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Climate Trends in Barometric Circulation Regime and the Thermal State in the Northern Hemisphere and its Individual Regions

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The space-time variability of atmospheric pressure fields, the air temperature and wind velocity in the troposphere of the Northern Hemisphere within the period from 1948 to 2013 has been described. A delay of air temperature low-frequency component against the atmosphere zonal circulation variations in the 30-70° N latitude zones in winter time has been revealed. The share of the wind velocity component in the temperature variation is 60%. As an example, the air temperature response to the impact of a number of circulation systems in the Volga region has been considered.

Key words: Macro-circulation system, zonal wind, circulation indexes, Correlation coefficient, air temperature, atmospheric pressure.

The purpose of the article is to analyze the variations of the circulation and thermic regimes in the Northern Hemisphere (NH) troposphere under the conditions of global warming since the mid-20th century to 2013. As it is well known, the large-scale mechanisms of atmospheric and oceanic circulation are the most important internal factors in the Earth's climate system, which are involved in the climate generation and variability[1].

A number of indexes have been proposed to estimate the influence of atmospheric circulation on the weather and climate variations. The most famous among them are: the North Atlantic Oscillation (NAO), the El Niño - Southern Oscillation, the Pacific-North American (PNA), Polar-Eurasian (POL), Western Pacific (WP), the East Atlantic (EA), Scandinavian (SCAND), Arctic Oscillation (AO), which are computed from pressure field at isobaric surface 700 hPa [2-4].

In this case, the atmospheric circulation is considered as a complex winds system closely related to the pressure field, and it is mainly this interaction that determines weather and climate variations.

With the current global warming, the structural variations in the atmospheric circulation and the pressure field also take place. The authors' previous studies[5, 6] present an analysis of the current variations in the temperature field both in the Northern Hemisphere (SP) and in individual regions. In this paper, these studies are developed and the most of the focus is on the variations of the barometric circulation in the Northern Hemisphere as a whole and in its 30 - 70° N latitude

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zone and on the estimation of the statistic relationships between the circulation systems and the pressure and air temperature characteristics of the Volga Federal District (VFD).

MATERIALS AND METHODS

The time series of monthly air temperatures (T) and atmospheric pressure (P) in the Volga Federal District within the period from 1966 to 2009 have been used as initial materials for this study, as well as the NCEP/NCAR data of the surface air temperature, atmospheric pressure and the wind velocity component reanalysis in the Northern Hemisphere (NH) troposphere over the past 66 years (1948-2013) distributed by NOAA /OAR/ESRL PSD, Boulder, Colorado, United States [7]. Indexes of atmospheric circulation have been taken from the following source: http://www.cpc.ncep.noaa.gov/data/teledoc.

The fields of long-term annual normal values and the temporal variability characteristics of the indicated meteorological variables for the NH have been constructed. The main attention has been paid to the study of processes in the temperate zone of the NH (30-70° N) including the territory of the Volga Federal District.

The temporal trends of meteorological values have been studied by the methods of trend analysis; low-frequency component has been found with the Potter low-frequency filter with a 10 years or more cut-off point.

Reanalyzing the grid-point and the regions data we have computed the correlation coefficients (r) of the temperature and pressure series, wind velocity component and circulation indexes.

RESULTS AND DISCUSSION

The space-time variations in the pressure field of the Northern Hemisphere and its regions The average multi-year charts showing the distribution of surface pressure space and one-sigma values (OSV) (built for each of the months) make it possible to follow the structural variations during the year, which most notably affect the behavior of atmosphere action centers (AAC) and the centers of OSV greatest variability in the pressure fields. The indexes of the meteorological values temporal variability attract the most interest. These parameters value naturally depends on the space averaging scale. Indeed, the average long-term annual range of atmospheric pressure (AP) at the sea level reaches its maximum value (H”8.79 hPa) for the Volga Federal District (VFD), for the 30-70° N latitude zones it is H”3.21 hPa and for the hemisphere as a whole it is H”3.10 hPa. The value of AP reaches the highest values in winter and the lowest in summer. Naturally, the area extension causes the smoothing, but in the Earth’s vast tropical zone the annual variations are small. The slope coefficient of the linear trend (SCLT) (hPa/10 years) has been computed basing on the AP average monthly values for the period of 1966-2009 in order to assess the temporary trends of the pressure field variations. The coefficients are shown in Table 1.

As it can be seen from Table 1, the SCLT values for the NH and the 30-70° N zone are unessential, due to the compensation of the opposite signs trends as a result of large area smoothing. On the territory of VFD the SCLT is universally negative in winter and the most significant in February, when the SCLT is up to -1.46 hPa/10 years, indicating the pressure decrease in this region in winter due to the cyclonic activity increasing and the warming. Note: the SCLT of air temperature in VFD has a positive sign and indicates winter warming. In summer months the SCLT in VFD is sign-alternating and statistically insignificant.

The degree of processes uniformity in the areas under study can be seen from the computed correlative relationships in the pressure field between the regions under study. As it can be seen from Table 2, they are closer in winter for VFD and 30-70° N latitude zone, which is natural, since VFD is included in this area, as well as between the pressure of the entire hemisphere and 30-70 ° N latitude zone. The relationships between VFD and NH (except in January) are weak, especially in summer, when the correlation coefficient is close to zero.

Computed at the NH grid-point, slope coefficients of the linear trend are shown in Fig. 1. The pressure in a large part of the extra-tropical latitudes of the Western Hemisphere reduced both in winter and in summer in the period from 1948 to 2013. This process was more active in winter. In the extra-tropical latitudes of Eurasia the variation of pressure approximated by a linear function in winter and in summer has the opposite direction. In order to identify the most informative indexes of the atmospheric circulation, the coefficients of linear correlation have been computed between the indexes of NAO, AO, SCAND and the temperature and pressure values in the 54 grid points uniformly covering the territory of the region. The correlation coefficients for each month are shown in Table 3. We have found that the closest ties are established with the indexes SCAND characterizing the degree of blocking the westerlies over the European territory. The annual variation is manifested in all cases. The *r* values are the highest in cold seasons and the lowest in warm ones. It is significant that the correlation relationships between the circulation indexes and the pressure and temperature values are of different signs.

The attention in meteorology is focused on the long-distant relationships. For example, papers[8, 9] have shown that the El Niño-Southern Oscillation affects the processes occurring in the

Table 1. The SCLT (hPa/10 years) of the AP average monthly values

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
NH	0.06	0.09	0.09	-0.02	0.03	0.07	0.07	0.06	0.02	0.07	0.04	0.04
30-70° N	0.06	0.07	0.11	-0.06	0.00	0.06	0.04	0.06	0.05	0.09	0.07	0.05
VFD	-1.34	-1.46	-1.08	0.24	-0.81	-0.17	0.32	-0.27	0.25	0.55	0.43	-0.18

Table 2. The linear correlation coefficient *r* between the series of average monthly atmospheric pressure (*r* * 100)

Object	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
VFD and NH	48	25	14	29	32	5	3	15	24	23	25	35	35
VFD and 30-70° N zone	57	61	63	58	60	43	60	54	53	47	57	69	56
NH and 30-70° N zone	59	51	48	42	45	37	43	38	64	58	40	44	45

Table 3. The linear correlation coefficients between the temperature and pressure series and the atmosphere circulation indexes (1948-2013) in VFD (*r* * 100)

r	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
T and NAO	33	32	46	-7	-32	-35	-11	-7	8	-6	-10	47	11
P and NAO	-23	-20	-5	-1	-14	0	12	30	9	3	15	-20	-20
T and AO	42	32	42	10	-7	-14	27	0	16	14	28	49	36
P and AO	-59	-36	-24	-28	-27	-5	20	0	-22	-29	-26	-32	-42
T and SCAND	-65	-64	-29	-38	-36	-13	0	-6	-28	-49	-25	-30	-51
P and SCAND	74	70	86	45	20	26	22	39	39	29	77	81	57

Table 4. The coefficients of linear correlation between the NAO indexes and the series of pressure (*P*) and temperature (*T*) averaged for VFD (*r* * 100)

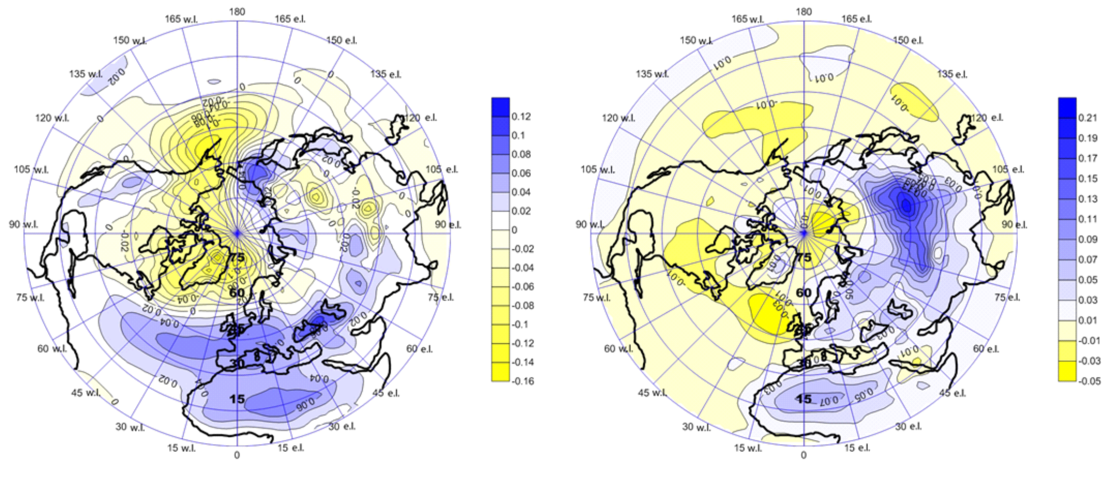
	1978-1998											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
r(NAO;P)	-60	-49	-68	17	16	-41	29	1	-20	-28	11	-1
r(NAO;T)	76	53	50	6	-6	-29	12	10	27	11	7	19
1948-1967												
r(NAO;P)	-56	-27	-51	-16	-19	-14	-1	31	-10	-18	0	21
r(NAO;T)	32	27	6	-40	-15	-18	6	21	-4	36	-11	8

atmosphere-ocean system at a considerable distance from the place of this phenomenon origin. In this paper we have computed the correlation coefficients between the air temperature and atmospheric pressure in 54 points located in the Volga Federal District and the NAO index series in El Niño active phase (1978-1998) and weak phase (1948-1967). The computation results are shown in Table 4, which suggest that the phenomenon of ENSO in its active phase in winter has a strong impact on the North Atlantic Oscillation, which in its turn contributes to the heat transfer from the Atlantic Ocean to the European part of Russia, including VFD, leading to high statistically significant correlation coefficients. Thus, strengthening of the NAO is a response to the active phase of the El Niño.

The main features of the long-term variations in the wind and air temperature regimes in the temperate latitudes of the Northern Hemisphere lower troposphere Let us reanalyze the data for the period of 1948 - 2013 and see in more details the processes in the temperate latitudes zones (30-70^{o} N) where a pronounced manifestation of baroclinic instability and eddy activity is registered. We have created long-term average zonal and meridional component charts of the wind velocity and air temperature at isobaric surfaces 850, 700 and 500 hPa in the period 1948 - 2013 for winter and summer in the Northern Hemisphere, which generally correspond to known climatic patterns[4].

Since the main attention is paid to the analysis of the long-term variations of investigated values, for establishing the relationship between the air temperature and atmospheric circulation the dynamics of their low-frequency component (LFC) has been considered. For this purpose, the zonal wind velocity and air temperature components were averaged for the 30 - 70^{o} N temperate latitude zone and 30 - 50^{o} N and 50 - 70^{o} N subzones for each year. Then, the low-frequency component with a period of more than 10 years was marked out in the derived time sequence.

The analysis of the time variation of the LFC zonal velocity component (ZVC) and the surface air temperature (SAT) in the period from 1948 to 2013 on isobaric surfaces 850 and 500 hPa (Figure 2) shows that in the 30 - 70^{o} N latitude zone on the ”$_{850}$ (absolute topography), a fairly consistent time variation of the ZVC and SAT is observed: their lowest values were observed in the 1962-1970 period, and their highest ones - in the 1990-2000 period. Then, by 2010, these meteorological values decrease again. Thus, in winter there is an oscillation regime when the temperature variation is delayed for about 8 years compared to the LFC. All this is true for the northern zone, but the pattern here is less smoothed. In the southern zone in the mid-1970s



January July

Fig.1. The slope coefficient of the linear trend of the pressure above mean sea level for the period from 1948 to 2013 in January and July

an anti-phase behavior of the LFC, SAT and ZVC was observed, in which the SAT reaches its minimum and the ZVC - its maximum. The temperature variation in this zone corresponds, in general terms, to the hemispheric one. The time variations of the ZVC over the 66-year period can be explained by long-term oscillations of the atmospheric circulation, which requires a special study.

Zonal component on the surfaces 850 and 500 hPa in the temperate zone of the NH (top), its north (left) and south (right) parts in winter. 1 -

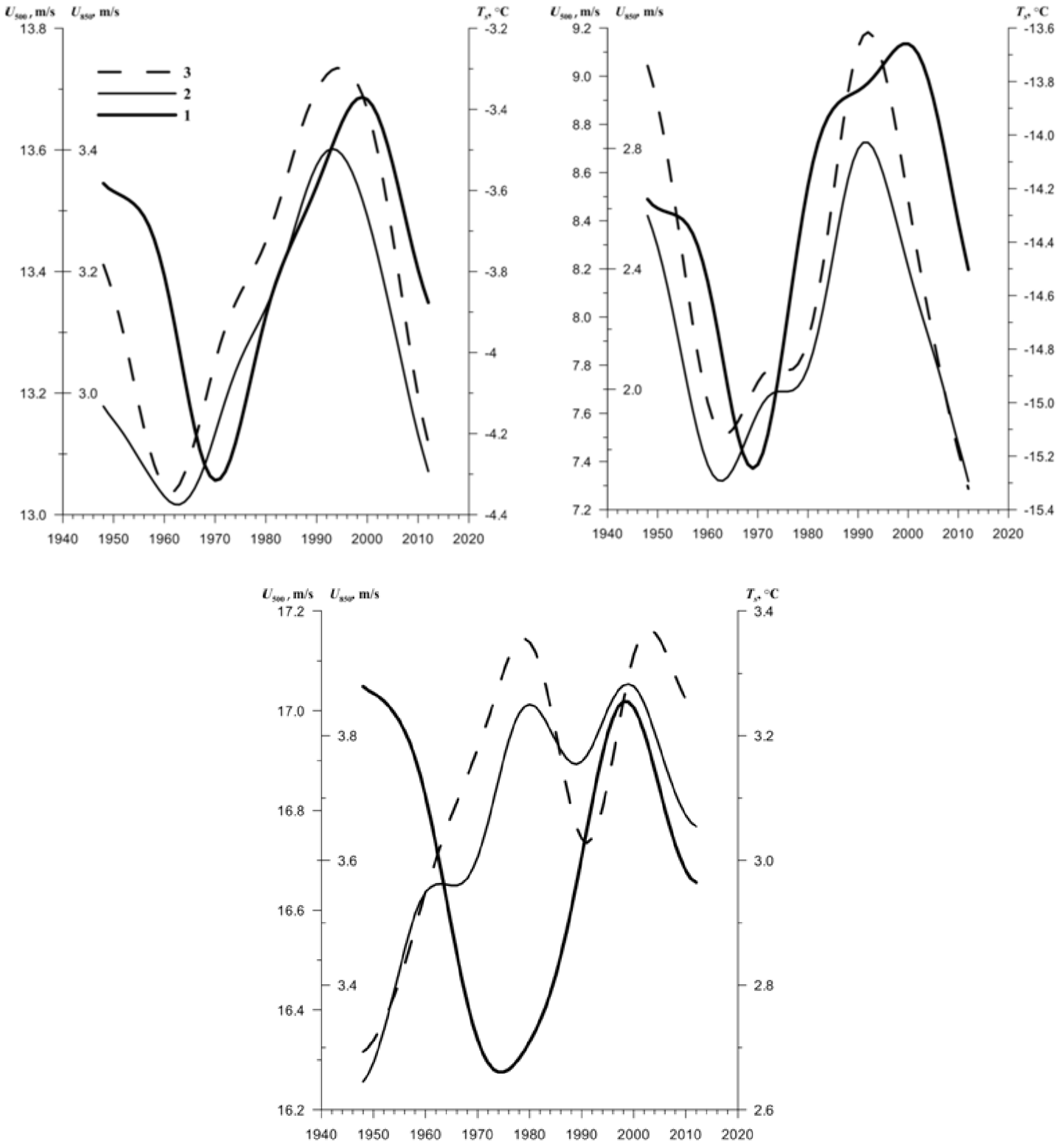


Fig. 2. LFC (over 10 years) of the surface air temperature and the wind velocity zonal component on the surfaces 850 and 500 hPa in the temperate zone of the NH (top), its north (left) and south (right) parts in winter. 1 - surface air temperature (T_s), 2 and 3 – zonal wind velocity component on pressure surface 850 (U_{850}) and 500 hPa (U_{500}) respectively

surface air temperature (T_s), 2 and 3 – zonal wind velocity component on pressure surface 850 (U_{850}) and 500 hPa (U_{500}) respectively.

Thus, throughout winter the SAT extremes delay against the ZVC is distinguished in the whole temperate latitude zone and in its northern part, indicating both the leading role of the atmospheric circulation and a pattern between the long-term variations of atmospheric circulation and SAT. Strengthening of the wind velocity western component is accompanied by a temperature increase. In the southern zone the increase in the ZVC in 1950 - 1970 was accompanied by a temperature decrease and only at the end of the period under review, since the 2000s a decrease both in SAT and the ZVC was observed.

In summer, there is an anti-phase behavior of the LFC, SAT and LFC. In general, the increase in the ZVC and then its decline was observed in the temperate zone during the period of 1950 - 1996. Since the mid-1970s the SAT has been steadily increasing. The pattern in the northern area is simpler than in the south. There has been observed a temperature rise and a decrease in wind velocity in recent years. The SAT in the southern zone has been rising since the mid-1970s, while the ZVC at “$_{500}$ has been decreasing since the 1960s. Thus, in recent years in summer the SAT has been increasing and the ZVC has been decreasing. The exception is the LFC of the zonal velocity “$_{850}$.

In summer, in general there was a decrease of the SAT at a rate of 0.27^o C/10 years in the zone during 1948-1975 (27 years), then its increase in the last 38 years at a rate of 0.24^o C/10 years. In the northern part of the zone the pattern is less uniform, but in the last 17 years an increase in temperature at a rate of 0.41^o C/10 years has been observed. In the southern zone during the 1948-1975 period the SAT decreased (0.29^o C/10 years), and in the last 38 years it has been increasing at a rate of 0.18^o C/10 years.

The computation of multiple correlation coefficients between the SAT and the wind velocity components at AT_{850} in winter and in summer has shown that the correlation field has a local nature. The correlation coefficients reach values of 0.8; therefore, the circulation contributes to 60% of temperature variations. The confidence coefficient of the areas allocated on the maps is 95%. A confidence limit for the 5% significance value for the sequence used in the study is the value of 0.62.

The coefficients of pair and partial correlation of the SAT and the ZVC in winter indicate the positive relations over Eurasia (the ocean warms the continent), the relations over the oceans are negative, i.e. under the westerlies intensification there is a decrease in temperature. In summer the pattern for the continents is the opposite. The correlation relationship of the temperature with the meridional component is mainly positive.

Thus, the main conclusion is that an intense winter warming in the last 30 years of the XX century has been followed by a decrease in winter temperatures no less intensive since the beginning of the XXI century. In summer, since 1975, there has been an intensive increase in the SAT in the northern part of the NH temperate zone that is consistent with the conclusions of the paper [10], which noted the increasing role of blocking processes in the Northern Hemisphere, mainly developing over the continents in winter and summer, which leads to an increase in summer and a decrease in winter temperatures, i.e. to an increase in the air temperature annual range.

The analysis of low-frequency variations in the ZVC in the lower half of the troposphere in winter during the 1948 - 2013 period shows that in recent years the velocity of the zonal transport has decreased, and its decrease started earlier than the decrease in SAT, whereas in summer, there is a decrease in the ZVC while the SAT is constantly increasing.

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