Climate changes in European Russia in 2001-2018

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Abstract  From the data of observations at 43 aerodromes in European Russia and the neighboring countries for 2001-2018, linear trends are calculated of temperature, humidity, and pressure, and then compared against the temporal changes in pressure field patterns. The latter are estimated on the basis of objective analysis data, using a special software. The linear trends show that the trends of annual-mean and season-mean temperature are positive practically at all the sites, though mean temperature in separate months can exhibit both decrease (in January) and strong increase (in December and summer months). The annual mean dew-point deficit increases in time almost everywhere, while surface pressure increases in the north (larger) part of the area and decreases in its south part. It is shown also, by means of objective classification of pressure field patterns, that the growth of cyclonic situations occurrence frequency dominates in the south part of the area, and the growth of anticyclonic situations occurrence frequency dominates in its main, north part. This result is consistent with the pressure trends distribution over the area.

1. Introduction
Within the general problem of global climate change, local climate changes in separate regions are of particular interest. In the paper, this respect of the problem is considered on an example of European Russia and the neighboring countries - Ukraine, Belarus, Moldova, and the Baltic states. The database of meteorological observations at 43 aerodromes situated in this area, and the data of objective analysis are used for the period of 2001-2018. It is a high temporal resolution (30 min) that we chose observational data at aerodromes for our analysis. Our approach differs to some extent from previous studies which have been summarized in [1], not only because of other time period and aerodrome observations used, but mainly because of dynamic characteristics included into consideration. The regression analysis of the aerodrome observations is carried out, and linear trends are determined of the weather main characteristics, such as air temperature, dew point deficit, surface pressure, and some characteristics of the clouds. The calculated trends at 5% significance level along with simultaneous changes in frequency of cyclonic and anticyclonic synoptic situations are presented and discussed below.

2. Air temperature
In Fig. 1, the spatial distribution of the linear trends of annual mean temperature is displayed. It can be seen that annual mean temperature increases with time everywhere. Positive trends are higher in the west and north parts of the area and lower in its east part. The trends are insignificant at 4 sites only (Nalchik, Chisinau, Riga, Ulyanovsk). The season-mean trends (not shown) are positive, too, almost
everywhere (with exception for negative trends of summer-mean temperature in Riga and autumn-mean in Ulyanovsk). Note that autumn-mean trends are insignificant at 24 aerodromes, while for other seasons, the trends insignificant at 5% level are obtained at 13-15 sites.

Figure 1. Linear trends of annual mean temperature at the aerodromes, °C/10 years.

However, within the season, month-mean temperature trends (not shown) are not homogeneous. For instance, in December, all the significant month-mean temperature trends are positive and often exceeding the values of annual-mean temperature trends, while in January, month-mean temperature trends are everywhere negative (with exception for Sochi) and in a number of sites exceed 1 °C/10 years and even 2 °C/10 years.

So, Decembers become warmer, and Januaries colder with time during the period under study. No other months with negative trends at a number of aerodromes are revealed. On the contrary, warming is observed in April (positive trends everywhere but Arkhangelsk), in May, June and September at all sites, and in August (but Riga).

3. Air humidity

Trends of annual-mean dew-point deficit quantity (Fig. 2) almost at all sites are positive, which imply the air humidity decrease, or, which is the same, the air dryness
increase, on annual average. At three coastal aerodromes - Arkhangelsk, Riga, and Anapa - the trends of annual-mean dew-point deficit are negative, that is, the air humidity increases with time (for 0.39, 0.32, and 0.62 °C/10 years, respectively). At other coastal aerodromes - St.-Petersburg, Tallinn, Odessa - the annual-mean trends are insignificant, with wintertime mean trends negative (not shown). It is to note that at many sites situated far from the coast the wintertime trends are also negative, and so are the month-mean trends in December. In fact, the trends of month-mean dew-point deficit in December are negative at 20 sites and positive at two sites only (Salekhard and Sochi). This is consistent with the above-mentioned warming in December. The humidity decrease, revealed by annual-mean trends, is a result mainly of positive trends of dew-point deficit in summer: at 34 sites, the summer-mean dew-point deficit trends are positive, and only in Riga and Arkhangelsk they are negative. In June, the month-mean dew-point deficit trends are especially high - up to 1, 2, and even 3 °C/10 years; only in Arkhangelsk, the trend is negative.

![Figure 2. Linear trends of annual mean dew-point deficit at the aerodromes, °C/10 years; yellow, < 0.5; orange, 0.5 to 1.0; red, > 1.](image)

In total, one can conclude that the air dryness growth cannot be considered homogeneous over the area or over all months or seasons. However, at a majority of
the aerodromes, annual-mean humidity decreases with time, mainly due to its strong decrease in summer.

![Figure 3. Linear trends of annual mean pressure at the aerodromes, °C/10 years: positive (yellow) and negative (blue).](image)

4. **Air pressure**

Let us consider now the trends of surface pressure (Fig.3). Note that the "background" pressure, that is, the first terms, $a$, in the regression equation $a + bt$, decrease smoothly from south to north: the contours of 1016, 1014, 1012 hPa are oriented almost along the latitude circles (not shown). On this background, the annual mean pressure trends are found positive in the north part of the area and negative in its south part. (The significant trends of annual mean pressure are obtained at 24 sites, from which, 6 trends, at the south part of the area, are negative). Distribution of the month-mean pressure trends is also informative (not shown). For instance, in January, the month-mean trends have almost everywhere the same sign as the trends of annual mean pressure, but exceed them in absolute values. Their distribution over the area is rather smooth. In April, July, and December, month-mean pressure decreases with time at all aerodromes where the trends are significant (that is, at 30, 30, and 22 sites, respectively). The only exception is Sochi, where the trend of month-mean pressure in April is positive. On the contrary, the pressure growth
with time is well pronounced in February (all 35 significant trends are positive), in August (from 32 significant trends, only two are negative - in Anapa and Saratov), and in November (all 37 significant trends are positive).

These results imply that there exist some features of atmospheric circulation operating at the whole area or at least at its larger part.

5. Pressure field topography and its trends

5.1. Objective classification of surface pressure patterns

Connection between surface pressure changes and atmospheric circulation evolution can be to some extent estimated by analyzing the surface field topography and its changes. The pressure objective analysis describes the latter well enough at the synoptic scales. We have used a software for objective classification of surface pressure field patterns (synoptic situations).

The program has been developed in [2] and then used as a part of a method for atmospheric front objective detection [2-4] and for other studies. This program has been designed to classify the synoptic situation within the grid square of 2.5x2.5° into one of the following 24 classes:

0 - low-gradient field,
1 - saddle,
2 - center of anticyclone,
3 - center of cyclone,
4 - ridge,
5 - trough,
6 - 13 - eight sectors of the anticyclone (NE, SW, NW, SE, W, E, S, N),
14 - 21 - eight sectors of the cyclone,
22 - rectilinear pressure contours,
23 - non-identified fields.

The program classifies the situation in the central square of an elemental field of 4x4 gridpoints, in which, the pressure values are given. This is carried out by means of a simple method of pattern recognition. For each of 24 classes, a set of standard fields is suggested. The 16-point elemental field is compared against each of standard fields by means of correlation rate calculation. The elemental field is classified to the class for which the correlation rate between the standard and elemental fields is maximum and not less than 0.7. (The correlation rates between the standard fields of different classes do not exceed 0.54 - the significance threshold for 16 points.) Thus each gridsquare is considered together with its vicinity, and the pressure field is not divided into parts with rigid boundaries.

5.2 Cyclonic and anticyclonic patterns and their trends

The program is applied to the surface pressure objective analysis fields for 00 and 12 UTC daily during the 2001-2018 period, within the latitude and longitude ranges of 37.5 to 72.5 °N and 7.5 to 82.5 °E, respectively, which embrace the area under consideration. Then, the gridquares with cyclonic situations (that is, the classes 3, 5, 14-21) and those with anticyclonic ones (the classes 2, 4, 6-13) are collected separately, and occurrence frequencies of both are calculated within the 2.5° latitude bands or in the gridquares in which the aerodromes are situated. When the
occurrence frequency trends are calculated, it is revealed that the trends are large enough and reasonably distributed over the area.

From Fig. 4 it can be seen that the annual-mean frequency trends for both types of situations are positive within the latitude ranges corresponding to European Russia. However, at the south, low positive or large negative trends of anticyclonic situations frequency occur along with large positive trends of cyclonic ones. As a result, cyclonic situations occurrence frequency will grow faster in the south part of the area. In the main, north part of the latter, frequencies of both types of situations grow with time, but that of anticyclonic situations grows faster. The trends of both types of situations are especially large in summer, and thus they determine the annual-mean frequency trends.

![Figure 4](image1.png)

**Figure 4.** Linear trends of cyclonic (right) and anticyclonic (left) situations frequency: annual mean (upper panel), winter mean (middle panel), and summer mean (lower panel). At the vertical axis, 10 units correspond to 1%/10 years changes in frequency.

This result is consistent with the above-mentioned surface pressure growth in the main (north) part of the area and pressure decrease in its south part.

From Fig. 4, it can be concluded that total occurrence frequency of cyclonic and
anticyclonic situations grows with time over the area under consideration. That implies increasing synoptic vortices activity in the area during the period.

As it has been pointed out in [5], the highs and lows - the synoptic-scale vortices with quasi-vertical axes - represent elements of so called geostrophic turbulence which develop preferentially in almost continuous belts in the midlatitudes over the globe and display certain systematic behavior in time and space. In particular, there exist areas with mainly cyclonic and mainly anticyclonic rotation of wind [6]. It would be of interest to reveal, at the time series with pronounced trends, if, along with changes in temperature and other weather characteristics, the geostrophic turbulence regime exhibits any changes, too.

6. Conclusions
As it is shown by the presented results of regression analysis of the aerodrome observations time series, significant linear trends exist in air temperature, humidity, and pressure during the 2001-2018 period at the majority of sites.

So, the annual-mean temperature increases with time over the whole area of European Russia and the neighboring countries. The same changes are typical, in general, for the season-mean temperature, while the month-mean temperature trends exhibit less homogeneous behavior. For example, it is found that Decembers become warmer and warmer practically over the whole area, while Januaries become colder. Also, April to June and August-September become warmer with time, which provide positive trends of the annual mean values.

Practically over the whole area, positive trends of annual-mean dew-point deficit (that is, air dryness growth) are obtained, so that the air humidity decreases with time on annual average and especially in summer, while in the winter months, humidity growth is observed at the majority of the sites.

The annual-mean surface pressure trends are positive in the north (larger) part of the area and negative in its south part. The seasonal and month-mean pressure changes are not homogeneous: in separate months, its growth or decrease occur over most part of the area. Simultaneously, occurrence frequency of the anticyclonic situations in the surface pressure field (as revealed by objective analysis data) increases faster in the north, larger part of the area, than that of cyclonic situations. In the south part of the area, on the contrary, faster growth is obtained of cyclonic situations frequency, which is consistent with the changes of surface pressure at the stations.

References
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