ISSN 1024-8560, Atmospheric and Oceanic Optics, 2017, Vol. 30, No. 1, pp. 55–62. © Pleiades Publishing, Ltd., 2017.
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Connections between Climatic Characteristics and Cyclonic Activity in Winter over Siberia in 1976–2011

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Received June 3, 2016

Abstract—The temperature, surface pressure, and cloud cover for Siberia (50°–70° N; 60°–110° E) in the winter period (December–February) are estimated over 1976–2011 based on data from 163 meteorological stations. Using surface synoptic maps, time series of winter cyclone characteristics, such as the total number and central pressure, are derived for the same period. Two time intervals are found in variations of climatic characteristics and cyclone activity characteristics: 1976–1990 and 1991–2011. In the first period, the temperature and cloud cover increased and the surface pressure fell, which reduced the number of cyclones and intensified (deepened) them. In the second period, opposite trends took place. The correlation analysis between the climate variables and cyclonic activity characteristics allowed us to consistently describe the impact of cyclones on the surface pressure and cloudiness.

Keywords: surface temperature, surface pressure, cloudiness, cyclonic activity, the territory of Siberia

DOI: 10.1134/S1024856017010109

INTRODUCTION

Cyclones strongly affect the weather and climate, since their passage cause significant variations in cloudiness and precipitation, temperature and wind. Variations in clouds change the radiation balance on the underlying surface, and extreme precipitations and wind during high-intensity cyclones adversely affect regional economies. This implies that connections between the climate change and variations in the cyclone characteristics over long time periods are of theoretical and practical interest.

The forecast simulation of cyclone characteristics for anthropogenic scenarios of global warming in the 21st century has been reported in many works [1–4]. The most common conclusions from these and some other works are the following: storm tracks (geographical regions with the highest frequency of detectable cyclones) shift poleward, the total number of cyclones decreases, especially in the winter period, and the number of intense cyclones increases. As for the last conclusion, it is valid only for certain regions in the Northern hemisphere (Northeastern Atlantic and the Northern Pacific) under the condition that the cyclone intensity is determined by its central pressure, but not by the pressure Laplacian or vorticity [5].

These conclusions generally agree with the studies of cyclonic activity where automated tracking is applied to available databases for reanalysis [6–8]. Thus, the winter climatology of cyclones in the Northern hemisphere in 1958–1999 is studied in [6], where a significant negative trend in the total number of cyclones is revealed, except for the Arctic, where this trend is statistically insignificant, but a significant positive trend in the number of intense cyclones is revealed.

The comparison of climate characteristics of cyclones is difficult, since different models [9, 10], reanalysis databases [11], or different methods for cyclone identification and tracking [12] can produce different output data.

The time from 1976 to 2011, considered in this work, is characterized by changes in global and regional climate. The global temperature, after the rapid rise in 1976–2000, entered a stage of very slow increase, from 2000 and until now, i.e., a pause in the modern global warming is observed [13, 14]. The pause-related regional studies show the formation of negative trends in winter temperatures in midlatitudes of the Northern hemisophere from the early 1990s [15–17], which affected the slowing down of global warming.

It is shown in [8] that the amplitude of interseasonal variations in the surface air temperature in the

Siberian midlatitudes is unambiguously connected with the winter average temperature over the 20th century. Considering the negative radiation balance in winter in these latitudes, one may assume that the cyclonic circulation determines the temperature regime in this period.

The cyclone climatology is considered in some works [6, 19] in connection with variations in the global indices of atmospheric circulation. The periodicity in characteristics of polar cyclones is shown in [20].

The aim of this work is the study of connections between variations in the climate variables and the cyclonic activity in Siberia (50°–70° N, 60°–110° E) in winter in 1976–2011.

INITIAL DATA AND STUDY TECHNIQUE

Daily observation data from 163 regional meteorological stations (NOAA data distribution center, ftp://ftp.cdc.noaa.gov) for 1976–2011 were used for the calculation of time series of region-averaged surface air temperature, surface pressure, and clouds for the winter period (December–February). The daily values were used for the calculation of the monthly average climate variables by the technique [21], which then were used for the calculation of the winter averages.

To eliminate the effect of spatial inhomogeneity of the arrangement of the meteorological stations, the seasonal values of the climate variables calculated were ordinary Kriging spatially interpolated to a grid of 1° × 1°. The area estimates, connected with the spatial distribution of a variable, were calculated in the equal-area projection. The variables calculated were used for the calculation of the sampling density $P_x(x)$ and the following calculation of the sampling distribution functions $F_x(x)$, which were used for the estimation of the region-averaged variables.

Surface synoptic maps (00, 06, 12, 18 GMT) were used as the initial base for the study of cyclone characteristics, which were then manually processed (tracked).

The manual tracking technique consists in the serial analysis by an operator of six-hour surface synoptic maps AT_{1000}. The cyclone position was detected visually by the configuration of the first close isobaric line. A cyclone was processed if it was centered within the region under study or out of the region, but its well-developed periphery covered no less than 25% of the region.

The cyclone center trajectories inside the region under study were not traced, but the direction from which each cyclone entered the region was considered. The analysis considered such parameters as the number of winter cyclones and their central pressure.

The reliability of results is an important question for any analysis technique, including the manual tracking. The errors in the cyclone detection by the automated tracking methods are estimated in [12]. The authors show that 15 different tracking techniques applied to the analysis of winter cyclones in the Northern hemisphere in 1989–2009 using the same ERA-Interim database give significantly different numbers of cyclones, with the best estimates for deep cyclones.

Most cyclone characteristics analyzed in this work were obtained by one operator. To calculate the individual error, the following technique was used [22]. The 1000 hPa geopotential heights in February were mapped for the territory (45°–80° N, 60°–180° E) throughout 1979–2011. Four operators carried out the manual tracking of the number of cyclones and their central pressure from those maps. The total numbers of all cyclones revealed by different operators agreed well (standard deviation is 1.2) except for two years at the initial processing stage, where the values by one operator differed significantly from three others. The standard deviation is equal to 0.8 for the number of intense cyclones (<980 hPa).

Detection of significant trends in time variations in the characteristics of cyclonic activity over the region under study was among the problems to be studied; therefore, the initial data were low-frequency filtered with the cutoff frequency corresponding to a 10-year period with the aim of decreasing high-frequency (two- and five-year) oscillations.

Baric formations are classified in [23] by the trajectories of their entering into the region under study. In this work, the cyclones are combined in three groups: west, north, and south. The west group includes cyclones that move with the western component along 60°–65° N and cyclones originating at the polar wave front near Yekaterinburg, Omsk, and Samara. The northern group includes cyclones moving from the Arctic and Kola Peninsula. The southern group includes south-western cyclones that move from the regions of Caspian Sea and Aral Lake, southern cyclones originating near the Balkhash Lake, and local cyclones originating in the Ob–Irtysh interfluve and in southern Siberia.

VARIABILITY OF CLIMATE VARIABLES

Interannual variability of the region-averaged winter temperature (December–February) is shown in Fig. 1a. The behavior of the smoothed curve here allows the division of the time period 1976–2011 into two segments: 1976–1990, where the temperature rose, and 1991–2011, where the temperature decreased.

The temperature rise in 1976–1990 reflects the global warming connected with an increase in the concentration of anthropogenic gases. The decrease in the temperature in 1991–2011 is most frequently related to the Arctic ice melting. An increase in the rate of surface air temperature rise over the Barents and Kara Seas due to accelerating ice melting weakens the meridional temperature gradient between low and high latitudes and noticeably decreases the western disturbance, which brings heat and moisture from the Atlantic to Eurasia. This effect is the most pronounced in the winter period, when the open water areas, remaining after the summer melting, ensure effective heat and moisture transfer from the warm ocean to the cold troposphere. The decrease in the western disturbance also promotes the formation of the blocking anticyclone in northern Europe due to ice melting [24–26].

The annual average winter temperature over 1976–2011 was –20.9°C, the warming trend was 0.16°C/year, and the cold trend was –0.13°C/year.

The region-averaged surface pressure (Fig. 1b) changes out of phase with the temperature. Such behavior of the winter pressure in the Asian midlatitudes is connected with the behavior of the Siberian Anticyclone.

The time series of winter surface air temperatures and pressures are given in [27] for the region (40°–60° N, 80°–120° E) over 1948–2003. The oppositely directed trends of temperature rise and pressure decrease are revealed; their connection with the weakening of the Siberian Anticyclone is shown. The decrease in the intensity of the Siberian Anticyclone in the region (40°–60° N, 70°–120° E) from middle 1970s to 1995 is also shown in [28]. However, the later work [29] gives data on variation in the intensity of the Siberian Anticyclone in 1949–2010; they show that the Siberian Anticyclone has intensified from the mid-1990s. This intensification is also shown in [30].

The variability of the region-averaged cloud amount calculated for the winter period from the observation data of the meteorological stations is shown in Fig. 1c.

In [31], the authors performed the model calculations of variations in the cyclonic activity parameters and clouds in extratropical latitudes of the Northern hemisphere in the 19th century for scenario A2 of variations in greenhouse gases. They revealed decreases in the total cloud amount and the cyclone packing density in 1860–2100 for that scenario.

Figure 1c confirms this conclusion for the total cloud amount in the period under study. The downward trend over the whole period 1976–2011 is 0.008 points/year, with a weak positive trend in 1976–1990 (0.002 points/year) and a stronger negative trend in 1991–2011 (–0.014 points/year). These estimates agree with the estimates of the total clouds for Asian Russia calculated in [32]. According to the estimates [32], the total clouds increased in 1961–1990 with a higher rate of 0.002 points/year and decreased with a rate of 0.001 points/year in 1971–2000.

Slightly different estimates of the total cloud variability are given in [33], where positive trends in the total cloud amount are revealed for 1976–2005, and negative trends, for 2006–2013 for regions 08 and 09.

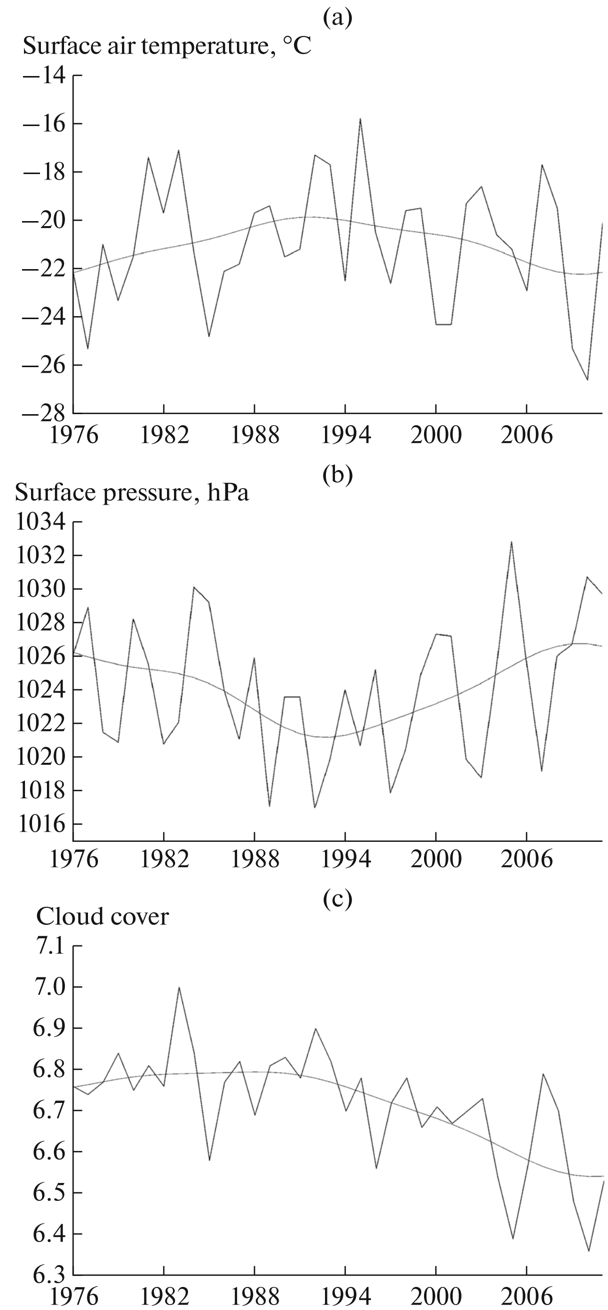

Fig. 1. Time series of (a) temperature, (b) surface pressure, and (c) cloud cover for 1976–2011 averaged over the region and three winter months (December–February). The smooth solid curve shows the 10-year sliding smoothing (also in Figs. 2 and 3).

VARIABILITY OF CYCLONE CHARACTERISTICS

Figure 2a shows the time variation in the total number of winter cyclones over the region under study, and Figs. 2b–2d, the time variations in the number of cyclones that move along the northern, western, and southern trajectories, respectively.

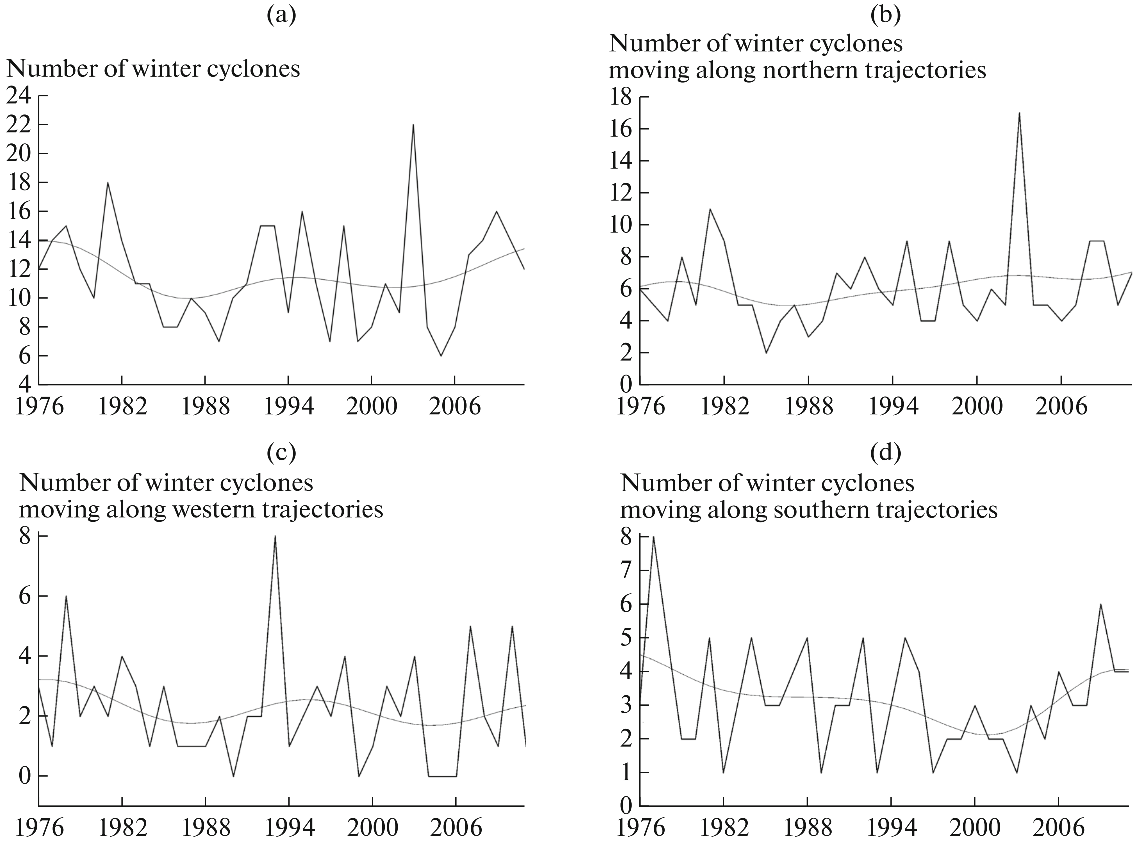

Fig. 2. Time dynamics of the number of winter cyclones: (a) all cyclones, (b) moving along northern trajectories, (c) moving along western trajectories, and (d) moving along southern trajectories.

The total number of winter cyclones in the region under study was 416, with an annual average of 12. Among them, 219 cyclones moved along the northern trajectories, 81, along western, and 116, along the southern trajectories, with annual averages of six, two, and three, respectively.

The total number of winter cyclones statistically insignificantly decreased (–0.02 cyclone/year) over the entire interval 1976–2011. In 1976–1990, where the temperature strongly rose, the decrease in the number of cyclones was significant (–0.33 cyclone/year). Finally, in 1991–2011, where the warming trend changed to the cooling trend, the number of cyclones slightly, but significantly, increased (0.08 cyclone/year). These data show the earlier revealed dynamics of winter cyclones in the Northern Hemisphere, namely, a decrease in their number at the end of the 20th century [6] and an increase in the beginning of the 21st century [12].

Western and southern cyclones contribute (by –0.02 cyclone/year) to the decrease in the number of cyclones over the period under study, while northern cyclones show a significant positive trend (0.03 cyclone/year). Cyclones of all directions showed a significant negative trend in 1976–1990 (≈–0.1 cyclone/year). The number of northern and southern cyclones significantly increased in 1991–2011 (0.07 and 0.05 cyclone/year), while the number of western cyclones significantly decreased (–0.02 cyclone/year).

Figure 3 shows the time series of the central pressure in winter. It was calculated at the stage of the maximal development, even if a center of low pressure was beyond the region under study at that time. In many works, e.g., in [6], the central pressure is considered a measure of the cyclone intensity, which is accepted in this work.

The pressure trend is positive and insignificant (0.02 hPa/year) for all cyclones (Fig. 3a) over the whole period under study. During warming, a significant negative pressure trend (–0.46 hPa/year) witnesses the intensification (deepening) of cyclones, and the intensification relates to cyclones of all directions: northern (–0.59 hPa/year), western (–0.54 hPa/year), and southern (–0.32 hPa/year). During the cooling in 1991–2011, northern (0.34 hPa/year) and western cyclones (0.20 hPa/year) become less intense, while the change in the intensity of southern cyclones was negligible (–0.01 hPa/year).

As follows from Fig. 3, northern cyclones are the most intense and southern cyclones are the least intense; western cyclones are in-between. If the com-

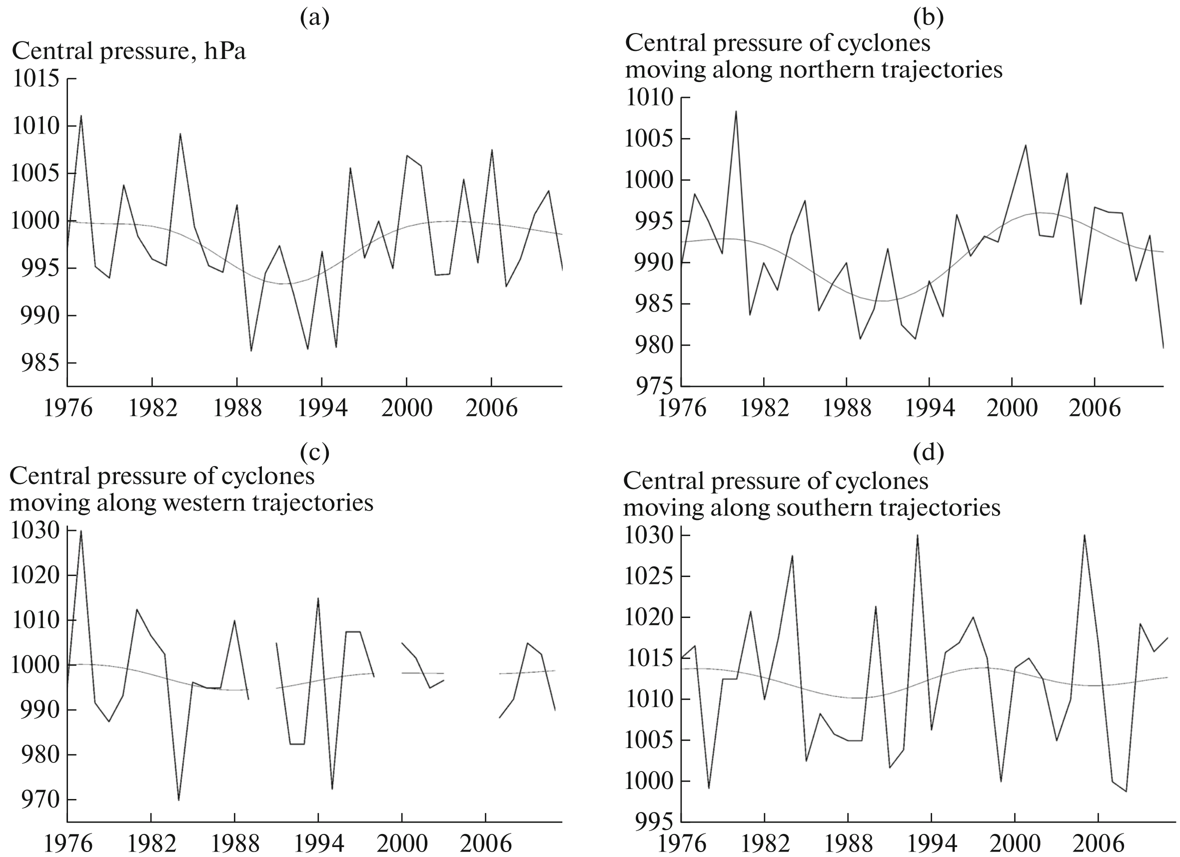

Fig. 3. Time dynamics of the central pressure in (a) all cyclones and cyclones (b) moving along northern trajectories, (c) moving along western trajectories, and (d) moving along southern trajectories.

mon threshold <980 hPa [6] is accepted as the definition of intense cyclones, then two such cyclones were recorded in the west (in 1984 and 1995, Fig. 3c) and one cyclone (in 2011, Fig. 3b) in the northern groups.

The time variation in the pressures (see Fig. 3a) qualitatively agree with the plot of winter cyclone intensity calculated in [34] for the region (40°–75° N, 0°–110° E) in 1978–2012.

CORRELATIONS BETWEEN CLIMATE VARIABLES AND CYCLONIC ACTIVITY

Table 1 presents the coefficients of correlation between the total number of cyclones and the temperature, surface pressure, and cloud amount in winter for the region under study, calculated from the smoothed series of these variables. Values statistically significant at a level of 95% are bold. The correlation coefficients calculated from nonsmoothed series vary within 0.07–0.37 and are statistically insignificant.

The correlations between the number of cyclones and the climate variables are the strongest in the warming period in 1976–1990 and weaken in the cooling period in 1991–2011. The negative correlation between the number of cyclones and the temperature for all three time periods corresponds to model calculations for the anthropogenic warming in a winter hemisphere, according to which the number of cyclones decreases as the temperature increases, and vice versa.

A positive correlation between the number of cyclones and the surface pressure in all the three intervals has no simple explanation. Thus, a decrease in the number of cyclones in the warming period in 1976–1990 should not decrease the surface pressure, as fol-

Table 1. Correlation coefficients between the total number of winter cyclones and the temperature, surface pressure, and cloud cover for Siberia in 1976–2011 calculated over smoothed series of these variables

Period, years	Surface temperature, °C	Surface pressure, hPa	Total cloud cover
1976–2011	**–0.74**	**0.62**	–0.24
1976–1990	**–0.92**	**0.80**	**–0.91**
1991–2011	**–0.71**	**0.63**	**–0.64**

Table 2. Correlation coefficients between smoothed and nonsmoothed series of the central pressure and climate variables for Siberia in 1976–2011

Period, years	Surface temperature, °C	Surface pressure, hPa	Total cloud cover
1976–2011	**–0.78 (–0.61)**	**0.81 (0.64)**	**–0.46 (–0.35)**
1976–1990	**–0.93** (–0.37)	**0.98 (0.88)**	**–0.64** (–0.26)
1991–2011	**–0.71 (–0.75)**	**0.76 (0.50)**	**–0.79 (–0.49)**

lows from Fig. 1b. The same is valid for the cooling period in 1991–2011, where the surface pressure increases simultaneously with the number of cyclones. This contradiction between variations in the number of cyclones and the surface pressure can be explained by the dependence of the surface pressure in the region under study in winter on the intensity of the Siberian Anticyclone.

Thus, according to [29], the intensity of the Siberian Anticyclone calculated in NCEP/NCAR and HadSLP2r databases for the region (40°–65° N, 80°–120° E) and the winter period decreased in 1977–1993 and increased in 1993–2007, which was also confirmed in [35]. Therefore, one may assume that the Siberian Anticyclone intensity is the main factor that forms the variability of the winter pressure field in the region under study.

The passage of a cyclone over the region is connected with the formation of cloud and precipitation fields caused by upward fluxes of warm and humid air in the cyclone circulation system [36]. Hence, a positive correlation between the number of cyclones and the total cloudiness is expected. However (see Table 1), the correlation between the number of cyclones and the cloud cover was negative and significant in 1976–1990 and 1991–2011, where the number of cyclones and the cloud cover changed out of phase. This can also be explained by the influence of the Siberian Anticyclone, the intensification of which suppresses the development of clouds. This question was studied in [30], where a statistically significant correlation between the total cloud cover and the intensity of the Siberian Anticyclone was found.

Table 2 presents the correlation coefficients between smoothed and nonsmoothed series of the central pressure and climate variables. Signs of the correlations are similar to those in Table 1, but the sense of the correlations changes. Thus, intensification of cyclones in 1976–1990 (Fig. 3a), along with a decrease in the number of cyclones (Fig. 2a), answers the regularities of variations in the parameters of winter cyclones in the Northern hemisphere during climate change as described in the Introduction. An inverse process is observed in 1991–2011.

Deepening of cyclones in 1976–1990 was codirected with a decrease in the intensity of the Siberian Anticyclones, which decreased the surface pressure and increased the cloud cover. An inverse process was observed in 1991–2011 and resulted in increases in the surface pressure and cloudiness.

CONCLUSIONS

The analysis of winter climate in the region under study in 1976–2011 allows this period to be divided into to two intervals: 1976–1990 and 1991–2011. In the first interval, the temperature and the total clouds increased and the surface pressure dropped. In the second interval, changes occurred in the opposite direction. Simultaneously, the total number of cyclones decreased and they intensified in the first interval, and a weak positive trend in the number of cyclones and weakening of their intensity against the negative temperature trend were observed in the second interval. The maximum number of winter cyclones was observed along the northern trajectories, and they were the most intense. The behavior of the cyclone characteristics with variations in the temperature agrees with the regularities revealed for winter cyclones in the Northern Hemisphere under anthropogenic climate warming, i.e., a decrease in the total number of cyclones and their intensification.

The conclusions that can be drawn from the calculated correlations between the cyclones and climate variables are not unambiguous. The correlations determined from smoothed data cause rather connections between trends, but not processes, and cannot always be interpreted reasonably. For example, high correlations between the number of cyclones and the surface pressure and cloudiness cannot be explained without considering the role of the Siberian Anticyclone. Considering also the absence of significant correlations between non-smoothed series of the total number of cyclones and climate variables, we may assume that the total number of cyclones is weakly connected with climate changes in the region under study in winter.

In contrast, the connections of the cyclone intensity, determined by the minimal central pressure, with climate variables are significant. This relates to the correlation between the cyclone intensity and the surface pressure and cloudiness. This correlation can be explained by the fact that the increase or decrease in the cyclone intensity is a factor that controls the intensity of the Siberian Anticyclone.

As for the connection between the cyclone characteristics and the temperature, the absence of statistically significant correlations between nonsmoothed series of the temperature and cyclone characteristics in the warming period in 1976–1990 does not allow unambiguous conclusions to be drawn about causes of this connection. Besides it can be indirect, e.g., via variations in cloudiness, variations in the atmosphere heat balance due to the passage of cyclones should be also considered, but this is beyond the scope of this work.

ACKNOWLEDGMENTS

The authors would like to thank E. V. Kharyutkina for her help in the calculations and S. V. Loginov for useful discussion.

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Translated by O. Ponomareva