The Nucleus **48**, No. 4 (2011) 273-277

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

# PERSISTENCY ANALYSIS OF CYCLONE HISTORY IN ARABIAN SEA

M.A. HUSSAIN[1], *S. ABBAS[2] and M.R.K. ANSARI[2]

[1]Bahria University Campus, Karachi, Pakistan

[2]Mathematical Sciences Research Centre, Federal Urdu University of Arts, Sciences and Technology, Gulshan-e-Iqbal Campus, Karachi, Pakistan

(Received July 12, 2011 and accepted in revised form November 01, 2011)

As we know that tropical cyclones (or hurricanes) act as giant heat engines, so it is logical to assume that an increase in sea surface temperatures (SSTs) will create more intense hurricanes. Indeed, there is a general consensus among hurricane scientists that an increase in SSTs due to global warming, should, in theory, lead to more intense hurricanes. This paper discusses the tropical cyclones history in Arabian Sea with respect to trend, underlying distribution of occurrence of tropical cyclones in 120 years (1891-2010), and its persistency / anti–persistency with the help of Hurst exponent calculations. We test for presence of any positive trend in cyclones frequency in the Arabian Sea by analyzing the cyclone data of 120 years. It has been shown that there exists a statistically significant positive trend in Arabian Sea cyclone frequency data. The underlying distribution of occurrence of tropical cyclones history came out to be lognormal, suggesting an increasing multiplicative complex physical process, which strengthens the finding of positive trend in cyclone frequency data. Hurst exponent of Arabian Sea annual cyclone frequency for 120 years came out to be 0.98, which shows a persistency in future cyclone frequency and bolsters the results of trend and distribution function of cyclone frequency history. Moreover, cyclone trend values of 120 years data for the months of May, June, October, and November are also significant. Finally, sea surface temperatures for these months also reveal persistency as the values of Hurst exponent are greater than 0.5 and seems to be proportional to the cyclone frequency slope (of fitted trends) values for the same months.

**Keywords:** Sea-Surface Temperatures (SSTs), Seawater Temperature Data (STD), Tropical Cyclones (TCs), Arabian Sea Cyclone(ASC)

## 1. Introduction

Hurricanes can be considered as giant heat engines, so the growing consenting among the hurricane scientists that an increase in SSTs due to global warming would lead to more intense hurricanes. It is predicted that hurricane wind speeds should increase about 5% for every 1 degree centigrade increase in tropical ocean temperature [1], which is also confirmed by computer models [2]. In case the warming of Earth's climate continues and increases from 1.5° to 4.5° C then, the frequency of category 4 and 5 storms will enhance, and will result in heavy rains associated with dust and thunderstorms in the coastal areas. Another research indicates a 30-year trend toward more frequent and intense hurricanes [3].

Most of the countries around the North Indian Ocean are threatened by storm surges associated with severe tropical cyclones. The destruction due to the storm surge flooding is a serious concern along the coastal regions of India, Bangladesh, Myanmar, Pakistan, Sri Lanka and Oman. Storm surges cause heavy loss of lives and property damage to the coastal structures and losses of agriculture [4]. The most recent example of a super cyclone was Cyclone Phet, which churned the Arabian Sea and hit coastal Gujrat, Rajisthan and Karachi in June 2010 [5]. However, research on possible future changes in hurricane frequency due to global warming is ambiguous, with most studies suggesting that future changes will be regionally dependent, and showing a lack of consistency in projecting an increase or decrease in the total global number of storms [6-8].

This communication we shall examine the Arabian Sea cyclone data of 120 years and shall

* Corresponding author : shaheen838@yahoo.com

attempt to explore some of its statistical properties. In this connection, Section 2 gives various analyses and Section 3 discusses the results obtained after data analysis. Finally, Section 4 gives conclusion and outlook.

## 2. Material and Method

This communication uses cyclone history data (1891-2010) from Pakistan Meteorological Department, Karachi. It also uses the sea surface temperature data from the period 1871-2009 from the *Hadley British Climate Centre*, UK. In following we outline the method of our analyses employed in this work.

### *2.1. Trend Analysis*

Trends, variances, etc. in the data set are important parameters, which could be helpful in forecasting future values [9]. This section develops trend models to serve as a guide in the assessment of impact of the global warming due to the heat absorption in the ocean. To do the linear trend analysis we define the following linear model.

$$y(t) = \alpha\, t + \beta \tag{1}$$

where parameters $\alpha$ and $\beta$ are estimated using least squares method, which gives following formulae

$$\alpha = \frac{\sum y_i \sum t_i^2 - \sum t_i \sum t_i y_i}{n\sum t_i^2 - \left(\sum t_i\right)^2} \tag{2}$$

$$\beta = \frac{n\sum y_i t_i - \sum t_i \sum y_i}{n\sum t_i^2 - \left(\sum t_i\right)^2} \tag{3}$$

$t_0$ represents years in the cyclone data series considered with $t_0$= 1891. Similarly, $y_i$ denotes Arabian Sea cyclones frequency per year. The above model was applied for cyclones frequency data and obtains the models in the form depicted by Eq. (1) for annual and four months (May, June, October and November) of the year in which the frequencies are ≥ 12 in 120 years.

To see the long-term fluctuating behavior of cyclone history, next we check for adequate underlying probability distribution function (pdf).

### *2.2 Probability Distribution of Cyclone History*

If underlying process follows lognormal probability distribution then such process is, in general, non-negative, increasing, and right-continuous process [10].

Environmental parameters are generally modeled with positively skewed probability distributions like, Lognormal, Gamma and Weibull distributions. A lognormal distribution is one, which results from random interaction of the physical parameters under study [11]. Mathematically, a lognormal distribution is defined as

$$f_X(x) = f_x(x)\frac{1}{x\sigma\sqrt{2\pi}}e^{\frac{1}{2}\left(\frac{\ln x-\mu}{\sigma}\right)^2} \quad (-\infty < x < +\infty), \tag{4a}$$

$$E(X) = e^{\mu+\frac{\alpha^2}{2}}$$

$$\mathrm{Var}(X) = e^{2\mu+\alpha^2}\left(e^{\sigma^2}-1\right) \tag{4b}$$

Eq. (4b), gives mean ($E[X]$) and variance (Var($X$)) of samples respectively.

For model adequacy check, we apply the Anderson-Darling $A^2$-test (AD test), where the hypothesis testing is based on comparing the parameter in question with the large values of the statistic

$$A^2 = -\frac{1}{n}\sum_{i}^{n}(2i-1)[\ln \mu_i + \ln(1-\mu_{n-i+1}) - n \tag{5}$$

Where $u_i$ is the value of the theoretical cumulative distribution at the $i^{th}$ largest observation, $n$ being as usual the number of observations [12]. To find more insights of the physical process under study, we compute the Hurst exponent of cyclone history data.

### *2.3 Persistency Analysis*

The Hurst exponent has been applied to diverse research fields [13]. It provides a measure for long-term memory of a time series of interest and has wide applicability for time series analysis. Hurst exponent ranges between 0 and 1, and based on the Hurst exponent value H, a time series can be classified into three categories. If H = 0.5 then it indicates a random series. If 0 < H < 0.5 then it indicates an anti-persistent series. In case of 0.5 < H < 1 it indicates a persistent series. A persistent series is trend reinforcing, that is, the direction of the next value is more likely the same as current value. The strength of trend increases as H approaches 1.0. Hurst exponent, H, can be estimated using spectral density p(f) for a scale invariant process with power-law behavior over a considerable frequency scale as given by (6):

$$p(f) \propto f^{-\beta} \qquad (6)$$

Estimated β from (6) is used to compute the Hurst exponent, H, using the following relationship:

$$\beta = 2H + 1 \qquad (7)$$

By taking the log of (6) we obtain a straight line giving β as the slope. A computer program coded in Mathematica was used to estimate β [14]. Now, we discuss the estimated results obtained using cyclone data in the next section.

Table 1. Frequency of Arabian Sea cyclone data in 120 years.

| *Cyclone data* (120 years) | *Frequency* |
|---|---|
| Total annual | 194 |
| January | 01 |
| February | 00 |
| March | 00 |
| April | 08 |
| May | 33 |
| June | 45 |
| July | 09 |
| August | 02 |
| September | 11 |
| October | 43 |
| November | 37 |
| December | 09 |

## 3. Results and Discussions

As given in Table 1, frequency of Arabian Sea cyclone data in 120 years is highest in the month of June and then in October. It is lowest in the months of January and February. Total annual frequency is 194. For analysis purpose, we take total annual frequency and the months, which have frequency ≥ 12 in 120 years as mentioned in Section 2.1. Therefore, we take total annual frequency, and the frequencies of four months of the year (May, June, October and November) was taken for doing analysis on. Applying trend analysis method mentioned in Section 2.1, we get following results obtained (at $\alpha = 0.05$ level) :

*Annual* trend: $y(t) = 1.007 + 0.0110\, t$

*May* trend : $y(t) = 0.219 + 0.0010\, t$

*June* trend : $y(t) = 0.266 + 0.0018\, t$

*Oct.* trend : $y(t) = 0.232 + 0.0021\, t$

*Nov.* trend : $y(t) = 0.111 + 0.0033\, t$

Analyzing slopes of these trends we can say that the slope of annual trend is the highest one. Similarly, more cyclones in the months of November and October in future. Figure 1 depicts the time plot of total annual Arabian Sea cyclones in 120 years with fitted trend model.

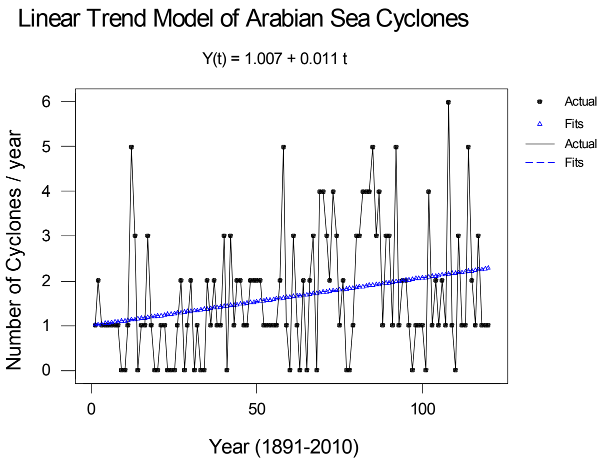


Figure 1. Time plot of total annual Arabian Sea cyclones in 120 years with fitted trend

To test for appropriate probability model for underlying process of annual cyclone frequency in the Arabian Sea, we first Histogram of 120 years cyclone data was obtained as shown in Figure 2. It revealed a lognormal (or any right tail distribution). Then, *Lognormal* distribution came out to be the most appropriate distribution (see Figure 3) among other tested distributions (Normal, Weibull and Extreme). Adequacy of *Lognormal* distribution also suggests an increasing nature of annual cyclone frequency in the Arabian Sea in future as explained in Section 2.2. Parameters of the fitted lognormal distribution and mean and standard deviation (StdDev) were estimated using MINITAB 13, which gave the following values of mean and standard deviation of total annual cyclone frequency in the Arabian Sea in 120 years.

*Mean* = 1.66 cyclones/year,

*StdDev* = 1.34

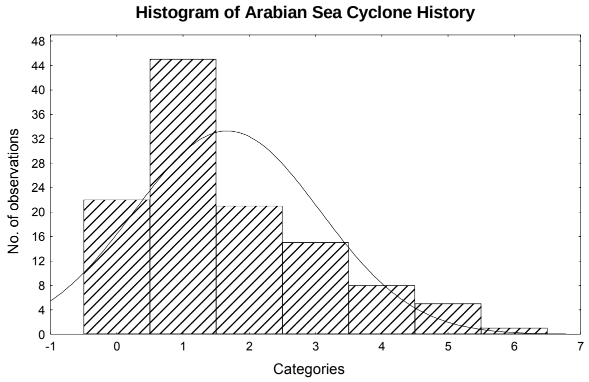


Figure 2. Histogram of total annual Arabian Sea cyclones in 120 years with fitted lognormal probability curve showing appropriateness for right tail distribution.

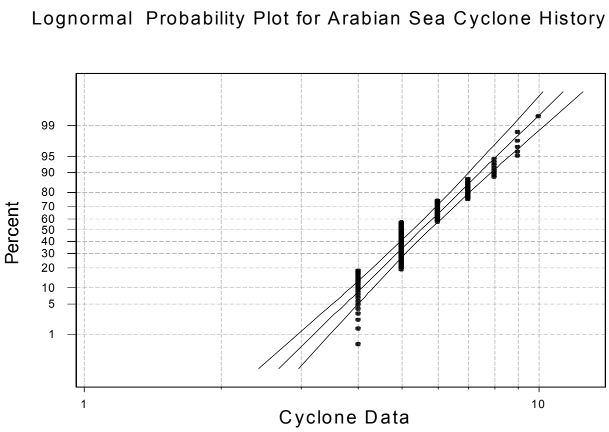


Figure 3. Lognormal probability of total annual Arabian Sea cyclones in 120 years showing adequacy for lognormal distribution. *Lognormal* gives the AD test statistic value: *AD* = 4.45

To further analyse the fluctuating behavior of annual cyclone frequency, the estimated values of the Hurst exponent for total annual cyclone frequency and SSTs of May, June, October and November (as the cyclone frequencies in these months are extremely low as compared to the annual cyclone frequency, and SSTs of these months are proportional to the respective frequencies) was examined using method discussed in Section 2.3. Values of estimated Hurst exponent have been tabulated in Table 2. The Hurst exponent value for the total annual cyclone frequency is very close to 1, bolstering the positive future trend value as shown by fitted trend in Fig. 1. Similarly, it is also important to note that the Hurst exponent values of May, June, October, and November SSTs are proportional to the slopes of the respective months. It means that one can expect higher frequency of cyclones during these months in future. Globally, researchers have observed that due to global warming the life time of cyclones and their intensities are also improving which might result in big economic losses in near and far future.

Table 2. Hurst exponent of Arabian Sea cyclone data in 120 years and SSTs for May, June, October and November. It also gives slopes of trend fitted models.

| Data sets | H | *Slopes in Trend Model* |
|---|---|---|
| Total cyclone data | 0.95 | 0.0110 per year |
| May Seawater temperature | 0.81 | 0.0010 per year |
| June Seawater temperature | 0.83 | 0.0018 per year |
| October Seawater temperature | 0.98 | 0.0021 per year |
| November Seawater temperature | 0.82 | 0.0033 per year |

The results obtained herein are an indication of climate variability in this region, which in the long term would constitute climate change. The problem of understanding of persistency and anti-persistency is also important in relation to global warming fluctuation as it ultimately affects the occurrence of cyclones in the possible future temperature behavior. The findings of this paper would be helpful in establishing reliable quantitative models necessary for any forecast and understanding of the dynamics of global warming.

## 4. Conclusion and Outlook

This research work corroborates the notion that interactive statistical analysis processes guide the researchers to examine the associations among the set of inter-related parameters, and facilitate a deeper understanding of the relationships. These techniques have been fused together into a powerful interactive analytics system and evaluated in a real-world hurricane frequency study. The results of a comprehensive tropical cyclone trend analysis case study reveal several important physical associations in the environmental data set, thereby facilitating a deeper understanding of the data.

In future, this research will be expanded to include additional seasonal statistics and climate study data sets. In addition, new multivariate analysis approach will be employed to enhance insights of data analysis, thus providing scientists with more effective ways of exploring the climate in the region.

**Acknowledgement**

We thank the Hadley British Climate Centre, UK, for providing the data used in this work. Some results of this paper are part of Ph. D. thesis of the second author to be submitted at the Mathematical Sciences Research Centre Federal Urdu University Arts, Sciences & Technology, Karachi.

**References**

[1] K.A. Emanuel, Nature **326** (1987) 483.

[2] T.R. Knutson and R.E. Tuleya, Journal of Climate **17** (2004) 3477.

[3] P.J. Webster et.al., Science **309** (2005) 1844.

[4] S. K. Dube et al., Mausam **48** (1997) 283.

[5] Masand Publication, The Times of India, Section : Times City, May 04 (2011).

[6] Henderson-Sellers, Bull. Amer. Meteor. Soc. **79** (1998) 9.

[7] J.F. Royer, F. Chauvin, B. Timbal, P. Araspin, and D. Grimal, Climate Dyn. **38** (1998) 307.

[8] M. Sugi, A. Noda and N. Sato, J. Meteor. Soc. Japan **80** (2002) 249.

[9] A. Naeem and M.S.J. Qureshi, J. Geography and Geology **2**, No. 1 (2010) 83.

[10] P. H. Algoet and T. M. Cover, The Annals of Probability **16**, No. 2 (1988) 876.

[11] F. P. Agterberg, Geophys. **14** (2007) 201.

[12] M.A. Hussain, Ph. D. Thesis Federal Urdu University, Karachi, Pakistan (2008).

[13] H.E. Hurst, Transactions of the American Society of Civil Engineers **116** (1951) 770.

[14] M.A. Hussain and M. R. K. Ansari, Arabian Journal for Science and Engg., Saudi Arabia **32** (2007) (2A) 189.