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Assessing runoff sensitivity to climate change in the Arctic basin: empirical and modelling approaches

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Abstract Empirical and modelling approaches to assessing runoff sensitivity to climate change are presented by the example of the large rivers of the Arctic basin. The empirical approach has been carried out for seven large Arctic rivers. It is based on comparing the climatic mean of runoff estimated for the "warm" years of observations with the corresponding mean for the "cold" years. The registered differences in maximum annual runoff estimated for the "warm" and "cold" years have been found statistically insignificant, even under the large (up to 4°C) differences in the observed annual temperature for these years. The differences in minimum annual runoff turned out significant for three of the seven rivers. The modelling approach has been demonstrated on the basis of the ECOMAG modelling system applied for the Lena River (catchment area 2 488 000 km^2). The parameters of the model have been adjusted through calibration against runoff hydrographs observed for the 10-year period 2000–2009. Validation of the model has been performed for the period 1986–1999. The numerical experiments have been carried out to analyse the sensitivity of the Lena River runoff regime to possible changes in annual precipitation and air temperature. It has been shown that one-degree increase of the annual temperature leads to decreasing simulated annual runoff of about 5–7%, mainly due to increasing evaporation. Ten percent increase of precipitation leads to 15–17% increase in simulated annual runoff.

Key words cold region hydrology; climate change; sensitivity

INTRODUCTION

High uncertainty is associated with the assessment of hydrological consequences of observed and projected climate changes. Part of the uncertainty is epistemic, a result of incomplete knowledge of the physical mechanisms of dynamics of climatic systems and interrelations with the hydrological cycle, deficiency of observations, etc., and this can be reduced by deepening knowledge and accumulating data. In addition, structural uncertainty, which cannot be reduced even if detailed information becomes available, is an essential feature of the climatic and hydrologic systems. Structural uncertainty is emphasized by physically-founded limits of predictability of atmospheric processes and unpredictability of the factors (e.g. development of technologies) affecting climate change, as well as by stochastic aspects of climatic and hydrological processes represented as non-static Hurst-Kolmogorov behaviour (Koutsoyiannis, 2003; Montanari, 2003). The relationship between the epistemic and structural uncertainties is a key question for understanding the opportunity for assessment of hydrological consequences of climate change, and there are different views on this relationship (see discussion in Koutsoyiannis *et al*., 2009). Taking into account significant and *a priori* unknown uncertainty of the climate projections, one can suggest that there is a very limited range of the problems (related to response of hydrological systems to climate change), which presume existing meaningful solutions. Assessing runoff sensitivity to climate change is an example of these problems.

Here, empirical (data-based) and physically-based modelling approaches to such assessment are presented by the example for the large rivers (or their tributaries) draining into the Arctic Ocean.

Climate over the Arctic region has changed significantly during the past few decades and climate models predict that the regional warming (2–9°C by the end of the 21st century) is very likely to exceed the global mean warming (Climate Change, 2007). The hydrological cycle of the Arctic river basins plays a central role in regulating the global climate system and investigation of their runoff regime is therefore critical to better understand and quantify the atmosphere-land-ocean interactions in the Arctic and consequent global impacts (Shiklomanov *et al*., 2000; Vörösmarty *et al*., 2001; Yang *et al*., 2004).

The ongoing changes of the Arctic river runoff are estimated differently. For example, according to Bates *et al*. (2008), annual runoff of the six greatest Eurasian rivers has slightly (7%) increased in