Structure of extreme precipitation field in Western Siberia

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ABSTRACT

The present paper introduces the results of analyzing the space-time structure of extreme characteristics of precipitation in Western Siberia. For each index, with the view of changes evaluation, differences between average values for periods 1951-1980 and 1981-2010 were calculated. The assessment of synchronicity in time and space with the use of factor and cluster analysis showed that changes in precipitation of Western Siberia are determined by global climate-forcing processes only by one-third. When taking into account the results of division into classes, the share of the explained variance increases to 40-60%. The performed classification confirmed an increase in synchronicity when decreasing the territory scale.

Western Siberia; extreme precipitation; extremality indices; classification; climatic patterns

1. INTRODUCTION

The ongoing climate changes of recent decades are accompanied by an increase in frequency of extreme climate regime manifestations [1-6]. The present paper suggests data on redistribution of climatic fields within the temporal structure. In particular, changes in frequency, intensity and duration of various types of extreme precipitation were recorded [7-10]. Changes of the annual amplitude of precipitation for the global average, with the exception of the intertropical zone were identified in [11]. When analyzing climate changes and estimating risks for the observed and the future climate changes, assessment of weather extremes compared to average characteristics appears to be the most informative, as the latter (average characteristics) require additional interpretation (with account of the averaging period ratio, variance estimation, etc.). In addition, while "climate warming" implies a shift of the surface air temperature distribution to a higher value area, the problem of precipitation is more complicated and often ambiguous. In part, due to this reason, space-time changes in precipitation are reproduced by modern global climate models with large approximations. Extremely heavy precipitation is enormously negative for any social and economic systems. It leads to flooding of urban and agricultural areas, eroding of communication lines, landslides, difficultly forecasted rainfall floods on rivers, as well as hinders activities of most enterprises. Adaptation of society to changing conditions of precipitation modes is possible on the basis of regular evaluation of changes, vulnerability assessment and a possibility to adapt various subsystems of the biosphere and the technosphere to critical levels of climate impacts. Spatial and temporal variability of extreme weather events formation is extremely high, which makes the study of it on a regional scale particularly actual.

2. METHODOLOGY

There are a number of definitions of the term "extremality". Extremity is defined as an extreme complex state of environment, as a degree of comfort or discomfort. Some authors define extremality of climatic indices as a sharp deviation from average annual values [12]. The IPCC gives the following definition in one of its reports: "An extreme weather event is a phenomenon that is rare within its statistical reference distribution in a particular place. This phenomenon occurs rarely as the tenth or ninetieth percentile "[13].

This paper presents the analysis results of the space-time structure of the extreme precipitation filed in Western Siberia according to several criteria (Table 1).[1]

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Table 1. Indices of the extreme precipitation regime investigated in the paper

Designation	Name	Definition	Units
R1d	Maximum amount of daily precipitation	The maximum precipitation of the year dropped per day	mm
R5d	Maximum five-day precipitation	The maximum amount of precipitation in the year dropped within five consecutive days (the index identifies situations associated with the occurrence of rainfall floods)	mm
SDII	Daily precipitation intensity index	The ratio of the annual amount of precipitation to the number of precipitation days (≥ 1 mm/day) in the year	mm/ day
R10mm	Number of days with precipitation ≥10 mm/day	The number of days in the year with daily precipitation of not less than 10 mm	days
R20mm	Number of days with precipitation ≥20 mm/day	The number of days in the year with daily precipitation of not less than 20 mm	days
Q15	Number of days with precipitation >15 mm/day	The number of days in the year with daily precipitation of more than 15 mm	days
Q5	Number of days with precipitation >5 mm/day at the temperature of <0°C	The number of days in the year with an amount of daily precipitation less than 5 mm at a negative temperature	days
CDD	Maximum duration of dry periods	The maximum number of consecutive dry days in the year (with precipitation <1 mm/day)	days
CWD	Maximum duration of wet periods	The maximum number of consecutive wet days in the year (with precipitation ≥1 mm/day)	days
R95p	Amount of heavy precipitation	The annual amount of heavy precipitation (more than 95% of the distribution of daily precipitation percentile for the period 1961-1990 in the total amount of precipitation in the year)	mm
PRCPTOT	Amount of precipitation	The annual amount of precipitation	mm

The extremality indices Q15 and Q5 were formulated taking into account climatic characteristics of the region under study [14]. Other extremality indices of the precipitation regime in the table were designed and recommended by the WMO (STARDEX Diagnostic Extremes Indices) [15].

For the purpose of calculating the indices we used daily data of the All-Russian Hydrometeorological Data Research Institute - International Data Centre [16] for the period 1951-2010 for 45 stations in Western Siberia. The period under study was divided into two 30-year intervals: 1951-1980 and 1981-2010. This choice was determined by the availability of reliable data series within these intervals of years, the correspondence of the period 1981-2010 to the period of global warming diagnosed by several researchers [1], as well as the possibility to take the period 1951-1980 as the basis when on average no significant changes in climate occurred in Russia [6]. Determination of the statistical significance of the differences was performed using the Statistica package based on the Student's t-test. In order to apply this criterion, it is necessary to meet the condition of the set under study belonging to the normal law of distribution. When testing this condition (based on the Kolmogorov-Smirnov, Lilliefors and Shapiro-Wilks test) the fact of the data sets belonging to the normal distribution was confirmed.

To evaluate the consistency of changes on the territory of the criteria discussed we applied the method of principal components proposed for use in this regard by authors [17]. The method also makes it possible to identify the leading factors of the variability of any climatic parameter [18]. Provided a high consistency in the dynamics of the considered indices within the territory, it could be argued that these changes are a response to global scale processes.

To identify areas in Western Siberia that are similar to each other with respect to the variability of criteria we used cluster analysis. This method allows structuring the source data into groups of stations which differ in the degree of change coherence. For clustering we used the method of k-means and the method of hierarchical classification (Ward

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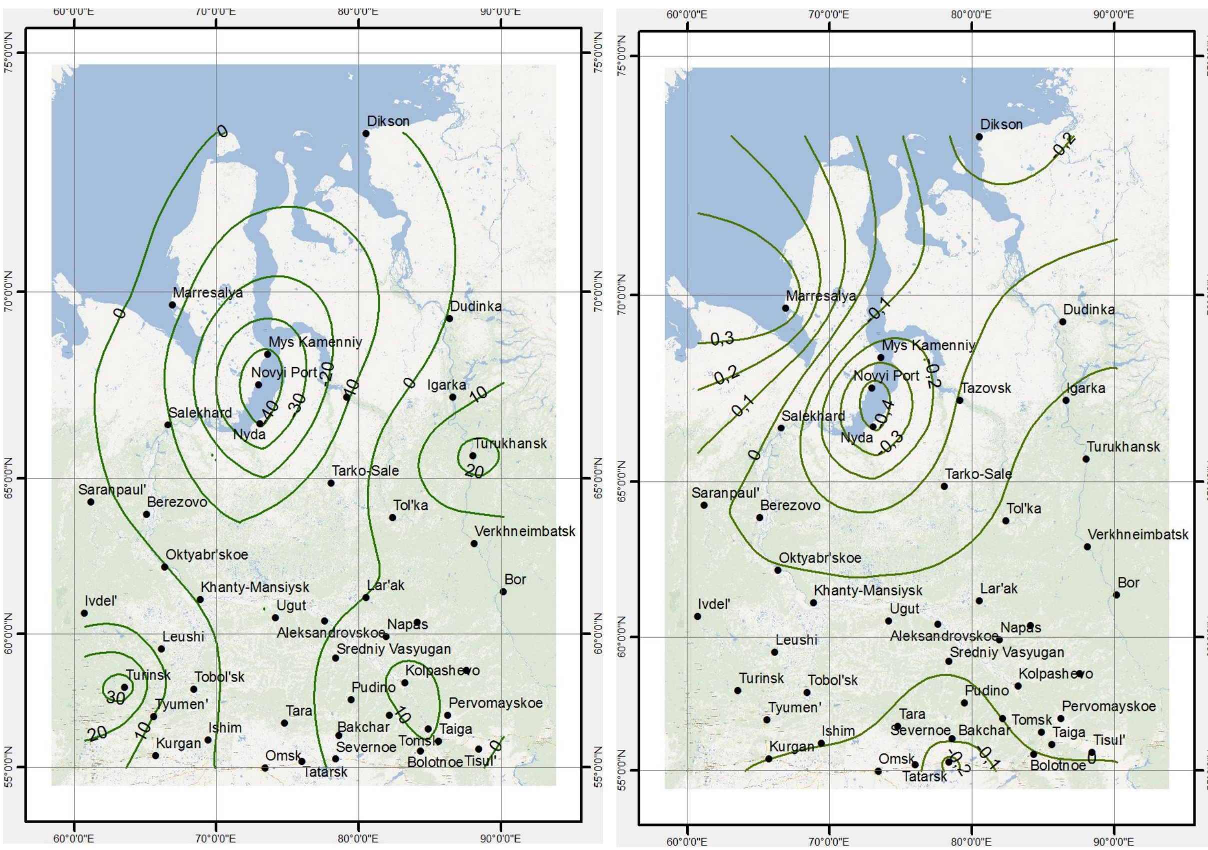
method); the algorithm of their application for climatological fields was described in [19] and practically implemented for two indices of extreme precipitation in [14].

3. RESULTS AND DISCUSSION

The analysis of temporal dynamics of the extreme precipitation regime indices in Western Siberia showed a high heterogeneity. In different parts of the region oppositely directed trends were revealed (Figure 1, example for two indices).



a b

Figure 1. Distribution of changes in the period 1981-2010 compared to 1951-1980; a - amount of heavy precipitation R95p (mm), b – daily index of precipitation intensity SDII (mm/day)

Negative trends for all extreme indices of precipitation over the past 30 years were found only in the northern part of the territory considered (the Gulf of Ob region). The study found here a decrease in the number of days with precipitation of varying intensity: 2 days - R10mm, 1.5 days - Q15. A reduction of maximum precipitation amounts is observed: at some stations R1d and R5d decreased by 6 mm, R95p – by 40 mm. The reduction of extreme indices influenced the annual precipitation which also declined by 30 mm at some stations. Under the influence of the annual precipitation (PRCPTOT is included in calculation of the index SDII) the daily intensity index SDII showed a negative trend which amounted up to -0.4 mm/day.

The south-west area of the territory is characterized by a growth of precipitation indices. Thus, indices of the number of days with precipitation of various intensities increased: R10mm – by 2 days, Q15 - by 1 day, Q5 - by1.5 days. Probably, the growth of these indices boosted the amount of heavy precipitation (R95p) up to 40 mm and caused an increase in annual precipitation – up to the maximum for the area value of 60 mm.

The south-east area of Western Siberia shows widely positive trends of changes of extreme precipitation indices. An increase in the maximum amount of precipitation is observed: R1d – by 2 mm, R5d – by 6 mm, which leads to an increase in the amount of heavy precipitation R95p by 20 mm. On average, the number of days with precipitation ≥10 mm increased by 1 day. The annual amount of precipitation over the past 30 years increased by 60 mm/year (at some stations).

The eastern part of the territory is characterized by an increase of Q5 by 2.5 days and Q15 by 1 day. The amount of heavy precipitation increased by 20 mm and the total amount of precipitation – by 30 mm. The exception was the index of maximum five-day amount of precipitation (R5d) which decreased compared to the period 1951-1980 (with a maximum reduction of 6 mm).

In the south of the territory we observed an increase in the number of days with heavy snowfall (Q5) by 1.5 days. The annual precipitation increased by 60 mm and the daily intensity index decreased by 0.2 mm/day.

The maximum duration of dry periods (CDD) in Western Siberia is characterized by a quasi-type of distribution, with values varying from more than 25 days in the north and more than 30 days in the south to 20 days per year in the central part. No significant changes in CDD over the past 30 years compared to the period 1951-1980 in Western Siberia were observed, which is consistent with the results published in The Second Assessment Report of the Russian Federal Service for Hydrometeorology and Environmental Monitoring on Climate Change and its Effects on the Territory of Russian Federation [19].

The component analysis of the extreme precipitation regime criteria of the territory under study confirmed the inconsistency of their changes within the territory. The total contribution of the first two components into the variability of criteria was approximately 35% (Table 2). This confirms the significant role of station location conditions and features of cyclonic activity over different parts of the selected area in the formation of precipitation. It can be concluded that changes in the precipitation regime of Western Siberia are determined by global climatic factors only by one-third. To construct a model of the atmospheric precipitation field for the given territory it is necessary to develop computing technologies using parameterizations which take into account local conditions.

Table 2. Results of component analysis of precipitation indices

Index	1st component	2nd component	3rd component	∑ variance
R1d	11,5	7,7	6,6	25,8
R5d	9,8	8,9	8,4	27,1
R10mm	26,0	7,8	7,1	40,9
R20mm	16,0	6,9	6,0	28,9
Q15	20,4	7,1	-	27,5
Q5	19,2	15,4	-	34,6
CDD	17,9	10,2	8,8	38,9
CWD	13,4	8,9	8,2	30,5
R95p	20,0	9,1	8,3	37,4
PRCPTOT	30,8	12,4	11,0	54,2

In view of the unsatisfactory result of the precipitation indices component analysis, a task to identify areas in Western Siberia which are similar to each other with respect to variability criteria was set. For this purpose, the series of indices were exposed to clustering procedures which were followed by obtaining classification options. Figure 2 shows an example of the classification result for distribution of maximum amounts of daily precipitation. As a result, for each criterion a division into three classes which is in good agreement with the spatial distribution of the long-term average (for the period 1951-2010) index values was received. On forming the classes, the component analysis in each of them was conducted. When taking into account the results of the division into classes, the share of the explained variance increased to 60%.

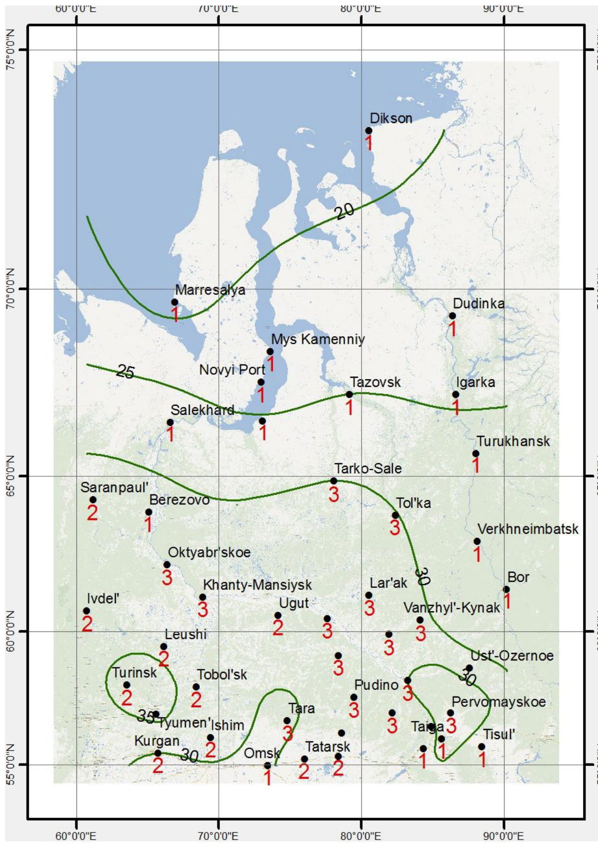


Figure 2. Distribution of classes on the basis of k-means for criterion R1d

4. CONCLUSION

Using the component and cluster analysis in evaluating the space-time structure of extreme precipitation field makes it possible to identify the degree of effect which is produced by various external factors on the territory's precipitation regime. In addition, the inverse problem is solved: a set of stations similar to each other in the degree of response to influencing factors is determined. Furthermore, reducing the dimensions of the feature space by applying the component analysis allows creating data sets for further study of the temporal structure of the extreme precipitation regime without losing information about the relations between the variables.

5. ACKNOWLEDGMENTS

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