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The influence of regional climatic changes on the flood regime in European Russia in the 21st Century

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Abstract. Possible changes in the average annual maximum snow reserves and flood runoff in European Russia (ER), on the basis of global climate modelling data was estimated. The data on precipitation and temperature from 5 AOGCMs (atmospheric and ocean general circulation models) of the CMIP5 project, based on the best reproduction of the current climate were used. The multidirectional changes in the maximum snow reserves and flood runoff are expected in ER, although there is a tendency in the southern territories towards a decrease in these characteristics; this intensifies near the end of the 21st Century and when using data from the 'hard' scenario of greenhouse gas emissions.

1. Introduction

Spring floods maximize the use of water and hydropower resources. Climatic changes significantly change current river flows and their intra-annual distribution says in IPCC [14]. According to Blöschl G. et al [5], the observed timing of floods has been constantly changing in many parts of Europe over the past 50 years as a result of climate change. The results of Blöschl G. et al [6], obtained from the most complete flood database in Europe, suggest that: an increase in the number of autumn and winter rains led to flooding increase in northwestern Europe; decreased precipitation and increased evaporation have resulted in less flooding in medium to large catchments in southern Europe; and the decrease in snow cover and snowmelt due to higher temperatures has led to fewer floods in Eastern Europe. This decrease is caused by the rise in temperature, which reduces the accumulation of snow in winter, resulting in less melt water in the spring as shown in Dzamalov [9]. Decreases in flood peaks have also been reported for Northern Europe in Andréasson et al [2], Arheimer and Lindstrom [3], Alfieri et al [1], Roudier et al [17] and Donnelly et al [8].

Under these conditions, it is vital to develop a long-term forecast of flood runoff that accounts for climatic changes. The most developed tool is the climate change method in AOGCMs (atmospheric and ocean general circulation models), which considers various greenhouse gas scenarios. Many publications have been published on large-scale flood forecasts covering the entire globe, such as Hirabayashi et al [12, 13], Dankers et al [7], Giuntoli et al [11] and Arnell and Gosling [4]. Kundzewicz et al [16] interprets differences in flood hazard projections across Europe and identifies likely sources of discrepancy, and it has been shown that it is not possible to recommend which large-scale studies might be considered the most reliable in certain regions of Europe. Tober [19] shows that high runoffs change in different directions with climate changes, depending on the genesis of the high

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1 water. In this paper, we consider only the case of spring flooding caused by melting snow and concurrent precipitation.

2. Materials and methods

Sidorova [18] said that the use of a limited number of characteristics provided by AOGCMs – namely, precipitation (P) and temperature (T) – facilitate a better assessment of future changes in runoff and its characteristics than the direct output of AOGCMs regarding river runoff characteristics were demonstrated. This study applies a tool for changing the flood runoff in the 21st Century (using two periods: 'mid', from 2041 to 2060, designated as 2050, and 'end', from 2081 to 2100, designated as 2100), based on AOGCM data from the CMIP5 project for two greenhouse gas emission scenarios: moderate (RCP 4.5) and more severe (RCP 8.5) according Van Vuuren [20]. From the ensemble of 35 AOGCMs of the project, we have selected 5 according to the criterion of the best impact of precipitation during the cold period in ER. These are the CNRM-CM5, miroc5, IPSL-CM5B-LR, CanEsm2, and GFDL-ES2G models.

The runoff for the period is primarily associated with the processes of snow drift, and its value is largely determined by the water reserves in the snow drift. Water reserves in the snow cover constitute the key characteristic of all quantitative relationships between hydrometeorological processes in both the snow cover and the soil. The SNEG2 algorithm was developed to convert the AOGCM data to the value of the water equivalent of snow cover. This algorithm is described in detail in Kislov [15]; it converts the average daily air temperatures t (°C) and daily precipitation p (mm) into daily values of snow storage S (mm), taking into account the freezing of the snow cover, its water retention capacity, and various melting coefficients.

The accuracy of the algorithm, tested for 65 weather stations in ER, is characterised by the following regression equation:

$$S_{28(ob)} = 0.94 \ S28(sneg2) \tag{1}$$

with a Pearson's correlation of (R)= 0.82, where $S_{28(ob)}$ represents the snow storage values according to observations on February 28 and *S28* (*sneg2*) represents the snow storage values calculated according to the SNEG2 algorithm for February 28. The dependence demonstrates some overestimation of the values by the algorithm, which may be explained by the underestimation of losses. It can be assumed that other values calculated by the SNEG2 algorithm (for example, the maximum snow reserves Smax) will correlate with the actual values in the same way.

To estimate the flood runoff, a calculation scheme was developed, applied, and presented in the work of Kislov [15]. As the initial data to substantiate the dependence for ER, we used the data on flood runoff from the Atlas map [10], interpolated into a regular grid (the reference period, hereinafter referred to as 1980). The data on the maximum snow reserves and precipitation during the flood were obtained by running the data interpolated into the grid of meteorological characteristics, using the SNEG2 algorithm.

The runoff layer of the spring flood y_{Sf} (mm) in ER is related to the values of the maximum snow storage by the following equation:

$$y_{Sf} = 0.0040(Smax)^{2.0563} \tag{2}$$

with a Pearson's correlation of (R) = 0.958 and RMSD = \pm 32 (mm), where Smax is the maximum snow storage (in mm).

The algorithm for calculating the flood runoff is as follows:

1) Daily precipitation and temperature values are run through the sneg2 algorithm:

P, T \rightarrow algorithm SNEG2 \rightarrow Smax (sneg2).

2) Equation (2) calculates the spring flood runoff for three periods: the baseline (1980) and two forecast periods (2050 and 2100).

Modern problems of reservoirs and their catchments – 8	IOP Publishing
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3) The relative change in the runoff of the spring flood ($Ky_{SF 2050} = y_{SF 2050} / y_{SF 1980}$ and $Ky_{SF 2100} = y_{SF 2100} / y_{SF 1980}$) is calculated. This calculation eliminates the systematic bias found for the SNEG2 algorithm, as well as the error of climate models inherited in the forecast periods.

3. Analysis of results and conclusions

According to the algorithm described above, were estimated possible changes in maximum snow storage in the 21^{st} Century in the territory of ER. The calculation according to the RCP 4.5 scenario illustrates a widespread decrease in this parameter, with the exception of the north-eastern edge of the territory, where the maximum snow storage will not decrease. The decrease intensifies from the north-eastern regions to the southwestern ones. For the middle of the 21^{st} Century, the K_{Smax} values from 0.4 to 1.0 are normal, where K_{Smax} is the change in maximum snow reserves relative to the base period. For the end of the century, the trend is somewhat stronger: the isolines are shifted to the south and the K_{Smax} values range from 0.4 in the Krasnodar region to 1 on the north-eastern outskirts of ER.

For the more severe RCP 8.5 scenario, the changes are more noticeable and have a more complex spatial distribution. By the middle of the century, a decrease in maximum snow reserves is also expected, especially on the southwestern outskirts of ER, to values of 0.3-0.5 of the values of the base period; for territories between 57°N and 65°N, no changes are expected. By the end of the century, the decrease in maximum snow reserves covers the entire study area, except for the extreme north-eastern margin. The maximum decrease is possible to values of 0.2 of the base period values. North of 55°N the decrease is characterised by values of 0.6-0.9 of the base period values.

The flood runoff in the study area also changes in a logical manner (figure 1). In both scenarios, flood runoff decreases. The tendency towards a decrease is most clearly manifested in the southwestern territories of the ER, where – even now – there is a significant decrease in flood runoff; in some areas, floods have disappeared as a phase of the water regime. Thus, according to the scenario RCP 4.5, Ky_{SF} is in the range of values 0.2–1 for the middle of the century (figure 1a) and in the range of 0.1–0.8 for the end of the century (figure 1b). For the RCP 8.5 scenario, in the middle of the century, one area remains unaffected by a decrease in high water, corresponding to the 'climatic ridge of runoff' from St. Petersburg at 60°N. The rest of the territories experience a decrease in flood runoff (figure 1c). The end of the century is characterised by the most striking possible decrease in high water runoff: from the complete disappearance of high water in the south to values of 0.5–0.8 from the values of the base period in the northeast (figure 1d).

A comparison of the results obtained earlier from assessing the changes in the spring flood runoff in Kislov [15] indicates their consistency. Both variants show a widespread decrease in the flood runoff layer: moderate on the northern slope of ER and strong on the southern outskirts – up to complete disappearance. Our results are consistent with the current trends described in Blöschl [6]. The work of Arnell [4] also shows a tendency towards a decrease in the volume of floods in southern ER and a possible increase in the north of the ER. The forecast made and similar developments should be understood as some approximate assessment of the possible consequences of anthropogenic climate warming. The reliability of the forecast depends on the degree to which the future climate matches the scenario used in the model and other accepted assumptions.

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Modern problems of reservoirs and their catchments – 8 IOP Conf. Series: Earth and Environmental Science **834** (2021) 012015 doi:10.1088

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Figure 1. Flood runoff layer (Ky) in the 21^{st} Century in fractions of the values of the base period, calculated using the ensemble 5 AOGCMs: a) the middle of the century (2041–60); b) the end of the century (2081–2100), according to the RCP 4.5 scenario; c) the middle of the century (2041–2060); d) the end of the century (2081–2100), according to the RCP 8.5 scenario.

IOP Conf. Series: Earth and Environmental Science 834 (2021) 012015 doi:10.1088/1755-1315/834/1/012015

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