Arctic Oscillation and its impact on Finland's climate

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Abstract

Arctic Oscillation (AO) represents large-scale atmospheric circulation variability in the Northern Hemisphere. It is seen as strengthening or weakening of the mid-latitude westerlies over the North Atlantic and Europe, depending on the phase of the AO, and it defines to a great extent the weather and temperature conditions in Finland, especially in winter.

1. INTRODUCTION

Arctic Oscillation (AO) is the most important mode of the atmospheric circulation variability in the Northern Hemisphere (NH). It is a topic studied thoroughly in recent years by e.g., Thompson and Wallace (1988, 2000) and Thompson et al. (2000), and has a close connection to the North Atlantic Oscillation (NAO), as discussed in Wallace (2000). The AO has a major impact on weather and temperature conditions in Europe and also in Finland.

In this paper, Arctic Oscillation is briefly discussed. First, a method of determining the AO is explained, and some basic properties of the AO are presented. Next, the different phases of the AO and the impact of the AO on temperature conditions e.g., in Finland, are discussed. Finally, some preliminary results from the predictability of the AO are presented.

2. EOF ANALYSIS AND ARCTIC OSCILLATION

The data used in the present study consists of daily 1000 hPa height analyses for the Northern Hemisphere, north of 20°N, from the NCEP/NCAR Reanalysis Project (Kalnay et al., 1996). The data cover the period 1951-2000, in total 18625 cases.

Empirical orthogonal function (EOF) analysis (e.g., Rinne et al., 1981) is applied to these daily analyses. The annual cycle is not removed in the computation of the covariance matrix as is usually done. This means that the anomalies used for covariances are computed using one general mean field, the mean of the 18625 analyses. Thus any 1000 hPa geopotential height field can be represented by

$$z(i,t) = zm(i) + \sum_{\nu=1}^{N} C_\nu(t) f_\nu(i), \qquad (1)$$

where *z(i,t)* is the geopotential height, with *i* and *t* referring to space (grid point) and time, respectively. Term *zm(i)* represents the long-term mean at each grid point. The sum term consists of the space-dependent part f_ν (the spatial EOF pattern) and the time-dependent coefficient C_ν, for component ν. Value *N* represents the point of truncation, the number of components taken to the EOF series.

Figure 1 shows the spatial patterns of the two leading EOFs. EOF-1 (lhs of Fig.1), explaining 22.9 % of the total variance of the 1000 hPa geopotential height, depicts the land/sea contrast with negative values over continents and positive values over oceans. The time-dependent coefficient (C_1) of EOF-1 shows a clear quasi-sinusoidal annual cycle with positive values in summer and negative values in winter.

EOF-2 (rhs of Fig. 1) accounts for 7.7 % of the total variance (10.3 % of the variance not including the annual cycle) and is associated with the Arctic Oscillation (AO). EOF-2 tends to strengthen or weaken the zonal flow in mid-latitudes, in particular in the North Atlantic sector, depending on the sign (+ or -) of the coefficient C_2, also called the AO index.

Figure 2 depicts the daily average of C_2, together with ± one standard deviation, for 1951-2000. C_2 shows an annual cycle with positive values dominating from July until January, when C_2 starts to decrease and becomes negative. C_2 reaches the minimum around the beginning of May, after which it quickly rises to the maximum around mid-summer. This means that, on average, the positive AO phase dominates from the mid-summer to early winter, while the negative AO phase dominates in late winter and spring. However, the year-to-year differences are large in the behavior of C_2, as the relatively large standard deviation suggests (Fig. 2).

3. PHASES OF THE AO

The sign of (+ or -) of the C_2 coefficient (AO index) affects the flow pattern over the North Atlantic and Europe significantly. This can be demonstrated with Fig. 3, showing the average mean-sea-level pressure for a negative AO phase (left) and for a positive AO phase (right). During the negative AO phase (January 1985) the Icelandic low is shifted towards west of its normal position and the westerly flow over the North Atlantic/European sector is weakened and directed to Spain and the Mediterranean. During the positive AO phase (February 1990), on the other hand, the Icelandic low is deeper than normally and the westerly flow over the North Atlantic is strengthened and directed towards western and northern Europe. These two different flow types result in much different weather and temperature conditions: the monthly mean temperatures in Helsinki and Sodankylä were -13.9°C and -23.2°C, respectively, in January 1985, but +1.6°C and -3.1°C in February 1990.

The AO index has experienced a clear positive trend during the last 50 years, i.e., the positive AO phase has become more frequent recently. This is demonstrated in Fig. 4, which shows the daily mean values of C_2 for two periods, 1951-1970 and 1981-2000. Figure 4 reveals that the value of C_2 has increased, i.e., the polar vortex has become more intense during the cold season, whereas little change is seen in summer and fall. This means that the strengthened westerly flow has been more dominant during the late 1900's compared to the 1950's and 1960's, which in turn has resulted in milder winters recently. Climate model studies (e.g., Shindell et al., 1999; Fyfe et al., 1999) suggest that the positive AO phase may become more frequent with enhancement of the atmospheric greenhouse effect.

Even though the positive phase of the AO has become more frequent in late 1900's, it does not mean that the negative phase has completely disappeared. This is demonstrated in Fig. 5, which shows the 5-day mean of the AO index together with the 5-day mean temperature at Vantaa for the period November 2004 to March 2005. The AO index was mainly positive from November to mid-February, when it suddenly became negative and stayed so until the end of March. Mild, above normal temperatures were measured until mid-February. Thereafter the cold winter weather dominated, with March being the coldest winter month. There was a clear positive correlation between the AO index and the Vantaa temperature. Correlation was as high as 0.75 on pentad basis and 0.65 on daily basis. The 50-year-long time series show that the correlation (on monthly basis) is 0.6 for winter months, but only 0.2 for summer months. Thus it can be concluded that the AO has a significant impact on the wintertime temperature conditions in northern Europe, whereas there is only little AO signature in the summertime temperature.

4. PREDICTABILITY OF THE AO

As the AO is a major mode in the NH circulation, it is of great interest to see how the NWP (Numerical Weather Prediction) models can predict the behaviour of the AO. A preliminary study of predictability of the AO in ECMWF (European Centre for Medium Range Weather Forecasts) operational forecasts has been carried out. The predictability is two-fold. Even a large, abrupt drop or rise in the AO index, i.e., a clear change in the circulation type, is sometimes perfectly predicted. But, there are also cases with a large uncertainty in prediction of the AO, which is seen in different behaviour of the AO index in forecasts of consecutive days. The EOF analysis reveals that the leading EOF pattern of the forecast error is "AO-like" in forecast ranges longer than four days, which might suggest that there are difficulties in prediction of the AO.

5. SUMMARY

The Arctic Oscillation has been briefly discussed. Apart from the annual cycle, the AO is the most important mode in the NH circulation. It has a large impact on weather and temperature conditions over the North Atlantic and Europe. The AO impact is prominent during the cold season, whereas there is only little AO signature in summer months. The positive phase of the AO results in mild and wet winters with westerly winds dominating. The negative phase, on the other hand, brings cold continental winter weather. The positive AO phase has become more frequent during the last 20 years compared to the 1950's and 1960's. This could be atmospheric response to greenhouse-gas forcing.

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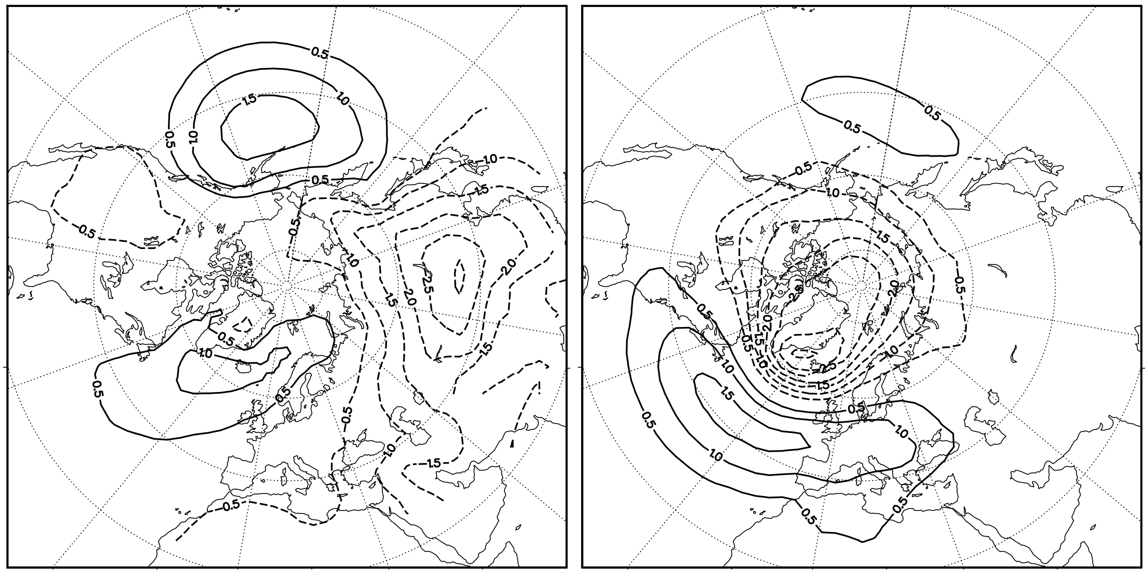

Figure 1: Two leading EOFs based on daily 1000 hPa geopotential height for 1951-2000: EOF-1 (left) and EOF-2 (right). Positive values are indicated with full lines and negative with dashed lines, the zero isoline is omitted. Contour interval: 0.5.

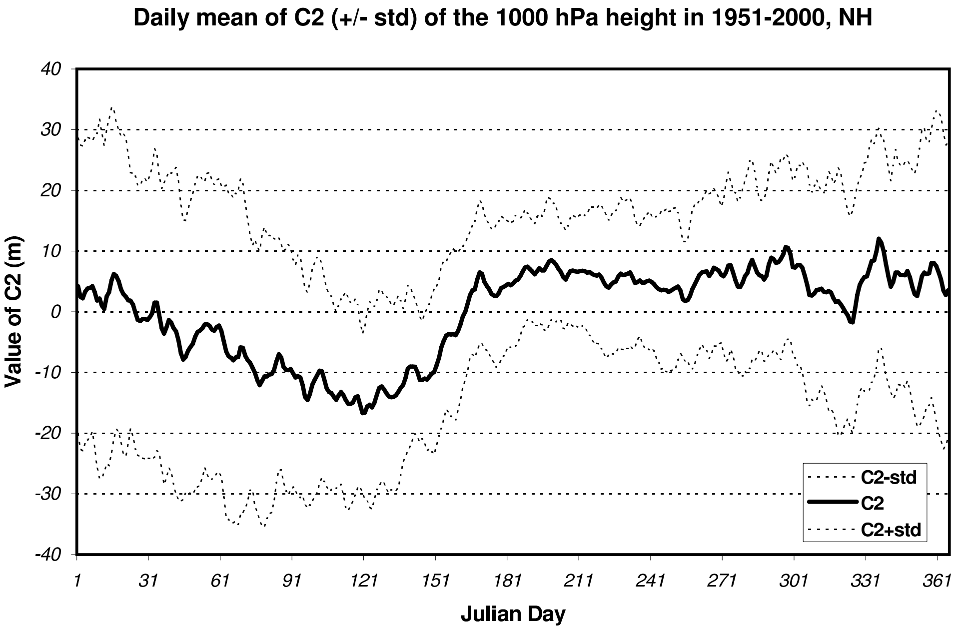

Figure 2: Daily mean value (full) of the time-dependent coefficient (C_2 or the AO index) associated with EOF-2, together with mean ± one standard deviation (dotted), in 1951-2000. Unit: m.

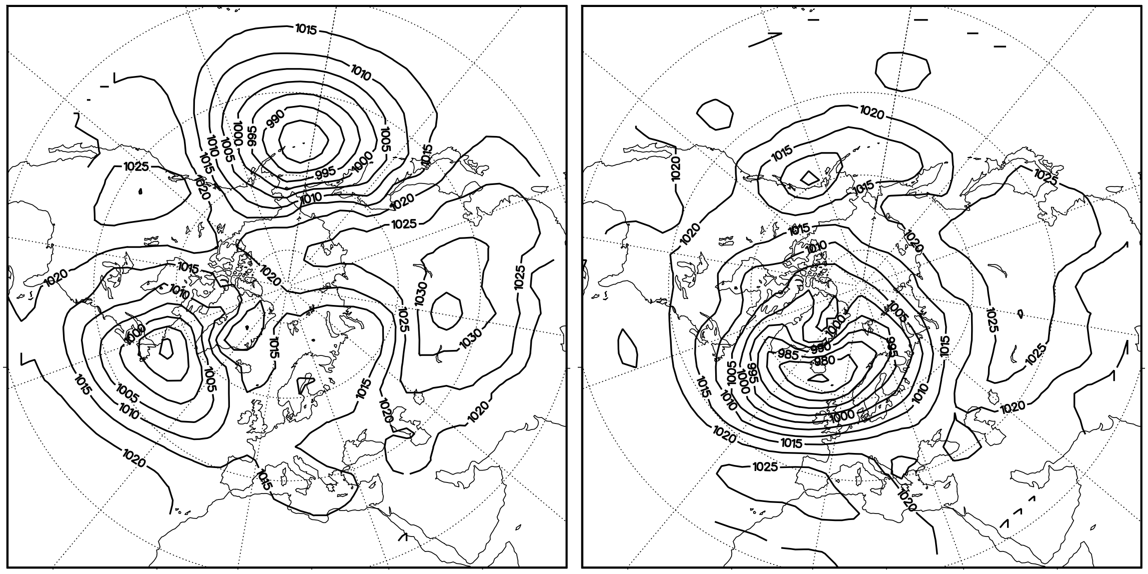

Figure 3: Average monthly mean-sea-level pressure for January 1985 (left) and for February 1990 (right). Contour interval: 5 hPa.

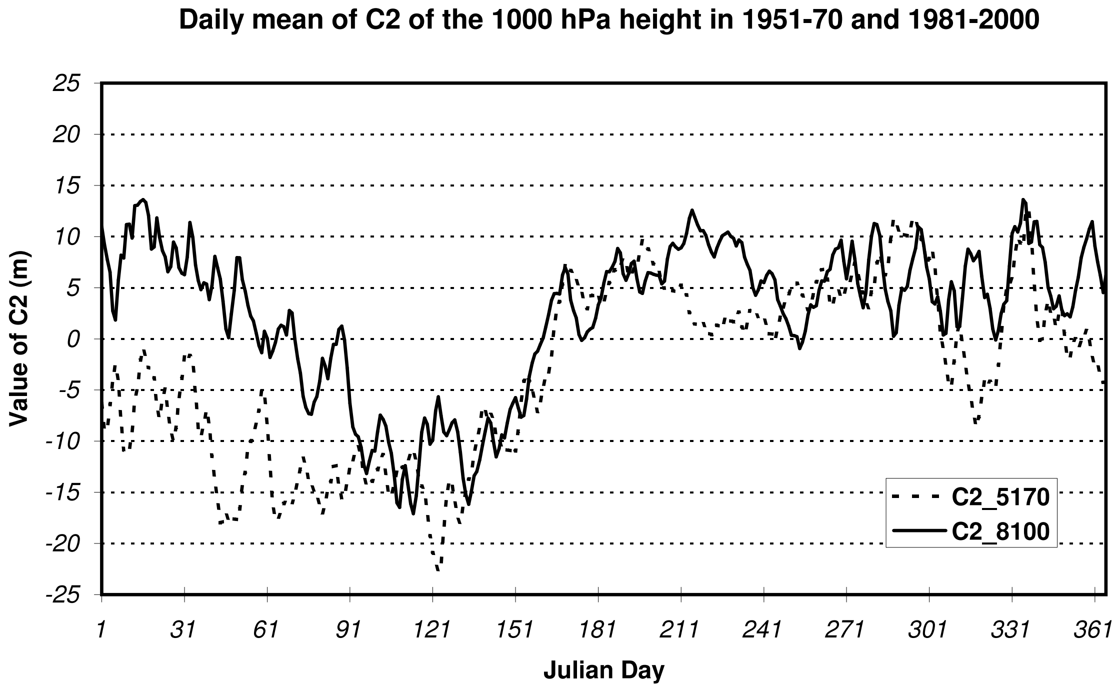

Figure 4: Daily mean value of the time-dependent coefficient (C_2 or the AO index) associated with EOF-2 for periods 1951-1970 (dashed) and 1981-2000 (full). Unit: m.

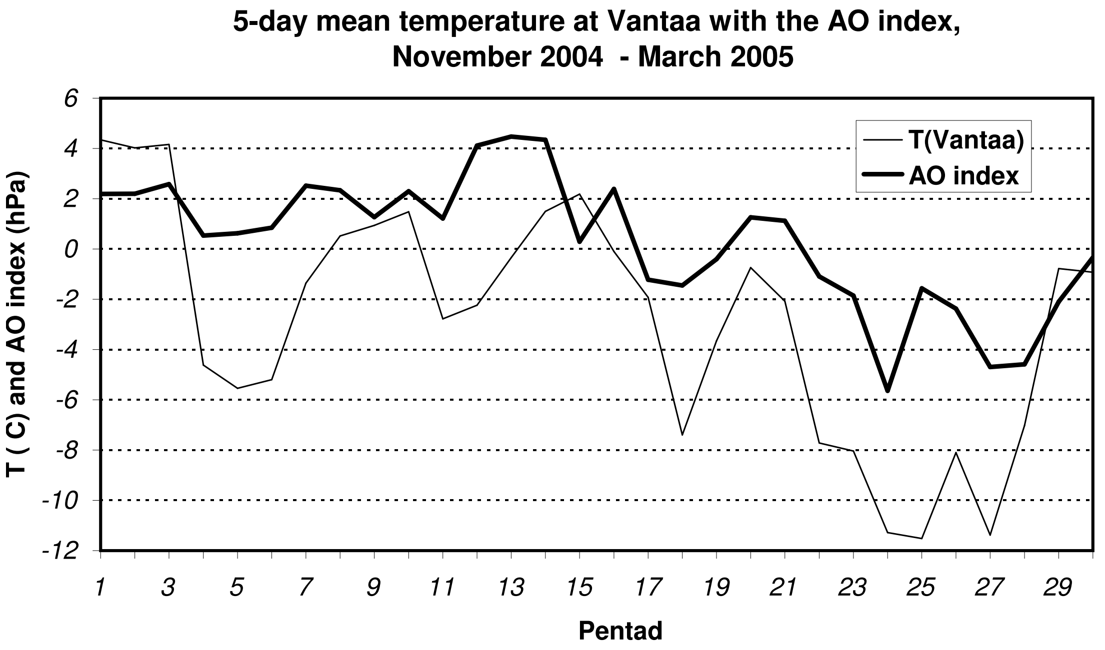

Figure 5: 5-day mean temperature at Vantaa (thin line) and the 5-day mean of the AO index (thick line) for the period 1 November 2004 - 30 March 2005.