Natural iron fertilization in the Southern Ocean

Overview of the KEOPS project (2004-2008)

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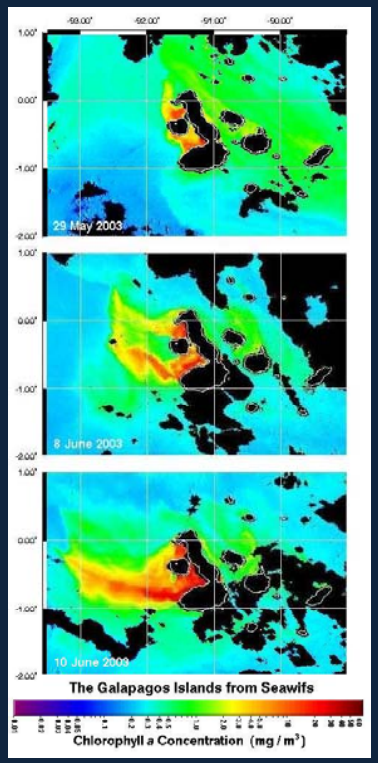
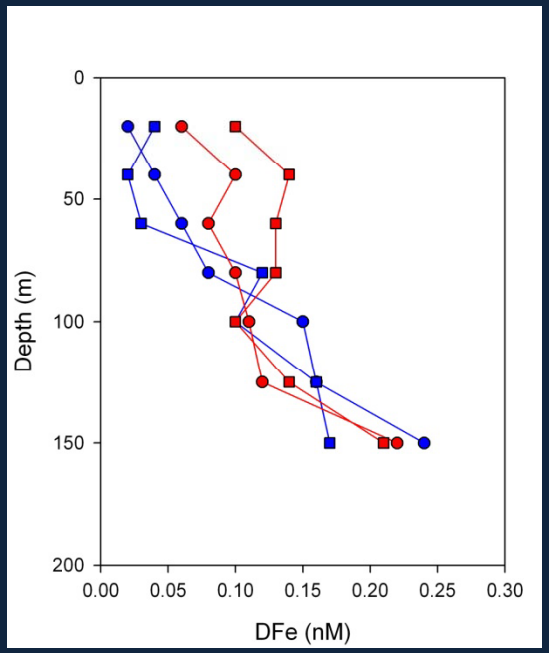
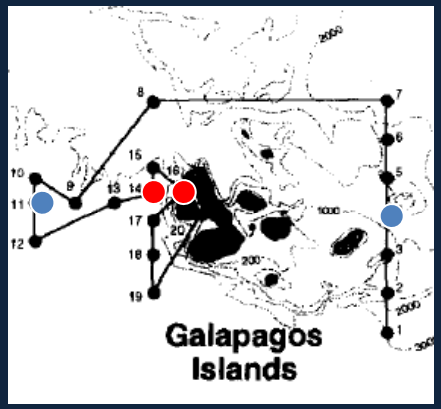
1992

"….In conjunction with this research a study will be made of the HNLC water west of the Galapagos Islands. This area is of interest since it appears to represent a natural enrichment experiment."

Summary of the NSF proposal, J. Martin 1992

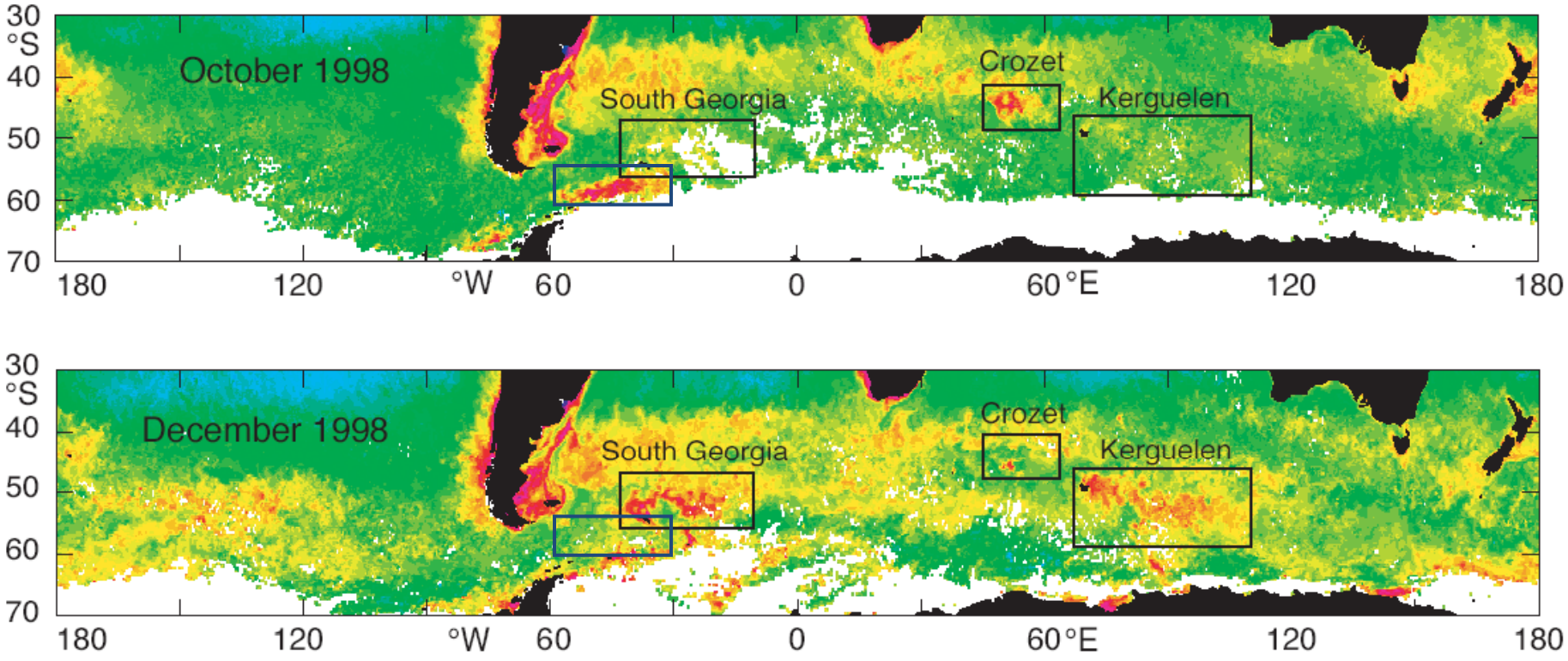






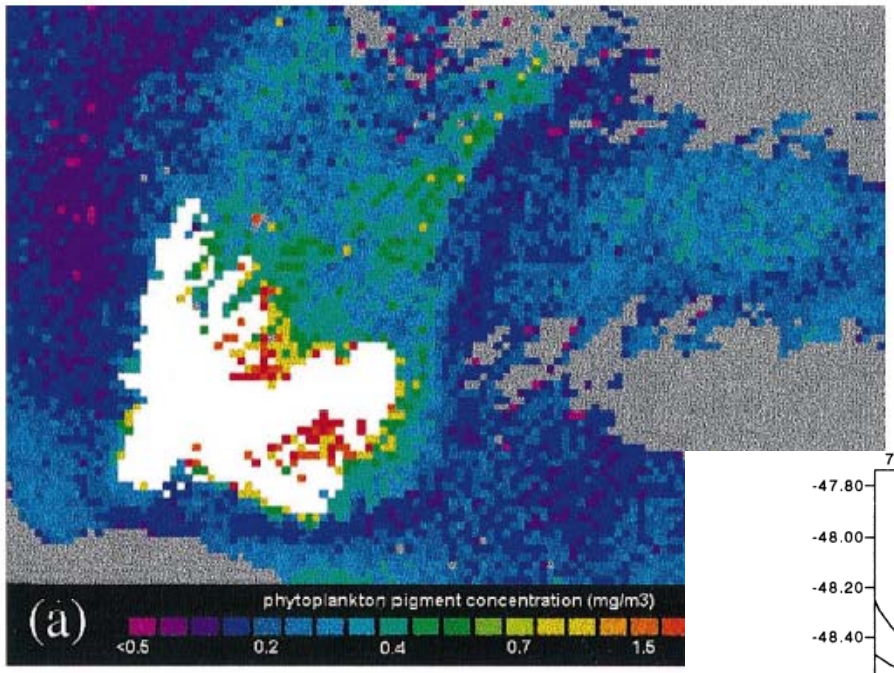
Gordon et al. 1998

Potentiel sites for natural iron fertilization studies in the Southern Ocean



Adapted from Pollard et al. 2000

1995 : preliminary study at Kerguelen



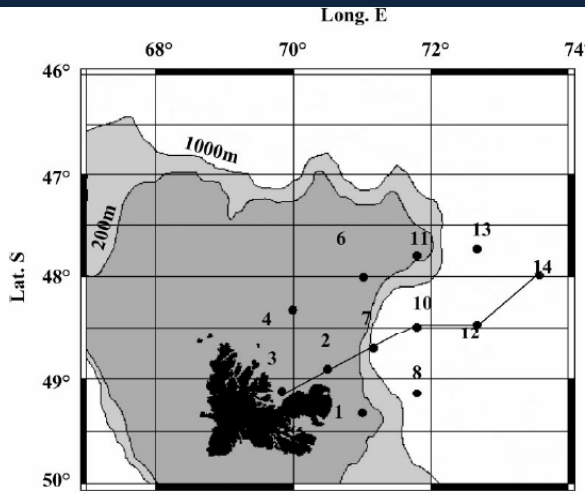
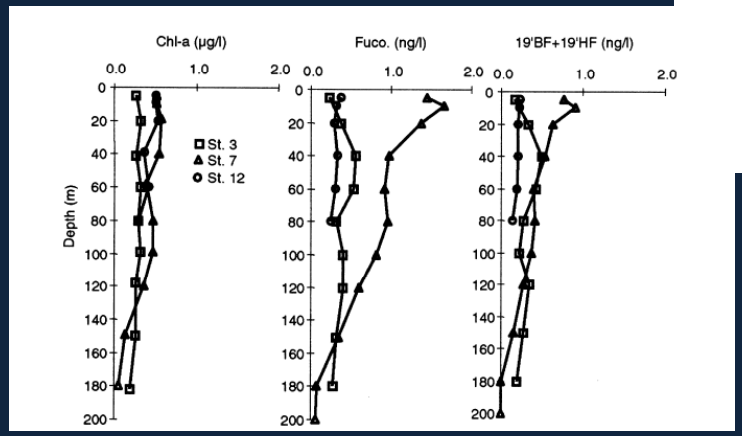
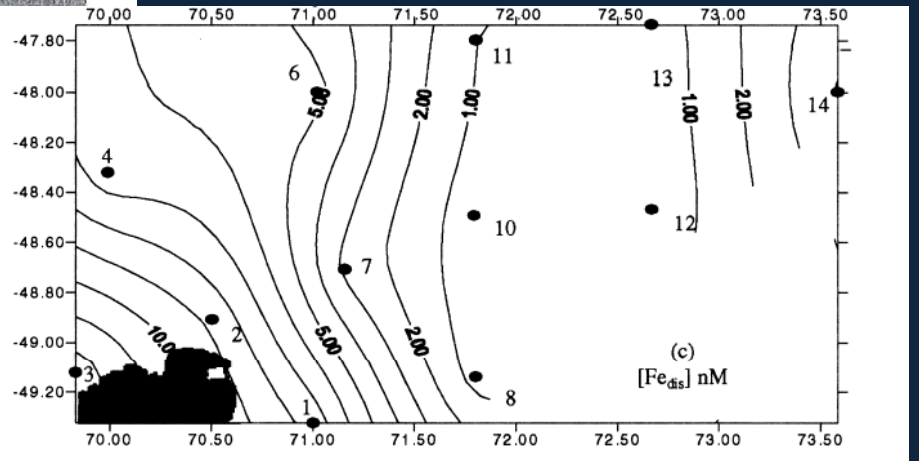


Fig. 2. Location of the stations occupied down stream of the Kerguelen Islands.

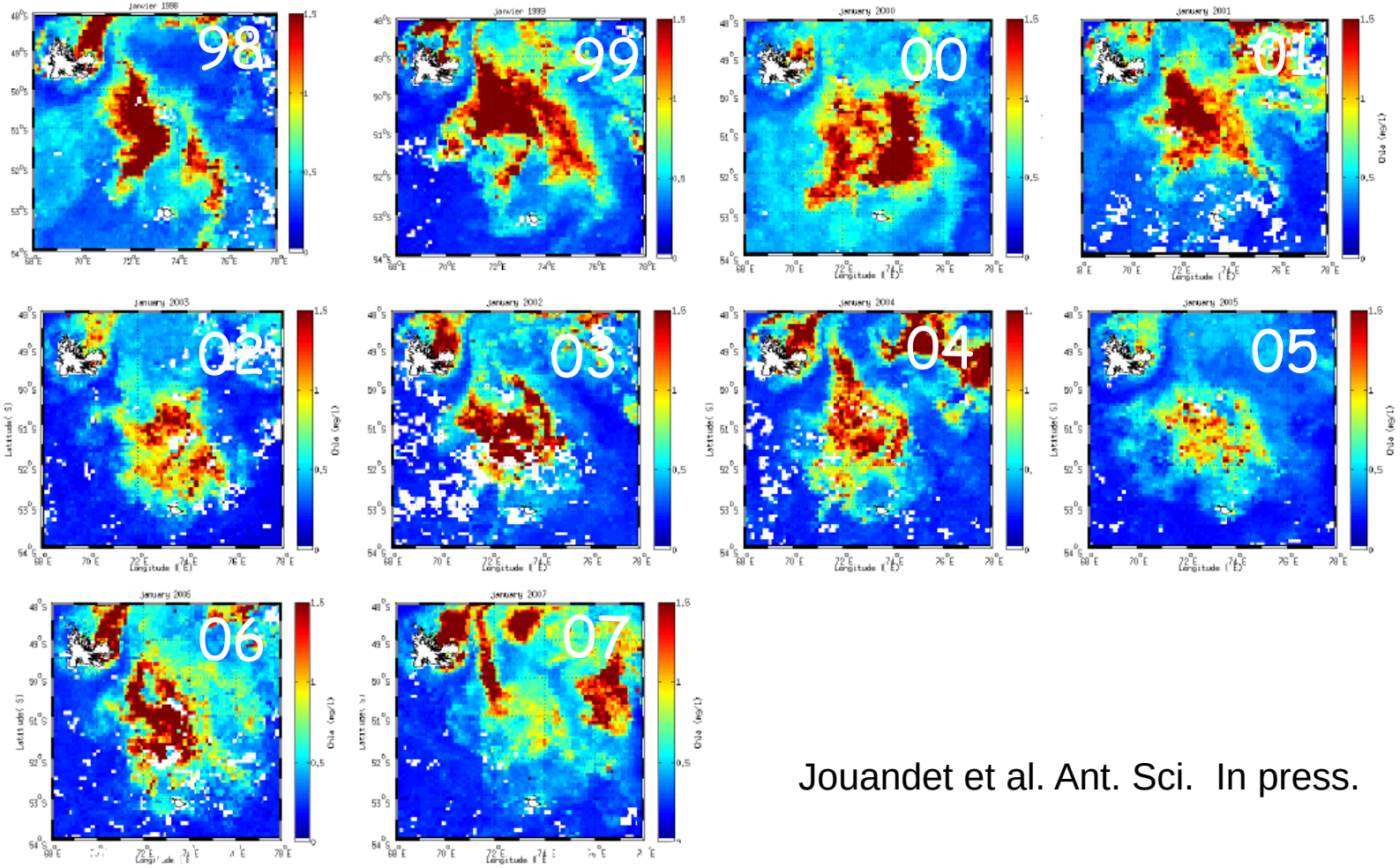




Blain et al. DSR 2001

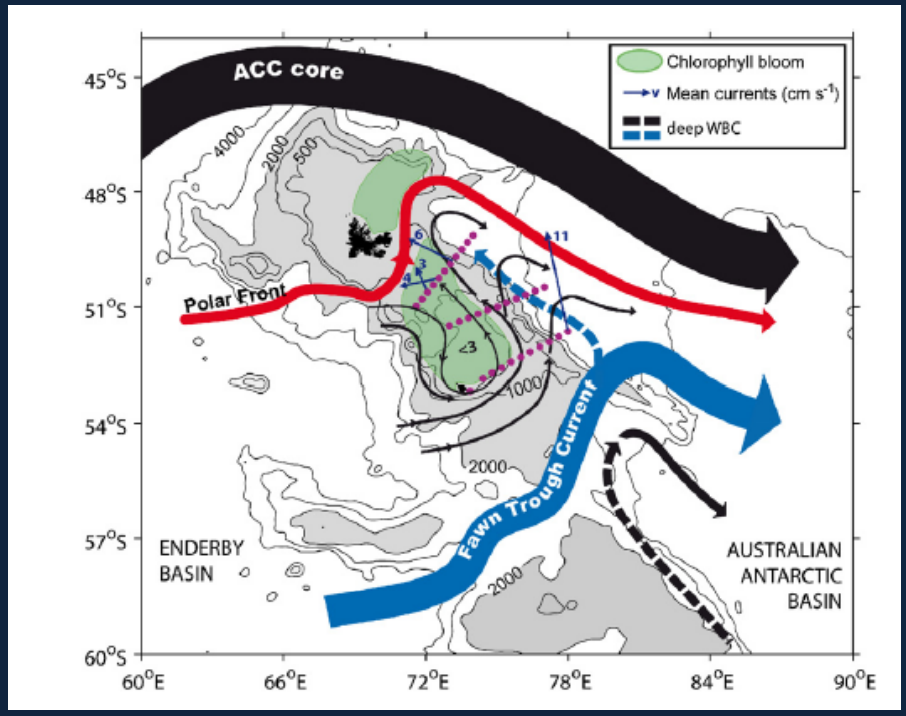
The interannual variability

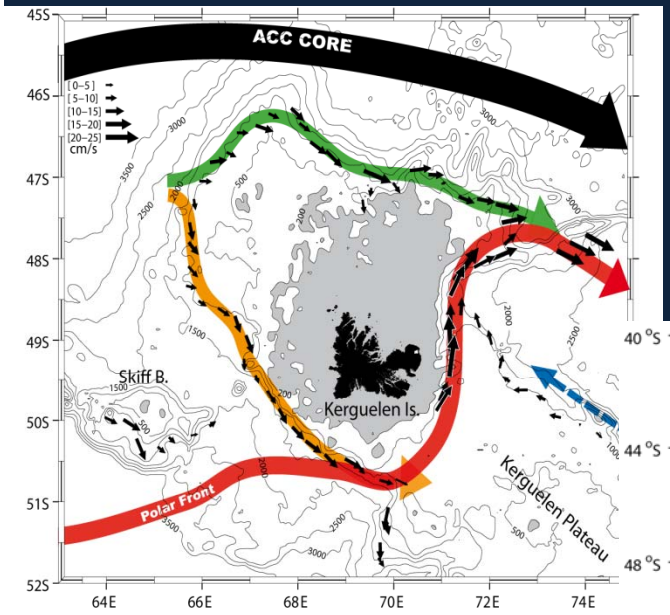
Monthly composite images (January)

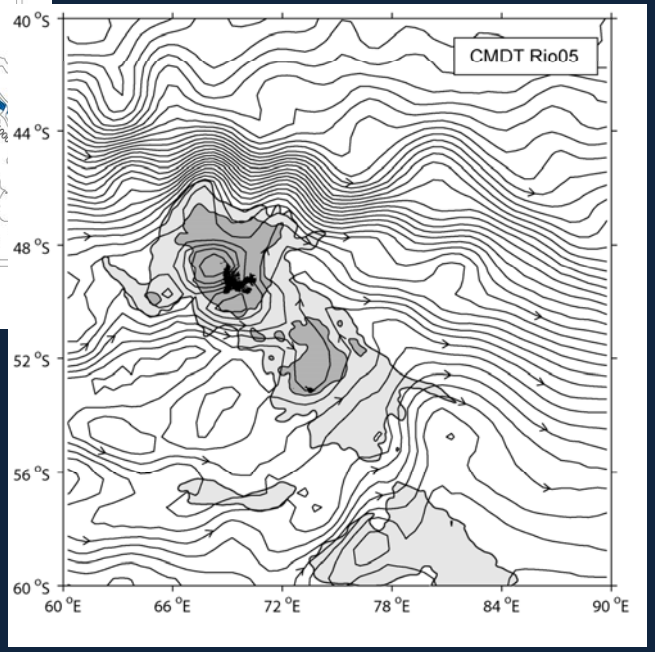


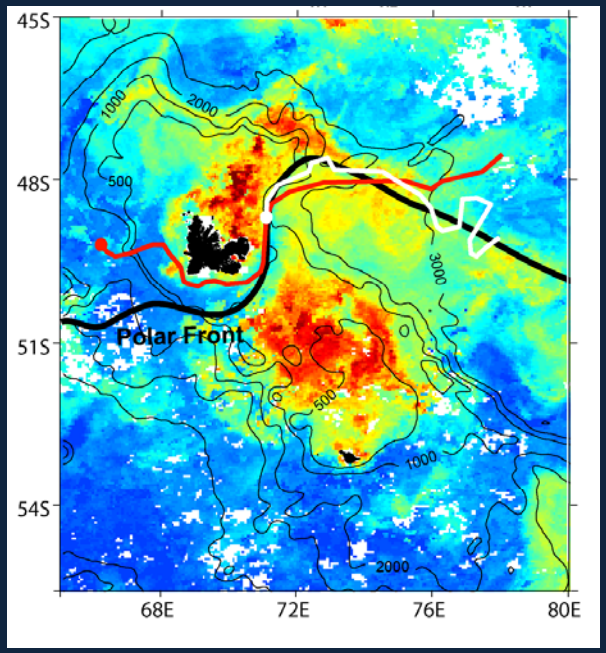
Jouandet et al. Ant. Sci. In press.

Circulation around Kerguelen





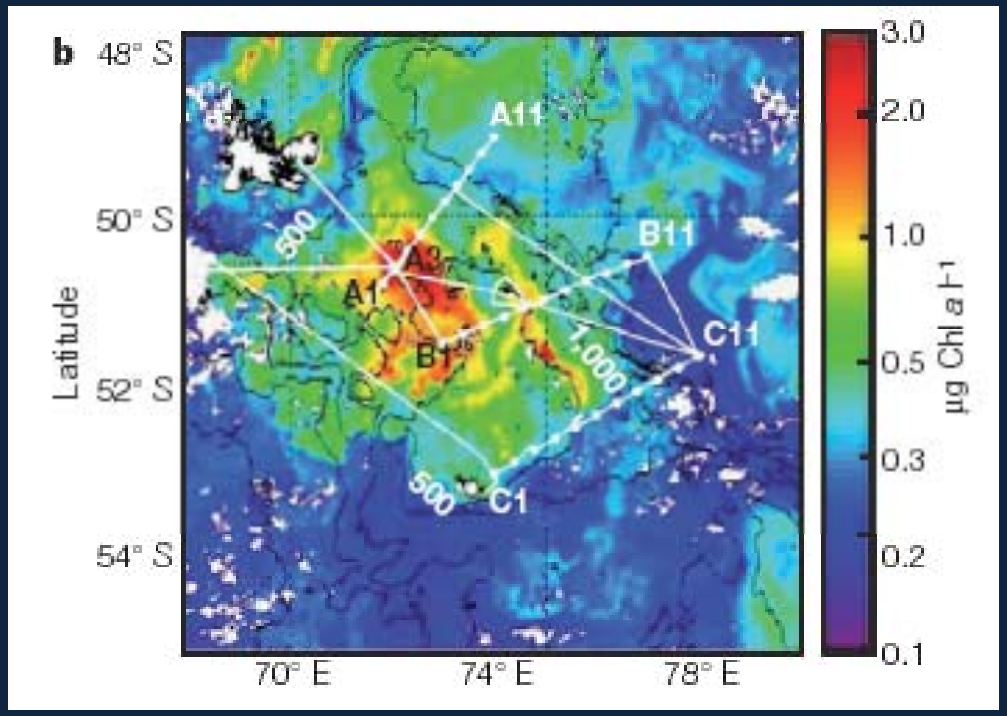


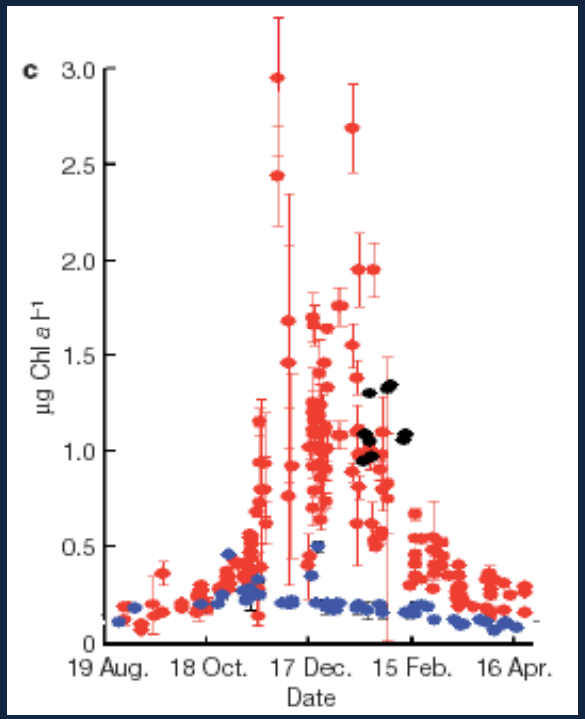


Park et al. 2008, 2009

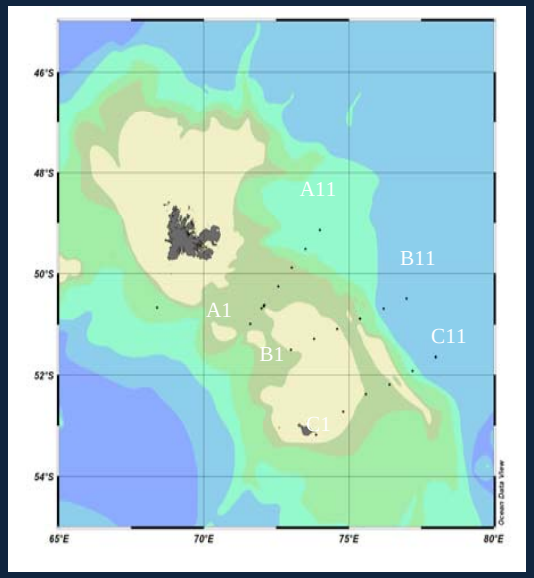
2005 KEOPS : Objectives

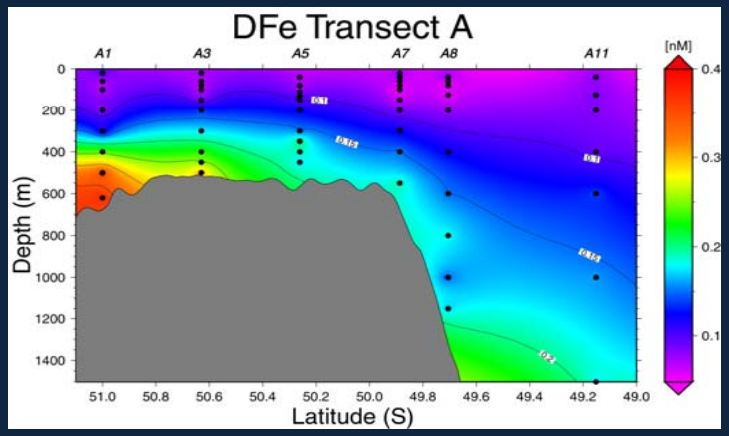
- ✓ To demonstrate that natural iron fertilization exists
- ✓ To describe the ecosystem structure and functioning in the fertilized area.
- ✓ To investigate the biogeochemical impacts of the natural fertilization.

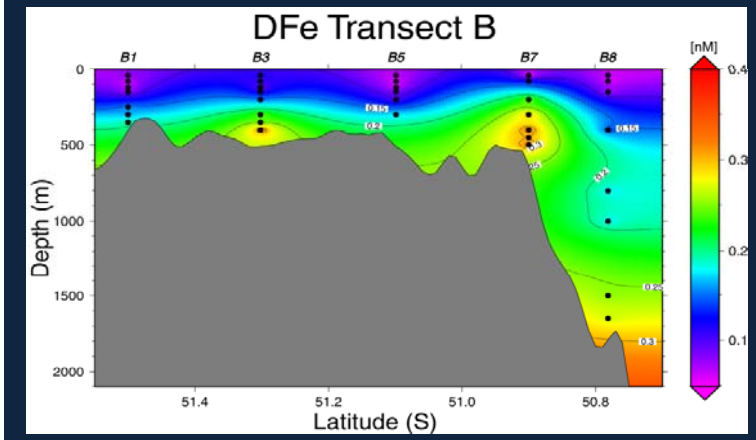


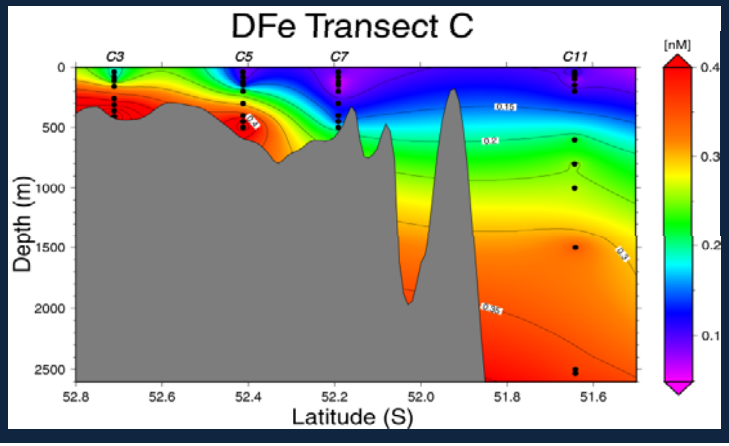


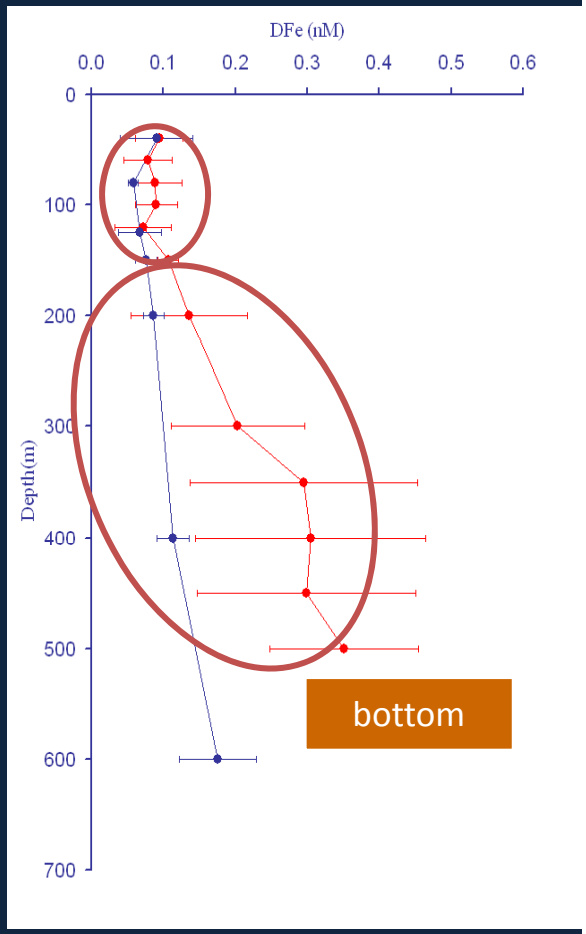
Iron fertilization





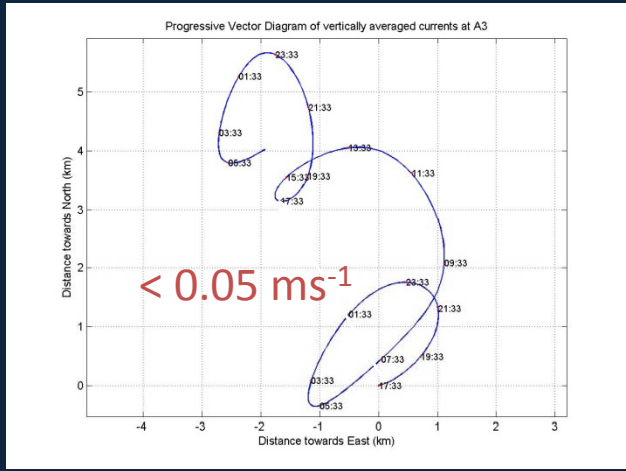




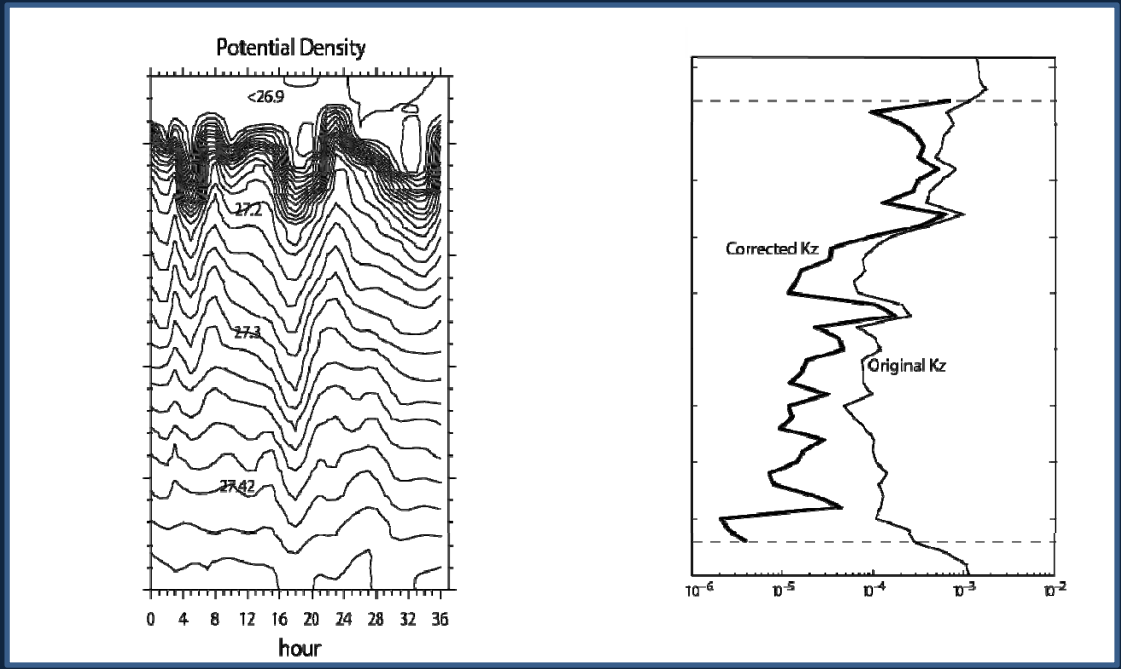


Blain et al. 2007, 2008

Dynamics above the plateau



Low advection above the plateau



Enhanced vertical mixing

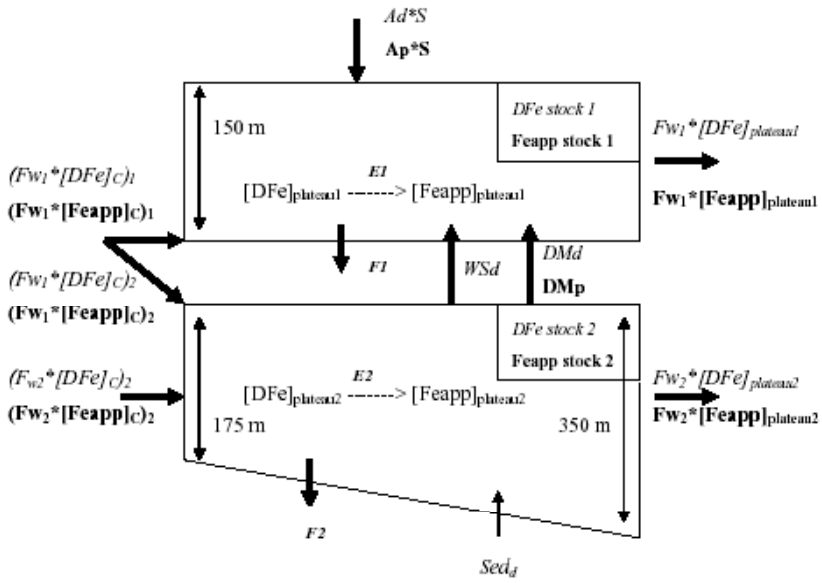
Iron budget :

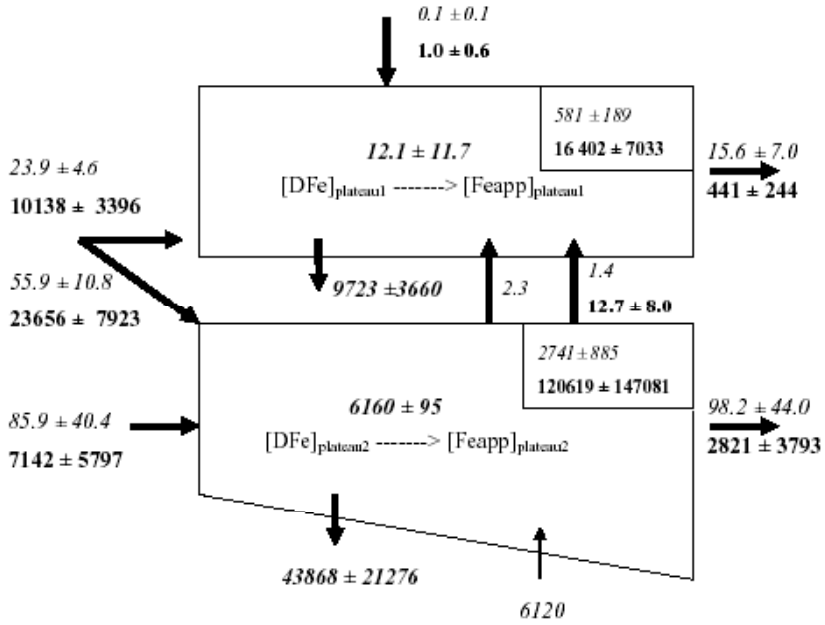
Table 2
DFe fluxes

Station	Bloom (A3)	HNLC(C11)
Short-term fluxes		
Vertical diffusivity (10^{-4} m^2 s^{-1})[a]	3.2	2.4
Vertical gradient (nmol m^{-4})[b]	1.12	0.2
Vertical supply (mmol m^{-2} d^{-1})[c]	31	4
Additional supply (mmol m^{-2} d^{-1})[d]	176	nd

Blain et al. 2007

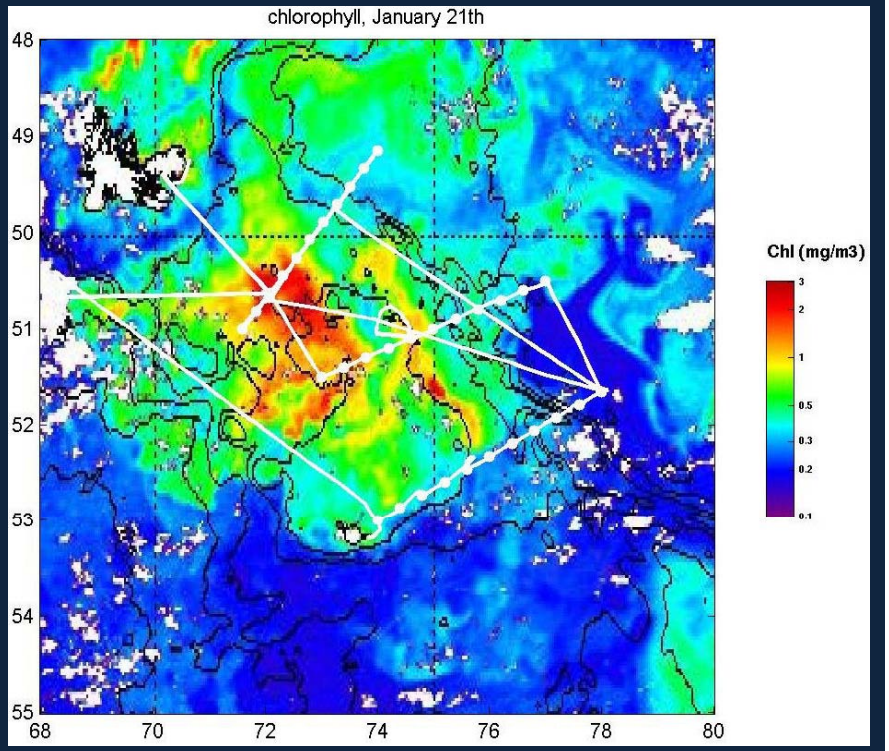
Detailed seasonal budgets of DFe and Feapp (TDFe-Dfe)

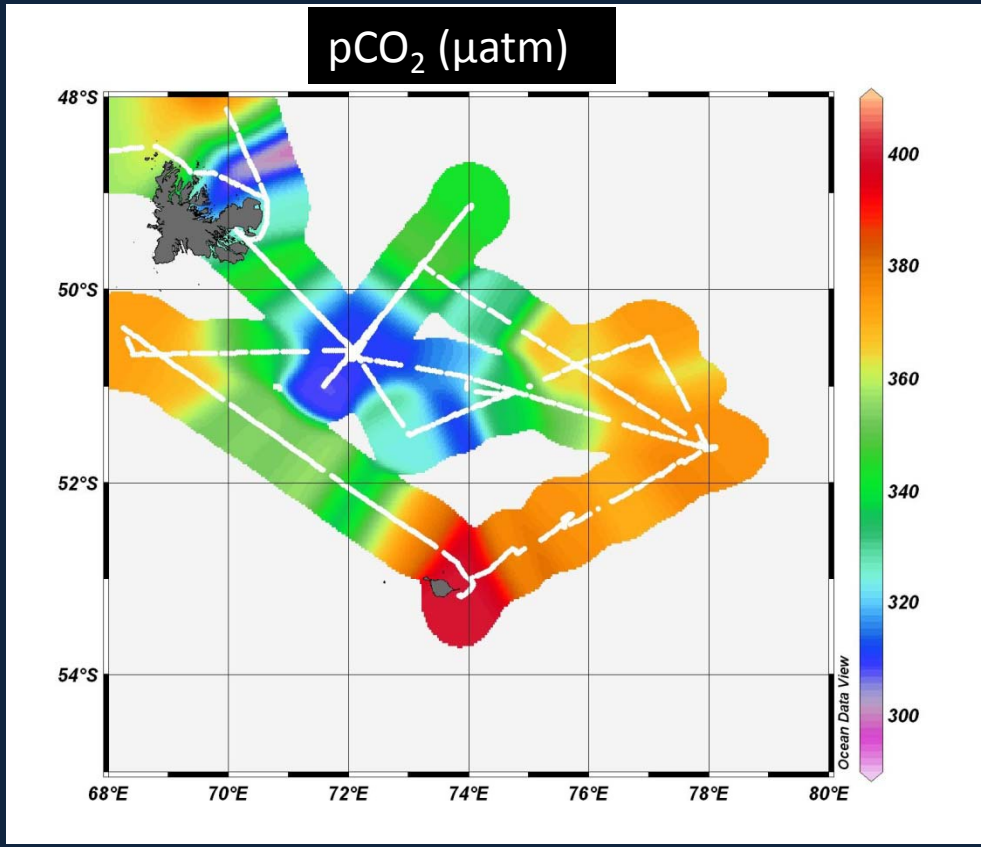




Chever et al. 2007, 2008

Carbon cycling

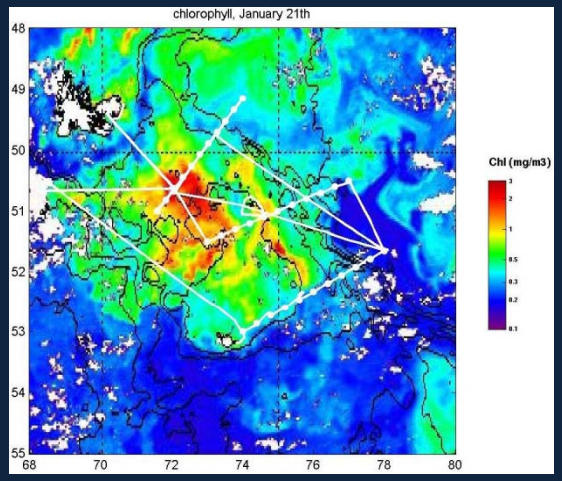


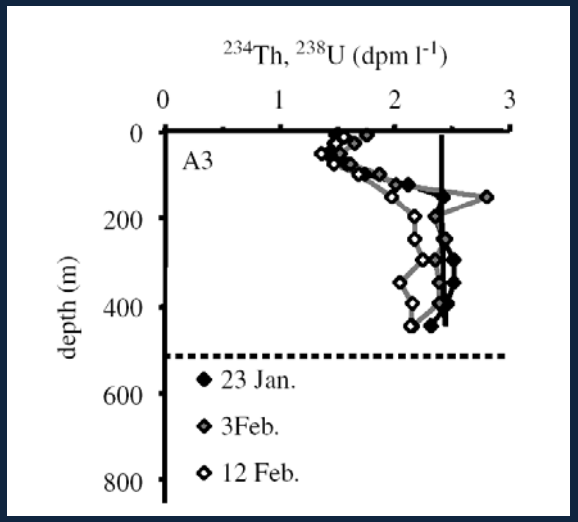


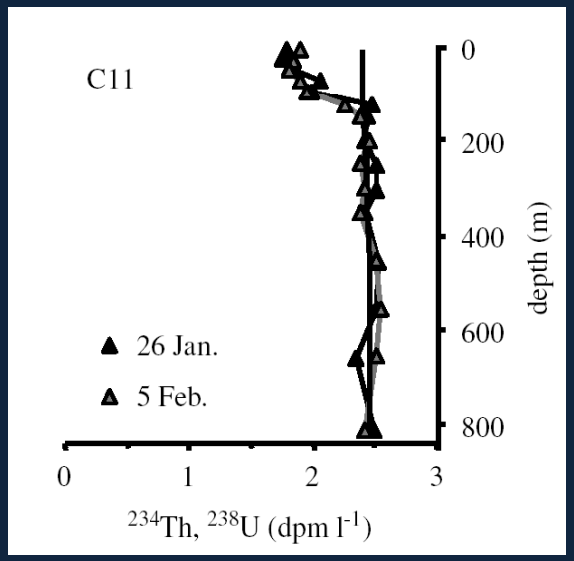
pCO_2 sink : 80 µatm

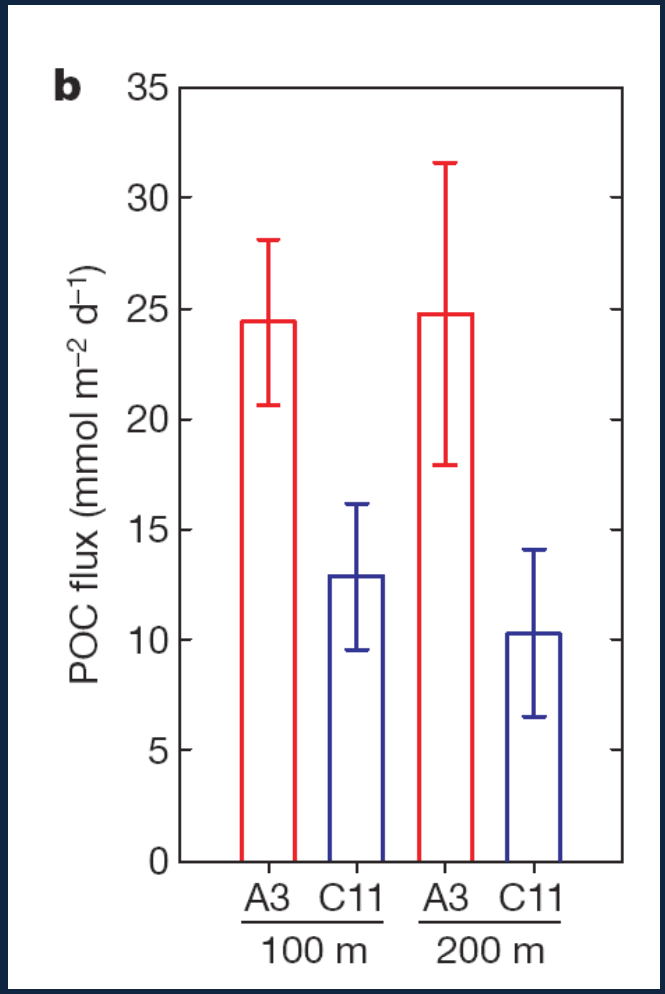
(Blain et al. 2007)

Short term carbon export (^{234}Th deficit method)









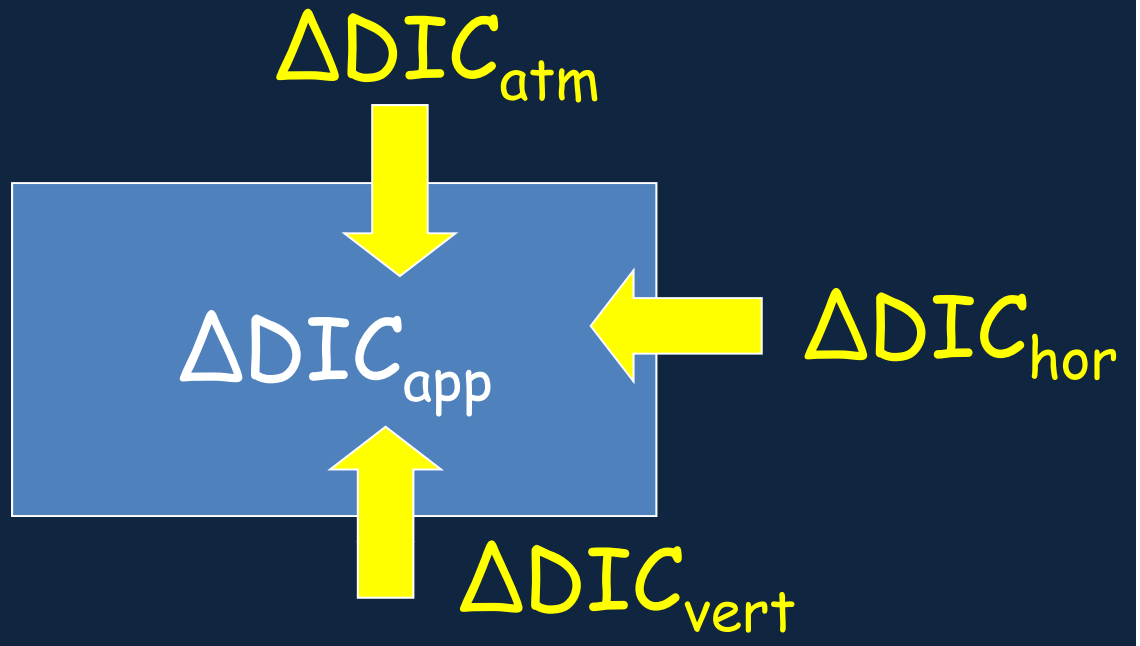
Excess of daily carbon export 10.8 ± 4.9 mmol *C* m^{-2} d^{-1} (Savoye et al. 2008)

Seasonal carbon budget :

seasonal NCP

+ Fe 6.6 ± 2.2 mol m^{-2}

-Fe 1.9 ± 0.4 mol m^{-2}



Excess of daily NCP 74±36 mmol m^{-2} d^{-1} ,

(Jouandet et al. 2008)

Excess of daily NCP by O_2 incubation 65-90 mmol m^{-2} d^{-1}

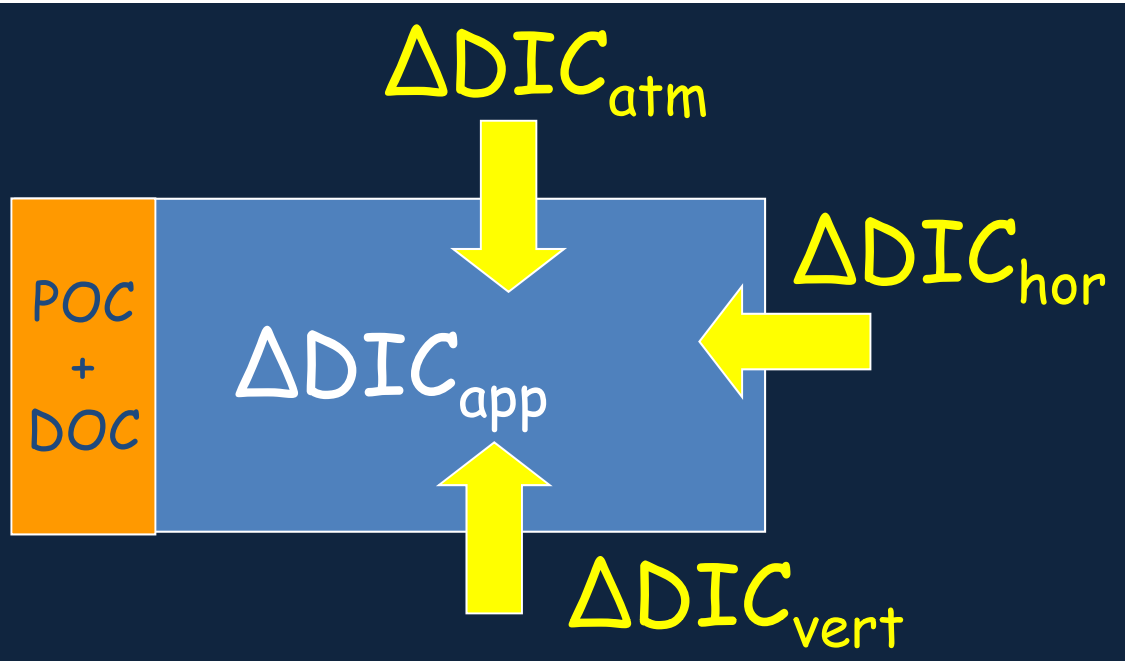
(Lefèvre et al. 2008)

Seasonal carbon export

seasonal C export :

+ Fe 5.4 ± 1.9 mol m^{-2}

- Fe 1.7 ± 0.9 mol m^{-2}

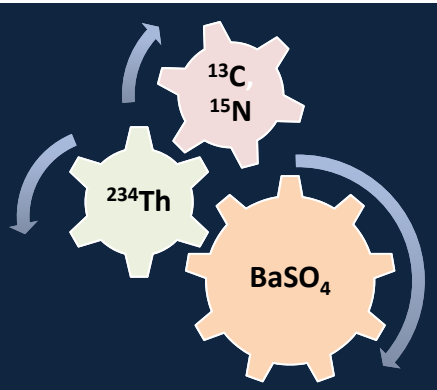


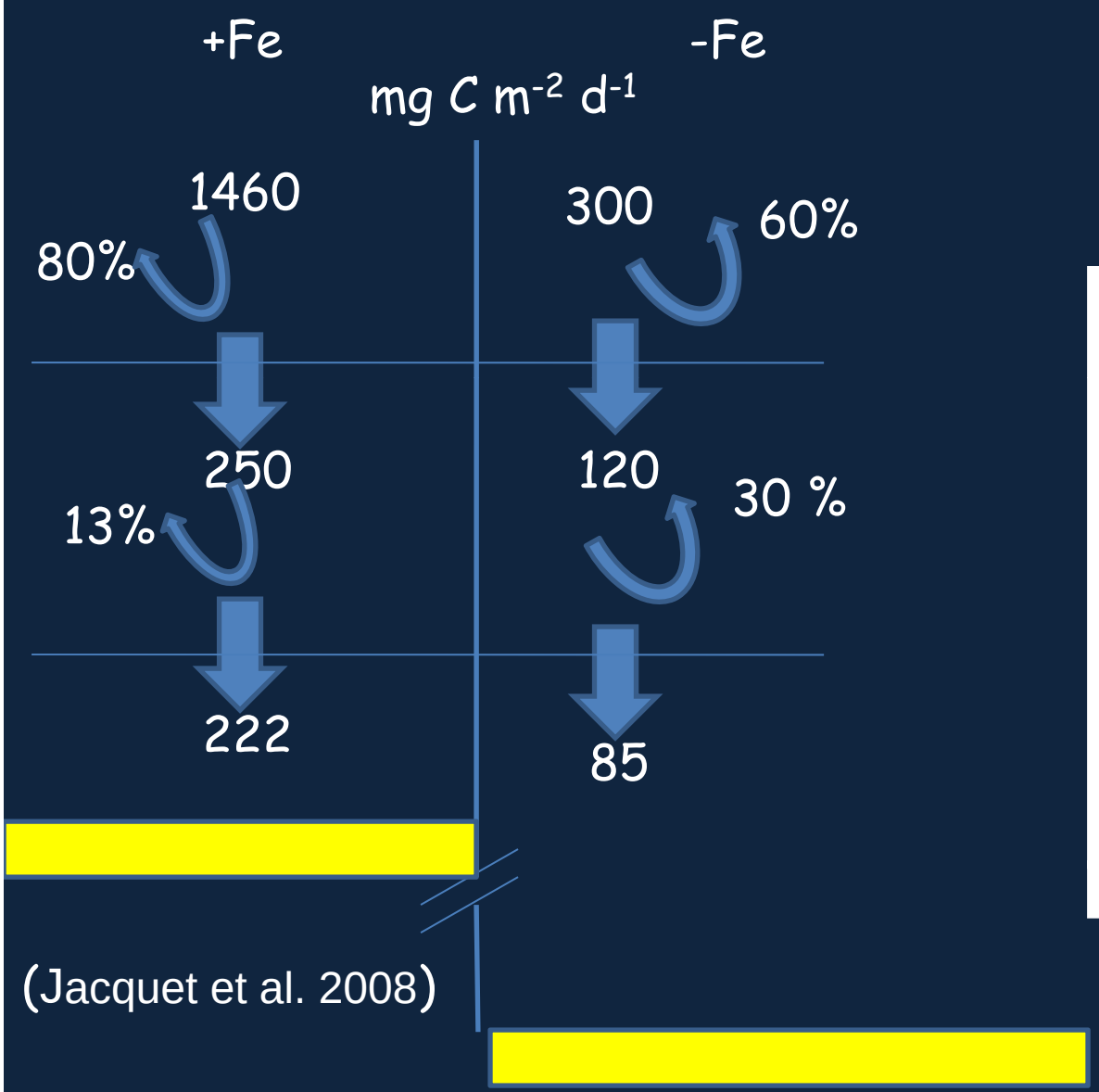
Excess of daily C export : 62 ± 33 mmol m^{-2} d^{-1}

From ^{234}Th : 10.8 ± 4.9 mmol C m^{-2} d^{-1} (Savoye et al. 2008)

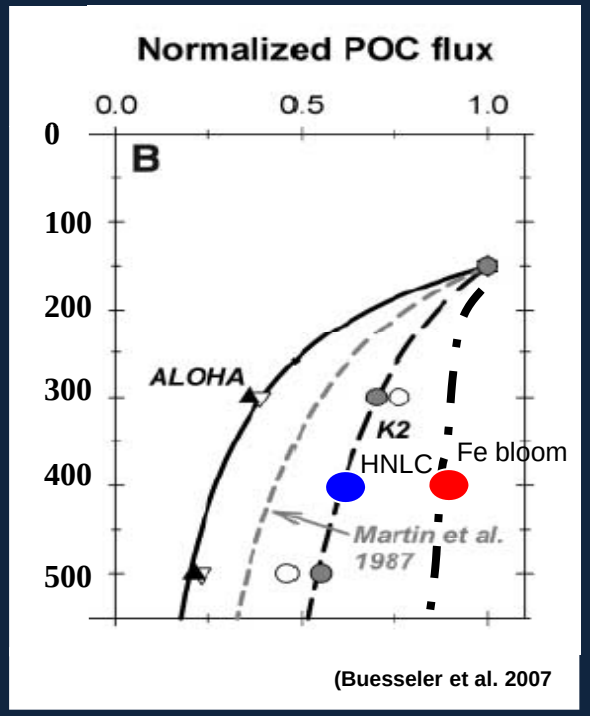
Site	Method (flux type)	Period	C flux mmol m^{-2} d^{-1}	Reference
Kerguelen Plateau	DIC mass balance (export)	entire season	23 - 85	Jouandet et al. 2008
Kerguelen Plateau	^{234}Th (export)	summer	12 - 24	Savoye et al. 2008
S.O. 145°E	NCP (O_2/Ar) (potential export)	Late summer	9 - 96	Cassar et al.
S.O. 145°E	New Production (potential export)	Late summer	8 - 27	Cavagna et al.
S.O. 145°E	^{234}Th (export)	Late summer	3 - 11	Jacquet et al.
S.O. 170°W	^{234}Th (export)	Spring to late summer	5 – 21 (44)	Buesseler et al.
Crozet	^{234}Th (export)	summer	2 - 20	Morris et al. 2007

Export production and remineralization





(Jacquet et al. 2008)



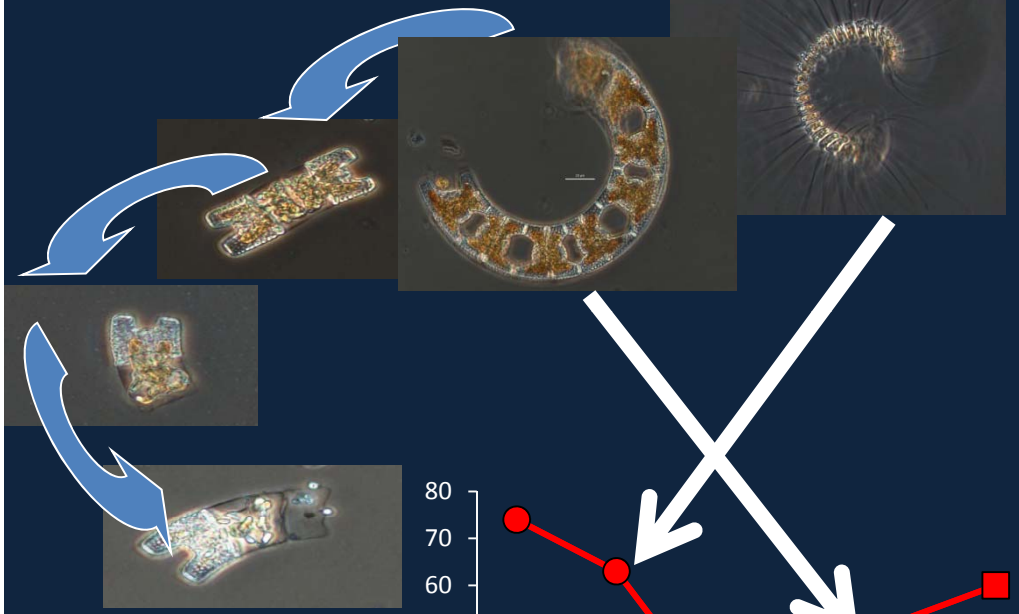
(Buesseler et al. 2007

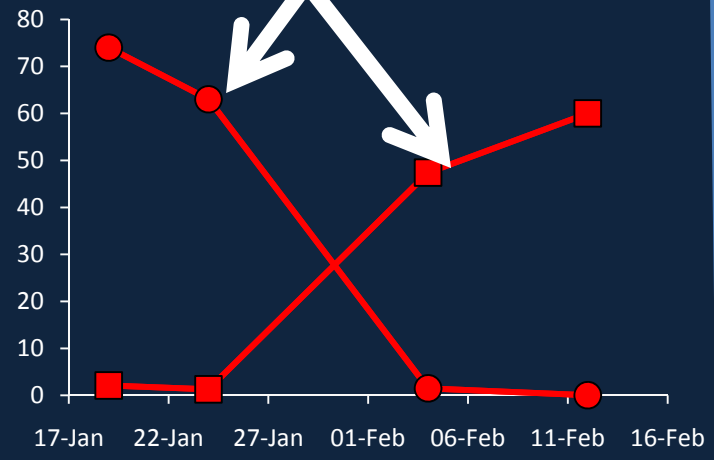
Key players of the phytoplankton community

+Fe

Eucampia antartica

Chaetoceros

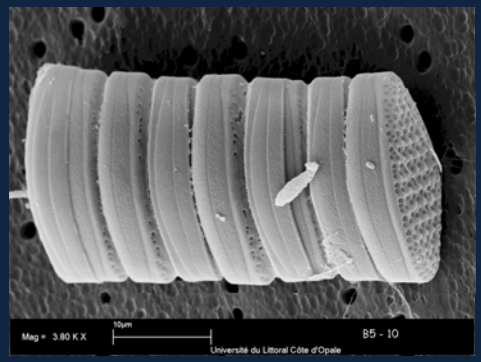


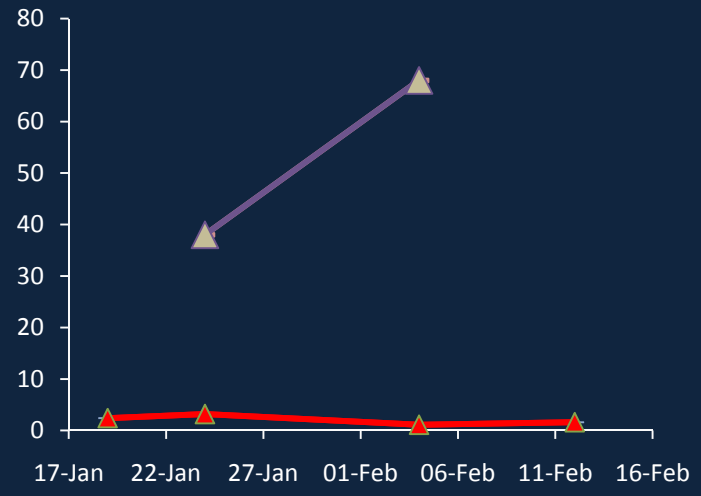


Si:C = 0.24
Uptake Si:C = 0.13

-Fe

Fragilariopsis kerguelensis
Fragilariopsis pseudonana

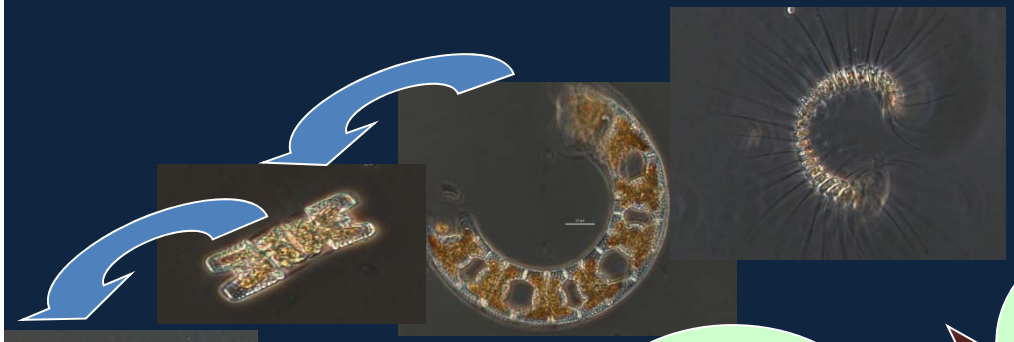




Si:C = 0.34
Uptake Si:C = 0.39

Armand et al. 2008

Role of grazing :



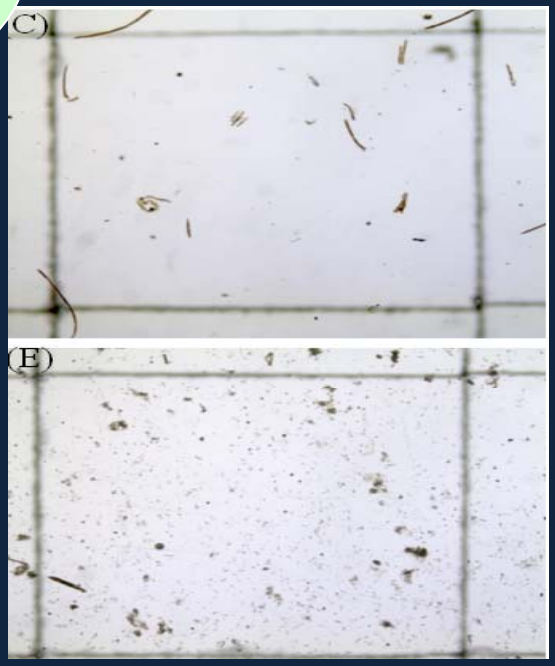
Armand et al. 2008

diatoms

copepods

N, P , Fe DIC Si

Mosseri et al. 2008, Carlotti et al. 2008
Uitz et al. 2009



Ebersbach et al. 2008

What is the efficiency of natural iron fertilization for carbon sequestration ?

$$R^{C:Fe}_{overall} = \frac{\Delta\Phi^{CO_2}_{air-sea}}{\Delta\Phi^{Fe}_{fertilization}}$$

$$R^{C:Fe}_{overall} = \frac{\Delta\Phi^{CO_2}_{air-sea}}{\Delta\Phi^{OrgC\&CaCO_3}_{export}} \times \frac{\Delta\Phi^{OrgC\&CaCO_3}_{export}}{\Delta\Phi^{Fe}_{fertilization}}$$

Sarmiento et al. 2010

What is the efficiency of natural iron fertilization for carbon sequestration ?

$$R_{utilization}^{Fe:C} = \frac{\Delta\Phi_{\exp ort}^{OrgC\&CaCO_3}}{\Delta\Phi_{fertilization}^{Fe}}$$

70,000 ± 40,000 Blain et al. 2007
154,000 Chever et al. 2010

8,500 (range 4,000-60,000) Pollard et al. 2009

2011-2014 KEOPS 2

Cruise :

Oct-Nov 2011