THE FLORIDA STATE UNIVERSITY
COLLEGE OF ARTS AND SCIENCES

REGIONAL ANALYSIS OF CANADIAN, ALASKAN, AND MEXICAN PRECIPITATION AND TEMPERATURE FOR ENSO IMPACT

By

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To my father, Joseph R. Green Sr., whose love, guidance, and support through the years made my education possible, as well as early comments such as “Shut the door, we don’t live in a barn, you are letting the cold in” made me wonder about the micro-scale weather systems I was tracking all over the house.

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ABSTRACT

The changes in seasonal average monthly temperature and precipitation associated with El Niño Southern Oscillation (ENSO) phases are assessed at 125 stations in Canada, Alaska, and Mexico. Forty years of monthly data are classified as occurring during either a warm phase (El Niño), cold phase (El Viejo or La Niña) or neutral phase of ENSO using sea surface temperature (SST) data from the equatorial Pacific Ocean.

Monthly mean temperature and monthly total precipitation are resampled to estimate population distributions for ten seasons in an ENSO year for each phase of ENSO. The differences in seasonal climate means are calculated between the cold (warm) phase and the neutral phase. An ENSO year is defined as the October after onset of the ENSO event through the following September.

The results for temperature indicate that Canada and Alaska tend to be cooler in the cold phase, and southern Canada tends to be warm during the warm phase. Mexico tends to be cooler in the warm phase and warmer in the cold phase.

The precipitation regime during these phases is complex and is dependent on region as well as season of the ENSO year. Eastern Canada generally has the warm phase wetter than the cold phase.

Canada generally has the warm phase wetter than the cold phase.

Western Canada and Alaska are generally wetter in the cold phase.

The coastal regions have a more complex regime. Mexico generally has a wetter warm phase year.

The warm phase is shown to be more significant in Mexico and the cold phase is shown to be more significant in Canada and Alaska. The results are generally consistent with the PNA and “reverse” PNA patterns.

1. INTRODUCTION

Variations in climate and weather can significantly impact our daily lives in subtle and not so subtle ways. From the heating bills from an extremely cold winter, to rising food prices due to crop failure from drought, to emergency conditions such as flooding, heat waves, and forest fires, we are irrevocably linked to our ecosystem. Many of our valuable resources are wasted due to lack of preparation and repairing damage is often more expensive than early prevention. Effective planning requires study of regional analysis of climatic variability, such as the effects associated with El Niño Southern Oscillation (ENSO).

The phenomena known as El Niño has been observed since at least the 1600's off the coast of Peru. At varying intervals, anomalously warm waters off the Peruvian coast appeared around Christmas and were dubbed El Niño, for the Christ child. The development of the El Niño phenomena has its origins in the west tropical Pacific Ocean. Easterly trade winds relax and a westerly wind anomaly develops, exciting westward propagating Kelvin waves along the equator. These waves suppress the thermocline, deepening the surface mixed layer. Warm sea surface temperature (SST) anomalies develop as a result, and spread eastward to the South

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American coast. Teleconnections, links between the El Niño event and higher latitudes, can take the form of many diverse air-sea interactive phenomena, such as excited Kelvin waves propagating up the coasts or alteration of synoptic weather patterns. Today El Niño is known to be only the warm extreme of an interannual climate fluctuation called El Niño Southern Oscillation. The cold extreme, (La Niña, El Viejo, cold phase) was recently found to have consequences of equal or greater importance than El Niño.

Both ENSO phases have sea level pressure anomaly patterns associated with them. During the warm phase of ENSO, the Pacific North American (PNA) pattern develops, characterized by a strong Aleutian low to the southeast of Alaska, a ridge over the Western Cordillera of Canada, and a trough over eastern North America (Philander 1990). During the cold phase, the 'reverse' PNA pattern, first suggested by Wallace and Gutzler (1981), develops. This pattern appears to be the opposite of the PNA pattern. The reverse PNA pattern consists of a ridge to the south of Alaska over the Pacific Ocean, lower pressure to the north of Alaska, a trough over the Western Cordillera of Canada, a strong high pressure system over central Arctic Canada and a ridge over the eastern US (Smith et. al. 1996). The PNA (reverse PNA) can occur without the warm (cold) phase, but occurs more frequently in conjunction with the warm (cold) phase.

Since the early twentieth century, global temperature, precipitation, and other weather phenomena have been examined for

precipitation, and other weather phenomena have been examined for

their connection with ENSO. In the 1920's, Walker (1923) was the first to study climatic anomalies linked with the Southern Oscillation (SO), the interannual pressure fluctuations between the Indian Ocean and the eastern tropical Pacific. Bjerknes (1966) first noticed that coherent sea surface temperature anomalies (such as the El Niño phenomena) accompanied SO extremes. Since then, parts of every continent, (Ropelewski and Halpert 1987, Kiladis and Diaz 1989), including Antarctica (Simmons and Jacka 1995), have been studied for connections to ENSO .

Early studies focused on El Niño, the warm phase of ENSO. However, recent studies (e.g. Ropelewski and Halpert 1996, Kiladis and Diaz 1989, Philander 1990) included investigation of the opposite phase of ENSO, i.e. the cold phase. Recent findings showed that the temperature and precipitation anomalies associated with the cold phase can be as or more significant than those associated with the warm phase (Sittel 1994).

Past investigations of North America temperature and precipitation anomalies associated with ENSO include the following studies. Shabbar and Khandelar (1996) investigated temperature anomalies associated with ENSO over Canada and found significant cold temperature anomalies in west Canada, consistent with the reverse PNA pattern. However, their studies spanned over a large grid, ignoring local variability due to topography, and ignoring Alaska. Yarnal and Diaz (1989) studied southeast Alaska and coastal British Columbia in terms of temperature and precipitation. They

British Columbia in terms of temperature and precipitation. They

found that precipitation anomalies could not be explained by the PNA and reverse PNA patterns as well as the temperature anomalies. Ropelewski and Halpert (1986) and Smith et al. (1996) propose that displacements of the subtropical and polar front jets in the warm and cold phases are better indicators of precipitation anomalies, as well as placement of longwave ridges and troughs (Smith et al 1996, Yarnal and Diaz 1986). Sittel (1994) analyzed temperature and precipitation anomalies associated with the warm and cold phases of ENSO over the United States and found synoptic anomaly patterns unique to each ENSO phase. These patterns indicate anomalies could logically extend to Canada, Alaska, and Mexico. Little has been done for Mexico as a regional study. Rogers (1988) included segments of Mexico as a part of a comprehensive Caribbean/Tropical America study and found significant higher precipitation anomalies in Mexico.

The purpose of this study is to analyze the surface air temperature and precipitation anomalies associated with ENSO extremes over Alaska, Canada, and Mexico. The evolution of the temperature and precipitation anomaly patterns for both the cold and warm phases will be examined. Seasonal and regional variability will be studied throughout these regions of North America. This investigation extends the previous studies of the United Studies (Sittel 1994) to tropical Mexico and the Canadian High Arctic. In the past, most studies have been focused on one specific region or on large scale features globally. I chose the North American continent because North America has a dense enough observing network that

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will allow regional analysis. Significant results are shown to preserve the continuity of the patterns associated with both phases of ENSO. During the investigation I found a large scale synoptic anomaly pattern extending throughout North America for both temperature and precipitation.

A developed set of historical monthly data (section 2) is utilized to estimate seasonal means associated with ENSO extremes. A description of the methodology appears in section 3. Results of anomalous temperature and precipitation are examined in section 4 and are finally synthesized and interpreted in section 5.

2. DATA

Monthly mean temperature and monthly precipitation totals for 84 Canadian, 14 Alaskan, and 27 Mexican stations (Figure 1, Table 1) are chosen from the Global Historical Climatology Network dataset (GHCN) (Vose et al. 1992). Data were subject to quality control and flagged by the GHCN for suspicious, revised, or largely discontinuous data.

The selected stations are poorly spaced due to the lack of development in the Canadian and Alaskan Arctic, and in the Mexican deserts and tropical lowlands (Figure 1). Most Canadian stations lie within 500 km of the United States. The most sparse regions in terms of station density are the Northwest Territories, Northern Quebec, and Labrador, due to continuous permafrost.

The time periods chosen are 1947-1986 for Canada/Alaska, and 1944-1983 for Mexico. These years are chosen in order to maximize the number of stations included in this study. For inclusion, each Canadian and Alaskan station must have less than 10% missing data. Of the 98 stations selected, 40 Canadian and Alaskan stations have no missing precipitation and temperature values and 48 have less than 5% missing. Mexican stations are selected if they have less than 15% missing precipitation and [illegible]
selected if they have less than 15% missing precipitation and
temperature records. The increase of missing data for Mexican

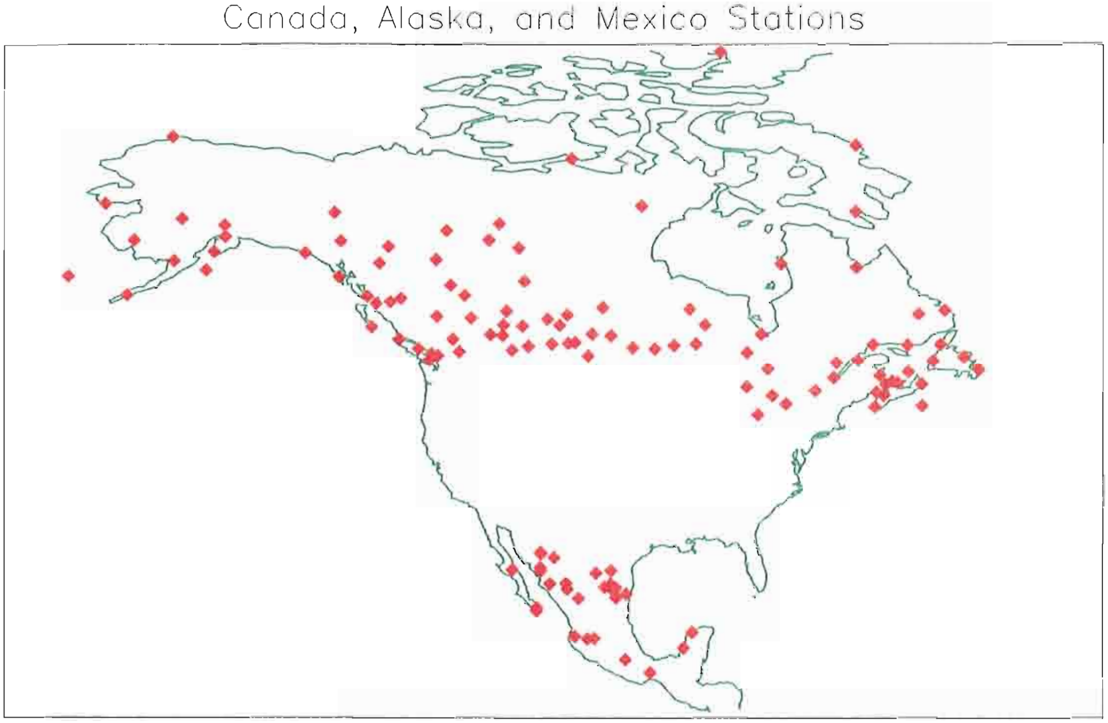

Figure 1: Station Density. Distribution of stations used in this study

Table 1: Latitude and longitude of stations used in this study (appendix).

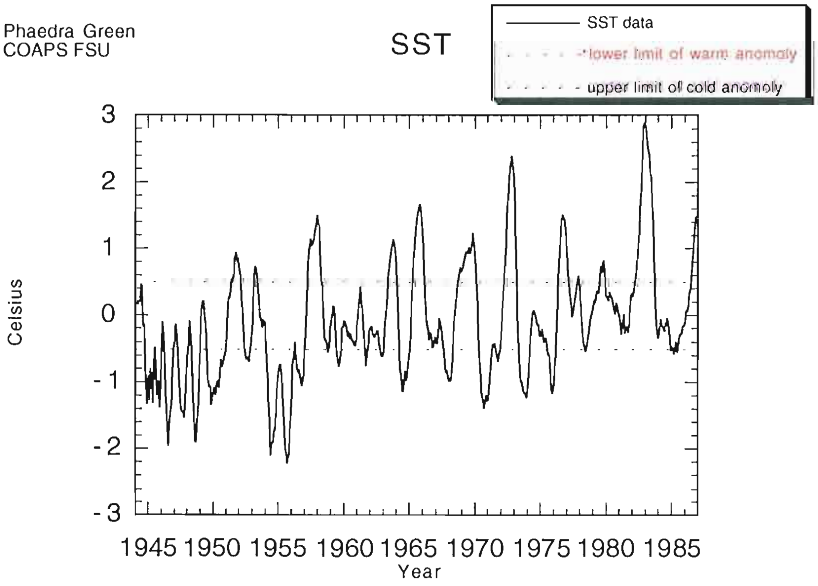

Figure 2: Mean monthly SST anomalies for the region 4°N to 4°S and 150°W to 90°W,

1945 1950 1955 1960 1965 1970 1975 1980 1985
Year

Figure 2: Mean monthly SST anomalies for the region 4°N to 4°S and 150°W to 90°W, these values are used in defining the JMA SST index. The threshold for extreme events is ±0.5°C.

stations is necessary in order to double the number of stations selected. If I use the Canadian criteria for selection, only 14 stations can be used and these stations are less uniform in spatial distribution across Mexico. Of the 27 Mexican stations selected, 4 stations have less than 5% missing and 10 stations have less than 10% missing.

The indicator used for classification of the extremes of ENSO events is a sea surface temperature (SST) index defined by the Japan Meteorological Agency (JMA). The JMA index has been used in past studies such as Sittel and O'Brien (1994), Richards and O'Brien (1995), and Sweeny and O'Brien (1996). The JMA index is based on monthly mean SST anomalies averaged for the area 4°N to 4°S and 150°W to 90°W (Figure 2). The SST anomalies are then smoothed using a five month running mean to reduce noise in the data. The JMA index is readily available for all the years in this study, except from 1944 to the latter part of 1949. Index data from this period were constructed in accordance with the index definition using SST anomaly data from the Comprehensive Ocean-Atmosphere Data Set (COADS)(Shriver 1993).

An ENSO year for this study is classified by the SST index, from October(0) to the following September(+1), so that the effects of ENSO can be observed from mature stage (winter after onset) through to dissipation in the following summer. This definition of the ENSO year is different than the canonical warm phase (El Niño) defined by Rasmusson and Carpenter (1982).

defined by Rasmusson and Carpenter (1982).

The GHCN Canadian, Alaskan, and Mexican data are classified as occurring during one of the three phases of ENSO, the warm phase of ENSO (El Niño), the cold phase of ENSO (El Viejo or La Niña), or neither, the neutral phase, depending on the JMA index. A warm (cold) phase classification is defined as an ENSO year in which the five month running means of the JMA monthly SST anomalies are +0.5°C or warmer (-0.5° or colder) for at least six consecutive months, starting before the first month (October) of the ENSO year, and including October, November, and December. October, November and December are the months that typically correspond with the maximum amplitude in the SST anomalies. The classification for the cold phase was selected to be symmetric to the warm phase for simplicity since there is no agreed upon definition of the cold phase at this time. (Sittel 1994). The resulting warm phase years generally agree with other studies. The number of cold phase years is slightly larger than in other studies (e.g., Diaz and Kiladis 1992) which classify 1971, 1967, 1956, 1955, 1954, 1948 and 1947 as neutral years. In this study these years are cold phase years (Table 3).

3. METHODOLOGY

The forty years of GHCN temperature and precipitation data are classified into appropriate ENSO categories: cold, neutral or warm phases, according to the JMA SST index. In each ENSO category, an average of all the Januarys is taken for a mean January value for that particular ENSO phase, as are the rest of the months. A three month running average is applied to the twelve averaged months to smooth out high frequency noise. The result is ten ENSO seasons as opposed to twelve, because of the overlap of the months. The ENSO year starts in October-November-December (OND) and ends in July-August-September (JAS)(Table 2) for the three ENSO categories. Deviations of the warm and cold phases from the neutral phase values indicate spatially variate results. Animations of these results, plus results from a similar study on the United States (Sittel 1994), are composed to show a comprehensive view of the deviations associated with the cold and warm phases for the entire North American continent.

Classification of the temperature and precipitation data into each ENSO category results in insufficient data to determine the underlying statistical distribution. For example, there are only nine climate values for each month in the warm phase category (Table 3).

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One problem that arises when inferences are made on such a small

Table 2: ENSO Season Abbreviations

Fall	OND	October/November/December
	NDJ	November/December/January
Winter	DJF	December/January/February
	JFM	January/February/March
	FMA	February/March/April
Spring	MAM	March/April/May
	AMJ	April/May/June
	MJJ	May/June/July
Summer	JJA	June/July/August
	JAS	July/August/September

Table 3: Years in research period by ENSO category. The years in each category corresponds to the first three months of the ENSO year namely October, November, and December. For example, the ENSO year 1970 starts October 1970 and ends September 1971.

Cold Phase	Neutral Phase	Warm Phase
1945	1944	1951
1946	1950	1957
1947	1952	1963
1948	1953	1965
1949	1958	1969
1954	1959	1972
1955	1960	1976
1956	1961	1982
1964	1962	1986
1967	1966	
1970	1968	
1971	1974	
1973	1977	
1975	1978	
	1979	
	1980	
	1981	
	1983	
	1984	
	1985	

1984
1985

sample is that a Gaussian assumption cannot be made with respect to the central limit theorem. Therefore the resampling technique applied by Sittel (1994) and based on the Bootstrap method (Diaconis and Efron 1983) is implemented for generating a larger representation of the data set for robust statistical distributions. This method was successfully applied in previous studies (Sittel 1994, Richards and O'Brien 1994). In the Bootstrap method, each value of the climate data for each month are considered independent (Sittel 1994). Precipitation data are independent and temperature data are semi-independent, therefore the technique is accurate for precipitation data and only approximate for temperature (Sittel 1994).

The resampling technique was implemented as follows. Each climatic data value is sorted by month and ENSO category with respect to the JMA index. One seasonal composite sample is created by replacing each of the three months in a season by one value selected at random from a set of all values in that particular month for any year of a particular ENSO category. The mean of the three selected months are averaged, producing a seasonal average. For example, a seasonal composite for MAM in the cold phase could consist of March 1946, April 1976, and May 1971 climate values. Temperature and precipitation data for each station, ENSO month, and ENSO category are randomly sampled in this way 10,000 times for each season in the ENSO phase. Ten thousand samples were found to be a sufficient amount in earlier studies (Sittel 1994). The

resulting 10,000 composites represent the distribution for that
to be a sufficient amount in earlier studies (Sittel 1994). The

resulting 10,000 composites represent the distribution for that particular ENSO phase and season. Means and standard deviations of the bootstrapped data are computed and compared to the statistics of the original data. The comparisons indicate that the bootstrap means deviate less than 1% from the original data means. The standard deviations of the bootstrap data are found to be smaller than that of the standard deviations of the original data. The resampled data are used to construct histograms showing the frequency and separation of the ENSO phases for precipitation and temperature (Figure 3a & 3b).

Prior works indicate a Gaussian distribution assumption can be made for the temperature data (Sittel 1994). A two-tailed statistical T-test, assuming unequal variance, is used for determining whether the means in the seasonal temperature data of the ENSO phases are significantly different. A significance level of .05 (confidence level of .95) is chosen to test the difference between the cold phase and neutral phase and the difference between the warm phase and the neutral phase. Two hypotheses are established. The null hypothesis states that for temperature there is insignificant difference between the neutral phase mean and cold (warm) phase mean. The alternate hypothesis states that the difference between the means is significant.

The combination of these methods, the difference in means, the resampling technique in constructing statistical histograms, and the T-test, is implemented to produce results clearly identifying the effect of ENSO related phenomena on Alaska, Canada, and Mexico precipitation and temperature patterns.

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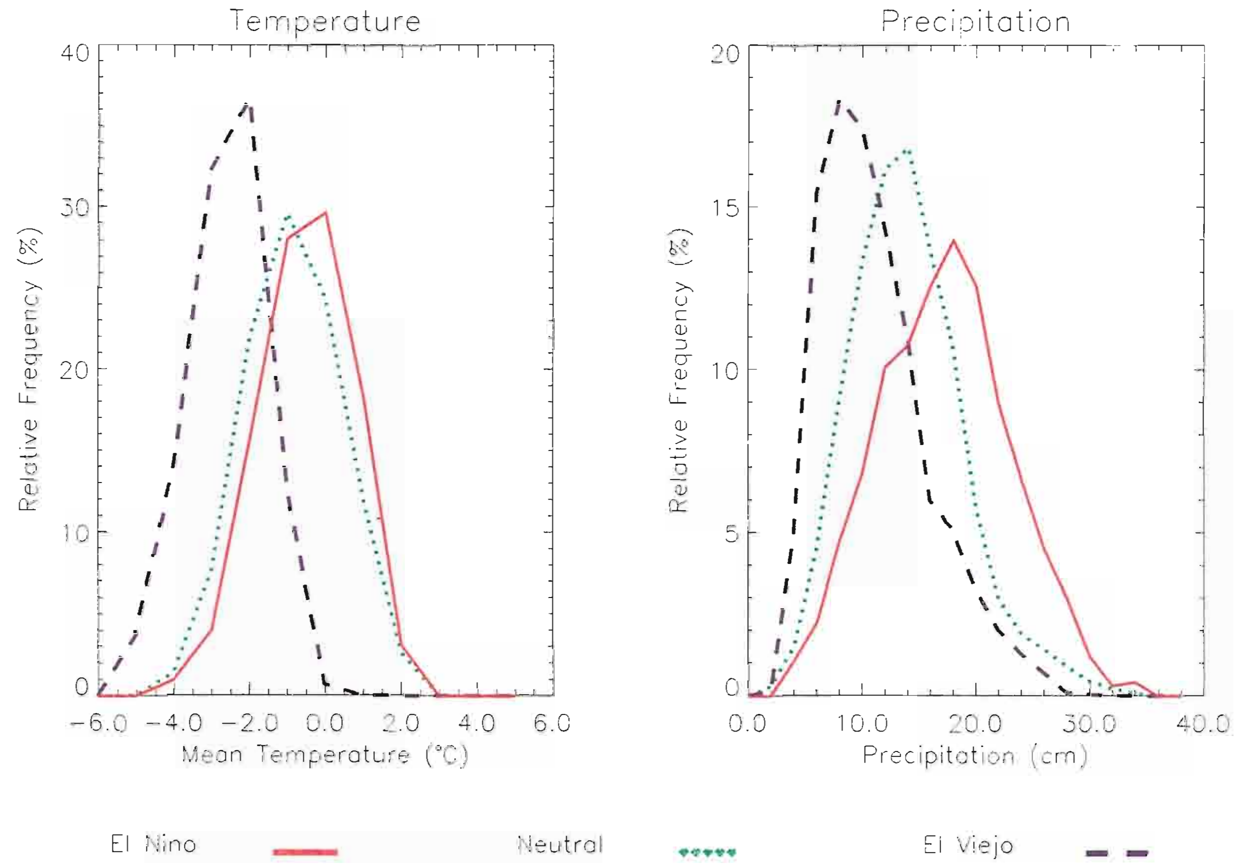
effect of ENSO related phenomena on Alaska, Canada, and Mexico

Figure 3a. and 3b. Kodiak Alaska Histograms of bootstrapped data for the ENSO month of DJF



4. RESULTS

Due to the large number of stations analyzed, the results are discussed by country, region, and then sub-regions for each climate variable. Canada and Alaska are discussed together in section 4.1 and Mexico in section 4.2. Alaska and Canada are broken into ten subregions and Mexico, five subregions, to assess the effect of ENSO on the diverse climatic areas in these regions. The stations within each sub-region have results comparable to the selected stations chosen to represent the sub-region in the following discussion and graphics. Significant deviations of other stations' results from the selected stations' results are noted.

In the following sections, discussion of the cold (warm) phase refers to the deviation of the cold (warm) phase means from the neutral phase means. Probability density functions are presented at the end of each section to illustrate the separation of phases.

4.1 Canadian and Alaskan Results

Selected stations in each of ten major regions in Alaska and Canada were chosen to represent findings from 98 stations. Nome, on the Seward peninsula, represents stations on the Bering Coast; and Talkeetna represents the Alaska-Yukon Interior. Port Hardy represents the Pacific Northwest: coastal British Columbia and the Alaskan Panhandle. Jasper, at an elevation of 1061 meters, represents the Western Cordillera region. The Pas represents the Interior: the plains of eastern Alberta, Saskatchewan and Manitoba. Quebec City represents the Eastern Interior: Quebec and Ontario. Sable Island represents the Eastern Maritime region. Kuujjuaq represents the Eastern Arctic, and Yellowknife represents the Western Arctic. Lastly, Eureka represents the High Arctic region, stations north of the 63° latitude. (Figure 4 and Table 4). The ten regions in Canada and Alaska are chosen and defined partially due to characteristics of the surrounding topography and climate, and the response to ENSO signal (which will be discussed in section 4.1.2).

4.1.1 Geography of Canadian and Alaskan regions

The Bering Coastal stations are roughly west of 160°W and south of the Seward Peninsula and contain the Alaska Peninsula and

south of the Seward Peninsula and contain the Alaska Peninsula and

Aleutian Islands. Since the mountain system in this region of Alaska is aligned southwest to northeast, the maritime influence is "experienced" up to one thousand kilometers inland. The climate is typically dry, with a wetter climate to the south in the Aleutian Islands and Alaska Peninsula. The Kilbuck, Kuskokwim, and Kaiyuh Mountain ranges bisect the Bering Coastal region into north and south sections. The north region has more of a continental influence in the winter with the encroachment of sea ice.

The Alaskan-Yukon Interior stations range from the south coast of Alaska to the Brooks Range in the north to the Richardson mountains in Yukon and west to the 160°W longitude. The stations generally have a larger range of temperature than the Bering Coastal stations. The Alaska Range bisects the region, leaving the greater part of the Alaskan-Yukon Interior cut off from maritime influence. North and northeast of the Alaska Range the climate regime is continental; drier with a larger range of temperature. The climate south of the Alaska Range is milder and moister due to its proximity to the Gulf of Alaska. The precipitation on the southern Alaskan coast is not as abundant as that of the Pacific Northwestern region.

The Pacific Northwestern region ranges from the contiguous US border north to the Wrangel-St. Elias Mountains in the northern Alaskan panhandle and is confined by the Coastal Mountains to the east and the Pacific Ocean to the west. This narrow region is one of the wettest regions in the world: rainfall can exceed 200 cm per year. Temperature range is relatively small due to the region's proximity to the ocean.

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proximity to the ocean.

Table 4: Canada and Alaska stations by region, station name and province or state

EASTERN INTERIOR CANADA
Trenton, ONT
London, ONT
Muskoka, ONT
Gore Bay, ONT
Earlton, ONT
Kapuskasing, ONT
Moosonee, ONT
Montreal, QUE
Quebec, QUE *
Mont Joli, QUE
Bagotville, QUE
Sept-Iles, QUE
Natashquan, QUE

WESTERN CORDILLERA
Quesnel, BC
Kamloops, BC
Penticton, BC
Fort St. John, BC
Fort Nelson, BC
Smithers, BC
Dease Lake, BC
Terrace, BC
Jasper, ALTA
Banff, ALTA *
Calgary, ALTA
Edmonton Municipal, ALTA
Lethbridge, ALTA

HIGH ARCTIC REGIONS
Barrow, AK
Eureka, NWT *
Clyde, NWT
Iqaluit, NWT
Baker Lake, NWT

EASTERN ARCTIC CANADA
Inukjuak, QUE
Kuujjuaq, QUE *
Cartwright, NFLD
Goose, NFLD

INTERIOR
Medicine Hat, ALTA
Coronation, ALTA
Red Deer, ALTA
Fort McMurray, ALTA
Grande Prairie, ALTA
Yorkton, SASK
Estevan, SASK
Regina, SASK
Moose Jaw, SASK
Saskatoon, SASK
Prince Albert, SASK
Swift Current, SASK
North Battleford, SASK
The Pas, MAN *
Winnipeg, MAN
Dauphin, MAN
Kenora, ONT
Sioux Lookout, ONT
Big Trout Lake, ONT
Armstrong, ONT
Lansdowne House, ONT

EASTERN MARITIME CANADA
Iles de la Madeleine, QUE
Greenwood, NS
Sable Island, NS *
Yarmouth, NS
St. John, NB
Summerside, PEI
Moncton, NB
Charlottetown, PEI
Sydney, NS
Chatham, NB
Gander, NFLD
Daniel's Harbour, NFLD
St. John's, NFLD
Stephenville, NFLD

WESTERN ARCTIC CANADA
Yellowknife, NWT *
Fort Simpson, NWT
Hay River, NWT
Fort Smith, NWT

Table 4 (cont.): Canada and Alaska stations by region

ALASKA-YUKON INTERIOR

Talkeetna, AK *
Anchorage, AK
Homer, AK
Kodiak, AK
Mayo, YT
Whitehorse, YT
Watson Lake, YT

BERING COAST

Nome, AK *
McGrath, AK
Bethel, AK
St. Paul, AK
Cold Bay, AK
King Salmon, AK

PACIFIC NORTHWEST

Annette Island, AK
Yakutat, AK
Sitka Magnetic Laboratory ,AK
Port Hardy, BC *
Cape St James, BC
Abbotsford, BC
Comox, BC
Victoria, BC
Vancouver, BC
Prince Rupert, BC

* indicates representative station for each region

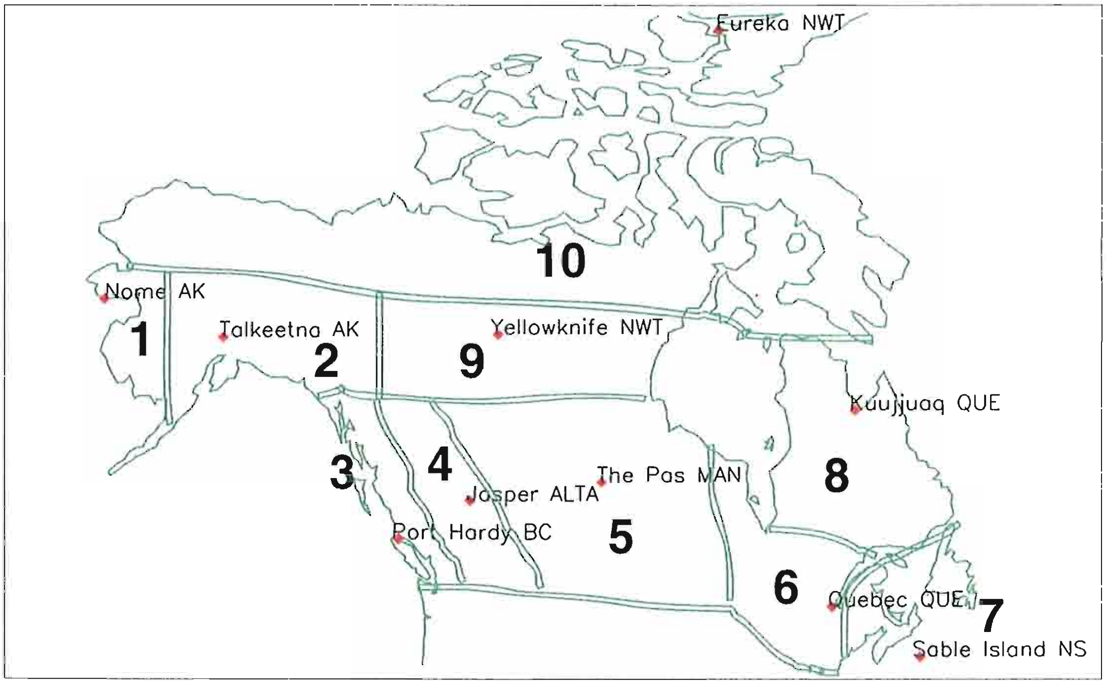


Figure 4: Representative stations for Canada and Alaska in their respective regions: 1 Bering Coastal, 2 Alaska-Yukon Interior, 3 Pacific Northwest , 4 Western Cordillera, 5 Interior, 6 Eastern Interior,7 Eastern Maritime, 8 Eastern Arctic, 9 Western Arctic, and 10 High Arctic.

Bering Coastal, 2 Alaska-Yukon Interior, 3 Pacific Northwest , 4 Western Cordillera, 5 Interior, 6 Eastern Interior,7 Eastern Maritime, 8 Eastern Arctic, 9 Western Arctic, and 10 High Arctic.

The Western Cordillera region extends from the Coastal Mountains, encompassing the Selkiak Mountains, to the foothills of the eastern extent of the Rocky Mountains in Alberta. Stations are drier with distance east due to the orographic effect of the multiple mountain ranges on the Pacific maritime airmass traversing the Western Cordillera region. Precipitation increases with altitude on both the leeward and windward sides of the mountains in the Western Cordillera. Temperatures are generally cooler and the annual range smaller than that of the interior stations.

The Interior region encompasses west Alberta to central Ontario, from the US border to the NWT. This region is flat and dry, with a large range in annual temperature that is typical of interior continental climates. The region is comprised of two major areas of topographic significance. The high plains area in the western portion of the interior, which is often called the breadbasket of Canada, has rich soil suitable for farming. In the eastern area of the interior, the soil is poorly drained due to the highly resistant properties of the underlying rock.

The Eastern Interior region extends from central Ontario to Labrador and the St. Lawrence River and from the Great Lakes to central Quebec. The climate in this region is milder and less continental in nature than that of the Interior region. The annual precipitation is greater for eastern interior stations due to contributions from the Great Lakes, St. Lawrence River and Hudson Bay (in summer).

Bay (in summer).

The Eastern Maritime region encompasses all of Nova Scotia, Prince Edward Island, New Brunswick, the island portion of Newfoundland, and the section of Quebec south and east of the St. Lawrence River. These stations are moist compared to most of Canada, but not as wet as those of the Pacific Northwest. The annual range of temperature is smaller than that of the interior stations. The eastern sections of the islands have more precipitation than the western sides.

The Eastern Arctic region comprises northern Quebec and Labrador. The region is mostly bounded by water: Hudson Bay to the west, Hudson Strait and Ungava Bay to the north, Labrador Sea to the east, and the Gulf of St. Lawrence to the southeast. The Eastern Arctic has a continental climate for most of the year due to the freezing of the waterways to the west and north. Winter cyclogenesis over the western Atlantic is responsible for wintertime precipitation. Most of the region receives over 50 cm of precipitation annually. Temperature ranges for the Eastern Arctic are smaller than that of the Western Arctic.

The Western Arctic region encompasses the Northwest Territories south of the 63°N latitude, extending from the Yukon border east to the Hudson Bay. The climate regime is dry with a large annual range of temperature. The land is flat, poorly drained, and speckled with lakes. Permafrost is discontinuous in this region.

The High Arctic region encompasses stations north of the Brooks Range in Alaska and Canadian stations north of the 63°N

Brooks Range in Alaska and Canadian stations north of the 63°N

latitude. This region is the largest in size and the sparsest region (in terms of station density) in my study. The stations in the High Arctic are grouped together for brevity; there are slight climatic differences between Barrow, AK and Iqualuit, NWT. Common to all stations are desert-like precipitation conditions in the winter months. The climatic regime is continental for most of the year due to sea ice extent. The region has a plethora of different topographic features, and permafrost is continuous, hampering plant growth.

4.1.2 Temperature anomalies

Canadian and Alaskan stations have cool anomalies in the cold phase, and have warm anomalies in the warm phase. Exceptions do occur. The time and location of the significant anomalies varies.

4.1.2a. Alaska-Yukon interior and Bering Coastal regions

All stations in the Alaska-Yukon region have a significantly cooler winter associated with the cold phase (Figure 5). During the peak seasons in Nome (JFM) and Talkeetna (DJF) winters are on average 3.1°C colder. All stations experience the coldest extreme in DJF except for the Bering coastal stations of Nome and Cold Bay (JFM), and St. Paul (FMA). The T-test results indicate all anomalies in these regions are significant for DJF, with the coastal stations' anomalies significant over six months out of the ENSO year in the cold phase (Figure 6a).

The anomalies during the warm phase in Alaska and the Yukon are significant less often than those of the cold phase. The Alaskan

[illegible]
are significant less often than those of the cold phase. The Alaskan

and Yukon interior stations have a slightly warmer than normal fall

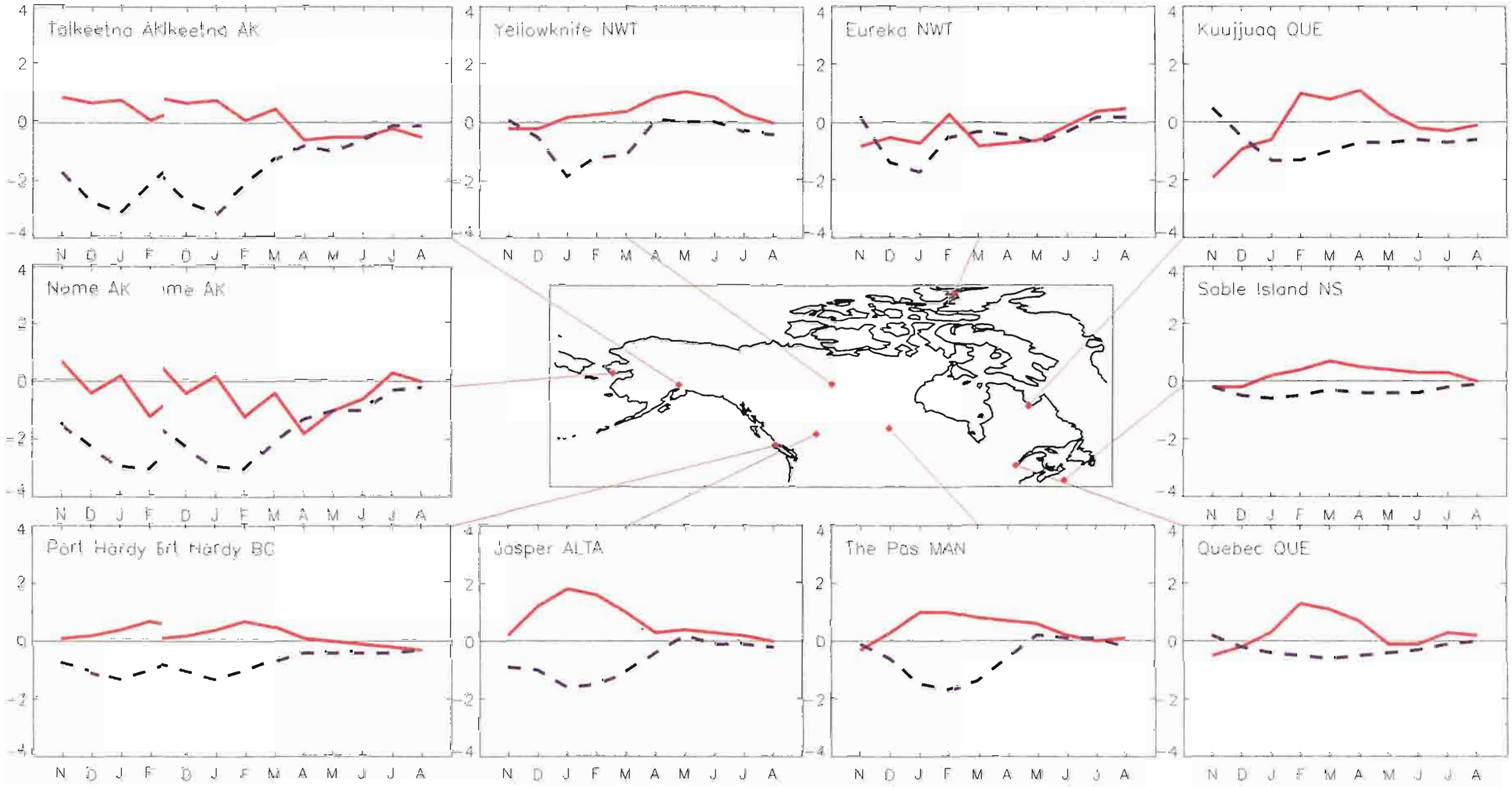
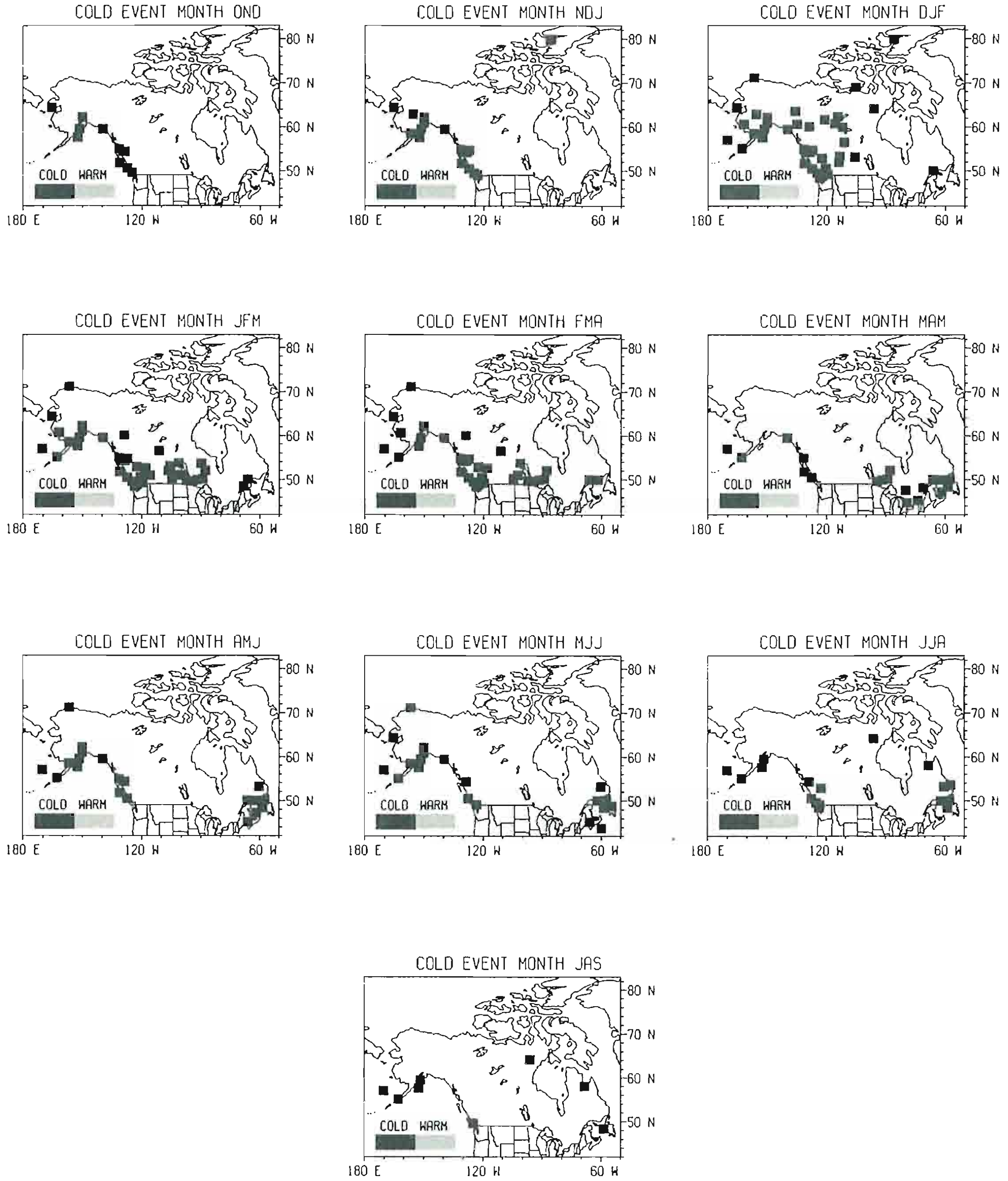


Figure 5: Dep 5: Departure from Neutral Mean in Degrees Celsius for Seasonal Mec Mean Monthly Temperature at Canadian and Alaskan Stations.



COLD EVENT MONTH OND

COLD EVENT MONTH NDJ

COLD EVENT MONTH DJF

COLD EVENT MONTH JFM

COLD EVENT MONTH FMA

COLD EVENT MONTH MAM

COLD EVENT MONTH AMJ

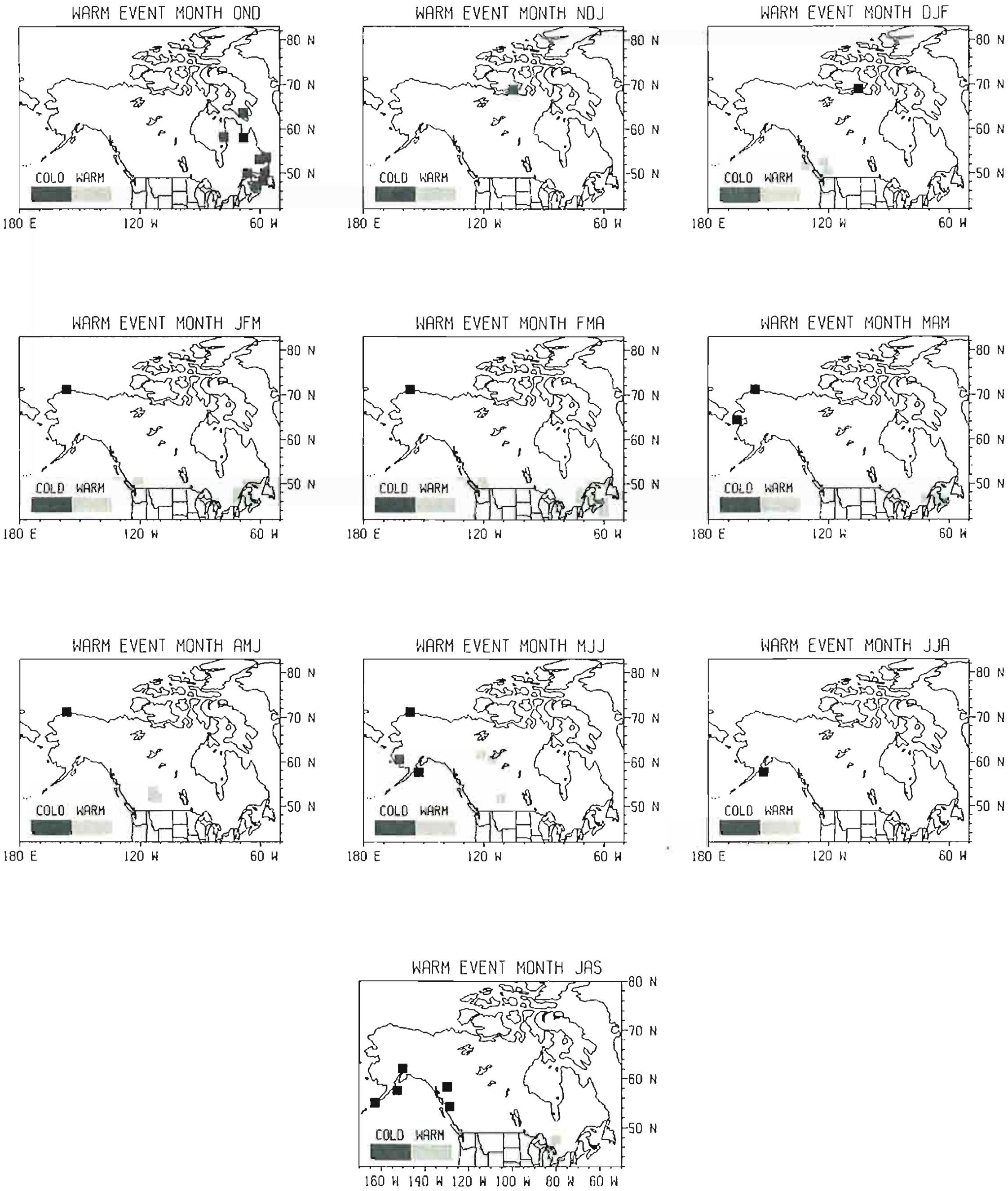
COLD EVENT MONTH MJJ

COLD EVENT MONTH JJA

COLD EVENT MONTH JAS

Figure 6.a: T-test results for Canada and Alaska during the cold phase.

Figure 6.a: T-test results for Canada and Alaska during the cold phase.



WARM EVENT MONTH OND

WARM EVENT MONTH NDJ

WARM EVENT MONTH DJF

WARM EVENT MONTH JFM

WARM EVENT MONTH FMA

WARM EVENT MONTH MAM

WARM EVENT MONTH AMJ

WARM EVENT MONTH MJJ

WARM EVENT MONTH JJA

WARM EVENT MONTH JAS

Figure 6.b: T-test results for Canada and Alaska during the warm phase.

Figure 6.b: T-test results for Canada and Alaska during the warm phase.

and winter. The Bering coastal stations are slightly warmer in fall; however, they become colder than neutral until the following summer. Nome (Figure 5) has no significant temperature deviations. Talkeetna has a slight, but statistically insignificant, warming of 0.9°C during the warm phase winter. The results from the T-test find no significant warming during the warm phase in the Alaska-Yukon region; however, significantly cooler than normal temperatures are experienced in select coastal Gulf of Alaska and Bering Coastal stations in spring and summer (Figure 6b).

4.1.2b. Pacific northwest and Western Cordillera regions

British Columbia, the Alaskan Panhandle and western Alberta can be broken up into two regions: Pacific Northwest (windward of the Western Cordillera) and the Western Cordillera. The Pacific Northwestern coastal stations have a damped, i.e. lower amplitude, ENSO-related response when compared to the continental stations. The continental stations are dominated by dry, warm subsidence from downslope flow. Results from Port Hardy and Jasper (Figure 5) demonstrate this observation. All stations in these western regions are colder than normal winter during the cold phase, with the maximum impact in DJF. Jasper has a winter as cold as -1.7°C below neutral in DJF, and Port Hardy BC, as cold as -1.4°C below the neutral case in DJF. The T-test (Figure 6a) results show all the Pacific Northwest stations and Western Cordillera stations on the windward side of the continental divide to be significantly colder during the cold phase from fall (OND) to spring (MAM). The highlands

windward side of the continental divide to be significantly colder during the cold phase from fall (OND) to spring (MAM). The highlands

(e.g. Jasper) have a larger annual range of temperatures than the coastal regions and they are significantly colder in winter. The southern region and far northern region also have a significant cold winter.

The warm phase in the Western Cordillera and the Pacific Northwest is associated with warmer than normal winters. The temporal occurrence of maximum warm anomalies vary by region. The West Cordilleran stations (e.g., Jasper Figure 5) have warm anomalies (1.8°C.) in DJF. In contrast, Port Hardy BC, a Pacific Northwest station, has the warm peak in JFM. Northern stations in the Western Cordillera have a slight sawtoothed appearance (i.e. large month to month variations) in the warm phase, with secondary warm peaks at FMA and AMJ. In the southern (northern) areas, the warm phase anomalies are slightly larger (smaller) in amplitude than the cold phase anomalies. Only the stations in south British Columbia are significantly warmer in winter during the warm phase (Figure 6b).

4.1.2c. High Arctic region

For the cold phase, high latitude Arctic stations, except Clyde, have colder winters with the maximum temperature anomalies (-1°C to -2°C) in DJF. The cold phase has little effect in spring and summer. T-test results indicate all western High Arctic stations are colder in DJF. Eureka (Figure 6a) has a significantly cold winter in NDJ as well, and Barrow stays significantly cold until spring (MAM).

Eureka (Figure 6a) has a significantly cold winter in
NDJ as well, and Barrow stays significantly cold until spring (MAM).

Only Baker Lake is significantly cooler during the summer.

During the warm phase, the winters are anomalously cool; but not as cold as during a cold phase. The warm phase temperatures approach neutral values in spring for the southernmost stations and summer for the northernmost stations (e.g., Eureka; Figure 5). T-test results show no significant warming in warm phases in the High Arctic (Figure 6b), except for the interior High Arctic stations in late summer (JAS). Barrow is significantly cold from late winter (JFM) to summer (MJJ). Only Iqaluit is significantly colder in the fall (OND).

4.1.2d. Western Arctic region

The typical western Arctic pattern during the cold phase is large anomalies in the earlier months of the ENSO year: the coolest temperature anomaly in DJF for Yellowknife (Figure 5) is -1.9°C. The T-test results confirm the entire region is significantly colder in winter (DJF) (Figure 6a).

The warm phase temperature anomalies peak later in the year (AMJ) at 1°C. Summers are slightly warmer than usual during a warm phase. The warm phase temperature anomaly pattern shows a "sawtoothed" ENSO-related response similar to that of the northern Western Cordillera and Alaska-Yukon Interior regions' pattern. The T-tests (Figure 6b) show that only the interior stations of Hay River and Fort Simpson are significantly warm in early summer (MJJ).

4.1.2e. Interior region

Interior Canada, encompassing the plains of eastern Alberta, Saskatchewan, Manitoba, and western Ontario show moderate sensitivity to ENSO phases. The Pas (Figure 5), has the largest cold phase anomaly of -1.7°C in JFM. Stations in Saskatchewan indicate a shift of the cold phase's minimum temperature peak month from DJF to JFM. T-test results show that the cold anomalies in eastern Alberta and western Saskatchewan in winter (DJF) and cold anomalies in eastern Saskatchewan, Manitoba, and western Ontario one month later (JFM) are significant (Figure 6a).

The warm phase in Interior Canada is associated with warmer winters. For The Pas (Figure 5), the warm phase maximum temperature anomaly of 1°C occurs in DJF. Stations in northern Saskatchewan show sawtoothed pattern common to stations at the higher latitudes. The T-test shows that in this region no significant warming occurs during a warm phase (Figure 6b).

4.1.2f. Eastern Interior region

Eastern Interior Canada, consisting of eastern Ontario and southern Quebec, generally has small temperature anomalies associated with ENSO. During the cold phase, cooler temperature anomalies occur in spring (MAM) in eastern Ontario and in southwestern Quebec. Eastern Quebec is cooler than the neutral phase earlier in the ENSO year, from DJF at the Atlantic sector stations of Quebec, to FMA at Quebec City (Figure 5). T-test results

phase earlier in the ENSO year, from DJF at the Atlantic sector
stations of Quebec, to FMA at Quebec City (Figure 5). T-test results

for the region show most eastern interior stations are significantly cooler in early spring (MAM). Natashquan and Sept Iles, the northeastern-sector on the St. Lawrence River, are significantly cooler from winter through summer (Figure 6a).

In all Eastern Interior stations, the warm phase is anomalously cold in the fall (OND) of the ENSO year, and has peak warm anomalies at JFM. Quebec (Figure 5) shows the typical pattern of this region, with maximum temperature anomaly of 1.3°C. T-test results show a significant warm winter (JFM and FMA) only for Gore Bay and Quebec stations near the St. Lawrence River (Figure 6b).

4.1.2g. Eastern Maritime region

The Eastern Maritime region consists of the island portion of Newfoundland, Nova Scotia, New Brunswick, and Prince Edward Island. The cold phase's effects are damped and less significant throughout this area. The anomaly for Sable Island (Figure 5) is largest in DJF and MJJ; however, according to the T-test, only the cold anomaly in early summer is significant. The T-test results also show significantly colder spring and summer seasons for the west coast of Newfoundland and Iles de la Madeleine. In summer, southern Nova Scotia is significantly colder (Figure 6a).

The warm phase has a slightly warmer (but significant) winter. The peak anomalies occur in JFM for western stations, and they occur in FMA in the eastern stations. In northeastern Labrador, the ENSO effects are greater in terms of amplitude than for the southern maritime stations. Sable Island (Figure 5) has the smallest

southern maritime stations. Sable Island (Figure 5) has the smallest

warm phase anomaly of 0.8°C in FMA. The T-test shows warm phase significance in early spring (FMA) for most of the region except the interior of the island portion of Newfoundland. Chatham and St. John are significantly warmer in winter and spring (Figure 6b).

4.1.2h. Arctic Eastern region

The cold phase is significant in Labrador and northern Quebec. In Kuujjuaq (Figure 5), the cold phase is associated with colder temperatures except in fall it is slightly warmer. Kuujjuaq has the cold peak of -1.2°C in winter (DJF). The T-test (Figure 6a) shows all stations except Inukjuak to be significantly colder in summer (JJA). Cartwright is also significantly colder in the spring and Kuujjuaq is significantly colder into the late summer (JAS).

The warm phase is less significant than the cold phase in the Eastern Arctic region. The warm phase has a slightly warmer late winter and spring (JFM to MAM) and a cold fall (OND) and summer. Kuujjuaq has a cold anomaly of -1.9°C during the warm phase fall and a warm maximum of 1.0°C during late winter and spring. Cartwright is the only station significantly warmer in spring (MAM). T-test results show all stations to be significantly colder during the fall (OND), matching Iqaluit's signal in the high Arctic region (Figure 6b).

The T-test results are such that all western Canadian and Alaskan stations have significantly colder winters (DJF, JFM, and FMA) during the cold phase of ENSO. The warm phase is shown to be less significant than the cold phase for Canada and Alaska (Figures 6a and 6b).

less significant than the cold phase for Canada and Alaska (Figures 6a and 6b)

4.1.3 Precipitation anomalies

Precipitation regimes during both phases of ENSO vary with region and season in Canada and Alaska. Generally the most pronounced changes in precipitation during ENSO phases are in the coastal regions.

4.1.3a. Alaska-Yukon Interior and Bering Coastal regions.

The warm phase in Alaska and Yukon has a slightly drier winter, a wet spring, and a dry summer. During the warm phase, Nome (Figure 7) and Bethel (north Bering coastal stations) have smaller precipitation anomalies in the winter and spring than the rest of the region. In the summer, warm phases are associated with a deficit of 15mm in Talkeetna (Figure 7), an Alaska-Yukon Interior station. The cold phase is associated with wetter winters and drier summers. Most of the Alaska-Yukon and Bering Coast stations resemble this pattern. The exceptions in the Alaska-Yukon Interior are the coastal stations of Homer and Kodiak, for which the precipitation pattern resembles that of the northern portion of the Pacific Northwest region (Figure 7a). The anomalies are wetter during winter in the warm phase and drier during winter in the cold phase.

4.1.3b. Pacific Northwest region

The Pacific Northwest region shows a gradual shift in anomalous precipitation winter regime from the north to the south. The northern coastal stations of British Columbia and the Alaskan

The northern coastal stations of British Columbia and the Alaskan

panhandle, such as Annette Island (Figure 7a), show the warm phase

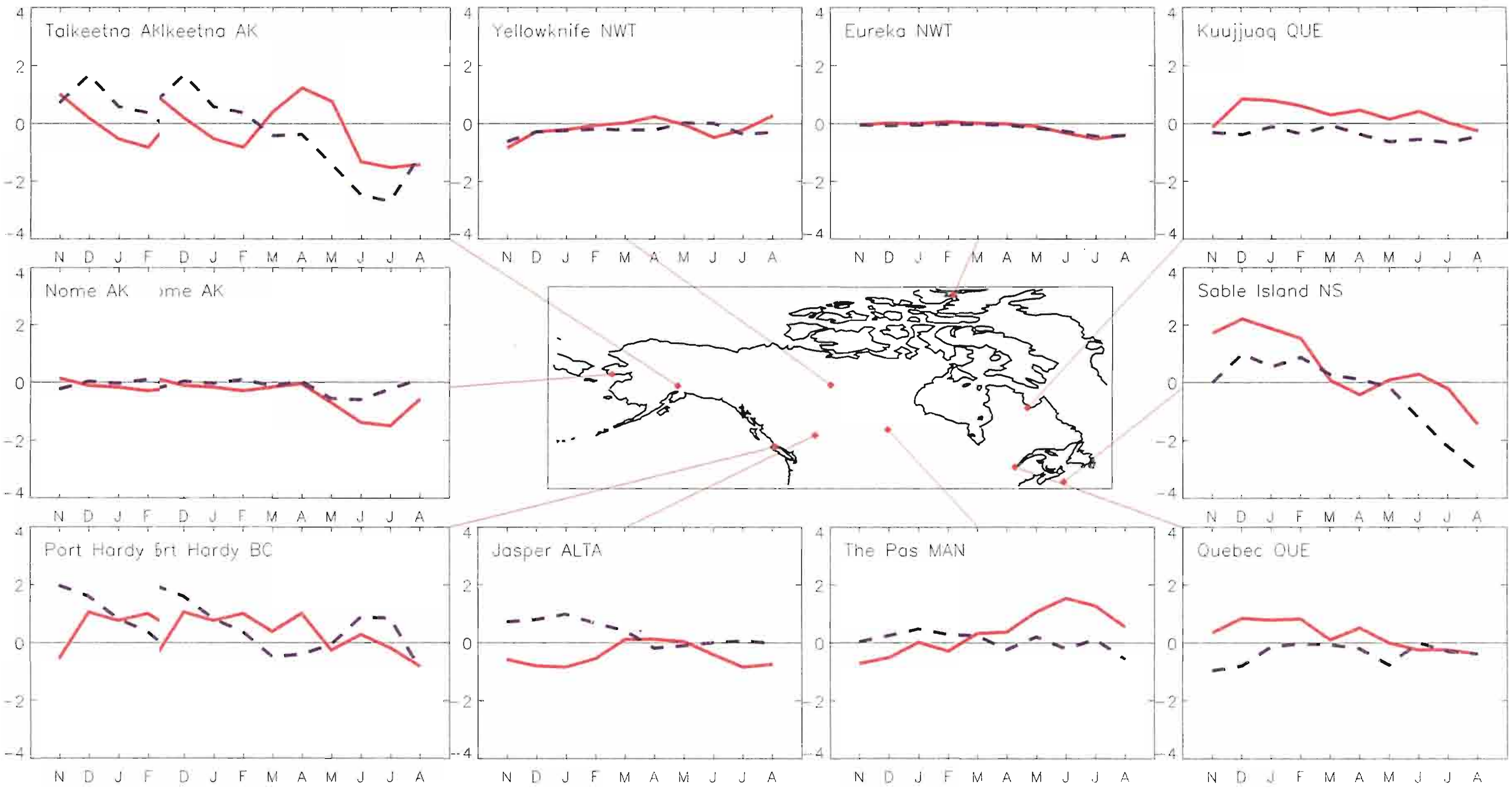


Figure 7: Dep: 7: Departure from Neutral Mean in Centimeters for Seasonal
Mec Mean Monthly Precipitation at Canadian and Alaskan Stations.

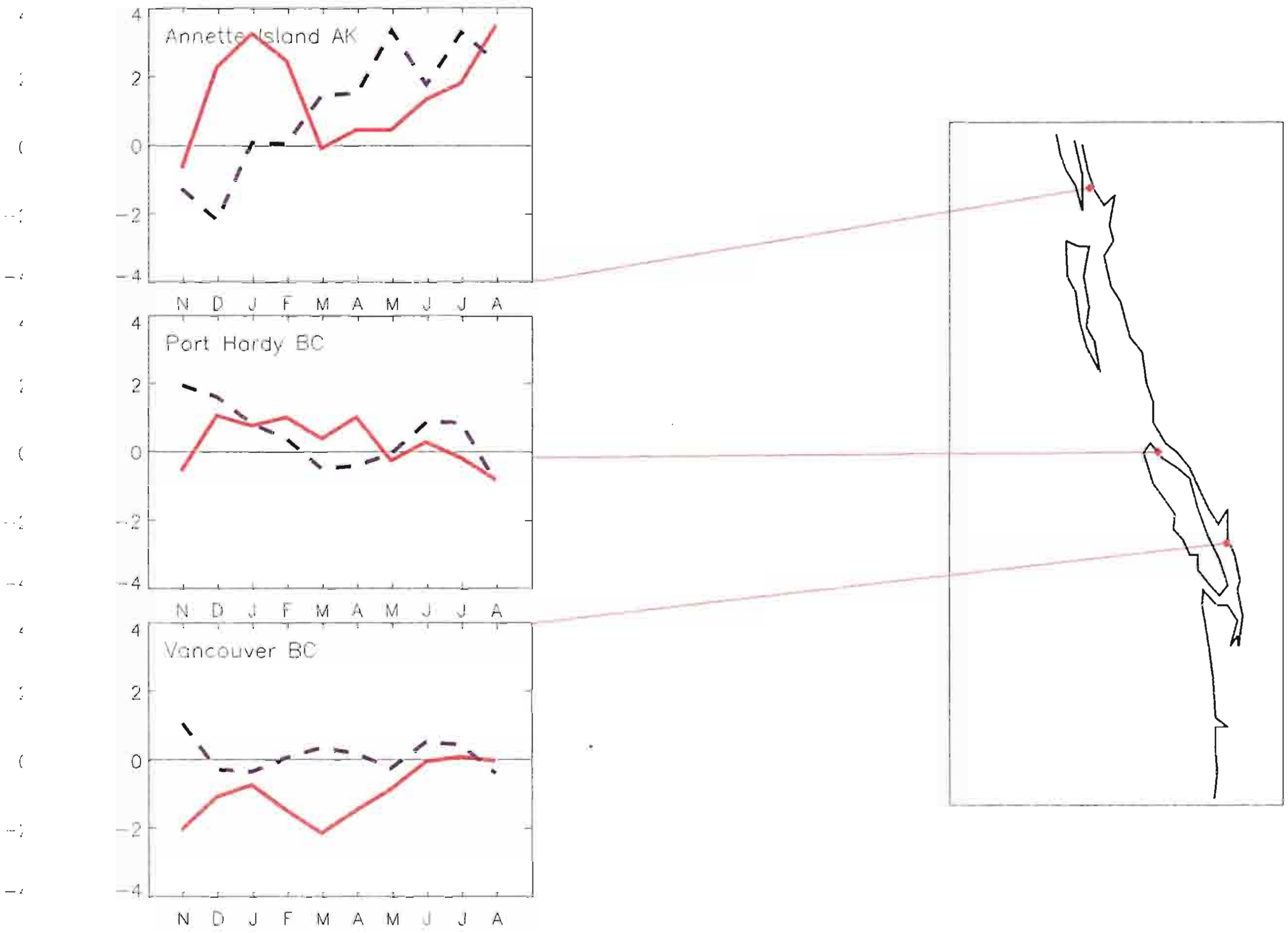


Figure 7a: De 7a: Departure from Neutral Mean in Centimeters for Seasonal Mec Mean Monthly Precipitation at Pacific NW Coastal Stations.

winters are anomalously wet and cold phase winters are slightly drier. Southern coastal stations of British Columbia, such as Vancouver (Figure 7a), have a similar pattern as the northwestern United States stations: anomalously wet winters in the cold phase, and anomalously dry winters in the warm phase.

Cold phases have a wet regime from fall to spring, and warm phases have a dry regime from fall to spring. Port Hardy (Figure 7a) is a transitional station between the northern and southern sections in this region, i.e. both warm and cold phases have a wet fall, the cold phase is slightly drier in the late winter. Both phases have smaller amplitudes at Port Hardy.

4.1.3c. Western Cordillera

The Western Cordillera region has slight differences between each phase in winter. In cold phase winters most stations are roughly 5mm per month wetter in winter except for four mountain stations which are 10-15mm per month wetter in winter: Banff, Jasper (Figure 7), Quesnel, and Smithers. Cold phase summers are slightly wetter or have little deviation from neutral phases. Only three stations are drier during the cold phase summer: Banff, Dease Lake, and Calgary (all mountain stations).

The precipitation regime during warm phases is slightly drier in winter, with anomalies within the range of 5mm per month below conditions in the neutral phases. Jasper and Banff range up to 10mm per month drier than neutral. Terrace, an inland valley station, is the

conditions in the neutral phases. Jasper and Banff range up to 10mm per month drier than neutral. Terrace, an inland valley station, is the

only station that is wetter during the warm phase winter and drier during the cold phase winter.

4.1.3d. High Arctic and Western Arctic regions

The Arctic climate resembles a desert, drier with increasing latitude, especially in winter. High Arctic stations show no discernible anomalies in winter, however in JAS all stations (e.g. Eureka NWT Figure 7), show a slightly drier regime of 5mm per month for both the cold and warm phases. Iqualuit NWT on Baffin Island is the only High Arctic station that shows a greater difference between the phases; the warm phase JFM anomalies are 6mm wetter and the cold phase is consistently drier.

The western Arctic regions are extremely dry: in winter there is little difference in precipitation in the warm or cold phase. Both phases are slightly drier at onset. In summer warm phases are slightly drier for Yellowknife (Figure 7)

4.1.3e. Interior region

Interior Canada has the driest stations in southern Canada. From fall to spring, neither the warm or cold phase is more than 10mm wetter or drier in each month than the neutral phase. For this small range all stations (e.g., The Pas Figure 7) have slightly more precipitation during the cold phase winters. The warm phase is slightly drier during the winter. In summer it is wetter; The Pas has a 15mm anomaly in MJJ.

a 15mm anomaly in MJJ.

4.1.3f. Eastern Interior region

In the Eastern Interior region, the cold phase is associated with a wetter late winter and a slightly dry summer. The two exceptions are on the St. Lawrence River: Quebec (Figure 7) and Mont Joli, which have a drier winter as well as a drier summer in the cold phase. The cold phase appears to be more significant than the warm phase in terms of magnitude. The warm phase is associated with a drier winter in an area near the Great Lakes, and with a slightly wetter winter in the northern section of the East Interior region.

4.1.3g. Eastern Maritime region

The maritime region has characteristic dry summers during the ENSO cold phase and wet winters for the southern maritime stations. In the north the cold phase winter signal is neutral; becoming slightly drier than normal during the winter with increasing latitude.

Most interior Eastern Maritime stations experience dry summers during the warm phase. In contrast, it is wetter than normal in summers on the outer islands and Atlantic coast. Sable Island behaves as an interior Eastern Maritime station; it is dry in late summer. During warm phases only the coastal stations have a wetter winter (e.g., Sable Island at 10mm in NDJ, Figure 7).

4.1.3h. Eastern Arctic region

The Eastern Arctic stations have a damped (i.e. low amplitude)

The Eastern Arctic stations have a damped (i.e. low amplitude) version of the ENSO pattern from the Eastern Interior. The warm

phase is slightly drier (wetter) than the cold phase in winter (summer). Only at Kuujjuaq QUE (Figure 7) is the warm phase wetter than the cold and neutral phases for all seasons. On the coast of Labrador the differences between the phases are greater in summer: in Goose NFLD the cold phase is 20mm drier in MJJ.

4.1.4. Probability density function section

ENSO probability density functions clearly show the separation and frequency of anomalies and indicate if the anomalies are significant. It should be noted that the significance for the temperature is conservative. The standard deviations of the bootstrap data are smaller than those of the original datas' standard deviations because of the correlations present in the monthly temperature data (i.e., semi-independence).

The fall (OND) temperature histogram map shows little effect in the Eastern and Arctic regions of Canada. The exception is the Eastern Arctic where the warm phase shows a colder autumn and the cold phase a slightly warmer autumn. The western stations show a colder autumn during cold phases (Figure 8a).

Fall (OND) precipitation histograms shows little difference in the Alaskan region and the Arctic regions. The warm phase is more likely to bring a drier regime to the west and interior Canada, and a wetter regime to east Canada and the High Arctic (Figure 9a). The cold phase brings a drier regime to the Eastern Maritime region, and a slightly wetter regime to the Western Cordillera.

a slightly wetter regime to the Western Cordillera.

In winter (DJF), the cold phase has a cooler winter in most of Canada. The exceptions are the Eastern Maritime and Eastern Interior regions. The warm phases are significantly warmer only in southern Canada (Figure 8b).

In winter (DJF), eastern Canada is more likely to be slightly drier during the cold phase and slightly wetter during the warm phase. In the interior west, the cold phase is likely to be wetter, and warm phases are usually drier. Alaska, the High Arctic, and coastal Canada shows little difference between the phases (Figure 9b).

The spring (MAM) probability density functions show little change in the High Arctic and significant cold anomalies in the western and eastern continental Canada during the cold phase. The southern Arctic and eastern Canada are warmer during the warm phase and Alaska is cooler during the warm phase (Figure 8c).

During cold phase spring (MAM) it is more likely to be drier in interior Alaska, the Eastern Arctic, and the Western Cordillera (Figure 9c). In these same regions, the warm phase spring is wetter.

By summer (JJA) only the maritime region shows a significant difference in temperature between the warm and neutral phase. The cold phase signal has little significance (Figure 8d). Summer (JJA) precipitation histograms show a drier regime in the maritime, Eastern Arctic, High Arctic and Alaskan interior during the cold phase. Alaska and western Canada are dry during the warm phase (Figure 9d).

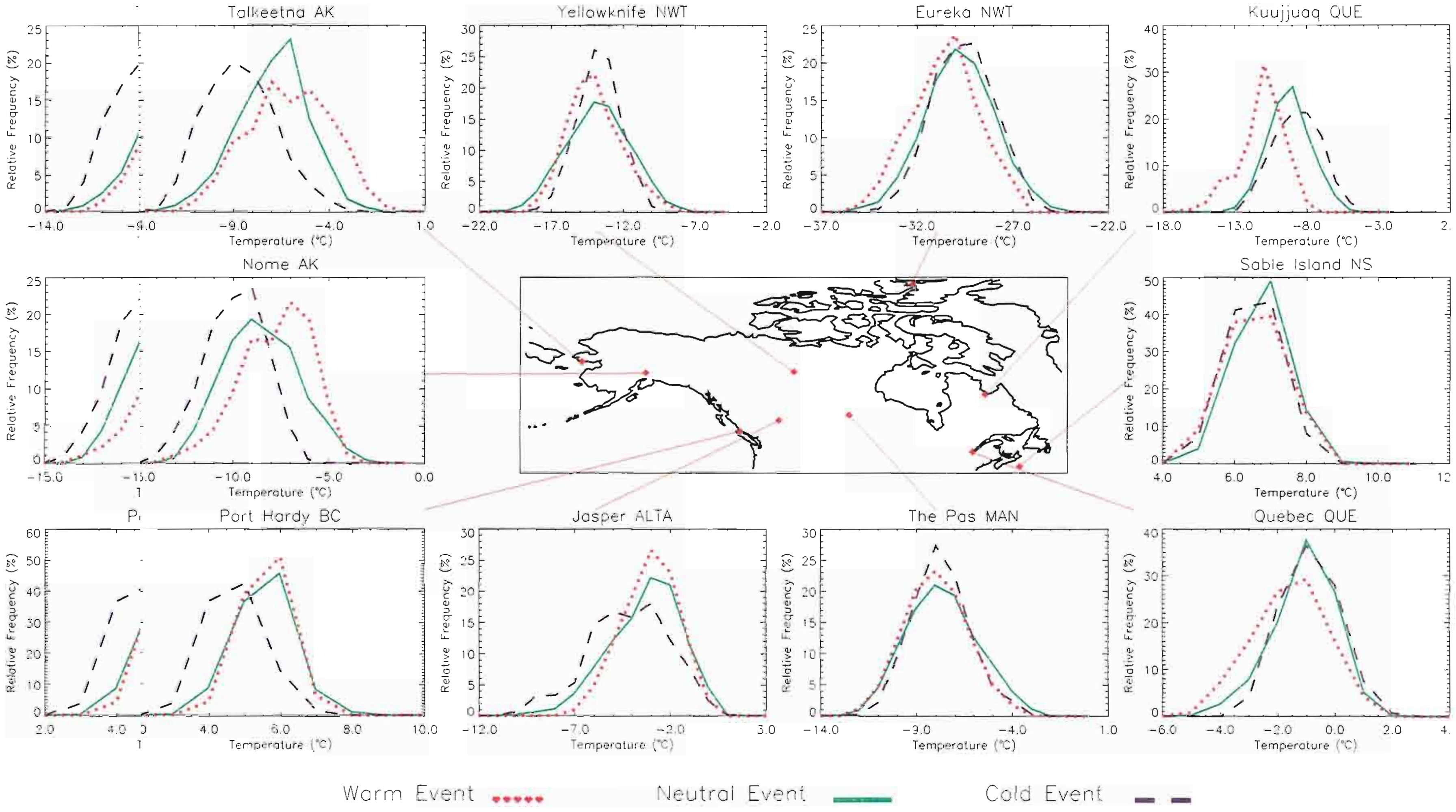


Figure 8a. Canada and Alaska Temperature Probability Density Functions for ENSO month OND

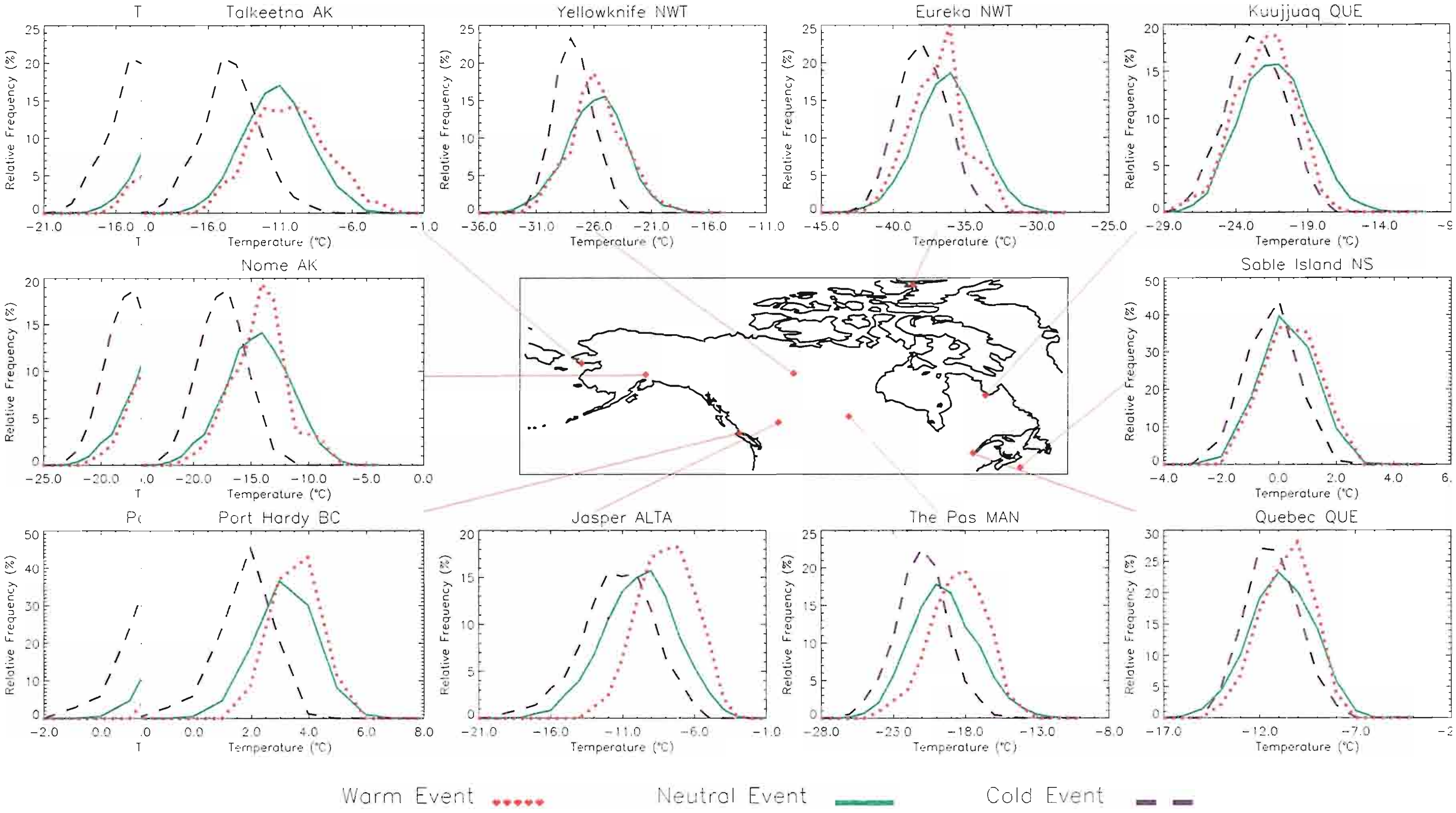


Figure 8b. Canada and Alaska Temperature Probability Density Functions for ENSO month DJF

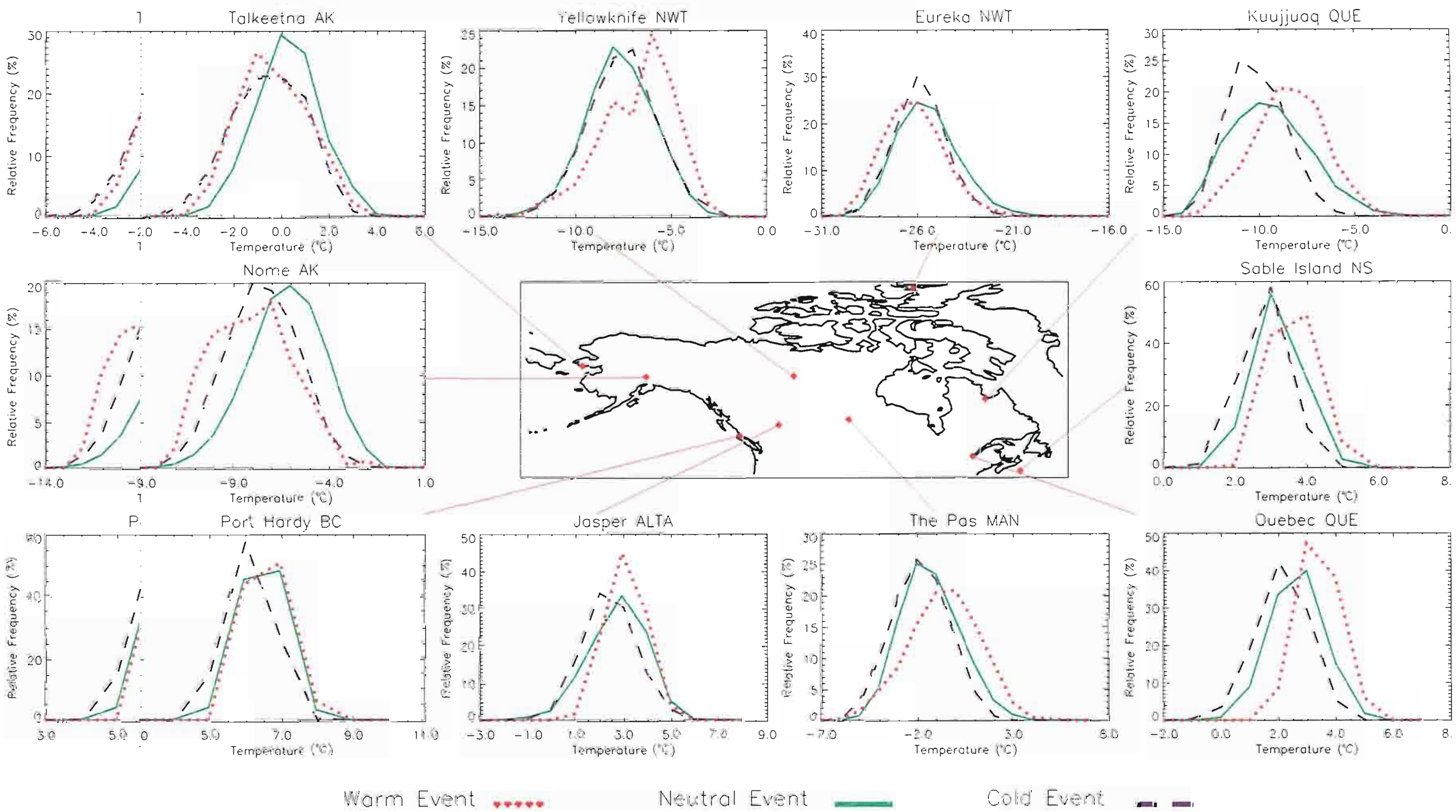


Figure 8c. Canada and Alaska Temperature Probability Density Functions for ENSO month MAM

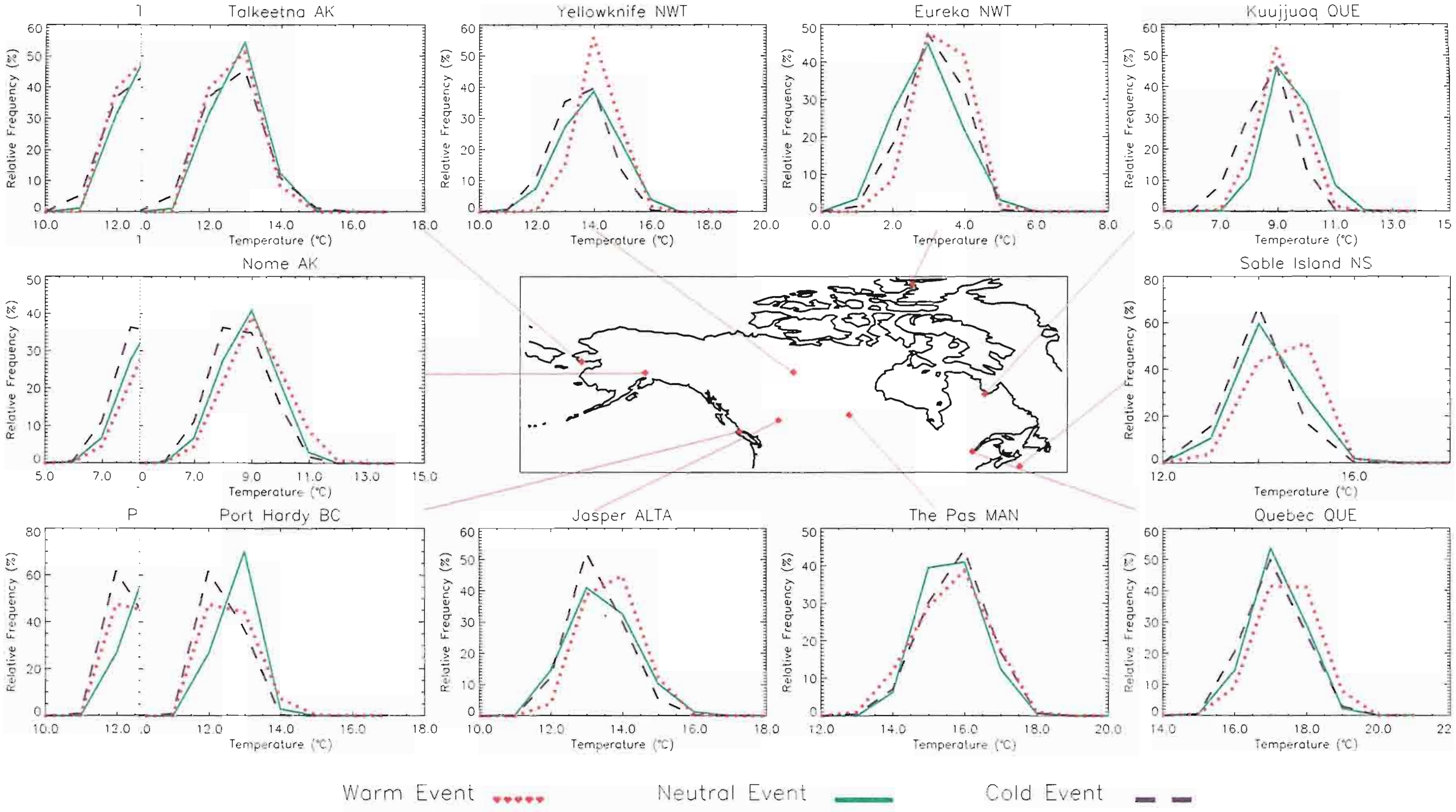


Figure 8d. Canada and Alaska Temperature Probability Density Functions for ENSO month JJA

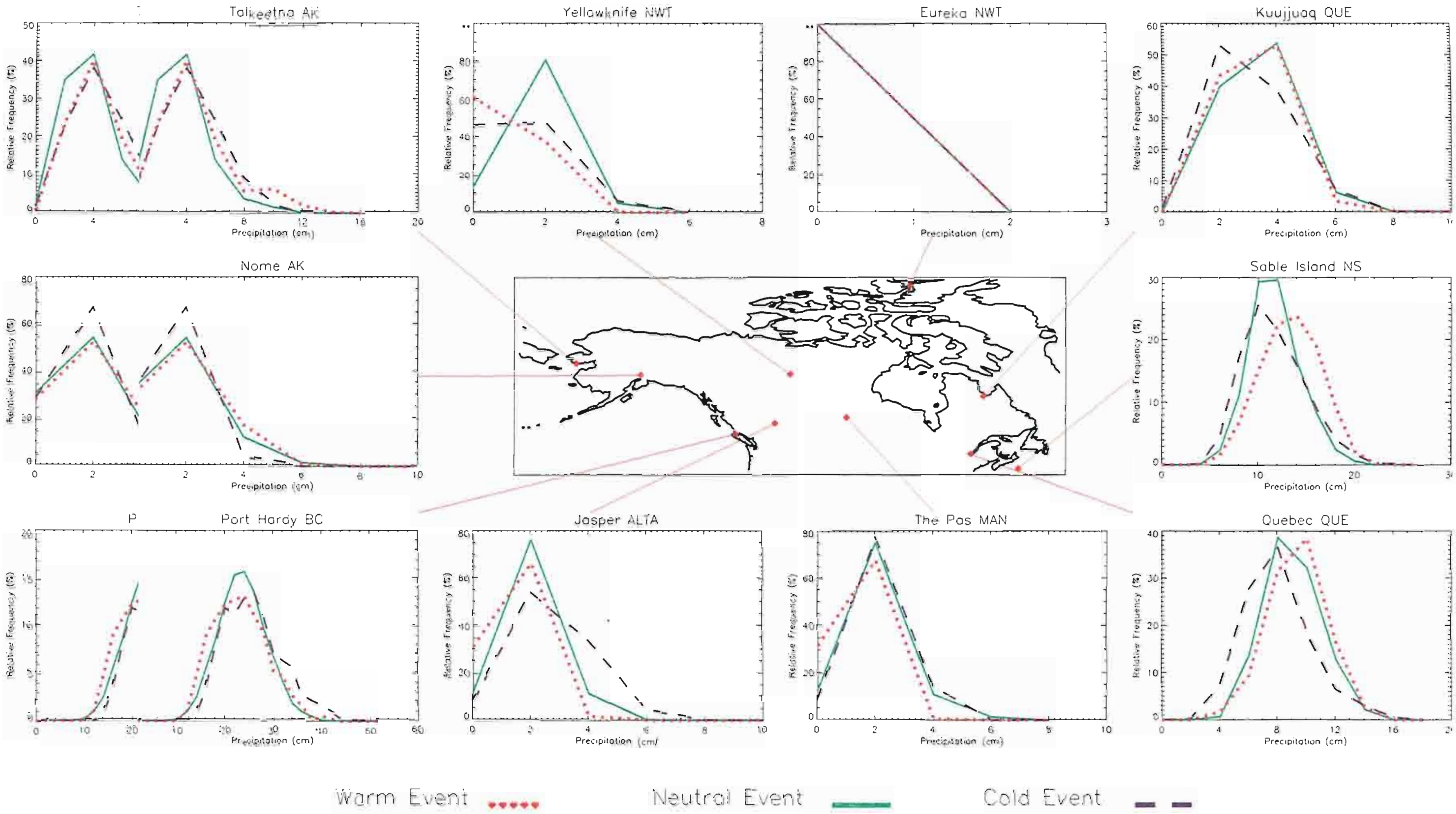


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Figure 9a. Canada and Alaska Precipitation Probability Density Functions for ENSO Month OND

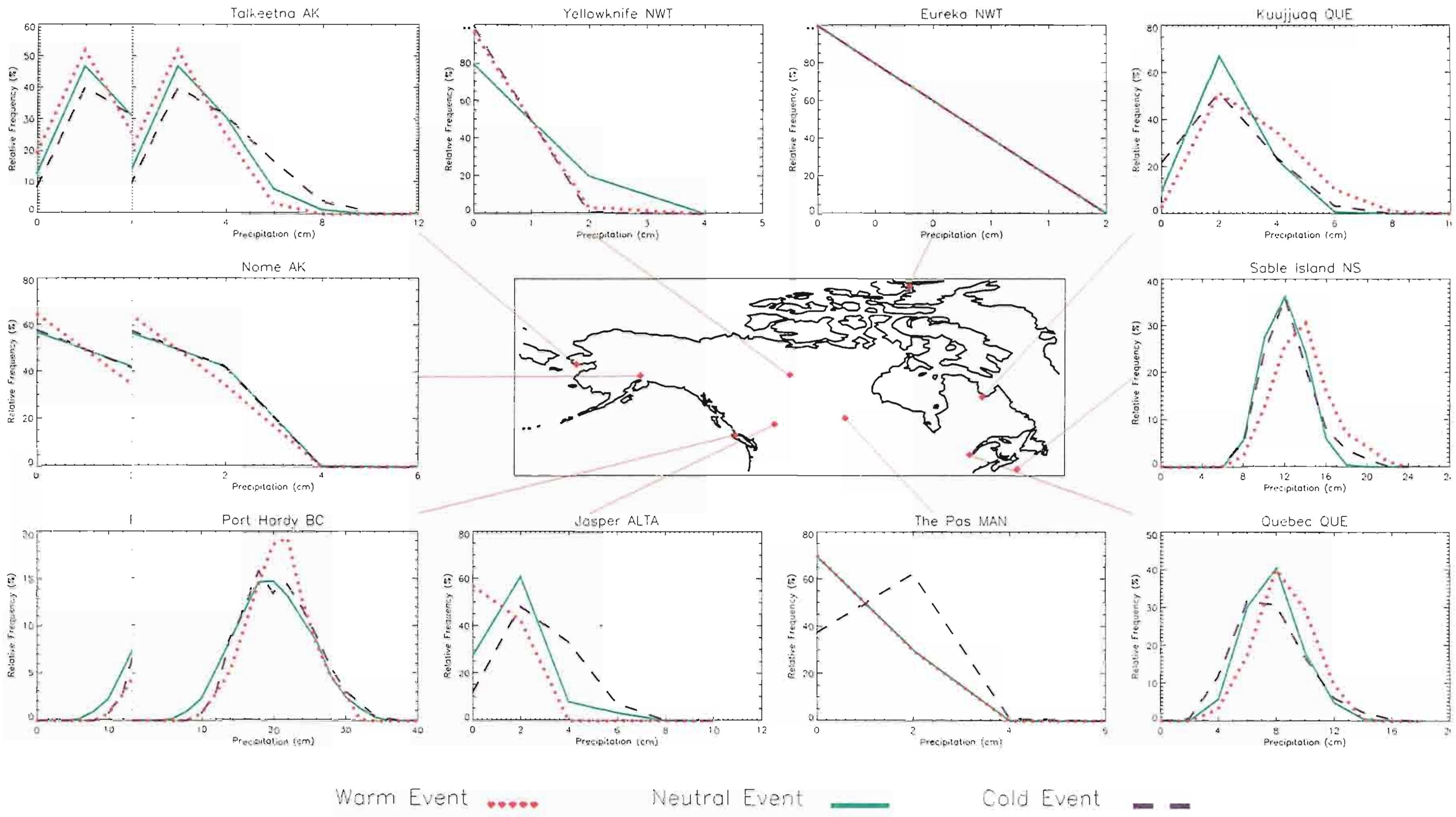


Figure 9b. Canada and Alaska Precipitation Probability Density Functions for ENSO Month DJF

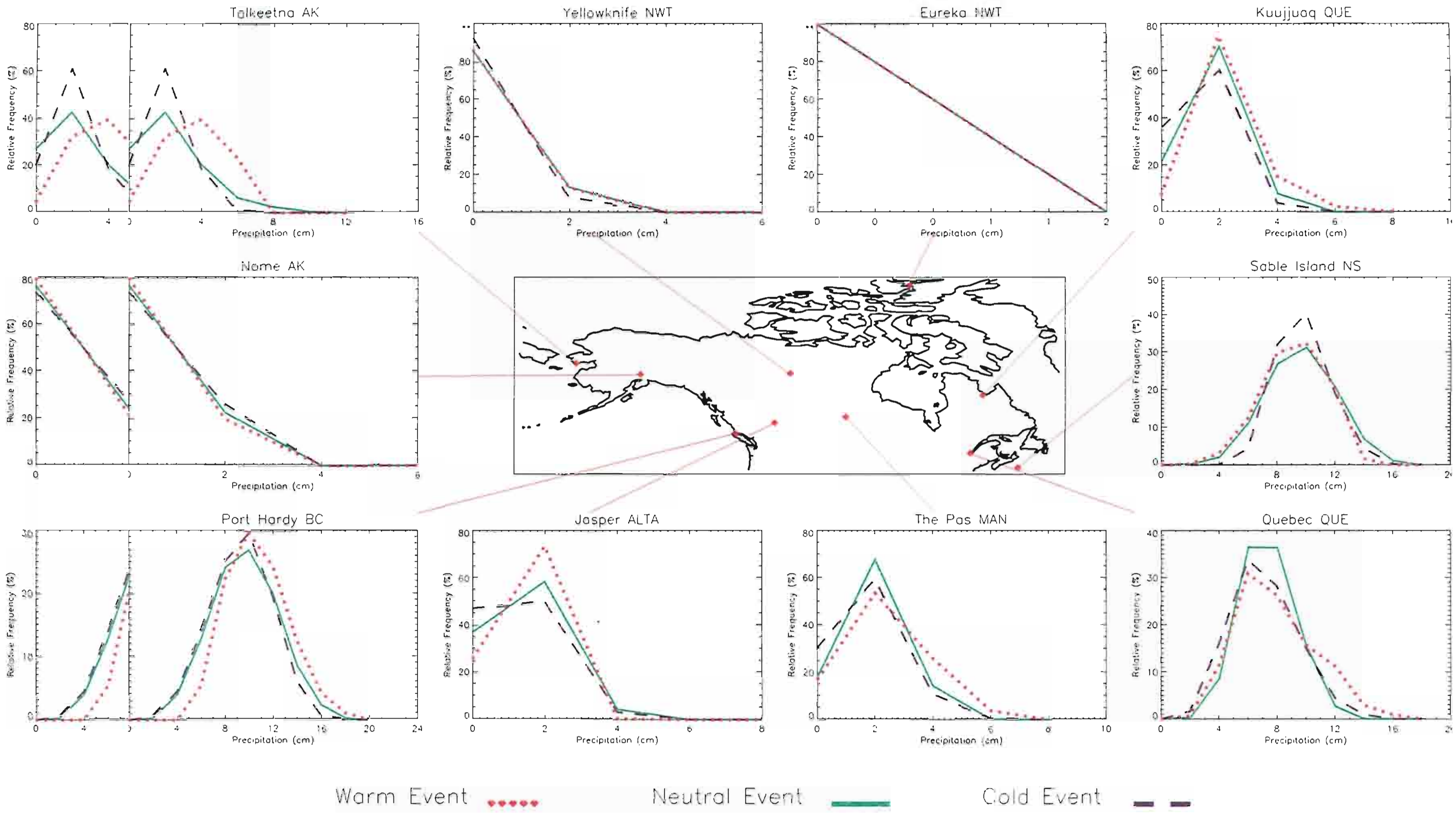


Figure 9c. Canada and Alaska Precipitation Probability Density Functions for ENSO Month MAM

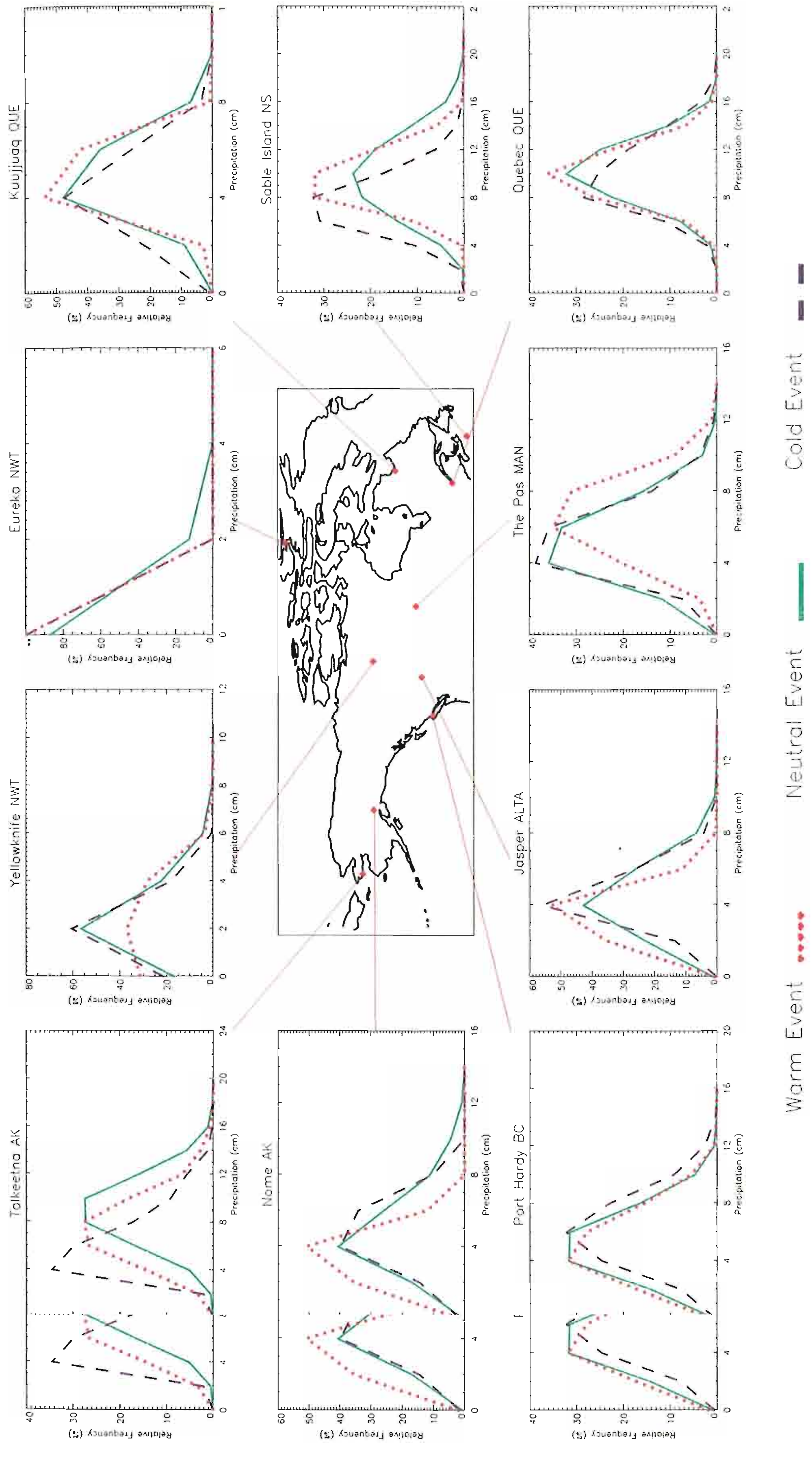


Figure 9d. Canada and Alaska Precipitation Probability Density Functions for ENSO Month JJA

4.2 Mexican Results

Five stations were chosen from the 27 Mexican stations to illustrate the differing effect of ENSO on the diverse regions of Mexico (Table 5, Figure 10). The stations chosen are Quiriego, Sonora, to represent Northwestern Mexico; Monterrey, Nuevo Leon to represent Northeastern Mexico; Champoton, Campeche, to represent the Yucatan and Tropical Lowlands; Yurecuaro, Michoacan, to represent the Tropical Highlands; and Santiago, Baja California to represent Baja California.

4.2.1 Mexican geography

Mexico has many and diverse types of climates; according to Trewartha and Horn (1980), there are at least six. Baja California has two, most of the peninsula has a coastal desert climate and in the far northwestern part is a subtropical dry summer type climate. The coastal desert climate in Baja California is among the driest in the world in terms of monthly and annual precipitation, yet due to its proximity to the ocean, the atmosphere is moist. The region is dominated by subsiding air, preventing convection.

Northern Mexico (excluding Baja California) is broken into two regions, Northwestern Mexico and Northeastern Mexico. Each of the

regions, Northwestern Mexico and Northeastern Mexico. Each of the

two regions has a mountain range, The Sierra Madre Occidental runs roughly northwest to southeast in northwestern Mexico and the Sierra Madre Oriental runs north to south in northeastern Mexico. The climates in these regions are that of tropical desert and semi arid steppe. The arid regions are aligned along the western (leeward) margins of the mountain ranges. Therefore, the coast along the northwestern region is arid and the coastal region of northeastern Mexico is only semi-arid. Both regions are bounded to the south by the tropical highland region, where both mountain ranges merge.

The Yucatan and Tropical Lowlands are bounded by the highlands to the north, the Pacific Ocean to the west and south, by the countries of Guatemala and Belize to the southeast, and the Gulf of Mexico. The terrain ranges from sea level to low mountains in the interior. The climate is mainly tropical (the range of temperature is slight) except for the tip of the Yucatan, which has a semi-arid climate. The wet season is usually May to November, with a rainfall maximum in June, and a second lesser maximum in September or October. Precipitation usually ranges from 100-200 cm annually for most of the region, with the rainfall annual totals decreasing with distance north on the Yucatan Peninsula.

The tropical highlands region is generally a low temperature variant of the Yucatan and Tropical Lowland region due to the decrease in temperature with higher altitude. Precipitation can exceed 100 cm annually in some parts. This region is the most densely populated region in Mexico due to the lower temperatures and abundant rainfall.

densely populated region in Mexico due to the lower temperatures
and abundant rainfall.

Table 5: Mexican stations by region, station name and state

NORTHEASTERN MEXICO
Cuartro Cienegas, COAHUILA
Ramos Arizpe, COAHUILA
Villagran, TAMAULIPAS
San Fernando, TAMAULIPAS
Granja Experimental, NUEVO LEON
Monterrey, NUEVO LEON *
Las Enramadas, NUEVO LEON
Montemorelos, NUEVO LEON

YUCATAN-TROPICAL LOWLANDS
Merida, YUCATAN
Champoton, CAMPECHE *
Matias Romero, OAXACA

BAJA CALIFORNIA
Santiago, B. CALIFORNIA *
San Felipe, B.CALIFORNIA
San Ignacio, B. CALIFORNIA

NORTHWESTERN MEXICO
Arivechi, SONORA
Sahuaripa, SONORA
Ciudad Guerrero, CHIHUAHUA
Tres Hermanos, SONORA
Quiriego, SONORA *
Jaina, SINOLA
Tepehuanes, DURANGO
Guanacevi, DURANGO
Francisco I. Madero, DURANGO

TROPICAL HIGHLANDS
Piaxtla, PUEBLA
Yurecuaro, MICHOACAN *
Macsota, JALISCO
Chapala, JALISCO

* indicates representative station for each region

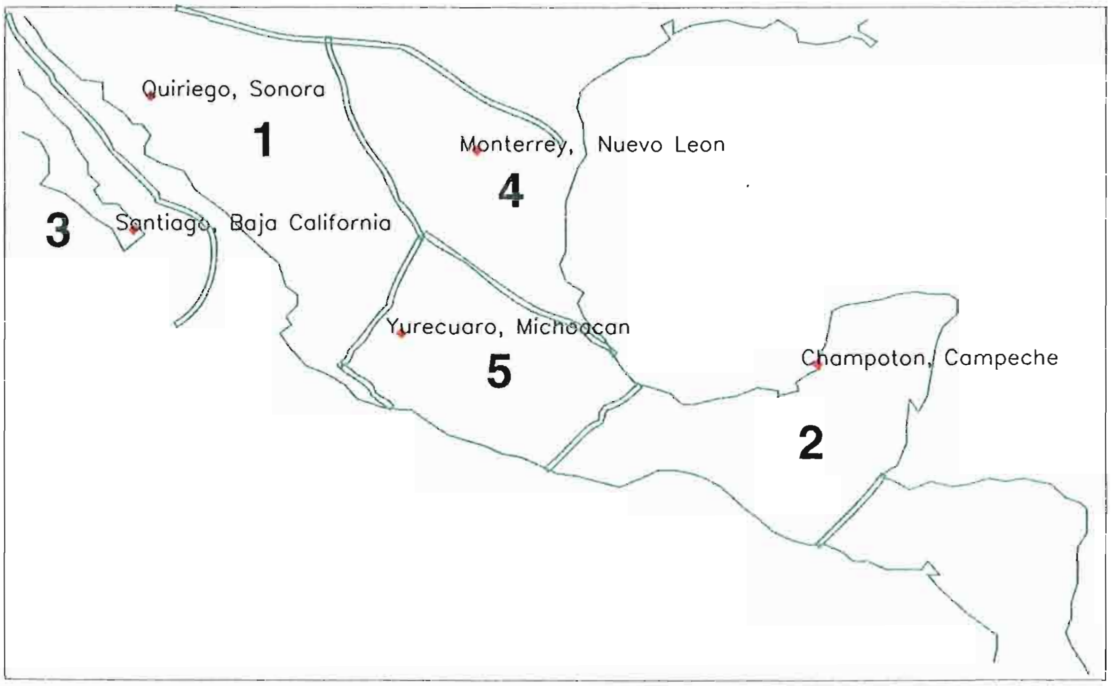


Figure 10: Representative Mexican stations in their respective regions: 1 Baja California, 2 Yucatan and Tropical Lowlands, 3 Northwest Mexico, 4 Northeast Mexico

Figure 10: Representative Mexican stations in their respective regions: 1 Baja California, 2 Yucatan and Tropical Lowlands, 3 Northwest Mexico, 4 Northeast Mexico, and 5 Tropical Highlands

4.2.2. Temperature anomalies

In general, Mexican regions are colder (warmer) than the neutral phase during the warm (cold) phase in the first half of the ENSO year.

4.2.2a. Northeastern region

The Northeastern region shows moderate temperature effects associated with ENSO. During the cold phase, Monterrey, Nuevo Leon (Figure 11) has a warmer winter and fall, with a temperature anomaly maximum of 1.1°C in NDJ. Cold phase summers are cooler; Monterrey has a cold minimum of -0.5°C in summer (JJA). The T-test (Figure 12a) shows that all stations in this region, except for the westernmost stations in Coahuila, are significantly warmer in fall and winter. All stations in this region, except for the coastal stations, are significantly cooler in summer (Figure 12a).

During the warm phase, northeastern Mexico is consistently cooler throughout the year. Monterrey (Figure 11c) has a cold anomaly of -0.9°C in winter (JFM). The T-test shows significant cold anomalies for most stations from winter to summer (JFM to JJA). In early winter, the western stations in this region are significantly cooler (NDJ to DJF). In late summer (JAS) and in the fall (OND) there are no significant cold anomalies in this region (Figure 12b).

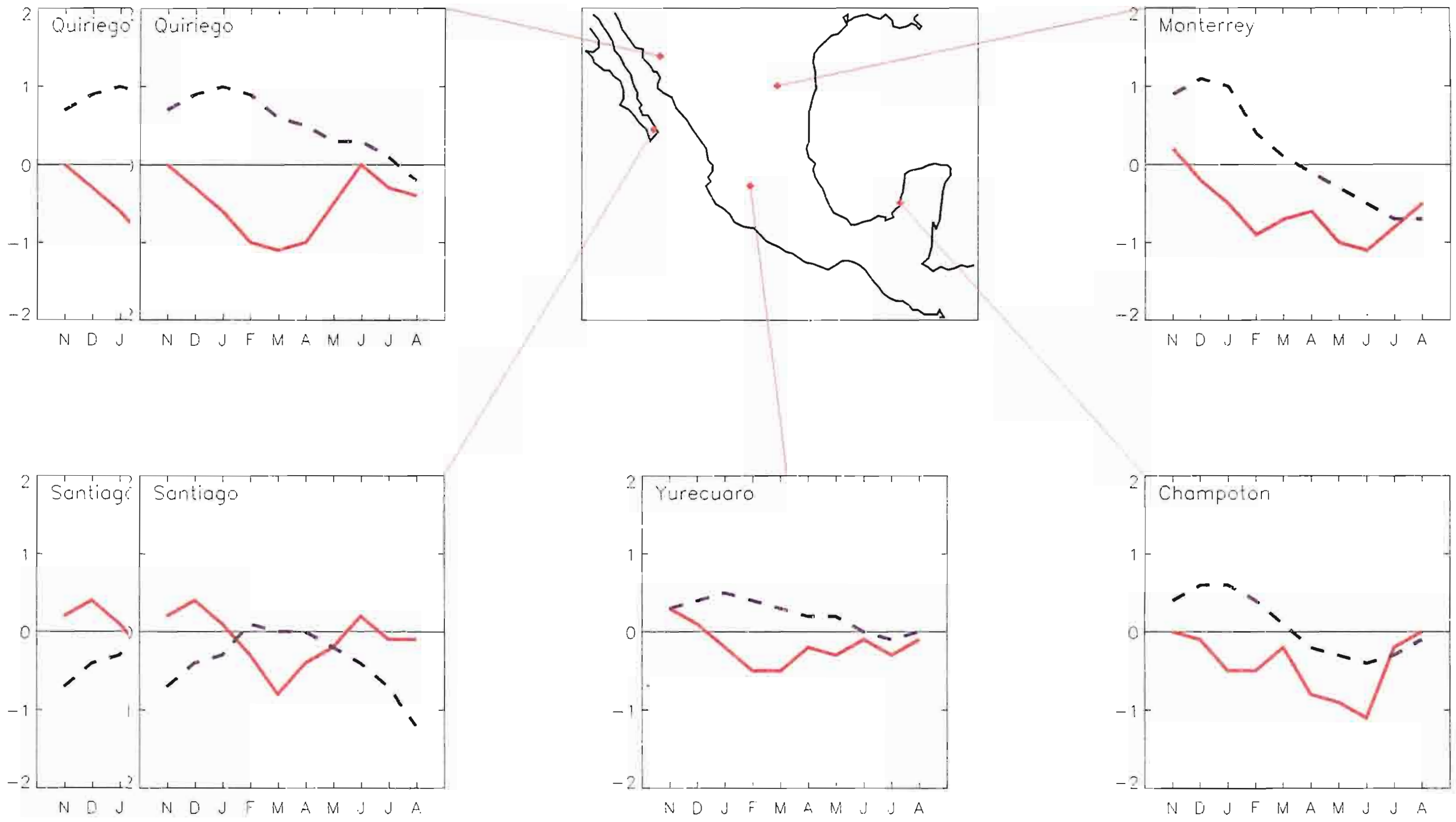


Figure 11: Dœ 11: Departure from Neutral Mean in Degrees Celsius for Seasonal Mec Mean Monthly Temperature at Mexican Stations.

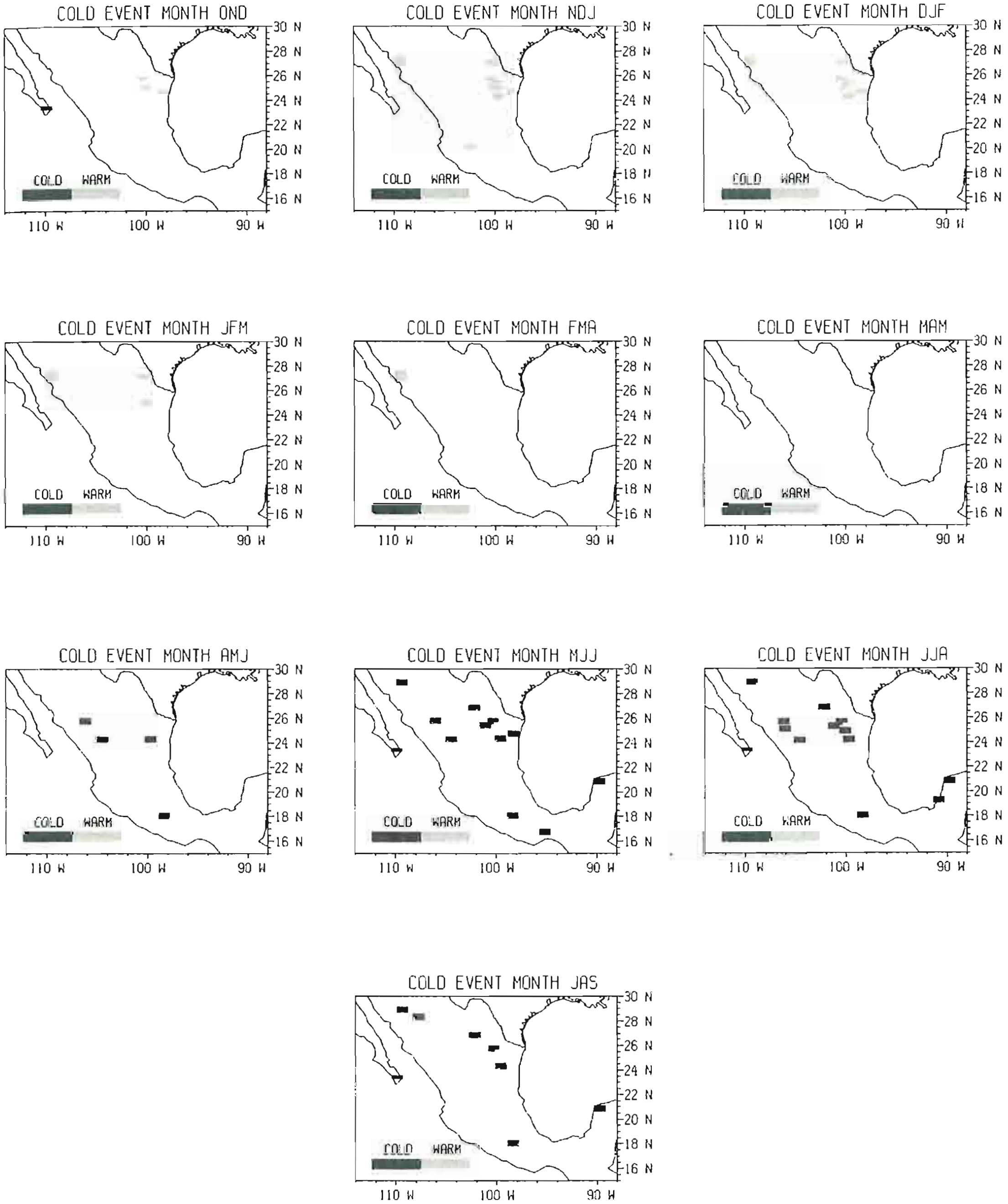


Figure 12.a: T-test results for Mexico during the cold phase.

Figure 12.a: T-test results for Mexico during the cold phase.

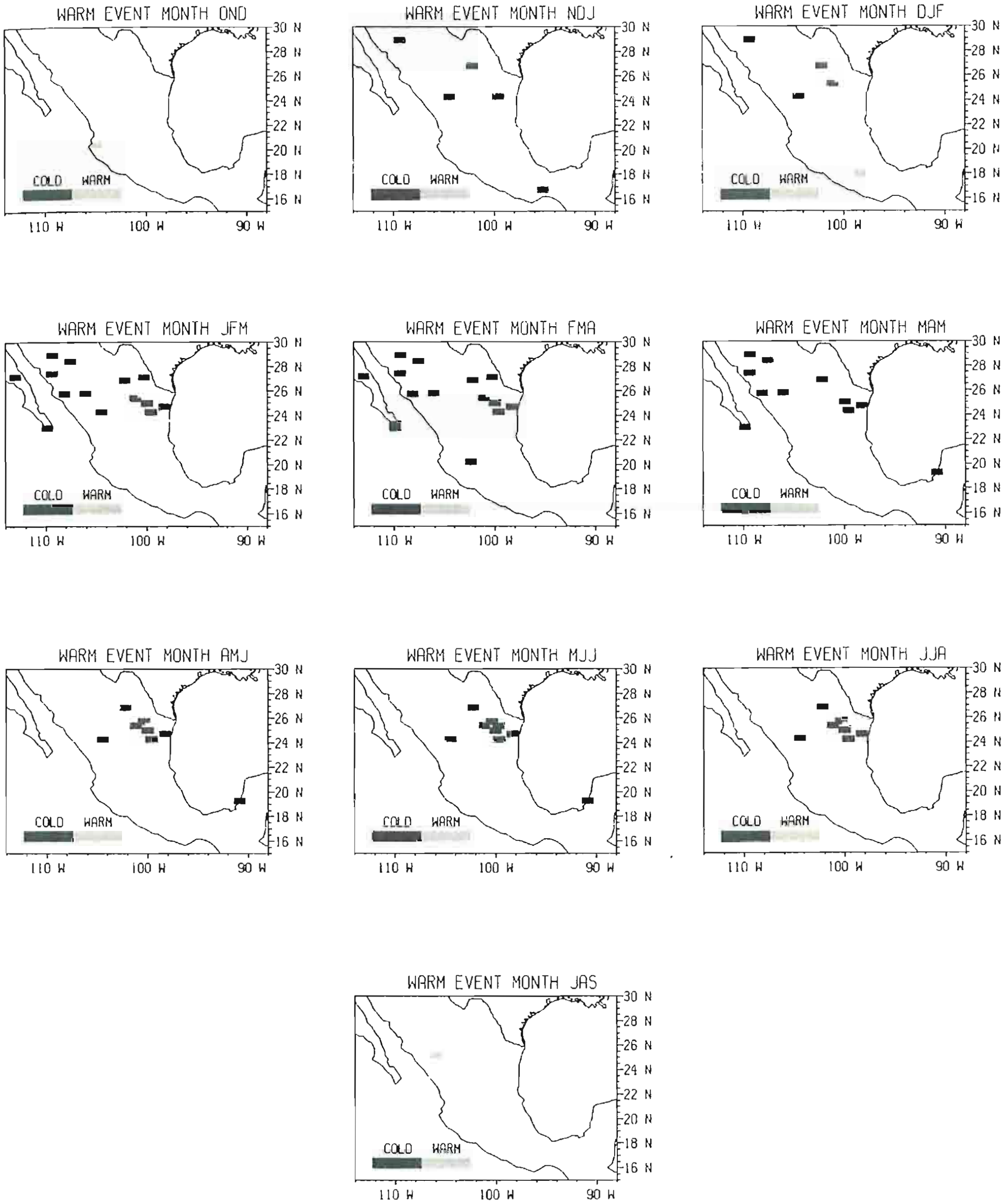


Figure 12.b: T-test results for Mexico during the warm phase.

Figure 12.b: T-test results for Mexico during the warm phase.

4.2.2b. Tropical Highlands region

The tropical highlands region, represented by Yurecuaro (Figure 11), has the cold phase associated with a slightly warmer year, except in summer, which has cooler anomalies. The lack of large temperature variation is expected, due to the normal temperature regime in the tropics. Yurecuaro has a warm winter (DJF) anomaly of 0.5°C. T-test results (Figure 12a) show Yurecuaro is significantly warmer in the winter (NDJ-DJF) and only Piaxtla is significantly colder in summer.

The warm phase in the tropical highlands are associated with slightly colder years, except at onset (OND). Yurecuaro has cold winter anomalies of -0.5°C at JFM. Piaxtla shows an anomalous effect; the warm phase year is warmer than neutral for the entire year. T-test results (Figure 12b) show Jalisco significantly warmer in fall (OND) and Yurecuaro is significantly colder in late winter (FMA). Piaxtla is significantly warm from late fall to spring (Figure 11).

4.2.2c. Northwestern Region

Northwestern Mexico shows moderate temperature effects associated with ENSO. The cold phase has warmer winters except Jaina, where there is little effect throughout the year. Quiriego, Sonora (Figure 11) reaches a warm maximum anomaly in winter (DJF) at 1°C. The T-tests (Figure 12a) show significantly warmer fall, winter, and spring in Tres Hermanos and Quiriego, which match

fall, winter, and spring in Tres Hermanos and Quiriego, which match

the significant warming to the west in Baja California. The eastern stations in this region are significantly cooler during summer.

The warm phase is associated with colder winters and early springs. For example, Quiriego, Sonora has a cold minimum in late winter (FMA). All stations except Tres Hermanos and Tepehuanes are significantly colder from winter (JFM) to spring (MAM). Only Francisco I. Madero is significantly colder in summer (Figure 12b).

4.2.2d. Baja California region

The Baja California region represents central and southern Baja; mostly coastal desert climate. The region has a cooler autumn and summer during the cold phase, while winters are neutral or slightly warmer. Santiago (Figure 11) shows the cold phase to be colder in fall and summer; however, in winter (JFM) there is little difference. The anomalously cold SSTs off the coast of Baja California (due to trapped Kelvin waves) could be a mechanism supporting the anomalously cold fall temperatures in the Baja California region. Santiago is significantly colder in the fall (OND) and summer. To the north, San Ignacio is significantly warmer during winter and spring. These anomalies continue the pattern in northwestern Mexico (Figure 12a).

The warm phase in Baja California has colder winters, and they are slightly warmer in fall and summer. The anomalous warming in fall could be attributed to the warmer SSTs along the coasts of Baja California. Santiago, Baja California (Figure 11) shows warm phases with cold anomalies in FMA. All stations are significantly colder in

California. Santiago, Baja California (Figure 11) shows warm phases

winter (JFM to FMA). In addition, San Felipe is significantly colder through spring (Figure 12b).

4.2.2e. Yucatan and the Tropical Lowlands region

Yucatan and the Tropical Lowlands in southern Mexico have the cold phase warmer than normal during the winter and slightly colder in the summer months. Champoton (Figure 11) is significantly warmer in winter (NDJ-DJF) and all stations are significantly colder during summer (Figure 12a).

Warm phases are colder throughout the year, with the exception of early spring where there is little difference from neutral (spring is also the season where the cold phase switches from warmer to colder than normal). Champoton (Figure 11) has two cold seasons in the warm phase: winter and summer. Champoton is significantly colder during late spring and early summer; and only Matias Romero is significantly cold in winter (Figure 12b).

4.2.3. Precipitation anomalies

Mexican regions generally have a regime of wetter than normal conditions during warm phase winters. The exceptions are scattered in the western interior.

4.2.3a. Northwestern region

Northwestern Mexican stations have generally a wetter year during the warm phase. However, all stations show a slightly drier

[illegible]
during the warm phase. However, all stations show a slightly drier

season during the warm phase in late spring to early summer (AMJ to

MJJ), with wetter late summers and winters. The southern stations in this region show a shift to a different climatic regime, from a desert region to a semi-arid region, with a summer rainfall maximum (Trewartha and Horn, 1980). This shift explains the larger amplitude of the warm phases summer precipitation anomalies when compared to winter precipitation anomalies. The northern stations, such as Quiriego (Figure 13), are more arid and have little difference in amplitude in the warm winter and warm summer.

The cold phase tends to be drier in the fall and slightly wetter in summer. The amplitudes of the cold phase are not as large as the warm phases.

4.2.3b. Northeastern region

The Northeastern Mexican region during the warm phase has a wetter winter and early summer. With distance southeast, the summer amplitude becomes greater than the winter amplitude. This change is due to the shift of climatic regimes from arid in the north to semi-arid in the south. Late summers tend to be slightly drier or similar to the neutral phase (e.g., Monterrey, Figure 13).

The cold phase in Northeastern Mexico has a slightly drier fall and wetter summer. With proximity to the Gulf of Mexico in the cold phase, the summer becomes wetter, and in late summer, tends to be drier.

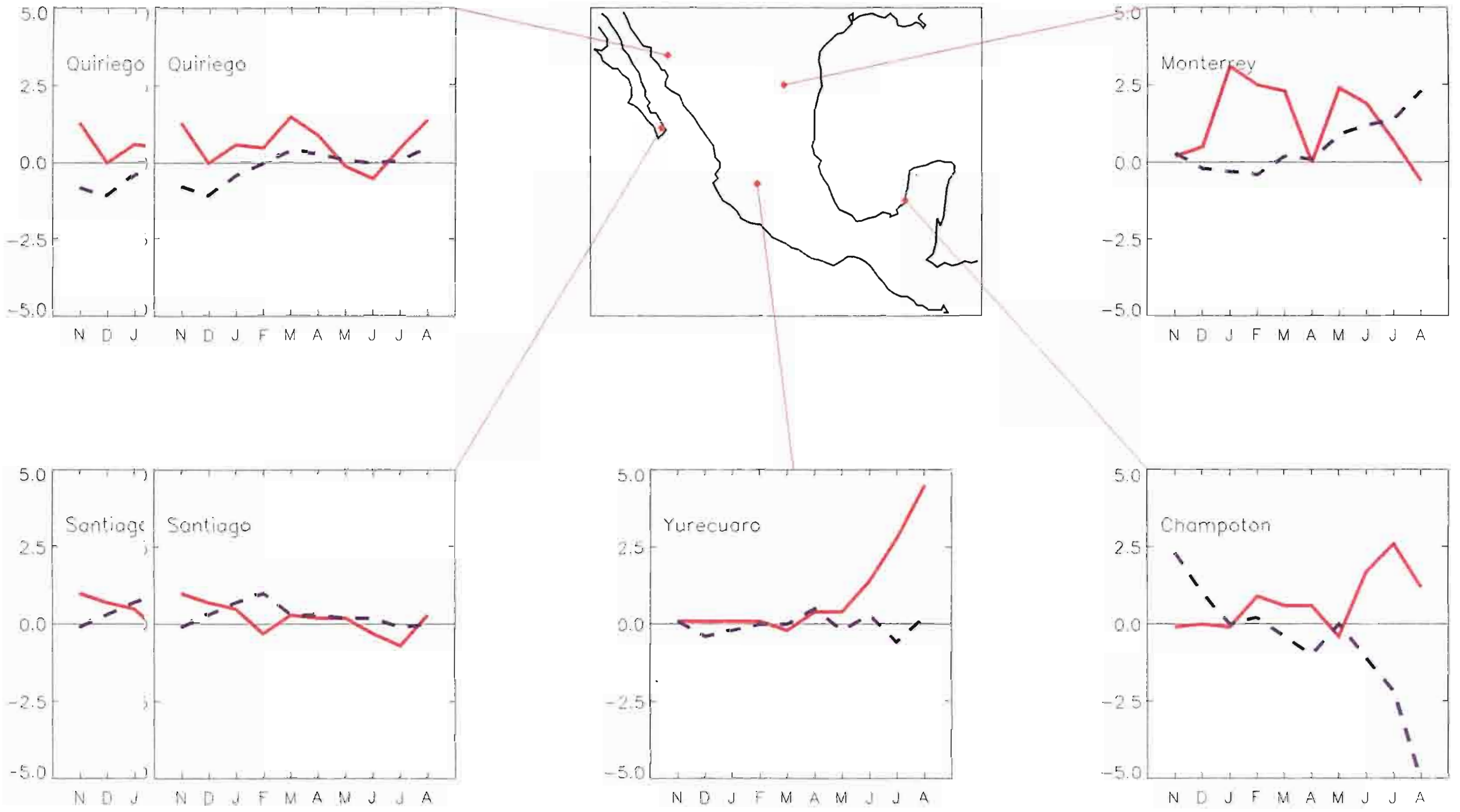


Figure 13: Dœ 13: Departure from Neutral Mean in Centimeters for Seasonal Mec Mean Monthly Precipitation at Mexican Stations.

4.2.3c. Baja California region

The Baja California stations in my study have the smallest ENSO precipitation signal of all the Mexican stations. The amplitudes are small because the climatic regime of the region is a desert, among the driest in the world in terms of monthly and annual precipitation, yet due to its proximity to the ocean, the atmosphere is moist. The region is dominated by subsiding air, preventing convection. Warm phases are slightly wetter in the fall, early spring and late summer (JAS); there are also dry periods in JFM and MJJ.

During the cold phase the effects vary from station to station; generally the winter and summer are slightly wetter. Santiago (Figure 13) is wetter in the winter, whereas San Felipe (at a higher elevation) is wetter in the summer.

4.2.3d. Tropical Highlands region

The warm phase in the tropical highlands region exhibit a slightly wetter fall and early winter with a peak wet anomaly in summer. In Yurecuaro (Figure 13), the JAS anomaly averages 4cm wetter. The warm phase has larger precipitation anomalies. Cold phases have variable effects in the tropical highlands, but all stations tend to be slightly drier than normal in winter and late summer.

4.2.3e. Yucatan and the Tropical Lowlands region

In the Yucatan and the Tropical Lowlands, the warm phase is

In the Yucatan and the Tropical Lowlands, the warm phase is wetter throughout the year except for a brief dry period in spring

and at onset (OND). The summer magnitude of phases is larger; during JJA in Champoton (Figure 13) it is 2.5cm wetter than in neutral years.

During the cold phase, the Yucatan and lowlands experience a wetter winter and a drier summer. The only exception is Merida, which has a wetter summer and dry late summer.

4.2.4. Probability density function results

Temperature and precipitation histograms clearly show the separation of phases and their significance for each season. It should be noted that the significance for the temperature is conservative since the standard deviations of the bootstrap data are lower than that of the original data's standard deviation. The correlations present in the monthly temperature data (semi-independent) biases the method. There is considerable overlap between the three probability density functions. Precipitation distributions have almost Guassian distributions in the summer, due to increase in precipitation during the Mexican monsoon (Douglas et. al. 1993).

Temperature distributions for fall (OND) show warm autumns during cold phases for most Mexican regions except Baja California is colder during cold phases, and the Yucatan has little change between phases. The warm phase is significant only in the Yucatan (Figure 14a). Precipitation distributions for the fall (OND) show a general tendency for Northwestern Mexico to be wetter during a warm phase and drier during the cold phase. Northeastern Mexico

general tendency for Northwestern Mexico to be wetter during a warm phase and drier during the cold phase. Northeastern Mexico

shows a tendency for the cold phase to have extreme wet periods, although the general distribution shows the warm phase to be slightly wetter than the cold phase (Figure 15a).

Temperature distributions for winter (DJF) show a warm winter during cold phases for all regions, except Baja California, which has a colder winter during the cold phase. Warm phase winters are significantly warmer in northern Mexico and the Yucatan (Figure 14b). Precipitation distributions for winter (DJF) indicate wetter warm phase winters in northern Mexico and the Highland region, and little difference between cold and neutral phases (Figure 15b) There is little discernible effect in Baja California in either phase.

Temperature distributions for spring (MAM) show little effect in the highlands for either phase. Warm phases are significantly cooler in the rest of the regions. The cold phase has significant impact in Northwest Mexico and Baja California: in Northwest Mexico it is warmer and in Baja it is colder (Figure 14c).

The spring (MAM) precipitation distributions show Sonora to be wetter during warm phases (Figure 15c). In the Yucatan region, there is a tendency for wetter warm phases and drier conditions during the cold phase. The highlands are wetter during the cold phase springs.

Summer (JJA) temperature distribution results show that the only affected regions are Baja California and Northeast Mexico: both phases bring about a colder summer (Figure 14d). Precipitation distributions for summer (JJA) show that warm phases have a
[illegible]
distributions for summer (JJA) show that warm phases have a
slightly wetter regime in all regions, except Baja California which

is drier (Figure 15d). Western Mexico has more wet extreme phases during warm phases. There is little difference between cold and neutral phases in summer precipitation regimes.

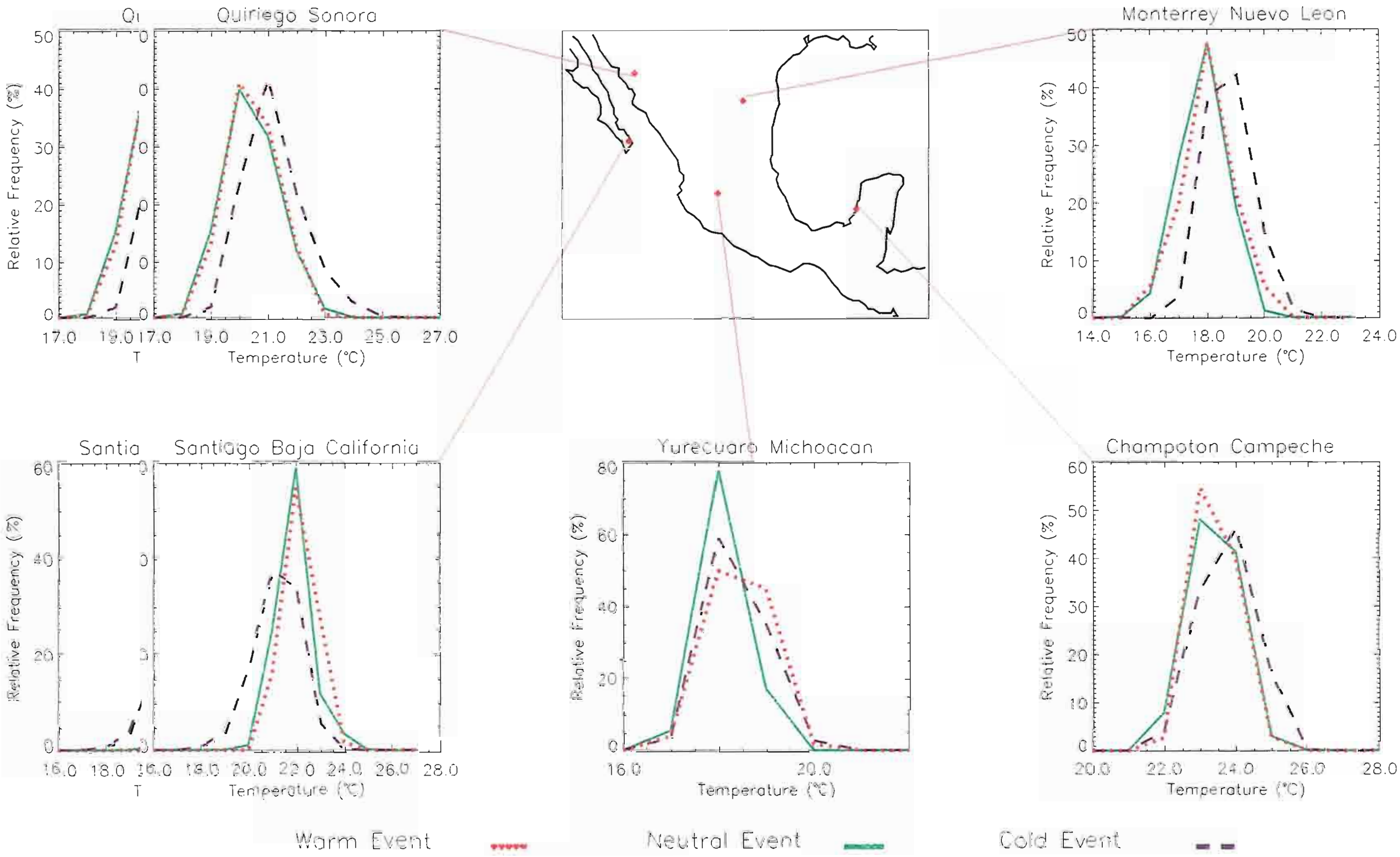


Figure 14a. Mexico Temperature Probability Density Functions for ENSO Month OND

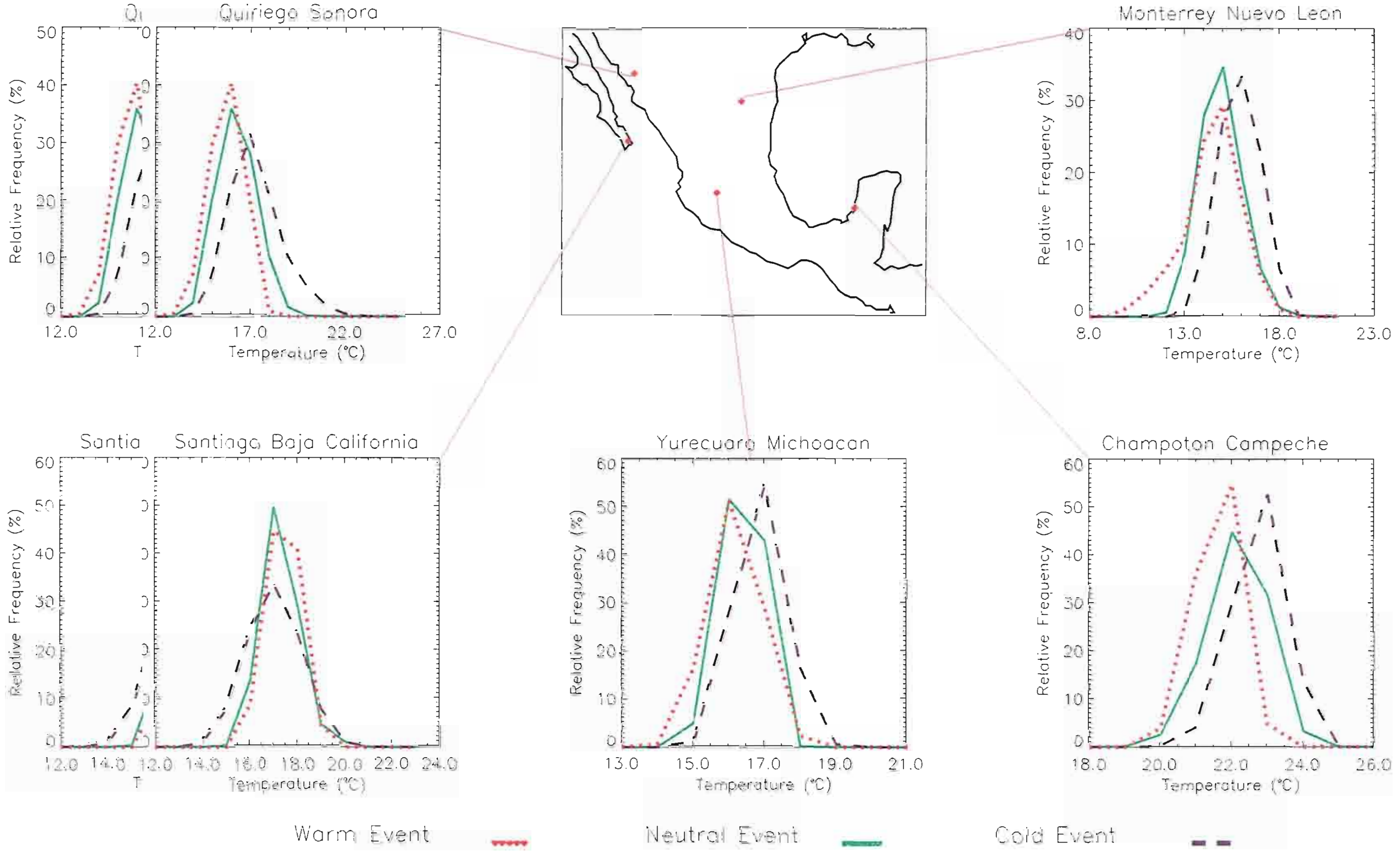


Figure 14b. Mexico Temperature Probability Density Functions for ENSO Month DJF

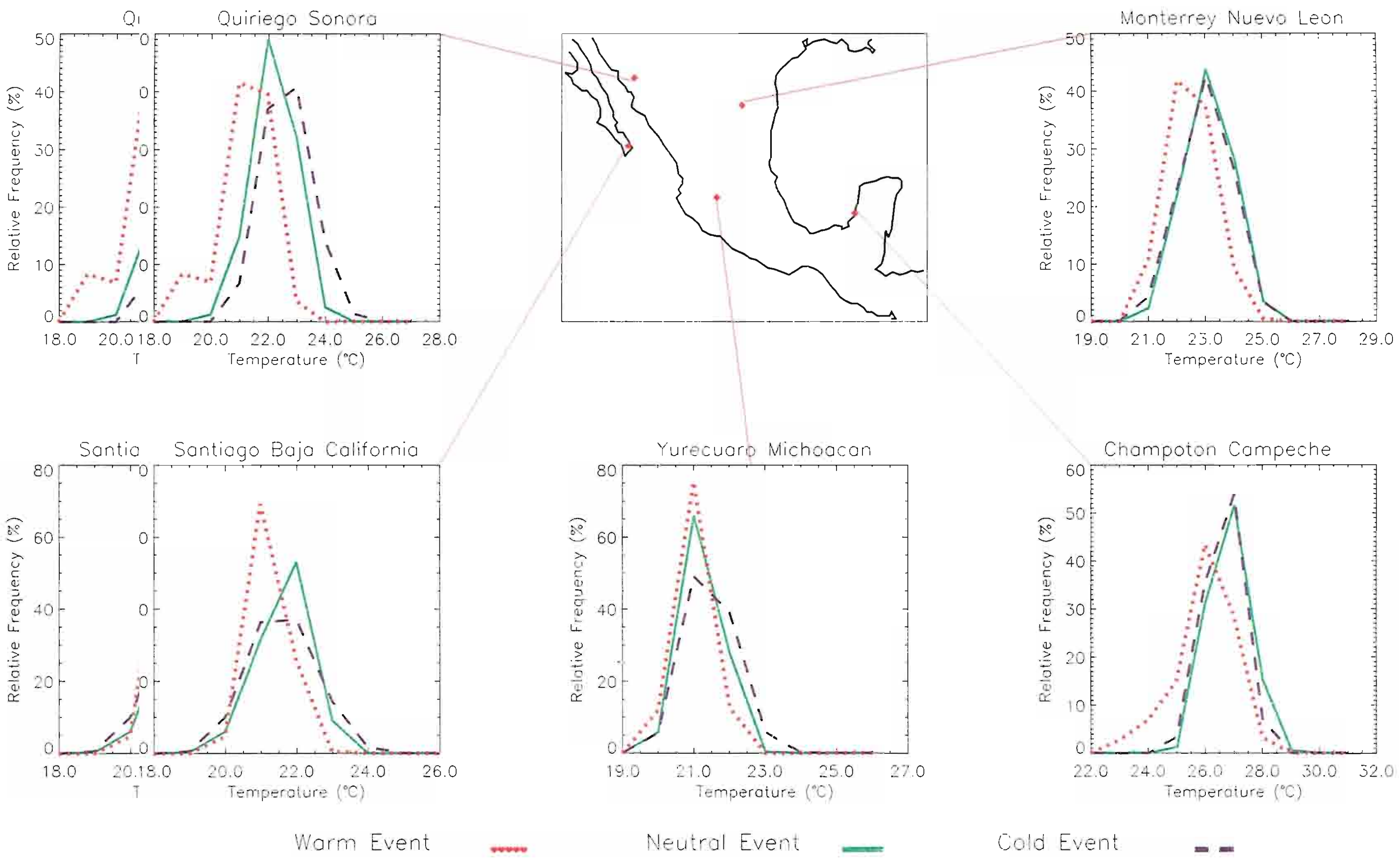


Figure 14c. Mexico Temperature Probability Density Functions for ENSO Month MAM

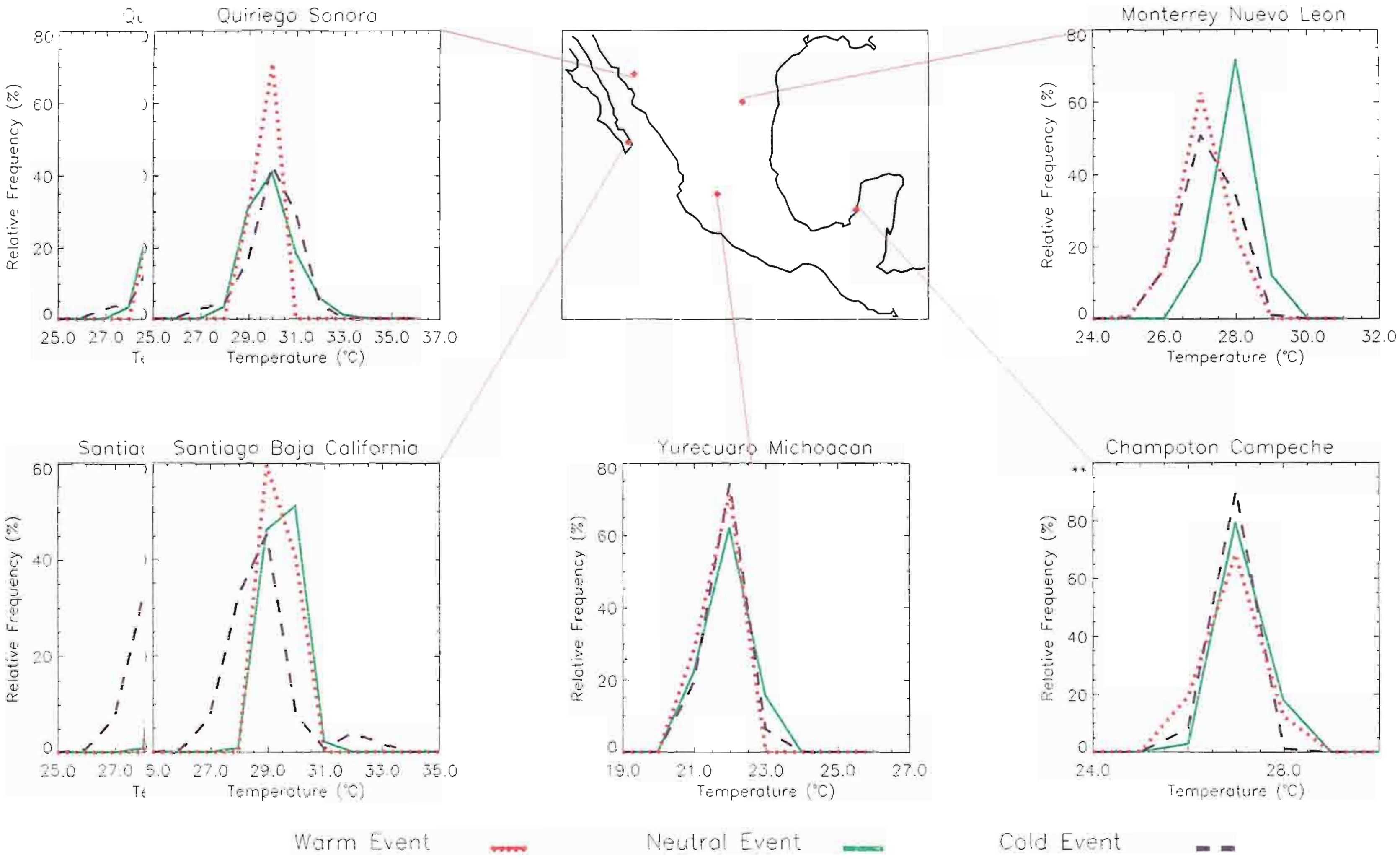


Figure 14d. Mexico Temperature Probability Density Functions for ENSO Month JJA

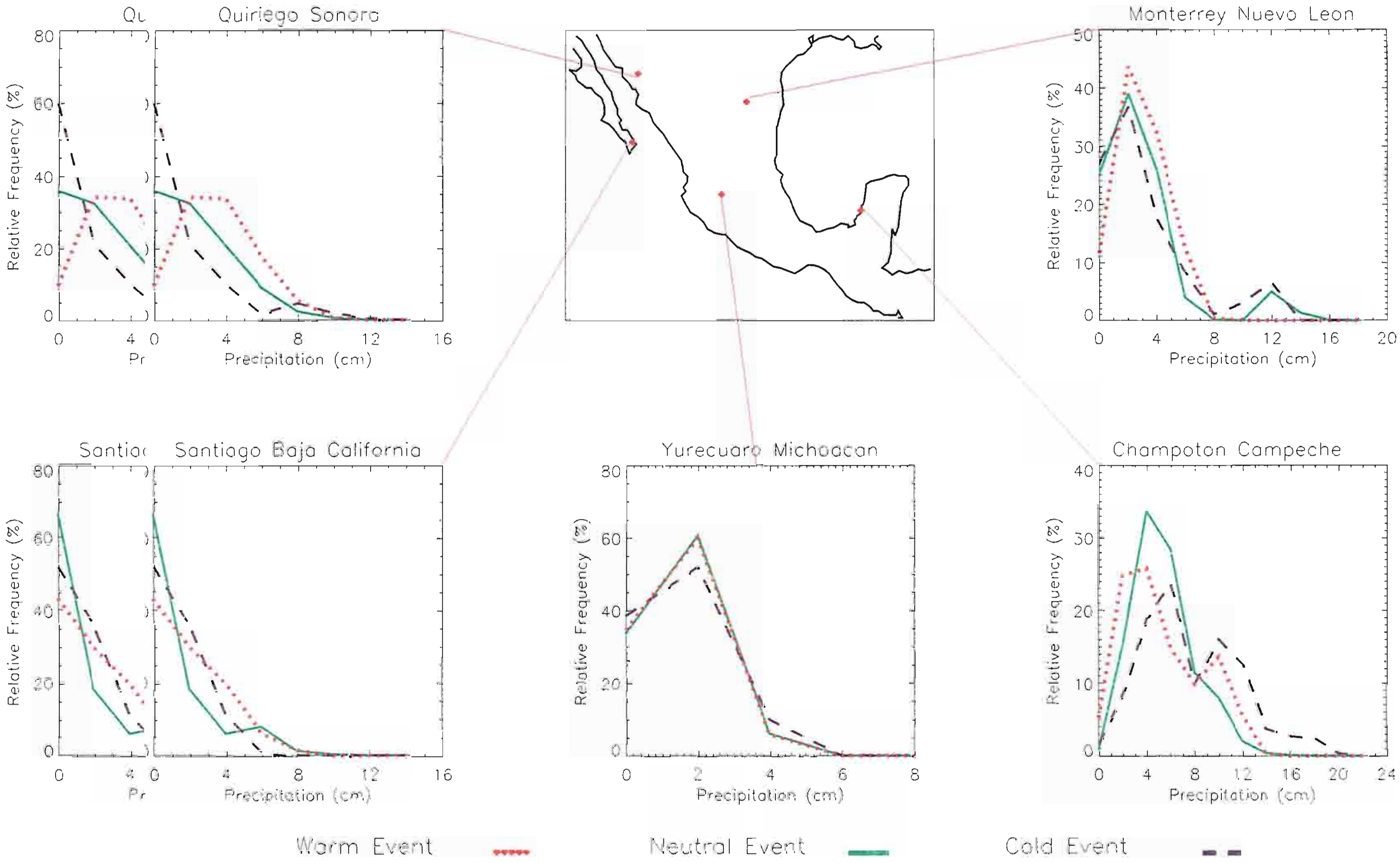


Figure 15a. Mexico Precipitation Probability Density Functions for ENSO month OND

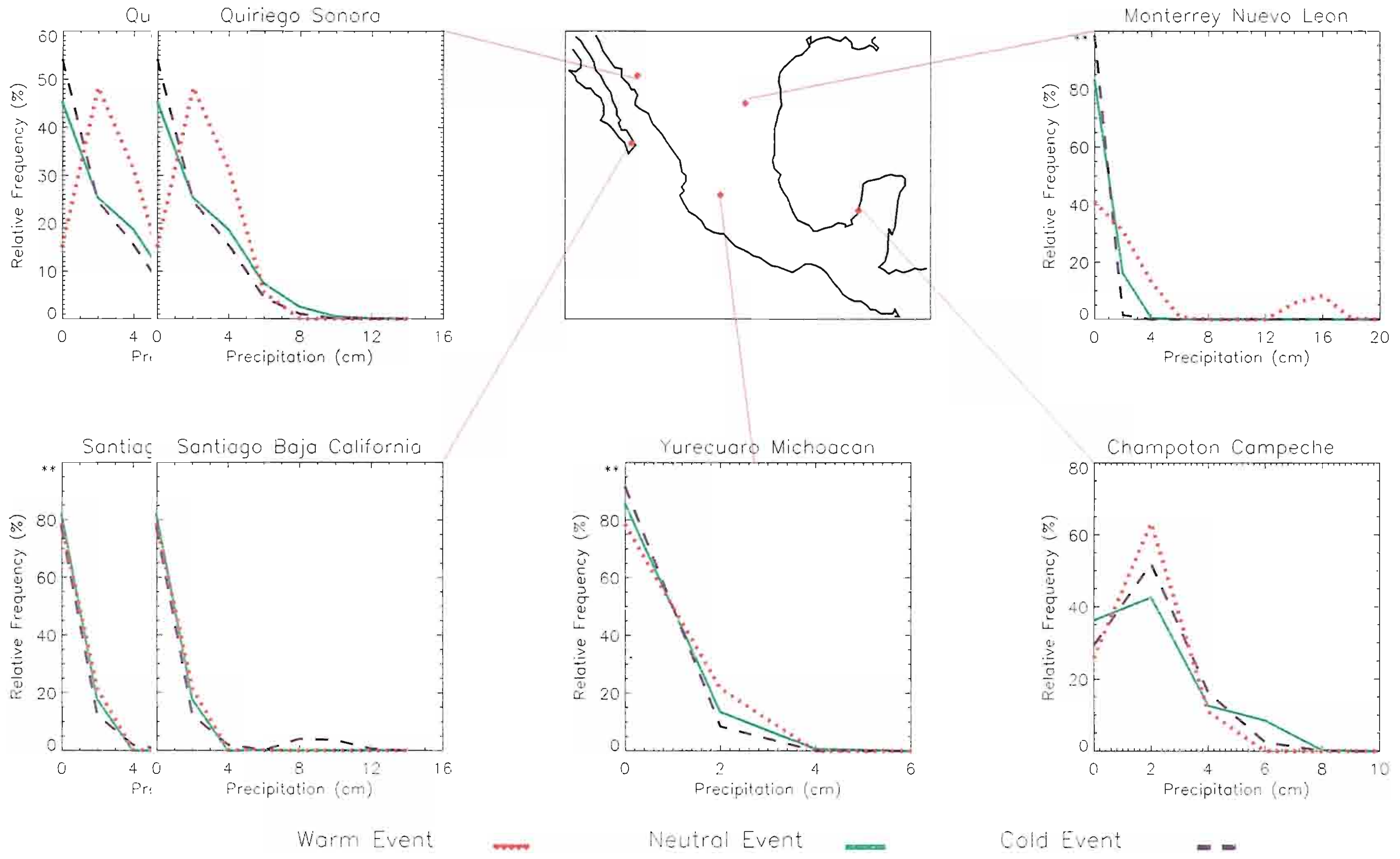


Figure 15b. Mexico Precipitation Probability Density Functions for ENSO month DJF

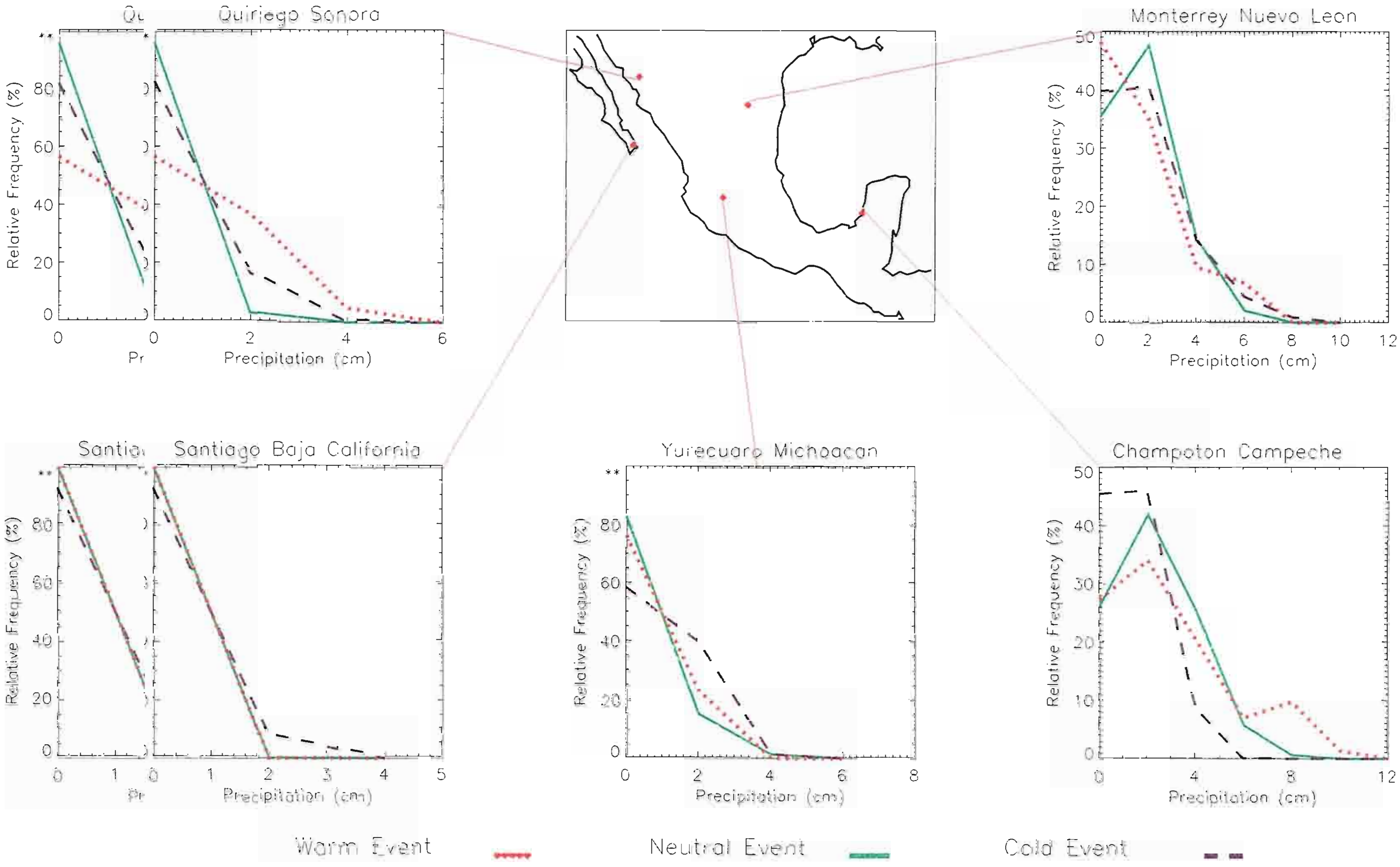


Figure 15c. Mexico Precipitation Probability Density Functions for ENSO month MAM

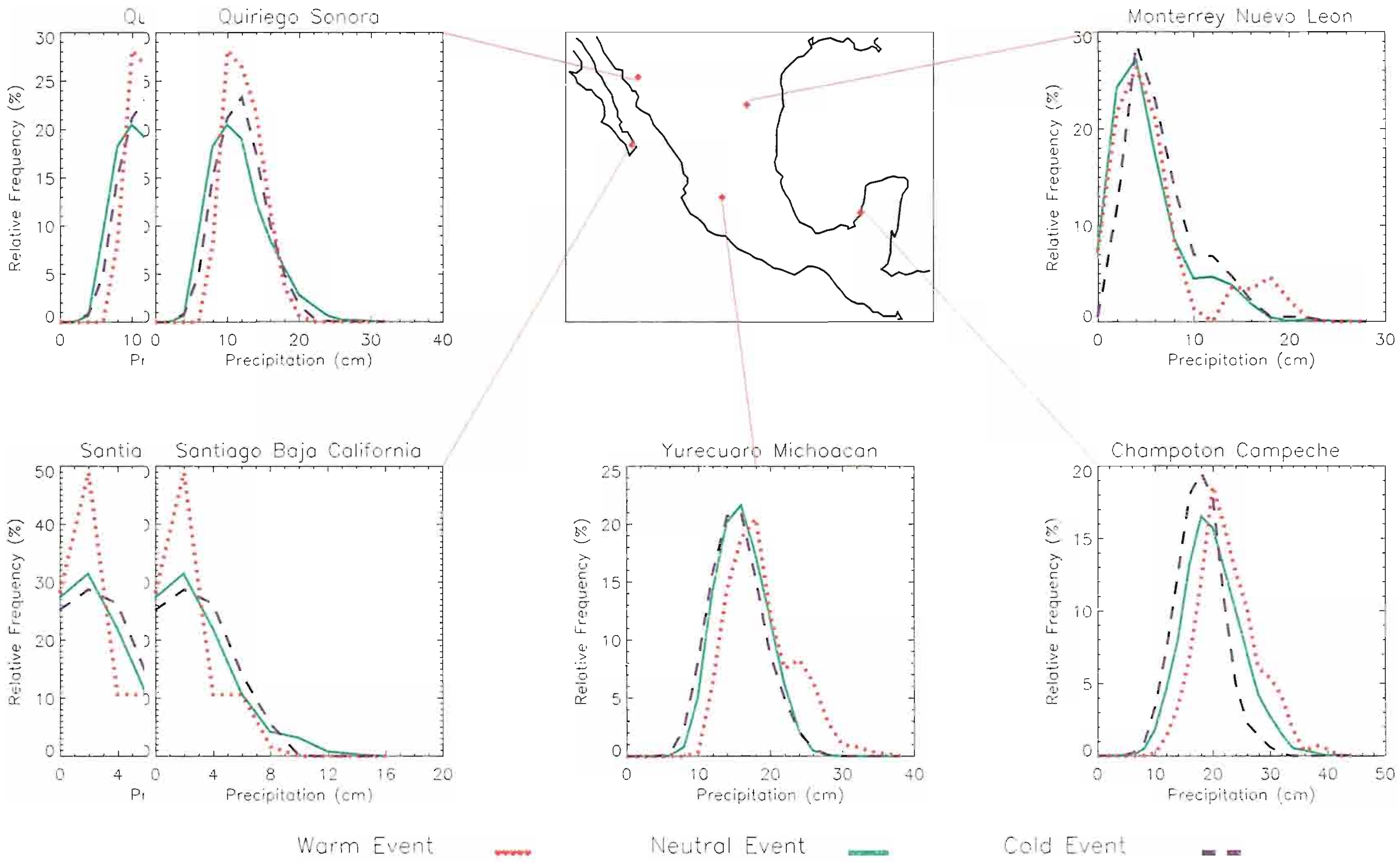


Figure 15d. Mexico Precipitation Probability Density Functions for ENSO month JJA

5. CONCLUSIONS

5.1. Summary of results

There are significant temperature and precipitation anomalies associated with ENSO phases in Mexico, Alaska, and Canada. The largest temperature anomalies occur during fall, winter, and spring of the ENSO year for both cold and warm phases. The magnitude of cold phase temperature anomalies are larger and more significant in Canada and Alaska. Mexican temperature anomalies and precipitation anomalies are both larger in magnitude during warm phases.

During cold phase fall and winter seasons, nearly all the Canadian and Alaskan stations experience cold temperature anomalies. These cold anomalies weaken in the late spring and summer. During warm phase winters, western and central Canada as well as southern Alaska encounter warm anomalies. In contrast, the Arctic north has cold anomalies. During warm phase springs, central and eastern Canada are warmer while Alaska and the high Arctic are colder than in neutral years.

During the cold phase, precipitation in most of eastern Canada is reduced, whereas most of western and interior Canada is wetter than normal. An interesting feature on the Alaskan and Canadian Pacific Coast is the spatial change in precipitation regime: wet in

Pacific Coast is the spatial change in precipitation regime: wet in

Vancouver, dry in Port Hardy, wet in Yakutat and dry in Kodiak.

During warm phase winters, interior and southern Canada are dry; whereas the northern Pacific coast and the maritime Atlantic coast are wetter than normal. Differences in coastal precipitation totals are higher than those of inland stations due to the plethora of moisture in proximity to the oceans. Due to the utter dearth of more than trace precipitation in fall and winter in the Arctic, clear ENSO patterns can only be seen in late spring and summer .

Mexico experiences warmer weather during cold phases, except for the summers which tend to be cooler. Nearly all of Mexico is cooler during the warm phase winter and spring. Mexico is slightly drier during cold phases, except for parts of the Yucatan. A pattern of anomalously wet conditions occurs during cold phase springs along the eastern coast of Mexico and drier conditions occur in the Yucatan during cold phase springs. This pattern appears to be an extension of the US pattern in Florida and Texas (Sittel 1994). Most of Mexico is wetter during the warm phase winter.

The largest amplitude warm phase temperature anomalies occur in the Western Cordillera of Canada. The regions with the most significant anomalies determined by T-tests are the eastern and western coastal regions. This finding mirrors previous studies of the US regions; coastal areas of the US were found to have more significant occurrences than the interior US (Sittel 1994). The coastal regions have lower amplitude temperature anomalies; however, for the natural temperature range in question, the change in temperatures were found to be significant. During the cold phase,

in temperatures were found to be significant. During the cold phase,

interior Alaska has the coldest temperature anomalies. Alaska remains significantly colder in fall and winter.

Mexican temperature anomalies are not as large as Canadian and Alaskan temperature anomalies. The range of the temperature anomalies is from -1.5°C to 1.5°C in both phases. These anomalies are small; however, these low values are significant by T-test results.

For both cold and warm phases, the largest precipitation anomalies are found in the coastal regions of southern Alaska, eastern Canada, and western Canada during fall and winter of the ENSO year. The largest precipitation anomalies in Mexico are found in coastal regions; excepting the coastal desert region in Baja California.

5.2. Comparison with other studies

There is agreement generally with conclusions of other studies. These results are compared to others in terms of the peak ENSO season, winter (DJF), because it is the month most often associated with the peak of the ENSO related anomalies (Sittel 1994). The author found that Sittel's (1994) pattern of warm temperature anomalies in the northern interior US continues into Canada (figure 18b) and up to just south of the High Arctic region. The High Arctic region throughout the warm phase winter remains cold. The warm phase cold temperature anomaly pattern in the southwestern US (Sittel 1994) continues into northern Mexico and the Yucatan. During the cold phase, the cooler temperature anomaly

southwestern US (Sittel 1994) continues into northern Mexico and the Yucatan. During the cold phase, the cooler temperature anomaly

patterns in the northwest US (Sittel 1994) continue into Canada and Alaska. Sittel's warm anomaly pattern in the southeast US continues into northeastern Mexico and the Yucatan. The propagation of the ENSO pattern eastward throughout the ENSO year in both the cold and warm phases, documented by Sittel's study (1994) matched seasonal evolution shown herein.

Shabbar and Khandelar (1996) also found significant western Canadian warm temperature anomalies that expanded eastward with time during warm phases. The author's temperature results for Canada are similar, except that their study of the region indicate no temperature changes in eastern Canada during the cold phase. I found significant cold anomalies in spring (MAM) for eastern Canada, as well as cold anomalies in parts of maritime Canada in early summers of cold phase years. A possible reason why the results differ may be the different choice of years as cold and warm phases. Another consideration is Shabbar and Khandelar's data were placed on a grid too coarse to examine the important small scale variability patterns in coastal regions.

Yarnal and Diaz (1986) also found Pacific coastal Alaska and British Columbia to be significantly colder in cold phases and warmer in warm phases. Their study noted the Alaskan and Pacific coast to have subregions of precipitation anomalies matching those of this study. Ropelewski and Halpert (1996) found the Gulf coast of north Mexico to be wet in the warm phase, matching this study of Mexico in that region.

Mexico in that region.

5.3. Physical connection

The physical mechanisms that bring about precipitation and temperature anomalies are identified in previous works (for example Philander 1990; Smith 1996). The north-south excursions of the polar jet in warm phases is 180 degrees out of phase with the polar jet in cold phases. These shifts in the jet-stream correspond to pressure anomaly patterns such as the Pacific-North American (PNA) Pattern and the reverse PNA pattern

The Pacific-North American (PNA) pattern has been associated with the climatic effects of warm ENSO phases over North America (Horace and Wallace 1981). The pattern is characterized by a strong Aleutian low displaced to the southeast, a Canadian Arctic high pressure system west of the Hudson Bay, a low pressure system over the southeast US and strong ridging over the Western Cordillera (Philander 1990). The ridge over the cordillera region brings warm anomalies to Canada through warm air advection on the windward side of the ridge. This pattern effectively “blocks” the maritime influence from the western US. Temperature data clearly show the pressure system patterns. The warm (cold) anomalies occur in the general vicinity of a high (low) pressure anomaly system in both the PNA and reverse PNA patterns.

The reverse PNA pattern is associated with the cold phase ENSO effects. Ridging occurs over the southeast, with a strong meridional flow towards the northeast. Troughing occurs in the western US (Smith 1996) and cold air advection results in cold anomalies in northern Mexico and the western US. Alaska has

western US (Smith 1996) and cold air advection results in cold

anomalous low pressure to the north and anomalous high pressure to the south over the north Pacific. Alaska's largest temperature anomalies in the cold phase winter may be due to the pressure systems channeling cold polar air over Alaska. Precipitation at the Alaska coast is suppressed in this stage, yet the interior stations receive more snow. A polar jet core anomaly south of Alaska in the cold phase causes enhanced uplift to the north of its exit region, and subsidence to the south of it (Smith 1996). This matches the pattern of anomalously wet conditions in the Pacific northwest region and dry conditions in California (Sittel 1994).

The precipitation and temperature results do not fit the popular paradigm that the cold phase and warm phase have opposite effects on a region. The cold phase and warm phase are opposite phenomena in terms of SST and pressure in the equatorial pacific, but the teleconnections to the region through the atmosphere are not as simple. For example, Alaskan stations are cooler during the cold and warm phases than in neutral years. Investigation of local processes that may affect the atmosphere-land interaction, such as sea-ice growth and retreat in the Bering Sea may explain these results.

5.4 Future applications

Evaluation of climatic variables are needed for the Northern Hemisphere as a whole to discern better the sequence of phases during the ENSO cycles. More study needs to be focused on the higher latitude connections with ENSO. Studies can be undertaken in a

during the ENSO cycles. More study needs to be focused on the higher latitude connections with ENSO. Studies can be undertaken in a

variety of fields connected with this study. For the Arctic coastal regions in Canada and Alaska, further study could include ENSO's effect on sea ice extent. Sea ice formation has a dramatic effect on the coastal environment. With its solidification in winter, the local climate regime can change from a maritime climate to that of a continental climate. Dangers of ice freeze include rapid encroachment of the ice, and cyclogenesis at the ice edge. These pose serious problems for fishing fleets and naval vessels. If ENSO has a significant effect on sea ice, then sea ice extent, freeze up, and break up may be predicted more effectively. Future work could also include relating temperature and precipitation anomalies to crop yields in interior Canada and Mexico. Some applications of this study could be used in preparation for ENSO related drought and forest fires. On the municipal scale, energy budgets for a city in the upcoming fiscal year could be made more effective with these ENSO effects in mind.

APPENDIX

Table 1
Stations used in study

City	State/ Province	Latitude (°N)	Longitude (°W)
Barrow	Alaska	71.30	-156.78
Nome	Alaska	64.50	-165.43
McGrath	Alaska	62.97	-155.62
Talkeetna	Alaska	62.30	-150.10
Anchorage	Alaska	61.17	-150.02
St. Paul	Alaska	57.15	-170.22
Cold Bay	Alaska	55.20	-162.72
King Salmon	Alaska	58.68	-156.65
Bethel	Alaska	60.78	-161.80
Homer	Alaska	59.63	-151.50
Kodiak	Alaska	57.75	-152.50
Yakatat	Alaska	59.52	-139.67
Annette Island	Alaska	55.03	-131.57
Sitka Magnetic Observatory	Alaska	57.10	-135.30
Clyde	Northwest Territories	70.48	-68.52
Quesnel	British Columbia	53.03	-122.52
Cape St. James	British Columbia	51.93	-131.02
Abbotsford	British Columbia	49.03	-122.37
Port Hardy	British Columbia	50.68	-127.37
Banff	Alberta	51.18	-115.57
Yorkton	Saskatchewan	51.27	-102.47
Daniel's Harbour	Newfoundland	50.23	-57.58
Greenwood	Nova Scotia	44.98	-64.92
Sable Island	Nova Scotia	43.93	-60.02
Yarmouth	Nova Scotia	43.83	-66.08
St. John's	New Brunswick	45.32	-65.88
Trenton	Ontario	44.12	-77.53
London	Ontario	43.03	-81.15
Montreal/Dorval	Quebec	45.47	-73.75
Muskoka	Ontario	44.97	-79.30
Summerside	Prince Edward Island	46.43	-63.83
Moncton	New Brunswick	46.12	-64.68
Charlottetown	Prince Edward Island	46.28	-63.13
Sydney	Nova Scotia	46.17	-60.05
Iles De La Madeleine	Quebec	47.42	-61.78
Quebec	Quebec	46.80	-71.38
Chatham	New Brunswick	47.02	-65.45
Mont Joli	Quebec	48.60	-68.22
Bagotville	Quebec	48.33	-71.00
Quebec	Quebec	46.80	-71.38
Chatham	New Brunswick	47.02	-65.45
Mont Joli	Quebec	48.60	-68.22
Bagotville	Quebec	48.33	-71.00
Gore Bay	Ontario	45.88	-82.57

Table 1 *(cont.)*

City	State/ Province	Latitude (°N)	Longitude (°W)
Earlton	Ontario	47.70	-79.85
Victoria	British Columbia	48.65	-123.43
St. John's	Newfoundland	47.62	-52.73
Gander	Newfoundland	48.95	-54.57
Sept-Iles	Quebec	50.22	-66.27
Natashquan.	Quebec	50.18	-61.82
Stephenville	Newfoundland	48.53	-58.55
Goose	Newfoundland	53.32	-60.42
Cartwright	Newfoundland	53.70	-57.03
Kapuskasing	Ontario	49.42	-82.47
Moosonee	Ontario	51.27	-80.65
Armstrong	Ontario	50.30	-89.03
Sioux Lookout	Ontario	50.12	-91.90
Lansdowne House	Ontario	52.23	-87.88
Big Trout Lake	Ontario	53.83	-89.87
Kenora	Ontario	49.78	-94.37
Winnipeg	Manitoba	49.90	-97.23
Dauphin	Manitoba	51.10	-100.05
Estevan	Saskatchewan	49.07	-103.00
Regina	Saskatchewan	50.43	-104.67
Moose Jaw	Saskatchewan	50.33	-105.55
Saskatoon	Saskatchewan	52.17	-106.68
The Pas	Manitoba	53.97	-101.10
Prince Albert	Saskatchewan	53.22	-105.68
Swift Current	Saskatchewan	50.28	-107.68
Medicine Hat	Saskatchewan	50.02	-110.72
Coronation	Alberta	52.07	-111.45
Lethbridge	Alberta	49.63	-112.80
North Battleford	Saskatchewan	52.77	-108.25
Calgary	Alberta	51.12	-114.02
Red Deer	Alberta	52.18	-113.90
Edmonton	Alberta	53.57	-113.52
Kamloops	British Columbia	50.70	-120.45
Jasper	Alberta	52.88	-118.07
Penticton	British Columbia	49.47	-119.60
Vancouver	British Columbia	49.18	-123.17
Comox	British Columbia	49.72	-124.90
Prince Rupert	British Columbia	54.30	-130.43
Kuujjuaq	Quebec	58.10	-68.42
Inukjuak	Quebec	58.45	-78.12
Iqaluit	Northwest Territories	63.75	-68.53
Eureka	Northwest Territories	79.98	-85.93
Cambridge Bay	Northwest Territories	69.10	-105.12
Baker Lake	Northwest Territories	64.30	-96.08
Fort McMurray	Alberta	56.65	-111.22
Eureka	Northwest Territories	79.98	-85.93
Cambridge Bay	Northwest Territories	69.10	-105.12
Baker Lake	Northwest Territories	64.30	-96.08
Fort McMurray	Alberta	56.65	-111.22
Fort Smith	Northwest Territories	60.02	-111.95

Table 1 *(cont.)*

City	State/ Province	Latitude (°N)	Longitude (°W)
Hay River	Northwest Territories	60.83	-115.78
Yellowknife	Northwest Territories	62.47	-114.45
Grande Prairie	Alberta	55.18	-118.88
Fort St. John.	British Columbia	56.23	-120.73
Fort Nelson	British Columbia	58.83	-122.58
Fort Simpson	Northwest Territories	61.75	-121.23
Smithers	British Columbia	54.82	-127.18
Terrace	British Columbia	54.47	-128.58
Watson Lake	Yukon	60.12	-128.82
Dease Lake	British Columbia	58.42	-130.00
Whitehorse	Yukon	60.72	-135.07
Mayo	Yukon	63.62	-135.87
Arivechi	Sonora	28.93	-109.18
Sahuaripa	Sonora	29.05	-109.23
Ciudad Guerrero	Chihuahua	28.55	-107.48
San Ignacio	Baja California	27.30	-112.88
Tres Hermanos	Sonora	27.20	-109.20
Quiriego	Sonora	27.52	-109.25
Jaina	Sinaloa	25.90	-108.02
Cuatro Cienegas	Coahuila	26.98	-102.07
Granjas Experimental	Nuevo Leon	27.23	-100.15
Tepehuanes	Durango	25.35	-105.78
Guanacevi	Durango	25.93	-105.95
Ramos Arizpe	Coahuila	25.55	-100.97
Monterrey	Nuevo Leon	25.87	-100.20
Las Enramadas	Nuevo Leon	25.50	-99.52
Montemorelos	Nuevo Leon	25.18	-99.83
Santiago	Baja California	23.47	-109.73
San Felipe	Baja California	23.13	-109.75
Francisco I. Madero	Durango	24.40	-104.32
Villagran	Tamaulipas	24.47	-99.50
San Fernando	Tamaulipas	24.85	-98.17
Mascota	Jalisco	20.53	-104.80
Chapala	Jalisco	20.30	-103.18
Merida	Yucatan	20.98	-89.65
Yurecuaro	Michoacan	20.33	-102.28
Champoton	Campeche	19.38	-90.73
Piaxtla	Puebla	18.20	-98.25
Matias Romero	Oaxaca	16.88	-95.05

COLD EVENT MINUS NEUTRAL EVENT

MEAN MONTHLY TEMPERATURE FOR ENSO MONTH OND

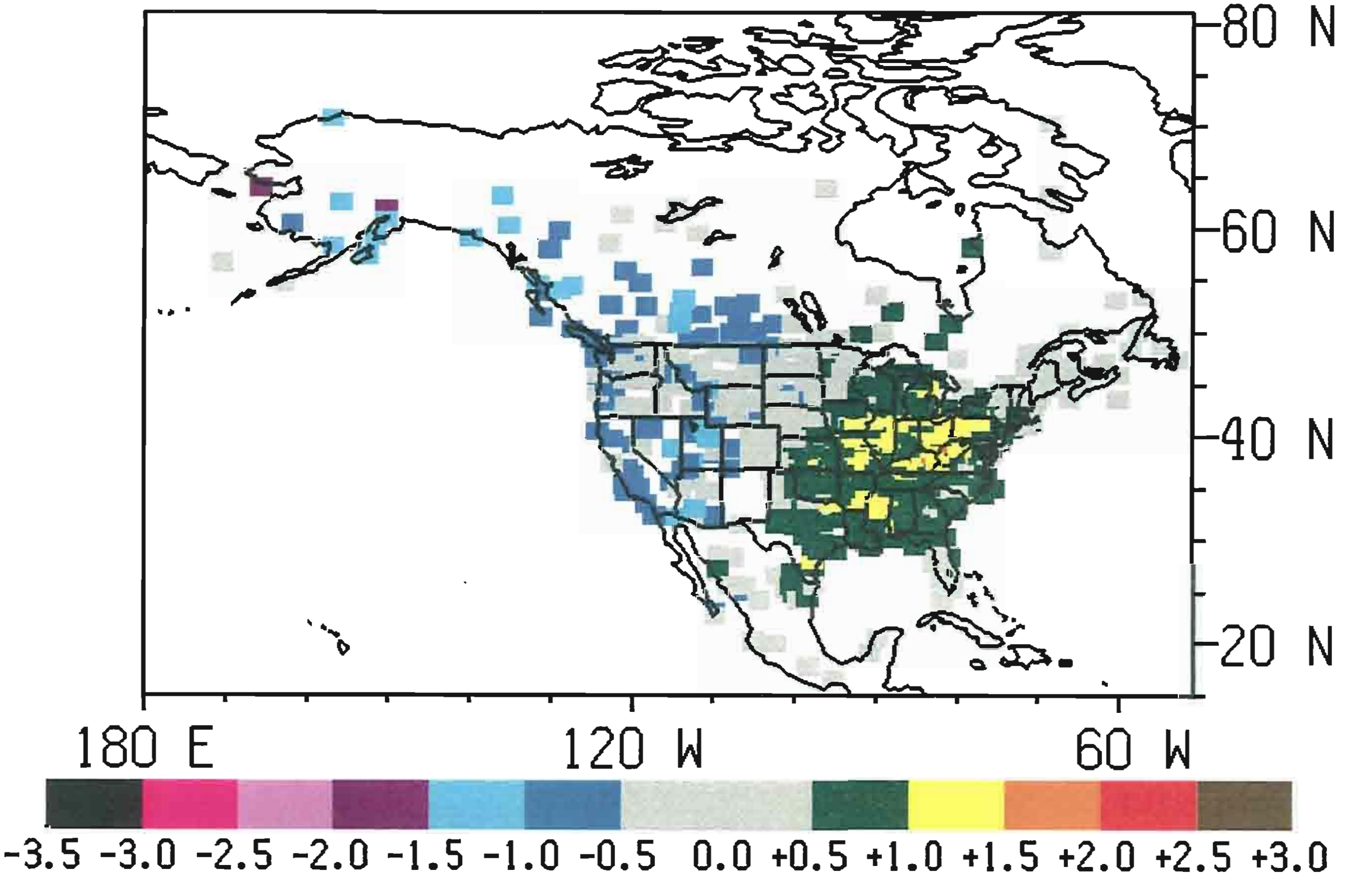


FIGURE 16A

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

COLD EVENT MINUS NEUTRAL EVENT

MEAN MONTHLY TEMPERATURE FOR ENSO MONTH DJF

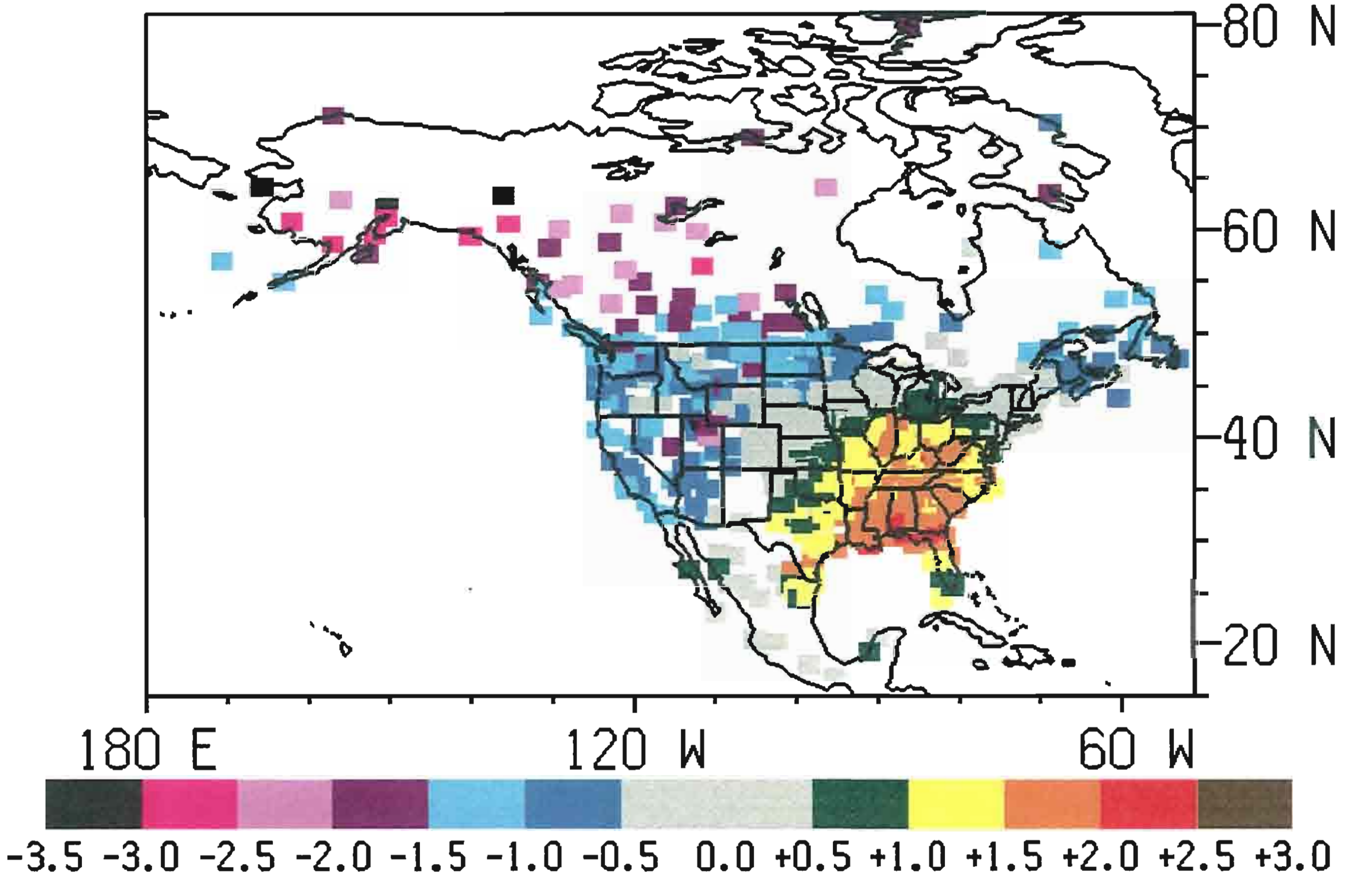


FIGURE 16B

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

COLD EVENT MINUS NEUTRAL EVENT

MEAN MONTHLY TEMPERATURE FOR ENSO MONTH MAM

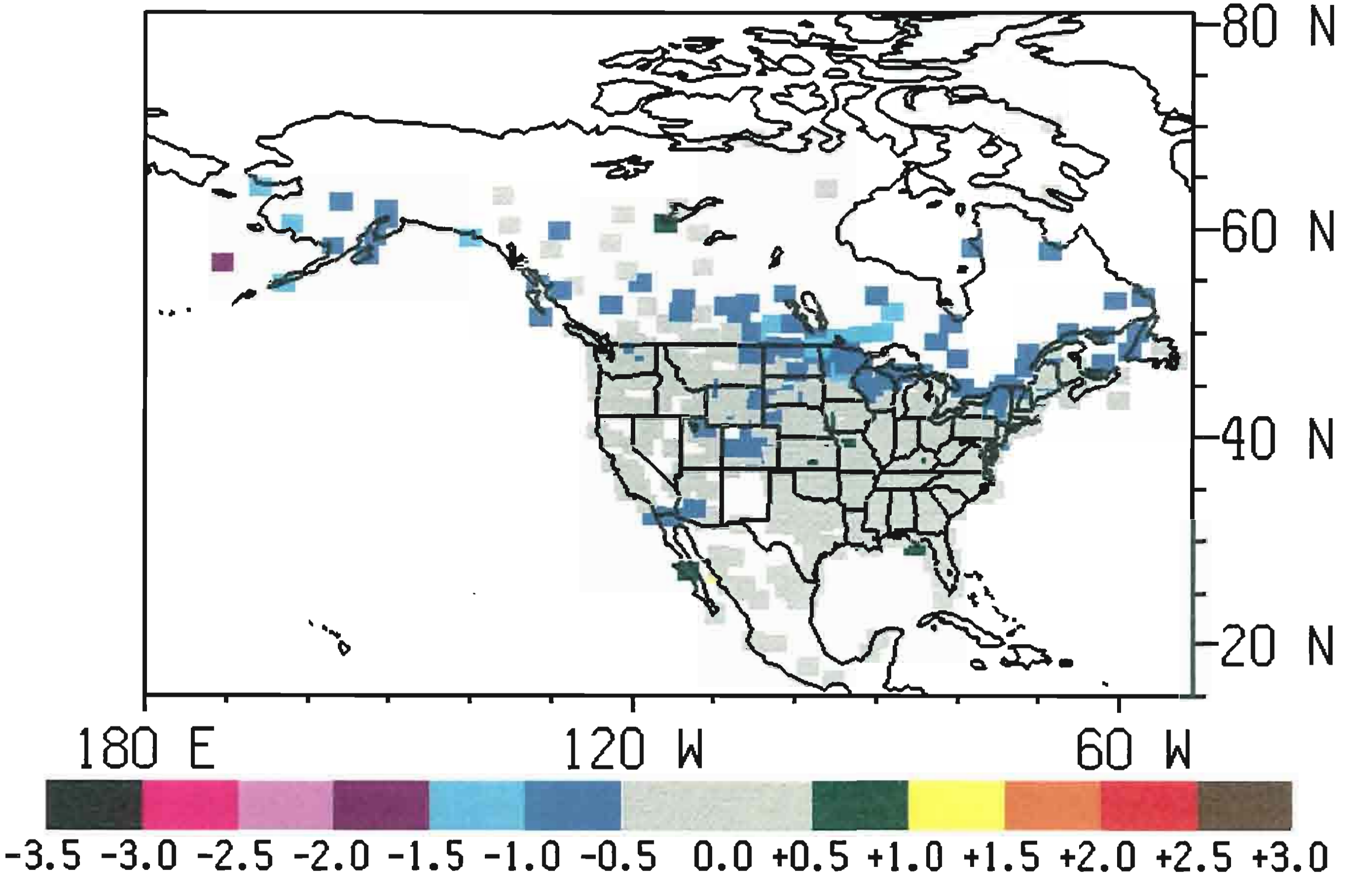


FIGURE 16C

DEGREES (C)

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

COLD EVENT MINUS NEUTRAL EVENT

MEAN MONTHLY TEMPERATURE FOR ENSO MONTH JJA

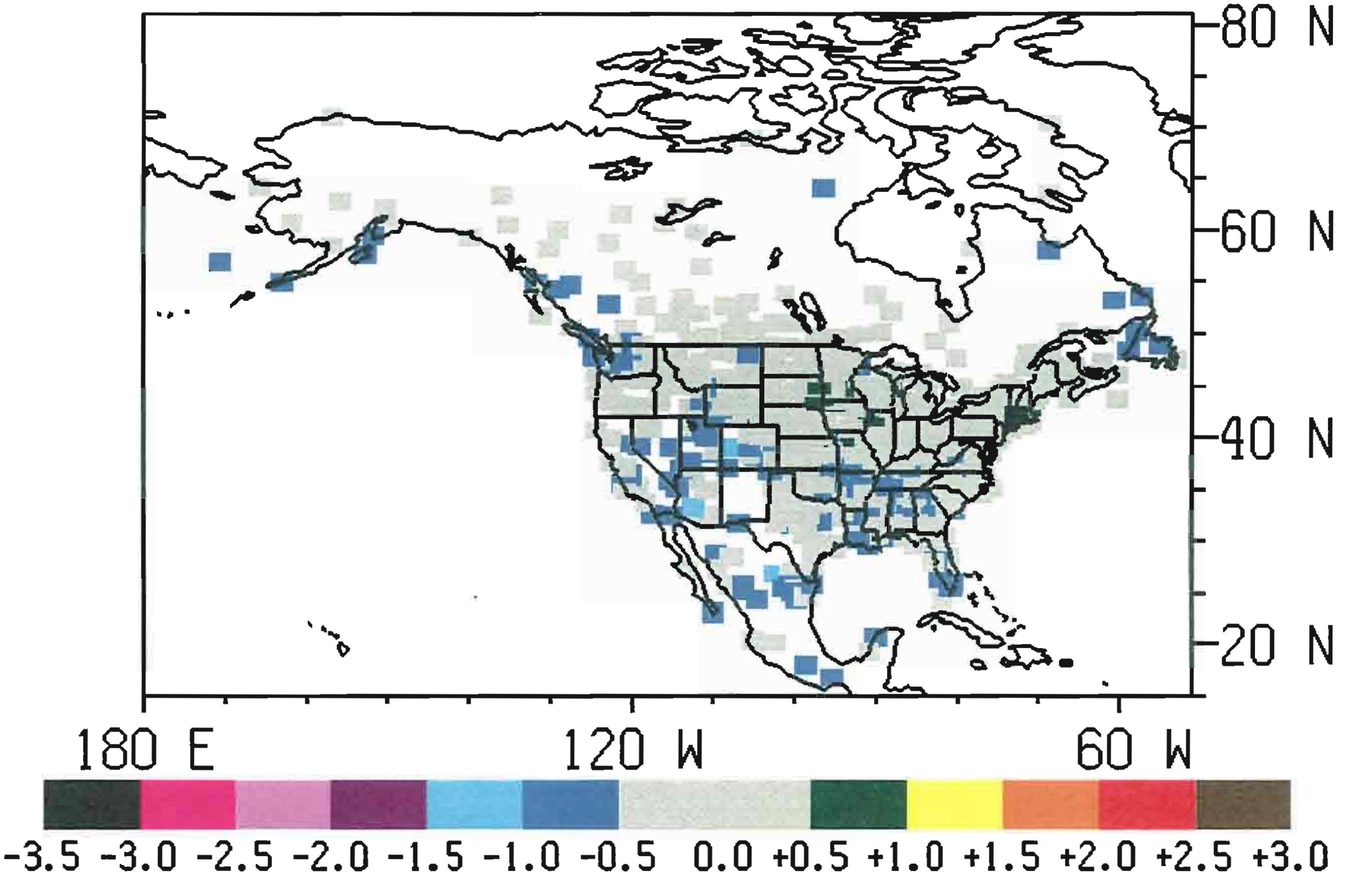


FIGURE 16D

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

WARM EVENT MINUS NEUTRAL EVENT

MEAN MONTHLY TEMPERATURE FOR ENSO MONTH OND

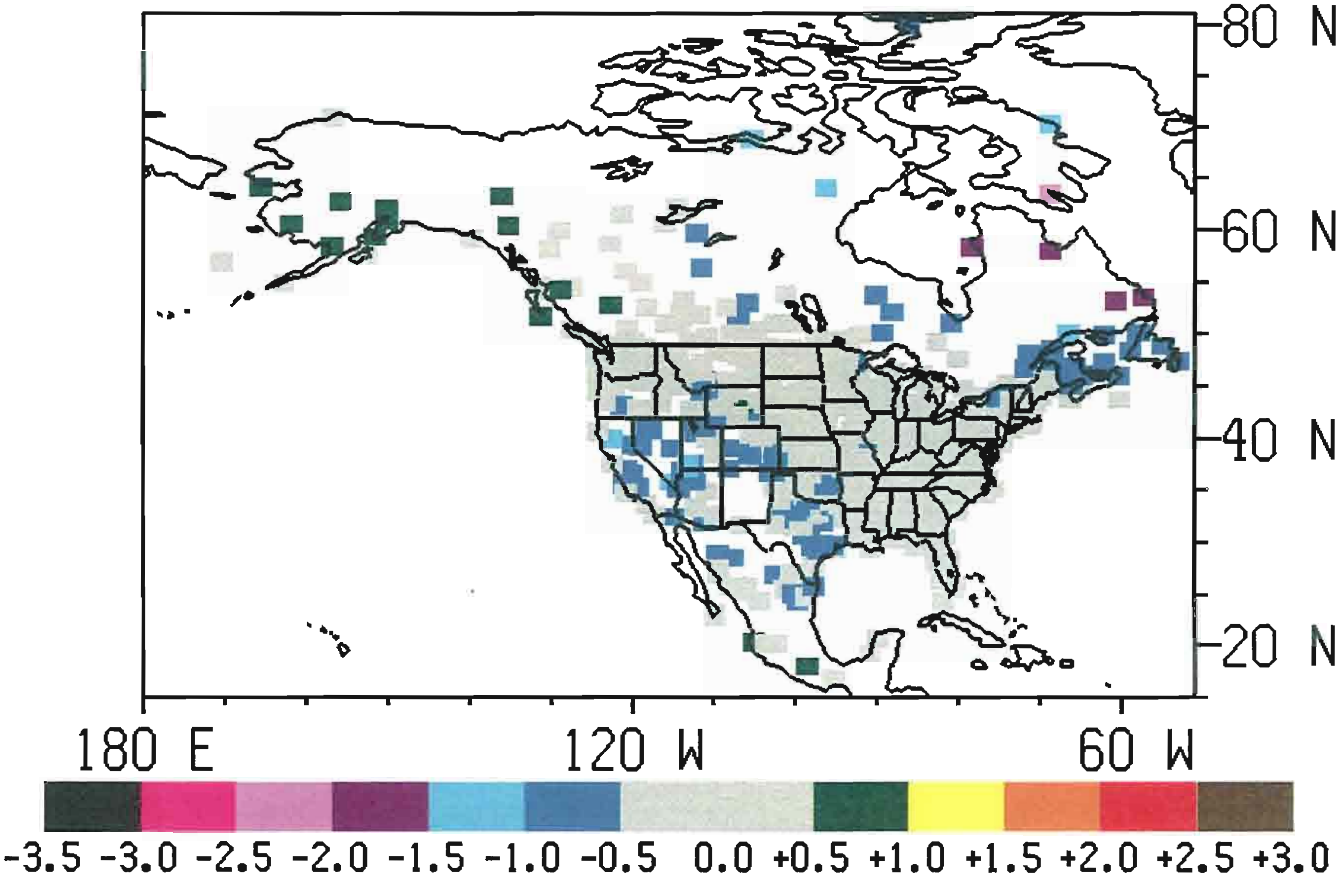
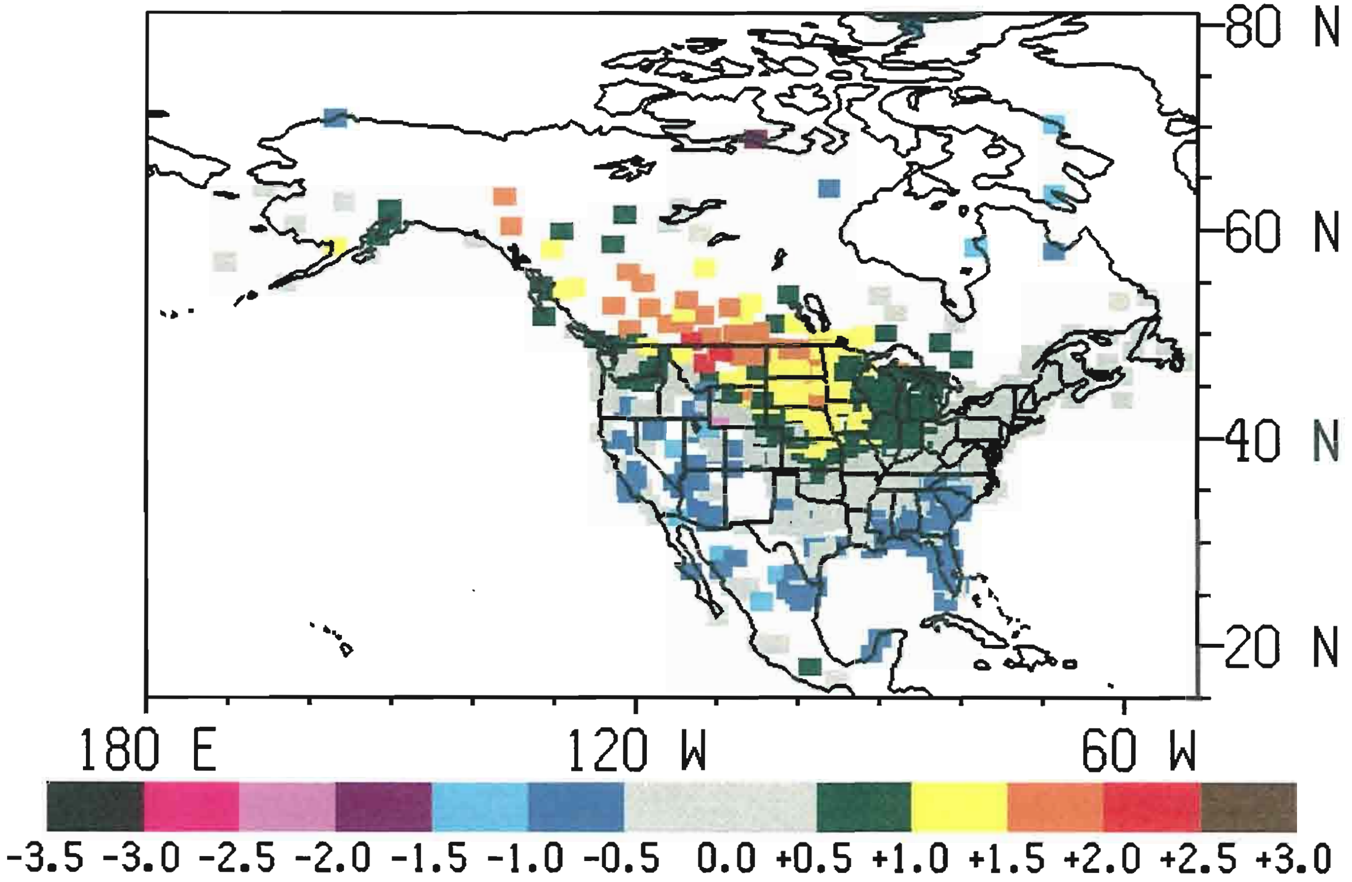


FIGURE 17A

DEGREES (C)

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY



WARM EVENT MINUS NEUTRAL EVENT

MEAN MONTHLY TEMPERATURE FOR ENSO MONTH DJF

FIGURE 17B

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

WARM EVENT MINUS NEUTRAL EVENT

MEAN MONTHLY TEMPERATURE FOR ENSO MONTH MAM

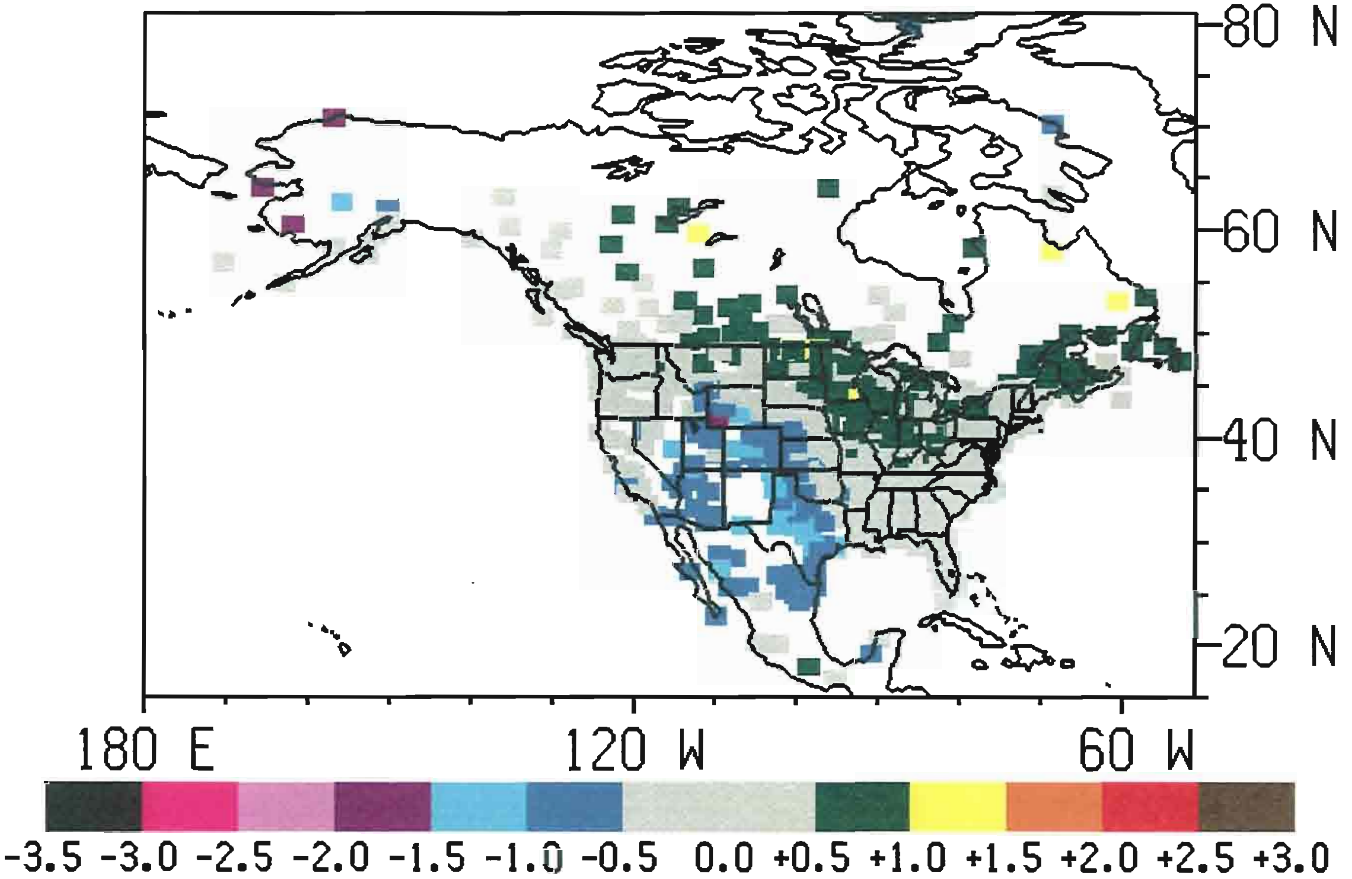


FIGURE 17C

DEGREES (C)

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

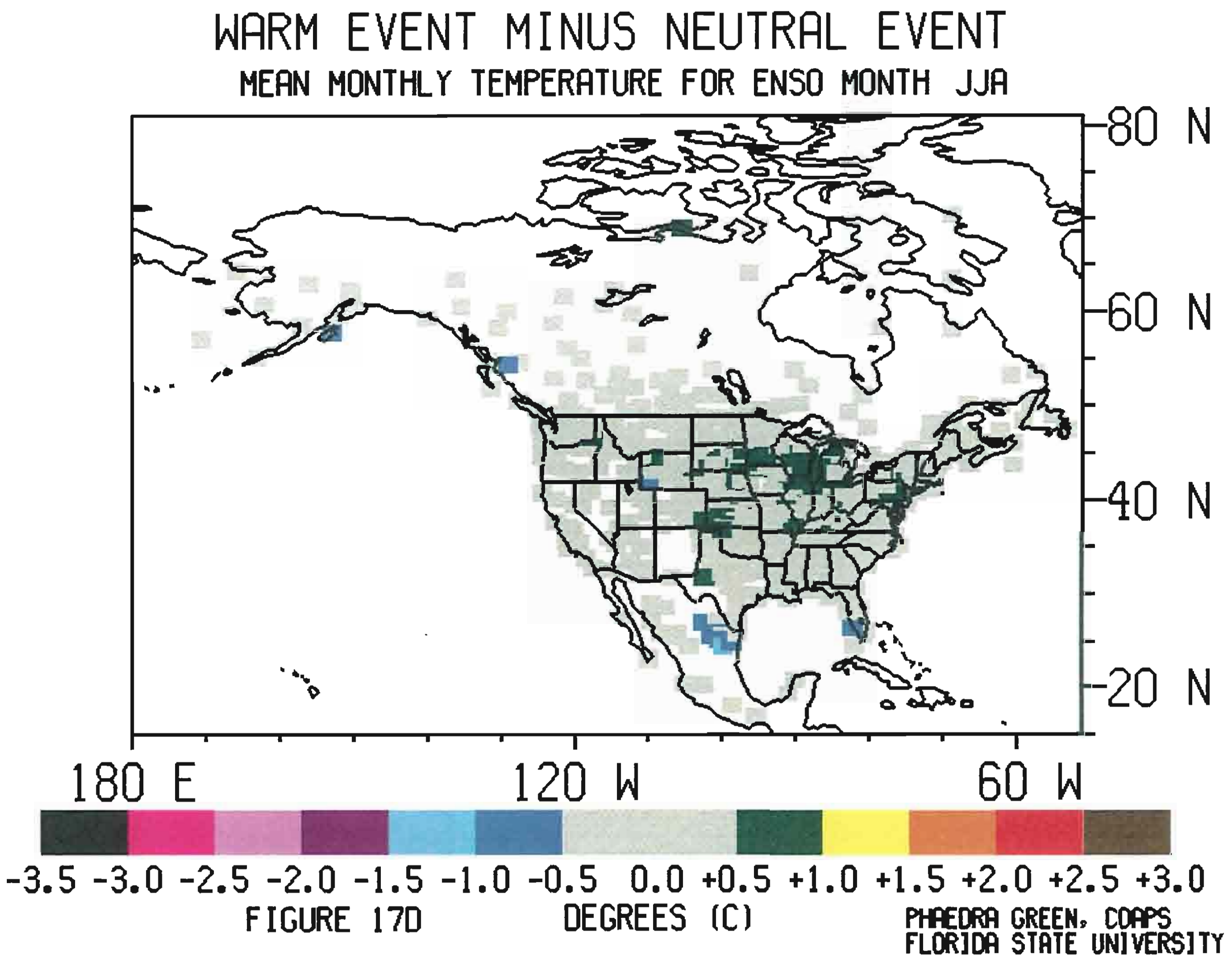
WARM EVENT MINUS NEUTRAL EVENT
MEAN MONTHLY TEMPERATURE FOR ENSO MONTH JJA
80 N
60 N
40 N
20 N
180 E
120 W
60 W
-3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 +0.5 +1.0 +1.5 +2.0 +2.5 +3.0
DEGREES (C)
PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

FIGURE 17D

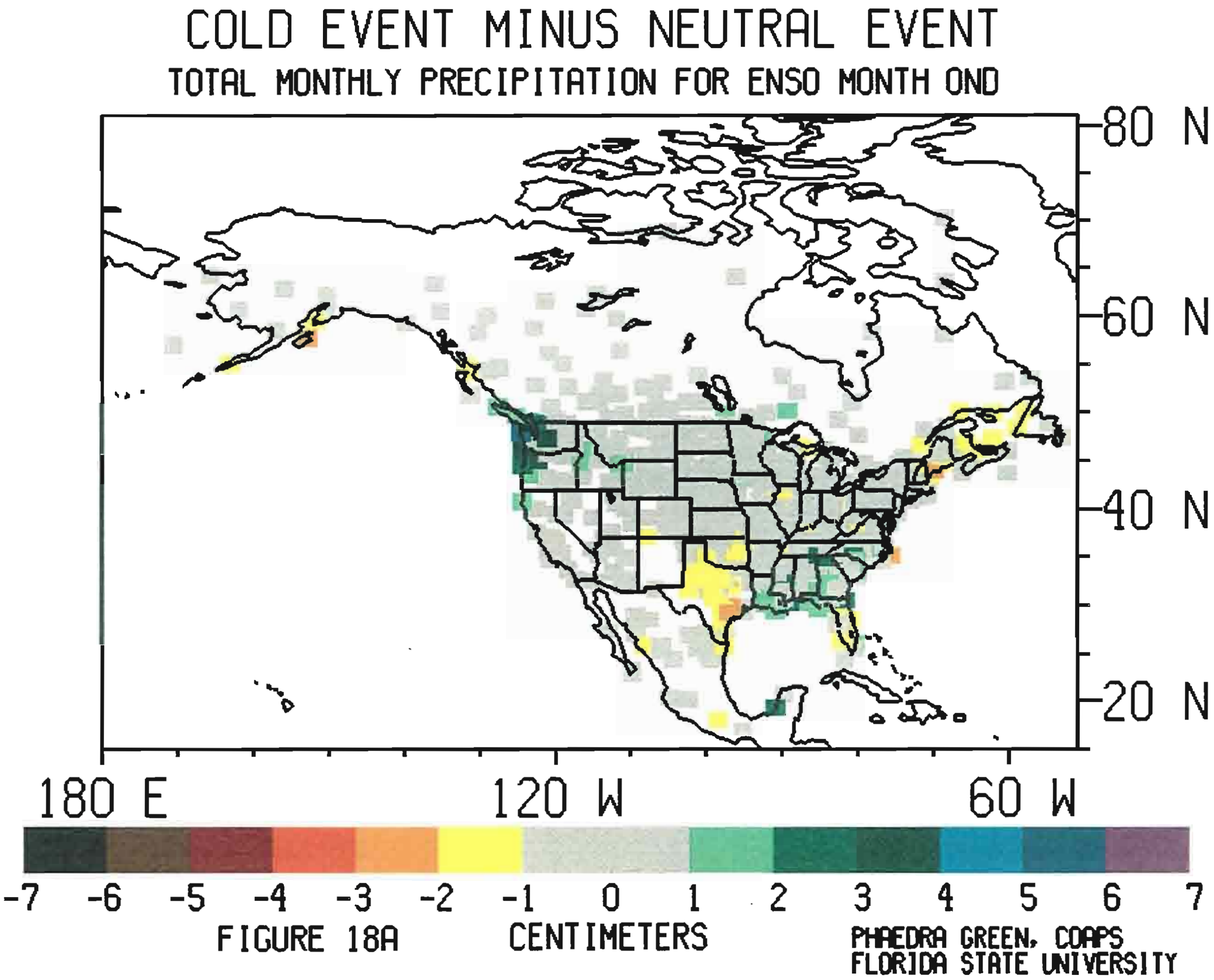

COLD EVENT MINUS NEUTRAL EVENT
TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH OND
80 N
60 N
40 N
20 N
180 E
120 W
60 W
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
CENTIMETERS
PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

FIGURE 18A

COLD EVENT MINUS NEUTRAL EVENT

TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH DJF

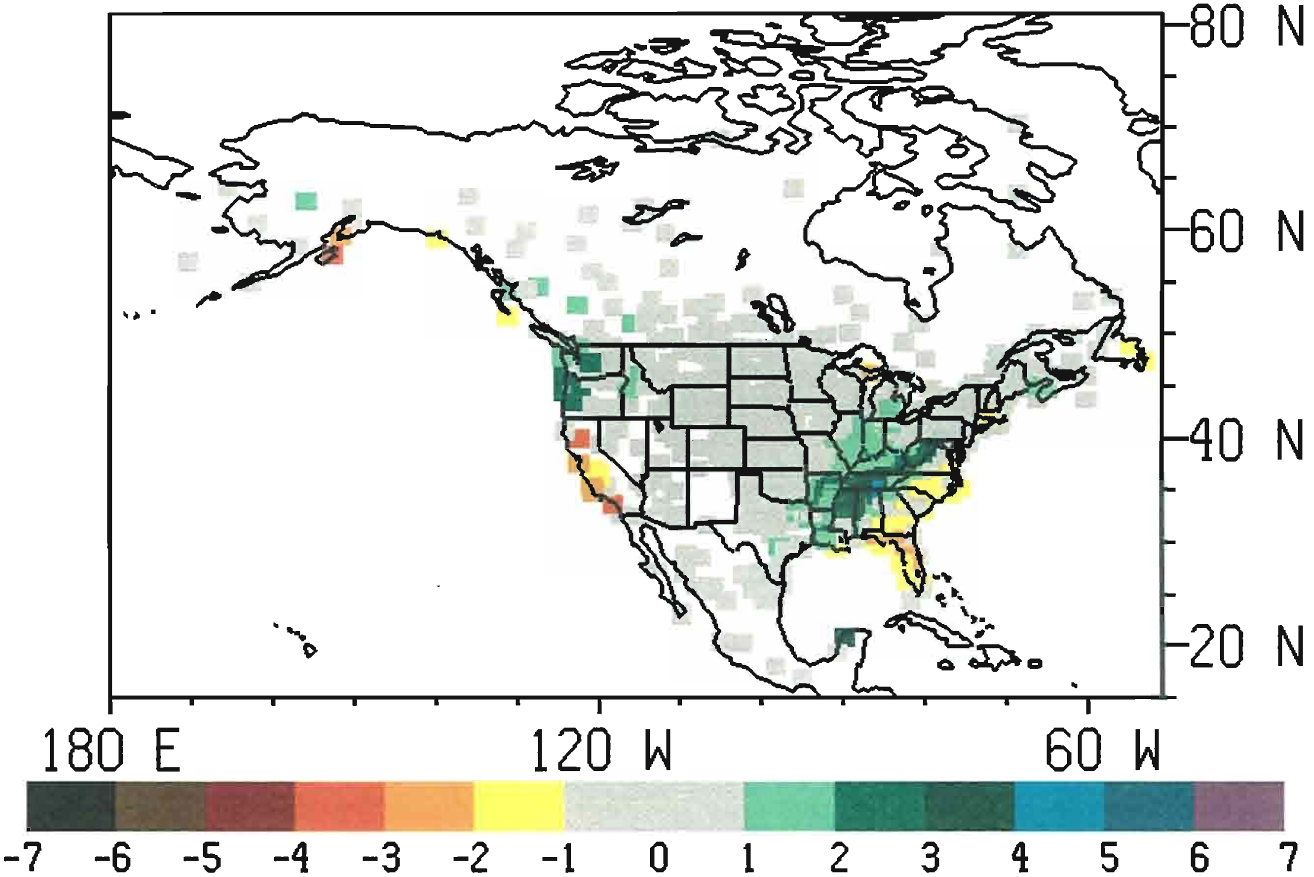


FIGURE 18B

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

COLD EVENT MINUS NEUTRAL EVENT

TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH MAM

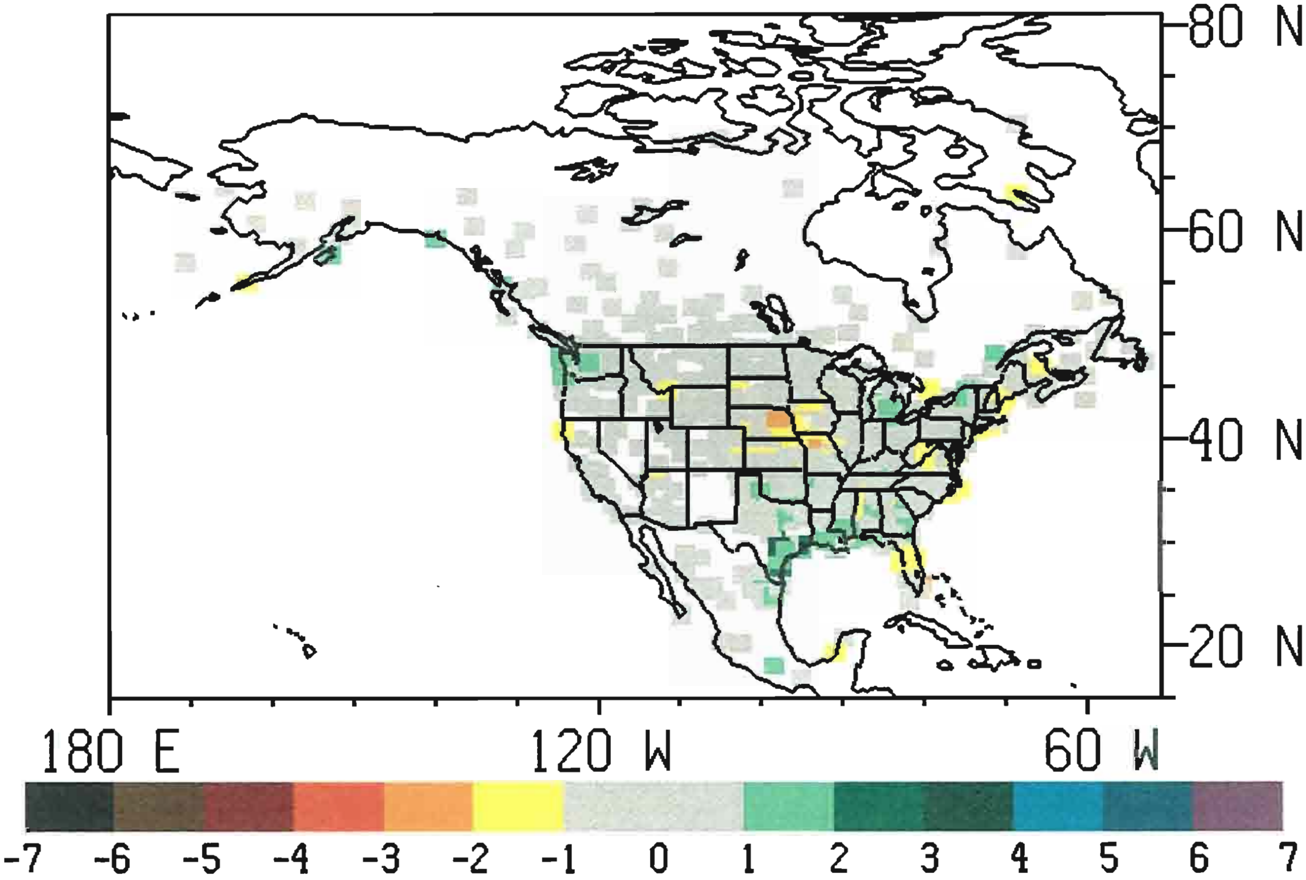


FIGURE 18C

CENTIMETERS

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

COLD EVENT MINUS NEUTRAL EVENT

TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH JJA

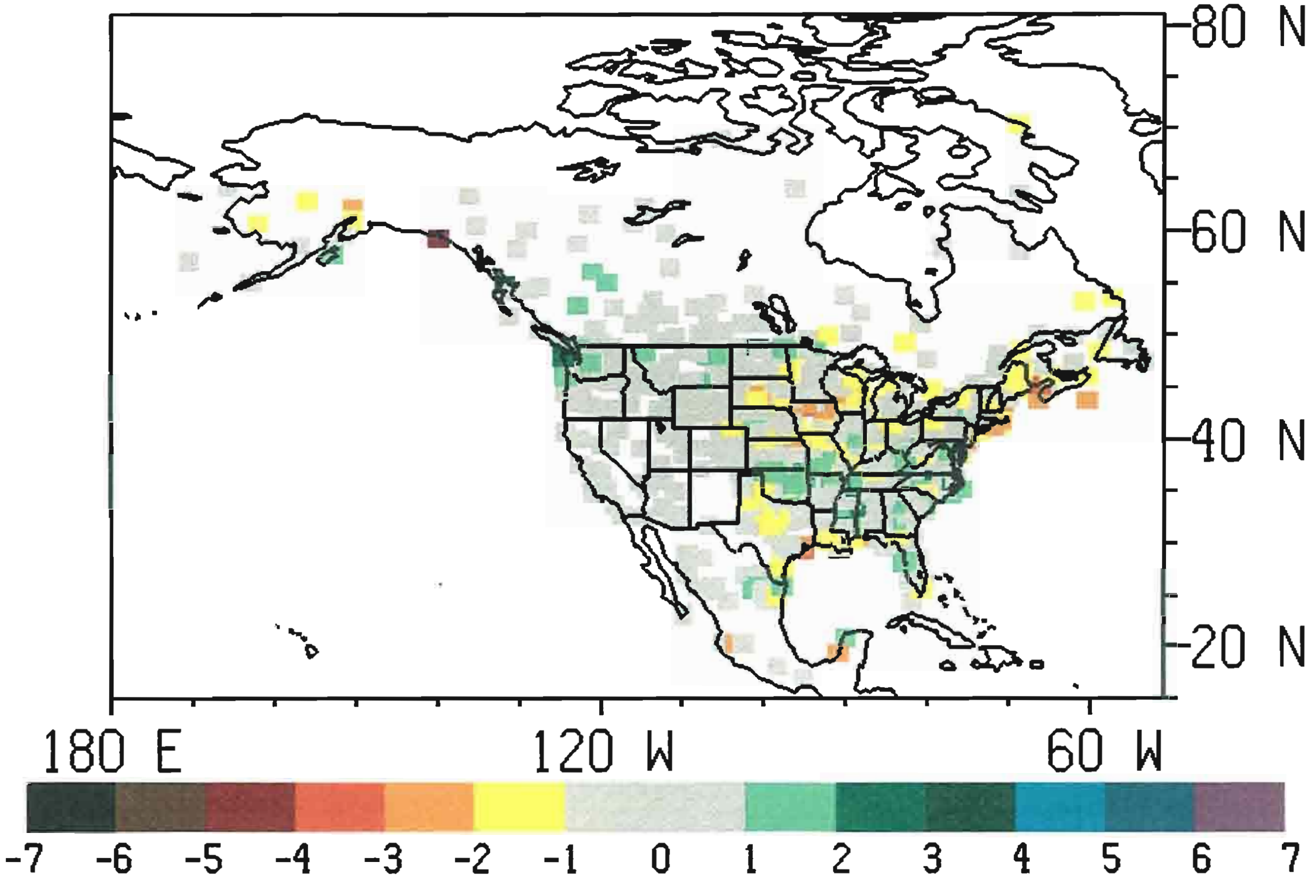


FIGURE 18D

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

WARM EVENT MINUS NEUTRAL EVENT

TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH OND

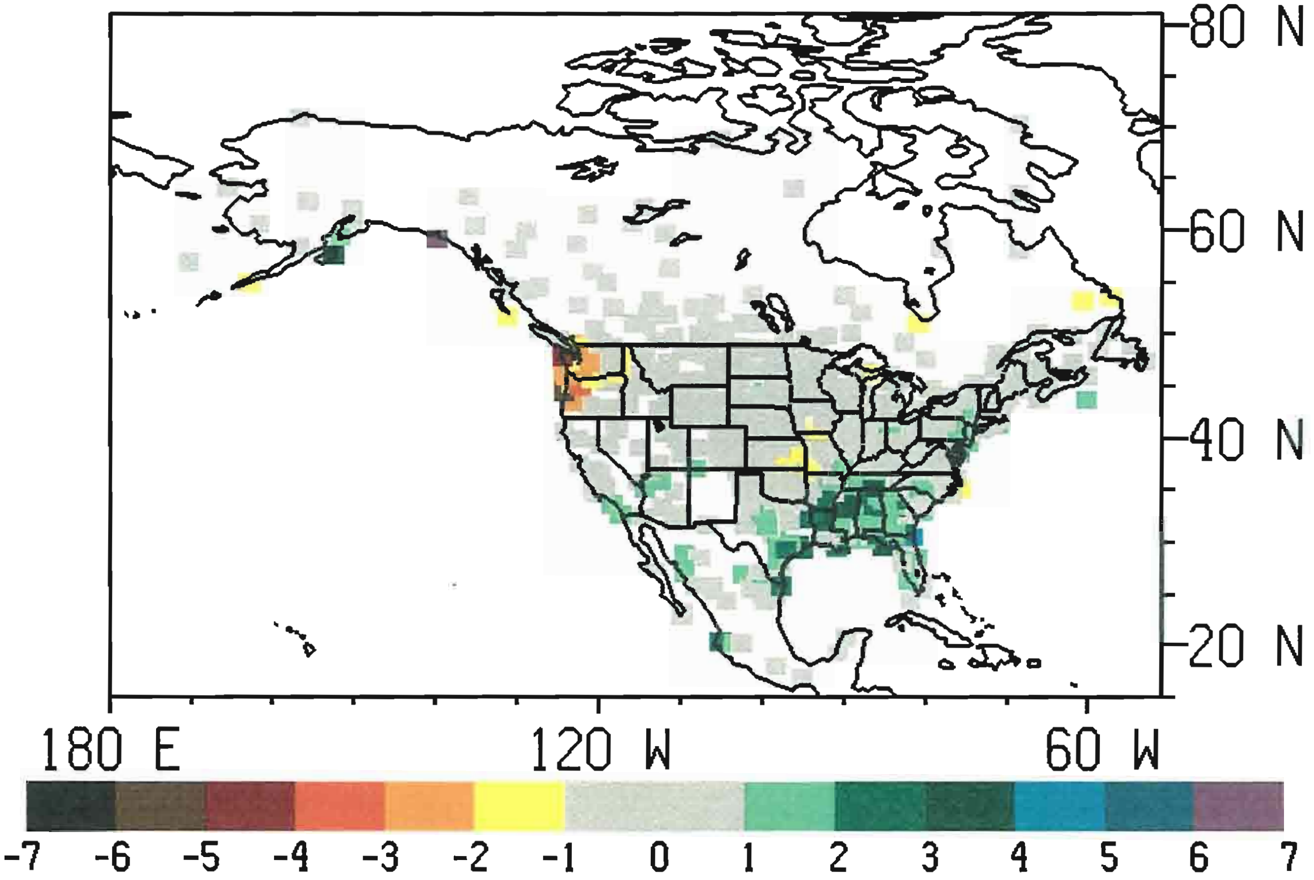


FIGURE 19A

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

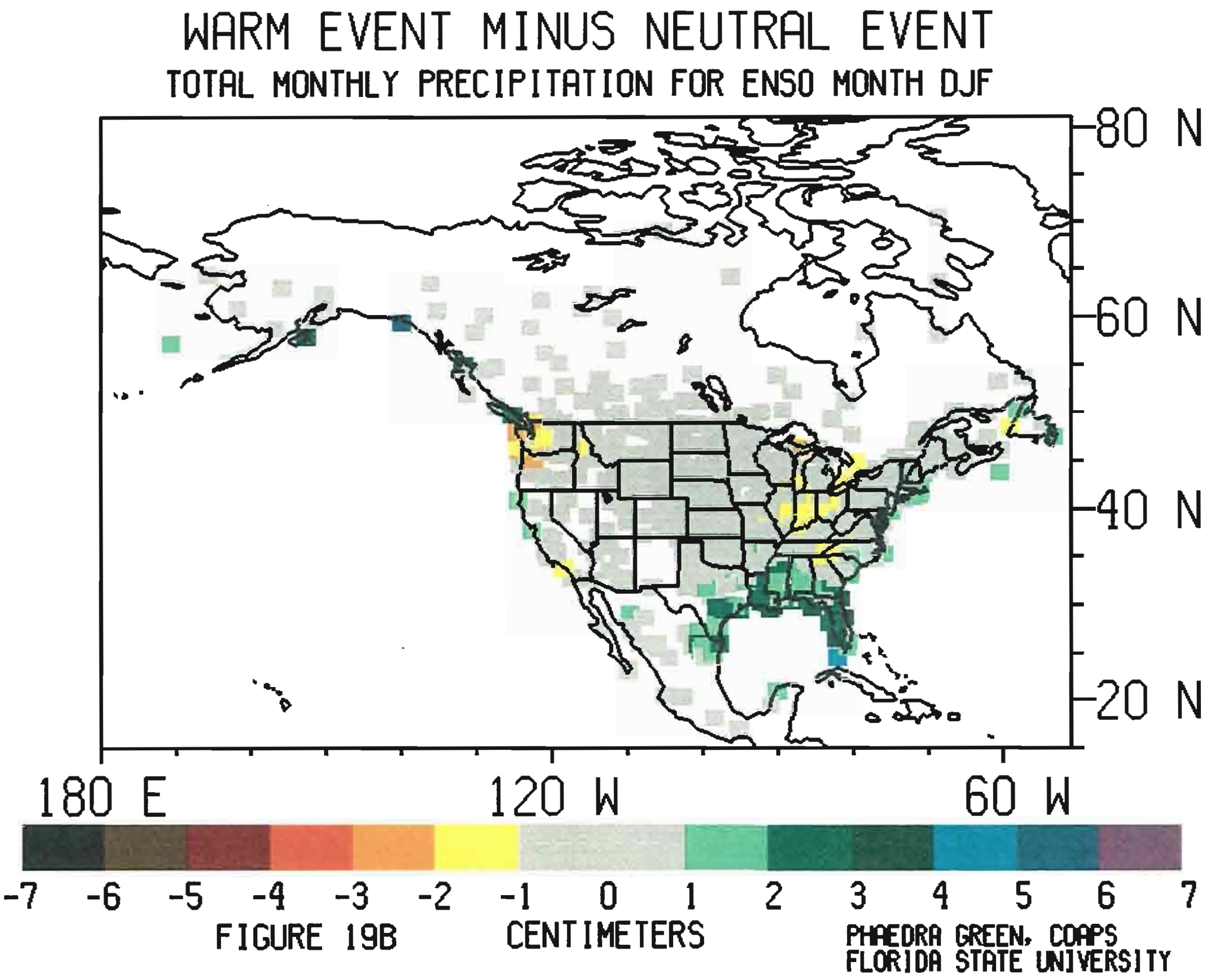

WARM EVENT MINUS NEUTRAL EVENT
TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH DJF
80 N
60 N
40 N
20 N
180 E
120 W
60 W
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
CENTIMETERS
PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

FIGURE 19B

WARM EVENT MINUS NEUTRAL EVENT

TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH MAM

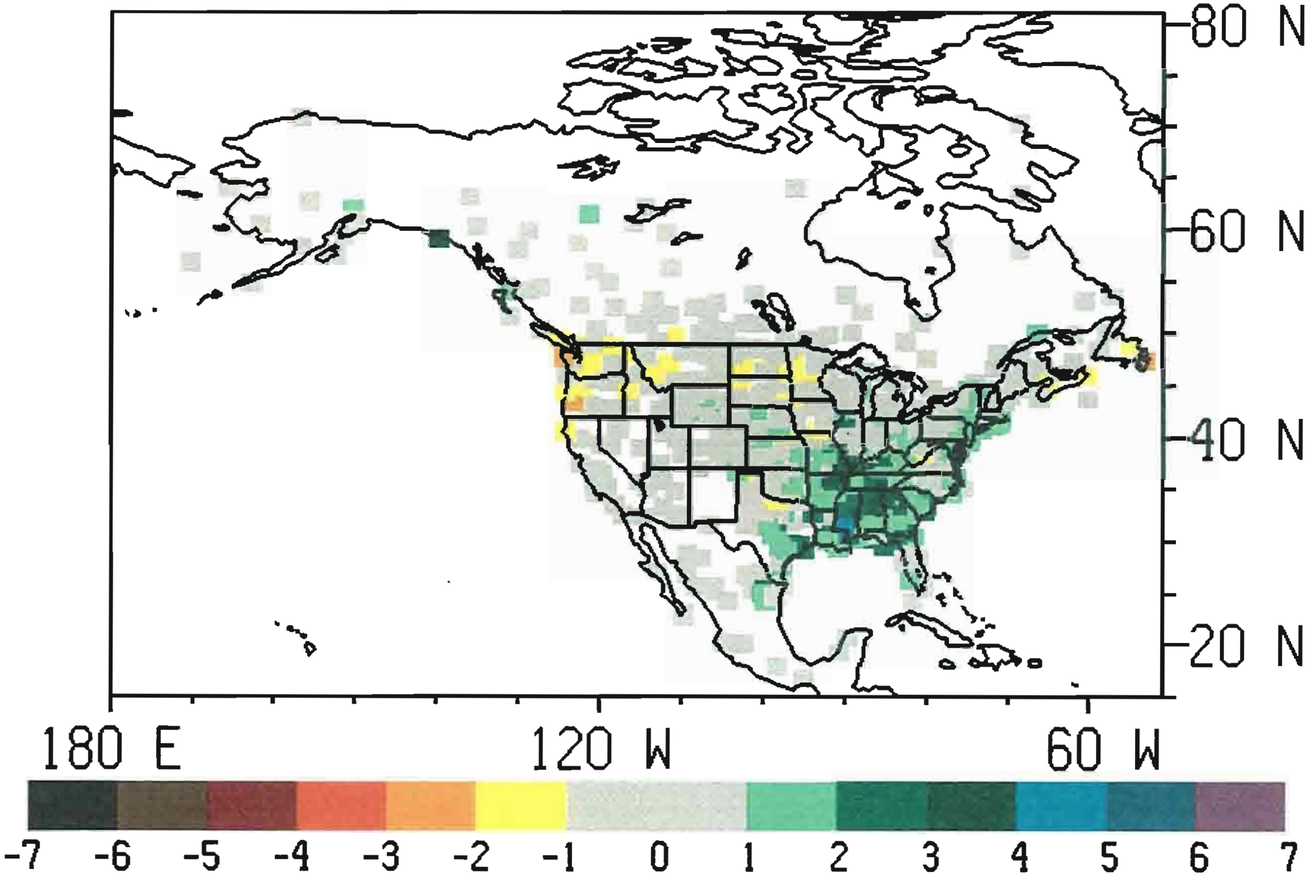
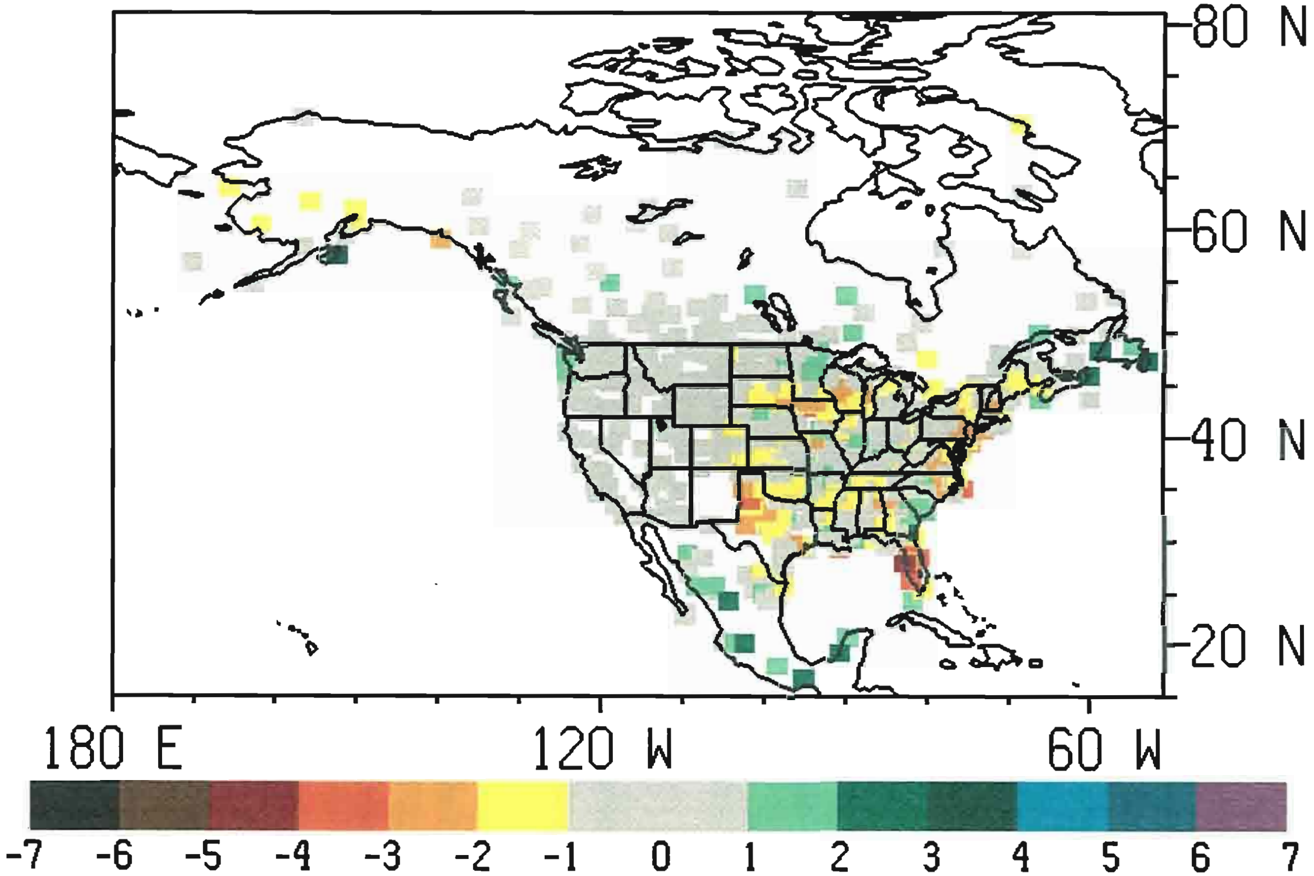


FIGURE 19C

CENTIMETERS

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY



WARM EVENT MINUS NEUTRAL EVENT

TOTAL MONTHLY PRECIPITATION FOR ENSO MONTH JJA

FIGURE 19D

CENTIMETERS

PHAEDRA GREEN, COAPS
FLORIDA STATE UNIVERSITY

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Biographical Sketch

Phaedra Green was born in Rahway, NJ on May 5, 1970. She graduated from John F. Kennedy High School, Iselin NJ in June 1988. During undergraduate studies she participated in summer internships at RSMAS, University of Miami, Miami FL and the Geophysical Institute, University of Alaska Fairbanks, Fairbanks AK, and held part time jobs such as tutoring at the Learning Assistance center at Kean College of NJ. She graduated from Kean College of NJ with a Bachelor of the Arts degree in Meteorology and a minor in Mathematics in May 1994. She started graduate work in the Center for Ocean and Atmospheric Prediction Studies in May 1994. She will complete her Masters of Science degree in Fall 1996.