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SHORT CONTRIBUTION

Principal components of monsoon rainfall

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Monsoon rainfall over India during the 120-day period from the beginning of June to the end of September exhibits interesting oscillations over the country. According to an analysis by Subbramayya (1968), there is a negative correlation in rainfall between the north-eastern and west-central parts of India. But his analysis does not indicate how much of the total variance of rainfall is explained by different rainfall patterns. We examined this aspect by expressing rainfall as a linear combination of orthogonal functions. This technique was suggested by Lorenz (1956). It was later used by Kutzbach (1967) and Weare (1977) to evaluate the principal components of sea-level pressure over the northern hemisphere, and sea surface temperature over the Atlantic Ocean.

Let P be a $n \times m$ matrix of monsoon rainfall over m stations and a series of n years. The elements (p_{rs}) of P represent departures of rainfall from their mean values for the sth station and the rth year. We used the data of 70 evenly distributed stations for a period of 60 years (1911–1970). As P represents the time and space variability of rainfall, we put

$$P = QF \tag{1}$$

Where the matrices Q and F represent, respectively, the time and space variation of rainfall. The elements of P are

$$p_{rs}(x,y,t) = \sum_{k=1}^{m} q_{rk}(t) \times f_{ks}(x,y) \tag{2}$$

As F is an orthonormal matrix

$$FF' = I \tag{3}$$

Where F' is the transpose of F and I is the identity matrix.

To determine F and Q from P we define a matrix S by

$$P'P = S$$

whence

$$F'SF = QQ' = D \tag{4}$$

Where D is a diagonal matrix. The columns of F are now the eigenvectors of S, while the elements of D are the eigenvalues of S. Each element of Q represents the amplitude of eigenvector, and every element of D is a measure of the percentage variance explained by the corresponding eigenvector.

F and D were determined from S by Jacobi's method (Greenstadt, 1960). This is an iterative process which utilizes successive rotations of each element of S. It was observed that the process converged sufficiently after about 2500 iterations. A tolerance of 10^{-5} was used before stopping further iterations.

Figs. 1–4 depict the first four principal components of P. A total of 15 components were examined. This accounted for 72% of the total variance of monsoon rain, but the first four components by themselves were able to explain 47% of the variance. The contributions by components beyond the 15th were negligibly small. The amplitudes of each component are shown at the bottom of each figure.

The opposition between north-east and western India appears to be the dominant feature of monsoon rain. This explained 26.9% of the total variance. We also observed that positive and negative amplitudes were evenly distributed over the last 60 years, with a tendency for more rapid oscillations in the two decades following 1950, but

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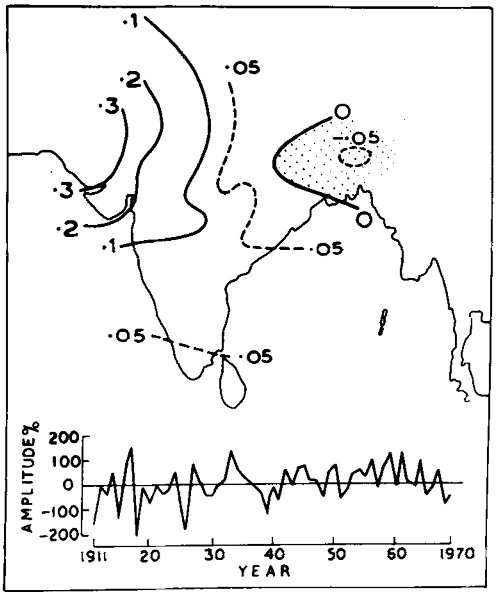

Fig. 1. First component. Variance explained: 26.9%. Figures represent numerical values of the eigenvector.

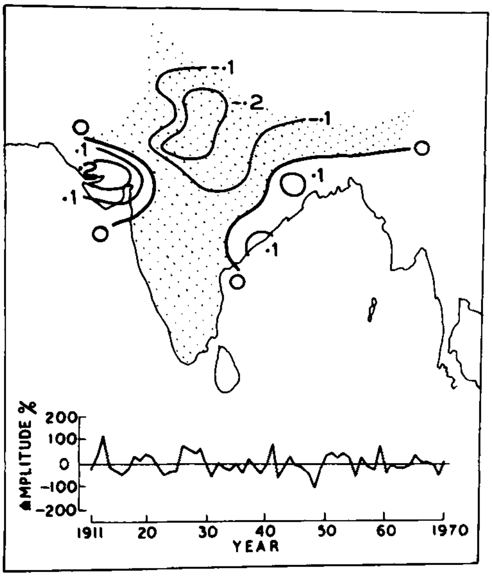

Fig. 2. Second component. Variance explained: 8.7%.

no significant trend could be discerned. The opposite response in rainfall over north-east and north-west India has, we feel, an interesting consequence. Whenever rainfall decreases over north-east India as the result of a depression in the Bay of

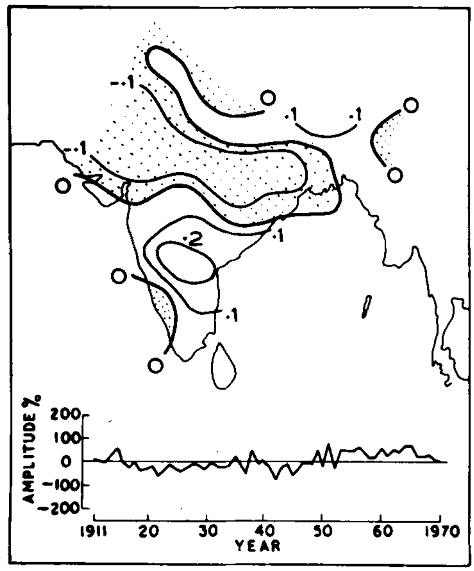

Fig. 3. Third component. Variance explained: 6.6%.

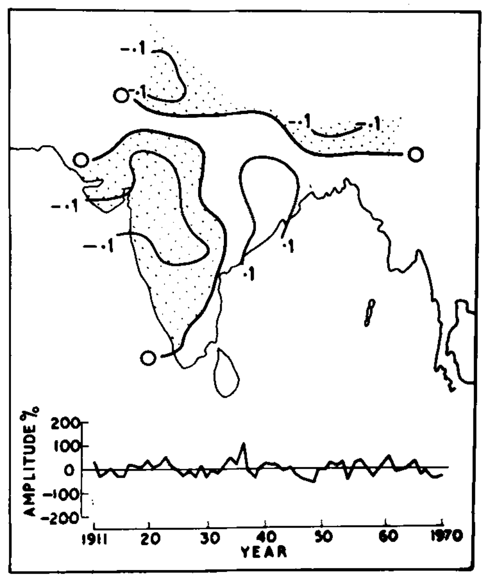

Fig. 4. Fourth component. Variance explained: 5.1%.

Bengal, or the southward movement of the monsoon trough, an increase in rainfall over western India may be expected.

Fig. 2 suggests that the rainfall patterns over the coastal regions of east India, and the states of Gujarat and north Maharashtra in the west, respond in a similar manner. This similarity in phase explained 8.7% of the total variance. It suggests that the formation of a depression in the north Bay of Bengal also favours the development of a mid-tropospheric low over west India. Both are well recognized features of monsoon rain. The amplitudes are again evenly distributed indicating the absence of a systematic trend.

In Fig. 3 we find that the region covered by the monsoon trough is in opposition to the Himalayan foothills of north-east India, and the southern half of the peninsula. This confirms a well-recognized feature of monsoon rainfall, because a northward movement of the monsoon trough leads to a cessation of rainfall over Central India. The amplitudes of this eigenvector are small in magnitude, without a systematic trend. The variance explained by this component was 6.6%.

The features shown in Fig. 4 were difficult to explain. The variance explained by this component was also small (5.1%). It does suggest, however, that there is some similarity in the response of the Himalayan foothills and west-central India. But there appears no obvious reason to explain this similarity.

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REFERENCES

Greenstadt, J. 1960. The determination of the characteristic roots of a matrix by Jacobi method. In *Mathematical methods for digital computers* (eds. A. Ralston and H. S. Wilf), John Wiley and Sons, 84–91.

Kutzbach, J. E. 1967. Empirical eigenvectors of sea-level pressure, surface temperature and precipitation complexes over North America. *J. Appl. Met. 6*, 791–802.

Lorenz, E. 1956. Empirical orthogonal functions and statistical weather prediction. Sci. Rep. No. 1, Statistical Forecasting Project, M.I.T., Cambridge, U.S.A.

Subbramayya, I. 1968. The inter-relations of monsoon rainfall in different sub-divisions of India. *J. Met. Soc. Japan 46*, 77–84.

Weare, B. C. 1977. Empirical orthogonal analysis of Atlantic Ocean surface temperatures. *Quart. J.R. Met. Soc. 103*, 437, 467–478.