Anomalous conditions of the inflow to reservoirs of the Volga-Kama cascade in the autumn-winter of 2019/2020

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Abstract. The peculiarities of the inflow regime to the reservoirs of the Volga-Kama cascade in the autumn-winter of 2019/20 are considered. Based on the analysis of long-term characteristics for the entire period of operation of the cascade, an assessment of the anomalous excess of inflow in October-March 2019/20 is given. The relationship between the autumn-winter inflow to the cascade and the autumn and winter circulation, particularly the phase of the wintertime Arctic oscillation on the background of a positive air temperature trend is shown.

1. Introduction
The Volga-Kama cascade (VKC) is the largest natural and geotechnical system in Europe. It includes water reservoirs located on the southern slope of the East European Plain. Its total catchment area is 1360 thousand km² (figure 1). Recent studies [1; 2; 3; 4] documented a significant increase in wintertime water runoff throughout most of the Volga basin since the late 1970s. This increase is caused by a significant wintertime warming and significant increase in wintertime precipitation and frequency of thaws [4; 5; 6; 7; 8].

In the study, an inflow to the VKC reservoirs during October-March period of hydrological year is analyzed. Even on the background of a general increase in the autumn-winter inflow after 1978 as compared with 1946-1977 [9], the autumn-winter 2019/20 was outstanding (figure 2). The prevailing meteorological conditions caused the extreme total inflow of 134 km³ to the VKC reservoirs in October-March, which significantly exceeded the previous maximum of 118 km³ in 1990/91.

The 2019/20 winter was the first in the historical records when stable snow cover was not established over most of the Volga basin throughout the entire winter. It was the winter of the extreme positive Arctic Oscillation (AO) event. The associated anomalous enhancement of the advection of warm and humid air from the North Atlantic [10] caused significant positive anomalies of temperature throughout the whole VKC catchment area and positive precipitation anomalies in its central and northern parts [8; 11].

2. Data and methods
We used monthly mean values of local inflow to the VKC reservoirs, generalized for the periods of 1946-1977 and 1978-2013 provided by the State Hydrological Institute [9; 12]. Characteristics of the extreme inflow to the VKC reservoirs of October-March 2019/20 are given in comparison with the averaged values of 1978-2013 basic period [4; 9].
We estimated the inflow to VKC in 2019/20 using the data provided by [13]. To confirm the legitimacy of the use of these data, a comparative analysis was carried out for the period 2001-2013. Comparison of the values of monthly local inflow to all reservoirs of the VKC showed that, on average, the difference in the values presented in [12; 13] is 10-15%. Moreover, the largest discrepancy (up to 20%) was recorded for the Uglich, Votkinsk, and Volgograd reservoirs, those with the lowest contribution to the total inflow to the VKC (figure 3). For the catchments of reservoirs,
where the highest contribution is formed (Cheboksary, Kama, Lower Kama, Kuybyshev), the discrepancy does not exceed 6-8%, which is acceptable for the purposes of this work.

We analyze monthly/seasonal anomalies of precipitation and temperature of the winter 2019/20 as deviations from the 40-year means (winters of 1979/80-2018/19). The monthly precipitation totals were taken from the GPCP database [14], and the monthly mean air temperature from Reanalysis-2 [15]. The AO index is provided by the NOAA Climate Prediction Center (https://www.cpc.ncep.noaa.gov).

**Figure 3.** Contribution of the reservoir’s local inflow to the VKC total inflow (%).

### 3. Results and discussion

In 2019/20, the enhanced total inflow to the VKC was observed during the entire summer-autumn-winter period, with the maximum excess being recorded in October-March.

Based on the data from [9; 12], we have divided the years of the positive VKC inflow anomalies during the October-March period into two groups in accordance with the timing of the positive anomaly occurrence. The first group consists of the years with the positive anomalies in the autumn inflow (October-November), the second group – in the wintertime inflow (December-March). Examples from the first group (e.g., 1990/91) and the second one (e.g., 2006/07) compared with 2019/20 are shown in figure 4 that demonstrates monthly inflow anomalies to the reservoirs mainly contributing to the total VKC inflow.

A characteristic feature of the timing of the positive anomalies of VKC inflow within October-March period always was a seesaw between the autumn and winter seasons. Enhanced inflow occurred either in the autumn or in the winter. Within an autumn-winter period, an enhanced autumn inflow was usually followed by a reduced or medium winter inflow. And vice versa, an enhanced wintertime inflow was usually preceded by a medium or reduced autumn inflow. The autumn-winter of 2019/20 was marked with first perturbation in the seesaw caused by the anomalous evolution of the AO [16]. The enhanced inflow occurred in both autumn and winter that resulted in the absolutely extreme total inflow to the VKC in October-March 2019/20 (figure 4).
Analysis of the monthly local inflow anomalies in 2019/20 has revealed that the absolute maximum of October-March total inflow to VKC was formed mostly due to reservoirs which catchment areas are located in the northern part of the Volga basin (figure 1). The largest anomalies of up to 250% of the basic period mean values (figure 4) were recorded for the reservoirs of the Upper Volga (Ivankovo-
Gorky Res.) and Upper Kama (Kama Res.), as well as for the Kuybyshev Res. because of its main northern tributary, the Vyatka River. Meanwhile, for reservoirs with catchment areas located in the central and southern parts of the Volga basin (Cheboksary Res. and Lower Kama Res.) monthly inflow anomalies vary within -30% … +50% of the means.

Anomalous inflow in the northern part of the Volga basin in October-March 2019/20 results in the significant re-distribution of the local inflows to the total VKC inflow (figure 5). For example, the percentage of the mean October-March local inflow to the Cheboksary Res. decreased from 27% during the basic period down to 16% in 2019/20, whereas the percentage of the local inflow to the Rybinsk Res. increased from 8% up to 18%.

![Figure 5. Contributions of the reservoirs local inflows to the VKC total inflow (%) for the October-March period.](image)

In the autumn of 2019, the extreme inflow to the VKC was caused by anomalous precipitation in the northern part of the Volga basin (figure 6a) and the positive temperature anomalies caused by increased cyclonic activity over the East European Plain (figure 6b) and the November blocking over the Urals.

![Figure 6. (a) Precipitation totals in October-November 2019 shown as percentage of the mean; (b) October 2019 sea level pressure anomalies (hPa).](image)

The winter of 2019/20 was a winter of the extreme positive AO event occurred on the background of a steady global warming [8; 16; 17]. Enhanced advection of warm and humid air from the North
Atlantic associated with the positive AO phase led to essential, regionally extreme, increase of the positive temperature and precipitation anomalies (figure 7). Particularly, the extreme positive AO event caused the wintertime temperature anomaly of about +5°C over the East European Plain, the steady global warming added about +1°C to it [8]. Enhanced precipitation at near-zero temperatures resulted in extreme water runoff rather than in forming of stable snow cover. These conditions led to the extreme wintertime inflow to the VKC reservoirs and to the shift of the maximum inflow from April-May to March in the northern part of the catchment area, particularly, to the reservoirs of the Upper Volga (Ivankovo-Gorky Res.) and Cheboksary Res., located in the area of the extreme temperature anomalies of up to +6.5°C.

Figure 7. (a) Wintertime (DJFM 2019/20) mean temperature anomalies (°C); (b) February 2020 total precipitation shown as percentage of the mean.

4. Conclusions
According to the results of climate change modeling [11] under forcing by an increase in the concentration of greenhouse gases, the global warming will continue. On the background of this steady global warming, we should expect more frequent warm and humid winters in the East European Plain during the positive AO events. The consequence of this will be an increase of winter inflow to the VKC reservoirs and a shift of the onset and maximum of the spring inflow to earlier dates as it was shown by [18].

The possible forthcoming changes in the VKC reservoirs inflow regime, demonstrated by the presented study, emphasis a necessity for updating of the Operation Rules and Regulations of Water Resources Management once again, supporting the suggestions by [1; 2; 3; 19].

References
[1] Bolgov M V, Filippova I A, Osipova N V, Korobkina E A and Trubetskova M D 2018 Present features of hydrological regime of the rivers in the Volga river basin Voprosy geografii 145 206-218 (In Russian)
[2] Georgievskii V Y, Grek E A, Grek E N, Lobanova A G and Molchanova T G 2018 Spatiotemporal Changes in Extreme Runoff Characteristics for the Volga Basin Rivers Russ. Meteorol. Hydrol. 43(10) 633–638. https://doi.org/10.3103/S1068373918100011
[3] Lavrov S A and Kalyuzhnny I L 2016 Influence of climatic changes on the spring flood runoff and factors of its formation in the Volga basin Vodnoe khozyaystvo Rossii 6 42-60 (In Russian)
[4] Georgievskii V Y and Shalygin A L 2012 Hydrological regime and water resources Methods for assessing the effects of climate change on physical and biological systems (Moscow: Roshydromet) 53-85 (In Russian)
[5] Soja A and Groisman P Y 2018 Earth Science and the integral climatic and socio-economic drivers of change across northern Eurasia: The NEESPI legacy and future direction Environ. Res. Lett. 13 040401 [available online https://doi.org/10.1088/1748-9326/aab834]

[6] Groisman P, Bulygina O, Henerby G, Speranskaya N, Shiklomanov A, Chen Y, Tehebakova N, Parfenova E et.al. 2018 Dryland belt of Northern Eurasia: contemporary environmental changes and their consequences Environ. Res. Lett. 13 115008 [available online https://doi.org/10.1088/1748-9326/aae43c]

[7] Akbari M, Baubekova A, Roozbahani A, Gafurov A, Shiklomanov A, Rasouli K, Ivkina N, et.al. 2020 Vulnerability of the Caspian Sea shoreline to changes in hydrology and climate Environ. Res. Lett. 15 115002 [available online https://doi.org/10.1088/1748-9326/abaad8]

[8] Kryjov V N 2021 Climate Extremes of the 2019/2020 Winter in Northern Eurasia: Contributions by the Climate Trend and Interannual Variability Related to the Arctic Oscillation Russ. Meteorol. Hydrol 46 61–68 DOI: 10.3103/S1068373921020011

[9] Scientific and applied reference book: Long-term characteristics of water inflow into the largest reservoirs of the Russian Federation 2017, ed. V Y Georgievsky (Moscow: RPC Ofort) 132 p (In Russian)

[10] Thompson D W J and Wallace J M 2000 Annular modes in the extratropical circulation. Part I: month to month variability J. of Clim. 13 1000–1016 [available online https://doi.org/10.1175/1520-0442(2000)013<1000:AMITEC>2.0.CO;2]

[11] Kryzhov V N and Gorelits O V 2015 The Arctic Oscillation and its impact on temperature and precipitation in Northern Eurasia in the 20th Century Russ. Meteorol. Hydrol. 40 711–721 [available online https://doi.org/10.3103/S1068373915110011]

[12] Georgievskii V Y, Alekseev L P, Litova T E, Dubrovskaya K A, Zadonskaya O V and Fuksova T V 2016 Water inflow into the reservoirs of the largest hydroelectric power plants in the Russian Federation for different time intervals Database Official Registration Certificate RU 2016621140, 22.08.2016 (In Russian)

[13] Information system on water resources and water management of the Russian river basins [available online http://gis.vodinfo.ru/]

[14] Adler R F, Huffman G J, Chang A, Ferraro R, Xie P, Janowiak J, Rudolf B, Schneider U, Curtis S, Bolvin D, et.al. 2003 The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979–present) J. Hydrometeorol. 4 pp 1147–1167 [available online https://doi.org/10.3390/atmos9040138]

[15] Kanamitsu M, Ebisuzaki W, Woollen J, Yang S-K, Hnilo J J, Fiorino M and Potter G L 2002 NCEP-DOE AMIP-II Reanalysis (R-2) Bull. Amer. Meteorol. Soc. 83 pp 1631–1643 [available online https://doi.org/10.1175/BAMS-83-11-1631]

[16] Juzbašić A, Kryjov V N and Ahn J B 2021 On the anomalous development of the extremely intense positive Arctic Oscillation of the 2019-2020 winter Environ. Res. Lett. (in press) [available online https://doi.org/10.1088/1748-9326/abe434]

[17] IPCC Fifth Assessment Report. Climate Change 2013: The Physical Science Basis Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 2013 (Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press) P 2216

[18] Kryjov V N and Gorelits O V 2019 Wintertime Arctic Oscillation and Formation of River Spring Floods in the Barents Sea Basin Russ. Meteorol. Hydrol. 44 pp 187–195 [available online https://doi.org/10.3103/S106837391903004X]

[19] Bolgov M V, Bubert A L, Komarovskii A A et al. 2019 Search for Compromise Decisions in the Planning and Managing of Releases into the Lower Pool of the Volgograd Hydropower System. 2. Tactical Planning and Dispatching Control Water Resour. 46 pp 480–491 [available online https://doi.org/10.1134/S0097807819030047]