CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

EVOLVING TRENDS OF RAIN OVER PRECIPITATION IN CANADIAN COLD SEASON DURING THE LATE 20TH CENTURY

Hatami, S.[1, 2], Nazemi, A.[1] and Amirjabbari, A.[1]
[1] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada
[2] s_hatam@encs.concordia.ca

Abstract: Cold season across the Canadian landmass is prolonged and includes regionally important hydrological processes such as snowfall and snow accumulation. These processes provide a reliable freshwater resource during the warm season, when the majority of environmental and socio-economic activities take place. Canada, however, is in the forefront of climate change and this implies less snow during the cold season. Understanding the historical evolution in characteristics of cold season precipitation during the recent past is therefore important for evaluating the extent of climate change, and is insightful for provision of adaptive water management in the country. Here we study the evolution in ratio of rain over total precipitation (R/P) during the cold-season at 46 high-quality stations in Canada during the common period of 1961 to 2000. We examine the trend in consecutive 10-, 20- and 30-year episodes at each station to provide a notion of evolution in monotonic change in form of cold season precipitation across the country. A coefficient of variation for moving trend is defined to compare the evolution in trends between different Canadian regions. Our findings clearly illustrate consistent increments in significant trends in 30-year episodes in Atlantic and Central Canada as well as the West Coast, while more variability in evolutions of trends are observed for 10- and 20-year time frames. Further study shows that in majority of stations, the evolution in 30-year trends in R/P during the cold season coincides with the evolution of trend in mean temperature.

Keywords: Cold season precipitation, Trend analysis, Coefficient of variation, Coefficient of determination.

1 INTRODUCTION

The warming occurred within the last decades, has been pronounced at higher latitudes and during the cold season (Rosenzweig et al. 2008). One of the most important manifestations of climate change in cold region is shift in the cold season precipitation from snow to rain. This can result in significant alteration in hydrology and land-surface processes in cold regions with important relevance to management of water resource systems (Hatami et al. 2018). Several studies have focused on cold season trends in climatic variables throughout cold regions in Canada. Zhang et al. (2000) found increments in the amount of winter total precipitation, generally falls as snow, from 1900 to 1998. Yagouti et al. (2008), observed an increasing trend in annual total precipitation as well as low-intensity rain in winter. In addition, decreasing trends in cold season precipitation were noted during the period of 1976 to 2010 in Athabasca River Basin, according to Bawden et al. (2014). However, it was revealed that patterns and trends in both temperature and precipitation variables could be different from one region to another which may be a manifestation of the role of geography on observed perturbations (Fortin and Hétu 2014). Screen and Simmonds (2012) diagnosed a significant decline in snowfall amount in Arctic Ocean and Canadian Archipelago as a result of climate change. This decline is mostly shown to be as a result of changes in precipitation form (snow turning to rain) while there is no significant decrease in amount of total precipitation. Despite these progresses, it is not yet clear how the trends in cold-season rain over precipitation (hereafter R/P) is evolving in time and how the changes in temperature translates to change in R/P. This study aims at providing a systematic approach to pursue these research question. We examine the evolution in the cold-season R/P as well as monthly mean daily temperature (hereafter T) over 46 stations in Canada for the period of 1961 to 2000. We further attempt to address how the trends in T corresponds with trends in R/P during cold seasons.

2 DATA

The data network used in this study consists of 46 high-quality climate stations. The considered stations spread over Canada, extending from 52º 44' to 128º 35' west and 42º 17' to 79º 59' north. Station selection is performed based on data quality, longevity and spatial and temporal coverage. The historical monthly local climate variables are directly obtained through Environment and Climate Change Canada's historical climate archive (http://climate.weather.gc.ca). For each station, T and R/P during the cold season are calculated for true winter of each water year. True winter is defined as months with available characteristics of cold climate (e.g. snowfall and snow accumulation). Besides conducting the study in station-scale, we divided the stations into five main regions to derive some large-scale understanding of evolving trends in T and R/P. The considered regions are A: Atlantic Canada (New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador), C: Central Canada (Quebec and Ontario), P: Prairies (Alberta, Saskatchewan and Manitoba), W: West Coast (British Colombia) and N: Northern Canada (Nunavut, Northwest Territories and Yukon).

3 METHODOLOGY

The Mann – Kendall trend test (Mann 1945) and Sen's Slope estimator (Sen 1968) are used to describe the existence of monotonic change in anomalies of cold season R/P and T over the period of 1961-2000. The threshold for identifying significant trends is considered as *p*-value = 0.05. To account for temporal changes in trends in anomalies of variables, moving windows of 10-, 20- and 30-year are considered. We slide the moving-windows over the timeseries of climatic variables year by year. Using this sampling procedure 31, 21 and 11 data snapshots are obtained, respectively for 10-, 20- and 30-year periods – see Nazemi et al. (2017) for more details on the methodology. By moving the window over the timeseries the evolution of trend for the considered variable can be quantified (see Jaramillo and Nazemi, 2018). To provide a notion for the variation in trend, we defined the scaled versions of the coefficient of variation for moving trend:

$$[1] \quad C_T = \frac{std(\bigcup_{i=1}^{m} S_n^m)}{S_{40}}$$

where C_T is the coefficient of variation for moving trend, $std(.)$ is standard deviation, S_n^m is the Sen's Slope over the m^{th} moving window with length of *n* and S_{40} is the trend throughout the whole forty year period. For quantifying the co-occurrence of trends in cold-season T and R/P, the Kendall's tau dependence coefficient (Kendall 1938) is used. Similarly, the threshold for identifying significant dependence is considered as *p*-value = 0.05. To assess the described variance of the trend in cold season R/P and T, the coefficient of determination (Legates and McCabe 2005) is used.

4 RESULTS AND DISCUSSION

4.1 Trends of Rain over Precipitation and Mean Temperature within 1961-2000

Considering the results of long-term dependency, R/P is significantly dependent to T in most of stations throughout all regions of Canada, specifically at coastal regions (all of stations showing significant dependency in Atlantic Canada and West Coast). The significant dependency throughout whole Canada is also observed over 87 percent of stations. All stations show positive dependency between R/P and T. The existing dependency between R/P and T must be further investigated to assess the possible effects of monotonic changes in temperature on rain over precipitation trends. Figure 1, right panels, illustrates the spatial distribution of long term trends in anomalies of cold season rain over precipitation (first row) and monthly mean temperature (second row). Upward and downward triangles are indicators of positive and negative trend respectively, while the red color saturation shows the magnitude of Sen's Slope at each station. Looking at anomalies of cold-season R/P, it is observed that this variable mostly increases throughout Canada. The strong positive trends are observed in Atlantic Canada, Central Canada and Prairies with more than 40 percent of stations with significant trends in each region. The anomalies of T have also increased significantly in 30 percent of stations throughout Canada – see Figure 1. Statistically significant positive trends are mostly observed in Northern Canada, Central Canada and Prairies. However, a few stations exhibit negative non-significant trends, which are mainly located at Atlantic Canada.

4.2 The Evolution of Trend for 10-, 20- and 30-Year Episodes and Coefficient of Variation for Moving Trend

Second, third and fourth column panels from left in Figure 1 portray the evolution of trend in anomalies of R/P and T for each station over 10-, 20- and 30-year windows respectively. The red color spectrum shows the positive values in trends while the blue color is an indicator of decreasing trends. Stations are sorted from east to west, arranged from bottom to upper rows, with stations located at Northern Canada on the very top rows of each subplot. The lines at each color-bar show the level of significance for trends in each window size. The figure clearly displays the higher variability in change and even sign of Sen's Slopes in windows with shorter time episodes for both R/P and T. However, many regional patterns are observed with rather same occurrence in different window sizes. The patterns for R/P coincides considerably with the same patterns in T in various occasions. For instance, there is an evident decline in positive trends over the first half of studied period, proceed by increment in the positive trend observed for both R/P and T over Atlantic Canada. The pattern is completely opposite in West Canada and Parries as the positive trends in anomalies of R/P and T are increased throughout the first half windows and then started descending in the rest of period.

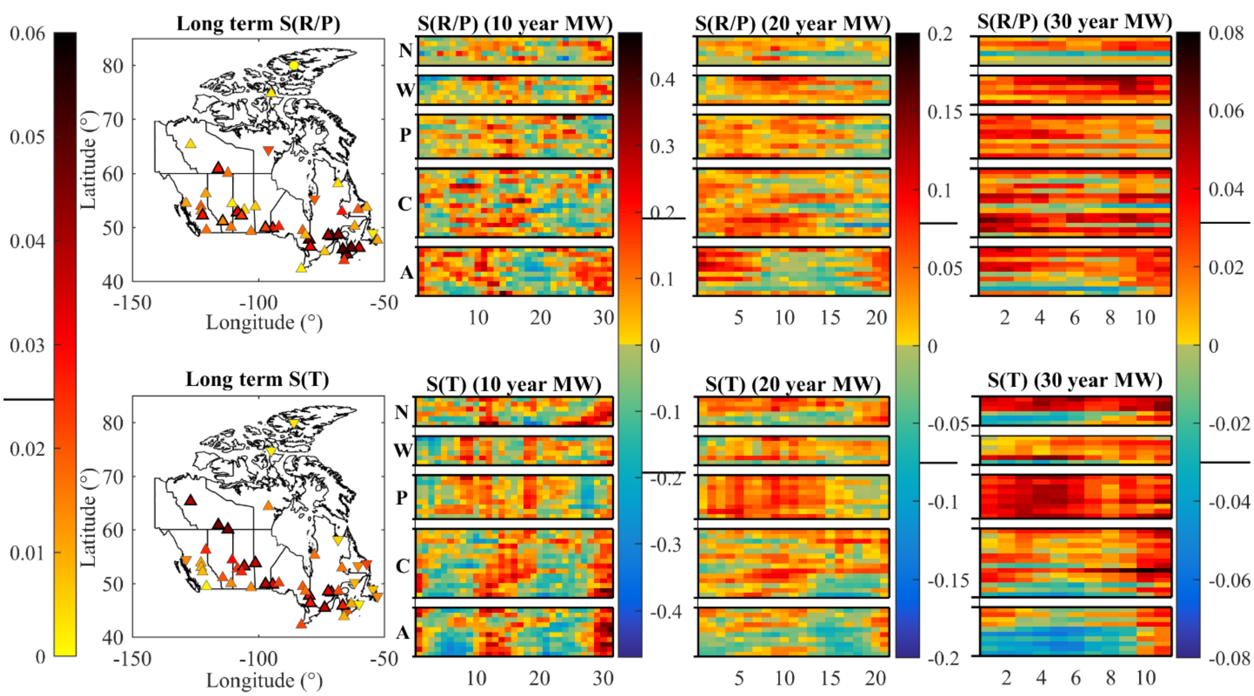

Figure 1: Distribution of long term trends in anomalies of cold season R/P and T (first column) and the evolution of trend for 10-, 20- and 30-year episodes (second, third and fourth columns respectively).

To investigate the variability of trend over time in each region and its sensitivity to the size of the moving window, Figure 2, depicts the coefficient of variation for the moving average for both R/P and T, in the five regions as well Canada (CAN) as whole. This figure illustrates significantly higher variability in trends when smaller moving windows are considered. Having said that, the variability is also largest at Northern Canada comparing to other regions considering R/P and T for all window size. This is consistent with the results obtained from the evolution of trends in Figure 1, showing higher fluctuation in magnitude and even sign of trends in Northern Canada over the period of study.

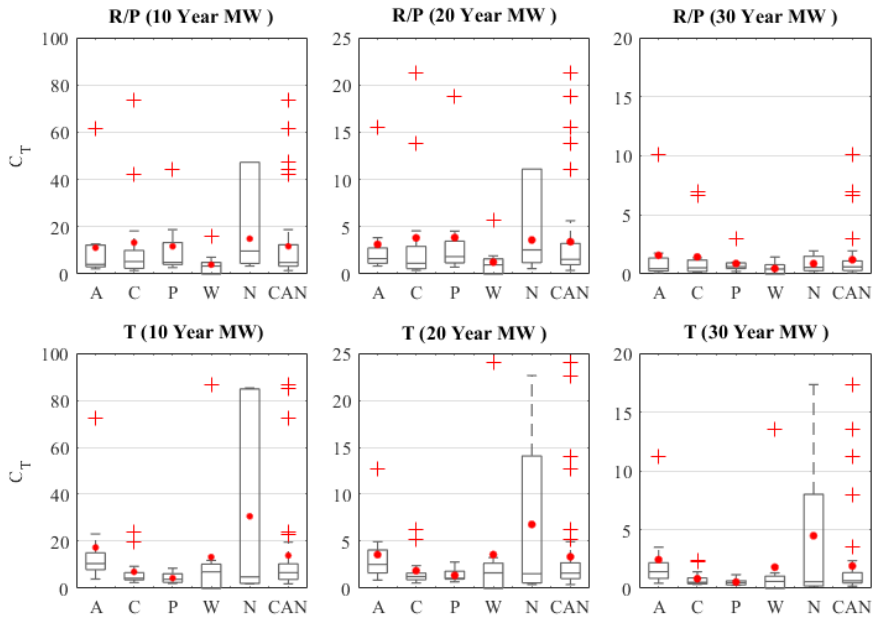

Figure 2: Coefficient of variation for moving trend of R/P and T in the five regions as well as Canada as a whole for 10- (first column), 20- (second column) and 30-year (third column) episodes.

4.3 Possible temperature drivers for evolution in trend in rain over precipitation

To assess the possible effects of changes in T on R/P, the coefficient of determination (R^2) between trends of R/P and T is estimated at each station – see Figure 3. The size of circles is related to the value of the R^2: the bigger the circle is, the higher the R^2. The blue color represents the negative dependency between the trends of R/P and T while the red color spectrum shows the positive dependency. Stations with non-significant positive or negative dependencies between R/P and T or the trends of these variables are shown in pink or light blue. Looking at this figure, there is clear pattern of stations at Atlantic and eastern Central Canada as well as few stations over West Coast and Parries with higher R^2 and significant dependency for all window sizes. This analysis shows stronger impacts of changes in temperature on trends of rain over precipitation over mentioned regions.

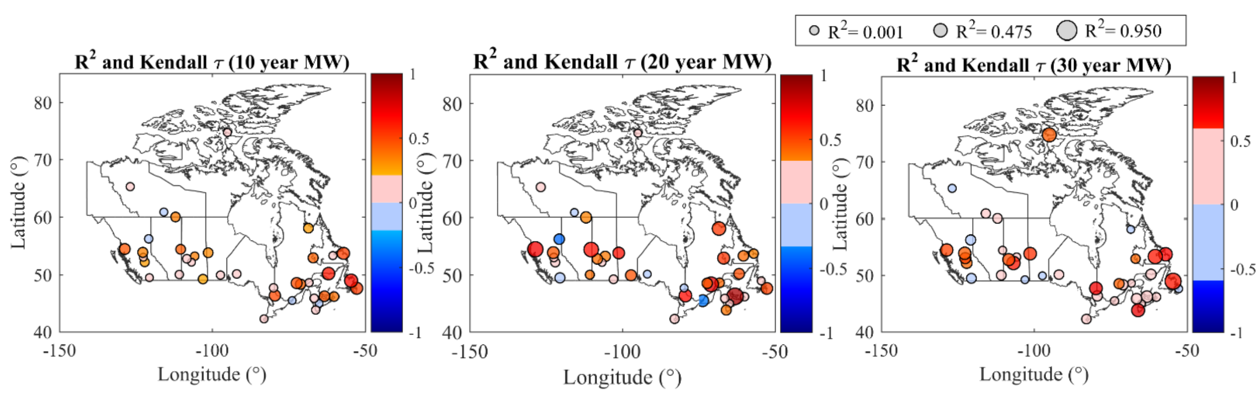

Figure 3: The R^2 between the Sen's Slope of R/P and T for 10- (first column), 20- (second column) and 30-year (third column) episodes.

5 CONCLUSION

Understanding the changes in characteristics of cold season precipitation and the causes of these changes is essential for evaluating the extent of climate change in cold regions. In this study, a systematic framework is proposed to quantify the long-term trends in rain over total precipitation as well as the evolution of this trend considering consecutive 10-, 20- and 30-year episodes during the cold season at 46 stations throughout Canada. We also attempt to find the possible impacts of changes in trend of temperature on the trends of R/P due to existing significant dependency between R/P and T in majority of stations. The trends in both variables are positive across Canadian landmass with significant trends mostly observed in Central Canada and Prairies. Considering the evolution of monotonic change in R/P and T for moving-windows of 10-, 20- and 30-year, similar patterns are observed for both variables while the observed patterns are not homogenous in different regions of Canada. Moreover, we show significantly higher variability in evolutions of trends when smaller moving windows are considered. Note that in terms of regional variations in trends of both R/P and T, Northern Canada has the highest variability comparing to other regions. There is also a clear pattern of stations at Atlantic and eastern Central Canada as well as few stations over West Coast and Parries in which trends in temperature are found to be significantly impactful on trends of rain over precipitation. These observations suggest the impacts of climate change on the form of cold season precipitation is one of the most important concerns for future studies of Canadian freshwater resources.

REFERENCES

Bawden, A.J., Linton, H.C., Burn, D.H. and Prowse, T.D. 2014. A Spatiotemporal Analysis of Hydrological Trends and Variability in the Athabasca River Region, Canada. *Journal of Hydrology,* **509**: 333–42. https://doi.org/10.1016/j.jhydrol.2013.11.051.

Fortin, G., and Hétu, B. 2014. Estimating Winter Trends in Climatic Variables in the Chic-Chocs Mountains, Canada (1970-2009). *International Journal of Climatology,* **34**(10): 3078–88.

Hatami, S., Zandmoghaddam, S., and Nazemi, A.. 2018. Statistical Modeling of Monthly Snow Depth Loss in Southern Canada. *Journal of Hydrologic Engineering,* **24**(3): 1–13. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001763.

Jaramillo, P. and Nazemi, A. 2018. Assessing Urban Water Security under Changing Climate : Challenges and Ways Forward. *Sustainable Cities and Society*, **41**(Aug): 907-918.

Kendall, M.G. 1938. A New Measure of Rank Correlation. *Oxford University Press on Behalf of Biometrika Trust* , **30**(1): 81–93. http://www.jstor.org/stable/2332226.

Legates, D.R. and McCabe, G.J. Jr. 2005. Evaluating the Use of 'Goodness of Fit' Measures in Hydrologic and Hydroclimatic Model Validation. *Water Resources Research,* **35**(1): 233–41.

Mann, H.B. 1945. Nonparametric Tests Against Trend. *Econometrica,* **13**(3): 245. https://doi.org/10.2307/1907187.

Nazemi, A., Wheater, H.S, Bonsal, B., and Mekonnen, M. 2017. Forms and Drivers of Annual Streamflow Variability in the Headwaters of Canadian Prairies during the 20th Century. *Hydrological Processes,* **31**: 221–239.

Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G., Menzel, A. et al. 2008. Attributing Physical and Biological Impacts to Anthropogenic Climate Change. *Nature,* **453** (May):353–58. https://doi.org/10.1038/nature06937.

Screen, J.A and Simmonds, I. 2012. Declining Summer Snowfall in the Arctic : Causes , Impacts and Feedbacks. *Climate Dynamics,* **38**: 2243–56, https://doi.org/10.1007/s00382-011-1105-2.

Sen, P.K. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association,* **63**(324): 1379–89.

Yagouti, A., Boulet, G., Vincent, L., Vescovi, L. and Mekis., E. 2008. Observed Changes in Daily Temperature and Precipitation Indices for Southern Québec, 1960-2005. *Atmosphere - Ocean,* **46**(2): 243–56.

Zhang, X., Vincent, L.A., Hogg, W.D., Niitsoo, A., 2000. Temperature and Precipitation Trends in Canada during the 20th Century. *Atmosphere-Ocean,* **38**(3): 395-429.