Analysis of climatic change for the period 1961-2020 according to the Nalchik weather station

Kesheva Lara Asirovna
Candidate of Physical and Mathematical Sciences,
High-Mountain Geophysical Institute
Teunova Nataliya Vyacheslavovna
Senior Researcher
High-Mountain Geophysical Institute

Abstract. The climate has always been and is one of the "parameters" of our atmosphere, which is most susceptible to changes. Over the past decade, many of the monthly average climatic characteristics of a number of meteorological quantities have changed significantly.

Thanks to numerous scientific studies, there is ample evidence of climate change on a global and regional scale. Local climate changes are of great interest.

The purpose of this article is to analyze changes in the temperature regime, precipitation regime and the thickness of the snow cover for the period 1961-2020 according to the data of the Nalchik meteorological station, located in the foothill zone of the Kabardino-Balkarian Republic, at an altitude of 500 m above sea level.

As a result of the study, it was found that during the period under study at the Nalchik m/station there was an increase in the growth rate of average annual temperatures with a record high anomaly in 2020 and a decrease in precipitation amounts in all seasons, except for spring. An increase in the growth rate of the average 10-day snow cover thickness was observed during the period of global warming.

Keywords: temperature, precipitation regime, snow cover thickness, meteorological station, trend, anomaly, rate of change.

In Russia, 2020 was the warmest year on record, and warming is happening here faster than the world average. If earlier scientists had to prove that the climate crisis is real, now the inhabitants of Russia notice with their own eyes climate change: more frequent and destructive hurricanes, ice rains, heat, drought, floods [1].

The fact of a significant increase in the average air temperature near the Earth's surface is beyond doubt. Regular observations of the worldwide network of meteorological stations confirm the change in average temperature [2].

According to research by Rankova E.Ya., in Russia in the twentieth century, in all seasons, an increase in temperature was observed, in magnitude exceeding the estimates for the

globe and the Northern Hemisphere as a whole. In the last 50 years, the trend decreased for the warm period, but increased significantly for the cold one. In Russia in the twentieth century the intensity of aridity increased in all seasons, but to a greater extent in the cold period. The intensity of warming over the 100th anniversary (1901-2000) averaged 0.9°C/100 years for the territory of Russia. The maximum warming was noted in 1995. In the last 50 years, there has been a tendency towards a decrease in annual and seasonal precipitation amounts for Russia as a whole [3].

The purpose of this article is to analyze changes in the temperature regime, precipitation regime and the thickness of the snow cover according to the data of the Nalchik meteorological station, located in the foothill zone of the Kabardino-Balkarian Republic, at an altitude of 500 m above sea level.

To study climate change, the data of hydrometeorological observations over a long period (1961-2020) were used.

The studies were carried out in the following directions: the time series of meteorological parameters were investigated by the methods of mathematical statistics and supplemented by linear trends characterizing the trend of the value under consideration for the full study period from 1961 to 2020 and for the period from 1976 to 2020, since 1976, according to the estimates of the Intergovernmental Panel on Climate Change (IPCC), is considered to be the beginning of global warming [4]. The trends were calculated by the well-known least squares method (LSM) [5]. The slope of the linear trend equation is a characteristic of the average rate of change of the climatic variable over the considered time interval and is expressed when analyzing the temperature regime in degrees per decade (°C/10 years), for the precipitation regime in millimeters/month per decade (mm/10 years) and for the average 10-day snow depth in centimeters per decade (cm/10 years). Average values were obtained for the period 1961-2020 standard deviations, norms and anomalies of mean temperatures, total precipitation and mean ten-day snow cover. The “norm” is understood as the long-term average value of the considered climatic variable for 1961-1990 (base period). Anomalies are defined as deviations of the observed value from the norm. To obtain the average annual series of snow cover, the average ten-day heights were averaged over 7 months of the cold season, from October to April, in the period 1960/61-2019/20.

Temperature regime

Data on annual and seasonal average temperatures, as well as data on changes in the temperature regime at the Nalchik meteorological station are shown in Table 1.

Table 1. Temperature regime and anomalies for 1961-2020, Nalchik

Temperature, ºC	**year**	**winter**	**spring**	**summer**	**autumn**
Average temperature (1961-2020)	9,9	-1,7	9,6	21,2	10,4

Standard deviation (1961-2020)	1,0	1,9	1,2	1,2	1,2
Climatic norm (1961-1990) , N	9,3	-2,3	9,1	20,4	10,0
Average anomaly (1961-2020)	0,6	0,6	0,5	0,7	0,4
The angular coefficient of the trend (1961-2020), ºC /10 *yrs*	0,4	0,4	0,3	0,5	0,3
The angular coefficient of the trend (1976-2020), ºC /10 *yrs*	0,6	0,6	0,5	0,7	0,5

At m/station Nalchik, the average annual temperature for the period 1961-2020 was t = 9.9°C at a rate of N = 9.3°C (1961-1990). Average seasonal temperatures also exceed the norm, especially the summer season, where the excess of the norm was 0.8°C.

There was an increase in the growth rate of average annual temperatures from 0.4°C/10 years in the period 1961-2020 up to 0.6°C/10 years in the period 1976-2020. The highest growth rate was observed in the summer period and amounted to 0.7°C/10 years (table 1).

Figure 1 shows that the number of positive anomalies is greater than negative (42:18), and since 1994 in Nalchik there have been extremely positive anomalies of average annual temperatures with a record high anomaly of +2.3°C in 2010 and +2.4°C in 2020, which exceeds the standard deviation by more than 2 times.

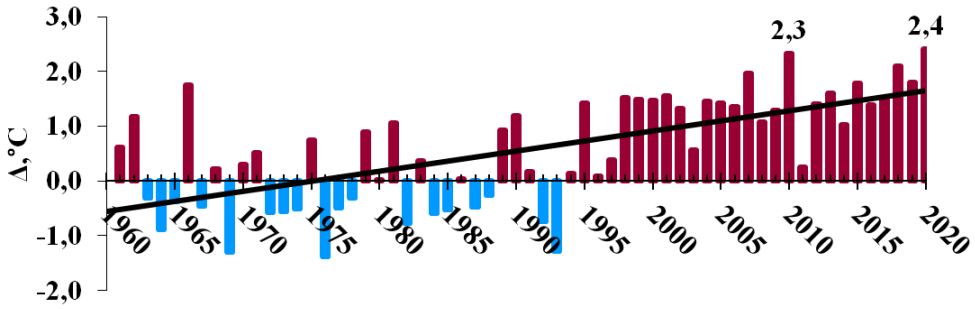

Figure 1. Annual average temperature anomalies, 1961-2020

Figure 2 shows the anomalies of mean annual and mean seasonal temperatures for 2020. In all seasons and throughout the year, positive anomalies of mean temperatures were observed the winter anomaly is in the lead, followed by the autumn and summer anomalies.

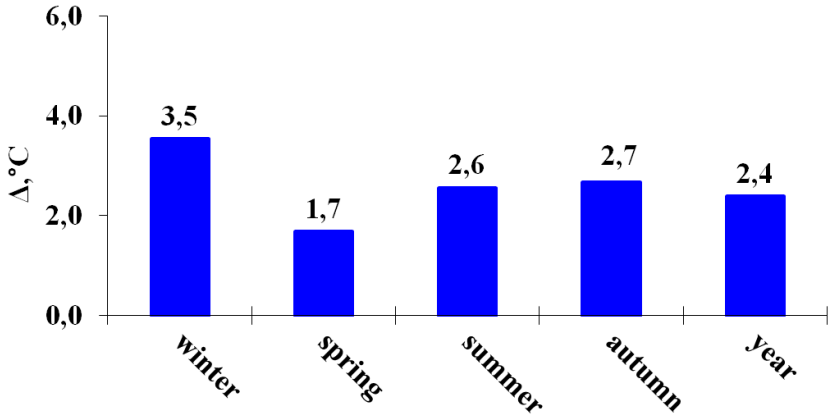

Figure 2. Seasonal mean temperature anomalies, 2020

Table 2 shows the years with the maximum and minimum values of the average monthly and average annual air temperature for the period from 1961 to 2020.

Table 2. Maximum and minimum values of the average monthly air temperature

Periods	**Months**												**Year**
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
year	2007	2002	2008	2012	2003	2019	2018	2006	2015	2012	2010	2010	2020
max	2,3	5,2	8,6	15,1	18,6	23,5	25,2	26,2	19,9	14,4	8,7	4,5	11,7
year	1972	1976	1985	2019	1981	1967	1967	1984	1978	1976	1993	2002	1976
min	-12,5	-9,9	-2,8	5,9	12,7	17,1	19,5	18,5	13,4	5,4	-5,5	-7,2	7,9
norm (1961-1990)	-3,6	-2,7	2,1	10,1	15,3	19,1	21,5	20,7	16,3	9,5	4,2	-0,7	9,3

The table shows that in the average annual air temperature at a rate of 9.3° C, the minimum was +7.9°C in 1976, and the maximum in 2020 +11.7°C.

It can be noted that the maximum values of the average monthly temperature were observed only after 2002 (2002-2020), and the minimum values before 2002 (1967-2002). The greatest deviation of the minimum from the climatic norm was 8.9 ° C and was observed in January 1972 with a value of -12.5°C.

Precipitation mode

In Nalchik, the average value of the average annual precipitation for 1961-2020 is 635.1 mm with a norm of 636.4 mm. The maximum amount of precipitation falls on the summer season – 232.5 mm, followed by the spring (196.6 mm), autumn (134.3 mm) and winter (71.0 mm) seasons. In all seasons (except for autumn) and the year as a whole, the average anomalies in the amount of precipitation are negative (Table 3).

In the period from 1961 to 2020, there was a negative trend in annual precipitation (-2.6 mm/10 years) with a further increase (-6.9 mm/10 years) in the period 1976-2020. The deficit of winter and spring precipitation during the period of global warming has decreased, while the sums of precipitation in summer and autumn have acquired negative trends.

Table 3. Precipitation regime and anomalies for 1961-2020, Nalchik

Precipitation, mm	**year**	**winter**	**spring**	**summer**	**autumn**
The amount of precipitation (1961-2020)	635,1	71,0	196,6	232,5	134,3
Standard deviation (1961-2020)	108,4	20,02	55,22	68,04	52,86
Climatic norm (1961-1990) , N	636,4	72,0	201,9	233,8	127,7
Average anomaly (1961-2020)	-1,3	-1,0	-7,0	-2,0	5,7
The angular coefficient of the trend	-2,6	-1,8	-2,6	1,1	1,0

(1961-2020), mm /10 yrs					
The angular coefficient of the trend (1976-2020), mm/ 10 yrs	-6,9	-0,8	2,3	-6,6	-2,1

The performed analysis of anomalies of annual precipitation amounts for the period from 1961 to 2020. showed that the number of positive and negative anomalies for the entire study period was distributed approximately equally (31:29). A record high positive anomaly was observed in 1992 (256.8 mm), and negative in 1986 with a value of -234.4 mm (Fig. 3).

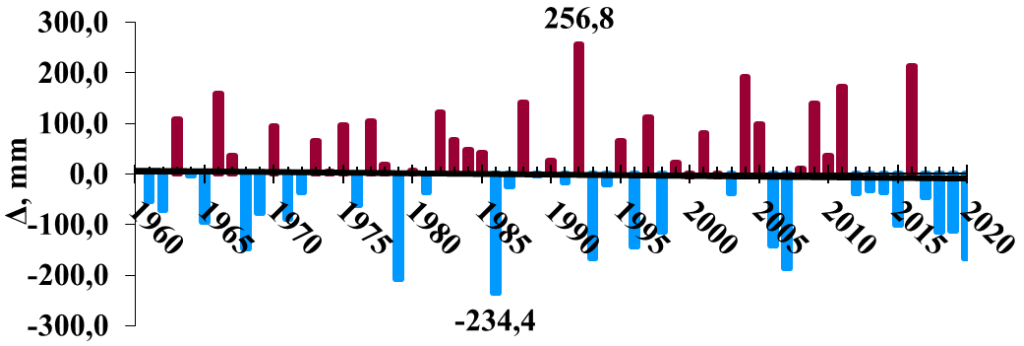

Figure 3. Annual precipitation anomalies, 1961-2020

Figure 4 presents an analysis of the anomalies of seasonal and annual precipitation amounts for 2020, from which it can be seen that this year there was a deficit in the amount of precipitation in the year and in all seasonal, except for spring.

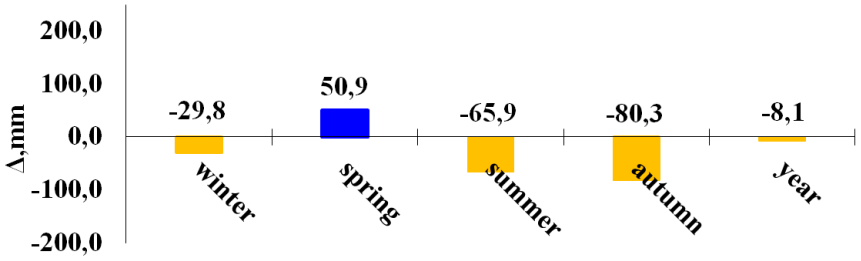

Figure 4. Seasonal precipitation anomalies, 2020

Table 4 shows the years with the maximum and minimum values of precipitation amounts for the period from 1961 to 2020.

Table 4. Maximum and minimum values of precipitation amounts

Periods	**Months**												**Year**
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
year	1966	1978	2018	1963	2016	2009	1997	1970	2009	1975	1992	2001	1992
max	54,0	59,1	94,6	166	177,2	211	179,5	148	173	162	90,2	79	893,2
year	1999	2017	1979	2009	2007	2006	2000	2006	1994	1974	2010	2011	1986
min	4,8	4	4,9	14	27	26	5	6	2,5	0	6	4	402,0
norm (1961-1990)	22,6	24,3	39,3	64,1	98,5	100,3	72,3	61,2	55,1	43,5	29,1	26,2	636,4

The table shows that in the annual precipitation amounts at a rate of 636.4 mm, the minimum was 402.0 mm in 1986, and the maximum in 1992 was 893.2 mm.

The largest deviation of the maximum from the climatic norm was 118.5 mm and was observed in October 1975 with a value of 162 mm, and the deviation of the minimum precipitation from the norm (-74.3 mm) in June 2006 with a value of 26 mm.

Снежный покров

One of the most important characteristics of the regional climate is the state of the snow cover. The analysis of observations of the regime of the thickness of the snow cover for the period 1960/1961 has been carried out to 2019/2020.

Seasons from October to April 1960/1961, 1961/1962 ,…, 2019/2020 hereinafter, for brevity, they are written as 1961, 1962, ..., 2020. As in previous works [6, 7], when analyzing the characteristics of the snow cover, for example, 1961, the data of October, November, December 1960 and January, February, March and April 1961 were used. Table 5 presents the statistical characteristics of the thickness of the snow cover.

Table 5. Snow cover regime and anomalies for 1961-2020

Snow cover, cm	**Year**
Толщина снежного покрова (1961-2020)	4,0
Standard deviation (1961-2020)	2,7
Climatic norm (1961-1990) , N	3,8
Average anomaly (1961-2020)	0,2
The angular coefficient of the trend (1961-2020), cm /10 *yrs*	0,04
The angular coefficient of the trend (1976-2020), cm /10 *yrs*	0,12

As can be seen from the calculation results, the average 10-day snow cover thickness was 4.0 cm, which is 0.2 cm higher than the climatic norm. There has been an increase in the growth rate of the average 10-day snow cover thickness from 0.04 cm/10 years to 0.12 cm/10 years since 1976.

Over the studied period, the number of positive anomalies (25) is less than negative (35). A record high anomaly was observed in 2012 with a value of 11.3 cm (Fig. 5).

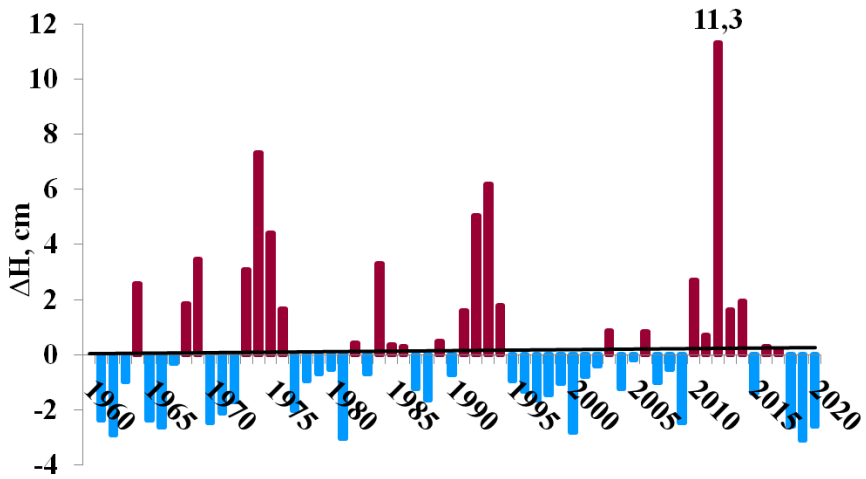

Figure 5. Annual anomalies of snow cover thickness, 1961-2020

Figure 6 shows the anomalies of the mean 10-day thickness of the SP by months of the cold period of 2020, which showed that there are no anomalies in October and November, and only negative anomalies were observed from December to April.

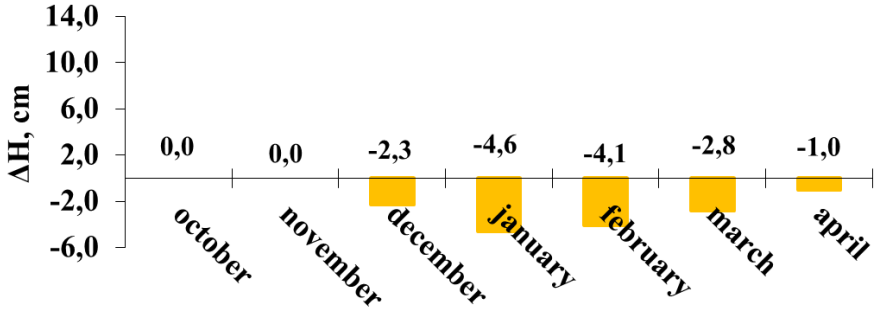

Figure 6. Anomalies in snow cover thickness by months, 2020

Studies on the distribution of the average 10-day SP thickness for the period from 1961 to 2020 showed that the highest averaged SP height at m/station Nalchik was obtained in January 4.4 cm and February – 6.0 cm (Table 6).

Table 6. Average 10-day SC height by months, 1961-2020

Months	October	November	December	January	February	March	April
Nalchik	0,8	1,7	3,2	**4,4**	**6,0**	3,2	1,2

The variation in the SP thickness over the observation period at the foothill m/station Nalchik ranges from 0.7 cm (2019) to 15.1 cm (2012), with an average long-term value of 4.0 cm.

Conclusions

At m/station Nalchik, an increase in the growth rate of average annual temperatures from 0.4°C/10 years was observed in the period 1961-2020 up to 0.6°C/10 years in the period 1976-2020. The number of positive anomalies exceeds the negative ones by more than 2 times (42:18) and since 1994 in Nalchik there have been extremely positive anomalies of average annual temperatures with a record high anomaly of + 2.3°C in 2010 and +2.4°C in 2020. Average value of the average annual precipitation for 1961-2020 is 635.1 mm with a norm of 936.4 mm. 1961 to 2020 at Nalchik station, a decrease in the amount of precipitation was observed in all seasons, except for the spring one. There has been an increase in the growth rate of the average 10-day snow cover thickness from 0.04 cm/10 years to 0.12 cm/10 years since 1976. A record high anomaly in the thickness of the snow cover was observed in 2012 with a value of 11.3 cm.

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