



# Climate Change

## Climate change in the south of European Russia in 1961-2015 and analysis of anomalies in 2010 and 2015

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Author contributions:

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*Ashabokov Boris A.* - formulated the statement of the problem and the main directions of research. Conclusions on the results of research are formulated. Editing with the final version of the article before publication.

*Tashilova Alla A.* - developed the algorithm necessary to solve the task. The analysis of the dynamics of changes in the temperature and precipitation regime, a comparative analysis of temperatures in 2010 and 2015, was carried out. Average annual and seasonal precipitation for 2015. The first version of the article before publication.

*Kesheva Lara A.* - time series of annual and seasonal meteorological parameters were computed by methods of mathematical statistics. The obtained statistics of the meteorological parameters are formed into tables, their description is given.

*Teunova Nataliya.V.* - an array of data was prepared, a check was made for the homogeneity of time series. Graphs with linear trends, graphs with anomalies of meteparameters are constructed.

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## General Note



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## ABSTRACT

Based on the temperature and precipitation data of the plain weather stations (<500 m above the sea level [a.s.l.]), foothill stations (500-1000 m a.s.l.) and mountain stations (> 1000 m a.s.l.), the tendencies of climate change for the last 55 years (1961-2015) and in the modern period of global warming (1976-2015) have been revealed. It is received that since 1976 the growth of average annual and seasonal temperatures in all climatic zones has been increasing. The change in the precipitation regime does not have unidirectional significant trend: both increase and decrease in annual and seasonal precipitation are observed, but a general trend for all weather stations is significant increase in the autumn precipitation. The comparative analysis of the anomalies of meteorological parameters in 2010 and 2015 as the most "hot" years in the history of instrumental observations showed that 2010 remains the record year for the magnitude of positive temperature anomalies.

**Keywords:** Temperature, precipitation, trend, anomaly, south of European Russia

## 1. INTRODUCTION

Studies of climate change, as well as the identification of possible consequences, have now become scientific problems that attract great deal of attention from researchers around the world <sup>1-9</sup>.

The goal of this work is the continuation of previous studies<sup>10-12</sup> on the study of changes in climatic variables (temperature, precipitation) in the south of European Russia (the North Caucasus) for 1961-2015 and 1976-2015, as well as comparative analysis of temperature anomalies in 2010 and 2015.

North Caucasus is region in the south of the Russian Federation, rich in diverse natural landscapes and diverse climatic zones. The territory of the North Caucasus is located between the Black and Caspian Seas, covers an area of 171,000 km<sup>2</sup>, divided according to climatic conditions into the plain (<500 m a.s.l.), foothills (from 500 to 1000 m a.s.l.), and mountain (> 1000 m a.s.l.) climatic zones. For the analysis, annual and seasonal meteorological parameters were used according to the data of weather stations [WS] of the North Caucasus: mountain WS -Akhty (latitude 41°28' N, longitude 47°44' E, 1281 m a.s.l.), Teberda (43°45' N, 41°45' E, 1335 m a.s.l.), Terskol (43°15' N, 42°30' E, 2.144 m a.s.l.), foothill WS Nalchik (43°22' N, 43°24' E, 500 m a.s.l.) and the plain WS Prokhladnaya (43°46' N, 44°05' E, 198 m a.s.l.).

In works<sup>13,14</sup> it is said that the obtained estimates of changes in surface temperature indicate the continuing climate global warming and 2015 was the warmest in the history of observations. In this study a comparative analysis was made of the temperature anomalies in seasonal and annual temperatures in southern European Russia in 2015 and 2010, well-known year with summer "heat waves" caused by a blocking anticyclone <sup>15-17</sup>.

## 2. MATERIALS AND METHODS

Data of the observations of the network hydrometeorological stations were provided by the North Caucasian Department of Hydrometeorological Service of the Russian Federation.

Time series were investigated by methods of mathematical statistics and supplemented by linear trends characterizing the trend of the value under consideration for the entire period of observations of 1961-2015 and for the period of modern warming (since 1976). Trends were calculated using the least-squares method <sup>18</sup>. The angular coefficient of the linear trend equation is expressed in degrees per 10 years (°C/10 years, temperature) and in millimeters/month per 10 years (mm/month/10 years, precipitation).

Average values, standard deviations, norms and anomalies of annual and seasonal mean temperatures, maximum and minimum temperatures in 2010 and 2015, as well as average annual and seasonal precipitation sums, daily maximum precipitation and the number of days with precipitation not less than 5 mm in 2015 were computed.

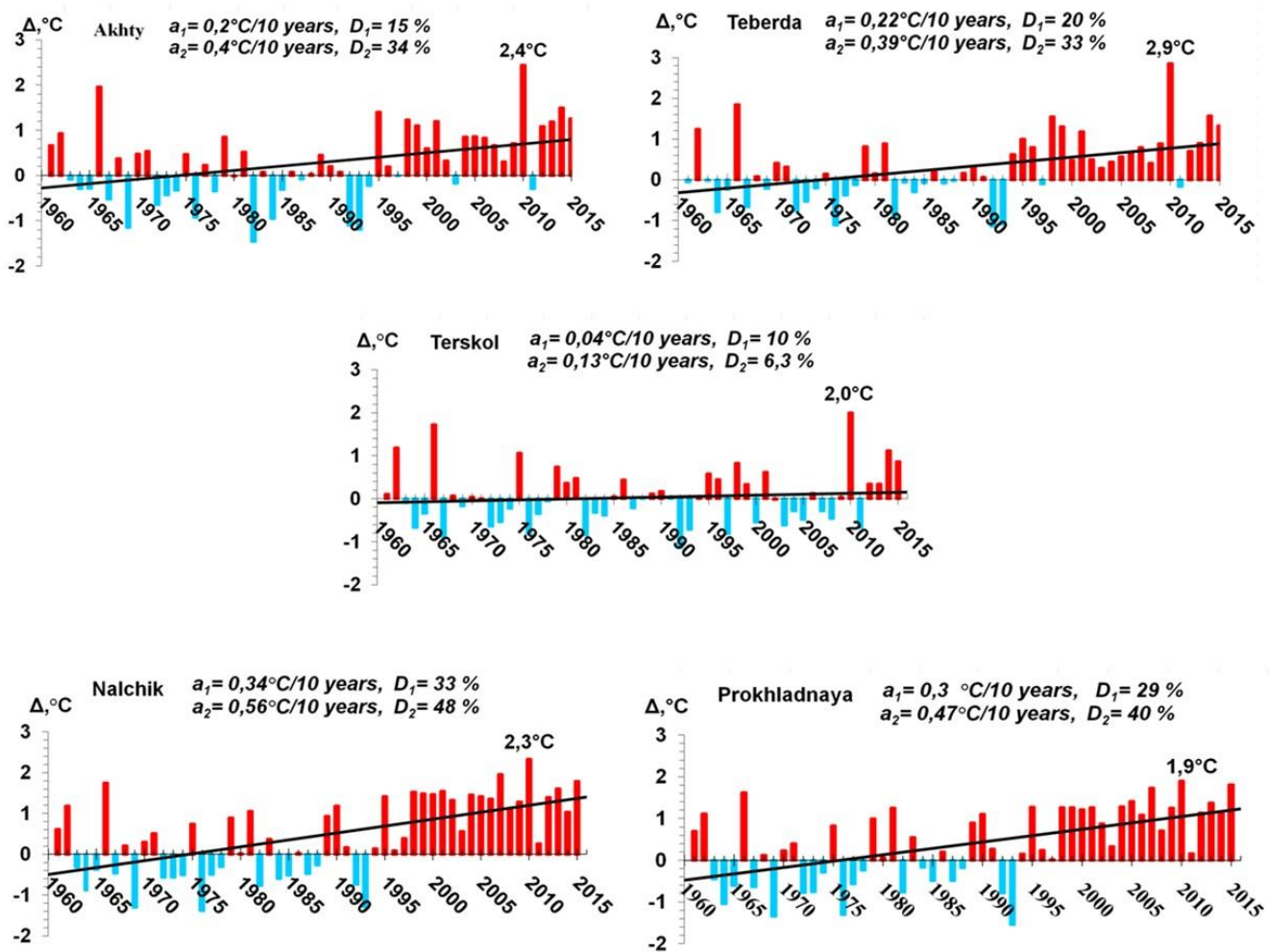
The World Meteorological Organization recommends a period of 30 years (1961-1990) as a standard period for estimating the climatic norm<sup>19</sup>. The deviation of the value of the meteorological parameter from the norm is an anomaly.

The choice of 2010 and 2015 is due to the fact that these years, according to the results of the researchers are the hottest years in the history of instrumental observations.

### 3. RESULTS AND DISCUSSION

#### 3.1 Temperature changes in the North Caucasus

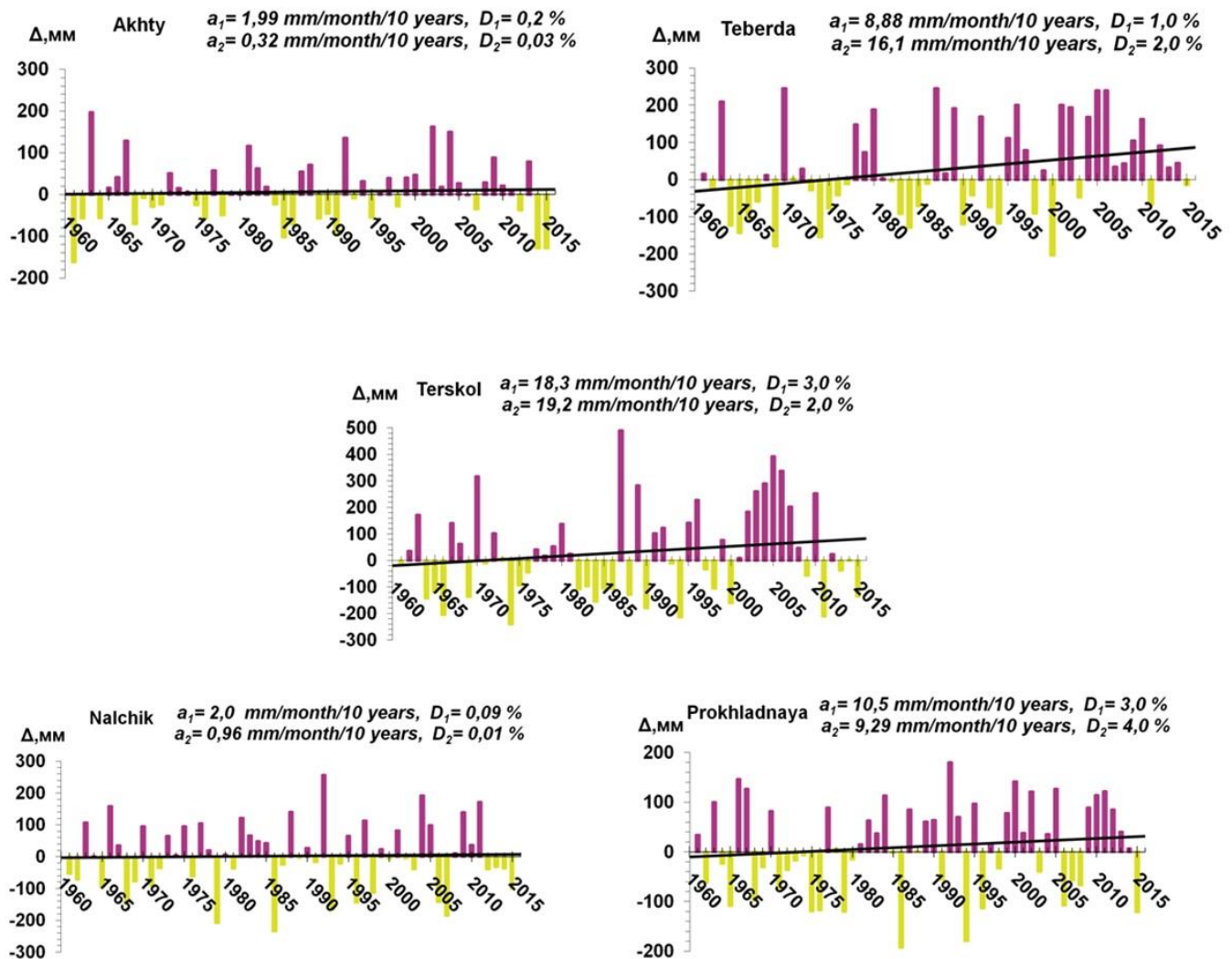
The scatter of mean annual temperatures characterizes significant variety of climatic zones of the North Caucasus from minimum at the high-altitude WS Terskol 2.57 °C (1961-2015) at the norm 2.55 °C (1961-1990) to maximum at plain WS Prokhladnaya 10.47 °C at the norm 10.09 °C. The average annual temperatures for the period 1961-2015 at the mountain WS Akhty and Teberda were 9.47 °C at the norm 9.20 °C and 6.77 °C at the norm 6.48 °C respectively, at the foothill WS Nalchik was 9.75 °C at the norm 9.31 °C.



**Figure 1**

Average annual temperature anomalies with linear trend;  $a_1$  ( $a_2$ ) - value of the angular coefficient of linear trend in 1961-2015(1976-2015), °C/10 years;  $D_1$  ( $D_2$ ) - % contribution to the total variance of the trend in 1961-2015 (1976-2015).

Figures 1 and 2 show the anomalies of mean annual temperatures and average annual precipitation amounts with the angular coefficients of linear trends  $a_1$  and the trend contribution to the total variance  $D_1$  for the period 1961-2015. and with index 2 ( $a_2, D_2$ ) for the period 1976-2015. Figure 1 shows that for 1961-2015 at all stations there are positive trends in temperature growth, which have intensified since the beginning of the 1990s last century. Since the end of the last century at all weather stations, with the exception of Terskol, there have been exceptionally positive temperature anomalies (red bars). For the whole period 1961-2015 extremely high mean annual temperatures occurred in 2010 at all weather stations: Akhty 2.4 °C, Teberda 2.9 °C, Terskol 2.0 °C, Nalchik 2.3 °C, Prokhladnaya 1.9 °C.



**Figure 2**

Average annual anomalies of sums of precipitation with linear trend of all weather stations;  $a_1(a_2)$  - value of the angular coefficient of linear trend in 1961-2015. (1976-2015), °C/10 years;  $D_1(D_2)$  (%) - contribution to the total variance of the trend in 1961-2015 (1976-2015)

For the period 1961-2015 persistent trends in the growth of average annual temperatures are observed: at the mountain stations of Akhty (0.2 °C/10 years), Teberda (0.22 °C /10 years); at the foothill station Nalchik (0.34 °C/10 years) and at the plain station Prokhladnaya (0.3 °C/10 years). The high-altitude station Terskol during this period is characterized by the absence of linear trend (0.04 °C / 10).

Since 1976 the temperature growth rate has been increasing at all weather stations: in Akhty and Teberda to 0.40 °C/10 years, at Nalchik to 0.56 °C/10 years and at Prokhladnaya to 0.47 °C/10 years. If from 1961 to 2015 in Terskol the trend of average annual temperatures was practically absent (0.04 °C/10 years), then since 1976 the growth rate of the average annual temperature also increases to 0.13 °C/10 years. At the same time, statistically significant trends occurred for all weather stations: Akhty ( $D_2 = 34\%$ ), Teberda ( $D_2 = 33\%$ ), Nalchik ( $D_2 = 48\%$ ) and Prokhladnaya ( $D_2 = 40\%$ ), except for Terskol ( $D_2 = 6.3\%$ ).

### 3.2. Precipitation changes in the North Caucasus

Altitudinal zoning has significant effect on the formation of features of the regime of precipitation. The maximum value of the average annual precipitation for 1961-2015 took place at the high-altitude MS Terskol, it was 967 mm at norm of 936 mm (1961-1990), and it was the largest of all mountain MS: 2.5 times higher than the annual precipitation in Akhty (388 mm) and 1.2 times the amount of precipitation in Teberda (799 mm). The annual amount of precipitation in the foothill MS of Nalchik was 640 mm at norm of 636 mm. The annual precipitation on the plain MS Prokhladnaya was 486 mm at norm of 475 mm. The maximum sum of precipitation at all stations falls on the summer season, then the autumn, spring and winter seasons are descending.

Unlike the change in the temperature regime, in the precipitation regime there are periods of both excess and deficit of average annual precipitation amounts relative to the norm, both for the whole period of the 1961-2015 study and for the modern period of 1976-2015.

For all stations at the same time there is general insignificant tendency to increase annual precipitation amounts (Fig. 2). Since 1976 in Akhty the growth rate of average annual precipitation has decreased from 1.99 mm/month/10 years to 0.32 mm / month/10 years. The same decrease in the amount of annual precipitation in the modern period was observed in Nalchik (from 2 to 0.96 mm /month /10 years) and Prokhladnaya (10.5 to 9.29 mm / month / 10 years). In Teberda since 1976 the growth rate increased to 16.1 mm/month/10 years, in Terskol also slightly increased to 19.2 mm/month/10 years.

In Teberda the growth in precipitation is due to the increase in the annual daily precipitation maximums, the number of days with average precipitation. For the period 1976-2015 at MS Terskol the observed increase in the average annual precipitation was due to significant increase in spring precipitation (18.56 mm /month /10 years) and autumn (15.3 mm /month /10 years) precipitation. The general trend for all weather stations is significant increase in the autumn precipitation.

### 3.3 Analysis of temperature and precipitation anomalies in 2010 and 2015

Since the maximum excess of the climate norm for all stations took place in 2010 as Fig.1 demonstrates, it is interesting to compare its with seasonal and annual temperature and precipitation anomalies 2015, characterized as the hottest year on the planet.

In order to obtain an estimate of the magnitude of the warming, it is necessary to compare it with the natural annual temperature variability (standard deviation  $\delta$ ), approximated as a normal distribution. The chance of deviation from the mean value by  $\pm 3\sigma$  is the probability  $p = 0.13\%$  with a normal variability distribution. Deviations  $\pm 4\sigma$ ;  $\pm 5\sigma$  from the mean values in the case of the normal distribution are negligible.

Below we analyze the temperature anomalies (average, maximum, minimum) in 2015 in comparison with the standard deviation of the corresponding values, and also for comparison with similar data for 2010 for all 5 stations. (Tables 1, 2 and Figure 3).

Tables 1, 2 show average annual (January-December) and seasonal anomalies  $\Delta T$  with standard deviations  $\sigma$  of surface air temperature for stations in Akhty, Teberda, Terskol, Nalchik, Prokhladnaya. Red cells are marked cells with positive anomalies in 2010, 2015, exceeding the positive - corresponding standard deviation  $\sigma$  by more than 3 times, pink anomalies exceeding by more than 1  $\sigma$ , but less than 3  $\sigma$ .

Table 1 shows that at all stations in 2010 as a whole, as well as in all seasons, with the exception of spring, there were significant positive anomalies in mean temperatures. Of annual / seasonal positive—the 75 combinations "weather station - abnormality", in 26 cases (37%, pink cells), there was an excess of the positive anomaly from 1 $\sigma$  to 3  $\sigma$ , and in 7 cases (9,3%) exceeding by 3 $\sigma$  and more. Thus, the risk of an event with a very high temperature is very large, more than implies a normal distribution. Probably the most important climate change is the appearance of new category of "extremely hot" years, exceeding the average initial period of 1961-1990 more than 3 $\sigma$ .

In the spring season of 2010 the temperature anomalies (average, maximum, minimum) did not exceed the interannual variability of temperature. Summer and autumn anomalies were the most significant both in absolute magnitude and in excess of the corresponding standard deviations (Table 1). In the summer season of 2010, anomalies were observed at all stations, in the autumn season and in the year at the Teberda station, exceeding the interannual variability of the surface air temperature by three

or more times ( $> 3\sigma$ ). In the autumn season the anomalies exceeded the standard deviation by a factor of 2. Winter season 2010 includes December 2009 and January, February 2010. Data for December 2010 on the determination of seasonal temperatures were not included in the winter season of 2010. Nevertheless, after analyzing the temperatures in December 2010, we have received that this year the highest average December temperatures and anomalies for the entire investigated period of 1961-2015 were observed. The following excess of the standard temperature anomalies occurred: in Akhty, Teberda, Nalchik, the anomalies were 2.6 times higher than the standard deviation, in Prokhladnaya, Terskol, 2 times.

**Table 1**

Average annual (January-December) and seasonal temperature anomalies ( $\Delta$ , °C) in 2010:  $\Delta$  - deviations from the norm (average for 1961-1990);  $\sigma$  – is the standard deviation for 1961-2010.

Weather station	Year		Winter		Spring		Summer		Autumn		
	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	
	average temperature										
Akhty	2,1	0,79	2,3	1,83	0,3	1,16	3,0	0,95	2,8	1,25	
Teberda	2,9	0,78	3,4	1,83	0,6	0,87	3,3	0,97	3,0	0,97	
Terskol	1,8	0,64	2,5	1,53	0,2	0,87	2,5	0,86	1,9	0,97	
Nalchik	2,1	0,95	1,0	1,77	1,0	1,14	3,6	1,19	2,6	1,14	
Prokhladnaya	1,9	0,89	1,1	1,84	0,8	1,04	3,1	1,10	2,0	1,09	
	maximum temperature										
Akhty	2,2	2,65	3,2	2,24	-1,3	2,02	1,7	2,53	5,4	2,96	
Teberda	2,1	2,23	2,1	2,06	1,0	1,86	2,6	2,22	2,9	2,44	
Terskol	no data available										
Nalchik	2,2	1,78	2,5	2,84	-0,4	2,4	2,9	1,8	3,8	2,48	
Prokhladnaya	1,7	1,0	1,8	3,29	-0,6	2,41	2,7	1,84	1,7	2,35	
	minimum temperature										
Akhty	1,2	2,48	3,3	2,82	0,6	3,69	-0,6	2,07	1,4	2,99	
Teberda	3,9	2,94	5,6	2,75	1,6	4,17	3,3	1,71	3,8	3,74	
Terskol	no data available										
Nalchik	2,1	4,28	-0,4	4,45	2,2	4,46	2,8	2,12	3,7	3,66	
Prokhladnaya	2,3	4,32	1,0	4,74	1,7	4,46	2,9	2,69	3,2	3,56	

Thus, although many studies provide estimates of the anomalous heat of 2010 only in the summer season, but according to our research, abnormally high surface air temperatures in 2010 occurred in the summer, autumn seasons, and also in December 2010 for all climatic zones of the south Russia, including the high-altitude MS Terskol. In January 2011, all average monthly temperatures were comparable to the climatic norm.

Table 2 shows that at all weather stations in 2015, during the summer seasons, there were positive anomalies of mean temperatures with an excess of interannual variability from  $1\sigma$  to  $3\sigma$  (pink cells). In 2015, anomalously high winter and autumn temperatures were observed at all stations. In 2015, as well as in 2010, there was not one negative temperature anomaly exceeding the standard deviation in absolute value (except for the negative anomaly of the summer minimum temperature in Akhty).

Thus, the anomalous values, both annual and seasonal, exceeding the inter-annual variability by more than  $3\sigma$  (red cells) in 2015 were not found in any of the studied stations, unlike in 2010.

**Table 2**

Average annual (January-December) and seasonal temperature anomalies ( $\Delta$ , °C) in 2015:  $\Delta$  - deviations from the norm (average for 1961-1990);  $\sigma$  – is the standard deviation for 1961-2015.

Weather station	Year		Winter		Spring		Summer		Autumn		
	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	$\Delta$ , °C	$\sigma$ , °C	
	average temperature										
Akhty	1,6	0,8	2,6	1,82	0,0	1,2	2,3	1,02	1,3	1,28	
Teberda	1,3	0,78	2,2	1,82	0,2	0,9	2,2	0,99	1,9	1,04	
Terskol	1,1	0,65	1,4	1,51	0,0	0,89	1,7	0,88	1,3	1,05	
Nalchik	1,6	0,95	2,2	1,78	0,6	1,2	1,9	1,18	1,9	1,2	
Prokhladnaya	1,8	0,9	2,2	1,82	0,6	1,1	2,3	1,13	1,8	1,15	
	maximum temperature										
Akhty	0,9	2,65	2,4	2,41	0,4	2,02	1,5	2,59	-0,9	2,96	
Teberda	1,1	2,2	2,2	2,23	0,5	1,85	1,4	2,21	0,3	2,42	
Terskol	no data available										
Nalchik	1,3	1,8	0,7	2,88	0,0	2,33	2,5	1,82	2,2	2,43	
Prokhladnaya	2,6	1,94	1,7	3,21	1,3	2,42	3,8	1,97	2,9	2,41	
	minimum temperature										
Akhty	0,9	2,48	3,1	2,8	2,2	3,61	-3,5	2,33	1,9	3,17	
Teberda	2,2	2,9	2,5	2,68	1,6	4,07	2,7	1,81	4,0	3,87	
Terskol	no data available										
Nalchik	2,2	4,23	2,6	4,4	3,1	4,36	1,3	2,12	2,0	3,72	
Prokhladnaya	2,1	4,43	2,1	4,77	3,3	4,31	1,1	2,69	1,9	3,57	

Comparison of seasonal and annual anomalies shows that positive anomalies of average temperatures in all seasons have occurred both in 2015 and in 2010. In this case, in the spring, summer and autumn seasons, absolute anomalies in 2010 exceed the anomalies of 2015 (Fig. 3).

In the paper by J. Hansen "Perception of Climate Change" (2012) <sup>20</sup>, the results of a study of temperature anomalies in recent decades are presented. The closer to the present moment, the wider the "bell" of the curve became, moving toward higher temperatures (right-sided asymmetry), that is, a deviation of three standard units ( $3\sigma$ ) now covers about 10% of the planet.

Let us now analyze the anomalous values of the precipitation regime (sum of precipitation, daily maximum, number of days with precipitation not less than 5 mm) in comparison with the standard deviation of the corresponding values according to 2015 data (Table 2 and Figure 4). From Table 3 and Figure 4 it can be seen that the deviations of the mean annual values from the climatic norms of precipitation take both positive and negative values.

Table 3 and Figure 4 show the annual (January-December) and seasonal anomalies of precipitation amounts in 2015 for mountain stations in the stations of Akhty, Teberda, Terskol, foothills station Nalchik and the plain station Prokhladnaya. The mode of precipitation in 2015 was in general close to the norm of 1961-1990.

In 2015 at the stations of Akhty, Prokhladnaya there was a negative anomaly of the sum of precipitation in the summer and autumn seasons and also in the year.. In Teberda and Terskol the spring amounts of precipitation slightly exceeded the interannual variability. For other stations, the annual and seasonal values of sums of precipitation, maximum daily precipitation and number of days with precipitation not less than 5 mm were within the standard deviation  $\sigma$  of the corresponding parameters. In general, there was a deficit of precipitation in 2015, the average annual precipitation was below the norm at all weather stations, staying within one standard deviation in Teberda, Terskol, Nalchik and slightly exceeding the standard deviation in Akhty and Prokhladnaya.

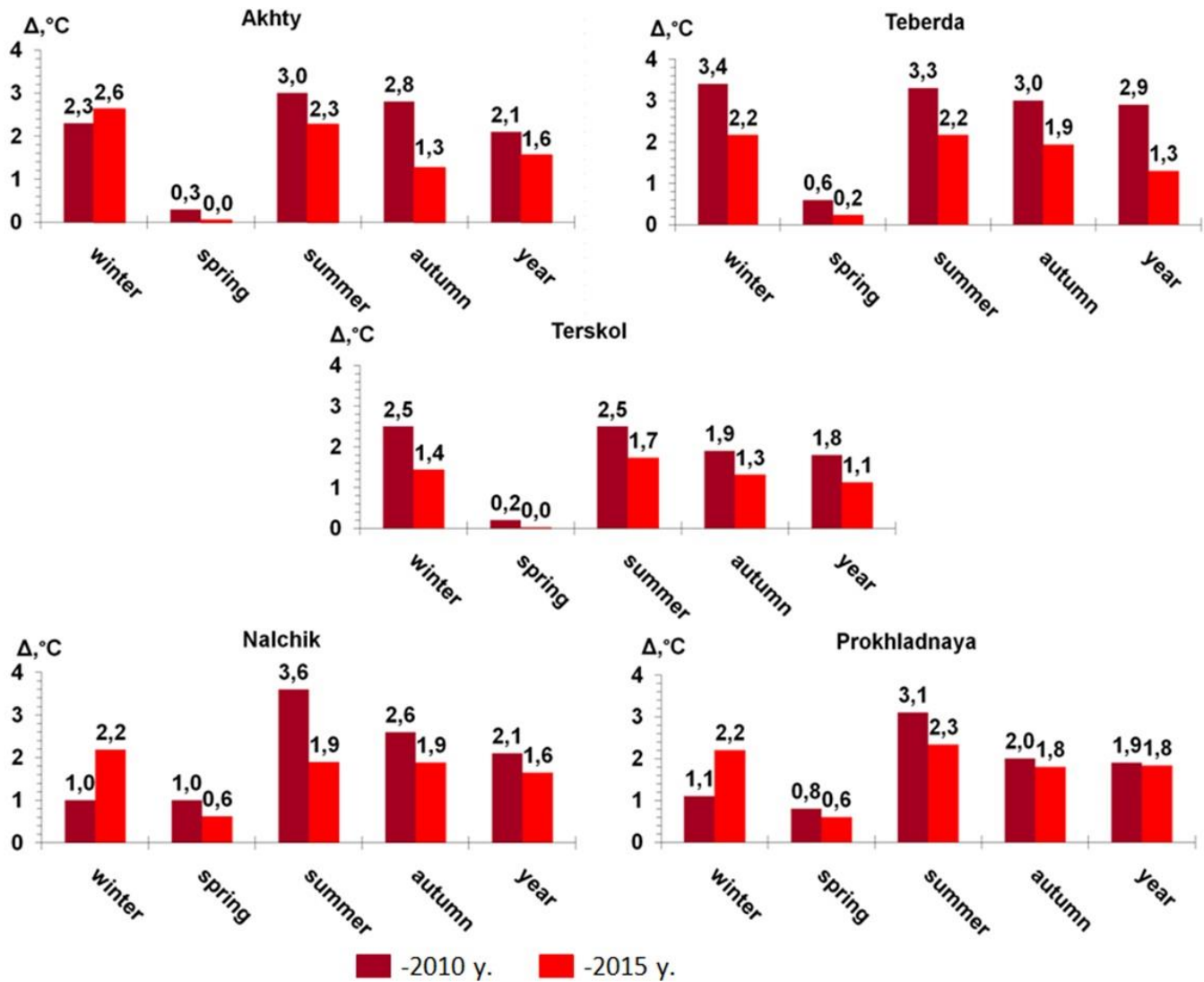


Figure 3

Average annual and seasonal anomalies of temperature in 2010 and 2015

Table 3

Annual (January–December) and seasonal anomalies of sums of precipitation in 2015:  $\Delta$ , mm - deviations from the norm (average for 1961–1990);  $\sigma$  – the standard deviation for 1961–2015

Weather station	Year		Winter		Spring		Summer		Autumn		
	$\Delta$ , mm	$\sigma$ , mm	$\Delta$ , mm	$\sigma$ , mm	$\Delta$ , mm	$\sigma$ , mm	$\Delta$ , mm	$\sigma$ , mm	$\Delta$ , mm	$\sigma$ , mm	
	sums of precipitation										
Akhty	-131,9	73,77	-14,5	14,61	-35,6	41,32	-87,0	45,07	-9,8	36,29	
Teberda	-41,4	123,54	9,3	83,13	111,1	63,13	-36,9	53,64	-124,9	83,06	
Terskol	-54,2	169,53	12,4	88,4	68,0	77,1	-50,0	66,3	-84,6	96,2	
Nalchik	-102,7	104,64	-18,1	19,35	-30,5	55,8	-6,8	69,63	-47,4	51,83	

Prokhladnaya	-133,2	90,06	-17,8	18,75	-25,6	47,06	-60,5	57,83	-29,3	43,97	
	maximum daily precipitation										
Akhty	-12,0	8,2	6,0	5,23	1,0	7,47	-6,0	9,51	2,0	9,43	
Teberda	-4,2	13,7	5,8	15,4	0,7	13,9	-9,4	11,9	-8,7	12,9	
Terskol	no data available										
Nalchik	0,0	11,43	-3,6	5,46	-7,2	10,8	3,4	10,5	-4,7	15,3	
Prokhladnaya	-17,8	15,67	-8,5	3,96	-10,7	14,69	-4,2	14,26	-17,8	13,5	
	days with precipitation not less than 5 mm										
Akhty	-5,0	4,36	-1,0	1,55	-1,0	2,86	-2,0	3,29	0,0	2,52	
Teberda	0,0	7,23	1,0	3,62	0,0	3,95	-1,0	3,81	0,0	4,48	
Terskol	no data available										
Nalchik	-6,0	6,72	0,0	1,84	0,0	3,49	-1,0	4,06	-1,0	3,39	
Prokhladnaya	4,0	5,55	0,0	1,97	0,0	2,81	1,0	3,43	0,0	2,63	

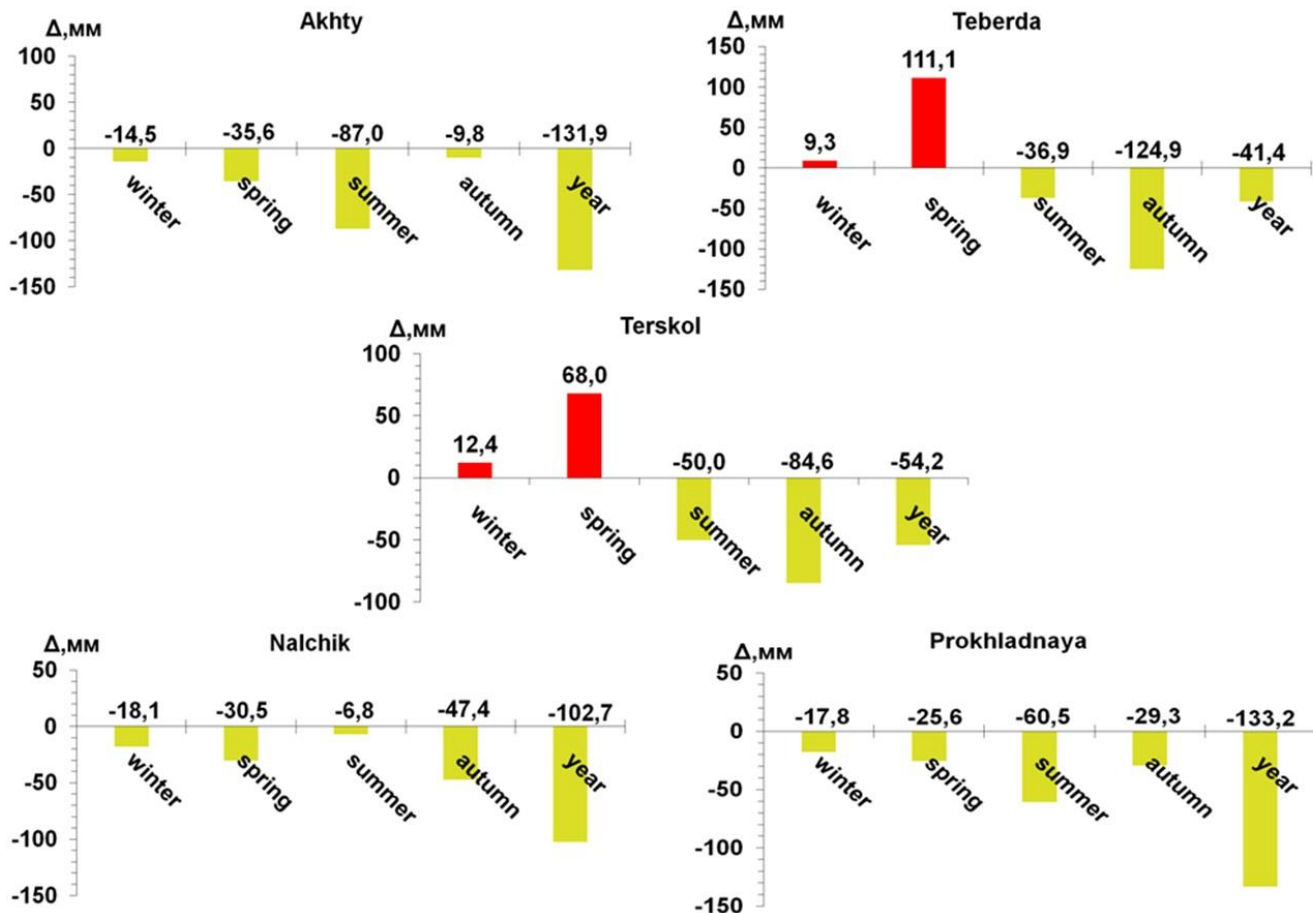


Figure 4

Annual (January-December) and seasonal precipitation anomalies in 2015

Table 3 shows that in 2015 at all stations there was no excess of precipitation by more than 1 $\delta$ , with the exception of spring precipitation sums in Teberda ( $\Delta = 111.1$  mm,  $\sigma = 63.13$  mm) and winter precipitation maximums in Akhty ( $\Delta = 6.0$  mm and  $\sigma = 5.23$  mm). Figure 4 shows that in 2015 there was deficit of seasonal and annual precipitation for all stations, except for the winter and spring seasons in Teberda and Terskol.

#### 4. CONCLUSION

In all climatic zones of the North Caucasus (mountain, foothill and plain) in the modern period the warming process increases, while the maximum warming is observed in summer and autumn. In the high-altitude MS Terskol, only in summer there is significant warming: in the remaining seasons and for the year as a whole, the temperature trends are insignificant.

For the period from 1961 to 2015 according to this study 2010 remains a record year for extremely high temperatures in the year as a whole due to extremely high summer and autumn temperatures.

For 1961-2015 the change in precipitation regime had a positive trend for different climatic zones of the North Caucasus, but the linear trends of annual and seasonal precipitation are insignificant, except for autumn precipitation sums.

With general long-term (55 years) trend of slight increase in precipitation amounts, including daily highs and the number of days with average precipitation, from the analysis of precipitation anomalies in 2015, it follows that there was deficit of annual and seasonal precipitation (negative anomalies).

Such combination of trends in the temperature regime and regime can create deterioration in climatic conditions with negative consequences for agriculture, ecology, life in the region, which will require adaptation to expected climate changes.

#### CONFLICT OF INTEREST

The authors declare no conflict of interest

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