GEOCHEMICAL TRACERS OF ARCTIC OCEAN CIRCULATION

Christopher Guay

Earth Sciences Division

Lawrence Berkeley National Laboratory

Fresh Water Cycle Maintains Stratification of Upper Arctic Ocean

- Stably stratified surface layer
  - -- ice formation
  - -- plankton growth
- Formation of cold halocline layer
- Export of positive buoyancy flux to North Atlantic

Arctic Ocean Freshwater Budget

Reference Salinity = 34.4

Goldner (1999), *JGR*, 104, 29,757-29,770.

FLUX	Q (Sv)	Salinity (PSS)	Effective Freshwater Flux ($km^3\ yr^{-1}$)
River runoff	0.108	0.0	3400
Bering Strait inflow	0.81	32.5	1420
Net Precipitation (P-E)	0.012	0.0	380
Arctic Archipelago outflow	-1.37	33.2	-1460
Barents Sea inflow	1.49	35	-820
Fram Strait Outflow			
Ice	-0.07	3.5	-1980
EGC Polar Water	-1.16	33.9	-560
EGC Atlantic Water	-2.14	34.9	960
EGC Deep Water	-1.03	34.9	490
Subtotal	*-4.40*		*-1090*
Fram Strait Inflow			
WSC Atlantic Water	2.65	35.0	-1490
WSC Deep Water	0.73	34.9	-340
Subtotal	*3.38*		*-1830*
NET	0.0		0.0

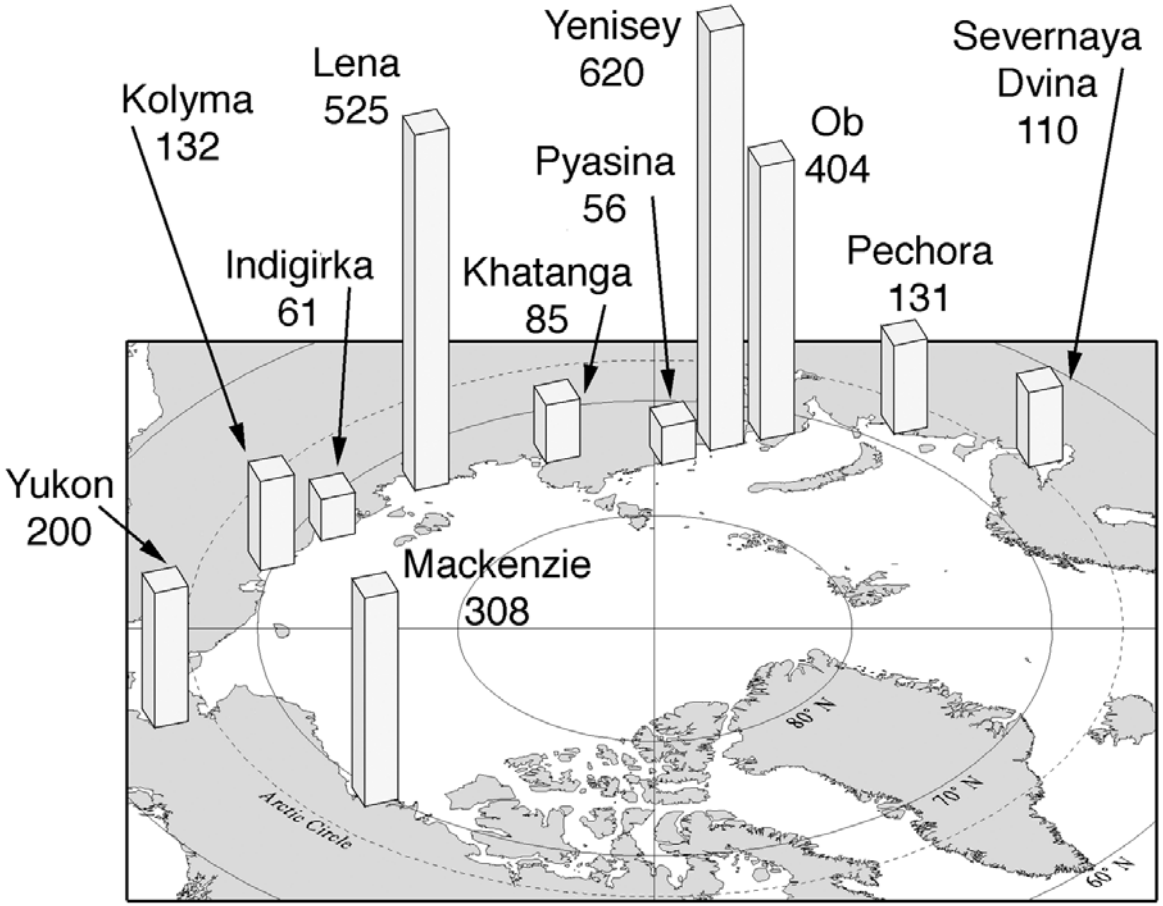
Arctic Ocean Freshwater Budget

Reference Salinity = 34.4

Goldner (1999), *JGR*, 104, 29,757-29,770.

FLUX	Q (Sv)	Salinity (PSS)	Effective Freshwater Flux ($km^3\ yr^{-1}$)
River runoff	**0.108**	**0.0**	**3400**
Bering Strait inflow	0.81	32.5	1420
Net Precipitation (P-E)	0.012	0.0	380
Arctic Archipelago outflow	-1.37	33.2	-1460
Barents Sea inflow	1.49	35	-820
Fram Strait Outflow			
Ice	-0.07	3.5	-1980
EGC Polar Water	-1.16	33.9	-560
EGC Atlantic Water	-2.14	34.9	960
EGC Deep Water	-1.03	34.9	490
Subtotal	*-4.40*		*-1090*
Fram Strait Inflow			
WSC Atlantic Water	2.65	35.0	-1490
WSC Deep Water	0.73	34.9	-340
Subtotal	*3.38*		*-1830*
NET	0.0		0.0

Discharge of Major Arctic Rivers ($km^3\ yr^{-1}$)



Total Arctic Runoff: 3400 $km^3\ yr^{-1}$ [10% of global total]

Arctic Ocean Freshwater Budget

Reference Salinity = 34.4

Goldner (1999), *JGR*, 104, 29,757-29,770.

FLUX	Q (Sv)	Salinity (PSS)	Effective Freshwater Flux ($km^3\ yr^{-1}$)
River runoff	0.108	0.0	3400
Bering Strait inflow	0.81	32.5	1420
Net Precipitation (P-E)	0.012	0.0	380
Arctic Archipelago outflow	-1.37	33.2	-1460
Barents Sea inflow	1.49	35	-820
Fram Strait Outflow			
Ice	-0.07	3.5	-1980
EGC Polar Water	-1.16	33.9	-560
EGC Atlantic Water	-2.14	34.9	960
EGC Deep Water	-1.03	34.9	490
Subtotal	*-4.40*		*-1090*
Fram Strait Inflow			
WSC Atlantic Water	2.65	35.0	-1490
WSC Deep Water	0.73	34.9	-340
Subtotal	*3.38*		*-1830*
NET	0.0		0.0

T and S alone are not sufficient tracers of freshwater in upper Arctic Ocean

- Two major freshwater sources: Runoff and Ice-melt
- Temperature is “non-conservative”
  - -- heat gain/loss in open water areas
  - -- seasonal temperature variability of river runoff

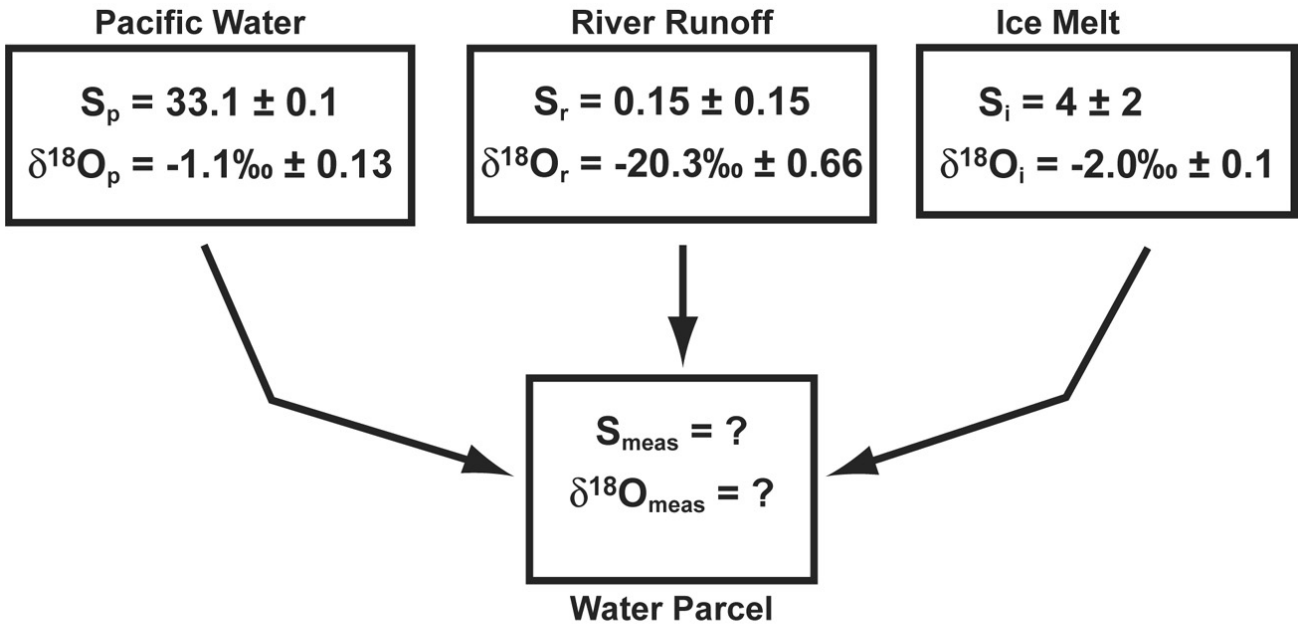
T and S alone are not sufficient tracers of freshwater in upper Arctic Ocean

- Two major freshwater sources: Runoff and Ice-melt
- Temperature is “non-conservative”
  - -- heat gain/loss in open water areas
  - -- seasonal temperature variability of river runoff
- Additional conservative tracer: Oxygen isotopes

$$\delta^{18}O\ (‰) = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}} \times 1000$$

Salinity-$\delta^{18}O$ Mass Balance for the Beaufort Sea

[Macdonald et al. (2002), *DSR I*, 49, 1769-1785]



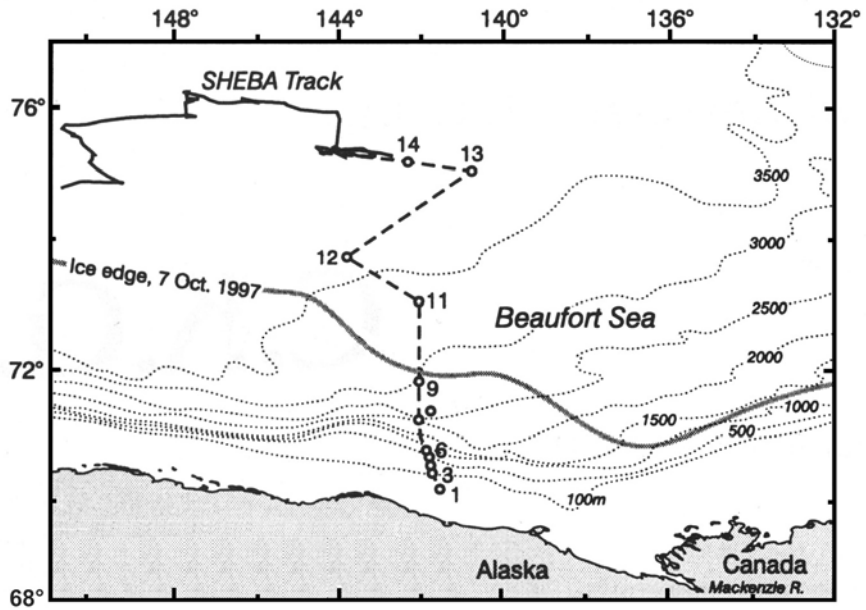
$$f_p + f_r + f_i = 1$$

$$f_p S_p + f_r S_r + f_i S_i = S_{meas}$$

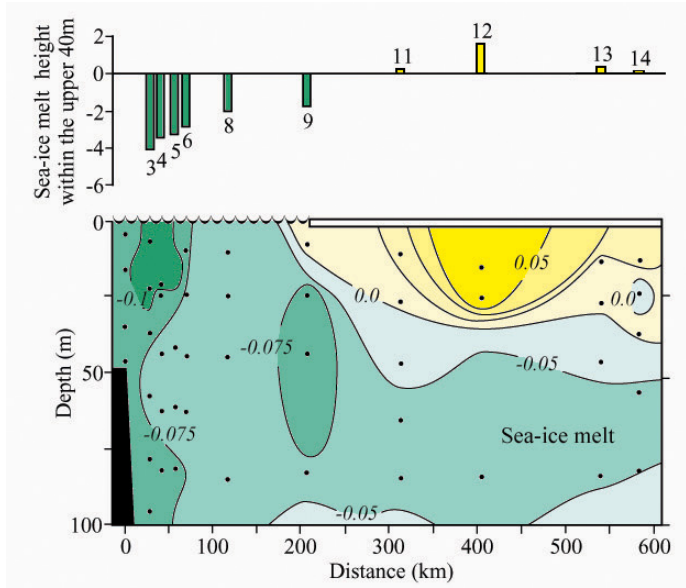
$$f_p(\delta^{18}O_p) + f_r(\delta^{18}O_r) + f_i(\delta^{18}O_i) = \delta^{18}O_{meas}$$

1997 Shelf-Basin Transect to Initial SHEBA Site

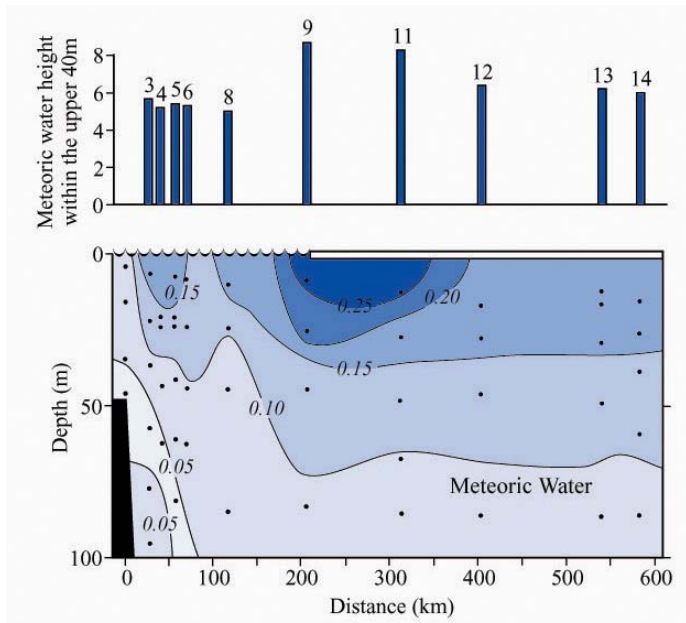
Macdonald et al. (2002)
***DSR I*, 49, 1769-1785.**



SEA ICE MELT

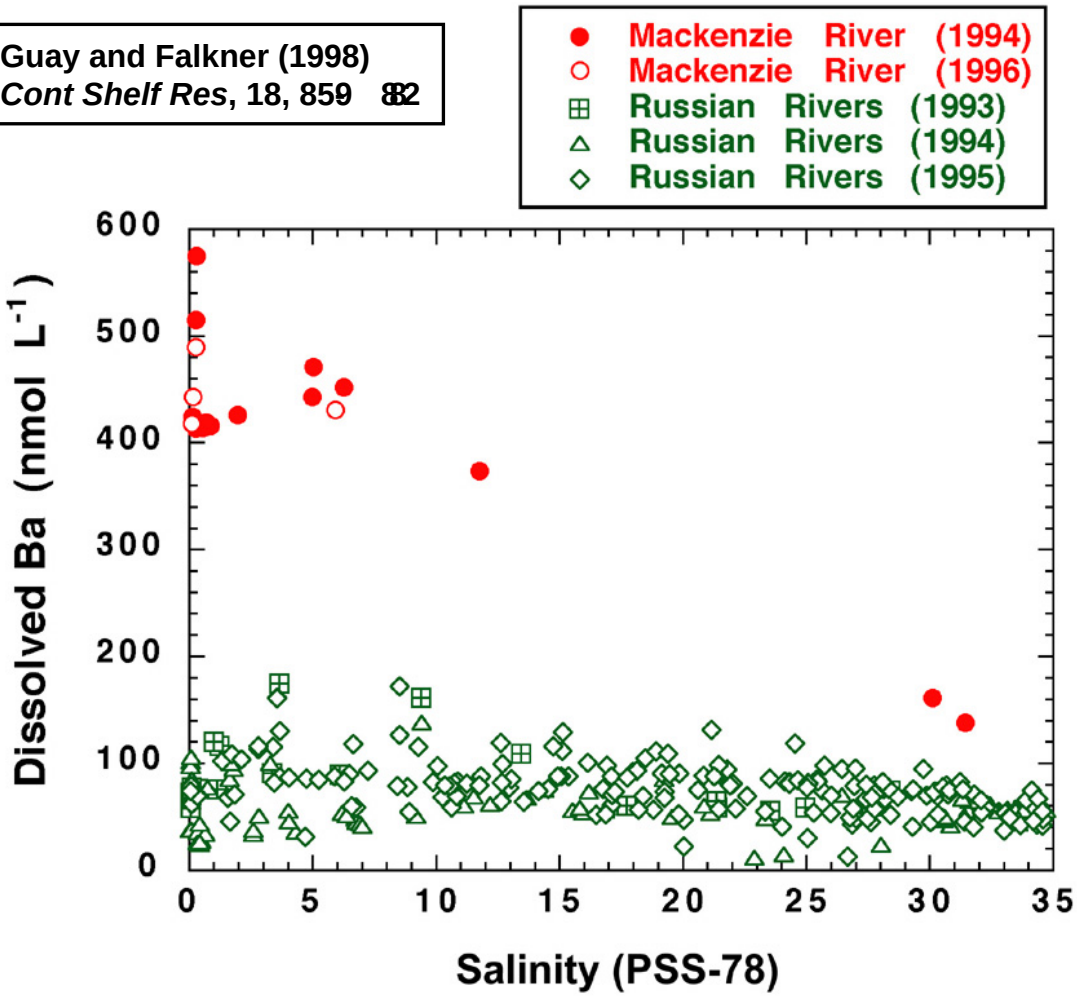


RUNOFF



Dissolved Barium in Major Arctic Rivers

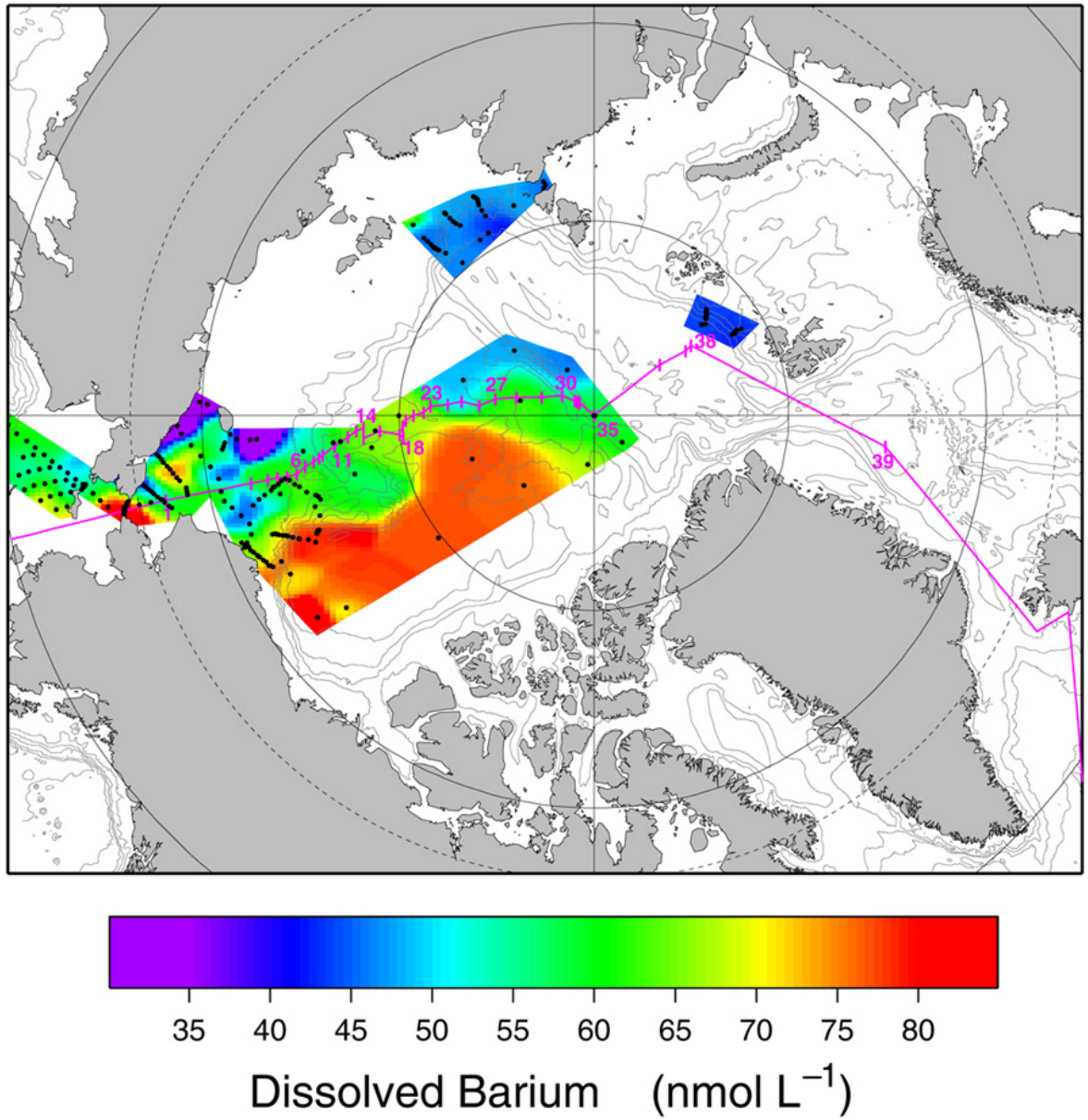
Guay and Falkner (1998)
Cont Shelf Res, 18, 859 882



End-Member Concentrations (nmol Ba L^{-1})	
Mackenzie River	520
Eurasian Rivers	90-150
Atlantic Inflow	42-45
Pacific Inflow	65-73

1993 Surface Mixed Layer

Composite from six cruises

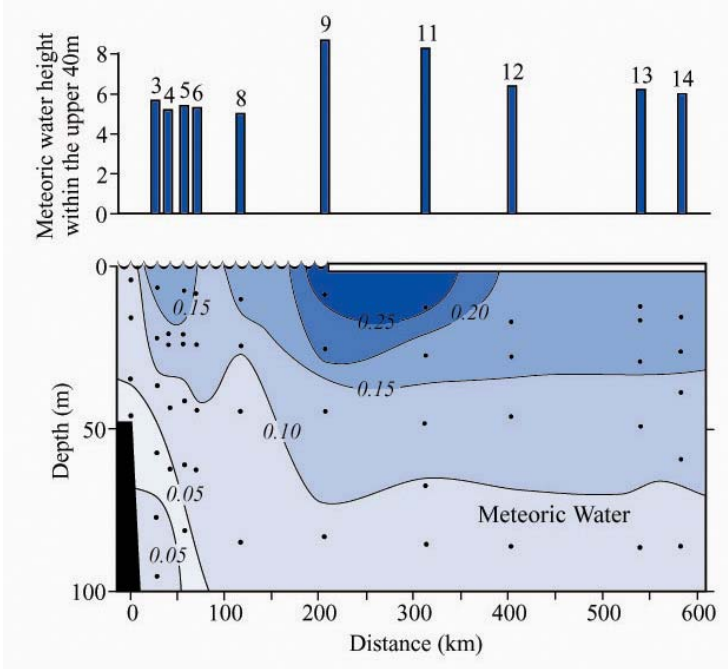


Guay and Falkner (1997)
DSR II, 44(8), 1543-1569.

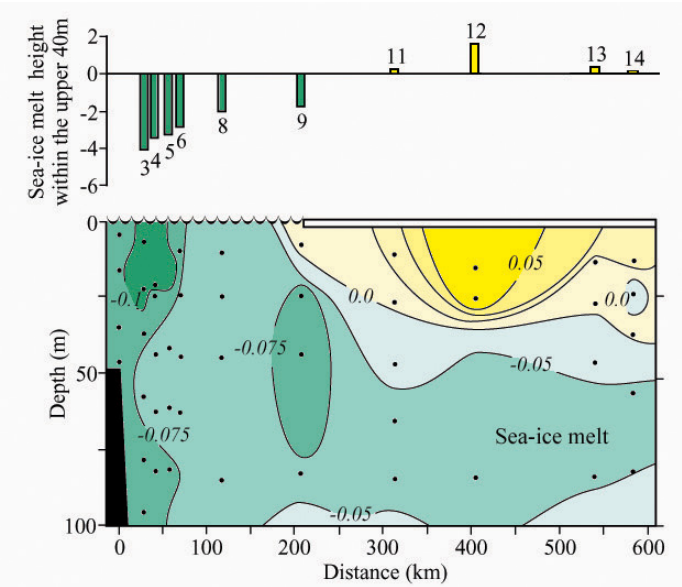
1997 Shelf-Basin Transect to Initial SHEBA Site

Macdonald et al. (1999)
***GRL*, 26(15), 2223-2226.**

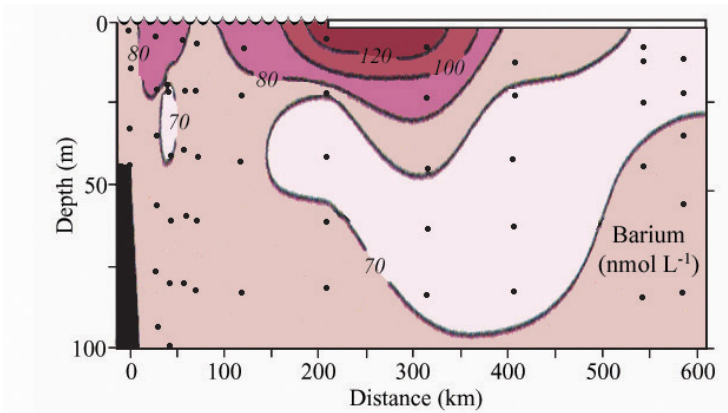
RUNOFF



SEA ICE MELT

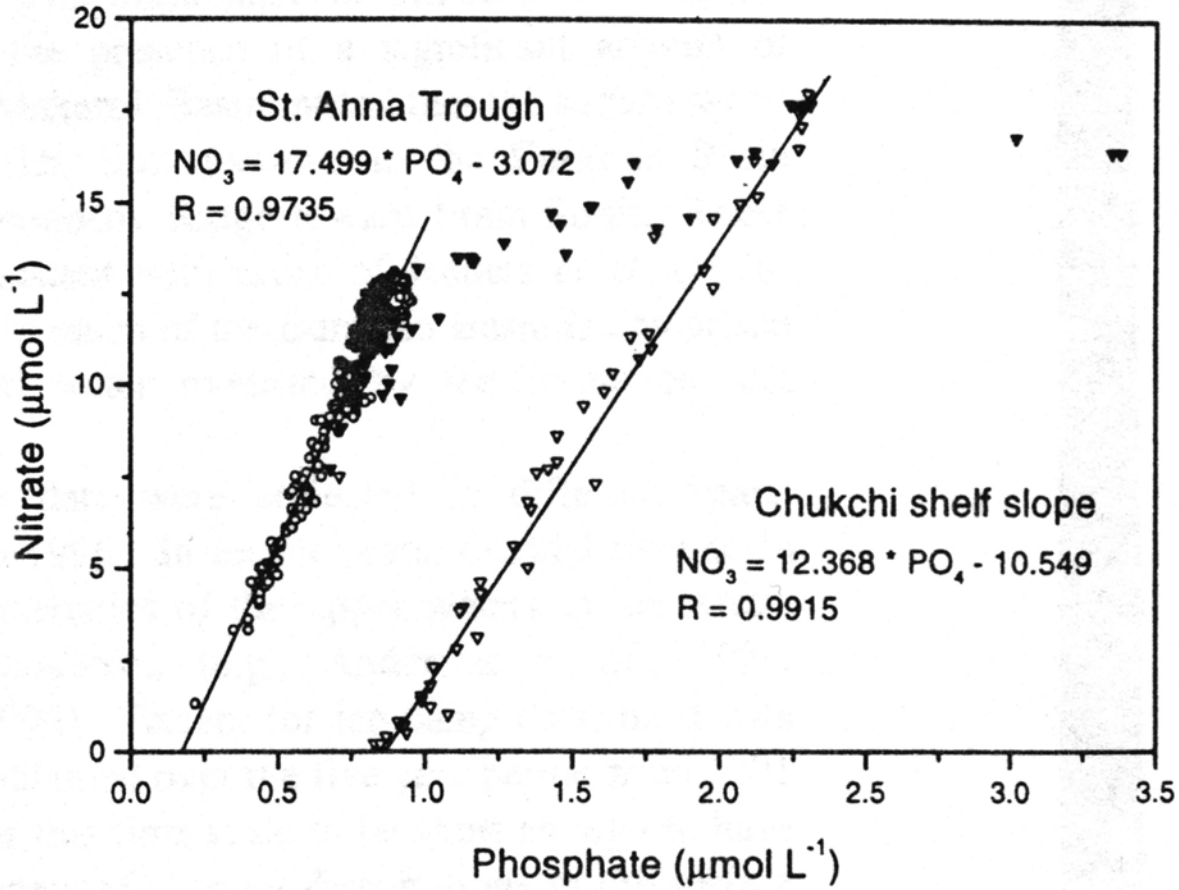


BARIUM



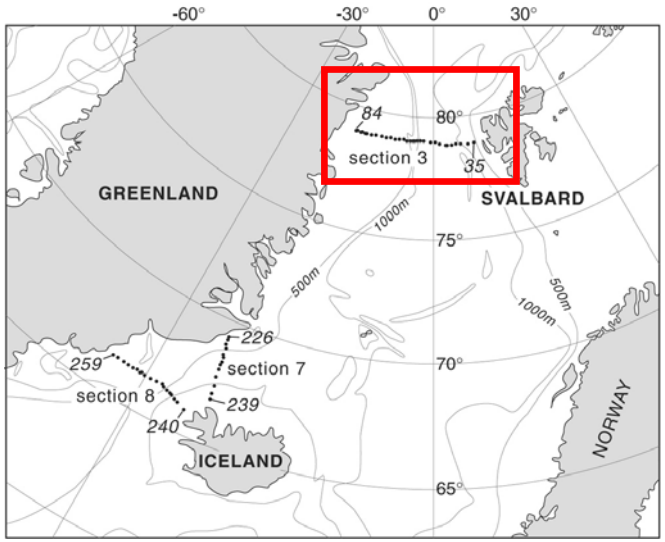
Using Nutrients to Differentiate Atlantic/Pacific Waters

Jones et al. (1998), *GRL*, 26(6), 765-768.

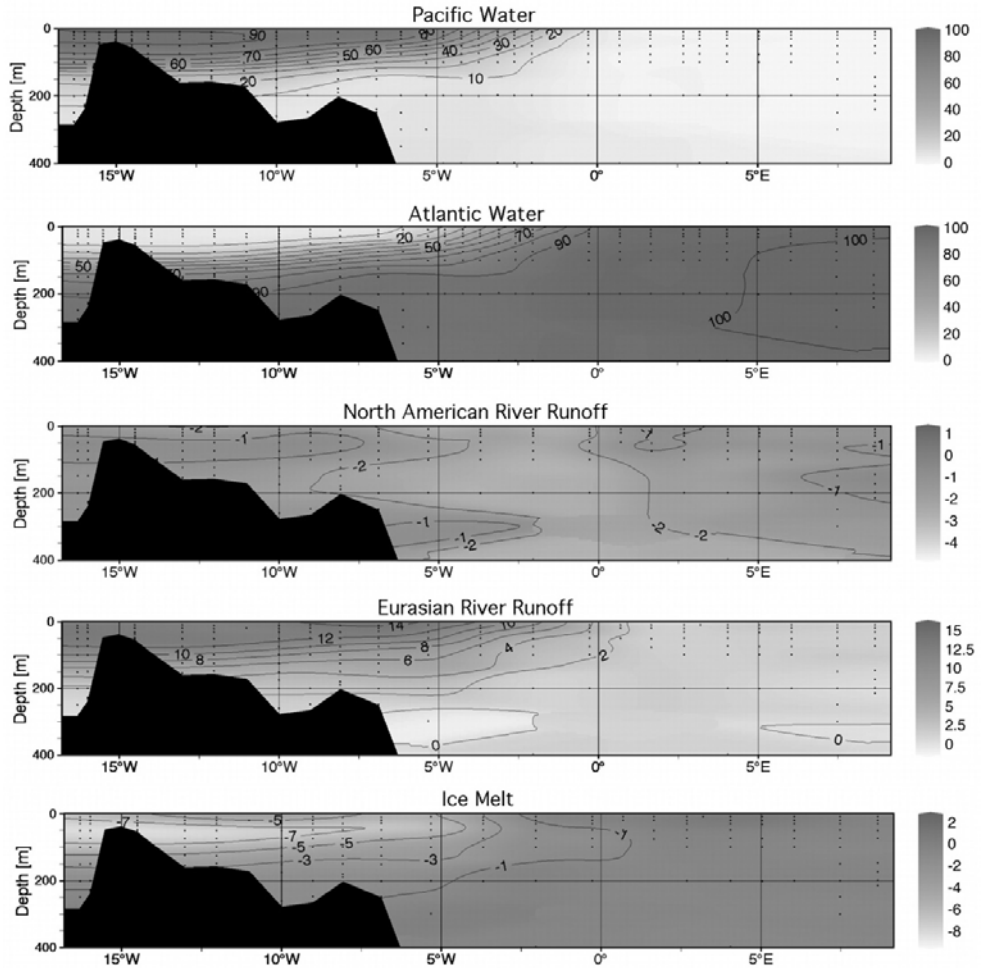


Water Mass Composition Derived From Multiple Tracers (S, $\delta^{18}O$, Ba, nutrients)

1998 ARKTIS-XIV/2



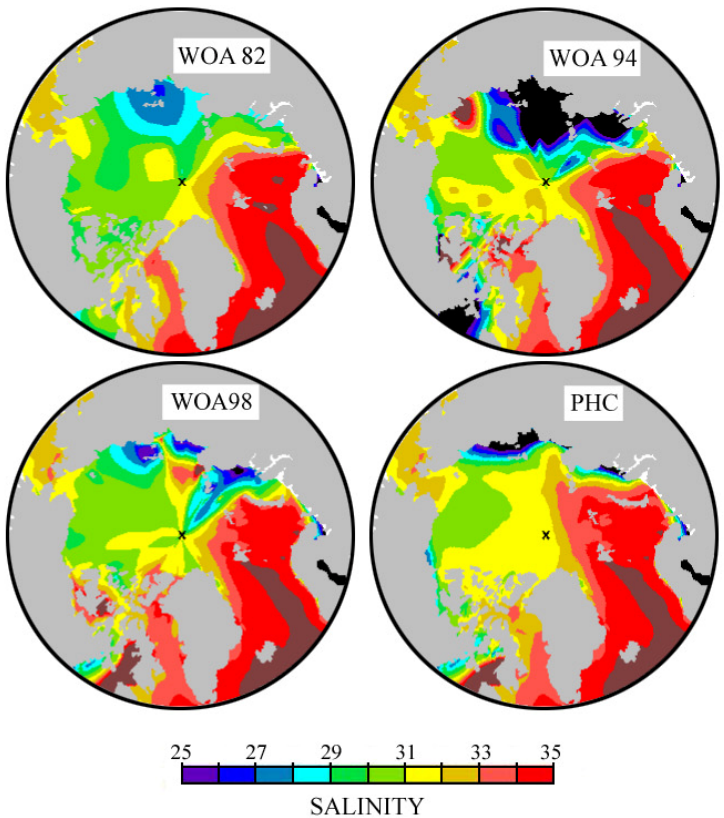
Taylor et al., *JGR* (in press).



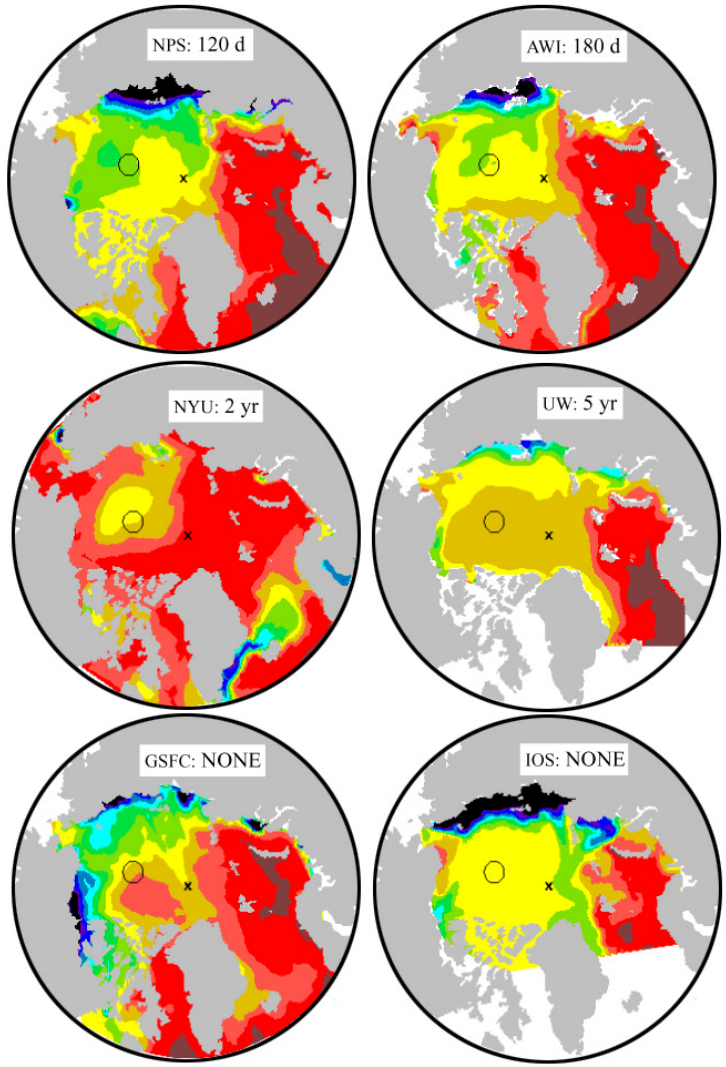
AOMIP April Mean Sea Surface Salinity

Steele et al. (2001)
***GRL*, 28, 2935-2938.**

CLIMATOLOGIES



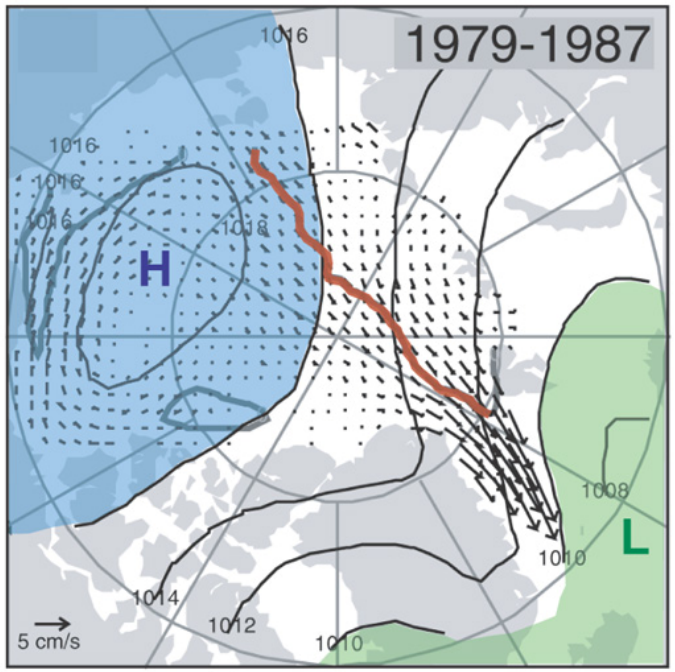
MODEL RESULTS

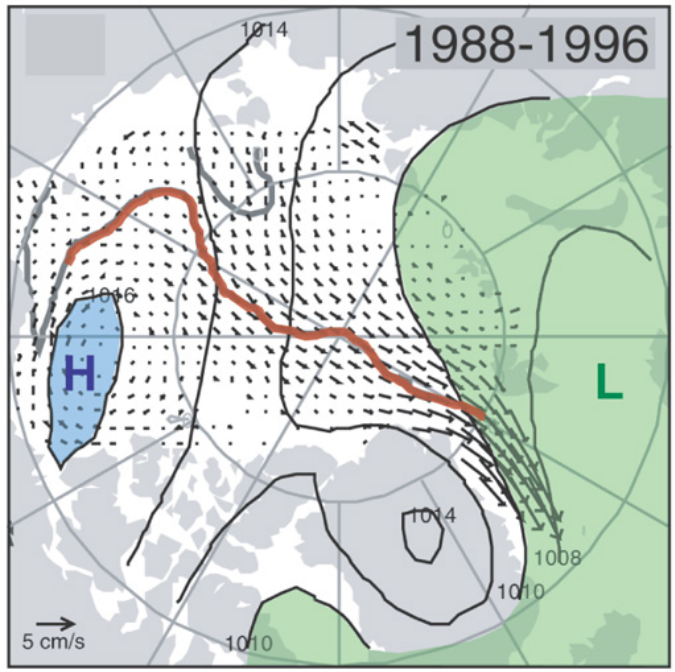


Response to Shift in Atmospheric Forcing

Steele and Boyd (1998), *JGR*, 103, 10,419-10435.

Figure: I. Rigor (UW/IABP)





Negative AO Index

- Weak polar vortex/high SLP
- Anti-cyclonic ocean circulation
- Eurasian runoff enters at Lomonosov Ridge
- Cold halocline formation in Eurasian Basin

Positive AO Index

- Strong polar vortex/low SLP
- Cyclonic ocean circulation
- Eurasian runoff enters at Mendeleyev Ridge
- Cold halocline retreat from Eurasian Basin

Scientific Questions

Freshwater cycle

- river runoff
- halocline formation
- ice formation/melting

Arctic Ocean inflows/outflows

- export through Canadian Archipelago

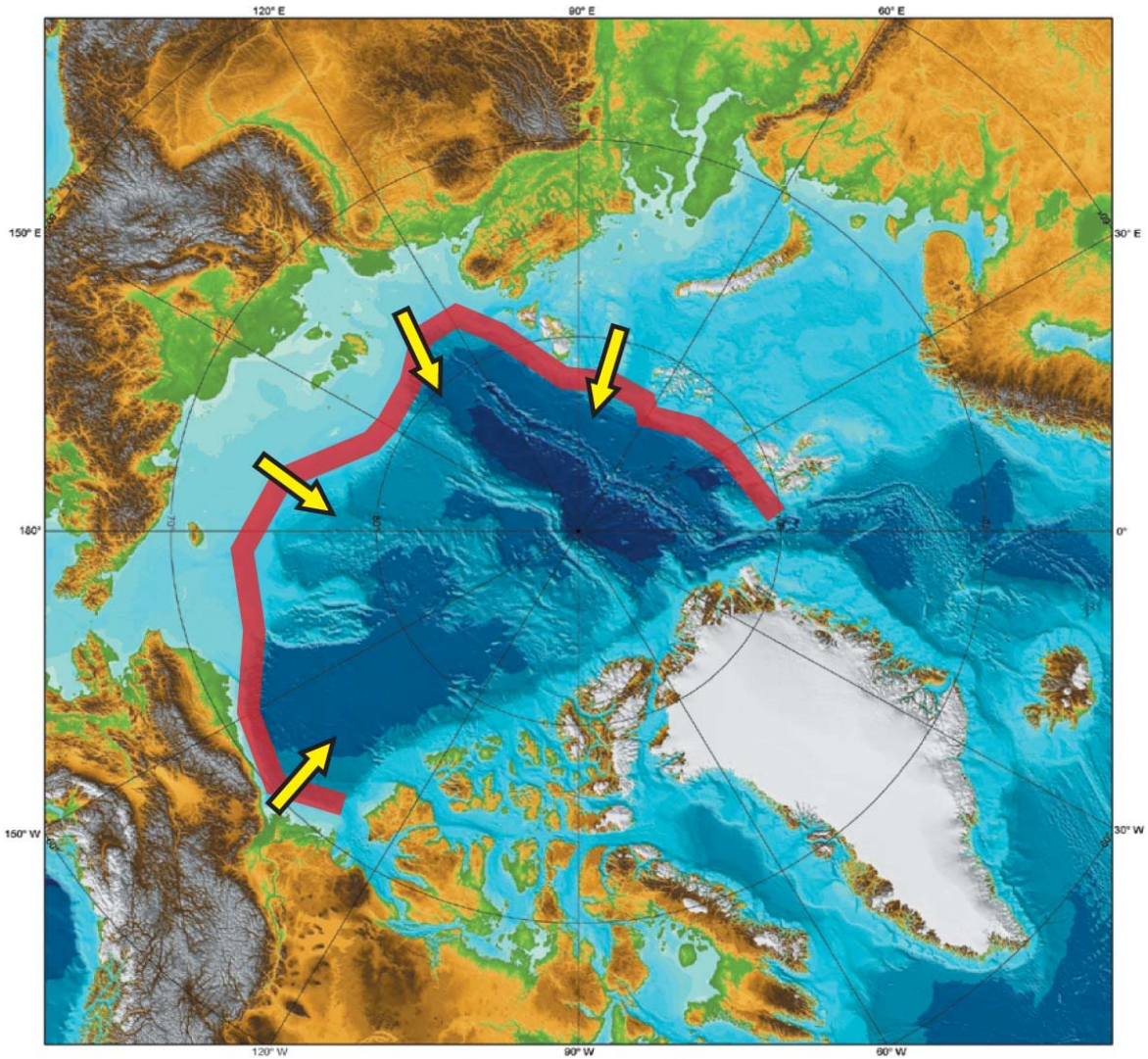
Long-term trends (relation to global climate change?)

- changes in circulation regime
- changes in terrestrial environment/signals
- changes in biota/ecosystem
- changes in carbon cycling

Required Geochemical Measurements

1. Circulation tracers
   - -- nutrients (N, P, Si, O_2)
   - -- stable isotopes (d18O, d13C, d15N, etc.)
   - -- trace metals (Ba, etc.)
   - -- radioisotopes (^{137}Cs, ^{128}I)
   - -- DOC, biomarkers
   - -- inorganic C: alkalinity, ΣCO_2, DIC
2. Water mass age tracers
   - -- He-tritium, CFCs
3. Particulate flux tracers
   - -- U, Th, POC, PON

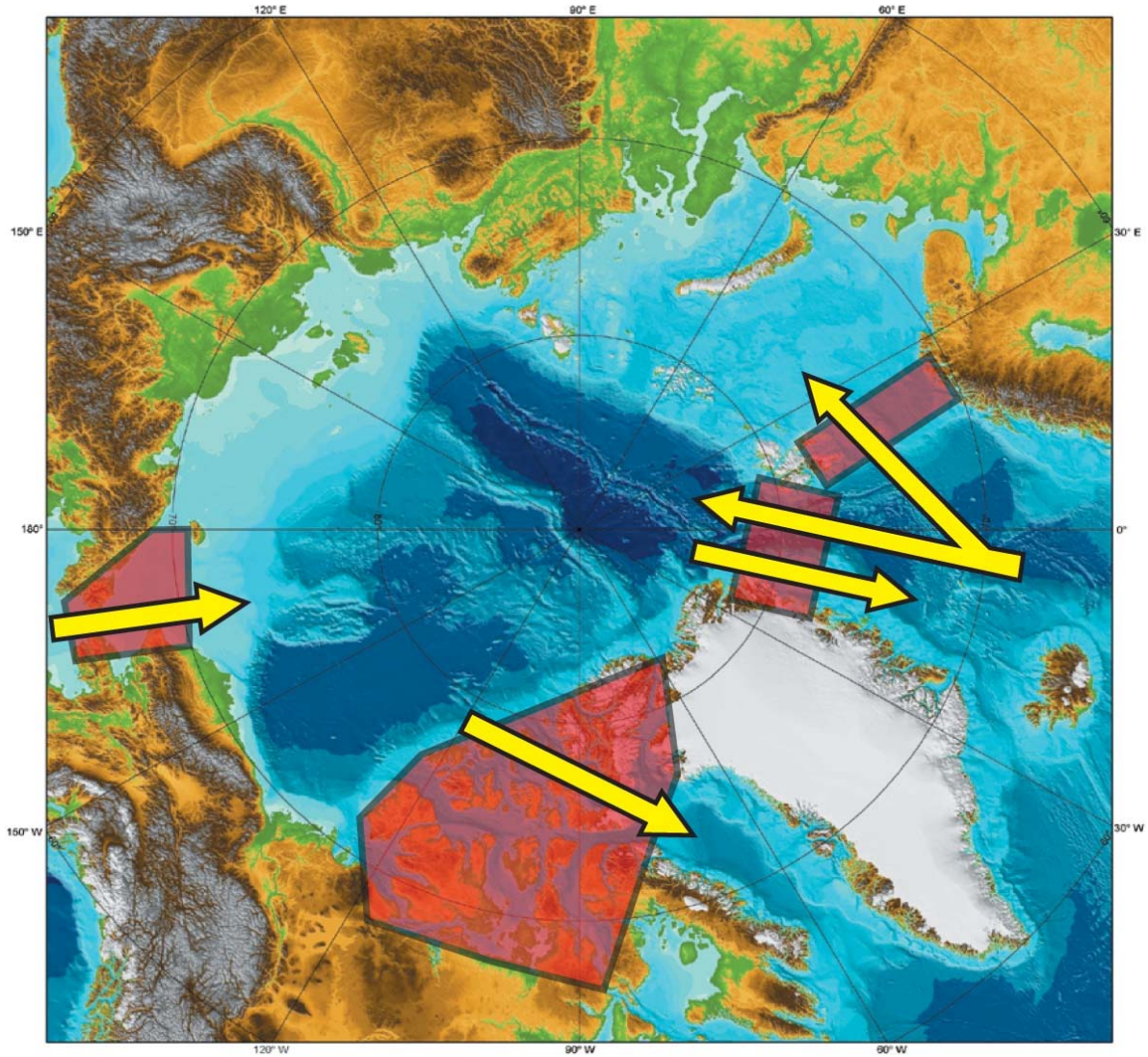
Critical Areas



Shelf Break

- shelf-basin exchanges
- river water pathways

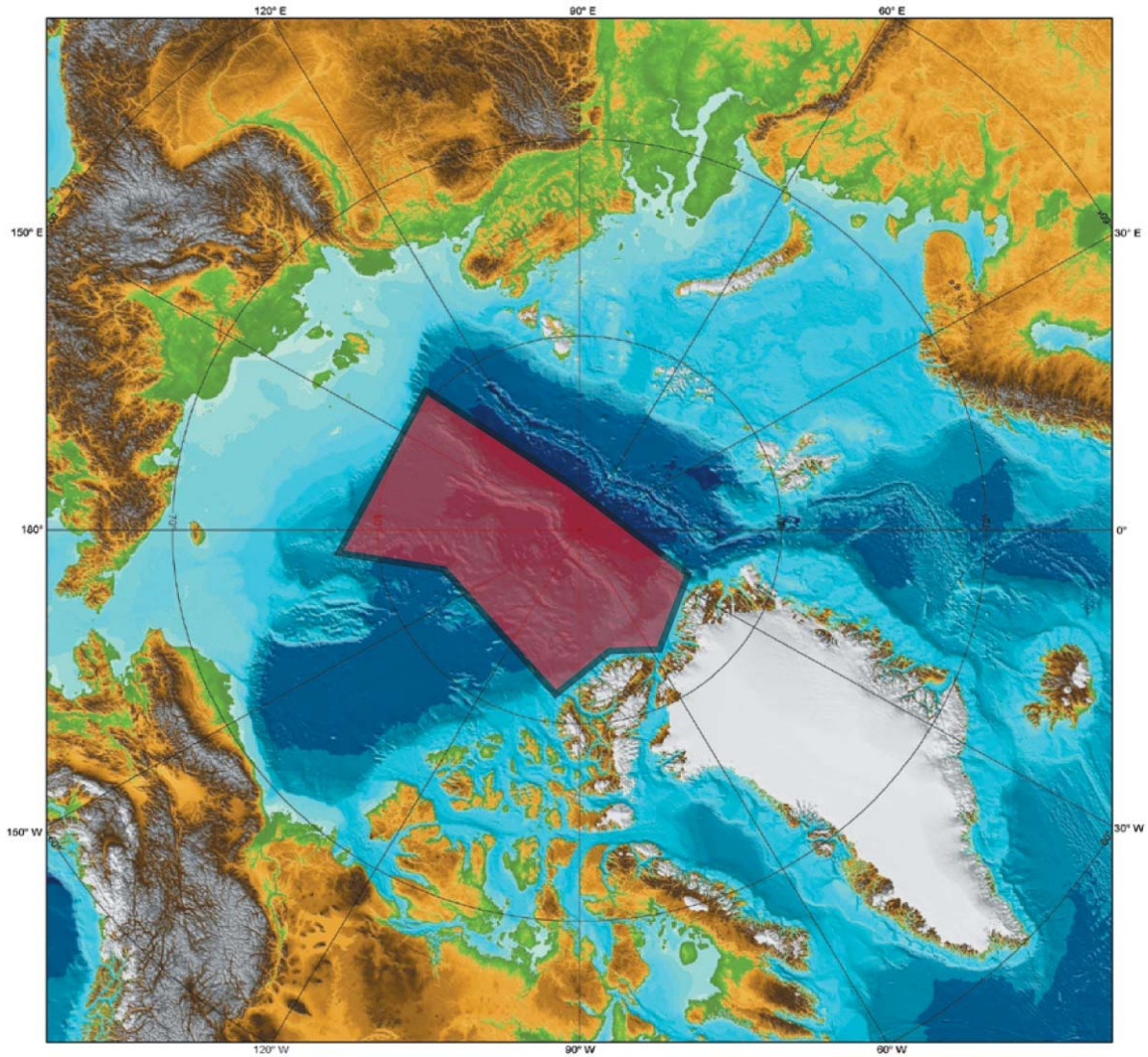
Critical Areas



Inflows/Outflows

- communication with global ocean
- export to North Atlantic areas of deep water formation
- export through Canadian Archipelago

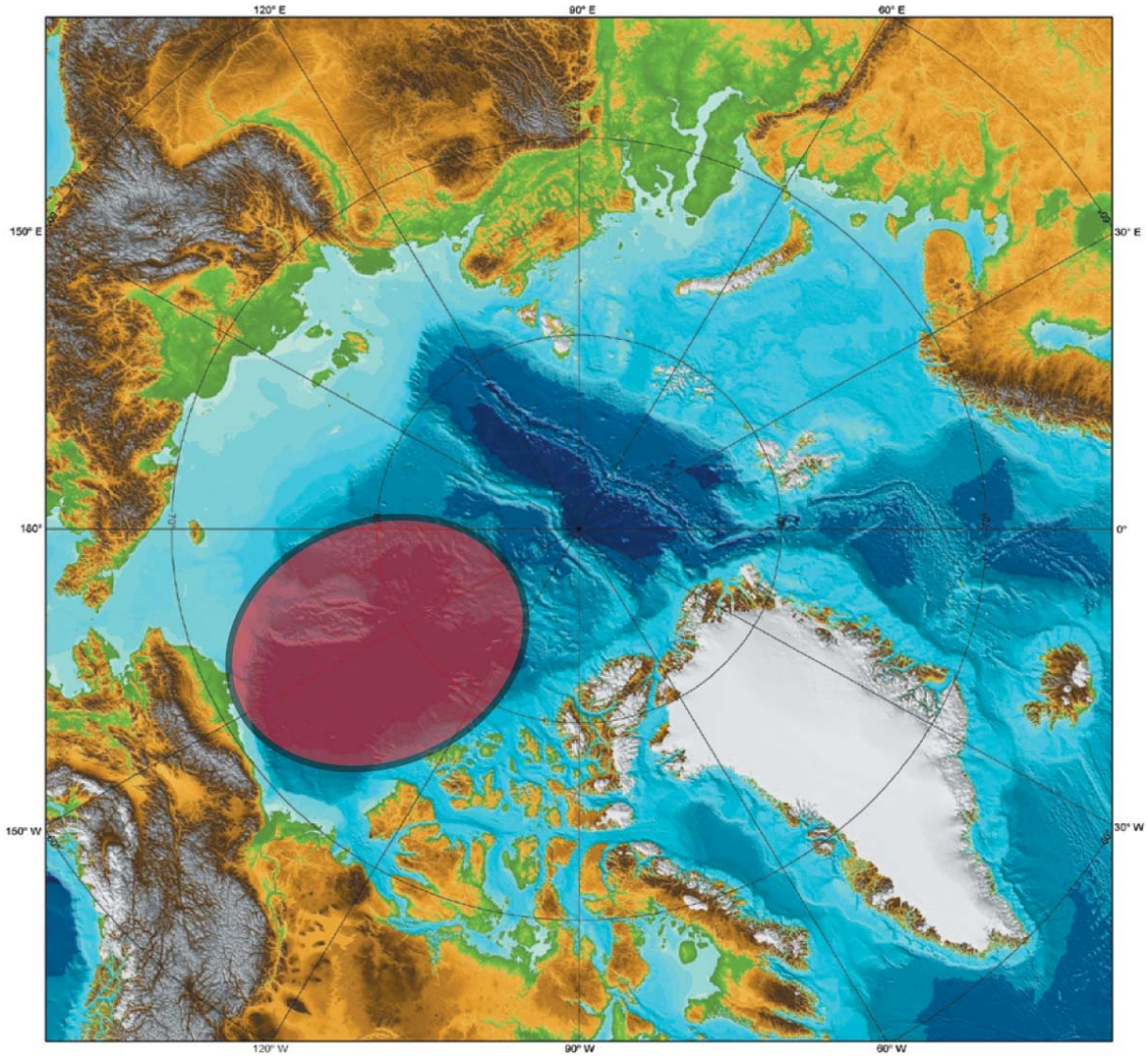
Critical Areas



Atlantic/Pacific Front

- boundary between Atlantic/Pacific, Eurasian/North American water mass assemblages
- Transpolar Drift
- area north of Greenland and Archipleago

Critical Areas



Beaufort Gyre

- expands/contracts with changes in circulation regime
- storage/release of freshwater

FUTURE DATA SETS NEEDED

- **Long-term time series**
- **High-resolution (temporal and spatial) observations**

Need for autonomous, *in situ* sensors

-- optical

-- chemical (MEMS/nanotechnology)