Spatial distribution of temperature and precipitation in the South Ural Region

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Abstract. The study presents the features of the spatial distribution of temperatures and precipitation within the Southern Urals based on the analysis of daily observations within 2004–2018. The study suggests the reasons for zones of temperature and precipitation distribution. There is a nature of the formation of climatic zones by the regime of moistening determined. The azonal differences of the western and eastern slopes of the Southern Urals are differentiated. Local causes of latitudinal differences in temperature and meridional physiographic features are shown. Monitoring observations of the annual course of precipitation and multidimensional classification identified 5 humidification zones. The causes are described by discriminant functions. This complicates the analysis of altitudinal differentiation and enhances the role of azonal factors. A set of identified causes is formed, including during human activities.

1. Introduction

The fluctuation of climatic indicators at the regional level are determined primarily by the physical and geographical features of the region, as well as the activity of the atmosphere. However, the natural boundaries to which the chains of low Ural mountains belong have a significant impact on the regime and distribution of temperature and precipitation in the territory of the Southern Urals. Fluctuations of air temperatures and precipitation are extremely spatially heterogeneous [1]. This is noted at the regional level, indicators [2, 3]. Also, one can not ignore that the natural causes of azonality are superimposed by anthropogenic. There is an azonal differentiation formed during the process of their interaction. Climatic zones and subzones are separated since the amount of precipitation has a main role. The aim of the study is to reveal the leading factors that influence the differentiation of temperature and humidification in space. The main tasks are focused on studying and characterizing the dynamics of average daily humidification and temperature regimes within 2004–2018, assessing quantitative and qualitative changes, as well as mapping the current spatial distribution of climatic parameters over the territory of the Southern Urals.

2. Methods and materials

The temperature conditions and humidification assessment was conducted using 15-year series of average daily observations of air temperature and precipitation at 24 meteorological stations in the Southern Urals: Ulu-Telyak, Verkhny Ufaley, Zlatoust, Katav-Ivanovsk, Miass, Nyazepetrovsk, Argayash, Bredy, Brodkalmak, Verkhneuralsk, Chelyabinsk, Troitsk, Kizilskoye, Kartaly, Magnitogorsk, Akyar, Zilair, Tukan, Kostanay, Dalmatovo, Shumikha, Kamensk-Uralsky, Mikhailovsk, Sysert.
The observation results were classified on the basis of mathematical and statistical methods [4] including cluster analysis of the similarity matrix calculated on the basis of the normalized Pearson correlation coefficient (1-\( r \)) with grouping into clusters according to the Ward method [5, 6]. Also, a non-parametric multidimensional data scaling was presented according to the values of temperature and precipitation, and the selected axes were estimated by the correlation method using the Tau-Kendall criterion and statistical methods [7]. The spatial distribution of temperature and precipitation was estimated by the results of spatial interpolation using the Inverse Distance Weighted (IDW) method.

3. Results

The nature of the spatial distribution of average annual temperatures in the Southern Urals determine the following features of the thermal regime of the territory (Fig. 1).

The spatial arrangement of the zones identified by the average monthly temperatures per year for the Southern Urals is characterized by meridional strike and considered different from the latitudinal arrangement. This is especially evident in the region of the mountain systems of the Southern Urals and Ural Tau.

The meridional zone of the western macro-slope and the western spurs of the Ural Range is limited, extending in the North-south direction and determined by the weather data of the stations Nyazepetrovsk, Verkhneuralsk-Tukan. The formation of this zone is associated with the meridional transport of cold air masses along the eastern slope and western ridges of the southern part of the Ural Mountains. This zone is characterized by the lowest monthly average temperatures for a calendar year [8].

The next zone to study is in the North-South and is determined by weather data from the Upper Ufaley – Zlatoust stations, as well as along the Argayash – Miass – Katav-Ivanovsk line. The azonal nature of the temperature distribution is associated with a complex orographic situation in the studied area. The area of the Katav-Ivanovsk-Miass weather stations gravitates to a zone of higher average annual temperatures close to the temperatures of the western macro slope of the Southern Urals. The formation of this zone is also associated with the meridional transport of cold air masses along mountain ranges. The Katav-Ivanovsk weather station area forms an alpine zone, and the higher temperatures of this zone and proximity to the temperatures of the southeastern part of Bashkortostan are probably associated with the railway crossing the southern part of the Ural Range. The highway forms a valley along which warm air masses penetrate the center of the highland zone.

The temperature distribution in the study area is characterized by a more sub-latitudinal strike in the Trans-Urals. This becomes significantly notable during the summer period everywhere on the European territory of the country [9]. In this case, the maximum temperature ranges are distinguished by a shift to the North-East, assuming a latitudinal position along the Argayash – Shumikha, Chelyabinsk – Brodokalmak lines, but the zone of influence of meridional transport remains on the eastern slope. Also, the closer to the eastern slope is, the meridional transition zone of the foothills are the more clearly defined. They are extended from the North-East to the South-West (along the Dalmatovo – Kamensk – Ural Argayash – Miass line) and characterized by average annual temperatures of up to 3 °C. According to the temperature terms this zone is close to the more northern territory in the south of the Sverdlovsk region (Sysert weather station). The flat gradient Trans-Ural zone lays in the direction of the South-East. The flat gradient of the Southern Urals belongs have a single temperature range. This part of the territory has two temperature zones – the Northern and Southern with a latitudinal distribution of temperatures. But the heterogeneous nature of temperature conditions determines local meridional temperature subbands [10]. The study area, Chelyabinsk and Kostanay (the Republic of Kazakhstan) are isolated, but not allocated, into separate zones of the territory of large agglomerations.

Thus, the distribution of temperature indicators in the Southern Urals is meridional in nature, associated with the meridional transfer of cold in the direction of the ridge and the influence of cold air masses rolling down from the ridge in the Eastern direction. Accordingly, the climatic zoning of the territory of the Southern Urals is known meridional.
Figure 1. Spatial distribution of average annual temperatures in the South Urals

The results of discriminant analysis confirmed the correct clustering of weather stations and the allocation of temperature zones – the classification accuracy for all groups of weather stations is 100%. Moreover, the model of discriminant analysis has three statistically significant functions distinguished. They determine the nature of the temperature distribution within the studied territory. An analysis of the structure of the model (Table I) showed that in the annual temperature dynamics, the determining factors for the formation of heat supply zones in the Southern Urals are (in decreasing order) average annual temperatures: January – September – March.

In addition, the factors determining the heat supply zones of the South Urals are: according to the first function (Root 1) – decrease in average annual temperatures and the highest temperatures in September, the second (Root 2) – the warmest July and coldest September, the third (Root 3) – the warmest are April and July.

Thus, the distribution of temperature indicators in the territory of the Southern Urals is associated with the influence of the southern part of the Ural Mountains, meridional cold transfer in the direction of the ridges, and the influence of cold air masses rolling down the ridge. The determining temperatures are the temperatures of January, September and March, as well as, to a much lesser extent, July and April temperatures. There is a peculiar set of meridional temperature zones in the area of mountain ranges characterized by the specificity of average monthly and annual average temperatures.
Table 1. Temperature indicators included in the discriminant analysis model and their connection with discriminant functions *

| Factors     | Discriminant Function Analysis Summary | Standardized Coefficients for Canonical Variables |
|-------------|----------------------------------------|-----------------------------------------------|
|             | Wilks' Lambda | Partial Lambda | F- remove | p-value | Root 1 | Root 2 | Root 3 |
| IV          | 0.01          | 0.88           | 0.58      | 0.64    | -0.43  | -0.17  | 1.78   |
| III         | 0.01          | 0.51           | 4.10      | 0.03    | -1.84  | 0.46   | -0.49  |
| I           | 0.03          | 0.21           | 16.52     | 0.00    | 2.30   | 1.31   | 1.20   |
| IX          | 0.02          | 0.41           | 6.36      | 0.01    | 4.58   | -3.37  | -1.24  |
| VII         | 0.01          | 0.63           | 2.56      | 0.10    | -1.06  | 3.29   | 1.45   |
| Yearly average | 0.01        | 0.55           | 3.55      | 0.04    | -5.07  | -1.50  | -1.16  |
| XI          | 0.01          | 0.74           | 1.50      | 0.26    | 2.04   | 0.44   | -0.26  |

* – statistically significant indicators are in bold

The spatial distribution of the yearly rainfall average in the Southern Urals is similar to the temperature distribution, but there are territories with a different distribution (Fig. 2).

The study revealed that the districts of the weather stations Nyazepetrovsk and Verkhneuralsk are allocated in a separate minimum precipitation zone, characterized by the lowest yearly average amounts, as well as the least snowy winter period. This is due to the fact that both regions are located in the rain shadow zone formed by the southern spurs of the Ural and the Ural-Tau ridge.

In the flat part, the dry zone of rain shadow forms a peculiar plume starting from Verkhneuralsk and conically expanding to the southern part of the Chelyabinsk region (weather stations Akyar and Breda), stretching to the North-East of the Orenburg region (weather station Akyar) and North-West of Kazakhstan. There are the lowest yearly rainfall average in the area of the Kizilskoye weather station.

The northern and central parts of the territory of the Southern Urals and the western part of Northern Kazakhstan cover one zone, with a yearly rainfall average of 40–45 mm. There is also a transition zone to the “rain shadow” with an average annual rainfall of 35–40 mm, which has the character of two loops extending north of Verkhneuralsk to the South-West (Magnitogorsk weather station) and to the southeast (Kartaly weather station). The reason for the decrease in precipitation is the weakening of the cyclonic circulation in the winter, at which time the territory is influenced by the region of increased pressure from Central Asia.

This is the area with high level (abnormal) of the yearly rainfall average. These are the cities of Chelyabinsk and Troitsk, with its high level of yearly average precipitation associated with industrial pollution of the air basin and high dustiness of the air, which forms the nuclei of condensation of precipitation. The Argayash weather station located in the leeward of the Ural ridge anomaly with a low amount of precipitation. And also the latitudinal anomaly of a high level of precipitation associated with the railway crossing the Urals is observed along the Ulu-Telyak-Katav-Ivanovsk-Zlatoust line. Accordingly, air masses from the West, stick along the highway and cause high temperatures, a significant amount of precipitation with immense precipitation in the Katav – Ivanovsk and Zlatoust regions.

Monitoring observations of the annual precipitation and multivariate classification reveal 5 humidification zones (Fig. 3), characterized by specific indicators of average monthly precipitation levels (Table II).

Firstly, the meridional southern steppe zone (1) is determined by the data of the Akyar – Kizilskoye – Bredy – Kartaly weather stations. This zone coincides with the highest temperature zone and the Southern and Central part of the Southern temperature zone and is characterized by the least amount of precipitation in late spring – the beginning of summer (May – June), and also at the end of summer and in the autumn period (August – November). Also, this zone has the lowest average values of precipitation per year. The reason for the decrease in precipitation is the weakening of the cyclonic circulation in the winter, at which time the territory is influenced by the region of increased pressure from Kazakhstan.
Table 2. Average sediments (mm) for the allocated water security zones of the South Urals

| Zone | I    | II   | III  | IV   | V    | VI   | VII  | VIII | IX   | X    | XI   | XII  |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1    | 22.4 | 26.5 | 30.1 | 34.4 | 33.9 | 43.2 | 47.4 | 33.4 | 26.3 | 32.8 | 22.1 | 26.4 |
| 2    | 24.3 | 22.2 | 38.1 | 41.3 | 64.8 | 78.8 | 78.7 | 60.9 | 56.8 | 46.2 | 43.4 | 27.0 |
| 3    | 23.4 | 22.5 | 32.6 | 36.8 | 47.4 | 54.9 | 85.3 | 66.0 | 35.9 | 33.4 | 29.3 | 26.2 |
| 4    | 22.0 | 18.6 | 29.9 | 30.4 | 52.0 | 66.3 | 89.0 | 49.8 | 37.0 | 36.6 | 32.8 | 22.0 |
| 5    | 25.1 | 27.1 | 40.0 | 40.5 | 35.5 | 48.3 | 38.5 | 47.6 | 46.0 | 52.5 | 44.9 | 34.6 |

Figure 2. Spatial distribution of yearly average precipitation in the Southern Urals

There is a transition zone formed in the Northern part of the Urals (3), which has a latitudinal strike and is determined by the data of the weather stations Magnitogorsk – Verkhneuralsk – Troitsk – Kostanay. The zone is characterized by "average" for the Southern Urals monthly precipitation for the calendar months and highest precipitation in July – August. This territory almost completely coincides with the Northern part of the Southern temperature zone. Also, the indicators of this zone correspond to the monthly average precipitation in the area of the Sysert weather system, located closer to the Middle Urals. This conditionally disjunctive nature of the zone is explained by the fact that the Sysert region is located in the Middle Urals rain shadow.

The central (forest-steppe) part of the Southern Urals is occupied by the moisture supply zone, determined by the data of the Upper Ufaley – Argayash – Chelyabinsk – Brodokalmak – Shumikha weather stations (4), characterized by meridional strike in its Northern and Central parts. This zone is also characterized by the "average" for the Southern Urals indicators of the average monthly rainfall.
for the growing and subsequent autumn period with a high level in July. But, unlike the more southern zone, it is characterized by the least rainfall for the Southern Urals in winter and spring (December – April). This zone coincides with the central part of the northern temperature zone of the Trans-Ural part.

Figure 3. Zoning of the Southern Urals territory by monthly average precipitation totals per year

The mountain and foothill zones of moisture supply (2), the windward northern and southern slopes, and the leeward northern parts, limited by the data of the Zlatoust – Katav-Ivanovsk weather stations (meridionally extending section of the mountain zone of the Southern Urals) and the foothill weather station Miass, meteorological station Mikhailovsky (Separately, stand out) are separately distinguished. western slope of the Northern Urals) and weather stations Kamensk-Uralsky and Sysert. The zone is characterized by the highest average annual rainfall and the highest rainfall during the calendar spring – summer – fall. At the same time, the mountainous region (weather stations Zlatoust – Katav – Ivanovsk) coincides with the high-mountain low-temperature zone of the Southern Urals and is characterized by the maximum rainfall for the region during the period of spring – autumn.

As for the pre-Ural zone (5) which is defined by the data of weather stations Nyazepetrovsk-Ulu-Telyak-Tukan-Zilair, has a meridional character of strike in the region of the western macro slope of the Southern Urals and Ural-Tau. The zone shows a combination with temperature indicators and is characterized by the highest average sums of precipitation in winter and early spring (March-April). The most significant increase in seasonal precipitation in Russia is observed in spring, and this is especially true for the territory of Western Siberia. In this connection, the formation of the zone is associated with air masses coming from the Arctic along the western ridges of the Ural Mountains during this period, as well as a change in baric fields over the European part of Russia, and especially over the open spaces of Western Siberia.

The results of discriminant analysis confirm the correctness of zoning – the accuracy of classification according to precipitation data, as in the assessment of temperatures, is 100 % for all groups of weather stations. However, the leading factors determining the moisture supply zones were not identified by discriminant analysis. The model suggests four discriminant functions: the first determined by the decrease in precipitation in the calendar spring (March to May), the second – by the high precipitation in summer, as well as in spring, the third – only by the high precipitation in spring,
finally the latter – by low precipitation in the calendar winter (especially December and February) and dry climate in July. Thus, all monthly precipitation totals turned out to be to one degree or another the determining features of the allocation of moisture supply zones. It should be noted that the time interval available for analysis includes a 10-year period of growth in spring precipitation (at a 1% level, it is noted as significant) in the ERP, the Urals, and Western Siberia, which undoubtedly affects the overall analysis, since each of the functions is a combination of the general trend. In addition, there are changes in temperature parameters in mountainous regions noted everywhere [10]. However, there are negative trends in temperature growth, as well as fluctuations in humidification regimes leading to shifts in high-altitude (landscape belts, changes in the productivity of high-mountainous landscapes and a decrease in stability due to an increase in the frequency of adverse short-term meteorological phenomena [11, 12].

4. Conclusion
The study results show the indicators of thermal and moisture supply for the territory of the Southern Urals. The character of the formation of climatic zones according to the humidification regime and the leading factors of their formation is obtained according to the monitoring of temperatures and precipitation.

The first stage of the study presents the thermal and moisture conditions of the weather stations of the Chelyabinsk region and adjacent territories.

The second stage presents the analysis and assessment of temperature and moisture availability indicators. It was determined that the distribution of temperatures and precipitation for the territory of the Southern Urals is characterized mainly by the meridional nature of zones, while the zones identified according to modern monitoring data differ from those previously determined. There are an abnormally cold and dry zones identified, localized in the area of the weather stations Nyazepetrovsk and Verkhneuralsk. Also, an abnormality in the distribution of temperatures and precipitation (high level) was revealed for the high mountain zone of the Chelyabinsk region, associated with the railway crossing the Urals in the latitudinal direction. Within the seasonal changes mainly latitudinal vectors of change of climatic zones are determined. The leading factor in this zone is the temperature during the active growing season, as well as warmth in December and dry weather in March. The second most important group of factors is formed by high temperatures from March to November (excluding July), as well as features of the monthly course of precipitation – their high level from January to March and arid – from April to November.

At the third stage, climatic parameters were mapped to obtain thematic maps for the territory of the Southern Urals. Five climatic zones are determined, the formation of which is associated within the influence of altitude, periodic droughts in the summer, and also seasonal temperature dynamics.

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