Increased Freshwater and Biogenic Fluxes: The flip side of Arctic sea-ice retreat

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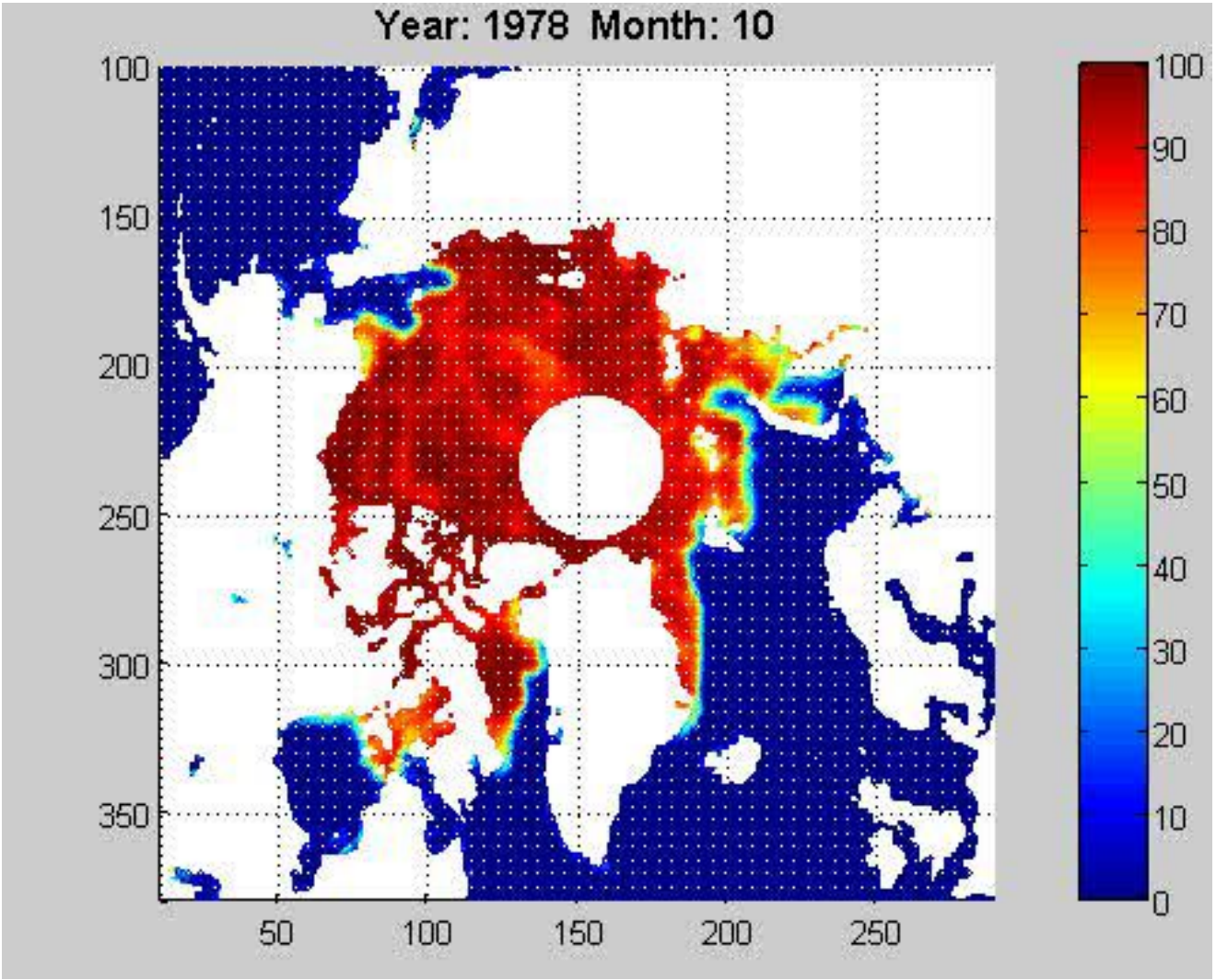
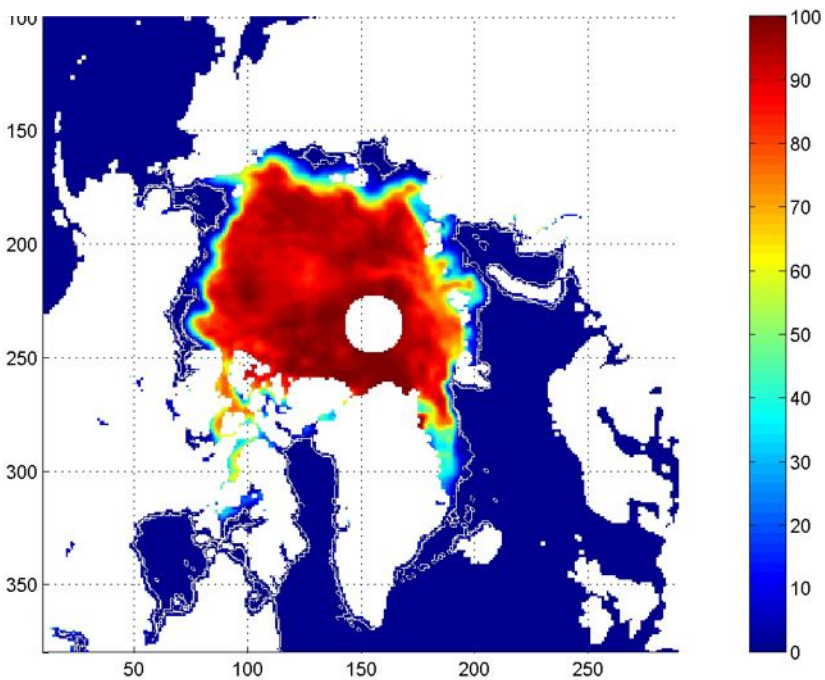
Sea Ice Concentration
Nimbus-7, 1979-2007

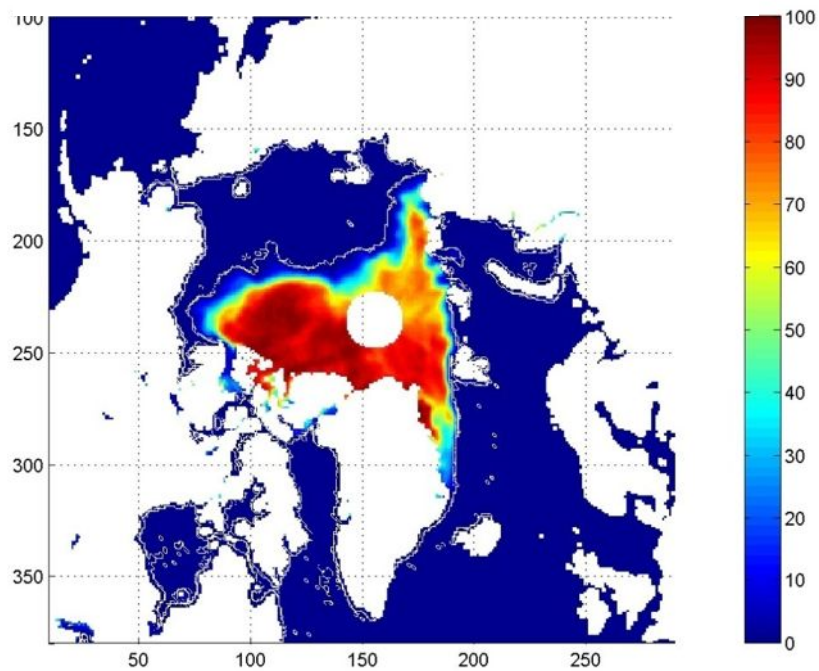


Summer ice extent retreating rapidly:

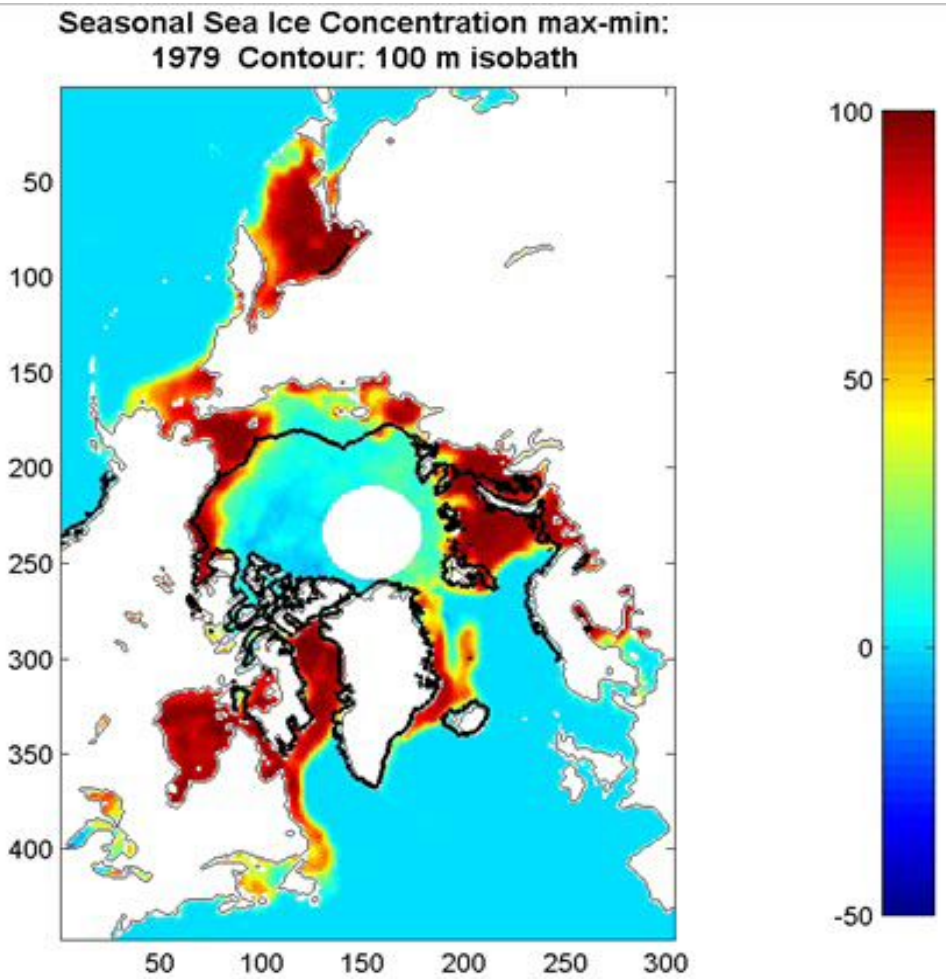
Mean sea-ice concentration September, 1987



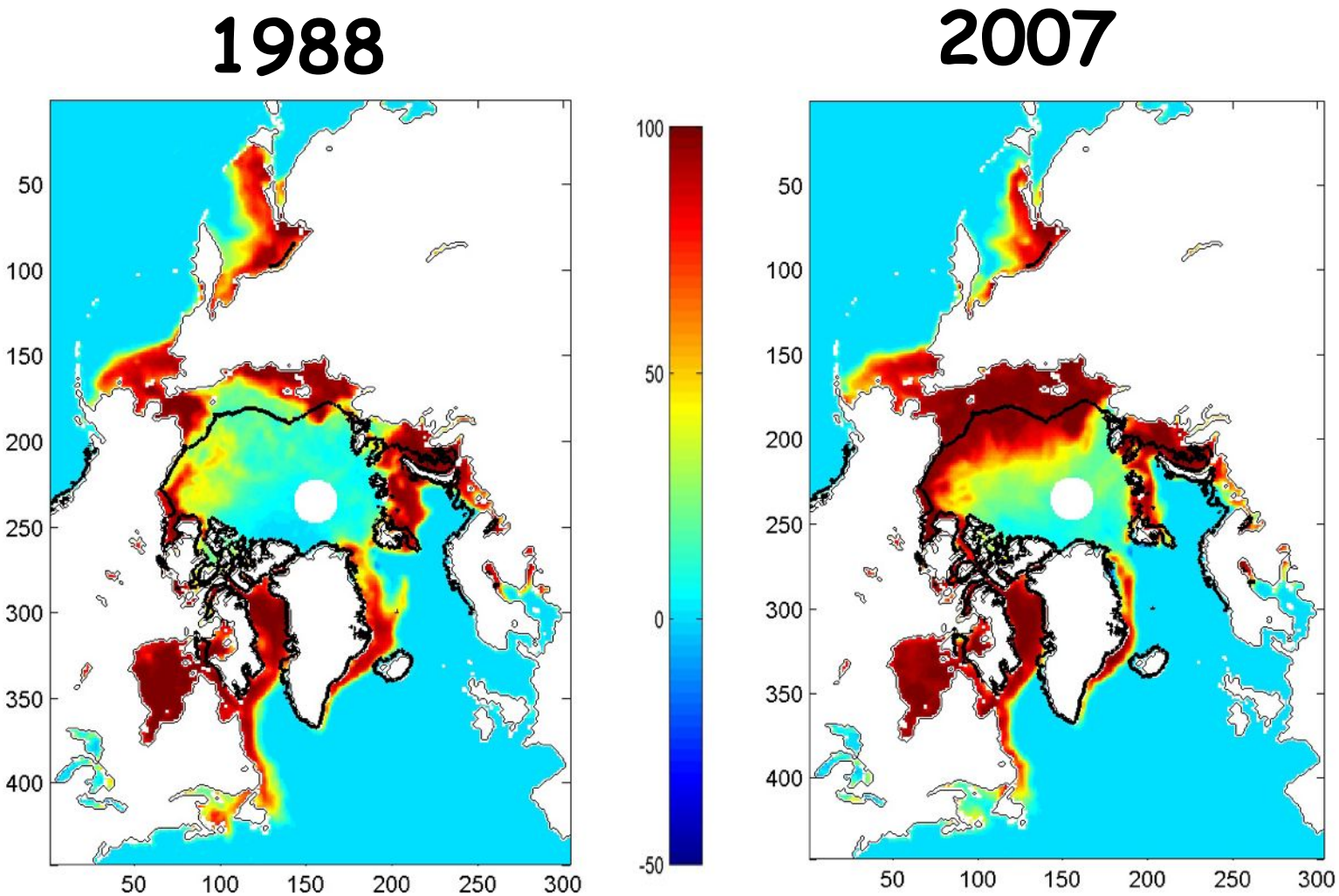
Mean sea-ice concentration September, 2007



Seasonal Ice Zone (SIZ): complement of ice changes:



Ice concentration: Mar – Aug



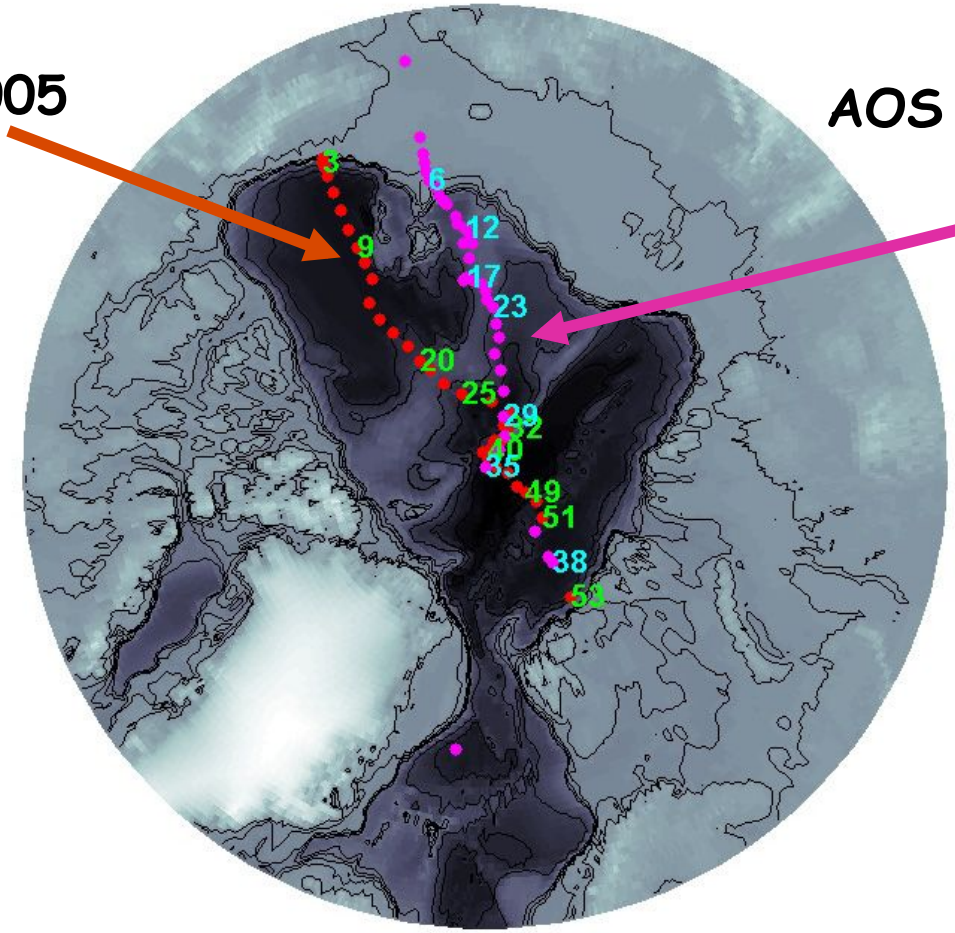
Want to think about two implications:

- Freshwater Flux:
  - Dominates density gradients,
  - Sets stratification,
  - Protecting ice from upwelling heat,
  - modulating biological productivity,
  - and deep water formation rates,
- Nutrient fluxes:
  - Critical to productivity
  - Limited by light and stratification
  - So modulated by sea-ice formation and melt
  - Important tracer for circulation and water masses

In the context of modern hydrographic cruises:

AOS (Oden) 2005

AOS (Polarstern) 1994



Surface circulation and river basins

Freshwater Sources:

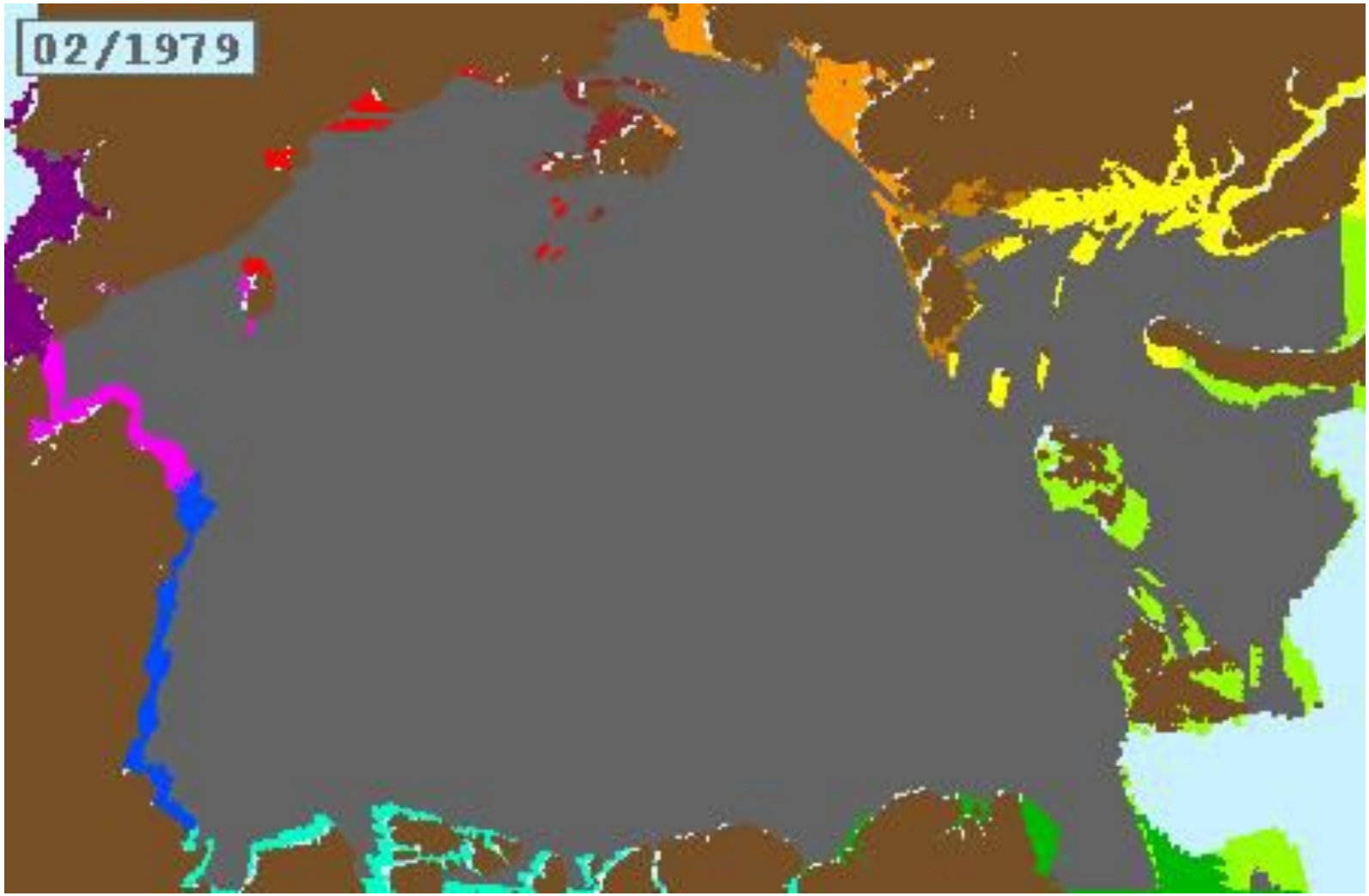
River runoff

Bering Strait inflow (N. Pacific is fresher than N. Atlantic)

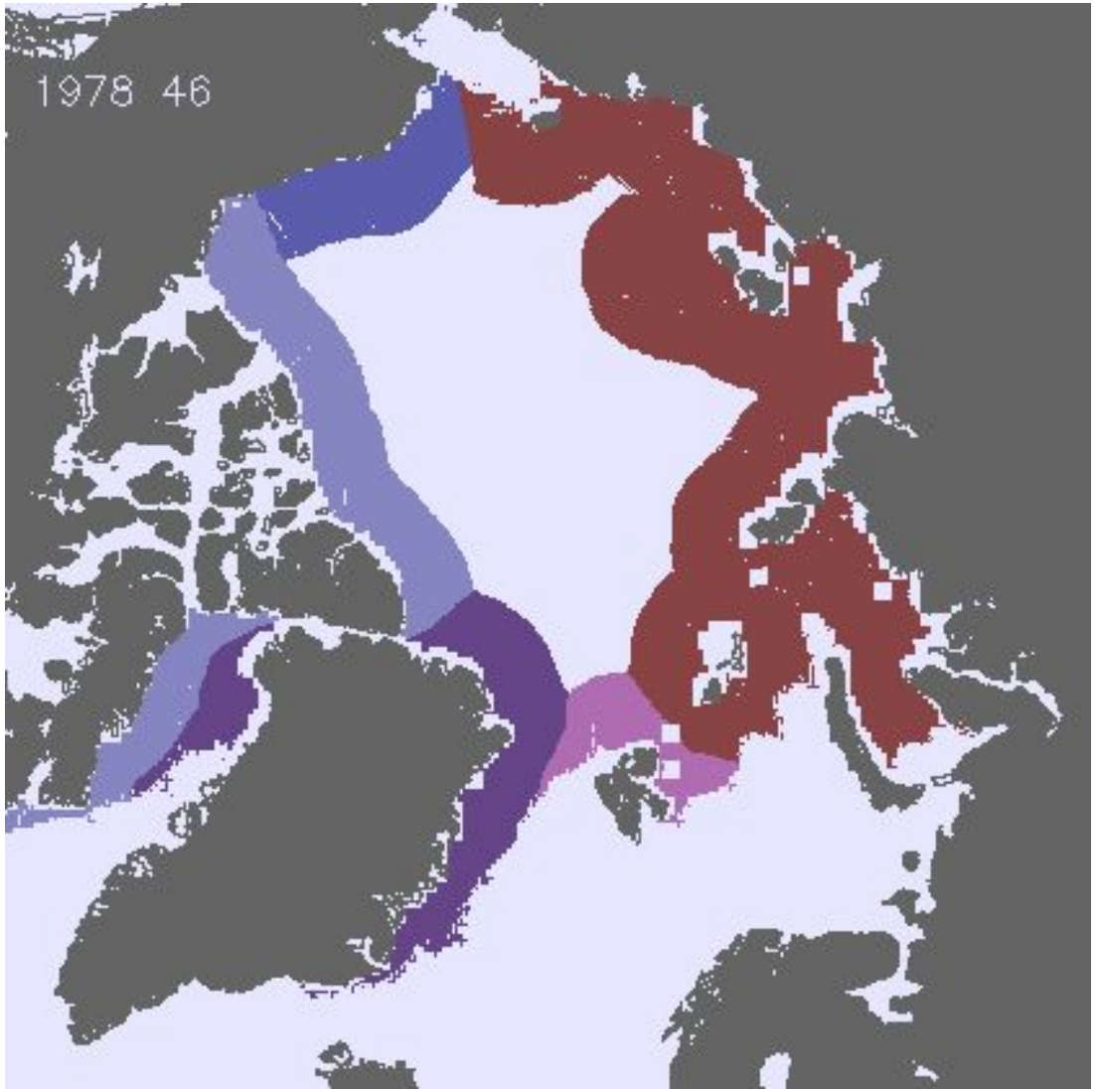
Local precipitation

Annual sea-ice cycle (asymmetry between fate of melt and freeze)

Coastal ice circulation from buoys:



EEZ ice flows from satellite images:



Ice transports fresh water (among other things):

- Changes in summer sea-ice melt locations should change the distribution of salinity and density gradients.
- Increasing area of the seasonal ice zone (SIZ) should <u>increase</u> total sea ice formation.
- A stronger sea ice pump (fresh water up, brine down) should increase stratification.
- Changing density distributions should impact on large-scale circulation … but how?

To evaluate impact of sea ice, need to separate sea ice meltwater and brines from other fresh/salty water sources:

$$f_a + f_p + f_r + f_i = 1,$$

$$f_a S_a + f_p S_p + f_r S_r + f_i S_i = S_m,$$

$$f_a \delta^{18}O_a + f_p \delta^{18}O_p + f_r \delta^{18}O_r + f_i \delta^{18}O_i = \delta^{18}O_m,$$

$$f_a PO_4{}^*{}_a + f_p PO_4{}^*{}_p + f_r PO_4{}^*{}_r + f_i PO_4{}^*{}_i = PO_4{}^*{}_m,$$

Note that a nutrient parameter is required to identify Bering Strait inflow (Pacific Water).

Basic water mass de-convolution technique: matrix inversion

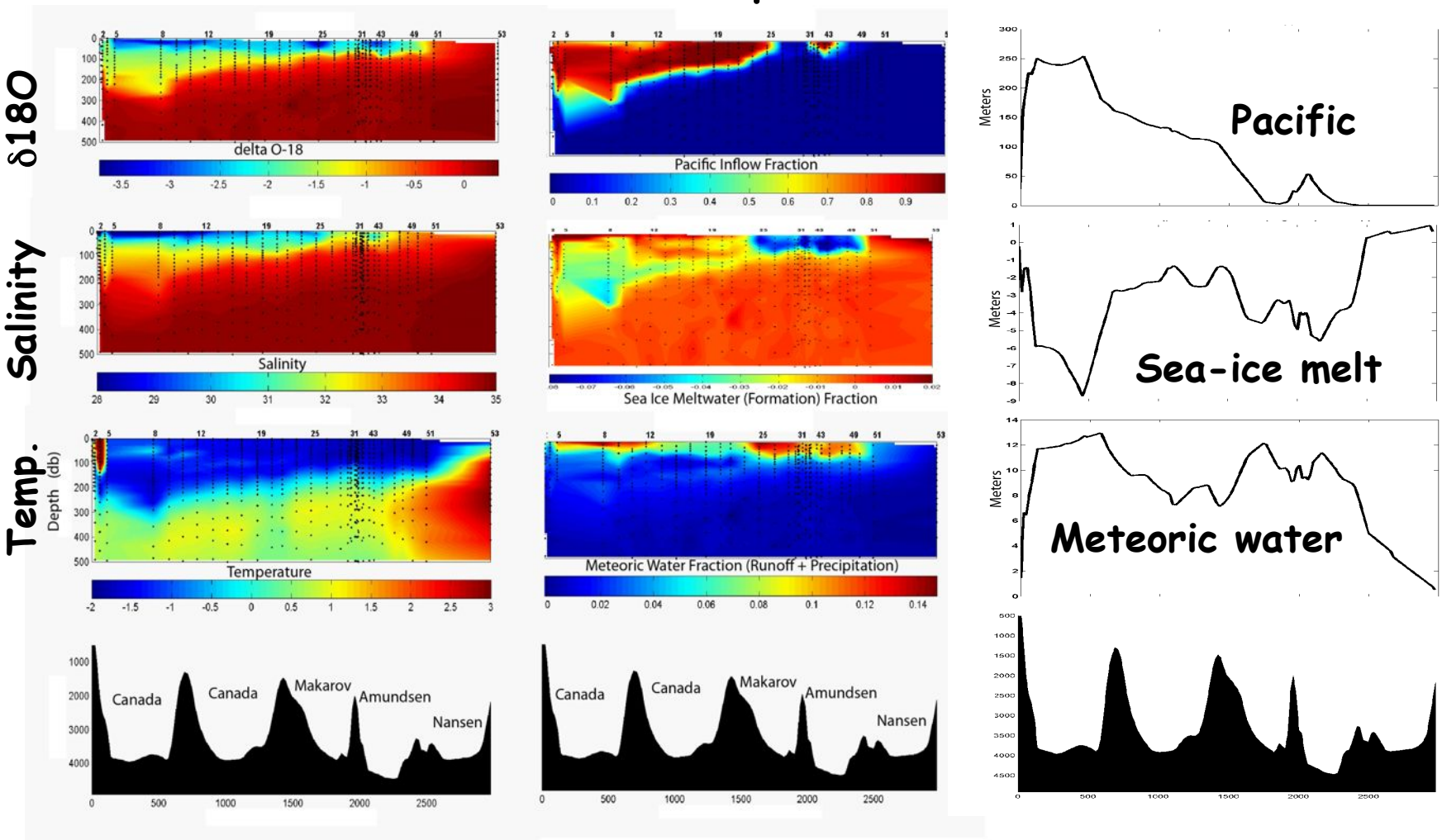
- System of tracer equations:
- Ef = d
- f = E\d
- Coefficients in E: end-member values
- d are the sample measurements.
- Can be exact (m = n = number of measured parameters) or
- Overdetermined (solved by least-squares minimization of a cost function).

Nutrient tracers are not conservative. Redfield combinations minimize impact of photosynthesis and respiration:

- PO* (Ekwurzel, Schlosser, Newton, Chen)
- N* (Newton)
- NO (Wallace)
- NO/PO (Wallace)
- Empirical N/P (Jones, Anderson, Matsumoto-Kawaii)

Physical properties and water mass fractions from AOS-05

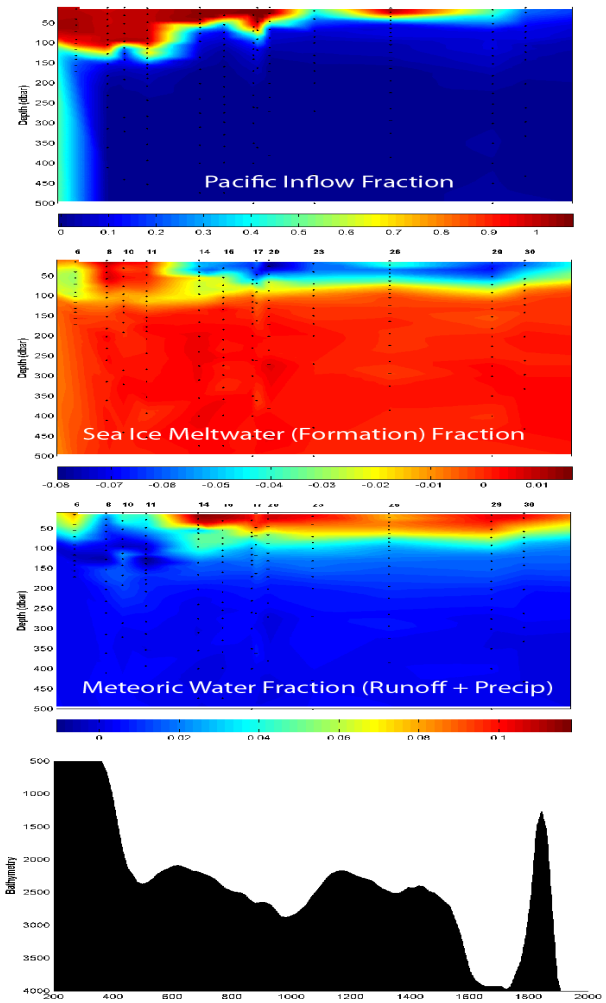
Observations | FW Components and water column sum



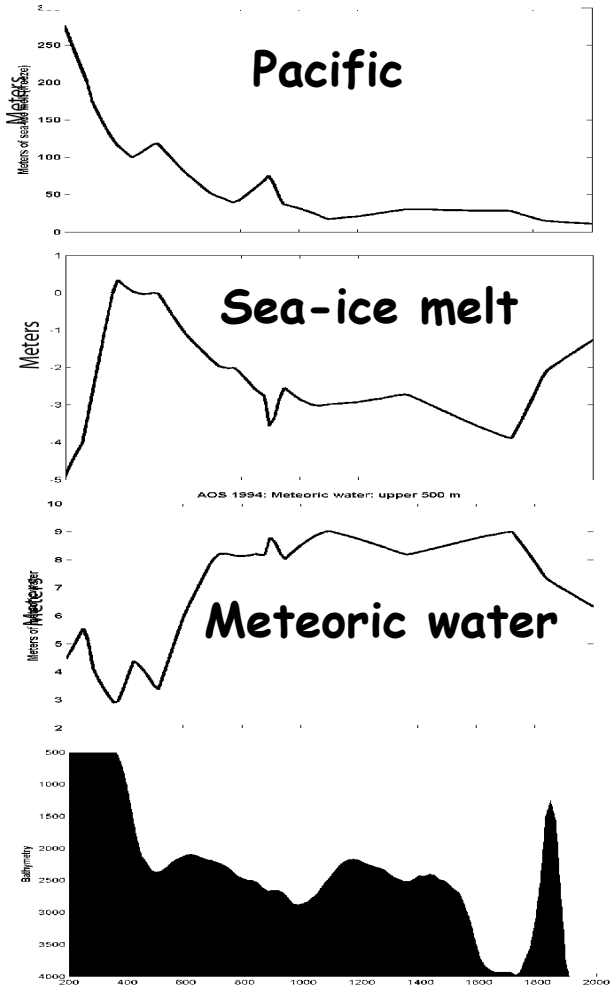
AOS 1994 Water mass fractions

Water mass fractions in 2005 and 1994 were comparable … As long as one uses the same end-member parameters and values …

Fractions



Water column sum



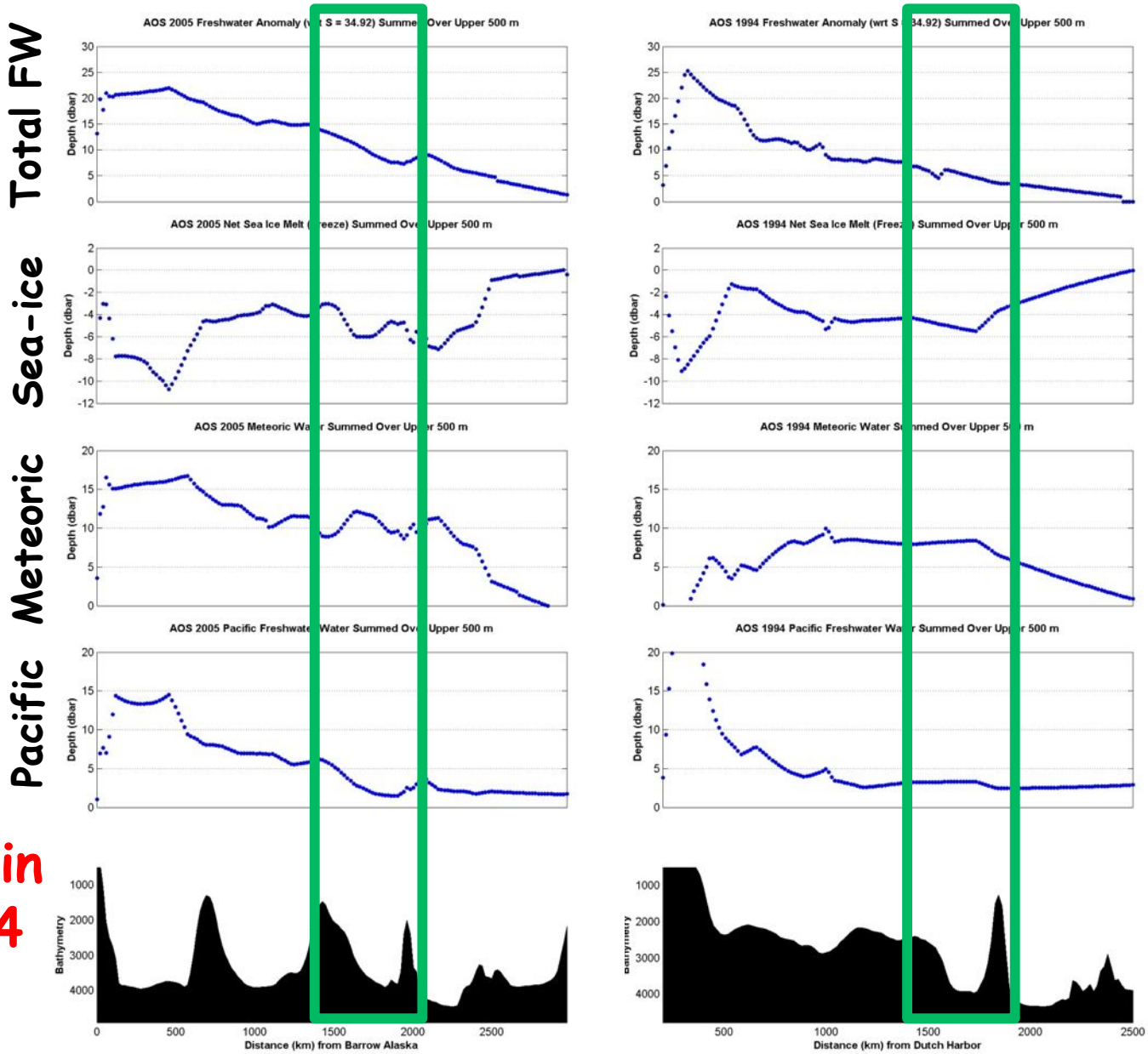
10.0-6.5
=3.5 m

(-5)-(-6)
= 1 m

10.5 – 8.0
= 2.5 m

3.5 – 3.5
= 0.0 m

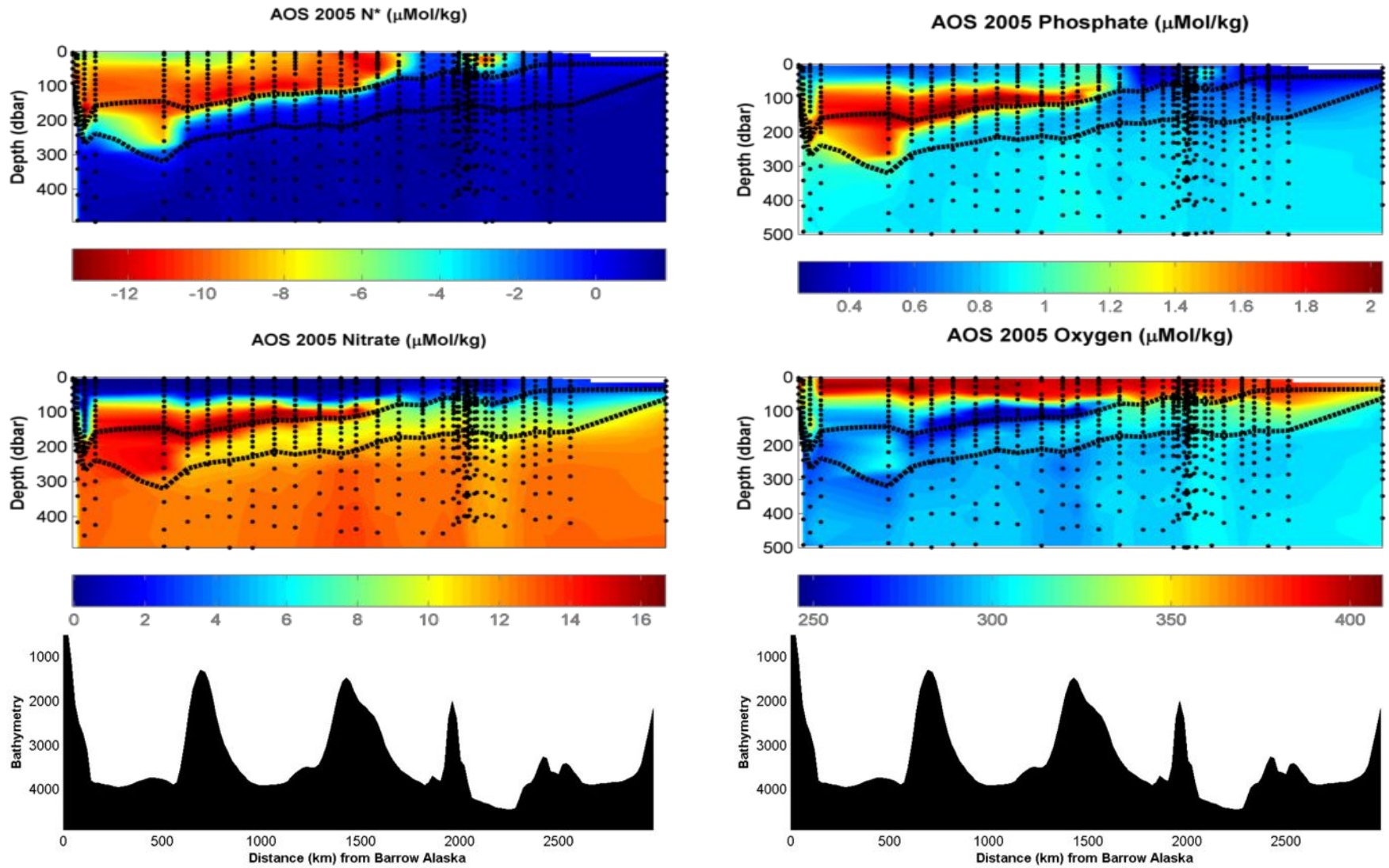
Makarov Basin 2005 – 1994 Difference



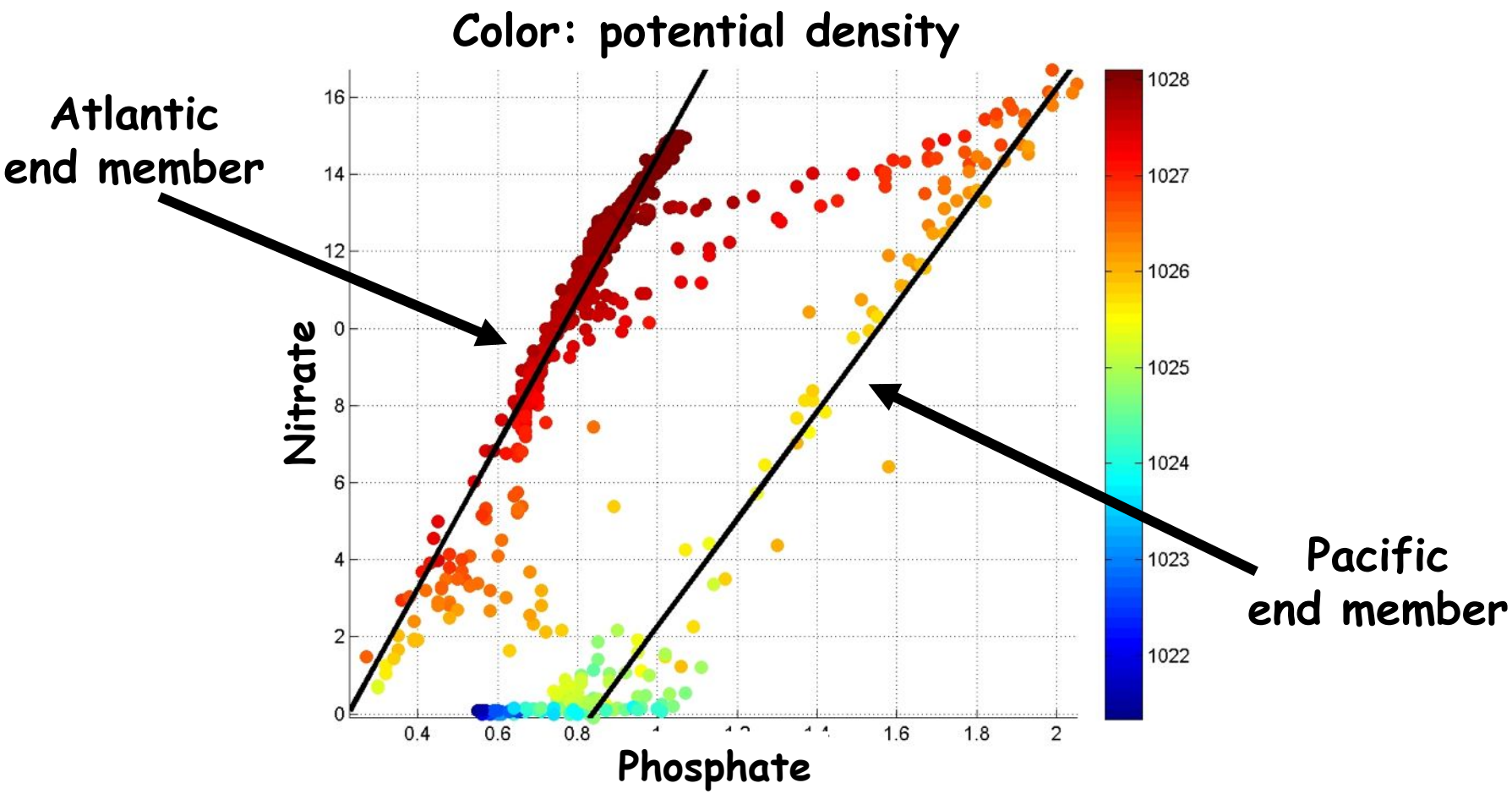
Increased stratification?

- There is a dramatic freshening of the upper layers over the Makarov Basin (3.5 m freshwater anomaly, 2004 – 1994).
- Increased sea-ice meltwater flux is a significant component (~ 1/3).
- But meteoric waters (runoff and local snowfall), driven mainly by changes in wind stress (Ekman transport) continue to dominate the anomalies.
- No convincing evidence of increased salinity in the halocline; residence times ~ 15 years implies this should follow the surface anomalies.

Nutrients on the AOS-2005



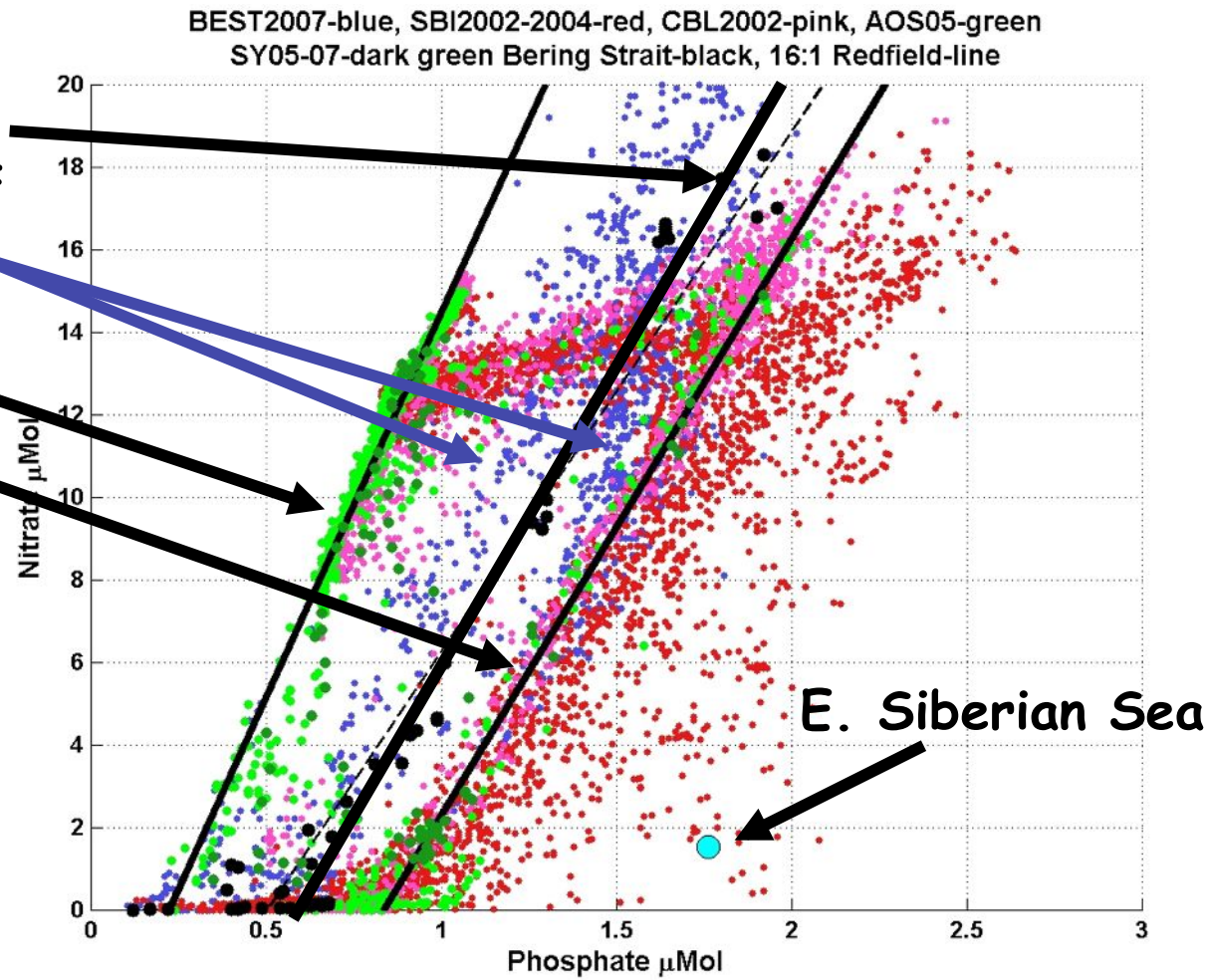
AOS-05 N-P data:
(well fit to empirical end-members)



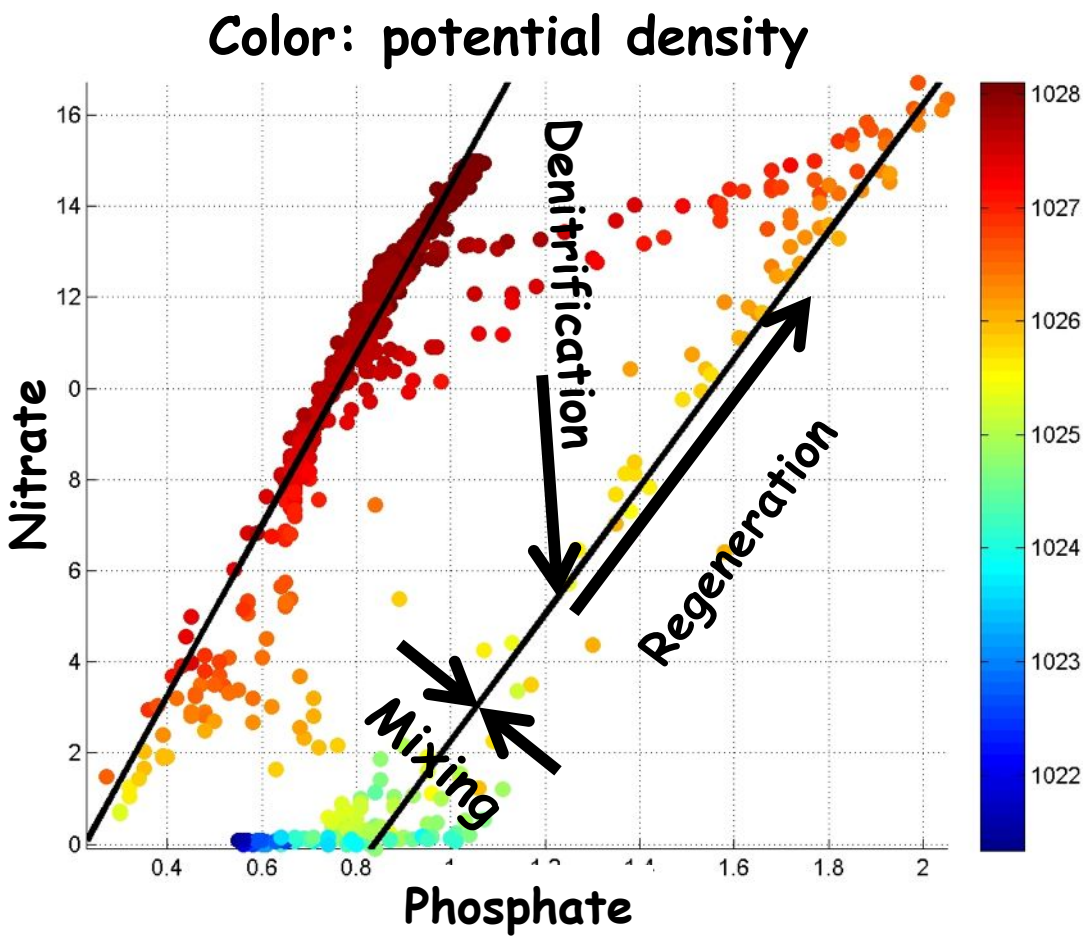
But implication is: significant processing on the Arctic shelves.

Bering Strait Inflow: reasonable average of shallow Bering Sea, and intermediate between Atlantic and Pacific N/P relationships.

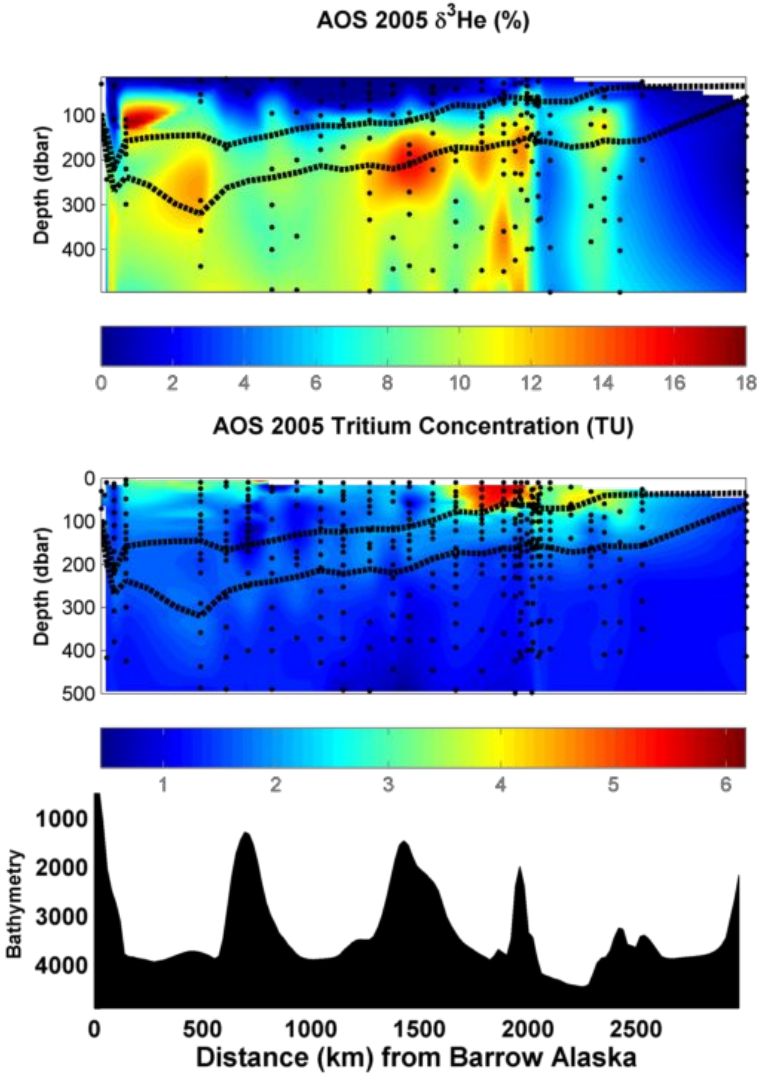
Transformation from BSI to the "Pacific" end member requires denitrification and/or Phosphate addition in the Chukchi Sea.

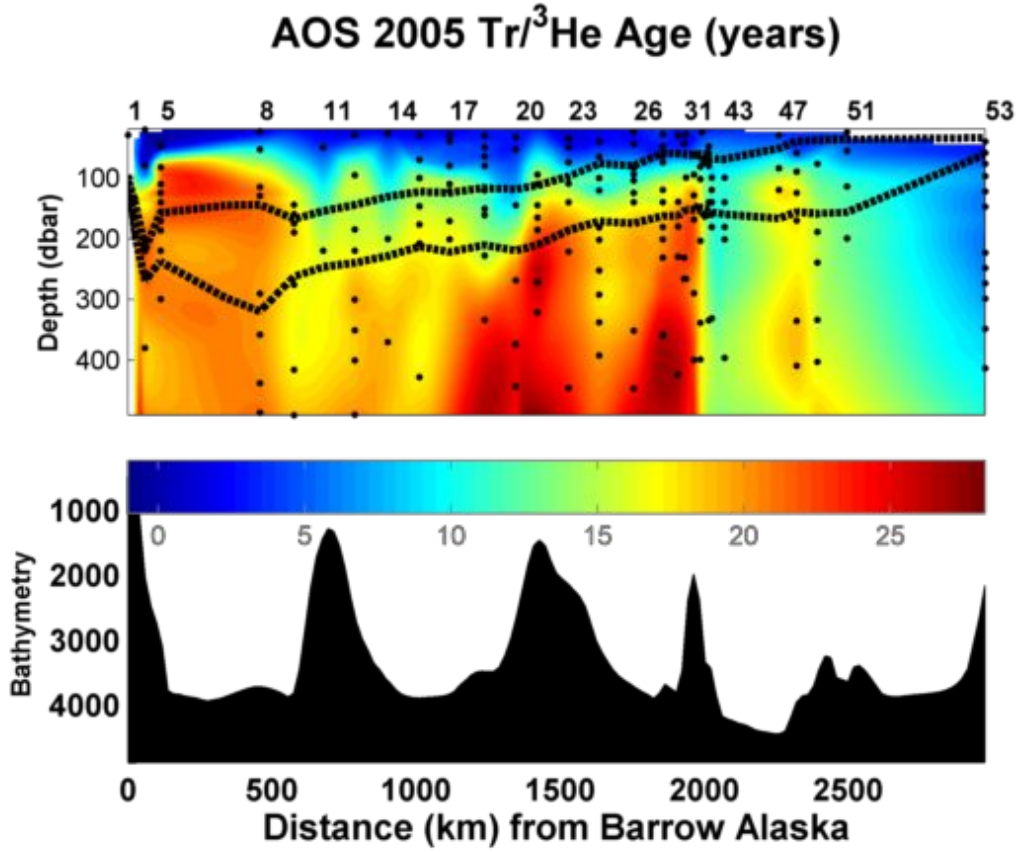


So nutrient patterns in the Arctic halocline reflect indigenous (Arctic) processing:

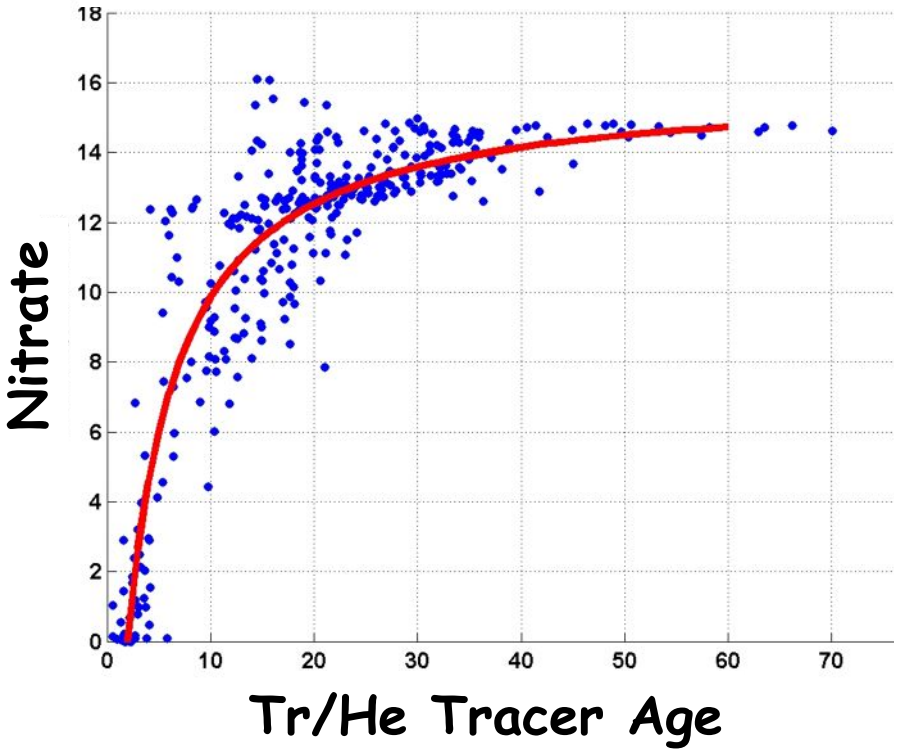


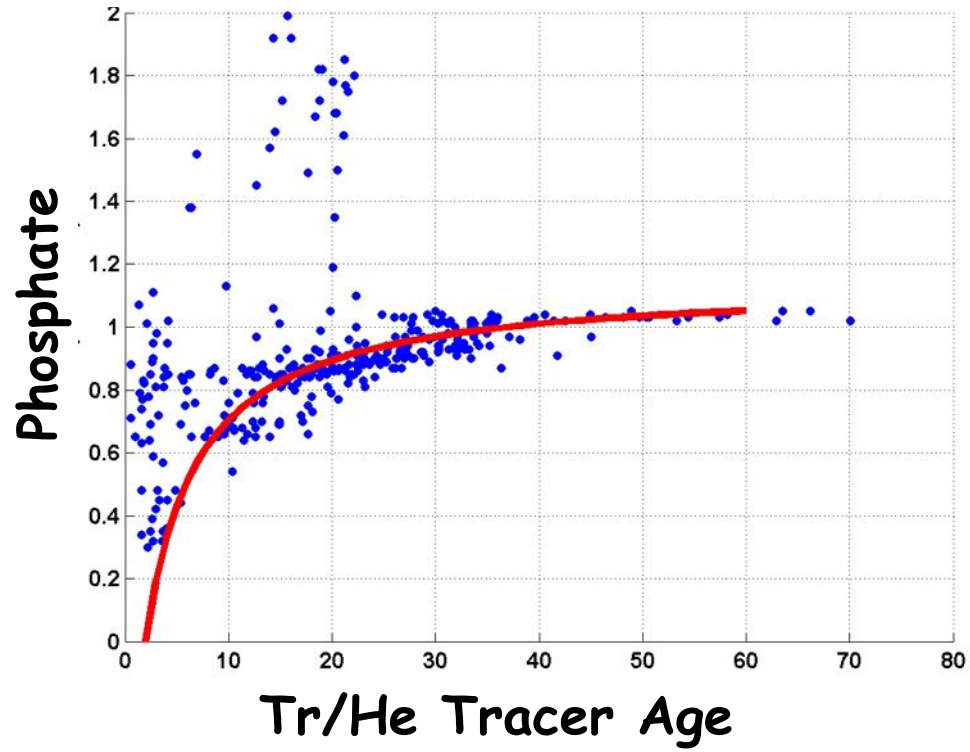
For process rates we need a clock:





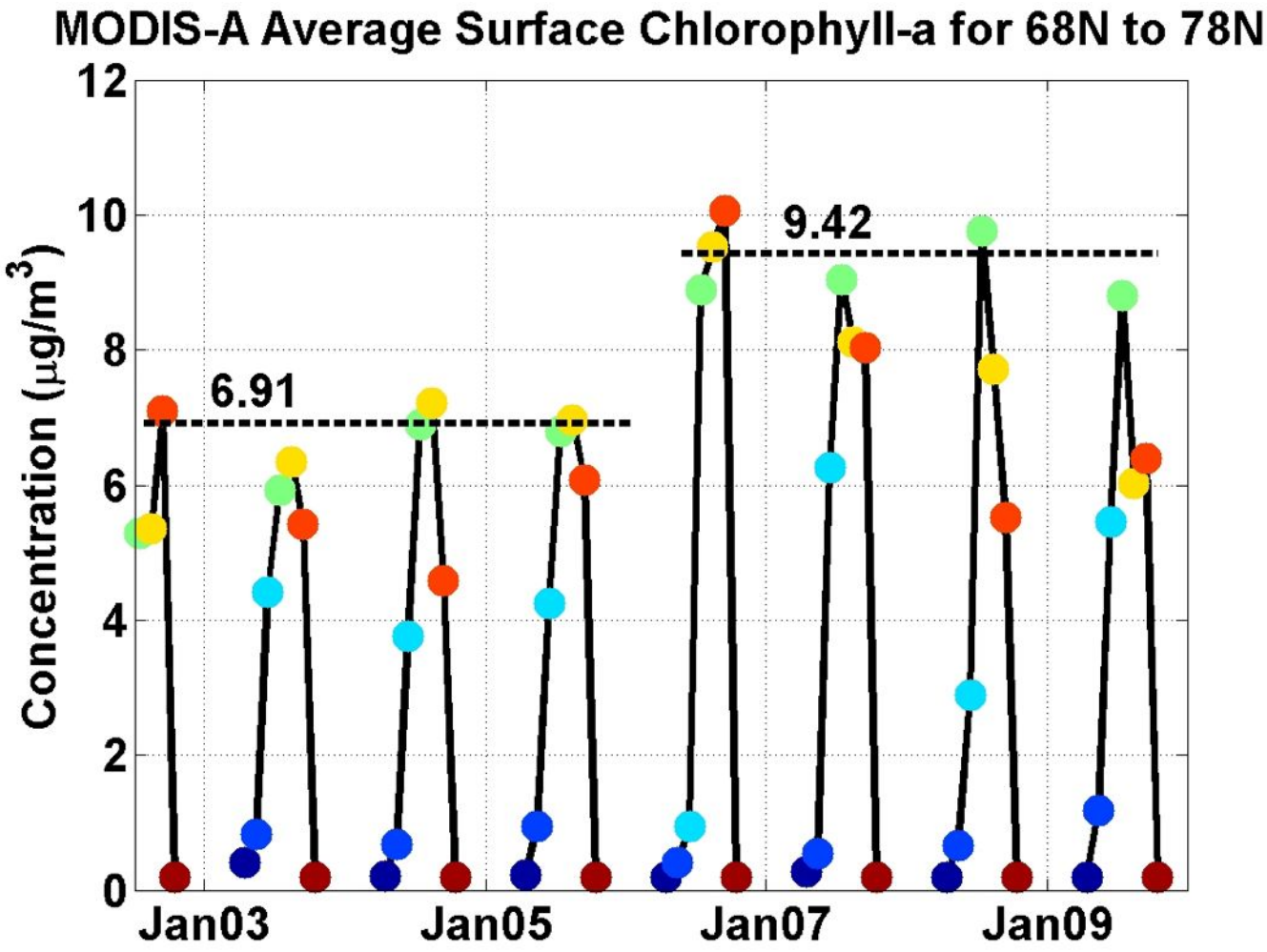
Halocline nutrient concentrations asymptote with Tr/He age:



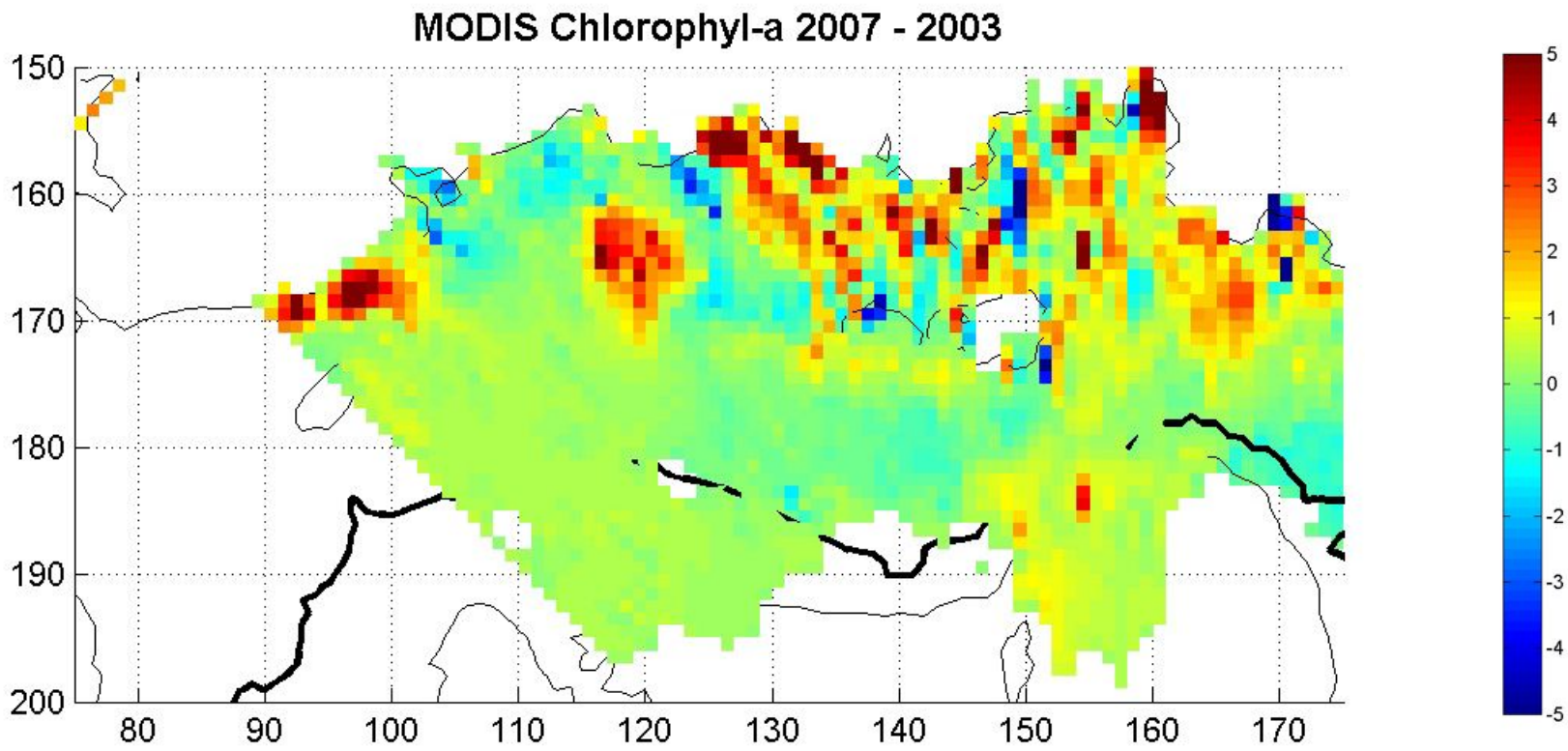


(So implied export productivity varies …
Upper halocline: ~3 gC/m^2; Lower halocline: ~6 gC/m^2)

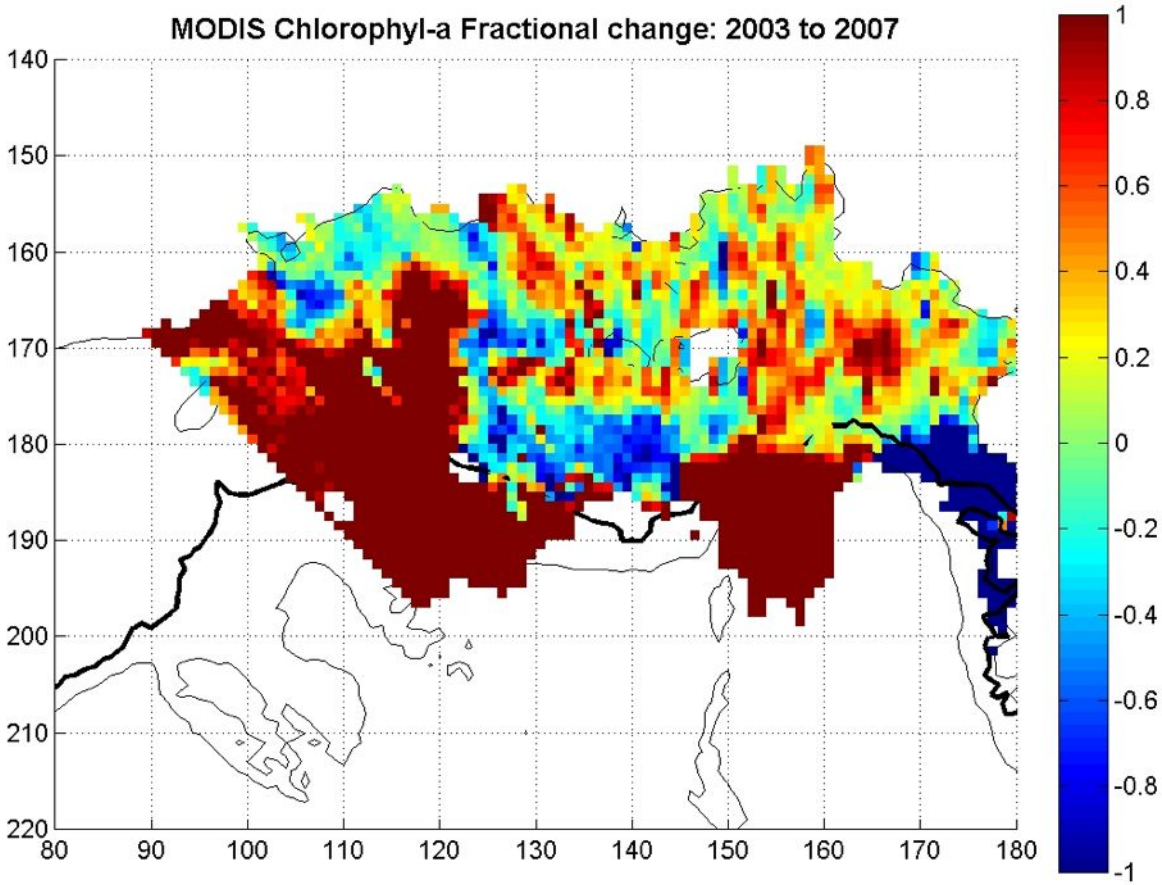
The Halocline nutrient system appears supply limited … and the supply may be increasing:



MODIS-A: Change in Chlorophyll in the E. Siberian Sea, 2007 – 2003:



Fractional change in ChlA:
1 = areas of new production



Increased nutrient flux?

- Nutrient regeneration in the Canadian Basin halocline appears to be limited by POC supply; current (~ last 20 years) limits: 16 mMol N/m^3.
- Redfield-derived (using C/N/P and Tr-age) POC export: upper halocline ~ 3gC/m^2; lower h.c.: ~ 6gC/m^2; mainly from production on shelves.
- Supply of organic material is increasing, perhaps dramatically (30% step in 2006), as the growing season lengthens and the water column is more stratified. Largest absolute increases on the shelves, which feed the halocline.
- New regions of productivity over the deep Canadian Basin ➔ greater vertical flux.