Response Experiments
with
NAO related forcing

by

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Abstract

Numerical experiments with realistic atmospheric forcing exhibit long term variations in ocean and sea ice in agreement with observations. Analysis of hindcast experiments can provide statistical relationships between sea ice, ocean and atmosphere time series. To identify the liable mechanisms in the hindcast experiments we employ response experiments with a coarse resolution model of the subpolar North Atlantic.

We concentrate here on the effect of long term changes in the wind forcing on the large scale oceanic circulation in the periods before and after 1980. Furthermore, the response to a sudden drop and following recovery of the NAO type forcing will be discussed.

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1 Introduction

The variability of many oceanic and sea ice quantities is linked to the *North Atlantic Oscillation* (NAO) (HURREL, 1995). One example is the ice export through Fram Strait as shown by VINJE ET AL. (1998). When the NAO index shifts from high to low in the winter 95/96, the ice export through Fram Strait is reduced by half (Fig. 1).

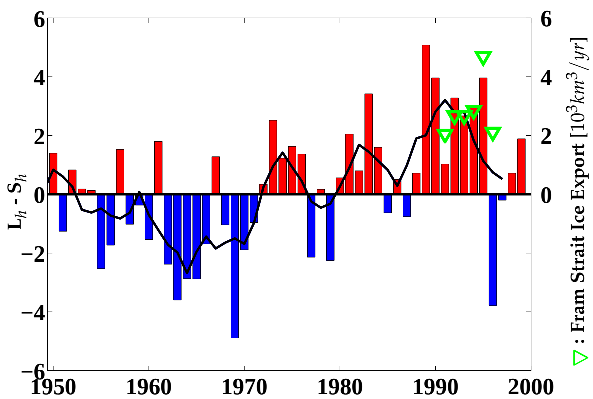

Figure 1: NAO Index (Dec-Mar) after HURREL (1995), 1950 - 1999, defined as the normalized sea-level pressure difference between Lisbon, Portugal (L_h) and Stykkisholmur, Iceland (S_h). The solid line shows a five-year running mean of the NAO and the triangles represent the Fram Strait ice export after VINJE ET AL. (1998)

The sudden drop and the following recovery of the NAO index is an outstanding climate event in the last 20 years in the northern North Atlantic. Here we use a coupled ocean-sea ice GCM to simulate the response to a wind forcing that reflects this development.

2 Model description and experimental design

The ocean model is based on the MOM-2 code (PACANOWSKI, 1995). The model domain encloses the Arctic Ocean and the North Atlantic Ocean down to approximately 20°S and has a horizontal resolution of $1° \times 1°$. A dynamic-thermodynamic sea ice model with a viscous-plastic rheology (HARDER ET AL., 1998) based on HIBLER (1979) model is coupled to the ocean model following the procedure of HIBLER AND BRYAN (1987).
Two different data sets for the windstress field are used. One field is derived as a composite for the "NAO+" period (1979-1993) from the *ECMWF* reanalysis data set (GIBSON ET AL., 1997). The other is a composite of the years 1958 - 1972 of the NCEP/NCAR reanalysis (KALNAY ET AL., 1996). This period is mainly governed by a "NAO-" sea-level pressure field (cf. Fig.1).
The other atmospheric forcing data are based on the *ECMWF* reanalysis data set. A typical year of the period 1979 - 1993 is generated as monthly data sets for 2 metre temperature, dew point temperature, precipitation and cloudiness (RÖSKE, 1999). The surface heat and fresh water fluxes are calculated by the model accorcing to the predicted SST and sea ice distribution.
Surface salinity is weakly restored to observed data from the EWG-atlas (EWG - ENVIRONMENTAL WORKING GROUP, 1997) to account for the Bering Strait inflow and continental run-off.
We will discuss three experiments that are illustrated in Fig. 2. A control experiment is calculated for 20 years with "NAO+" wind stress forcing. This forcing reflects the high NAO index state of the atmosphere that existed since the early 1970s. In the "Switch" experiment the wind stress is switched to "NAO-" forcing after 10 years of spin-up that are identical to the control experiment. The "Switch" experiment looks at the consequences of a sudden but sustained shift in the atmospheric circulation. The further experiment, "Peak", starts from year 11 of "Switch" when the wind stress is reverted to "NAO+" forcing. This

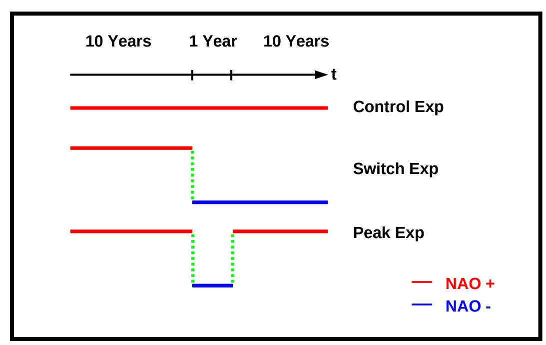

Figure 2: Experimental design

experiment investigates the consequences of a sudden and short lived shift in the atmospheric circulation, like the observed shift of winter 95/96 and the following recovery of the NAO index.

3 Results

For the analysis, means of the winter half year (NDJFMA) are generated. Winter means of the control experiment were substracted from the winter means of “Switch” and “Peak”. In the following paragraph, these anomalies are shown and evaluated for different parameters.

3.1 Sea surface salinity

In the first winter after switching the wind stress forcing from “NAO+” to “NAO-” a negative surface salinity anomaly of approximately -1 psu fills the eastern Eurasian Basin (Fig.3). In the vicin-

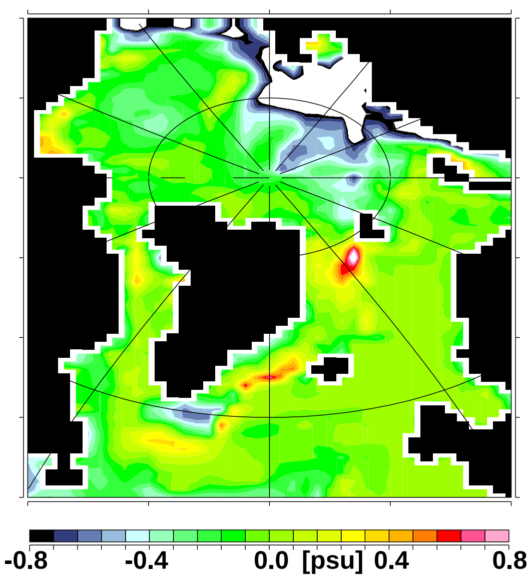

Figure 3: SSS winter 10/11 of the “Switch” experiment, white areas indicate values out of range

ity of the East Greenland Current (EGC) a positive salt anomaly appears. Five years later in the ”Switch” experiment, the anomaly is enhanced in amplitude and in extent (Fig. 4). The negative salt anomaly now covers much of the Eurasian Basin, the Kara and Laptev Seas, the eastern part of the

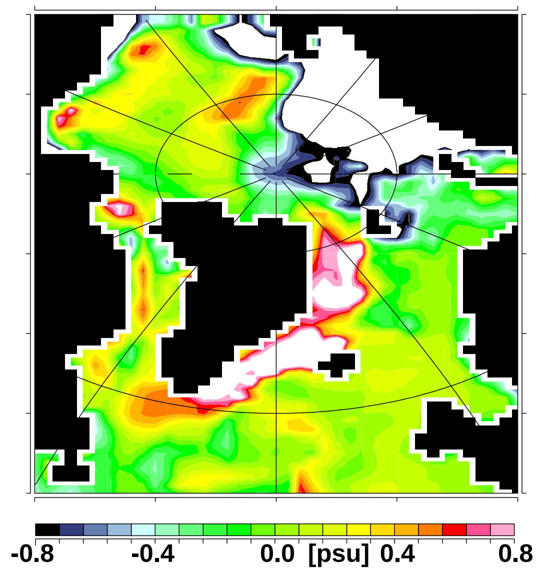

Figure 4: SSS for the winter 15/16 of the “Switch” experiment

East Siberian Sea, and the Chukchi Sea. The positive salt anomaly covers the whole region of the EGC. In the “Peak” experiment, the anomaly develops differently. One year after shifting back to “NAO+”-wind stress forcing (Fig. 5), the negative salt anomaly in the Eurasian Basin is already

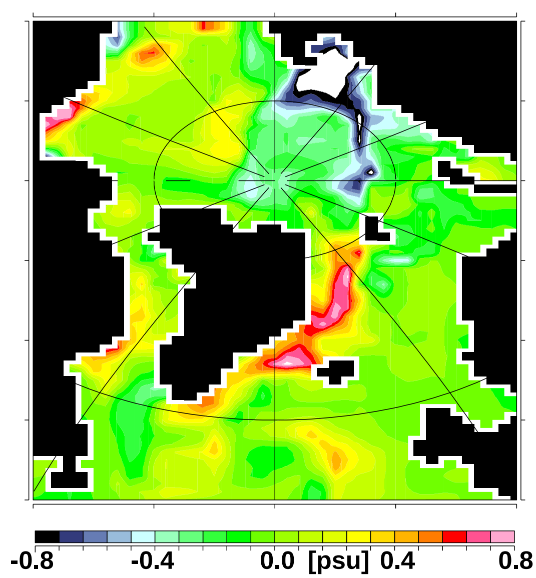

Figure 5: SSS for the winter 11/12 of the “Peak” experiment

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reduced compared to the previous winter (compare Fig. 3). The positive anomaly in the EGC is strengthened in this winter, however, one year later (Fig. 6), almost all the anomalies have vanished.

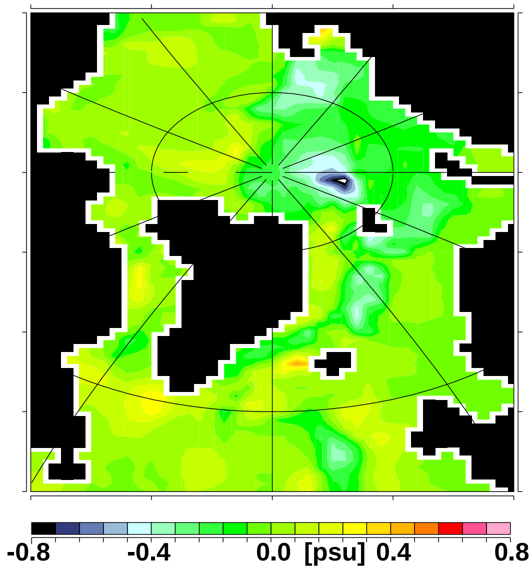

Figure 6: SSS for the winter 12/13 of the "Peak" experiment

The SSS anomaly patterns of both experiments are related to the response of the sea ice distribution. In the control experiment, a strong, northerly wind over the Eurasian Basin forces the sea ice margin away from the coast. So every winter new sea ice grows in this open ocean area. This sea ice formation is a continuous source of salt for the ocean. In the "NAO-" case, the northerly winds over the Eurasian Basin are weaker than in the "NAO+" case. The production of sea ice is suppressed as the ice moves towards the Siberian coast. Therefore, in the "Switch" experiment a negative salt anomaly turns up compared to the repeated sea ice formation and its salt release in the control experiment (cf. Fig. 4). Sea ice transport from the Arctic Ocean towards the Nordic Seas is reduced with "NAO-" wind forcing (HILMER ET AL. (1998)). Reduced sea ice inflow and reduced melting of sea ice lead to the positive surface salinity anomaly in the EGC. Both anomalies are short lived in the "Peak" experiment as the fresh water fluxes typical for high NAO index resume after year 11 of the integration. The somewhat more persistent salinity anomalies in the EGC during this experiment reflect the life time of sea ice anomalies once they have left their production areas.

3.2 Sea surface temperature

In the winter which follows the shift from "NAO+" to "NAO-" the "Switch" experiment shows in the sea surface temperature (SST) some minor anomalies at the edge of the EGC which are mostly due to shifts of the current position (Fig. 7).

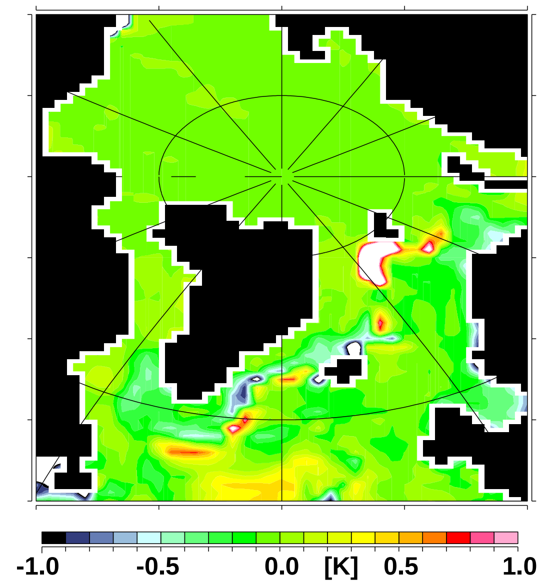

Figure 7: SST for the winter 10/11 of the "Switch" experiment

A positive anomaly turns up south of Spitsbergen and extends into the Barents Sea. This anomaly is continuously present in the rest of the experiment and seems locked to the sea ice margin. On the other hand, in the "Peak" experiment, the anomaly changes sign in the winter 11/12 (Fig. 8).

KAUKER ET AL. (1999) forced the same coupled ocean - sea ice model with the atmospheric surface data from the NCEP/NCAR reanalysis (KALNAY ET AL., 1996). The correlation between the NAO index and the last 20 years of SST (1979-1995) was calculated. In Fig. 9 the pattern of the SST associated with 1 SD (standard deviation) NAO is shown.

A pattern of positive SST anomaly (high temperature for high NAO index) is present south of Spitsbergen and in the Barents Sea. This pattern

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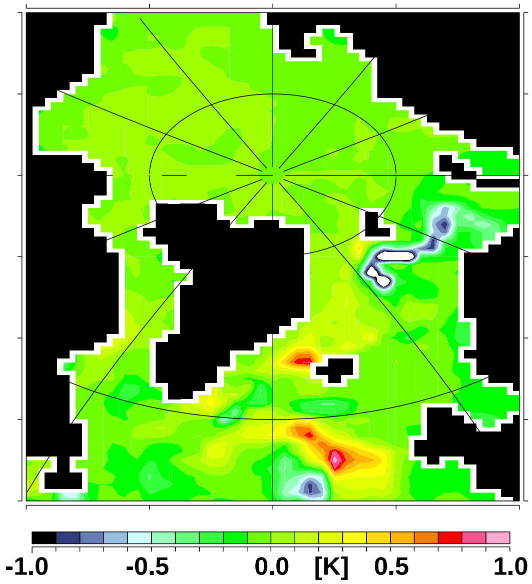

Figure 8: SST for the winter 11/12 of the "Peak" experiment

is similar to the "Switch" experiment result and we thus conclude that it is mostly wind driven. A second, negative SST anomaly is present on the south-east coast of Greenland and in the Labrador Sea in Fig. 9. This pattern occured neither in the "Switch" nor in the "Peak" experiment, suggesting that this anomaly is mainly the result of heat flux and fresh water flux variations associated with the NAO, which are not included in the two experiments.

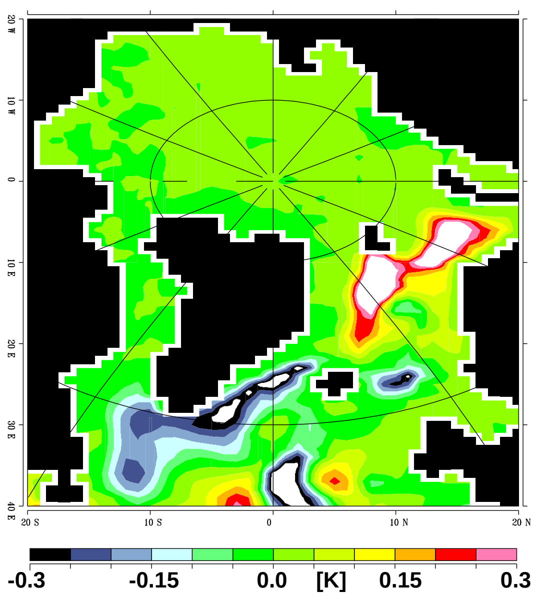

Figure 9: Teleconnection map between SST and NAO

4 Summary

The presented experiments show a clear response to a sudden drop of the NAO forcing and the following recovery. There is a direct connection between the wind stress forcing and the sea ice cover and a subsequent reaction of the SSS and SST fields. A continuing negative NAO index wind forcing leads to prolonged anomalies in SSS and sea ice concentration. A short episode with negative NAO index wind forcing generates anomalies in surface salinity that prevail only one year.

The SST distribution reveals also some important coherences. In the described experiments an anomaly south of Spitsbergen which extends into the Barents Sea turns up. It is also found in a correlation analysis between SST and NAO in another experiment, which was conducted with more comprehensive forcing KAUKER ET AL. (1999). There, an additional anomaly is present, which is situated at the south coast of Greenland and in the Labrador Sea. This anomaly is not visible in our experiments and seems to be generated by heat flux and salt flux anomalies. The anomaly south of Spitsbergen and in the Barents Sea is generated by NAO related wind stress forcing, however, a possible contribution from anomalous heat and salt fluxes can not be ruled out at this stage.

It is now important to have a closer look at the influence of the forcing in deeper layers and at the general circulation itsself.

Acknowledgments

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References

EWG - ENVIRONMENTAL WORKING GROUP, 1997: *Joint U.S. Russian Atlas of the Artic Ocean*, NSIDC/CIRES, University of Boulder, CO, USA.

GIBSON, J., P. KALLBERG, S. UPPALA, A. NOMURA, E. SERRANO and A. HERNANDEZ, 1997: ERA description. ECMWF reanalysis project report 1: project organisation, Tech. rep., European Centre for Medium Range Weather Forecast, Reading, UK.

HARDER, M., P. LEMKE and M. HILMER, 1998: Simulation of sea ice transport through Fram Strait: Natural variability and sensitivity to forcing, *J. Geophys. Res.*, **103** (C3), 5595 – 5606.

HIBLER, W. I., 1979: A dynamic thermodynamic sea ice model, *J. Phys. Oceanogr.*, **9**, 815 – 846.

HIBLER, W. I. and K. BRYAN, 1987: A diagnostic ice-ocean model, *J. Phys. Oceanogr.*, **17**, 987 – 1015.

HILMER, M., M. HARDER and P. LEMKE, 1998: Sea ice transport: a highly variable link between Arctic and North Atlantic, *Geophys. Res. Letters. Soc.*, **25** (17), 3359 – 3362.

HURREL, J. W., 1995: Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation, *Science*, **269**, 676 – 679.

KALNAY, E., M. KANAMITSU, R. KISTLER, W. COLLINS, D. DEAVEN, L. GANDIN, M. IREDELL, S. SAHA, G. WHITE, J. WOOLLEN, Y. ZHU, A. LEETMAA, R. REYNOLDS, M. CHELLIAH, W. EBISUZAKI, W. HIGGINS, J. JANOWIAK, K. MO, C. ROPELEWSKI, J. WANG, R. JENNE and D. JOSEPH, 1996: The NCEP/NCAR 40-year Reanalysis Project, *Bull. Amer. Met. Soc.*, **77** (3), 437 – 495.

KAUKER, F., R. GERDES and C. KÖBERLE, 1999: Propagation of temperature and salinity anomalies in the Nordic Seas as derived from a multidecadal OGCM simulation, in *ICES CM 1999, L:12*.

PACANOWSKI, R. C., 1995: MOM 2 Documentation, User's Guide and Reference Manual, Tech. Rep. 3, GFDL Ocean Group, Princeton, New Jersey.

RÖSKE, F., 1999: Ocean model intercomparison project (OMIP): Common forcing and atlas based on ECMWF reanalysis data, Tech. rep., Max-Planck-Institut for Meteorology, Hamburg, in preparation.

VINJE, T., N. NORDLUND and Å. KVAMBEKK, 1998: Monitoring ice thickness in Fram Strait, *J. Geophys. Res.*, **103** (C5), 10437 – 10449.

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