Impact of global warming on the Siberian rivers runoff

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Introduction

Much attention is paid to the fresh water content (FWC) in the Arctic Ocean and its variations as FWC is a source of fresh water for the North Atlantic. The annual fresh water inflow to the Arctic Ocean is defined mainly by river runoff (42%), inflow through the Bering Strait (32%) and net precipitation (26%) (Serreze et al., 2006). Half of the annual river runoff into the Arctic accounts for the 3 large Siberian rivers: Ob, Yenisei, and Lena. The purpose of this research is to assess the impact of global and regional changes in atmospheric circulation, precipitation and air temperature on three major Siberian rivers runoff.

Data and methods

Data of surface air temperature and atmosphere moisture content from reanalysis ERA/Interim (Dee et al., 2011), global precipitation on land from PREC/L (Chen et al., 2002), and global precipitation climatology GPCC from the Global Precipitation Climatology Center (Adler et al., 2003) were used for investigation. Rivers discharge for the period 1936-2018 was received from the datasets R- ArcticNet (Lammers at al., 2016), ArcticGRO (Shiklomanov et al., 2018).
The catchment areas of 3 rivers and their total catchment area were approximated by the following geographical regions: Ob catchment area: 51.25-68.75° N, 61.25-88.75° E, Yenisei catchment area: 51.25-68.75° N, 91.25-108.75° E, Lena catchment area 51.25-68.75° N, 111.25-131.25° E, total catchment area: 50- 70° N, 60-160° E. The monthly mean surface air temperature and precipitation in the regions were defined. Indexes of zonal, meridional and general circulation in the northern hemisphere were calculated according to the monthly mean surface air temperature at the nodes of the geographical grid (Alekseev, 2014). Methods of multidimensional mutual-correlation and mutual-spectral analysis, calculation of low and high values repeatability of less than 10% and more than 90% probability were used.

Results

All correlation coefficients between the indexes and climatic parameters (mean values of air temperature, atmosphere moisture content and precipitation) at the catchment areas confirm the significant impact of atmospheric transports in the cold period of the year on surface air temperature, atmosphere moisture content and lesser on precipitation.
In summer amplification of zonal circulation is accompanied by a decrease in the air temperature over the catchment areas while meridional transports enhance the air temperature even more than in winter. Whereas the winter zonal transport forms similar changes in mean air temperature, moisture content and precipitation in all regions of the catchment areas, in summer the changes have no connection in the Ob and Lena catchment areas.
The impact of surface air temperature and precipitation changes on the river runoff is estimated by correlation coefficients between mean air temperature, mean precipitation in the catchment areas and annual river discharge. Mostly mean annual precipitation affects the river runoffs, especially discharge of the river Lena (figure 1). Summer precipitation in June and July also affects.

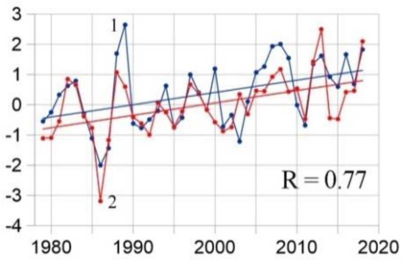

Figure 1. Correlation between annual Lena discharge and precipitation in the Lena catchment area (normalized data, 1 – discharge, 2 – precipitation)

The maximal positive trends of mean air temperature and precipitation in the catchment areas are observed in spring. Trend coefficient of mean air temperature in April is 0.11 °C in the Ob catchment area, 0.08 °C in the Lena catchment area, 0.10 °C in the Yenisei catchment area.

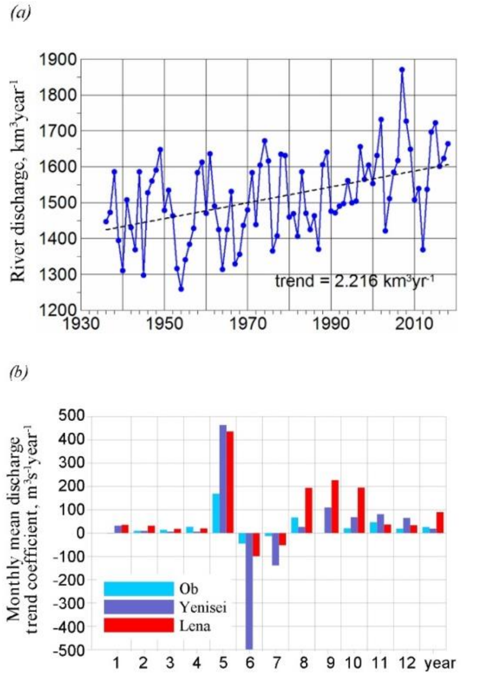

Figure 2. Total annual runoff of 3 rivers in 1936-2018 (*a*), monthly mean discharge trend coefficients, $m^3s^{-1}year^{-1}$ in 1979-2018 (*b*)

The positive trend indicates the increase of annual runoff of Ob, Lena and Yenisei. The trend is maximal for the Lena runoff (500.41 $m^3s^{-1}year^{-1}$ for 1936-2018 and 1079.73 $m^3s^{-1}year^{-1}$ for 1979-2018). Total annual runoff of 3 rivers was also increased during 1936-2018 (figure 2a) with the absolute maximum in 2007 and a linear trend of 2.216 km^3year^{-1}. Monthly runoff of 3 rivers increased in May. In June, when the runoff is maximum, the runoff of 3 rivers decreased in 1936-2018 and 1979-2018 (figure 2b). June trends in 1979-2018 are -51.77 $m^3s^{-1}year^{-1}$ for Ob, -98.86 $m^3s^{-1}year^{-1}$ for Lena, -387.36 $m^3s^{-1}year^{-1}$ for Yenisei.

To assess the frequency of the runoff maximums, the integral frequencies of low and high maximums of less than 10% and more than 90% probability function, respectively, were calculated. An increase in the number of low runoff maximums in 1940-50s and in the 2000s was found as well as an increase in the number of high maximums in 1970-1980s. It means that during warming low maximums dominate, while during cooling of climate the number of high maximums rises.

Conclusions

The effect of the atmospheric transport of heat and moisture is most prominent in the cold part of the year, especially in November and March. In summer, the increase of zonal transport is accompanied by a decrease of air temperature in the area of catchments, and meridional transport enhances the temperature. The atmospheric transport in winter leads to similar changes in the mean values of temperature, moisture content and precipitation in all catchment areas.

The greatest influence on runoff, especially on the Lena's runoff, is exerted by the increase of average annual precipitation. The effect of temperature changes is noticeable when annual temperature is averaged over all three basins. The annual discharge of rivers increases, especially the discharge of Lena. The total annual runoff of the three rivers was increasing during 1936–2018 with a rate of 2.216 km^3year^{-1}.

In the 2000s, the frequency of low maximums of runoff increased, while the frequency of high maximums decreased. The high occurrence of large maximums was noted in 1970–1980s. Such distribution of the frequency of low and high maximums is associated with climate warming in the 2000s and cooling in the 1970–1980s.

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