1.8 PRECIPITATION AND TEMPERATURE RELATED CLIMATE INDICES FOR CANADA

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1. INTRODUCTION

Climate affects just about every aspect of nature and human life. Canada's climate has begun to change in a number of ways. Climate change indices help us to determine how our climate is changing, and also to identify the direction and prospect for the future. Many recent studies are based on indices derived from temperature and precipitation (Groisman et al. 2003; Klein-Tank and Können, 2003; Frich et al. 2002; Peterson et al. 2001; Vincent and Mekis, 2004) and results are also presented on web sites (ECA; ETCCDMI). It is very important to separate results originated from archive and from "homogenized and/or adjusted" datasets. Using "homogenized and/or adjusted" data provides the advantage of having non-climatic influences (such as changes of instrumentation) taken into account. In addition, observations from close-by stations are occasionally joined to produce longer datasets. The present analysis is based on the Adjusted Historical Canadian Climate Database (AHCCD) developed by Climate Research Branch. The methodology to compute the indices follows the guidelines provided in the European Climate Assessment (ECA) project. Additional indicators were included to describe the major climate characteristics of Canada. The separate existence of daily rain gauge and snow ruler measurements provide an additional opportunity of studying the changes of precipitation elements further. As of today 54 different annual and seasonal, rain, snow and total precipitation indices and 56 annual and seasonal minimum, mean and maximum temperature indices are computed and analysed for the periods 1900-2003 and 1950-2003. The objective of this work is to present the trends and variations of selected, mainly snow related indices.

2. DATA AND METHODS

2.1 *Temperature indices*

Daily maximum, minimum and mean temperatures for 210 stations across the country were used to calculate the temperature indices. Homogeneity problems due to station relocation and changes in observing procedures were addressed using a procedure based on regression models (Vincent et al. 2002). Table 1 presents the list of the temperature indices. The annual average of the daily mean temperature illustrates the significant warming observed in Canada. Indices of economic and hydrologic interest are also presented. The frost days are the days with night time temperature falling below 0°C. The frost-free season represents the period of time during which the night time temperature remains above freezing. Its starting and ending dates correspond to the last day and first day of frost respectively, which mostly occur during the spring and fall. Finally, the growing degree days and growing season length are used as indicators of crop viability. The growing degree days are based on the daily mean temperature departures from a constant (5°C is used here) and the departures are summed to determine the annual number of degree days. The growing season length is the period during which the running 5-day daily mean temperature remains above 5°C.

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2.2 *Precipitation indices*

The Canadian Historical Rehabilitated Precipitation Dataset (Mekis and Hogg, 1999) used in the study contains 495 long-term and adjusted daily rain and snow. For each rain gauge type, corrections to account for wind undercatch, evaporation and gauge specific wetting loss were implemented. For snowfall, density corrections based upon coincident ruler and Nipher measurements were applied to all ruler measurements. Trace corrections were added to the original measurements depending on the station location and measurement program. The list of the selected precipitation indices are in Table 1. The indicator computation was only applied for greater then trace events (except for the first 3 elements of the table). The changes in annual total precipitation and annual snow are presented. The ratio of snowfall to total precipitation describes the change in the form of precipitation. To study the changes in precipitation frequencies, trends are computed on the annual number of days with rain or snow, and with snow separately. To measure the intensity of the events, the simple day intensity index (ratio between annual total amount and number of days) for both total precipitation and snow is examined. The number of maximum consecutive dry days is used to characterize long dry spells at each location and countrywide.

Table 1. Number of stations with significant negative, not significant [ns] and significant positive trends for temperature and precipitation indices over 1900-2003 and 1950-2003 respectively (significant at 5% level). The number in bold and shaded indicates that more than 10% and 20% of the stations displays a significant trend respectively.

	Indices - definition	Unit	1900-2003				1950-2003				Fig.
			-	ns	+	tot	-	ns	+	tot	
Temperature	Annual mean temperature	°C	0	23	**36**	59	0	97	**57**	154	1a
	Frost days	# days	**40**	25	0	65	**49**	108	2	159	1b
	Frost-free season	# days	0	30	**35**	65	0	124	**35**	159	1c
	Frost free season starting date	Julian date	**41**	24	0	65	**34**	125	0	159	1d
	Frost free season ending date	Julian date	1	44	**20**	65	0	145	14	159	
	Growing degree days	°days	0	31	**28**	59	0	103	**51**	154	
	Growing season length	# days	0	51	**8**	59	0	140	14	154	
Precipitation	Annual total precipitation	mm	2	35	**35**	72	5	176	**28**	209	
	Annual snow	mm	**8**	54	**14**	76	**34**	177	10	221	2a
	Snow to total precipitation ratio	%	**17**	48	7	72	**44**	161	4	209	2b
	Days with rain or snow	# days	1	20	**51**	72	8	101	**99**	208	
	Days with snow	# days	2	38	**36**	76	**31**	161	**29**	221	2c
	Simple daily intensity index of total precipitation	mm/day	**40**	30	2	72	**57**	142	9	208	
	Simple daily intensity index of snow	mm/day	**40**	30	4	74	**59**	149	13	221	2d
	Max no of consecutive dry days	# days	**47**	25	0	72	**34**	172	2	208	

2.3 *Methods*

The trend computation is performed not using the conventional least square method but the non-parametric Kendall's test which is less sensitive to the non-normality of a distribution and less affected by extreme values and outliers. Since serial correlation is often present in many climatological time series, the procedure also takes into account the first lag autocorrelation: a detailed description of the trend computation can be found in Zhang et al. 2000. For missing values, the 3/5 rule was applied for both temperature and precipitation indices (in any month if more than 3 consecutive days or more than 5 random days are missing, then the month is missing for the year). For each station, trends are computed only if more than 80% of the data is present. Since very few stations have climate observations prior 1945 in the northern regions of the country (north of 60°N), trends are analysed and mapped for two separate time periods: 1950-2003 and 1900-2003.

3. RESULTS

3.1 *Trends in temperature indices*

The findings are summarized in the first part of Table 1 for both periods. For 1950-2003, more than third of the stations experience significant annual mean temperature increase. Figure 1a shows that the warming is across the country with the exception of a small region in the northeast where several stations show decreasing non-significant trends. The temperature increase reaches as much as 2°C at many stations. The number of frost days has decreased almost everywhere and significant decreasing trends of 10 to 20 days are found at several stations both on western and eastern regions (Fig. 1b). The frost free season is longer (Fig. 1c) mostly due to an early start (Fig. 1d) while the ending date remains constant. Over the same period, the growing degree days have increased by 100 to 150 °days at many stations while the growing season is longer (significant trends are found only in the west). The signals are similar for the longer 1900-2003 period. Significant warming of 1 to 2°C is observed across the country which leads to less frost days and to longer frost free season. Significant increasing trends in growing degree days are also observed at more than the third of the stations while the growing season length has not really changed over the past century.

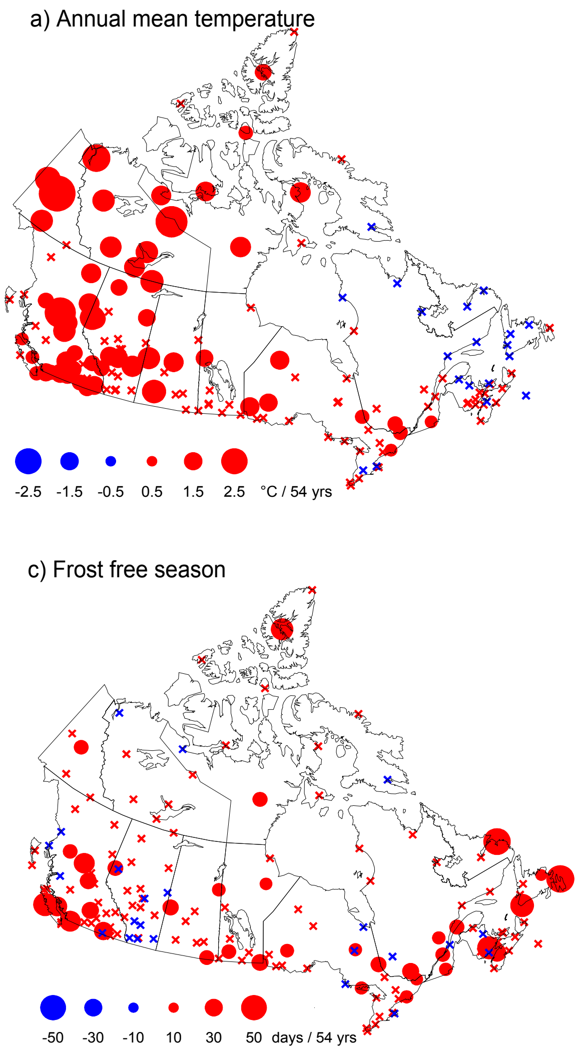

Figure 1. Trends in four temperature indices over 1950-2003. Crosses indicate non-significant trends at the 5% level.

3.2 *Trends in precipitation indices*

Trend results for both periods are summarized in the second part of Table 1. The direct consequence of the warming and fewer frost days is the decrease of snowfall in most regions of the country (Fig. 2a) in spite of the fact that a third of the stations display increasing annual precipitation. The relation of snowfall to total precipitation is further explored by computing the snow to precipitation ratio. Figure 2b displays very similar pattern to the annual snow with a stronger decreasing signal, since snow is decreasing and total precipitation in increasing. The only exception is a few stations located on the north where the most typical form of precipitation is snow. The number of days with precipitation has strongly increased through the whole country, the change is occurring mainly in the form of rain which corresponds well with the increase observed in frost free season length. The number of days with snow shows a mixture of positive and negative trends for the recent 54 years of data (Fig. 2c). The change is more significant for the 1900-2003 period: at half of the 76 stations the days with snowfall are more frequent. The generally decreasing picture of the simple day intensity index of snow suggests that the average snow intensity has decreased in time (Fig. 2d). Similar pattern was found in the simple day intensity index of precipitation. The decrease of maximum number of consecutive dry days is in agreement with the generally increasing number of precipitation event.

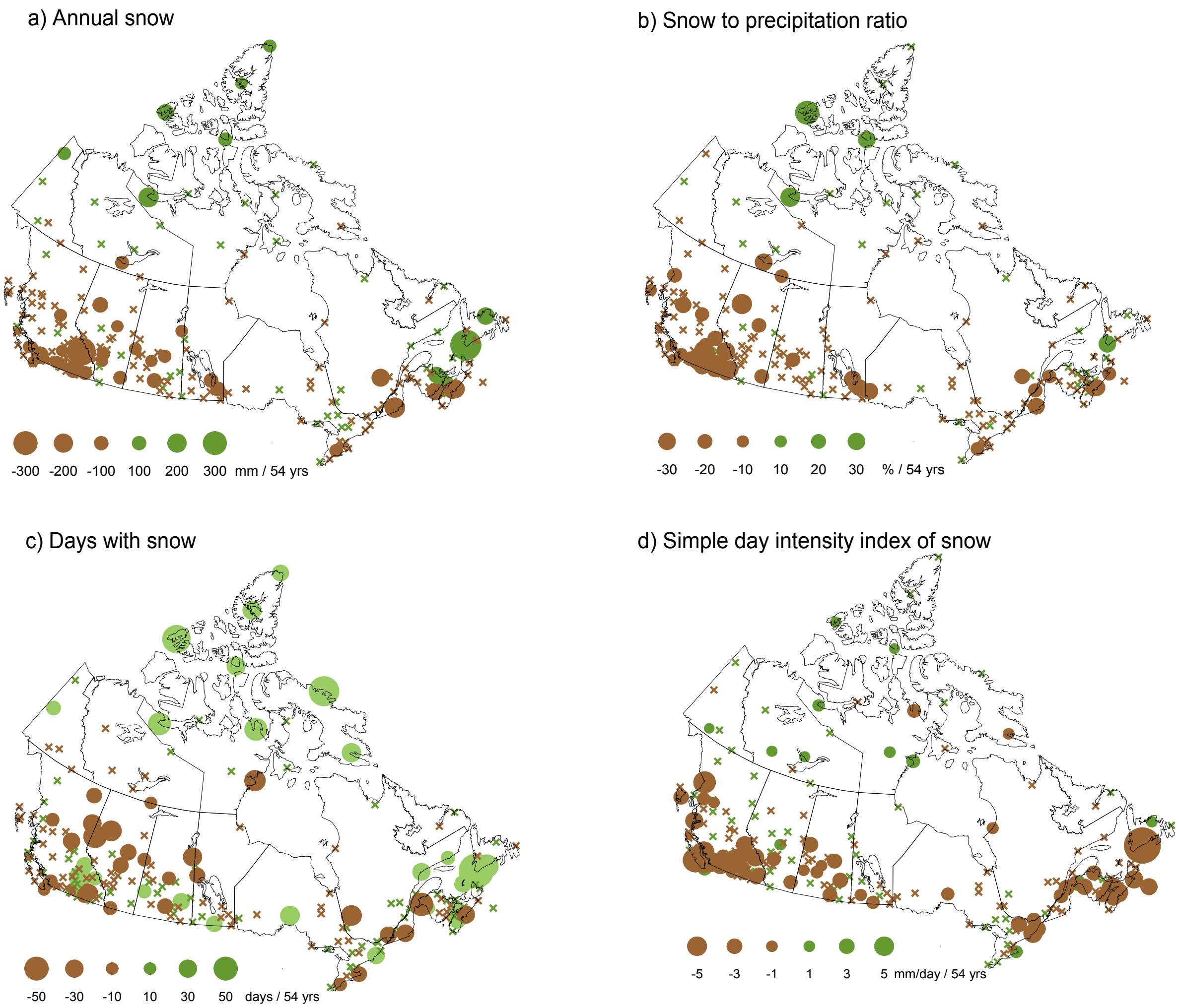

Figure 2. Trends in four precipitation indices over 1950-2003. Crosses indicate non-significant trends at the 5% level.

Annual snow to total precipitation ratio was averaged for all stations in Canada (Fig. 3). Due to the higher number of stations included in time (any station could qualify if the given year had good quality data) the message is slightly different. The 11-year running average clearly identifies periods with increasing trend (from the 1930's until the early 1970's) and decreasing trend (last 30 years) trend. This example demonstrates clearly that summaries originated from individual station trend results (Table 1) and time series characterizing the whole country by including more locations (Fig. 3) can provide slightly different message.

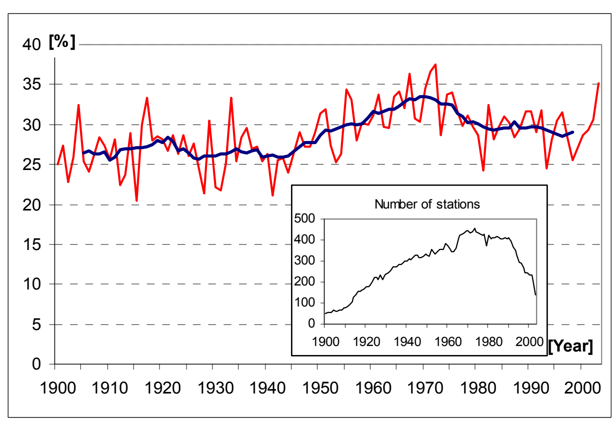

Figure 3. Snow to total precipitation ratio for Canada over the 1900-2003 period.

4. CONCLUSION

In previous studies it was found, that the changes in precipitation events were mainly due to the changes in frequency and not in extremes (Zhang et al, 2001, Vincent and Mekis, 2004). In this preliminary study, the major focus was to explore of the connection between temperature and precipitation. To get a stronger climate change signal it is important to find out whether the messages from several climate change indicators are consistent. Increasing temperature, less frost days, earlier start of the frost free season, more growing degree days all lead to the decrease of snow amount, especially relative to the total precipitation. The simple day intensity index of snow also shows that the average daily snow has decreased.

5. REFERENCES

Frich, P. and co-authors, 2002: Observed coherent changes in climate extremes during 2nd half of the 20th century. Clim. Res. 19: 193-212.

Groisman, P.Y., S. Bomin, R.S. Vose, J.H. Lawrimore, P.H. Whitfield, E. Førland, I. Hannssen-Baur, M.C. Serreze, V.N., Razuvaev and G.V. Alekseev, 2003: Contemporary climate changes in high latitudes of the northern hemisphere: daily time resolution. Proceedings of the 14th Symposium on Global Change and Climate Variations.

Klein-Tank, AMG, G.P. Können, 2003: Trends in indices of daily temperature and precipitation extremes in Europe, 1946-99. J. Climate, 16, 3665-3680.

Mekis É. and W.D. Hogg, 1999: Rehabilitation and analysis of Canadian daily precipitation time series. Atmosphere-Ocean, 37, 53-85.

Peterson, T.C., C. Folland, G. Gruza, W. Hogg, A. Mokssit and N. Plummer, 2001: Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998-2001. Report WCDMP-47, WMO-TD 1071, World Meteorological Organization, Geneva, Switzerland.

Vincent, L.A., X. Zhang, B.R. Bonsal and W.D. Hogg, 2002: Homogenization of daily temperatures over Canada. J. of Climate, 15, 1322-1334.

Vincent L. and É. Mekis, 2004: Variations and trends in climate indices for Canada. CD-ROM Proceedings, 15th Symposium on Global Change and Climate Variations, Seattle, Washington, USA.

Zhang, X., L.A. Vincent, W.D. Hogg and Ain Niitsoo, 2000: Temperature and precipitation trends in Canada during the 20th Century. Atmosphere and Ocean, 38, 395-429

Zhang, X., W.D. Hogg and É. Mekis, 2001: Spatial and temporal characteristics of heavy precipitation events over Canada. J. Climate, 14, 1923-1936.

Related important links:

Adjusted Historical Canadian Climate Data AHCCD web site: http://www.cccma.bc.ec.gc.ca/hccd/
Monitoring and Analysis of Climate Variability and Change web site:
http://www.ncdc.noaa.gov/oa/wmo/ccl/index.html
ETCCDMI Expert Team on Climate Change Detection Monitoring and Indices web site:
http://cccma.seos.uvic.ca/etccdmi/index.shtml
ECA European Climate Assessment and Dataset web site: http://eca.knmi.nl/