Long-term dynamics of the climatic factors of the natural hazards formation in the Northern Caucasus

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Abstract. Within the framework of the study on the North Caucasus territory exposure to hazardous natural processes, attention is paid to the climatic factor of their formation. This paper presents the results on the study of the main climatic characteristics dynamics in the mountainous regions of the North Caucasus in different phases of river runoff formation. The dynamics of the surface air temperature and precipitation from the middle of the last century to the present has been studied. The possible influence of reliable changes in monthly, seasonal and annual climate characteristics on changes in the frequency of floods and mudflows in the region is analyzed. The largest number of statistically significant positive trends of air temperature and precipitation in the region was found during the season of mudflow and flood activity.

1. Introduction

Climate change research is in the focus of both the public and scientists’ attention. The points of view from which this subject is of concern are varied. The main perspective, of course, is the safety of life and the economy. In this aspect, the actual issue is the impact of climate change on the activity and frequency of hazardous natural processes. The study on the exposure of the territories of the North Caucasus to natural hazards cannot ignore the presence of stable trends in the dynamics of the climate in the region.

Statements that the number and intensity of hazardous natural events have increased noticeable are widespread. The frequency of hazardous atmospheric events is increasing, as a result of which an increase in the number of hazardous hydrological events and associated threats to the population and the economy is expected. But the conclusions of scientists on this score are ambiguous.

In works based on modeling, it is shown that the precipitation maximums increase in parallel with the rise in temperature in those regions of the globe where there is high humidity and decrease in moisture-deficient regions [1]. This explains the observed diversity of climate dynamics options observed in different territories. The authors of [2] came to similar conclusions based on the analysis of observations and modeling.

At the same time, the analysis of observational data showed that the expected increase in the number and power of floods in the context of modern climate change often does not occur [3]-[5]. An explanation can be the deficit of moisture in the soil associated with an increase in air temperature, an increase in the duration of periods without precipitation, and a decrease in winter snow accumulation [4].

It was shown in [4] that there is little evidence that an increase in the frequency of intense precipitation in a warmer atmosphere leads to an increase in river runoff. In many regions of the...
world, a decrease in river runoff was observed with an increase in the temperature characteristics of the climate. The exception was small catchments, where an increase in precipitation at higher temperatures leads to an increase in runoff.

As the most common mechanisms of climate formation with an increased frequency of extreme meteorological and hydrological phenomena, researchers refer to the change in the nature of atmospheric circulation [6] (from the point of view of synoptic processes), an increase in moisture content in the heated atmosphere (from the point of view of atmospheric physics) [7].

Despite the fact that river runoff in the mountainous regions of the North Caucasus is formed in special conditions of complex relief and a large gradient of climatic characteristics due to altitudinal zonation, its formation is influenced by such general factors as the amount of precipitation, soil condition, the time of the onset and the course of the high water period, etc. The study of regional changes in air temperature and precipitation is relevant for understanding the ongoing processes and assessing the possible consequences of existing climate trends for the economy and security of the population.

This paper presents the results on the study of the main climatic characteristics dynamics in the mountainous regions of the North Caucasus in different phases of river runoff formation.

2. Materials and methods
Methods of mathematical statistics and big data analysis were used to solve the set tasks. The most important stage for the successful application of these methods is the selection of the input data. The data presented in specialized arrays of Russian Research Institute of Hydrometeorological Information - World Data Center [8] are recommended for monitoring modern climate changes from the territory of Russian Federation.

As a result of processing the data of the meteorological station, interval time series of the levels of surface air temperature and precipitation averaged over the month, year and calendar seasons were formed. The daily characteristics were also studied for precipitation.

One of the objectives of this work is to compare the dynamics of climatic characteristics of average seasonal temperatures and the amount of precipitation for different seasons. Such characteristics have very different absolute values and measurement scales. In this regard, the series have been transformed to a new form by the procedure of centering and normalizing to the standard deviation. The resulting procedure allows one to obtain series in dimensionless units, all levels of which are in the range [-1..1].

A method of standardizing values based on centering and normalization was applied as follow:

$$y_i = \frac{(Y_i - \bar{Y})}{\sigma_Y}$$

where $y_i$ – are estimates of the transformed series levels,
$Y_i$ – climatic characteristic levels of the initial series,
$\bar{Y}$ – the average value of the original series,
$\sigma_Y$ – the original series standard deviation.

The transformed time series has a mean of 0 and a standard deviation of 1.

3. Results
In the mountainous regions of the North Caucasus dangerous natural processes associated with the features of the terrain and its influence on the climate and hydrological objects are common (for example, mudslides and high floods that occur in some areas of the Caucasus all year round). The greatest damage in the North Caucasus is caused by floods. Catastrophic mudflows in the mountains of Kabardino-Balkaria and Dagestan, floods in Karachay-Cherkessia and North Ossetia-Alania have brought disasters regularly in recent years.

Conventionally, the territory of the North Caucasus is divided into three parts. The territory from the Black Sea coast to Mount Elbrus is called the Western Caucasus. The Central Caucasus is located
between the Elbrus and Kazbek mountains and has the most high-mountainous relief. The Eastern Caucasus stretches from Mount Kazbek to the coast of the Caspian Sea.

3.1. **Western Caucasus**

The mountainous zone of the Western Caucasus is represented by data from the Zelenchukskaya meteorological station, (43°52’ N 41°34’ E, 928 m above sea level) and the Klukhor Pass (43°15’ N 41°50’ E, 2037 m above sea level) [9], the meteorological data of which characterize the climate in the eastern part of the Kuban basin. For the dynamics of air temperature in low-mountainous regions, it is characteristic that the maximum values of long-term average values (30-year, 10-year) were found for air temperature indicators, the calculation period of which includes the last years of the considered period 1959-2017. In this area, air temperature trend indicators are characterized by positive trends for all seasons. At the same time, trends are statistically significant only in spring and summer. During modern intense warming since 1976 only the winter trend remained insignificant.

No fundamental differences in local tendencies of the precipitation dynamics in the low-mountain zone (the eastern part of the Kuban River basin) with the corresponding tendencies in the North Caucasus were found. The positive trends in the average seasonal amounts revealed for the spring, summer and year, are statistically insignificant.

Standardized 10-year mean seasonal precipitation levels allow comparison of their long-term dynamics (figure 1).

![Figure 1. Standardized levels of mean seasonal precipitation, Zelenchukskaya meteorological station.](image)

The monthly resolution revealed a significant rainfall decrease trends for the period from 1960 to 2018 in April, August and December. Precipitation for the other months increased. Trend estimates were found to be statistically unreliable based on tests conducted at the 0.05 level. The exception is the statistically significant precipitation increase in March and October. A seasonal precipitation increase in autumn is recognized as reliable too.

The precipitation levels fluctuation in the mountainous zone is high (more than 30%) in the autumn-winter and reaches its maximum value in the winter season (38%). In the six months of spring-summer, the fluctuation is moderate (23-25%). At the same time, on the flat part of the region, precipitation is highly variable in all calendar seasons with a maximum in autumn.
The high-mountainous part of the Western Caucasus has a peculiarity in temperature dynamics. In 1951-1960 all seasonal temperature anomalies are positive and annual levels are close in value and amount to 0.41 and 0.43, respectively (figure 2).

Figure 2. Standardized monthly air temperature levels, meteorological station Klukhorsky pass.

In the high-mountainous zone of the Western Caucasus, an increase in both average and extreme characteristics of air temperature was found from May to August. This time of the year is characterized by the highest activity of such dangerous processes as mudflows and high floods [9].

In the high-altitude regions at the headwaters of the Kuban basin rivers, according to the data of the Klukhorsky meteorological station, it was revealed that a decrease in the number of days with precipitation in December, an increase in the number of days with precipitation in March is statistically significant. The next most noticeable trend in the highlands of the Western Caucasus is an increase in the average daily intensity of precipitation in September, October, and for autumn as a season as a whole. In October, the increase in daily maximum atmospheric precipitation is also significant. Average seasonal precipitation tends to decrease in winter and summer, and to increase in spring and autumn.

3.2. Central Caucasus
In the highlands of the Central Caucasus, it was found that the decade 2006-2015 is the period when for the first time since 1951-1960 all seasonal temperature anomalies became positive, except for the winter one. But, unlike in 1951-1960 - the previous local maximum - the main contribution to the annual positive anomaly was made by summer (76%) and spring (15%) levels [10].

During the study period, the largest precipitation levels increase was detected in spring, but the highest growth rate was found in the autumn and made 6.4 mm / month / decade. The increase in the amount of precipitation for the period of high mudflow and flood hazard (May-September) was 27%, precipitation for the cold period (November-April) is 34% higher than the climatic norm in the region.

Investigations in the flat part of the Central Caucasus were carried out for the high floods formation period in this part of the region from May to September.

We express the indices as follows:

$$x_{jk} = \frac{\bar{x}_{jk}}{\bar{x}_{nk}}, \quad (2)$$

where $x$ – a climate element (we use $t$ for temperature and $p$ for precipitation),
- In this investigation \( j \in (1961-1970; 1971-1980; 1981-1990; 1991-2000; 2001-2010; 2007-2016); \n  k \in (\text{May-September, May, June, July, August, September}). \n
The results are presented in Table 1. The maximums are in bold, the minimums are in bold italics.

**Table 1. Decade indices of the air temperature \((t)\) and precipitation \((p)\) during the period of high floods**

| Month or season, \(k\) | Periods, \(j\) | 1881-1960 | 1961-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2010 | 2007-2016 |
|------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                        |                | \(t\)     | \(t\)     | \(t\)     | \(t\)     | \(t\)     | \(t\)     | \(t\)     |
| May-Sept.              |                | 1.01      | 0.99      | 1.03      | 1.00      | 0.90      | 1.00      | 1.08      |
| May                    |                | 0.99      | 1.02      | 1.03      | 1.00      | 0.89      | 0.98      | 1.08      |
| June                   |                | 1.01      | 0.99      | 1.06      | 1.00      | 0.80      | 1.01      | 1.15      |
| July                   |                | 1.02      | 0.99      | 1.06      | 1.00      | 0.91      | 1.01      | 1.03      |
| August                 |                | 1.03      | 0.99      | 0.98      | 1.01      | 0.85      | 1.00      | 1.17      |
| September              |                | 0.98      | 0.98      | 0.95      | 1.00      | 1.20      | 1.02      | 0.85      |

In all months a tendency of temperature increase was revealed, the degree of completeness stability of the tendency is moderate. Only the tendency for the air temperature increase in May is not statistically reliable. It was found that for the studied period 1961-2016 aridity increased strongly in August. At the same time, the decade 2007-2016 characterized by the highest temperature index (10% above the norm) and the lowest precipitation index (56% of the norm) in August.

In September the temperature trend behavior is similar to that in August, in 2007-2016 one of the highest temperature indices (1.09) is observed. At the same time, the precipitation index reached its maximum and amounted to a record 1.86. As a result, the monthly precipitation fluctuations in August and September are the greatest among the period of mudflow and flood hazard in the region.

In the foothill zone of the Central Caucasus (Vladikavkaz meteorological station) for the period 1939-2017, 1961-2017 there are positive temperature trends in all seasons, which are significant at the level of 0.05. The highest growth rate of the seasonal temperature was found in winter and is 0.38 °C / month / decade. The lowest is in summer (0.21 °C / month / decade).

In the time interval 1976-2017 the growth rate of winter temperatures remains one of the highest (0.4 °C / month / decade), but the maximum value here belongs to summer temperatures (0.46 °C / month / 10 years) (figure 3).

### 3.3. Eastern Caucasus

In the low-mountainous part of the Eastern Caucasus, changes in air temperature were detected in various phases of the mountain rivers runoff formation. For the period 1966-2019 all monthly temperature trends are positive, except for November [11]. Warming trends are statistically significant for the period February and March, summer months and September. The nature of the average seasonal temperature dynamics in this part of the North Caucasus according to the data of the Akhty meteorological station is shown in figure 4.

3.3. Eastern Caucasus
In the high-mountainous part of the Eastern Caucasus, it was established that the wettest years fell on the period 1996-2013. Seasonal precipitation in summer, autumn and winter has the highest ranks since the mid-90s of the last century.

The most important results for this sub-region are as follows. Long-term dynamics (1931-2018) shows a precipitation decrease in April and May, along with their increase in March and December, i.e. during the snow accumulation by the beginning of the floods and mudflows season. During modern intense warming since 1976, the increase in monthly and daily precipitation characteristics in March is statistically significant. An alarming sign is the statistically significant increase in monthly precipitation and average daily intensity in July, as the dangerous hydrological events frequency is the highest this month.

4. Conclusion
Revealing the features of local and regional climate dynamics remains a topical research in the current century. In the North Caucasus, these tasks are closely related to the problem of intensification of hazardous natural processes.
In the mountainous and alpine zones of the eastern part of the Kuban basin (Western Caucasus) the largest number of statistically significant trends in climatic characteristics were found in the period June-September. The period is characterized by the greatest mudflow and flood hazard in the region.

The decade 2009-2018 is defined as the wettest in the low-mountainous part of the Western Caucasus. The maximum levels of winter precipitation, wet springs, the most humid summer, as well as abundant rainfall in autumn contribute to the fact that conditions favorable for the activation of dangerous hydrological processes in the region develop all year round for the for the last decade.

An intensive air temperature increase in the area of mountain rivers headwaters from June to September contributes to the intensive melting of glaciers and snow during the mudflow-prone period.

In the mountainous regions of the Eastern Caucasus for the period from 1996 to the present, there are decades with the 10 highest values in the ranked series for all seasons.

In the highlands of the Eastern Caucasus for long periods of time (1932-2018, 1936-2014), a precipitation decrease in April and May was noted along with a precipitation increase in March and December, i.e. during the period of accumulation of snow reserves by the beginning of the period of high floods in the region. In this area, from the side of atmospheric precipitation, conditions conducive to the intensification of hazardous hydrological phenomena have developed since 1993 and up to the present have statistically confirmed tendencies.

It is important to note that an air temperature increase in the mountainous regions of the North Caucasus can contribute to a decrease in the frequency of occurrence of high levels in rivers due to a lack of moisture in the ground, a decrease in the proportion of solid precipitation that accumulates by the beginning of snow melting, etc.

References
[1] Prein A F, Rasmussen R M, Ikeda K, Liu C H, Clark M P and Holland G J 2017 The future intensification of hourly precipitation extremes Nature climate change 7 48
[2] Yin J, Gentine P, Zhou Sh, Sullivan S C, Wang R, Zhang Y and Guo Sh 2018 Large increase in global storm runoff extremes driven by climate and anthropogenic changes Nature communications 9 4389
[3] Blöschl G, Hall J, Viglione A et al. 2019 Changing climate both increases and decreases European river floods. Nature 573 108–111
[4] Sharma A, Wasko C and Lettenmaier D. P. 2018 If Precipitation Extremes Are Increasing, Why Aren’t Floods? Water resources research 54 8545–51
[5] Wasko C and Sharma A 2017 Global assessment of flood and storm extremes with increased temperatures Scientific reports 7 7945
[6] Malygina N, Papina T, Kononova N et al. 2017 Influence of atmospheric circulation on precipitation in Altai Mountains. J. Mt. Sci. 14 46–59
[7] Trenberth K 2011 Changes in Precipitation with Climate Change. Climate Change Research. Climate Research 47 123–138
[8] Bulygina O N and Razuvaev V N 2012 Daily temperature and precipitation data for 518 Russian meteorological stations (Oak Ridge: Carbon Dioxide Information Analysis Center/ Oak Ridge National Laboratory/U.S. Department of Energy)
[9] Korchagina E A 2018 The research on stability of tendencies of climate elements in the highlands of Karachay-Cherkessia from 1959 to 2017 Vestnik KRAUNC. Fiz.-mat. nauki. 23 106–115
[10] Korchagina E A 2019 The investigation on temperature regime in the highlands of the Kabardino-Balkarian and Karachay-Cherkes republic from 1951 to 2015 Sustainable development of mountain territories 11 449–458
[11] Korchagina E A 2021 Longterm air temperature variations in the low mountain zone of the Eastern Caucasus during flood formation season News of Kabardino-Balkarian scientific center of the Rus. acad. of sci. 100 139–147