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Variability and extreme of Mackenzie River daily discharge during 1973–2011

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ABSTRACT

This study systematically analyzes long-term (1973–2011) daily flow data collected near the Mackenzie basin outlet. It clearly defines the variability, extreme events, and changes in daily flow records over the past 4 decades. The results of this study accurately determine the seasonal cycle of river discharge, including the range of highest and lowest daily flows. The interannual variation of daily flow is generally small in the cold season, highest in the spring melt period, and large over the summer months mainly due to rainfall storm activities and associated floods. This study also shows that Mackenzie River flow regime has changed over the past 4 decades due to climate variation, with the advance of snowmelt peak timing by several days, decrease in maximum spring flows by about 3000 m^3/s, and weak rise of cold season base flows. These results are the consequence of hydrological response to regional climate warming, and they provide new knowledge to improve our understanding of large-scale environmental changes over the broader northern regions.

1. Introduction

Climate warming is most significant over the past several decades in the northern regions. Climate models project a 1–4 C° global surface air temperature increase in the 21st century, with even greater increase in the Arctic regions (Kattsov et al., 2005; IPCC, 2013). This warming trend will impact the structure, function, and stability of both terrestrial and aquatic ecosystems and alter the land–ocean interaction in the Arctic. Arctic rivers are the dynamic component of the global climate system. Discharge from the Arctic rivers contributes as much as 10% to the upper 100 m of water column of the entire Arctic Ocean. The amount and variation of this freshwater in flow critically affect the ocean salinity, surface temperature, and sea ice formation, and may also exert significant control over global ocean thermohaline circulation (Aagaard and Carmack, 1989).

Arctic hydrologic systems exhibit large temporal variability due to changes in large-scale atmospheric circulation and poleward moisture transport (Saito et al., 2013; Zhang et al., 2013). This variation (particularly extreme events) significantly influences the cross-shelf movement of water, nutrients and sediments. Examination of streamflow regime and change in the major northern river basins and their relations to surface climate and atmosphere are critical to better understand and quantify the atmosphere–land–ocean interactions in the Arctic and consequent global impacts. Many studies report remarkable changes in water cycle components of the northern hydrology systems, such as increases of Eurasian Arctic river discharge (Peterson et al., 2002; McClelland et al., 2006), discharge increases in winter and decreases in summer for the Yenisei, Lena, Ob' watersheds in Siberia (Ye et al., 2003; Yang et al., 2004a,b), earlier melt of snow cover (Yang et al., 2007; Brown and Mote, 2009; Shi et al., 2013) and river ice breakup (Bonsal et al., 2006; Prowse et al., 2010), shift of peak flows in the spring season (Yang et al., 2007; Ge et al., 2012), and record high floods in 2007 for the large Siberian rivers (Shiklomanov and Lammers, 2011) along with an extreme loss of Arctic summer sea ice (Comiso et al., 2008). Ge et al. (2012) found that Yukon River annual flow increase by 8% over the past 40 years; summer flows have a higher fluctuation, and peak snowmelt flow slightly increases with its timing shifted to an earlier date. These changes in streamflow hydrology features are caused by climate variations and human impacts, particularly winter flow increase as the result of reservoir storage and regulation in Siberian regions (Ye et al., 2003, Yang et al., 2004a,b).

Streamflow records observed at the watershed outlet reflect basin integration of both natural variations and human-induced changes, such as changes of land cover/land use and regulations of large dams within the watersheds. Discharge data collected at

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the river mouth are particularly important as they represent freshwater input to the ocean and are often used for basin-scale water balance calculations, climate change analysis, and validations of land surface schemes and GCMs over large spatial scales. It is therefore important to understand the fundamental characteristics, including temporal variations and changes in basin streamflows at various time scales (such as daily, monthly, yearly to decadal time steps). Many studies use monthly and yearly flow data to examine and document arctic hydrology changes (Lammers et al., 2001; Peterson et al., 2002; Ye et al., 2003; Yang et al., 2004a,b; McClelland et al., 2006; Adam et al., 2007; Shiklomanov et al., 2007; Rawlins et al., 2010) and biogeochemical processes (Liu et al., 2005; Holmes et al., 2012; Tank et al., 2012). It has been recognized that monthly flow data and analyses are not always suitable for hydrological process investigations over the cold regions, especially during the spring snowmelt period that may last from a few weeks up to several weeks, and summer rainfall floods (most often lasting up to a few days to a week). Yang et al. (2002) used daily, monthly, and annual flow data to study Lena river hydrology changes; their analysis of the long-term daily discharge records at the Lena basin outlet confirms an advance of snowmelt peak flood from June toward late May. Yang et al. (2003) also generated weekly flow data from the daily records for the large Siberian Rivers and compared them with weekly snow cover extent and SWE data, and established regression relationships between snowmelt and spring season flows. These relationships are useful for the prediction of spring flows over the large northern regions.

River flows significantly vary at the inter-annual time scale in the arctic regions. Daily flow data are necessary to accurately

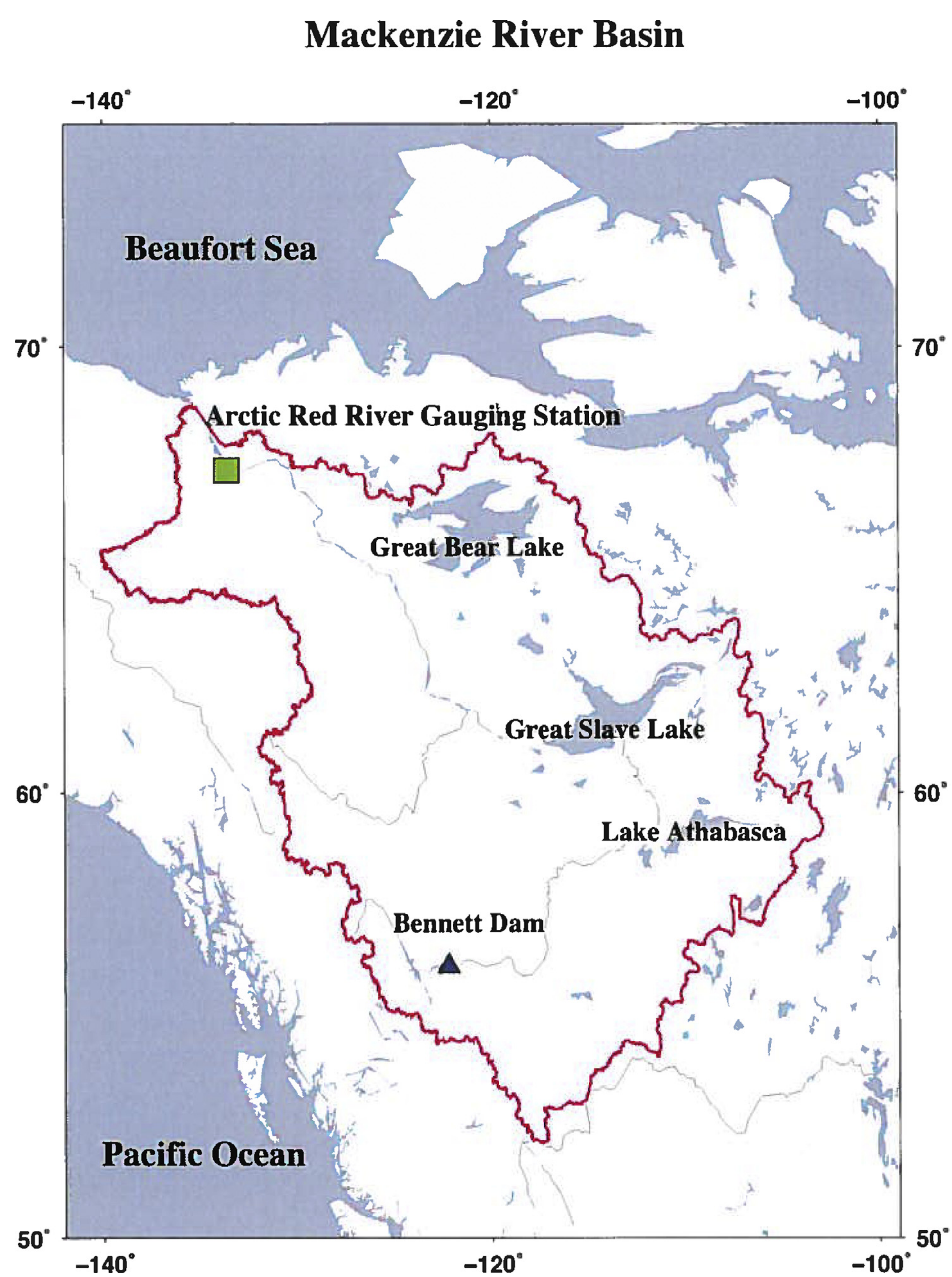

Fig. 1. The Mackenzie River system, including major sub-basins and locations of large lakes, reservoir, and the Arctic Red River gauging station near the basin outlet. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)