Effect of the large-scale atmospheric circulation on the Arctic Ocean freshwater and heat exchange

Alexandra Jahn

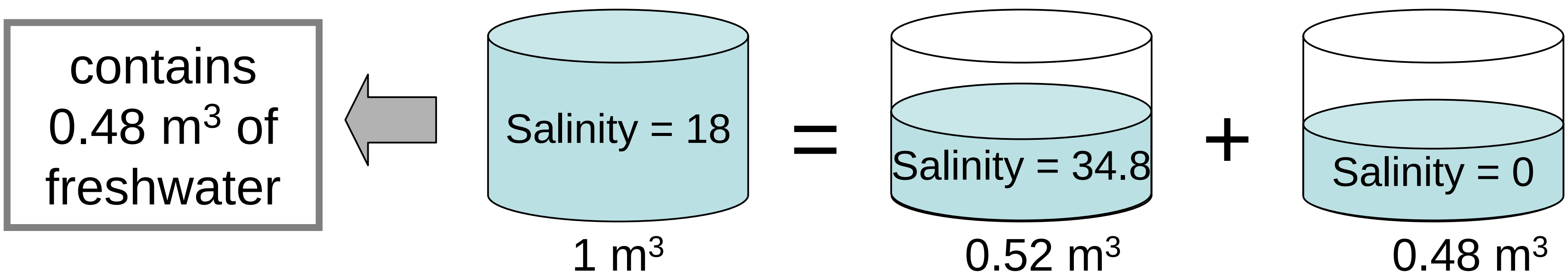
McGill University, Montreal, Canada

Co-authors: Bruno Tremblay, Lawrence A. Mysak, Bob Newton

CCSM Polar Climate Working Group Meeting, January 16th 2008

Definition of freshwater

- Freshwater (FW) is defined relative to $S_{ref}=34.8$
  (Aagaard and Carmack, 1989)
- Amount of FW in volume V: $V_{FW}=(S_{ref}-S)/S_{ref} * V$



Freshwater stands for the amount of zero-salinity water contained in a volume of water with a given salinity relative to a reference salinity

Freshwater in the Arctic Ocean

FW sources:

- River runoff
- Bering Strait inflow
- P-E

FW sinks:

- Fram Strait export
- CAA export

Objectives

- What controls the variability of the liquid FW export from the Artic Ocean?

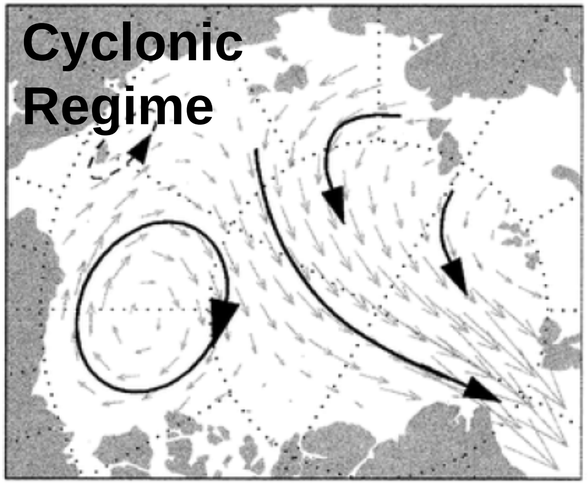
- How does the liquid FW export variability affect

    a) the MOC in the North Atlantic?

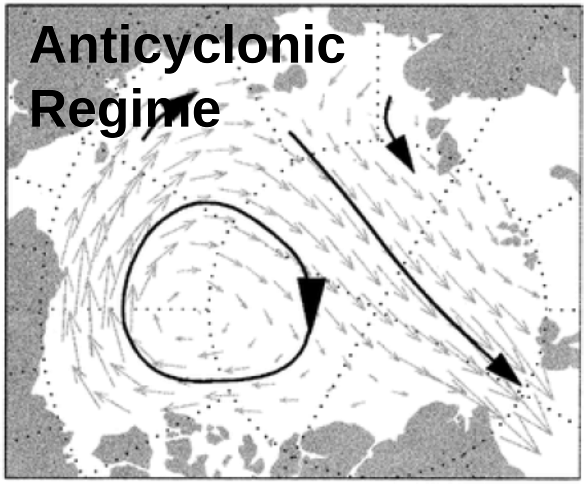
    b) the ocean heat transport into the Arctic Ocean?

Liquid freshwater transport

- **Hypothesis 1:** Release of freshwater stored in Beaufort Gyre during cyclonic circulation regimes, due to changes in Ekman pumping (Hunkins and Whitehead, 1992; Proshutinsky et al., 2002)



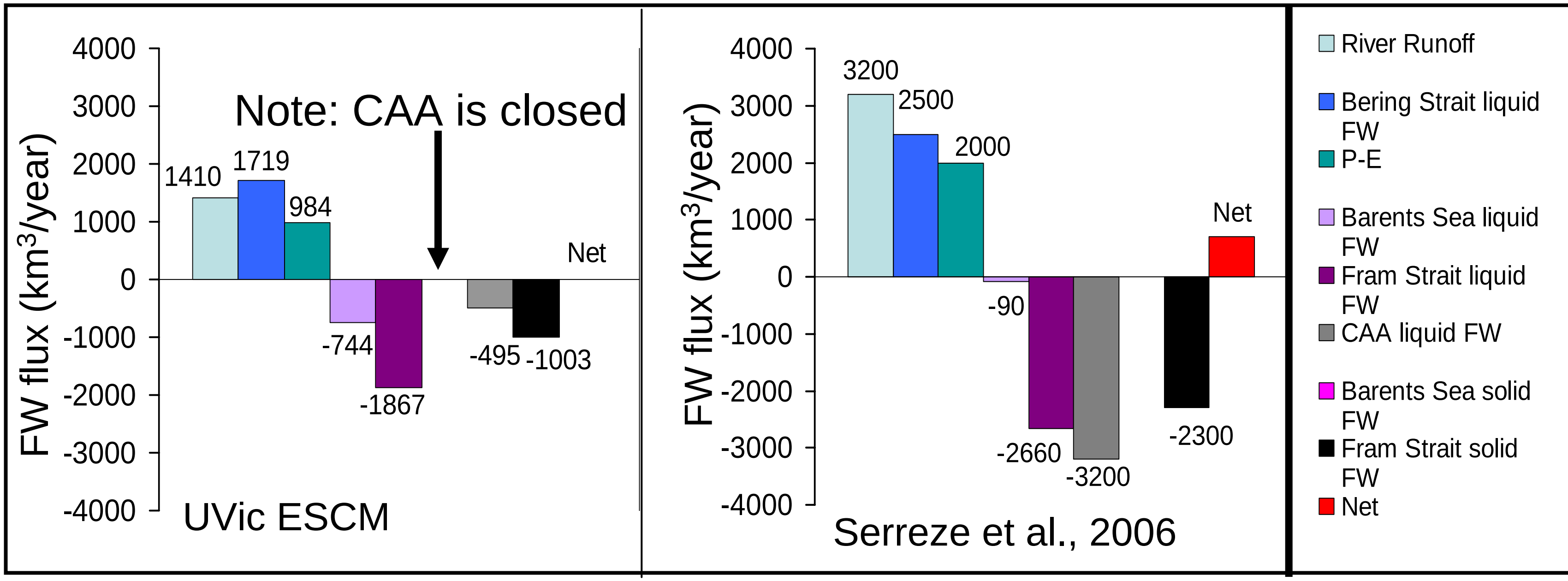
- **Hypothesis 2:** Increased barotropic transport through Fram Strait during cyclonic regimes (associated with increased advection of Atlantic water into the Arctic Ocean) (Häkkinen and Proshutinsky, 2004)



UVic ESCM, version 2.8

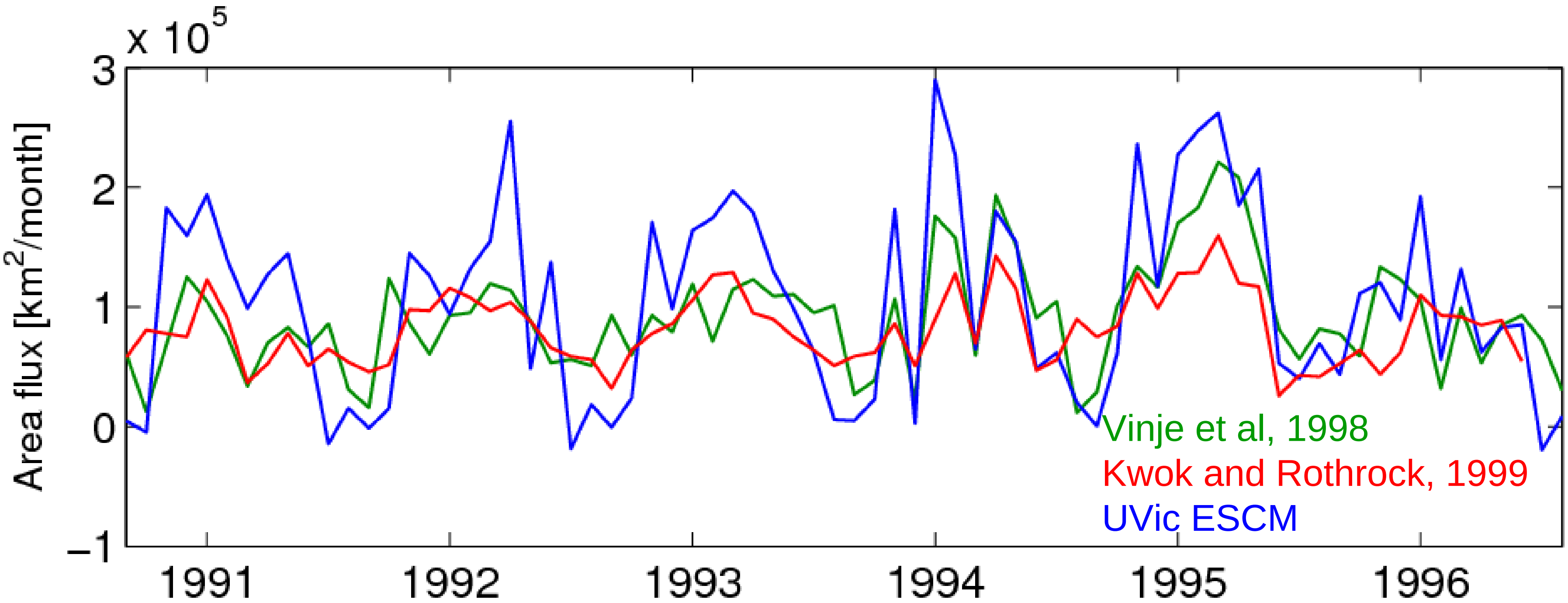
- Resolution of 1.8° longitude by 0.9° latitude
- Model components:
  - Ocean: MOM 2.2; 32 unequally spaced vertical levels
  - Sea ice:
    - Zero-layer thermodynamic scheme (Bitz et al., 2001)
    - elastic-viscous-plastic dynamics (Hunke and Dukowicz,1997)
  - Atmosphere:
    - EMBM with prescribed daily NCEP winds and CO_2 (Weaver et al., 2001)
  - Terrestrial surface:
    - Land surface model MOSES
    - Dynamic vegetation model TRIFFID

Climatological FW budget



FW fluxes are underestimated, but their variability is captured well

Fram Strait sea-ice area export

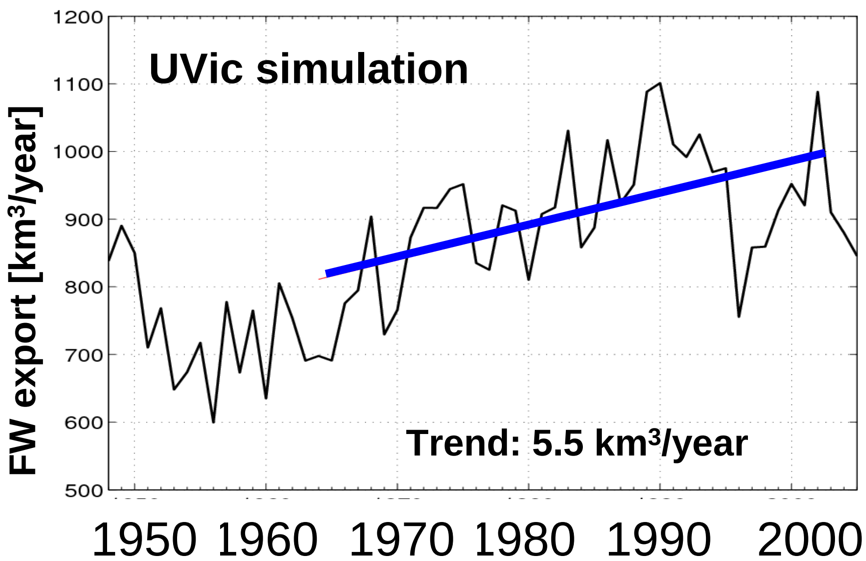


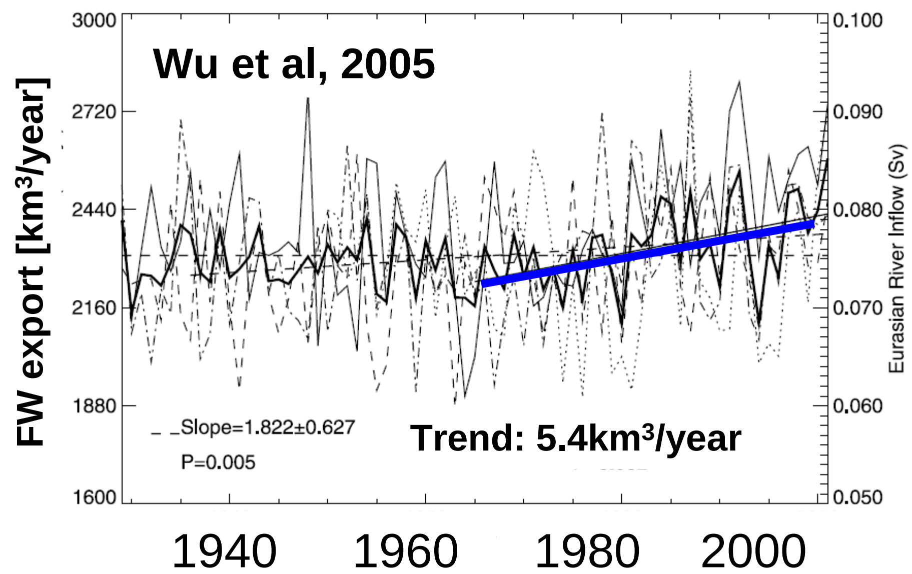
r=0.73 compared with Vinje et al., 1998

r=0.74 compared with Kwok and Rothrock, 1999

Good correlation of simulated monthly Fram Strait sea-ice area flux with observations

Eurasian river runoff

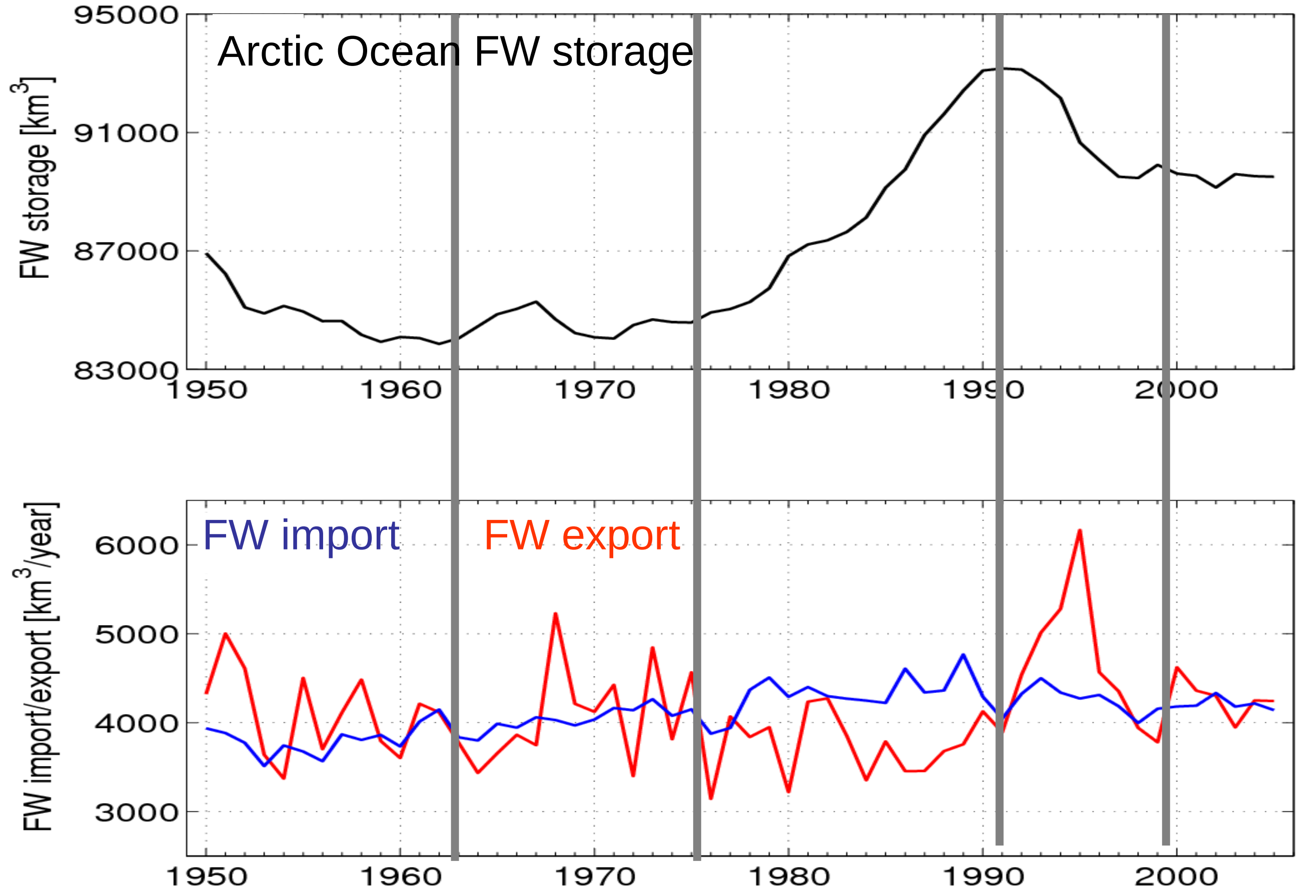




McClelland et al.(2006) also find a trend of 5.4 km³/year in runoff data from Eurasia

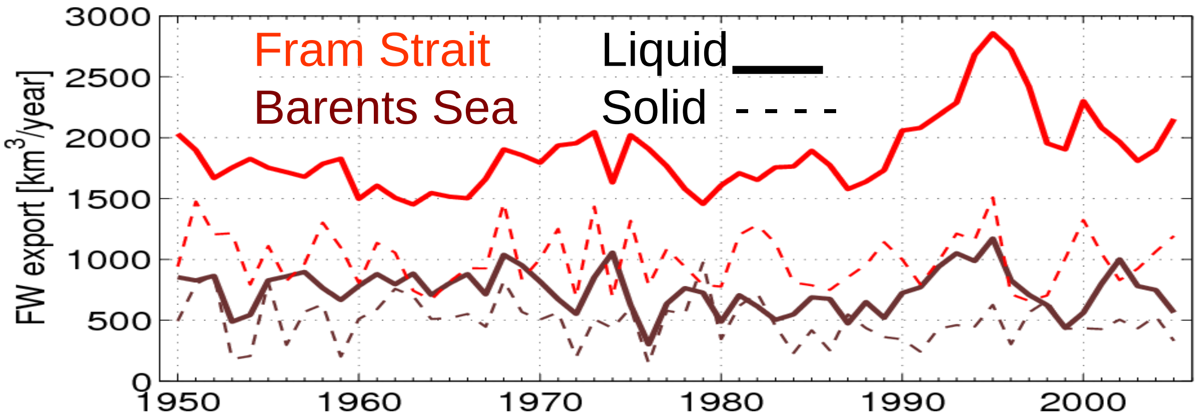
Increase in river runoff from Eurasia is in good agreement with other model results and data

FW balance over time

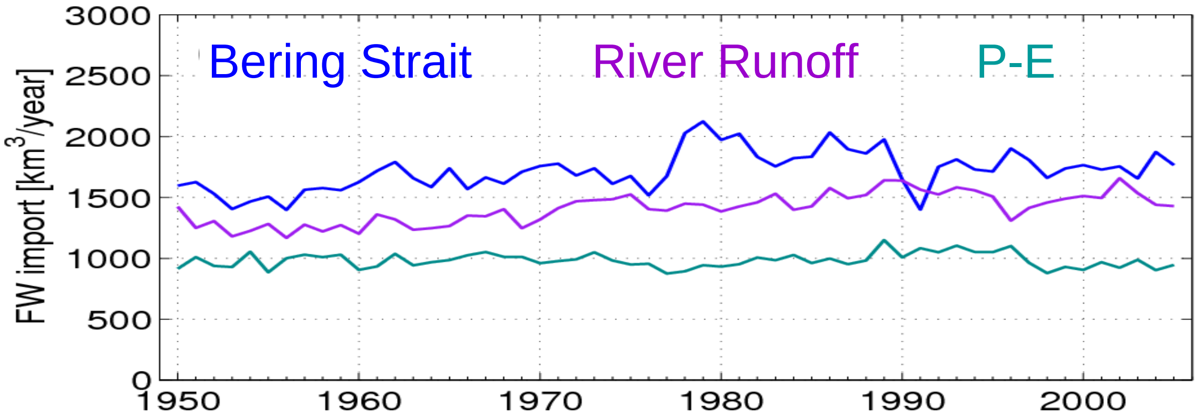


The FW balance is mainly controlled by changes in FW export

Individual terms of the Arctic Ocean FW budget



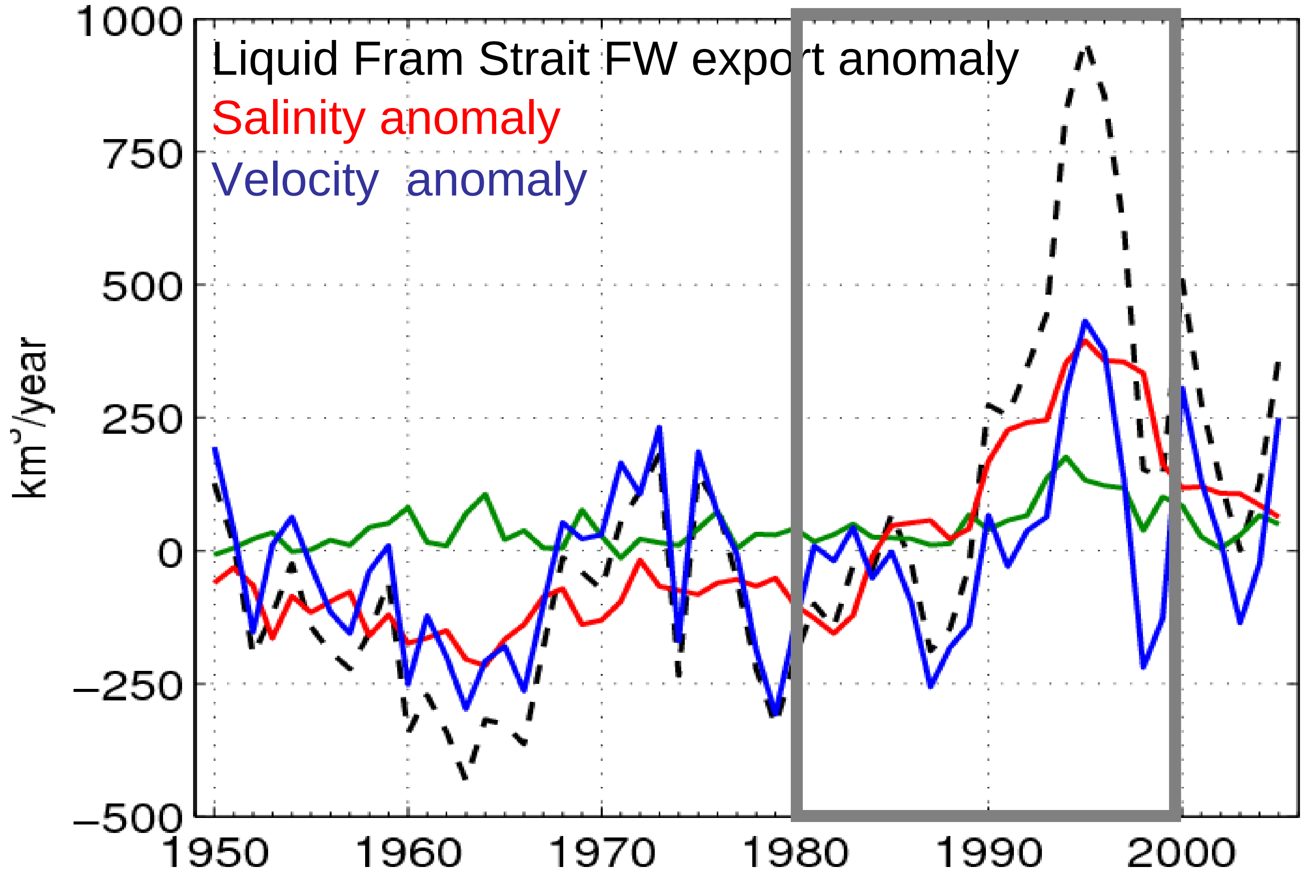
FW sinks



FW sources

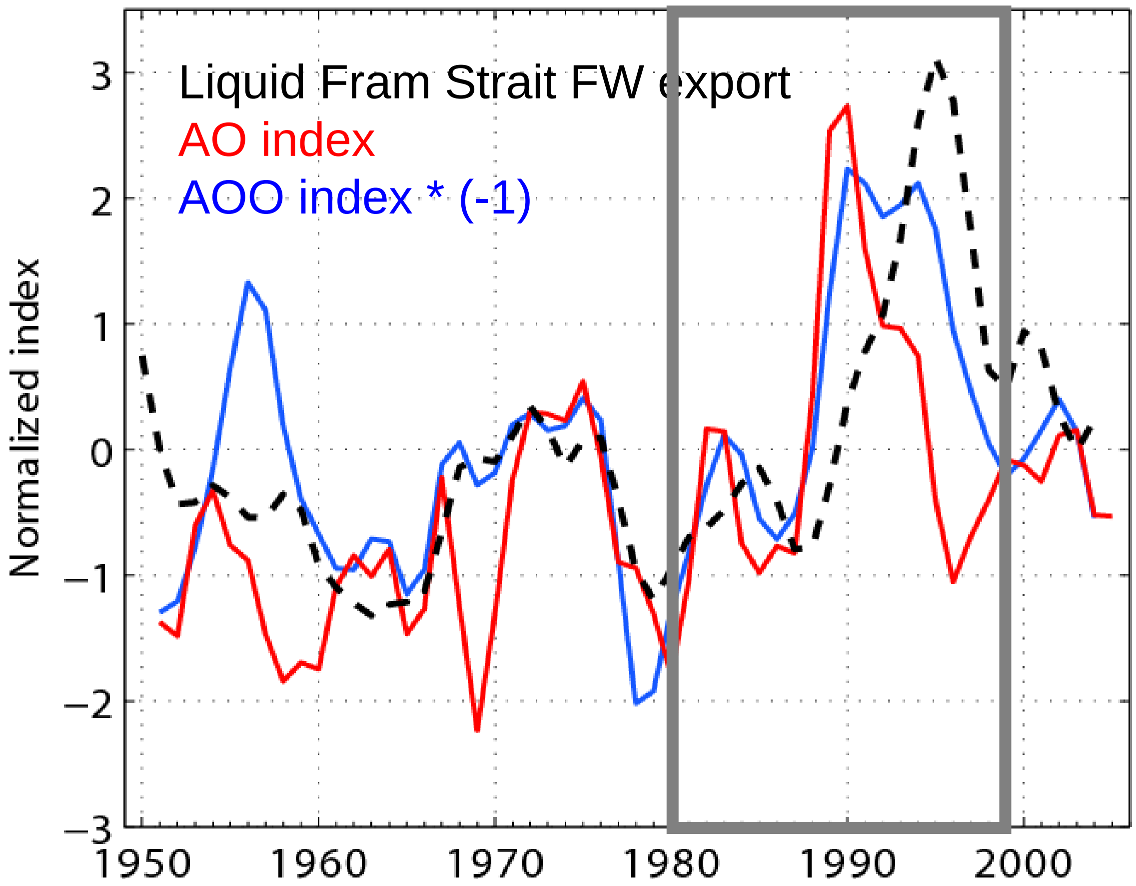
Fram Strait liquid FW export dominates the variability in the FW budget in the UVic ESCM

Controlled by velocity or salinity anomalies?



Both salinity and velocity anomalies are important for the variability of the liquid FW export through Fram Strait

Large scale atmospheric forcing



Maximum correlations (for 2y running means):

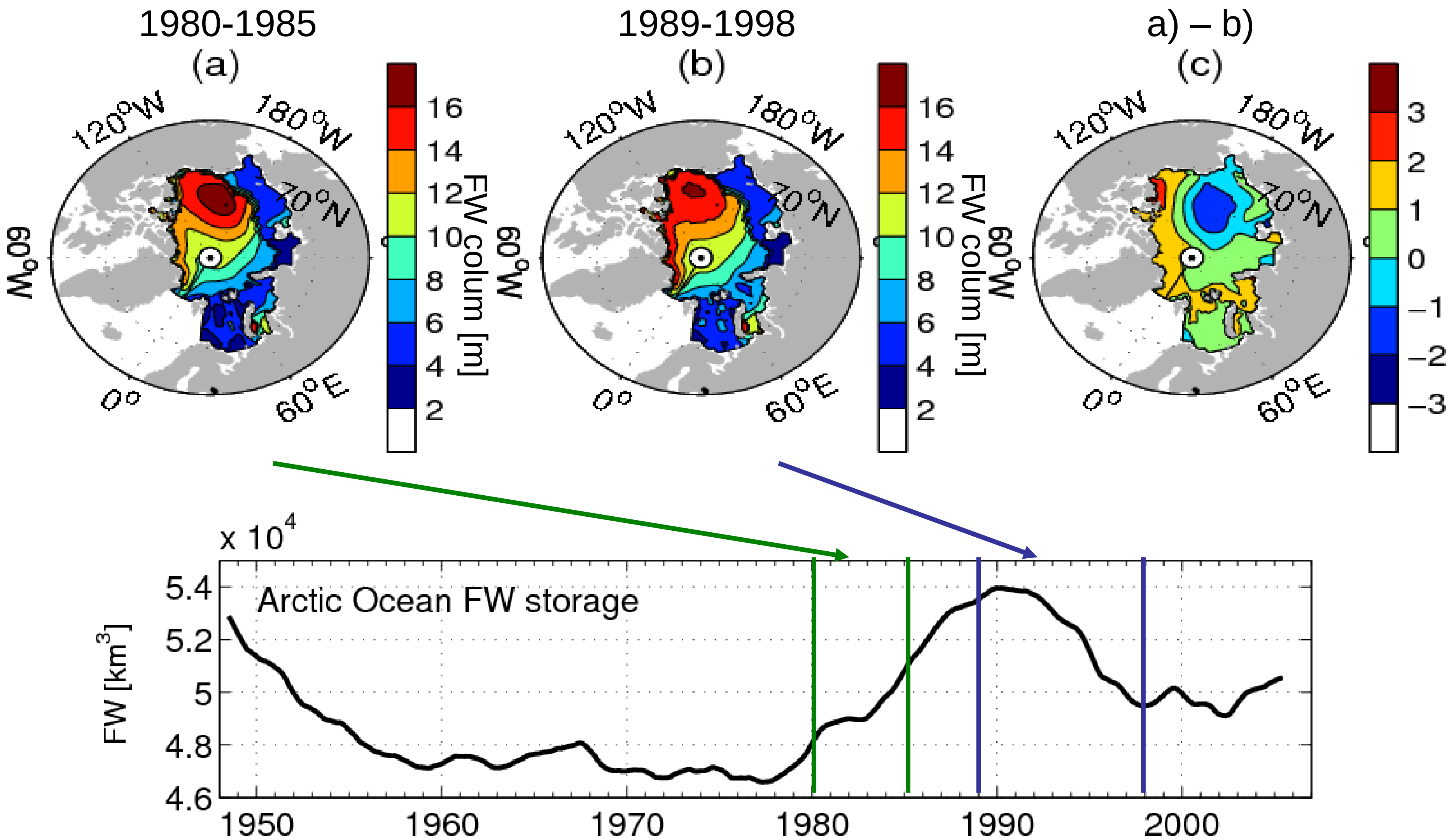
AO:FW r=0.65 (5 year lag)

AOO:FW r=-0.77 (2 year lag)

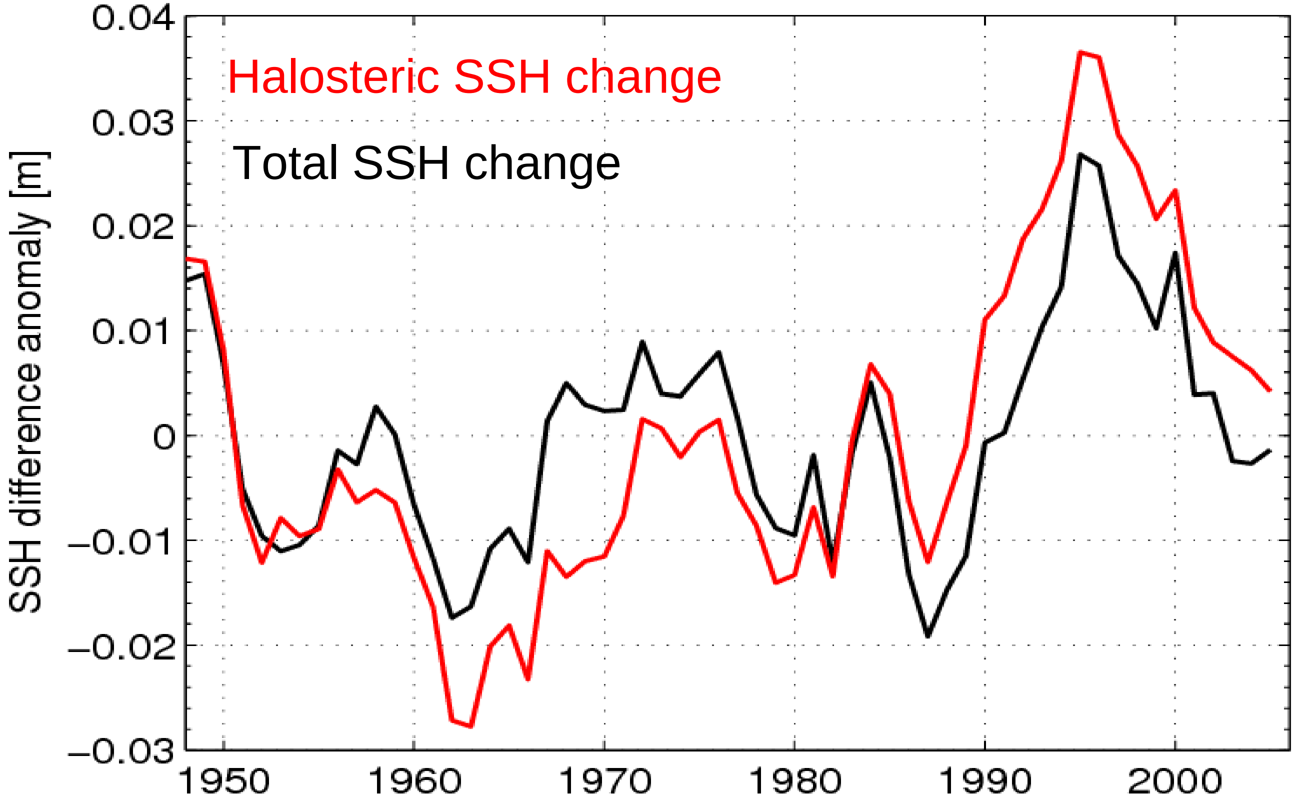
AO:AOO r=-0.71 (1 year lag)

The Fram Strait liquid FW export is controlled by the low-frequency variability of the atmospheric forcing over the Arctic

FW storage in the Arctic

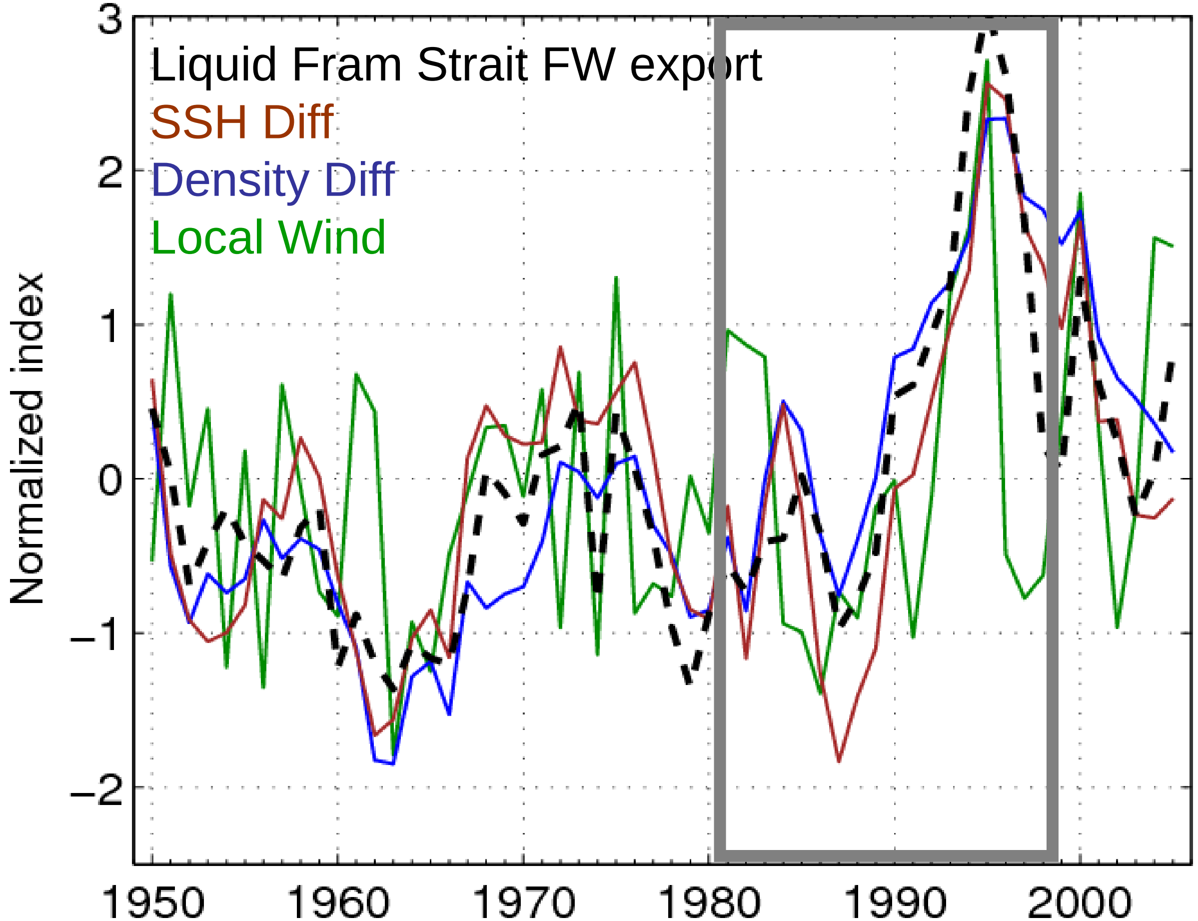


Effect on SSH



Changes in the FW distribution explain large fraction (~72%) of the SSH difference changes across Fram Strait

Local forcing



Maximum correlations:

SSH Diff: r=0.84

Density Diff: r=0.87

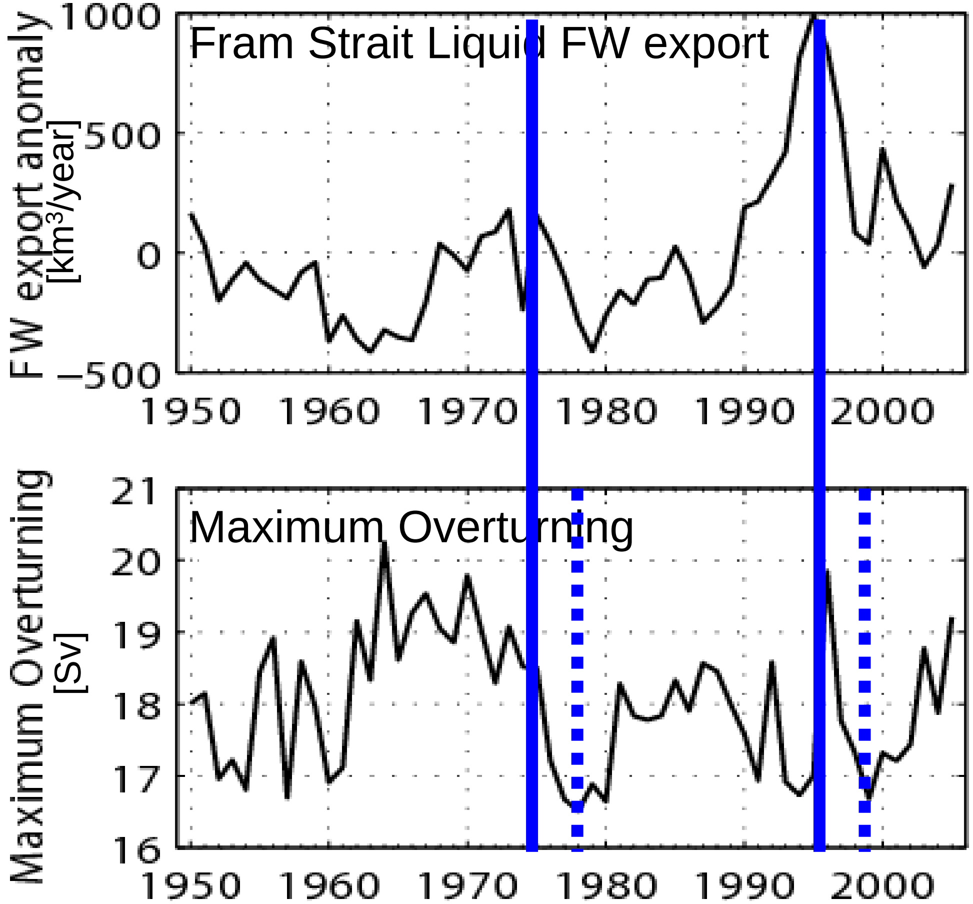
Local Wind: r=0.46

Changes in the SSH and the salinity upstream of Fram Strait can explain ~70% of the variance, the local wind forcing 21%.

Mechanism

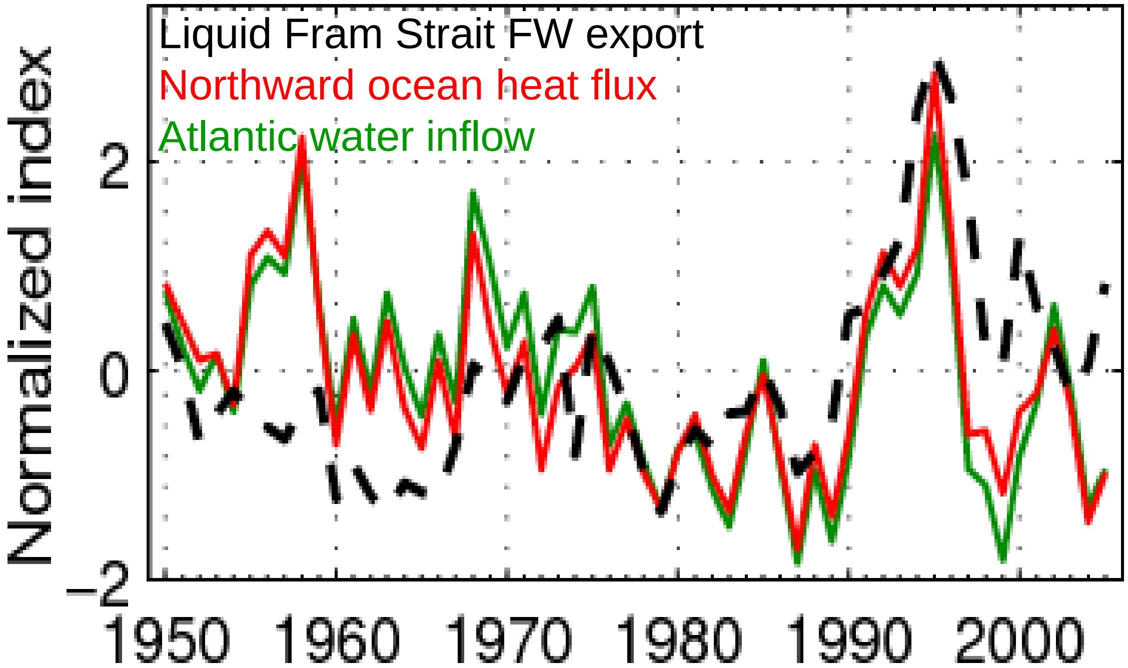
- Mechanism that controls the variability of the Fram Strait liquid FW export:
  - → large scale changes in atmospheric forcing
  - → changes in the Ekman pumping in the Beaufort Gyre
  - → SSH and density difference across Fram Strait change, mainly due to changes north of Fram Strait
  - → changes in liquid FW export through Fram Strait (due to salinity and velocity changes), about 2-5 years after changes in the large scale atmospheric forcing.

Influence on the MOC



Fram Strait liquid FW export effects strength of Atlantic MOC at a lag of 3-7years

Heat flux into the Arctic



- Cold Arctic water is replaced by warm Atlantic water →net heat flux northward
- Increased export of cold Arctic water leads to increased inflow of warm Atlantic water

Strong coupling between heat flux into the Arctic Ocean and the export of FW from the Arctic Ocean

Conclusions

- Mechanism that controls the variability of the Fram Strait liquid FW export:
  - → large scale changes in atmospheric forcing
  - → changes in the Ekman pumping in the Beaufort Gyre
  - → SSH and density difference across Fram Strait change, mainly due to changes north of Fram Strait
  - →changes in liquid FW export through Fram Strait (with a lag of 2-5 years behind the large scale atmospheric forcing)

- SSH and the salinity changes upstream of Fram Strait can explain **~70%** of the variance of the liquid FW export through Fram Strait, the local wind forcing can explain only **21%.**

Conclusions

- The liquid FW export from the Arctic and the ocean heat transport into the Arctic are strongly linked →This can have important implications for the future, when liquid FW export is predicted to increase (e.g. Holland et al., 2006)

- The liquid Fram Strait FW export leads to changes of up to 16% in the strength of the MOC three to seven years after a large liquid FW export event

Future work

- Use the CCSM to further investigate the mechanisms that govern the release of FW from the Arctic
  - →Use dye tracers to track the freshwater from different sources in the Arctic Ocean

Future work

- In simulation for 20th century:
  - Contribution of FW from different sources to liquid FW export through Fram Strait?
  - Changes in FW pathways in response to atmospheric forcing?
- For simulation for 21st century:
  - Changes in the FW pathways during the transition to a seasonal ice-free Arctic Ocean?
  - Feedbacks with the ocean heat transport into the Arctic Ocean?

Questions?

Picture credit: Blake Trask