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# Modern Changes of the Ground Thermal Regime in the Volga Federal District (VFD) and Accompanied Changes of Synoptic Processes in the Atlantic-European Sector of Northern Hemisphere.

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## ABSTRACT

The paper provides the evaluation of climate warming speeds at the Volga Federal District for the historical period of 1955 - 2009 and its final part (1966 - 2009 gg.). The results of the joint analysis for a long-term (1966 - 2009) dynamics of the surface thermal regime in the Volga Federal District and the occurrence of the atmospheric circulation forms according to the classification of G.Ya. Wangenheim - A.A. Girs. It is shown that the warming trend prevailed in the long-term dynamics of the thermal regime. It was found that the long-term changes of synoptic processes stimulated the paces of winter warming and reduced them during the summer period. In the long-term changes of air temperature in the VFD their distinctive features were shown due to the influence of climate developing regional factors. It was found that the highest rates of warming were observed in the VFD during March (0,80˚C/10 years), which exceeded the similar figure for the Northern hemisphere 4.4 times. The slowest rate of warming in VFD were observed in May (0,02 ˚C/10 years), and within the Northern Hemisphere - during the period from May to September (0,13 ˚C/10 years). Thus, the annual differentiation of the warming rate in the VFD greatly exceeds the same indicator for the Northern Hemisphere.

**Keywords**: air temperature, global warming, long-term changes of air temperature

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## INTRODUCTION

The existing views on the nature of modern global warming are characterized by considerable uncertainty and contradictoriness [1 - 7]. And the ongoing debate around the future climate change scenarios continues.

Meanwhile, most researchers agree that the ongoing climate warming makes a destabilizing influence on the environment and the economy. At the present stage, it was the cause of a considerable growth concerning social and economic losses and the costs for their elimination.

Currently, the problem of climate change and its adverse impacts are so urgent that it has already reached the level of interstate relations (Kyoto Protocol, 1997). In 2011, this issue was discussed at the meeting of the Russian Federation Security Council for the first time [8].

In search of possible explanations for modern global warming the researchers put forward a variety of hypotheses about its origin, based on the account of climate-forming factors importance of different backgrounds [2; 4 - 7; 9; 10]. At that in most cases at a first glance, the effect of the following obvious factor is overlooked: the long term ("epoch-making" [10, 11]) changes of atmospheric circulation conditions [12].

A significant shift in attitudes about the importance of circulating factors in the long-term climate variations and, in particular, its thermal performance occurred recently and is associated with the release of the basic works written by O.A. Anisimova et al [13], A.V. Mescherskaya et al. [11] and [14]. The work [13], in particular, shows that the character of the spatial distribution along the territory of the Volga region of the average monthly air temperature anomalies and precipitation is closely dependent on the type of prevailing synoptic processes. For example, in January, with the dominance of the processes that are attributable to the west (W) circulation form [11] in that region the positive temperature anomalies are observed as a rule, while at the dominance of processes that are attributable to the east (E) form of circulation the negative temperature anomalies (in most parts of the region) are observed.

Volga Federal District (VFD) geographically belongs to the Volga region, as it follows from [13]. However, from the results of the works [1; 6] show that the long-term dynamics of the thermal regime in the VFD to a large extent different from the same dynamics of the thermal regime in other parts of the region, as well as on the world in general and its hemispheres [6]. From the same data it follows that the warming in the VFD DURING the last 55 years (1955 - 2009) is far ahead of global warming average rate during the same years on the world in general, and on its hemispheres. It may be assumed that a higher rate of climate warming in the VFD was determined by the specificity of the regional origin factors [6; 15]. The revealing of these factors importance is classified as a very challenging one [16; 17], the solution of which may have a significant scientific and practical interest. However, the partial achievement of this goal may be performed through a comparative analysis of a long-term series of air temperature in the VFD with the same rows, obtained by its averaging over the Earth surface and its hemispheres. Primary and very limited results in this direction were obtained in [1].

The results of [11; 13] allow us to say with confidence that in the long-term variations of the thermal regime in the VFD a definite role was played by the lasting changes of atmospheric circulation conditions. With regard to the long-term dynamics of the thermal regime in the VFD this issue was never raised despite its importance.

## MATERIALS AND METHODS OF RESEARCH

The structure of this work informative base includes long-term monthly series: a) of the average monthly and annual air temperature (t) for 215 stations of VFD (Archive (1955 - 2009) of FGBU VNIIGMI-MTSD [6]); b) of the same temperature indicators, averaged over the Earth surface and its hemispheres (Archive (1955 - 2009) of climatic research unit, University of East England [18]); c) of atmospheric circulation forms occurrence according to G.Ya. Wangenheim - A.A. Giers (1966 - 2009) [19].

The averaging of the air temperature on the territory of the area was carried out using a known "weighted average formula" [9], taking into account the uneven distribution of stations in the district space.

The repeatability of circulation forms was defined (in percent) as the ratio of the number of days with its kind ($N_W$, $N_E$, $N_C$) to the number of days in the current month.

In order to suppress the above-mentioned multi-year series of short ("random") vibrations and identify the trends the ranks of mean monthly air temperatures and the occurrence of atmospheric circulation forms W, E, C were subjected to linear smoothing. Thus, the behavior of systematic components in these ranks was approximated by a line equation [20; 21]

$$y(\tau) = a\tau + a_0.(1)$$

Here $y(\tau)$ – is the smoothed value of the analyzed trait, $a$ – the slope ratio of the linear trend (SRLT), $a_0$– a free element, $\tau$ – time function.

This trend analysis was also accompanied by the estimates of the coefficients concerning the linear (synchronous) correlation [r(t,W), r(t,E), r(t,C)] between the abovementioned series of air temperature (t) for the VFD and the repeatability of the circulation forms according to G.Y. Wangenheim - A.A. Girs [12, 19].

As an objective measure of the consistency for a long-term (1955 - 2009) air temperature changes in the VFD (x) in the world as a whole (y), the North (z) and the South (m) hemispheres the work uses the integrated indicators of vector similarity [1]

$$\xi(x,y) = x^T y[(x^T x)(y^T y)]^{-0,5} + [1 + (x-y)^T (x-y)^{-1}], \qquad (2)$$

and similar indicator $\xi(x,z)$, $\xi(x,m)$. At that it is easy to show that

$$-1 \le \xi(x,y) \le 2,0 \ [1].$$

Using the parameters of similarity (2) involves the mapping of compared time series as n-dimensional vectors (x, y, z, m) with their subsequent transposition (T).

The first term on the right side (2) characterizes the degree of phase synchronism oscillations for the characteristics in compared series, described by the angle cosine value between the vectors x and y. The second term takes into account the square of the Euclidean distance between the vectors. At a full coincidence (similarity) of compared rows $\xi(x,y)=\xi(x,z)=\xi(x,m)=2,0$, and at its full anti similarity $\xi(x,y)=\xi(x,z)=\xi(x,m)=-1,0$.

When $\xi(x,z)= 2,0$ all members of compared rows which have the same sequence number (i) coincide with each other, i.e., $x_i=z_i$. Here $i=\overline{1,N}$, $N$ – the sample volume and the indicator i is simultaneously the year indicator. Thus, the condition $x_i=z_i$ allows some possibility to suggest that the thermal conditions of the i-th year in the Volga Federal District (x), and on the average in the Northern Hemisphere (z) are formed under the impact of one and the same complex of climatic factors.

As an objective measure of climatic informative content concerning the interannual variability for the circulation forms W, E, C in respect of long-term dynamics of the thermal regime in VFD a numeric index was used

$$R^2{}_{t.W,E,C} = \left[\frac{\sigma^2(t)_{W,E,C}}{\sigma^2(t)}\right] 100\% \qquad (3)$$

known as the function determining the behavior of a productive attribute [17], which are the averaged over the territory the average monthly air temperatures (t), at a full account of varying circulation conditions impact (repeatability of W, E, C).

In (3) the following designations are used: $R_{\ t.W,E,C}$ – multiple correlation ratio [6; 20; 21] between the attribute t and the complex of specified t factorial signs; $\sigma^2(t)$ – total dispersion within the area territory of air temperatures, calculated on the basis of 34-year (1966 – 2009) observations; a $\sigma^2(t)_{W,E,C}$ – a part of the total dispersion, reproducible in view of the factorial complex action. In this regard the parameter $R^2{}_{t.W,E,C}$ is often defined by authors [22 et al.] as the value of the determination coefficient. At that it is easy to see that 0≤$R^2{}_{t.W,E,C}$≤100%.

## RESULTS AND THEIR DISCUSSION

From the examination of the previous work results [1], the most important feature of the thermal regime long-term dynamics in the Volga Federal District within the period under review (1955 - 2009) is the predominance of long-term warming trend that is also consistent with the results of the works [11; 13], relating to the European part of Russia and to the Volga region.

The warming climate was developed most rapidly in March ($a = 0{,}796^{\circ}\mathrm{C}/10\ years$). Thus, the average temperature on the territory of the district for this month, during the last 55 years increased by almost 4,4 ˚C, which was almost 4.4 times more than in February for the Northern hemisphere.

**Table 1: KNLT (a) of the average monthly air temperature (t) (°C/10 years) and the occurrence of atmospheric circulation forms (%/10 years) and their determination errors (in parentheses), 1966 - 2009**

| Months | t | W | E | C |
|---|---|---|---|---|
| January | 1,76(±0,38) | 10,46(±2,07) | -13,77(±2,49) | 3,30(±1,69) |
| April | 0,10(±0,26) | 6,23(±0,98) | -5,51(±1,16) | -0,71(±0,97) |
| July | 0,31(±0,17) | 2,24(±0,88) | -2,48(±1,25) | 0,35(±0,92) |
| October | 0,64(±0,20) | 7,38(±1,42) | -2,96(±1,51) | -4,42(±0,91) |

The climate warming in the VFD manifested in all seasons. However, it was developed most rapidly in winter (up 0,680˚C / 10 years in January), and, as mentioned above, in March. However, it developed most slowly in May (0,02˚C / 10 years) and June (0,15˚C / 10 years).

The very significant indicator for the winter (January) warming in the VFD was the fact that after the peak warming in 2007 the trend of climate coldness appeared, which to some extent consistent with the results of [4; 11].

As mentioned above, the rates of climate warming on the territory of the Volga Federal District were significantly different. The geographic localization of foci with the highest and lowest values of KNLT (a) in January and July were largely similar. The highest rates (from 1,55 ˚C/10 years - in January and 0,55˚C/10 years - in July) warming developed in northern, north-western part of the Volga Federal District, on the left bank of the river Volga and in Bashkortostan, and the slowest values (from 1,25˚C/10 years - in January and to 0,05˚C/10 years - in July) - the southern and south-eastern parts of the county [1].

We have already noted that the rate of climate warming in the VFD during the last decade especially in winter and early spring were significantly ahead of the same indicators for the Earth as a whole and its hemispheres [1; 6]. Because of the long warming VFD inevitably experienced the significant changes in a number of different parameters of the thermal regime, widely used in climatology, during the planning of agriculture and other activities in the field of practice. We are talking about the changes of stable transition dates concerning the average daily temperatures at 0, 5, 10, 15 °C. During spring their offset was observed within early terms, and within later terms during autumn period. As a result, during the 55-year period (1955 - 2009) the duration of the warm period in the Volga Federal District increased at an average (for VFD) of 18 days and the duration of the period with temperatures over 15 °C lasted almost for 8 days [1].

The search for the causes of the rapid warming in the VFD is as problematic as in respect of its global manifestation [6; 15]. In this regard, the results of the previously mentioned publications [11; 13; 14] are of considerable interest, in which the climate changes of the past decades are considered due to the long-term changes of atmospheric circulation conditions.

To determine the significance of circulating factors in the long-term dynamics of the VFD thermal regime we carried out an appropriate tightness testing and the direction of synchronous links between long-term changes of air temperatures (t) averaged over the territory of the Volga Federal District and the corresponding changes of atmospheric circulation forms occurence according to G.Y. Wangenheim - A.A. Giers (W, E, C). The specified testing was performed during the 34-year observation period (1966 - 2009).

The examined table 1 shows that the climate warming within a specified period of history was accompanied by (statistically significant) the tendencies increasing the frequency of quasi zone (W) synoptic processes and the reduction of the eastern (E) form of circulation. The antiphased nature of long-term changes concerning the frequency of these forms of circulation was first described in [11]. According to the same data, the correlation coefficient between the rows of the annual days with the form W and E (1891 - 2012) made r (W, E) = - 0,77. The trends of long-term changes concerning the frequency of meridional (C) form of circulation according to our data were expressed weakly (Table. 1) (during the spring and summer time they were insignificant), and only in October there was a significant decrease of this type of synoptic processes frequencies (Table 1). Thus, within the considered historical period two opposing trends were dominated: the trend of quasi zone frequency increase (W) for synoptic processes and the trend of the east (E) circulation form decrease.

The analysis of the Table 1 data shows that these dominant and mutually opposing trends in the long-term variations of macrosynoptic processes W, E stimulated the winter (January) warming [r (t, W) = 0,59; r (t, E) = - 0,47] and, on the contrary, held back the pace of the summer (July) warming [r (t, W) = - 0,19; r (t, E) = 0,42]. In the above table the alphabetic variable $r_{0,05}$ = 0,30 represents the most random correlation coefficient [22] at a significance level of α = 0,05. As we see, the considered relations have a stochastic nature.

In support of the said facts, let's pay attention to the following important fact. In January, the maximum repeatability of the western form (NW = 20 days) was reached in 1988 [11], after which there was a long-standing tendency of its decrease. However, the January peak of warming, as was said, was recorded in 2007 (Table. 2).

The thermostatic importance of long-term fluctuations of circulation processes is quite obvious (Table. 2). This table shows the monthly amounts of days $N_W$, $N_E$, $N_C$ with the circulation forms and their deviations from the standard (at the averaging period of 1961 - 1990) during the years with extreme values of mean monthly air temperature anomalies (Δt) in the Volga Federal District for the entire measurement period (1966 - 2009).

**Table 2: Macrosynoptic conditions of the extreme air temperature anomalies (Δt, °C) development in the Volga Federal District (1966 - 2009)**

| Month | Years | Δt,°C | $N_W(\Delta N_W)$ | $N_E(\Delta N_E)$ | $N_C(\Delta N_C)$ |
|---|---|---|---|---|---|
| a) extremely cold years | | | | | |
| January | 1969 | -10,7 | 3 (-5,5) | 28 (12,8) | 0 (-7,3) |
| April | 1979 | -5,2 | 0 (-4,7) | 23 (5,4) | 7 (-0,7) |
| July | 1968 | -3,0 | 10 (4,4) | 4 (-14,8) | 17 (10,4) |
| October | 1976 | -6,9 | 0 (-10,7) | 27 (14,3) | 4 (-3,7) |
| б) extremely warm years | | | | | |
| January | 2007 | 8,4 | 20 (11,5) | 0 (-15,2) | 11 (3,7) |
| April | 1975 | 6,2 | 11 (6,3) | 12 (-5,6) | 7 (-0,7) |
| July | 1988 | 3,2 | 0 (-5,6) | 31 (12,2) | 0 (-6,6) |
| October | 1991 | 3,9 | 9 (-1,7) | 16 (3,3) | 6 (-1,7) |

Table 2 shows that all the biggest anomalies of the thermal regime were accompanied by the significant anomalies of atmospheric circulation conditions. For example, it is clear that if in the warmest January of 2007, the abnormal development were presented by the synoptic processes attributable to the W-shaped circulation ($\Delta N_W$ = 11,5 days), and in coldest January 1969 the synoptic processes attributable to the eastern circulation form ($\Delta N_E$ = 12.8 days) repeated abnormally often. Another example of the same kind: during the coldest July of 1968 the abnormal development was presented by the processes attributable to the meridional circulation form ($\Delta N_C$ = 10.4 days), and in the hottest July of 1988 the processes attributable to the E-form ($\Delta N_E$ = 12.2 days) prevailed. The circulation nature of extreme thermal conditions in April and October is no less obvious (Table 2).

Thus, the long-term fluctuations of the thermal regime in the Volga Federal District during the studied period under a certain extent were associated with the changes in the nature of long macrosynoptic processes. This is also evidenced by the estimates of multiple correlation coefficient values $R_{t,W,E,C}$ and the functions of air temperature (t) behavior taking into full account the cumulative impact of the changing circulation conditions on it. In the abovementioned table the literal value of $R_{0.05} = 0,42$ characterizes the most random value of multiple correlation coefficient [22] at the significance level of $\alpha = 0,05$. In this regard, we may see that the estimates $R_{t,W,E,C}$ in February, March, June, July, October and December are significant ones.

## SUMMARY

All cases of extreme thermal conditions in the Volga Federal District (1966 - 2009) were developed at large anomalies of atmospheric circulation conditions. However, a long-term climatic informative content of macrosynoptic processes relative to the same thermal mode dynamics is quite not the same and varies widely depending on the time of year - from 34 to 44% in February, August and December and no more than 10 - 13% in April and September, which is useful to consider during the development of theoretical climate models.

## CONCLUSIONS

- At the long-term dynamics of the thermal regime in the VFD from the beginning of the study period (1955) and up to (approximately) the middle of the first decade of this century the trend of global warming prevailed, which caused the decrease in the amplitude of the annual variation of air temperature, the change its stable transition dates through various limits (0, 5, 10, 15 °C) during spring into early periods and later into more long periods during autumn.
- The climate warming in the VFD was accompanied by long-term trends of western (W) circulation form frequency and the decrease of the eastern (E) circulation form frequency. These divergent trends stimulated the pace of winter warming and, on the contrary, held back the paces of summer warming in the VFD.

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