Smelting og ferskvann svekker ikke nødvendigvis Atlanterhavsstrømmen

Three papers on the way towards NORTH

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TOR ELDEVIK, DOROTEA IOVINO, ANDERS OLSSON, ANNE BRITT SANDØ, HELGE DRANGE, MIRJAM GLESSMER, KJETIL VÅGE, ERIK BEHRENS.
The dense water formation in the Nordic Seas and Arctic is an important part of the global conveyor belt.

- Fresh water may limit dense-water formation.
The Nordic Seas limb of the conveyor belt is the Greenland (and Iceland) Sea Gyre.
Background and traditional concepts 3

Freshwater from the Arctic to the Nordic Seas can (and will) slow down the conveyor there
Outline of my talk

Three papers on the way towards NORTH

1. Sources for change in the deep overflows
   • Eldevik et al., Nature Geoscience, 2009
2. Sources for freshwater changes in the Nordic Seas
   • Glessmer et al., Nature Geoscience, 2014
3. A consistent framework for the Arctic–Atlantic Thermohaline Circulation
   • Eldevik and Nilsen, Journal of Climate, 2013
4. A project to test it all (NORTH)
   • Starting next week.
Observed sources and variability of Nordic Seas Overflow
The hydrography of the AW-in-OW-out loop

Nilsen et al. (2008)

Eldevik et al. (Nature geo. 2009)
The observed hydrography 1950-2005

No clear correlation with Greenland Sea (wo/w lag) – in contrast to what models generally show

The NISE dataset (Nilsen et al., 2008).
Eldevik et al. (Nature geo. 2009)
Anomalies travel the loop $\text{AW-in-OW-out}$

**Figure a**
- Normalized salinity over time:
  - NAW: Red line
  - RAW: Black line
  - DS: Red line

Values: $0.49; 0.46$

**Figure b**
- Normalized temperature ($^\circ$C) over time:
  - NAW: Red line
  - RAW: Black line
  - DS: Red line

Values: $0.47; 0.42$

NAW $\rightarrow$ 1 yr $\rightarrow$ RAW $\rightarrow$ 2 yr $\rightarrow$ DS

Eldevik et al. (Nature geo. 2009)
A “new” overturning loop

NAW → 1 yr → NNAW → 1 yr → FSC

Eldevik et al. (Nature geo. 2009)
Anomalies travel the loop AW-in-OW-out

Eldevik et al. (Nature geo. 2009)
Findings – based on the observational record

- Anomalies are carried with the Nordic Seas’ loop of Atlantic-derived waters
  - Predictability: Atlantic inflow #1 candidate
  - For the Faroe Shetland Channel a local Norwegian Basin overturning loop is suggested

- Overflow variability is not associated with deep convective mixing/Greenland Sea
  - as opposed to the traditional understanding and climate model diagnoses

Eldevik et al. (Nature geo. 2009)
What about the freshwater changes in these oceans? First, where do they come from ...
Atlantic origin of observed and modelled freshwater anomalies in the Nordic Seas
• Between 1965 and 1990, the waters of the Nordic Seas and the North Atlantic Ocean freshened substantially.

• The Nordic Seas are key sites in the Atlantic Meridional Overturning Circulation, with deep water formation inhibited if the surface salinity is too low.

• The Arctic Ocean also became less saline over this time, as a consequence of increasing runoff.

• Not clear whether flow from the Arctic was the main source of the Nordic Seas salinity anomaly.

See also Curry & Mauritzen (SCI, 2005)

Glessmer et al. (Nature geo. 2014)
Sources of freshwater *anomalies* to the Nordic Seas

1. Atlantic Ocean
2. Arctic Ocean ice
3. Arctic Ocean liquid

Glessmer et al. (Nature geo. 2014)
Accumulation of freshwater in the Nordic Seas

From the south:

Integrating inflow salinities and assuming constant volume inflow (8 Sv).

Glessmer et al. (Nature geo. 2014)
Accumulation of freshwater in the Nordic Seas

From the north:

Using variable volume transports and inflow salinities to calculate freshwater transports.

Glessmer et al. (Nature geo. 2014)
• **Freshwater anomalies** within the Nordic Seas can mostly be explained by less salt entering with the relatively saline Atlantic inflow.
• Seemingly little contribution from the Arctic.
• Hydrographic changes in the Nordic Seas are primarily related to changes in the Atlantic Ocean.
• If the Atlantic inflow and Nordic Seas both freshen similarly, Atlantic Meridional Overturning Circulation is relatively insensitive to Nordic Seas freshwater content.
Next, the fresh water and cooling in concert

So, the freshwater changes in these oceans, what do they do? …

And how do they work together with the cooling?
The Arctic–Atlantic Thermohaline Circulation

\[ U \approx 9 \text{ Sv} \]
\[ \Delta T \approx 8 \, ^\circ \text{C} \]
\[ \Delta S \approx 1 \]
\[ \text{heat loss } \approx 300 \text{ TW} \]

\[ \text{freshwater input } \approx 0.15 \text{ Sv} \]

TOR ELDEVIK. & J.EVEN Ø. NILSEN, JOURNAL OF CLIMATE 26, 2013
The estuarine circulation & the overturning circulation

- Arctic–Atlantic THC = two branch system
- A circulation of heat and salt => two degrees of freedom

1. Fresh water outflow
2. Mixing
3. Compensating inflow
Our system: The Arctic–Atlantic THC constrained at GSR

Circulation:
- freshwater Input
- heat loss

Pot. temperature

Salinity

EGC
Iceland
Salinity

FSC

GSR

PW

AW

OW

Thermohaline

Input

heat loss

1.AW

2.PW

3.OW
Our model: Conservation equations at GSR

\[ U_1 + U_2 + U_3 = 0 \]

\[ S_1 U_1 + S_2 U_2 + S_3 U_3 = q_S \]

\[ T_1 U_1 + T_2 U_2 + T_3 U_3 = q_T \]
Our model: Solved for the circulation (i.e., THC)

\[ U_1 = \frac{q_S(T_2 - T_3) - q_T(S_2 - S_3)}{\Delta} \]

\[ U_2 = \frac{q_S(T_3 - T_1) - q_T(S_3 - S_1)}{\Delta} \]

\[ U_3 = \frac{q_S(T_1 - T_2) - q_T(S_1 - S_2)}{\Delta} \]
Sensitivity to northern heat and FW forcing anomalies

\[ U_1 = \frac{(q_S(T_2-T_3)-q_T(S_2-S_3))}{\Delta} \]

\[ U_1 = 0 \iff q_T/q_S = \frac{(T_2-T_3)}{(S_2-S_3)} \]

\[ q_S = 0, q_T > 0 \implies U_1 > 0 \]

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Sensitivity to northern heat and FW forcing anomalies

\[ U_1 = \frac{q_S(T_2 - T_3) - q_T(S_2 - S_3)}{\Delta} \]

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\[ U_3 = \frac{q_S(T_1 - T_2) - q_T(S_1 - S_2)}{\Delta} \]
Strengthening of the Atlantic Inflow with a blue Arctic?

- FW: +0.03 Sv [ref. 1965; Peterson et al 2006] weakening of THC

- COOL: +50 TW, 40 yr of sea ice retreat
  [−0.4 mill km²; 1967–present; Kvingedal 2005; +138 W/m²; Årthun et al 2012] strengthening of THC

- FW + COOL strengthening of THC

Overflow

Polar outflow

Atlantic inflow

GSR

+1 Sv  +0.5Sv  +1.5 Sv

Polar outflow

Overflow

Atlantic inflow

GSR

+1 Sv  +0.5Sv  +1.5 Sv
Summary and implications

› Consistent framework to diagnose Arctic–Atlantic THC and change

› THC is not overflow

› FW increase does not imply weaker THC

› The relative strength of estuarine vs overturning circulation reflects FW input

› Present changes in the Arctic contributes to increased THC

› Observed increasing TH-contrasts implies a more robust THC

\[
U_1 + U_2 + U_3 = 0 \\
S_1 U_1 + S_2 U_2 + S_3 U_3 = q_S \\
T_1 U_1 + T_2 U_2 + T_3 U_3 = q_T
\]
NORTH – NORthern constraints on the Atlantic ThermoHaline circulation

NFR, 2014–2017

• Scrutinize the thermohaline Knudsen model
• Develop a northern Stommel ‘double-estuary’ model
• Laboratory experiments
• Comparisons with numeric ocean model
• “Mobile THC laboratory”

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Overall summary

Hydrographic anomalies are carried to the overflows with the Nordic Seas’ loop of Atlantic-derived waters

Overflow variability is not associated with the Greenland Sea

Freshwater anomalies within the Nordic Seas mostly explained by less salt entering with the Atlantic inflow

Thermohaline circulation (THC) is not overflow

FW increase does not imply weaker THC

Present changes in the Arctic contributes to increased THC

Observed increasing TH-contrasts implies more robust THC