Variability of the circulation processes in the Lower Volga Region on the background of global climate trends

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Abstract. In this article we consider variability of the character of atmospheric circulation during different periods of climatic variability in the Lower Volga region as part of the Atlantic-Eurasian hemisphere sector. Variability of the circulation regime is analyzed with the involvement of the regional typification of synoptic processes by V. L. Arkhangelsky - E. A. Polyanskaya. It is shown that during the phase of the second wave of global warming compared to the period of stabilization in the South-East of the Russian Plain we actually see the decrease of the polarfront cyclones occurrence frequency, the increase of cyclones frequency on the Arctic front and the intrusion of Arctic anticyclones. The revealed character of synoptic processes changes is reflected in the reconstructions of geopotential fields at the middle level of the troposphere. The climatically meaningful conclusion was also made about the stabilizing role of the atmospheric circulation and the formation of the specific features of the climatic variability that does not have analogues in the period of regular meteorological observations.

1. Introduction
Climate changes occurring on the Earth generally and in certain regions are obvious. However, the question about the reasons these changes stays debatable. Today except anthropogenic ones, natural reasons are also indicated, such as change in the flow of solar radiation, volcanic eruptions, phenomena and processes in the ocean [1-4]. Undoubtedly, in short-time intervals (within several decades) climate variability primarily is defined by regime fluctuation of general circulation of atmosphere (GCA). A great number of publications is devoted to studying of the regime of general circulation, curriculum vitae of which is are in IPCC. In earlier researches, carried out by the authors of the current article, the variability of circulating processes in different climatic periods was studied by the nature of the pressure field on the average level of troposphere, since climate ridges and troughs on AT-500 are integral indicators out of all the variety of synoptic processes ongoing above the Earth’s surface [5-8].

2. Material and methods.
The most striking indicator of modern climate tendencies are changes in air temperatures. According to the data of (http://www.cru.uea.ac.uk/cru/data/temperature/#datdow), the authors of the web-site
made a chart of temporary motion of anomalies of average annual air temperature of the Northern hemisphere (figure 1). In this graph the time intervals clearly state, where average near-surface temperature has the same variability tendency:

1) Little ice age in Europe, shown in the graph by interval since the middle of the 19th century until the end of 1900s.
2) The first wave of global warming was observed since the middle of 1840s until the middle of 1905 until 1940s.
3) The period of stabilization (relative cold snap) that came out in the 1950s-1960s.
4) The second wave of global warming started in the middle of 1970s and continued until the present moment with an essential slowdown.

Variability of the average hemispheric air temperature in each of the four aforementioned intervals you can see the trend lines. As the graph shows, the lines have different incline that value of linear coefficients $\alpha$. They differ not only in value but in sign as well. To define if the noticed change is climatically significant, we checked those with the synoptic one. We used the confidence interval methods with applying to Student’s statistics and 95% level of significance by the formula:

$$\bar{x} \pm t_\gamma \frac{s}{\sqrt{n}},$$

in which $\bar{x}$ - average value; $t_\gamma$ - Student's statistics, $\gamma$ - Significance level indicator (95 %); $s$ - mean square; $n$ - Number of members of the series.

Analysis of synoptic processes near the earth's surface was carried out with the help of regional typification of Arkhangel'skiy [10] and Polyanskaya [11], Morozova [12]. According to this typification, 7 types of synoptic processes are distinguished in the Lower Volga region.  
I. The cyclonic activity on the Arctic front.  
II. The impact of the Arctic anticyclone.  
III. The impact of the winter Asian anticyclone.  
IV. The impact of the subtropical anticyclone.  
V. Flat pressure gradient of high and low pressure.  
VI. The cyclonic activity on the Polar front.  
VII. Field of deformation.

3. Results and discussion
Using the formula above we calculated the borders of confidence intervals, which are represented in table 1. Except for this, in the table shows several statistical characteristics for each of the time period.
Table 1. The statistical significance estimation of anomalies change of the average annual North hemisphere’s temperature.

| Periods, years               | Statistical characteristics of the significance of changes. | Confidence Intervals       |
|------------------------------|-------------------------------------------------------------|----------------------------|
|                              | $\alpha$  | $\bar{x}$ | $\sigma$ |                                             |
| 1) Small glacial age (1850-1907) | -0.0014   | -0.28     | 0.147    | [-0.508; -0.315]                           |
| 2) First wave (1908 – 1943)   | 0.0163    | -0.19     | 0.194    | [-0.240; -0.130]                           |
| 3) Stabilization (1944 – 1974) | -0.0058   | -0.02     | 0.124    | [-0.078; 0.038]                            |
| 4) Second wave (1975 – 2016)  | 0.0240    | 0.357     | 0.320    | [0.273; 0.439]                             |

According to the average quadratic deviation ($\sigma$), characterizing the range of random value concerning its average value, we can see that the greatest variability is typical for the second wave of global warming. It is noteworthy that during the little ice age and period of stabilization, the temperature range was less than in relative warm ones. Maximum variability of the temperature regime in the second wave of global warming compared to all other periods shows the increase in climatic instability.

Estimating the confidence intervals (table 1) and making sure they do not overlap, we can conclude the statistical significance of changes. Since the changes were statistically significant, the null hypothesis about the homogeneity of a series is rejected, and significant climate changes are seen. The conclusion about the statistical significance of climate change allowed the author call natural climatic periods of the earth's climate system (ECS) selected periods of time, although, undoubtedly, natural changes have an anthropogenic component.

Variability in circulation was studied in three locations: Samara, Volgograd, Astrakhan. In each of them the annual frequency of SYNOPTIC processes (average number of days) was calculated within a period 1949 – 1969 years, corresponding to stabilization period and 1998-2007 years which is also called the second wave of global warming (table 2).

You can see from the exact analysis of the represented data (table 2) that the stabilization period in all three areas, with the exception of Samara, the process of cyclonic activity on the polar front prevailed over all others. In Samara repeatable processes, cyclonic activity at polar and Arctic fronts are equally probable.

According to the data in table 2 we can conclude that during the second studied period (the second wave of global warming) compared to the first (stabilization) is the frequency of occurrence of cyclonic activity on the Arctic front, and, as a result, an increasing number of Arctic incursions into the region. At the same time there is reduction of the frequency of occurrence of polarfront cyclones. Also there are much less prominent cases of the influence of subtropical highs in the Lower Volga Region. The number of days with the influence of the Asian winter anticyclone has decreased slightly (from 37 to 33 days per year). Simultaneously with it, low-gradient fields of high and low pressure increases in frequency from the stabilization period to the second wave of global warming. Moreover, these trends are typical for all locations.

Climatically significant effects of the analysis can be considered as a conclusion about the stabilizing role of the General atmospheric circulation. The increase in the invasion region of the Arctic anticyclone contributes to more frequent penetration of the relatively warm areas of cold air masses, which somewhat moderates the growth of near-surface air temperature. The increase in the frequency of low-gradient fields may indicate a greater uncertainty about the future character of development of the atmospheric circulation. Thus, the atmospheric circulation can be regarded as a stabilizing factor, tending to the preservation of climatic and ecological balance on the Earth's climate system. This conclusion does not contradict the role of the General circulation of the atmosphere as climate-forming factor, smoothing temperature contrasts between the Pole and the equator.
We can note that synoptic processes in different seasons of the year determine different weather conditions. For instance, the cyclonic activity softens weather conditions: in the winter—causing relative warmth, in the summer—reducing hot temperature background. Arctic anticyclones in the winter determine the dramatic intense cold waves in the summer. Under their influence a particularly severe drought was formed. Therefore, the increase of the frequency of occurrence of the invasion of Arctic anticyclones in the second analyzed period is typical only for summer season. In winter, the frequency of their incursions becomes less in winter and summer, also during both seasons the frequency of cyclones, developed in the phase of the second wave of global warming is a bit less than in the period of stabilization. The number of cases of the subtropical ridges impact become larger in winter and summer. Under their influence a particularly relative warmth was formed. Therefore, the increase of the frequency of occurrence of the invasion of the Arctic anticyclones frequency in the second analyzed period is represented. It is constructed from data on the

We considered the repeatability of synoptic processes in a differentiated way, in summer and winter (table 3).

Analyzing the seasonal differences of the synoptic processes occurrence frequency in the region (table 3), we note that in winter and summer from the first to the second period the number of impacts on a region of cyclonic activity on the Arctic front increases. It is interesting, that the increase of the invasion of the Arctic cores frequency in the second analyzed period is typical only for summer season. In winter, the frequency of their incursions in the phase of the second wave of global warming is a bit less than in the period of stabilization. The number of cases of the subtropical ridges impact becomes less in winter and summer, also during both seasons the frequency of cyclones, developed in the polar front is reduced. Flat pressure gradient and deformation fields from the first to the second period become larger in winter and summer.

The most interesting and important for the physical theory of climate factor is the summer increase in the frequency of invasion of the Arctic anticyclone. As already mentioned, the integral characteristic of earth-surface processes is the structure of the pressure field of the middle troposphere. In the figure presented the pressure field on the middle level of the troposphere over the same study periods for the Central month of the summer season is represented. It is constructed from data on the
value of the geopotential at the nodes of a regular grid with increments in latitude and longitude 5°. Data visualization was performed using MAPINFO software complex on the basis of GIS-technologies.

**Table 3.** The average number of days with synoptic processes in the Lower Volga Region.

| Type of process | Periods, years | Samara winter | Samara summer | Volgograd winter | Volgograd summer | Astrakhan winter | Astrakhan summer |
|-----------------|----------------|---------------|---------------|------------------|------------------|------------------|------------------|
| I               | 1949-1969      | 25.1          | 14.4          | 19.3             | 7.6              | 15.3             | 5.0              |
|                 | 1998-2007      | 30.5          | 18.6          | 19.9             | 14.2             | 13.8             | 9.2              |
| II              | 1949-1969      | 15.9          | 15.3          | 14.4             | 11.2             | 13.5             | 10.3             |
|                 | 1998-2007      | 12.3          | 30.0          | 12.9             | 27.3             | 12.6             | 26.2             |
| III             | 1949-1969      | 22.3          | -             | 17.5             | -                | 18.8             | -                |
|                 | 1998-2007      | 22.2          | -             | 18.7             | -                | 19.7             | -                |
| IV              | 1949-1969      | 2.7           | 16.9          | 5.0              | 23.5             | 5.9              | 26.2             |
|                 | 1998-2007      | 0.6           | 10.7          | 3.1              | 14.1             | 2.8              | 17.8             |
| V               | 1949-1969      | 4.4           | 11.4          | 4.8              | 11.4             | 5.0              | 13.1             |
|                 | 1998-2007      | 10.6          | 20.6          | 13.9             | 22.9             | 21.0             | 28.7             |
| VI              | 1949-1969      | 14.8          | 29.5          | 24.8             | 34.2             | 21.8             | 30.0             |
|                 | 1998-2007      | 8.6           | 9.0           | 12.4             | 11.5             | 11.5             | 7.5              |
| VII             | 1949-1969      | 1.8           | 1.2           | 4.5              | 3.9              | 3.5              | 1.5              |
|                 | 1998-2007      | 5.3           | 4.8           | 4.7              | 3.9              | 4.9              | 4.9              |

As can be seen from the image, the pressure fields on the middle level of the troposphere differ significantly among themselves in two studied time intervals. Pressure field on the space of the first natural synoptic region (I n.s.r.) in the stabilization period, presented by ample narrow southern, especially distinct over the North Atlantic and the Black sea (figure 2a), the existence of which identify areas of negative values of the geopotential anomalies over these regions (figure 2b). In the same period, anticyclonic axis of the clamping forces, directed from the region of the Azores to the Arctic is well observed. It determines the background of high pressure over Western Europe (except the Northern territory), the European part of Russia and Western Siberia. Over Central Asia an extensive area of geopotential heights negative deviations stands out. The centerline (572 hPa) of the planetary high-altitude frontal zones (PHFZ) in this period is about 50° N. The quasialtitudinal location PHFZ indicates poorly developed meridionality of the space I n.s.r. in that period. Note that in the period of stabilization the Lower Volga region was located in front of the high-altitude pressure narrow. The front part of the narrow is the area of active cyclogenesis. High frequency of the polarfront cyclones prevented the development of long and extensive drought.

In the phase of slow warming 1998-2007 (figure 2c) there were noticeable changes in the structure of the isohips field. It turns out to be quite perturbed with chaotic arrangement of ridges and narrows, reflecting the unstable nature of atmospheric processes. Over the regions small pressure waves are detected. Small-scale ridges are observed over the North Sea and the West of Scandinavia, and also over Ukraine, the Middle and Lower Volga region. Over Central Europe there is a small high-altitude narrow. The centerline PHFZ over the Atlantic and Western Europe decreased to 45 degrees latitude, and above the East moved 3° to the North. This curvature of the centerline PHFS is testified of increased meridionality of air currents.

Analysis of geopotential anomaly fields (figure 2d) shows that the area of low values of the geopotential (corresponding to the Icelandic low) has moved south and has occupied the whole investigated part of the Atlantic, with the result that the Azores ridge was over the Mediterranean Sea and united with the anticyclone located in the South-East ETR. Probably, this anticyclone emerged as a result of the interaction of the Azores and Arctic centers of atmosphere action. Thus, the center of positive geopotential deviations emerged over the Middle and Lower Volga, which means frequent
penetration of the Arctic cores in this period in the South-East ETR that contributed to the formation of blocks and severe droughts. According to [2], during the second wave of global warming the frequency of droughts does not increase, but their intensity and geographical coverage.

Thus, over the Middle and Lower Volga Region was the center of positive deviations of the geopotentiality, which means frequent penetration in this period of time in the South-East ETR Arctic cores that contributed to the formation of blocking and severe droughts. According to [2] during the second wave of global warming increases the frequency of occurrence of droughts and their intensity and geographical coverage.

Thus, we can conclude that in the future with a possible increase in average global temperature, the contribution of the temperatures of summer seasons caused by increase in temperature due to anticyclone conditions, needs to become more meaningful. If in the second wave of the global warming temperature increase was determined mainly by increasing temperatures in the cold part of the year, in the future a significant contribution to this increase will be brought by summer seasons as well due to the increased meridionality of processes, and, as a consequence, the formation of positive temperature anomalies. Based on the data represented above, we can point out some trends of regional climate change, namely the increase in the frequency of dry phenomena in summer in the Volga region.

From the period of stabilization to a phase of slow warming in the Lower Volga region we see an increase in the number of days with the processes of cyclonic activity on the Arctic front and as a consequence an increase in the number of intrusions in the Lower Volga region of the Arctic cores. Subtropical anticyclones began to affect the Lower Volga region less also polar front activities decreased over the region. In this case above the Lower Volga region we observed flat pressure gradient more, generally, of high pressure. The preservation of the identified trends may cause a
further increase in surface temperature without changing the degree the climate continentality. This feature has no analogs in the era of instrumental meteorological observations.

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