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Long-term annual water balance analysis of the Lena River

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Abstract

Historical data analyses show that the Lena River and its major tributaries experienced an extended low water period over 1936–1957 and high water periods over 1974–1983 and 1988–2001. Higher than normal river discharge and annual precipitation is particularly pronounced since the late 1960s due to large-scale changes in atmospheric circulation patterns. The trend in runoff observed in the Lena River basin increased by 10% from 1936 to 2001 due to extended wet periods during the second part of last century. The trend is weakened for the Vilui River basin since it experiences reservoir regulation, which causes additional water losses through reservoir filling and increased evaporation. Runoff regulation strongly affects the winter runoff regime of both the Vilui River and the lower reaches of the Lena River causing an increased winter discharge at the Lena river outlet station of approximately 33%.

Keywords: Lena River; Arctic; Water balance; Anthropogenic impact; Climate

1. Introduction

Paleoclimatic studies provide evidence of enormous changes experienced by the Laptev Sea region since the last glacial maximum (Polyakova et al., 2000; Bauch et al., 2001; Mueller-Lupp et al., 2003). The rate of changes for many environmental characteristics observed during the last century is quite likely unprecedented (Vörösmarty et al., 2000). Overpeck et al. (1997) reported that from 1840 to the mid-20th century, the Arctic warmed to the highest temperatures in last four centuries. The arctic hydrological system is particularly sensitive to the temperature rise since it is strongly affected by both the meteorological factors (precipitation, air temperature, evapotranspiration) and land-surface processes affecting runoff (development and propagation of taliks, active layer dynamics) (Hinzman and Kane, 1992). A recent analysis of discharge records from the six largest Eurasian rivers including the Lena River indicates an increase in annual runoff of 7% from 1936 to 1999 (Peterson et al., 2002). Sazonova et al. (2004) examined the impact of various scenarios of climatic warming to the depth

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of thaw of the active layer over the East-Siberian transect, which covers the central part of the Lena River basin from the headwaters to the delta. Results indicate that an air temperature rise of 3–7 °C will produce additional thawing of the active layer by 0.5–2.0 m within the transect. Zhang et al. (2003) believe that permafrost degradation produce sufficient water to increase the runoff over the major Siberian river basins, whereas Holmes et al. (2003) argue that permafrost thawing is not a significant contributor to the observed long-term river runoff increase. Precipitation variability is a primary factor controlling the change in river discharge in northern regions. The correlation coefficient of summer precipitation (June–August) with Lena River runoff in June–September (which is approximately 82% of the annual mean runoff) is 0.89 for 1979–1995 (Fukutomi et al., 2003). Yang et al. (2002) report that the magnitude of changes in precipitation and air temperature is large enough to alter the hydrological regime of the Lena River.

The primarily goal of this paper is to analyze the annual variability of the Lena River water balance in light of a changing climate as well as assess the human impacts on the basin hydrology. The long-term variability of the river discharge has been analyzed to detect the statistical significance of changes in stream flow. Water balance analyses have been applied to identify how the changes in meteorological processes affect the variability of river discharge.

2. Data

Hydrological information has been primarily provided by the digital data bank R-ArcticNET version 2.0 of observed discharge across the pan-Arctic region (Lammers et al., 2001). Most of the database covers the period from 1936 to 1990 for the stations within the Laptev Sea watershed with the exception of outlet station (Kusur), where the most recent data available are from 1994. Recent monthly discharge data (1995–2001) for the Kusur station have been kindly provided by the Regional Tiksi Hydrometeorological Service. There are 46 stations used in this study that have an observational period of more than 50 years (Fig. 1). Meteorological information (monthly air temperature, precipitation, relative humidity), provided by the Russian Federal Service for Hydrometeorology and Environment Monitoring (Roshydromet), has been collected for 52 stations. These data partly available through the All-Russia Research Institute of Hydrometeorological Information—World Data Center (Obninsk) and the National Snow and Ice Data Center, Boulder Colorado (NSIDC). Data on ice regime and water temperature for eight stations were obtained from Hydrological Yearbook published by Roshydromet for the period 1948–1987. Several years (1960, 1981) are missing because of technical difficulties in data collection.

Since the available long-term data set is based only on observational records, we must carefully assess the nature and quality of the data (Legates and Willmott, 1995). This is especially true for the precipitation records, which have a high bias of gauge measurements. Available precipitation data have been adjusted to Nipher-shielded rain gauge replacement in late 1940s to early 1950s (Shver, 1965). Adjustments of the Tretyakov gauge measurements consist of wind-induced undercatch, wetting loss and trace amount of precipitation (Groisman et al., 1991). Wetting loss corrections have been applied according to Nechaev (1966). Wind undercatch has been incorporated based on the results in Yang and Ohata (2001) derived from the WMO Solid Precipitation Measurements Intercomparison data set (Goodson et al., 1998). The mean annual wind correction factor was estimated for each sub-basin (Fig. 1) as a function of air temperature, precipitation and wind speed in Yang and Ohata (2001). Then the annual precipitation for each sub-basin was adjusted to account for wind undercatch.

3. Methods

The hydrometeorological data have been analyzed to determine the temporal homogeneity using tests of mean and variance. The parametric tests have been estimated on the basis of the simple Markov chain model, which is sensitive to the correlation between adjacent terms of the time series (Rojdestvensky, 1984; Saharyk, 1981). The temporal homogeneity of average was tested using Student's test (t^*) and the variance stationarity was tested by application of Fisher's test (F^*) (Mendenhall and Sincich, 1996). The Kolmogorov–Smirnov test (K^*), based on the difference between two empirical probability func-