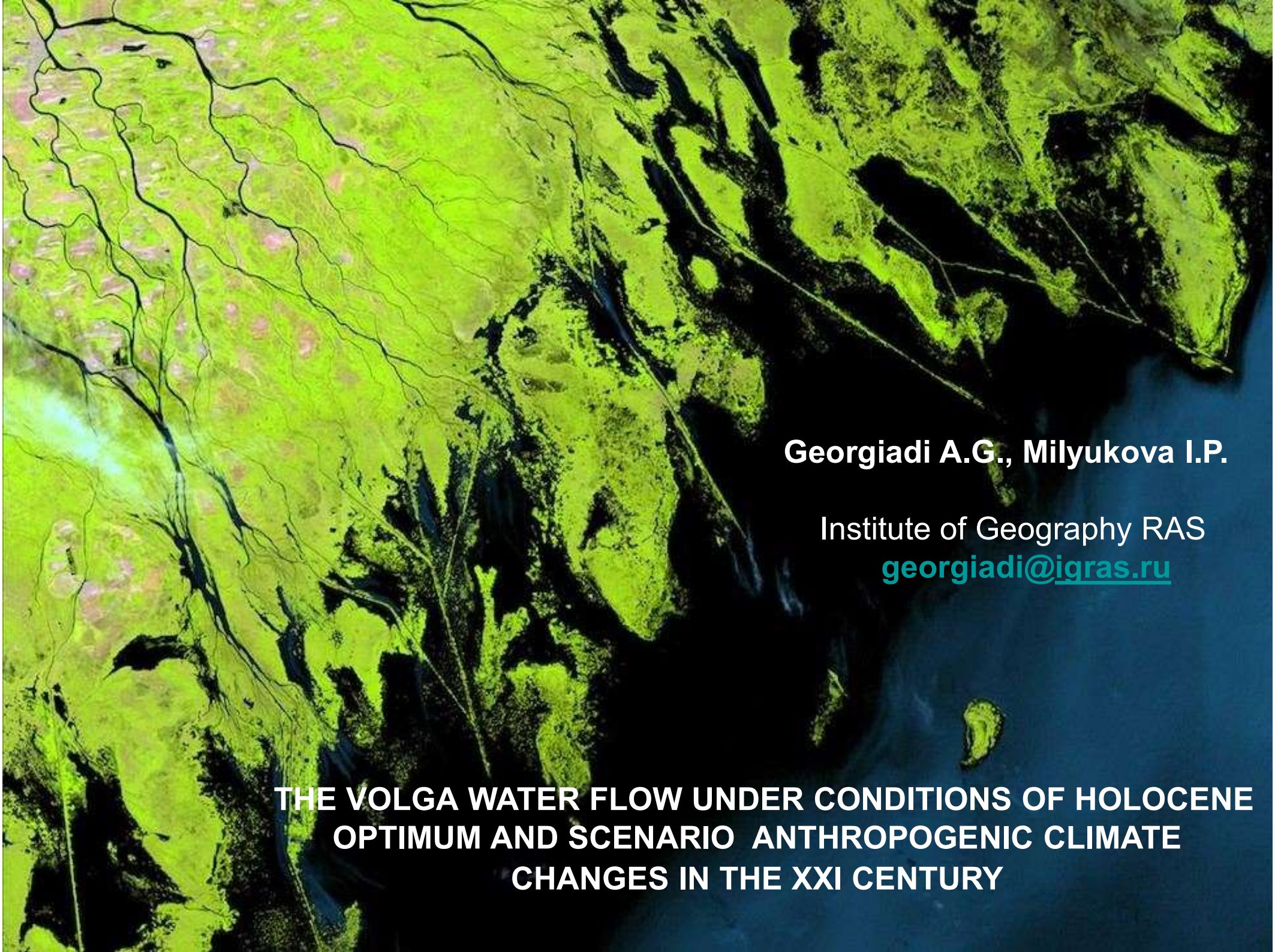

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THE VOLGA WATER FLOW UNDER CONDITIONS OF HOLOCENE OPTIMUM AND SCENARIO ANTHROPOGENIC CLIMATE CHANGES IN THE XXI CENTURY

The features of the Volga and the Don river runoff changes during the Holocene Optimum as well as at scenario conditions of global climate warming in the current century and the Volga river runoff changes in the warm epochs in 3 and 9 thousand years ago were revealed.

Paleoclimatic reconstructions based on data of spore and pollen analysis of fossil plants (Velichko and his collegues) and on calculations carried out on the ensemble of global climate models of PMIP-II program, as well as the paleoclimatic reconstruction based on results of experiments on the global climate model of Moscow State University (Kislov, 1993) were used. Scenarios of climate warming in future, performed on an ensemble of global climate models of CMIP3 and CMIP5 programs, were used.

Hydrological changes were evaluated on the basis of the monthly water balance model.

We also compared the scale of above mentioned changes with the modern observed differences between runoff typical for long-term periods of decreased / increased runoff based on observational data for XX-XXI centuries.

Characteristics of the paleoclimatic reconstructions

To carry out paleohydrological estimates for the conditions of the Holocene optimum, data from traditional paleoclimatic reconstructions of deviations of air temperature and precipitation for January and July from their modern values were used. They were obtained on the basis of zonal and information-statistical methods (Klimanov, 1976; Khotinsky, 1985).

Hydrological assessments were carried out for two variants of paleoclimatic reconstructions. In one of them, the absolute value of the statistical error was added to the deviation of the climatic characteristic calculated from palynological data (and the resulting value was taken as the "maximum deviation" from the current values of the climatic characteristic). In another case, the statistical error was subtracted from the initial deviation and the resulting value was determined as the "minimum deviation". Data on January deviations were distributed for the months of the cold half-year (October-March), and July-for the months of the warm half-year (April-September).

Model paleoclimatic reconstructions of the average monthly anomalies of the above-mentioned climatic characteristics for each month of the average annual year were obtained by averaging the results of restoration carried out on 18 global climate models included in the PMIP-II program.

The results of estimating the deviations of the annual runoff, as well as its intra-annual distribution from their modern values observed in the Volga River basin, Volgograd during the warm epochs of the Holocene (3, 6 and 9 thousand years ago) were based on the paleoclimatic reconstruction based results of experiments on the global climate model of Moscow State University (Kislov, 1993).

Projected changes.

The climate scenario, following the definition of the Intergovernmental Panel on Climate Change (IPCC), is understood as a plausible (or probable) evolution of the climate in the future, consistent with scenarios of greenhouse gas emissions and other atmospheric impurities (scenarios of the international Climate Model Comparison Project CMIP3-Coupled Model Intercomparison Project 3 (Meehl et al., 2007) or changes in the concentration of anthropogenic greenhouse gases, and not their emissions (scenarios of the CMIP5 international project (http://cmip-pcmdi.llnl.gov/cmip5/) with existing ideas about the impact of changes in the concentration of these impurities on the climate. Accordingly, the climate change scenario means the difference between the climate scenario and the current state of the climate.

As climatic scenarios, groups of scenarios with the most (A2 from the CMIP3 program) and RCP 8.5 (CMIP5)) and least (B1 (CMIP3) and RCP 2.6 (CMIP5)) intensive growth of the global average annual air temperature were used.

Estimates of climate change were based on data on the model values of modern (averaged for the period 1960-1990) and scenario (averaged for the periods 2010-2039 and 2040-2069, which are conditionally assigned respectively to 2025 and 2050) average monthly values of air temperature and precipitation and deltas between them.

At the same time, an ensemble of 10 models (out of more than 20 models included in this project) was used for calculations based on the results of the CMIP3 project. They were selected by A.V. Kislov and co-authors (2008) based on a comparison of the current model and observed climate for the territory of the Russian Plain. And in the case of the CMIP5 project, the results of calculations obtained for all (about thirty) climate models included in this project were used.

The average scenarios of changes in the average monthly values of air temperature and atmospheric precipitation for each of the groups of selected contrasting scenarios were obtained based on averaging the data obtained on each of the climate models included in these groups of scenarios.

Monthly Water Budget Model

The model is based on a conservation equation of average long-term monthly water balance of river catchments. In general it can be written down for each cell of a regular grid in the following way:

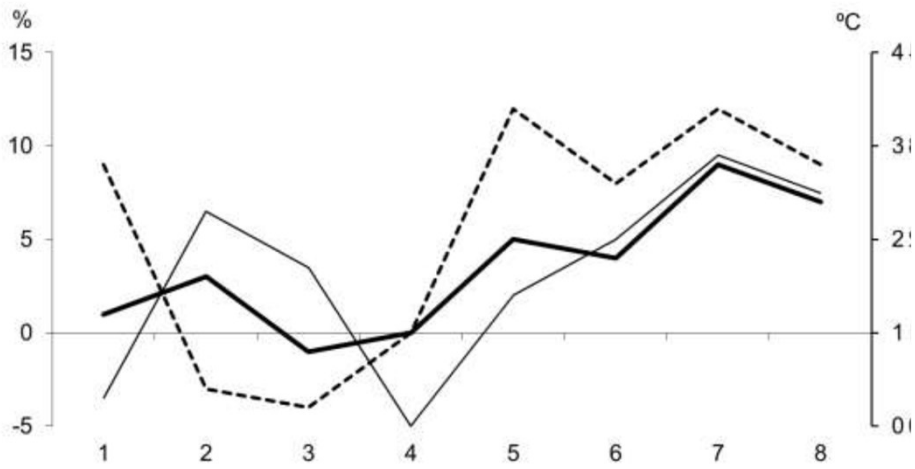
$$Q_s(t)+Q_{gr}(t)=P(t)-E(t)-I_d(t)-dW/dt$$

Qs (t) - the total surface and subsurface (seasonal active layer) flow (mm)
Qgr (t) - groundwater flow (mm)
Qs (t) + Qgr (t) - full river runoff
P (t) - atmospheric precipitation (mm)
E (t) - evaporation (mm)
Id (t) - infiltration of water to deep horizons of underground water outside of active water exchange zone (mm)
dW/dt - change of water amount in active water exchange zone of the river basin for the time interval *dt*

The model simulates the following processes:

- infiltration and moisture accumulation in the soil
- evaporation (based on a modified Thornthwhaite's method)
- movement of the freezing front calculated from a simplified solution for classical single-front Stefan problem
- formation of surface, subsurface and groundwater flow in the rivers and full river runof
- water accumulation in the snow cover and snow melting (based on V.D. Komarov's method

Deviations of the long-term average annual hydrolimatic characteristics: river runoff dR (% of modern runoff), precipitation dPr (% of modern values) and air temperature dT (^{0}C) in the warm epochs of the Holocene Optimum and scenario future climate, for the Volga

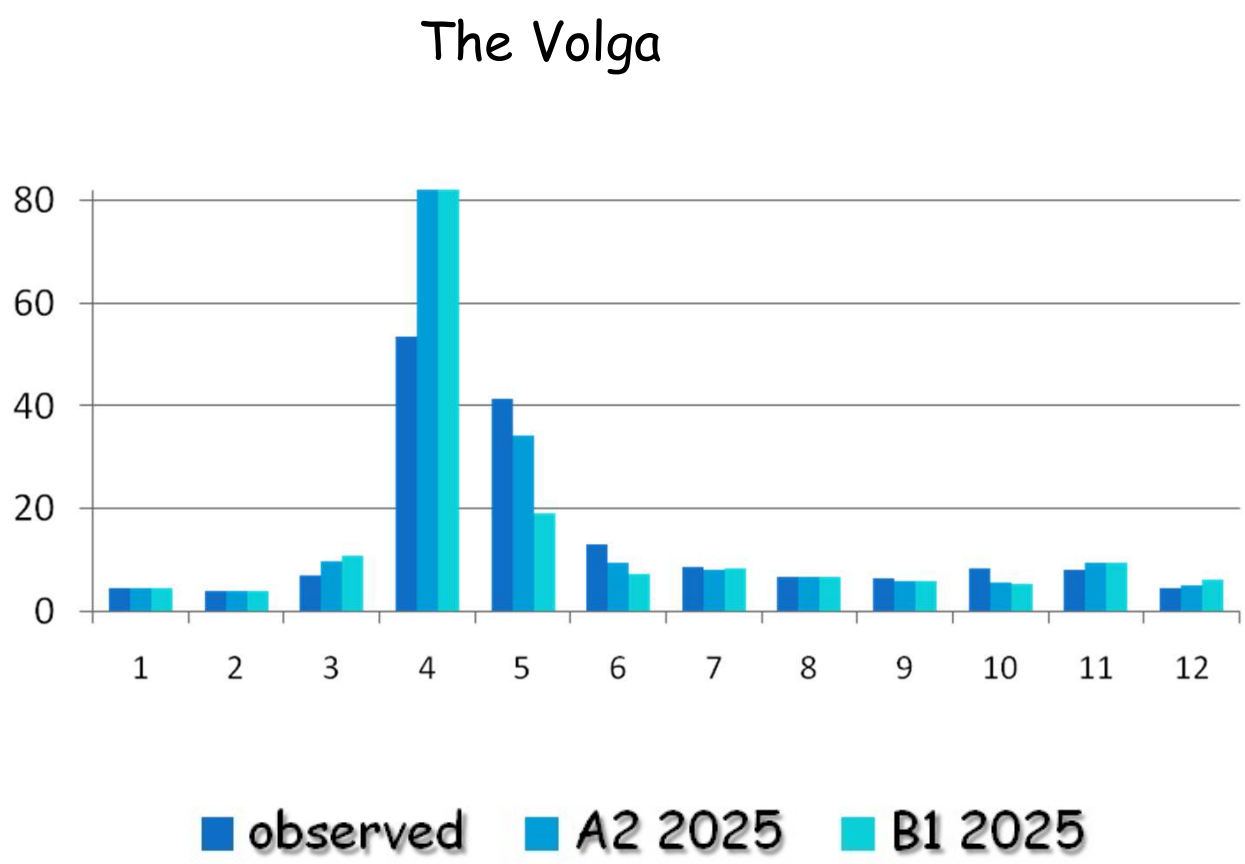


Volga river runoff, air temp. and atm. prec. for scenario climate are higher than their modern values.
During the Holocene Optimum air temp. and atm. prec. are higher than their modern values also. But river runoff could be lower than modern one (based on data of traditional paleoclimatic reconstruction) or higher than modern value based on PMIP-II paleoclimatic data.

On the abscissa axis:
1 – the Holocene optimum according to PMIP-II,
2 – the Holocene optimum according to (Paleoclimate…, 2009) with maximum deviations of Pr and T,
3 – the Holocene optimum according to (Paleoclimate…, 2009) with minimum deviations of Pr and T;
4 - the modern level taken as zero reference,
5 - according to IPCC scenario A2 for 2025,
6- according to IPCC scenario B1 for 2025,
7 - according to IPCC scenario A2 for 2050,
8 - according to IPCC scenario B1 for 2050.

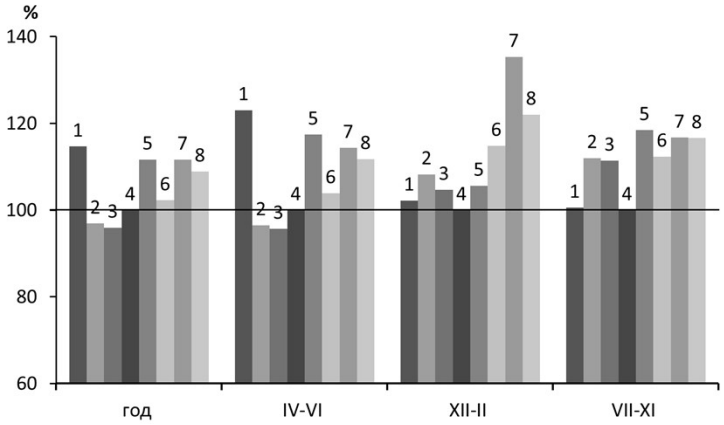
For all cases we compared paleo and scenario river runoff with runoff averaged for period 1930-1980.

Main Trends for River Runoff Changes (mm)



The flood wave shifts slightly to earlier dates and the runoff is redistributed for the month with the highest runoff (April). At the same time, the winter runoff increases slightly.

Deviations (%) from the current values (taken as 100%) of the average long-term annual (year), snow melt flood (IV-VI), winter (XI-II) and summer-autumn (VII-XI) runoff in the warm epochs of the Holocene optimum and scenario future, for the Volga.

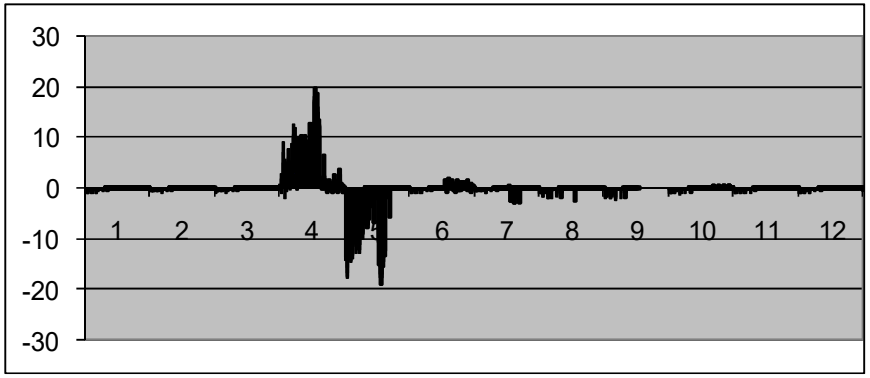


Year Flood Winter Sum-Aut

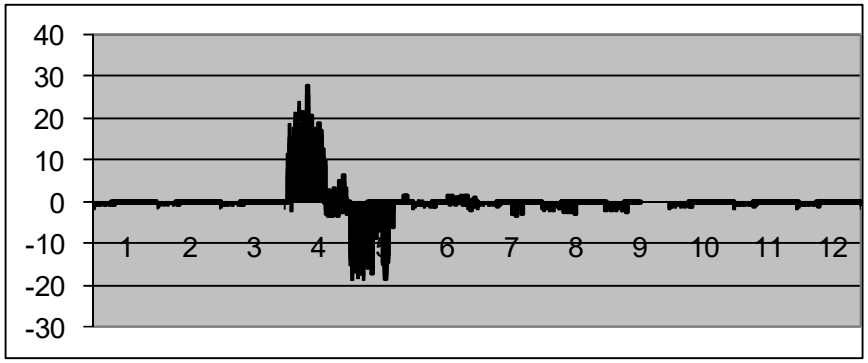
On the abscissa axis:
1 – Holocene optimum according to PMIP-II,
2 – Holocene optimum according to [19] with maximum deviations of Pr and T,
3 – Holocene optimum according to [19] with minimum deviations of Pr and T,
4 – the modern level, taken as 100%,
5 - according to the A2 scenario for 2025,
6- according to the B1 scenario for 2025,
7 - according to the A2 scenario for 2050,
8 – according to the scenario B1 for 2050.

According to reconstruction based on PMIP-II paleoclimatic data flood runoff (as well runoff for whole year) was higher as modern one on the Volga, but based on traditional paleoclimatic reconstruction data it was decreased slightly.
The same picture we can see and for future runoff. Runoff for low-flow seasons is higher than modern one as for the Holocene as for future climate.

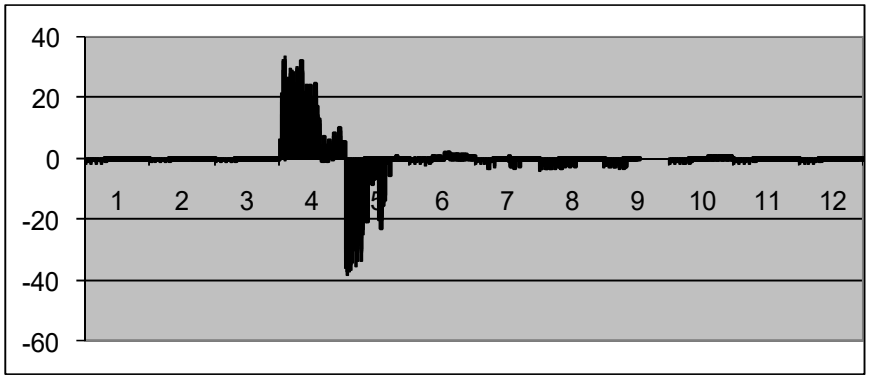
3 thou. Years ago

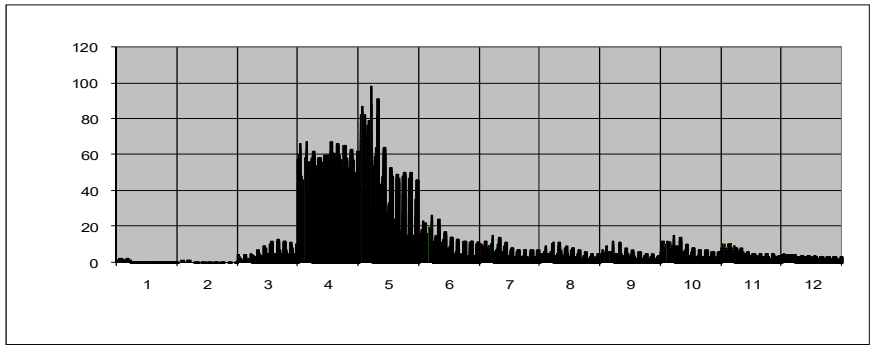


6 thou. Years ago



9 thou. Years ago





Intra-annual distribution of the values of deviations of the average monthly river flow from its modern values (ΔQ, mm) for the warm epochs of the Holocene, generalized by the nodes of the regular grid for the Volga River basin near Volgograd:

a) 3 thousand years ago (sub-Atlantic warming);
b) 6 thousand years ago (Atlantic optimum);
c) 9 thousand years ago (early boreal optimum);

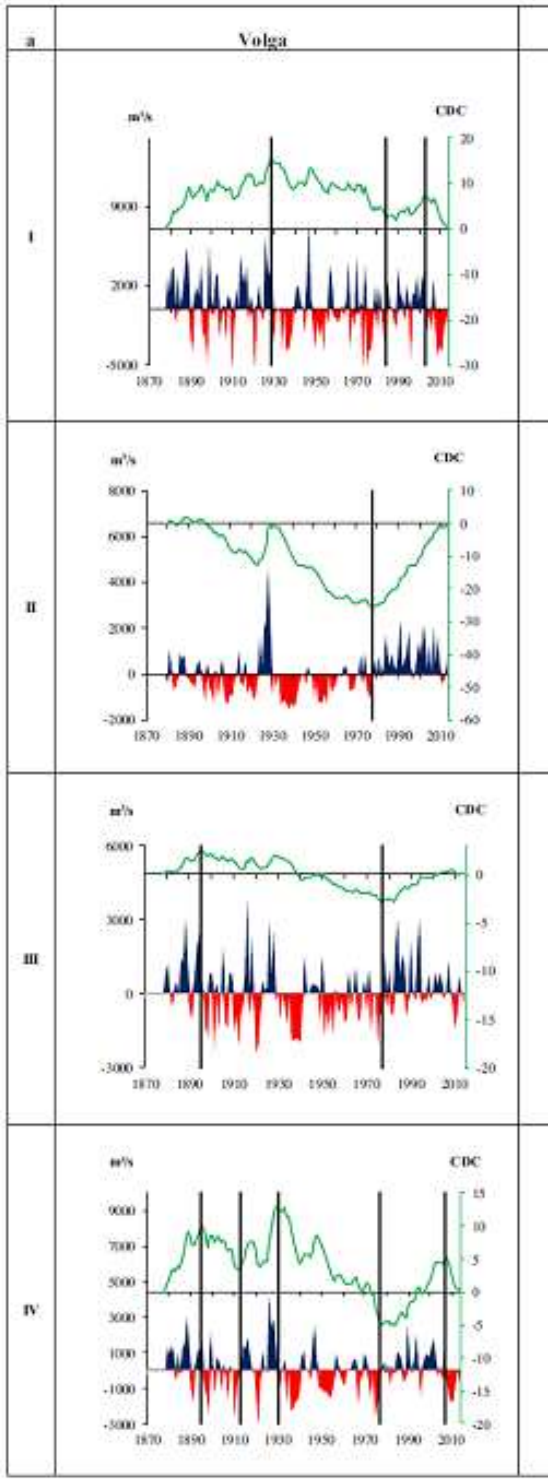
on the ordinate axis - the values of deviations of the average monthly river flowfrom its current values (ΔQm, mm)
along the abscissa axis – months of the year;

d) intra-annual distribution of the average monthly values of the river the flow (Q, mm) generalized by the nodes of the regular grid for the Volga River basin near Volgograd according to the data of instrumental observations

on the ordinate axis - the average monthly values of river flow (Qm, mm);
on the abscissa axis – months of the year

The similar picture we can see on the Volga for sub-Atlantic, Holocene optimum and early Boreal warming based on MSU model paleoclimatic reconstructions.

About differences between runoff in relatively cold and warm climate during period of instrumental observations.



snow melt flood

winter

summer- autumn

entire year

Long-term changes flow in snow-melt floods (I), winter (II), summer-autumn period (III) and whole year (IV) presented in the form of deviations from the long-term mean values (red and blue) and normalized cumulative deviations curve (green).

The vertical black lines show the boundaries of the long-term phases of the increased/decreased water flow (phase change points).

Climate-induced changes in the average annual runoff over whole year, winter season and snow flood on average over the season over the period of modern climate warming relative to their naturalized values for the basic period (from the middle of 1930s to the 1980).

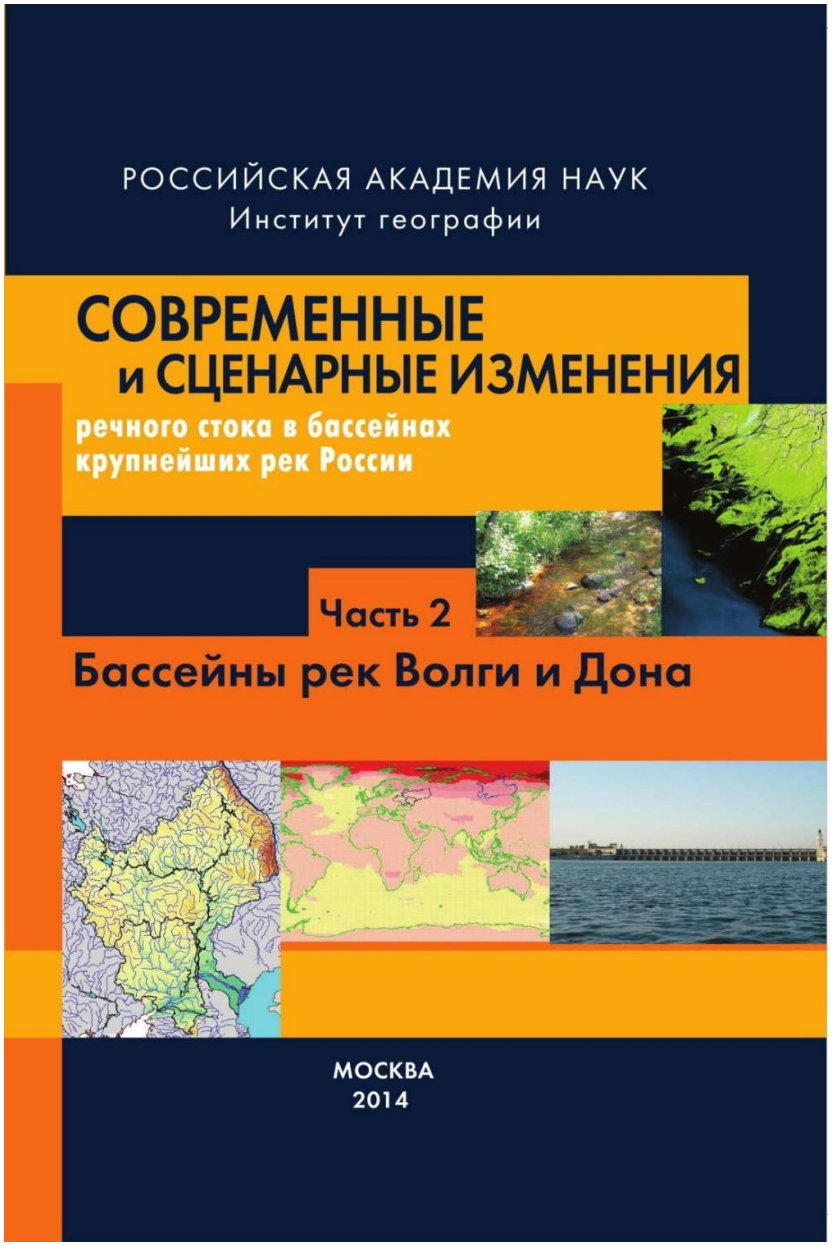
River-gage	Average annual runoff of the reference (relatively cold) period (middle of 1930s-1980), km^3			Changes in the average annual runoff in the period of modern climate warming (1981-2014), km^3/ %		
	year	flood	winter	year	flood	winter
Volga, Volgograd	246.7	166.3	27.2	19.3/8	2.4/1.5	12.3/45

During the period of modern global warming (the beginning of which was adopted from 1981), the naturalized (with excluded anthropogenic change) annual runoff of the Volga increased (by 8%) compared to the preceding period with a relatively colder climate (from the middle of 1930s to the 1980), as well as in the warm climatic epochs of the geological past (PIMP-II data) and the scenario future. The runoff of the flood has practically not changed (increased by 1.5%), while the runoff of the winter has increased the most noticeably (by 45%), which is also characteristic of the considered warm epochs of the past, in which the scale of changes in air temperature and atmospheric humidification was different. Thus, the average annual air temperature during the period of modern global warming was higher than the temperature of the base period by 1^0C (which is significantly lower (except for the reconstruction of PMIP-II) compared to the considered warm epochs), and the annual amount of precipitation during this period was higher by 25 mm compared to the base period (which is comparable with their changes in the Mikulino interglacial 125 thou. yo, as well as with their scenario changes).

Conclusions

1.The conditions of the late Atlantic optimum of the Holocene, reconstructed from palynological data (Paleoclimate …, 2009), are the closest in terms of the scenario thermal regime in the Volga, characteristic of the first third of the current century.
2.At the same time, the annual river flow of the Volga according to the results of calculations on the model of the monthly water balance turned out to be lower than the modern one if is used data of traditional paleoclimatic reconstruction.
3.This result is consistent with the paleo river flow estimates for the Holocene optimum obtained earlier for the Volga on the basis of zonal dependencies of the annual runoff (Velichko et al., 1992), and with the results of the reconstruction of the runoff from paleo meanders (Sidorchuk, Panin, Borisova, 2012).
Under scenario climatic conditions and paleoclimatic reconstructions based on an ensemble of climate models of the PMIP-II program, it turns out to be higher than the modern one.
4.In the conditions of the climate of the scenario future (in the first third and the middle of the current century), the annual flow of the Volga is likely to increase as the climate warms.
5.During the period of modern global warming, the naturalized (with excluded anthropogenic change) annual runoff of the Volga increased compared to the preceding period with a relatively colder climate (from the middle of 1930s to the 1980), as well as in the warm climatic epochs of the geological past (according to PIMP-II paleoclimatic data) and the scenario future. The runoff of the flood has practically not changed by 1.5%), while the runoff of the winter has increased the most noticeably, which is also characteristic of the considered warm epochs of the past, in which the scale of changes in air temperature and atmospheric humidification was different.

Publications



A.G. Georgiadi, N.I. Koronkevich, I.P.Milyukova, E.A.Kashutina, E.A. Barabanova.

Contemporary and Scenario River Runoff Changes in the Largest River Basins of Russia. Part 2. The Volga and Don river basins: - Moscow: MAKS Press, 2014. – 216 p.

The results of studies for contemporary and scenario river runoff changes in the Volga and Don basins, probable in the first third of the XXI century, under the influence of the global climate change and socio-economic transformation are presented. Originality of these investigations lies in the fact that there were revealed long-term phases of changes for the naturalized annual and seasonal Volga and Don river runoff since the end of the XIX to the beginning of the XXI century, and their affection by the complex of anthropogenic factors are revealed, and the integrated assessment of changes for the river runoff, based on ensemble of climatic scenarios and alternative scenarios of water consumption is given as well.

Key words: river basins, river runoff, hydrological changes, long-term phase changes, climatic and anthropogenic factors, climate and hydrological scenarios changes, hydrological models

THANKS FOR YOUR ATTENTION