EFFECTS OF EL NIÑO AND LA NIÑA EVENTS ON PRECIPITATION, TEMPERATURE, AND NATURAL RUNOFF VOLUMES IN ALBERTA, CANADA

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ABSTRACT

Precipitation, temperature and natural runoff volumes over the province of Alberta, Canada were associated with the two extreme phases of Southern Oscillation, namely El Niño and La Niña. Spatial and temporal data were analyzed for the 1911-1995 period for the first winter following the onset of the El Niño and La Niña cycles in Alberta. The strongest signal for El Niño and La Niña appeared in the December to February period following their onset with some signal apparent in the November to March period. This paper includes a general description of the climate processes involved and the results for the December to February period following the onset of El Niño and La Niña events. The analyses include 22 El Niño and 14 La Niña events that occurred in the study period with an update on the current 1997-98 El Niño event.

The results for the December to February (winter) period following the onset of El Niño show statistically significant above-average temperatures in all areas of Alberta. Decreased winter precipitation was evident at all stations following the onset of El Niño, however differences were very small at most locations. Natural runoff volume (computed for the February to July period) on average, provided below-average values following El Niño winters.

Conversely, significant below-average temperatures were found in Alberta for the winter following the onset of a La Niña event. La Niña events provided significantly above-average precipitation at all sites and subsequently, above-average natural runoff volumes were found.

INTRODUCTION

Every three to eight years, the easterly trade winds that usually blow from South America to Australia subside and as a result, a large area of anomalously warm water forms in the eastern tropical Pacific. This large-scale abnormal warming in the equatorial Pacific off the coast of South America is called El Niño.

The Southern Oscillation Index (SOI), which measures the sea-level pressure difference between Tahiti and Darwin in the South Pacific, is used to determine the strength of an El Niño and its counterpart, La Niña. El Niño is a disruption of the normal ocean-atmosphere system in the tropical South Pacific and is associated with the negative phase of the SOI. La Niña is associated with the positive phase of the SOI.

ENSO (El Niño/Southern Oscillation) has many impacts on climate worldwide. During El Niño events, the large pool of abnormally warm water which forms off the coasts of North and South America influences weather patterns over western North America. Typically during an El Niño winter, a broad scale ridge is formed over the southwestern United States. The high pressure ridge allows warmer, drier air to flow into the southern prairies. The effects of El Niño are felt strongest in the North American winter.

La Niña (the opposite of El Niño), is a large scale cooling in the tropical Pacific off the coast of South America. La Niña is typically associated with an abnormally strong high pressure system off the coast of South America. As a result, anomalously cold water resides in the eastern tropical Pacific. During a La Niña winter, colder than normal air presides over Alaska and western Canada.

Temperature and precipitation anomalies observed over Western Canada during the winter following the onset of El Niño and La Niña have been attributed to upper-air circulation anomalies, particularly the Pacific North American Pattern (PNA) (Horel and Wallace, 1981; Shabbar et al., 1997). In particular, El Niño (La Niña), which

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is associated with the positive (negative) phase of PNA, alter the normal upper-atmospheric flow patterns, thus affecting precipitation and temperature patterns over Western Canada (Yarnal and Diaz, 1986; Shabbar et al., 1997).

Shabbar et al. (1997) studied Canadian precipitation patterns associated with the Southern Oscillation. In their analysis, they used the individual years of El Niño and La Niña events determined by Rasmusson (1984), Ropelewski and Jones (1987), Halpert and Ropelewski (1992), and Shabbar and Khandekar (1996). Strong to moderate El Niño (La Niña) events were defined by Rasmusson (1984) as those years in which the five month running mean SOI remained in the lower (upper) 25% of the distribution for five months or longer. During this period, 1911-1995, there were 22 El Niño and 14 La Niña years (Table 1). Years in which El Niño and La Niña occurred in consecutive years, the analysis treated these years separate events.

Table 1 Years of onset of El Niño and La Niña Events (after Rasmusson, 1984)

	1911-19	1920-29	1930-39	1940-49	1950-59	1960-69	1970-79	1980-89	1990-95
EL NIÑO	1911	1925	1930	1941	1951	1965	1972	1982	1991
	1912	1926	1939		1953	1969	1976	1986	
	1914	1929			1957				
	1918				1958				
	1919								
LA NIÑA	1916	1924	1938		1950	1964	1970	1988	
	1917	1928			1955		1971		
					1956		1973		
							1975		

Shabbar et al. (1997) stated that during El Niño events, there is a deeper than normal Aleutian low, a stronger and eastward displacement of the western Canadian ridge, and negative height anomalies over the southeastern United States. This pattern is similar to the positive PNA pattern and is likely associated with a split in the jet stream over North America, with one branch diverted northward into the Northwest Territories and the other moving over California. For La Niña cases, a weaker than normal Aleutian low (also associated with negative PNA) would include stronger than normal westerlies moving across the eastern Pacific and into Southern Canada (Shabbar et al., 1997).

IMPACTS OF EL NIÑO AND LA NIÑA EVENTS ON ALBERTA

Analysis of the impact of El Niño and La Niña events on hydrometeorologic parameters (temperature, precipitation, and natural runoff volume) was carried out for Alberta. As reported earlier, El Niño and La Niña are seasonal episodes that dominate the weather patterns over western Canada and are typically the strongest in the winter. This analysis examined the winter (December to February) period following the onset of El Niño and La Niña events.

The analysis examined monthly temperature (15 stations) and precipitation (36 stations) data within the province of Alberta (Figure 1) and the naturalized streamflow for the six major river systems for the winter period from 1912 to 1995. The climate stations selected were based on the length and quality of data sets (the station needed to have more than 50 years of record) and are shown in Table 3.

Temperature

Mean average monthly temperatures were calculated at fifteen stations in Alberta for the December to February (winter) period from 1912 to 1995. Mean monthly temperatures for the three winter months were averaged together to determine the winter average. The winter averages were then grouped into years in which the winter followed the onset of an El Niño or La Niña event to determine if there was a difference in the temperature patterns. Statistical testing was done using the Student T-test.

The analysis indicated that all fifteen stations recorded a December to February average temperature that was 1° to 2°C warmer during El Niño events compared to the long-term average (computed for 1912-95 period) and were all significant at the 95% confidence interval. A statistically significant (at the 95% confidence interval) decrease in temperature of similar magnitude was observed for La Niña cases. The results are shown in Table 2.

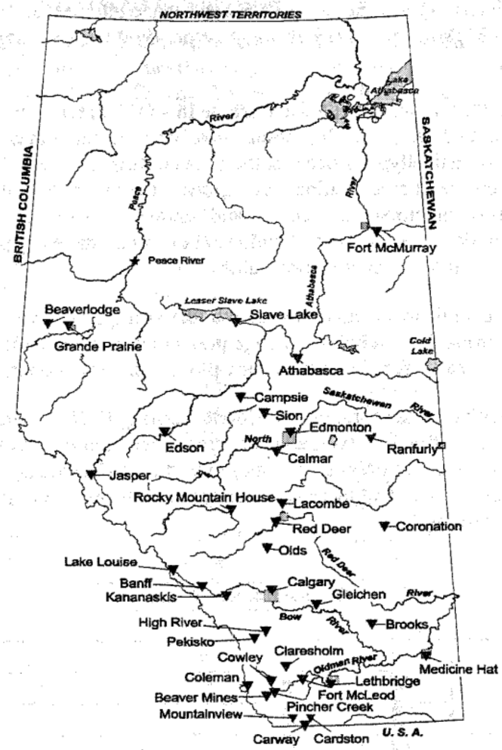

Figure 1 Map of Climate Stations in Alberta

Table 2 December to February Mean Temperatures (°C) for years of El Niño and La Niña compared to the long-term average (all differences are significant at the 95% confidence interval)

Station	El Niño Years	Average	La Niña Years
Pekisko	-6.1°	-8.0°	-9.8°
Beaver Mines	-4.4°	-6.1°	-7.2°
Pincher Creek	-4.4°	-6.3°	-7.8°
Lethbridge	-5.1°	-6.8°	-8.7°
Medicine Hat	-6.9°	-8.8°	-10.9°
Lake Louise	-11.5°	-12.8°	-13.7°
Banff	-7.7°	-8.9°	-10.2°
Kananaskis	-5.4°	-6.8°	-8.8°
Calgary	-6.3°	-8.1°	-10.2°
Red Deer	-10.3°	-12.0°	-14.1°
Jasper	-6.9°	-8.7°	-10.7°
Edmonton	-9.5°	-11.4°	-13.6°
Athabasca	-12.5°	-14.3°	-16.5°
Beaverlodge	-9.6°	-11.7°	-13.9°
Fort McMurray	-16.1°	-18.0°	-19.9°

Precipitation

Precipitation from 36 climate stations in Alberta was analyzed for the December to February period. Statistical testing was done using the Student T-test to determine if there was a difference in precipitation patterns during El Niño and La Niña events.

All stations in Alberta indicated higher precipitation totals, ranging from 12% to 55% above the long-term average, during the December to February period for La Niña years (Table 3). The increased precipitation during La Niña events was statistically significant (at the 95% confidence interval) at 28 of the 36 stations. Of the remainder, only three (Fort McMurray, Slave Lake, and Lethbridge) were not significant at the 90% confidence interval.

For El Niño events, all stations indicated a decrease in winter precipitation, however the decreases were very small at some stations. Only 14 of the 36 stations in Alberta indicated that the decrease in precipitation during El Niño events was statistically significant at the 95% confidence interval (Table 3). However, 22 out of 36 stations showed that the decrease in precipitation was significant at the 90% confidence interval. It appears that El Niño has greater impacts on precipitation in central and northern Alberta than in the southern areas. One possible reason for the small departures during El Niño years was that the early portion of the data set (prior to 1950) was dominated by several large precipitation values.

While El Niño events indicated a minor decrease in the average December to February precipitation, there was a significantly greater probability of below-average precipitation for El Niño years and above-average precipitation during La Niña years. A relative frequency plot for precipitation at Banff is shown in Figure 2.

Banff was representative of most stations in Alberta. During El Niño winters, a majority of the years recorded below-average precipitation however, above-average precipitation was still possible although there was a much lower probability of such an occurrence. The majority of La Niña events recorded above-average precipitation. This figure emphasizes that there is an increased probability for below-average precipitation during El Niño winters on most occasions.

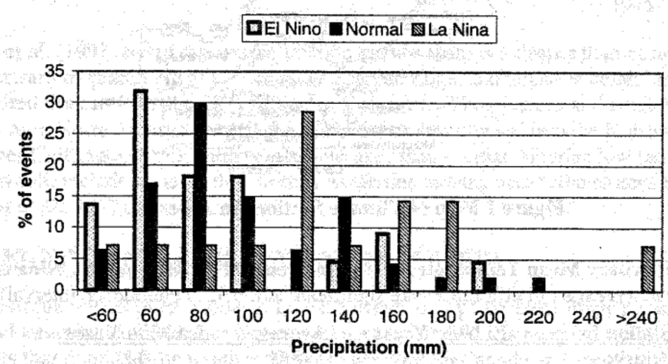

Figure 2 Precipitation Frequency Distribution for El Niño and La Niña Years for Banff

Natural Runoff Volumes

Natural runoff volumes were calculated for the February to July period from 1912 to 1995 to assess the impact of El Niño and La Niña on runoff. This period was chosen because it would incorporate the high elevation snowmelt season, which dominates streamflow in these rivers. The analysis considered only the first spring after the onset of El Niño or La Niña. The results for the six major river systems in Alberta are shown in Table 4.

The Oldman River at Lethbridge indicated a significant (at the 95% confidence interval) decrease in volume of 16.7% from the long-term average for El Niño events. La Niña years indicated higher volumes (11.5%). The Bow at Calgary showed a 4.4% decrease in runoff volumes for El Niño events and a 6.8% increase in volumes following La Niña winters. The Red Deer at Red Deer indicated very little change between El Niño and La Niña events. On average, these events tended to be about 6% above the long-term average. The North Saskatchewan at Edmonton showed little change for El Niño events (0.3% increase) but when an extreme outlier (1915) was removed from the analysis, a decrease of 3.9% was noted. During La Niña events, volumes were on average 5% higher than the long-term average. The Athabasca River at Athabasca indicated small decreases for El Niño events (2.7%) however significant (at the 90% confidence interval) increases (15.6%) for La Niña events.

Table 3 Average December to February Precipitation and departures (in %) during El Niño and La Niña events for climate stations in Alberta

Station	Avg. Dec-Feb precipitation (mm)	Departure from mean during El Niño Years	Departure from mean during La Niña Years	Data Length	Years of Record
SOUTHERN ALTA					
Pekisko	98.3	-12.2%*	17.8%*	1912-92	80
Beaver Mines	127.8	-10.6%	23.1%**	1913-95	79
Coleman	123.8	-12.0%	45.5%**	1913-95	73
Mountainview	122.0	-12.7%*	21.6%**	1913-95	74
Cowley	99.8	-2.9%	19.6%**	1913-95	78
Pincher Creek	84.4	-14.0%**	16.2%*	1915-94	75
Claresholm	63.4	-18.6%**	25.3%**	1913-95	73
Cardston	74.2	-22.0%*	31.0%**	1926-95	61
Carway	92.1	-9.1%	30.2%**	1915-95	78
Fort McLeod	60.7	-9.4%	17.8%*	1912-94	81
Lethbridge	56.3	-12.0%*	12.4%	1912-95	84
Medicine Hat	49.0	-11.8%	32.7%**	1912-95	83
Lake Louise	203.9	-2.2%	21.8%**	1916-95	78
Banff	91.7	-17.3%*	34.7%**	1912-95	83
Kananaskis	91.5	-15.9%	54.4%**	1940-95	53
Calgary	42.9	-7.7%	22.9%**	1912-95	84
High River	69.5	-18.5%**	20.0%**	1917-95	76
Brooks	48.8	-14.7%*	43.5%**	1916-95	68
Gleichen	47.3	-2.9%	26.8%**	1917-95	73
CENTRAL ALTA					
Red Deer	52.9	-5.9%	32.0%**	1916-95	80
Lacombe	51.3	-18.0%**	40.7%**	1912-95	81
Olds	52.0	-10.9%	32.7%**	1920-95	72
Coronation	53.2	-28.1%**	50.6%**	1945-95	50
Rocky Mountain	62.5	-18.9%**	39.8%**	1918-95	68
Jasper	77.9	-21.4%**	39.6%**	1919-95	67
Calmar	62.4	-19.7%**	48.4%**	1916-94	77
Edmonton	64.9	-17.3%**	32.6%**	1912-95	84
Sion	76.3	-23.9%**	23.5%**	1912-93	71
Ranfurly	60.4	-13.0%*	26.2%**	1912-95	84
Edson	64.5	-19.6%**	28.7%**	1920-93	74
NORTHERN ALTA					
Campsie	64.3	-20.3%**	33.6%**	1912-95	84
Athabasca	72.4	-26.1%**	17.6%*	1912-95	84
Grande Prairie	87.3	-12.7%	17.7%*	1931-95	65
Beaverlodge	85.6	-12.9%*	27.2%**	1913-95	83
Slave Lake	74.3	-20.1%**	17.3%	1925-94	70
Fort McMurray	60.2	-7.7%	16.0%	1920-95	76

** - significant at the 95% confidence interval
* - significant at the 90% confidence interval

The Peace River at Peace River, the largest in Alberta, indicated very small increases in natural runoff volumes for El Niño and La Niña events.

The small departure in runoff for El Niño and La Niña events in the North Saskatchewan, Athabasca, and Bow River basins may be partly attributed to meltwater from glaciers. It is speculated that this meltwater dampens the magnitude of the extreme events.

The frequency of natural runoff volumes indicated a similar response to that of precipitation, with the exception of the Red Deer River. The exception appears to be attributed to heavy summer rains early in the data record. El Niño events tended to indicate a higher frequency of below-average runoff volumes while La Niña events indicated a higher frequency of above-average runoff volumes.

Table 4 Natural Runoff Volumes for El Niño and La Niña Years

River	Average Feb-Jul Natural flows (dam3)	Departure from mean during El Niño Years	Departure from mean during La Niña Years
Oldman River at Lethbridge	2709586	-16.7%**	11.5%
Bow River at Calgary	1874141	-4.4%	6.8%
Red Deer River at Red Deer	1039068	6.5%	6.2%
North Saskatchewan River at Edmonton	4242128	0.3% (-3.9%)	5.0%
Athabasca River at Athabasca	8482361	-2.7%	15.6%*
Peace River at Peace River	41060519	1.3%	1.5%

** - significant at the 95% confidence interval
* - significant at the 90% confidence interval

CURRENT CONDITIONS

The 1997-98 El Niño episode is one of the strongest on record. Temperature and precipitation data were analyzed for the December to February period to compare this year's results to the long-term findings presented earlier. Temperature data were available for ten of the 15 sites used in the previous analysis. Temperatures ranged from 2.4° to 9.5°C above the long-term average. This range is greater than the average found during previous El Niño episodes.

Precipitation data were available for 23 of the 36 stations and was analyzed for the December to February 1997-98 El Niño event. Precipitation averaged 47% of normal (long-term average) for the 23 stations with individual stations ranging from 12.3% to 91.1% of normal (long-term average).

SUMMARY

El Niño and La Niña events have great impacts on the climate of Alberta. Average temperatures during El Niño events were about 1° to 2°C above the long-term average for the December to February period. A decrease of 1° to 2°C from the long-term average in December to February temperatures was found for La Niña events.

Substantially above-average precipitation was noted during La Niña events, with some stations indicating up to a 50% increase. El Niño events indicated below-average precipitation for all stations compared to the long-term average but some of the decreases were relatively small. While El Niño events generally indicated an increased probability of below-average precipitation, it was still possible to record average or above-average precipitation.

Natural runoff volumes for the six major rivers in Alberta provided above-average flows for the February to July period following La Niña winters. Runoff volumes were generally below-average following El Niño winters except in the Red Deer and Peace Rivers.

The last few El Niño events (since the early 1950's) have indicated an even lower level of precipitation and natural runoff volumes than was shown by the analysis of the entire 1912-95 period. The explanation for the lower values is uncertain, however it may be that the quality of data in the early part of the record is less reliable or it may indicate that El Niño itself has changed over time, as noted by some researchers.

The current 1997-98 El Niño episode is one of the strongest on record. The winter of 1997-98 saw temperatures in Alberta ranging from 2.4° to 9.5° above-average for the December to February period. Precipitation averaged 47% of the long-term average for the same time period, with individual stations ranging from 12% to 90% of the long-term average.

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