On Arctic Ocean dynamics and its linkages with lower latitudes

Michael Karcher

With contributions from

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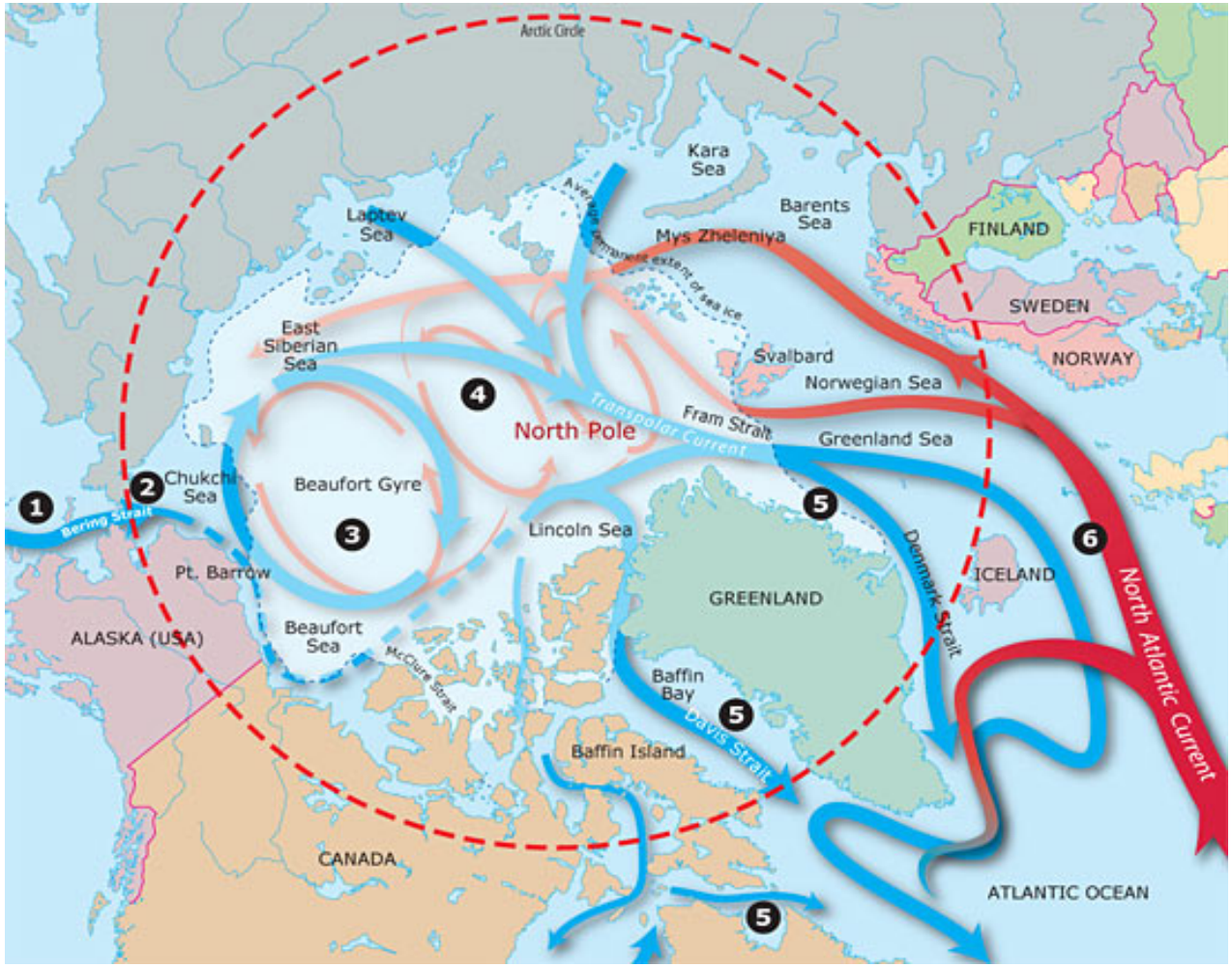
Rüdiger Gerdes, Ursula Schauer, John. N. Smith

Arctic ocean circulation

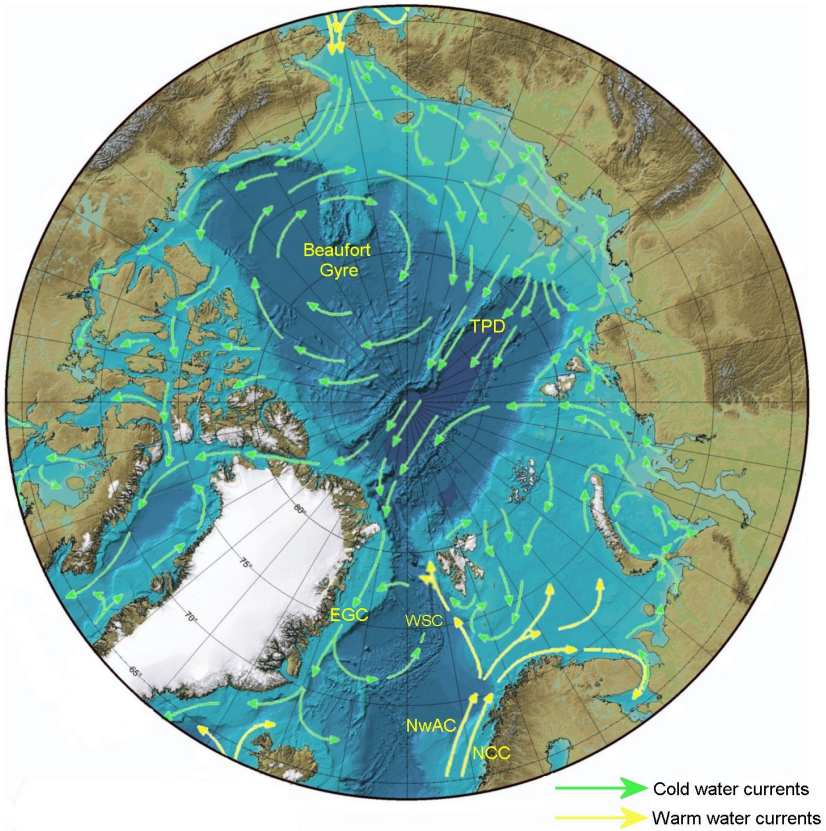


source: WHOI (following Rudels et al. 94)

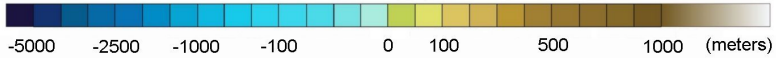
Outline

- Variability of Arctic Ocean circulation
- Freshwater storage and release
- Warm and saline
- Mid-depth outflows.

Arctic Ocean surface circulation



Bathymetric and topographic tints

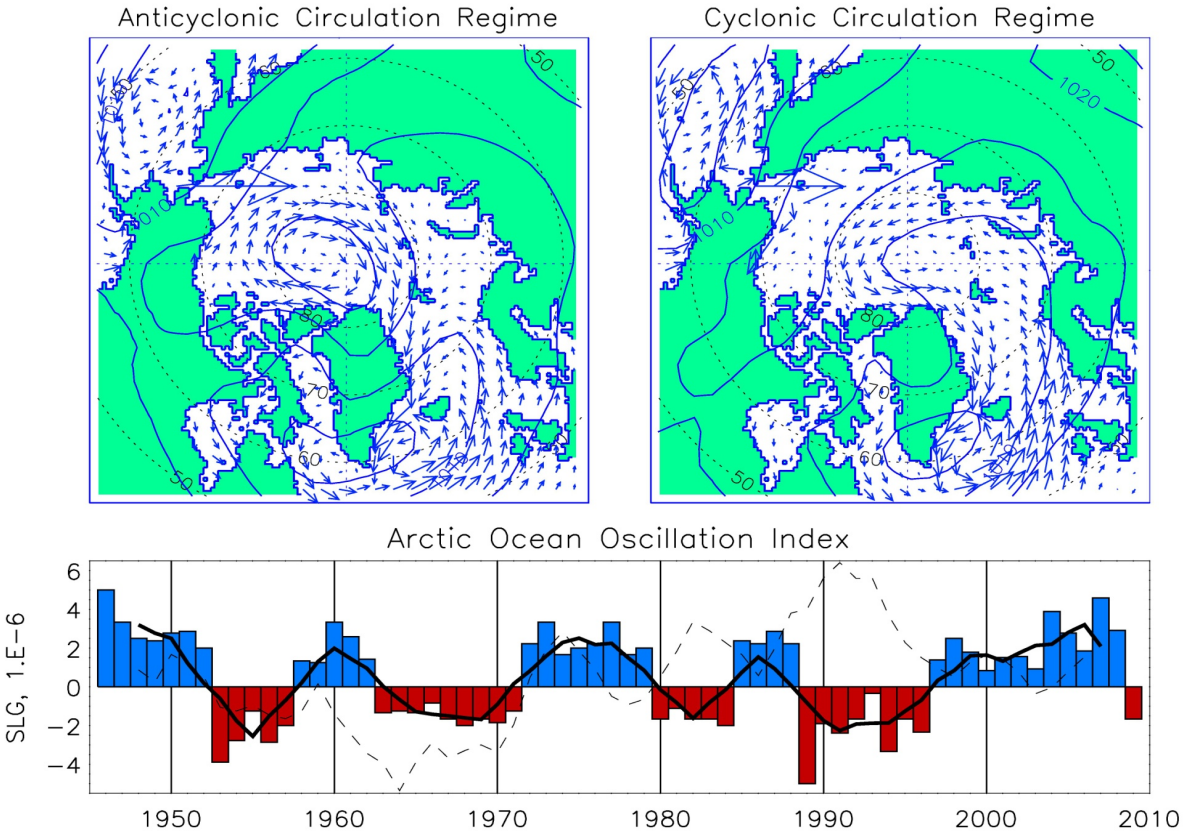


EGC - East Greenland Current WSC - West Spitsbergen Current
NwAC - Norwegian Atlantic Current NCC - Norwegian Coastal Current
TPD - Transpolar Drift

Map: IBCAO

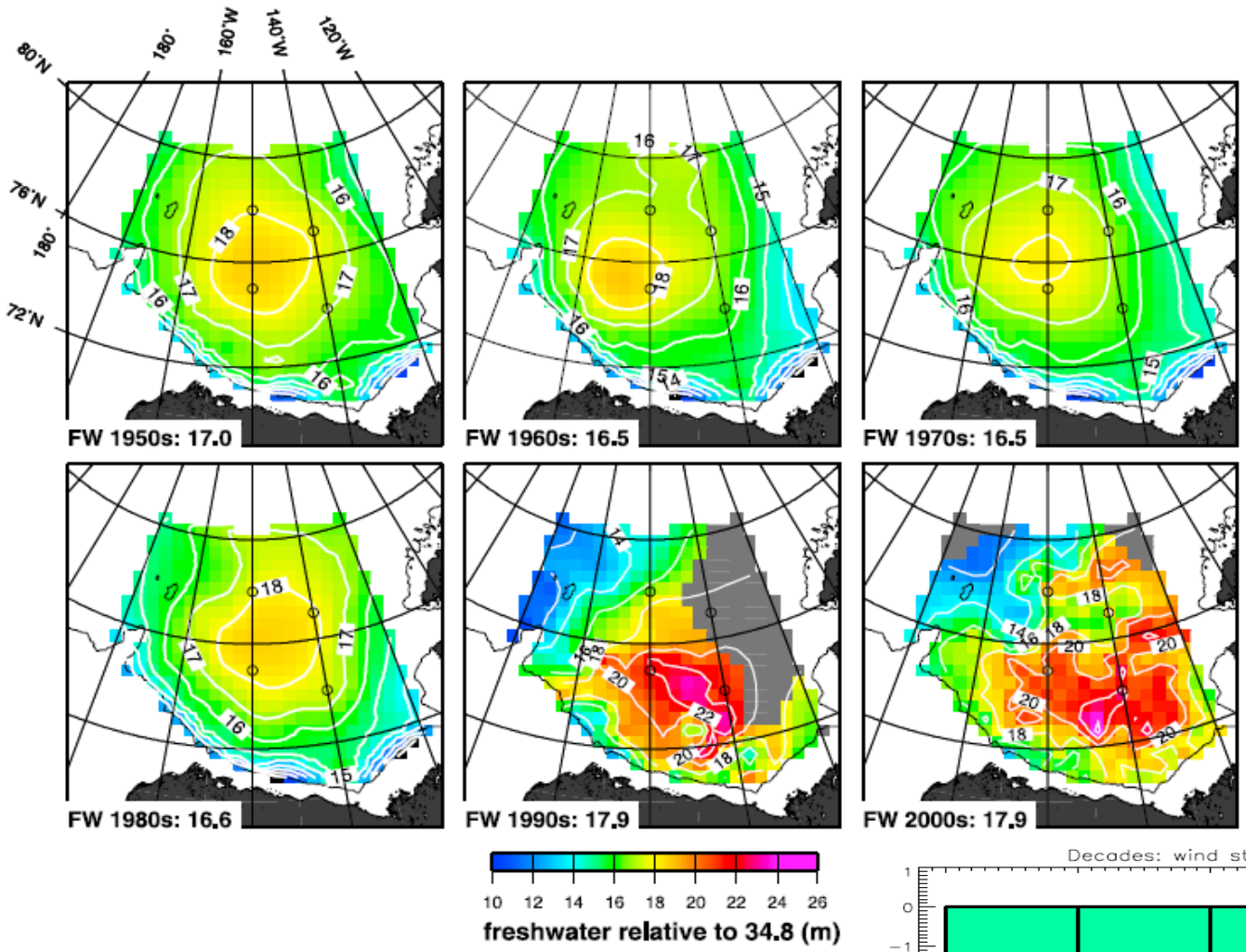
Arctic Ocean surface circulation: modes

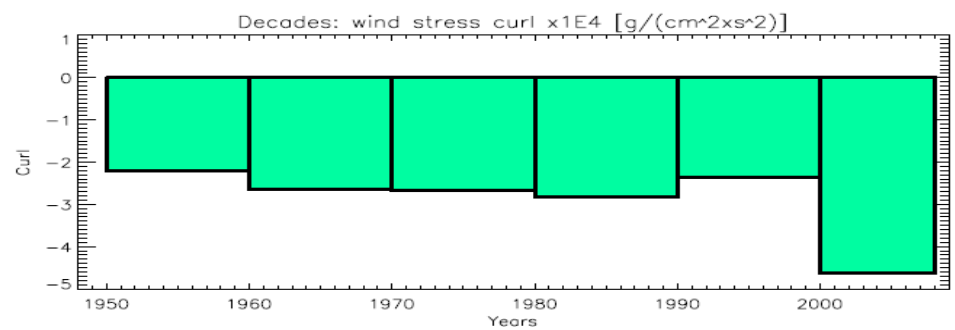
Two modes of circulation



(Proshutinsky et al. 2002)

FWC in the BG: decadal wind stress curl changes

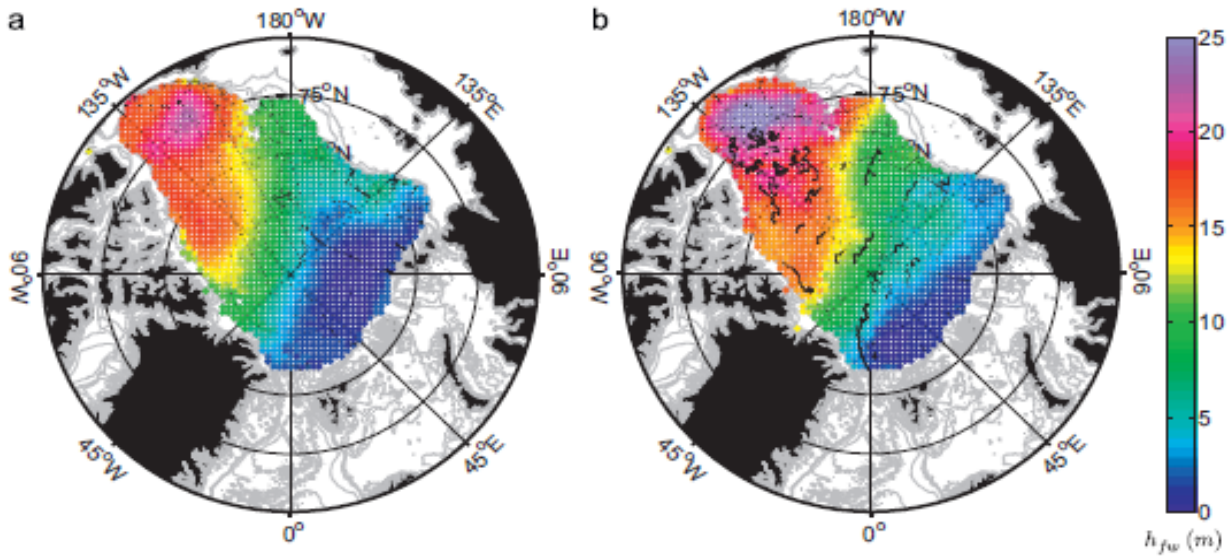




(Proshutinsky et al., 2009)

Freshwater content JAS 2006-08 vs 1992-99

92-99

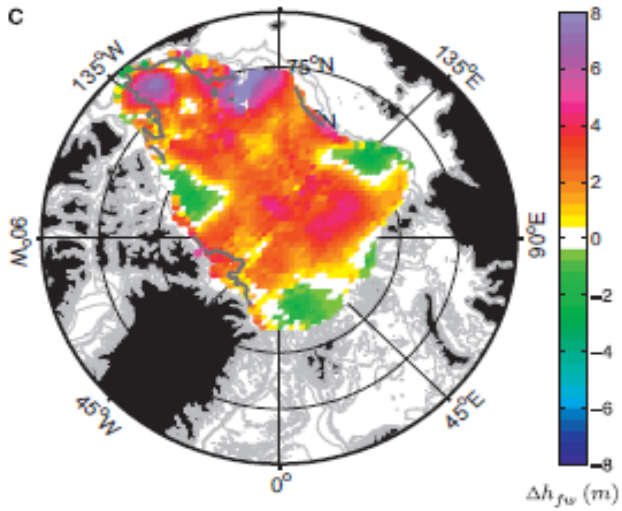


06-08
IPY

FWC increase:

Observ.:
8200 (±2000) km^3

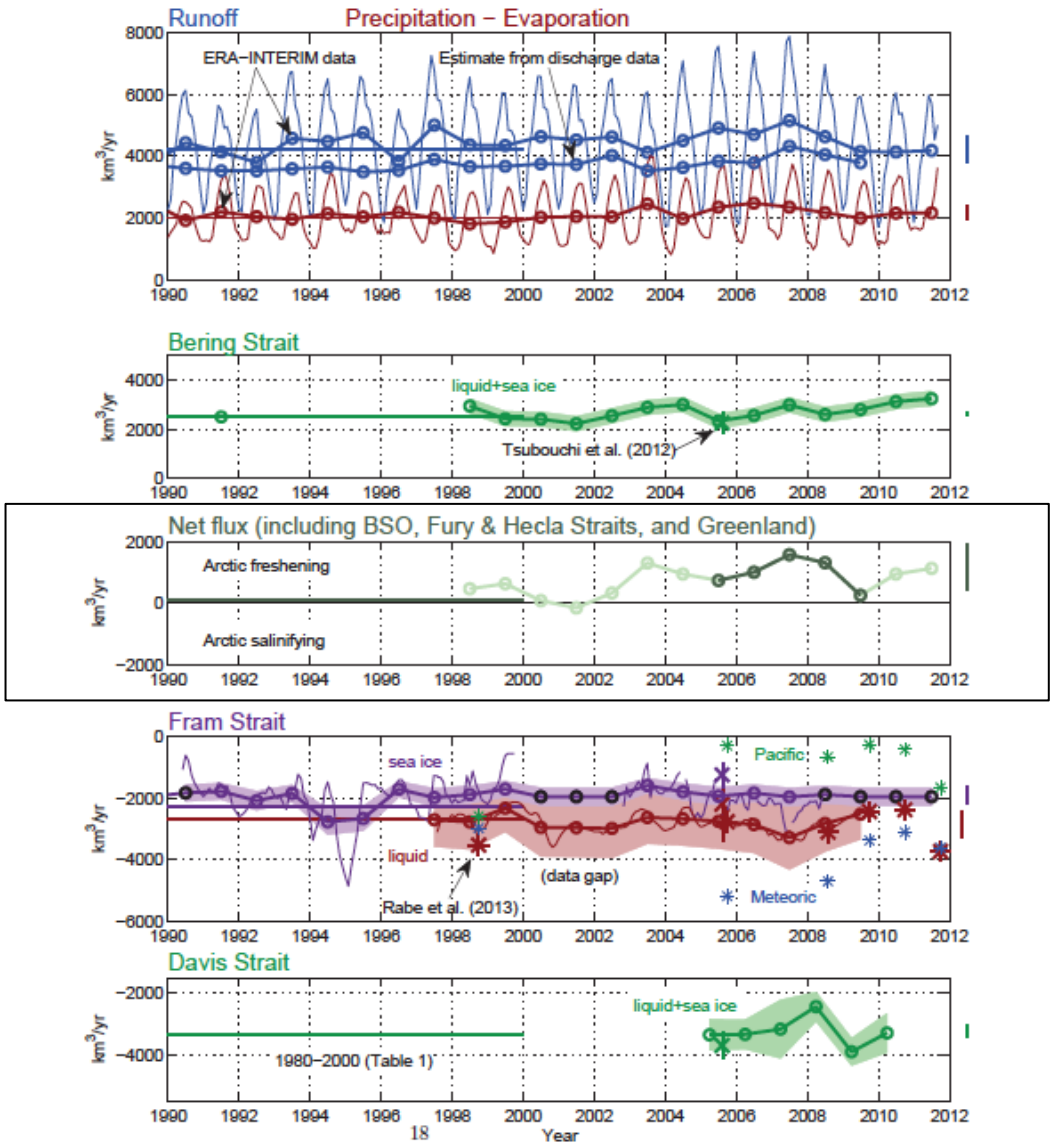
NAOSIM Model:
6120 km^3



06-08 minus 92-99

[Rabe et al., DSR 2011]

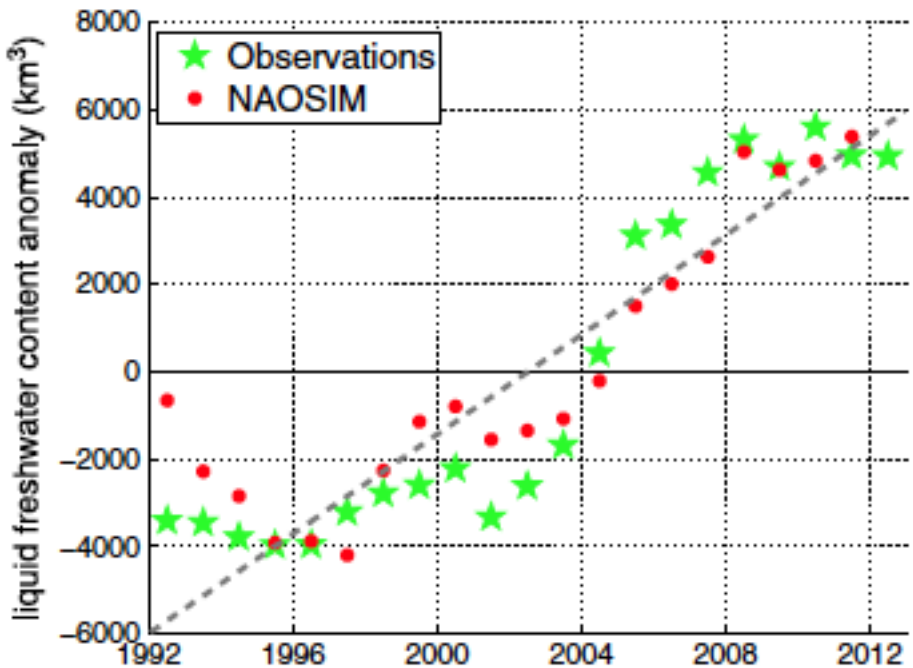
Oberserved FW flux changes



Haine et al., in press

Arctic Ocean Freshwater content increase

Arctic Ocean freshwater content (central basins, observed and simulated)
(in mixed layer, rel. to 35.0)



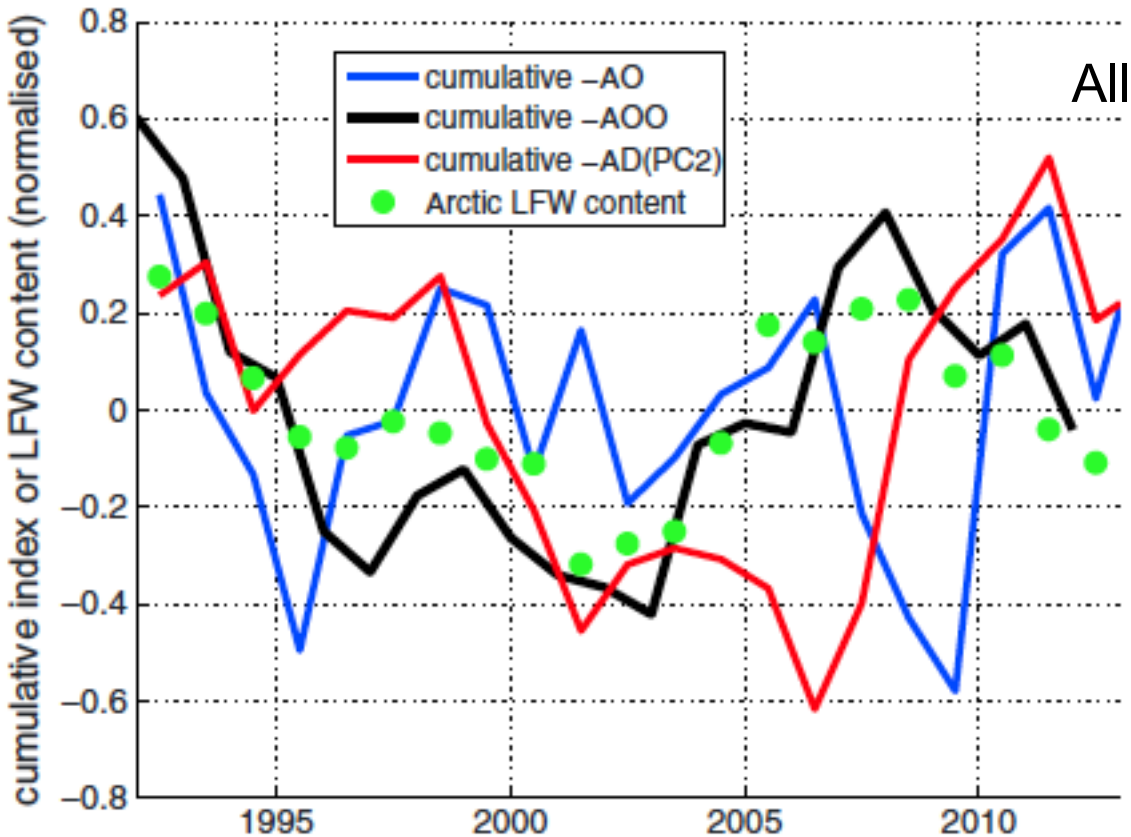
FWC increase:

Min to Max:
~ 10 000 km^3

Obs: 2/3 by salinity change
1/3 by thickness change

Rabe et al., 2014

SLP patterns connected to changes of FWC



All data detrended

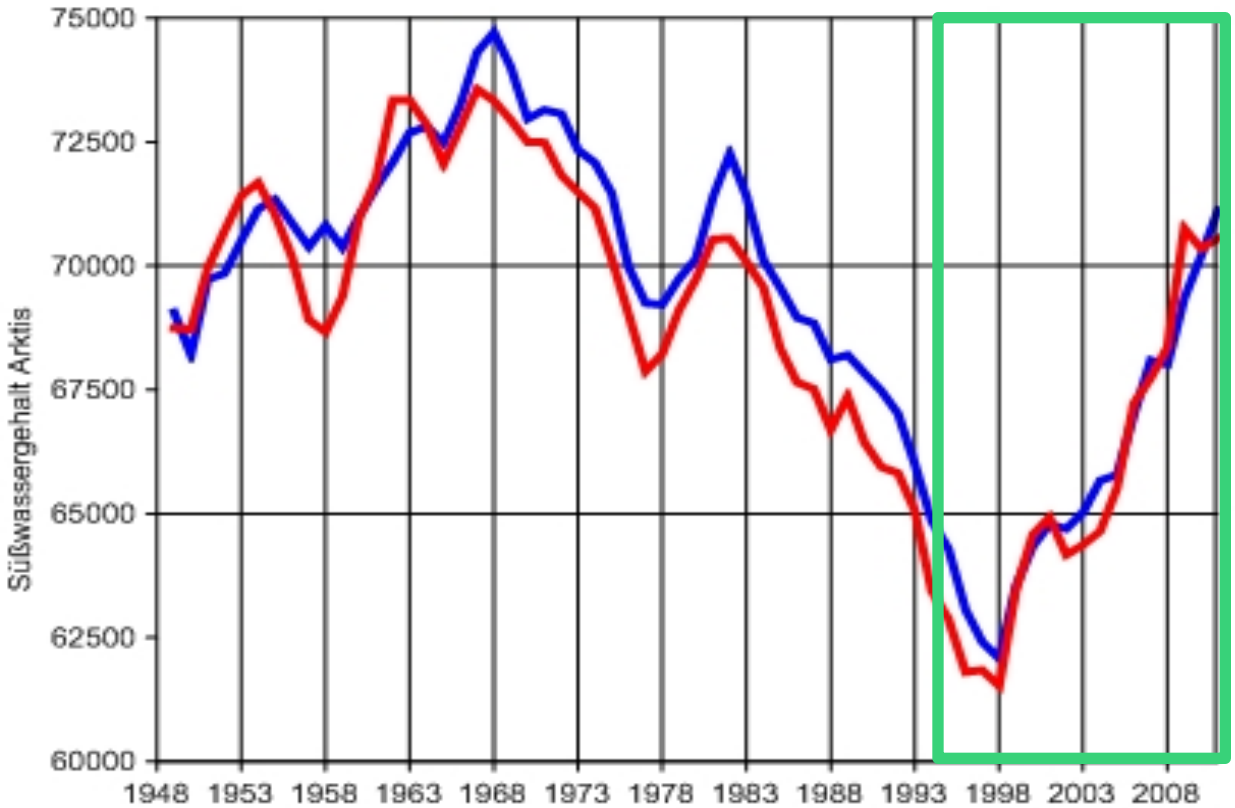
Rabe et al., 2014

-> response of FWC to AOO mode of circulation
-> regional wind stress curl

Arctic Ocean Freshwater content changes

Arctic Ocean freshwater content
(in mixed layer, rel. to 35.0)

km^3

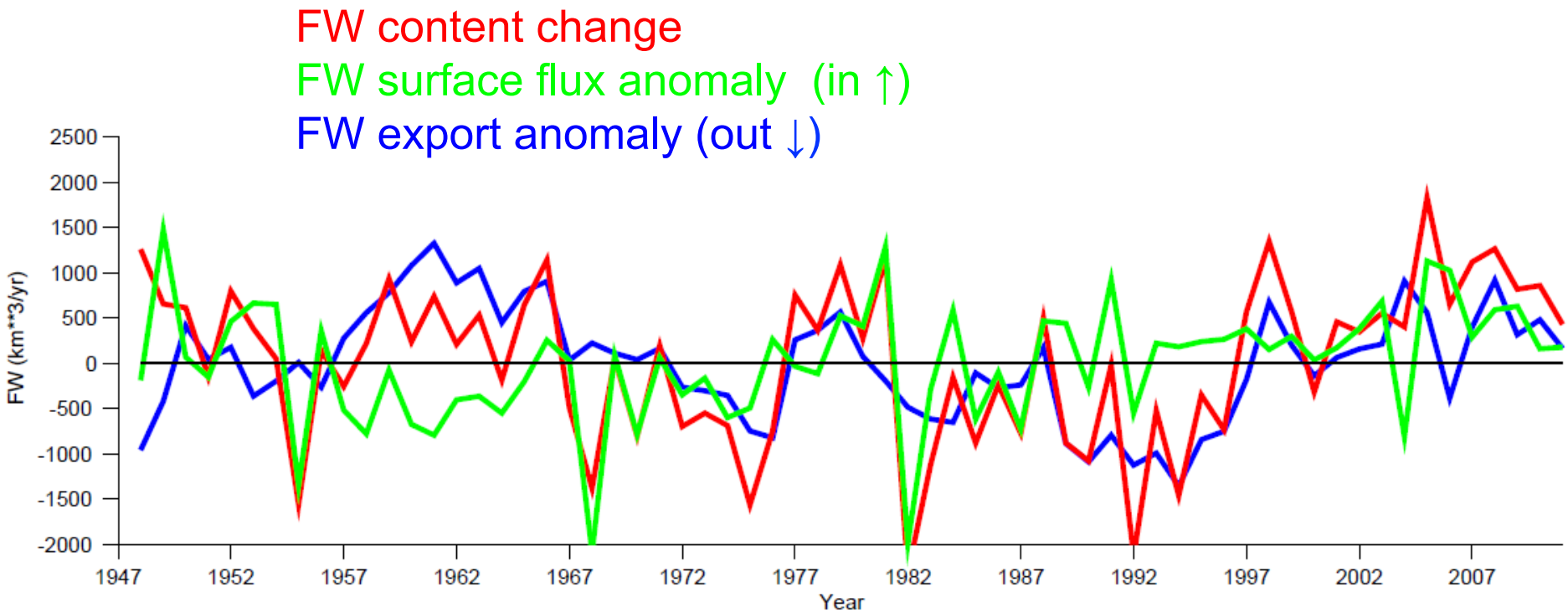


Arctic all

Arctic (no shelves)
offset 23000 km^3

Changes on pent.-dec. time scale
Large additional loss in 90s and rise in 2000s

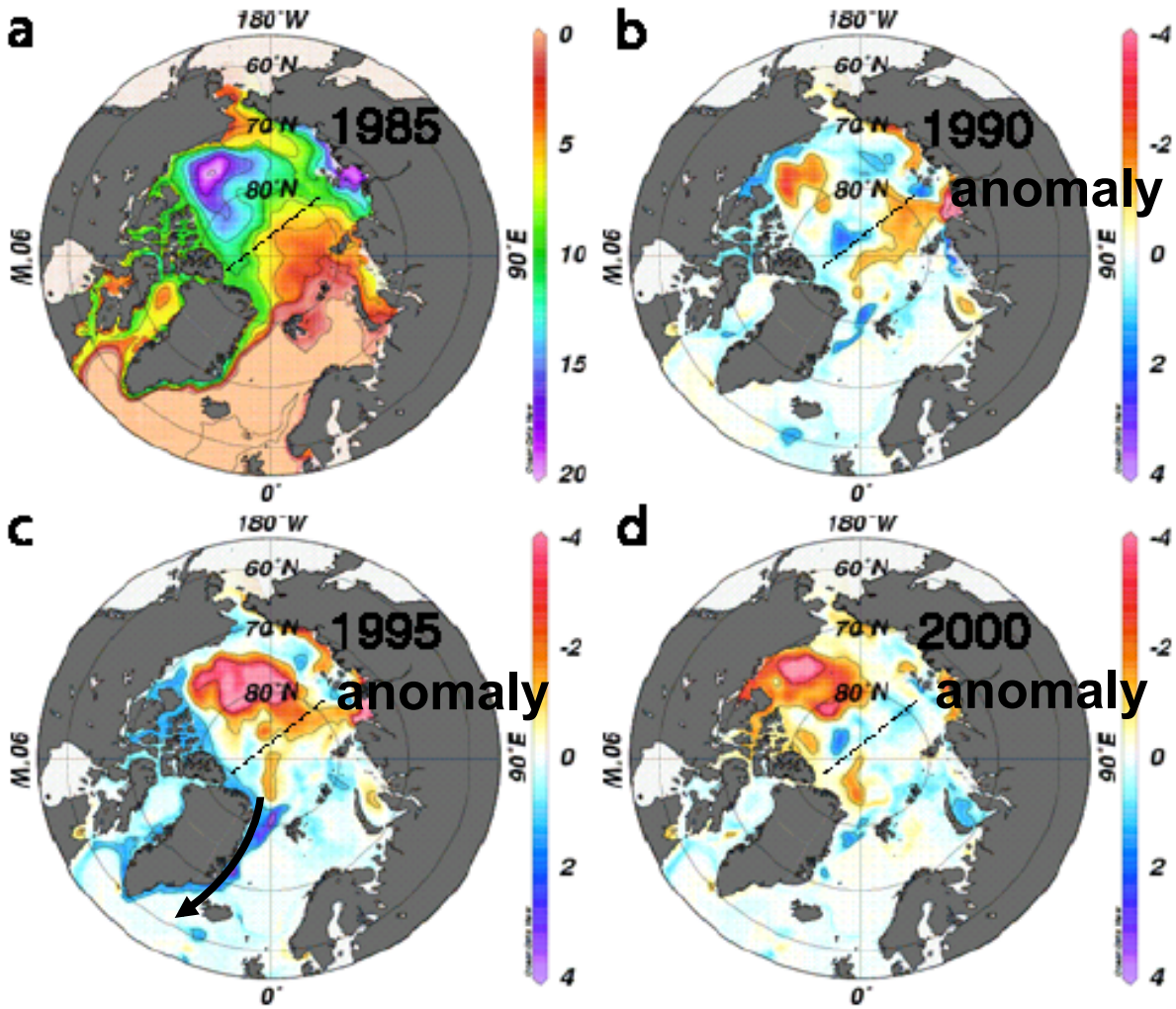
Arctic FW gain and loss: sources and sinks



1990s: large changes in hydrography

AWI

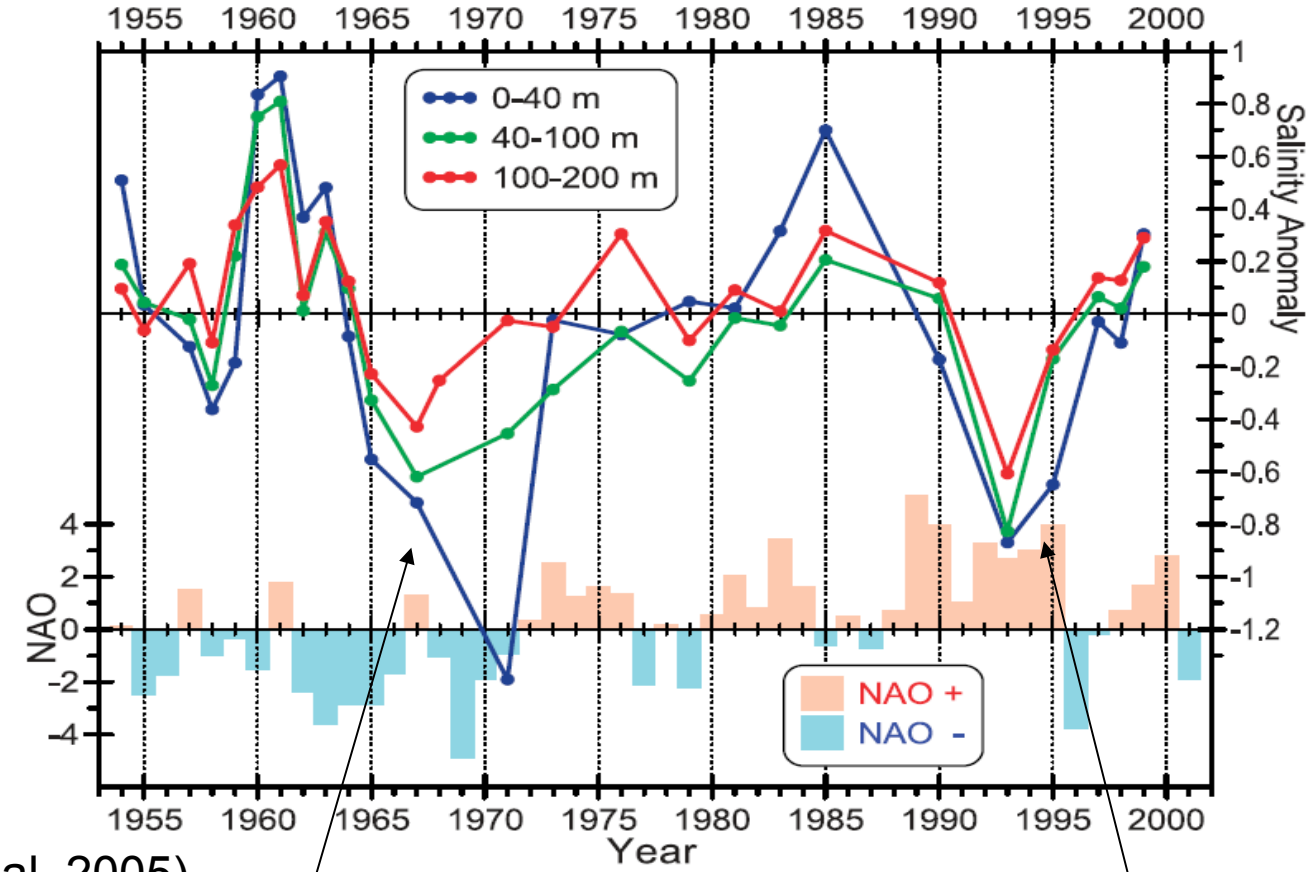
Upper 250m freshwater content shifts (rel. 34.8)



Karcher et al. GRL, 2005

HELMHOLTZ GEMEINSCHAFT

Observed salinitiy anom. in Denmark Strait

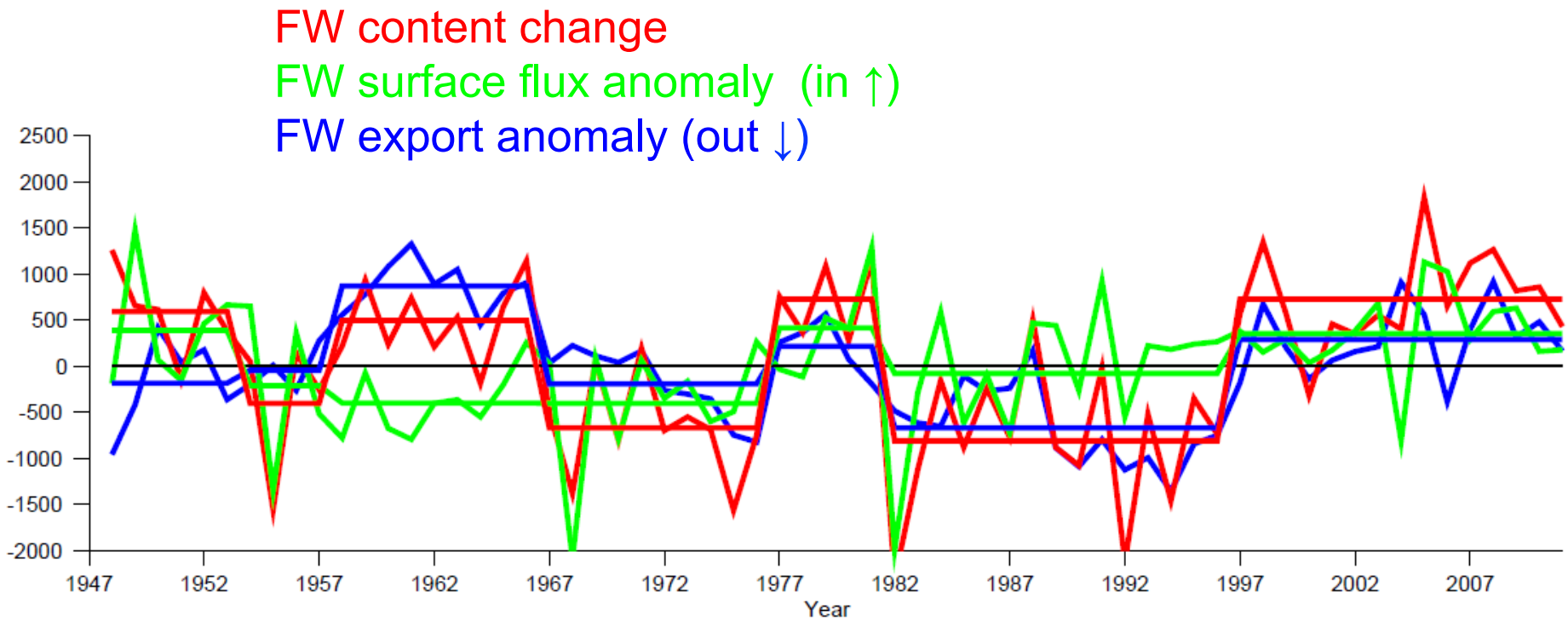


(Karcher et al, 2005)

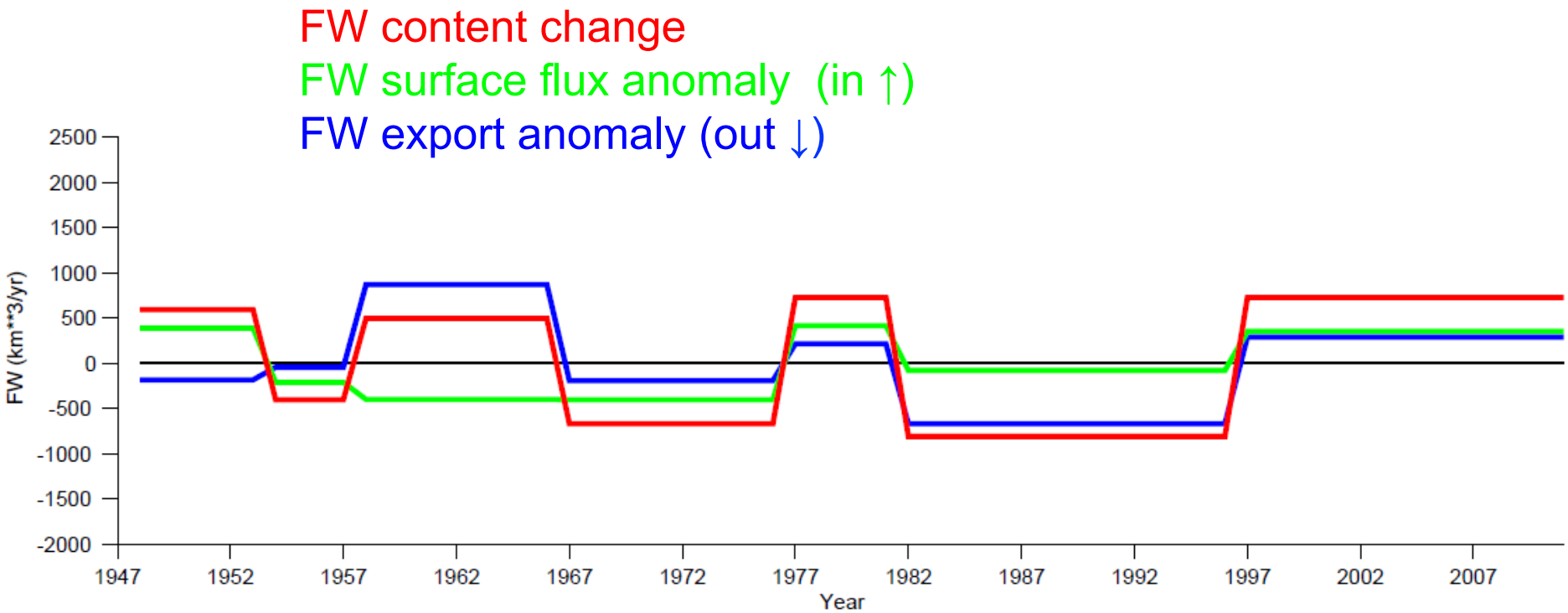
GSA

90s freshwater export event

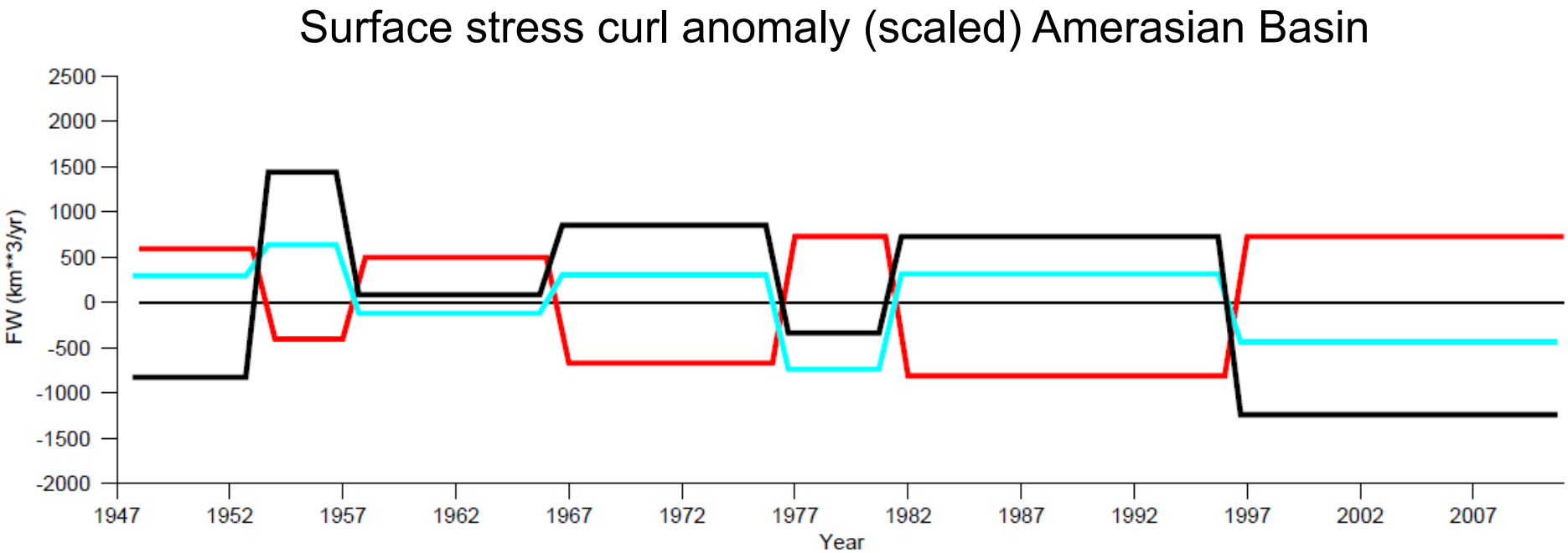
Arctic FW gain and loss: sources and sinks



Arctic FW gain and loss: sources and sinks

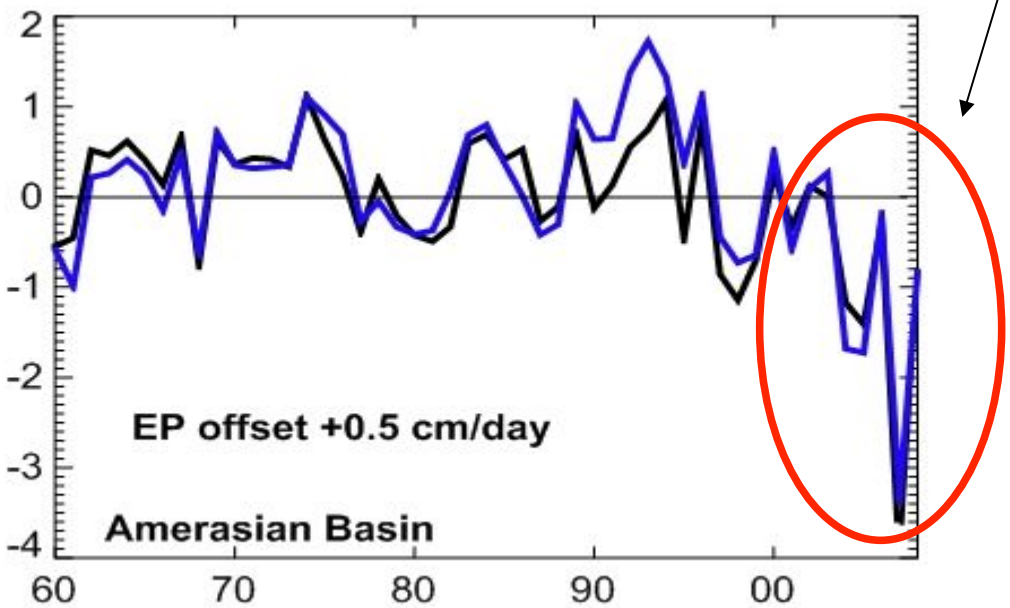


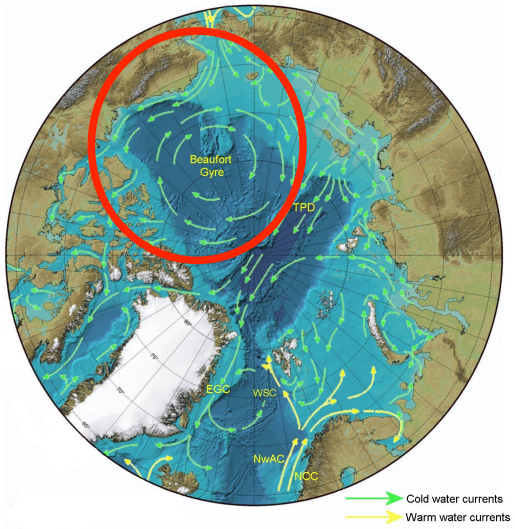
Arctic FW gain and loss: causes



Amerasian Basin: EP and halocline

Strongly increased Ekman Pumping and strengthening of the Beaufort Gy after 2004





EP velocity: black

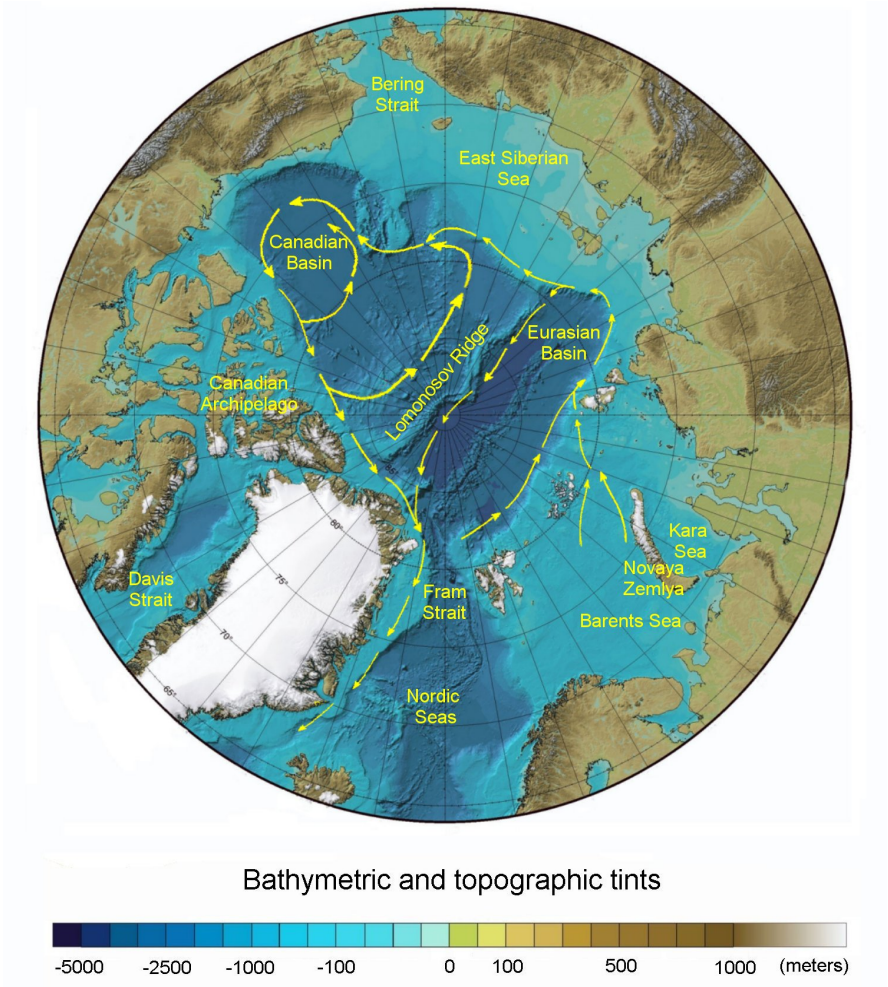
Vel. of 34.0 isohaline: blue

Consequences for the mid-depth AWL?

- Drivers of FWC and export changes: AO/NAO, Local stress curl (cyclonicity), and surface FW fluxes

- Problem of observationally derived budget: small imbalances change FWC on decadal timescale

Arctic Ocean mid-depth circulation: AWL



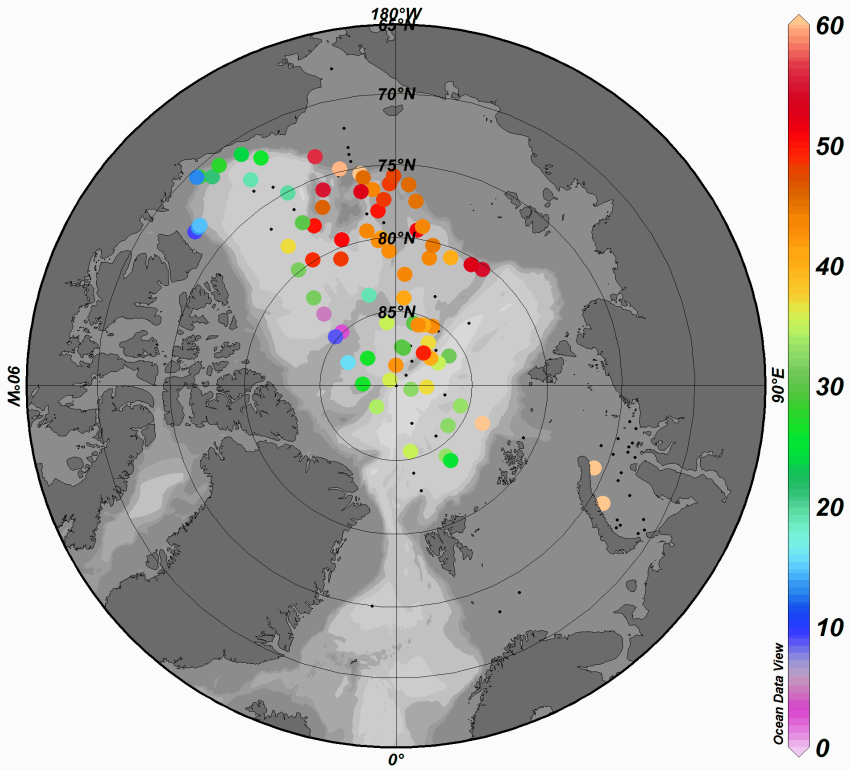
Circulation after Rudels et al. (1994)

Map: IBCAO

Atlantic Water tracer: ^{129}I

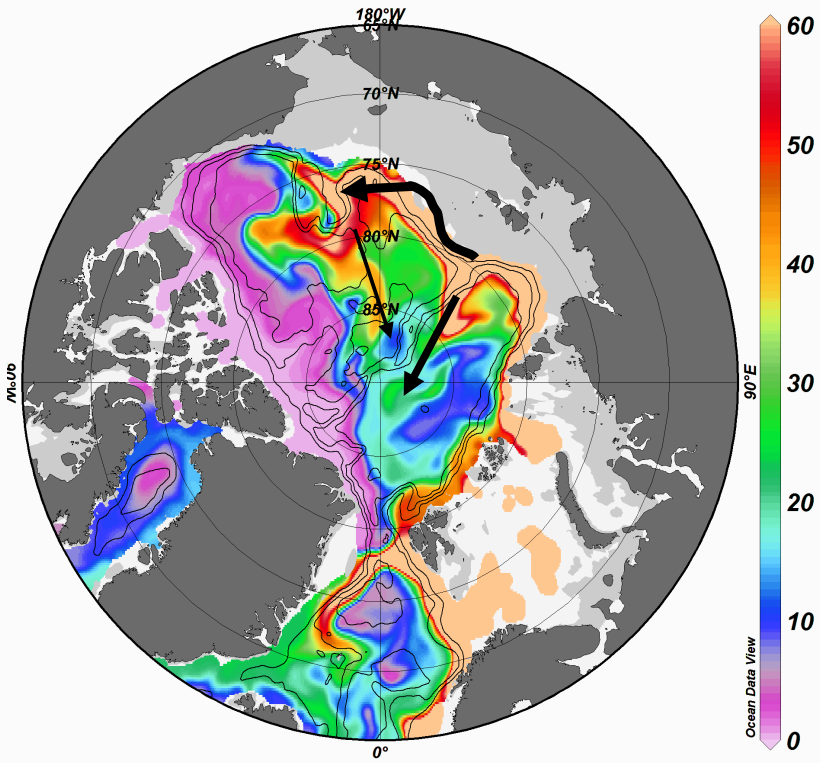
(240m) concentration of ^{129}I (10^7 at/l)

1995



Observations

1995



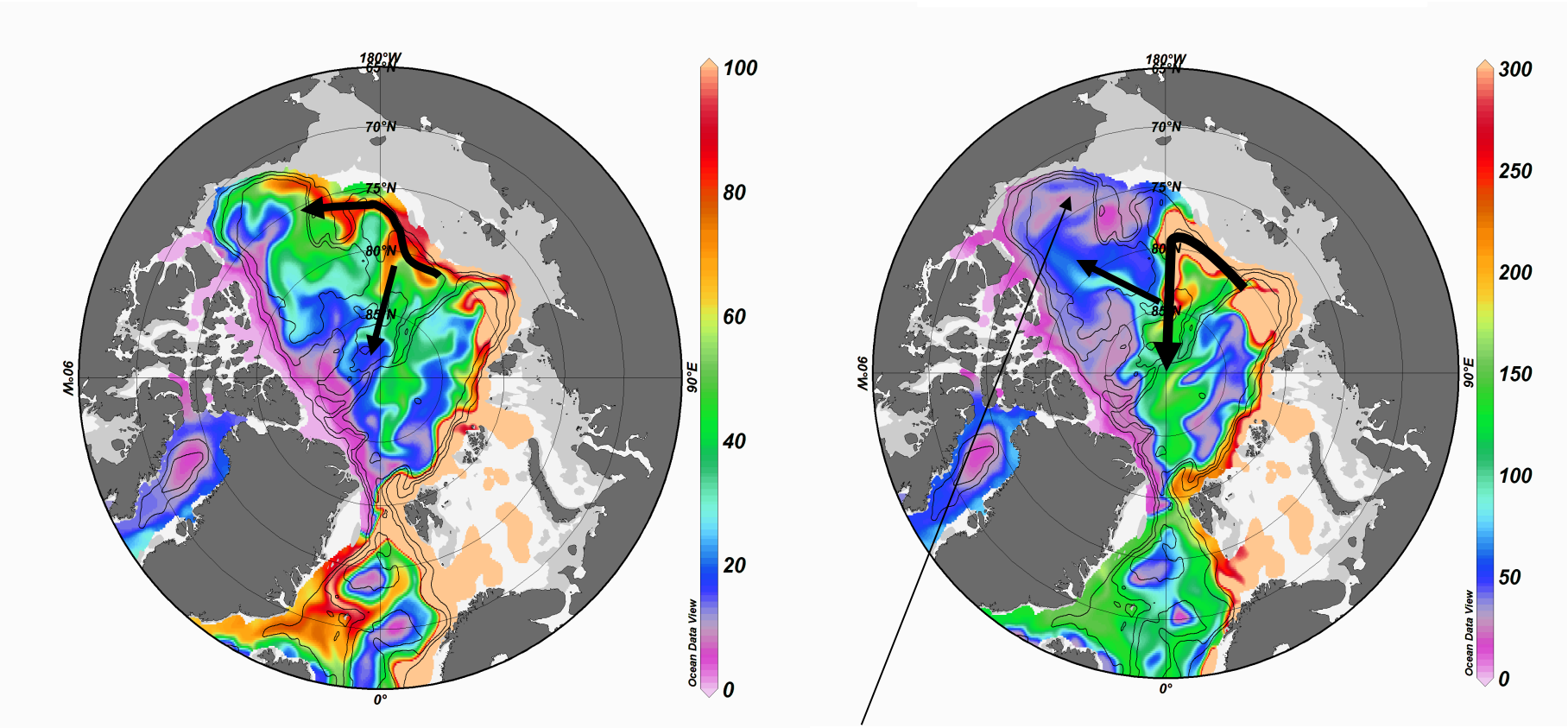
Model (NAOSIM)

(Karcher et al., 2012)

Atlantic Water tracer: ^{129}I

(240m) concentration of ^{129}I

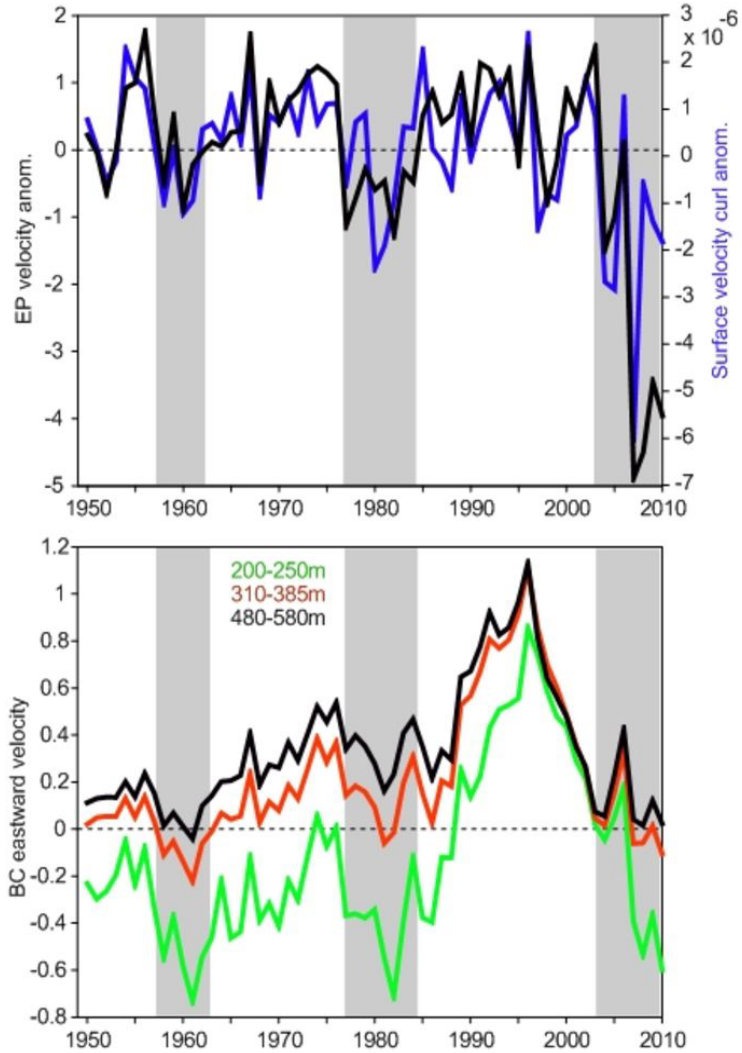
2000 (10^7 at/l) 2008



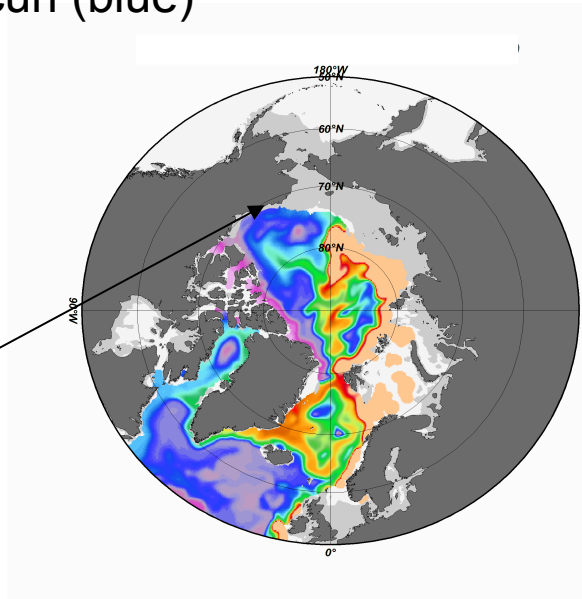
Blocking of cyclonic AW flow in the CB

(Karcher et al., 2012)

AWL – boundary current: cyclonic flow



EP velocity Beaufort Sea (black)
Surface velocity curl (blue)

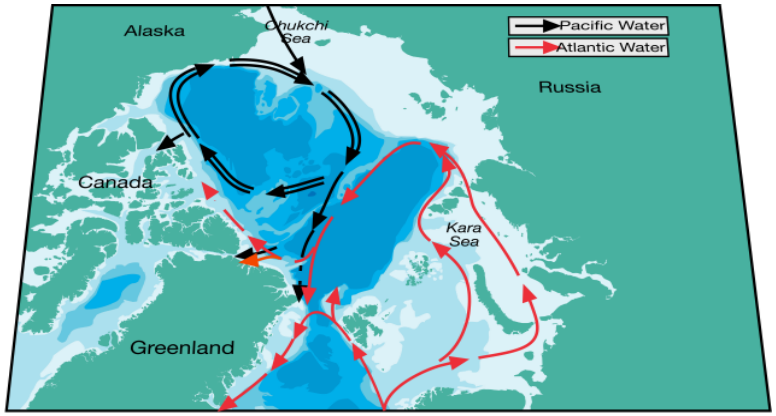


AWL cyclonic velocity at Alaskan slope of the Beaufort Sea

(Karcher et al., 2012)

AWL: changed circulation after 2004

(Karcher et al., 2012)

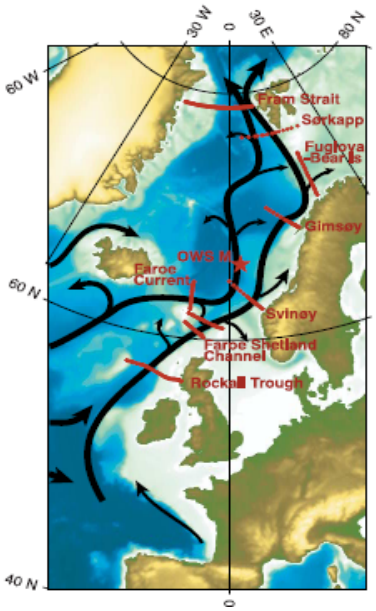


surface

AWL (200-800m)

- Surface and Mid-depth circulation linked
- Long periods of basin decoupling possible
- Consequences for outflows/overflows?

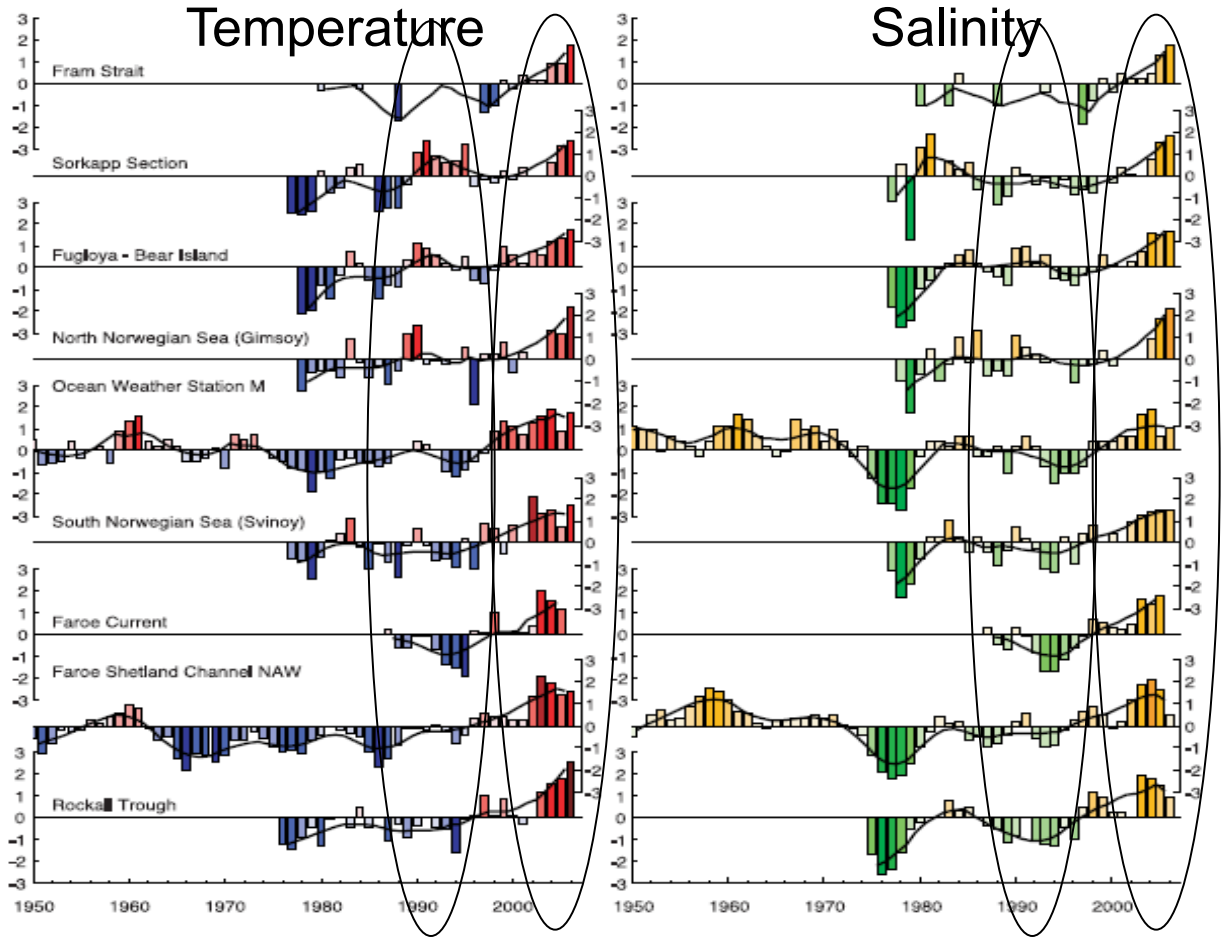
Arctic Ocean warming: continued in 2000s



Normalized Anomalies

Temperature

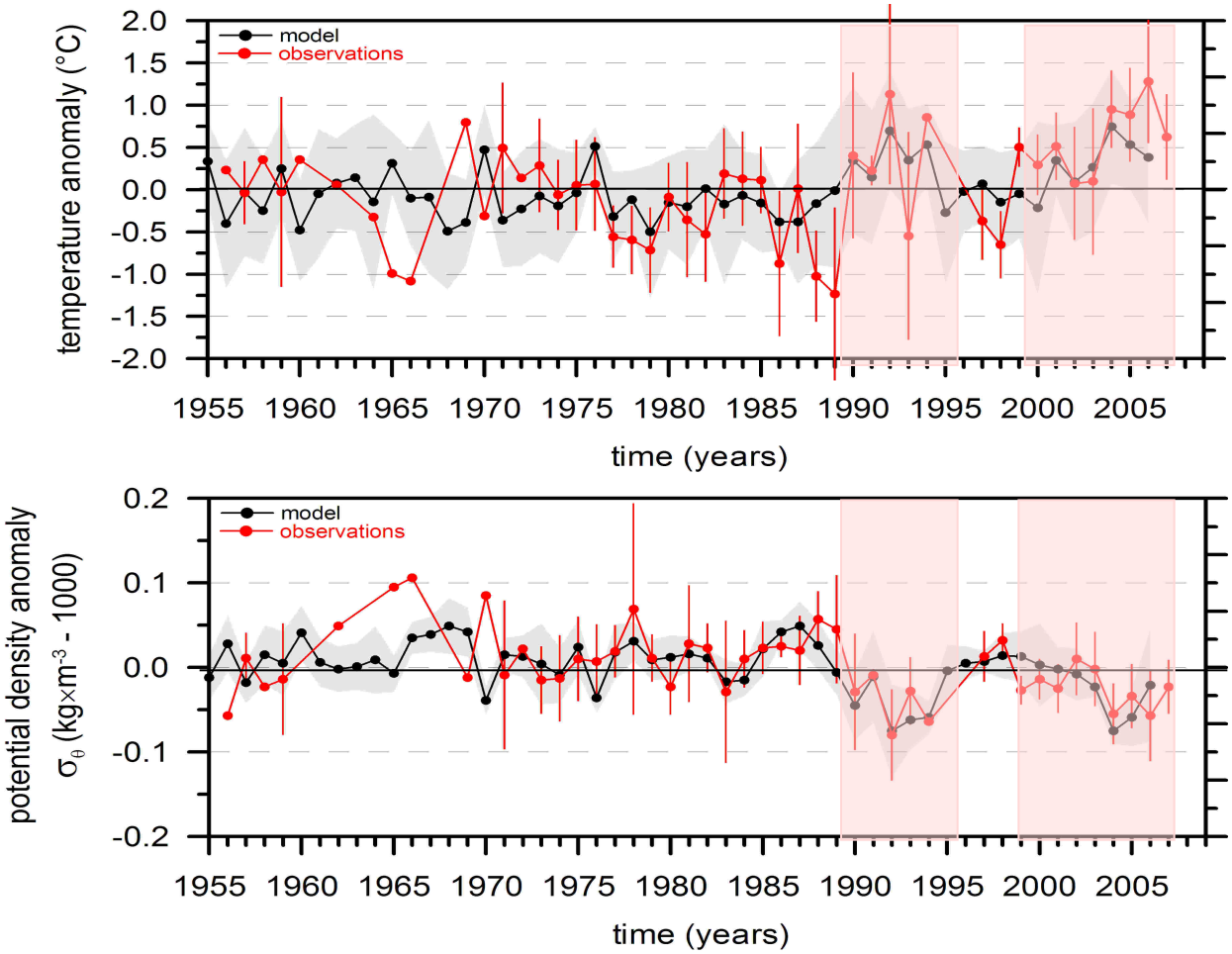
Salinity



[Holliday et al., 2008]

Density anomalies enter and propagate in the AWL

Fram Strait: Observed and simulated T_{pot} and σ_θ

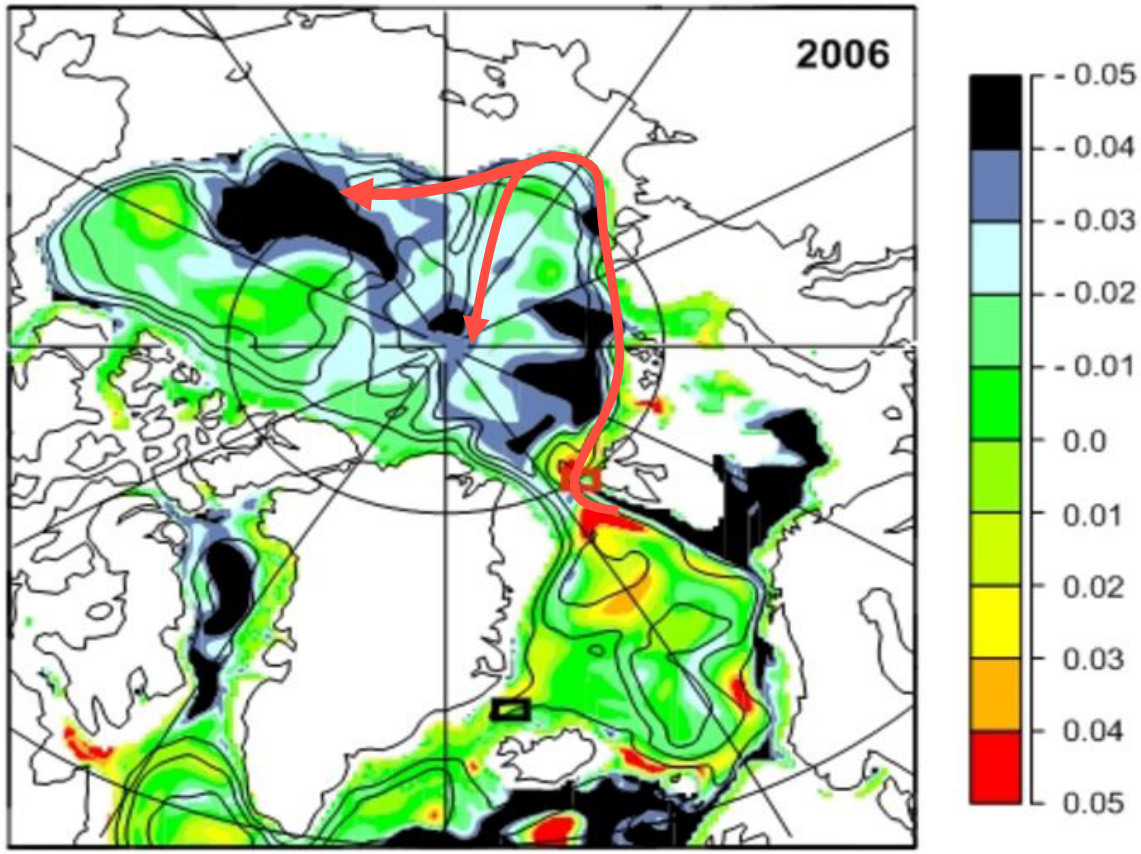


Data source: WOA05, Hydrobase2, AWI, NPI, IOPAS

[Karcher et al., JGR 2011]

Propagation of density anomalies

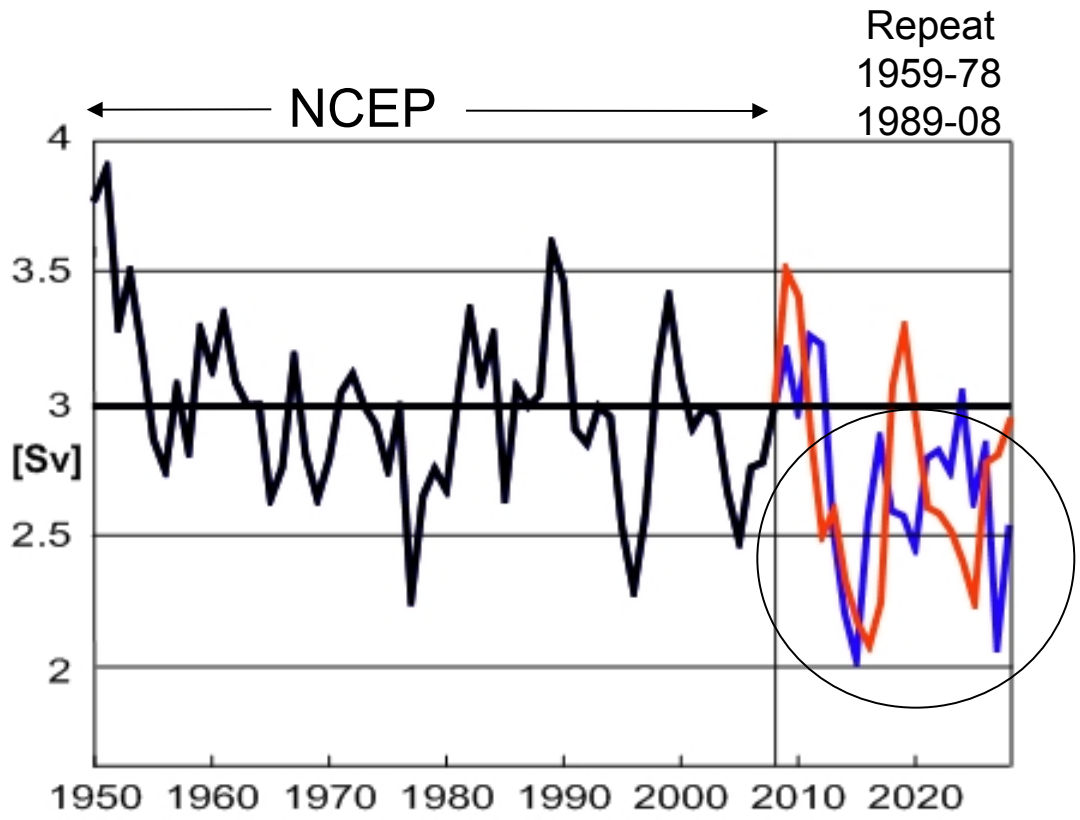
Atlantic water layer density anomaly
(rel to 1960-89)



[Karcher et al., JGR 2011]

DSOW: Arctic density anomalies

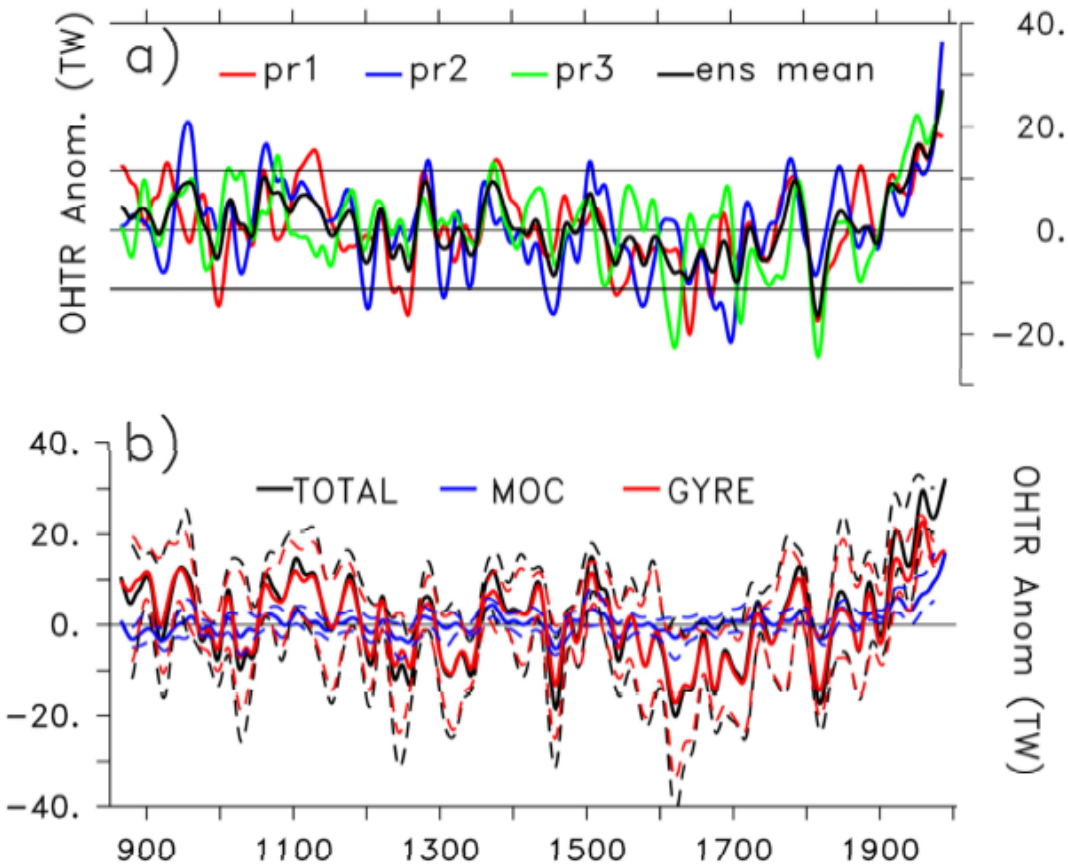
Denmark Strait Overflow volume



Recirculating Atl. Water density anomalies can impact the overflows

[Karcher et al., JGR 2011]

Oceanic heat inflow: past to present



20th cent. increase of ocean heat trans to Arctic

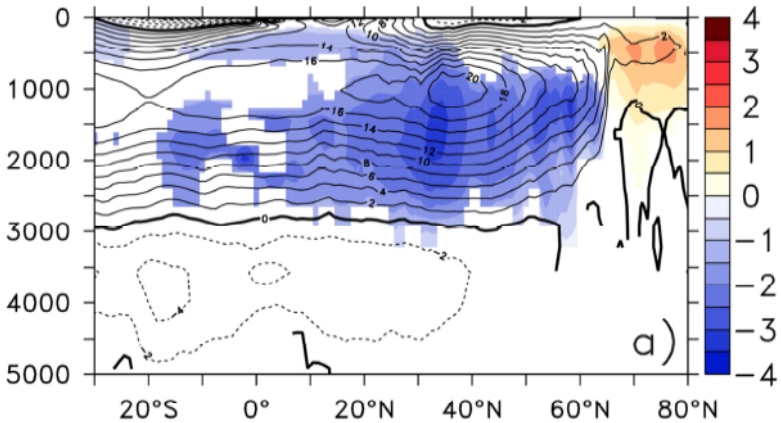
MOC versus GYRE component

GYRE dominates in 20th cent.

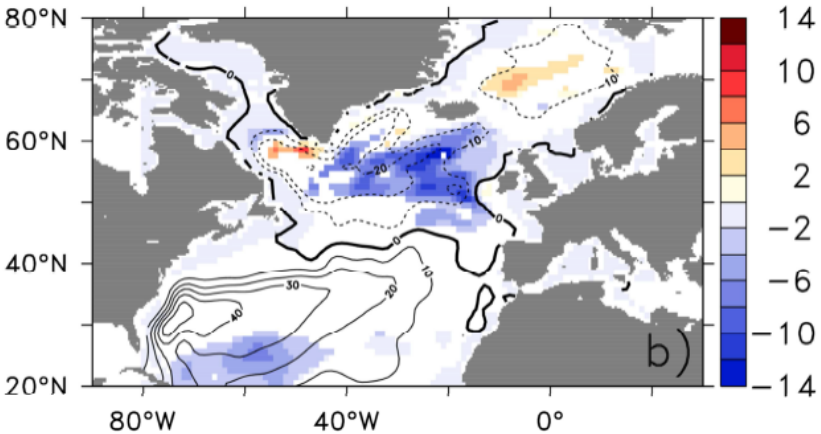
Jungclaus et al., 2014

Oceanic heat inflow: past to present

AMOC 20th cen trend (mean)



Horiz. Streamfunction trend (mean)



Reduced deep water formation in the Labrador Sea

Weaker overturning,

Accelerated SPG and heat transport to high lat.

Jungclaus et al., 2014

Conclusions

- Arctic Ocean circulation variable, link of surf. and mid depth stronger than anticipated
- Decoupling of Arctic basins' circulation

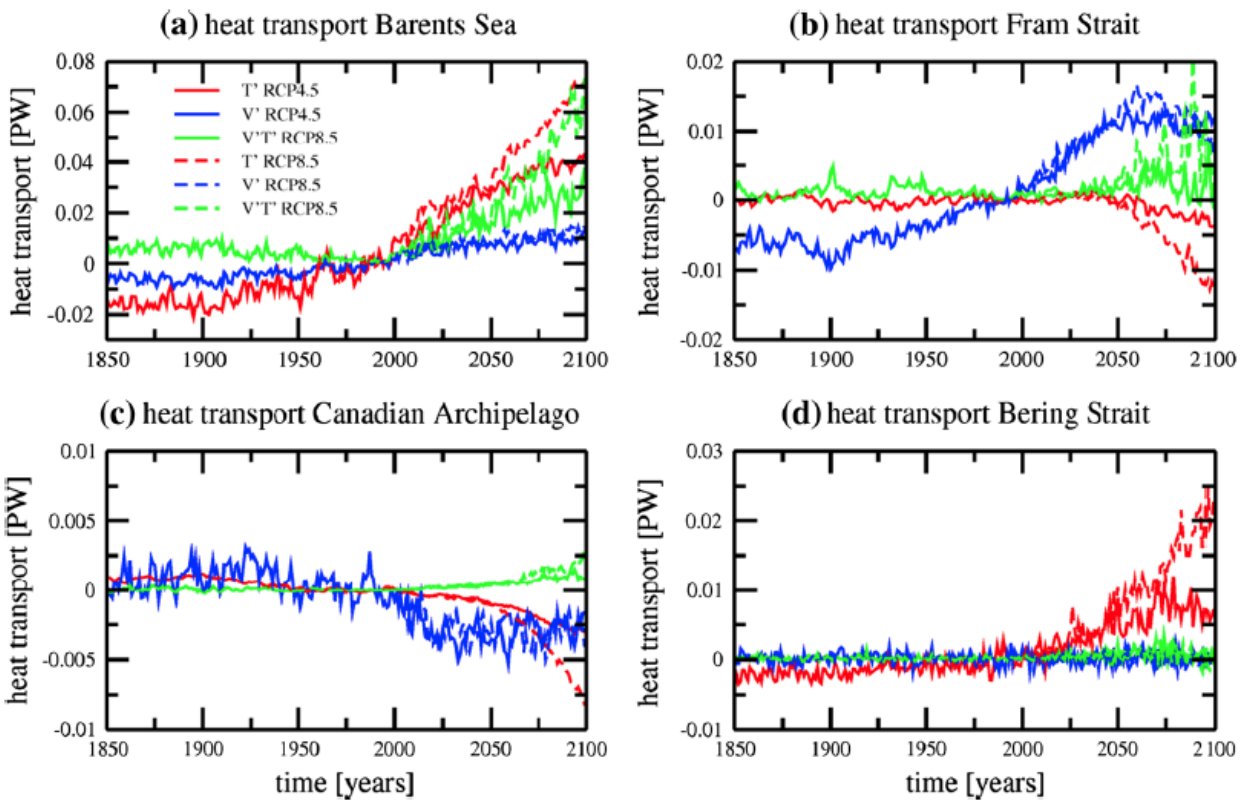
- FWC variability driven by surface fluxes and atmospheric circulation (AO, stress curl)
- Increase of FWC over almost 2 decades
- Observations: short and with large error bars

- Heat inflow to Arctic Ocean: role of deep water formation and coupled gyre response?
-

Conclusions

- What triggers the regional stress curl changes (triggering the FW releases)
- Is there a predictive potential?
- What are maximum storage and release rates?
- What are the consequences of momentum transfer changes due to less and weak sea ice?
- What determins the outflow routes of FW (CAA or Fram Strait)?
- What are the consequences for increasing heat input to Arctic Ocean at mid depth and overflows?
- How does the link work from increased heat inflow to the outflows and impacts on the Labrador Sea dense water formation via the Arctic loop (ocean and atmosphere)?
- How well do CMIP model represent internal FWC mechnisms and heat inflow via the Barents Sea?

Oceanic heat inflow



Increased heat inflow (Temp dominated, related to NAO+)

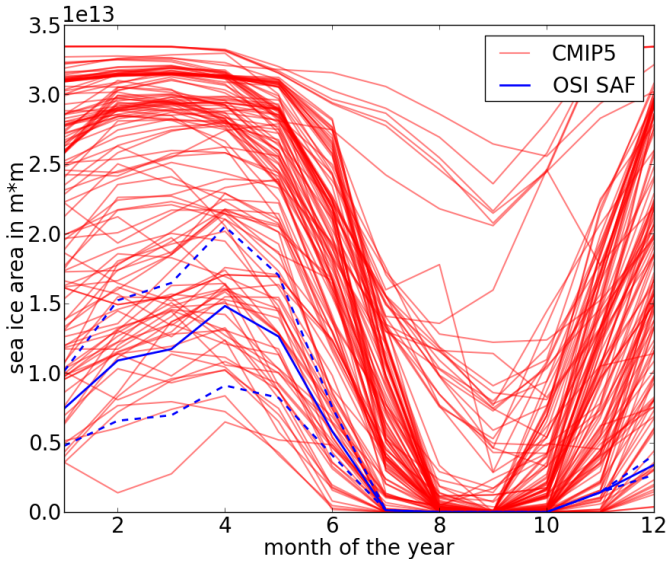
->1y lead on SLP

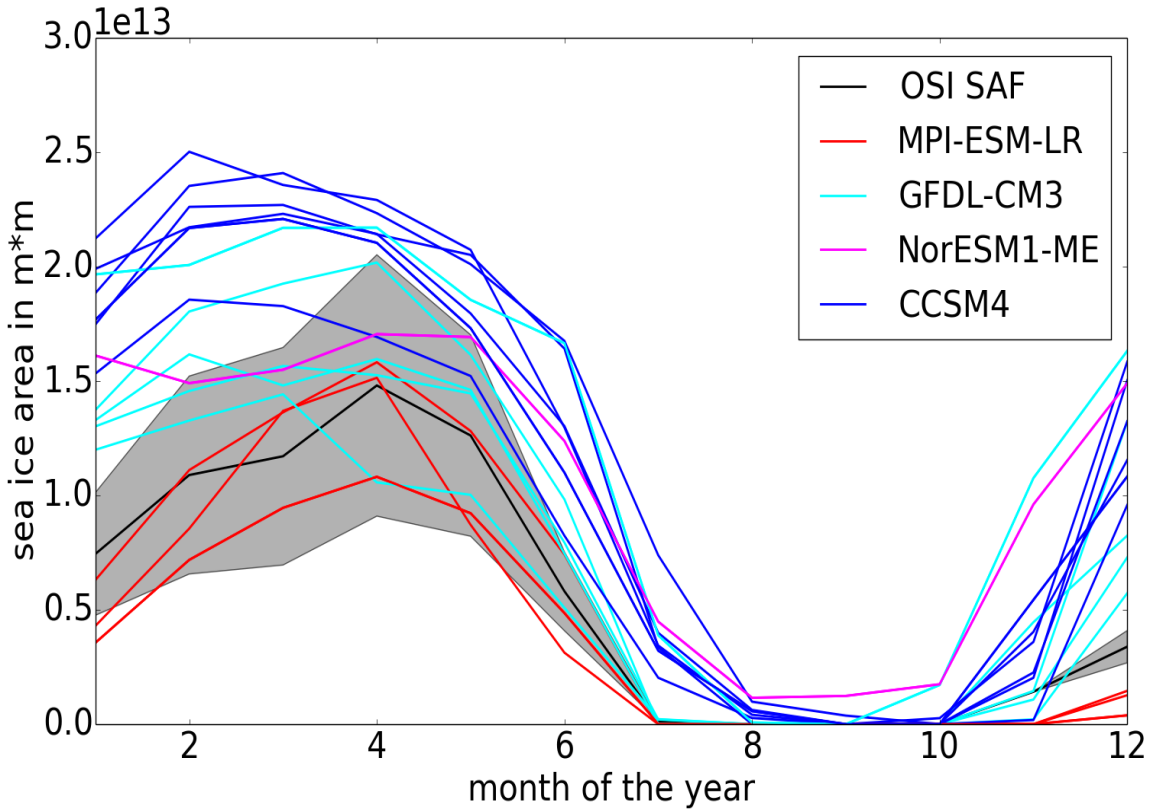
-> sea ice reduction, SAT increase

-> addit. heat input to mid depth AWL

Koenigk and Brodeau, 2014

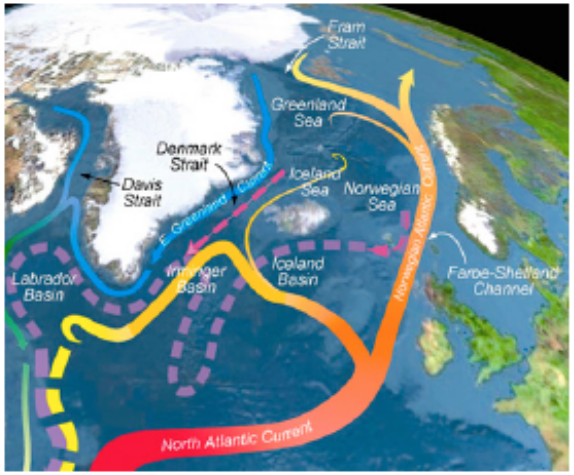
Sea Ice Concentration(sic): CMIP5 models 20th cent.



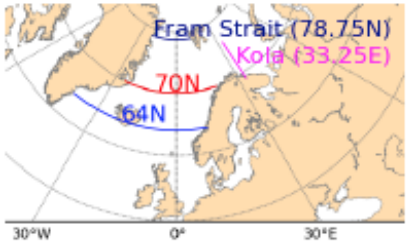


Mean seasonal cycle
1979-2005
area integrated sic
Southern Barents Sea

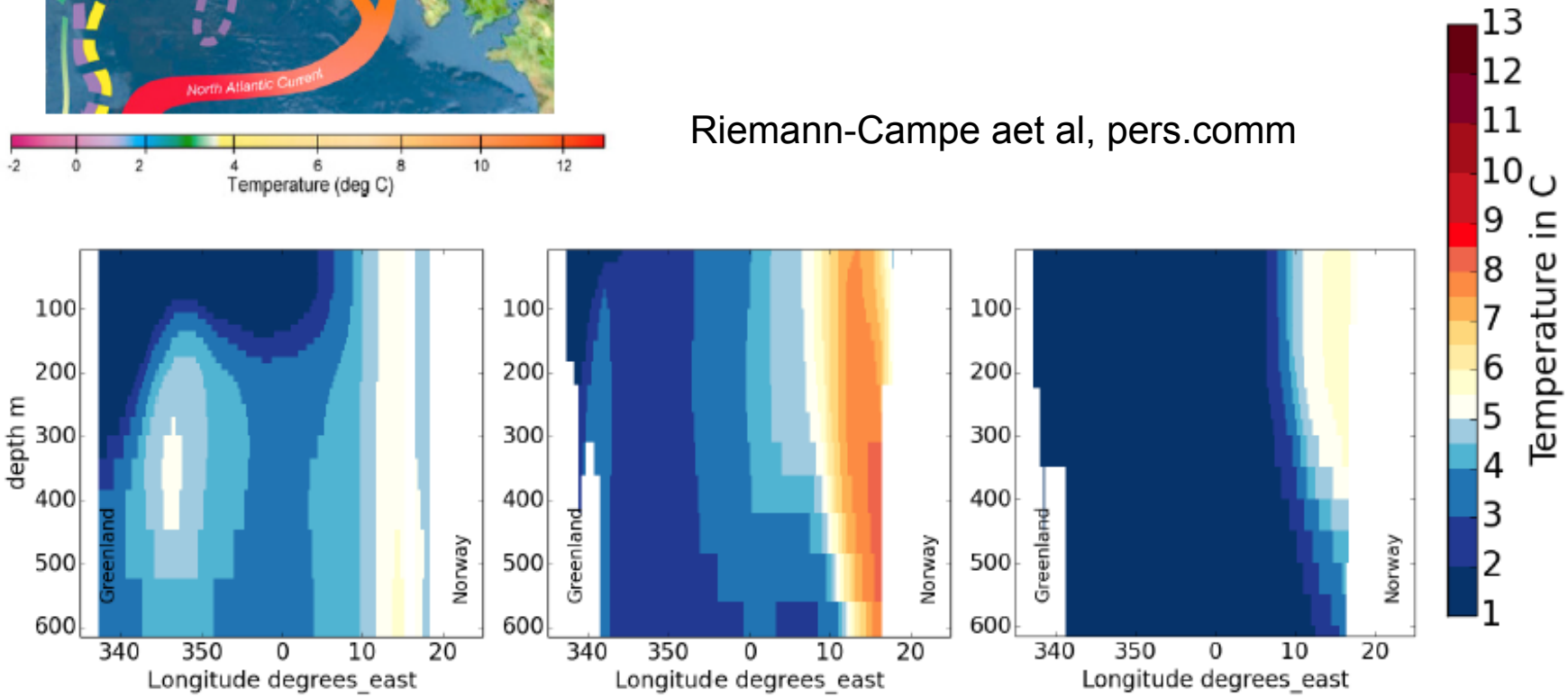
Section at 70°N



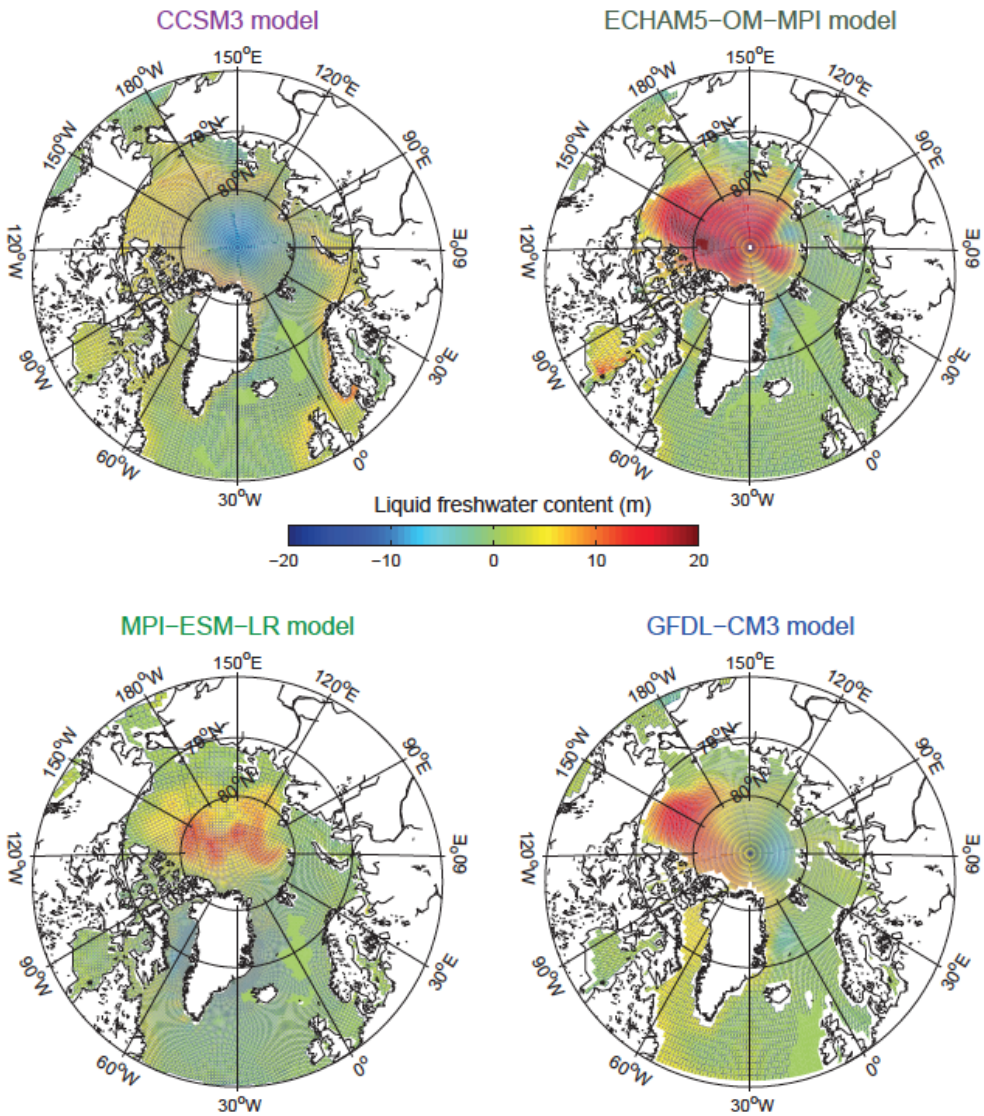
- March Mean 1991-2005



Riemann-Campe aet al, pers.comm



Liquid freshwater content difference (2090-2100) to (2010-2020)



FWC changes in CMIP models

Haine et al, in press

Arctic Ocean surface circulation: drivers

Arctic Oscillation index (cpc.ncep NOAA)