Gulf of Alaska shelf ecosystem: model studies of the effects of circulation and iron concentration on plankton production

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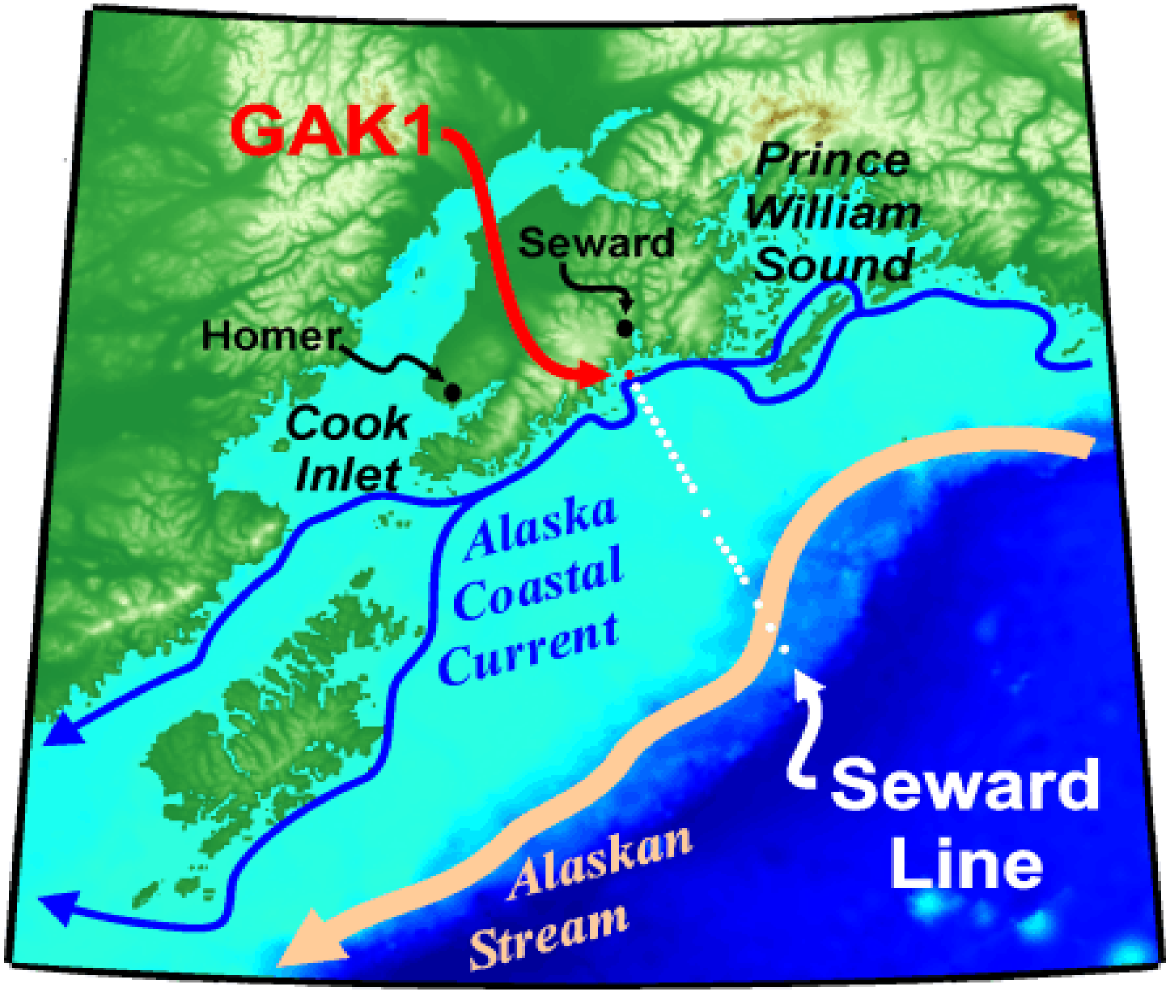
GLOBEC Study



Goal: Elucidate mechanisms linking oceanography and ecosystem response to climate forcing on the northern Gulf of Alaska Shelf.

Reality: Support for a single line of stations with 6 collections per year (1998 – 2004) for observations.

Tool: ROMS numerical model with ecosystem component calibrated using observations from the Seward Line.

Complications: Complex system of currents resulting in a varying mix of oceanic and neritic communities in space and time.

Approach:

•Use a 1D version of ROMS for simulations at sampling stations.

•Adjust model equations and parameters to conform to observations.

• Apply the optimized model in 3D to the whole Gulf of Alaska region.

Ecosystem Model Requirements

1. Reproduce the contrast between small and large phytoplankton communities in the HNLC offshore and LNHC coastal regimes.
2. Simulate the timing of the spring phytoplankton bloom.
3. Simulate the seasonal vertical nutrient distributions
   - Nitrate exhaustion in the upper 10-20 m in May-June.
4. Simulate the range of primary production on the shelf
   - maximum of 4 g C m^{-2} d^{-1} in May-June
   - 0.5 – 1 g C $m^{-2}d^{-1}$ in July – August,
   - <= 0.5 g C m^{-2} d^{-1} in October.
5. Reproduce the observed carbon biomass of the state variables within the 95% confidence interval of the observations.

Physical Model:

1) Regional Ocean Modeling System (ROMS)

2) Coastal Gulf of Alaska (CGOA) grid with 3-4 km resolution

3) Ocean boundaries of the CGOA open allowing entry and exit of Alaska Stream waters

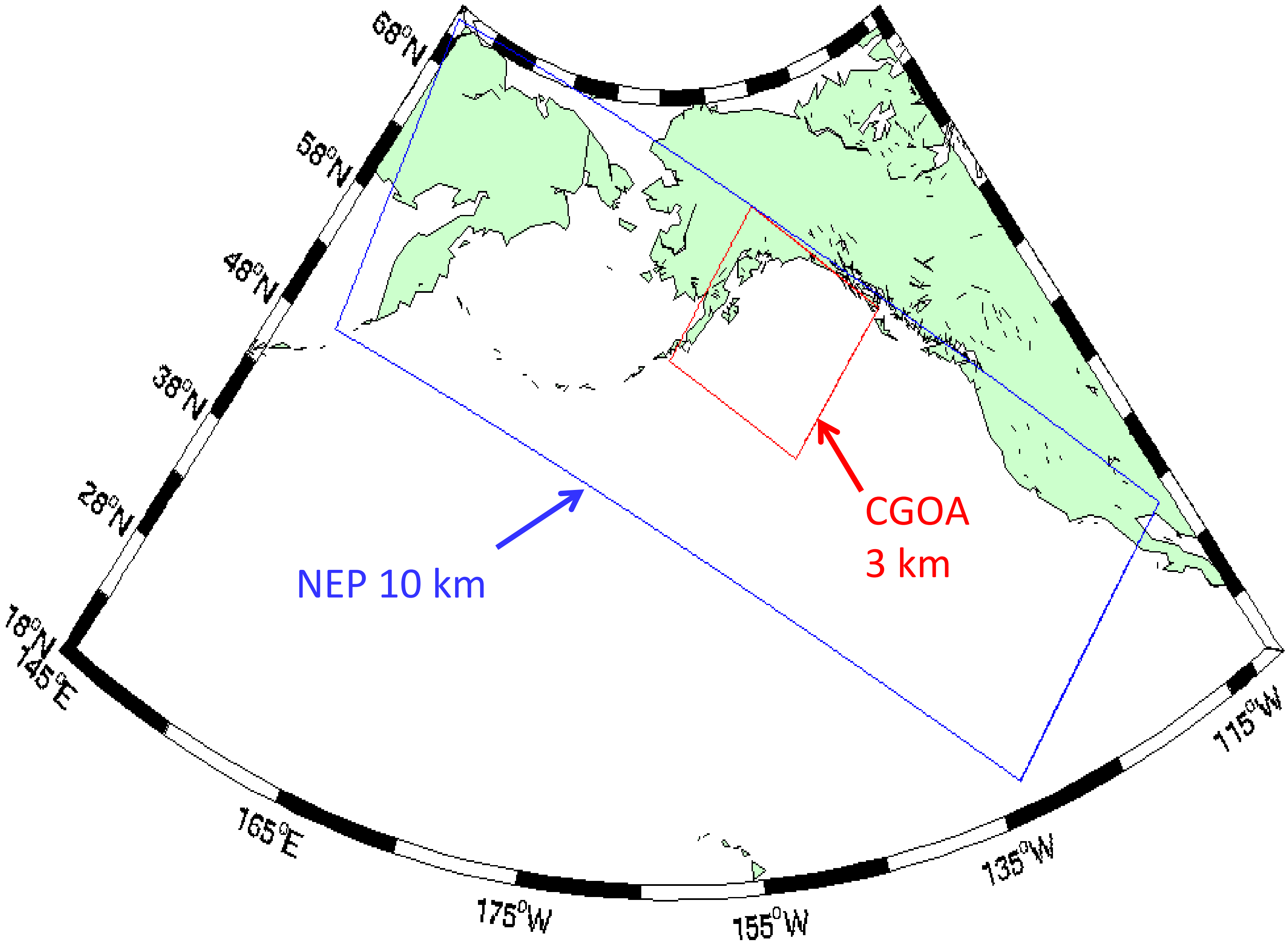
4) Bathymetry was derived from ETOPO5 and finer-scale bathymetric data.

5) The model has 42 layers, layers are concentrated near the surface.

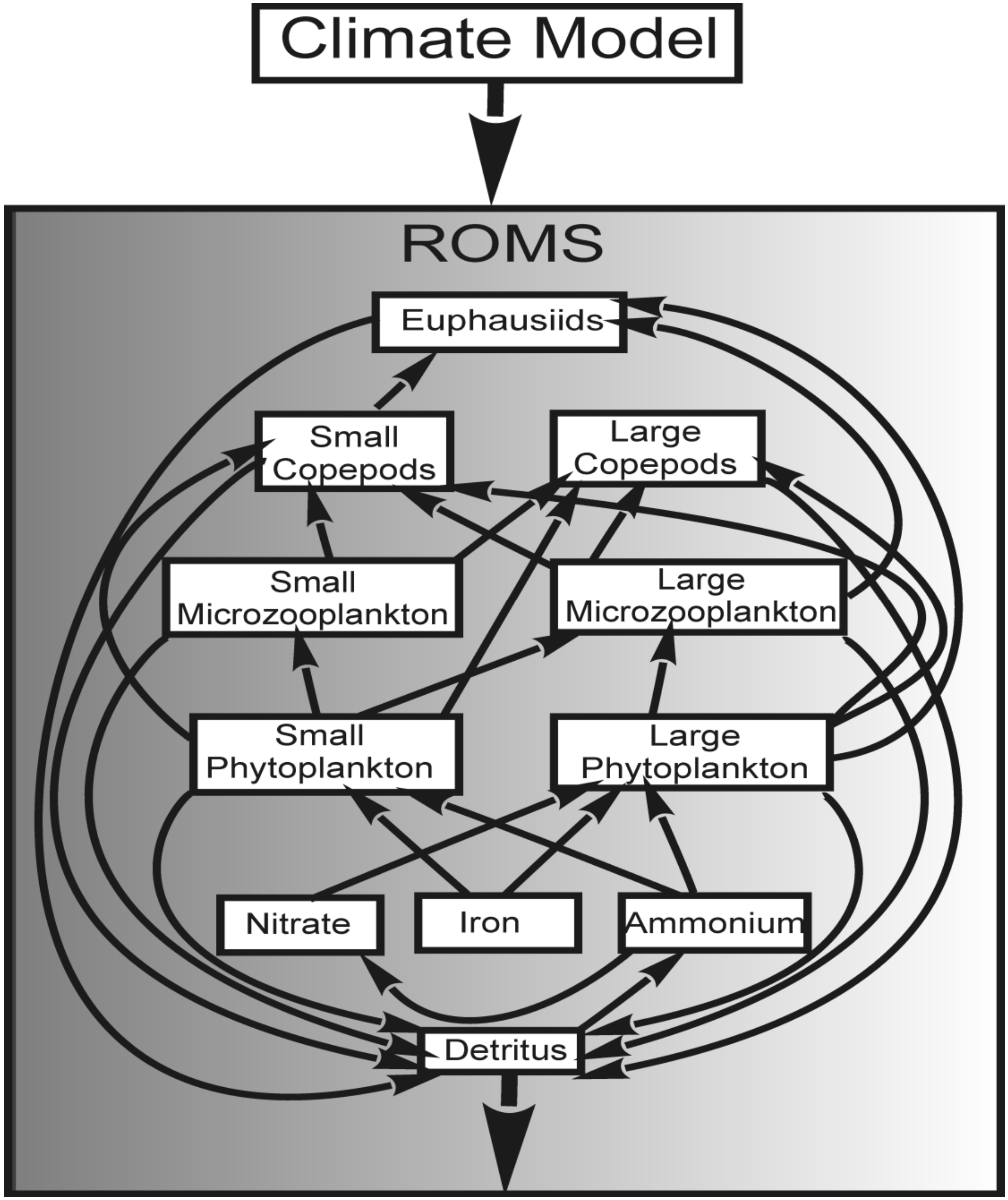
6) Physical model is driven by CCSM climate model output.

7) Iron was **not** added with freshwater discharge.

Model Grids



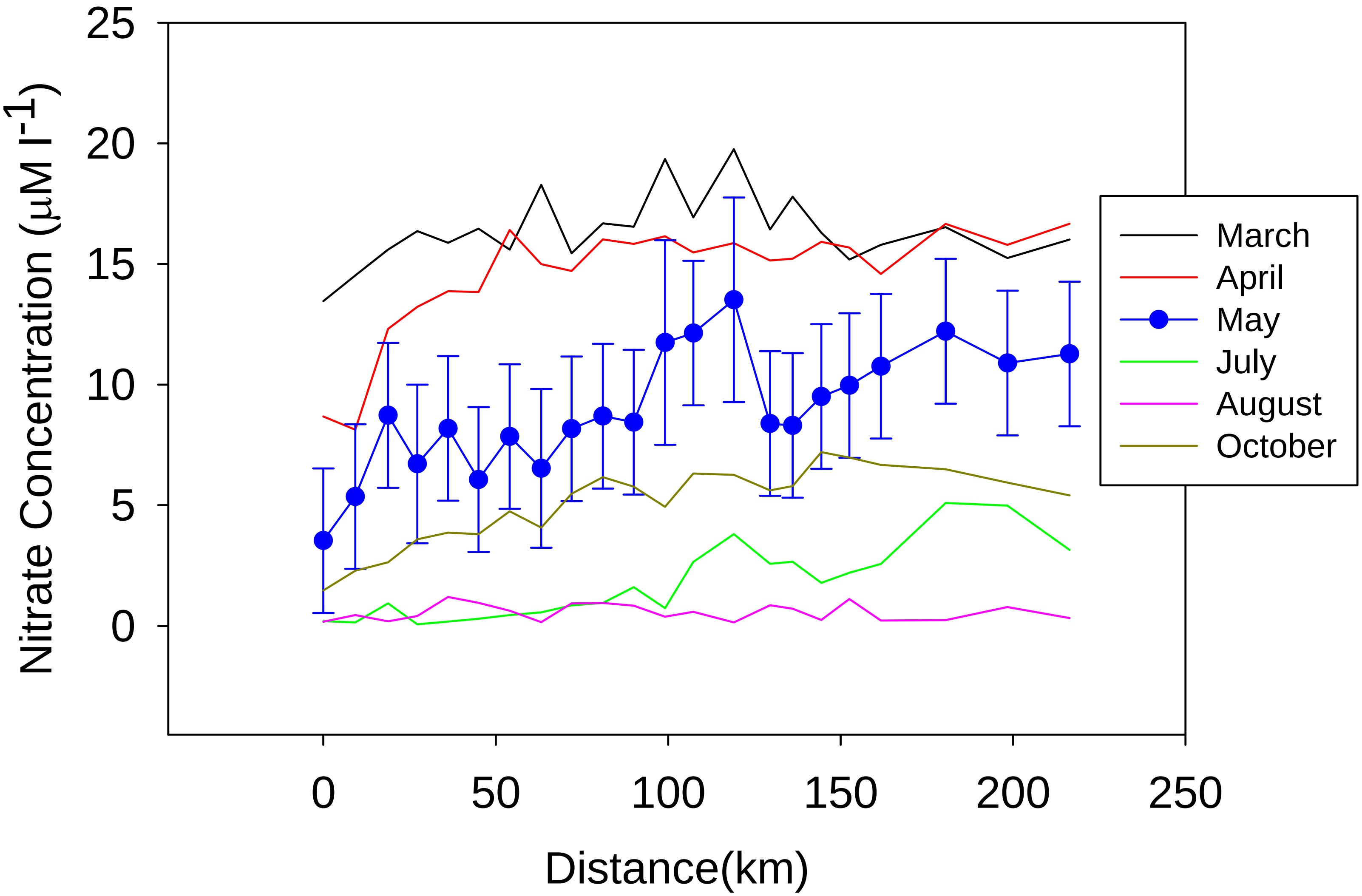
68°N
58°N
48°N
38°N
28°N
18°N
145°E
165°E
175°W
155°W
135°W
115°W
NEP 10 km
CGOA
3 km



Climate Model
ROMS
Euphausiids
Small Copepods
Large Copepods
Small Microzooplankton
Large Microzooplankton
Small Phytoplankton
Large Phytoplankton
Nitrate
Iron
Ammonium
Detritus

Annual Cycle of Nitrate Concentration in the Upper 15 m Along the Seward Line

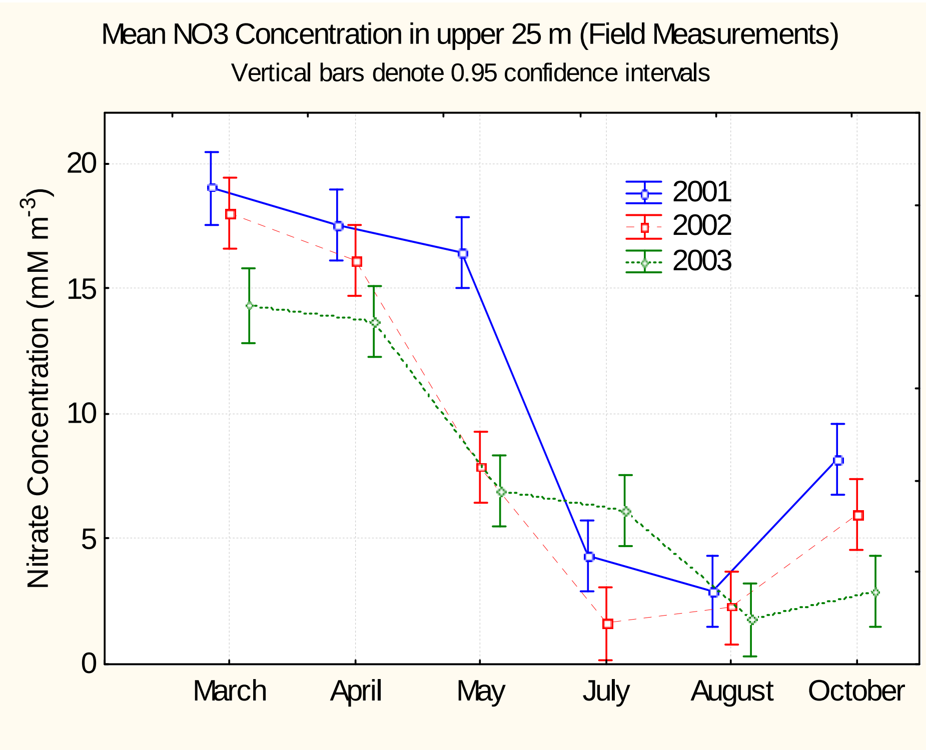
Mean of 1998 - 2003 data

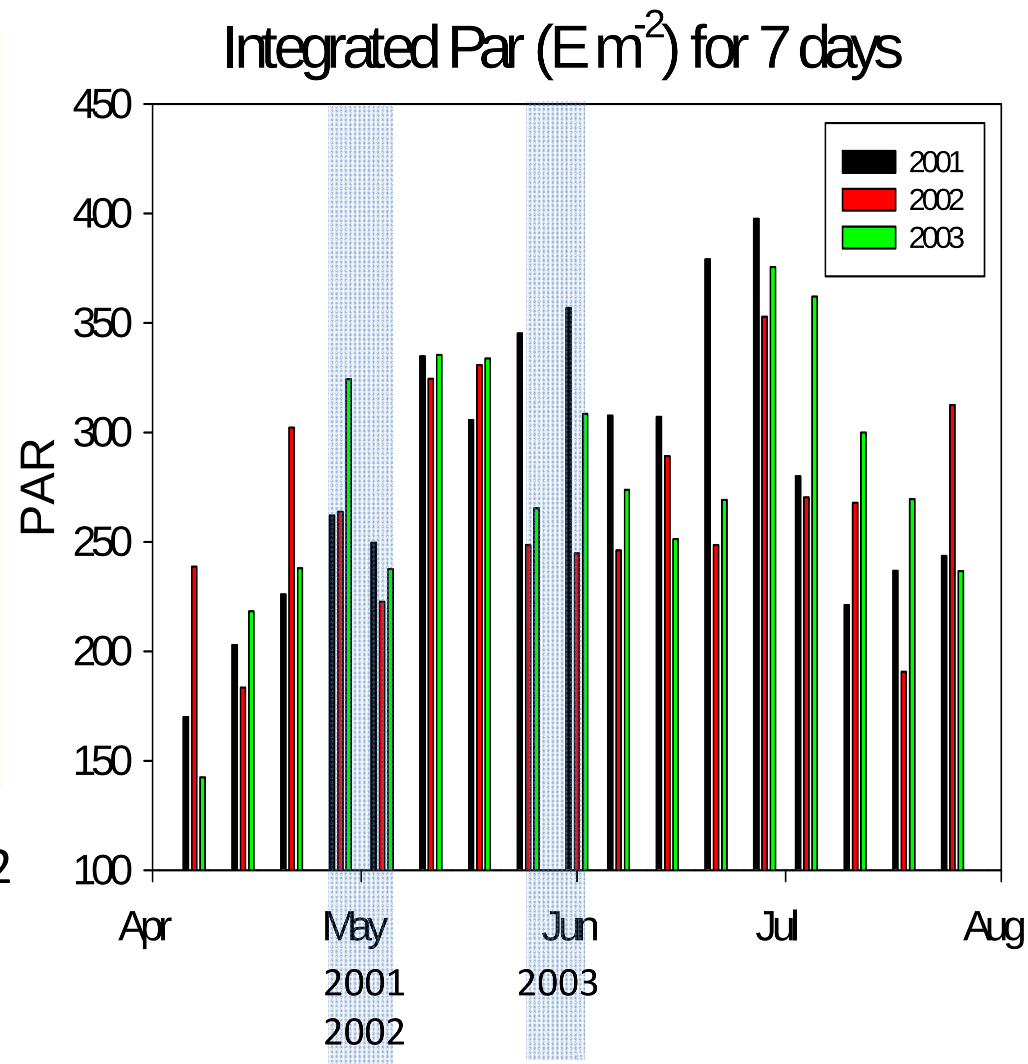


Error bars indicate 95% confidence intervals

1) Nitrate about 15 – 18 µM from km 50 to 220 in March and April
2) Nitrate declines substantial in May
3) Nitrate absent from inner 100 km in July and from the entire line in August/
4) Nitrate increases again in October

Nitrate Utilization and surface PAR (Station GAK4)

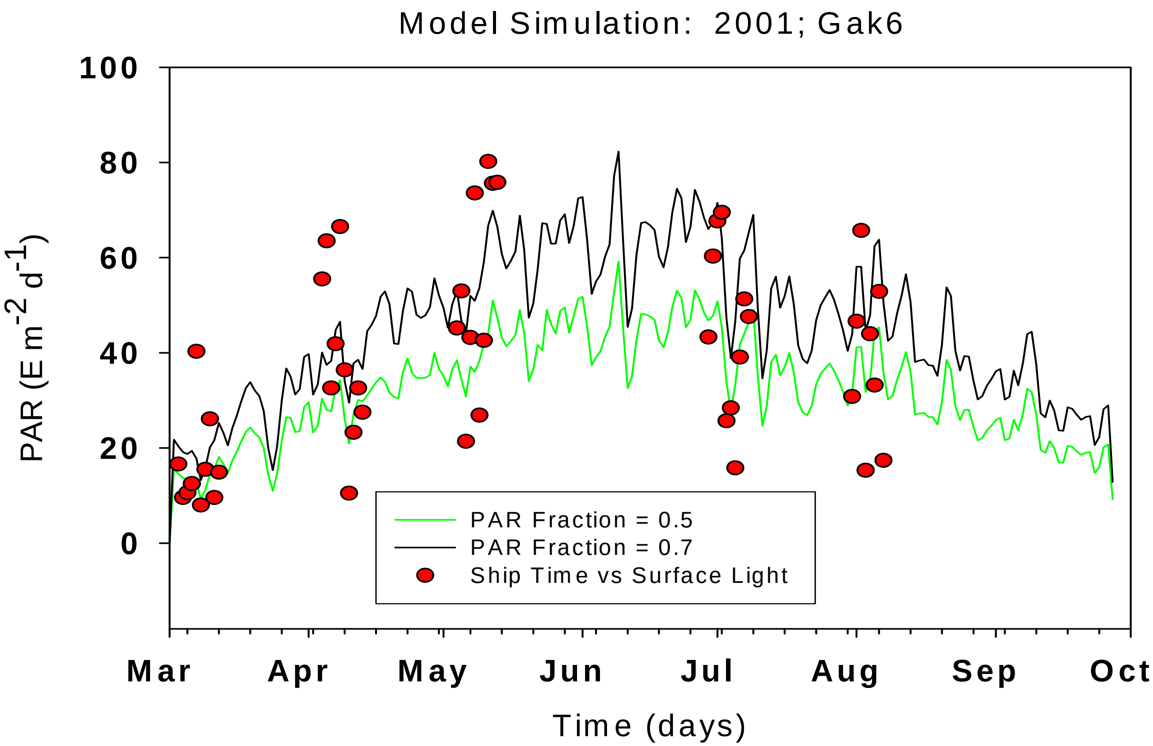




1) Bloom delayed in 2001 relative to 2002 (Sampling delayed in 2003)
2) Lower light levels in April 2001 & 2003 relative to 2002
3) Elevated NO3 in July 2003 probably not light-related (light levels in 2003 >= 2002 during late May-June)

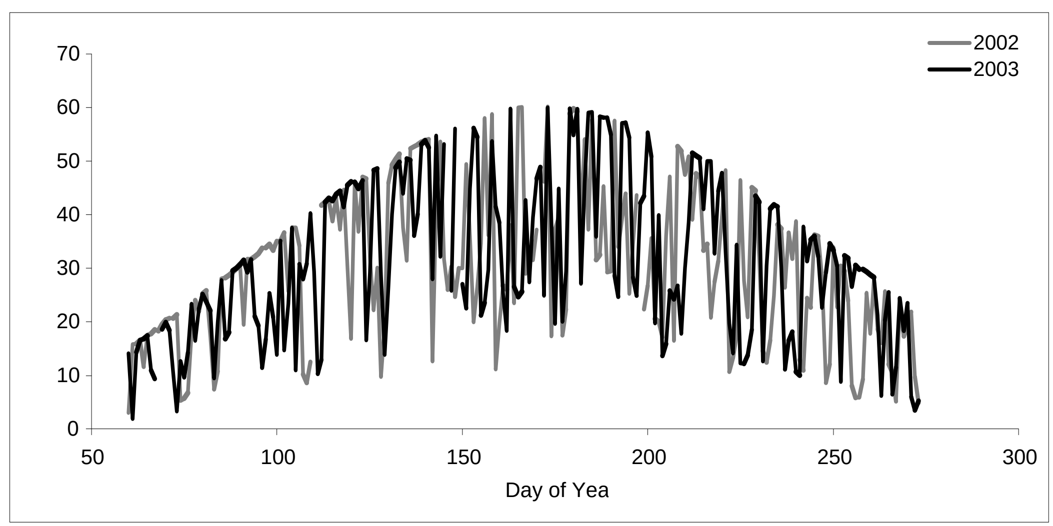
Website for PAR data:
ftp://oceans.gsfc.nasa.gov/SeaWiFS/Mapped/Daily/PAR

Measured and modeled photosynthetically active radiation (PAR)



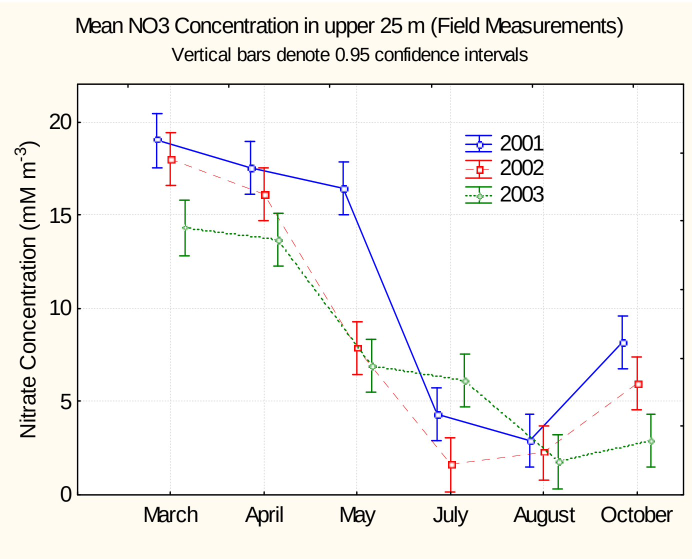
Daily PAR (E m^{-2} d^{-1}) from climate models (lines) and ships measurements during GLOBEC cruises

SeaWiFS Satellite PAR Data



Daily PAR (E m^{-2} d^{-1}) for Seward Line from 2002 and 2003 using SeaWiFS

Seward Line Nitrate Concentration and Salinity in July

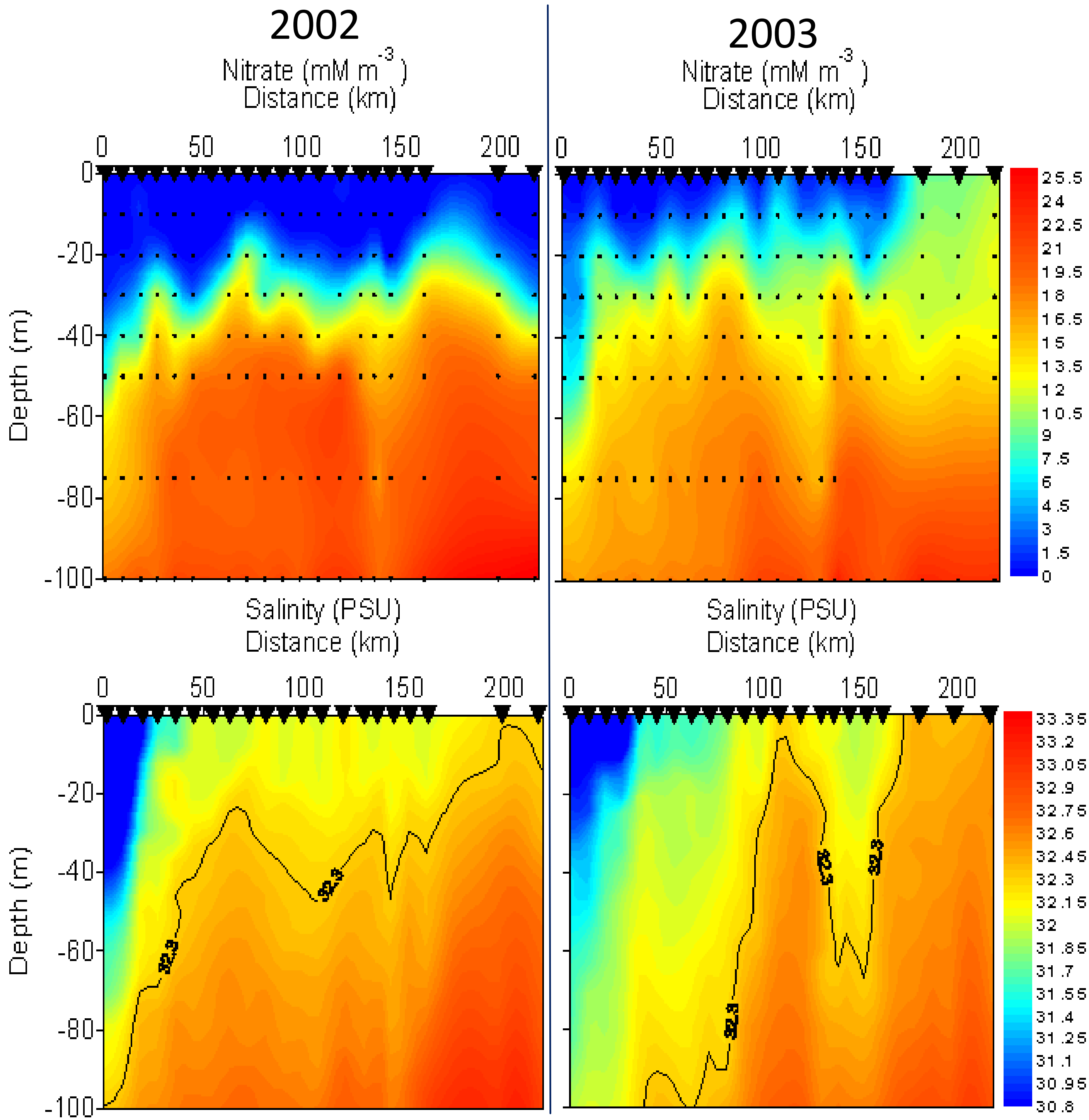


•2002: Nitrate gone from upper water column along entire line.

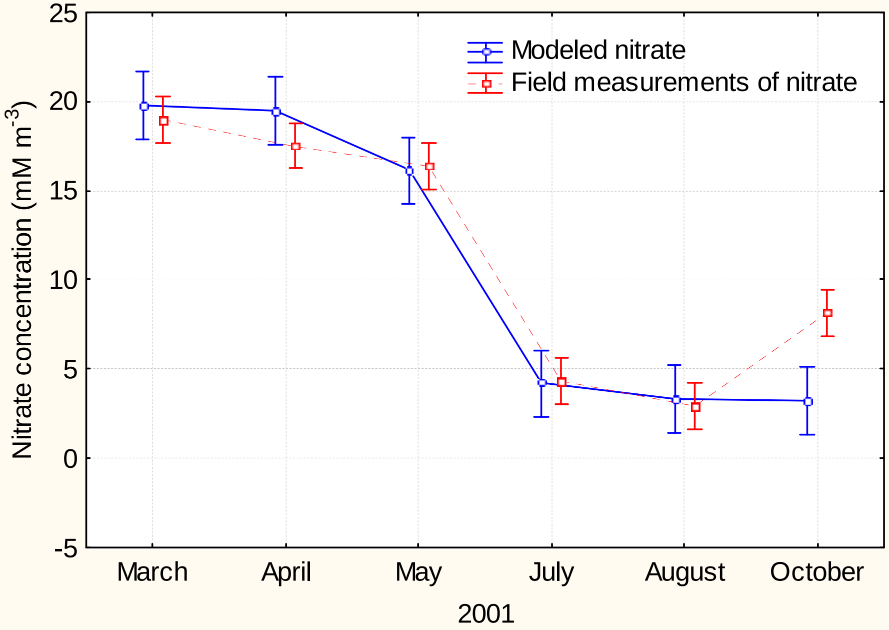
•2003: Nitrate present in surface and surface on outer and middle line.

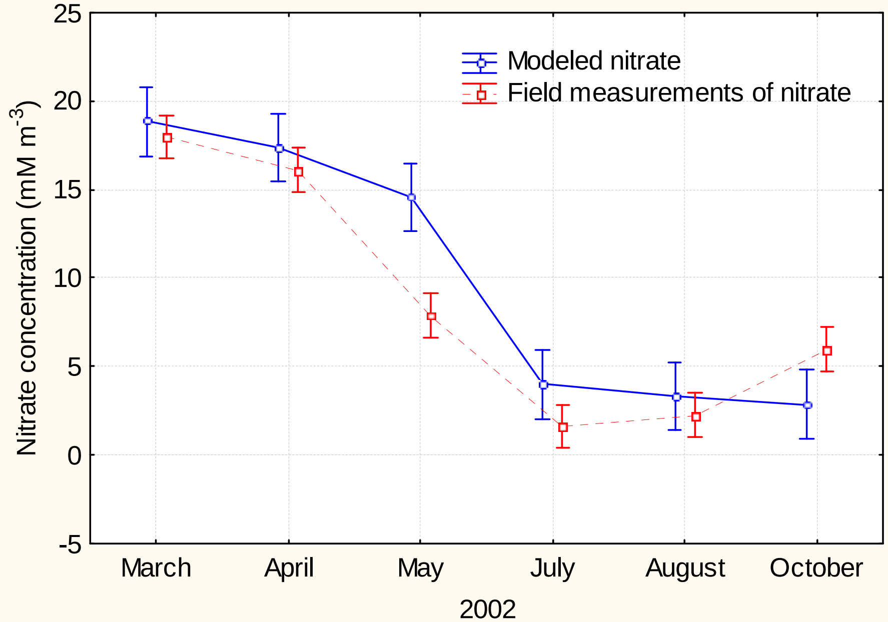
•2002: coastal water mixed across the surface to the end of the line.

•2003: oceanic water near surface into km 100.

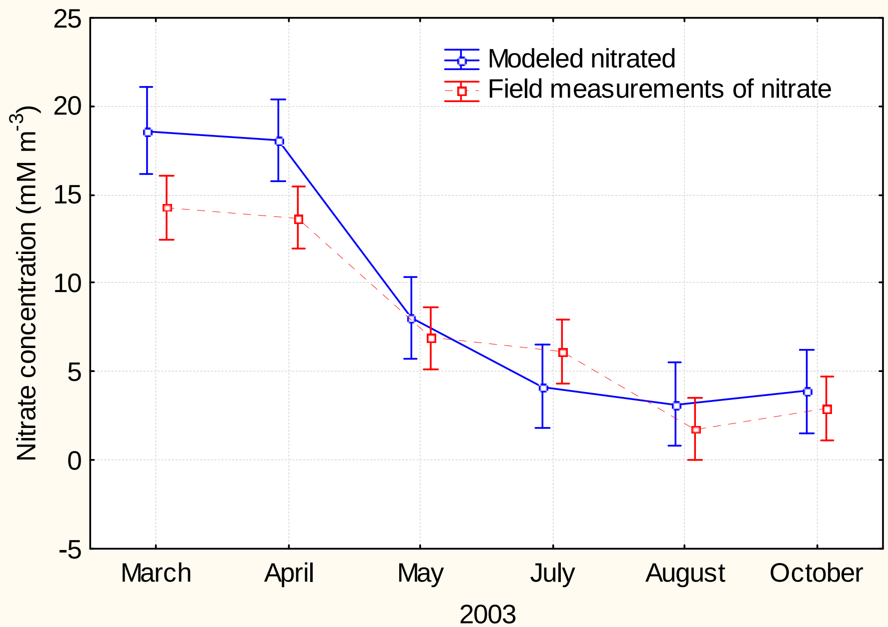


Model (Blue) and Measured (red) Nitrate Concentration in upper 25 m

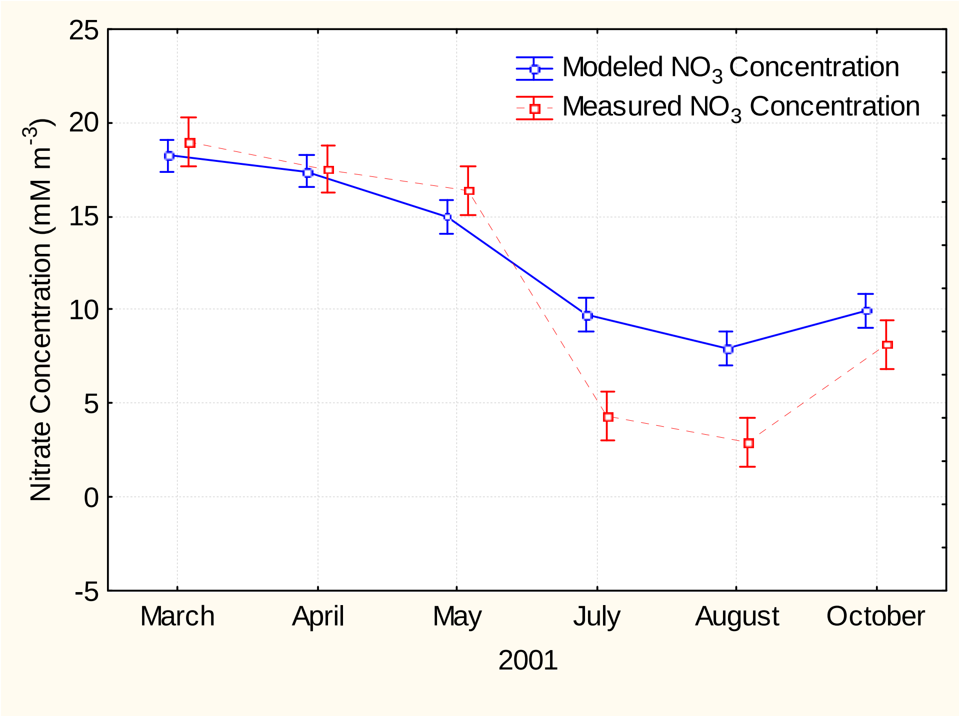


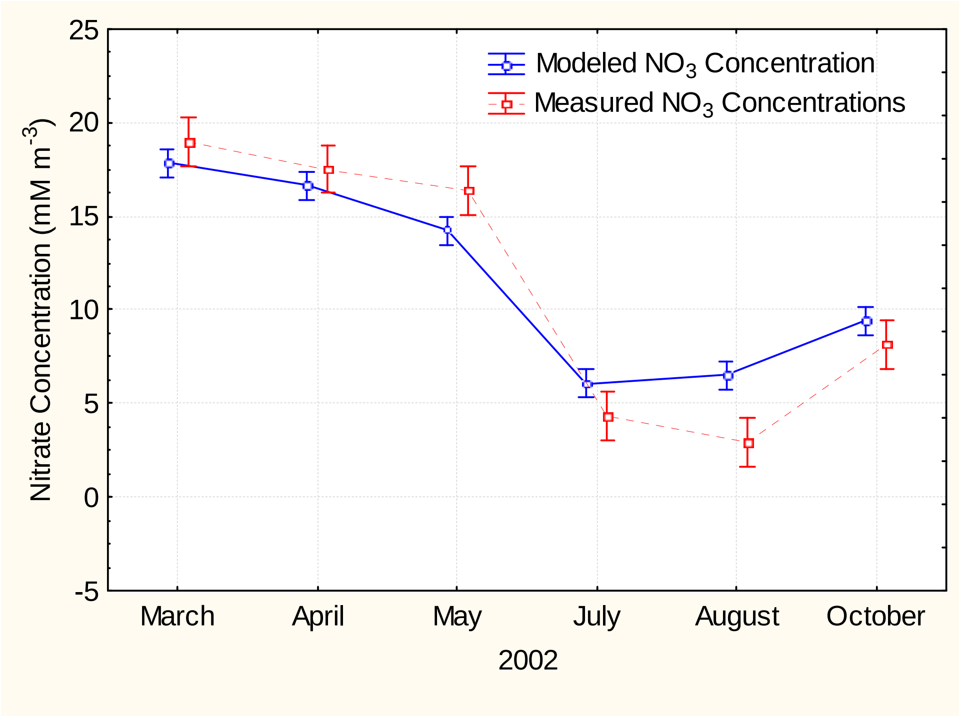


Nitrate Concentration: 1D simulations and field measurements of mean values in the upper 25 m along the Seward Line for 2001 – 2003. Error bars are 95% confidence intervals.

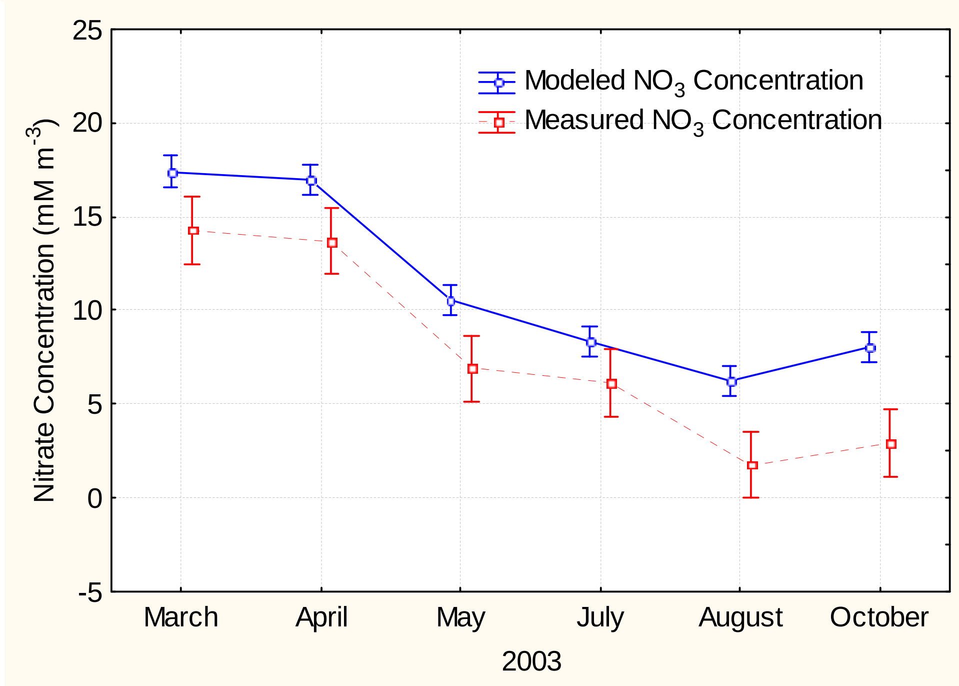


Effect of circulation on simulated nitrate concentration along Seward Line





Nitrate Concentration: 3D model simulations and Field measurements of mean values in the upper 25 m along the Seward Line for 2001 – 2003. Error bars are 95% confidence intervals.



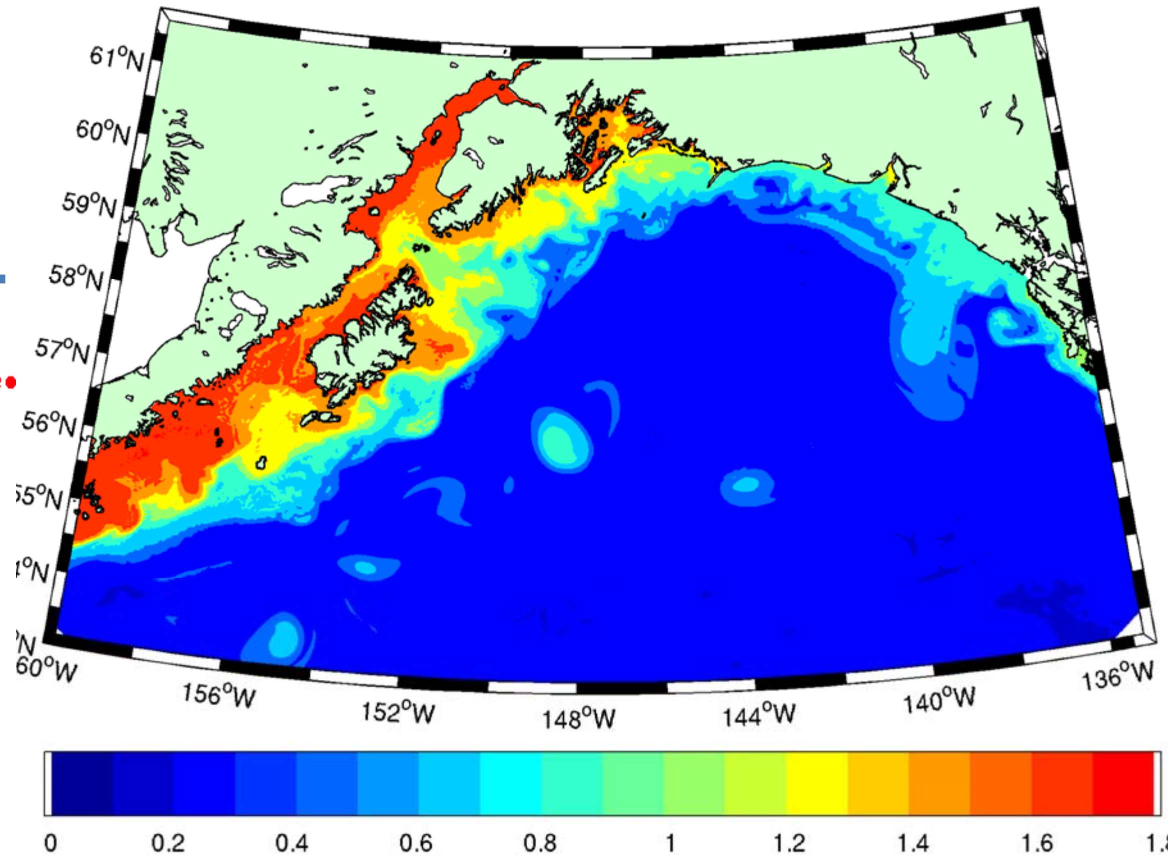
Nitrate Utilization Is Affected by Iron Concentration

Dissolved Iron (nM) on the Northern Gulf of Alaska Shelf

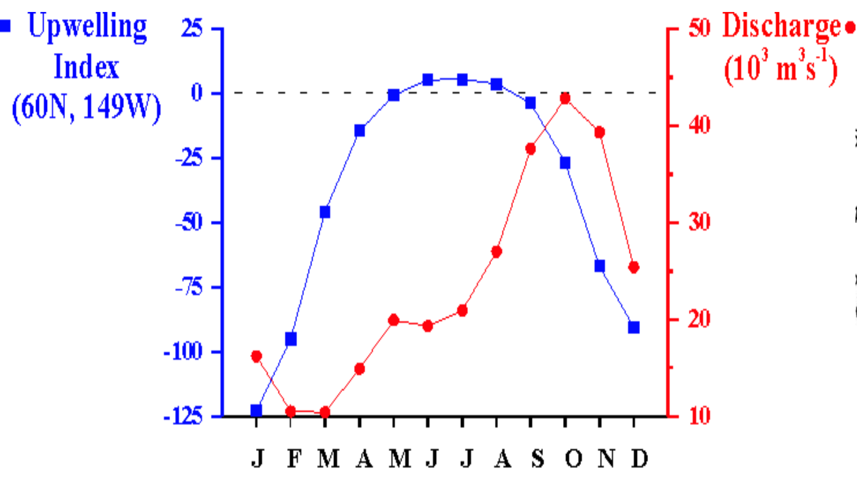
Simulated Iron

May 2

Upper 15 m



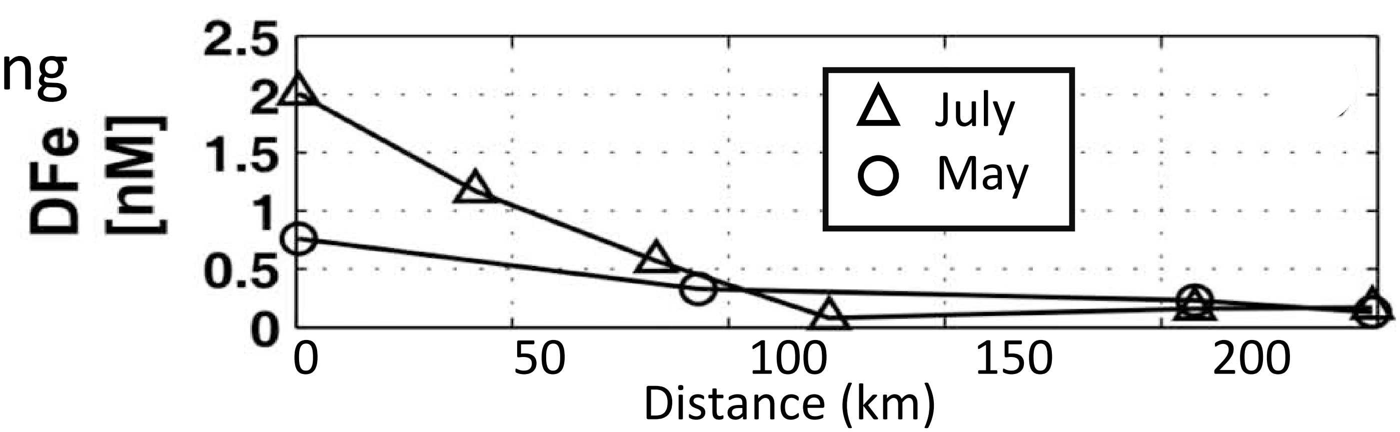
From Weingartner et al. 2002



Measured Iron along Seward Line, 2004

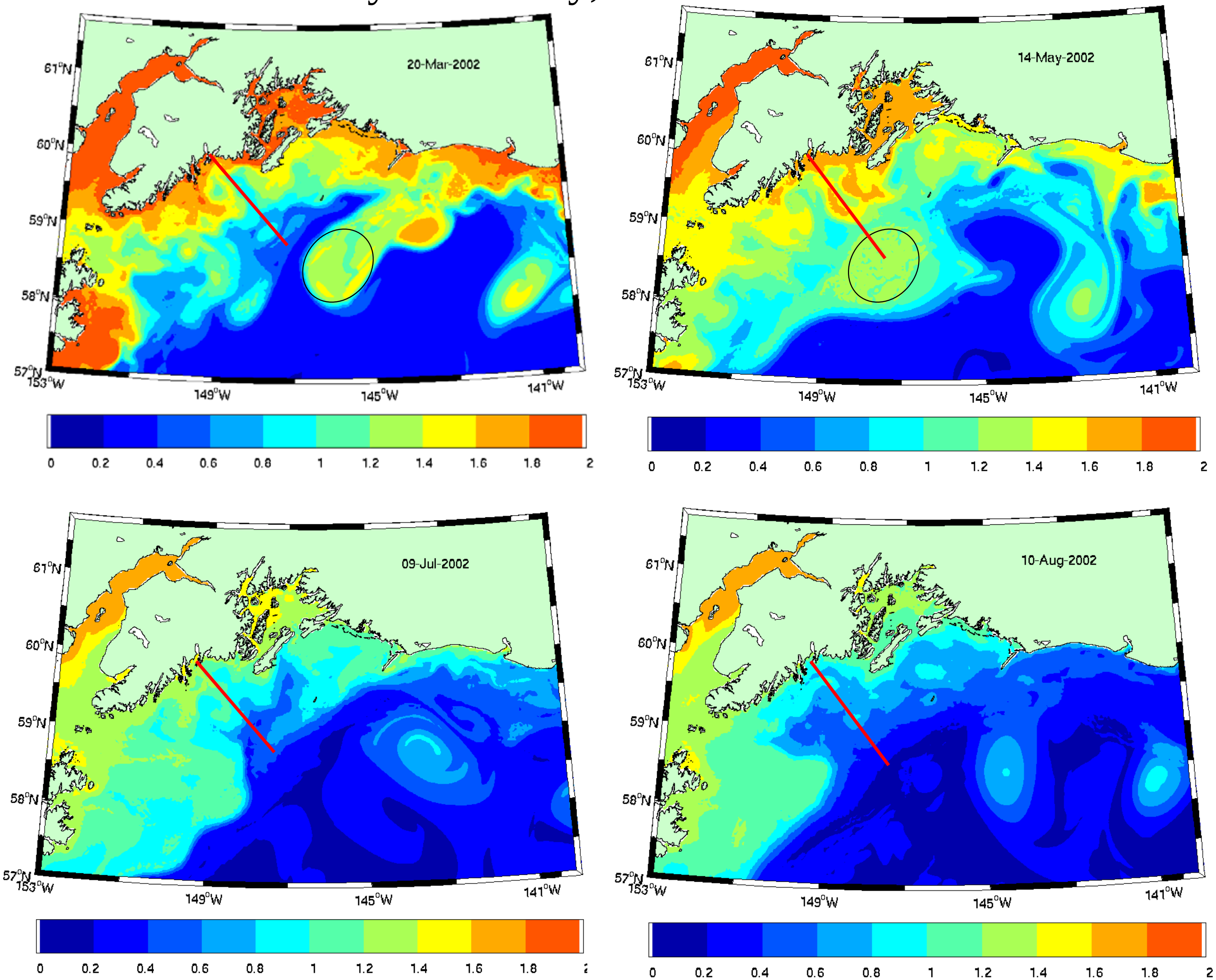
Upper 30 m

From: Wu et al., 2009



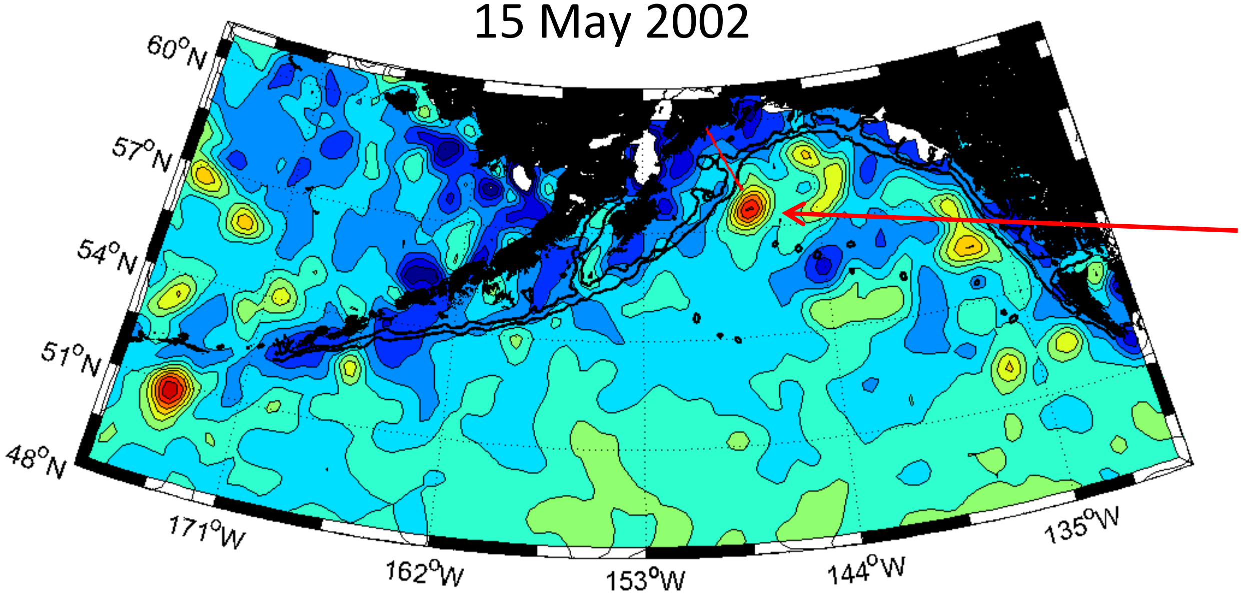
Simulated mean iron concentration (nM) in the upper in the upper 15 m of northern Gulf of Alaska in 2002 **without iron addition with freshwater**
Black circle outlines an anticyclonic eddy, red line = Seward Line

- Eddies east of the Seward Line move HNLC low-iron water onshore.
- Eddies off or west of the Seward Line move LNHC high-iron water offshore.
- Eddies disappear when approaching Kodiak Island.



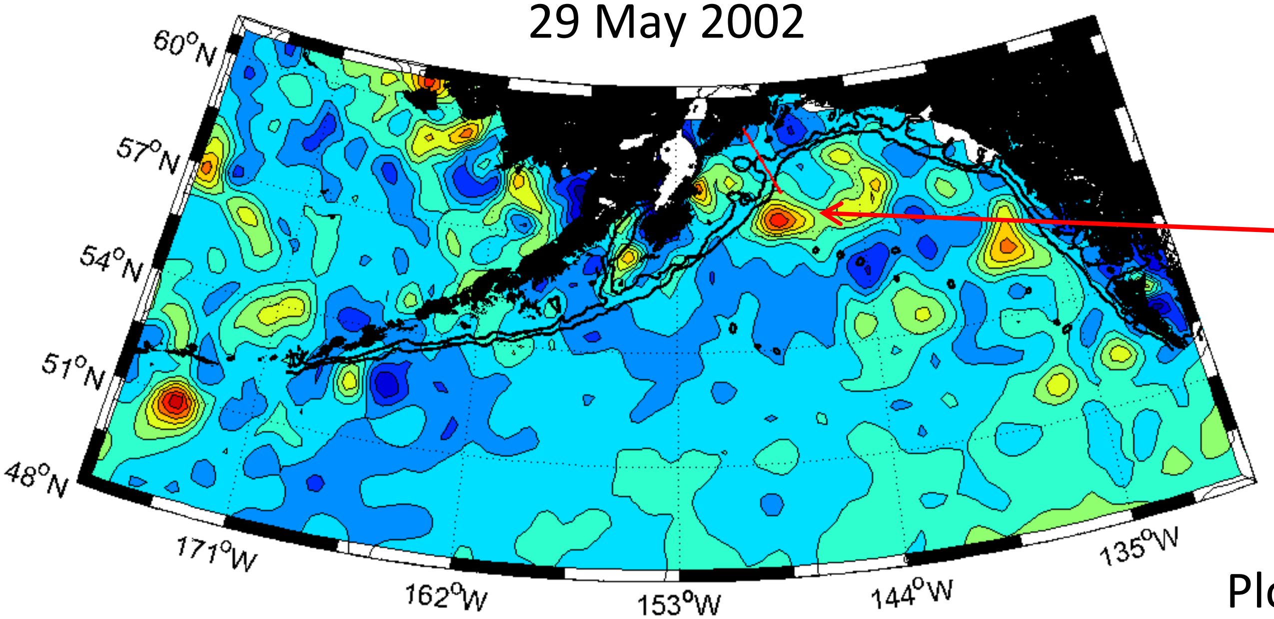
Satellite altimetry data showing an eddy near the Seward Line in May 2002.

15 May 2002



Eddy off the Seward Line potentially moving coastal water offshore.

29 May 2002

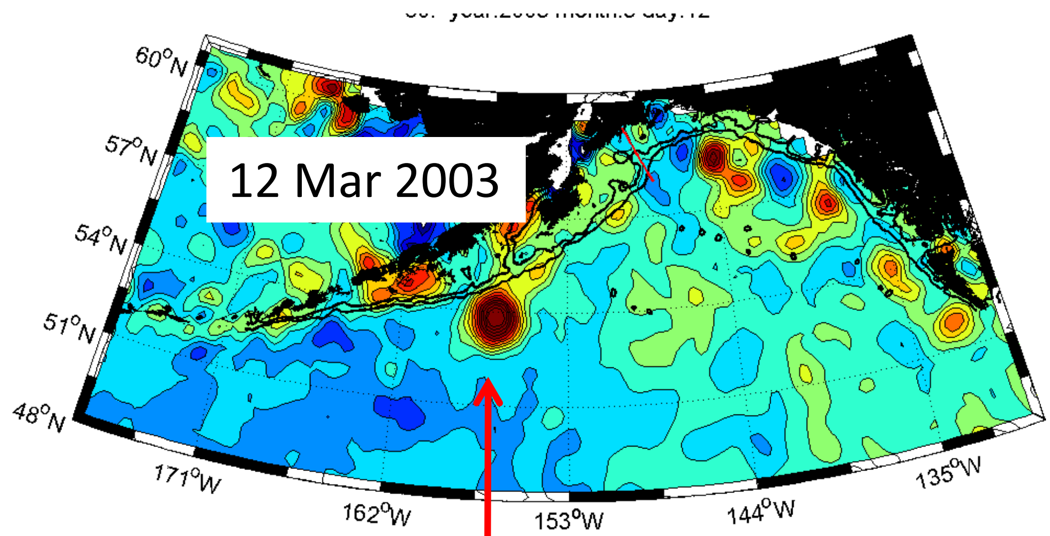


Eddy west of the Seward Line potentially moving coastal water offshore.

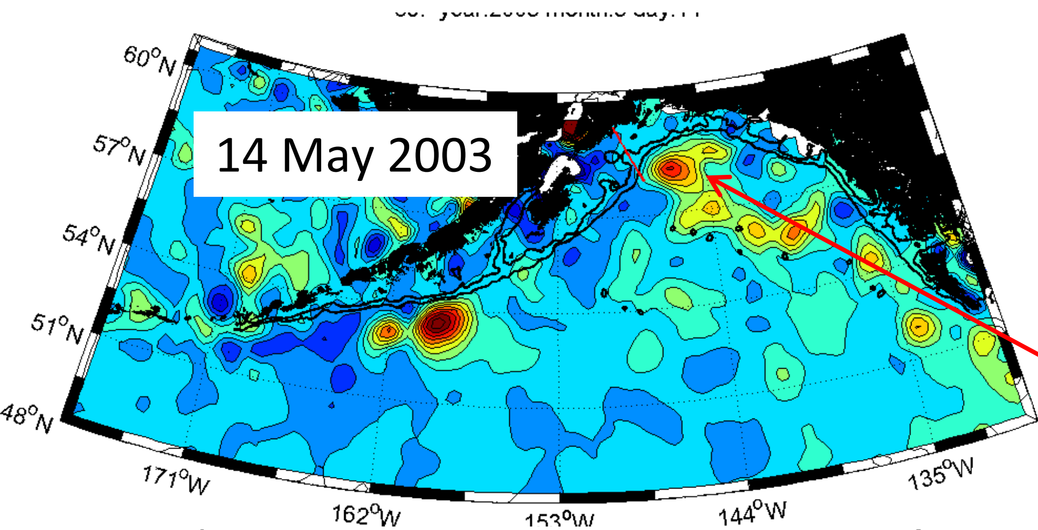
Plots provided by Markus Janout

Eddies affecting cross shelf circulation near the Seward Line (from Satellite Altimetry data)

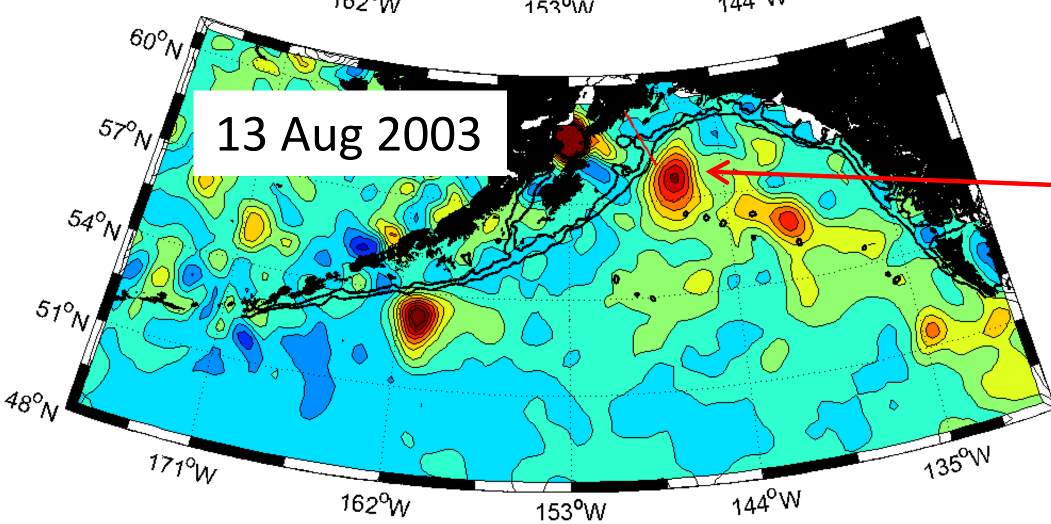
Plots provided by Markus Janout



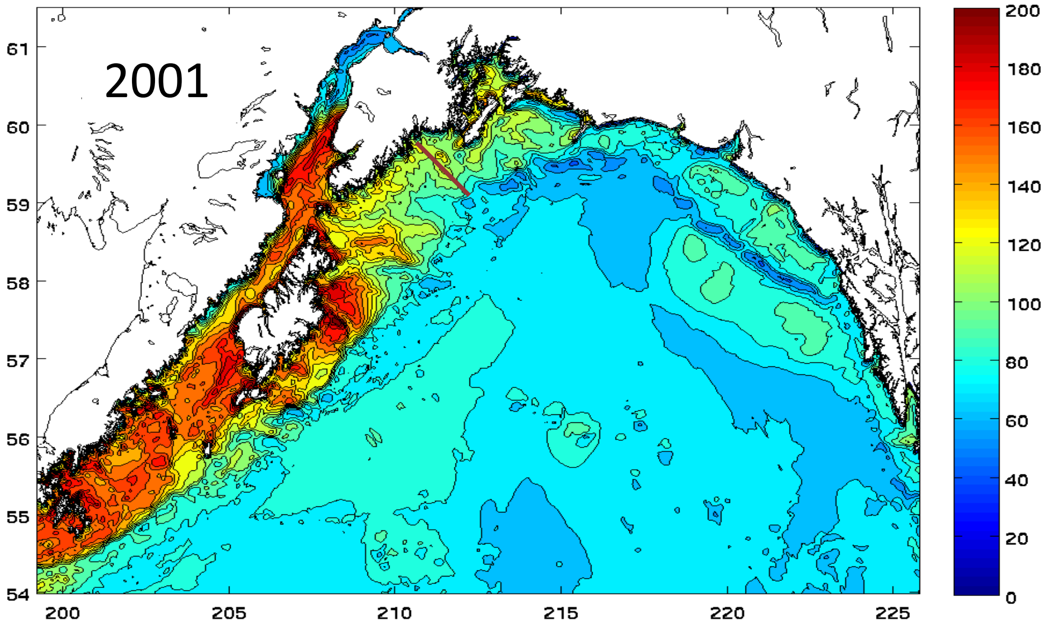
Eddies persist to the west of Kodiak Island and often last for years at a time. The large eddy was off the Seward Line in May 2002.

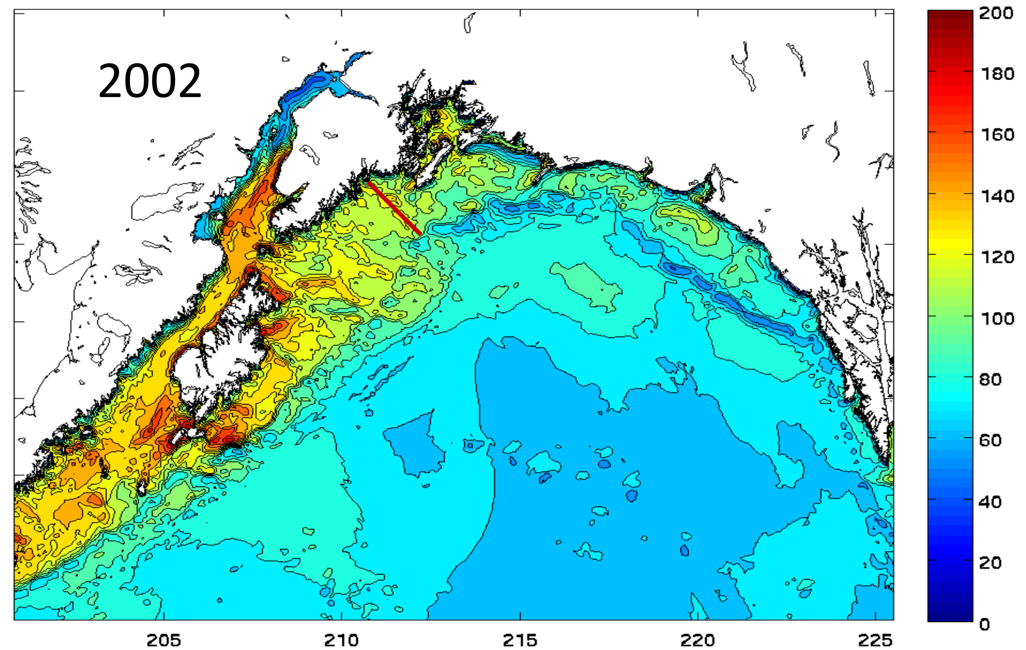


Eddy was present to the east of the Seward Line in May 2003, potentially moving HNLC oceanic water onshore.



The same eddy was still off the Seward Line three months later but was starting to move westward, potentially far enough westward to move coastal water offshore.



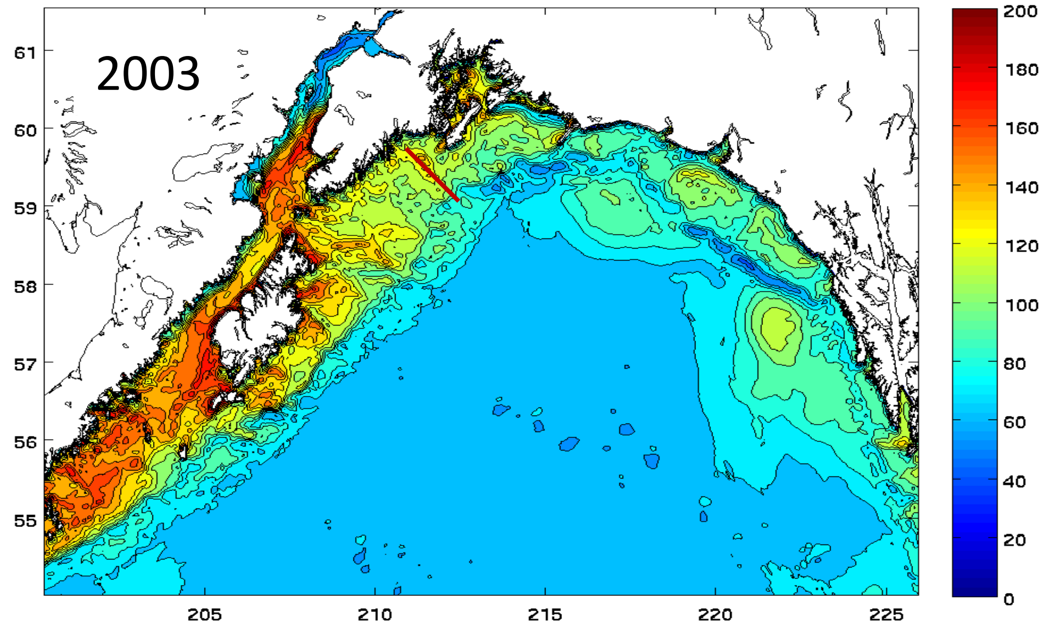


Simulated primary production (g C m^{-2} y^{-1}) in the northern Gulf of Alaska in 2001 - 2003.

These values could change substantially with:

1)Addition of iron with freshwater runoff.

2)Modification of physical model to more accurately simulate movement and duration of eddies

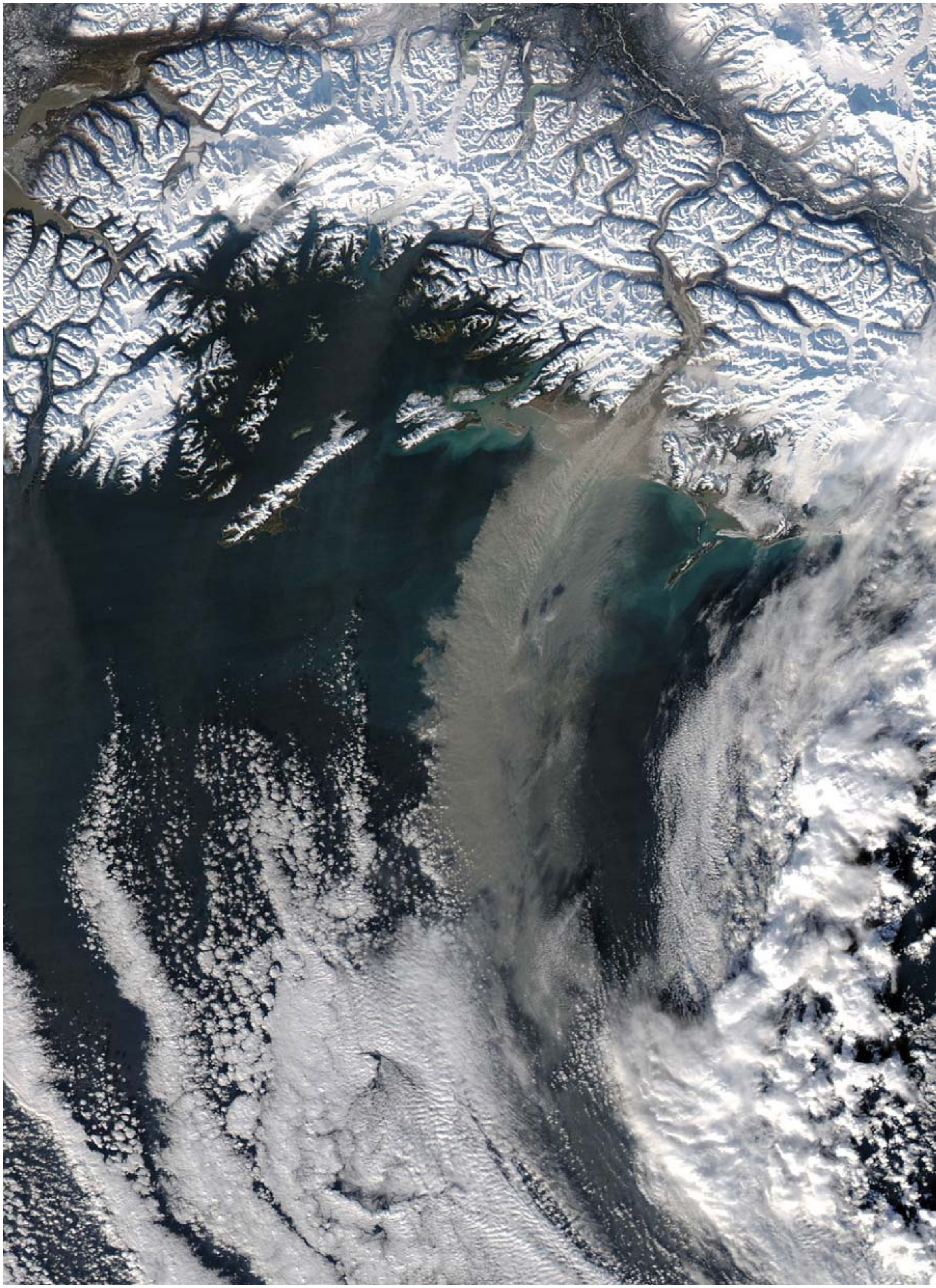


Potential Iron Source:
Dust storm from the Copper River.
November 5, 2005.
From MODIS satellite image.

Such winds may cause upwelling and iron injection to surface waters on the shelf

Climate Drivers may need sufficient resolution to discriminate these events.

http://earthobservatory.nasa.gov/IOTD/view.php?id=6003



Summary

- The timing and magnitude of spring production is highly influenced by cloud attenuation of PAR. Springs with consistent intense cloud cover will have lower spring production or delayed production.
- Elevated summer nitrate concentrations in 3D simulations was apparently due to loss of iron from the shelf environment.
- Iron was washed from the shelf in 3D simulations, partly due to the influence of eddies in the simulations.

CONCLUSION

Requirements for Simulating Interannual Differences in the Production Cycle

- Injection of iron with freshwater. Nudging iron to a climatological mean will mask interannual differences in production due to differences in precipitation, snowmelt and runoff.

- Eddies influence cross-shelf distribution of nutrients.   The physical model must reproduce the timing, intensity and duration of anticyclonic eddies along the shelf break.

- Interannual differences cloud attenuation of daily PAR must be captured by the driver data.

- If gap winds or dust storms are influencing the nutrient cycle, the driver files will have to discriminate winds at greater than 2^{o} resolution.

Acknowledgments

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Data contribution and technical support:

1) *Aid in running circulation model*: Kate Hedstrom, Wei Cheng, Georgina Gibson
2) *Physical data*: Tom Weingartner, Tom Royer, Seth Danielson
3) *Nutrient, primary production data*: Terry Whitledge, Dean Stockwell
4) *Phytoplankton and microzooplankton carbon biomass, carbon chlorophyll ratios*: Evelyn Lessard
5) *Small phytoplankton alpha values, rate data for microzooplankton*: Suzanne Strom
6) *Iron values*: Jingfeng Wu
7) *Zooplankton community structure*: Michael Dagg
8) *Zooplankton rate measurements*: Russell Hopcroft.