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Long-term Variations in Surface Air Pressure and Surface Air Temperature in the Northern Hemisphere Mid-latitudes

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Abstract—The spatiotemporal variability of surface air pressure and surface air temperature in the Northern Hemisphere troposphere in 1990–2014 is described. In 2005 the low-frequency component (LFC) of average air temperature in January averaged over the latitude zone of 32.5 –67.5 N has stopped its increase that lasted for 35 years (from 1970). The LFC of air temperature in July has continued growing since 1975 (for 39 years). The anomalies of air pressure and air temperature for thirty-year periods and the dynamics of LFC of air temperature and air pressure in the atmospheric centers of action are analyzed.

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INTRODUCTION

The publication of summarizing reports on the problem of the modern climate change [5, 17] does not reduce the interest to this issue. This is related both to the instability of modern climate and to its possible negative and positive effects on natural and socioeconomic processes. There are different opinions on the reasons for the climate warming.

The authors of some papers [1, 3, 6, 11, 12, 14] dealing with the analysis of the modern climate change note a need in considering not only anthropogenic factors but also the natural ones, such as solar and volcanic activity, atmosphere–ocean interaction, El Niño events, etc. In particular, it is demonstrated in [21] that intense circulation processes related to the atmosphere–ocean interaction cause significant variations (from interannual to interdecadal) in air temperature in the mid-latitudes in winter. These variations are superimposed on the general process of global warming and considerably modify its manifestation. In view of this, J.M. Wallace in his latest paper [20] defined the priority areas of climate change investigation including a need in studying its interdecadal variations which are largely caused by the intraseasonal and intraannual variability of the climate system. Many authors identify and consider long-period variations in the climate system for explaining its processes.

According to the data of [7], cyclic variations with the period of 20–25 and 10–11 years are detected in the different parameters of ocean, ice cover, and atmosphere; in particular, long-term variations are detected in the North Atlantic Oscillation (NAO) index. It is noted in [4] that the appreciable contribution to the climate change is made by the natural oscillations whose existence is directly related to the presence either of ocean patterns or of patterns in the coupled atmosphere–ocean system which have the typical period of about several decades. The author of [8] associates the pressure wave oscillations in the Atlantic and Pacific regions with the cycles of solar activity. N.S. Sidorenkov [15] considers decadal climate changes (the global anomalies of air temperature and atmospheric circulation) jointly with variations in the Earth angular velocity, and the authors of [9] assess the statistical correlation between air temperature and precipitation in Northern Eurasia in the 20th century and the Arctic Oscillation which significantly varied during that period.

In the previous paper [13] the authors analyzed spatiotemporal variations in temperature and wind in the Northern Hemisphere as a whole and in its mid-latitudes in 1948–2013. Special attention was paid to long-period variations in air temperature and wind. The present paper analyzes the thermobaric regime in the Northern Hemisphere extratropical latitudes in 1900–2014. To reveal the dynamics of thermobaric processes, they are considered for different periods of time (1900–1929, 1930–1959, 1960–1987, 1988–2000, and 1988–2014) which are related to the major climate events. According to the analysis of climate monitoring data presented in the review section of [2], three periods were separated in the global variations in air temperature: the warming in 1910–1945, the slight cooling in 1946–1975, and the most intense warming after 1976.

DATA AND METHODS

Initial data are the time series of air temperature and air pressure at the points of the regular latitude-longitude grid for the period of 1900–2014 which were prepared by the Climatic Research Unit of the University of East Anglia and by the Met Office Hadley Centre [16–19] (hereinafter, the CRU dataset). It should be noted that the authors had data on air temperature for 1900–2014 and data on air pressure for 1900–2000.

At first the average long-term values of air temperature (T) and air pressure (p) were calculated for January and July for the whole analyzed period. Then the distributions of average long-term values of p and T were mapped as well as the fields of average anomalies for 1900–1929, 1930–1959, 1960–1987, 1988–2000, and 1998–2014 for air temperature and for 1900–1929, 1930–1959, 1960–1987, and 1988–2000 for air pressure (the period of 1988–2000 was selected due to the limited air pressure series).

The attempt was made to clarify the possibility of extending the air pressure series from the reanalysis data. For this purpose the coefficients of correlation were computed between the air pressure series from the CRU dataset and NCEP-DOE reanalysis for the overlapping period from 1979 to 2000. It was found that the high correlation between the CRU and reanalysis data is not observed in all regions of the Northern Hemisphere. Therefore, to remove the data inhomogeneity for analyzing the anomalies of air pressure and air temperature, the authors used the CRU data only. However, at the most of grid points mainly located in the Northern Hemisphere mid-latitudes, in the mentioned period the correlation coefficients for different months vary within 0.96–0.98, and the sample means and variances do not differ at the significance level of 0.05. As a result, at these grid points and in the mid-latitude zone as a whole the CRU air pressure series were extended from the reanalysis data to the year 2014 by the linear regression method.

The similarity of the fields of anomalies was assessed both visually and using the similarity criterion calculated at the grid points [10]:

$$\frac{n \qquad n}{k}$$

where k is the total number of regular grid points; n_+ is the number of grid points where the signs of anomalies of two fields coincide; n_- is the number of grid points where the signs of anomalies of two fields are opposite. The values of the criterion vary within –1 1.

The long-period variations in the series of air temperature and in the series of air pressure extended to 2014 were obtained as a result of initial data smoothing with the Potter low-pass filter. They were analyzed for the atmospheric centers of action. The series of climate parameters in the atmospheric centers of action were considered for the closest point to the average long-term position of these centers in 1900–2014.

To identify the general trend in air temperature in the Northern Hemisphere mid-latitudes (32.5 – 67.5 N) in 1990–2014 (115 years), the initial gridded data were averaged over the whole latitudinal zone for January and July. The statistical processing was provided for the obtained time series. Figure 1 presents data on long-term variations in air temperature where, along with the initial data, average values are separated for 1900–1929 (30 years), 1930–1959 (30 years), 1960–1987 (28 years), and 1998–2014 (27 years), i.e., for the approximately equal time periods. Besides, the initial series were smoothed with the Potter filter: the low-frequency component (LFC) is presented for estimating the long-period variability, i.e., all waves with the period of less than 20 years were filtered.

ANALYSIS OF RESULTS

The analysis of data presented in Fig. 1 reveals that in January every next time period turned out to be warmer than the previous one. The average values of air temperature for these periods are equal to –4.6,

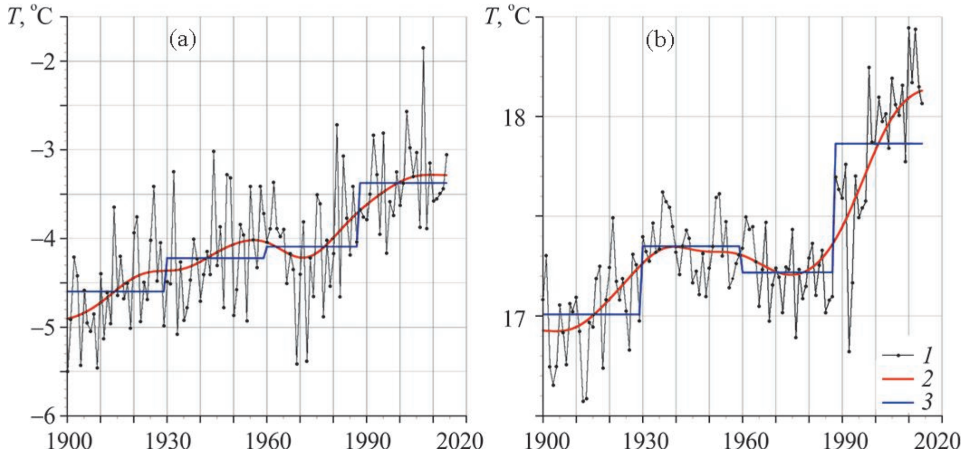

Fig. 1. The long-term variations (1900–2014) in air temperature in the Northern Hemisphere mid-latitudes (32.5 –67.5 N) in (a) January and (b) July. (*1*) Initial series; (*2*) LFC with the period of more than 20 years; (*3*) average values for 1900–1929, 1930–1959, 1960–1987, and 1988–2014.

–4.2, –4.1, and –3.4 C, respectively, i.e., the value of LFC of average air temperature in January increased by 1.6 C in 115 years and by 0.95 C in 35 years during the active phase of warming in 1970–2014. In general, the LFC curve has a trend towards increase during 115 years except for the slight decrease in 1955–1970 and in the last period (2005–2014), when there was a pause in the warming.

In July air temperature variations are slightly more complex because the period of active warming in 1910–1940 changed into the period of insignificant cooling in 1940–1975, and after it air temperature rose considerably. The average values of air temperature for the respective time periods are equal to 17.0, 17.3, 17.2, and 17.9 C (the variation is ~0.9 C that is smaller than in January). At the same time, the intense air temperature rise in 1975–2014 (by 0.95 C for LFC) should be noted. In general, the air temperature rise in January and July was equal to 1.6 and 1.2 C, respectively, i.e., the warming in the mid-latitudes over the whole analyzed period in winter is more intensive than in summer; however, the rate of the air temperature rise during the active phase of warming in January in 1970–2005 and in July in 1975–2014 is almost the same. Judging by the LFC variations, the warming in January started 5 years before that in July.

The average surface values of air temperature and air pressure for January and July in the extratropical zone from 20 N to the North Pole were mapped using the gridded average values calculated for the long-term period (1900–2014 for air temperature and 1900–2000 for air pressure).

In general, the pattern of fields presented on these maps well simulates the known climatic regularities of the spatial distribution of analyzed meteorological parameters. In particular, the Icelandic and Aleutian lows and the Siberian High are identified on the map for January; the North Pacific and Azores highs and the vast Asian Low are observed for July.

To observe variations in surface air temperature and air pressure, the maps of the anomalies of air temperature (T) and air pressure (p) were constructed. At first, the air pressure field was analyzed: the gridded values of p were averaged for four periods: 1900–1929, 1930–1959, 1960–1987, and 1988–2000. Then the normals which were preliminarily computed for the whole period (1900–2000) were subtracted from these averaged values. As a result, eight maps were obtained representing the spatial distribution of air pressure anomalies in January and July for the zone of 20 –90 N. The maps of air temperature anomalies were constructed for the periods of 1900–1929, 1930–1959, 1960–1987, 1988–2000, and 1998–2014.

The analysis of these maps for January demonstrates that the value of p varies over the territory under study from –3 to 3 hPa in 1900–1929 (Fig. 2a). The vast zone of the positive anomaly up to 3 hPa was observed in the polar zone and covered the most of the Arctic Ocean, the northern part of the coast of North America and Eurasia, and the Northwest Pacific, where the Aleutian Low and North Pacific High are situated; on the contrary, the zone of the negative anomaly of air pressure with the core of p = –3 hPa was formed over Greenland and the Icelandic Low. The vast zone of low pressure (p = –1 hPa) was observed over Western and Central Siberia and Central Asia. However, the most of the territory under study is characterized by the positive background of air pressure anomalies.

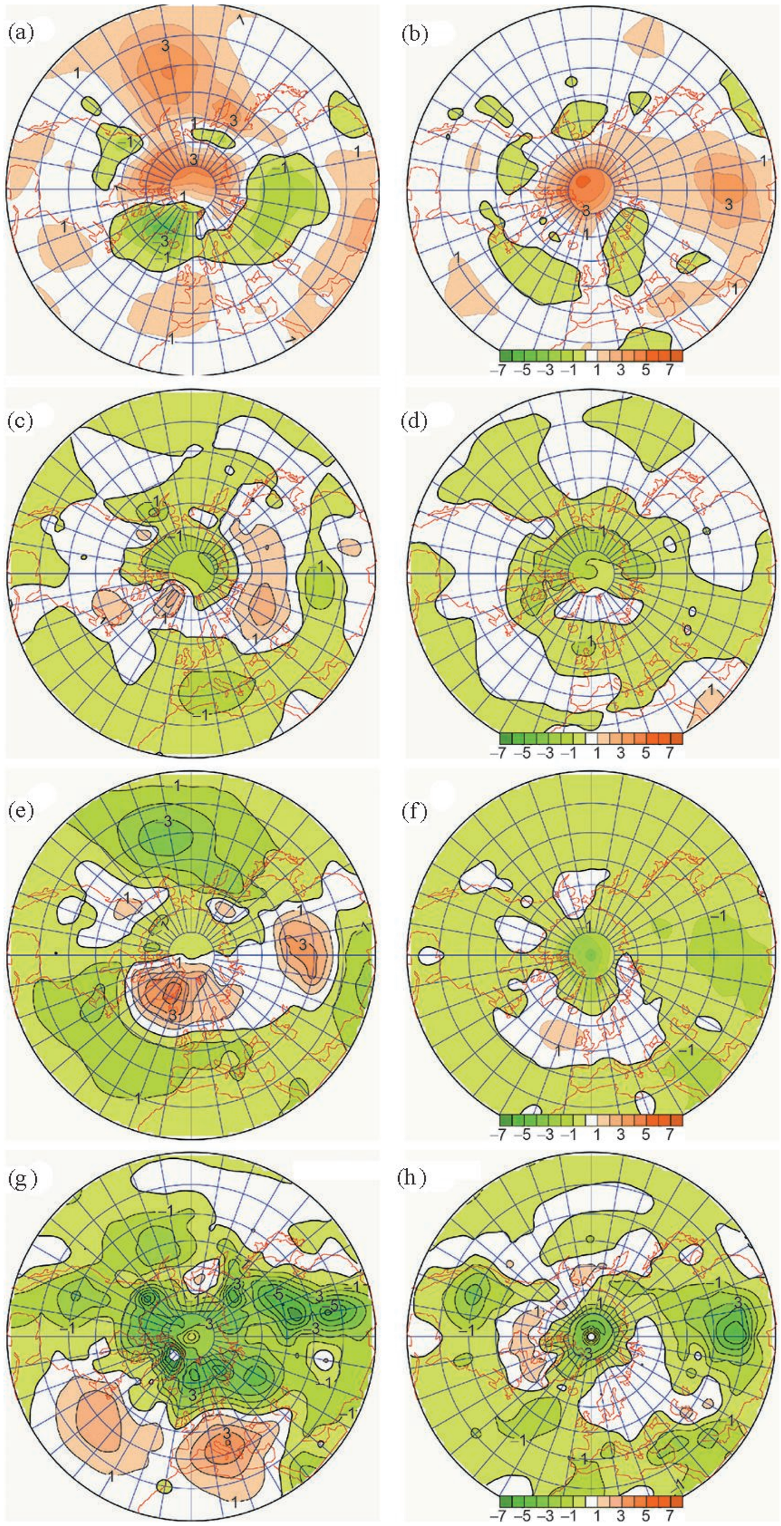

Fig. 2. The anomalies of air pressure (hPa) in (a, c, e, g) January and (b, d, f, h) July in (a, b) 1900–1929, (c, d) 1930–1959, (e, f) 1960–1987, and (g, h) 1988–2000.

The analysis of the map of air temperature anomalies for this period (Fig. 3a) reveals that almost over the whole analyzed territory air temperature is below the normal for 1900–2014, i.e., the period was cold, and the maximum values of negative anomalies of air temperature are registered in the Arctic zone, in the

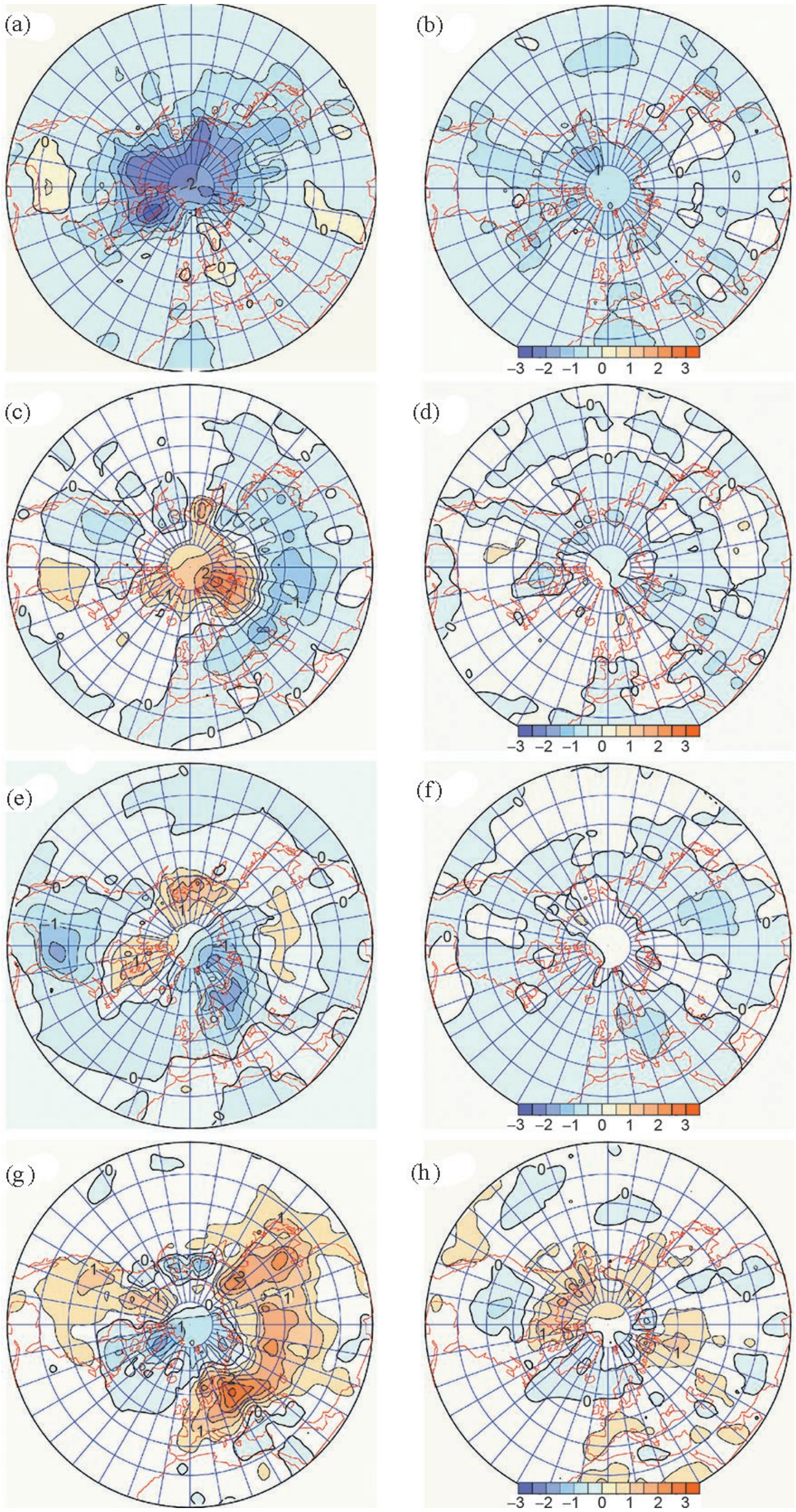

Fig. 3. The same as in Fig. 2 for air temperature (C).

polar regions of Canada and Eurasia. For example, $T = -2$ C over Greenland. The values of the positive anomalies of air temperature are small.

Thus, the trend towards the high values of surface air pressure prevailed in the early 20th century, whereas the trend towards low values dominated in the air temperature field that was caused by the cooling at the beginning of the century.

The period of 1930–1959 was characterized by insignificant deviations of air pressure from the normal in January (Fig. 2c). For example, the value of p reached 1 hPa over Eastern Europe, Eurasia, and North America; the slightly increased background of air pressure was registered over the North Atlantic, in the area of the Icelandic low. In the North Pacific and adjoining polar regions including the most of the Arctic Ocean basin, the negative anomalies of air pressure were observed (to –1 hPa). Thus, the air pressure drop is registered at first in the polar region and in the western part of the Pacific Ocean, and later the prevalence of air pressure rise is observed in the lower latitudes (Fig. 2c).

The strongly pronounced warming in the Arctic region (up to 1.5 C), North Atlantic, and Pacific Ocean was observed in the field of air temperature during that period. At the same time, air temperature decreased (T = –1 C) over the most of Eurasia and over the seas adjoining it in the east. In general, air temperature was below the normal in the most of the Eastern Hemisphere; on the contrary, the air temperature rise was registered in the Western Hemisphere except for the northern and western parts of North America (Fig. 3c).

Thus, in 1930–1959 in January, high air temperature (the anomaly up to 2 C) was observed in the polar regions and in the Russian sector of the Arctic, and low temperature was registered in Eurasia; in the polar region the air pressure background was relatively slightly low (the anomalies in the center and east of the Arctic were equal to –1 hPa).

In 1960–1987 in January, the most of the Northern Hemisphere was characterized by the low air pressure, and against its background the high pressure zone with the pronounced centers over Greenland, Iceland (p = 3 hPa) and northern China (up to 3 hPa) stretched from the western coast of North America to northern China. The zone of the extremely negative anomaly of air pressure equal to –3 hPa was registered over the North Pacific High (Fig. 2e).

In that period the air temperature pattern is more complex (Fig. 3e); in January the air temperature anomaly up to 1 C is observed over the Canadian Arctic and further to the east over the Pacific Ocean; at the same time, the anomaly is negative (to –1.5 C) further to the south, over North America; the significant negative anomaly of T is also observed in the northern part of the North Atlantic and in the western sector of the Arctic: on the vast territory from Greenland to the East Siberian islands and in the areas of Northern Eurasia adjoining the Arctic Ocean. The vast zone with the positive anomaly of T covers Central Asia, Eastern Siberia, the Far East, and the North Pacific, where the maximum of T equal to 1 C is registered in the area of the Aleutian Low.

The period of 1988–2000 was characterized by the low air pressure in January in the vast zone of the Arctic region, over the northern part of Greenland and Canada (Fig. 2g). The dramatic weakening of the Siberian High with the anomaly p = –5 hPa was observed in Asia; the zone with the anomaly p = –5 hPa was also formed over China. The low-pressure zone was registered over North America, in the area of the North Pacific High, and the high-pressure zone was observed over the central part of the North Atlantic, Southern Europe (the anomaly up to 3 hPa), and the Mediterranean region. At the same time, the considerable air temperature rise (the anomaly up to 2 C) relative to the long-term normal (Fig. 3g) occurred over Eurasia, North America, and the North Pacific. On the contrary, air temperature dropped by 1 C in the western part of the Arctic and in Greenland. The especially intense warming was observed in Europe (the air temperature anomaly up to 2 C), Siberia, and the Far East.

In 1988–2014 almost the whole territory of the Northern Hemisphere extratropical latitudes was occupied by the significant anomalies of air temperature. The most significant air temperature rise was observed in Central and Eastern Europe, in the east of Eurasia and Canada (the anomalies up to 2 C, Fig. 3g). The warming was most strongly pronounced over the Northern Hemisphere continents.

Thus, the air temperature field varied less significantly in winter in 1990–1929, when the cooling embraced almost the whole Northern Hemisphere, and in 1988–2014, when the intensive warming also occupied the whole Northern Hemisphere. Rather homogenous patterns were observed. In the polar regions winters were cold in the first period, whereas they were extremely warm in the last period. The opposite pattern was observed for air pressure: in the polar regions and in the area of the Aleutian Low, the high values of air pressure in the early 20th century changed to the lower values in the late 20th century. Air temperature and air pressure varied in the opposite phase.

It should be noted that the air pressure anomalies of opposite signs were formed in the Atlantic and Pacific parts of the Arctic in 1990–1929, 1930–1959, and 1960–1987. These anomalies were less pronounced in 1988–2000 during the phase of active warming.

Let us consider the spatial distribution of anomalies p in July (Figs. 2b, 2d, 2f, and 2h). In 1900–1929 the zone of high air pressure (p = 5 hPa) was situated over the Arctic, and the second zone with p = 3 hPa was formed over northern China (Fig. 2b). The abnormally high air pressure was observed almost over the

The values of the similarity criterion of patterns of air temperature and air pressure in different periods (27.5 –67.5 N)

Period	January					July				
	I	II	III	IV	V	I	II	III	IV	V
Air temperature anomalies										
I	1					1				
II	0.26	1				0.07	1			
III	–0.12	–0.30	1			0.22	–0.17	1		
IV	–0.67	–0.46	0.08	1		–0.59	–0.28	–0.20	1	
V	–0.80	–0.41	0.04	0.85	1	–0.72	–0.18	–0.43	0.70	1
Air pressure anomalies										
I	1			1	–	1				–
II	–0.39	1			–	–0.13	1			–
III	–0.69	0.28	1		–	–0.70	–0.13	1		–
IV	0.06	–0.28	–0.27		–	–0.31	–0.27	0.38	1	

Note: I is 1900–1929; II is 1930–1959; III is 1960–1987; IV is 1988–2000; V is 1988–2014.

whole Northern Hemisphere except for some regions. In 1930–1959, the low-pressure zone (the anomaly of –1 hPa) situated inside the high-pressure zone was observed over Europe (except for its southwestern part), Siberia, Central Asia, and the territory adjoining India (Fig. 2d). In 1960–1987 (Fig. 2f), the most of the Northern Hemisphere was occupied by the negative background of air pressure anomaly (p = –1 hPa), and only the North Atlantic and the most of Europe (expect for the southwestern part in the zone of 40 –70 N) were occupied by the high-pressure zone (p = 1 hPa). In 1988–2000 (Fig. 2h), the pattern of air pressure anomalies becomes less uniform. The Arctic zone is occupied by the low-pressure zone (p is to –3 hPa), and the northern part of Europe, Canada, and the Pacific Ocean are situated in the high-pressure zone (the anomaly is 1 hPa). The zone with the negative anomaly up to –3 hPa is identified over northern China. Thus, the field of air pressure anomalies in July is less contrast, and the anomaly zones are not so vast and intensive.

In 1900–1929 in July the pattern of surface air temperature anomalies (Fig. 3b) is rather uniform (except for the small low-intensity zones in Asia), and the anomalies are negative (in the polar region T = –1 C), i.e., the cold phase is observed almost on the whole territory. In 1930–1959, the field of anomalies T changed (Fig. 3d): the North Atlantic, Greenland, Northern and Central Europe, and the central and southern parts of North America were occupied by the positive anomaly of 0.5 C; the eastern Arctic, Siberia, and the North Pacific were characterized by the negative background of T (–0.5 C). In 1960–1987, air temperature was below the normal over the most of the Northern Hemisphere; only the area stretched from the coast of northern Canada through the Arctic to West Siberia was characterized by the positive anomaly. However, in 1988–2000 (Fig. 3h) and especially in 1988–2014, air temperature was above the normal: for example, T = 1 C in Canada, Siberia, and the Arctic. In 1988–2014, only positive anomalies of air temperature were registered: 1.5 C in Canada and 1 C in Southern Europe, North Africa, and the Near East. Thus, the significant warming as compared with the reference period (1900–2014) was observed both in January and July.

To assess the geometric similarity of patterns of air temperature and air pressure anomalies for different periods, the similarity criterion was used [10]. The values of calculated for different time periods of the 20th and 21st centuries for the anomalies of air pressure and air temperature in the zone of 27.5 –67.5 N are presented in the table. It should be noted that the parameter was also computed for other latitude zones: 17.5 –87.5 , 27.5 –67.5 , 52.5 –67.5 , and 27.5 –47.5 N (not presented).

The highest level of the statistical relation of air temperature in January (= –0.80) is observed for 1900–1929 and 1988–2014, when the air temperature anomalies have opposite signs at the most of grid points. The periods of 1960–1987 and 1988–2000 are poorly interrelated (= 0.08). At the same time, the high level of similarity of air temperature anomalies is registered in 1988–2000 and 1988–2014 (= 0.85),

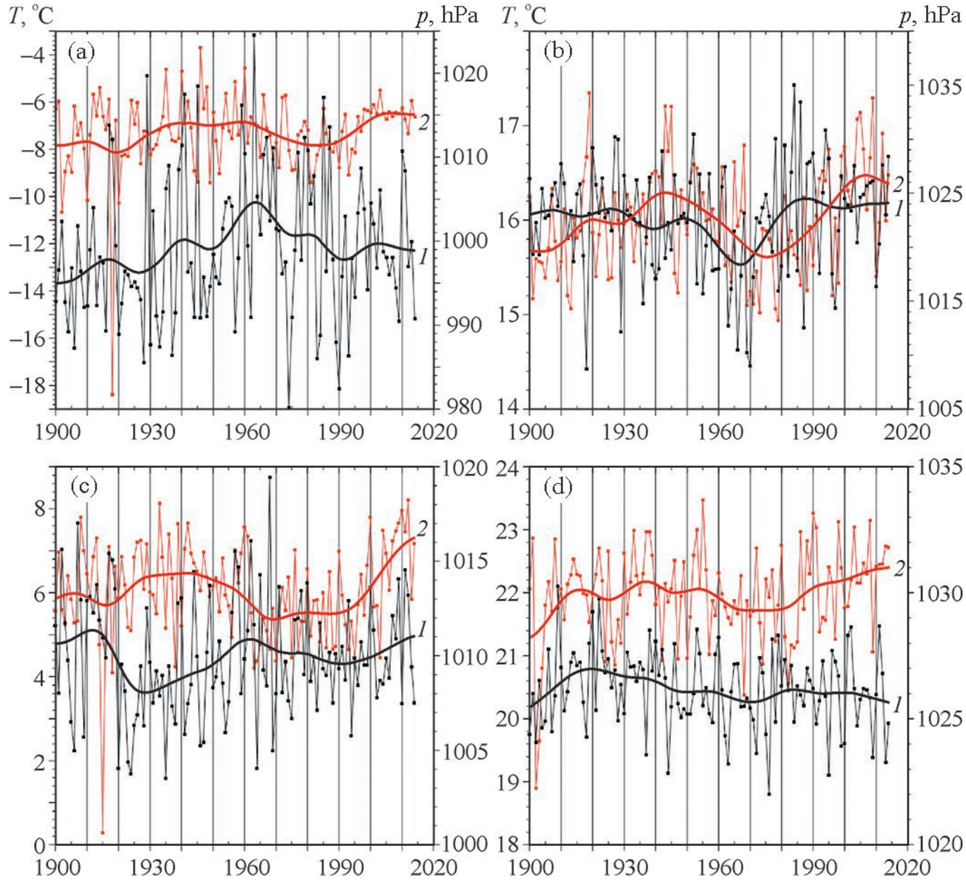

Fig. 4. The long-term variations in (*1*) air pressure and (*2*) air temperature in the area of (a, c) the Icelandic Low and (b, d) Azores High in (a, b) January and (c, d) July.

when the uniform process of modern climate warming was observed. In July the numerical values of are slightly smaller than in January. For example, the highest negative relation is observed between the air temperature anomalies in 1900–1929 and 1988–2014 (= –0.72), i.e., the processes in the early 20th century and at the turn of the 20th and the 21st centuries are oppositely directed; the values of the similarity criterion are high for 1988–2000 and 1988–2014 (= 0.70).

There is a rather strong relation between the periods of 1900–1929 and 1960–1987 for the patterns of air pressure anomalies in January (= –0.69). The air pressure anomalies at the beginning and end of the 20th century are almost not interrelated (= 0.06). In July the periods of 1900–1929 and 1960–1987 are also characterized by the strong coupling, when = –0.70, i.e., the air pressure anomalies of different signs prevailed at the considered grid points.

It was interesting to consider long-term variations in the time series of air temperature and air pressure smoothed with the Potter filter (the low-frequency component with the period of more than 20 years) for the Northern Hemisphere atmospheric centers of action for 1900–2014.

At first, let us consider the following circulation couple: the Icelandic Low and the Azores High. The LFC of air temperature and air pressure slightly varied in the area of the Icelandic Low in January in 1900–2014 (Fig. 4a). Since the 1980s air temperature rose by about 1.2 C and was equal to –6.5 C, and air pressure reached the maximum in 1965 (~1004 hPa), started dropping, and was equal to 999 hPa at the end of the analyzed period. Certainly, the air pressure curve exhibits more complex dynamics than the air temperature curve. In July air temperature (Fig. 4c) from 1990 till now is in the active phase of increase (by LFC): it rose from 5.5 to 7.3 C; before that, air pressure and air temperature varied in the opposite phase (1910–1960), whereas air pressure was slightly rising and reached 1011 hPa in the concluding period. It should be noted that in the Icelandic Low air pressure reached its minimum (1008 hPa) in 1925.

In January the pattern observed in the area of the Azores High was more complex than that in the area of the Icelandic Low: the wavy variations in LFC of air pressure and air temperature took place. Air pressure rose from 1018 hPa in 1965 to 1024 hPa in 1990 and started dropping afterwards; air temperature rose from 15.6 C (1975) to 16.4 C (2005) at first and started decreasing afterwards. In July (Fig. 4d) variations in thermodynamic parameters were small and gradual. Air temperature insignificantly rose since 1980 and reached 22.4 C in 2014, and, on the contrary, air pressure slightly dropped and was equal to 1025.6 hPa at the end of the analyzed period.

The analysis of LFC of air temperature and air pressure in the North American couple (the Aleutian Low and the North Pacific High) revealed that the most pronounced variations in the area of the Aleutian Low in January are the air pressure drop by 7.5 hPa (from 1005.0 to 997.5 hPa) in 1910–1930 and the air temperature rise by 1.2 C in 1910–2014 (the figure is not presented). In July the appreciable air temperature rise by about 1 C was observed from 1950 till now. The low-frequency component of air pressure varies with the small amplitude. The comparison of temporal variations in the air pressure LFC in the areas of the Icelandic and Aleutian lows indicates the antiphase pattern of these variations.

In the area of the North Pacific High both in January and July thermobaric processes are rather stable, and there are no significant temporal variations. Only the slight air temperature decrease and air pressure rise may be noted in January in recent decades, and the insignificant decrease both in air pressure and air temperature has been observed in recent years in July.

The Siberian High was characterized by the dramatic air pressure drop, from 1039 to 1030 hPa, that occurred in January from the late 1960s till 1994. Then air pressure started rising and reached 1036 hPa. Air temperature varied in the phase opposite to the air pressure phase, and its considerable rise was registered from the 1930s till 1990 (from –25.6 to –22.2 C). During the concluding phase (since 1990), an insignificant decrease in air temperature LFC was observed.

Thus, the analysis of LFC of air temperature and air pressure in the considered regions allows assessing their long-period variations caused by the superposition of a number of physical factors: the cloudiness and sea surface temperature, the heat and moisture exchange between the environments, the atmosphere and ocean circulation, etc. [4, 9, 11, 21]. To study in more detail the conditions for the formation of low-frequency variations in the anomalies of air pressure and air temperature in the Northern Hemisphere, the authors plan to investigate the dynamics of regional circulation patterns and vorticity using the well-known circulation indices: NAO, PNA, EA, SCAND, etc.

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