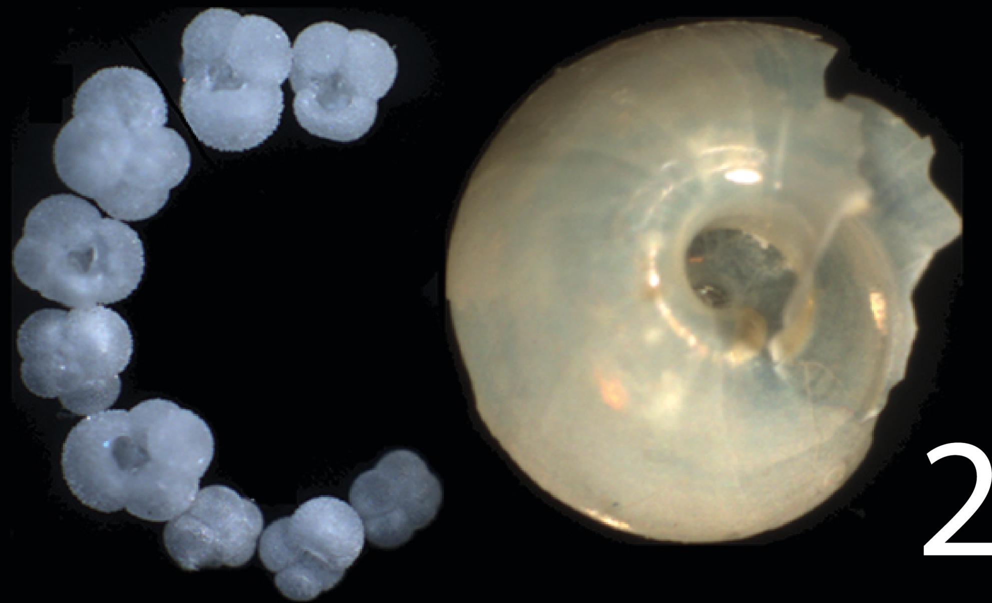
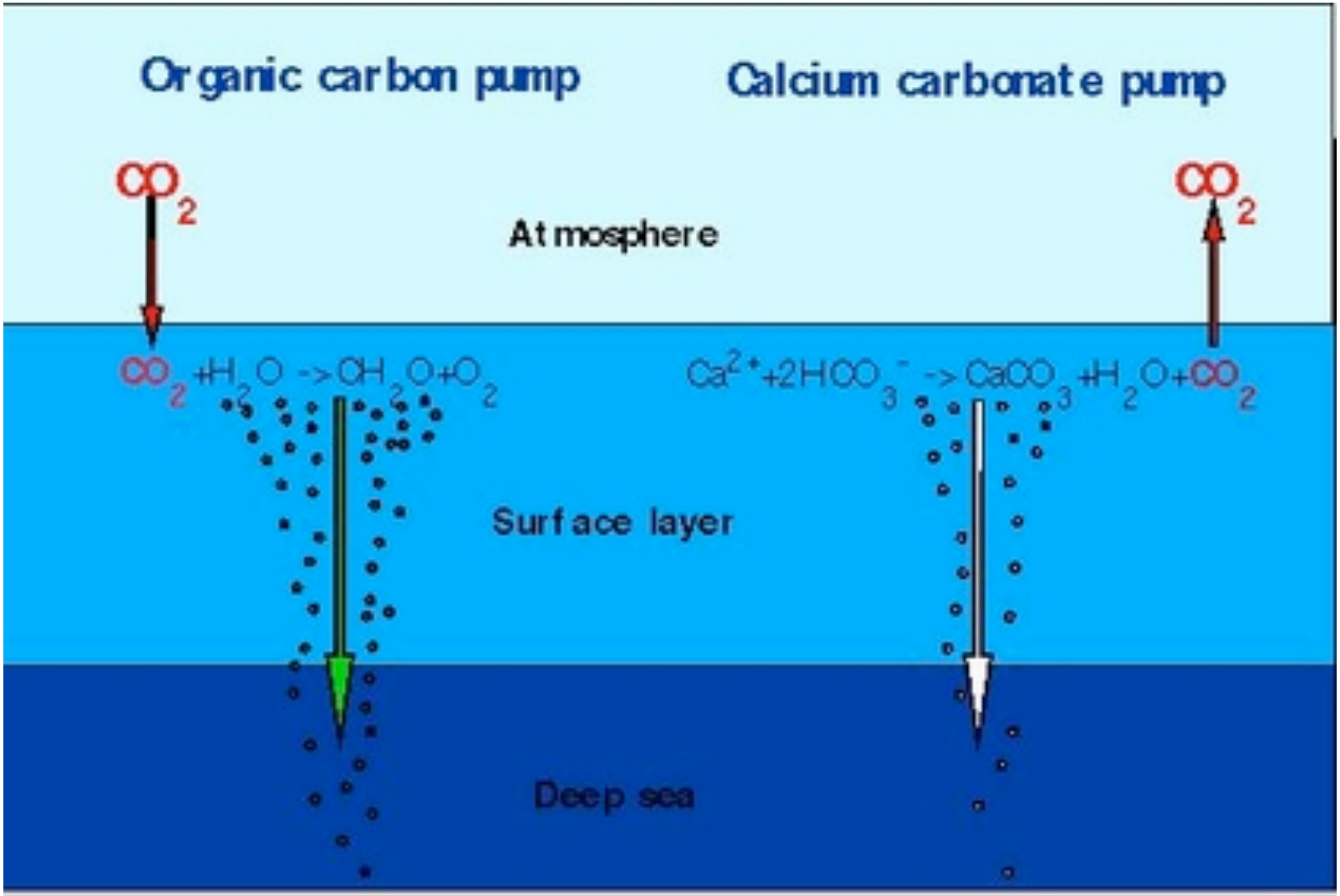
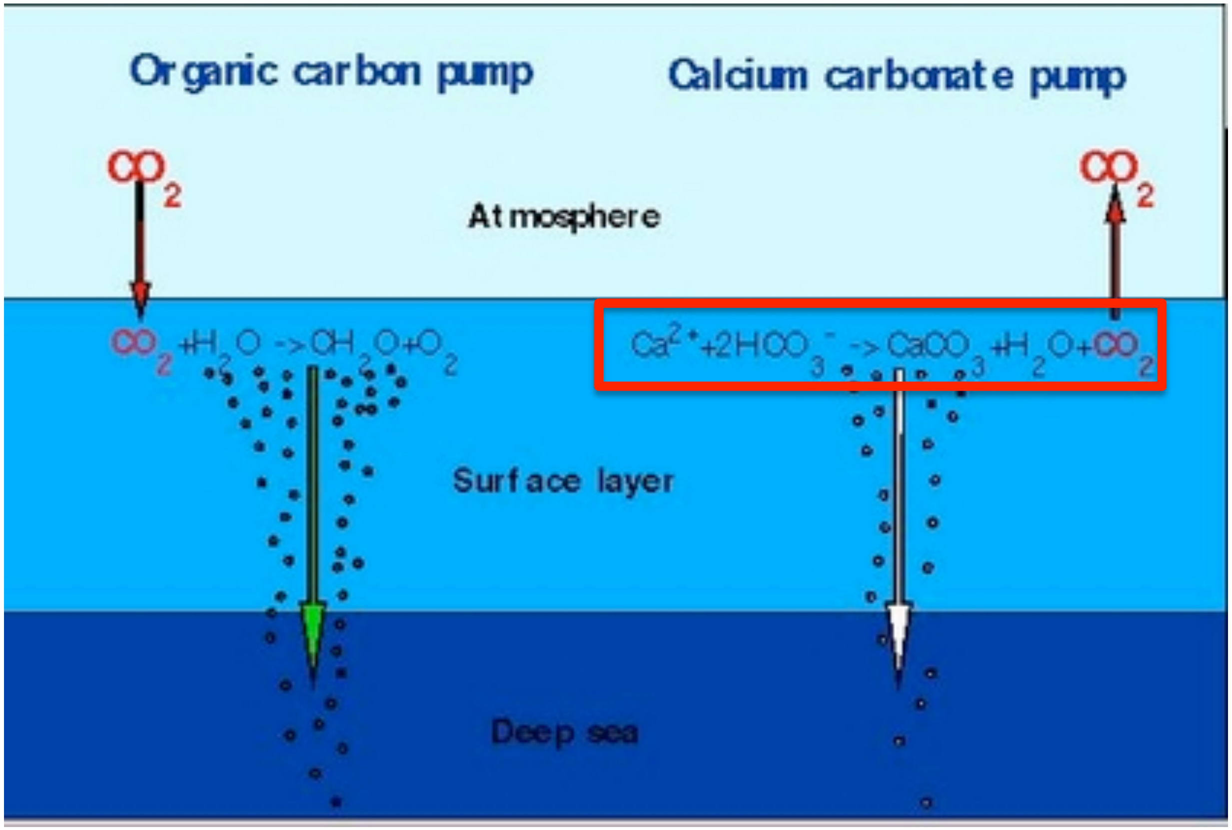
Carbonate counter pump stimulated by natural iron fertilization in the Polar Frontal Zone



Ian Salter*, Ralf Schiebel, Patrizia Ziveri, Aurore Movellan, Richard Lampitt, George Wolff

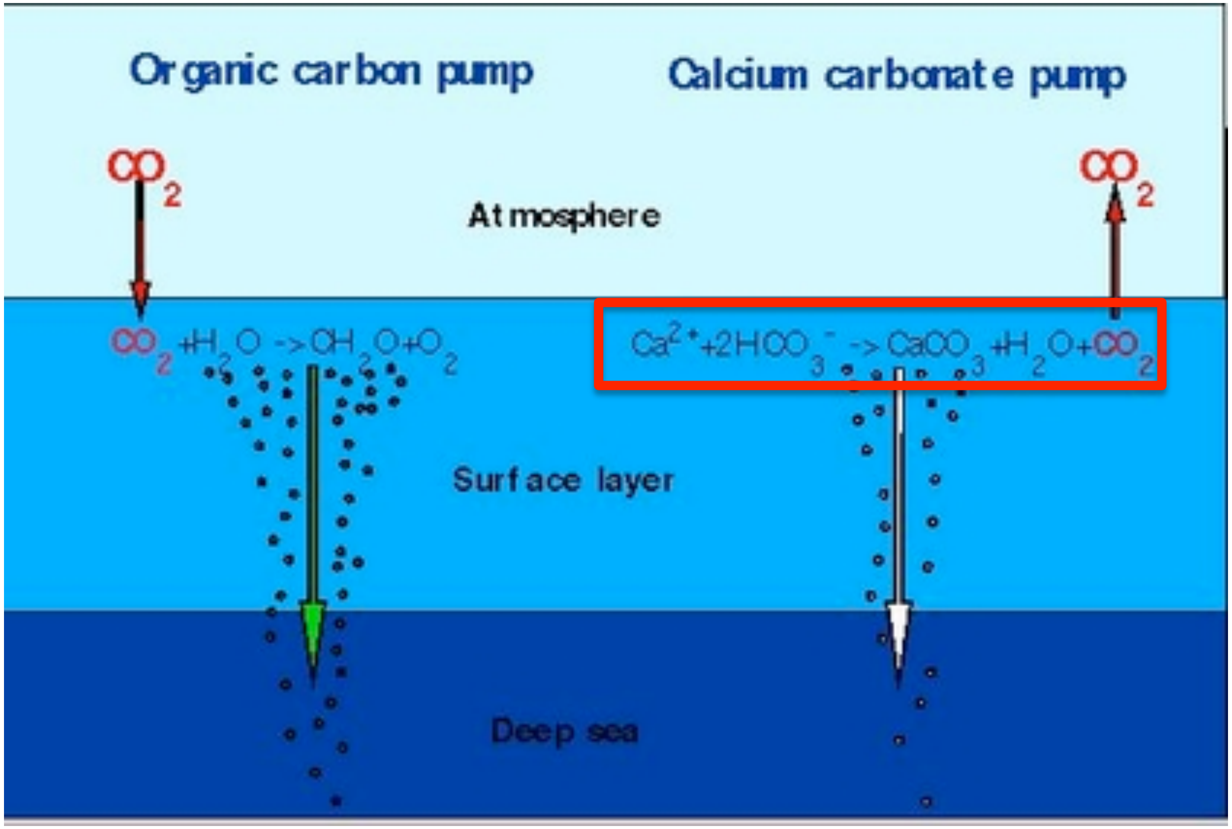
**Alfred-Wegner-Institute for Polar and Marine Science, Bremerhaven, Germany*


Organic carbon pump
Calcium carbonate pump
CO2
CO2
Atmosphere
CO2+H2O ->CH2O+O2
Ca2++2HCO3- -> CaCO3+H2O+CO2
Surface layer
Deep sea

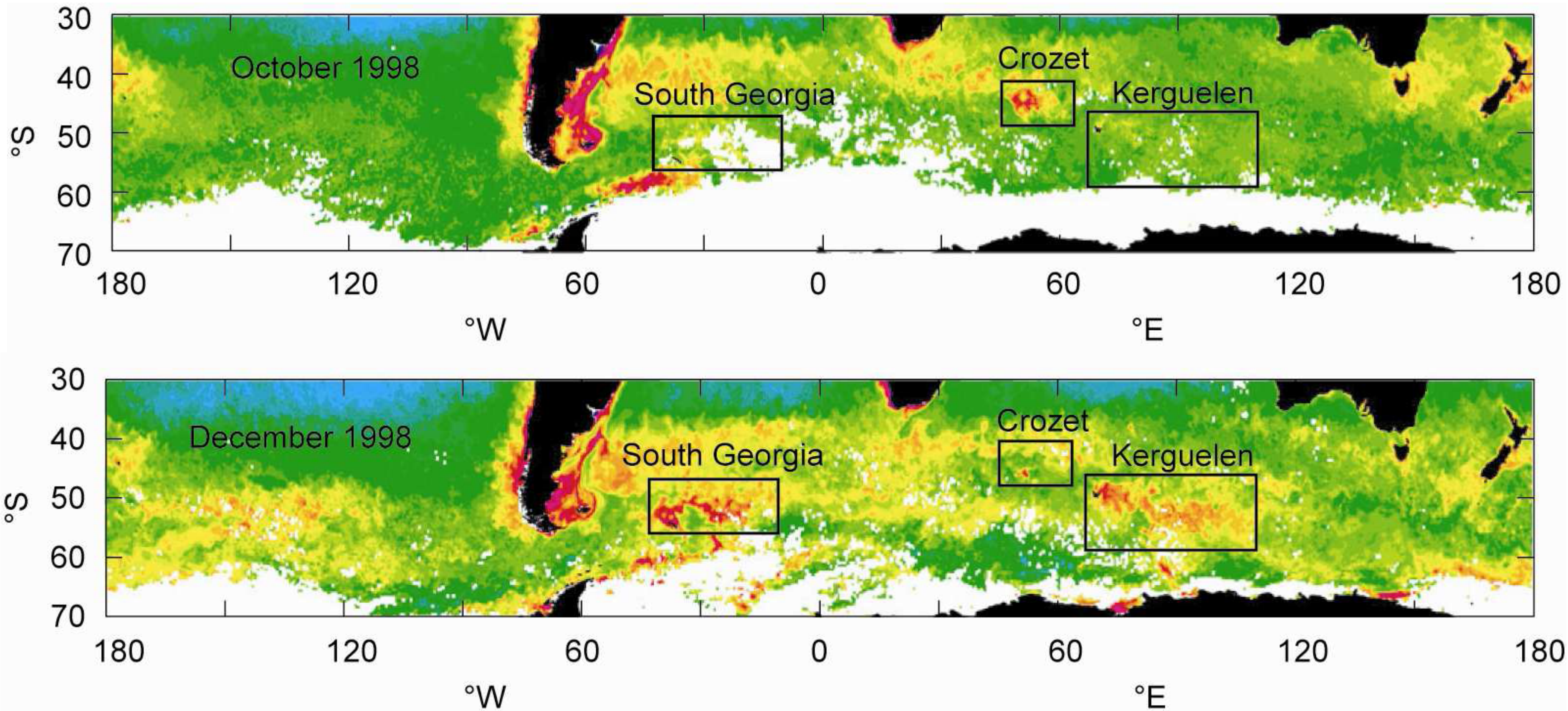


$CaCO_3$ production in the surface and transport to depth increases atmospheric CO_2.

On millenial time-scales CCP leads to shifts in the vertical distribution of TCO_2 and TA

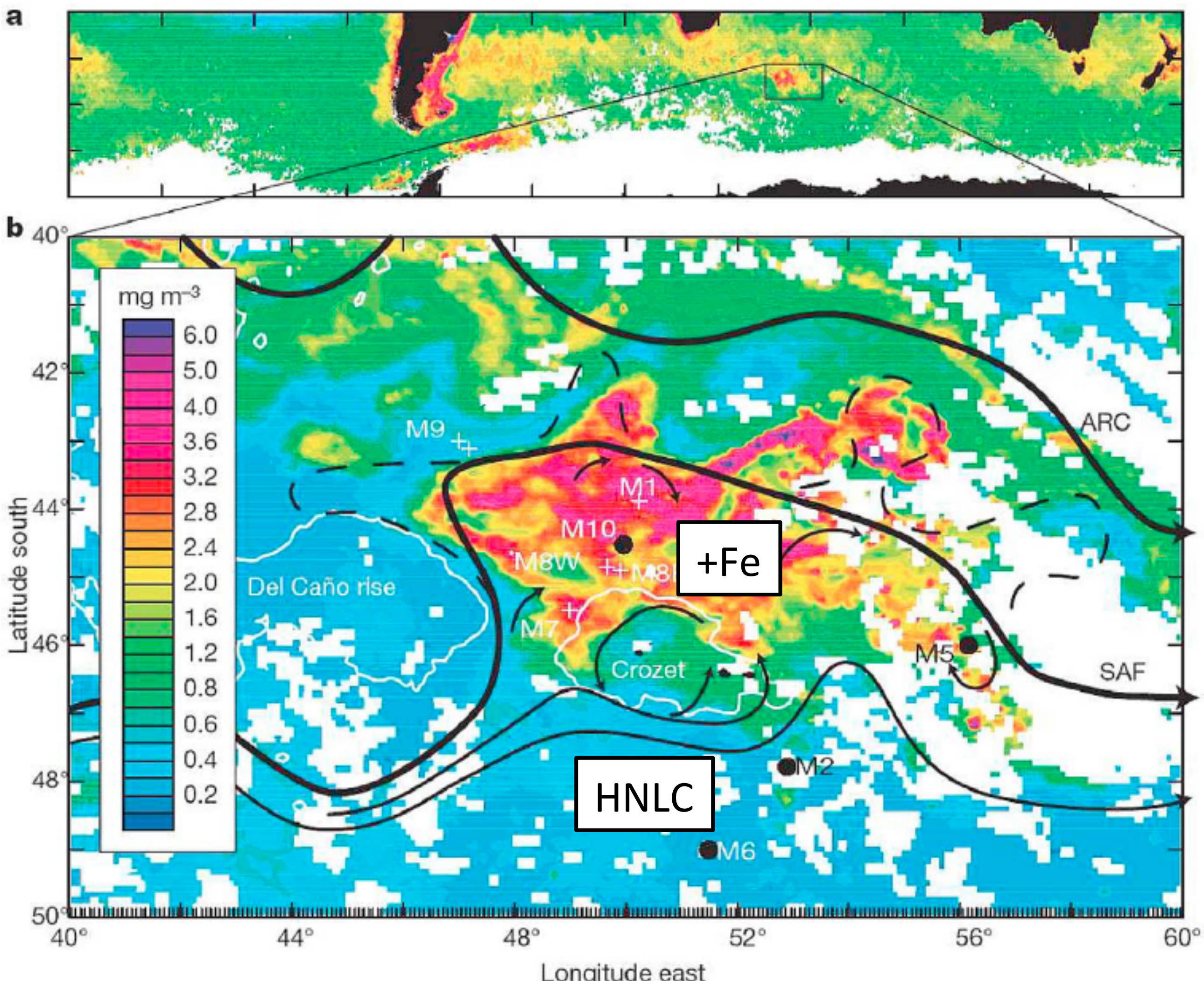


Constrain the opposing effects of these counter-acting components of the biological carbon pump



Island-associated blooms in Southern Ocean

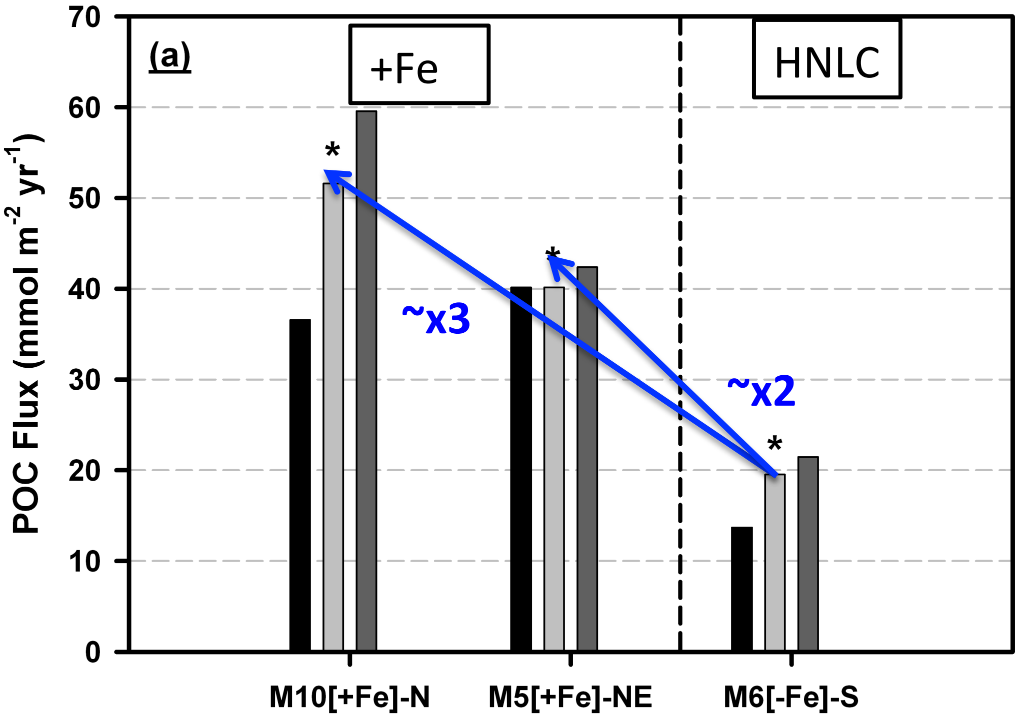
Iron-supply enhances ecosystem productivity and POC export



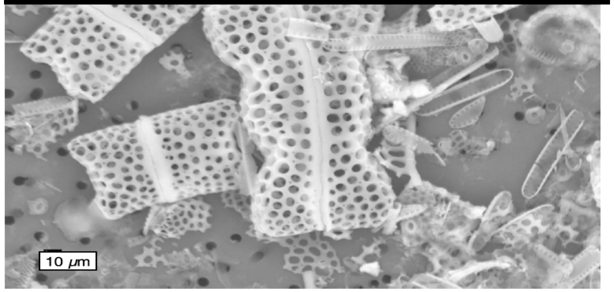
Pollard et al. 2009 Nature

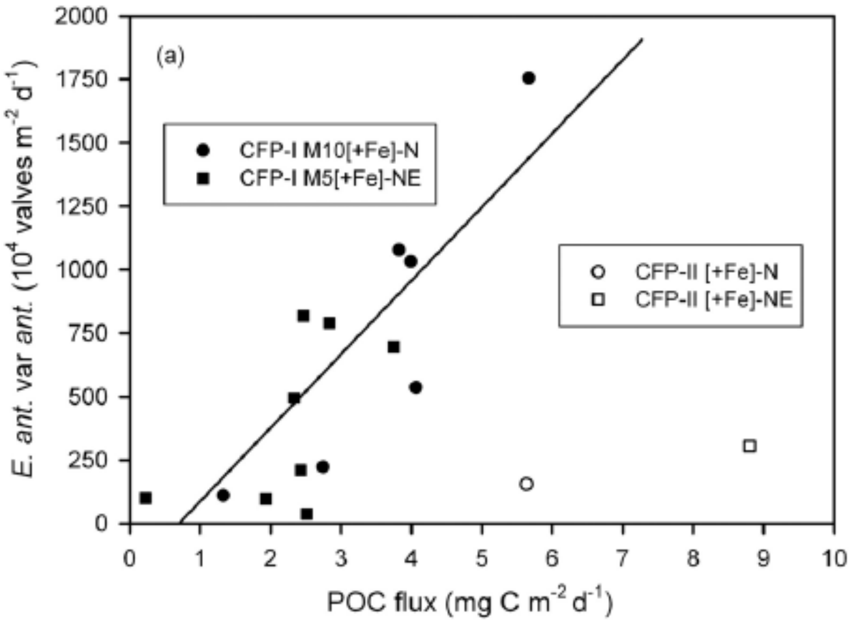
[+Fe]-fertilized bloom to the North; [HNLC] to the south

Organic carbon pump



E. antarctica var. _antarctica_



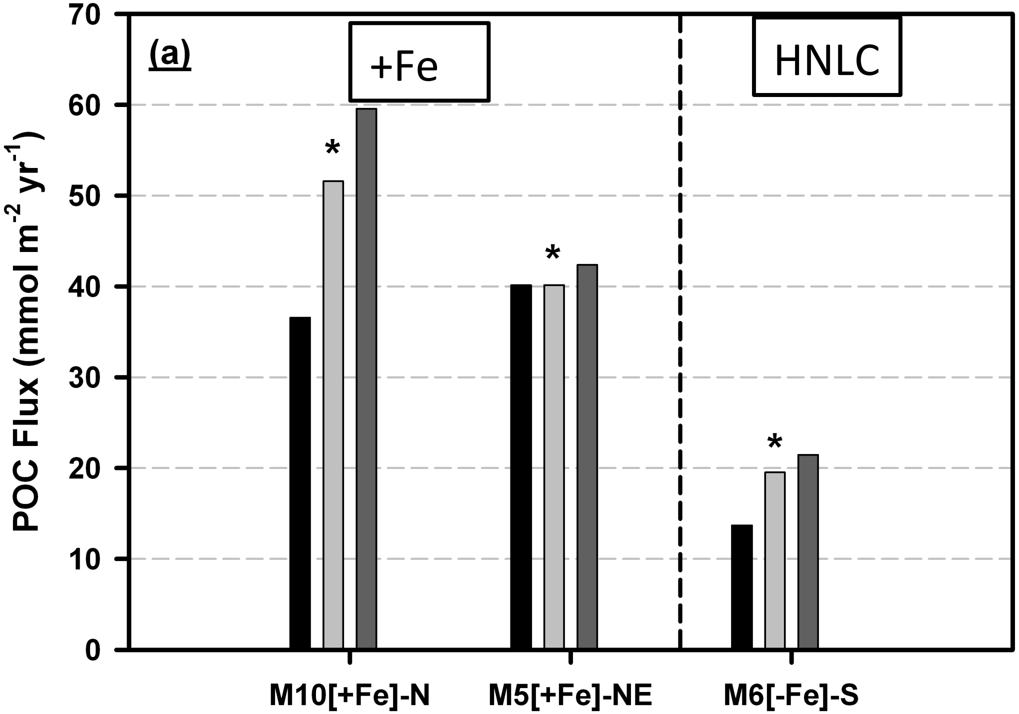


Salter et al. 2012 Glob. Biogeo Cy.

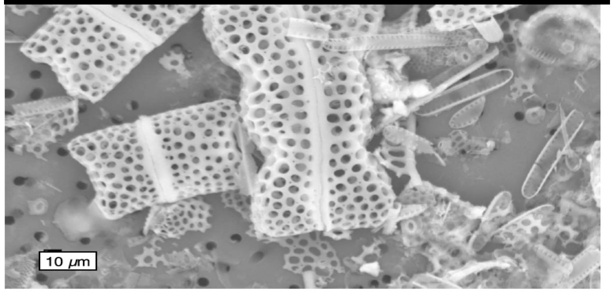
POC fluxes enhanced by a factor of ~2-3 as a result of iron fertilization

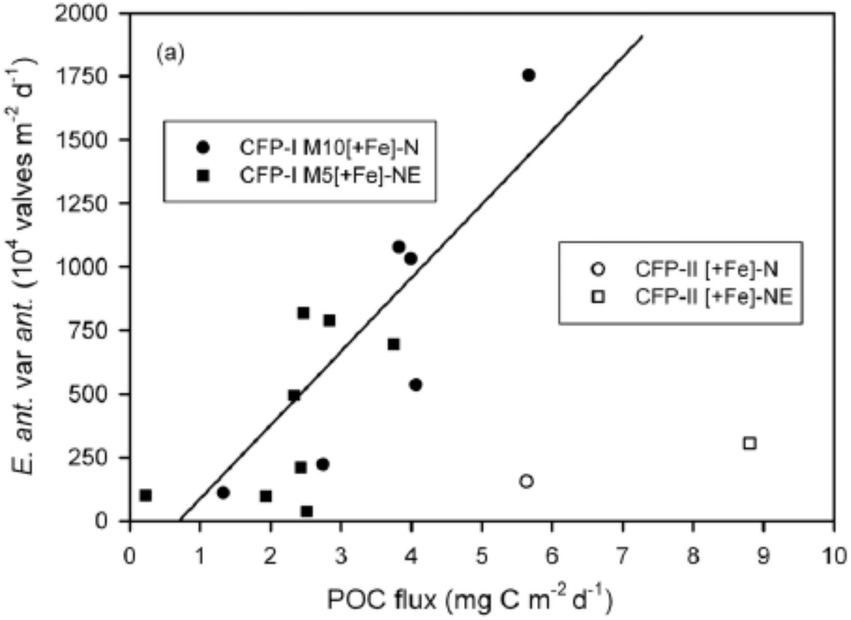
Driven by resting spore formation of *Eucampia antarctica* var *antarctica*

Organic carbon pump



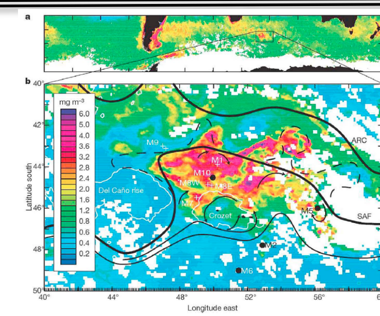
E. antarctica var. antarctica



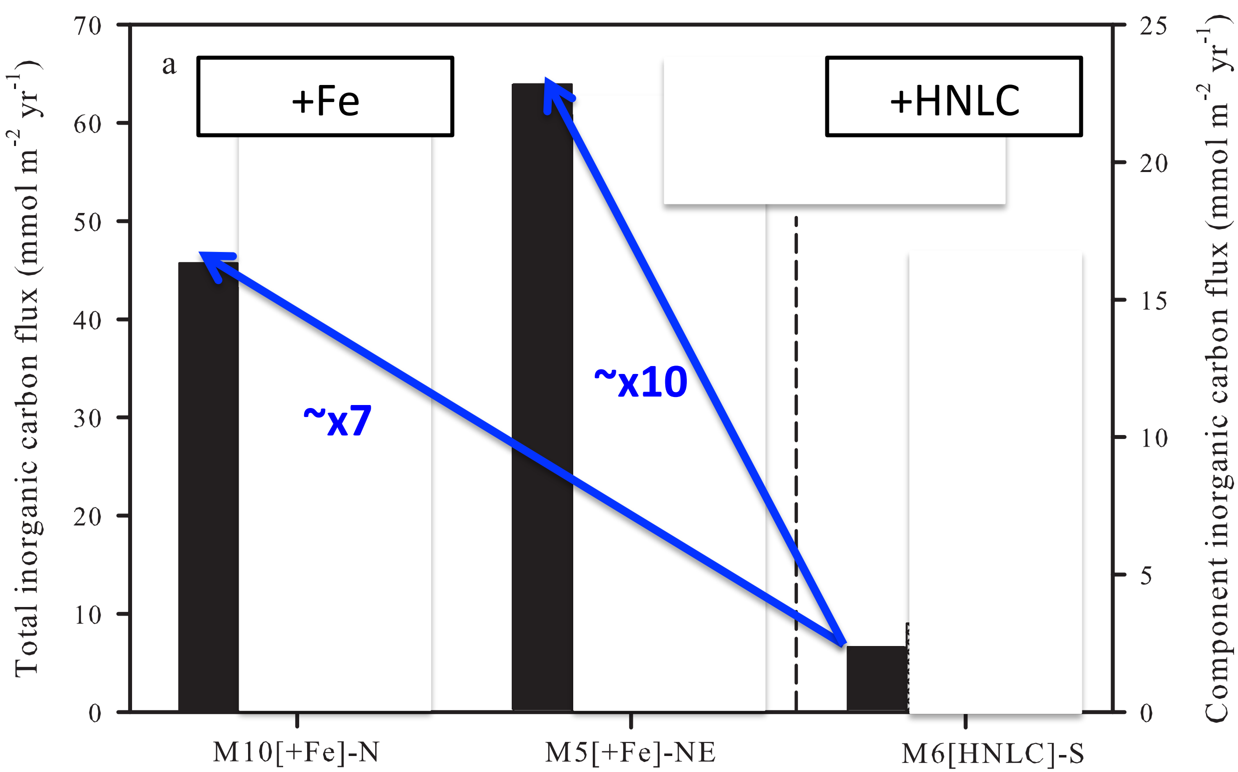


Ecological vectors of carbon and biogenic silicon export over the naturally fertilized Kerguelen Plateau

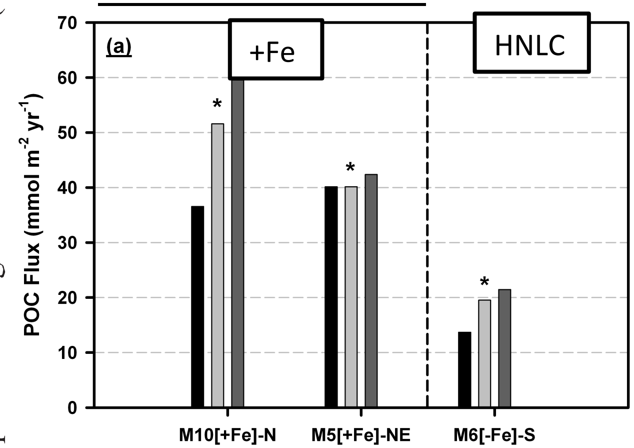
M. Rembauville[1], I. Salter[1,2] and S. Blain[1]
[1]Laboratoire d'Océanographie Microbienne (LOMIC), Observatoire Océanologique de Banyuls-sur-mer, UPMC/CNRS, Banyuls-sur-mer, France
[2]Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany
Corresponding author: rembauville@obs-banyuls.fr



Inorganic carbon pump



POC flux
2-3 fold increase



- Annual $CaCO_3$ fluxes were 7-10 times higher in [+Fe] regime

- Large excess $CaCO_3$ fluxes than excess POC fluxes : ↓ **POC:PIC ratio**

(1) How are $CaCO_3$ fluxes distributed across different calcifying groups?

(2) How significant is the carbonate counter pump for iron-fertilized sequestration of atmospheric CO_2?

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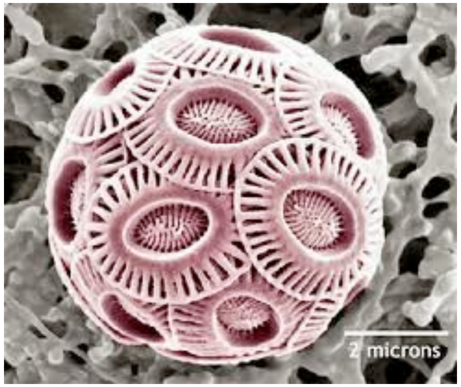


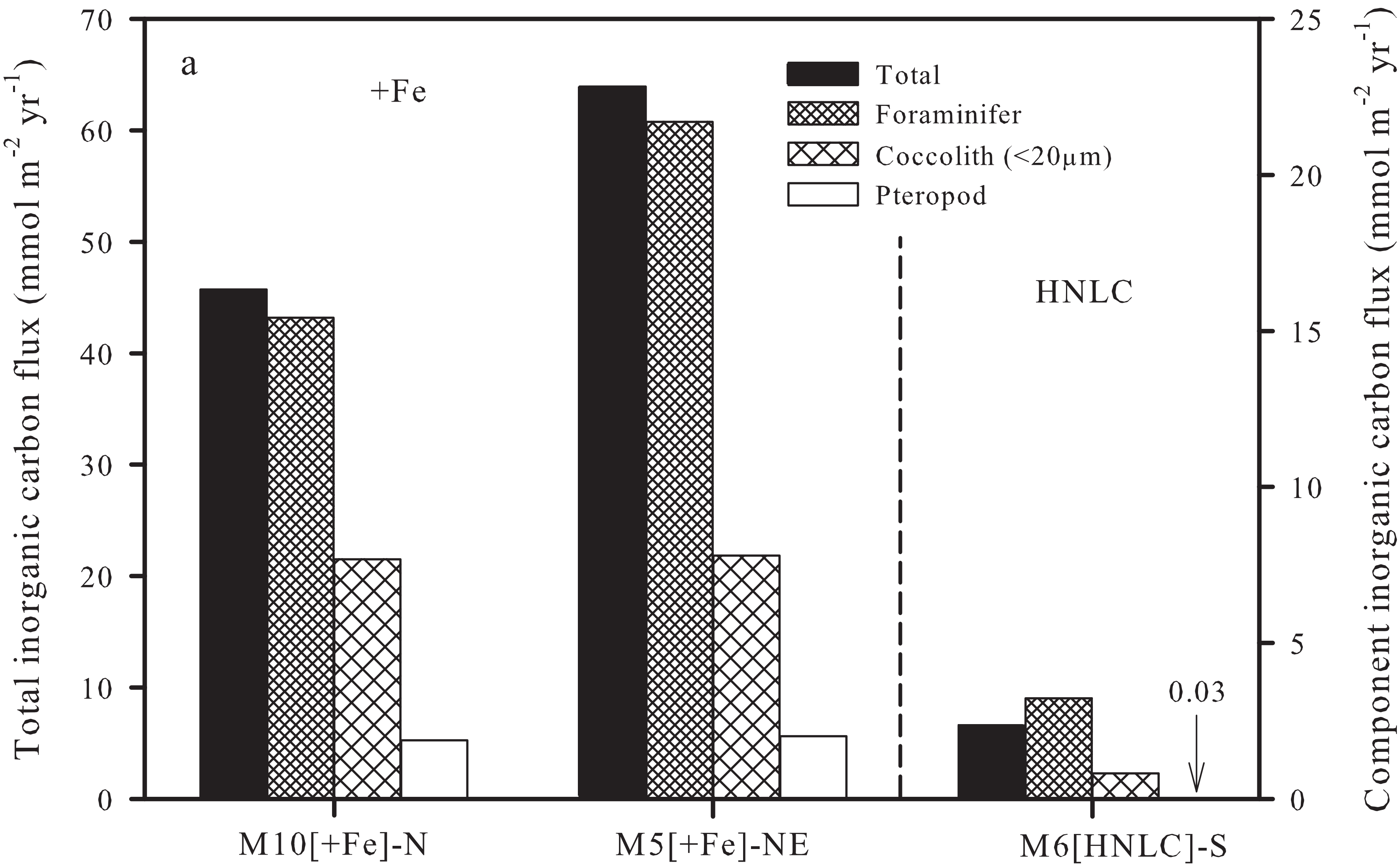
Coccolith **Foraminifer** **Pteropods**

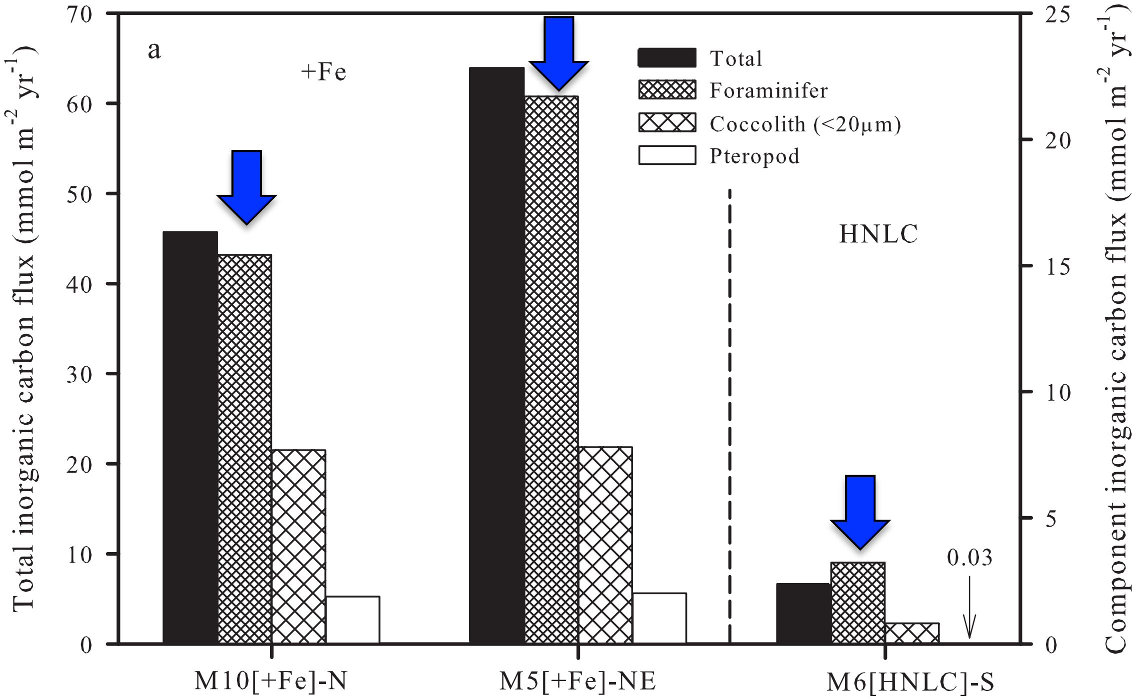
Methods:

Coccolith-derived $CaCO_3$ - fine-fraction (< 20 um and 20-63 um) Ca (ICP-AES)

Pteropod species enumerated, removed and weighed with fragments

Foraminifera – automated image analysis (63-100 and >100 um) Manual species ID.


a
+Fe
HNLC
Total
Foraminifer
Coccolith (<20μm)
Pteropod
0.03
Total inorganic carbon flux (mmol m-2 yr-1)
Component inorganic carbon flux (mmol m-2 yr-1)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
M10[+Fe]-N
M5[+Fe]-NE
M6[HNLC]-S



Salter et al. 2014 *Nat. Geosci*.

Table 1 | Excess fluxes resulting from iron fertilization.

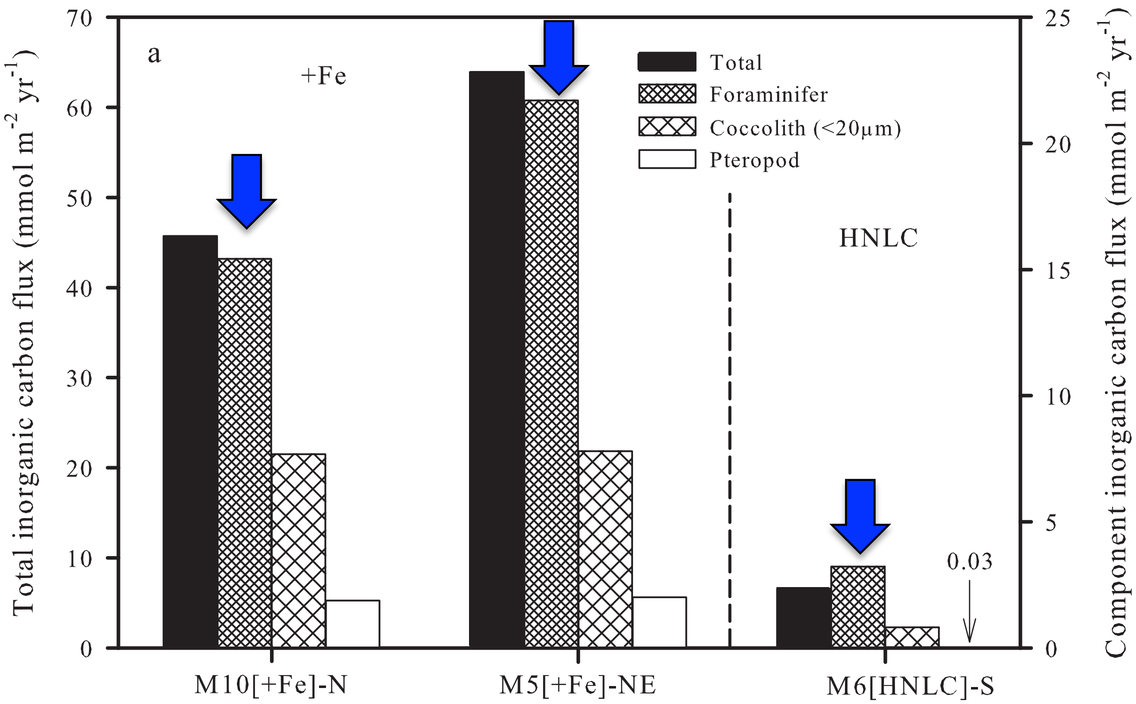
	C_{org} Total	C_{inorg} Total	C_{inorg} Foraminifer	C_{inorg} Pteropod	C_{inorg} <20 μm
Excess fluxes*	24–27	39–57	13–19	1.9–2.0	6.9–7.0
Increase†	~3	7–10	6–8	64–68	~9

*Excess fluxes in mmol m^{-2} yr^{-1} calculated as [+Fe] – [HNLC] annual fluxes. †Factor increase, calculated as [+Fe]/[HNLC].

Foraminifer dominate $CaCO_3$ flux (35-50%)

Largest relative difference in pteropod flux

Excess PIC fluxes > excess POC fluxes in all fractions



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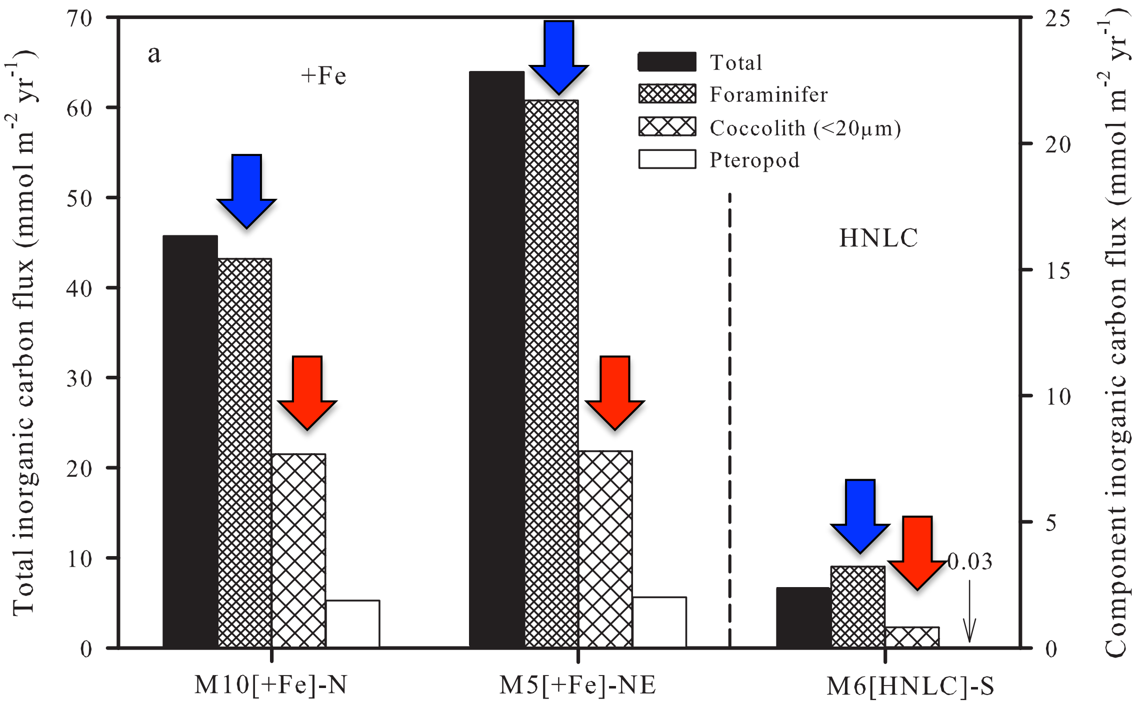

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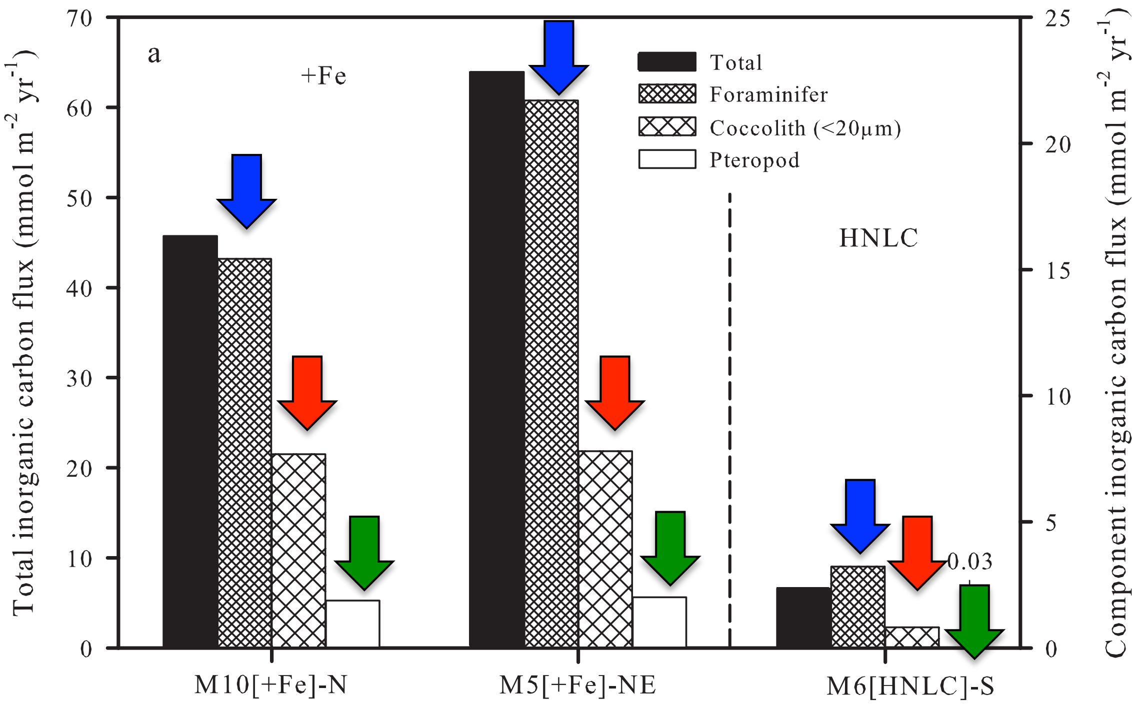

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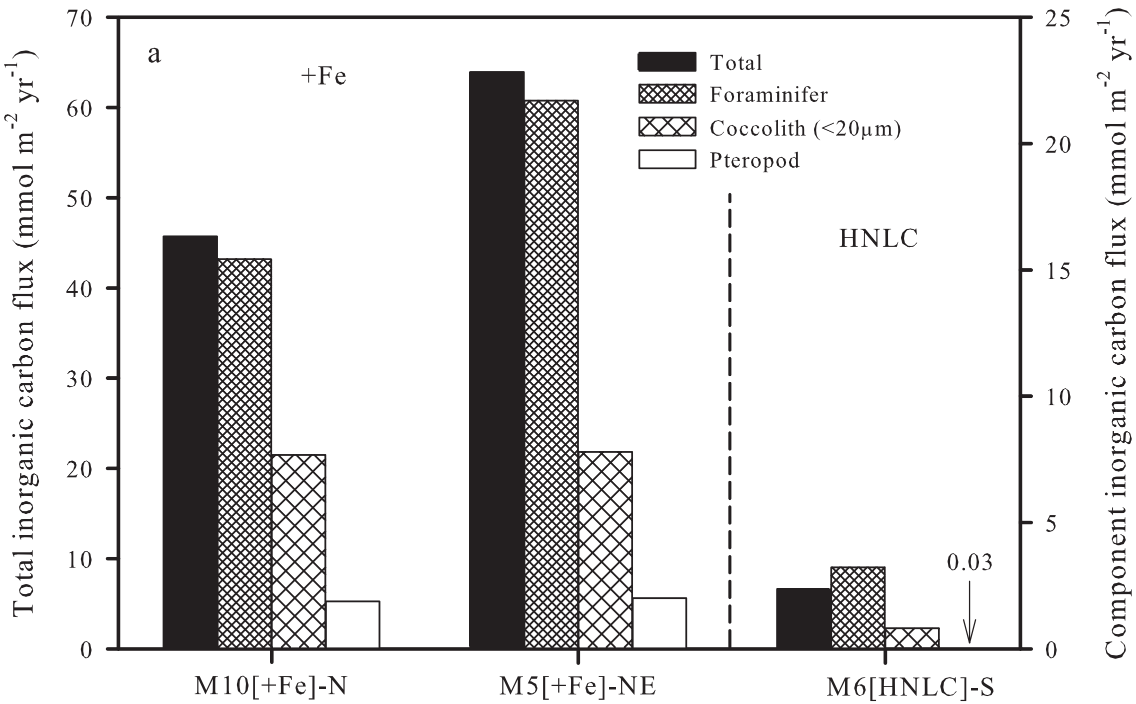

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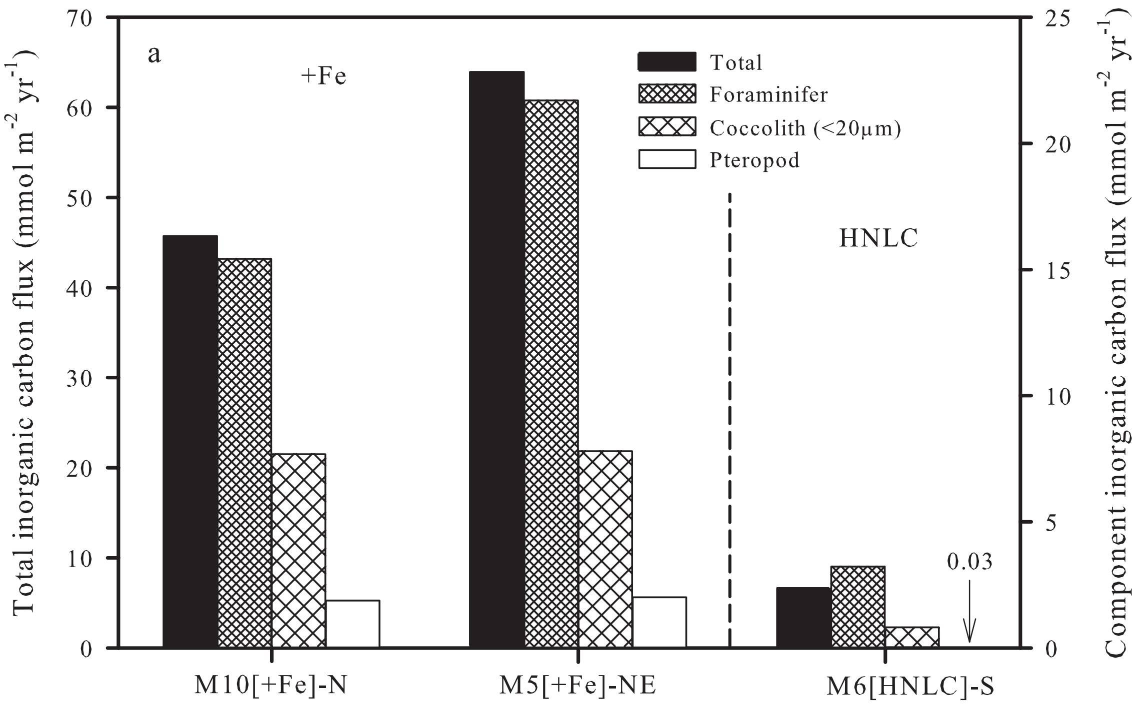

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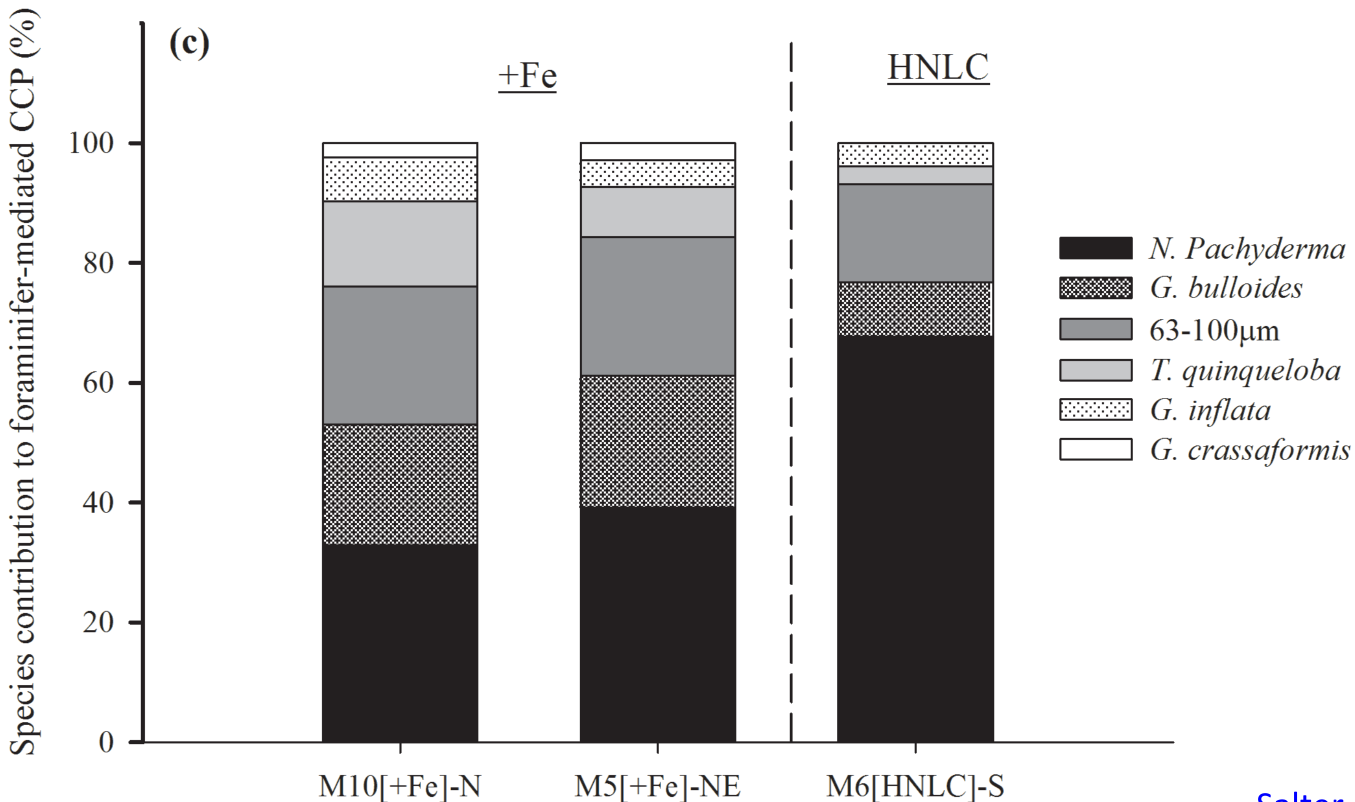


Salter et al. 2014 *Nat. Geosci*.

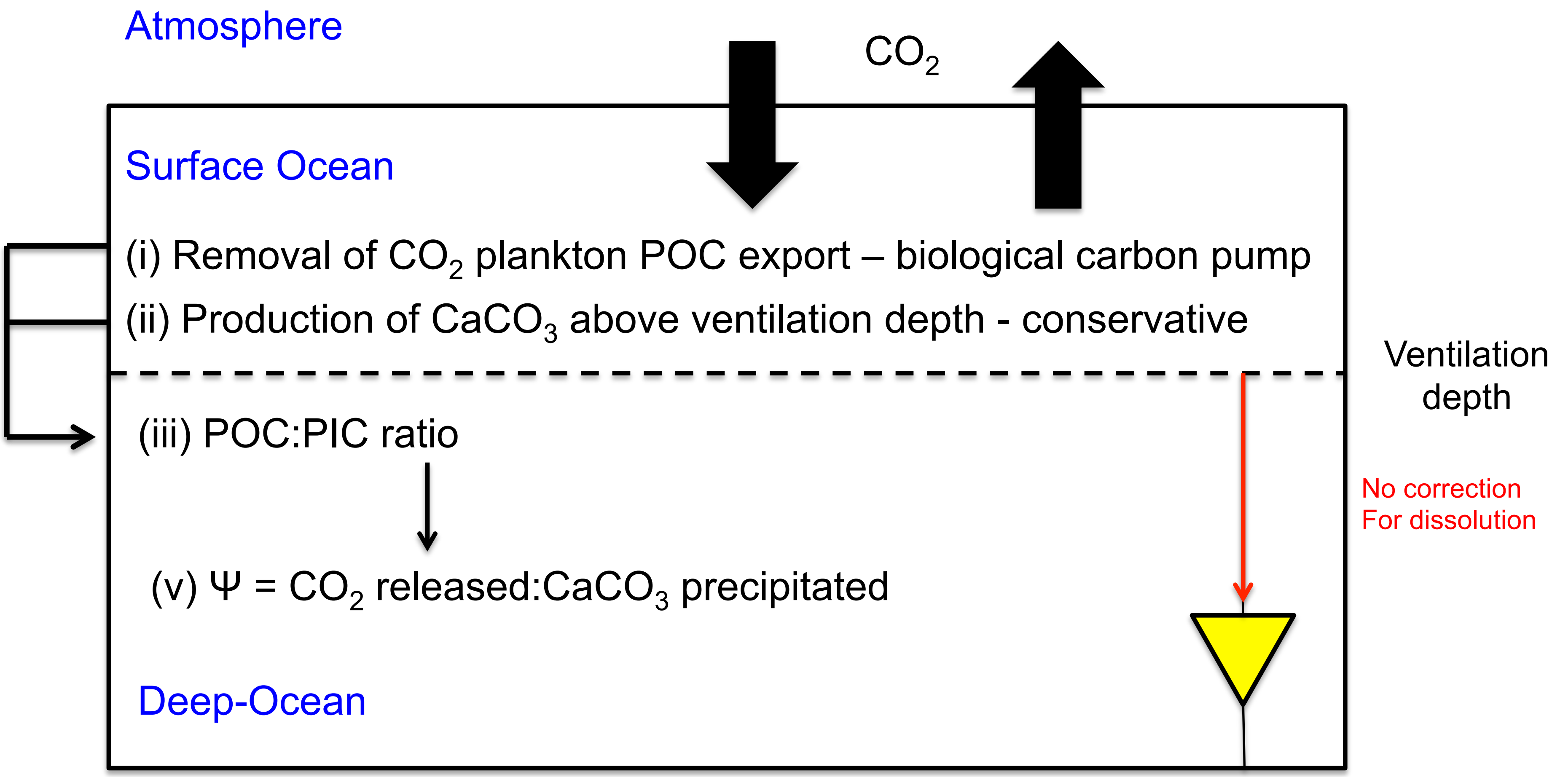
N. Pachyderma dominate foram-$CaCO_3$ fraction

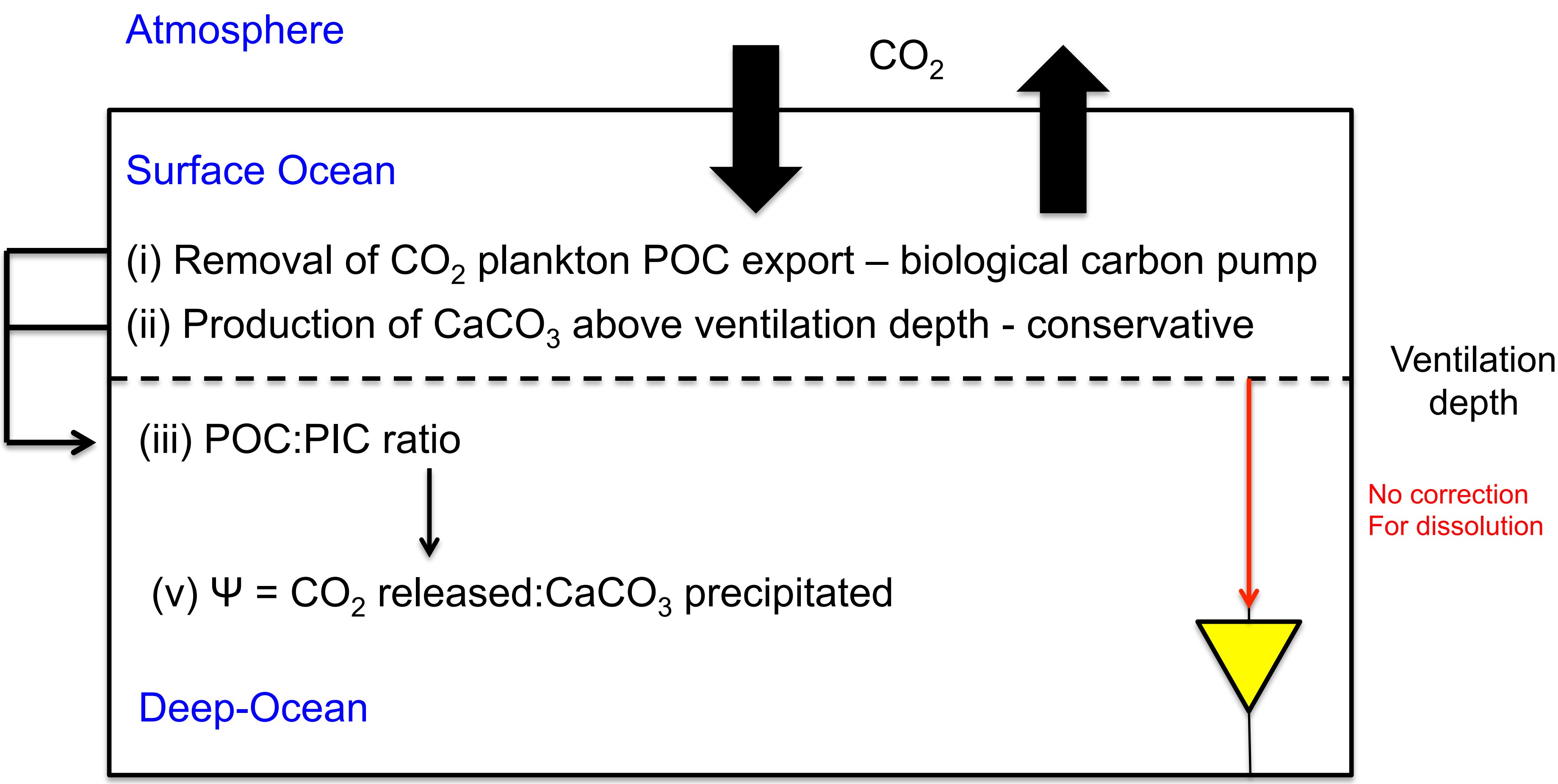
Larger species more important at iron fertilized site

Changes in foram-$CaCO_3$: (i) increase production (ii) assemblage shifts

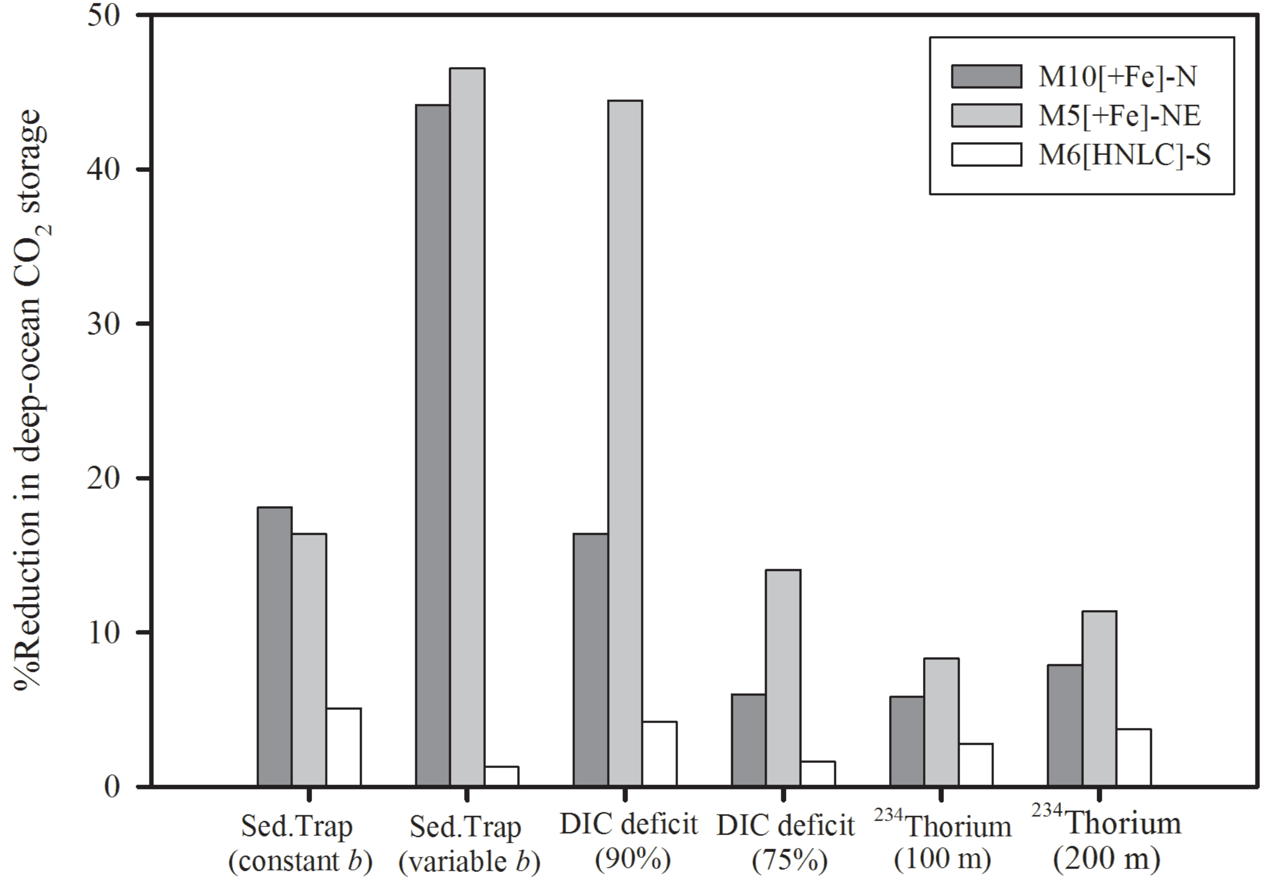
(1) How are $CaCO_3$ fluxes distributed across different calcifying groups?

(2) How significant is the carbonate counter pump for iron-fertilized sequestration of atmospheric CO_2?


Atmosphere
CO_2
Surface Ocean
(i) Removal of CO_2 plankton POC export – biological carbon pump
(ii) Production of $CaCO_3$ above ventilation depth - conservative
Ventilation depth
(iii) POC:PIC ratio
No correction
For dissolution
(v) Ψ = CO_2 released:$CaCO_3$ precipitated
Deep-Ocean



1. $\{[(\text{gross } CO_2 \text{ sink}) - (\text{net } CO_2 \text{ sink})]/(\text{gross } CO_2 \text{ sink})\} * 100$
2. **Gross CO_2 sink**= $(FPOC_{WML})$
3. **Net CO_2 sink** = $[(FPOC_{WML}) - (FPIC_{WML} \times \Psi\ )$

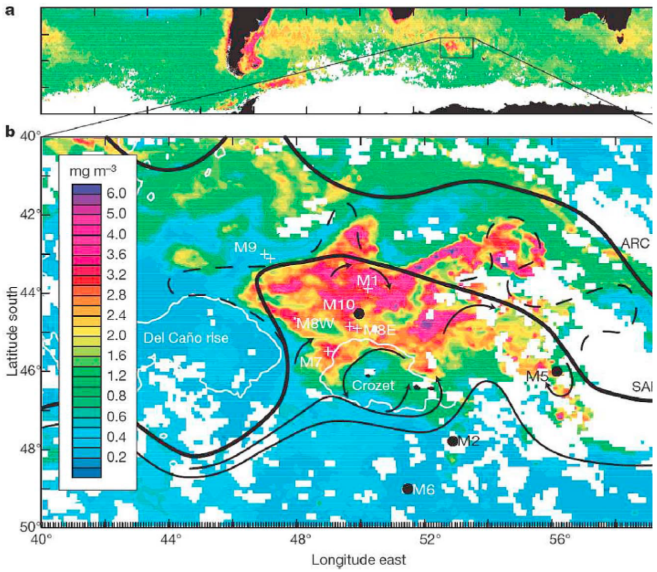


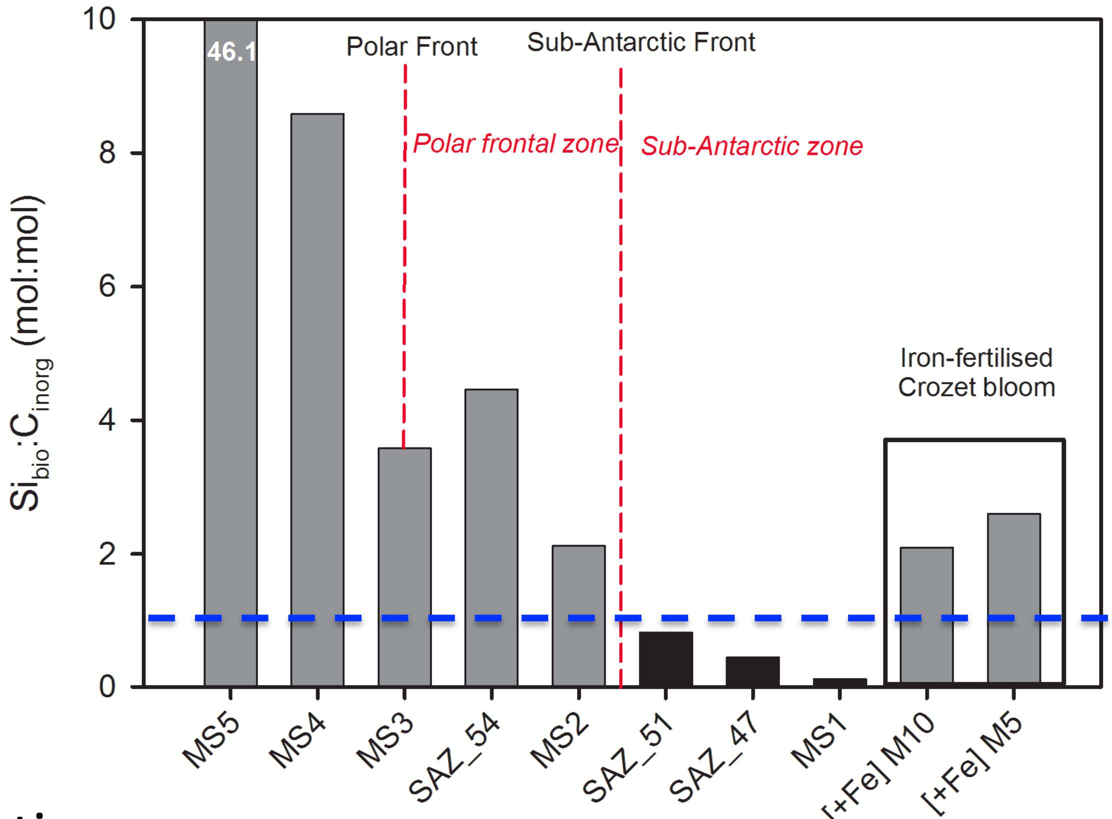
Salter et al. 2014 *Nat. Geosci*.

Expressed as % reduction in deep-ocean CO_2 storage

CCP effect: 6-32% in [+Fe] region

1-4% in [HNLC] region



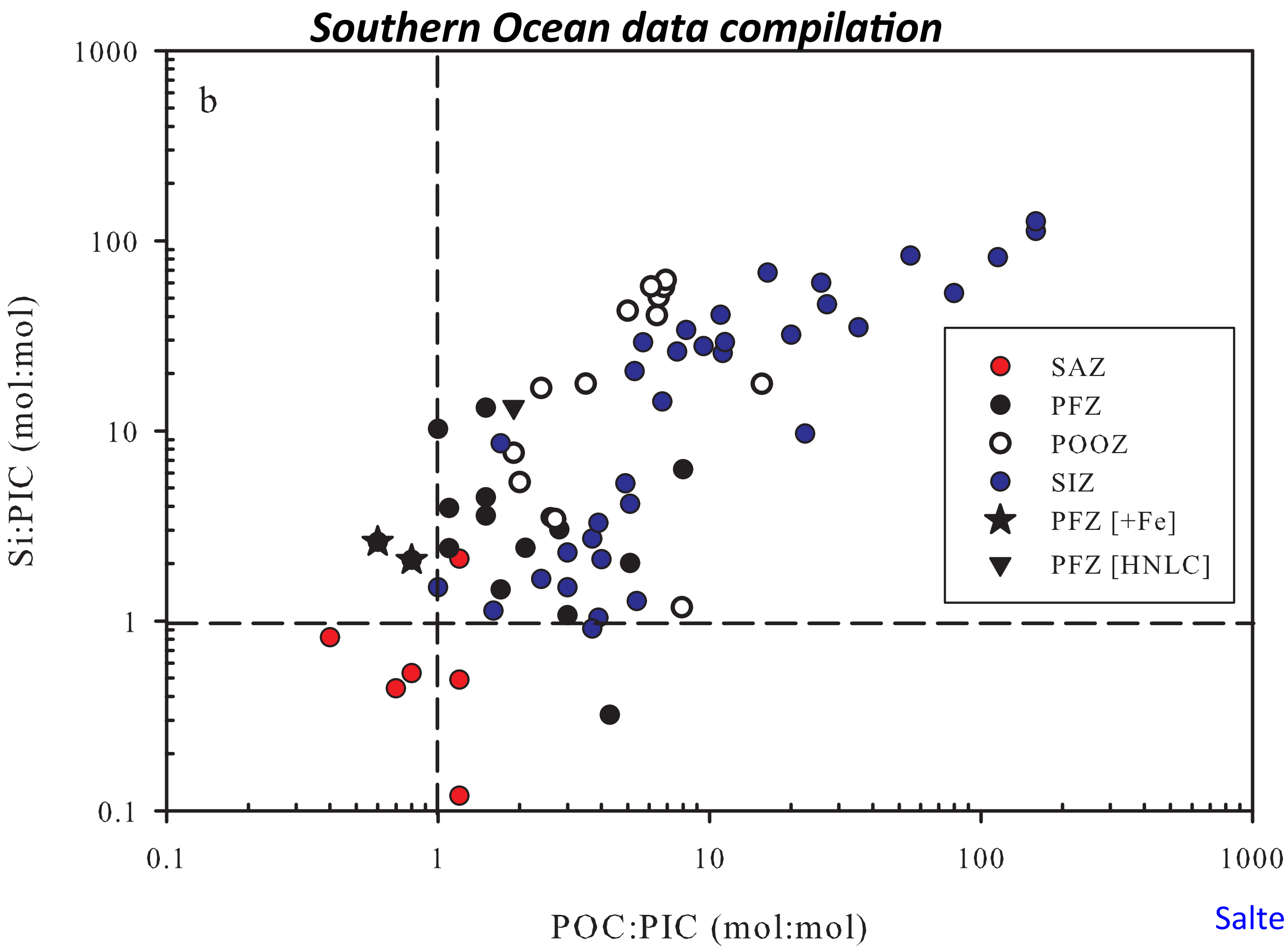


Importance of bloom location

Salter et al. 2014 *Nat. Geosci*. SI

SAF transition from Si to $CaCO_3$ dominated production/export

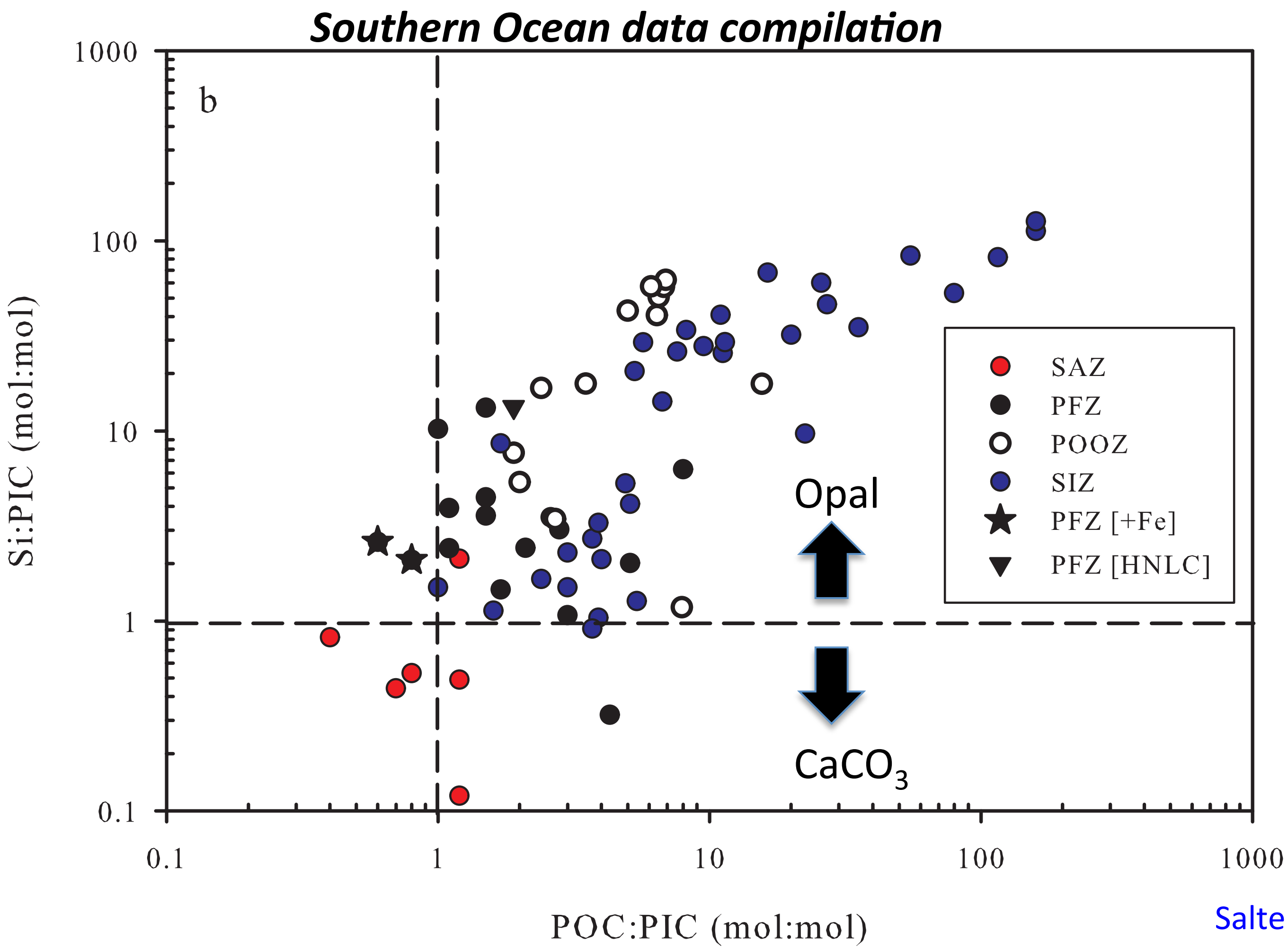
Si:PIC ratios characteristic of PFZ



Salter et al. 2014 *Nat. Geosci*.

[+Fe] PFZ unique : opal dominated export, excess PIC over POC fluxes

CCP due to increases in PIC production/transport relative to both Si and POC



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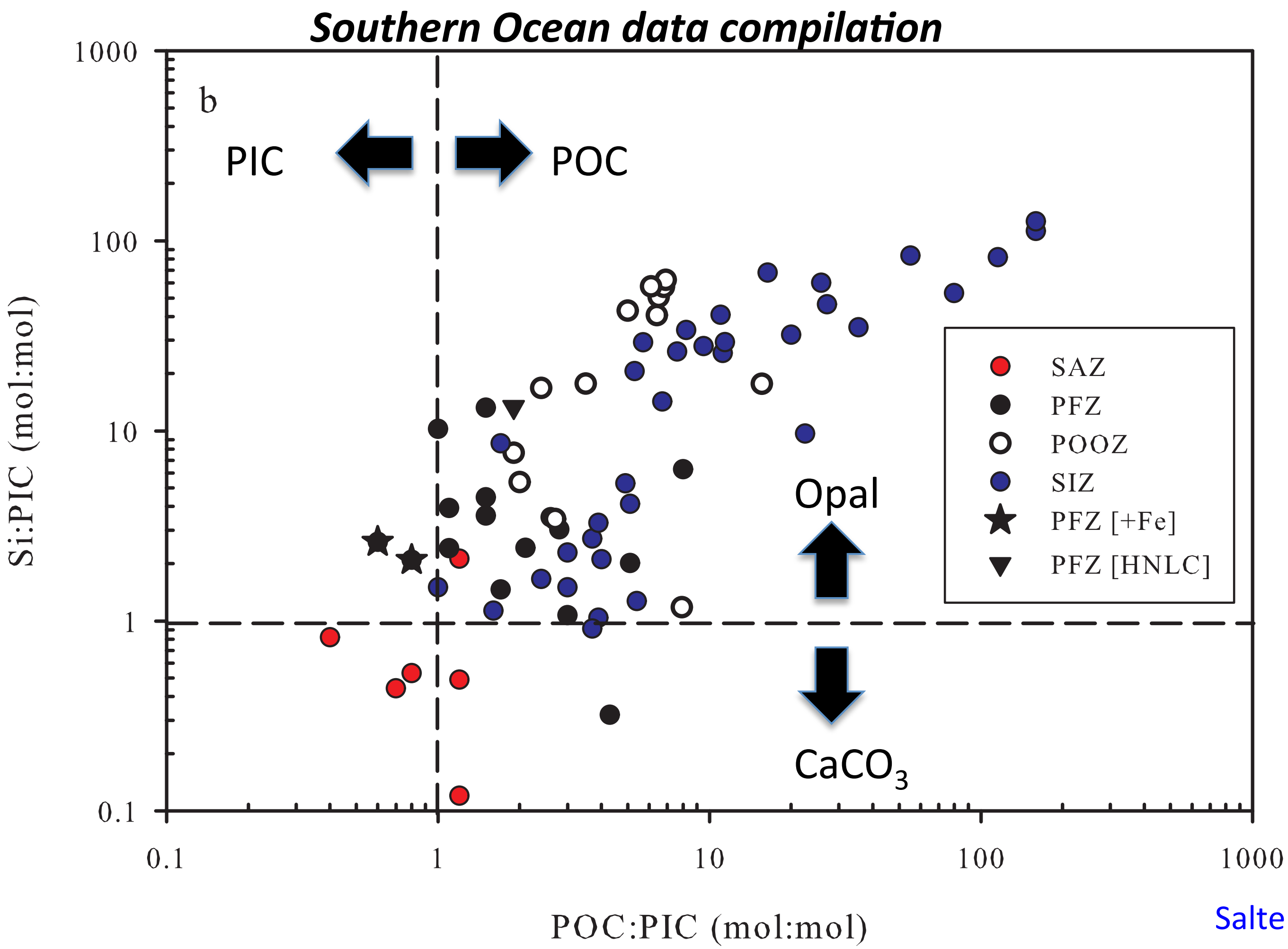

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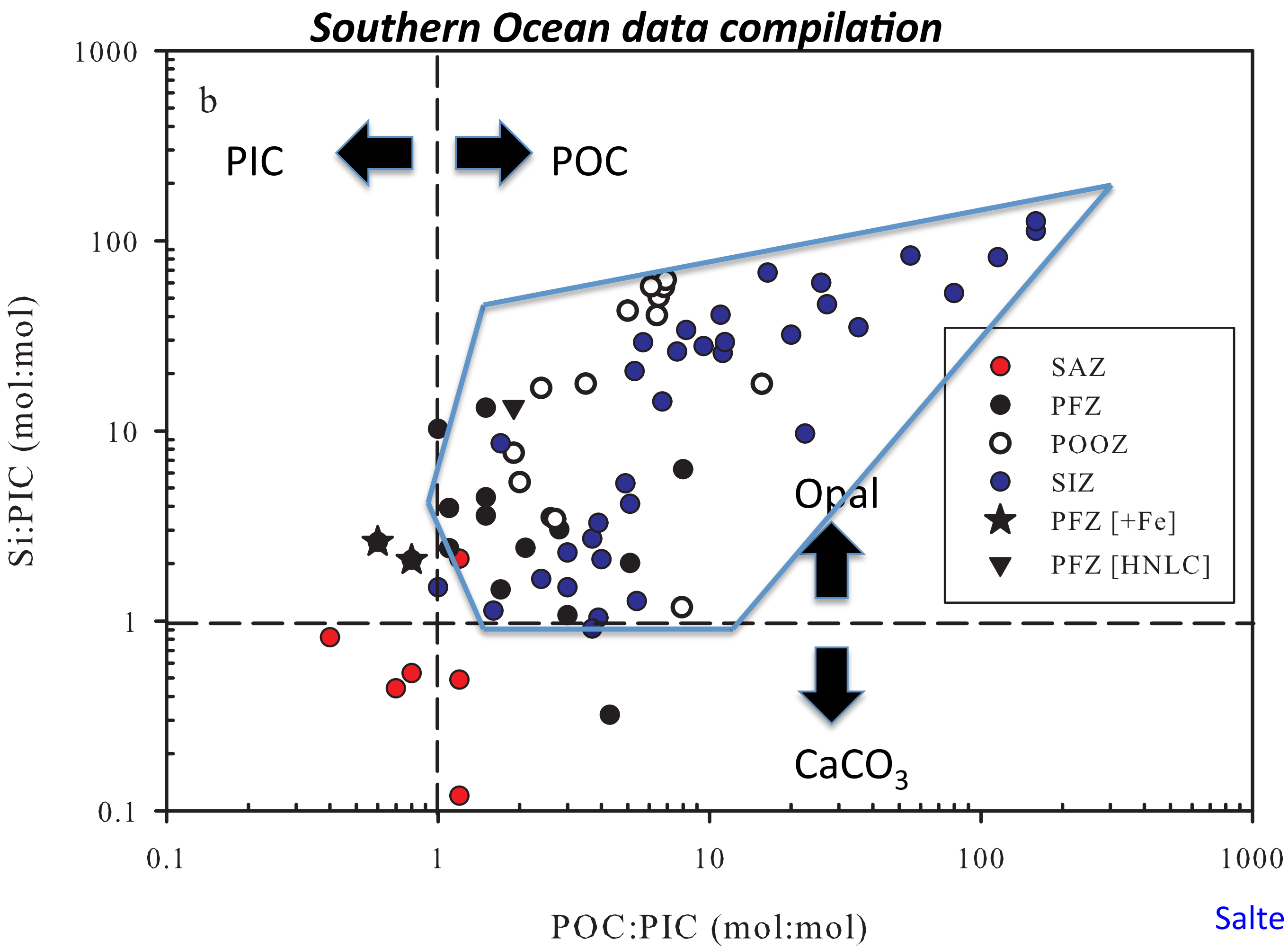

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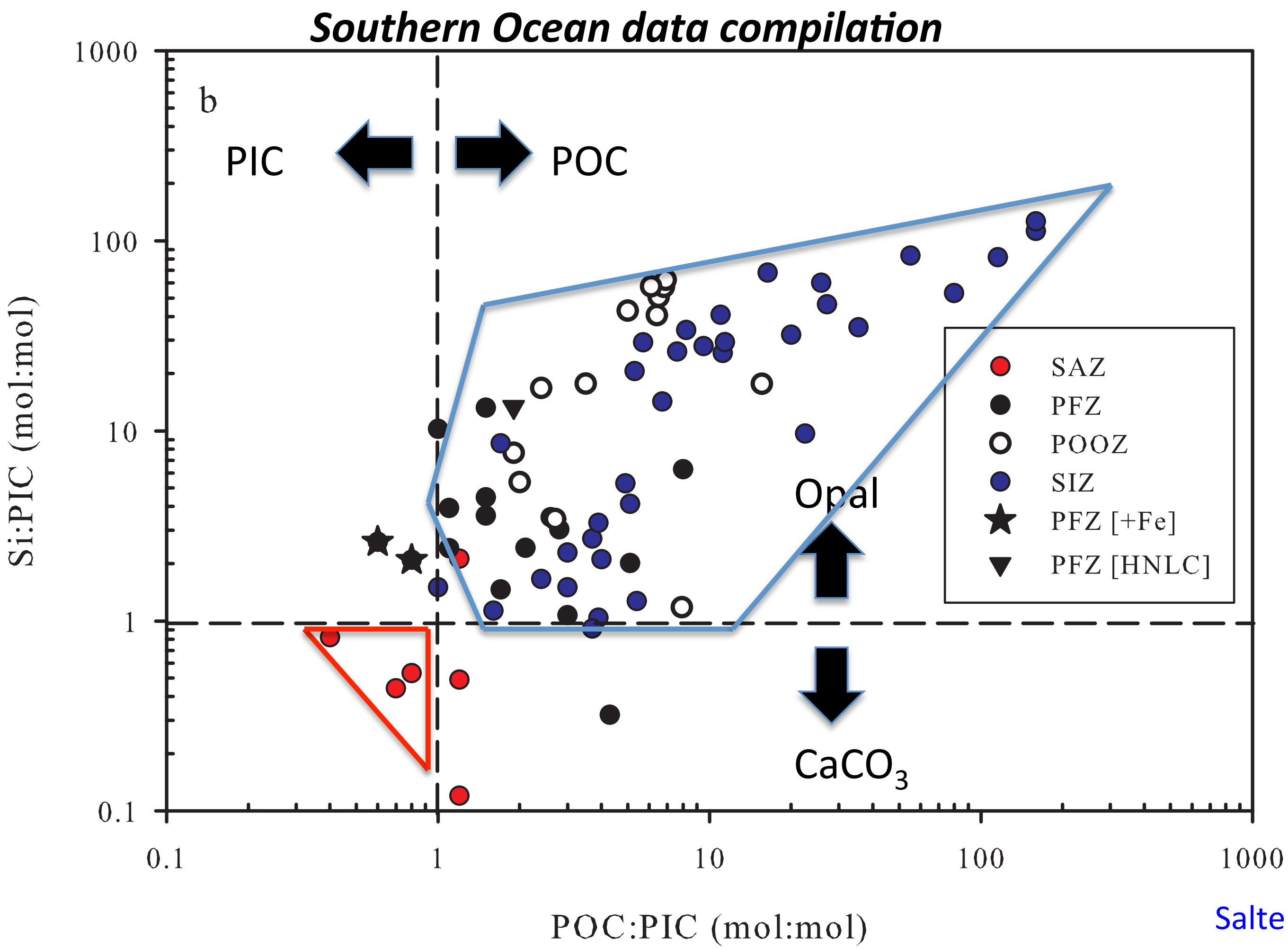

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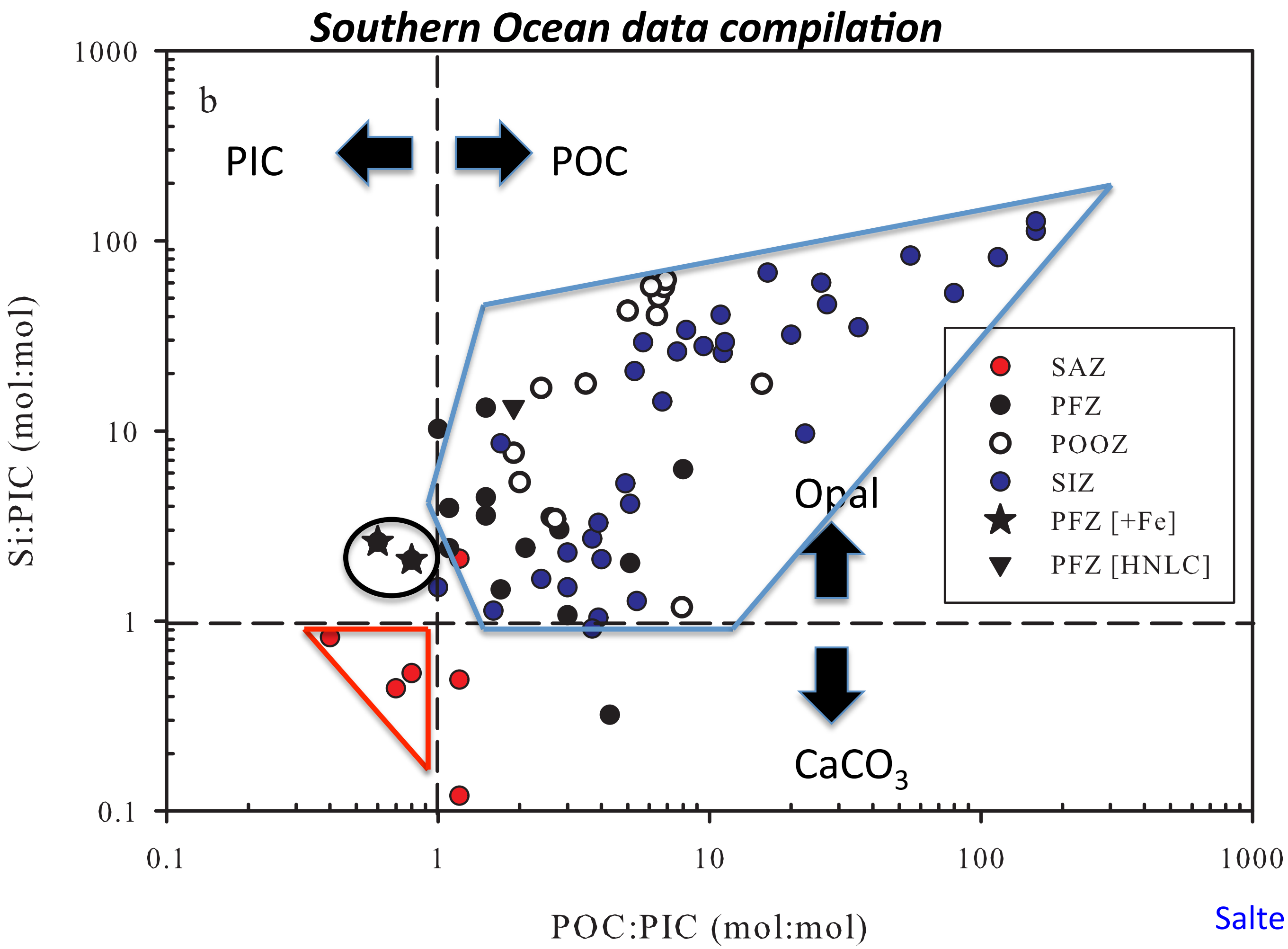

Salter et al. 2014 *Nat. Geosci*.

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CCP due to increases in PIC production/transport relative to both Si and POC

SUMMARY and Acknowledgements

[+Fe] enhances $CaCO_3$ flux in PFZ

Foraminifer dominant $CaCO_3$ flux fraction

Effective CO_2 transfer by BCP may be reduced 10-30%

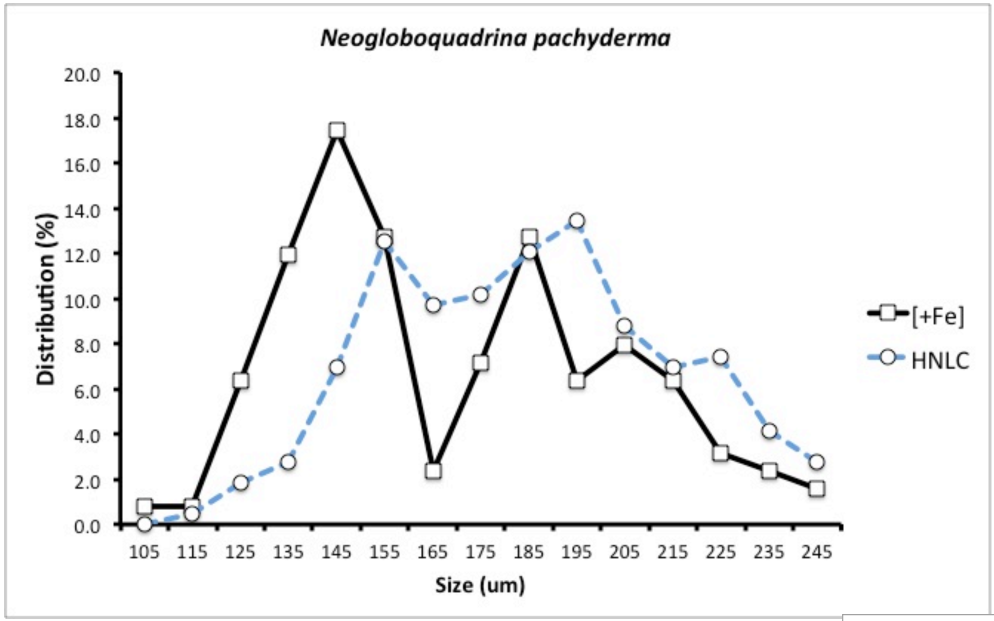
POC:PIC < 1 in Si:PIC>1 unique to polar frontal zone iron fertilization

Thank you for your attention

Further Acknowledgments

- Raymond Pollard (NOC)
- Richard Sanders (NOC)

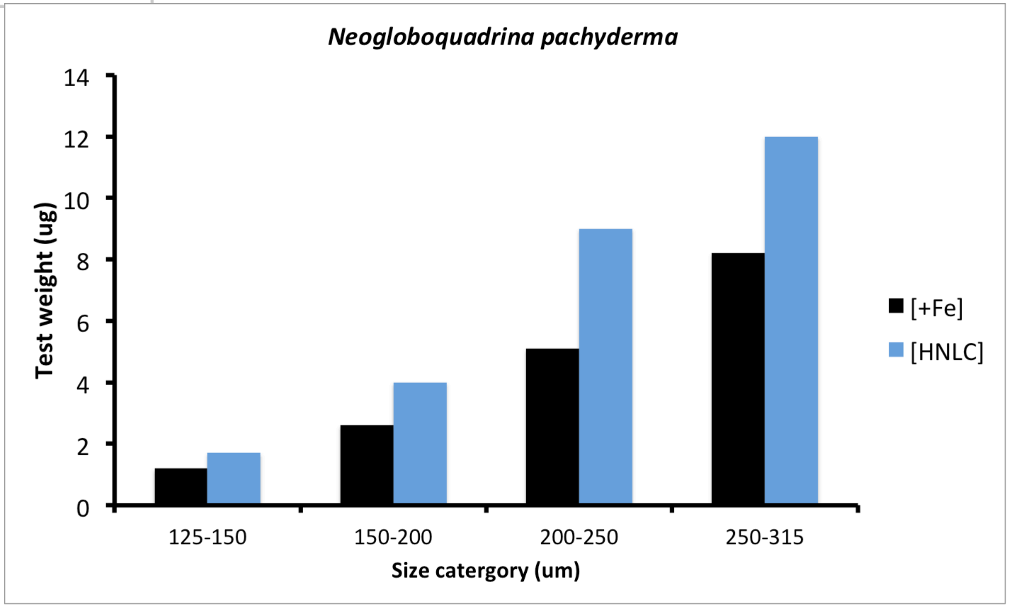
NATURAL ENVIRONMENT RESEARCH COUNCIL

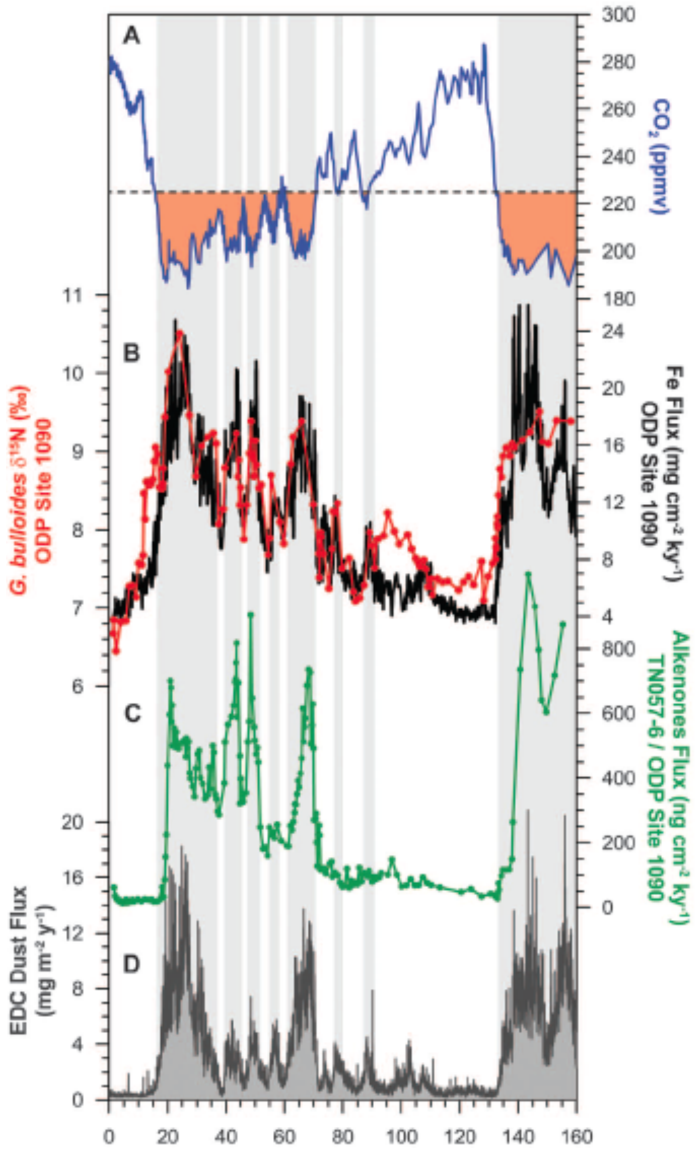


Test-size distributions

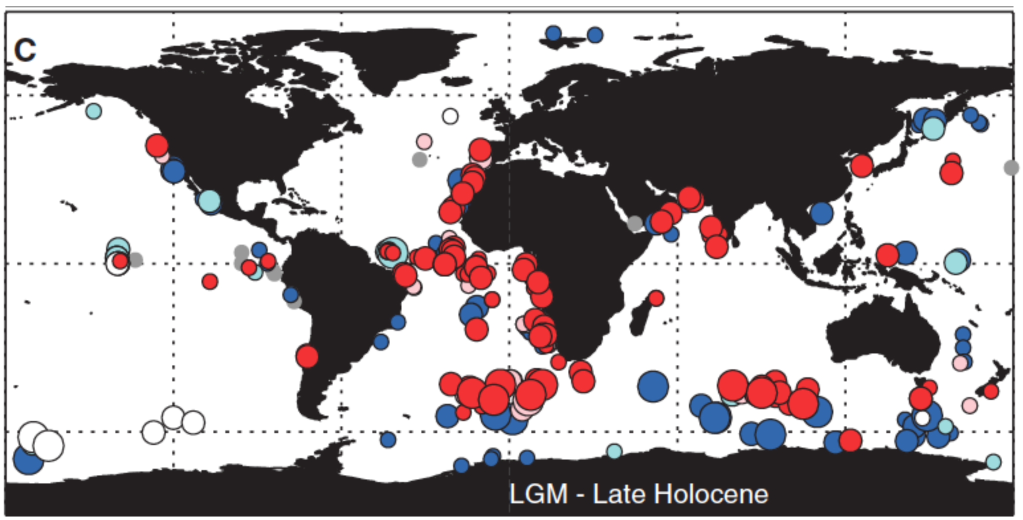
Size-normalized test weights

Foram-$CaCO_3$ flux





Martinez-Garcia et al. 2014 Science

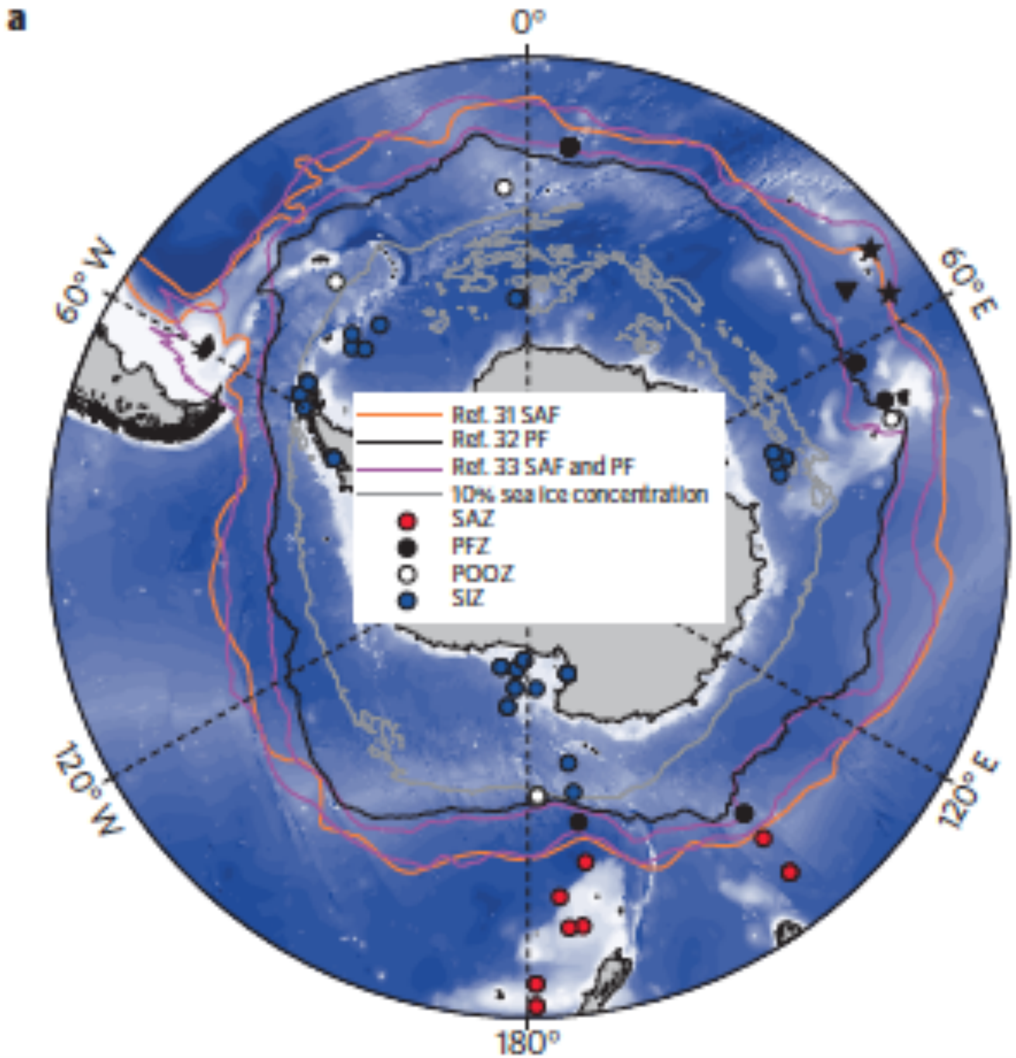


Kohfeld et al. 2005 Science

LGM increases in export occurred in sub-antarctic zone

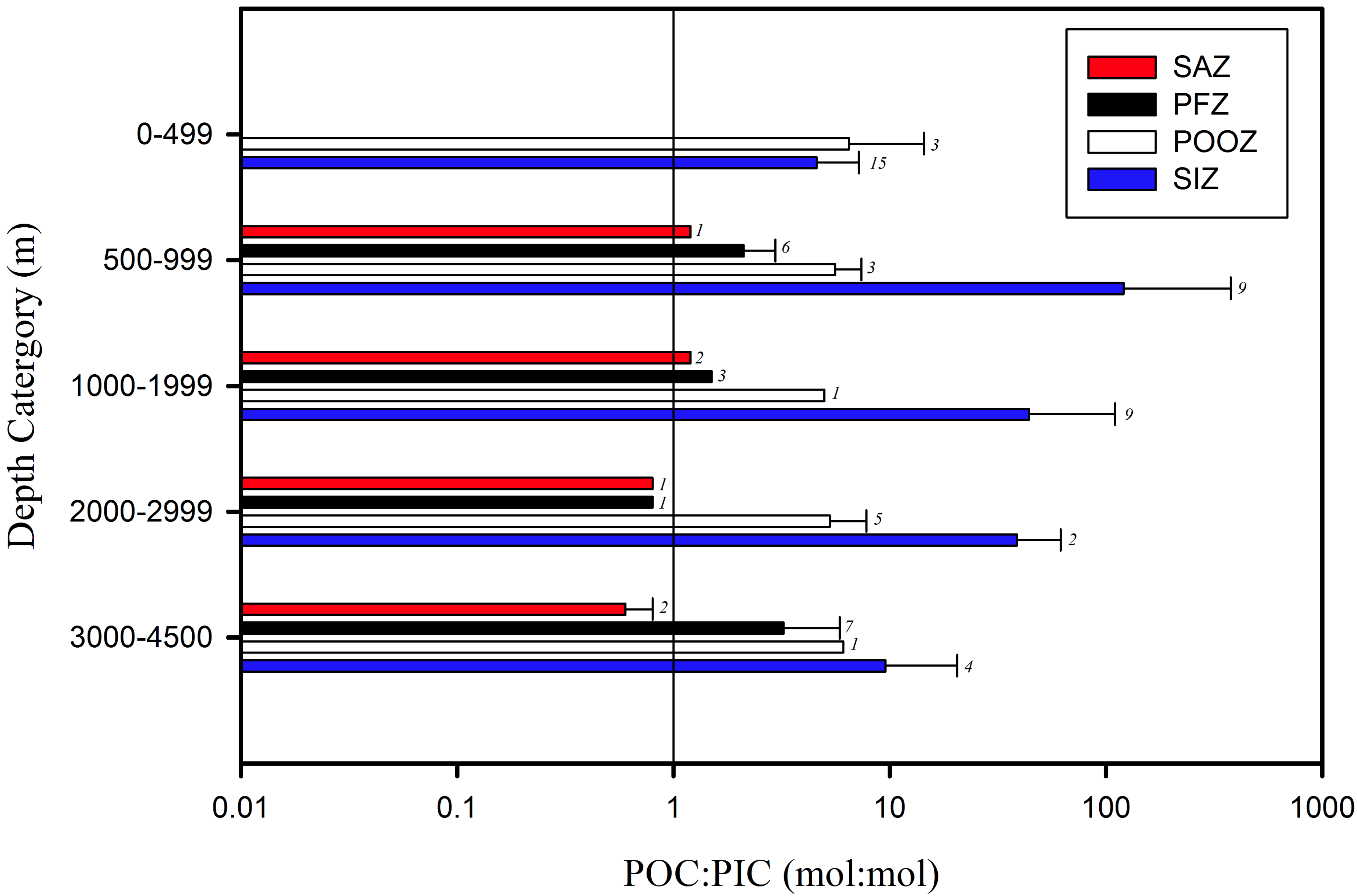
Increases in OC export were possibly accompanied by a strengthened carbonate counter pump

Decreased significance of BCP for regulating glacial Interglacial tranisitions in atmospheric CO_2



Southern Ocean data-set compiled

Classified in relation to frontal position



SAZ
PFZ
POOZ
SIZ
Depth Catergory (m)
0-499
500-999
1000-1999
2000-2999
3000-4500
POC:PIC (mol:mol)
0.01
0.1
1
10
100
1000
3
15
1
6
3
9
2
3
1
9
1
1
5
2
2
7
1
4

Data Source	Mooring Name	Frontal Position	Depth	POC: PIC	δ m	δ POC:PIC	Change
Trull et al. 2001	47-1000	SAF-STF	1060	1.2			
Trull et al. 2001	47-2000	SAF-STF	2050	0.8	990.0	-0.4	Decrease
Trull et al. 2001	54-800	PF-SAF	830	1.1			
Trull et al. 2001	54-1500	PF-SAF	1530	1.5	700.0	0.4	Increase
Fischer et al. 2000	PF-3	<PF	614	2.6			
Fischer et al. 2002	PF-3	<PF	3196	5.1	2582.0	2.6	Increase
Fischer et al. 2002	PF-5	<PF	654	3.0			
Fischer et al. 2002	PF-5	<PF	3219	4.3	2565.0	1.3	Increase
Fischer et al. 2002	PF-7	<PF	636	2.8			
Fischer et al. 2002	PF-7	<PF	3056	8.0	2420.0	5.3	Increase
Fischer et al. 2002	PF-8	<PF	687	1.1			
Fischer et al. 2002	PF-8	<PF	3110	1.7	2423.0	0.6	Increase
Wefer et al. 1988	KG-1_500	<PF	494	3.0			
Wefer et al. 1988	KG-1_1600	<PF	1588	1.0	1094.0	-1.9	Decrease
Fischer et al. 2000;2002	BO-1	<PF	450	1.9			
Fischer et al. 2000;2002	BO-1	<PF	2194	2.4	1744.0	0.5	Increase
Fischer et al. 2000;2002	BO-1-2-3	<PF	456	2.0			
Fischer et al. 2000;2002	BO-1-2-3	<PF	2183	2.7	1727.0	0.7	Increase

Fischer et al. 2000;2002	BO-5	<PF	515	6.4			
Fischer et al. 2000;2002	BO-5	<PF	2251	6.5	1736.0	0.1	Increase
Accornero et al. 2003	D-1996-180m	<PF	180	11.4			
Accornero et al. 2003	D-1996-868m	<PF	868	16.4	688.0	5.0	Increase
Dunbar et al. 1998	RSM-B	<PF	230	3.7			
Dunbar et al. 1998	RSM-B	<PF	519	3.9	289.0	0.2	Increase
Dunbar et al. 1998	RSM-C	<PF	230	1.6			
Dunbar et al. 1998	RSM-C	<PF	493	7.6	263.0	6.0	Increase
Langone et al. 2000	Mooring B	<PF	224	4.9			
Langone et al. 2000	Mooring B	<PF	560	20.0	336.0	15.1	Increase
Collier et al. 2000	AESOPS-7b	<PF	206	3.9			
Collier et al. 2000	AESOPS-7b	<PF	481	3.7	275.0	-0.2	Decrease
Tesi et al. 2012	O-1300	<PF	1300	5.0			
Tesi et al. 2012	O-3700	<PF	3700	6.1	2400.0	1.1	Increase
Trequer et al. 1998	Antares-M2	PF-SAF	1300	1.5			
Treguere et al. 1998	Antares-M2	PF-SAF	4000	1.0	2700.0	-0.5	Decrease
Treguere et al. 1998	Antares-M3	<PF	1300	11.0			
Trequer et al. 1998	Antares-M3	<PF	3500	5.3	2200.0	-5.7	Decrease

POC:PIC CHANGES WITH DEPTH FROM MULTI-TRAP DEPTH MOORINGS