Predicting Atlantic Tropical Cyclone Activity Using Global Circulation Model Seasonal Forecasts

Shanna T. L. Pitter

Abstract

Predicting Atlantic tropical cyclone activity has been a task dominated by the Tropical Meteorology Project (TMP) team at Colorado State University led by Dr. William Gray. Their procedure takes into consideration many parameters. Among them is the state of the El Nino Southern Oscillation, the phase of the Quasi-Biennial Oscillation, and precipitation in West Africa. The purpose of this study is to develop an equation that can be used to predict TC activity in April, two months before the start of the hurricane season. The equation makes use of sea surface temperatures and precipitation data relating to hurricane formation. A forecast for hurricane season 2002 is done and compared to the TMP forecast.

1. Introduction

Atlantic tropical cyclones (TCs) are a major cause for concern for the Unites States as they have the potential to harm the coastal US population and cause many natural disasters including flooding, tornadoes, and high winds. Researchers have been studying these storms with some hope to predict their occurrence. Dr. William Gray of Colorado State University is one such researcher. His Tropical Meteorology Project (TMP) team have been known to develop empirical formulae to compute the occurrence of TC activity up to 6 months in advance. The TMP team concentrates on forecasting the number of TCs, hurricanes, intense hurricanes, and landfall possibilities. This study is only concentrating on forecasting the number of hurricanes so that researchers can plan a field project. The idea is to avoid loss of money and time if the hurricane season is inactive and a major field project was planned. It does not use actual data as the TMP study does. Instead, the data are taken from the NCEP climate model.

According to the TMP website, the major contributors to the TMP scheme are the status of the El Nino Southern Oscillation (ENSO) and the Atlantic Sea Surface Temperature (SST) Anomaly. Up to 9 parameters are used in their scheme. This study deviates from the TMP scheme by using only the state of the ENSO, sea surface temperature averaged over the Atlantic Ocean, and precipitation in the Gulf of Guinea. In addition, this study is designed to produce a forecast of TC activity by April using data from the March 2002 forecast. This is because the NCEP model forecasts 6 months in advance and the data are not available from them until the middle of the month.

ENSO conditions, Atlantic SSTs, and precipitation in West Africa are chosen because studies by Gray and others. Gray (1984) have shown that when a strong to moderate El Nino is present, the number of hurricanes observed is decreased by 44% from non-El Nino years. This is because high Pacific SSTs induces westerly wind shear in the tropical North Atlantic and Caribbean atmosphere, which destroys a growing tropical disturbance. The Atlantic SSTs are used because hurricanes need warm waters to help with hurricane genesis and intensification. Precipitation is used because Gray has found strong positive relationships between the West African rainfall and TCs (1990). However, since precipitation has been low for the past few years, the TMP team have abandoned its usage. These parameters are used to see if the modeled parameters have the same relationships.

2. Approach

a. Data

The data used in this study are over the period 1979 – 1999. TC, ENSO observations, and modeled data are used to develop an index which predicts TC in the Atlantic 2 months in advance of the official hurricane season and 4 months in advance of the more intense part of the hurricane season beginning in August.

TC observations are taken from the archives of the National Hurricane Center, which is easily accessible from their website. The data are presented on a map with each storm's track and intensity throughout its lifetime. The names of the storms as well as their highest classification and dates of their lifetime are given. Figure 1 shows a typical map. The data used are only for tropical storms and hurricanes, thus named systems. Those classified as subtropical are not included in this study.

ENSO observations are taken from the National Center for Environment Prediction (NCEP) /Climate Prediction Center which are on their website. The data are presented in Table 1, which illustrates the condition of the SST anomaly for a three-month span. The categories are moderate, strong, weak, and neutral event. The events are either warm or cold, suggesting an El Nino with a warm event, and a La Nina with the cold event.

The data used to develop the index are taken from a global circulation model run by NCEP. The 6 months hindcasts are taken from the June 2001 model run. The data are 1m surface temperature in Kelvin, and precipitation in m/s, both of which are on a 128 x 64 grid. The surface temperature data over the oceans are forced using actual SST observations, therefore 1m surface temperatures are assumed to be SSTs.

Table 1. ENSO conditions between 1979-1999.(N is neutral, W for moderate warm event, C for moderate cold event, - for weak, and + for strong)

Year	JFM	AMJ	JAS	OND
1979	N	N	N	N
1980	W-	N	N	N
1981	N	N	N	N
1982	N	W-	W	W+
1983	W+	W	N	C-
1984	C-	C-	N	C-
1985	C-	C-	N	N
1986	N	N	W-	W
1987	W	W	W+	W
1988	W-	N	C-	C+
1989	C+	C-	N	N
1990	N	N	W-	W-
1991	W-	W-	W	W
1992	W+	W+	W-	W-
1993	W-	W	W	W-
1994	N	N	W	W
1995	W	N	N	C-

1996	C-	N	N	N
1997	N	W	W+	W+
1998	W+	W	C-	C
1999	C+	C	C-	C

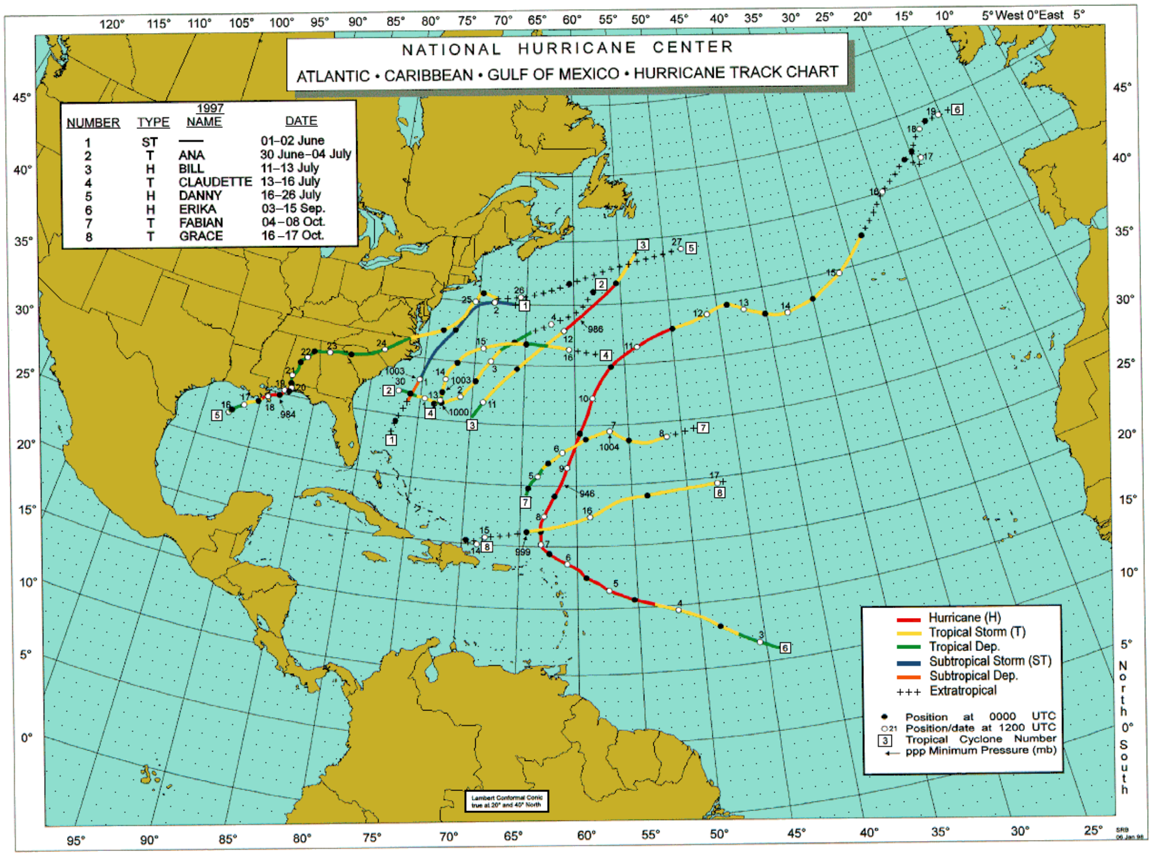

Figure 1. Typical TC activity map that provided the observations

b. Procedure

SSTs in the Pacific Ocean and the Atlantic Ocean in addition to precipitation in the Gulf of Guinea are collected from the model using the programs made available for this class. Table 2 gives the latitudes and longitudes of the data points used. The SSTs in the Pacific are compared to the ENSO data from NCEP/CPC to see how well the models capture temperature anomalies. To determine which data points and which months to use, a correlation study is done. Only locations and variables that shows a R^2 of greater than 0.2 are used. In regions like the Pacific and the Gulf of Guinea, using one data point gives much higher correlation coefficients than averaging over many data points. In the Atlantic, there difference is not as pronounced so the regional average is used. After the variables have been determined, multiple linear regression is done on the data to create an index. The multiple linear regression is done using the Data Analysis package of Microsoft Excel.

The multiple linear regression is developed using 10 randomly picked years of data from all the variables previously determined. Then the equations are tested with the remaining 11 years to see how well the linear model worked. The procedure is repeated several times using a different combination of years to make the equation and to test it. The final equation is the best fit returned by the multiple linear regression.

Table 2. Parameters used to develop the TC index

Parameter	Location
SST in Pacific (July and August)	0N, 170W
SST in Atlantic (July) averaged	5N 20W 10N 30W 15N 40N 15N 50W 18N 60W
Precipitation in the Gulf of Guinea	5N 5W

3. Results and Discussion

a. Development of the index

Table 3. Individual R^2 values for each parameter

Parameter	R^2
SST in the Pacific (July)	0.4556
SST in the Pacific (August)	0.3492
SST in the Atlantic (July)	0.3664
Precipitation in the Gulf of Guinea	0.2127

The multiple linear regression equation derived from the parameters in Table 3 is used to predict tropical cyclone activity. Figure 2 shows the results of the calibration equation on the original data. Several random samples are drawn, but the range of coefficients varies largely with each sample. However, when the predicted data are compared to the actual in the validation data set, the same kind of agreement is seen. Figure 3 shows how the predicted data fits the actual data with a R^2 value of 0.5533. The regression equation is:

Number of TC = -3.87427* SST in the Pacific (July)+3.755974* SST in Pacific (August) + 5.60211* SST in the Atlantic (July) +590713960.17* precipitation in the Gulf of Guinea -1638.26 (1)

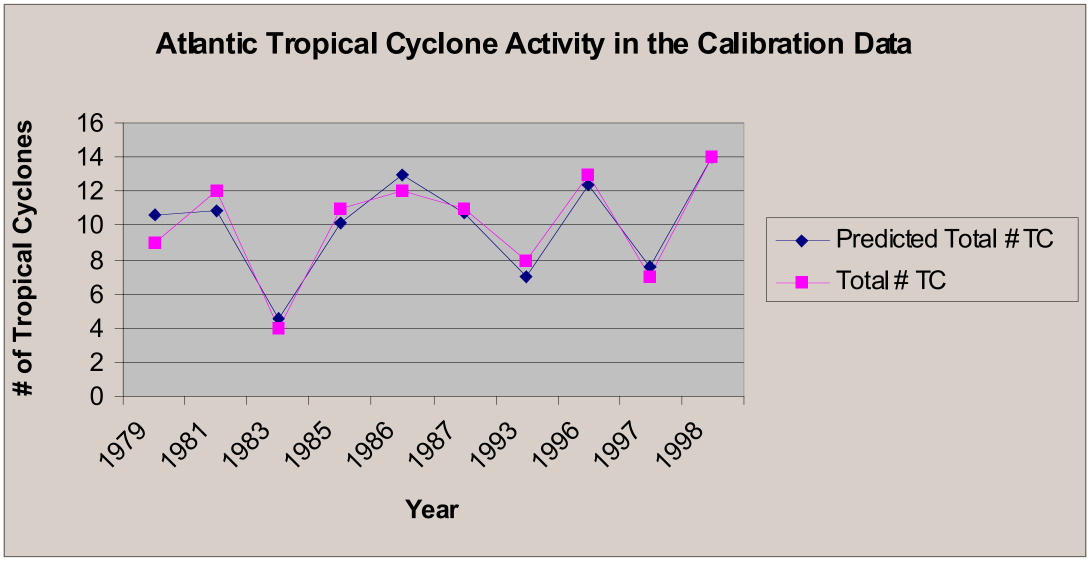

Figure 2. Atlantic Tropical Cyclone activity in the calibration data set

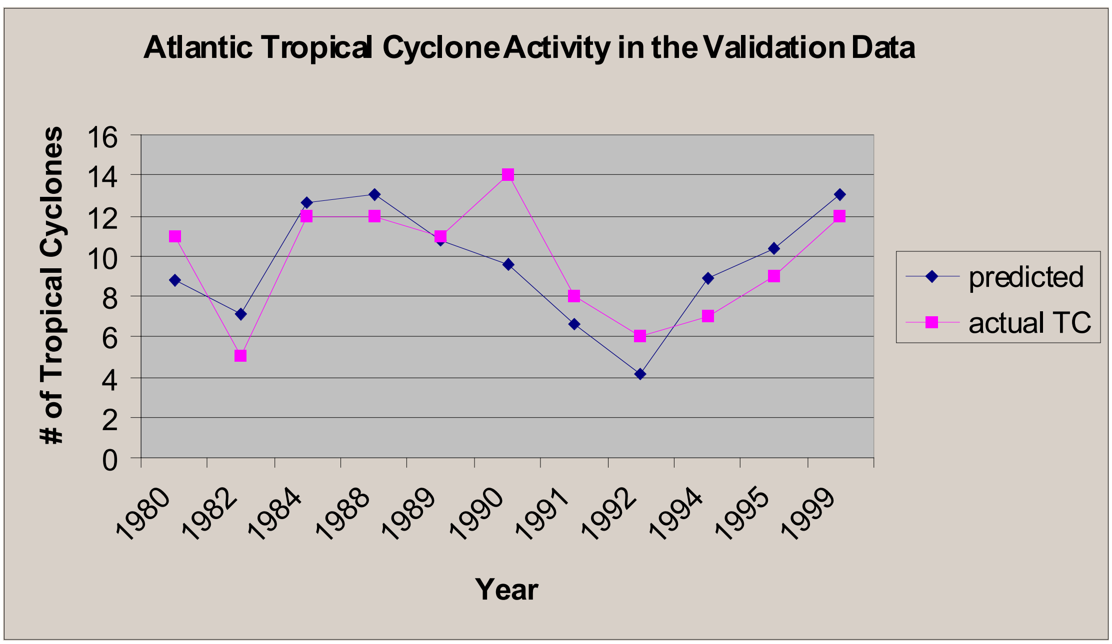

Figure 3. Predicted tropical cyclone activity from the regression equation

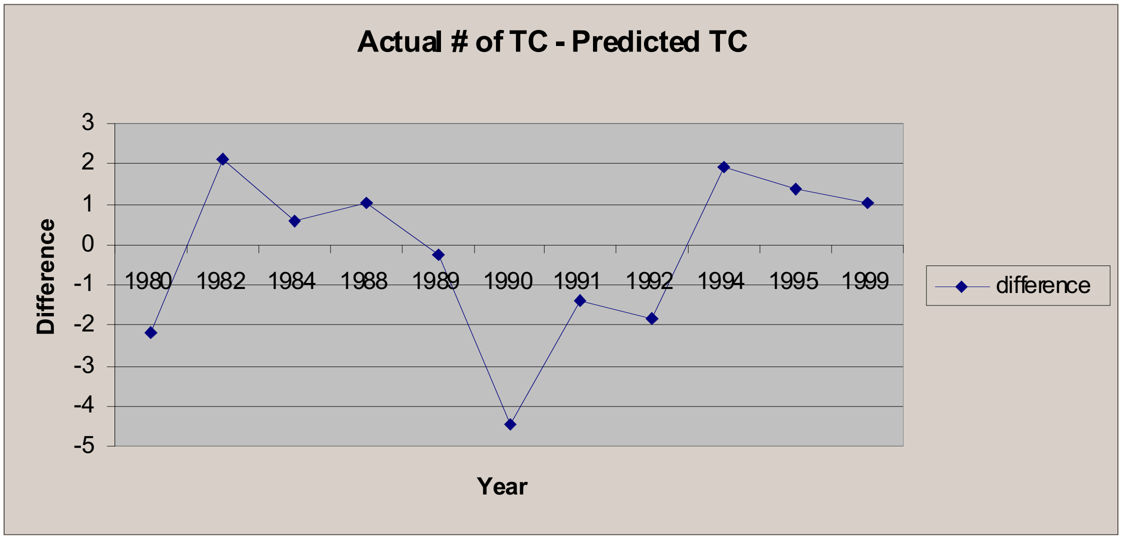

Figure 4. Actual observations – predicted TC in the validation data

As shown by Figure 3, the fit of the regression equation is good. Figure 4 shows that the model under-predicts the activity in the late 1980s – early 1990s. The rest of the period is over-predicted. This may be explained by the SSTs in the Pacific. The late 1980s – early 1990s are dominated by weak to moderate El Nino events while the rest are variable. The calibration data did not have any weak El Nino events so the model could not handle such events. A larger sample would alleviate this problem. For this index to be used in weak warm event years, an upward adjustment is required. Also, the extreme events are not accurately captured. Table 1 shows that 1982 had a strong El Nino which should give less TCs. The index underestimates the TC activity on that year so predictions in expected extreme warm event years should be lowered for operational use. The index does well for cold ENSO events, neutral ENSO events, and moderate warm ENSO events. It could be used by researchers and others anticipating the upcoming hurricane season.

To improve the quality of the regression equation, a larger data set would have been better. As seen with the weak El Nino events, generating a random sample from such a small data set does not accurately represent the entire data set. Therefore the regression equation will not be able to handle those events not adequately sampled in the calibration data set. Also, a wider area of data points would improve the regression equation's fit. Sampling SSTs in the Gulf of Mexico and the Caribbean Sea may have shown great correlations. Some points were sampled from these regions but they showed low correlation coefficients and R^2 values.

b. Forecast for hurricane season 2002

A forecast for hurricane season 2002 is done using the March 2002 forecast. The same parameters in Table 3 are used to issue a forecast. The value derived from the index in Equation 1 is 12 TCs. The forecast by the NCEP model calls for warm Pacific SSTs, so an El Nino event. However with a temperature of 302K, this is a strong event yet not as strong as the 1997 event, but on par with the 1982 event. The Atlantic SSTs are at average warmth, 300K. The African precipitation is wetter than normal at 4.79 *10^-9 m/s. These combine to give an above average hurricane season. An average hurricane season would have 9 named storms. Since the model over-predicted the 1982 event and since 1982 was drier than this year with relatively the same Atlantic SSTs, the official forecast from this index should be lowered to around 11 TCs. The TMP forecast calls for 10 TCs. Their forecast is derived using their different parameters. Only the upcoming hurricane season can verify this forecast.

4. Conclusion

Atlantic TC activity is computed using a multiple linear regression equation. The lead time of the forecast is 2 months before the official start of the hurricane season, but 4 months before the more intense part of the season. The parameters used are the state of the ENSO, Atlantic SSTs, and precipitation in the Gulf of Guinea. These are chosen based on work done by the famous TMP team, which is lead by Dr. William Gray. They use up to 9 parameters based on actual data in their regression equation while this index uses modeled data from the NCEP climate model. The equation developed is tested on 11 years of data and shows high correlations and explains over 55% of the variance. There are problems forecasting weak to moderate ENSO events, ie it underestimates TC occurrence. To use this index, adjustments should be made in the index's problem areas. With this in mind, a forecast of the 2002 Hurricane Season is done and a raw value of 12 storms is returned. However, with the adjustments, the official forecast is for 11 storms. This is close to the TMP forecast of 10 storms. The accuracy of this forecast can only be determined at the end of the upcoming hurricane season.

5. References

Gray, W. M., 1984b: Atlantic seasonal hurricane frequency: Part II: Forecasting its variability. *Mon. Wea. Rev.,* **112**, 1669-1683

-- ,1990: Strong association between West African rainfall and U.S. Landfall of intense hurricanes. *Science*, **249**, 1251-1256

-- , C. W. Landsea, E. Blake, P. Klotzbach, 2002: Updated forecast of Atlantic Seaonal Hurricane Activity and US landfall strike probabilities for 2002. http://typhoon.atmos.colostate.edu/forecasts/2002/april2002/

Landsea, C.W, W.M. Gray, P.W. Miekle, K. J. Barry, 1994: Seasonal Forecasting of Hurricane Activity. *Weather,* **49,** 00. 234-284

National Center for Environmental Prediction Climate Prediction Center website, http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.html

National Hurricane Center Tropical Prediction Center website, http://www.nhc.noaa.gov/pastall.html