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Climatic aspects of sustainable development of the Republic of Tyva

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Abstract. The results of the work of the meteorological station in Kyzyl for 135 years are considered. The features of global climate warming in mountain basins are largely represented. To trace the dynamics of temperature changes over a longer period, the results of observations of changes in the average monthly and annual temperatures of the low-lying air of the city of Kyzyl in the Tuva basin and at the nearest meteorological station in the city of Minusinsk in the basin of the same name were used. The distance between them is about 350 km. Data analysis from 1885 to 2020 He showed that in the conditions of the mountainous climates of Siberia, it is not enough to focus on the generalizing results of changes in climatic conditions, fluctuations in the temperature regime, which may exceed the rate of modern warming in the polar regions. In this regard, when conducting climate monitoring of environmental facilities, it is important to assess the regional features of climate change.

1 Introduction

In the modern period of climate change, the assessment of its current state and possible future changes is an urgent and important scientific and practical problem. It is known that climate has always had and is having a great impact on all aspects of life on Earth, but nowadays, due to the huge increase in the scale of economic activity, society's dependence on climate and its changes has increased dramatically. The growing interest in the problem of climate and its changes is associated with a number of rather large climatic anomalies in recent decades. Another important factor influencing the increased interest in climate change is the understanding that, as a result of increasing economic activity, humanity itself has unintentionally begun to influence the climate.

The next important factor increasing interest in the problem of climate change was the lack of a scientific base to assess the impact of climate on the economy, geoecological and social aspects of the further development of society.

The main reason for this situation is that the climate problem has proven to be very complex. It is one of the complex interdisciplinary scientific problems, and in the past the necessary scientific and logistical base was not created to solve it.

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The problem of changes in the climate system is global in nature. The study of climate change cannot be solved either partially or completely at the regional or global level. Climate change is currently being monitored through a network of meteorological stations in different countries. Assessments of climate change and the role of anthropogenic factors have been carried out by, assessment reports have been published, and assessment reports on the territory of the Russian Federation have been published, which are the final generalizations of Russian scientists in this field.

Many generalizing materials claim significantly higher rates of increase in surface temperature due to anthropogenic factors within the Russian Federation compared to other territories and global indicators. This conclusion is highly doubtful because the economic development of the eastern regions did not occur quickly, and the population density is extremely low in most of the territory.

As follows of the Russian Hydrometeorological Service, in recent decades it has been warming in Russia almost twice as fast as in the Northern Hemisphere: by 0.51 °C per decade, while every decade since 1981-1991 [1-3]. In this regard, in [4], the spatial and temporal features of the surface temperature regime in the Russian Federation were considered using ERA5 reanalysis data for 1950-2020. As a result of the study, the authors identified nine quasi-homogeneous climatic regions for the entire continental territory of Russia:

- The north of the European part of Russia (EDR) and Western Siberia.
- The northern part of Eastern Siberia and Yakutia.
- Chukotka and the north of Kamchatka.
- The center of the Arctic.
- The center and south of Western Siberia.
- The center and south of Eastern Siberia.
- The Far East.
- Altai and Sayan Mountains.
- Southern region.

Significant differences in the rates of temperature regime change are noticeable in the selected climatic regions.

The proposed work examines in more detail the changes in the temperature regime in 49% of the mountainous territory of the Republic of Tuva.

The interest in the influence of mountain systems is associated with a very strong influence on the thermal regime of the absolute altitude of the terrain, orographic conditions, meteorological stations are located mainly in wide mountain valleys or basins, where the most favorable living conditions for people are created. In the eastern regions of the Russian Federation, in the conditions of the formation of the Asian anticyclone during the cold period and the occurrence of temperature inversions, a peculiar effect of changes in surface temperature may occur.

2 Materials and methods

The data at meteorological stations located within the Republic of Tuva were used. In various forms of relief, including in intermountain basins.

Meteorological observations began at the Kyzyl station in 1943. The study of climatic conditions within the Republic of Tyva was carried out by many authors [5-8]. Unlike many types of scientific and technical information, information about the state of the climate does not become obsolete over time. Its value increases over the years. The longer the series of observations, the more useful information can be obtained about climate change. To trace the dynamics of temperature changes over a longer period, the results of observations were used at the Minusinsk meteorological station closest to Kyzyl, where meteorological observations began in 1885. The distance between these stations in a straight line is about 350 km, which suggests the possibility and expediency of extending the series of average monthly surface air temperatures at the Kyzyl station until 1885. It is known that it is advisable to bring the average monthly air temperatures at a distance of 300-400 km [9]. The uniformity of the main climate-forming processes in southern Siberia made it possible to restore the values of air temperature in Kyzyl according to observations in Minusinsk. The average monthly air temperatures at the Kyzyl station were adjusted according to the data of the Minusinsk station using the regression method. The criterion for the reasonableness of reduction [9] is determined by the formula (1):

$$r(a,b) > \frac{0.5\sigma(\mathrm{a})}{\sigma(\mathrm{b})} \quad (1)$$

Where r(a,b) is the correlation coefficient between temperatures at station a (Kyzyl) and station b (Minusinsk); σ(a) is the average square deviation of a series of temperature observations at the cited Kyzyl station.; σ(b) is the average square deviation of a number of temperature observations at the Minusinsk reference station.

The calculations used data from simultaneous temperature observations at both stations over a multi-year period (1943-2020). Table 1 shows the coefficients of linear paired correlation of average monthly air temperatures, their average square deviations at the Kyzyl and Minusinsk stations, and the results of calculating the criterion for the expediency of bringing average monthly air temperatures for the Kyzyl station.

Table 1. Criteria for the expediency of bringing the average monthly air temperatures at the Kyzyl station according to the Minusinsk station.

Indicators	**Months**											
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
r(a, b)	0.82	0.76	0.75	0.81	0.90	0.89	0.81	0.82	0.86	0.86	0.82	0.86
σ(*a*) Kyzyl	3.6	4.4	4.3	2.9	1.8	1.8	1.6	1.5	1.5	1.7	3.5	3.9
σ(*b*) Minusinsk	4.5	4.7	3.8	2.2	1.7	1.6	1.2	1.1	1.2	1.7	3.7	4.6
0.5 σ(*a*)/σ(*b*)	0.40	0.47	0.56	0.66	0.53	0.56	0.67	0.68	0.63	0.50	0.47	0.42

3 Results and Discussions

Calculations have shown that in all months of the year there is a high correlation between the average monthly air temperature at the Kyzyl and Minusinsk stations, at a significance level of 5%. Therefore, bringing the average monthly air temperatures at the Kyzyl station according to the Minusinsk station is considered appropriate in all months of the year, as it meets all the criteria. When determining the parameters of the regression equations and correlation coefficients, the statistical significance of the correlation coefficients was evaluated [10]. As a result of the reduction, the duration of the series of average monthly and annual air temperatures at the Kyzyl station increased and reached almost 140 years.

To analyze in the Tuva Basin, the entire observation period is divided into 30-year periods, which the World Meteorological Organization recommends using as standard for climate descriptions. A total of five periods have been identified from 1885 to 2020. The first period turned out to be shorter, but this period of meteorological observations of air temperature at the end of the nineteenth century differed very little from the period of the beginning of the twentieth century.

With small fluctuations in the temperature regime, temperature trends, even in neighboring months, may have a statistically insignificant opposite direction. In this regard, it is advisable to analyze seasonal changes in surface temperature. The extensive modern scientific literature on the problems of modern climate change provides studies ranging in scale from global, by hemisphere, by continent, by individual regions of states, etc. At the same time, it is emphasized that the rate of temperature change (linear trend slope coefficients °/10 years) they may differ significantly. For example, in Siberia, when studying climate change over the past 70 years, five quasi-homogeneous climatic regions have been identified in relation to the rate of temperature change [11]. One of these regions is the Altai-Sayan mountain country. A special feature of this region is the complex relief, the presence of large inhabited mountain basins, in which the basin effect is clearly manifested [11], especially during the cold season.

An analysis temperatures of surface air showed that from the end of the nineteenth century to 1930 they changed relatively little (Table 2).

Table 2. Long-term average seasonal and annual values of surface air (°C) in Kyzyl (climatic norms).

No. period	Years	December–February	March–May	June–August	September–November	For the year
1	1885–1900	-28.5	-0.8	17.2	-1.4	-3.4
2	1901–1930	-28.6	-0.3	16.9	-1.5	-3.4
3	1931–1960	-30.0	-1.3	17.4	-1.9	-4.0
4	1961–1990	-27.8	0.9	18.1	-1.6	-2.6
5	1991–2020	-25.4	3.1	19.3	0.1	-0.7

In the third climatic period of 1931-1960. In Kyzyl, there was a decrease in the average annual air temperature by 0.6 °C. In subsequent periods, there was an increase in temperature. In 1961-1990 increased by 1.4 °C, and in the subsequent period (1991-2020) it increased by another 1.9 °C. The main contribution to the increase in average annual temperatures over the last two climatic periods was made by winter and spring temperatures of 4.6 °C and 4.4 °C, respectively. In summer and autumn, the temperature growth rates were significantly lower and did not exceed 2.0 °C.

Changes in the temperature regime at the Kyzyl station during various climatic 30-year periods are shown in Table 3. During the first and second climatic periods, there was a tendency for air temperature to decrease for most of the year, only in the autumn period there was a tendency for climate warming. In the third period, the cooling trend also continued for most of the year, but there was a warming in the summer, which eventually led to a slight cooling.

Table 3. Long-term average seasonal and annual values of surface air (°C) in Kyzyl (climatic norms).

No. period	Years	December–February	March–May	June–August	September–November	For the year
1	1885–1900	–0.64	–1.46	–0.29	0.96	–0.36
2	1901–1930	–0.94	–0.02	–0.06	0.38	–0.16
3	1931–1960	–0.34	–0.13	0.86	–0.41	–0.01
4	1961–1990	1.69	1.12	–0.04	0.62	0.85
5	1991–2020	–0.24	0.78	0.33	0.54	0.35

4 Conclusion

The highest rates of increase in average annual temperatures were observed in the fourth and fifth climatic periods. Moreover, in the fourth period, the air temperature had a slight tendency to cool down. In the fifth period (1991-2020), a cooling trend was observed in winter. The rest of the year saw an increase in temperature. In general, there is a significant increase in air temperature for the Tuvan mountain basin during this period [13] shows that the rate of warming in Russia has been about 2.5 warming since the mid-1970s. High rates of warming are observed in all seasons of the year. The most intense warming is observed in spring at 0.63 °C/10 years, in summer and autumn at 0.39 °C/10 years and 0.43 °C/10 years, respectively, in winter at 0.39 °C/10 years. It should be noted that the final reports provide generalized information for the whole of Russia or large regions. Temperature changes in mountainous regions are usually ignored. At the Kyzyl station in winter, the warming intensity reached 1.7 °C/10 years, and the cooling -0.9 °C/10 years. In spring, the warming reached 1.1 °C /10 years, and the cooling reached -1.5 °C/10 years. In summer, the trend values reached 0.9 °C/10 years and -0.3 °C/10 years, respectively. In the autumn period, the temperature growth rate reached almost 1.0 °C/10 years, but there were cooling trends of -0.41 °C/10 years. All this suggests that in the conditions of the mountainous climates of Siberia, it is not enough to focus on the generalizing results of changes in climatic conditions. In the natural conditions of the Republic of Tuva, temperature fluctuations can exceed the rate of modern warming in the polar regions. This is especially true for vast mountain basins. When conducting climate monitoring of environmental facilities, it is important to assess the regional features of climate change.

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