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Wintertime High Flow Regime in Northern Maine, USA: A Hydroclimatic Diagnostic Study

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We analyze the historical streamflow record for Saint John River Basin with a view to understand recent changes in the wintertime (January-February) high flow regime. Commingled large-scale climatic and local influences (such as, ice-breakup) exert considerable influence on the magnitude of wintertime high flow events. Analysis results point to systematic changes in the episodic warm-up events during January-February (JF) period that appear to trigger melt or ice-breakup, as well as occasional rainfall. While the wintertime temperatures show links to Tropical Northern Hemisphere (TNH) teleconnection pattern, the observed secular trends in temperature appear limited to the upper quantiles; the daily temperature distribution for the JF period has remained relatively unchanged. Our analysis point to the important role of both secular trends and interannual variability (in this case, with origins in the tropic Pacific) as key drivers of changes in the flow regime, which is likely to not only reshape the Springtime streamflows, but also impact river biota.

1. Introduction

Seasonal and annual high flows convey critical information regarding watershed-scale hydrologic variability. Furthermore, flow regime and variability are 'master variables' for stream ecosystems. Consequently, a timely diagnosis of changes and understanding of causal factors is an increasingly important research area in water resources sustainability research. In snowmelt-dominated watersheds, changes in temperature and precipitation statistics, individually and jointly, have the potential to engender dramatic shifts in the magnitude and timing of streamflow. For example, in the northeastern United States, analysis of historical records indicates an advance in the timing of springtime runoff pulse [Hodgkins et al., 2003] and a trend towards decreasing ice thickness in central Maine [Huntington et al., 2003], consistent with the springtime temperature variability and trends. Collins [2009] found that trends towards increases in the magnitude of annual floods in New England occurred as a step change over second half of the 20th century. In snowmelt-dominated regions, some attention has been devoted to low-frequency variability and trends in magnitude and timing for annual maximum floods [Dettinger and Cayan, 1995; Jain and Lall, 2000; Hodgkins and Dudley, 2005], however, limited knowledge regarding changes in the wintertime flow regime exists—these shifts have the potential to cause unanticipated fluctuations in seasonal and annual flow regimes.

Changes in wintertime flow regime entails complex nature of large-scale weather and climate phenomena, as well as in-stream processes, such as, ice breakup, temporary ice barriers, and melts that result in somewhat less predictable yet dramatic shifts in flow [Beltaos et al., 2003]. In this study, we pursue a detailed analysis of changes in daily streamflow and temperatures for the JF season in the St. John River region. Our analyses focus on understanding and explaining the observed variability in high flows, and linkages with the large-scale atmospheric circulation patterns (TNH teleconnection pattern), as well as the joint temperature and precipitation characteristics leading up to the seasonal high flow events. Results from previously published data on ice-breakup are also incorporated in our analyses.

2. Data and Methods

Daily discharge data for the Saint John River at the Fort Kent (USGS station number 0101400) was considered for this study based on an 81-year long streamflow archive maintained by the U.S. Geological Survey (http://waterdata.usgs.gov/nwis). We also used temperature and precipitation data, for which we had continuous daily records and which met specific data completeness criteria. The precipitation data were obtained from the NOAA CPC (Climate Prediction Center) based on daily data.

In this study, the relationship between temperature and precipitation was analyzed based on flow events, as well as ice jam and breakup occurring in the coldest months of winter (January-February). The temperature considered here was taken as the maximum of the daily temperatures recorded on the date of the seasonal peak flow event and the three preceding days. In addition, we pursue a diagnostic study to identify characteristics signatures of winter hydrologic variables within the context of local weather and climate. A Poisson-based regression approach was applied to model the number of warm-up episodes as a function of TNH teleconnection index.

3. Recent Changes in Hydroclimatic Variables: Streamflow and Temperature

Streamflow

An examination of the daily streamflow record for the January-February period shows substantial interannual and decadal scale variability (Figure 1). Year-by-year distribution of streamflow is summarized as boxplots, and it helps reveal the somewhat nonlinear nature of flow variability in winter. In particular, there are three instances during the 1940-1950 decade when the entire distribution of flows shows record low flows, as well as maximas. However, in years when the temperatures are warmer, and the daily flow distribution shows a higher median and/or range of variability, the seasonal maximas (shown as grey circles) have a much higher range. This is consistent with the thermal and radiative process thresholds linked to snow and ice. At the same time, it is also clear that interannual variations and trends in temperatures may result in nonlinear changes in streamflow, ones that may remain deceptively mild until thermal thresholds linked to melt are reached. In Figure 1, the dashed lines represent statistically significant trends at the 95% confidence level. Both median flows and seasonal maximas have undergone increases.

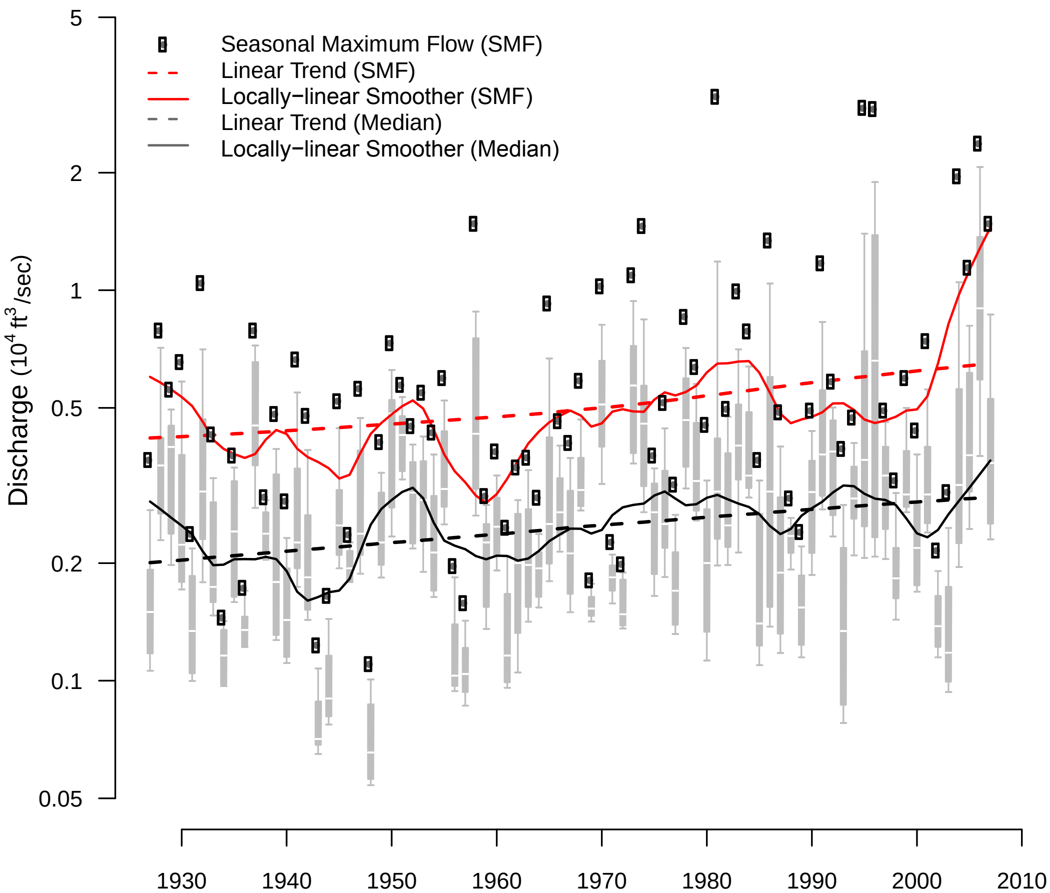

Figure 1 Historical variations in daily streamflow (January-February), and its extremes for the St. John River. The grey shaded circles highlight the seasonal maximum flood for each year. The dotted line shows a linear trend and the solid line represents a trend of seasonal maximum flood using LOWESS (locally-weighted linear regression) with an 11-year span.

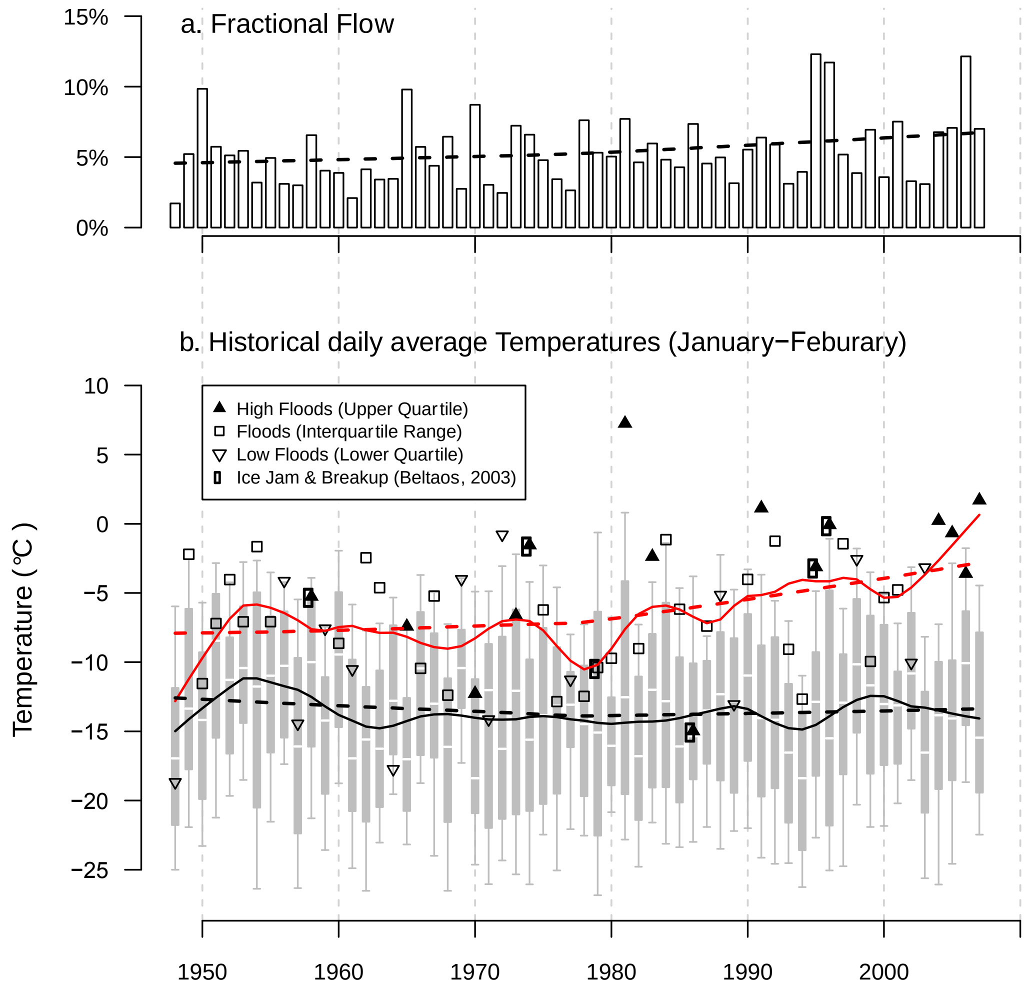

Figure 2. Temperature trend based on seasonal high flows (a) Fractional flow. The fraction of flow was plotted corresponding to the ratio of total water year flow. The dotted line shows a linear trend of the fractional flow using LOWESS (locally-weighted linear regression). (b) box plot for historical daily average temperature derived by reanalysis over the period 1948-2007. The dotted line shows a linear trend and the solid line represents a trend of temperature using LOWESS (locally-weighted linear regression) with an 11-year span.

Temperature

Winter flows are sensitive to temperature, particularly in snowmelt-dominated watersheds. Here, we examined the temperature trends using a quantile regression approach. In Figure 2a, the fraction of flow was plotted corresponding to the ratio of total water flow per year. As the linear regression indicates, there are no significant trends in the years up to 1970. However, upward trends have increased in recent years. Figure 2b shows temperatures grouped by year over the period 1948-2007. The median temperature shows slight downward trend. On the other hand, higher quantile values do show an increasing trend. There are no trends seen in the years up to 1980. However, the past 30 years clearly show that upward trends are evident in winter high flows. Changes in the high flow regime that have emerged in recent years may be considered a significant challenge for engineering, design and analysis as they have the potential to engender dramatic shifts in the magnitude and timing of winter and spring streamflows.

4. Linkages between Climate and Extreme Weather Events

It has been recognized that changes in climate may influence on the frequency or intensity of weather extreme events. These weather extremes affect springtime flow regime, as well as an emergent wintertime flood regime.

Table 1. Poisson Regression Analysis

	Estimate	Std. Error	Z value	p-value
Intercept	1.53	0.06	25.12	2×10^{-16}
TNH	-0.16	0.08	-2.13	0.033

Northern Hemisphere teleconnection pattern: Tropical/Northern Hemisphere (TNH)

As the first step, we applied a Poisson-based regression approach to assess the extent to which the number of warm-up events during January-February period may be linked to the wintertime Tropical Northern Hemisphere teleconnection index. Regression analysis results are presented in Table 1. There is a statistically significant relationship between TNH and warm event counts, with the negative phase on TNH (consistent with El Nino conditions in the tropical Pacific) predisposes the region to warmer winters, and an increased likelihood for high flow and also increases in the seasonal high flows.

5. Conclusions

The analysis presented here highlights the low-frequency variability and trends in the winter flow regime for St. John River. Given the snowmelt-dominated nature of the flow regime, the increases in winter flows and substantial changes in the flow extremes may signal emergence of flow regime with higher interannual variability and peaks into the future. While beyond the scope of this study, implications for ecosystems, as well as increases flood hazards are being investigated.

Acknowledgments

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