On the reaction of planetary altitudinal frontal zone to climatic changes

S V Morozova, K E Denisov, K S Kondakov, E A Polyanskaya, E I Ormeli, N K Kononova

1Saratov State University, Saratov, Russia
2Saratov State Agrarian University named after N.I. Vavilov, Saratov, Russia
3Russian Scientific Research and Design Technological Institute for Sorghum and Corn, Saratov, Russia
4Institute of Geography, Russian Academy of Sciences, Moscow, Russia
5A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS, Sevastopol, Russia

e-mail: swetwl@yandex.ru

Abstract. This article examines the dynamics of the planetary high-altitude frontal zone in two natural climatic periods of the state of the earth's climate system - the stabilization period and the second wave of global warming. A change in the area and intensity of the altitudinal frontal zone in different climatic periods was found. The planetary altitudinal frontal zone area expands and its intensity decreases from the stabilization period to the second wave of global warming. The climatic change in the area of planetary altitudinal frontal zone is opposite to the seasonal dynamics of this characteristic. Climate change in intensity is similar to seasonal change. The mechanism of action of negative feedback (air temperature - dynamics of the planetary altitudinal frontal zone) is discovered and described. For the first time, negative feedback has been applied to predict climate variability at finite time scales.

1. Introduction

The current state of the earth climatic system is regarded as global warming. The rise in surface air temperature for the entire globe is estimated at 0.075 °C per 100 years. Most experts believe that the observed increase in temperature is anthropogenic and explain this effect by the influence of carbon dioxide [9]. The results of model experiments, regularly published in the IPCC Assessment Reports, show a further steady increase in air temperature [3, 24]. Scenarios of upcoming climatic changes are considered to be rather mild and extremely radical as well [3, 24].

However, it should be noted that progressive changes in the earth climatic system (ECS) are extremely heterogeneous due to complex nonlinear interactions between its components. Assessment of nonlinear interactions in hydrodynamic models of the atmosphere is the most difficult task. Physical and statistical modeling gives an opportunity to assess the dynamics of nonlinear interactions and use obtained results for the development of a future scenario climate forecast. According to the authors, the most convenient and simple way of physical and statistical modeling is the use of feedbacks.

Feedbacks acting in the earth climatic system are the most important regulator of climatic dynamics. Positive feedbacks enhance the initial impact, thereby striving to disrupt the equilibrium state and cause irreversible changes in the ECS. Negative feedbacks contribute to the maintenance of an equilibrium state in the ECS, preserving the stability of the climate.

According to the authors [4], positive feedbacks are of the greatest interest, since they enhance the effect of anthropogenic impact. The authors of this work believe that the study of negative feedbacks
is also very important. Understanding the mechanisms of their action will make it possible to assess future climate trends, which is an important aspect of reducing climate risks and a necessary condition for the adaptation of human society to climate change.

Obviously, climatic changes at relatively short time intervals are determined by the planetary circulation regime, namely, by the dynamics of its structural elements. The purpose of this publication is to investigate the dynamics of the structural element of the planetary circulation for the upcoming assessment of climate fluctuations.

Materials and methods
The object of research was the planetary altitudinal frontal zone - a three-dimensional element of the atmospheric circulation on a global scale. Let us point out that its dynamics determines the weather and climatic instability in temperate latitudes. The section of the planetary altitudinal frontal zone was considered at the middle level of the troposphere on the isobaric surface of AT-500 hPa.

Let us point out that at present this structural object of circulation is increasingly becoming an object of research [7, 10, 11, 14, 20, 21, 23].

To characterize the planetary altitudinal frontal zone, many indicators are used, such as its length, intensity, latitude of the axial isohypse, area, tortuosity, etc. [1, 2, 22]. We point out that some of these characteristics are linearly related to each other, for example, the length and tortuosity, the latitude of the axial isohypse and the area bounded by this isohypse, etc.

In the present study, we selected such characteristics of planetary altitudinal frontal zone that do not exhibit a linear relationship with each other. These characteristics are area and intensity. It should be noted that the correlation coefficient between these values is close to zero.

The area of the planetary altitudinal frontal zone is understood as the circumpolar space bounded from the south by the axial line, or axial isohypse [1, 9]. The values of the center line for each month were selected according to the methodological developments of Yu. B. Khrabrov [22].

The magnitude of the geostrophic wind was taken as the intensity of the planetary altitudinal frontal zone. This characteristic was calculated using the well-known formula (1).

\[
V_g = \frac{9.8}{\ell} \frac{\partial H}{\partial n}
\]

where \( \ell \) is the Coriolis parameter \( (\ell = 2\omega \sin \phi) \),
\( \omega \) is the earth angular velocity,
\( \phi \) is the latitude of the axial isohypse,
\( H \) is the height of the geopotential of the isobaric surface, \( H = 500 \text{hPa} \),
\( \partial H/\partial n \) is the derivative of the geopotential height in the direction perpendicular to the tangent to the isohypse.

The data on the selected characteristics of the planetary altitudinal frontal zone are taken from the electronic supplement to the Reference monograph [18]. In [18], the latitude difference is taken as the intensity of the planetary altitudinal frontal zone. We assume that this characteristic is inversely proportional to the wind speed, so the authors of this publication decided to use the geostrophic wind speed as the intensity.

The dynamics of the planetary altitudinal frontal zone was calculated with reference to periods of climatic variability, which were called the Little Ice Age in Europe, the first wave of global warming, the period of stabilization, and the second wave of global warming. Figure 1 shows a graph of changes in the average surface air temperature anomalies in the Northern Hemisphere, plotted according to the site [http://www.cru.uea.ac.uk/cru/data/temperature/#datdow]). In this graph the time intervals clearly stand out, 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 XIX 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 at the middle of 1970s and continued until the present moment with an essential slowdown.

Let us point out that the authors did not work with the air temperature, but with its anomalies. Practically in all reputable domestic and foreign publications, in the works of highly respected scientists, studies of the temperature regime in the climatic plan are carried out on the basis of air temperature anomalies [3, 6, 19, 24]. We also note that the statistical processing of materials by the stepwise trend method requires the use of anomalies in the value [5, 8, 13]. Base period 1961 - 1990 (site http://www.cru.uea.ac.uk/cru/data/temperature/#datdow).

Figure 1. Variability of the average hemispheric air temperature

Trend lines are plotted at each of the four above-mentioned intervals. As can be seen from the Figure, the lines have different slopes, which is clearly from the values of the coefficients of linear trends $\alpha$, that differ not only in value but in sign as well. The boundaries of the intervals were determined by the stepwise trend method using the Kolmogorov-Smirnov criterion (95% significance level) [5, 8, 13]. 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 (2):

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

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.

The above formula calculated the boundaries of the confidence intervals, which are presented in Table 1. In addition, this table contains some statistical characteristics for each of the time series segments.

Table 1. Assessment of the statistical significance of changes in the average annual temperature anomalies in the Northern Hemisphere

| Period, year | Statistical characteristics of changes significance | Confidence interval |
|--------------|----------------------------------------------------|---------------------|
|              | $\alpha$ | $\hat{x}$ | $\sigma$ |                          |
| 1) Little Ice Age (1850-1907) | -0.0014 | -0.283 | 0.147 | [-0.508; -0.315] |
| 2) first wave (1908 – 1943) | 0.0163 | -0.185 | 0.194 | [-0.240; -0.130] |
| 3) stabilization (1944 – 1974) | -0.0058 | -0.020 | 0.124 | [-0.078; 0.038] |
| 4) second wave (1975 – 2016) | 0.0240 | 0.356 | 0.320 | [0.273; 0.439] |
According to Table 1, the coefficients of linear trends have an opposite slope in adjacent climatic periods. The absence of overlapping of the boundaries of the confidence intervals allows one to conclude that the change in the surface air temperature in the Northern Hemisphere is statistically significant. S.V. Morozova [17, 25, 26] suggested calling these climatic intervals the natural climatic periods of the state of the earth climatic system.

In this study, the state of the planetary altitudinal frontal zone was studied in two natural climatic periods - the stabilization period (1949-1974) and the period of the second wave of global warming (1975-2010).

Since changes in the character of atmospheric circulation were noticed in the mid-1990s, the interval of the second wave of global warming was divided into two smaller ones - the first, active phase of the second wave of global warming (1975 - 1995) and the second phase, the phase of warming development (1996 - 2010).

1996 was chosen as the boundary between these intervals, since according to the materials of the Evaluation Report [3] in the mid-90s of the XX century there was a sharp change in the frequency of occurrence of processes corresponding to the three main forms of circulation - E, W and C; an increase in the frequency of occurrence of the E and C form processes and a decrease in the frequency of W form processes. N.K. Kononova [12] showed that since 1995, the greatest total duration of elementary circulation mechanisms has been observed. She [12] found out that since 1995 the greatest total duration of elementary circulation mechanisms has been observed. The sharp change in the prevailing forms of circulation indicates active restructuring processes in the atmosphere. Thus, the boundaries of the identified phases within the second wave of global warming are supported by circulation. Moreover, the application of the Kolmogorov - Smirnov criterion revealed that 1996 was the year of the homogeneity violation.

2. Results

Since the dynamics of the planetary altitudinal frontal zone is considered against the background of the observed climatic variability, and the best indicator of climatic variability is the near-surface air temperature, we will estimate the degree of linear relationship between the selected characteristics of the planetary altitudinal frontal zone and the average near-surface temperature of the Northern Hemisphere.

Table 2 shows the correlation coefficients between the planetary altitudinal frontal zone area and the average hemispheric surface air temperature in the natural climatic periods selected for the study. The significance of the correlation coefficients (α = 0.05) was estimated by the formula / r / <t<σ (t<σ is Student's test, σ is the standard deviation of the correlation coefficient).

**Table 2.** The values of the correlation coefficients between the global temperature anomalies and the area of the planetary altitudinal frontal zone (significant correlation coefficients are put in bold).
According to Table 2, only half of all correlation coefficients were statistically significant. In addition, the correlation coefficients have different signs. Such heterogeneity indicates instability of connections. The revealed nonstationarity confirms the complexity and nonlinearity of interactions between the selected characteristics, as well as the nonlinearity of interactions within the earth climatic system between its components. We point out that similar conclusions were made when assessing the correlations between changes in the average hemispheric temperature of the surface air layer and the intensity of the planetary altitudinal frontal zone.

To study the nonlinear interactions between the studied characteristics (the area of the planetary altitudinal frontal zone, its intensity and air temperature), we will consider the change in the area and intensity of the planetary altitudinal frontal zone against the background of the observed climatic variability.

Table 3 shows the change in the area of planetary altitudinal frontal zone in two climatic periods as a whole for the year and in the central months of the winter and summer seasons. According to Table 3, during the transition from a colder period to a warmer one (from the stabilization period to the second wave of global warming), an increase in the planetary altitudinal frontal zone area occurred. Moreover, such dynamics is observed both throughout the year as a whole and in the central months of the main seasons of the year [15, 16]. The revealed dynamics corresponds to the displacement of the axial line of the planetary altitudinal frontal zone to more southern latitudes, which results in the expansion of the area of the planetary altitudinal frontal zone. It should be noted that with the seasonal dynamics from the cold to the warm period (from winter to summer), there is a reverse movement - the area of the planetary altitudinal frontal zone shrinks, and the planetary altitudinal frontal zone itself shifts to the north. Thus, it was found out that the climatic dynamics of the planetary altitudinal frontal zone area is opposite to its seasonal dynamics [1, 2, 9].

Table 3. Changing the areas of the planetary altitudinal frontal zone in various natural periods of the earth climatic system state.

| Period                        | Area of the planetary altitudinal frontal zone, mln km² |
|-------------------------------|--------------------------------------------------------|
|                               | average annual | January  | July                      |
| 1949-1974 (stabilization)     | 56.97          | 62.44    | 56.15                     |
| 1975-2010 (second wave of     | 57.77          | 64.19    | 59.58                     |
| global warming)               | an increase of 1.5% | an increase of 3% | an increase of 6%         |

Unfortunately, the graphic representation of the planetary altitudinal frontal zone in two climatic periods is very indistinct and difficult to read due to the large number of superimposed isohypsoms. Therefore, the figure is not shown.

Let us consider another characteristic of the planetary altitudinal frontal zone - its intensity. Figure 2 shows the change in the average annual speed of the geostrophic wind in two natural climatic periods of the state of the earth climatic system - stabilization and the second wave of global warming.
Figure 2. Change in the average annual speed of the geostrophic wind

According to Figure 2, during the transition from the cold to the warm period, the geostrophic wind speed decreases. A similar trend can be traced practically in all months. The table 4 shows the slope coefficients of the linear trends in the geostrophic wind speed for all months of the year (tabl.4).

Table 4. Coefficients of the linear trends

| Month     | Coefficient values | Month     | Coefficient values | Month     | Coefficient values | Month     | Coefficient values |
|-----------|--------------------|-----------|--------------------|-----------|--------------------|-----------|--------------------|
| December  | -0.004             | March     | -0.057             | June      | -0.071             | September | -0.016             |
| January   | -0.047             | April     | -0.031             | July      | -0.029             | October   | -0.005             |
| February  | -0.010             | May       | -0.002             | August    | 0.006              | November  | -0.004             |

It should be noted that the climatic change in the planetary altitudinal frontal zone intensity is consistent with the seasonal dynamics: atmospheric circulation becomes less intense in warmer periods (the second wave of global warming, summer seasons).

Thus, it is possible to conclude, that during the climatic transition from the cold to the warm period, the intensity of atmospheric circulation decreases, while the planetary altitudinal frontal zone moves to the south and its area expands.

The movement of the planetary altitudinal frontal zone to the south presupposes an increase in the area of the circumpolar space, that is, the area of below zero temperature anomalies. Thus, the rise in hemispheric mean temperatures is inhibited. This conclusion does not contradict the role of the planetary altitudinal frontal zone in climatic processes - the separation of areas of negative and positive temperature anomalies, and smoothing of temperature contrasts between the pole and the equator. The difference is that, in synoptic processes, the contrasts between the pole and the equator are equalized by means of inter-latitudinal air exchange by increasing the degree of meridionality of flows.

Let us check the last assumption on the materials of 1975 - 2010, corresponding to the second wave of global warming, in the development of which a significant decrease in its rate was recorded.

Table 5 shows the change in the area of the planetary altitudinal frontal zone during two phases of the second wave of global warming.

Table 5. Changing the areas of the planetary altitudinal frontal zone.

| Period                  | Area of the planetary altitudinal frontal zone, mln km² |
|-------------------------|--------------------------------------------------------|
|                         | average annual | January | July            |
| 1975-1995 (active phase)| 58.51          | 68.5    | 60.03           |
| 1996-2010 (retarding phase)| 56.70        | 58.15   | 58.98           |
|                         | decreasing by 3% | decreasing by 15% | decreasing by 2% |
According to Table 5 the area of the planetary altitudinal frontal zone decreases during the second wave of global warming.

The analysis of the dynamics of the planetary altitudinal frontal zone area during the second wave of global warming showed that in most months, during the transition from the first phase of warming to the second phase, there is a decrease in the average areas of the planetary altitudinal frontal zone in eight months. At the same time, at the end of the studied interval of the second wave of global warming in some months, an increase in the speed of the geostrophic wind was observed. As an example, we can cite the change in the speed of the geostrophic wind in August (Figure 3), which is the most “quiet” month in relation to the variability of the wind regime.

Figure 3 shows a decrease in the speed of the geostrophic wind from the stabilization period to the second wave of global warming and an increase in the intensity of atmospheric circulation during the second phase of the second wave of global warming. Let us note that a decrease in wind speed during the active phase of the second wave of global warming is indicated in other publications [3, 19, 24].

\[ \Delta t > 0 \rightarrow \Delta S > 0 \rightarrow \Delta V < 0 \rightarrow \Delta t < 0 \]

\[ \Delta t < 0 \rightarrow \Delta S < 0 \rightarrow \Delta V > 0 \rightarrow \Delta t > 0 \]

**Figure 3.** Change in geostrophic wind speed in August

Described dependences of the characteristics of the global circulation object (planetary altitudinal frontal zone) and the air temperature can be represented in the form of negative feedback, reflecting the operation of the natural model (Figure 4). In this figure, the symbols \( \Delta t \), \( \Delta S \), and \( \Delta V \) denote changes in the average temperature of the hemisphere, the area of the planetary altitudinal frontal zone and the average speed of the zonal wind, respectively.

According to the above, the general circulation of the atmosphere can be considered as a factor hindering the development of modern warming and contributing to the preservation of a fragile climatic and ecological balance in the earth climatic system. This conclusion does not contradict the position of the climate theory about the role of the planetary circulation as a mechanism that puts the earth climatic system into a state of equilibrium.

The revealed tendency of changes in the area of the planetary altitudinal frontal zone and the average speed of the zonal wind can determine the nature of the upcoming climatic changes - the onset of the next short period of stabilization against a higher temperature background, followed by an increase in the wind regime in the hemisphere.

The suspension of global warming observed since the mid-10s of the XXI century confirms the existence and effect of the identified negative feedback. Figure 5 shows a short stabilization period, representing climatic fluctuations against the background of warming.
Figure 5. Northern Hemisphere mean temperature changes and natural climatic periods

Thus, we can conclude that using physical and statistical modeling it is possible to predict short-term climatic fluctuations.

3. Conclusions
In the course of the study, the following conclusions were obtained:
1. The object of circulation on a global scale (the planetary altitudinal frontal zone) reacts to climatic changes in the Northern Hemisphere by changing its characteristics - area and intensity.
2. During the transition from a colder period to a warmer one, the area of the planetary altitudinal frontal zone expands and its intensity decreases.
3. The climatic change in the intensity of the planetary altitudinal frontal zone is similar to the seasonal, the climatic change in the area of the planetary altitudinal frontal zone is opposite to the seasonal one.
4. Changes in the characteristics of the planetary altitudinal frontal zone against the background of the observed climatic trends are implemented as a negative feedback.
5. Physical and statistical modeling of processes in the terrestrial climate system makes it possible to predict short-term climatic fluctuations.

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5. References
[1] Baidal M Khanzhina DG 1986 Long-term variability of macrocirculation climate factors. (Moscow)
[2] Bashkirova L I and Ped D A 1996. Proceedings of the State Medical Center 328 19-34
[3] Second Assessment Report of Roshydromet on Climate Changes and Their Consequences on the Territory of the Russian Federation 2014 (Moscow)
[4] Ginzburg AS and Demchenko PF 2019 Physics of the atmosphere and ocean 5594 – 113
[5] Gmurman V E 2003 Theory of Probability and Mathematical Statistics (Moscow)
[6] Gruza G V and Rankova E.Ya 2012 Observed and expected climate changes in Russia: air
temperature (Moscow)

[7] Durneva E A and Chkhetiani O A 2021 *Meteorology and Hydrology* 6 24-33.
[8] Isaev A A 1988 Statistics in meteorology and climatology (Moscow)
[9] Kanter CA 1965 *Climate and weather issues in the Lower Volga region* 1 29-39
[10] Kleshchenko L K and Aristova L N 2007 *Proceedings of VNIGMI-MCD* 173 128-136.
[11] Kleshchenko L K and Rankova E Ya 2007 *Proceedings of VNIGMI-MCD* 173 97-112.
[12] Kononova NK Classification of the circulation mechanisms of the Northern Hemisphere according to B.L. Dzerdzeevsky 2009 (Moscow)
[13] Malinin V N 2007 Statistical methods for the analysis of hydrometeorological information (Saint-Petersburg)
[14] Martynova Yu V and Krupchatnikov V N 2015. *Proceedings of the Russian Academy of Sciences. Physics of the atmosphere and ocean* 51 346-357.
[15] Morozova S V 2014 *Izvestiya of the Saratov University* 14 25-30.
[16] Morozova S V 2015 *Proceedings of VNIGMI-MCD* 180 67-75.
[17] Morozova SV The role of planetary circulation objects in global climatic processes 2019 (Saratov)
[18] Neushkin AI, Sidorenkov NS, Sanina AT, Ivanova TB, Berezhnaya TV, Pankratenko NV and Makarova ME 2013 Monitoring of the general atmospheric circulation. North hemisphere. (Obninsk)
[19] Perevedentsev Yu P 2009 Climate theory (Kazan)
[20] Razorenova O A 2016 *Meteorology and Hydrology* 1, 5-16.
[21] Razorenova O A and Shabanov P A 2020 *Turbulence, Atmosphere and Climate Dynamics*, 95.
[22] Khrabrov Yu B 1957 *Proceedings of the TsIP* 63 3-19
[23] Chichasov G N 2020 *Hydrometeorology and Education* 1, 9-19.
[24] Intergovernmental Panel on Climate Change, Climate change 2013 (Cambridge)
[25] Morozova SV, Polyanskaya EA, Ivanova GF, Levitskaya NG, Denisov KE and Molchanova NP 2018 *IOP Conference Series: Earth and Environmental Science* 107
[26] Morozova S V, Polyanskaya E A, Kononova N K, Molchanova N P and Solodovnikov AP 2019 *IOP Conference Series: Earth and Environmental Science* 381