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Mathematical modeling of the Siberian regional climate*

A.A. Fomenko and V.N. Krupchatnikoff

The regional model of the atmospheric dynamics is presented. The model is a component of the global climatic model ECSib [1, 2], has the increased spatial resolution and is designed for the reproduction of the climatic atmospheric characteristics on spatial scales not described by the global model. In the model, the processes of interaction with the surface are taken into account in more detail. The surface and active layers of soil take into account the presence of vegetative cover, layer of snow on the surface, processes of heat and moisture transfer in the soil layer, processes of melting of snow on the surface, receipt of moisture into the soil at the expense of the large-scale and convective precipitation, interception of precipitation by the vegetative cover, effects of moisture filtration [3]. Some results of numerical modeling of Siberia climate are presented.

1. Introduction

The global models of general circulation which are now widely used for the modeling of climate, research of the influence of a number of the external factors on climatic variations on various temporal scales, for the study of the reverse influence of the Earth's surface covered with ice or vegetation, etc., have nevertheless a number of restrictions on the applicability. First, because of nonadequacy of the description of subgrid physical processes (cloudiness, precipitation, turbulence flows in the boundary layer, etc.), such factors strongly affect on mesoscale processes. Second, because of the rough resolution of spatial finite-difference grid. Third, because of the rough consideration of features of the Earth's surface (as a rule, this is consequence of the second reason). One of the approaches which allows us to exclude the two last reasons, is modeling of the regional climate. The spatial resolution in the regional models of climate is increased so that it is possible to explicitly describe mesoscale phenomena which are due to the mesoscale specific features of the regional underlying surface. On the lateral borders, as boundary conditions either results of the global analysis of real data or modeling of general circulation of the atmosphere with the help of numerical models are used. Application of the global analysis data is more

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preferable, as in this case the large-scale errors of modeling will be excluded. Probably, the first publication, where the possibility and validity of such an approach were shown, was [4]. The authors have shown that it is possible to improve results of modeling of a regional climate on an example of the USA territory. The idea of regional modeling was further developed [5], and has gained wide recognition in the research of the regional climate of Europe [6, 7] and the Arctic region [8].

In the present paper, when constructing the regional atmospheric dynamics model, the main attention was given to the perfection of physical processes parameterization of subgrid scales, in particular, the processes of the atmosphere and surface interaction. Such a statement of the problem is caused by the interest connected with studying the influence on climate of specific features of the Siberian landscape, such as large forest areas, huge spaces of swamps and tundra. Parameterization of the land surface – atmosphere interaction processes is one of the major parts of development of climatic models. Conditions on the surface (the boundary conditions), as they are, largely determine the quasi-stationary state which we wanted to obtain as a result of numerical modeling.

At the present time, there are many publications dealt with the problem with the description of the parameterization schemes with rather a complete consideration of major aspects of the interaction, in particular [9–12].

In this paper, some results of numerical modeling of the atmospheric dynamics for the Siberian region are presented. The results have been obtained on the basis of the new scheme of the surface parameterization [3] which is an essential extension of the scheme used in the earlier versions of the atmospheric general circulation model and the weather forecast [1, 2].

2. The regional atmospheric model

The regional atmospheric model is a component of the global climatic model ECSib [1]. The results of mathematical modeling of climate on the basis of the global model makes it possible to obtain, on the whole, the qualitatively correct picture of distribution of the basic atmospheric characteristics [2]. However, whereas the global model has the horizontal spatial resolution $5°\times4°$, it does not allow studying a detailed fine structure of regional features. In this connection, the regional atmospheric dynamics model having the spatial resolution $1.66°\times1.25°$ was developed, that in the middle latitudes gives an almost square integration cell with the horizontal resolution about 130 km. The number and disposition of the vertical levels coincide with the global model. The area of integration is the spherical rectangular 40–146.6°E and 40–80°N. The choice of an integration area is caused by the increased interest in the Siberian region.

On the whole, the mathematical realization of the regional model does not practically differ from the global one. The specific feature consists in the necessity to formulate the lateral boundary conditions ensuring its interaction with the global model. As the lateral boundary conditions the values of evolution variables on the area border obtained from the global model with the help of interpolation on a fine grid are set. When integrating, the generation of "parasitic" short waves is possible as a result of false reflection on the border in the area of flowing out. For the solution of this problem, the Davies relaxation method of boundary conditions assimilation is used [13].

3. Parameterization of the basic physical processes

As opposed to the earlier versions of the surface schemes [1, 2], in the present model the new parameterization version of the surface has been developed [3]. This variant of the model combines rather a complete consideration of the physical factors for estimation of effects of the atmosphere – surface interaction. In the present model of the active soil layer, the vegetative cover, the presence of snow on the surface, processes in the upper soil layer are taken into account. The processes of melting, the decrease of moisture on the surface at the expense of its filtration deep into the soil, the surface run-off, the receipt of moisture at the expense of the large-scale and convective precipitation and snow precipitation, interception of precipitation by the vegetative cover are taken into account. At each time step, the surface temperature, temperature of the four soil layers, the turbulence heat flow from the surface, the heat flow into the soil, moisture of the surface, moisture in the upper soil level, the moisture flow from the surface are calculated.

In this model, the one-layer representation of the vegetative cover, which is pulled off into thin sheets near the ground is used. The water content in the upper soil level is determined in terms of precipitation, evaporation, melting processes. A turbulence flow of moisture is calculated on the basis of the moisture data on the surface and nearest computational level. In the model, the total receipt of moisture from the surface layer consisting of the moisture flow from the snow surface, of the turbulence flow of moisture from the vegetative cover, bare surface and transpiration are calculated. The recalculation of the surface temperature and the depth of a snow cover is done with allowance for the heat caused by the melting of snow. At each step, the moisture of the upper soil level, the moisture on the surface, the flowing out on the surface, filtration of moisture deep into the soil are recalculated with the receipt of precipitation and processes of melting taken into account.

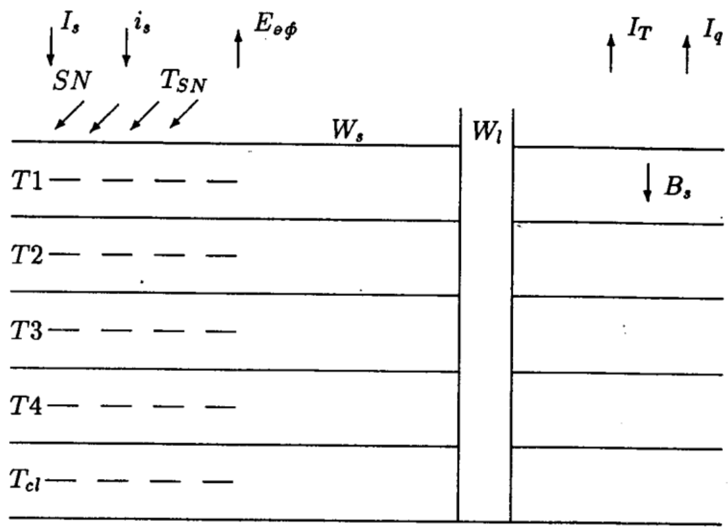

Figure 1. Representation of the soil–vegetation–atmosphere system for the model of the atmosphere – active soil layer interaction

The soil–vegetation–atmosphere system is schematically shown in Figure 1.

Here the external parameters as related to the given system are the following: temperature and moisture of air, speed of wind, precipitation, direct radiation (I_s), scattered radiation (i_s), outgoing radiation (E_{ef}), temperature on the lower layer of the soil (T_{cl}).

The model is described in detail both in terms of mathematical formulas and their realization [3].

4. The results of mathematical modeling

An experiment on the research of sensitivity of the regional atmospheric model to the new parameterization scheme of its interaction with the surface was carried out as follows. First, a quasi-equilibrium climatic state of the atmosphere on the basis of the 10-year integration of the global model with allowance for the annual behavior of the solar radiation was obtained. When integrating, the zenith angle of the Sun daily varied depending on a day of a year. The diurnal behavior of the solar radiation was not taken into account. As input parameters the monthly averaged climatic values of the ocean surface temperature taken from the AMIP data, distribution of ice cover, monthly averaged climatic values of temperature and moisture of soil in the depth were set. In the model, the height of topography, which is characteristic of the given spatial resolution, and the parameter of roughness above the land dependent on the type of the surface, urbanization

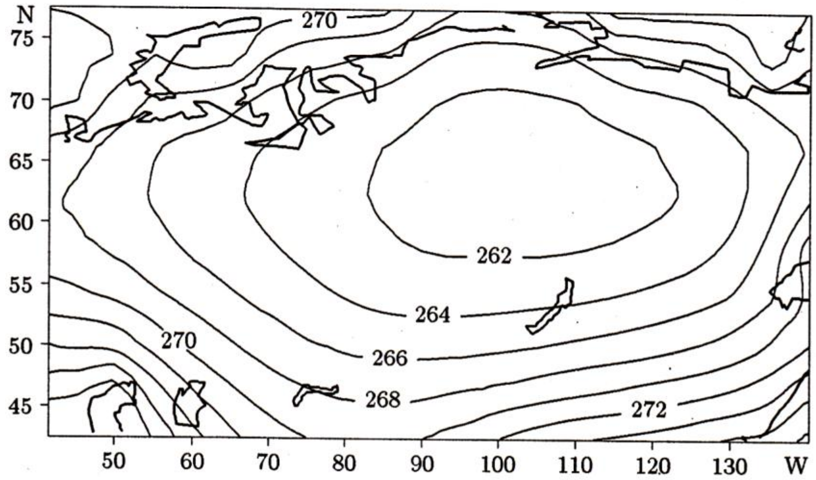

Figure 2. Mean February distribution of the surface temperature (°K), calculated by the global model

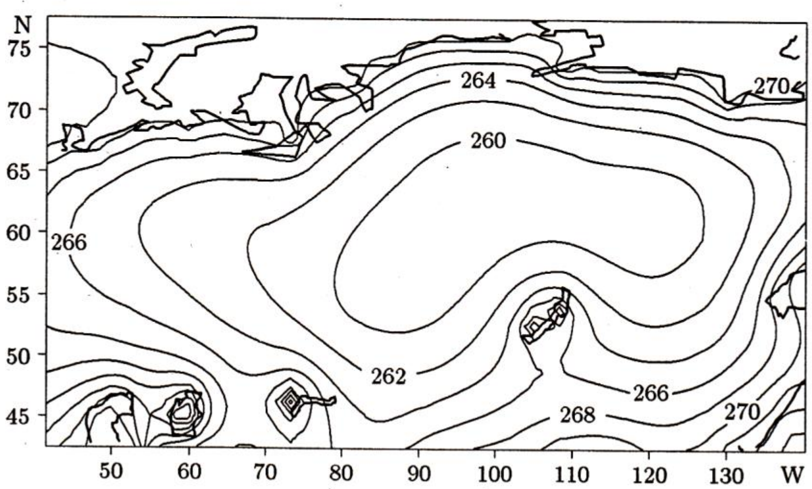

Figure 3. The same as in Figure 2, but for the regional model

and topography are fixed. Values of the surface albedo were dependent on characteristics of the surface and varied in time with their change.

On the basis of the obtained state, the calculations using both the global model and the regional model with the new parameterization scheme for a one year period during the last year of integration were done. All the external parameters for the regional model were taken with allowance for the increased spatial resolution. Some results of modeling are presented in Figures 2–9.

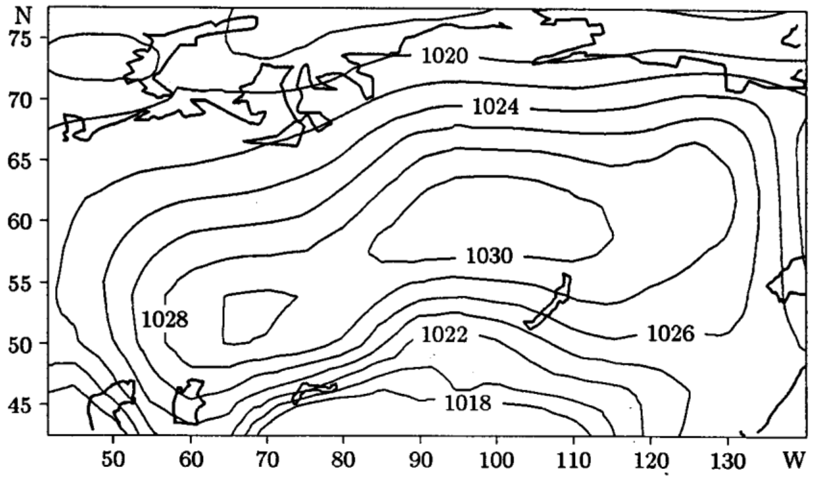

Figure 4. Mean February distribution of the surface pressure (hPa), calculated by the global model

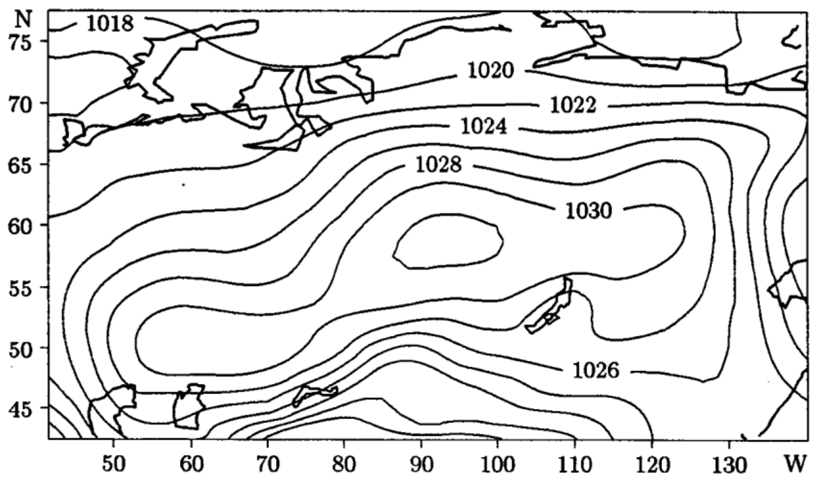

Figure 5. The same as in Figure 4, but for the regional model

The spatial distribution of the calculated characteristics, such as surface temperature, surface pressure, precipitation shows, that the increase of the spatial resolution and the use of advanced parameterization of processes of the interaction of the atmosphere with the Earth's surface allows us to obtain a more detailed picture, in which the regional features are brightly distinct. In particular, in the regional model, the heat zones above the water surface in winter months (Baikal, Balkhash, Aral) are well expressed. It is not observed in the global model, as the given formations are not described with the spatial resolution, used in it (see Figures 2 and 3). It is natural

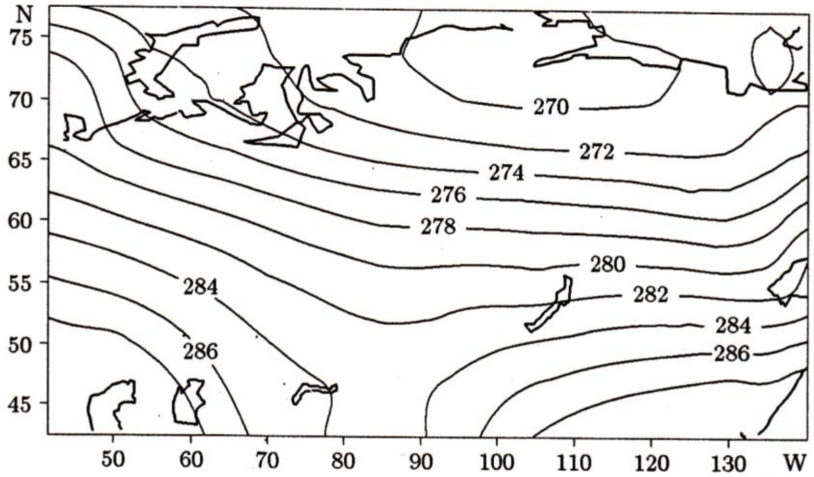

Figure 6. Mean July distribution of the surface temperature (^oK), calculated by the global model

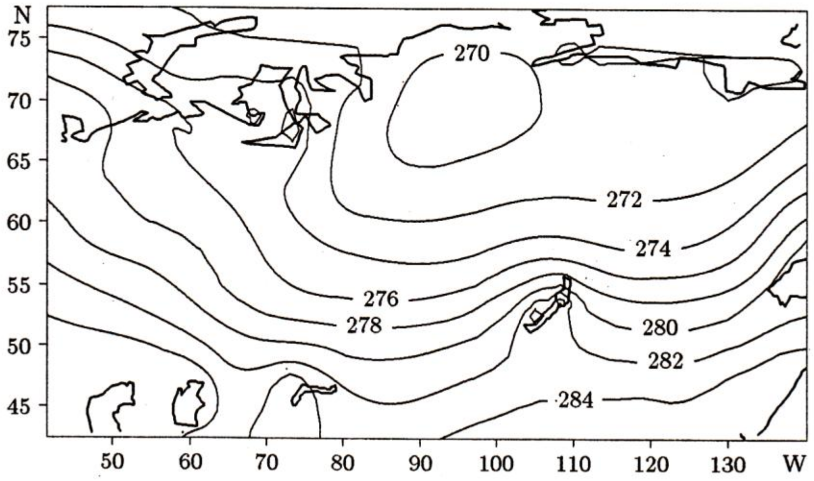

Figure 7. The same as in Figure 6, but for the regional model

that it had an effect on the surface pressure, which has decreased above the areas, in which water pools of the regional scale are located. It, in turn, has resulted in the change of a general picture of distribution of the surface pressure (see Figures 4 and 5).

In summer months, the picture completely changes, as the contrast between the water surface temperature and the temperature of land practically disappears (see Figures 6 and 7). Thus, the difference in reproduction of the surface pressure is caused mainly by the dynamic factors (see Figures 8 and 9). The use of the regional model has allowed us to obtain a finer struc-

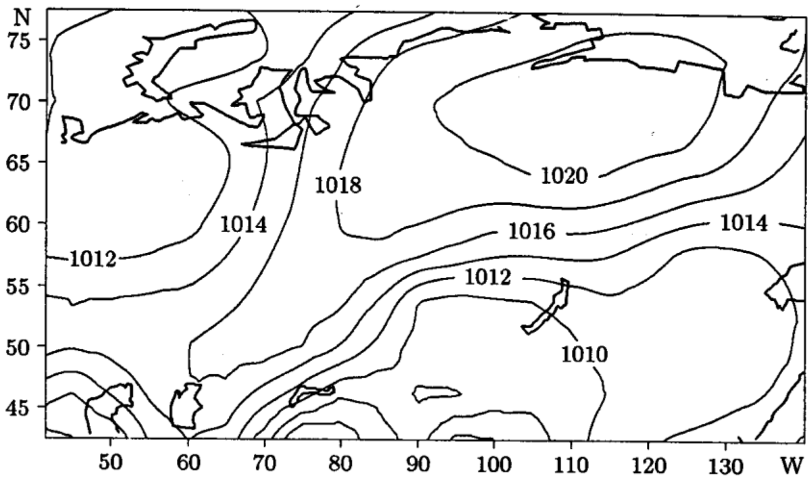

Figure 8. Mean July distribution of the surface pressure (hPa), calculated by the global model

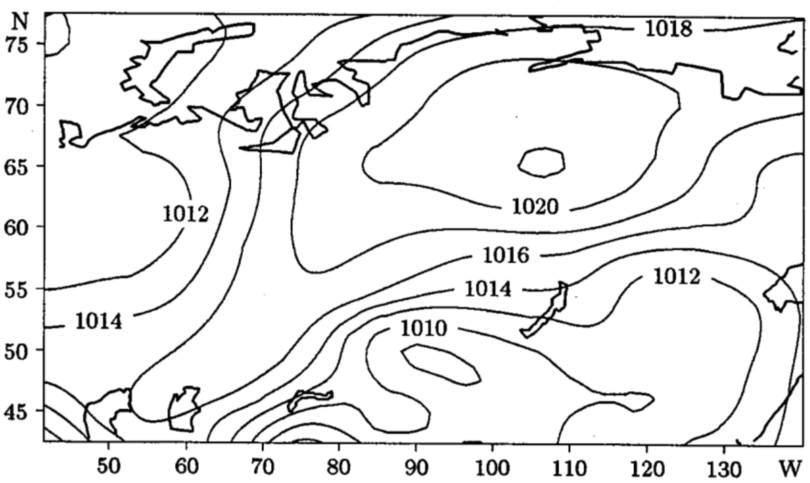

Figure 9. The same as in Figure 8, but for the regional model

ture of distribution of precipitation, soil moisture, sensible and latent flows of heat on the surface, that cannot be attained with the help of the global model. It is, in turn, reflected in the dynamic near the surface characteristics, which show the occurrence of the mesoscale circulation.

5. Concluding remarks

In the presented version of the regional atmospheric model with the advanced scheme of parameterization of the active layer of soil, rather a complete account of the physical factors for estimation of effects of the interaction of the atmosphere with surface has been done. The scheme of parameterization of the heat – moisture transfer in the active layer of soil takes into account the nonlinearity and nonstationarity of these processes, explicitly describes the vegetative cover functions and satisfactorily – the hydrological cycle.

The results obtained in the numerical modeling have allowed us to obtain a finer regional structure of distribution of the considered characteristics. In addition, the use of the new parameterization scheme enables the reproduction of a number of characteristics which were not calculated in the global model, such as temperature and water content of soil, moisture run-off and filtration of moisture in the soil.

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