C32 Drivers of freshwater distribution in the Arctic and Atlantic oceans

ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

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Freshwater anomalies in the Arctic and North Atlantic

Being connected by a network of currents, the Arctic and North Atlantic Oceans exchange a large volume of water of different characteristics. As a consequence, their freshwater budgets are also connected.

Averages for two decades before 2000 picture an approximate balance between Arctic freshwater intakes and exports. However, freshwater fluxes to and from the Arctic Ocean, and thus the storage of freshwater are not constant, and have not been in recent years either. According to observations, the **liquid freshwater content of the Arctic Ocean increased** by around 10,000 km^3 between 1992-2012 (Rabe et al. 2014, Fig. 1).

The freshwater system of the Arctic linked to the North Atlantic appears to be dynamic with changes and anomalies on different time scales. The comparison of the **freshwater content anomalies of the Arctic Ocean**, and the **Subpolar North Atlantic and the Nordic Seas** shows a significant anti-correlation (95 % confidence). Moreover, the similar size of freshwater anomalies **suggest an oscillation** (Horn et al. in prep. Fig. 2).

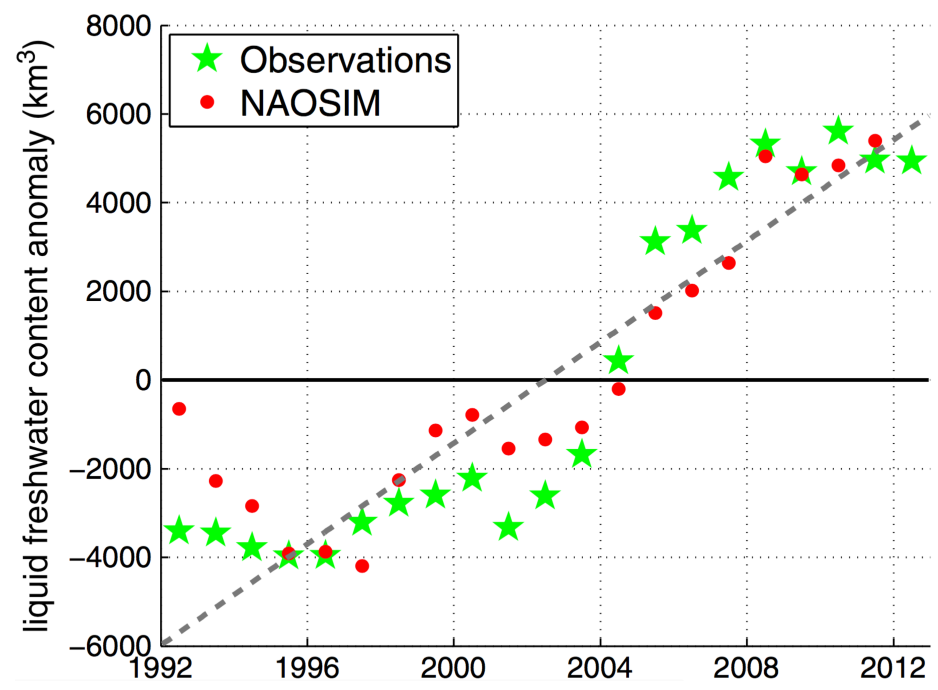

Fig. 1. Time series of Arctic Ocean liquid freshwater content anomalies for 1992-2012 (Rabe et al. 2014)

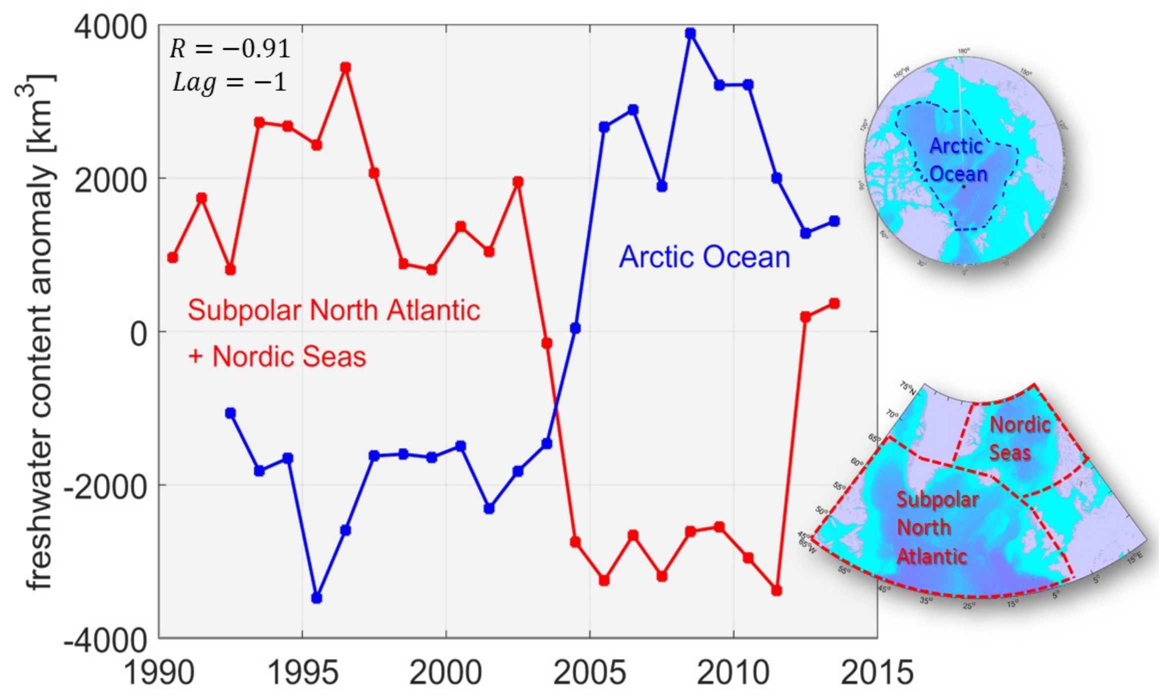

Fig. 2. Freshwater content anomalies in the Arctic Ocean, and the Subpolar North Atlantic and the Nordic Seas (Horn et al. in prep.)

The evolution of liquid **freshwater content** in the Subpolar North Atlantic **correlates** with time series of cumulative **AO and NAO indices** (Horn et al. in prep. Fig. 3.)

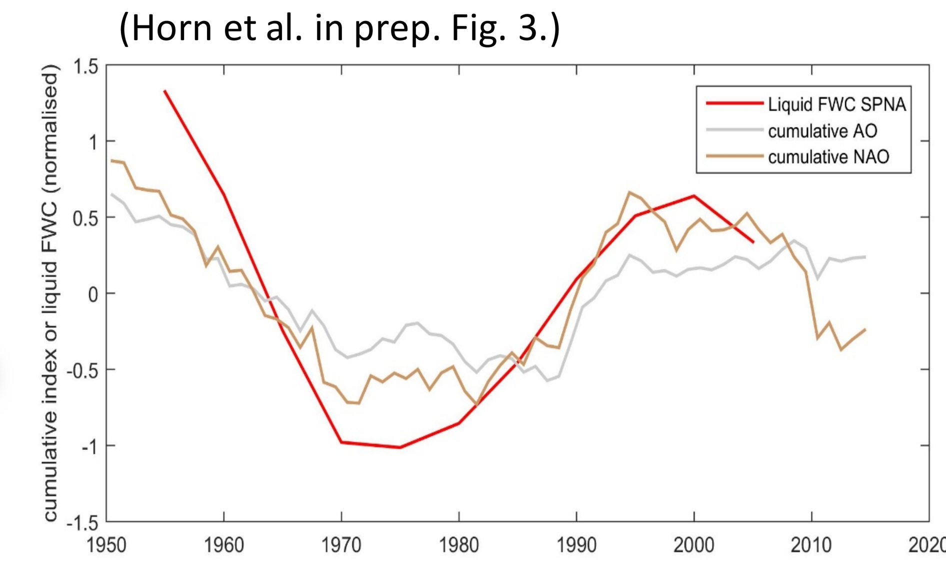

Fig. 3. Time series of liq. freshwater content in the Subpolar N-Atlantic, and cumulative atmospheric indices of the Arctic Oscillation and the North Atlantic Oscillation (Horn et al. in prep.)

What is the future outlook?

Faster warming in high latitudes and enhanced hydrological cycle

Freshening in the N-Atlantic and the Nordic Seas

Slow-down of overturning and gyre circulation (Gerdes et al. 2006)

Weakening AMOC

These changes set a stage for competing forces that have opposite effects.

Climate change could weaken the AMOC, while a stronger positive NAO acts as a driver of the circulation.

Increasing NAO

Enhanced heat and salt transport to key deep water forming regions

Stronger convection, more deep water is formed

Strengthening AMOC

What is the future of the NAO?

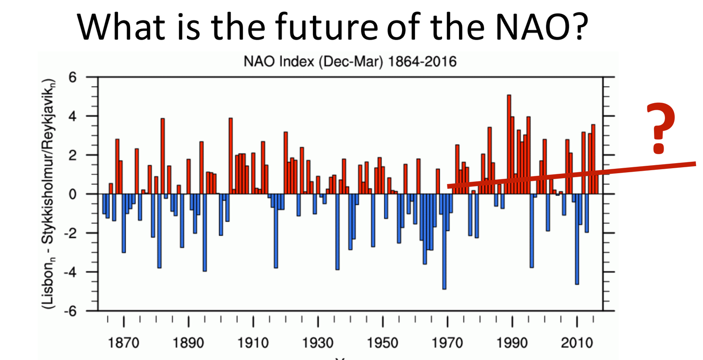

Fig. 4. Time series of Winter (Dec-Mar) NAO for 1864-2016 (Climate Data Guide; A. Phillips)

Predominant high NAO index, a positive trend that could continue into the 21. century.

Hypothesis and Aims

The freshwater budgets of the Arctic and the North Atlantic oceans are linked. The distribution of freshwater in their basins is subject to significant changes. The hypothesis is that these changes are driven by atmospheric forcing:

Freshwater distribution in the Arctic and North Atlantic oceans is governed by wind stress forcing.

The aim is to investigate the role of atmospheric forcing in shaping freshwater reservoirs and exchanges between different subregions of the Arctic and North Atlantic oceans. What are the processes affecting the circulation? What role does the wind stress play? What changes of freshwater do different NAO state favor, where and how does it influence the distribution?

Methods – MPI-ESM and Modini

The tool for experiments is the fully coupled Earth System Model of the Max Planck Institute (MPI-ESM), using a partial coupling technique (Modini-MPI-ESM), to incorporate reanalysis wind fields to enable studies with different wind stress scenarios.

MPI-ESM-LR (low resolution)

Atmosphere – ECHAM6: T63 horizontal res.
47 vertical levels

Ocean – MPIOM: 1.5° horizontal res.
poles over Antarctica and Greenland
40 vertical levels

Coupling – OASIS: exchange of fluxes and state variables
24 hour cycle

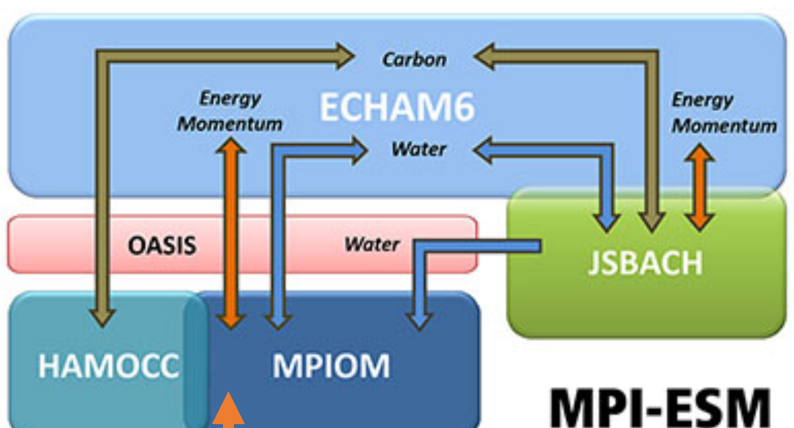

Fig. 5. MPI-ESM structure of model components (Giorgetta et al., 2013)

Observations *Energy/Momentum* → **Modini**

The Modini approach is a partial coupling technique which enables the MPIOM, the ocean component of the MPI-ESM (Fig. 5) to be driven by **prescribed 6 hourly wind stress anomalies**, while **maintaining consistency** of heat and energy exchanges between the atmosphere and ocean. External wind forcing can be enabled or disabled in a **flexible** way, while the rest of the coupling remains the same as in the original MPI-ESM configuration. Thus the atmospheric model component ECHAM6 still computes its own wind field and responds to the external forcing only through receiving coupled parameters from MPIOM (Thoma et al., 2015).

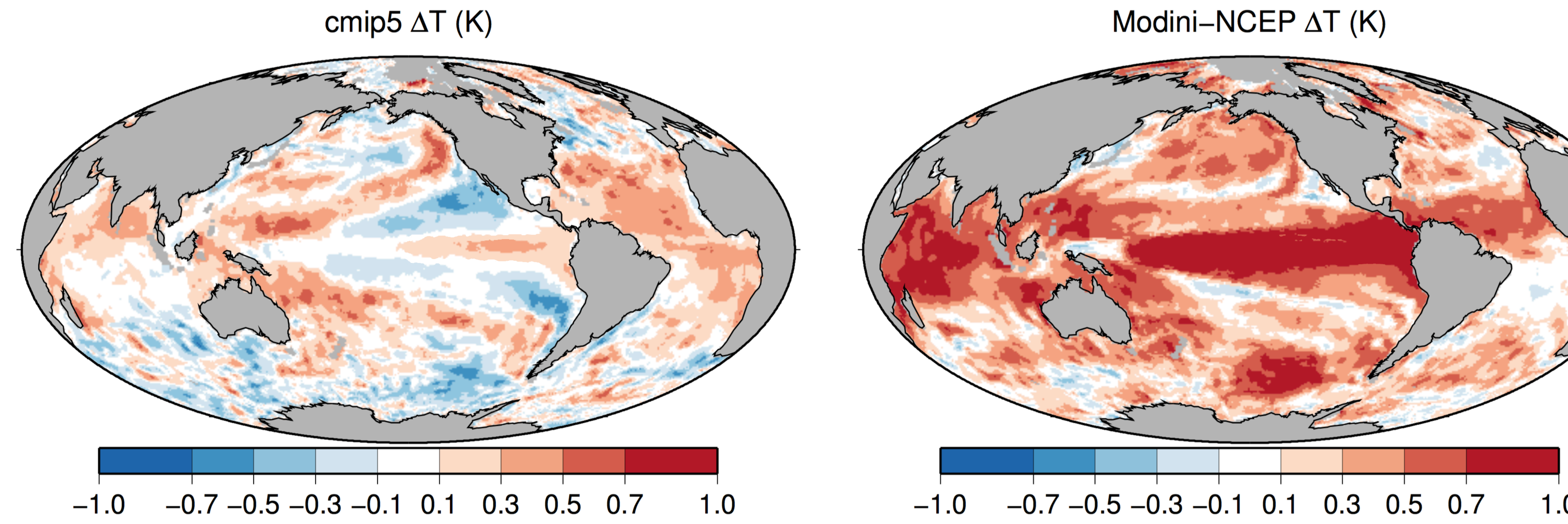

Fig. 6. Improvement of the correlation between the model and the reference (HADIsst) SST (detrended annual means from 1980 (CMIP5) and 1981 (Modini-NCEP)). Left: original MPI-ESM as in the CMIP5 experiment; Right: partially coupled Modini-MPI-ESM with NCEPcfsr wind forcing (Thoma et al. 2015)

The wind forcing of Modini brings an **improvement** between the **correlation of the modeled and observed SST.** The improvement is most pronounced in the Pacific and Indian oceans, but there is an increase in the Arctic too (Fig. 6).
The upwelling regions of the North Atlantic suffer from known biases in the MPI-ESM as in most Earth system models, however, an improvement is still visible from wind forcing, especially in the Labrador Sea (Fig. 6).

Modini applicability and experiment design

External forcing data: NCEPcfsr (Saha et al. 2010) → Wind speed data → Interpolation, Calculation from ocean momentum → Wind stress data → Anomalies, applying them to model climatology → Wind stress anomalies

Experiments:

spin-up → time

How do different NAO states affect the distribution of freshwater? How do they influence the AMOC?

- CONTROL
- high NAO
- SWITCH_NtoP
- SWITCH_PtoN

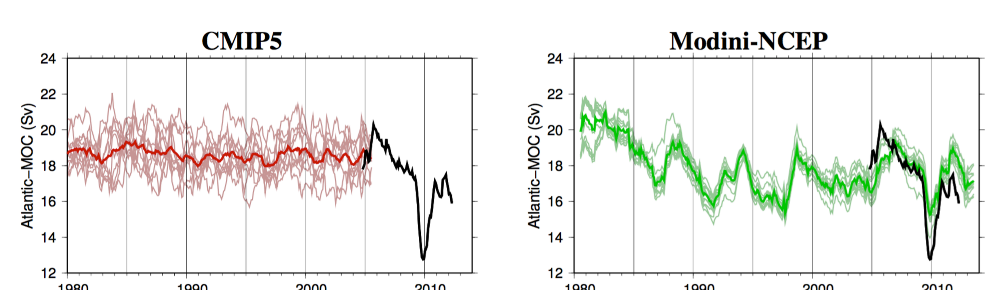

Fig. 7. Monthly means of AMOC strength (at 26°N) for the original MPI-ESM as in the CMIP5 experiment (red) and Modini-MPI-ESM (green). Reference (black) is RAPID mooring array data (Thoma et al. 2015)

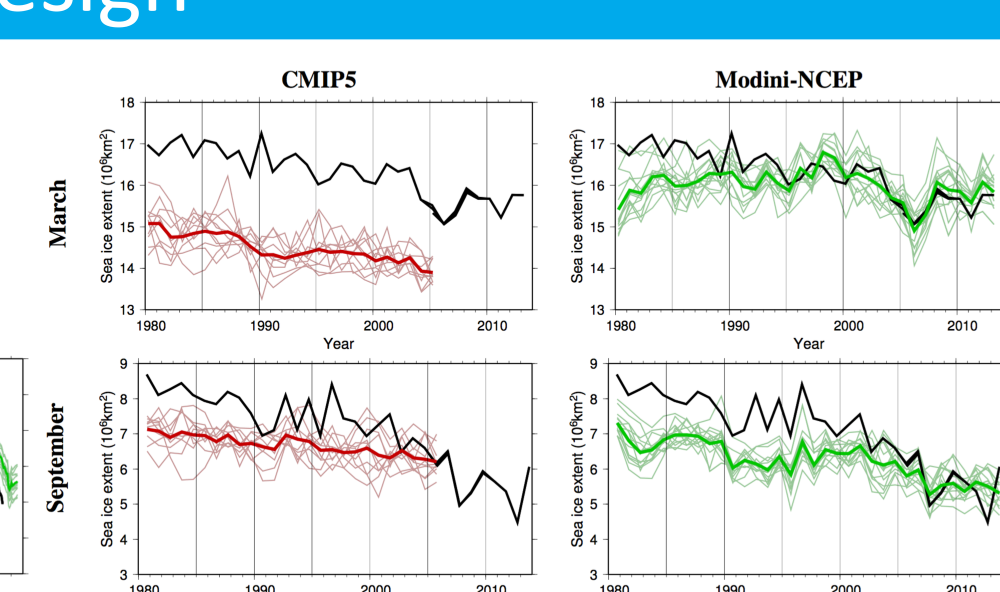

Fig. 8. Monthly means of Arctic sea ice extent (conc. > 15%) for March (top) and September (bottom) for the original MPI-ESM as in the CMIP5 experiment (red) and Modini-MPI-ESM (green). Reference is OSISAF data in black line (Thoma et al. 2015)

Modini-MPI-ESM with NCEPcfsr wind forcing shows **skills in reproducing the timing of climate events**. Variations in the strength of the AMOC are particularly well captured (Fig. 7). The model performance increases in the Arctic as well using Modini (Fig. 8), even though wind speed over open ocean in such high latitudes is relatively weakly constrained in reanalyses due to observation availabilities (Thoma et al., 2015)

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