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Changes in the relationship NAO–Northern hemisphere temperature due to solar activity

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Abstract

The influence of the North Atlantic Oscillation (NAO) on wintertime Northern Hemisphere Temperature (NHT) is investigated. The results suggest that this relationship has different sign according to the phase of the solar cycle. For solar maximum phases NAO and NHT are positively correlated – a result assumed up to the moment – but for solar minimum phases correlations are not significant or even negative. This result is in agreement with the different extension of the NAO for solar cycle phases [Kodera, Geophys. Res. Lett. 29 (2002) 14557–14560] – almost hemispheric for maximum phases and confined to the eastern Atlantic for minimum phases.
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1. Introduction

The North Atlantic Oscillation (NAO) is a seesaw of surface pressure in the eastern part of the North Atlantic between high latitudes and subtropics (e.g. [2]). NAO is recognized as the main mode of climate variability in the extratropical Northern Hemisphere, reproducing approximately the 60% of the total sea-level pressure variance. Its influence over European weather conditions is strong [3] and relatively well-characterized [4], but perhaps the most significant finding about NAO was reached by Hurrell [5], who demonstrated a statistical linkage between the increasing trend in the winter NAO index and that in the winter Northern Hemisphere surface temperature (NHT) which could explain, at least partially, the global heating. Since then, many efforts have been made to clarify this relationship ([6–9]). The influence can be explained in terms of temperature advection by the zonal winds ([5,10]). When NAO is in its positive phase (pressure higher than normal over the subtropics and lower than normal over high latitudes) the stronger than usual westerlies over most of the European continent result in more extended areas with positive temperature anomalies and in higher values of these

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anomalies, due to the fact that regions with positive anomalies are mostly continental areas (low specific heat) whereas regions with negative anomalies are oceanic areas (high specific heat). However, recent studies do not support this assumed idea. Thus, the relationship between the NAO and wintertime NHT seems to be a function of the state of the NAO; there are energetic modes of coherent variability between temperature and NAO in the time domain of 2–6 yr for 1857–1879 and 1978–1984, and in the domain of 6–10 yr from 1961 to 1991 [11]. Another reason to disagree with this point of view is the fact that the NAO index appears to integrate aspects of both zonal and meridional flow types ([12,13]). In this last study, the authors conclude that the relationship between the NAO index and temperatures downstream of the Atlantic is associated with zonal flow, whereas the infuence of the NAO on temperatures upstream is more closely linked to meridional flow patterns. This result is in agreement with Castro-Diez et al. [14], who found that temperatures in southern Europe are sensitive not only to the phase of the NAO, but also to the exact location of the NAO centers of action. However, the main disagreement is based on the fact that running correlations do not show an obvious link between the NAO index and the secular temperature trend. Correlations between NAO indices and Northern Hemisphere temperatures are significant for the second half of the last century – this was about the period analyzed by Hurrell [5], but there are no significant correlations when the studied period is run across the whole last century or since the mid-19th century (Fig. 1).

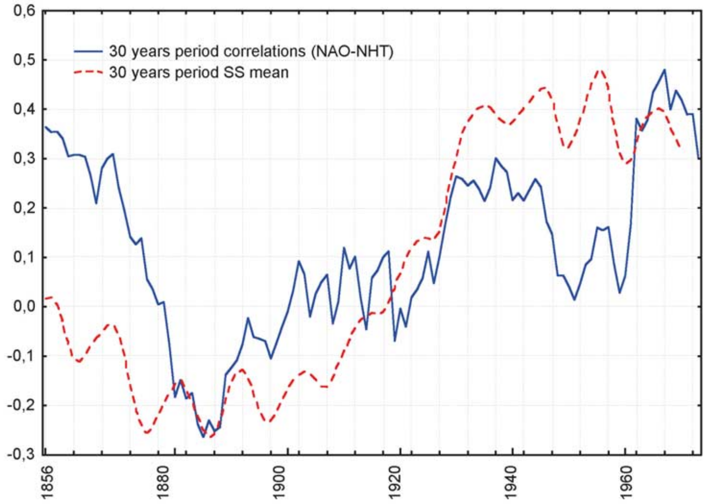
In this report, we test a hypothesis based on the solar cycle modulation of the relationship North Atlantic Oscillation–Hemispheric temperature. In a recent study, Kodera [1] shows that the spatial structure of the NAO differs significantly according to the phase of the solar cycle. For the solar maximum phases, the NAO has a hemispherical structure extending into the stratosphere, which is similar to the Arctic Oscillation (AO) [10] except for the Pacific sector. However, for the minimum phase the NAO is confined to the eastern Atlantic sector in the troposphere. The pattern of correlations between NAO and surface temperature is also different (figure 3 in [1]). Thus, for solar maximum phases the region of positive temperature anomalies over continents extends to a great portion of the Eurasian continent and eastern North America, being clearly more extended than the region with negative temperature anomalies, while for solar minimum phases it is limited to northern Europe, being of similar size as the area of negative anomalies over northern Africa. This suggests that the positive correlation between NAO and temperature could be produced exclusively during high solar activity and that for low solar activity the relationship could be inexistent or even of different sign.

2. Data

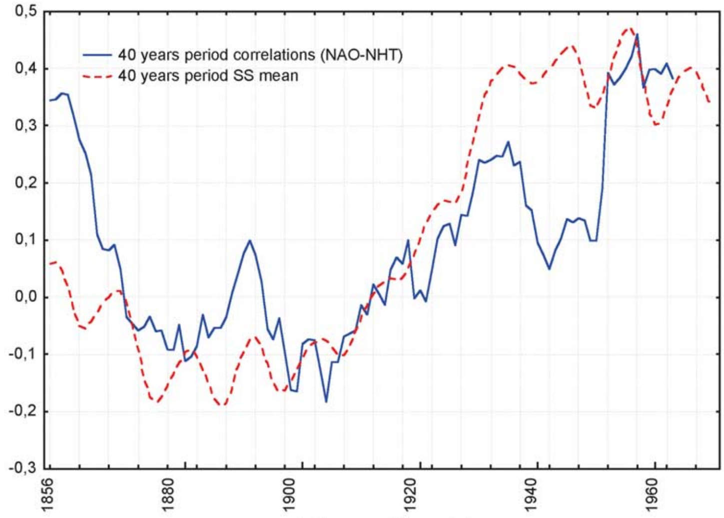
Due to the fact that NAO is more intense for winter, most studies are referred exclusively to wintertime. In this study we used wintertime means – computed as December–January–February (DJF) – for the period 1856–1999. The NAO index employed in this study was that calculated in [15] as the difference in the normalized annual mean sea-level pressure between Ponta Delgada (Azores) and Reykjavik (Iceland). Anomalies of Northern Hemisphere surface temperature data (combined land-surface and sea-surface temperature) used were those compiled by [16]. For a measure of the solar activity the annual number of sunspots derived from the International Sunspot Numbers is used. The use of numbers of sunspots instead of 10.7 cm solar radio flux permits us to consider 13 11-yr solar cycles instead of the four cycles used by Kodera [1], which is important to assure the significance of this study.

3. Results

30 and 40-yr running mean series of sunspot numbers are displayed in Fig. 1 as well as 30 and 40-yr running correlation series between NAO and NHT. In general terms, there is a good agreement between the series in each graph, which suggests a solar intensity modulation of the



a)



b)

Fig. 1. (a) 30-yr running correlation coefficients between wintertime NAO and NHT anomalies (blue) and 30-yr sunspot number running mean (red). (b) The same as panel a, but for 40-yr periods. The *x*-axis indicates the starting year of the period.

relationship NAO–NHT. A low number of sunspots is related to low positive or even negative correlations between NAO and NHT, while a high number of sunspots is always related to high and sometimes significant positive correlations. This visual inspection is also supported by correlation analysis. Thus, correlations between the series are significant at 0.01 confidence level ($r = 0.58$ for 30-yr series and $r = 0.72$ for 40-yr series). Similar results occurred when 20 and 50-yr periods were used. When number of sunspots (SS), NHT and NAO for the 1856–1999 period are plotted in a single figure (Fig. 2) this idea seems to be confirmed. NAO anomalies (color scale, hPa) are plotted vs NHT anomalies (°C) and sunspot numbers. For sunspot numbers

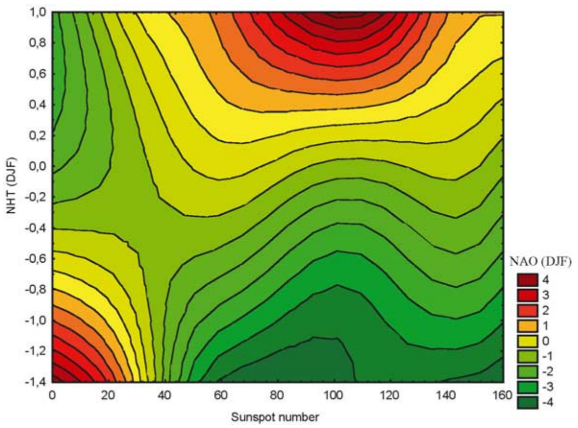


Fig. 2. Contour plot of wintertime (December, January and February) NAO (hPa) vs. wintertime NHT (°C) anomalies and annual sunspot number (Distance Weighted Least Squares).

from 70 to 130, NAO anomalies increase as NHT anomalies increase. When sunspot number is low, the behavior is the opposite. To check the hypothesis that the solar cycle is modulating this relationship, the sample was divided into two groups, one included the years corresponding to the three consecutive lowest values of sunspot number for every 11-yr cycle (43 years) and the other the ones corresponding to the three consecutive highest numbers (39 years) for every 11-yr cycle. The scatterplots between NAO and NHT anomalies for the two subgroups are displayed in Fig. 3 together with the regression line (solid) and the 95% confidence lines (dotted). A clear difference in the slope of the regression line can be seen; this is negative for low sunspot number and positive for high sunspot number. However, there is an important number of years outside of the 95% confidence lines, especially in the case of the low sunspot number group. If the data of each year were independent, the correlation coefficients between NAO index and NHT for 43 (39) years would be 0.30 (0.32) at the 95% confidence level. The correlation index corresponding to the solar minimum phases was −0.17 and to the solar maximum phases 0.35. The second result is statistically significant and indicates that there are periods when a positive phase of the NAO is related to positive anomalies of NHT, a result that supports our current idea of the influence of the NAO on temperature; but there are other periods when NAO and NHT are not correlated. Changes in atmospheric circulation due to NAO have imme-

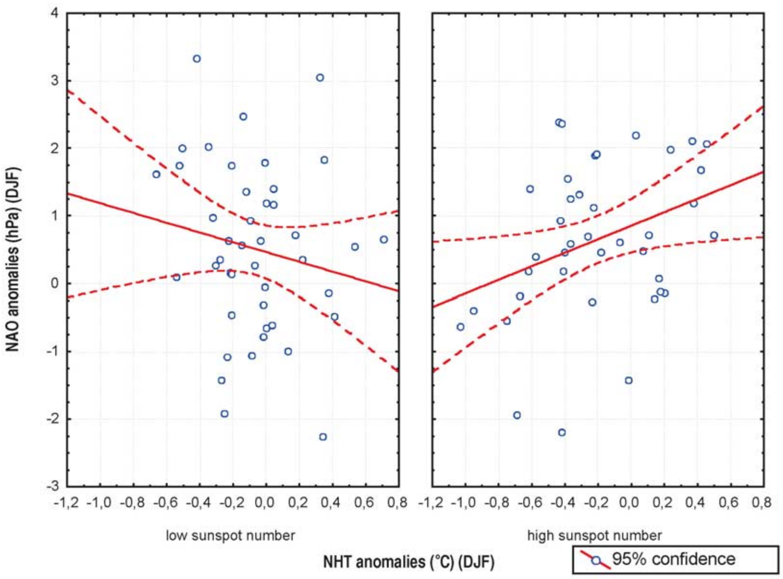


Fig. 3. Scatterplots between DJF (December, January, February) NAO and NHT anomalies for the two sunspot number subgroups together with the regression line (solid) and the 95% confidence lines (dotted).

diate effects on temperature fields due to changes in advection of temperature, the strength of the wind and the cloud cover, but delayed effects when other factors are considered, such as the sea surface temperature (SST) or the snow cover. Thus, correlations between wintertime NAO and spring (MAM), summer (JJA) and fall (SON) NHT were also computed for both solar minimum and maximum phases. Correlations are not significant for maximum phases but they are negative and significant for minimum phases (−0.37 with spring NHT and −0.40 with fall NHT). These results are in agreement with studies about the influence of snow cover on NAO. Thus, in a recent study, Bojariu and Gimeno [17] suggest that in mid-winter and early spring NAO-type atmospheric circulation influences the extent of snow cover and it is also possible that the snow cover feeds back to the atmosphere. In late spring, summer and early autumn, the most likely mechanism implies the existence of related snow cover influences on the atmospheric circulation, with predictive potential. Among the other months, November and December are different from the standpoint of snow extent/atmosphere relation. The persistence mechanism that seems to work in other months, for which all correlation coefficients either with the previous NAO winter or with the next one are negative and quite strong, is not present in November and December. Due to the fact that December is included in our wintertime NHT, this can be the reason for the lack of significance in the correlation between wintertime NHT and NAO. To check this possible reason, correlation between NHT computed as January–February and wintertime NAO was also calculated for solar minimum phases being significant and negative (−0.41).

Our result is clearly in agreement with the results reached by Kodera [1], as described in Section 1, and partially with the results reached in [18], who found a minimum of temperature over Europe during the minimum in solar radiance known as the Maunder minimum (from mid-1600 to the early 1700s). The discrepancy with this study resides in assigning this minimum to a negative phase of the NAO. According to our study, it was even more probably a positive NAO phase. Although a robust mechanism to explain the results reached in this study needs to be found, there are physical arguments that can partially explain it. It has been found that an anomalous strength in the stratospheric vortex precedes anomalous intensity in the tropospheric westerlies (positive phase of the NAO). This relationship is causal. Stratospheric processes have the potential ability to induce changes in the NAO [19] and even in Northern Hemisphere weather [20]. The zonal wind anomalies produced by solar activity in the stratopause [21] can propagate downward into the tropopause through interaction with planetary waves ([22–24]) or through induction of the meridional cell in the troposphere [25].

4. Concluding remarks

The present analysis suggests that the relationship between the North Atlantic Oscillation and the Northern Hemisphere surface temperature is dependent on solar activity, being positive for high solar activity and not significant or even negative for low solar activity. This result is physically supported by the different extension of the NAO through the 11-yr solar cycle [1] and by the possible downward propagation of westerlies–anomalies from the stratosphere to the troposphere due to solar activity variability. The number of 11-yr solar cycles analyzed – not only wintertime means – indicates that these results do not simply seem a statistical artefact.

The results reached in this study also suggest that major modes of climate variability such as NAO or ENSO could modulate the relationship between solar activity and global temperature. Although this needs to be investigated in further studies, an exploratory analysis suggests that it is true for NAO but not for ENSO.

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