The role of ocean mixing in Southern Ocean iron-fueled phytoplankton blooms: insight from radium isotopes

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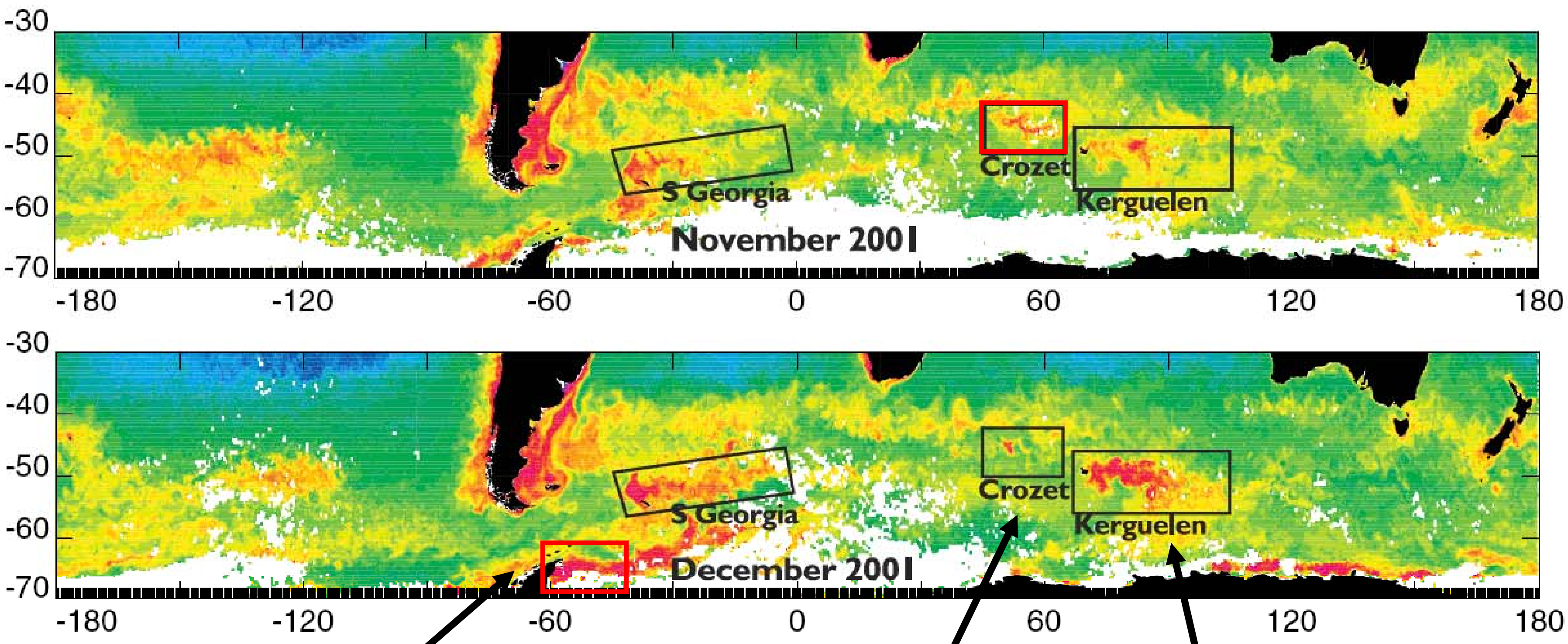
Funding from NSF (US), NERC (UK), and CNRS (France)

Intense Phytoplankton Blooms in HNLC Waters



1.Kerguelen Plateau

2.Shackelton Fracture Zone/Southern Scotia Sea

3.Crozet Plateau

Objectives

Key question(s):

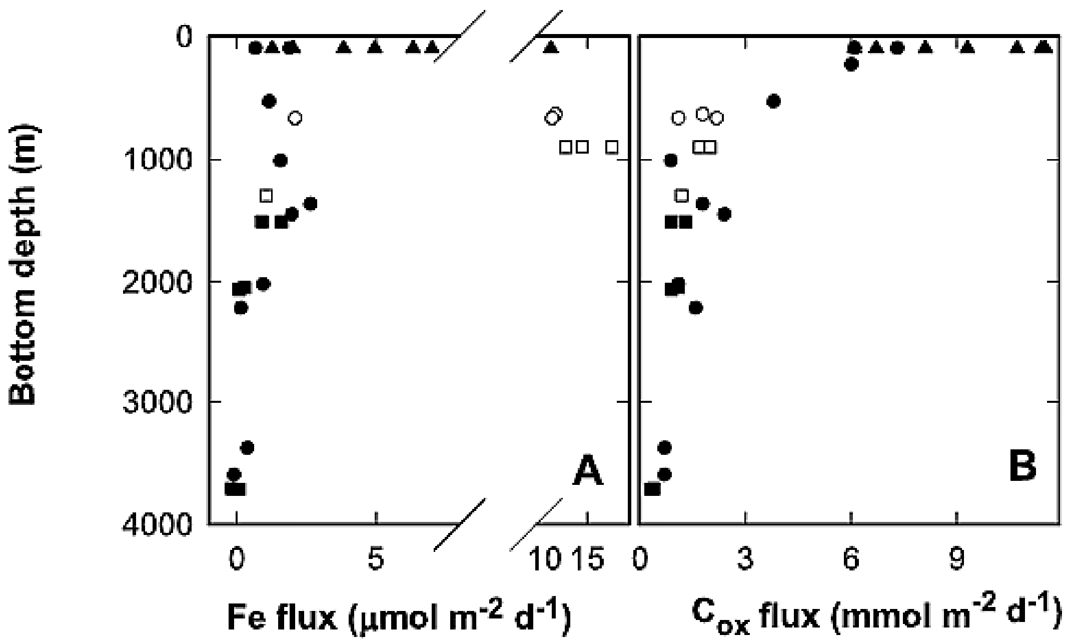
What are the sources of iron that fuel Southern Ocean phytoplankton blooms?

(a) Shelf/Island source?
    -propagation of the short-lived radium isotopes away from shore

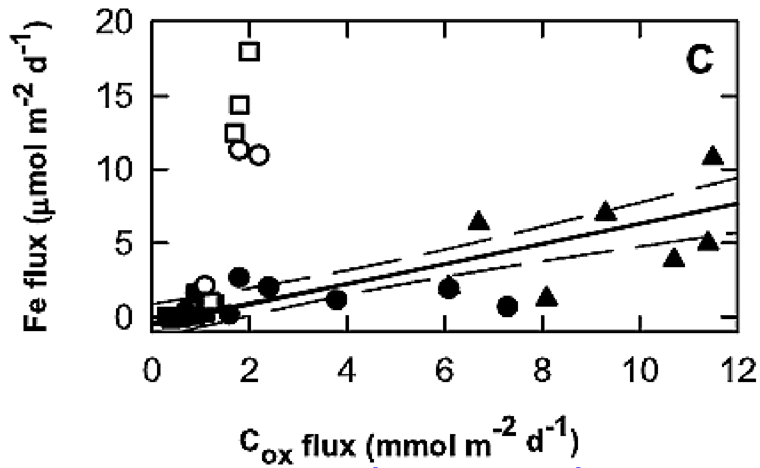
(b) Vertical mixing (sub-euphotic zone) source?
    -vertical gradient in a longer-lived radium isotope

Iron Fluxes from Continental Shelf Sediments

Elrod et al., 2004

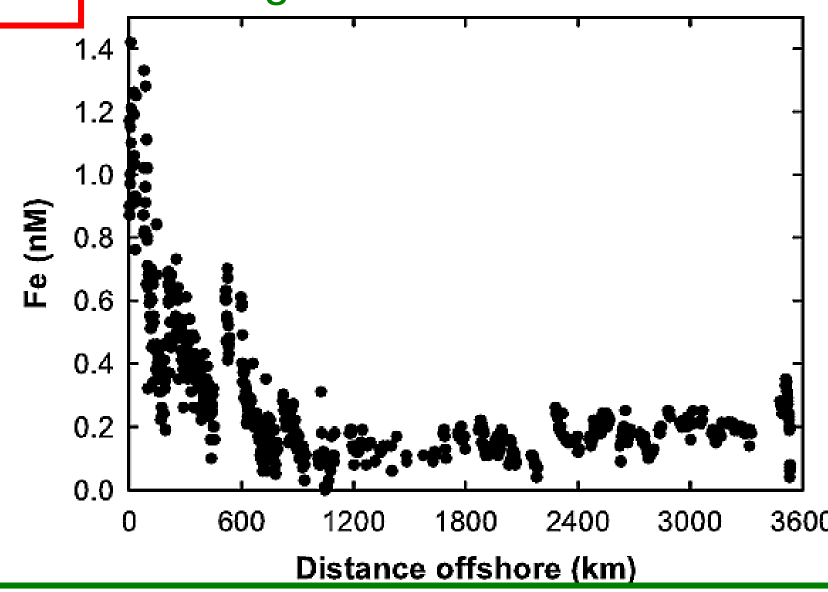


Highest in shallow marine sediments

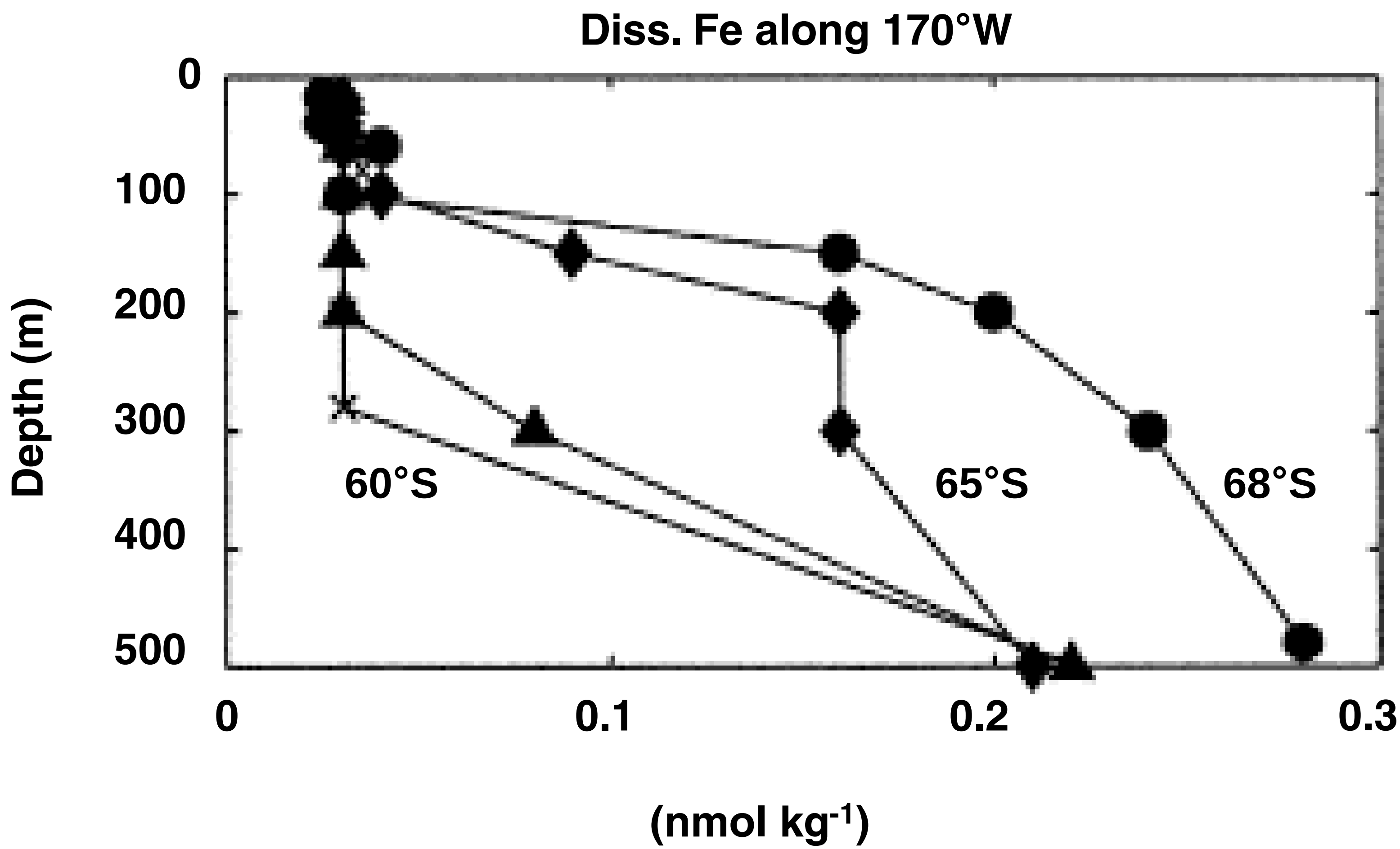


Increase in proportion to sediment O_2 consumption

Water column concentrations highest over shelves



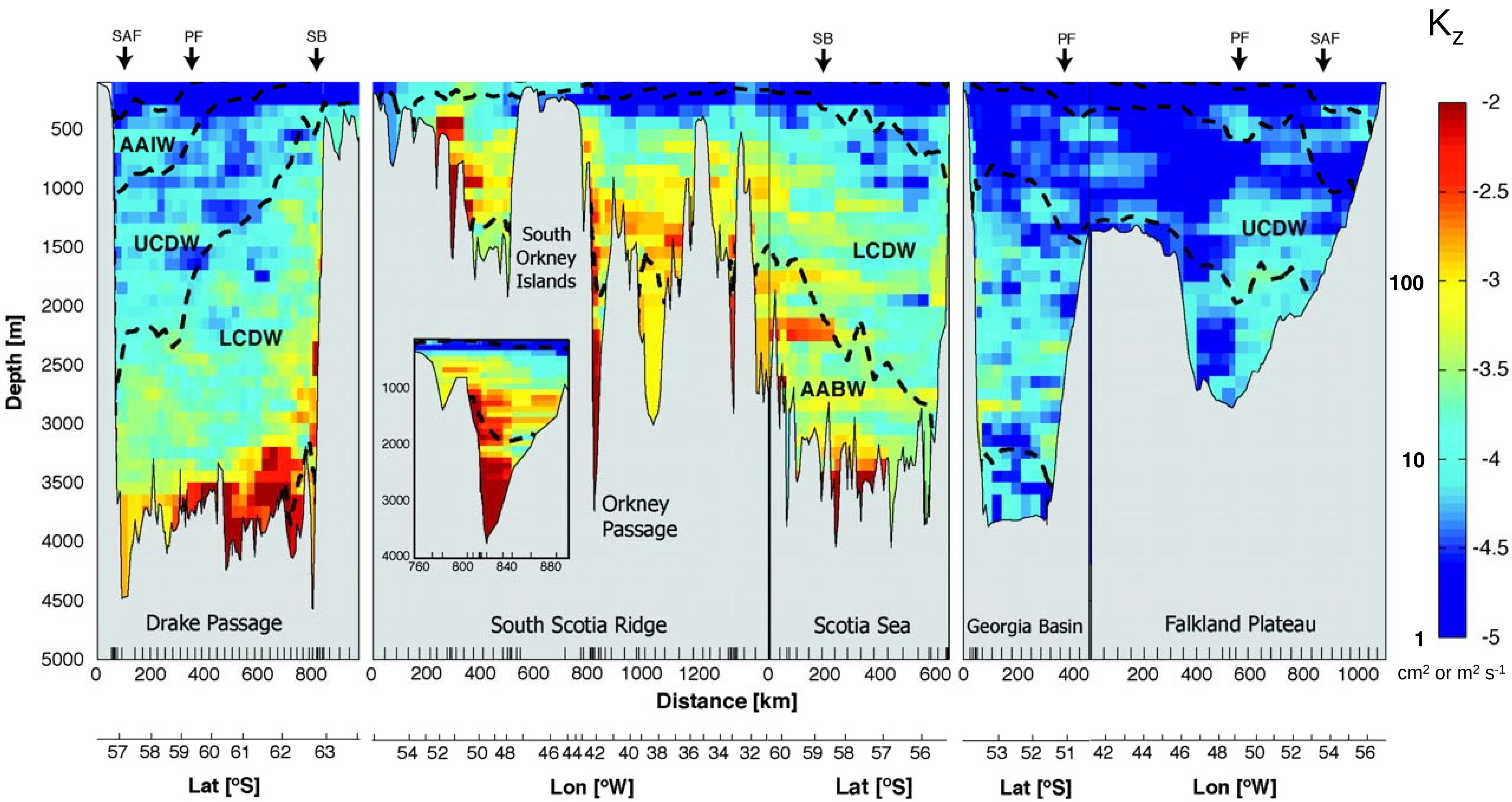
Vertical Mixing of Deep Water Iron



-Iron concentration increases with depth
-Diapycnal mixing may supply the necessary iron

Coale et al., 2005

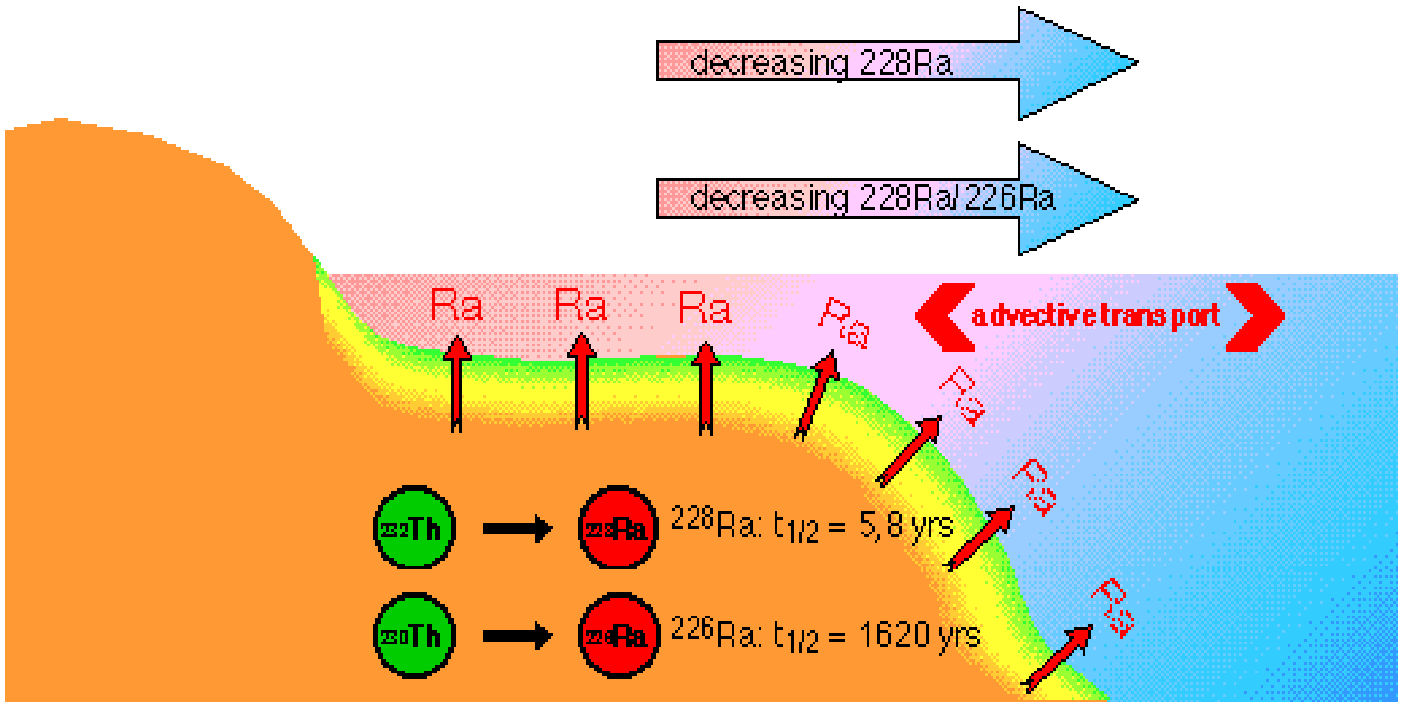
Enhanced Turbulent Mixing Over Rough Topography



-mixing rates increased 10-100x above and downstream of ocean plateaus and ridges
-increases observed >500-1000 m above the seafloor

Garabato et al., 2004

Radium isotopes (^{223}Ra, ^{224}Ra, ^{226}Ra, ^{228}Ra): Sources

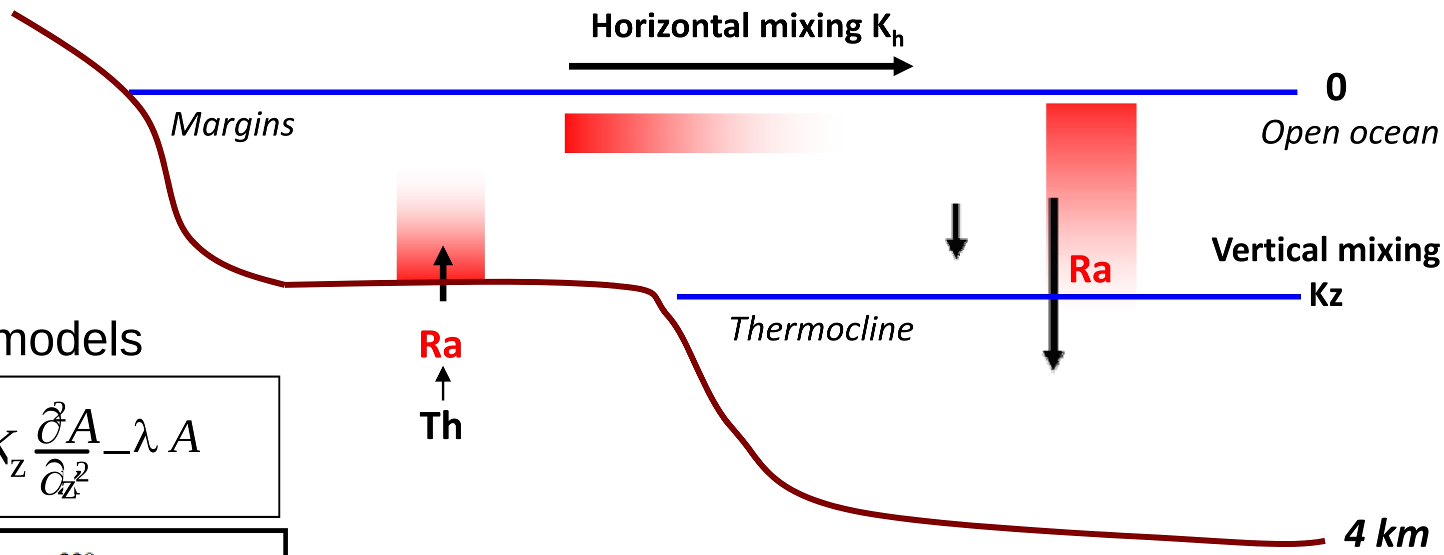


- Like iron, water above shelves is enriched in radium, which is not biologically or chemically scavengened

- Enrichments may be transferred to the open ocean by advection/diffusion transport processes

Estimate of transit time (Ra : chronometers)

Radium isotopes (^{223}Ra, ^{224}Ra, ^{226}Ra, ^{228}Ra): Mixing Tracers



2 models

$$\frac{dA}{dt} = K_z \frac{\partial^2 A}{\partial z^2} - \lambda A$$

$$t = \ln \frac{{}^{224}Ra_i / {}^{228}Ra_i}{{}^{224}Ra_o / {}^{228}Ra_o} * \frac{1}{\lambda_{224}}$$

Vertical Mixing: $^{230}Th \rightarrow$ ^{226}Ra, $^{232}Th \rightarrow$ ^{228}Ra

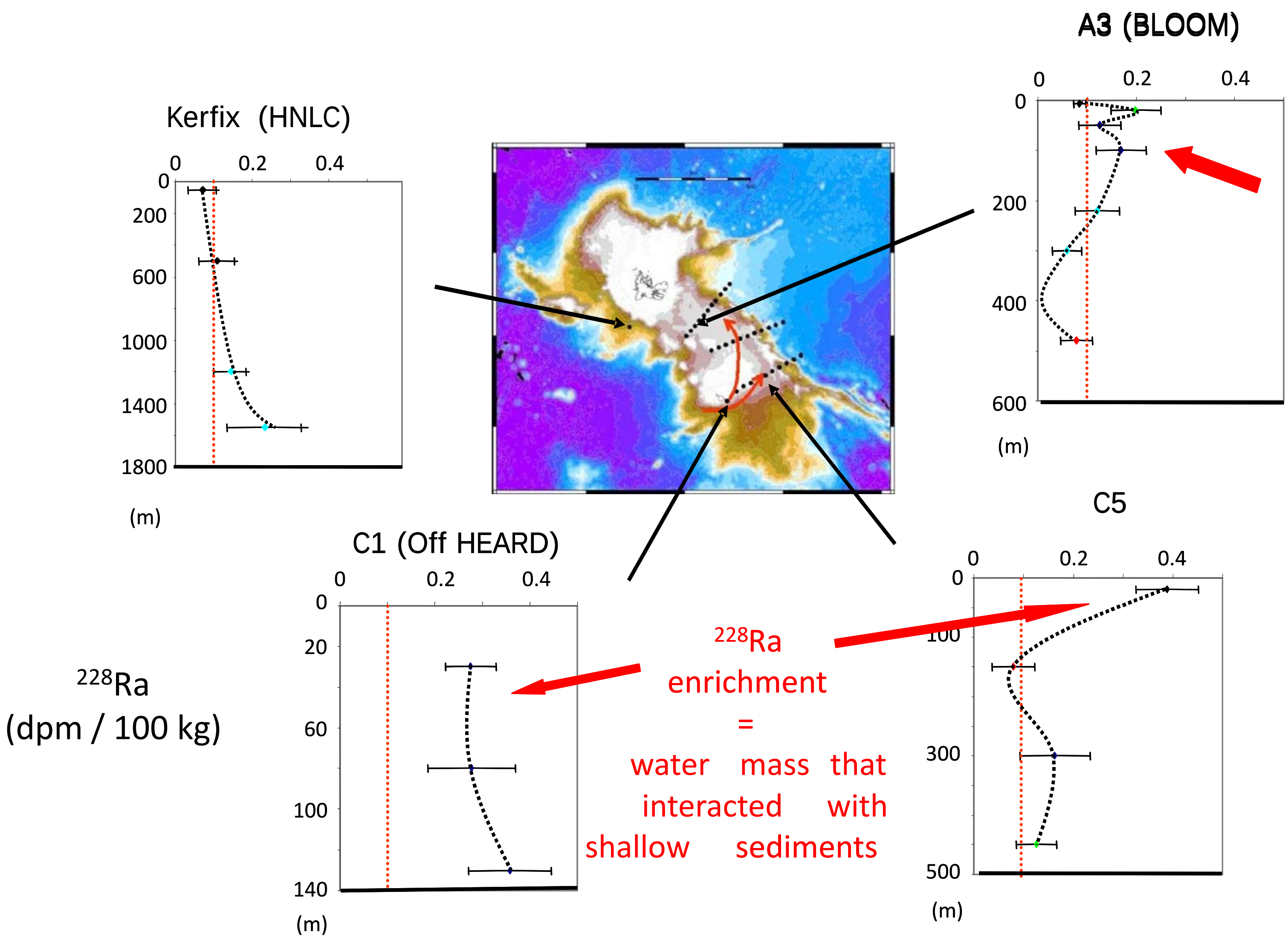
Horizontal Mixing: $^{227}Th \rightarrow$ ^{223}Ra, $^{228}Th \rightarrow$ ^{224}Ra

			Time scale
^{230}Th →	^{226}Ra	: 1600 y	
^{232}Th →	^{228}Ra	: 5.75 y	30 years
^{227}Th →	^{223}Ra	: 11.4 d	~2 months
^{228}Th →	^{224}Ra	: 3.66 d	~2 weeks

Kerguelen Plateau

KEOPS

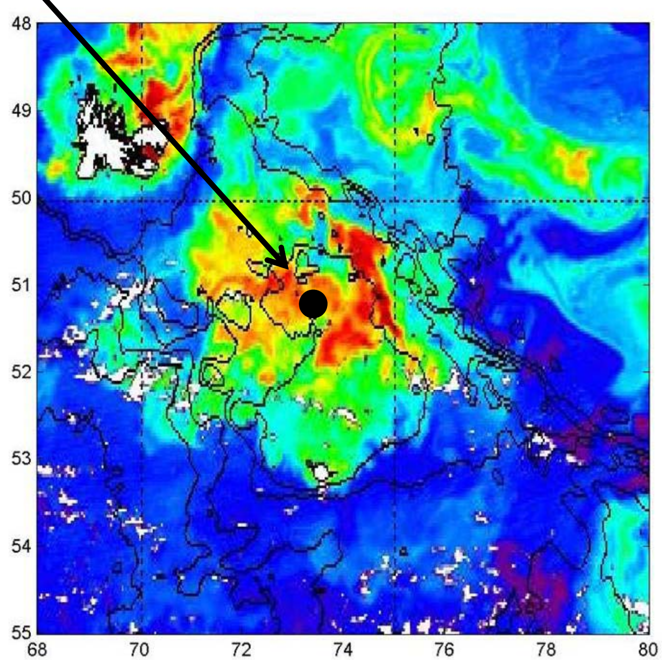
^{228}Ra : Tracing water masses that interacted with shallow sediments = advection

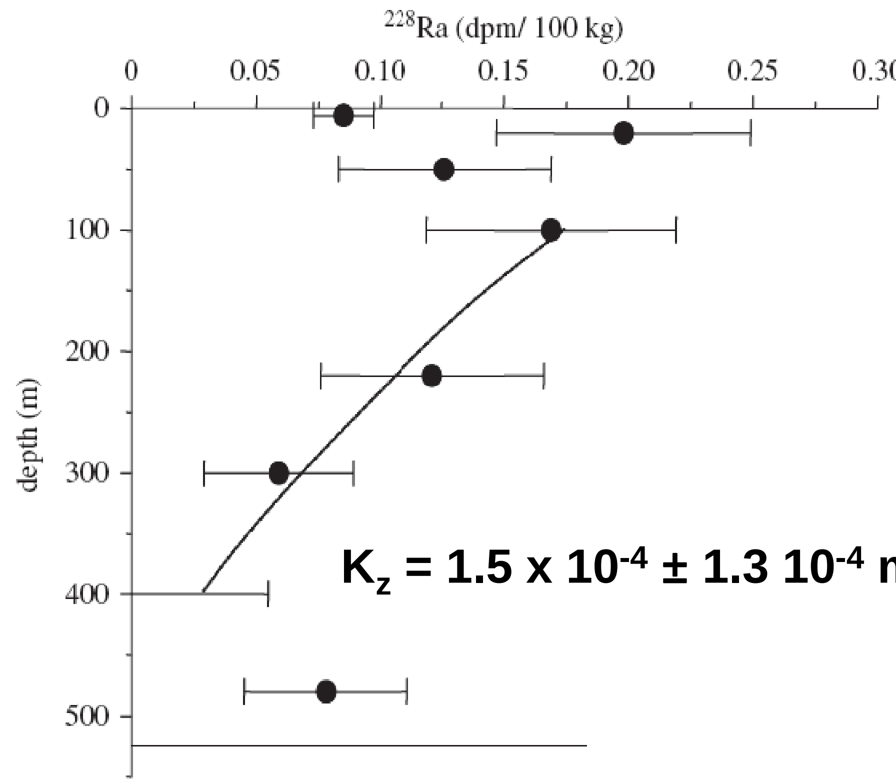


van Beek et al, 2008
Bourquin et al., 2008

^{228}Ra : quantification of the vertical mixing

Station A3





K_z = 1.5 x 10^{-4} ± 1.3 10^{-4} m^2 s^{-1}

Vertical Fe Flux on the Kerguelen Plateau = 1.0 - 14.3 nmol / m^2 d

Fe demand : 208 ± 77 nmol/ m^2 d

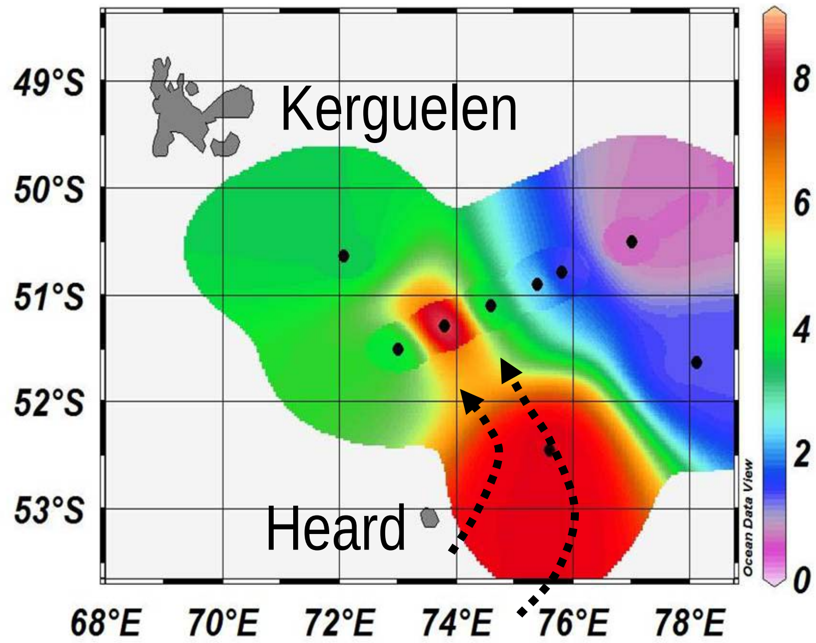
<u>Diapycnal mixing cannot supply enough iron to sustain the bloom</u>

van Beek et al, 2008

Distribution of Total Dissolvable Fe on the Kerguelen Plateau

(F. Chever et al.)

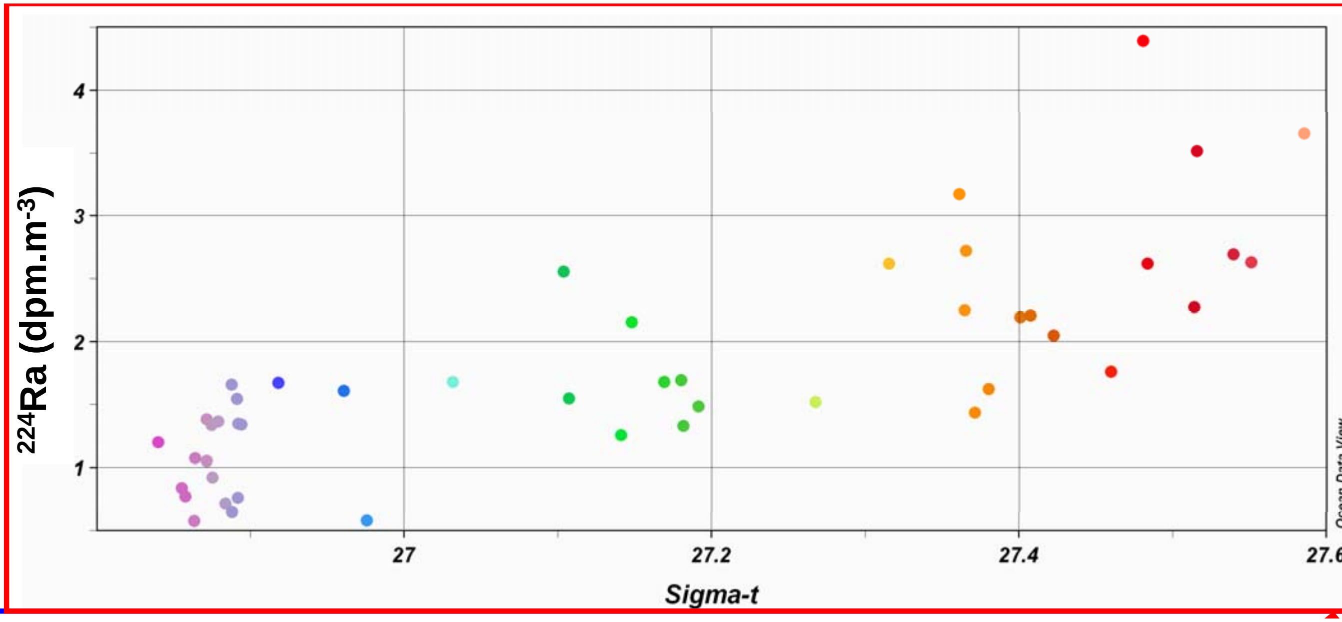
TDFe concentrations (nM) 0 - 500 m ; except C1



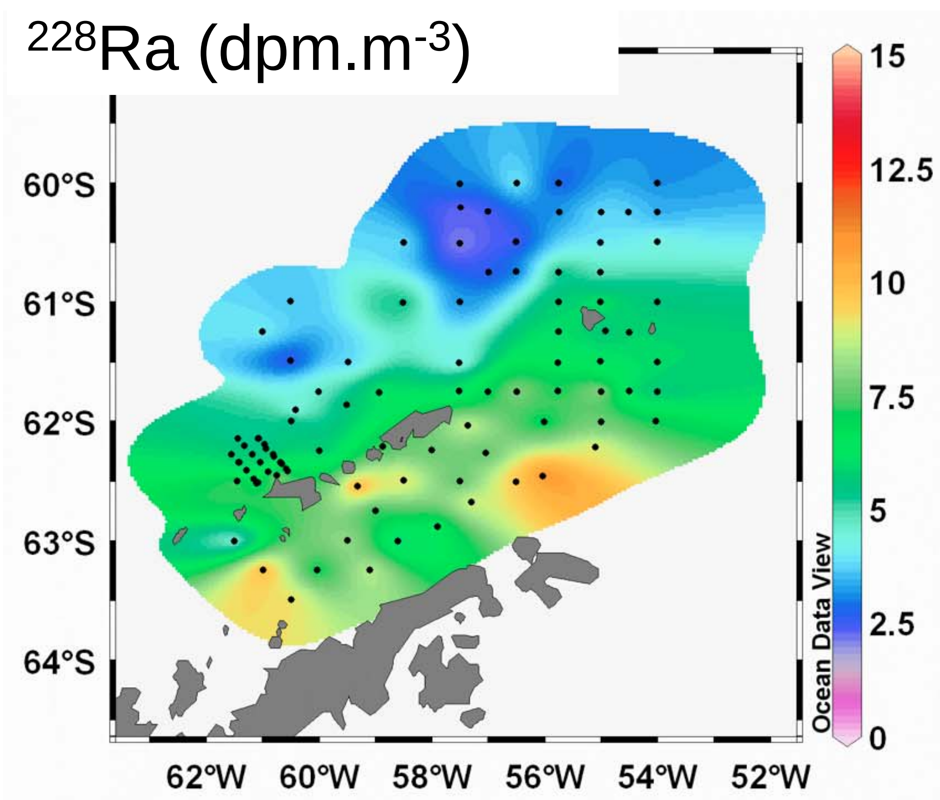
→ **Lateral transport : potentially significant Fe source for the Plateau**

Shackelton Fracture Zone

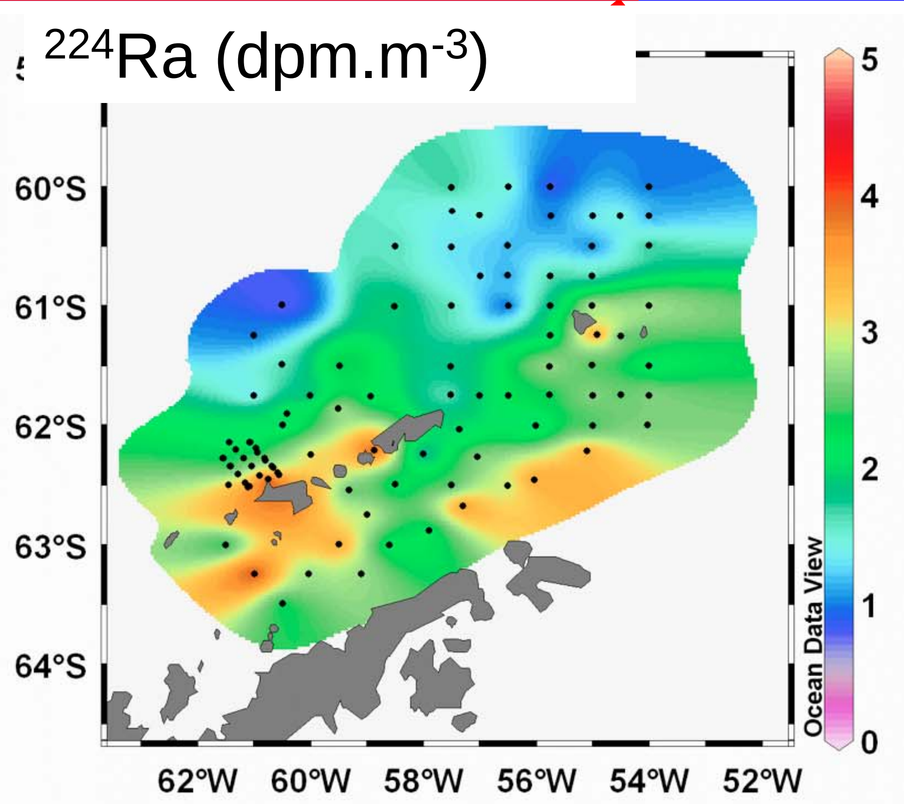
Jan-Feb
2006



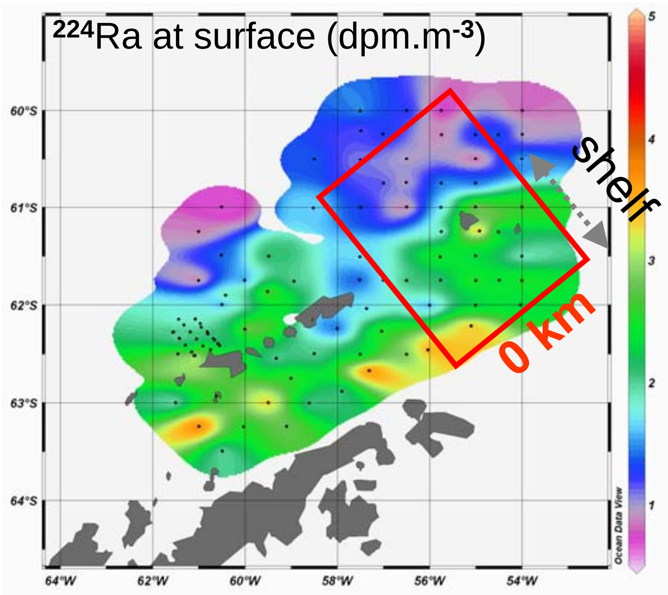
224Ra (dpm.m-3)
Sigma-t
4
3
2
1
27
27.2
27.4
27.6
Ocean Data View



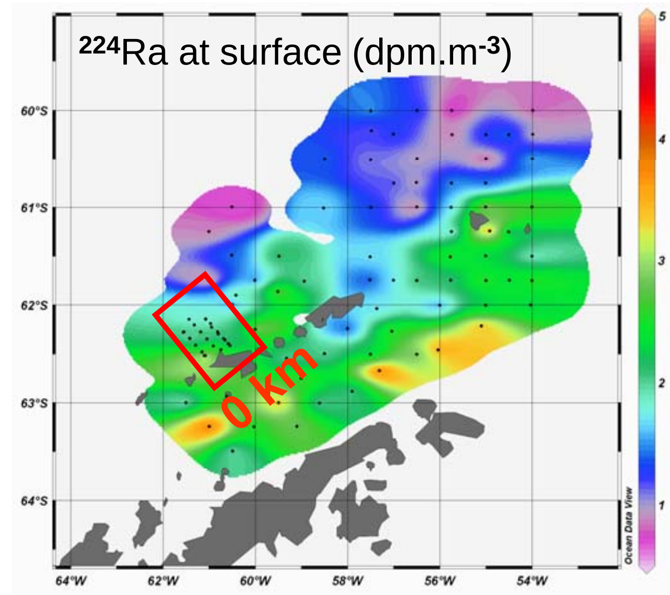
228Ra (dpm.m-3)
60°S
61°S
62°S
63°S
64°S
62°W
60°W
58°W
56°W
54°W
52°W
15
12.5
10
7.5
5
2.5
0
Ocean Data View

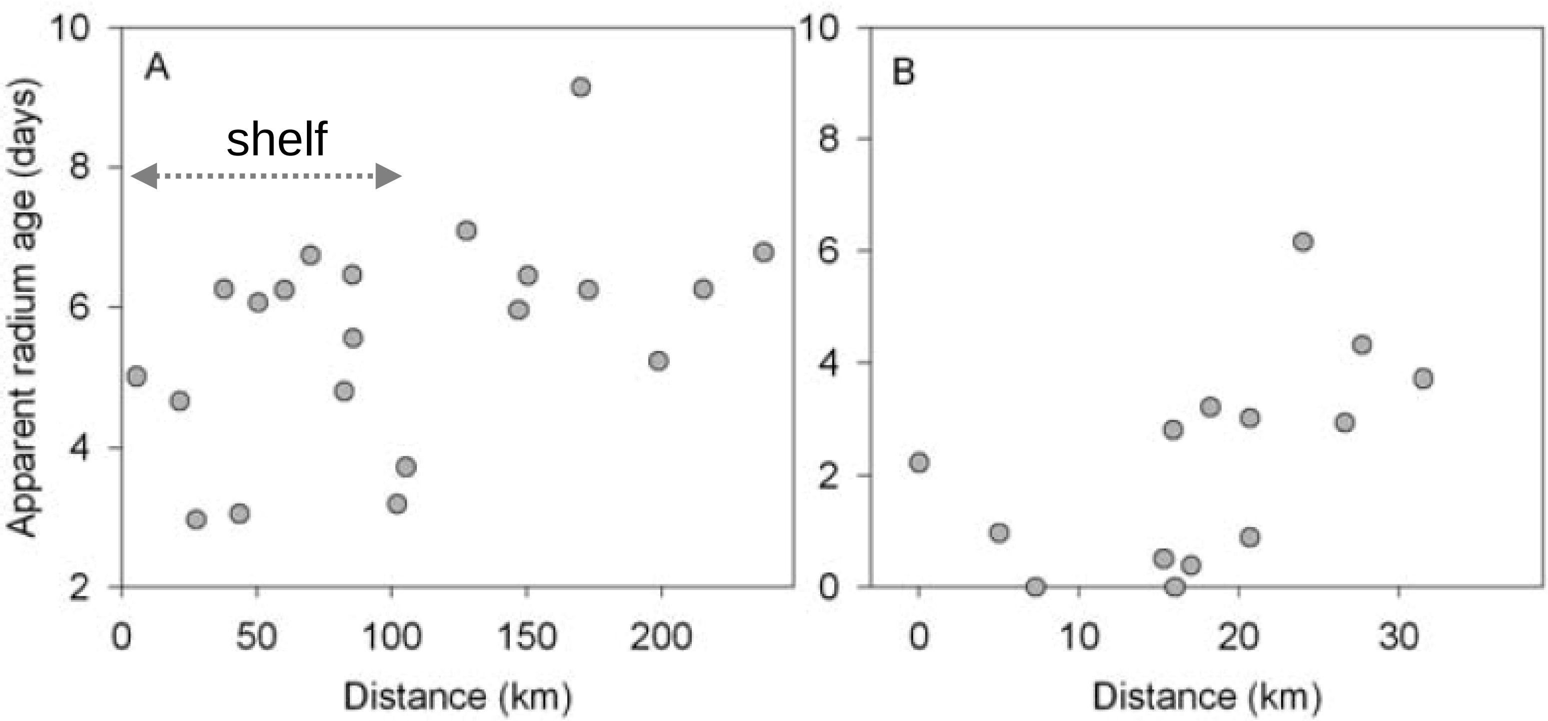


224Ra (dpm.m-3)
60°S
61°S
62°S
63°S
64°S
62°W
60°W
58°W
56°W
54°W
52°W
5
4
3
2
1
0
Ocean Data View

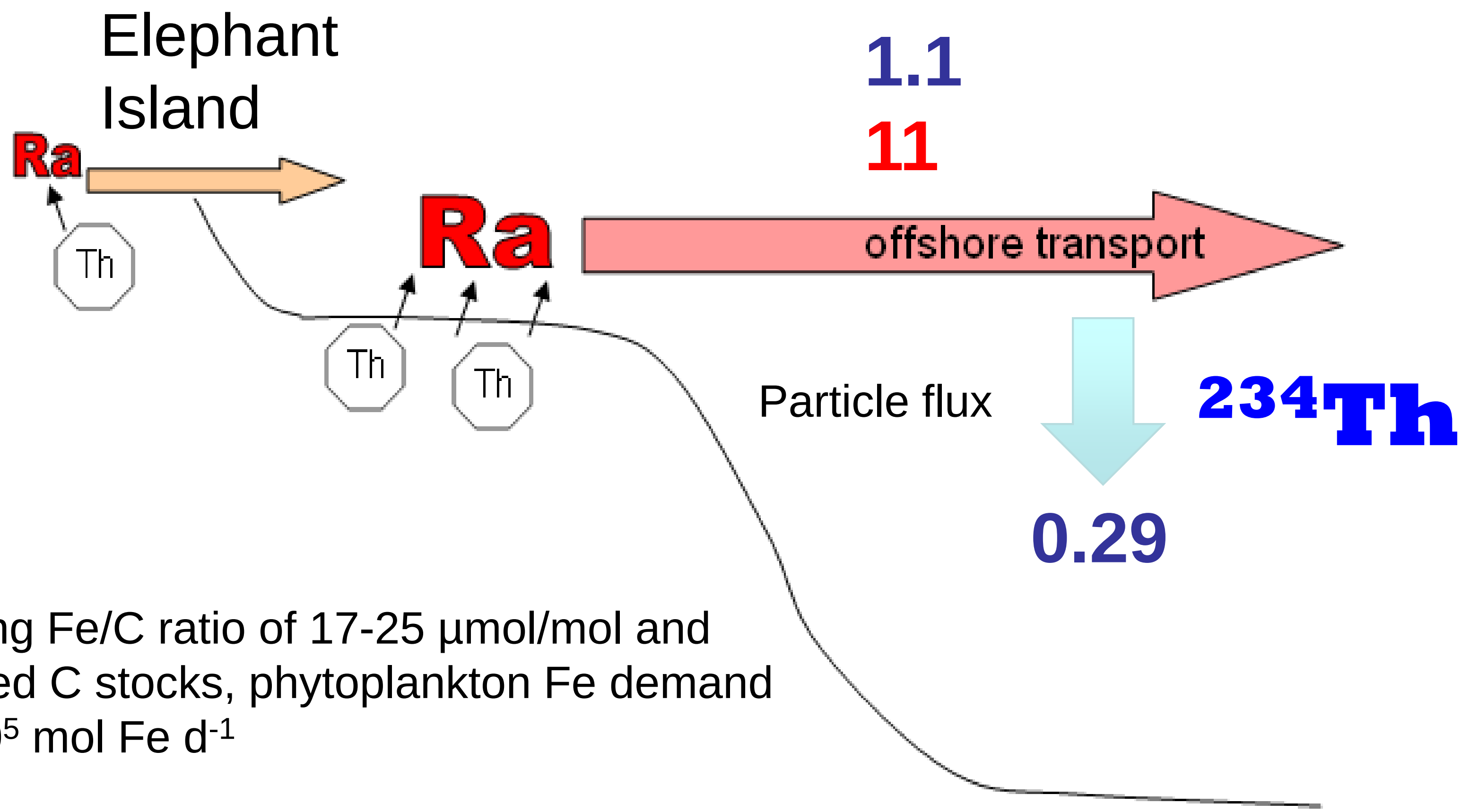


Apparent $^{224}Ra/^{228}Ra$ water ages





Fe Budget (10^5 mol d^{-1})
Jan-Feb 2006



Assuming Fe/C ratio of 17-25 µmol/mol and measured C stocks, phytoplankton Fe demand = 1-4 10^5 mol Fe d^{-1}

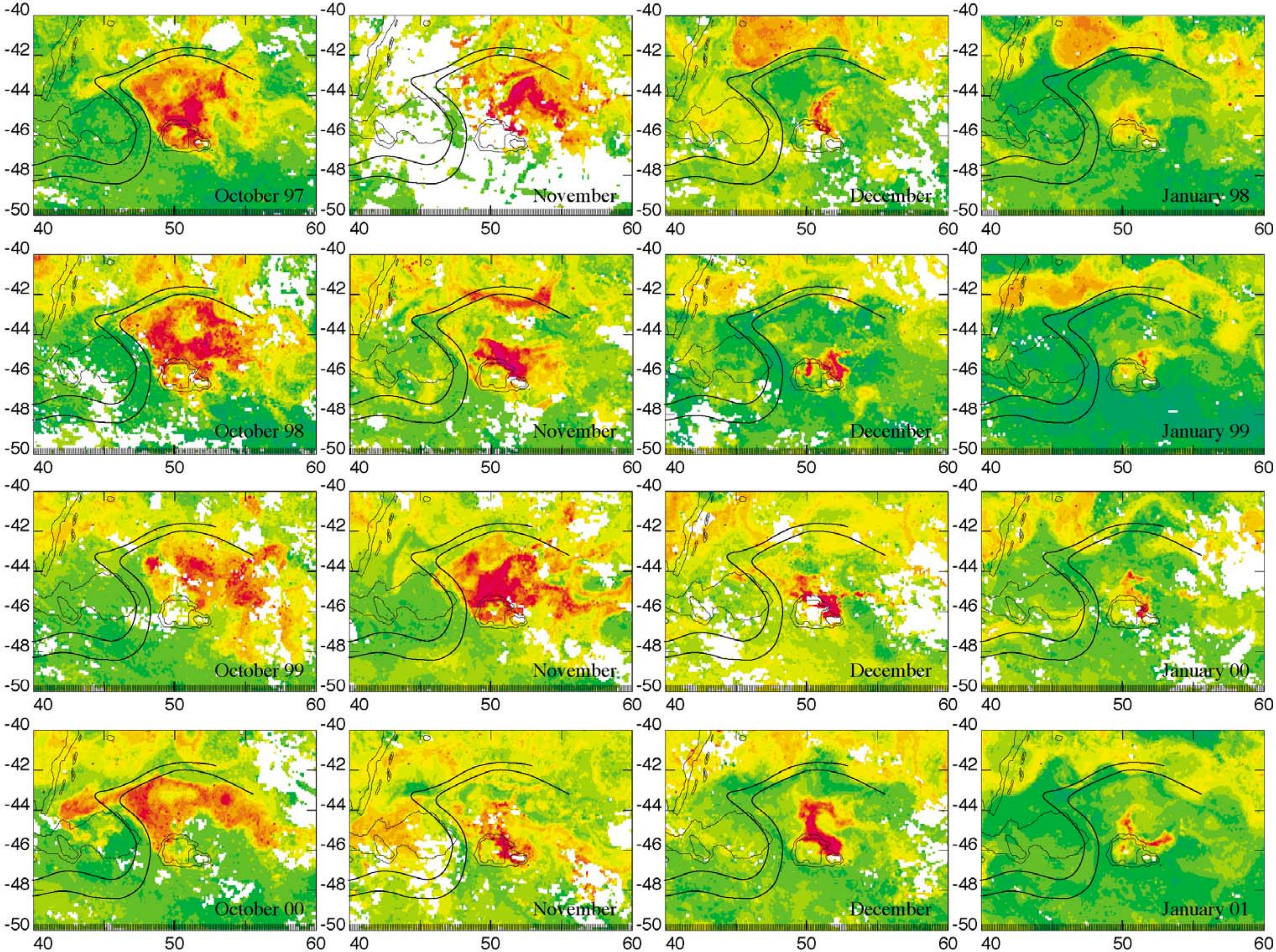
Flux = **4900 nmol m^{-2} d^{-1}** if bloom area = 2.25 x 10^{10} m^2

Dissolved

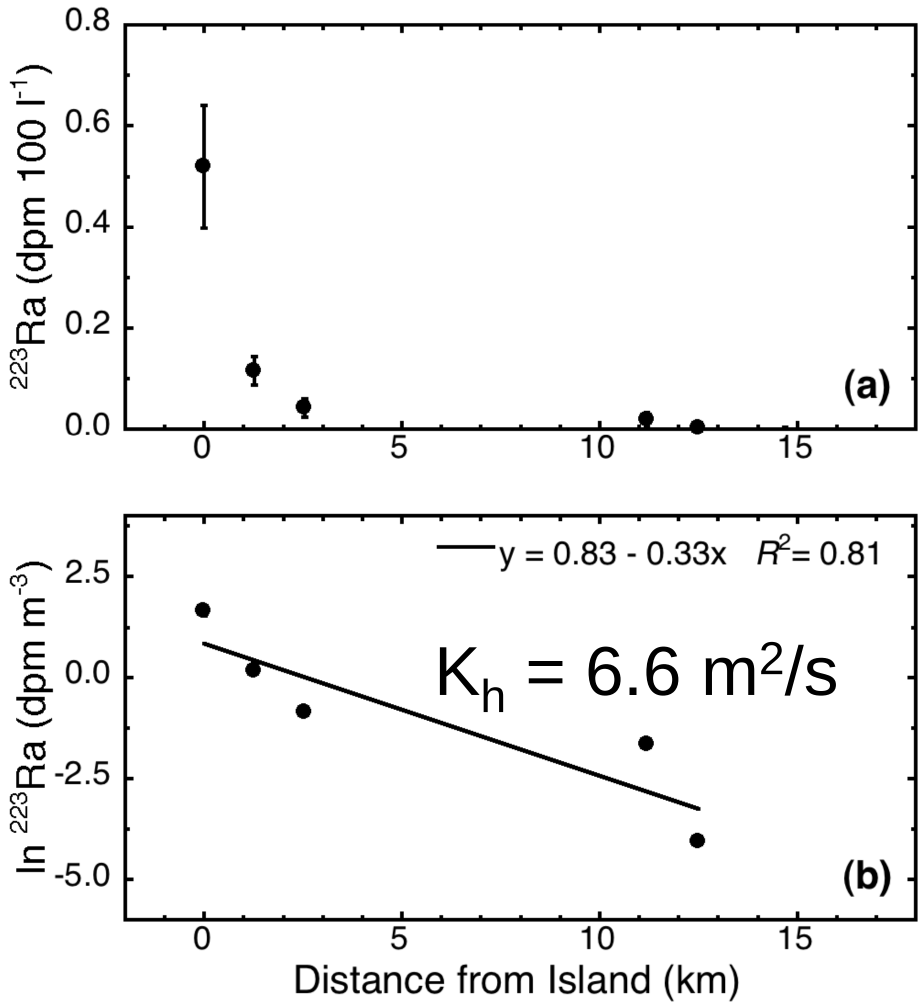
Total

Dulaiova et al. (2008), GBC

Crozet Plateau


October 97
November
December
January 98
October 98
November
December
January 99
October 99
November
December
January 00
October 00
November
December
January 01
-40
-42
-44
-46
-48
-50
40
50
60

Horizontal Mixing Away from the Plateau

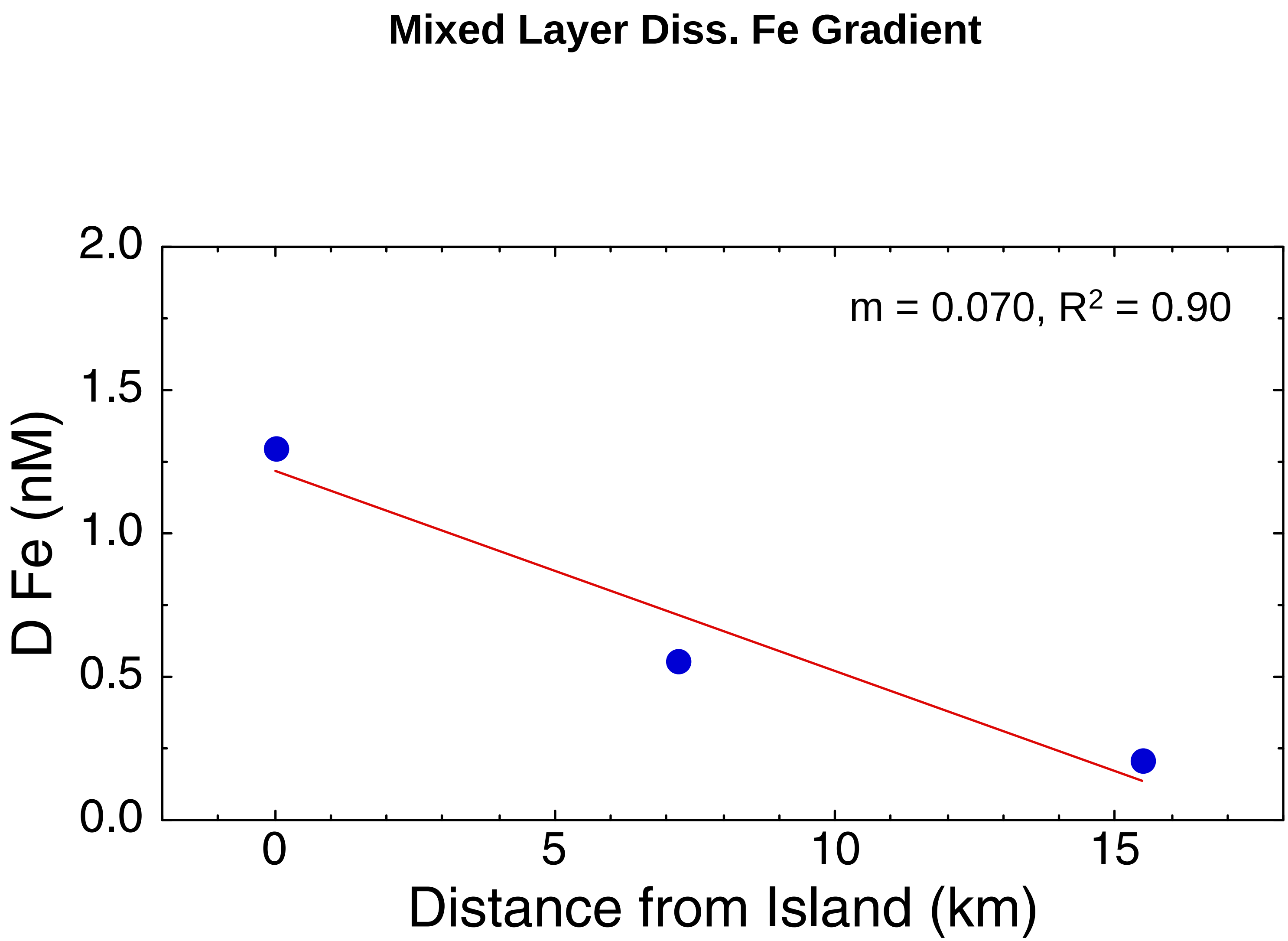


K_h from ^{223}Ra
($t_{1/2}$=11.4 d)

-diffusion model can be fit to the transect gradient

-mixing is not necessarily constant across the entire transect

Charette et al. (2007) DSR II



Mixed Layer Diss. Fe Gradient
m = 0.070, R2 = 0.90
D Fe (nM)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
Distance from Island (km)

Plateau Derived Fe Flux

Assume:

Dissolved **Fe gradient** of:
~1300 $nmol/m^3$ (0 km) to 200 $nmol/m^3$ (15 km) =
0.070 $nmol/m^3/m$

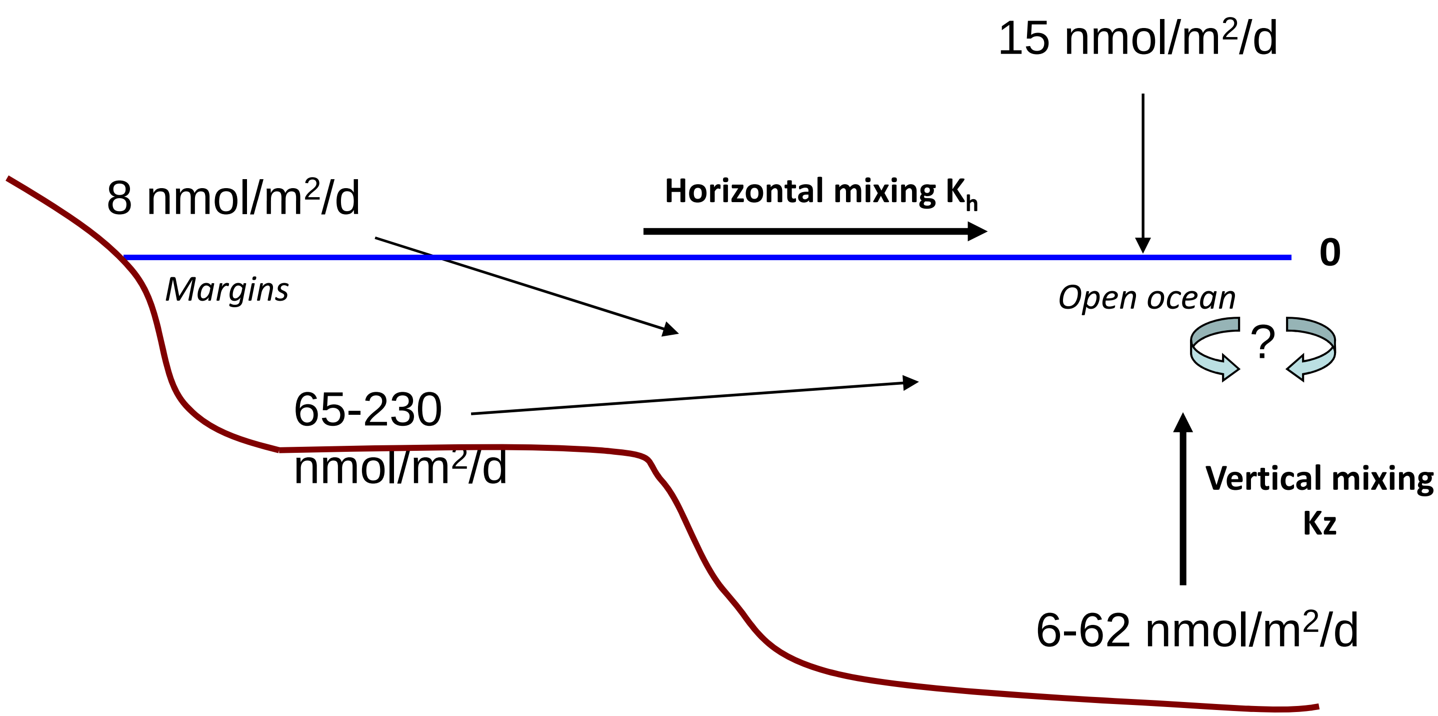
Ra-derived K_h of:
6.6-39 m^2/s (5.7 x 10^5 m^2/d)
$\mathbf{F_{Fe}}$ = 0.070 $nmol/m^4$ x 5.7-34 x 10^5 m^2/d = 40-240 $\mu mol/m^2/d$

Total plateau derived Fe (70 m MLD):
$\mathbf{F_{Fe}}$ = 140 $\mu mol/m^2/d$ x 70 m x 600,000 m = 5,900 mol Fe/d

Total plateau derived Fe (250 m MLD):
$\mathbf{F_{Fe}}$ = 140 $\mu mol/m^2/d$ x 70 m x 2,100,000 m = 21,000 mol Fe/d

Normalized to bloom region (300 km x 300 km):
$\mathbf{F_{Fe}}$ = 65-230 **$nmol/m^2/d$**

Crozet Plateau Dissolved Fe Budget



Total Fe supply to the mixed layer: **85-300 nmol/m²/d (could elevate pre-winter Fe to ~0.6-0.8 nM)**

Total Phytoplankton Fe requirement: **25-1000 nmol/m²/d**

Summary

-The Ra quartet show promise as tracers of micronutrient fluxes in HNLC waters

-Lateral iron fluxes appear to dominate over vertical exchange in Southern Ocean natural iron fertilized blooms (*though in some cases the "vertical" source may be linked to subsurface horizontal supply*)

nmol m^{-2} d^{-1}

Study Area	Vertical	Horizontal
Kerguelen	1-14	?
Shackelton FZ	27-135	4800
Crozet	6 - 62	65-230

-but….

-Detection is a problem (large volumes required)

-Lateral input may complicate 1-D model for 228-Ra derived K_z estimates

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