On the character of recent climatic changes on the south coast of Lake Baikal

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This paper describes the climatic conditions in Southern Baikal based on the routine observations of air temperature, atmospheric precipitation and river discharge. Changes in the type of moistening and thermal regime of the area have been revealed, which result to some extent in formation of flows of a substance from the atmosphere.

Introduction

In the regions with high atmospheric pollution the intensity of aerosol flows to the underlying surface is mainly determined by moisture conditions and thermal regime of the terrain. Within the limits of mountainous surroundings of Lake Baikal the atmospheric air is highly polluted at the south coast area located at the mountainside of Khamar-Daban ridge facing the lake.

The climate formation in this region, as throughout the coast, is of a complex character and proceeds in conditions of high orographic isolation and considerable thermal inertia of the lake, which determines the temperature contrast in the system "lake–land"; meridional extension of mountain ranges, at windward slopes of which the vertical orographic flow are developed and strengthen processes of cloud and precipitation formation. The increased humidity and the presence of temperature inversions are among climatic factors of the region, affecting the arrival of matters from atmosphere, which then pollute the soil cover and surface waters. The elevated atmospheric pollution in this region is determined by the transport of aerosols and gases from the Irkutsk–Cheremkhovo Industrial Complex and by the presence of a high-power local pollution source – the Baikal Pulp-and-Paper Mill.

In its turn, the regime of precipitations and other climate characteristics are significantly transformable, depending on the aerosol amount in atmosphere.[1]

Extensive material in hand on the atmospheric precipitation in the South Baikal along with well-known general regularities in interdependence between chemical compositions of precipitations and atmosphere[2,3] includes a lot of estimates of the qualitative composition of atmospheric aerosols and precipitations, as well as calculations of flows of individual substances from the atmosphere.[4–6] All they testify about an increasing pollution of atmosphere in the region, affecting chemical composition of surface waters,[7] which, in turn, cause corresponding changes in the impurity composition of air over the observed territory. Finally, this material enables one to estimate the scale of the atmospheric component in the pollution of the south part of Lake Baikal.

At the same time, the relation between climate characteristics and atmospheric precipitation[4,8,9] has been poorly studied. Therefore, the role of temperature and humidity conditions, as well as their variability and participation in aerosol pollution of the territory still remains debated. On this basis, the goal of the present paper is to analyze the present-day climatic variations in the region of interest.

We used as initial data the continuous observations of the Russian Hydrometeorologic Service for the air temperature and atmospheric precipitation conducted by meteorological stations located at populated areas at the southeast coast of Lake Baikal: Baikalsk, Slyudyanka, Tankhoi, and the high-mountain station "Khamar-Daban" (985 m above the sea level, 10 km distant from the lake). The river discharge regime on the territory was estimated by the data about the water content of the main local rivers: Snezhnaya, Utulik, Khara-Murin.

In addition to annual data we used the data on hydrometeorological elements for warm (April–September) and cold (October–March) seasons.

General characteristics of climatic conditions of the territory

The air temperature in different regions of the Baikal coast, as well as at coastal slopes of mountains differs considerably, however, basic temperature variations occur consistently along the entire Baikal basin. Moreover, all south part of Siberia refers to a region of cophased variations of annual and seasonal air temperatures.[10] By the data of stations located throughout the lake coast, the correlation coefficient r for the annual air temperature is 0.5–0.8 and for cold seasons 0.6–0.9. Absolute extremes of air temperature are close: minimum is –40...–43°C, and maximum is 30–32°C.[11] Thermal stratification in the south of Baikal is

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characterized by the surface and elevated inversion reaching a 500–750 m height.[11]

Early in the warm season Lake Baikal makes a cooling effect on the coastal territories; while late in the season and in the beginning of winter the effect becomes warming.

The most characteristic peculiarity of the climate on the territory of the Khamar-Daban slope is the increased moisture, particularly, in the area of the Baikalsk–Tankhoi coast. This is due to the orographic characteristics of the terrain, namely, the Primorskii Ridge lowering to the river Angara source, through which the northwestern air masses arrive there (this is supported by the growth of the atmospheric optical depth above Lake Baikal at this point[12]) carrying the main body of moisture and atmospheric impurities. As a result, the annual precipitation at the lake coast ranges from 500 to 700 mm. It is twice as much in the mountains. The precipitations bring yearly up to 1.3 t/km^2 of sulfates at the high-mountain areas of the northwestern mountainside of Khamar-Daban, whereas the sulfate quantity falling on the opposite southern slope is less by an order of magnitude.[8]

The distribution of precipitation and especially of river discharge during year is very irregular – up to 80–90% of the annual amount falls on the warm period, which is favored by intensification of the cyclonic activity above the Mongolia, from where the south cyclones often come to the Lake Baikal south.

The water content in rivers of the region is also high. The modulus of river discharge from this part of the slope reaches 20–25 l/s per km^2 (Ref. 13), while on the average it is about 4 l/s per km^2 (Ref. 14).

The chemical composition of the Khamar-Daban river waters is formed at a low rate of chemical disintegration; and under conditions of increased moistening this predetermines the formation of waters with low ion concentration. This allows one to trace even insignificant changes in their qualitative composition especially with regard to ingredients noncharacteristic to the waters.

Considerable changes in the ion composition of atmospheric precipitation and river waters,[4,7,15] especially an increase of sulfates and reduction of hydrocarbonates and calcium, registered in the second half of the twentieth century, are indicative of the growing pollution of atmosphere in this region. When analyzing the reasons, it is necessary first to determine the degree of variability or stability of climatic factors participating in these processes.

Variability of basic hydrometeorological parameters

The global warming, strengthened late in 1970s, manifested itself in Lake Baikal region more distinctly than on the average on the Earth, although somewhat weaker than on the areas surrounding the lake.[16] Besides, the temperature growth began there from the end of the first decade of the last century and continued up to the middle of the century. Then, due to formation of the intrasecular temperature cycle decay branch, the temperature has been lowering up to 1970. The next period of the temperature lowering began in the region in 1996.

In the south of Baikal the temperature variations were the same, slightly differing on the coast and in the mountains. Thus, in mountains the warming in 1970–1995 was evident only in the middle of the period. This is in agreement with the high-mountain station Ilchir (eastern Sayan) data[17] on the temperature variations and confirms a higher stability of thermal conditions in high-mountain regions.

More significant differences between the coast and mountain temperatures can be observed when comparing seasonal values (Figs. 1*b* and *c*), which are evidently due to the thermal effect of Lake Baikal. For example, at the station Khamar-Daban the air temperature during warm seasons increased essentially after the cold 1983 year, at a considerable increase during the last five years of the last century. At the coast the temperature growth during these seasons after 1990 was not significant. The air temperatures in cold seasons decreased during the last decade of the twentieth century both in the mountains and at the coast, especially since 1996. Noticeable anomalies in the annual temperature behavior at the station Khamar-Daban during this period were not observed.

Long-term climate tendencies during cold periods are also more noticeable at the coastal area. Thus, for example, the temperature increase in 1966–2002 cold seasons for Baikalsk on the average was 0.08°C, and for the station Khamar-Daban it was only 0.03°C per year.

Long-term variations of annual air temperatures, as a whole, depend more on the temperature variations in cold seasons due to a greater amplitude of their variations. For the station Khamar-Daban, for example, the correlation coefficient r for these characteristics is 0.59. The temperature of warm seasons is connected weaker with the annual temperature ($r = 0.44$). Thermal conditions of warm and cold seasons are not connected practically ($r = 0.09$). At the coast, the connection between annual and seasonal temperatures (and between seasonal ones) is more significant: the values of r are on average higher by 0.2–0.3.

Against the background of the increasing annual mean air temperature in the area under study some decrease of the annual atmospheric precipitations stipulated by moisture lowering in warm seasons is observed (Fig. 2*a*). This tendency is typical for most adjacent territories, including those around Lake Baikal.[17] Nevertheless the maximal annual precipitations both around and eastwards Lake Baikal fall on the beginning of 1970s. The smoothed behavior of precipitations demonstrates evident 20–25-year cycles, therefore, the above maximum can be attributed to the intrasecular rhythm in the regional moisture. In 1973, the above maximum was observed throughout the territory. The precipitation maximum in mountains made 1940 mm (the station Khamar-Daban), and at the coastal stations (Kultuk, Slyudyanka, Tankhoi) it was 800–900 mm. In Baikalsk the precipitation maximum (1043 mm) was observed earlier – in 1971.

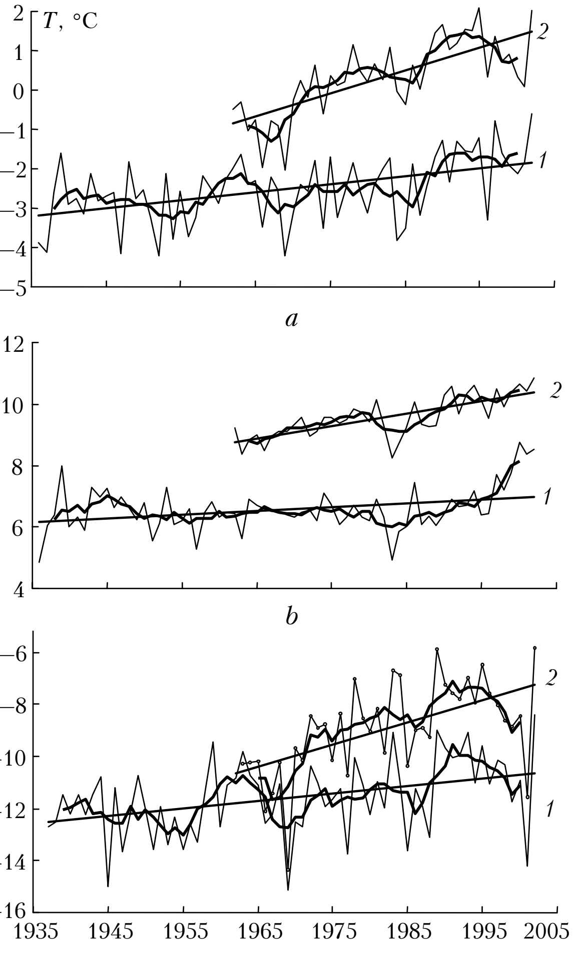

Fig. 1. Variations of annual (*a*) air temperature during warm (*b*) and cold (*c*) periods based on data of meteorological stations Khamar-Daban (*1*) and Baikalsk (*2*). The heavy line shows current values smoothed-out by five years; straight line shows the trend.

As in the case of air temperatures, the long-term tendencies of precipitations do not coincide in seasons: in warm seasons the precipitations, on the whole, gradually decrease, while in cold seasons they, on the contrary, increase (Fig. 2*b*). The latter was confirmed by the increase of water-content in snow late in winter, which was shown by results of snow surveying.

The average decrease of precipitation during warm seasons is 2.7 mm/year for Khamar-Daban, and somewhat less for Baikalsk and Slyudyanka: 0.8–1.0 mm/year. The positive trend of precipitation for cold seasons is much lower: 0.2–0.5 mm/year.

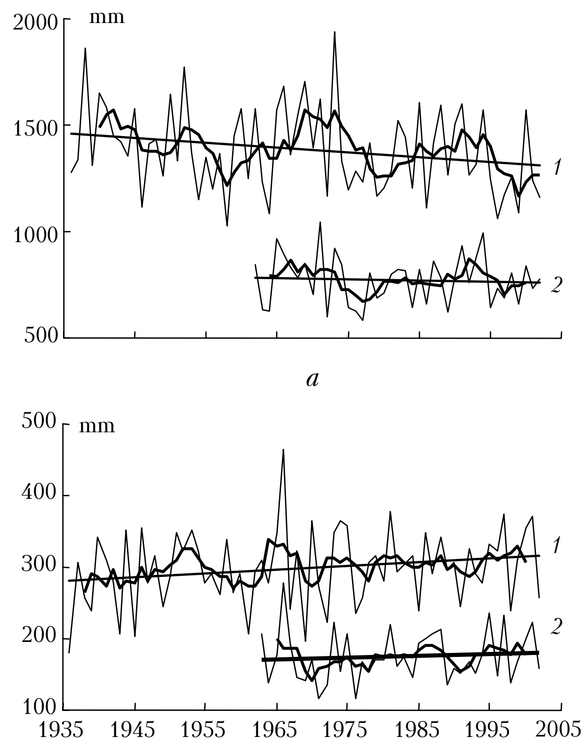

Fig. 2. Long-term variations of precipitations during warm (*a*) and cold (*b*) periods based on data of meteorological stations Khamar-Daban (*1*) and Baikalsk (*2*).

Analysis of the long-term variability of the annual flow discharge of Khamar-Daban rivers has revealed a stable alternation of low-water- and high-water-content years and periods, supporting the increased variability of main factors determining them: the precipitation and air temperature. The long-term trend in the river discharge variations shows a statistically insignificant tendency to decrease. At the same time the water content in winter months, on the contrary, increases, and this tendency for individual rivers is not of the accidental character. Thus, for the Khara-Murin area the significance of the tendency for the river in January-March (0.02 m^3/s) exceeds 1% level of significance (Fig. 3).

The increase of river water content in winter is, most probably, a consequence of the above-mentioned general warming of climatic conditions in cold seasons, which motivates the early start of the spring snow melting.

The above changes of climatic factors in the south of Lake Baikal and the rise of mean air temperatures in different regions of the Northern hemisphere proceed at a simultaneous intensification of warm episodes of the El Niño–South Oscillation and the increase of activity of atmospheric centers in North Atlantic and North Pacific Ocean, the effects of which strengthen or weaken the influence of enhanced concentration of greenhouse gases on the air temperature.[18,19]

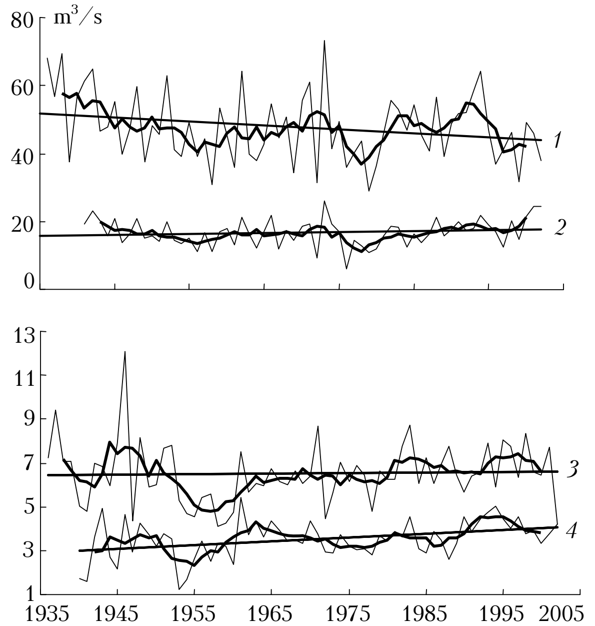

Fig. 3. Variability of annual river discharge of rivers Snezhnaya (*1*) and Utulik (*2*), and the winter water content (January–March) of rivers Snezhnaya (*3*) and Khara-Murin (*4*).

Under conditions of the climate destabilization the importance of regional peculiarities of atmospheric circulation increases, which is manifested itself in the change of intensity of zonal and meridional circulations. In XX century, the meridional circulation in the Siberian sector increased, which repetition (by the classification of Vangenheim–Girs) in the Western Siberia increased by 59 days per year,[20] although a reverse tendency was marked since 1984. The greatest changes were observed in spring and summer seasons. Thus, annual precipitations in the south of the territory under consideration decreased by 50 mm.

At the end of the last century, a stable tendency of the Asian anticyclone attenuation was observed. Relative to the middle of the twentieth century, the ground pressure by the end of the century lowered on the average in the Yakut center by 12 hPa, in the Mongolian one – by 22 hPa, and in the TransUral – by 24 hPa.[21] The above-mentioned attenuation of the Asian maximum proceeded against the background of the strengthened zonal transfer and more frequent intrusions of warm air masses to the continent. And vice versa, the anomalously cold winters of 2000–2001 (and January 2006), as a consequence of strengthening Asian anticyclone, are, probably, the response of the Siberian sector to incidentally occurring temperature anomalies at the ocean surface in the tropical zone of the Pacific Ocean due to El Niño events, in phase with which the meridional north group of circulation is developed over the continent and extremely low temperatures are observed in Siberia.[22]

Conclusion

Analysis of long-term variability of basic characteristics of the climate and the river flow discharges at the north-western slope of the Khamar-Daban ridge in the South Baikal has shown significant changes of these characteristics in the second half of the last century, especially, in its latter part. On the whole, they agree with the behavior of general climatic trends in the Siberian region, however, due to natural peculiarities of the territory, they have their distinctive features. The climate warming, which began in 1970s, manifesting itself both in the behavior of annual and seasonal temperature variations, is more evident in the coastal areas as compared to the mountains. The last five years of the century, on the contrary, are characterized by significant temperature increases in warm seasons in mountains.

At the cost of changed conditions of atmospheric circulation in the Siberian region and under the influence of local natural properties, the decrease of precipitation in warm seasons and the increase in cold seasons were observed. Analogous changes were typical for the river discharge.

Undoubtedly, the changed climatic conditions reflect on the processes of aerosol pollution of the territory open to air flows from polluted industrial areas and having local pollution sources with a high generation rate of aerosol particles. The presence of near-ground inversions and heavy precipitation favor the fall of considerable amounts of some pollutants from atmosphere. This affects the chemical composition of river waters indicating the corresponding oscillations in intensity of the aerosol pollution on the territory and the tendency to its increase.

Based on the predicted in the scientific literature continuation of the current climate warming, the reconstruction of processes of the heat and moisture convective transfer can be expected, as well as the redistribution of different aerosol substances capable of affecting the components of radiation and heat balance in the atmosphere. In this connection, the time variability of climatic conditions in the region should remain a matter of the increased attention.

Acknowledgments

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