The Influence of Teleconnections on Eastern Montana Temperature during El Niño and La Niña Events

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1. Introduction

Customers call our office each season wanting to know how the Climate Prediction Center's temperature and precipitation outlooks will affect their operations locally. Farming and ranching, which are two of the main livelihoods across eastern Montana, are directly affected by changes in the weather. Generally, these customers want to have an idea of when to expect significant changes in the weather so they can plan accordingly.

A local study focusing on what triggers significant deviations from normal temperature across eastern Montana would be needed to answer the customers' questions. The best place to start with a study of this nature is to look at mechanisms that can influence the strength and/or track of weather patterns. Fluctuations in sea surface temperatures (SST) and atmospheric pressure at sea level for a few of the known oscillations were compared to the observed temperature at two selected locations to determine the strength of influence.

2. Data and Methodology

a. Weather data

Two stations located in eastern Montana with long historical records and with minimal influence from higher terrain were chosen. The data used for this study was the homogenized data set that was developed by the NOAA National Climatic Data Center (NCDC); which is described by Menne and Williams 2005 as:

To develop this dataset, NCDC used a homogenization procedure that included a monthly/daily value internal consistency check, a data bias adjustment to a midnight-to-midnight observation schedule, spatial quality control, and the detection and adjustment to artificial change points.

These records date back to 1925 for both Glasgow (Glasgow International Airport/National Weather Service Forecast Office) and Miles City (Frank Wiley Field Airport). Of note, the Automated Surface Observing System (ASOS) equipment was implemented in the 1990's and correction augmentations to ASOS data ceased by October 2002 for Glasgow and by April 2001 for Miles City.

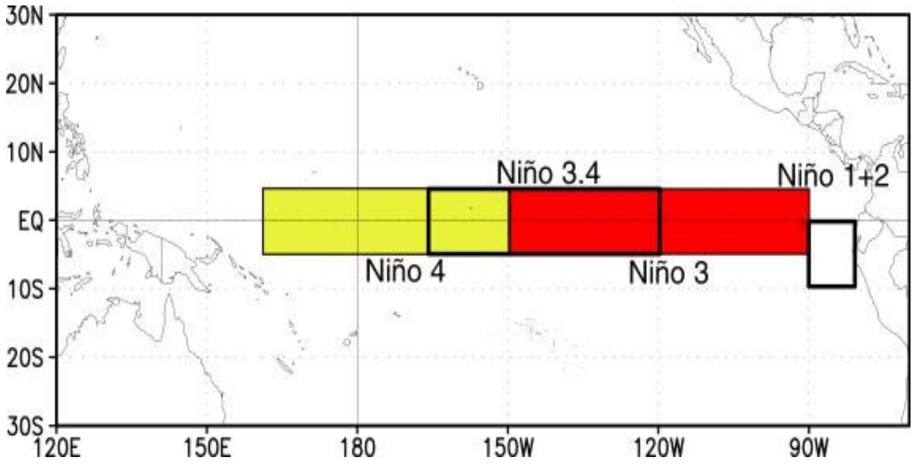
For the purpose of this study maximum temperature and minimum temperature data were used from December 1, 1949 to April 30th, 2011. All seasons consist of three months. The winter season is comprised of December, January and February. Spring consists of March, April and May. Even though the temperature data stopped with April 2011, the spring season of 2011 includes May 2011 for continuity. June, July and August make up the summer season. And lastly, the fall season contains data from September, October and November.

b. *Oscillations and Teleconnections*

The El Niño Southern Oscillation (ENSO) can be described as variations in the sea surface temperature (SST) across the eastern portion of the tropical Pacific Ocean and surface pressure across western portions of the Pacific Ocean. ENSO events occur on irregular intervals with each event typically lasting 9 months to 2 years. There are two phases of ENSO; El Niño and La Niña. According to the Climate Prediction Center (CPC) an El Niño event must have five consecutive 3-month periods with SSTs equal to or greater than 0.5 degrees C. El Niño events typically accompany high surface pressure in the western Pacific. A La Niña event will have SSTs equal to or less than -0.5 degrees C for at least 5 consecutive 3- month periods and will typically accompany low surface pressure in the western Pacific.

The four regions monitored by the Climate Prediction Center are shown below in Figure 1. Niño 3.4 is the most commonly used and recognized of the four regions. The northwest region of the United States experiences reduced snowfall during an El Niño winter, is wetter than average during an El Niño summer, and typically has above-average precipitation during La Niña events.

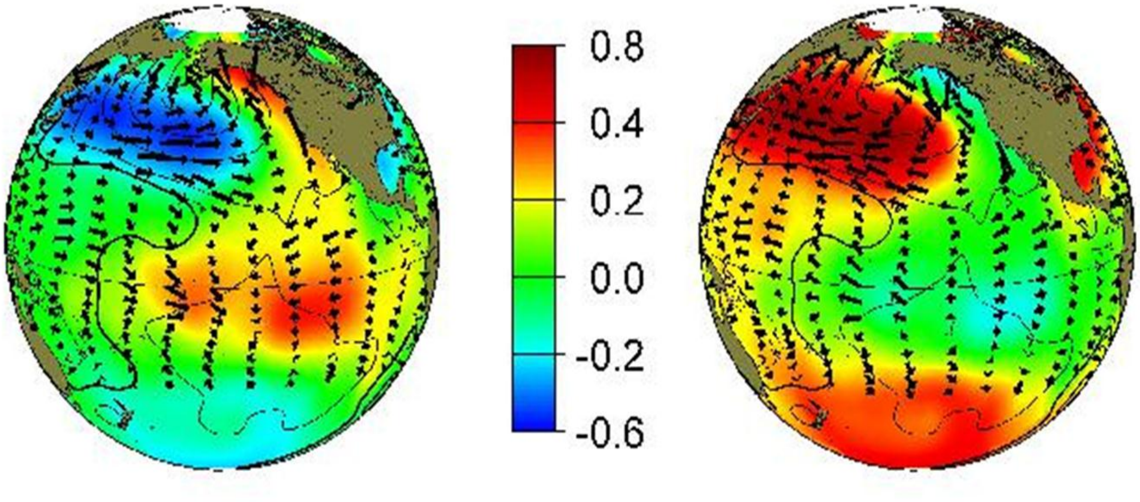
Figure 1. Graphical depiction of the four Niño regions (taken from Climate Prediction Center).



What follows is the definition and description of the Pacific Decadal Oscillation from the Joint Institute for the Study of the Atmosphere and Ocean (JISAO):

The Pacific Decadal Oscillation (PDO) can be defined as the variability in the ocean's surface temperature north of 20°N. There are two phases of the PDO: warm (positive SST values) and cold (negative SST values) with each phase typically lasting 20 to 30 years. During a warm phase, western portions of the Pacific Ocean will cool while areas in the east will warm. The opposite will occur during a cold phase as shown in Figure 2. This phenomenon correlates to relatively wetter or drier periods across western portions of the North American continent. The PDO closely mimics deviations in the SSTs and influences on precipitation to those of ENSO; however, the time scale is much longer.

Figure 2. Typical wintertime Sea Surface Temperature (colors, °C), Sea Level Pressure (contours), and surface wind stress (arrows) anomaly patterns during warm and cool phases of the PDO (taken from JISAO). The left image is representative of the warm phase and the cold phase is on the right.



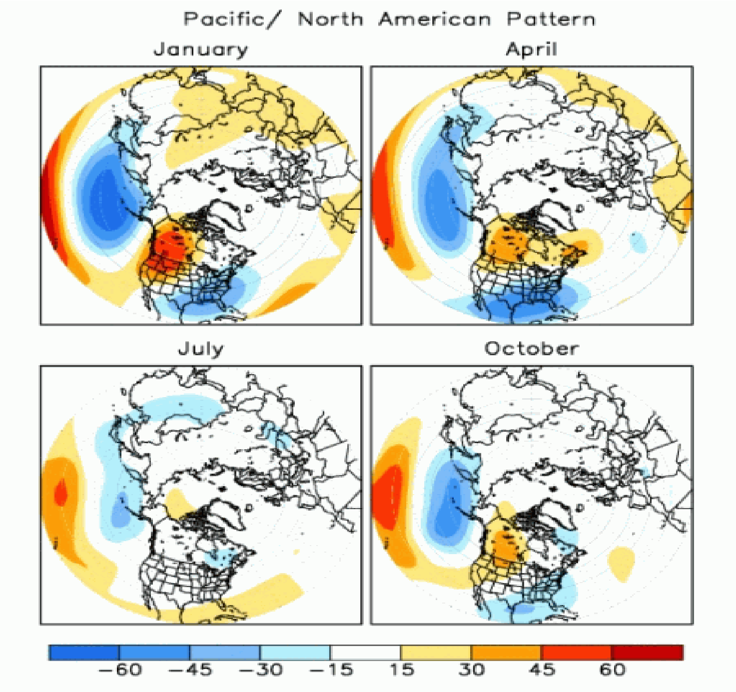
What follows is the definition and description of the Pacific-North American teleconnection pattern from the CPC:

The Pacific-North American teleconnection pattern (PNA) refers to the relationship of the atmospheric circulation pattern over northern portions of the Pacific Ocean to the pattern occurring over the North American continent. The PNA affects the track and strength of the East Asian Jetstream; which ultimately influences regional weather in North America. The PNA loading pattern is defined as the second leading mode of the Rotational Empirical Orthogonal Function analysis of monthly mean 500 hPa height from 1950-2000.

Refer to Figure 3 for an illustration of this relationship. It is considered a large-scale pattern with two distinct modes, positive and negative. During a positive phase of the PNA, above-average barometric pressure heights are observed near Hawaii and the intermountain region of North America; while below-average heights occur in areas south of the Aleutian Islands of Alaska and over southeastern portions of the United States. This in turn enhances the strength of the mid-latitude jet as it tracks from eastern Asia across the Pacific Ocean; resulting in increased prospects of above-average temperatures for western Canada and western-most portions of the United States, while temperatures in the south-central and southeastern states are below-average. A positive PNA phase is also associated with a reduction in wintertime precipitation across the Pacific Northwest and the eastern half of the United States.

The negative phase of the PNA typically is associated with: a weaker jet stream, high-pressure "blocking" of the atmospheric flow along the higher latitudes of the Pacific Ocean, and a split-flow pattern that occurs over north-central portions of the Pacific Ocean. The temperature and precipitation departures are opposite of those that occur during a positive phase. Although the PNA is independent of any other mode of climate variability, the positive phase has a tendency to mirror El Niño conditions while the negative phase copies La Niña conditions.

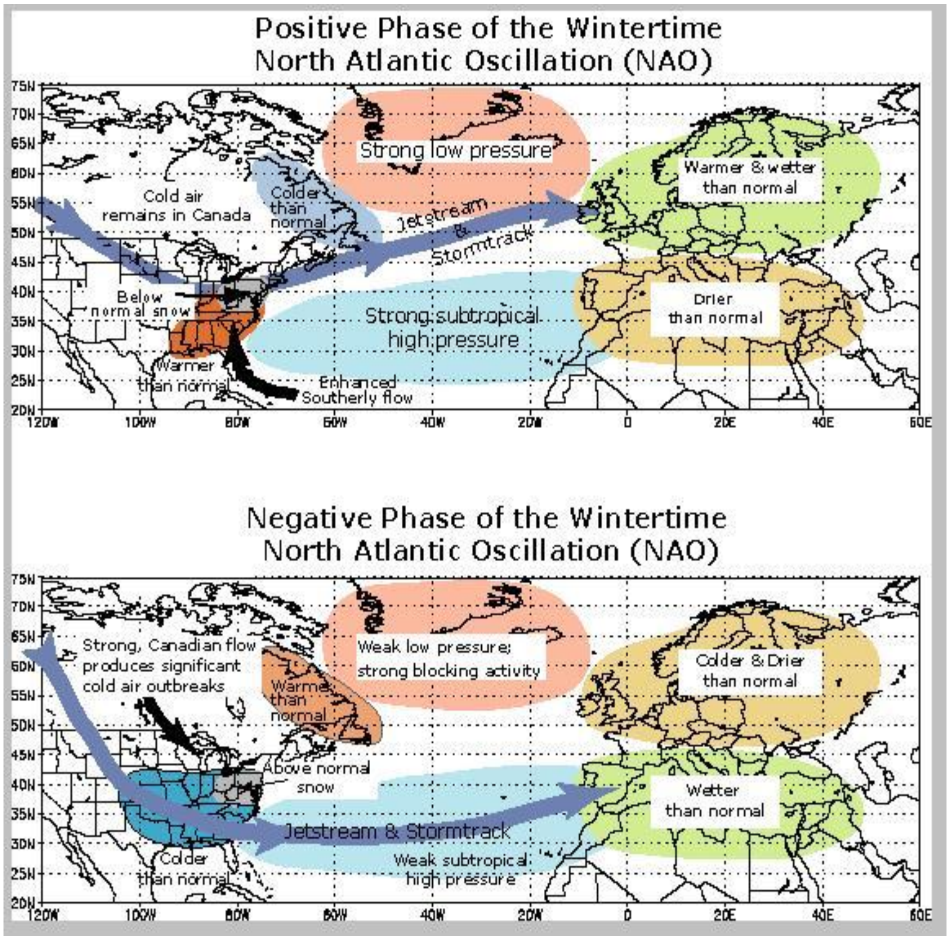
Figure 3. The PNA loading patterns for January, April, July, and October, are displayed so that the plotted value at each grid point represents the temporal correlation between the monthly standardized height anomalies at that point and the teleconnection pattern time series valid for the specified month (taken directly from CPC, units on scale are hPa).



Finally, the explanation of the North Atlantic Oscillation according to the CPC is:

The North Atlantic Oscillation (NAO) refers to fluctuations in pressure differences between the Icelandic low and the Azores high located in the North Atlantic Ocean. This in turn affects the strength and direction of the westerly winds and the general track of storms moving across northern portions of the Atlantic Ocean. Although the majority of impacts of the NAO affect Europe, weather over eastern North America can be affected (Figure 4). When the NAO phase is high (positive) during the winter months, the Icelandic low pulls a stronger, south-westerly circulation over the eastern half of the North American continent. This limits, or prevents, the southward plunge of Arctic air; and when combined with El Niño, temperatures will be significantly warmer for southeast Canada and northeast United States. A low NAO phase (negative) naturally would allow a more pronounced Arctic plunge into the previously mentioned region. The fluctuations in the NAO phase can influence the overall large-scale pattern in the upstream flow over the western half of the continent.

Figure 4. Depiction of the phases of the NAO (taken directly from National Climatic Data Center)



The period of record varies among the oscillations; so for the purpose of this study, I chose to use the data period from January 1950 to August 2011. This aligns quite nicely with the homogenized temperature dataset.

c. Departures from normal

Several calculations were made to determine what was considered normal, or average, for the chosen years. Temperatures were clustered by each month to find the monthly average for the years 1950-2011 and then the seasonal average was determined by taking the sum of the temperatures for each month of the previously specified months. First and second standard deviations were calculated to determine periods that experience well-above or well-below normal temperatures.

The actual degree of departure for temperatures was found by taking the difference of the observed from the newly determined average. These anomalies were then compared to the anomaly values for each of the oscillations/teleconnections in order to determine the degree of correlation. From the initial comparison, the data was filtered to examine only anomalies occurring during La Niña and El Niño episodes. Finally, a second subset was taken to separate the events by the warm and cold phases of the PDO; which were from the years 1977 to 1997 for the warm phase and from the years 1950 to 1976 and from 1998 to present (or August 2011) for the cold phase.

d. 500 hPa Height Reanalysis

Seasonal composites were generated using NCEP reanalysis data for each season from December 1949 to May 2011. These images were used to discover if similar upper-level flow regimes occurred during La Niña and El Niño episodes.

3. Results

a. Correlations

Correlation coefficient values range from -1 to 1. The closer the number is to either -1 or 1 the stronger the relationship between the two parameters. Positive values indicate that the relationship is direct; meaning when one parameter increases the other one will do so as well. The same concept applies when a decrease occurs. Negative values represent an inverse relationship; as one parameter increases, the other decreases. When a value is near 0, then one parameter virtually has little-to-no influence over the other parameter.

A large correlations coefficient value does not necessarily equate to being statistically significant. The resultant value obtained is based on the two parameters and the number of total data pairs. Thresholds for statistical significance of correlation coefficients at 95% confidence (p value = 0.05) were calculated. However, the 95% confidence level varied for each subset of data due to different sample sizes. The values that met, or exceeded, the 95% confidence level in the tables below are in bold.

Temperature values used in the comparison were the departure from normal, or anomaly, for each given month. These values were calculated by subtracting the actual recorded average for a particular month from the determined average (i.e. monthly average for December 1986 deducted from the average of all Decembers). The monthly temperature anomalies were compared to the corresponding monthly SST anomalies of ENSO and PDO and the monthly atmospheric pressure anomalies of the PNA and NAO. There were 735 total data pairs used for Table 1 encompassing the entire dataset (includes ENSO and Non-ENSO months).

Table 1. Correlation coefficients between the oscillations/teleconnections and weather from January 1950 to April 2011. Bold values = or > +/- 0.07 are statistically significant at a 95% confidence level.

	Glasgow		**Miles City**	
	Tmax	Tmin	Tmax	Tmin
El Niño Region 1+2	**0.08**	**0.08**	0.04	**0.08**
El Niño Region 3	**0.10**	**0.11**	**0.07**	**0.09**
El Niño Region 3.4	**0.10**	**0.08**	**0.08**	**0.08**
El Niño Region 4	**0.11**	**0.12**	**0.08**	**0.09**
PDO	**0.15**	**0.18**	**0.11**	**0.14**
PNA	**0.32**	**0.36**	**0.30**	**0.33**
NAO	**0.23**	**0.21**	**0.24**	**0.23**

In Table 1 the relationships were all direct and the data is representative of the entire dataset from 1950 to 2011. All four Niño regions of ENSO, for both Glasgow and Miles City, had a comparatively weak relationship. In general, it appears that the minimum temperatures had a slight influence from all four Niño regions. The connections between PNA and NAO to the maximum and minimum temperatures at both locations were stronger.

The first subsets of data are shown in Table 2 and Table 3. The relationship values for only the La Niña events from 1950 to 2011 are displayed in Table 2 (208 pairs of data) and only the El Niño events from 1950 to 2011 are shown in Table 3 (182 pairs of data). The amounts barely increased in all four of the Nino regions (Table 2). The connections remained fairly weak for both Glasgow and Miles City. A majority of the values for PDO, PNA, and NAO increased after filtering out the non-ENSO months for both locations. Minimum temperatures in conjunction

Table 2. Correlation coefficients between the oscillations/teleconnections and weather using only La Niña events from January 1950 to April 2011. Bold values = or > +/- 0.14 are statistically significant at a 95% confidence level.

	Glasgow		Miles City	
	Tmax	Tmin	Tmax	Tmin
El Niño Region 1+2	0.06	0.00	0.00	0.05
El Niño Region 3	-0.03	-0.06	-0.04	-0.04
El Niño Region 3.4	0.01	0.00	0.00	-0.05
El Niño Region 4	-0.01	-0.02	-0.03	-0.06
PDO	**0.17**	**0.18**	0.11	0.11
PNA	**0.36**	**0.37**	**0.33**	**0.35**
NAO	**0.23**	**0.21**	**0.21**	**0.19**

with the PNA for both Glasgow and Miles City had moderate correlation coefficients and were deemed statistically significant. The relationship between minimum temperatures at Glasgow and the NAO were relatively weak but considered significant.

Most of the values had a noticeable increase in the four Niño regions when comparing Table 3 to Table 1. The highest values were in regions 3 and 4. These two regions had a stronger connection for minimum temperatures for both locations.

Table 3. Correlation coefficients between the oscillations/teleconnections and weather using only El Niño events from January 1950 to April 2011. Bold values = or > +/- 0.15 are statistically significant at a 95% confidence level.

	Glasgow		Miles City	
	Tmax	Tmin	Tmax	Tmin
El Niño Region 1+2	0.13	0.14	0.11	0.14
El Niño Region 3	**0.16**	**0.20**	**0.15**	**0.20**
El Niño Region 3.4	0.11	0.03	0.14	0.08
El Niño Region 4	**0.19**	**0.23**	**0.18**	**0.23**
PDO	**0.18**	**0.16**	0.13	0.14
PNA	**0.26**	**0.30**	**0.27**	**0.29**
NAO	**0.22**	**0.22**	**0.21**	**0.22**

The values for PDO overall increased or stayed nearly the same. The relationship slightly weakened for PNA, although it still influenced temperatures directly. The relationship with both locations' temperatures and PNA, and Glasgow's temperatures with PDO, were statistically significant. NAO virtually remained unchanged from the original dataset and was significant for both maximum and minimum for Glasgow and Miles City.

The next two datasets, shown in Table 4 and Table 5, examine only the La Niña events that were separated by the phases of the PDO. Table 4 (170 data pairs) shows the events that occurred during the cold phase which was the years of 1950 through 1976 and 1999 through April of 2011. Table 5 (103 data pairs) shows the events that occurred during the warm phase; 1977 through 1998.

The correlations for the El Niño regions stayed nearly the same or increased when comparing the data in Table 4 to all La Niña events in Table 2. Miles City's temperatures and Glasgow's maximum temperature depict a direct relationship after the separation. Also, Glasgow's minimum temperature relationship with region 1+2 changed to indirect and both maximum and minimum temperatures for Glasgow switched to direct. Largely, the connections with PDO, PNA and NAO increased for both locations with all being statistically significant. The PNA and NAO had a more pronounced relationship to temperatures than the PDO.

The El Niño regions in Table 5 were nearly the same as the values for the cold years shown in Table 4, although the sign of the relationship fluctuated a bit. PNA again had a strong connection with temperatures. All of the correlation values for PNA and NAO were statistically significant.

Table 4. Correlation coefficients between the oscillations/teleconnections and weather using only La Niña events during the cold phase of the PDO (1950-1976 and 1999-2011). Bold values = or > +/- 0.15 are statistically significant at a 95% confidence level.

	Glasgow		**Miles City**	
	Tmax	Tmin	Tmax	Tmin
El Niño Region 1+2	0.08	-0.01	0.04	0.06
El Niño Region 3	0.02	-0.03	0.01	0.01
El Niño Region 3.4	0.04	0.03	0.01	-0.02
El Niño Region 4	0.02	0.00	-0.02	-0.03
PDO	**0.21**	**0.25**	**0.17**	**0.19**
PNA	**0.36**	**0.38**	**0.31**	**0.33**
NAO	**0.30**	**0.26**	**0.31**	**0.27**

Table 5. Correlation coefficients between the oscillations/teleconnections and weather using only La Niña events during the warm phase of the PDO (1977-1998). Bold values = or > +/- 0.33 are statistically significant at a 95% confidence level.

	Glasgow		Miles City	
	Tmax	Tmin	Tmax	Tmin
El Niño Region 1+2	-0.05	0.01	-0.07	-0.02
El Niño Region 3	-0.02	0.05	-0.01	0.00
El Niño Region 3.4	0.05	-0.04	0.09	0.04
El Niño Region 4	-0.02	0.04	-0.03	0.00
PDO	0.12	0.10	0.10	0.14
PNA	**0.33**	**0.33**	**0.34**	**0.35**
NAO	**0.28**	**0.31**	**0.27**	**0.31**

Table 6 and Table 7 display only the El Niño events that were separated by the phases of the PDO; cold and warm, respectively. Overall, the values for all Niño regions ranged from little-to-no influence up to a slight influence on temperatures in Table 6 (38 data pairs). The correlation values for temperature and region 3 were statistically significant; in addition, the relationship between Miles City's minimum temperature and region 4 was statistically significant. Values for the PDO were lower when compared to all El Niño events in Table 3. Temperatures at both locations saw an increase in influence by the PNA and a decrease by the NAO during the cold phase. Only the PNA, and the relationship between PDO and Miles City's minimum temperature, had statistically significant values.

Table 6. Correlation coefficients between the oscillations/teleconnections and weather using only El Niño events during the cold phase of the PDO (1950-1976 and 1999-2011). Bold Values = or > +/- 0.19 are statistically significant at a 95% confidence level.

	Glasgow		Miles City	
	Tmax	Tmin	Tmax	Tmin
El Niño Region 1+2	-0.04	0.00	-0.10	0.00
El Niño Region 3	**-0.27**	**-0.19**	**-0.25**	**-0.26**
El Niño Region 3.4	-0.13	-0.14	-0.04	-0.16
El Niño Region 4	-0.15	-0.12	-0.08	**-0.19**
PDO	-0.06	-0.14	-0.06	**-0.23**
PNA	**0.36**	**0.31**	**0.41**	**0.40**
NAO	-0.04	-0.03	-0.17	-0.11

Like the La Niña events during the warm phase of the PDO, the El Niño events that occurred in the warm phase had noticeably higher temperature influences by all the Niño regions, which are shown in Table 7 (79 data pairs). Niño regions 3 and 4 had the best relationships of the four regions and were statistically significant. Glasgow's and Miles City's maximum temperatures had a moderate correlation with the Niño 3.4 region; the value was considered significant. A majority of the PDO, PNA and NAO values saw a reduction when compared to those in Table 3. Only the relationship with the minimum temperatures at both locations and the PNA was considered statistically significant.

Table 7. Correlation coefficients between the oscillations/teleconnections and weather using only El Niño events during the warm phase of the PDO (1977-1998). Bold values = or > +/- 0.22 are statistically significant at a 95% confidence level.

	Glasgow		**Miles City**	
	Tmax	Tmin	Tmax	Tmin
El Niño Region 1+2	0.19	0.15	0.18	0.19
El Niño Region 3	**0.23**	**0.24**	**0.22**	**0.29**
El Niño Region 3.4	**0.22**	0.14	**0.23**	0.14
El Niño Region 4	**0.32**	**0.33**	**0.32**	**0.36**
PDO	0.13	0.09	0.09	0.03
PNA	0.19	**0.27**	0.20	**0.22**
NAO	0.06	0.01	0.07	0.03

b. Temperature Departures

Given that the number of days per month is variable, the collective number of days for each month for this study differed. The months of December, January, March, May, July, and August all had 1922 days. February, the shortest month, had 1751 total days. Both April and June had 1860 days. There were 1981 days for the month of October. Finally, both September and November had 1830 days. The temperature breakdown for each threshold is shown in Table 8 for Glasgow and Table 9 for Miles City. The average temperatures are listed below the μ in each table and the standard deviations are listed below the σ. The values listed to the left of the average temperature are the first- and second- standard deviations below average; the values to the right are above average.

The actual range of 'normal' temperature values, those that fall within 1 standard deviation (σ) of the average, is larger November through March. This should not come as a surprise given that these are the months that can have strong cold fronts. April through October has a smaller range, although strong departures can occur during these months as well.

Table 8. Average temperature and associated sigma ranges for Glasgow in °F (left-maximum temperature, right-minimum temperature).

	σ	-2σ	-1σ	μ	+1σ	+2σ
Dec	7.9	9.7	17.6	25.5	33.4	41.3
Jan	9.1	1.2	10.3	19.4	28.5	37.6
Feb	8.5	9.4	17.9	26.4	34.9	43.4
Mar	8.2	22.1	30.3	38.5	46.7	54.9
Apr	5.4	44.2	49.6	55.0	60.4	65.8
May	4.1	58.4	62.5	66.6	70.7	74.8
Jun	3.8	67.9	71.7	75.5	79.3	83.1
Jul	3.9	76.1	80.0	83.9	87.8	91.7
Aug	4.5	73.8	78.3	82.8	87.3	91.8
Sep	5.0	60.4	65.4	70.4	75.4	80.4
Oct	4.3	48.6	52.9	57.2	61.5	65.8
Nov	6.7	25.4	32.1	38.8	45.5	52.2

	σ	-2σ	-1σ	μ	+1σ	+2σ
Dec	7.1	-7.2	-0.1	7.0	14.1	21.2
Jan	8.8	-16.5	-7.7	1.1	9.9	18.7
Feb	8.3	-9.0	-0.7	7.6	15.9	24.2
Mar	6.7	4.8	11.5	18.2	24.9	31.6
Apr	3.1	25.2	28.3	31.4	34.5	37.6
May	2.4	37.4	39.8	42.2	44.6	47.0
Jun	2.8	45.6	48.4	51.2	54.0	56.8
Jul	2.5	51.9	54.4	56.9	59.4	61.9
Aug	2.9	49.7	52.6	55.5	58.4	61.3
Sep	2.7	39.1	41.8	44.5	47.2	49.9
Oct	2.7	27.8	30.5	33.2	35.9	38.6
Nov	5.8	7.3	13.1	18.9	24.7	30.5

Table 9. Average temperature and associated sigma ranges for Miles City in °F (left-maximum temperature, right-minimum temperature).

	σ	-2σ	-1σ	μ	+1σ	+2σ
Dec	7.8	14.7	22.5	30.3	38.1	45.9
Jan	9.1	7.7	16.8	25.9	35.0	44.1
Feb	8.1	17.0	25.1	33.2	41.3	49.4
Mar	7.0	29.6	36.6	43.6	50.6	57.6
Apr	4.7	47.7	52.4	57.1	61.8	66.5
May	4.1	60.0	64.1	68.2	72.3	76.4
Jun	4.2	69.9	74.1	78.3	82.5	86.7
Jul	4.2	79.6	83.8	88.0	92.2	96.4
Aug	4.2	77.8	82.0	86.2	90.4	94.6
Sep	5.0	63.3	68.3	73.3	78.3	83.3
Oct	4.3	51.0	55.3	59.6	63.9	68.2
Nov	6.5	22.6	29.1	42.1	48.6	55.1

	σ	-2σ	-1σ	μ	+1σ	+2σ
Dec	6.6	-2.4	4.2	10.8	17.4	24.0
Jan	8.8	-11.3	-2.5	6.3	15.1	23.9
Feb	7.5	-2.5	5.0	12.5	20.0	27.5
Mar	5.5	10.5	16.0	21.5	27.0	32.5
Apr	3.0	27.2	30.2	33.2	36.2	39.2
May	2.3	39.4	41.7	44.0	46.3	48.6
Jun	2.7	47.9	50.6	53.3	56.0	58.7
Jul	2.8	54.6	57.4	60.2	63.0	65.8
Aug	3.0	52.1	55.1	58.1	61.1	64.1
Sep	3.3	39.9	43.2	46.5	49.8	53.1
Oct	2.6	32.4	35.0	35.0	37.6	40.2
Nov	5.2	10.8	16.0	21.2	26.4	31.6

A second method was used to observe temperature departures for this study. This approach only used La Niña and El Niño events. It involved plotting the monthly average maximum and minimum temperatures for the length of each specific event, with shading between the two in order to show the ‘normal range’. Also, the monthly maximum and minimum temperature for that particular event were overlaid to show the temperature departures. If the actual temperature (both maximum and minimum) rose above the average temperature, then that portion of the event experienced warmer-than-normal temperatures. If it fell below average, then that portion of the event experienced colder-than-normal temperatures. A temperature departure graph was constructed for both Miles City and Glasgow for all ENSO events, however only the most representative events are included here.

Refer to Figures 5 through 10 for ENSO events' temperature departure graphs, which can be found in the Appendix. Each individual figure will have an 'a' and a 'b' section; Glasgow and Miles City, respectively, for each event.

Upon examining the La Niña events during the cold phase of the PDO (Figure 5 is most representative), it was discovered that a majority of the springs and the early portions of summers had highly variable temperatures. By the end of the summer and into the fall season, these temperatures generally climbed well-above normal. Temperatures took a noticeable plunge by early-December and stayed well-below normal for prolonged periods.

Figure 6 was the most representative of the El Niño events that occurred during the cold phase of the PDO. Overall these events had cooler temperatures late in the summer that transitioned to above-normal temperatures for the fall and the first half of winter. The periods of prolonged, well-below normal temperatures occurred later in the winter season.

Figure 7 was also a unique case where an on-going La Niña event transitioned from the cold phase of the PDO to the warm phase. Below-normal temperatures were observed late in the season and the length of this colder period was not very long.

Although there were fewer La Niña events during the warm phase of the PDO, a general trend was found (Figure 8 is most representative). Temperatures typically were well-above normal during the summer before transitioning to a cooler fall. Temperatures dropped well-below normal by early December, although prolonged cold periods occurred late in the winter season. By spring, temperatures rose above-normal.

Figure 9 was the most representative of El Nino events during the warm phase of the PDO. Winters during the warm phase were generally well-above normal, although a short burst of well-below normal temperatures did occur. Temperatures in the spring and fall were above normal. The summer months were cooler than average.

Figure 10 was a unique case given that the PDO switched from the warm to the cold phase while the event occurred. For this event specifically: the drastic drop in temperatures occurred later than usual during the winter season, the maximum temperatures were highly variable during the spring and summer months, the minimum temperatures were cooler than normal during the spring and summer months, and temperatures remained well-above normal from fall through late spring of 2000.

c. Upper-level flow regimes

Seasonal composites of the upper-level flow for each ENSO event were made to determine if a common flow regime were present during similar events (overall trends are described below). However, only the composites that match the selected events from the previous section were included (Figures 11-16 in the Appendix). Each 3-month season that occurred during an event was represented in that particular figure.

Generally, upper-level flow regimes over eastern Montana tend to be oriented from the northwest. This occurs when the area lies east of the ridge axis or when the area is located on the backside of a trough. Systems that originate over the west coast draw moisture from the Pacific Ocean; which generally result in higher precipitation events for eastern Montana. An airmass that travels over the northwestern states, or sweeps through Canada before reaching eastern Montana, typically is continental and drier. Systems in zonal flow tend to bring an increase in high clouds, but have lower precipitation values due to the number of mountain ranges they cross before reaching eastern Montana.

Upon examination, a majority of winters during both the warm and cold phases of the PDO had a well-defined trough centered near the Hudson Bay area that extended south of the Great Lakes region. Given that this placement is the average over the course of three months, it is fair to conclude that the mean trough retrogrades toward central Canada or shifts toward the northeastern United States. When the mean trough retrogrades far enough west or southwest, the pattern corresponds with Arctic air in eastern Montana yielding well-below normal temperatures.

Summers during the cold phase of the PDO often had a trough present over the western states that dug into the desert southwest, or had the trough axis in-line with the west coast. With varying strengths of ridging over the southern and central plains, the Pacific Northwest and inter-mountain west had southwest flow aloft. During the warm phase of the PDO these patterns, as a whole, were less-defined, and often had very broad troughs encompassing most of the United States. This commonly resulted in westerly flow or varying degrees of southwest flow.

Summers where semi-permanent ridging occurred over the southern and central plains resulted in eastern Montana being in an active pattern; either in west-northwest flow overriding the top of the ridge or southwest flow streaming up from the warm Pacific. The majority of cases when this happened were during the cold phase of the PDO. Precipitation values generally were suppressed during the warm phase of the PDO when the top of the ridge extended into the northern plains.

4. Summary and Conclusions

The results from the correlations confirm that PDO, PNA, and NAO have a slightly more pronounced influence on temperatures in eastern Montana than ENSO. In fact, the degree of correlation overall increased between temperatures and the PNA and NAO as non-ENSO data was removed and the ENSO events were sorted. Low values can be significant when tested at a 95% confidence level. It was found that most of the relationships between PDO, PNA, NAO, and temperatures were indeed statistically significant.

La Niña events frequently had well-defined drastic drops in temperatures towards the end of November/early December. They also tended to have warmer than normal temperatures in late summer and fall before the sharp drop in temperatures. El Niño events tended to have slightly cooler summer and fall temperatures, with above normal temperatures during the winter months. Periods of colder than normal temperatures usually occurred late in the winter season with shorter durations.

A frequent height pattern that developed in the winter regardless of the PDO phase was a deep low over the Hudson Bay area with an associated trough that extended to, or south of the Great Lakes region. The strength of the summer-time ridge and the placement of its axis also played a large role in enhanced or suppressed flow into eastern Montana.

The overall results of this study concluded that temperatures across eastern Montana were indeed influenced by large-scale changes in the atmospheric flow by fluctuations in the teleconnections/oscillations. The correlation values established the fact that the PNA had more influence on local departures than ENSO. Little research has been done on the local effects of PNA and would be an excellent extension of this study. Results from a future study could potentially enhance climatic projections, ultimately improving local understanding and support services. Providing the products and services that protect life and property, as well as, enhancing the national economy is what we do as an agency. Taking the extra step to improve decision support services to our local customers not only satisfies the goals of the National Weather Service, but also enhances the relationship between our local WFO and our partners.

5. References

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6. Appendix

Figure 5a. Temperature departures for Glasgow during the La Niña event spanning from April 1954 to December 1956 (Cold Phase of PDO).

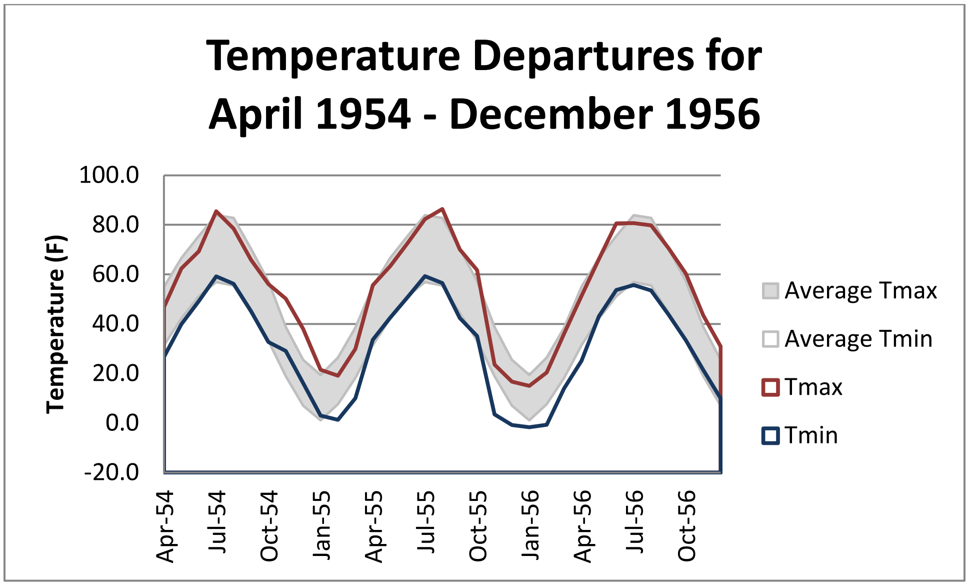


Figure 5b. Temperature departures for Miles City during the La Niña event spanning from April 1954 to December 1956(Cold Phase of PDO).

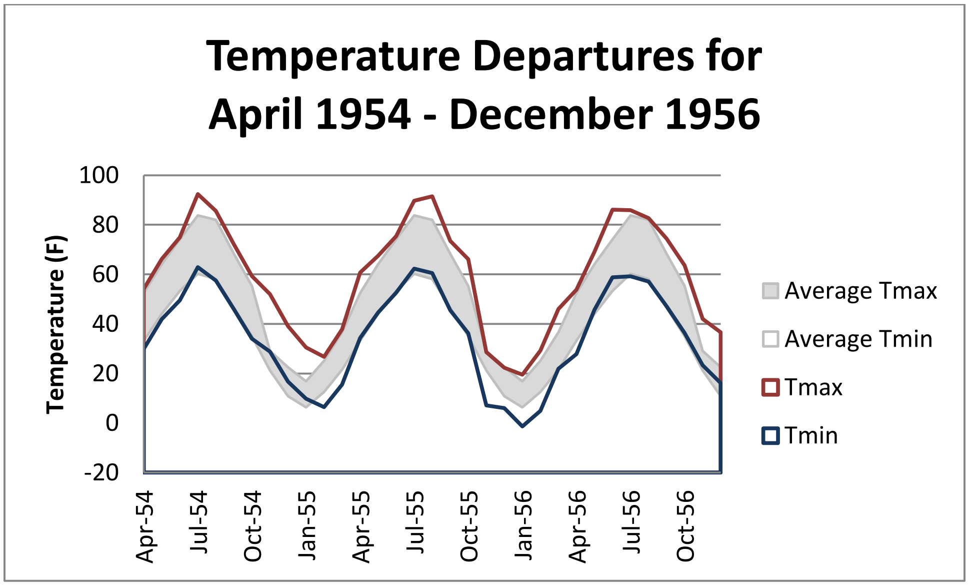


Figure 6a. Temperature departures for Glasgow during the El Niño event spanning from June 1965 to April 1966 (Cold Phase of PDO).

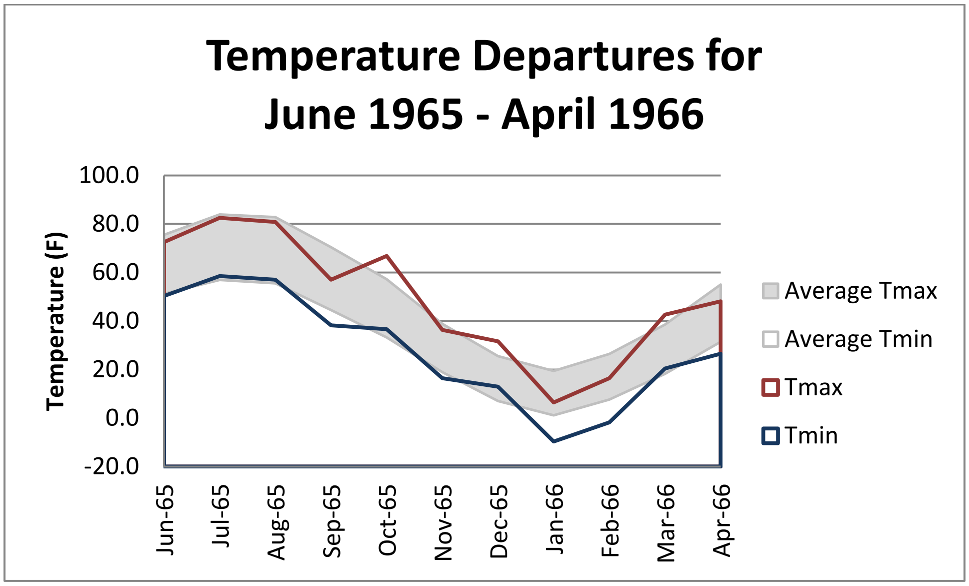


Figure 6b. Temperature departures for Miles City during the El Niño event spanning from June 1965 to April 1966 (Cold Phase of PDO).

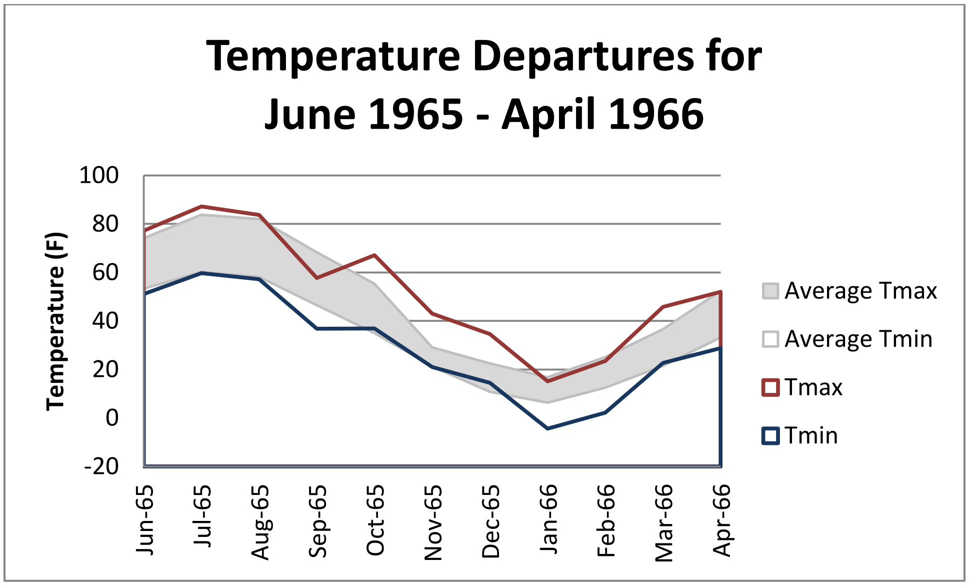


Figure 7a. Temperature departures for Glasgow during the La Niña event spanning from July 1998 to June 2000 (Warm Phase of PDO transitioning to the Cold Phase).

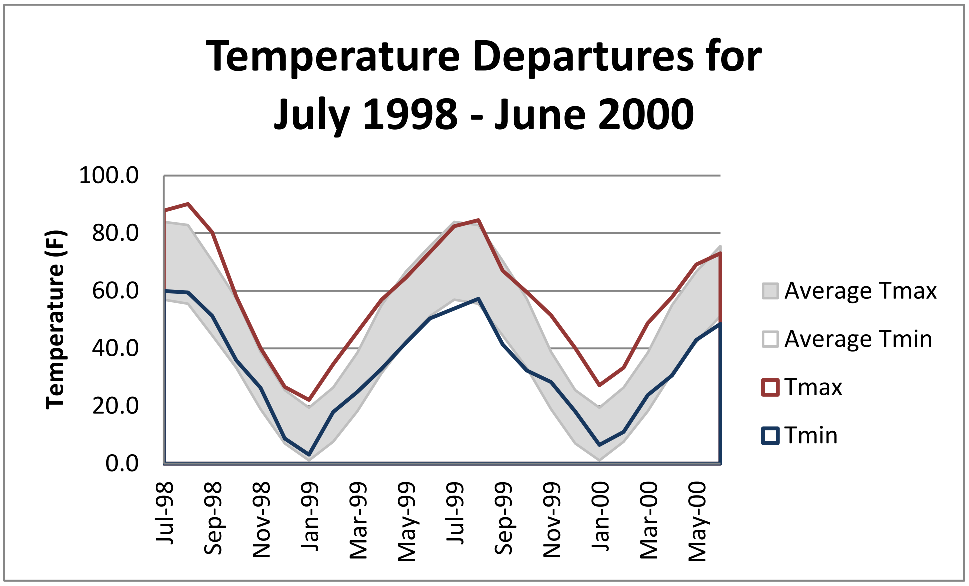


Figure 7b. Temperature departures for Miles City during the La Niña event spanning from July 1998 to June 2000 (Warm Phase of PDO transitioning to the Cold Phase).

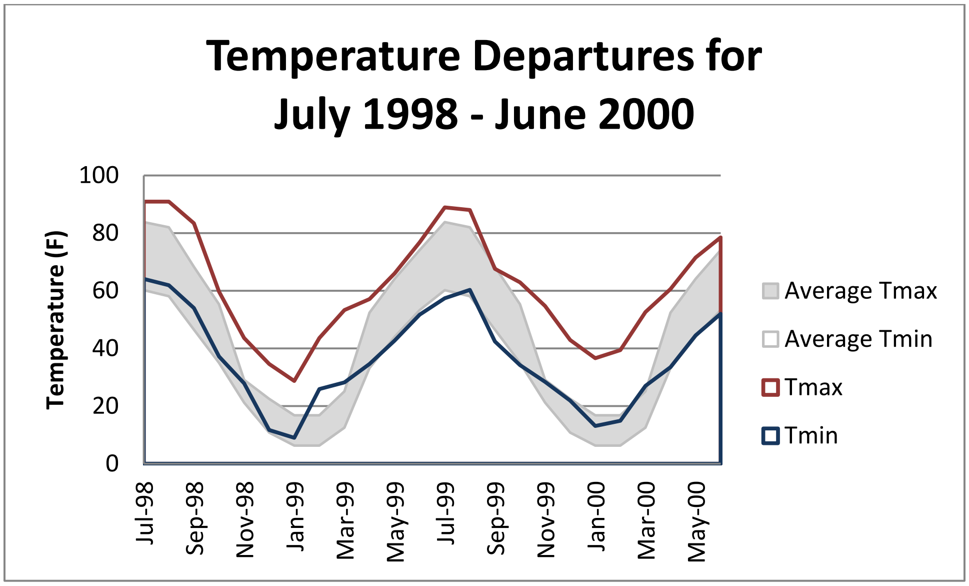


Figure 8a. Temperature departures for Glasgow during the La Niña event spanning from October 1984 to September 1985 (Warm Phase of PDO).

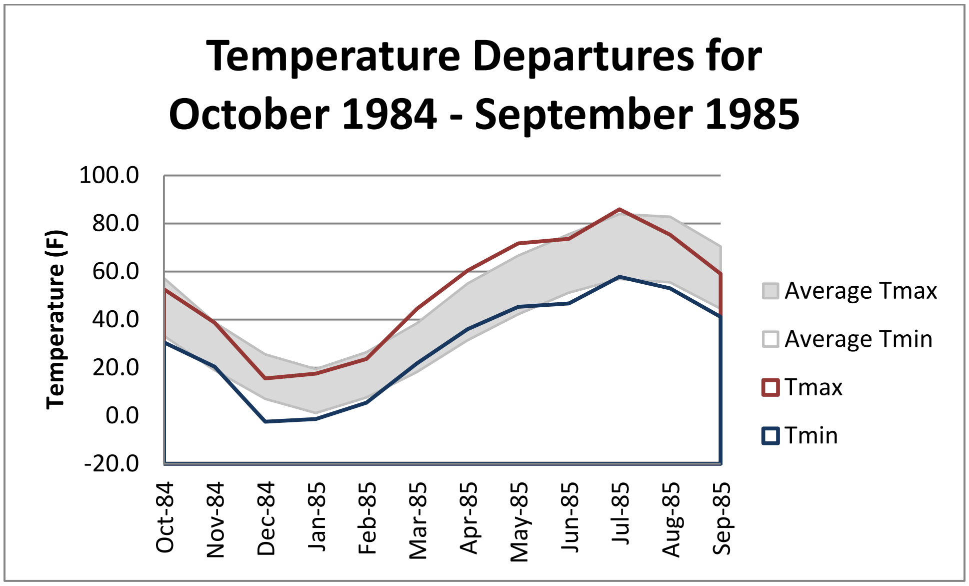


Figure 8b. Temperature departures for Miles City during the La Niña event spanning from October 1984 to September 1985 (Warm Phase of PDO).

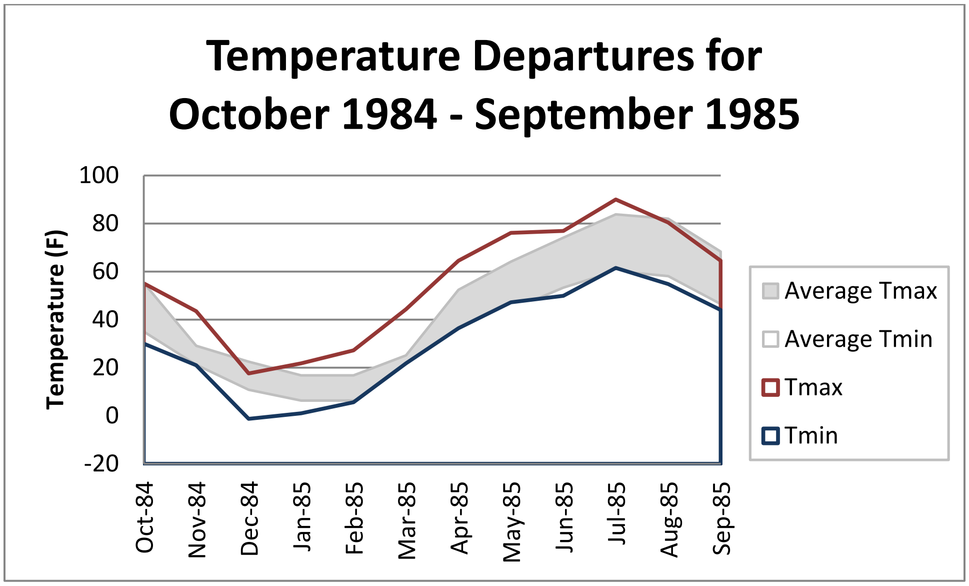


Figure 9a. Temperature departures for Glasgow during the El Niño event spanning from May 1982 to June 1983 (Warm Phase of PDO).

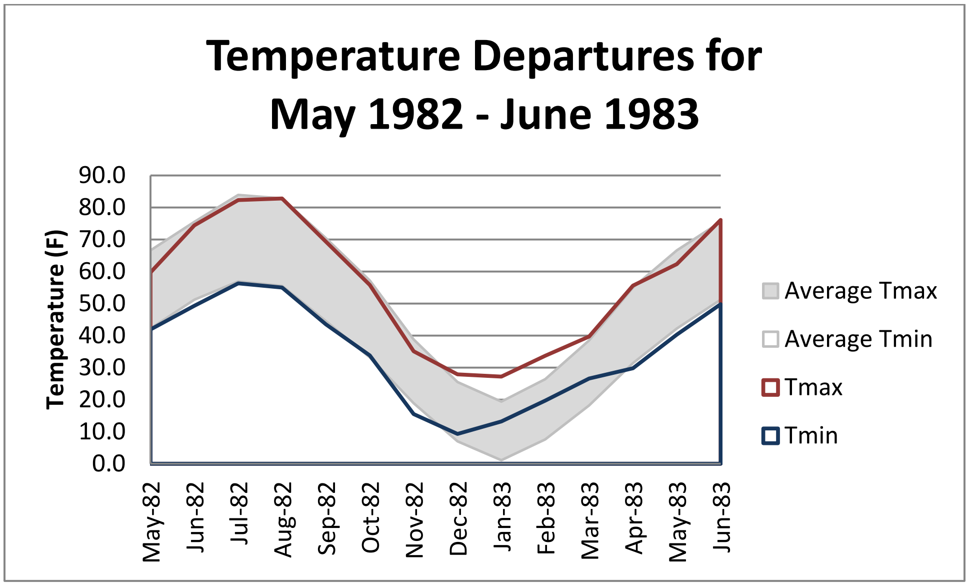


Figure 9b. Temperature departures for Miles City during the El Niño event spanning from May 1982 to June 1983 (Warm Phase of PDO).

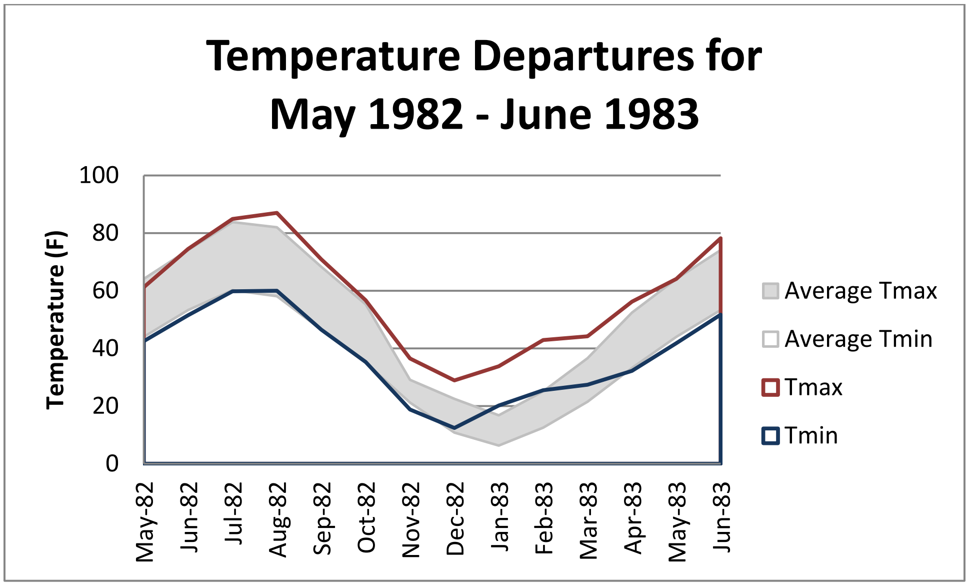


Figure 10a. Temperature departures for Glasgow during the El Niño event spanning from September 1976 to February 1977 (Cold Phase of PDO transitioning to the Warm Phase).

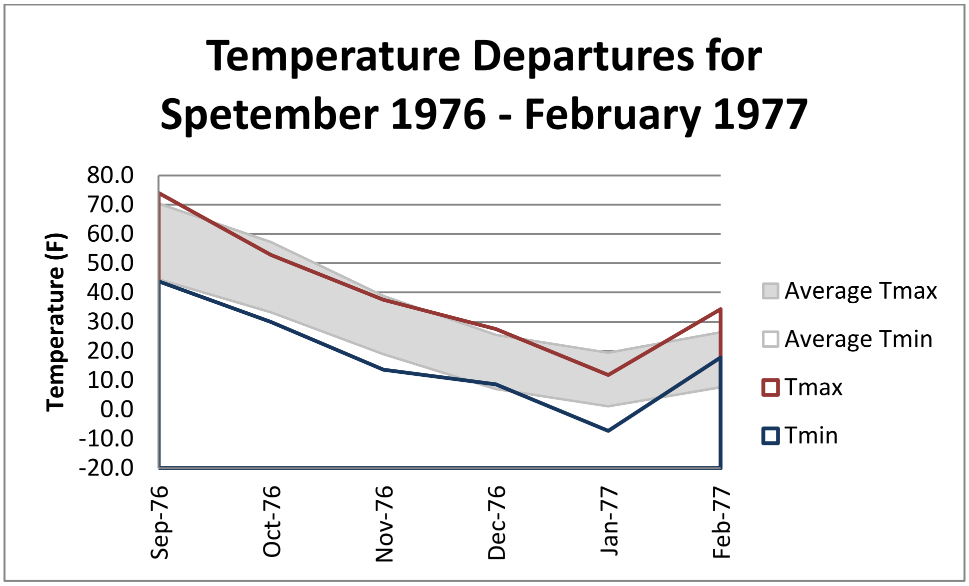


Figure 10b. Temperature departures for Miles City during the El Niño event spanning from September 1976 to February 1977 (Cold Phase of PDO transitioning to the Warm Phase).

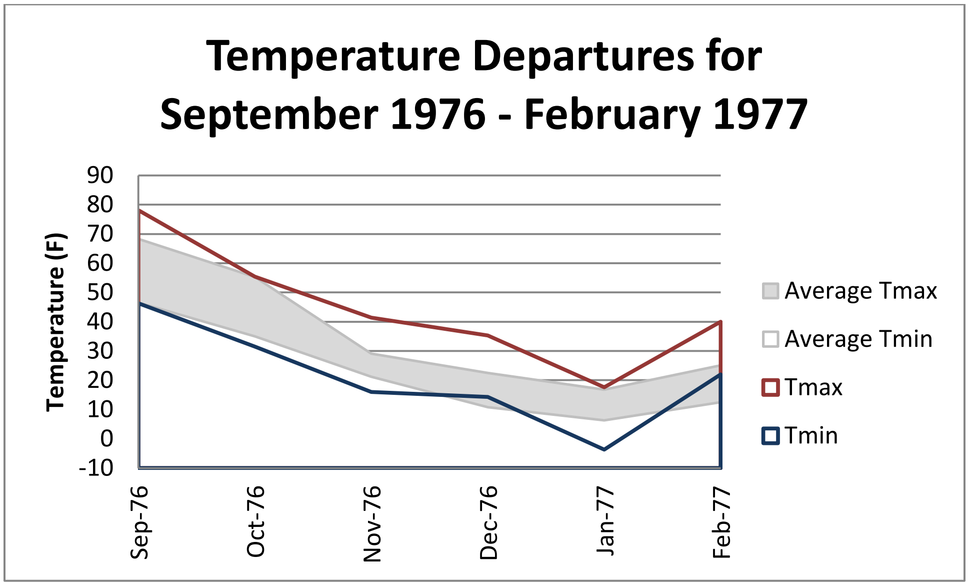
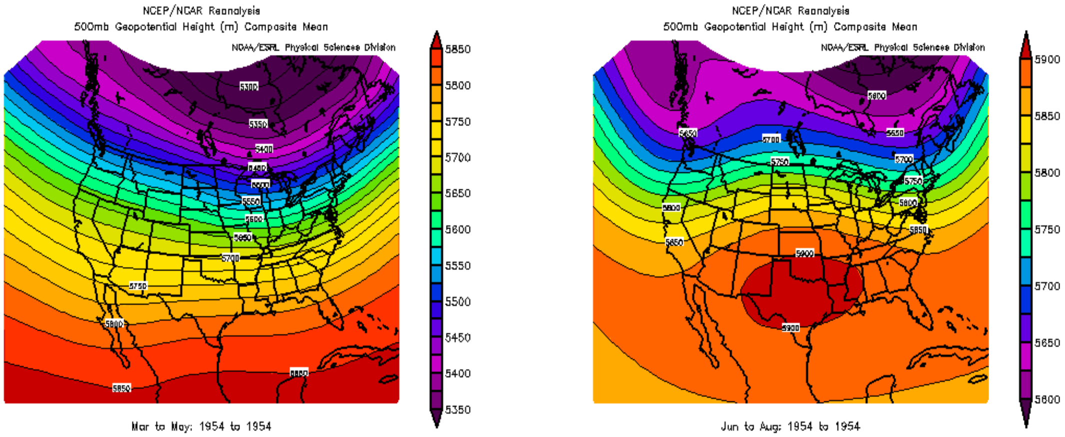
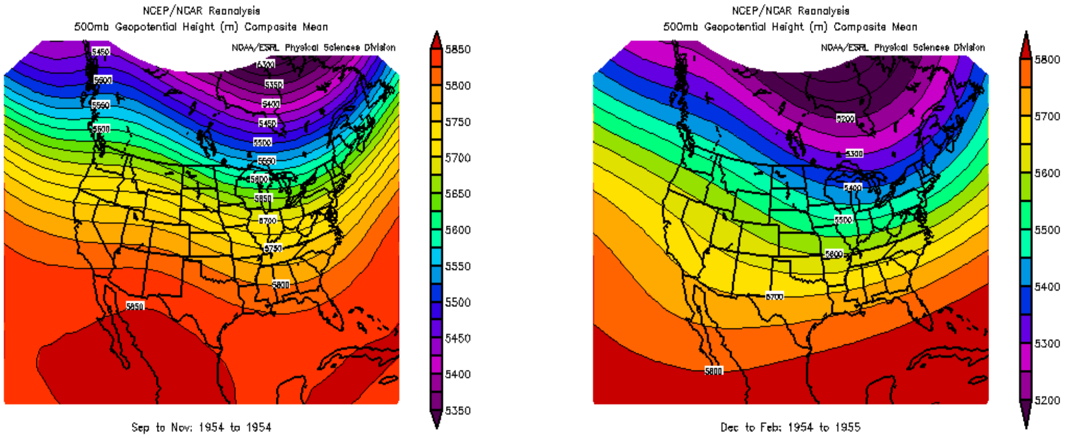


Figure 11a-h. 500-mb height reanalysis for the La Niña event spanning from April 1954 to December 1956 (Cold Phase of PDO).

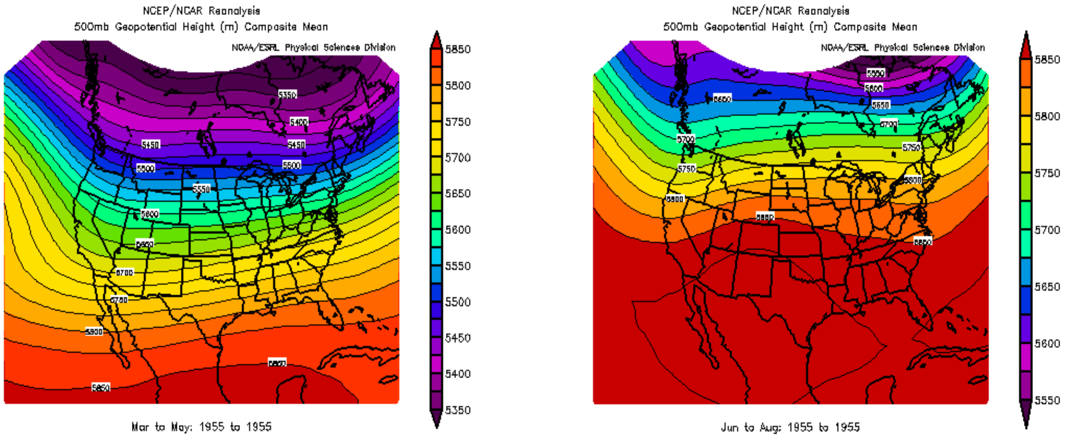
a) Spring 1954 b) Summer 1954



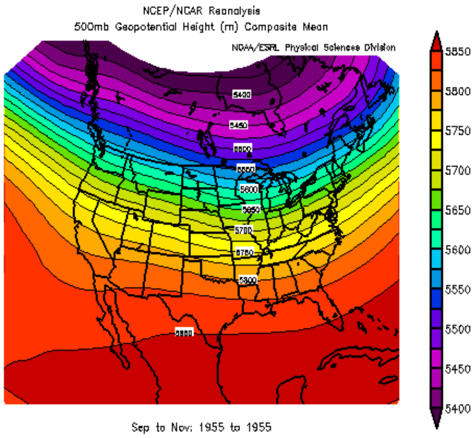
c) Fall 1954 d) Winter 1954/1955



e) Spring 1955 f) Summer 1955



g) Fall 1955



h) Winter 1955/1956

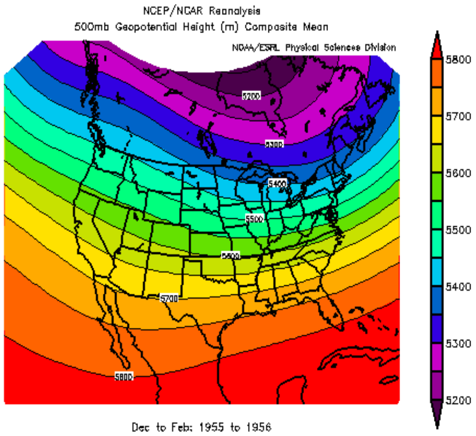
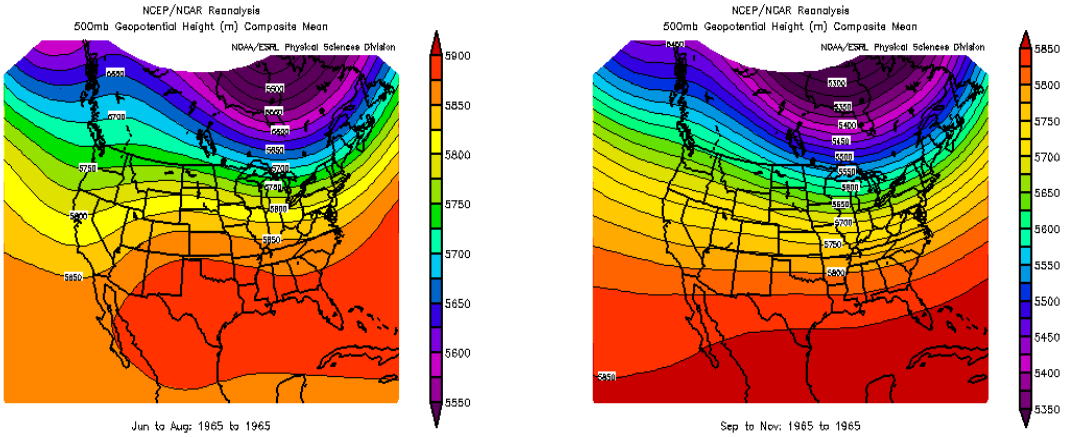


Figure 12a-d. 500-mb height reanalysis for the El Niño event spanning from June 1965 to April 1966 (Cold Phase of PDO).

a) Summer 1965

b) Fall 1965



c) Winter 1965/1966

d) Spring 1966

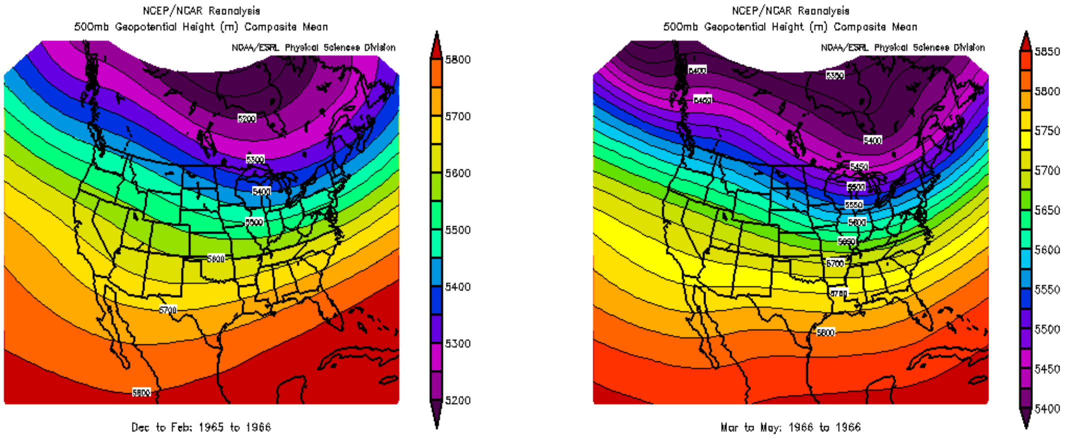
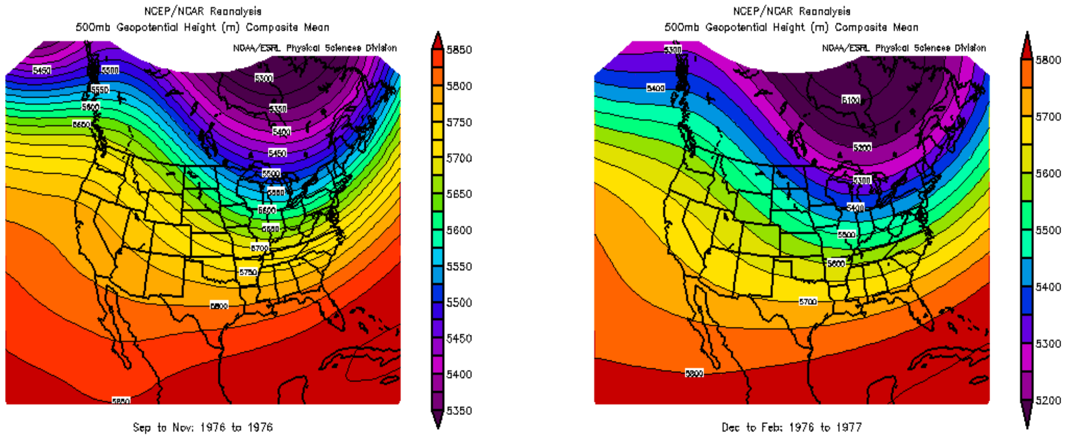


Figure 13a-b. 500-mb height reanalysis for the El Niño event spanning from September 1976 to February 1977 (Cold Phase transitioning to the Warm Phase of the PDO).

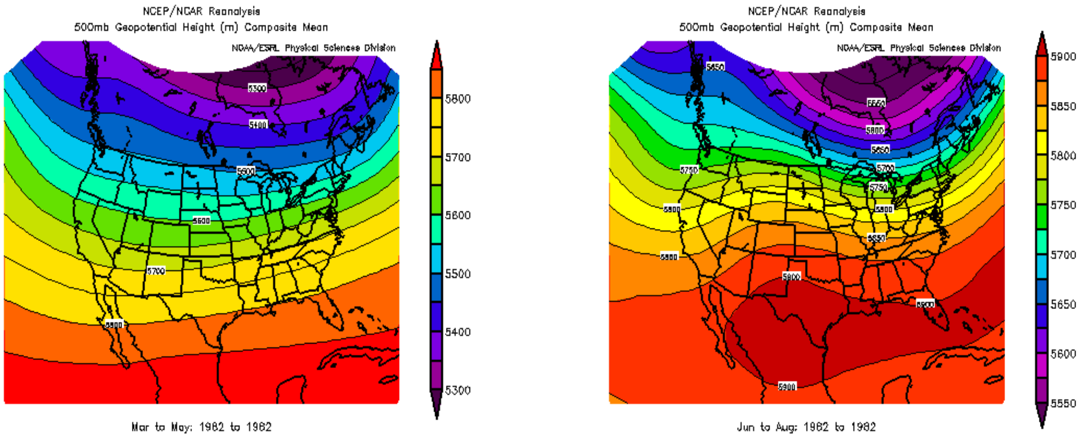


a) Fall 1976

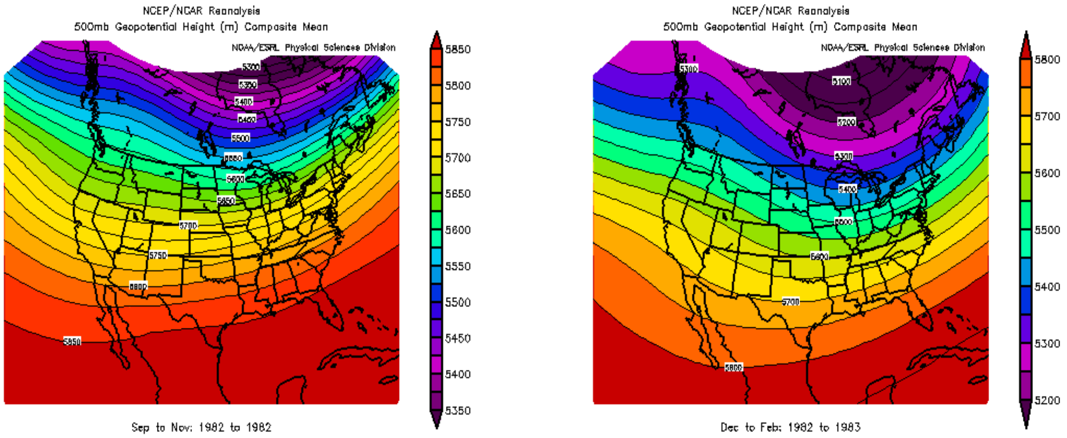
b) Winter 1976/1977

Figure 14a-f. 500-mb height reanalysis for the El Niño event spanning from May 1982 to June 1983 (Warm Phase of PDO).

a) Spring 1982 b) Summer 1982



c) Fall 1982 d) Winter 1982/1983



e) Spring 1983 f) Summer 1983

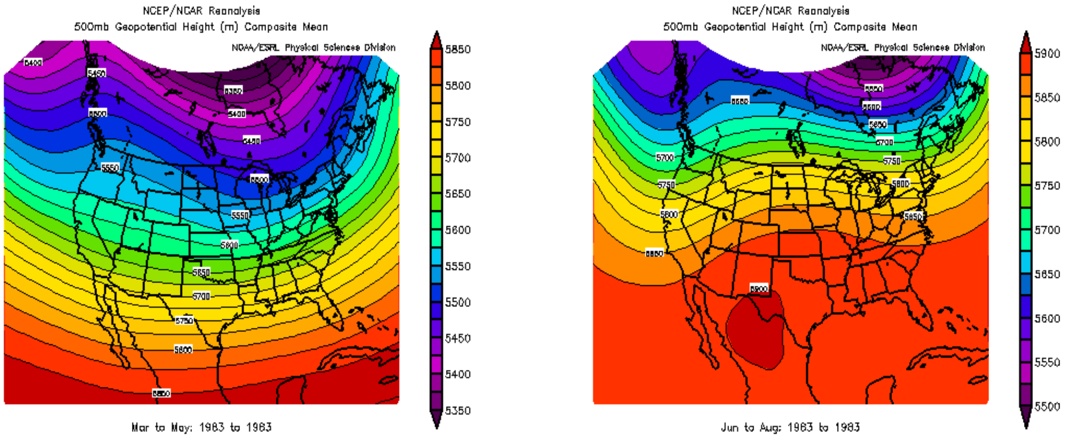
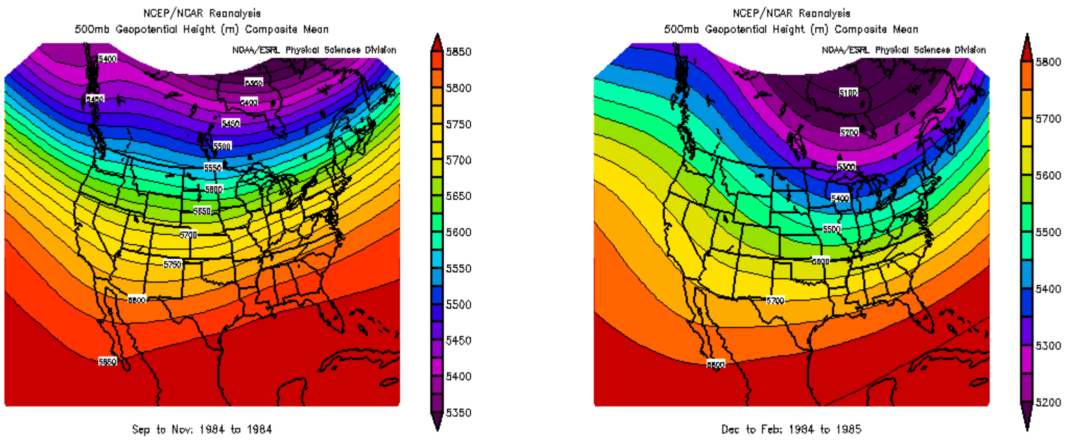
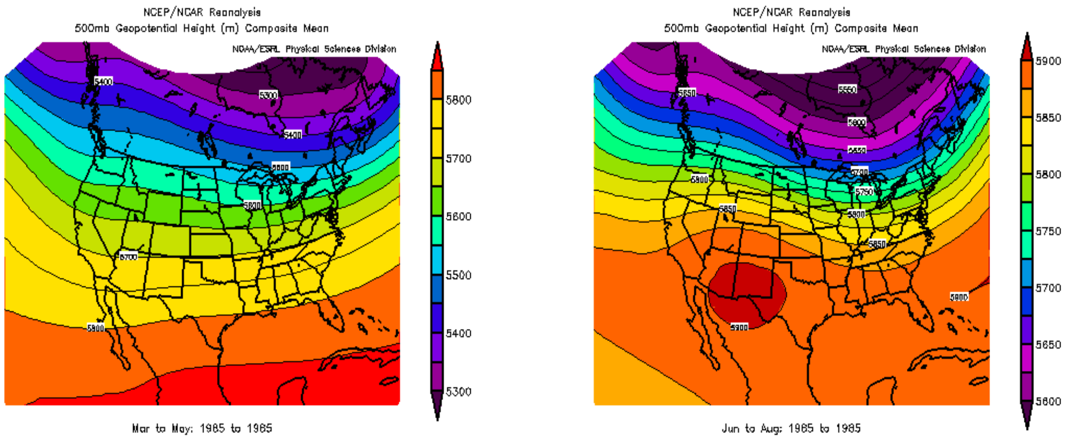


Figure 15a-e. 500-mb height reanalysis for the La Niña event spanning from October 1984 to September 1985 (Warm Phase of PDO).



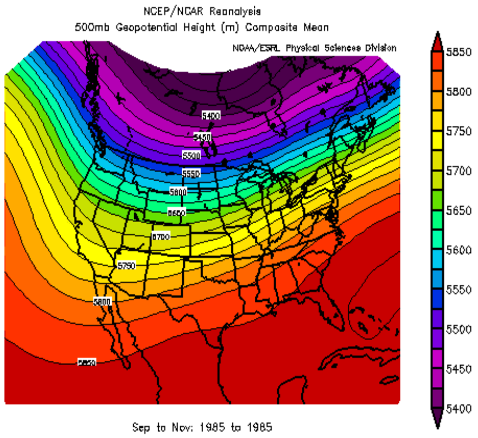
a) Fall 1984

b) Winter 1984/1985



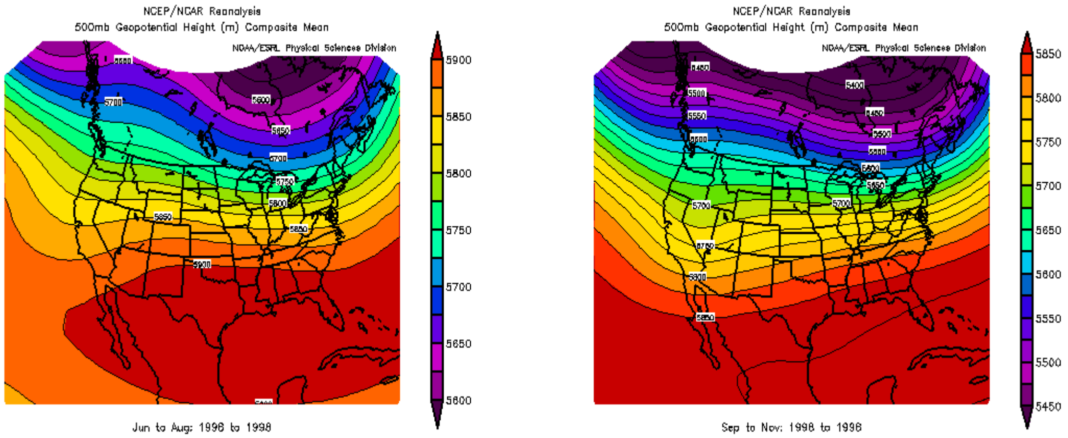
c) Spring 1985

d) Summer 1985



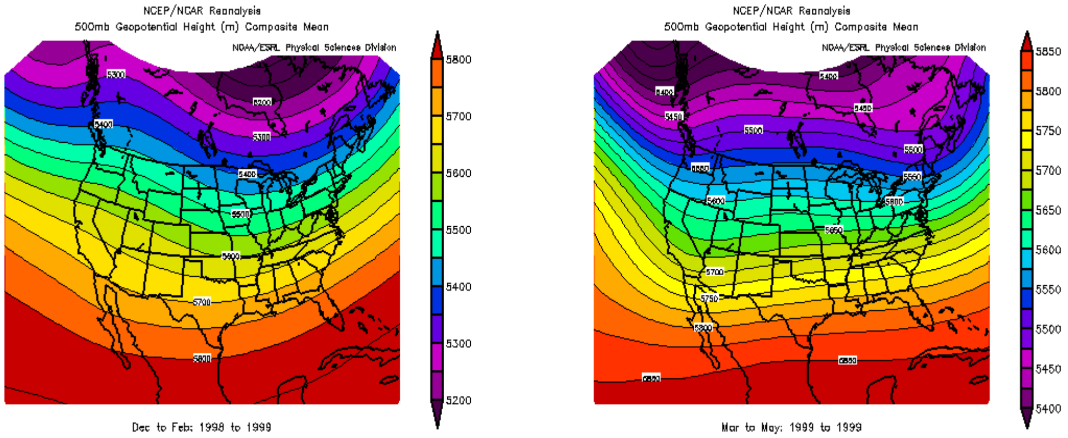
e) Fall 1985

Figure 16a-i. 500-mb height reanalysis for the La Niña event spanning from July 1998 to June 2000 (Cold Phase of PDO).



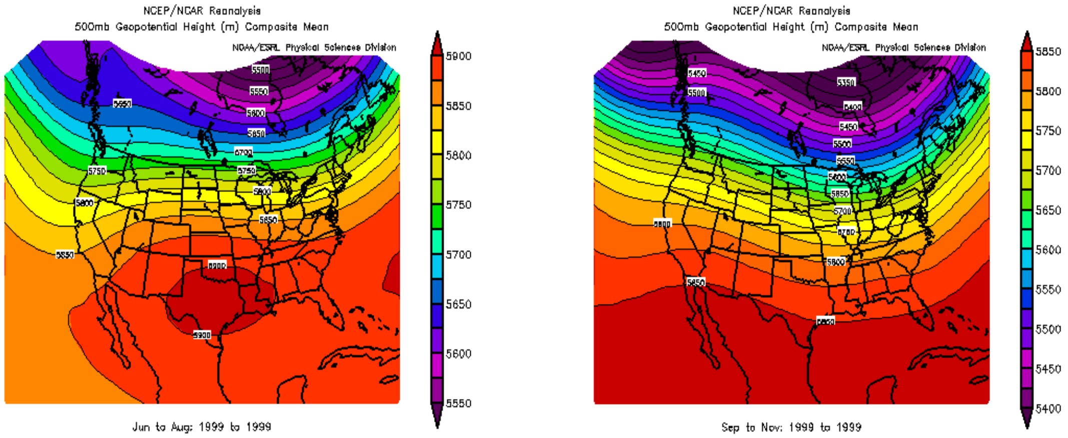
a) Summer 1998

b) Fall 1998



c) Winter 1998/1999

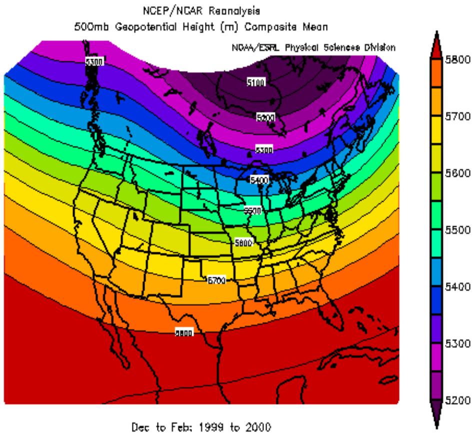
d) Spring 1999



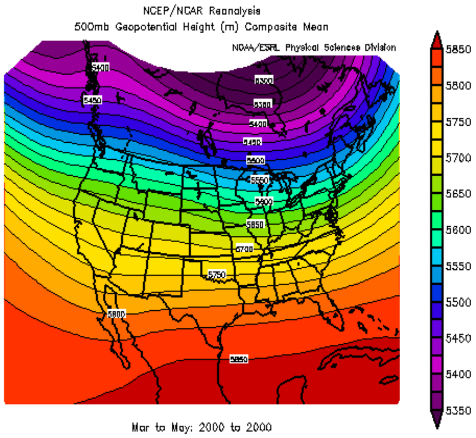
e) Summer 1999

f) Fall 1999

g) Winter 1999/2000



h) Spring 2000



i) Summer 2000