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EVOLUTION OF CLIMATE FROM THE LATE MAUNDER MINIMUM (1675-1715 AD) TO PRESENT DAY WITH SPECIAL FOCUS ON POLAND

Ewolucja klimatu od późnego Minimum Maundera (1675–1715) do dzisiaj, ze szczególnym uwzględnieniem Polski

Streszczenie. Pogoda i warunki klimatyczne zimą w Europie są związane ze zmiennością wielkoskalowej cyrkulacji atmosferycznej. W Polsce na wahania temperatury w zimie z roku na rok duży wpływ ma Oscylacja Północnoatlantycka. W artykule określono przebieg klimatyczny zimy w Polsce od Minimum Maundera (1700 r.) do końca XX wieku na podstawie symulacji klimatu chwilowym, sprzężonym modelem ogólnej cyrkulacji atmosferycznej. Model stanowi pionową, rozszerzoną wersję modelu ECHO-G i obejmuje stratosferę i mezosferę. Okazuje się, że długookresowa zmiana aktywności Słońca i antropogeniczne stężenie gazów cieplarnianych wpływa na Oscylację Północnoatlantycką (NAO), poprzez zmiany średniego ciśnienia na poziomie morza. Średnia temperatura w Polsce podczas późnego Minimum Maundera (1675–1715) była niższa o ponad 2 K niż współcześnie (1960–1990), na skutek czego średnia temperatura na półkuli północnej będzie jeszcze wyższa.

Słowa kluczowe: mała epoka lodowa, Oscylacja Północnoatlantycka, model ogólnej cyrkulacji atmosferyczno-oceanicznej, długoterminowa zmiana klimatu
Key words: Little Ice Age, North Atlantic Oscillation, ocean-atmosphere general circulation model, long-term climate change

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INTRODUCTION

The North Atlantic Oscillation (NAO) explains a large amount of the winter season's interannual temperature and precipitation variations over Europe (e.g. Hurrel 1995). While high correlation coefficients between NAO time series and precipitation are mainly found for north-western and south-western parts of Europe (i.e. British Isles, Norway and Iberian Peninsula), the NAO explains more than 25% of the winter-to-winter near surface temperature variations in Poland during the 20th century (Fig. 1). Regarding time-scales of several centuries, a number of studies mention variations in climate modes to explain regional climate anomalies as for example during the Little Ice Age (~1400-1700 AD) or the so-called Medieval Climate Anomaly (~950-1250 AD, cf. Mann et al. 2009). The period from the Maunder Minimum (~1700 AD) to present provides

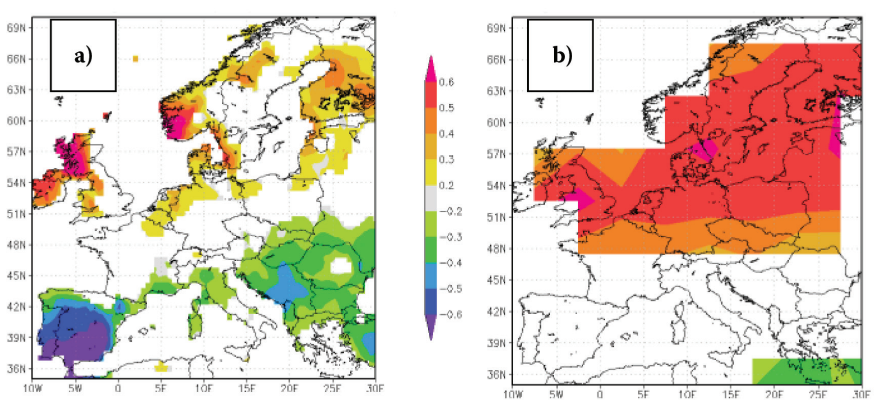

Fig. 1. Relationship of winter mean (DJF) NAO index after Jones et al. (1997) with precipitation (only land) and near surface temperature for the period 1901-1999: a) linear correlation coefficient between NAO index and precipitation (CRU TS3, updated CRU TS2.1, cf. Mitchell and Jones 2005, CRU 2010). b) linear correlation coefficient between NAO index and near surface temperature (CRUTEM3+HadSST3, cf. Brohan et al. 2006; Rayner et al. 2006). P-value < 0.1 for coloured areas. Figures produced with KNMI Climate Explorer which is publicly available (http://climexp.knmi.nl)
Ryc. 1. Związek między średnią wartością indeksu NAO z okresu zimowego (grudzień--luty) wg Jones'a i in. (1997) i opadami atmosferycznymi na lądach oraz średnią przypowierzchniową temperaturą w okresie 1901-1999: a) współczynnik korelacji liniowej między indeksem NAO i opadami (CRU TS3, uaktualnione CRU TS2.1, patrz Mitchell i Jones 2005, CRU 2010). b) współczynnik korelacji liniowej między indeksem NAO i przypowierzchniową temperaturą powietrza (CRUTEM3+HadSST3, patrz Brohan i in. 2006, Rayner i in. 2006). Wartości p < 0,1 na obszarze pokolorowanym. Wyniki uzyskano na podstawie powszechnie dostępnego KNMI Climate Explorer (http://climexp.knmi.nl)

a case study to investigate the role of external forcing factors (e.g. GHG concentrations, solar activity, volcanic eruptions) for long term European winter climate variability. Relevant coupling processes between different atmospheric layers (e.g. troposphere and stratosphere) including interactions with the ocean can be investigated by simulating this period with complex atmosphere-ocean general circulation models (AO-GCM) (cf. Spangehl et al. 2010 and references therein). In the present study we illuminate the evolution of climate from the late 17^{th} century to present on the basis of transient simulations with a complex AO-GCM with special focus on Poland.

METHODS

The main research tool is EGMAM which is a vertically extended version of the ECHO-G AO-GCM (cf. Huebener et al. 2007; Körper et al. 2009; Spangehl et al. 2010 and references therein for a detailed description of EGMAM). The atmosphere component includes 39 vertical levels with the top level located at 0.01 hPa (~80 km) thereby covering the troposphere, stratosphere and lower mesosphere. The horizontal resolution is T30 corresponding to 3.75 deg. lat. (~ 410 km). The coupled ocean model consists of 20 vertical levels and includes explicit representation of the deep ocean. EGMAM was already used for a number of studies which all highlight the role of stratospheric coupling processes for representation of tropospheric circulation variability on longer (multi-decadal to centennial) time-scales (Huebener et al. 2007; Spangehl et al. 2010; Schimanke et al. 2010).

In the present study we discuss simulations for the period from 1630 to 2000. These were performed by driving the model with time dependent solar activity, greenhouse gas (GHG) concentrations and volcanic eruptions (Spangehl et al. 2010). To explicitly account for variations in the UV/visible part of the solar spectrum an improved radiation scheme by Nissen et al. (2007) was implemented. Two simulations were performed with the standard radiation code. While the first simulation (EGMAM-1) uses fixed climatological ozone concentrations the second simulation (EGMAM-2) accounts for solar induced variations in stratospheric short-wave heating rates by prescribing time dependent ozone concentrations (Spangehl et al. 2010). A third simulation (hereafter referred to as EGMAM-3) additionally accounts for spectrally high resolved variations in the UV/visible part of the solar spectrum. The change in total solar irradiance (TSI) from the Maunder Minimum to present is 0.1 percent in EGMAM-3 (new solar forcing data for EGMAM-3 provided by N. Krivova) contrary to the 0.3 percent change used for EGMAM-1 and EGMAM-2.

RESULTS

Simulations EGMAM-1 and EGMAM-2 reveal a change of the annual NH mean temperature from the Late Maunder Minimum (1676-1715, referred to as LMM hereafter) to a period representing present-day conditions (1961-1990, PD) of 1.37 and 1.38 K respectively. As shown by Spangehl et al. (2010) the vertical extension of the model does only play a moderate role for the simulated evolution of climate on the hemispheric scale. The comparably large temperature increase in these simulations is partly explained by the absence of sulphate aerosol forcing. By contrast the simulation employing the newer solar forcing estimate (EGMAM-3) shows a temperature increase from LMM to PD of only 0.75 K which can partly be attributed to the lower TSI forcing (spin-up effects and changes in UV may also play a role). A clear cooling during the Maunder Minimum (which is found in EGMAM-1 and EGMAM2, cf. Spangehl et al. 2010) is not found in EGMAM-3 (figure not shown here). Regarding dynamical changes in the stratosphere, simulated long-term changes in the strength of the stratospheric polar vortex reveal clear evidence for a solar impact. The simulations employing direct stratospheric solar forcing (EGMAM-2 and EGMAM-3) both show a distinct strengthening of the polar vortex during the 18th century (Fig. 2). This strengthening is related to an increase in solar activity from the end of the Maunder Minimum (which represents a minimum in solar activity) onwards. The relationship of polar vortex strength to solar forcing is less clear during the 20th century (cf. Fig. 2). Here the increase in GHG concentration is related to a weakening of the polar vortex thereby counteracting the solar effect.

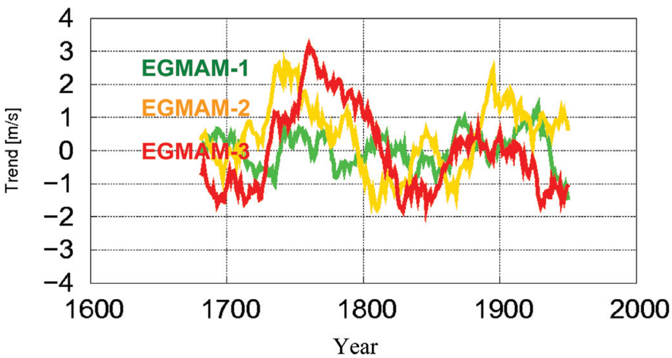

Fig. 2. Centred 101-year trend of stratospheric polar vortex strength (defined as zonal mean zonal wind in 60° N, 10 hPa) for three different simulations with EGMAM (green: EGMAM-1, orange: EGMAM-2, red: EGMAM-3)

Ryc. 2. Główny 101-letni trend siły stratosferycznego wiru polarnego (zdefiniowany jako średnia strefowa wiatru strefowego na 60°N, 10 hPa) według trzech różnych symulacji EGMAM (zielony: EGMAM-1, pomarańczowy: EGMAM-2, czerwony: EGMAM-3)

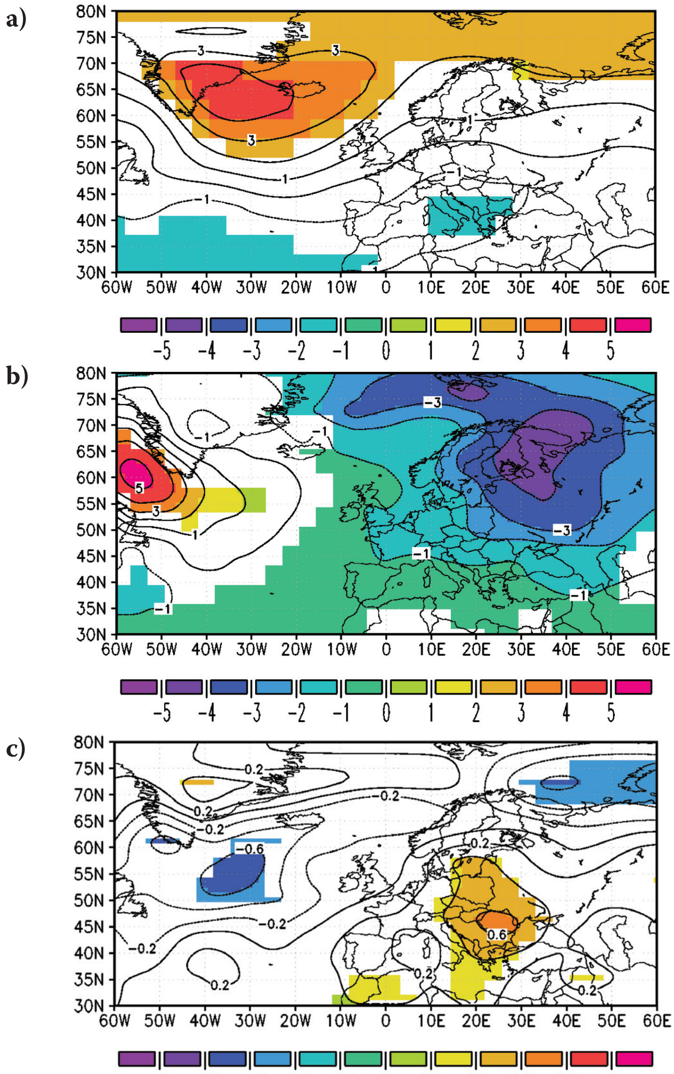

Fig. 3. Long term winter (DJF) mean differences between LMM (1675-1715) and PD (1960-1990). a) Mean Sea Level Pressure (hPa), b) 2 m temperature [K] and **c)** storm track (standard deviation of 2.5-8 day band-pass filtered daily Mean Sea Level Pressure) (hPa). Coloured areas are statistically significant above the 95th percentile value after Student's t-test

Ryc. 3. Różnice długotrwałych zim (grudzień-luty) między LMM (1675-1715) i PD (1960-1990). a) ciśnienie zredukowane do poziomu morza (hPa), b) temperatura powietrza na wysokości 2 m (K) i **c)** szlaki sztormów (odchylenie standardowe 2,5-8 dnia przy środkowo-przepustowym filtrowaniu średniego dobowego ciśnienia atmosferycznego na poziomie morza)(hPa). Zaznaczono obszary istotne statystycznie na poziomie 95% według testu t-Studenta

Such changes in the strength of the stratospheric polar vortex might be of relevance for AO/NAO like variability in the troposphere (cf. Spangehl et al. 2010 and references therein).

The simulation employing the new solar forcing estimate (EGMAM-3) reveals a NAO-negative like MSLP change pattern during LMM when compared to PD (Fig. 3a). The simulated weakening of the zonal flow is consistent with other simulations though the amplitude and exact location of the MSLP anomalies is sensitive to the vertical model resolution and the implemented solar forcing (cf. Spangehl et al. 2010). The associated change in near surface temperature during LMM shows a general European cooling with near surface temperatures being about 2 K below present-day values for Poland (Fig. 2b) thereby exceeding changes in Northern Hemispheric mean temperature. Moreover the simulation reveals a southward shift of "storm tracks" (calculated as standard deviation of 2.5-8 day band-pass filtered MSLP) over Europe and adjacent ocean areas indicating an increase in synoptic-scale activity over Poland (Fig. 3c).

CONCLUSIONS

Transient AO-GCM simulations that cover the period from the Maunder Minimum to present suggest that long tem changes of atmospheric GHG concentrations and solar activity result in changed atmospheric circulation and explain lower winter temperatures in Poland during the Late Maunder Minimum when compared with a present-day winter climate.

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