POC Export from Natural Iron Fertilization –

Investigating the Sequestration Efficiency

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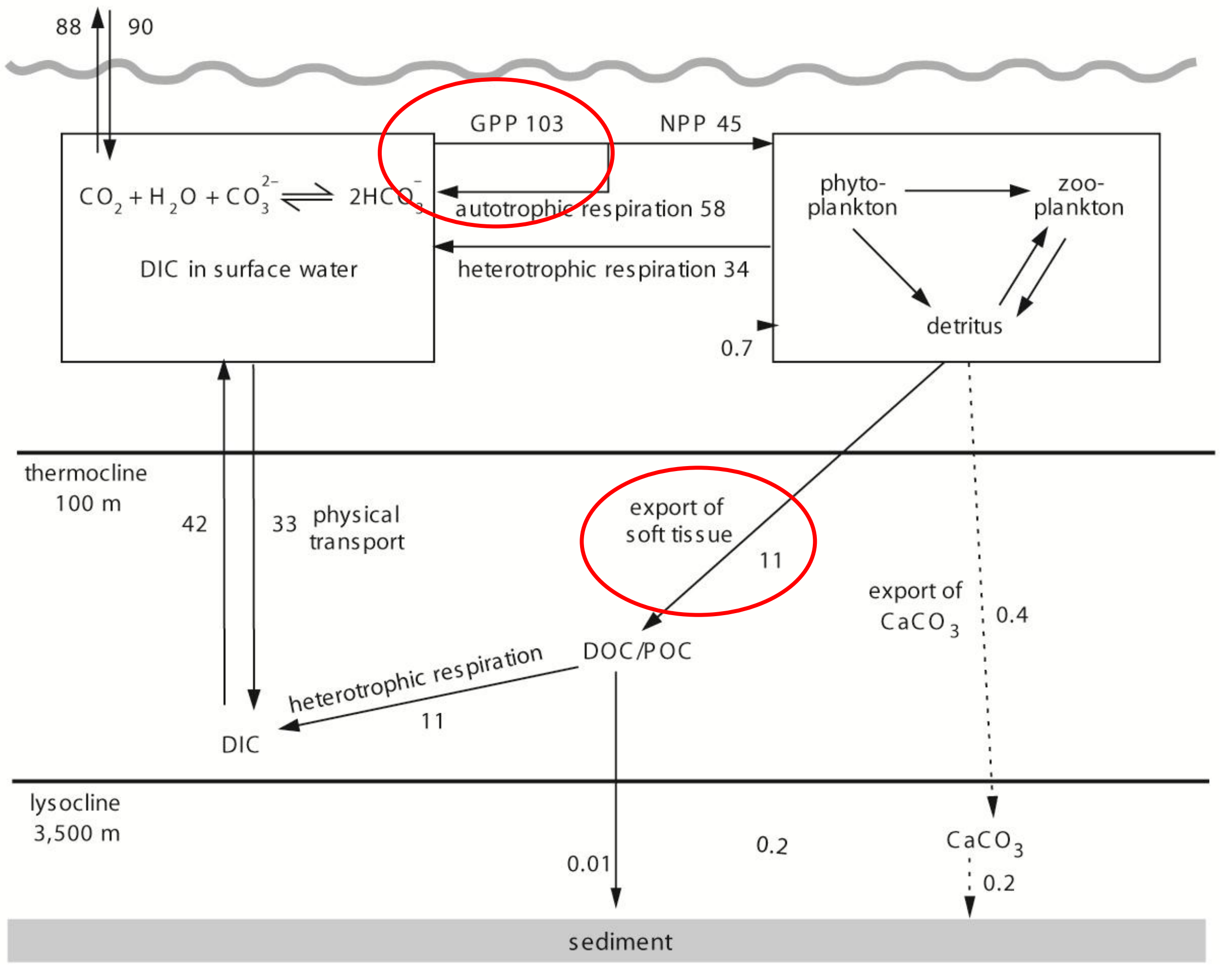
Talk Overview

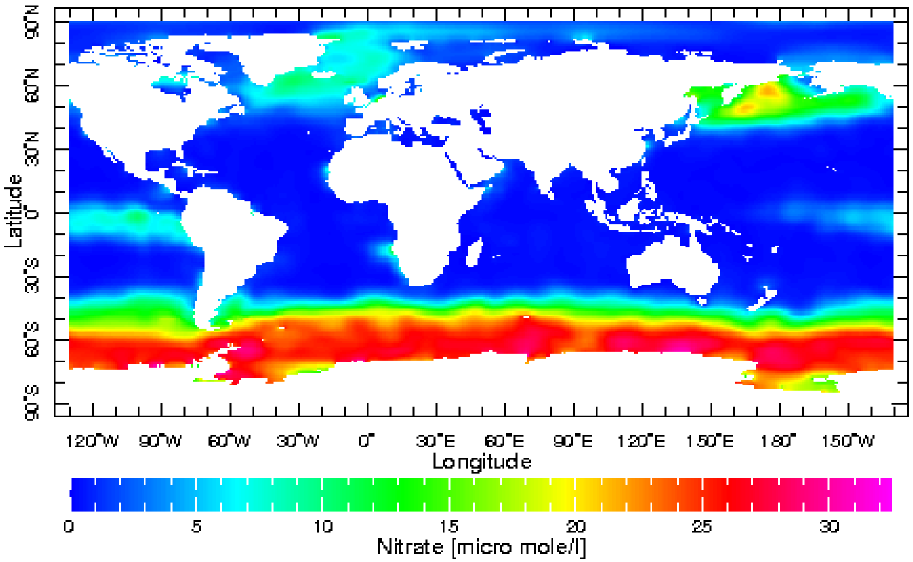
- Marine carbon cycle
- HNLC Southern Ocean and regions of interest
- Range of POC export estimates
- Scaling daily POC export to seasonal estimates
- Sensitivity of the sequestration efficiency
- New data from the Blue Water Zone – BWZ
- Summary

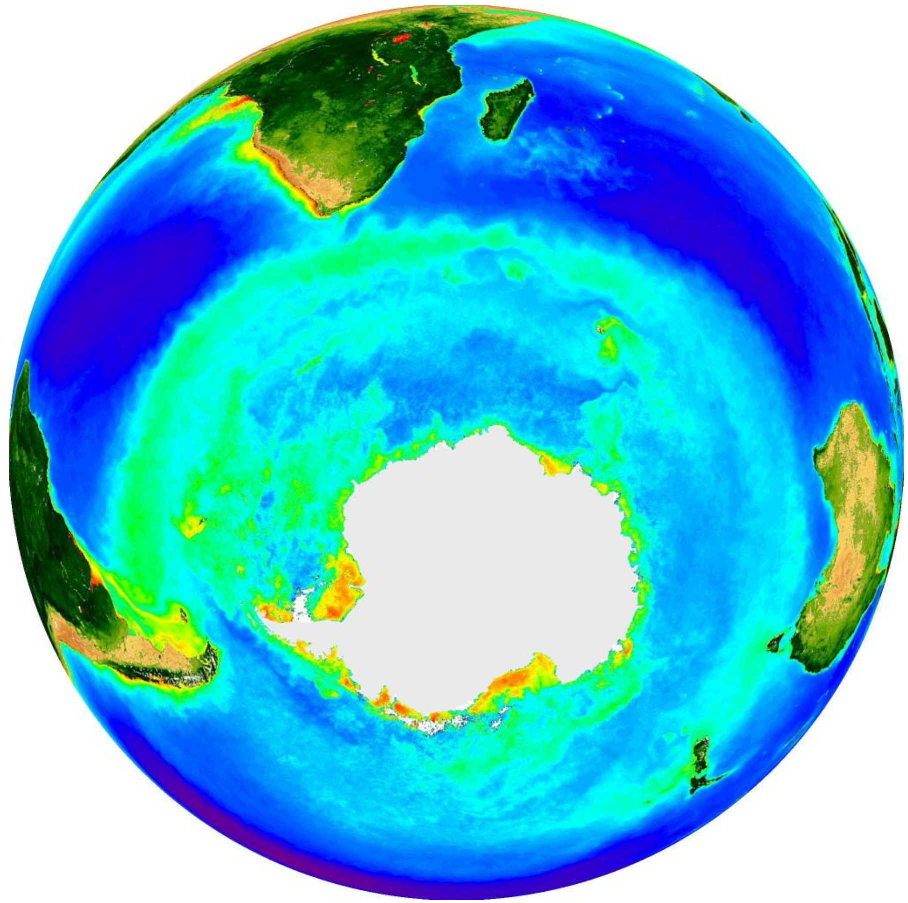
Marine Carbon Cycle



Modified from Prentice *et al.* (2001) IPCC Report

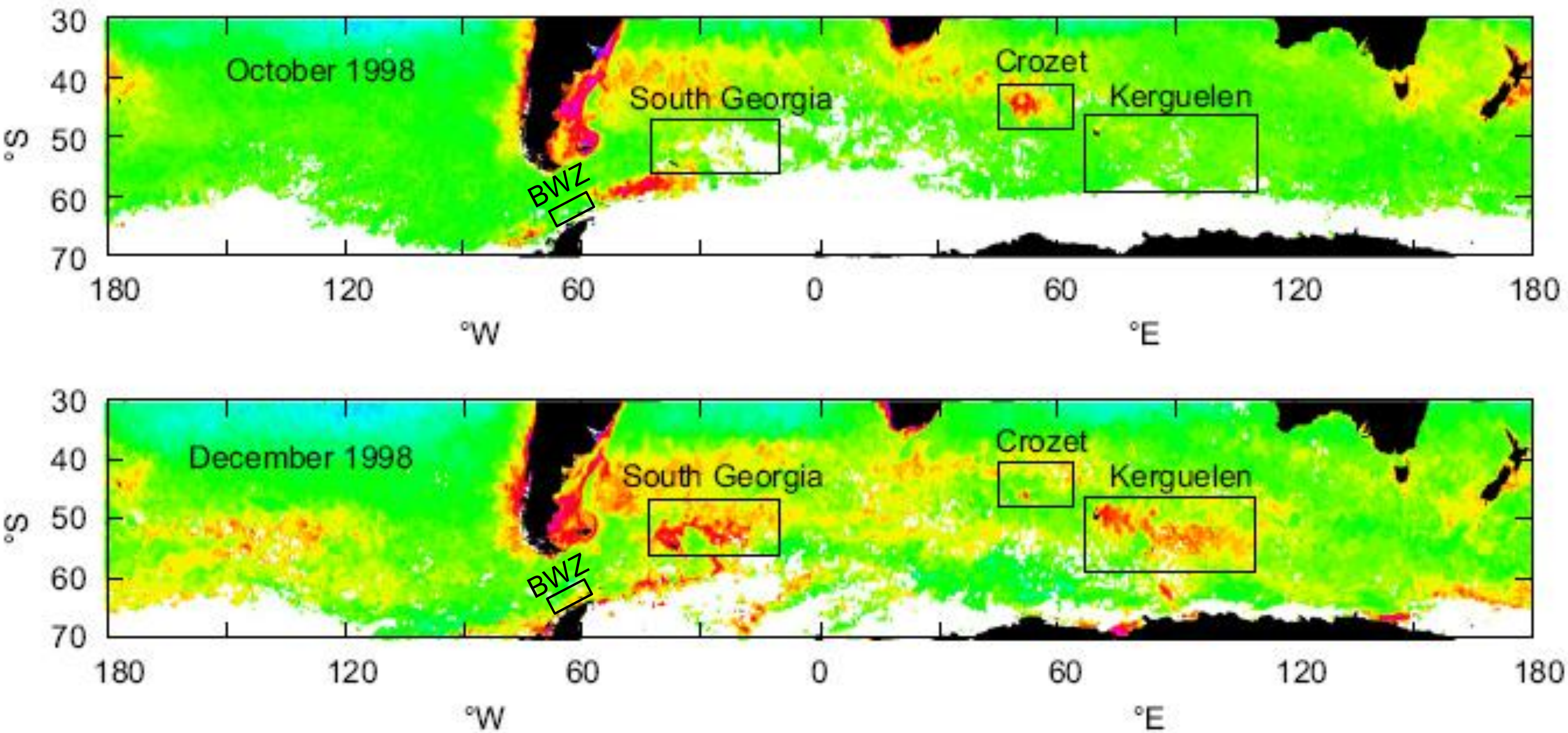
The HNLC Southern Ocean





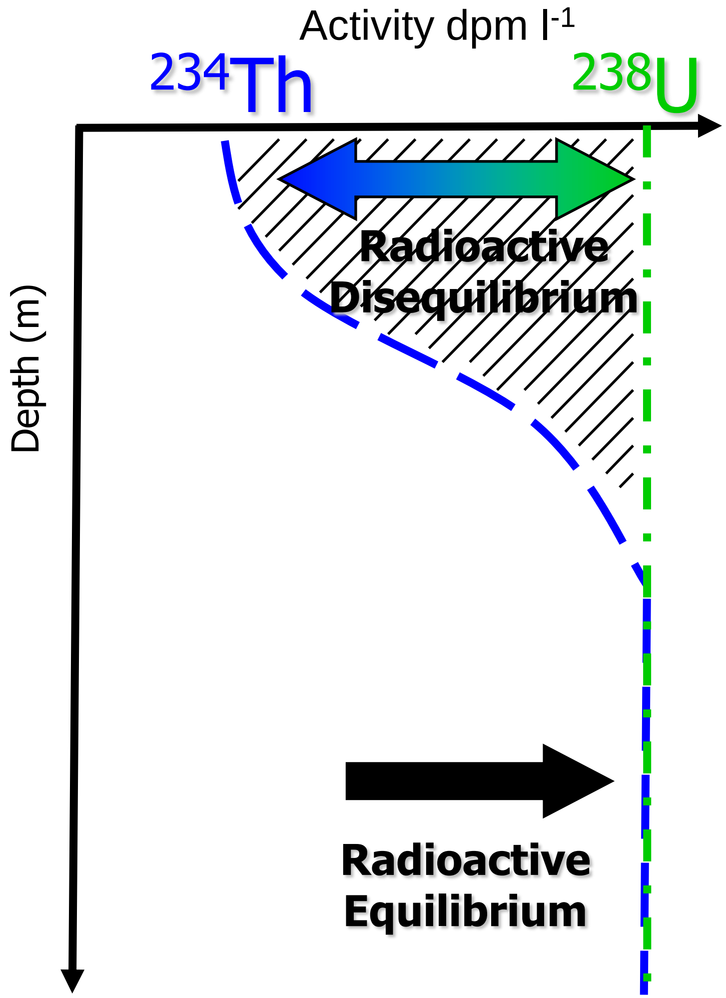
- Region of interest
- Southern Ocean nutrient levels are high
- However, large areas have persistently low chlorophyll
- Iron limitation

The HNLC Southern Ocean

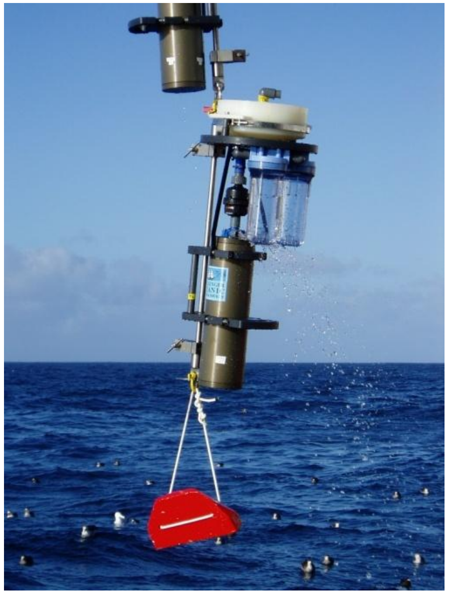


- Large regions of relatively low chlorophyll despite high nutrients
- Topographically associated blooms
- Hypothesis: Are these regions areas of enhanced carbon export?

^{234}Thorium Method

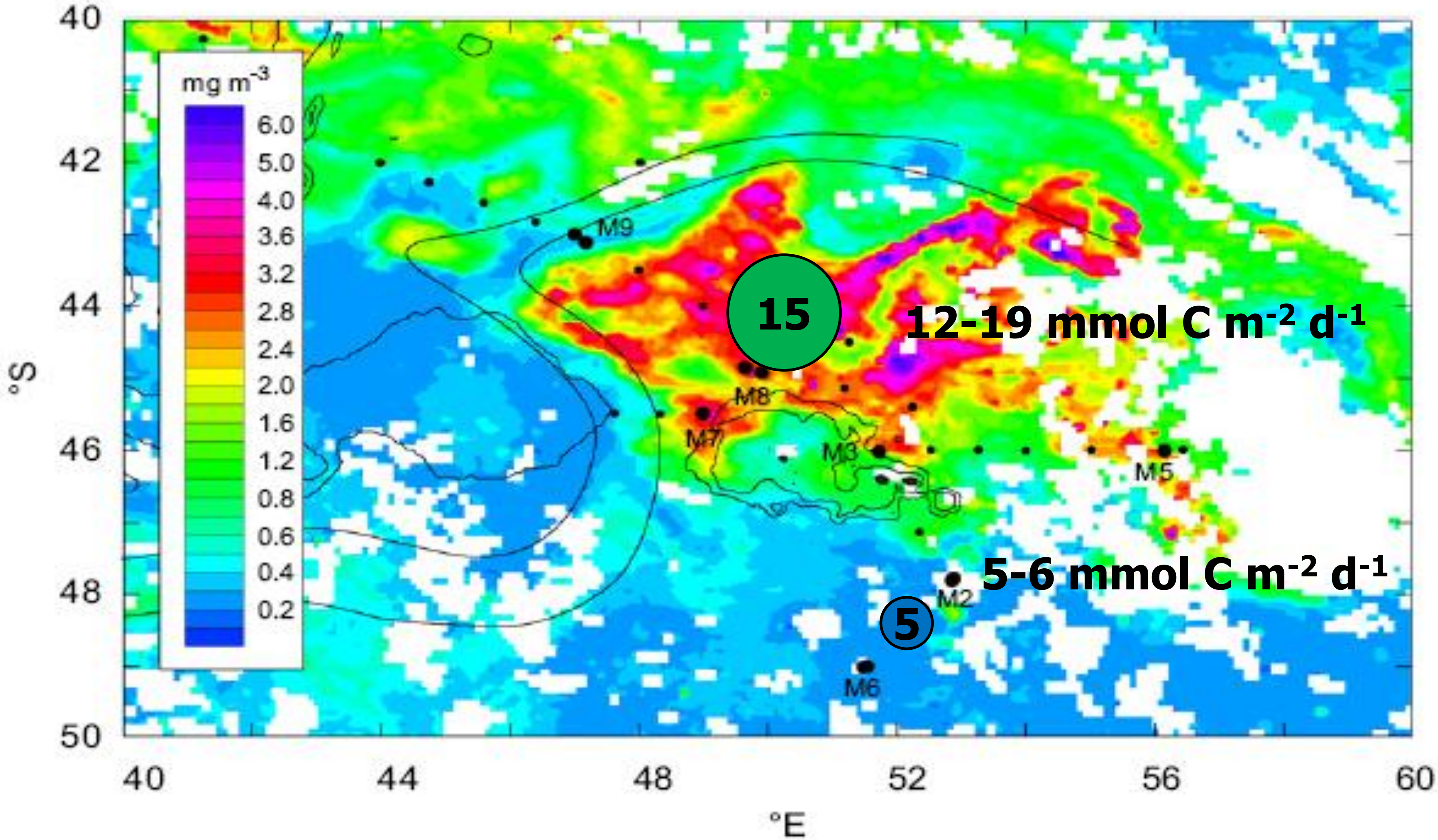


- MnO_2 precipitation method
  Rutgers van der Loeff & Moore (1999)
- C:Th ratio samples collected with *in situ* pumps with 50 µm mesh



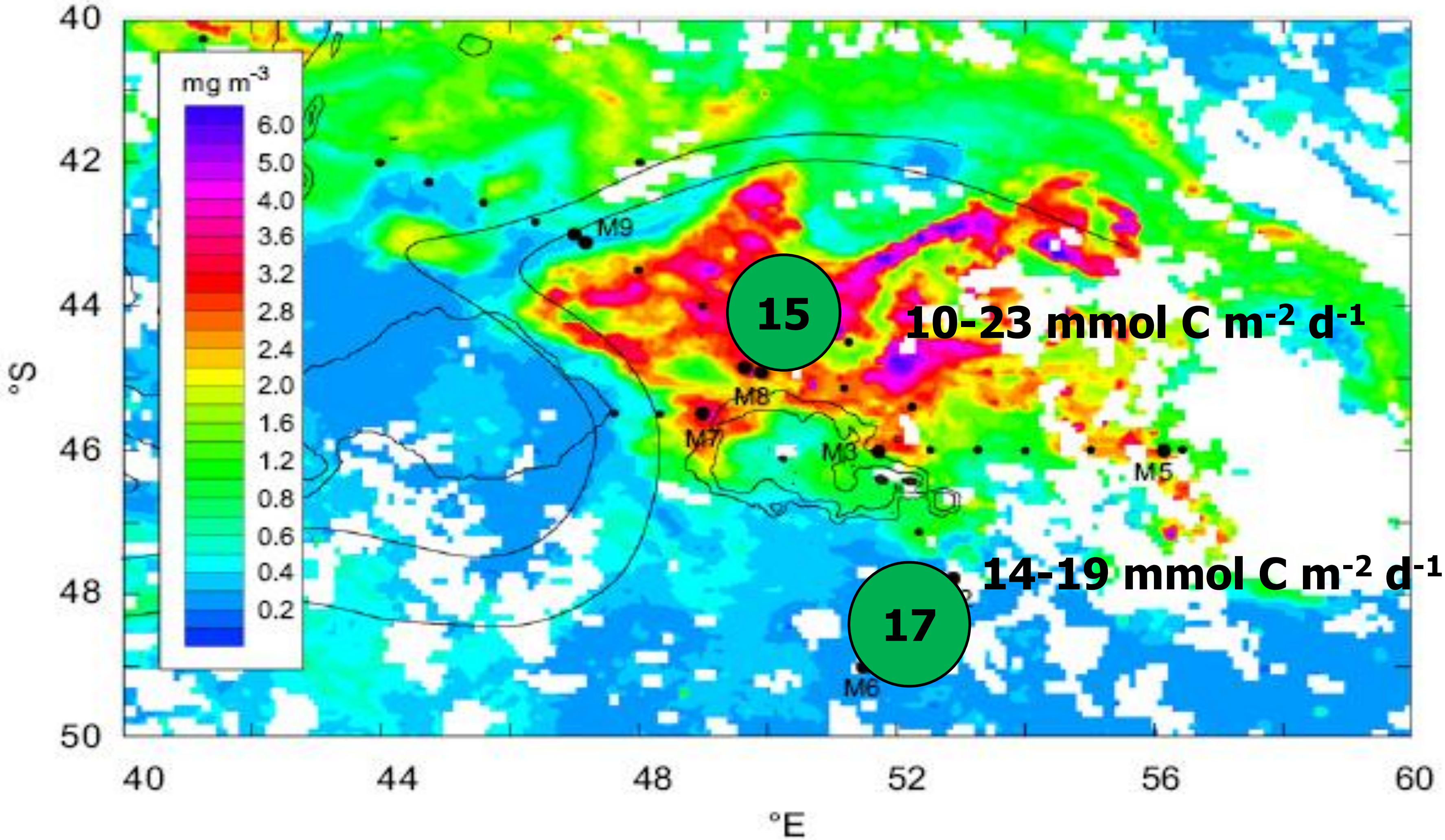
POC Export = ^{234}Th Flux x POC/^{234}Th ratio

Carbon Export – CROZEX Leg 1



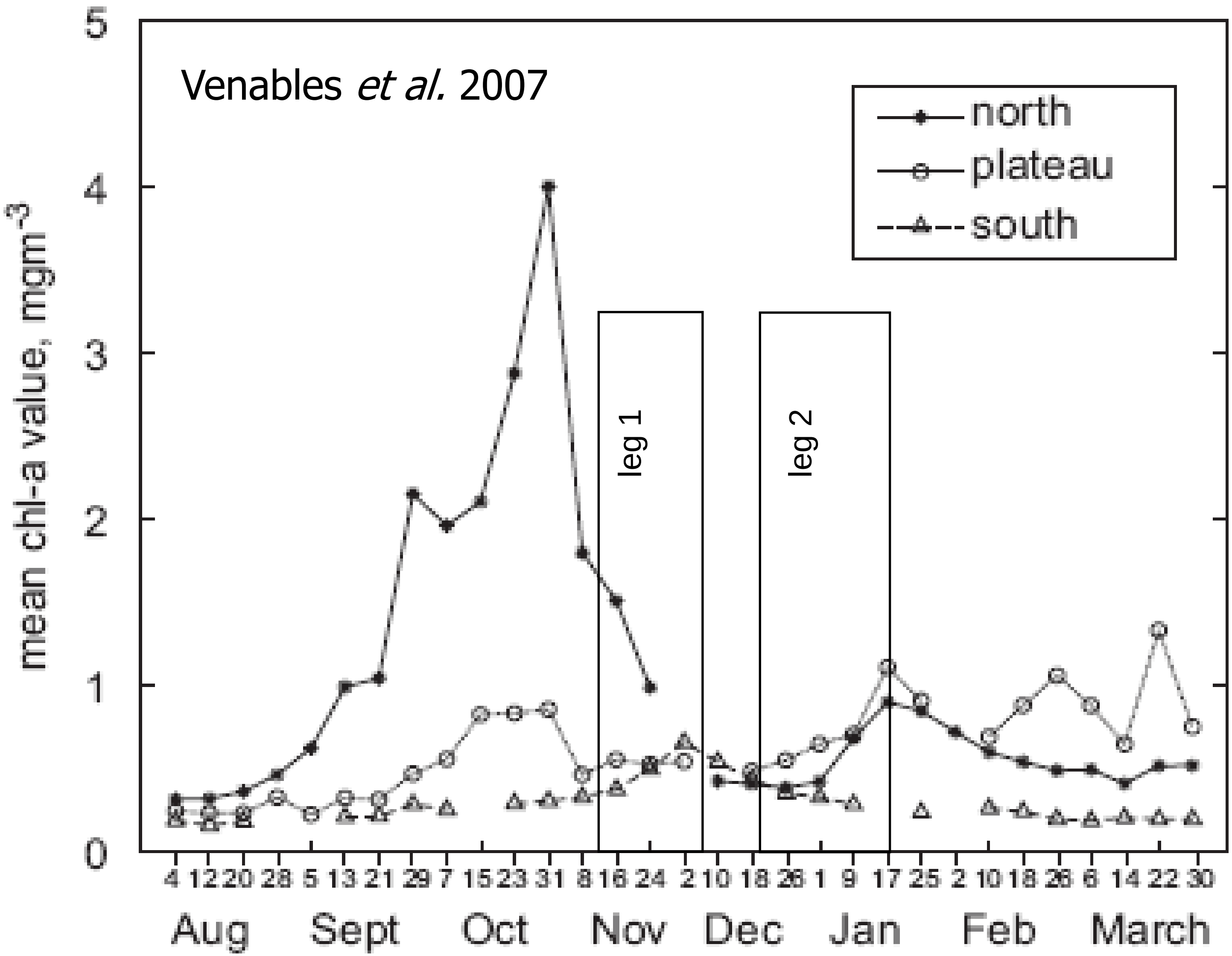
Morris et al. 2007

Carbon Export – CROZEX Leg 2

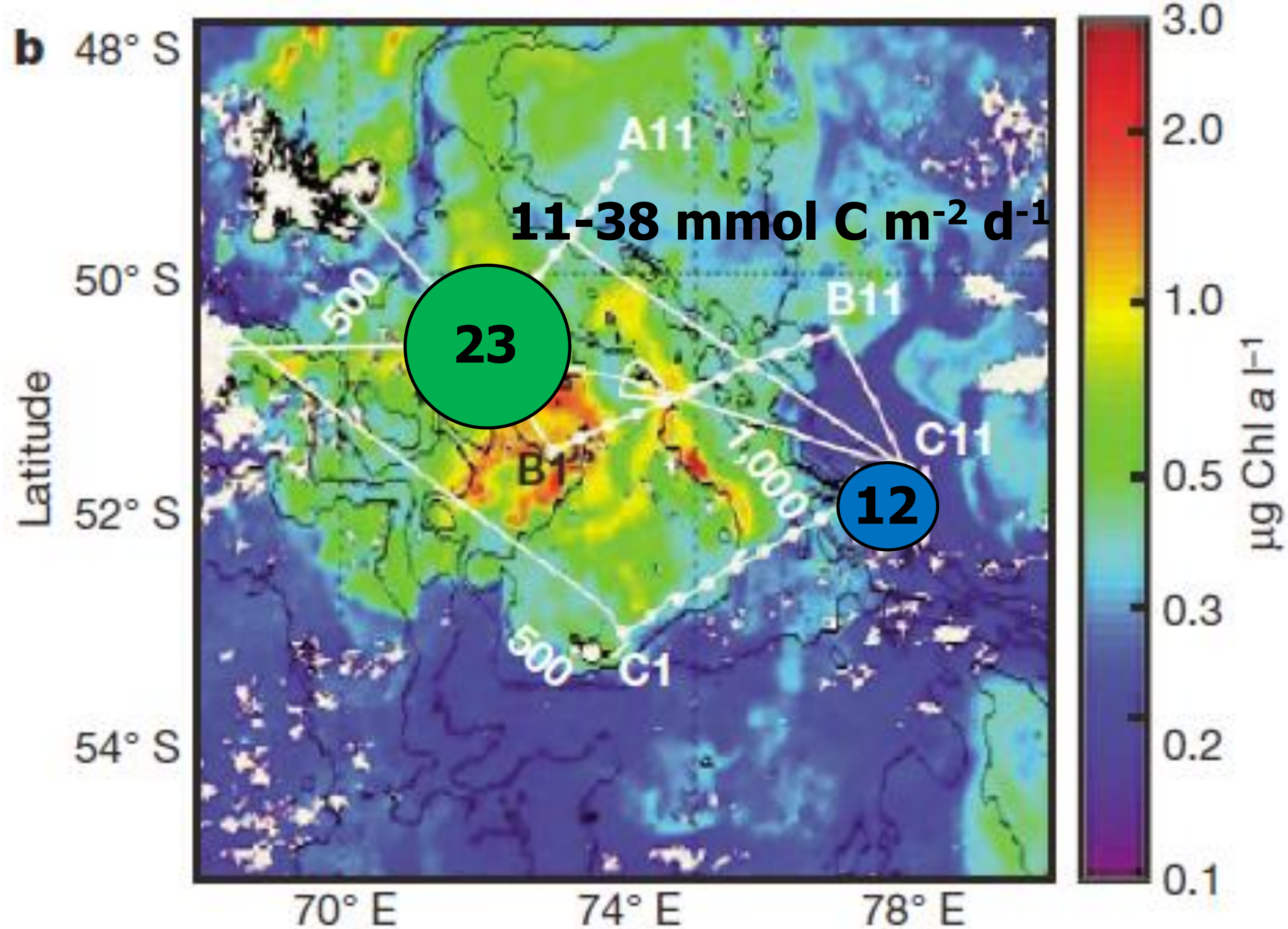


Morris et al. 2007

Bloom Progression



Carbon Export – KEOPS



Savoye et al. 2008

Daily Export to Seasonal Export

KEOPS – Blain et al. 2007

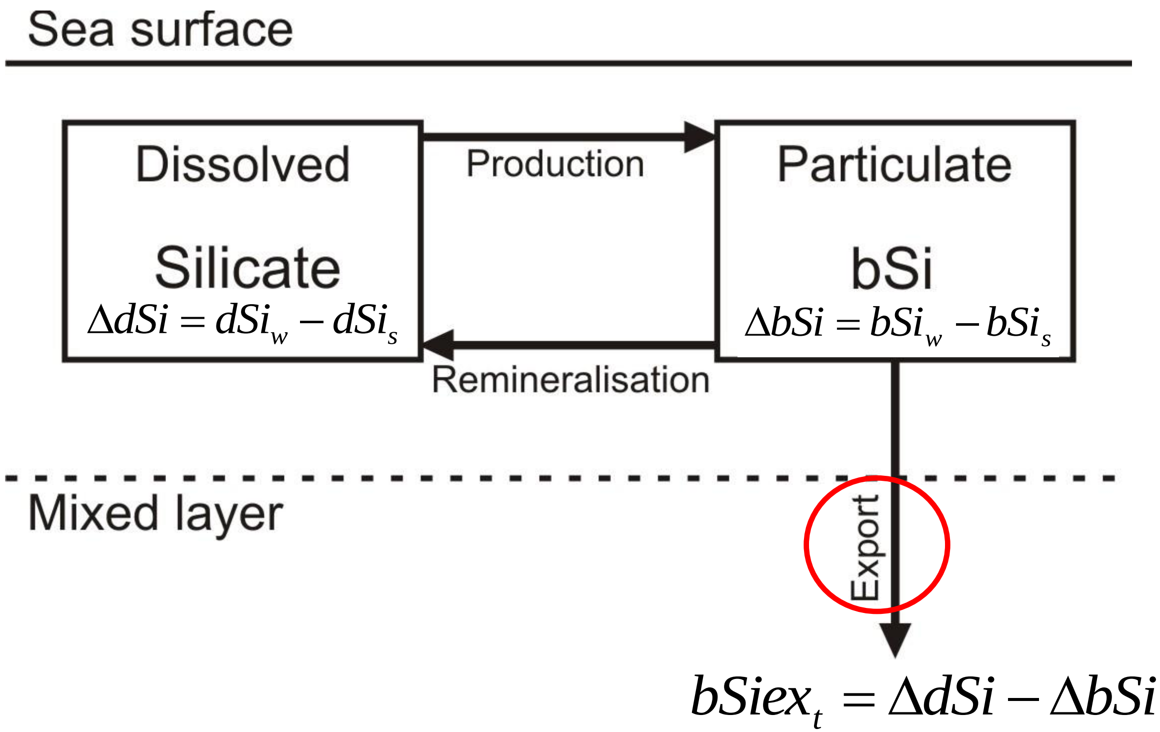
- POC export =
  - DIC draw down
  - \+ DIC vertical supply
  - \+ DIC air-sea supply
  - \- POC accumulation
  - \- DOC accumulation

- Assumes:
  - MLD export ≈ 200 m export
    - Based on ^{234}Th profiles
- +Fe = 5.0 mol m^{-2}
- -Fe = 1.7 mol m^{-2}
- Xs export = 3.3 mol m^{-2}

CROZEX – Pollard et al. 2009

- Lacked DOC data
- Independently scaled POC export by closing the silicon budget

CROZEX – Pollard et al. 2009



- What duration of the export is needed to balance the mixed layer silicon budget?
- This budget exercise was performed on the bloom and control region

Pollard et al. 2009

Daily Export to Seasonal Export

- What duration of export is needed to balance the mixed layer silicon budget?

$$t = \frac{bSiex_t}{^{234}Th\text{–}bSiex}$$

- t = Duration of export event
- $bSiex_t$ = model-derived theoretical seasonal biogenic silica export
- $^{234}Th\text{-}bSiex$ = measured daily rates of biogenic silica export

$$Cex_t = {}^{234}Th\text{–}Cex \times t$$

- Cex_t = model-derived theoretical seasonal carbon export
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Pollard et al. 2009

Daily Export to Seasonal Export

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CROZEX – Pollard et al. 2009

- Lacked DOC data
- Independently scaled POC export by closing the silicon budget
- Assumes:
  - Average 100 m MLD
  - $F_{200} = F_{100}(200/100)^{-0.99}$
- +Fe = 1.0 mol m^{-2}
- -Fe = 0.3 mol m^{-2}
- Xs export = 0.7 mol m^{-2} (100 m)
- Xs export = 0.3 mol m^{-2} (200 m)

Sequestration Efficiency – C:Fe Ratio

KEOPS – Blain et al. 2007

- Xs export = 3.3 mol m^{-2}
- Xs Fe supplied to bloom
  - 0.000005 mol Fe m^{-2}
- C:Fe = 668,000 mol mol^{-1}

CROZEX – Pollard et al. 2009

- Xs export = 0.3 mol m^{-2}
- Xs Fe supplied to bloom
  - 0.000039 mol Fe m^{-2}
- C:Fe = 8,640 mol mol^{-1}

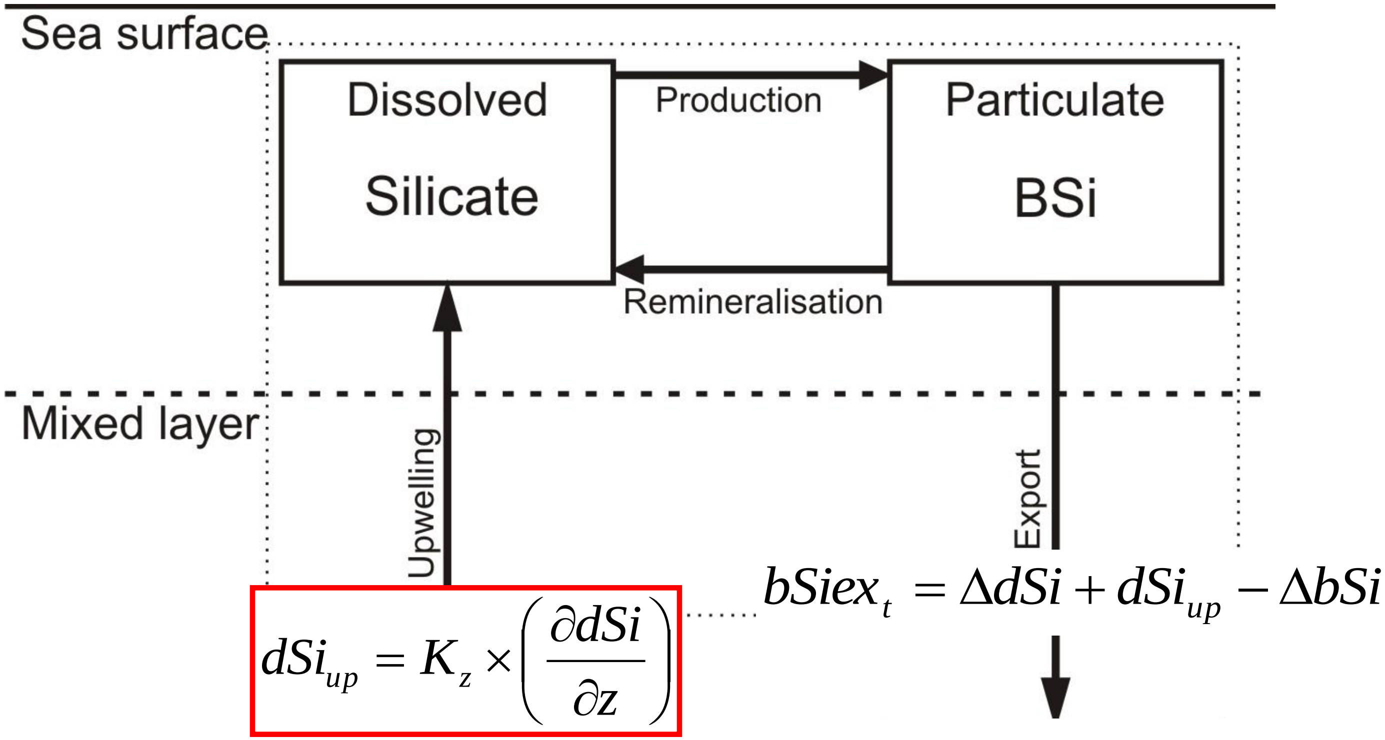
77-fold difference at 200 m

C:Fe ratios have since been re-assessed

Blain et al 2008

Planquette et al. & Charette et al. 2007

Daily Export to Seasonal Export



- For CROZEX the Si-scaling model was updated to include an upwelling component

Morris & Sanders 2011

Daily Export to Seasonal Export

- What duration of export is needed to balance the mixed layer silicon budget?

$$t = \frac{bSiex_t}{^{234}Th\text{–}bSiex}$$

- t = Duration of export event
- $bSiex_t$ = model-derived theroetical seasonal biogenic silica export
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Sequestration Efficiency – C:Fe Ratio

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77-fold difference at 200 m

Sequestration Efficiency – C:Fe Ratio

KEOPS – Chever et al. 2010

- Xs export = 3.3 mol m^{-2}
- Xs Fe supplied to bloom
  - 0.000022 mol Fe m^{-2}
- C:Fe = 154,000 mol mol^{-1}

CROZEX – Morris & Sanders 2011

- Xs export = 0.5 mol m^{-2}
- Xs Fe supplied to bloom
  - 0.000062 mol Fe m^{-2}
- C:Fe = 8,450 mol mol^{-1}

18-fold difference at 200 m

Sensitivity of the C:Fe Ratio

KEOPS – Chever et al. 2010

- Xs export = 1.7 mol m^{-2}

Extrapolate 100 m export to 200 m with b = -0.99 (Pollard et al. 2009)

- Xs Fe supplied to bloom
  - 0.000022 mol Fe m^{-2}
- C:Fe = 77,300 mol mol^{-1}

CROZEX – Morris & Sanders 2011

- Xs export = 0.5 mol m^{-2}
- Xs Fe supplied to bloom
  - 0.000062 mol Fe m^{-2}
- C:Fe = 8,450 mol mol^{-1}

9-fold difference at 200 m

$$F = F_{100}\left(\frac{z}{100}\right)^{b}$$

Martin et al. 1987

b = -0.99 (based on 3000 m)

KEOPS b value?

Sensitivity of the C:Fe Ratio

KEOPS – Chever et al. 2010

- Xs export = 3.3 mol m^{-2}
- Xs Fe supplied to bloom
  - 0.000022 mol Fe m^{-2}
- C:Fe = 154,000 mol mol^{-1}

CROZEX – Morris & Sanders 2011

- Xs export = 1.0 mol m^{-2}

  Assume 100 m export = 200 m export
- Xs Fe supplied to bloom
  - 0.000062 mol Fe m^{-2}
- C:Fe = 17,200 mol mol^{-1}

9-fold difference at 200 m

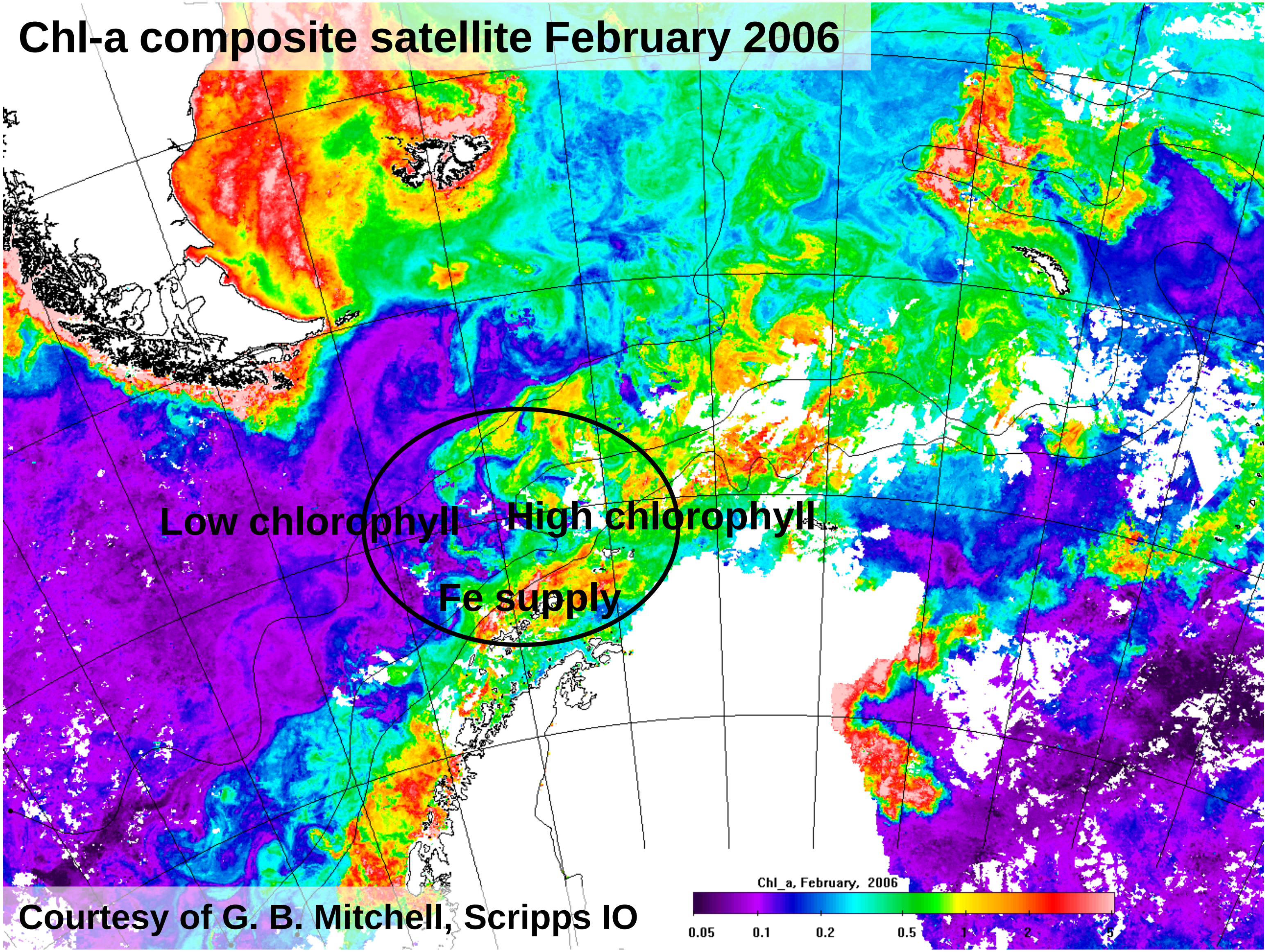
$$F = F_{100}\left(\frac{z}{100}\right)^{b}$$

Martin et al. 1987

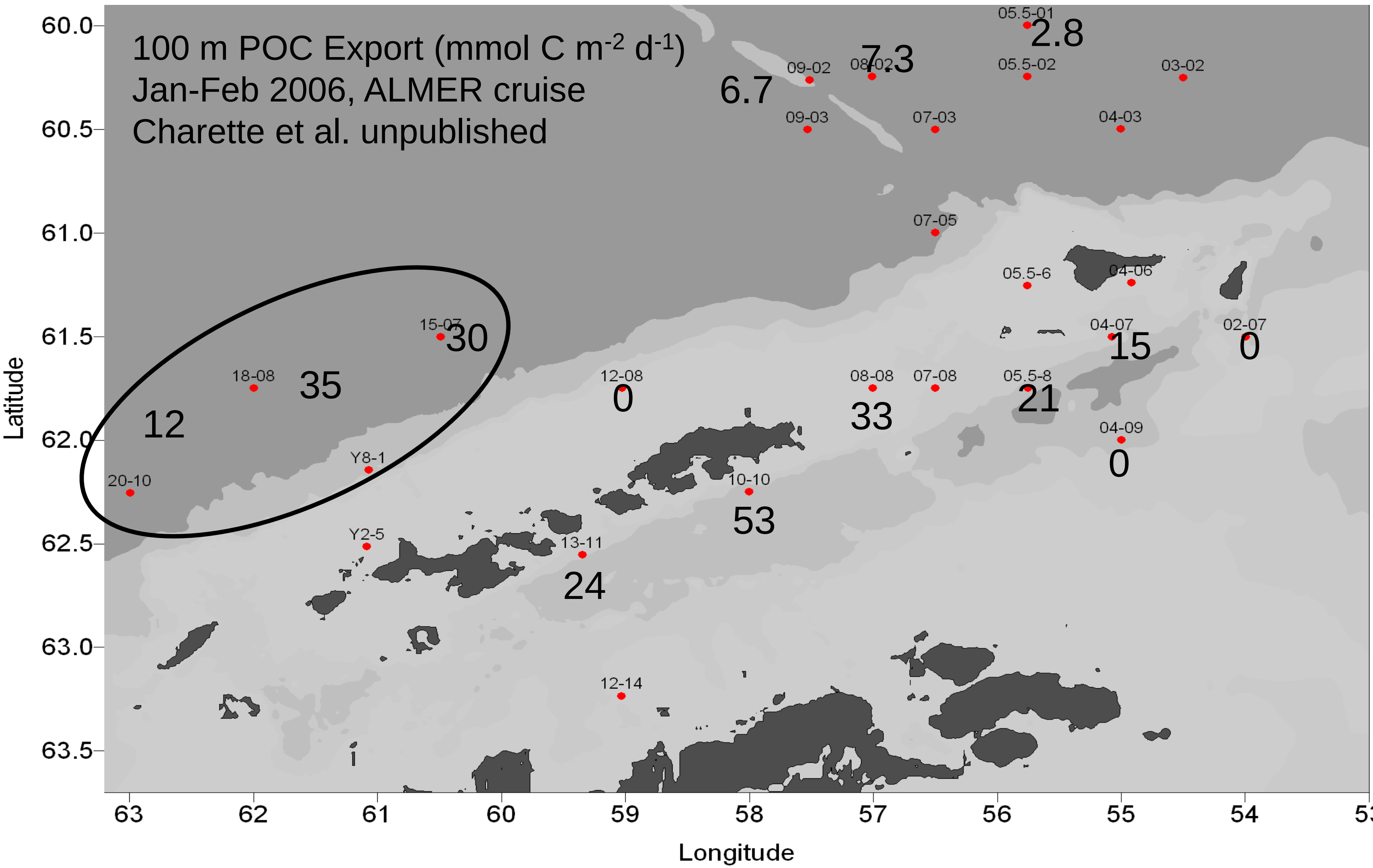
b = -0.99 (based on 3000 m)

KEOPS b value?

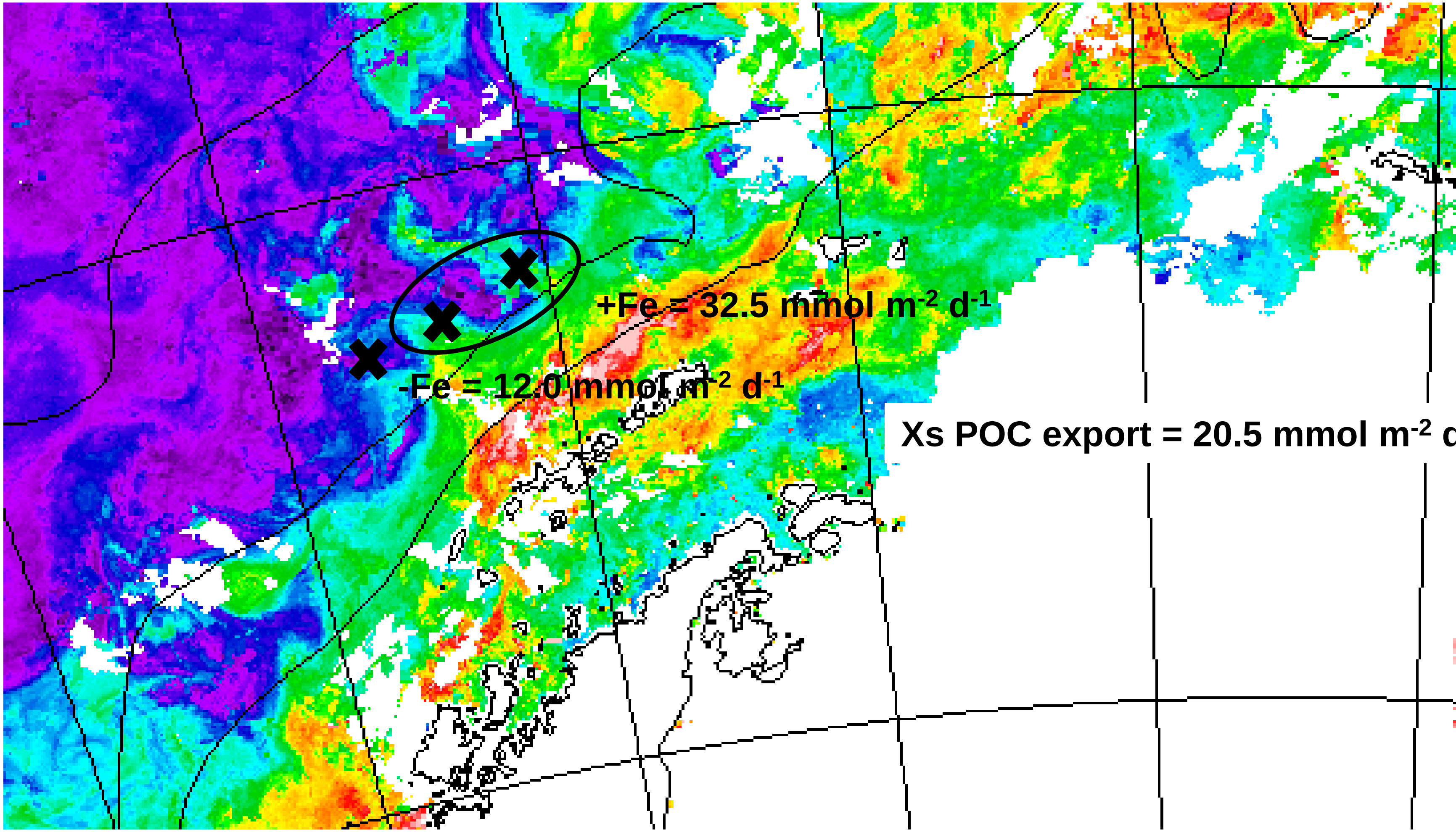
BWZ Study Region



BWZ – ^{234}Th-derived POC Export



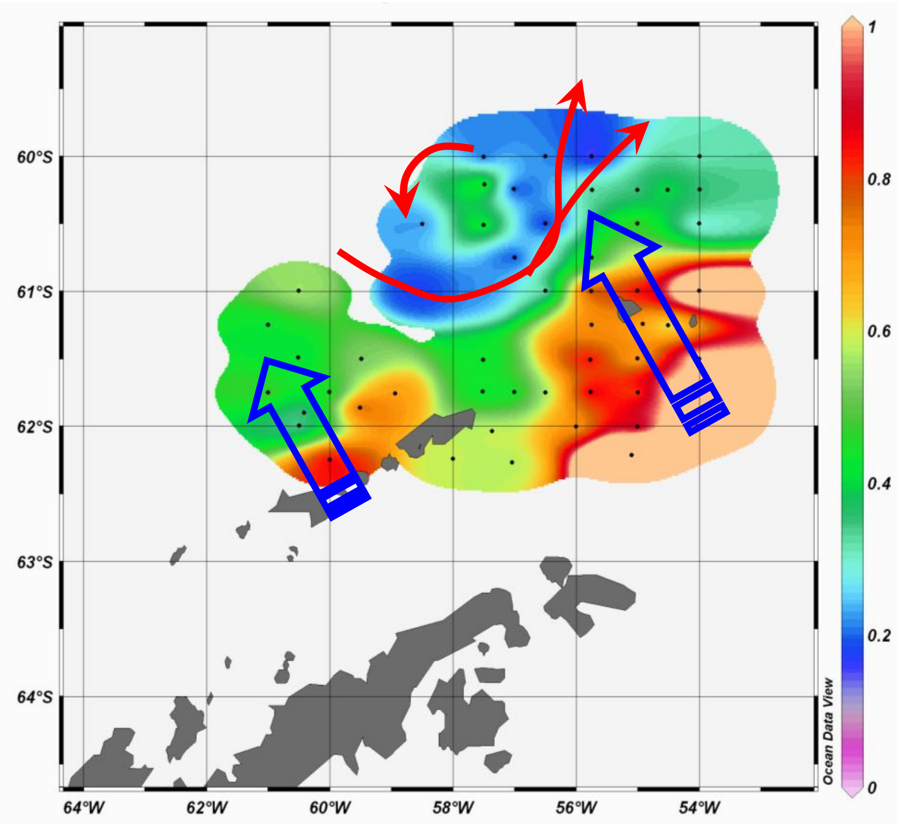
BWZ – Back of the Envelope C:Fe Ratio



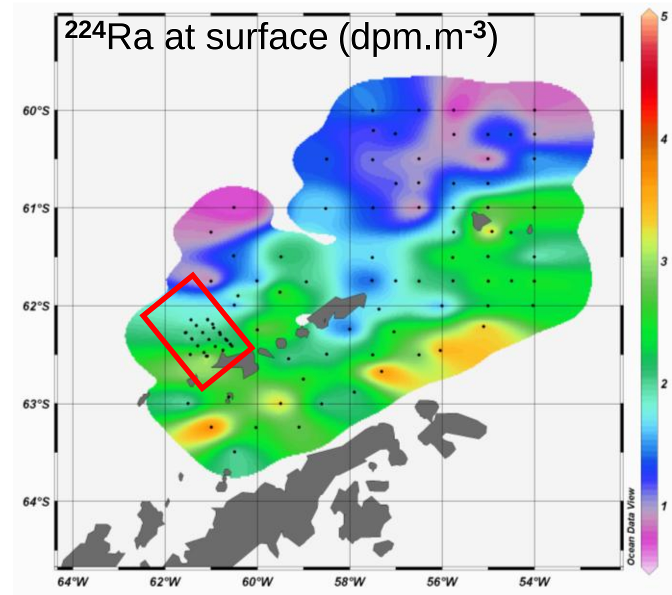
Charette et al. unpub

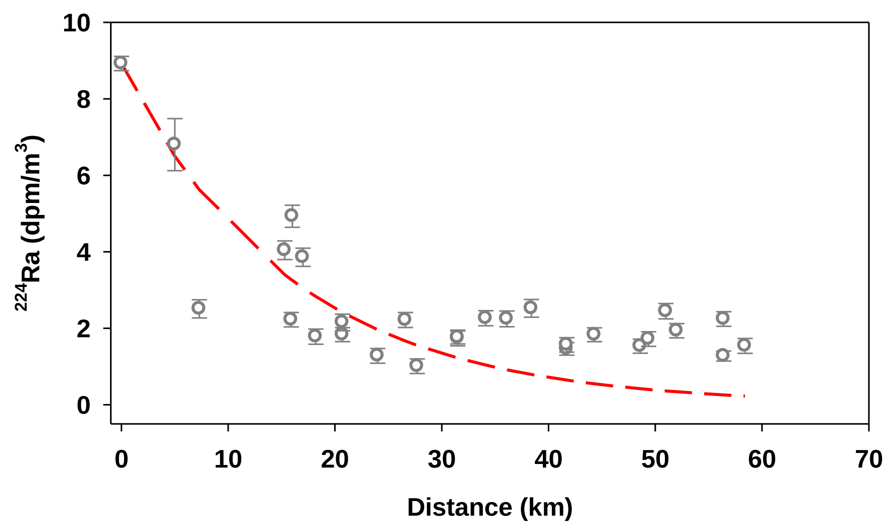
BWZ – Fe supply

Salinity-derived mixing index for the upper 50 m
Dulaiova & Charette unpublished



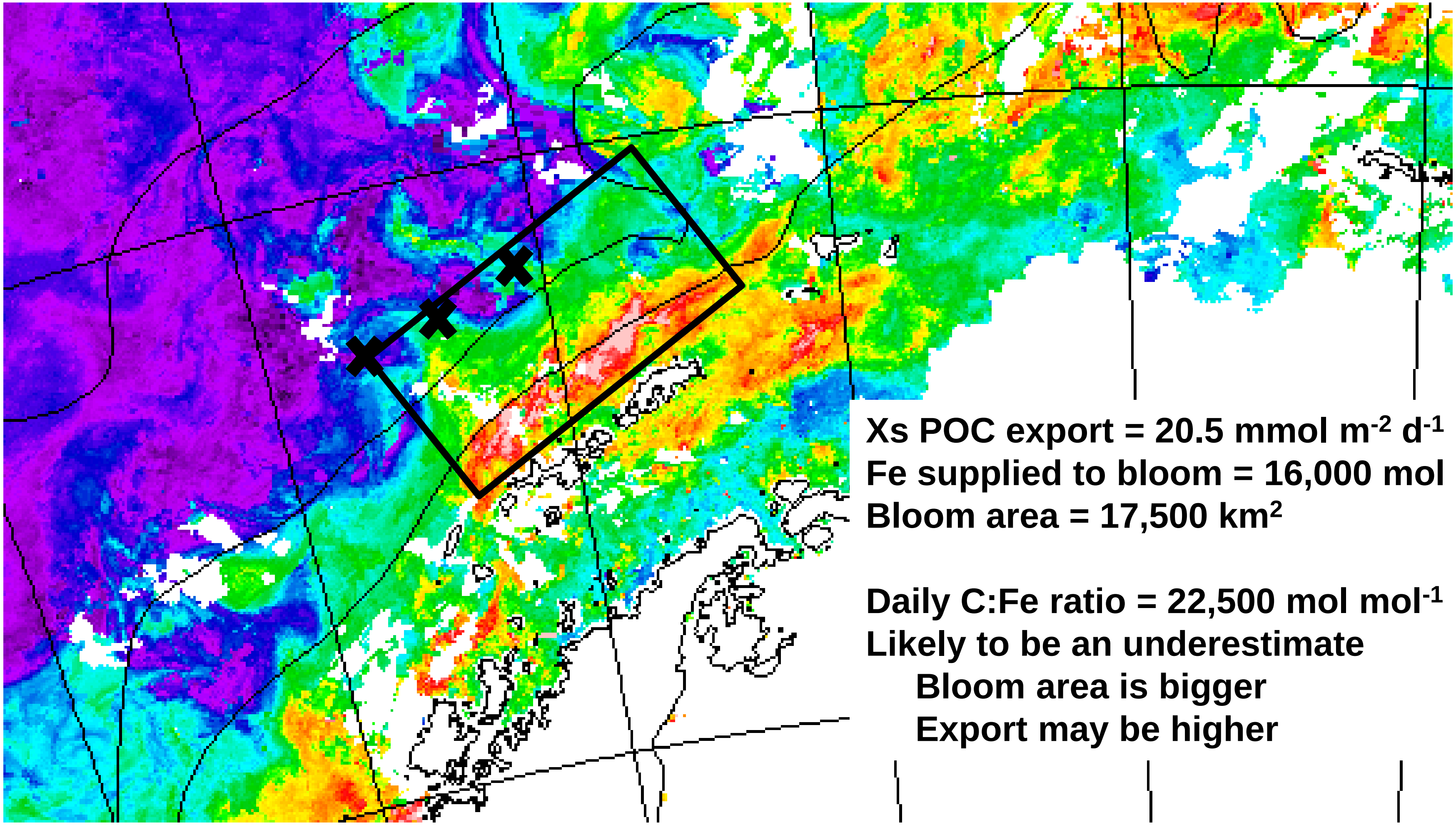
$$DW = \frac{1}{2}\int_0^Z \left\{ \left(\frac{T - T_A}{T_S - T_A} \right)^2 + \left(\frac{S - S_A}{S_S - S_A} \right)^2 \right\} dz$$





Dulaiova et al. 2009; Charette et al. unpub

BWZ – Back of the Envelope C:Fe Ratio



Xs POC export = 20.5 mmol m^{-2} d^{-1}
Fe supplied to bloom = 16,000 mol d^{-1}
Bloom area = 17,500 km^2

Daily C:Fe ratio = 22,500 mol mol^{-1}
Likely to be an underestimate
- **Bloom area is bigger**
- **Export may be higher**

Dulaiova et al. 2009; Charette et al. unpub

BWZ C:Fe Ratio in Context

- 100 m daily C:Fe ratio (not a seasonal estimate)
  - 22,500 mol mol^{-1}
- Daily 100 m C:Fe ratios for CROZEX & KEOPS
  - CROZEX – 28,200 mol mol^{-1}
  - KEOPS – 45,000 mol mol^{-1}
- How would a seasonal C:Fe ratio for BWZ look?
  - CROZEX – 17,200 mol mol^{-1}
  - KEOPS – 154,000 mol mol^{-1}

Summary – Areas of consideration

- Integration depth
  - 100 m, 200 m, winter mixed layer, site specific…
  - The C:Fe ratio is very sensitive to the integration depth
- Methods of integration over a seasonal cycle
  - What is the best approach?
  - DIC, Si-scaling, different approaches = different C:Fe
- Can we agree on a common approach for cross comparisons?

Acknowledgements

Southern Ocean deep-water carbon export enhanced by natural iron fertilization

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Effect of natural iron fertilization on carbon sequestration in the Southern Ocean

Stéphane Blain[1], Bernard Quéguiner[1], Leanne Armand[1], Sauveur Belviso[2], Bruno Bombled[2], Laurent Bopp[2], Andrew Bowie[3,4], Christian Brunet[5], Corina Brussaard[6], François Carlotti[1], Urania Christaki[7], Antoine Corbière[5], Isabelle Durand[8], Frederike Ebersbach[3], Jean-Luc Fuda[9], Nicole Garcia[1], Loes Gerringa[6], Brian Griffiths[10], Catherine Guigue[11], Christophe Guillerm[12], Stéphanie Jacquet[13], Catherine Jeandel[14], Patrick Laan[6], Dominique Lefèvre[11], Claire Lo Monaco[5], Andrea Malits[15], Julie Mosseri[1], Ingrid Obernosterer[16], Young-Hyang Park[8], Marc Picheral[15], Philippe Pondaven[17], Thomas Remenyi[3], Valérie Sandroni[1], Géraldine Sarthou[17], Nicolas Savoye[13,18], Lionel Scouarnec[12], Marc Souhaut[14], Doris Thuiller[5], Klaas Timmermans[6], Thomas Trull[3,10], Julia Uitz[15], Pieter van Beek[14], Marcel Veldhuis[6], Dorothée Vincent[7], Eric Viollier[19], Lilita Vong[1] & Thibaut Wagener[15]

BWZ team