Atlantic Water variability in the 20th century Arctic Ocean from observations and a global ocean model

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PhD project description

During my Phd (started Dec. 2016) the following will be investigated:

- Atlantic Water variability and circulation in the twentieth century Arctic Ocean
- Influence of Atlantic Water on Arctic sea ice north of Svalbard (N-ICE2015)
- Response of a global ocean model (NorESM-O) to abrupt changes in the Arctic Ocean; e.g. changes in freshwater inflow or wind forcing

Using the following methods:

- Analysis of simulations from the ocean-sea ice component of the Norwegian Earth System Model (NorESM-O) forced by a Twentieth Century Reanalysis data set (He et al., 2016)
- Comparison of model simulations with historical and recent observations
- A coordinated model comparison experiment within the FAMOS (Forum for Arctic Modeling and Observational Synthesis) framework
- Calculation of "Climate Response Functions" (CRFs) — the transient response of key observable indicators such as sea-ice extent, freshwater content of the Beaufort Gyre, Atlantic Water flow, etc. — to abrupt "step" changes in forcing fields across a number of arctic models (Marshall et al., 2017)

Background

Warm and salty Atlantic Water (AW) enters the Arctic Ocean through the Fram Strait and the Western Barents Sea (Fig. 1). This Atlantic Water is present below the Arctic sea ice cover, but the depth varies by region and over time. In regions north of Svalbard the Atlantic Water has a direct impact on the sea ice cover.

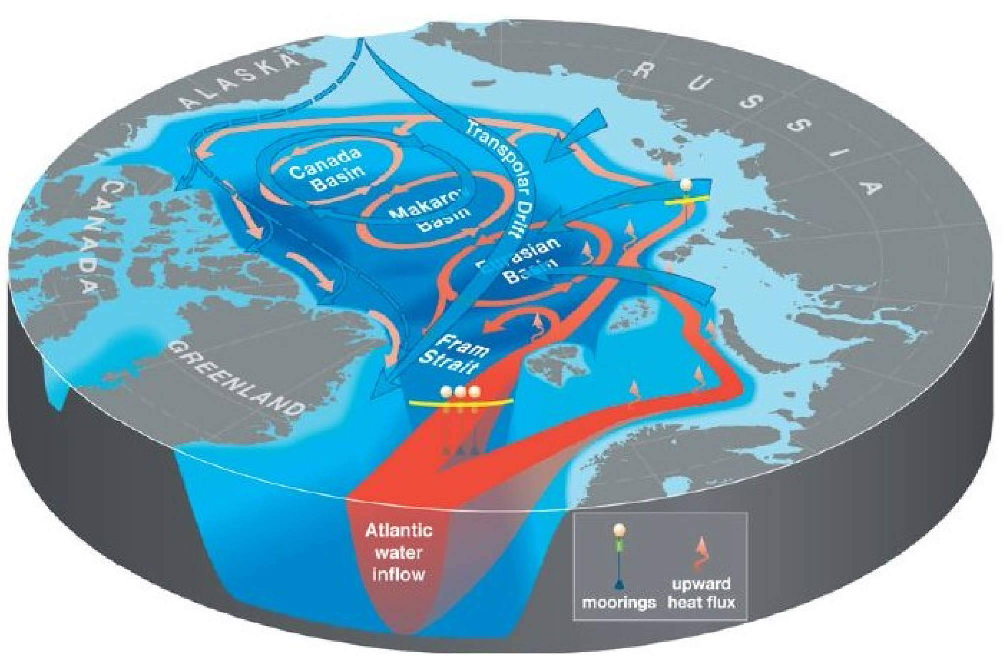


Figure 1: Regional circulation schematic of Atlantic Water inflow and circulation in the Arctic Ocean. Figure from Polykov et al. (2012).

Both historical observations and outcome from a fully coupled earth system model show a warming trend in core temperature of the Atlantic Water inflow over the last few decades (1977-2015) (Fig.2, Muilwijk,2016).

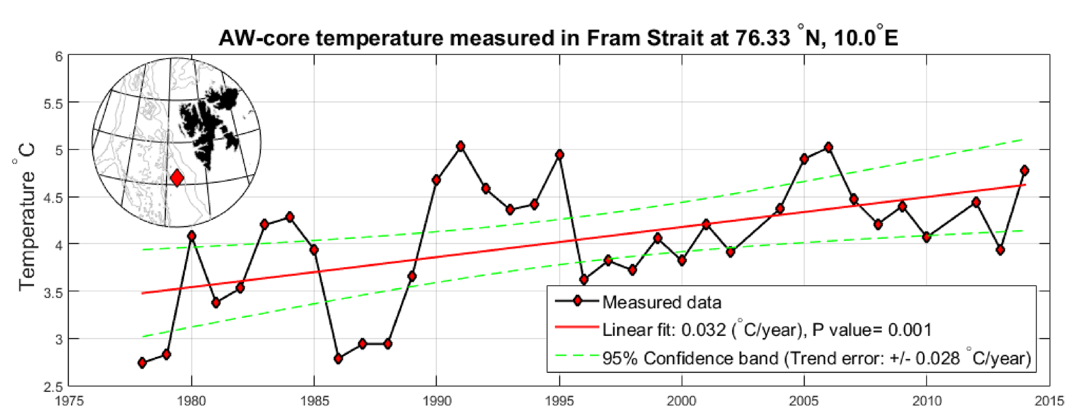


Figure 2: Timeseries of AW-core temperature (black) measured in the Fram Strait. Data from the Norwegian Institute of Marine Research. Figure from Muilwijk (2016).

Observational data: N-ICE2015 and climatologies

Between January and June 2015 the R.V. Lance completed four drifts in the Arctic sea ice north of Svalbard (Fig. 6). On each floe, an ice camp was set up and oceanographic, atmospheric, sea ice, snow, and biologic observations were collected (Granskog et al., 2016). Below the mixed layer Atlantic Water (AW) is found with a mean depth of the upper interface at 107 m in winter (Fig. 4).

During winter there is extensive bottom melting in the region of AW inflow, likely due to upward heat flux from AW driven by turbulent mixing (Peterson et al., 2017).

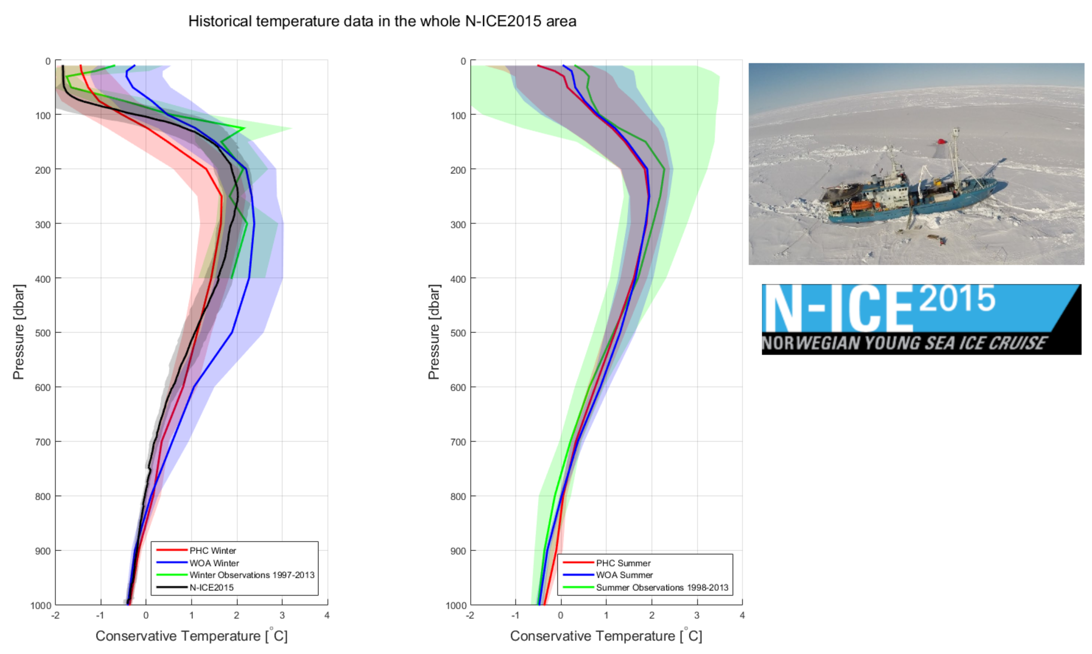


Figure 3: Historical mean temperature profiles from two climatologies (PHC3.0 and World Ocean Atlas 2013) compared with N-ICE2015 observations and available observations in the period 1998-2013. Figure from Muilwijk (2016)

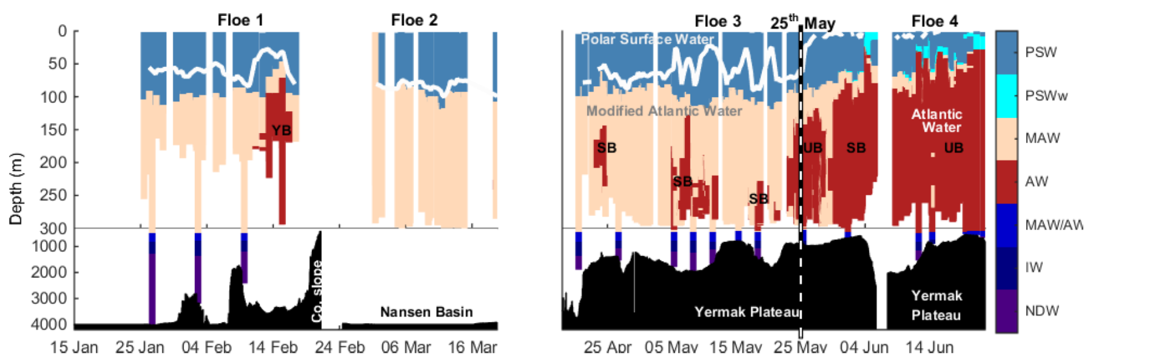


Figure 4: Vertical distribution of water masses along the N-ICE2015 drift trajectory. Watermasses are labelled by color: (Atlantic Water (AW), Modified Atlantic Water (MAW), Polar Surface Water (PSW), Warm Polar Surface Water (PSWw), Intermediate Water (IW), and Nordic Deep Water (NDW) following Rudels et al. (2000)'s definitions. Patches of Atlantic Water are indicated coming from either the Svalbard Branch (SB), the Yermak Branch (YB),or undetermined (UB). Overlying the water masses color scale is a contour of the mixed layer depth (white line). Figure from Meyer et al. (2017).

Ongoing work: Atlantic water variability and passive tracers

Over the twentieth century, the Atlantic Water temperature records from observations show two warm periods, in the 1930s-40s and in recent decades, and two colder periods, early in the 1900s and in the 1960s-70s (Muilwijk, 2016). We believe that the Atlantic Water warming trend in the Arctic Ocean may be part of long-term multidecadal variability, which is influenced and reinforced by strong anthropogenic forcing. We will investigate this variability and the physical mechanism behind using NorESM-O forced by a twentieth century reanalysis data set for the period 1871-2009 (He et al., 2016).

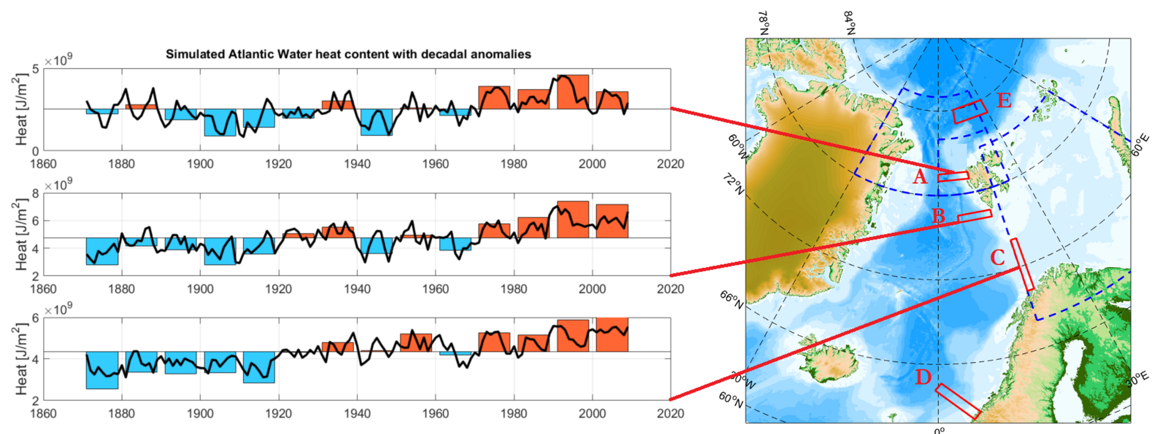


Figure 5: Simulated yearly mean Atlantic Water heat content from NorESM-O forced by twentieth century reanalysis in the Fram Strait (A, West Spitsbergen Current (B)) and the Barents Sea Opening (C). Red and blue bars show decadal anomalies.

a) Fram Strait
b) Barents Sea Opening
c) Bering strait
d) Svinoy section
e) Kara Sea
f) Laptev Sea
g) Beaufort Sea

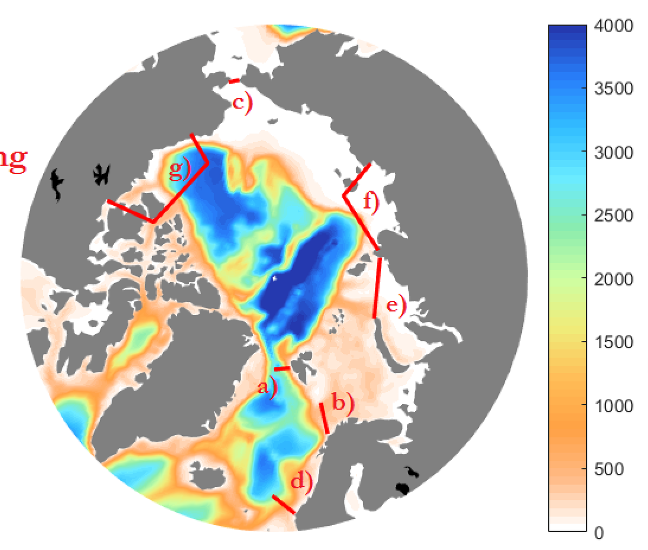
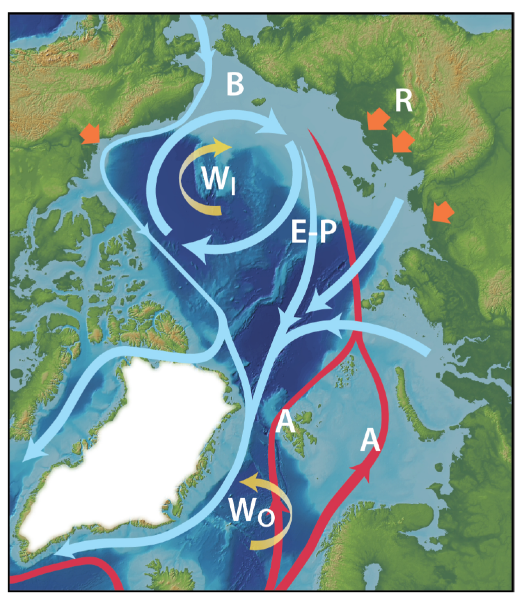


Figure 6: Atlantic Water and freshwater pathways in the Arctic Ocean will be investigated in NorESM-O using passive tracers released on locations a)-g) for the period 1871-2009.

Ongoing work: Climate Response functions in the Arctic Ocean



Another set of simulations with the ocean-sea ice component of the Norwegian Earth System Model (NorESM-O) has been run. This simulation is part of a coordinated set of Arctic modeling experiments where our goal is to compute and compare "Climate Response Functions" (CRFs) - the transient response of key observable indicators such as sea-ice extent, ice export through the Fram Strait, freshwater content of the Beaufort Gyre, Atlantic Water flow, etc - to abrupt "step" changes in forcing fields across a number of Arctic models (Marshall et al., 2017). The idea is that the convolution of time series from this forcing with the respective CRF then yields a (linear) response of observable indicators.

Figure 7: A schematic of circulation pathways in the Arctic Ocean and key "switches" that can perturb it. Thick blue pathways show general branches of sea ice drift and surface water circulation. Red arrows represent inflows of warm Atlantic waters entering the Arctic Ocean. Key "switches" for the Arctic, that will be perturbed the model, are also indicated: winds interior (WI in the Beaufort Gyre) and exterior (WO in the Greenland Gyre) to the Arctic basin, and river runoff (R, orange arrows). Figure from Marshall et al., (2017)

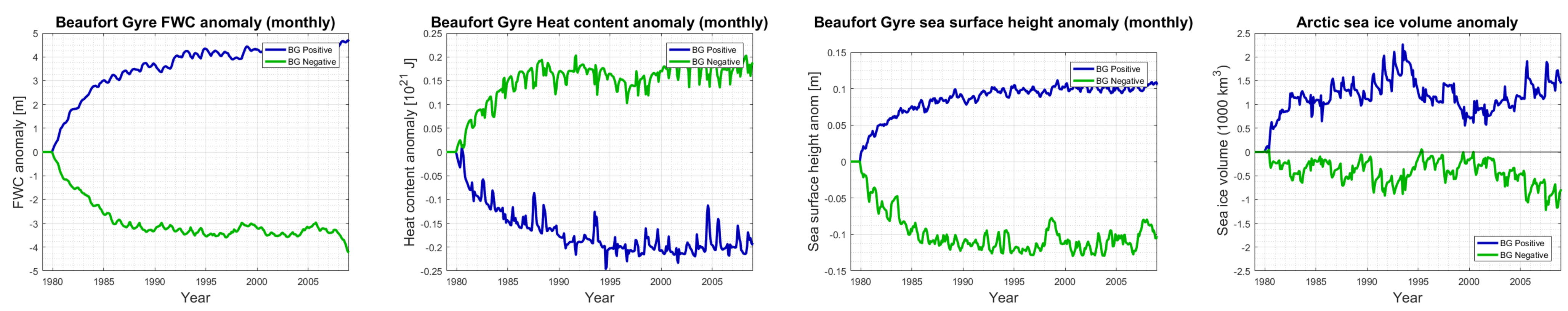


Figure 8: Preliminary results of CRF's after perturbing NorESM-O with a positive and negative wind anomaly in the Beafort Gyre.

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References: Granskog et al. (2016), Arctic research on thin ice: Consequences of Arctic sea ice loss, EOS, 97. **He et al. (2016)**, Simulated Atlantic Meridional Overturning Circulation in the 20th century with an ocean model forced by reanalysis-based atmospheric data sets, Ocean Modelling 100: 31-48. **Meyer et al. (2017)**, Winter to summer oceanographic observations in the Arctic Ocean north of Svalbard. *Journal of Geophysical Research: Oceans*. **Muilwijk (2016)**, Bottom melting of Arctic Sea Ice in the Nansen Basin due to Atlantic Water influence (Master thesis). **Peterson et al. (2017)**, Turbulent heat and momentum fluxes in the upper ocean under Arctic sea ice. *Journal of Geophysical Research: Oceans*. **Marshall et al. (2017)**, Climate Response Functions for the Arctic Ocean: a proposed coordinated modelling experiment. *Geosci. Model Dev. Discuss., 2017: 1-25*. **Polyakov et al. (2012)**, Warming of the intermediate Atlantic Water of the Arctic Ocean in the 2000s, *Journal of Climate*.