Physical Processes Governing Natural Iron Fertilization in the Southern Drake Passage

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plus input from
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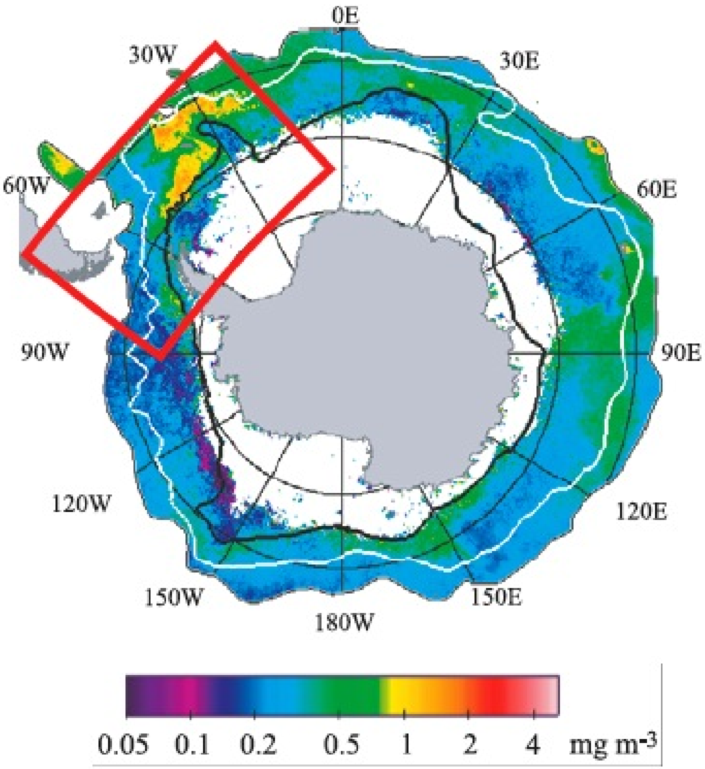
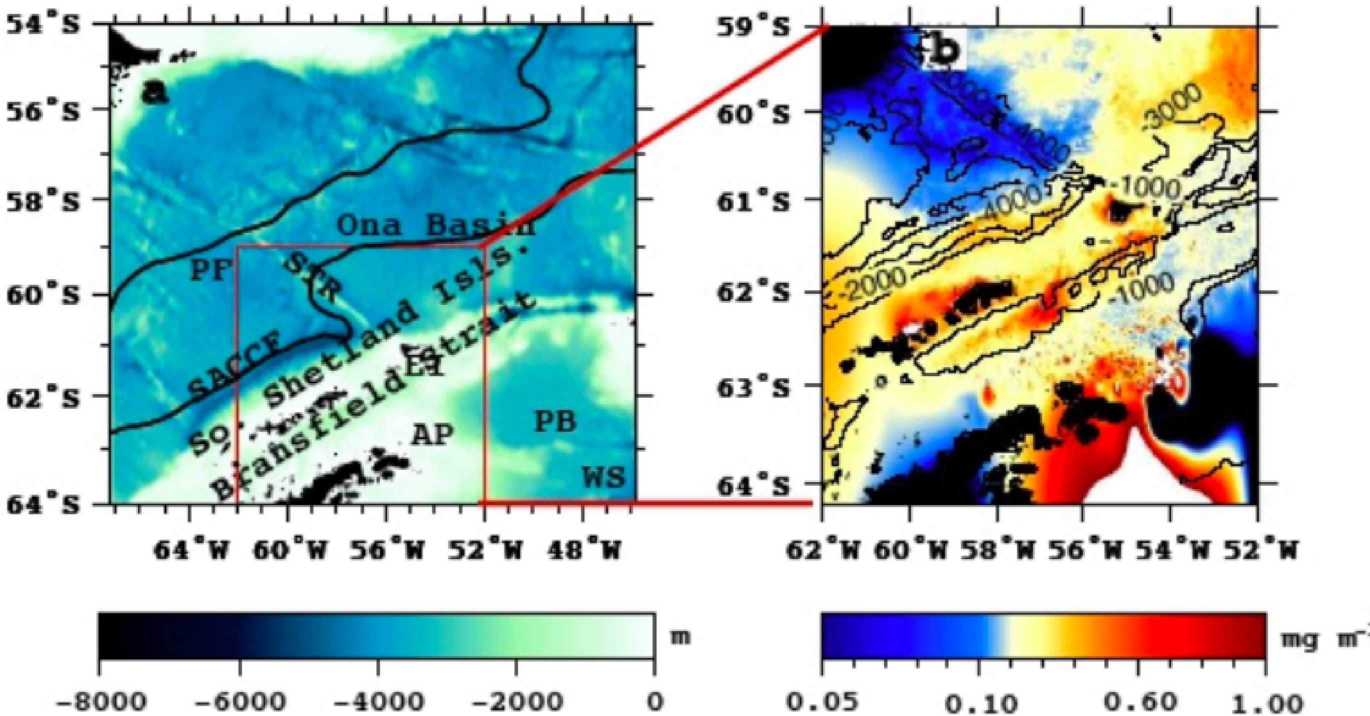
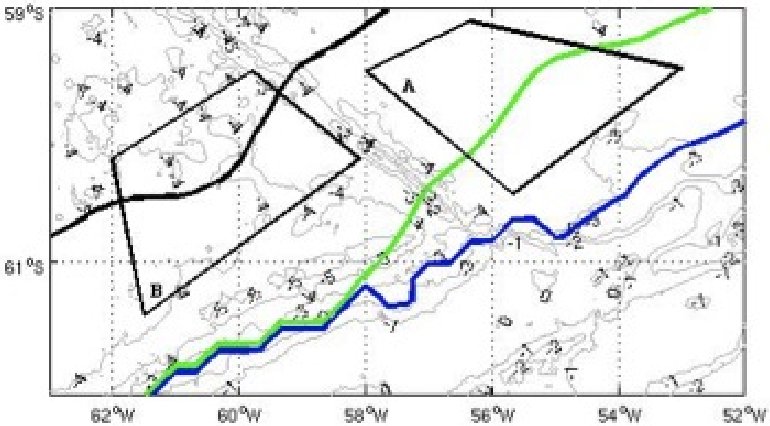


Kahru et al, 2007

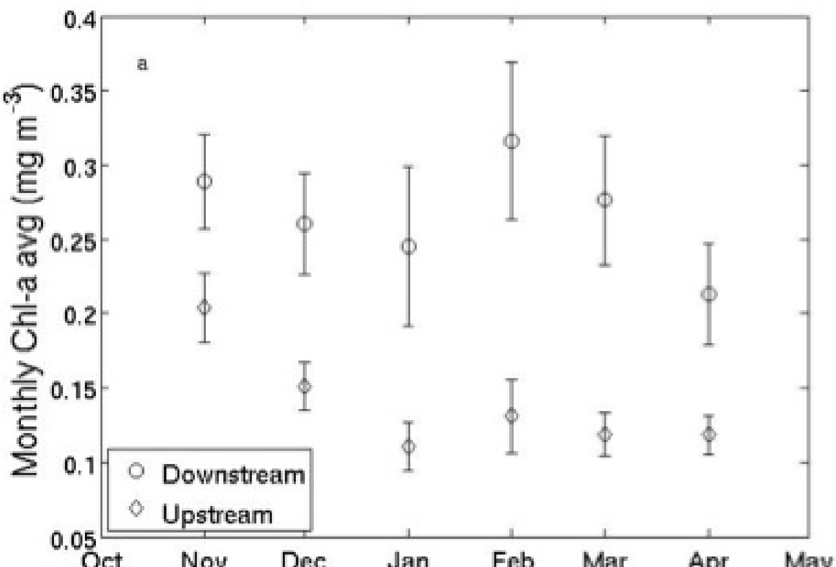
Bathymetry and chlorophyll-a in Southern Drake Passage

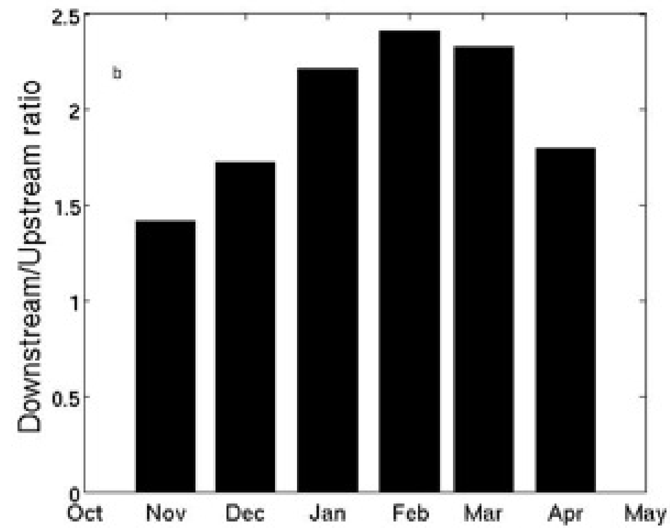


Frants et al, in prep, 2011a



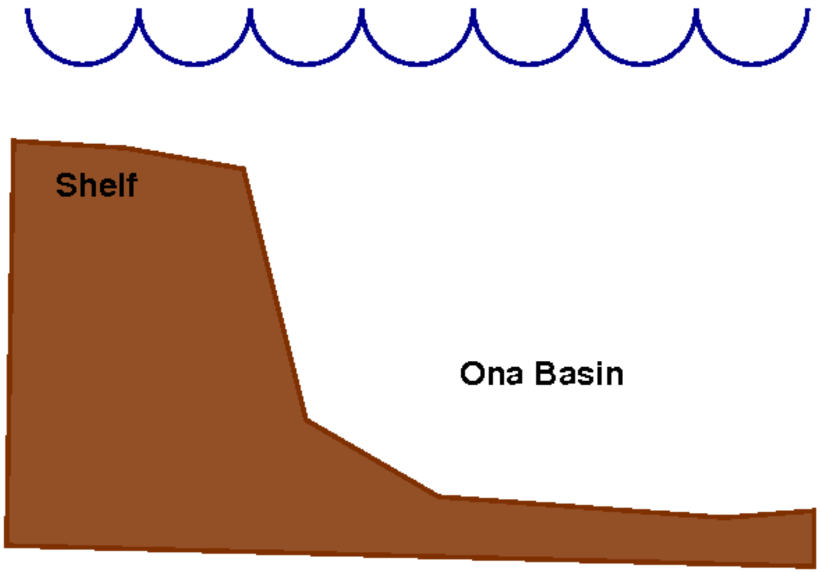
Chl-a levels downstream of STR (region A) persistently higher than upstream (region B).





Frants et al, in prep, 2011b

Can physical processes explain the persistent bloom?



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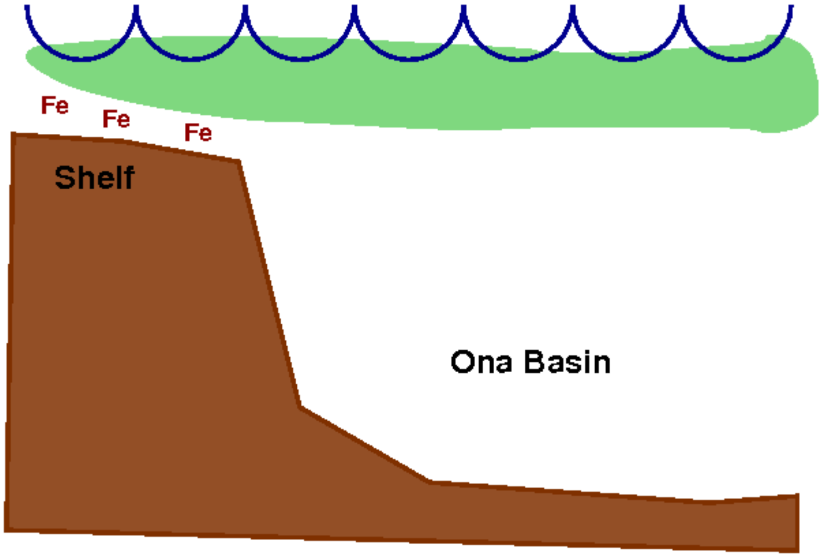

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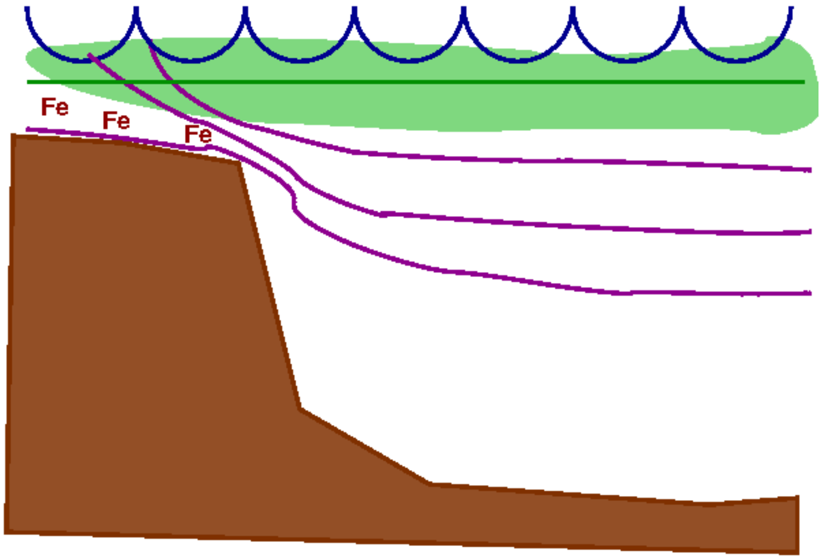

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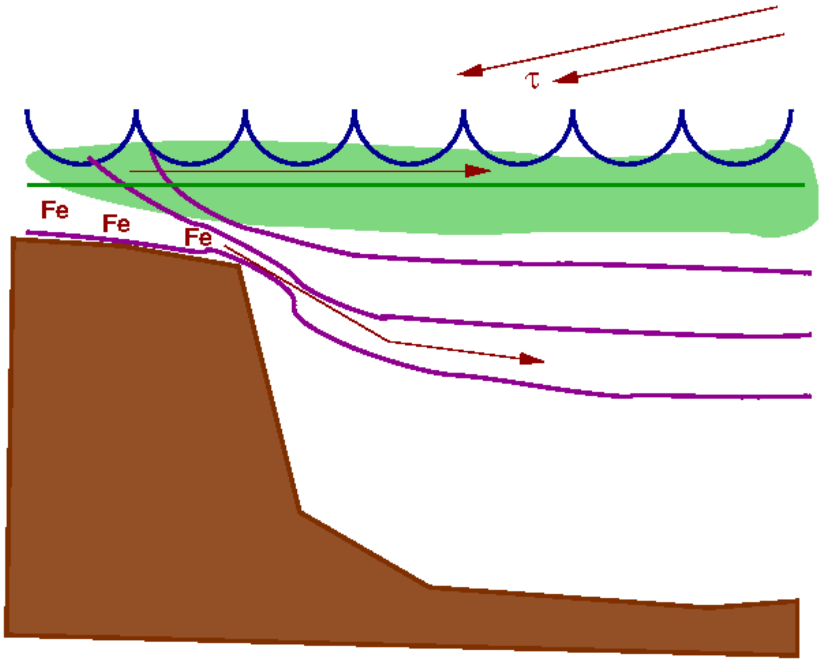
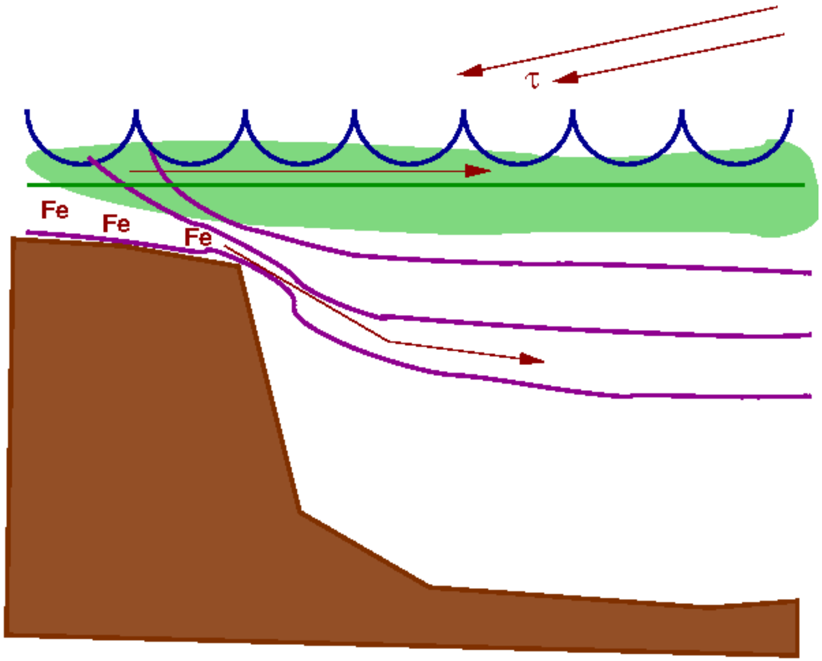


Potential iron sources:

- Aeolian transport from South America.
- Horizontal advection off the shelf.
- Along-isopycnal advection off the shelf followed by vertical mixing.

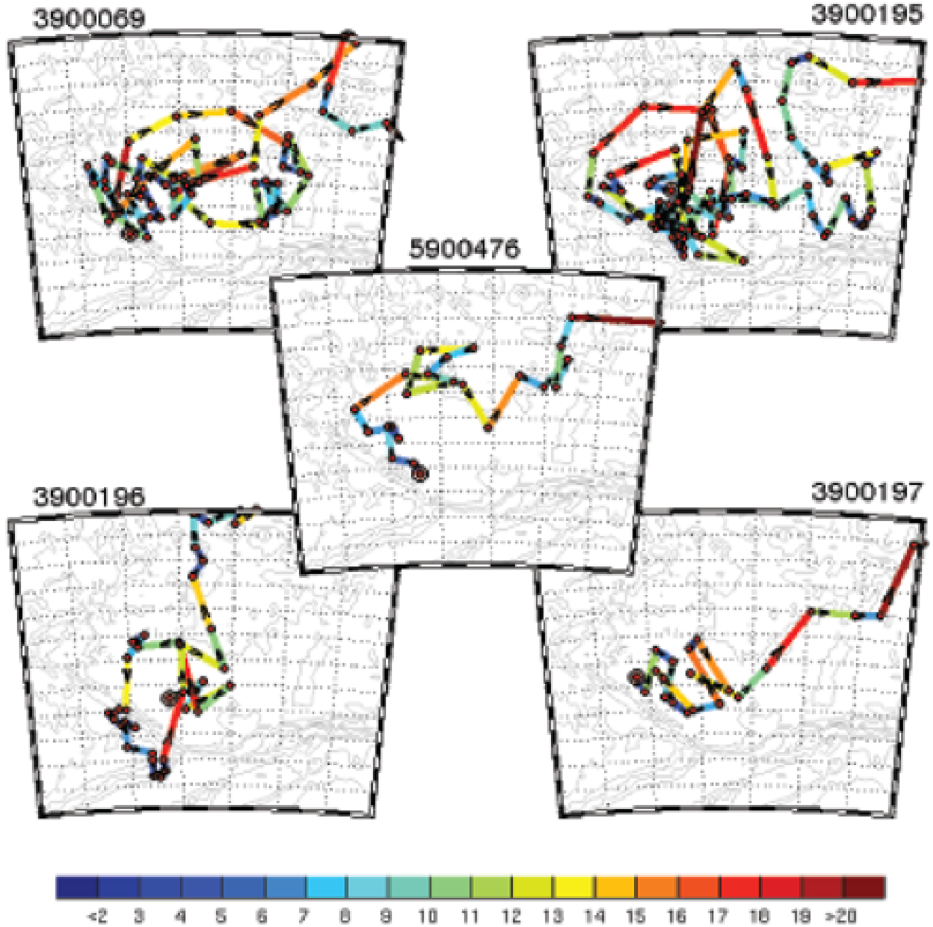
Can physical processes explain the bloom?



Potential iron sources: Problems

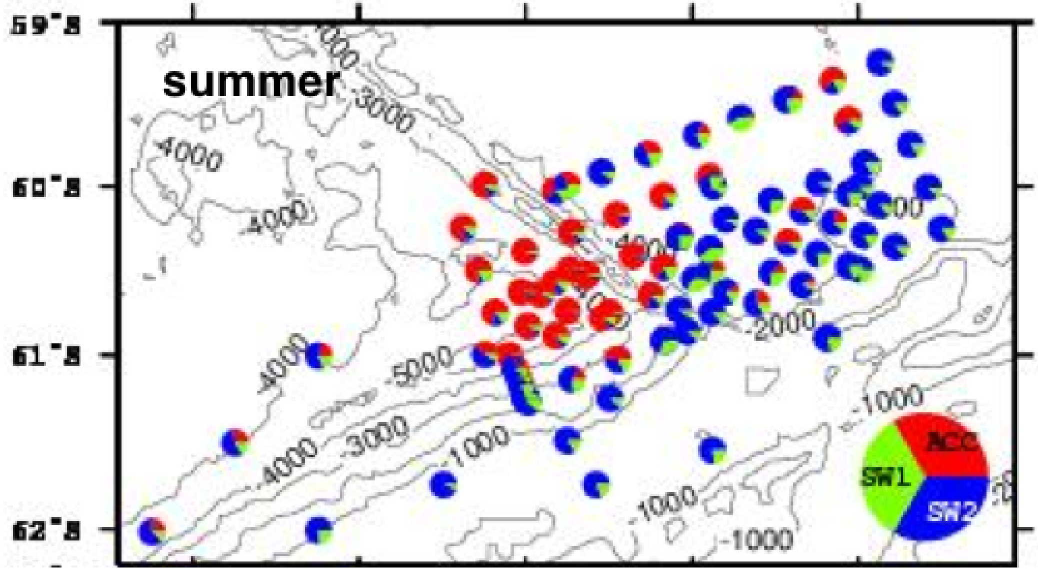
- Aeolian transport from South America: Horizontal scales of atmospheric storms are O(600 km)—too big to explain small-scale structure of bloom
- Horizontal advection off the shelf: Water tends to mix along density surfaces
- Along-isopycnal advection off the shelf followed by vertical mixing: Need mechanism to account for vertical mixing

Horizontal Transport to the Ona Basin: Substantial eddy activity seen by Argo floats



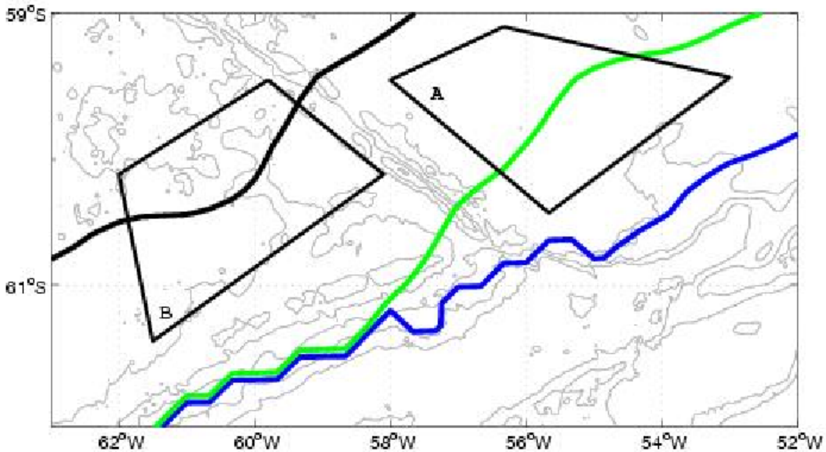
Barré et al., JGR, 2008

Hydrographic Data Imply Substantial Shelf Water Input to Ona Basin



Frants et al, in preparation, 2011

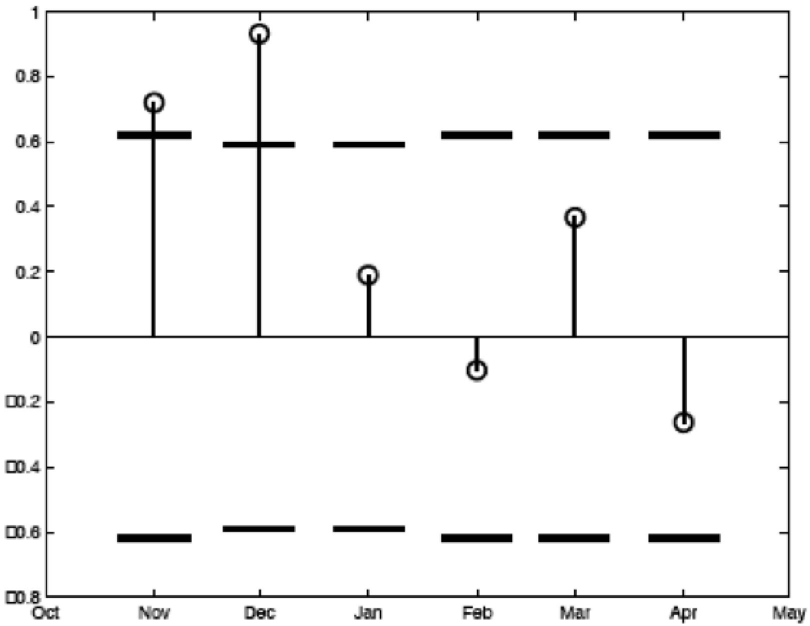
How Much Shelf Water is in the Ona Basin?



Frants et al, in preparation, 2011

- Shelf water is cold and dense.
- Southern ACC Front (green line) marks penetration into Ona Basin.
- Identify this water from sea surface height contour (64 cm ssh relative to 1500 db).
- Correlate time series of shelf water versus productivity.

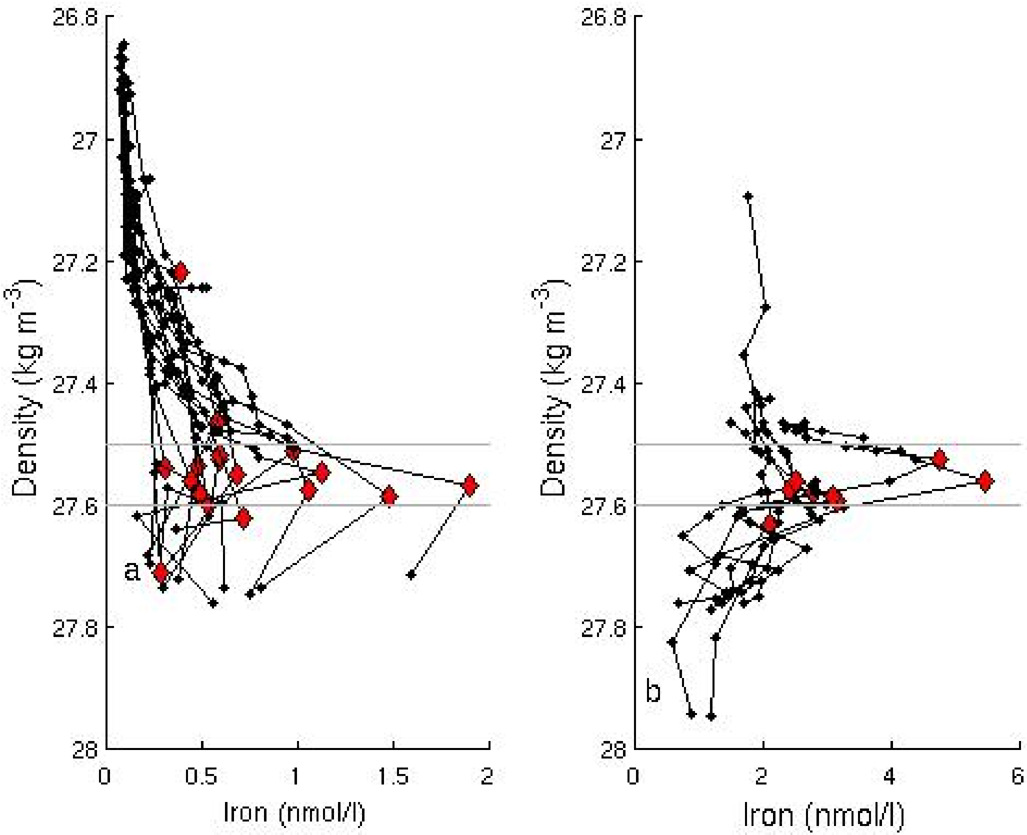
Horizontal Transport Alone is Insufficient



- Spring: High correlation between sea surface height and chl-a
- January onward: No correlation

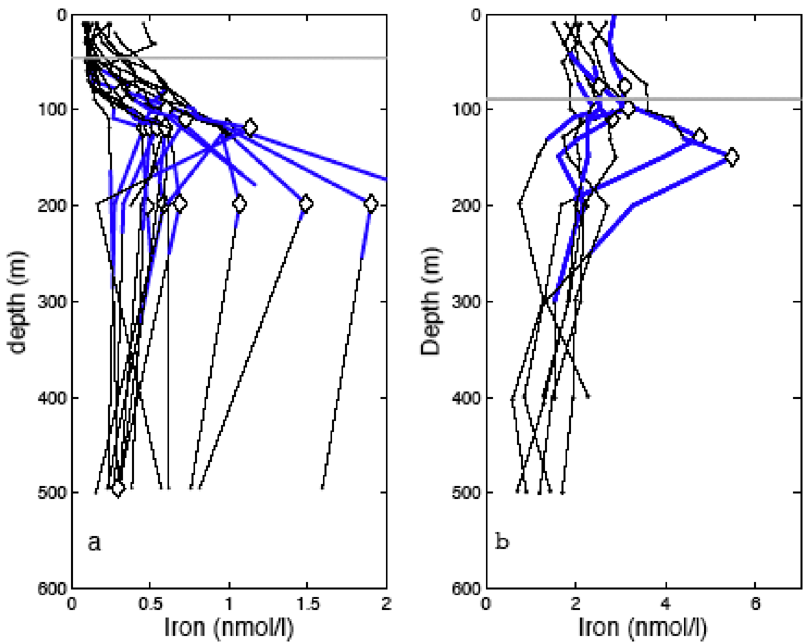
Frants et al, in preparation, 2011

Iron maximum on a fixed isopycnal



Frants et al, in preparation, 2011

Iron maximum 100-200 m deep: Vertical transport needed

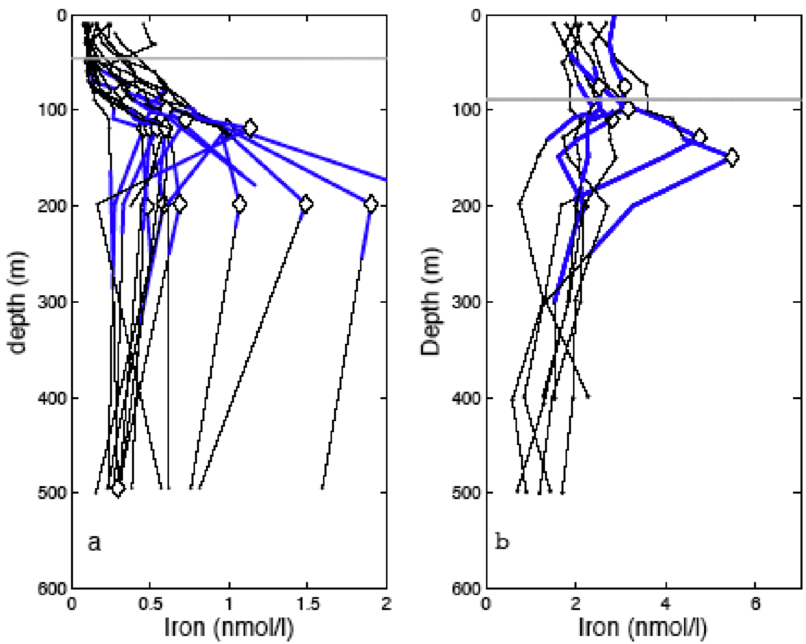


Iron requirements to sustain bloom in summer:

- 286 nmol m^{-2} day^{-1}: Bransfield Strait (Ardelan et al., 2010)
- 208 $\pm$ 77 nmol m^{-2} day^{-1}: Kerguelen Island (Blain et al., 2007)

Frants et al, in preparation, 2011

Iron maximum 100-200 m deep: Mechanisms for moving iron



Frants et al, in preparation, 2011

Mechanisms for vertical mixing of iron

- Simple diffusion:

$$F_z = -\kappa \frac{\partial Fe}{\partial z}.$$

- Mixed-layer depth variability leads to entrainment
- Other possibilities: vertical velocities associated with flow over bathymetry or due to secondary circulation induced by mesoscale eddies

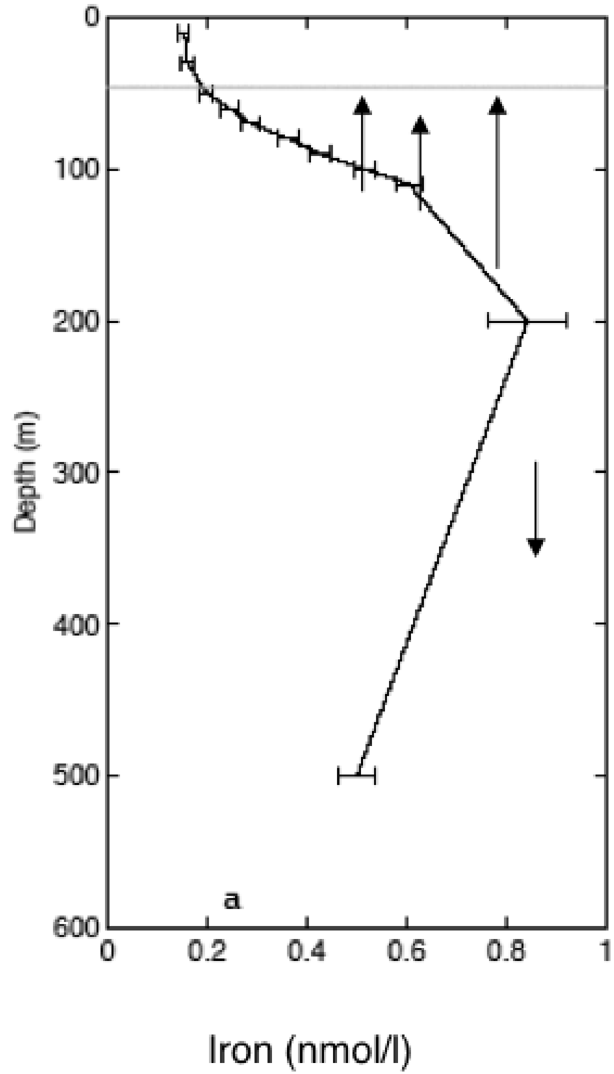
Simple diffusion

$$F_z = -\kappa \frac{\partial Fe}{\partial z}.$$

with $\kappa = O(10^{-4})$ m^2 s^{-1} and observed gradients.

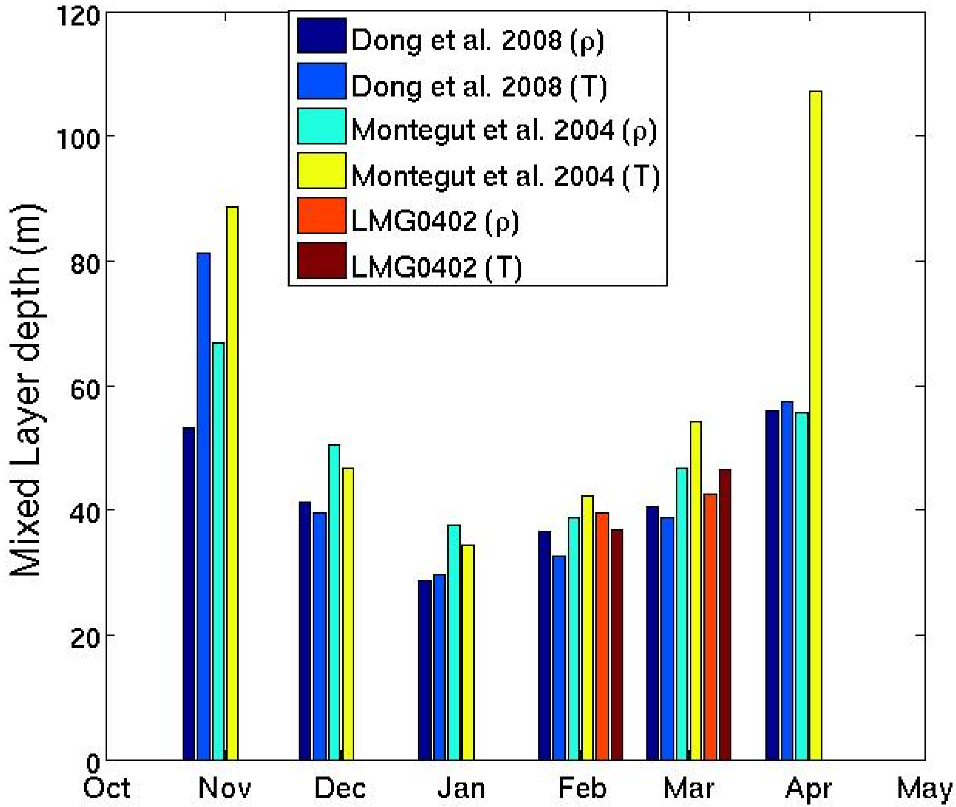
Flux: $F_z = 96 \pm 9$ nmol m^{-2} day^{-1}

Half of required 200 to 300 nmol m^{-2} day^{-1}.



Frants et al, in preparation, 2011

Mixed Layers Deepen from January to April



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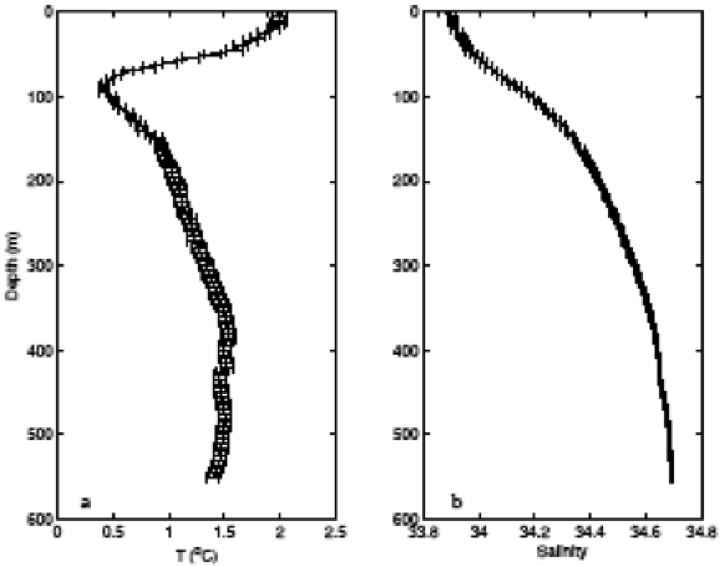
Use One-Dimensional Mixed-Layer Model to Assess Entrainment



Frants et al, in preparation, 2011

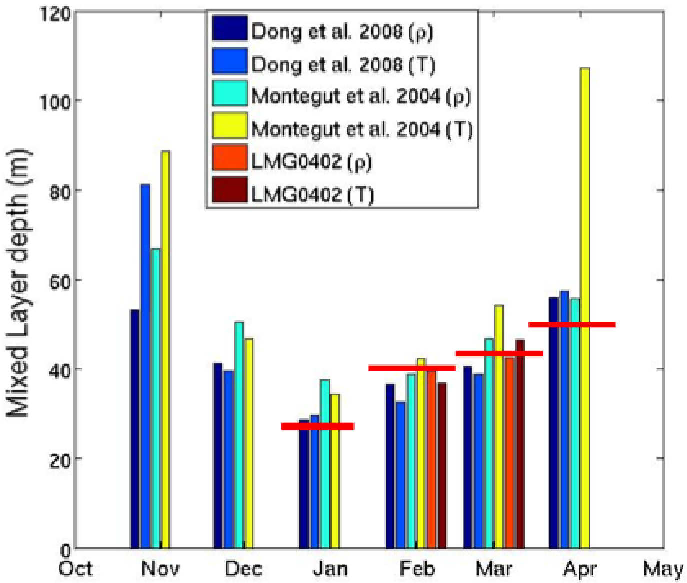
Price Weller Pinkel (PWP) Model for diurnal variability of upper ocean using wind stress and buoyancy forcing.

- Wind and buoyancy forcing from NCEP/NCAR Reanalysis fields. (4 times daily)
- Wind stress:

$$\tau = \rho_a C|u|u,$$

$u =$ wind velocity at 10 m
$\rho_a =$ density of air
$C =$ drag coefficient (Yelland et al, 1998)

Mixed-Layer Depth Entrainment Impact

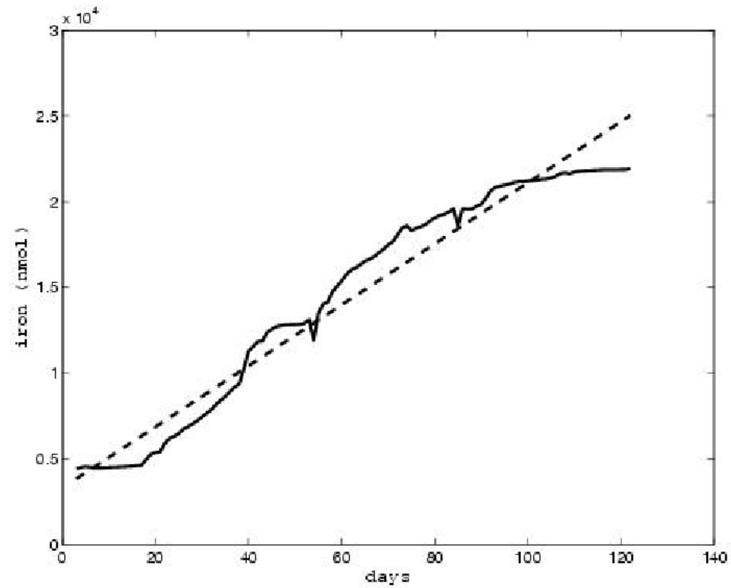


Frants et al, in preparation, 2011

- 120-day simulation with PWP
- Modeled evolution of mixed layer parallels observations
- Implies $F_z = 12 \pm 9$ nmol m^{-2} day^{-1} (Compare with 200 to 300 nmol m^{-2} day^{-1} required for bloom)

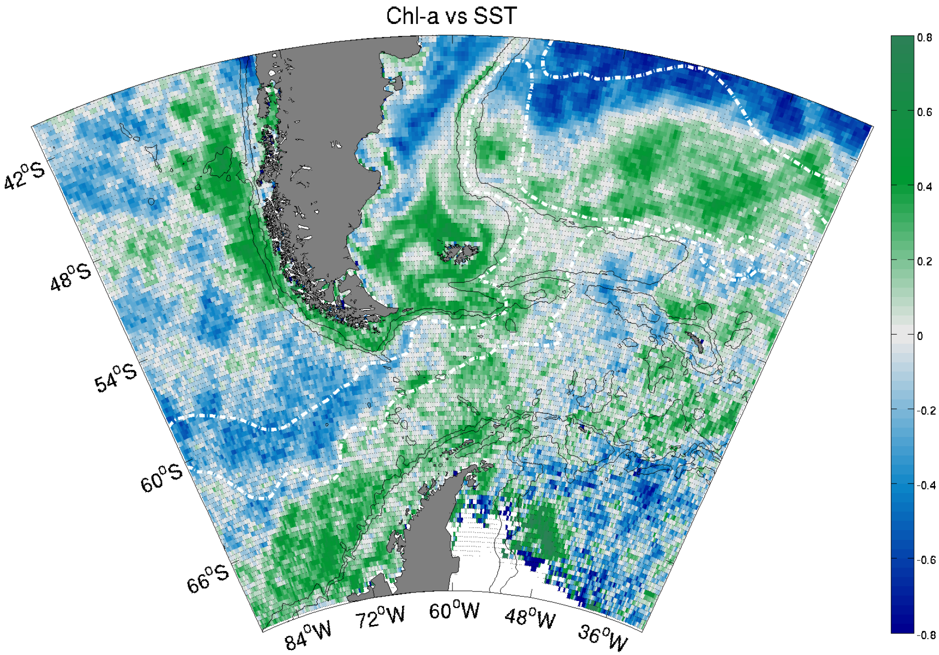
Entrainment and Diffusion

- Modify PWP model to include diffusion and entrainment
- Implies $F_z = 174 \pm 44$ nmol m^{-2} day^{-1}
  (Compare with 200 to 300 nmol m^{-2} day^{-1} required for bloom)



Frants et al, in preparation, 2011

Broader Geographic Perspective



In Ona Basin, Chl-a positively correlated with SST and wind speed (and wind speed variance).

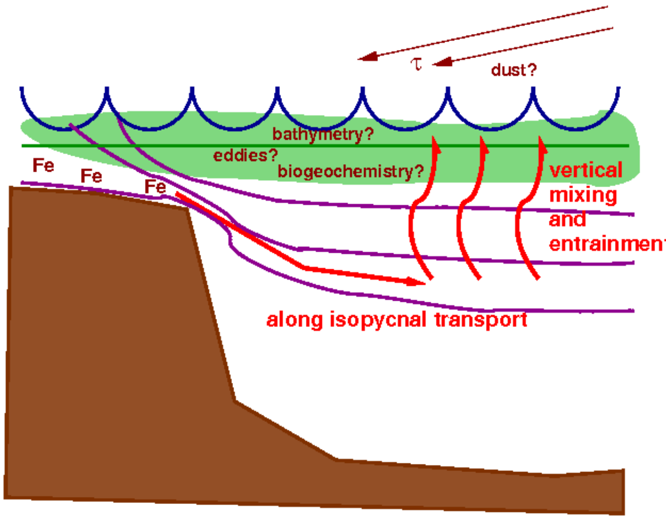
Suggests that strong winds drive upper ocean mixing and/or deepen mixed-layer.

Carranza et al, in preparation, 2011

Summary

Physical processes alone can just about explain persistent bloom in Ona Basin.

- Iron advected offshore from shelf along isopycnals
- Iron supplied to euphotic zone through combination of vertical diffusion and entrainment: $F_z = 174 \pm 44$ nmol m^{-2} day^{-1}.



Additional iron could result from:

- Aeolian deposition (dust)
- Eddy-induced mixing
- Bathymetrically-induced mixing
- Biogeochemistry: ligand chemistry, remineralization, etc.