Relationship between Siberian autumn snow cover and winter Arctic Oscillation: features of its time manifestation

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Abstract. Features of time manifestation of the influence of the Western Siberia autumn snow cover on the Arctic oscillation at the surface in the following winter are considered. 1979–2016 observational data are used. Each winter month (December, January, February) and the winter season as a whole are considered. The obtained results confirm the fact that the manifestation of a statistically significant linear connection between the October snow cover area and the AO index in the following winter in Western Siberia is sensitive to the choice of the time period of the study. The results also show that the mechanism of the relationship between the parameters under consideration starts and exists at some successful coincidence of the background conditions and it is not a driver itself.

1. Introduction

The influence of autumn snow cover anomalies in the middle and high latitudes of the Northern Hemisphere on the atmospheric conditions forming in the subsequent winter season has been of considerable interest to the scientific community for many years. Various aspects of this influence are being studied. The influence of snow cover anomalies on the tropospheric-stratospheric interaction is considered in general [1–3], and on the Arctic Oscillation (AO) [4, 5] and air temperature at the surface in the subsequent winter season in particular [6]. The stationarity of the influence of the autumn snow cover on the winter atmospheric conditions and its possible connection with various atmospheric processes, for example, the quasi-biennial oscillation (QBO), are studied [7, 8]. The relationship between the snow cover and regional atmospheric blockings is also considered [9, 10].

In 2007, a group of scientists led by Cohen J. formulated and presented a possible mechanism for the effect of anomalies of the autumn snow cover area on the following winter atmospheric conditions in the Northern Hemisphere [1]. According to this mechanism, the snow cover area of the territory under consideration is increasing rapidly, exceeding the normal value and causing non-adiabatic cooling, which promotes an increase in the pressure at the surface. This, in turn, leads to a decrease in the temperature below the norm. As a result of cooling in the troposphere, the vertical fluxes of wave energy are amplified which, due to their absorption in the stratosphere, leads to the destruction of the polar vortex and the formation of a secondary (anomalous) circulation. The resulting anomalies of geopotential heights and winds gradually spread downward from the stratosphere through the troposphere to the surface where, as a result, a strong negative phase of the AO appears. In addition, the weakening of the polar vortex contributes to an increase in the temperature in the stratosphere and a weakening of the jet stream and its shift to the South, so that this secondary circulation often takes the form of blocking. Thus, the variation of the autumn snow cover can be regarded as a predictor both for the anomalous atmospheric conditions formed in the following winter season at the surface and for sudden stratospheric warming. This is one of possible mechanisms for linking the atmospheric dynamics of the Arctic and mid-latitudes.

Due to the climatic features of Eurasia, the most extensive snow cover is formed in its Siberian part. According to the satellite observations of the National Oceanic and Atmospheric Research Administration (NOAA), the main snow cover formation in Siberia occurs precisely in October [11, 12], which is associated with the change of seasons and the corresponding change of the atmospheric circulation for this territory. Moreover, it was revealed that the territory of Siberia is a so-called "hot spot" [13], i.e. local changes in this territory can cause global climatic and ecosystem changes.

There are works showing that the identification of this mechanism manifestation can depend on the period of time chosen for study [14, 15]. In addition, the mechanism of the effect of the autumn snow cover anomalies on the atmospheric conditions of the following winter in the Northern Hemisphere has not been fully studied, however, researchers agree that it is very complex and requires a comprehensive study [5, 7]. There are some works suggesting that the influence of snow cover variation on the AO is not subject to any physical mechanism, but is a stochastic effect (e.g. [8]).

The purpose of this paper is to identify the features of time manifestation of the influence of the autumn snow cover variation on the sign and magnitude of an AO mode at the surface in the following winter. This could help to improve the quality of seasonal forecasts of meteorological conditions, and also improve qualitatively the assessment of risks of extreme events.

2. Data and methods

2.1. Region

In this paper, attention was focused on the territory of Western Siberia (WS). The boundaries of the territory were set as $55 - 74°$ N and $60 - 90°$ E.

2.2. Data

The snow cover data were taken from the NOAA satellite data archive with a weekly time resolution, available for downloading on the official website of the Global Snow Lab of the Rutgers University (`https://climate.rutgers.edu/snowcover/`). Using these data, the maximum October snow cover area was calculated for each year for WS (S_{max}). These values were used as an indicator of the snow cover area size formed by the end of October in the territory under consideration.

Monthly values of the AO index were taken from the official website of the National Weather Service Climate Prediction Center (NOAA NWS CPC). Due to the fact that these AO index values are de-facto taken as the observed AO index, they can be used together with the data on the snow cover area obtained from the satellite observations. Each winter month (December, January, February) and the winter season as a whole were considered.

The study covered the period of 1979–2016.

2.3. Method

Using the obtained data series, the procedure of checking of all nested periods (PCANP) for manifesting a statistically significant linear connection between the S_{max} and the AO index was performed [16]. Here the correlation coefficients between S_{max} and the AO index were calculated for the whole time period of 1979–2016, as well as for all nested periods.

Thus, first the correlation coefficient for the whole 38-year ($n = 38$) period was calculated. Then the length of the period was decreased by 1 year, and the correlation was calculated for two nested periods: 1979–2015 and 1980–2016. Further, the length of the period was decreased for one more year and the calculations were carried out for three nested periods: 1979–2014, 1980–2015, 1981–2016. And so on, until the length of the nested periods reached 10 years.

The correlation coefficients were calculated for the original and detrended data series. The exclusion of the trend made it possible to assess the impact of a low-frequency component on the relationship between S_{max} variations and the AO mode at the surface. It should be noted that the trend exclusion was carried out for each nested period separately. The statistical significance of the obtained correlation coefficients was also determined for each nested interval separately.

3. Results

The interannual variability of S_{max} shows a clear upward trend. This may indicate both an increase in the intensity of the snow cover area extension and an earlier start of the snow cover accumulation in WS. According to the mechanism proposed by Cohen J., with an abnormally large snow cover area a strong negative mode of AO should appear at the surface in the following winter [1].

In this study, in the second half of the whole period under consideration S_{max} significantly exceeds the average value by more than a standard deviation value (σ) in some years (2001, 2002, 2006, 2011, 2014, 2015 and 2016), which can be regarded as an anomaly. The AO indices in December of these years in the second half of the period show negative values of greater magnitude than in the first half. In January, February, and in the winter season as a whole, the absolute values of positive indices decreased in the second half of the period in comparison to its first half (Figure 1). Such a behavior of the values allowed us to assume that there is a connection between them, but the correlation coefficients between the autumn S_{max} and the AO indices in the following winter did not demonstrate a statistically significant linear relationship between them (Table 1). A similar result was obtained for the detrended data. The correlation coefficients obtained for the winter of the whole period under consideration are insignificant.

Table 1. Correlation between S_{max} and AO index, $\alpha = 0.1$, $t_{cr} = 0.2705$ for $n = 38$.

Data	December	January	February	Winter season
Original	-0.022	0.031	-0.061	-0.024
Detrended	-0.033	0.084	-0.111	-0.029

However, earlier studies show that the result of detection of the statistically significant linear relationship can greatly depend on the choice of the time interval [14, 15]. The PCANP applied to both the original and detrended data showed a statistically significant negative linear relationship between the autumn S_{max} and the AO index for some separate periods for the following December and February and its absence for all nested time intervals for the following January. All statistically significant values of the correlation coefficients range from -0.761 to -0.325 for the periods of different lengths. The map-schemes obtained using the PCANP (Figures 2 and 3) allow one to reveal features of the periods with a significant linear relationship.

First, for the considered data a significant linear relationship did not appear in periods longer than 30 years for the WS. The highest statistically significant absolute values of the correlation coefficient were obtained for the shortest periods.

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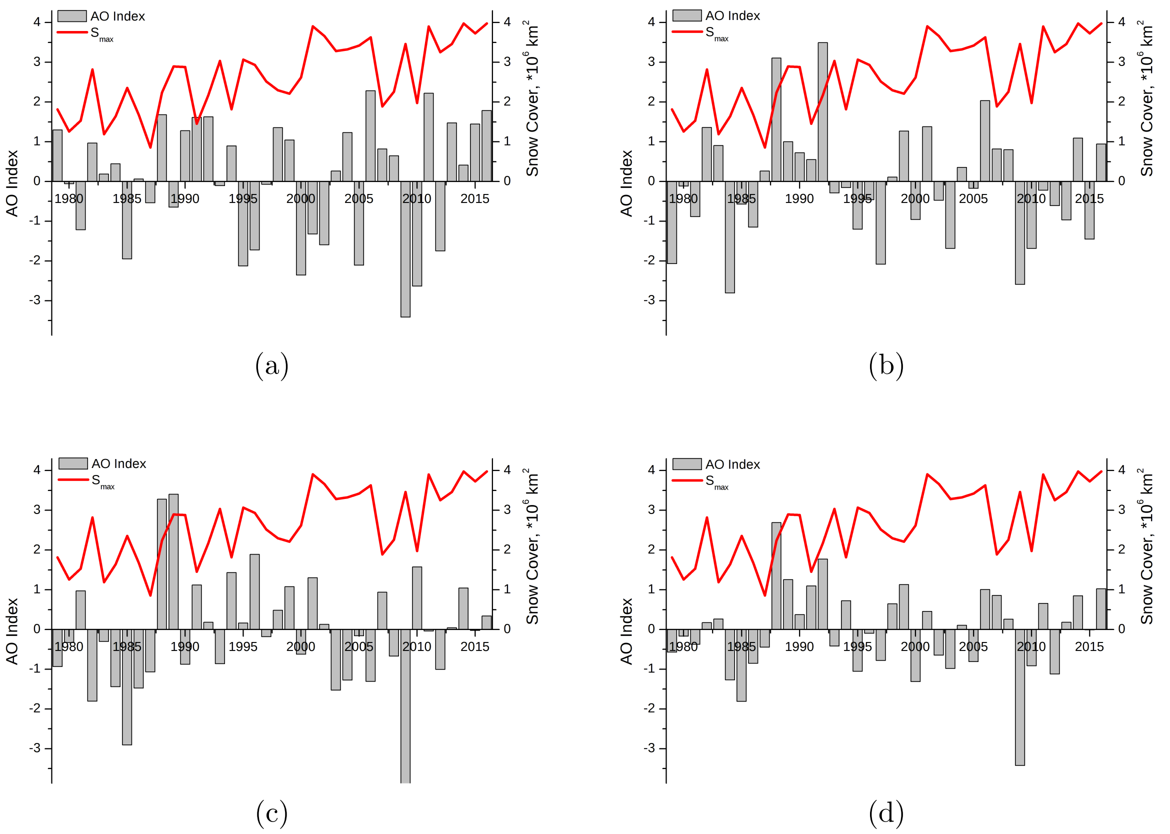

Figure 1. Interannual variability of S_{max} and AO index for December (a), January (b), February (c), winter season (d), 1979–2016.

Second, grouping of points denoting the statistically significant correlation coefficients between S_{max} and the AO index into diagonal and vertical structures was obtained. The points on one diagonal line denote periods that have different years of the period start and the same year of its end. The points on one vertical line denote the opposite: different years of the period end and the same years of its start.

Thirdly, a sharp transition from statistically significant to insignificant values of the correlation coefficient was shown. A shift of the period start and/or the end by only one year causes a change of the correlation coefficient value from the statistically significant to the insignificant (or vice versa). In most cases this change was not smooth but jump-like with a sharp difference from the critical significant values. For example, for the original data for December for 1992–2009 the correlation coefficient is significant and is -0.442. The critical value for this 18-year period is 0.398. However, by shifting this period by one year, 1993–2010, the correlation coefficient value became equal to -0.251, whose absolute value is significantly lower than the critical one.

4. Discussion and conclusion

The results obtained confirm the fact that the manifestation of a statistically significant linear connection between October S_{max} and the AO index in the following winter in WS is sensitive to the choice of the time period of the study. The low-frequency component of variation of the parameters does not determine the occurrence and strength of the connection between them,

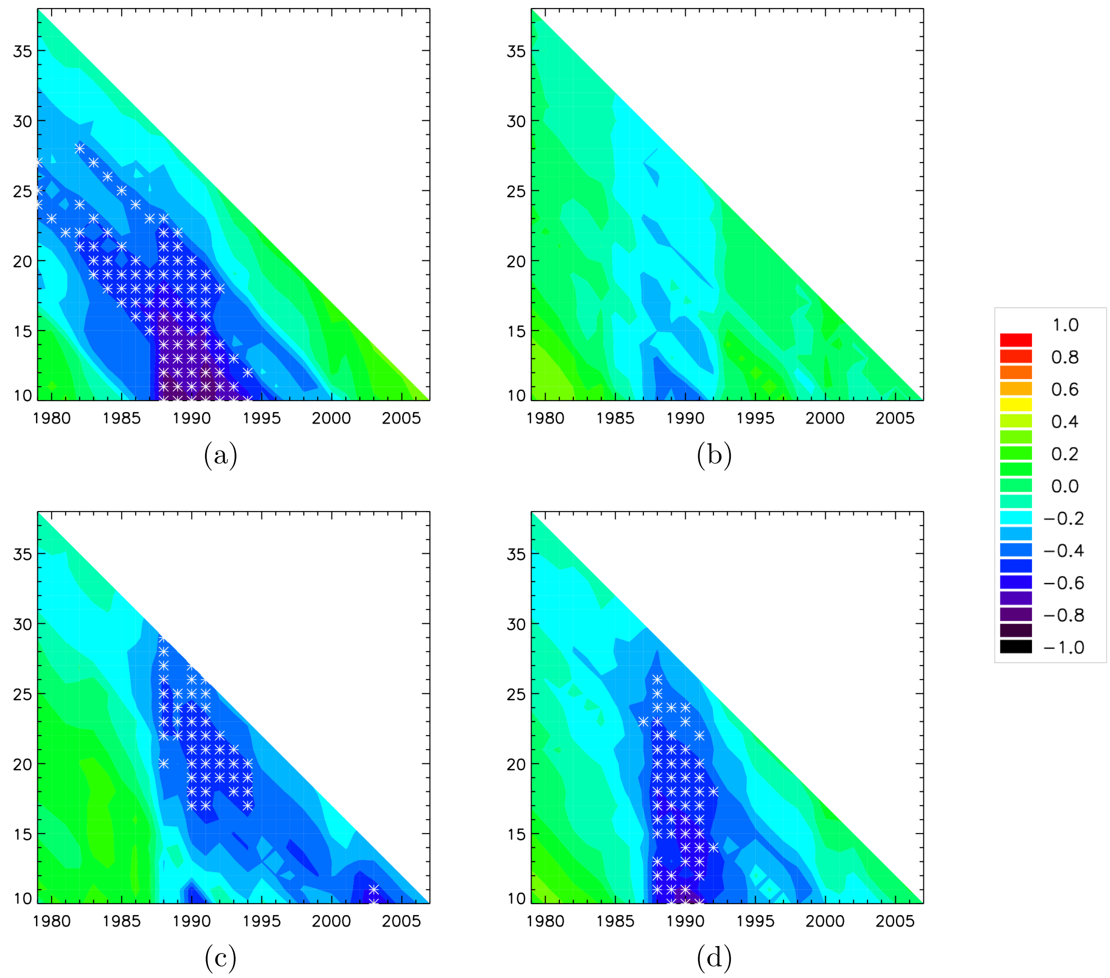

Figure 2. Correlation coefficients between the autumn S_{max} and the AO index for the following December (a), January (b), February (c), winter season (d) for the original data, $\alpha = 0.1$.

as indicated by the fact that the difference between the results obtained from the original and detrended data is small.

As to the manifestation of this linear relationship in time, it would be incorrect to consider it as fully stochastic. Otherwise the points on the obtained map-schemes denoting statistically significant values of the correlation coefficient between S_{max} and the AO index would have been located in a random order and would not have been grouped into structures. In the present study the point grouping into diagonal and vertical structures may indicate that in some time periods the variation of the S_{max} may be in opposite phases with the AO index variation and, as a result, a significant linear relationship with negative sign is obtained.

The results suggest that the interaction mechanism formulated by Cohen J. [1] is not a driver, but it can help to explain the nature of the interaction between the atmospheric processes for periods with a significant linear relationship. It is likely that the mechanism starts and performs at a successful coincidence of the background conditions.

Further detailed studies of the features of the mutual behavior of the autumn snow cover in WS and the manifestation of the AO mode at the surface in the following winter using data of various types (observations, reanalysis, climate scenario modeling) are necessary.

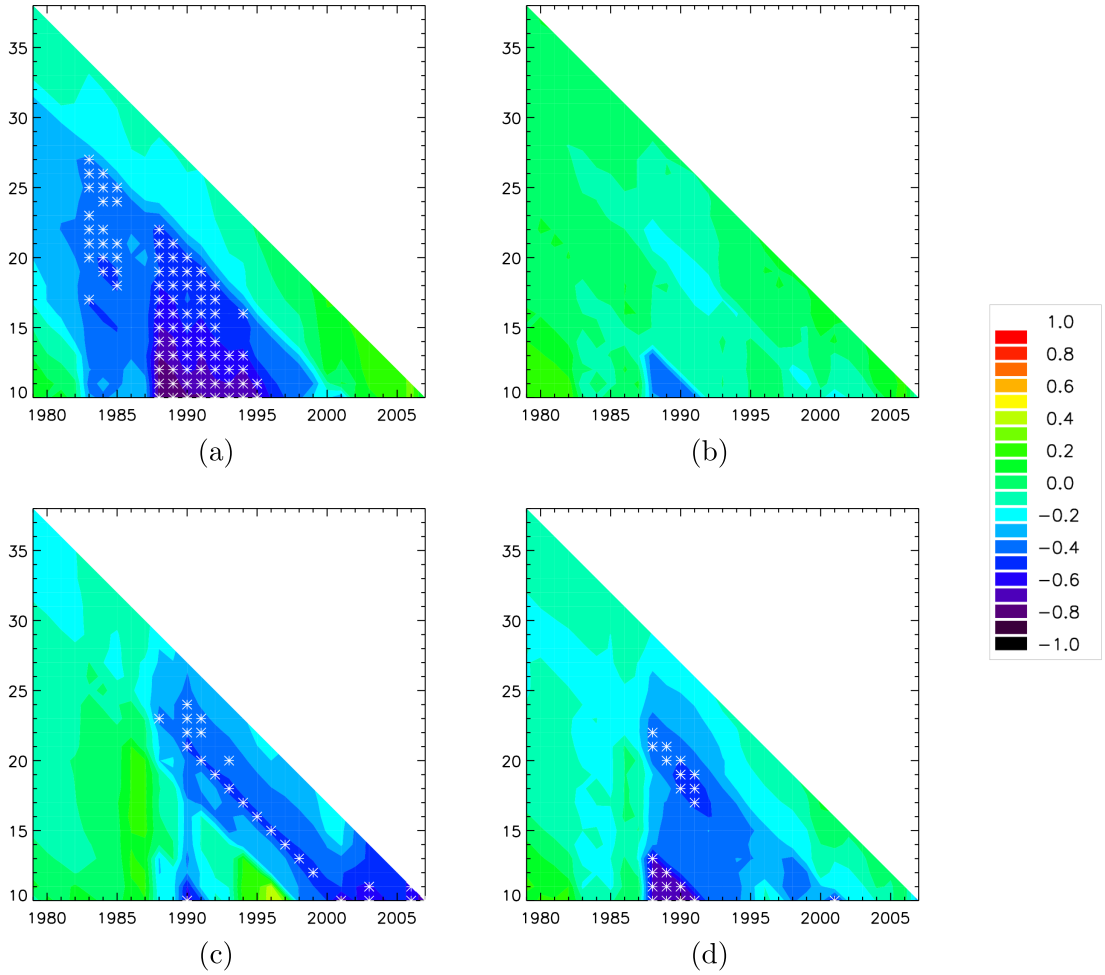

Figure 3. The same as Figure 2 but for the detrended data.

Acknowledgments
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