An Examination of the Impact of ENSO Phases on Gulf Coast Tropical Cyclones

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ABSTRACT

Hazards associated with tropical cyclones impact residents along the United States coastline annually. Despite advances in weather forecasting, injuries or fatalities continue to be seen as these systems move onshore. Prior studies have discussed some of the factors which could influence the development and/or subsequent track of tropical cyclones. In this study, the authors chose to examine the influence of ENSO phase on landfall frequency along the southern Texas coast, then compare the results to a similar study area western Florida Peninsula. National Hurricane Center, Climate Prediction Center, and National Centers for Environmental Prediction Center data were used to examine the origins of and conduct a statistical analysis on a total of 41 landfalling tropical cyclones affecting the Texas and Florida study areas between 1950 and 2008. Preliminary results indicated the South Texas and West Florida coastlines are more likely to experience a landfalling tropical cyclone during the neutral or cold phases of ENSO, and suggested a possible relationship between ENSO phase and landfall frequency.

1. INTRODUCTION AND BACKGROUND

Tropical cyclones are large storm systems characterized by a low pressure center fueled by the latent heat of condensation, as shown in Figure 1. In the Atlantic and Gulf of Mexico basins, these storms are called tropical storms when maximum wind speeds exceed 17 ms^{-1}, and hurricanes when maximum wind speeds exceed 33 ms^{-1}. Regardless of their strength, the United States coastline is vulnerable to the impacts from a landfalling tropical cyclone.

Many studies demonstrate some relationship between the impacts of ENSO to tropical cyclone. Pielke (1999) shows that, on average, storms are more likely to cause damage during La Niña (cold phase of ENSO) than El Niño (warm phase of ENSO). Studies such as Gray (1984) show an increased number of tropical cyclones during the La Niña phase and a decrease during the El Niño phase. According to Gray (1984), this is attributed to an "anomalous increase in the westerly winds over the Caribbean basin and the equatorial Atlantic. Such anomalous westerly winds inhibit tropical cyclones activity by increasing tropospheric vertical wind shear and giving rise to a regional upper level environment which is less anticyclonic and consequently less conducive to cyclone development and maintenance."

Elsner (2003) referenced the need to know what climatic factors influence a tropical cyclone's track. Given these possible factors, this study examined named tropical cyclones occurring since 1950 along the southern Texas coastline during various phases of ENSO. These results were then compared to named tropical cyclones along a similar region of the western Florida Peninsula.

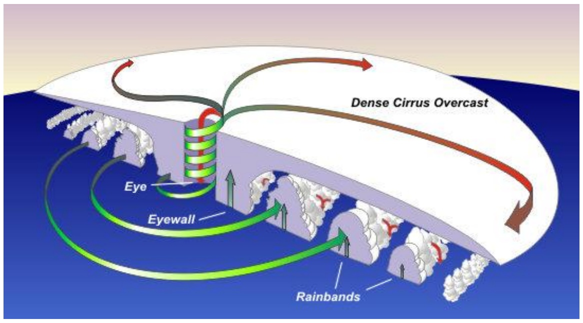


Figure 1. *An example of tropical cyclone structure.*

Bove et al. (1998) mentioned that the mean number of landfalling hurricanes in the United States annually was 1.04 during El Niño years, 1.61 during Neutral years and 2.23 during La Niña years between 1900 and 1997. Through a Poisson process, these authors also found that the probability for two or more landfalling hurricanes during La Niña phases was 66%, 28% during El Niño and 48% during Neutral years. Also, his studies demonstrate that the probabilities for a major hurricane landfall are 23% during El Niño conditions, 63% during La Niña conditions, and 58% during Neutral conditions.

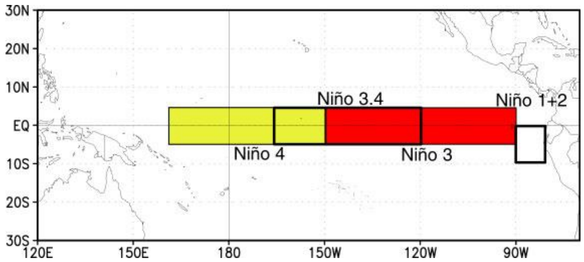


Figure 2. *All regions where the anomalies from ENSO phases are more frequented in the Pacific basin (Niño 4, Niño 3.4, Niño 3 and Niño 1+2).*

Anomalies in the Sea Surface Temperature (SST) have been studied for the past several years in an effort to make a correlation between ENSO phases and tropical cyclone activity. The Climate Prediction Center (CPC) "considers El Niño or La Niña conditions to occur when the monthly Niño 3.4 OISST departures meet or exceed +/- 0.5°C along with consistent atmospheric features. These anomalies must also be forecast to persist for 3 consecutive months" (CPC/NCEP 2011). Figure 2 shows Region 3.4 and the other regions in the Pacific basin.

2. STUDY REGIONS

Figure 3 illustrates the tropical cyclones which have affected the Texas study area between 1950 and 2008. While 16 tropical cyclones have impacted this region, many of these events have had significant impacts. Conversely, the Florida study area has been impacted by 25 tropical cyclones during the same 58 year period (Figure 4).

To determine landfall frequencies, portions of Texas and Florida coastlines along the same latitude were studied. The Florida study area was centered just southwest of Port Charlotte (26.810°,-82.303°), while the Texas study area was centered near the northern portion of Laguna Madre (26.810°, -97.614°). Both areas included data from tropical cyclones passing within a 150 km radius of these locations. These study areas are depicted in Figures 5 and 6, respectively. Also, the Gulf of Mexico, Caribbean and the Atlantic were divided into different regions (Figure 7) in order to determine the origin of the tropical cyclones.

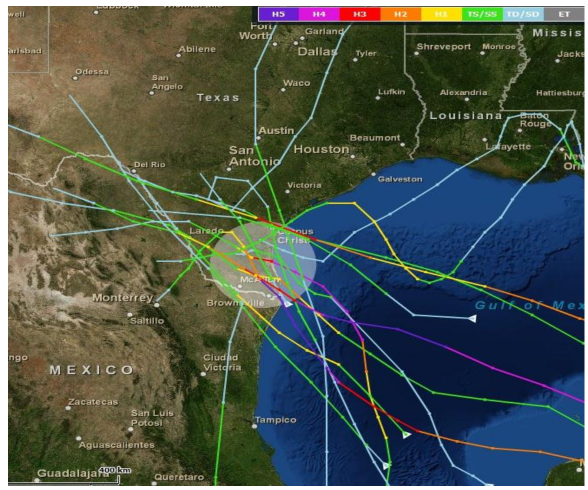


Figure 3. *All tropical cyclones affecting the Texas area, 1950-2008.*

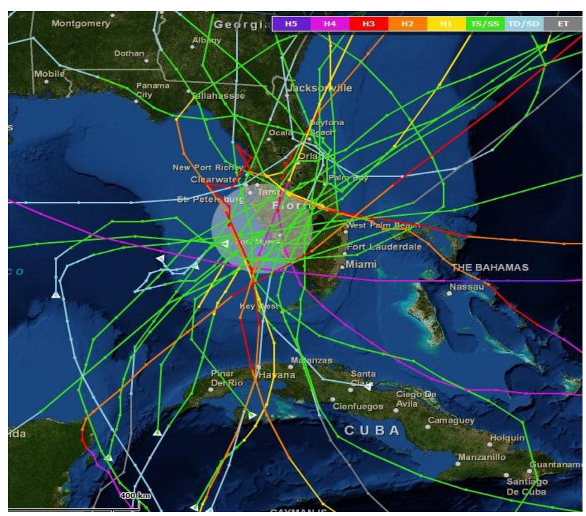


Figure 4. *All tropical cyclones affecting the Florida area, 1950-2008.*

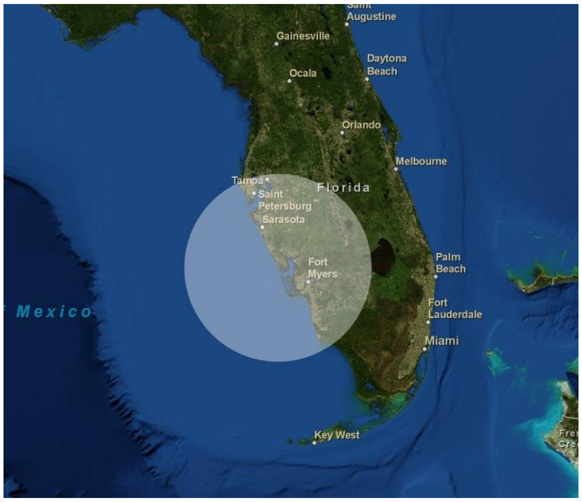


Figure 5. *Florida study region (Centered 26.810°, -82.303°).*

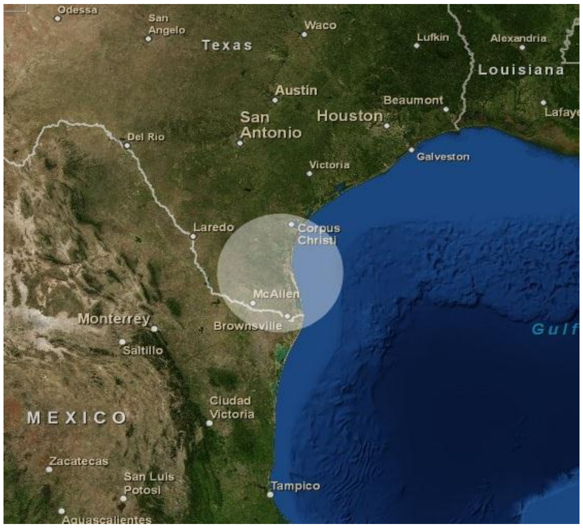


Figure 6. *Texas study region (Centered 26.810°, -97.614°).*

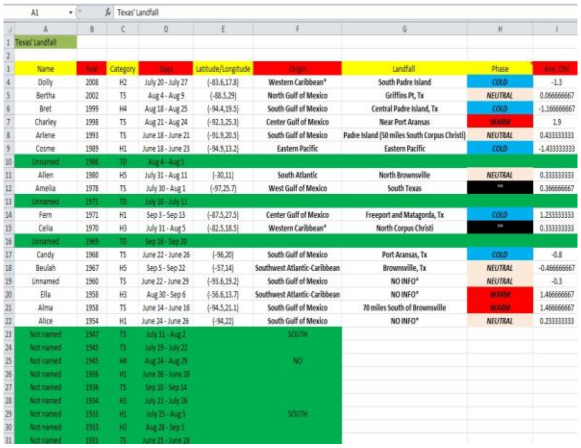
Figure 7. *Gulf of Mexico study area definitions.*

3. PROBLEM STATEMENT

Many similar studies have been completed for the Caribbean and other parts of the United States. In this work, the main focus area is the coastlines of southern Texas and western Florida. The authors wished to determine whether a correlation existed between ENSO phases and the landfall frequencies of tropical cyclones along the Lower Texas Coast. These results were then compared to a similar study area along the western Florida peninsula. This study may contribute to better preparedness for future hurricane seasons if a certain ENSO phase is in progress.

4. METHODOLOGY

Data were collected from National Hurricane Center (NHC) archives, CPC, and the National Centers for Environmental Prediction (NCEP) reanalysis data. Using NHC archives, we were able to determine a near exact day and location of development, tropical cyclone strength, and landfall location. The Historical Hurricane Tracks tool allowed us to see if a tropical cyclone affected our study area. Those systems that passed through the study area with wind speeds greater than 17 ms^{-1} were chosen. An example for the data collected from the hurricane archives can be seen in Figure 8.


Texas' Landfall

	Name	Year	Category	Days	Latitude/Longitude	Origin	Landfall	Phase	Ave. ONI
4	Dolly	2008	H2	July 20 - July 27	(-83.6,17.8)	Western Caribbean*	South Padre Island	COLD	-1.3
5	Bertha	2002	TS	Aug 4 - Aug 9	(-88.5,29)	North Gulf of Mexico	Griffins Pt, Tx	NEUTRAL	0.066666667
6	Bret	1999	H4	Aug 18 - Aug 25	(-94.4,19.5)	South Gulf of Mexico	Central Padre Island, Tx	COLD	-1.166666667
7	Charley	1998	TS	Aug 21 - Aug 24	(-92.3,25.3)	Center Gulf of Mexico	Near Port Aransas	WARM	1.9
8	Arlene	1993	TS	June 18 - June 21	(-91.9,20.5)	South Gulf of Mexico	Padre Island (50 miles South Corpus Christi)	NEUTRAL	0.433333333
9	Cosme	1989	H1	June 18 - June 23	(-94.9,13.2)	Eastern Pacific	Eastern Pacific	COLD	-1.433333333
10	Unnamed	1986	TD	Aug 4 - Aug 5					
11	Allen	1980	H5	July 31 - Aug 11	(-30,11)	South Atlantic	North Brownsville	NEUTRAL	0.333333333
12	Amelia	1978	TS	July 30 - Aug 1	(-97,25.7)	West Gulf of Mexico	South Texas	**	0.366666667
13	Unnamed	1971	TD	July 10 - July 11					
14	Fern	1971	H1	Sep 3 - Sep 13	(-87.5,27.5)	Center Gulf of Mexico	Freeport and Matagorda, Tx	COLD	1.233333333
15	Celia	1970	H3	July 31 - Aug 5	(-82.5,18.5)	Western Caribbean*	North Corpus Christi	**	0.333333333
16	Unnamed	1969	TD	Sep 16 - Sep 20					
17	Candy	1968	TS	June 22 - June 26	(-96,20)	South Gulf of Mexico	Port Aransas, Tx	COLD	-0.8
18	Beulah	1967	H5	Sep 5 - Sep 22	(-57,14)	Southwest Atlantic-Caribbean	Brownsville, Tx	NEUTRAL	-0.466666667
19	Unnamed	1960	TS	June 22 - June 29	(-93.6,19.2)	South Gulf of Mexico	NO INFO*	NEUTRAL	-0.3
20	Ella	1958	H3	Aug 30 - Sep 6	(-56.6,13.7)	Southwest Atlantic-Caribbean	NO INFO*	WARM	1.466666667
21	Alma	1958	TS	June 14 - June 16	(-94.5,21.1)	South Gulf of Mexico	70 miles South of Brownsville	WARM	1.466666667
22	Alice	1954	H1	June 24 - June 26	(-94,22)	South Gulf of Mexico	NO INFO*	NEUTRAL	0.233333333
23	Not named	1947	TS	July 31 - Aug 2		SOUTH			
24	Not named	1945	TS	July 19 - July 22					
25	Not named	1945	H4	Aug 24 - Aug 29		NO			
26	Not named	1936	H1	June 26 - June 28					
27	Not named	1936	TS	Sep 10 - Sep 14					
28	Not named	1934	H1	July 21 - July 26					
29	Not named	1933	H1	July 25 - Aug 5		SOUTH			
30	Not named	1933	H3	Aug 28 - Sep 5					
31	Not named	1931	TS	June 25 - June 28					

Figure 8. *Data table example.*

Data related to the Oceanic Niño Index (ONI) were provided by CPC. These data were classified by year, month, and values of ONI. Years were then classified as having a cold, neutral, or warm ENSO phase based upon the ONIs between December and April.

A chi-square goodness-of-fit test was used to determine the statistical validity of our results. In this test, the test statistic was calculated (to the 95% confidence interval) for the 11 years in the ENSO warm phase, 23 years in the neutral phase, and 16 years in the ENSO cold phase, where 3, 6 and 5 tropical cyclones formed during that phases (respectively) for the Texas study area (5, 10 and 6 respectively for the Florida study area). These data are shown in Table 1. The equation for the chi-square goodness-of-fit test is as follows:

$$\chi^2 = \sum \frac{[O_i - E_i]^2}{E_i}$$

where χ^2, is a random variable for the chi-square test statistic, O_i is the observed frequency count for the i th level of the categorical variable and E_i is the expected frequency count for the i th level of the categorical variable.

Two chi-square tests were used for this study. With the first test, the authors wanted to examine if there was a relationship between the occurrence of landfalling tropical cyclones and ENSO phases for the Texas study area. (The test was similarly conducted for the Florida study area.) Data from this test are shown in Table 2. Secondly, the authors wished to ensure the datasets from the Texas and Florida study areas were comparable. For this second test, the authors initially used the number of landfalls in the study area to represent the "observed" variable in the chi-square equation. The test was conducted again to allow the number of landfalls in the study area to represent the "expected" variable. As the data in Table 3 show, the results were unchanged.

Phase	Number of Occurrences of Each Phase (Expected)	Number of Landfalls: TX Study Area (Observed)	Number of Landfalls: FL Study Area (Observed)
Warm	11	3	5
Neutral	23	6	10
Cold	16	5	6

Table 1. *Data used in the chi-square goodness-of-fit test.*

5. RESULTS AND ANALYSIS

Many tropical cyclones have passed through the Florida and Texas study areas in the past several years. In the 58-year study, 16 tropical cyclones affected our Texas study area, while 25 affected Florida, for a total of 41 tropical cyclones. Statistical tests showed that tropical cyclones in these two study areas may have been affected by ENSO phases, when occurring in warm, cold, or neutral phases. Transition years (those years where the phase of ENSO changes) were not studied as part of this project. We found that 34.1% of the landfalling tropical cyclones occurred during the neutral phase, 31.1% during the cold phase and 19.5% during the warm phase. Furthermore, in our study, it appears as if tropical cyclones were more likely to develop in the Caribbean Sea than other regions. Figures 9 and 10 provide a better look at the landfall of tropical cyclones by phases and the origins.

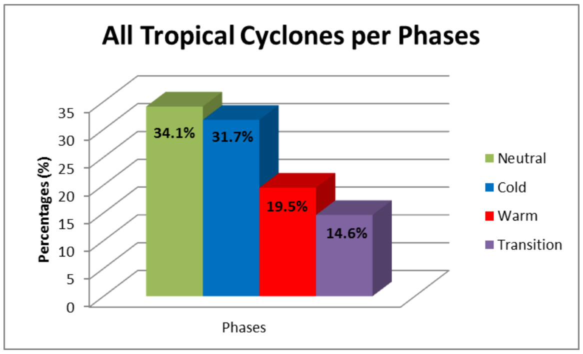


Figure 9. *Percentages for all the tropical cyclones by ENSO phases, 1950-2008.*

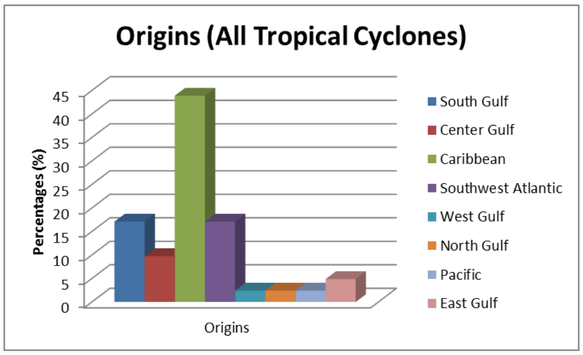


Figure 10. *Origins for all the tropical cyclone, 1950-2008.*

5.1. Texas

Since 1950, the Texas region was affected by 16 named tropical cyclones. Most (37.5%) of these tropical systems made landfall during the neutral phase, with 31.25% of the systems making landfall during the cold phase, and 18.75% during the warm phase. This information can be seen in Figure 11.

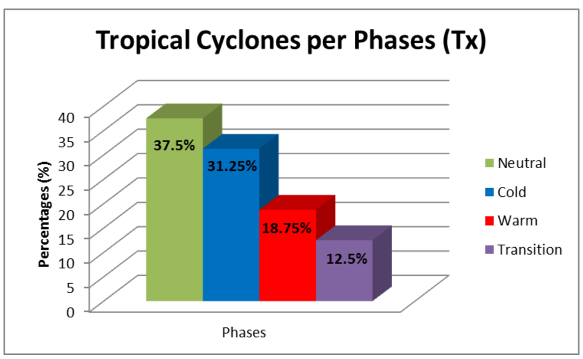


Figure 11. *Percentages for tropical cyclones by ENSO phases within the Texas region, 1950-2008.*

Most of the tropical cyclones (43.75%) that have affected South Texas originated in the South Gulf of Mexico. The Central Gulf of Mexico, Caribbean Sea and Southwest Atlantic were tied, and served as the source for 12.5% of named tropical cyclones. No tropical cyclones formed in the East Gulf for this study region (Figure 12).

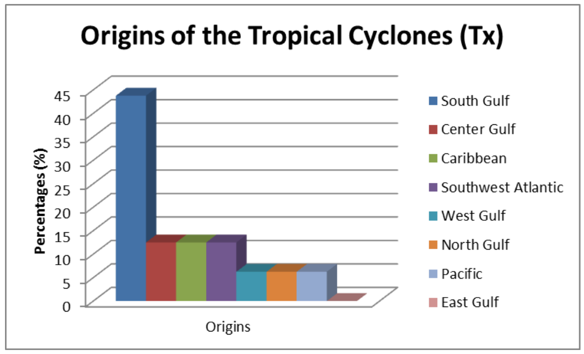


Figure 12. *Percentages of origins by tropical cyclones within the Texas region, 1950-2008.*

5.2 Florida

Since 1950, 25 tropical cyclones impacted the Florida study area. Most (40%) of these tropical systems made landfall during the neutral phase, with 24% occurring during the cold phase, and 20% during the warm phase (Figure 13).

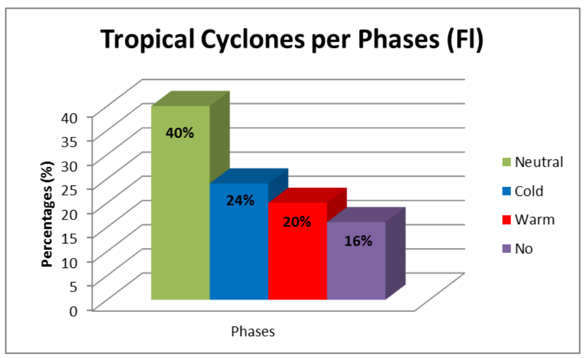


Figure 13. *Percentages for tropical cyclones by ENSO phaseswithin the Florida region, 1950-2008.*

Most of the tropical cyclones in the Florida study area formed in the Caribbean (64%). The Southwest Atlantic had the second greatest number of origins with 20% (Figure 14).

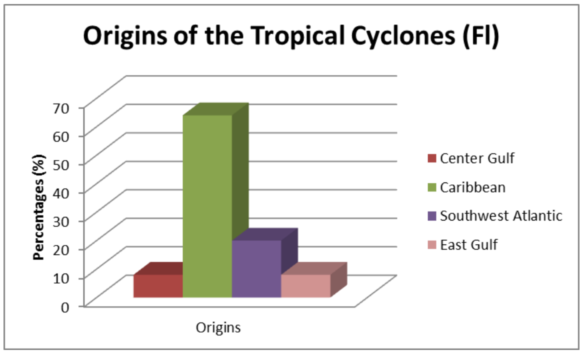


Figure 14. *Percentages of origins by tropical cyclones within the Florida region,1950-2008.*

Table 2 shows the results from the chi-Square tests. As previously stated, these tests were conducted using a 95% confidence interval. These results were accepted or rejected based upon information in a chi-square distribution table, found in a statistics textbook (Wilks 2006).

Region	χ^2
Texas	25.9459
Florida	16.8705

Table 2. *The chi-square test statistic computed for the Texas and Florida regions.*

Region	χ^2
Texas (as the expected variable)	4.2
Florida (as the expected variable)	2.5667

Table 3. *Results from the chi-square test between them using Texas as expected and Florida as expected.*

6. CONCLUSION

Hazards from tropical cyclones impact many people along the United States coastline each year. Along the coastal areas of South Texas, 16 such storms have made landfall since 1950. This research paper started as an effort by the National Weather Service in Brownsville to understand what, if any, correlation exists between landfalling tropical cyclones and ENSO phases in their weather forecast area.

There appears to be some relationship between ENSO phase and the occurrence of landfalling tropical cyclones in these two regions. These results were confirmed using a chi-square goodness-of-fit test (at the 95% confidence interval) upon rejection of the null hypotheses.

Tropical cyclones appear to occur most frequently in the neutral ENSO phase (Figs. 9 and 11). This is contrary to other studies, which show that the La Niña, or cold phase of ENSO, has the highest number of landfalling systems. As Gray (1994) concluded, this seems to be due to strong westerly winds creating an increased amount of vertical wind shear.

Given these preliminary results, it appears that knowing the ENSO phase could assist people in the coastal areas of South Texas in annual hurricane season preparations. The results presented in this paper will continue to be refined in future studies.

8. REFERENCES

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