EL NIÑO/SOUTHERN OSCILLATION AND PACIFIC DECADAL OSCILLATION EFFECTS ON RIO GRANDE VALLEY PRECIPITATION

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ABSTRACT

El Niño Southern Oscillation (ENSO) has been shown to have a large effect on global precipitation patterns. Specific studies have gone even further, discussing the modulating effect the Pacific Decadal Oscillation (PDO) may have on ENSO precipitation. These studies are usually focused on a large regional scale whereas this study focused on the localized impacts on the Rio Grande Valley of South Texas. Does a positive (negative) phase PDO enhance (reduce) the chances for high precipitation events in the Rio Grande Valley during El Niño fall/winter? How might the data be useful for agricultural use? This study conducted a correlation analysis to discover any relations between precipitation at Brownsville, Harlingen, and McAllen, TX, with ENSO and PDO. A direct comparison analysis between El Niño plus positive PDO events and El Niño plus negative PDO events was done to discover any modulating effects PDO might have on El Niño precipitation. The same comparison analysis was done for La Niña events.

1. INTRODUCTION

The El Niño Southern Oscillation (ENSO) has far reaching hydrological impacts around the world (Figure 1). Positive El Niño (La Niña) phases are associated with warmer (cooler) sea-surface temperature (SST) anomalies in the Eastern Pacific. Increased atmospheric convection is typically centered over the Western equatorial Pacific and shifts to the Eastern equatorial Pacific during El Niño episodes, creating drought conditions in Australia and Southeast Asia. In North America, wetter fall and winter conditions are typically seen during El Niño episodes over the Gulf region of the United States (Ropelewski and Halpert, 1986).

The Pacific Decadal Oscillation (PDO) is also a measure of SST anomalies over the North Pacific Ocean, except that it focuses on anomalies poleward of 20^{o}N (Mantau and Hare, 2002). PDO phases also persist on timescales of decades, whereas ENSO shifts occur typically every few years.

A key question that arises is how might the phase of PDO modulate El Niño/La Niña events? One study that attempted to answer this question was Kurtzman and Scanlon (2007), which used statistical regression analysis to find any correlations between seasonal precipitation patterns over the southwestern and southern United States with ENSO and PDO. Their findings showed increased precipitation over the southern Gulf region during El Niño years in a positive PDO phase, and drier conditions over the same region during La Niña years in a negative PDO phase.

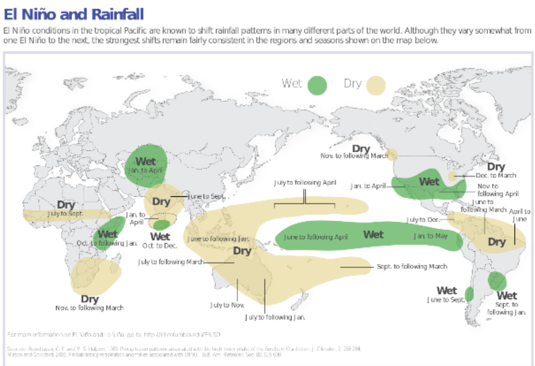

Figure 1. Global El Niño precipitation patterns, from Ropelewski and Halpert, 1986.

The previous studies were done on a large regional scale. This study will focus on the Rio Grande Valley of South Texas, specifically Brownsville, Harlingen, and McAllen. Similar to the motivation of Kurtzman and Scanlon (2007), the results of this study will be of considerable interest to decision makers in agricultural and other communities dependent on water resources.

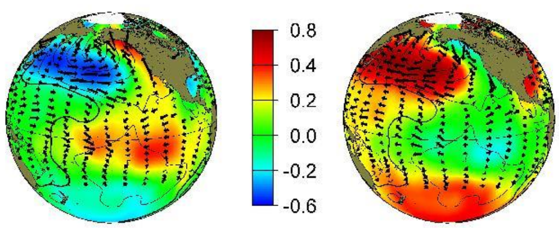

Figure 2. SST anomalies over the North Pacific during negative (left) and positive (right) phases of PDO, from JISAO.

2. PURPOSE

Previous studies that have focused on PDO modulation of ENSO events have been on a regional or continental scale. None have focused specifically on the Rio Grande Valley using precipitation data from the area. Does PDO have any modulating effects on local precipitation amounts during the months of October – December (OND) during El Niño or La Niña events? This study aimed to answer this question.

3. METHODOLOGY

The local study focused on monthly precipitation totals for the cities of Brownsville, Harlingen and McAllen, TX. These are the three main population centers for the Rio Grande Valley.

These three precipitation data sources were individually correlated to the Oceanic Niño Index (ONI) and the PDO Index where precipitation was the dependent variable and ONI and PDO were the independent variables.
A multivariate regression analysis was performed to discover any significant correlation between precipitation and ENSO plus PDO. Three month averages of precipitation, ENSO and PDO from October through December, were used in the regression analysis.

Further analysis was done to compare average El Niño precipitation with La Niña precipitation. El Niño and La Niña events were split into two regimes, one with positive PDO and the other with negative PDO, to discover any modulating effects PDO might have on El Niño or La Niña precipitation.

3.1 Data Sources

The precipitation data sources originated from a combination of Automated Surface Observing System (ASOS) / Weather Bureau Airport Stations (WBAS) and Cooperative Observer Network (COOP) sources. Daily precipitation observations for ASOS/WBAS sites are collected for a calendar day (12 AM to 11:59 PM Local Time). COOP data are collected generally from 7 am to 7 am leaving the possibility that some rain observations actually occurred on the previous day. Discrepancies in the COOP data would only arise for monthly totals if a rain event occurred on the first or last day of the month.

ASOS/WBAS was the preferred source. COOP sites were used to fill in missing gaps in the data and to extend the data further back in time to enlarge the sampling. Brownsville used COOP data from 1911 to 1949, WBAS from 1950 – 1994, and ASOS from 1994 – 2014. Harlingen used COOP data from 1911 – 1952 and 1962 – 1998; WBAS calendar day observations from 1952 to 1962, and ASOS from 1998 – 2014. McAllen used WBAS from 1961 through 1996 and ASOS from 1996 – 2014.

The ENSO ONI index was collected from NOAA's Climate Prediction Center (CPC). The ONI is a 3-month average of SST anomalies across the equatorial Pacific. For example, the ONI for October would be the average anomalies for August, September and October. The data ranged from 1950 to 2014. To extend the ONI data back to 1911, a Multivariate ENSO Index (MEI) was collected from the Hadley Centre measure of Pressure and SSTs over the equatorial Pacific. These data use bi-monthly averages whereas the ONI uses tri-monthly averages.

The PDO Index originated from NCDC reconstruction of SSTs. This was done to extend the original Mantua PDO index further back to the 1850s. This study uses this index from 1911 – 2014.

4. RESULTS

The period of 1911 – 2014 saw 30 unique El Niño events, and 23 unique La Niña events. This gave a sample size of 52 for the regression analysis done for Brownsville and Harlingen. For each case, both locations showed a positive trend of precipitation with higher index values (Figures 3 – 6).

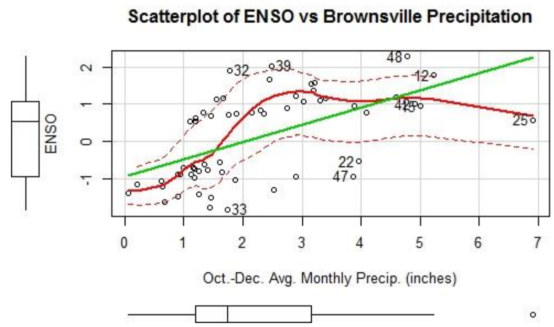

Figure 3. ENSO vs Brownsville Precipitation (inches).

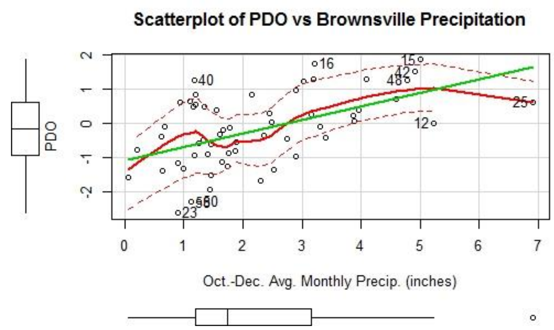

Figure 4. PDO vs Brownsville Precipitation (inches).

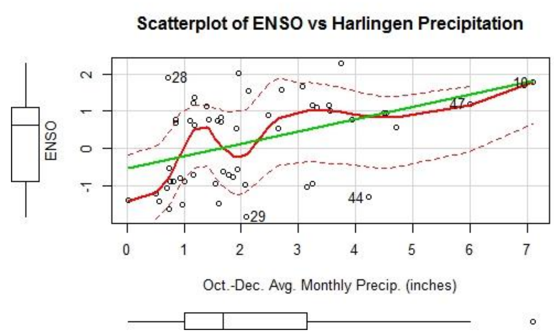

Figure 5. ENSO vs Harlingen Precipitation (inches).

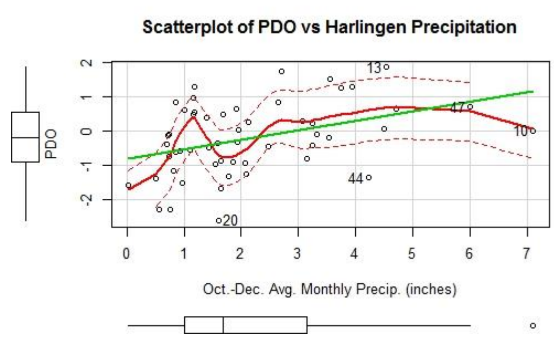

Figure 6. PDO vs Harlingen Precipitation (inches).

Brownsville precipitation showed a statistically significant correlation with both ENSO and PDO. A power transformation, a function that makes these data more normally distributed for more robust statistics, was applied to the Brownsville precipitation, since it displayed a positive skewness. Both the raw and transformed models resulted in a significant positive trend with ENSO and PDO. The models show that ENSO played a stronger role than PDO in its correlation with precipitation as seen in Tables 1 and 2.

Table 1. Brownsville Regression Model.

Variable	Coeff	Std Error	p-value	adj-r^2
ENSO	0.48	0.17	0.00599	0.35
PDO	0.39	0.18	0.0378	

Table 2. Brownsville Transformed Regression Model.

Variable	Coeff	Std Error	p-value	adj-r^2
ENSO	0.37	0.11	0.00122	0.38
PDO	0.22	0.12	0.06146	PT λ=0.5

Harlingen showed similar results with less significance. The precipitation also displayed a positive skewness, and there were two regression models run with raw and transformed precipitation. Although both ENSO and PDO displayed a positive correlation with precipitation, only ENSO was significant at the 90% confidence level (Tables 3 and 4). Precipitation outliers with high leverage at Harlingen may be influencing the significance of these results, in particular in 1930 and 1998. In 1930, the highest average OND rainfall total occurred at 7.10 inches. There is a corresponding strong El Niño event; however the PDO value during OND 1930 is neutral at 0.01. This value has high leverage in reducing the correlation of precipitation and PDO closer to the null hypothesis. In 1998, high precipitation occurred with 4.23 inches during the OND period, during a strong negative phase in both ENSO and PDO. Despite the lack of significant results, the higher precipitation events for OND with 5 or more inches occurred during positive ENSO and PDO phases, rather than during negative phases.

Table 3. Harlingen Regression Model

Variable	Coeff	Std. Error	p-value	adj r^2
ENSO	0.37	0.21	0.08	0.175
PDO	0.31	0.23	0.18	

Table 4. Harlingen Transformed Regression Model

Variable	Coeff	Std. Error	p-value	adj r^2
ENSO	0.25	0.14	0.07	0.2
PDO	0.23	0.15	0.13	PT λ=0.5

Precipitation at McAllen also showed positive skewness, and it was deemed a power transformation would be useful again in providing a more normally distributed dataset. The results only show that PDO had a significant positive trend. This was evident when 5 of the 6 highest average OND precipitation values occurred during positive PDO phase events; the lone negative phase high precipitation event occurred in 2009.

Table 5. McAllen Regression Model

Variable	Coeff.	Std. Error	p-value	adjr^2
ENSO	0.17	0.14	0.22	0.23
PDO	0.32	0.16	0.059	

Table 6. McAllen Transformed Regression Model

Variable	Coeff.	Std. Error	p-value	adjr^2
ENSO	0.15	0.11	0.19	0.24
PDO	0.25	0.13	0.06	PT λ=0.5

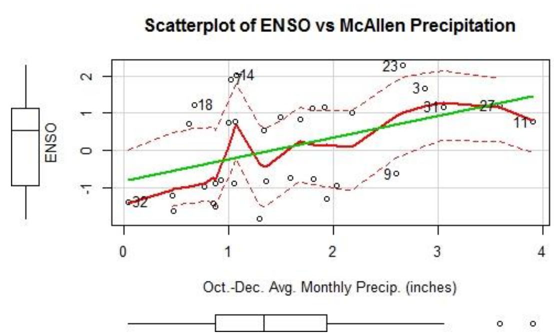

Figure 7. McAllen ENSO vs Precipitation

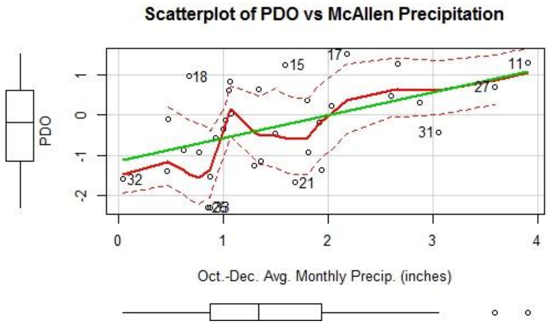

Figure 8. McAllen PDO vs Precipitation

Precipitation data for McAllen began in 1961 which severely limited the sample size. Based on McAllen's location farther inland than Brownsville and Harlingen, the rainfall events in McAllen tend to be lower. This can limit the range of the precipitation at McAllen and lower the significance of any regression model.

The question of whether or not PDO modulates ENSO with impacts on Rio Grande Valley precipitation remains. This question was approached by comparing mean precipitation amounts at each location, differentiating between El Niño with positive PDO (E+) and El Niño with negative PDO (E-) for each month of the OND period. The same comparison was done with La Niña events (L+, L-) (Tables 7 – 12).

Table 7. Brownsville precipitation (in) for ENSO with Positive PDO vs. ENSO with negative PDO.

Brownsville El Niño			
Mth.	Pos. PDO	Neg. PDO	E+/E- Events
Oct.	5.28	4.12	19/12
Nov.	2.51	2.29	19/12
Dec.	1.98	2.07	22/8

Table 8. Harlingen precipitation (in) for ENSO with Positive PDO vs. ENSO with negative PDO.

Harlingen El Niño			
Mth.	Pos. PDO	Neg. PDO	E+/E- Events
Oct.	3.65	3.24	19/12
Nov.	2.18	1.85	19/12
Dec.	2.29	2.50	22/8

Table 9. McAllen precipitation (in) for ENSO with Positive PDO vs. ENSO with negative PDO.

McAllen El Niño			
Mth.	Pos. PDO	Neg. PDO	E+/E- Events
Oct.	1.81	1.78	10/7
Nov.	1.67	0.75	10/7
Dec.	1.55	2.17	11/5

While the regression analysis revealed significantly higher precipitation amounts during El Niño events than during La Niña events, and even revealed the same for direct comparison between positive and negative PDO events, direct comparison of El Niño to La Niña events did not reveal any strong PDO modulation.

Due to the positive correlation between PDO and precipitation, it could be hypothesized that we should see higher precipitation during positive PDO events than negative PDO events in both El Niño and La Niña years. Tables 7 – 9 show this

Table 10. Brownsville precipitation (in) for ENSO with Positive PDO vs. ENSO with negative PDO.

Brownsville La Niña			
Mth.	Pos. PDO	Neg. PDO	L+/L- Events
Oct.	2.71	2.34	6/21
Nov.	0.44	1.14	5/22
Dec.	0.91	0.87	7/20

Table 11. Harlingen precipitation (in) for ENSO with Positive PDO vs. ENSO with negative PDO.

Harlingen La Niña			
Mth.	Pos. PDO	Neg. PDO	L+/L- Events
Oct.	2.28	2.63	6/21
Nov.	0.73	1.23	5/22
Dec.	1.27	0.68	7/20

Table 12. McAllen precipitation (in) for ENSO with Positive PDO vs. ENSO with negative PDO.

McAllen La Niña			
Mth.	Pos. PDO	Neg. PDO	L+/L- Events
Oct.	3.32	1.68	4/12
Nov.	0.44	0.68	4/12
Dec.	1.40	0.66	4/12

for El Niño years in all three locations, except for December. The same is observed in La Niña years with the exception of November at all locations and Harlingen October where L+ observed lower precipitation than L-.

During El Niño events, higher mean precipitation is experienced for 6 E+ observations, compared with 3 observations where the higher mean precipitation is experienced during an E- event. During La Niña events, the higher mean precipitation is experienced for 5 L+ observations, compared with 4 observations where the higher mean precipitation is experienced during an L- event.

While this in itself might signal a trend, there were only two observations where an E+ event exceeds its negative counterpart by more than half an inch: McAllen November, and Brownsville October. These observations on average have seen 0.92, and 1.16 more inches respectively during E+ then during E-.

During La Niña years, McAllen was the only site that showed observations where L+ years had marginally higher events than L- years. Those months at McAllen are October (1.64” higher) and December (0.74” higher). These numbers at McAllen are not significant, as the sample sizes are very small and limited. As seen in Table 12, there were only 10 E+ events, and 4 L+ events. For all sites, El Niño events were predominantly coupled with positive PDO events, while La Niña events were predominantly coupled with negative PDO events.

The same was true at Brownsville and Harlingen, where El Niño events were predominantly coupled with positive PDO events by approximately 50%. La Niña events were predominantly coupled with negative PDO events by approximately 300%.

For high precipitation events, where the observation was at least two times the mean for that specific month, location, and PDO phase, we found some evidence supporting PDO modulation (see Table 13). At Brownsville, when ENSO and PDO were in sync, the number of high precipitation events outnumbered when ENSO and PDO were not in sync by 17:5. The same is true at Harlingen and McAllen, but to a lesser degree, 13:8 and 6:4 respectively. This could be explained away by comparing the percentage of high precipitation events for each combination of ENSO and PDO (Table 13). The percentage of high precipitation events for any ENSO and PDO combination were nearly the same with only a small variance. The reason for the disparity in total events arises from the number of in-sync ENSO and PDO events largely outnumbering when ENSO and PDO were not in sync.

For the top three precipitation events at each location for each month, El Niño is dominant in terms of the number of events. This analysis took the top 3 precipitation events for each month at each location and categorized them according to their ENSO and PDO phase. Of the 27 total events (3 per month x 3 months x 3 locations = 27 events), 24 were during El Niño, and 16 of those El Niños had a corresponding positive PDO compared with 8 that did not.

Table 13. Number and percentage of precipitation totals that were at least two times higher than the average for their respective month, location, and ENSO phase. BRO - Brownsville, HRL - Harlingen, and MFE - McAllen.

BRO/HRL/MFE			
E+	E-	L+	L-
7/5/4	3/5/2	2/3/2	10/8/2
.12/.08/.13	.09/.16/.11	.11/.17/.17	.16/.13/.06

Table 14. No. of top 3 precipitation events for each month in the OND period at each city. BRO – Brownsville, HRL – Harlingen, MFE – McAllen

City	E+	E-	L+	L-
BRO	7	2	0	0
HRL	4	3	0	2
MFE	5	3	0	1
TOT	16	8	0	3

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5. CONCLUSION

This study explored precipitation patterns for three municipalities in the Rio Grande Valley including, Brownsville, Harlingen, and McAllen. The questions raised here regarded the impacts of ENSO on precipitation and if PDO had any modulating effects during ENSO events. The multivariate regression analysis revealed that both ENSO and PDO had significantly positive correlations in Brownsville. Harlingen observed a significant positive correlation with ENSO only, while McAllen observed a significant positive correlation with PDO only.

Despite the direct comparison between E+ and E- events showing the majority of E+ having higher average precipitation amounts, this difference was not by a significant amount. A caveat is a small sample size in McAllen, with only 16 La Niña events and 17 El Niño events. More specifically, there were only 4 to 7 L+ events in the dataset, dependent upon the month.

El Niño events were usually associated with positive PDO. The reverse was true for La Niña events, which were predominately associated with negative PDO. This result ties back to the regression analysis, where the positive pattern with PDO and precipitation may simply be due to convenience. El Niño events are dominant during the much longer positive phase of PDO. The reverse is true for La Niña events being dominant during the longer negative phase PDO, noted previously in a study by Newman et al. (2003).

Despite the results in the comparison analysis suggesting PDO may not improve the chances of a high precipitation event in an E+ year over an E- year, E+ events are twice as likely to occur. The average monthly precipitation for E+ years is higher than E- years at all three locations during October, a month that has the highest potential for flooding during the OND period. This alone can be reason enough for stakeholders in agriculture, water use, drainage, and emergency management to pay extra attention to the possibility of high precipitation events during E+ events.

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