ANALYSIS AND MODELING OF CHANGES IN THE CLIMATIC SYSTEM OF WESTERN SIBERIA

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Results of processing and analysis of many-year series of observations of variability of the climatic characteristics for Western Siberia on the basis of the simplest statistical models are presented. The main parameters of the climatic model of the atmosphere developed at the Computing Center of the SB RAS and model parametrization used in it are described. Preliminary results of modeling of year-to-year variability are presented.

1. INTRODUCTION

The problem of prediction and estimation of the impact of climatic changes that take place at present and will take place in future on the evolution of the biosphere, society, and the Earth's system as a whole is of primary importance for modern science. The importance of its solution is determined by the necessity of choosing the strategy for further development of our society to prevent global and regional climatic and ecological disasters.

Understanding of the importance of these investigations dates back to the World Climate Research Program (WCRP), in which the particular emphasis was placed on possible consequences of natural and anthropogenic climatic changes. Further the integrated approach to investigation of this problem was formulated in the International Program on Global Changes of the Geosphere and the Biosphere (IGBP) in 1986. In the Program on Global Changes the role of the regional components in the estimation of the global consequences of climatic changes has been transformed significantly as a consequence of the fact that practical interests of our society are concentrated on regional manifestations of the climatic system changes as well as on possible impact of local zones of the Earth on the climate on the global scale.

This idea provided the basis for organization of investigations in the Computing Center of the SB RAS aimed at studying interaction of global climatic changes and regional climatic peculiarities for the Siberian region.

The Siberian region is a special climatic zone characterized by moderate-continental climate in its central part. This climatic zone is affected by the Arctic basin and air masses of Central Asia. In this connection the global climatic changes can be manifested in a very specific manner in these regions, engendering variations of regional climatic parameters.

In addition, economic activity that exploits resources of Western Siberian is accompanied by processes of deforestation, drainage of marches, and pollution of air and water basins. This may change the climatic characteristics on regional and possibly, global scales.

Investigations into the variability of the climatic characteristics of Western Siberia at the Computing Center of the SB RAS are carried out in two directions: 1) processing and analysis of many-year observations of climatic characteristics on the basis of statistical models; 2) calculations of scenarios to study possible variations of the Western Siberia climatic state on the basis of numerical modeling of the atmospheric and oceanic dynamics.

2. ANALYSIS OF MANY-YEAR SERIES OF OBSERVATIONS OF HYDROMETEOROLOGICAL CHARACTERISTICS OF WESTERN SIBERIA

Regional manifestations of climatic changes for the Siberian region can be established primarily from the data of hydrometeorological stations collected for a hundred years. For example, let us consider the data for such climatic characteristics as average annual temperature, precipitation, and discharge and debacle of rivers for same remoted sites of Western Siberia. The data were provided by the Siberian Regional Scientific-Research Hydrometeorological Institute.

Without going into thorough analysis of the data of undubitable interest that are the subject of our further investigations, we point out only basic features of the tendencies for hydrometeorological characteristics manifested for a hundred-year period that confirm their spatial in homogeneity even for Western Siberia. For our analysis we selected the time series recorded at two stations of the Western Siberian region. They are measurements at the Barnaul station that characterize the conditions of the southern part of the region and the lower reaches of the Ob' river and at the Salekhard station located in the northern part of the region and entire Ob'-Irtysh basin.

In Fig. 1 the average annual values and linear trends of the temperature and precipitation are shown. From Fig. 1 it can be seen that for the temperature the

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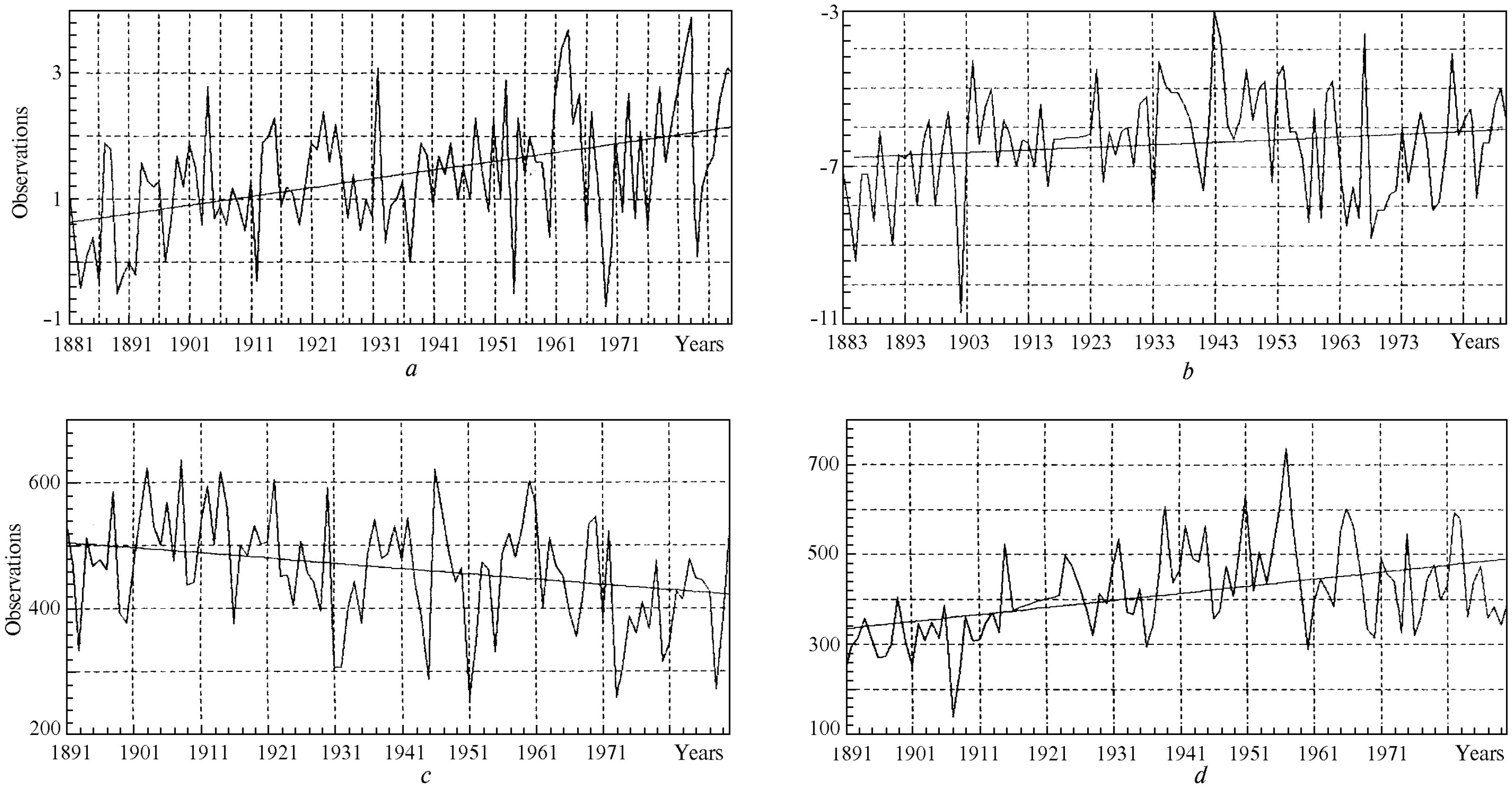

FIG. 1. Variations of climatic characteristics: the average annual temperature in Barnaul (°C) (a); the annual precipitation in Barnaul (mm) (b); the average annual temperature in Salekhard (°C) (c); and the annual precipitation in Salekhard (mm) (d).

noticeable positive tendency is observed in both sites. At the same time, precipitation distribution is much more inhomogeneous. Thus, for the southern part of the examined region (Barnaul) the tendency to the decrease of precipitation is observed. For Salekhard, however, the amount of precipitation increases noticeably. These climatic changes of the precipitation amount are also correlated with the discharge of the Ob' river at these sites.

Thus, these data indicate significant spatial inhomogeneity of a number of climatic characteristics, for example, precipitation and river discharge. To elucidate reasons and mechanisms that determine the distribution, an analysis of climatic system on the level of mathematical modeling is required. Let us consider further some preliminary results obtained in this direction.

3. MATHEMATICAL MODELING OF THE ATMOSPHERIC CLIMATE

The ECSib atmospheric climatic model of the Novosibirsk Computing Center is the modification of a version of the model of the European Center for Medium–Range Weather Forecast (ECMRWF). The program package for parametrization of physical processes on subgrid scales was based on the results published in Refs. 6–8, whereas the dynamic part of the program was fully developed in Novosibirsk.[2,5] In this model the experience of leading specialists of the European Center and Institute of Computing Mathematics of the RAS was taken into account. In so doing, we proceeded from available potentials of our computers.

The model was formulated in terms of σ-system of coordinates and had 15 nonuniformly distributed altitude levels in the troposphere and the lower stratosphere. The *C*-grid of Arakawa with 5×4° resolution was used in the horizontal plane. A finite difference scheme of the second order was used that obeyed the law of potential enstrophy conservation in case of advection of a vortex with a horizontal speed (in the barothropic atmosphere[1,4]).

Special choice of hydrostatic equation approximation permitted us to construct the schemes along the vertical that conserved the angular momentum. Possibility of long-period integration was provided by keeping in the form of differences a number of global invariants for this differential problem (in addition to the above-indicated parameters, they are the mass, energy, and specific humidity). In a statistical sense, this made dynamics of the atmosphere reproduced by the discrete model close to the dynamics of the realistic continuous atmosphere. The scheme of integration of the system of equations over time was based on the semi-implicit scheme.

Horizontal diffusion in the model was considered by using the linear scheme of the fourth order. Calculation of surface fluxes was based on the Monin-Obukhov theory of similarity with the wind and temperature profiles depending on the external parameters and surface fluxes of momentum and heat. Model equations for the fluxes of momentum, heat, and moisture were different for stably and unstably stratified surface layer.

Fluxes above the surface layer were calculated on the basis of the mixing depth theory with the diffusion coefficients specified differently for stable and unstable stratifications. Before calculation of the basic variables in each time step, the convective adaptation was made.

To eliminate negative values of the moisture field that may be caused by truncation errors of the central difference scheme together with the condensation processes we used the scheme that conserved the total moisture content.

Parametrization of convective cloudiness realized in the examined model was based on the Kuo method.[7] The main difference of the employed scheme from the Kuo parametrization was that it considered not only convective clouds caused by air rising from the Earth's surface, but also clouds of higher levels where the moisture convergence also may be observed.

The sea surface temperature was preset. This was done not only for open water, but also for the water surface covered with ice. In case of dry land, a thin layer of soil with the given heat capacity was considered, which exchanged by heat and moisture with the atmosphere and deep soil (active layer of soil). Snow melting was considered every time the snow was present and the dry land temperature increased the temperature of ice melting. Above the sea the air humidity was equal to the saturated humidity at the given temperature. Ground moistening and snow cover were predicted with consideration of precipitation, evaporation, thaw water, and discharges and diffusion of water in soil.

On the basis of this climatic model, the integration over a period of 10 years was made with consideration of the annual behavior of the solar radiation. In the process of integration the zenith angle of the sun was changed as a function of the day of the year. Its diurnal variations were not considered. The average monthly temperature of the underlying surface (ocean) calculated from the AMIP data was used as an external parameter. Evidently, a 10-year period of integration is insufficient for obtaining reliable climatic characteristics; however, definite conclusions can be drawn. In Fig. 2 shown are variabilities of a number of characteristics for the last year of integration (in relative units). Analysis of the results indicates principal spatial inhomogeneity of model characteristics, which is confirmed by the data of field observations presented in the foregoing section and indicates the necessity of detailed consideration of regional peculiarities. At present a new scheme of parametrization of interaction of the atmosphere with the underlying surface has been developed that considers more adequately the components of the hydrological cycle and processes of interaction with the plant cover.

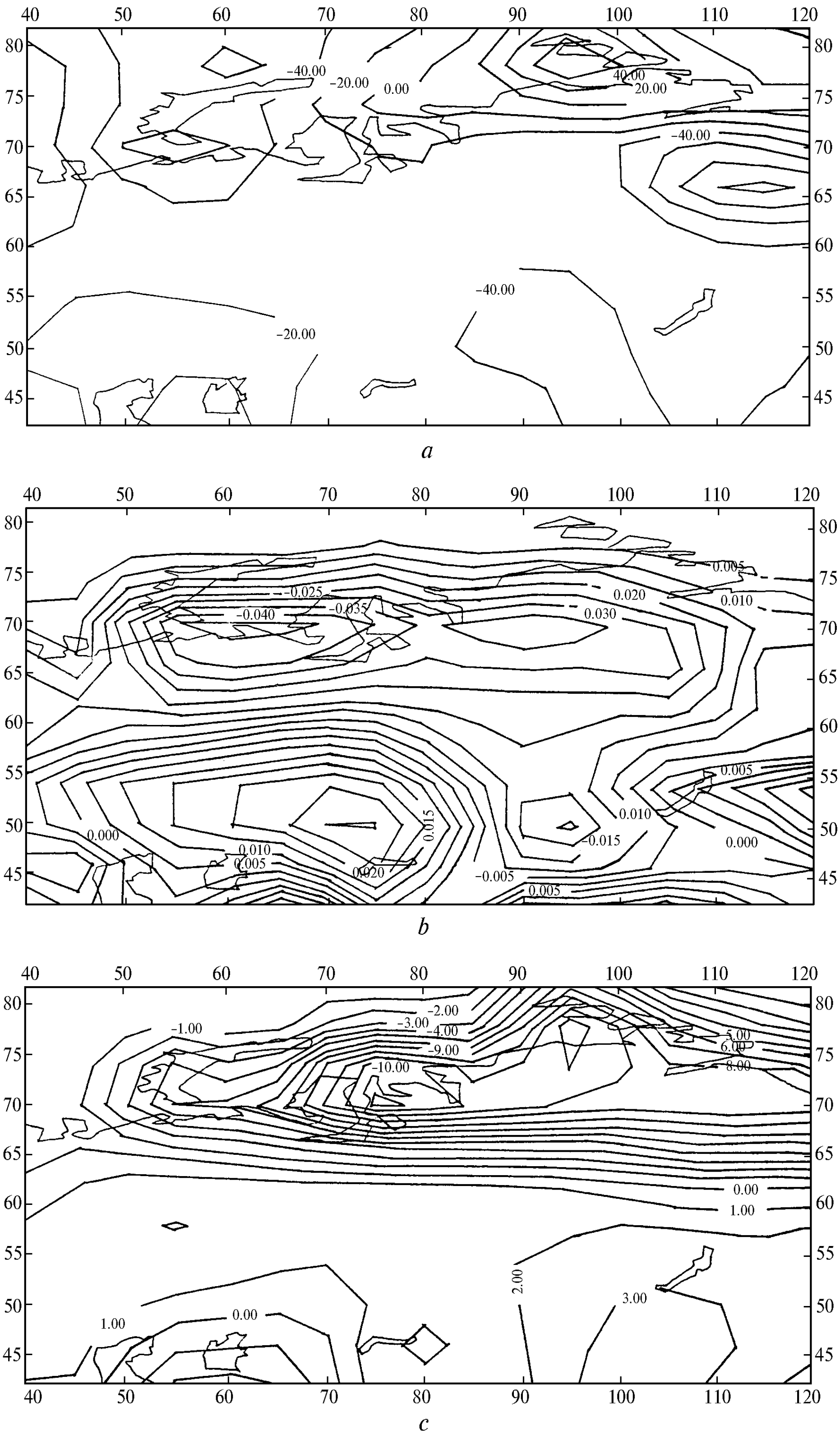

FIG. 2. Variability of hydrometeorological characteristics calculated by integration of the ECSib model: radiation balance (a), ground moistening (b), and temperature (c).

CONCLUSION

Preliminary results of our analysis of hydrometeorological data obtained for the last hundred years indicate significant spatial inhomogeneity of variations in the climatic characteristics even for such limited region as Western Siberia. Among the characteristics is the annual amount of precipitation and so on. These facts are confirmed by the results of numerical modeling on the basis of the ECSib climatic model. The results of calculations indicate unambiguous regional manifestations of global climatic changes for Siberia.

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