ISSN 1068-3739, Russian Meteorology and Hydrology, 2016, Vol. 41, No. 9, pp. 601–609. Allerton Press, Inc., 2016.
Original Russian Text A.A. Tashilova, L.A. Kesheva, N.V. Teunova, Z.A. Taubekova, 2016, published in Meteorologiya i Gidrologiya, 2016, No. 9, pp. 16–26.

Analysis of Temperature Variability in the Mountain Regions of the North Caucasus in 1961–2013

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Received September 15, 2015

Abstract—Annual and seasonal series of temperature values are analyzed using the data of Akhty, Teberda, and Terskol weather stations (the height above the sea level is >1000 m) for 1961–2013 as well as from 1976 to 2013 in order to reveal changes in the mountain climate in the period of contemporary global warming. Mean values, standard deviations, norms, and anomalies of annual and seasonal values of temperature as well as the rate of their variation in the mentioned periods are obtained. It is found that the temperature rise is observed in all seasons and for the year as a whole at the mountain weather stations except Terskol station. According to the results of studying temperature variability, Akhty and Teberda weather stations were united into the group "mountain weather stations" with the subsequent averaging of climatic variables. Terskol weather station was singled out as an independent high-mountain weather station.

DOI: 10.3103/S1068373916090028

Keywords: Mountain weather stations, average temperature, absolute maximum of temperature, absolute minimum of temperature, trends, anomalies, temperature variations

INTRODUCTION

The study of regional variations in surface air temperature is most important for understanding the contemporary global climate change. According to the definition from the "Glossary of Terms" of the IPCC Third Assessment Report, "Climate change refers to a statistically significant variation persisting for an extended period (typically decades or longer) in either the mean state of the climate or in its variability" [2]. Climate change exerts significant influence on atmospheric processes and natural and climatic characteristics almost in all regions of the globe. The studies of climate variability as well as the clear determination of potential consequences have become the scientific problems which attract attention of the world scientists [1, 3, 9]. In 1988 the World Meteorological Organization (WMO) and United Nations Environment Program (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) which prepared a number of assessment reports as well as the Summary for Policy-makers of the Special Report "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" in order to provide scientific fundamentals of climate change risk [7]. In December 2009 the Climate Doctrine of the Russian Federation was adopted. As a result, the climatic policy of the country became systematic and consistent [6]. As the need in reliable information on the regional anomalies and climate change has increased, since 2005 yearly reports have been published [4] on climate conditions in the whole Russian Federation as well as in six large physiographic regions and eight federal districts of the Russian Federation including the North Caucasian Federal District. It is known that the North Caucasus climate is characterized by significant diversity and depends on the horizontal and altitudinal zoning. Based on the terrain features, the territory of the North Caucasus is usually divided into three zones: flat (<500 m above the sea level), piedmont (500–1000 m above the sea level), and mountain (>1000 m above the sea level) zones characterized by different temperature regimes.

DATA AND METHODS

The present study uses the time series of climatic parameters obtained as a result of instrumental measurements at three mountain weather stations in the North Caucasus. The data on their physiographic location are the following:

Station	Akhty (Republic of Dagestan)	Teberda (Karachay-Cherkess Republic)	Terskol (Kabardino-Balkar Republic)
Coordinates			
N	41 28	43 45	43 15
E	47 44	41 45	42 30
Altitude above the sea level, m	1054	1280	2144

To estimate the air temperature trends, 15 time series of climatic parameters for the period of 1961–2013 were analyzed using the data on the series of mean values of surface air temperature, the absolute maximum temperature, and the absolute minimum temperature (annual and seasonal).

To investigate the temperature regime, the estimates, anomalies, and trends averaged for the calendar seasons and for the whole year were considered. The average annual values are referred to the calendar year, i.e., to the time period from January to December in the year under consideration, and the average seasonal values were obtained by averaging monthly mean values for the seasons. Winter includes December of the previous year. The series of maximum and minimum absolute seasonal temperature were formed of maximum and minimum values selected for three months of every season (winter, spring, summer, and autumn) from 1961 to 2013.

The studies were carried out in the following directions:

—linear trends for the whole period under study from 1961 to 2013 were constructed for all series of climatic parameters measured at Akhty, Teberda, and Terskol weather stations; the estimates of coefficients of linear trends b were obtained by the least-squares method (C/10 years);

—linear trends were constructed for the period from 1976 to 2013 that characterize the climate change in the period of contemporary global warming; the values of angular coefficients of trends are presented;

—statistical computations were carried out to obtain mean values, standard deviations, norms, and anomalies of average values of temperature; the norm is the average long-term value of the climatic variable for 1961–1990 (the reference period recommended by WMO); temperature anomalies are defined as the deviations of the observed value from the norm;

—the averaged values of absolute maxima and minima of temperature are obtained for 1961–2013 as well as for the reference period of 1961–1990.

STUDYING THE TEMPERATURE VARIATIONS IN THE CAUCASUS MOUNTAIN REGIONS

Akhty weather station is situated in the south of the Republic of Dagestan (the East Caucasus) at the altitude of 1054 m above the sea level. Average annual air temperature for 1961–2013 is 9.4 C (the norm is 9.2 C). Characteristics of temperature variations at Akhty station are presented in the table. It is clear from the table that the increase in average annual values of temperature with the rate of 0.16 C/10 years took place at Akhty weather station in 1961–2013 with the subsequent increase in temperature rise rate to 0.38 C/10 years in 1976–2013. This occurred due to the significant increase in the absolute annual minima both for the whole period under study (1961–2013) with the rate of 0.5 C/10 years and for the period from 1976 to 2013 with the rate of 0.45 C/10 years. On the contrary, the absolute maxima of temperature showed the trends towards the decrease by 0.12 C/10 years in 1961–2013; however, in the subperiod 1976–2013, the trend changed and the increase in the absolute maxima started with the rate of 0.25 C/10 years.

Let us analyze the contribution of seasonal values of temperature to the revealed trend towards the increase in average annual temperature (see the table and Figs. 1a, 1b, 1c, and 1d). In winter in 1961–2013 the increase in mean values of temperature by 0.6 C/10 years was observed; the respective rate for 1976–2013 is equal to 0.4 C/10 years (see the table). In 1961–2013 the mean anomaly of temperature in winter was equal to 0.2 C and the significant contribution was made by the anomaly of the absolute maximum temperature in winter (0.6 C), whereas the anomaly of the absolute minimum temperature was 0.3 C. In Fig. 1a the column stands out of the positive anomaly of the maximum temperature in winter in 2010–2011 (December 2010) with the exceeding over the norm by 7.6 C.

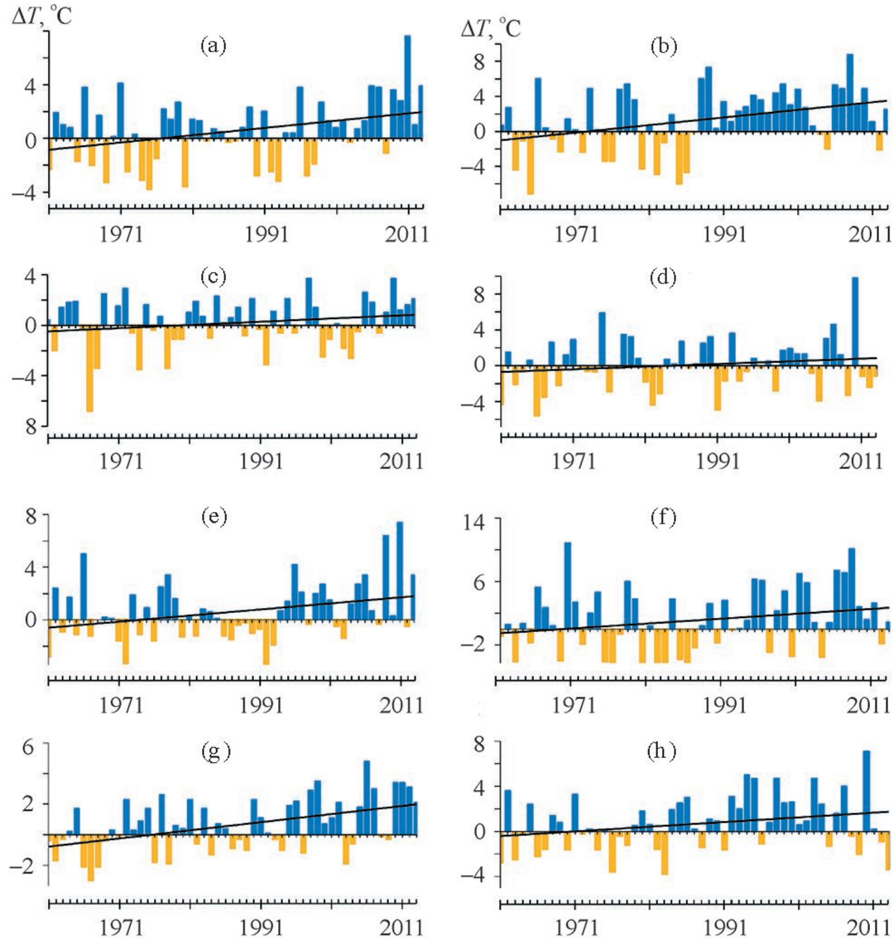

Fig. 1. The seasonal values of temperature anomalies T with linear trends (the straight lines) at (a–d) Akhty and (e–h) Teberda stations in 1961–2013. (a, e) Winter temperature maxima; (b, f) spring temperature minima; (c, g) summer temperature minima; (d, h) autumn temperature maxima.

In spring the slight increase in average temperature occurred by 0.11 C/10 years since 1961 and by 0.24 C/10 years since 1976. The mean anomaly of average spring temperature for the whole 52-year period was equal to 0.1 C, the anomaly of the average minimum spring temperature at Akhty station (the largest anomaly for all seasons and stations) was 1.3 C, and that of the average spring maximum temperature was 0.0 C. As clear from Fig. 1b, the negative anomalies of the minimum temperature (1988–2013) were observed in spring only in 2004, 2005, and 2012 over the 25-year period. In the other years of the period the positive anomaly varied from 0.3 C in 1990 to 8.8 C in 2008.

In summer the increase in the rate of average temperature rise from 0.28 C/10 years since 1961 to 0.44 C/10 years since 1976 was observed due to the increase in summer minima (see the table and Fig. 1c). The mean anomaly of average summer temperature values over the 52-year period was equal to 0.3 C. The contribution to the positive anomaly of average temperature was made by the positive anomalies of the minimum temperature values (0.2 C), and the anomaly of the maximum values of temperature was negative (–0.3 C) in summer. It is clear from Fig. 1c that the most significant positive anomalies of the minimum summer temperature (3.7 C) were registered in 1998 and 2010.

Since the autumn of 1961 the increase in average autumn temperature by 0.17 C/10 years was observed with the subsequent increase in the rate up to 0.48 C/10 years (since 1976). The anomaly of average autumn temperature was equal to 0.3 C, the anomaly of the maximum values was equal to 0.1 C, and the anomaly of the minimum values was 0.0 C. As clear from Fig. 1d, the largest anomaly of the maximum temperature values (9.8 C) was registered in the autumn of 2010.

The statistical estimates of temperature and its anomalies at three weather stations in the North Caucasus in 1961–2013

Parameter	Period	Year	Winter	Spring	Summer	Autumn
			Akhty			
$\bar{T}$	1961–2013	9.4	–0.3	8.9	19.0	10.1
(T)		0.22	0.27	0.17	0.13	0.2
Norm	1961–1990	9.2	–0.5	8.7	18.7	9.8
T	1961–2013	**0.2**	0.2	0.1	**0.3**	**0.3**
$b(T1)$	1961–2013	**0.16**	0.6	0.11	**0.28**	**0.17**
$b(T2)$	1976–2013	**0.38**	0.4	0.24	**0.44**	**0.48**
$\bar{T}_{max}$	1961–2013	34.4	19.9	29.1	34.1	30.9
(T_{max})		0.38	0.34	0.29	0.19	0.41
$\bar{T}_{max}$	1961–1990	34.5	19.3	29.1	34.4	30.8
T_{max}	1961–2013	–0.1	**0.6**	0.0	–0.3	**0.1**
$b(T_{max\ 1})$	1961–2013	–0.12	**0.54**	0.1	–0.33	**0.3**
$b(T_{max\ 2})$	1976–2013	0.25	**0.8**	0.02	–0.08	**0.27**
$\bar{T}_{min}$	1961–2013	–16.2	–15.9	–9.1	7.2	–6.5
(T_{min})		0.35	0.44	0.51	0.29	0.68
$\bar{T}_{min}$	1961–1990	–16.8	–16.2	–10.4	7.0	–6.5
T_{min}	1961–2013	**0.6**	0.3	**1.3**	**0.2**	0.0
$b(T_{min\ 1})$	1961–2013	**0.5**	0.33	**0.87**	**0.25**	0.03
$b(T_{min\ 2})$	1976–2013	**0.45**	0.3	**0.95**	**0.38**	0.04
			Teberda			
$\bar{T}$	1961–2013	9.7	–1.5	6.5	15.2	7.1
(T)		0.12	0.26	0.13	0.15	0.14
Norm	1961–1990	6.5	–2.1	6.3	14.7	6.9
T	1961–2013	**0.2**	**0.6**	0.2	**0.5**	0.2
$b(T1)$	1961–2013	**0.2**	**0.6**	0.11	**0.39**	0.16
$b(T2)$	1976–2013	**0.36**	**1.06**	0.21	**0.54**	0.4
$\bar{T}_{max}$	1961–2013	31.1	15.2	25.5	31.0	27.7
(T_{max})		0.32	0.32	0.26	0.31	0.35
$\bar{T}_{max}$	1961–1990	30.5	14.6	25.2	30.5	27.0
T_{max}	1961–2013	**0.6**	**0.6**	0.3	0.5	**0.7**
$b(T_{max\ 1})$	1961–2013	**0.3**	**0.46**	0.27	0.25	**0.42**
$b(T_{max\ 2})$	1976–2013	**0.5**	**0.77**	0.38	0.5	**0.46**
$\bar{T}_{min}$	1961–2013	–19.7	–19.9	–12.2	2.2	–10.1
(T_{min})		0.41	0.39	0.58	0.25	0.54
$\bar{T}_{min}$	1961–1990	–19.9	–20.2	–13.3	1.6	–10.5
T_{min}	1961–2013	**0.2**	0.3	**1.1**	**0.6**	0.4
$b(T_{min\ 1})$	1961–2013	**0.37**	0.4	**0.6**	**0.53**	0.33
$b(T_{min\ 2})$	1976–2013	**0.17**	0.13	**1.42**	**0.67**	0.98

Table. (Contd.)

Parameter	Period	Year	Winter	Spring	Summer	Autumn
			Terskol			
$\overline{T}$	1961–2013	2.5	–6.7	1.8	11.3	3.7
(T)		0.63	1.8	0.87	0.86	1.05
Norm	1961–1990	2.5	–6.6	1.8	11.0	3.7
T	1961–2013	**0.0**	–0.1	0.0	**0.3**	0.0
$b(T1)$	1961–2013	**0.01**	0.0	–0.03	**0.28**	–0.04
$b(T2)$	1976–2013	**0.06**	–0.08	0.00	**0.4**	0.03
$\overline{T}_{max}$	2006–2013	21.1	1.2	14.1	21.1	16.2
$b(T_{max\,3})$	2006–2013	–0.7	0.5	0.14	–0.7	–0.4
$\overline{T}_{min}$	2006–2013	–13.2	–12.9	–7.4	5.2	–5.9
$b(T_{min\,3})$	2006–2013	0.3	0.56	–0.04	0.08	0.4

Note: $\overline{T}$ is the average value of temperature for the period, C; is the standard deviation, C; T is the mean value of the anomaly, C; b is the angular coefficient of the trend for the period, °C/10 years (°C/year for Terskol station); $\overline{T}_{max}$ and $\overline{T}_{min}$ are average values of the absolute maxima and absolute minima of temperature, respectively, C. The largest contributions of estimated parameters to the variations in average annual temperature are bolded; the negative trends in temperature are underlined.

Teberda weather station is located on the northern slopes of the Central Caucasus. Average annual temperature over the period of 1961–2013 was equal to 6.7 C (the norm is 6.5 C). The summary of temperature variations in Teberda in 1961–2013 is presented in the table.

It is clear from the table data that variations in all temperature components both in 1961–2013 and in 1976–2013 were characterized by the increase in seasonal and annual values of temperature. In 1961–2013 the increase in average annual values of temperature with the rate of 0.2 C/10 years took place at Teberda station. In 1976–2013 the rate increased up to 0.36 C/10 years that is comparable with temperature variations at Akhty station. The increase in average annual values of temperature in 1961–2013 occurred both due to the increase in absolute maxima (0.3 C/10 years) and due to the increase in absolute minima of annual values of temperature (0.37 C/10 years).

In winter in 1961–2013 the trend was observed towards the increase in average temperature with the rate of 0.6 C/10 years with the subsequent increase to 1.06 C/10 years since 1976 due to the increase in the maximum and minimum temperature (see the table and Fig. 1e). The mean anomaly of average winter temperature was equal to 0.6 C with the largest contribution of maximum (0.6 C) and minimum (0.3 C) values of temperature. As clear from Fig. 1e, the most significant positive anomaly of the maximum temperature (7.4 C) was registered in the winter of 2010/2011 (December 2010).

In spring the average temperature rose by 0.1 C/10 years since 1961 and the rate of temperature rise increased to 0.2 C/10 years since 1976. The rate of increase in minimum values of temperature in spring was 0.6 C/10 years since 1961 and 1.42 C/10 years since 1976. As clear from Fig. 1f, the negative anomalies of the minimum temperature in spring over the 20-year period (1993–2013) were registered only in 1997, 2000, 2004, and 2012. In the other years of the period the anomaly was positive with the maximum value of 10.1 C in 2008.

The average summer temperature rose by 0.39 C/10 years since 1961 and by 0.54 C/10 years since 1976. It is clear from Fig. 1g that the maximum number of positive anomalies of minimum temperature was registered in summer since 1990.

The autumn is not an exception in the revealed positive trends in temperature. In 1961–2013 the increase was observed in average autumn values of temperature with the rate of 0.16 C/10 years. In 1976–2013 this rate increased to 0.4 C/10 years since 1976 (see the table). This increase is caused by the significant increase in the maximum and minimum values of temperature in autumn. As clear from Fig. 1h, the great number of years with the significant positive anomalies of the maximum values of temperature was observed from 1984 to 2013 with the maximum exceeding over the norm by 7.1 C in 2010.

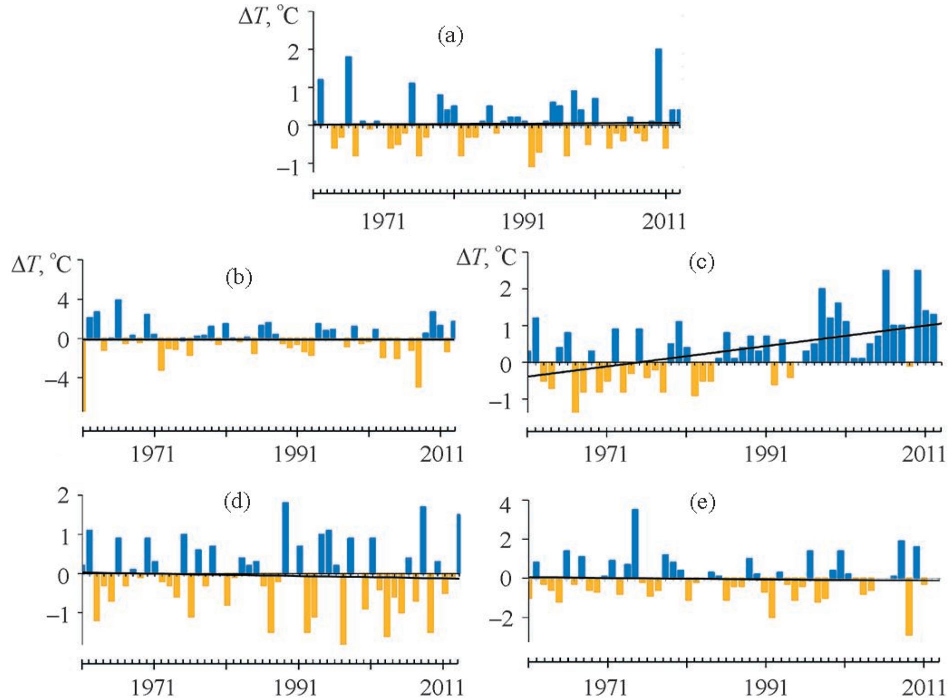

Fig. 2. The anomalies of average seasonal and annual values of temperature T with linear trends at Terskol station in 1961–2013. (a) Year; (b) winter; (c) summer; (d) spring; (e) autumn.

Terskol is the high-mountain weather station situated in the Baksan Gorge in the Central Caucasus (the Elbrus region, the Kabardino-Balkar Republic). Average annual temperature at Terskol weather station is 2.5 C and is the lowest of all stations: almost by 4 times lower than that in Akhty (9.4 C) and by about 2.5 times lower than in Teberda (6.7 C); this is caused by the altitudinal zoning. Let us analyze the variations in average annual and seasonal values of temperature at Terskol station in 1961–2013. The data on the absolute maxima and minima of temperature for Terskol are presented for the period from 2006. The results of studying temperature variations in Terskol are presented in the table and in Fig. 2.

It is clear from the table data that at Terskol weather station in 1961–2013 the average annual temperature was almost constant (the anomaly is 0.0 C, the rate of temperature rise is 0.01 C/10 years). In 1976– 2013 the slight increase in the linear trend in average annual temperature by 0.06 C/10 years was observed.

In winter stable average temperature was observed at Terskol station in 1961–2013. In 1976–2013 the slight decrease by 0.08 C/10 years took place (see the table and Fig. 2b). In spring both in 1961–2013 and in 1976–2013 the stable course of average temperature was registered. Unlike in winter and spring, the average temperature in summer rose with the rate of 0.28 C/10 years since 1961 and by 0.4 C/10 years since 1976 (see the table). As clear from Fig. 2c, only positive anomalies of average summer temperature were observed at Terskol station since 1995 with the maximum anomaly equal to 2.5 C in 2006 and 2010. The exception was the summer of 2009 when the insignificant negative anomaly of –0.1 C was observed.

Since 2006 the decrease in the absolute seasonal maxima and the increase in seasonal minima of temperature prevailed (see the table). As the period of 2006–2013 is much shorter than the investigated series of average temperature for 1961–2013, it is impossible to make conclusions on the stable trends in the absolute minimum and maximum values of temperature for this station and on their contribution to the variations in average annual and seasonal values at Terskol weather station. Most likely these variations are a fragment of long-term variations in these climatic parameters.

THE ANALYSIS OF TEMPERATURE VARIATIONS

The temperature regimes of Akhty and Teberda mountain stations have some common and some distinctive features. At both stations the similar trend towards the increase in average annual values of temperature approximately with the same rate was observed in 1961–2013 and 1976–2013. The mean anomaly of average annual temperature at both stations was equal to 0.2 C.

The absolute maxima and minima in Akhty and Teberda contribute to the increase in average annual temperature in different ways.

In Akhty the positive anomaly of average annual temperature (0.2 C) is caused by the significant positive anomaly of the annual absolute minima (0.6 C), and the annual maxima are characterized by the negative anomaly of 0.1 C. In Teberda the positive anomaly of the average annual temperature (0.2 C) is caused by the significant positive anomaly both of annual absolute maxima (0.6 C) and annual minima (0.2 C). The seasonal contribution is caused by the significant positive anomalies of the minimum spring temperature (1.3 C in Akhty and 1.1 C in Teberda) and by the anomalies of the maximum winter temperature in winter (0.6 C) for both stations.

Terskol weather station differs much in temperature variations. In 1961–2013 at this station the linear trend in average annual temperature was stable. The mean anomaly of average annual temperature was equal to 0 C that was caused by the stability of average temperature in spring and autumn (the anomalies are equal to 0 C). The insignificant negative anomaly of the average values of winter temperature (–0.1 C) was compensated by the positive anomaly in summer (0.3 C).

The obtained results reveal that in order to describe temperature variations in the mountain region, it is reasonable to average the climatic parameters from Akhty and Teberda stations and consider Terskol station as a separate high-mountain station.

COMPARISON BETWEEN AVERAGED TEMPERATURE VARIATIONS AT AKHTY AND TEBERDA MOUNTAIN WEATHER STATIONS AND TERSKOL HIGH-MOUNTAIN WEATHER STATION

Let us carry out the comparative analysis of temperature variations at mountain weather stations and at Terskol high-mountain weather station. Figures 3a, 3c, 3e, 3g, and 3i present the graphs of average seasonal and annual values of temperature plotted from the data of mountain weather stations with the coefficients of linear trends for 1961–2013 (b, C/10 years) and the 11-year moving averages for each time series. The moving averaging reveals not only the trend in the climatic parameter but also the periods of its increase and decrease. It is clear from Fig. 3i that average annual temperature at mountain weather stations in 1961–2013 rose with the rate of 0.18°C/10 years and this rise was especially intense from 1993. The average winter temperature increased with the rate of 0.37 C/10 years (Fig. 3a), and the average spring temperature rose with the rate of 0.11 C/10 years with the certain periodicity and with the slight increase in the maxima (Fig. 3c). The average summer temperature increased with the rate of 0.34 C/10 years (Fig. 3e), and this increase was especially intense from the early 1990s. The rate of the average autumn temperature rise was equal to 0.17 C/10 years, and the especially intense rise after the insignificant drop was observed from the middle of the 1990s (Fig. 3g).

Figures 3b, 3d, 3f, 3h, and 3j present temporal variations in seasonal and annual values of temperature in Terskol with the 11-year moving averages. It is clear from Fig. 3f that the average summer temperature rose with the rate of 0.3 C/10 years and this rise was especially intense from the middle of the 1980s. The trend and the rate of increase in average summer temperature in Terskol are similar to those at mountain weather stations. At Terskol high-mountain weather station winter, spring, summer and the year as a whole were characterized by the stability of temperature during the 52-year period under study (Figs. 3b, 3d, 3h, and 3j).

CONCLUSIONS

In 1961–2013 the similar trend towards the increase in average annual values of temperature was observed at Akhty and Teberda weather stations due to the prevailing increase in the average values of temperature in winter and summer. The seasonal maxima of temperature significantly increased in the cold seasons (winter and autumn), and the seasonal minima increased in the warm seasons (spring and summer). Since 1976 the rate of the rise in average annual and seasonal values of temperature increased; the maximum values of the positive anomalies of seasonal temperature (winter maxima, autumn maxima, and summer minima) were observed in 2010.

In 1961–2013 the stable course of average annual temperature was observed at Terskol high-mountain weather station due to the winter, spring, and autumn seasons, while the average values of temperature in summer significantly increased and the rate of this rise has grown since 1976. The maximum positive anomaly of summer temperature minima was registered in 2010.

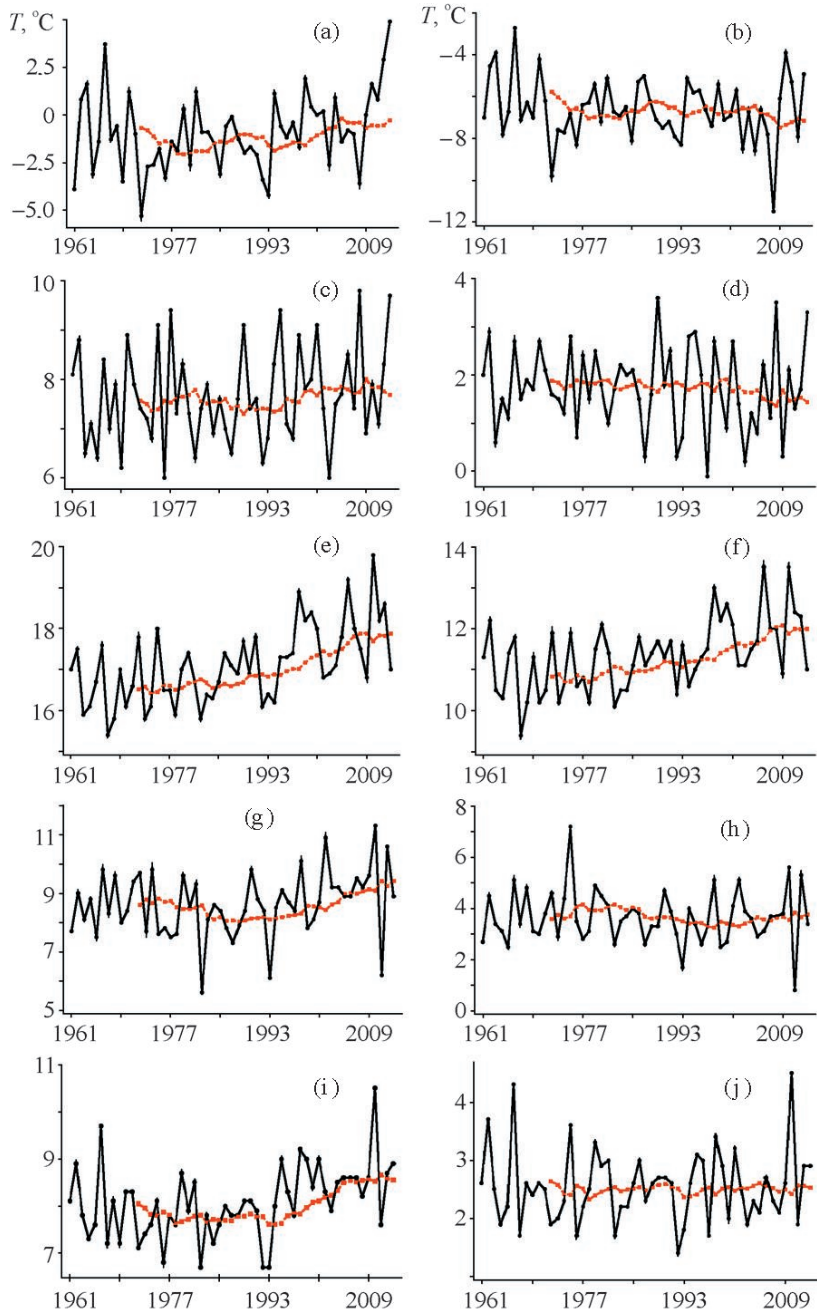

Fig. 3. Temporal variations in average annual (the solid line) and seasonal (the dotted line) values of temperature with the 11-year moving average at (a, c, e, g, i) mountain stations and (b, d, f, h, j) Terskol high-mountain station in (a, b) winter, (c, d) spring, (e, f) summer, (g, h) autumn, and (i, j) for the year as a whole in 1961–2013. (a) $b = 0.37$ C/10 years; (b) $b = 0.0$ C/10 years; (c) $b = 0.11$ C/10 years; (d) $b = -0.03$ C/10 years; (e) $b = 0.34$ C/10 years; (f) $b = 0.3$ C/10 years; (g) $b = 0.17$ C/10 years; (h) $b = -0.04$ C/10 years; (i) $b = 0.18$ C/10 years; (j) $b = 0.01$ C/10 years.

The results of the analysis of variations in average surface air temperature in the steppe and piedmont areas of the North Caucasus [1, 5, 8] and in the mountain regions (Akhty and Teberda) reveal that the increase in all seasonal and annual values of temperature is observed in all mentioned regions except Terskol high-mountain weather station (where the increase is observed only for the average summer temperature). This is probably caused by the fact that the altitudinal zoning prevails over the horizontal one. It leads not only to the well-known regularities in the distribution of average values of temperature depending on the altitude above sea level, but also to the formation of special trends in temperature at Terskol high-mountain weather station where local conditions such as orography and glaciers also affect.

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