Bettina Sohst

Reactive iron in the Alaska Coastal Current and a Kenai Eddy in the Gulf of Alaska: the delivery of iron to high-nutrient, lower than expected chlorophyll waters

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2010 Knauss Fellow

Marine Debris Program

Office of Response & Restoration

National Ocean Service

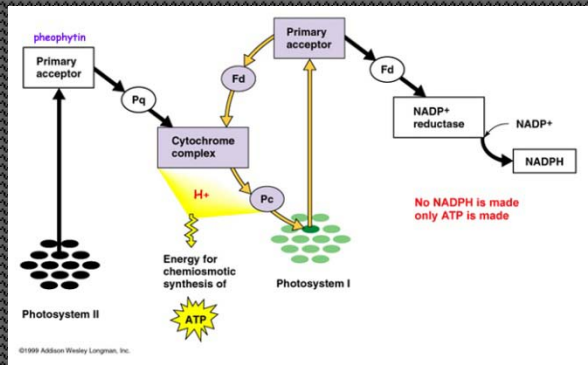
Why iron?

- Phytoplankton require nutrients
  - Redfield (1934): $C_{106}N_{16}P_1$
  - Relative concentrations of macronutrients in phytoplankton & seawater

$$(C_{106}Si_{18}N_{16}P_1)_{x1000}Fe_5Zn_{0.8}Mn_{0.4}Cu_{0.2}Co_{0.2}Cd_{0.1}$$

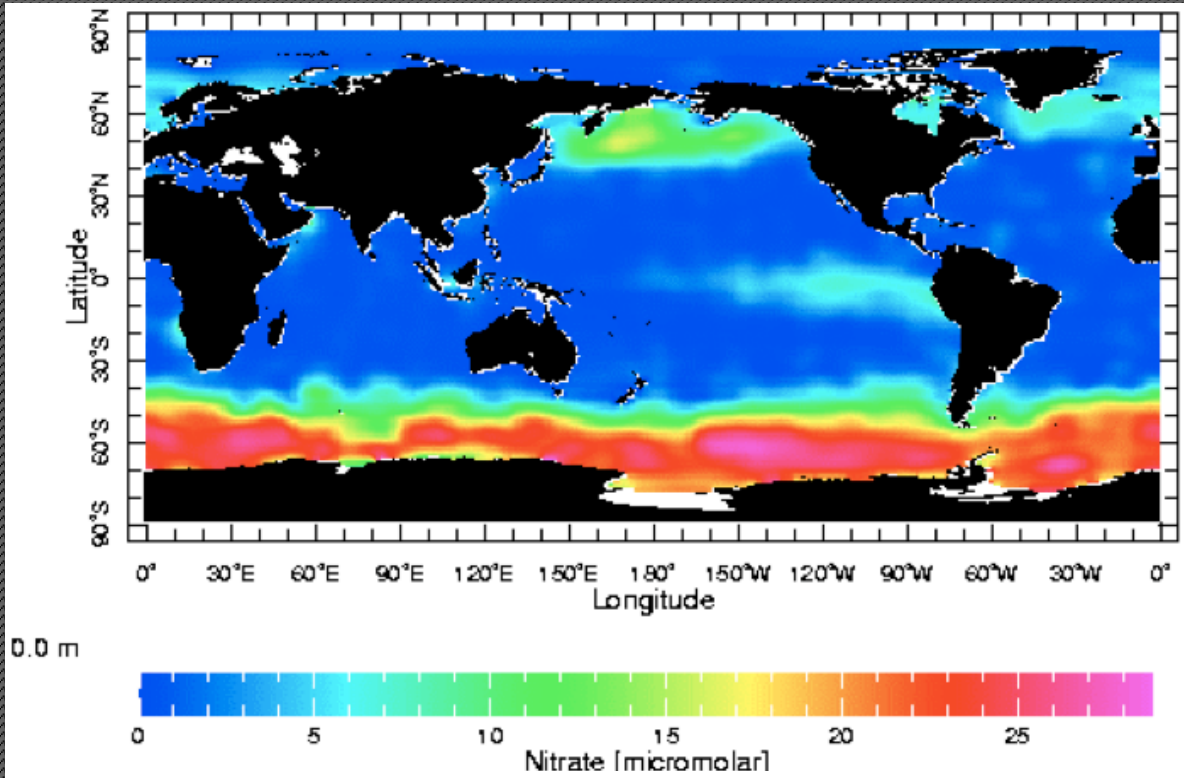
Coastal diatoms from offshore California (Bruland et al. 1991)

- ~ 50 μmol Fe : mol C
- Fe is required for photosynthesis



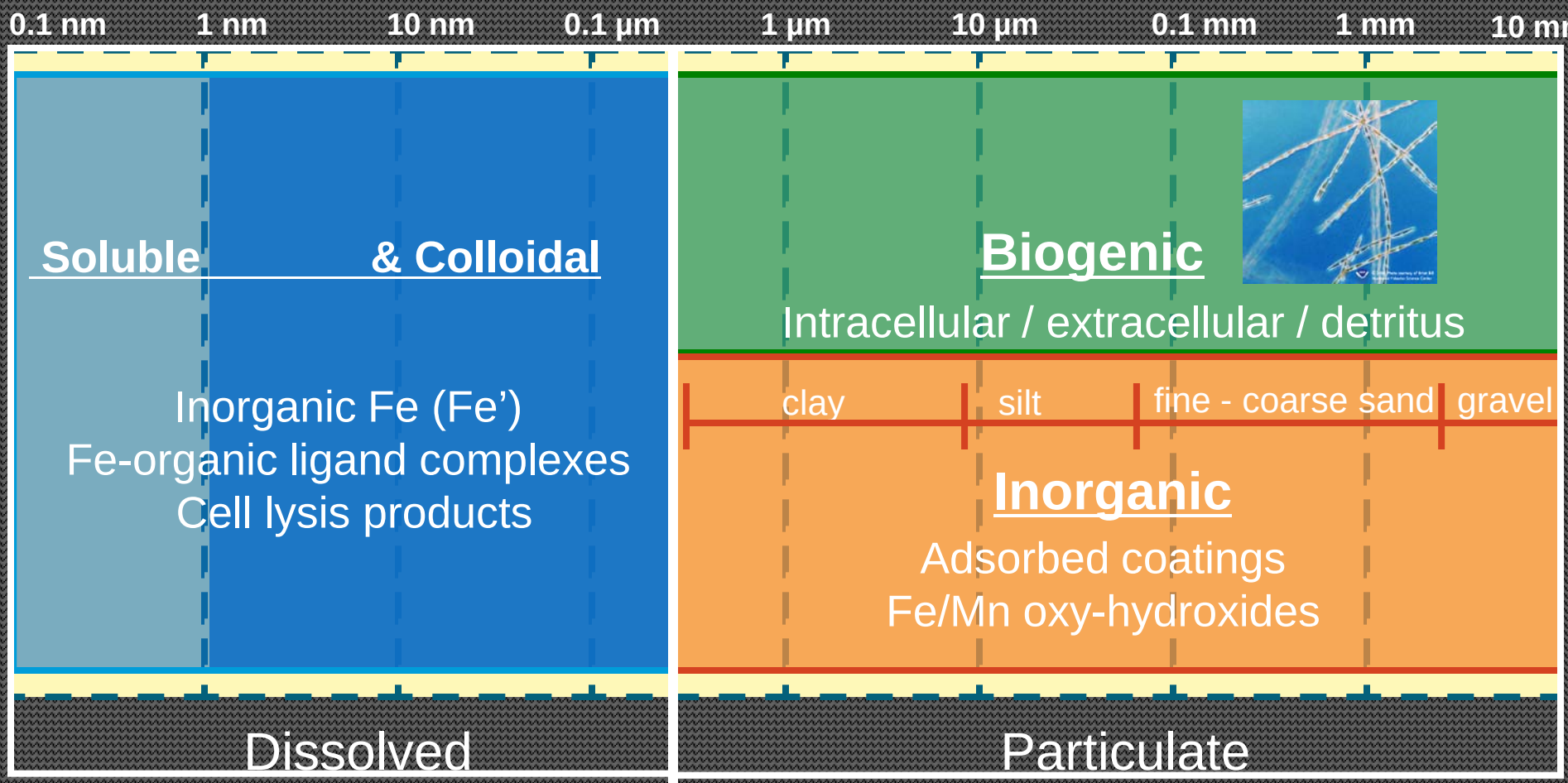
High Nutrient, Low(er than expected) Chlorophyll Regions

- Excess macronuts
- Primary productivity is limited by the supply of Fe
- Sources of Fe
  - Rivers
  - Shelf sediments
  - Atmospheric dust



NODC_WOA94 data provided by the NOAA/OAR/ESRL PSD
http://www.esrl.noaa.gov/psd/

Dissolved versus Particulate Fe



0.2 µm pore size filter

Figure adapted from C. Berger, Bruland and Rue 2001

Bioavailability of Fe

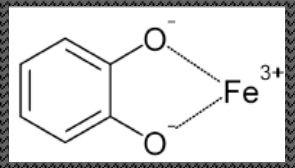
- Dissolved Fe most accessible
- At seawater pH, Fe(III) is sparingly soluble, and in oxygenated seawater Fe(II) is unstable
- A portion of the particulate Fe can be solubilized on timescale of days
  - Redox conditions in seds, water column
  - Photochemical reduction (dust)
  - Ligand-assisted dissolution
  - Grazing / remin. of biogenic matter

Wells et al. 1995; Landing and Bruland 1987; Barbeau et al. 2001; Buck et al. 2007

Dissolved Fe

Fe' $Fe(OH)_2^+$ $Fe(OH)_3^0$

FeL



L = Fe-binding organic molecules + siderophores

Leachable Fe

Weakly bound or biogenic Fe that can become dissolved *i.e.* (oxyhydr)oxide coatings, ferritin

Reactive Fe = Dissolved + Leachable Particulate

Particulate Fe

Refractory Fe

Locked within mineral lattices, insoluble on timescale of days

i.e. alumino-silicates

Leachable Fe

Weakly bound or biogenic Fe that can become dissolved

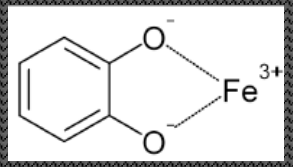
i.e. (oxyhydr)oxide coatings, ferritin

Dissolved Fe

Fe' $Fe(OH)_2^+$

$Fe(OH)_3^0$

FeL



L = Fe-binding organic molecules + siderophores

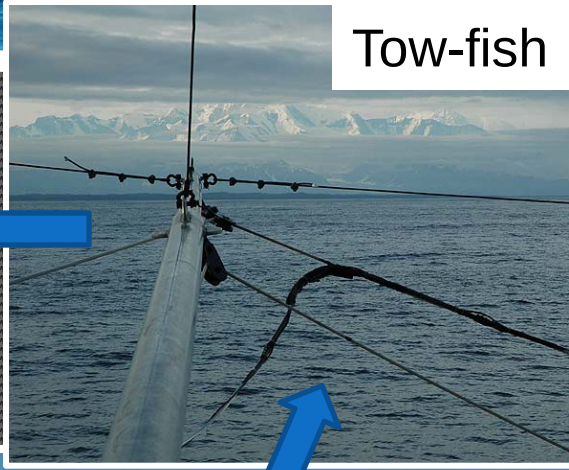
Berger, Lippiatt, Lawrence, and Bruland (2008).
Application of a chemical leach technique…. *JGR-Oceans*

Methods

Trace metal clean sample collection and processing…

Particulate samples

Bubble



Tow-fish

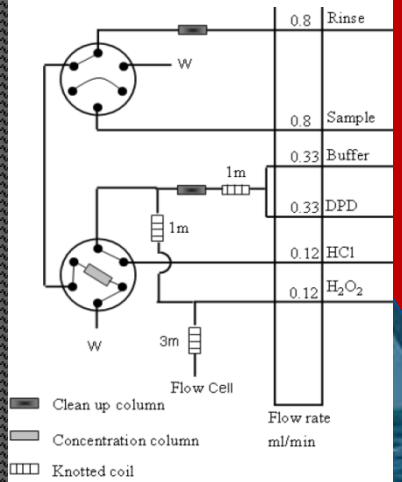
Back in the lab…

Leaches/digestions

ICP-MS

Dissolved samples

Shipboard FIA



Setting the stage for investigating the importance of eddies in mixing coastal Fe into HNLC central GoA:

What is the distribution of *reactive* (potentially bioavailable) Fe in coastal waters?

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/marchem

The distribution of reactive iron in northern Gulf of Alaska coastal waters

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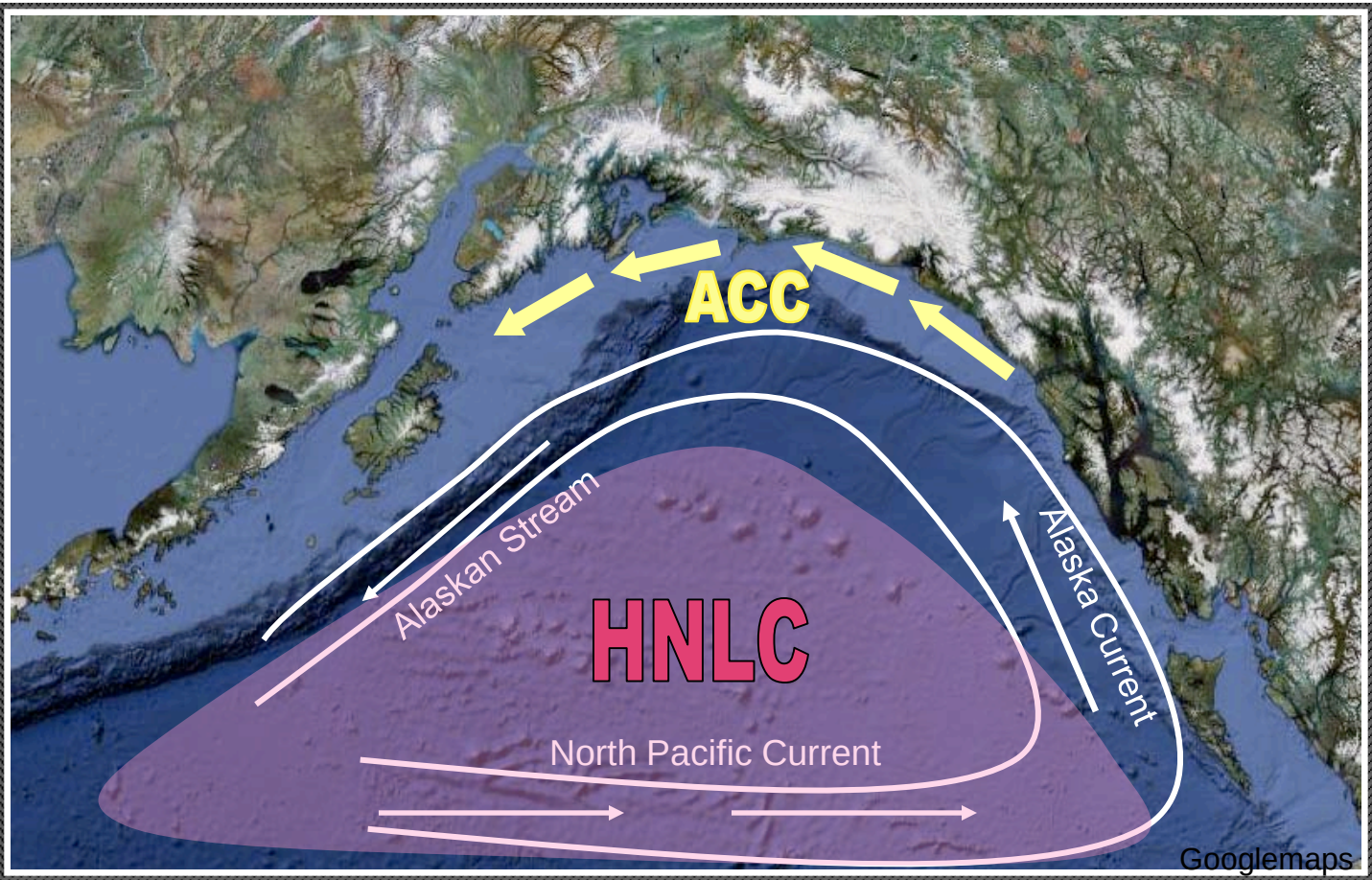
[b] Marine Institute, University of Plymouth, Drake Circus, Plymouth PL4 8AA, United Kingdom

Coastal GoA



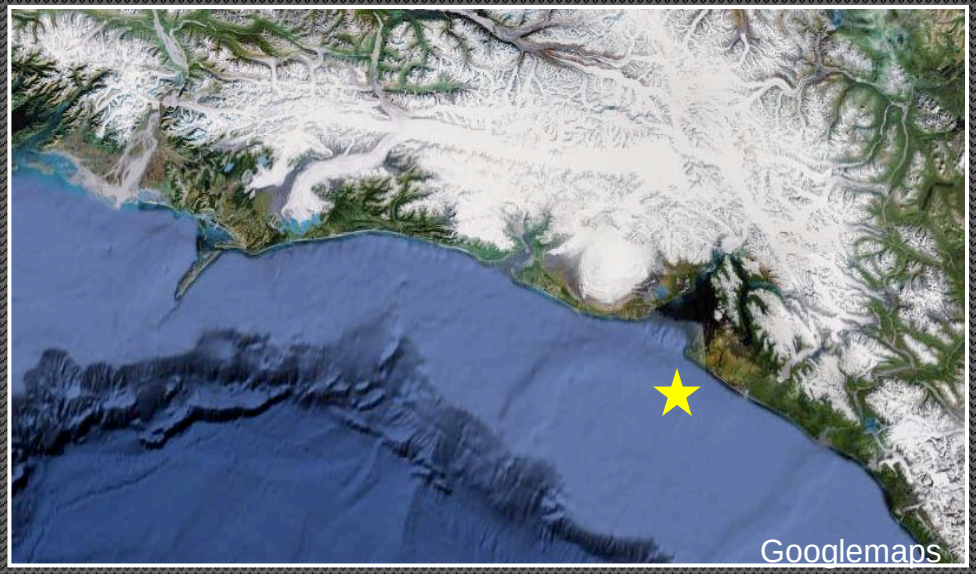
- Wind and buoyancy-driven Alaska Coastal Current (ACC)
- Fed by Fe rich glacial runoff
- Mixing between two regimes drives productivity

fresh glacial flour

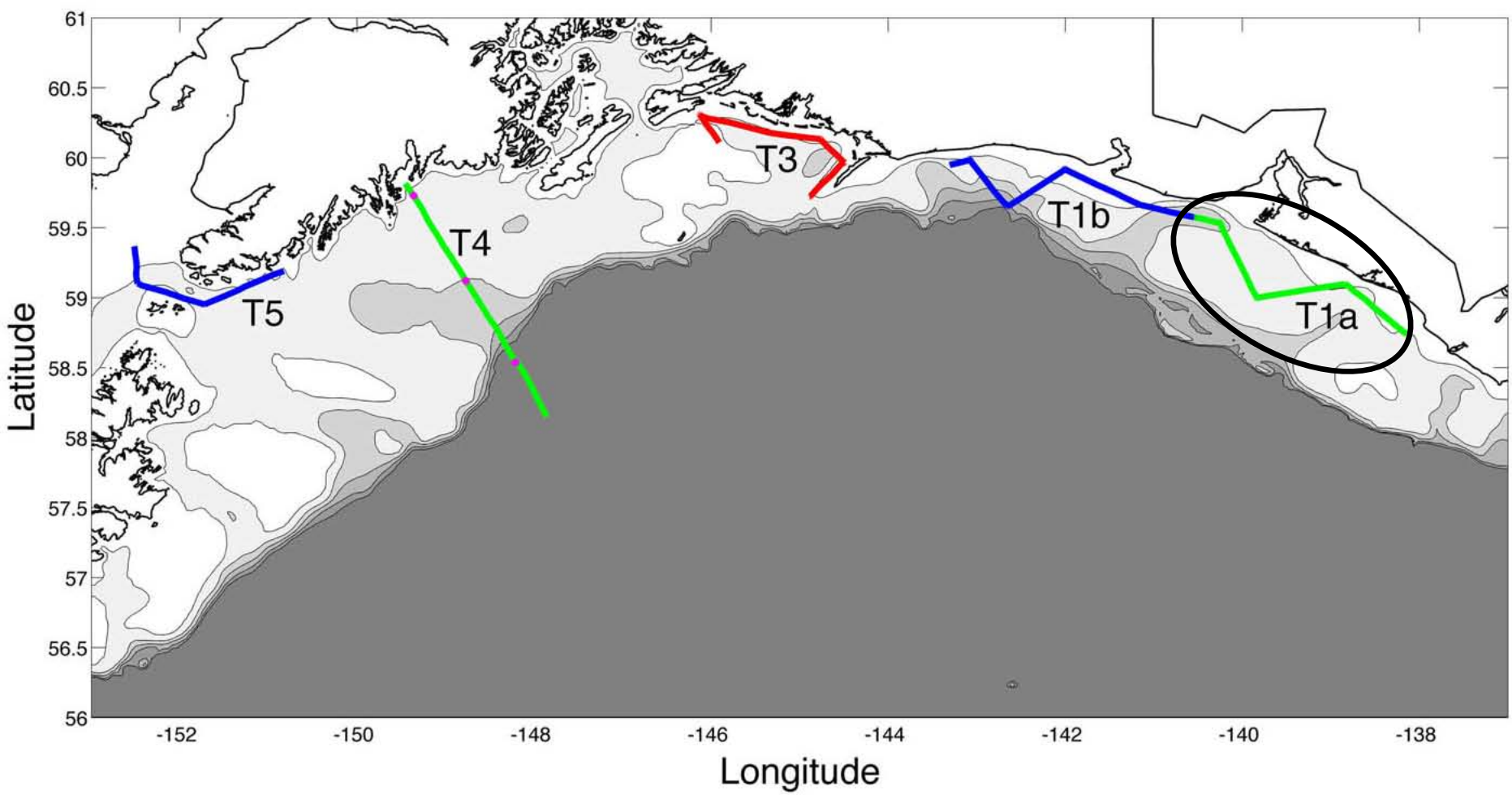
shelf waters

Glaciers described as "buzzsaws" physically weathering underlying sediments (Spotila et al., 2004)

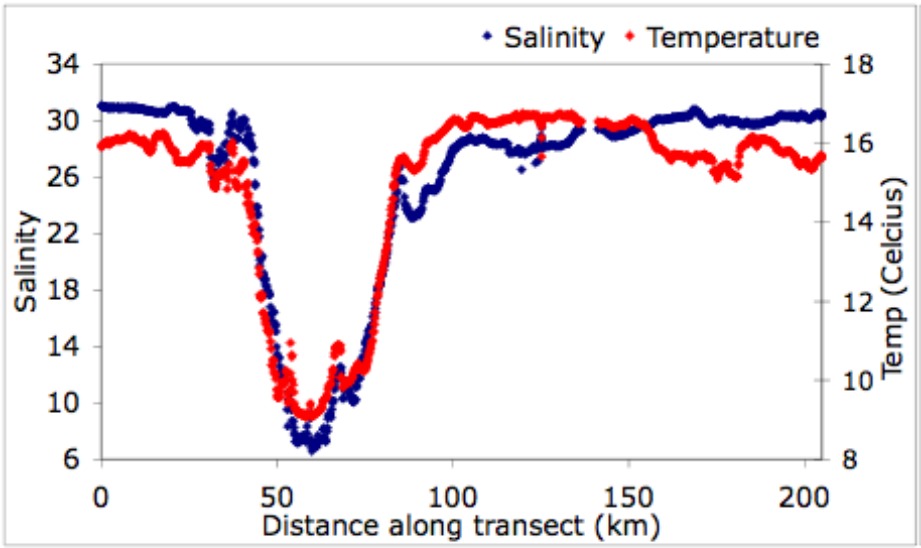
Glacial meltwaters are a significant source of Fe but not nitrate

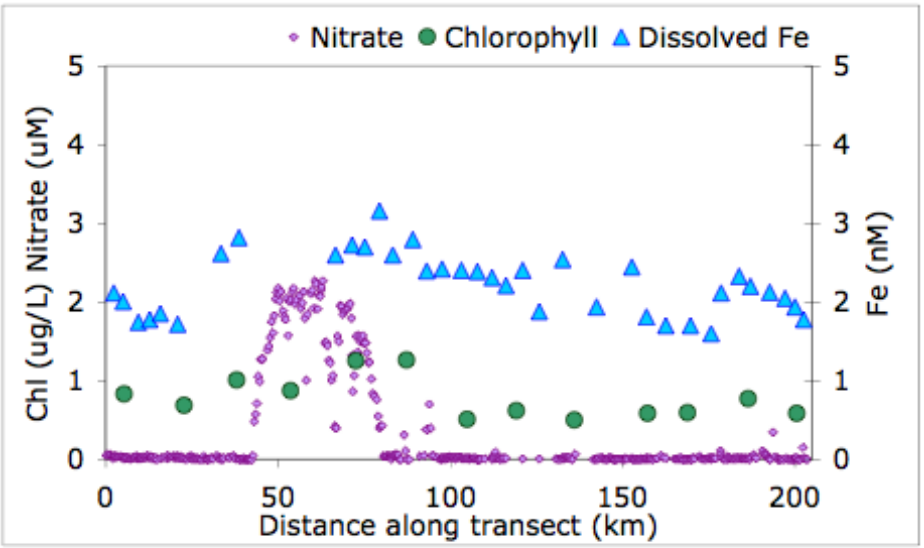


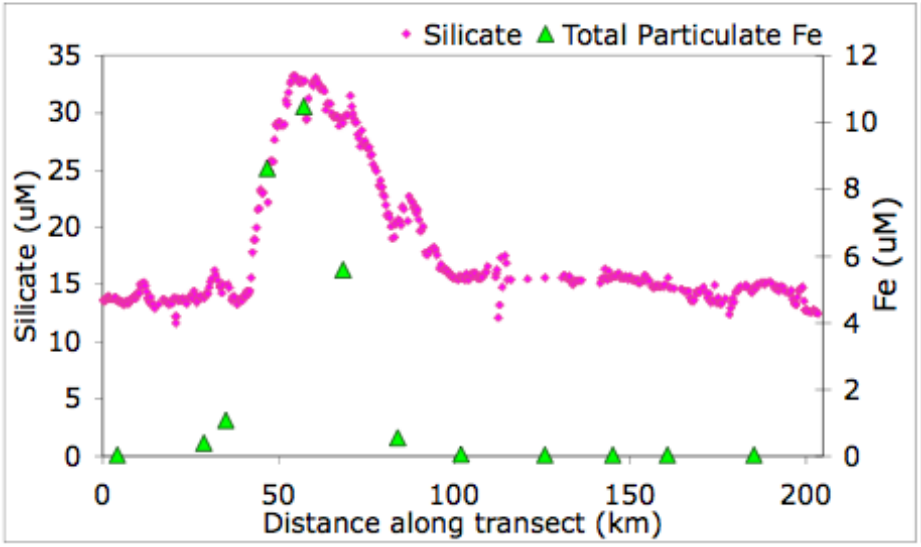
Coastal GoA

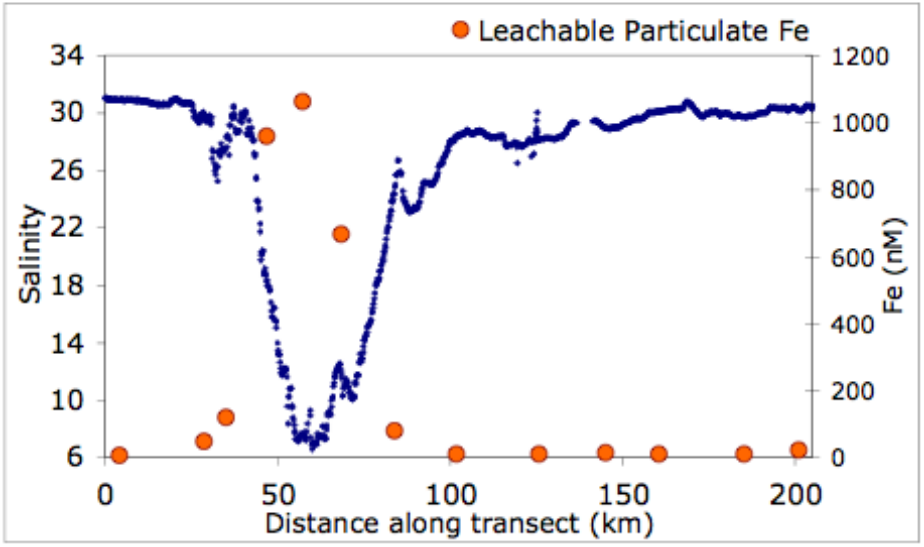

T5
T4
T3
T1b
T1a
Latitude
Longitude
61
60.5
60
59.5
59
58.5
58
57.5
57
56.5
56
-152
-150
-148
-146
-144
-142
-140
-138

Coastal GoA

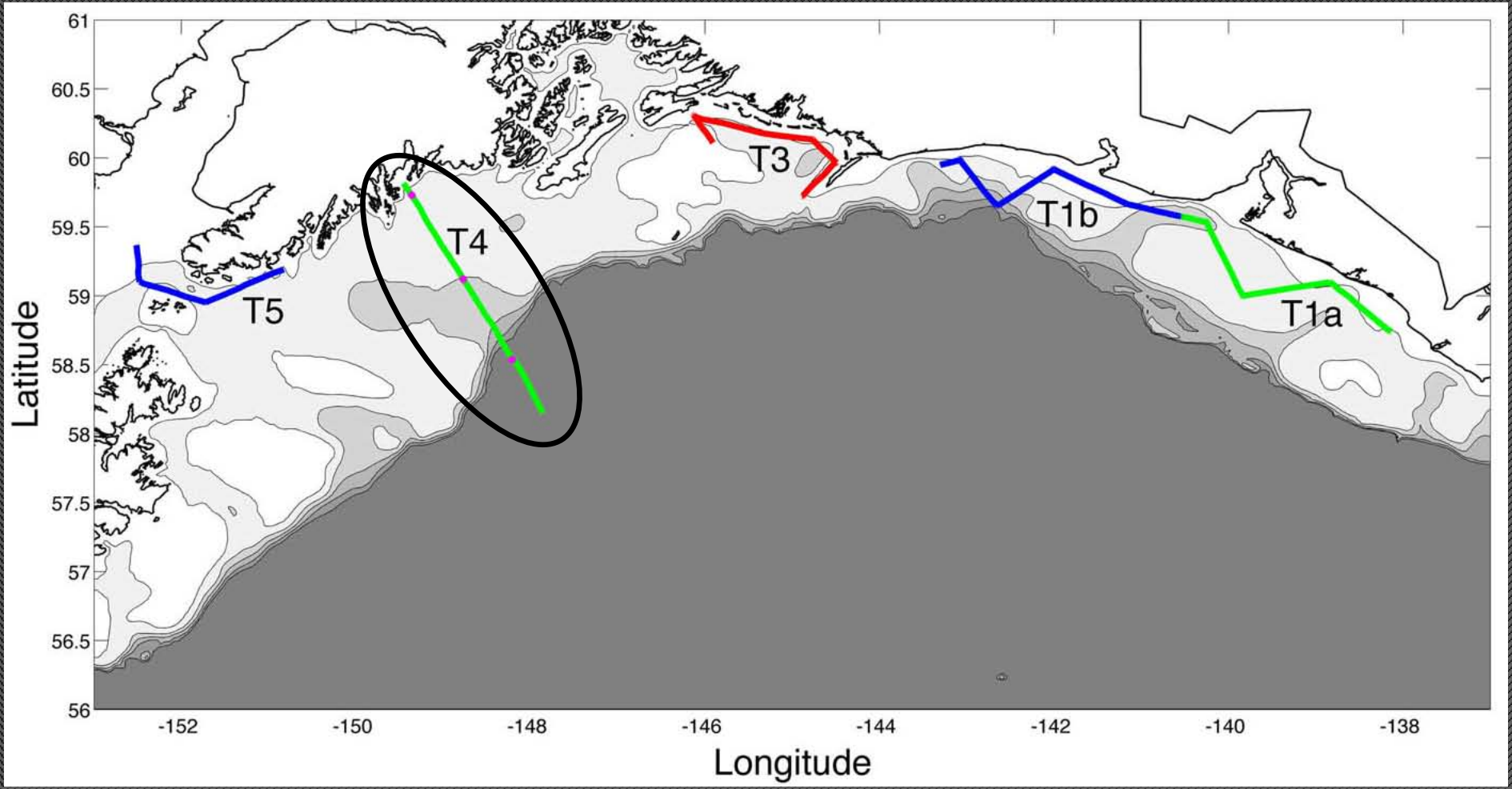

Salinity
Temperature
Salinity
Temp (Celcius)
Distance along transect (km)


Nitrate
Chlorophyll
Dissolved Fe
Chl (ug/L) Nitrate (uM)
Fe (nM)
Distance along transect (km)


Silicate
Total Particulate Fe
Silicate (uM)
Fe (uM)
Distance along transect (km)


Leachable Particulate Fe
Salinity
Fe (nM)
Distance along transect (km)

Coastal GoA


T5
T4
T3
T1b
T1a
Latitude
Longitude
61
60.5
60
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59
58.5
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57
56.5
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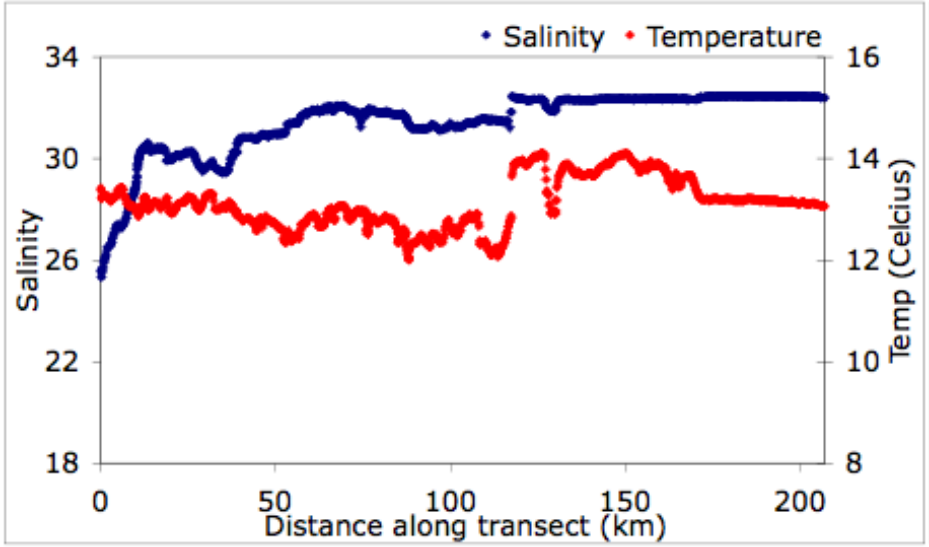
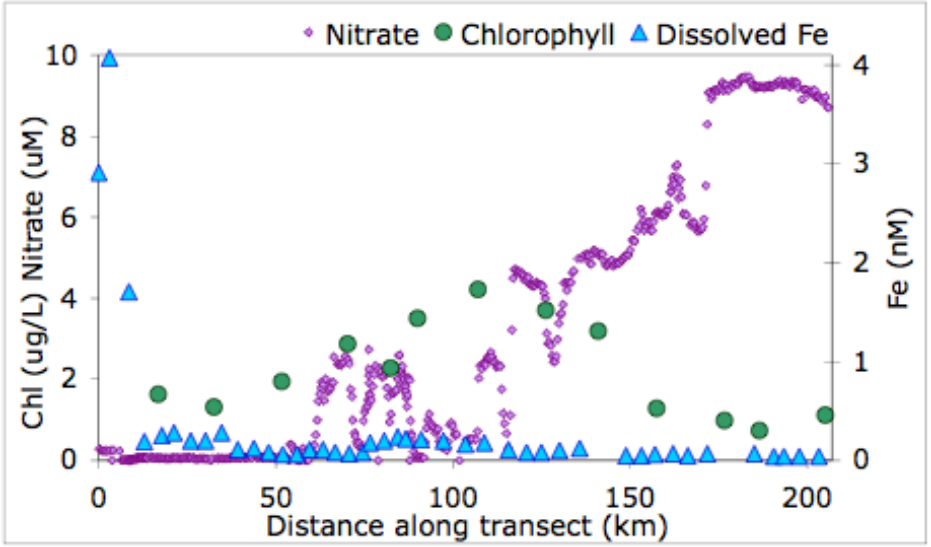
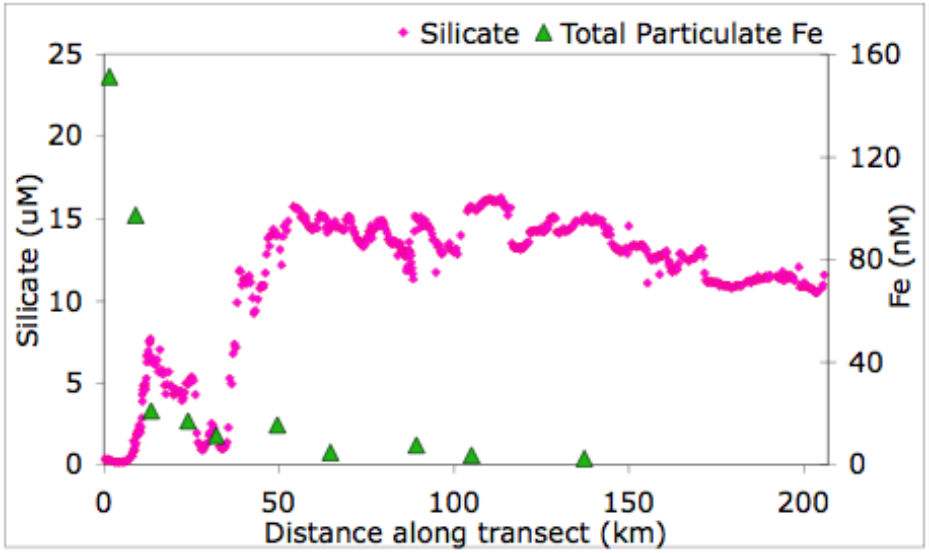
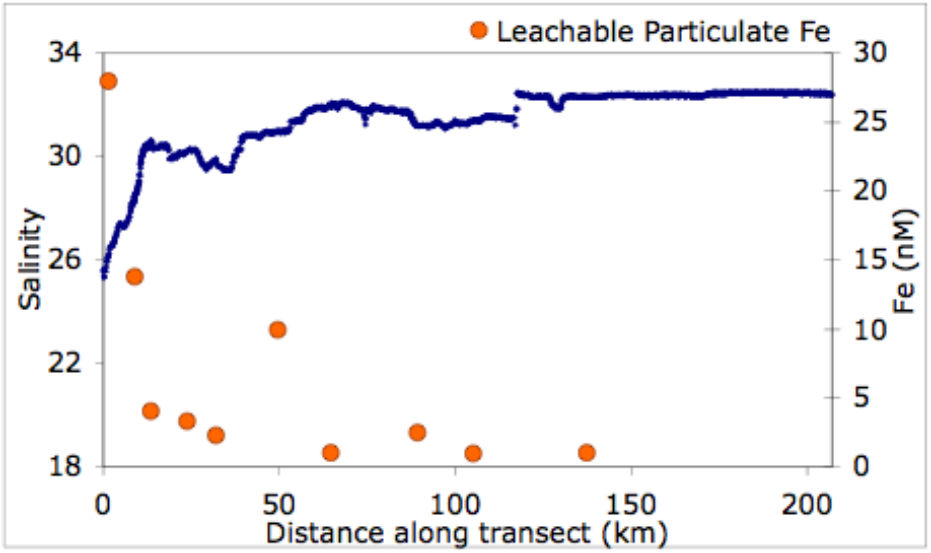
-152
-150
-148
-146
-144
-142
-140
-138

Coastal GoA

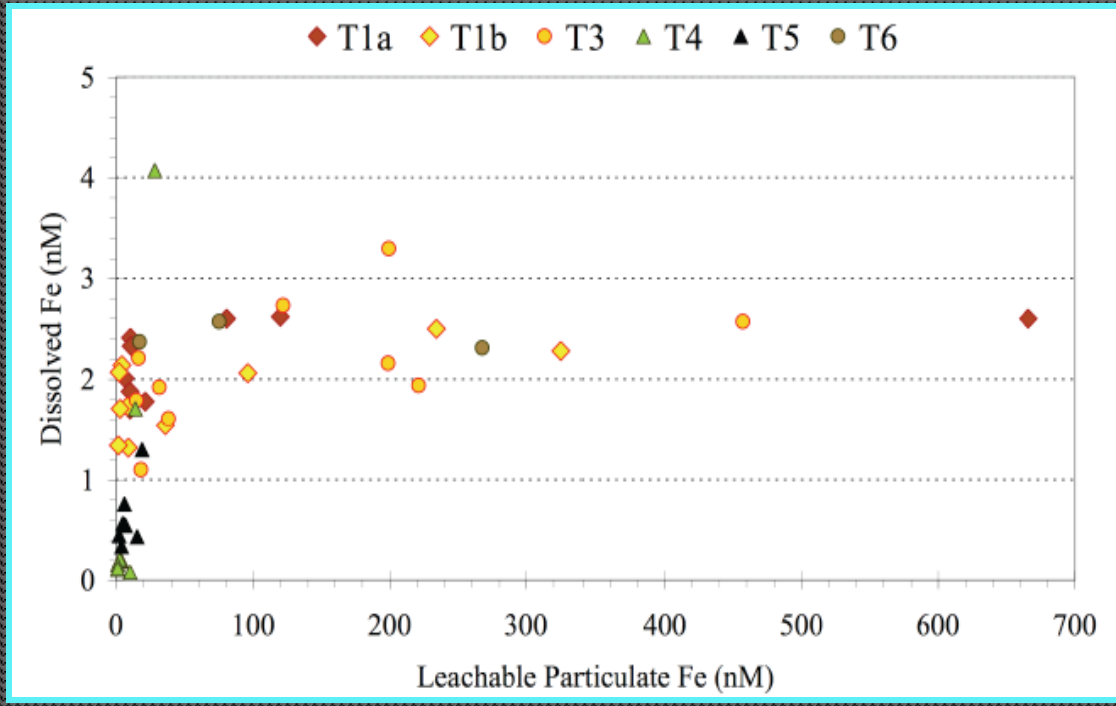

Salinity
Temperature
Salinity
Temp (Celcius)
Distance along transect (km)


Nitrate
Chlorophyll
Dissolved Fe
Chl (ug/L) Nitrate (uM)
Fe (nM)
Distance along transect (km)


Silicate
Total Particulate Fe
Silicate (uM)
Fe (nM)
Distance along transect (km)

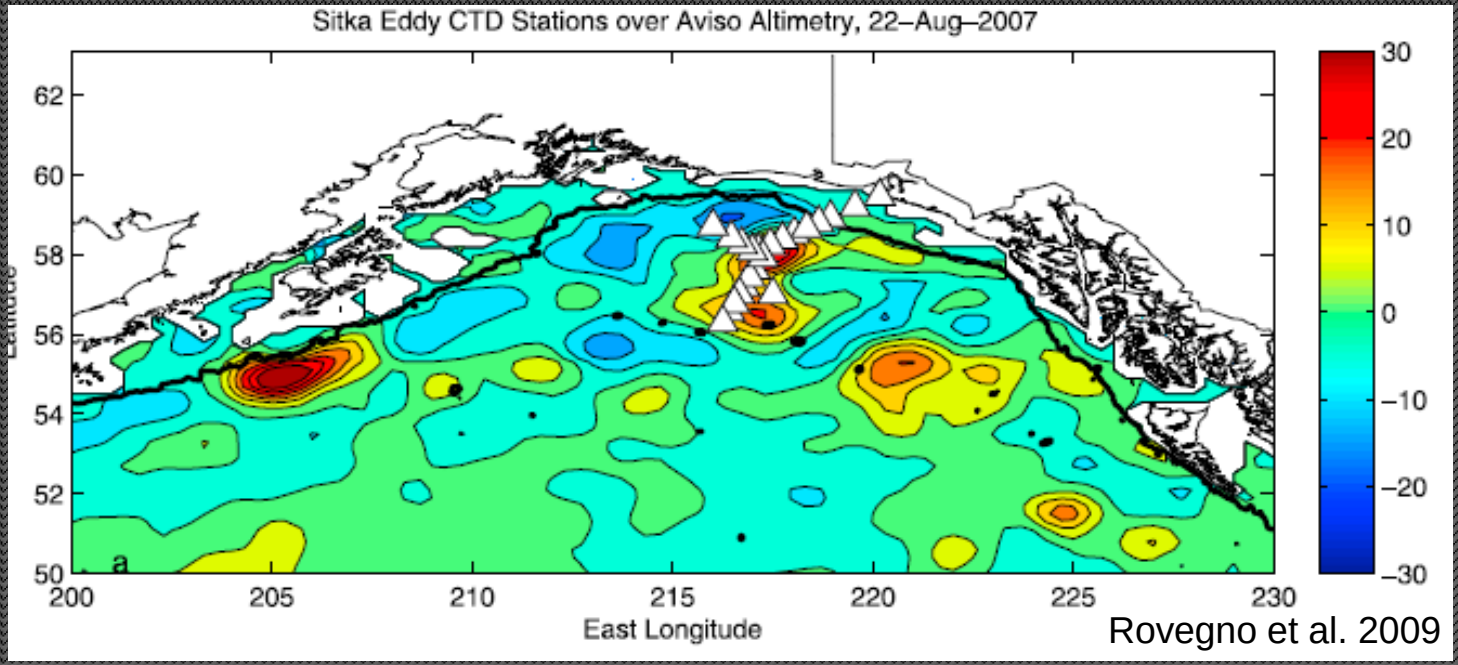

Leachable Particulate Fe
Salinity
Fe (nM)
Distance along transect (km)

- [Dissolved Fe] is "capped" around 2 – 3 nM regardless of [leachable particulate Fe]
- The availability of strong Fe(III) – binding organic ligands controls [dissolved Fe] (Buck et al. 2007)
- Glacial runoff has very low DOC (little exposure to soil and plant organic matter, LaFreniere and Sharp, 2004)
- The large excess of leachable part. Fe acts as a capacitor or buffer to supply diss. Fe to keep Fe(III) – ligands titrated.



GoA Eddies

Large (~ 200 km diameter) anticyclonic eddies form in coastal waters

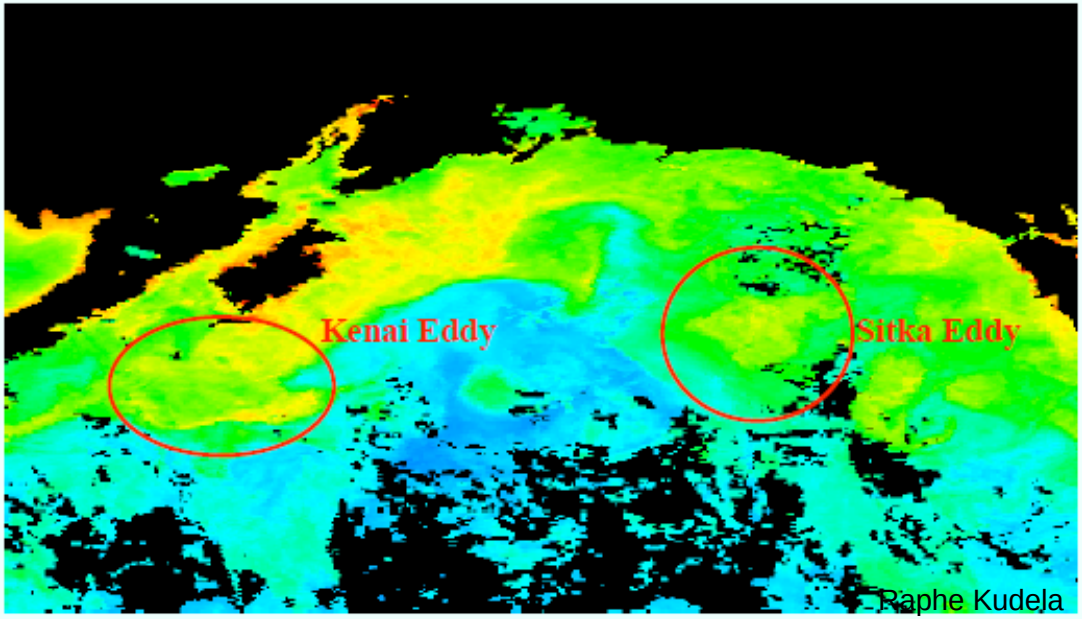


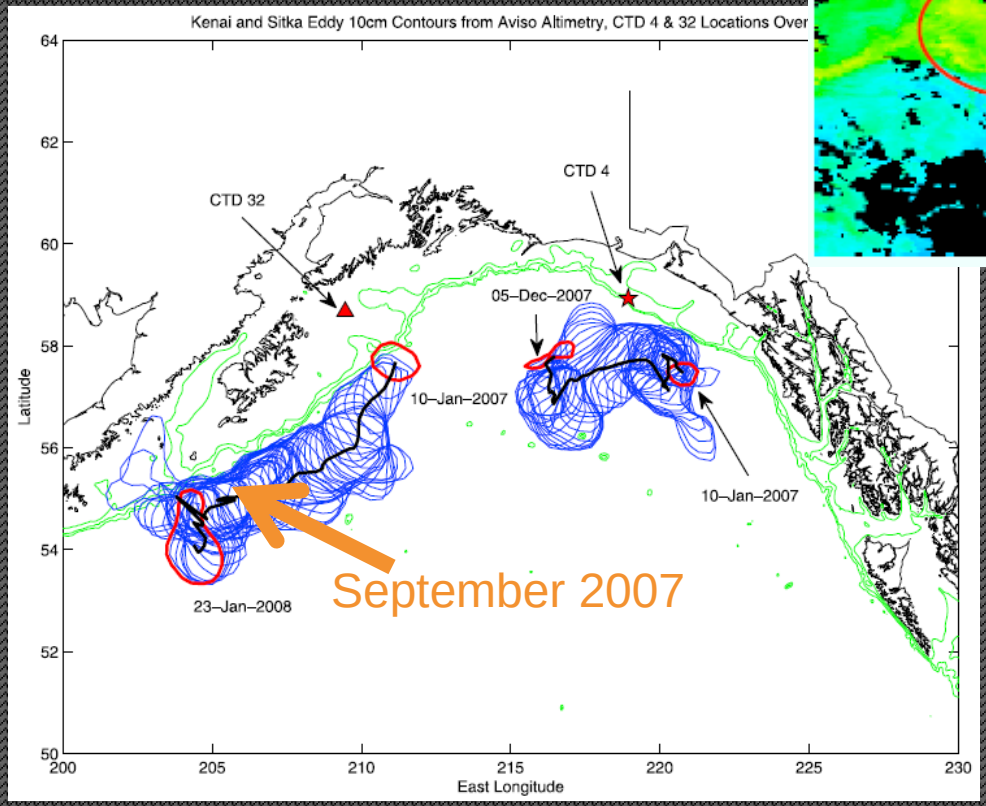
Rovegno et al. 2009

Suggested to have significant contribution to cross-shelf exchange of coastal and HNLC waters (Stabeno et al. 2004)

Kenai Eddy

Eddy formed January ’07
Sampled 8 months later

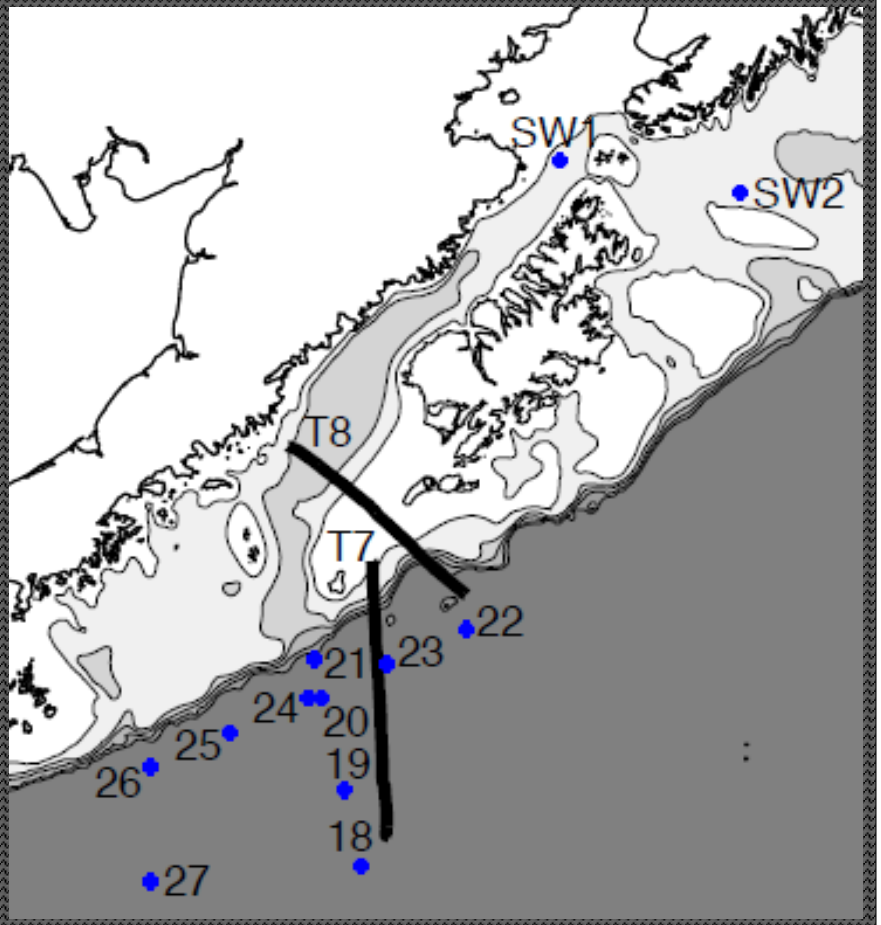


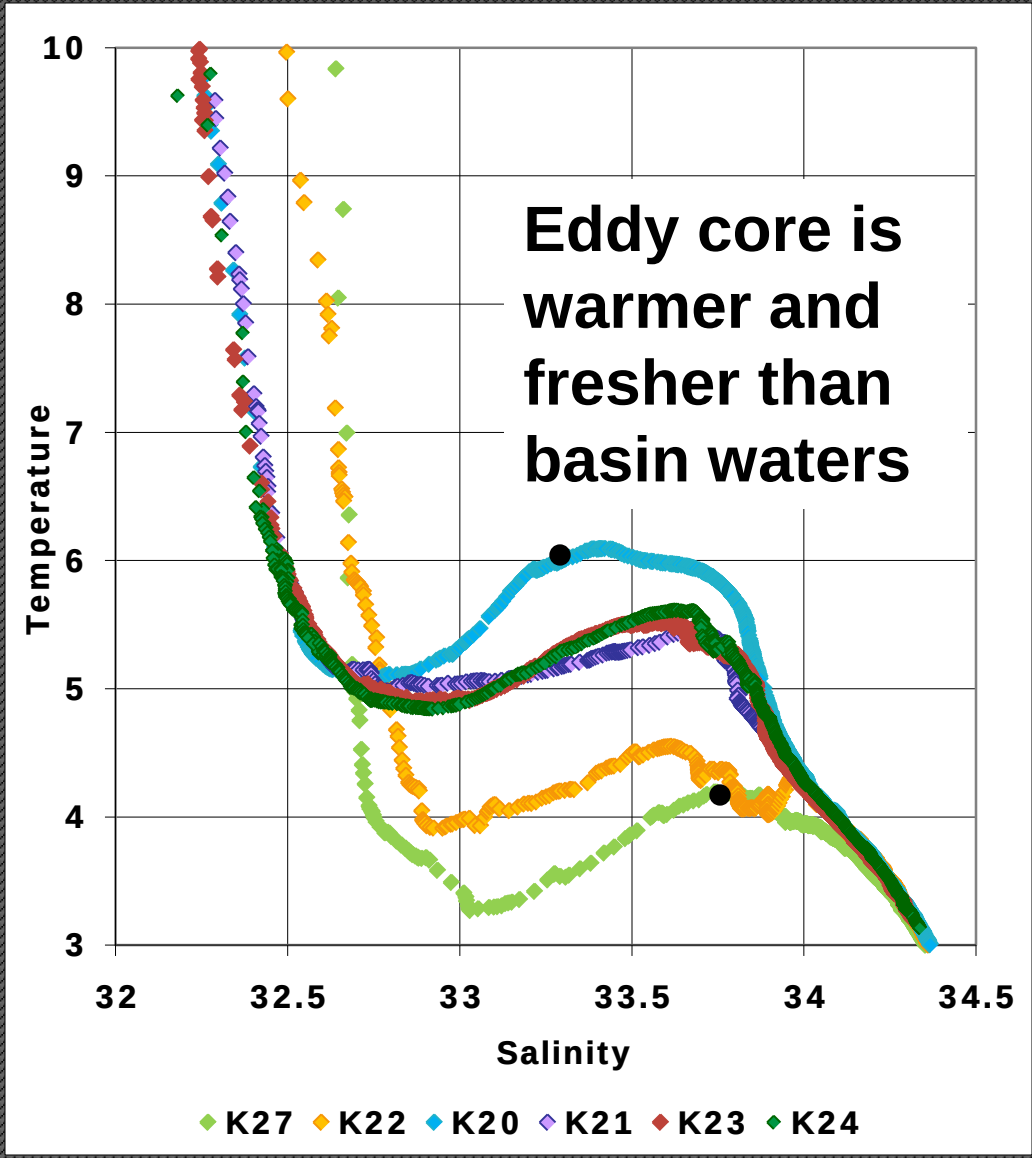


SeaWIFS image shows enhanced Chl *a* around the eddy edges

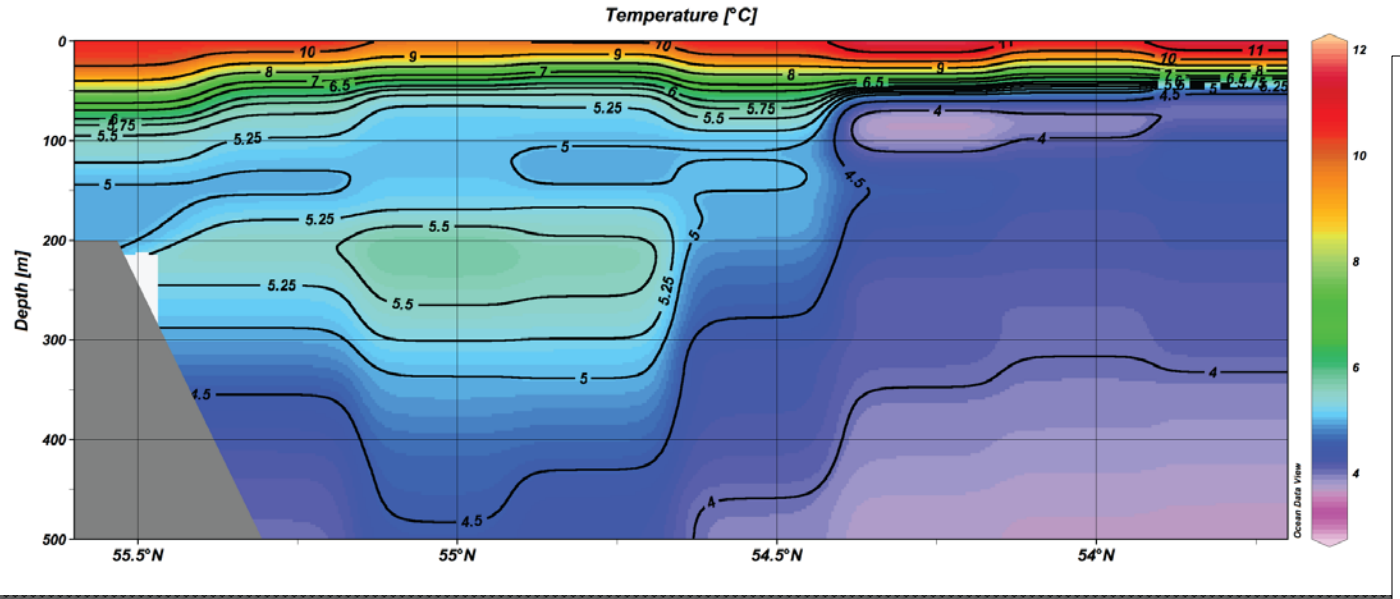
Rovegno et al. 2009

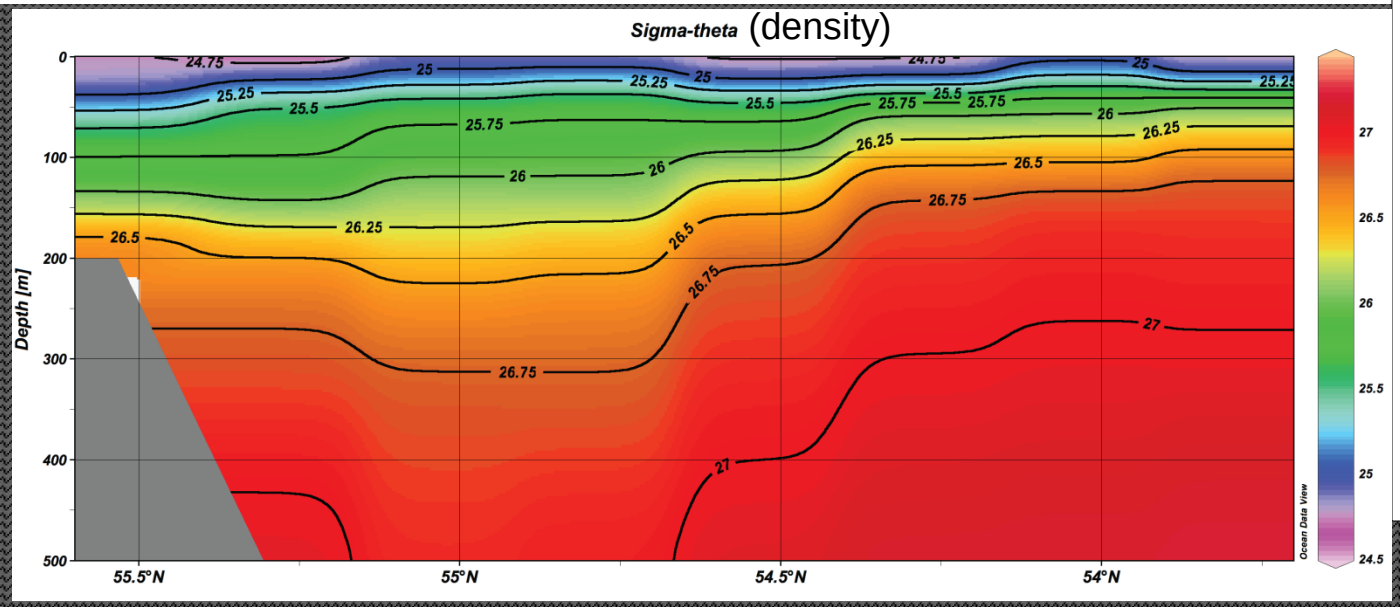
Kenai Eddy

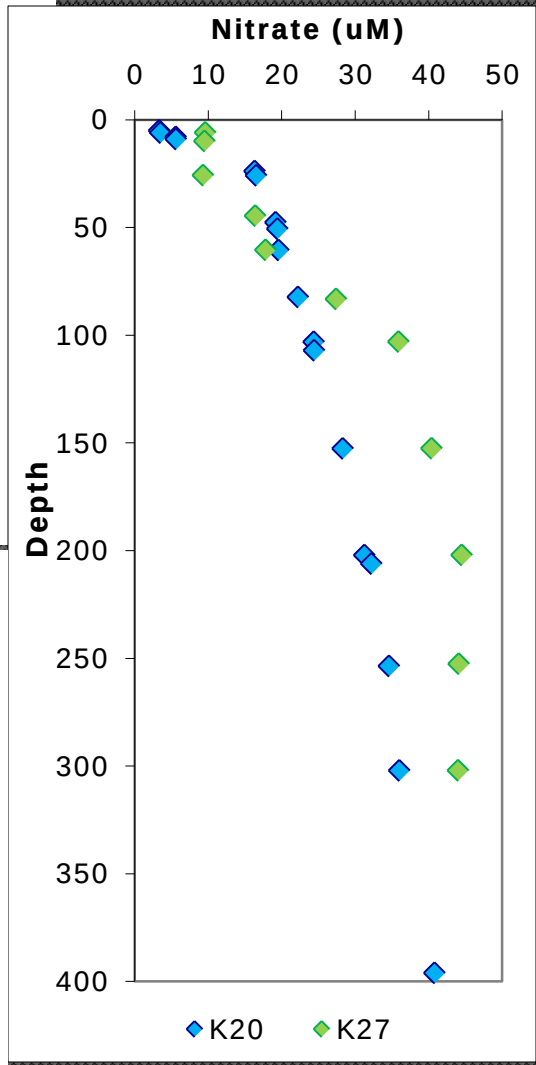

SW1
SW2
T8
T7
22
21
23
24
20
25
19
26
18
27


Eddy core is warmer and fresher than basin waters
Temperature
Salinity
10
9
8
7
6
5
4
3
32
32.5
33
33.5
34
34.5
K27
K22
K20
K21
K23
K24

Kenai Eddy


Temperature [°C]
Depth [m]
55.5°N
55°N
54.5°N
54°N
Ocean Data View


Sigma-theta (density)
Depth [m]
55.5°N
55°N
54.5°N
54°N
Ocean Data View


Nitrate (uM)
Depth
K20
K27

Iron **outside** and **in the core** of the eddy (50 to 100 m)

Dissolved Fe:

Outside eddy, Diss Fe = 0.04 nM

Eddy core, Diss Fe = 0.38 nM

Leachable Part Fe:

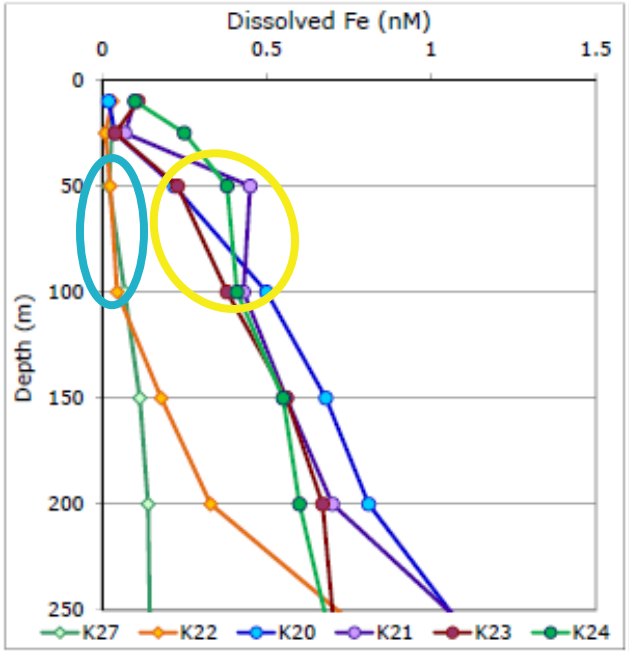
Outside eddy, Leachable Part Fe = 0.15 nM

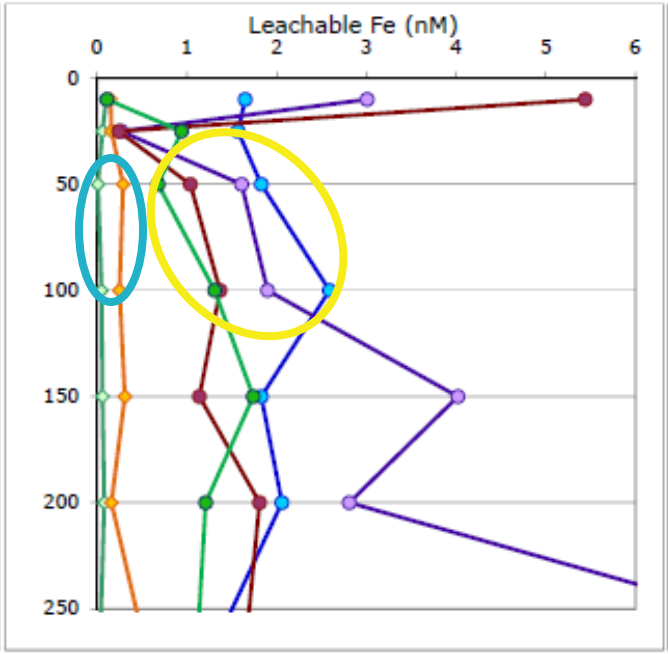
Eddy core, Leachable Part Fe = 1.54 nM

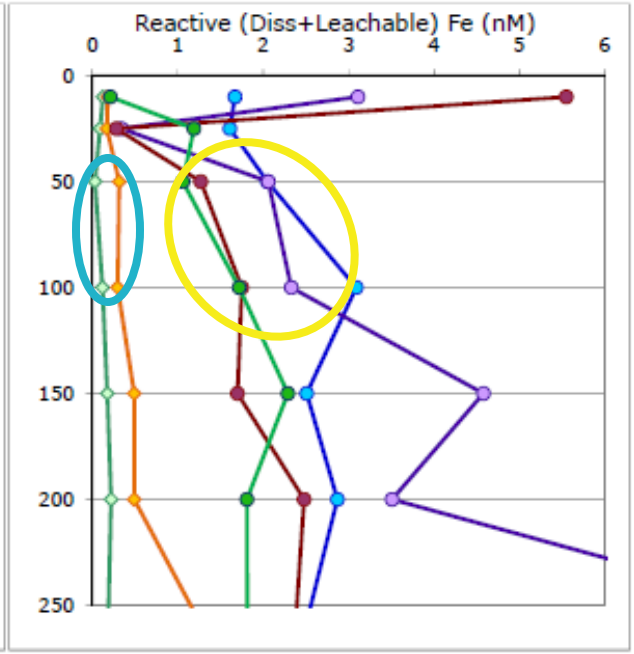
Reactive Fe:

Outside eddy, 0.19 nM

Eddy core, 1.9 nM







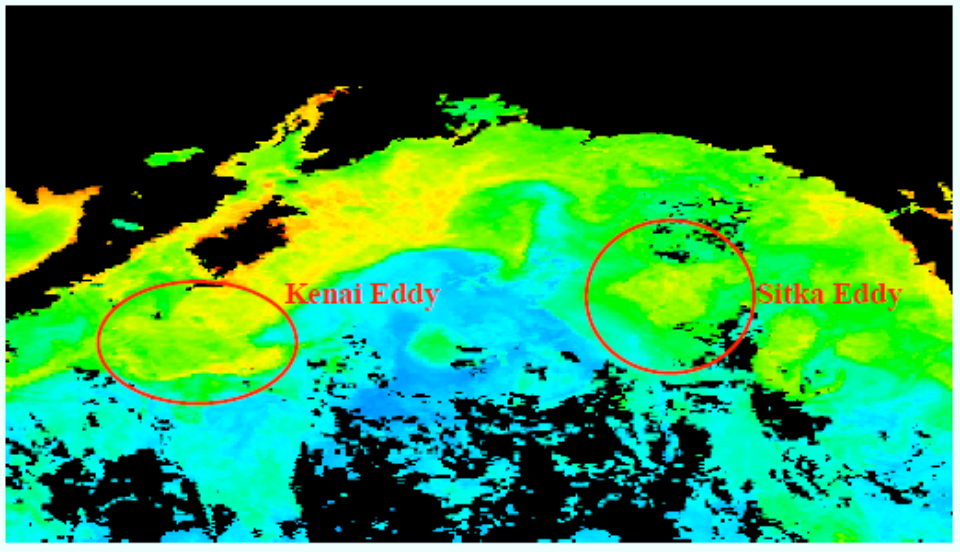
~ 10x more reactive Fe within the core at depths of 50 to 100 m to go with the 20 μM nitrate. Can support drawdown of ~ 6 μM nitrate.

The Delivery of Fe to HNLC Waters via Eddies

- Induces mixing between shelf and offshore waters
- Deep winter mixing (50 – 100 m)
- Ventilation or “leakage” of higher Fe waters along isopycnals to shallower depths
- Propagation to central GoA + relaxation of the eddy

This work should be published next year, in the meantime:

Ladd, C., et al., 2009. A synoptic survey of young mesoscale eddies in the Eastern Gulf of Alaska, Deep Sea Research II, 56(24).



Conclusions

- In coastal areas with high concentrations of suspended particles with Fe coatings, the strong Fe(III)-binding organic ligands appear to control the dissolved Fe concentrations.
- The large excess of leachable particulate Fe acts as a capacitor to supply dissolved Fe to keep the strong Fe(III)- binding organic ligands titrated.
- Eddies have a significant role in mixing and advecting Fe into the central GoA.
- An important question is the residence time of particulate Fe in the relatively long lived eddies.

Thanks!

Bruland Lab
Gulf of Alaska 2007

Bettina Sohst

- Biotite weathering (Anders et al., 2003)
  - $K(Mg, Fe)_3AlSi_3O_{10}(F, OH)_2$
- Preferential solubilization
  - Si > Al > Fe (Brown et al., in press)
- Low DOC in runoff
  - Decreased Fe solubility
  - Reactive Fe coatings