Past and projected future changes of North Atlantic polar low frequency

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Introduction

Method and results of Matthias Zahn's PhD work on past frequency changes of North Atlantic polar lows and the results of a subsequent study on their future changes in an assumed anthropogenically warmed climate were presented. Assessing frequency changes of atmospheric phenomena such as polar lows requires data that cover a long enough time period, are high enough in spatial detail and most importantly are not suffering from any inhomogeneities. Measurements meeting all these requirement are not available for the purpose of deriving a long-term polar low climatology. Thus we used the dynamical downscaling approach for our study, in which the regional climate model CLM [Rockel et al, 2008] was driven by global re-analysis or global climate model data. Dynamical downscaling makes use of the well represented large scale atmospheric state of the coarse global data, but introduces details in the region of interest. Our presentation has been subdivided into 4 parts:

1. In an ensemble of case studies it was shown that the dynamical downscaling approach is capable of reproducing polar lows.
2. Our automated detection procedure for polar lows has been presented.
3. The results of frequency changes derived from downscaling global reanalysis data of the past 6 decades have been show.
4. The results for the future projections derived from downscaling IPCC global climate model data have been discussed.

Case studies

It has been shown for three polar low cases (one in Sep 1993, Dec 1993 and Jan 1998) chosen from (ref, Rasmussen and Turner), that polar lows in principle are reproducible with CLM driven by NCEP/NCAR reanalysis data [Kalnay et al, 1996] in climate mode, in which the model was initiated 2 weeks prior to the actual polar low formation. CLM was driven the conventional way in which boundary conditions enter the simulation via the surface and a so called 'sponge zone' at the lateral boundaries. In a second ensemble, spectral nudging [von Storch et al, 2000] is applied additionally. Spectral nudging is a method that nudges the driving data's large scale information into CLM during the simulation. It was found, the spectral nudging inhibits ensemble variability, and that polar lows in principle can be simulated with CLM. However, there may be differences in the dynamical details compared to weather analysis data such as a shifted position or too high core pressure. It was demonstrated that using a two-dimensional discrete spatial bandpass filter [Feser and von Storch, 2005] it is possible to extract mesoscale information from the regional climate model's output fields. The results have been published in Zahn et al [2008].

Automated polar low tracking procedure

To detect polar lows the bandpass filter is applied to the mean sea level pressure of the output fields of the regional climate model. Minima below -2 hPa are recorded and merged to tracks of the positions of two consecutive time steps (3 hours) are not farther apart than 200 km. Finally, further criteria are requested according to the properties of polar lows. The detection procedure has been published in Zahn and von Storch [2008a].

Past polar low activity

For the period 1948 through 2006 global NCEP/NCAR reanalysis data have been dynamical downscaled with spectral nudging applied and polar lows have been detected in the output data. It has been shown that the tracks of the three polar lows discussed in the case studies could be reproduced and tracked even after a simulation time of more than 40 years.

On average a number of 56 polar low cases was counted per polar low season (PLS, Fig.1), which is defined as the time lasting from July the one year through June the next. This number reveals large year to year variability, but remains on a similar level over the investigated 6 decades. We thus conclude there has been no systematic change in polar low frequency. These results have been published in Zahn and von Storch [2008b].

Comparison with limited observational evidence of polar lows reveals similar statistical properties such as same peak years and annual cycles. Also the spatial properties of 2 major an one minor region of more pronounced polar low genesis are similar to a previous study [Bracegirdle and Gray, 2008].

Projected future polar low activity

Applying the tracking algorithm to the 4 downscaled IPCC-scenarios reveals a dramatic decrease to only half as many polar low cases per PLS towards the projected end of the 21st century (Fig.2, left hand side). This decrease is more pronounced, the stronger the increase of Greenhouse Gases and thus the temperature rise is assumed. The decrease in polar low frequency is associated with a mean increase in vertically stable atmospheric conditions as expressed by the vertical temperature gradient between the sea surface and the temperature at the 500 hPa level (Fig2, right handside). This signal of higher vertical stability over the ocean is found consistently across a set of various IPCC global models. Another remarkable feature found is the high inter-model bias of up more than 4 K.

In the future the polar low genesis regions are projected to move northwards over the North Atlantic. An above average decrease of polar lows in the region between Iceland and Greenland contributes to this average shift northwards, but also new development regions in the north, which are covered by ice in the 20th century but frequently open in the projected 21st century winters. These results are published in Zahn and von Storch [2010]. An article summarising these results is currently in press [Zahn and von Storch, 2012].

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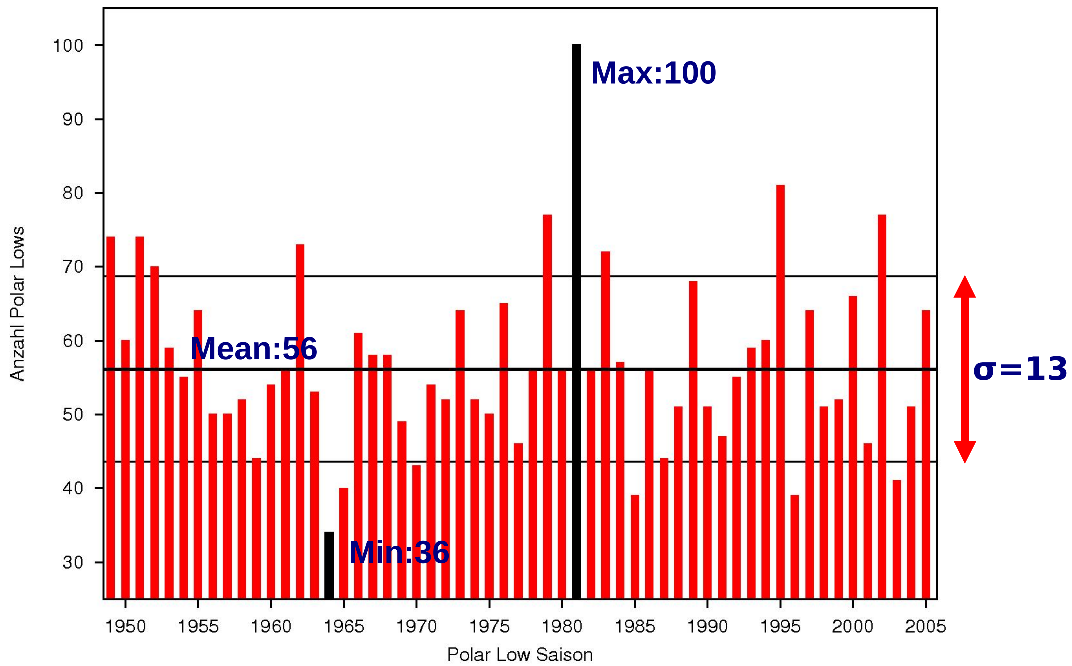

Figure 1: Number of detected polar lows per polar low season. One polar low season is defined as the period starting 1 July and ending 30 June the following year [after Zahn and von Storch, 2008b].

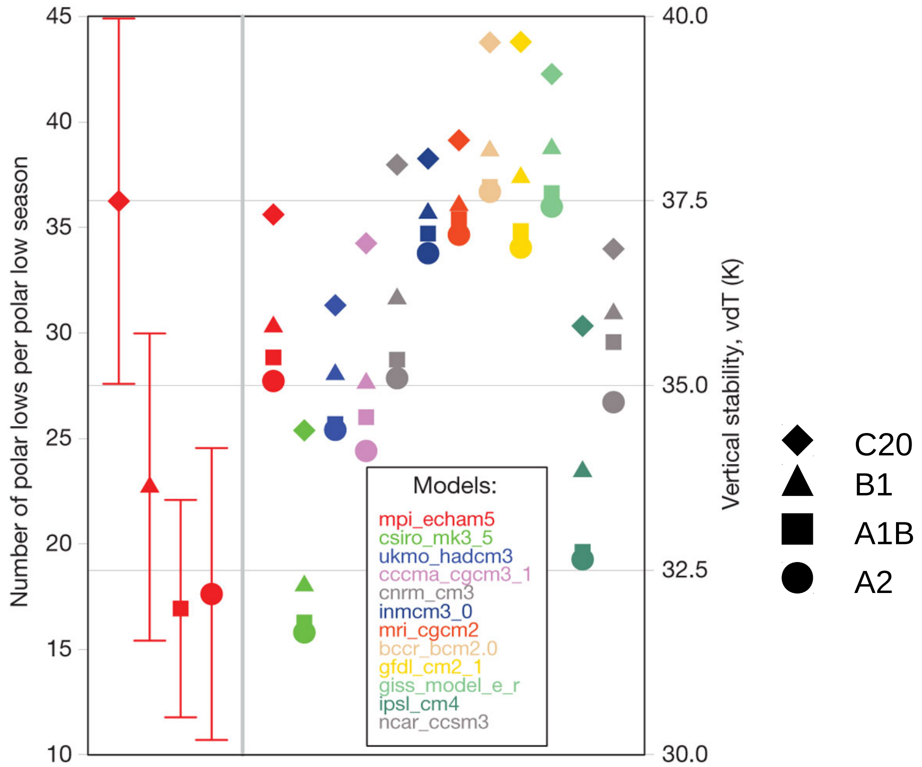

Figure 2: The left panel shows the average number and standard deviation of polar lows per polar low season. The right panel shows the mean static/vertical stability as given by the vertical temperature difference (vdT) between sea surface and air at 500 hPa (in Kelvin) for the period October to March over 30 years (1960–1989 for IPCC-AR4 scenario C20 and 2070–2099 for scenarios B1, A1B and A2). Vertical stability is calculated over ice-free ocean grid cells in our simulation area. Data are derived from four IPCC scenarios: C20 (diamonds), B1 (triangles), A1B (squares) and A2 (circles) [from Zahn and von Storch, 2010].