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Characteristics of Cyclones and Anticyclones over Siberia in the Late 20th and Early 21st Century

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Abstract—The characteristics of cyclones and anticyclones (number, pressure in the center, and duration) over the territory of Siberia (50 –70 N, 60 –110 E) in 1976–2011 obtained using surface weather charts are investigated. The relationship between the variability of these characteristics and the variability of surface air temperature is revealed.

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INTRODUCTION

Migratory atmospheric vortices (cyclones and anticyclones) affect weather and climate in extratropical latitudes [9]. This influence is manifested in the change in the fields of cloudiness and wind that leads to the variability of radiation conditions, precipitation, and interlatitudinal exchange of heat, moisture, and momentum.

The data of the modeling of cyclone characteristics in the changing climate [3, 5, 7, 10] demonstrate that the trend towards a decrease in the total number of cyclones and towards the displacement of storm tracks (the trajectories of pressure centers) to the poles in both hemispheres will be observed in the 21st century. An increase in the number of intense cyclones is predicted for some regions only.

The cyclone dynamics was also investigated using the database of surface air pressure observations and the reanalysis data [13]. The authors of [6] studied the climatology of the Northern Hemisphere winter cyclones in 1958–1999 using the procedure of automatic tracking based on the NCEP/NCAR reanalysis. It was revealed that the decrease in the number of cyclones in the mentioned period was observed both for the hemisphere as a whole and for the Atlantic, Pacific, and Arctic sectors. At the same time, the significant positive trend was revealed for the number of cyclones in the Arctic sector in whose centers the pressure did not exceed 980 hPa.

The analysis of the Northern Hemisphere winter cyclones in 1959–1997 provided by the authors of [8] demonstrated the statistically significant decrease in the number of mid-latitude cyclones and the increase in the number of high-latitude cyclones. This means the poleward displacement of storm tracks. Besides, it was found that the number of intense cyclones increased in both latitude zones. As shown in [1], significant quantitative differences in cyclone characteristics can be observed from the analysis of cyclonic activity. These differences are caused by differences both in the methods of their identification and in the reanalysis data used as initial data. The insufficient grid spacing in the reanalysis data does not allow registering low-intense cyclones [12]. Almost all the above studies note regional differences in the characteristics of cyclones.

The present paper investigates the dynamics of the characteristics of pressure centers (cyclones and anticyclones) over the territory of Siberia (50 –70 N, 60 –110 E) for the climatically significant time period of 1976–2011 and studies the relationship between these characteristics and surface air temperature variations. The 1000 hPa weather charts for 00:00, 06:00, 12:00, and 18:00 UTC with the subsequent manual tracking were used as an initial base.

METHOD OF ANALYSIS

The method of manual tracking means that 6-hour 1000 hPa surface weather charts were consecutively analyzed by an operator. The position of the cyclone (or anticyclone; hereinafter, cyclone) was identified visually from the configuration of the first closed isobar. The cyclone was taken into account if its center was situated either within the territory under consideration or outside it, when its well developed periphery covered not less than 25% of the region area.

The trajectories of cyclones inside the territory under consideration were not systematized; however, the directions from which each cyclone entered the region under study were taken into account.

Such characteristics as the number of cyclones, pressure in their centers, and the duration of the cyclone presence within the region under study (hereinafter, the presence duration) were considered.

The use of manual tracking poses the problem of reliability of the results obtained. The authors of [11] estimated the error of detection of cyclones by the methods of automatic tracking and revealed that the differences in the estimation of the number of cyclones, for example, for the Northern Hemisphere winter, may be significant for 15 considered approaches to the automatic tracking. The best estimates were obtained for the intensity of cyclones and for the detection of deep cyclones.

The most characteristics of cyclones and anticyclones analyzed in the present paper were obtained as a result of the processing of weather charts by one operator. To determine the level of permissible individual error, the independent analysis of weather charts for February in 1993 and 2003 was carried out by four operators. The months characterized by considerable differences in the characteristics of vortices obtained with the manual and automatic tracking were selected for the analysis. The average number of cyclones for every month was determined by averaging the number of cyclones obtained from the data of each of four operators. Individual deviations from the mean did not exceed 20% of the mean (the individual error of one operator).

One of the study problems was the revelation of significant time trends in the characteristic of vortex activity over the territory under consideration. In view of this, to reduce the effect of high-frequency (two- and five-year) variations, the low-frequency filtering with the cutoff frequency corresponding to the period of 10 years was applied to the initial data. Provided that the value of is constant over the whole time period, the use of the filter with the prescribed characteristics also allowed the significant (at the significance level = 0.1) separation of the years with the extreme values of the average annual number of cyclones: 1995 (the maximum) and 2006 (the minimum).

The classification of pressure centers following the trajectories of their entry to the region under study is presented in [2]. The authors of the present paper combined pressure centers to three groups: western, northern, and southern.

The group of western cyclones included the cyclones moving with the western component along 60 – 65 N and the western cyclones generated on the polar front wave in the area of Yekaterinburg, Omsk, and Samara. The group of northern cyclones included the cyclones moving both from the Arctic and from the Kola Peninsula area. The group of southern cyclones included the southwestern cyclones coming from the areas of the Caspain and Aral seas, southern cyclones generated in the area of Lake Balkhash, and local cyclones formed in the area of the Ob–Irtysh interfluves or in the south of Siberia.

The group of western anticyclones is formed of the anticyclones moving from west to east from the European part of Russia. The northern group includeds the anticyclones coming from the Arctic and generated over the Urals. The southern group includes the anticyclones generated over the Republic of Tyva, Altai, and Mongolia as well as those arriving from the Black and Caspian seas.

RESULTS

The temporal dynamics of the average annual number of cyclones and anticyclones in 1976–2011 is presented in Fig. 1.

The total number of cyclones detected over the territory under study in 1976–2011 is 1704 with the average annual value equal to 47; the respective numbers of anticyclones are 1398 and 39. The ratio of the number of cyclones to the number of anticyclones is 1.2 : 1. The number of cyclones which followed the northern, southern, and western trajectories is 731, 613, and 360, respectively; average annual values were equal to 20, 17, and 10, respectively. For anticyclones the distribution is as follows: 441 anticyclones moved on the northern trajectories, 595 anticyclones, on the southern, and 362 anticyclones, on the western trajectories; average annual values were 12, 17, and 10, respectively.

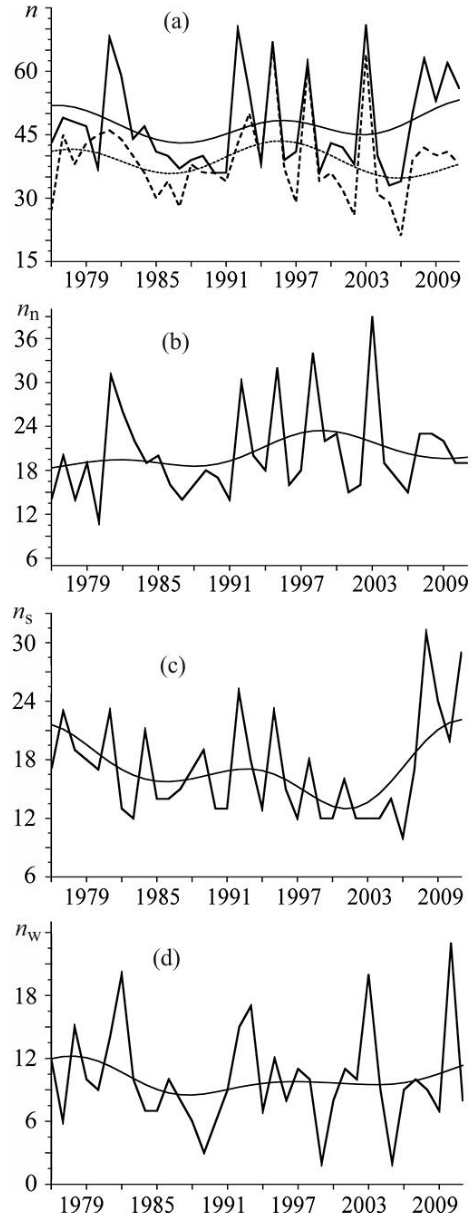

Fig. 1. The number of cyclones and anticyclones over Siberia in 1976–2011. (a) The total number of cyclones (the solid line) and anticyclones (the dash line); (b–d) the total number of cyclones which followed the northern, southern, and western trajectories, respectively. Here and in the other figures, the smooth curves are the values smoothed with the 10-year window.

The variability of the number of cyclones was analyzed using the linear trends. The statistically significant increase was revealed in the number the northern cyclones only (1.4 event/10 years). The positive trend was also revealed for the total number of cyclones (1.3 event/10 years); however, it was statistically insignificant. The total number of anticyclones statistically insignificantly decreased (–0.4 event/10 years) due to such trends for the northern and southern anticyclones. It is clear from the comparison of Figs. 1a and 1b that the pattern of the characteristic peaks of the number of cyclones in 1991–2003 is basically formed due to the cyclones of northern direction. To reveal the nature of these peaks, it is necessary to broaden the study area by including the North Atlantic and the Arctic and to provide the detailed trajectory analysis. It should be noted that the local cyclogenesis does not make considerable contribution to the formation of these peaks: the number of local cyclones is 200 (the total number of cyclones is 1704), and they are included to the number of cyclones following the southern trajectories.

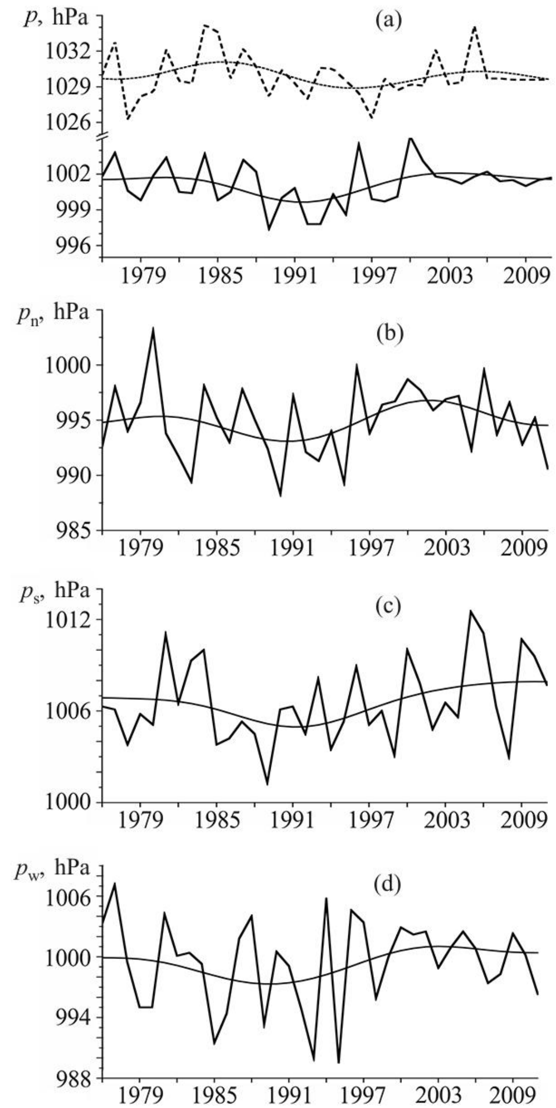

Fig. 2. Air pressure in the centers of cyclones (the solid line) and anticyclones (the dash line) over Siberia in 1976–2011. (a) For all cyclones; (b–d) for the cyclones which followed the northern, southern, and western trajectories, respectively.

The analysis of intraannual variations in the number of cyclones and anticyclones averaged over the period of 1976–2011 revealed the existence of seasonal variability. The number of cyclones increases from January to May and reaches the absolute maximum (more than four events) in May. Then it decreases from May to the absolute minimum in July (a little more than three events). In August to December the number of cyclones does not vary considerably and corresponds to the average level between May and July.

Temporal variations in the average annual value of air pressure in the centers of cyclones and anticyclones are presented in Fig. 2a. Air pressure in the center averaged over the whole time period was equal to 1001.2 hPa for cyclones and 1029.9 hPa for anticyclones. The variability of average annual air pressure in the centers of cyclones following the northern, southern, and western trajectories is observed in Figs. 2b, 2c, and 2d. The average air pressure over the period under consideration is 994.9 hPa for the northern cyclones, 1006.5 for the southern cyclones, 999.4 hPa for the western cyclones; for the northern anticyclones, 1028.5 hPa, for the southern anticyclones, 1032.6 hPa, and for the western anticyclones, 1028.3 hPa.

The minimum air pressure in the group of northern cyclones is registered in the centers of northwestern cyclones coming from the Kola Peninsula; the same cyclones dominate over the region under study in the cold season, whereas southern and western cyclones prevail in the warm season. The analysis of data on air

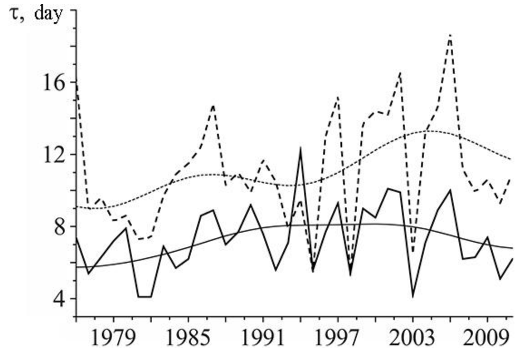

Fig. 3. The average duration of presence of cyclones (the solid line) and anticyclones (the dash line) over the territory of Siberia.

pressure in the centers of anticyclones revealed that its minimum is observed in the centers of northern anticyclones and its maximum is registered in the centers of southeastern anticyclones.

The analysis of intraannual distribution of air pressure in the centers of cyclones and anticyclones revealed that the maximum of surface air pressure is registered in May in the centers of cyclones and in February in the centers of anticyclones. The minimum values of air pressure are observed in January in the centers of cyclones and in July in the centers of anticyclones. The periods of strengthening and weakening of the Asian High are clearly observed from the intraannual distribution of air pressure in the pressure centers. For example, in winter, when the Asian High strengthens and is stationary, the minimum values of air pressure are observed in the centers of cyclones and the maximum values are registered in the centers of anticyclones. On the contrary, in summer, when the Asian High weakens, the maximum values of air pressure are observed in the centers of cyclones and the minimum values are registered in the centers of anticyclones.

The estimation of temporal variability of air pressure in the center of pressure formations using the linear trends did not reveal statistically significant trends for all cyclones and anticyclones. As to different trajectories, the statistically significant positive linear trend in air pressure (0.6 hPa/10 years) is observed for the southern cyclones only.

The data on the number of days during which cyclones and anticyclones were observed over the territory under study were analyzed (Fig. 3). If several, for example, cyclonic vortices were registered over Siberia, the total duration of their presence was determined.

Over the region under consideration a cyclone is observed for 7 days and an anticyclone, for 11 days on average (Fig. 3). The average duration of presence of both cyclones (0.3 day/10 years) and anticyclones (0.7 day/10 years) has a positive trend; it is significant for anticyclones (the significance level < 0.05).

The duration of presence of the northwestern cyclones coming to Siberia from the Kola Peninsula area is 9 days and that of local cyclones is 3 days. The short-term presence of local cyclones over Siberia is caused by the fact that these cyclones are formed directly in the region under study and they are most often manifested in the form of one closed isobar (i.e., they are low and unstable formations and, hence, dissipate rapidly). The duration of presence of the western anticyclones coming to the territory under study from the European part of Russia is 10 days and that of the southwestern anticyclones generated in the area of the Black and Caspain seas is 7 days.

The intraannual distribution of the duration of presence of cyclones was analyzed; the analysis revealed that the maximum is observed in October and the minimum is registered in May. The spring maximum may be explained by the fact that the duration of presence of the great number of cyclones passing over the territory is insignificant in transition seasons. The autumn maximum indicates that in October synoptic conditions are rather stable and this period is not characterized by the frequent change in air masses and pressure centers. The maximum duration of presence of anticyclones is observed in January, and the minimum is registered in August; the winter maximum is an effect of the stationary Asian High over the region under study in the cold season.

The results of the investigation of average long-term characteristics of different types of cyclones and anticyclones in 1976–2011 (see the table) were analyzed. The analysis revealed that the average number of cyclones and anticyclones varies from 3 to 12 and from 4 to 10, respectively. The value of air pressure (p)

Average long-term values of climatic parameters of cyclones and anticyclones over the territory of Siberia in 1976–2011

Type of pressure centers	*n*	*p*, hPa	, day
Cyclones			
northern	8.2 (3.7)	996.5 (3.5)	6.2 (1.9)
northwestern	12.1 (4.8)	994.2 (3.9)	8.7 (2.4)
moving with the western component along 60 –65 N	3.1 (3.8)	996.5 (6.1)	6.1 (2.1)
western	6.9 (3.0)	1001.0 (4.0)	6.8 (2.2)
southwestern	6.1 (3.2)	1001.8 (3.2)	5.4 (2.1)
southern	5.3 (3.4)	1003.4 (2.6)	4.7 (1.7)
local	5.6 (4.0)	1012.3 (5.2)	2.8 (1.1)
Anticyclones			
northern	8.3 (2.9)	1027.4 (2.7)	8.8 (3.0)
northwestern	3.9 (2.5)	1030.0 (4.5)	10.2 (4.9)
western	10.1 (3.7)	1028.0 (3.1)	10.2 (3.9)
southwestern	7.0 (5.0)	1028.7 (4.3)	8.0 (2.3)
southeastern	9.6 (3.5)	1035.3 (3.9)	9.2 (2.9)

Note: The standard deviation ( ) of climatic parameters of pressure centers is given in brackets.

in the centers of pressure formations varies within 994.2–1012.3 hPa for cyclones and within 1027.4–1035.3 hPa for anticyclones. The average duration of presence ( ) over the region under study is 7 days for a cyclone and 11 days for an anticyclone.

Although the cyclones moving with the western component along 60 –65 N and the western cyclones have similar genesis, their long-term characteristics differ. In view of this, it is reasonable to divide them into two separate types. For example, the cyclones moving with the western component are observed much more rarely and are deeper than the western cyclones. The northwestern cyclones coming from the Kola Peninsula are characterized by the maximum values of all the characteristics considered (as compared not only with the northern cyclones arriving from the Arctic but also with other types of cyclones). The local cyclones have a minimum value for all investigated characteristics (see the table) except for frequency and the maximum value of pressure in the centers. This is indicative of their small depth and, hence, their poor development and short lifetime. So, the conclusion is corroborated that these pressure formations are very unstable and are subjected to rapid decay. The southwestern cyclones moving from the Caspian and Aral seas and the southern cyclones generated in the area of Lake Balkhash, in the areas of Ashkhabad and Tashkent, or in the interfluve of the Amu Darya and Syr Darya rivers, are characterized by the medium values of climatic parameters.

The northwestern and western anticyclones are similar in trajectories but differ in the type: the northwestern anticyclones are of the blocking type in the area of the Urals whereas the western anticyclones moving from the European part of Russia pass over the Urals and continue their movement. Besides, these two types of anticyclones differ much in their number: the blocking anticyclones are registered by almost three times less often. The southeastern anticyclones coming from the Republic of Tyva, Altai, and Mongolia are characterized by the maximum value of pressure in the centers, and the southwestern anticyclones arriving to the region under study from the Black Sea area have the minimum duration of presence. The northern anticyclones coming from the Arctic are characterized by medium values for almost all climatic parameters.

The pressure centers grouped according to their trajectories were analyzed. To provide the more detailed assessment, the cyclones mainly moving with the western, northern, and southern components were separated. It was found that the greatest number of cyclones came to the territory of Siberia following the northern trajectories and their number over the period under study is 731 (the number of such cyclones considerably increased since the early 1990s). The smallest number of cyclones (360) came to the territory under study following the western trajectories. The interannual variations in the number of cyclones grouped according to their trajectories and in the total number of cyclones are comparable. The trend in the number of western cyclones is negative (–0.1 cyclone/10 years); the trend in the number of northern cy-

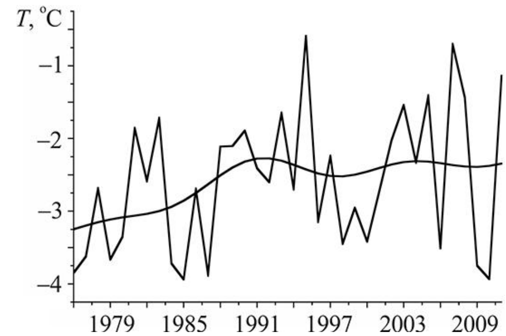

Fig. 4. The variations in average annual air temperature over the territory of Siberia in 1976–2011.

clones is positive (1.0 cyclone/10 years) and significant; the trend in the number of southern cyclones is positive (0.3 cyclone/10 years).

Thus, the number of northern cyclones increased by the end of the period under study, air pressure in their centers almost did not vary, and the presence duration decreased (i.e., they became more frequent and less durable). The number and duration of presence of western cyclones decreased by the end of the period under study, and air pressure in their centers almost did not change (i.e., they became less frequent and less durable). These data corroborate the conclusion made by other authors that in the recent decades the trajectories of pressure centers have displaced northward. The number of southern cyclones, air pressure in their centers, and the presence duration increased. This means that southern cyclones became less deep, more durable, and more frequent by the end of the period under study.

It was revealed that the duration of presence of cyclones increased by the end of the period under consideration for the southern cyclones (from 6 to 8.5 days) and decreased for the northern and western cyclones (from 4.5 to 3.5 days).

To investigate the activity of anticyclones, they (as well as cyclones) were grouped according to the trajectory. The analysis revealed that the largest number of anticyclones (595) over the period under consideration came to the territory of Siberia following southern trajectories; their number as well as the number of cyclones increased since the early 1990s. The smallest number of anticyclones (362) as well as of cyclones arrived to the region under study following western trajectories. The interannual variations in the number of anticyclones grouped according to their trajectories and in the total number of anticyclones are comparable. The trend in the number of western anticyclones is positive (0.2 anticyclone/10 years) and the trend in the number of northern and southern anticyclones is negative (–0.1 and –0.4 anticyclone/10 years, respectively). By the end of the period under study air pressure in the centers of anticyclones of all types decreases in a greater degree for northern and southern anticyclones and to a lesser extent for western anticyclones. The analysis of duration of presence of pressure centers revealed that the opposite pattern was obtained for anticyclones as compared to cyclones. By the end of the period under study the average duration of presence of anticyclones increased for northern and western anticyclones (from 5 to 7.5 days) and decreased for southern anticyclones (from 7.5 to 7 days).

Thus, the number of northern anticyclones almost did not vary at the end of the period under study as compared with its beginning, air pressure in their centers dropped, and the presence duration increased (i.e., they became less intense and more durable). The number of western and northern anticyclones almost did not change by the end of the period under study, air pressure in their centers decreased but not as significantly as for northern anticyclones, and the duration of presence increased (i.e., western anticyclones as well as northern ones became less intense and more durable). The number of southern anticyclones, air pressure in their centers, and the presence duration decreased (i.e., they became less intense and less durable).

The characteristics of cyclones and anticyclones were compared with the variability of average annual surface air temperature (Fig. 4).

The relationship between the characteristics of cyclones and anticyclones and air temperature variations has been studied before. The author of [4] revealed that positive and negative trends in air temperature in the Northern Hemisphere are related to the increase and decrease in the number of both cyclones and anticyclones. These conclusions contradicting model simulations were criticized in [8]. The authors of [8] studied the dynamics of the Northern Hemisphere winter cyclones for 1959–1997 and revealed that mid-latitude cyclones are characterized by the negative correlation (–0.58) between their number and air temperature, and the high-latitude cyclones are characterized by the positive correlation (0.38). The positive correlation (0.25) was revealed between air temperature and the intensity of high-latitude cyclones, and the negative correlation (–0.13) was obtained for mid-latitude cyclones.

The correlations between the number of cyclones and anticyclones (n_c and n_a) and air pressure in their centers (p_c and p_a), and surface air temperature (T) were determined for the region under study. The data determined from the smoothed values for the territory of Siberia in 1976–2011 are presented below:

Characteristics	n_c, T	n_a, T	p_c, T	p_a, T
Correlation coefficient	–0.30*	–0.25	–0.25	–0.28

(*the correlation coefficient is significant at the level of 95%).

The negative correlation was revealed between air pressure in the cyclone centers and air temperature; i.e., as air temperature rises, air pressure in the centers of cyclones drops and they become more intense. Such type of correlation between air temperature and the intensity of cyclones for the Eurasia mid-latitudes was also noted in [8]. The correlation between the number of anticyclones and air temperature is similar to that typical of cyclones but is slightly lower. The correlation between air pressure in the centers of anticyclones and air temperature is significant and positive in the period of 1976–1990 and is insignificant and negative over the rest of the time period.

The analysis of variability of average annual air temperature (Fig. 4) revealed the presence of two different time periods. The first period (1976–1990) is characterized by the rapid increase in air temperature (0.06 C/year) and by the significant correlation with variations in the number of cyclones (–0.74 cyclone/year) and anticyclones (–0.41 anticyclone/year) as well as variations in air pressure in the centers of cyclones (–0.13 hPa/year) and anticyclones (0.08 hPa/year). In the second time period (1991–2011) the trend in average annual air temperature is equal to zero, i.e., the pause in the warming occurred on the territory under consideration several years earlier than the pause in the global warming starting from 1998. During that time period the trend in the number of cyclones is positive (0.21 cyclone/year) and the trend in the number of anticyclones is negative (–0.41 anticyclone/year). Air pressure in the centers of cyclones and anticyclones rose by 0.12 hPa/year for cyclones and by 0.05 hPa/year for anticyclones.

CONCLUSIONS

The peculiarities of long-term dynamics of atmospheric circulation over Siberia in the late 20th–early 21st century were analyzed as well as the relation between atmospheric circulation and surface air temperature. The results led to the following conclusions.

Over the whole period under study the number of cyclones defining climatic conditions in Siberia is greater than the number of anticyclones (by 1.5–2 times in some years).

The total number of cyclones over the period under study statistically insignificantly increases (1.3 event/10 years), and the number of anticyclones statistically insignificantly decreases (–0.4 event/10 years). The number of northern cyclones increases statistically significantly (1.4 event/10 years). The average long-term value of air pressure in the centers of cyclones over the territory of Siberia during the period under study varies within 997.4–1006.0 hPa, and that in the centers of anticyclones varies within 1026.3–1034.2 hPa. By the end of the period under study cyclones became deeper and anticyclones became less intense. The average presence duration over the territory of Siberia in the period under consideration was 7 days for a cyclone and 11 days for an anticyclone.

The correlation between characteristics of cyclones and anticyclones and air temperature is the highest in 1976–1990, when air temperature rose rapidly. In that period the statistically significant negative correlation was revealed between air temperature and the number of cyclones and anticyclones as well as air pressure in the centers of cyclones; the statistically significant positive correlation was revealed between air temperature and air pressure in the centers of anticyclones.

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