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INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART IV

COMPREHENSIVE ARTICLES ON SELECTED TOPICS

18·3 . MONSOONS OF INDIA :

SOME ASPECTS OF THE " BREAK" IN THE INDIAN SOUTHWEST MONSOON DURING JULY AND AUGUST

BY

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18.3 Monsoons of India:

Some aspects of the "Break" in the Indian Southwest Monsoon during July and August

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1. Introduction

1.1 The Indian Southwest Monsoon sets in over the Kerala coast by about the beginning of June and the whole of India comes under its influence by about the first week of July. It starts withdrawing from northwest India from the beginning of September. During the course of these four months, the country gets its much needed rainfall on which depends the economy of the whole sub-continent. In this period, there are spells of strong monsoon activity due to disturbances like depressions that move across the country from east to west, resulting in heavy rains in and around the areas through which they traverse. There are also periods of lulls in the monsoon when the rainfall decreases over a major portion of the country and increases along the foot of the Himalayas. Severe floods occur in Assam and Bihar owing to the rivers rising in spate consequent upon the heavy rainfall in their catchment areas during these periods. The latter type of distribution of rainfall occurs during periods which have been described as "Breaks in the Monsoon", particularly when it lasts for more than two days.

1.2 This feature of the interruption in the monsoon rains has been found to be associated with a definite synoptic pattern in the surface and lower tropospheric levels. The term "break in the monsoon", has been in use in the meteorological literature of our country for a long time and the associated synoptic features on the surface chart are also well known, as will be seen from the following extracts from the Indian Daily Weather Reports for two typical dates:

30 August 1888	:	"The conditions are on the whole unchanged and the break in the rains is becoming more pronounced in Central and Western India and in the Punjab".
11 July 1913	:	"The trough of low pressure is now against the hills and westerly winds prevail over the greater part of the country".

1.3 The present report deals with certain aspects of the breaks in the Southwest Monsoon as noticed in the surface pressure patterns, rainfall distribution and lower, middle and upper tropospheric wind circulations. "Breaks in the Monsoon" has been the subject of investigation by various workers, particularly during the last two or three decades and considerable amount of literature exists on the subject. With the availability of extended area charts and better upper air observations since the early forties, a number of workers have studied the occurrence of break conditions in India in relation to changes in the broadscale circulation patterns in the middle and upper troposphere as well as surface synoptic conditions outside India. Their conclusions will be referred to in this report at the appropriate places.

1.4 The synoptic and upper air charts for a typical Break Monsoon day are shown in Fig. 1. It will be seen that on the surface chart the axis of the trough of low pressure which normally runs northwest-southeast from Punjab to the Head Bay of Bengal is very much towards the north. According to Malurkar (1950) the shift of the axis of the monsoon trough towards the foothills of the Himalayas occurs when a depression has moved to the Himalayas and broken up there. From this he deduces that one of the stationary low pressure areas in west China and Chinese Turkestan is concurrently more marked than usual, partly due to more southerly travel of the extra-tropical perturbations. When there is no low or depression in the Bay of Bengal, a western disturbance or westerly wave moving across the extreme north of the country and eastern Himalayas, also helps the monsoon trough to shift to the foot of the Himalayas (Kulkarni 1956, Mooley 1957). Under such situations, there is a general "Break" in the monsoon rains over the country.

1.5 Raman (1955) has pointed out some association between the breaks and the northward movement of typhoons in the southern Pacific. According to him, when a depression or typhoon in the China Seas moves to the north of Lat. 30°N the axis of the monsoon trough shifts to the Himalayas. The break does not occur if simultaneously there is a depression or typhoon in the China Seas to the south of Lat. 30°N, or unsettled conditions in the Bay of Bengal or a depression in the Indian area.

2. Data

As a first step, all the breaks that have occurred during the past 80-years (1888-1967) in the months of July and August were catalogued. For this purpose, situations when the trough of low pressure was not seen on the surface chart and the easterlies were practically absent in the lower tropospheric levels upto about 1.5 km a.s.l. were taken to be break situations. Till about 1932, the cataloguing has been done mainly with reference to the surface charts; subsequently, the upper wind charts have also been consulted as far as possible. Necessary reference has also been made to the departmental publications like the Indian Daily Weather Report, Weekly Weather Report, Monthly Weather Report, the Memorandum of Rainfall etc. which have been critically gone through so that there is not much divergence in the information so collected.

3. Periods of breaks*

3.1 During the 80-year period (1888-1967), there were as many as 113 breaks in the months of July and August (53 in July, 55 in August and 5 in July-August), their durations varying from 3 to 21 days. Breaks which lasted only for one or two days have not been taken into account. The breaks so catalogued are given in Table I.

Table I.

Particulars of breaks during the 80-year period 1888-1967

Year	Period of breaks		
	July	August	July-August
1888	..	14-16; 29-31	..
1889	23-27	29-31	..
1890	5-7; 25-28	24-26	..
1891	5-11	..	..
1892	..	..	..
1893	1-4; 21-29	11-16	..
1894	..	10-12; 24-26	31-2
1895	3-9	15-21	..
1896	5-8	..	..
1897	..	19-21	..
1898	..	..	..
1899	10-13; 24-31	3-9; 15-18	..
1900	20-24	22-24	..
1901	12-15	..	..
1902	..	9-15	..
1903	..	12-15	..
1904	12-14; 25-29	..	..
1905	15-18	6-14	..
1906	9-15	..	29-18
1907	..	..	..
1908	14-18	..	..
1909	19-22	4-19	..
1910	8-20; 24-27	15-17	..
1911	15-25	..	..
1912	..	13-23	..
1913	1-4; 10-12	12-20	..
1914	..	1-4; 10-13; 26-31 (extended upto 1 September)	..

Year	Period of breaks		
	July	August	July-August
1915	6-12	9-17	..
1916	..	9-11	..
1917	5-11; 25-27	..	..
1918	7-23	7-12	..
1919	15-18	..	..
1920	18-20	9-14; 18-20	..
1921	1-4	15-17; 27-30	..
1922	..	7-13	..
1923	..	..	..
1924	..	12-19	..
1925	22-24	9-12	..
1926	16-21	..	29-1
1927	..	1-5	..
1928	..	3-14	..
1929	..	..	..
1930	..	22-28	..
1931	..	..	..
1932	..	9-28	..
1933	..	13-20	..
1934	11-18	..	..
1935	..	8-10; 19-23	..
1936	..	..	..
1937	..	8-15	..
1938	..	..	..
1939	25-28	..	..
1940	..	..	..

Year	Period of breaks		
	July	August	July-August
1941	16-24	..	..
1942	..	7-10	..
1943	..	..	..
1944	..	..	..
1945	..	..	29-9
1946	9-11	29-31 (extended upto 3 September)	..
1947	6-9	3-10	..
1948	..	1-3	..
1949	19-23	21-25	..
1950	..	15-24	..
1951	1-3; 11-13; 15-17	24-29	..
1952	9-12	..	..
1953	24-26	..	..
1954	18-29	21-25	..
1955	22-29	..	..
1956	..	23-26	..
1957	27-31	5-7	..
1958	..	10-14	...
1959	..	16-18	..
1960	16-21	..	..
1961	..	..	..
1962	..	18-22	..
1963	10-13; 17-21	..	..
1964	14-18	..	28-3
1965	6-8	4-15	..
1966	2-11	23-27	..
1967	7-10	..	..

3.2 The distribution of the duration of these breaks is given in Table II.

Table II.

Frequencies of breaks of different durations

(Figures in brackets represent percentage frequencies)

Duration of breaks (No. of days)	July	August	July-August
3	12 (22)	17 (31)	1 (20)
4	16 (30)	8 (14)	1 (20)
5	8 (15)	7 (13)	..
6	2 (4)	5 (9)	..
7	5 (9)	5 (9)	1 (20)
8	3 (6)	4 (7)	..
9	2 (4)	3 (5)	..
10	1 (2)	1 (2)	..
11	1 (2)	1 (2)	..
12	1 (2)	2 (4)	1 (20)
13	1 (2)	..	..
14	..	..	..
15	..	..	..
16	..	1 (2)	..
17	1 (2)	..	..
18	..	..	..
19	..	..	..
20	..	1 (2)	..
21	..	..	1 (20)
Total.	53 (100)	55 (100)	5 (100)

3.3 It may be seen from Table II that 52% of the breaks in July last for 3-4 days while 45% of the breaks in August last for the same duration. Breaks of 5 days duration are 15% in July and 13% in August. Malurkar (1951) and Parthasarathy (1954) have mentioned that the breaks which occur in July are short-lived extending to three or four days, while in August and September the breaks may last longer. However, Table II shows that although shorter breaks of 3-4 days are slightly more frequent in July (which may not be statistically significant), longer breaks are equally frequent in both the months. The longest break was for 21-days, from 29 July to 18 August 1906. During the 80-year period, there was atleast one break every year in July or August except in the years 1892, 1898, 1907, 1923, 1929, 1931, 1936, 1938, 1940, 1943, 1944 and 1961. The total rainfall for the whole country during the 12 years when there were no breaks either in July or August was generally either normal or in excess. The years 1899 and 1951 were characterised by four breaks during these months, the total duration being 23 days in the former year and 15 days in the latter, However, the total maximum duration of 28 days of break was obtained in the year 1906 though there were only 2 breaks during this year. The total number of break days for the 80-year period is 306 for July and 356 for August. This works out to 3.8 and 4.5 days of break in the mean for July and August respectively.

3.4 According to Malurkar (1954), sometimes long breaks in the months of August and September may terminate the monsoon.

3.5 A distribution of the number of break days during each ten-day period of July and August is shown in Table III.

Table III.

	July			August		
	1-10	10-20	21-31	1-10	10-20	21-31
No. of break days	81	117	108	115	159	82

This distribution when statistically tested gives a χ^2 value of 43.4 which is highly significant even at 0.1% level. It would, therefore, appear that breaks are not uniformly distributed in the months of July and August. They are most frequent in the middle of August and least frequent in the beginning of July and end of August. About 65% of breaks in August had occurred between 7th and 17th.

3.6 To study the secular variation of the occurrence of breaks during the 80 year period, 10 year running means of the number of breaks were prepared (Fig. 2). The curve shows an interesting tendency for the number of breaks to decrease from the twenties of the present century, reaching a minimum in the forties and then again increase (Ten year running means of the number of days of break also show a similar distribution). Ten year running means of storms and depressions in the Indian area in July and August for the same period are also given in the figure for comparison. These two curves, in a general way, confirm the thesis that breaks and monsoon depressions are mutually exclusive.

4. Distribution of Surface Pressure during breaks

4.1 To get an idea of the distribution of pressure departure from normal during breaks, 0300 GMT surface charts for the period 1954-1967 in respect of 11 breaks (Totalling 72 days) were examined and the mean pressure departure chart at 0300 GMT during breaks (Fig.3) was prepared.

4.2 Fig. 3 shows that the highest positive pressure departures of the order of 2-3 mb occur over the area comprising of Gujarat Region, Madhya Pradesh, Orissa and the adjoining Central and Northwest Bay of Bengal. The positive pressure departures over this area vary from 2 to 4 mb to as much as 8 mb on individual occasions. The pressure departures are negative over Punjab, Himachal Pradesh and along the foot of the Himalayas. Another area of negative pressure departure is observed over the extreme south of the Peninsula. Negative pressure departures of the order of 1-2 mb, sometimes even becoming as much as 4 mb are occasionally observed over this area, when mid-tropospheric vortices move from east to west across the Peninsula (Koteswaram 1950). Although the pressure departures are not shown over the Arabian Sea in Fig. 3, Dallas (1900) has pointed out that a persistent abnormally high barometric pressure prevailed over the Arabian Sea during the monsoon months of 1899 which was a year of the failure of the Southwest Monsoon rains over India.

4.3 Apart from the shift of the seasonal trough towards the foot-hills of the Himalayas, the other features of the surface isobaric pattern during the break are as follows:

(a) Pressure gradient is weak over the country and the Indian Seas except over Gujarat, Rajasthan and the adjoining areas. The pressure difference between Dahanu and Trivandrum is, on an average, only about 3 mb during the break conditions (on individual occasions reaching as low as 1 mb), whereas the normal pressure difference between these two stations in the middle of July is about 7 mb.

(b) Isobars droop southwards on either side of the west coast of the Indian Peninsula (i.e. a ridge along the coast) which Malurkar (1950) considers as the effect of the Western Ghats. While discussing the chart for a typical day in August 1899 during the disastrous break in the rains, Simpson (1921) pointed out how the surface synoptic conditions over India and the adjoining sea areas during the break monsoon are similar to those in May. According to him "one of the most frequent causes of breaks in the monsoon is the establishment of an area of relatively high pressure over Western India".

5. Distribution of Rainfall during breaks

5.1 It is a well-known fact that during active monsoon conditions, the rainfall is well-distributed over the country. During these periods, with the axis of the monsoon trough in its normal position, viz. from Punjab to the Head Bay of Bengal, well-distributed rainfall occurs all over the country, except in the eastern parts of the south Peninsula. However, during breaks the rainfall pattern undergoes a striking change. The rainfall becomes heavy along the Himalayas, with heavier falls along the eastern Himalayas (North Assam, sub-Himalayan West Bengal and northern parts of Bihar Plains). The rainfall along the west coast continues, but with much less intensity. Rainfall increases in the southeastern parts of the Peninsula mainly due to thunderstorm activity. The rainfall almost ceases over the rest of the country, particularly the central parts. This qualitative picture of rainfall distribution was well-known even as early as 1889. Such a distribution has been described in the Indian Daily Weather Report of 31 August, 1889 as follows:

> "The chief feature at present is the great weakness of the Bombay current. A general break in the rains obtains in western India. Under such conditions southern India usually obtains local showers."

On 4 July 1895, the Indian Daily Weather Report reads

> "As is ordinary the case when a break in the rains occurs in northwestern India, there has been more rain than of late in Madras".

5.2 To get a quantitative idea of the distribution of the rainfall during breaks all over India 12 periods of breaks were selected over the 17-year period 1951-1967 (5 in July, 6 in August and 1 in July-August). These are:

1.	24-29 August 1951	...	6 days
2.	18-29 July 1954	...	12 days
3.	21-25 August 1954	...	5 days
4.	22-29 July 1955	...	8 days
5.	23-26 August 1956	...	4 days
6.	18-22 August 1962	...	5 days
7.	17-21 July 1963	...	5 days
8.	28-July - 3 August 1964	...	7 days
9.	4 -15 August 1965	...	12 days
10.	2 -11 July 1966	...	10 days
11.	23-27 August 1966	...	5 days
12.	7-10 July 1967	...	4 days
	Total	...	83 days

Since the intention of the study was to compare the actual rainfall during breaks with the normal, 265 stations having rainfall normals spread over the whole of India were selected (Arabian Sea Islands and the Bay Islands have not been included in this study). The departures from normal of rainfall for each of the 12 break periods in respect of each meteorological sub-division are given in Table IV*. The meteorological sub-divisions for the purpose of this study are the same as those that existed in 1967 so that homogeneity could be obtained. The mean percentage departures from normal in respect of all the above 12 breaks are also shown in Fig. 4 for ready reference.

5.3 An examination of Table IV will immediately reveal that the meteorological sub-divisions that get above normal rainfall (i.e. greater than +19%) in ten or more occasions out of twelve, are North Assam, sub-Himalayan West Bengal and Madras State. In the mean Assam, sub-Himalayan West Bengal, Bihar Plains, Rayalaseema and Madras State get above normal rainfall during breaks. The sub-divisions that get below normal rainfall (i.e. less than -19%) on ten or more occasions out of twelve are Orissa, Bihar Plateau, Jammu and Kashmir, Rajasthan, Madhya Pradesh, Vidharba, Gujarat State, Madhya Maharashtra and Telangana.

5.4 In the south, the meteorological sub-division that gets above normal rainfall, ranging from +40% to +303%, is Madras State on 83% of occasions. The other sub-division in the Peninsula which gets above normal rainfall on 42% of occasions, ranging from +64% to +357%, is Rayalaseema. The west coast (Konkan, coastal Mysore and Kerala) gets below normal rainfall on a majority of occasions (Konkan 75%, coastal Mysore 58% and Kerala 75%)

* See Page No. 7 for Table IV.

5.5 Though rainfall along the foot hills of the Himalayas during break period is very much above normal, day-to-day rainfall can vary appreciably. This variation in day-to-day rainfall seems to be influenced by the eastward movement of low pressure waves.

6. Distribution of rainy days during breaks

6.1 The percentage number of rainy days (rainfall of 2.5 mms and above per day) at all the 265 stations during all the twelve break periods referred to in para 5.2, was worked out and plotted. This is shown in Fig. 5. From this it will be seen that extreme north Assam and sub-Himalayan West Bengal get rainfall on more than 90% of the break days. There is also a secondary maximum (80 to 97%) of rainy days over south Assam. The western Himalayas get rainfall only on 46-73% of the days of breaks. Coastal Mysore and major portion of Konkan and Kerala get rainfall on 47-77% of the days of breaks.

6.2 As we have seen earlier (vide Fig. 4), the meteorological sub-divisions that get "above normal" rainfall during breaks are Assam, sub-Himalayan West Bengal, Bihar Plains, Rayalaseema and Madras State. Since the percentage number of rainy days in respect of each station has already been computed (vide Fig. 5), it was also thought worthwhile to compare this distribution with the mean number of rainy days (during July and August) in respect of all the 265 stations, so that one can get readily a clear picture of the excess or deficient number of rainy days during breaks as compared with the means for both these months. Fig. 6 gives this distribution. It will be clear from this that the excess number of rainy days (as compared with the normal) occurs in Madras State, Rayalaseema (excluding its extreme northern portion), parts of Interior Mysore, extreme south coastal Andhra Pradesh, Assam, sub-Himalayan West Bengal, most parts of Bihar Plains and extreme northeast Uttar Pradesh. It is interesting to note that the central parts of Madras State (especially Tiruchchirappalli, Kodaikanal and Madurai) get about 21-23% more rainy days (during July and August).

Table IV

Percentage Departure (from normal) of rainfall in the Meteorological Sub-Divisions of India during twelve break periods

Meteorological Sub-Division	Break Period: 24 – 29 August 1951	18 – 29 July 1954	21 – 25 August 1954	22 – 29 July 1955	23 – 26 August 1956	18 – 22 August 1962	17 – 21 July 1963	28 July –3 Aug. 1964	4 – 15 August 1965	2 – 11 July 1966	23 – 27 August 1966	7 – 10 July 1967	Mean Dep.
North Assam	+ 81	+ 65	+ 62	+ 83	+ 60	+ 166	+ 9	+ 104	+ 27	+ 22	+ 98	+ 105	+ 73
South Assam	+ 308	+ 150	+ 246	+ 118	− 15	+ 166	− 44	+ 127	+ 40	− 1	+ 211	+ 170	+ 123
Sub-Himalayan West Bengal	+ 97	+ 76	+ 3	+ 123	+ 61	+ 125	+ 47	+ 109	+ 64	+ 28	+ 265	+ 230	+ 102
Gangetic West Bengal	− 45	− 44	− 47	+ 19	+ 28	+ 19	− 2	+ 9	− 40	− 51	− 43	− 11	− 17
Orissa	− 54	− 70	− 65	− 63	− 5	− 36	− 47	− 51	− 37	− 74	− 73	− 31	− 51
Bihar Plateau	− 75	− 49	− 54	− 42	− 5	+ 15	− 37	− 54	− 69	− 73	− 40	− 49	− 44
Bihar Plains	− 15	+ 54	− 14	+ 28	+ 126	+ 211	+ 35	+ 21	− 33	− 52	+ 35	+ 49	+ 37
East Uttar Pradesh	− 65	+ 33	− 67	− 28	0	+ 246	− 32	+ 28	− 85	− 89	− 55	− 38	− 13
West Uttar Pradesh: Plains	− 88	+ 9	− 85	− 93	+ 53	− 5	− 43	− 10	− 85	− 97	− 54	− 37	− 45
Hills	− 60	+ 23	+ 87	− 74	− 31	+ 52	+ 2	− 46	− 61	− 46	+ 27	+ 105	− 2
Punjab	− 75	+ 5	− 98	− 91	+ 35	+ 169	− 81	− 1	− 63	− 63	− 98	+ 29	− 28
Himachal Pradesh	+ 1	− 17	+ 22	− 56	− 36	− 31	+ 117	− 57	− 79	− 78	− 63	− 32	− 26
Jammu and Kashmir	− 26	− 80	− 98	− 75	− 33	− 35	− 13	− 28	− 56	− 32	− 92	− 95	− 55
West Rajasthan	− 100	− 55	− 100	− 100	− 97	0	− 90	− 92	− 99	− 50	− 100	− 77	− 80
East Rajasthan	− 100	− 77	− 90	− 98	− 85	− 46	− 66	− 81	− 99	− 92	− 100	− 75	− 84
West Madhya Pradesh	− 95	− 56	− 91	− 59	− 92	− 63	− 67	− 81	− 80	− 92	− 92	− 88	− 80
East Madhya Pradesh	− 89	− 39	− 41	− 39	− 80	− 51	− 39	− 75	− 73	− 91	− 76	− 74	− 64
Vidarbha	− 55	− 51	− 89	− 51	− 94	− 62	− 95	− 69	− 70	− 91	− 98	− 96	− 77
Gujarat Region	− 95	− 57	− 84	− 81	− 44	− 34	− 77	− 65	− 97	− 92	− 100	− 91	− 76
Saurashtra and Kutch	− 99	− 77	− 94	− 79	− 97	− 77	− 80	− 76	− 96	− 82	− 100	− 69	− 85
Konkan	− 65	− 18	− 31	+ 108	− 76	− 58	− 54	+ 3	− 70	− 87	− 73	− 56	− 40
Madhya Maharashtra	− 65	− 41	− 67	− 53	− 56	− 53	− 79	− 44	− 55	− 56	− 70	− 68	− 59
Marathwada	− 100	+ 4	− 99	+ 55	− 86	+ 11	− 89	+ 1	+ 13	− 43	− 100	− 100	− 44
Coastal Andhra Pradesh	+ 3	+ 31	+ 26	− 3	+ 11	− 14	− 5	− 46	− 57	− 65	− 6	− 90	− 18
Telangana	− 47	− 7	− 93	− 55	− 83	− 36	− 62	− 43	− 79	− 88	− 94	− 97	− 65
Rayalaseema	+ 13	+ 357	− 69	+ 13	− 77	+ 13	+ 126	+ 243	+ 85	+ 64	− 95	− 77	+ 50
Madras State	+ 59	+ 123	+ 40	− 44	+ 138	+ 94	+ 71	+ 303	+ 128	+ 121	+ 108	− 11	+ 94
Coastal Mysore	− 88	+ 19	− 91	+ 74	− 87	+ 54	− 61	+ 78	− 72	− 60	− 84	− 12	− 27
North Interior Mysore	− 53	+ 42	− 51	− 13	− 85	− 21	− 88	+ 140	− 15	− 44	− 100	− 73	− 30
South Interior Mysore	− 66	− [illegible]9	− 41	− 50	− 97	− 63	− 66	+ 100	− 1	− 25	− 95	− 55	− 39
Kerala	+ 18	− 29	− 95	− 17	− 88	− 81	− 76	+ 44	− 24	− 31	− 71	− 44	− 41

7. Spatial Distribution of Rainfall During Breaks

7.1 The spatial distribution of rainfall in the various meteorological sub-divisions of the country in terms of the different categories (widespread: 76 - 100% of the stations, fairly widespread: 51 - 75%, scattered 26 - 50% and isolated: 1 - 25% of stations, having 2.5 mm or more rainfall daily) was worked out in respect of all the break periods mentioned in para 5.2. These are presented in Table V.

Table V

Mean Spatial Distribution of Rainfall during Breaks (expressed as percentage)

Meteorological Sub-Division	Category of Distribution				
	Wide-spread	Fairly Wide spread	Scat-tered	Iso-lated	Dry
North Assam	55	28	13	4	-
South Assam	62	24	12	2	-
Sub-Himalayan West Bengal	87	9	3	1	-
Gangetic West Bengal	13	17	22	42	6
Orissa	1	19	31	43	6
Bihar Plateau	17	11	36	24	12
Bihar Plains	27	19	25	18	11
East Uttar Pradesh	9	17	24	30	20
West Uttar Pradesh: Hills	17	28	35	-	20
West Uttar Pradesh: Plains	10	10	19	38	23
Punjab	4	7	17	27	45
Himachal Pradesh	29	18	15	19	19
Jammu and Kashmir	-	5	11	22	62
West Rajasthan	-	-	8	7	85
East Rajasthan	1	1	12	26	60
West Madhya Pradesh	1	5	21	50	23
East Madhya Pradesh	6	15	39	26	14
Vidarbha	4	6	10	42	38
Gujarat Region	-	2	34	16	48
Saurashtra and Kutch	-	-	8	35	57
Konkan	41	17	27	7	8
Madhya Maharashtra	4	6	28	56	6
Marathwada	6	-	30	-	64
Coastal Andhra Pradesh	-	9	30	42	19
Telangana	2	10	25	21	42
Rayalaseema	4	13	16	25	42
Madras State	4	7	45	36	8
Coastal Mysore	54	12	16	-	18
North Interior Mysore	5	4	28	37	26
South Interior Mysore	6	19	31	21	23
Kerala	25	16	21	15	23

7.2 This table shows that Assam and sub-Himalayan West Bengal get widespread to fairly widespread rainfall on 83% - 96% of the break days. The rainfall activity along the west coast does not very much diminish spatially, even though the rainfall amounts are much lower. Konkan and coastal Mysore get fairly widespread to widespread rainfall on 58% - 66% of the days while Kerala gets such a distribution on 41% of the days only. It is interesting to see that Madras State gets scattered rainfall on 45% of the days, fairly widespread rainfall on 7% of the days and widespread rainfall on 4% of the days. The number of days when this sub-division gets no rainfall during break periods (i.e. occasions when rainfall was less than 2.5 mm at all the stations) is only 8% whereas even coastal Mysore (which gets higher percentage number of rainy days than Madras State during breaks - vide Fig. 5) gets as much as 18% of dry days. The maximum number of rainless days occurs in West Rajasthan (85%) with Marathwada coming next (64%), followed by Jammu and Kashmir (62%).

7.3 Out of the meteorological sub-divisions that get a large excess of rainfall during the break periods, Assam and Sub-Himalayan West Bengal get fairly widespread to widespread rainfall on most days, whereas in Madras State the spatial distribution is only scattered or isolated. Similarly heavy to very heavy falls are quite common in Assam, sub-Himalayan West Bengal and Bihar Plains whereas Rayalaseema and Madras State generally get only light to moderate precipitation; heavy falls (i.e. falls greater than 7 cm in 24 hrs) are rare. During the 83 days of break in 1951 to 1967, there were only four to five occasions when rainfall exceeding 7 cm was reported in Rayalaseema and Madras State; on such occasions the heavy rainfall was also generally isolated.

8. Upper Wind Flow Patterns

8.1 In order to study the changes that take place in the lower, middle and upper tropospheric levels during the break periods, 0000 GMT upper winds at 850, 700, 500, 300, 200, 150 and 100 mb levels during seven break periods were examined and mean charts were prepared for the above seven levels in respect of each break period. The seven break periods selected are:

1. 18 - 22 August 1962
2. 17 - 21 July 1963
3. 28 July - 3 August 1964
4. 4 - 15 August 1965
5. 2 - 11 July 1966
6. 23 - 27 August 1966 and
7. 7 - 10 July 1967

Total No. of days = 48

Since the flow pattern did not vary much from one break situation to another, a mean picture in respect of all the breaks was constructed for these levels. The mean flow patterns are given in Fig. 7(a to g). Similar mean upper air charts were also prepared for the following five spells of active monsoon, for purposes of comparison with the charts of break periods:

1. 16 - 24 July 1961
2. 8 - 15 July 1962
3. 28 July to 1 August 1963 — Total No. of days = 42.
4. 15 - 22 August 1963 and
5. 2 - 13 July 1964

Of these five spells, there were no monsoon depressions during the two spells in 1963. These charts are given in Fig. 8(a to g). The results of comparison of both the mean patterns are discussed in ensuing paragraphs.

8.2 Lower Troposphere

(i) 850 mb (1.5 km) - Figs. 7(a) and 8(a)

In the mean, the axis of the monsoon trough at this level runs through Bikaner, Jabalpur, Balasore and thence southeastwards into the Head Bay of Bengal during active monsoon periods. Strong westerlies appear over Peninsular India on many days at this level in July (Joseph and Raman, 1966). In the mean, the westerly maximum (30 kts) is near about the latitude of 15°N. During break periods, the axis of the monsoon trough is completely absent over the Gangetic plains. A strong ridge of high pressure is observed along Long. 75°E between Lat. 15°N and 30°N. A trough line runs from Lat. 5°N to Lat. 15°N over the Bay of Bengal roughly along Long. 88°E. The westerlies over the Peninsula are comparatively weaker and westerlies of speed 20 kt are observed over the Laccadives, south Kerala and the area extending from Gujarat and south Rajasthan to Bihar Plateau.

(ii) 700 mb (3.0 km) - Figs. 7(b) and 8(b)

1. During active monsoon periods the axis of the monsoon trough at this level runs from Baroda to Ambikapur. There is a closed cyclonic circulation over north Orissa and adjoining parts of Gangetic West Bengal and Bihar Plateau and another over Saurashtra and Kutch and adjoining parts of south Gujarat region. During periods of breaks, the axis of the monsoon trough is completely absent as in the lower levels. The winds over most parts of the country are westerlies to northwesterlies and weak. A feeble trough is seen over south Interior Mysore and adjoining parts of coastal Mysore and of Kerala. A ridge from northwest protrudes into southwest Rajasthan.

2. During the breaks there is a total absence of low level easterly winds over Uttar Pradesh, Bihar and Assam in the surface and lower tropospheric levels and southwesterlies and westerlies prevail upto the foot hills of the Himalayas. When the break is prolonged, these westerlies over northern India become dry similar in character to the winds of the hot weather season. Over the south Peninsula the westerlies are not only weak during the break, but their depth also decreases considerably and on some occasions weak easterlies prevail over Madras even at 3.0 km (Ananthakrishnan and Ramakrishnan 1964).

8.3 Mid-Troposphere

500 mb (5.4 km) - Figs. 7(c) and 8(c)

The position of the monsoon trough at this level is round about Lat. 20°N during active monsoon periods. The cyclonic circulation over north Orissa and neighbourhood observed at 700 mb level now lies over the north Bay of Bengal at this level. The other cyclonic circulation over Saurashtra and Kutch and neighbourhood lies over south Gujarat State and adjoining parts of Konkan and of north Madhya Maharashtra. During break periods, the axis of the monsoon trough is completely absent at this level also and the whole country north of about Lat. 16°N is under the influence of westerlies. The ridge from northwest which was seen only over southwest Rajasthan at 700 mb level, protrudes considerably eastwards at 500 mb level and covers the whole of north Peninsula, Gujarat State and most of Madhya Pradesh. There is also another anticyclone over south Bay of Bengal and south Andaman Sea. In the mean the winds over Madras and Port Blair are very light. However, during some breaks this anticyclone shifts northwards and a broad easterly flow prevails over south Bay and Ceylon. A trough line runs from Darjeeling to east of Vishakhapatnam. This mean pattern is somewhat similar to the mean 500 mb level flow pattern in May especially north of Lat. 17°N. Some of these features of the 500 mb level circulation have been discussed in greater detail by Pisharoty and Asnani (1958) and Dixit and Jones (1965). On a few individual occasions during break periods, well-marked troughs in the westerlies are also seen over northwest India and adjoining west Pakistan; this will be discussed in Sec. 10.

8.4 Upper Troposphere

(i) 300 mb (9.0 km) - Figs. 7(d) and 8(d)

1. During periods of active monsoon conditions the sub-tropical ridge at this

level runs roughly along Lat. 30°N; there is one cell over Tibet and another over West Pakistan. However, during breaks there is a definite displacement of this ridge-line southwards to about Lat. 26-27°N. Delhi winds which are southeasterlies at this level during active monsoon periods, become westerlies during breaks confirming the shift of the ridge line to the south. The anticyclonic cell over West Pakistan during active monsoon period pushes eastwards upto east Uttar Pradesh during the break period. The other cell is over Assam, West Bengal and East Pakistan. Thus there is a general extension of the anticyclonic circulation southeastwards to western India between 700 mb and 300 mb levels, during the break.

(ii) 200 mb (12.0 km) - Figs.7(e) and 8(e)

1. Ramaswamy (1962) who studied the break in the Indian Southwest Monsoon as a phenomenon of interaction between the easterly and the subtropical westerly jet streams, has concluded that during break situations, there is a secondary westerly jet maximum round about Lat. 32°N or in any case at 36°N, there is a secondary easterly jet maximum near about Lat. 20°N and that the westerly jet stream makes a very definite approach towards the easterly jet stream over the Peninsular India during breaks in the monsoon. He has also concluded (Ramaswamy 1958) that the upper tropospheric easterlies are replaced by westerlies upto 200 mb or 150 mb level over northwest India and upto 350 mb level over northeast India during weak monsoon, and, therefore, the westerly circulation predominates under these conditions at least upto 350 mb level. Koteswaram (1958, 1963), on the other hand, pointed out that the easterlies continue over India in the upper levels even during breaks and the easterly jet shifts northwards indicating an increase instead of decrease in the upper easterly circulation. Ramamurthy, Keshavamurthy and Jambunathan (1965) found that the upper tropospheric west wind maximum is located more or less over the same region (i.e. along Lat. 40°N) at 200 mb level with practically the same speed during strong and weak monsoon conditions.

2. An examination of the seven mean wind charts during the individual break periods and the combined mean of all the break periods does not lead one to any definite conclusion regarding the secondary westerly jet maximum over north Indian latitudes (c.f. Ramaswamy, 1962) though wind speeds of the order of 50-55 knots over Srinagar in the levels 300 to 150 mb are recorded on individual occasions and in the mean one gets only a wind speed of 43 knots at 200 mb and 42 knots at 150 mb levels. Stronger winds are noticed much further north of Srinagar in the working charts for some of the years. However, there is little doubt that strong westerlies do penetrate into the Indo-Pakistan latitudes during break periods as can be seen from the mean time-section for break periods (around the mean meridian 78°E) reproduced in Fig. 9. An examination of all the mean charts of the seven breaks and also the individual day-to-day winds at 200 mb level shows some interesting features, if one compares the mean winds during breaks at Srinagar (representing the regime of westerlies) and also the winds at Visakhapatnam, Nagpur and Bombay (representing the regime of easterlies). Generally, when the winds at 200 mb level over Srinagar are stronger, the easterly winds at the same level at a lower latitude are weaker and whenever Srinagar winds are weaker, the easterlies at lower latitudes are stronger. It is also seen that the strong westerlies are confined to Srinagar only and that too between 200 mb and 150 mb levels and are seen at 300 mb only on a few occasions. The westerlies are weaker at 100 mb.

3. During the break periods, there is a tendency for the upper tropospheric easterlies to start strengthening from 200 mb itself, whereas during spells of active monsoon, they start strengthening from 150 mb only.

4. The sub-tropical ridge which runs around Lat. 30°N at this level during active monsoon periods, shifts slightly southwards during breaks and runs roughly about Lat. 27-28° over the country.

(iii) 150 mb (14.1 km) - Figs. 7(f) and 8(f)

1. The strongest easterlies are near Lat. 8°N during active monsoon periods; whereas during break periods, the easterlies are nearly of same strength over the whole of south Peninsula. During active monsoon periods, the sub-tropical ridge line at this level runs roughly along Lat. 30°N. During breaks, this ridge line runs slightly south of Lat. 30°N over the country. During active monsoon periods, easterlies of the order of 50 kt are seen upto about Lat.19°N whereas during breaks, they appear to extend somewhat northwards.

2. Fig. 10 shows a time-section of zonal winds at 150 mb level across India between 16th and 31st August 1966. There was a break between 23 and 27th August 1966. The following changes in the wind field with the setting in of the break, may be noted:-

(a) strengthening of the easterlies in the south Peninsula.

(b) strong easterlies extending to more northerly latitudes (note the run of the 40 kt, 60 kt and 80 kt isotachs)

(c) extension of westerlies to more southerly latitudes over extreme north of the country.

(iv) 100 mb (16.2 km) - Figs. 7(g) and 8(g)

1. During active monsoon spells as well as during breaks, the subtropical ridge line runs roughly along Lat. 30°N at this level. During active monsoon spells, the strongest easterlies lie near about Lat. 13°N with a mean speed of 65 kt in the core. During break periods, the easterly maximum shifts to a more northerly latitude and lies near about Lat. 15°N, and the speed in the core reaches 80 kt. This fully agrees with the views of Koteswaram (1958, 1963) and Srinivasan (1960). While during active monsoon spells the winds of Ahmedabad at this level are somewhat stronger than those of Bombay, such a tendency is not noticed during break periods.

2. A comparison of the upper tropospheric easterlies during active and break monsoon periods will immediately reveal that they are comparatively stronger during break periods (see also Ananthakrishnan and Ramakrishnan, 1964). This does not support the observations made by Parthasarathy (1958) that the "easterlies at 8 to 13 km get disorganised and remain so as long as the break situation lasts".

8.5 Meridional Circulation

From the mean upper winds discussed in the preceding paragraphs, meridional sections for the break and active monsoon periods were constructed (Fig.11). The cross-section for the active monsoon is similar to the mean cross-section for July (Rao, 1962) except for the absence of the southerlies in the upper troposphere over the extreme north of the country. The meridional section for the break monsoon shows a striking contrast from the section for active monsoon. The monsoon cell or the reverse Hadley Cell (with southerlies in the lower troposphere and northerlies in the upper troposphere) dominates the entire Indian latitudes in the active monsoon; whereas in the break, this cell is confined to the south of Lat. 18°N, while the direct Hadley type circulation prevails over the northern India.

9. Movement of low Pressure Waves from East to West Across the South Bay of Bengal During Breaks

Koteswaram (1950) has drawn attention to westward moving 'lows' at low latitudes during the breaks in the southwest monsoon. These lows are mostly seen at 700 mb level and move from south Andaman sea to southeast Arabian Sea. Their movement into higher latitudes, eg. central Bay of Bengal and central Arabian sea creates conditions favourable for the strengthening of the monsoon from the south. The charts for the 20-year period 1948-1967 were looked into for the purpose of tracing such "lows" during the relevant break periods. Out of the 20-year charts that were examined (during which period, 19 years had breaks), it was found that at least in 11 years these upper air lows (very often termed as upper air troughs or low pressure waves) moved across the Bay of Bengal. On these eleven occasions the break commenced generally within two days (earlier or later) of the date when eastward moving 'low' was first observed. These lows could be broadly grouped as follows:

(a) Those that moved east to west from southeast Bay of Bengal to Kerala-Mysore coasts and became unimportant (August 1948, August 1950, July 1953 and July 1955). See Fig. 12 for one such situation in July 1953. The low could be traced first on 22nd July and the break conditions prevailed between 22 and 26th and monsoon revived along west coast on 26th.

(b) Those that moved east to west from the southeast Bay of Bengal to Kerala coast and then moved northnorthwestwards to Lat. 20°N occasionally appearing at the lower tropospheric levels also (August 1949, July 1954, July 1960, July-August 1964, August 1965 and July 1966). See Fig. 13 for one such situation in August 1965. The low was first noticed on 7th August; the break conditions prevailed between 4 and 15 August and monsoon revived along the west coast on 16th.

(c) Those that moved east to west from the southeast Bay of Bengal, then moved along the east coast of India to central and adjoining north Bay of Bengal where they became unimportant (July 1952). See Fig. 14. The low was first noticed on 8 July; the break commenced on 9th and monsoon revived on 12th.

For the sake of brevity, only four selected days' charts for each type of situation are shown.

10. Movement of Disturbances in Westerlies During the Break Conditions

10.1 A number of workers have drawn attention to movement of disturbances in the westerlies across the Himalayas and Tibet leading to break monsoon conditions. Some workers have traced these systems even on the surface chart by following 24 hrs pressure changes. Ramaswamy (1962, 1965) has described the features of the westerly circulation at 500 mb and 300 mb levels during break conditions as follows:

During break conditions pronounced low index circulation prevails in the middle latitude westerlies north of the Himalayas. This leads to large amplitude troughs in westerlies extending to latitudes south of 40°N, and protruding into Indo-Pakistan area at 500 mb level and aloft; they also get retarded and elongated further during their eastward movement across the Tibetan Plateau which is a region of weak basic current. The Tibetan high at the 500 mb level is sometimes destroyed completely by the invading large amplitude trough. The high persists in the higher levels although in a weaker state. The troughs move relatively slowly and are highly diffluent with wind speeds of jet intensity upstream at 300 mb level and aloft, rapidly decreasing downstream. They contribute to upper divergence and cause heavy rainfall over and near the Himalayas. The distribution of rainfall will naturally depend upon the configuration of individual troughs and their locations and the availability of monsoon air in the lower troposphere underneath such troughs. In association with these eastward moving troughs the anticyclone over Iran and Arabia extends into northwest and central India and the northern parts of Indian Peninsula at 500 mb level and aloft. This results in dry weather over the greater part of these regions. When the break lasts for a week or more the large amplitude trough remains more or less quasi-stationary over north India with the Iranian high extending into India south of Lat. 30°N.

10.2 Pisharoty and Desai (1956) also noticed that passage of westerly waves across the Tibetan Plateau and the adjoining Himalayas in quick succession leads to break monsoon conditions. They found the mean monthly upper air contours for 500 mb level for July 1954, showed a 'low' towards the north of the eastern Himalayan range, instead of the high shown by the normal charts and associated this feature in the upper air with the unprecedented floods in Assam, north Bengal and Bihar during that month.

10.3 An example of the passage of a trough in the middle latitude westerlies across the extreme north of India and Tibet during a break period (7 to 10 July 1967) is illustrated in Fig. 15 by a sequence of 300 mb charts. On the 4th a well marked trough was extending from northwest Russia to northeast Iran, and a closed 'low' had formed in the trough to the north of Aral Sea. During the next 24 hrs the trough moved into West Pakistan and the extreme north of India. On the 7th the southern portion of the trough was cut off from the northern half and extended from 50°N, 70°E to Nepal. It moved eastwards rather slowly during the next 3 days and on 10th it was extending from 53°N 75°E to Eastern Himalayas. Subsequently the trough flattened out. An interesting feature of the trough was the strong northwesterlies reaching 90-100 kts at 300 mb level in the western portion of the trough (a feature which has already been pointed out by Ramaswamy). Concurrent with the passage of the trough, the monsoon trough over India shifted to foot hills of Himalayas on 7th (the day on which the Westerly trough came over Himalayas) and began to shift southwards on 11th, 24 hours after the large amplitude westerly trough flattened out.

11. Conclusions

11.1 The breaks in the Indian Southwest Monsoon occur almost every year. Their duration can extend to 21 days in the extreme. During these periods, the axis of the monsoon trough shifts to foot-hills of Himalayas and the pressures over most parts of the country are above normal. The rainfall pattern undergoes a striking change; the eastern and Nepal Himalayas and the southeastern parts of the Peninsula get abnormal rainfall. The strong westerlies in the lower troposphere shift very much to the north and are to be found north of Lat. 20°N. "Lows" in the mid-tropospheric levels move westwards in the southern latitudes in the Bay of Bengal, some of them crossing the south Peninsula into Laccadives area. Strong westerlies penetrate into the extreme northern parts of India and West Pakistan between 300 mb and 150 mb levels and large amplitude troughs in westerlies move across the Himalayas and Tibet. The upper tropospheric easterly jet shifts slightly to the north with its axis around Lat. 15°N. The sub-tropical ridge in the upper tropospheric levels seems to shift southwards between 300 and 150 mb levels.

11.2 The break monsoon usually terminates with the formation of a low or a depression in the north Bay of Bengal when the axis of the monsoon trough swings southwards to the normal position. The low is sometimes seen only in the lower tropospheric levels and not at the sea level. An examination of the departmental weather reports showed that 45% to 50% of the breaks/were terminated by such perturbations. It is also believed that movement of troughs in upper easterlies over the north Bay of Bengal may cause the shift of the axis of the monsoon trough southwards from the foot hills (Srinivasan, 1960).

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1. Proceedings of the Symposium on Meteorological and Hydrological Aspects of Floods and Droughts in India, 18-20 April 1958, India Met. Dept., New Delhi.

2. Proceedings of the Symposium on Hydro-meteorology of India with special reference to Flood Forecasting and Warning. Indian Journal of Meteorology and Geophysics, April 1966 Vol. XVII Special Number.

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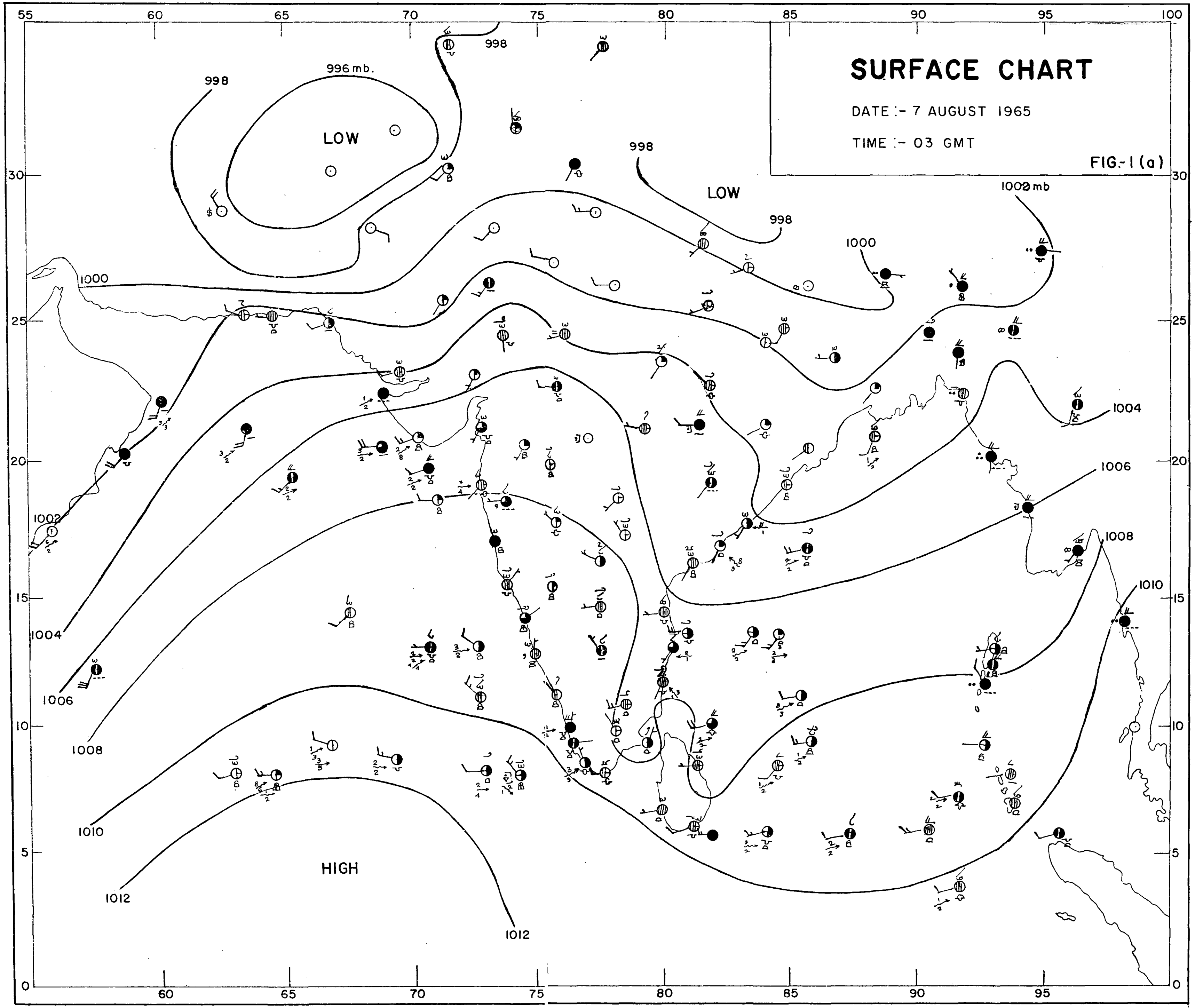

SURFACE CHART
DATE :- 7 AUGUST 1965
TIME :- 03 GMT
FIG.- I (a)
LOW
996 mb.
998
1000
1002
1002 mb
1004
1006
1008
1010
1012
HIGH
55
60
65
70
75
80
85
90
95
100
0
5
10
15
20
25
30

FIG. 1(b)

DATE :- 7 AUGUST 1965 TIME :- 03 GMT

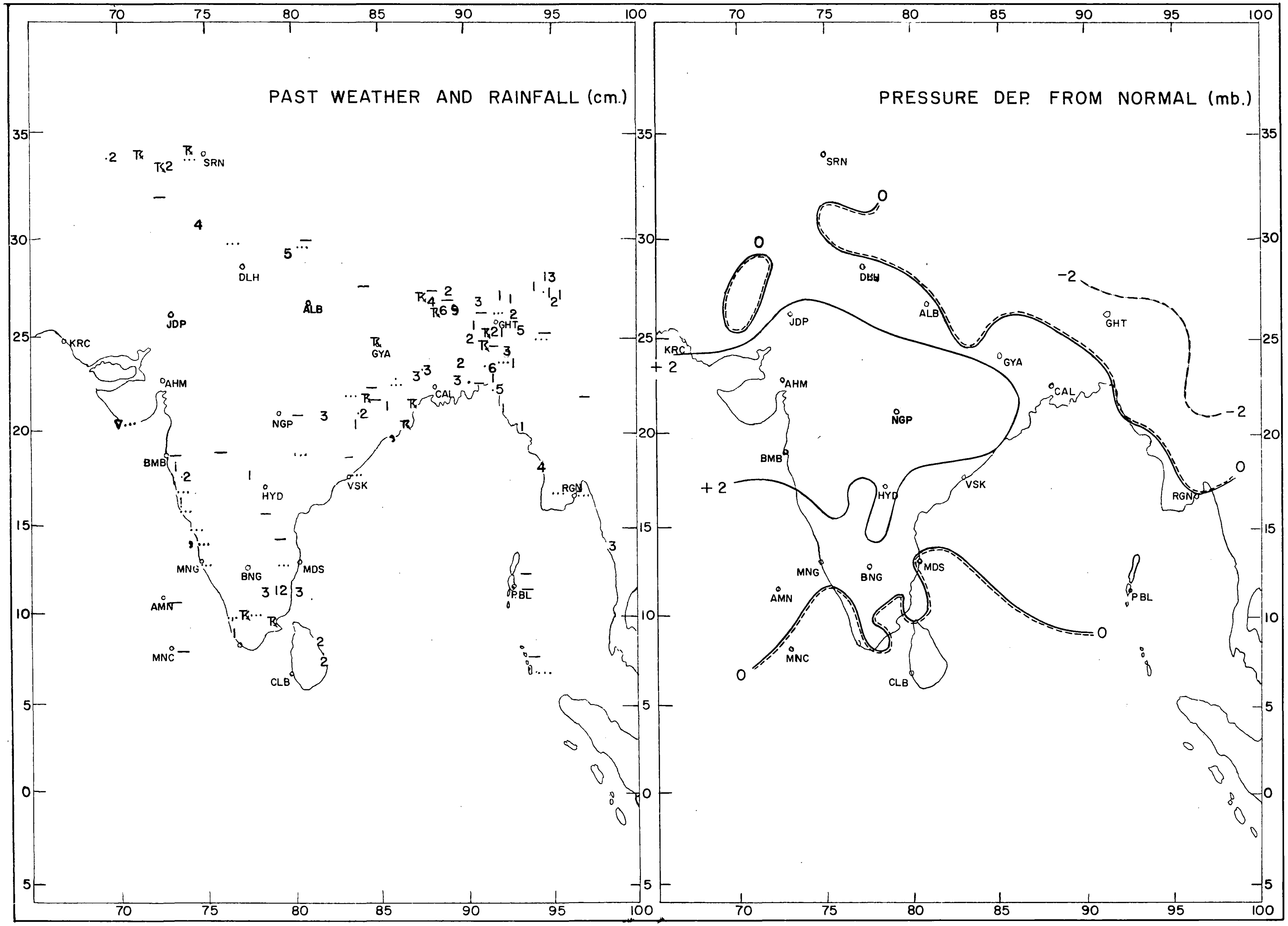


FIG. 1(c) : UPPER WINDS DATE:- 7 AUGUST 1965 TIME:- 00 GMT

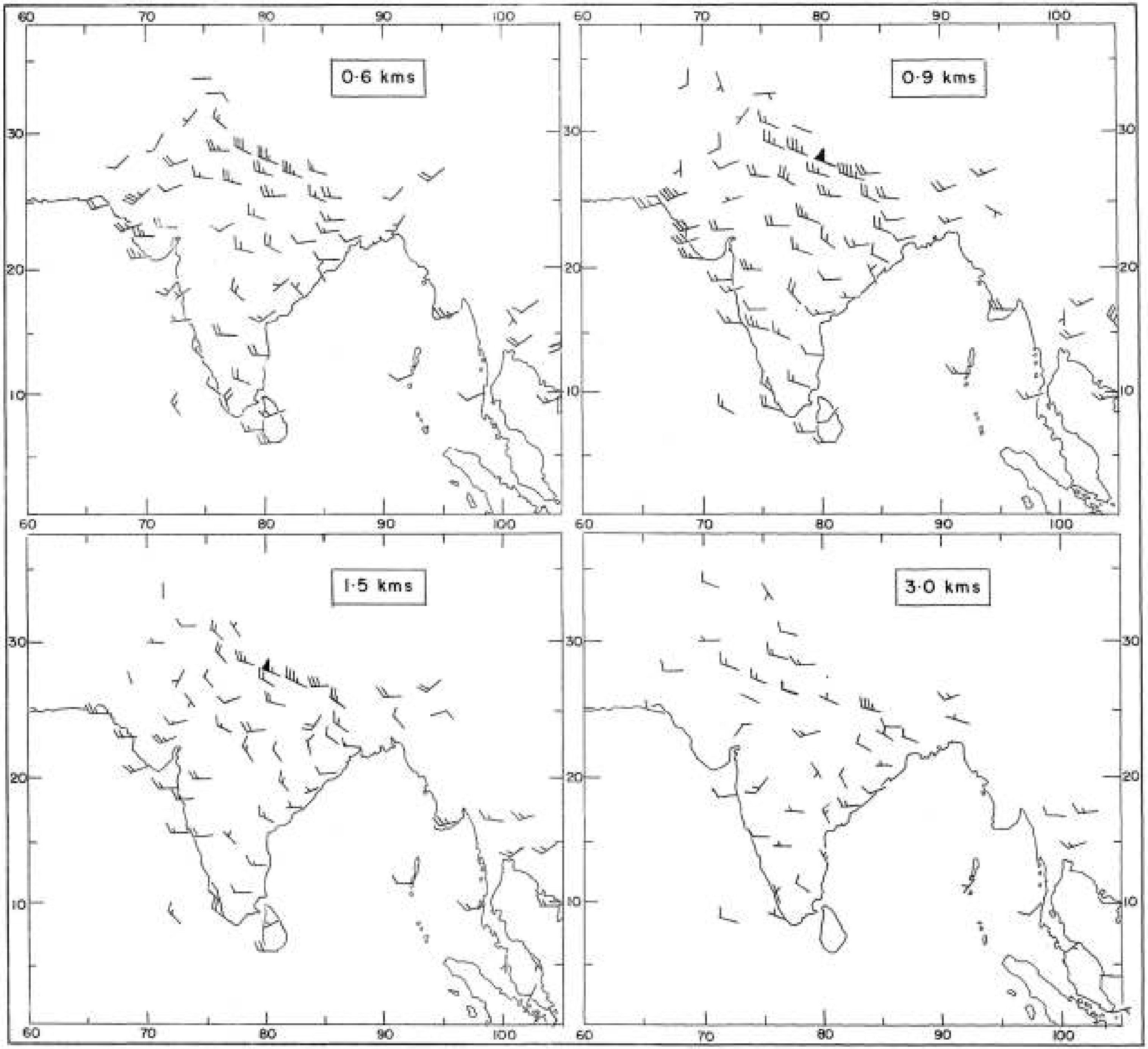


FIG. 1(d) : UPPER WINDS DATE – 7 AUGUST 1965 TIME – 00 GMT

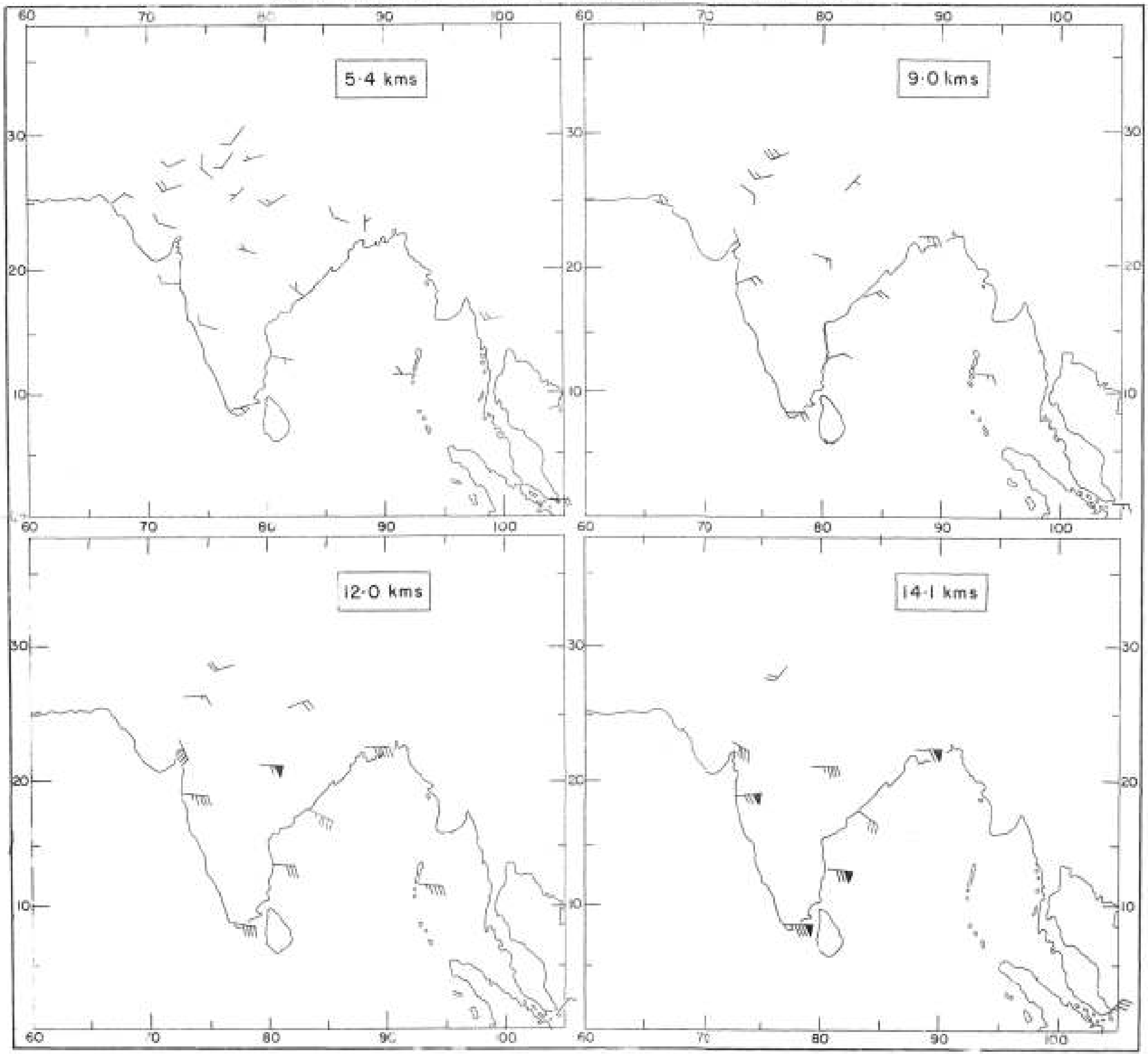


FIG. 2 TEN YEAR RUNNING MEANS OF (i) BREAKS, (ii) DEPRESSIONS AND STORMS DURING JULY AND AUGUST

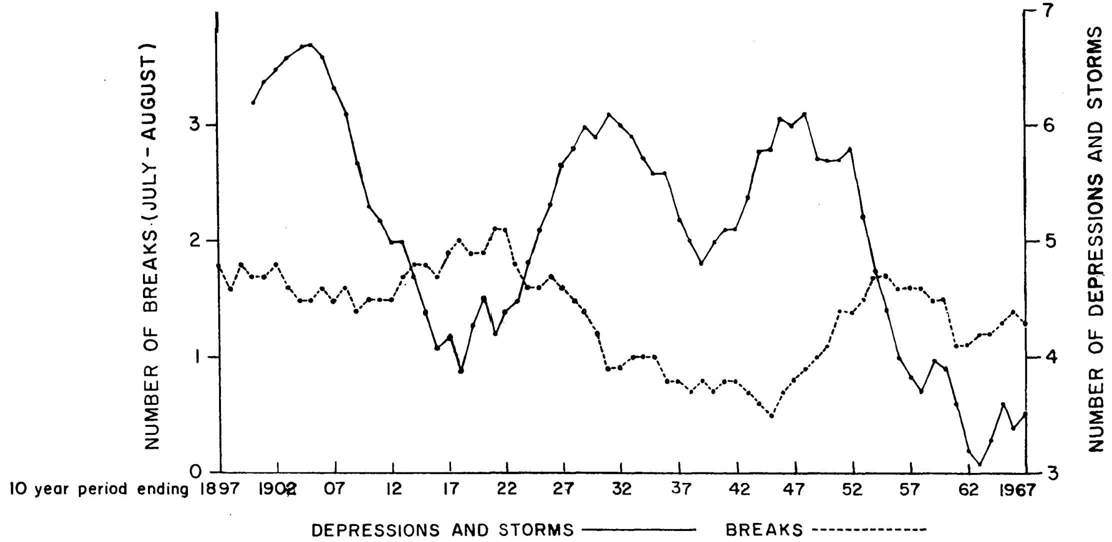


FIG. 3 MEAN PRESSURE DEPARTURE (03 GMT) DURING BREAKS

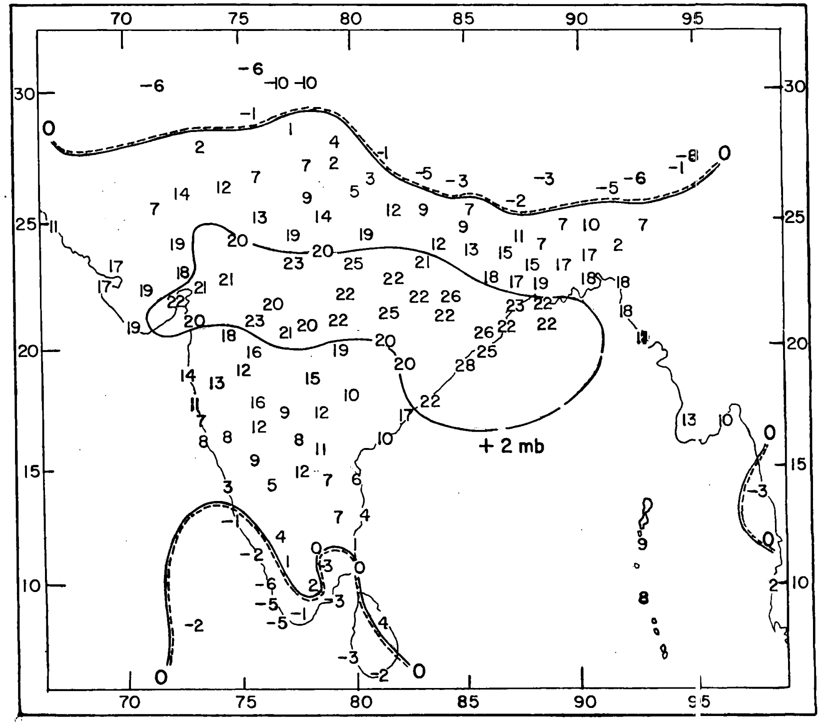
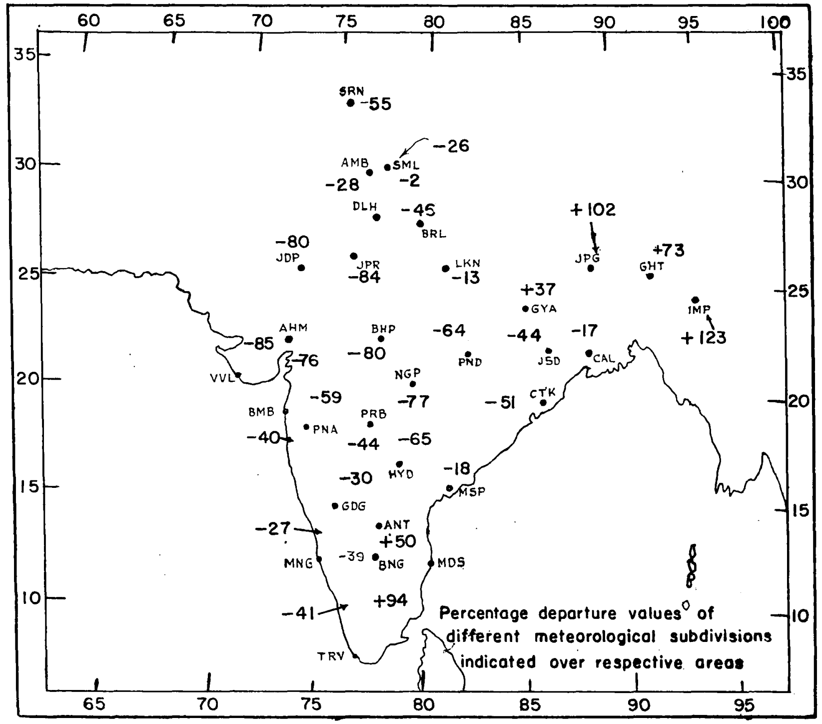


FIG. 4 MEAN DEPARTURE (%) OF RAINFALL DURING BREAKS



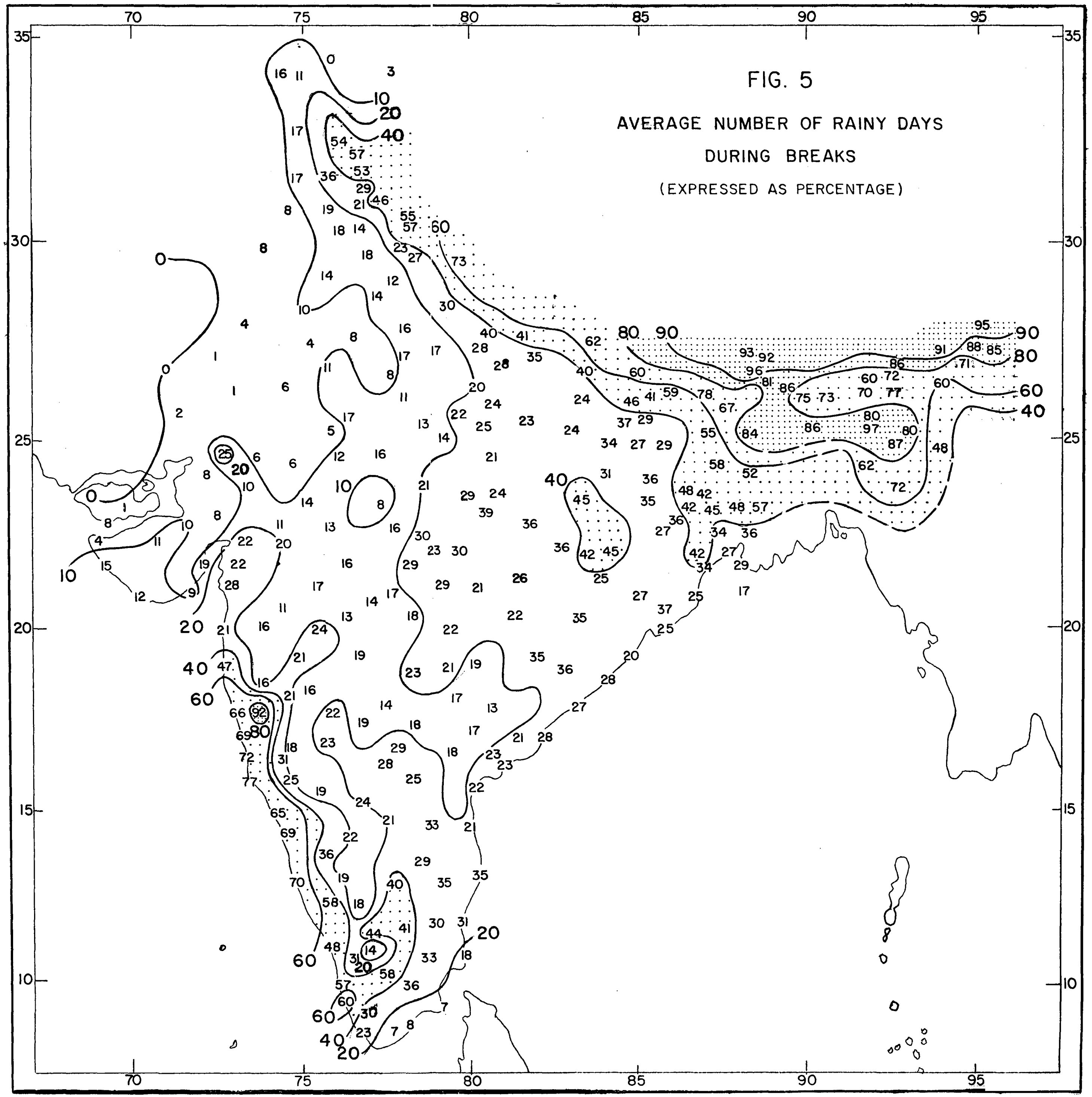


FIG. 5

AVERAGE NUMBER OF RAINY DAYS DURING BREAKS

(EXPRESSED AS PERCENTAGE)

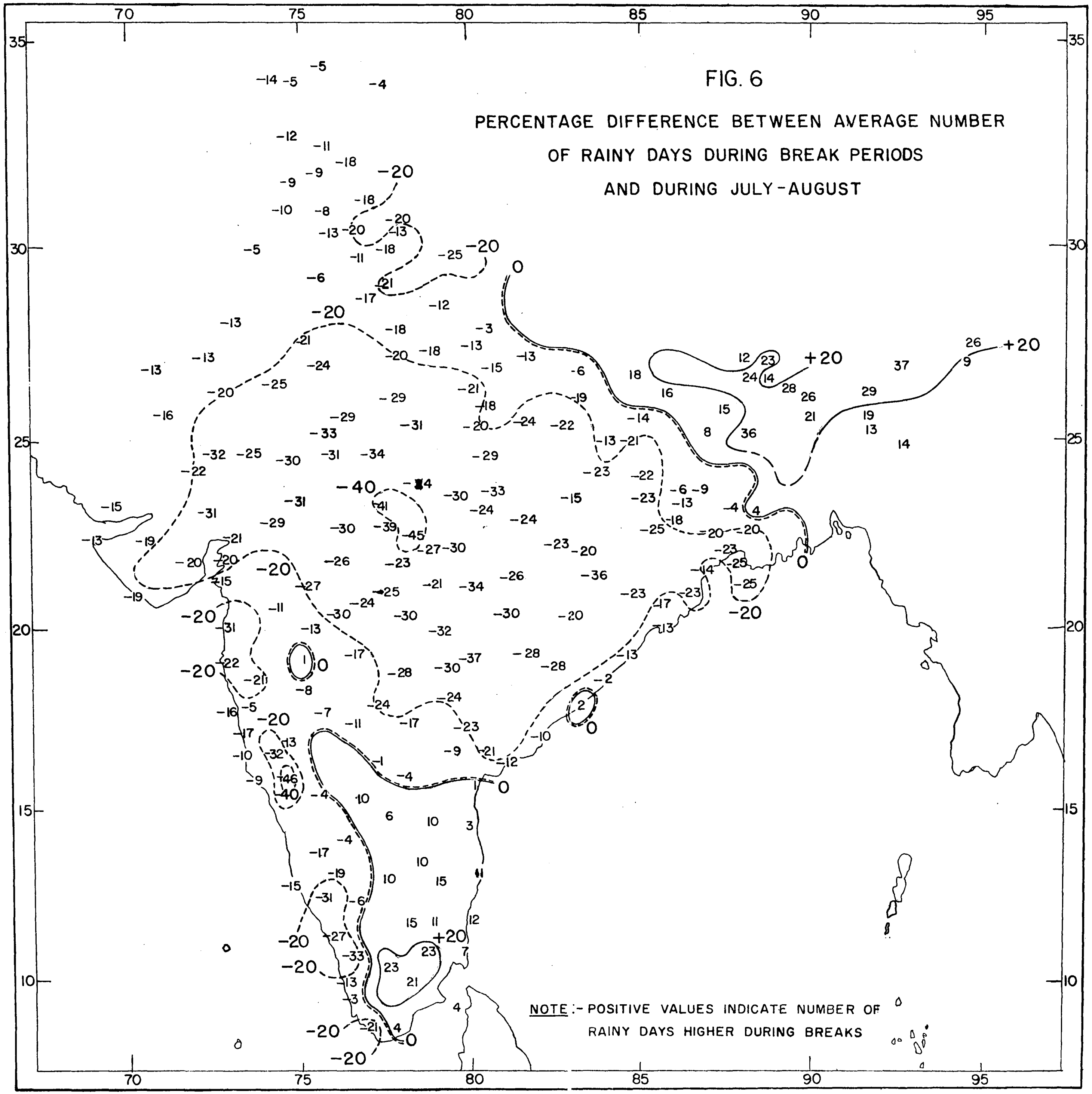


FIG. 6

PERCENTAGE DIFFERENCE BETWEEN AVERAGE NUMBER OF RAINY DAYS DURING BREAK PERIODS AND DURING JULY-AUGUST

NOTE :- POSITIVE VALUES INDICATE NUMBER OF RAINY DAYS HIGHER DURING BREAKS

FIG. 7 MEAN UPPER WIND FLOW PATTERNS DURING BREAK MONSOON

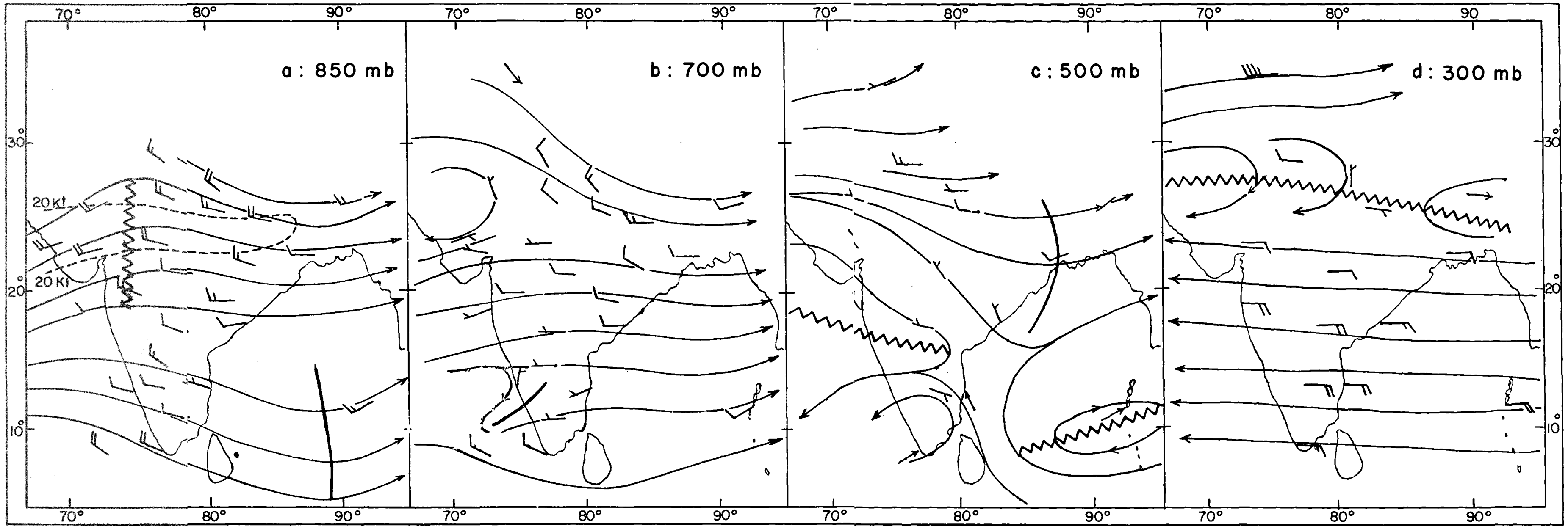
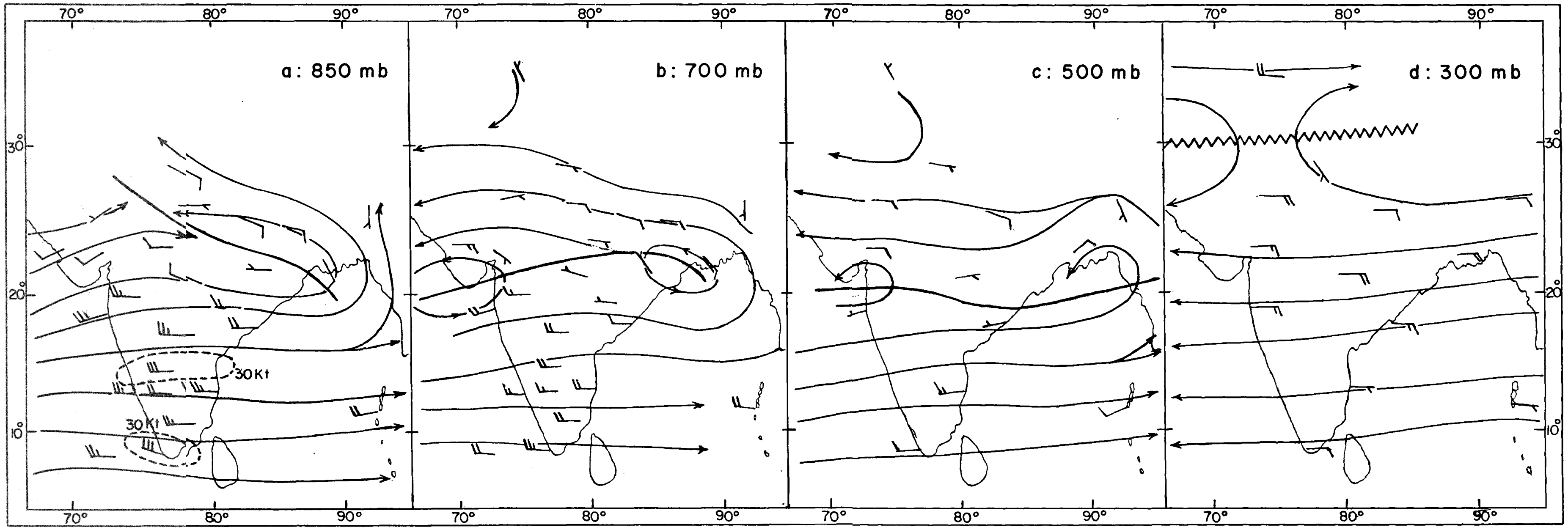


FIG. 8. MEAN UPPER WIND FLOW PATTERNS DURING ACTIVE MONSOON



TROUGH LINE. RIDGE LINE.

FIG. 7. MEAN UPPER WIND FLOW PATTERNS DURING BREAK MONSOON

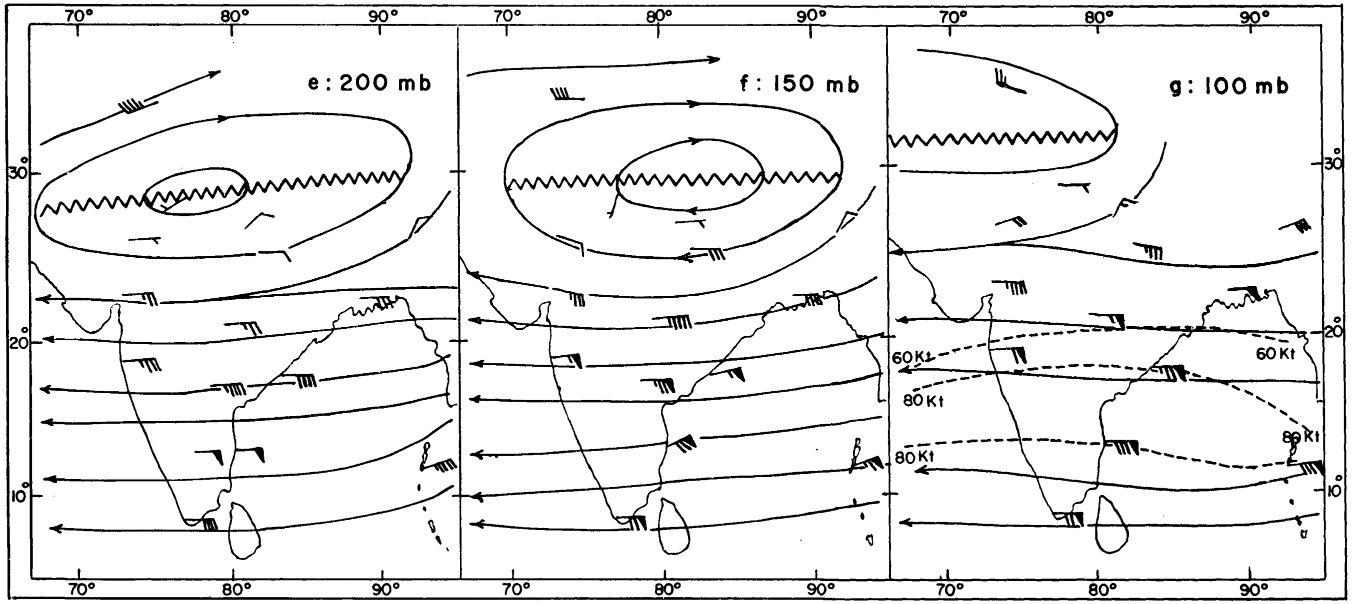
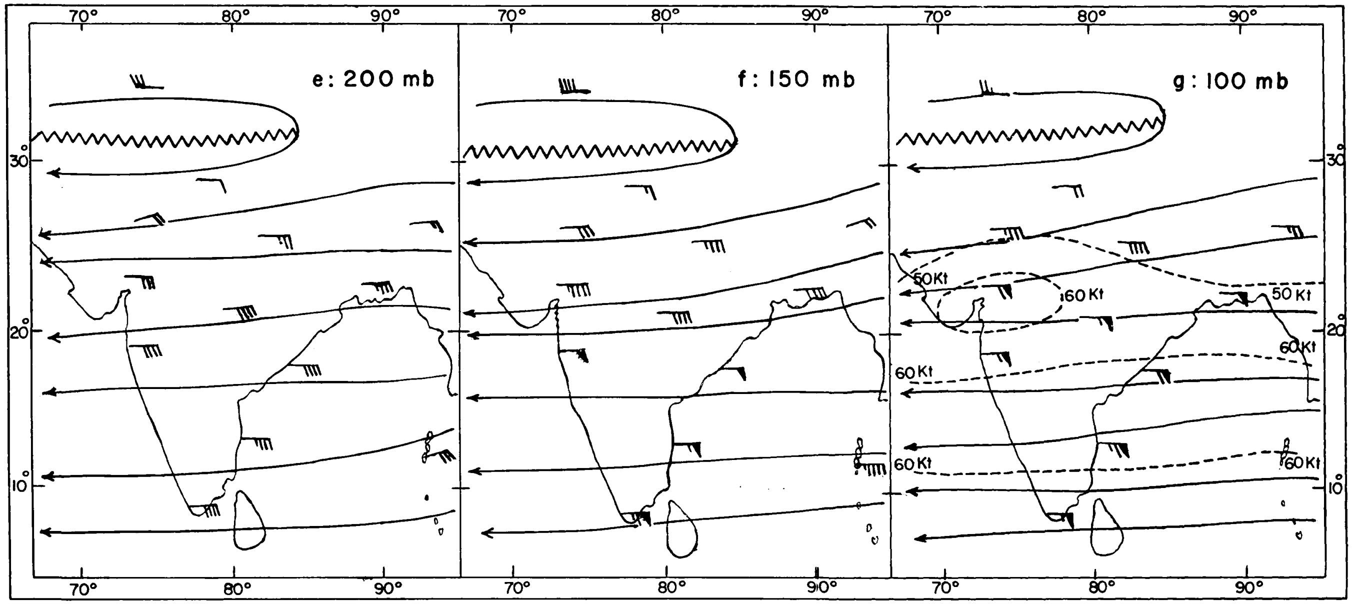
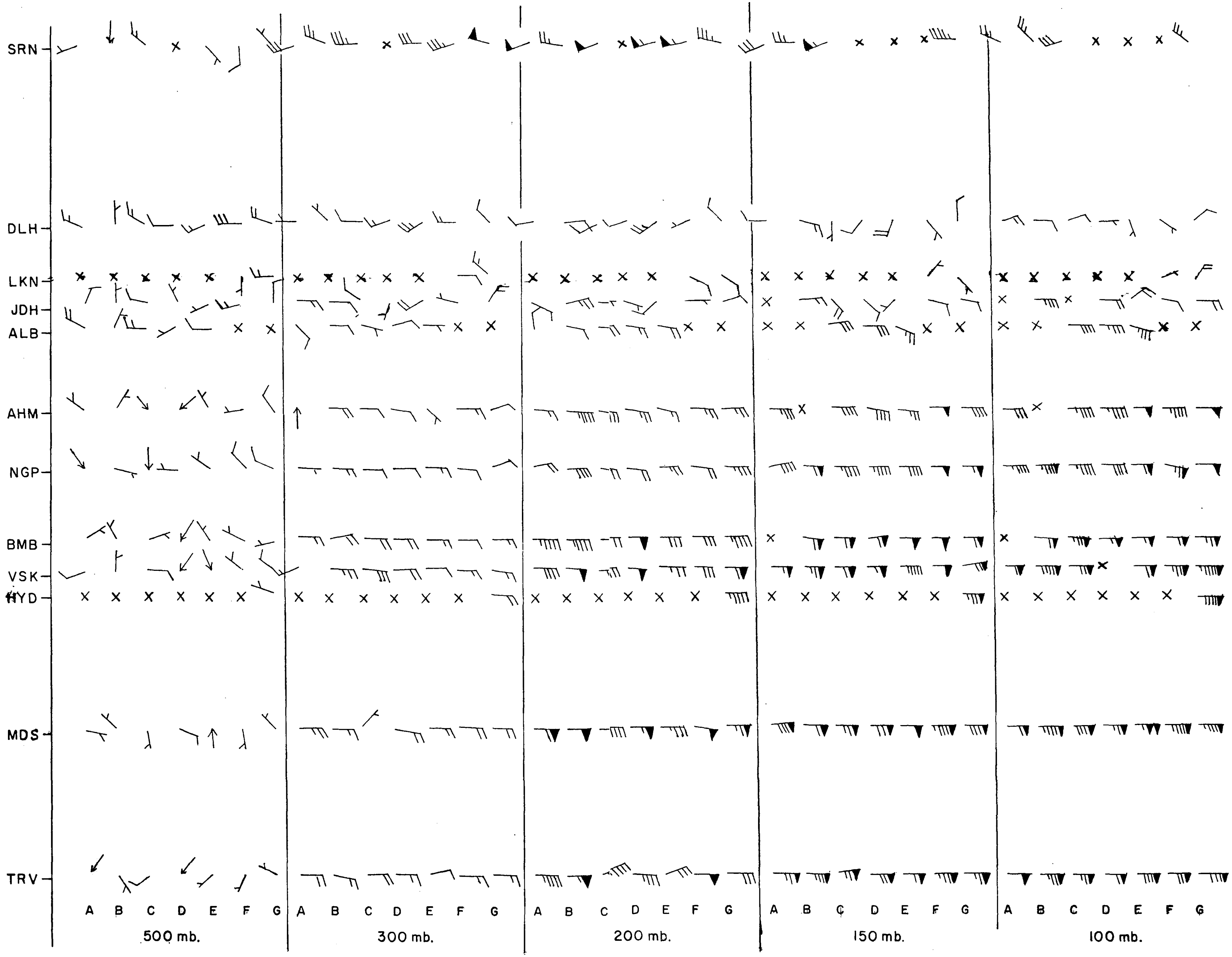


FIG. 8. MEAN UPPER WIND FLOW PATTERNS DURING ACTIVE MONSOON



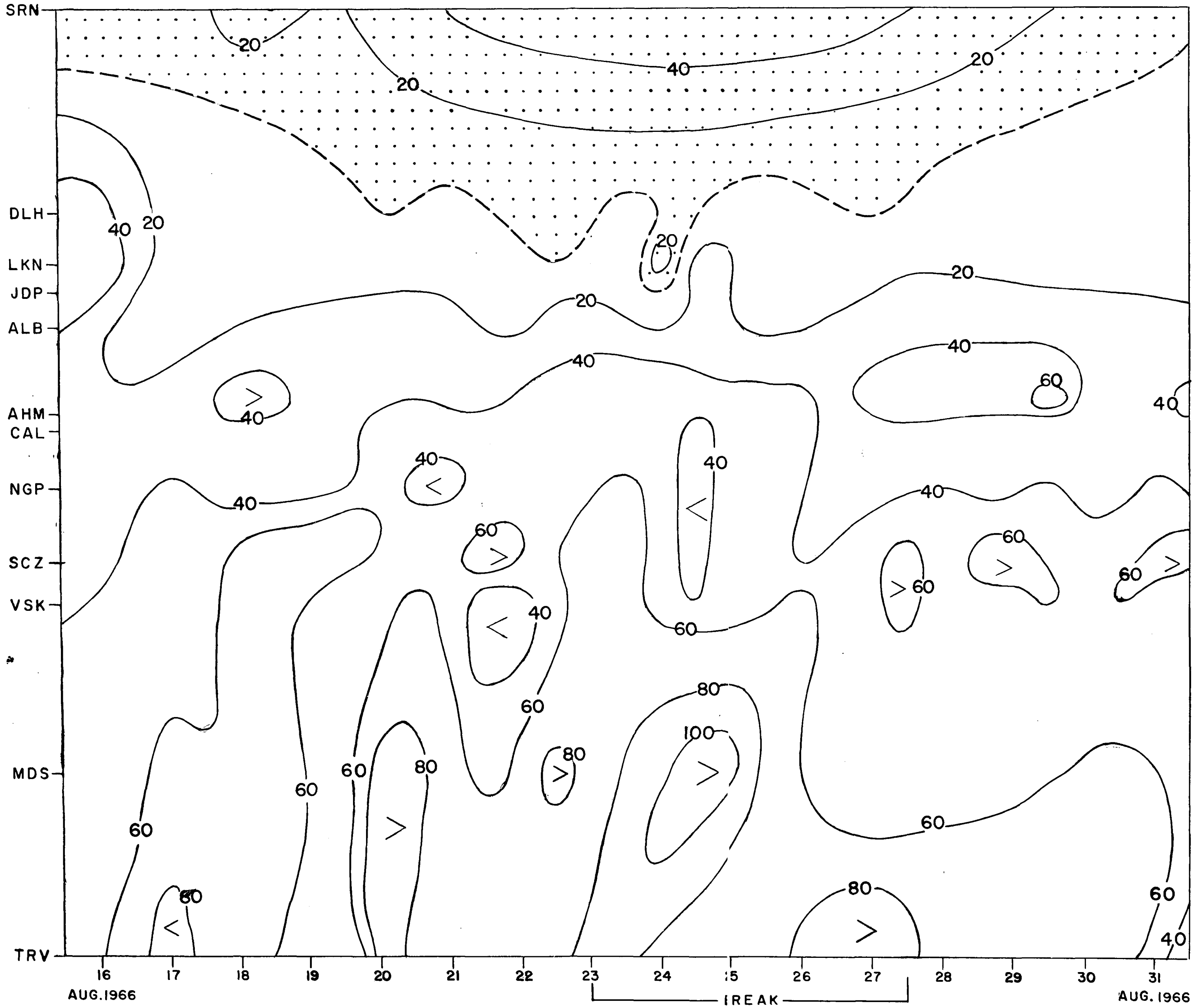
TROUGH LINE RIDGE LINE



A :- 18 - 22 AUG. 1962 B :- 17 - 21 JUL. 1963 C :- 28 JUL. - 3 AUG. 1964 D :- 4 - 15 AUG. 1965 E :- 2 - 11 JUL. 1966 F :- 23 - 27 AUG. 1966 G :- 7 - 10 JUL. 1967

FIG. 9 MEAN TIME SECTION ALONG LONGITUDE 78° E (±5°) IN RESPECT OF BREAK PERIODS

FIG 10:TIME-SECTION OF ZONAL WINDS AT 150 mb LEVEL ACROSS INDIA



NOTE:- (i) ISOPLETHS IN KNOTS (ii) DOTTED AREA : WESTERLIES

FIG. II: MEAN MERIDIONAL CIRCULATION OVER INDIA

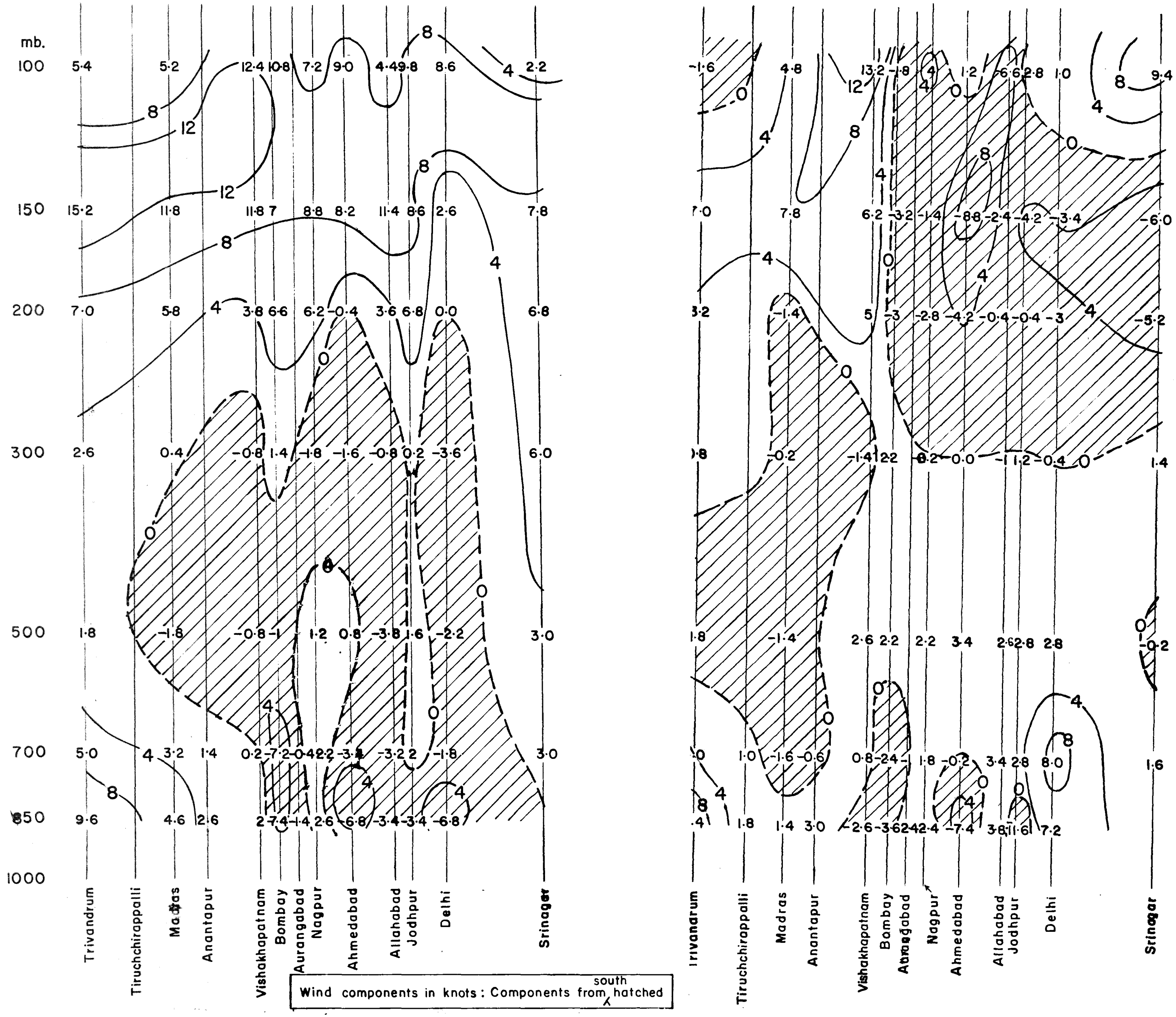


FIG. 12: MOVEMENT OF UPPER AIR LOW FROM SOUTH BAY OF BENGAL TO KERALA - MYSORE COASTS

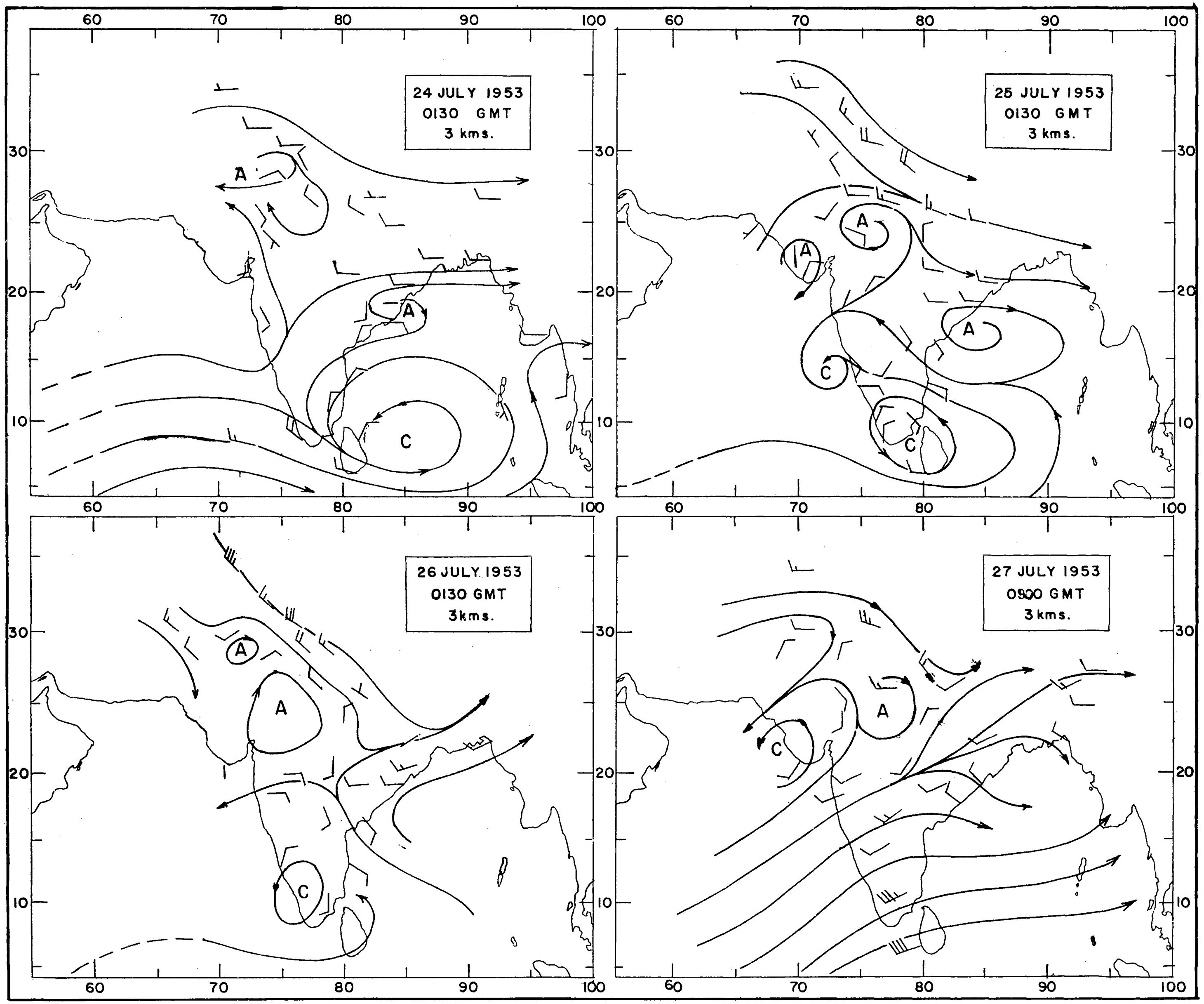


FIG. 13 : MOVEMENT OF UPPER AIR LOW FROM SOUTH BAY OF BENGAL TO KERALA COAST AND THENCE NORTH—NORTHWESTWARDS

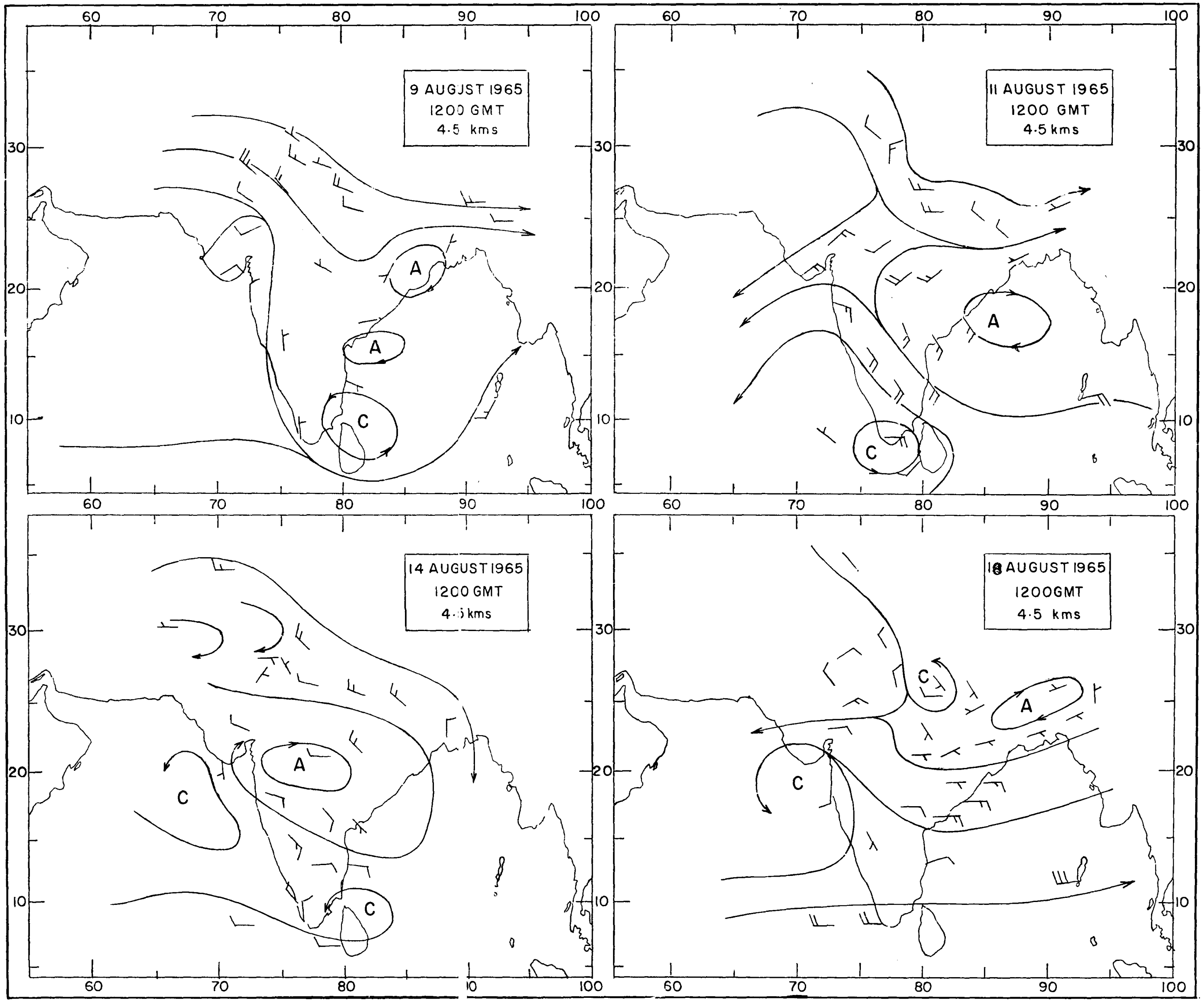


FIG. 14 : MOVEMENT OF UPPER AIR LOW FROM SOUTH BAY ALONG THE EAST COAST OF THE PENINSULA TO CENTRAL AND NORTH BAY OF BENGAL

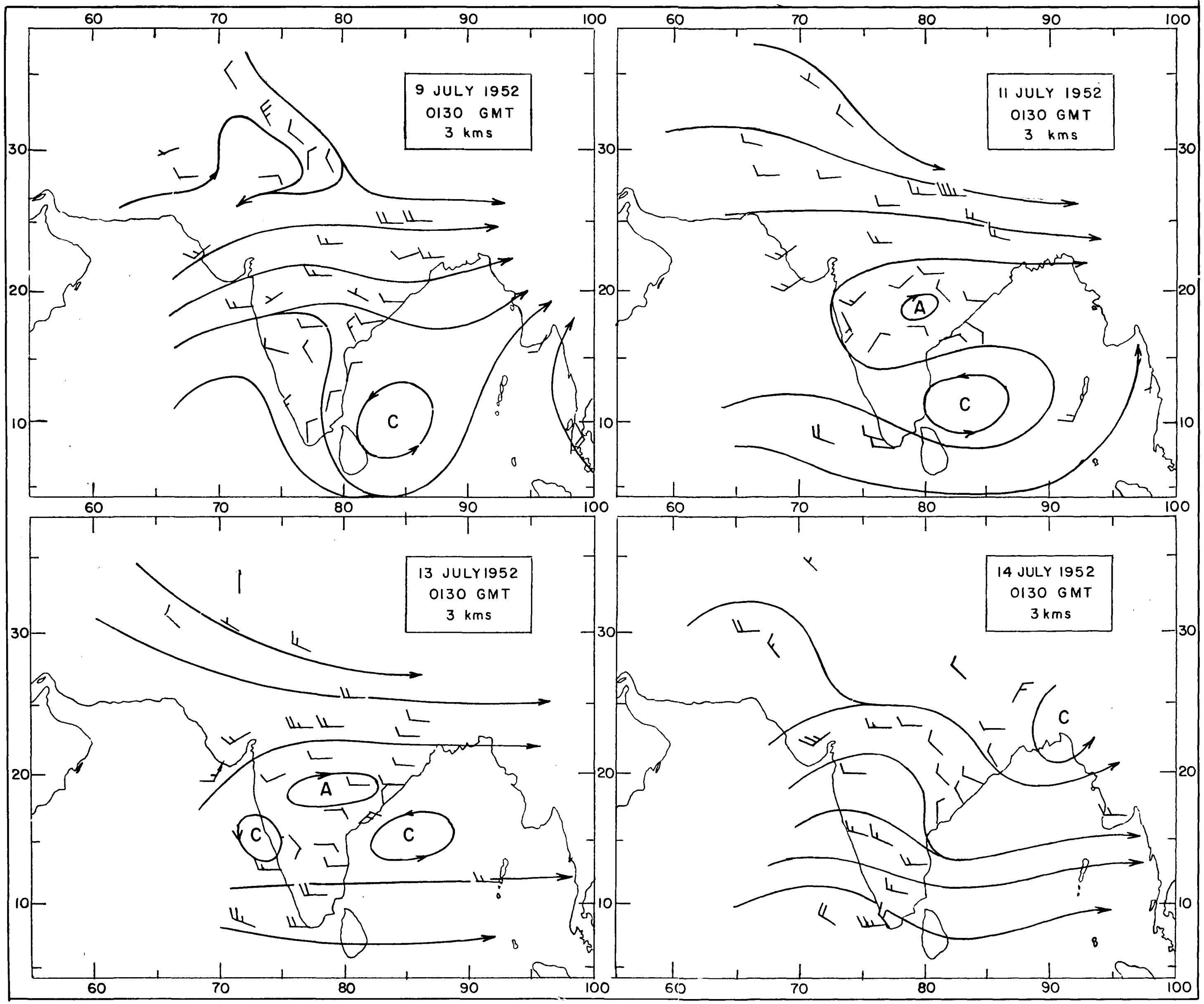
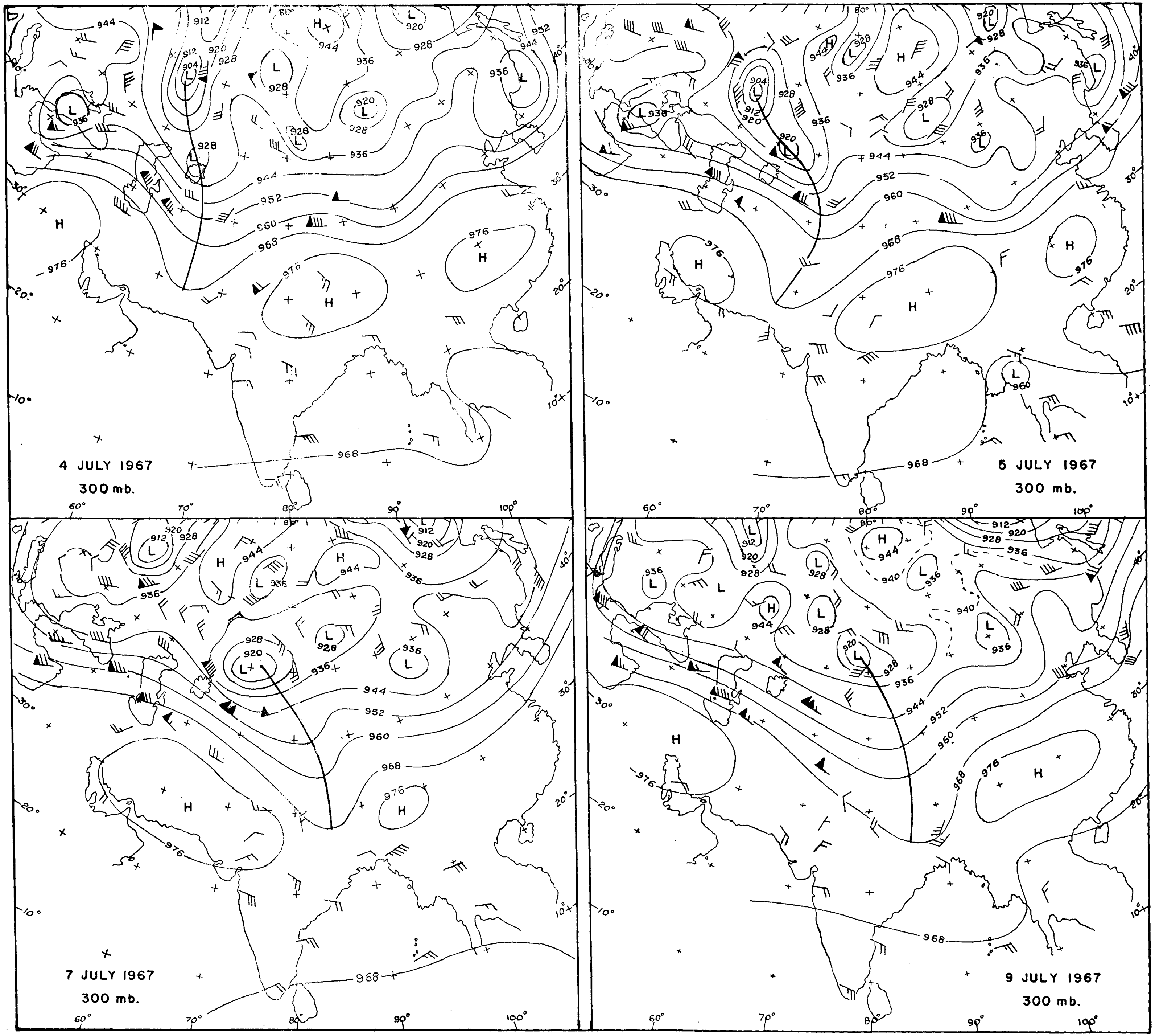


FIG. 15: PASSAGE OF TROUGH IN WESTERLIES DURING BREAK



Note :- Analysis mainly based on published Russian daily weather charts