

Effect of Sea Surface Temperature on Monsoon Rainfall in a Coastal Region of India

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The Indian Monsoon, the onset and strength of which decides the fate of millions of people in the Indian sub continent, depends on a number of global parameters and phenomena – most of which are continuous. It is well established that almost all global climatic phenomena are inter-related. Sea Surface Temperature (SST) is one of the key factors influencing the Indian monsoon. Even roughly predicting the Indian Monsoon helps considerably the economies of the countries in the Indian sub continent – most of which are agriculture based. In the present study, an attempt is made to establish a relationship between Sea Surface Temperatures across the globe and monsoon rainfall in coastal region of Orissa State, India. This study aims at evolving and analyzing the correlation contour patterns using GrADS (Grid Analysis and Display System) software for different lead times and then interpret the salient features, to predict monsoon in Orissa based on SST anomaly data. The correlation contours generated in this study will prove quite useful for predicting the rainfall pattern over Coastal Orissa, based on variation in sea surface temperatures across the globe and in marking out the regions of influence.

Introduction

In the tropics, where the weather is warm round the year, monsoons alternate with dry seasons and each year has its own distinct pattern of prevailing winds. At times the tropical Pacific Ocean and large expanses of global atmosphere seem to behave in an aberrant way, disrupting the normal pattern of life of countless species of plants and animals, in addition to hundreds of millions of human beings. This alternation between the “normal climate” and a different but recurrent set of climatic conditions in the pacific region, called El Niño, is the causative phenomenon. It is a well-established fact that this phenomenon affects the Indian Monsoon Rainfall. Some studies have been made to investigate the relation between the El Niño/Southern Oscillation (ENSO) events and the corresponding precipitation pattern and to predict the variations in the Indian monsoon rainfall. A comprehensive review of Seasonal forecasting of Indian summer monsoon rainfall is presented by Krishna Kumar et al. (1995).

Sea Surface Temperature data provides both the synoptic view of ocean and a high frequency of temporal occurrences, facilitating evaluation of basin-wide upper ocean dynamics. For Pacific SST, an anomaly in the range of 1.5 to 3.5 is considered characteristic of El Niño; the warmer and more widespread the event, the stronger the El Niño effect. The teleconnection pattern between All India Rainfall (AIR) anomalies and tropical SST is dominated by negative correlation in the East pacific and positive correlation in the West pacific (Stephenson et al, 1997, Singh et al., 1992). The positive correlation in the West pacific tends to be associated with SST anomalies of the opposite sign, which occurs as a complimentary pattern during the developed phase of El Niño. While the largest correlation occurs in central

and eastern pacific regions, there are also some other areas where this is quite significant. To establish the influence of SST anomalies on the interannual variability of the Indian summer monsoon, it is necessary to consider regions other than those covered by classical El Niño signal.

The influence of anomalies of SST may be different during different phases of monsoon. By placing emphasis only on seasonal mean anomalies, important sub-seasonal variations in the same may be left unconsidered but may be crucial for a clear understanding of interannual variability of the Indian Summer Monsoon and the ability to predict the same.

In the present study, an attempt is made to study the relation between monsoon rainfall pattern of the coastal Orissa region in India and the Sea Surface Temperature (SST) data across the globe. Some regions are identified which are found to have a significant influence on the monsoon rainfall over Orissa. The monsoon depends on various other phenomena as well but the influence of SST data alone is considered in this study.

Data used

The monthly rainfall data for June, July, August and September (JJAS) for coastal Orissa for the years 1982 to 1993 is considered for analysis. Representative rainfall over this region is given by Indian Meteorological Department (IMD) based on rainfall data observed at a number of stations in the region (Parthasarthy et al. 1985). This region is chosen as the study area, as the rainfall patterns over this region are said to have significant teleconnection with the variation in SST and SST anomalies (Rajagopalan, 1999). The present study aims at analyzing this relationship and verifying its dependability.

SST data is available at $1^\circ \times 1^\circ$ (Latitude and longitude) spatial resolution of the globe for every month for the years 1981 to 1997 from CIDC (Kyle et al., 1998). Concurrent data of monthly rainfall and SST for the period 1982 to 1993 (12 years) was used in the study.

Methodology

In order to determine the relationship between SST and monsoon rainfall in Orissa, several factors had to be considered, such as: (i) how is the correlation between them, (ii) what are the areas of influence for this relation, and, (iii) what is the lead time for this relationship. To determine these factors, correlation between the two time series were performed for several lead times. The Orissa monsoon rainfall data gives a time series that has a single value for each time and the SST data gives a separate time series for each grid. The first set of time series is correlated to the time series for each grid point of the second set. The result is a 2-D grid of correlation values and the contours connecting equal correlation values are plotted. GridAnalysis and Display System, GrADS (Doty, 2001) is used to generate the contour plots.

Initially analysis of all the 12 years data is carried out. Four lead times are analyzed for the months from February through May. Figure 1 shows the correlation contours between the concurrent SST data for February and the corresponding year's monsoon rainfall (June, July, August, September - JJAS). Every point in the figure indicates the correlation between 12 pairs (corresponding to 12 years of data) of SST data and monsoon rainfall. Similar correlation contours are obtained using the SST data for the months of March, April and May but are not presented here to restrict the paper length.

For more detailed analysis, it was decided to subdivide the rainfall data ascribing three different classes based on the mean rainfall. The rainfall data is presented in Table 1. The mean values of rainfall is 1160 mm for JJAS. The years having rainfall more than mean + 1 standard deviation are considered as Class A. The years having rainfall within mean \pm 1 standard deviation are grouped as Class B and the rest are put in Class C (i.e., less than mean - 1 standard deviation). Year-wise classification is detailed below.

Class A: 1984, 1986, 1989, 1991 and 1993

Class B: 1985, 1990 and 1992

Class C: 1982, 1983, 1987 and 1988

Concurrent SST data corresponding to each of the three classes are also grouped accordingly. Then study is carried out for the lead periods of 4, 3, 2 and 1 month. For example, for a four month lead time, SST data of February for a particular class were correlated with the rainfall data for all the years of that class. In the same way the process was repeated with SST data of March (3 month's lead), April (2 month's lead) and May (1 month lead) for the three classes. The contour pattern of correlation coefficients of the plots thus obtained is analyzed. In all 12 plots are obtained and studied for similarities and contrasts. Contour interval adopted is 0.3, which is quite a high value.

Table 1. Monsoon Rainfall in Coastal Orissa from year 1982 to 1993

Year	JJAS rainfall (mm)
1982	1074.0
1983	1009.2
1984	1287.9
1985	1164.0
1986	1252.2
1987	908.8
1988	1096.1
1989	1263.9
1990	1201.3
1991	1223.5
1992	1144.9
1993	1285.2

Results and Discussions

A study of all the contour plots of correlation coefficients obtained is conducted for similarities and contrasts. The salient features of the plots are explained below.

Observations of contour plots obtained using all the rainfall data of 12 years:

Case 1: For 4-month lead i.e. February

The regions having high correlation values, as can be seen in Fig. 1, are identified as near Darwin (Australia), region between North America and Africa, part of eastern and central pacific region, near southern South America, south and south eastern Africa and parts of Bay of Bengal.

Case 2: For 3-month lead i.e. March

In this case the regions having high correlation value are identified as part of central pacific zone, near Darwin, regions between North America and Africa, between South America and Africa and parts of Bay of Bengal.

Case 3: For 2-month lead i.e. April

In this case the regions of high correlation values are identified as parts of eastern, central and western pacific region, near Darwin, a considerably larger region between South America and Africa, North America and Africa and the same parts of Bay of Bengal.

Case 4: For 1-month lead i.e. May

In this case the regions are identified as near Darwin, eastern and central pacific region, a prominent region near north western Africa and the same parts of Bay of Bengal.

Observations of contour plots obtained using the rainfall data of classes A, B and C:

Contour plots obtained for class B data (average rainfall situation) are presented Figures 2 to 5 for the lead times of 4, 3, 2 and 1 months respectively. Contour plots obtained for classes A and C are not presented here for want of space.

Case 1: For 4-month lead i.e. February

The contours of Class B and Class C are almost identical across the globe. Near Darwin these two classes are showing identical shapes. But the pattern is different in case of

Class A. In Pacific Ocean region also Class B and Class C contours are identical, but those of Class A are significantly different. Especially, in western Pacific Ocean, correlation coefficients for Classes B and C are quite high (-0.9). In case of Class A there are points of very high correlation (0.9) in eastern Pacific Ocean lying between 0-35 S and 75W-100W. Between South America and Africa again the contour patterns in case of Class B and Class C are closer. There is a significantly large area having high correlation coefficient in Class B and Class C. While in case of Class A there is no such significant area in this region.

Case 2: For 3-month lead i.e. March

In this case the contour patterns are different. In eastern Pacific region the points of very high correlation coefficient are present in Class B only. There is no such region in the other two classes for the same area. In central Pacific region high correlation coefficients can be seen in contours of Class B and Class C. In western Pacific region, near to South American continent there is a significantly large area of high correlation for Class A and Class B. For Class C the area is smaller near South America. Between South America and Africa, the points of high correlation coefficient are present in Class A and Class B, though there is more contrast in contour patterns in case of Class A. The points of high correlation coefficient are also present in area near South East Asia in Class B, while these are absent in other two classes.

Case 3: For 2-month lead i.e. April

In this case also the contours are all different. Difference is remarkable near Darwin and Indian subcontinent. In Class

B, the areas of high correlation are present all over central, eastern and western Pacific region. In case of Class C the area is concentrated in central Pacific. While in case of Class A there is no such significant region in central Pacific. In this case also the contours are all different. Difference is remarkable near Darwin and Indian subcontinent. In Class B, the areas of high correlation are present all over central, eastern and western Pacific region. In case of Class C the area is concentrated in central Pacific. While in case of Class A there is no such significant region in central Pacific region. In eastern Pacific region there is a large area of high correlation in case of Class A and Class B. For Class B, the regions of large correlation are quite visible between South America and Africa. This region is quite large. These are absent in the other two classes. Between North America and Europe also the pattern is same.

Case 4: For 1-month lead i.e. May

Here also the patterns are different. For Class B and Class C, regions of high correlation are situated in western Pacific region. This can be also seen in central Pacific for Class B. In eastern Pacific the contours of high correlation are present in Class B only. Between South America and Africa there is a large area having very high value in Class B. For the other two classes the area is quite small. For the other two classes the area is quite small. For Class A and Class B, there are some regions of high correlation near South East Asia also.

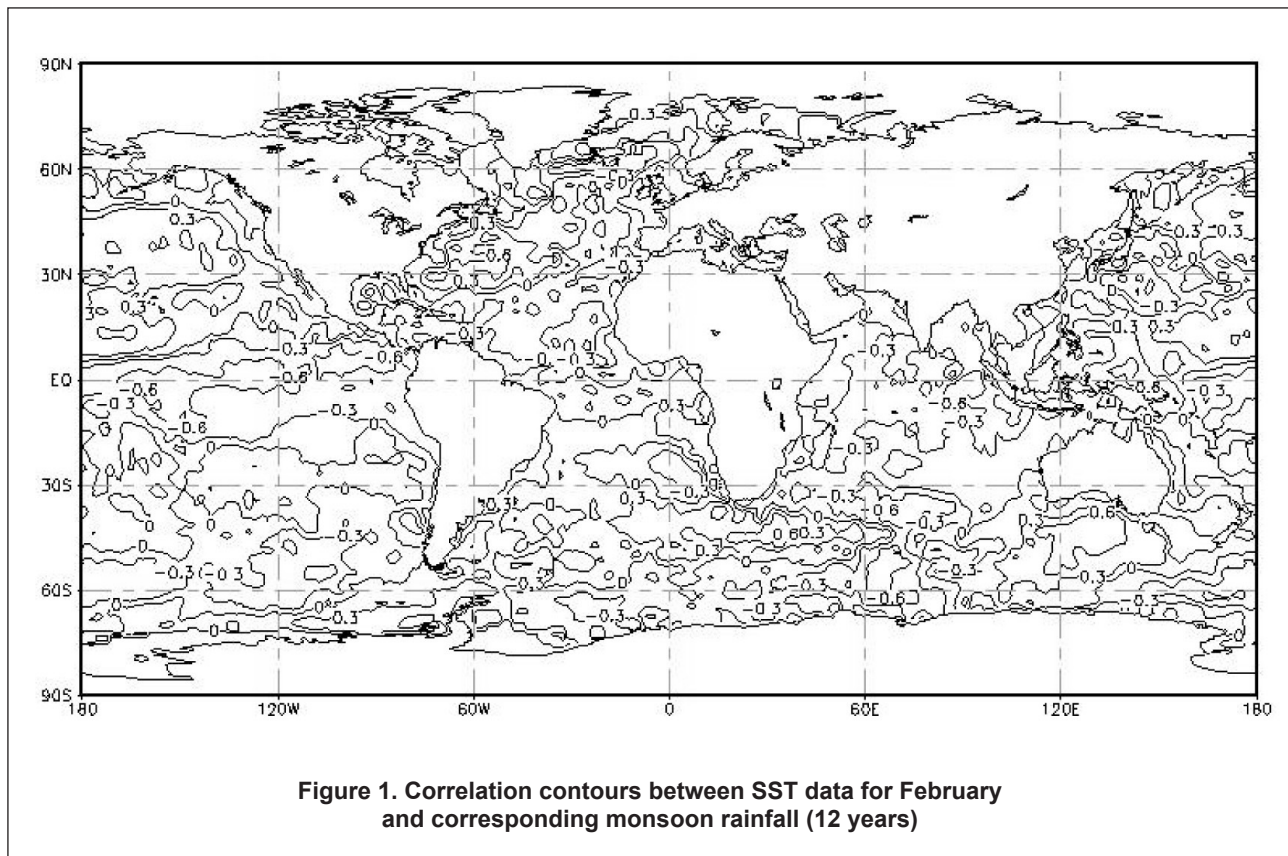


Figure 1. Correlation contours between SST data for February and corresponding monsoon rainfall (12 years)

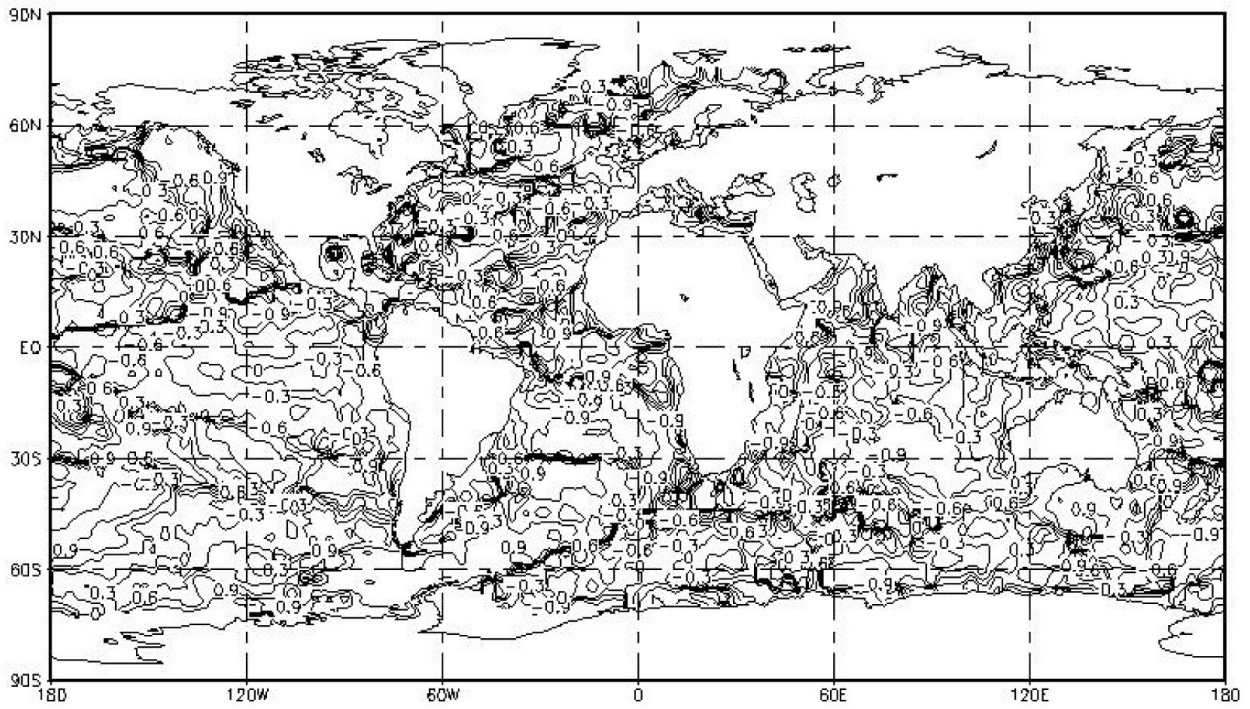


Figure 2. Correlation contours between SST and monsoon rainfall (Class B) with lead time of four months (February)

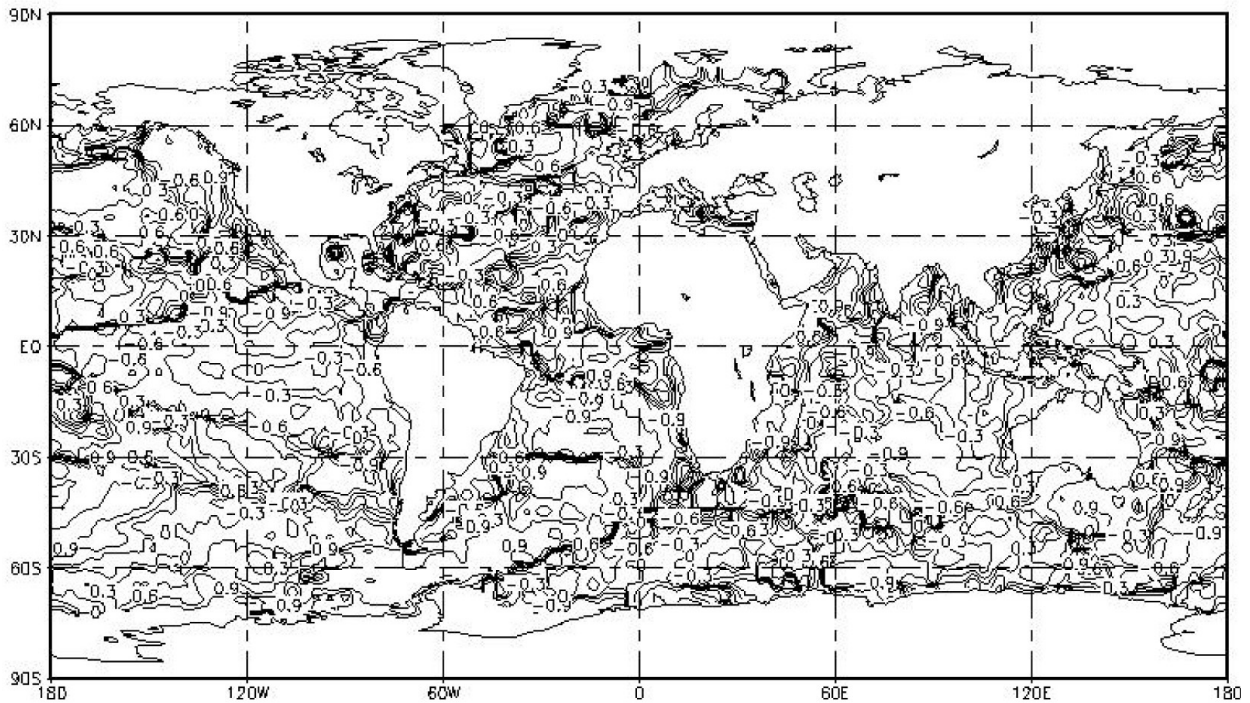


Figure 3. Correlation contours between SST and monsoon rainfall (Class B) with lead time of three months (March)

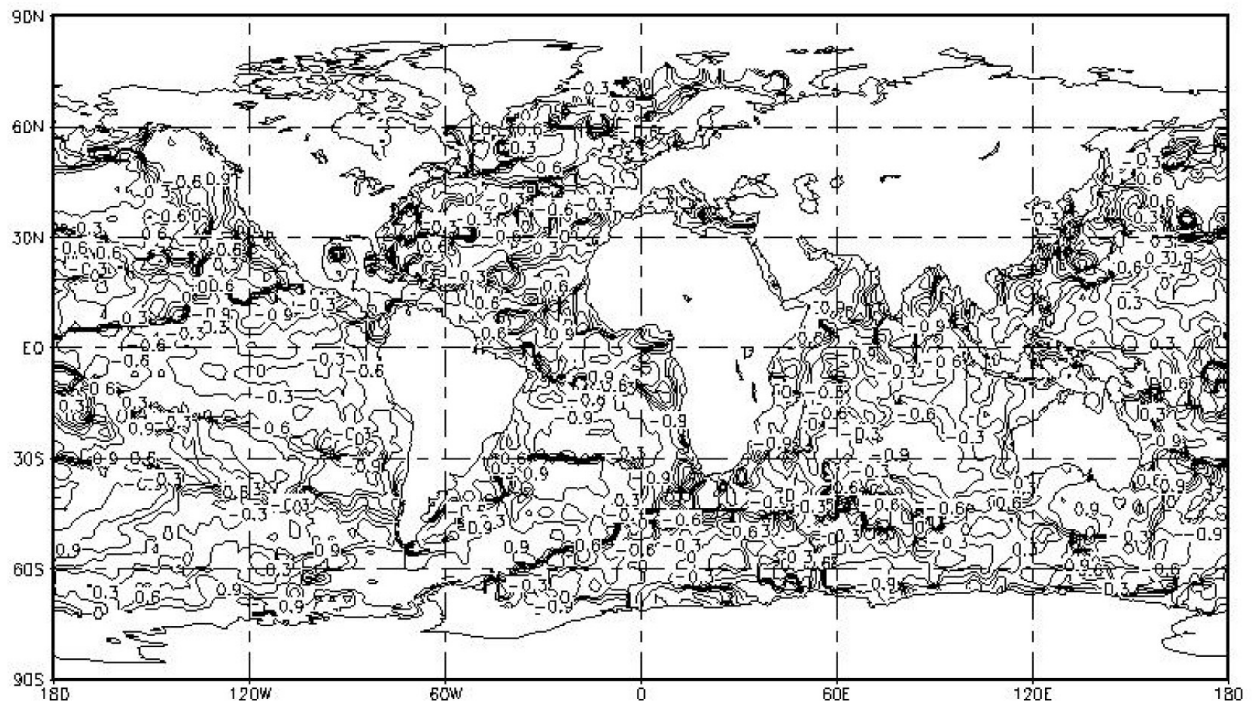


Figure 4. Correlation contours between SST and monsoon rainfall (Class B) with lead time of two months (April)

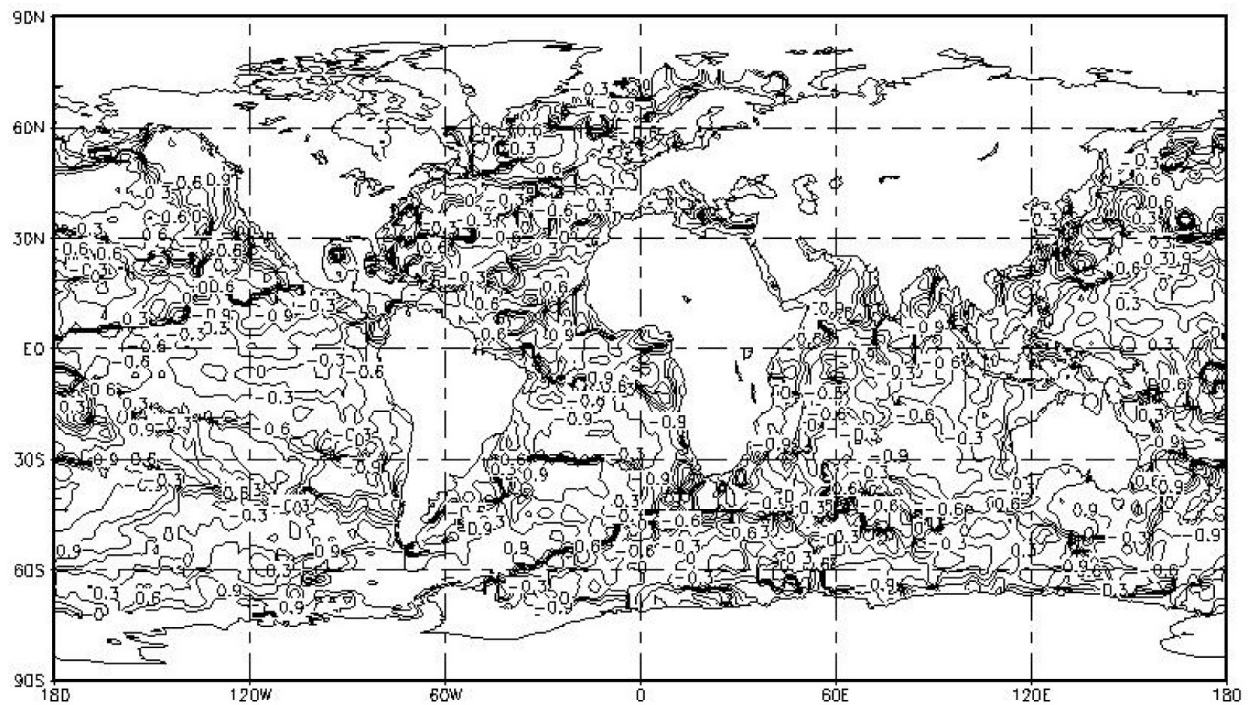


Figure 5. Correlation contours between SST and monsoon rainfall (Class B) with lead time of four months (May)

Conclusions

A preliminary study of the correlation contour patterns generated between SST data and the monsoon rainfall in Orissa, India is presented. By observing the prevailing contour pattern, SST values of different regions influencing the rainfall can be identified. As the correlation contours across the globe are presented, for any particular place of interest, the corresponding correlation coefficients can be picked up and processed by multiple linear regression analysis. The results of this study can thus form a basis for applicability for any region. However, as the data available is not sufficiently large to conduct a more detailed analysis, the methodology presented can be applied for places for which more extensive data can be collected.

It is found from this analysis that some regions in eastern, western and central pacific region, a small region near Darwin, parts of Bay of Bengal, some regions between South America and Africa and between North America and Africa are having significant correlation with the phenomenon under investigation. So these regions can be considered for further analysis.

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