Effects of ENSO Cycles on South-West Monsoons in Andhra Pradesh and their Quantification

KOTLA. SIVA SANKAR RAO[1] Director & CH. HARI KIRAN[2], Andhra Pradesh State Development Planning Society (APSDPS), Andhra Pradesh, India.

Introduction

El-Niño Southern Oscillations (ENSO), are periodic departures from sea surface temperatures (SSTs) over the equatorial Pacific Ocean. ENSO cycles are composed of two phases- El-Niño and La-Niña. El-Niño represents higher than normal temperatures over the equatorial Pacific ocean whereas La-Niña represents lower than usual temperatures. These varying temperatures can affect weather patterns all over the globe by causing low and high pressure regions, change in wind speeds and directions over different pressure levels in the atmosphere and consequently increase in precipitation in some regions and decrease in some others.

These global weather cycles affect the South-West Monsoons over India. South-West monsoons are caused by a seasonal reversal of winds over the Indian Ocean due to differential pressure over land and water bringing in large amount of rainfall over the sub-continent during the months June – September. Moisture laden winds blowing from the Bay of Bengal onto the Indian subcontinent cause the south-west monsoons, responsible for about 86% of rains in India. The two phases of ENSO cycles affect the precipitation differently, with El-Niño phase leading to lower than usual rainfall whereas the rainfall increases during La-Niña.

In this article, I would like to present a model to predict the rainfall over Andhra Pradesh, a state in India during the El-Niño and La-Niña phases by analyzing the anomalies in surface temperature in the grid formed by latitudes 5°N - 20°N and longitudes 72.5°E – 82.5°E and the anomalies in precipitation over Andhra Pradesh during El-Niño and La-Niña years since 1980 over the months June-September and relation between these anomalies.

Data and Methodology

ENSO cycles are predominantly characterized by unusual temperatures over the Pacific Ocean, change in wind speeds and wind directions at different pressure levels – 1000mb, 850mb and 200mb, and also changes in outgoing long wave radiation all over the globe.

The anomalies in these variables are very small, indeed insignificant when compared to the effect these variables produce on global weather indicators like precipitation rate or precipitation water. The temperature of Sea surface during the ENSO years varies by a maximum of 2°C or 2K from the normal. The vector winds on the other hand have more or less the same magnitude in their wind speeds but their directions changed dramatically during the El-Niño and La-Niña as compared to the years with the absence of ENSO cycles.

Outgoing Long wave Radiation is an important factor to be considered while discussing climate changes and predictions. These radiations extensively affect the cloud formation in upper atmosphere levels and the rate of evaporation at sea surface and consequently the precipitation. Evaporation does affect the skin surface temperature over sea and the relative humidity in air, affecting the temperature of the land mass as well. This means that we can use SST for our study as a whole ignoring Outgoing Long wave Radiation as it well includes the role of Outgoing Long wave Radiation.

To draw an empirical relation between the anomalies in the afore mentioned variables and anomaly in rainfall over Andhra Pradesh, I have concluded that change in a scalar variable like temperature can be easily accommodated to build this empirical relation as compared to change in a vector variable like vector wind. And so I have extensively studied the influence of sea surface temperature or more precisely surface skin temperature in the grid formed by latitudes 5°N - 20°N and longitudes 72.5°E – 82.5°E over the rainfall during the months of June – September which make up the season of South-West monsoons in India.

For this study, the data has been obtained from the following sources:

- Sea Surface Temperatures (SSTs) and their anomalies in the El-Niño and La-Niña years beginning from 1981 have been obtained from U.S Department of Commerce's ESRL/NOAA division from their website http://www.esrl.noaa.gov/psd/data/composites/day/ . (El-Niño and La-Niña years have been listed in Table-1)
- Average Rainfall data has been taken from the records of Directorate of Economics and Statistics, Andhra Pradesh with the help of APSDPS.

Table 1 : El-Niño and La-Niña Years since 1980

EL-NIÑO Years	LA-NIÑA Years
1982, 1986, 1987, 1991, 1994,1997,2002,2004, 2006, 2009, 2015	1983, 1984, 1988, 1995, 1998, 1999, 2000, 2007, 2010, 2011

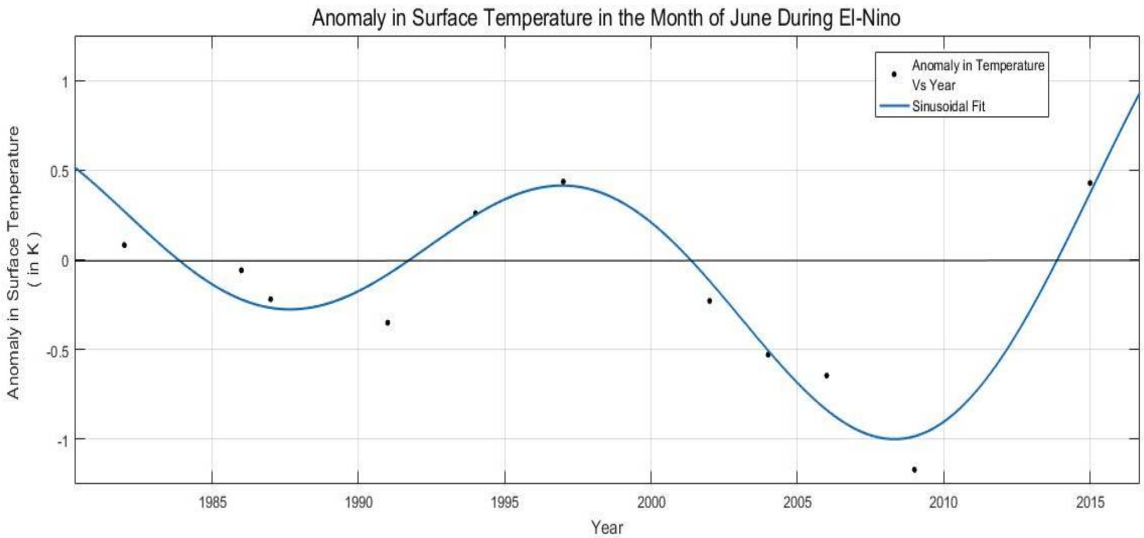
Results and Discussion

The mathematical model presented below is developed to predict the rainfall over Andhra Pradesh during phases of ENSO in the months of June – September and the season of South-West Monsoons ranging over the afore mentioned months. We shall not predict the rainfall directly but the deviation in rainfall will be computed using this model, which can thereafter be used to compute the average rainfall. The deviation in rainfall can be calculated using the anomaly in skin surface temperature over the grid formed by latitudes 5°N - 20°N and longitudes 72.5°E – 82.5°E, which shall be predicted as discussed below.

The data over the last 35 years has been used to model the following mathematical equations. From 1981 onwards, the data has been divided into two parts based on the occurrence and phase of ENSO cycle, as mentioned in table-1. For all the El-Niño years, the anomaly in skin surface temperature over the chosen grid has been modelled using a time-series analysis of the pattern over the years. These anomalies have been observed to follow a sinusoidal curve during the months of June – September and the entire season of South-West Monsoon. This trend can be used to predict the anomaly in SST over the grid in the years to come. The recorded anomalies in SST have been correlated to deviation in rainfall over Andhra Pradesh during the same El-Niño years. These correlation curves are also surprisingly sinusoidal in nature. This means that using the anomaly in SST, we can predict the deviation in Rainfall and consequently the average rainfall for the months of June – September and the season of South-West Monsoons. The same thought flow has been applied to the years of La-Niña.

The above mentioned mathematical models have been presented below:

1) <u>Trend and Correlation for the month of June during El-Niño:</u>

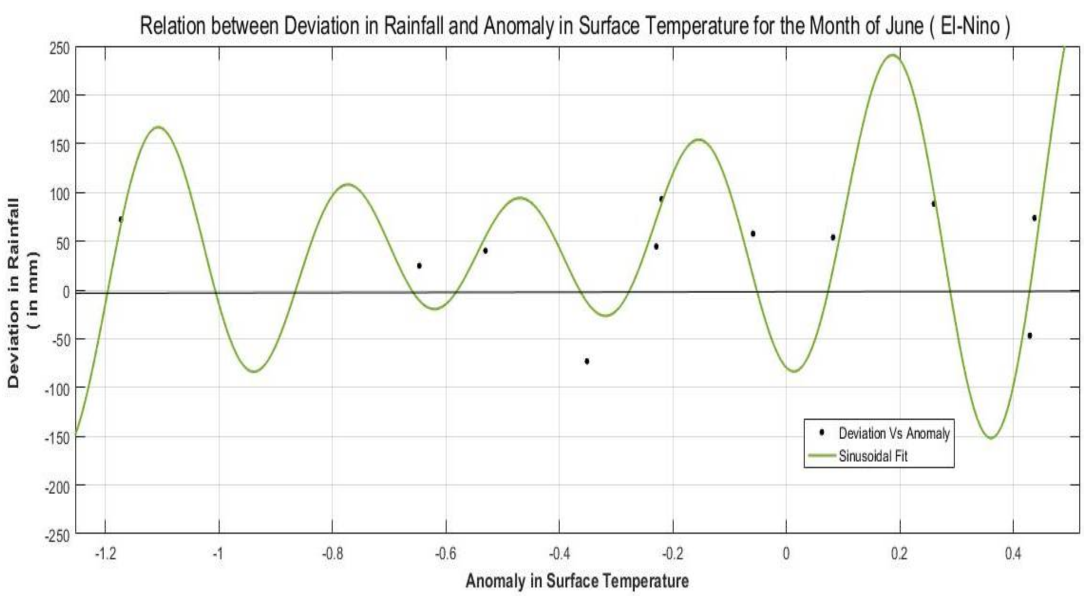


This sinusoidal fit can be represented by the equation

$f(x)$
$= 30.76\sin(0.236x + 290)$
$+ 30.51\sin(0.2342x - 275)$

Where x represents year.

This sinusoidal fit tracks the data correctly up to 90.56%.

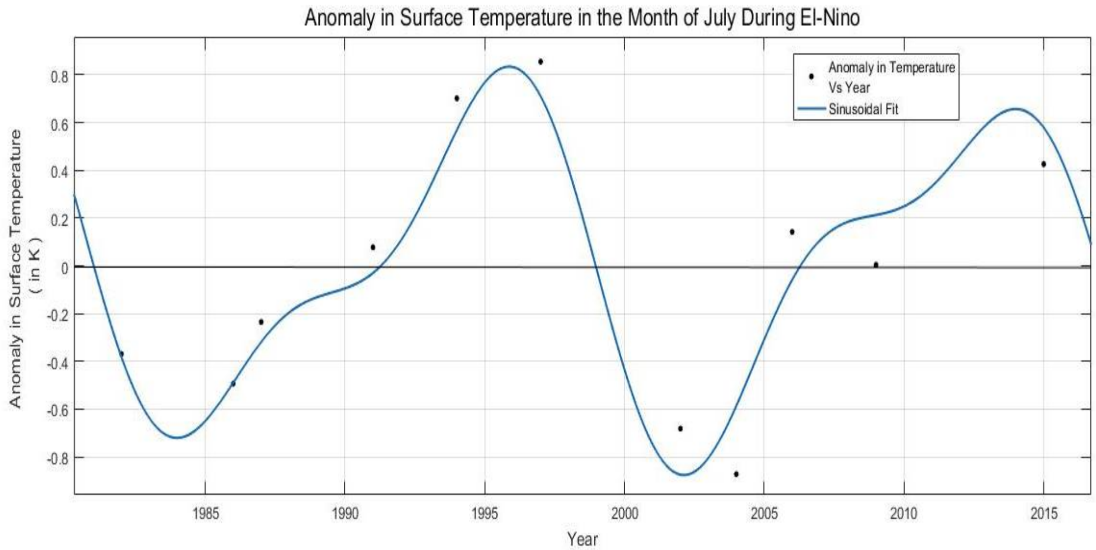


The sinusoidal fit can be represented by the equation

$f(x)$
$= 3476\sin(0.009268x$
$+ 0.01606)$
$- 2767\sin(17.58x + 9.625)$
$+ 2819\sin(17.67x - 2.896)$

Where x in the above equation represents anomaly in SST.
The correlation between these two anomalies is 54.57%.

2) Trend and Correlation for the month of July during El-Niño:

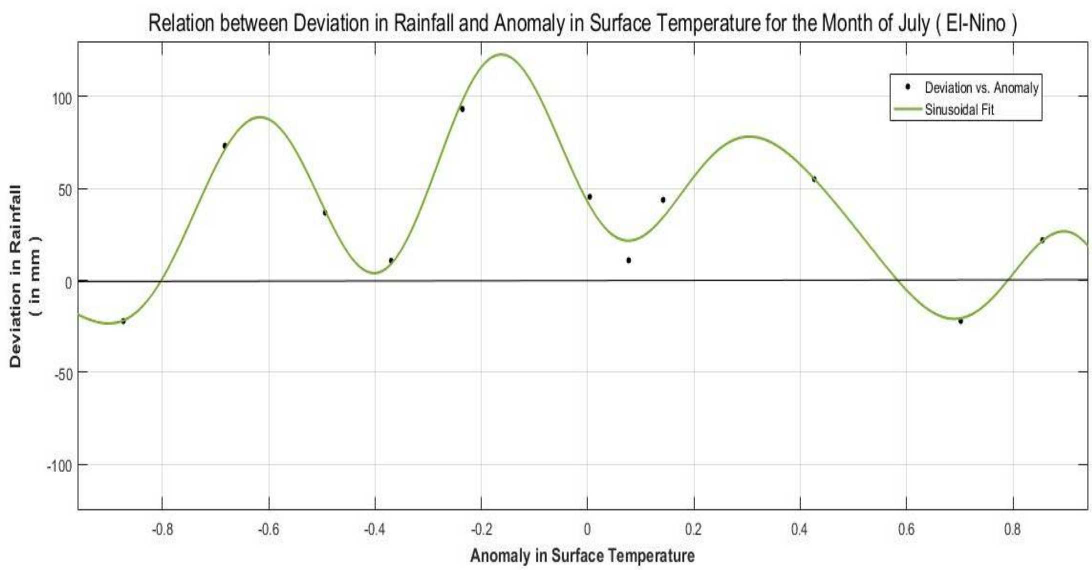


This sinusoidal fit can be represented by the equation

$$f(x) = 0.6635\sin(0.3614x + 40.93) + 0.2985\sin(0.6733x - 177.6)$$

Where x represents year.

This sinusoidal fit tracks the data correctly up to 90.78%.



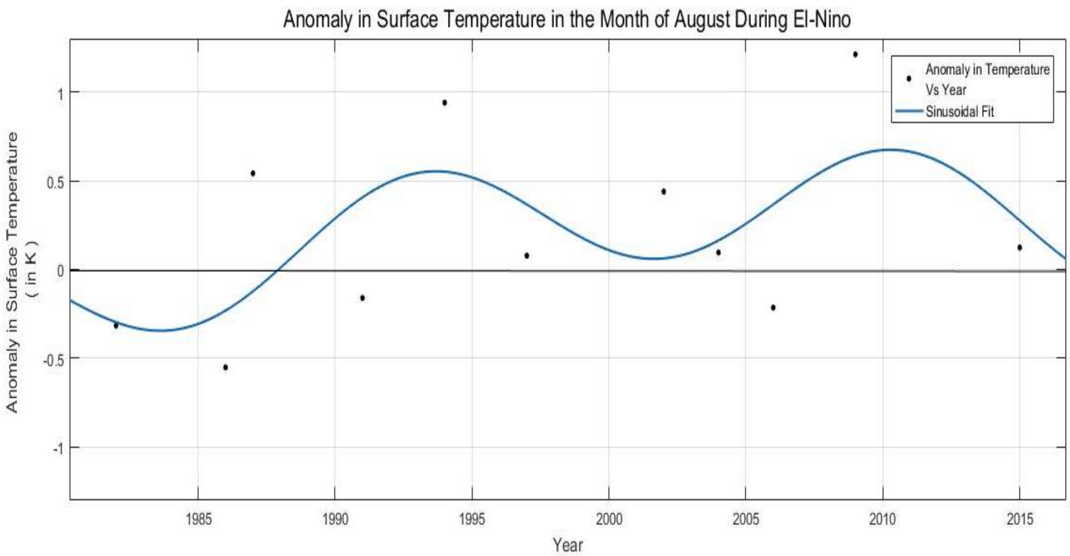
The sinusoidal fit can be represented by the equation

$$f(x) = 69.12\sin(1.826x + 1.767) + 15.5\sin(16.23x - 1.645) + 40.69\sin(40.69x - 2.909)$$

Where x represents anomaly in SST.

The two anomalies in July are related by 98.03%.

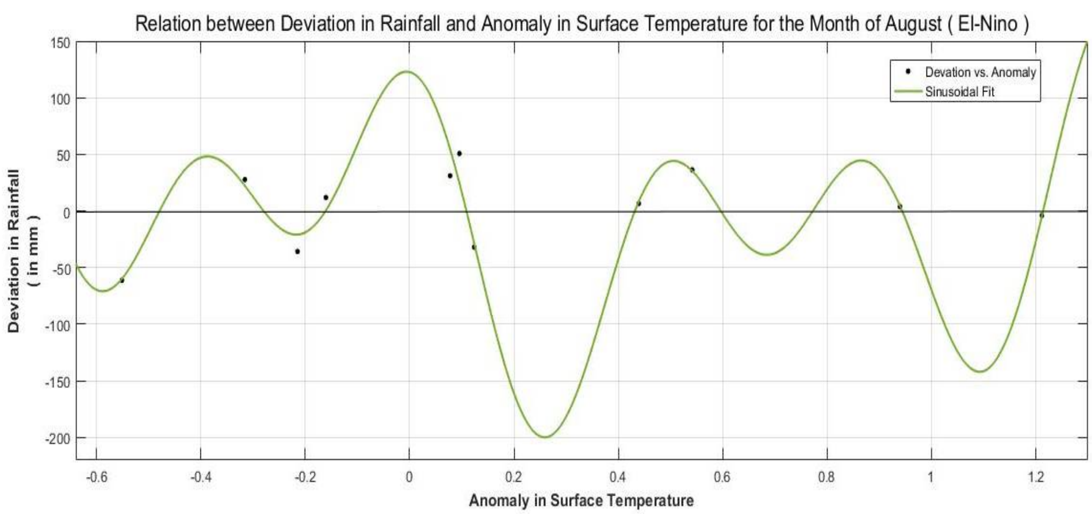
3) Trend and Correlation for the month of August during El-Niño:



Sinusoidal fit can be represented by the equation

$$f(x) = 0.39\sin(0.07754x + 34.57) + 0.3158\sin(0.3158x - 44.95)$$

Where x represents year. The curve the data up to 33.53% accurately, the only fit that doesn't capture the data in an expected sinusoidal fashion. *

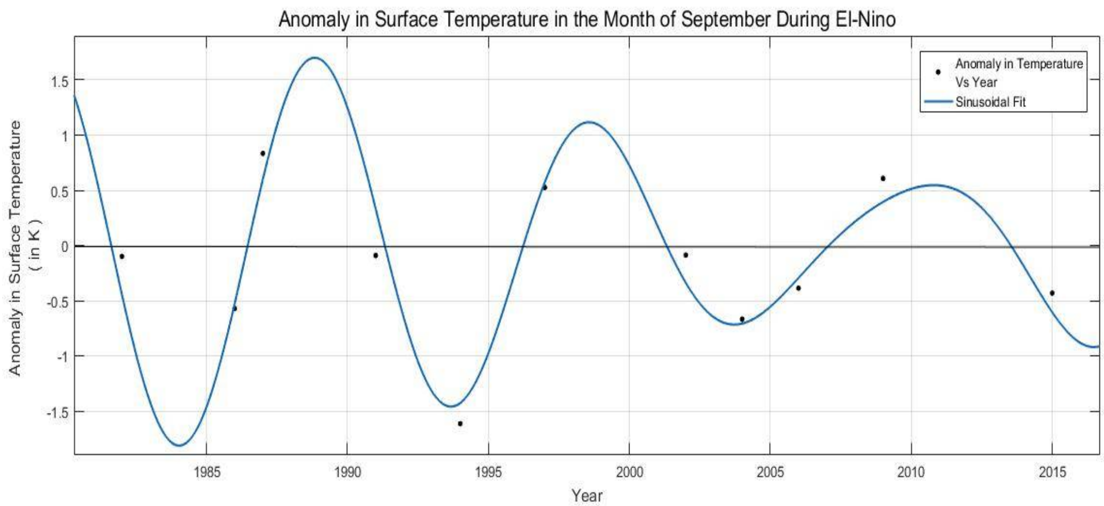


The sinusoidal fit can be represented by the equation

$$f(x) = 82.84\sin(14.43x + 1.159) - 45.58\sin(2.813x + 0.2828) + 81.98\sin(8.337x - 2.328)$$

Where $x$represents anomaly in SST.
The two anomalies in August are related by 86.11%.

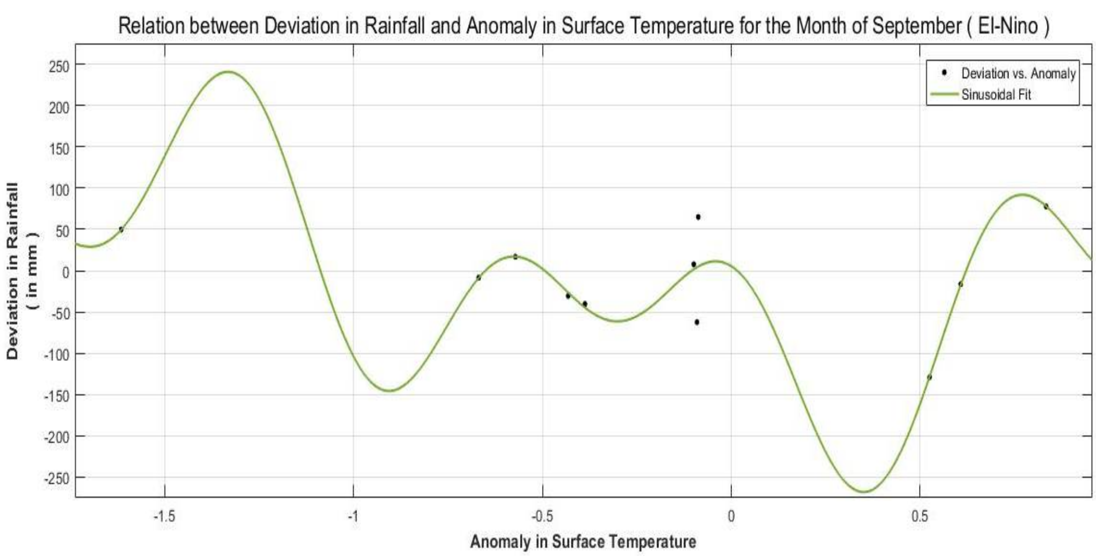
4) Trend and Correlation for the month of September during El-Niño:



Sinusoidal fit can be represented by the equation

$$f(x) = 1.166\sin(0.6059x - 66.47) + 0.6559\sin(0.7254x + 73.49)$$

Where x represents year. This curve fits the data as good as 77.1%.

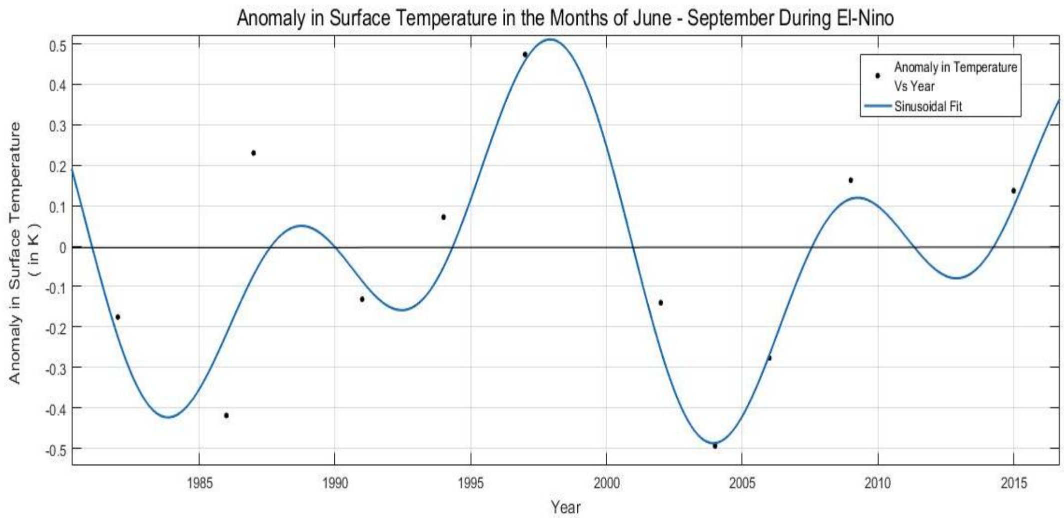


The sinusoidal fit can be represented by the equation

$$f(x) = 65.06\sin(3.561x - 0.6844) + 85.01\sin(8.256x - 1.277) + 48.56\sin(14.95x - 1.414)$$

Where x represents anomaly in SST.
The two anomalies are related by 85.86%.

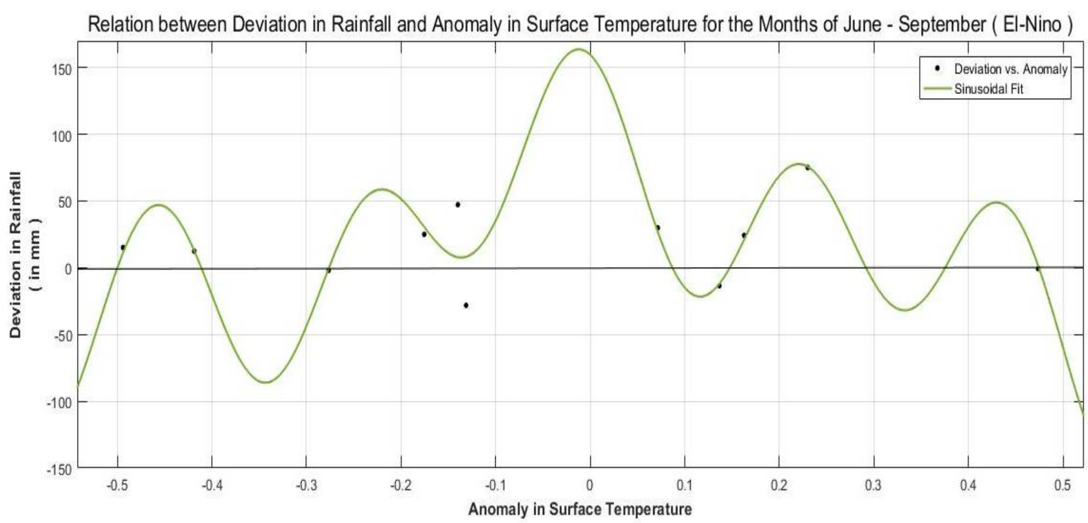
5) <u>Trend and Correlation during the months of June- September during El-Niño:</u>



Sinusoidal fit can be represented by the equation

$$f(x) = 0.2775\sin(0.3262x + 110.7) + 0.2812\sin(0.6202x - 100.6)$$

Where x represents year. This fit represents the data points up to 80.39% accurately.

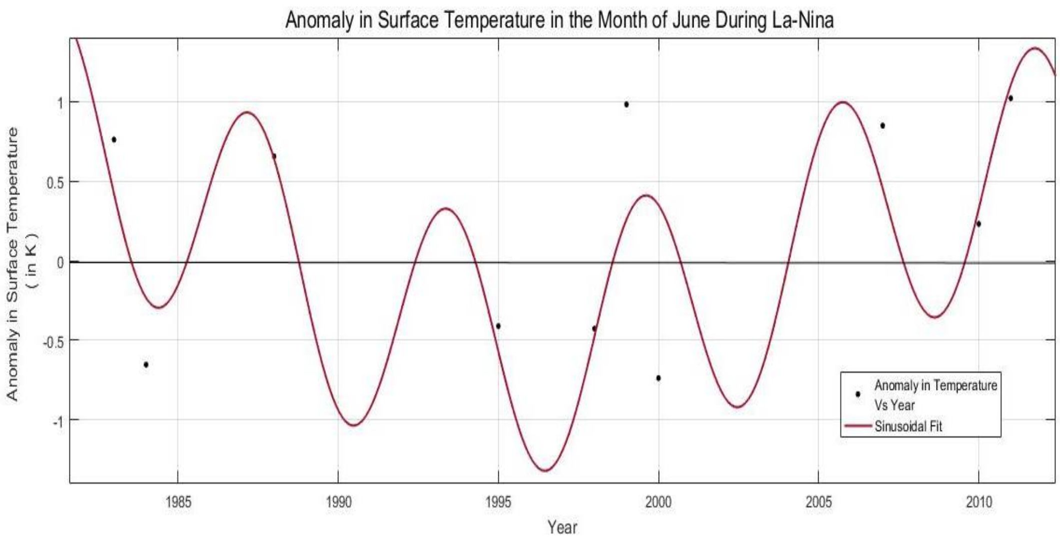


The sinusoidal fit can be represented by the equation

$$f(x) = 73.03\sin(4.874x + 1.499) + 61.77\sin(27.79x + 1.779) + 35.07\sin(14.81x + 2.292)$$

Where $x$represents anomaly in SST.
The two anomalies are related by 64.16%.

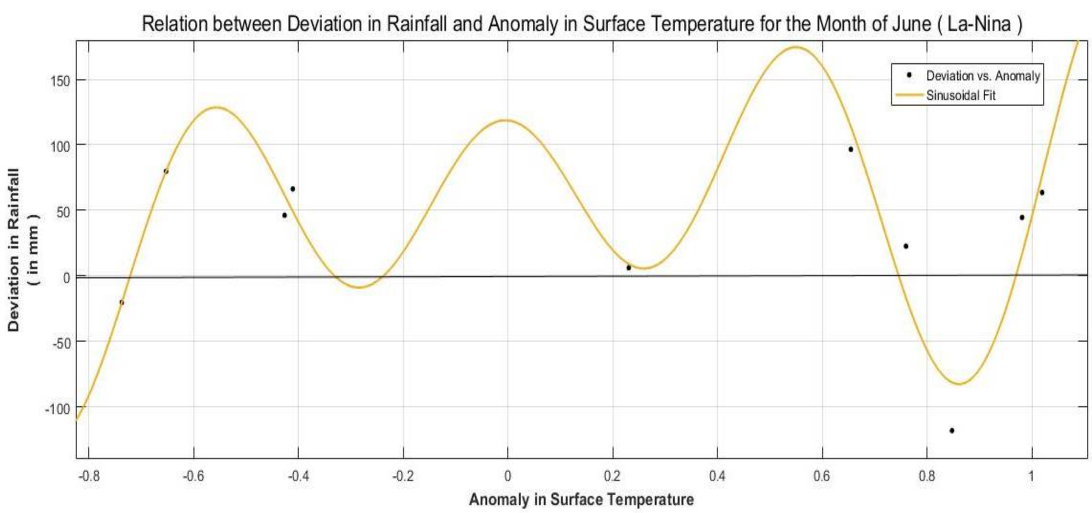
6) <u>Trend and Correlation for the month of June during La-Niña:</u>



Sinusoidal fit can be represented by the equation

$$f(x) = 0.7961\sin(1.028x - 263.4) + 0.453\sin(0.02849x + 172.2) + 0.6395\sin(0.1827x + 86.26)$$

Where x represents the year. This fit represents the data up to 52.12% correctly.

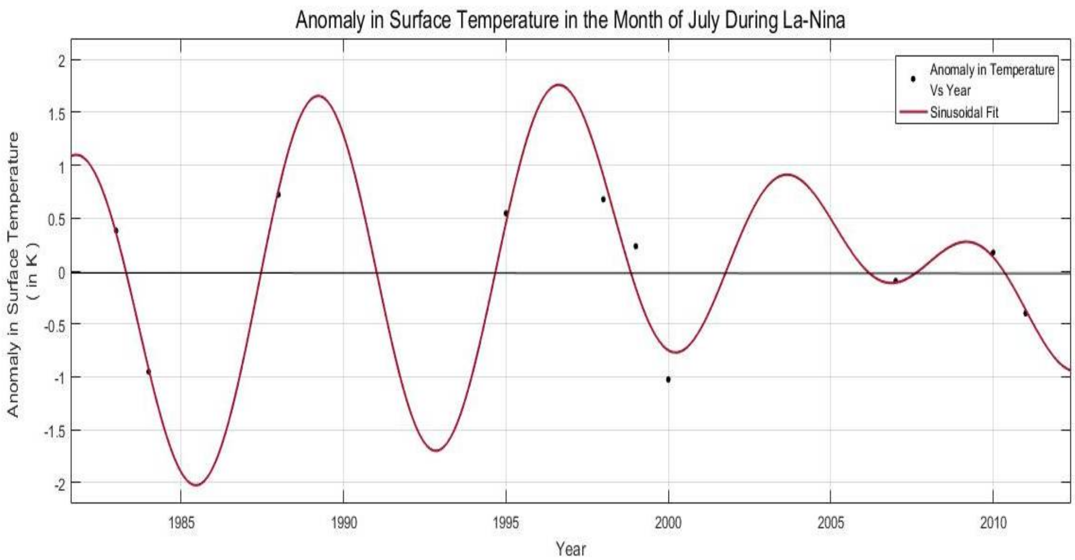


The sinusoidal fit can be represented by the equation

$$f(x) = 1.976 \times 10^4\sin(9.658x + 1.605) + 74.04\sin(1.179x + 1.142) + 1.971 \times 10^4\sin(9.65x - 1.536)$$

Where x represents anomaly in SST.
The two anomalies are related by 86.58%.

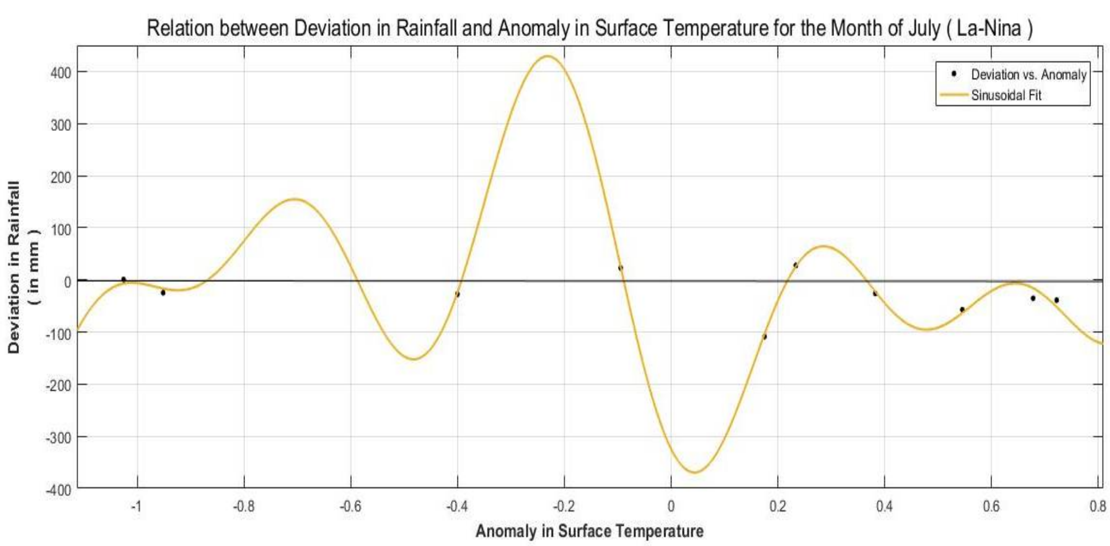
7) Trend and Correlation for the month of July during La-Niña:



The above sinusoidal fit can be represented by the equation

$$f(x) = 1.012\sin(0.9149x - 34.03) + 0.3386\sin(0.1864x + 74.84) + 0.8159\sin(0.7413x - 134.7)$$

Where x represents year. This curve fits the data up to 91.79% accurately.

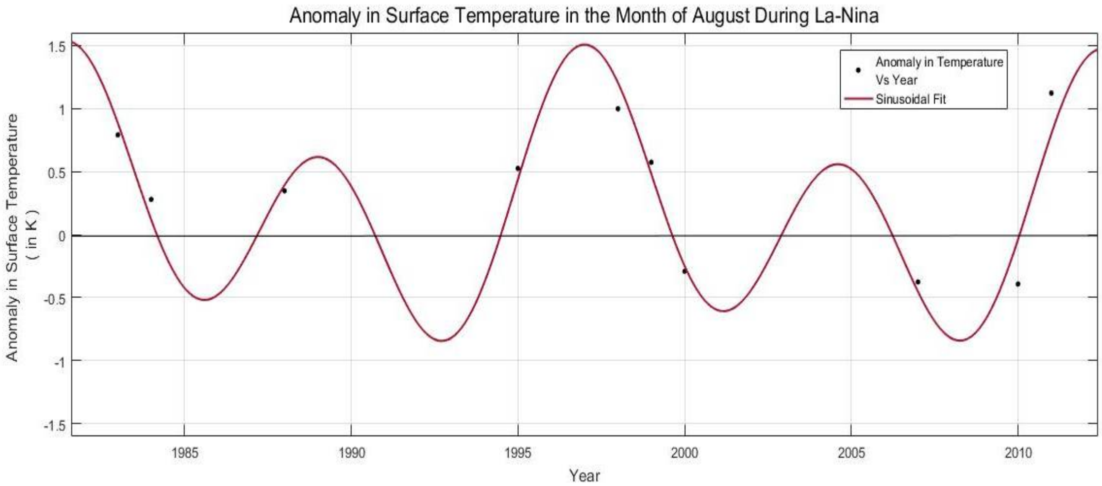


The sinusoidal fit can be represented by the equation

$$f(x) = 122.9\sin(4.261x - 2.873) + 159.7\sin(14.2x - 1.646) + 193\sin(9.843x - 2.382)$$

Where x represents anomaly in SST.
The two anomalies are related by 94.55%.

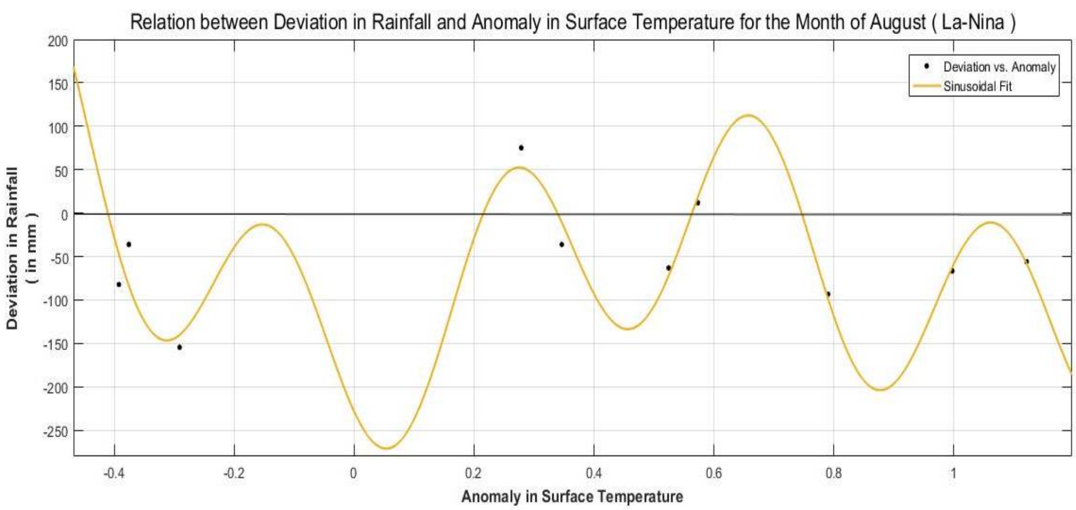
8) Trend and Correlation for the month of August during La-Niña:



Sinusoidal fit can be represented by the equation

$$f(x) = 0.4934\sin(0.005842x + 211) - 0.479\sin(0.4012x + 77.47) + 0.8629\sin(0.8629x + 179.7)$$

Where x represents year. This sinusoidal fit captures the data 88.07% accurately.

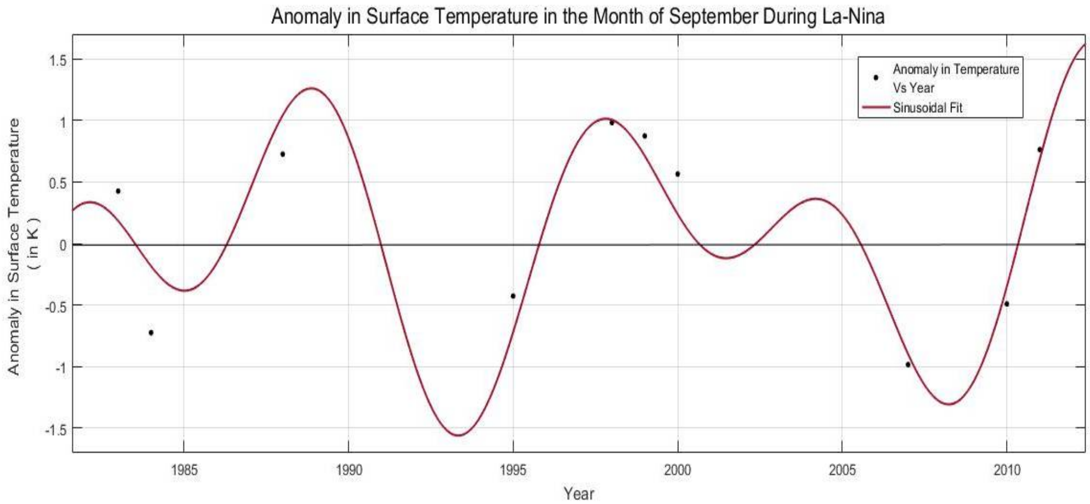


The sinusoidal fit can be represented by the equation

$$f(x) = 2399\sin(3.476x - 3.432) + 124.1\sin(15.63x - 2.517) + 2398\sin(3.596x - 0.3586)$$

Where $x$represents anomaly in SST.
The two anomalies are related by 85.35%.

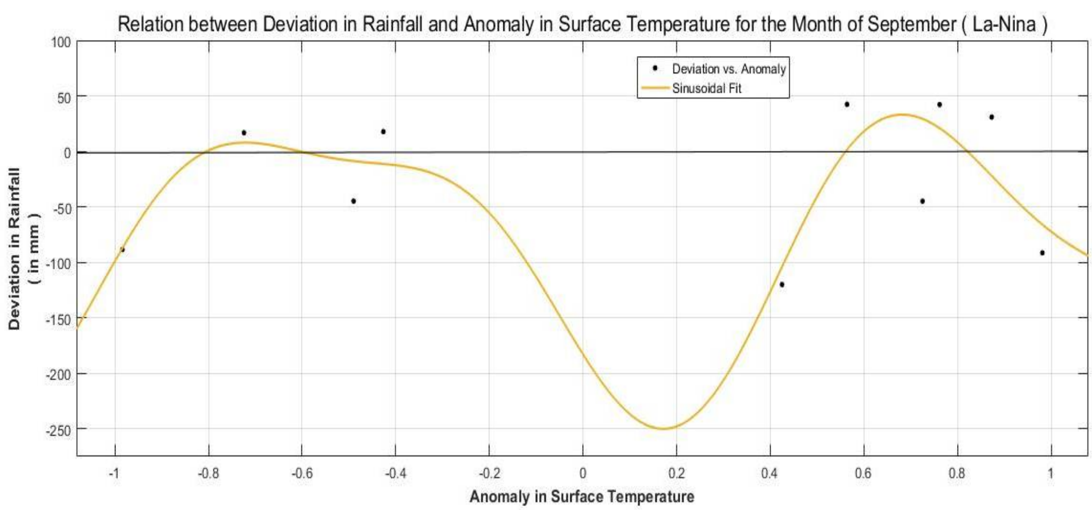
9) Trend and Correlation for the month of September during La-Niña:



Sinusoidal fit can be represented by the equation

$$f(x) = 0.7729\sin(0.4838x - 67.51) + 9.956\sin(0.8558x + 86.23) + 10.73\sin(0.8526x - 356.7)$$

Where x represents year.
The fit represents the data up to 85.82% correctly.

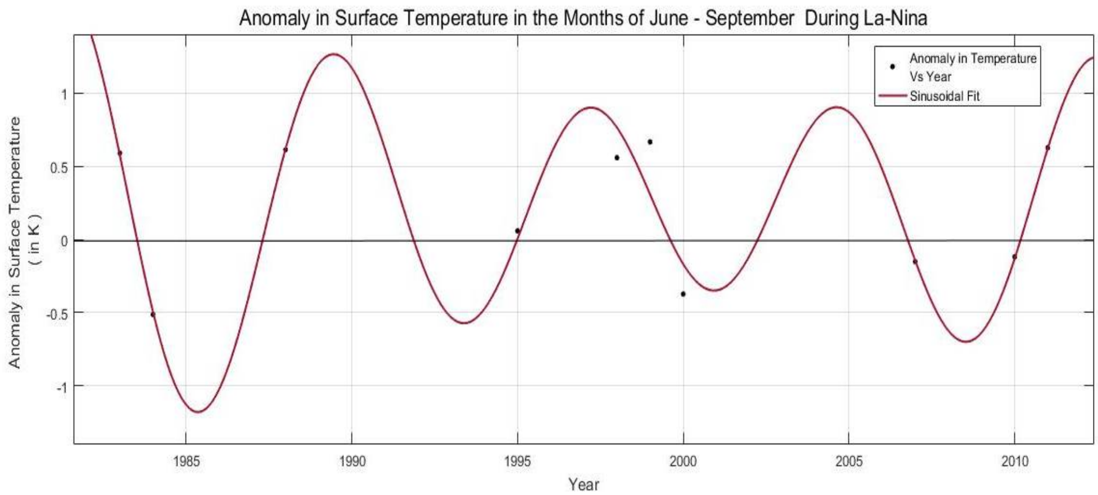


The sinusoidal fit can be represented by the equation

$$f(x) = 305.7\sin(0.04821x - 2.844) + 120.2\sin(4.629x - 2.128) + 43.65\sin(8.427x + 2.944)$$

Where $x$represents anomaly in SST.
The two anomalies are related by 60.12%.

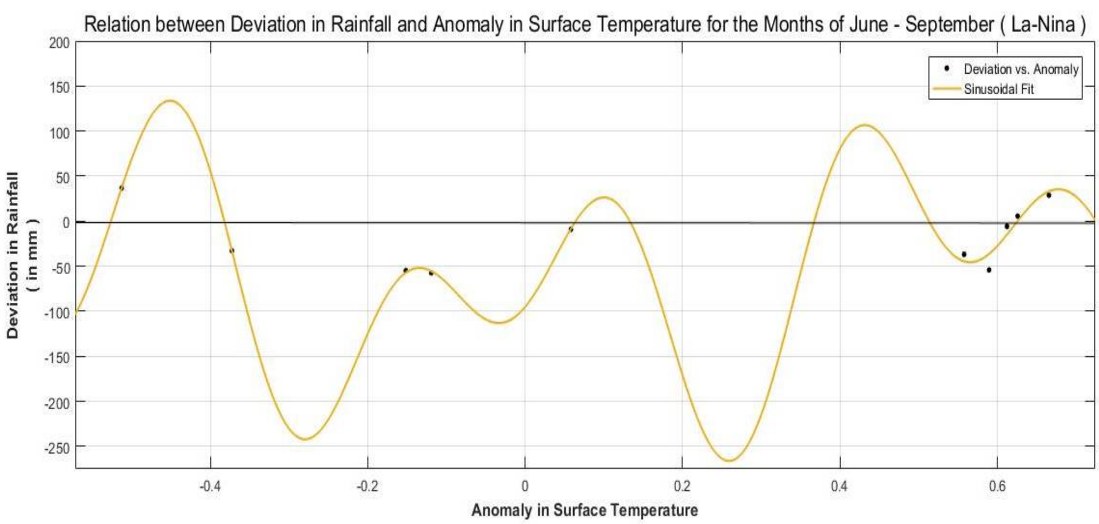
10) <u>Trend and Correlation for the months of June - September during La-Niña:</u>



Sinusoidal fit can be represented by the equation

$f(x)$
$= 0.7729\sin(0.4838x$
$- 67.51)$
$+\ 9.956\sin(0.8558x$
$+ 86.23)$
$+\ 10.73\sin(0.8526x$
$- 356.7)$

Where x represents year.
The fit represents the data up to 85.82% correctly.



The sinusoidal fit can be represented by the equation

$f(x)$
$= 101.6\sin(2.437x - 1.482)$
$+ 95.66\sin(13.15x + 1.397)$
$+\ 95.56\sin(22.22x$
$- 1.176)$

Where $x$represents anomaly in SST.
The two anomalies are related by 95.15%.

All the above curves have been sketched using MATLAB R2016a using 95% confidence in variables with manual fit for the range of coefficients.

The following can be observed distinctly from the above Sinusoidal curves and patterns:

- The trends in Skin Surface Temperature follow a sinusoidal pattern instead of an expected linear plot. From the previous studies on ENSO cycles, we know that during El-Niño, the Sea surface Temperature is warmer than usual in the Pacific Ocean and lower than usual during La-Niña phase. India, being considerably closer to the waters of Pacific Ocean must also have an elevated Skin Surface temperature during El-Niño and lower than usual during La-Niña. But the trend observed is far away from the expected one. The anomaly in Skin Surface Temperature over the grid mentioned oscillates between positive and negative values during both the phases of ENSO instead of expected positive during El-Niño and negative during all of La-Niña. This indicates that even though there is a prevalent El-Niño (La-Niña) phase on a global scale, the Indian sub-continent needn't experience the effects of El-Niño (La-Niña). Thus, these global weather patterns have not more than 45% chance of influencing the South-West monsoons in Andhra Pradesh. Thus, El-Niño season in India needn't imply a time of drought or La-Niña, a period of excessive rainfall. And the above presented mathematical equations can be used to determine the effect of ENSO cycles on the South-West Monsoons.

- The correlation curves between anomaly in SST and deviation in rainfall surprisingly is a sinusoidal curve and not a linear fit. This implies that elevated Skin Surface Temperatures doesn't necessarily mean decrease in rainfall or increase in rainfall. Thus, to know the effect of an anomaly in SST over the rainfall, we are bound to use the equations discussed above.

- We see that the trends in SST during El-Niño and La-Niña are described by different set of equations; El-Niño by sum of two sines, La-Niña by sum of three sines. This is because the anomalies in SST during La-Niña years oscillates between positive and negative values much more rapidly over years than anomalies during El-Niño and to fit these oscillations more effectively, we are bound to use sum of three sines instead of two for La-Niña phase to emphasise these rapid oscillations.

- (*)The sinusoidal curve for anomalies during august over years during El-Niño phase doesn't seem to fit the data as well as the other curves for different months and seasons. The plausible reasons for this inefficient fit requires extensive studying of other atmospheric variables during El-Niño phase.

- The above sketches of Sinusoidal Curves tells us that the month of July rightly indicates the effects of ENSO cycles on the South-West Monsoons in India, and the strength of ENSO cycle. The sine curve used to fit the data for July during La-Niña and El-Niño has an accuracy of more than 90% in each case and so the reliability of the data obtained from this curve is evidently high. Thus, Julys' curves can be used to predict the strength, and effects of ENSO phases in Andhra Pradesh and also the whole of India for we can obtain the relative strength of an ENSO phase from these curves.

Conclusion

The mathematical models presented in this article can be used to forecast the anomaly in Skin Surface Temperature in the grid formed by latitudes 5°N - 20°N and longitudes 72.5°E – 82.5°E. These anomalies can be thus used to predict the deviation in rainfall for the months of June – September and the season of South-West monsoon. These deviations can be used to estimate average rainfall over Andhra Pradesh for the same period of time.
These forecasts in anomaly in SST and deviations in rainfall and average rainfall can be used to estimate other atmospheric variables using time series analysis over years. Also, from the above relations we can estimate the strength of ENSO phase for the grid mentioned and extrapolate it to other grids and geographical locations.

At the end, all these estimations and calculations can be used for early warning predictions of natural disasters such as droughts and floods and their effects on agriculture in the state and crop yield and thus, the contribution of agriculture to the GDP. These may be over simplified models of atmospheric variables and economy but provide startling insights into the working of different variables and their relations.