

About trend assessment of maximum annual values of snow load on the ground in Krasnodar Krai

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Abstract. Paper addresses maximum annual values of snow load on the ground at plain and mountainous regions of Krasnodar Krai, which served as a basis for establishing snow loads on buildings in SNKK 20-303-2002 "Loads and Actions. Snow Loads and Wind Actions". Given the fact that average annual temperature has increased by two degrees in Kuban region during last 30 years of observations it is important to estimate the influence of this shift on the values of snow loads and the possibility of future changes of snow loads. The research employs time series of snow-measuring observations during 1946–1999 for mountain regions and 1946-2012 for plain regions. Inversion criterion was used for assessing the significance of the linear trend of maximum annual values of snow load. Assessment was made for 20 meteorological stations in plain part of the region and for 3 snow courses in mountainous areas of West Caucasus at heights of 500 to 2000 m, including mountain cluster of the 2014 Winter Olympics Games Venues. It was established that in all cases with the level of statistical certainty 0.95 trend is absent. In the foreseeable future during next several decades snow loads in Krasnodar Krai may be assumed to remain stable, if characteristics of climate will not change under the influence of anticipated decrease of solar activity.

1. Introduction

In the mid-1980s global warming was merely considered to be one of the possible scenarios of future climate change. At present time it has already translated into reality having an impact on human's living conditions and economic activities and on natural ecosystem. According to data provided by Krasnodar center of hydrometeorology and environmental monitoring [1] in the last 30 years annual average air temperature increased by 2 degrees with 1.5 of them in last 10 years. At the same time on some days of coldest months air temperature rises to +10 °C, and sometimes even to +20 °C.

According to forecast of Roshydromet [2] and Intergovernmental Panel on Climate Change [3] rise of temperature in European part of Russia will be larger than average on the land of Northern Hemisphere, and only in the North Caucasus it will not exceed average changes. Rise of global and regional temperatures will come with change of the precipitation picture. According to recorded data [3] during the period from 1951 to 2010 in the major part of European part of Russia 5-10 % increase of precipitation was registered.

Scenario of most probable level of global warming [2] demonstrates explicit increase of precipitation in Krasnodar Krai in the cold half of the year, whereas in the warm season only minor changes are anticipated. Trend of dynamics of moistening in mountainous (and partly in piedmont) territories may be not that unambiguous due to possible catalyzation of regional convection processes. According to data [4] peak of aridity in mountainous territories of Krasnodar Krai and Adygea was



passed in the late 1990's – early 2000's when droughts occurred simultaneously both in plains and mountains. In the work [5] author expects the precipitation in mountainous territories of Krasnodar Krai to increase or to stay at current level in the cold period of the year.

Being focused on construction and transport, report of Roshydromet [2] regards following as possible consequences of global warming for Russia: alteration of parameters of heating season, rising of thermal efficiency of existing buildings and energy usage reduction in wintertime, concerns about overheat of buildings in warm period of the year and heavy increase of energy usage index for cooling of buildings in Southern Federal District, accelerated deterioration of building envelope due to increase in the number of freeze-thaw cycles, negative impact on transport infrastructure, power engineering facilities, hydraulic structures, etc. At the same time report does not consider the issue of possible change of snow loads.

Only one Russian research [6] found in literature assesses the trend of maximum annual values of ground snow loads in St. Petersburg and two inhabited localities of Leningrad Oblast. The analyzed period 1939 – 1983 (28 to 40 winters) does not comprise years when the global warming became a significant factor. Positive trend is shown for maximum values of snow load in rural areas while no significant trend was found in St. Petersburg.

The purpose of this paper is to assess the effect of climate change in European part of Russia in the end of XX – early XXI century on the change of snow loads in plain and mountainous regions of Krasnodar Krai. During this period, approximately since 1950, first changes in many climate and meteorological phenomena began to appear. This effect became more evident in mid-1970s.

2. Parameters of the required linear trend for annual maximums of the snow load on the ground

Maximum annual values of snow load on the ground (SLG) serve as a basis for design values of snow loads on buildings in codes of all countries with solid precipitation in winter period. For this purpose results of long-term observations over water content of snow in each winter period are considered. These results are combined in continuous time series. Statistical characteristics of these series are different for all meteorological stations. Characteristic and design values of SLG calculated on this basis with a specified probability are used for snow load zoning of different countries and development of snow load maps, which are adopted in design codes.

These maps are intended to predict snow loads on buildings designed for use in subsequent decades and even centuries. By doing so, by default, it is assumed that in subsequent years rainfall and snowfall patterns will be the same as in previous decades. That is, hypothesis of climate permanence is postulated in each geographical location over at least one century.

For construction science the question of possible global climate change is by no means idle. If it occurs consistently, snowfall pattern in subsequent years might change, and it is not clear how this process will affect the snow loads over vast territory of Russia. One way or another, it can lead to increase of the load in certain regions which is fraught with enormous economic harm due to damage or collapse of structures and social impact – loss of health or even life in accidents with structural failure.

The purpose of this paper is to assess the trend, if any, of regular change of maximum winter snowfall on the basis of available records of maximum SLG values for more than half a century. The background is provided by time series of water content measurement of snow from more than two dozens of meteorological stations from plain regions of Krasnodar Krai and of three snow courses located in mountains of West Caucasus.

The notion of trend is related to the sequence of data in space and/or time. Set of uniform measurements of a certain variable made with the increase of time constitute time series differing from sampling by a known order of their acquisition. Time can be replaced by coordinates – the numbers by assignment of which position of a point on any surface or in space is defined. Trend is a pattern describing a general long-term tendency in variations of time series indices. It is usually assumed that

any of observed values z may be presented as the sum of two terms. One of them is F which may be regarded as nonrandom function of coordinates, and another one φ – as a random function $z(x) = F(x) + \varphi(x)$. With that random component $\varphi(x)$ being a function of multiple independent factors is assumed to be normally distributed.

With the problem of trend detection two objectives arise: identification of general tendency in changes in character of z and isolation of the local component as alternating deviations from trend. Time dependencies of the factor may take different forms. They are therefore described by various functions: linear, exponential, power, polynomial with different degrees, etc. At present time possible explicit dependence or correlation between trends of SLG and rise of average atmospheric temperature are still not clear. Taking these facts into account in this research for analysis the simplest working hypothesis was assumed – linear trend of SLG, possibly negative. This is consistent with forecast of further linear increase of surface air temperature in XXI century [3]. Similar approach is used in the research fulfilled by Ledovskoy and Uspasskaya [6].

Nonrandom component of linear trend $F(x)$ is calculated by ordinary method of least squares. Figures 1 and 2 show general tendency of change of maximum SLG values for two inhabited localities (meteorological stations) in general case in the form of inclined straight line (dashed) and random deviations from common component.

For Krasnodar nonrandom component (dashed line on figure 1) demonstrates regular decrease of SLG during 1946-1997, whereas for one station of snow course on the slope of the mountain Aishkha (figure 2) the opposite tendency is evident – this component increases during 1979 – 1997.

General tendency (trend) was calculated with method of least squares with evaluation of parameters S_0 and a of the linear relationship for 28 meteorological stations of Krasnodar Krai located in plain and mountainous regions

$$S_m = S_0 + a(T - T_0), \quad (1)$$

where S_m - ground snow load as a value of nonrandom function in the current year;

S_0 – required mean value of nonrandom function of SLG for a given meteorological station during the period under consideration;

a – rate of linear trend – positive (increase) and negative – which is an average change of SLG maximums in one year;

T – year for which value of the nonrandom function of SLG was determined;

T_0 – medium year of the considered period of SLG observations which corresponds to S_0 .

Table 1 gives values of parameters a and S_0 of nonrandom function of linear trend $F(x)$: in columns 3 and 4 – for the period of observation in XX century (54 years), which were used in developing regional code SNKK [7], in columns 4 and 5 – for extended time series of observations including 13 years of XXI century for plain regions of Krasnodar Krai and Adygea (data for mountainous regions is absent).

In 20 cases out of 28 downward trend of SLG maximums is observed, whereas in another cases values of SLG increase. Such dissimilarities are present both in plain and mountainous regions. For five inhabited localities trend is less pronounced, and after increase of time series the sign of trend has changed (values of a in table 1 are italicized). Thus, the obtained inconsistent results do not support a conclusion on general consistent change of maximum values of snow load over different meteorological stations for more than half a century of weather observations.

Given that the maximum annual values of SLG in close inhabited localities with virtually same climate are often observed in different years, it can be concluded that their values are heavily influenced by various factors: terrain features, presence and type of vegetation, distance from mountains and seas, etc. It therefore seems appropriate to provide an average estimate using data of meteorological stations having similar periods of observations from 1946 to 2012. There are 16 of such stations in plain regions of Krasnodar Krai.

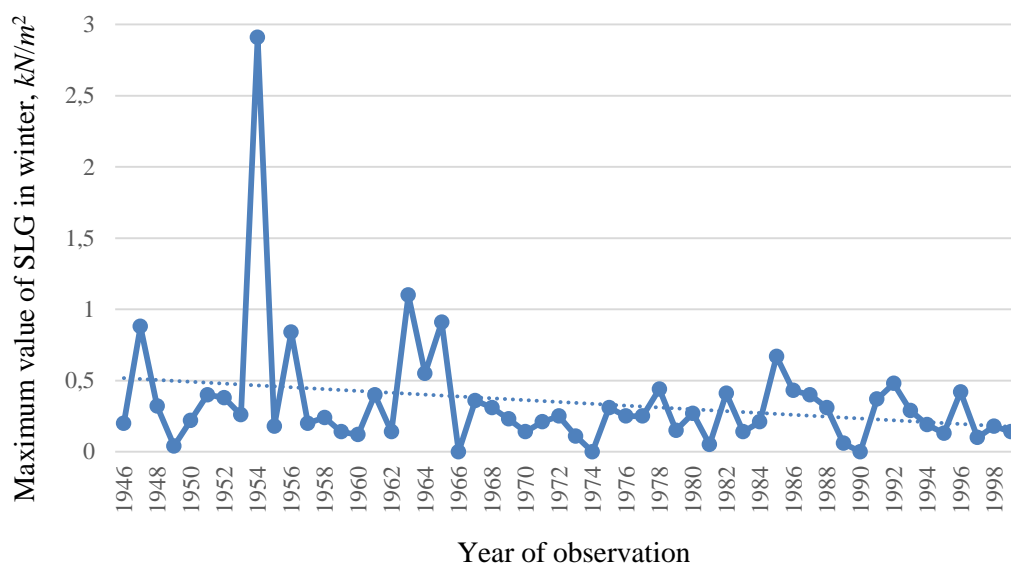


Figure 1. The graph of changes in the maximums of the SLG for Krasnodar.

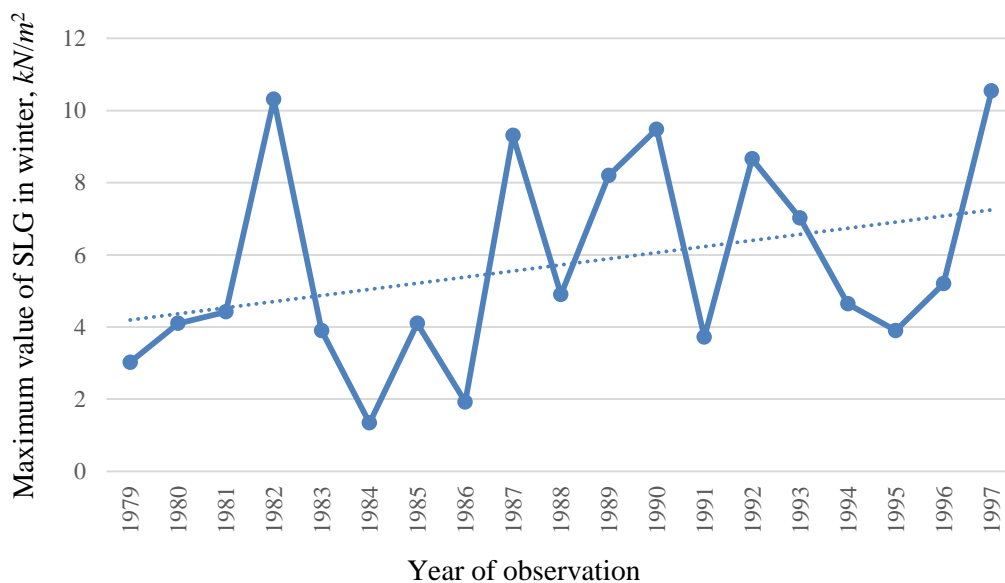


Figure 2. The graph of changes in the maximums of the SLG on the slope of the Aishkha Ridge at 1200 meters above sea level (mountain cluster of 2014 Olympic Winter Games venues).

Table 2 gives results of approximate estimate tendency in variations of SLG maximum values on these meteorological stations over same 67 years period. Last two columns of this table show design values of SLG S_{g25} and S_{g50} with 4% and 2% fractile accordingly. They were calculated using the parameters α and β of double exponential Type-1 Gumbel distribution of maximums [9]

$$P(S) = \exp\{-\exp[(\alpha - S)/\beta]\} \quad (2)$$

and correspond to average 25- and 50-year return period. Values of S_{g25} were previously used as design snow loads in codes [7] and [8], and S_{g50} serves as a basis for current version of the code [10]. Distribution function (2) is recommended for use by standards [11] and [12].

Table 1. Parameters of the linear trend of SLG for the periods of 54 and 67 years

No.	Location	Parameters of nonrandom function $F(x)$			
		1946-1999 years		1946-2012 years	
		a_{54} , kN/m ² in year	S_o , kN/m ²	a_{67} , kN/m ² in year	S_o , kN/m ²
1	Armavir	-0.00105	0.315	-0.00096	0.309
2	Belaya Glina	-0.00285	0.353	-0.00121	0.323
3	Belorechensk	-0.00161	0.431	-0.00124	0.424
4	Kanevskaya	-0.00124	0.275	-0.00066	0.264
5	Krasnodar	-0.00646	0.524	-0.00303	0.456
6	Krymsk	-0.00469	0.430	-0.00175	0.371
7	Kropotkin	0.00211	0.231	0.00154	0.245
8	Kushevskaya	0.00007	0.275	0.00080	0.261
9	Labinsk	-0.01037	0.762	-0.00178	0.709
10	Maikop	-0.00154	0.418	0.00026	0.382
11	Otradnaya	-0.00001	0.318	0.00008	0.314
12	Slavyansk-on-Kuban	-0.00319	0.324	-0.00024	0.266
13	Sosyka	-0.00091	0.289	0.00052	0.262
14	Starominskaya	-0.00373	0.399	-0.00265	0.378
15	Tikhoretsk	-0.00234	0.386	-0.00108	0.363
16	Timashevsk	-0.00249	0.343	0.00024	0.290
17	Ust-Labinsk	-0.00134	0.365	0.00083	0.325
18	Korenovsk	-0.00235	0.331	0.00012	0.286
19	Gorniy	0.01542	0.849	0.01104	0.937
20	Psebay	0.00166	0.281	0.00041	0.301
21	Primorsko-Akhtarsk	-0.00087	0.204		
22	Mount Oshten, +1260 m	0.03470	0.936		
23	Mount Oshten, +2020 m	-0.21975	10.250		
24	Mount Fisht, +1000 m	-0.00566	1.940		
25	Mount Fisht, +1810 m	0.01591	10.120		
26	Aishkha Ridge, +500 m	0.13626	0.393		
27	Aishkha Ridge, +1200 m	0.16942	4.030		
28	Aishkha Ridge, +1940 m	-0.04104	10.430		

Parameters of cumulative distribution function (2) were found for all meteorological stations in developing the regional code SNKK [7] in 2000 [13, 14] and refined 13 years later with additional data for plain regions over 2000-2012. Calculation of S_{gT} was based on the length N of utilized static series of SLG values

$$S_{gT} = \bar{S} - \sigma \left\{ \frac{1}{\sigma_N} \left[\bar{y}_N + \ln \left(-\ln \left(\frac{T-1}{T} \right) \right) \right] \right\} \quad (3)$$

where \bar{S} and σ – mean and standard deviation for sample with N observations

$$\bar{S} = \alpha + 0.5776\beta \quad (4)$$

$$\sigma = 1.286\beta \quad (5)$$

\bar{y}_N and σ_N - similar parameters of distribution of reduced extreme values $\Phi(x) = \exp(-e^{-y})$ tabulated for sample number $N=8 \dots 1000$.

Table 2. Influence of the linear trend on the design values of the SLG for the same observation period of 67 years in the plain areas (1946-2012).

No.	Location	S_m in 1946, kN/m ²	S_m in 2012, kN/m ²	Increase over 67 years, kN/m ²	Annual increase, kN/m ²	S_{g25} , kN/m ²	S_{g50} , kN/m ²
1	Belaya Glina	0.323	0.242	-0.081	-0.00121	0.67	0.94
2	Belorechensk	0.424	0.341	-0.083	-0.00124	0.87	1.11
3	Kanevskaya	0.264	0.220	-0.044	-0.00066	0.65	0.99
4	Krasnodar	0.456	0.253	-0.203	-0.00303	0.87	1.00
5	Krymsk	0.371	0.254	-0.117	-0.00175	0.96	1.24
6	Kropotkin	0.245	0.348	+0.103	+0.00154	0.84	0.96
7	Kushevskaya	0.261	0.315	+0.054	+0.00080	0.80	0.88
8	Labinsk	0.709	0.590	-0.119	-0.00178	1.05	1.34
9	Maikop	0.382	0.399	+0.017	+0.00026	0.90	1.04
10	Otrdnaya	0.314	0.320	+0.006	+0.00008	0.86	0.94
11	Slavyansk-on-Kuban	0.266	0.249	-0.017	-0.00024	0.71	1.03
12	Sosyka	0.262	0.297	+0.035	+0.00052	0.69	0.81
13	Starominskaya	0.378	0.200	-0.178	-0.00265	0.76	1.04
14	Tikhoretsk	0.363	0.291	-0.072	-0.00108	0.83	1.16
15	Timashevsk	0.290	0.306	+0.016	+0.00024	0.77	1.14
16	Ust-Labinsk	0.325	0.380	+0.055	+0.00083	0.90	1.06

The calculations showed that average annual decrease of value of nonrandom SLG change function of was only 0.0006 kN/m², i.e. 0.17% of initial average value in 1946. Similar decrease for standard period between major repairs of buildings 50 years is equal to 8.3 %.

More important for construction practice is the decrease along trend with respect to design values of snow loads in current version of the code [10]. It is only 2.3 % over 50 years which is comparable with accuracy of engineering calculations.

Interestingly, the highest decrease rate of SLG maximums over 1946-2012 in plain regions $a_{50} = -0.00303$ kN/(m² · year) is in Krasnodar, which is the largest city of the region (table 1). This can be attributed to rapid growth of population and area of the city, such that meteorological station «Kruglik» which was located on the skirts in 1946 is nowadays in the central part of the city. It is common knowledge that tendencies of change of maximum SLG values in big cities and adjacent rural areas can differ [6].

However, all of the aforesaid is merely some qualitative assessment, which does not have complete mathematical validation from the point of view of random data analysis tools. Low rate of change of maximum annual SLG values, its multidirectionality in different geographic points and even

variability of direction with increase of time series demand mathematical justification of existence of significant monotone trend of SLG for all available snow survey data.

It should be emphasized, that in fact in long-term fluctuations of water content of snow nonlinear trends within certain periods can take place. The following discusses only general linear trend to assess its significance since to date there is no technique for assessment of nonlinear trend significance [13].

3. Assessment of trend significance by inversion criterion

Inversion criterion [16] is considered to be the most effective index of trend significance. Inversion criterion is nonparametric, and therefore distribution function of random components x_i does not have effect on allocation of sampling functions. This test has high strength towards linear trend [17]. It also allows avoiding any assumptions concerning distribution function of examined data.

In combinatorics inversion refers to disturbing the normal order of two elements in permutation regardless of whether these two elements stand close or are separated from each other by some elements. For our purposes let us consider sequence of N observations of random variable x_i ($i = 1, 2, 3 \dots N$). In our case these are maximum values of SLG during each winter in strict chronological order. The number of times when in increasing sequence of values x_i inequality $x_i > x_j$ for $i < j$ is true is counted. Each of these inequalities is called inversion. Similarly by definition in monotonically decreasing sequence for inversion to occur inequality $x_i < x_j$ must be true. The following reasons are valid for both cases.

Let A stand for the total number of inversions. Formally A is calculated as follows. For set of observations x_1, x_2, \dots, x_N

$$h_{ij} = \begin{cases} 1, & x_i > x_j; \\ 0, & x_i \leq x_j. \end{cases} \quad (6)$$

Then

$$A_1 = \sum_{j=2}^N h_{1j}, \quad A_2 = \sum_{j=3}^N h_{2j}, \quad A_3 = \sum_{j=4}^N h_{3j}, \quad (7)$$

Total number of inversions for all initial compared values x_1, x_2, \dots, x_{N-1} will be

$$A = \sum_{i=1}^{N-1} A_i \quad (8)$$

If the sequence of N observations consists of independent outcomes of one and the same random value, number of inversions is a random variable A with a mean value μ_A and variance σ_A^2

$$\mu_A = \frac{N(N-1)}{4} \quad (9)$$

$$\sigma_A^2 = \frac{2N^3 + 3N^2 - 5N}{72} = \frac{N(2N+5)(N-1)}{72} \quad (10)$$

Let us check the trend in the series of $N = 54$ observations over maximum values of SLG from 1946 to 1999 for Krasnodar with the significance level $\alpha = 0.05$ (common value for such problems). Similar worked example can be found in [16].

Let the working hypothesis be that observations are independent outcomes of random value $x = S$, i.e. there is no trend. Acceptance region takes the form of

$$[A_{54,1-\alpha/2} < A < A_{54,\alpha/2}] \quad (11)$$

Calculation of total number of inversions with equation (8) gives $A = 781$. Expected value of number of inversions calculated with (9) is $\mu_A = 715.5$. Standard deviation is a square root of variance (10) equal to $\sigma_A = 67.0$. From the table of critical values of Student's t-distribution for confidence level 0,95 and $N = 54$ we find fractile $t = 2.01$. Range of A for significance level $\alpha = 0.05$ from (11)

$$[A_{54,1-\alpha/2}; A < A_{54,\alpha/2}] = \mu_A \pm t \times \sigma_A = 715.5 \pm 2.01 \times 67.0 = 581...850. \quad (12)$$

Total number of inversions $A = 781$ falls into this range. Thus there is no significant trend of SLG for Krasnodar.

Similar calculations have been made for 27 inhabited localities and snow courses with period of observations 1946-1999 and for 20 plain land meteorological stations taking into account increase of time series up to 2012. Results of these calculations are presented in tables 3 and 4. In all cases with high level of statistical certainty 0.95 significant trend of SLG is absent.

Table 3. Confidence interval for $\alpha = 0.05$ and total number of inversions A for all initial compared values of SLG maximums over 1946-1999.

No.	Location	N	$A_{N,1-\alpha/2}$	A	$A_{N,\alpha/2}$
1	Armavir	49	471	605	705
2	Belaya Glina	54	581	739	850
3	Belorechensk	54	581	767	850
4	Kanevskaya	54	581	659	850
5	Korenovsk	52	536	641	790
6	Krasnodar	54	581	781	850
7	Krymsk	54	581	747	850
8	Kropotkin	54	581	615	850
9	Kuschevskaya	54	581	630	850
10	Labinsk	54	581	792	850
11	Maikop	54	581	735	850
12	Otradnaya	54	581	656	850
13	Slavyansk-on-Kuban	54	581	703	850
14	Sosyka	54	581	648	850
15	Starominskaya	54	581	703	850
16	Tikhoretsk	54	581	706	850
17	Timashevsk	54	581	674	850
18	Ust-Labinsk	54	581	728	850
19	Gorniy	44	373	400	573
20	Psebay	42	337	409	524
21	Primorsko-Akhtarsk	35	226	304	369
22	Mount Oshten, +1260 m	26	116	152	209
23	Mount Oshten, +2020 m	26	116	198	209
24	Mount Fisht, +1000 m	23	87	113	166
25	Mount Fisht, +1810 m	23	87	119	166
26	Aishkha Ridge, +1200 m	19	55	63	116
27	Aishkha Ridge, +1940 m	19	55	89	116

Standards [11] and [12] say, that “when developing national or regional maps for ground snow loads, it is important to note that confined ensembles of annual extremes or peaks over a specific threshold can contain random positive or negative trends. The evaluation of possible climate change effects has to consider this randomness. Climate change scenarios can provide information on the basic shape of trends which should be considered in the analysis”. Our research shows that the original

Table 4. Confidence interval for $\alpha = 0.05$ and total number of inversions A for all initial compared values of SLG maximums over 1946-2012.

No.	Location	N	$A_{N,1-\alpha/2}$	A	$A_{N,\alpha/2}$
1	Armavir	62	781	1018	1110
2	Belaya Glina	67	921	1128	1290
3	Belorechensk	67	921	1193	1290
4	Kanevskaya	67	921	1007	1290
5	Korenovsk	65	864	958	1216
6	Krasnodar	67	921	1090	1290
7	Krymsk	67	921	1077	1290
8	Kropotkin	67	921	981	1290
9	Kuschevskaya	67	921	937	1290
10	Labinsk	67	921	1221	1290
11	Maikop	67	921	1091	1290
12	Otrdnaya	67	921	1033	1290
13	Slavyansk-on-Kuban	67	921	971	1290
14	Sosyka	67	921	965	1290
15	Starominskaya	67	921	1110	1290
16	Tikhoretsk	67	921	1094	1290
17	Timashevsk	67	921	993	1290
18	Ust-Labinsk	67	921	1031	1290
19	Gorniy	57	653	683	943
20	Psebay	55	604	740	881

database of SLG annual maximums used in developing regional code of Krasnodar Krai [7] with time series extended by 13 years remains stable up to the present day. Observed rise of average air temperature has not had significant effect on pattern of snowfall in Krasnodar Krai so far. At the same time peaks of extreme values in certain winters over last 30-40 years became smoother as compared to the middle of XX century.

However, it is risky to forecast stationarity of random process of SLG annual maximums alternation over several decades since at present time, in addition to the observed climate warming, a lot of experts point out the possible opposite tendency in nearest future. The possibility of onset of long cold snaps is assumed similar to the one that took place in the second half of XVII century during Maunder minimum [18, 19]. The work of V.N. Ishkov [20] shows that beginning with 23rd solar cycle since 1996 Earth enters a period of medium or low magnitude solar cycles which may last for 5 – 6 solar cycles with total duration of 50 – 70 years. In this case snowfall pattern can substantially change for sufficiently long period, and significant growth trend of SLG may take place.

In the end it can be concluded, that at present time there is no convincing statistical evidence to confirm the hypothesis of average significant decrease of snow load in Krasnodar Krai due to global warming. At the same time the possibility of future increase of snow load resulting from other global natural processes cannot be ruled out.

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