Advances in Geosciences, 6, 149–153, 2006
SRef-ID: 1680-7359/adgeo/2006-6-149
European Geosciences Union

Advances in Geosciences

The impact of El Niño-Southern Oscillation on the Canadian climate

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Received: 19 August 2005 – Revised: 16 December 2005 – Accepted: 21 December 2005 – Published: 30 January 2006

Abstract. The quasi-periodic El Niño -Southern Oscillation (ENSO) phenomenon in the tropical Pacific Ocean produces the largest interannual variation in the cold season climate of Canada. The diabatic heating in the eastern tropical Pacific, associated with the warm phase of ENSO (El Niño), triggers Rossby waves which in turn gives rise to the Pacific-North American teleconnection (PNA) over the North American sector. The strongest cell of the PNA pattern lies over western Canada. In most of southern Canada, mean winter temperature distribution is shifted towards warmer values, and precipitation is below normal. The presence of El Niño provides the best opportunity to make skillful long-range winter forecast for Canada. A strong El Niño event, while bringing respite from the otherwise cold winter in Canada, can be expected to cost the Canadian economy two to five billion dollars.

1 Introduction

Second only to the seasonal cycle, the El Niño-Southern Oscillation (ENSO) phenomenon provides one of the strongest sources of interannual variability in the Canadian climate. The quasi-periodic, anomalous, diabatic heating in the tropical Pacific Ocean forces anomalies in tropical convection, which in turn forces strong upper tropospheric divergence in the tropics and convergence in the subtropics. This dynamical response appears as a standing Rossby wave, with energy propagating from the tropics into the midlatitudes, characteristically producing a pattern reminiscent of the Pacific-North American teleconnection pattern (Wallace and Gutlzer, 1981). There is a strong theoretical framework for the midlatitude circulation response to the tropical heating (Hoskin and Karoly, 1981). The strongest midlatitude centre of the PNA teleconnection lies over western Canada. The PNA pattern not only changes the mean boreal winter and spring climate conditions in Canada, but it also affects the extremes in such parameters as temperature, precipitation and wind speed (Shabbar and Khandekar, 1996). The deleterious effects of a strong El Niño on the Canadian economy are between two to five billion dollars. The focus of this paper is on the impact of the warm phase of ENSO on the Canadian climate.

El Niño also provides the best opportunity to make skillful long-range forecasts for Canada. Both the dynamical and statistical forecast models are designed to fully recognize major El Niño events, and are expected to produce the most skillful seasonal forecasts during such events (Derome et al., 2001; Shabbar and Barnston, 1996). The success enjoyed provides a boost to the long-range prediction program in Canada. The early warning system in place assures preparedness by both the public and the industrial sector.

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2 Definition of El Niño and circulation

Over time, a number of indices have been used to measure the intensity of El Niño. One such measure is the Oceanic Niño Index (ONI). It is defined as the running three-month mean SST anomaly for the Niño 3.4 region. Niño 3.4 encompasses the area from 5° N to 5° S and 120° to 170° W. ONI is now most frequently used to identify El Niño (warm) and its counterpart La Niña (cool) events in the tropical Pacific. Warm events are defined when the five month standardized anomaly exceeds 0.5. Strong El Niño events are characterized by values higher than 1.5. Figure 1 shows the evolution of the ONI from 1950 to 2005. The very strong 1982–83 and 1997–98 events clearly stand above all others during the last half of the twentieth century.

In response to the changes in the quasi-stationary Rossby waves, the storm track over the Pacific also changes. During El Niño winters, the main jet stream over the North Pacific is likely to split on its approach to North America (Shabbar et al., 1997). Figure 2 shows that a weaker branch is diverted northward into the Arctic while the stronger lower

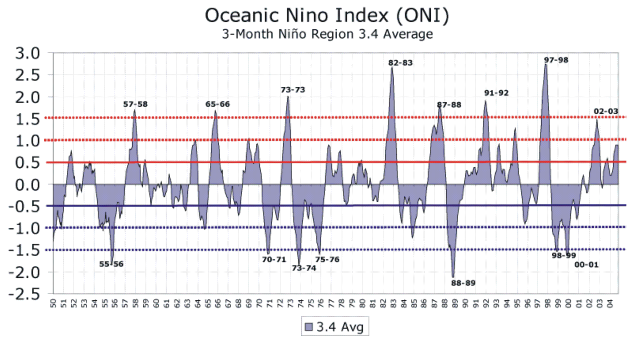

Fig. 1. SST anomalies in the Niño 3.4 region (5° N–5° S, 120°–170° W).

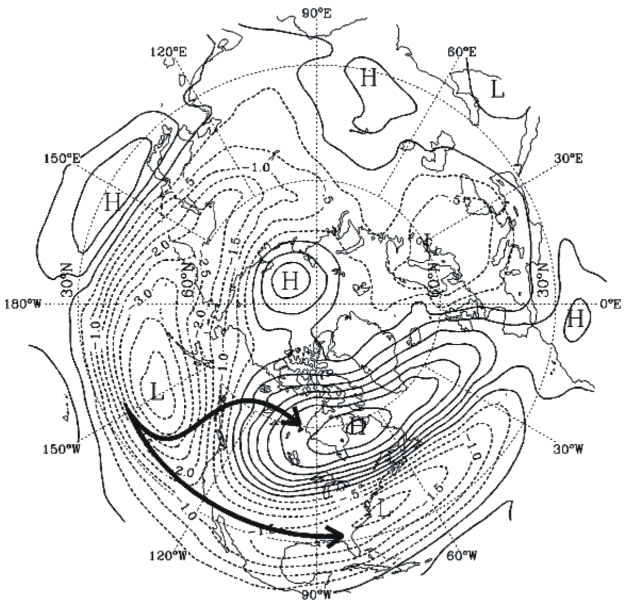

Fig. 2. Anomaly in 500 hPa height during El Niño winters. Jet stream position is indicated by heavy arrows.

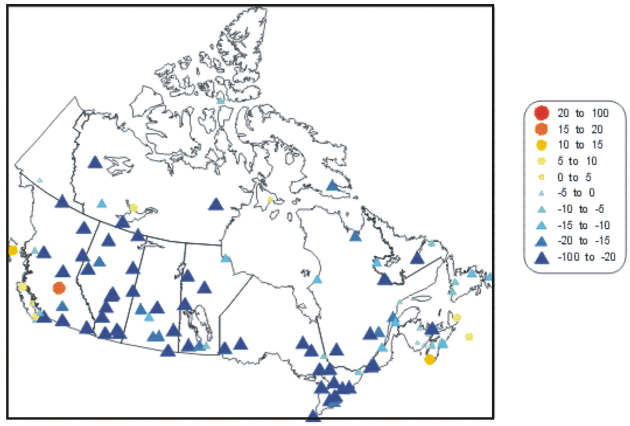

Fig. 3. Percent change in mean peak wind between El Niño and neutral years.

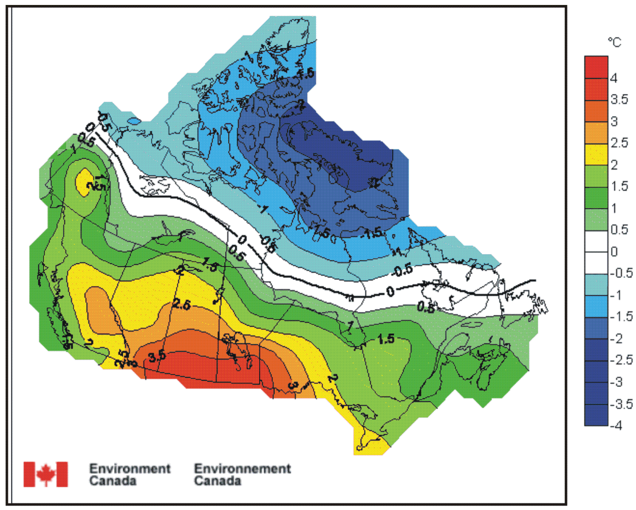

Fig. 4. Composite winter temperature departure from 1951–2000 normal during strong ONI events.

subtropical branch (whose mean position is over the Pacific northwest United States and southwestern Canada) is shifted several degrees of southward. The southern Canadian region lies in between the two jets and receives milder and drier-than-normal winters, while southern California experiences above-normal precipitation (Cayan and Peterson, 1989).

With the establishment of a positive anomaly centre over the western two-third of southern Canada, peak winds at the surface show a distinct reduction over Canada during El Niño winters (Fig. 3). Here, peak wind is defined as a wind speed of at least 28 km/h. Reduction in wind speed has implications for the generation of wind energy during El Niño years.

3 Climatic impact of El Niño

3.1 Temperature

In response to the Rossby wave, the PNA teleconnection becomes established over western Canada, and naturally induces changes in extratropical atmospheric circulation (Horel and Wallace, 1981). The result is the amplification of the western Canadian ridge. Positive surface temperature anomalies emerge over northwestern Canada in late autumn. The positive temperature anomalies strengthen and expand eastward to cover most of southern Canada during the course of the winter season (Shabbar and Khandekar, 1996). Figure 4 shows positive December–January–February temperature anomalies from the Yukon through southern Canada to the Maritime Provinces. The polar jet stream over northeastern Canada keeps the Arctic air mass over the high Arctic and northeastern Arctic, resulting in colder-than-normal winter in those regions.

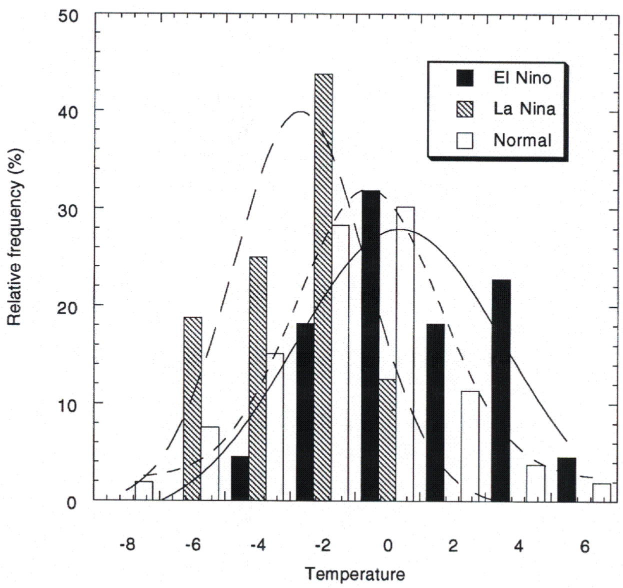

Fig. 5. Frequency distribution of El Niño, La Niña and ENSO-neutral events.

A composite of the mean temperature anomaly distribution for El Niño, La Niña and ENSO-neutral years over western Canada (west of 100° W) during the January–February–March period is shown in Fig. 5. A Gaussian curve is fitted to each of the three distributions separately. Distribution of temperature in El Niño years is shifted toward warmer values relative to the ENSO-neutral years and the distribution of temperatures in La Niña years is shifted toward colder values.

3.2 Precipitation

El Niño has a significant impact on the precipitation pattern over southern Canada during the first winter following its onset. The results show that a distinct pattern of negative precipitation anomalies in a region stretching from British Columbia, through the Canadian Prairie Provinces, and into the Great Lakes region. The precipitation anomalies can be explained by the associated mid-tropospheric flow, which, following the onset of El Niño, resembles the positive phase of the PNA. The diversion of the jet stream southward leaves most of southern Canada in a drier-than-normal regime. Unlike the eastward propagative nature of the temperatures, no progression of precipitation anomalies is evident in the analysis. Figure 6 highlights December–January–February precipitation anomalies (mm/day) in response to a strong ONI.

4 El Niño and climatic extremes

Shown in Fig. 7 are the changes in the likelihood of an extreme warm temperature anomaly in percent above average during an El Niño episode. Chances of warm temperature anomalies are increased over southern Canada from early winter to early spring. These statistics are based on past events (1900–1995) and there is no guarantee that the same relationships will exist in future El Niño events.

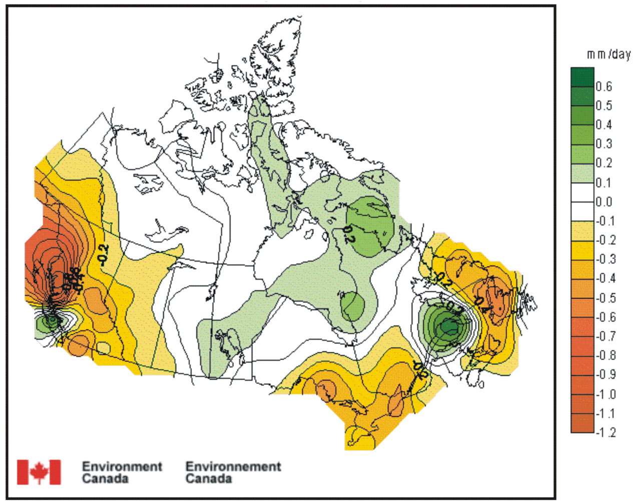

Fig. 6. Composite winter precipitation departure from 1951–2000 normal during strong ONI events.

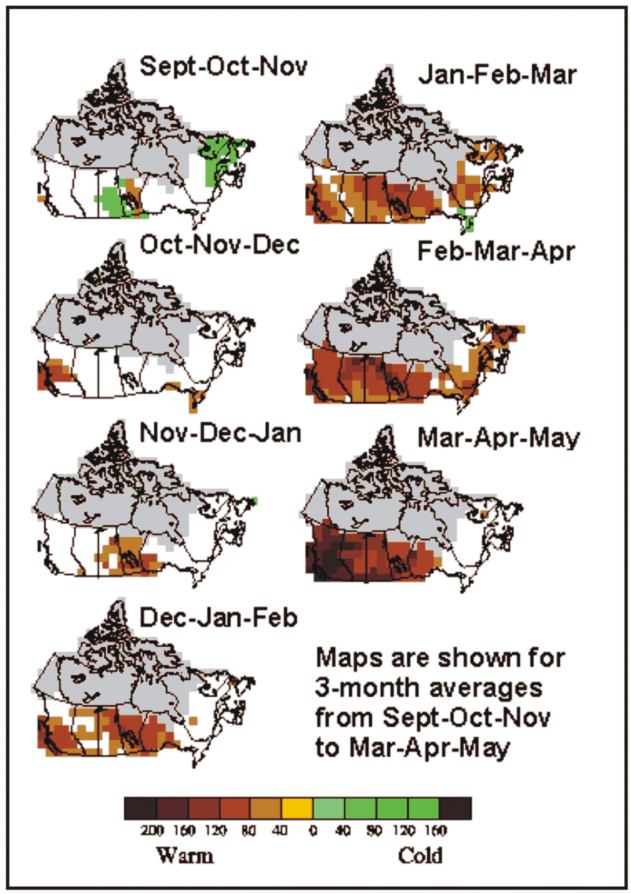

Fig. 7. The likelihood of temperature extremes (in % above chance) increases following the onset of El Niño. The probability of extreme warmth increase substantially across southern Canada.

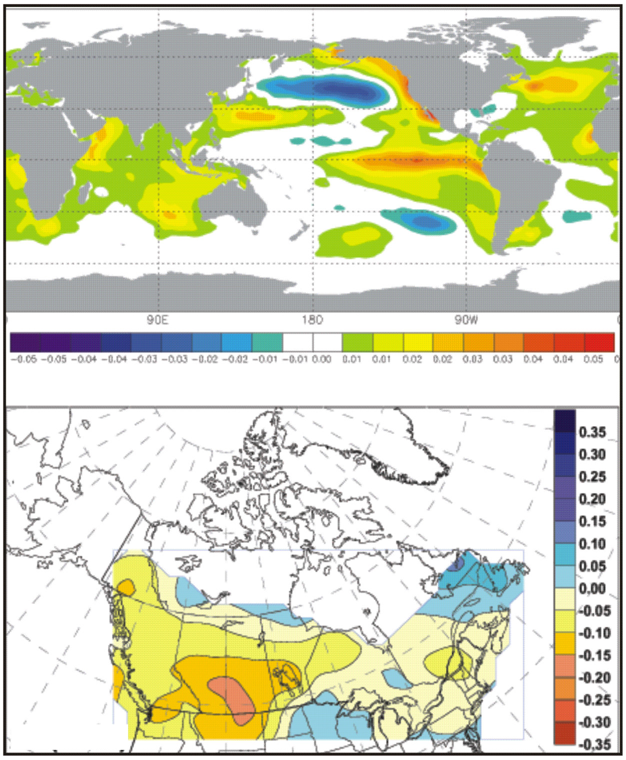

Fig. 8. Coupled singular decomposition mode between winter SSTs (top) and summer PDSI (bottom) over Canada.

Anomalous winter global SSTs in the tropical Pacific Ocean also affect probability of extreme dry and wet summer conditions in Canada. Investigation of the coupled modes, as revealed by the singular value decomposition (Bretheton et al., 1992), between the wintertime global SSTs and subsequent summer moisture availability in Canada reveals that El Niño events lead to a summer moisture deficit in the western two-thirds of Canada (Fig. 8). The moisture availability is measured by the Palmer Drought Severity Index (PDSI). Nearly one-half of the squared covariance fraction between the SSTs and the PDSI is explained by the ENSO-like annual and interdecadal variability (Shabbar and Skinner, 2004).

5 Seasonal forecast

The skill of long-range forecasting of Canadian temperatures and precipitation is evaluated in the hindcast mode by two dynamical models over the 26-year period. Hindcast skill is examined in an ensemble framework, and the boundary condition SSTs are prescribed by the previous month's global values. Skill is measured as a percent-correct score in three equi-probable classes. The 500 hPa geopotential height anomaly forecasts averaged over the season (one-month lead predictions) show skill in winter over the north-eastern Pacific, western Canada and eastern North America. Figure 9 shows that the temperature skill originates from ENSO years. For the non-ENSO years, predictions show little skill (Derome et al., 2001).

6 Economic impact of El Niños

To an otherwise cold-climate country like Canada, El Niño brings respite from the very cold winters. But some sectors of the Canadian economy are impacted adversely by the presence of El Niño. Foremost among them is the agriculture industry. The dearth of snowfall, especially in the grain growing areas of Canada, often exacerbates any existing droughty conditions. Hydroelectric generation capacity is reduced by the decrease in spring precipitation and spring runoff. The west coast fishery is also affected by El Niño. The presence of warm water along the west coast of North America encourages the migration into the west coast fishing grounds, of species that do not normally live there. In 1982/83, 1991/92, 1992/93, 1997/98, mackerel ranged farther north than usual. These are voracious feeders and prey on juvenile salmon. The effect can be very large. Mackerel caught in Barkley Sound in 1992 and 1993 were discovered to have an average of six to eight juvenile salmon in their stomachs. Some of the main impacts on the Canadian climate during the 1997–98 El Niño were:

– Crop loss owing to dry weather or prolonged drought exacerbated by El Niño: $2.0 billion

– Loss to the heating industry owing to low heating demand: $1.5 billion

– Loss to the recreation industry (lack of snow for winter recreation): $300 million

– Loss to the fishery industry (mainly Pacific salmon): $400–500 million

– Loss to the ice wine industry in the Niagara Peninsula: $20–30 million

Edited by: P. Fabian and J. L. Santos
Reviewed by: two anonymous referees

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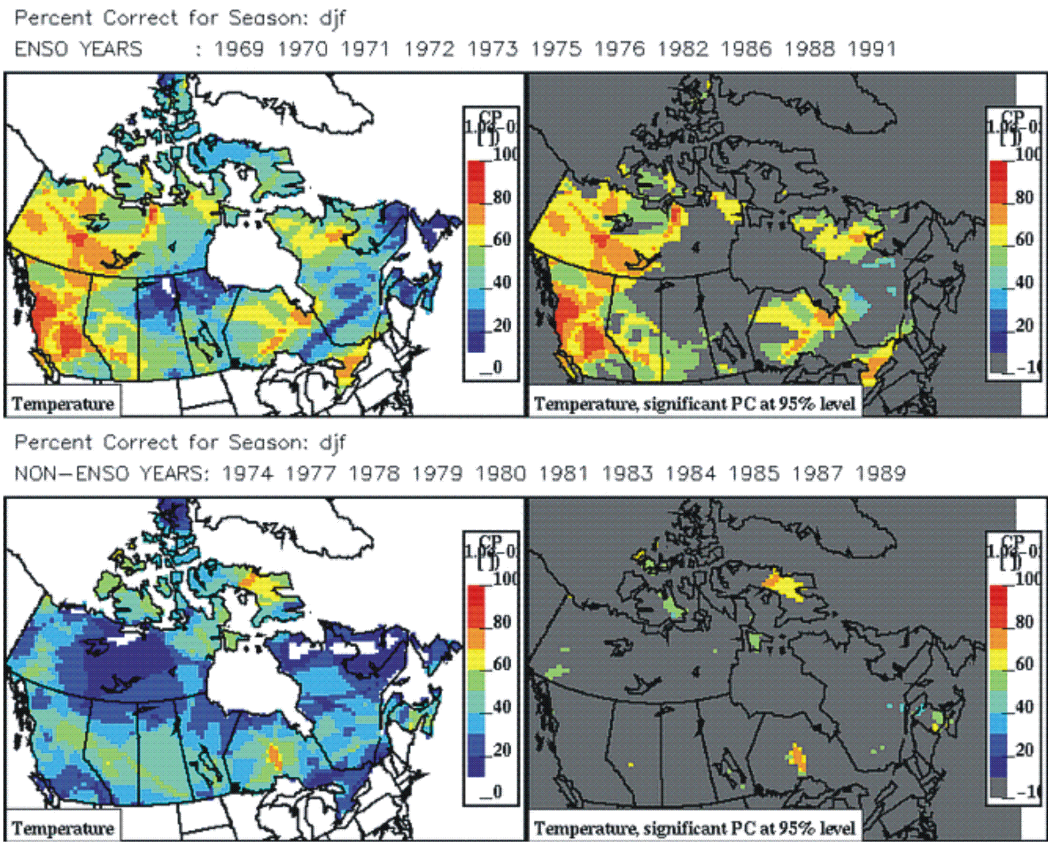

Fig. 9. (Top panels) Percent-correct skill score of temperature (left) and its statistical significance (right) over the hindcast period 1969–94 in ENSO years. (Bottom panels) Same as top panels but for non-ENSO years.

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