DYNAMICS OF THE THIRTY-YEAR MOVING AVERAGE VALUES OF THE AIR TEMPERATURE IN TBILISI AND ST.-PETERSBURG WITH 1851 TO 2010 AND THEIR EXTRAPOLATION TO 2051-2080

[1]A. AMIRANASHVILI, [1]Kh. CHARGAZIA, [2]L. TROFIMENKO
[1]M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University
2 Russian Research Institute of Hydrometeorological Information-World Data Center
e-mail: khatuna.chargazia@gmail.com

Abstract. In recent years the problem of observed and expected climate change on our planet acquired special urgency. This problem has high value in Georgia, because of the variety of climatic regions in its territory, and also, naturally, in Russia, with its extensive territory and variety of natural and climatic conditions. In our last studies with the use of different statistical models the estimations of the expected changes of the air temperature for the next decades in Tbilisi and other regions of Georgia were carried out. On the basis of 100-years (1907-2006) and 163-years (1850-2012) time-series of observations the analysis of the dynamics of the changeability of the average annual air temperature in Tbilisi and St.-Petersburg was carried out. With the use of a 100-years time-series of observations the expected change of the air temperature in these cities is evaluated. In the present work, which is the continuation of the indicated studies, the statistical structure of the thirty-year moving average values of the temperature of air in Tbilisi and St.-Petersburg with 1851 to 2010 (1851-1880, 1861-1890..., 1981-2010) is studied and with the use of two models (ARIMA, EXPERTMODELER) their extrapolation for 2051-2080 is carried out. Within the limits of each thirty-year period of observations autocorrelation in the time-series of air temperature, their stability in time, trends, speed of change of temperature, etc. is studied. Prognostic calculations showed that in 2051-2080 the average annual air temperature in Tbilisi is expected 14.0±0.4 ºC (ARIMA) and 14.8±1.4 ºC (EXPERTMODELER) against 13.7 ºC in 1981-2010, while in St.-Petersburg - 6.4±0.4 ºC (ARIMA) and 8.6±4.0 ºC (EXPERTMODELER) against 5.8 ºC in 1981-2010. The comparative analysis of the indicated results with the obtained earlier prognostic estimations of the air temperature in Tbilisi, St.-Petersburg, and also its mean global values is carried out.
Key words: Climate change, air temperature.

Introduction

In recent years the problem of observed and expected climate change on our planet acquired special urgency. This problem has high importance in Georgia, because of the variety of climatic regions in its territory [1, 2], and also, naturally, in Russia, with its extensive territory and variety of natural and climatic conditions [3-6].

In our last studies with the use of different statistical models the estimations of the expected changes of the air temperature for the next decades for some regions of Georgia, including Tbilisi city, were carried out [7-10]. On the basis of 100-years (1907-2006) and 163- years (1850-2012) time-series of observations the analysis of the dynamics of the changeability of the average annual air temperature in Tbilisi and St.-Petersburg was carried out [10-13]. With the use of a 100-years time-series of observations the expected change of the air temperature in these cities for 2056 is evaluated [10, 11].

In the work [11] the statistical structure of time series of the mean annual values of the air temperature in Tbilisi and St.-Petersburg in 1907-2006 is investigated. Autocorrelation in the time-series of observations in St.-Petersburg is manifested in the first two lags (lag = 1 year), and also into the 14 lag. In Tbilisi the autocorrelation in a temperature time-series practically is absent. The peaks of periodicity for Tbilisi approximately feel 20 and 5 years, whereas for St.-Petersburg – 14 and 8 years. The process of warming-up in St.-Petersburg is more intense than in Tbilisi. The statistical prognostication of the expected changes of the temperature of air in these cities up to 2056 years with the use of three methods is carried out (1 - linear extrapolation, 2 - the prognostication of the smoothed functions taking into account two periodicities in the series of observations, 3 - linear prognostication taking into account one periodicity in the series of observations).

It is obtained that the following change in air temperature in 2052-2056 in comparison with its mean values in 1951-1980 is expected: method 1) - increase in Tbilisi and St.-Petersburg by 0.6 ºC and 1.9 ºC respectively; method 2) - decrease in Tbilisi by 0.2 ºC and invariability (0 ºC) in St.-Petersburg; method 3) - increase in Tbilisi and St. Petersburg by 0.3 ºC and 2.1 ºC respectively [11].

As further analysis showed, the statistic structure of the average annual temperature of air in Tbilisi and St.-Petersburg substantially depends on the time-series number. Thus, in contrast to the above-indicated 100-year measurements [11], autocorrelation in 163- year series of observations for St.-Petersburg is manifested in the first 11 lags and into the 14 lag; in Tbilisi - in the first 6 lags, and also the 8 and the 9 lags. The peaks of periodicity for Tbilisi feel approximately 40, 23, 12, 5 and 4 years, and for St.-Petersburg - 12, 8, 5, 2 years. Trends of the air temperature in Tbilisi and St.-Petersburg for 163 year period of observations by the fourth degree polynomial are satisfactorily described [12].

In the work [13] the comparative analysis of secular variations of air temperature in Tbilisi, St.-Petersburg and its mean global values is carried out. In particular, it is obtained that the averaging of data of the long-term observations of different meteorological stations must be carried out taking into account the analysis of autocorrelation and periodicity in time-series of each of them.

In the present work, which is the continuation of the indicated studies [11-13], the statistical structure of the thirty-year moving average values of the temperature of air in Tbilisi and St.-Petersburg with 1851 to 2010 is studied and their extrapolation to 2051-2080 is carried out.

Study area and methods

Data of the Hydro meteorological department of Georgia (Tbilisi) and the Russian Research Institute of Hydro meteorological Information – World Data Center (St.-Petersburg) are used.

The statistical structure of the thirty-year moving average values of the temperature of air in Tbilisi and St.-Petersburg with 1851 to 2010 (1851-1880, 1861-1890..., 1981-2010) is studied with the aid of the statistical methods of processing dynamic series of observations [14]. Extrapolation of air temperature to 2051-2080 with the use of two models (ARIMA, EXPERTMODELER) is carried out.

Obtained results of the forecast of the air temperature with previously obtained data of extrapolation executed three methods are compared [11]. Method 1 is the linear extrapolation. Method 2 – the prognostication of the smoothed functions taking into account two periodicities in the series of observations: Tbilisi – 5 and 20 year, St.-Petersburg – 8 and 14. Method 3 – linear prognostication taking into account one periodicity in the series of observations: Tbilisi – 20 year, St.-Petersburg – 14 year.

The following designations will be used below: Min – minimal values, Max - maximal values, σ – standard deviation, C_v – coefficient of variation (%), R – coefficient of linear correlation, R_a – coefficient of autocorrelation with lag = 1 year, α – the two-sided level of significance. According to Student's criterion ($\alpha \leq 0.2$) the significant value of R and R_a (for the time-series of observations in each period of 30 years) is 0.24. UCL and LCL – 95% confidence interval of upper and lower calculated level accordingly. The dimensionality of the air temperature (°C) in the text in the majority of the cases is omitted.

Results and discussion

Results are given in the tables 1-4 and fig. 1. In the table 1 the statistical characteristics of the thirty-year moving average values of the air temperature in Tbilisi and St.-Petersburg with 1851 to 2010 are presented. As follows from this table, the thirty-year mean air temperature in 1981-2010 in comparison with 1851-1880 growth in Tbilisi to 0.9 and in St.-Petersburg – to 2.1 degrees. Variations of the air temperature in each of 14 investigated periods of time in Tbilisi are considerably lower than in St.-Petersburg. In Tbilisi $C_v = 3.4 \div 5.4$ %, in St.-Petersburg $C_v = 16.2 \div 31.9$ %. The difference between max and min temperatures of air in all 14 periods in Tbilisi composes 3.9 °C and in St.-Petersburg – 6.9 °C.

In Tbilisi the linear correlation between the air temperature and years for 14 investigated periods of time is observed only for 5 periods, in St.-Petersburg – for 4. The moderate negative correlation between the air temperature and years in 1871-1900 was observed in Tbilisi. In 1911-1940, 1941-1970 and from 1971 to 2010 this correlation in Tbilisi is positive. In St.-Petersburg correlation between the air temperature and years is positive and in 1911-1940 and from 1961 to 2010 is observed. In Tbilisi the autocorrelation of the air temperature in 14 investigated periods of time into 4 periods observed, in St.-Petersburg – into 5.

Table 1. The statistical structure of the thirty-year moving average values of the air temperature in Tbilisi and St.-Petersburg with 1851 to 2010

Parameter	Mean	Min	Max	σ	C_v	R	(α)R	R_a	(α)R_a
Period	Tbilisi								
1851-1880	12.8	11.5	14.0	0.64	5.0	0.23	No	0.28	0.14
1861-1890	12.7	11.5	14.0	0.64	5.0	0.05	No	0.36	0.05
1871-1900	12.7	11.6	14.0	0.64	5.1	-0.51	0.003	0.20	No
1881-1910	12.5	11.9	13.3	0.43	3.4	0.00	No	-0.25	0.2
1891-1920	12.6	11.1	13.5	0.59	4.7	0.15	No	-0.03	No
1901-1930	12.7	11.1	13.5	0.59	4.7	0.19	No	0.16	No
1911-1940	12.8	11.1	13.6	0.59	4.6	0.25	0.2	0.19	No
1921-1950	12.9	12.0	13.7	0.48	3.8	0.08	No	0.17	No
1931-1960	13.0	11.9	14.2	0.54	4.2	0.15	No	-0.08	No
1941-1970	13.1	11.9	15.0	0.70	5.4	0.28	0.14	-0.11	No
1951-1980	13.3	11.9	15.0	0.67	5.0	0.05	No	-0.23	No
1961-1990	13.4	12.4	15.0	0.63	4.7	0.05	No	-0.08	No
1971-2000	13.5	12.4	14.8	0.61	4.6	0.42	0.02	0.21	No
1981-2010	13.7	12.4	14.8	0.58	4.3	0.39	0.03	0.26	0.17
Period	St.-Petersburg								
1851-1880	3.7	1.2	5.8	1.16	31.7	-0.14	No	-0.17	No
1861-1890	3.7	1.2	5.8	1.17	31.9	0.19	No	-0.24	0.2
1871-1900	3.8	1.4	5.2	1.00	26.4	0.21	No	-0.03	No

1881-1910	4.0	2.0	5.6	0.98	24.4	0.16	No	-0.19	No
1891-1920	4.1	2.0	5.9	0.99	24.0	0.22	No	-0.17	No
1901-1930	4.3	2.0	5.9	0.92	21.6	0.08	No	-0.28	0.14
1911-1940	4.6	2.7	6.4	1.01	22.1	0.37	0.04	0.09	No
1921-1950	4.6	1.8	6.4	1.16	25.5	0.09	No	0.32	0.09
1931-1960	4.6	1.8	6.4	1.18	25.6	-0.15	No	0.28	0.14
1941-1970	4.4	1.8	6.3	1.06	24.0	0.15	No	-0.08	No
1951-1980	4.6	3.0	6.6	0.96	20.8	0.14	No	0.00	No
1961-1990	5.0	3.2	7.6	1.14	23.0	0.26	0.17	0.17	No
1971-2000	5.4	3.2	7.6	1.09	20.2	0.26	0.17	0.17	No
1981-2010	5.8	3.2	7.6	0.94	16.2	0.40	0.03	0.32	0.09

As a whole, correlation and autocorrelation relations in the indicated 14 periods in the majority of the cases are absent, and available - moderated or weak. Thus, variations in the air temperature in each of the investigated periods of time have random or close to it nature. However, the sequential chain of these periods is manifested in the positive tendency of the changeability of the air temperature in Tbilisi, and especially in St.-Petersburg. These tendencies are noticeable, especially in recent years: in Tbilisi – from 1971 to 2010, in St.-Petersburg – from 1961 to 2010.

The dynamics of the changeability of air temperature of in the indicated cities are different. Fig. 1 presents the data about the mean per annum speed of change of the air temperature Tbilisi and St.-Petersburg in 14 different thirty-year periods of time (calculations according to the data of work [12] about the air temperature trends in these cities are carried out).

In particular, as it follows from this figure, in St.-Petersburg the first extremum of the speed of growth of the air temperature in 1881-1920 was observed (0.015 °C/year). Then this speed diminished to 0.009 °C/year (1931-1960). In recent years a continuous growth of air temperature variation rate occurs, which in 1981-2010 reached 0.051 °C/year. In Tbilisi the max growth rate of the air temperature in 1951-1990 was observed (0.015 °C/year, as in St.-Petersburg in 1881-1920). In recent years in Tbilisi occurs the tendency of the retardation of the growth rate of the air temperature (0.012 °C/year in 1981-2010).

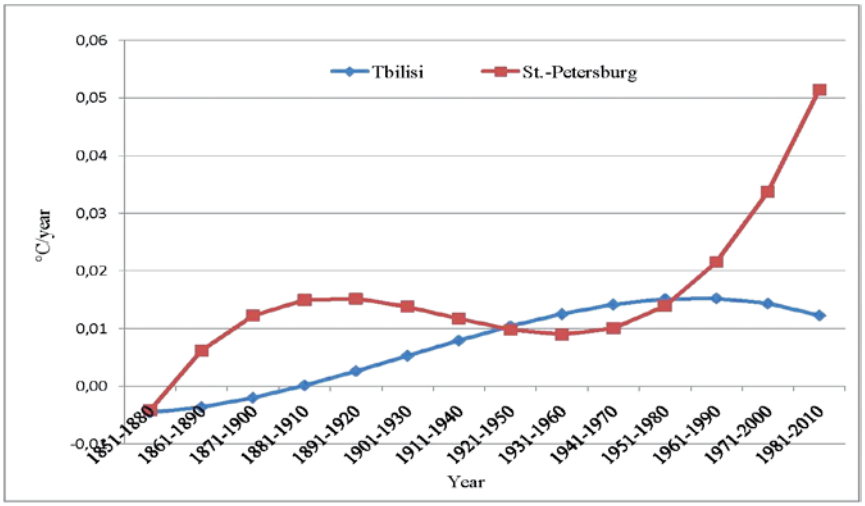

Figure 1 Mean per annum speed of change of the air temperature in Tbilisi and St.-Petersburg in different periods of time

Differences in the statistical structure of the real data about the air temperature of the indicated cities are manifested also in the forecasted tendencies of its changes by several decades. In table 2 data of extrapolation of the thirty-year moving average values of the air temperature in Tbilisi and St.-Petersburg for 2051-2080, calculated on the models ARIMA and EXPERTMODELER are presented.

In particular (table 2) prognostic calculations showed that in 2051-2080 the average annual air temperature in Tbilisi is expected 14.0±0.4 °C (ARIMA) and 14.8±1.4 °C (EXPERTMODELER) against 13.7 °C in 1981-2010, while in St.-Petersburg - 6.4±0.4 °C (ARIMA) and 8.6±4.0 °C (EXPERTMODELER) against 5.8 °C in 1981-2010. Thus, on the average in indicated periods of time, in Tbilisi temperature increase to 0.3 °C (ARIMA) and 0.8 °C (EXPERTMODELER), whereas in St.-Petersburg - to 0.6 °C (ARIMA) and 2.8 °C (EXPERTMODELER) are expected.

However, taking into account the broadband of the confidence intervals of forecast (especially in the model EXPERTMODELER), it cannot be excluded both the tendencies toward the stabilization of the changeability of the air temperature, and sharper warming-up, or cooling processes in the indicated cities.

For a comparative analysis of the indicated results with the obtained earlier prognostic estimations of the air temperature in Tbilisi, St.-Petersburg, and also its mean global values, let us turn to tables 3 and 4. In table 3 the forecasting values of the

mean annual air temperature and 95% confidence intervals of forecast in Tbilisi and St.-Petersburg in 2011-2040 and 2021-2050, calculated with three methods [11], and in table 4 the global mean air temperature of the land change in 2046-2065 in comparison with 1986-2005 in the correspondence with different scenarios [15] are presented.

Table 2. Extrapolation of the thirty-year moving average values of the air temperature in Tbilisi and St.-Petersburg to 2051-2080

Parameter	LCL	Forecast	UCL	LCL	Forecast	UCL
Model	ARIMA			EXPERTMODELER		
Period	Tbilisi					
1991-2020	13.2	13.6	13.9	13.6	13.8	14.1
2001-2030	13.3	13.6	14.0	13.6	14.0	14.4
2011-2040	13.4	13.7	14.1	13.6	14.2	14.7
2021-2050	13.4	13.8	14.2	13.6	14.3	15.0
2031-2060	13.5	13.9	14.3	13.5	14.5	15.4
2041-2071	13.6	14.0	14.3	13.5	14.6	15.8
2051-2080	13.7	14.0	14.4	13.4	14.8	16.2
Period	St.-Petersburg					
1991-2020	5.0	5.5	6.0	5.8	6.2	6.6
2001-2030	5.2	5.7	6.1	5.8	6.6	7.4
2011-2040	5.3	5.8	6.3	5.7	7.0	8.3
2021-2050	5.5	5.9	6.4	5.5	7.4	9.3
2031-2060	5.6	6.1	6.6	5.3	7.8	10.3
2041-2071	5.7	6.2	6.7	4.9	8.2	11.5
2051-2080	5.9	6.4	6.8	4.6	8.6	12.6

Table 3. The forecasting values of the mean annual air temperature and 95% confidence intervals of forecast in Tbilisi and St.-Petersburg into 2011-2040 and 2021-2050, calculated by three methods [11]

Period	Method 1			Method 2			Method 3		
	Tbilisi								
Parameter	LCL	Forecast	UCL	LCL	Forecast	UCL	LCL	Forecast	UCL
2011-2040	12.1	13.4	14.7	10.9	13.0	15.0	12.2	13.4	14.6
2021-2050	12.2	13.5	14.8	10.9	13.0	15.0	12.2	13.4	14.7
	St.-Petersburg								
2011-2040	3.9	6.0	8.1	1.2	4.8	8.4	3.9	6.1	8.1
2021-2050	4.1	6.2	8.3	1.3	4.9	8.4	4.1	6.3	8.4

Table 4. The global mean air temperature of the land change in 2046-2065 in comparison with 1986-2005 in the correspondence with different scenarios [15]

Scenarios	LCL	Forecast	UCL
RCP 2.6	0.4	1.0	1.6
RCP 4.5	0.9	1.4	2.0
RCP 6.0	0.8	1.3	1.8
RCP 8.5	1.4	2.0	2.6

Thus, for instance, in 2021-2050 the following values of air temperatures are expected. Tbilisi: 13.5±1.3°□(Method 1), 13.0±2.0 °C (Method 2), 13.4±1.3 °C (Method 3), 13.8±0.4 °C (ARIMA), 14.3±0.7 °C (EXPERTMODELER). St.-Petersburg: 6.2±2.1 °C (Method 1), 4.9±3.6 °C (Method 2), 6.3±2.1 °C (Method 3), 5.9±0.4 °C (ARIMA), 7.4±1.9 °C (EXPERTMODELER). For the average values of air temperature both for Tbilisi and St.-Petersburg, method 1, method 2 and ARIMA give approximately similar results. For both cities method 2 for the average values of air temperature shows the tendency of cooling, and EXPERTMODELER - tendency of sharp warming-up. However, an attention should be focused on the fact that in the correspondence with all methods, estimations of the forecasting values of the air temperature within the limits of confidence interval give approximately similar results.

In 2041-2071 in comparison with 1981-2010 the air temperature change in Tbilisi and St.-Petersburg respectively comprises: ARIMA – 0.3±0.3 °C and 0.4±0.5 °C, model EXPERTMODELER – 0.9±1.1 °C and 1.4±3.3 °C. The dynamics of air temperature growth in Tbilisi and St.-Petersburg in the model ARIMA does not coincide not with any other models of global

air temperature changeability (table 4). The results of the forecast of an increase in the air temperature in Tbilisi in model EXPERTMODELER are analogous to the uses of the changeability of global air temperature according to the model RCP 2.6. For St.-Petersburg the same results in the model RRR are analogous to models RCP 4.5 and RCP 6.0 (tables 3, 4).

Conclusions

Investigation of climate variation and reasons for these changes - one of the most important modern problems. As a whole, an increase in the air temperature occurs everywhere. These changes on the planet occur unevenly in also the time, there are places, where the processes of temperature drop are observed. Georgia, where both processes, simultaneously occur can be an example: preferred warming-up in eastern Georgia, invariability or small temperature drop- in Western Georgia. Complications of the study of the processes of climate variability are related with a small quantity of meteorological stations with the long series of observations of the air temperature. Partly these deficiencies they are deprived of Tbilisi city and St.-Petersburg, where parallel of the measurements of temperature from 1850 are conducted. This made it possible to carry out the comparative analysis of the dynamics of the changeability of air temperature for the period with the real observations, and to also conduct with use of different statistical methods of predicting their values by several decades forward.

The results of the analysis of data and prognostic estimations showed an essential difference in the dynamics of the changeability of the air temperature in these cities, which indicates the need of continuing the studies in this direction, in particular, the development of the latitude effects of the changeability of climate for the separate points with the long series of observations (taking into account local and global geophysical effects). The solution of these problems is planned in the near future.

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