MAUSAM, **69**, 4 (October 2018), 553-562

551.583 (470)

Changes of temperature and precipitation regimes in the south of European Russia in 1961 - 2015

B. A. ASHABOKOV*[#], M. N. BEYTUGANOV*, A. A. TASHILOVA*,

L. M. FEDCHENKO* and A. V. SHAPOVALOV*

**High-mountain Geophysical Institute, 2 Lenina av. 360030 Nalchik, Russia*

[#]*Information Science and Regional Management Institute of the Kabardino-Balkarian Research, Centre of the Russian Academy of Science, Armand street 360000 Nalchik, Russia*

(*Received 20 February 2018, Accepted 24 September 2018*)

e mail : editor4@academicpapers.org

सार – इस शोध पत्र में यूरोपीय रूस के दक्षिणी भागों के भिन-भिन्न जलवायु क्षेत्रों में कई ऋतुओं के तथा 1961 से 2015 तक के वार्षिक तापमान एवं वर्षा विश्लेषण का सारांश प्रस्तुत किया गया है। 1976 से 2015 तक की रैखिक प्रवृतियां (ढलान अनुपात बताए गए फैलाव के प्रवृति में योगदान) वर्तमान उष्णन में हुई वृद्धि का निरूपण करती हैं। इस विश्लेषण में दक्षिणी यूरोपीयन रूस के भिन्न-भिन्न जलवायु क्षेत्रों में स्थित 5 मौसम स्टेशनों के डेटा का उपयोग किया गया है जिसमें दो पर्वतीय स्टेशन-आख्ती (समुद्र तल से 1,281 मी.ऊपर), तेबरदा (1,335 औसत माध्य समुद्र तल), अधिक ऊँचाई वाला पर्वतीय स्टेशन - टेर्सकोल (2144 औसत माध्य समुद्र तल) और गिरिपद एवं मैदानी (घास के मैदान) क्षेत्रों के दो मौसम स्टेशन - नलचिक (500 औसत माध्य समुद्र तल) तथा प्रोकलादनाया (198 औसत माध्य समुद्र तल) शामिल हैं। इस अध्ययन में अलग-अलग जलवायु क्षेत्रों में वायु तापमान और वर्षा की स्थिति में परिवर्तन के सामान्य तथा विभिन्न विशेषताओं को निर्धारित किया गया है। यह पता चला है कि सभी स्टेशनों पर ग्रीष्मकालीन औसत तापमानों में वृद्धि दर सभी जलवायु क्षेत्रों के लिए सांख्यिकीय रूप से महत्वपूर्ण है उसमें टेर्सकोल भी शामिल है। ऊँचाई पर स्थित पर्वतीय स्टेशन - टेर्सकोल में वार्षिक औसत तापमान में लगातार वृद्धि हो रही है जबकि अन्य जलवायु क्षेत्रों में वृद्धि हो रही है। वर्षा की स्थितियों में परिवर्तन उनके वितरण की विषमता और पृथक प्रकृति के कारणों से अधिक जटिल हो जाती है। कुछ मौसम स्टेशनों में कई वर्षों से वर्षा और दैनिक अधिकतम वर्षा में वृद्धि की प्रवृत्ति, मौसमी कुल वर्षा (गर्मी और सर्दियों में) में कमी की प्रवृत्ति पाई गई है।

ABSTRACT. This work summarises the analysis of temperature and precipitation regimes in different climate zones of the south of European Russia over the seasons and annually in 1961 - 2015. Linear trends (the slope ratio, the contribution of the trend in the explained dispersion) over the period from 1976 through 2015 supplement the description of the changes of the value in question since the year of conventional beginning of the modern warming. The analysis uses the data of 5 weather stations situated in different climate zones of the south of European Russia to include two mountain stations – Akhty (1,281 above sea level), Teberda (1,335 m asl), high-mountain station Terskol (2,144 m asl) and two weather stations in the piedmont and the plain (steppe) regions of Nalchik (500 m asl) and Prokhladnaya (198 m asl). The study determines common and different features of changes in the air temperature and precipitation regimes in different climate zones. It was revealed, that the growth rate of average summer temperatures is statistically significant for all the stations in all the climate zones to include Terskol. The annual average temperature varies steadily at the high-mountain station Terskol while in the other climate zones it grows. The changes in the precipitation regime are much more complex due to the heterogeneous and discrete nature of their distribution. With the overall years-long trend towards increasing precipitation and daily maximums at some weather stations, seasonal precipitation totals (in summer and winter) tend to decrease.

Key words – Caucasus climate zones, Seasons, Temperature, Precipitation, Trend, Anomalies.

1. Introduction

Our planet's climate has never been constant. It has been changing noticeably during the last several hundred thousand years [Borisenkov Ye and Pasetskiy, 1988; Jouzel *et al*., 2007; New *et al*., 1999; Podrezov, 2009; Kobyshevoy, 2001; Klimenko and Sleptsov, 2003 and Budyko, 1980]. The authors of Gruza and Rankova (2012) note that the global warming which started in the beginning of the XX century has not been uniform. There are three intervals: the warming of 1910-1945, the slight cool-down of 1946 - 1975 and the most intensive warming starting after 1976. The beginning of the XXI century remains the warmest quindecennial of the whole history

TABLE 1

Linear trend *b* of the average annual and seasonal temperature regime over 1961-2015 and 1976-2015

Year/ Season	Temp.	Akhty		Teberda		Terskol		Nalchik		Prokhladnaya	
		1961-2015	1976-2015	1961-2015	1976-2015	1961-2015	1976-2015	1961-2015	1976-2015	1961-2015	1976-2015
Year	T	0.19	0.41	0.22	0.39	0.04	0.13	0.34	0.56	0.3	0.47
	Min	0.47	0.4	0.38	0.21	-	-	0.11	-0.05*	0.43	0.13
	Max	-0.03*	0.39	0.33	0.51	-	-	0.38	0.76	0.48	1.05
Winter	T	0.17	0.43	0.19	0.39	-0.09*	0.01	0.34	0.45	0.31	0.37
	Min	0.31	0.25	0.32	0.01	-	-	0.07	-0.14*	0.19	-0.07
	Max	0.53	0.74	0.46	0.74	-	-	0.3	0.02	0.32	0.26
Spring	T	0.14	0.28	0.13	0.24	0.01	0.07	0.29	0.51	0.23	0.37
	Min	0.9	1.0	0.59	1.29	-	-	0.1	1.2	0.99	0.95
	Max	0.15	0.13	0.31	0.44	-	-	-0.1	0.38	0.05	0.72
Summer	T	0.33	0.52	0.41	0.55	0.29	0.41	0.44	0.70	0.42	0.66
	Min	0.05	-0.03*	0.58	0.74	-	-	0.25	0.56	0.45	0.64
	Max	-0.2*	0.14	0.28	0.44	-	-	0.38	0.76	0.48	1.06
Autumn	T	0.15	0.43	0.18	0.41	-0.02*	0.01	0.27	0.56	0.24	0.45
	Min	0.07	0.1	0.75	1.19	-	-	0.14	0.27	0.3	0.37
	Max	0.19	0.08	0.43	0.43	-	-	0.49	0.96	0.43	0.81

* = Negative trends of variables

[T - average temperature, Min - absolute minimum, Max - absolute maximum, *b* - linear trend slope ratio (°C/10yrs)]

of instrumental observation. Russia is much more susceptible to climate influences than the North Hemisphere and the Earth as a whole. In Russia, the scope of average annual temperature anomalies is 3-4 °C while it is only slightly above 1.0-1.5 °C [Jones and Moberg (2003); Bekryaev *et al*. (2010)] for the globe and the land of the North Hemisphere. Since 1970s, the average temperature of the surface air has been rising in Russia at 0.43°C per decade which is twice as fast as the global warming [Ashabokov *et al*., 2015; Ashabokov *et al*., 2016; Bulygina *et al*., 2000; Projections and Impacts (Russia); http://www.cru.uea.ac.uk/cru/].

Studying global and regional climate changes is one of the priorities caused by the need to adjust industry and agriculture to them [Kobak *et al*., 2002; Larionov, 2001; Bedritskiy *et al*., 2004]. The North Caucasus depends on climate as well being one of the important agricultural regions of Russia [Ashabokov *et al*., 2008; Arkhestov and Tashilova, 2014]. The peculiarities of the climate of the south of European Russia have several causes to include altitudinal zonation. In respect of relief, the North Caucasus is usually divided into the plain, piedmont and mountain zones with their specific temperature and precipitation regimes [Ashabokov *et al*., 2015; Tashilova *et al*., 2016; Ashabokov *et al*., 2017]. The study analyses the sets of climatic variables over the period of 1961-2015 for two mountain weather stations – Akhty (1,281 m asl) and Teberda (1,335 m asl), high-mountain station Terskol (2,144 m asl), and two weather stations in the piedmont and plain (steppe) areas - Nalchik (500 m asl) and Prokhladnaya (198 m asl). The article compares changes in the temperature and precipitation regimes over 1961-2015 and 1976-2015 (*i.e*., since the modern warming began according to WMO) using data collected by 5 weather stations. Seasonal and annual sets of meteorological parameters were analysed including the average surface air temperature, absolute maximal temperatures, absolute minimal temperatures, average precipitation amounts and daily precipitation maximums.

2. Materials and method

The sets of meteorological parameters were provided by the Hydrometeorology Service North Caucasus Administration. The time series were studied with statistic methods using SPSS 15.0 software [Isayev, 1988; Byuyul and Tsefel, 2002] and supplemented with linear trends of the examined variables over the whole observation period (1961-2015 and 1976-2015). Linear trend ratios were estimated as required by the standard linear regression theory (least squares method) [Seber, 1980] and expressed in °C/10yrs or mm/month/10yrs (hereinafter - mm/10yrs). As regards temperature, average values, anomalies (deviations of observed values from the norms) as well as seasonal and annual (January to December) trends were studied. The norm means an average years-long value of a climatic variable over the base period of 1961-1990 [www.ccl-16.wmo.int]. Anomalies are determined as deviations of observed values from relevant norms. Precipitation data were averaged by calendar seasons and annually. As a result, seasonal and annual precipitation totals are shown in mm/month, *i.e*., brought to the monthly scale.

3. Findings and discussion

3.1. *Temperature*

The main peculiarities of the temperature regime in the North Caucasus over 1961-2015 and the sub-period of 1976-2015 determined from observations taken by five weather stations are provided in Table 1.

Akhty (Dagestan) is the easternmost of the stations situated in the south of Dagestan at 1,054 m asl. The average temperature here over 1961-2015 was 9.47 °C at the norm of 9.20 °C (average for 1961-1990). Table 1 shows, that average temperatures at Akhty had been growing over 1961-2015 at 0.19 °C/10yrs and at 0.41 °C/10 yrs over 1976-2015.

Since 1961, annual average temperatures grew at 0.19 °C/10yrs due to a fast increase of the minimal temperatures (0.47 °C/10yrs). In 1976, the trend of the maximal temperatures also changed to growth (0.39 °C/10yrs) comparable with that of the minimal ones (0.4 °C/10yrs). The positive average temperatures anomaly made +0.3°C over 1961-2015 most heavily contributed by positive anomalies of the absolute minimums (+0.6°C).

The average winter temperature (-0.2 °C over 1961-2015) was slightly above the climatic norm (-0.5 °C over 1961-1990). Average winter temperatures grew at 0.17 °C/10yrs since 1961 and at 0.43 °C/10yrs since 1976. The growth was due to the increasing maximums (0.53 °C/10yrs) as well as minimums (0.31 °C/10yrs). In *spring*, the average was 8.9 °C at the norm of 8.7 °C growing at 0.14 °C/10yrs since 1961 because of the increase of spring maximums (0.9 °C/10yrs) and absolute maximums (0.15 °C/10yrs). The averaged anomaly at Akhty is the highest of all the stations over all the seasons (+1.4 °C). The average summer temperature was 19.1 °C at the norm of 18.7 °C growing faster than that of the other seasons at 0.33 °C/10yrs since 1961 and at 0.52 °C/10yrs since 1976 due to the growing summer minimums. The maximal anomaly of the average summer temperature was in 2010 when the norm was exceeded by 3 °C. In 1961-2015 absolute summer maximums decreased at 0.2 °C/10yrs and since 1976 the trend changed for +0.14 °C/10yrs. In autumn, (average 10.1 °C at the norm of 9.8 °C) the average temperatures grew at 0.15 °C/10yrs since 1961 and the speed of growth increased to 0.43 °C/10yrs since 1976. Absolute autumn maximums increased at 0.19 °C/10yrs since 1961 and at 0.08 °C/10yrs since 1976 while absolute minimums remained practically unchanged.

The greatest anomaly of absolute maximums at Akhty over the whole observation period was in autumn of 2010 (ΔT = +10 °C). Afterwards, (in 2011, 2012, 2013 and, especially, 2014) the temperatures were below the norms.

Teberda (Karachay-Cherkessia) is situated on the northern slopes of the Greater Caucasus at 1,335 m asl. If differs from the other stations by the absence of the negative average, absolute maximum and absolute minimum temperature trends during the period in question. Over 1961-2015, the average annual temperature here was 6.8 °C at the norm of 6.5 °C. There was an average annual temperatures growth at 0.22 °C/10yrs since 1961 while in 1976-2015 it increased to 0.39 °C/10yrs. Since 1994, (save for 1997 and 2011) there were only positive annual average temperature anomalies with the record high of +2.8 °C in 2010. In 1961-2015, average annual temperatures grew due to the increase of the annual absolute maximums (0.33 °C/10yrs) as well as the absolute minimums (0.38 °C/10yrs). In 1976-2015, the maximums boosted the growth to 0.51 °C/10yrs while the minimums went down to 0.21 °C/10yrs.

The averaged anomalies of the annual average temperatures were +0.3 °C contributed mostly by the absolute maximums (+0.6 °C). Seasonally, summer anomalies (+0.5 °C), autumn maximums (+0.7 °C) and especially, spring maximums (+1.2 °C) are most evident, which is similar to the seasonal temperature regime in Akhty.

Terskol (Kabardino-Balkaria) is a high-mountain station situated in the Baksan Canyon near the Mt. Elbrus between the Mt. Cheget and Terskol Valley at 2,144 m asl. Over 1961-2015, the average annual temperature here was 2.57 °C which is the studied stations' minimum. Interestingly, the climatic norm

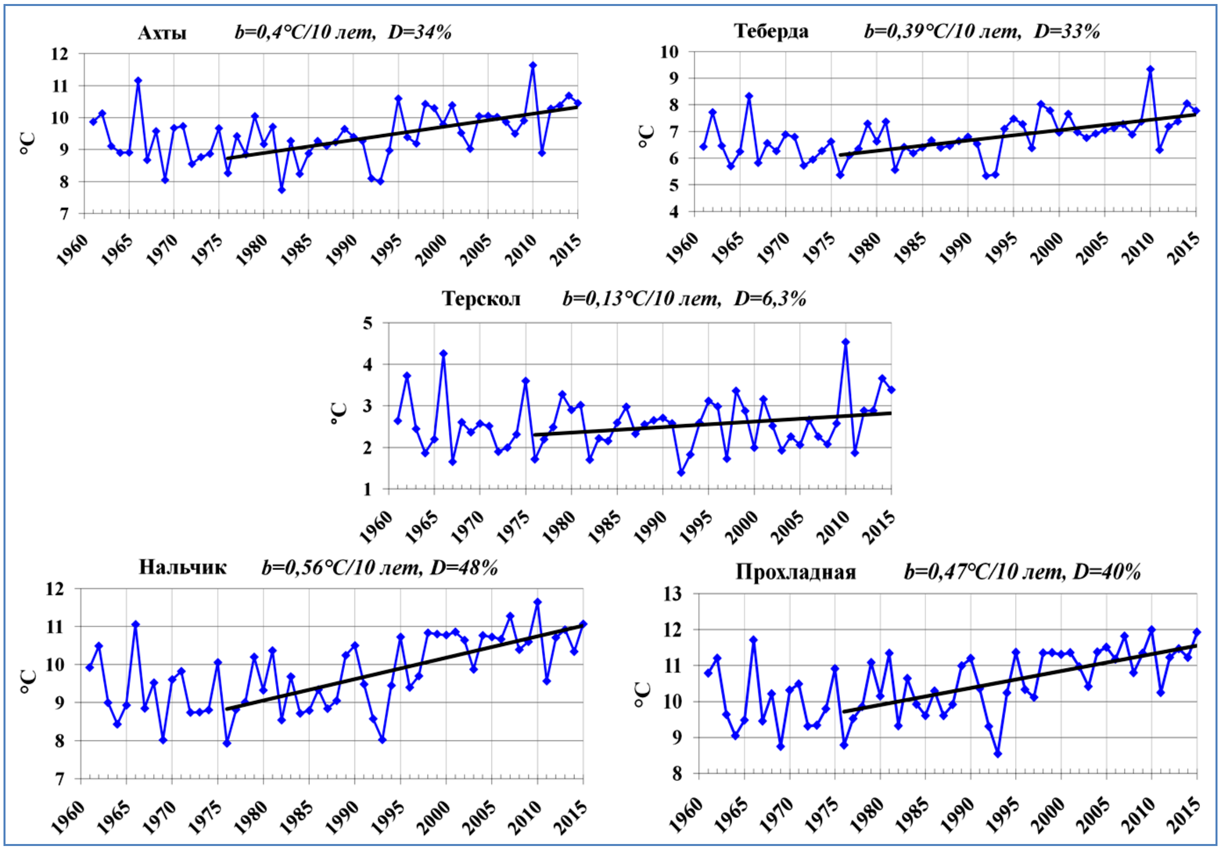

Fig. 1. Annual variation of temperature with individual trends at Akhty, Teberda, Terskol, Nalchik and Prokhladnaya stations over 1976-2015; b – linear trend slope ratio (°C/10yrs), D (%) - trend's contribution to overall dispersion

is 2.54 °C (1961-1990) while the average annual temperature over 1961-2014 was 2.55 °C making the difference of only 0.01°C which is indicative of the slowness of temperature changes at this station over the long period of time. However, the temperature averaged over 1961-2014 and 1961-2015 grew by 0.02 °C, *i.e.*, the temperature growth during this year is unexpectedly sharp revealing the considerable temperature growth in recent years.

In 1961-2015 at Terskol, no trend (0.04 °C/10yrs) is fixed and the average annual temperature is practically constant. However, since 1975 it grows faster at a speed of up to 0.13 °C/10yrs. A slight decrease of the average winter temperature was registered at the Terskol station over 1961-2015 (-0.09 °C/10yrs). Since 1976, average winter temperatures begin to grow here at a pace of up to 0.01 °C/10yrs. In spring and autumn, the temperature dynamics was unchangeable over the same periods. Unlike the spring and autumn, average temperatures in summer tend to grow at a speed comparable to those at the other stations. Over 1961-2015, it reaches 0.29 °C/10yrs and grows to 0.41 °C/10yrs over 1976-2015. The warming accelerating involves melting of glaciers (Atakuyev *et al.*, 2016). The greatest summer temperature anomalies were in 2006 and 2010 (+2.5 °C).

During the last decade (2006-2015), seasonal and annual absolute maximums grow at the Terskol station doing it especially steadily and contributing considerably to their overall dispersion (b = 1.1 °C/year, D = 68%). Since 2009, at the Terskol station there was no temperature minimum. Over 2006-2015, all the seasonal and annual absolute minimums decreased along with the most steady decrease of the sprin absolute minimums (-1.06 °C/year). Since the period of 2006-2015 is significantly shorter than the studied one, no inferences as to a change of the absolute minimums and maximums trend can be made for this station as well as for their contribution to the change of the average annual and seasonal temperatures there. Most probably, all those changes are parts of longer-term fluctuations of these climatic variables.

Nalchik (Kabardino-Balkaria) is situated in a piedmont district of the Central Caucasus at 500 m asl. Over 1961-2015, the average annual temperature was 9.75 °C at the norm of 9.31 °C. Average annual temperatures grew over 1961-2015 at the Nalchik station at 0.34 °C/10yrs and over 1976-2015 the growth increased to 0.56 °C/10yrs. Since 1994, there were only positive temperature anomalies the greatest of them being +2.3 °C in 2010.

In 1961-2015, the average annual temperatures grew by absolute maximums (0.38 °C/10yrs) as well as minimums (0.11 °C/10yrs).

The averaged anomaly of annual temperatures at the Nalchik station is +0.5 °C which is the highest value for all the stations. Positive annual anomalies of the average temperatures were due to the contribution of all seasonal temperatures, especially, summer and autumn ones (there are no negative anomalies since 1995). The maximal anomaly of the summer averages was in 2010 (+3.6 °C), the same of the automn averages was in 2010 as well (+3.2 °C).

Prokhladnaya (Kabardino-Balkaria) is situated in a steppe (plain) area at 198 m asl. The average annual temperature over 1961-2015 was 10.47 °C at the norm of 10.09 °C growing at 0.3 °C/10yrs and at 0.47 °C/10 over 1976-2015. Since 1994, annual average temperature anomalies in Prokhladnaya were only positive as in Nalchik the greatest of them being in 2010 (+2.0 °C). The increase was to the absolute maximums (0.48 °C/10yrs) and absolute minimums (0.43 °C/10yrs) alike. The averaged annual temperature anomalies are +0.4 °C. Since the beginning of the 90s, there is a long-lasting anomaly of summer averages in Prokhladnaya as well as in Nalchik. The maximum summer and autumn anomalies were in 2010 (+3.0 °C) and (+3.1 °C) respectively.

In the modern time (1976-2015), all the North Caucasus stations retain the values and angles of the seasonal and annual trends with a certain decrease in growth of the average temperature in spring and a faster growth during the rest of the seasons.

Fig. 1 shows the annual temperature variation with the linear trend at the mountain Akhty and Teberda stations, the high-mountain Terskol station, the piedmont station in Nalchik and steppe station in Prokhladnaya over 1976-2015. During the same period, the growth trend was identic at Akhty and Teberda (0.4 °C/10yrs and 0.39 °C/10yrs respectively). And if the temperature did not grow at Terskol in 1961-2015 (0.04 °C/10yrs), its growth accelerated since 1976 (0.13 °C/10yrs). At the piedmont station in Nalchik and steppe station in Prokhladnaya the average annual temperature was growing at the maximal degrees of 0.56 ^{o}C/10yrs and 0.47 ^{o}C/10yrs respectively. Statistically significant trends were observed at all the stations except for Terskol (*D* = 6.3%): Akhty (*D* = 34%), Teberda (*D* = 33%), Nalchik (*D* = 48%); Prokladnaya (*D* = 40%).

For all the stations, the average summer temperatures contribute most to the growth of the annual averages: Akhty (0.52 °C/10yrs at *D* = 32%), Teberda (0.55 °C/10yrs at *D* = 41%), Terskol (0.41 °C/10yrs at *D* = 30%), Nalchik (0.70 °C/10yrs at *D* = 48%), Prokhladnaya (0.66 °C/10yrs at *D* = 44%).

The analysis of seasonal absolute maximums and minimums at Akhty, Teberda, Nalchik and Prokhladnaya reveals the following:

(*i*) The growth of the average annual temperature at all the stations is due to the predominating growth of absolute average annual maximums with most significant trends in the piedmont and steppe zones: *b* = 0.76 °C/10yrs, *D* = 23% in Nalchik and *b* = 1.06 °C/10yrs, *D* = 35% in Prokhladnaya.

(*ii*) At all the stations, the growth of the annual average temperature is due to the growth of winter maximums. In Akhty and Teberda there are also spring minimums that matter. Absolute maximums grow significantly in winter in Akhty and Teberda. In Nalchik and Prokhladnaya, the summer and autumn maximums grow faster.

Thus, the trend of average and maximal temperatures (annual as well as seasonal) is positive for all the North Caucasus since 1976. A negative trend with small rates is typical for minimal temperatures in the following cases: annual minimum in Nalchik (-0.05 °C/10yrs, *D* = 0.02%); winter minimum in Nalchik (-0.14 °C/10yrs, *D* = 0.2%) and Prokhladnaya (-0.07 °C/10yrs, *D* = 0.004%); summer minimum in Akhty (-0.03 °C/10yrs, *D* = 0.02%). However, since the changes are insignificant over 10 years, their contribution to the overall dispersion is minimal (0.004% to 0.2%) which makes it possible to consider them stable.

3.2. *Precipitation*

Precipitation regime changes are not so evident as those of the temperature one since they depend more on local conditions (landscape) and react to the global warming indirectly. All the stations see the increase and the decrease of seasonal totals. Table 2 shows the figures of the linear trend *b* over 1961-2015 and 1976-2015 of some indicators of the annual and seasonal precipitation average at the studied stations.

The annual average at the **Akhty** station over 1961-2015 was 387.7 mm at the norm of 381.1 mm

TABLE 2

Linear Trend *b* of the Average Annual and Seasonal Temperature Regime over 1961-2015 and 1976-2015

Year/ season	Temp	Akhty		Teberda		Terskol		Nalchik		Prokhladnaya	
		1961-2015	1976-2015	1961-2015	1976-2015	1961-2015	1976-2015	1961-2015	1976-2015	1961-2015	1976-2015
Year	R	1.99	0.32	21.12	16.1	18.3	19.24	2.0	0.96	7.3	9.3
	Max	0.29	-0.6*	1.36	0.08	-	-	0.41	0.43	2.16	3.7
Winter	R	1.68	0.33	1.48	-5.2*	0.03	-4.19*	-1.8*	-0.38*	1.2	3.11
	Max	0.64	0.48	-0.05*	-2.87*	-	-	-0.3*	-0.06*	0.12	0.55
Spring	R	-1.6*	-0.43*	11.5	20.6	10.54	16.84	-5.32*	-1.29*	1.8	6.61
	Max	-0.13*	0.8	1.9	1.32	-	-	-1.4*	-2.24*	1.28	1.85
Summer	R	-2.3*	-0.31*	1.61	-4.77*	-2.13*	-2.63*	3.58	-3.87*	7.5	-12.6*
	Max	0.16	-0.01*	-1.1*	-3.14*	-	-	1.55	1.52	0.85	2.85
Autumn	R	4.38	3.44	10.85	5.66	11.55	10.02	6.16	6.94	12.3	12.6
	Max	0.01	-0.6*	1.53	0.32	-	-	0.25	-1.09*	3.03	5.51

* = Negative trends of variables
[R - precipitation total, Max - daily maximum, *b* - linear trend slope ratio (mm/10yrs)]

(1961-1990). The greatest seasonal totals here are in summer (136.7 mm), so are the daily maximums (25.5 mm). Since 1961 until 2015, the annual precipitation totals were growing inconsiderably at 1.99 mm/10yrs. The annual trend of daily maximums changed its direction from +0.29 mm/10yrs to -0.6 mm/10yrs since 1976 which is characteristic of the decrease of shower rainfall nowadays.

Table 2 shows, that since 1961 until 2015, the winter precipitation total was increasing at 1.68 mm/10yrs as well as the daily maximums (0.64 mm/10yrs). The total and daily maximums of spring and summer amounts decreased over the same period of time. The autumn amount had a positive trend over 1961- 2015 (4.38 mm/10yrs) as well as over 1976-2015 (3.44 mm/10yrs). At the same time, the daily maximums were growing slightly, but since 1976, there is a negative trend with the slope ratio of -0.6 mm/10yrs.

At the **Teberda** station, the annual total is considerable making 798.3 mm (1961-2015) at the norm of 771.3 mm. Teberda is in the group of stations where most of the precipitation falls in autumn – 223.1 mm. Generally, it is distributed almost evenly over the seasons: 219.4 mm in summer, 211.0 mm in autumn and 144.1 mm in winter. Since 1961 until 2015, the annual precipitation total grows at Teberda station at 21.12 mm/10yrs while over 1976-2015, the growth decelerated slightly down to 16.1 mm/10yrs. Over 1961-2015, the daily maximums were growing at 1.36 mm/10yrs bringing down the rate of growth down to 0.08 mm/10yrs in the modern sub-period of 1976-2015.

Analysing the contribution of seasonal precipitation in the growth of the annual totals, since 1961, winter amounts were growing at 1.48 mm/10yrs, but since 1976, they were decreasing at -5.2 mm/10yrs. Since 1976, the maximal winter daily totals decrease by 2.69 mm every decade. Over 1961-2015, there was a trend for the spring precipitation to increase at 11.5 mm/10yrs which accelerated since 1976. Since then, daily maximums are growing as well. Since 1961, there was a trend for the summer precipitation to increase. Over 1976-2015, it changes its direction and summer precipitation decrease at 4.8 mm/10yrs. The trends of the summer daily maximums are negative: over 1961-2015 – -1.1 mm/10yrs and since 1976 – -3.14 mm/10yrs. The both periods saw the increase of the autumn precipitation by 10.85 mm/10yrs and 5.66 mm/10yrs, respectively, while the daily maximums were growing as well.

At the **Terskol** station, the annual average precipitation amount over 1961-2015 was 966.9 mm at the norm of 935.9 mm. In Terskol, it is the greatest of all the mountain stations being 2.5 times as large as in Akhty (387.7 mm) and 1.2 times as large as in Teberda (798.3 mm). The maximum falls at summer (299.7 mm) followed by autumn, spring and winter in descending order. Over 1961-2015, the annual precipitation total is decreasing here at 18.3 mm/10yrs and as fast as at 19.24 mm/10yrs over 1976-2015. The trend of the winter

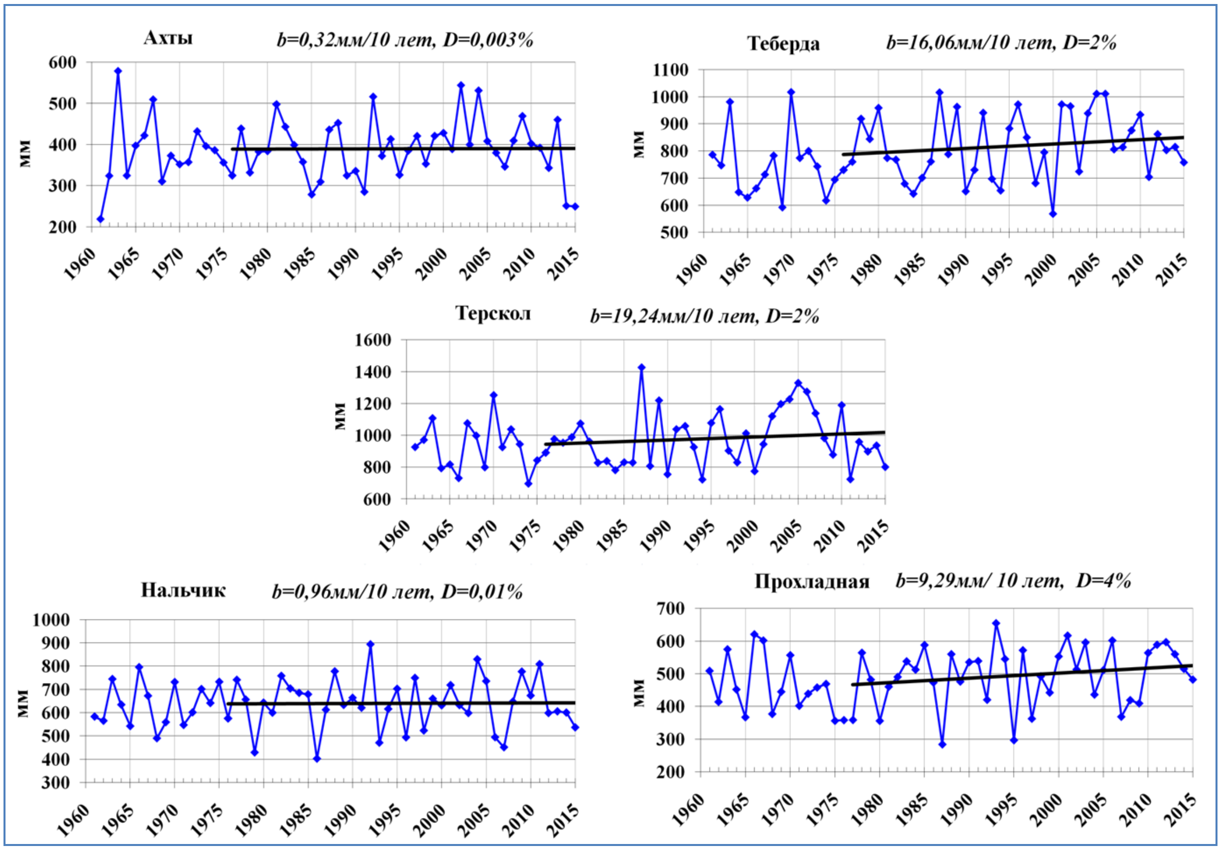

Fig. 2. Annual Variation of Precipitation Totals with Individual Trends at Akhty, Teberda, Terskol, Nalchik and Prokhladnaya Stations over 1976-2015; *b* – linear trend slope ratio (°C/10yrs), *D* (%) – trend's contribution to overall dispersion

precipitation is practically constant over the whole observation period (0.03 °C/10yrs), although since 1976, there is a negative trend of -4.19 mm/10yrs. The spring precipitation increases at 10.54 mm/10yrs over 1961-2015 accelerating to 16.84 mm/10yrs since 1976. Over 1961-2015, the trend of the summer totals is negative (-2.13 mm/10yrs) persisting over the 1976-2015 sub-period (-2.63 mm/10yrs). The growth of the autumn precipitation is comparable to that of the spring one making 11.55 mm/10yrs over 1961-2015 and 10.02 mm/10yrs over 1976-2015. During the last 10 years, the station saw a decrease of seasonal and annual daily maximums which the autumn ones being the fastest to grow and contributing most to the overall dispersion (*b* = -2.86 mm/yr, *D* = 32%).

A comparative analysis of climate changes in the Caucasus mountain areas and piedmont plains used the data received from the Nalchik (piedmont) and Prokhladnaya (steppe) weather stations.

The annual precipitation total in **Nalchik** is 639.1 mm at the norm of 636.4 mm. The greatest precipitation totals are in summer – 234.2 mm followed by spring (194.8 mm) and autumn (138.2 mm). The least values are in winter (71.44 mm). Over 1961-2015, there was a trend towards an inconsiderable decrease of the annual total by 2 mm/10yrs shrinking to 0.96 mm/10yrs since 1976. In Nalchik, precipitation amount decreases in spring and summer and winter precipitation lowers slightly as well (Table 2). The daili maximums increase at 0.41 mm/10yrs over 1961-2015 and at 0.43 mm/10yrs over 1976-2015. In winter and autumn, the daily maximums decrease over 1961-2015 as well as presently. Over 1976-2015, this decrease is observed in autumn as well.

The annual precipitation total at the **Prokhladnaya** station is 486 mm at the norm of 475.3 mm. In Prokhladnaya, as well as in Nalchik, most of the precipitation falls in summer (178.2 mm) folowed by spring (138.4 mm) and autumn (101.8 mm). Winter is the driest season with only 670 mm. Over 1961-2015, there was a positive trend of the annual total growing by 7.3 mm/10yrs while over 1976-2015 it was negative (- 9.3 mm/10yrs). Over 1976-2015, summer precipitation amounts decreased by 12.6 mm/10yrs and grew in the other seasons, especially, in autumn. The daily maximums increase at 2.16 mm/10yrs over 1961-2015 and at 3.7 mm/10yrs over 1976-2015 mostly contributed to by the autumn daily maximums.

Thus, the change of the precipitation regime is not as unidirectional as the change of the temperature regime. Both, the increase and decrease of precipitation totals, are observed at all the stations. Fig. 2 presents the linear trend *b* over 1976-2015 of some indicators of the annual average precipitation regime at the North Caucasus weather stations.

Since 1976 at the Akhty and Teberda stations there was a positive trend of precipitation totals at the rate of 0.32 mm/10yrs and 16.1 mm/yr, respectively, contributed mostly by the annual daily maximums. In Akhty, the autumn precipitation increases significantly. In Teberda, the autumn and spring amounts increase as well as the daily maximums.

Over 1976-2015, at the Terskol high-mountain station the annual precipitation total grew (19.24 mm/10yrs) due to the considerable increase of the spring (16.84 mm/10yrs) and autumn (10.02 mm) totals. Over the same period, the winter and summer amounts went down. Over 2006-2015, the daily maximums had a negative trend.

At the piedmont Nalchik station and steppe station Prokhladnaya there was a growth of the annual precipitation amounts since 1976 at the rate of 0.96 mm/10yrs and 9.3 mm/10yrs, respectively. The considerable increase of the autumn amounts for all the stations is common for all the stations. In Prokhladnaya, the daily maximums grow steadily as well.

Thus, over 1961-2015 the positive trend of the annual precipitation amounts was the case for all the North Caucasus weather stations, while the linear trends of the annual and seasonal totals are inconsiderable save for the autumn ones.

(*i*) In Akhty, the rates of increase of the average annual amounts over 1961-2015 and 1976-2015 are positive but are tending to decrease. The growth of the autumn totals contributes to the increase of the annual amounts most, while the spring and summer ones tend to decrease.

(*ii*) At the mountain station Teberda, the annual averages increase for the account of the spring and autumn precipitation. Since 1976, the winter and summer totals decrease slightly while the spring and autumn ones increase.

(*iii*) At the high-mountain station Terskol, the increase of the average annual amounts is contributed also by the spring and autumn ones. The winter totals are practically unchanged since 1961 and decrease slightly since 1976. The summer precipitation decrease inconsiderably over the period.

(*iv*) In Nalchik, the growth of the annual averages is slow and comparable with that in Akhty. Save for the autumn totals, other seasons' precipitation amounts tend to decrease.

(*v*) In Prokhladnaya, the growth of the annual totals is due to the growth of the spring and autumn ones. The winter and summer amounts tend to decrease.

Thus, the study leads to the conclusion of the different change rates of the temperature and precipitation regimes over different periods in question: 1961-2015 and 1976-2015. Nevertheless, the warming trend predominates in all climate zones of the Caucasus to include that of the high-mountain station Terskol. The maximal warming is registered in all climate zones of the North Caucasus in summer and autumn. At the Terskol station, a considerable warming is observed only in summer while for the rest of the seasons and the year as a whole the temperature trends are inconsiderable.

The change of the precipitation regime is not that unidirectional. Given the overall years-long trend towards the increase of precipitation amounts and daily maximums, the analysis of the precipitation regime reveals the steady trend towards the decrease of the seasonal (summer and winter) totals at some weather stations. The steady increase of the autumn precipitation is common for all the North Caucasus climate zones.

Disclaimer

The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Arkhestov, G. Kh. and Tashilova, A. A., 2014, "The Tasks of Definition and Reconciliation of Target Indicators in the Problem of Adaptation of the Agrarian Sector to the Changes in the Agricultural and Climatic Resources of the Region", (Zadachi opredeleniya i soglasovaniya tselevykh indikatorov v probleme adaptatsii agrarnogo sektora k izmeneniyu agroklimaticheskikh resursov regiona), *Izvestiya KBNTS RAN*, **6**, 56, 17-23.

Ashabokov, B. A., Bischokov, R. M., Zherukov, B. Kh., Kalov, Kh. M., 2008, "Analysis and Forecast of Climatic Changes of the Precipitation and Air Temperature Regime in Different Climate

Zones of the North Caucasus", (Analiz i prognoz klimaticheskikh izmeneniy rezhima osadkov i temperatury vozdukha v razlichnykh klimaticheskikh zonakh Severnogo Kavkaza), *Monografiya. Nalchik: Izdatelstvo KBNTS RAN*, p182.

Ashabokov, B. A., Tashilova, A. A. and Kesheva, L. A., 2015, "Trends in Precipitation Amounts and Temperature Changes over the Periods of 1961-2011 and 1976-2011", (Tendentsii izmeneniya summ osadkov i sredney temperatury za periody 1961-2011 i 1976-2011 na yuge yevropeyskoy territorii Rossii) / II Mezhdunarodnaya nauchnaya konferentsiya s elementami nauchnoy shkoly Innovatsionnyye metody i sredstva issledovaniy v oblasti fiziki atmosfery, gidrometeorologii, ekologii i izmeneniya klimata Stavropol, 21-25 sentyabrya, g. 140-146.

Ashabokov, B. A., Tashilova, A. A., Kesheva, L. A., and Taubekova, Z. A., 2017, "Trends in Changing of Precipitation Regime Properties in Climate Zones of the South of Russia (1961-2011)", [Tendentsii izmeneniya rezhimnykh kharakteristik osadkov v klimaticheskikh zonakh yuga Rossii (1961-2011)], *Meteorologiya i gidrologiya*, **3**, 18-28.

Ashabokov, B. A., Tashilova, A. A., Kesheva, L. A., Teunova, N. V. and Taubekova, Z. A., 2015, "Report on Peculiarities of the Climate in the Russian Federation in 2014", Sections: "Temperature", "Precipitation" (Doklad ob osobennostyakh klimata na territorii Rossiyskoy Federatsii za g. Razdely: Temperatura Osadki), *M. Rosgidromet*, p107.

Ashabokov, B. A., Tashilova, A. A., Kesheva, L. A., Teunova, N. V. and Taubekova, Z. A., 2016, "Report on Peculiarities of the Climate in the Russian Federation in 2015", Sections: "Temperature", "Precipitation" (Doklad ob osobennostyakh klimata na territorii Rossiyskoy Federatsii za 2015 g. Razdely: Temperatura; Osadki), *M. Rosgidromet*., p 68.

Atakuyev, Zh. K., Bekkiyev, M. Yu., Dokukin, M. D., Kalov, Kh. M., Kalov, R. Kh., Tashilova, A. A. and Khatkutov, A. V., 2016, "Influence of Climate Changes on Dynamics of Glaciers, Environmental Processes and Recreational Complexes near the Mt. Elbrus", (Vliyaniye klimaticheskikh izmeneniy na dinamiku lednikov, ekzogennyye protsessy i rekreatsionnyye kompleksy Prielbrusya), *Doklady Adygskoy (Cherkesskoy) Mezhdunarodnoy akademii nauk (AMAN)*, **18**, 1, 61-79.

Bedritskiy, A. I., Korshunov, A. A., Khandozhko, L. A. and Shaymardanov, M. Z., 2004, "Climatic System and Ensuring Hydrometeorological Security of Russia" (Klimaticheskaya sistema i obespecheniye gidrometeorologicheskoy bezopasnosti zhiznedeyatelnosti Rossii), *Meteorologiya i gidrologiya*, **4**, 120-129.

Bekryaev, R. V., Polyakov, I. V. and Alexeev, V. A., 2010, "Role of Polar Amplification in Long-Term Surface Air Temperature Variations and Modern Arctic Warming", *Journal of Climate American Meteorological Society*, **23**, 3888-3906.

Borisenkov Ye, P. and Pasetskiy, V. M., 1988, "The Millennial Chronicle of Unusual Phenomena", (Tysyacheletnyaya letopis neobychaynykh yavleniy prirody), *M: Mysl*., p524.

Budyko, M. I., 1980, "Climate in the Past and Future (Klimat v proshlom i budushchem)", *L. Gidrometeoizdat*, p351.

Bulygina, O. N., Korshunova, N. N., Kuznetsova, V. N., Razuvayev, V. N., Trofimenko, L. T. Analiz, 2000, "Inconsistencies of Climate in Russia over Recent Decades", (Izmenchivosti klimata na territorii Rossii v posledniye desyatiletiya), *Trudy VNIIGMI-MTSD*, **167**, 315.

Byuyul, A. and Tsefel, P., 2002, "SPSS: The Art of Processing Information. Statistic Data Analysis", (SPSS: iskusstvo obrabotki informatsii. Analiz statisticheskikh dannykh i vosstanovleniye skrytykh zakonomernostey), *DiaSoft YUP*, p608.

Climate: Observation. Projections and Impacts (Russia); http://www.cru.uea.ac.uk/cru/.

Gruza, G. V. and Rankova, E. Ya., 2012, "Observed and Expected Changes in Climate of the Russian Federation: Air Temperature", (Nablyudayemyye i ozhidayemyye izmeneniya klimata Rossiyskoy Federatsii: temperatura vozdukha), *Obninsk, FGBU VNIIGMI-MTSD*, p194.

Isayev, A. A., 1988, "Statistics in Meteorology and Climatology", (Statistika v meteorologii i klimatologii), *M. Izdatelstvo MGU*, p248.

J. Jouzel, V. Masson-Delmotte, O. Cattani, G. Dreyfus, S. Falourd, G. Hoffmann, B. Minster, J. Nouet, J. M. Barnola, J. Chappellaz, H. Fischer, J. C. Gallet, S. Johnsen, M. Leuenberger, L. Loulergue, D. Luethi, H. Oerter, F. Parrenin, G. Raisbeck, D. Raynaud, A. Schilt, J. Schwander, E. Selmo, R. Souchez, R. Spahni, B. Stauffer, J. P. Steffensen, B. Stenni, T. F. Stocker, J. L. Tison, M. Werner and E. W. Wolff, 2007, "Antarctic Climate Variability over the Past 800,000 Years", *Science*, **317**, 5839, 793-796.

Jones, P. D. and Moberg, A., 2003, "Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001", *J. Climate*, **16**, 206-223.

Klimenko V. V., Sleptsov A. M., 2003 "A Comprehensive Reconstruction of the Climate of Eastern Europe over Last 2,000 Years", (Kompleksnaya rekonstruktsiya klimata Vostochnoy Yevropy za posledniye 2000 let), *Izvestiya RGO*, **6**, 45-53.

Kobak, K. I., Kondrasheva, N. O. and Turchinovich, I. Ye., 2002, "Influence of Climate Changes on Natural Zoning and Environmental System of Russia", (Vliyaniye izmeneniy klimata na prirodnuyu zonalnost i ekosistemy Rossii), *Izmeneniya klimata i ikh posledstviya. SPb.: Nauka*, 205-210.

Kobyshevoy N. V., 2001 "The Climate of Russia [Klimat Rossii]", Habil. (geography), *Gidrometeoizdat*, p655.

Larionov, Yu. A., 2001, "Changes in the Limits of Agricultural and Climatic Sub-regions in Connection with Climate Change", (Izmeneniye granits agroklimaticheskikh podrayonov v svyazi s izmeneniyem klimata), *Ekologo-geograficheskiy vestnik Yuga Rossii*, **2**, 104-106.

New M., Parker D. E., Martin S., Rigor I. G., 1999, "Surface air temperature and its changes over the past 150 years", *Rev. Geophys*, **37**, 173-199.

Podrezov O. A., 2009, "The Change of the Modern Climate", (Izmeneniye sovremennogo klimata), *Vestnik KRSU*, **9**, 1, 123-138.

Seber, G., 1980, "Linear Regression Analysis", (Lineynyy regressionnyy analiz), *M. Mir*, p456.

Tashilova, A. A., Kesheva, L. A., Teunova, N. V. and Taubekova, Z. A., 2016, "Analysis of Variability of Temperatures in the Mountain Area of the North Caucasus over 1961-2013", (Analiz izmenchivosti temperatury na gornoy territorii Severnogo Kavkaza za 1961-2013), *Meteorologiya i gidrologiya*, **9**, 16-26.

www.ccl-16.wmo.int