Chapter 1

Comparison of the Temporal Variability of Maximum Daily Temperatures for Summer Months in Relation to El Nino Events in Southern Québec

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Additional information is available at the end of the chapter

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Abstract

The goals of this study were (1) to compare the long-term trend of the interannual variability of maximum daily temperatures for four summer months (June, July, August, and September) using the Spearman's rank correlation coefficient and Mann-Kendall tests and (2) to analyze the link between these temperatures and El Niño events of varying intensities using the linear correlation method. Data from 23 stations for the period from 1950 to 2010 were analyzed. As far as the analysis of the long-term trend is concerned, the observed warming is greater for the last 2 months (August and September) than for the first 2 months (June and July) of the summer season, likely as a result of the warming of ocean surface waters. As for the link between El Niño events and summer maximum daily temperatures, a negative correlation was highlighted for the first time between these two variables for southern Quebec. However, this correlation is only observed for the two "cooler" summer months (June and September), likely due to a weak influence of site (station) characteristics on maximum daily temperature variations.

Keywords: maximum daily temperatures, summer, El Niño events, long-term trend, correlation, southern Quebec

1. Introduction

It is a well-established fact that, in cool temperate regions, the extent of climate warming will vary seasonally. Several studies have compared the interannual variability of temperatures between seasons in Canada (e.g., [1–7]). These studies have shown that, since 1950, climate warming is more pronounced in winter and spring than in summer and fall. However, Guerfi et al. [8]

showed that, in Quebec, climate warming is not as strong in winter, with very few stations analyzed recording a significant increase in maximum and minimum daily temperatures since 1950. Assani et al. [9] showed that, in Quebec, climate warming is more generalized and greater in summer than in winter. Thus, unlike what is observed for winter, the significant increase in summer maximum and minimum daily temperatures since 1950 is observed at many stations. Moreover, the observed nighttime warming in summer is greater than the observed daytime warming. These studies, however, only looked at variability between seasons, and do not address interannual variability for individual seasons (intraseasonal variability) in order to see if the extent of warming is the same or not for each month of a given season. The first objective of this study is, therefore, to compare the long-term trend of the interannual variability of maximum daily temperatures for the four months (June, July, August, and September) that make up the summer season in Quebec. The underlying hypothesis is that the increase in temperature is similar for the four summer months in southern Quebec.

In addition, analysis of the relationship between large-scale climate oscillations and summer climate in Canada has revealed that the links between these variables are relatively weak and variable compared to what is observed for the same variables in winter (e.g., [10]). However, no study has looked at the relationship between El Niño events and summer temperatures in Quebec. El Niño events affect temperatures at the global scale, and intense El Niño events are generally associated with relatively high temperatures (positive anomalies) at the global scale (e.g., [11]). The question is, therefore, whether there is a link between the intensity of El Niño events and maximum daily temperatures during the four summer months in Quebec, something that has not been addressed before.

2. Methods

2.1. Choice of stations

Twenty-three stations were selected to analyze the temporal variability of summer (June–September) temperature and rainfall (**Table 1** and **Figure 1**). The selection of these stations was primarily based on the availability of continuous measurements of temperature over the period from 1950 to 2010. This period was selected in order to analyze the largest possible number of stations. Prior to 1950, there were very few stations in Quebec where temperature and rainfall was measured. Since 2000, to streamline the measurement of hydroclimate variables in Canada and Quebec, many weather and hydrometric stations were shut down. For this study, all stations for which hydroclimate variables have been measured quasi-continuously for at least 50 years during the period from 1950 to 2010 were used. Summer temperature and rainfall data were taken from the Environment Canada website (http://www.climate.weatheroffice.ec.gc.ca/, viewed in March 2016). For each summer month, a series of maximum daily temperatures was produced.

As far as El Niño events are concerned, only events of differing intensities (weak, moderate, strong, and very strong) following the NOAA classification ([12]) were selected. From 1950 to 2010, 22 El Niño events were recorded, including 11 events of weak intensity

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Stations	Code	Years	ID	Latitude (N)	Longitude (W)	Altitude (m)
Coaticook	01	1950–2010	7021840	45°09′	71°48′	259
Les Cèdres	02	1950–2010	701429	45°18′	74°03′	47
Magog	03	1950–2010	7024440	45°16′	72°07′	274
Montréal (Trudeau)	04	1950–2010	7025250	45°28′	73°45′	36
Oka	05	1951–2010	7015730	45°30′	74°04′	91
Philipsburg	06	1950–2010	7026040	45°02′	73°05′	53
St Ephrem	07	1950–2010	7027200	46°04′	70°58′	312
St-Malo d'Auckland	08	1950–2010	7027520	45°12′	71°30′	564
Ste Anne de la Pérade	09	1950–2010	7016840	46°38′	72°14′	16
Valleyfield	10	1950–2010	7028680	45°17′	74°06′	46
Bagotville	11	1950–2010	7060400	48°20′	71°00′	159
Mont Joli A	12	1950–2006	7055120	48°36′	68°13′	48
Natashquan A	13	1950–2002	7045410	50°11′	61°48′	575
Sept îles A	14	1950–2001	7047910	50°13′	66°16′	310
Ste Rose de Dégelis	15	1950–2001	7057720	47°34′	68°38′	151
Trois-Pistoles	16	1950–2001	7058560	48°09′	69°07′	58
Chelsea	17	1950–2010	7031660	45°31′	75°47′	112
La Tuque	18	1950–2001	7074240	47°24′	72°47′	152
Nicolet	19	1950–2010	7025440	46°12′	72°37′	30
Nominingue	20	1950–2010	7035520	46°23′	75°03′	305
St Alban	21	1950–2010	7016800	46°43′	72°05′	76
St Jérôme	22	1950–2010	7037400	45°48′	74°03′	169
Milan	23	1950–2010	7024920	45°37′	71°07′	482

Table 1. Some data from analyzed stations.

(1951–1952, 1952–1953, 1953–1954, 1958–1959, 1968–1969, 1969–1970, 1976–1977, 1979–1980, 1994–1995, 2004–2005, and 2006–2007), 6 events of moderate intensity (1963–1964, 1986–1987, 1987–1988, 1991–1992, 2002–2003, and 2009–2010), 3 events of strong intensity (1957–1958, 1965–1966, and 1972–1973), and 2 events of very strong intensity (1982–1983 and 1997–1998). Based on Oceanic Niño Index (ONI, the running 3-month mean SST anomaly for the Niño 3.4 region) values, an event is considered to be an El Niño event when the ONI values for five consecutive overlapping 3-month periods are at or above the +0.5^{o} anomaly. The threshold is further broken down into weak (with a 0.5–0.9 SST anomaly), moderate (1.0–1.4), strong (1.5–1.9), and very strong (≥2.0) events [12]. However, for this study, rather than using ONI values, Southern Oscillation Index (SOI) values were used because they are available and widely used in the scientific literature. Moreover, using SOI values makes it

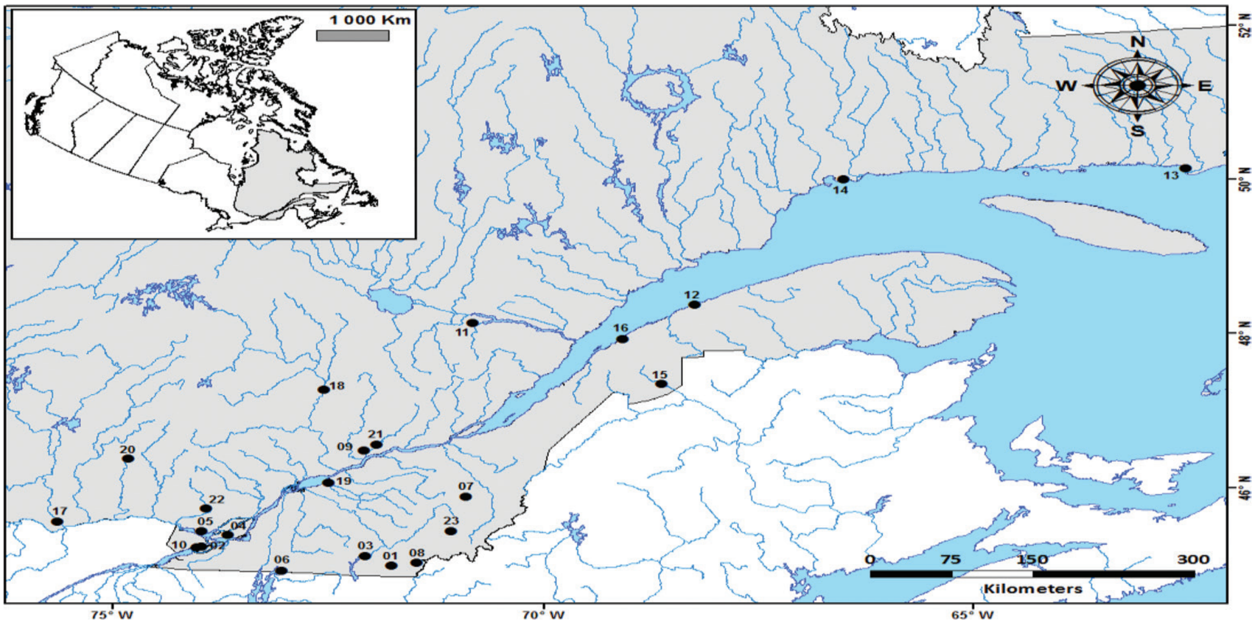

Figure 1. Location of stations analyzed.

possible to readily compare the results of this study with those of previous work. It is, however, important to note that SOI values associated with the different El Niño intensities are negative because they are derived from differences in pressure, whereas ONI values are measurements of surface water temperatures of the tropical Pacific Ocean. Be that as it may, the two types of indices (SOI and ONI) lead to the same results due to their strong correlation.

For each of the 22 El Niño events, the following six seasonal mean values of SOI indices were then derived: AMJ-1 is the mean SOI value for the months of April, May, and June of the previous years; JAS-1 is the mean SOI value for the months of July, August, and September of the previous year; OND-1 is the mean SOI value for the months of October, November, and December of the previous year; JFM is the mean SOI value for the months of January, February, and March of the current year; AMJ is the mean SOI value for the months of April, May, and June of the current year; and JAS is the mean SOI value for the months of July, August, and September of the current year. SOI index data were taken from the NOAA website (National Oceanic and Atmospheric Administration, http://www.cdc.noaa.gov/ClimateIndices/List, viewed on November 23, 2017). Indices for the previous year, when the El Niño event is ongoing in the Pacific Ocean, were included because the influence of El Niño events on climate in Quebec is observed after a lag of at least 6 months.

2.2. Statistical analysis

Statistical analysis of data was conducted in two steps. In the first step, the Spearman's rank correlation coefficient and Mann-Kendall tests were used to constrain the long-term trend of the temporal variability of maximum daily temperatures for the four summer months. Both tests are widely used in climate science and have been described in many articles (e.g., [13]). Because both tests yielded the same results, we only present results obtained using the Spearman's rank coefficient test. It is important to note that the series analyzed did not show any autocorrelation.

Spearman's correlation coefficient is calculated using the following equation [13]:

$$r_s = \frac{\sum i\, y_i - (\sum i)^2/n}{s_i\, s_{yi}} \tag{1}$$

$$s_i^2 = \sum i^2 - (\sum i)^2/n \quad \text{and } s_{yi}^2 = \sum y_i^2 - (\sum i)^2/n \tag{2}$$

where n is the sample size (number of years during which streamflow was measured) and *yi* is the rank of the value of streamflow measured in year i for streamflow values ranked in order of increasing magnitude.

The test critical value is calculated using the following equation:

$$t_s = r_s\sqrt{\frac{n-2}{1-r_s^2}} \tag{3}$$

The null hypothesis (absence of a significant trend) is rejected if the value of t_s is higher than the value appearing in the table of Student's t values for a given probability level with n-2 degrees of freedom.

The last step consisted of correlating maximum daily temperatures for the four summer months with the six SOI series for the 22 El Niño events of differing intensities. It is important to note that years that do not match the years of occurrence of an El Niño event were excluded from this analysis so as to only look at the influence of El Niño events on the interannual variability of summer maximum daily temperatures. No previous study has considered El Niño events exclusively. In this study, only the simple correlation method was used because multivariate analysis methods (canonical correlation analysis and redundancy analysis) did not yield conclusive results due to the relatively small sample size (22).

3. Results

3.1. Comparison of the long-term trend of maximum daily temperatures for the four summer months

Results obtained using the Spearman's rank correlation coefficient test is presented in **Table 2**. Very little change in the long-term trend is observed for June and July, with only three stations recording changes for these two months. In contrast, changes in the long-term trend are observed at numerous stations (more than 40% of stations analyzed) for August and September. For all four summer months, these changes reflect a positive long-term trend or a significant increase in maximum temperatures over time. Thus, statistically significant values of rare all positive (see **Figure 2**). These results are identical to those obtained using the Mann-Kendall test.

Stations	June		July		August		September	
	r_s	t_s	r_s	t_s	r_s	t_s	r_s	t_s
Coaticook	−0.1386	1.0750	−0.1887	1.4760	−0.0015	0.0112	0.1217	0.9419
Les Cèdres	0.1416	1.0988	0.1899	1.4855	**0.2854**	**2.2870****	**0.2548**	**2.0242****
Magog	−0.0615	0.4739	−0.0512	0.3940	0.1266	0.9804	**0.2542**	**2.0191****
Montréal (Trudeau)	0.0580	0.4462	0.0902	0.6958	0.1976	1.5481	**0.2602**	**2.0696****
Oka	0.0841	0.6428	0.0307	0.2339	0.1534	1.1820	**0.2419**	**1.8989***
Philipsburg	−0.0232	0.1782	−0.0173	0.1330	0.1329	1.0298	0.1817	1.4195
St Ephrem	0.1794	1.4000	0.1734	1.3525	**0.4047**	**3.3993*****	**0.3172**	**2.5695****
St-Malo d'Auckland	**0.2887**	**2.3165****	0.0883	0.6811	**0.3743**	**3.1000*****	0.2115	1.6620
Ste Anne de la Pérade	−0.0017	0.0128	−0.0992	0.7662	0.1803	1.4077	0.2206	**1.7376***
Valleyfield	−0.0861	0.6581	−0.0143	0.1087	0.0701	0.5357	0.1032	0.7902
Bagotville	0.1750	1.3656	0.1961	1.5360	**0.3212**	**2.6055****	**0.3231**	**2.6222****
Mont Joli A	**0.2428**	**1.8562***	0.1761	1.3267	**0.3751**	**3.0010*****	**0.3231**	**2.5317****
Natashquan A	**0.2643**	**1.9572****	**0.3389**	**2.5724****	**0.5119**	**4.2550*****	**0.5245**	**4.4000*****
Sept Îles A	0.0601	0.4256	−0.0199	0.1405	0.0882	0.6264	−0.0404	0.2859
Ste Rose de Dégelis	0.2388	1.7390	0.0272	0.1930	**0.2661**	**1.9518****	−0.1369	0.9771
Trois-Pistoles	0.1110	0.7896	0.0117	0.0830	**0.2447**	**1.7849***	−0.1021	0.7264
Chelsea	0.1468	1.1398	0.1838	1.4359	**0.2940**	**2.3626****	**0.2725**	**2.1758****
La Tuque	0.1318	0.9405	−0.1172	0.8348	0.0913	0.6482	−0.1772	1.2733
Nicolet	0.1210	0.9361	−0.0954	0.7364	0.0672	0.5174	0.1750	1.3654
Nominingue	−0.0862	0.6648	0.0023	0.0174	0.1605	1.2491	0.1373	1.0645
St Alban	0.1903	1.4890	0.1995	1.5640	**0.4039**	**3.3913*****	**0.3668**	**3.0282*****
St Jérôme	0.0142	0.1089	0.0084	0.0646	0.1933	1.5131	0.1200	0.9287
Milan	0.0436	0.3349	0.1632	1.2706	**0.2796**	**2.2369****	0.1953	1.5294

*Statistically significant value at the 10% level.
**Statistically significant value at the 5% level.
***Statistically at the 1% level.
The statistically significant values are shown in the bold.

Table 2. Analysis of the long-term trend of monthly maximum daily temperatures in summer using the Spearman's rank correlation coefficient method.

3.2. Relationship between El Niño events and maximum daily temperatures for the four summer months

Coefficient of correlation values are presented in **Table 3**. Only the AMJ-1 and JAS-1 SOI values associated with El Niño events are significantly correlated with maximum daily temperatures.

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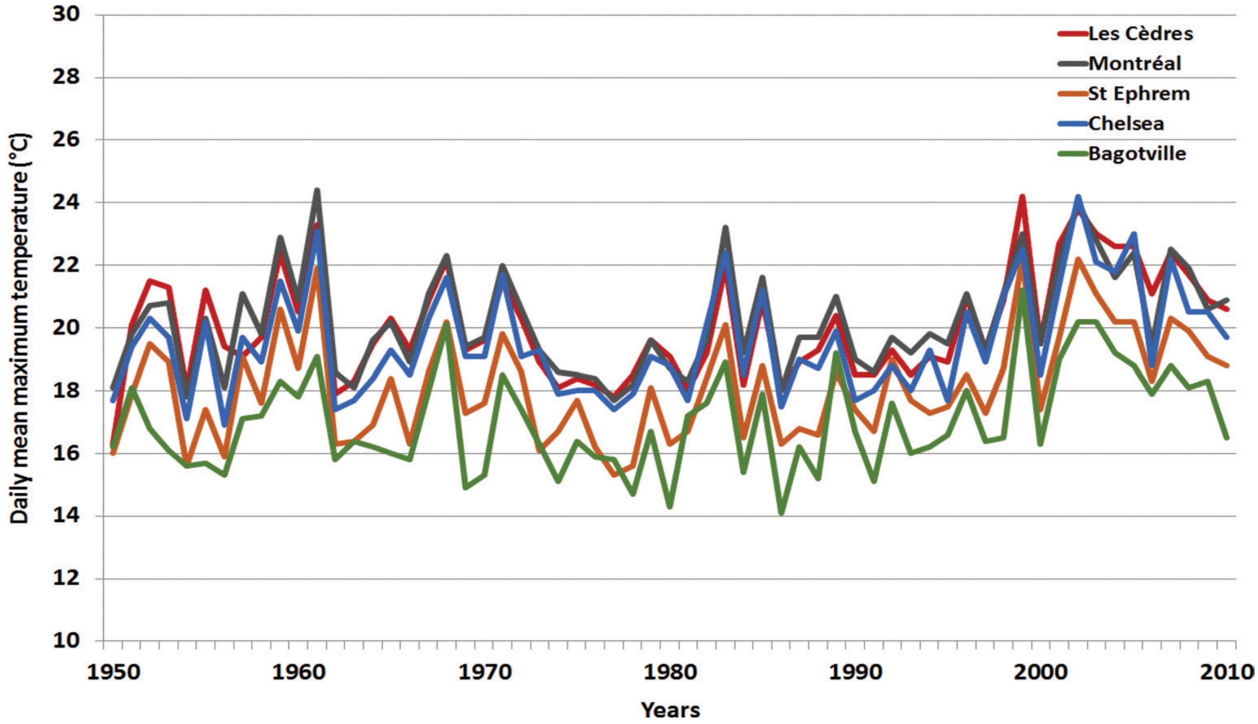

Figure 2. Example of the interannual variability of maximum daily temperatures in August at the five stations.

Stations	June		July		August		September	
	AMJ-1	JAS-1	AMJ-1	JAS-1	AMJ-1	JAS-1	AMJ-1	JAS-1
Coaticook	−0.1578	**−0.4229***	0.1142	−0.0181	0.0393	−0.0484	0.1897	−0.2378
Les Cèdres	−0.1889	−0.1544	−0.0280	0.0392	−0.0391	−0.0786	0.1130	−0.2273
Magog	−0.1486	−0.2777	0.0966	0.0594	0.0233	−0.0141	0.2079	−0.1615
Montréal (Trudeau)	−0.2117	−0.2669	−0.0734	−0.0871	−0.0002	−0.0588	0.0310	−0.3406
Oka	−0.2892	−0.3465	−0.1437	−0.0270	−0.0474	−0.0781	−0.0137	**−0.3906***
Philipsburg	−0.2595	−0.2013	0.0904	0.0198	0.1249	0.1328	−0.0474	**−0.3620***
St Ephrem	**−0.3941***	**−0.4142***	−0.1213	−0.1357	−0.0621	−0.1164	0.1026	−0.2777
St-Malo d'Auckland	−0.2322	−0.3153	−0.0176	−0.0052	−0.0089	−0.0296	0.1948	−0.1651
Ste Anne de la Pérade	**−0.4070***	**−0.4218***	−0.0825	−0.0085	−0.0383	−0.1160	−0.0207	**−0.3662***
Valleyfield	−0.2639	−0.2861	0.1386	−0.0373	0.0839	0.0769	0.1323	0.2561
Bagotville	−0.3206	−0.3052	−0.1385	−0.0618	−0.2458	**−0.3806***	−0.1456	−0.3262
Mont Joli A	−0.2874	**−0.4049***	−0.1402	0.0169	−0.3218	−0.2273	−0.0543	**−0.4301***
Natashquan A	0.0502	−0.0133	−0.3629	−0.1946	−0.2454	0.0236	−0.4491	**−0.6531***
Sept Îles A	−0.3191	−0.2441	−0.0870	0.1571	−0.1390	−0.0413	0.0187	**−0.3861***
Ste Rose de Dégelis	**−0.3791***	**−0.5610***	−0.1091	−0.0026	−0.1689	−0.1560	0.0176	**−0.4217***

Stations	June		July		August		September	
	AMJ-1	**JAS-1**	**AMJ-1**	**JAS-1**	**AMJ-1**	**JAS-1**	**AMJ-1**	**JAS-1**
Trois-Pistoles	**−0.3804***	**−0.3627***	−0.1865	−0.0088	−0.2863	−0.1797	−0.1605	**−0.4842***
La Tuque	**−0.4994***	−0.2942	−0.1440	−0.0798	−0.1968	−0.3281	−0.1425	**−0.4572***
Nicolet	**−0.4994***	−0.2942	−0.1440	−0.0798	−0.1968	−0.3281	−0.1425	**−0.4572***
Nominingue	**−0.5110***	**−0.5678***	0.0272	0.0702	0.1166	0.2012	0.1466	−0.0546
St Alban	−0.2803	**−0.3733***	0.0424	−0.0856	0.2354	−0.0953	0.1877	−0.1157
St Jérôme	**−0.3717***	−0.3599	−0.2435	−0.3010	−0.0073	−0.1750	0.0529	−0.3200
Milan	**−0.4178***	**−0.4380***	−0.1107	−0.1471	−0.1157	−0.1191	0.1206	−0.2606

*Statistically significant value at the 5% level.
The statistically significant values are shown in the bold.

Table 3. Coefficients of correlation calculated between El Niño events and monthly maximum daily temperatures in summer in Quebec (1950–2010). .

There is no significant correlation for the other four SOI values. No statistically significant correlation was found between El Niño events and maximum daily temperatures in July, and such a correlation is only observed for one station for the month of August. In contrast, a correlation is found at nearly half of the stations for the months of June and September, the two coolest summer months. All statistically significant correlations are negative. Thus, maximum daily temperatures tend to increase with the intensity of El Niño events. It is worth pointing out that such a relationship is not observed with La Niña events (results not presented herein). Also of note, temperatures in June are correlated with the AMJ-1 and JAS-1 climate indices, whereas temperatures in September are only correlated with the JAS-1 index (**Table 3**).

4. Discussion and conclusion

Comparison of the long-term trend of maximum daily temperatures for four summer months (June, July, August, and September) using the Spearman and Mann-Kendall tests highlighted a statistically significant increase in temperature in southern Quebec over the period from 1950 to 2010. However, this increase is not uniform for the four months. The warming trend is observed at nearly half of the stations analyzed for the months of August and September, but at fewer than 15% of stations for the months of June and July. The first main conclusion arising from the study is the fact that the last two months of the summer season are warming faster than the first two months. For July, a warming trend is only observed at one station. This suggests that the warm summer season tends to end late in southern Quebec. It was not possible to constrain the potential climate factors that could account for the warming trend for the months of September and August. One hypothesis is the increasingly widely observed warming of ocean surface waters, in the Atlantic and Pacific Oceans among other places, the influence of which on temperature in continental North America has been highlighted by a number of authors (e.g., [11, 14]). It should be recalled that, due to thermal inertia, the warming of ocean surface waters accelerates in August in the northern hemisphere.

There is a widespread assumption that, in Canada in general and in Quebec in particular, El Niño events have no impact on summer climate. This assumption is not always based on an analysis of the relationship between climate variables and these events. The analysis carried out in this study revealed the existence of a significant negative correlation between maximum daily temperatures and El Niño events of varying intensities during the period from 1950 to 2010. Like the long-term trend of the interannual variability of temperature, this correlation varies between the four summer months. It is not observed for the months of July and, to a lesser extent, August, but is observed at nearly half of the stations analyzed for June (early summer) and September (late summer), the two coolest summer months in southern Quebec. The lack of correlation between El Niño events and maximum daily temperatures in July and August, the two warmest months of summer, may be explained by the fact that, as a result of relatively substantial warming during these two months, the influence of local site (station) characteristics on daily daytime temperature variations becomes more important (microclimate effect) than that of regional climate factors (air mass circulation and fronts). Thus, during the warmest part of summer, local warming enhances the strong spatial variability of convective movements that affect daytime temperatures in general and maximum temperatures in particular. These convective movements produce convective clouds and localized and dispersed storms, thus inducing differences in maximum temperatures between sites.

The negative correlation highlighted between maximum daily temperatures and El Niño events suggests that an increase in the intensity of these events in the current climate warming context, as predicted by many climate models, would lead to an increase in maximum daily temperatures particularly in June and September in southern Quebec. Thus, the four summer months will become increasingly warmer in southern Quebec.

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References

[1] Casati B, de Elia R. Temperature extremes from Canadian Regional Climate Model (CRCM) climate change projections. Atmosphere-Ocean. 2014;**52**(3):191-210

[2] Mekis E, Vincent LA, Shepard MW, Zhang X. Observed trends in severe weather conditions based on humidex, wind chill, and heavy rainfall events in Canada for 1953-2012. Atmosphere-Ocean. 2015;**53**(4):383-397

[3] Turner JK, Gyakum JR. Trends in Canadian surface temperature variability in the context of climate change. Atmosphere-Ocean. 2010;**48**(3):147-162

[4] Vincent LA, van Wijngaarden WA, Hopkinson R. Surface temperature and humidity trends in Canada for 1953-2005. Journal of Climate. 2007;**20**:5100-5113

[5] Wang XL, Feng Y, Vincent LA. Observed changes in one-in-20 year extremes of Canadian surface air temperatures. Atmosphere-Ocean. 2014;**52**(3):222-231

[6] Yagouti A, Boulet G, Vincent L, Vescocvi L, Mekis E. Observed changes in daily temperature and precipitation indices for southern Québec, 1960-2005. Atmosphere-Ocean. 2000;**3**:395-429, 46(2);243-256

[7] Zhang X, Vincent LA, Hogg WD, Niitsoo A. Temperature and precipitation trends in Canada during the 20th century. Atmosphere-Ocean. 2000;**3**:395-429

[8] Guerfi N, Assani AA, Mesfioui M, Kinnard C. Comparison of the temporal variability of winter daily extreme temperatures and precipitations in southern Quebec (Canada) using the Lombard and copula methods. International Journal of Climatology. 2015; **35**:4237-4246

[9] Assani AA, Maloney-Dumont V, Pothier-Champagne A, Kinnard C, Quéssy J-F. Comparison of the temporal variability of summer temperature and rainfall as it relates to climate indices in southern Quebec (Canada). Theoretical and Applied Climatology. 2017 (under review)

[10] Bonsal B, Shabbar A. Oscillations climatiques à grande échelle ayant une incidence sur le Canada, de 1900 à 2008. Biodiversité canadienne : état et tendances des écosystèmes en 2010. Rapport technique thématique n°4. Ottawa (ont.): Conseils canadiens des ministres des ressources; 2011. iii+15 p http://www.biodivcanada.ca/default.asp?lang=Fr&n=137E1147-1

[11] Trenberth KE, Fasullo JT. An apparent hiatus in global warming. Earth's Future. 2013; **1**:19-32

[12] Null J. El Niño and La Niña years and intensities based on Oceanic Niño index (ONI). 2016. http://ggweather.com/enso/oni.htm. [Viewed December 14, 2016]

[13] Sneyers R. Sur l'analyse statistique des séries d'observations. Note technique n°143. Genève: Organisation Météorologique Mondiale; 1975. 192 p

[14] Sutton RT, Hodson DLR. Atlantic Ocean forcing of North American and European summer. Climate Sciences. 2005;**309**:115-118