MAUSAM, 49, 2 (April 1998), 229-234

551.553.21 : 551.577 : 551.526.6 (67 : 265)

Relationship between Indian summer monsoon rainfall and sea surface temperature anomalies over equatorial central and eastern Pacific

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(Received 10 April 1996, Modified 12 February 1997)

सार — इस शोध-पत्र में, भूमध्यरेखीय प्रशान्त महासागर के तीन मुख्य क्षेत्रों अर्थात् निनो (1+2), निनो 3 तथा निनो 4 पर समुद्र सतह तापमान (एस. एस. टी.) की विसंगतियों तथा भारतीय ग्रीष्मकालीन मानसून वर्षा के साथ उनके संबंधों की जाँच की गई है। मासिक आधार पर, तीन मुख्य क्षेत्रों के समुद्र सतह तापमान की विसंगतियों के साथ भारतीय मानसूनवर्षा के दोलनकारी किस्म के पश्चता सहसंबंधों का पता चलता है, मानसून ऋतु (सहसंबंधों के मान 0.3 के आसपास) से लगभग एक वर्ष पूर्व के सकारात्मक सहसंबंध शनैःशनैः उल्लेखनीय रूप से नकारात्मक सहसंबंधों में परिवर्तित हो कर मानसून ऋतु के दौरान/बाद में सितम्बर - अक्तूबर में उच्च स्थिति में पहुँच जाते हैं। ऋतुओं के आधार पर भी विसंगतियों की गति मासिक आधार के सामान ही पाई गई हैं, किन्तु उनकी प्रकृति अधिक स्पष्ट है। एक ही प्रकार के मानसून वर्षों के संयुक्त विश्लेषण से यह पता चलता है कि कम (अधिक) वर्षा वाली मानसून वर्षों के दौरान तीनों ही क्षेत्रों की समुद्र सतह तापमान विसंगतियों में अपेक्षाकृत उष्णता (अपेक्षाकृत शीतलता) की प्रवृत्ति पाई जाती है, जो कि मानसून ऋतु से छः माह पूर्व ही आरम्भ हो जाती है। भारत मौसम विज्ञान विभाग में कार्य कर रहे एल. आर. एफ. मॉडल में इस समय उपयोग में आ रहे एल निनो श्रेणी की अपेक्षा निनो 3 तथा निनो 4 क्षेत्रों से पिछले शीतकाल (डी. जी. एम.) से लेकर ग्रीष्मकाल (एम. ए. एम.) तक की ऋतुओं के समुद्र सतह तापमान की विसंगतियों की पूर्व सूचना अधिक अच्छी तरह से मिली है। एल निनो श्रेणी के स्थान पर एल निनो 4 क्षेत्र से समुद्र सतह तापमान की प्रवृत्ति का उपयोग करते हुए भारत मौसम विज्ञान विभाग के 16 प्राचलों वाले प्रचालन शक्ति समाश्रयण मॉडल को संशोधित किया गया है। नए पूर्वानुमान मॉडल से पूर्वानुमान त्रुटियों में काफी कमी आई है।

ABSTRACT. Sea surface temperature (SST) variations over the three key regions over equatorial Pacific, *viz.*, Nino (1+2), Nino 3 and Nino 4 and their relationships with Indian summer monsoon rainfall have been examined in this study. On monthly scale, SST anomalies over the three key regions show an oscillatory type of lagged correlations with Indian monsoon rainfall, positive correlations almost one year before the monsoon season (CC's are of the order of 0.3) which gradually change to significant negative correlation peaking in September/October during/after the monsoon season. The variations on seasonal scale also exhibit the same pattern of monthly variations but more smooth in nature. Composites of similar monsoon years show that during deficient (excess) monsoon years SST anomalies over all the three regions have warmer (cooler) trend which starts about 6 months prior to monsoon season. Tendencies of SST anomalies from previous winter (DJF) to summer (MAM) seasons over Nino 3 and Nino 4 regions are better predictors than El-Nino categories currently being used in IMD's operational LRF model. By using tendency of SST over El- Nino - 4 region, in place of the category of El-Nino, the 16 parameter operational Power Regression Model of IMD has been modified. The new forecast model shows better reduction in the forecast error.

Key words — El-Nino, Long-range forecast, Monsoon rainfall.

1. Introduction

Relationships between the Indian summer monsoon and El- Nino/Southern Oscillation(ENSO) phenomenon have been studied since the early part of this century. Periods, during which sea surface temperature (SST) in the central and eastern tropical Pacific Ocean is excessively warmer than normal, are referred to as El-Nino. During El-Nino years, generally the warm SST anomaly first appears off the coast of Peru and then extends westwards. The relationship between the variation of SST over the equatorial Pacific Ocean and Indian monsoon rainfall have been studied by a number of investigators (Khandekar 1979, Sikka 1980, Rasmusson and Carpenter 1983, Mooley and Parthasarathy 1983, Parthasarathy and Sontakke 1988, and Verma 1994). These studies in general confirmed that SST anomalies in the equatorial Pacific were highly correlated

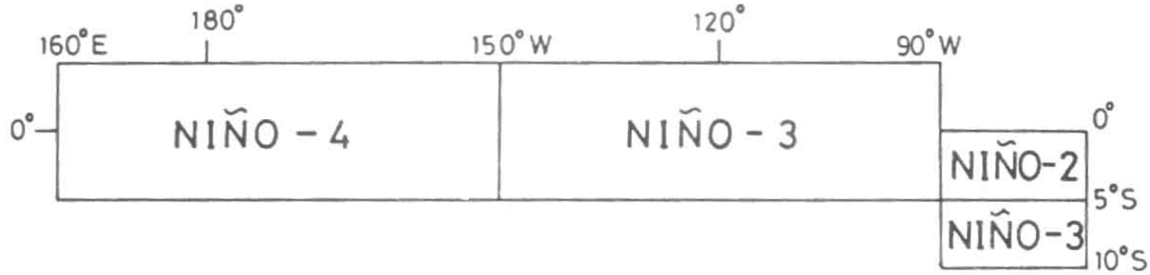

Fig.1. Areas of Nino regions

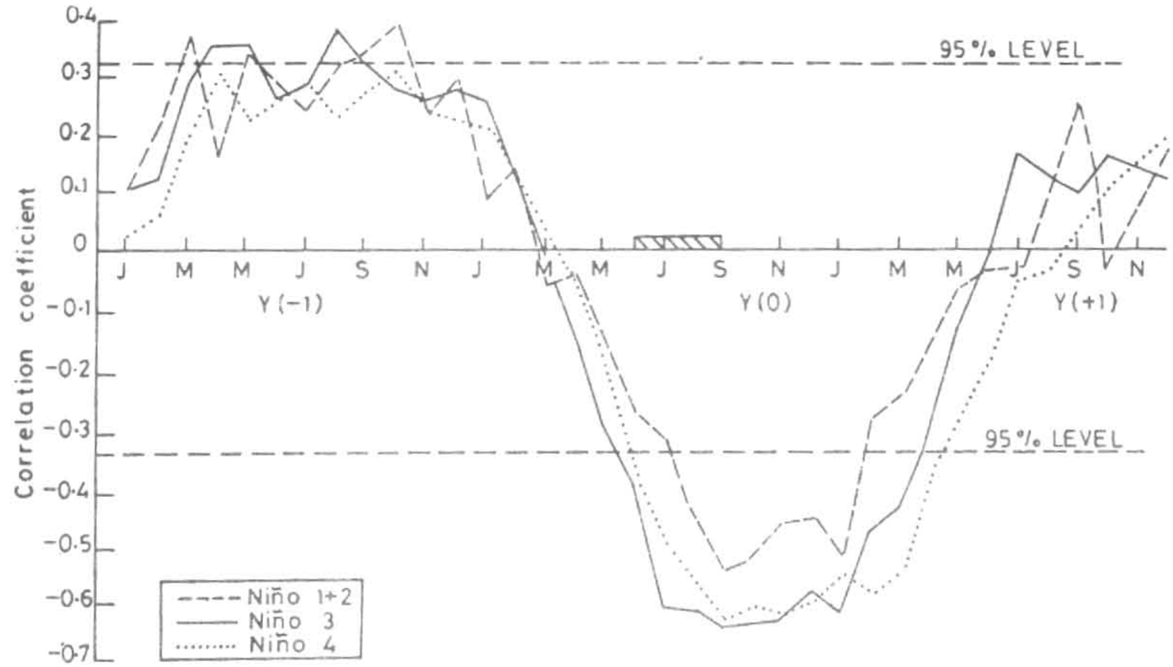

Fig.2. Correlation coefficients between all India monsoon rainfall and monthly SST anomalies over the three El-Nino regions

TABLE 1

All India summer monsoon rainfall percentage departure (1951-96)

Year	0	1	2	3	4	5	6	7	8	9
1950	--	-19	-8	10	3	10	14	-2	-10	14
1960	0	22	-3	-2	10	-18	-13	0	-10	0
1970	12	4	-24	8	-12	15	2	4	9	-19
1980	4	0	-15	13	-4	-7	-13	-19	19	1
1990	6	-9	-7	0	10	0	3	-	-	-

with rainfall over India. In majority cases, all India summer monsoon rainfall was found below normal during moderate and strong El-Nino years.

For recent four decades, a good set of data of SST anomaly over equatorial Pacific are available. Climatic Analysis Centre, NOAA, Washington, USA publishes monthly SST anomalies over three key areas over equatorial Pacific. These areas are called Nino (1+2), Nino 3 and Nino 4 as shown in Fig.1. The temperature variations over these key areas are considered to be good indicators of El- Nino activity.

In this study we examined the SST variation over these three key regions and their relationship with Indian monsoon rainfall. We have also examined the predictive signal of SST variations over these regions for long range forecasts of monsoon rainfall over India. Attempts were made to

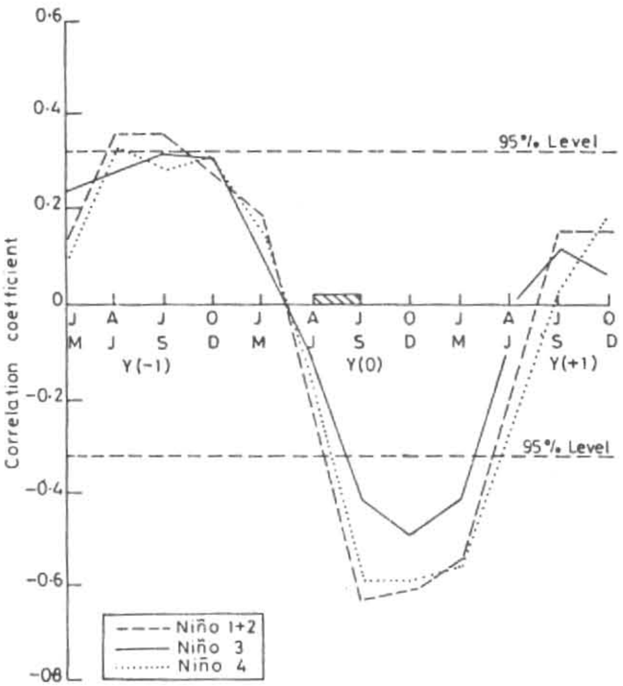

Fig.3. Correlation coefficients between all India monsoon rainfall and seasonal SST anomalies over the three El-Nino regions

identify the best SST anomalies over different Nino regions as a predictor and used with 16 parameters operational model of IMD.

2. Data used

Monthly sea surface temperature (SST) data for past 45 years (1951-95) averaged over the three key Nino regions of equatorial Pacific ocean have been obtained from Climate Analysis Centre, Washington, USA. Indian monsoon rainfall time series as the area weighted seasonal (June-September) rainfall averaged over India as a whole has been obtained from Thapliyal (1990 and 1996). For ready reference, the updated monsoon rainfall data for past 45 years (1951-95) are given in Table 1.

3. Analysis and results

3.1. *Relationship between monthly SST anomalies and monsoon rainfall*

Peru Ecuador coast mean monthly SST of previous August has been identified by Thapliyal (1990) as one of the predictors for monsoon rainfall over India. For some years, the India Meteorological Department (IMD) used this as one of the predictors in its operational multiple regression model (Thapliyal and Kulshrestha 1992). An attempt is, therefore, made here to examine the relationship of Indian monsoon rainfall with the SST of all the 3 key regions of the central Pacific. Fig.2 shows the lag correlations between the Indian monsoon rainfall and monthly SST anomalies over the three

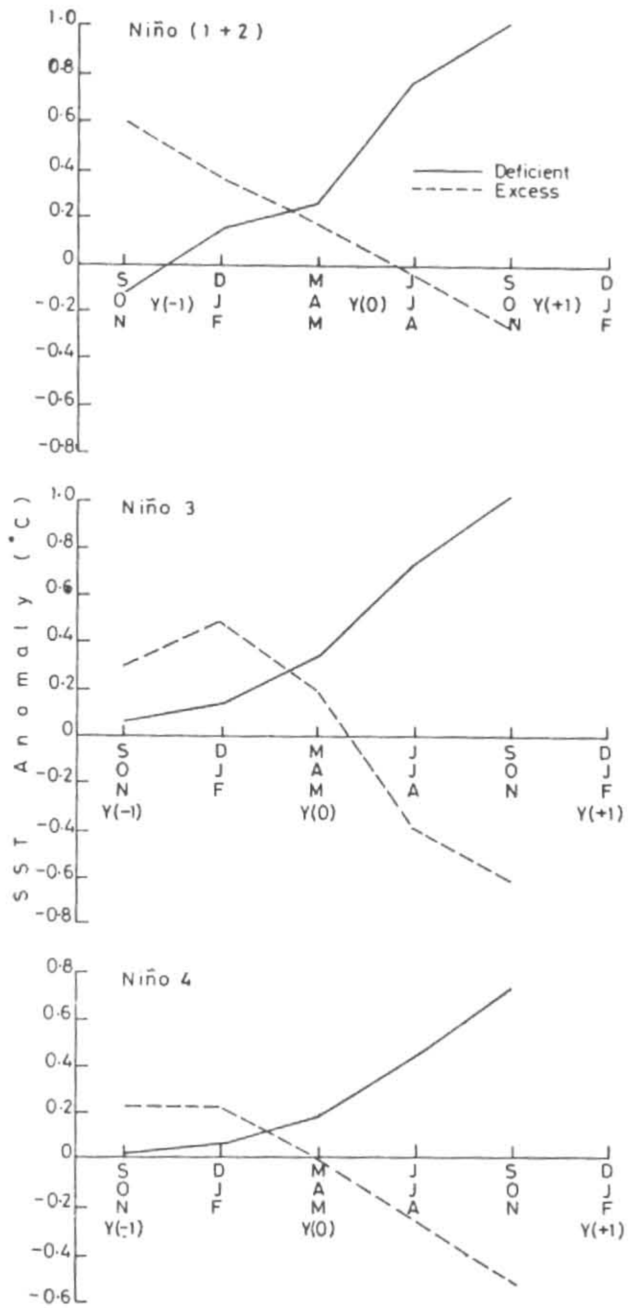

Fig.4. Composite SST anomalies over the three El-Nino regions during the excess/deficient monsoon years

regions based on 35 years (1958-92) data. The correlation coefficients (CC) gradually change from +ve during the summer of previous years $Y(-1)$ to the following winter of previous year. It is seen from the Fig. 2 that monsoon rainfall shows positive CC with the SSTs of all 3 Nino regions, from previous year December. The CC fluctuates around 0.3. The sign of CC changes rapidly from previous year December to July of current year when it becomes significantly negative ($r = -0.6$). During the current year the maximum nega-

TABLE 2

Correlation coefficients between Indian monsoon rainfall and SST anomalies during MAM season and tendencies of SST anomalies from winter to summer

(Period : 1958-93)

S. No.	Region	MAM	Tendency (MAM-DJF)
1.	Nino (1+2)	-0.09	-0.26
2.	Nino 3	0.24	-0.43*
3.	Nino 4	-0.07	-0.43*

*Significant at 99% level

TABLE 3

Standard error for the period 1958-87 and 1988-94 using 16- parameter power regression model

S.No.	One of the 16 parameters as	Standard Error (%) Sample period (1958-87)	Test period (1988-93)
1.	El-Nino category -Same year (Gowariker *et al.* 1991)	4.08	8.81
2.	Nino (1+2) tendency	4.23	8.92
3.	Nino (3) tendency	4.10	8.44
4.	Nino (4) tendency	3.78	7.69

tive CC is noted in September, when monsoon starts withdrawing from northern parts of India. After September of the current year, the CC starts changing rapidly and becomes almost zero around June of the subsequent year $Y(+1)$. The type of variation of CC is the same in all three regions. The maximum positive correlation (0.40) is observed for Nino (1+2) region during the previous year $Y(-1)$. The maximum negative correlation for all the regions is observed in the same year $Y(0)$ at the end of the monsoon season. For Nino 3 region, maximum negative correlation (-0.65) is obtained during September and October months of the same year $Y(0)$. Nino 3 region exhibits highest negative correlation with Indian monsoon rainfall. It is interesting to note that CC's of SST's during the premonsoon months of current year $Y(0)$ are very small in all cases.

3.2. *Relationship between seasonal SST anomalies and monsoon rainfall*

Fig.3 shows the variation of CC's between seasonal (3 months) averaged SST (starting from the period Jan-Feb-Mar) of $Y(-1)$ to [Oct-Nov-Dec of $Y(+1)$] and Indian monsoon rainfall. It is seen from the Fig.3 that the temporal variation of the CC is oscillatory in character and resembles the monthly CC's reported above. The highest positive correlation (of the order of 0.3) is observed during July and September months of the year $Y(-1)$ and highest negative correlation is observed during July to September months of the year $Y(0)$. The highest negative correlation ($r = -0.64$) is observed in case of Nino-3 region. In this case also, the CC's of SST anomalies during the premonsoon season of year $Y(0)$ are insignificant for all three regions.

3.3. *SST patterns and tendencies during flood and drought years*

In order to examine whether there are significant differences in the SST anomalies and their seasonal trends during drought (deficient) and flood (excess) years we have made composites of SST anomalies for three regions, separately for drought years (1965, 1966, 1968, 1972, 1974, 1979, 1982, 1986 and 1987) and excess years (1956, 1959, 1961, 1970, 1975, 1983 and 1988). If the seasonal monsoon rainfall in a year is less than 90% of the long period average, the monsoon is termed as drought year. When the rainfall is more than 110% of the long period average, the monsoon is termed as excess year. Thus the normal monsoon indicates rainfall within ± 10% of the average, which is nearly equal to the standard deviation of the rainfall. SST anomalies for two composite cases (drought and excess) are shown in Fig.4. It is seen from Fig.4 that during deficient (excess) years SST anomalies show a warming (cooling) trend from previous year to the latter year in all the three regions. The warming (cooling) trends in fact start just at the end of previous year $Y(-1)$ and continues till the end of year $Y(0)$.

It is interesting to note that there is little difference in temperature anomalies between the two extreme cases during MAM season of year [$Y(0)$] and thus the mean anomalies during MAM may not be an ideal predictor for LRF purposes. On the other hand, largest difference between the temperature anomalies occurs after the monsoon season.

Since there is a significant difference in the temperature anomaly trends (*i.e.*, warming/cooling during drought/excess years), the usefulness of this information for long range forecasting has been explored.

3.4. *Utility of SST tendencies for long range forecasting*

Thapliyal (1990) has identified and used the tendency of SST from January to March Ecuador coast as a predictor for monsoon rainfall over India. By using this tendency as one of the predictors, he formulated a power regression model with 14 parameters, which showed that nearly same results can be obtained with 14 parameters as are found by

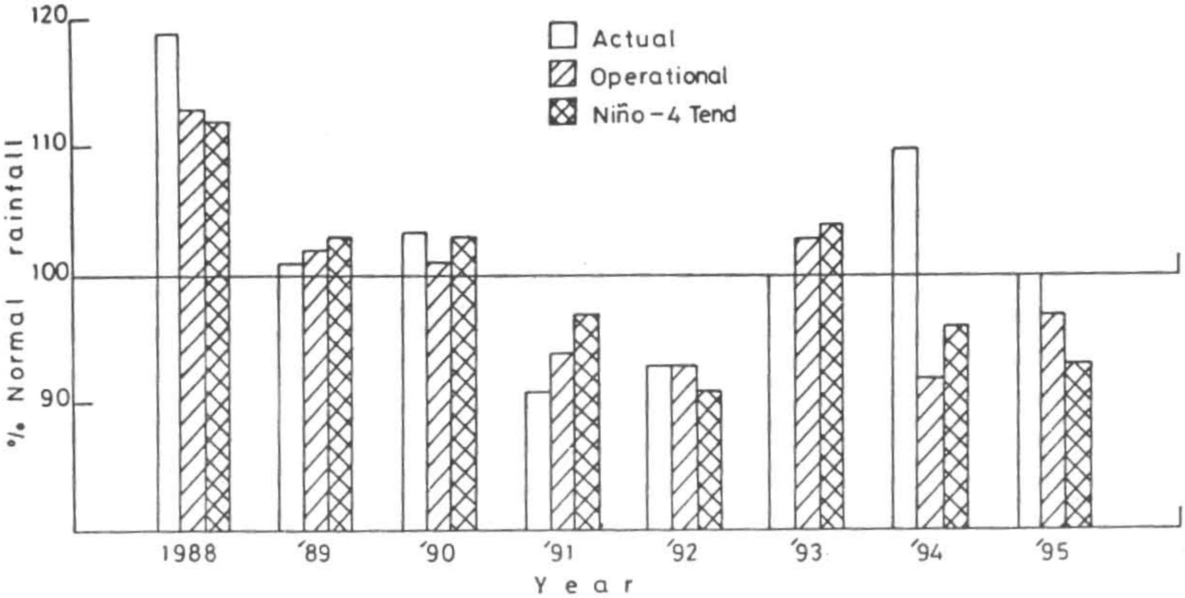

Fig.5. Comparison of monsoon rainfall forecasts of the modified and operational 16-parameter power regression models

using 16 parameters in the power regression model (Gowariker *et al.* 1991). We, therefore, made a time series of tendencies of temperature anomalies (MAM-DJF) for the three regions separately. These time series were correlated with monsoon rainfall and the results are shown in Table 2.

It is seen from the table that tendencies of temperature anomalies in all the three regions exhibit higher correlation with monsoon rainfall than mean temperature anomalies during MAM season. Temperature tendencies over Nino 3 and Nino 4 regions have shown higher correlations with monsoon rainfall compared to the tendency observed in Nino (1+2) region. Mooley and Paolino (1989) found that warming/cooling years are mutually exclusive events.

We have further examined the usefulness of these tendency parameters by using them in 16-parameter power regression model (Gowariker *et al.* 1991). The 16-parameter model uses category of El-Nino in the region Nino (1+2) as one of the predictors. This parameter has been replaced by the more objective parameter, SST tendency in different El-Nino regions, identified for the first time in this study. To start with, we have estimated the standard errors of the 16 parameters power regression model (Gowariker *et al.* 1991). Then, the El-Nino categories were replaced by tendencies over Nino (1+2), Nino (3), and Nino (4) regions in the power regression model and standard errors were recalculated. The standard errors for the model for sample period 1958-87 and test period 1988-93 are given in Table 3.

It can be seen from Table 3 that when we replace El-Nino categories (same year) by regional SST tendencies, the model results improve except for Nino (1+2) region. For example, if we replace El-Nino category by SST tendencies over region Nino 4, standard error of the model for test period (1988-93) is reduced from 8.81 to 7.69%. For Nino 3 region also, results show improvement. Thus it is fair to argue that SST tendencies over Nino 3 and Nino 4 regions are better predictors than El-Nino category which is being used in IMD's operational power regression model for LRF.

Out of the three El-Nino related parameters namely El-Nino (category same year and SST tendency over Nino-3 and Nino-4), the Nino-4 SST tendency gives the best results. Therefore, El-Nino category in 16 parameters operational model has been replaced by the Nino-4 SST tendency. Based on 30 years' (1961-90) data, the modified power regression model is given below:

$$
\begin{aligned}
R(t) = & -0.5968 - 0.2139\,E{-03}\,X_1^{1.7} \\
& + 0.3533\,E\,00\,X_2^{-1.2} \\
& - 0.5385\,E{-01}X_3^{-4.0} + 0.5533\,E - 02\,X_4^{4.0} \\
& + 0.3294\,E{-05}\,X_5^{4.0} + 0.3935\,E{-02}\,X_6^{4.0} \\
& + 0.4175\,E{-04}\,X_7^{4.0} + 0.1423\,E\,05\,X_8^{-4.0} \\
& - 0.3890\,E\,03\,X_9^{-4.0} + 0.6399\,E{-03}\,X_{10}^{4.0} \\
& - 0.1314\,E\,03\,X_{11}^{-4.0} - 0.1198\,E{-02}\,X_{12}^{4.0} \\
& - 0.1140\,E\,02\,X_{13}^{3.9} - 0.1499\,E\,00\,X_{14}^{1.4} \\
& + 0.2735\,E\,03\,X_{15}^{-4.0} + 0.1239\,E\,02\,X_{16}^{3.3}
\end{aligned}
\qquad (1)
$$

Where, R is monsoon rainfall as percentage of long period average for India as a whole,

TABLE 4

Standard error (%) of operational and modified model

S. No.	Period	Operational	Nino-4 tendency + El-Nino (PR) category
1.	1958-87	3.04	2.94
2.	1988-95	7.17	6.77
3.	1958-95	4.25	4.05

X_1 = 50 hPa East-West Ridge,
X_2 = Eurasian Snow cover,

X_3 = 500 hPa Ridge,
X_4 = May Vidarbha Temperature,

X_5 = 10 hPa Zonal Wind,
X_6 = March East Coast Temperature,

X_7 = N. H. Pressure Anomaly,
X_8 = Argentina Pressure,

X_9 = N.H. Temperature,
X_{10} = S.O.I,

X_{11} = El-Nino (Previous Year),
X_{12} = North India Temperature,

X_{13} = Equatorial Pressure,
X_{14} = Nino 4 Temperature Tendency,

X_{15} = Himalayan Snow Cover,
X_{16} = Darwin Pressure.

Forecasts obtained from the modified and operational model are shown in Fig.5. It is seen from the Fig.5 that the performance of both the models is comparable. The root mean square errors for the different periods are shown in Table 4.

5. Conclusions

(*i*) On monthly scale, SST anomalies over the three key Nino areas show an oscillatory type of lagged correlations with Indian monsoon rainfall; positive correlations almost one year before the monsoon season (CC's are of the order of 0.3) which gradually changes to significant negative correlation peaking in September/October (CC between 0.54 to 0.65), during/after the monsoon season.

(*ii*) On seasonal scale also SST anomalies show similar oscillatory type of lagged correlations with Indian monsoon rainfall as reported for the monthly SST variations.

(*iii*) During deficient (excess) monsoon years, SST anomalies over all the three regions show a warming (cooling) trend which starts about 6 months prior to monsoon season.

(*iv*) Tendencies of SST anomalies from previous DJF to MAM seasons over Nino 3 and Nino 4 regions are better predictors than El-Nino categories currently being used in the operational LRF model of IMD. Introduction of SST tendency over Nino-4 region in the 16- parameter operational power regression model of IMD has reduced the forecast errors of the model further.

Acknowledgement

We are thankful to Dr B.C. Biswas, DDGM(PM) for his encouragement and Shri S.G. Nargund for the computations and Smt. N.S.Satbhai for typing the manuscript.

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