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The Pulse of the Atmosphere – Decadal Ups and Downs*

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Abstract: Some aspects of the low-frequency variability of the atmospheric circulation have been presented in terms of teleconnection patterns and atmospheric flow regimes. Therefore, the spatial patterns and the temporal variations of the Arctic and Antarctic teleconnection patterns (Arctic Oscillation and Antarctic Oscillation) have been analysed on the basis of the NCEP /NCAR reanalysis data. Their role for decadal variability has been discussed within the framework of the concept of circulation regimes. Furthermore, the global impact of Arctic sea-ice albedo parameterization and of interactive stratospheric chemistry in the polar vortex has been investigated by means of model studies.

Zusammenfassung: Ausgewählte Aspekte der niederfrequenten Variabilität der atmosphärischen Zirkulation werden im Hinblick auf Telekonnektionsmuster und atmosphärische Zirkulationsregime präsentiert. Dafür werden die räumlichen Muster und die zeitlichen Variationen der Arktischen und Antarktischen Telekonnektionsmuster (Arktische Oszillation und Antarktische Oszillation) auf der Basis der NCEP/NCAR Reanalyse Daten analysiert. Im Rahmen des Konzeptes der Zirkulationsregime wird die Rolle der Telekonnektionsmuster für dekadische Klimavariabilität diskutiert. Des Weiteren werden die globalen Auswirkungen von Parameterisierungen der arktischen Meereisalbedo und einer interaktiven stratosphärischen Chemie im Polarwirbel in Modellstudien untersucht.

INTRODUCTION

Arctic and Antarctica are the cold poles of the atmospheric circulation and influence the global circulation via the meridional gradient of the radiative energy between the poles and the tropics. The sea ice covered Arctic Ocean is partly enclosed by landmasses and coupled to the polar atmosphere through a seasonally varying sea ice with a thickness of 1-5 m. The Arctic land areas are snow covered from October until May and present polar droughts with small vegetation and are permanently frozen. This permafrost melts during summer in the thin active upper layer.

Atmospheric observations in the polar regions of Arctic and Antarctic are very sparse since only a few observation stations exist, which deliver long-term data. Therefore beside satellite data, the reanalysis data of the European Centre for Medium Range Weather Forecast delivers usable data sets for the polar regions, which have been produced by the assimilation of existing observational and satellite data into a global weather forecast model.

The Arctic winter circulation in the middle troposphere is determined by a polar vortex, which exist with its pressure minimum over North America and extends to West Europe. This pressure distribution results from the Earth's topography, the continent-ocean distribution and the outgoing long wave radiation during the Polar Night. The polar vortex weakens in summer and becomes more zonally symmetric. During winter the pressure distribution at sea-level is dominated by the Icelandic Low, the Aleutian Low in the North-Pacific basin and the Siberian High. The Icelandic Low and the Aleutian Low are determined by the relative warm ocean in the vicinity of cold air masses. The Siberian High is mainly due to longwave radiative cooling. The Icelandic Low in summer is much weaker than during winter. The summer pressure distribution reduced to mean sea level shows highest values over Greenland, the Barents-Sea and the Beaufort-Sea. Low pressure exists in the Icelandic Low, but also over Siberia. The mean winter circulation is determined by large-scale planetary wave structures, which are much weaker pronounced during summer.

TELECONNECTION PATTERNS

These global patterns of sea level pressure and temperature distribution changed significantly in the years 1948-2009. During winter a significant warming occurred and during the summer a weak cooling appeared. The observed winter warming is connected with changes in the northern hemispheric atmospheric circulation and in the teleconnection patterns of the North-Atlantic Oscillation (NAO) and of the Arctic Oscillation (AO). Over the North Atlantic-European region, these natural variability patterns are marked by large-scale pressure variations in the region of the Icelandic Low and of the Azores High. A negative pressure anomaly in the Icelandic region and a positive pressure anomaly in the Azores region characterizes the positive NAO/AO phase, whereas a positive pressure anomaly in the Icelandic area and a negative pressure anomaly over the Azores are typical for the negative phase. These pressure anomalies coincide with an enhanced zonal circulation over the North Atlantic during the positive phase and a weaker zonal circulation and enhanced planetary wave pattern in the negative phase. These variations exert a strong impact on the climate of Europe. In the positive NAO/AO phase more warm and humid oceanic air masses enter North and Central Europe, whereas in the negative phase due to enhanced large-scale atmospheric waves, cold polar air masses are transported to Europe.

Figure 1 presents the temporal variations of the AO index and the spatial AO pattern, calculated for the Northern Hemisphere

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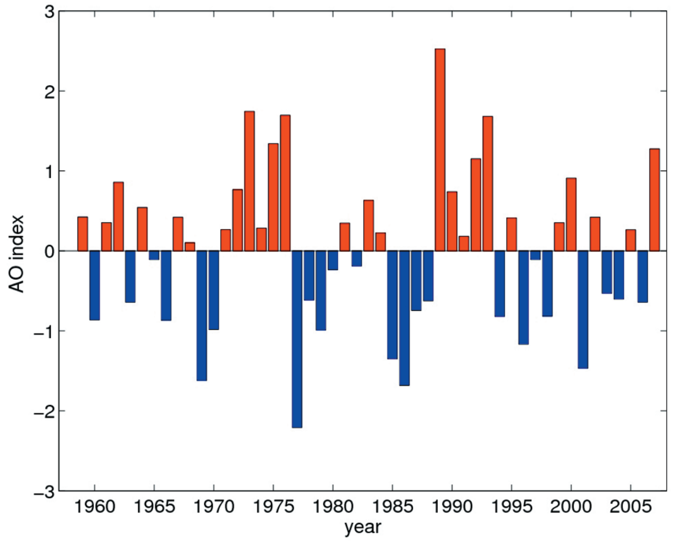

Fig. 1a: Time-series of the Arctic Oscillation (AO) Index, determined from mean sea-level pressure NCEP/NCAR Reanalysis data, winter means 1958-2008.

Abb. 1a: Zeitreihe des AO-Index, bestimmt aus den Bodenluftdruckdaten der NCEP/NCAR-Reanalyse, Wintermittelwerte (DJF) von 1958-2007.

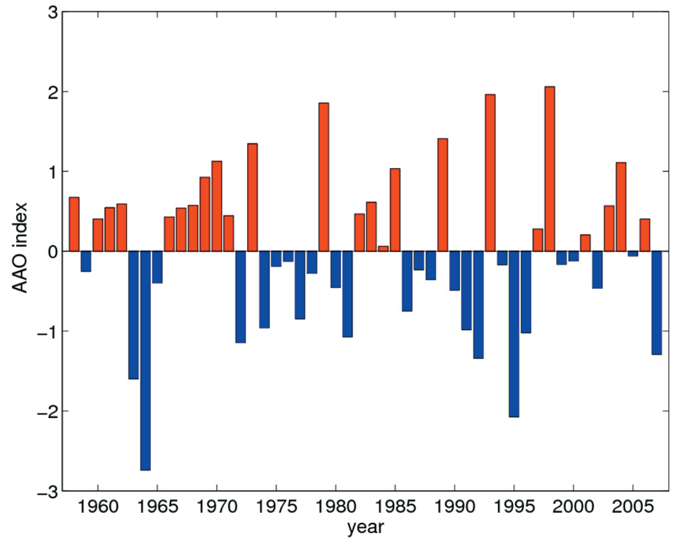

Fig. 2a: Time-series of the Antarctic Oscillation (AAO) Index, determined from mean sea-level pressure NCEP/NCAR- Reanalysis data, winter means 1958-2008.

Abb. 2a: Zeitreihe des AAO-Index, bestimmt aus den Bodenluftdruckdaten der NCEP/NCAR-Reanalye, Wintermittelwerte (JJA) von 1958-2007.

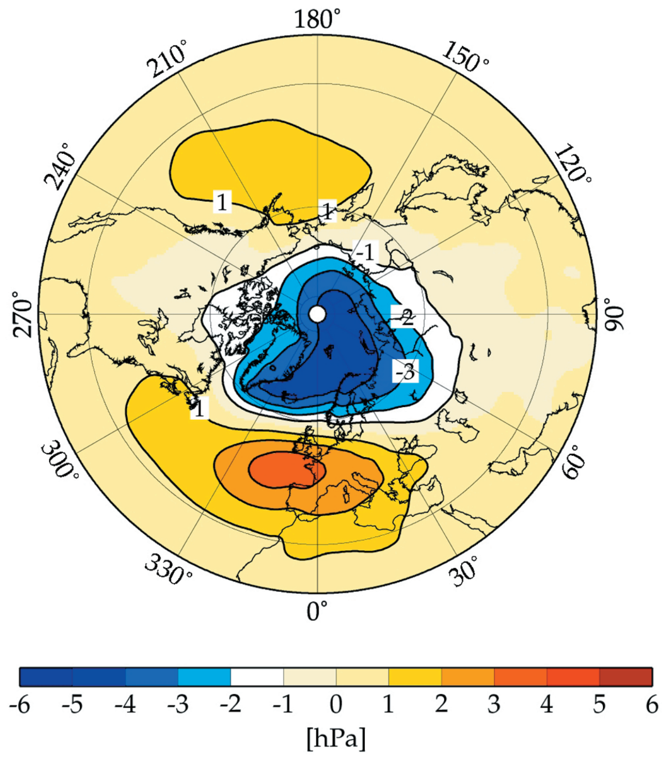

Fig. 1b: Pattern of mean sea-level pressure (hPa) of the positive phase of the Arctic Oscillation (AO), determined from NCEP/NCAR-Reanalysis data, winter means 1958-2008.

Abb. 1b: Räumliches Bodenluftdruckmuster (hPa) der positive Phase der Arktischen Oszillation (AO), bestimmt aus den Daten der NCEP/NCAR-Reanalyse, Wintermittelwerte von 1958-2007.

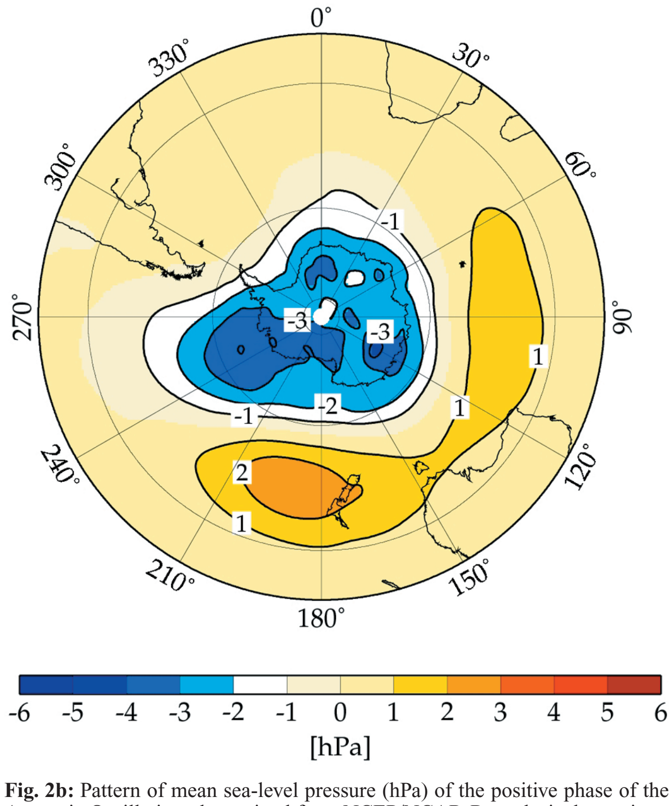

Fig. 2b: Pattern of mean sea-level pressure (hPa) of the positive phase of the Antarctic Oscillation, determined from NCEP/NCAR-Reanalysis data, winter means 1958-2008.

Abb. 2b: Räumliches Bodenluftdruckmuster (hPa) der positive Phase der Antarktischen Oszillation (AAO), bestimmt aus den Daten der NCEP/NCAR-Reanalyse, Wintermittelwerte von 1958-2007.

based on NCEP/NCAR reanalysis mean sea level pressure data from 1958-2008 by means of an Empirical Orthogonal Function (EOF) analysis. The Southern Hemiphere counterpart, the Antarctic Oscillation (AAO) is shown in Figure 2. Again, the index and the spatial pattern are determined by an EOF analysis of the NCEP/NCAR reanalysis mean sea level pressure data from 1958-2008 for the Southern Hemisphere. The AO is closely connected to the NAO and exists as a result of the Earth's surface orography, the land-ocean contrasts and the cyclonic activity (SEMPF et al. 2007). A zonally-symmetric AO structure can be excited already in a model atmosphere without continents and oceans. By taking into account the Earth's orography the observed zonal asymmetries of the AO distribution and the storm tracks of the synoptical cyclones over the oceans can be reproduced. With an additional longitude dependent thermal forcing owing to oceanic sea surface temperatures the AO can propagate into the stratosphere. From this follows, that this teleconnection pattern is connected with feedbacks in the atmosphere-ocean-sea ice system, influenced by tropo-stratospheric interactions and the stratospheric ozone layer. Beside these natural processes, atmospheric teleconnection patterns are influenced also by anthropogenic factors like greenhouse gas concentrations and the aerosol loading.

CIRCULATION REGIMES

The basic concept to understand decadal climate variability on global and regional scales is the assumption of atmospheric circulation regimes. It is well known, that atmospheric variability arises due to irregular transitions between a few preferred large-scale atmospheric circulation patterns. The concept of atmospheric circulation regimes connects the observed climate changes with the atmospheric dynamics. Accordingly, climate changes are connected with changes in the frequency of regime occurrence.

Comparison studies with atmospheric models, data analysis, analysis of model simulations with increased greenhouse gas concentrations and paleo-climate model simulations show, that changes in the external forcing can be projected on natural variability patterns accompanied by changed frequency of the occurrence probability in different circulation regimes. Circulation regimes can be detected with the help of sophisticated statistical methods. The detected regimes project on the different phases of the well-known teleconnection patterns, e.g. on the positive and negative AO or NAO phases, the leading variability pattern in the Atlantic-European region. These patterns vary on time scales from years to decades and their occurrence in negative/positive phases causes an up and down of decadal circulation anomalies in the atmosphere. The influence of the leading variability pattern reaches into the stratosphere. The positive phase of the AO is connected with a stronger and colder polar vortex. The strength of the polar vortex impacts on the propagation of planetary waves from the troposphere into the stratosphere and the transmission of extreme anomalies from the stratosphere down to the troposphere.

EARTH SYSTEM MODELS

Model experiments (DETHLOFF et al. 2006) have shown, that changes in Arctic process descriptions, e.g. snow and sea-ice albedo parameterization can exit AO like anomalies and impact on the planetary wave trains and the synoptical cyclone tracks. This implies an influence on the meridional coupling between the energy source in the tropics and the Arctic energy sink, whereby Arctic climate processes can have global implications. Anthropogenically caused climate changes and phase changes of the AO/NAO superpose each other. The development of reliable regional climate projections requests the forecast of persisting future atmospheric circulation regimes and the understanding of the underlying processes.

A coupled Earth system model with integrated stratospheric chemistry was described by BRAND et al. (2008) to investigate the interactions between the atmospheric model dynamics and the distribution and concentration of stratospheric trace gases and to understand the feedbacks between chemistry and dynamics. Results of these model simulations show stronger tropospheric jet streams in the Northern Hemisphere winter owing to the feedbacks between chemistry and atmospheric dynamics. This causes changed zonal wind distributions and global atmospheric wave pattern, which influence the AO structure. These results underline the importance of dynamical-chemical interactions between troposphere and stratosphere.

OUTLOOK

To describe the current and future Arctic climate with high confidence, it is necessary to develop climate models, which are able to simulate circulation regimes and their variability more realistically. It was shown by HANDORF & DETHLOFF (2009) and HANDORF et al. (2009) that current climate models reproduce the spatial circulation pattern, but not their temporal ups and downs. This requires an improved physical understanding of the origin of climate regimes and their spatial and temporal changes under the influence of changing external boundary conditions. Beside the development of improved Arctic process parameterizations new model concepts are under development, e.g. the construction of an adaptive atmospheric model (LÄUTER et al. 2008). This can lead to an improved multi-scale modelling, which allows the resolution of interactions between planetary and synoptical waves with meso-scale circulation structures.

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