On the intrasecular variability of the climate of Western Siberia

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An analysis of hydrometeorological data on rainfall and ground-level air temperature during the period 1901–1996 in the region of Western Siberia is presented. The first five empirical orthogonal functions are analyzed, as well as the 30-year average hydrometeorological characteristics for the southern and northern regions. The temperature trend for the last ninety years is characterized by a general warming for the entire region whereas the rainfall increased in the northern part and decreased in the southern part of the region. The circulation in the region became more meridional and the number of days with anticyclonic circulation decreased.

Introduction

According to the data of the World Meteorological Organization (WMO)[9] during the last 100–130 years the global mean temperature of the ground layer of air has increased by 0.3–0.6°C. This increase in temperature has taken place nonuniformly in time and space and has differed during two periods: during the 30-year period from 1910 to 1940 and during the last 20 years. There is a tendency toward an increase in warming over large areas of the continents during the last several decades, mainly because of an increase in nighttime temperatures.

The variability of warming during the last decade on the whole agrees with predictions obtained from climate models taking into account the concentration of greenhouse gases, but in terms of order of magnitude it is found to lie within the limits of natural climate fluctuations; therefore, it has not been possible to give an unambiguous answer regarding the reasons for this increase in warming. Further increase of the temperature of the ground layer of the atmosphere can lead to a change in the radiation budget of the Earth, which would entail a change in the geographical distribution of ground climate zones, and hence a reorientation in such areas of the world economy as the production of foodstuffs, the utilization of water resources, energetics, etc. The problem is so urgent that studies have been undertaken on it since 1979 under the auspices of the WMO. Of especial importance in this regard is the need for effective cooperation in the development of research aimed at detecting regional responses to climate changes on a larger scale.

Climate studies of recent years, in the absence of a common opinion regarding the main reasons for global warming,[2,10,12,14,15] have noted a growth of the temperature on average by 0.5°C over a period of 100 years against the background of a variety of temporal and regional manifestations.[4,8,13,16,17,etc.]

The aim of the present study is to reveal the climate changes that have taken place in Western Siberia during the twentieth century.

Technique

Such fundamental concepts as “climate” and “norm” should, in our view, be interpreted in terms of the mathematical expectation value of a process. Indeed, if (in the one-dimensional case) by a norm we understand the most probable value, or the value dividing a set into two equal parts, then for a symmetric unimodal distribution function, these definitions of a norm coincide with each other and with the mathematical expectation value. Therefore, by the “norm of a meteorological element” we mean the mathematical expectation value of the stochastic process of the corresponding meteorological element. We will draw a distinction between the norm of a meteorological element, by which we mean the mathematical expectation value, and an estimate of the norm obtained by some approximation of the mathematical expectation value.

In practice, by virtue of the existence of a unique realization of the process, the norm of a meteorological element is usually estimated with the help of an approximation of the mathematical expectation value by a piecewise constant function. Such an approach,

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of course, is convenient from the technical point of view, but sometimes a piecewise linear approximation aided by the local-climate model[4] is more justified, along with other more complicated types of approximations of the mathematical expectation value.

Whereas the norm is a characteristic of the meteorological element for a specific year, the climate is an integrated (in time and space), multidimensional characteristic of the state of the atmosphere of a given region. The spatial characteristic of the climate can vary over its entire range from the entire Earth to an isolated point. A set of climates can be distinguished, depending on the analyzed time interval: intrasecular, secular, supersecular, etc.[3] Consequently, when using the term "climate," it is necessary to indicate the minimum time interval characterizing the given climate, which we will call the "climate interval." For example, WMO recommends that the climate interval be chosen to be 30 years to model intrasecular climate changes.

We will carry out the analysis with the help of three methods: by smoothing using the moving average (with a 30-year climate interval), by the integral–difference transformation, and using the local climate model (LC model).

Uncritical application of the moving average can lead to the appearance of spurious oscillations, known as the Slutzky–Yule effect. We avoid this effect with the help of two approaches: first, we compare the results obtained with the results of other methods and, second, we estimate the statistical significance of the apparent climate oscillations.

The integral–difference transformation transforms a constant function into a linear function, and a linear function, into a parabola, etc. In particular, if the transformed function turns out to be close to a piecewise linear function, then the starting function should, obviously, be a piecewise constant function. This fact underlies the method of identifying piecewise constant norms of hydrometeorological elements with the help of the local climate model. The essence of the method is as follows. Let there be a stochastic process with a piecewise constant mathematical expectation value and additive "red" noise. Applying the integral transformation to this process, we obtain a process with a piecewise linear mathematical expectation value and additive "white" noise, from sample values of which the mathematical expectation value of the original process is estimated with the help of the local climate model.

The local climate model represents the investigated process by the sum of the piecewise linear mathematical expectation value and the noise component, e.g., "white" noise.[6] With the help of this model a Catalog of intrasecular piecewise linear trends of the monthly average air temperatures and monthly precipitation totals and their first five empirical orthogonal components (EOC's) was created.[5] In the Catalog the climate interval was chosen on the basis of a number of considerations to be equal to 12 years. We will make use of the results of the Catalog in our application of the LC model to the EOC's.

Data

Data from the period 1901–1996 on the atmospheric circulation indices, monthly average, seasonal, and annual totals of atmospheric precipitations and ground-level air temperature taken over a grid of hydrometeorological stations (HMS's) of Western Siberia were subjected to analysis. This grid of stations included Khanty–Mansiisk, Tarko–Sale, Tobol'sk, Kolpashevo, Aleksandrovo (temperature), Oktyabr'skoe (precipitations), Tomsk, Omsk, "arabinsk, Novosibirsk, "arnaul, and Kemerovo (temperature). The atmospheric circulation was characterized by the Wangenheim–Girs circulation indices in the first empirical synoptic region,[1] and also by the number of days with Whittles anticyclonic circulation in the third and eighth regions (the north part of Western Siberia and the south part of Western Siberia together with northern Kazakhstan, respectively[3]).

With the aim of checking the reliability of the obtained results, we have included hydrological data: river runoffs of Western Siberia, their freezing and extent of ice cover.

Analysis

For Western Siberia the first two EOC's (EOC-1 and EOC-2) account for 88% of the total variance of the monthly average ground-level air temperatures and 47% of the total variance of the atmospheric precipitation totals. EOC-1 of the air temperature is interpreted as some sort of average value of the meteorological element over the entire grid. For the precipitations the interpretation is the same with the exception of the summer months, in which the contribution of the northernmost hydrometeorological stations is opposite in sign to that of the remaining stations. EOC-2 is the difference of mean values of the northern and southern stations, in other words the contrast of temperatures (or precipitations) between the north and south of Western Siberia. The dividing line runs along the 58th parallel (Tables 1 and 2).

These results allow us to substitute an analysis of the intrasecular variability of the meteorological elements over the grid of 15 hydrometeorological stations by an analysis of EOC-1 and EOC-2, which have, in addition to their simplicity, a clear meteorological interpretation.

Sometimes it is more convenient to consider in place of the pair EOC-1, EOC-2 a different, equivalent pair of statistics: the mean values of the meteorological elements north and south of the 58th parallel.

Table 1. Monthly amounts of precipitation in Western Siberia.

Meteorological station	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
	Coefficient of e n C-1											
Salekhard	21	21	20	22	8	−17	−5	−21	−20	−11	19	11
Targo-Sale	25	19	17	15	32	3	15	−16	−1	−12	21	22
Khanty-Mansiisk	32	29	34	38	30	17	22	7	9	19	34	28
Oktyabr'skoe	32	31	33	30	23	7	7	1	−6	−2	31	26
Surgut	38	36	38	36	33	12	30	−3	12	17	34	33
Tobol'sk	33	28	34	30	23	19	30	27	24	25	31	28
Kolpashevo	37	29	30	26	34	34	35	29	29	29	28	32
Tomsk	31	30	27	30	28	39	34	37	38	42	31	34
Omsk	30	33	26	29	30	30	27	22	36	30	34	36
Barabinsk	26	31	29	31	34	41	38	39	40	40	33	27
Novosibirsk	20	27	23	30	35	37	31	35	40	43	24	34
Barnaul	6	23	20	19	20	37	35	42	38	31	18	18
Semipalatinsk	0	18	18	13	16	31	26	35	23	24	9	19
%D	32	36	31	29	24	25	22	24	28	28	29	27
average	76	61	68	83	140	154	223	131	105	108	120	95
rms	23	22	23	28	36	51	63	55	40	36	32	24
	Coefficient of e n C-2											
Salekhard	−31	−42	−18	−28	−32	29	43	23	27	33	32	−40
Targo-Sale	−22	−28	−38	−40	−21	28	35	37	28	38	31	−31
Khanty-Mansiisk	−25	−33	−23	−24	−32	44	39	51	51	40	24	−29
Oktyabr'skoe	−27	−33	−11	−26	−32	43	46	33	42	42	32	−31
Surgut	−14	−21	−13	−27	−40	49	31	48	47	43	23	−33
Tobol'sk	−05	−13	−16	−13	4	28	16	30	32	31	13	−12
Kolpashevo	7	15	−5	4	−6	10	2	24	14	20	−12	6
Tomsk	35	39	37	18	5	2	33	−1	−9	−10	−28	27
Omsk	14	9	−26	22	29	−8	−20	17	4	6	−6	6
Barabinsk	31	24	23	21	22	0	−11	−5	5	−7	−29	22
Novosibirsk	36	36	35	35	26	−21	−23	3	−12	−14	−38	29
Barnaul	45	29	49	43	39	−7	−23	−5	−13	−22	−41	34
Semipalatinsk	36	11	31	33	36	−28	−23	−17	−16	−6	−28	33
%D	21	17	13	18	15	16	19	17	19	25	23	18
average	−2	10	7	−2	−14	109	88	175	125	91	−14	−3
rms	17	7	17	22	28	43	59	52	41	35	31	21

Table 2. Monthly mean air temperature in Western Siberia.

Meteorological station	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
	Coefficient of e n C-1											
Salekhard	15	15	19	20	21	21	22	21	20	19	12	13
Targo-Sale	23	23	25	23	24	23	25	26	25	25	22	21
Khanty-Mansiisk	25	25	25	26	25	25	26	24	26	26	26	24
Oktyabr'skoe	22	23	24	23	24	23	23	22	24	23	24	21
Surgut	27	27	27	28	26	28	28	28	27	28	27	24
Tobol'sk	28	28	27	26	24	24	24	24	25	27	28	28
Kolpashevo	29	29	29	29	28	28	28	29	28	29	29	30
Tomsk	28	29	28	29	28	27	27	28	28	28	29	29
Omsk	29	29	27	26	27	27	27	28	28	28	26	30
Barabinsk	30	30	28	28	29	29	29	29	29	29	29	30
Novosibirsk	29	29	28	28	28	28	28	29	28	29	29	30
Kemerovo	28	28	28	28	26	28	24	26	27	27	28	29
Barnaul	27	27	26	26	27	27	27	26	25	26	27	27
Ongudai	15	15	19	20	21	20	21	18	20	16	16	16
Volchikha	26	26	24	24	27	26	26	26	26	24	26	27
%D	70	69	73	71	74	71	71	66	71	71	72	68
average	−74	−69	−43	−2	30	58	69	57	34	1	−39	−66
rms	13	12	11	9	7	6	6	5	5	7	12	14

Table 2. (continued)

Meteorological station	1	2	3	4	5	6	7	8	9	10	11	12
						Coefficient of e n C-2						
Salekhard	−45	−44	−44	−42	−39	33	35	37	−41	−41	−49	−44
Targo-Sale	−32	−33	−29	−30	−24	21	10	17	−23	−28	−34	−35
Khanty-Mansiisk	−30	−30	−31	−29	−33	34	33	35	−31	−28	−27	−32
Oktyabr'skoe	−35	−34	−35	−37	−39	39	40	39	−36	−35	−34	−37
Surgut	−25	−25	−24	−21	−22	22	20	23	−20	−26	−25	−24
Tobol'sk	−15	−12	−13	−18	−23	30	34	29	−25	−19	−10	−16
Kolpashevo	2	−6	−2	0	6	−9	−14	−6	2	0	−3	2
Tomsk	14	12	13	13	17	−20	−24	−18	17	16	12	14
Omsk	8	12	13	4	−1	6	11	2	3	6	8	5
Barabinsk	11	11	14	15	9	−9	−7	−11	8	8	10	10
Novosibirsk	18	18	17	18	20	−21	−21	−20	20	19	17	16
Kemerovo	19	20	18	18	25	−23	−32	−23	19	21	19	18
Barnaul	25	26	23	27	28	−30	−27	−31	31	29	25	23
Ongudai	41	40	40	38	39	−35	−29	−35	40	42	41	39
Volchikha	25	27	33	33	23	−26	−21	−26	29	31	25	26
%D	20	20	17	17	13	14	14	18	15	19	20	23
average	9	10	9	11	11	−5	−2	−2	4	7	10	12
rms	7	7	6	5	3	3	3	3	2	4	7	8

Applying the moving average with a 30-year climate interval to the annual and seasonal values of the northern and southern parts of Western Siberia gave the following results. On the annual scale the climate of the southern part of Western Siberia warmed since the beginning of the century by 0.9 degrees (Fig. 1), with this warming starting around 1940 with an average climb of 0.05 deg/yr. In the northern part of the region there was a climb in the temperature by 0.5 degrees from the beginning of the century to the end of the 1930's, which then gave way to a cooling, by the same amount, lasting into the 1960's, and a new warming, with the same rate as existed in the south since 1940.

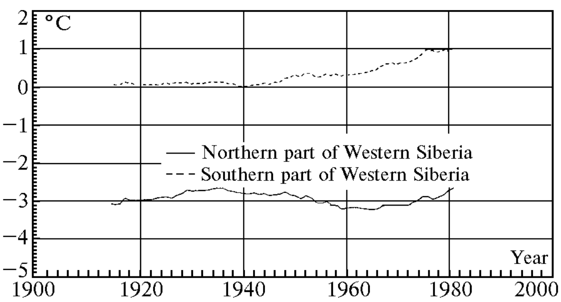

Fig. 1. Regional mean air temperature smoothed over 30 years (1901–1996). Annual mean values.

On the seasonal scale the positive temperature trend with an amplitude of 1.5 degrees is most clearly noticeable in the spring in the south, and with an amplitude of 1 degree in the north. In the north positive anomalies prevailed during the period 1920–1950 and during the last 20 years, and in the south, during the period 1920–1940 and during the last 20 years.

The variability of precipitation on an annual scale of averaging is shown in Fig. 2. The precipitation picture is different in the north and the south: in the north the annual precipitation amounts grew from the beginning to the middle of the century by 60 mm, and in the south, they decreased by 50 mm. The maximum contrast in the precipitation between the north and the south of Western Siberia occurred at the beginning of the 1960's.

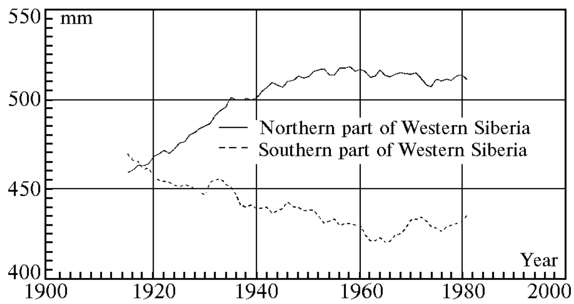

Fig. 2. Regional mean precipitation smoothed over years (1901–1996). Annual mean values.

The seasonal precipitation values on the whole replicate the annual pattern, except for the summer values in the south.

During the entire century the total atmospheric circulation over Western Siberia has become more meridional (Fig. 3). The number of days with the western pattern of circulation (W) decreased by 55 days per year, and with meridional, increased by 59 days per year. That is, a tendency set in toward stationing of the altitude crest above the European part of the CIS and the altitude trough above Western Siberia. This tendency ceased in 1984 and a growth of the western pattern of circulation was noted, which was especially noticeable in the winter.

Overall, during the past century the continental character of the climate has decreased, as is indicated by the dynamics of the continental index (difference between summer and winter temperatures), shown in Fig. 4. Simultaneously, the duration of the vegetation period increased in the south part of Western Siberia. The number of days with anticyclonic circulation decreased by 20 days per year.

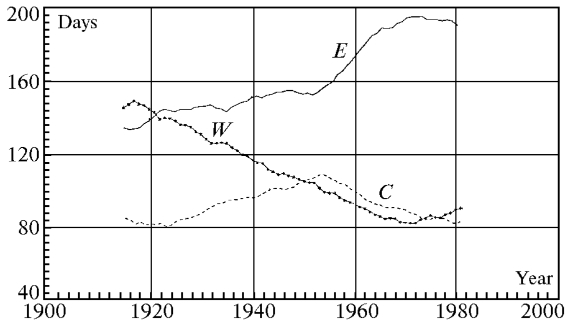

Fig. 3. Circulation indices *W*, *E*, and *C* smoothed over 30 years. Annual mean values.

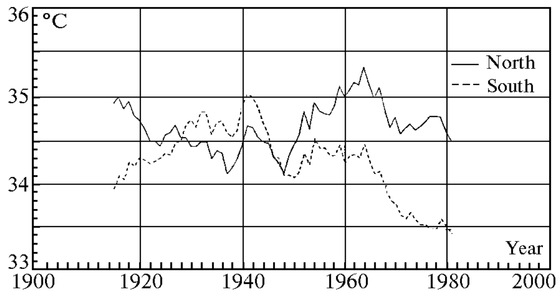

Fig. 4. Continental index smoothed over 30 years.

The reliability of the results was checked by comparing the variability of the meteorological parameters of the climate vector with the variability of the corresponding hydrological parameters: the duration of the period without ice correlates with variations of the vegetation period, and the periods of freezing and ice cover of the river Ob' agreed with the autumn and spring air temperatures. " ut, overall, the variability of the hydrological parameters of the climate vector has its own peculiar structure and requires separate study apart from the atmospheric parameters.

Conclusions

1. The variability of the climate of Western Siberia has a different character in the north and in the south. The dividing line passes through the 58th parallel.

2. The climate of Western Siberia in this century has warmed by almost 1 degree. The warming is more significant in the south than in the north.

3. Precipitation increased in the north and decreased in the south up to 1980. After 1980 a stabilization and even growth during the winter and summer was noted.

4. The atmospheric circulation became more meridional: the number of days per year with the western pattern of circulation decreased by 55 days, and the number of days with the meridional pattern increased by 59 days per year. This tendency ceased in the mid 1980's, and this cessation was especially noticeable in the winter. The number of days per year with anticyclonal circulation decreased by 20.

5. The continental character of the climate decreased with a simultaneous increase in the duration of the vegetation period in the south.

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