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EL NIÑO/SST OF PUERTO CHICAMA AND INDIAN SUMMER MONSOON RAINFALL: STATISTICAL RELATIONSHIPS

B. PARTHASARATHY**
N. A. SONTAKKE*

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RESUMEN

Utilizando datos para el período 1871-1985, se presenta una investigación estadística de la relación entre la precipitación pluvial durante el monzón de verano para todo el territorio de la India y la temperatura de la superficie del mar (SST) de Puerto Chicama, Perú, durante El Niño. Durante los eventos Fuerte-Moderado de El Niño, la precipitación monzónica se encuentra 11 por ciento por debajo de la normal y es estadísticamente significativa al 0.1%. El coeficiente de correlación (CC) entre las dos series es −0.33 y es altamente significativo. El análisis de superposición de épocas también indica que durante el año de El Niño, la precipitación durante el monzón se encuentra muy por debajo de la normal.

La SST de Puerto Chicama (8^{o}S, 79^{o}W), la cual es un buen indicador del fenómeno de El Niño, muestra una relación significativa con la precipitación de la India, para diferentes meses y estaciones durante el período 1925-1980.

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* *Indian Institute of Tropical Meteorology, Pune - 411 005, INDIA.*

** *Present address: Cooperative Institute for Environmental Sciences (CIRES), Campus Box 449, University of Colorado, Boulder, CO 80309, U. S. A.*

El CC con el mes de mayo de SST es −0.5, el cual es altamente significativo, utilizándose esta relación en el desarrollo de la ecuación de regresión para estimar la precipitación de toda la India. La ecuación de regresión encontrada para el período 1925-1980 es $y = 128.3 - 2.42x$; donde y es la precipitación monzónica de toda la India y x es la SST de mayo de Puerto Chicama. Las estimaciones encontradas a partir de esta relación, aplicada a los años independientes 1981-1985, son alentadoras.

La relación entre la precipitación monzónica subdivisional y la SST de Puerto Chicama, para diferentes regiones de la India, es significativa al nivel de 5% o por arriba de este valor para 11 subdivisiones, principalmente aquellas áreas que se ubican al norte de los 16°N y el oeste de los 80°E.

ABSTRACT

A detailed statistical investigation of the relationship between All-India (India taken as one unit) summer monsoon (June to September) rainfall and El Niño/SST of Puerto Chicama has been made in the study based on the available data for the period 1871-1985. During the strong/moderate El Niño events, the All-India monsoon rainfall is about 11% below the normal and this is statistically significant at 0.1% level (Student's t-test). The correlation coefficient (CC) between the two series is −0.33 which is highly significant. Superposed epoch analysis has also indicated that monsoon rainfall is very much below normal during El Niño year.

Puerto Chicama (8°S, 79°W) sea surface temperature (SST) which is a good indicator of El Niño phenomenon, showed significant relationship with All-India rainfall for the period 1925-80 with different seasons as well as months. The CC with the month of May SST is −0.5 which is highly significant and this relationship is utilized in the development of the regression equation to estimate the All-India rainfall. The regression equation developed for the data years 1925-80 is $y = 128.3 - 2.42x$ where y is the All-India monsoon rainfall and x is the May SST of Puerto Chicama. Estimates from this relationship for the independent years 1981-85 are found to be encouraging.

The relationship between sub-divisional monsoon rainfall for different regions of India and May SST of Puerto Chicama is significant at 5% level or above for 11 sub-divisions, mainly these areas lie north of 16°N and west of 80°E.

INTRODUCTION

Within the tropics, rainfall is the most important climatic element, since in many countries irrigation is meager and crops are mostly rain-fed. The Indian summer monsoon which gives about 70 - 90 percent of annual rainfall over most parts of the country during the four months, June to September, is the most outstanding feature of Indian meteorology. The highly monsoon-dependent economy of India urgently needs an accurate advance estimate of the country monsoon rainfall. The Asian summer monsoon which is the basic manifestation of the influence of the seasonal heating and cooling over Asiatic landmass constitutes an important element of the global atmospheric and oceanic circulation. Therefore, attempts were made by the Indian meteorologists to correlate Indian monsoon rainfall with different circulation features, so that the relationship can be utilized for long-range forecast of the Indian monsoon. A review of these attempts has been made by Jagannathan (1960) and Rao (1965).

El Niño, the warming of the oceanic mixed layer from the coast of Peru (South America) to the international dateline has attracted the attention of many meteorologists and oceanographers. The energy received as abundance in equatorial areas is transported by winds and ocean currents to polar and high latitudes and these circulations in the atmosphere and ocean control the global distribution of momentum, mass, water vapour and heat in the atmosphere. Scientists working with El Niño-related problems have described and attempted to explain the role of El Niño in weather and climatic prediction. This activity has gained lots of interest during recent years because of the El Niño's potential for better understanding and prediction of the regional and remotely related phenomena over the globe.

The prospect of using sea surface temperature (SST) variations over the equatorial Pacific Ocean to obtain seasonal prediction of Indian summer monsoon as well as of the atmospheric flow patterns has been considered by Khandekar (1979, 1982), Sikka (1980), Angell (1981), Rasmusson and Carpenter (1982, 1983), Ramage (1983), Shukla and Paolino (1983), Mooley and Parthasarathy (1983, 1984b), Khandelar and Neralla (1984), Mooley *et al.* (1985), Kiladis and Díaz (1986) and Parthasarathy and Mooley (1986). The study of meteorological teleconnections or relationships between temporal fluctuations of meteorological parameters at widely distant locations has received much recent attention because of the insight that such relationships give to the understanding of climate and weather variability. In order to establish the statistical relationship and to develop the regression equation between Indian summer monsoon rainfall and El Niño or equatorial Pacific SST (Puerto Chicama SST) we have examined the data for the period 1871-1985, in this study.

DETAILS OF DATA

The climatological nature of the study requires reasonably long period of observations of rainfall and sea surface temperatures (SST). In the present study we have examined the Indian rainfall, El Niño and Puerto Chicama SST for the longest possible period *i.e.,* 1871-1980 for the establishment of relationship and 1981-85 for prediction purposes. The following are the details of data used in the study.

All-India summer monsoon rainfall

India, excluding predominantly hilly portions is the area considered here. Figure 1, shows the different meteorological sub-divisions into which India has been divided

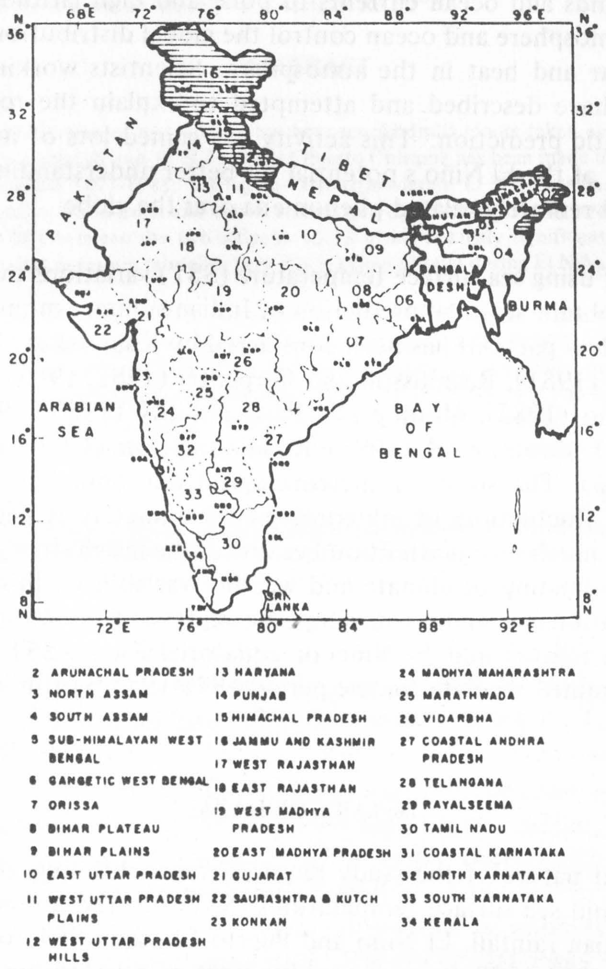

Fig. 1. Meteorological sub-divisions of contiguous India. Hatched mountainous areas are not considered.

and also indicates the hatched mountainous area which is not considered. Three hundred and six raingauge stations, one from each of the districts in the plain region of India, have been selected to form the fixed homogeneous network. The relevant rainfall data of these 306 stations for the period 1871-1985 were collected from the records of the Office of the Additional Director General of Meteorology (Research), India Meteorological Department, Pune. From these data, series of area-weighted summer monsoon (June-September) rainfall were constructed for India as one unit (to be referred to hereafter as All-India rainfall series) and for each of the 29 meteorological sub-divisions of India, the weights assigned to each raingauge station were the area of the district in which the station was located. The spatial averages remove random component present in data for individual stations and are thus more representative of large scale conditions of that area.

The statistical details of All-India monsoon rainfall are discussed and the actual data points are given for the period 1871-1983 in the paper by Mooley and Parthasarathy (1984a). Similarly, for 29 different sub-divisional rainfall data series of India and the detailed statistical analysis are discussed in the study of Parthasarathy *et al.* (1987).

El Niño events

El Niño may be understood as an anomalous oceanic and meteorological event characterized by the sudden appearance of abnormally warm surface water on a scale of a few thousand kilometers off Peru and Ecuador coast of South America.

The appearance of warm water off South American coast is not an isolated local effect but is coupled and coincides with the changes in the ocean-atmosphere system over the entire equatorial Pacific as a thermally direct Walker circulation in the equatorial zonal plane which operates a large tapping of potential energy by combining the large-scale rise of warm moist air and descent of cold dry air (Bjernkes, 1969). The equatorial Pacific SST is a crucial parameter in the coupled ocean-atmosphere system. It is a function of the surface energy flux, horizontal and vertical advection, mixed layer depth, attenuation of solar radiation, etc. During El Niño period the eastern tropical Pacific is in its warm phase, associated with a western shift in atmospheric mass and a dramatic alteration in the Walker and Hadley atmospheric circulations (Rasmusson, 1984). In the low latitudes a large-scale circulation in meridional plane (of which trade winds are a part) plays a major role in both horizontal and vertical transport. El Niño causes dramatic changes in the currents, thermal structure and sea level along the eastern boundary of the South Pacific. Each phase of El Niño affects the strength, steadiness and structure of the Peru undercurrent in a different manner.

Quinn *et al.* (1978) on a thorough examination of all the available sea surface data and historical records, prepared a chronology of El Niño events since 1726 and have classified them according to the intensity of the event as strong (S), when the sea surface temperature (SST) is 4°C warmer or more than the normal, moderate (M), when SST 3°C or above than normal, weak (W), when SST 2°C or more than normal and very weak (VW), when SST 1°C or above than normal. Quinn *et al.* (1978) referred the event of intensity as 1 very weak; 2 weak; 3 moderate and 4 strong. A total of 34 El Niño events were identified during the period 1871-1980. There are 22 strong or moderate events in this 110 year period, about an average of one event per 5 years.

Puerto Chicama SST

Many studies have indicated that SST of Puerto Chicama (7°42'S; 79°27'W) is a good indicator of El Niño phenomenon, namely by Khandekar (1979), Rasmusson (1984) and Estoque *et al.* (1985). Therefore, we have examined the Puerto Chicama SST from the available period *i.e.*, 1925-1985. The scrutinized Puerto Chicama SST data used in the study, has been obtained from Dr. E. M. Rasmusson, Climate Analysis Center, USA National Meteorological Center, Washington, D. C.

Figure 2 shows the All-India summer monsoon rainfall and monthly mean May SST of Puerto Chicama for the period 1925-85.

STATISTICAL TECHNIQUES ADOPTED

In order to establish and to understand the association between the Indian summer monsoon and the El Niño phenomenon or with the SST for Puerto Chicama the following tests have been carried out: *(i)* Student's t-test, *(ii)* Correlation analysis, *(iii)* Superposed epoch analysis, *(iv)* Consistency of CCs with different sliding window widths and *(v)* Development of the regression equation.

While assessing the significance of cross-correlation between the two series, the influence of the persistence in the individual data series involved has been considered and necessary adjustment in the degrees of freedom wherever necessary has been made as suggested by Quenouille (1952) and Sciremammano (1979).

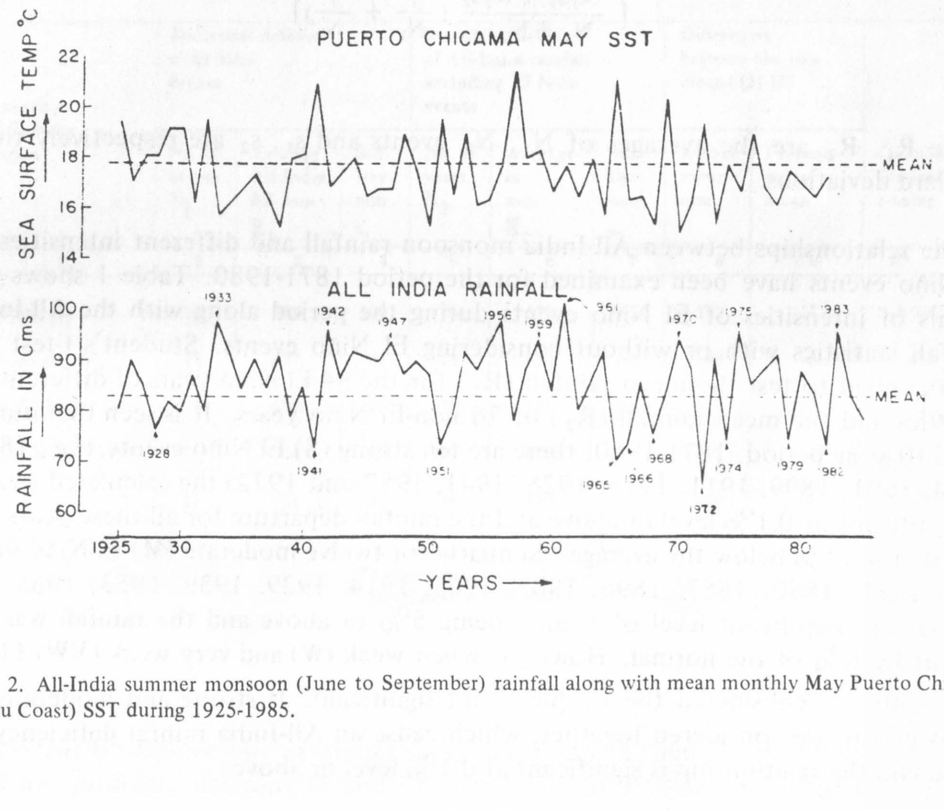

Fig. 2. All-India summer monsoon (June to September) rainfall along with mean monthly May Puerto Chicama (Peru Coast) SST during 1925-1985.

RELATIONSHIP WITH EL NIÑO PHENOMENON

Student's t-test

In the analysis of the climatic fluctuations, one may be interested in the comparison of different averages of the series, when two different types of circulations are affected over different periods (or years) of the data record. The Student's t-test (WMO, 1966) has been used to test the significance, if any, of the differences in the two means. The Student's t-statistic can be computed as follows:

$$t = \frac{\overline{R_2} - \overline{R_1}}{\left[\frac{N_1 s_1^2 + N_2 s_2^2}{N_1 + N_2 - 2} \left(\frac{1}{N_1} + \frac{1}{N_2} \right) \right]^{1/2}}$$

where $\bar{R}_1$, $\bar{R}_2$ are the averages of N_1, N_2 events and s_1, s_2 are respectively their standard deviations.

The relationships between All-India monsoon rainfall and different intensities of El Niño events have been examined for the period 1871-1980. Table 1 shows the details of intensities of El Niño events during the period along with the All-India rainfall statistics with or without considering El Niño events. Student's t-test has been applied to test the mean rainfall ($\bar{R}_1$) for the 34 El Niño years of different intensities and the mean rainfall ($\bar{R}_2$) of 76 non-El Niño years. It is seen that during the 110-year period, 1871-1980, there are ten strong (S) El Niño events, (*i.e.*, 1877, 1884, 1891, 1899, 1911, 1918, 1925, 1941, 1957 and 1972) the calculated t-value is significant at 0.1% level or above and the rainfall departure for all these years put together is 17% below the average. Similarly for twelve moderate (M) El Niño years (*i.e.*, 1871, 1880, 1887, 1896, 1902, 1905, 1914, 1929, 1939, 1953, 1965 and 1976), the significant level of t-value being 5% or above and the rainfall was deficient by 6% of the normal. However, when weak (W) and very weak (VW) El Niño events are considered the t-value is not significant. If strong and moderate, El Niño events are considered together, which cause an All-India rainfal deficiency of 11% and the relationship is significant at 0.1% level or above.

Correlation analysis

To understand the association between the two series, the correlation analysis has been carried out. For the purpose of calculations, the strong El Niño event (year) has been assigned a number 4 and moderate event a number 3, remaining data points have been assigned as zero. The calculated CC is -0.33 and is significant at 0.1% level or above. It is recognized that a CC exceeding 95% confidence limit might

Table 1: Relationship between All-India summer monsoon rainfall and different intensities of El Niño events during 1871-1980

Mean = 853 mm
Std. Dev. = 83 mm
N = 110

Intensity of El Niño events	Statistical details of El Niño events			Statistical details of All-India rainfall excluding El Niño events			Differences between the two means (3)-(6)		
	No. of events N_1	Average All-India RF mm $\bar{R}_1$	Std. Dev. mm s_1	No. of years N_2	Average in mm $\bar{R}_2$	Std. Dev. mm s_2	Actual value mm	Percentage of mean	Calculated Student's t-value
1	2	3	4	5	6	7	8	9	10
Strong (S)	10	730	100	76	872	69	-142	-17	-5.69***
Moderate (M)	12	823	67	76	872	69	-49	-6	-2.26*
Weak (W)	7	830	88	76	872	69	-42	-5	-1.49
Very Weak (VW)	5	904	42	76	872	69	+32	+4	+1.00
S + M	22	781	94	88	870	70	-89	-11	-4.95***

*** Significant at 0.1% level
* Significant at 5% level

well occur by chance one in twenty cases. However CC significant at 99% (or 1%) level are probably meaningful and CC significant at 99.9% (or 0.1%) level is undoubtedly meaningful.

Superposed epoch analysis

The technique of superposed epoch analysis was employed to examine the association of the events in time, if any, between the 22 strong or moderate El Niño events and All-India rainfall. Similar procedure is also used by Bradley *et al.* (1987) to find the relationship between ENSO (El Niño Southern Oscillation) signal and the continental surface air temperature and precipitation over the northern hemisphere regions. For details of application of superposed epoch analysis to Indian rainfall data, refer to Ananthakrishnan and Parthasarathy (1984). The All-India rainfall (percentage departure from normal) during the El Niño year (taken as lag 0) and four years previous and following the El Niño event (lag-4, lag-3, lag-2, lag-1, lag-0, lag+1, lag+2, lag+3 and lag+4) are tabulated for 22 strong or moderate years and the progressive averages have been worked out for each of the lags in time. This is to state that the occurrence of El Niño event has been kept constant (say year 1877) and the All-India rainfall has been moved backward (1873, 1874, 1875, 1876) and forward (1878, 1879, 1880, 1881) in time (four years). Similarly, for other El Niño

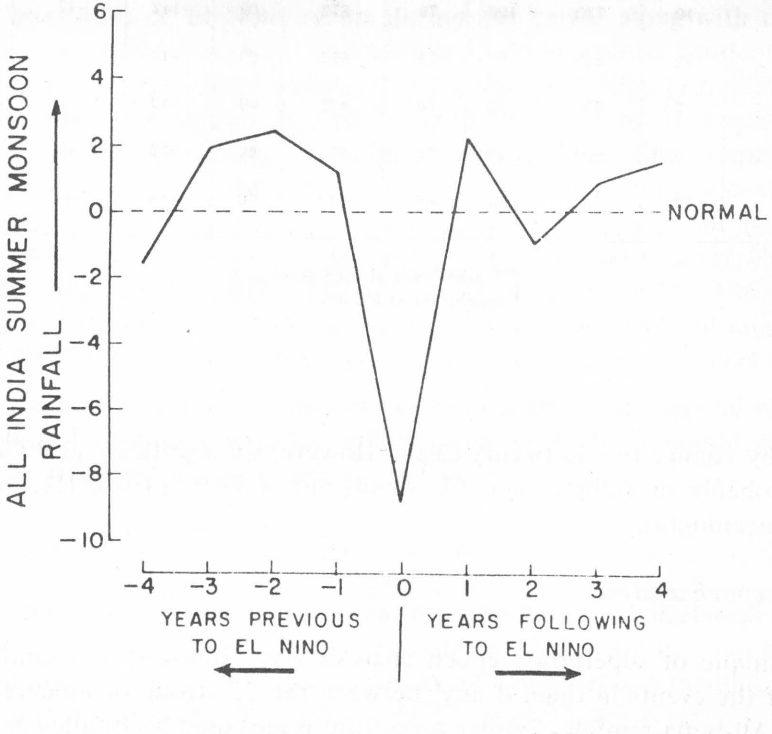

Fig. 3. Superposed epoch analysis of All-India summer monsoon rainfall (percentage departure from normal) with respect to El Niño events (strong or moderate) for the period 1871-1980.

events the rainfall data has been separated (or grouped) and averages are worked out in each of the lags. Figure 3 shows that mean All-India rainfall (percentage departure from mean) during the El Niño year (lag 0), before and after four years of the event. All-India rainfall is more before one to three years of El Niño event, it is very much below during the El Niño year (about - 8%) and it again rises afterwards. It can be inferred that El Niño event has definite influence on Indian rainfall.

It can be concluded by all the above statistical tests that the strong or moderate El Niño events are having a definite negative association with All-India rainfall. However, it is difficult to say that El Niño events are always noticed prior to the onset of the monsoon rainfall. Therefore, in order to predict the Indian rainfall, a parameter in the region of El Niño which occur definitely earlier to monsoon season will be very much useful. It is possible that the general circulation of the atmosphere is rather more sensitive to changes in tropical oceanic surface temperatures than changes in mid latitude oceanic temperatures.

It is shown by Khandekar (1979) and Rasmusson (1984) that the SST at Puerto Chicama which lies in the El Niño occurring region of South American coast is one of the best represented stations regarding the indication of onset and decay of the phenomenon and also can be used for the prediction of Indian rainfall. Therefore, we have examined the association of Puerto Chicama SST for the available data length *i.e.*, 1925-80, with Indian rainfall, in order to develop a regression equation. The purpose of this paper is to examine more closely the relation between SST in the equatorial eastern Pacific ocean and Indian monsoon rainfall, with emphasis on the longer period of record and attention to the significance of the derived relations.

RELATIONSHIP WITH PUERTO CHICAMA SST

Correlation analysis

In order to quantify the relations between SSTs and the All-India rainfall, lagged CCs have been calculated up to two seasons either side of the zero-lag correlation.

The correlation coefficients (CCs) calculated between the All-India monsoon (JJAS) rainfall series and the different seasons of Puerto Chicama SST are as follows. *(i)* the previous winter season, DJF, two seasons earlier to monsoon (lag-2), *(ii)* the spring season, MAM, one season earlier to monsoon (lag-1), *(iii)* the summer season, JJA, concurrent monsoon season (lag 0), *(iv)* the autumn season, SON one season after monsoon (lag+1) and *(v)* the succeeding winter season, DJF, two seasons after monsoon (lag+2).

Table 2 gives the CC values for the full length (56 years) period, 1925-80 and two

Table 2: Correlation coefficients between All-India summer monsoon (June to September) rainfall and for different seasons of SST at Puerto Chicama for the period 1925-1980.

Seasons of SST	Length and period of data		
	Full length 56 years 1925-1980	1st half 28 years 1925-1952	2nd half 28 years 1953-1980
Previous winter DJF: lag -2	-.08	-.19	00
Spring MAM: lag -1	-.41***	-.56***	-.31†
Summer JJA: lag 0	-.49***	-.49**	-.49**
Autumn SON: lag +1	-.46***	-.51**	-.49**
Succeeding Winter DJF: lag +2	-.38**	-.35*	-.46**
April+May	-.43***	-.62***	-.32†

*** Significant at 0.1% level
** Significant at 1% level
* Significant at 5% level
† Significant at 10% level

equal half periods of 28 year length *i.e.,* 1925-52 and 1953-80. It is seen from Table 2 that all CCs are negative and significant at 1% level or above for all seasons except lag-2 (DJF), during the full length period 1925-80 as well as two half periods. In the first period, 1925-52, the CCs are significant at 5% level or above, however, for lag-1 season it is significant at 0.1% level or above for lag 0, lag+1 and lag+2 seasons but it is significant at 10% for lag-1 season. The second half period, 1953-80, the CCs are significant at 1% level or above. It is observed from the CC analysis that All-India rainfall is negatively related with Puerto Chicama SST, the relationship is highly significant for full length of data for lag-1 through lag+2 seasons. It is also further seen that the CCs of SST for April + May months (prior to Indian monsoon) are also quite good.

The monthly data of Puerto Chicama is further subjected to correlation analysis to understand the relationships in detail. Figure 4 shows the monthly CCs between SST and rainfall of the same year (for example, the monsoon rainfall of the year 1926 and each month SST, *i.e.,* January to December of 1926), six months of previous years SST (SSTs of July to December of 1925 and rainfall of 1926) and rainfall and six months of following years SST (SSTs of January to June of 1927 and rainfall of 1926) and rainfall. This is to state that All-India rainfall has been kept constant and monthly mean SSTs of Puerto Chicama moved backward and forward to find their relationships in time. It is seen from the figure that CCs are small and positive during the previous months SSTs and CCs have become negative with current months SSTs and they are statistically significant at 1% level from month May through the next year January and CCs became insignificant afterwards. The month May which is earlier to monsoon season is highly significant and is a very useful indicator. This information could be used to forecast the Indian monsoon rainfall.

Examination of extreme years

Figure 2 gives yearly All-India summer monsoon rainfall along with Puerto Chicama monthly mean May SST for the period 1925-85. The mean Rainfall ($\overline{R}$) is 858mm and standard deviation (s) is 76 mm for the period 1925-80. It is reasonable to assume that the rainfall values in excess of $\overline{R}$+s are taken as excess rainfall years and $\overline{R}$− s as deficient rainfall years (this criteria has been used by Ananthakrishnan and Parthasarathy, 1984, and Mooley *et al.,* 1986, in classification of Indian rainfall). These excess and deficient rainfall years are marked over rainfall curve in Figure 2. There are nine excess rainfall years (1933, 1942, 1947, 1956, 1959, 1961, 1970, 1975 and 1983) spread more or less uniformly during the period. There are ten defi-

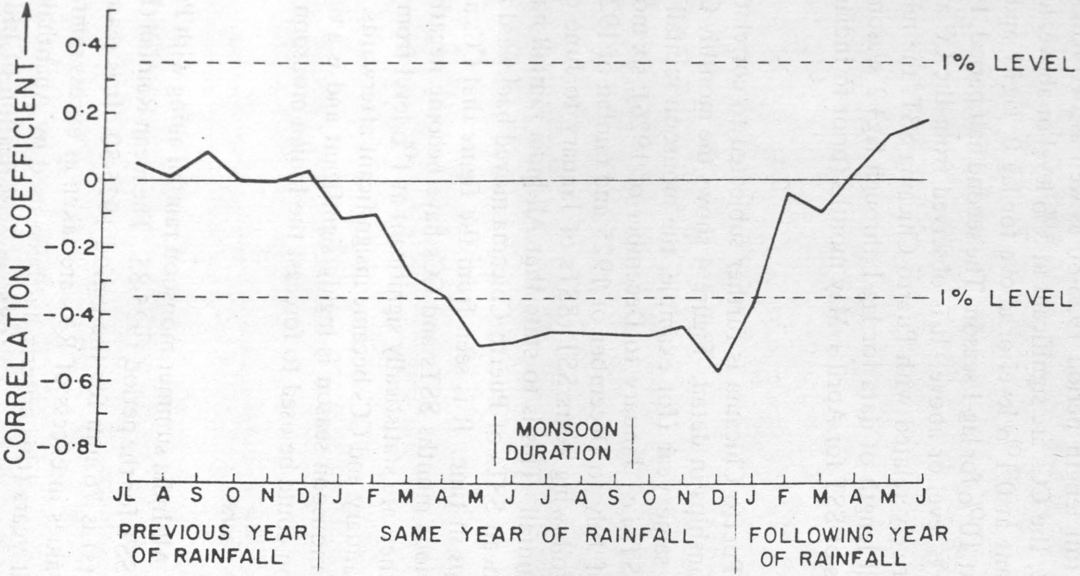

Fig. 4. Correlation coefficients between All-India summer monsoon rainfall and for different monthly Puerto Chicama SST for the period 1925-1980.

cient rainfall years (1928, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979 and 1982) during the entire period, only three deficient rainfall years are noticed during the first half period and the remaining seven mainly lie during the period 1965-82. There are three cases of a deficient year followed by an excess year: 1941, 1942; 1974, 1975 and 1982, 1983. There are no cases of an excessive year followed by a deficient year. While there is one case of deficient monsoon rainfall in successive years, 1965-1966; there were no cases of successive years of excess rainfall.

It is observed from Puerto Chicama May SST and All-India rainfall curves (Fig. 2) that the tendency is more or less opposite, *i.e.,* when rainfall increases, SST shows a decrease. Therefore, we have examined the behaviour of monthly SST prior to monsoon season during the excess and deficient years of All-India monsoon rainfall.

The table below shows the details of averages (SST values in °C are departure from longterm mean) for the groups during excess and deficient years.

	Feb.	Mar.	Apr.	May.	Jun.
Deficient years (10)	−0.30	0.37	0.55	0.97	0.69
Excess years (9)	−0.30	−0.79	−0.52	−0.64	−0.77

It is seen from the above table that the SST is positive during deficient rainfall years and negative in excess years for the months March to June. It can be inferred that warmer temperatures over Pacific Ocean regions during March to June are not favorable for normal Indian monsoon rainfall. The magnitude of difference between the deficient and excess series is more than 1°C; however, the maximum of difference 1.6°C is observed during May. From this it can be concluded that May is the most suitable and appropriate month to be used in forecasting the Indian rainfall. The CC between All-India rainfall and Puerto Chicama for the month of May SST for the period 1925-80 is −0.49 which is significant at 0.1% level. When the series is divided into two equal halves, the CC for the first half (period 1925-52) is -0.70

which is significant at 0.1% level and for the second half (1953-80) the CC is – 0.36 which is significant at 5% level.

Consistency of the relationship

Consistency of the relationship for different periods of the series is examined by calculating the variations of the CC by the sliding window method as suggested by Bell (1977) using window widths of 10, 20 and 30 years. The variation of CC between All-India rainfall and May SST of Puerto Chicama for different sliding intervals is shown in Figure 5. It is seen from Figure 5 that the CCs are significant at 5% lev-

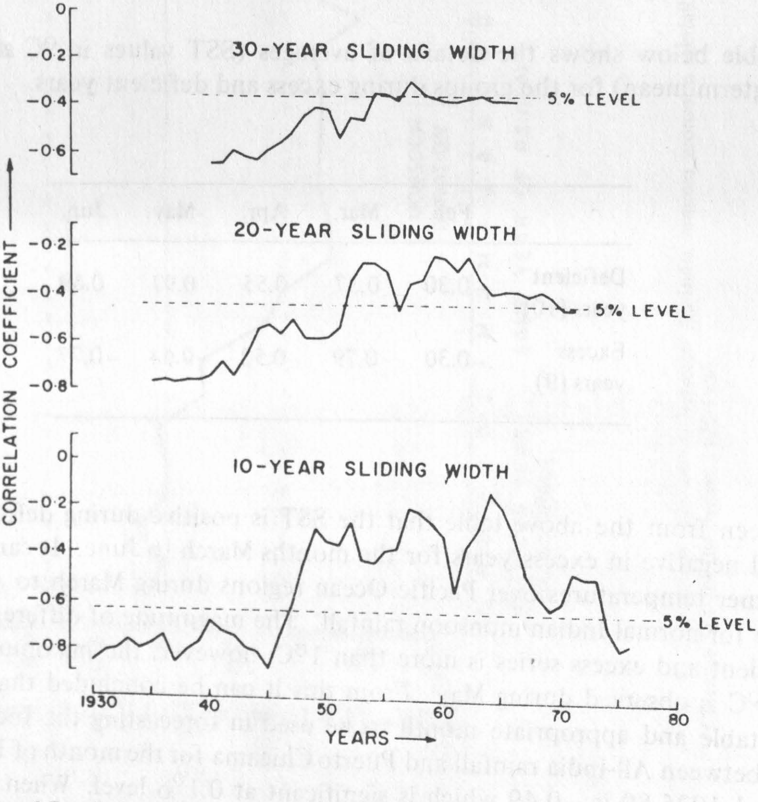

Fig. 5. Variation of Correlation coefficient with 10-, 20-, and 30-years sliding window width between All-India summer monsoon rainfall and mean May SST of Puerto Chicama during 1925-1980.

el or above for the years up to 1946 and that the rest are not significant for 10-year sliding width. The CCs of 20-year sliding width curve is less oscillatory compared to 10-year width curve and the CCs are significant at 5% level or above up to the year 1952. The 30-year sliding curve CCs have attained the maximum stability and almost all CCs are significant at 5% level except on one or two cases. Thus, it can be concluded that the lowest period for which the relationship is stable and consistently significant is 30 years.

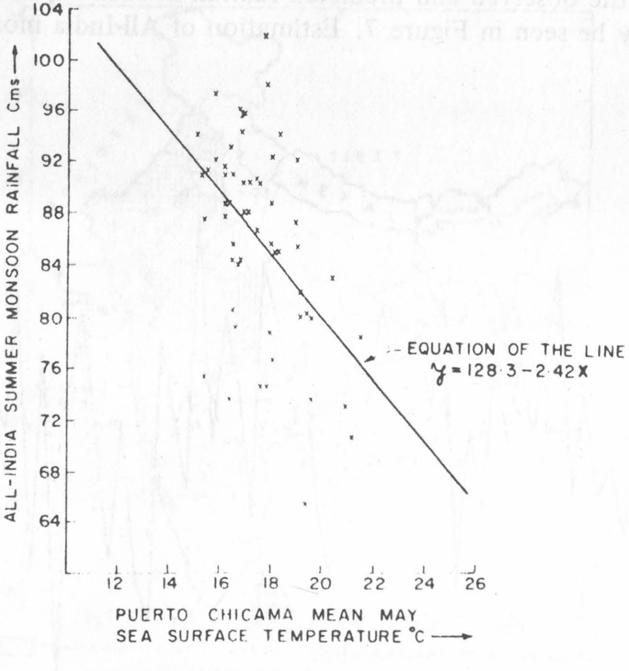

Fig. 6. Scatter diagram along with fitted regression line showing relationship between All-India summer monsoon rainfall and mean May SST of Puerto Chicama for the period 1925-1980.

Development of regression equation

Utilizing the information regarding the All-India monsoon rainfall and mean May SST of Puerto Chicama which are having stable and consistent relationships, a regression equation relating All-India rainfall (y, in cm) to the May SST of Puerto Chicama (x, in ^{0}C) on the basis of data for the period 1925-80 has been developed. It is given by the equation $y = 128.3 - 2.42x$.

Figure 6 shows the regression line along with the scatter of the data points. Using the above regression equation, the All-India rainfall for the independent years 1981-85 are estimated. Figure 7 shows the computed and observed monsoon rainfall for both dependent as well as the independent sample of the data series. Good resemblance between the observed and predicted rainfall in both dependent and independent sample may be seen in Figure 7. Estimation of All-India monsoon rainfall on

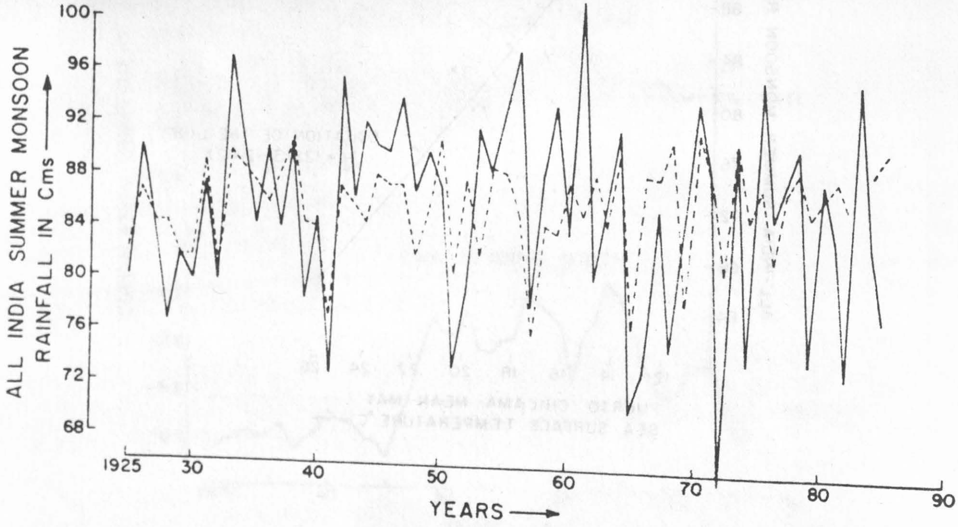

Fig. 7. All-India summer monsoon rainfall (Actual: ——— and estimated: - - - - -) values during 1925-1985.

the basis of May SST of Puerto Chicama alone will have its own limitations because the estimated and observed values for deficient/excess years differ more than normal rainfall year values.

The Indian monsoon is an important component of the global atmospheric circulation. Its predictability, therefore, depends not only on its own dynamics but also upon the dynamics of the global circulation. Therefore, inclusion of Puerto Chicama May SST (or any suitable SST over Pacific Ocean region) along with other regional /global circulation parameters in the final regression equation may result in better estimation of All-India monsoon rainfall.

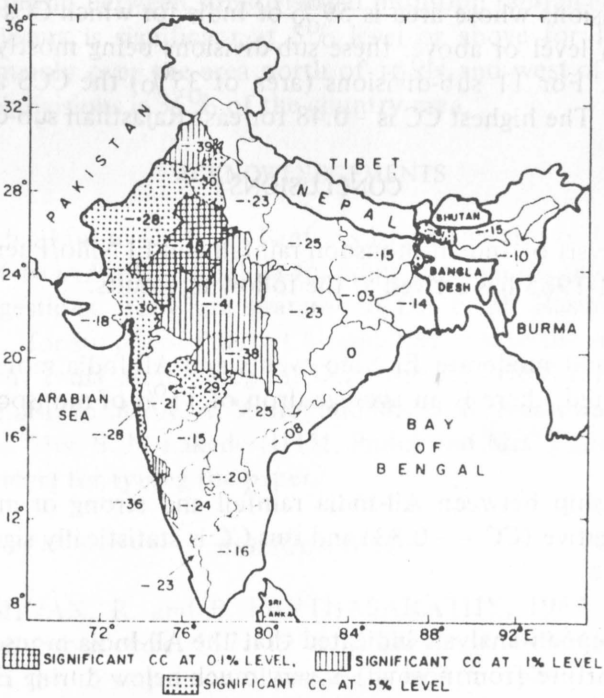

Fig. 8. Correlation coefficients between monsoon rainfall of different meteorological subdivisions of India and mean May SST of Puerto Chicama during 1925-1980.

RELATIONSHIP BETWEEN SUB-DIVISIONAL MONSOON RAINFALL AND MAY SST OF PUERTO CHICAMA

India as one unit, though too big an area for practical purposes, provides an overall view of the rainfall fluctuations and abnormalities which are helpful to the planners and scientists studying general circulation and changes therein. It is well-known that the spatial variability of rainfall within the country is large. The rainfall of meteorological sub-divisions in the Northeastern parts of the country is poorly or negatively correlated with the sub-divisions in the other regions (Parthasarathy, 1984). In view of this, we have examined the relationships between the May SST and summer monsoon rainfall of different sub-divisions of India (Fig. 1) for the period 1925-80. The correlation coefficients and their significance are shown in Figure 8. There are 17 contiguous sub-divisions whose area is 59% of India for which CCs are negative and significant at 10% level or above, these sub-divisions being mostly north of 16°N and west of 80°E. For 11 sub-divisions (area of 35%) the CCS are significant at 5% level or above. The highest CC is – 0.48 for east Rajasthan sub-division.

CONCLUSIONS

The statistical analysis of Indian monsoon rainfall and El Niño/Puerto Chicama SST for the period 1871-1985 has arrived at the following results:

(i) The strong and moderate El Niño events and All-India monsoon rainfall are strongly related, there is an average drop of 11% of monsoon rainfall during these years.

(ii) The relationship between All-India rainfall and strong or moderate El Niño events is negative (CC = – 0.33) and this CC is statistically significant at 0.1% level of above.

(iii) Superposed epoch analysis indicated that the All-India monsoon rainfall (percentage departure from normal) is very much below during El Niño year than before and after the phenomenon.

(iv) All-India summer monsoon rainfall and Puerto Chicama SST for seasons spring (MAM) through succeeding winter (DJF) is highly significant for the period 1925-80.

(v) Warmer temperatures over the Pacific Ocean region during March to June are not favorable for the occurrence of normal (or good) Indian monsoon rainfall.

(vi) The stability and consistent relationships between All-India rainfall and the monthly mean May SST of Puerto Chicama have been obtained for sliding width of 30-years.

(vii) The regression equation between All-India summer rainfall (y) and the May SST of Puerto Chicama (x) is $y = 128.3 - 2.42x$ developed for the data years, 1925-80.

(viii) The relationship between sub-divisional monsoon rainfall and the May SST of Puerto Chicama is significant at 5% level or above for 11 contiguous subdivisions, mainly over the area north of 16°N and west of 80°E and the area of these subdivisions is 35% of the country area.

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