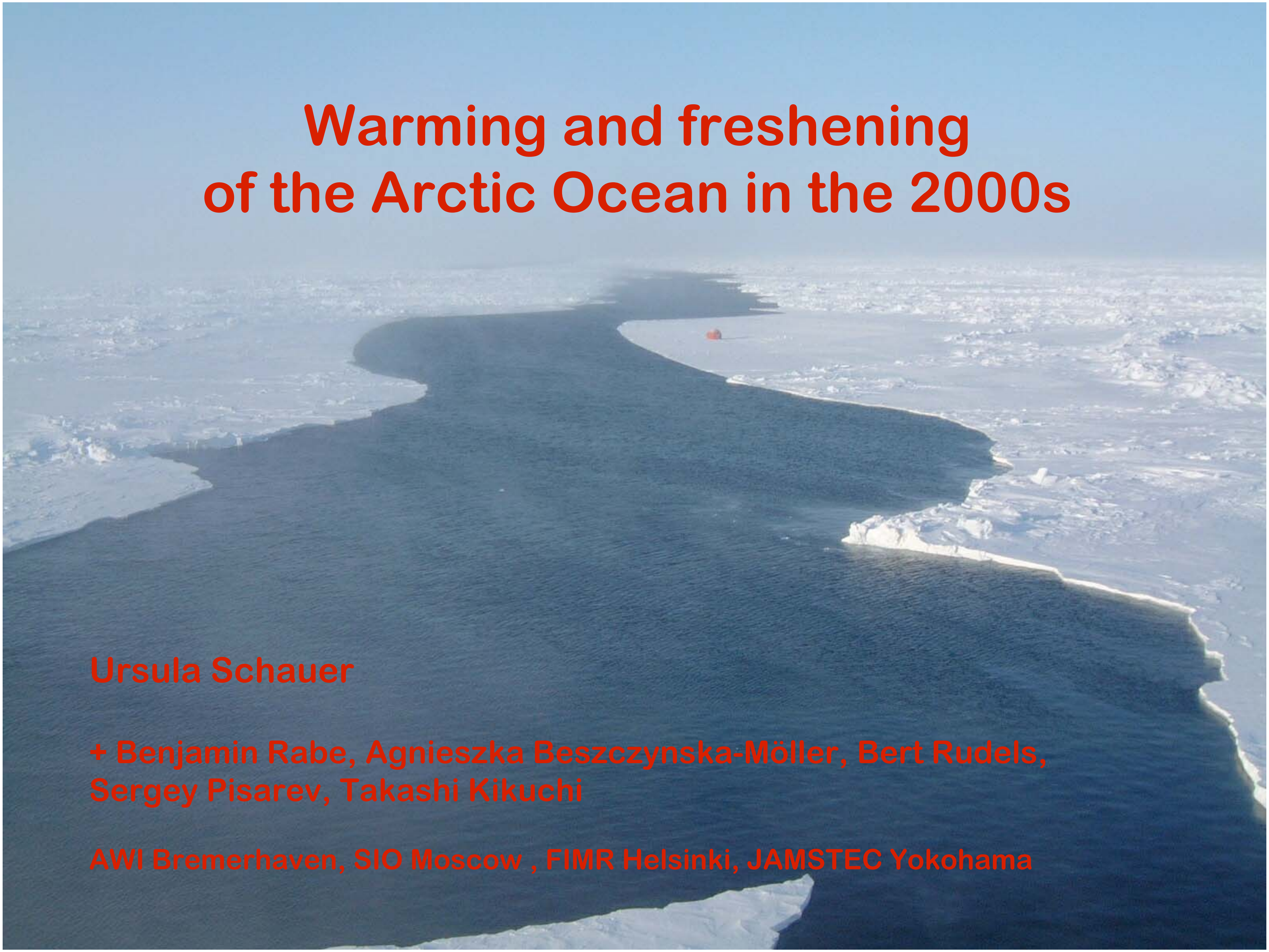


Warming and freshening of the Arctic Ocean in the 2000s

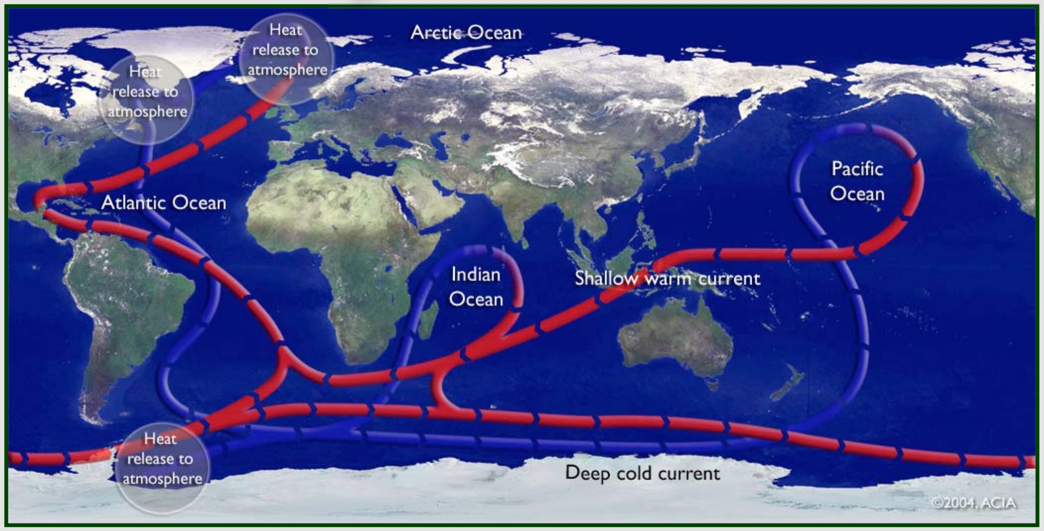
Ursula Schauer

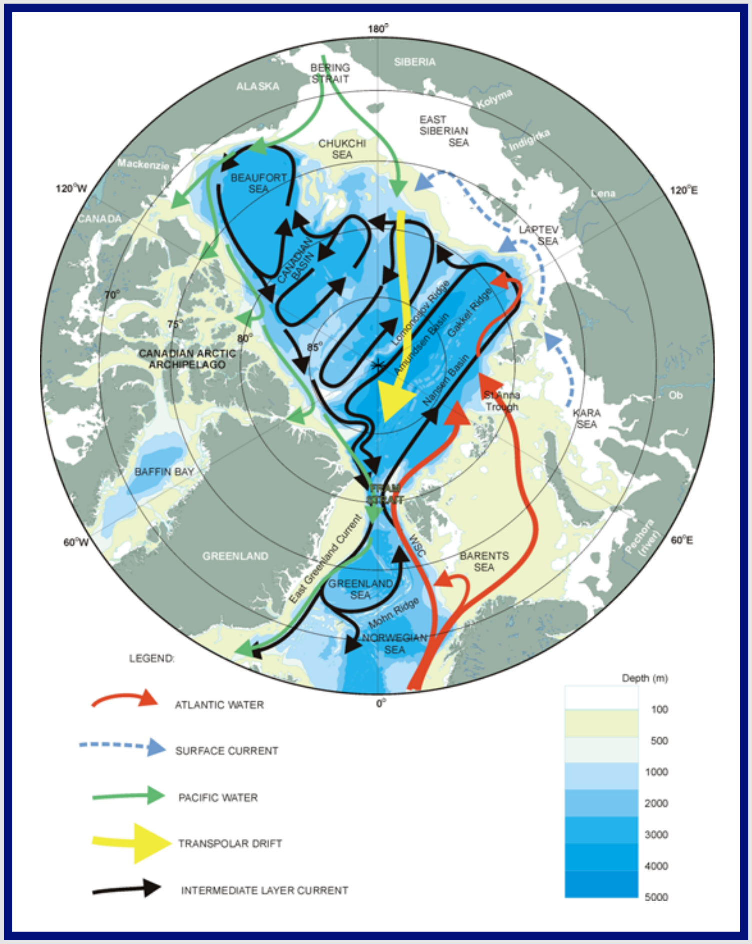
+ Benjamin Rabe, Agnieszka Beszczynska-Möller, Bert Rudels, Sergey Pisarev, Takashi Kikuchi

AWI Bremerhaven, SIO Moscow , FIMR Helsinki, JAMSTEC Yokohama

Arctic Ocean takes part in the global circulation

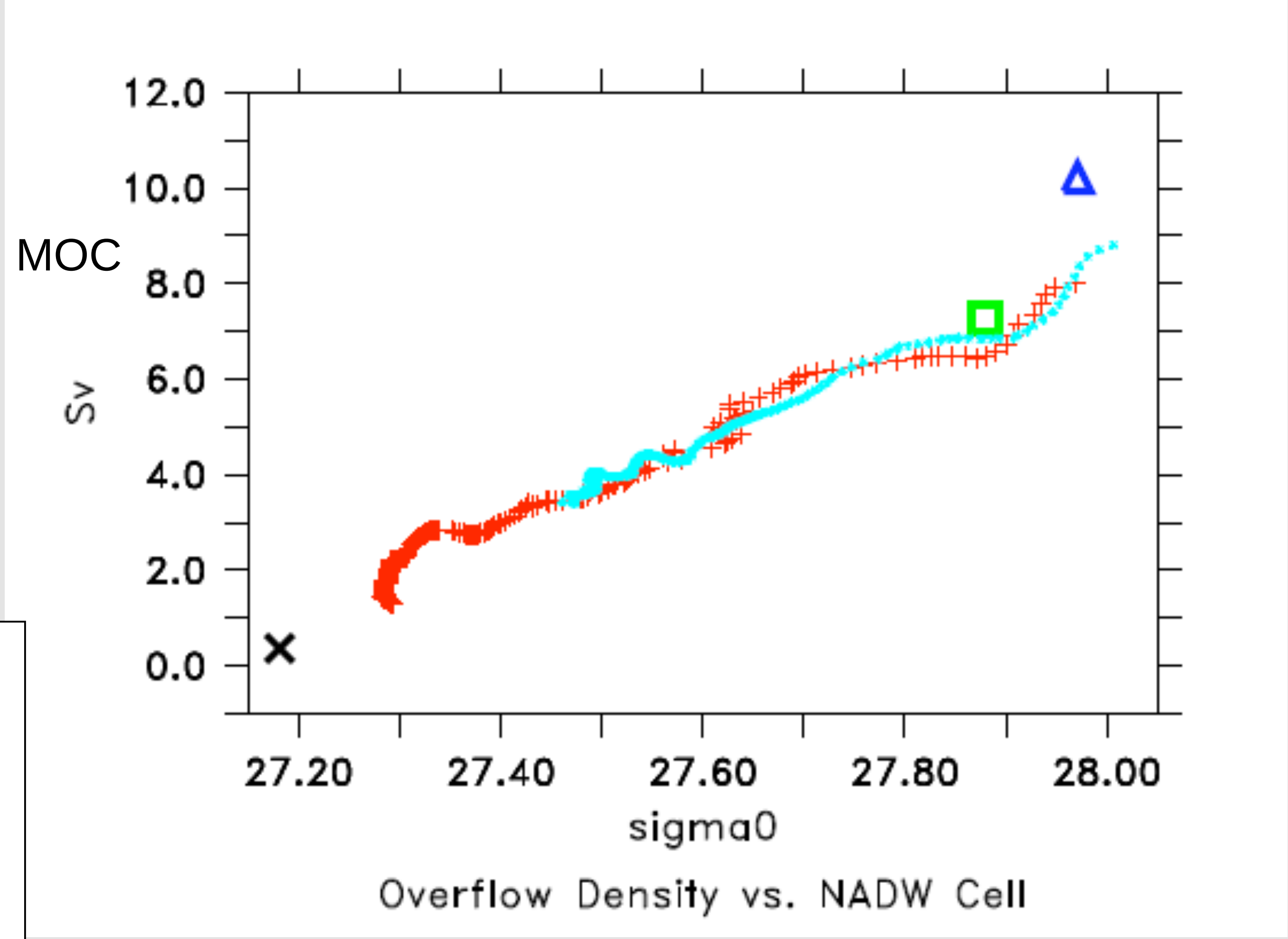
- Inflow from Pacific and Atlantic
- Modification on shelf seas
- Outflow to Atlantic
- continental runoff





Østerhus after Rudels

Strength of Atlantic meridional overturning and overflow density



ORCA-CORE simulations; IfM-GEOMAR Kiel

Black: No restoring

Red: Weak restoring

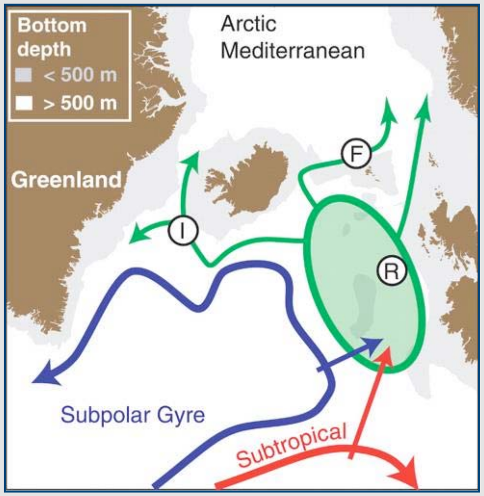
Light blue: As in „red“, except reduced Arctic precipitation

Blue: strong restoring

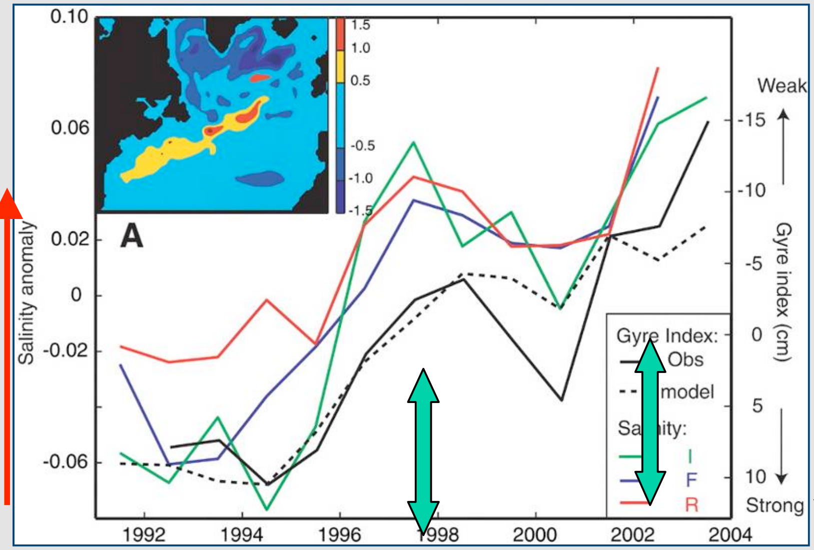
Green: strong restoring in subpolar oceans (esp. north of 65°N)

Griffies et al., 2009

Anomalies in the Subpolar and Subtropical North Atlantic

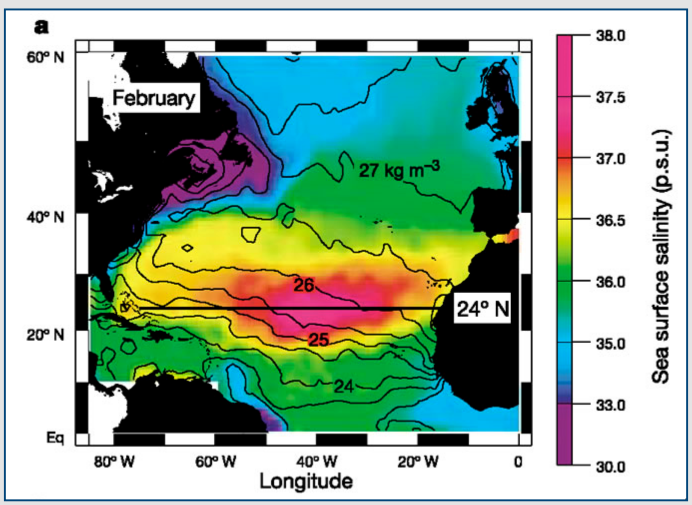


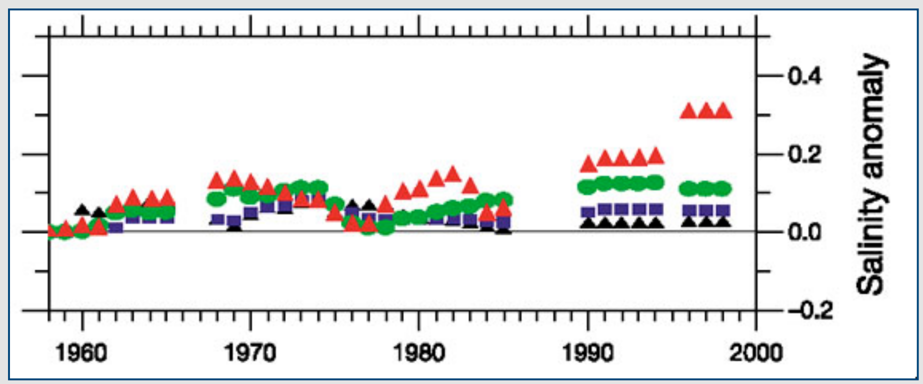
Salinity anomaly



Gyre strength

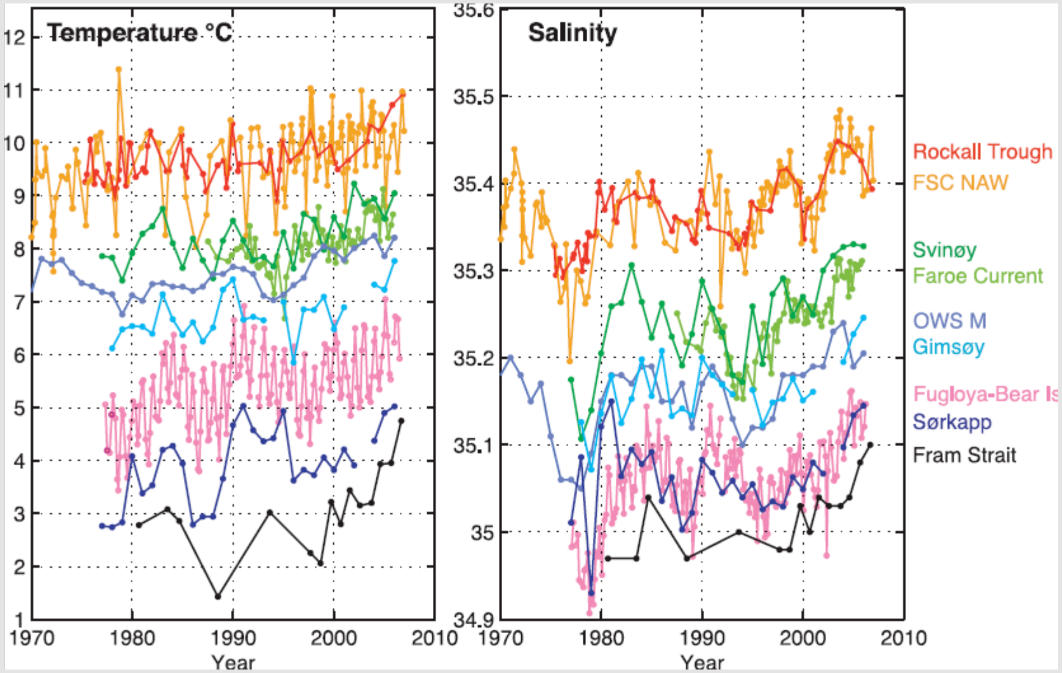
Hátún et al., 2005: Changes of the Subpolar Gyre

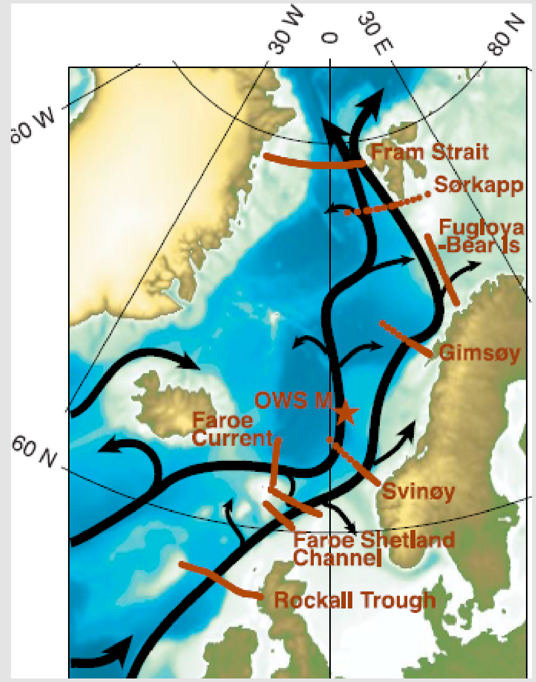


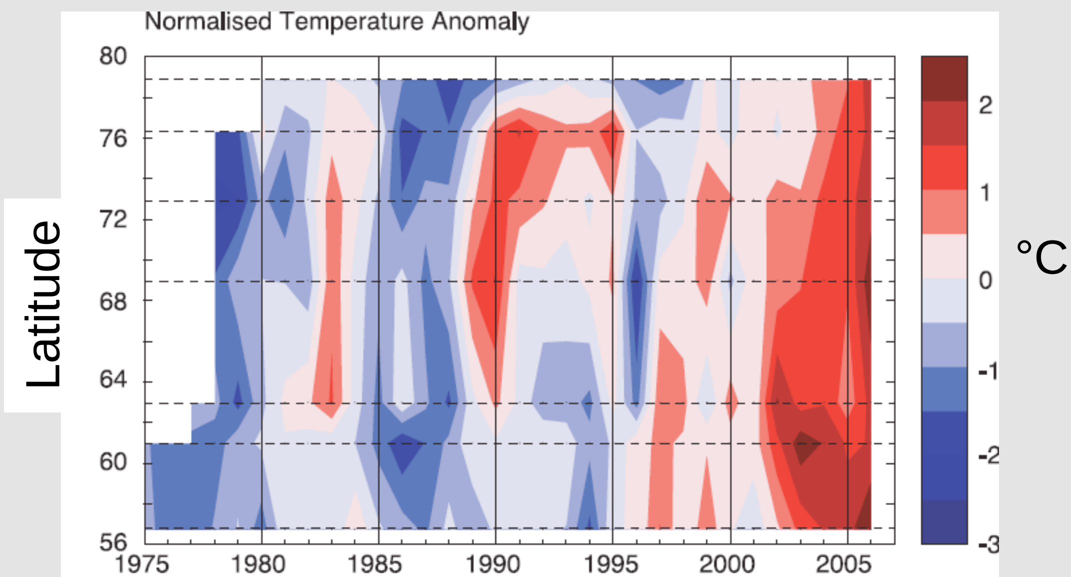


Curry et al., 2005 Changes of the Subtropical Gyre

Northward propagation of warm, saline anomalies





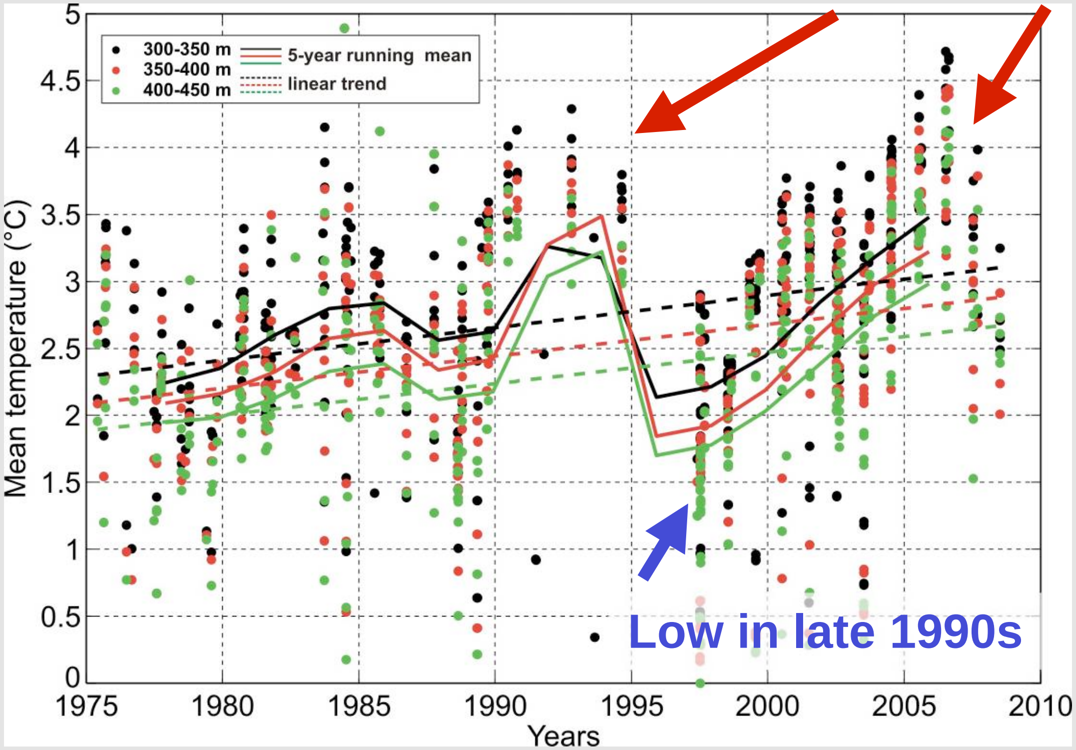


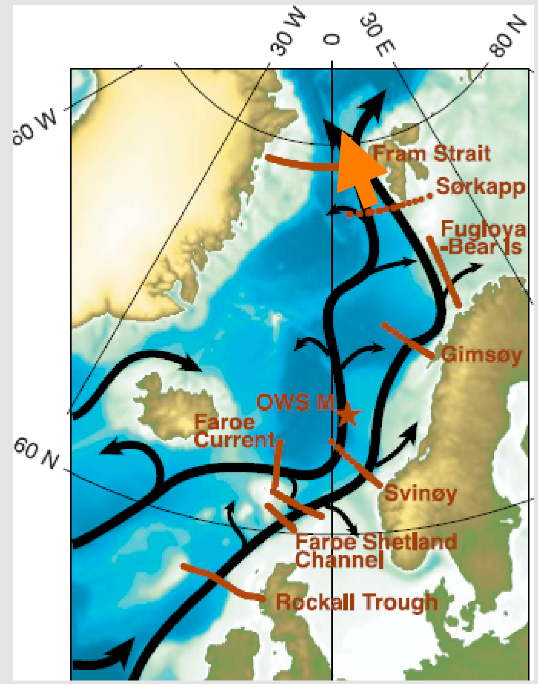
Holliday et al., 2008

Temperature in the Fram Strait Atlantic Water from summer CTD surveys

300-450 m in the WSC

High in early 1990s and 2000s

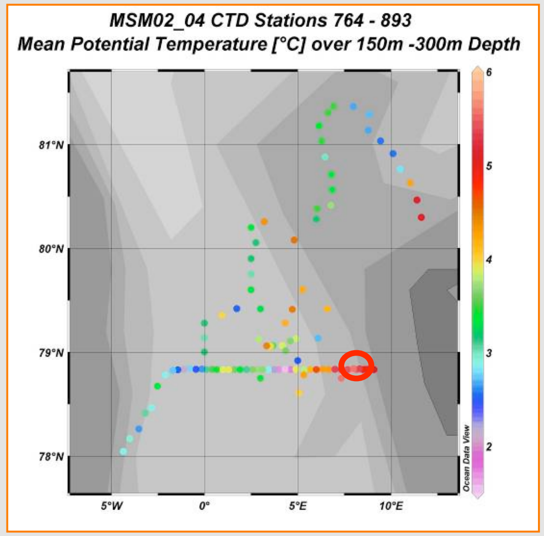


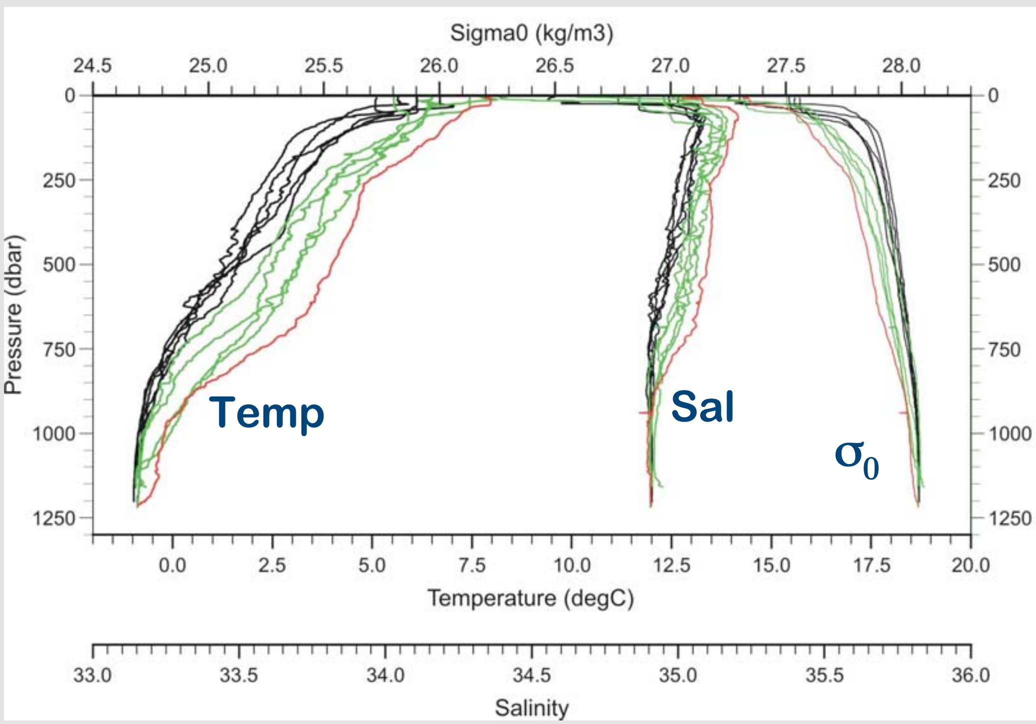


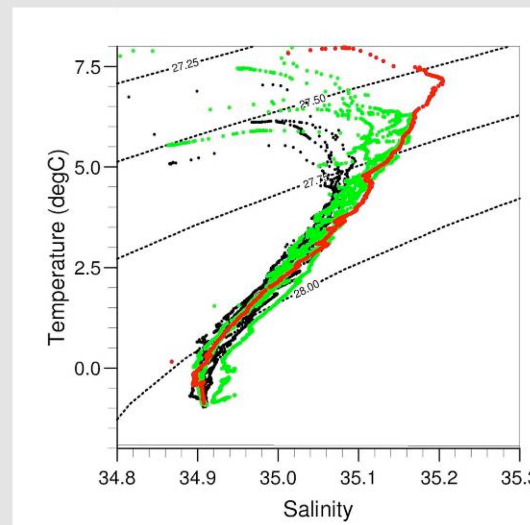
Mooring programme
to observe fluxes

• Increase of AW temperature and salinity, drop in density

1997-2001
2002-2005
2006

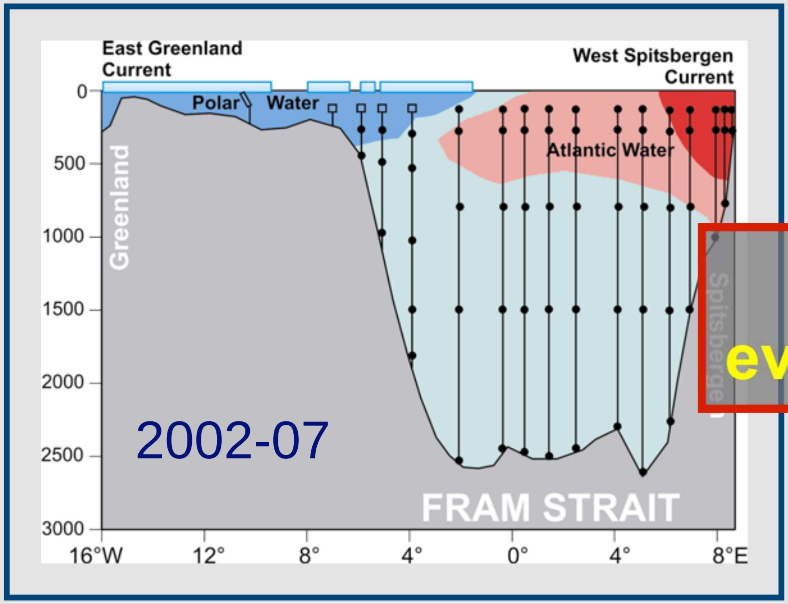


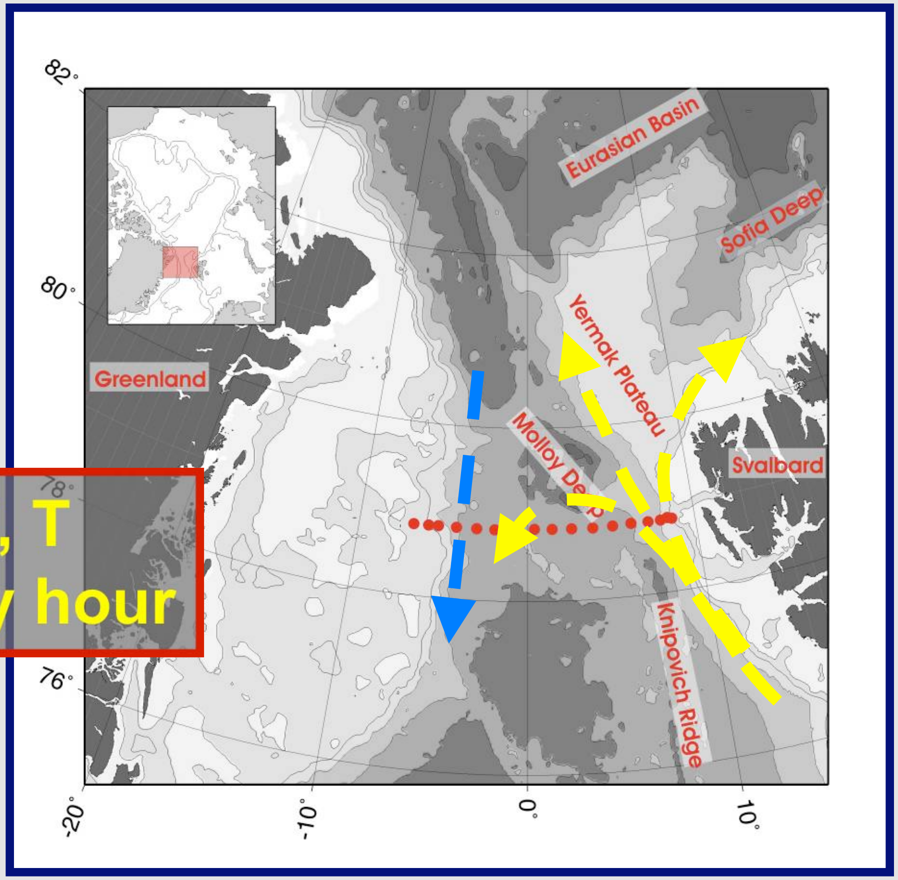




10 years measurements of oceanic fluxes through the Fram Strait

- 1997 - 1999 : 14 moorings
- 1999 - 2000 : 11 moorings
- 2000 - 2002 : 14 moorings
- 2002 - 2008 : 17 moorings



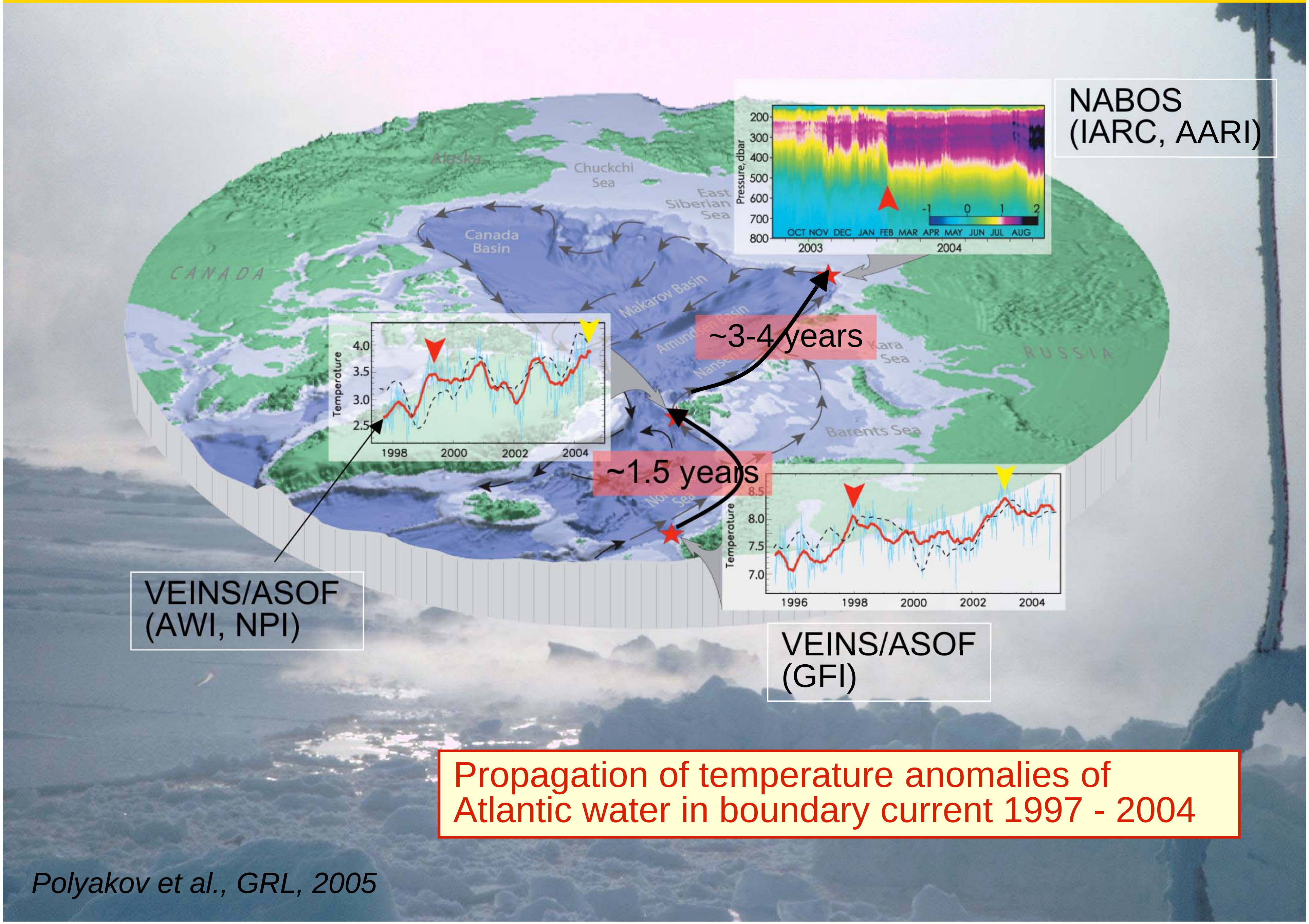


AWI, NPI

EU-Projects VEINS, ASOF-N, DAMOCLES

Contribution to international ASOF (Arctic-Subarctic Ocean Fluxes)

Combination of international mooring programmes



Propagation of temperature anomalies of Atlantic water in boundary current 1997 - 2004

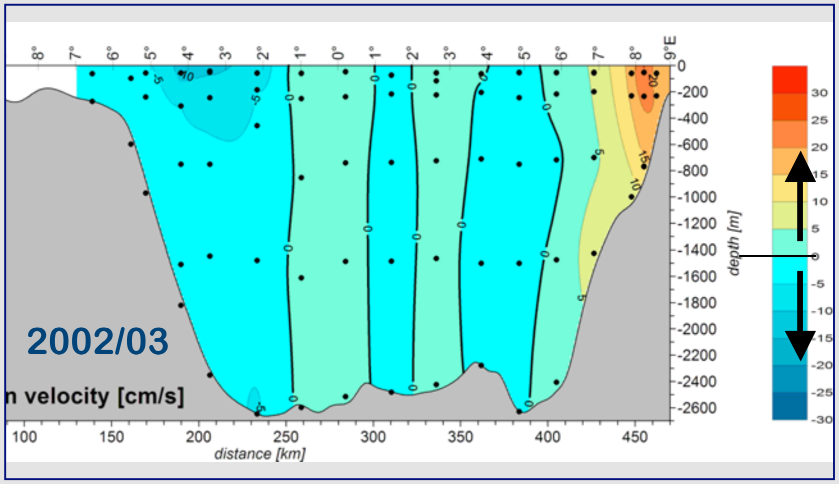
Polyakov et al., GRL, 2005

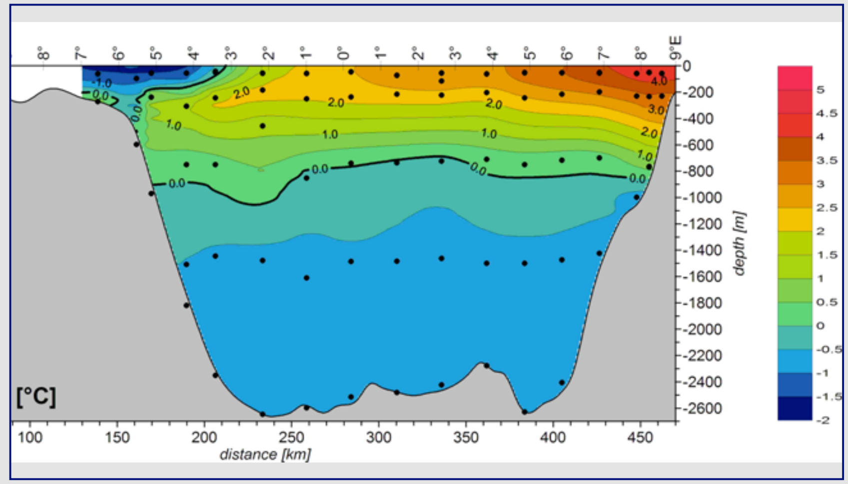
• Time averaging, linear interpolation across section

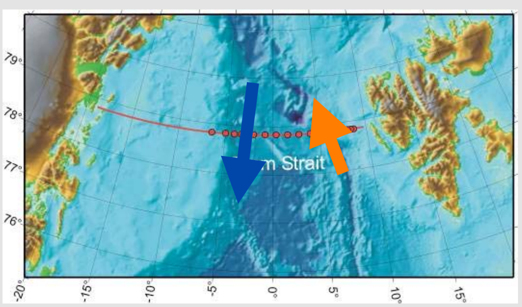
Annual mean velocity, cross section component

Annual mean temperature

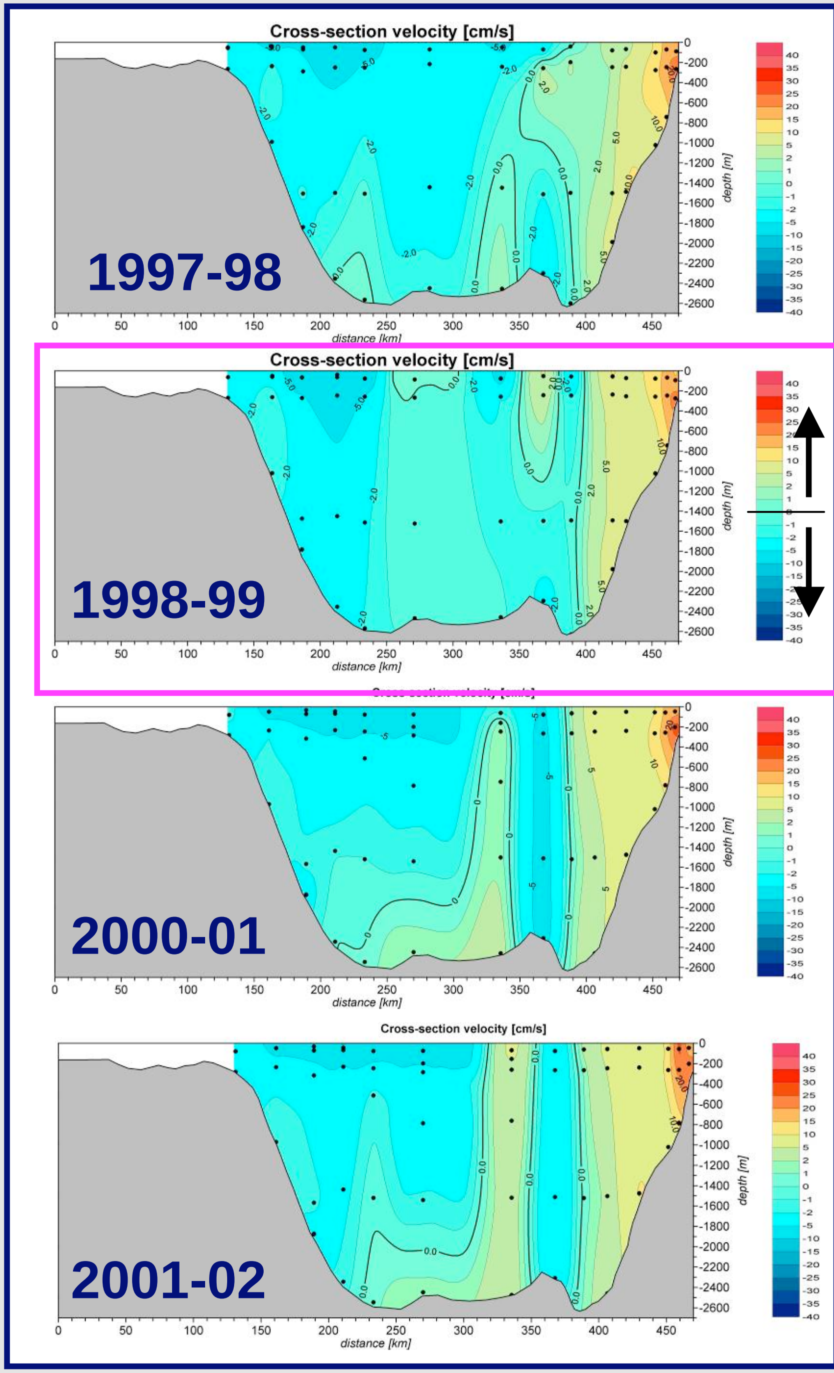
2002-2006: 17 moorings, 5 levels

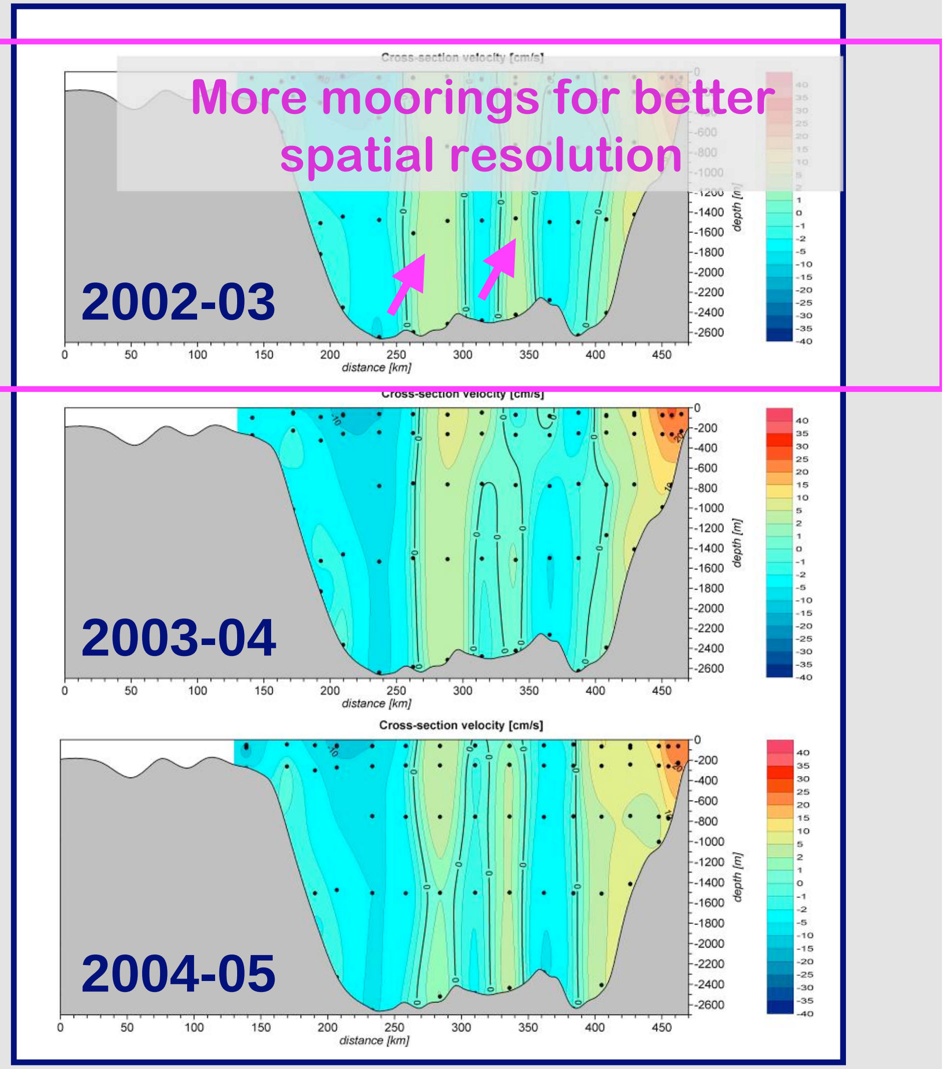




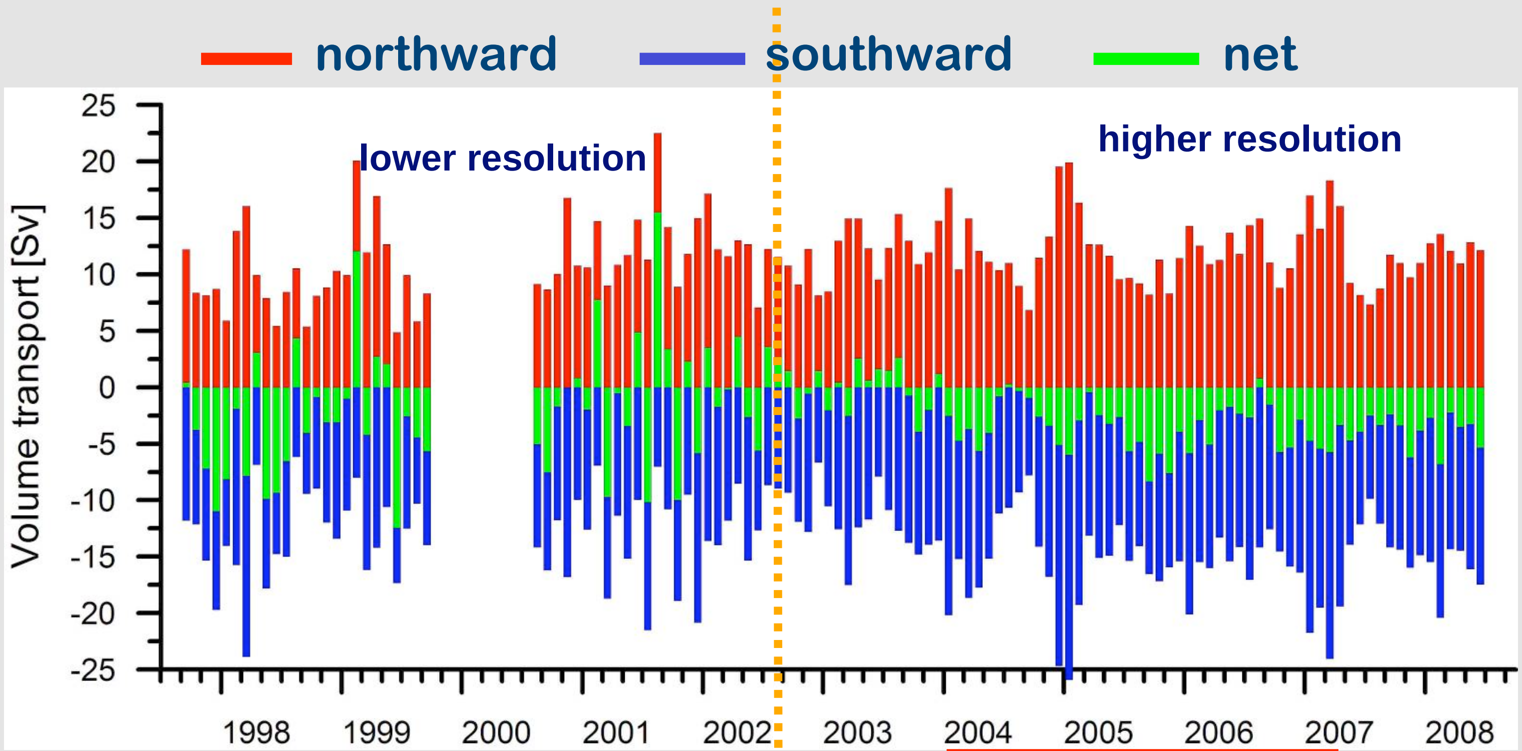


Yearly mean northward flow





• Volume fluxes through Fram Strait – monthly mean values



net mean 2.1 Sv
std 5.9 Sv

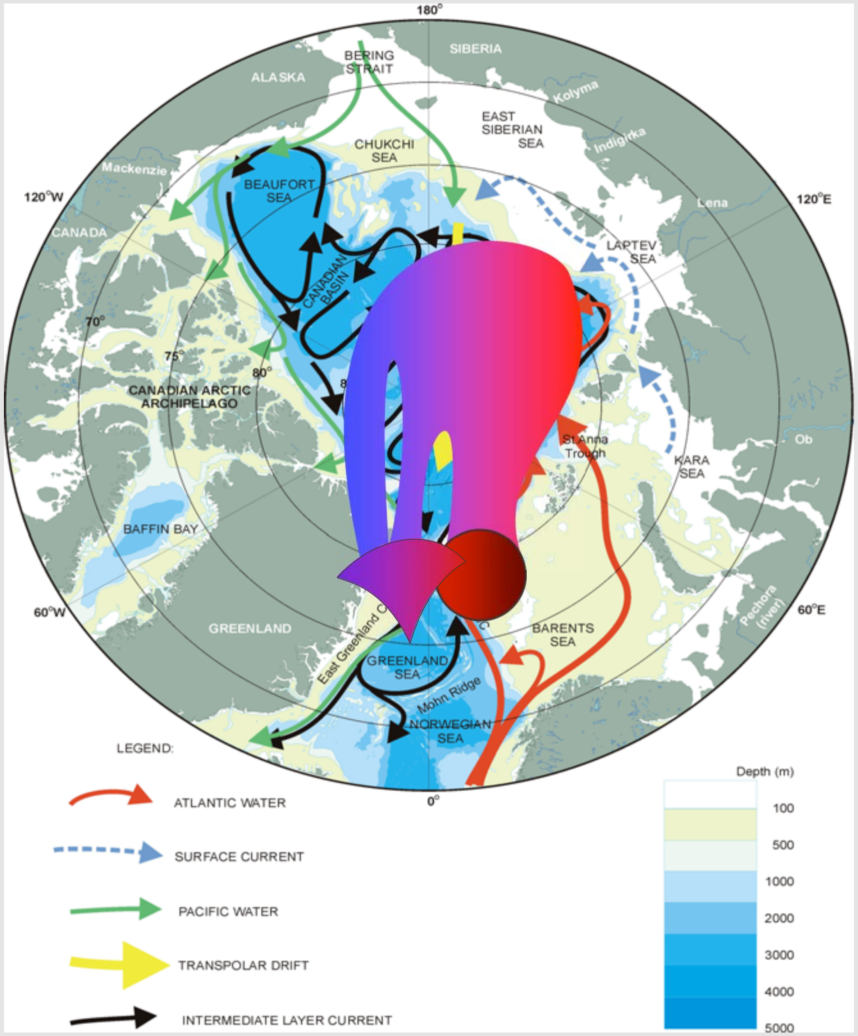
net mean 2.8 Sv
std 2.6 Sv

1 Sv = 10^6 m^3/s

- Northward/southward flow O(10 Sv)
- Barotropic
- Banded structure – topographic influence

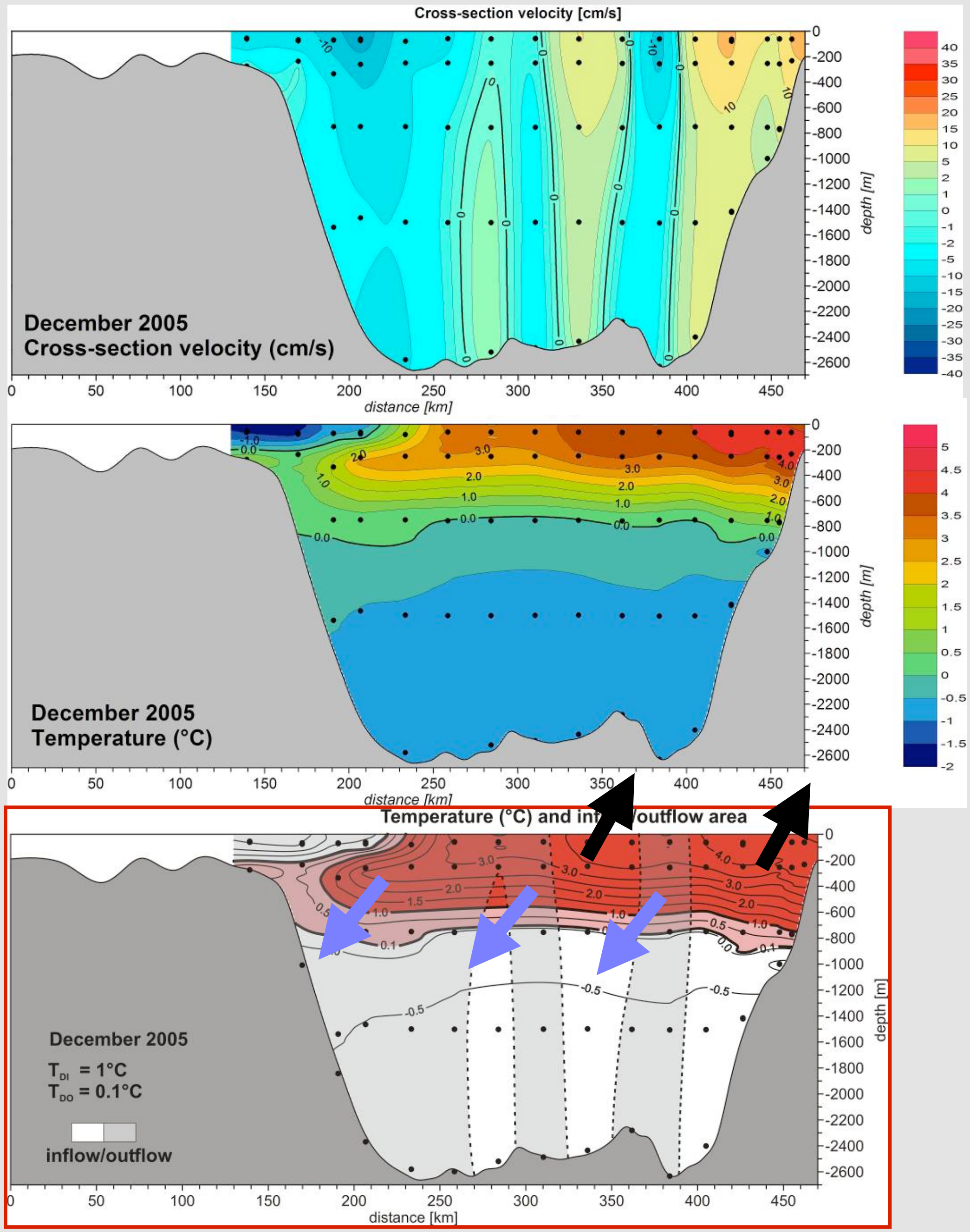
- **… Seasonal variability but no trend in volume transport**

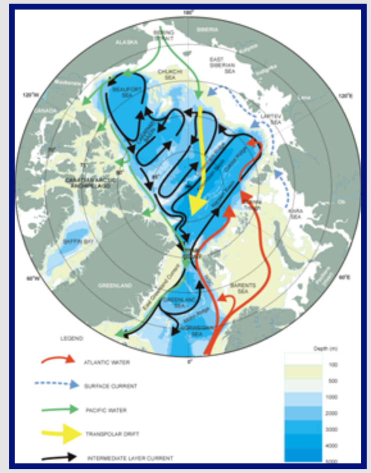
Computation of heat transport through Fram Strait only reasonable with the assumption of a stream tube



i.e. if water can be traced from inflow to outflow

• Heat transport through Fram Strait can be estimated only with assumptions …





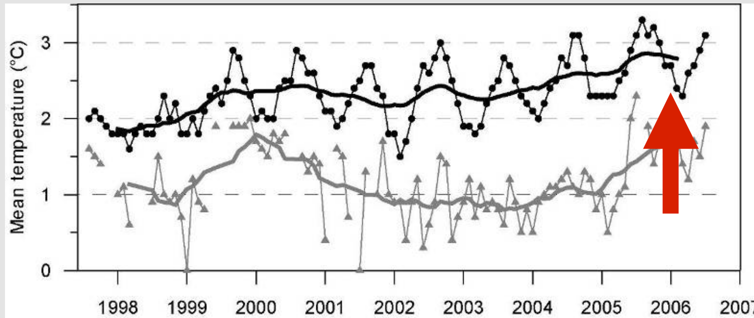
Stream tube of
Fram Strait inflow water
through Arctic Ocean:

Inflow:
Only water with T>1°C considered.
Assumption: Can only return at same temperature or colder.
Outflow:
Integrated until net volume flux is zero.

Atlantic Water (T>1°C) flow into the Arctic via the West Spitsbergen Current

Temperature of inflow

of outflow

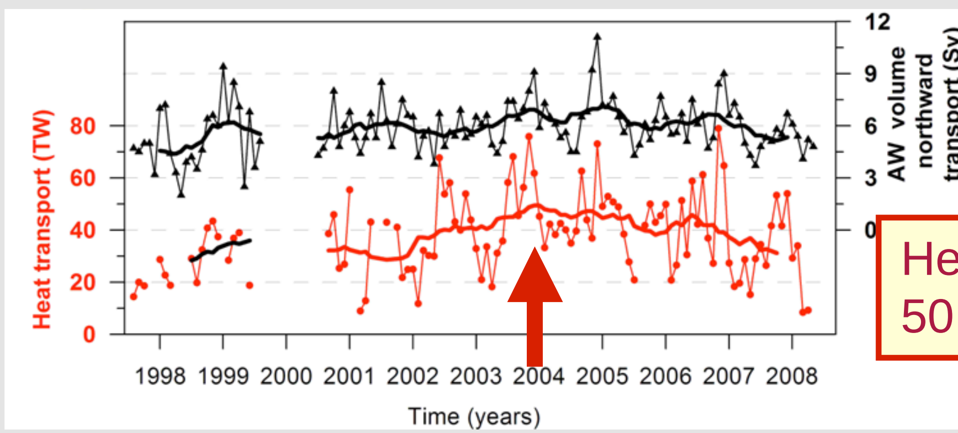


max

Inflow temperature rise from 2°C in 1997 to 3°C in 2006

But also outflow temperature increase in 2005/2006

Heat transport



max

Heat flux maximum 50 TW in 2004

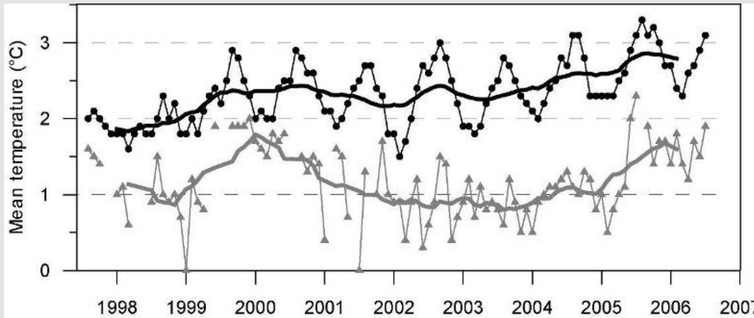
Schauer et al., 2008

Schauer et al., 2009

Atlantic Water (T>1°C) flow into the Arctic via the West Spitsbergen Current

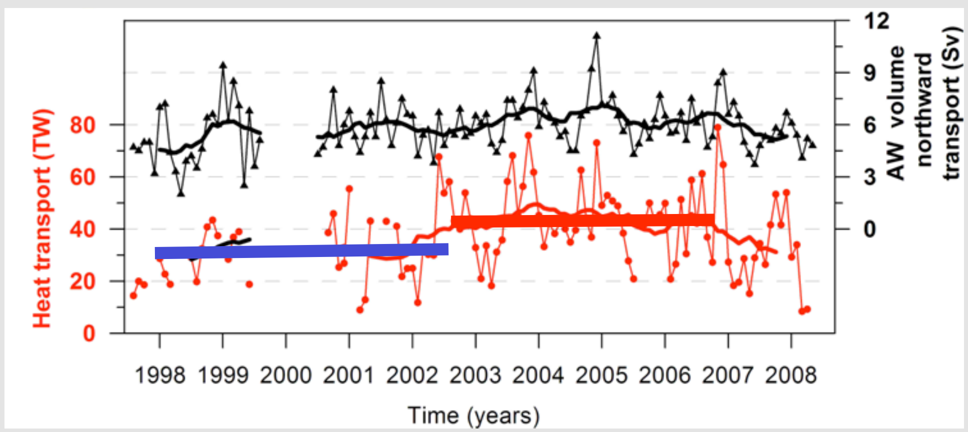
Temperature of inflow

of outflow



Inflow temperature rise from 2°C in 1997 to 3°C in 2006

But also outflow temperature increase in 2005/2006



Heat transport

40 TW for 4 years

30 TW

Additional 10 TW for 4 years = $12.6 \cdot 10^{17}$ kJ

Schauer et al., 2008

Schauer et al., 2009

• Variability of heat transport through Fram Strait

Computational:

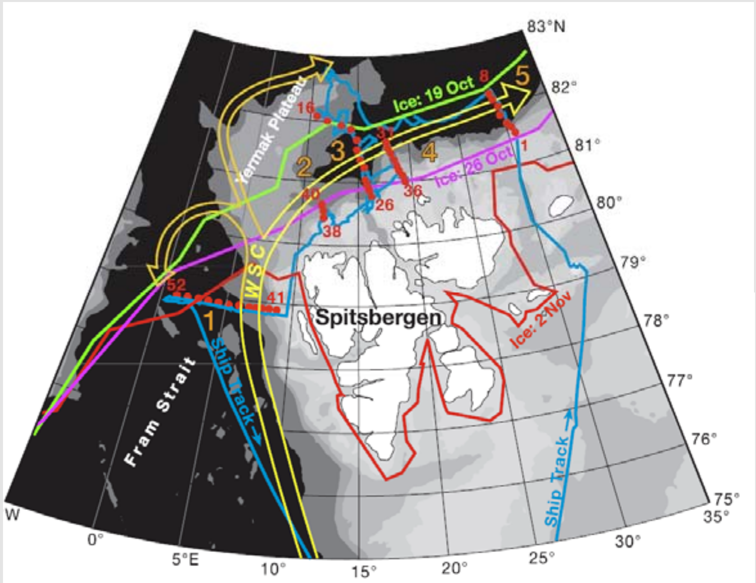
12.6×10^{17} kJ corresponds to 4 m of ice melt in Eurasian Basin (10^{12} m^2)

Sink
Heat loss to ice
and/or atmosphere

$$Heat\ transport\ through\ Fram\ Strait = \frac{\partial H}{\partial t} + S(t)$$

Arctic warming
Quadfasel et al. 1991
Morison et al., 2000
Schauer et al., 2002
Morison et al., 2005:
…

Heat loss north of Svalbard?



Cokelet et al., 2008:
October 2001
520 W/m² in upper 500 m
over 500 km *100 km.

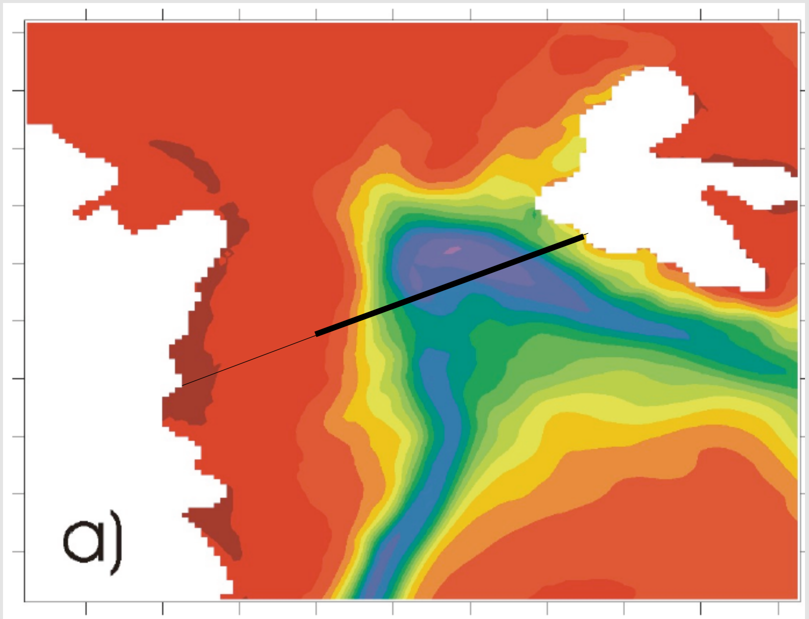
➔ **26 TW**

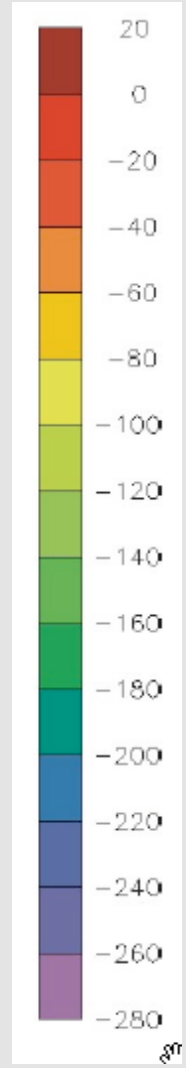
Heat flux through Fram Strait before 2002 about **30 TW**.

Compares well, but 500 W/m2 considered too high by atmospheric community.

Heat loss in northern Fram Strait?

NAOSIM (1/12 deg) simulation





Annual mean (1995 – 2004)
surface heat flux (in Wm-2)

Fieg et al., submitted

• What balances the variable heat transport through Fram Strait?

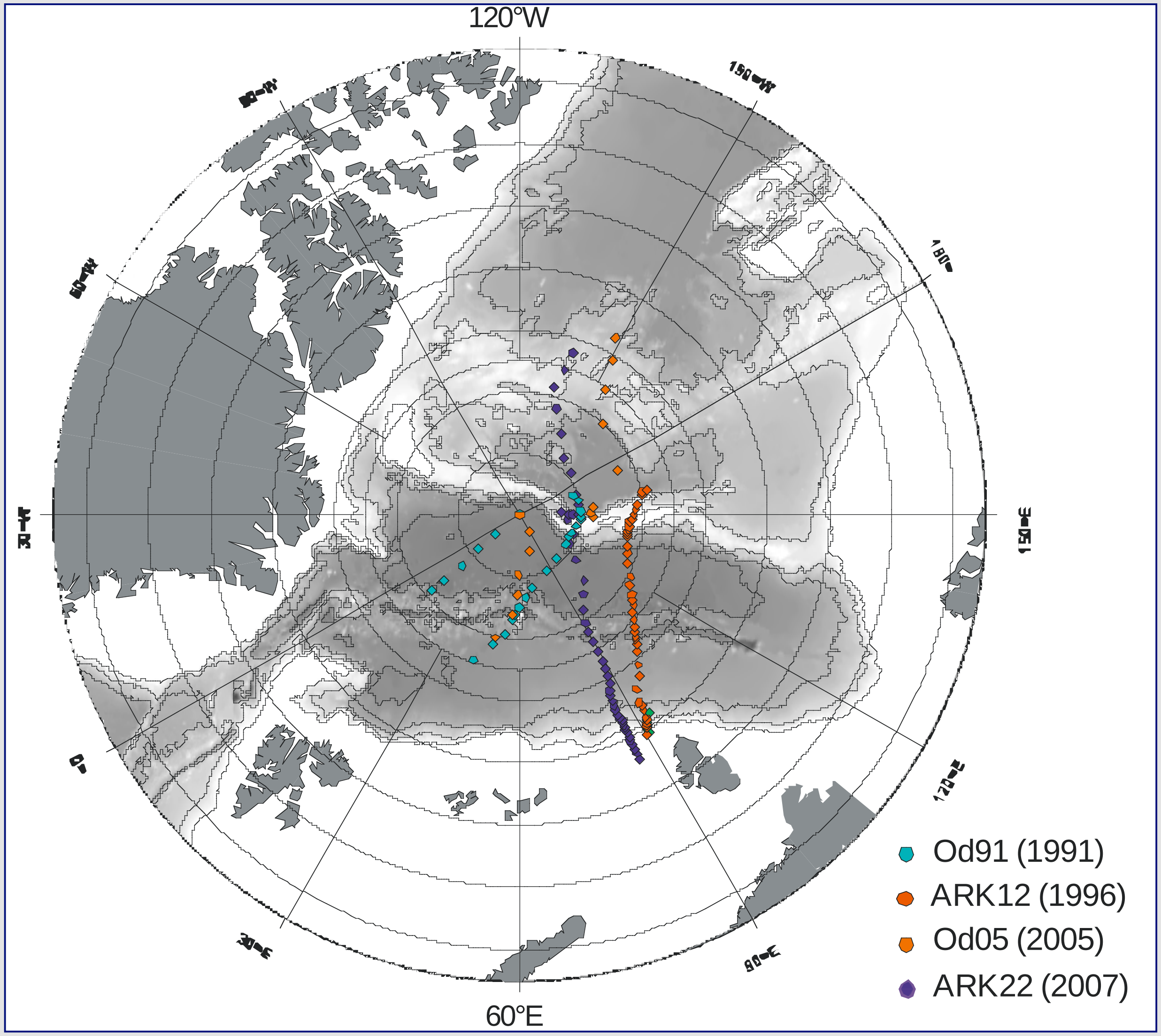
Heat flux through Fram Strait
Before 2002 about 30 TW, after 2002 about 40 TW

=> Additional 10 TW for 4 years = 12.6*10^{17} kJ

$$S_{normal} = \oint_{(t)} dy \int_{0}^{Z(t)} c_p \cdot \rho \cdot v_{\perp}(y,z,t) T(y,z,t) dz$$

S: Sink

Changes of ocean properties in the Eurasian Basin since 1991

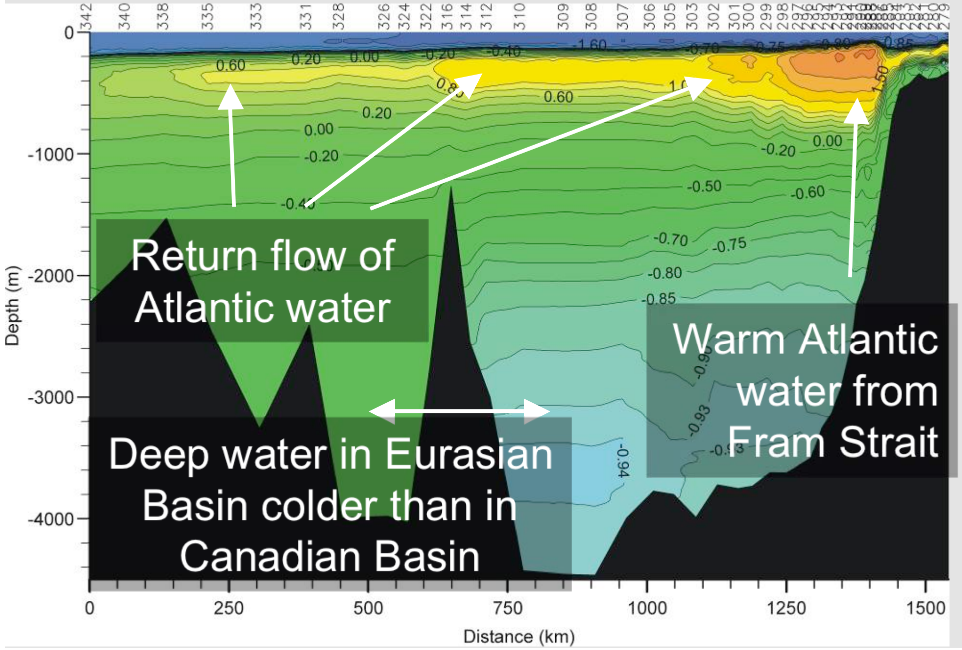


Assumption: Sections represent Basin Properties

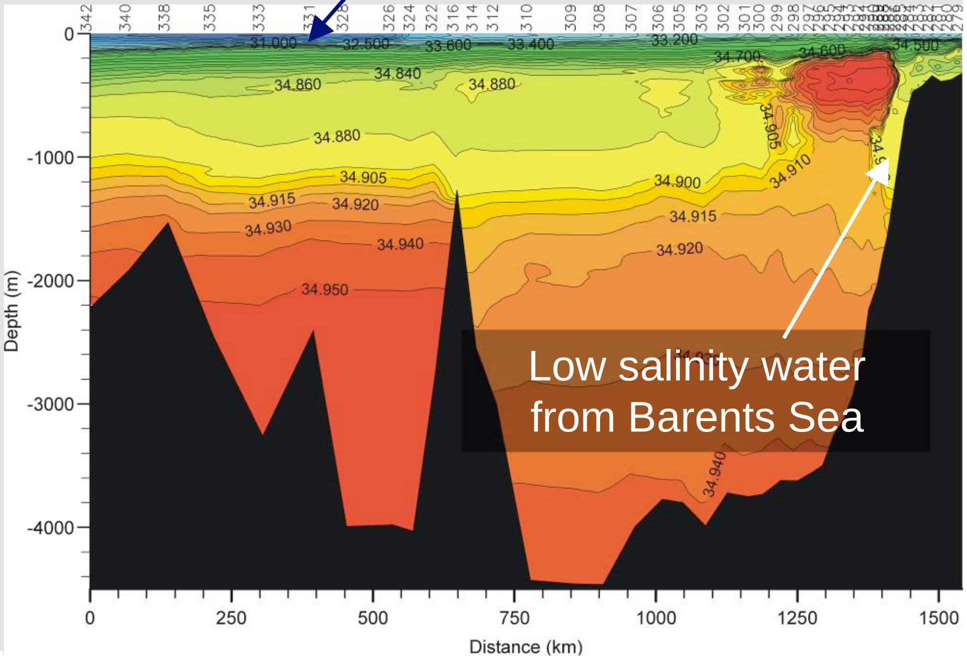
Photo: Stefan Kern

Central Arctic section - Polarstern 2007

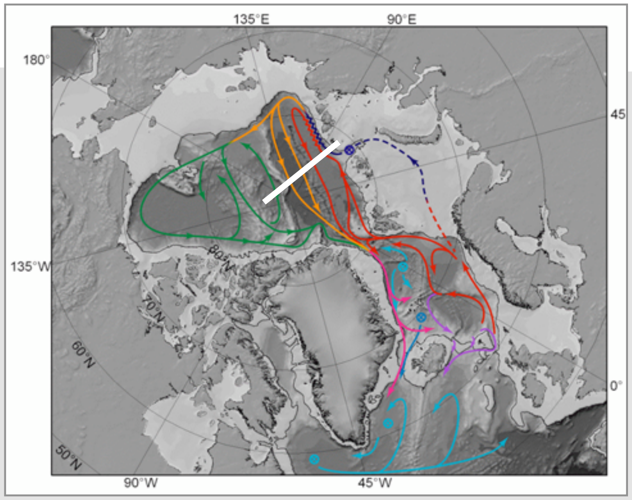
Fresh water – high stratification



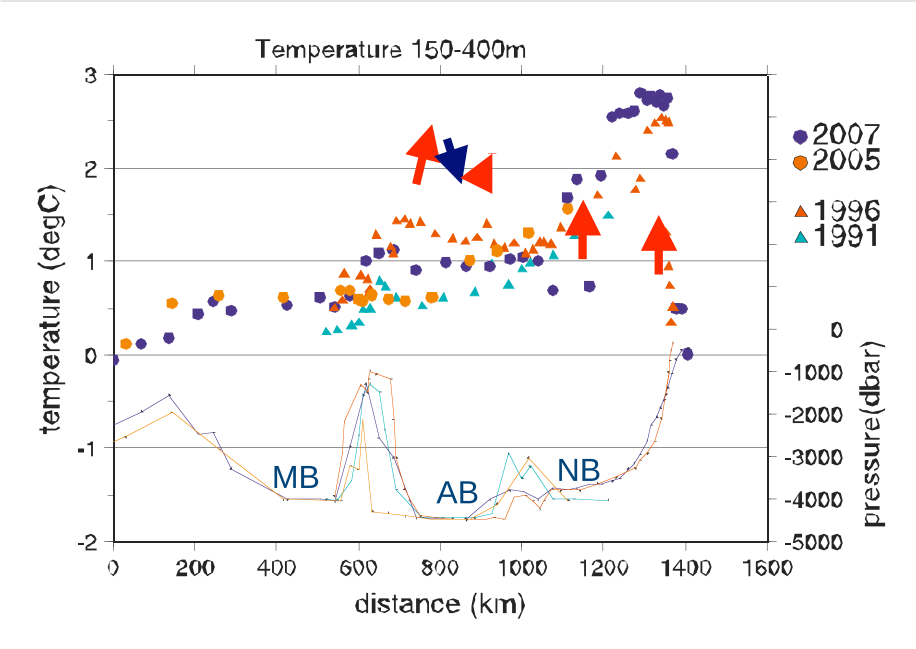
Temperature

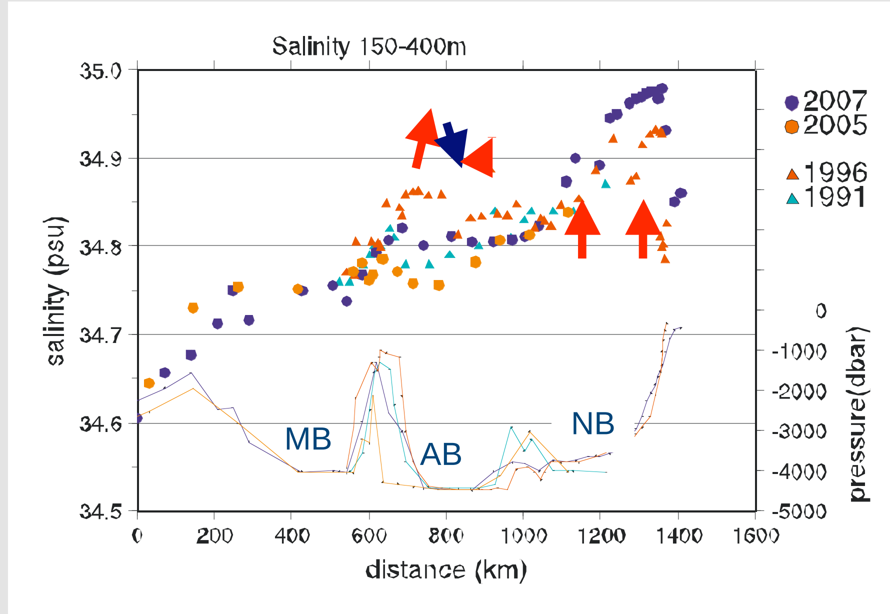


Salinity



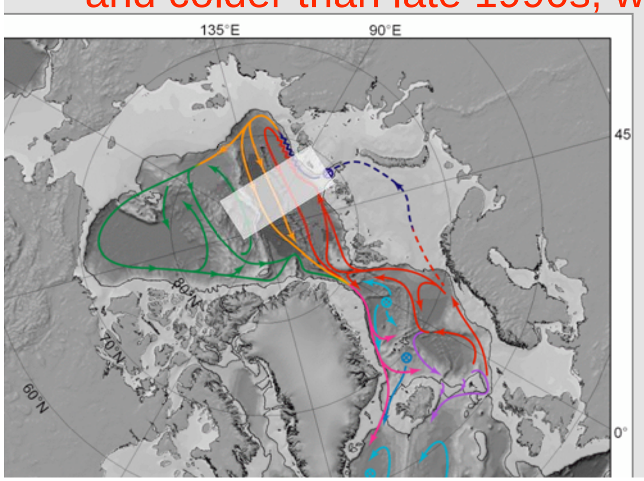
Atlantic Water (warm core, 150 – 400 m)





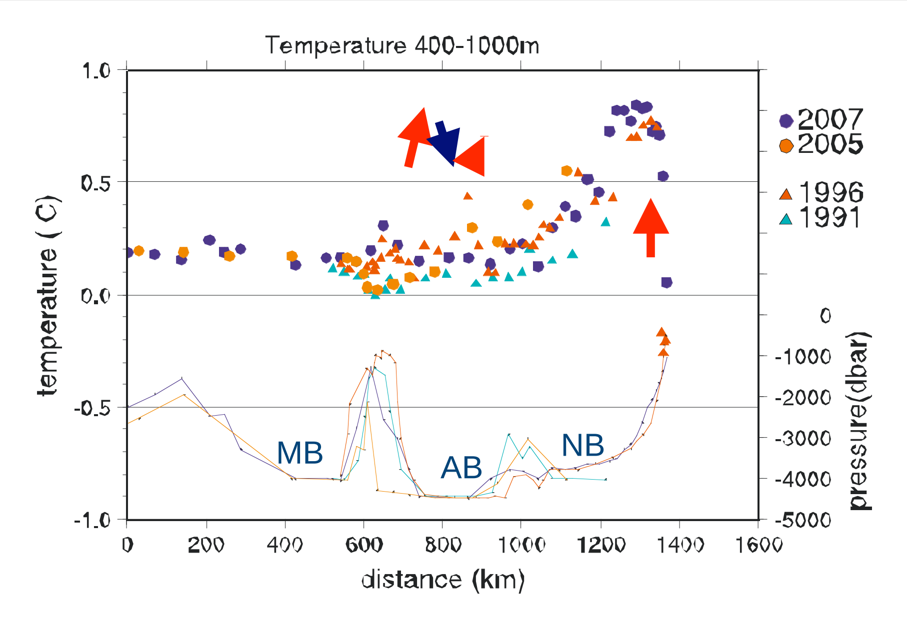
- AW boundary current warmer and more saline
- Return flow in Nansen B warmer by 0.5K and more saline
- Return flow in Amundsen B warmer than early and colder than late 1990s, warmer than 2005

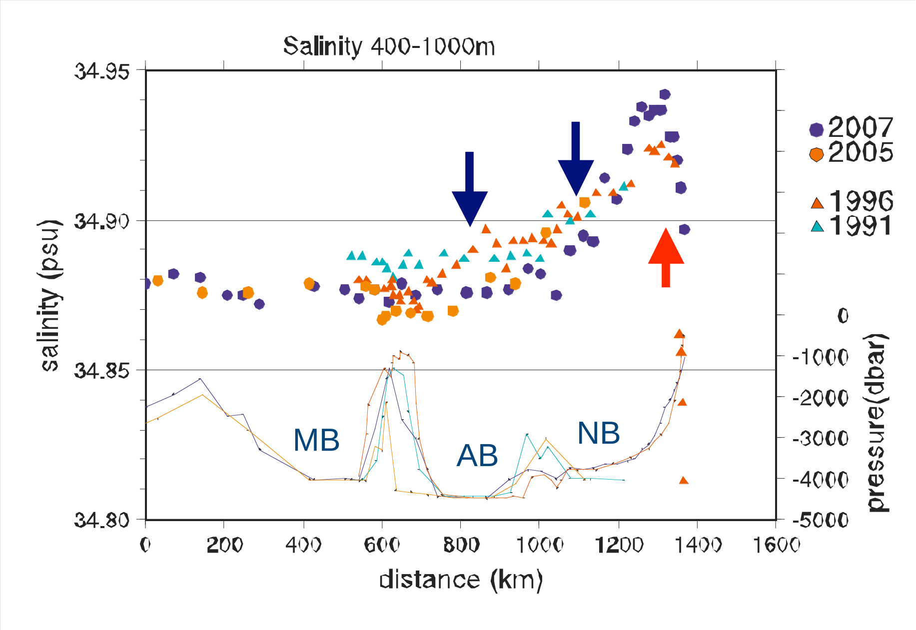
Nansen Basin
Area ca. 0.5 * 10^6 km^2



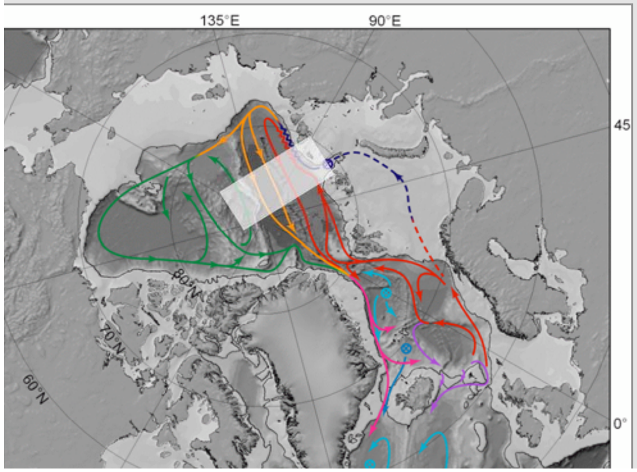
Heat increase = 2.5 *10^{17} kJ

Atlantic Water (lower part, 400 -1000 m)



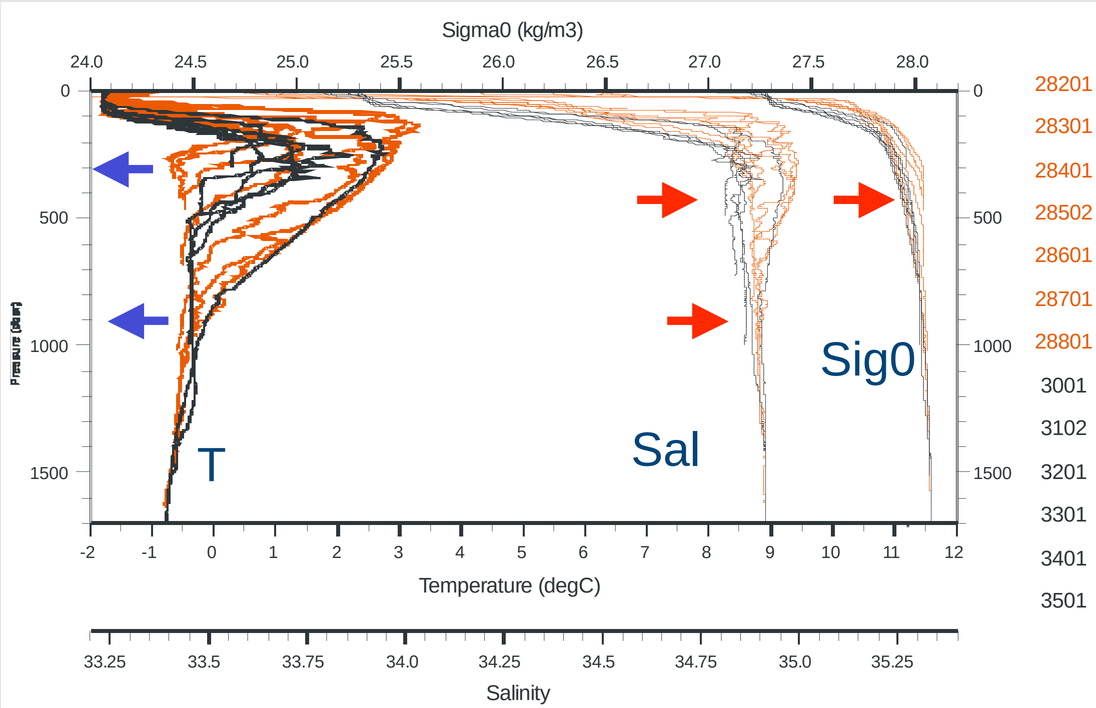


- Same tendencies in BC and Nansen Basin (dT=0.2K)
- Similar T change in Amundsen B return flow



Heat increase = 2.4 $*10^{17}$ kJ

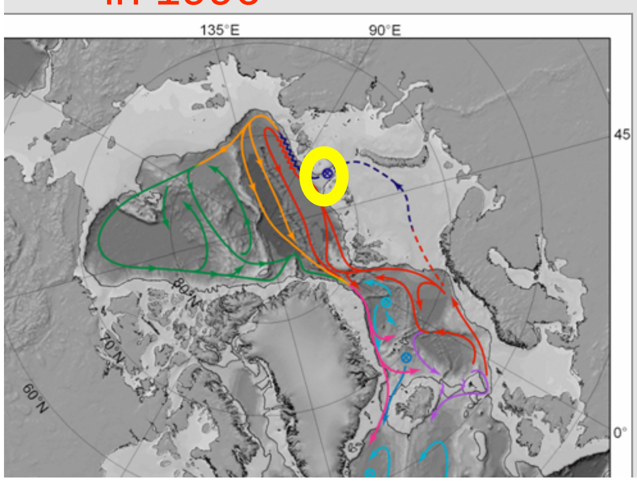
Inflow of Barents Sea branch of Atlantic Water

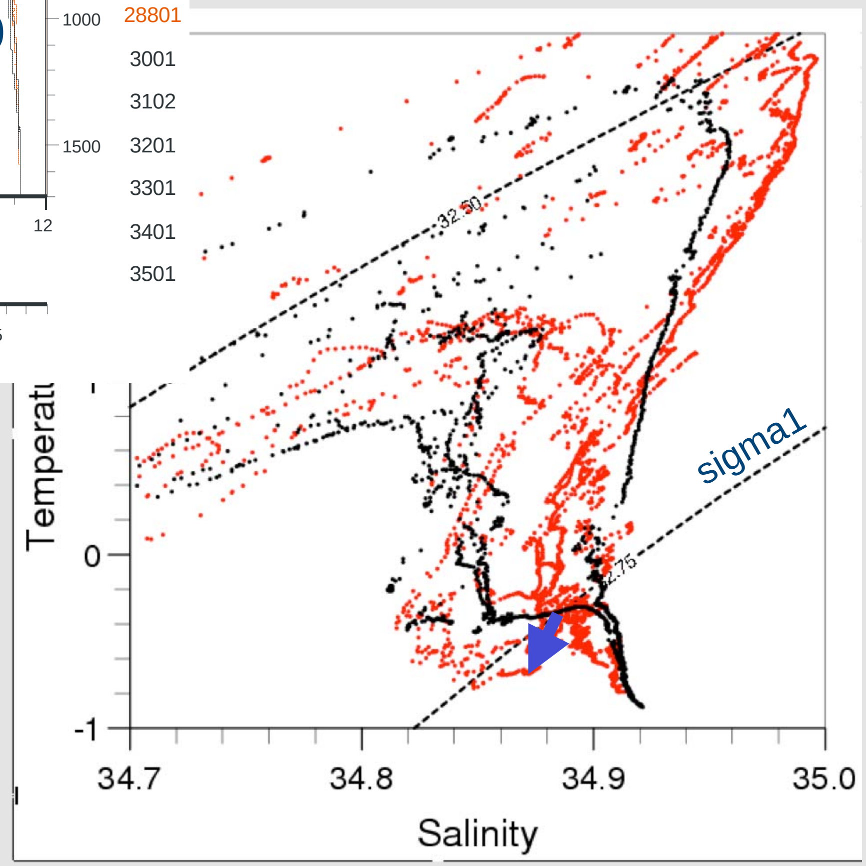


28201
28301
28401
28502
28601
28701
28801
3001
3102
3201
3301
3401
3501

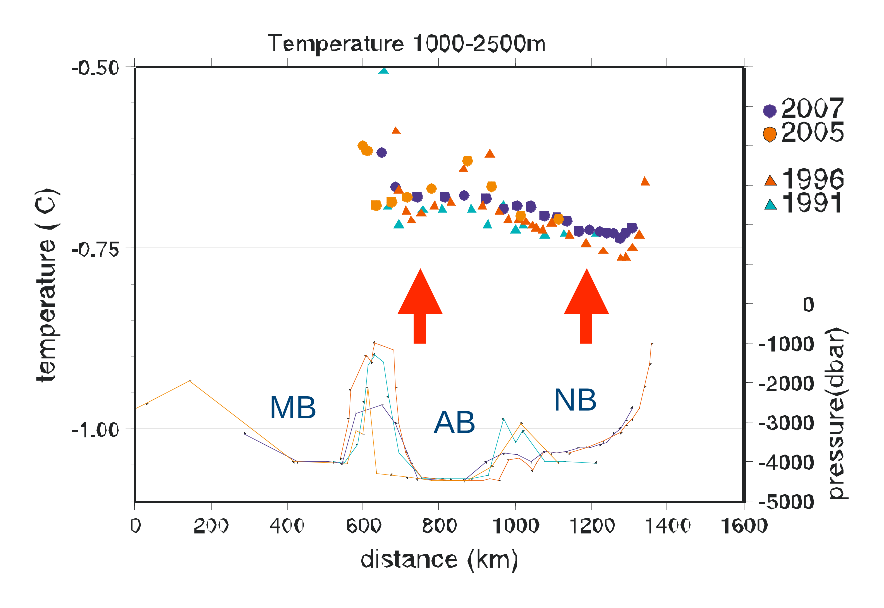
1996
2007

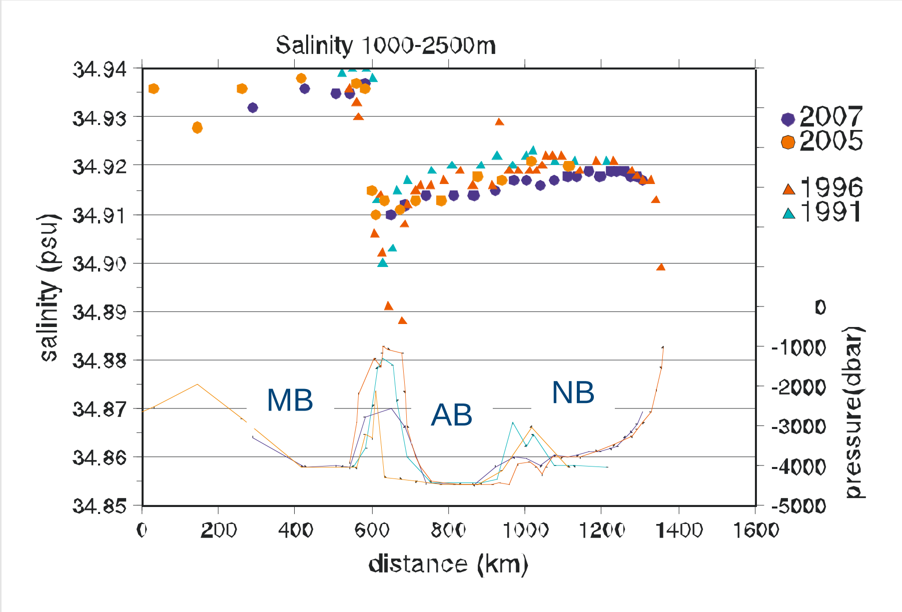
Barents Sea inflow **colder** in 2007 than in 1996





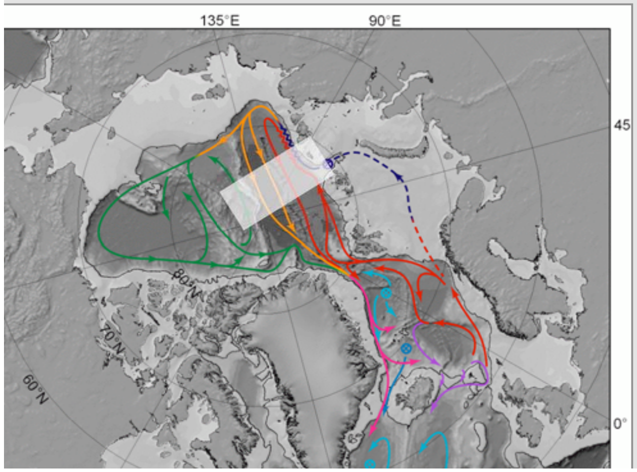
Deep Water (1000 – 2500 m)





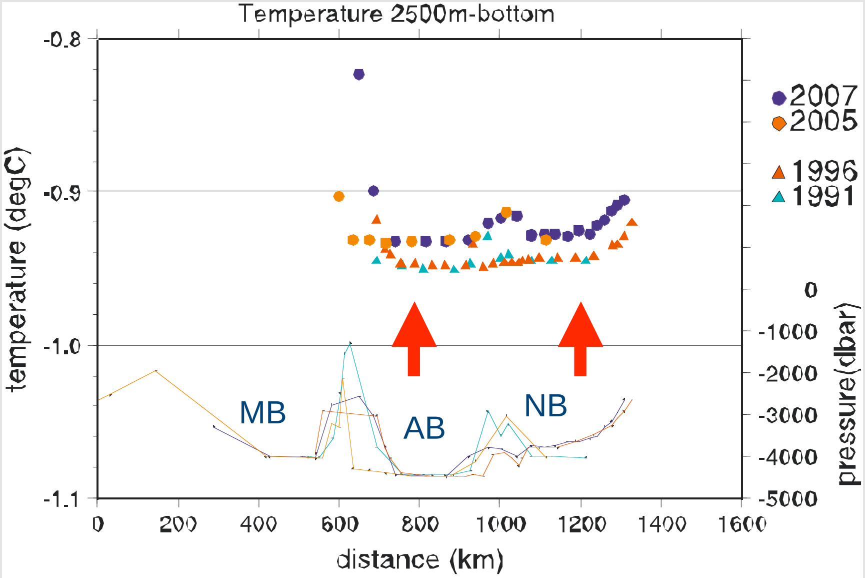
Increase by 0.02K in Nansen Basin

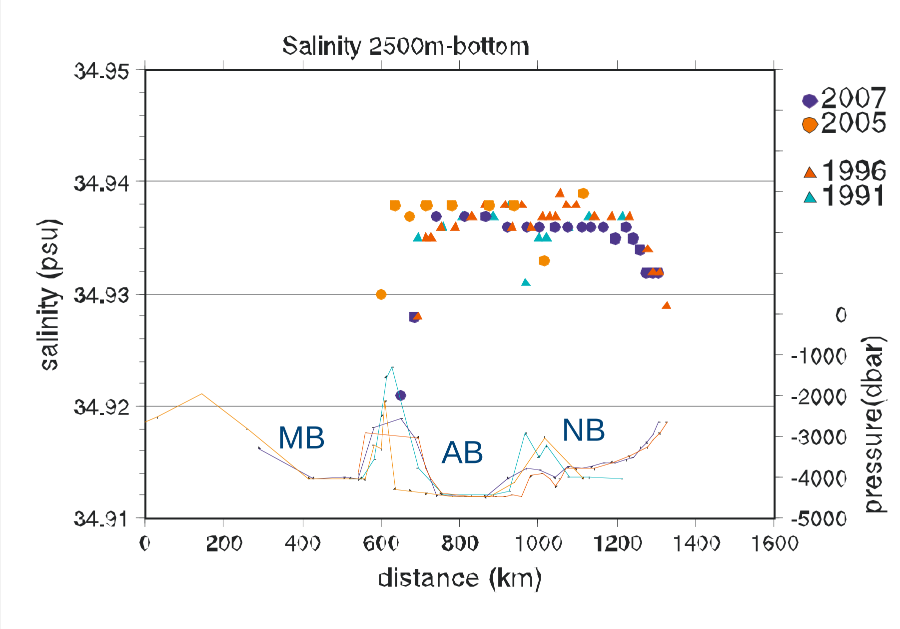
Decrease in salinity (approx. 0.01 psu) in both basins



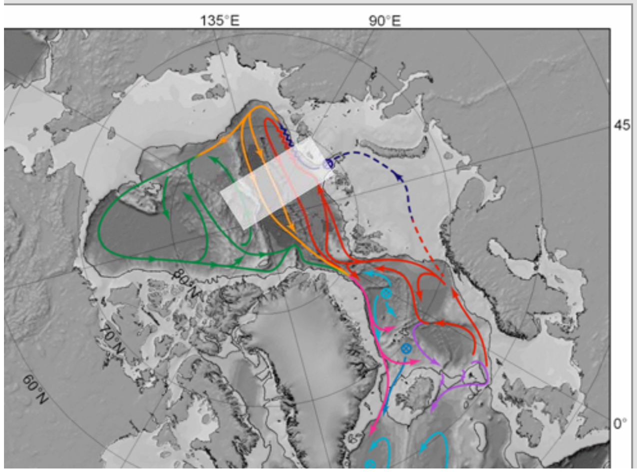
Heat increase = 0.6 *10^{17} kJ

Bottom Water (2500 m to bottom (up to 4500 m))





Both basins warmer by 0.02 °C



Heat increase = $2*10^{17}$ kJ

• Heat balance

Fram Strait additional 10 TW for 4 years = $12.6 \cdot 10^{17}$ kJ

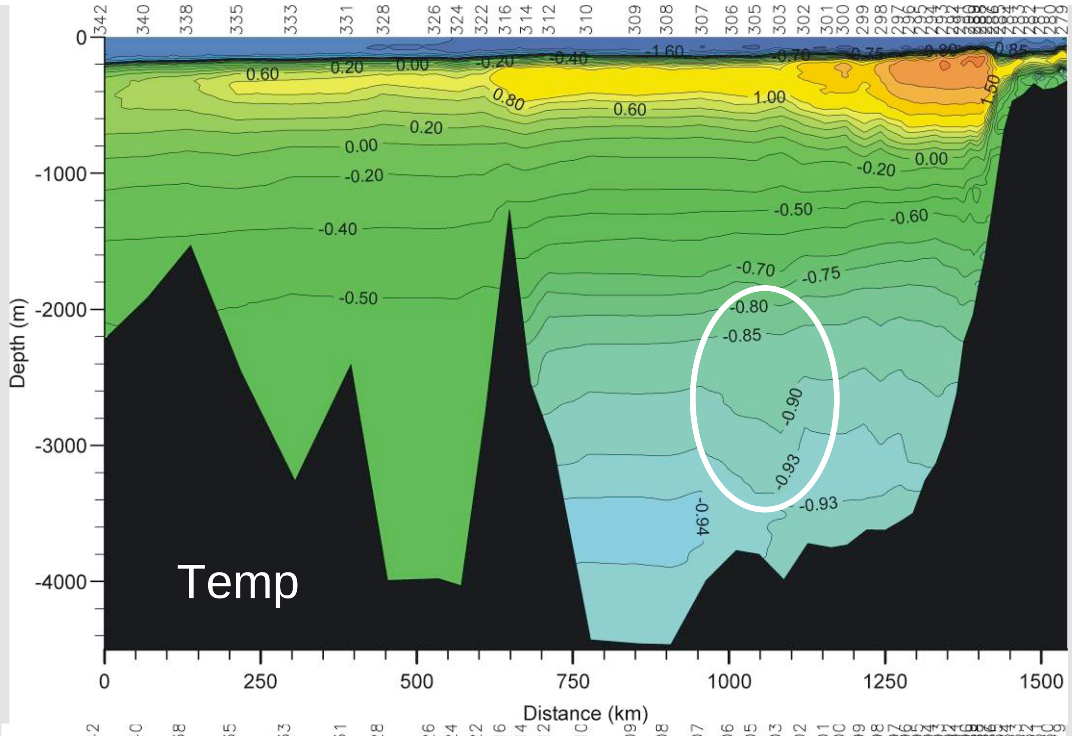
$$\frac{\partial H}{\partial t} + S(t) = heat\ transport\ through\ Fram\ Strait$$

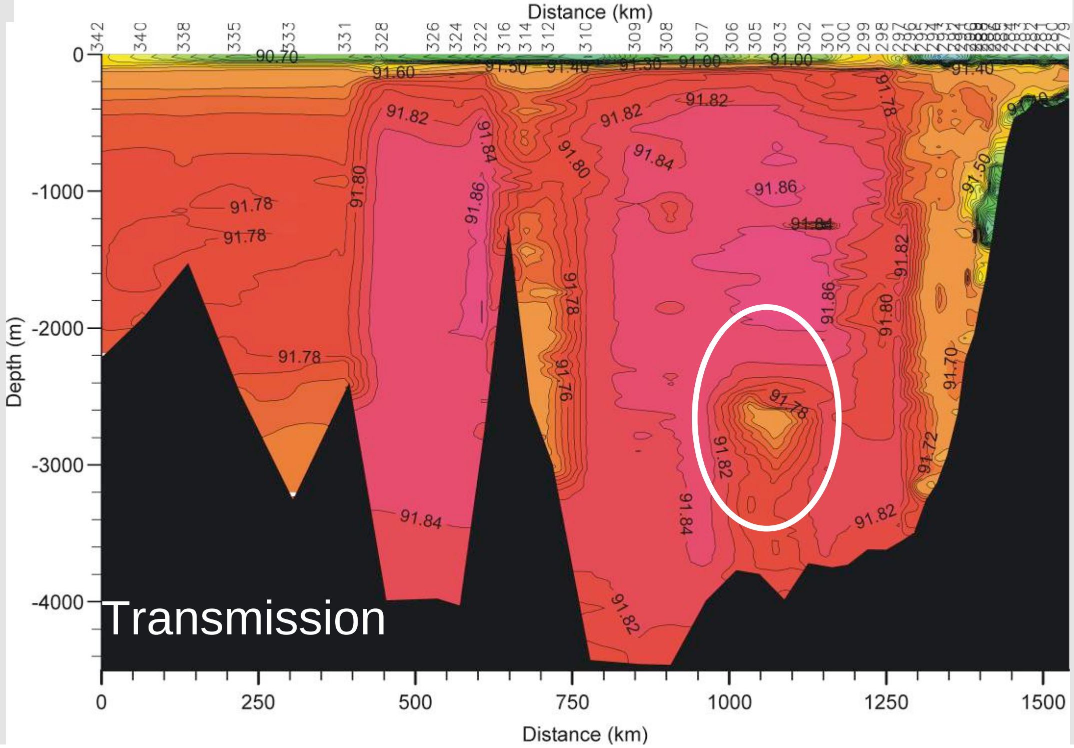
AW core	2.5E+17 kJ
AW deep	2.4E+17 kJ
EBDW	6E+16 kJ
EBBW	2E+17 kJ
	7.5E+17 kJ

Increased heat loss to ice and/or atmosphere?

Refers to 60% of the additional heat transport

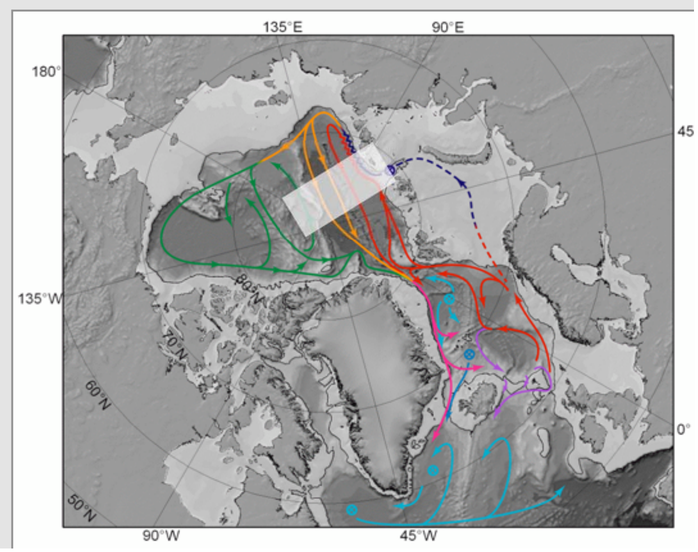
Missing:
Estimate of warming in the Canadian Basin.



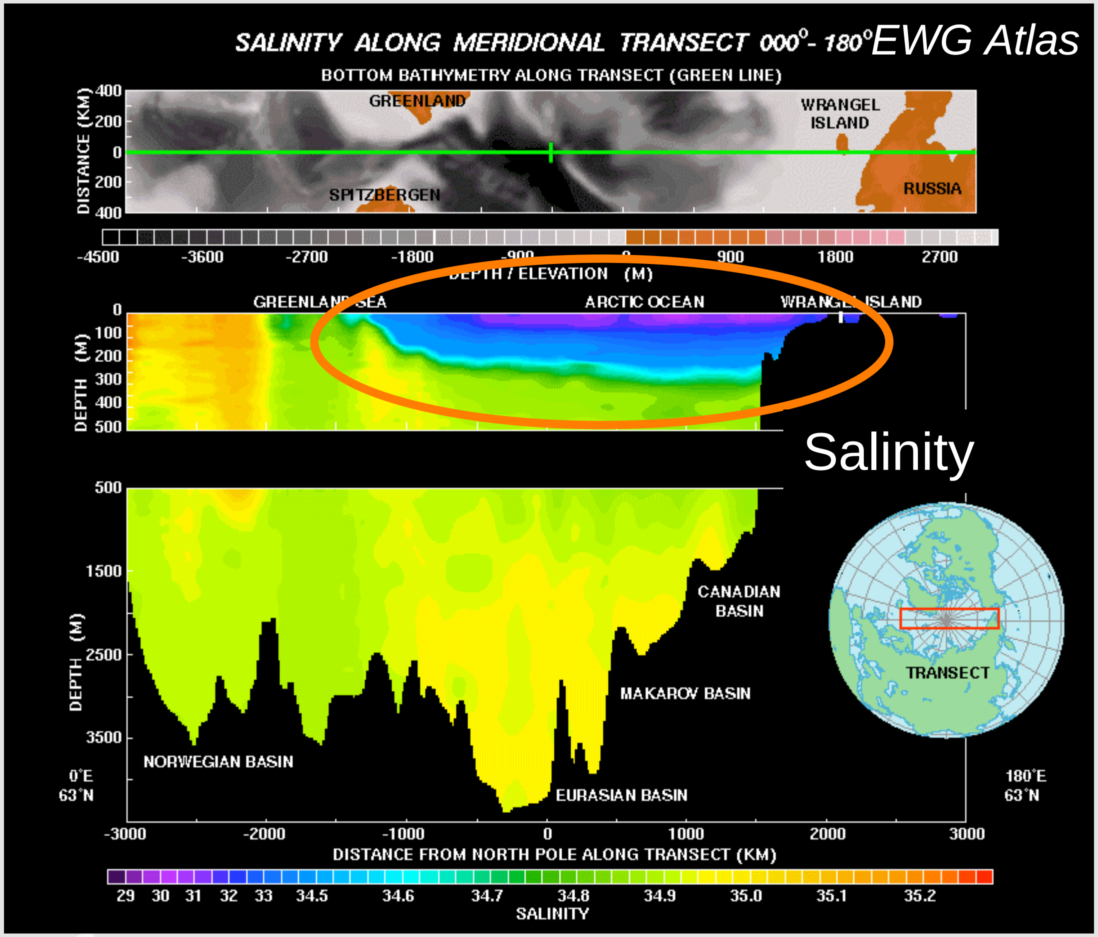


Section 3 2007

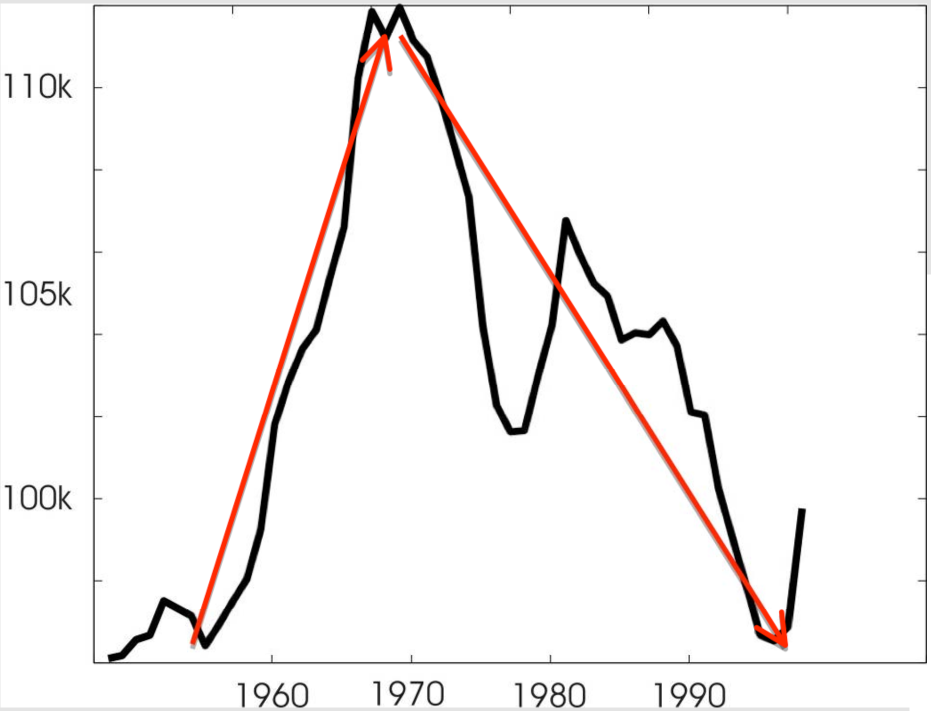
Deep water warming through variable geothermal heating?



Upper fresh water layer (Polar water)

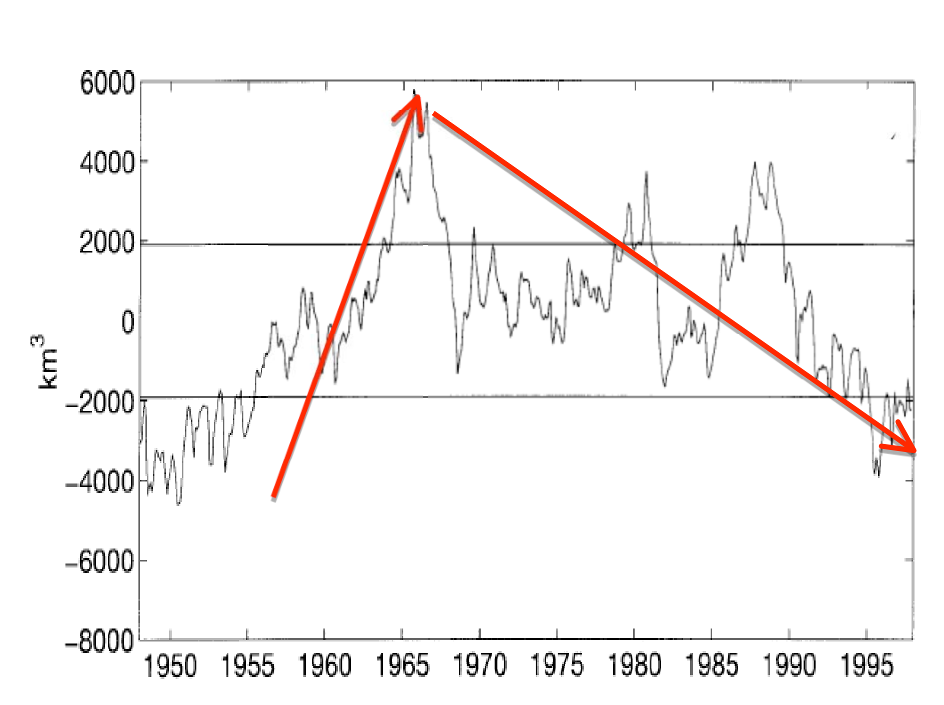


NAOSIM - Simulated Arctic fresh water content 1950 - 2000



Liquid fresh water content

Sea ice volume

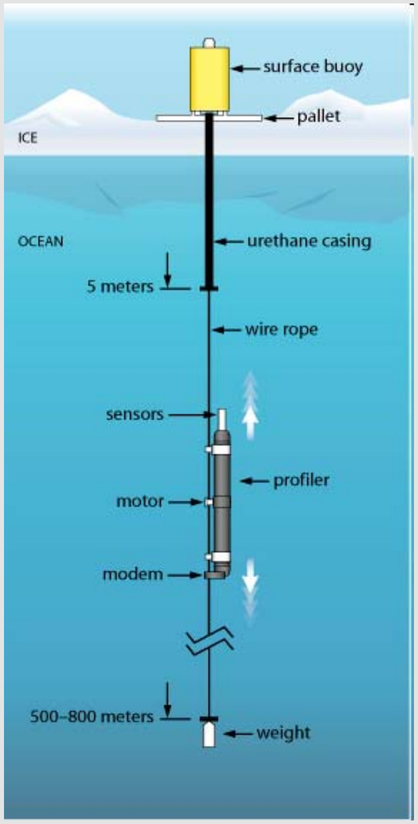


Köberle and Gerdes, 2007

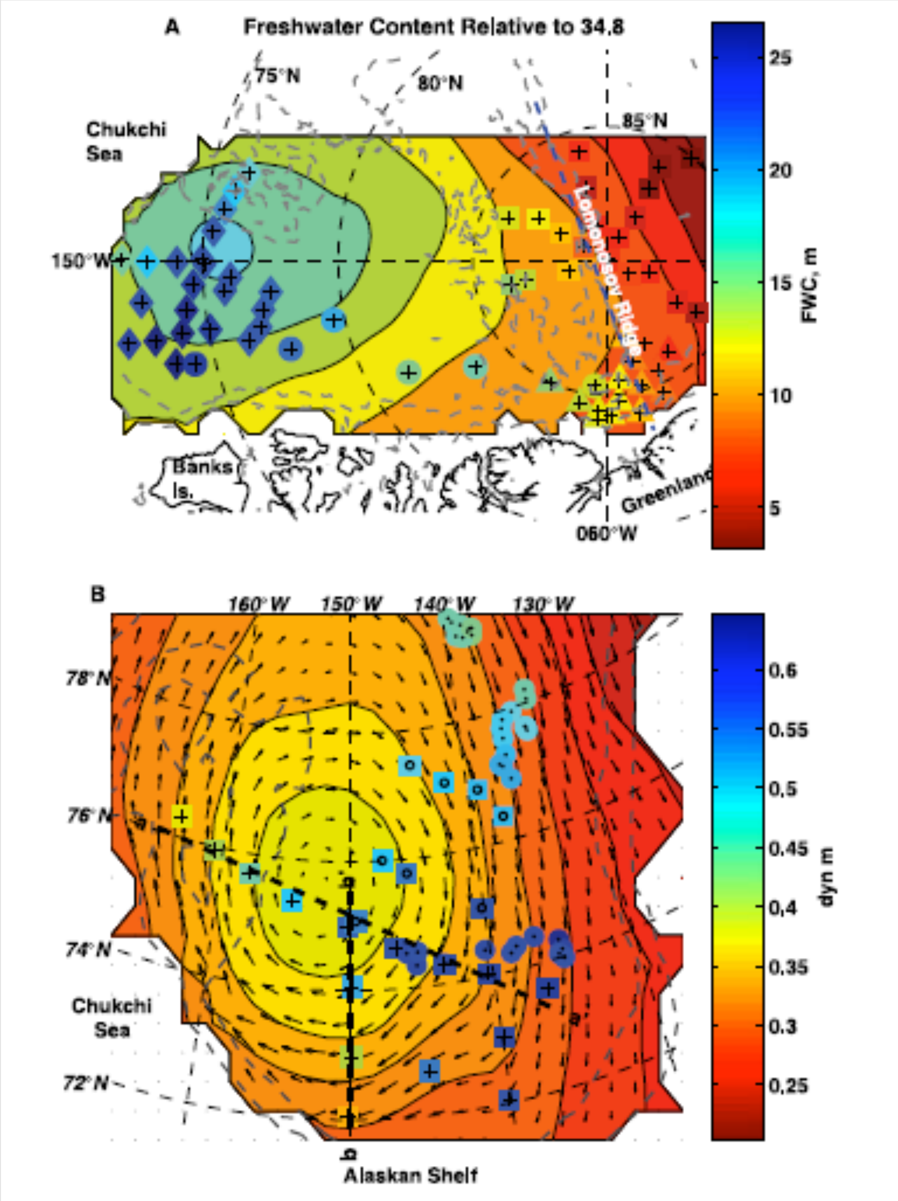
Freshwater circulation

Shipborne, airborne, submarine CTD

IPY 2007/08:
Deployment of 17 Ice-tethered platforms
International effort



Freshwater accumulation in the Canada Basin



Increase of up to 11 m FW (Sref =34.8) as compared to EWG climatology

… causes strong surfcae geostrophic flow towards Fram Strait and Canadian Archipelago

McPhee et al., 2009

Summary

- Temperature anomalies advected from subpolar Atlantic

- Heat transport computation through Fram Strait possible only with fierce assumptions
=> 20 - 30 TW late nineties, increase by 30% during early 2000s

- Eurasian Basin warming explains 60% of the *increased* heat transport in the early 2000s (more if Canadian Basin warming is included)

- The remaining 40% (or less if …) probably increase of the heat loss north and west of Svalbard (from 30 TW to 35 TW).

- Strong warming of deep and bottom waters: Other heat sources?

- Freshening of the Arctic during 2000s – mostly in the central part