A Link Between Reduced Arctic Sea Ice and Cold Winter Extremes over Northern Continents

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Motivation

The recent Northern Hemisphere warming was accompanied by several severe northern continental winters, in particular extremely cold winter 2005/2006 in Europe and northern Asia (**Figure 1a-c**).
A gradual decline of the Arctic winter sea ice since 1950s was followed by a rapid drop in the winter 2005/2006, with the greatest reduction of the ice extent in the Barents and Kara Seas (**Figure 1d-f**).

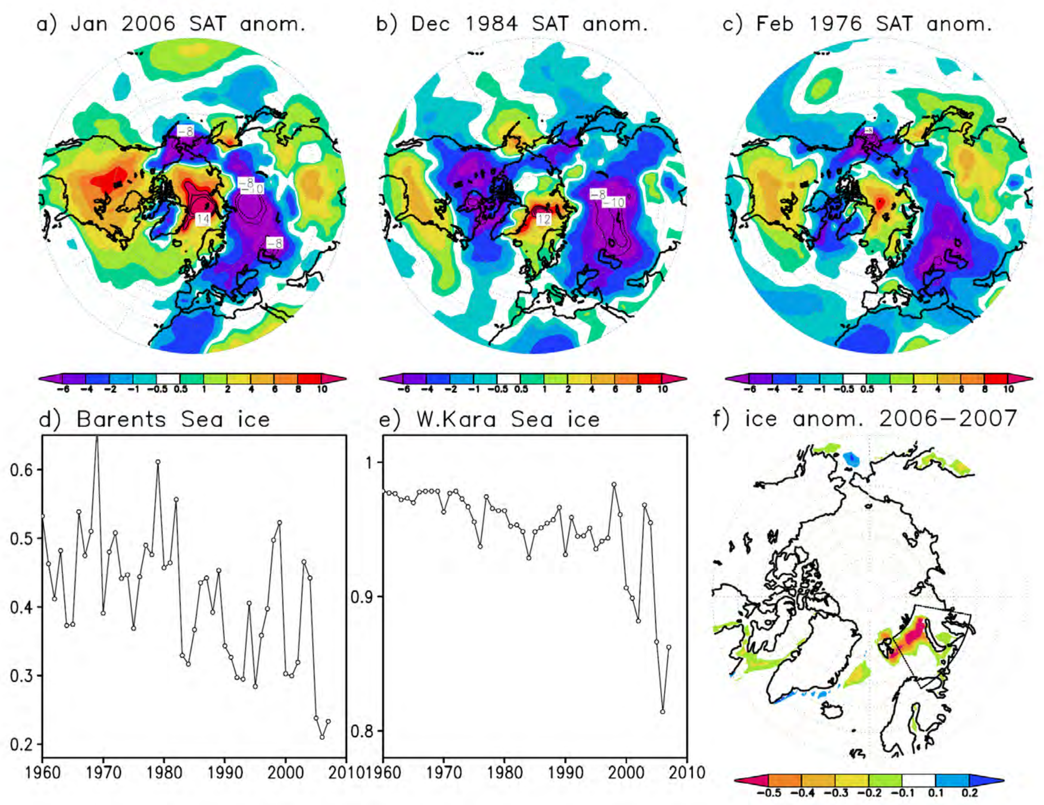


Figure 1: Examples of the observed winters with cold continental temperatures contrasting warm Arctic, and sea ice anomalies in the Barents and Kara Seas. Surface air temperature anomalies (in °C) relative to the (1948-2006) mean for January 2006 (a), December 1984 (b) and February 1976 (c), NCEP data12. Time series of the mean sea ice concentration (as a fraction of one) for DJF in the Barents Sea (30-60E, 70-80N) (d) and the western Kara Sea (60-80E, 70-80N) (e); (f) DJF sea ice concentration anomalies (as a fraction of one) averaged over the years 2006 and 2007 relative to the (1981-2000) mean; the marked 30-60E/65-80N sector is the area, where the sea ice concentration was set to, respectively, 1%, 20%, 40%, 60%, 80% and 100% for winter months (November through April) in the six model simulations.

There are several examples when cold temperatures over northern continents have been contrasting warm Arctic and low sea ice cover in the Barents and Kara Seas (**Figure 1,2**). This inspires a hypothesis:

Could low sea ice concentrations in the Barents and Kara Seas and associated strong turbulent heating cause an atmospheric circulation anomaly favoring low temperatures over northern continents?

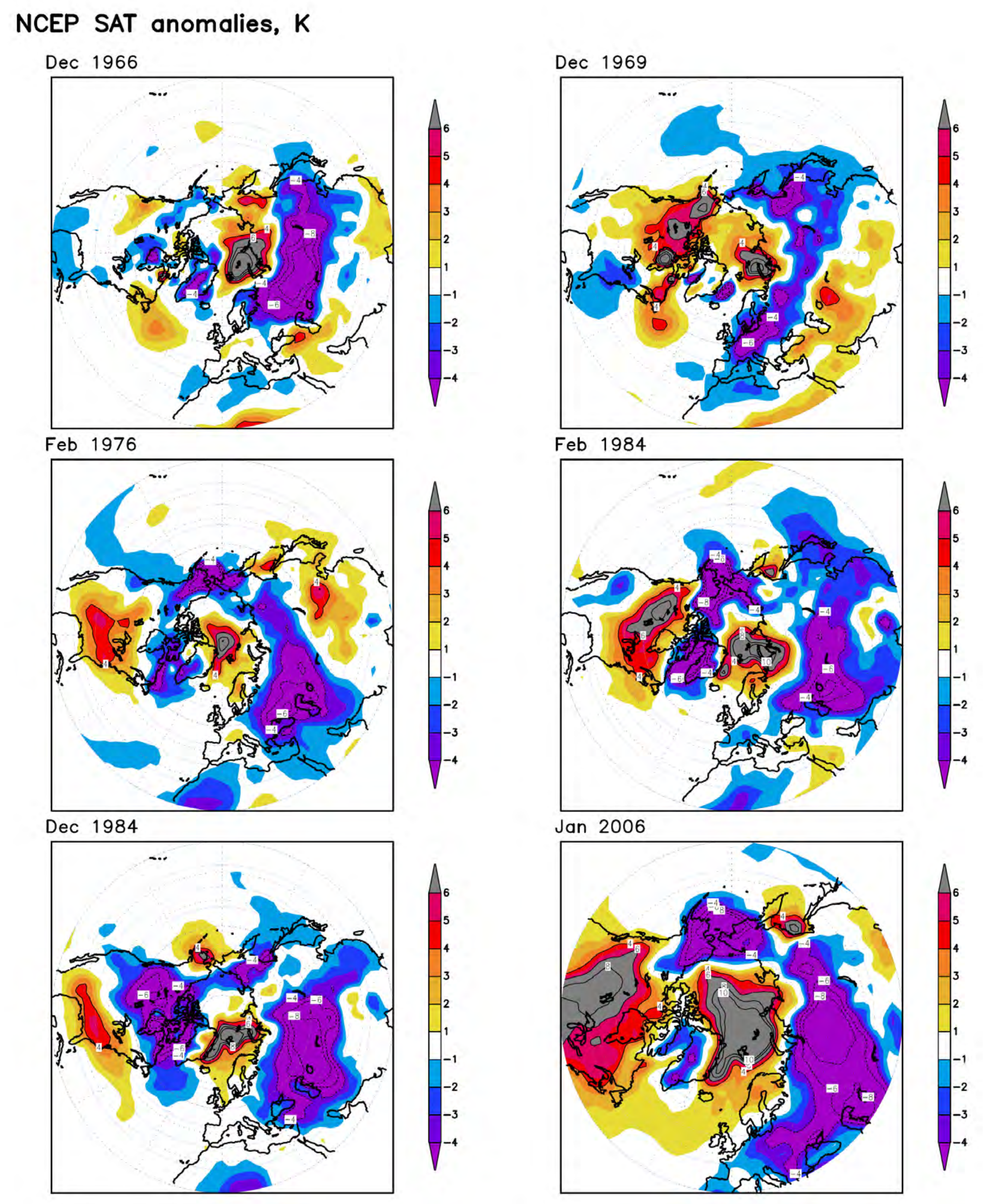


Figure 2: Observed monthly SAT anomalies for different winter months exhibiting "warm Arctic – cold continent" pattern. Anomalies are in °C, relative to (1948-2006) mean based on NCEP data.

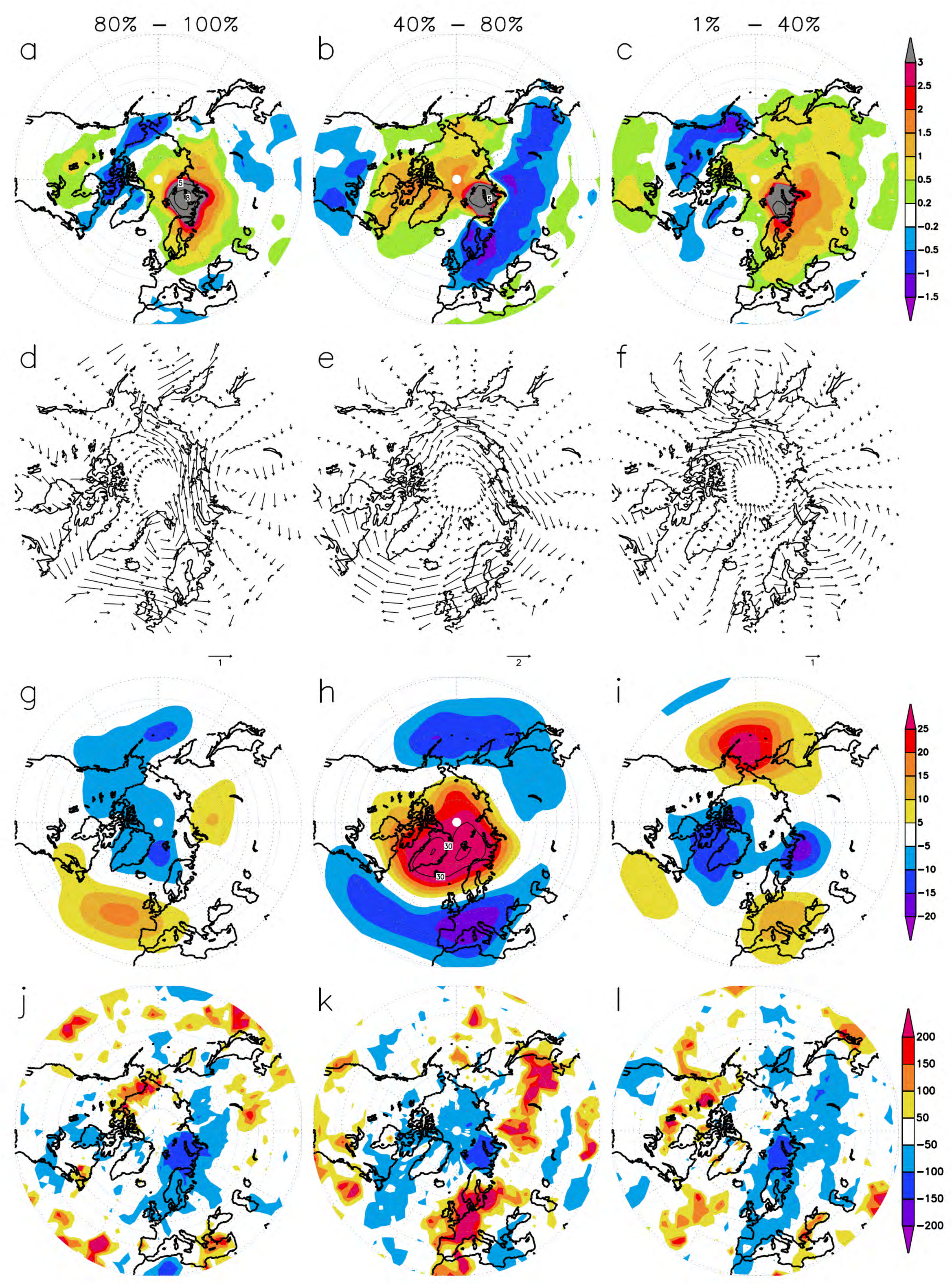
Model simulation setup

Heating of the low troposphere over the Barents and Kara Seas results in decreased meridional temperature gradient in sub-Arctic latitudes, which brings about changes in thermal steering of the atmospheric circulation (via thermal wind relation) with a possible weakening of zonal winds in mid-latitudes. This may cause a cooling of the northern continental areas. To elaborate this idea, a series of simulations with the atmospheric general circulation model (AGCM) ECHAM5 was performed.
In six 100-year model experiments, the same annual cycle of SSTs and sea ice concentrations (SIC) was prescribed, except for the sector (30-80E, 65-80N, see **Fig. 1f**) covering the Barents and western Kara Seas, where the winter (November through April) SIC was set to, respectively, 1%, 20%, 40%, 60%, 80% and 100%.

Results

Simulations with the AGCM ECHAM5 demonstrate that anomalous easterly advection may arise over northern continents as a response to atmospheric heating over the Barents-Kara Seas caused by changes in the ice cover (**Figure 3**).

Figure 3: Simulated SAT and low-troposphere circulation responses to Barents-Kara SIC transitions from 100% to 80%, 80% to 40%, and 40% to 1%, for February. Differences between SAT (in °C) in the ECAHM5 model runs with **(a)** 80% and 100%, **(b)** 40% and 80% and **(c)** 1% and 40% prescribed sea ice concentrations in the Barents-Kara Seas; **(d-f)** same as **(a-c)** but for wind at 850 hPa (in m/s); **(g-i)** same as **(a-c)** but for the geopotential height at 850 hPa (Z850, in gpm); **(j-l)** same as **(a-c)** but for probabilities (in %) for the February SAT to be less than -1.5 standard deviation. The reference probabilities in all cases correspond to higher SIC.



In the model, the anomalous continental-scale winter cooling due to the indicated effect reaches -1.5°C, and a probability of extremely cold winter months increases more than three times (**Figure 3k**).

The model response is nonlinear and suggests that the recent decrease in the Barents-Kara sea ice area may favor a continental cooling (**Figure 4**).

Figure 4: Simulated winter temperature and zonal wind over Europe as a function of prescribed sea ice concentrations in the Barents-Kara Seas. Monthly mean SAT (in °C, upper row) and zonal wind at 850 hPa (in m/s, lower row) averaged over the European region (10-30E, 45-55N), for December (a,d), January (b,e) and February (c,f).

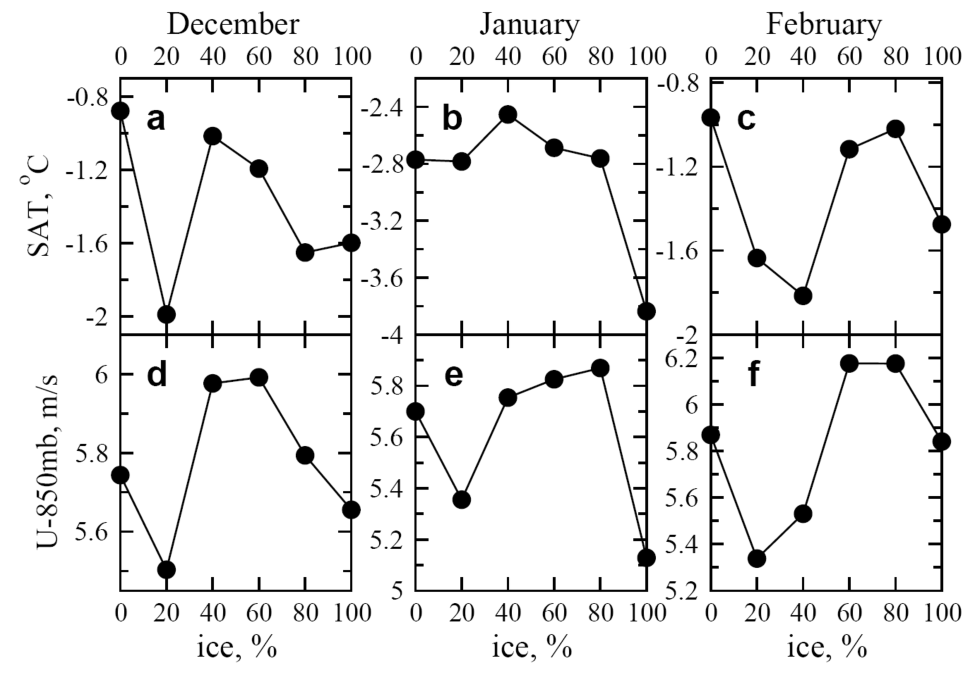
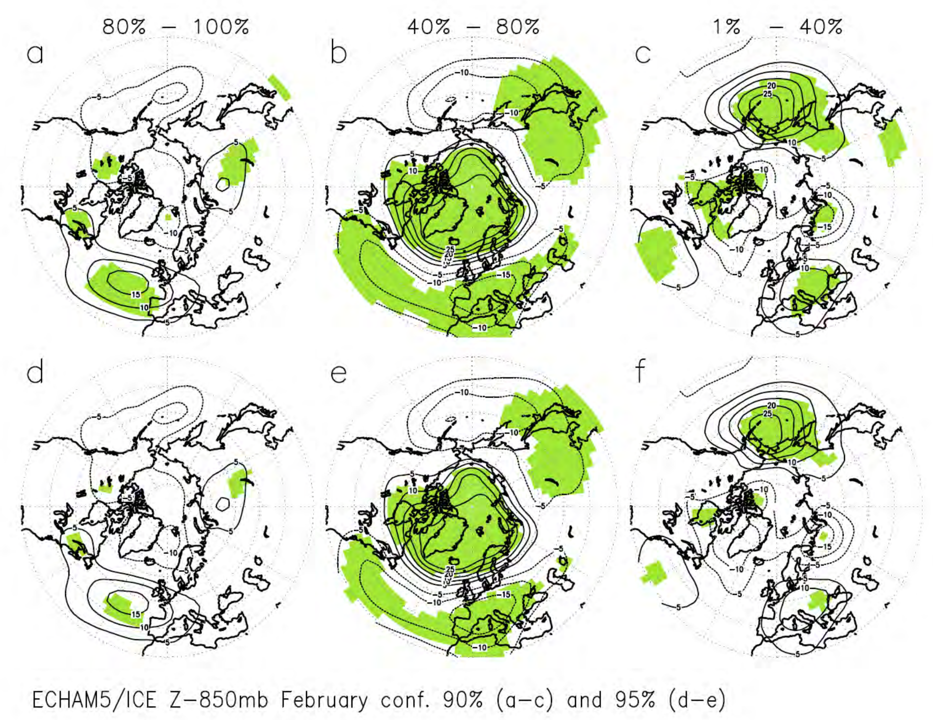


Figure 5: Statistical significance of the Z_{850} changes shown in Fig. 3 g-i. Areas where the changes are significant at the 90% (a-c) and 95% (d-f) significance level according to a *t*-test are green shaded. Contours correspond to the Z_{850} changes as shown in **Fig. 3 g-i**.



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