–415	5,420–60,360
Deep flux† at 3,000 m	25.0	7.1	—
Best estimate‡	28.9	11.6	440
Range‡	25.0–34.2	7.1–17.4	195–1,506
Core top§	9.3 ± 0.5	4.5 ± 0.4	123
Interpolated flux at 150 m¶	642	194	11,487
Interpolated flux at 200 m¶	483	146	8,641

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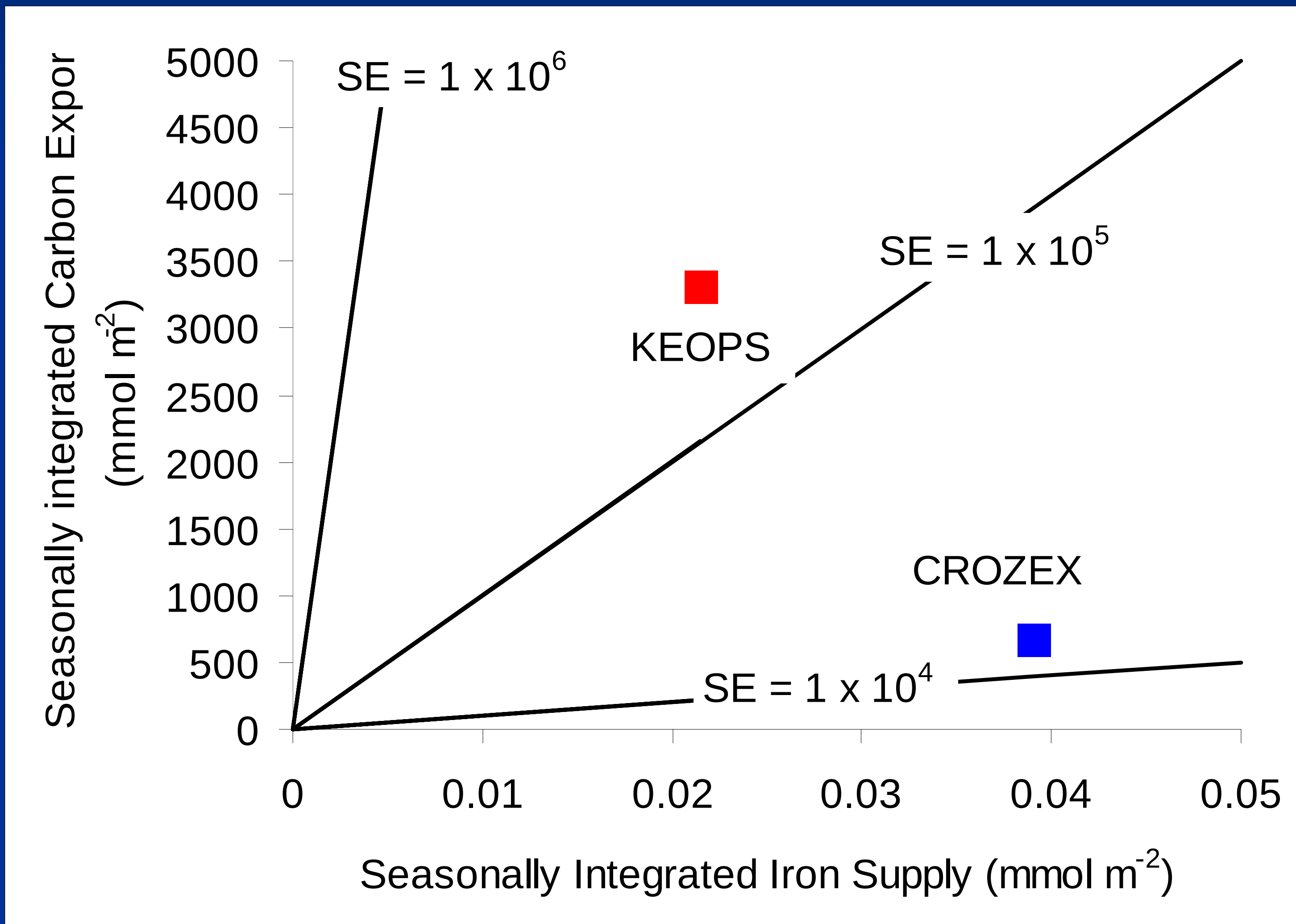
Sequestration efficiency SE – Carbon exported per Fe added

$$\frac{\text{(+Fe C export at 200m – HNLC C export at 200m)}}{\text{iron supply}}$$

= 8641 mol/mol

The SE – links supply of biolimiting nutrient to key ecosystem service



Why are the numbers different

- H1 – systems are really different

	CROZEX[4]	KEOPS[8]
Location	44°S 50°E South of SubAntarctic Front	50°S 73°E South of Polar Front
Area of bloom	300 km x 400 km	300 km x 400 km
Water depth	3000 m	500 m
Temperature in bloom	6°C[34]	3.5°C[35]
Circulation	similar[c], weak[13]	similar[c], weak[35]
Peak chl a	6 mg chl a m^{-3}	3 mg chl a m^{-3}
Bloom duration (> 1 mg chl m^{-3})	10 weeks 13 Sep - 24 Nov 2004	11 weeks 19 Nov 2004 - 2 Feb 2005
Phaeocystis	dominated late bloom[15]	ship-board experiments only[36]
Silicate[d] in bloom	0.1 - 2 μM	1 - 2 μM
Silicate[d] in HNLC area	18 μM (Nov), < 4 μM (Jan)	25 μM[37]
Nitrate[d] in bloom	16 - 24 μM	> 20 μM[37]
Nitrate[d] in HNLC area	23 - 25 μM	29 μM

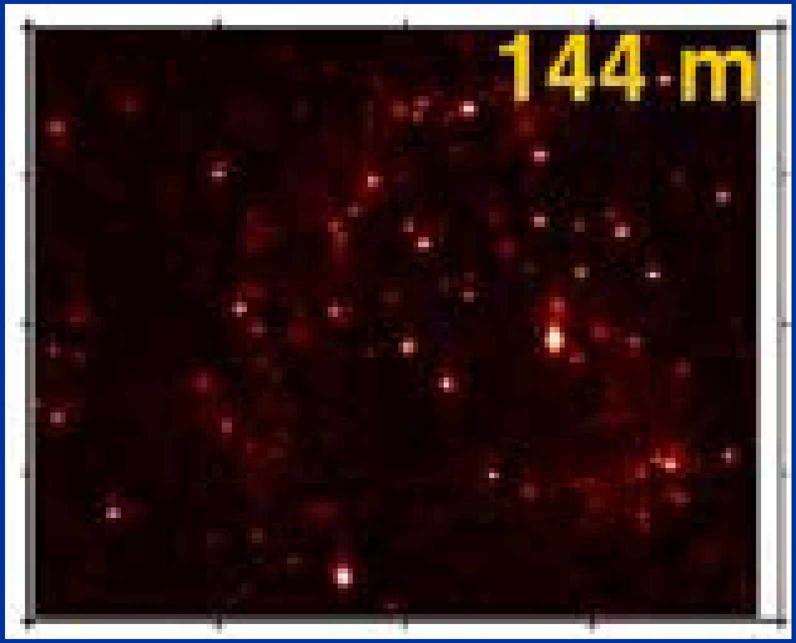
Pollard et al., 2009, Nature

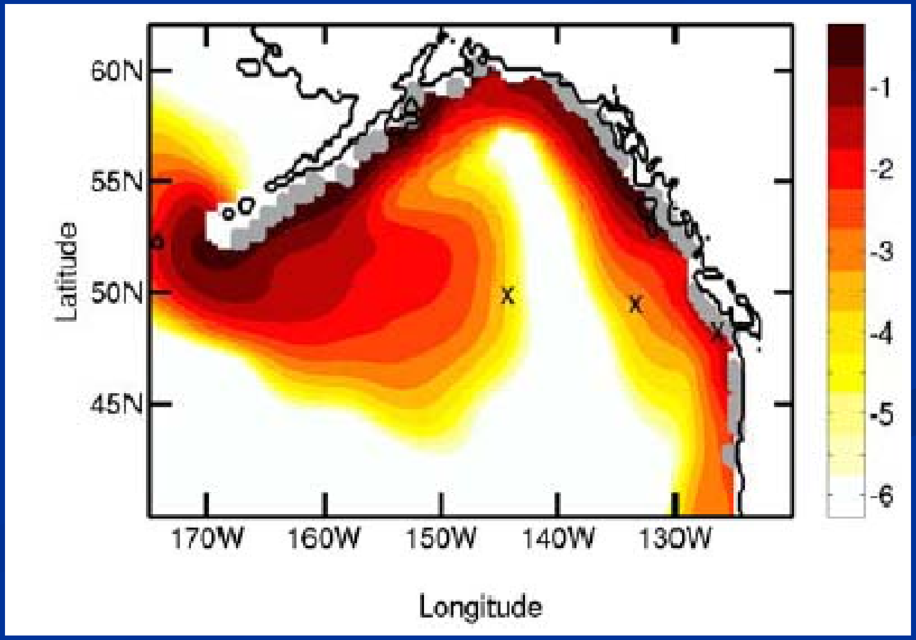
Why are numbers so different

- H2 – one or both of the terms at one or both of the sites has been incorrectly estimated
- In my view the most likely scenario
- Critically examine key Crozex calculations and identify solutions
- Then bid for CROZEX II

Problems I – Iron supply

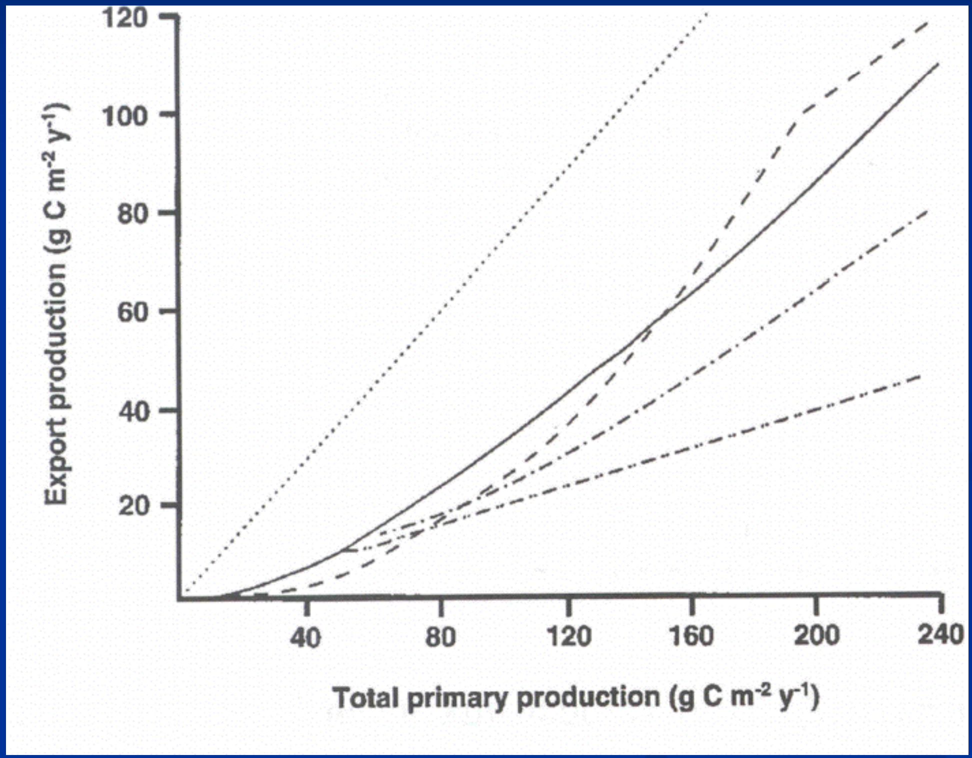
- Only offshore iron flux in dissolved phase considered - What if there is a major iron flux in the particulate phase and its bioavailable? – Lam *et al.*, N Pacific





Problems II – export numbers

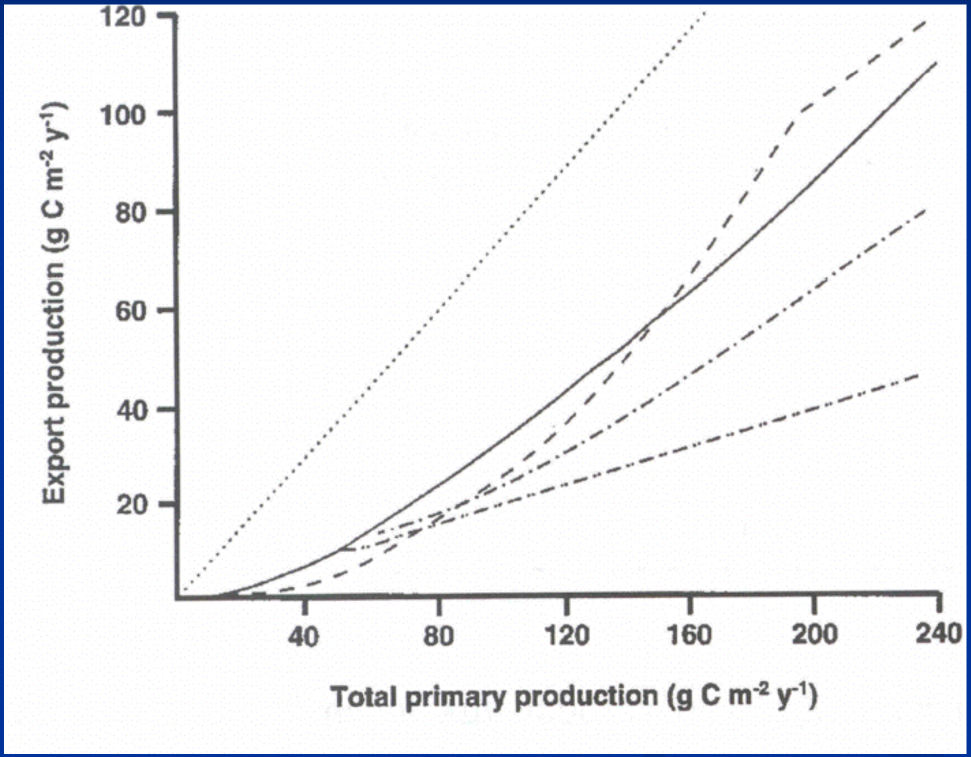
- In high productivity N instantaneous export was similar to low productivity S
- Seems counterintuitive
- More P, more bigger cells, more aggregation, more export



Suess (1980) (.........), Eppley & Petersen (1979) (- - - - -), Betzer et al. (1984) (-.-.-.-.-), Pace et al. (1987) (-..-..-..-) and Wassmann (1990) (-).

Problems II – export numbers

- Inconsistent with annual literature estimates (Wassman, 2004)
- But maybe its right (HBLE regimes)
- Maybe rate doesn't respond, just goes on for longer
- Did we miss high export rates at bloom peak



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Problem III – using a Martin curve to extrapolate from 100m to sequestration depth

Simplistic to assume there is a single value of b

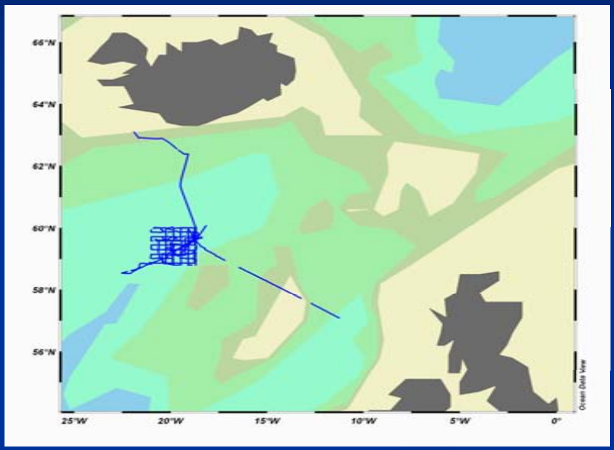
Marsay et al., in prep

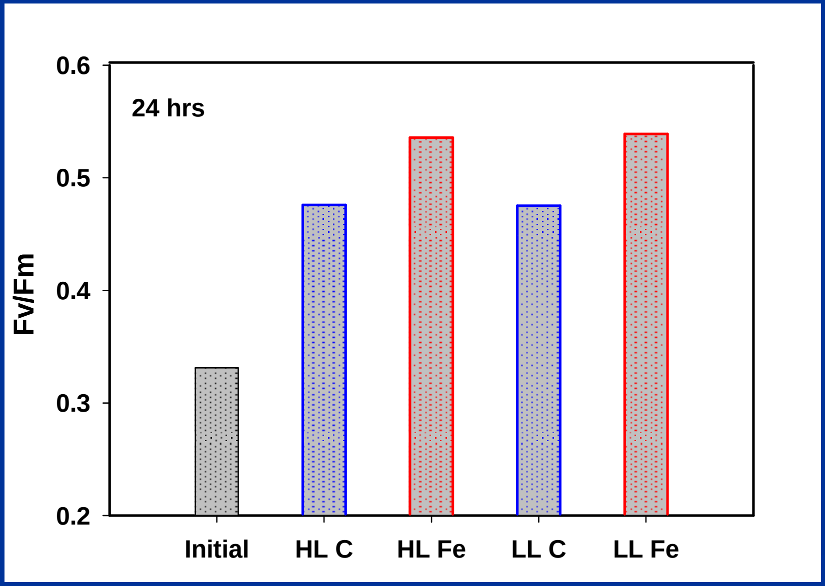
Three problems with CROZEX analysis

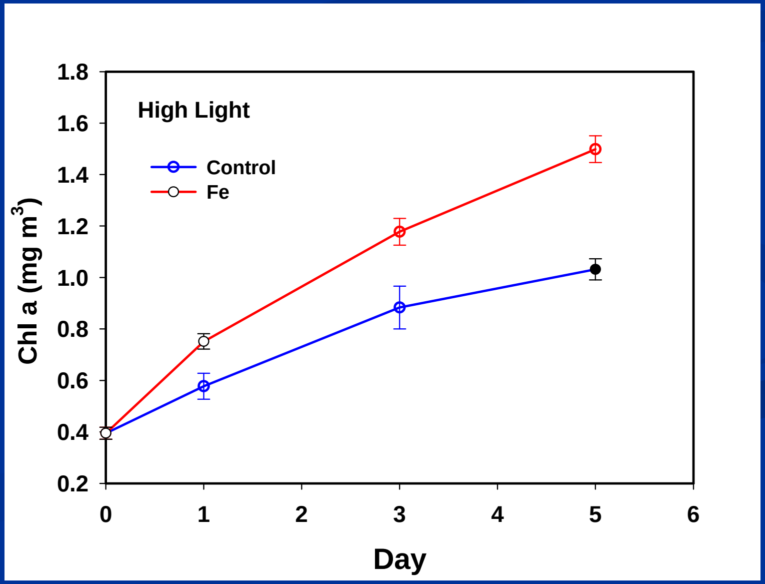
- Only considered dissolved iron
- Missed bloom peak – were export rates the same N and S after the bloom and the e ratio thus inversely related to P – seems unlikely but possible – HBLE regimes
- Used 2 point martin curve (100m and 3000m) to estimate flux at sequestration depth

How to fix these issues I

- Do the right experiments
- Find out if dust/ sand stimulates production
- Nielsdottir *et al.*, 1009



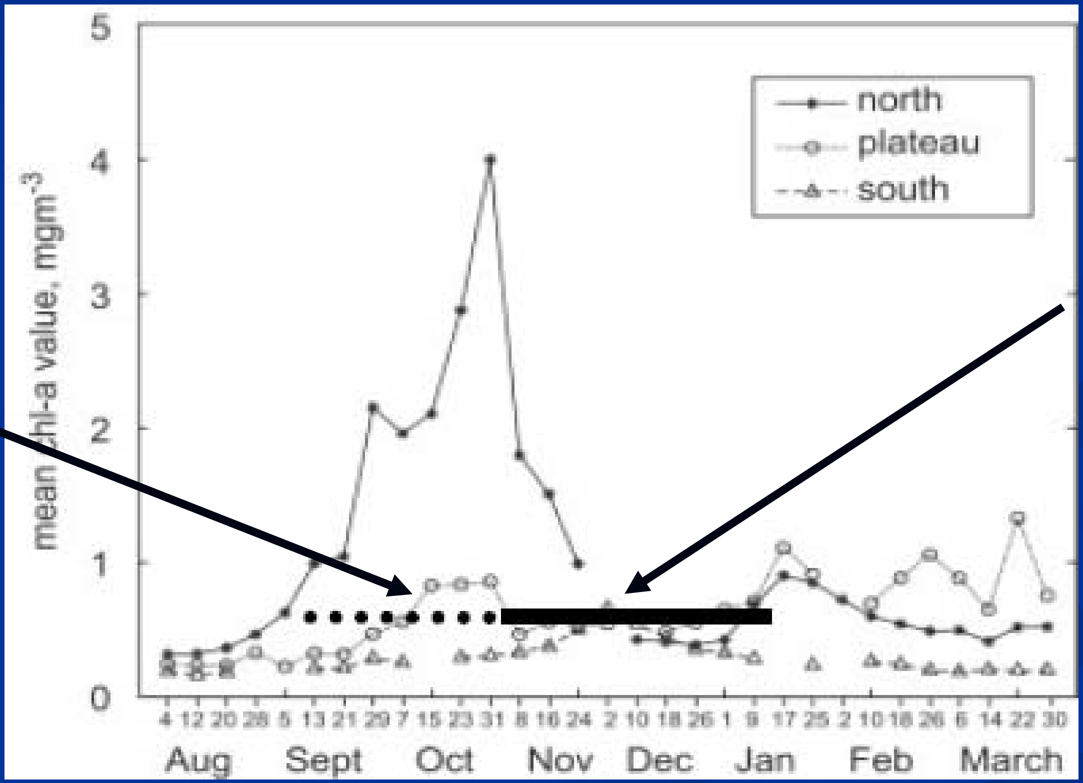




How to fix these issues II

- Go at the right time – when does e happen?

When we should go next time



When we went last time

How to fix these issues III

- Take the right kit and use it properly – obtain time series of e at sequestration depth

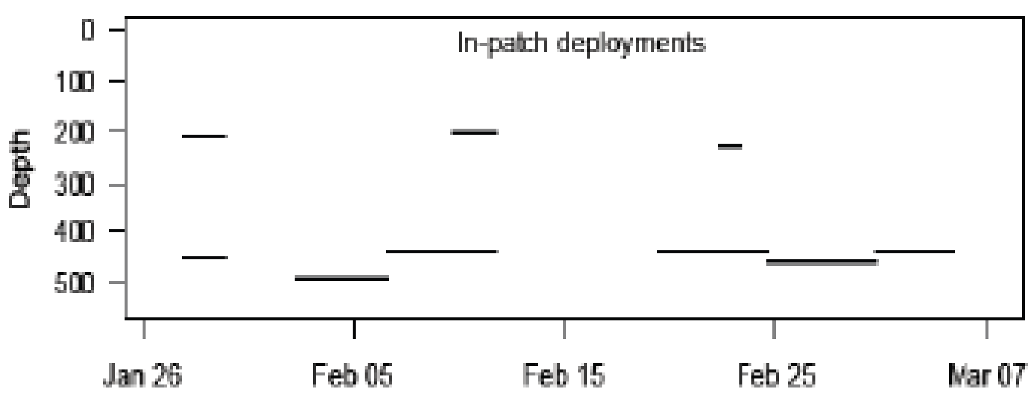


Figure 4. Pelagra deployment strategy employed on Lohafex. Our serial deployment strategy allowed nearly continuous observations at a single depth of ca 450m, complemented by occasional deployments at a shallower depth.

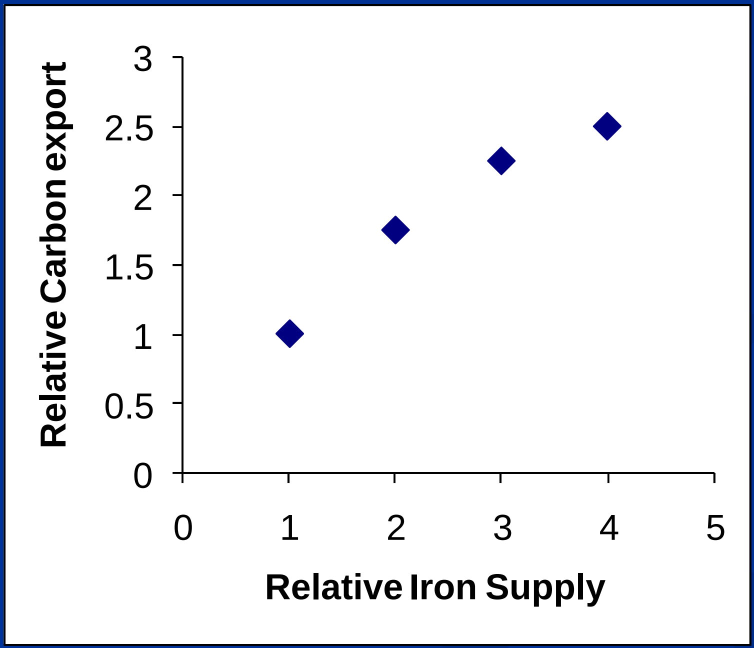
Patrick Martin, unpublished thesis work on LOHAFEX

How to do CROZEX better

- Consider the right iron pool - estimate bioavailability of particulate lithogenic iron
- Go at the right time – when export may be larger
- Measure export at the right depth

Benefits of redoing CROZEX

- Better quantification of linkage between limiting nutrient and ecosystem service
- But working at one Fe level inadequate
- Carbon export and iron supply do not have to be linearly related
- Export becomes saturated at high levels of iron supply (light or grazing control).
- System evolves such that at low iron levels it uses iron more efficiently.
- Need to test these biological ideas more robustly

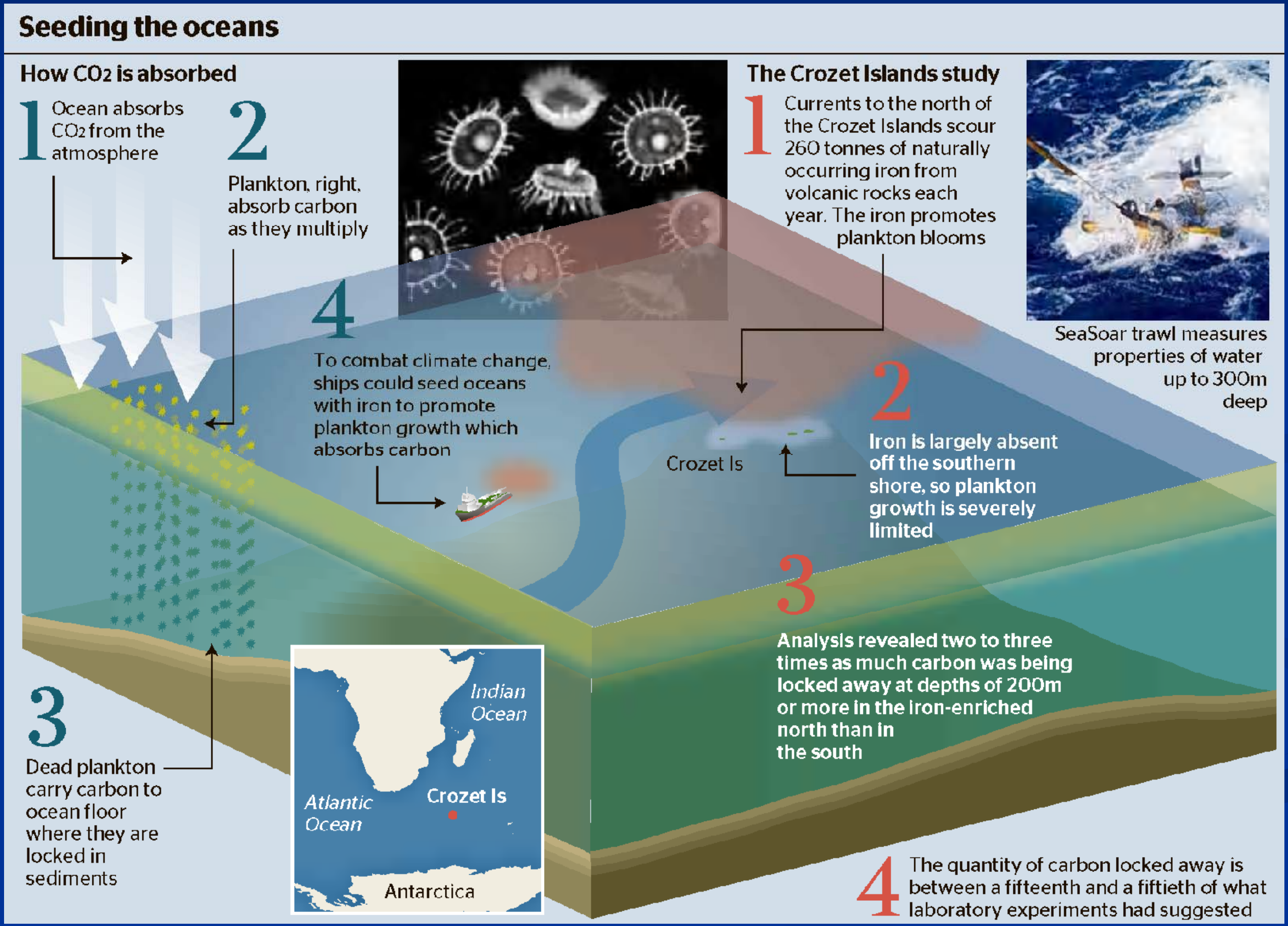


Iron stressed		Iron Replete

Low	Biomass & production	High
Small	Organism size	Large
Long	Food chain length	Short
High	Grazing pressure	Low
High	Fe regeneration rates	Low
Very low	Fe export	High
Low	C export	High

High??	Sequestration Efficiency (C exported/ Fe supplied)	Lower??

Benefits of redoing CROZEX – better information to pass impartial comment should an aspiring geoengineer decide to do this for profit



The Times, February 2009