Modern engineering technology to adapt to the adverse weather and climatic conditions at mountain ski resorts

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Abstract: In the last decade, ski tourism, the development of which is supported at the state level, became the most popular and prestigious type of recreation for Russian in winter. One of the main localization area of ski centres and mountain ski resorts (MSR) in Russia is the Krasnodar region, which is characterized by its unique natural and climatic resources. This study focuses on the identification of current trends in regional climate according to the state network of meteorological stations with the aim of using this information to build strategies for adaptation of MSR activities to the negative effects of adverse weather and climate events. Different variants of weather anomalies and modern engineering technology that allow significantly reducing the risks and increasing the cost-effectiveness and sustainability of the MSR were taken into consideration. It is shown that one of the objects of the Olympic heritage of the XXII Olympic Winter Games "Sochi-2014" — the ski centre "Krasnaya Polyana" — is not only a new infrastructure that conforms to international standards but also modern engineering technology that allow to significantly reduce the risk of abnormal weather. There are given the examples of the cost of adaptation measures to ensure the quality of the snow cover of the ski slopes.
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1. Introduction

One of the most popular and prestigious way of recreation, including for the Russians, in recent years has become a ski tourism, which for some developed countries is a priority of the national economy. The development of highly lucrative industry of winter recreation involves the construction of modern mountain ski centers and the organization of tourist mass recreation, providing them the highest-level service.

To enhance the development of tourism in Russia there were adopted federal targeted programs: "On the establishment of the tourism cluster in the North Caucasus Federal District of Krasnodar region and the Republic of Adygea" [1] and "Development of domestic and inbound tourism in the Russian Federation for the period of 2011-2018" [2]. A specific role in these programs is given to the development of winter tourism and sports based on favourable natural and climatic resources of the country and the creation of modern high-tech infrastructure, part of which are mountain ski centers and mountain ski resorts (MSR).

Major ski regions of Russia: Caucasus and the Urals. The main mountain ski resorts of the Caucasus: Krasnaya Polyana, Dombay and Elbrus.

The only mountain ski center (MSC) in Russia at the moment that corresponds to the world standards is MSC "Krasnaya Polyana", which includes the four MSR (Table. 1). It should be noted that MSC "Krasnaya Polyana" is included in the list of objects of the Olympic legacy of the XXII Olympic Winter Games "Sochi-2014" [3].

Table 1. The main ski centers and ski resorts of Krasnodar region

№	Ski resort	Altitude difference, m	Maximum length of of slopes, m	Quantity of tracks	Ski resort's work period
Ski center "Krasnaya Polyana"					
1	Alpica-Service	1698	7500	10	December-April
2	Gornaya Karusel	1660	7000	8	December-April
3	Laura Gazprom	575	2390	15	December-April
4	Roza Khutor	1745	4250	6	December-April

It is known that the development of tourism depends on the interaction of the time-personal factors such as: natural-climatic, environmental, economical, technological, demographic, etc. The study of climate trends, risk assessment methods and technologies for MSR adaptation to a changing environment is a key issue for the development of domestic and inbound tourism in general, and the ski resorts and ski centers in particular. The studies by foreign [4-7] and local authors [8-10] devoted to the exploration of these issues. One of the first Russian studies on the risks and possible mechanisms of adaptation of MSR activity to climate change in Alps and the Western Caucasus, is the article [9].

However, many problems in the theory and practice of assessing the impact of current climate trends in the development of ski resorts and ski centers are still not sufficiently developed. This applies particularly to the risk assessment, including socio-economical, from adverse climatic conditions and the development of modern adaptation mechanisms.

Climate change indirectly but significantly affects the finances of the tourist markets. Investors begin to re-evaluate companies, including tourism, whose activities are subject to risks associated with global climate change. MSR losses from climate change are increasing, because the development of technologies for adaptation to new climatic conditions requires a restructuring of entire sectors of the economy, which leads to additional costs [6,7,9,11]. For example, the cost of a modern high-tech equipment for the snow coating of the ski slopes can amount to tens of millions of dollars. Therefore, the question arises whether there is currently a technology, which could allow the industry to reduce the damage from modern anomalies climate and weather to the skiing industry? Since there is currently MSC "Krasnaya Polyana" of Krasnodar region after the Olympic Winter Games "Sochi-2014" is not only the most modern infrastructure in the country and international level is a kind of proving ground for testing the latest engineering technology industry ski tourism and sports, then we will study for example in the region.

2. Source data and research methods.

To assess trends of changes in regional climate of the major MSR of Krasnodar region various domestic and foreign sources of data were used on the average monthly air temperature (T^0C) and precipitation (R_{MM}) at meteorological stations (MS) of Krasnodar region and the Western Caucasus [12-14]. Meteorological data for all months of the cold season (November-March), i.e. period of high tourist season was used for this analysis. Basic statistical characteristics (BSC) of time series were calculated, the curves of the actual and theoretical distribution T^0C and R_{mm} were build and BSC errors were calculated on the basis of 5 (MS). To determine the presence of positive or negative trends in the long-term course of meteorological variables (MV) a linear climate trends (T_L) were calculated:

$T_L = aX_i + b$ (1);

where X_i is a serial number of the year (i - 1 to N, N - the instrumental record period); where a and b are the coefficients of the equation of linear regression. For comparative evaluation of the sampling distribution of the actual and theoretical normal distribution of MV for all stations and months of the study period the graphs of the distribution curves were constructed. Number of gradations was determined by the Sturges rule:

$K = 1+3,32\lg N$ (2);

where N is the sample size, row length; K is the number of gradations.

In assessing, the statistical significance of the identified dependencies correlation analysis, a well-known Student criterion (t_C) and Pearson's chi-squared test (χ^2) were used.

3. Results and discussion.

As shown by the calculations, the trends of regional climate change, study region for the period of active operations of the MSR (November-March) happen with multi-directional long-term trends and progress of T^0C and R_{mm} and with varying intensity. During the period of instrumental observations from November to March, for example, the MS "Krasnaya Polyana" (Figure 1) and "Klukhori pass" (Figure 2) mainly the negative T_l in the terms of T^oC were observed. The MS "Klukhori pass" in November, the correlation coefficient of the trend $r_T = - 0.31$, Student criterion $t_C = -2.2647$, in December $r_T = - 0.28$, $t_C = -1.9871$. Peculiarity of MS "Krasnaya Polyana" is the presence of an mildly positive trend T^oC in January. However, the identified positive trends were not statistically significant, the greatest one amounted to $r_T = 0.11$, $t_C = 0.7623$.

In the distribution of R_{MM} by MS "Krasnaya Polyana" mildly positive trends were identified in November, February and March. In February $r_T = 0.26$, $t_C = 1.6959$. In December and January statistically significant negative trends ($r_T < -0.12$) were set. The MS "Klukhori pass" in November, February and March there is a positive trend, that tends to be the most pronounced in March $r_T = 0.27$, $t_C = 1.7796$. At the same time in December and January the R_{MM} trend tends to be negative (January $r_T = -0.15$, $t_C = -1.0135$).

Considering the specifics of the ski resorts in addition to data on air temperature and precipitation (Table 2) the MV as: the date of occurrence and melting of the snow cover formation and destruction of the snow cover, the number of days with snow cover (Table 3); information on snow depth (Table 4); date of sustainable transition temperature through 0° C and minus 5° C; avalanche danger, and others are also important.

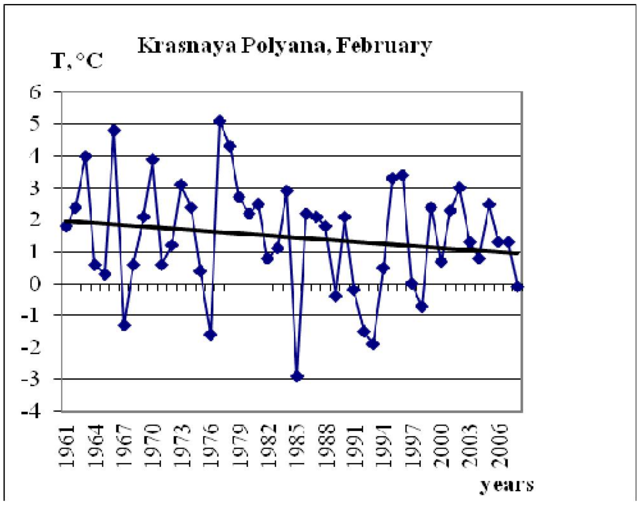

Fig. 1. Time course (◆—◆) and linear climate trends (____) of the mean monthly air temperature (T^{0}C) according to meteorological stations "Krasnaya Polyana" in February

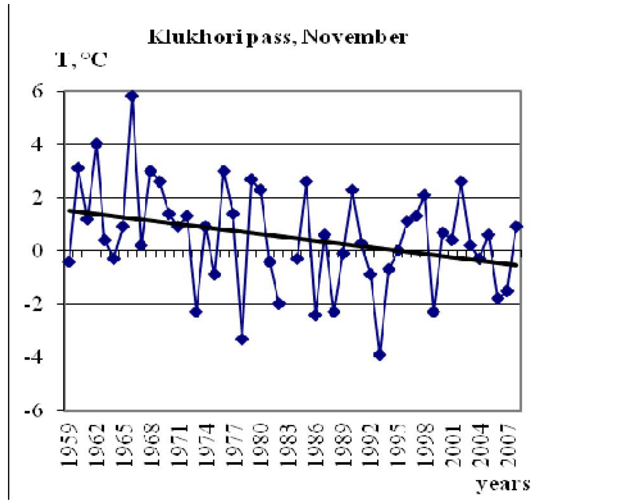

Fig. 2. Time course (◆—◆) and linear climate trends (____) of the mean monthly air temperature (T^{0}C) according to meteorological stations "Krasnaya Polyana" in November.

Table 2. The main climatic characteristics of the ski resort "Krasnaya Polyana" by MS "Achishkho" [13]

Characteristics	Months of the cold season (November-March)					Year
	XI	XII	I	II	III	
Average monthly and annual air temperature ° C	1.0	-2.7	-3.0	-4.7	-2.5	3.9
Absolute maximum daily air temperature, ° C	11.9	9.1	7.9	12.8	10.6	23.6
Absolute minimum daily air temperature, ° C	-13.6	-16.6	-22.6	-19.9	-15.0	-22.5
Monthly and annual average amount of precipitation in mm	342	413	363	326	301	3202
Average monthly and annual soil surface temperature, ° C	-2	-6	-8	-7	-5	3
Average monthly and annual relative humidity, %	71	74	76	78	77	75

Table 3. Date of the snow cover appearance and melting, formation, destruction of cover and average number of days with snow cover on the MS "Achishkho" [13]

Number of days with snow cover	Dates of appearance of snow cover		Dates of the stable snow cover formation		Dates of the stable snow cover disruption		Dates of snow cover melting	
	The earliest	The latest	The earliest	The latest	The earliest	The latest	The earliest	The latest
228	8.IX	30.XI	27.IX	2.XII	1.V	6.VII	1.V	6. VII

Table 4. Monthly average, maximum and minimum snow depth (cm) for the month on MS "Achishkho" [13]

Characteristics	Months						
	X	XI	XII	I	II	III	IV
The average monthly snow depth, cm	29	62	155	278	376	438	384
Maximum height of snow for the month, cm	112	237	481	667	744	770	812
Minimum height of snow for the month, cm	0	0	2	85	103	199	128

The conducted analysis of trends in regional climate, in the region under study suggests that the current state and trends of climate prediction based on the linear regression equation is very favourable for the development of the ski industry in the Krasnodar region. As is evident, (Figure 1) during the cold season (November-March), in most cases, a poorly marked reduction in average monthly temperatures is present. At the same time, the majority of MS display a slight increase in precipitation. The increase in precipitations is particularly noticeable in March.

In order to evaluate the variability of MV curves of the actual selective distribution and theoretical normal distribution were built for all MS for all months. It turned out that at some stations (about

48%) T^0C actual distribution that is very close to the normal distribution of the values is being observed. It should be noted that 80% of cases a sign of T_I trend matches (Table 5), but by Student's test for the sample (48 years) set relations, except for Novembers on MS "Kluhorsky Pass", were not statistically significant (<90% of the significance).

Table. 5 The values of the correlation coefficient (r_T) and Student's criterion (t_c), characterizing the sign, size and stability of linear climate trend of the average monthly air temperature (T^0C).

The meteorological station name	Criterion	Months of the cold season (skiing season)				
		November	December	January	February	March
Krasnaya Polyana	r_T	-0.17	-0.10	0.11	-0.17	0.01
	t_C	-1.1500	-0.7105	0.7623	-1.1753	0.1224
Klukhori pass	r_T	-0.31	-0.28	-0.17	-0.17	0.01
	t_C	-2.2647	-1.9871	-1.1854	-1.1730	0.1108

In the last 10-15 years, the international ski tourism industry developed rapidly, various engineering technologies were designed to greatly reduce the risk and damage from adverse climatic and weather conditions in the operation of MSR (Table 6).

Table 6. Extreme adverse environmental phenomena that cause risks to operate ski resorts and modern technology to eliminate possible damage

Name of extreme adverse environmental phenomena	**Innovative technologies that aim to reduce or neutralize the risk/damage**
Lack of precipitation in the form of snow or sleet (Unprepared ski tracks)	Production of artificial snow with the help of various snow guns: snow boxes, snow cannons, snow rifles, snow atomizers.
Precipitation in the form of snow, but the amount of precipitation is <1 mm per day during the week before the opening of the holiday season or competition (Unprepared ski tracks)	Production of artificial snow with the help of various snow guns: snow boxes, snow cannons, snow rifles, snow atomizers.
Precipitation in the form of rain (any amount) (Unprepared ski tracks)	Unprepared ski tracks. Such extreme situations require procuring of natural or artificial snow (snow storage establishment) and storing it under a special coating and special equipment to cover the ski tracks
Positive air temperature: > 0^oC; > 5^oC; around 10 ^oC (Unprepared ski tracks)	The preparation of artificial "snow" in the form of ice crystals is possible. However, for some ski track the use of such coatings is prohibited.
Positive air temperature: > 0^oC; > 5^oC; around 10 ^oC (Unprepared ski tracks)	The preparation of artificial "snow" in the form of ice crystals is possible. However, for some ski track the use of such coatings is prohibited.
Avalanche danger (Death of people, closing of the ski tracks)	Cleaning of the ski tracks in the case of natural avalanches or an artificial avalanche events followed by snow removal.

Depending on the climate data and weather forecasts for the upcoming ski season, it has individual snowmaking system, which takes into account: topography, slope exposure, climatic resources, wind load, the quantity and quality of water for snowmaking, the average air temperature at the beginning and during the season, and other environmental parameters. Snowmanager calculates the optimal technological flow chart for snowmaking. For example, a multi-nozzle snowmaking system [11] begins to work intensively with the weather from minus 4-5^{o}C. This allow opening of the first ski tracks for 1-2 weeks earlier than usual, thus enhancing the competitiveness of the MSR and improving the economic performance of the resort [9, 11].

Thus, now a number of engineering technologies has been developed to reduce the risk of adverse effects of adverse climatic conditions and to increase the stability of the MSR. However, the effectiveness and efficiency of these technologies depends primarily on the state of the environment, in particular, — climatic anomalies. The costs of equipment and adaptation measures may at times increase the price of the tourists stay in the MSR or bring the company on the brink of the bankruptcy.

What is the economic component used in almost all weather technologies for reducing or substantially neutralize the impact of adverse effects of the environment on the performance of MSR? In order to determine the price range, we will use the data from different open access sites and specialized media related to the preparation and holding of the Olympic Winter Games (OWG) "Sochi-2014". To reduce the risk of failure of the OWG "Sochi-2014" an ANO Organizing Committee "Sochi-2014" had developed a special program called "Sochi-2014: the guaranteed snow ". [15] This program provided for the accumulation of snow in the seasons previous to the Olympics, the summer storage, as well as an elaborate scheme of snow transportation to the sports facilities in the mountain cluster. In Sochi, storehouses of the snow were created, totaling 750,000 cubic meters. Given the cost of procuring and storage 1 cube of snow amounts to 1357 RUB the average cost of the project to conserve snow totalled to nearly 1 billion RUB. In addition, in the facilities area of the mountain cluster 464 snow cannons were installed, also several dams and culverts were built. The cost of these projects is around a few billion roubles. To control the state of the weather and the forecast avalanches organizers of OWG "Sochi-2014" established about 100 automatic weather stations along remote ski tracks.

4. Conclusion.

The current climate change is having a significant impact on sustainable development and income regions with ski centers and ski resorts. However, to reduce the risk of adverse climate and weather conditions, the international ski industry of Tourism and Sports has developed a modern engineering technology to improve the sustainability and efficiency of the MSR. The environmental information carries a special role in management decisions when developing adaptation activities at ski resorts.

These technologies have been successfully tested in Olympic sports facilities at the XXII Olympic Winter Games "Sochi-2014" and substantially reduce the risks associated with carrying out this major international sporting event.

Thus, not only infrastructure, but also the most modern and efficient technologies that can be successfully replicated in other tourist ski country clusters are now the legacy of the Olympic Winter Olympic Games "Sochi-2014" for the ski resorts of Krasnodar region.

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