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Hydro-climatic changes and their monitoring in the Arctic: Observation-model comparisons and prioritization options for monitoring development

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SUMMARY

The Arctic undergoes particularly large and rapid hydro-climatic changes, and information on hydrological responses to these changes is crucial to plan for societal adaptation. We investigate hydro-climatic change severity and monitoring in 14 major hydrological basins across the pan-Arctic, in view of different possible strategies for their monitoring prioritization. Results show that the current distribution of monitoring density in these basins is more relevant for so far observed precipitation changes than for observed temperature changes, or for projected future temperature and precipitation changes. Furthermore, present and projected future hot-spots of greatest hydro-climatic change differ spatially, so that major spatial shifts must occur in the future among the different Arctic basins in order for observations and climate model projections to converge with regard to hydro-climatic change severity. Also temporally, observation-model convergence requires that important change direction shifts occur in major Arctic basins, which have currently decreasing precipitation while model projections imply future increasing precipitation within them. Different prioritization options for rational development of hydro-climatic monitoring can be argued for based on the present results. The divergent prioritization options imply a need for an explicit strategy for achieving certain information goals, which must be selected from a larger set of different possible goals based on societal importance.

1. Introduction

The effects of global change on society and the Earth system will to a large degree appear through changes to the water cycle, such as altered precipitation, evapotranspiration and runoff patterns, and drought and flood pressures (Askew, 1987; McCabe et al., 2004; Pall et al., 2011; Bengtsson, 2010; Destouni et al., in press; Jarsjö et al., 2012). In the rapidly changing Arctic region, climate change brings large hydrological changes (Vörösmarty et al., 2001), as well as hydrologically mediated ecological regime shifts (Karlsson et al., 2011). The Arctic is also particularly vulnerable to changes related to water due to extensive reliance on hydro-climatically dependent infrastructure such as ice roads and construction on permafrost (Nelson et al., 2002; Stephenson et al., 2011). Furthermore, evidence indicates that the rate of climate change so far is particularly high in the Arctic, with warming rates twice the global average (ACIA, 2005; Christensen et al., 2007). At the same time, projections based on different scenarios presented in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) indicate a very wide range of future states of the Arctic region, with modeled increases in regional average temperature ranging from about 2 °C to over 10 °C by the end of this century (Christensen et al., 2007, their figure 11.18).

The imminent but uncertain climate change, its strong feedback to and coupling with the water system, and the strong dependence in the Arctic on the physical state of water implies that relevant monitoring of the water cycle in the Arctic will be critical to successful adaptation in the region. However, several recent studies have highlighted the declining number of hydrological monitoring stations (Lammers et al., 2001; Shiklomanov et al., 2002; Arctic-HYDRA consortium, 2010), and also identified critical spatial gaps with regard to monitoring of changes in water chemistry (Bring and Destouni, 2009) and ecosystems (Karlsson et al., 2011). Bring and Destouni (2011) showed in particular that the decline in hydrological stations has been greatest in areas where future climate change is expected to be greatest.

The reduction in monitoring networks implies that prediction and understanding of the water system is hindered. For instance,

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Spence et al. (2007) showed that the closure of 12 out of 34 discharge monitoring stations in the Mackenzie basin lead to 16% larger extrapolation errors in forecasting streamflow. Notwithstanding reductions, the station density in many parts of the PADB, for example Northern Canada, is below World Meteorological Organization (WMO) recommendations (Mishra and Coulibaly, 2009).

Some international efforts, such as the Sustaining Arctic Observing Networks (SAONs) process, aim to generally strengthen monitoring in the Arctic. Nevertheless, the question of how to develop the monitoring of discharge and water chemistry in the face of its severe limitations and the uncertain future climate development in the Arctic has so far received little attention, despite its importance for deciding on where to spend limited monitoring and adaptation funds. Monitoring systems should be designed and extended with both today's and tomorrows expected environmental conditions in mind, and observation system design must explicitly take the non-stationarity of hydrological variables into account (Milly et al., 2008). The degree to which changes can be reliably predicted and the spatiotemporal distribution of the most severe changes are therefore essential in deciding monitoring priorities, as is the fundamental question of which rationale that should guide the distribution of monitoring effort. These questions all fall within the grand challenge of developing, enhancing and integrating observation systems to manage global and regional environmental change, a task identified to be of highest priority for Earth system science (Reid et al., 2010).

In this study, we investigate the relevance of hydrological monitoring, and the prioritization basis for it, in the region draining to the Arctic Ocean (AO), specifically with regard to climate change. Over a time horizon to the mid-2050s, we identify two extreme ends of future projected climate change for the 14 largest Arctic basins (Fig. 1), and investigate how the hitherto observed climate change agree with the patterns of projected climate change for these two scenario ends. Furthermore, we analyze the present distribution of the discharge monitoring effort across the Arctic basins and investigate how it relates and may need to be adapted to the currently observed or the projected future severity of climate change. Finally, we also study how the current monitoring of discharges into the AO relates to the relative contribution of different river basins to the total discharge into AO from the whole pan-Arctic drainage basin. A general aim is to investigate if and how different hydro-climatic change perspectives can form a consistent relevance and prioritization basis for formulation of a robust hydrological monitoring strategy to capture and follow up the most severe hydro-climatic changes in the Arctic.

2. Materials and methods

Based on the R-ArcticNET 4.0 database of Arctic hydrological monitoring stations (http://www.r-arcticnet.sr.unh.edu; Lammers et al., 2001), we identified 14 independent major Arctic drainage basins with an area of at least 2×10^5 km^2 (Fig. 1); an area sufficiently large to include a reasonable number of grid points for

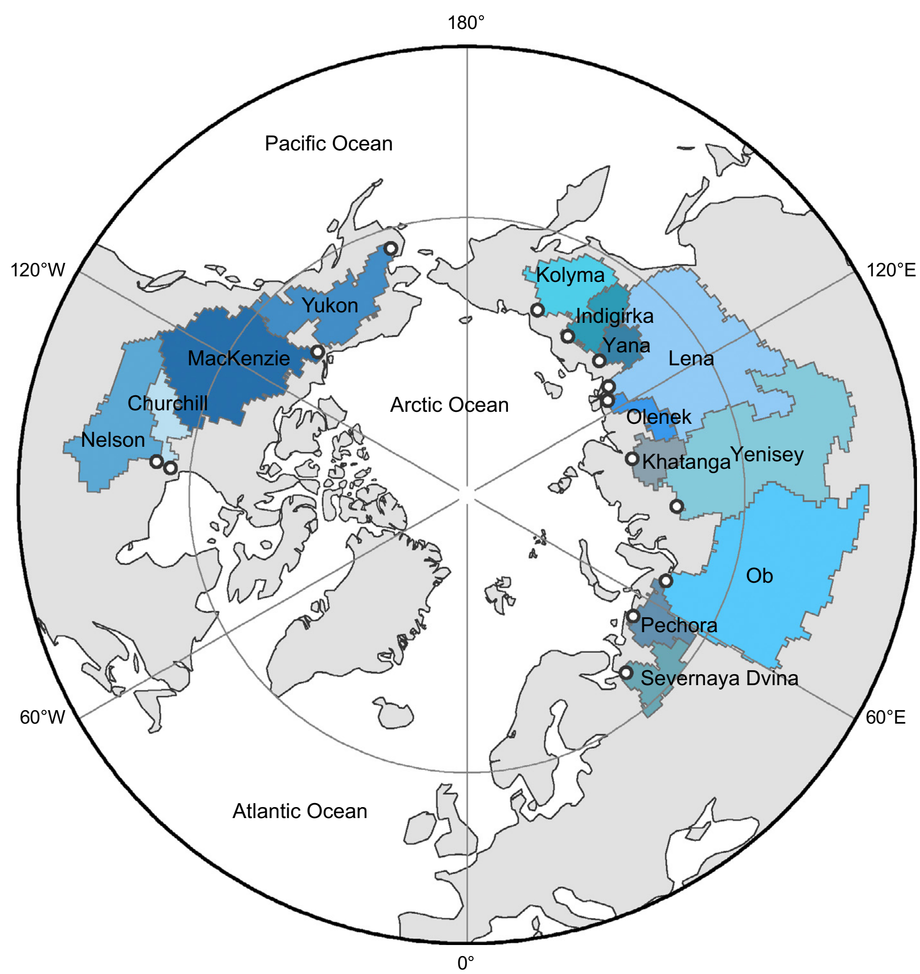

Fig. 1. Map of the investigated 14 major Arctic basins.