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## WATER RESOURCES AND THE REGIME OF WATER BODIES

# Assessing Possible Changes in Selenga R. Water Regime in the XXI Century Based on a Runoff Formation Model

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**Abstract**—The runoff of the Selenga R., the largest tributary of Lake Baikal, in recent two decades corresponds to a low-water period. Such decrease can be due to the global climate processes, which have an effect on the amounts of precipitation onto and evaporation from Selenga drainage basin, which is located in arid climate zone. The adaptation of Ecomag software complex to simulating river runoff in the Selenga Basin based on global databases (relief, soils, vegetation, and weather information) is described. The model was calibrated and verified, and the statistical estimates of calculation efficiency were constructed. The obtained model of runoff formation in the Selenga Basin was used to assess the possible changes in the climate and water regime in the XXI century with the use of data of global climate models under different scenarios of greenhouse gas emissions. Throughout the XXI century, the Selenga R. runoff may decrease by 10–40%, depending on the forecasted climate conditions.

**Keywords:** river runoff, runoff formation model, Selenga, Lake Baikal, water regime variations, CMIP5
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## INTRODUCTION

The Selenga R. is the main tributary of Lake Baikal. Selenga drainage area is 447 thous. km$^2$ (of which, ~2/3 lies in Mongolian territory) or ~80% of Lake Baikal drainage basin; the river is 1024 km long. The location range of the Selenga Basin is 46°–53° N and 96°–113° E. The strongly continental climate over the Selenga Basin determines extremely irregular space and time variations of the precipitation volume. Selenga water regime is of Far-Eastern type. The nourishment of rivers in the basin is mostly by rain in summer; however, the spring flood can be high in some years. The mean annual discharge of the Selenga is 911 m$^3$/s, which is equivalent to the runoff of 28.7 km$^3$/year.

As shown in [6, 23], in the past 70 years, air temperature in the Selenga Basin increased by 1.6–1.8°C, which is twice the growth rate of global air temperature. In these years, several low-water periods were recorded in the Selenga R., e.g., in the 1970s–early 1980s. The following period, up to 1996, showed higher water abundance. The dry period that followed, with water content of the river 23% below the mean value, was a consequence of the general attenuation of circulation in the zone of convergence of air masses of moderate latitudes and East Asian Monsoon [1]. Such cyclicity of the Selenga runoff is governed by the distribution of precipitation over time. However, the present-day dry period lasts for two decades and is likely to continue. Therefore, the assessment of long-term variations of Selenga runoff, a possible implementation of which is given in this study, is of particular importance. Sutyrina [4] mentions an increase in the trend toward a decrease in Selenga water discharges since the second half of the XX century, the precipitation remaining the same. This is attributed to the additional effect of landscape degradation and irrational management of forestry and agriculture. At the same time, estimates in [7] show that more than triple increase in Mongolia population, followed by an increase in urban population from 35 to 68.5%, caused considerable growth in the use of surface water resources.

Several studies into the possible effect of climate changes on the hydrological cycle and water availability in the Central Asian region, including the Selenga Basin, were carried out in the XXI century [16–19, 23, 24]. The study [23] gives estimates of variations in climate and runoff in the Selenga Basin based on calculations of for an ensemble of global climate models in CMIP5 Project (Coupled Model Intercomparison Project Phase 5) [13, 22]. The ensemble runoff of the Selenga R. is shown to slightly increase by the late XXI century. However, it is worth mentioning that these results are based on data of global models, whose efficiency is largely limited by simplifying assumptions regarding river runoff formation processes. The majority of climate models include a description of the hydrological cycle with no regional features of runoff formation taken into account. In this case, the main attention is focused on the evaluation of evaporation, and the runoff is calculated as the difference between precipitation $P$ and evaporation $E$. Such calculation of river runoff may lead to errors far in excess of the possible runoff variations. In addition, runoff estimate as $P–E$ fails to simulate the seasonal features of the annual runoff distribution, associated with the processes of snow accumulation and melting on the watershed [5]. More reliable estimates of climate-induced runoff variations can be derived from a regional model of runoff formation in the Selenga Basin, developed by the authors.

## INPUT DATA FOR THE RUNOFF FORMATION MODEL

Runoff formation in the Selenga Basin was described by a physically based distributed model ECOMAG (Ecological Model for Applied Geophysics), developed in the Water Problems Institute, Russian Academy of Sciences [3, 21]. The ECOMAG software complex, in addition to the physical-mathematical model, contains soil, landscape, and hydrometeorological databases. The runoff formation model takes into account the processes of continental land cycle in accordance with the following scheme. In summer, the precipitation falling as rain partially penetrates into soil. The excess of water not absorbed by soil, after filling the depressions on the land surface in the basin area, flows along surface slope into river network. Part of the moisture penetrated into the soil can move downslope over temporal, relatively impermeable aquicludes. The water that has not reached river network is spent for evaporation or drainage into deeper soil horizons. In the cold season, hydrothermal processes in snow cover and soil are taken into account, including the formation of snow cover and its melting, soil freezing and thawing, and meltwater infiltration into frozen soil.

With a one-day time step and the spatial resolution equal to the size of elementary watersheds, the model calculates the characteristics of snow cover and snow melting, moistening, freezing and thawing of soil, surface (slope), subsurface (within-soil), and subsoil flow, and the motion of water through the channel network. Examples of model application to describe river runoff formation on watersheds of different size (from tens to millions of square kilometers) and with different natural conditions are given in [2, 10, 11, 20].

The boundary conditions in the model are many-year series of daily total precipitation and mean daily air temperature and humidity, which can be derived from the available observational data from hydrometeorological monitoring network and meteorological reanalysis data or calculated by global climate models.

Because of the transboundary location of the Selenga Basin and the irregular distribution of weather stations over its territory, the formation of a single base of source meteorological data, required for the specification of model input data for the period of calibration and verification, was based on the data of global meteorological reanalysis ERA–Interim, developed by the European Center of Medium-Range Weather Forecasts (ECMWF) [8]. The database prepared for the Selenga Basin includes time series of mean daily air temperature and humidity, total daily precipitation, referred to a regular model grid with a spatial resolution of 0.5° × 0.5° over period from 1989 to 2011.

To carry out climate experiments, a database of global climate models was prepared based on ISI-MIP2 Project (Inter-Sectoral Impact Model Intercomparison Project Phase 2). The input data of all models were pre-interpolated onto 0.5° × 0.5° grid, and a bias-correction procedure was implemented for the observation period [12].

The schematization of the Selenga Basin consists in the construction of a model river network and the identification of partial watersheds between river network nodes; the schematization was based on HYDRO1k digital elevation model with a cell size of 30 × 30 s (equivalent to the spatial resolution of 1 × 1 km). An elementary watershed is a calculated unit for simulating a large river basin comprising a set of such watersheds. The total number of the constructed elementary watersheds in the Selenga Basin is 519, and its mean area is 970 $km^2$.

The model parameters distributed all over the basin area were derived from global databases: soil base HWSD (Harmonized World Soil Database) [9] and landscape base GLCC (Global Land Cover Characterization) [15]. For each of the 31 soil types in the Selenga Basin, pedotransfer functions and the data on percent concentrations of sand, clay, gravel, and organic matter were used to calculate the soil-hydrological constants, to be specified as model parameters: volumetric density, porosity, minimal field capacity, welting point, and hydraulic conductivity. For each of the 23 identified landscape types in the Selenga Basin, the following model parameters were determined: factors for the coefficients of vertical hydraulic conductivity and thawing, soil moisture evaporation, and soil freezing.

For the implementation of hydrological calculations by the runoff formation model, a database of hydrological characteristics was prepared, including data on daily water discharges at different hydrometric gages in the Selenga R. Basin (Fig. 1).

## MODEL OF RIVER RUNOFF FORMATION IN SELENGA BASIN

Parameters of the runoff formation model were derived from global database of soil and vegetation

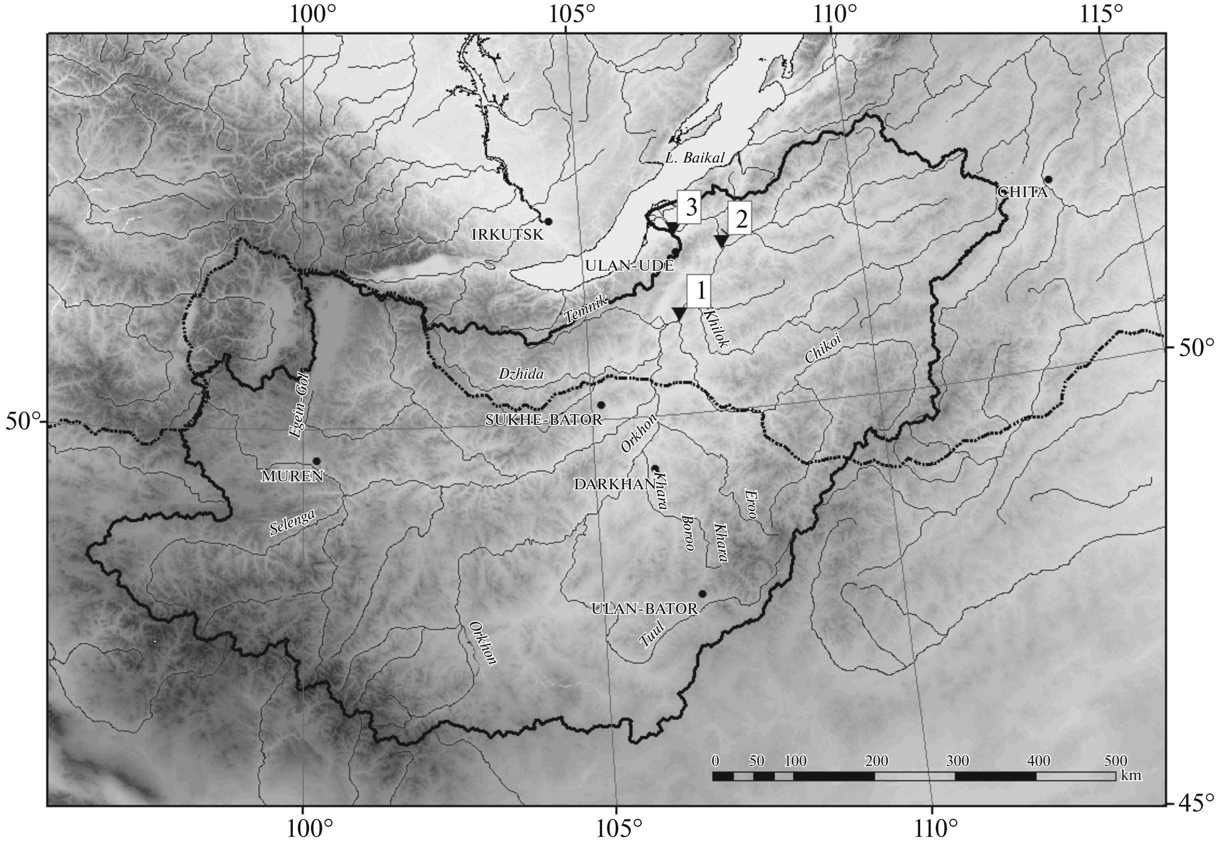

**Fig. 1.** Scheme of the Selenga Basin with the location of gages data from which were used to calibrate the runoff formation model: (1) Novoselenginsk, (2) Mostovoi, (3) Kabansk.

characteristics. Each elementary watershed has a set of soil and landscape types. In the course of model calibration, an adjusting factor is fitted, rather than the absolute values of the parameter for each type of soils and vegetation cover; this allows the initial proportion between the values of a parameter to be kept constant. The calibration of the runoff formation model was carried out with a single set of parameters for the entire Selenga Basin, i.e., the calculations were adjusted for all gages simultaneously, rather than for individual gages.

The model was calibrated against data on mean daily water discharges over a 10-year period from 1991 to 2000. Water discharge from Lake Khubsugul was accounted for with the use of a linear capacity model. The adjustment of model parameters was accompanied by evaluating the quality of water discharge calculations at the gages of Novoselenginsk, Mostovoi, and Kabansk (the outlet gage for the Selenga R.). The model was verified against independent data over period from 2001 to 2010. Figure 2 gives the measured and calculated daily hydrographs at the gages of the Selenga R.

The efficiency of the calculation quality of the Selenga R. water regime was evaluated with the use of Nash–Sutcliffe criterion $NSE$ and bias error $BIAS$ for daily hydrographs. To assess the relationship between the measured and simulated monthly runoff volume, the coefficient of determination $R^2$ was evaluated.

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_f - Q_s\right)^2}{\sum_{i=1}^{n}\left(Q_f - \overline{Q}\right)^2},$$

$$BIAS = \frac{\overline{Q_f} - \overline{Q_s}}{\overline{Q_f}} \times 100\%,$$

where $Q_f$ and $Q_s$ are the measured and calculated value of water discharge on the $i$th day, respectively; $\overline{Q}$ is the mean value of the measured discharges over period $i = 1, 2, 3 \ldots n$.

The results of calculations are considered good at $NSE > 0.7$ and $BIAS < 10\%$, and satisfactory at $NSE > 0.5$ and $BIAS < 15\%$. The statistical estimates of calcu-

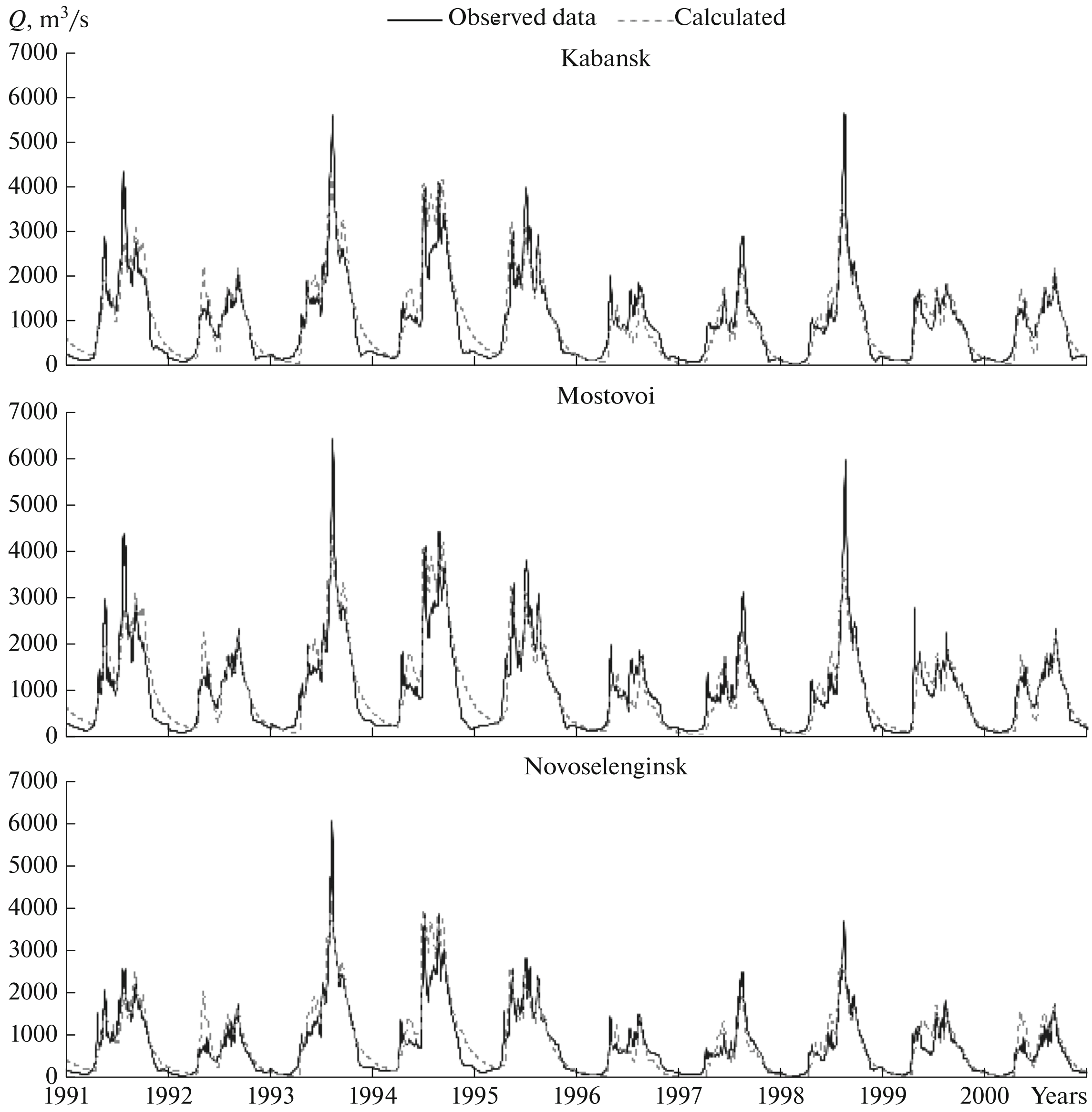

**Fig. 2.** Observed and calculated daily hydrographs at different Selenga gages.

lation efficiency of the daily and monthly runoff in the Amur R. basin are given in Table 1.

Judging by the categories of quality criteria *NSE* and *BIAS* for different gages, the results of daily hydrograph calculation are good. It should be mentioned that the estimation of runoff calculation quality for several gages is a stricter requirement to the model than, for example, its fitting by data on the outlet gage alone. Note also that the simulation for the Selenga gages shows good agreement between the measured and calculated values for both the high-water period up to 1996 and the subsequent low-water period, thus demonstrating the potential of the model for evaluating water resources in the basin under study.

## ASSESSMENT SELENGA RUNOFF VARIATIONS OVER AN ENSEMBLE OF GENERAL ATMOSPHERIC CIRCULATION MODELS OVER THE HISTORICAL PERIOD

A preliminary analysis of Selenga runoff sensitivity to variations in climate parameters with the use of "delta—change" method showed that, the precipitation remaining the same, an increase in the basin-averaged climatic air temperature by 1°C leads to a decrease in the simulated mean annual Selenga runoff by 7% because of an increase in the calculated evaporation from basin surface [14]. Air temperature remaining the same, an increase in the basin-averaged climatic total precipitation by 10% will lead to an

**Table 1.** The values of calculation quality criteria for daily and monthly runoff in the Selenga Basin

| Gage | Drainage area, thous. km$^2$ | Calibration period 1991–2000 | | | Verification period 2001–2010 | | |
|---|---|---|---|---|---|---|---|
| | | day | | month | day | | month |
| | | *NSE* | *BIAS* | $R^2$ | *NSE* | *BIAS* | $R^2$ |
| Novoselenginsk | 360 | 0.82 | 4.5 | 0.89 | 0.66 | −6.1 | 0.79 |
| Mostovoi | 440 | 0.84 | 5.3 | 0.89 | 0.72 | −9.4 | 0.80 |
| Kabansk | 445 | 0.85 | 9.7 | 0.90 | 0.75 | −7.4 | 0.83 |

increase in the simulated mean annual Selenga runoff by 20%, likely, because of the decrease in surface runoff losses caused by additional moistening of the basin.

The hydrological consequences of climate changes in the Selenga Basin were assessed with the use of the results of calculation over an ensemble of global climate models (GCMs—Global Climate Models) from CMIP5. As mentioned above, this study used data of the following global climate models from ISI-MIP2 project: CCSM4, CNRM-CM5, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M. The ensemble of the data over the historic period for the majority of climate models contains data up to 2006; therefore, period 1991–2005 was taken as the basis in calculations.

The reliability of estimates of the future climate is assumed to be determined by the ability of the models to simulate its current state in accordance with the available observation data. With this taken into account, it was of importance to evaluate the accuracy of simulation by the chosen GCMs of the climate characteristics on the Selenga R. watershed, i.e., at a regional scale. Such estimate was calculated with the use of reanalysis data series ERA—Interim of mean daily air temperature and humidity, and precipitation depth over period 1991–2005. For the Selenga Basin, the average long-term air temperature over this period was –4.5°C, the annual precipitation was 190 mm, and air humidity deficit was 1.6 mBar. According to calculations by global climate models, the mean annual air temperature and humidity, and precipitation, averaged over the Selenga Basin and over the historical period, differ from the average long-term values obtained with the use of reanalysis. In the Selenga Basin, GCMs data overestimate the temperature by 2.2°C, annual precipitation by 120 mm, and air humidity deficit, by 0.8 mBar. Therefore, to use GCMs calculation data as input data for the hydrological model, these data were pre-corrected. The correction commonly consisted in minimizing the bias error of GSM-based calculations (the so-called bias-correction procedure) compared with meteorological reanalysis data.

In this study, the series of mean daily values of precipitation and air temperature and humidity, calculated by six GCMs were corrected. To do this, correction factors were introduced in the weather data for precipitation and air humidity deficit (%) and for air temperature (°C) to convert the simulated mean annual values, averaged over Selenga Basin area, to those determined by data of ERA—Interim reanalysis, over the period 1991–2005. The corrected results of calculation by GCMs of the series of mean daily meteorological characteristics were specified as input data for the model of Selenga runoff formation.

The average Selenga annual runoff over 1991–2005 calculated by reanalysis data was 27.9 km$^3$ with an error of determination of 1.6% relative to the observed value. The relative error of river runoff calculation by the data of global climate models averaged 9% (Table 2).

For each individual climate model, its intrinsic bias errors are largely random with respect to ensemble-averaged values, where they compensate one another.

**Table 2.** Results of the calculation of average annual runoff of the Selenga R. at Kabansk gage by data of global climate models over period 1991–2005

| Meteodata | Runoff, km$^3$ | Relative error in runoff calculation, % |
|---|---|---|
| CCSM4 | 24.8 | −9.5 |
| CNRM-CM5 | 28.4 | 3.7 |
| HadGEM2-ES | 25.7 | −6.4 |
| IPSL-CM5A-LR | 23.7 | −13.6 |
| MIROC-ESM-CHEM | 24.5 | −10.6 |
| NorESM1-M | 22.5 | −18.2 |
| Ensemble GCMs | 24.9 | −9.1 |
| Reanalysis ERA–Interim | 27.9 | 1.6 |
| Measurements | 27.4 | |

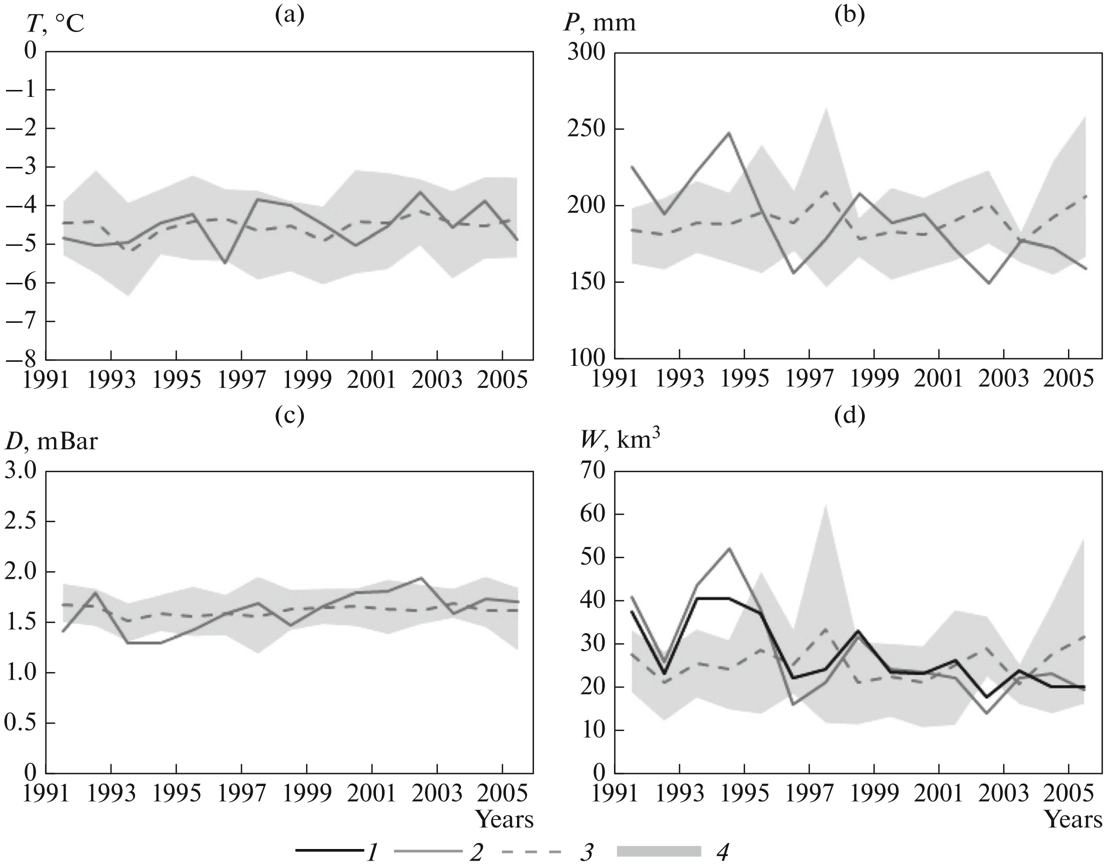

**Fig. 3.** Year-to-year variations of meteocharacteristics averaged over the Selenga Basin ((a) air temperature, (b) total precipitation, (c) air humidity deficit) and (d) river runoff volumes over period 1991–2005: (*1*) observed data, (*2*) ERA–Interim reanalysis data, (*3*) GCMs-ensemble average, (*4*) range of estimates by different GCMs.

Therefore, in the analysis of the quality of model calculations of annual Selenga runoff volumes, we assessed the possibility to simulate the observed trend in the annual Selenga runoff by data of GCMs ensemble. The annual Selenga runoff, calculated by reanalysis data, and the measured runoff show negative trends of 1.6 and 1.2 km$^3$/year, respectively (Fig. 3). Averaging for GCMs ensemble yielded a less pronounced trend of 0.1 km$^3$/year. This difference may be due to the orientation of climate model on the simulation of climate evolution at much longer time scales. Thus, GCMs simulate the mean annual Selenga runoff within the error of its measurements, but they are worse in the simulation of year-to-year variations of river runoff values (Fig. 3).

Thus, it is shown that the method used to assess the possible climate changes in the Selenga Basin with the use of global climate models simulates only the general character of such variations over long periods in the future.

## ASSESSING POSSIBLE CHANGES IN THE CLIMATE AND WATER REGIME IN THE XXI CENTURY UNDER DIFFERENT SCENARIOS OF GREENHOUSE GAS EMISSIONS

Scenario-based calculations of climate-governed changes in Selenga runoff in the XXI century were carried out under different scenarios of changes in the external radiation impacts (RCP-scenarios—Representative Concentration Pathways). In GCMs, the changes in the external parameters expected in the XXI century was specified taking into account the scenario of anthropogenic greenhouse emissions in accordance with the radiation impact level RCP for each of the four scenarios expected for 2010: RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5 (2.6, 4.5, 6.0 and 8.5 W/m$^2$, respectively). Based on six climate models at four RCP scenarios of the future anthropogenic impacts, an ensemble of trajectories of possible changes in meteorological characteristics in the XXI century was obtained with the correction factors

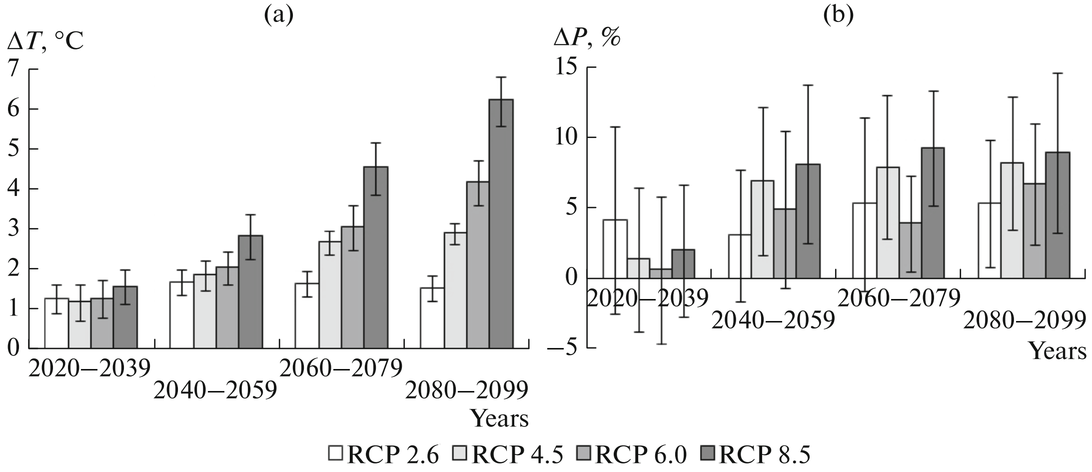

**Fig. 4.** Variations in (a) Selenga basin-averaged mean annual air temperature Δ*T* and (b) annual precipitation Δ*P* for periods of the XXI century under different scenarios of greenhouse gas emission with demonstration of the root-mean-square error of the forecast. The scenarios of greenhouse gas emissions: RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5.

that have been determined for the basic period of 1991–2005.

The climatic characteristics for assessing climate changes were taken to be air temperature and precipitation averaged over the Selenga Basin. As the result, estimated the anomalies of air temperature (°C) and precipitation (%) as relative deviations from the value estimated over the historical period of 1991–2005. Calculated climate projections under different RCP-scenarios were used to average the anomalies of meteorological characteristics over four individual twenty-year periods of the XXI century: 2020–2039, 2040–2059, 2060–2079, and 2080–2099. Figure 4 gives plots of the anomalies of the Selenga Basin-averaged mean annual air temperature in the XXI century for different scenarios of anthropogenic impact with the specification of the root-mean-square error (RMSE) of the forecast. To do this, the results of ensemble calculations were pre-averaged over each scenario.

The trend in the anomaly of the mean annual air temperature in the Selenga Basin in the XXI century under different scenarios was 1 for RCP 2.6, 2.5 for RCP 4.5, 4 for RCP 6.0, and 6°C/100 years for RCP 8.5. In the analysis of air temperature averaged over twenty-year periods, it was found that the scenario RCP 2.6 shows an increase in air temperature in the first half of the XXI century, followed by its minor drop to the end of the century. The scenario RCP 4.5 shows a decrease in the rate of warming in the last third of the XXI century up to its cessation, while the scenarios RCP 6.0 and RCP 8.5 show a steady temperature rise at different rate during the century (Fig. 4). The obtained estimates of air temperature changes in the Selenga Basin during the XXI century are in excess of the RMSE value for the forecasts under all scenarios of radiation impact. A common feature of all scenarios in what regards changes in precipitation is an increase in the wetness of the Selenga Basin during the XXI century. The trend in the anomaly of the annual precipitation under different scenarios was 5 for RCP 2.6, 8 for RCP 4.5, 7 for RCP 6.0, and 12%/100 years for RCP 8.5. In this case, changes in precipitation by more than 5% was predicted for the second half of the XXI century. The calculated values of changes in the amount of precipitation in the Selenga Basin during the second half of the XXI century are in excess of the values of RMSE of the forecast for the radiation impact scenarios RCP 4.5, RCP 6.0, RCP 8.5.

The model of runoff formation in the Selenga Basin, with meteorological characteristics calculated by GCMs under some RCP-scenario used as inputs, were used to calculate an ensemble of many-year runoff hydrographs, corresponding to these climatic trajectories. Next, data of each GCM were used to evaluate Selenga runoff anomalies relative to the average long-term runoff over the reference period of 1991–2005. Under RCP 2.6 scenario, the anomalies of the annual runoff of the Selenga showed a positive trend of 5%/100 years, while under other scenarios, they showed a negative trend of –11 for RCP 4.5, –28 for RCP 6.0, and –45%/100 years under RCP 8.5.

The analysis of Selenga runoff dynamics, averaged over twenty-year periods showed that, under scenario RCP 2.6, in period 2020–2039, an increase in the runoff relative to the reference period can take place, followed by a small drop with a subsequent increase in the late XXI century (Fig. 5). Under scenario RCP 4.5, a gradual decrease in Selenga runoff is likely with a positive trend only in period 2040–2059. Under scenarios RCP 6.0 and RCP 8.5, Selenga water content can be decreasing throughout the century with a rate

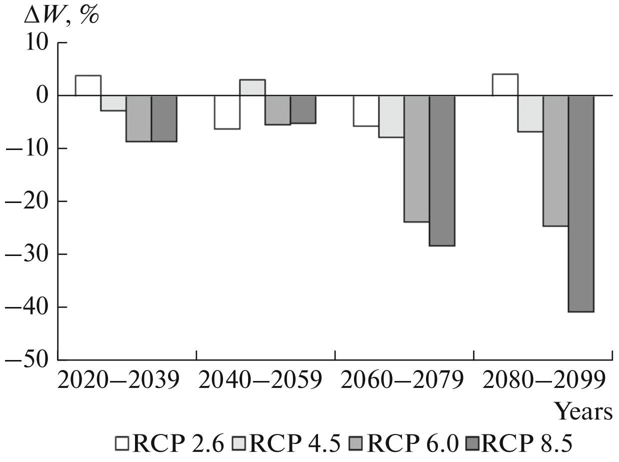

**Fig. 5.** Variations of the average Selenga long-term runoff $\Delta W$, %, over periods in the XXI century under scenarios of greenhouse gas emissions.

especially distinct in its second half. The results of calculations of changes in Selenga runoff by individual models and scenarios of anthropogenic impact, along with a forecast of RMSE, are given in Table 3.

## CONCLUSIONS

Global databases of the characteristics of soils, vegetation, and weather information were used to develop a regional model of river runoff formation for the entire Selenga R. basin. The model simulates the observed daily runoff hydrographs over a many-year period with an acceptable accuracy. The potentialities of the regional runoff formation model are examined as applied to assessing many-year characteristics of Selenga water regime over the observation period with results of ensemble calculations of global climate models used as input data.

The hydrological model of the Selenga Basin was used to assess the possible changes in many-year characteristics of river water regime in the XXI century with the use of ensembles of climate projections, calculated by global climate models under different scenarios of radiation impact. An increase in air temperature by 1–6°C and in precipitation by 5–12%, can take place in the Selenga Basin, depending on the future scenarios of anthropogenic impacts. Such changes in climate characteristics in the Selenga Basin in the XXI century are shown to lead to a decrease in water content almost throughout the century whatever the scenario of greenhouse gas emissions. Such decrease will

**Table 3.** Variations of average annual runoff, %, of the Selenga by periods of the XXI century under different scenarios of greenhouse gas emissions

| Period, years | RCP | CCSM4 | CNRM-CM5 | HadGEM2-ES | IPSL-CM5A-LR | MIROC-ESM-CHEM | NorESM1-M | Ensemble GCMs | RMSE for ensemble GCMs |
|---|---|---|---|---|---|---|---|---|---|
| 2020–2039 | 2.6 | – | 1.7 | 11.9 | –0.2 | –2.6 | 7.0 | 3.6 | 19.5 |
| | 4.5 | 1.9 | 4.9 | 2.9 | –23.8 | –2.8 | –1.6 | –3.1 | 15.5 |
| | 6.0 | – | – | –2.3 | –16.0 | –14.0 | –3.3 | –8.9 | 12.8 |
| | 8.5 | –3.7 | – | –22.3 | –8.6 | –2.8 | –7.1 | –8.9 | 10.2 |
| 2040–2059 | 2.6 | – | –12.8 | –18.5 | –10.1 | –0.1 | 8.9 | –6.5 | 14.5 |
| | 4.5 | –2.1 | 19.5 | 4.8 | –8.0 | –11.4 | 14.9 | 3.0 | 15.8 |
| | 6.0 | – | – | –4.2 | –10.4 | –7.8 | 0.1 | –5.6 | 11.5 |
| | 8.5 | 9.0 | – | –20.1 | –8.8 | –17.0 | 10.0 | –5.4 | 16.0 |
| 2060–2079 | 2.6 | – | 18.6 | –12.1 | –12.5 | –14.0 | –9.1 | –5.8 | 17.8 |
| | 4.5 | –13.1 | 6.3 | –7.7 | –21.2 | –11.6 | –1.8 | –8.2 | 13.6 |
| | 6.0 | – | – | –23.9 | –26.6 | –35.3 | –10.5 | –24.1 | 8.5 |
| | 8.5 | –16.0 | – | –21.7 | –29.9 | –39.7 | –35.7 | –28.6 | 14.9 |
| 2080–2099 | 2.6 | – | –3.6 | 30.0 | –1.0 | –23.5 | 17.1 | 3.8 | 15.6 |
| | 4.5 | –6.0 | 15.7 | –31.5 | –10.2 | –14.0 | 4.6 | –6.9 | 12.3 |
| | 6.0 | – | – | –23.0 | –31.8 | –19.8 | –24.5 | –24.8 | 10.9 |
| | 8.5 | –46.9 | – | –41.6 | –42.8 | –45.4 | –27.6 | –40.8 | 9.3 |

be especially pronounced in the second half of the century under scenarios RCP 6.0 and RCP 8.5, when the expected values of runoff decrease by 20–40% relative to the historic period are greater than the root-mean-square error over the ensemble of global climate models.

The method used in this study allows one to assess the possible effect of global anthropogenic changes in the climate on regional river runoff in a basin. Note that local anthropogenic interventions, such as large-scale hydroengineering construction, can have an additional adverse effect on the river system.

## ACKNOWLEDGMENTS

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