6.4 ASSOCIATIONS BETWEEN LOW FREQUENCY VARIABILITY MODES AND WINTER CLIMATIC EXTREMES IN CANADA

Amir Shabbar[1] and Barrie Bonsal[2]
[1]Meteorological Service of Canada, [2]National Water Research Institute, Environment Canada

1. Introduction

One of the key themes of current climatological research is the detection and attribution of changes in climatic extremes. Shabbar and Bonsal (2002) recently analyzed trends in winter temperature extremes over Canada. Results showed substantial decreases in the frequency, duration and intensity of winter cold spells over western regions of the country. Conversely, eastern Canada experienced opposite trends in these variables. This study analyzes the influence of low frequency variability modes (namely, El Niño-Southern Oscillation (ENSO), the Arctic Oscillation (AO) and the Quasi-Biennial Oscillation (QBO)) on the frequency and duration of winter cold and warm periods over Canada during the second half of the 20th century. Additionally, singular value decomposition (SVD) analysis is used to examine and measure the strength of large-scale relationships between winter warm and cold spells and the dominant patterns of global oceanic circulation.

2. Data and Methodology

Temperature data consist of daily minimum and maximum values for 210 relatively evenly distributed stations across Canada. The data have been adjusted for inhomogeneities caused by station relocation and changes to instrumentation and observing practices (Vincent et al. 2002). Climatological observations prior to the 1950s are sparse in the northern regions (north of 60^{o}N) of Canada. Therefore, analyses are confined to the 1950-98 period. Furthermore, stations having more than 20% of their observations missing are excluded from the computations.

To define cold spells, the 20th percentiles of the daily winter (JFM) minimum temperature distributions are determined for each station during the 1961-90 period. Individual spells are then defined as those events in which the minimum temperatures remained below this threshold for at least three consecutive days. Similarly, warm spells are defined as those events in which the winter maximum temperatures remained above the top 20th percentile of the daily winter maximum temperature distribution for at least three consecutive days.

Corresponding Author: Amir Shabbar
4905 Dufferin St. Downsview, Ont. Canada, M3H 5T4
Email: Amir.Shabbar@ec.gc.ca

The main focus of this investigation is to examine differences in the frequency, duration and the number of days in cold and warm spells between the opposite phases of ENSO, the AO and the QBO. These differences are assessed for statistical significance at the 5% level using a Monte Carlo procedure. SVD is used to identify relationships between winter cold spells and global sea surface temperatures (SSTs).

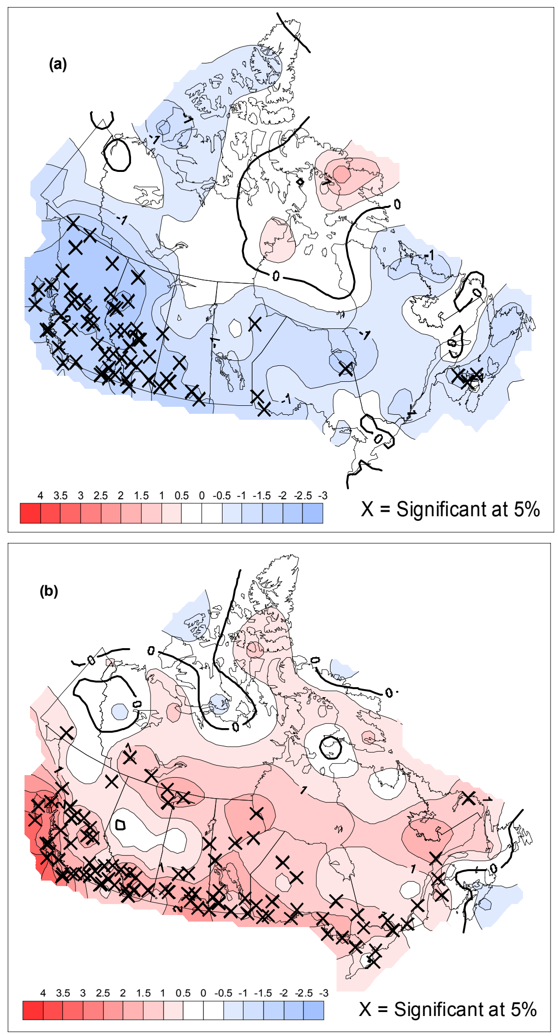

Figure 1. *Differences in (a) the frequency of winter cold spells and (b) the frequency of winter warm spells between the warm and cold phases of ENSO (warm minus cold).*

3. Results

a) ENSO-related Impacts

Classification of warm (El Niño) and cold (La Niña) ENSO events is based on the magnitude of SST anomalies in the Nino 3.4 region of the tropical Pacific for the JFM period 1950-1999. Years in which the magnitude of the anomaly was more (less) than 0.5 (-0.5) standard deviations from the long-term mean were classified as warm (cold) ENSO years. Statistical significance is determined by the Monte Carlo technique in which composite differences of 1000 randomly selected samples constitute a distribution against which the actual difference is assessed.

Figure 1a shows differences in the frequency of winter cold spells between warm and cold ENSO years. The map reveals fewer cold spells in warm years throughout most of southern Canada. A large portion of western Canada shows statistically significant differences at the 5% level.

Differences in warm spell frequencies are shown in Figure 1(b). Most of southern Canada from British Columbia to the St. Lawrence Valley experiences significantly more warm spells in warm ENSO years when compared to cold years.

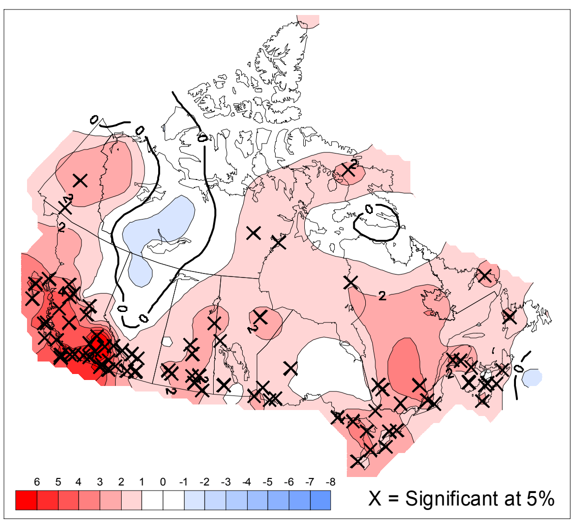

Figure 2. *Same as Figure 1b except showing differences in the duration of warm spells (in days).*

Relative to cold ENSO years, the duration of winter warm spells is significantly longer in warm years across southern Canada (Figure 2). This is especially true in southern British Columbia, where the spells are on average, more than three days longer. There are no significant differences in the length of winter cold spells between the two phases of ENSO (not shown).

These results are consistent with the findings of Shabbar and Khandekar (1996) who showed that the distribution of mean temperatures is shifted towards the warmer side of normal during El Niño episodes and vice versa for La Niña episodes over much of Canada. This was attributable to changes in large-scale atmospheric circulation patterns associated with the two phases of ENSO.

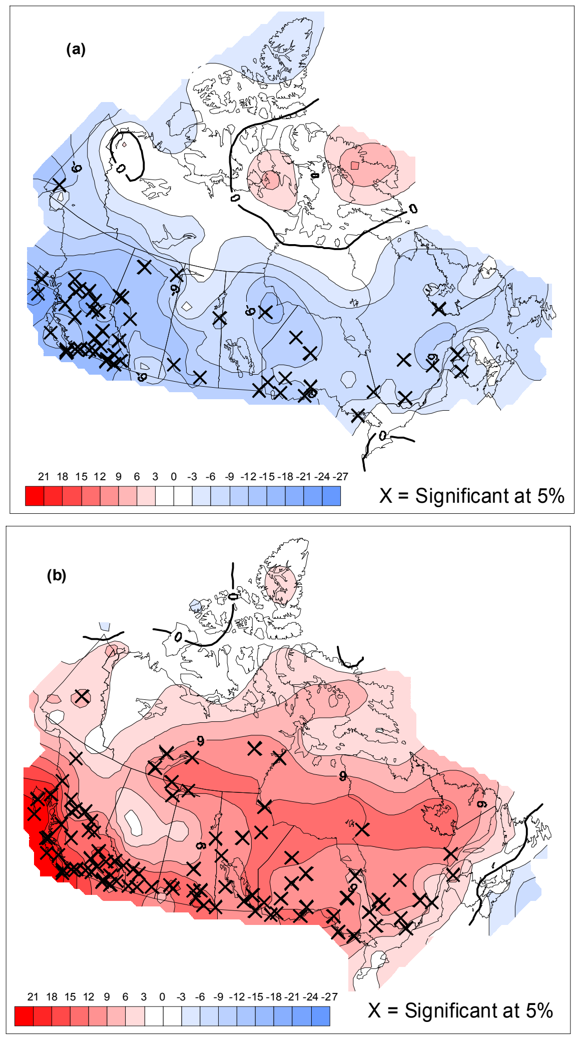

***Figure 3**. Same as Figure 1 except showing differences in the percentage of days (a) below the 10th percentile of winter minimum temperature and (b) above the 90th percentile of winter maximum temperature.*

Differences in the percentage of days below the 10th percentile and above the 90th percentile for the two phases of ENSO are displayed in Figures 3a and 3b respectively. Consistent with Figure 1, there are fewer days below the 10th percentile in warm years as compared to cold years. The percentage of days above the 90th percentile in warm years exceeds those in the cold years by 12 to 18% across the southern regions of western Canada. Most locations across southern Canada exhibit statistical significance at the 5% level.

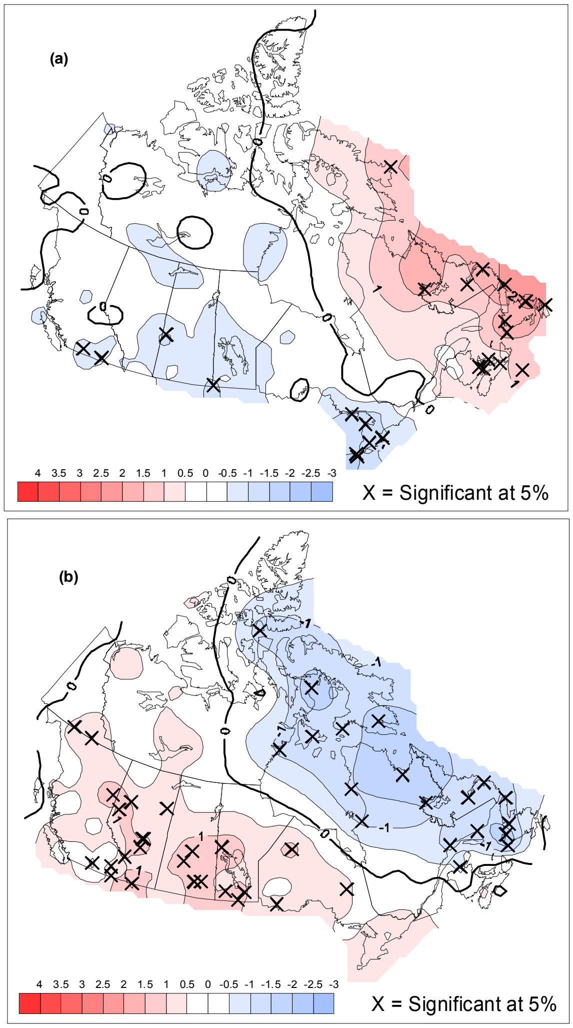

Figure 4. Same as Figure 1 except for *differences between the high and low index phases of the AO (high minus low).*

b) AO-related Impacts

The dominant mode of Northern Hemisphere (NH) extratropical variability is the AO which is defined as the leading principal component of NH monthly sea level pressure (Thompson and Wallace 1998). High (low) index phases are defined when the standardized value of the index exceeds 0.5 (-0.5) for the JFM period 1950-1999. Composite differences between the high and low AO phases for the frequency of cold and warm spells are shown in Figures 4a and 4b respectively.

During the high index phase, more cold spells are observed along the east coast of the country, while the Great Lakes Basin has fewer cold spells (Figure 4a). The duration of cold spells is also longer over eastern Canada (Figure 5). Figure 4b shows significantly more warm spells across western Canada, and fewer warm spells over the eastern one-third of the country. The high index phase of the AO favours an influx of cold northwesterly air that is likely to produce more cold spells and fewer warm spells over eastern Canada.

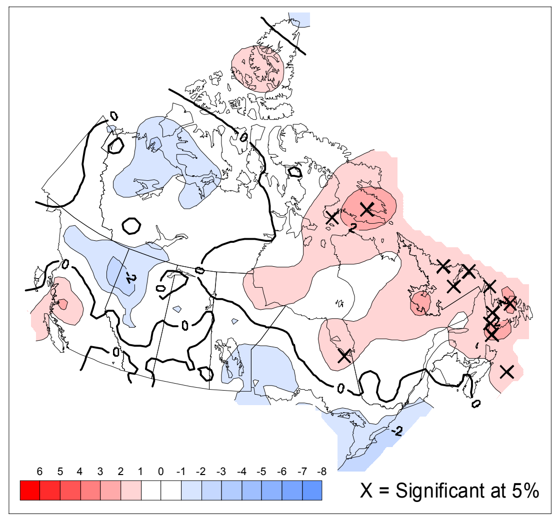

Figure 5. *Same as Figure 4a except showing differences in the duration of cold spells (in days).*

The percentage of days below the 10th percentile shows more days for the high index phase than the low index phase over eastern Canada, but fewer days over the lower Great Lakes and south eastern Prairies (Figure 6a). The percentages of days above the 90th percentile show an opposite and more robust pattern of fewer days for eastern Canada and more days for the Great Lakes and the southern Prairies.

c) QBO-related Impacts

In a recent investigation, Thompson et al. (2002) concluded that the strength of the stratospheric polar vortex determined the phase of the QBO which in turn has an impact on the extreme cold events over the mid to high latitudes of the NH.

In particular, they observed that the easterly phase of the QBO favours an increased incidence of extreme cold events, and vice versa. This investigation examines QBO signatures associated with Canadian winter temperature extremes.

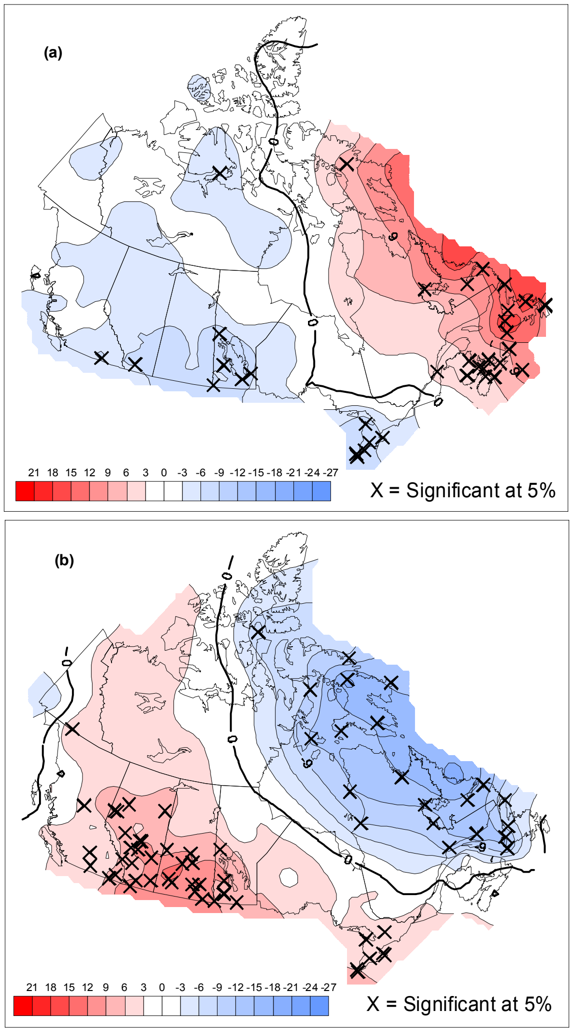

Figure 6. *Same as Figure 3 except for differences between the high and low index phases of the AO.*

Zonal wind anomalies at 50 hPa at the equator in the NCAR-NCEP reanalysis (Kalnay et al. 1996) are taken for the Dec-Mar period as a measure of QBO. Easterly phase of the QBO occurs when the wind anomalies are easterly in the winter months and vice versa. Figure 7 shows the difference in the frequency of warm spells between winters when the QBO is easterly and westerly. Significantly more warm spells are observed over the Canadian Prairies, and fewer warm spells are evident over northern Quebec and southern Baffin Island (although generally not significant). The percentage of days above the 90th percentile is higher over western Canada, and lower over eastern Canada for the easterly minus westerly phase of the QBO (Figure 8b). A somewhat opposite pattern emerges for the percentage of days below the 10th percentile (Figure 8a), although considerably fewer locations exhibit statistical significance. The easterly phase of the QBO favours a weaker polar vortex, and therefore anomalies in the tropospheric circulation are more reminiscent of the low index phase of the AO (see Figure 6).

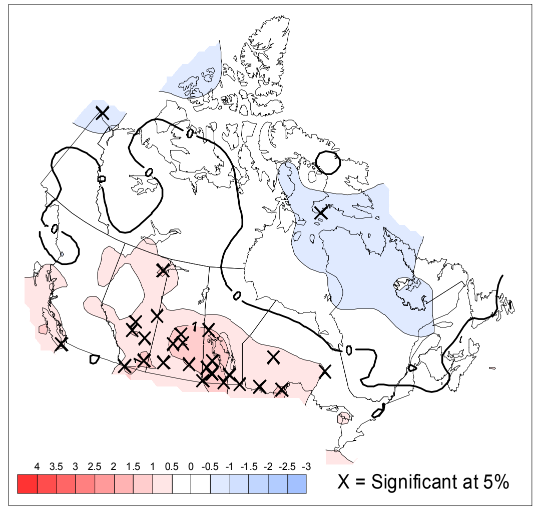

Figure 7. Same as Figure 1b except for *differences between the easterly and westerly phases of the QBO (easterly minus westerly).*

d) SVD Analysis

For this investigation, SVD analysis is used to examine relationships between the spatial pattern in the frequency of cold spells and global SSTs. SVD decomposes the covariance matrix of the two fields into orthogonal pairs of spatial patterns that maximizes the squared temporal covariance between the two variables (Bretherton et al. 1992). The relative strength of the relationship between the two fields is given by the percentage of squared covariance fraction (SCF). The normalized root-mean-squared covariance (NCF) measures the absolute importance of the SVD mode in the relationship between the two fields (Iwasaka and Wallace 1995). Similarity between the time variations of the patterns of the two fields is measured by the correlation coefficient (r).

SVD mode has two time series that represent the variations in the two fields. Most notable is the heterogeneous correlation pattern, which shows correlation pattern of one field based on the time coefficient of the mode in the other field. This pattern shows how the two fields are related to one another and how much of the amplitude of the variations is explained by the SVD mode.

The heterogeneous pattern for the first SVD expansion mode for the SSTs indicates the

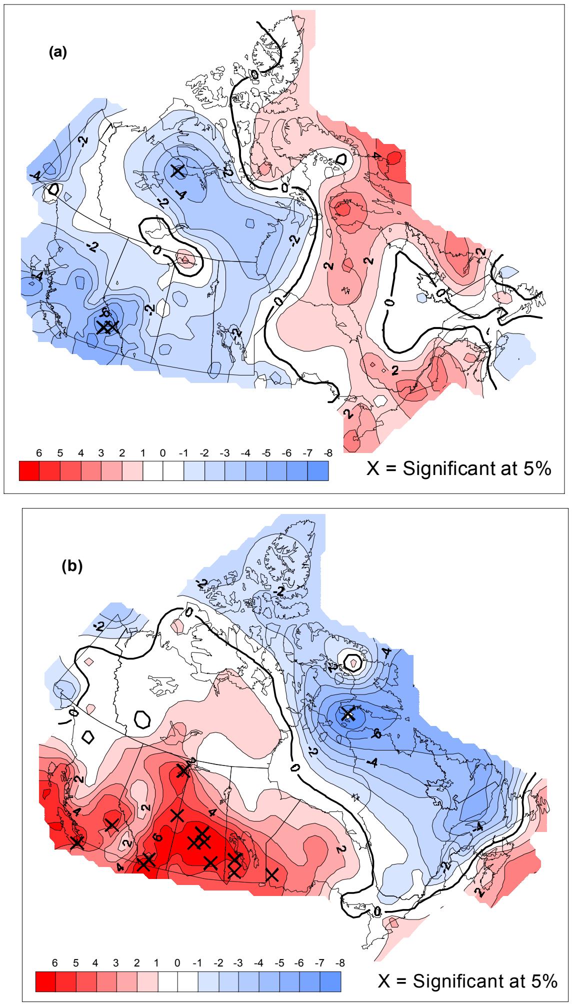

Figure 8. *Same as Figure 3 except for differences between the easterly and westerly phases of the QBO.*

strength of winter cold spells relative to the global SSTs (Figure 9). This pattern is suggestive of the negative phase of the widely known ENSO mode (Zhang et al. 1997). Thus the negative phase of the ENSO mode favours more winter cold spells in Canada. This is consistent with the ENSO composite results shown in Figure 1. The heterogeneous correlation between the time coefficient of the first SST SVD mode with the number of cold spells is shown in Figure 10. The pattern on this map is similar to the number of cold spells composite for ENSO forcing (Figure1 a).

This suggests that the spatial response of the cold spells is indeed due to ENSO. The first mode captures about 78% of the squared covariance. The NCF for the first mode is about 16%, and the correlation coefficient between the time expansion

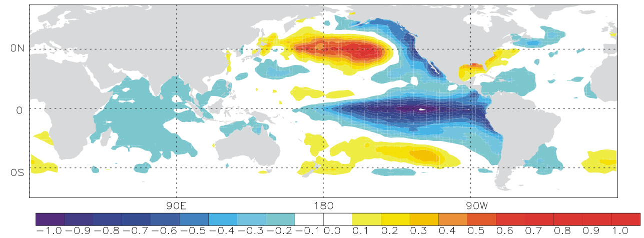

Figure 9. *Heterogeneous correlation map for the first SVD mode between the winter cold spells and SSTs.*

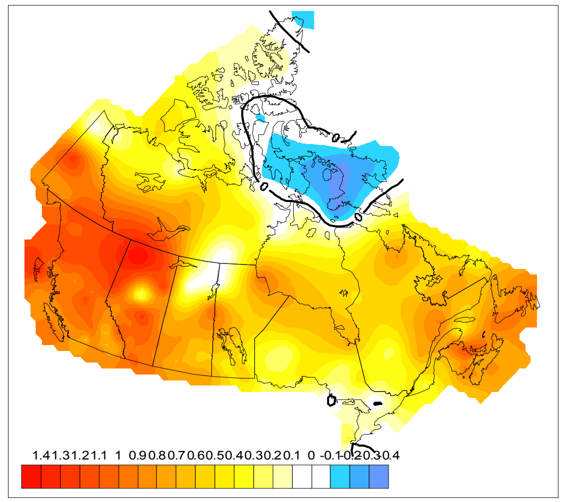

Figure 10. *Heterogeneous correlation map for the first SVD mode between the SSTs and the winter cold spells.*

series of the first SVD mode of the SSTs and the winter cold spells is 0.60. Test shows that all three statistics are beyond the 95% confidence level.

4. Conclusions

Differences in composite between the opposite phases of ENSO, AO and QBO of the winter cold and warm spells during the 1950-1998 period are examined. Frequency, duration and the number of days in the cold and warm spells for the above oscillations are analyzed and assessed for statistical significance through Monte Carlo shuffling. Results show that relative to the cold phase of ENSO, the number and duration of winter warm spells are significantly enhanced over most of southern Canada during the warm phase. Moreover, there are more days with maximum temperatures above the 90th percentile and fewer days with minimum temperatures below the 10th percentile. These results are in agreement with the behaviour of mean monthly temperatures during the warm and cold phases of ENSO.

The difference between the high and low index phase of the AO shows higher frequency and duration of winter cold spells over eastern Canada. The frequency of winter warm spells, however, increases over the Canadian Prairies. These differences also show more days below the 10^{th} percentile over eastern Canada and significantly more days above the 90^{th} percentile over the Prairie provinces.

Thompson et al. (2002) have shown that the stratosphere exerts a significant influence on the extreme cold temperatures of the NH through the different phases of the QBO. The difference between the easterly and the westerly phase of the QBO was used to composite cold and warm regimes over Canada. Figures 7 and 8 show that the frequency of warm spells as well as the number of days above the 90^{th} percentile are significantly increased over the southern prairies during the easterly phase of the QBO, which has been associated with the low index phase of the AO.

Finally, SVD analysis was used to capture the dominant coupled mode between winter cold spells and global SSTs. The first mode, which captured about 78% of the joint variance, was associated with a strong ENSO mode in the Pacific basin. The results of SVD analysis corroborate the ENSO composites shown in Figure 1.

This study has provided further insight into the association between global teleconnections and extremes regimes in Canadian temperatures. Statistically significant impacts on the persistence of temperature extremes were found by all three oscillations. Whereas the impact of ENSO on the extreme temperature regimes is of the same sign throughout most of southern Canada, the effects of the AO and QBO events on western Canada is opposite to those found in eastern Canada.

Given the possibility of climate change and advancements in climate modelling, projected changes in these teleconnections will likely lead to a better understanding into the changing nature of the extremes in the climates of Canada.

5. References

Bretherton, C. S., C. Smith, and J. M. Wallace, 1992: An intercomparison of methods for finding coupled patterns in climate data. *J. Climate*, **5**, 541-560.

Iwasaka, N, and J. M. Wallace, 1995: Large scale air sea interaction in the northern hemisphere from a view point of variations of surface heat flux by SVD analysis, *J. Meteor. Soc. Japan*, **73**, 781-794.

Kalnay E. M., and Coauthors, 1996: The NCEP/NCAR 40-year reanalysis project. Bull. Amer. Meteor. Soc., 77, 437-471.

Shabbar, A., and M. Khandekar, 1996: The impact of El Nino-southern oscillation on the temperature field over Canada, Atmos-Ocean, **34**, 401-416.

Shabbar, A., B. Bonsal, 2002: An assessment of changes in winter cold and warm spells over Canada. *Natural Hazards*, in press.

Thompson, D. W. J., and J. M. Wallace, 1998: The arctic oscillation signature in the wintertime geopotential height and temperature fields. *Geophys. Res. Lett*., **25**, 1297-1300.

Thompson, D. W. J., M. P. Baldwin, and J. M. Wallace, 2002: Stratospheric connection to Northern Hemisphere wintertime weather: implications for prediction. *J. Climate*, **15**, 1421-1428.

Vincent, L.A., X. Zhang, B.R. Bonsal, and W.D. Hogg. 2002. Adjusted daily temperatures for the analysis of trends in extremes over Canada, *J. Climate* **15**, 1322-1334.

Zhang, Y., J. M. Wallace, and D. S. Battisti, 1997: ENSO-like interdecadal variability: 1900-1993. *J Climate*, **10**, 1004-1020.