How fast is Arctic climate changing?
Insights from quasi equilibrium coupled model simulations

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Introduction
Observations of last decades indicate an ongoing climate change in the Arctic, which has been linked to winter atmospheric circulation anomalies in mid-latitudes. However, the short observational time series in a transient climate make it difficult to fully distinguish the trend that is due to greenhouse gas warming from natural variations. In this study, we simulate the states of Arctic climate and their interactions with lower latitudes under different levels of anthropogenic forcing.

Model and simulations
The model used in this study is the version 3.0.1 of the global coupled climate model EC-Earth. The atmosphere is based on cycle 36r4 of IFS and used at a T255 resolution with 91 vertical levels. The ocean component is based on NEMO3.3.1 with a resolution of about 1° (ORCA1) and 46 vertical levels.

Three 100-year long simulations with EC-Earth were performed, forced with three different constant greenhouse gas concentrations corresponding to observed concentration levels of year 2000 (EXP2000) and respective levels from the RCP4.5 emission scenario for 2015 (EXP2015) and 2030 (EXP2030). All three simulations were started from the same initial conditions obtained from the end of a 200-year long present day (using constant year 2000 forcing) control simulation. For most of the analysis, year 21-100 of the simulations are used; the first 20 years are disregarded to allow the model to adjust to the modified external forcing.

Simulated states of Arctic climate under different levels of warming

The model simulations indicate an accelerated warming and ice reduction in the Arctic under year-2030 conditions compared to the change between the year-2015 and year-2000 simulations (Fig. 1 and 2). Arctic warming and ice reduction are closely linked to an increase of ocean heat transport into the Arctic. Decadal variations of Arctic sea ice extent and ice volume are of the same order of magnitude as the observed ice extent reductions in the last 30 years. Despite a general warming of mid and high northern latitudes, a substantial cooling is found in the subpolar gyre of the North Atlantic. This cooling is related to a strong reduction in the AMOC (Fig. 5), itself due to reduced deep water formation in the Labrador Sea a few years ahead (Fig. 4). Changes in DMV and AMOC affect ocean heat transport into the Arctic and Arctic climate.

The simulated SLP differences between the three runs over the do not reproduce the observed trends (Fig. 2). However, 30-year periods with negative NAO-like responses and related T2m-responses occur (Fig. 3).

Linkage between sea ice and atmospheric circulation

In none of the three different climate states, we find a large impact of Arctic ice variations on remote regions in mid and high latitudes when considering the entire length of the simulations (Fig. 6a-c); we mainly find a local temperature response in the area of the ice anomaly. This local response increases from recent past to near future (Fig. 6d-f).

The analysis of different 30-year periods shows large variations in the response of the large-scale atmospheric circulation to sea ice variations and we find 30-year periods with NAO+ responses and others with NAO- responses after low November ice in the Barents and Kara Seas (Fig. 7).

Conclusions

- The Arctic shows an amplified warming under 2030-forcing and an accelerated reduction of ice extent.
- Simulated decadal ice variations reach two-thirds of the observed trend and are governed by ocean heat transports.
- A cold blob in the North Atlantic is found, related to a reduced AMOC and reduced deep water formation in the Labrador Sea.
- The DMV in the Labrador Sea is a good predictor for Arctic climate several years ahead.
- Simulated change patterns of SLP and T2m and simulated linkages between sea ice and atmosphere differ from observations of the last 30 years.
- Selected 30-year periods show both the observed relations as well as exactly the opposite.

→ The observational period might be too short to make robust statements over Arctic trends and linkages to lower latitudes.