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Concurrent association between 700-mb 5-day mean contour patterns and 5-day rainfall anomaly over India during July*

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ABSTRACT. Utilising pentad charts for July for the years 1957-1966, broadscale features of 5-day mean contour patterns associated with widespread abnormal and subnormal rainfall over five large areas, *viz.*, northeast, northwest, central, western and southern India have been examined. The association between monsoon trough axis location and rainfall anomaly over these large areas has been brought out. Association between monsoon trough axis location and rainfall has also been investigated for all the sub-divisions of India. The study reveals that for most of the sub-divisions of India the concurrent association between location of monsoon trough axis and occurrence of non-subnormal and non-abnormal rain is high. In conjunction with forecast 5-day mean 700-mb contour chart these relationships could be used to forecast non-subnormal and non-abnormal rainfall over most sub-divisions of India.

1. Introduction

One of the basic problems in meteorology is the relationship between contour or isobaric patterns and weather. Even if it were possible to forecast contour or isobaric chart with 100 per cent accuracy it does not follow that weather could be forecast with that accuracy, since there does not appear to be a unique relationship between contour patterns and weather. When we are concerned with the forecasting of weather for 5-day period two approaches to the problems can be examined.

(1) Obtain the concurrent relationship between 5-day mean contour patterns and weather, predict the 5-day mean contour chart and apply the concurrent relationship to the predicted contour chart to predict weather for the next 5-day period.

(2) Search for predictor parameters which have a good relationship with the weather in the next 5-day period and apply the prognostic relationship to the values of the current 5 day mean parameters on the contour charts.

In this study it is proposed to confine to 5-day mean 700-mb contour chart covering the area from 20° to 140°E and equator to 50°N and explore its utility from the viewpoint of getting concurrent association between 5-day mean 700-mb contour patterns and 5-day rainfall anomaly and to bring out associations, if any.

2. Data used

5-day mean 700-mb contour charts and 5-day rainfall anomaly charts giving rainfall anomaly at about 150 stations for July for the period 1957 to 1966 were utilised in this study. These charts were prepared in the Medium Range Forecast Section and the details about their preparation have been given by Pant (1964). These charts covered overlapping periods, the extent of overlap being 2 or 3 days. The three classes of 5-day rainfall anomaly have been designated as subnormal (S), normal (N) and abnormal or above normal (A). The limits for these classes were obtained from 30 years' data in such a way that each of the classes had a probability of $\frac{1}{3}$.

It may be mentioned that on 5-day mean contour chart, all fast-moving systems are suppressed. On the daily charts depressions or lows are seen to move about 15 to 25 km per hour; the track of such a system is seen as trough axis on 5-day mean contour chart.

3. Normal contour patterns

The weekly normal 700-mb contour charts show that from beginning of June till about the end of 3rd week there is a trough over east India with axis along 90°E. Thereafter, the trough undergoes changes in orientation. It extends further west and runs from southwest to northeast. Towards the end of June the trough axis runs east-west across the central parts of the country. The normal monsoon trough with east-west orientation is established towards end of June by which time monsoon has set in over most parts of the country.

From the study of daily synoptic charts, Normand (1937) has stated that monsoon trough

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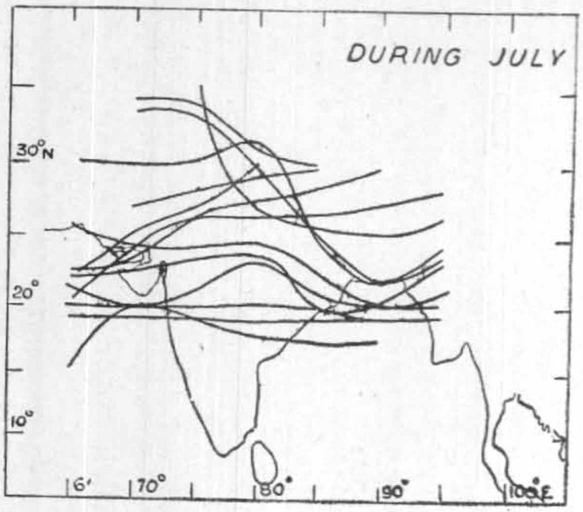

Fig. 1

Orientation of trough over India and neighbourhood on individual pentad charts during July

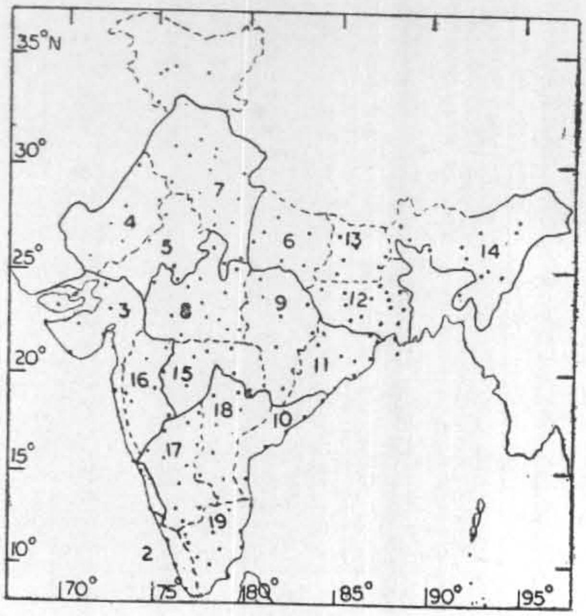

Fig. 2

Five broad divisions, all sub-divisions and rainfall stations in India

is not stationary but moves north or south of its normal position and affects rainfall distribution, while Malurkar (1944) has mentioned that the variations of the position and strength of monsoon trough and westward movement of lows and depressions from north Bay across the country are important from the view point of rainfall.

On the normal monthly 700-mb contour chart for July, the monsoon trough runs east-west with its axis along 22°N between 60° and 110°E. However, on individual pentad charts during July, the axis of the monsoon trough shows a wide variety of orientation. These changes in orientation and variation in rainfall over different parts of the country appear to be associated. Fig. 1 shows these orientations.

Attempt has been made to seek association between 5-day mean 700-mb monsoon trough axis location and 5-day rainfall anomaly over different parts of India.

4. Broad-scale association between trough axis and rainfall anomaly

It was first decided to investigate the broadscale association, if any, in the 5-day mean contour patterns and rainfall anomaly. This was investigated by studying the broadscale features of 700-mb 5-day mean contour patterns associated with widespread character of abnormal and subnormal rain over five large areas, *viz.*, northeast, northwest, central, western and southern India as shown in Fig. 2. From these 5-day mean individual chart composite contour charts associated with widespread abnormal and subnormal 5-day rain were prepared for each of these large areas. These do show some distinct features in respect of the monsoon trough and orientation of its axis.

(a) *Northeast India (East U.P., Bihar Plains, Chota Nagpur, West Bengal and Assam)* — In the composite charts associated with abnormal rain, the monsoon trough axis is north of 25°N over the area. While in the composite chart associated with subnormal rain the trough axis is south of 20°N.

(b) *Northwest India (West Uttar Pradesh, Haryana, Punjab and Rajasthan)* — Trough axis over the longitudinal extent of the area is located at about 25°N in the chart associated with abnormal rain, while it is either south of latitude 21°N or over Himalayas in the charts associated with subnormal rain.

(c) *Central India (Madhya Pradesh, Vidarbha, Marathwada, Orissa)* — In the chart associated with abnormal rain, the trough axis runs along 22°N from 60° to 95°E. There are two types of contour charts associated with subnormal rain. In the first type, the trough axis is at a low latitude, about 18°N. In the second type the trough axis is over foot hills of Himalayas.

(d) *Western India (Gujarat-Saurashtra-Kutch, Konkan-Kanara and Madhya Maharashtra)* — In the chart associated with abnormal rain, the trough axis is at about 22°N, while in the chart associated with subnormal rain, the axis is north of 30°N.

(e) *Southern India (Interior Mysore, Andhra Pradesh and Tamil Nadu)* — Trough axis is south of 21°N in the chart associated with abnormal rain while it is over Gangetic plains about 26°N in the composite chart associated with subnormal rain.

It is thus seen that axis location is different in contrasting situations with widespread abnormal and subnormal rain over large areas and thus a broad scale association exists between the 5-day mean monsoon trough axis location and 5-day rainfall anomaly. In addition to the composite charts, individual component charts associated with widespread subnormal and abnormal rain over these five areas of India were examined in detail with reference to the location of the trough axis on the mean longitude of the area. Fig. 3 summarises the details regarding axis locations and associated anomaly of widespread character. The locations associated with abnormal and subnormal rain are well-separated.

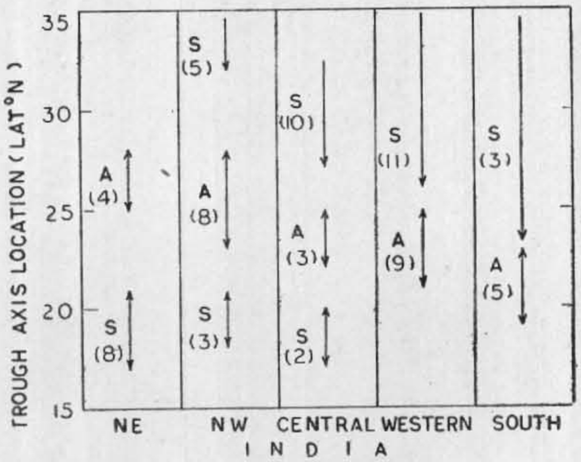

Fig. 3

Monsoon trough axis location associated with widespread abnormal and subnormal rain during July

(Figures in brackets below A and S denote the number of cases)

5. Association between trough axis location and rainfall anomaly over sub-divisions

It was felt worthwhile investigating whether trough axis location could discriminate each of the three classes of 5-day rainfall anomaly over sizeable sub-divisions of India. If it cannot discriminate the three classes of rainfall anomaly, can it discriminate one category from the other two or one of the two categories in which the rainfall anomaly can be put ? The 19 sub-divisions considered are shown in Fig. 2. It may be seen that small meteorological sub-divisions have been combined to have sizeable sub-divisions.

For each of these sub-divisions rainfall anomaly was obtained for all pentads in July during the period 1957-66. If one particular character of rainfall anomaly was widespread in the sub-division in a particular pentad then that anomaly character was taken for the sub-division for that pentad. When rainfall anomaly for the sub-division for any pentad could not be determined this way, then the total rainfall for all the stations in the sub-divisions was computed for the pentad and utilising the tercile rainfall limits for that pentad for the sub-division in question the rainfall anomaly for the pentad under consideration was classified as S, N, or A for the sub-division. Next, for each of the sub-divisions and for each of the pentads the location of the monsoon trough axis on the mean longitude of the sub-division was noted down from the 700-mb 5-day mean contour charts for July. For each sub-division a graph was prepared between pentad rainfall anomaly and axis location. These were carefully examined to see if the axis location could discriminate all the three rainfall anomaly characters, or one type of anomaly from the remaining two or abnormal from the subnormal type. The critical locations of axis which provided maximum possible discrimination of rainfall anomaly were noted down. A typical graph for Gujarat-Saurashtra-Kutch is shown under Fig. 4. This graph shows that when trough axis along Long. 72·5°E is south of Lat. 25°N, probability of subnormal rainfall is very small and when the axis is at or north of 25°N the probability of abnormal rain is very small. Thus the axis location at 25°N is critical from the point of view of rainfall anomaly in Gujarat-Saurashtra-Kutch. The critical axis locations were thus obtained for each sub-division.

Next for each sub-division, a 2×3 contingency table was prepared. This has two classes for axis location and three classes of rainfall anomaly. It is seen that for the sub-divisions Konkan-Kanara, Kerala, Gujarat-Saurashtra-Kutch, and interior Mysore when trough axis is south of Lat. 25°N rainfall is abnormal in 60 to 70 per cent of such cases. In the case of coastal Andhra Pradesh, when trough axis is south of 23°N rainfall is abnormal in 63 per cent of such cases. Contingency tables for these areas are given under Tables 1 (a) to 1(e). For all the remaining 14 sub-divisions the probability of any rainfall anomaly corresponding to any type of axis location is less than 0·6. Thus, except for the good association between axis location and abnormal rain in the case of the forementioned five sub-divisions, the general association between axis location and each of the three types of rainfall anomaly is not satisfactory.

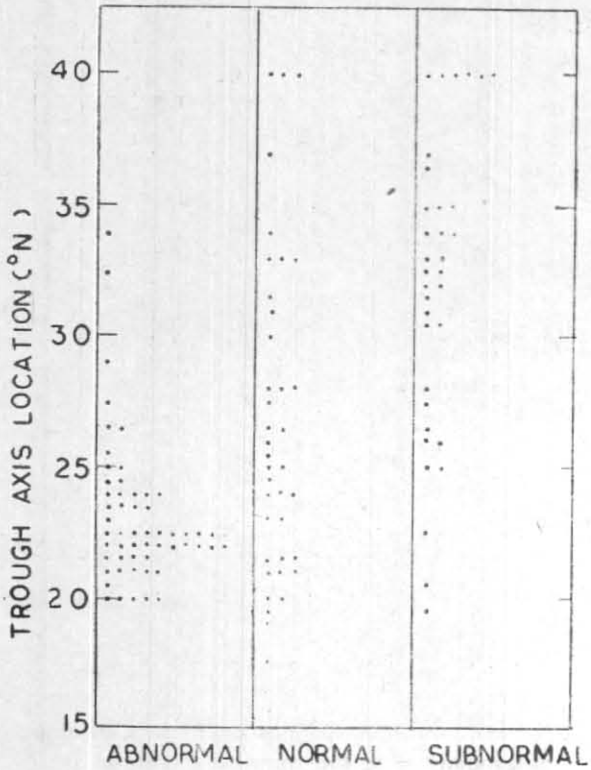

Fig. 4

Rainfall anomaly in Gujarat-Saurashtra-Kutch in relation to monsoon trough axis on Long. 72·5°E

To investigate the association between axis location and two types of rainfall anomaly each of the 2×3 contingency table was converted into two 2×2 contingency table by combining normal category with abnormal and subnormal categories. These have been given under Tables 2 (a) to 2(s). These show associations between trough axis location and non-occurrence of abnormal or subnormal rain for most areas. The significance of association for each tables was tested by Chi-square test. The null hypothesis tested is that axis position and rainfall anomaly are independent and the alternative hypothesis is that of non-independence, *i.e.*, association. The level of significance adopted was ·001.

Yule and Kendall (1965) have given a number of coefficients which could be used as measures of strength of association in 2×2 tables. Of these, Pearson's coefficient of mean square contingency (PCC) which is given by the expression $\sqrt{\chi^2/(\chi^2+N)}$ is computed, where χ^2 is the value of Chi-square for the contingency table and N is the total number of cell frequencies in the table. Since the maximum attainable PCC for a 2×2 table is ·707, relative PCC was further calculated by dividing PCC by .707.

TABLE 1

Rainfall anomaly	South of 25°N	At or north of 25°N	Total
(*a*) Kerala—Location of monsoon trough axis (MTA) on 75°E			
S	3 (5)	27 (41)	30
N	14 (22)	27 (41)	41
A	46 (73)	12 (18)	58
Total	63 (100)	66 (100)	129
(*b*) Konkan-Kanara — Location of MTA on 75°E			
S	1 (2)	27 (41)	28
N	24 (38)	29 (44)	53
A	38 (60)	10 (15)	48
Total	63 (100)	66 (100)	129
(*c*) Gujarat-Saurashtra-Kutch — Location of MTA on 72·5 E			
S	3 (5)	33 (52)	36
N	17 (25)	21 (33)	38
A	46 (70)	9 (15)	55
Total	66 (100)	63 (100)	129
(*d*) Interior Mysore — Location of MTA on 75°E			
S	3 (5)	24 (36)	27
N	21 (33)	32 (48)	53
A	39 (62)	10 (14)	49
Total	63 (100)	66 (100)	129
(*e*) Coastal Andhra Pradesh — Location of MTA on 82·5°E			
S	4 (7)	16 (21)	20
N	15 (30)	38 (51)	53
A	35 (63)	21 (28)	56
Total	54 (100)	75 (100)	129

Table 4 give Chi-square values and relative PCCs for all sub-divisions. The table consists of two parts, the first dealing with association between axis location and non-subnormal rain and the second dealing with association between axis location and non-abnormal rain. In the first part, for 14 sub-divisions, χ^2 is significant, thus contradicting the null hypothesis of independence. Hence significant association exists between axis location and non-subnormal rain. For east U.P., Orissa, Coastal Andhra Pradesh, Telangana, Rayalaseema and Tamil Nadu there is no significant association. In the second part of the table, for 13 sub-divisions χ^2 value is significant. The hypothesis of independence is contradicted. Thus significant association exists between axis location and non-abnormal rain for these sub-divisions. For East Rajasthan, West U. P., Haryana and Punjab, Vidarbha-Marathawada, Orissa,

TABLE 2

Location of MTA on		Rainfall anomaly			
Long.	Lat.	S	non-S	non-A	A
		(a) Konkan-Kanara			
75°E	South of 25°N	1	62	25	38
	At or north of 25°N	27	39	56	10
		(b) Kerala			
75°E	South of 25°N	3	60	17	46
	At or north of 25°N	27	39	54	12
		(c) Gujarat-Saurashtra-Kutch			
72·5°E	South of 25°N	3	63	20	46
	At or south of 25°N	33	30	54	9
		(d) West Rajasthan			
72·5°E	Between 21 and 30°N	9	70	42	37
	Outside 21-30°N belt	22	28	46	4
		(e) East Rajasthan			
75°E	Between 21-28°N	13	63	56	20
	Outside belt 21-28°N	24	29	46	7
		(f) East Uttar Pradesh			
82·5 E	South of 25°N	35	36	64	7
	At or north of 25°N	17	41	35	23
		(g) West U.P., Haryana and Punjab			
77·5°E	Between 22° and 30°N	9	73	45	37
	Outside belt 22-30°N	20	27	39	8
		(b) West Madhya Pradesh			
77·5°E	Between 22 and 28°N	8	59	43	24
	Outside belt 22-28°N	30	32	59	3
		(i) East Madhya Pradesh			
82·5°E	Between 22 and 26°N	6	52	35	23
	Outside belt 22-26°N	34	37	67	4
		(j) Coastal Andhra Pradesh			
82·5°E	South of 23°N	4	50	19	35
	At or north of 23°N	16	59	54	21
		(k) Orissa			
85°E	Between 20-25°N	12	62	46	28
	Outside belt 20-25°N	22	33	47	8
		(l) Gangetic West Bengal and Chota Nagpur			
87·5°E	Between 21-25°N	7	53	41	19
	Outside belt 21-25°N	31	38	64	5
		(m) Bihar Plains			
85°E	South of 24°N	40	33	70	3
	At or north of 24°N	7	49	33	23
		(n) Assam and sub-Himalayan West Bengal			
92·5°E	South of 23°N	26	45	66	5
	At or north of 23°N	4	54	29	29
		(o) Vidharbha and Marathwada			
77·5°E	South of 25°N	8	55	35	28
	At or north of 25°N	28	38	53	13
		(p) Madhya Maharashtra			
75°E	South of 25°N	4	58	36	26
	At or north of 25°N	21	46	43	24
		(q) Interior Mysore			
75°E	South of 25°N	3	60	24	39
	At or north of 25°N	24	42	56	10
		(r) Telangana and Rayalaseema			
80°E	South of 25°N	7	57	32	32
	At or north of 25°N	23	42	52	13
		(s) Tamil Nadu			
77·5°E	South of 25°N	8	53	41	20
	At or north of 25°N	13	56	41	27

Madhya Maharashtra and Tamil Nadu, no significant association exists between axis location and non-abnormal rain. The common sub-divisions are Orissa and Tamil Nadu for which there is no significant association either between axis location and non-subnormal rain or between axis location and non-abnormal rainfall.

Sub-divisions in order of decreasing strength of association between axis location and non-subnormal rain are — (1) Gujarat-Saurashtra-Kutch (2) Konkan-Kanara (3) Bihar Plains (4) Kerala (5) East M. P. (6) West M. P. (7) Interior Mysore (8) West Rajasthan (9) West U. P., Haryana and Punjab (10) Gangetic West Bengal and Chota Nagpur (11) Assam and Sub-Himalayan West

TABLE 3

Sub-division	Association between axis location and non-subnormal rain		Association between axis location and non-abnormal rain	
	Chi-square	Relative PCC	Chi-square	Relative PCC
Konkan-Kanara	29·33*	0·68	28·14*	0·67
Kerala	23·60*	0·61	39·16*	0·79
Gujarat-Saurashtra-Kutch	36·66*	0·76	40·46*	0·80
West Rajasthan	17·83*	0·53	21·30*	0·58
East Rajasthan	12·12*	0·44	3·24	0·23
East Uttar Pradesh	5·30	0·29	15·88*	0·50
West Uttar Pradesh, Haryana and Punjab	17·09*	0·52	10·39	0·40
West Madhya Pradesh	20·58*	0·57	18·68*	0·54
East Madhya Pradesh	21·03*	0·58	22·33*	0·59
Coastal Andhra Pradesh	4·65	0·27	17·32*	0·52
Orissa	9·19	0·38	8·50	0·37
Gangetic West Bengal and Chota Nagpur	17·09*	0·52	12·64*	0·45
Bihar Plains	24·48*	0·62	26·90*	0·65
Assam and sub-Himalayan West Bengal	15·80*	0·50	30·35*	0·69
Vidarbha and Marathwada	14·16*	0·47	9·10	0·38
Madhya Maharashtra	12·77*	0·45	0·51	0·01
Interior Mysore	19·45*	0·55	29·90*	0·69
Telangana and Rayalaseema	10·80	0·41	12·78*	0·45
Tamil Nadu	0·78	0·01	0·66	0·01

*Denotes significant chi-square values, level of significance = 0·001

Bengal (12) Vidarbha-Marathwada (13) Madhya Maharashtra (14) East Rajasthan.

Sub-divisions in order of decreasing strength of association between axis location and non-abnormal rain are — (1) Gujarat-Saurashtra-Kutch (2) Kerala (3) Assam and Sub-Himalayan West Bengal (4) Interior Mysore (5) Konkan-Kanara (6) Bihar Plains (7) East M.P. (8) West Rajasthan (9) West M.P. (10) Coastal A.P. (11) East U.P. (12) Telangana and Rayalaseema (13) Gangetic West Bengal and Chota Nagpur.

It is seen that the best association exists for Gujarat-Saurashtra-Kutch which occupies first rank in both the lists arranged in order of decreasing association.

6. Results

(*i*) Broad-scale association exists between five-day mean monsoon trough axis location and pentad rainfall anomaly.

(*ii*) Axis location is unable to discriminate each of the three types of rainfall anomaly.

(*iii*) For the five sub-divisions, Kerala, Gujarat - Saurashtra - Kutch, Coastal Andhra Pradesh, Interior Mysore and Konkan-Kanara, axis location is able to discriminate abnormal rain. Under certain types of axis location the probability of occurrence of abnormal rain is ·6 to ·7. In conjunction with prognostic 5-day mean 700-mb contour chart, this association could be used for forecasting abnormal rain in these sub-divisions.

(*iv*) For most sub-divisions there is significant association between axis location and non-subnormal rain and also between axis location and non-abnormal rain. In conjunction with prognostic 5-day mean contour chart, this association could be used to forecast non-occurrence of subnormal rain and non-occurrence of abnormal rain. Such negative forecasts would be of use only to clients for whom occurrence of sub-normal and abnormal rain are critical conditions against which some precautionary steps can be taken.

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