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Surface pressure anomaly pattern types and their application in forecasting daily rainfall distribution over India

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सार — लुण्ड (1963) द्वारा प्रस्तावित चार्ट दर चार्ट सहसंबंध विधि से तीस वर्षों (1946– 75) के आंकड़ों का उपयोग करके जुलाई और अगस्त के दैनिक दाब असंगति चार्टों का वस्तुनिष्ठ वर्गीकरण करके उन्हें प्रत्येक मास के लिए दस दीर्घमापों वाली किस्मों में बांटा गया है। 15 वर्षों (1958-72) के आंकड़ों का उपयोग करके समस्त भारत के 31 मौसम विज्ञान उपसंभागों के लिए प्रत्येक दाब असंगति किस्म से संबद्ध वर्षा के औसत स्थानिक बंटन की गणना की गई है। 3 वर्ष (1973-75) के चार्टों का उपयोग करके अगामी 24 घंटों में देश के पश्चिमी एवं केन्द्रीय भागों में स्थित 10 उपसंभागों में वर्षण बंटन के पूर्वानुमान में इन वर्षा बंटन किस्म की सप्रतिबंध जलवायुओं की उपयोगिता की पुष्टि की गई हैं। पुष्टि से पता चला है कि दाब असंगति चार्ट के सरल स्तरीकरण की सहायता से भी पूर्वानुमान उतनी ही दक्षता से दिए जा सकते है जितनी दक्षता से कोई अनुभवी पूर्वानुमानकर्ता समस्त सिनॉप्टिक सूचनाओं का उपयोग करके देता है।

ABSTRACT. Daily pressure anomaly charts for July and August are objectively classified into ten large scale types for each month, utilising thirty years (1946-75) of data, through a chart-to-chart correlation method proposed by Lund (1963). Average spatial distribution of rainfall associated with each of the pressure anomaly types are computed for 31 meteorological sub-divisions covering entire contiguous India using 15 years (1958-72) of data. Usefulness of these rainfall distribution type conditional climatologies in forecasting precipitation distribution over 10 sub-divisions lying in western and central parts of the country for the next 24 hours, is verified using 3 years (1973-75) of charts. The verification reveals that the forecasts as skillful as given by an experienced forecaster using all synoptic information can be made by simple stratification of pressure anomaly charts.

1. Introduction

Improvement in public weather forecasts is a task of paramount importance. Advancement in the knowledge of meteorology should contribute towards improvement of weather forecasts. Application and success of Model Output Statistics (MOS) (Glahn and Lowry 1972) in the USA and its increasing popularity in other countries proves that at present good results in forecasting weather can be achieved by a combination of dynamical and statistical methods. Thus one may like to develop MOS if satisfactory predictions of atmospheric circulation become available. Where satisfactory dynamic prediction models are not yet available, it will be worthwhile to examine the extent to which the synoptic methods can be used to produce objective weather forecasts.

In India public weather forecasts valid for 24 and 48 hr are issued in the morning and evening utilising 03 and 12 GMT observations respectively. The forecasts of spatial distribution of rainfall are expressed in terms of percentage of stations likely to receive equal to or more than 2.5 mm rainfall in various subdivisions (SD's). These forecasts which can be interpreted as expected areal coverage or average point probability (symbolised by P in this study) are expressed in one of the following 5 categories of P, *viz.*, Dry (D)-0%; Isolated (I), 1-25%; Scattered (S), 26-50%; Fairly widespread (F), 51-75%; and Widespread (W), 76-100%; where the percentage figures specify the range of the category, *e.g.*, the rainfall will be isolated if 1 to 25% of the stations report rain. Given the synoptic charts for several levels and other meteorological information the forecaster aggregates intuitively the information and issues the forecast based on his experience of the behaviour of similar past circulation systems and the rainfall caused by them and the qualitative use of results of theoretical or observational (empirical) research. No operational guidance forecast is available like the MOS in USA.

It is worthwhile to investigate the extent to which this synoptic experience can be made objective. To achieve this Singh *et al.* (1978) (hence-forth to be referred as I) classified objectively daily 700 mb contour patterns over India into 5 main synoptic types for each summer monsoon month and computed the type conditional probabilities of rainfall at 107 stations widely distributed over India. For several types conditional probabilities differed from the climatic probabilities of rainfall by 0.2 to 0.4 over large parts of central and western India. It is natural to inquire how well the type conditional probabilities of rainfall will differ from the climatic probabilities for the circulation at other levels. Surface pressure anomaly data were collected in a form suitable for machine processing as a first step. As a preliminary investigation, correlation coefficients between daily pressure anomaly averaged over the blocks (*see* section 2) covering a sub-division (SD) and subsequent 24 h P of the particular SD, were computed for 31 SD's covering entire India. These correlations reveal that the local pressure anomaly is significantly correlated with the following 24 hr rainfall distribution for the SD's lying between latitudes 15 deg. N & 25 deg. N (Fig. 1). Gupta *et al.* (1979) found pressure anomaly gradients useful in forecasting rainfall amount over an area lying between latitudes 23 deg. N and 25 deg. N and longitudes 86 deg. E and 89 deg. E. Since the pressure anomaly pattern contain information about local pressure anomaly as well as pressure anomaly gradients one can expect them to be useful for forecasting. Hence in the present study, the usefulness of surface pressure anomaly patterns (PAP's) in simulating objectively the subjective assessment of forecaster about the P distribution over India in the following 24 hr periods is investigated. This investigation is conducted by objectively classifying the PAP's in each month into 10 broad types (section 3) by computing the expected values of P over each SD for each type (section 5) and by verifying the P forecasts issued with the help of these type dependent rainfall distribution statistics for the 10 SD's lying in the above mentioned belt of high correlation between pressure anomaly and rainfall distribution (section 6).

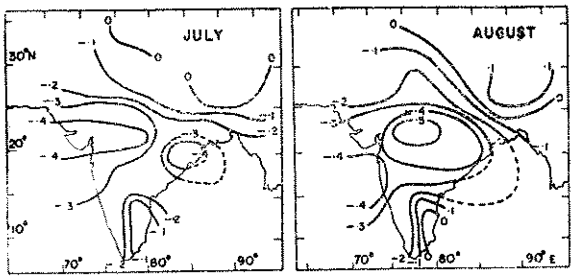

Fig. 1. Geographical distribution of correlation coefficients between local 03 GMT surface pressure anomaly and following 24 h P for various meteorological subdivisions of India for July and August. The correlation isolines have been drawn at 0.10 interval

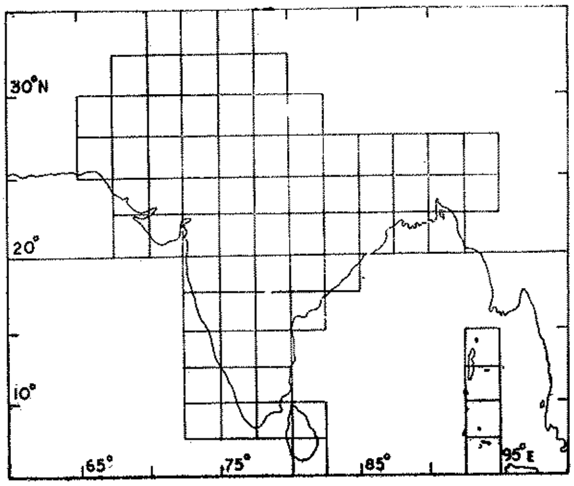

Fig. 2. The seventy-two, 2.5° Lat./Long. square blocks covering Indo-Pak region used for chart classification

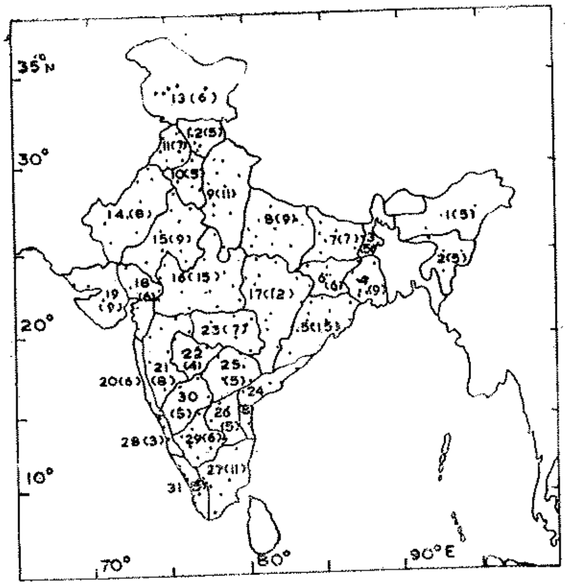

Fig. 3. The thirty-one mateorological subdivisions over the Indian region. Dots represent the locations of the rainfall stations. The serial number of the subdivision followed by number or stations in the subdivision in parenthesis are also indicated

2. Data

Pressure anomalies for seventy two, 2.5 deg. Lat./ Long. blocks (Fig. 2) are extracted from 0300 GMT charts for each day of July and August for a 30-year (1946-75) period. 930 charts in each month are used. Daily (24 hr) rainfall data of 227 stations (Fig. 3) are used to compute the daily P for all 31 SD's for a 15-year (1958-72) period. Daily P values have been extended for 3 verification years (1973-75) for 10 SD's using rainfall data of 84 stations.

3. The classification procedure

The chart-to-chart correlation method used by Lund (1963) and by Singh *et al.* in I is used to objectively classify the PAP's. As pointed out in I and also by Singh (1980) the classification results depend on the threshold correlation coefficient chosen. Thus great care is to be exercised in choosing the threshold. The choice of this threshold should depend on the amount of intercorrelation between the PAP's. In order to get an idea about the amount of intercorrelation between PAP's, about 1000 correlation coefficients between randomly selected pairs of charts from each month

TABLE 1

The pattern typing information for both months. The date of each typical pattern, and the number of occurrences in each of the 10 typical types in 30-year as well as 15-year period are shown. Patterns having correlation coefficient less than the threshold value (0.5) are gropped as unclassified

	July				August		
Pattern type	Date of type	30 years (1946-75)	15 years (1958-72)	Pattern type	Date of type	30 years (1946-75)	15 years (1958-72)
A	31-7-74	151	70	B	8-8-69	112	72
B	25-7-72	107	78	A	22-8-58	127	50
C	21-7-69	51	30	C	29-8-71	42	22
D	27-7-67	46	24	D	4-8-56	63	25
E	27-7-75	50	19	K	24-8-57	36	26
F	16-7-75	45	21	E	18-8-71	36	21
G	17-7-56	51	23	L	8-8-74	54	21
H	8-7-75	41	27	M	20-8-74	24	12
I	1-7-61	28	21	F	2-8-58	64	39
J	24-7-47	31	13	N	22-8-62	50	28
Unclassified	—	329	139		—	322	149

were computed and their frequency distribution determined. The PAP pairs separated by less than a 10-day period were excluded as these might have introduced high correlations due to persistence. It was found that 5% correlations lie above 0.6 in both months and 15% (10%) lie above 0.5 in July (August). It may be noted that for 72 observations the significant value of correlation coefficient at 5% level is 0.23. Thus while threshold of 0.7 as used in I will be too high for these sets of charts, a value of .23 will be too low. After some experimentation with different threshold values, ranging from 0.4 to 0.6, 0.5 is found as most appropriate.

Due to the limited memory of the computer used, the 30 years of data were split into 3 sets of 10 years (1946-55, 56-65, 66-75) each. Eight types in each of these decades were determined for each month by a procedure identical to that followed in I. The 3 periods of one decade each produced almost identical pattern types suggesting the stability of the classification procedure, a desirable attribute according to Kendall (1971, p. 360). These total of 24 pattern types obtained for each month are examined for similarity visually and with the help of intercorrelation coefficients, 10 typical patterns (Fig. 4) which accounted for nearly all 24 types are identified for further use. Six types in each month appearing similar are given common names, *viz.*, A, B, C, D, E and F and remain-into a type and further computations all the 10 patterns *viz.*, G, H, I and J in July and K, L, M and N in August. However, for assignment of individual patterns into a type and further computations all the 10 patterns as shown in Fig. 4 are retained in each month. An individual chart is assigned into one of the 10 types with which it is maximaly correlated provided the correlation is not less than 0.5. Smooth generalised patterns were prepared by averaging 5 patterns having highest correlations with the typical patterns. These smooth patterns possessed excellent resemblance with the corresponding individual types. Thus it is believed that most of the individual patterns will retain their type if final assignment is carried out on the basis of these smooth patterns. There is, however, danger of borderline cases changing their types and thus necessitating recomputation of pattern dependent rainfall climatologies. Further Lund (1972) did not find any improvement in forecasting skill by considering generalised types. Due to these reasons generalised types are not used further.

The dates of the typical patterns and the frequency of various types of patterns during the entire period and during the 15-year period (1958-72) for which the daily P values were available are given in Table 1. It can be seen that nearly 35% of the charts remain unclassified as against 10-20% of charts remaining unclassified after considering only 5 types in I. In an objective classification procedure based on correlation coefficient some charts will always remain unclassified (Singh 1980). Since our aim is to achieve reasonable difference (stratification) between the type conditional rainfall distribution climatologies (TCRC's) and unconditional rainfall distribution climatologies (URC's), it is desirable to assign only those patterns into a type which resemble reasonably well to any typical pattern lest it will dilute the stratification which we are seeking. Circulation charts at other levels and other synoptic information can be used for forecasting on these unclassified occasions.

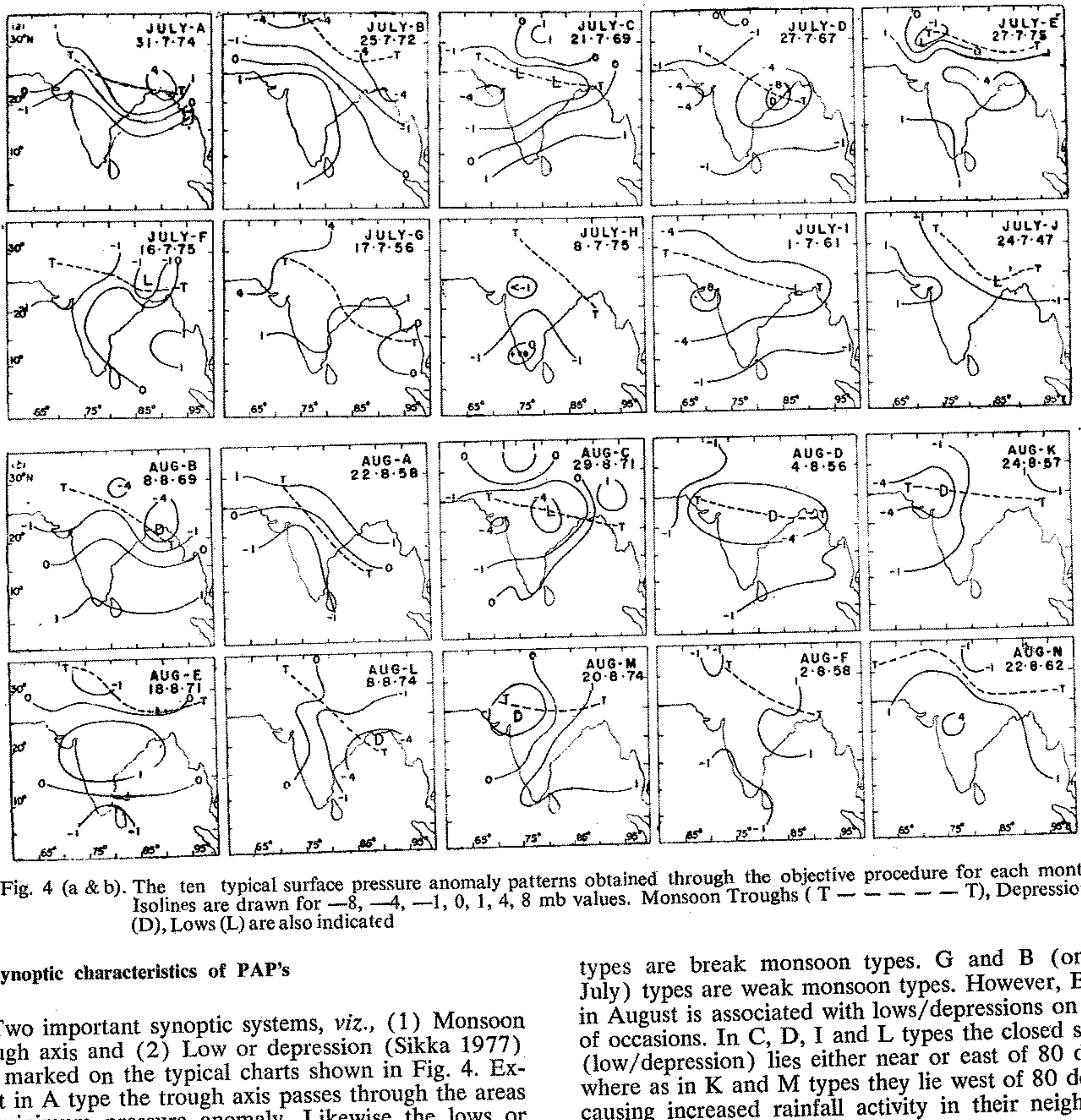

Fig. 4 (a & b). The ten typical surface pressure anomaly patterns obtained through the objective procedure for each month. Isolines are drawn for —8, —4, —1, 0, 1, 4, 8 mb values. Monsoon Troughs (T — — — — — T), Depressions (D), Lows (L) are also indicated

4. Synoptic characteristics of PAP's

Two important synoptic systems, *viz.*, (1) Monsoon trough axis and (2) Low or depression (Sikka 1977) are marked on the typical charts shown in Fig. 4. Except in A type the trough axis passes through the areas of minimum pressure anomaly. Likewise the lows or depressions are also located in the areas of minimum pressure anomaly. Rainfallwise the monsoon is usually active when the monsoon trough is located in normal or relatively southern latitudes and/or a low/ depression is present in the favourable areas. On the contrary the monsoon is weak when the trough is comparatively in northern latitudes and low/depression is absent. Complete desiccation of rainfall over the central parts of the country (or break) occurs when the trough shifts to the foot of Himalyans (Raghavan 1973). The pressure anomaly charts convey this synoptic meaning in most cases. An experienced synoptic meteorologist identified the B, E, F and N types as break, monsoon types, A and G types as weak monsoon types and C, D and I as active monsoon types. We examined individual charts for the synoptic features portrayed on typical charts. This revealed that C, D, H, I, J and L are often associated with lows or depressions in favourable positions. E, F and N types are break monsoon types. G and B (only in July) types are weak monsoon types. However, B type in August is associated with lows/depressions on 60% of occasions. In C, D, I and L types the closed system (low/depression) lies either near or east of 80 deg. E where as in K and M types they lie west of 80 deg. E, causing increased rainfall activity in their neighbourhood.

5. Rainfall climatology of PAP's

For study of associated rainfall distribution with various PAP's only 15 years (1958-72) of data for which daily P values were available, have been used. For all PAP types average P values (Pt) and their distribution in the 5 categories, *viz.*, D, I, S, F and W are computed. For better exposition of the stratification in P caused by various PAP's the difference between Pt and average P for the month ($\overline{P}$) are determined for each of the 31 SD's covering entire India (Fig. 5). Although we have verified the utility of these type conditional rainfall distribution statistics for only 10 SD's, the (Pt—$\overline{P}$) are obtained for all the 31 SD's as shown in Fig. 5 for giving complete overall picture. It is noted that types A, B, C, D, E, F, L. M and N are associated with higher (Pt—$\overline{P}$) (or

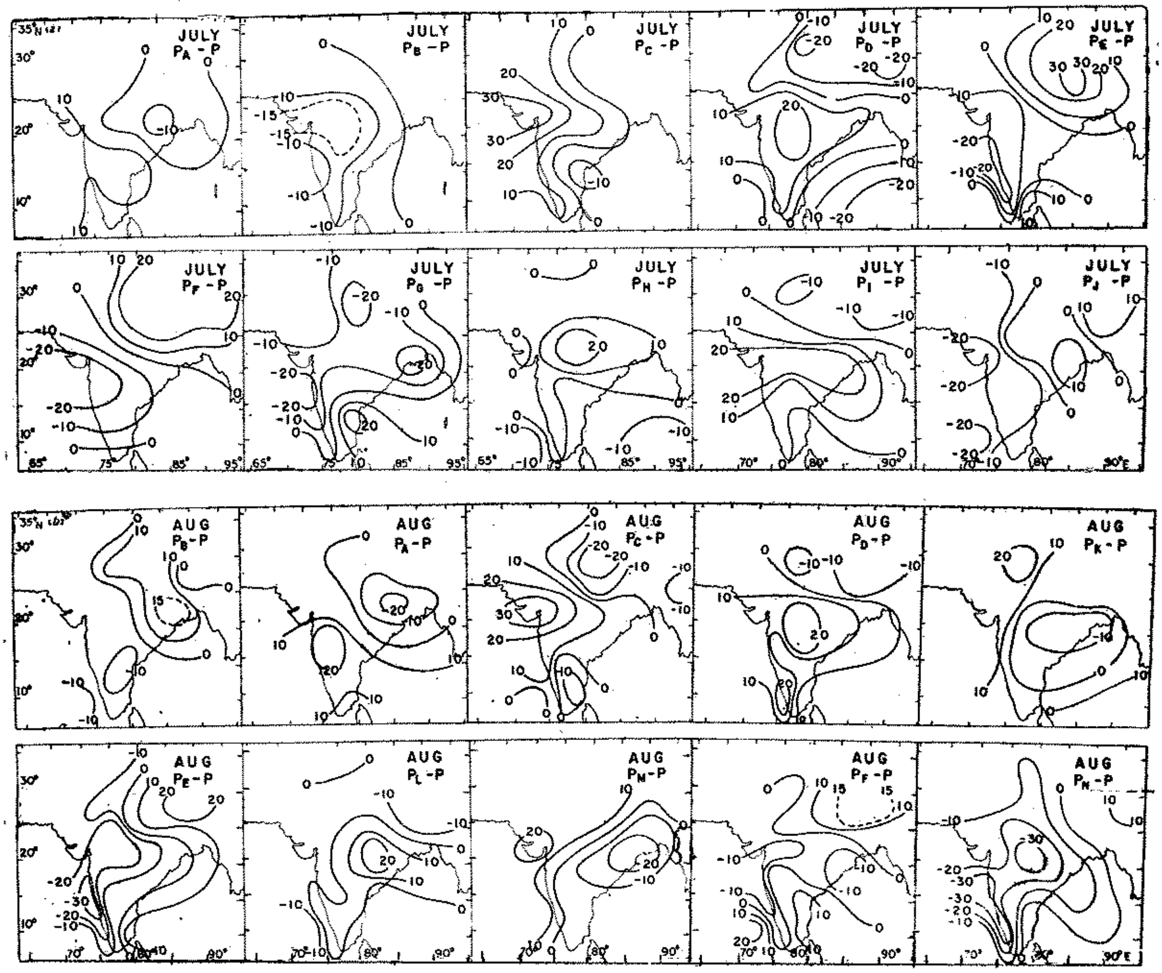

Fig. 5 (a&b). Differences ($Pt-\overline{P}$) between average P associated with a type (Pt) and average P for the month ($\overline{P}$) for each surface pressure anomaly pattern for each month. The smoothed isolines are drawn at intervals of 10 assuming the ($Pt-\overline{P}$) values valid at the centre of the sub-divisions. Broken isolines are drawn at intervals of 5. $\overline{P}$ and Pt values are expressed in percentages

stratification) for selected areas. The types C, D, E, F, G, I and N cause stratification over larger parts of the country. These stratification in P, *i.e.*, ($Pt-\overline{P}$) are tested for significance by student's t-test for each type and each of the 31 SD's. It is found that neither significant change in P from climatological values is created by a type for all the SD's nor any SD experiences significant change in P value due to all types. The types which cause significant change in P according to the t-test are shown in Table 2. In this table the types which show significant stratification in P have been labelled as wet (dry) types when Pt is greater (smaller) than $\overline{P}$. The table reveals that significant stratification in P occurs in association with more types for the SD's lying in the main monsoon belt. Type frequency weighted absolute stratification charts were found to be similar to the correlation charts presented in Fig. 1 with maximum overall stratification occurring over the area corresponding to high negative values of correlation coefficients. The overall stratification in P over this area ranged from 0.10 to 0.19.

6. Application in forecasting

The usefulness of these relationships between the PAP's and the rainfall distribution over the country during the next 24 hr are verified by making forecasts for 3 years (1973-75). An individual chart is recognised as belonging to a particular type with which it is maximaly correlated provided the correlation equals or exceeds 0.5. The categories of spatial distribution of rainfall (out of D, I, S, F and W) in which the Pt's fall are displayed in Table 3 for the 10 SD's. The corresponding categories are used as forecast, whenever a type is identified. A total of 62 (69) forecasts are made in July (August). A forecast is verified correct if the observed category of rainfall distribution turns out to be the same as forecast category. They are verified as correct within one category (using the ordered set D, I, S, F and W) if the observed spatial distribution of rainfall falls in the same or in the category adjacent to the forecast category. The results of verification are displayed in Table 4. On an average (*see* last row total in the table) about 30% forecasts are correct in the same category of spatial distribution of rainfall and about 80% are correct within one category. The forecaster marginally scores over PAP rainfall climatology for forecasts correct within same category in August where as reverse is true for forecasts correct within same category in July and correct within one category in July and August. Except for west Rajasthan in August where the forecasters are

TABLE 2

For each sub-division, the various chart types for which (Pt—$\overline{P}$) is significant are shown with Pt and 't' values in parenthesis for dry and wet circulation types. Also shown are the $\overline{P}$ values and the model category (M) in the frequency distribution of P in each month for each subdivision. The $\overline{P}$ and Pt values are multiplied by 100 and rounded to nearest whole number and the 't' values are rounded to first place of decimal

Sl. No.	Sub-division name (SDN)	July				August			
		$\overline{P}$	M	Dry type	Wet type	$\overline{P}$	M	Dry type	Wet type
1	North Assam	57	W	D(34, —2.2)	F(79, 2.1)	49	S		F(67, 2.2)
2	South Assam	60	W			56	S		
3	Sub-Himalayan W. Bengal	60	W		E(84, 2.1)	57	W	D(39, —2.1)	
4	Gangetic W. Bengal	47	I	G(25, —2.1)		50	S	A(35, —2.1)	B(68, 3.1)
5	Orissa	49	S		I(72, 2.2)	45	S		B(57, 2.0)
6	Bihar Plateau	51	S	A(38, —2.1)		52	S	A(30, —3.1)	B(69, 2.9)
7	Bihar Plains	40	S		E(70,2.7); F(69, 2.7); E(66, 2.5);	43	S	A(26, —2.6)	B(56, 2.3); F(61, 2.3)
8	Uttar Pradesh East	38	I			44	S		
9	Uttar Pradesh West	41	S	G(18, —2.3)	F(62, 2.2)	45	S	C(25, —2.0)	
10	Haryana	26	D			32	D	N(14, —2.0)	B(46, 2.6)
11	Punjab	26	D			26	D		K(47, 2.4)
12	Himachal Pradesh	59	W	D(38 ,—2.1); G(32, —2.6)		58	W		K(77, 2.0)
13	Jammu and Kashmir	17	D			18	D		
14	Rajasthan West	12	D	B(5, —2.0)	C(29, 2.7)	11	D		
15	Rajasthan East	28	I	B(12, —3.1)	C(45, 2.1)	32	I	E(7, —2.4); N(8, —2.8)	
16	Madhya Pradesh West	42	S	B(26, —2.9)	C(62, 2.2); D(67, 2.5); H(66, 2.5)	45	F	E(23, —2.1); N(12, —3.5)	C(69, 2.2); D(66, 2.1)
17	Madhya Pradesh East	55	F	B(42, —2.1)	H(74, 2.0)	54	S	A(39, —2.1); N(30, —2.5)	L(81, 2.5)
18	Gujarat	41	I	B(25, —2.6); J(9, —2.3)	C(75, 3.8)	34	D	E(11, —2.2); F(16, —2.3)	C(70, 3.6)
19	Saurashtra and Kutch	31	D	B(13, —3.4); F(10, —2.0)	A(46, 2.8); C(70, 4.7); I(56, 2.5)	19	D	N(5, —2.0)	C(55, 4.3); M(48, 2.5)
20	Konkan	79	W	E(52, —2.9); F(55, —2.7); G(54, —2.8)	A(89, 2.1); D(98, 2.3)	69	W	E(37, —3.1); N(39, —3.4)	A(86, 2.6); D(88, 2.1)
21	Madhya Maharashtra	34	S	B(22, —2.2); F(13, —2.0)	I(58, 2.3)	30	I	N(9, —2.4); B(19, —2.0)	A(55, 3.9)
22	Marathwada	36	D	B(20, —2.9); F(7, —2.7)	A(52, 2.8); D(64, 2.9)	32	D	B(15, —3.4); N(5, —3.3)	A(59, 3.7); C(57, 2.2); D(56, 2.3)
23	Vidarbha	51	W	B(35, —2.8)	D(78, 2.7); I(73, 2.0)	48	S	E(23, —2.3); N(15, —3.5)	D(73, 2.5)
24	Coastal Andhra Pradesh	31	I		A(44, 2.6)	27	I		
25	Telangana	40	D	B(27, —2.4)	A(53, 2.2); D(61, 2.1)	37	D	B(25, —2.1)	D(58, 2.2)
26	Rayalaseema	23	D	C(8, —2.0)	A(36, 2.7); G(46, 2.7)	22	D	B(9, —2.6)	A(41, 3.3); F(41, 2.9)
27	Tamil Nadu	16	I			20	I		F(32, 2.0)
28	Coastal Mysore	90	W	E(65, —3.5); F(76, —2.1)		78	W	E(46, —3.6); N(47, —4.2)	D(96, 2.1)
29	Interior Mysore North	36	I			28	I		A(48, 3.1)
30	Interior Mysore South	32	S	B(19, —2.5)	C(49, 2.0)	25	D	B(15, —2.0)	A(40, 2.5)
31	Kerala	73	W	B(58, —3.0); E(52, —2.1)		57	W	E(36, —2.0); N(27, —3.2)	A(75, 2.6); D(84, 2.8)

TABLE 3

Rainfall distribution categories associated with each pattern type for 10 sub-divisions in Western and Central India. Last column shows category of average P value $(\overline{P})$ for the month. D-Dry, I-Isolated, S-Scattered, F-Fairly widespread, W-Widespread., The locations of the sub-divisions are shown in Fig. 3

S.D. No.	Type										
	A	B	C	D	E	F	G	H	I	J	$\overline{P}$
					July						
14	I	I	S	I	I	I	I	I	I	D	I
15	S	I	S	S	I	S	I	S	S	S	S
16	S	S	F	F	I	S	S	F	F	S	S
17	S	S	F	F	F	F	S	F	F	F	F
18	S	S	F	F	S	S	S	F	F	I	S
19	S	I	F	S	I	I	I	I	F	I	S
20	W	F	W	W	F	F	F	W	W	F	W
21	S	I	S	S	I	I	S	S	F	I	S
22	F	I	S	F	I	I	S	S	S	I	S
23	F	S	F	W	S	S	S	F	F	S	F
					August						
	B	A	C	D	K	E	L	M	F	N	$\overline{P}$
14	I	I	I	I	I	I	I	I	I	I	I
15	I	S	S	S	S	I	S	S	S		S
16	S	S	F	F	S	I	S	S	S	I	S
17	F	S	F	F	S	S	W	S	S	S	F
18	S	S	F	S	S	I	S	F	I	I	S
19	I	S	F	S	S	I	I	S	I	I	I
20	F	W	W	W	W	S	F	W	F	S	F
21	I	F	S	S	S	I	S	S	S	I	S
22	D	F	F	F	S	I	S	I	S	I	S
23	S	F	F	F	S	I	F	S	F	I	S

TABLE 4

Results of verification of forecasts of rainfall distribution over 10 sub-divisions by the official forecaster and those obtained objectively with the help of the Type Conditional Rainfall Climatologies (TCRC's). Forecasts correct in same (within one) category of rainfall distribution are labelled by 0(1). The locations of the sub-divisions are shown in Fig. 3

S.D. No.	July (Total forecasts=62)				August (Total forecasts=69)			
	Official forecaster		TCRC's		Official forecaster		TCRC's	
	0	1	0	1	0	1	0	1
14	20	51	17	60	33	52	12	61
15	15	48	17	54	25	52	20	62
16	29	59	19	60	27	58	26	54
17	26	54	31	57	21	55	17	61
18	8	41	9	34	13	40	21	43
19	16	41	16	46	20	52	18	55
20	31	57	28	53	37	63	37	59
21	16	47	25	49	23	54	21	60
22	9	39	10	39	15	45	16	47
23	10	50	13	43	18	44	19	52
Total	180	487	185	495	232	515	207	554

correct within same category on 3 times of the occasions (33 *vs* 12) than the forecasts made correct in the same category with the help of PAP based rainfall climatology, there seems to be no difference in the skill of the two types of forecasts.

7. Summary and remarks

It was possible to classify the PAP's in a few distinct types by Lund type correlation approach. Most of these PAP's corresponded well with the synoptic situations prevailing during the mid-monsoon months. The forecasts of spatial distribution of rainfall for the next 24 hr made with the help of PAP dependent rainfall climatology are found to be as skillful as the forecasts issued by the official forecaster for the 10 SD's lying in the western and central India.

We should not except that the forecasts more skillful than those of the official forecaster can be made by using large scale distribution of a single meteorological field at a single level. Smaller scale systems play significant role in causing rainfall. For example, sea level troughs off west coast and mid-tropospheric cyclones over northeast Arabian Sea and adjoining land area affect significantly rainfall distribution over coastal and neighbouring sub-divisions. The official forecaster aware of this, incorporates their influence and also of other synoptic information in his forecasts in some way. We believe that if these factors are considered, the objective forecasts will show improvement. Such refinements of the synoptic climatology are being attempted. Till then the forecasters can use the conditional rainfall climatology confidently for at least some types of PAP's for some SD's.

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References

Glahn, H. R. and Lowry, D. A., 1972, The use of model output statistics (MOS) in objective weather forecasting, *J. Appl. Met.*, **11**, 1203 1211.

Gupta, G.R., Srivastava, K.K., Mehra, H.C. and Jesra, T.C., 1979, Forecasting storm rainfall over Bhagirathi catchment due to depressions/cyclonic storms, *Mausam*, **30**, 139-156.

Kendall, M.G., 1971, In discussion on—A review of classification by Cormack, R.M., *J. Roy. Statis. Soc. A*, **134**, 321-353.

Lund, I.A., 1963, Map pattern classification by statistical method *J. Appl. Met;* **2**, 56-65.

Lund, I.A., 1972, Climatology as a function of map type, Environmental Research Papers, No. 391, Air Force Cambridge Research Laboratories, Bedford, Massachusetts, 15 pp.

Raghavan, K., 1973, Break-monsoon over India, *Mon. Weath. Rev.*, **101**, 33-43.

Sikka, D.R., 1977, Some aspects of the life history, structure and movement of monsoon depressions, *Pageoph*, **115**, 1501-1529.

Singh, S.V., Mooley, D.A. and Kripalani, R.H., 1978, Synoptic climatology of the daily 700 mb summer monsoon flow patterns over India. *Mon. Weath. Rev.*, **106**, 510-525.

Singh, S.V., 1980, The problems of classification in Meteorology and Climatology, *Bulletin of Classification Society*, **4**, 10-15.