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Historical trends and extremes in boreal Alaska river basins

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SUMMARY

Climate change will shift the frequency, intensity, duration and persistence of extreme hydroclimate events and have particularly disastrous consequences in vulnerable systems such as the warm permafrost-dominated Interior region of boreal Alaska. This work focuses on recent research results from nonparametric trends and nonstationary generalized extreme value (GEV) analyses at eight Interior Alaskan river basins for the past 50/60 years (1954/64–2013). Trends analysis of maximum and minimum streamflow indicates a strong (>+50%) and statistically significant increase in 11-day flow events during the late fall/winter and during the snowmelt period (late April/mid-May), followed by a significant decrease in the 11-day flow events during the post-snowmelt period (late May and into the summer). The April–May–June seasonal trends show significant decreases in maximum streamflow for snowmelt dominated systems (<−50%) and glacially influenced basins (−24% to −33%). Annual maximum streamflow trends indicate that most systems are experiencing declines, while minimum flow trends are largely increasing. Nonstationary GEV analysis identifies time-dependent changes in the distribution of spring extremes for snowmelt dominated and glacially dominated systems. Temperature in spring influences the glacial and high elevation snowmelt systems and winter precipitation drives changes in the snowmelt dominated basins. The Pacific Decadal Oscillation was associated with changes occurring in snowmelt dominated systems, and the Arctic Oscillation was linked to one lake dominated basin, with half of the basins exhibiting no change in response to climate variability. The work indicates that broad scale studies examining trend and direction of change should employ multiple methods across various scales and consider regime dependent shifts to identify and understand changes in extreme streamflow within boreal forested watersheds of Alaska.

1. Introduction

Extreme hydroclimatic responses in regional-scale Alaskan boreal forest watersheds are influenced by both climate change and natural climate variability, and lead to shifts in water storages that impact fresh water resource availability and quality. The signal of mean change in hydrologic systems has been well documented in previous work (ACIA, 2005; Hinzman et al., 2005) and include shifts in: snow cover extent (Brown, 2010); permafrost distribution (Osterkamp, 2005); lake and river freeze up and breakup (Magnuson et al., 2000); glacial mass-balance (Moore et al., 2009); and regional synoptic river discharge (Déry and Wood, 2005). Much of the work to-date focuses on climate change impacts in Arctic runoff in large river systems (Forbes and Lamoureux, 2005; Peterson et al., 2002b; Yang et al., 2002, 2003), or small watersheds (Kane et al., 2003, 2008). However, analysis of changing streamflow extremes that are occurring in regional-scale boreal watersheds is lacking.

Observed changes in mean streamflow indicates that the tails of the streamflow distributions are also changing and this could have an impact on human and ecological systems at a regional-scale in the boreal forest (Zhang and Zwiers, 2013). Industries and resources are at risk due to increased occurrence of extreme events in critical watersheds, such as those being considered for future power and hydro-electric resources (i.e. Susitna), or rivers like the Yukon that are utilized for food and transport to numerous villages throughout Alaska (Alaska Energy Authority, 2014; Brabets et al., 2000). Flooding and low flows will have a great effect on mining, infrastructure, ecology, and society in all parts of the state. Understanding these changes allows for thorough review of existing planning measures, including tailing ponds and spillway allowances, bridge maintenance, and flood evacuation protocols in regions and basins where changes are occurring or have occurred in the historical record.

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Comprehensive analysis of changes in extreme streamflow in the subarctic region of Alaska has been limited. This is because the building blocks for regional hydrologic modeling remain unclear, including the understanding of hydro-climatologic regimes, snowmelt and freeze–thaw dynamics and antecedent moisture storage conditions driving events (Woo et al., 2008b). The lack of long term, high-quality, continuous records of streamflow available for in-depth analysis, and for model calibration and validation also plays a large role in the paucity of research. Additionally, previous work on changes in extreme streamflow for Interior Alaskan boreal forest basins is sparse. Major papers have looked at streamflow hydrology in the Kuparuk River basin, a high latitude watershed located on the North Slope of Alaska, adjacent to the Arctic Ocean (Kane et al., 2000, 2003, 2008; McNamara et al., 1998). Jones and Rinehart (2010) examined small watersheds located in the Caribou-Poker Creek to relate storm flow to permafrost and precipitation. Changes in streamflow attributable to the Pacific Decadal Oscillation (PDO) are presented in Neal et al. (2002) for southeast Alaska, for the Yukon River by Brabets and Walvoord (2009), and for a broad range of coastal to interior sites for Alaska by Hodgkins (2009).

Large-scale Arctic river networks have been analyzed in a number of seminal research papers (Peterson et al., 2002b; Serreze et al., 2002, 2006; Slater et al., 2006; Yang et al., 2002). Some of this work highlights the changing nature of hydrologic regimes with shifts in climate, namely the acceleration of the hydrologic cycle in northern regions, which is a major hypothesis for the change in extreme events within the Arctic (Rawlins et al., 2010; Serreze et al., 2009, 2000). However, the direction of streamflow changes and the proposed mechanisms driving those changes is not agreed upon in the literature. Declining flow trends have been observed across northern, coastal Canadian rivers and rivers flowing into the Ungava, James and Hudson Bays (Déry et al., 2005; Déry and Wood, 2005). An updated paper by Déry et al. (2009) revealed a trend reversal toward increasing flows and flow variability for rivers in northern Canada when the time series was extended by four years (1964–2007). Increasing flows have been reported in Interior river networks of the Northwest Territories (St. Jacques and Sauchyn, 2009) and the Yukon River (Walvoord and Striegl, 2007), attributable to enhanced infiltration due to permafrost thawing (Smith et al., 2007). In the Mackenzie River basin, no trends were found in flow magnitudes from 1973 to 1999, although variability was noted to be increasing (Woo and Thorne, 2003; Zhang et al., 2001). Janowicz (2011), focusing on the Yukon River region, associated streamflow declines with regions of thawing permafrost, owing to deeper infiltration and runoff reductions. Spence et al. (2011) attributed increased winter baseflow to greater fall precipitation leading to a switch in systems from a purely snowmelt dominated system to a snowmelt–rainfall regime, a change that is most apparent at small systems not dominated by lakes.

The detection of long term trends can be confounded by low-frequency climate variability and the time scale of analysis. Contextualizing the nature of streamflow variability within climate regimes allows for linkages to be made between process shifts occurring within basins and regionally. For example, Moore and Demuth (2001) examined streamflow at Place Glacier and found it to be declining. The basis for this was a correlation between winter and net glacier mass balance with the PDO, while summer glacier balance was negatively correlated with summer air temperature, and showed a positive correlation with preceding winter balance. Fleming et al. (2006) presented a study examining the effects of the Arctic Oscillation (AO) on streamflow in northern Canada, finding that the AO was correlated in glacial basins but not in snowmelt driven systems. Déry and Wood (2004) examined the impact of the AO on declining streamflow into Hudson Bay; isolating the changes and linkages to streamflow regimes particular to the region. While annual trends in streamflow have been broadly considered (Déry et al., 2009; Peterson et al., 2002a; St. Jacques and Sauchyn, 2009), seasonal studies are less common, although at finer scales of analysis process shifts can be determined (Whitfield et al., 2002).

This paper seeks to understand historical changes in hydroclimate extremes through trends analysis of maximum and minimum flows, and through the use of nonstationary generalized extreme value theory (GEV) analysis from comprehensive, long term records in regional-scale boreal Alaska watersheds. The objective is to document historical shifts in extreme streamflow and link observed changes associated with spring breakup peak flow with time, climate (air temperature and precipitation) and/or climate variability. These variables are investigated as covariates in the GEV analysis. The study is undertaken at eight watersheds across Interior and Western Alaska with variable hydrologic regimes – from glacial–snowmelt to snowmelt–rainfall. The paper outlines the study sites and the methodology used in our analysis, including nonparametric trends and nonstationary GEV statistical tools. Results are presented for trend and time-dependent GEV analyses and for each GEV covariate analysis. Our discussion focuses on a hypothesis-based presentation on the causes of changes occurring in these watersheds. The conclusion of the paper summarizes the major points and the implications of this research.

2. Methods

2.1. Study area

The streamflow stations considered for this analysis span a range of climate and topographic conditions (Table 1), extending from the central Interior region of Alaska near Fairbanks, southwest to the village of Dillingham, and east to the town of Eagle near the Yukon Territory, Canada (Fig. 1). The sites are a sample of Interior stations exhibiting both glacial and snow melt influences (glacial–nival), and snowmelt and rainfall influences (nival–rainfall). Some stations gage very large river basins (i.e. the Yukon at Eagle), while others capture flow from smaller sub-watersheds of major basins (i.e. the Chena River, Table 1).

Historical streamflow in the Susitna and Talkeetna River (SUS, TAL, Fig. 2) watersheds illustrate the characteristic glacial–nival shape of their hydrographs, with an initial snowmelt peak and a secondary peak in August associated with precipitation combined with glacial melt. The Kuskokwim River (KUS, Fig. 2) is a complex system owing to the division between high elevation, mountainous and glacial headwater regions and expansive low-elevation, boreal lowland/wetlands through which its drainage flows. The Kuskokwim River therefore displays a subarctic nival–rainfall regime with some glacial influence. The Nuyakuk River (NUY, Fig. 2) drains a large lake complex, glacial and perennial snow and ice fields of the Aklun Mountains and lowland wetlands in the Bristol Bay region of Alaska, approximately 100 km north of the city of Dillingham (pop. ~ 2300). The Nuyakuk River is the most southern system analyzed. The lakes act to delay the snowmelt peak in this watershed into June. The Nuyakuk is hence classified as a prolacustrine–nival system.

The Yukon River watershed at Eagle drains a large expanse of Canadian landscape and has a sharp peak and a long recessional tail owing to snowmelt contributions from high elevation regions of the watershed and glaciers of the White River basin in the Wrangell-St. Elias Mountain range (Table 1, Fig. 2, Brabets et al., 2000). The glaciers in this area are receding and ablation is considered to dominate over changes in precipitation, based on a 30-year record from the Gulkana River glacier (Brabets et al., 2000).