Intrasecular climate change in Eastern Siberia

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The main objective of the present study is to continue analysis of intrasecular climate changes based on long-term measurements. Variations of the surface air temperature and precipitation in Eastern Siberia were studied. An attempt was undertaken to find a relation between the past climate changes and changes in the atmospheric circulation in the Northern Hemisphere and to separate out regularities, which could help assessing future climatic changes for the next 10–20 years.

Early in the year 2000, the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) was approved.[1] As to the Russian scientific literature, the modern ideas on observed climate changes, climate models, the anthropogenic impact on climate, and expected climate changes have been considered most thoroughly, in our opinion, in Ref. 2.

During the 20th century, the global surface air temperature increased by (0.6 ± 0.2)°C. Global warming was strongest since 1910 until 1945 and since 1976 until 2000, and in 1946–1975 some cooling was observed. The surface air temperature increased largely due to the increase in the minimum nighttime temperature. This made the cold-less period longer in many regions in middle and high latitudes.

The level of the World Ocean rose for the past century by 0.1–0.2 m. Observations over the temperature of lower ocean layers evidence the growth of the ocean heat since late 1950s. The amount of atmospheric precipitation in the 20th century increased by 0.5–1.0% a decade in most regions in high and middle latitudes of the Northern Hemisphere.

In spite of the progress achieved in climate investigations, some problems connected with the interpretation of current climate changes, regional responses to larger-scale climate changes, and assessment of future changes in climate parameters are poorly studied yet. Climate changes in Western Siberia based on 100-year data on the monthly mean surface air temperature, monthly precipitation, and Vangengeim–Girs indices of atmospheric circulation W, E, C were analyzed in Refs. 3 and 4. To obtain a more complete pattern of the climate changes and their relation to atmospheric circulation in the Northern Hemisphere, analysis of intrasecular climate changes was continued as applied to the Eastern Siberia.

1. Initial data

For analysis we used data for the period of 1901–2000 concerning the monthly mean surface air temperature, monthly precipitation, and Vangengeim–Girs atmospheric circulation indices in the first and second natural synoptic regions (hereinafter, NSRs). The first NSR covers the territory of the Northern Hemisphere to the north from 30°N from Greenland to Taimyr. It is characterized by the indices W (westerly circulation), E (easterly circulation), and C (meridional circulation). The second NSR embraces the territory of the Northern Hemisphere to the north from 30°N from Taimyr to the Bering Strait. It is characterized by the indices Z (westerly), $M1$ (meridional), and $M2$ (easterly) circulation. The data on these atmospheric circulation indices were taken from the catalogue of macro-synoptic processes of the Department of Long-Term Meteorological Forecasts of the Arctic and Antarctic Research Institute (St. Petersburg).

The territory of Eastern Siberia was divided into the northern and southern parts with the boundary along 60°N based on the analysis of natural orthogonal functions (NOFs) considered in detail below. According to the air temperature data, 12 weather stations were divided into seven northern ones (Dikson, Chelyuskin, Turukhansk, Tura, Podkamennaya Tunguska, Erbogachen, Vilyuisk) and five southern stations (Krasnoyarsk, Kirensk, Nizhneudinsk, Chita, Irkutsk). According to the precipitation data, ten weather stations were divided into four northern ones (Tura, Turukhansk, Podkamennaya Tunguska, Vilyuisk) and six southern ones (Krasnoyarsk, Kirensk, Bratsk, Irkutsk, Nizhneudinsk, Ulan-Ude).

2. Technique

The World Meteorological Organization recommends using 30-year averaging periods for climate analysis. The following three averaging periods are commonly accepted: 1901–1930, 1931–1960, and 1961–1990. For analysis of climate changes, at the first stage we used natural orthogonal functions for separating out spatially homogenous parts of a region, and then we

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applied a sliding 30-year average with the first point corresponding to 1915 and the last one corresponding to 1985. The analysis was conducted with the annual, seasonal, and monthly resolution, and the seasons were defined as follows: spring from March to May, summer from June to August, fall from September to November, and winter from December to February. Meteorological elements were analyzed in the form of secular anomalies, that is, the average values for 1901–2000 that are tabulated below were subtracted from the seasonal mean values.

3. Analysis of surface air temperature

Proceeding from initial series of monthly mean air temperature to their NOFs shows that 3/4 of temperature variability in a region is concentrated in the first two NOFs. In this case, NOF-1 can be interpreted with a good approximation as the mean over the region, and NOF-2 can be interpreted as a difference between the means (contrast) for the northern and southern parts of Eastern Siberia (boundary at 60°N). Therefore, the main attention in analysis of temperature variations should be paid to NOF-1 and NOF-2 or equivalent pair of characteristics: mean values for the northern and southern parts of the region.

The seasonal air temperature smoothed over 30 years for the north and south of Eastern Siberia is depicted in Fig. 1. For the past century, the annual air temperature increased by 0.9° in the south and by 0.4° in the north of the Eastern Siberia. Warming was observed mostly in the southern part of the region in winter, spring, and fall seasons, for which it was 2, 0.9, and 0.9°, respectively. It should also be noted that the highest warming was observed in recent 20–25 years.

4. Analysis of precipitation variations

Consideration of NOFs shows that, as in the case of analysis of the surface temperature, it is worth considering the north and south separately, since NOF-1 and NOF-2 are interpreted similarly to the case of temperature and each of them represents a half of the total variability of precipitations.

Anomalies of seasonal precipitation smoothed over 30 years are depicted in Fig. 2. For the past century, the annual precipitation in Eastern Siberia increased, especially, in the northern part of the territory (by 80 mm).

On the whole, variability of seasonal precipitation was similar in the northern and southern parts, but the amount of precipitation in the southern part was smaller, as well as its increase, except for the summer season, in which the precipitation increase in the first half of the past century was alternated by a decrease in the second half.

Mean values of seasonal meteorological elements for Eastern Siberia (for the period of 1901–2000)

Element	Season				Year
	Winter	Spring	Summer	Fall	
Surface air temperature, °C:					
North	−28.2	−9.8	10.8	−7.9	−8.67
South	−20.6	−0.4	16.1	−1.4	−1.44
Net precipitation, mm					
North	63	71	169	122	425
South	37	52	208	82	380
Atmospheric circulation indices:					
Z	28.8	36.0	34.0	42.9	141.6
*M*1	13.6	21.4	38.8	17.1	91.0
*M*2	47.8	34.6	19.2	31.0	132.7

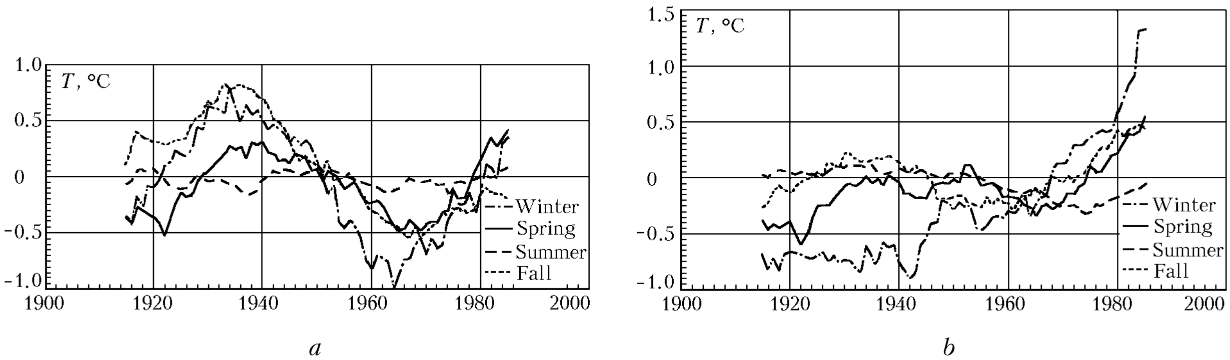

Fig. 1. Anomalies of mean seasonal air temperatures smoothed over 30 years in Eastern Siberia: north (*a*) and south (*b*).

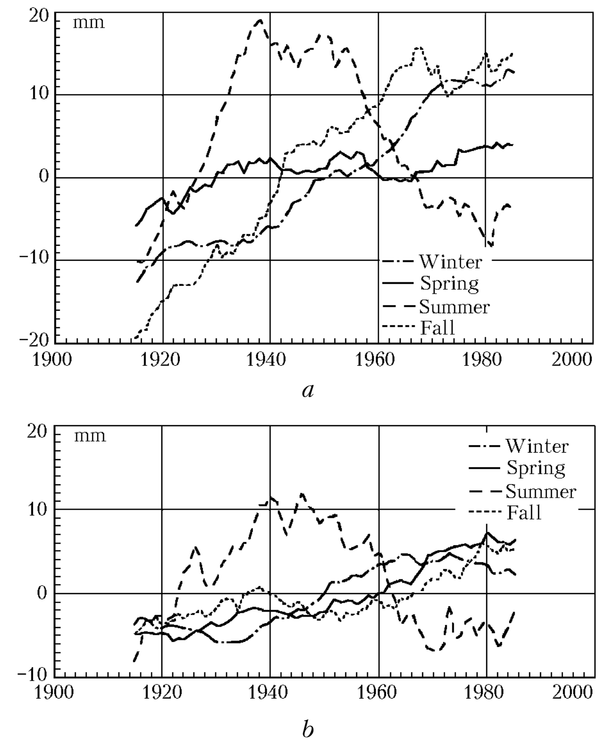

Fig. 2. Anomalies of net seasonal precipitation in Eastern Siberia smoothed over 30 years: north (*a*) and south (*b*).

5. Analysis of atmospheric circulation

The initial data are the number of days in a month with every circulation form in the first (*W*, *E*, *C*) and second (*Z*, *M*1, *M*2) NSR. The circulation forms are connected with a certain character of prevailing tropospheric transfer. Thus, at the westerly circulation form (*W*, *Z*), baric formations move mostly from the Atlantic Ocean to the east. The temperature gradient between the tropics and the poles is high, and the intense western air mass transfer prevails in the tropospheric depth. The meridional mass and heat exchange is weak.

A typical pattern is the development and propagation of small-amplitude waves from the west to the east along with related migratory near-surface depressions and anticyclones of atmospheric fronts. At the meridional circulation form (*C*, *M*1) the interlatitude heat and mass exchange in the Northern Hemisphere is intense. Powerful meridional mass transfers are concentrated over oceans in winter and over continents in summer. The Iceland depression is weak. Vast cold zones are situated over Canada and Eastern Siberia, while warm weather prevails in the Western Siberia. Processes of the easterly form (*E*, *M*2) are connected with movement of baric formations, mostly anticyclones, from the east in the western direction. The Siberian High is well developed and displaced to the west relative to its climatic position. Processes of the easterly circulation form are mostly established through approach of the Siberian High.

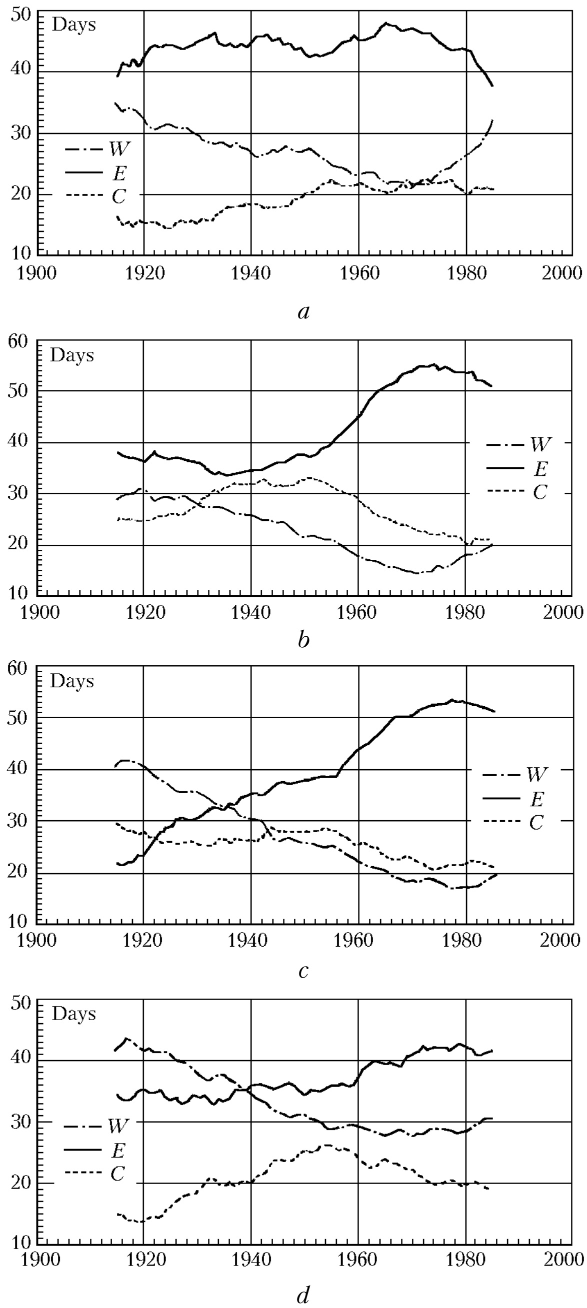

Fig. 3. Atmospheric circulation indices smoothed over 30 years for the first NSR. Seasonal values: winter (*a*), spring (*b*), summer (*c*), fall (*d*).

The atmospheric circulation indices smoothed over 30 years are depicted in Fig. 3 (first NSR) and in Fig. 4 (second NSR). Analysis of the plots shows that the circulation indices in the 20th century had a rather ordered behavior, namely, the eastern circulation form *E* prevailed in the first NSR by the 1970s, and then the number of days with the western transfer began to increase, especially, in winter. In the second NSR the number of days with different circulation forms was close to the norm by 1960, and then the zonal circulation form began to prevail, especially, since the mid-1970s.

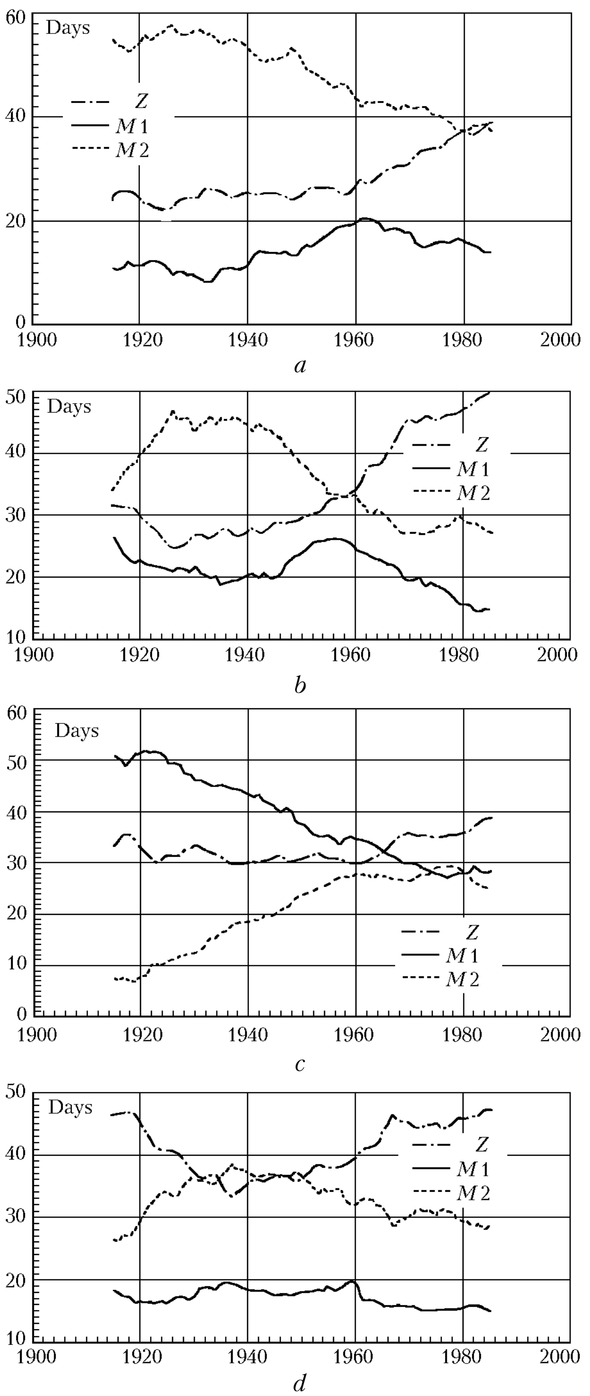

Fig. 4. Atmospheric circulation indices smoothed over 30 years for the second NSR. Seasonal values: winter (*a*), spring (*b*), summer (*c*), fall (*d*).

Thus, the last quarter of the 20th century, in which most intense temperature rise was observed in the Northern Hemisphere, as a whole, and in Siberian regions under study, is characterized by the prevalence and intensification of the western transfer, especially, in winter all over the tropospheric depth from Greenland to the Bering Strait (the third NSR is beyond the scope of this paper). If the temperature rise is a result of the anthropogenic impact, then one of the circulation mechanisms of this impact may be regeneration of depressions over large industrial regions, their longer lifetime, and more intense migration in Eurasia reaching even Eastern Siberia.

Conclusions

1. In the 20th century the surface air temperature rose on the territory of Eastern Siberia, as well as on the global scale. The rise in the northern part of the studied region was comparable with the rise of the global annual temperature and equaled to 0.4°, and in the southern part of the region the rise was somewhat higher than the rise of the global annual temperature and equaled to 0.9° for 100 years. The main contribution to the rise of the annual air temperature is due to the winter season: 2° for 100 years.

2. The annual amount of precipitation increased considerably in the Eastern Siberia in the 20th century, especially, in the northern part of the region (by 80 mm).

3. Analysis of macro-circulation characteristics of the atmosphere in the first and second NSRs shows a considerable increase in the zonal circulation indices, especially, in the last quarter of the 20th century, thus evidencing the intensification of the near-surface cyclonic activity and penetration of air masses from the Atlantic far into Eurasia reaching Eastern Siberia.

Acknowledgments

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