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# A study of the mutual influence of global circulation objects by a method of dispersive analysis

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**Abstract.** Three structural elements of the general circulation of the atmosphere on a global scale are considered: the Arctic oscillation, the Southern Oscillation, and the planetary tall frontal zone. The degree of influence of the Arctic Oscillation and the Southern Oscillation on the dynamics of the planetary tall frontal zone is estimated. The assessment is carried out by a method of analysis of the variance, which allows assessing the significance of the influence of one or more meteorological quantities of the studied value. A comparison of the variances has shown that the degree of influence of these objects on the dynamics of the planetary high altitude zone is 6% from the Arctic Oscillation and 7% from the Southern Oscillation. A comprehensive analysis has shown that the planetary high-altitude frontal zone has the highest intensity with negative anomalies of the Arctic Oscillation and the Southern Oscillation, and the lowest one with negative anomalies of the Arctic Oscillation and positive anomalies of the Southern Oscillation. A comparison with the Fisher criterion has not revealed any statistical significance. An important conclusion is formulated about the predominance of the influence of inherent internal processes in the dynamics of the planetary high-altitude frontal zone in comparison with the circulation structures adjacent to it.

## 1. Introduction

It is well-known that the greatest climatic variability is typical for the temperate latitudes, whose main circulation feature is active cyclonic activity. The directions of the air flow are determined by the deformation of the planetary tall frontal zone (PTFZ) - a three-dimensional object of circulation on a global scale encircling the entire globe. The curvature of the PTFZ and strong development of wave processes in it lead to an increase in the degree of meridionality of the flows, so that sharp invasions of cold air masses into the southern latitudes occur in the rear parts of the baric hollows, and powerful heat removal to the Arctic is observed in the rear parts of the high-altitude baric ridges.

This process is accompanied by the activation of the Arctic center of action, which is reflected in a more active penetration into the moderate latitudes of the Arctic anticyclones. At the same time, a cyclonic curvature is formed in the deformation region of the PTFZ. When the ridges of subtropical anticyclones propagate northward, an anticyclonic curvature arises in the PTFZ.

Thus, the PTFZ functions not isolated from other structures of the general circulation of the atmosphere, and it is directly affected by their influence. Circulating objects of the arctic and tropical latitudes are adjacent to it. The main circulation structures in them are the Arctic Oscillation and the Southern Oscillation, respectively.

It remains an open question: to what extent do the circulation objects adjacent to it have a strong influence on the planetary tall frontal zone, do the wave processes in the PTFZ develop under the influence of smaller-scale structures (centers of action of the atmosphere), or the curvature of fluxes in the PTFZ results from its own internal dynamics? It should be noted that parametric estimates of the



interaction and mutual influence of the structural elements of the general atmospheric circulation of various space-time scales are practically absent.

The purpose of this paper is to assess the influence of the Arctic Oscillation and the Southern Oscillation on the dynamics of the planetary altitude frontal zone.

In this work, the task is to assess the influence of circulation structures of high and low latitude on the planetary high-altitude frontal zone.

Assessment of the influence of one or more factors on the object being studied can be carried out by different methods. Thus, the authors of [1] evaluated the contribution of the radiation exposure of greenhouse gases and multidecadal oscillations to the near-surface temperature trends using an autoregressive model.

The contribution of a single factor to the studied value is estimated much more simply. The authors of [2] obtained a quantitative assessment of the influence of one variable on another by a determination coefficient  $R^2$ . The predictor is the second variable in the case of an obvious causal relationship.

In papers [3, 4], the contribution of the influence of one quantity on another is also estimated using the coefficient of determination, but in this case the causal relationship does not seem obvious.

According to the authors of this study, in cases where a causal relationship is not obvious, it is better to use the analysis of variance (factor analysis). Factor analysis allows us to assess the significance of the influence of one quantity on another. This technique makes it possible to evaluate individually the effect of the first investigated quantity on the second one, and vice versa, the effect of the second quantity on the first one. This method of factor analysis also allows you to evaluate the influence of a set of factors on the value being studied.

## 2. Material and methods

The source materials for the study were the data on the Arctic Oscillation and the Southern Oscillation taken from the site ([origin.cpc.ncep.noaa.gov](http://origin.cpc.ncep.noaa.gov)).

Quite a few parameters are used to characterize the planetary height frontal zone: the area, length, tortuosity, intensity, width of the location of the axial isohypse, etc. [5]. In the present study, for the analysis of the dynamics of PTFZ, its characteristic was chosen as intensity.

The rate of geostrophic wind  $V_g$  at the average level of the troposphere is taken as the intensity of the PTFZ. The geostrophic wind speed is calculated by the formula

$$V_g = \frac{9.8}{l} \frac{\partial H}{\partial n}, \quad (1)$$

where  $l$  is the Coriolis parameter ( $l = 2\omega \sin\varphi$ ),

$\omega$  is the angular velocity of the Earth's rotation,

$\varphi$  is the latitude of the axial isohypse,

$H$  is the height of the geopotential of the isobaric surface of 500 hPa,

$\frac{\partial H}{\partial n}$  is the derivative of the geopotential height in the direction perpendicular to the tangent

to the isohypse.

In the numerical estimation of  $V_g$ , the derivative was approximated by the ratio  $\Delta H / \Delta n$ , where  $\Delta H$  is the difference in the geopotential heights, and  $\Delta n$  is the distance along the normal to the tangent drawn at a given point of the isohypse. Given that in monthly (and even more so in annual) averaging, isohypses on an AT-500 map are usually parallel, the change in the distance normal to the tangent was considered identical to the change in the distance along the meridian. In this case  $\Delta n = \Delta \varphi \cdot 111 \cdot 10^3 \text{ m}$ .

By formula (1), the average annual geostrophic wind speeds from 1957 to 2015 were calculated. The obtained values are taken as the intensity of the PTFZ.

The problem posed in this study was solved by using the methods of analysis of variance, allowing one to evaluate the significance of the influence of one value (or several values) on another. The essence of the analysis of variance consists in comparing the factor dispersion generated by the effect of a factor and the residual dispersion due to random causes. If the difference between these variances is significant, the factor has a significant impact on the quantity  $X$  being studied.

Let  $S_x$  denote the total sum of squares of deviations of the observed values from the total average;  $S_f$  is the factor sum of the squared deviations of group means;  $S_z$  is the residual sum of the squares of deviations of the observed values of the group from the group average. Then  $S_x$  characterizes the scattering of values relative to a common average;  $S_f$  is scattering between the groups; and  $S_z$  is scattering within the group.

Thus, we find that  $S_x$  characterizes the overall variability of  $X$ ;  $S_f$  is the variability of the magnitude under the action of the studied factor  $f$ . If the factor has a significant impact on the value of  $X$ , the group of observed values of the trait at one particular level will differ from the groups of observations at other levels. Consequently, the group averages will also differ, and the more they are scattered around a common average, the stronger will be the influence of the factor. The value of  $S_z$  characterizes the variability due to the influence of random or unrecorded factors [6,7].

Since the magnitude of  $X$ , in addition to the factor  $f$ , is also affected by random causes, the observations of the same group are different and scattered around their group average. Therefore, to estimate random causes, the deviations of the observed values of each group from their group average are calculated. In this case, the average of the observed values at each level (in each gradation) will also differ significantly.

Hence,  $S_x = S_f + S_z$ .

In practice, the sum of the deviations  $S_x$  and  $S_f$  is usually calculated, and the residual sum of the deviations is found as  $S_z = S_x - S_f$  [1].

For calculations we use the formula [1]

$$S_x = \sum^n x_i^2 - \frac{1}{n} (\sum^n x_i)^2 \quad (2)$$

$$S_f = \sum^q \frac{\sum^{m_i} (x_i)^2}{m_i} - \frac{1}{n} \left( \sum^n x_i \right)^2; \quad (3)$$

Dispersions are found, respectively, by the expressions:

$$\sigma_f^2 = \frac{S_f}{K_f}, \sigma_z^2 = \frac{S_z}{K_z}, \sigma_x^2 = \frac{S_x}{K_x}, \quad (4),$$

In this case,  $K_f = q - 1$ ,  $K_z = K_x - K_f$ ,  $K_x = N - 1$  are the numbers of degrees of freedom, where  $q$  is the number of levels (gradations) of the studied factor;

$N$  is the total number of observations.

In multivariate analysis of variance, the study breaks down into two stages. At the first stage, the significance of the influence of all complexes on the studied value is revealed. This is done according to the single-factor analysis formulas. Since the uniformity (randomness) of each complex of factors is important in multivariate analysis, the formulas change.

$$S_x = \sum^q \sum^p x_i^2 - \frac{1}{pq} \left( \sum^q \sum^p x_i \right)^2, \quad (5)$$

$$S_f = \frac{1}{p} \sum \left( \sum x_i \right)^2 - \frac{1}{pq} \left( \sum \sum x_i \right)^2, \quad (6)$$

where  $q$  is the number of complexes, and

$p$  is the number of cases in each complex.

If the first stage is established, then we proceed to the second stage. At the second stage, the significance of the influence  $F > F_p$ , of each combination of factors on the studied value  $x$  is established. This is done based on the calculation of the Fisher criterion according to the formula [7]:

$$F = \frac{pqp}{(pq + p)\sigma_z^2} (\bar{x}_q - \bar{x}_{pq})^2, \quad (7)$$

where  $\bar{x}_q$  is the average value for this complex; and

$\bar{x}_{pq}$  is the total average.

Complexes for which  $F > F_p$  have a significant impact on the change in  $x$ . The value  $F_p$  is found based on the level of significance (usually 5%) and degrees of freedom  $k_f = 1$  and  $k_z = k_{z1}$ , where  $k_{z1}$  is the number of degrees of freedom found at the first stage.

### 3. Results and discussion

Since the influence of the characteristics of the Arctic Oscillation and the Southern Oscillation on the intensity of the PTFZ is being studied, it is these characteristics that are divided into gradations. For splitting into gradations, we apply the standard statistical procedure: by the formula  $k = 5 \ln N$  we determine the number of gradations, and by the formula  $l = (x_{max} - x_{min}) / k$  we determine the width of the gradation.

The values of the PTFZ intensity are distributed according to the gradations [2]. The table shows the distribution of the intensity of the PTFZ from the intensity of the Arctic oscillations.

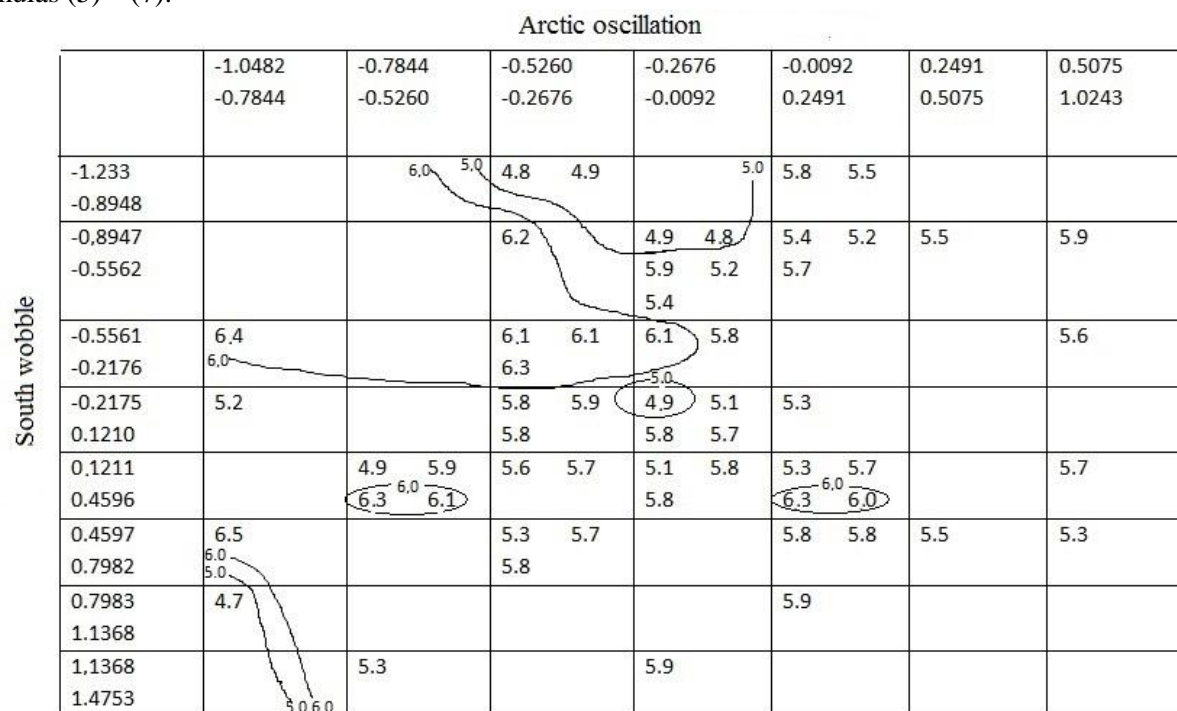
The total sum of squared deviations calculated over the entire series was 1888.3, while the factor sum of squares was 233.3. The ratio of the calculated variances according to Fisher's criterion at the 95% significance level did not show the statistical significance of the contribution of the Arctic Oscillation to the change in the PTFZ intensity. The contribution of the Arctic Oscillation to the variability of PTFZ is estimated at 6%. Similar results on the absence of the influence significance were obtained for the Southern Oscillation. The contribution of the Southern Oscillation to the PTFZ intensity is estimated at 7%.

**Table.** Interval values of PTFZ intensity depending on Arctic oscillations.

Characteristic	Gradations of intensity of the Arctic Oscillation						
	1.04;-0.78	-0.78;-0.53	-0.5;-0.27	-0.27;-0.01	-0.01;0.25	0.25;0.51	0.51;1.02
Amounts	22.6	27.9	80.0	87.2	73.6	22.2	22.5
Number of cases	4	5	14	16	13	4	4
Average value	5.7	5.6	5.7	5.5	5.7	5.6	5.6

The calculated correlation coefficients between the intensity of the planetary tall frontal zone and the indices of the Arctic Oscillation and the Southern Oscillation turned out to be 0.02 and -0.03, respectively.

In addition to one-factor analysis, the authors performed a multivariate analysis. The simultaneous influence of two factors — the Arctic Oscillation and the Southern Oscillation — on the variability of the planetary altitudinal frontal zone was estimated. The calculations were carried out according to formulas (5) – (7).



**Figure 1.** Dependence of the intensity of the planetary high-altitude frontal zone on the intensity of the Arctic Oscillation and the Southern Oscillation.

The figure shows a graphical interpretation of the influence of two factors - the Arctic Oscillation and the Southern Oscillation - on the PTFZ intensity. One can see in the figure that the lowest values of the PTFZ intensity are observed for negative anomalies of the Arctic Oscillation and positive anomalies of the Southern Oscillation. That is, when the Arctic anticyclone is weakened and the subtropical one intensifies, the PTFZ intensity is weakened. The highest intensity of the PTPZ is observed with negative anomalies of both the Arctic oscillations and the Southern Oscillation. That is, in the case of weakening of both the Arctic and subtropical anticyclones, the PTFZ exhibits the highest intensity. Thus, in this study we obtained parametric estimates of the impact of adjacent circulating structures – the Arctic and the Southern Oscillations - on the planetary frontal zone. However, these estimates did not show the statistical significance of such an impact. Therefore, it is possible to make an important conclusion that the dynamics of the planetary high-altitude frontal zone is determined more by the processes occurring in the region of its localization than by the effect of circulating structures adjacent to it.

## Conclusions

1. The planetary tall frontal zone is affected by objects of circulation of high and low latitudes adjacent to it: the Arctic Oscillation and the Southern Oscillation. The degree of influence is estimated as six and seven percent, respectively.

2. The intensity of the planetary tall frontal zone depends on the intensity of the Arctic Oscillation and the Southern Oscillation. The PTFZ has the highest intensity with negative anomalies of the Arctic Oscillation and the Southern Oscillation, and the lowest one with negative anomalies of the Arctic Oscillation and positive anomalies of the Southern Oscillation. However, this effect is statistically insignificant according to the Fisher criterion.

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