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Modeling for simulation of the river runoff in the Ob-Irtysh basin*

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Abstract. This paper presents the results of modeling of the river runoff for the Ob-Irtysh basin using the climate runoff model in the XXth and XXIst centuries. This model is a linear reservoir one. The flow of water is divided into the surface runoff, the river flow and the groundwater flow. The model takes into account the influence of marshes and lakes depending on the percentage in a cell. The input data for the model are: precipitation, evaporation, melting of snow and temperature of the surface. For calculation of the discharge in the XXth century the reanalysis data ERA40/ECMWF and MERRA/NASA were used. For verification of the results, the data of the gauging stations on the rivers Irtysh and Ob were used. Possible changes in the hydrological regime of the discharge in the XXIst century are calculated based on the data of the CNRM/France model.

Introduction

The global hydrological cycle in the atmosphere and the ocean plays a critical role in determining the state of the climate on the Earth. This cycle is of paramount importance for the climate of continents, as it is associated with the arrival of moisture on the soil surface. Of special interest are regional characteristics of the hydrological cycle and runoff, in particular, in the Siberian region [1].

This paper deals with the climate model of the river runoff. It discusses the results of the calculations carried out for one and the largest river basin of Asia: the Ob and the Irtysh rivers, covering 2,990 thousands square km. The Ob-Irtysh River system is the longest river system in the world through China, Kazakhstan and Russia. The nature of the water regime significantly changes during a year. The upper values of the runoff begin in April, maximum in April–June, the decline lasts until October. The river flow is regulated. On the Irtysh river, there are several hydroelectric power stations, such as Bukhtarma, Ust-Kamenogorsk, Shulbinskaya just above the city of Pavlodar. The Irtysh water picks up the Irtysh-Karaganda canal flowing to the west. One of the largest tributaries of Irtysh is Tobol. Its runoff is also regulated by hydroelectric stations and water reservoirs such as Karatomar and Verhnetobolskoe. This watershed is of interest in terms of specific features of the hydrological system of Western Siberia, determined

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by extensive marsh areas of the region. Estimates of the annual climatic river runoff have variations in the meanings given in the literature. In [2], on the basis of data from hydrological stations there are given statistical estimates with a standard deviation equal to the value of 397 ± 61 km^3.

The above values of the annual runoff are average over a period of several decades. According to the hydrometeorological measurements [3, 4], the total annual runoff for the period from 1936 to 1990, is undergoing significant interannual variations. Changes range from 25 to 30 %. Apparently, as follows from [5–7], an important role in this variability is played by the interannual climatic variations of the atmospheric circulation and the surface soil characteristics. However, a direct correlation between these processes for the summer and autumn seasons, according to our calculations, does not exceed 0.6 magnitude with a shift in one or in two months. A difference may be related to variations in the influence of evaporation and discharge from wetland systems, which resulted in the river runoff as compared to the average rainfall with coefficient of 0.24 [8, 9].

In this paper, we discuss the results of calculations on the linear reservoir model of the climatic streamflow of the Ob-Irtysh basins using the ECMWF ERA40 reanalysis and the GMAO MERRA data. Possible changes in the hydrological regime of the watershed in the XXIth century are calculated using the data model CNRM/France. The calculation results are compared with the data obtained at the Salekhard gauging station and with those obtained in the upper reaches of the rivers Irtysh and Ob for the second half of the XXth century.

1. The model of climatic river discharge

The developed model is a linear reservoir one. This model is composed of linear reservoir grid cells. This means that the flow from the cell linearly depends on the slope is proportional to the inflow, to the cell and inversely proportional to a distance between the centers of the cells. In the specific implementation of the model, the flow of water in the soil is divided into three components: the surface runoff, the subsurface runoff, the river flow. The surface and the subsurface drains are single cells, and the river runoff is represented as cascades of cells. The number of stages is calculated by the size, inclination and the size of the cell delay factor.

The rate of a change in the flow from a cell or a cascade of cells in the model of a simplest Kalinin–Milyukova version [10–12] is based on solving a sequence of linear ordinary differential equations. A general solution to these equations with zero initial conditions is the Duhamel convolution integral. In a specific implementation of the model, the structure proposed in the Max Planck Institute in Hamburg, Germany [12] is used. For the delay factor for the groundwater flow, a cell is assumed to be constant. Each unit cell model has eight possible directions of the flow in the adjacent cells: four geographic coordinate-wise directions: N, E, S, W, and four diagonal directions: NE, SE, SW, NW, determined by the slope of the bottom topography. In each cell, the percentage of wetlands and lakes is taken into account.

2. Simulation results

In carrying out the numerical experiments with the climatic river runoff model, the resolution of 1/3 degrees in latitude and longitude, respectively, was selected. The orography, obtained with a resolution of $30''$ by interpolation and subjective correction allows one to simulate the fresh water runoff of the major Siberian rivers to the Arctic Ocean. The construction of river areas, surface and subsurface drains was based on the analysis of graphs of the relief drains on the surface and in the river discharge. The data on the surface topography were adjusted to the uniqueness of the direction of the flow from each grid cell. Accounting swamps and lakes was based on an array of the global distribution processing swamps and lakes [13, 14].

The results of model calculations of the climatic river runoff in the basin were obtained with the use of the model described. At the first step, the data on changes in climatic and hydrological characteristics of the basin of the Ob River were analyzed in the second half of the XXth century based on ERA40 reanalysis and MERRA for the periods 1958–2001 and 1980–2011, respectively. For the XXIst century, possible climatic variations were adopted from the results based on the data of the CNRM model (2006–2100) of the IPCC Project. Based on these data, the river runoff for the XXth century and possible changes in the hydrological regime in the XXIst century, the numerical simulation of the interannual variability of the river flow was carried out. The results of calculations as compared to the averaged hydrological data from the hydrological station of the Ob-Salekhard gives a difference in the amplitude for reanalysis: ERA40 is -0.03 %, for MERRA is -0.5 %, and for CNRM is $+4.3$ %.

These spring floods for the Ob River to the mean climatological annual hydrograph for the reanalysis data provide a complete phase coincidence. A difference in the maximum amplitude is: $+0.09$ % for ERA40, $+8.2$ % for MERRA, and -0.25 % for CNRM (Figure 1). The CNRM model gives a less pronounced spring maximum l in phase and this means the appearance of a maximum spread over two months.

To assess the appropriateness of the model for the runoff distribution on the total river basins flow, the made calculations were compared to the data obtained at intermediate gauges Tyumen, Shadrinsk, Sergeevka, Tobolsk, Barnaul, Kamen-na-Obi, Novosibirsk and Belogorie. After introduction of the regulation parameter of the flow at the locations of hydroelectric reservoirs, rather a good agreement with the data of these gauging stations was

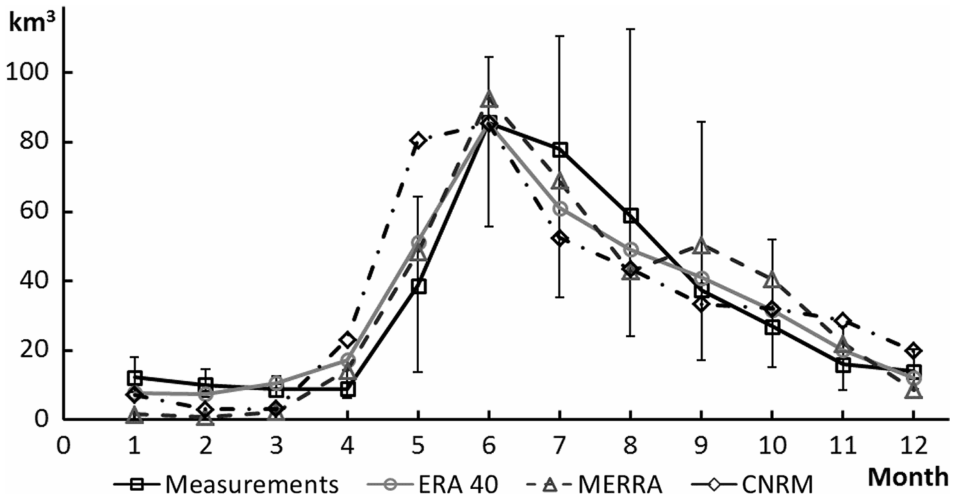

Figure 1. Averaged data at the annual hydrograph gauges Ob-Salekhard. Amplitudes of the interannual variability of monthly runoff are represented by vertical lines

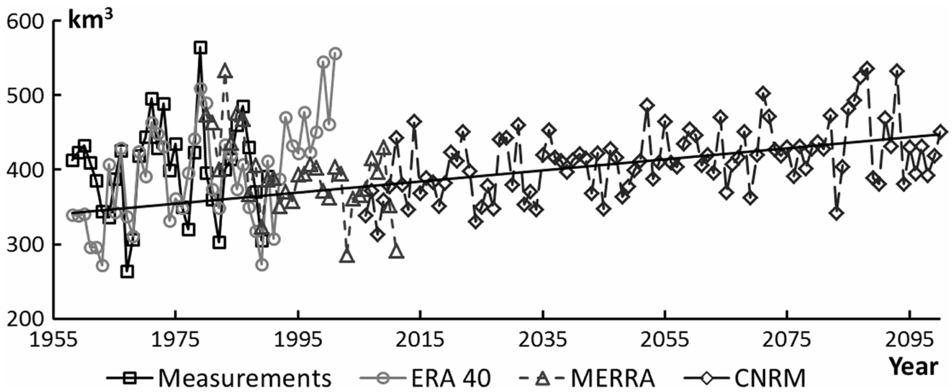

Figure 2. The annual XXth and XXIst centuries runoff of the Ob-Irtysh basin

revealed. For the XXIst century, a slightly increased in the CNRM linear trend of the annual runoff can be observed (Figure 2).

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