

# **El Niño and La Niña Episodes and Their Impact On The Weather In The Tucson Metropolitan Area**

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## **Introduction**

El Niño and La Niña episodes have been shown through numerous studies to have widespread weather impacts on larger scale atmospheric patterns. The purpose of this work is to look at the impacts of El Niño and La Niña on a more local scale to determine their impacts and better assess correlations to the weather in the Tucson area on a downscaled basis.

## **Methodology**

Oceanic Niño Index (ONI) values were obtained from the Climate Prediction Center (CPC) from 1950 to present. These values are defined as sea surface temperature anomalies in the Niño 3.4 region (located at 5°N to 5°S and 120° to 170°W), based on a base period from 1971-2000. These ONI values were then analyzed for departure values of greater than +0.5°C for El Niño and -0.5°C for La Niña episodes respectively. To meet the criteria for the definition of an El Niño or La Niña episode the departure must be greater than +/- 0.5°C for five consecutive overlapping three month seasons. This is the same criteria that CPC uses to define El Niño or La Niña episodes. These episodes were then defined into July-June periods as the main impacts are during the cool season. The one exception to this was when looking at monsoon precipitation as the monsoon is defined as June 15<sup>th</sup>-September 30<sup>th</sup> and thus occurs during the warm season. For the purposes of Monsoon Precipitation, an El Niño or La Niña episode was determined using the same +/- 0.5°C criteria but must have started no later than the May, June, July three month season and have continued completely through the summer.

Once a determination was made that an El Niño or La Niña episode met the criteria, it was then rated into a weak, moderate or strong category based upon the ONI value. The ONI values to define each event are as follows:

For El Niño episodes:

Weak – ONI values from +0.5°C to +0.9°C

Moderate – ONI values from +1.0°C to +1.8°C

High – ONI values greater than +1.8°C

For La Niña episodes:

Weak – ONI values from  $-0.5^{\circ}\text{C}$  to  $-0.9^{\circ}\text{C}$

Moderate – ONI values from  $-1.0^{\circ}\text{C}$  to  $-1.8^{\circ}\text{C}$

High – ONI values greater than  $-1.8^{\circ}\text{C}$

When looking at Monsoon Precipitation, given that El Niño and La Niña is weakest during the warm season with the smallest anomalies, these periods were not given a strength definition. Local climate data was obtained from the Tucson International Airport, as observations have been taken here continuously since 1948 and this is the official climate station for Tucson. The climate of Southeast Arizona varies considerably due to significant elevation differences. However, the majority of the population in Southeast Arizona lives near the Tucson area. Thus, this study concentrates on the Tucson given that nearly 1 million people live in this area. The Tucson International Airport is located about 6 miles south of downtown and fairly well represents the overall climate in the Tucson area. It should be noted that there are numerous microclimates in the area, particularly with respect to monsoon rainfall and low temperatures in the cooler months that will not be fully represented given the airport location. With that said, the airport does still represent the most complete dataset in the Tucson area which is why it was chosen.

ESNO episodes produce significant societal impacts for Southeast Arizona. This study focuses on precipitation and temperature as they receive the greatest impact during ENSO phases. Precipitation was reviewed for the following periods; July through June, November through April, December through February and each individual month from November through April. In addition, precipitation during the monsoon season of June 15<sup>th</sup> through September 30<sup>th</sup> was reviewed. Temperatures during the cool season were evaluated during the meteorological winter period of December-February. Due to the changes in land use in recent years, mainly through urbanization, comparing conditions to the standard 30 year normals may introduce biases, especially when investigating minimum temperature. Thus, it was determined to compare values from each decade to a 30 year rolling average in addition to the latest 30 year normals from 1981-2010. The 30 year rolling normal comparison was accomplished by using data during a given 30 year normal period (i.e. 1941-1970) with that normal value representative for any year within the decade of the 1950s.

### **Winter Precipitation**

The table below lists precipitation totals during El Niño episodes. The data is broken out by seasons inclusive of a total year from July through June and then the winter seasons from November through April and December through February. Above normal precipitation totals are shaded in green and were determined by being greater 110 percent from the mean precipitation values during the respective season. Below normal precipitation are shaded in brown and were determined by being less than 90 percent from the mean precipitation values during the respective season.

| El Niño Episodes              | Strength of Episodes | July-June Total Precipitation                                      | November-April Total Precipitation                                  | December-February Total Precipitation                              |
|-------------------------------|----------------------|--|---|--|
| 1951-1952                     | Weak                 | 13.07"   | 6.35"   | 1.31"  |
| 1957-1958                     | Moderate             | 13.22"   | 4.90"   | 2.04"  |
| 1962-1963                     | Weak                 | 8.42"  | 3.48"   | 2.33"  |
| 1963-1964                     | Weak                 | 9.67"  | 3.09"   | 0.35"  |
| 1965-1966                     | Moderate             | 14.36"   | 10.09"  | 9.01"  |
| 1968-1969                     | Weak                 | 8.00"  | 4.36"   | 1.56"  |
| 1969-1970                     | Weak                 | 9.58"  | 3.80"   | 1.16"  |
| 1972-1973                     | Moderate             | 18.40"   | 5.79"   | 2.27"  |
| 1976-1977                     | Weak                 | 7.59"  | 3.99"   | 2.34"  |
| 1977-1978                     | Weak                 | 12.52"   | 6.36"   | 5.13"  |
| 1982-1983                     | Strong               | 14.28"   | 6.95"   | 4.23"  |
| 1986-1987                     | Moderate             | 12.65"   | 5.56"   | 3.51"  |
| 1987-1988                     | Moderate             | 10.35"   | 4.38"   | 2.44"  |
| 1991-1992                     | Moderate             | 13.62"   | 7.56"   | 4.45"  |
| 1994-1995                     | Moderate             | 12.32"   | 9.09"   | 6.44"  |
| 1997-1998                     | Strong               | 13.41"   | 8.77"   | 6.25"  |
| 2002-2003                     | Moderate             | 8.93"  | 2.52"   | 1.74"  |
| 2004-2005                     | Weak                 | 8.15"  | 4.47"   | 3.33"  |
| 2006-2007                     | Weak                 | 12.53"   | 2.11"   | 1.37"  |
| 2009-2010                     | Moderate             | 8.09"  | 5.17"   | 4.29"  |
| Weak Years Average            |                      | 9.95"  | 4.22"   | 2.10"  |
| Moderate/Strong Years Average |                      | 12.69"   | 6.43"   | 4.24"  |
| All El Niño Years Average     |                      | 11.46"   | 5.44"   | 3.28"  |
| 20 Episodes of all strengths  |                      | 11 years above average, 8 years below average, 1 year near average | 11 years above average, 4 years below average, 5 years near average | 9 years above average, 10 years below average, 1 year near average |
| Weak Years                    |                      | 3 years above average, 6 years below average                       | 2 years above average, 3 years below average, 4 near average        | 2 years above average, 7 years below average                       |
| Moderate and Strong Years     |                      | 8 years above average, 2 years below average, 1 near average       | 9 years above average, 1 year below average, 1 year near average    | 6 years above average, 3 years below average, 2 years near average |
| 80 Year Normal (1930-2010)    |                      | 11.23"   | 4.19"   | 2.63"  |

During the entire July through June season, there were 11 occurrences above average, or 55% of the seasons. However, when taking into account only those El Niño episodes of moderate or greater strength, 8 of 11 occurrences, or 73% of the seasons had above average precipitation. During the cool season of November through April, when the bulk of precipitation occurs outside the monsoon, 11 years were above average, or 55% of the seasons. During moderate or greater strength El Niño episodes, 9 years or 82% of the occurrences were above normal. The trends for El Niño episodes of all strengths becomes a bit less defined in just the core December through February period when 9 seasons, or

45% were above normal. However, during moderate and strong years, 6 seasons, or 55% were above normal.

The table below lists precipitation totals during La Niña episodes. The data is broken out by seasons inclusive of a total year from July through June and then the winter seasons from November through April and December through February. Above normal precipitation totals are shaded in green and were determined by being greater than 110 percent from the mean precipitation values during the respective season. Below normal precipitation are shaded in brown and were determined by being less than 90 percent from the mean precipitation values during the respective season.

| La Niña Episodes             | Strength | July-June Precipitation  | November-April Precipitation                                       | December-February Precipitation                                    |
|------------------------------|----------|--|--|--|
| 1949-1950                    | Moderate | 8.97"  | 3.05"  | 2.62"  |
| 1950-1951                    | Weak     | 9.04"  | 3.30"  | 1.52"  |
| 1954-1955                    | Moderate | 9.33"  | 2.17"  | 2.14"  |
| 1955-1956                    | Strong   | 16.02"   | 2.26"  | 1.95"  |
| 1956-1957                    | Weak     | 9.07"  | 4.04"  | 2.95"  |
| 1964-1965                    | Moderate | 17.83"   | 3.08"  | 1.90"  |
| 1967-1968                    | Weak     | 14.60"   | 7.50"  | 4.61"  |
| 1970-1971                    | Moderate | 10.81"   | 1.53"  | 0.97"  |
| 1971-1972                    | Weak     | 11.99"   | 2.67"  | 1.97"  |
| 1973-1974                    | Strong   | 4.24"  | 1.95"  | 0.93"  |
| 1974-1975                    | Weak     | 12.25"   | 2.85"  | 0.82"  |
| 1975-1976                    | Moderate | 6.69"  | 2.40"  | 1.11"  |
| 1984-1985                    | Weak     | 16.95"   | 7.19"  | 6.09"  |
| 1988-1989                    | Moderate | 11.02"   | 2.61"  | 1.24"  |
| 1995-1996                    | Weak     | 8.62"  | 2.22"  | 1.04"  |
| 1998-1999                    | Moderate | 9.73"  | 2.47"  | 0.46"  |
| 1999-2000                    | Moderate | 10.95"   | 1.22"  | 0.29"  |
| 2000-2001                    | Weak     | 13.86"   | 4.79"  | 1.70"  |
| 2007-2008                    | Moderate | 10.14"   | 3.37"  | 2.15"  |
| 2010-2011                    | Moderate | 6.95"  | 1.01"  | 0.71"  |
| Weak Years                   |          | 12.05"   | 4.32"  | 2.59"  |
| Moderate/Strong Average      |          | 10.22"   | 2.26"  | 1.37"  |
| All La Nina Years Average    |          | 10.95"   | 3.08"  | 1.86"  |
| 20 Episodes of all strengths |          | 4 years above average, 9 years below average, 4 years near average | 3 years above average, 16 years below average, 1 year near average | 3 years above average, 16 years below average, 1 year near average |
| Weak Years                   |          | 2 years above average, 3 years below average, 3 near average       | 3 years above average, 4 years below average, 1 near average       | 3 years above average, 5 years below average                       |
| Moderate and Strong Years    |          | 2 years above average, 6 years below average, 4 near average       | 12 years below average   | 1 years near average, 11 years below average                       |
| 80 Year Normal (1930-2010)   |          | 11.23"   | 4.19"  | 2.63"  |

During the entire July through June season, there were 9 occurrences below average, or 45% of the seasons. When taking into account only those La Niña episodes of moderate

or greater strength, 6 of 12 occurrences, or 50% of the seasons had above below precipitation. During the cool season of November through April, when the bulk of precipitation occurs outside the monsoon, 16 years were below average, or 80% of the seasons. During moderate or greater strength La Niña episodes, all 12 seasons were below normal. The trends for La Niña episodes of all strengths remains well defined in just the core December through February period when 16 seasons, or 80% were below normal. During moderate and strong years in the December through February season, 11 years, or 92% of the occurrences were below normal.

**Monsoon Precipitation**

The table below lists El Niño episodes of all strengths that were ongoing and continued through the Monsoon season which is defined as June 15<sup>th</sup> through September 30<sup>th</sup>. Above normal precipitation totals are shaded in green and were determined by being greater than 110 percent from the mean precipitation values. Below normal precipitation is shaded in brown and was determined by being less than 90 percent from the mean precipitation values.

| Monsoon El Niño                                   | June 15-Sept 30 Precipitation |
|---|-------------------------------|
| 1957  | 5.26"                         |
| 1965  | 4.07"                         |
| 1972  | 8.01"                         |
| 1982  | 7.46"                         |
| 1987  | 5.46"                         |
| 1991  | 4.15"                         |
| 1994  | 2.58"                         |
| 1997  | 4.26"                         |
| 2002  | 5.78"                         |
| 2004  | 2.42"                         |
| 2006  | 10.20"                        |
| All El Niño Average                               | 5.42"                         |
| 80 Year (1930-2010) Monsoon Precipitation Average | 5.96"                         |

The correlation between monsoon precipitation and El Niño is somewhat ill defined with all El Nino monsoon seasons averaging 5.42". This is slightly below the 5.96" monsoon precipitation average during El Niño years

The table below lists La Niña episodes of all strengths that were ongoing and continued through the Monsoon. Above normal precipitation totals are shaded in green and were determined by being greater than 110 percent from the mean precipitation values. Below normal precipitation are shaded in brown and were determined by being less than 90 percent from the mean precipitation values.

| Monsoon La Niña                                   | June 15-Sept 30 Precipitation |
|---|-------------------------------|
| 1950  | 6.97"                         |
| 1954  | 8.54"                         |
| 1955  | 13.08"                        |
| 1956  | 4.62"                         |
| 1964  | 13.84"                        |
| 1971  | 7.22"                         |
| 1973  | 2.33"                         |
| 1974  | 7.18"                         |
| 1975  | 3.96"                         |
| 1985  | 6.26"                         |
| 1988  | 6.28"                         |
| 1999  | 8.33"                         |
| Average La Niña Years                             | 7.38"                         |
| 80 Year (1930-2010) Monsoon Precipitation Average | 5.96"                         |

The correlation between monsoon precipitation and La Niña is better defined with all La Niña monsoon seasons averaging 7.38". This is above normal by about 1.42" inches above the 80 year monsoon precipitation average.

### Temperature

The table below lists temperature averages during El Niño episodes during meteorological winter (December through February). Above normal temperature values are shaded in orange and were determined by being greater than 2°F above normal, while cooler than normal seasons are shaded in blue and were defined as those with departures of less than 2°F below normal.

| El Niño Episodes       | Strength of Episodes | Tucson Average Temperature Compared to 30 Year Normal | Tucson Average Temperature Compared to Rolling ~30 Year Normal |
|------------------------|----------------------|---|--|
| 1951-1952              | Weak                 | 51.6  | 51.6   |
| 1957-1958              | Moderate             | 53.9  | 53.9   |
| 1941-1970 Normal: 52.1 |                      |   |  |
| 1962-1963              | Weak                 | 53.1  | 53.1   |
| 1963-1964              | Weak                 | 49.3  | 49.3   |
| 1965-1966              | Moderate             | 49.2  | 49.2   |
| 1968-1969              | Weak                 | 53.0  | 53.0   |
| 1969-1970              | Weak                 | 53.0  | 53.0   |
| 1951-1980 Normal: 52.3 |                      |   |  |
| 1972-1973              | Moderate             | 49.9  | 49.9   |
| 1976-1977              | Weak                 | 53.1  | 53.1   |
| 1977-1978              | Weak                 | 54.5  | 54.5   |

| 1961-1990 Normal: 52.6                 |          |      |      |
|--|----------|------|------|
| 1982-1983                              | Strong   | 52.2 | 52.2 |
| 1986-1987                              | Moderate | 52.4 | 52.4 |
| 1987-1988                              | Moderate | 54.1 | 54.1 |
| 1971-2000 Normal: 52.9                 |          |      |      |
| 1991-1992                              | Moderate | 54.3 | 54.3 |
| 1994-1995                              | Moderate | 55.5 | 55.5 |
| 1997-1998                              | Strong   | 50.9 | 50.9 |
| 1981-2010 Normal: 53.5                 |          |      |      |
| 2002-2003                              | Moderate | 54.5 | 54.5 |
| 2004-2005                              | Weak     | 54.3 | 54.3 |
| 2006-2007                              | Weak     | 51.6 | 51.6 |
| 2009-2010                              | Moderate | 52.8 | 52.8 |
| 1991-2010 Normal 53.6                  |          |      |      |
| 1981-2010 30 Year Normal               | N/A      | 53.6 | N/A  |
| Average for Moderate and Strong Events | N/A      | 52.7 | N/A  |

Temperatures during moderate to strong El Niño episodes tended to average near to below normal. During weak El Niño episodes, there was no distinct correlation. The increase in normal temperatures over the past 60 years also makes it difficult to determine any defined correlations.

The table below lists temperature averages during La Niña episodes during meteorological winter (December through February). Above normal temperature values are shaded in orange and were determined by being greater than 2°F above normal, while cooler than normal seasons are shaded in blue and were defined as those with departures of less than 2°F below normal.

| La Niña Episodes      | Strength | Tucson Average Temperature Compared to latest 30 Year Normal | Tucson Average Temperature Compared to Rolling ~30 Year Normal |
|-----------------------|----------|--|--|
| 1949-1950             | Moderate | 52.6   | 52.6   |
| 1950-1951             | Weak     | 53.6   | 53.6   |
| 1954-1955             | Moderate | 49.6   | 49.6   |
| 1955-1956             | Strong   | 53.5   | 53.5   |
| 1956-1957             | Weak     | 55.6   | 55.6   |
| 1941-1970 Normal 52.1 |          |  |  |
| 1964-1965             | Moderate | 52.4   | 52.4   |
| 1967-1968             | Weak     | 53.2   | 53.2   |

| 1951-1980 Normal 52.3                  |          |      |      |
|--|----------|------|------|
| 1970-1971                              | Moderate | 51.5 | 51.5 |
| 1971-1972                              | Weak     | 51.0 | 51.0 |
| 1973-1974                              | Strong   | 51.4 | 51.4 |
| 1974-1975                              | Weak     | 49.1 | 49.1 |
| 1975-1976                              | Moderate | 54.6 | 54.6 |
| 1961-1990 Normal 52.6                  |          |      |      |
| 1984-1985                              | Weak     | 51.5 | 51.5 |
| 1988-1989                              | Moderate | 53.1 | 53.1 |
| 1971-2000 Normal 52.9                  |          |      |      |
| 1995-1996                              | Weak     | 55.4 | 55.4 |
| 1998-1999                              | Moderate | 54.1 | 54.1 |
| 1999-2000                              | Moderate | 54.5 | 54.5 |
| 1981-2010 Normal 53.5                  |          |      |      |
| 2000-2001                              | Weak     | 52.2 | 52.2 |
| 2007-2008                              | Moderate | 52.0 | 52.0 |
| 2010-2011                              | Moderate | 53.4 | 53.4 |
| 1991-2010 Normal 53.6                  |          |      |      |
| 1981-2010 30 Year Normal               | N/A      | 53.6 | N/A  |
| Average for Moderate and Strong Events | N/A      | 52.7 | N/A  |

Temperatures during La Niña episodes were typically below average when compared to the latest 1981-2010 average temperatures. However, there was little correlation when compared to the 30 year normal temperatures that were valid during the time period when the La Niña episode occurred. Thus, once again as with El Niño episodes, it is difficult to draw any conclusions given the increase in temperatures over the past 60 years.

### **Correlations with other Observable Climate Phenomena**

An attempt was made to determine what happened during years that did not fit the observed trends with regard to precipitation during cold season El Niño and La Niña episodes. During these cases, the resulting Arctic Oscillation (AO), North Atlantic Oscillation (NAO) and Pacific North America Index (PNA) were reviewed ([http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily\\_ao\\_index/teleconnections.shtml](http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/teleconnections.shtml)) to see if there were any noticeable trends. The AO and NAO was the most difficult to assess in that there is little correlation to precipitation across Arizona over the course of the cold season as seen in Figure 1 and Figure 2 (<http://www.esrl.noaa.gov/psd/data/correlation/>) Even more difficult is that with respect to the AO is that there are more noticeable correlations that occur within specific one month periods. Even taking this into account and looking at the monthly precipitation data there was nothing that stood out with regard to these outlier years. With regard to the NAO, there was nothing observable in the trends with dry El Niño and wet La Niña cold seasons as well. Finally, there is a better correlation to the PNA as seen in Figure 3, but



this is not a surprise since the positive phase of the PNA does tend to occur more often during El Niño.

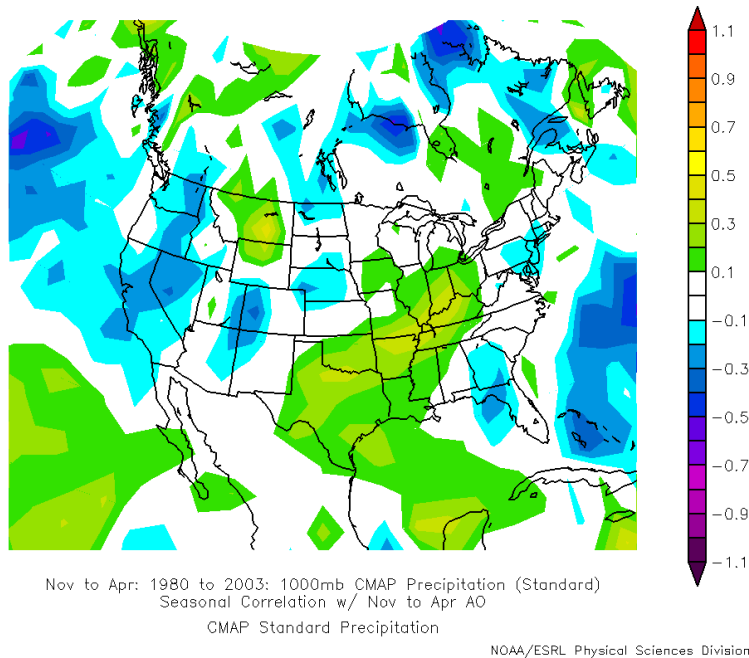


Figure 1- November to April, 1980 to 2003 seasonal correlation of precipitation to the Arctic Oscillation.

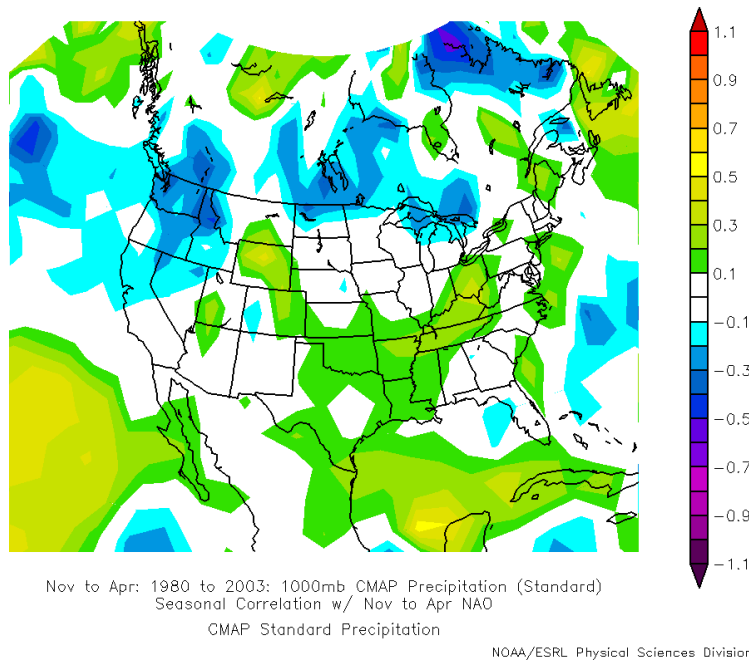


Figure 2- November to April, 1980 to 2003 seasonal correlation of precipitation to the North Atlantic Oscillation.

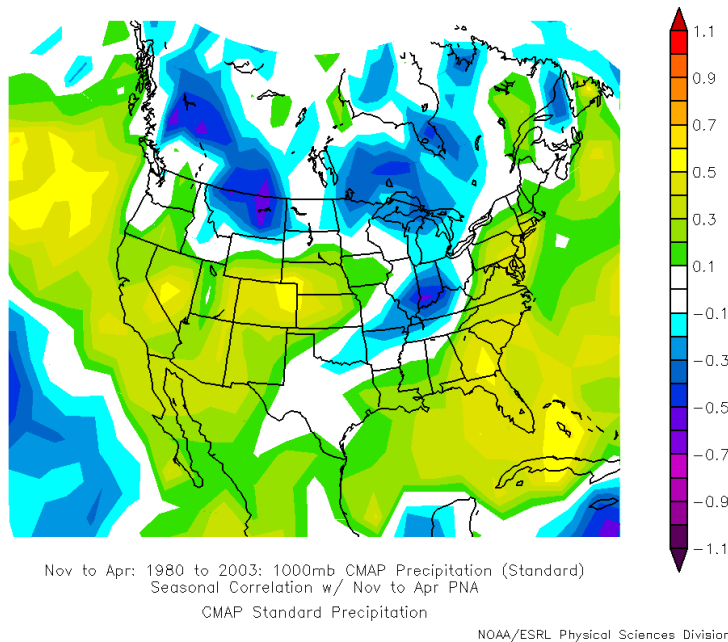


Figure 3- November to April, 1980 to 2003 seasonal correlation of precipitation to the Pacific North America Index.

### Conclusions

The most significant correlations for El Niño and La Niña episodes in the Tucson area occurred with respect to precipitation during the cooler months. It was found that for El Niño episodes, and mainly those that are moderate or strong in intensity, above average precipitation occurred. An interesting finding is that one needs to look at a more extended stretch of cool season precipitation from November through April for this to be valid. For meteorological winter (December through February), the values were still above average for moderate and strong El Niño episodes but the occurrences were less often. In addition, weak El Niño episodes during meteorological winter exhibited below normal precipitation. Meanwhile, for La Niña episodes during the cool season, precipitation averaged below normal in nearly all cases. For weak La Niña episodes, precipitation was still below normal but there were a few seasons with above normal precipitation. During the anomalous years, several other large scale circulations such as the NAO and PDO were examined to determine if they provided some influence on the anomalous data. This study found no significant correlation with these circulations to the anomalous years. This underscores that outside of the ENSO state, there is little to hang our hat on with regard to seasonal precipitation forecast. During the monsoon, the impacts of El Niño were ill defined while there was a tendency for above normal precipitation during La Niña episodes.

Regarding temperature, the best trends were observed with moderate to strong El Niño episodes which resulted in temperatures trended normal to below normal in the cool

season. During weaker El Niño episodes and during La Niña episodes the temperature correlations were ill defined.

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