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Assessment of river flow future changes in the Upper Volga and Kama basins based on climate modeling data

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Abstract. The ongoing climate changes affect water resources and the water bodies' regime. This is reflected in the water management complex operation. Analysis of possible hydrological changes in the Upper Volga and Kama basins in the 21st century is based on projections of future climate in the ensemble of atmospheric and oceanic general circulation models (AGOGS) of the CMIP6 project (Coupled Model Intercomparison Project). Models were selected according to the reliability of regional climate reproduction. An assessment of possible changes in the annual average river flow in the 21st century for five reservoir basins of the Upper Volga and three Kama reservoirs basins was made. The assessment was carried out according to two scenarios - optimistic and pessimistic, which provides a wide range of assessments of future changes. It is shown during the 21st century no fundamental changes in river flow are expected in the study areas.

The problem of assessing and forecasting the characteristics of river flow over a period of several decades has always been one of the most pressing in scientific hydrology, since it is directly related to solving the most important problems water supply planning for the population and the economy, justifying large-scale water management measures and the practice of hydraulic engineering design. The ongoing climate changes have caused changes in river flow. In general, there have been significant changes in annual and maximum water flows for the territory of Russia in recent decades. In the European part of Russia, changes occurred in the mid-1970s – mid-1980s [1].

In the 20th century, methods for assessing hydrological characteristics were developed and successfully applied, based on the hypothesis of stationarity of hydroclimatic conditions for the river flow formation in the past and in the foreseeable future on a scale of several decades. So as a basis for predicting the natural (not changed by economic activity) hydrological regime for the coming decades, the statistical characteristics of river flow are transferred to the future period for water management operation systems and hydraulic structures.

Currently, the validity of the stationarity of long-term fluctuations in the hydrological conditions of river flow formation concept is called into question due to of global warming that intensified in the last quarter of the 20th century. Quantitative assessment of climatic

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changes in river flow is of particular relevance against the background of the existing and increasing shortage of water resources taking into account the reliability of the occurred warming and the high probability of its continuation during the 21st century. Such assessments is also important for the ecological state of water systems control in areas of intensive water consumption and increased anthropogenic load, which include large part of the European territory of Russia.

Global climate modeling is the main tool for long-term forecasting of climate and water balance characteristics in modern scientific practice. This work forecast estimates are based on the climate modeling results under the auspices of the World Climate Research Program (WCRP) [2]. according to the CMIP6 project (Coupled Model Intercomparison Project 6). This is an intercomparison project of coupled atmospheric-ocean general circulation models that combines global climate modeling results from different countries. Based on AOGCM data, changes in the flow rate were assessed for the basins of 5 reservoirs of the Upper Volga and Kama. Possible risks for the water sector in the study area conclusions can be drawn on these assessments.

To assess changes in runoff and its characteristics, we used data from general circulation models of the atmosphere and ocean from an ensemble of models selected earlier [3]. An ensemble of 9 models was selected: FGOALS-f3-L, GISS-E2-2-H, CESM2, BCC-CSM2-MR, E3SM-1-1-ECA, BCC-ESM1, NorESM2-MM, CESM2-WACCM, FIO-ESM-2-0, however, in this work the assessment is based on 4 models that had sufficient data sets and high quality reproduction of the studied characteristics. These are models BCC-CSM2-MR, CESM2-WACCM, FGOALS-f3-L, FIO-ESM-2-0.

The period 1985-2014 was considered as the base period. As forecasts, there are two 20-year periods, conditionally characterizing the conditions of the “middle” of the 21st century 2041-2060 and the “end” of the 21st century – 2081-2100. Periods of this length were chosen because climate models characterize changes in long-term average characteristics.

A feature of climate modeling, shown earlier in [4,5], is that the output of general circulation models for different periods is highly correlated with each other (Fig. 1). This suggests that the errors discovered during the assessment of the reproduction of the characteristics of the modern climate will be largely inherited in the forecast periods. Therefore, in a forecast, when operating with relative values, it is possible to partially or completely eliminate the mentioned systematic biases and minimize individual errors. For example, $K_{y\ 2050}$ is the relative change in the model values of the runoff rate in the period 2041-2060 relative to the model values of the base period:

$$K_{y2050}=Y_{2050}/Y_{баз} \quad (1)$$

In follows, we analyze only the relative change in values.

Change estimates are carried out for two ScenarioMIP scenarios, SSP (shared socio-economic pathways): of four combinations that cover, given the level of radiative forcing, approximately the same range as that used for CMIP5.

This scenario SSP1 -2.6: sustainable and green path describes an increasingly sustainable world. The global commons are preserved, the boundaries of nature are respected. The focus is more on human well-being than on economic growth. Income inequality between and within states is declining. Consumption is focused on minimizing the consumption of material resources and energy.

And the most “pessimistic” scenario SSP5 – 8.5: fossil fuel development. Global markets are becoming increasingly integrated, leading to innovation and technological advancement. However, social and economic development is based on the increased exploitation of fossil fuel resources with a high percentage of coal and energy-intensive lifestyles throughout the world. The global economy is growing and local environmental problems such as air pollution are being successfully addressed [6].

These scenarios can be assessed as a kind of range of possible changes, an “above and below” assessment.

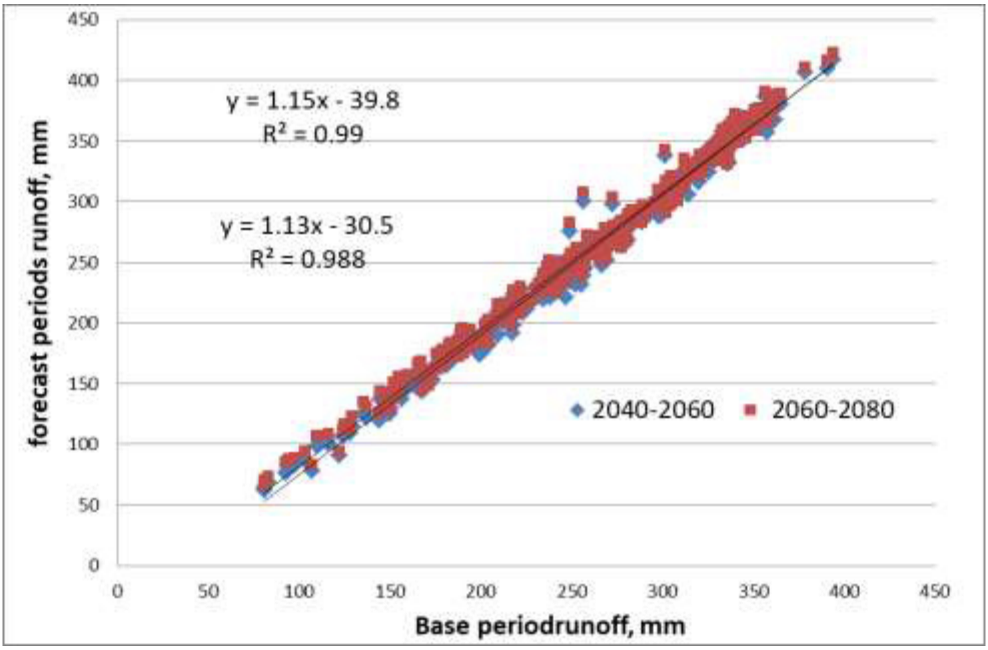

Fig. 1 Correlation of annual runoff fields for the base and forecast periods (calculation using an ensemble of 5 models).

The climate models output includes two variables characterizing river flow: total river flow (total runoff flux, *mrro*) and surface runoff (surface runoff flux, *mrros*) (by the data from https://data.ceda.ac.uk/badc/ cmip6/data). In [7], the authors tested the average long-term river flow reproduction using AOGCM data. It was found the data for the *mrros* variable (surface runoff flux, surface runoff) are significantly underestimated, which is consistent with the data given in [8]. Therefore, the work investigated the *mrro* (total runoff) variable, which also includes the underground component. However, for studies of long-term (climatic) runoff, this variable is suitable as a long-term component of the territory water balance.

The results of annual awerage runoff estimating of the Upper Volga and Kama reservoir basins based on an experiment with an ensemble of 4 models are generally consistent with the work of most authors who conducted studies of possible changes in runoff based on AOGCM implementations for these CMIP 3-5 projects [9-11]. No articles have yet been published for this territory according to the CMIP 6 project. The data obtained are also consistent with the authors’ research for this territory on previous CMIP projects [7].

The significance of the results was determined by comparing the predicted change with the error in estimating the average long-term runoff taking into account autoregression. Assuming that the modern period is stationary and described by a simple Markov chain, it is necessary to compare the change with the quantity:

$$\varepsilon = \frac{Cv}{\sqrt{n}} \frac{(1+r_1)}{(1-r_1)}, \tag{2}$$

where n is the length of the series (35 years), r_1 – autocorrelation coefficient.

Autocorrelation coefficient (correlation coefficient between the runoff of adjacent series members), characterizing the moisture passing from year to year in river basins. For most sections of the Upper Volga basin, the autocorrelation coefficient was 0.25 – 0.30.

[12](WGH explosive), for the Kama basin 0.25-0.45 [13](WGH). The significance calculation was carried out for the value of 0.14, determined from the AOGCM data. Series of annual runoff at grid points of 0.5×0.5 degrees of the base period were used. Climate models underestimate spatial and temporal variations in characteristics, so the autocorrelation coefficient range of 0.1-0.5 was tested - a difference of about 8% of grid points changes significance.

According to the RCP 2.6 scenario, by the middle of the 21st century. in the northern part of the Upper Volga basin, relative changes in runoff (Ku) are small (less than 10%). An increase in precipitation in a given area, compensates for the increase in evaporation. The southern parts of the study areas show a statistically insignificant decrease in flow. By the end of the century, both multidirectional trends in changes in the average long-term runoff are slightly increasing. Weighted average changes for reservoir basins are given in Table 1 and show that noticeable changes in the flow rate under scenario 2.6 are not expected by the end of the 21st century.

According to the RCP 2.6 scenario, the territorial distribution of trends remains: for the basins of the Upper Volga reservoirs (Ivankovskoye, Rybinsk, Uglichskoye), an increase in the flow rate is possible, which intensifies by the end of the 21st century, and for the basin of the Cheboksary Reservoir. a decrease in the flow rate is expected, also increasing towards the end of the century (Fig. 2, 3). The significance of the changes is increasing by the end of the 21st century and covers almost all the studied basins.

The work assessed possible changes in the average long-term river flow for the Upper Volga and Kama basins in the 21st century. Analysis of calculations for ensemble 4 AOGCMs showed that the annual runoff remains virtually unchanged in the 21st century in the study area. Both scenarios show minor changes for the study area, which is confirmed by the authors' previous estimates based on the previous release of AOGCM (CMIP-5) [7]. Changes similar in sign and significance for this territory are given in the review of river flow forecasts for the territory of Russia [14].

Table 1. Weighted average relative changes in the average annual river runoff as a share of the modern change for reservoir basins.

Pool area	**RCP 2.6 scenario**		**RCP 8.5 scenario**	
	2041-2060	**2081-2100**	**2041-2060**	**2081-2100**
Cheboksary Reservoir	0.99	0.96	0.97	0.95
Ivankovskoye Reservoir	0.96	1.01	1.05	1.11
Kama Reservoir	0.98	0.95	0.97	0.94
Nizhnekamsk reservoir	0.95	1.00	0.91	0.91
Rybinsk Reservoir	1.00	1.01	1.07	1.11
Uglich Reservoir	0.96	1.02	1.04	1.12
Votkinsk Reservoir	0.98	0.95	0.95	0.94
Gorky Reservoir	1.00	0.94	1.07	1.08

Changes of more than 10% are shown in color.

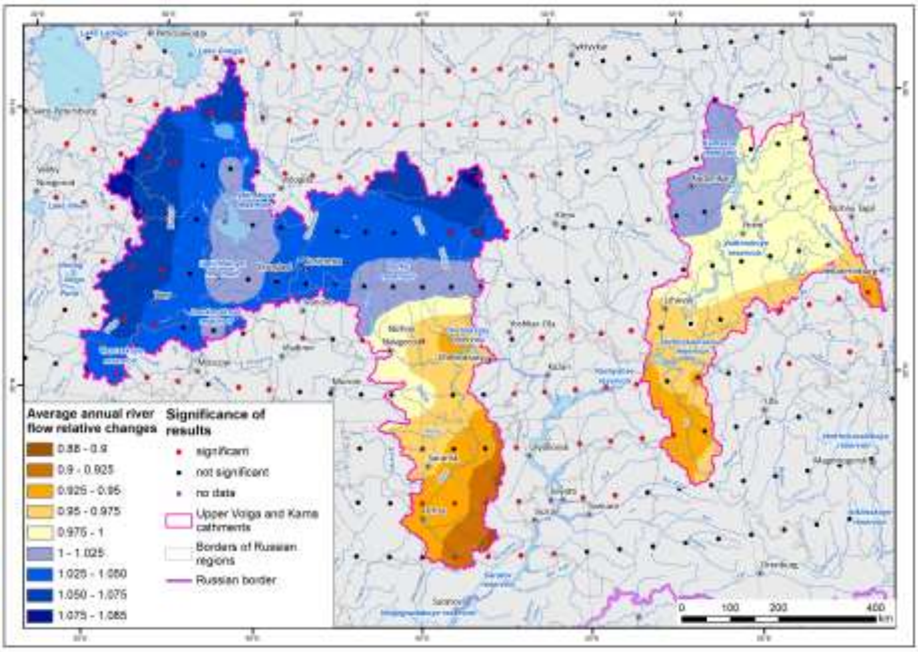

Fig.2 Relative changes in average long-term river flow in shares of modern ones, taking into account the level of significance (RCP 8.5), period 2041-2060. Red dots indicate a grid point with a significant change.

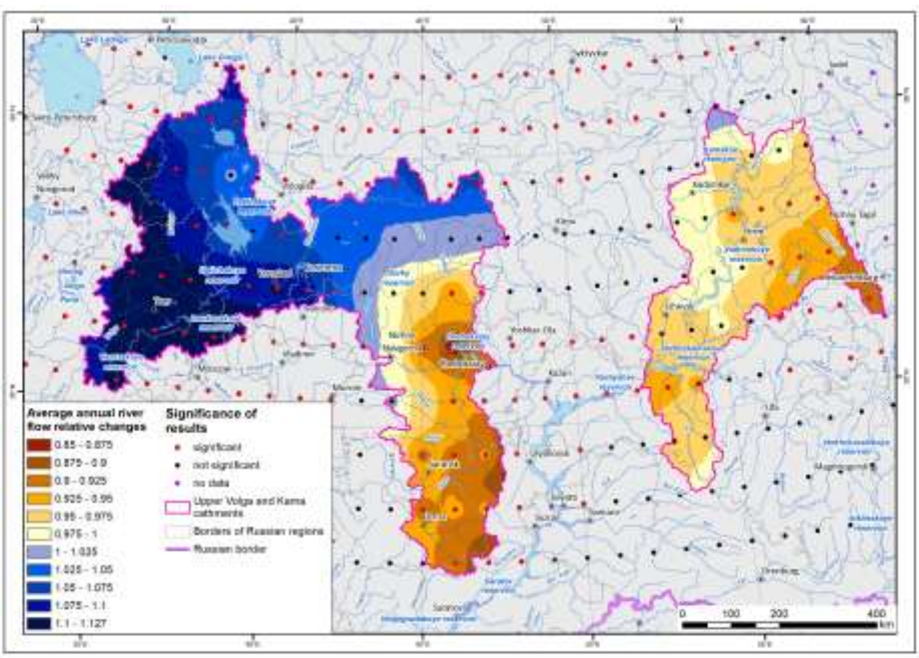

Fig.3 Relative changes in average long-term river flow in shares of modern ones, taking into account the level of significance (RCP 8.5), period 2080-2100. Red dots indicate grid points with significant change.

Such changes must be taken into account in the water sectors strategic planning, multi-year and annual reservoirs regulation projects and other water use projects.

Worth noting the estimates shown provide estimates of responses to a very broad range of climate change. It can be assumed that during the 21st century, no fundamental changes in the water regime and moisture conditions are expected in the study areas, which allows the use of models and forecasting techniques based on data from the modern period.

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References

1. N.L. .Frolova, D.V. Magritsky, M.B. Kireeva, V.Yu. Grigoriev, A.N. Gelfan, A.A.,Sazonov, A.I. Shevchenko, Water Resources, **49(3)**, 251-269 (2022)
2. K.E. Taylor, R.J. Stouffer, G.A. Meehl, Bulletin of the American Meteorological Society, **93**(**4**), 485-498 (2012)
3. M. Sidorova, M. Alieva, E. Shtol, A. Oderkova, S. Yasinsky, E3S WoC, **407**, 02011 (2023)
4. M.V. Sidorova, E.A. Kashutina. E.A. Cherenkova, *Water Resource Planning, Development and Management*, 1-34 (Nova Science Publishers Inc., US, 2020).
5. V.M. Evstigneev, A.V. Kislov, M.V. Sidorova, Vest. Moscow State University. Ser. 5. eography, **2**, 3-10 (2010)
6. B.C. O'Neill, C.,Tebaldivan, D. P. Vuuren, V. Eyring, P. Friedlingstein, G. Hurtt, R. Knutti, E. Kriegler, J.-F. Lamarque, J. Lowe, G.A. Meehl, R. Moss, K. Riahi, and B.M. Sanderson, Geosci. Model Dev., **9**, 3461–3482 (2016)
7. M.V. Sidorova, E.A. Kashutina, E.A. Cherenkova *Collection Questions of Geography of the Russian Geographical Society. №157 Water problems and their solutions* (Media press, Moscow, 2023)
8. M.V. Georgievsky O.F. Golovanov, Vestn. St. Petersburg University. Geosciences? **64(2)**, 206-218 (2019)
9. V.M. Kattsov, V.A. Govorkova, Proc. GGO, **569**, 75-97 (2013)
10. 1A.V. Frolov, *VII Hydrol. congress St. Petersburg, November 19–21, 2013. Abstracts of plenary reports*, 1-5 (St. Petersburg, 2013)
11. 1I.M. Shkolnik, V.P. Meleshko, I.L. Karol, A.A. Kiselev, E.D. Nadezhina,V.A. Govorkova, T.V. Pavlova, Tr. GGO im. AI Voeykova, **575**, 65-118 (2014)
12. Georgievsky V.Yu (eds), *Scientific and applied reference book: Basic hydrological characteristics of the rivers of the Upper Volga basin* [Electronic resource] (Livny: Publisher G.V. Mukhametov, 2015)
13. Georgievsky V.Yu (eds), *Scientific and applied reference book: Basic hydrological characteristics of the rivers of the Kama basin* [Electronic resource] (Livny: Publisher G.V. Mukhametov, 2015)
14. A.N. Gelfan, E.M. Gusev, A.S. Kalugin, I.N. Krylenko, Yu.G. Motovilov, O.N. Nasonova, N.L., Frolova, Water Resources, **49(3)**, 270 (2022)