The analysis of the long – term dynamic of the amount of atmospheric precipitation on the territory of the republic of Bashkortostan

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Abstract. The article presents the analysis of long-term dynamics of the amounts of atmospheric precipitation on the territory of the Republic of Bashkortostan for the 30 meteorological stations for the period between 1966 and 2015. The territorial patterns in the distribution of precipitation, the analysis of time variability were described. The trend analysis was used to analyse the time variability, the tendencies on the Republic and its separate regions were revealed. The authors made an attempt to link interannual changes with indices of atmospheric circulation.

1. Introduction
The role of precipitation is big for the formation of hydrothermal conditions and water balance of any territory. This important hydrothermal indicator is experiencing significant changes in individual years or seasons due to the steady trend of global warming. Climate changes also in the regional level.

Currently, there are many works that are devoted to climate change and individual climate elements. A number of scientific studies reflect the influence of atmospheric circulation on the long-term dynamics of air temperature and precipitation. This paper presents studies on the analysis of long-term changes in precipitation using the example of the territory of Bashkortostan.

The territory of the Republic of Bashkortostan (hereinafter – RB) has a complex orthography, because it’s located at the junction of the Russian plain and the Ural Mountains. This leads to a significant differentiation in the territorial distribution of precipitation. The territory of the republic is divided into the Pre-Urals, Trans-Urals (more flat parts) and the Southern Urals (mountainous part). Changes in the amounts of precipitation appear in these regions in different ways.

2. Materials and methods
Data of long – term meteorological observations from 30 meteorological stations between 1966 and 2015 were used to analyse long – term dynamics of atmospheric precipitation. The authors used the traditional methods of statistical processing, where the basic method was the trend analysis. The form of the linear trend equation $y (t) = at + b$, where $y (t)$ is the average sum values of the precipitation at the time $t$ (1,2,3,..., n), $a$ is the angular slope coefficient of the trend line which characterizes the rate
of change of the precipitation sum, \( b \) is a free term (the initial value of the trend line). Thus, a positive value of the angular slope coefficient of the trend line shows an increase in precipitation, and a negative value indicates a decrease [9, 10, 12].

3. Results

During the consideration the spatial patterns of distribution of atmospheric precipitation in the Republic of Bashkortostan it should be noted that, in general, precipitation amounts increase from South to North, but overall zonal distribution is strongly influenced by relief. The average annual precipitation varies from 816 millimeters on the Ufa Plateau (Pavlovka meteorological station) to 332 millimeters in the Trans-Urals (Akyar meteorological station). The amount of precipitation is strongly depends on orographic conditions. They range from 600 millimeters per year in the Northern part to 420 – 450 millimeters per year in the Southern part in the lowland part of the Urals and they increase in the Bugullminsko – Belebeevskaya upland to 550 millimeters per year. The precipitation increases in the Ufa plateau (to 550 millimeters/year). The annual amount increases to 580 – 680 millimeters per year in the mountains of the southern Urals. There is also a natural decrease in precipitation in the southern part of the mountainous region (between 680 and 570). The amount precipitation decreases in the Bashkir Trans-Ural which is located in the “rain shadow”. The amount of precipitation decreases from North to South in the meridional extended Trans-Ural region (between 430 and 330 millimetres per year).

The distribution of precipitation during the cold period (November – March) has a more complex character – the latitudinal distribution is replaced in this season almost by the meridional one. During the cold period, they are influenced by the orographic features. The largest number is typical for the mountainous and northern parts of the republic (150 – 250 millimetres on average). The average precipitation is 120 – 160 millimetres with an increase of up to 200 millimetres in the Pre-Urals. The amount of precipitation in the cities of Ufa and Sterlitamak exceed the above-mentioned zonal distribution (212 and 192 millimetres per period). The smallest amounts fall out in the Trans-Urals and the northeastern part of the republic (95 – 105 and 110 – 130 millimetres). The average number for the cold period in the republic is 170 millimetres; the largest amount is noted on the Ufa Plateau (333 millimetres), the smallest is in the Trans-Urals (94 millimetres) [3, 4].

Territorial differences in the distribution of precipitation are somewhat smoothed out in the warm period. The largest precipitation is typical for the central region of the Southern Urals. The amount of precipitation decreases in all directions from the Southern Urals, although the largest value is noted on the Ufa Plateau (483 millimetres).

The temporal and interannual variability of this element terms of annual, seasonal and monthly periods was characterized by the coefficient of variation. The coefficient of variation of the annual precipitation increases from north to south from 16 – 18% to 23 – 25%. The distribution of seasonal precipitation has a similar pattern. The highest values fall in February, March, April (on average 67%), October (64%), the lowest values – in December (51%), October (52%), November (53%). Thus, the coefficients of variation have a large variation in the warm period which forms the largest contribution to the temporal variability of annual sums [3].

The results of the analysis of interannual changes and their main trends boil down to the following main conclusions. In general, throughout the territory of the Republic, the angular slope coefficient of the trend line of the annual precipitation is positive (Fig. 1). This sign is determined by significant values of the annual angular slope coefficient of the trend line at the Sterlitamak, Pavlovka, Buzdyak, Karaidel meteorological stations and the predominance of a positive sign in most of the weather stations.

The averaged coefficient of the angular slope of the trend line for annual precipitation in the Republic of Bashkortostan is 5.03 millimetres per 10 years. The range of fluctuations is very significant (from – 22.33 millimetres to 21.51 millimetres per 10 years). It should be noted that only 7 stations are characterized by negative trends. Minimal negative values are observed in the southern part of the Southern Urals (from – 22.33 millimetres to – 14.27 millimetres per 10 years). The
maximum positive values fall on the southern part of the Pre-Urals (from 17.53 millimetres to 21.51 millimetres per 10 years).

![Angular slope of the trend line of the average monthly and annual precipitation amounts](image)

**Figure 1.** The angular slope of the trend line of the average monthly and annual precipitation amounts (Millimetres per 10 years) (1966-2015).

The highest average of the positive coefficient of the angular slope of the trend line in the country is observed in March (3.22 millimetres / 10 years). In this case, trend lines are characterized by a good degree of significance. The maximum values in this month fall again in the southern part of the Pre-Urals (5.68 – 7.75 millimetres per 10 years), as well as the Ufa Plateau (6.02 millimetres per 10 years). Also significant angular slopes of the trend line are observed in May and August and they account for 2.24 and 2.22 millimetres per 10 years, respectively.

July (-5.36 millimetres per 10 years), September (-1.09 millimetres per 10 years), June (-0.96 millimetres per 10 years), October (-0.33 millimetres per 10 years) are characterized by negative averaged values of the angular slope of the trend line in the republic. Consequently, in all months of the warm period there is a decrease in precipitation (except August).

The July distribution of the angular slope of the trend line is of interest because of the significant variability of precipitation. All meteorological stations have negative coefficients this month. Such kinds of results are not observed in any other month. The most significant angular slope of the trend line appears very locally and with several hot spots. On the one hand, the northern half of the republic is experiencing the largest decline in July precipitation (from -9.26 to -7.35 millimetres per 10 years); on the other hand, the northern parts of the Southern Urals and Trans-Urals (from -7.69 to -7.37 millimetres per 10 years) are also characterized by significant coefficients.

Interannual changes are caused by the peculiarities of the frequency of circulation processes, which are also reflected in the dynamics of the multi – year relationship between the zonal and meridional components of the general circulation of the atmosphere. Atmospheric circulation fluctuations have been defined as circulation periods of a zonal and meridional character depending on the relative dominance of different forms of circulation during these periods. The authors examined the mechanisms of influence of the indices of atmospheric circulation of NAO, AO, SCAND on atmospheric precipitation [5, 8, 11].
The effect of circulation indices on precipitation and their changes (and also variability) is complex. The results of the analysis of pair correlation by month are presented in Table 1. It can be noted that for the warm period with the NAO index, the highest correlation values fall in April ($r = 0.42$). The contribution of the April connection is reflected in the values for the entire warm period and even for a year.

**Table 1. Correlation of precipitation for cold, warm, annual periods (averaged over the Republic of Bashkortostan) with atmospheric oscillation indices by months (1966-2015).**

| Period | with NAO index | with AO index | with SCAND index |
|--------|----------------|---------------|------------------|
|        | C.P. W.P. C.P. W.P. C.P. W.P. | C.P. W.P. C.P. W.P. |
| I      | -0.04 0.10 | -0.03 0.10 | -0.03 -0.19 |
| II     | 0.04 0.09 | 0.03 0.07 | -0.48 -0.58 |
| III    | 0.16 0.16 | 0.13 0.10 | -0.40 -0.03 |
| IV     | -0.13 0.42 | 0.03 0.12 | -0.25 0.14 |
| V      | -0.13 0.20 | 0.08 0.10 | -0.005 0.12 |
| VI     | -0.11 0.18 | 0.09 0.21 | -0.04 0.01 |
| VII    | 0.17 -0.06 | -0.09 -0.24 | 0.11 -0.01 |
| VIII   | -0.06 -0.03 | 0.13 -0.17 | -0.28 -0.02 |
| IX     | -0.15 -0.10 | -0.08 0.09 | 0.07 -0.19 |
| X      | -0.08 0.15 | 0.14 0.20 | -0.04 -0.16 |
| XI     | -0.17 0.26 | -0.14 0.17 | -0.28 -0.03 |
| XII    | -0.003 0.27 | 0.10 0.16 | -0.22 0.08 |
| Year   | -0.11 0.36 | 0.08 0.21 | **-0.44** -0.12 |
| C.P.   | 0.07 0.12 | 0.02 0.06 | -0.14 -0.16 |
| W.P.   | -0.16 0.24 | 0.13 0.18 | -0.15 -0.05 |

Weak direct NAO connections in November and December are found with precipitation of the warm period. No significant relationships were found with precipitation of the cold period.

The largest positive values of the AO index are in June, October (0.21, 0.20, respectively) and negative – in July (-0.24). As in the case of the NAO, the connections of precipitation of the cold period with monthly indices of AO are insignificant.

The opposite situation is observed with the SCAND index. The largest values of the correlation coefficients fall on precipitation of the cold period. It is important to note that they are almost all negative. The most significant values are found in February and March (-0.48 and -0.40, respectively). Weak feedbacks are in August, November, April and December. The inverse relationship is -0.44 with the annual value of the index (20% contribution).

### 4. Discussion

The territory of Bashkortostan has a complex orography, which is manifested in the uneven distribution of precipitation. Global warming has an impact on the change of a given climate element throughout the entire territory.

### 5. Conclusion

The annual precipitation for the period between 1966 and 2015 (averaged over the republic) is 525 millimetres. In general, there is a zonal distribution of precipitation – a decrease in their number from north to south. At the same time, the amount of precipitation increases within the South Urals and it decreases in the Trans-Urals. During the analysing the changes, a positive trend appears. Thus, the annual amount of precipitation increases by 5 millimetres per decade. Maximum values are typical for the southern half of the Cis-Urals. However, there are some regions with negative trends which were identified (the southern part of the Ural Mountains). The largest intra – annual changes are detected in
March, for most meteorological stations the trend lines are positive with a good degree of significance. The highest correlation coefficients of precipitation amounts were found with the circulation index SCAND (the most significant connections are negative and are typical for the months of the cold period).

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