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Rainfall fluctuations in India and Sri Lanka and large-scale rainfall anomalies

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सार — भारत और श्रीलंका के स्टेशनों की वर्षा की शृंखला में एकरूपता, कालिक प्रवृति, स्थानीय एवं कालिक बंटन के उतार चढ़ावों का अन्वेषण करने के लिए सांख्यिकीय विधियों का उपयोग किया गया है। अन्वेषण में भारतीय वर्षा और भूमध्यरेखीय प्रशांत महासागरीय ऊष्ण क्षेत्र में हुई वर्षा में दूर-संबंध पर भी प्रकाश डाला गया है। पिछले 100 वर्षों में भारत में वर्षा की कोई एक समान प्रवृति नहीं रही है, लेकिन कुछ भारतीय स्टेशनों पर सार्थक दीर्घकालिक उतार-चढ़ाव दिखाई देते हैं। भारत में सूखों की बारंबार आवृत्ति और दक्षिण अमेरिका के पश्चिमी तट पर 'एल नीनो परिघटना' में सादृश्य की संभावना का भी विवेचन किया गया है।

ABSTRACT. Statistical methods were used to investigate the homogeneity, temporal trends, and spatial and temporal distribution of fluctuations in rainfall series for stations in India and Sri Lanka. The investigations also looked at teleconnections between Indian rainfall and rainfall in the equatorial Pacific dry zone. It appears to be no uniform trend in India over the last 100 years, but significant long-period fluctuations are evident at certain Indian stations. There appears to be a linkage between the recurrent Indian droughts and the E1 Nino phenomena along the west coast of South America.

1. Introduction

In 1972 northern India suffered from a widespread failure of the vital monsoon rains. During 1972, world-wide climatic anomalies considerably affected the production of food in tropical countries. The aim of this study is to contribute to a better understanding of the temporal behaviour and spatial distribution of rainfall fluctuations.

2. Observational material

The data base consists of monthly sums and regional averages obtained from a variety of sources. From *World Weather Records* (1880-1960) and *Monthly Climatic Data for the World* (1955 - 1972) monthly sums were obtained for 42 Indian stations with complete records for the reference period 1901 - 1960. The India Meteorological Department generously provided data for the four stations Ahmednagar (1875-1971), Karachi (1856-1971), Malegaon (1875 - 1973) and Sholapur (1875 - 1973) as well as their calculated regional means for Gujarat (1875-1974), Bangla-Desh (1901 - 1960) and northern Pakistan (1901-1960). The stations used in calculating the regional series are given by Schweitzer (1978). Dr. V. Lengerke (Heidelberg) also provided 22 time series of monthly totals in the Nilgiris region of southwestern India, and Dr. de Mel (Colombo) made available the data for 13 stations in Sri Lanka with records covering at least 101 years from 1875 to 1975.

Figs. 1 (a, b and c) show the distribution of stations. Gaps in the station records were filled in using the respective long-term monthly mean value for the station. Both annual totals and the meteorologically more significant seasonal totals were derived from the monthly data. The annual rainfall march and general circulation upon which this depends suggest the following seasonal divisions :

(1) from December to February, the dry NE monsoon/winter

(2) from March to May the first inter-monsoonal period

(3) from June to September, the wet SW monsoon

(4) from October to November a second inter-monsoonal period.

A detailed representation of annual and seasonal means is found by Ananthakrishnan and Pathan (1970) for India and by Domros (1974) for Sri Lanka. Maps showing monthly, seasonal and annual rainfall, rainy days and coefficient of variation based on about 2700 stations may be seen in the *Rainfall Atlas of India* published by India Met. Dep.

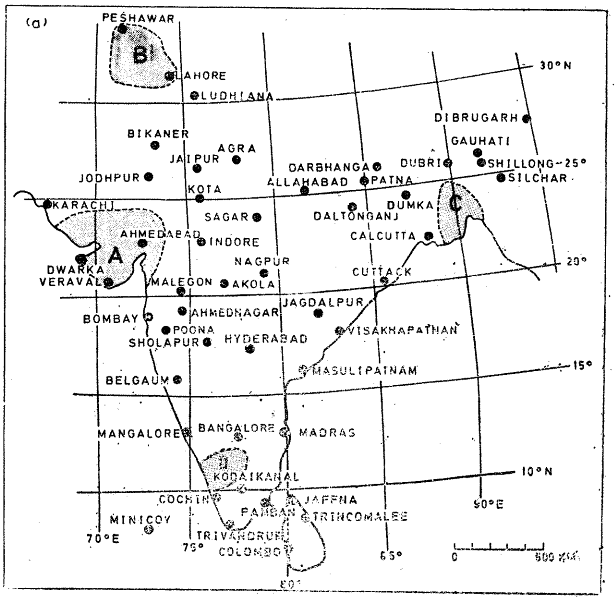


Fig. 1(a). Location of stations in the Indian subcontinent [Regional means : A-Gujarat, B-North Pakistan, C-Bangla Desh, D-Nilgiris]

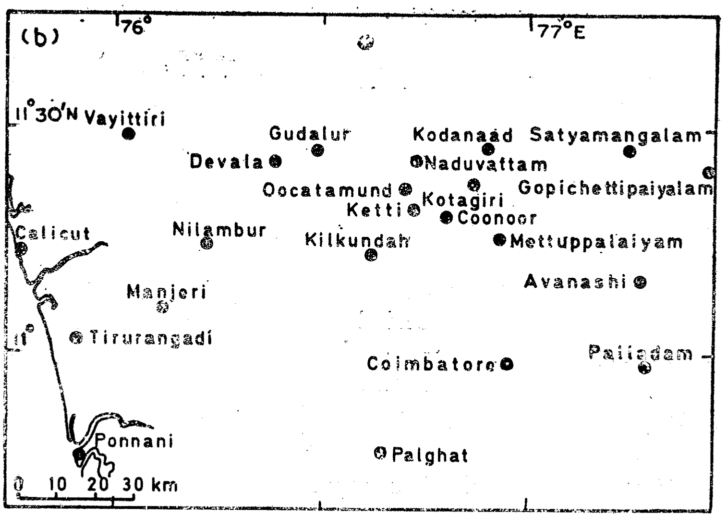


Fig. 1(b). Location of stations in Nilgiris region

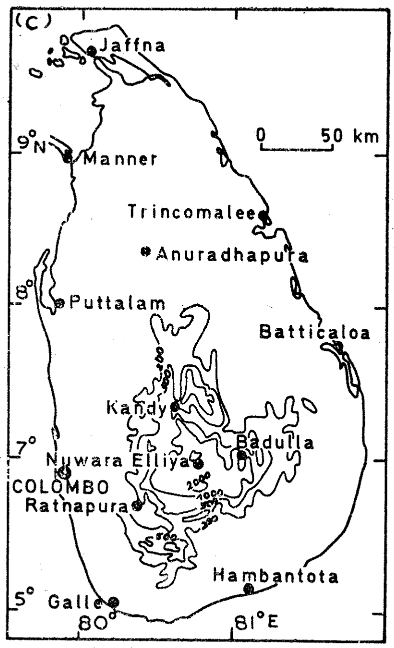


Fig. 1(c). Location of stations in Sri Lanka

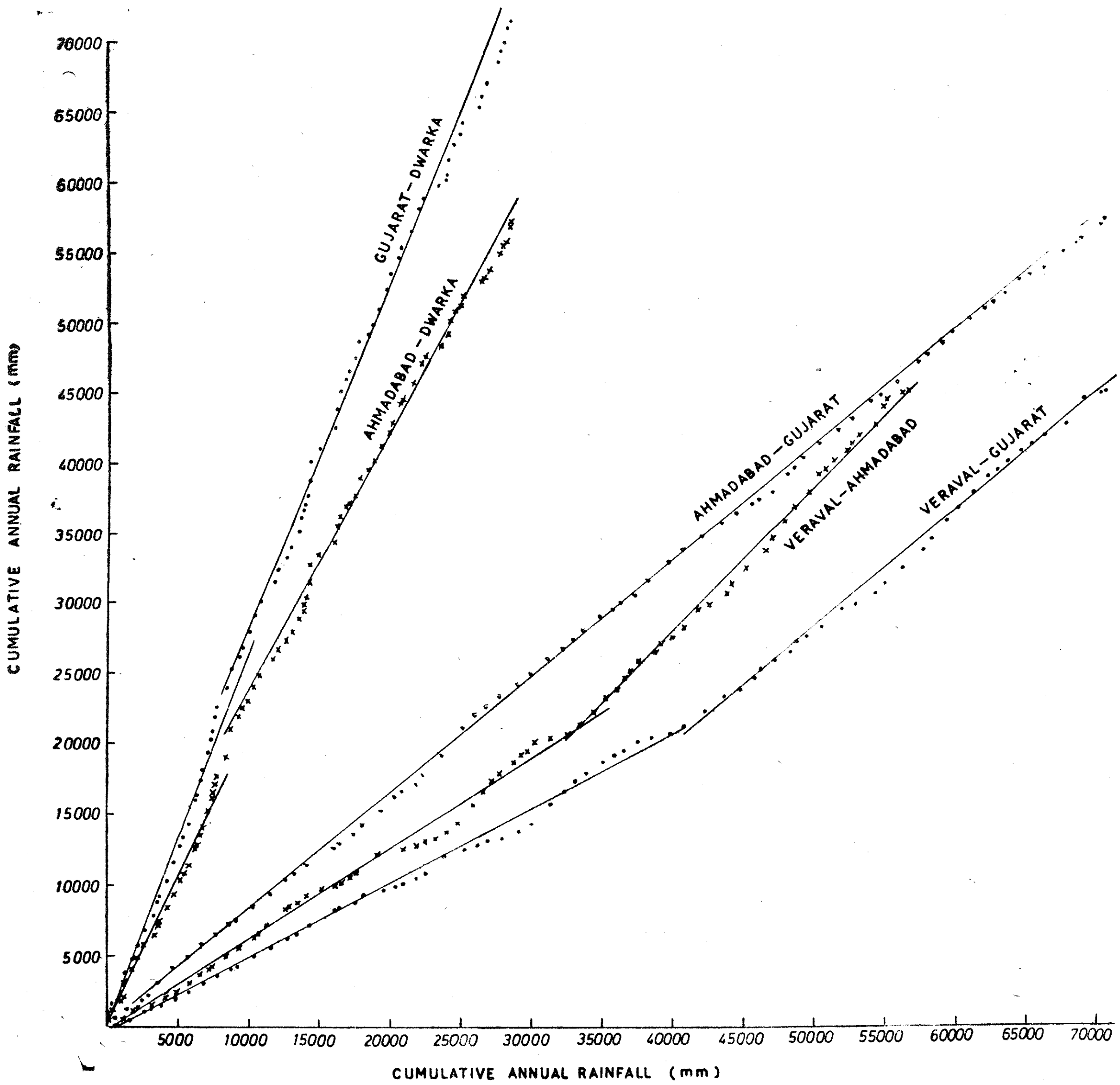
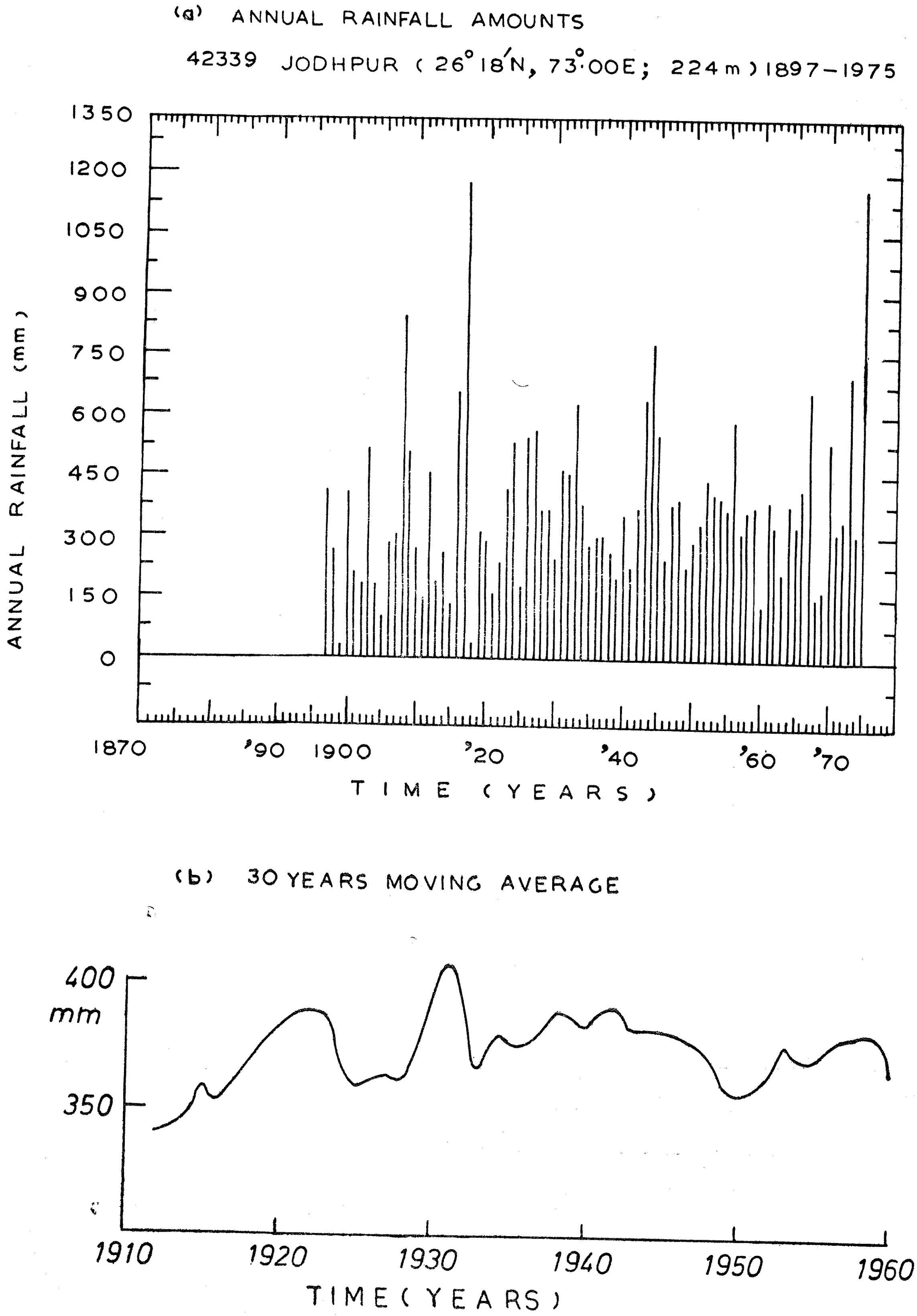


Fig. 2. Double-mass-test

3. Tests of homogeneity and trend

Analyses of trend and homogeneity were carried out in using double-mass curves (Kohler 1949), the Spearman-Rank-test, the Student-t-test and the Cramer-test, which are described by Mitchell (1966). The tests indicated that the series for Veraval, Jagdalpur and Colombo are inhomogeneous. A primary cause of inhomogeneity in meteorological series is station relocation, which is known to have occurred in 1921 in Colombo, for example. Since at Colombo observations were made concurrently at both stations for a lengthy period, a correction factor could be determined, which gave the optimal fit of the old series to the new one (Raatz 1970). No correction could be made for the inhomogeneity in the series for Veraval and Jagdalpur (Fig. 2). The regional series for Gujarat, the calculation of which included data for Veraval, is nevertheless considered to be homogeneous, as are the other regional series obtained from the India Meteorological Department.

The series for Dwarka, Indore, Sagar and Shillong, as well as Calicut, Gudalur, Naduvattam, Ketti, Kotagiri, Conoor, Kodanaad, Satyamangalam and Gopichettipalaiyam from the Nilgiris region and Batticaloa, Nuwara Eliya and Hambantota in Sri Lanka contain significant trends. The tendency for increasing rainfall in NE India and along the southwest coast and the tendency for decreasing rainfall in NW India and along the east coast, which Pramanik and Jagannathan (1953) found using orthogonal polynomials, could not be confirmed with our data and procedures. The analysis of trends, which shows no



Figs. 3(a & b). Time series analysis of Jodhpur

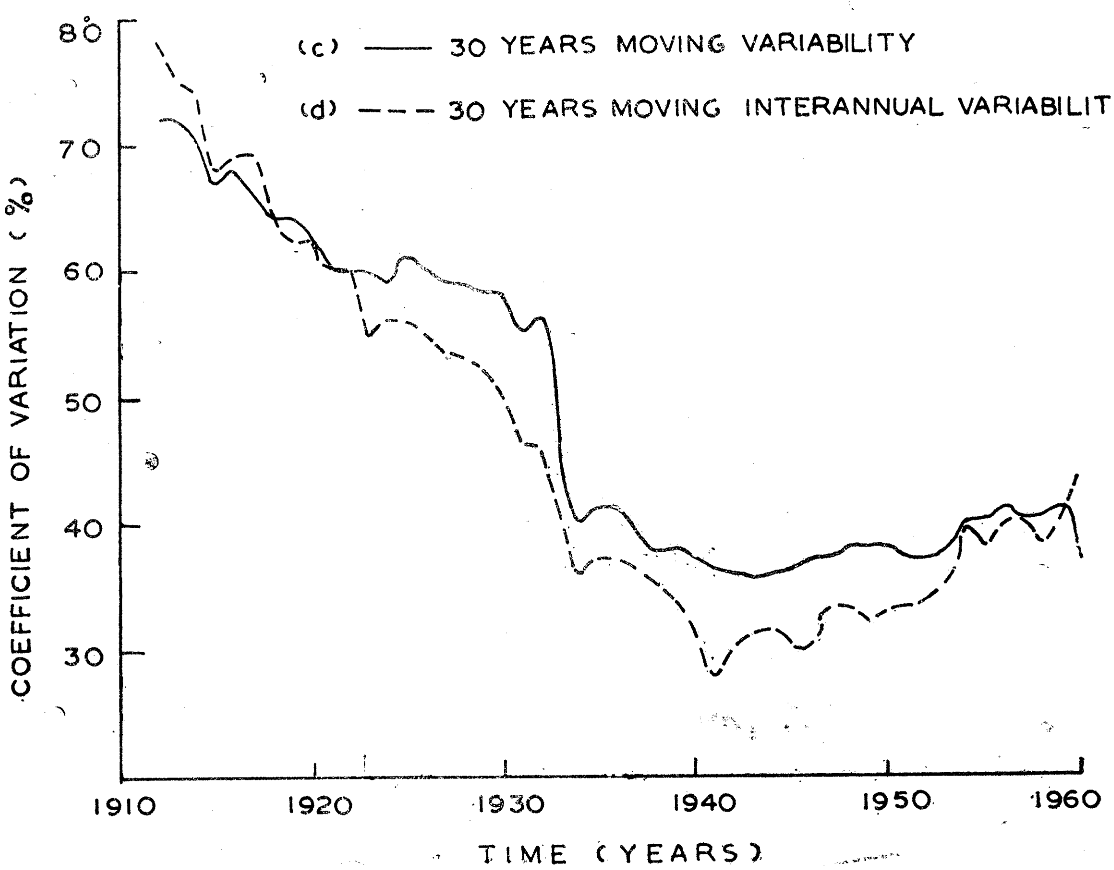


Fig. 3(c & d). Time series analysis of Jodhpur

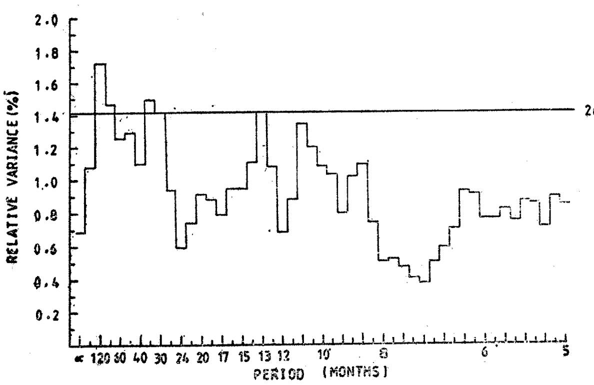


Fig. 4. Variance spectrum of Jodhpur

recognizable, uniform trend in a large area, suggests in agreement with Rao and Jagannathan (1963) that there has been no significant change in rainfall amounts over India during the last 100 years.

4. Rainfall fluctuations

The rainfall series for Indian stations are characterised by pronounced spatial and temporal variations. The temporal fluctuations are investigated using running means, variabilities/auto-correlation and variance spectrum.

Fig. 3 provides an example of series for Jodhpur in NW India :

(a) annual totals
(b) running 30-year means
(c) running 30-year values of variability
(d) running 30-year values of interannual variability.

Although no significant long-term fluctuations are apparent in the series of running means, in some spectra of monthly anomalies certain periodicities contribute significantly to the variance. The most widespread periodicity in the Indian stations is the 11-year cycle, which was shown also by Sen Gupta (1957), Jagannathan and Parthasarathy (1973), Jagannathan and Bhalme (1973), Bhalme (1973), Parthasarathy and Dhar (1976), Srivastava (1977), and others has been questioned by Pittock (1978). Cycles in the interval close to 11-year are significant at the 95%-level in the spectra for Rangoon, Mandalay, Silchar, Hyderabad, Satyamanyalam, Nilambur, Kota and Jodhpur (Fig. 4). The periodicity does not, however, appear to be related to the 11-year sunspot cycle because stations in the immediate neighbourhood do not show the same behaviour (Fleer 1982).

The 5-year wave in Indian rainfall described, for example, by Rao *et al.* (1973), Jagannathan and

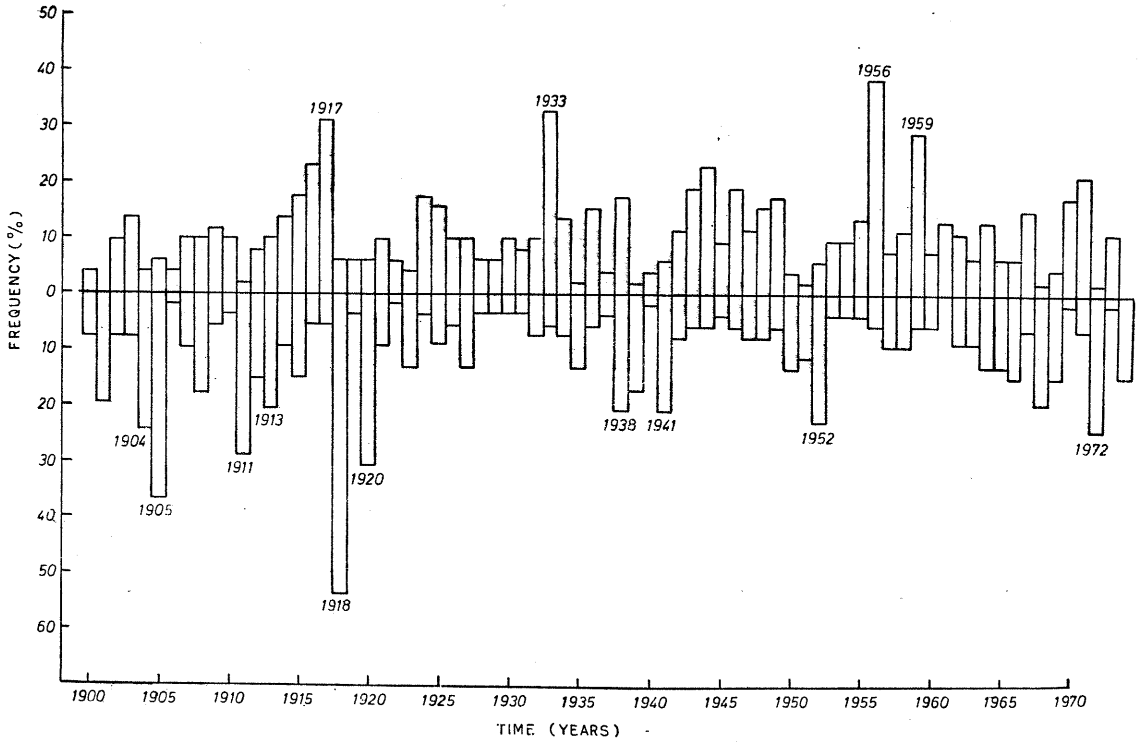


Fig. 5. Relative frequency of station rainfall totals below the lowest decile and above the highest decile

Parthasarathy (1973) is significant only in the spectra for Mandalay and Ketti. The quasi-biannual oscillation, a global phenomenon, is very widespread in Indian rainfall series according to Bhargava and Bansal (1969), Rao *et al.* (1973), Jagannathan and Parthasarathy (1973), Jagannathan and Bhalme (1973), Parthasarathy and Dhar (1974), Bhalme (1975), Parthasarathy and Dhar (1976) and Kraus (1977). In our calculation exceeds the 2-σ confidence level only Silchar, Hambantota and Kodaikanal. The longer periodicities in rainfall fluctuations are, with certain exceptions, masked by atmospheric "noise". Most spectra can be considered more or less "white". The fluctuations which occur at individual stations are not of any value for forecasting as the numerical band pass filtering shows (Fleer 1981).

A quantile analysis indicates that the most widespread drought in the period 1900-1974, for which data are available for nearly all stations, occurred in 1918. In this year at 53% of the stations rainfall totals were below the lowest decile (Fig. 5). Other widespread droughts occurred in India in 1904, 1905, 1911, 1918, 1920, 1938, 1941, 1952 and 1972. Extreme dryness prevailed, therefore, in the first part of the twentieth century. Extensive droughts between 1850 and 1900 occurred in 1877 and 1899 (Schweitzer 1978). Widespread wet years occurred in India in 1917, 1933, 1956 and 1959. The strong rainfall fluctuations at the turn of the century are also apparent in the time series of the rainfall variability. The running 30-year mean variability and the interannual variability decrease respectively from 72% and 78% in 1912 to 36% and 28% in 1941. In this case, 1912 represents the period 1897 to 1926 and 1941 represents the period 1926 to 1955.

The exponential decrease of the variability with increasing rainfall amounts (Rao *et al.* 1972) is only approximately valid for Indian stations. The rainfall variability is rather variable itself. The range of fluctuations of running variabilities is generally larger than the range of fluctuations of running means.

5. Correlation analysis

A correlation analysis was carried out using 15 base stations in order to delineate climatic regions and to test the possibility of deriving regional means. Fig. 6 presents the results when Nagpur in central India is used as a base station. The spatial representation of

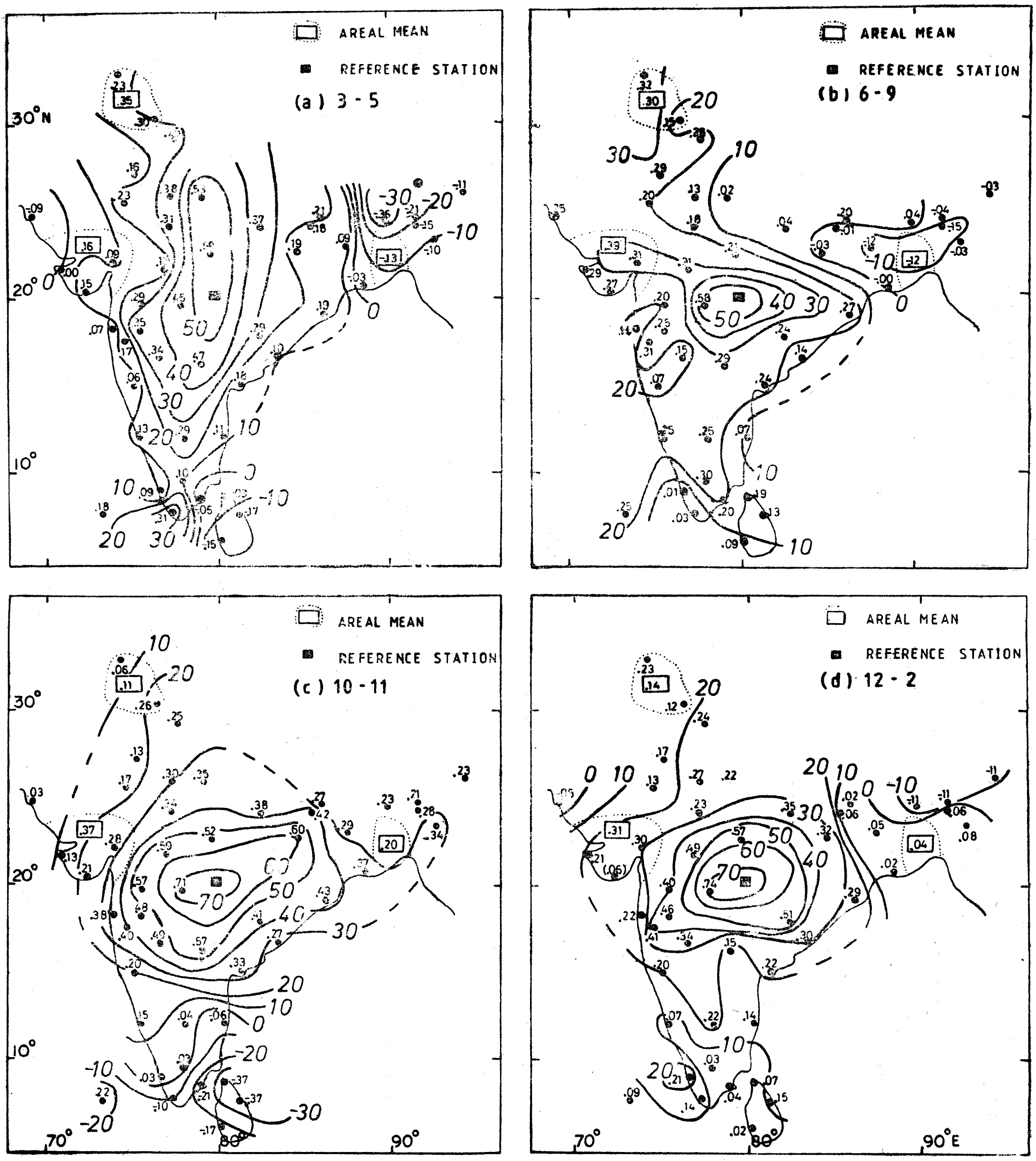
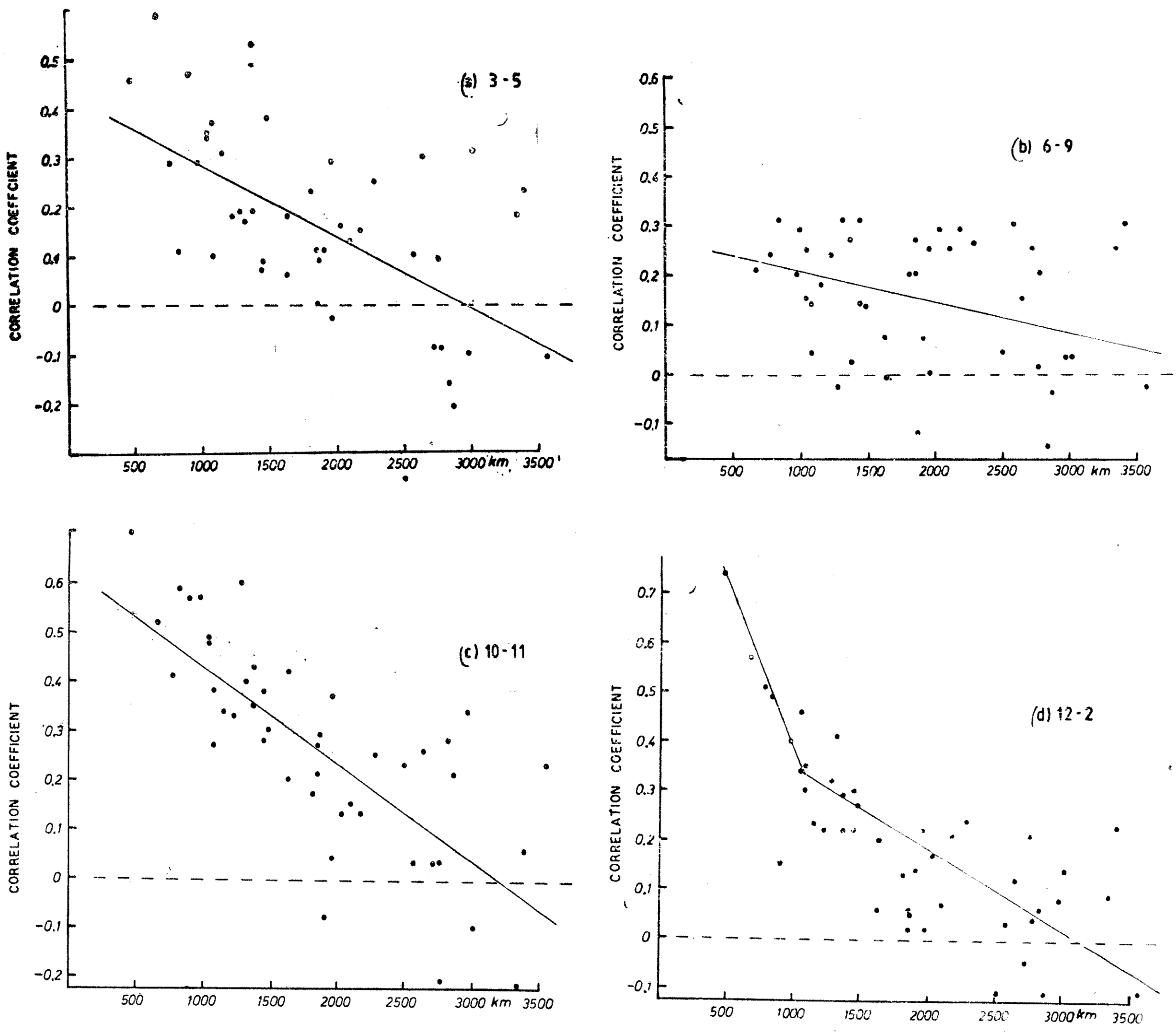


Fig. 6. Regional distribution of correlation coefficients of seasonal rainfall amounts. Base station: Nagpur

the distribution of cross-correlation coefficients is remarkably homogeneous. In the first inter-monsoon period (March to May) there is a clear meridional orientation of the lines of equal correlation, which is determined by the frequent position of a trough in the extra-tropical westerlies over India. During the SW monsoon (June to September) the orientation of the isolines is instead zonal. The second inter-monsoon period (October to November) and the NE monsoon are characterized by a nearly symmetrical distribution. The correlation is greatest during the dry period. The correlation coefficients for monthly and seasonal totals decrease exponentially as the distance from the base station increases up to 20 miles (Huff and Shipp 1969), but decrease approximately linearly with greater distance (Fig. 7). The decrease is most gradual during the summer monsoon. In Bangla-Desh, southeast India and Sri Lanka the correlation with Nagpur is negative during the first inter-monsoon period. Rainfall fluctuations in the northeast and Bangla-Desh also correlate



Figs. 7(a-d). Correlation coefficients of seasonal rainfall amounts in dependence of the distance from the base station Nagpur

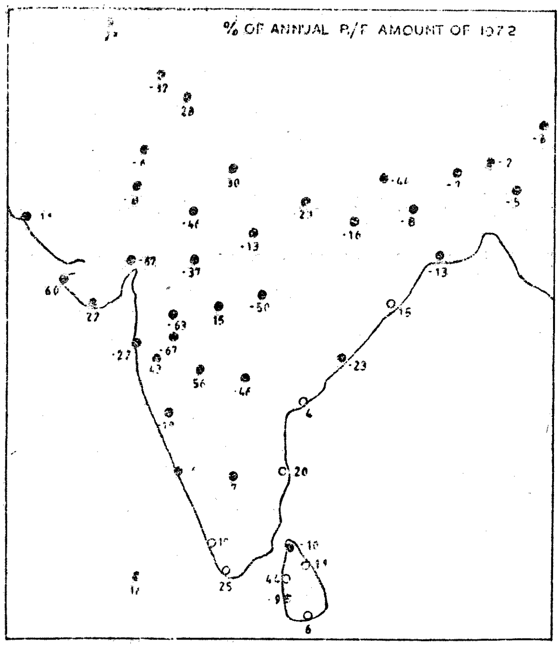


Fig. 8. Percentage of the annual rainfall amount of 1972 from the long term mean

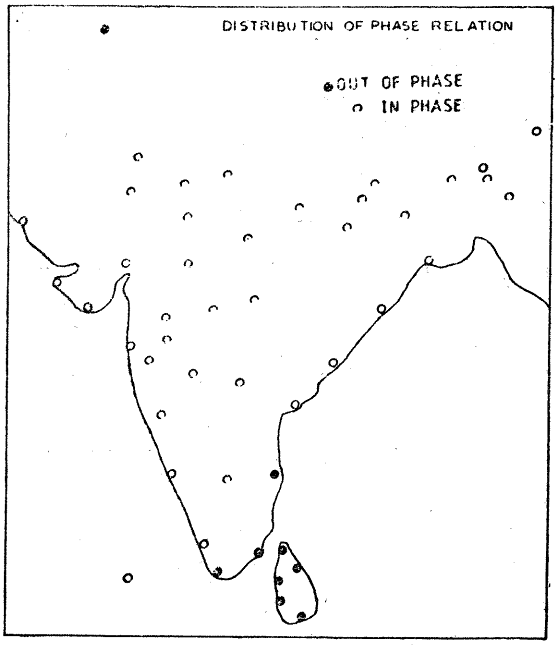


Fig. 9. Regional distribution of the phase relation between seasonal rainfall anomalies and the southern oscillation index (Period range : 5 years)

negatively with Nagpur during the SW and NE monsoon. As during the first inter-monsoonal period, stations in southern India and Sri Lanka correlate negatively with Nagpur during the second inter-monsoonal period, but not during the SW and NE monsoons. The smaller scale correlation study for the Nilgiris region and for Sri Lanka indicates that regional means can be calculated for SW Ceylon, NE Ceylon, west Nilgiris and east Nilgiris (Raatz 1977).

6. Teleconnections

In 1972 India suffered from a widespread failure of the monsoon rains, upon which the country is so dependent. At some stations in the southwestern part of the subcontinent (Fig. 8) rainfall was only 50% of normal. During the same year, extraordinarily high rainfall was registered in the equatorial Pacific. At Nauru (0 deg. 34 ′S, 166 deg. 55′ E), an island in the equatorial Pacific dry zone, rainfall totalled 3980 mm in 1972, *i.e.,* 93% above the long-term mean. This extraordinary rainfall excess extended in the equatorial region from c. 160 deg. E more than 100 degrees of longitude eastward to the west coast of South America. Along the coast, a particularly strong E1 Nino occurred. E1 Nino occurs when the cool and nutrient rich water which normally upwells from several hundred metres below sea level is suppressed by the warm and far less nutrient rich surface waters. A further investigation of long-term series of tropical and subtropical rainfall and sea-surface-temperatures shows that in all years with rainfall deficits in India, high sea-surface-temperatures and excess rainfall occur in the equatorial Pacific (Flohn and Fleer 1975). Correlation and coherence analyses show that these anomalies are statistically dependent and significant and that they are characterized by quasi-periodic fluctuations of 5 to 6 years (Fleer 1981). The synchronous occurrence of these rainfall anomalies can be explained by a coupling of the Indian monsoon and the upwelling in the equatorial Pacific. Such a linkage is possible through the so-called Walker-Circulation (Bjerknes 1969; Flohn 1971).

In E1 Nino years the Walker-Circulation is either reduced or disrupted by the weak atmospheric pressure gradient between the subtropical Pacific high and the Malayan-Indonesian low and by the decreasing equatorial zonal sea-surface-temperature gradient. The rainfall and sea-surface-temperature anomalies are connected with the so-called "Southern Oscillation", that is, the large-scale tropical-subtropical pressure variations. Wright (1975) computed with empirical orthogonal functions the most representative Southern Oscillation Index. A high (low) index corresponds to high (low) atmospheric pressure in the southeast Pacific subtropical high and to low (high) pressure in the Malayan-Indonesian low. Coherence analysis between this Southern Oscillation Index and seasonal rainfall totals of Indian and Pacific stations shows that the most significant fluctuations are in the range of approximately 5 years. A high (low) index that corresponds to a strongly developed (reduced) Walker-Circulation and to an intensified (weakened) upwelling along the equator and off the west coast of South America is connected with high (low) Indian and low (high) Pacific precipitation (Fig. 9).

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