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Severity of Tropical Cyclones atypical during El Nino—A Statistical Elucidation

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Abstract: Tropical cyclones are one of nature's most violent manifestations and potentially the deadliest of all meteorological phenomena. The casualty associated with major cyclones in the Indian sub-continent gives an idea about its enormous destructive capability.

The effect of El Nino over Indian Ocean is not fully understood yet. The present study is an attempt to establish a relationship between El Nino and severity of tropical cyclones. The rationale of the present study is to view whether a persistent cyclonic disturbance leads to the development of a tropical cyclone or severe tropical cyclone during an El Nino year. Statistical techniques are adopted to attain the objectives. The results of the study reveal that in the El Nino year cyclonic disturbances may turn to tropical cyclones but turning to its severity is absolutely unusual.

Key words: El Nino, tropical cyclone, regression analysis, ANOVA testing, F statistics.

Introduction

El Nino is referred to as a weak, warm current appearing around the Christmas along the coast of Ecuador and Peru, which last for only a few weeks to a month or more. Every three to seven years, an El Nino event may last for many months, having significant economic and atmospheric consequences worldwide (Lorentz, 1963). Over the last nine decades, ten major El Nino years are recorded, among which the El Nino event during 1982-1983 was the significant one. Some of the El Nino events have persisted for more than a year.

In the tropical Pacific, trade winds generally drive the surface water westward. The surface water becomes progressively warmer while approaching westward because of its longer exposure to solar heating. El Nino is observed when the easterly trade winds weaken, allowing warmer water of the western Pacific to migrate eastward and eventually reach the South American Coast (Gleeson, 1967). The cool nutrient-rich seawater normally found along the coast of Peru is replaced by warmer water depleted of nutrients, resulting in a dramatic reduction in marine fish and plant life.

In the non-El Nino years the trade winds accumulate warm surface water around Indonesia, raising the sea level roughly half a metre higher in the western Pacific. As upwelling persists, the level of the thermocline rises to shallower depths off the South American coast and is depressed in the western Pacific. The upwelled water is rich in nutrients and supports an abundance of fish and marine life. As surface water propagates westward, the atmosphere and the sun warm the water to accumulate in the western Pacific (Richardson, 1981). The cooler water in the eastern Pacific cools the air above and consequently, the air becomes too dense to raise and produce clouds and rain. In the western Pacific, however, the warmer water below heats the overlying air, destabilizing the lower atmosphere and increasing the likelihood of precipitation (Sikka et al., 1992).

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The effect of El Nino over Indian Ocean is not fully understood till now (Branston et al, 1992). Tropical cyclone is the most devastating event over Indian Ocean. The present study is an attempt to find a relationship between El Nino and the occurrence of severe tropical cyclones. Tropical cyclones develop in maritime airmass over sea areas where sea-surface temperature is greater than 26.5°C and the overlying tropical atmosphere is convectively unstable (Asnani, 1993).

Methodology and the Implementation Procedure

The time series analysis for different datasets of cyclonic disturbances, tropical cyclones and severe tropical cyclones in the El Nino years is done in this study. A relation is tried between cyclonic disturbances and tropical cyclones (Akaike, 1974) by computing the correlation coefficient between the persistence of cyclonic disturbances and the occurrence of tropical cyclones during an El Nino year. A linear and positive correlation between the two incidences is observed with the available dataset. Hypothesis testing is then applied to test the turning of cyclonic disturbances to tropical cyclones (Epstein, 1985; Chaudhuri et al., 2007).

This is done by defining the null hypothesis:

$H_{0:}$ The yearly frequency of cyclonic disturbances and yearly frequency of tropical cyclones in El Nino years are mutually independent.

The alternative proposition against which H_0 is to be tested is defined:

H_1: The yearly frequency of cyclonic disturbances and yearly frequency of tropical cyclones in El Nino years are not mutually independent.

To check the goodness of fit of the null hypothesis, the chi-square test is performed (Daniel, 1990). The expected frequencies are computed from the contingency table and then the observed and expected frequencies are prepared in the chi-square (χ^2) statistics as:

$$\chi^2 = \sum_{i=1}^{n}\sum_{j=1}^{m} \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}} \tag{1}$$

where $O_{i,j}$ is observed frequencies of the (i,j) cell of the contingency table and $E_{i,j}$ is expected frequencies of the (i,j) cell of the contingency table. The degree of freedom for this statistics is $(m - 1) \times (n - 1)$.

Table 1: Computed and tabular chi-square values for different changes

	Computed Chi-square	*Tabular Chi-square*	*Decision regarding Null hypothesis*
CD to TC	2.873646	30.578	Accepted
TC to STC	342.9211	30.578	Rejected
CD to STC	138.7438	30.578	Rejected

Computed values of Chi-square are compared with the standard tabular values with appropriate degrees of freedom (Wilks, 1995). The null hypothesis is accepted if the tabular value exceeds the computed value, otherwise rejected. Test is carried out at 0.01% level of significance. It is found from the test that null hypothesis is accepted (Johnson, 1987). Thus, the yearly frequency of cyclonic disturbances and yearly frequency of tropical cyclones in an El Nino year are observed to be mutually independent.

The next task is to fit a regression line to the given datasets (Draper et al., 1981). A linear regression equation of the form

$$\hat{y} = a + bx \tag{2}$$

is tried to fit the data set of the persistent cyclonic disturbances and the occurrence of tropical cyclones.

Frequency of cyclonic disturbances (CD) is considered to be the predictor (x) and frequency of tropical cyclones (TC) as predictand (y). $\hat{y}$ represents the predictand value of y (Michaelson, 1987). Thus, expression (2) leads to

$$b = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} (x)^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{3}$$

and

$$a = \bar{y} - E\bar{x} \tag{4}$$

where n is number of observations.

Hypothesis testing is again performed for the purpose. The null hypothesis in this case is defined as

H_{00}: The regression line is a good fit.

The alternative proposition against which H_{00} is to be tested is

H_{11}: The line is not a good fit.

Predictor variable in this situation is considered as the cyclonic disturbance while the occurrence of tropical cyclone is the predictand variable. With the given datasets the null hypothesis is tested with the help of chi-square statistics (Morrison, 1976). It is observed that the null hypothesis is accepted and the regression line becomes a good fit. The error between the actual and the predicted value is evaluated and the percentage error is computed.

Analysis of variance (ANOVA) is executed to test the goodness of fit of the regression line to the observed dataset (Panofsky et al., 1958). Total sum of squares (SST), regression sum of squares (SSR), sum of the squared error (SSE), mean squared regression (MSR), mean squared errors (MSE) are computed.

$$SST = \sum_{i=1}^{n} y_i^2 - n\bar{y}^2 \tag{5a}$$

$$SSR = E^2\left[\sum_{i=1}^{n} x_i^2 - n\bar{x}^2\right] \tag{5b}$$

$$SSE = \sum_{i=1}^{n}\left[y_i - \hat{y}(x_i)\right]^2 \tag{5c}$$

$$MSE = \frac{1}{(n-2)}(SST - SSR) \tag{5d}$$

$$MSR = \frac{SSR}{1} = SSR \tag{5e}$$

F-Statistic is then constructed as:

$$F = \frac{MSR}{MSE} \tag{6}$$

Construction of F-Statistics is based on the null hypothesis H_{000}:

H_{000}: The estimated error is significantly high.

This is tested against an alternative hypothesis H_{111}.

H_{111}: The estimated error is not very high.

The computed value of F when exceeds the tabular value with suitable degree of freedom, then the null hypothesis will be rejected otherwise accepted.

Measure of goodness of fit of a regression equation is the coefficient of determination R^2:

$$R^2 = \frac{SSR}{SST} \tag{7}$$

After fitting the F- statistics to the dataset of cyclonic disturbances and its turning to tropical cyclones, the correlation coefficient of the dataset of turning of tropical cyclones to severe tropical cyclone are also computed (Murphy, 1988). The result shows the values to be very less, indicating that these two data sets are not so significantly correlated with each other. The hypothesis testing is carried out for this dataset to check whether the tropical cyclones over the Indian Ocean during the El Nino years turn to severe tropical cyclones. To do this, null hypothesis is tested as:

H_{0000}: The yearly frequency of occurrence of tropical cyclones and yearly frequency of occurrence of severe tropical cyclones in the El Nino years is mutually independent.

The contradictory proposition against which H_{0000} is to be tested is:

H_{1111}: The yearly frequency of occurrence of tropical cyclones and yearly frequency of occurrence of severe tropical cyclones in the El Nino years is not mutually independent.

To check the goodness of fit of the hypothesis the chi-square statistics is computed. The computed value of the chi-square is tested with the tabular value at 0.01% level of significance with the suitable degrees of freedom. It reveals that the null hypothesis is not accepted indicating that in the El Nino years turning of tropical cyclones into severe tropical cyclone is not well evident.

The procedure is also applied for checking the turning of cyclonic disturbances to severe tropical cyclones in the El Nino years. The test reveals that turning of cyclonic disturbances into severe is not apparent in the El Nino years.

Table 2: ANOVA table with coefficient of determination for linear regression

Source	*Degrees of freedom*	*Sum of square*	*Mean of squares*	*F-statistics*	*Coefficient of determination*
Total	16	40.8861			
Regression	1	23.6459	19.20181	8.86	0.578336
Residual	15	17.2402	1.2314		

Results and Discussion

The yearly distribution of cyclonic disturbance (CD), tropical cyclone (TC) and severe tropical cyclone (STC) occurring over the coastal regions of India during the El-Nino years between 1902 and 1987 (Mandal, 1991) is considered in this study.

Initially the correlation coefficients of different datasets are computed to check the degrees of association between different datasets. It is observed that the correlation coefficient is maximum for turning of cyclonic disturbances (CD) into tropical cyclones (TC) (Figure 1). It indicates that cyclonic disturbance and tropical cyclone are significantly positively and linearly correlated (Figure 2).

The correlation values for other cases are found to be very low. The scatter diagram (Figure 3) shows that the turning of TC into STC is not linearly correlated and there exists no particular trend as well. The scatter diagram (Figure 4) shows that there exists no significant pattern for turning of CD to STC.

Variations of chi-square values, variation of F-statistic and the tabular value at the same level of significance with same degrees of freedom for different cases and ANOVA (Figures 5 and 6) clearly show that the turning of cyclonic disturbances into tropical cyclones is highly

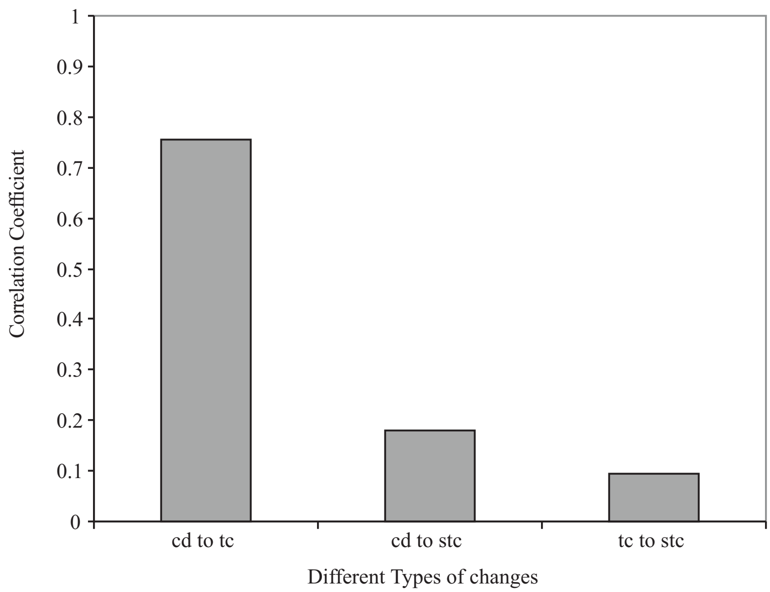

Figure 1: Diagram showing the variations of correlation coefficient for different changes.

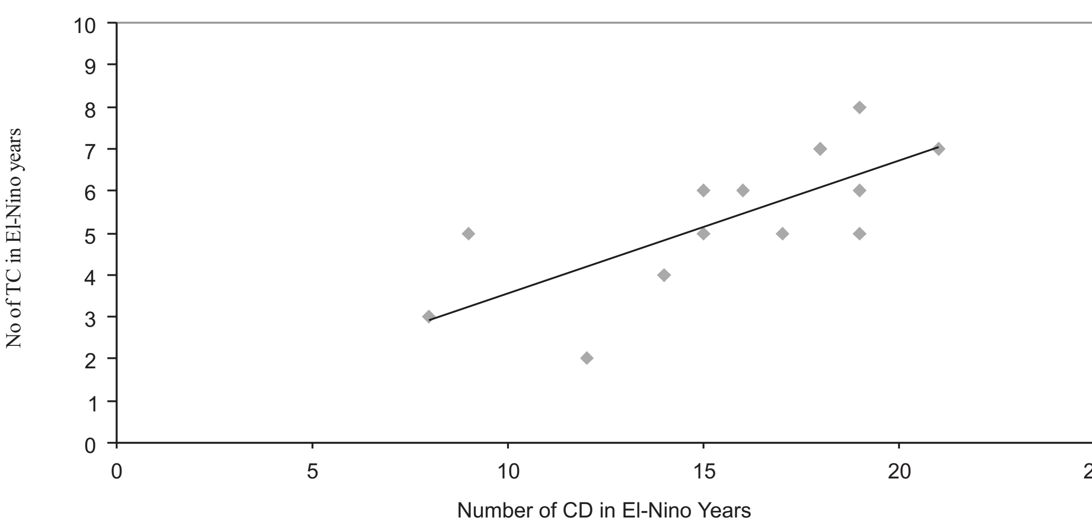

Figure 2: Scatter diagram for cyclonic disturbance (CD) as predictor and tropical cyclone (TC) as predictand.

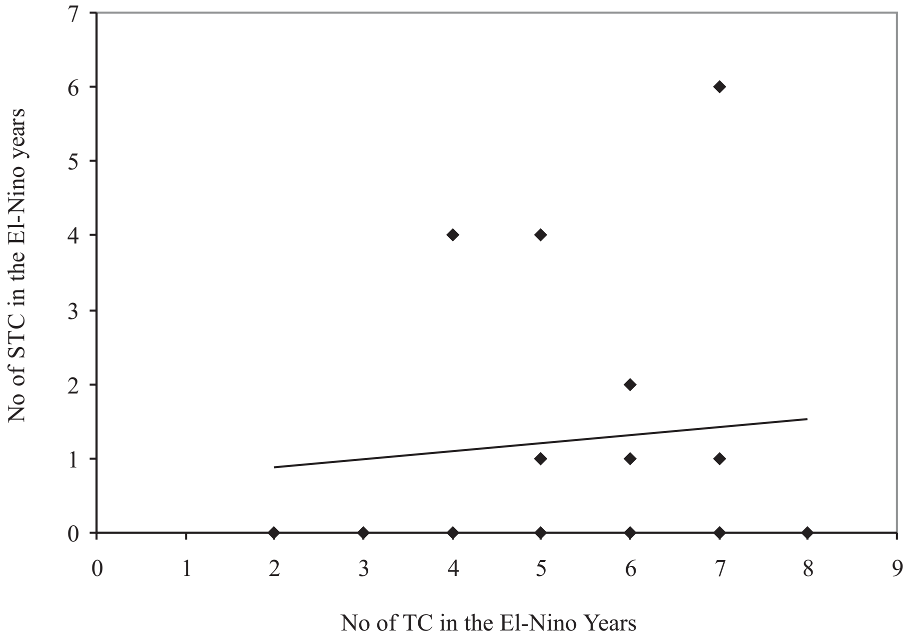

Figure 3: Scatter diagram for tropical cyclone (TC) as predictor and severe tropical cyclone (STC) as predictand.

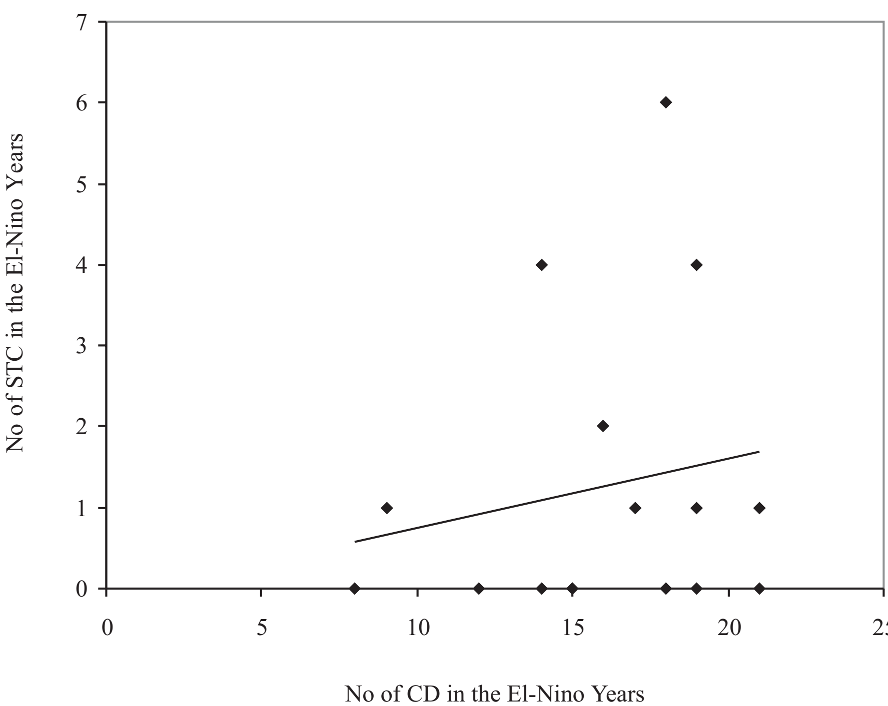

Figure 4: Scatter diagram for cyclonic disturbance (CD) as predictor and severe tropical cyclone (STC) as predictand.

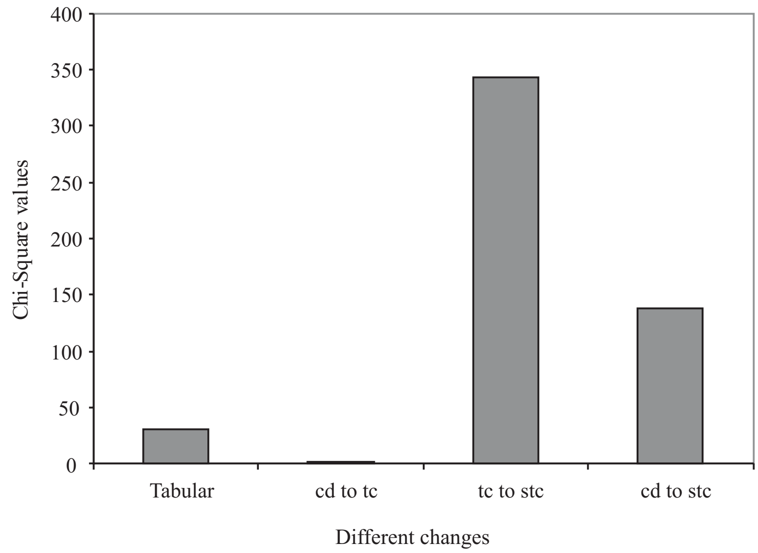

Figure 5 Schematic diagram showing the variations of Chi-square values for different changes.

Figure 6: Schematic diagram showing the actual and predicted values of occurrence of tropical cyclones in the El Nino years.

favourable in the El Nino years but turning to severe tropical cyclone is unusual.

Conclusions

The results of the study lead to conclude that the persistence of cyclonic disturbances during an El Nino year may lead to the generation of tropical cyclones, but the tropical cyclones will never turn to severe tropical cyclones. The finding confirms the theory that during the El Nino years there will be drought in southern India.

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