Using nutrients as tracers:

Tracing Pacific water entering the Polar Ocean through the Bering Strait using N/P ratio signatures

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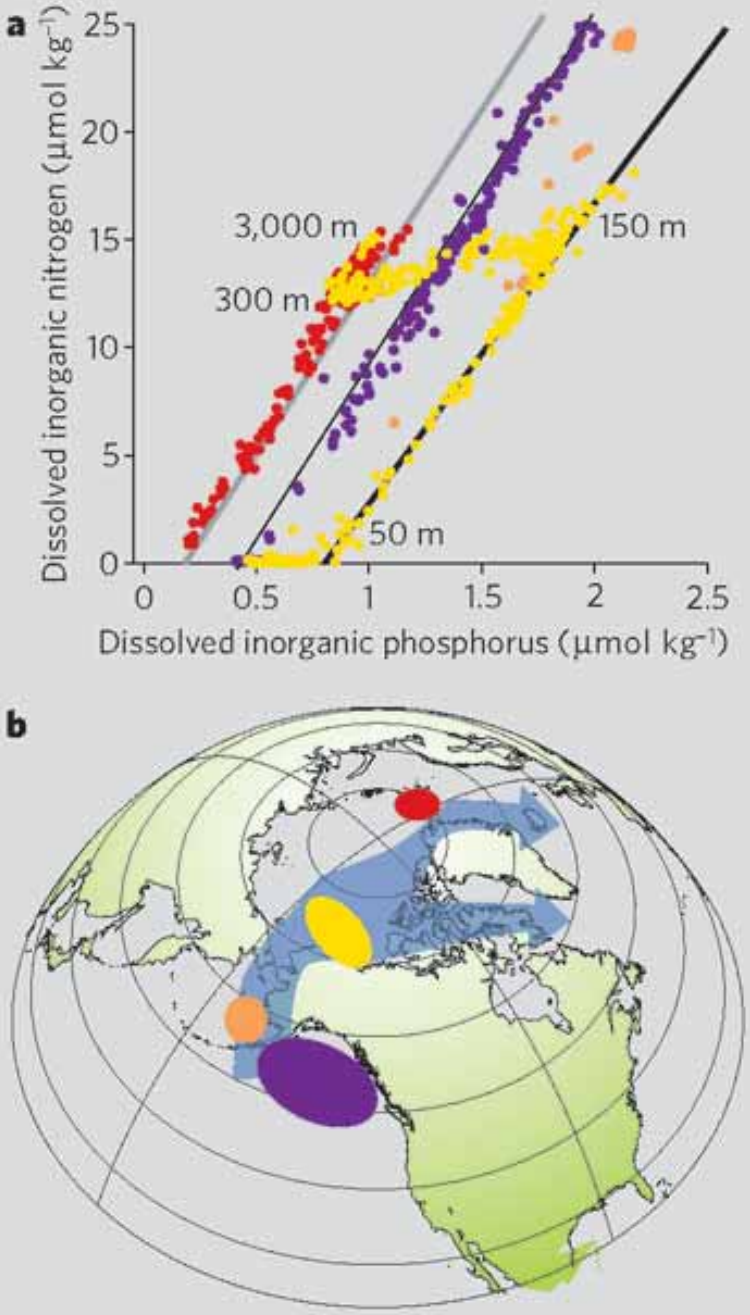
Outline

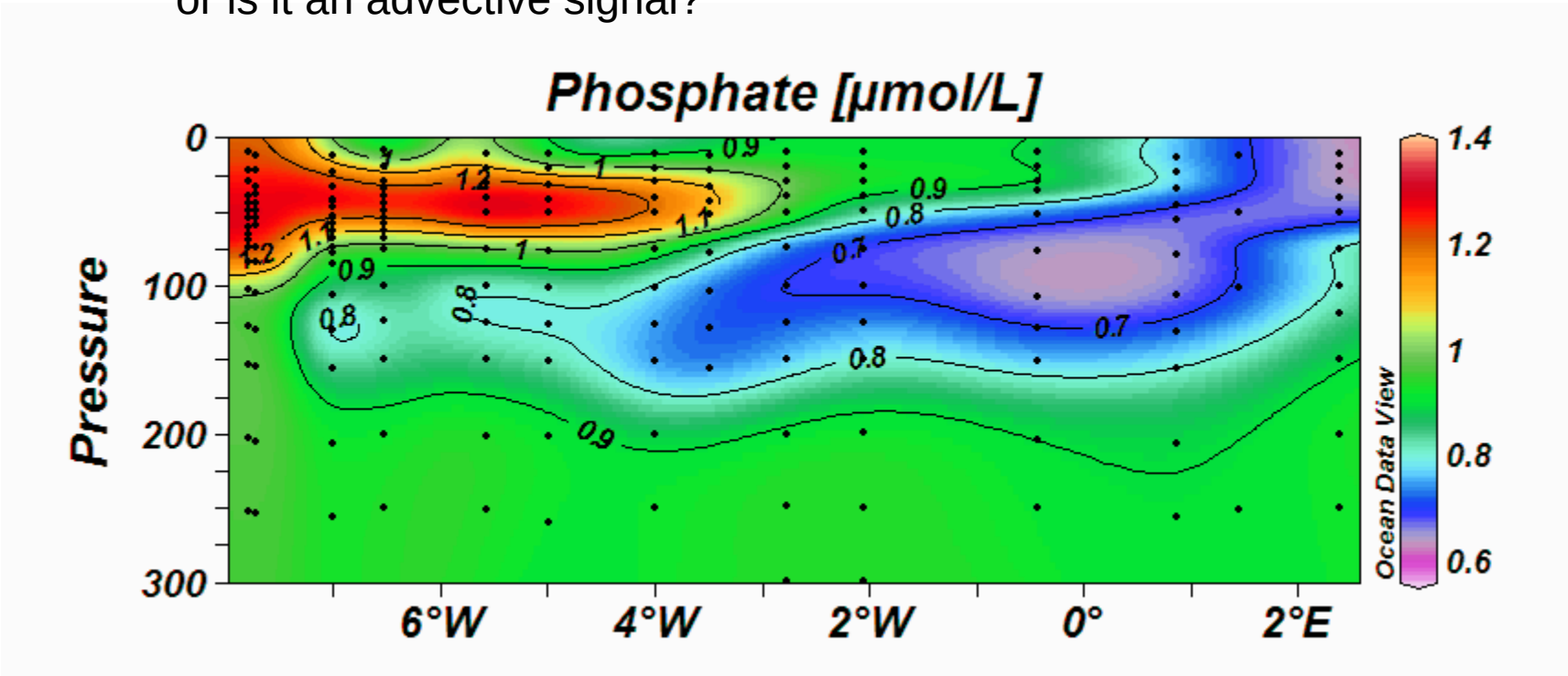
- Nutrient concentrations provide a valuable tool to trace water masses.
- A very good example is waters of Pacific origin entering the Atlantic Ocean.
- Water of Pacific origin, entering the Arctic Ocean through the Bering Strait, can exit the Arctic Ocean through the Canadian Archipelago and the Fram Strait.
- Although the Pacific Water is originally less saline than the Atlantic Water, it is not easy to separate them by the use of salinity and temperature, but the relationship between nitrate and phosphate is an excellent tool to distinguish between waters of Pacific and Atlantic origin.
- The Polar Water, which exits the Arctic through the Fram Strait, actually consists of several distinct water masses, which might be of either Pacific or Atlantic origin.
- Nutrient and hydrographic data from different cruises to the area north and east of Greenland during the last two decades show that substantial changes have occurred lately in the amount of waters of Pacific origin delivered to the Fram Strait and hence further to the Atlantic Ocean.



Relationship between dissolved inorganic nitrogen and dissolved inorganic phosphorus in waters in regions identified by colour on the map in **b**. Data are from the World Ocean Database 01 (red and purple), and from JAMSTEC (*RV Mirai* expeditions in 2000 and 2002; orange and yellow, respectively). The grey, thin black and thick black lines are regression lines for the uppermost 150 metres of the global ocean[2], northeastern Pacific waters and Canada Basin, respectively. Dissolved inorganic nitrogen comprises nitrates, nitrites and ammonium for the *Mirai* data set, and nitrates for the other data sets. Numbers indicate approximate depths in the Canada Basin. *Mirai* data were provided by T. Takizawa, K. Shimada, A. Murata and S. Nishino. **b**, Map showing the pathway followed by waters of Pacific origin into the North Atlantic[5, 6] (blue arrows). Colours show areas from which data plotted in a originate.

Nutrient concentrations provide a valuable tool to trace water masses.

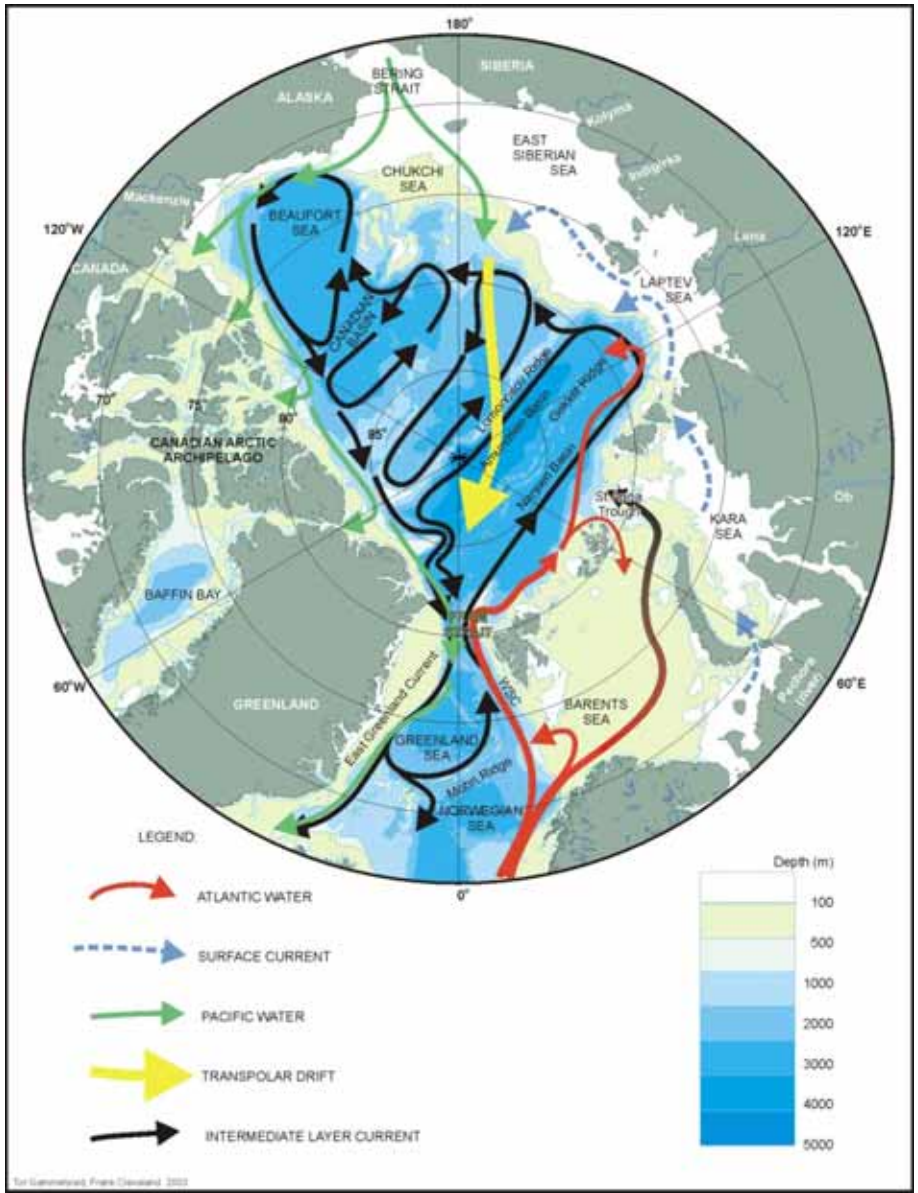
Can this distribution be explained by local biological processes or is it an advective signal?



Northern Fram Strait, 81ºN

A good example is waters of Pacific origin entering the Atlantic Ocean.

Generally all the Water leaving through the Canadian Archipelago is of Pacific origin (mixed with river runoff and sea ice melt water).

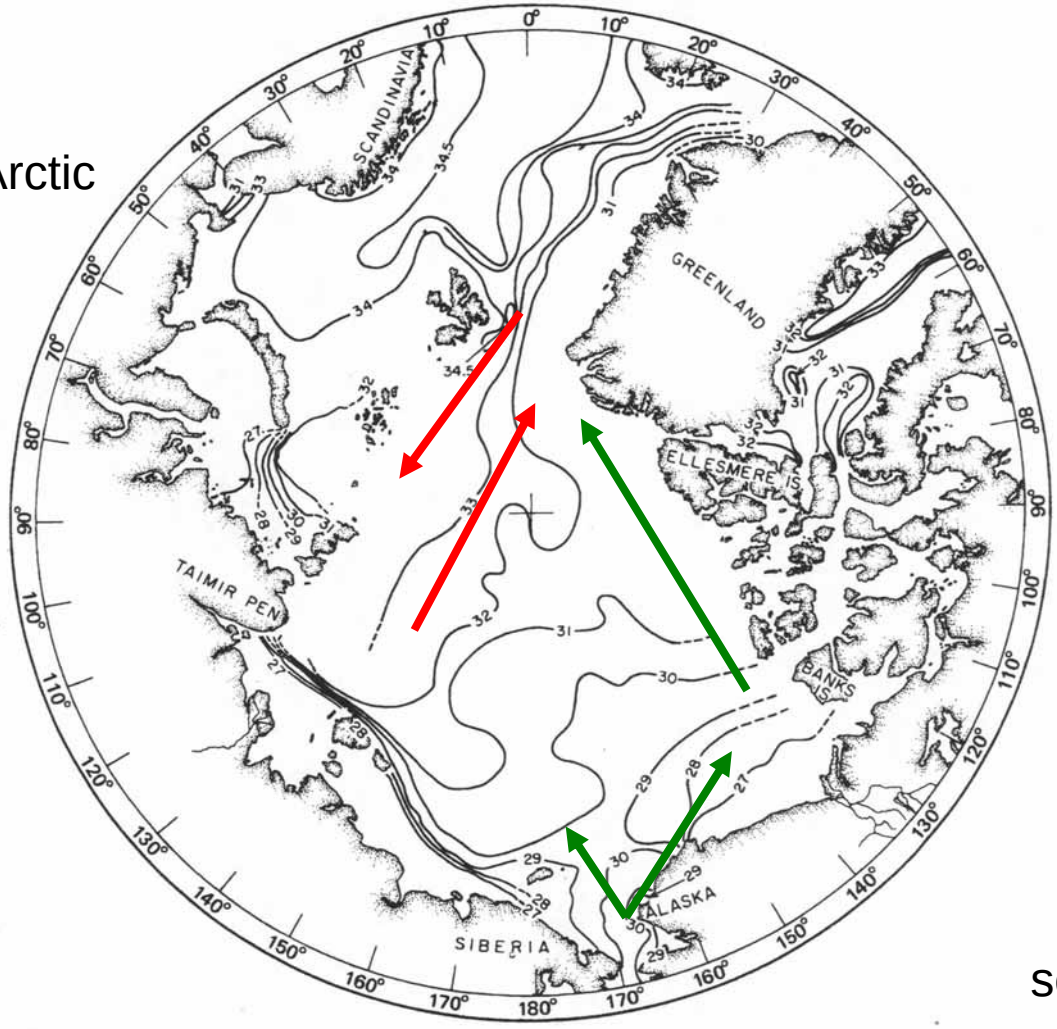


In my work I have looked at the water masses leaving the Arctic Ocean through the Fram Strait.

Without nutrient measurements it would have been impossible to get a detailed picture of the contributions of the different water masses contained in what is known as Polar Water.

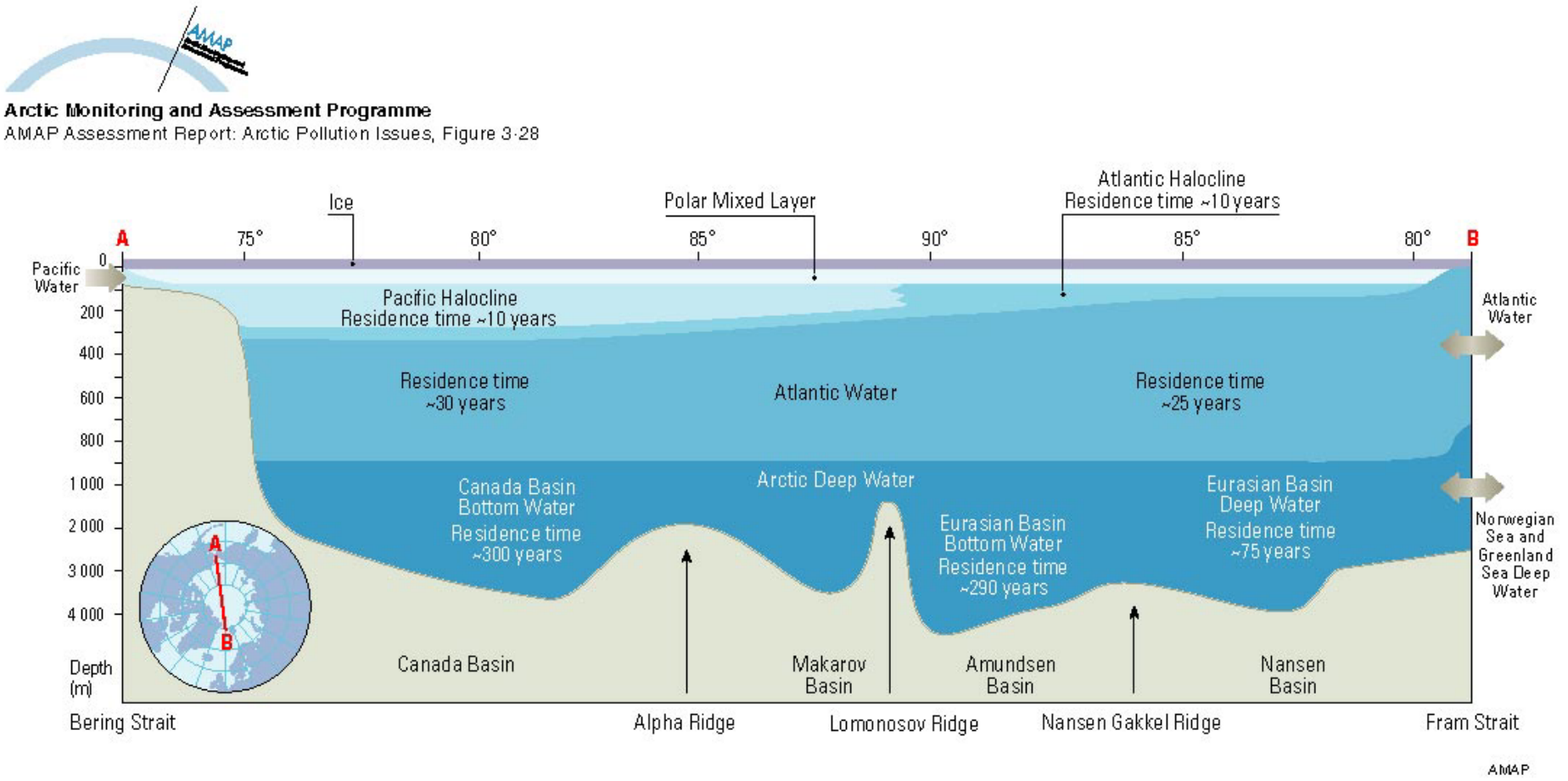
Although the Pacific Water is originally less saline than the Atlantic Water, it is not easy to separate them by the use of salinity and temperature,

Much of the Atlantic Water entering the Arctic Ocean through the Fram Strait and Barents Sea submerges and flows as an intermediate layer while the inflow of Pacific Water is contained in the Surface layer.



But one has to remember that the surface layer in the Eurasian Basin is in reality a mixture of Atlantic Water, river runoff, and sea ice melt water.

Variation of surface salinities (Wadhams, 2000)



We see that the surface layer (0 – 200-300m) of the Arctic Ocean consists of water of either Pacific or Atlantic origin (or a mixture of these)

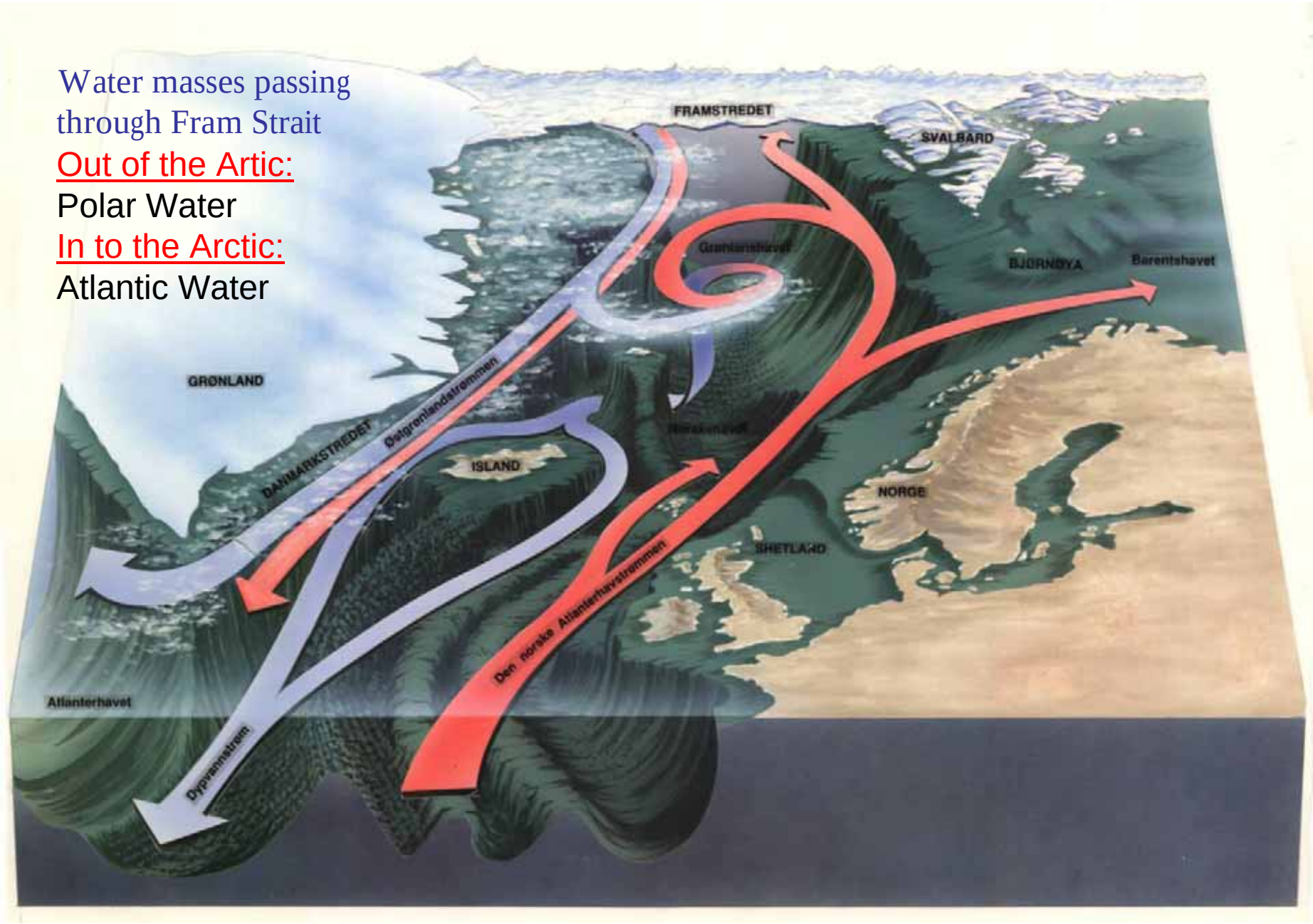
Water masses passing through Fram Strait

Out of the Artic:

Polar Water

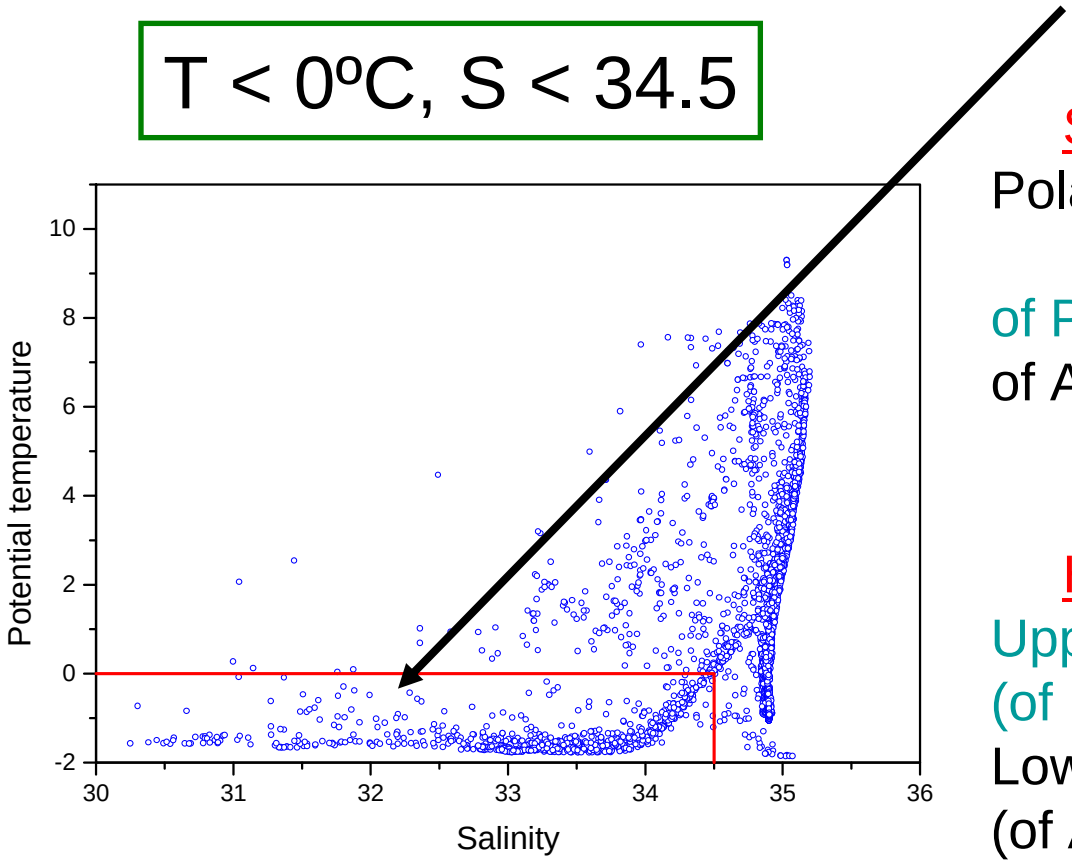
In to the Arctic:

Atlantic Water



A closer look at the Polar Water

$T < 0^{o}C$, $S < 34.5$



Surface waters

Polar Surface Water (PSW)

of Pacific origin

of Atlantic origin

Halocline waters

Upper Halocline Water (UHW)

(of Pacific origin)

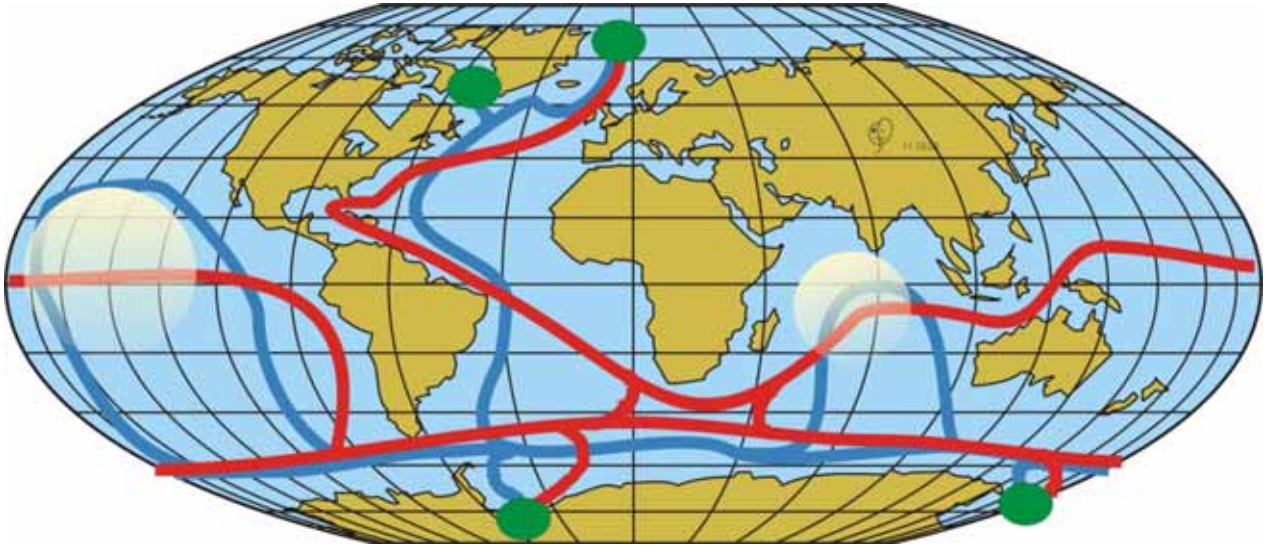
Lower Halocline Water (LHW)

(of Atlantic origin)

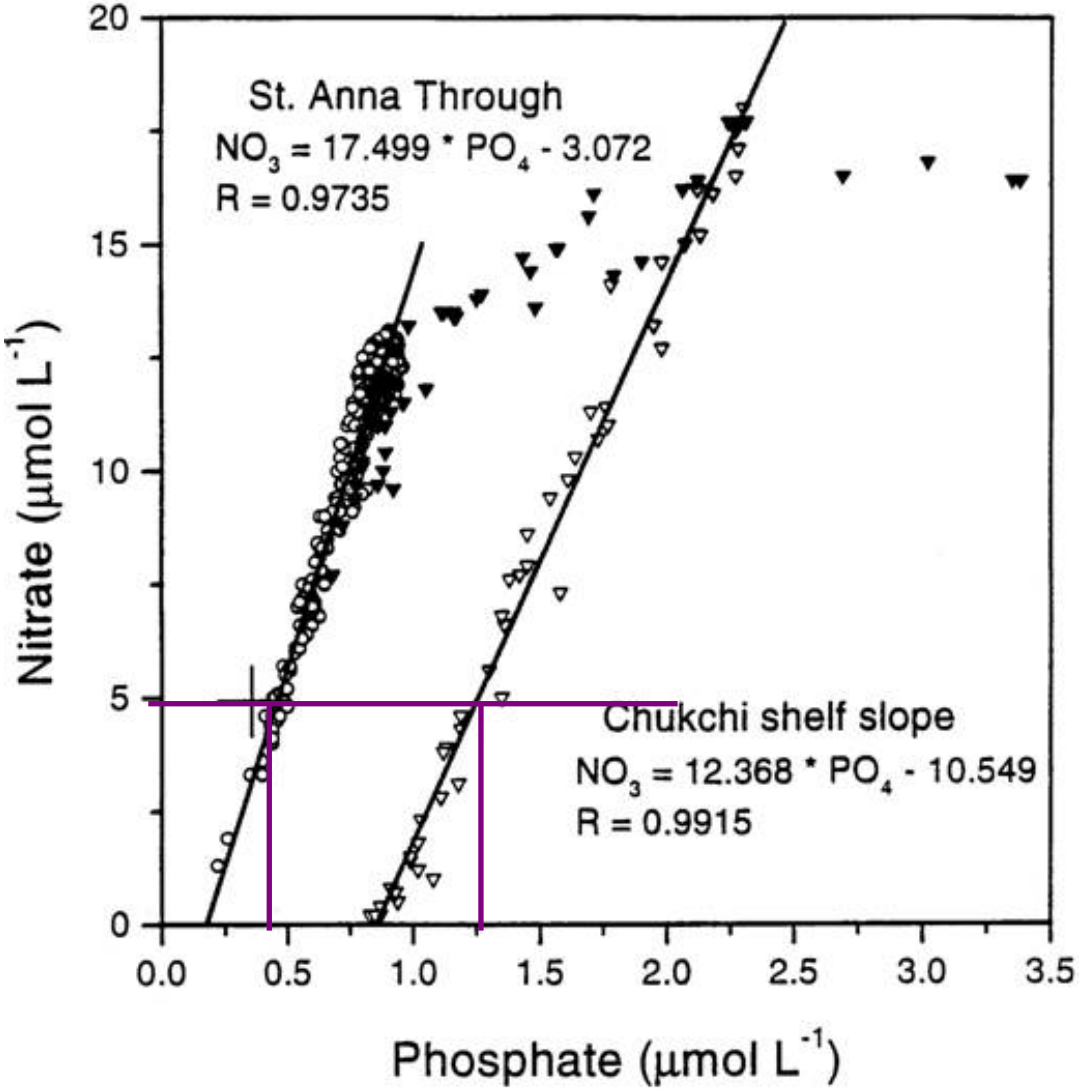
A typical TS-diagram from the Greenland Sea

but the relationship between nitrate and phosphate is an excellent tool to distinguish between waters of Pacific and Atlantic origin.

- Waters from the northern Pacific Ocean have much higher nutrient concentrations than waters from northern Atlantic Ocean.



- Waters from the northern Pacific exhibits a deficit in nitrate (NO_3) relative to phosphate due to denitrification in low oxygen waters.

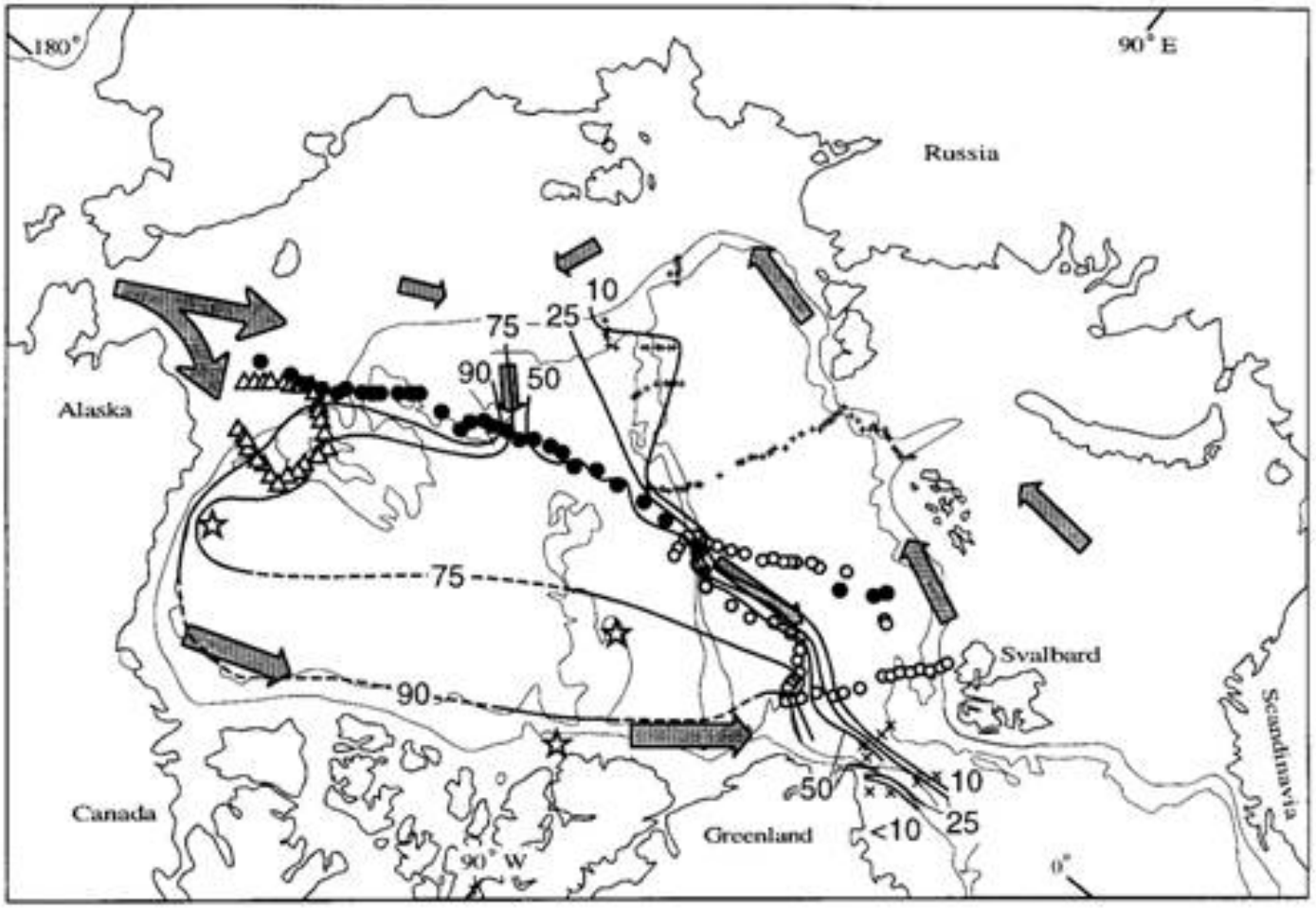


+ assumed concentrations of river and sea ice melt water

Jones et al. 1998

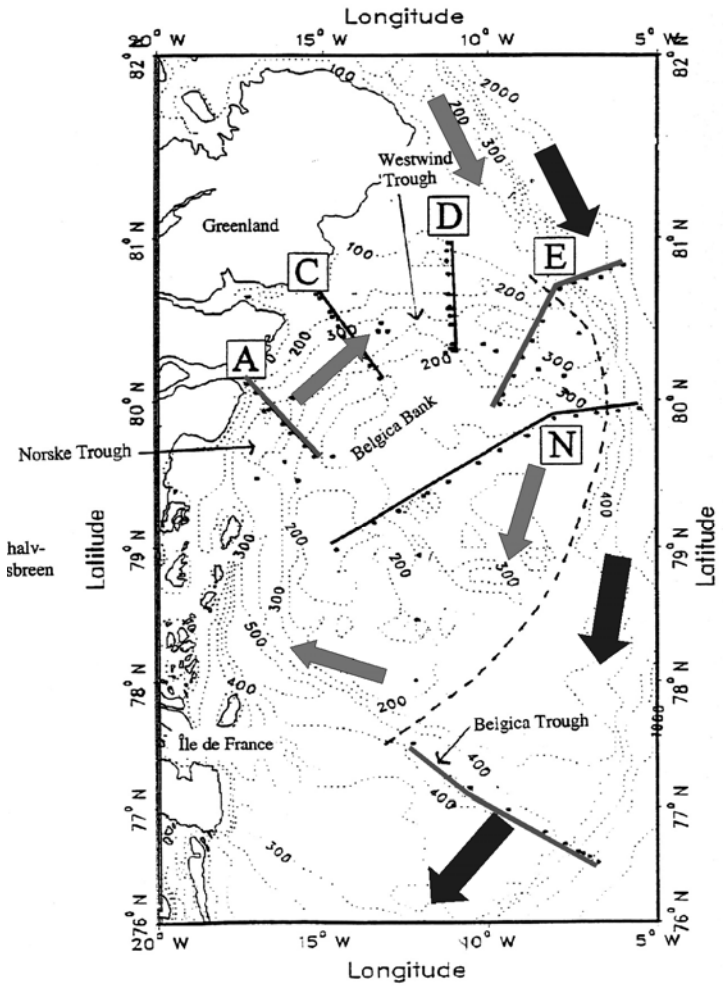
Distribution of Atlantic and Pacific waters in the upper Arctic Ocean: Implications for circulation

(Jones et al., Geophys. Res. Lett., 1998)

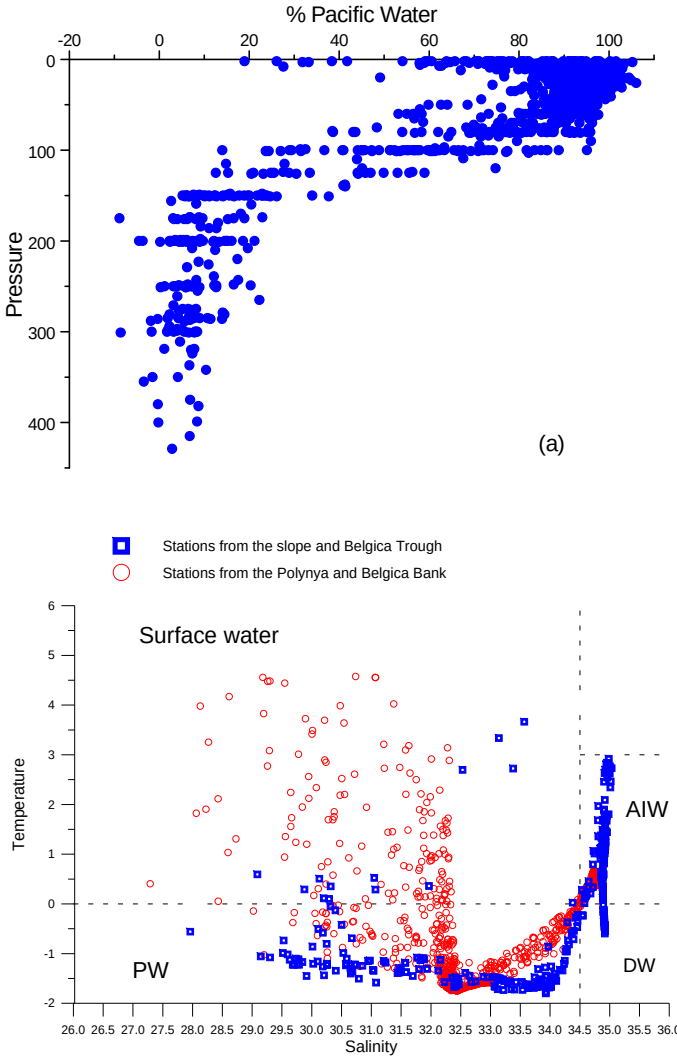


Suspect: A significant amount of Pacific water must exit the Fram Strait

Contribution of waters of Atlantic and Pacific origin in the Northeast Water Polynya (Falck, Polar Res. 2001)

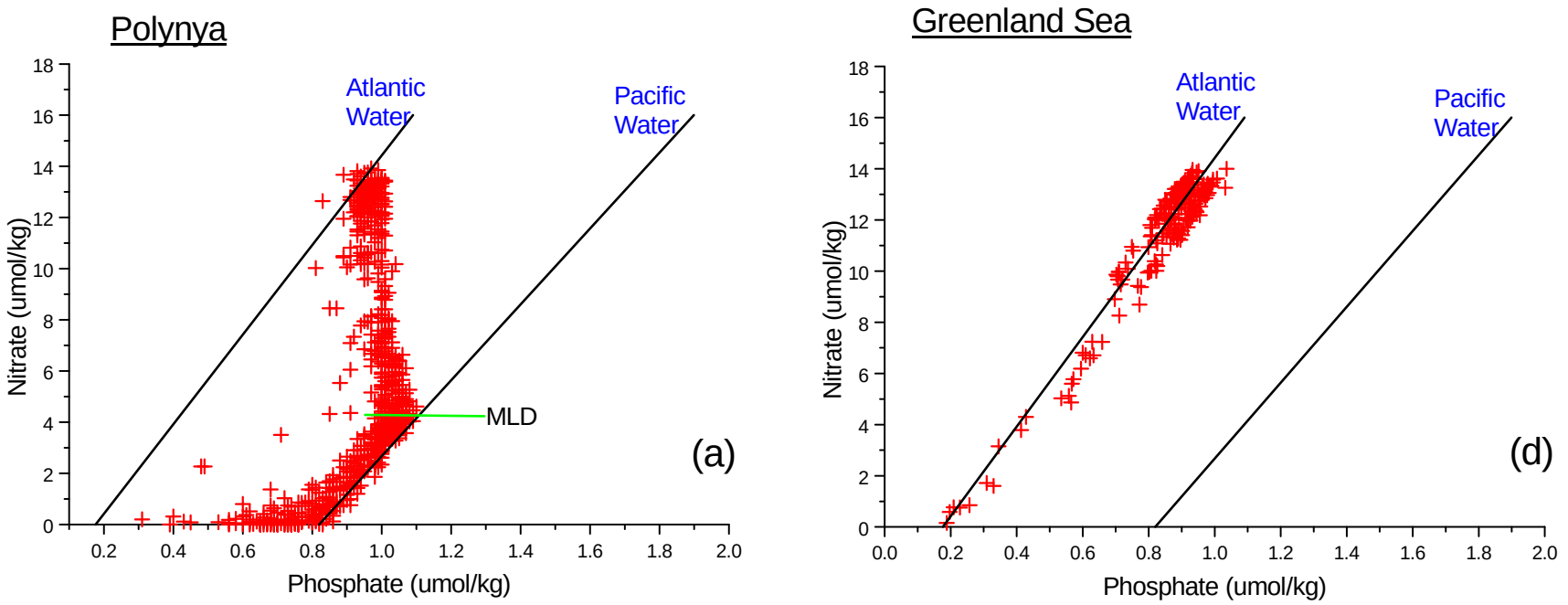


data collected between 22 of July and 17 of August 1993 on board the United States Coast Guard Cutter *Polar Sea*



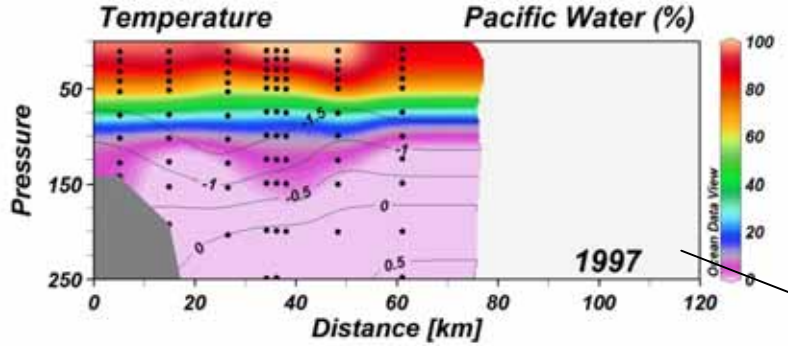
$NO_3^{AW} = 17.499 \times PO_4 - 3.072$

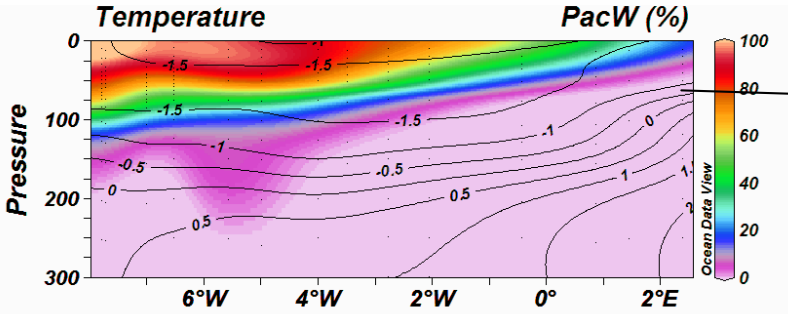
$NO_3^{PW} = 14.828 \times PO_4 - 12.6$

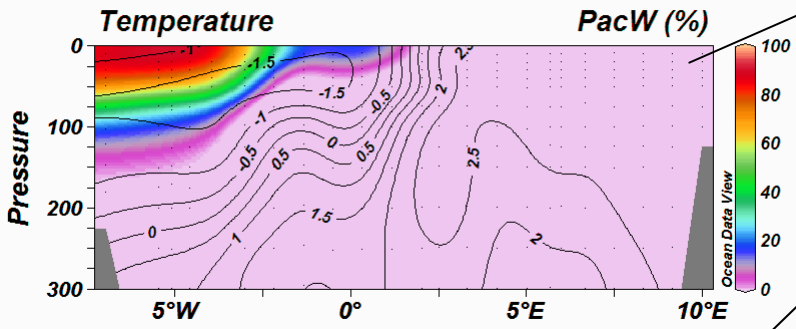


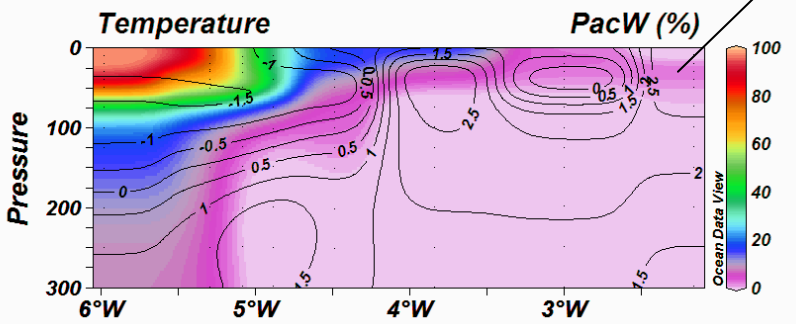
Compared to data from the Greenland Sea, which only show a N-P relation of typical Atlantic Water, the data from the Northeast Water Polynya (1993) show that the upper waters of the Polynya bear a clear signal of waters of Pacific origin.

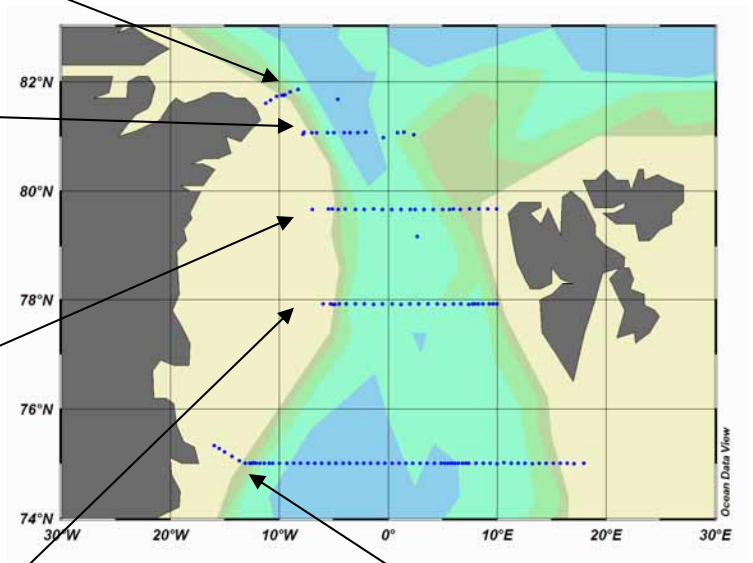
Polarstern 1997

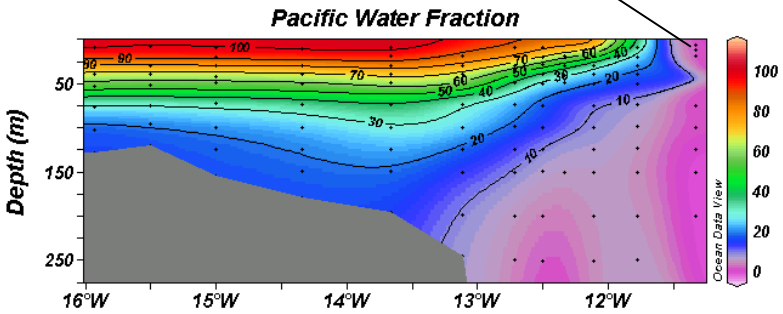




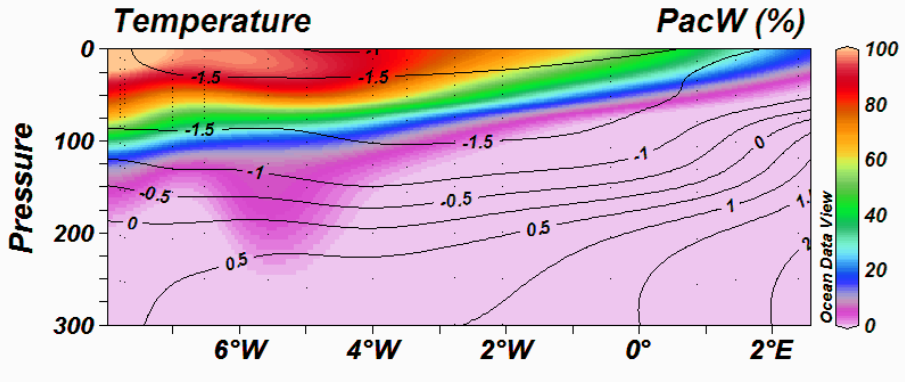


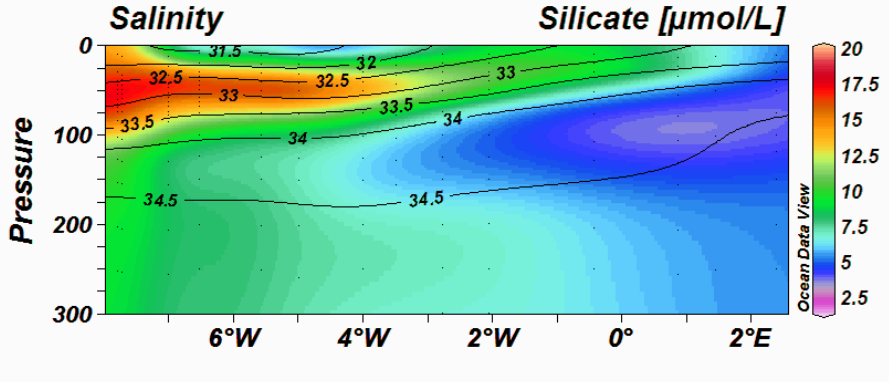




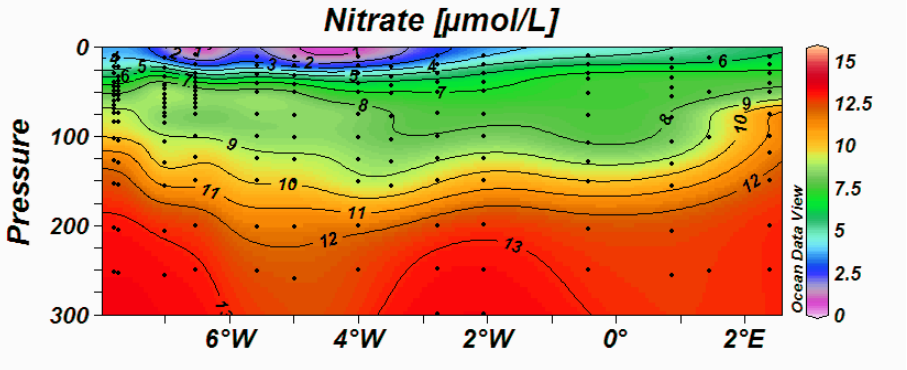


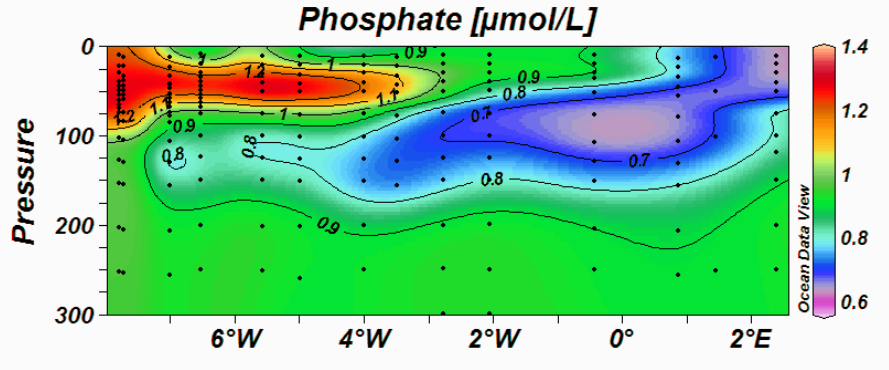
The Polar Water, which exits the Arctic through the Fram Strait, actually consists of several distinct water masses, which might be of either Pacific or Atlantic origin.



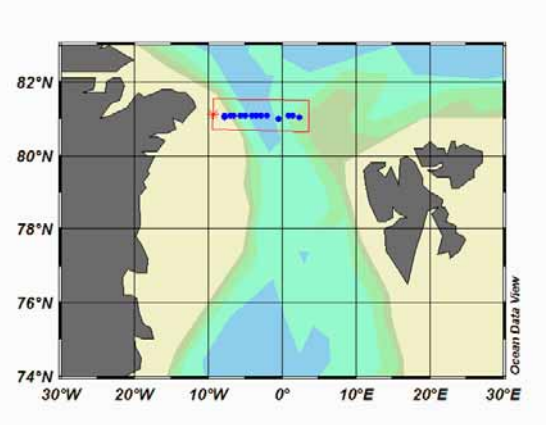


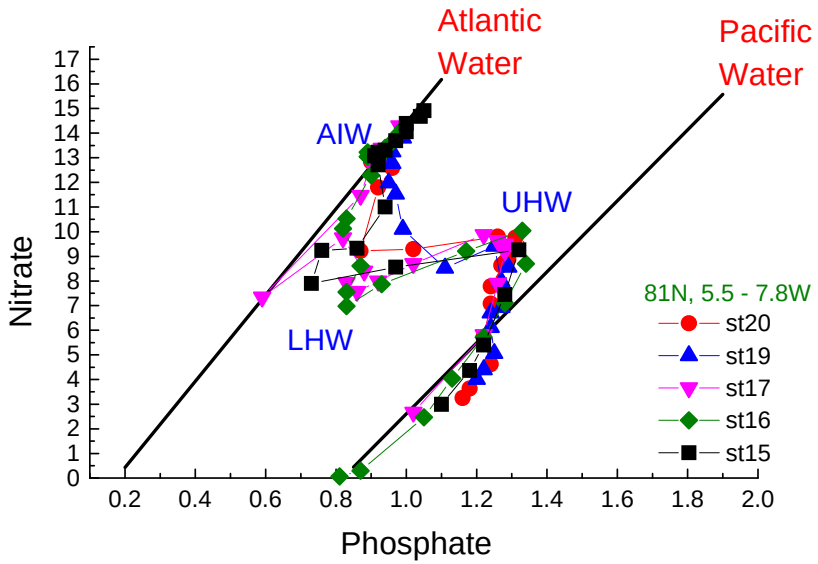
81ºN 1997

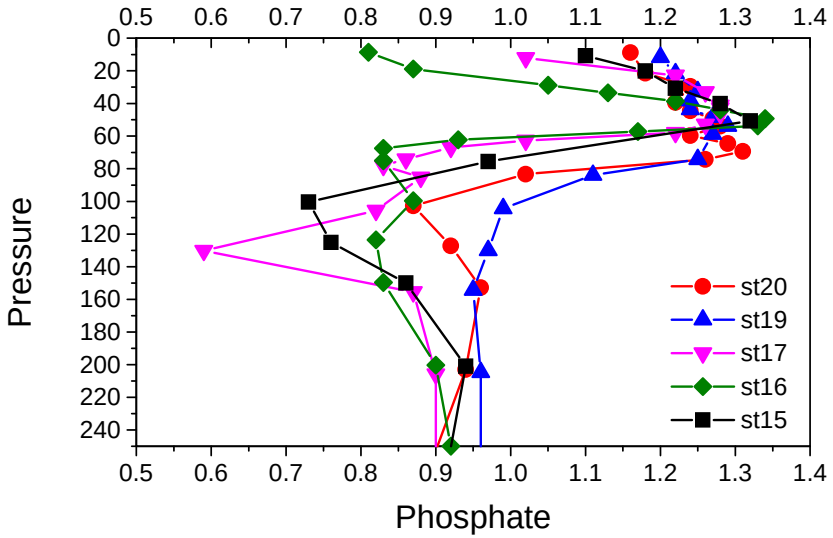




Polar Water: T < 0ºC, S < 34.5

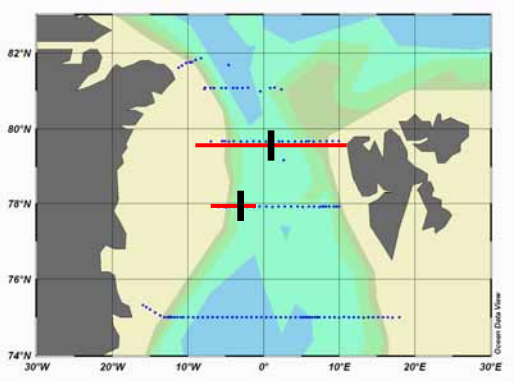






Unfortunately these clear signals between UHW and LHW are soon lost due to mixing.

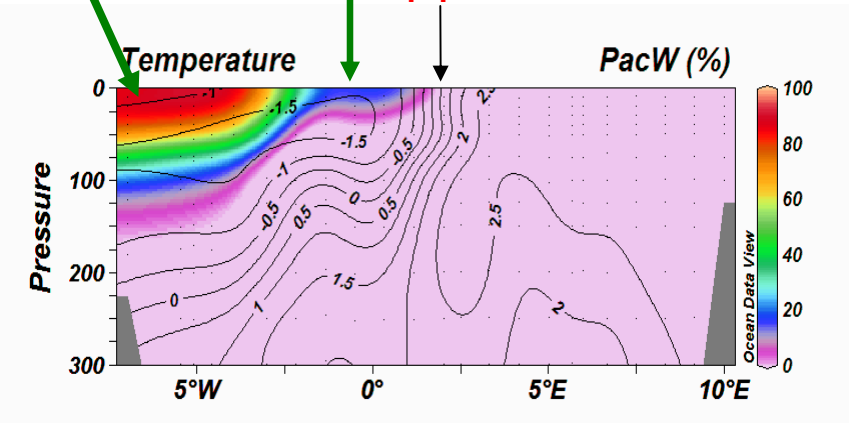
So we have actually found our four water masses

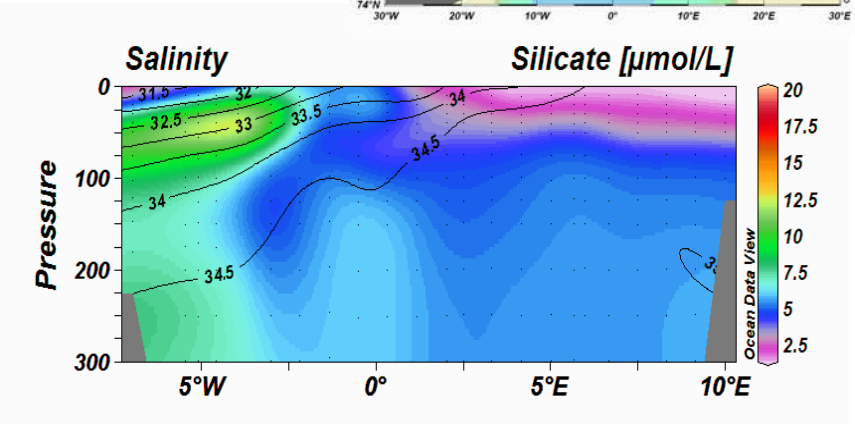


Pacific origin Atlantic origin

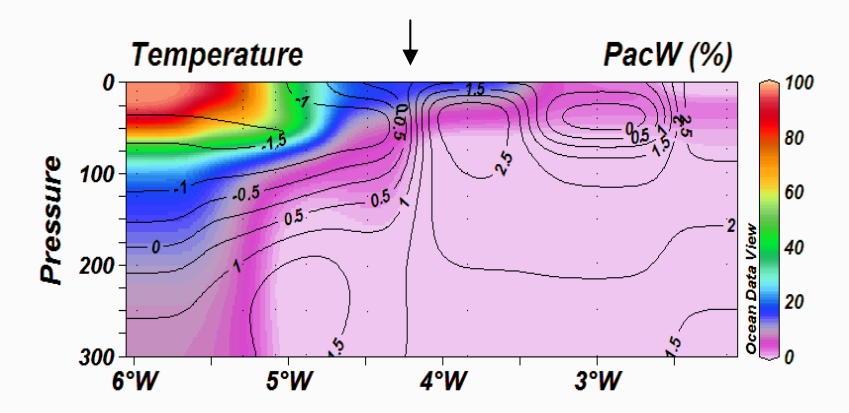
1997

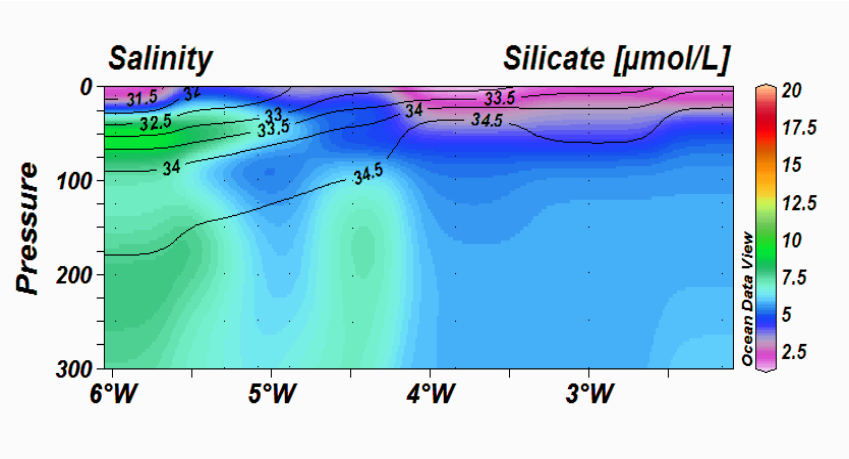
PF





PF

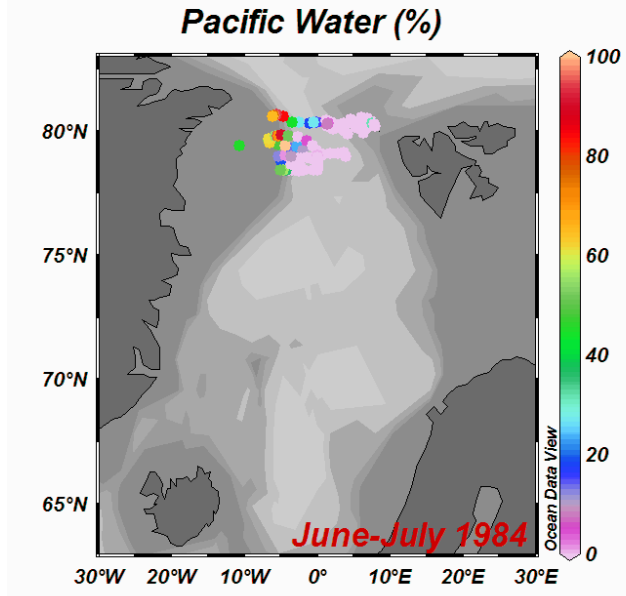


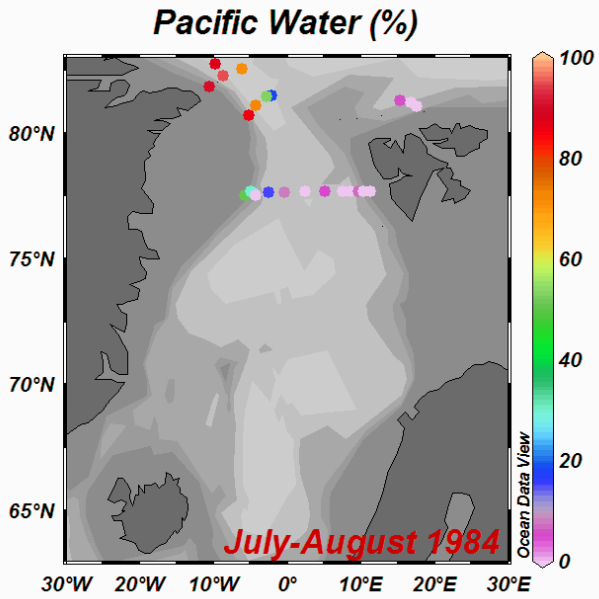


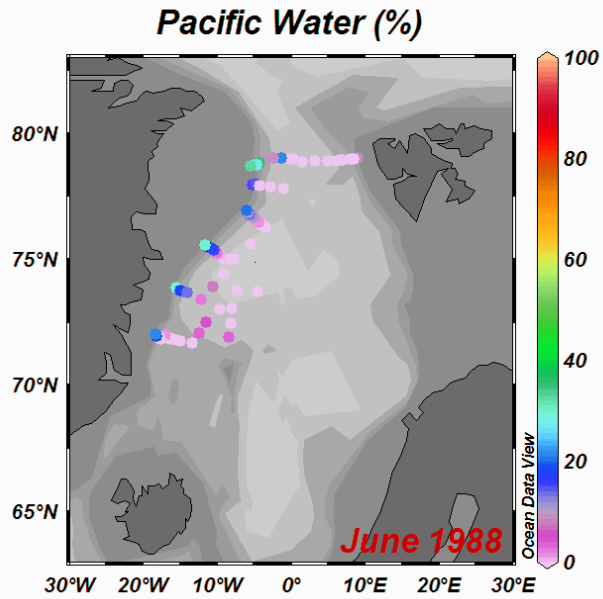
(PF = Polar Front)

Nutrient and hydrographic data from different cruises to the area north and east of Greenland during the last two decades

1984 - 1991


Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
June-July 1984
Ocean Data View
100 80 60 40 20 0


Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
July-August 1984
Ocean Data View
100 80 60 40 20 0


Pacific Water (%)
80°N
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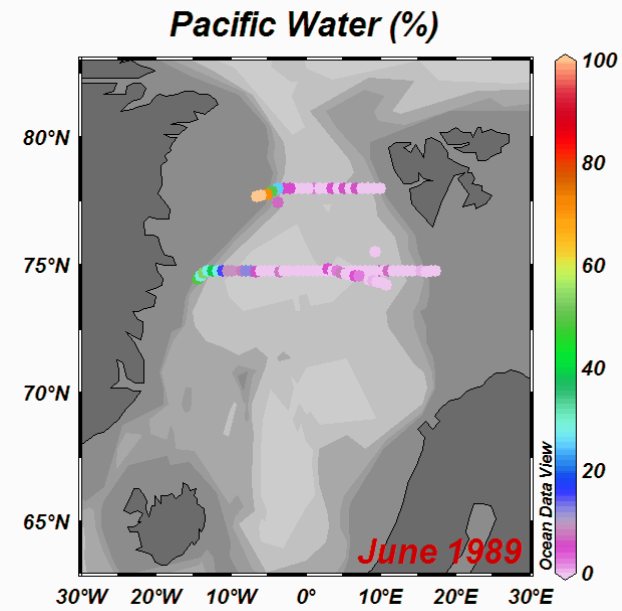
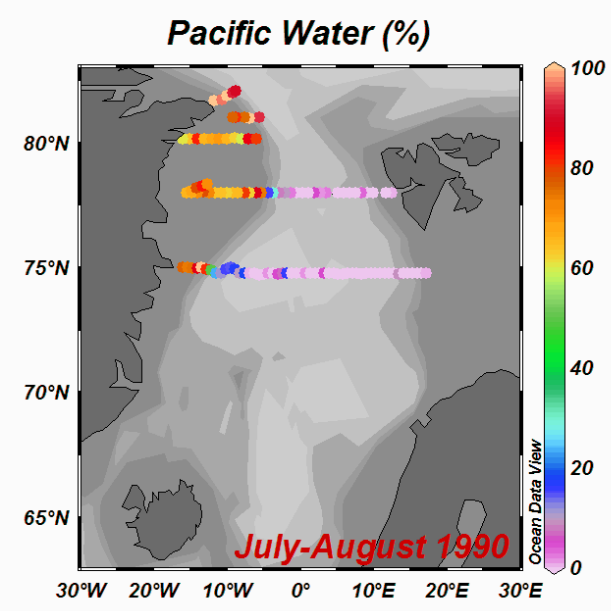
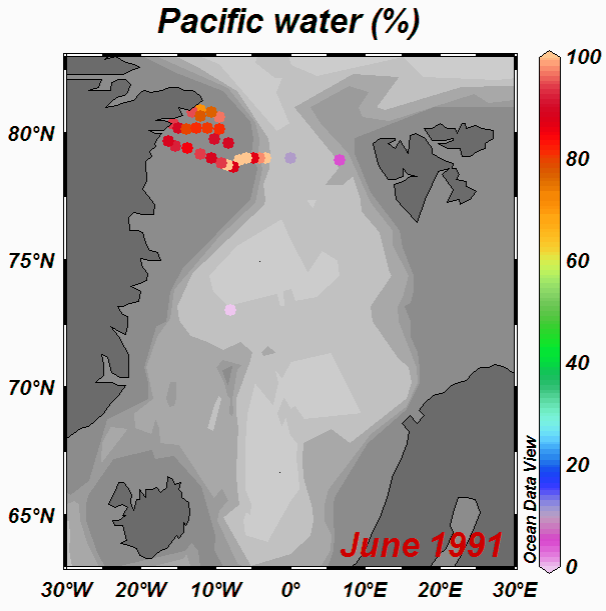
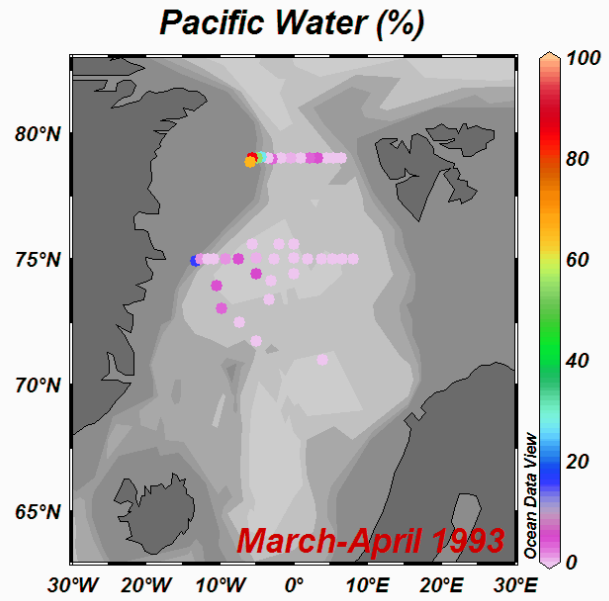
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
June 1988
Ocean Data View
100 80 60 40 20 0

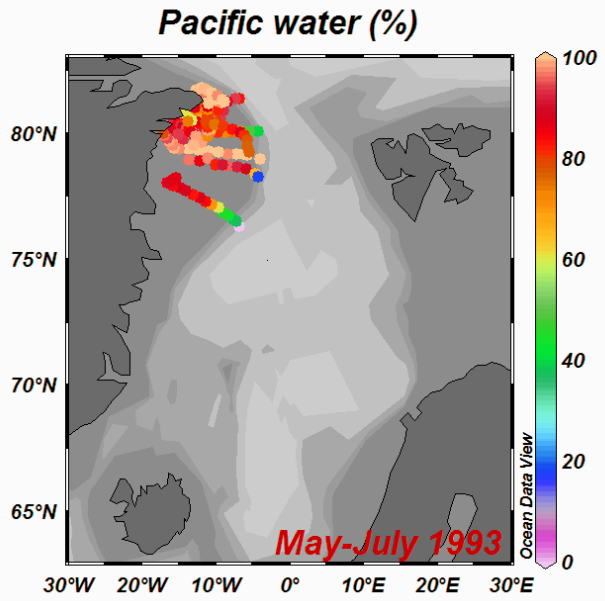

Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
June 1989
Ocean Data View
100 80 60 40 20 0


Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
July-August 1990
Ocean Data View
100 80 60 40 20 0


Pacific water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
June 1991
Ocean Data View
100 80 60 40 20 0

1993 - 1998


Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
March-April 1993
100 80 60 40 20 0
Ocean Data View


Pacific water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
May-July 1993
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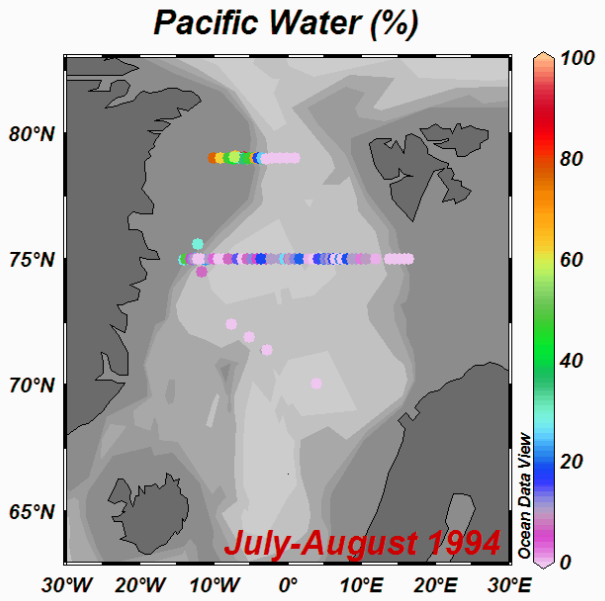
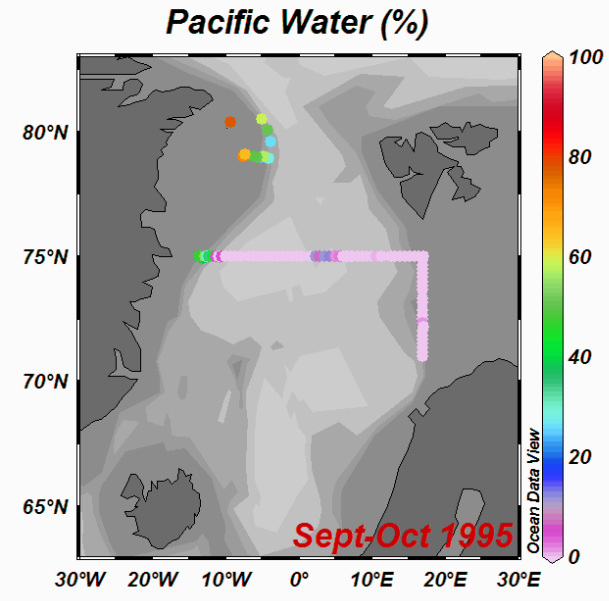
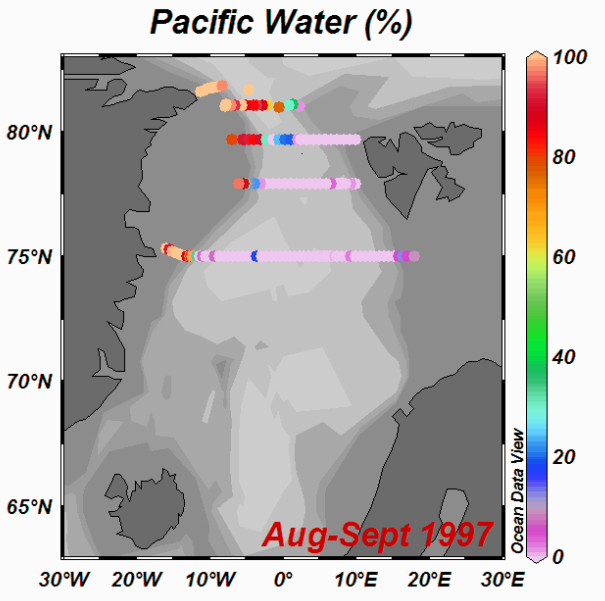
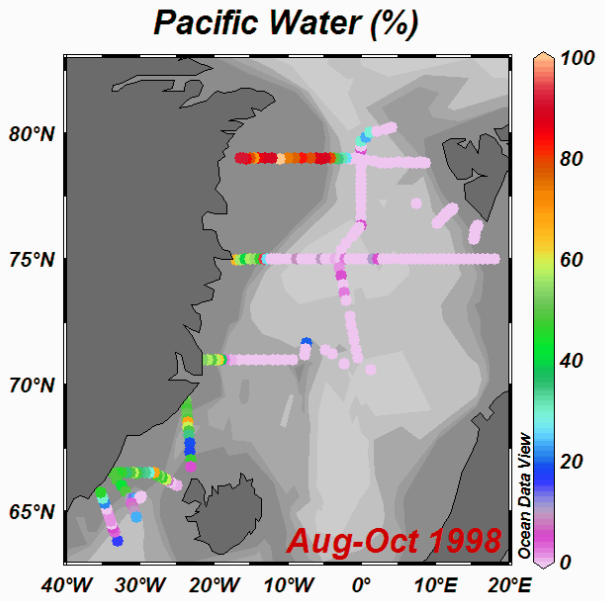
Ocean Data View

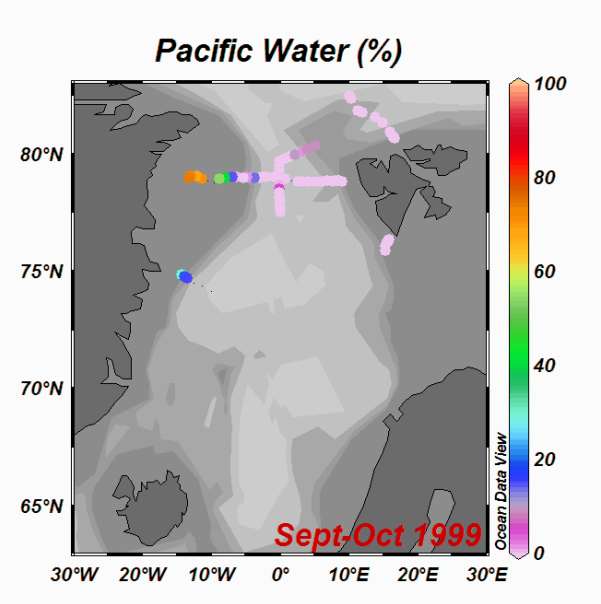

Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
July-August 1994
100 80 60 40 20 0
Ocean Data View

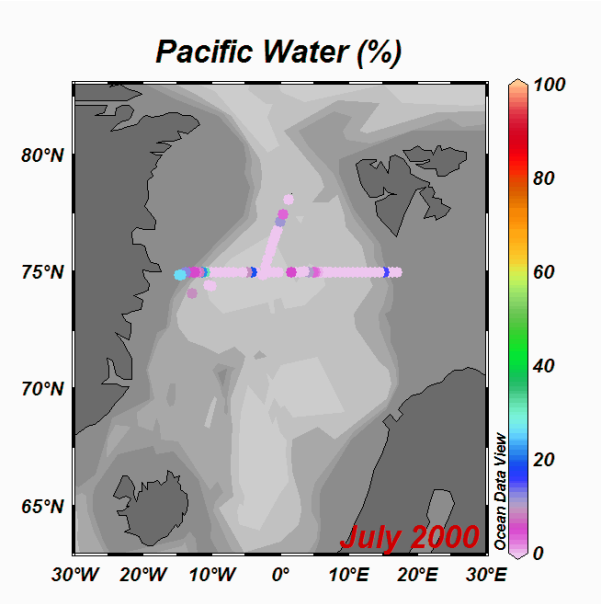

Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
Sept-Oct 1995
100 80 60 40 20 0
Ocean Data View

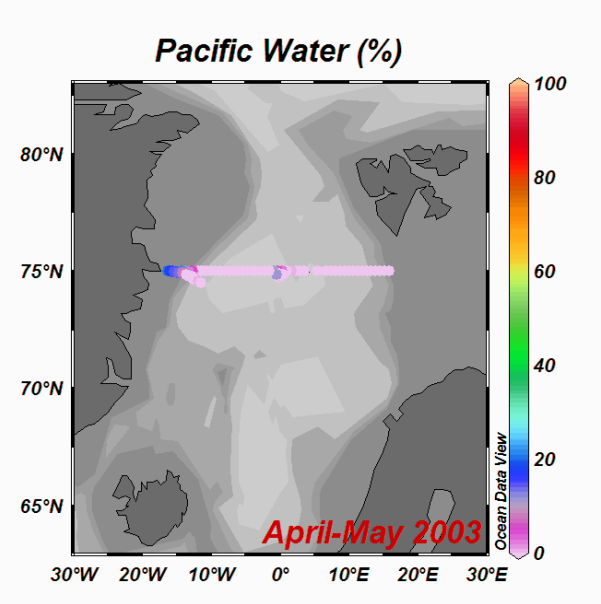

Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
Aug-Sept 1997
100 80 60 40 20 0
Ocean Data View

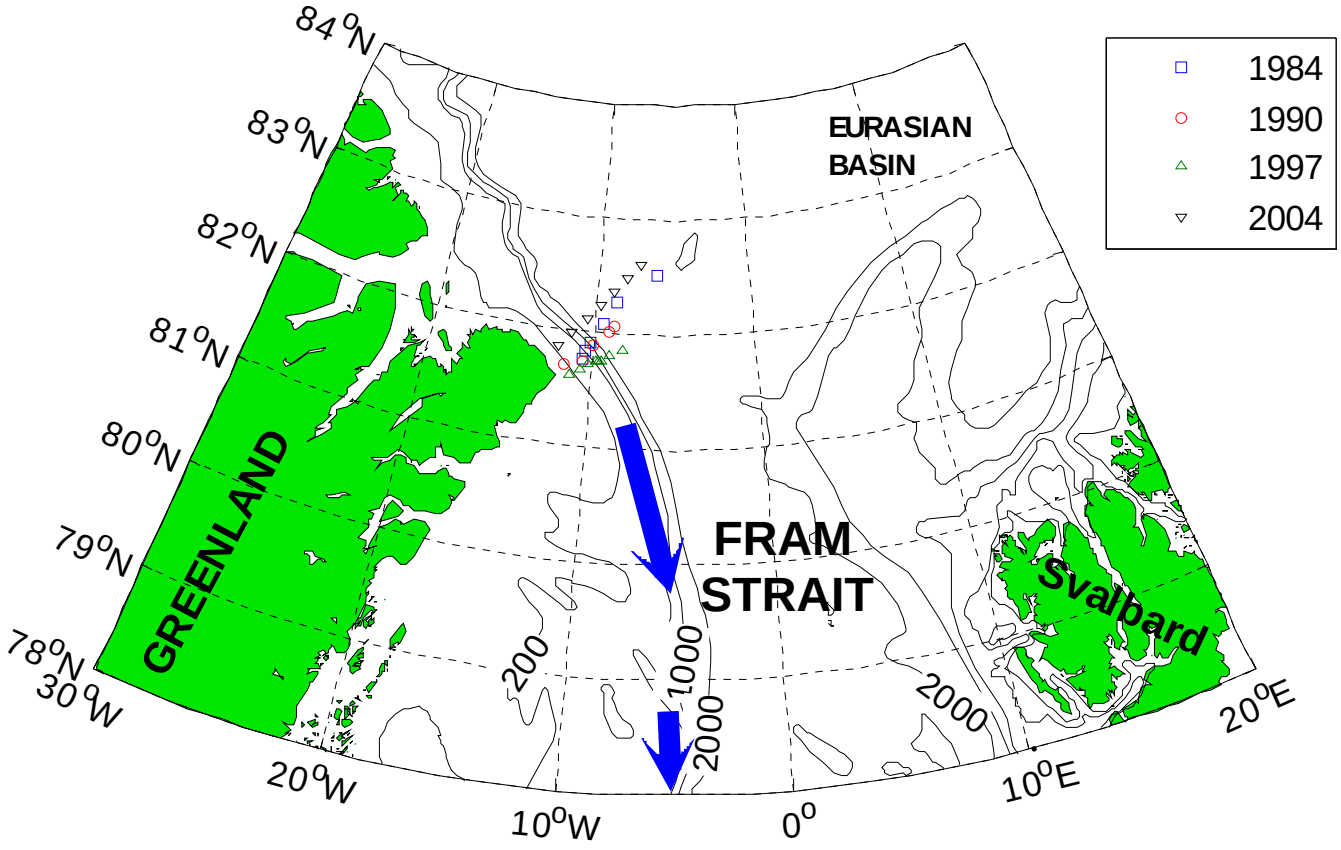

Pacific Water (%)
80°N
75°N
70°N
65°N
40°W 30°W 20°W 10°W 0° 10°E 20°E
Aug-Oct 1998
100 80 60 40 20 0
Ocean Data View

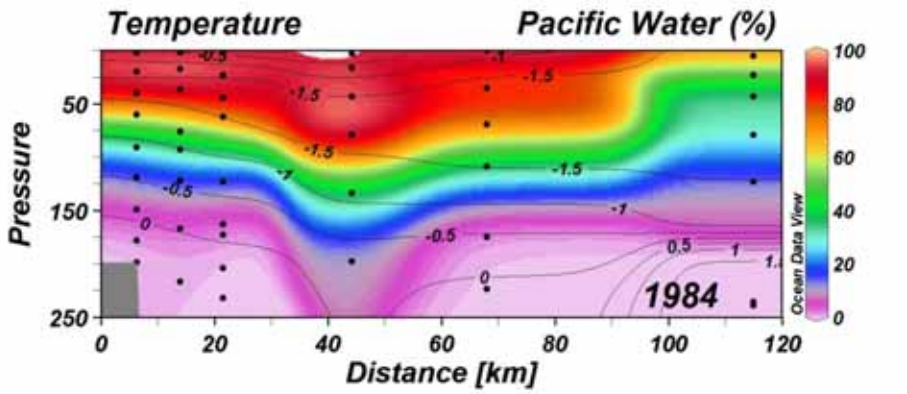
1999 - 2004

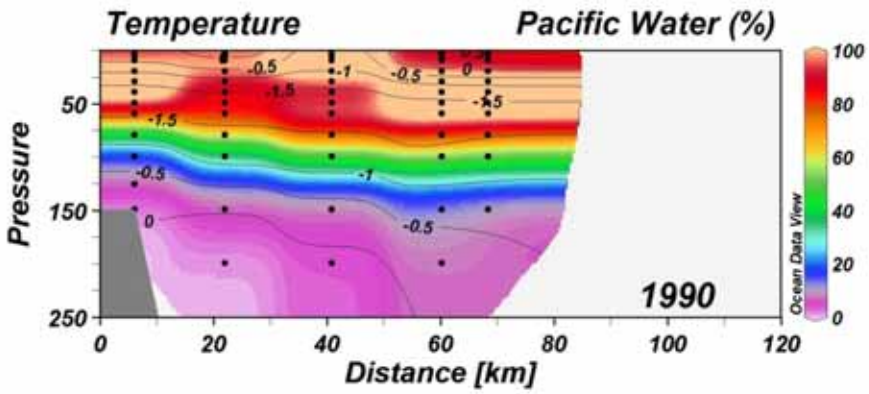

Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
100
80
60
40
20
0
Ocean Data View
Sept-Oct 1999

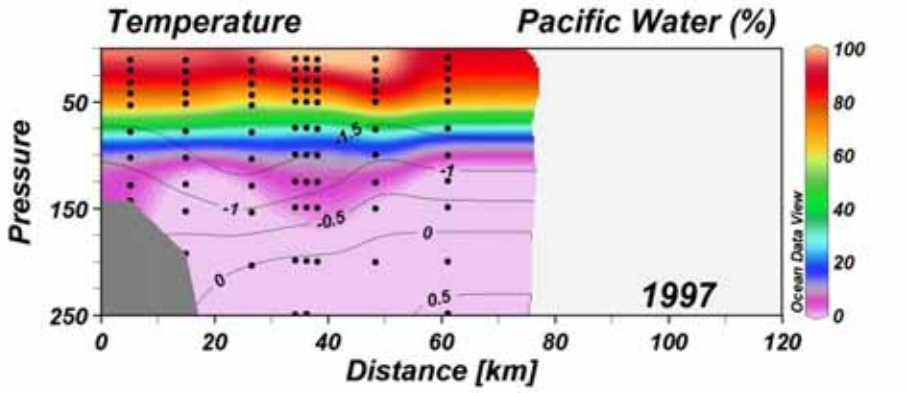

Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
100
80
60
40
20
0
Ocean Data View
July 2000

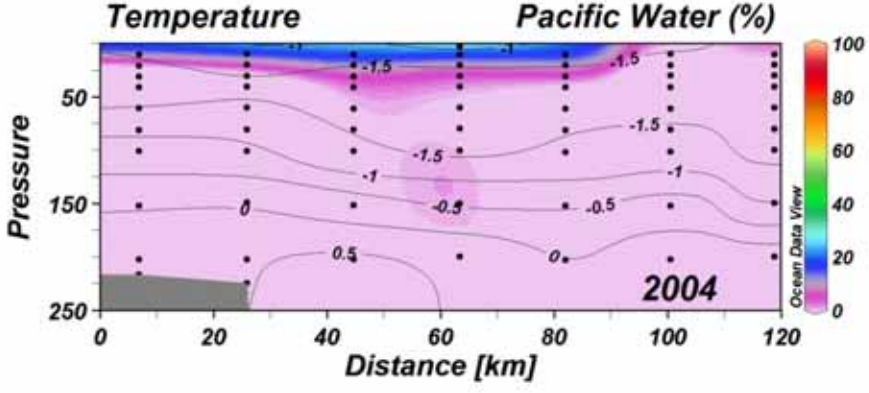

Pacific Water (%)
80°N
75°N
70°N
65°N
30°W 20°W 10°W 0° 10°E 20°E 30°E
100
80
60
40
20
0
Ocean Data View
April-May 2003


84°N
83°N
82°N
81°N
80°N
79°N
78°N
30°W
20°W
10°W
0°
10°E
20°E
EURASIAN
BASIN
GREENLAND
FRAM
STRAIT
Svalbard
200
1000
2000
2000
1984
1990
1997
2004





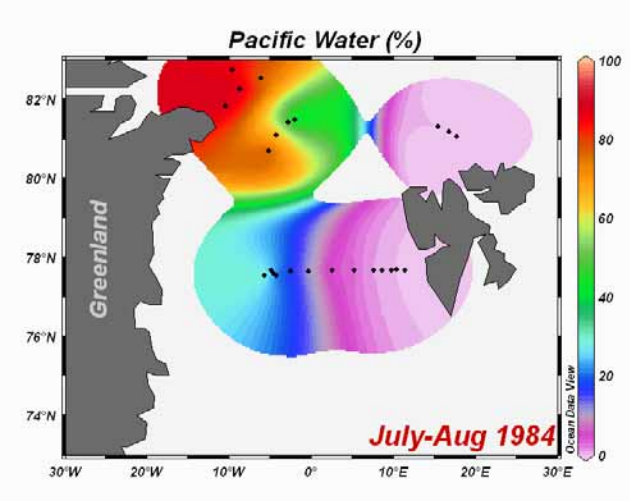


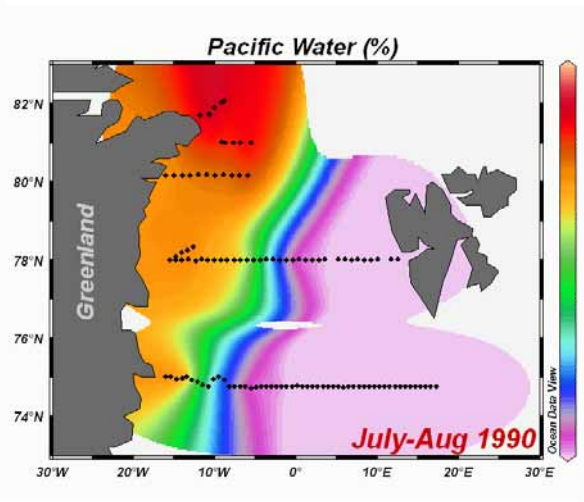


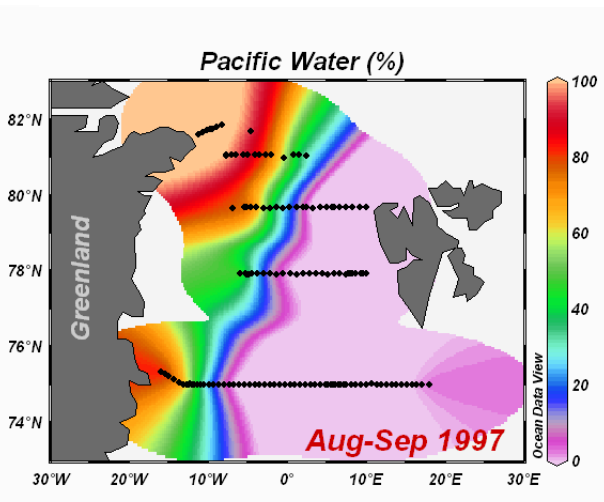
Disappearance of Pacific Water in the northwestern Fram Strait

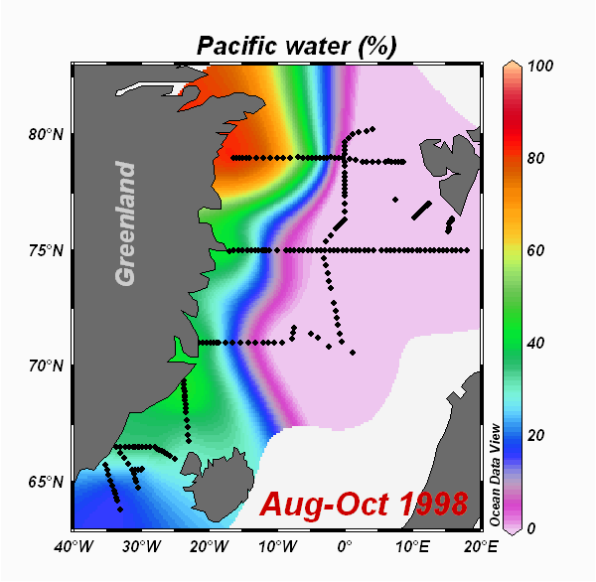
(Falck, Kattner, and Budéus, GRL 2005)

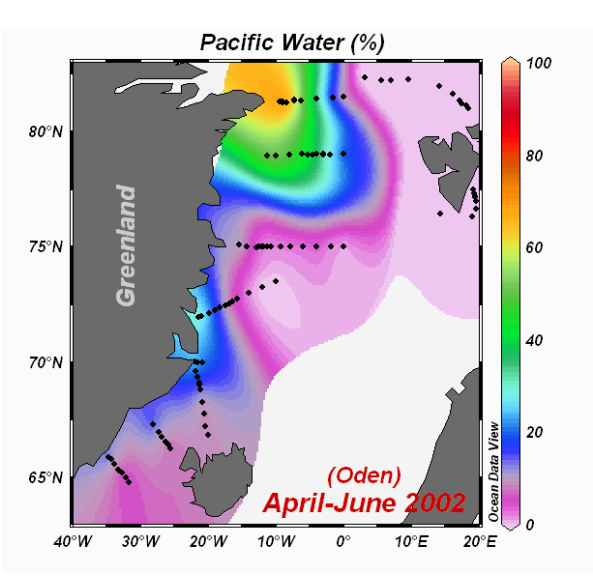
- that substantial changes have occurred lately in the amount of waters of Pacific origin delivered to the Fram Strait and hence further to the Atlantic Ocean.

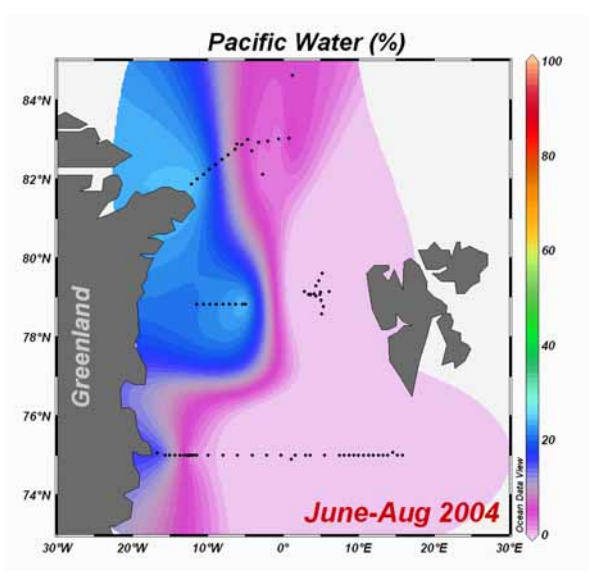


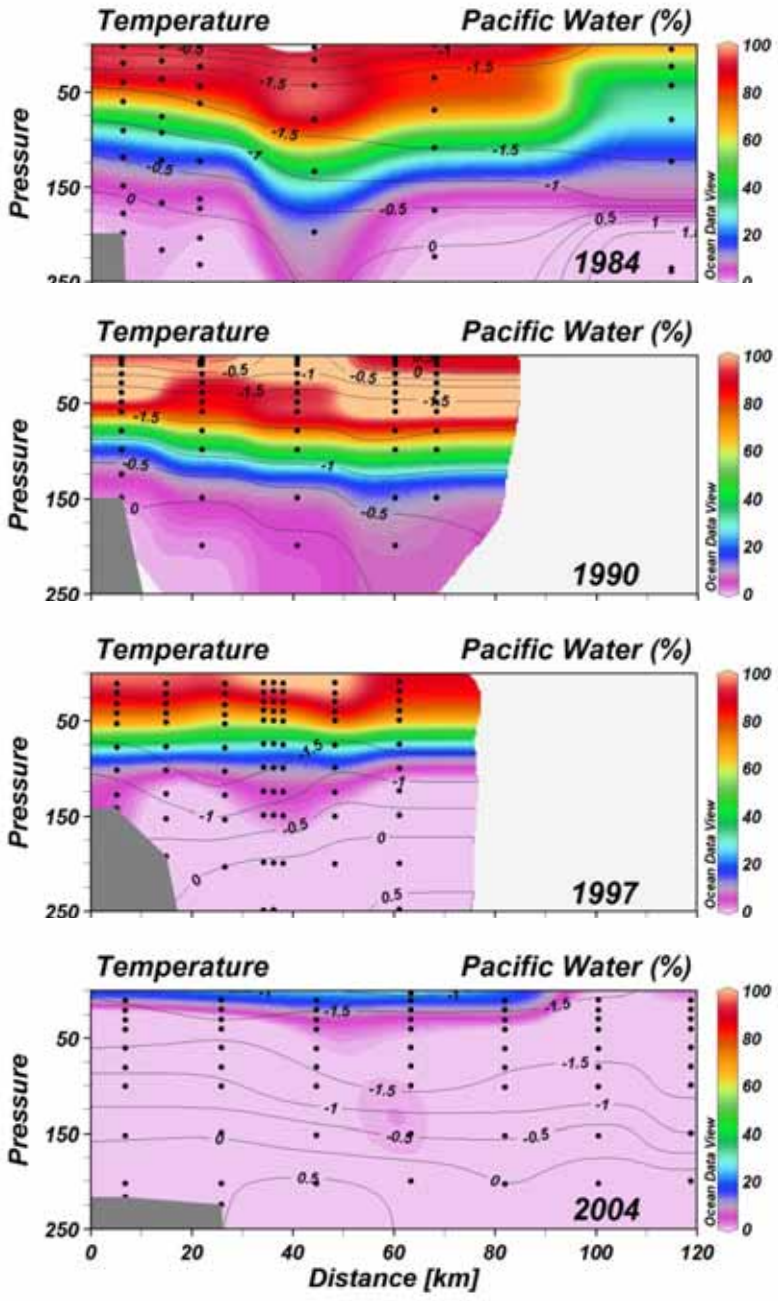


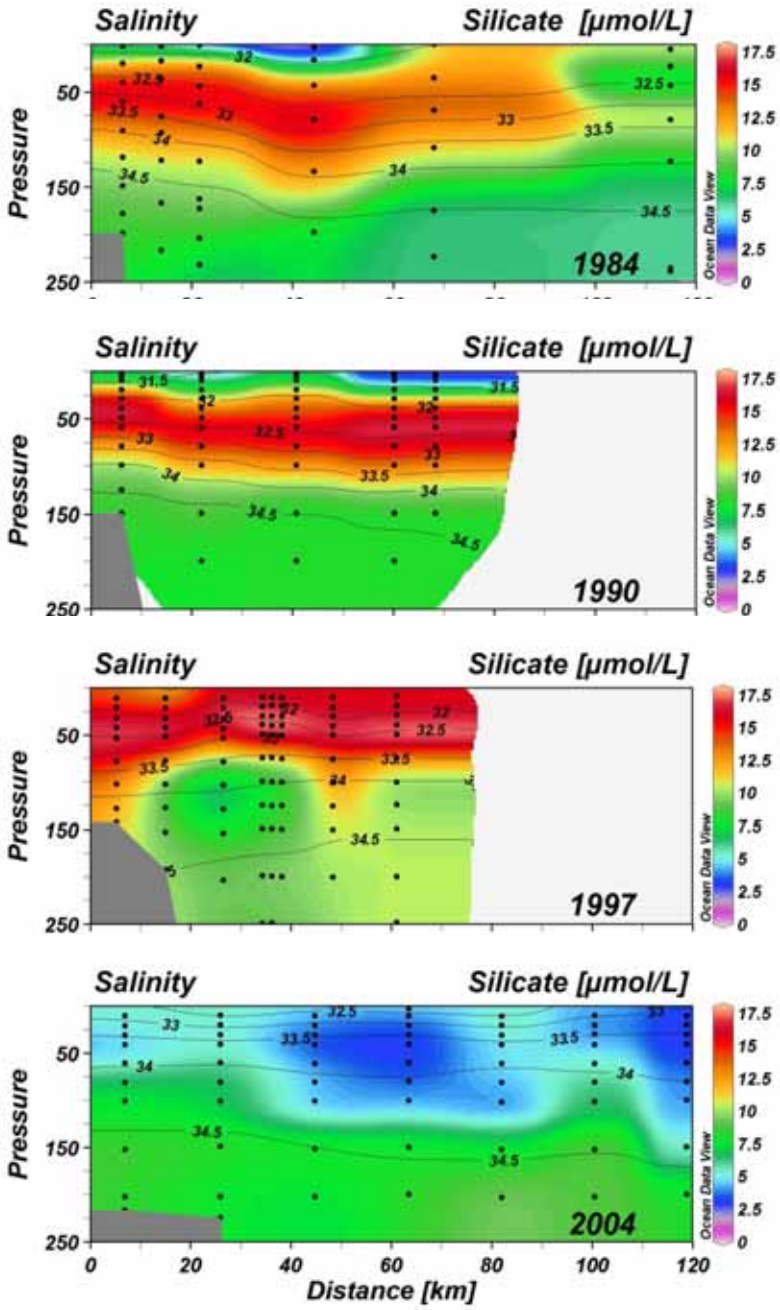









Temperature
Pacific Water (%)
Pressure
1984
1990
1997
2004
Ocean Data View
Distance [km]


Salinity
Silicate [µmol/L]
Pressure
1984
1990
1997
2004
Ocean Data View
Distance [km]

Conclusions

- Nutrients are a useful tracer to distinguish between waters of Pacific and Atlantic origin.
- The most reasonable explanation for the disappearance of Pacific Water in the Fram Strait is a change in the position of the Transpolar Drift Stream, cutting off the route to the Fram Strait for the Pacific Water.
- The Pacific Water must therefore either be stored in the Beaufort Gyre and/or drained through the passages of the Canadian Archipelago.
- It is now important to monitor how long it takes before the Pacific Water again exits the Fram Strait.