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A Statistical Technique for Medium Range Forecasting of Rainfall over Calcutta during the Southwest Monsoon Season

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ABSTRACT. An objective procedure for predicting the rainfall of Calcutta during each of the 5-day periods of the monsoon season has been evolved. The technique is the same as was developed by Jagannathan and Ramamurthi (1961) for the prediction of 5-day rainfall at Bombay. The daily rainfall data of Alipore (Calcutta) for the period 1921 to 1950 were used for the classification of the rainfalls. The technique was evolved on the basis of available Indian radiosonde data for 1950 to 1958 and tested on the basis of independent data for 1959 to 1961. This has shown a skill score of 0·46.

Besides, the study has revealed the close relationship between the topography of the 700 and 500 mb pressure surfaces over India and the subsequent pentad rainfall over Calcutta particularly during the monsoon season.

1. Introduction

Attempts at forecasting weather for periods longer than 3 days or for seasons of the year, have been made in several countries. Considering the importance of the problem, a scheme for developing suitable techniques for forecasting weather 4—7 days ahead has been in operation during the Third Five Year Plan.

Jagannathan and Ramamurthi (1961) have evolved a technique for forecasting 5-day rainfall over Bombay during the monsoon season on the basis of Indian upper air data. The aim has been to predict the class (A, N or S each of which has a climatological probability of one-third) in which the rainfall at Bombay, during successive pentads of the southwest monsoon season, will fall. In brief, the technique has been evolved after studying the contrasting upper air patterns associated with abnormal rainfall at Bombay on the one hand and subnormal rainfall on the other. The upper air parameters which also satisfied certain statistical tests were selected and graphically correlated by means of scatter diagrams, with precipitation during the subsequent pentad; and the prospective predictors chosen along with their classification character. Using the classification thus obtained, contingency tables—parameter *versus* rainfall—were constructed. The information ratio I_c calculated was compared with its expectancy I_e on the 'Null hypothesis'. If the probability of $I_c - I_e$ was less than 5 per cent, the 'parameter' was used in the prediction. Three such parameters were chosen as predictors. The combined effect of several predictors is obtained as the product of the *normalised contingency ratios* separately in each class of the predictand for the appropriate class of each predictor. The class of the predictand having the highest product is selected as the forecast. The technique was tested on independent data for the subsequent period and claimed a 'skill score' of 0·46. As the relationship between the pressure heights at the selected stations and the subsequent rainfall over Bombay was not linear they stressed that the contingency technique was the most appropriate for the purpose under consideration.*

Prompted by the success, attempts are being made for evolving the necessary techniques for forecasting pentad rainfall at a

*For greater details of the technique described, the reader may refer to the original paper network of selected stations in India. Further, work is on hand for deriving "factors of representativeness" of single station rainfall for representing area rainfall over areas round the station. Thus with the techniques of forecasting single station rainfall, the forecasting of rainfall over small areas could be achieved with sufficient degree of accuracy.

In this paper, the results of attempts made in regard to forecasting Calcutta rainfall are discussed. The method and the procedure adopted are practically similar to those of Jagannathan and Ramamurthi (*loc.cit.*)

2. Data utilised

The daily rainfall data of Alipore (Calcutta) for the 30-year period (1921—50) were used for the classification of Calcutta rainfall as 'Abnormal *A*', 'Subnormal *S*' and 'Normal *N*'. For each pentad, the lower limit *a* of abnormal rainfall and the upper limit *s* of subnormal rainfall have been determined such that a third of the frequency occurs above *a*, a third below *s* and the remaining third between *a* and *s*. The value of the limits *a* and *s* for Calcutta for each of the 24 pentads commencing from 31 May to 27 September are given in Table 1. All available upper air data from 1950 to 1958 have been utilised for the evolution of the technique and subsequent data for the period 1959—61 were used for testing the technique and assessing the skill score.

The predictors chosen are generally based on height contour values at some significant points on the 700 and 500 mb surfaces pertaining to the previous 5-day or 1-day periods as found appropriate.

3. Composite charts

Corresponding to the occasions of abnormal and subnormal rainfall over Calcutta in each month, composite 5-day charts and composite 1-day charts of upper-air contour heights and their anomalies were prepared. Six spells, one for each pentad of the month when rainfall of the pentad was abnormal and similarly when it was subnormal, were chosen. Contour heights and their anomalies over 5 days or 1 day (prior to the pentads of abnormal and subnormal rainfall) were averaged for all the occasions of abnormal and subnormal rainfall at Calcutta. These are referred to as 5-day (or 1-day) mean circulation patterns corresponding to abnormal and subnormal rainfall. Two series of composite charts, one representing the 5-day mean circulation pattern and the other the mean circulation pattern prevailing on the day just prior to the rainfall pentads concerned, were prepared. The rainfall pentads and the corresponding periods used for the 5-day and 1-day mean upper air composite charts are given in Table 2. The scrutinized data of available radiosonde stations were used in the preparation of these charts. Isopleths of mean heights were drawn at intervals of 20 metres and those of anomalies at intervals of 10 metres. Sample composite 5-day and 1-day mean anomaly charts for 700 mb and 500 mb levels corresponding to excessive rainfall and scanty rainfall at Calcutta are given in Figs. 1 (a) and 1 (b). The contrasting patterns revealed in these composite charts are utilised for drawing up the preliminary list of predictors. The important features revealed by the 5-day and 1-day mean anomaly charts in the different months June to September are given in Table 3.

Utilising the composite charts as guide, the parameters, for further graphical correlation with the precipitation of the subsequent pentad at Calcutta, were selected. As in the previous work, the actual values of pressure heights at the chosen stations were used instead of the anomaly values. For each of the parameters the range of values amongst the six members of each group was utilised to estimate the standard deviation in the group. The significance of the difference between the means of the two contrasting groups one corresponding to excessive rainfall and the other to deficient rainfall was tested by the usual *t*-test. The parameters which showed significant difference at the 5 per cent level were selected for further consideration.

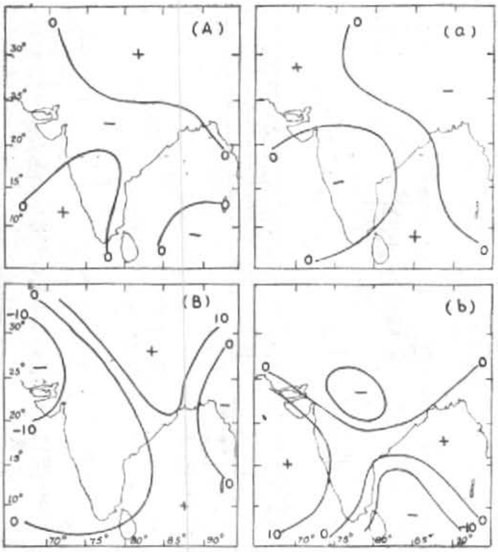

Fig. 1 (a). Composite anomaly charts for 700-mb level—July

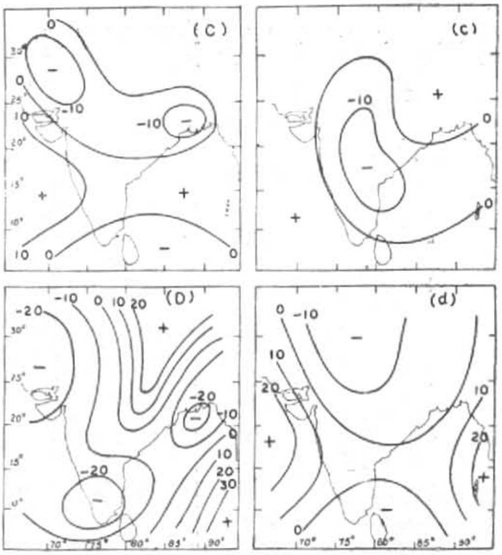

Fig. 1 (b). Composite anomaly charts for 500-mb level—July

(A), (C) 5-day mean anomaly chart antecedent to abnormal rainfall at Calcutta
(a), (c) 5-day mean anomaly chart antecedent to subnormal rainfall at Calcutta
(B), (D) 1-day mean anomaly chart antecedent to abnormal rainfall at Calcutta
(b), (d) 1-day mean anomaly chart antecedent to subnormal rainfall at Calcutta

4. Graphical correlation

The selected parameters were classified according to their values into three different groups a, ν and σ so that the association between the parameters and the rainfall at Calcutta classified as A, N and S could be determined by the contingency analysis. As the upper air data available are rather meagre we have to resort to graphical methods.

With the values of two predictors X and Y on the co-ordinate axes, the classification of rainfall (W_i) in a particular pentad as A, N or S is plotted against X_i and Y_i which are the antecedent values of the predictors.* As in the Bombay case, the scatter of values A, N or S in the (X_i Y_i) field could be easily separated into plots a, ν and σ.

The predictor pairs (X Y) which showed such clear cut grouping were considered at the final stage, and the others rejected. The scatter diagrams which are henceforward to be used in the prediction scheme are given in Figs. 2 (a) and (b).

Contingency Analysis

Utilising the classifications obtained from the scatter diagrams, contingency tables were constructed with the selected pairs of parameters on the one hand and the rainfall of the following pentad on the other, and the Shannon Information ratios I_c calculated in respect of each of the predictor-pairs

$$I_c = 1 - \frac{\sum_{i=1}^{k} f_i \log f_i - \sum_{i=1}^{k} \sum_{j=1}^{l} f_{ij} \log f_{ij}}{N \log N - \sum_{j=1}^{l} f_j \log f_j} \qquad \ldots\ldots (1)$$

where f_{ij} is the frequency in the cell at the i^{th} row of the predictor class (divided

*The 5-day or 1-day periods corresponding to a particular rainfall pentad are given in Table 2

TABLE 1

Values of the lower limit a of 'Abnormal' and upper limit s of 'Subnormal' rainfall at Calcutta (Alipore) during each of the pentads from 31 May to 27 September

Pentad No.	Pentad period	Upper limit s of subnormal rain (cents)	(mm)	Lower limit a of abnormal rain (cents)	(mm)
31	31·5— 4·6	0	0	058	14·7
32	5·6— 9·6	041	10·4	094	23·9
33	10·6—14·6	027	6·9	195	49·5
34	15·6—19·6	069	17·5	192	48·8
35	20·6—24·6	094	23·9	294	74·7
36	25·6—29·6	109	27·7	216	54·9
37	30·6— 4·7	078	19·8	189	48·0
38	5·7— 9·7	106	26·9	230	58·4
39	10·7—14·7	121	30·7	211	58·6
40	15·7—19·7	045	11·4	152	38·6
41	20·7—24·7	116	29·5	189	48·0
42	25·7—29·7	181	46·0	325	82·5
43	30·7— 3·8	122	31·0	274	69·6
44	4·8— 8·8	127	32·3	192	48·8
45	9·8—13·8	140	35·6	261	66·3
46	14·8—18·8	092	23·4	205	52·1
47	19·8—23·8	110	27·9	266	67·6
48	24·8—28·8	078	19·8	174	44·2
49	29·8— 2·9	122	31·0	226	57·4
50	3·9— 7·9	074	18·8	164	41·7
51	8·9—12·9	104	26·4	200	50·8
52	13·9—17·9	082	20·8	266	67·6
53	18·9—22·9	064	16·3	155	39·4
54	23·9—27·9	040	10·2	145	36·8

TABLE 2

Pentad periods to which rainfall forecasts relate and the corresponding periods for the composite 5-day and 1-day charts of upper air contour anomalies

Pentad periods to which rainfall forecasts relate		Periods to which upper air data (for the preparation of composite 5-day charts) relate	Dates to which upper air data (for the preparation of composite 1-day charts) relate
Pentad No.	Period		
		JUNE	
31	31·5— 4·6	25·5—29·5	29 May
32	5·6— 9·6	30·5— 3·6	3 Jun
33	10·6—14·6	4·6— 8·6	8 Jun
34	15·6—19·6	9·6—13·6	13 Jun
35	20·6—24·6	14·6—18·6	18 Jun
36	25·6—29·6	19·6—23·6	23 Jun
		JULY	
37	30·6— 4·7	24·6—28·6	28 Jun
38	5·7— 9·7	29·6— 3·7	3 Jul
39	10·7—14·7	4·7— 8·7	8 Jul
40	15·7—19·7	9·7—13·7	13 Jul
41	20·7—24·7	14·7—18·7	18 Jul
42	25·7—29·7	19·7—23·7	23 Jul
		AUGUST	
43	30·7— 3·8	24·7—28·7	28 Jul
44	4·8— 8·8	29·7— 2·8	2 Aug
45	9·8—13·8	3·8— 7·8	7 Aug
46	14·8—18·8	8·8—12·8	12 Aug
47	19·8—23·8	13·8—17·8	17 Aug
48	24·8—28·8	18·8—22·8	22 Aug
		SEPTEMBER	
49	29·8— 2·9	23·8—27·8	27 Aug
50	3·9— 7·9	28·8— 1·9	1 Sep
51	8·9—12·9	2·9— 6·9	6 Sep
52	13·9—17·9	7·9—11·9	11 Sep
53	18·9—22·9	12·9—16·9	16 Sep
54	23·9—27·9	17·9—21·9	21 Sep

TABLE 3

Contrasting features revealed by composite charts

Serial No.	Month	Particulars of composite charts	Salient features associated with	
			'Abnormal' rainfall at Calcutta	'Subnormal' rainfall at Calcutta
(1)	June	5-day mean anomaly charts 700 mb	Two distinct areas of negative anomalies exist—one over northwest and the other over northeast India and Bay of Bengal with large negative values over north Bay and adjoining West Bengal	A general reversal of the pattern. The areas of negative anomalies replaced by positive values and *vice versa*
		1-day mean anomaly charts 700 mb	Anomalies generally negative over the country north of Lat. 13°N with largest anomalies over north Andhra Pradesh and adjoining Madhya Pradesh. The south Bay of Bengal and south peninsula are under the regime of positive anomalies	The system has moved generally northwestwards with another negative anomaly area appearing over Andaman Sea. Two wedges of positive anomalies from the northwest and southwest have made the anomalies over the eastern peninsula positive
		5-day mean anomaly charts 500 mb	Two wedges of positive anomalies extending from Nepal to north Madhya Pradesh and from west Arabian Sea to Kutch flank the area of negative anomalies	Pattern almost reversed
		1-day mean anomaly charts 500 mb	Two areas of negative anomalies are over north Arabian Sea and the other over Bay of Bengal and adjoining parts of east and central India flanked by areas of positive anomalies	A steep wedge of positive anomalies extending from Upper Burma to coastal Andhra Pradesh has broken up the area of negative anomalies over the Bay and neighbourhood into two concentrated cells, one over central and northwest India and the other over Andaman Sea
(2)	July	5-day mean anomaly charts 700 mb	Except for a stretch of positive anomalies along the sub-Himalayan region and the extreme south Peninsula, the entire country is under negative anomalies with probably two concentrated areas one over the Andaman Sea and the other over north Arabian Sea and Baluchistan	General reversal of conditions

TABLE 3 (*contd*)

Serial No.	Month	Particulars of composite charts	Salient features associated with 'Abnormal' rainfall at Calcutta	Salient features associated with 'Subnormal' rainfall at Calcutta
(2)	July	1-day mean anomaly charts 700 mb	The entire Peninsula, Arabian Sea and adjoining parts of Sind and Baluchistan are under negative anomalies while the Hindustan plains and the central and south Bay of Bengal under positive anomalies	More or less reversal of the pattern with a shift of the col westwards
		5-day mean anomaly charts 500 mb	Two systems of negative anomalies exist–one over north India and north Peninsula and the other over the Indian Ocean with positive anomalies in between	A general reversal of the pattern
		1-day mean anomaly charts 500 mb	A steep wedge of positive anomalies advancing from the northeast lies over east U.P., Bihar and northeast Madhya Pradesh. Another steep wedge of positive anomalies lies over southeast Bay and South Burma. Flanked by these two wedges is a flat area of negative anomalies with large negative values concentrated over Madras—Kerala, the north Bay of Bengal and the northwest India and adjoining West Pakistan	The wedge of positive anomalies over east U.P., Bihar and northeast Madhya Pradesh has withdrawn making the whole area extending from West Bengal and Orissa to Rajasthan and Punjab an area of negative anomalies. An area of positive anomalies moving in from the west has spread over the whole of Arabian Sea, Kutch and Saurashtra. The wedge of positive anomalies over southeast Bay and South Burma has shifted northwards and now lies over the whole of Burma and east Bay of Bengal
(3)	August	5-day mean anomaly charts 700 mb	An area of negative anomalies extends from Punjab to West Bengal. Anomalies are also negative over extreme south Peninsula and the Indian Ocean. In between there is an extensive area of positive anomalies with large values concentrated over Andhra Pradesh	A wedge of positive anomalies protruding from the northeast has made the anomalies over east U.P., Bihar and West Bengal positive. The area of negative anomalies in the south has deepened and also extended to South Burma and east Bay of Bengal
		1-day mean anomaly charts 700 mb	A belt of positive anomalies runs across the country between Latitudes 21°N and 11°N with negative anomalies on either side	The eastern end of the belt of positive anomalies has deepened and extended northwestwards making anomalies over West Bengal, Bihar and east U.P. positive

TABLE 3 (*contd*)

Serial No.	Month	Particulars of composite charts	Salient features associated with	
			'Abnormal' rainfall at Calcutta	'Subnormal' rainfall at Calcutta
(3)	August	5-day mean anomaly charts 500 mb	A steep wedge of positive anomalies extends from southwest Bay to south Orissa with large values concentrated near coastal Andhra Pradesh. Another wedge of positive anomalies with fairly large values lies over northwest India. Negative anomalies prevail in the area lying between the two wedges	A general reversal of the pattern
		1-day mean anomaly charts 500 mb	Anomalies are negative over south Peninsula and the area extending from north Rajasthan to Bihar	Except for pockets of negative anomalies over the extreme northern parts, the country was under a regime of positive anomalies
(4)	September	5-day mean anomaly charts 700 mb	Negative anomalies over the country except in the extreme north and the Andaman Sea where anomalies are slightly positive	Positive anomalies prevail over the whole country with concentration of large values over the central and eastern parts
		1-day mean anomaly charts 700 mb	An area of negative anomalies lies over northwest India. Tongue of negative anomalies projecting from the extreme south peninsula and Ceylon extends upto west Bay of Bengal	Negative anomalies completely wiped out. The whole country is under a regime of positive anomalies with larger values towards north
		5-day mean anomaly charts 500 mb	The entire country except northeast India and the extreme northern parts are in the grip of negative anomalies	Anomalies have become positive over the whole country except the northern parts where anomalies are slightly negative
		1-day mean anomaly charts 500 mb	An area of negative anomalies lies over northwest India with another negative zone over central and south Bay and the adjoining east coast. Positive anomalies prevail over rest of the country	Generally positive anomalies over the country outside west Rajasthan and south Bay which are under the regime of negative anomalies

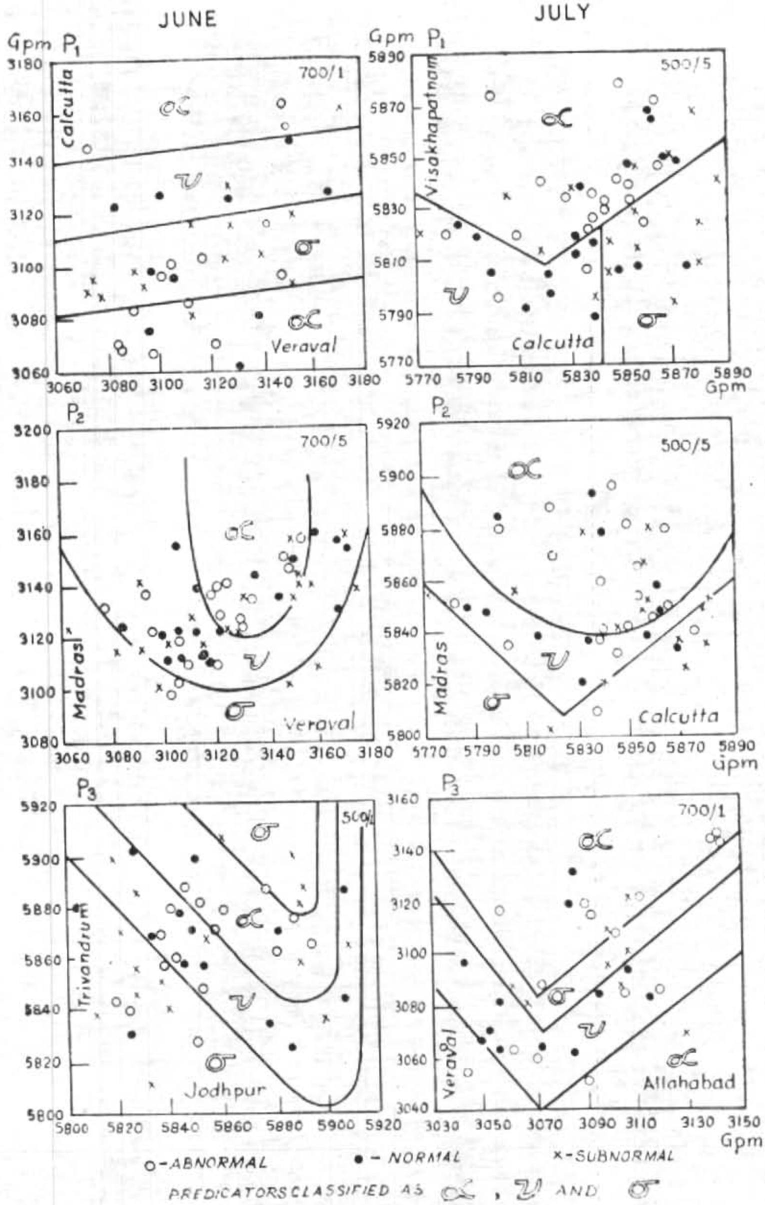

Fig. 2 (a). Scatter diagram

(The pressure height level and composite period are indicated as 700/5, 700/1 etc. 700/5 means 5-day mean height at 700-mb level)

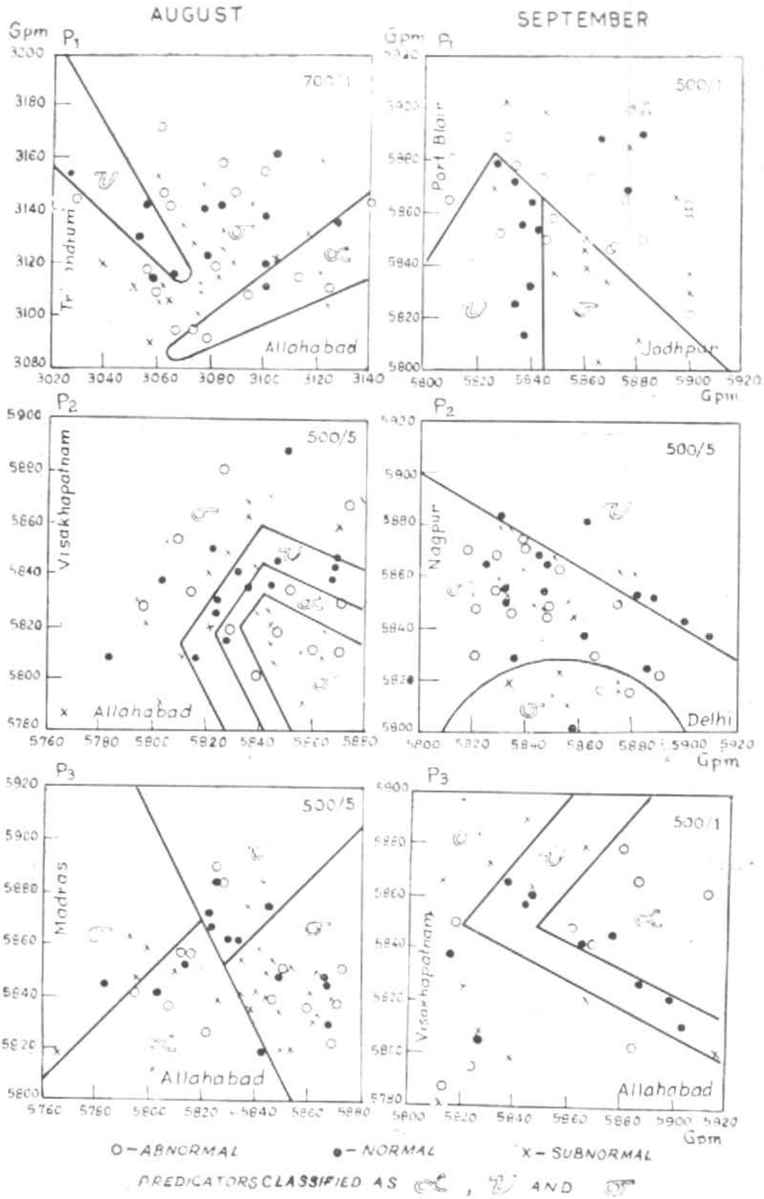

Fig. 2(b). Scatter diagram

(The pressure height level and composite period are indicated as 700/5, 700/1 etc. 700/5 means 5-day mean height at 700-mb level)

TABLE 4

Predictors, their Information ratios I_c and 95 per cent Upper Confidence Limits L_{IE}

	Predictors*	I_c	L_{IE}
June	(1) Pressure height values of 700-mb level over Calcutta and Veraval	0·2044	0·1160
	(2) 5-day mean pressure height values of 700-mb level over Madras and Veraval	0·2519	0·0803
	(3) 5-day mean pressure height values of 500-mb level over Trivandrum and Jodhpur	0·1157	0·0922
July	(1) 5-day mean pressure height values of 500-mb level over Visakhapatnam and Calcutta	0·1636	0·0832
	(2) 5-day mean pressure height values of 500-mb level over Calcutta and Madras	0·1846	0·0821
	(3) Pressure height values of 700-mb level over Allahabad and Veraval	0·1851	0·1091
August	(1) Pressure height values of 700-mb level over Trivandrum and Allahabad	0·1665	0·0935
	(2) 5-day mean pressure height values of 500-mb level over Visakhapatnam and Allahabad	0·2619	0·0894
	(3) 5-day mean pressure height values of 500-mb level over Madras and Allahabad	0·0935	0·0863
September	(1) Pressure height values of 500-mb level over Port Blair and Jodhpur	0·1620	0·1240
	(2) 5-day mean pressure height values of 500-mb level over Delhi and Nagpur	0·0711	0·0616
	(3) Pressure height values of 500-mb level over Visakhapatnam and Allahabad	0·1784	0·1210

*For predicting the rainfall of a particular pentad, the predictors should correspond to the periods indicated in Table 2

into k classes) and the j^{th} column of the predictand class (divided into l classes).

$$\sum_{i=1}^{k} f_{ij} = f_j \;\; ; \;\; \sum_{j=1}^{l} f_{ij} = f_i$$

$$\sum_{i=1}^{k} \sum_{j=1}^{l} f_{ij} = \sum_{j=1}^{l} f_j = \sum_{i=1}^{k} f_i = N$$

and logarithms are to the base e. The expectancy of the Information ratio on the Null hypothesis is

$$I_e = \tfrac{1}{2}(k-1)\,(l-1)/(N \log N - \sum_{j=1}^{l} f_j \log f_j) \quad \ldots\ (2)$$

If the probability of $I_c - I_e$ is less than 0·05 then the predictor is used in the prediction scheme.

The predictors selected for prediction of pentad rainfall of Calcutta in the different months of June—September, the respective information ratios and the 95 per cent upper confidence limits are given in Table 4.

5. Preparation of the forecast

Corresponding to the observed frequency f_{ij} in the (i, j) cell, the frequency f°_{ij} expected on the hypothesis of independence, is calculated as —

$$f^{\circ}_{ij} = (f_i \,.\, f_j)\,/\,N \quad (3)$$

The contingency ratio R_{ij} and the normalized contingency ratio R'_{ij} are then calculated as under

$$R_{ij} = f_{ij}\ /\ f^{\circ}_{ij} \quad (4)$$

$$R'_{ij} = 1 + (R_{ij} - 1)\left[f^{\circ}_{ij} \,.\, k \,.\, l/N_{\circ} \right]^{\frac{1}{2}} \quad (5)$$

TABLE 5

Values of $(10{\cdot}0000 + \log R'_{ij})$ based on data for 1950-58*, used in the present study

Predictor No.	Predictor Class	Predictand Class: JUNE S	JUNE N	JUNE A	JULY S	JULY N	JULY A	AUGUST S	AUGUST N	AUGUST A	SEPTEMBER S	SEPTEMBER N	SEPTEMBER A
I	σ	10·2032	9·7423	9·8701	10·2842	9·9074	9·5237	10·1862	9·7978	9.8515	10·1926	9·6632	9·5669
	ν	9·9554	10·2748	9·5944	9·7339	10·2676	9·7886	9·7259	10·1842	9·8879	9·8723	10·2744	9·6739
	α	9·5884	9·9681	10·2271	9·8504	9·7035	10·2393	9·8138	9·9134	10·2032	9·9371	9·8479	10·1426
II	σ	10·2600	9·5228	9·8833	10·3135	9·6769	9·7279	10·2115	9·3269	10·0041	10·1710	9·7834	9·5120
	ν	9·7497	10·2628	9·8484	9·5006	10·3138	9·8270	9·6907	10·3449	9·5552	9·8586	10·2482	9·6921
	α	9·9729	9·7069	10·1838	9·9211	9·7366	10·1881	9·3911	10·1006	10·2435	9·9702	9·8929	10·1131
III	σ	10·2010	9·7035	9·8908	10·2818	9·8140	9·7456	10·1604	9·8048	9·9109	10·1574	9·8973	9·8869
	ν	9·8914	10·2321	9·8238	9·6037	10·2694	9·8582	9·6619	10·3335	9·7335	9·9613	10·1587	9·7486
	α	9·6856	9·9113	10·2236	9·9775	9·6753	10·1785	9·6556	9·9730	10·2335	9·5689	9·9136	10·2794

*Data for the subsequent three years 1959—1961 were used for testing the technique and assessing the skill score

TABLE 6

Values of $(10{\cdot}0000 + \log R'_{ij})$ (based on data for the period 1950-1960) to be used by field forecasters for preparing forecasts of 5-day rainfall at Calcutta

Predictors* No.	Predictors* Class	Predictand Class: JUNE S	JUNE N	JUNE A	JULY S	JULY N	JULY A	AUGUST S	AUGUST N	AUGUST A	SEPTEMBER S	SEPTEMBER N	SEPTEMBER A
I	σ	10·1830	9·9121	9·7719	10·2875	9·8781	9·5201	10·210	9·8289	9·7356	10·2693	9·6020	9·8553
	ν	9·9157	10·2719	9·6328	9·8758	10·2448	9·7257	9·7495	10·2918	9·8621	9·8300	10·3025	9·6272
.	α	9·7141	9·8310	10·2565	9·7537	9·7897	10·2483	9·7050	9·8698	10·2507	9·8446	9·8403	10·1909
II	σ	10·2550	9·5528	9·8781	10·3124	9·6679	9·6996	10·2370	9·5986	9·8162	10·2095	9·8573	9·8424
	ν	9·8478	10·2543	9·7370	9·6824	10·2824	9·8305	9·8262	10·3498	9·4857	9·9106	10·2146	9·7395
	α	9·9157	9·7163	10·2203	9·8530	9·8516	10·1805	9·2076	9·9430	10·3282	9·9036	9·8929	10·1459
III	σ	10·2320	9·6257	9·8652	10·2783	9·8534	9·6339	10·1480	9·8011	9·9183	10·1928	9·9414	9·7601
	ν	9·7218	10·2709	9·8886	9·6976	10·2617	9·8458	9·6936	10·3500	9·7538	9·9376	10·1495	9·8427
	α	9.8442	9·8236	10·2053	9·8991	9·7172	10·2121	9·6324	9·9980	10·2232	9·5253	9·8347	10·3015

*For details of different predictors for each month, *see* Table 4

where N_0 is the largest N in the different contingeny tables. The combined effect of the several predictors is then determined by obtaining the product of the normalized contingency ratios R'_{ij} in respect of each predictand class for the appropriate class of each predictor

$$\pi_j = \prod_{i=1}^{k} R'_{ij} \tag{6}$$

or taking logarithms

$$\log_{10} \pi_j = \sum_{i=1}^{k} \log_{10} R'_{ij} \tag{7}$$

The class of the predictand having the highest log-sum is selected as the forecast.

To speed up and simplify the preparation of forecasts, the number 10·0000 has been added to log R'_{ij} to avoid negative values. In this way the simple addition of (10·0000+ log R'_{ij}) for each predictand class j will give the forecast as outlined above. The values of (10·0000+log R'_{ij}) for each of the three predictors based on data for 1950 to 1958 used in this study are given in Table 5.

Another set of values of (10·0000+log R'_{ij}) utilising the data from 1950 to 1960 are given in Table 6. These values may be used by the field forecaster in preparing forecasts of pentad rainfall at Calcutta in the coming years.

6. Verification of forecasts

Forecasts were prepared for each of the 24 pentads for the subsequent three years 1959 to 1961 and compared with the actual rainfall at Calcutta. The results are presented below.

		Precipitation class forecasted			
		S	*N*	*A*	Total
Observed precipitation class	*S*	18	4	7	29
	N	5	6	7	18
	A	2	1	22	25
	Total	25	11	36	72

It is recalled that the limits of the three classes S, N and A have been fixed such that each class has one-third probability.

It is seen that on 36 occasions abnormal rain was forecast against an actual number of 22 (approx. 60 per cent).

The extent to which each class of rainfall was correctly forecast is shown below—

Percentage of occasions each observed category was correctly forecast

Observed class	Forecast class			
	S	*N*	*A*	Total
Subnormal	62	14	24	100
Normal	28	33	39	100
Abnormal	8	4	88	100

It is seen from above that the occurrence of abnormal rainfall was correctly forecast on 88 per cent of the occasions.

7. The Skill Score

The Skill Score S given by the expression $S=(R-E)/(T-E)$ has been calculated, where T is the total number of forecasts issued, R is the number of correct forecasts and E the number expected on climatological considerations alone. It will be seen that

$$S=0 \text{ when } R=E$$
$$\text{and } S=1 \text{ when } R=T$$

The Skill Score of the present technique for forecasting Calcutta rainfall is 0·46. This is of the same order as was obtained in the previous study.

8. Acknowledgements

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Appendix 1

An example illustrating the method of working out of different steps leading to the preparation of final forecast

Procedure

(1) From Table 2 determine the 5-day and 1-day periods (corresponding to the forecast period) to which the predictors should refer.

(2) From Table 4 select the predictors to be used. In respect of each predictor the relevant upper air data for the periods determined by reference to Table 2 to be collected.

(3) The classification of the predictors is then determined from the scatter diagrams given in Fig. 2.

(4) The values of $(10 \cdot 0000 + \log R'_{ij})$ corresponding to each predictor class are determined from Table 5 and summed up for each class of the predictand.

(5) The predictand class having the highest total is given as the forecast.

As an illustration let us take the case of preparing forecast of 5-day rainfall at Calcutta during the period 5 to 9 June 1959.

The classification of predictors (selected by reference to Tables 2 and 4) determined from the scatter diagrams is as under—

Predictor I α , Predictor II α, Predictor III ν

Referring to Table 5, we get the values of $(10 \cdot 0000 + \log R'_{ij})$ for each of the predictors and find the total for each predictand class as under—

	Values of $(10 \cdot 0000 + \log R'_{ij})$ for the predictand class		
	S	*N*	*A*
Predictor I Class α	9·5884	9·9681	10·2271
Predictor II Class α	9·9729	9·7069	10·1838
Predictor III Class ν	9·8914	10·2321	9·8238
Total	29·4527	29·9071	<u>30·2347</u>

As predictand class A (underlined) has the highest total, that is the forecast. The forecast may, therefore, be issued as—

'The rainfall at Calcutta during the period 5 to 9 June 1959 will be Abnormal'*.

*The lower limit of Abnormal rainfall at Calcutta during the period 5 to 9 June determined from Table 1 is 0·94 inches or 23·9 mm